Higgs-gauge operators

D6 Lagrangian for Run 2 [SMEFT]

- Higgs operators [renormalizable]

$$\mathcal{O}_{GG} = \phi^\dagger \phi G^a_{\mu\nu} G^{a\mu\nu} \qquad \mathcal{O}_{WW} = \phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{BB} = \cdots$$

$$\mathcal{O}_{BW} = \phi^\dagger \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{W} = (D_\mu \phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \phi) \qquad \mathcal{O}_{B} = \cdots$$

$$\mathcal{O}_{\phi,1} = (D_\mu \phi)^\dagger \phi \, \phi^\dagger \, (D^\mu \phi) \qquad \mathcal{O}_{\phi,2} = \frac{1}{2} \partial^\mu \left(\phi^\dagger \phi \right) \partial_\mu \left(\phi^\dagger \phi \right) \qquad \mathcal{O}_{\phi,3} = \frac{1}{3} \left(\phi^\dagger \phi \right)^3$$

- basis after equation of motion, field re-definition, integration by parts

$$\mathcal{L}_{\rm D6} = - \frac{\alpha_s v}{8\pi} \frac{f_g}{\Lambda^2} \mathcal{O}_{GG} + \frac{f_{BB}}{\Lambda^2} \mathcal{O}_{BB} + \frac{f_{WW}}{\Lambda^2} \mathcal{O}_{WW} + \frac{f_B}{\Lambda^2} \mathcal{O}_{B} + \frac{f_W}{\Lambda^2} \mathcal{O}_{W} + \frac{f_{\phi,2}}{\Lambda^2} \mathcal{O}_{\phi,2}$$

- Higgs couplings [derivatives = momentum]

$$\begin{aligned} \mathcal{L}_{\rm D6} = &\; g_g \; H G^a_{\mu\nu} G^{a\mu\nu} + g_\gamma \; H A_{\mu\nu} A^{\mu\nu} \\ &+ g_Z^{(1)} \; Z_{\mu\nu} Z^\mu \partial^\nu H + g_Z^{(2)} \; H Z_{\mu\nu} Z^{\mu\nu} + g_Z^{(3)} \; H Z_\mu Z^\mu \\ &+ g_W^{(1)} \; \left(W^+_{\mu\nu} W^{-\,\mu} \partial^\nu H + \text{h.c.} \right) + g_W^{(2)} \; H W^+_{\mu\nu} W^{-\,\mu\nu} + g_W^{(3)} \; H W^+_\mu W^{-\,\mu} + \cdots \end{aligned}$$

plus Yukawa structure $f_{\tau,b,t}$

- one more operator for TGV

$$\mathcal{O}_{WWW} = \text{Tr} \left(\hat{W}_{\mu\nu} \hat{W}^{\nu\rho} \hat{W}^\mu_\rho \right)$$

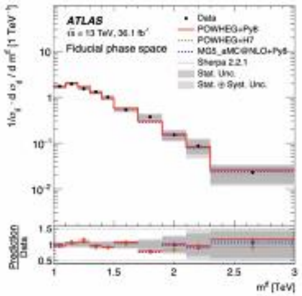
$\Rightarrow$ Bosonic electroweak sector: 10 operators

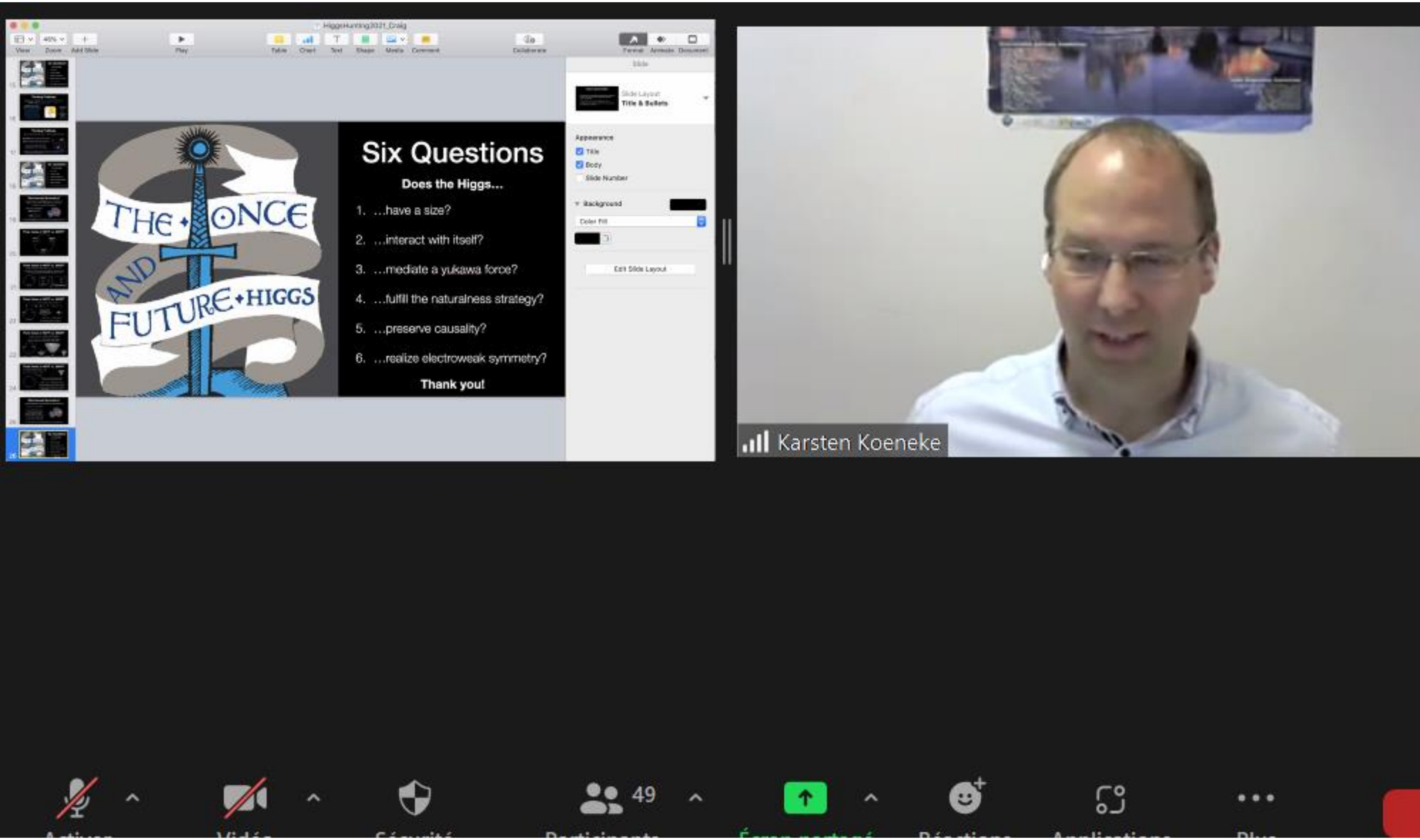
Higgs-gauge-top legacy

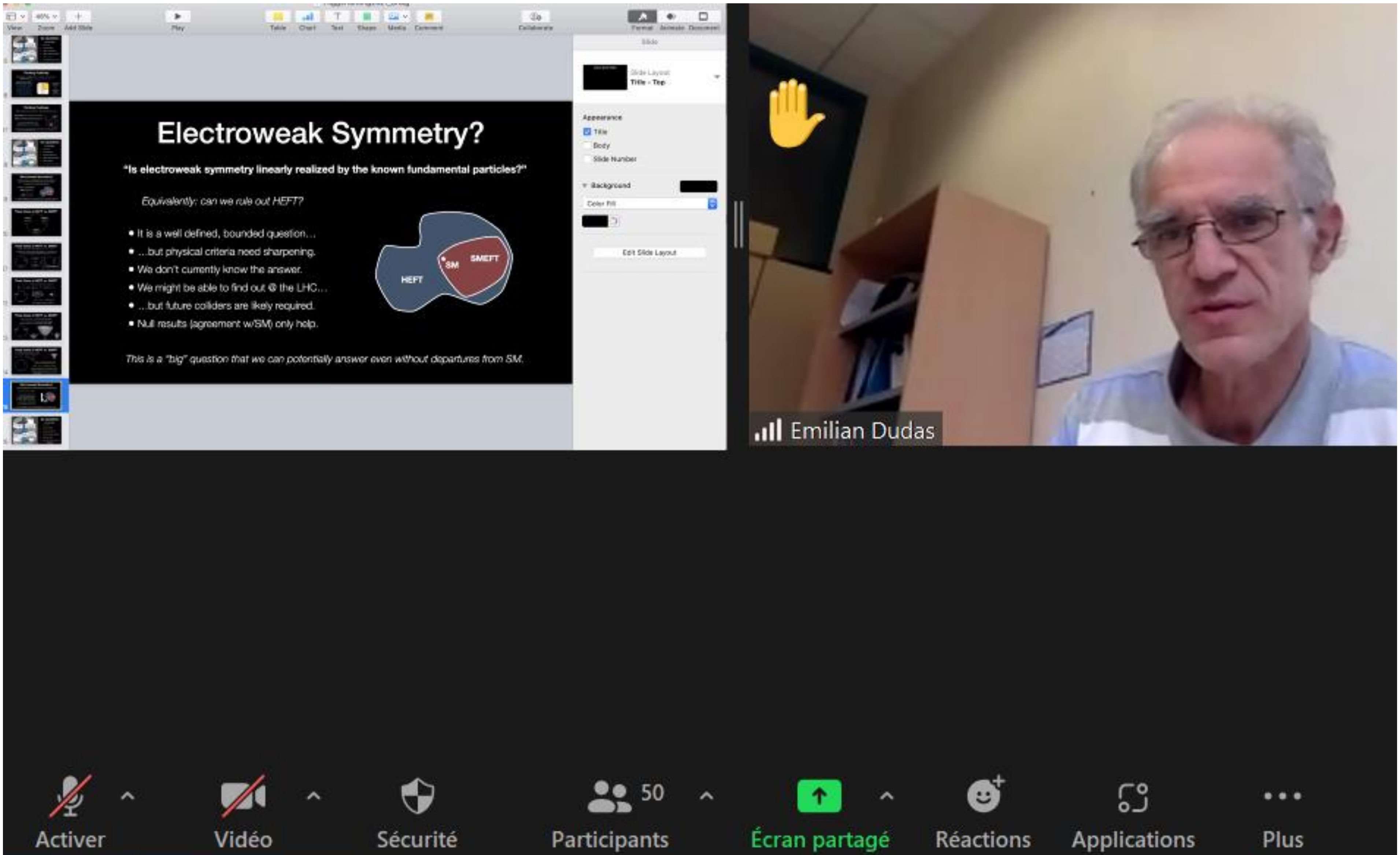
Top sector, executive summary [Brivio, Bruggisser, Maltoni, Moutafis, TP, Vryonidou, Westhoff, Zhang]

- production channels $t\bar{t}$, $t\bar{t}V$, tj, tV, plus top decays
- NLO predictions, theory uncertainties not only from scales
- $m_{tt}, p_{T,t}$ distributions unfolded
- highly correlated 4-fermion sector
- flat directions circular

⇒ Still no anomalies




HiggsHunting2021_Craig
THE ONCE AND FUTURE HIGGS
Six Questions
Does the Higgs...
1. ...have a size?
2. ...interact with itself?
3. ...mediate a yukawa force?
4. ...fulfill the naturalness strategy?
5. ...preserve causality?
6. ...realize electroweak symmetry?
Thank you!
Karsten Koeneke
49


Electroweak Symmetry?
"Is electroweak symmetry linearly realized by the known fundamental particles?"
Equivalently: can we rule out HEFT?
• It is a well defined, bounded question…
• …but physical criteria need sharpening.
• We don't currently know the answer.
• We might be able to find out @ the LHC…
• …but future colliders are likely required.
• Null results (agreement w/SM) only help.
HEFT
SM
SMEFT
This is a "big" question that we can potentially answer even without departures from SM.
Emilian Dudas
Activer
Vidéo
Sécurité
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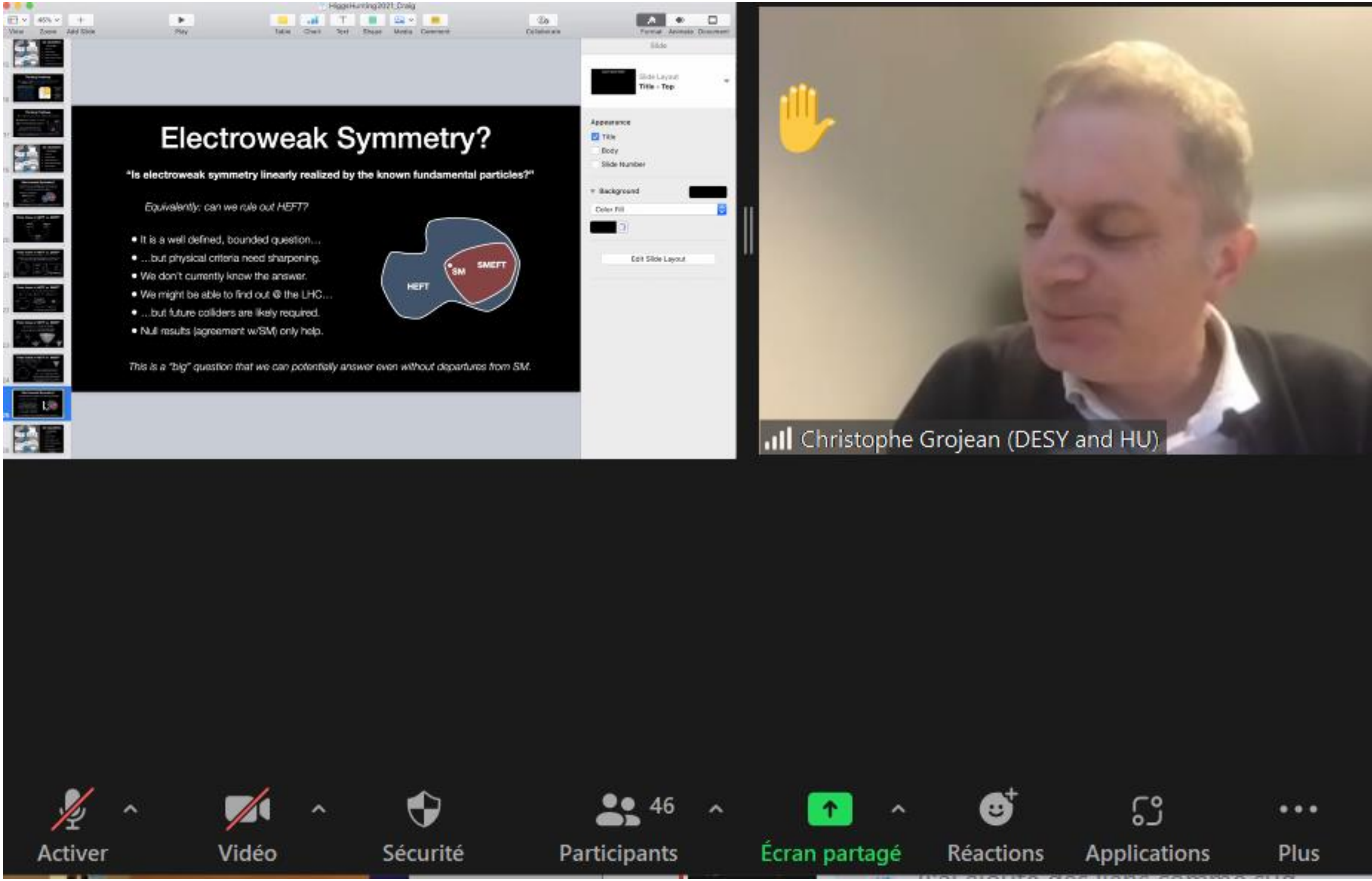
Participants
Écran partagé
Réactions
Applications
Plus


Electroweak Symmetry?
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HEFT
SM
SMEFT
This is a "big" question that we can potentially answer even without departures from SM.
Christophe Grojean (DESY and HU)
Activer
Vidéo
Sécurité
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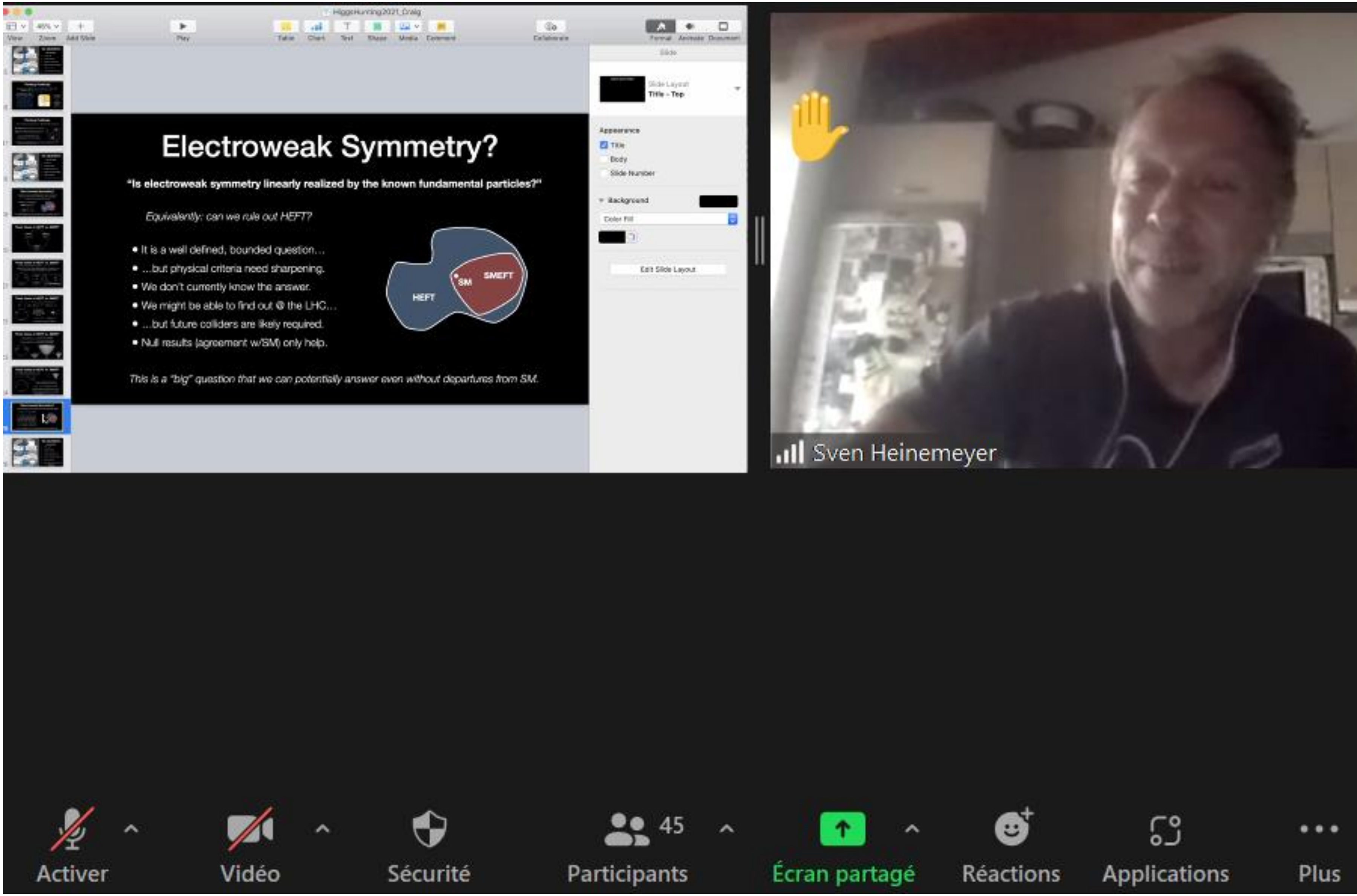
Participants
Écran partagé
Réactions
Applications
Plus


Electroweak Symmetry?
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HEFT
SM
SMEFT
Sven Heinemeyer
Activer
Vidéo
Sécurité
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Écran partagé
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Nathaniel Craig
Christophe Grojean (D...
Emilian Dudas
Enregistrement...
Karsten Koeneke
Activer
Vidéo
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Réactions
Applications

Outlook

LHC the best data set for decades

- steps in modern data analysis overdue
- rate measurements fairly uninteresting
- measurements of fundamental parameters much better
- measurements with BSM impact even better
- BSM discoveries what we really want

Future Higgs physics

- link Higgs to dark matter
- link Higgs to baryogenesis
- search for extended Higgs sectors
- search for symmetries: Z_2, CP, ...

Vidéo Sécurité Participants 77 Sondages Discussion Écran partagé Réactions Applications Plus

Precise predictions for double-Higgs production via vector-boson fusion

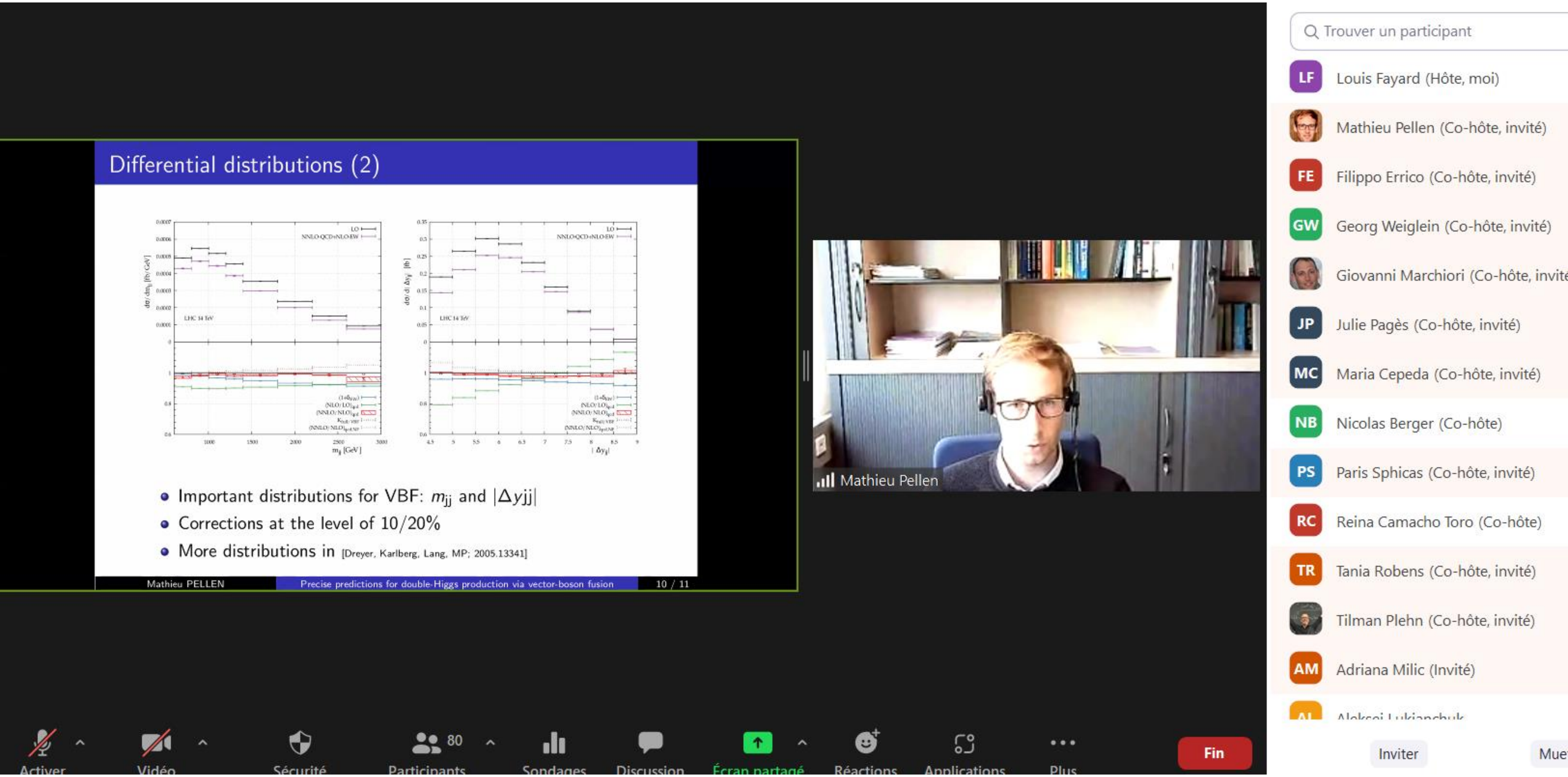
Mathieu PELLEN

University of Freiburg

Based on arXiv:2005.13341 - EPJC 80 (2020) 11

In Collaboration with:
Frédéric A. Dreyer, Alexander Karlberg, Jean-Nicolas Lang

Higgs Hunting 2021, Paris (France)
20^{th} of September 2021


Differential distributions (2)
LO
NNLO-QCD+NLO-EW
LHC 14 TeV
m_{jj} [GeV]
$|\Delta y_{jj}|$
Important distributions for VBF: m_{jj} and $|\Delta y jj|$
Corrections at the level of 10/20%
More distributions in [Dreyer, Karlberg, Lang, MP; 2005.13341]
Mathieu PELLEN
Precise predictions for double-Higgs production via vector-boson fusion
10 / 11
Mathieu Pellen
Trouver un participant
Louis Fayard (Hôte, moi)
Mathieu Pellen (Co-hôte, invité)
Filippo Errico (Co-hôte, invité)
Georg Weiglein (Co-hôte, invité)
Giovanni Marchiori (Co-hôte, invité
Julie Pagès (Co-hôte, invité)
Maria Cepeda (Co-hôte, invité)
Nicolas Berger (Co-hôte)
Paris Sphicas (Co-hôte, invité)
Reina Camacho Toro (Co-hôte)
Tania Robens (Co-hôte, invité)
Tilman Plehn (Co-hôte, invité)
Adriana Milic (Invité)
Activer
Vidéo
Sécurité
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Écran partagé
Réactions
Applications
Plus
Fin
Inviter

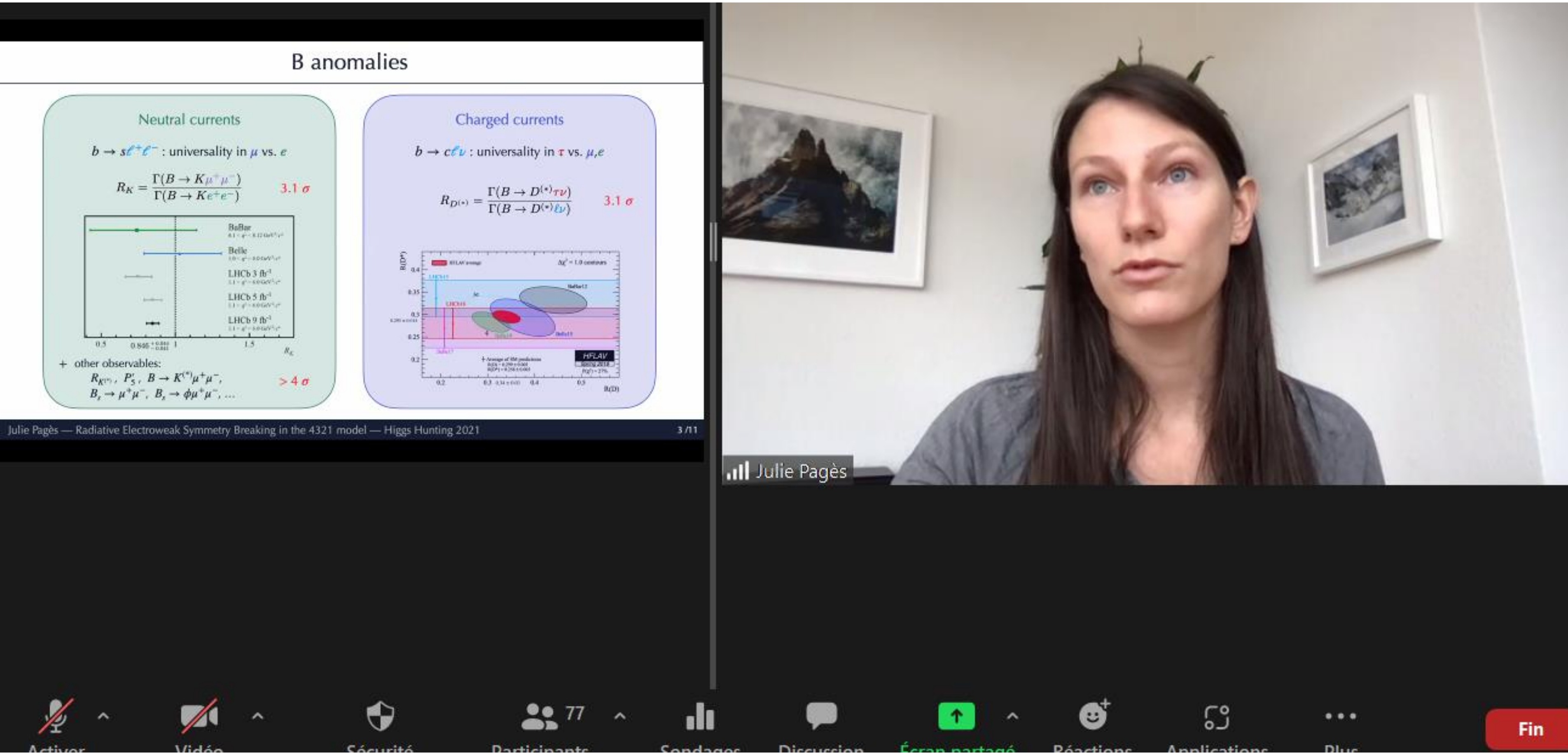
Universität Zürich[UZH]

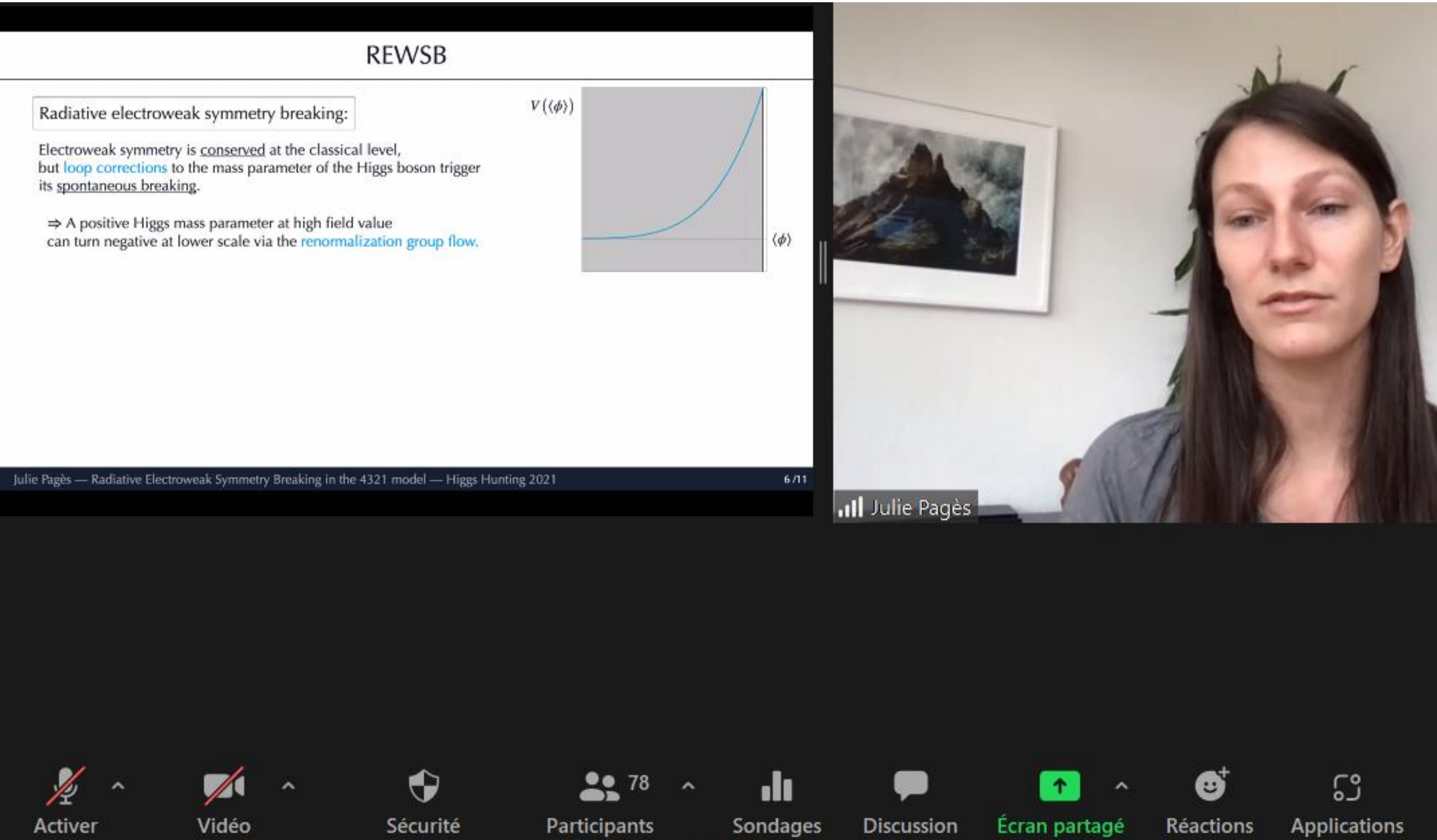
Radiative Electroweak Symmetry Breaking in the 4321 model

Higgs Hunting 2021, Young Scientist Forum, 20 September 2021

Julie Pagès
University of Zurich (UZH)

In collaboration with
R. Houtz (Durham U., IPPP) and *S. Trifinopoulos (SISSA, Trieste)*


B anomalies
Neutral currents
$b \to s\ell^+\ell^-$: universality in μ vs. e
$R_K = \frac{\Gamma(B \to K\mu^+\mu^-)}{\Gamma(B \to Ke^+e^-)}$
3.1 σ
BaBar
Belle
LHCb 3 fb^{-1}
LHCb 5 fb^{-1}
LHCb 9 fb^{-1}
+ other observables:
$R_{K^{(*)}}$, P_5', $B \to K^{(*)}\mu^+\mu^-$,
$B_s \to \mu^+\mu^-$, $B_s \to \phi\mu^+\mu^-$, ...
$> 4\,\sigma$
Charged currents
$b \to c\ell\nu$: universality in τ vs. μ, e
$R_{D^{(*)}} = \frac{\Gamma(B \to D^{(*)}\tau\nu)}{\Gamma(B \to D^{(*)}\ell\nu)}$
3.1 σ
HFLAV
Julie Pagès — Radiative Electroweak Symmetry Breaking in the 4321 model — Higgs Hunting 2021
3/11
Julie Pagès
77
Fin


REWSB
Radiative electroweak symmetry breaking:
Electroweak symmetry is conserved at the classical level,
but loop corrections to the mass parameter of the Higgs boson trigger
its spontaneous breaking.
⇒ A positive Higgs mass parameter at high field value
can turn negative at lower scale via the renormalization group flow.
$V(\langle\phi\rangle)$
$\langle\phi\rangle$
Julie Pagès — Radiative Electroweak Symmetry Breaking in the 4321 model — Higgs Hunting 2021
6 /11
Julie Pagès
Activer
Vidéo
Sécurité
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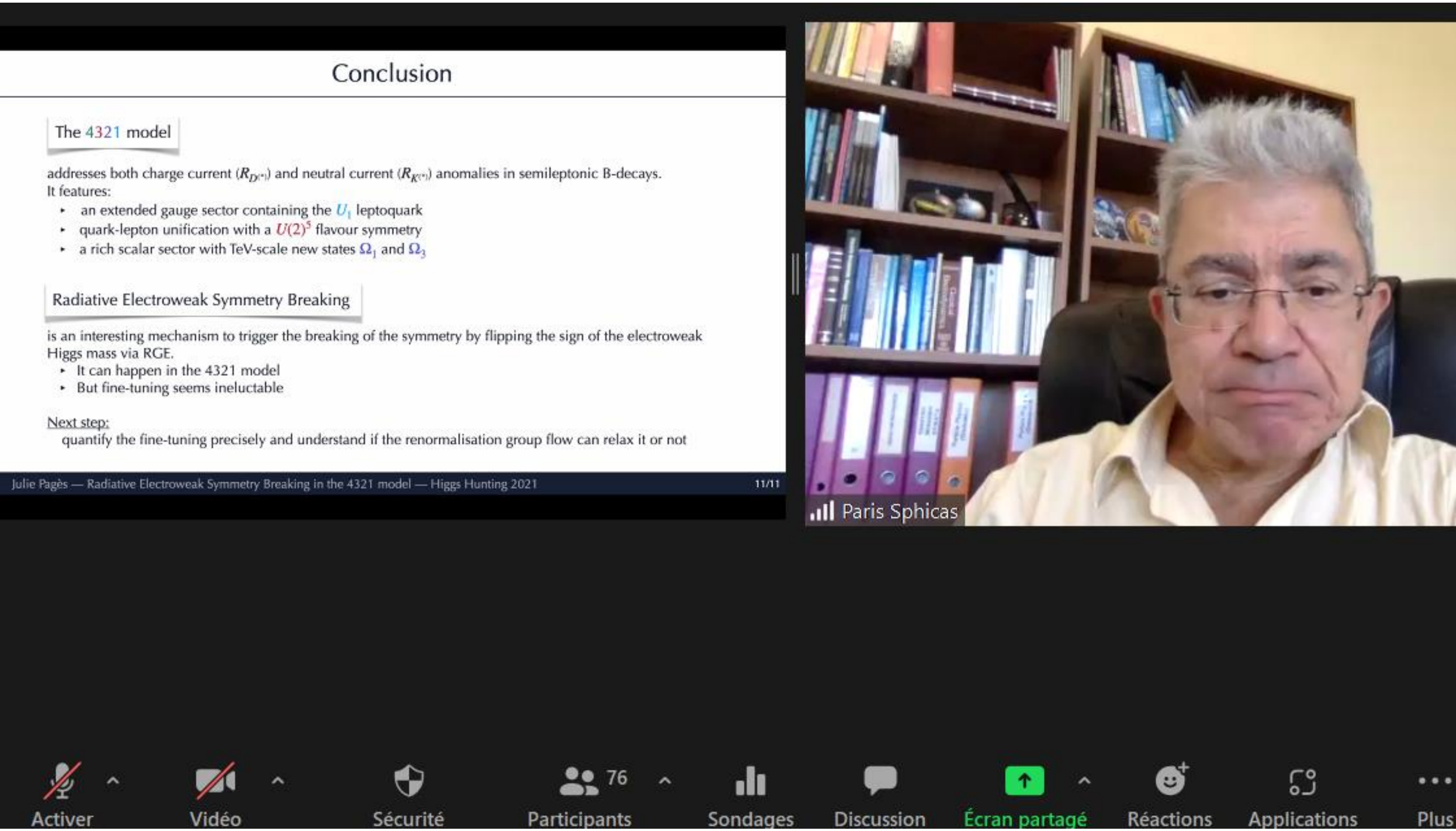
Conclusion
The 4321 model
addresses both charge current ($R_{D^{(*)}}$) and neutral current ($R_{K^{(*)}}$) anomalies in semileptonic B-decays.
It features:
an extended gauge sector containing the U_1 leptoquark
quark-lepton unification with a $U(2)^5$ flavour symmetry
a rich scalar sector with TeV-scale new states Ω_1 and Ω_3
Radiative Electroweak Symmetry Breaking
is an interesting mechanism to trigger the breaking of the symmetry by flipping the sign of the electroweak Higgs mass via RGE.
It can happen in the 4321 model
But fine-tuning seems ineluctable
Next step:
quantify the fine-tuning precisely and understand if the renormalisation group flow can relax it or not
Julie Pagès — Radiative Electroweak Symmetry Breaking in the 4321 model — Higgs Hunting 2021
11/11
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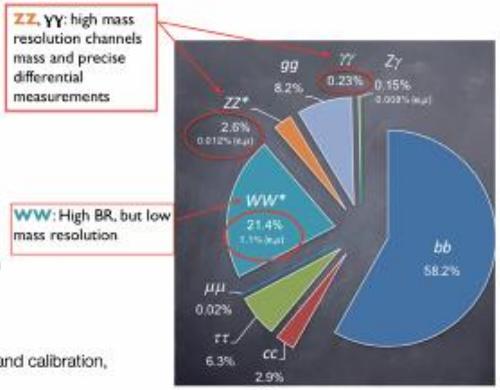
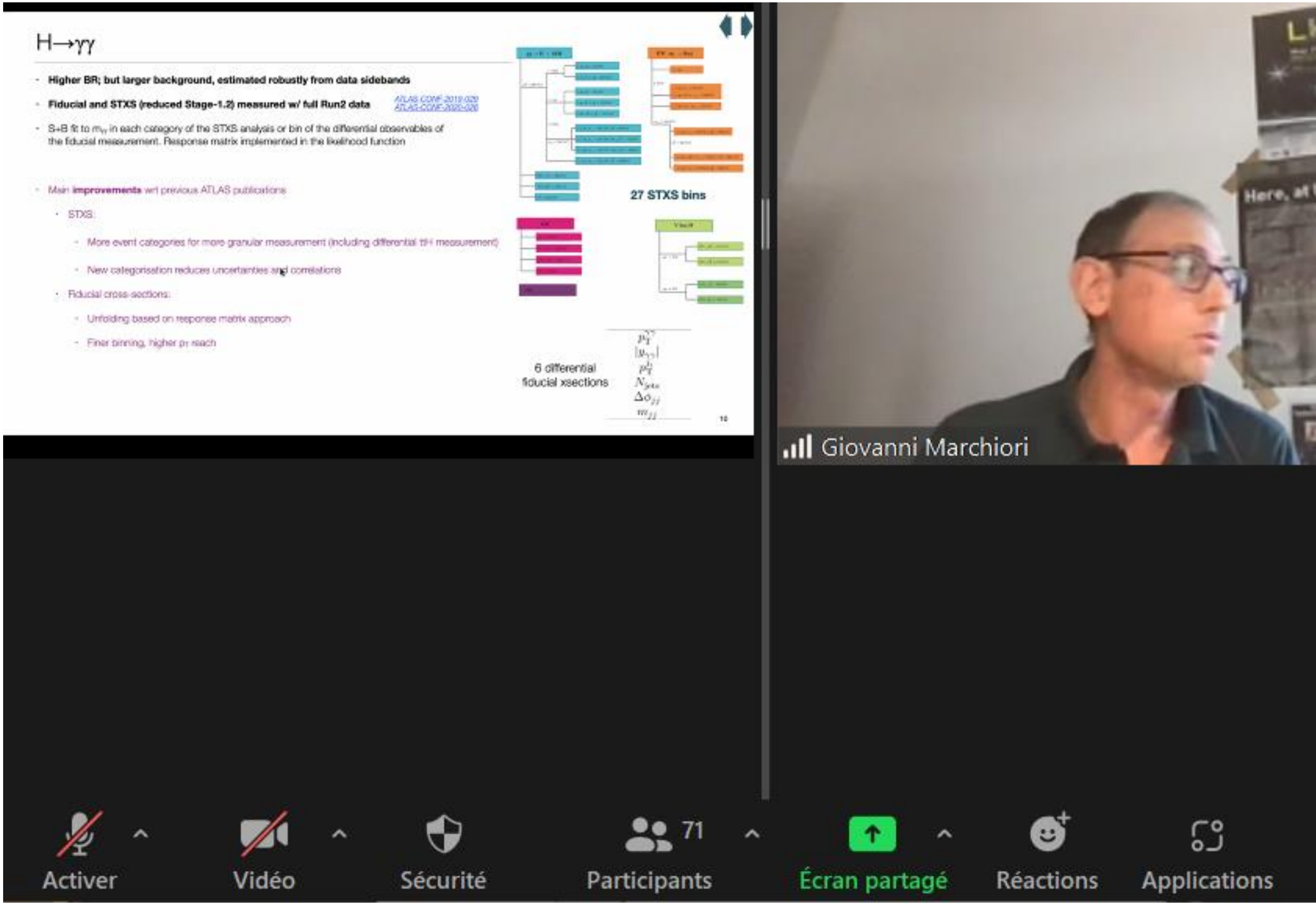
Réactions
Applications
Plus


Julie Pagès
Paris Sphicas
Enregistrement...
Paris Sphicas

Introduction

- This talk will focus on:
  - **Higgs mass measurement w/ $H \to ZZ^* \to 4l$ ($l=e,\mu$) and $H \to \gamma\gamma$**
  - **Fiducial and simplified template cross sections with $H \to$**
    - **$ZZ^* \to 4l$**
    - **$\gamma\gamma$**
    - **$WW^* \to e\nu\mu\nu$**
- **Almost all results** (except mass w/ $H \to \gamma\gamma$) **w/ full ATLAS Run2 data** (139/fb). **Improvements wrt previous publications**:
  - 4x more data
  - improved electron, photon and jet reconstruction, lepton selection and calibration, b-tagging ..
  - Improvements in analysis-techniques (in violet in the following)




H→γγ
Higher BR; but larger background, estimated robustly from data sidebands
Fiducial and STXS (reduced Stage-1.2) measured w/ full Run2 data
ATLAS-CONF-2019-029
ATLAS-CONF-2020-026
S+B fit to $m_{\gamma\gamma}$ in each category of the STXS analysis or bin of the differential observables of the fiducial measurement. Response matrix implemented in the likelihood function
Main improvements wrt previous ATLAS publications
STXS:
More event categories for more granular measurement (including differential ttH measurement)
New categorisation reduces uncertainties and correlations
Fiducial cross-sections:
Unfolding based on response matrix approach
Finer binning, higher p_T reach
27 STXS bins
6 differential fiducial xsections
$p_T^{\gamma\gamma}$
$|y_{\gamma\gamma}|$
p_T^{j1}
N_{jets}
$\Delta\phi_{jj}$
m_{jj}
10
Giovanni Marchiori
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Sécurité
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Écran partagé
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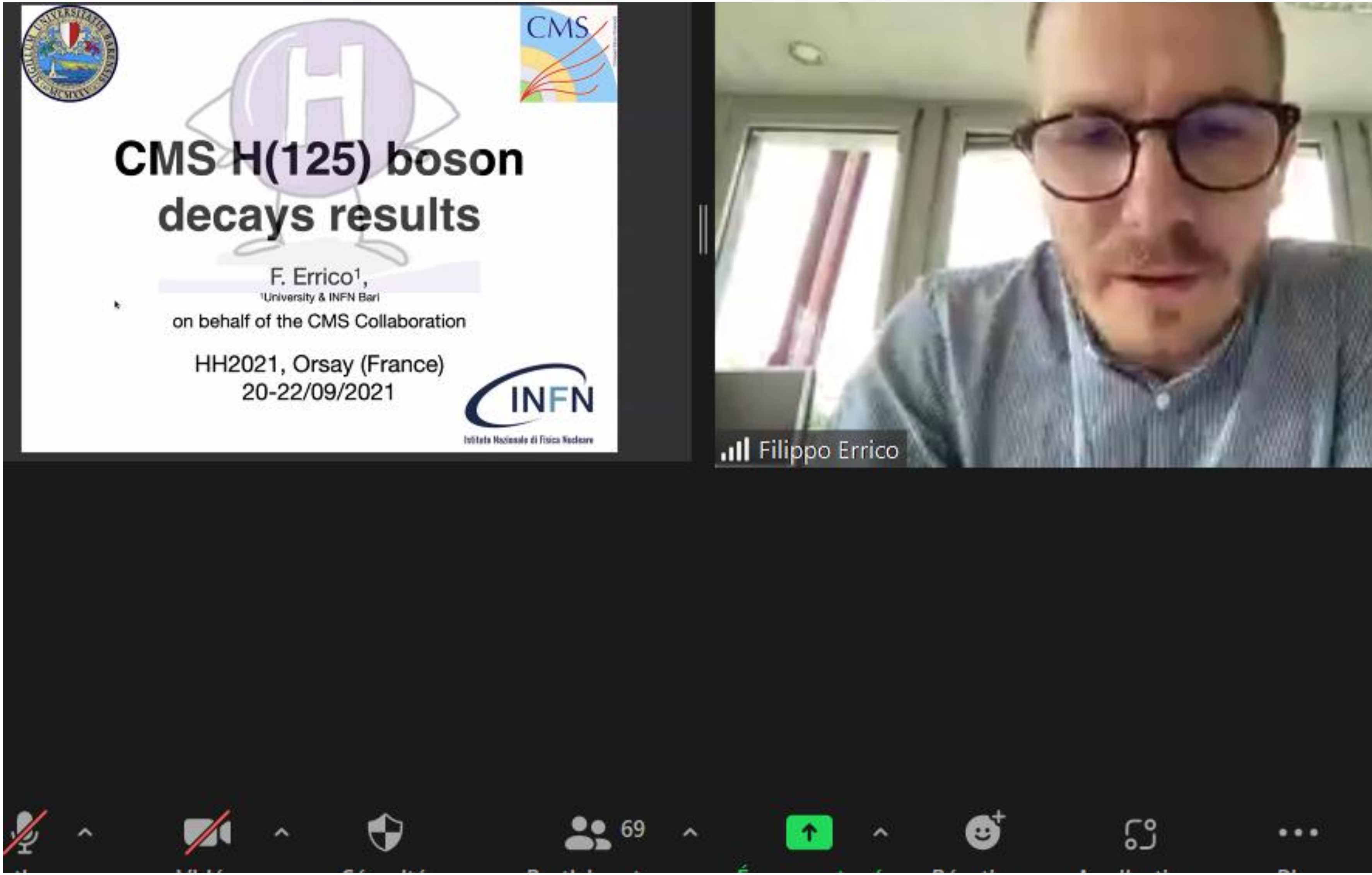
Applications


CMS
CMS H(125) boson
decays results
F. Errico[1],
[1]University & INFN Bari
on behalf of the CMS Collaboration
HH2021, Orsay (France)
20-22/09/2021
INFN
Istituto Nazionale di Fisica Nucleare
Filippo Errico
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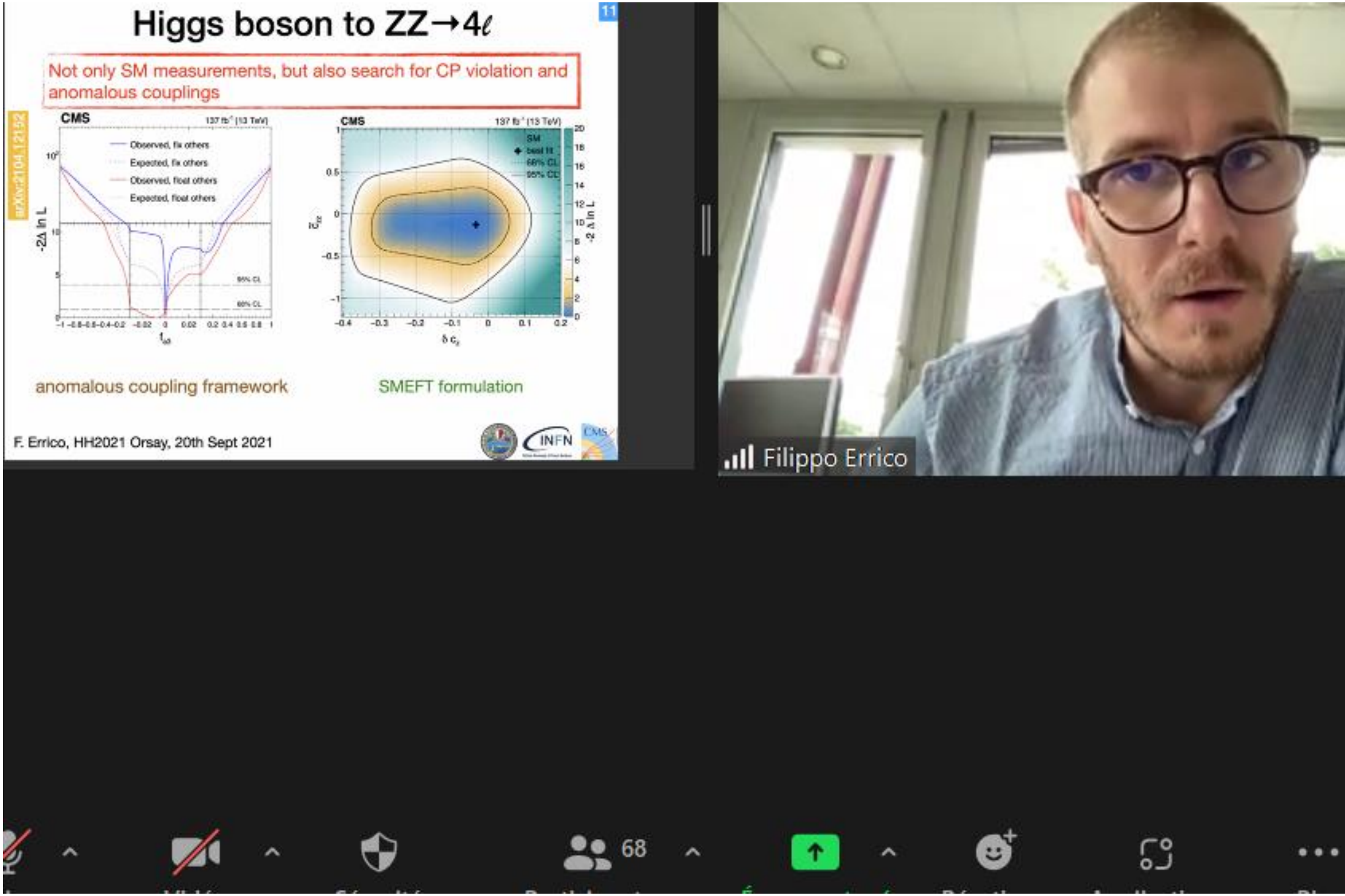
Higgs boson to ZZ→4ℓ
Not only SM measurements, but also search for CP violation and anomalous couplings
arXiv:2104.12152
CMS
137 fb⁻¹ (13 TeV)
Observed, fix others
Expected, fix others
Observed, float others
Expected, float others
-2Δ ln L
95% CL
68% CL
SM
best fit
68% CL
95% CL
-2 Δ ln L
δ c_z
anomalous coupling framework
SMEFT formulation
F. Errico, HH2021 Orsay, 20th Sept 2021
INFN
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Filippo Errico
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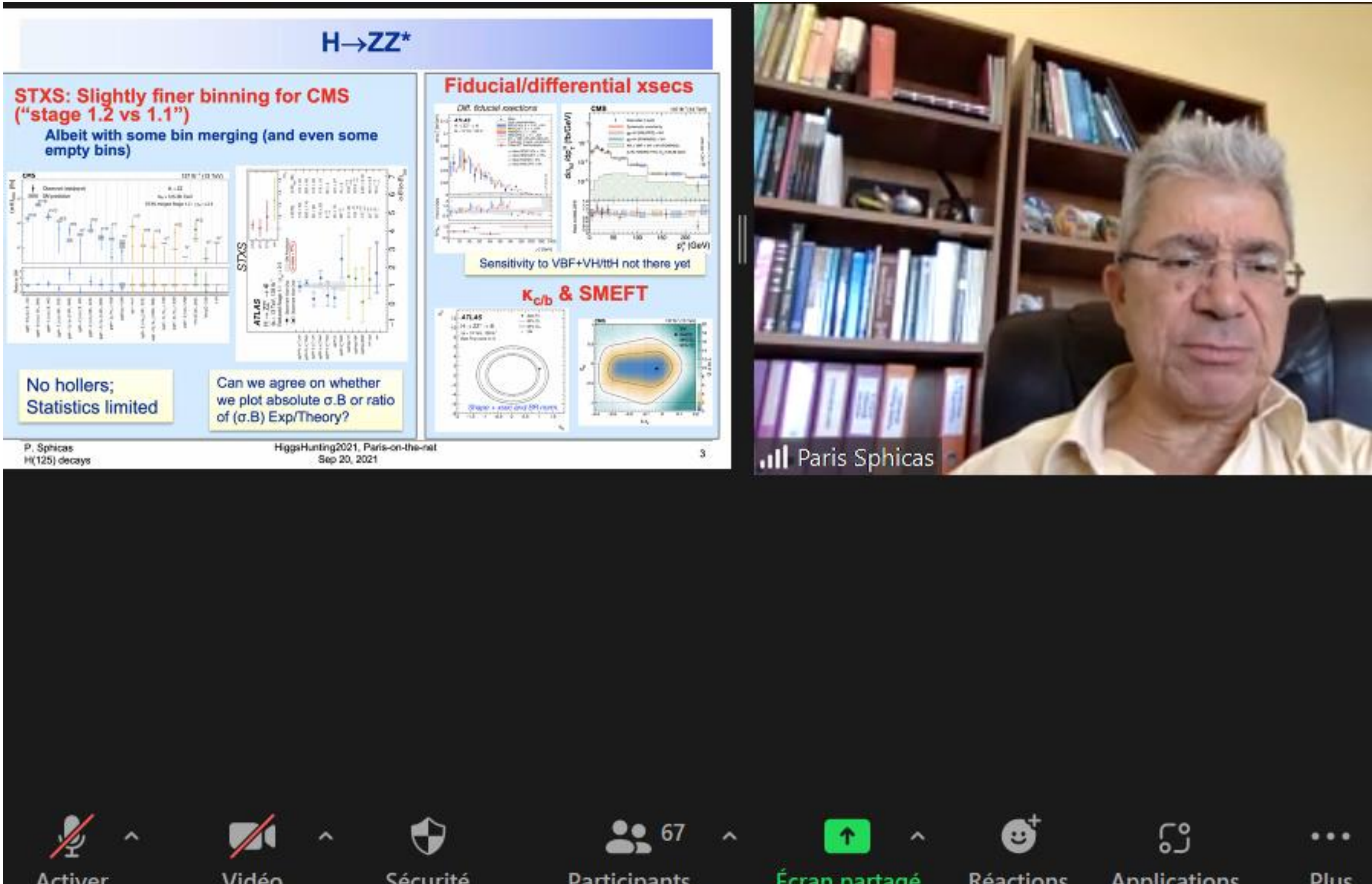
H→ZZ*
STXS: Slightly finer binning for CMS ("stage 1.2 vs 1.1")
Albeit with some bin merging (and even some empty bins)
STXS
ATLAS
No hollers; Statistics limited
Can we agree on whether we plot absolute σ.B or ratio of (σ.B) Exp/Theory?
Fiducial/differential xsecs
Diff. fiducial xsections
ATLAS
CMS
Sensitivity to VBF+VH/ttH not there yet
κc/b & SMEFT
ATLAS
CMS
P. Sphicas
H(125) decays
HiggsHunting2021, Paris-on-the-net
Sep 20, 2021
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Paris Sphicas
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Écran partagé
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Applications
Plus


Filippo Errico
Giovanni Marchiori
Paris Sphicas
Enregistrement...
Arrêter l'enregistrement (Alt+R)
Paris Sphicas
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Écran partagé
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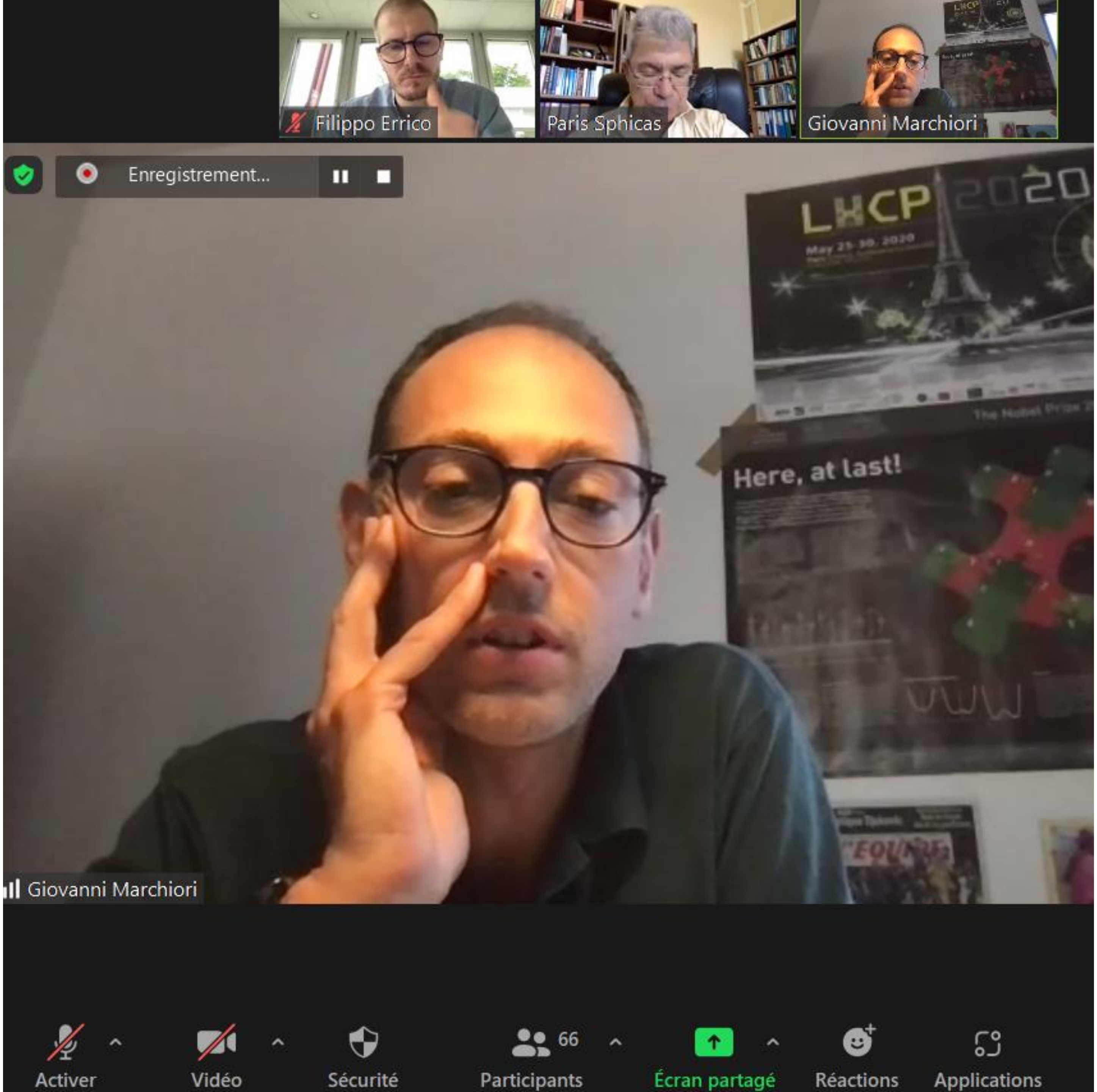
Plus



Filippo Errico
Paris Sphicas
Giovanni Marchiori
Enregistrement...
LHCP 2020
May 25-30, 2020
Here, at last!
Giovanni Marchiori
Activer
Vidéo
Sécurité
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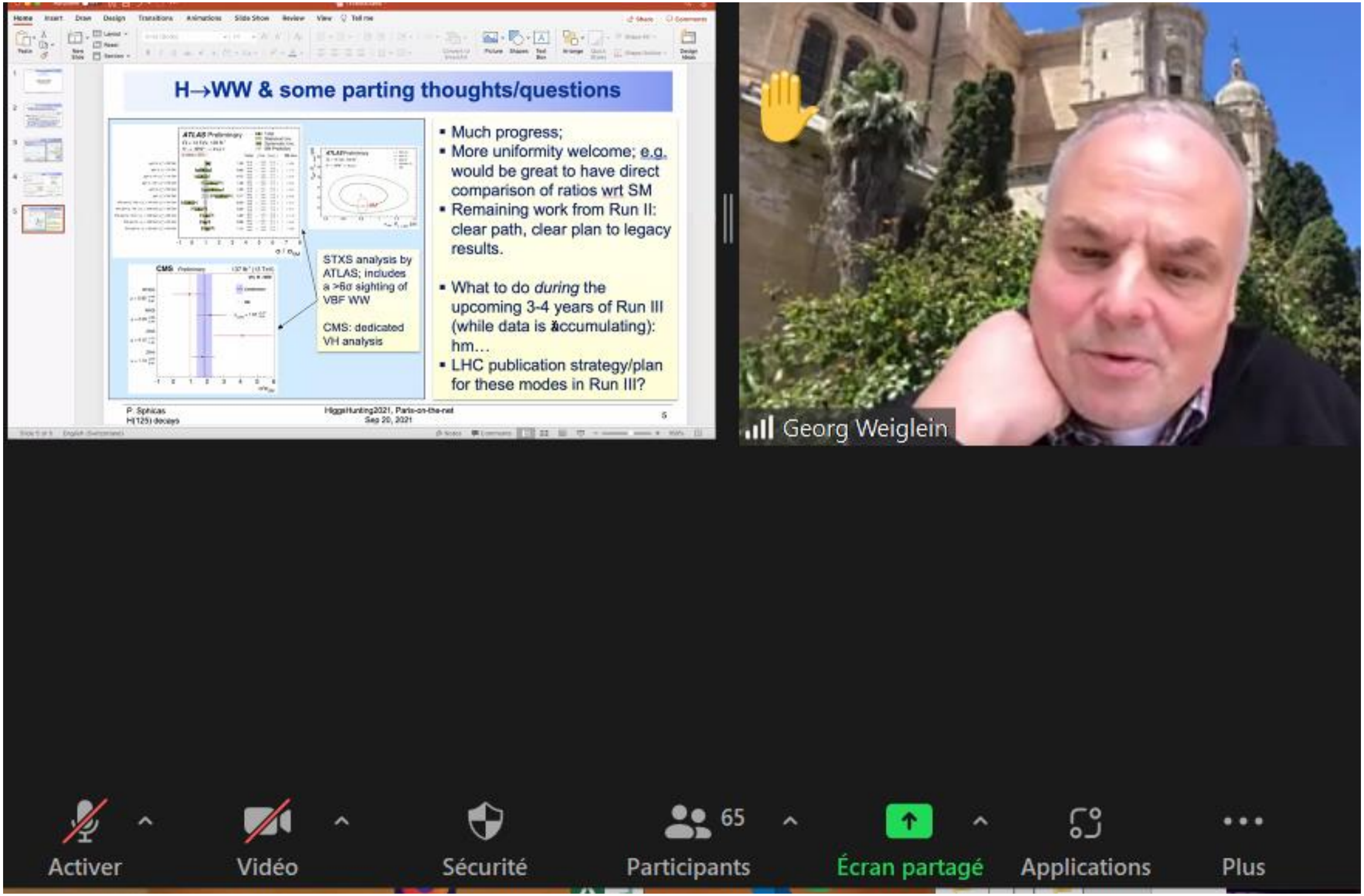
Participants
Écran partagé
Réactions
Applications


H→WW & some parting thoughts/questions
Much progress;
More uniformity welcome; e.g. would be great to have direct comparison of ratios wrt SM
Remaining work from Run II: clear path, clear plan to legacy results.
What to do during the upcoming 3-4 years of Run III (while data is accumulating): hm…
LHC publication strategy/plan for these modes in Run III?
STXS analysis by ATLAS; includes a >6σ sighting of VBF WW
CMS: dedicated VH analysis
P. Sphicas
H(125) decays
HiggsHunting2021, Paris-on-the-net
Sep 20, 2021
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Georg Weiglein
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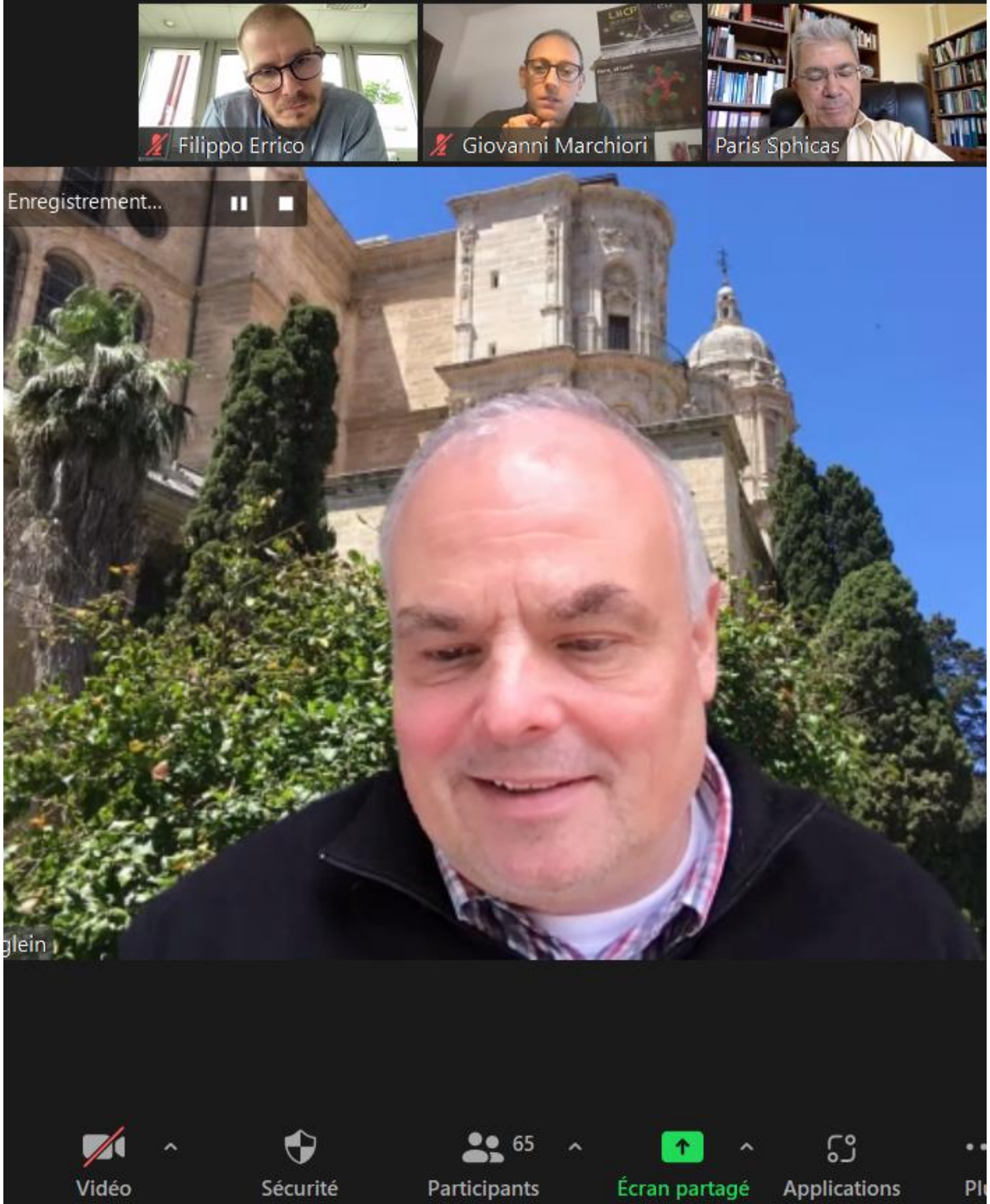
Plus


Filippo Errico
Giovanni Marchiori
Paris Sphicas
Enregistrement...
glein
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Applications


Filippo Errico
Giovanni Marchiori
Georg Weiglein
strement...
Vidéo
Sécurité
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Écran partagé
Applications


Andrei Gritsan
Andrei Gritsan
Activer
Vidéo
Sécurité
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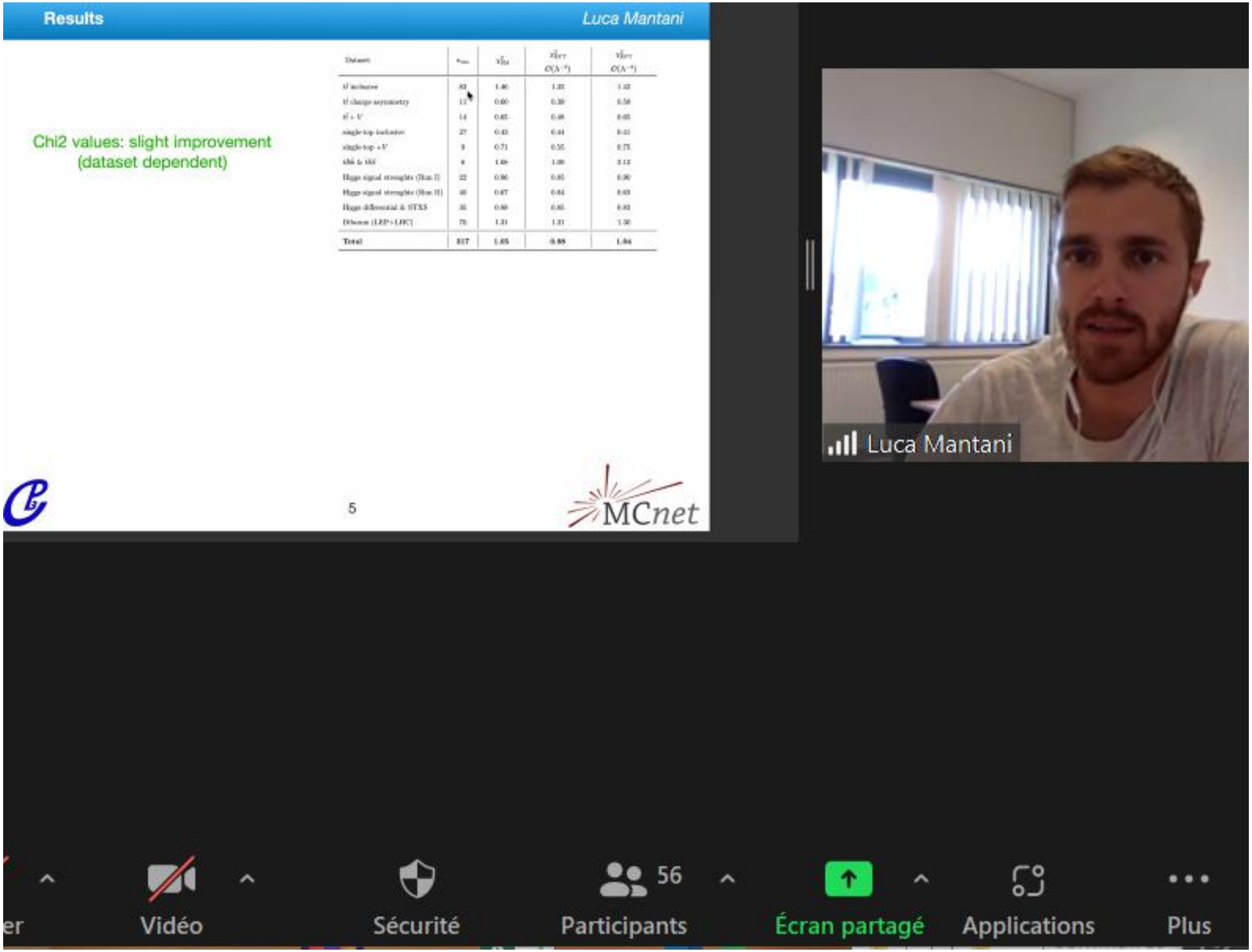
Participants
Écran partagé
Applications
Plus

Data

Luca Mantani

Category	Processes	$n_{\rm dat}$
Top quark production	$t\bar{t}$ (inclusive)	94
	$t\bar{t}Z$, $t\bar{t}W$	14
	single top (inclusive)	27
	tZ, tW	9
	$t\bar{t}t\bar{t}$, $t\bar{t}b\bar{b}$	6
	Total	**150**
Higgs production and decay	Run I signal strengths	22
	Run II signal strengths	40
	Run II, differential distributions & STXS	35
	Total	**97**
Diboson production	LEP-2	40
	LHC	30
	Total	**70**
Baseline dataset	**Total**	**317**

MCnet


Results
Luca Mantani
Chi2 values: slight improvement
(dataset dependent)
Total
5
MCnet
Luca Mantani
Vidéo
Sécurité
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Participants
Écran partagé
Applications
Plus

EFT operators

Luca Mantani

EWPO

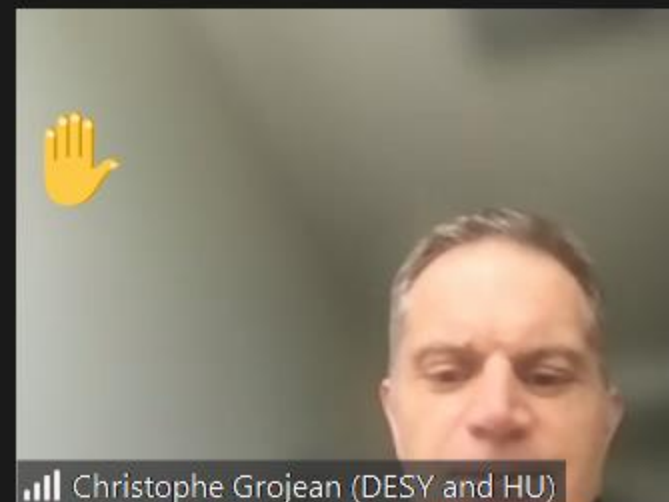
$$\frac{1}{4}g_1^2\left(-2c_{\varphi l_1}^{(3)}-2c_{\varphi l_2}^{(3)}+c_{ll}\right)-\frac{c_{\varphi D}g_w^2}{4}-g_1 g_w c_{\varphi WB},$$
$$c_{\varphi l_i}^{(3)}-f\left(-\frac{1}{2},-1\right)+f\left(\frac{1}{2},0\right)\quad i=1,2,3,$$
$$f\left(-\frac{1}{2},-1\right)-\frac{c_{\varphi l_i}^{(3)}}{2}-\frac{c_{\varphi l_i}^{(1)}}{2}\quad i=1,2,3,$$
$$f(0,-1)-\frac{c_{\varphi e}}{2},\quad f(0,-1)-\frac{c_{\varphi\mu}}{2},\quad f(0,-1)-\frac{c_{\varphi\tau}}{2},$$
$$f\left(\frac{1}{2},\frac{2}{3}\right)-\frac{c_{\varphi q}^{(-)}}{2},\quad f\left(-\frac{1}{2},-\frac{1}{3}\right)-\frac{c_{\varphi q}^{(-)}}{2}-c_{\varphi q}^{(3)}$$
$$f\left(0,\frac{2}{3}\right)-\frac{c_{\varphi u}}{2},\quad f\left(0,-\frac{1}{3}\right)-\frac{c_{\varphi d}}{2},$$

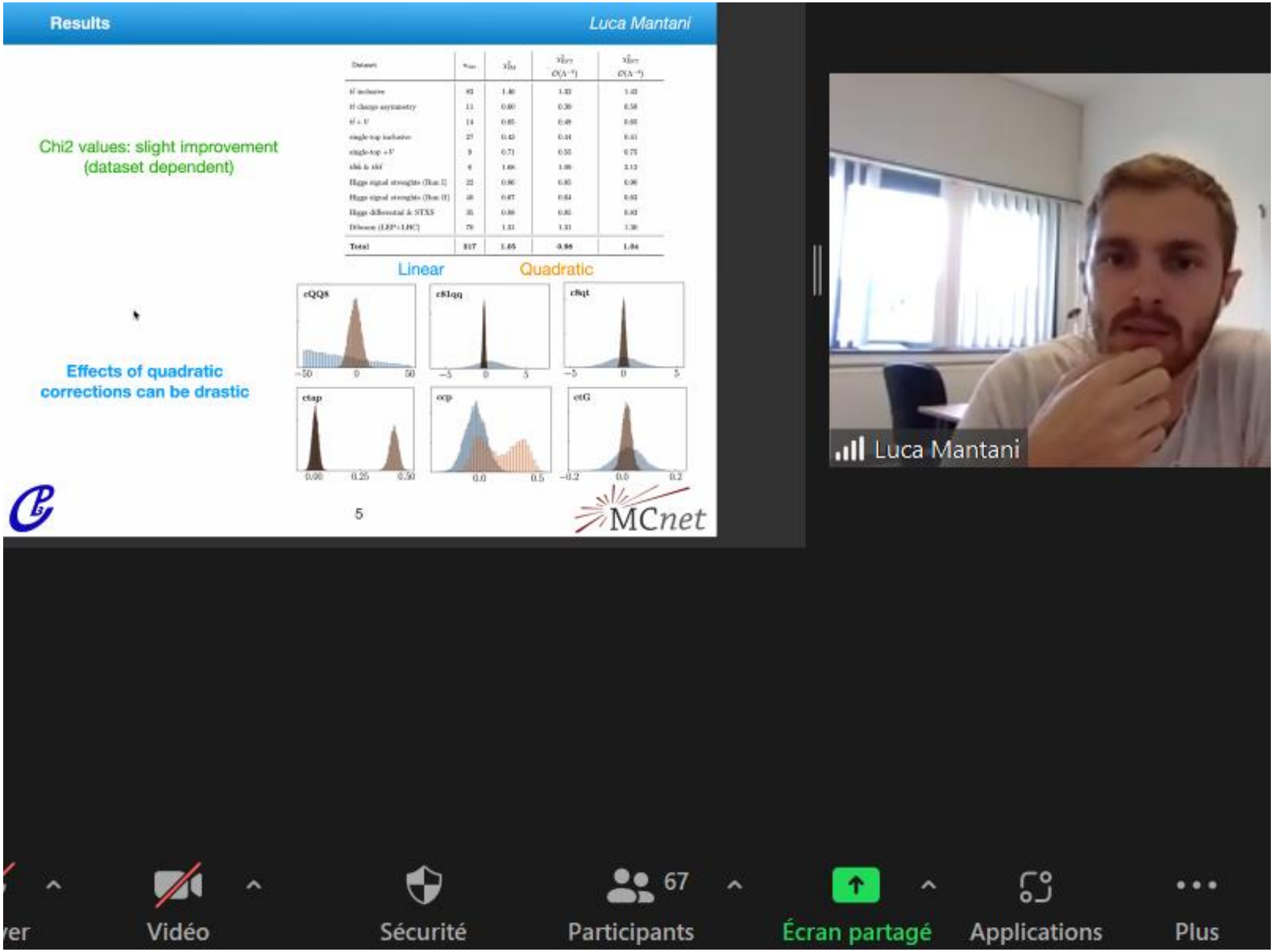
where the function f is given by:

$$f(T_3,Q)=\left(-\frac{c_{\varphi l_1}^{(3)}}{2}-\frac{c_{\varphi l_2}^{(3)}}{2}+\frac{c_{ll}}{4}-\frac{c_{\varphi D}}{4}\right)\left(\frac{g_1^2 Q}{g_w^2-g_1^2}+T_3\right)$$
$$-c_{\varphi WB}\frac{Q g_1 g_w}{g_w^2-g_1^2},$$

Class	N_{dof}	Independent DOFs	DoF in EWPOs
four-quark (two-light-two-heavy)	14	$c_{Qq}^{1,8}, c_{Qq}^{1,1}, c_{Qq}^{3,8}, c_{Qq}^{3,1}, c_{tq}^{8}, c_{tq}^{1}, c_{tu}^{8}, c_{tu}^{1}, c_{Qu}^{8}, c_{Qu}^{1}, c_{td}^{8}, c_{td}^{1}, c_{Qd}^{8}, c_{Qd}^{1}$	
four-quark (four-heavy)	5	$c_{QQ}^{1}, c_{QQ}^{8}, c_{Qt}^{1}, c_{Qt}^{8}, c_{tt}^{1}$	
four-lepton	1		c_{ll}
two-fermion (+ bosonic fields)	23	$c_{t\varphi}, c_{tG}, c_{b\varphi}, c_{c\varphi}, c_{\tau\varphi}, c_{tW}, c_{tZ}, c_{\varphi Q}^{(3)}, c_{\varphi Q}^{(-)}, c_{\varphi t}$	$c_{\varphi l_1}^{(1)}, c_{\varphi l_1}^{(3)}, c_{\varphi l_2}^{(1)}, c_{\varphi l_2}^{(3)}, c_{\varphi l_3}^{(1)}, c_{\varphi l_3}^{(3)}, c_{\varphi e}, c_{\varphi\mu}, c_{\varphi\tau}, c_{\varphi q}^{(3)}, c_{\varphi q}^{(-)}, c_{\varphi u}, c_{\varphi d}$
Purely bosonic	7	$c_{\varphi G}, c_{\varphi B}, c_{\varphi W}, c_{\varphi d}, c_{WWW}$	$c_{\varphi WB}, c_{\varphi D}$
Total	50 (36 independent)	34	16 (2 independent)

MCnet




Results
Luca Mantani
Chi2 values: slight improvement (dataset dependent)
Linear
Quadratic
Effects of quadratic corrections can be drastic
cQQ8
c81qq
c8qt
ctap
ccp
ctG
5
MCnet
Luca Mantani
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Applications
Plus

A NLO+PS generator for H → VV production in gluon fusion including non-resonant and offshell effects

UNIVERSITY OF OXFORD

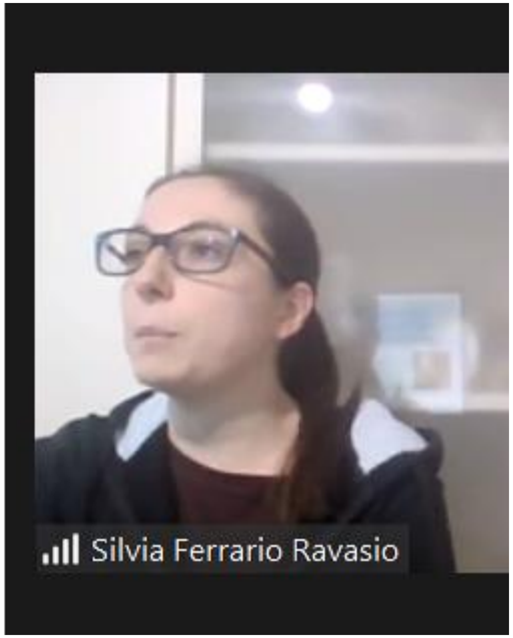
Silvia Ferrario Ravasio
Oxford University

erc

Higgs Hunting 2021

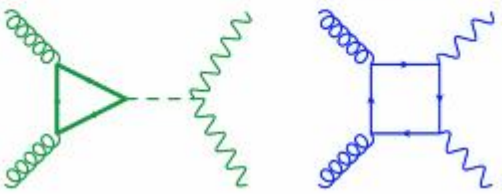
Orsay-Paris, online, 20th September 2021

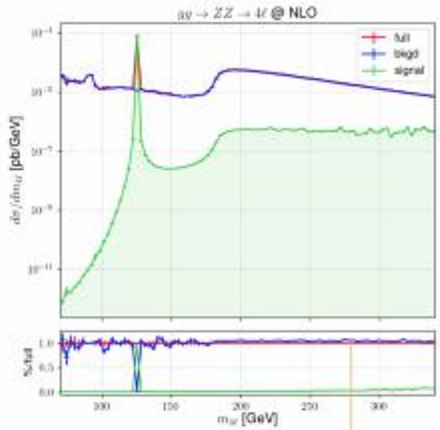
based on *Eur. Phys. J. C* 81, 687 (2021), [2102.07783], S. Alioli, S.F.R., J.M. Lindert and R. Röntsch



Anatomy of $gg \to H \to VV$

- Gluon fusion is the dominant mechanism for Higgs production at the LHC
- $H \to VV$ sensitive to the Higgs - gauge bosons coupling
- Roughly 10% of $gg \to H \to VV$ comes from $m_{VV} > m_V$
- Offshell Higgs cross section important to determine $\Gamma_H \ll$ detector resolutions
- **QCD bakground $gg \to VV$** is dominant and cannot be distinguished from the **signal**
- The **full** contribution is given by the sum of background, signal as well as their **interference**





Sizeable and negative **interference** for large m_{VV}

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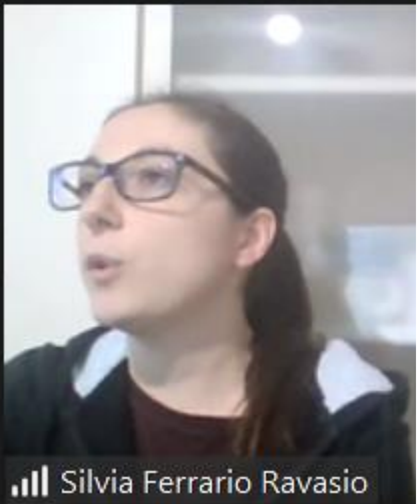

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Anatomy of pp → VV → 4l

- gg → VV contributes to the NNLO QCD corrections to pp → VV, and can be computed separately

Contribution	σ [fb]
LO	$36.8^{+2.9}_{-2.6}$
NLO	$49.0^{+1.5}_{-1.4}$
NNLO (no gg)	$52.1^{+0.7}_{-0.7}$
gg @ LO	$4.3^{+1.1}_{-0.8}$
gg @ NLO	$7.8^{+1.3}_{-1.1}$

ATLAS fiducial cuts for gg → ZZ → 4l @ 13 TeV, 1902.05892

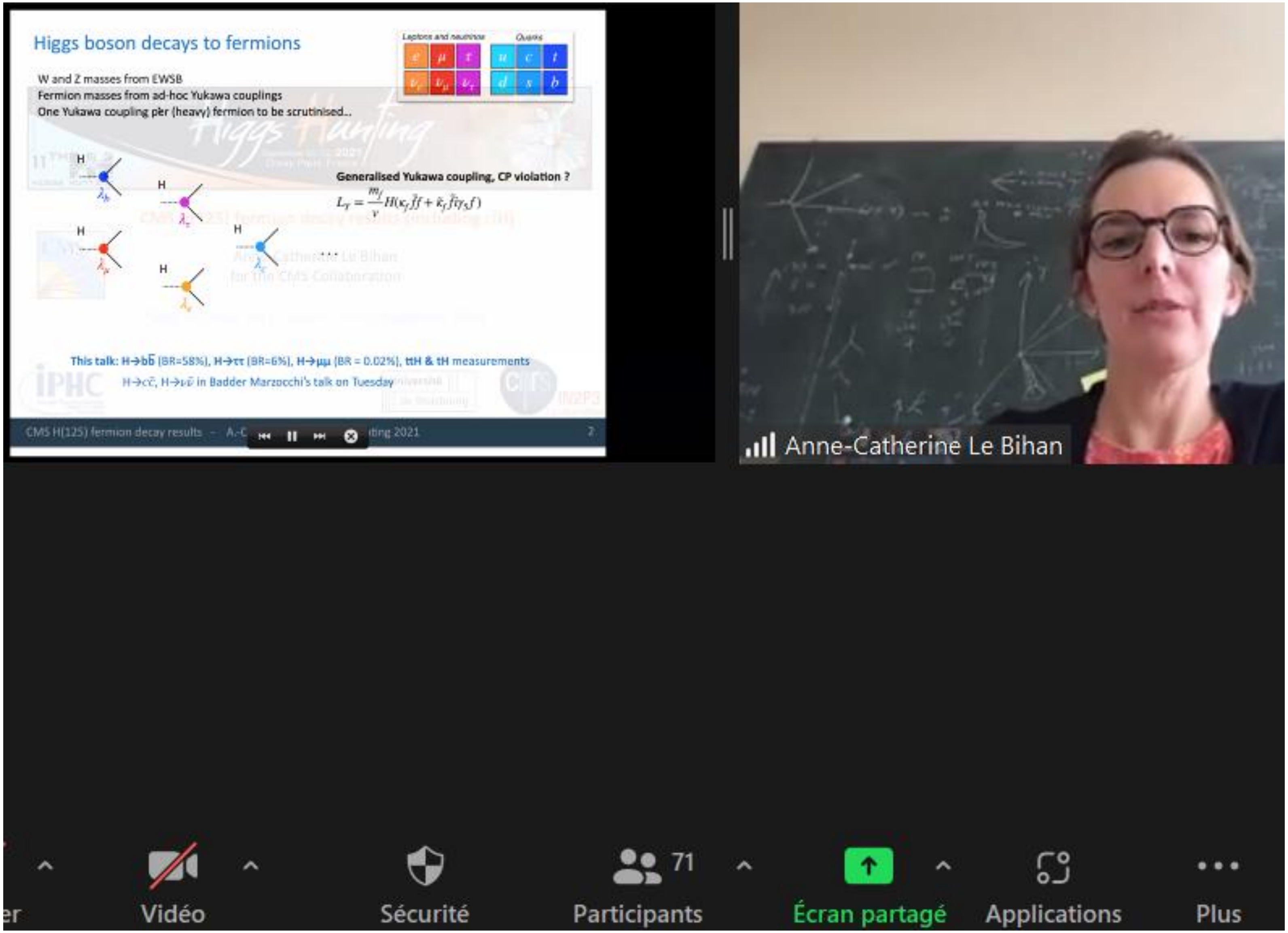
Grazzini, Kallweit, Wiesemann, Yook '21

$O(\alpha_s^2)$= 3.1 + **4.3** pb, the gluon-fusion channel is enhanced by the large gluon luminosity

Large NLO corrections

A lot of recent activity!

- pp → WW → 4l (MiNNLO$_{PS}$, Lombardi, Wiesemann, Zanderighi '21, [Re, Wiesemann, Zanderighi '18]) and pp → ZZ → 4l (GENEVA, Alioli, Broggio, Gavardi, Kallweit, Lim, Nagar, Napoletano '21; MiNNLO$_{PS}$: Buonocore, Koole, Lombardi, Rottoli, Wiesemann, Zanderighi '21) are both known at **NNLOPS**.
- In this talk: **gg → VV → 4l at NLOPS** in **POWHEG BOX RES**, with spin correlations, interferences and off-shell effects are included exactly, top-quark mass effects are included approximately in the QCD bkgd (S. Alioli, S.F.R., J.M. Lindert and R. Röntsch '21)


Higgs boson decays to fermions
W and Z masses from EWSB
Fermion masses from ad-hoc Yukawa couplings
One Yukawa coupling per (heavy) fermion to be scrutinised...
Generalised Yukawa coupling, CP violation ?
This talk: H→bb̄ (BR=58%), H→ττ (BR=6%), H→μμ (BR = 0.02%), ttH & tH measurements
H→cc̄, H→νν̄ in Badder Marzocchi's talk on Tuesday
CMS H(125) fermion decay results
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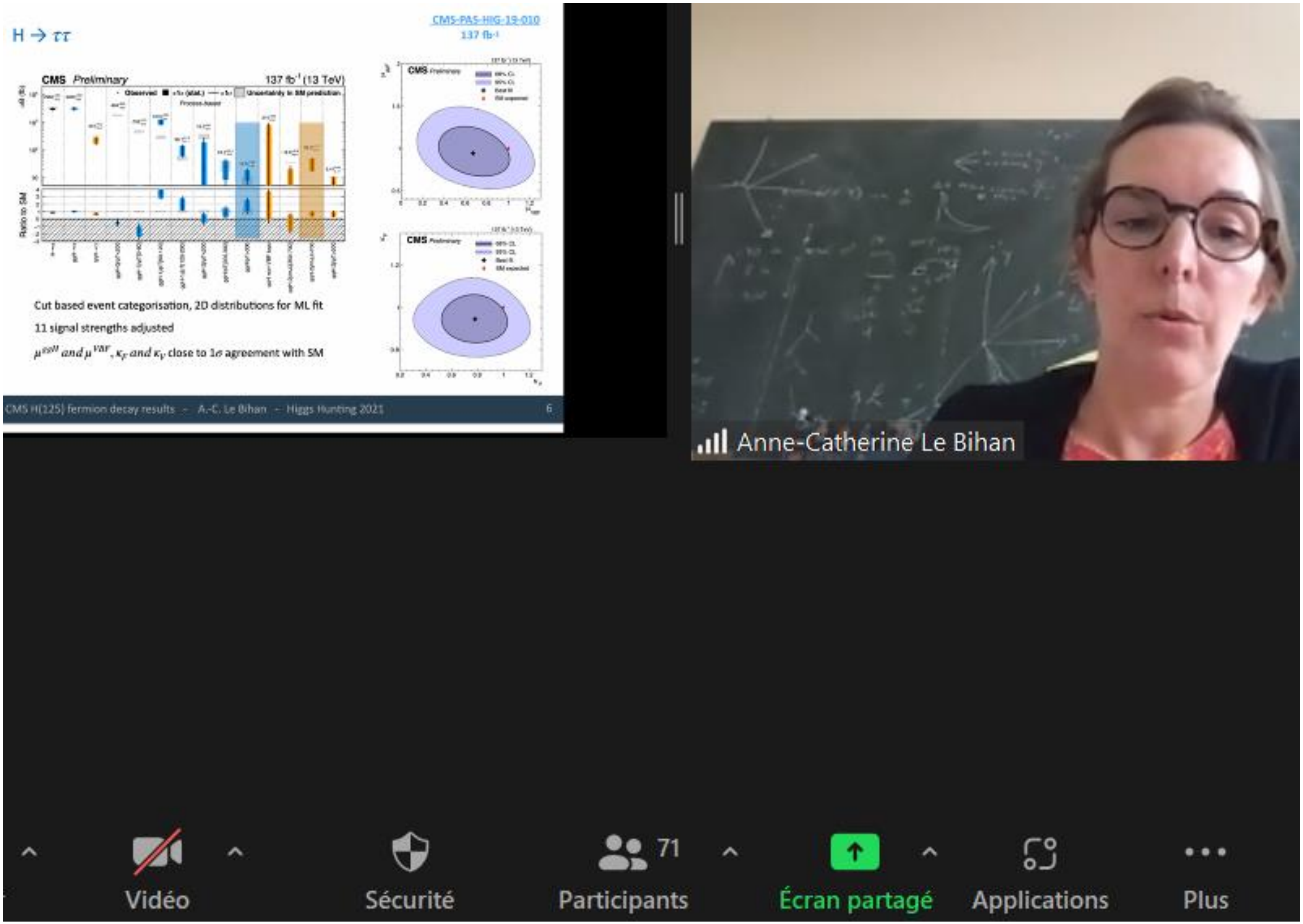
H → ττ
CMS-PAS-HIG-19-010
137 fb-1
CMS Preliminary
137 fb-1 (13 TeV)
Cut based event categorisation, 2D distributions for ML fit
11 signal strengths adjusted
μggH and μVBF, κF and κV close to 1σ agreement with SM
CMS H(125) fermion decay results - A.-C. Le Bihan - Higgs Hunting 2021
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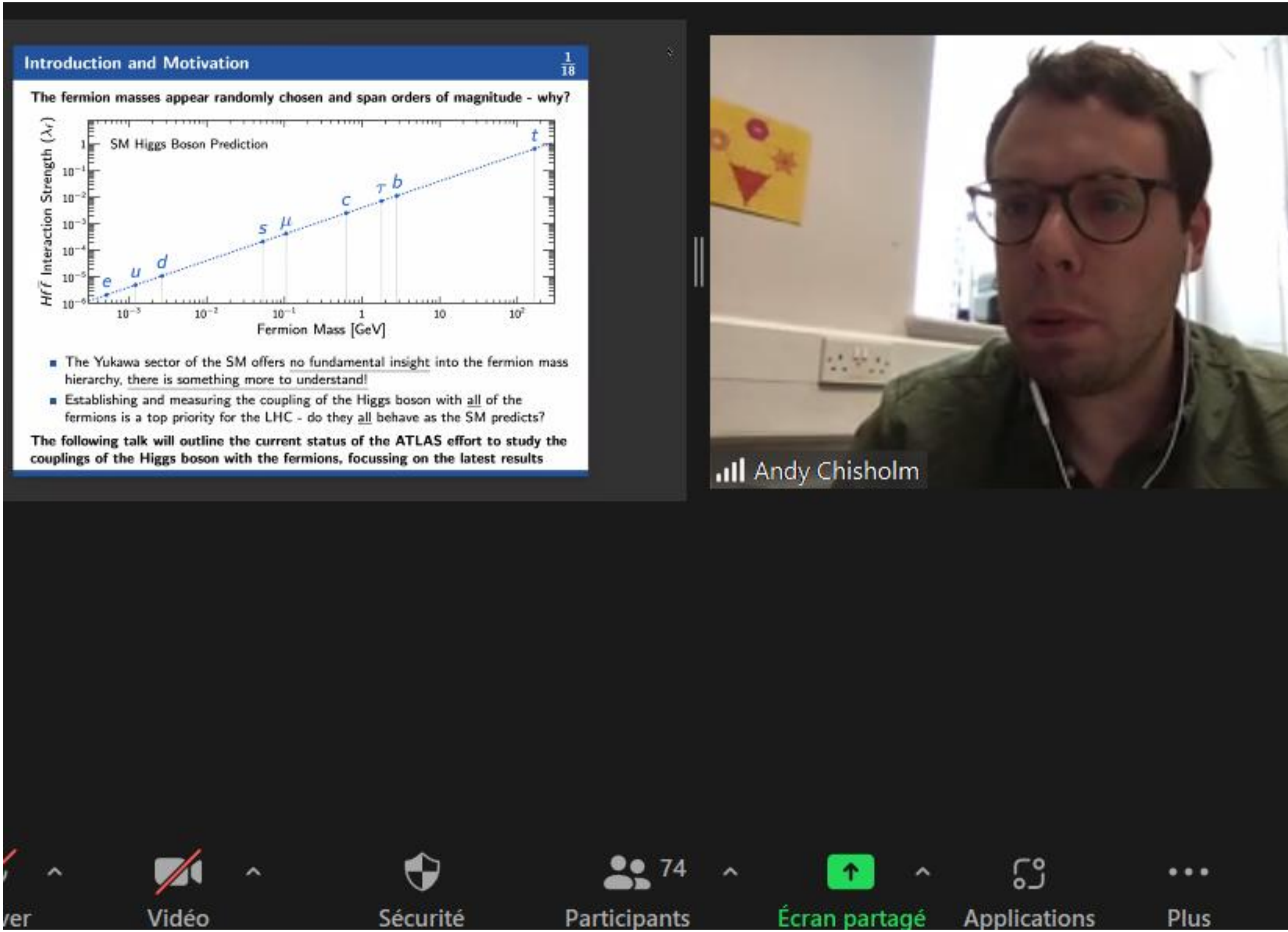
Introduction and Motivation
1/18
The fermion masses appear randomly chosen and span orders of magnitude - why?
SM Higgs Boson Prediction
Hff̄ Interaction Strength (λf)
Fermion Mass [GeV]
e u d s μ c τ b t
The Yukawa sector of the SM offers no fundamental insight into the fermion mass hierarchy, there is something more to understand!
Establishing and measuring the coupling of the Higgs boson with all of the fermions is a top priority for the LHC - do they all behave as the SM predicts?
The following talk will outline the current status of the ATLAS effort to study the couplings of the Higgs boson with the fermions, focussing on the latest results
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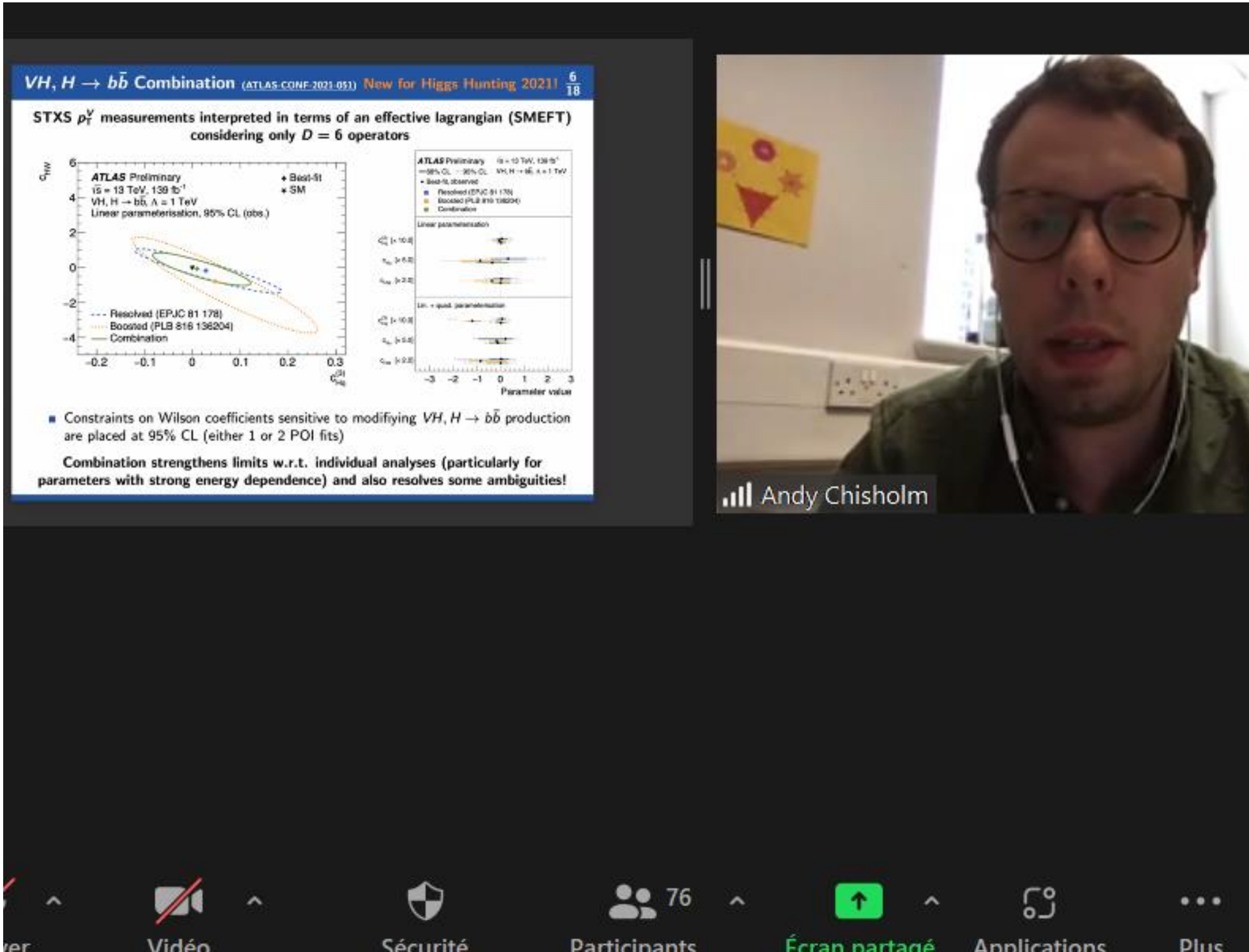
VH, H → bb̄ Combination (ATLAS-CONF-2021-051) New for Higgs Hunting 2021! 6/18
STXS p_T^V measurements interpreted in terms of an effective lagrangian (SMEFT) considering only $D = 6$ operators
ATLAS Preliminary
√s = 13 TeV, 139 fb⁻¹
VH, H → bb̄, Λ = 1 TeV
Linear parameterisation, 95% CL (obs.)
Best-fit
SM
Resolved (EPJC 81 178)
Boosted (PLB 816 136204)
Combination
Linear parameterisation
Lin. + quad. parameterisation
Parameter value
Constraints on Wilson coefficients sensitive to modifiying $VH, H \to b\bar{b}$ production are placed at 95% CL (either 1 or 2 POI fits)
Combination strengthens limits w.r.t. individual analyses (particularly for parameters with strong energy dependence) and also resolves some ambiguities!
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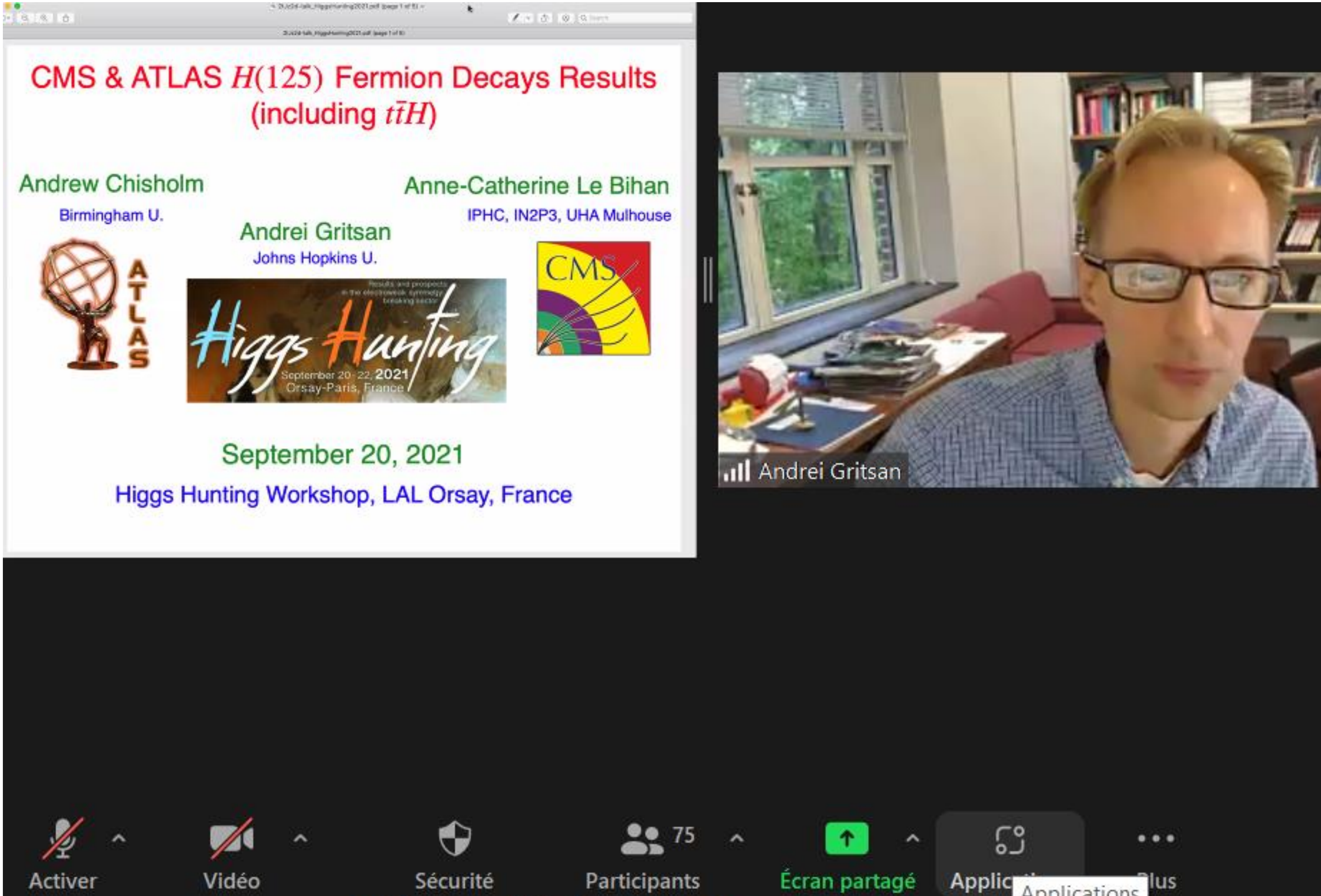
CMS & ATLAS $H(125)$ Fermion Decays Results
(including $t\bar{t}H$)
Andrew Chisholm
Birmingham U.
Anne-Catherine Le Bihan
IPHC, IN2P3, UHA Mulhouse
Andrei Gritsan
Johns Hopkins U.
ATLAS
Higgs Hunting
September 20-22, 2021
Orsay-Paris, France
CMS
September 20, 2021
Higgs Hunting Workshop, LAL Orsay, France
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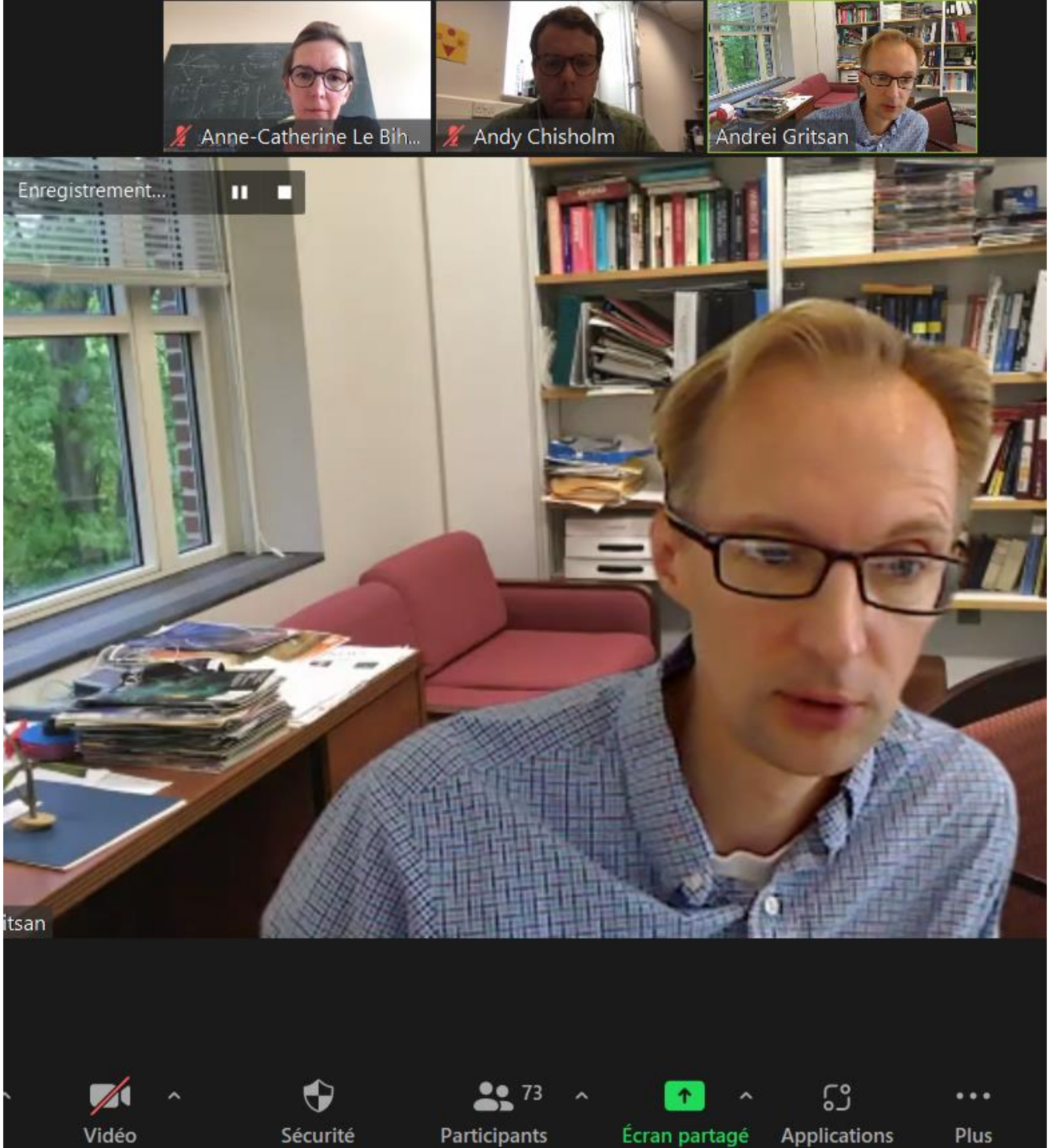
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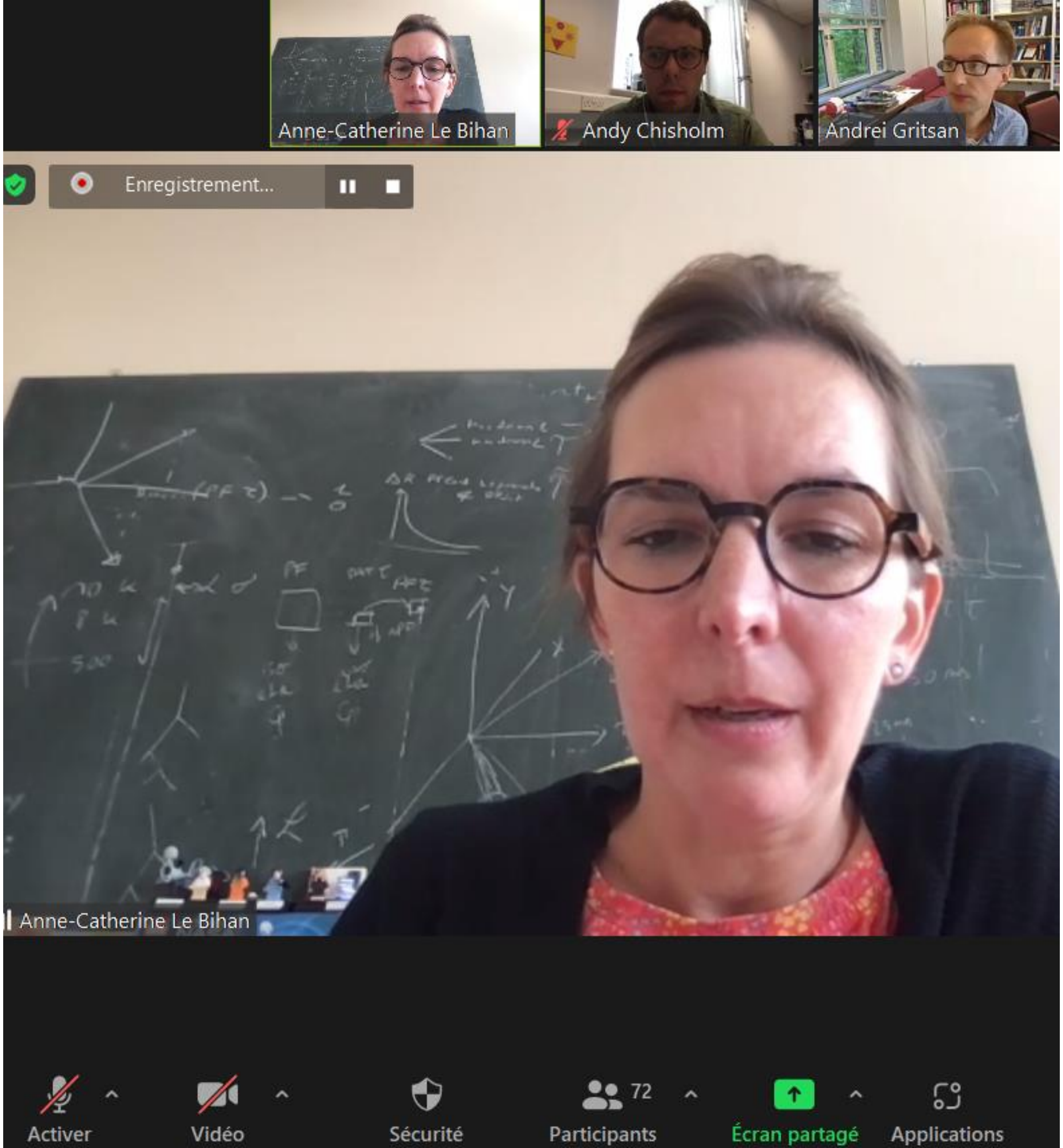
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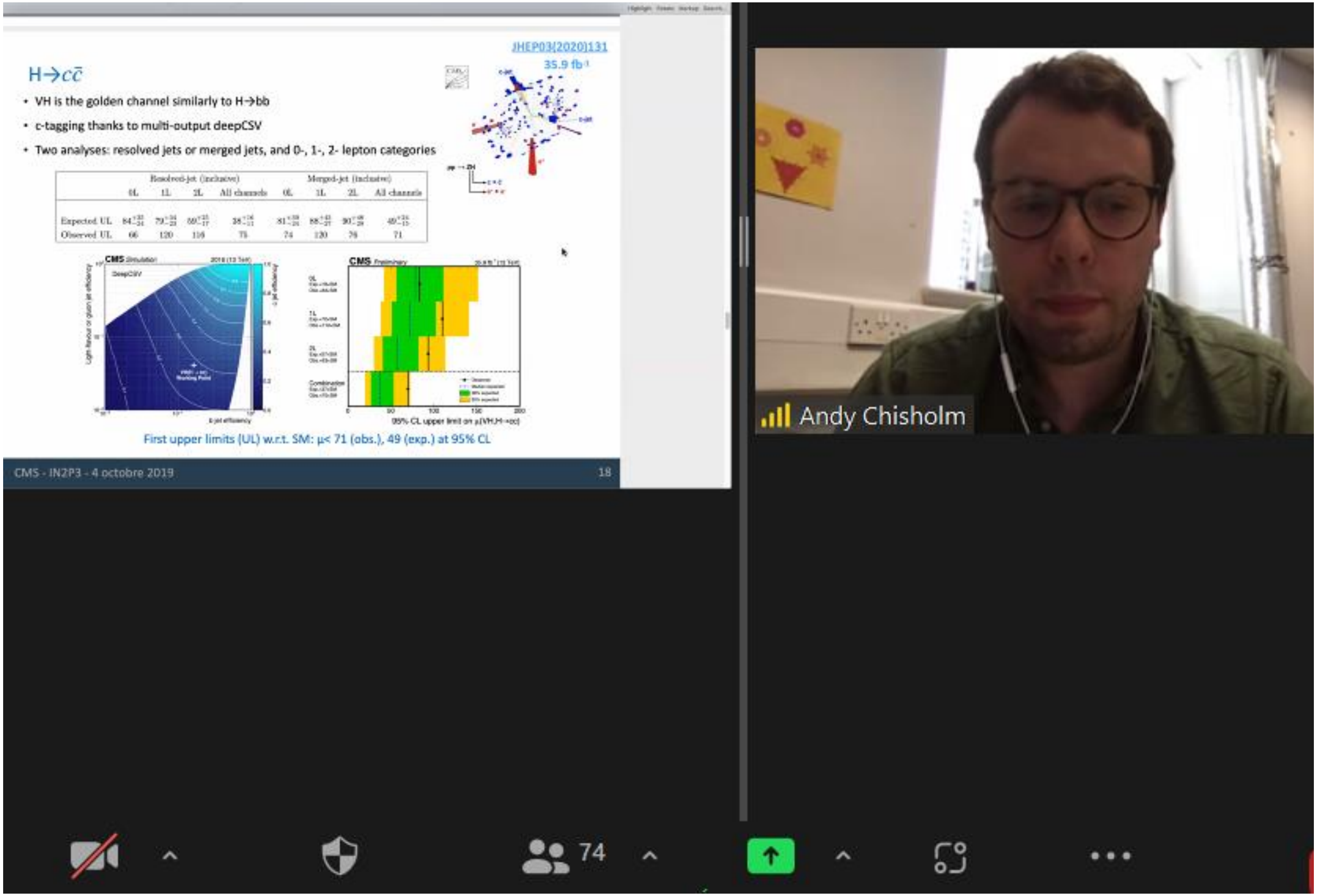
JHEP03(2020)131
35.9 fb-1
H→cc̄
• VH is the golden channel similarly to H→bb
• c-tagging thanks to multi-output deepCSV
• Two analyses: resolved jets or merged jets, and 0-, 1-, 2- lepton categories
Resolved-jet (inclusive)
Merged-jet (inclusive)
0L 1L 2L All channels 0L 1L 2L All channels
Expected UL
Observed UL
CMS Simulation
DeepCSV
CMS Preliminary
95% CL upper limit on μ(VH,H→cc)
First upper limits (UL) w.r.t. SM: μ< 71 (obs.), 49 (exp.) at 95% CL
CMS - IN2P3 - 4 octobre 2019
18
Andy Chisholm
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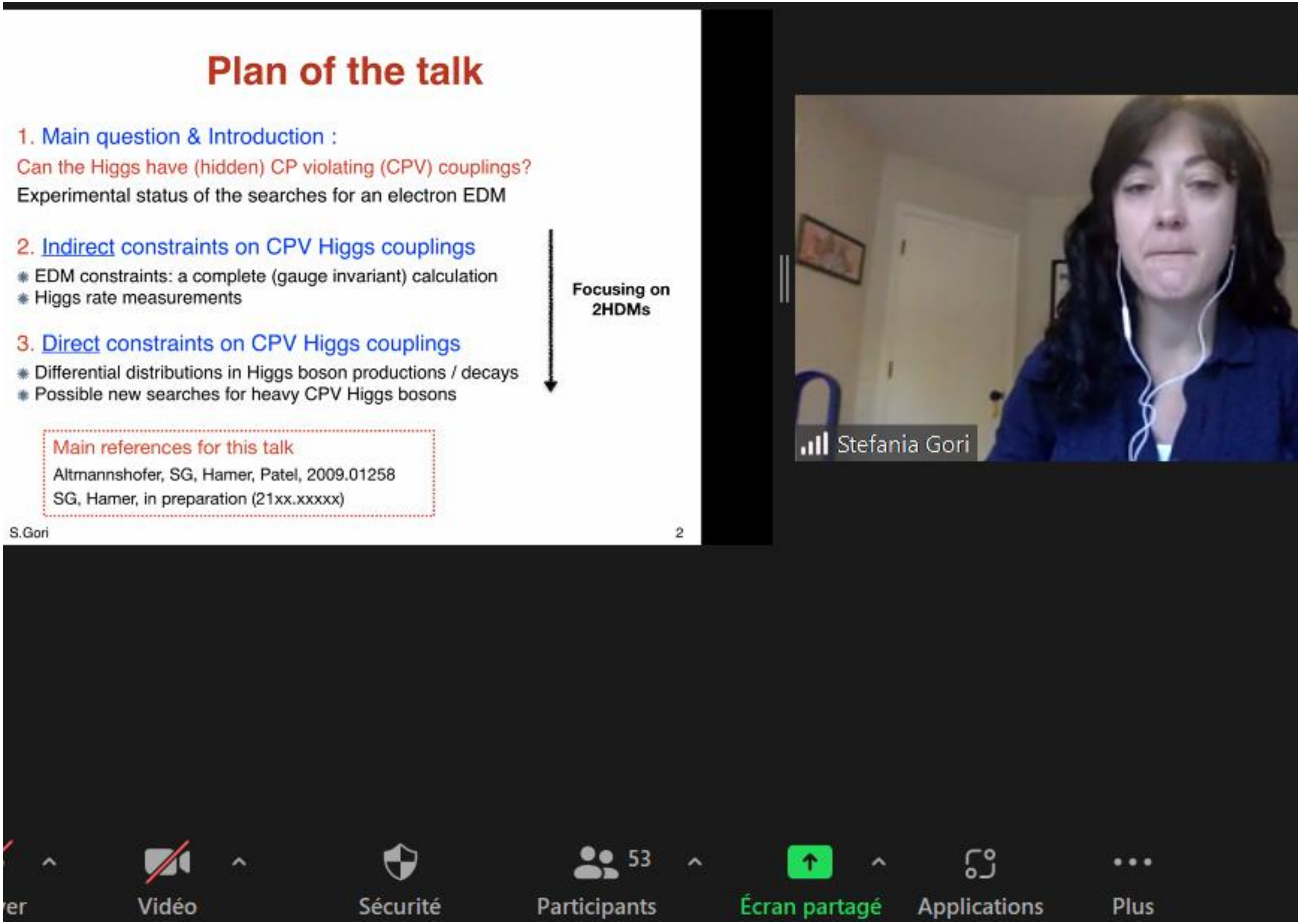
Plan of the talk
1. Main question & Introduction :
Can the Higgs have (hidden) CP violating (CPV) couplings?
Experimental status of the searches for an electron EDM
2. Indirect constraints on CPV Higgs couplings
EDM constraints: a complete (gauge invariant) calculation
Higgs rate measurements
3. Direct constraints on CPV Higgs couplings
Differential distributions in Higgs boson productions / decays
Possible new searches for heavy CPV Higgs bosons
Focusing on 2HDMs
Main references for this talk
Altmannshofer, SG, Hamer, Patel, 2009.01258
SG, Hamer, in preparation (21xx.xxxxx)
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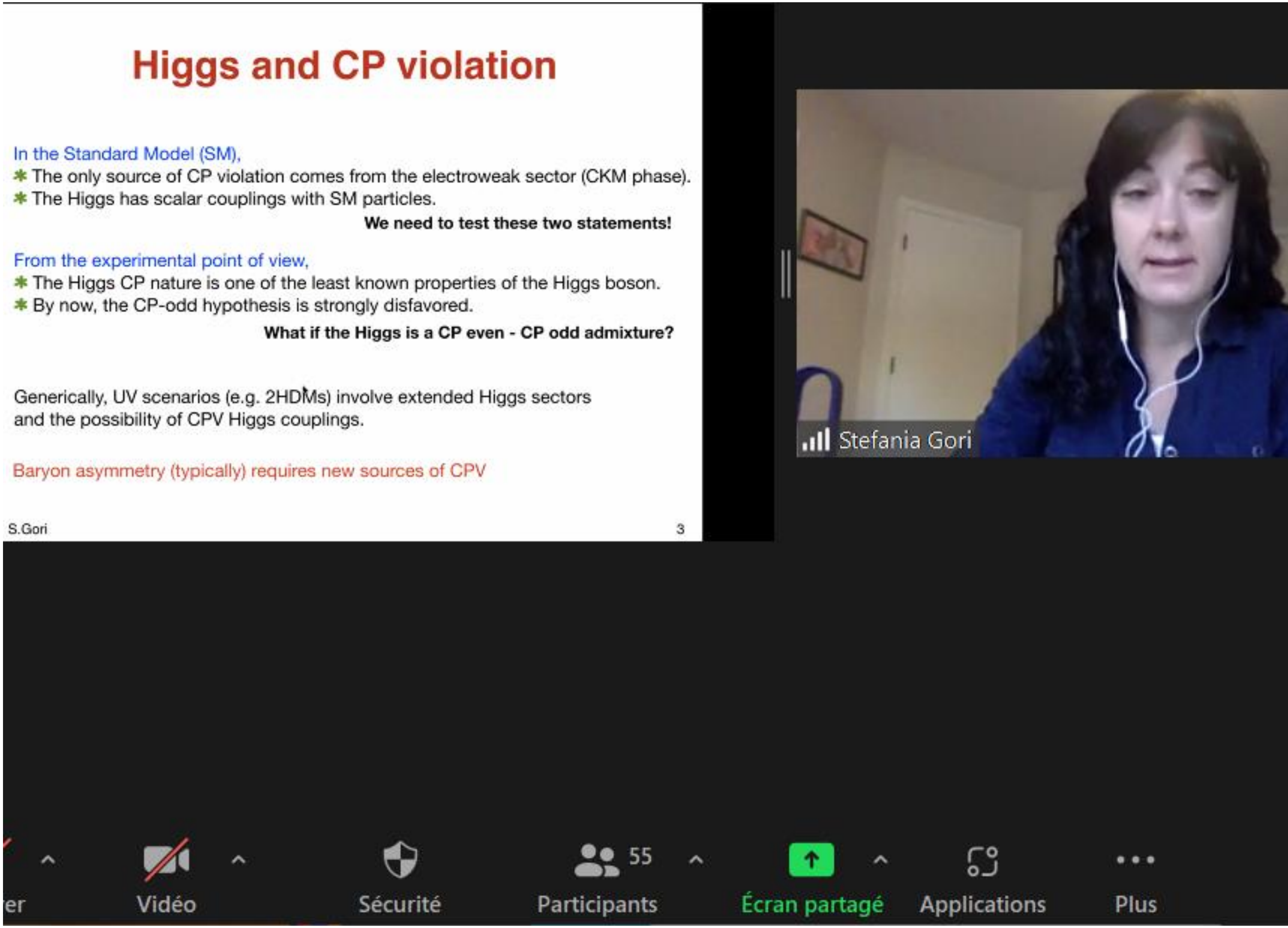
Higgs and CP violation
In the Standard Model (SM),
The only source of CP violation comes from the electroweak sector (CKM phase).
The Higgs has scalar couplings with SM particles.
We need to test these two statements!
From the experimental point of view,
The Higgs CP nature is one of the least known properties of the Higgs boson.
By now, the CP-odd hypothesis is strongly disfavored.
What if the Higgs is a CP even - CP odd admixture?
Generically, UV scenarios (e.g. 2HDMs) involve extended Higgs sectors and the possibility of CPV Higgs couplings.
Baryon asymmetry (typically) requires new sources of CPV
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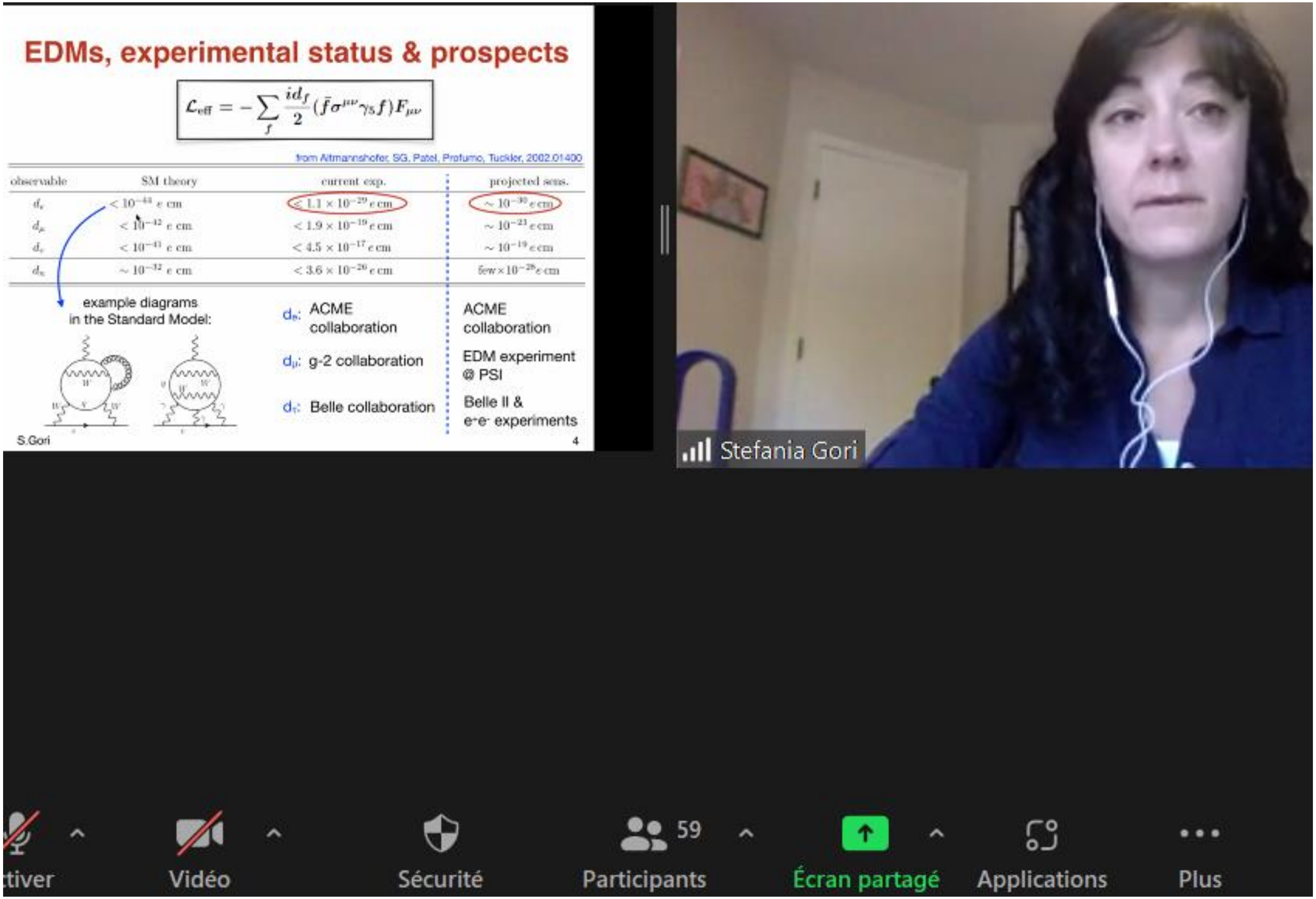
EDMs, experimental status & prospects
$\mathcal{L}_{\rm eff} = -\sum_f \frac{i d_f}{2} (\bar{f} \sigma^{\mu\nu} \gamma_5 f) F_{\mu\nu}$
from Altmannshofer, SG, Patel, Profumo, Tuckler, 2002.01400
observable | SM theory | current exp. | projected sens.
d_e | $< 10^{-44}$ e cm | $< 1.1 \times 10^{-29}$ e cm | $\sim 10^{-30}$ e cm
d_μ | $< 10^{-42}$ e cm | $< 1.9 \times 10^{-19}$ e cm | $\sim 10^{-21}$ e cm
d_τ | $< 10^{-41}$ e cm | $< 4.5 \times 10^{-17}$ e cm | $\sim 10^{-19}$ e cm
d_n | $\sim 10^{-32}$ e cm | $< 3.6 \times 10^{-26}$ e cm | few $\times 10^{-28}$ e cm
example diagrams in the Standard Model:
d_e: ACME collaboration
d_μ: g-2 collaboration
d_τ: Belle collaboration
ACME collaboration
EDM experiment @ PSI
Belle II & e+e- experiments
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The complex 2HDM

Most general Higgs potential for a 2HDM with a softly broken Z_2 symmetry:

$$V(\Phi_1, \Phi_2) = m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - \frac{1}{2}(m_{12}^2 \Phi_1^\dagger \Phi_2 + \text{h.c.}) + \frac{1}{2}\lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2}\lambda_2 (\Phi_2^\dagger \Phi_2)^2$$
$$+ \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) + \frac{1}{2}(\lambda_5 (\Phi_1^\dagger \Phi_2)^2 + \text{h.c.})$$

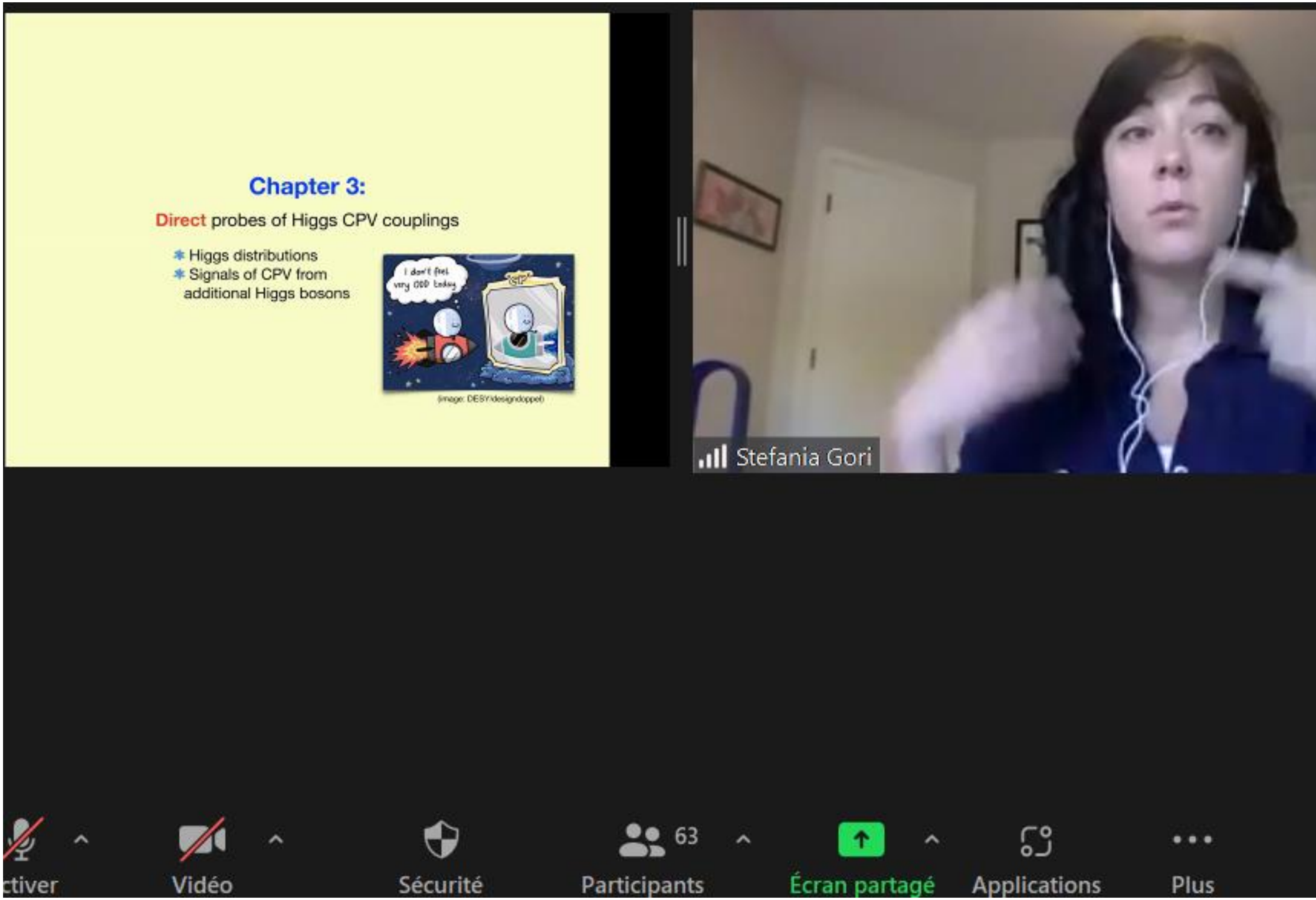
Only one independent phase

125 GeV Higgs → h_1

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = \mathcal{R} \begin{pmatrix} \rho_1 \\ \rho_2 \\ A \end{pmatrix}$$

mass eigenstates — basis used above

$$\mathcal{R} = \begin{pmatrix} -s_\alpha c_{\alpha_2} & c_\alpha c_{\alpha_2} & s_{\alpha_2} \\ s_\alpha s_{\alpha_2} s_{\alpha_3} - c_\alpha c_{\alpha_3} & -s_\alpha c_{\alpha_3} - c_\alpha s_{\alpha_2} s_{\alpha_3} & c_{\alpha_2} s_{\alpha_3} \\ s_\alpha s_{\alpha_2} c_{\alpha_3} + c_\alpha s_{\alpha_3} & s_\alpha s_{\alpha_3} - c_\alpha s_{\alpha_2} c_{\alpha_3} & c_{\alpha_2} c_{\alpha_3} \end{pmatrix}$$


Chapter 3:
Direct probes of Higgs CPV couplings
* Higgs distributions
* Signals of CPV from additional Higgs bosons
I don't feel very ODD today
(image: DESY/designdoppel)
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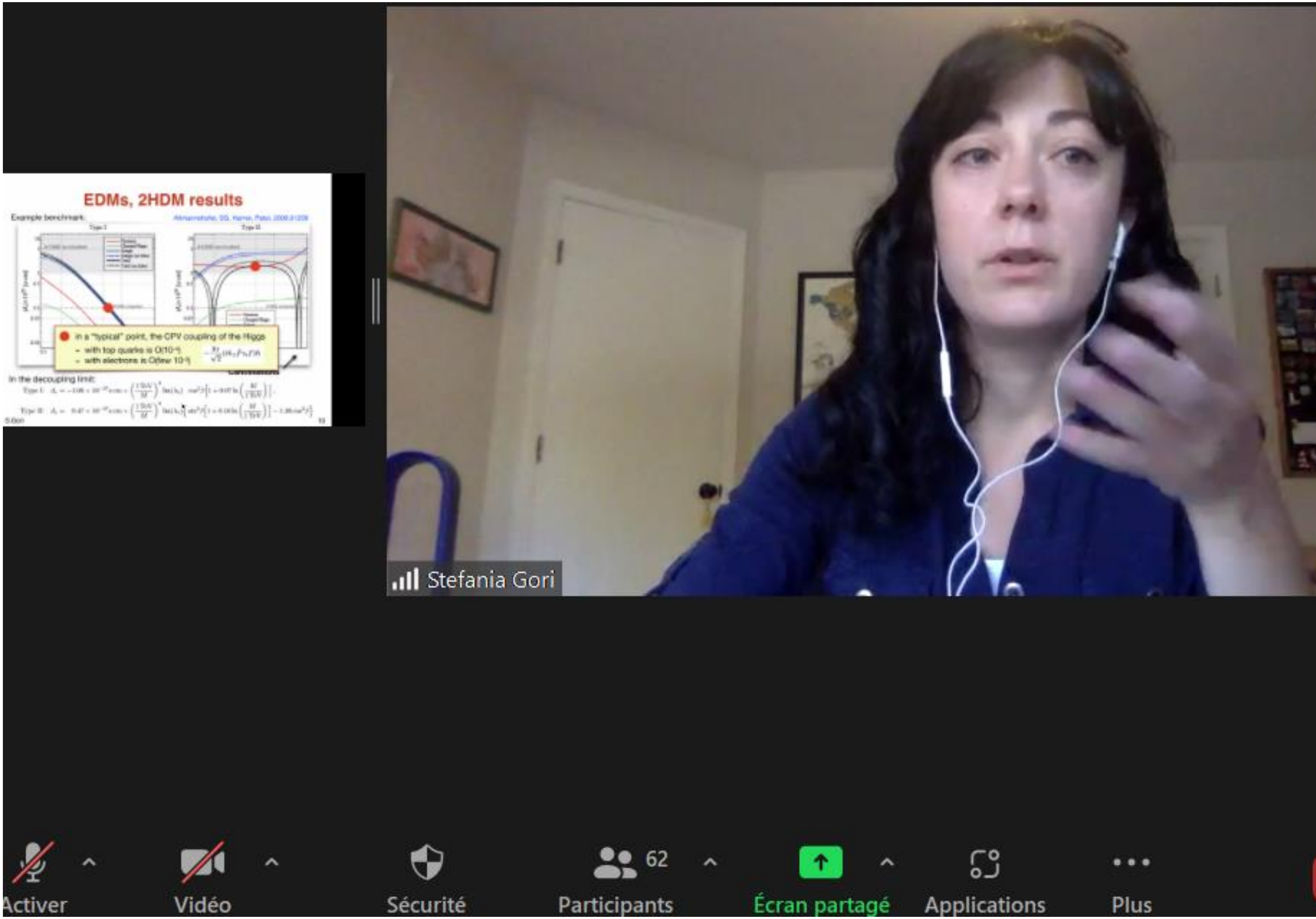
EDMs, 2HDM results
Example benchmark
In the decoupling limit:
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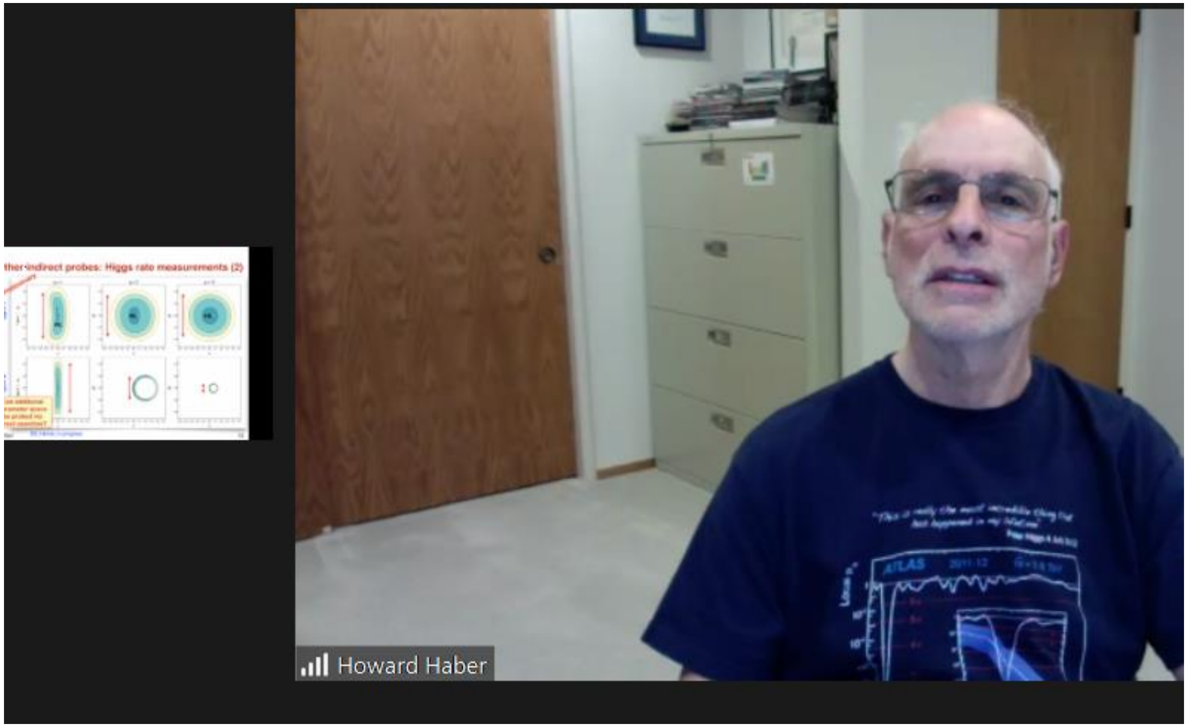
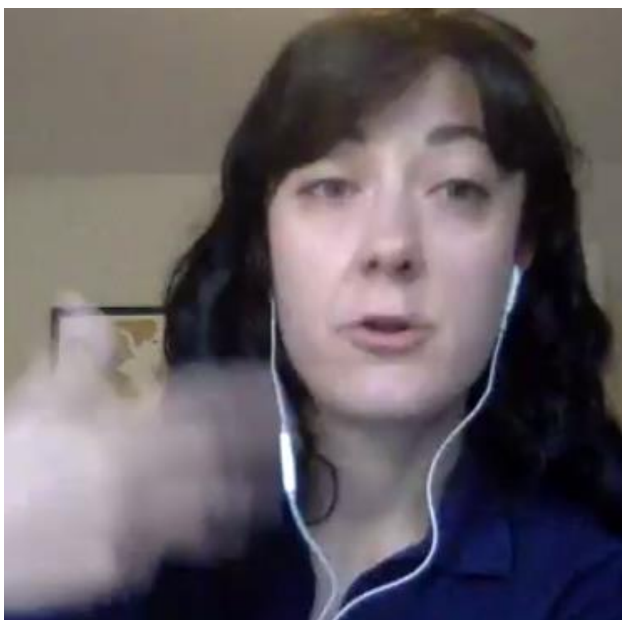
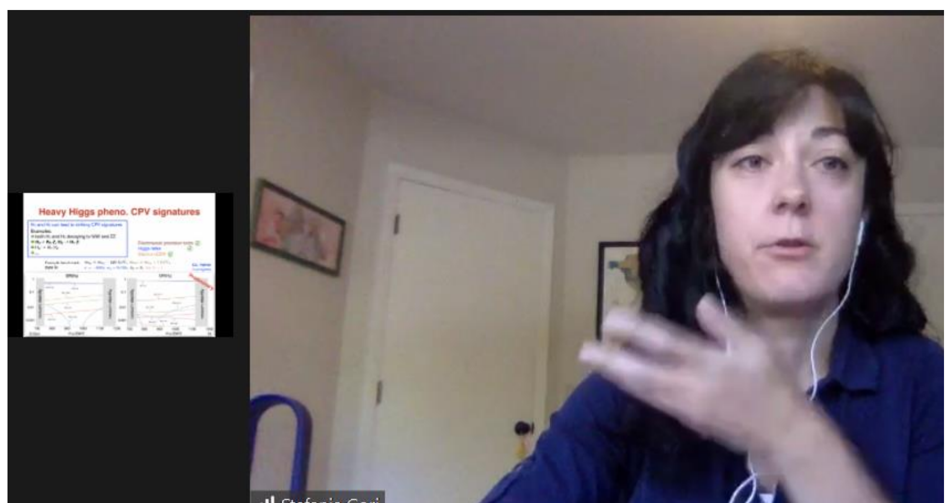
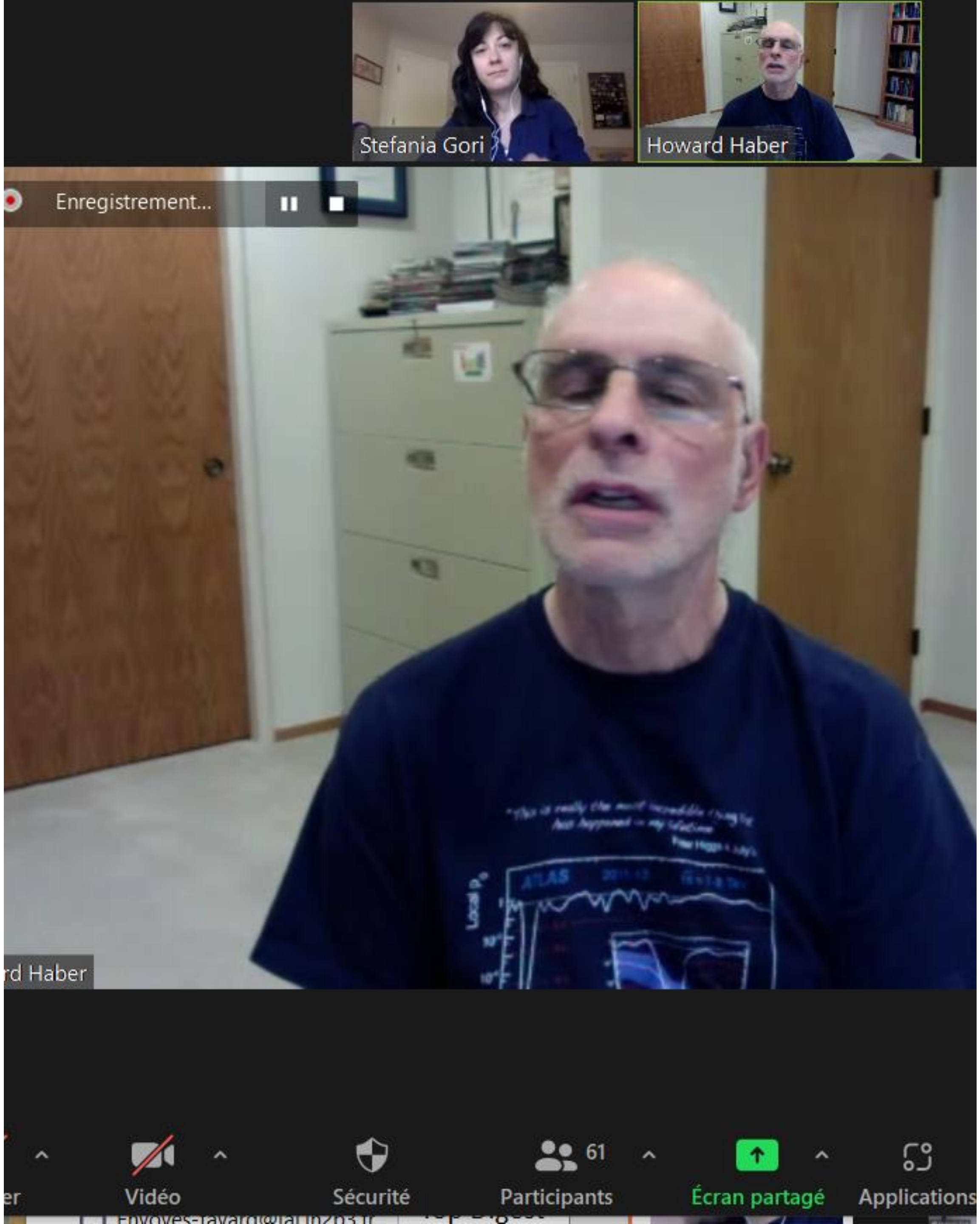

ther indirect probes: Higgs rate measurements (2)
Howard Haber




Heavy Higgs pheno. CPV signatures
Stefania Gori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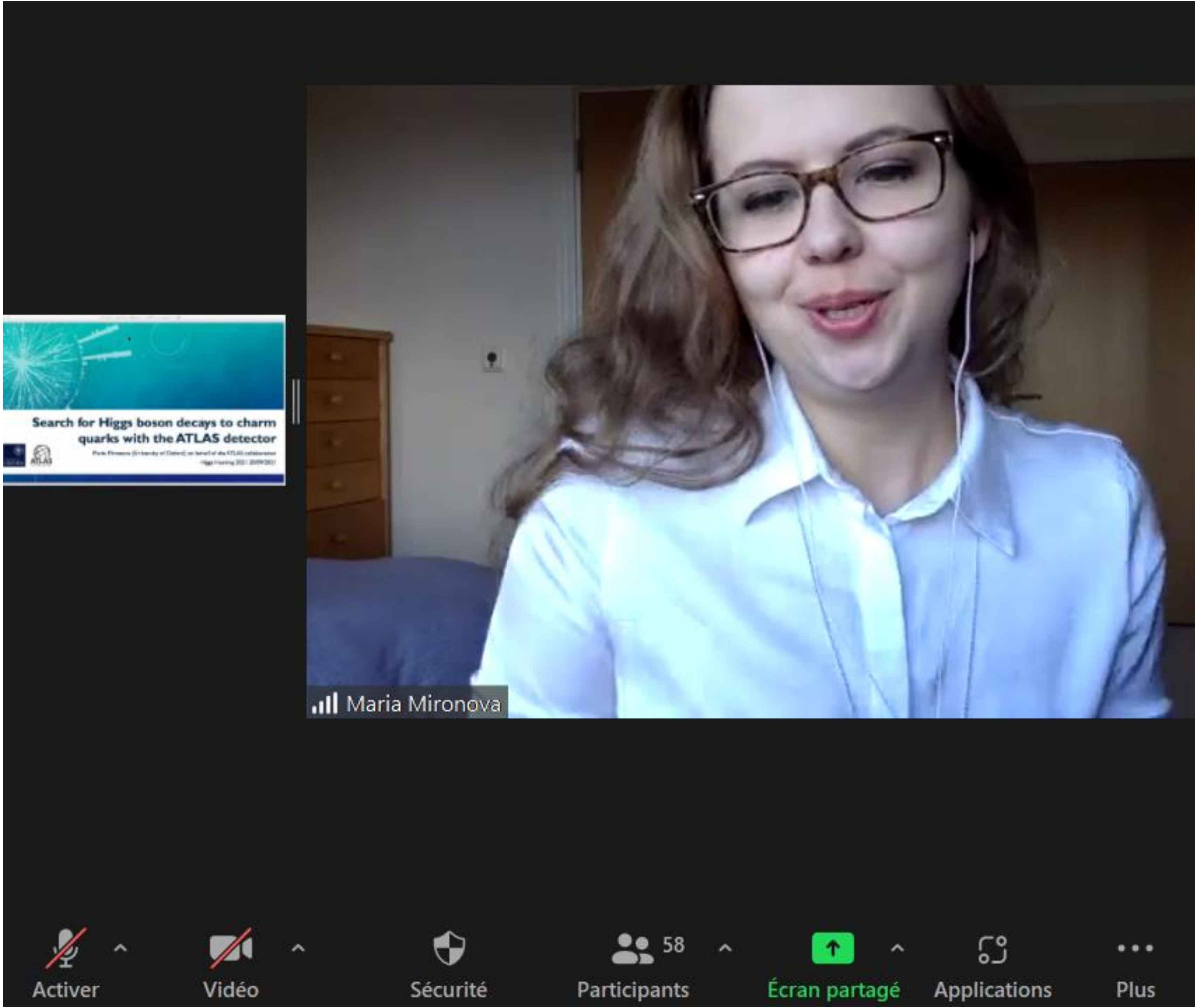
Search for Higgs boson decays to charm
quarks with the ATLAS detector
ATLAS
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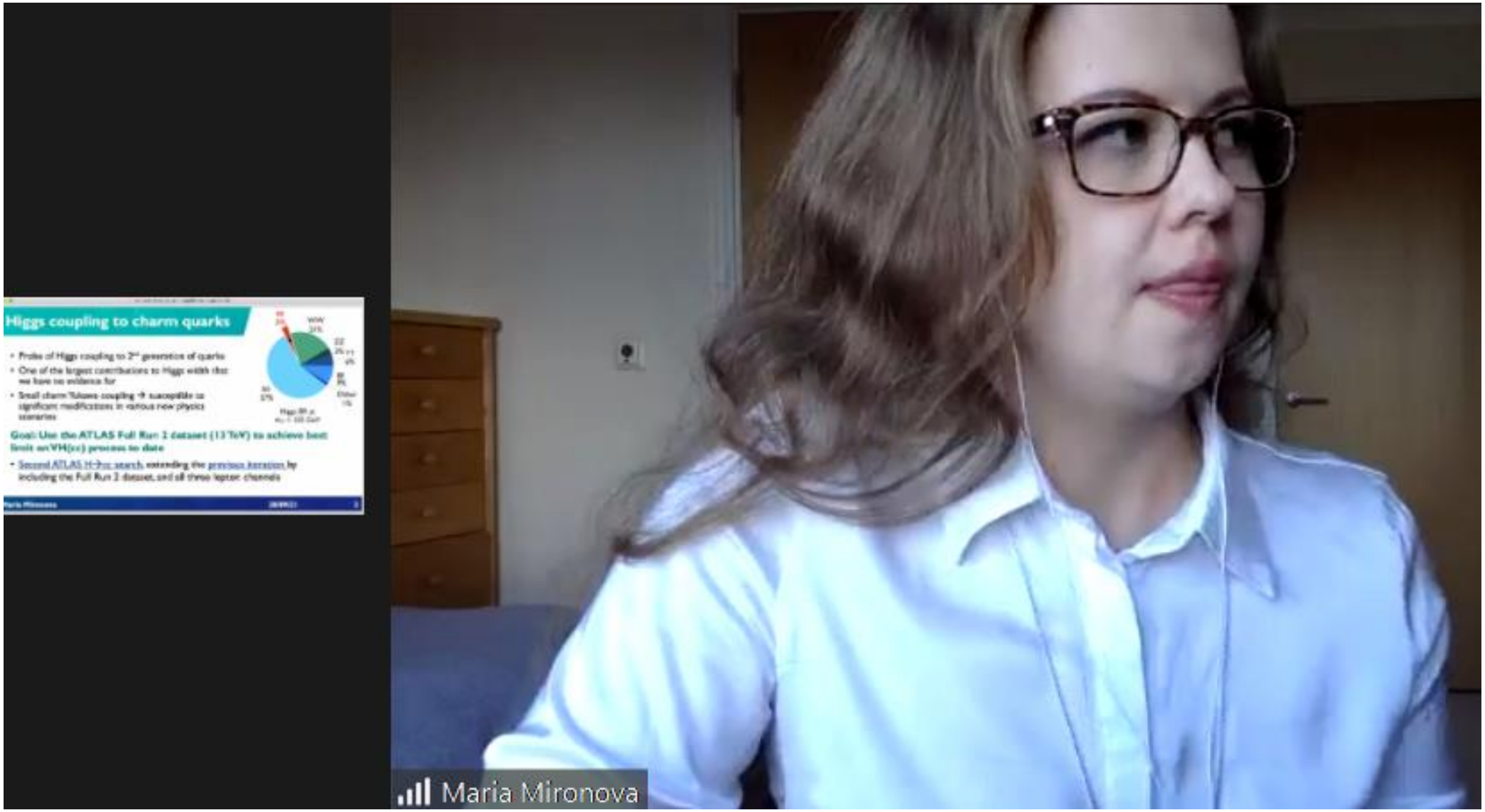
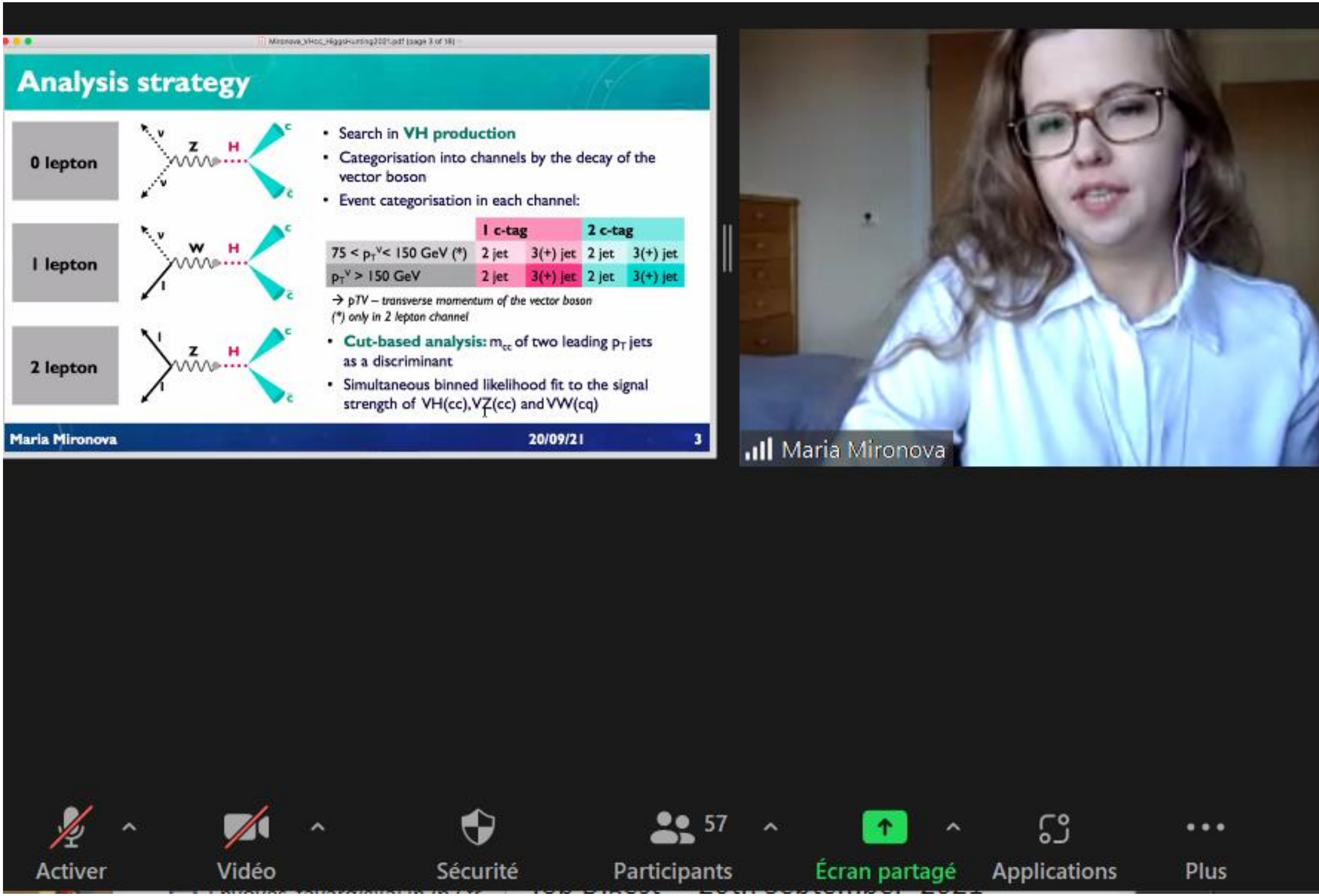

Higgs coupling to charm quarks
Goal: Use the ATLAS Full Run 2 dataset (13 TeV) to achieve best limit on VH(cc) process to date
Maria Mironova


Analysis strategy
0 lepton
1 lepton
2 lepton
Z
W
H
• Search in VH production
• Categorisation into channels by the decay of the vector boson
• Event categorisation in each channel:
1 c-tag
2 c-tag
75 < pTV < 150 GeV (*)
pTV > 150 GeV
2 jet
3(+) jet
→ pTV – transverse momentum of the vector boson
(*) only in 2 lepton channel
• Cut-based analysis: mcc of two leading pT jets as a discriminant
• Simultaneous binned likelihood fit to the signal strength of VH(cc), VZ(cc) and VW(cq)
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20/09/21
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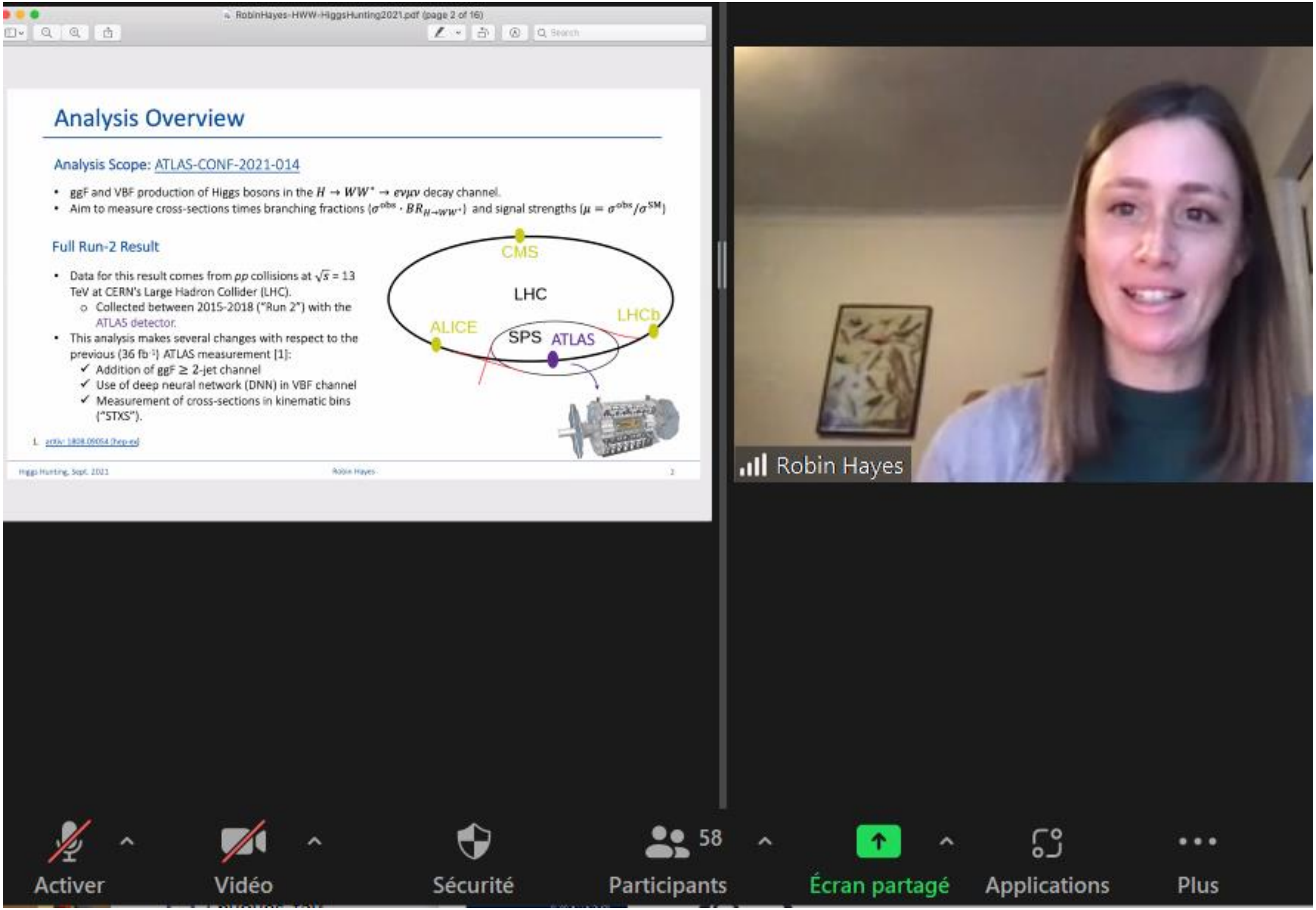
RobinHayes-HWW-HiggsHunting2021.pdf (page 2 of 16)
Analysis Overview
Analysis Scope: ATLAS-CONF-2021-014
• ggF and VBF production of Higgs bosons in the $H \to WW^* \to e\nu\mu\nu$ decay channel.
• Aim to measure cross-sections times branching fractions ($\sigma^{obs} \cdot BR_{H \to WW^*}$) and signal strengths ($\mu = \sigma^{obs}/\sigma^{SM}$)
Full Run-2 Result
• Data for this result comes from pp collisions at $\sqrt{s}$ = 13 TeV at CERN's Large Hadron Collider (LHC).
o Collected between 2015-2018 ("Run 2") with the ATLAS detector.
• This analysis makes several changes with respect to the previous (36 fb^{-1}) ATLAS measurement [1]:
✓ Addition of ggF ≥ 2-jet channel
✓ Use of deep neural network (DNN) in VBF channel
✓ Measurement of cross-sections in kinematic bins ("STXS").
CMS
LHC
LHCb
ALICE
SPS
ATLAS
1. arXiv: 1808.09054 [hep-ex]
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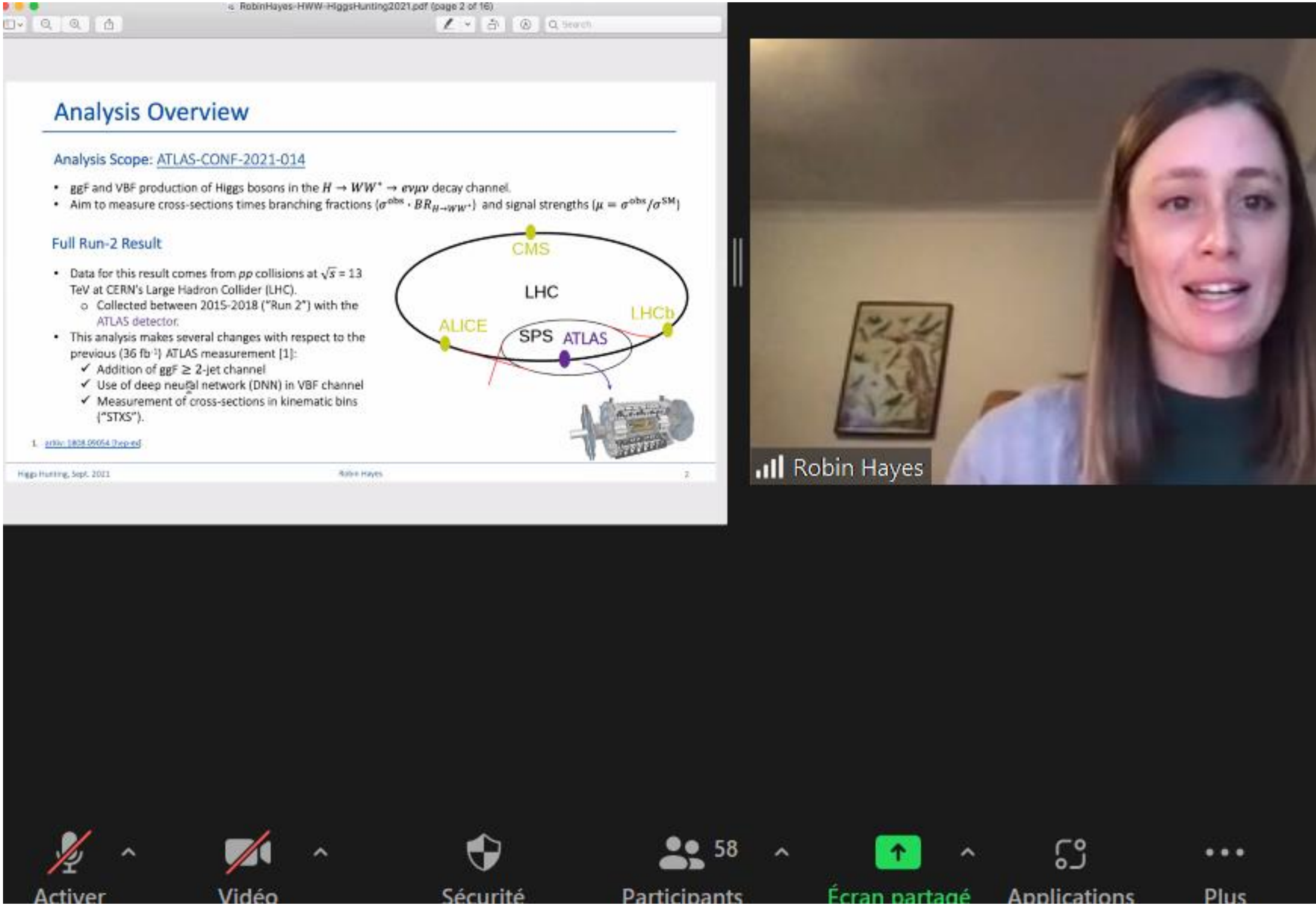
RobinHayes-HWW-HiggsHunting2021.pdf (page 2 of 16)
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CMS
LHC
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LHCb
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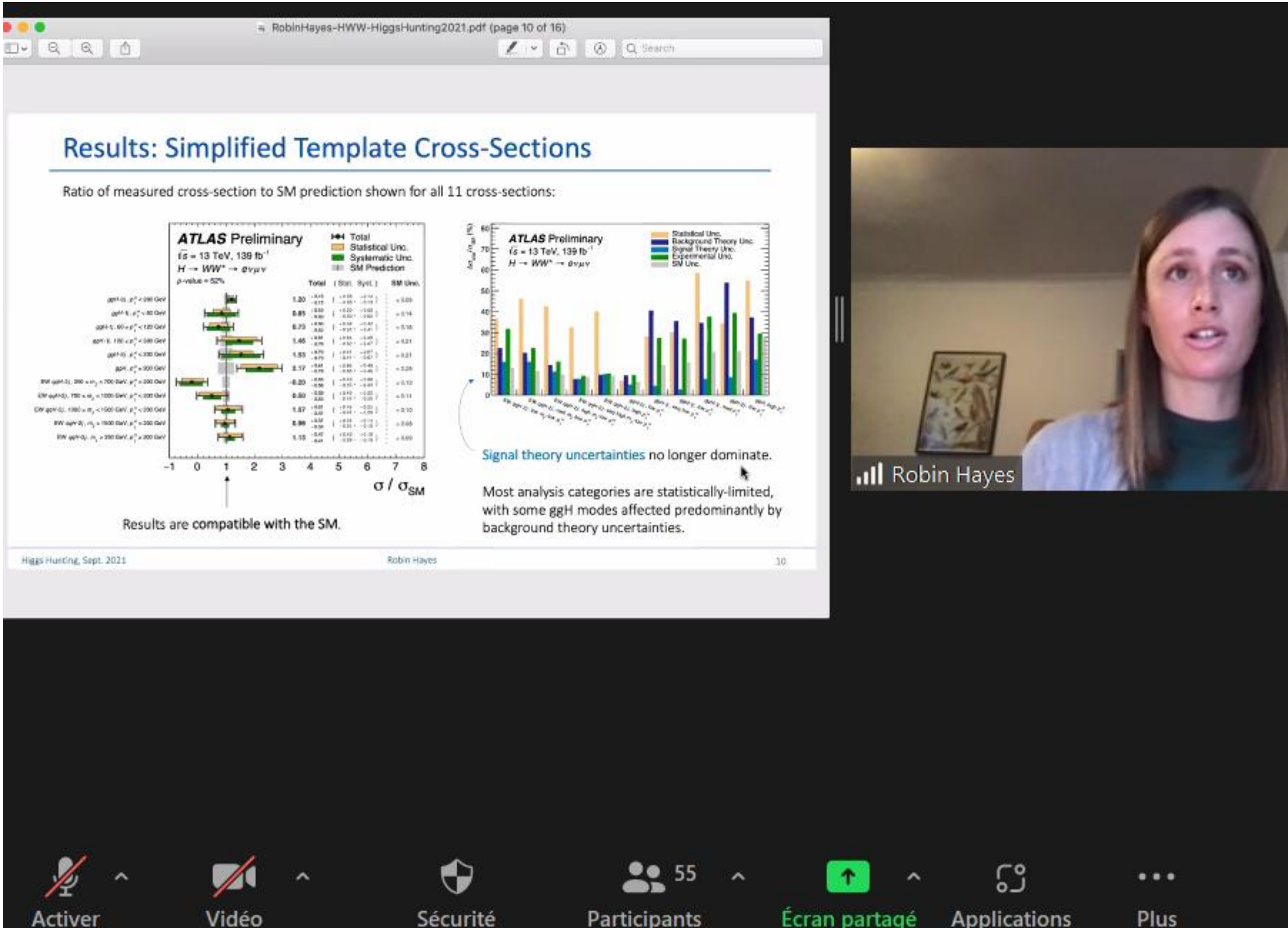
RobinHayes-HWW-HiggsHunting2021.pdf (page 10 of 16)
Results: Simplified Template Cross-Sections
Ratio of measured cross-section to SM prediction shown for all 11 cross-sections:
ATLAS Preliminary
√s = 13 TeV, 139 fb⁻¹
H → WW* → eνμν
Total
Statistical Unc.
Systematic Unc.
SM Prediction
−1 0 1 2 3 4 5 6 7 8
σ / σSM
Results are compatible with the SM.
ATLAS Preliminary
√s = 13 TeV, 139 fb⁻¹
H → WW* → eνμν
Statistical Unc.
Background Theory Unc.
Signal Theory Unc.
Experimental Unc.
SM Unc.
Signal theory uncertainties no longer dominate.
Most analysis categories are statistically-limited, with some ggH modes affected predominantly by background theory uncertainties.
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Tom's iPad
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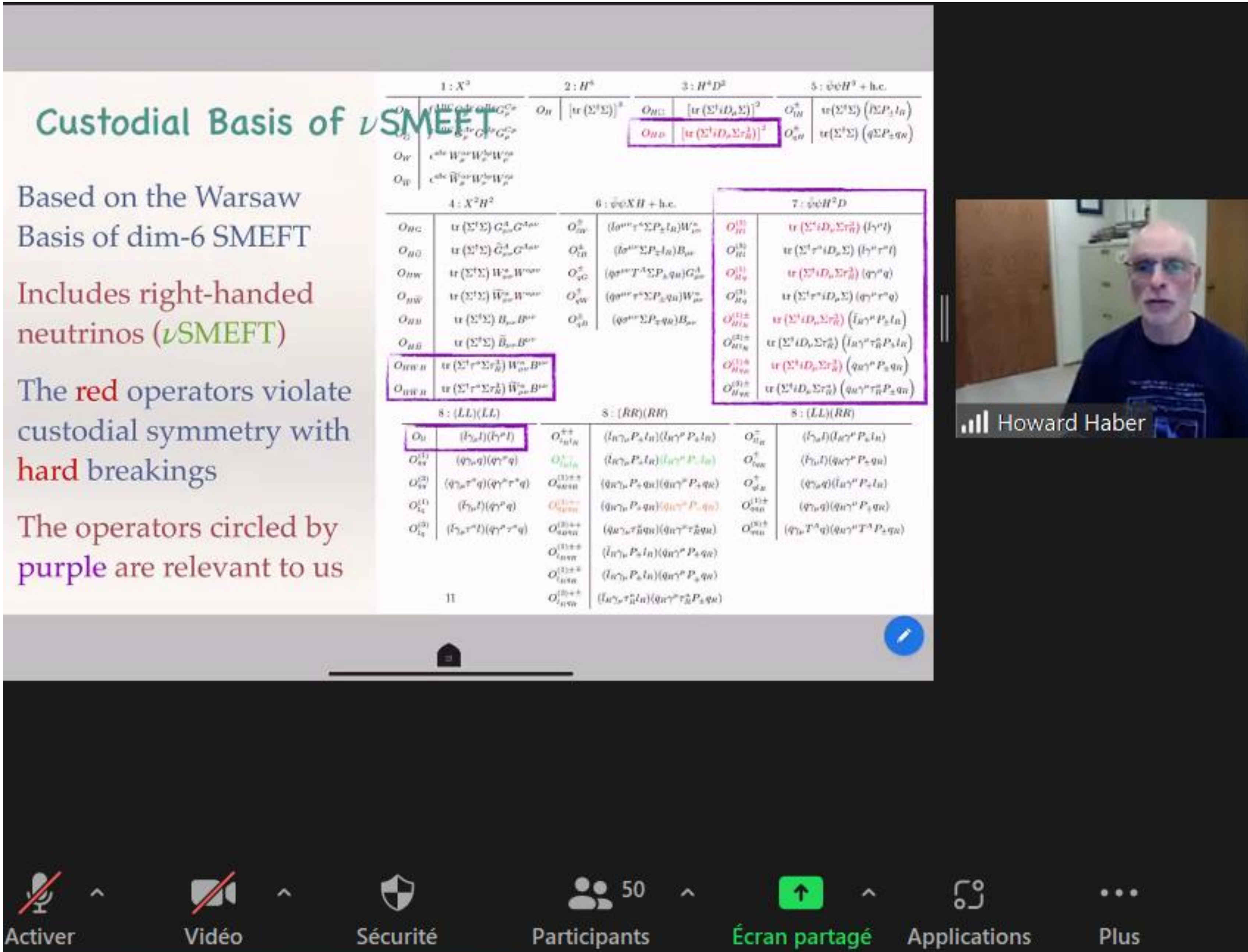
Custodial Basis of νSMEFT
Based on the Warsaw Basis of dim-6 SMEFT
Includes right-handed neutrinos (νSMEFT)
The red operators violate custodial symmetry with hard breakings
The operators circled by purple are relevant to us
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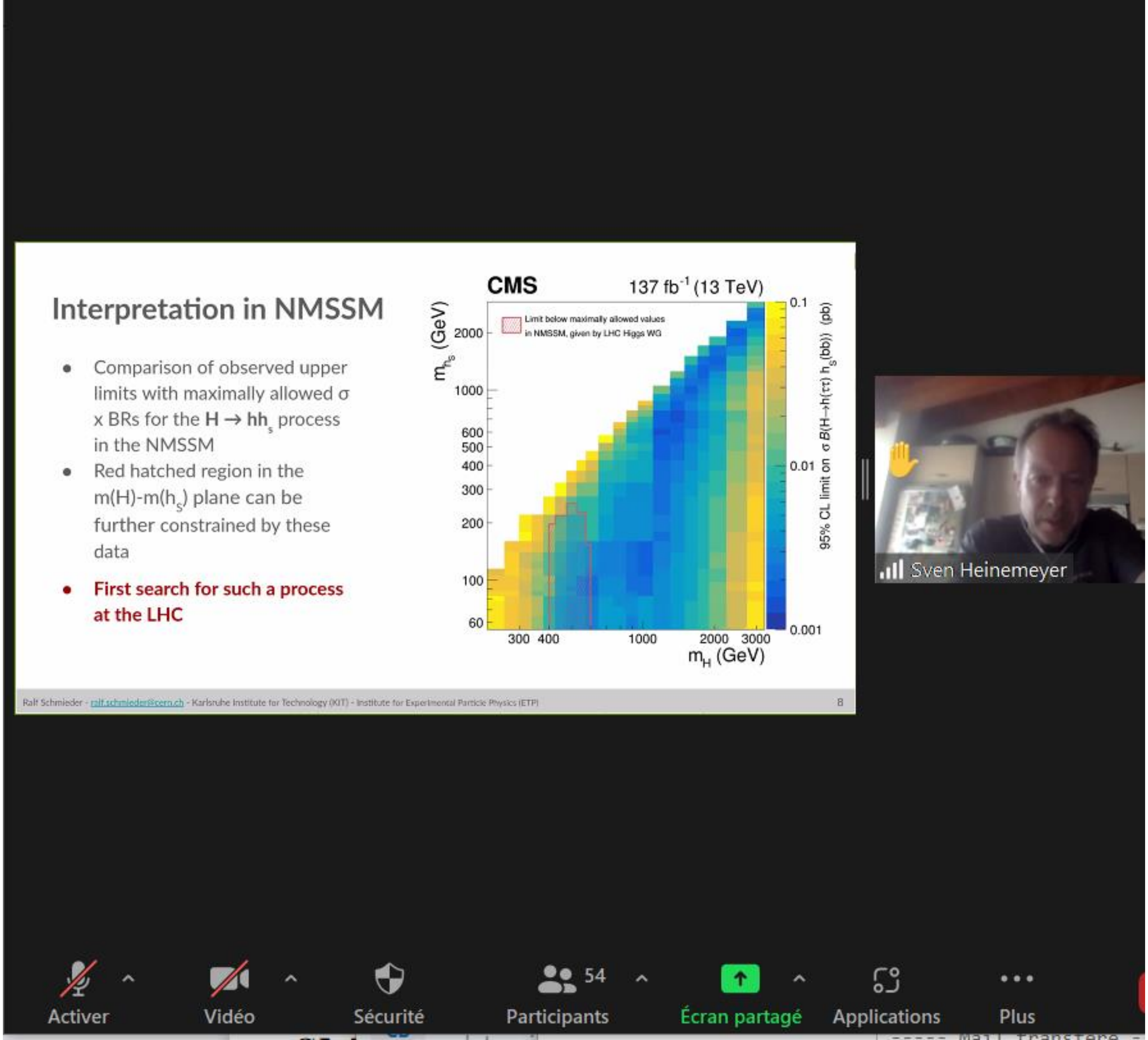
Interpretation in NMSSM
Comparison of observed upper limits with maximally allowed σ x BRs for the H → hh_s process in the NMSSM
Red hatched region in the m(H)-m(h_s) plane can be further constrained by these data
First search for such a process at the LHC
CMS
137 fb^-1 (13 TeV)
Limit below maximally allowed values in NMSSM, given by LHC Higgs WG
m_hs (GeV)
m_H (GeV)
95% CL limit on σ B(H→h(ττ) h_s(bb)) (pb)
Ralf Schmieder - ralf.schmieder@cern.ch - Karlsruhe Institute for Technology (KIT) - Institute for Experimental Particle Physics (ETP)
8
Sven Heinemeyer
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Vidéo
Sécurité
54
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Écran partagé
Applications
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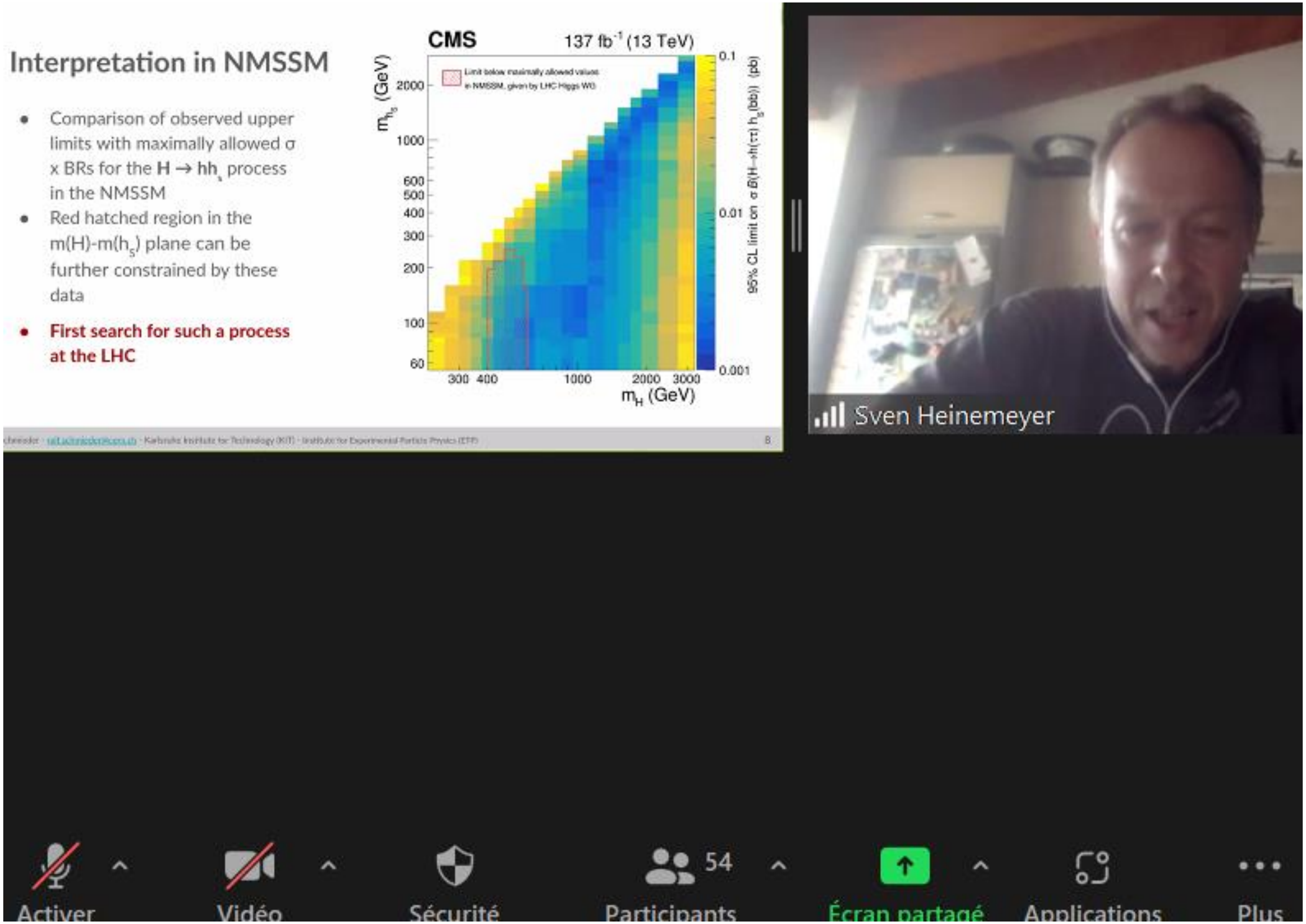
Interpretation in NMSSM
Comparison of observed upper limits with maximally allowed σ x BRs for the H → hh$_s$ process in the NMSSM
Red hatched region in the m(H)-m(h$_s$) plane can be further constrained by these data
First search for such a process at the LHC
CMS
137 fb^{-1} (13 TeV)
Limit below maximally allowed values in NMSSM, given by LHC Higgs WG
m_{h_s} (GeV)
m_H (GeV)
95% CL limit on σ B(H→h(ττ) h$_s$(bb)) (pb)
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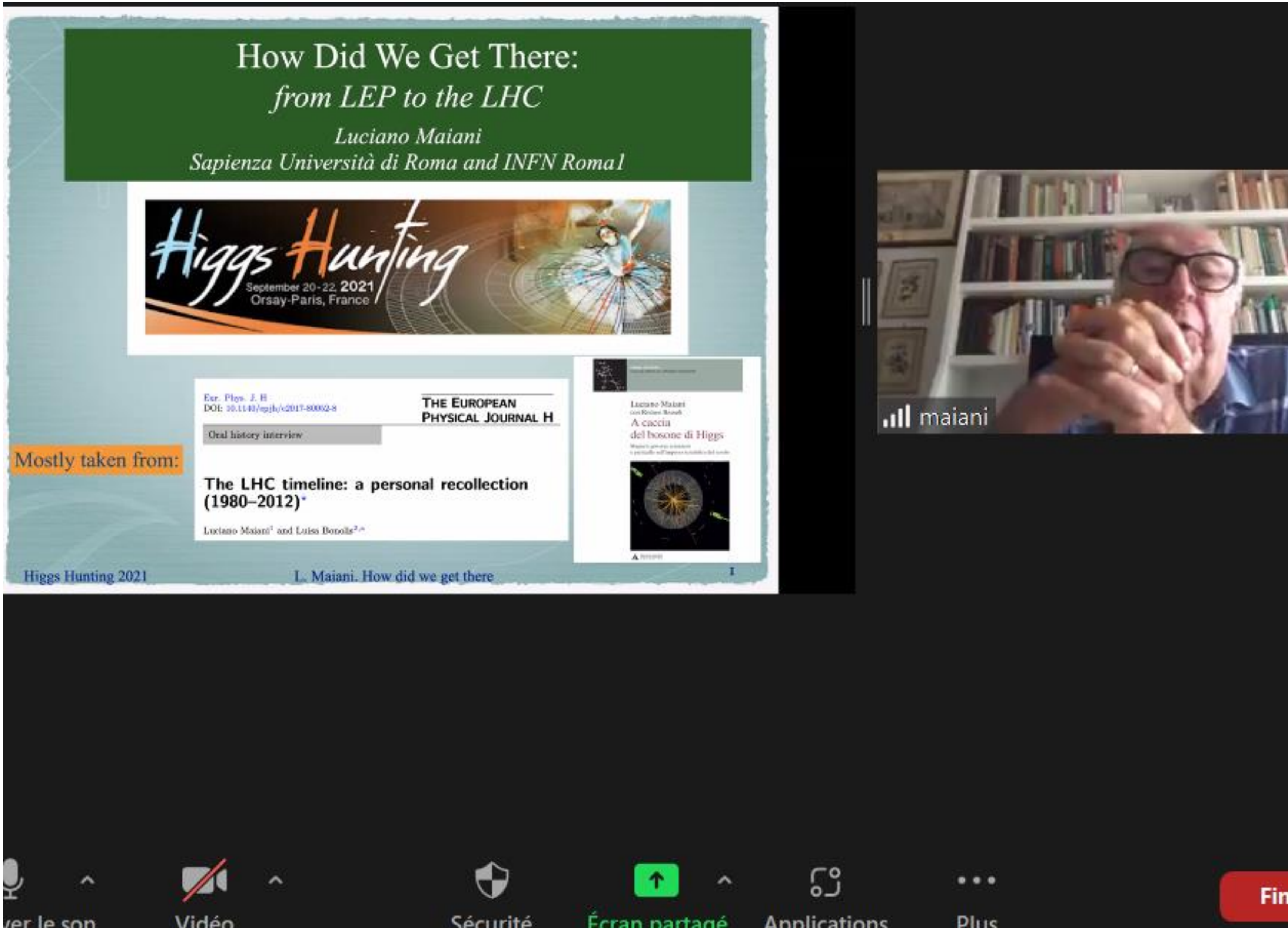
How Did We Get There:
from LEP to the LHC
Luciano Maiani
Sapienza Università di Roma and INFN Roma1
Higgs Hunting
September 20-22, 2021
Orsay-Paris, France
Mostly taken from:
Eur. Phys. J. H
THE EUROPEAN PHYSICAL JOURNAL H
Oral history interview
The LHC timeline: a personal recollection (1980–2012)
Luciano Maiani and Luisa Bonolis
Luciano Maiani
A caccia del bosone di Higgs
Higgs Hunting 2021
L. Maiani. How did we get there
1
maiani
ver le son
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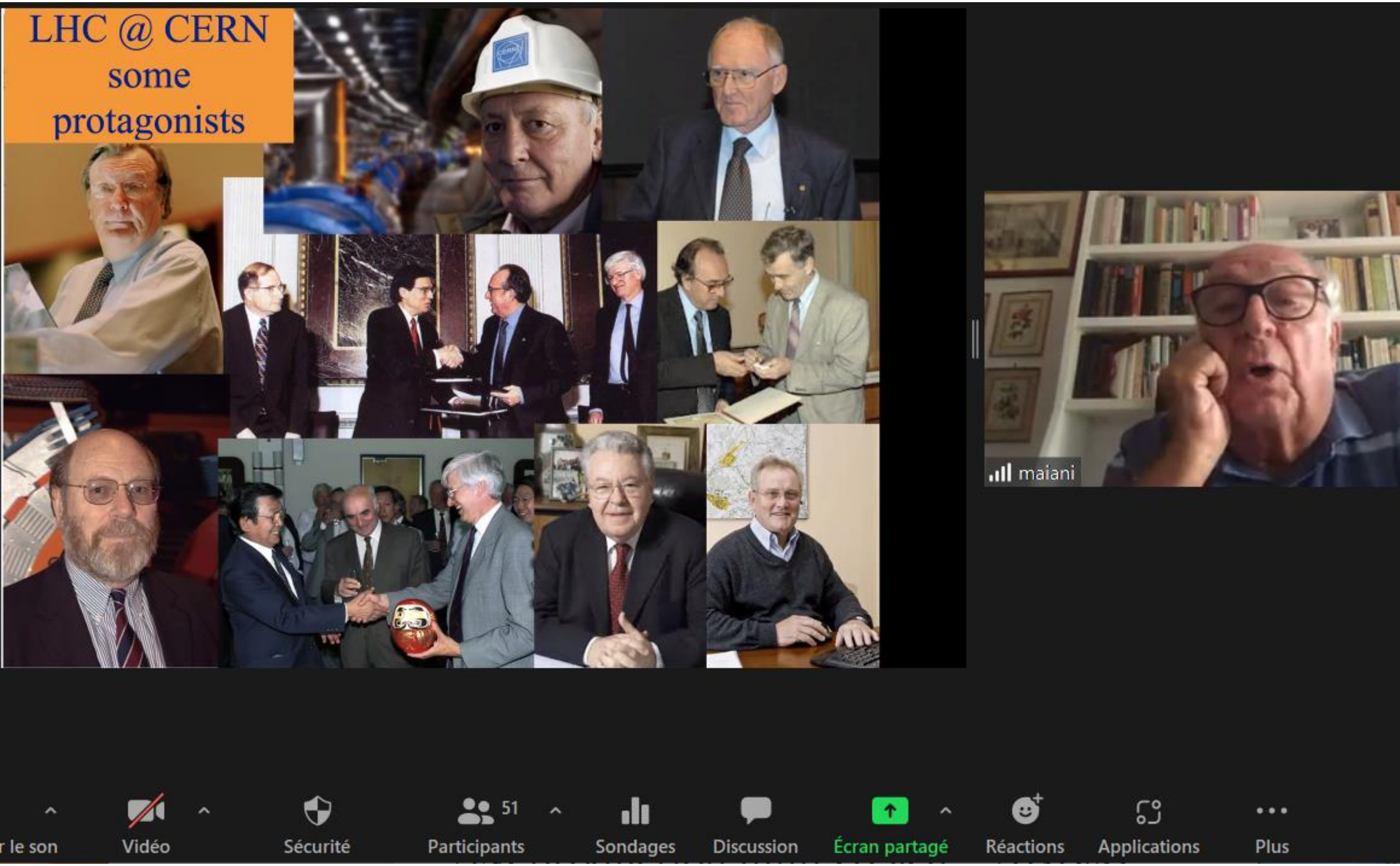
Plus
Fin


LHC @ CERN
some
protagonists


maiani


LHC @ CERN
some
protagonists
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r le son
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Discussion
Écran partagé
Réactions
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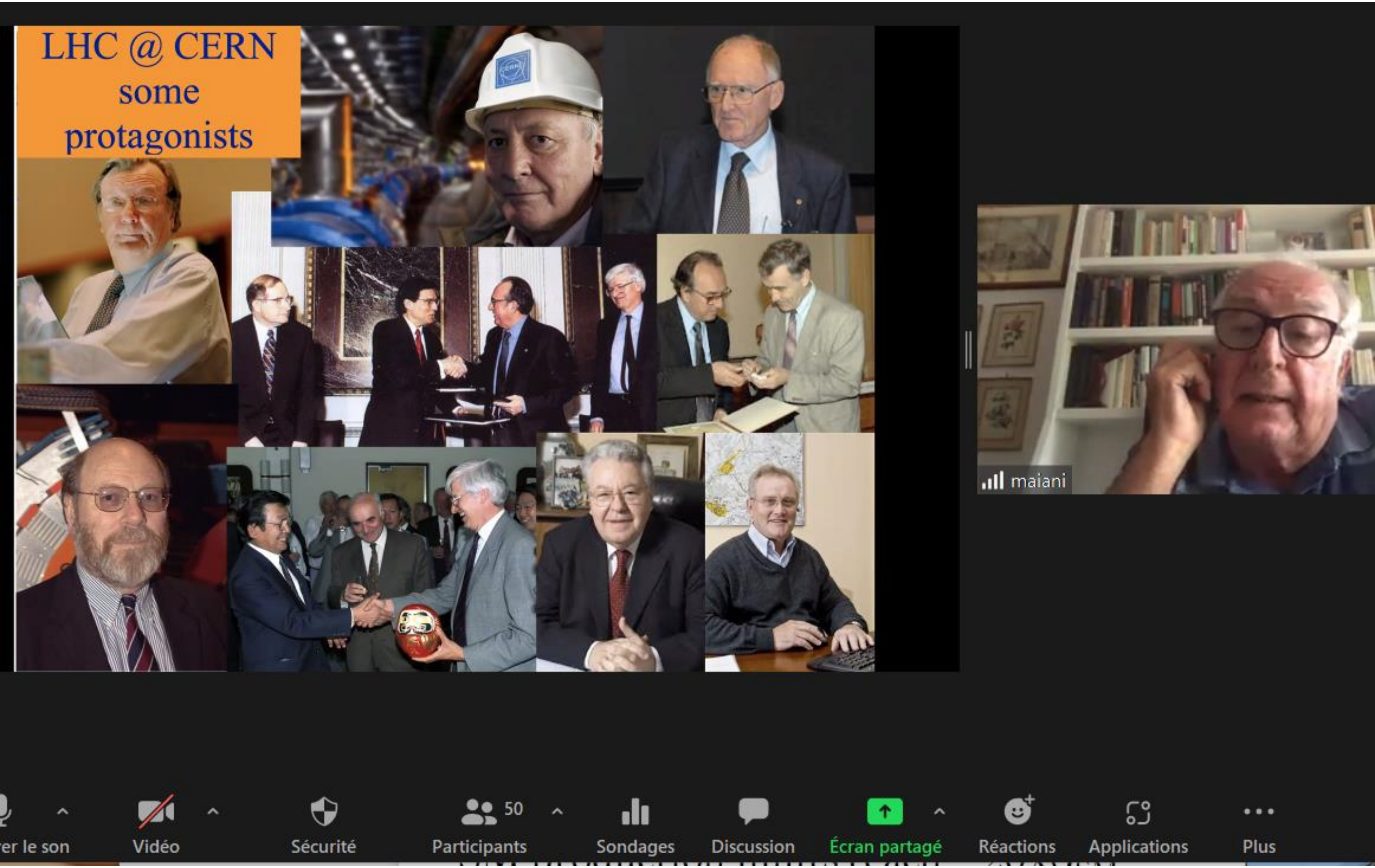
LHC @ CERN
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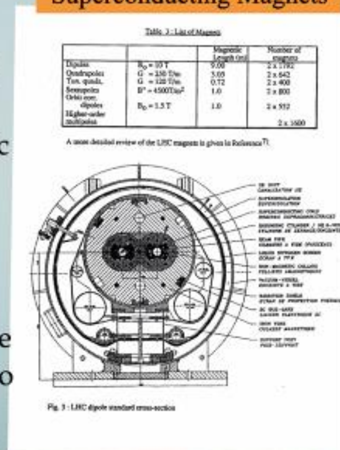
1. Prologue: the LEP tunnel

- Physicists had thought to make the tunnel wider than what was strictly needed, so as to be able to install later a proton machine with superconducting magnets
- The ECFA study (Roma 1978, chaired by A. Zichichi) had made a recommendation in this direction, nothwitstanding the resistence of those afraid that the implied cost increase would put the LEP project at risk
- As a compromise, a tunnel of 4 meters diameter was accepted. However, this was not enough for a cryogenic system with two independent magnets (such as was designed for the SSC).
- CERN was forced to develop a new advanced design: "two-in-one", more compact and less expensive
- The choice of tunnel's dimensions, all in all, is a positive story: an admirable compromise that made it possible to prolong the lifetime of CERN well above 20 years.

Two-in-one Dipole Superconducting Magnets



November 1988.
SSC approved at a new site: Waxahachie, Texas, Fermilab loses the competition for hosting the SSC

- **1988** **SSC approved,** proton-proton, 20 TeV/beam, 87 km tunnel, cost 4-5 B US$;
  1989 SSC construction starts.
- **1993** SSC discontinued by the US Congress after a bitter discussion which invested all the scientific community (projected cost >10 B US$, 2 B US$ spent).

10 November 1988. Leon Lederman, wearing a Stetson hat, annoounces to the Laboratory that Fermilab has not been chosen as the SSC site. FNAL Visual Media Service.

Shaft to the SSC tunnel di SSC, located at about10 meters underground. The planned tunnel had a circumference of 87 km.

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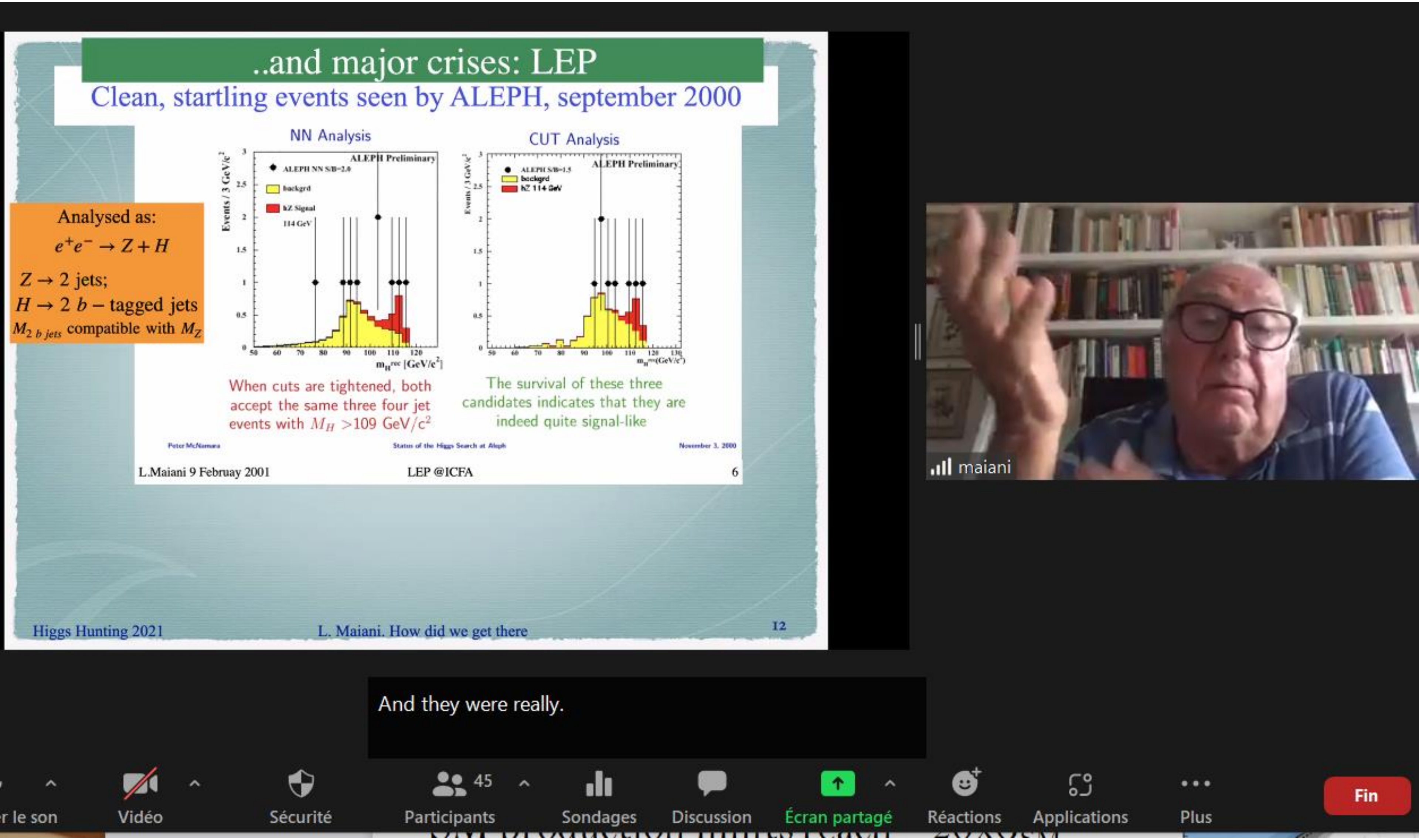
LHC agreements: 1995 to 1997

Chris Llewellyn Smith (right), with Hubert Curien, President of Council (center) receives a Daruma Doll from Kaoru Yosano, Japan Minister of Education, Science and Culture, June 1st 1995 at the signature of the Japan-CERN agreement for Japan participation in LHC (machine and experiments.

Agreements were made with several other countries, among them:

- Russia: warm magnets for the beam transfer line from SPS to the LHC (over 150 MCHF)
- India: hardware, software and skilled superconductor manpower
- Pakistan: detector construction (RPC); barrel yoke (35 tons) for the CMS detector

Signature of the USA-CERN agreement for the US participation in LHC (machine and experiments), Washington 8 december 1997. From left: Neil Lane, Director NSF, Federico Peña, Secretary for Energiy, Luciano Maiani, President of Council, Chris Llewellyn Smith, Director General of CERN.


..and major crises: LEP
Clean, startling events seen by ALEPH, september 2000
NN Analysis
CUT Analysis
ALEPH Preliminary
ALEPH Preliminary
Analysed as:
$e^+e^- \to Z + H$
$Z \to 2$ jets;
$H \to 2\ b-$tagged jets
$M_{2\ b\ jets}$ compatible with M_Z
When cuts are tightened, both accept the same three four jet events with M_H >109 GeV/c^2
The survival of these three candidates indicates that they are indeed quite signal-like
L.Maiani 9 Febraury 2001
LEP @ICFA
6
Higgs Hunting 2021
L. Maiani. How did we get there
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maiani
And they were really.
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To prolong LEP running for one year, required to stop the LHC civil works for the connection of SPS to the LHC tunnel, with an estimated cost of ~ 120 MCHF, to be added to the overall LHC budget.

Letter to G. Kalmus, Chair Scientific Policy Committee
November 4th, 2000

…an interesting evidence for the Higgs boson in LEP data. However, I am much more sceptical that a year running may allow us to get any better. ….Indeed, even the more optimistic analyses conclude that there are no golden plated events to be seen, all relying on small statistical effects accumulating here and there. This may well be the case, by the way, of LHC experiments, but when we shall be there we shall have all the time and the energy to improve the statistics as much as we want, a much more comfortable situation.

The idea that we may find ourselves in September 2001 with 3.5-4 sigmas, CERN's financial position aggravated, LHC delayed and LHC people disbanded is not very encouraging. I am not going to go along this way.

CERN Council, DG report, Dec. 15, 2000

The future of CERN is in the LHC !!!

CC Statement

"*On 17th November 2000, the CERN Committee of Council held a meeting to examine a proposal by the Director-General concerning the continuation of the existing CERN programme, which foresees the decommissioning of the LEP accelerator at the end of the year 2000.*

The Committee has expressed its recognition and gratitude for the outstanding work done by the LEP accelerator and experimental teams.

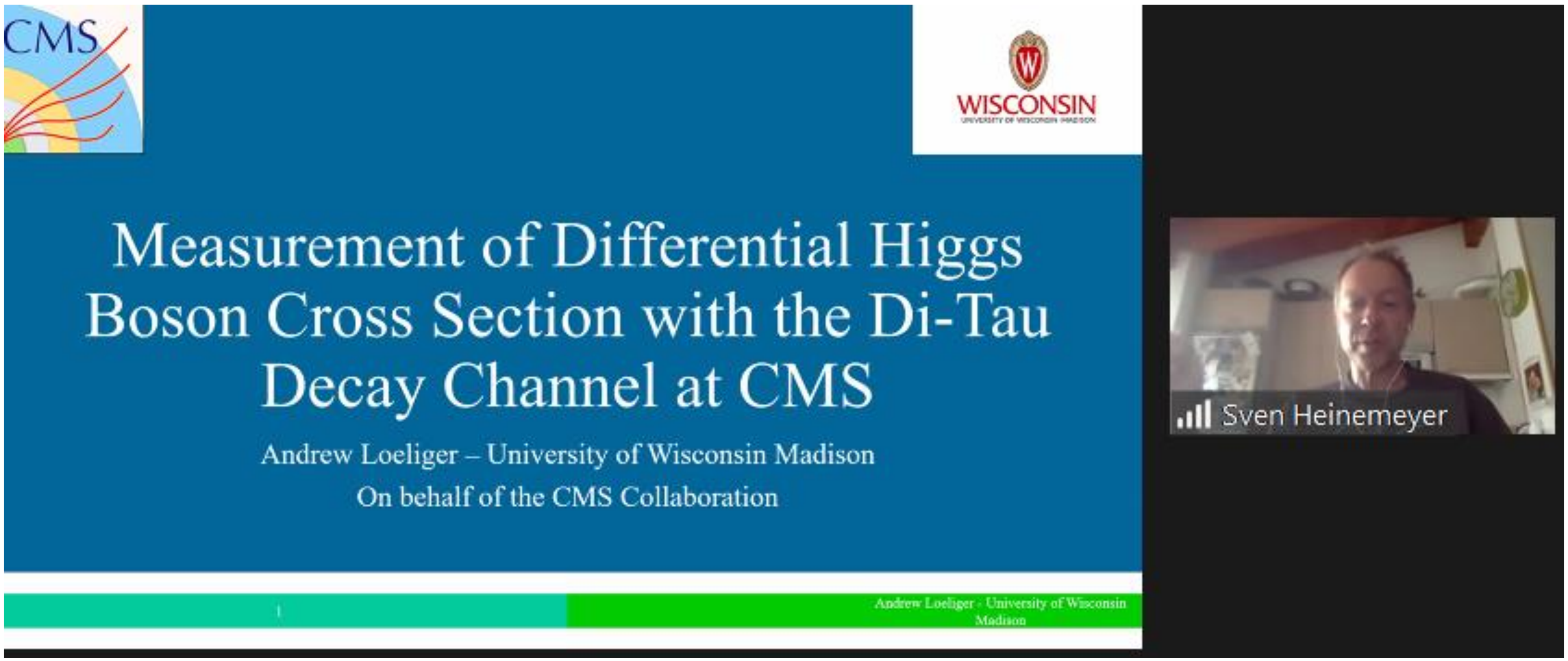
It has taken note of the request by many members of the CERN Scientific Community to continue LEP running into 2001 and also noted the divided views expressed in the Scientific Committees consulted on this subject.

On the basis of these considerations and in the absence of a consensus to change the existing programme, the Committee of Council supports the Director-General in pursuing the existing CERN programme."

This decision moves us definitely into the LHC era
A powerful complex, machine and detectors, to fully explore the Higgs and SUSY region

Le Roi est mort
Vive le Roi !!

15/12/2000 L. MAIANI. Status Report 2000


CMS
WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON
Measurement of Differential Higgs Boson Cross Section with the Di-Tau Decay Channel at CMS
Andrew Loeliger – University of Wisconsin Madison
On behalf of the CMS Collaboration
1
Andrew Loeliger - University of Wisconsin Madison
Sven Heinemeyer

Introduction

Analysis	Link To Documentation	arXiv link
$H\tau\tau$ Differential Cross Section Analysis	CMS-PAS-HIG-20-015	2107.11486

- $H \rightarrow \tau\tau$ decays…
  - … provide direct observation of the yukawa coupling
  - … have a high branching fraction that allows for measurements of rarer parts of Higgs Phase space (high transverse momentum, large jet multiplicity, etc)
- The $H \rightarrow \tau\tau$ had its first observation in 2016, and is now the target of increasingly precise measurements
  - STXS measurements (Anne-Catherine's Talk) (Official Documentation)
  - Differential Measurements

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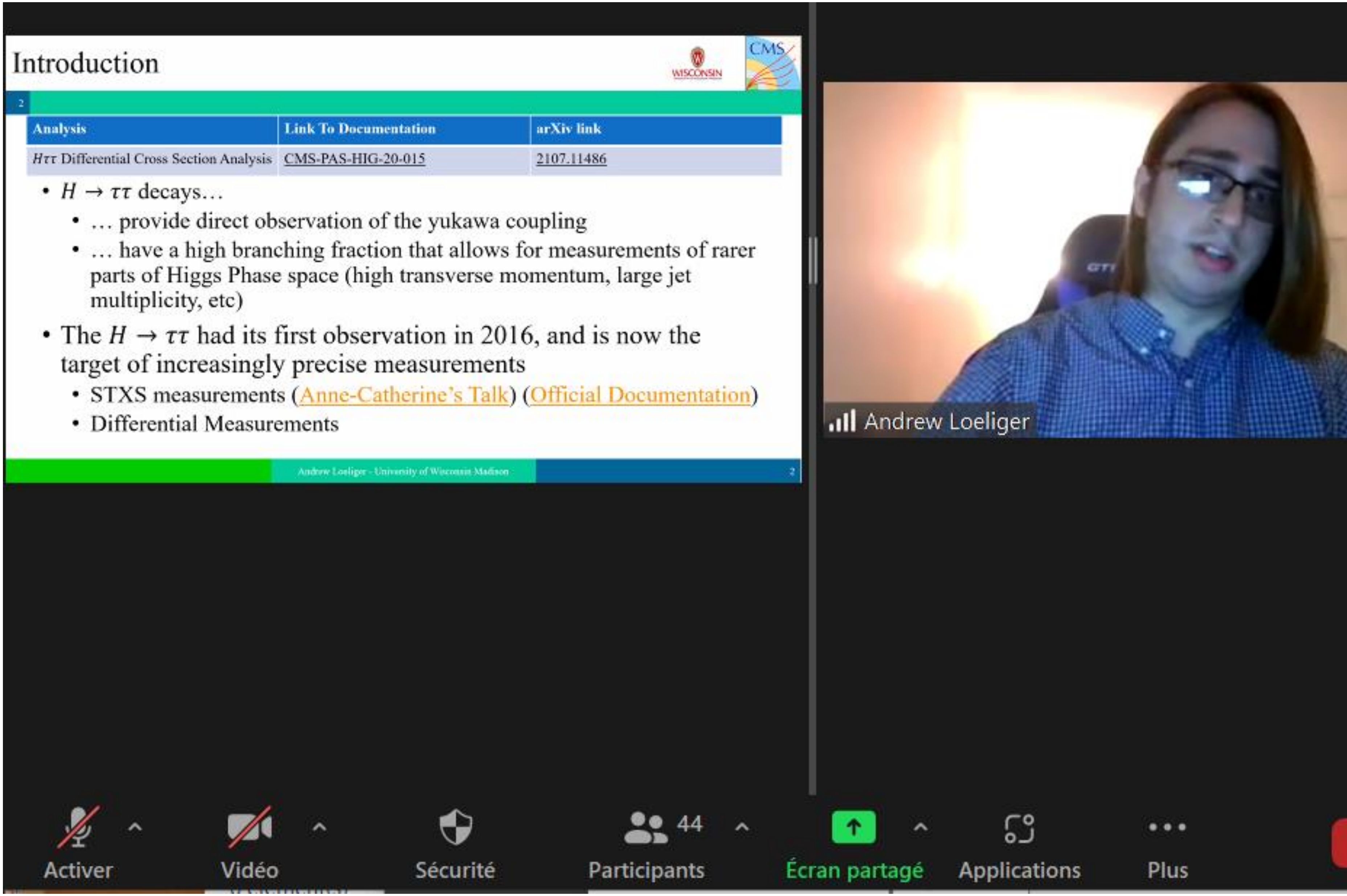
Introduction
Analysis | Link To Documentation | arXiv link
Hττ Differential Cross Section Analysis | CMS-PAS-HIG-20-015 | 2107.11486
• H → ττ decays…
• … provide direct observation of the yukawa coupling
• … have a high branching fraction that allows for measurements of rarer parts of Higgs Phase space (high transverse momentum, large jet multiplicity, etc)
• The H → ττ had its first observation in 2016, and is now the target of increasingly precise measurements
• STXS measurements (Anne-Catherine's Talk) (Official Documentation)
• Differential Measurements
Andrew Loeliger - University of Wisconsin Madison
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Andrew Loeliger
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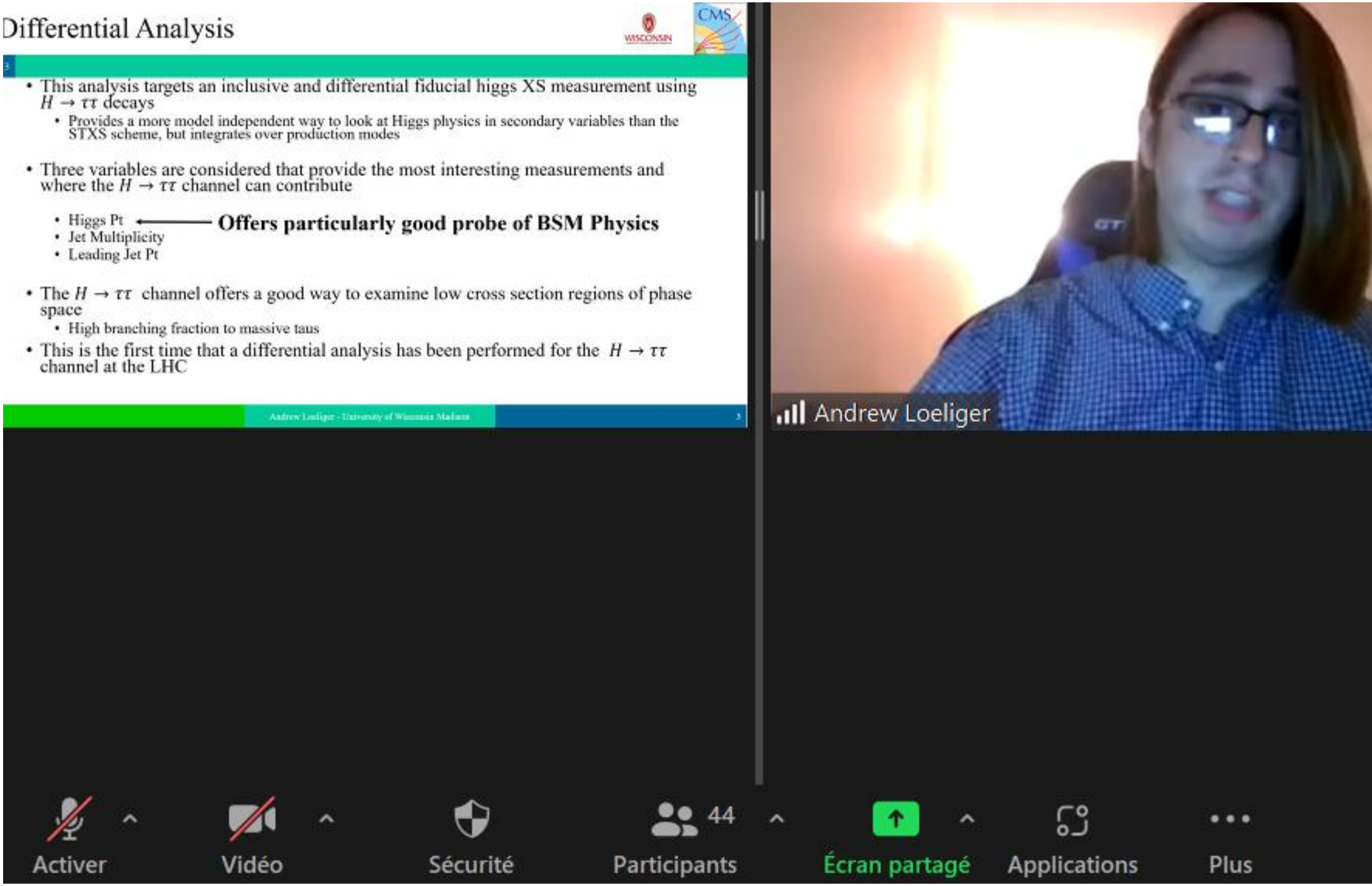
Differential Analysis
WISCONSIN
CMS
• This analysis targets an inclusive and differential fiducial higgs XS measurement using $H \to \tau\tau$ decays
• Provides a more model independent way to look at Higgs physics in secondary variables than the STXS scheme, but integrates over production modes
• Three variables are considered that provide the most interesting measurements and where the $H \to \tau\tau$ channel can contribute
• Higgs Pt
Offers particularly good probe of BSM Physics
• Jet Multiplicity
• Leading Jet Pt
• The $H \to \tau\tau$ channel offers a good way to examine low cross section regions of phase space
• High branching fraction to massive taus
• This is the first time that a differential analysis has been performed for the $H \to \tau\tau$ channel at the LHC
Andrew Loeliger - University of Wisconsin Madison
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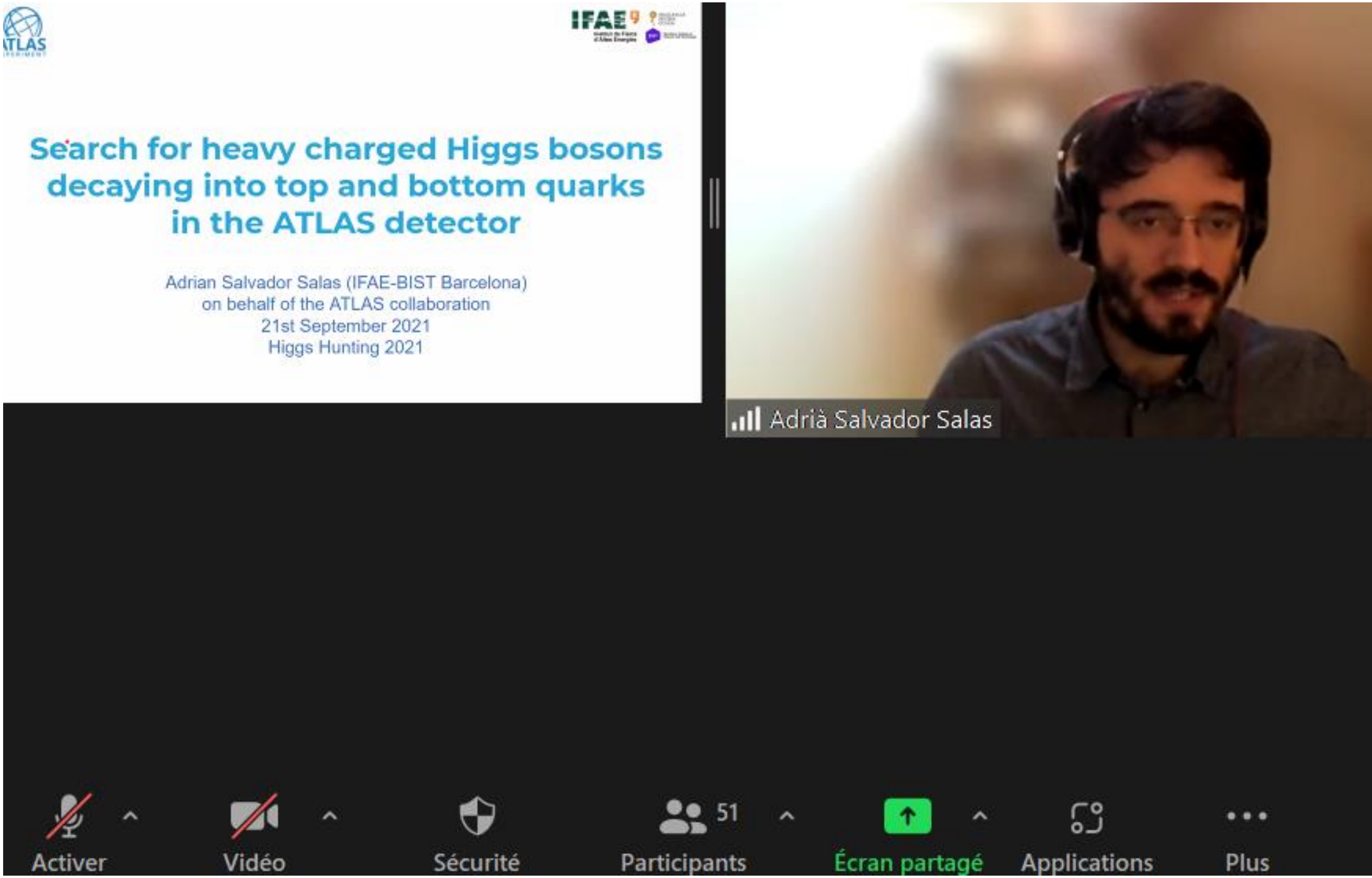
Enregistrement...
Sven Heinemeyer


Search for heavy charged Higgs bosons decaying into top and bottom quarks in the ATLAS detector
Adrian Salvador Salas (IFAE-BIST Barcelona)
on behalf of the ATLAS collaboration
21st September 2021
Higgs Hunting 2021
IFAE
Adrià Salvador Salas
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Applications
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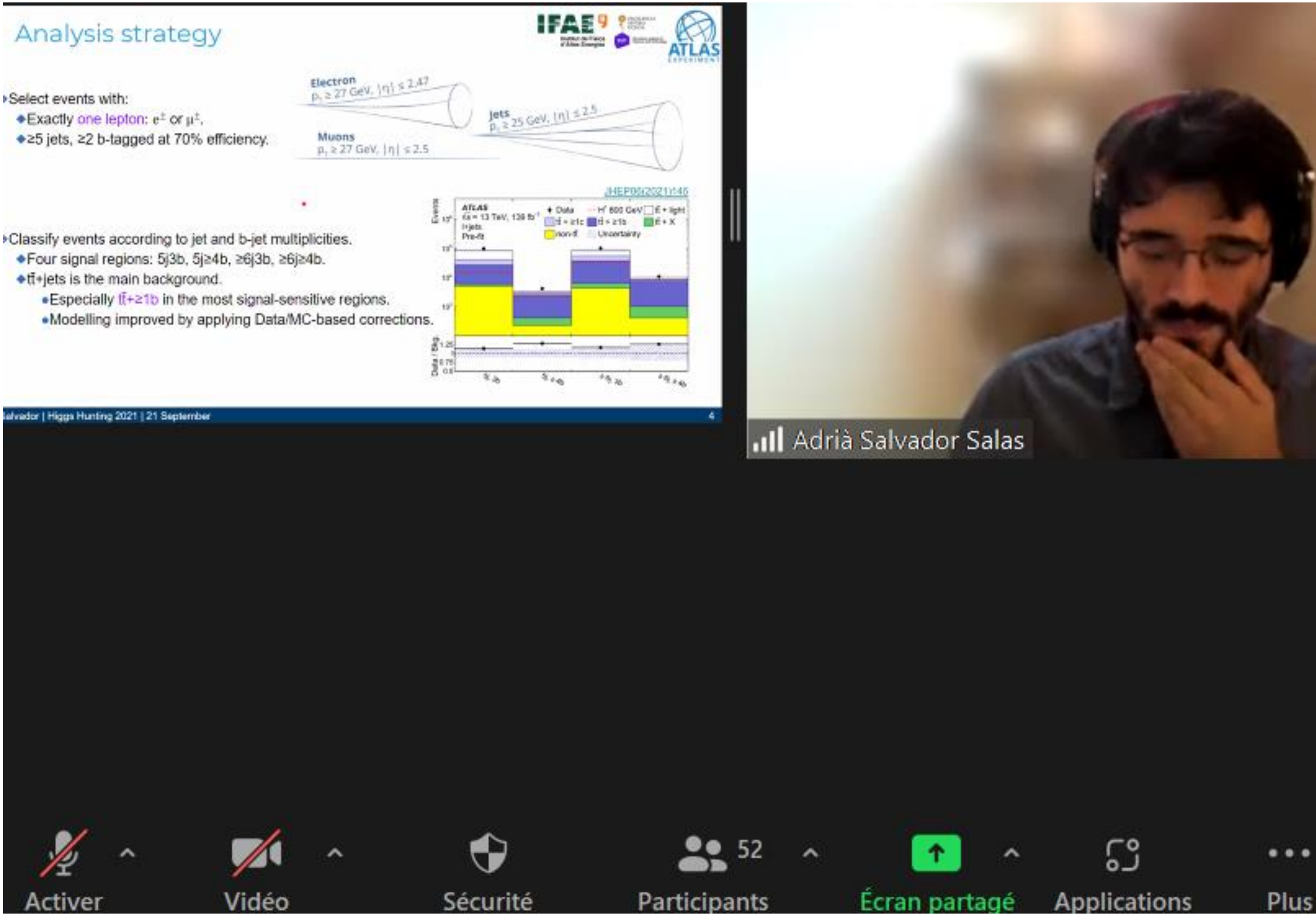
Analysis strategy
IFAE
ATLAS
Select events with:
Exactly one lepton: e± or μ±.
≥5 jets, ≥2 b-tagged at 70% efficiency.
Electron
Muons
Jets
Classify events according to jet and b-jet multiplicities.
Four signal regions: 5j3b, 5j≥4b, ≥6j3b, ≥6j≥4b.
tt̄+jets is the main background.
Especially tt̄+≥1b in the most signal-sensitive regions.
Modelling improved by applying Data/MC-based corrections.
JHEP06(2021)145
alvador | Higgs Hunting 2021 | 21 September
4
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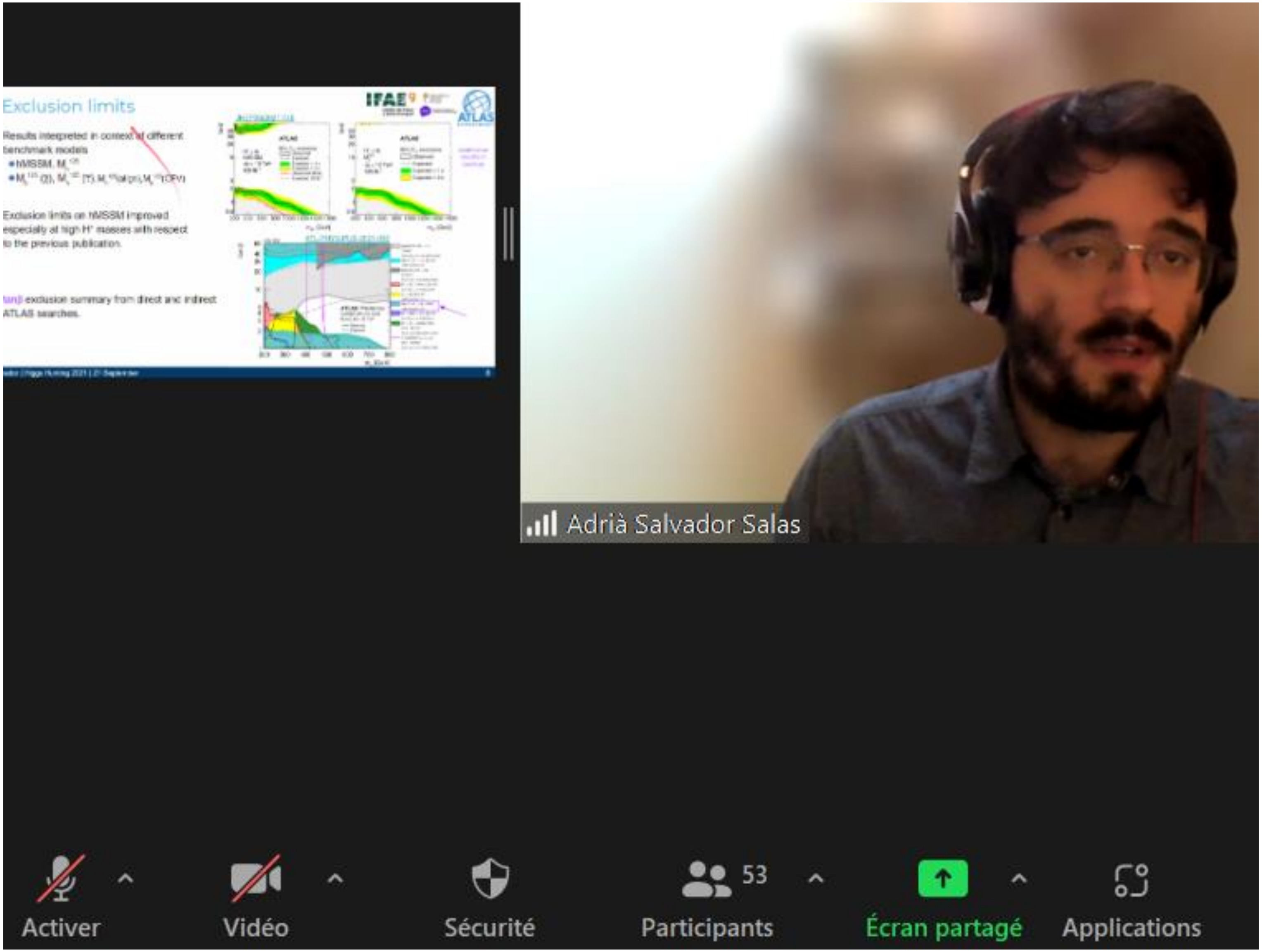
Exclusion limits
Results interpreted in context of different benchmark models
Exclusion limits on hMSSM improved especially at high H+ masses with respect to the previous publication.
exclusion summary from direct and indirect ATLAS searches.
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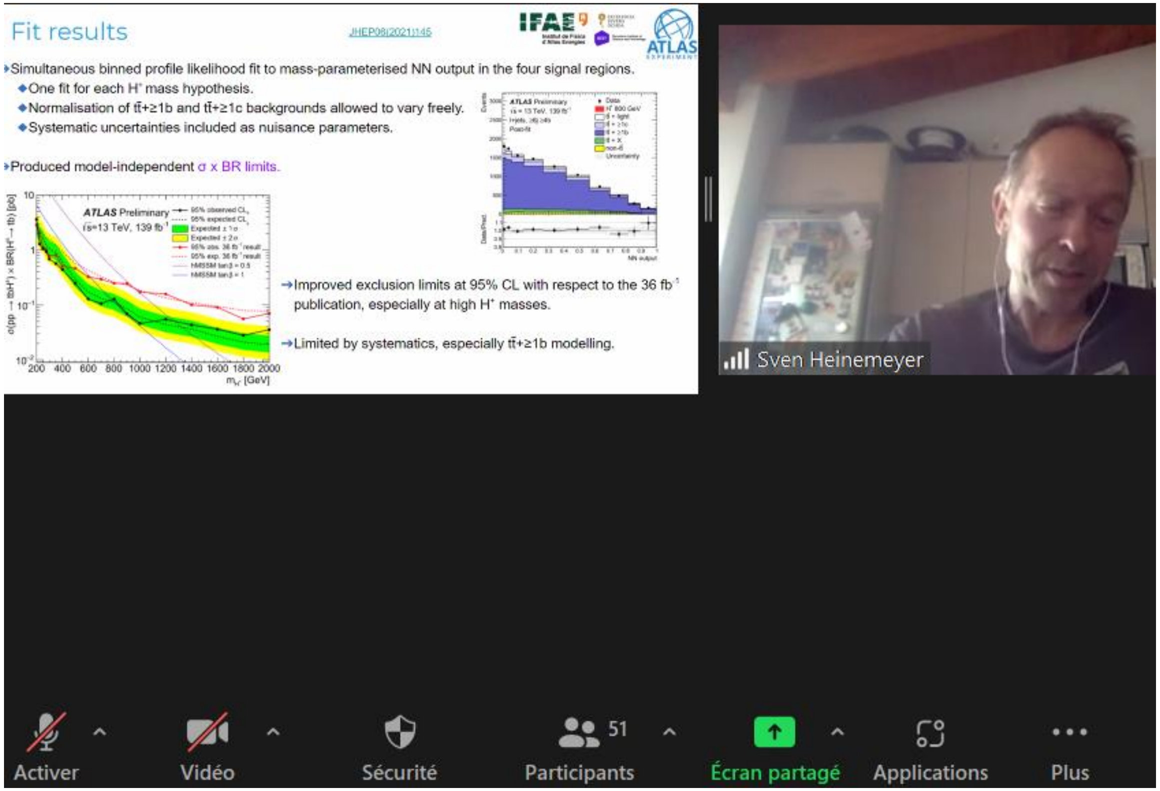
Fit results
JHEP08(2021)145
Simultaneous binned profile likelihood fit to mass-parameterised NN output in the four signal regions.
One fit for each H+ mass hypothesis.
Normalisation of tt̄+≥1b and tt̄+≥1c backgrounds allowed to vary freely.
Systematic uncertainties included as nuisance parameters.
Produced model-independent σ x BR limits.
ATLAS Preliminary
√s=13 TeV, 139 fb-1
95% observed CLs
95% expected CLs
Expected ± 1σ
Expected ± 2σ
m_H+ [GeV]
NN output
→Improved exclusion limits at 95% CL with respect to the 36 fb-1 publication, especially at high H+ masses.
→Limited by systematics, especially tt̄+≥1b modelling.
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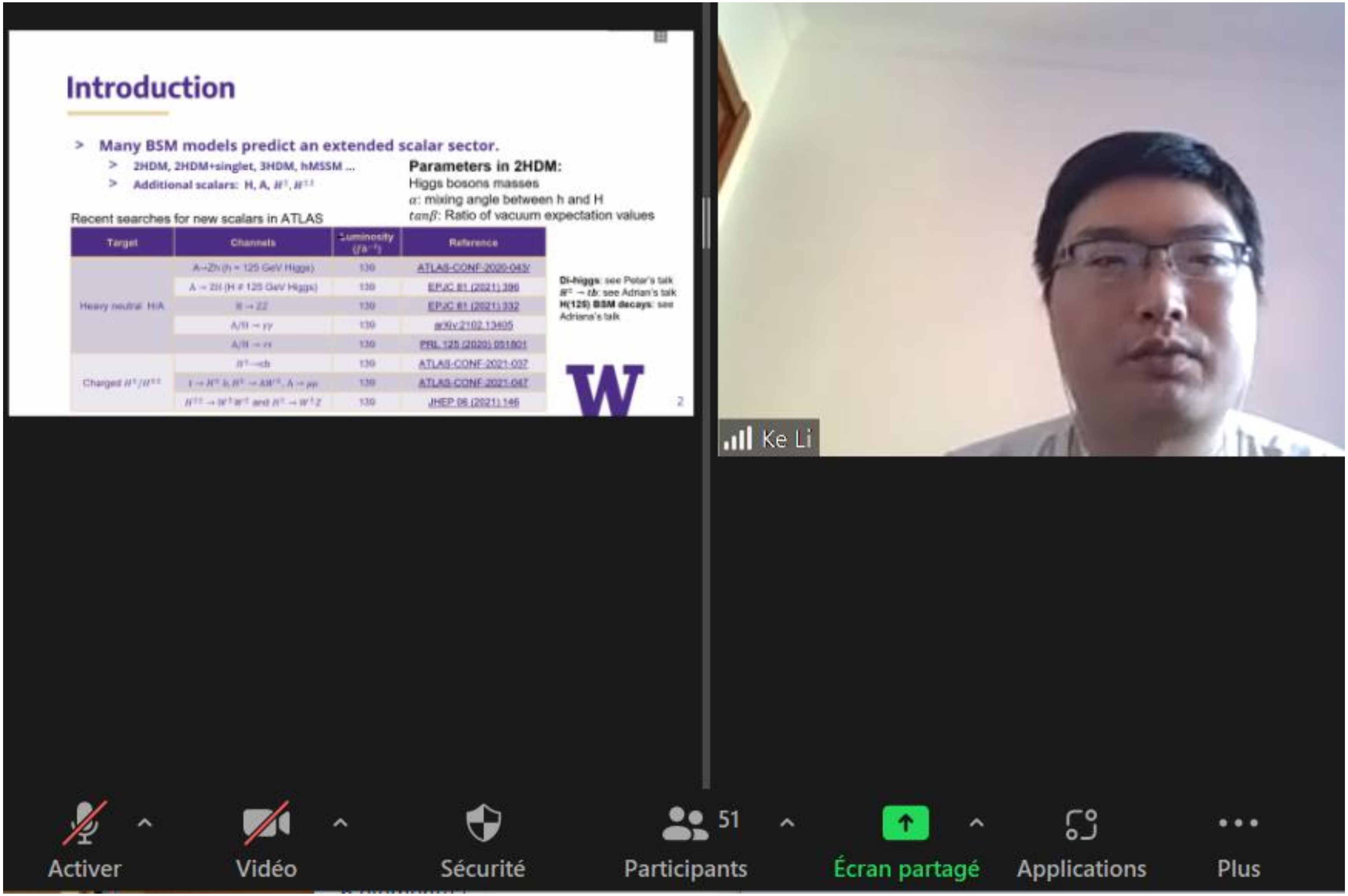
Adrià Salvador Salas


Introduction
Many BSM models predict an extended scalar sector.
2HDM, 2HDM+singlet, 3HDM, hMSSM ...
Additional scalars: H, A
Parameters in 2HDM:
Higgs bosons masses
α: mixing angle between h and H
tanβ: Ratio of vacuum expectation values
Recent searches for new scalars in ATLAS
Target
Channels
Luminosity
Reference
Heavy neutral H/A
ATLAS-CONF-2020-043
EPJC 81 (2021) 396
EPJC 81 (2021) 332
arXiv:2102.13405
PRL 125 (2020) 051801
Charged
ATLAS-CONF-2021-037
ATLAS-CONF-2021-047
JHEP 06 (2021) 146
Di-higgs: see Peter's talk
see Adrian's talk
H(125) BSM decays: see Adriana's talk
2
Ke Li
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Heavy neutral Higgs: A→Zh (h=125 GeV Higgs)
> Zh → llbb and vvbb from ggF.
> Good sensitivity for small tanβ.
> h → bb could be resolved (2 small-R jets) or merged (1 large-R jet).
> Dominant background: tt̄ and Z+jets, constrained from data.
vvbb
llbb
ATLAS Preliminary
• Largest excess is at 500 GeV (llbb channel) with a local significance of 1.6σ.
S-CONF-2020-043/
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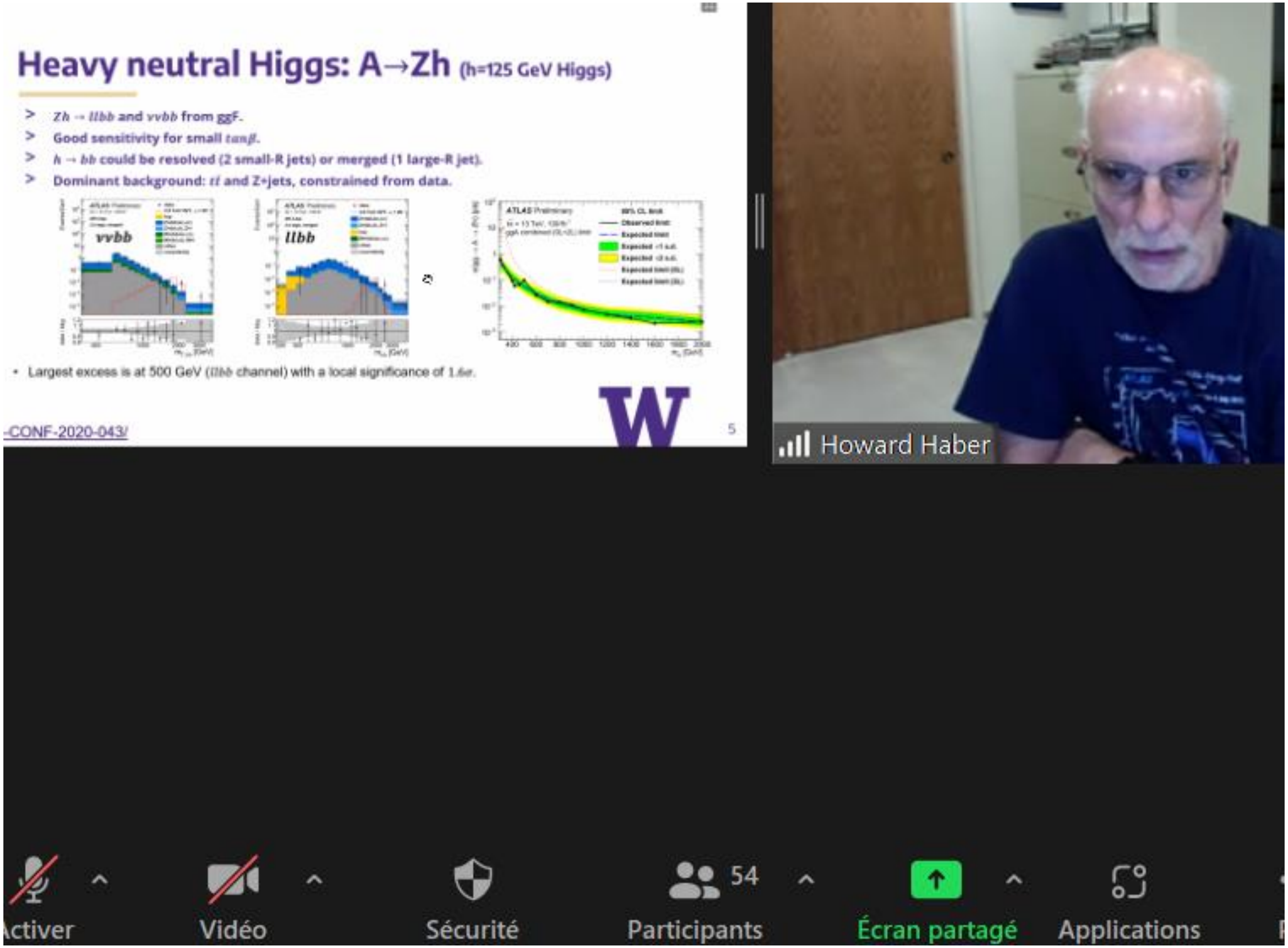
Heavy neutral Higgs: A→Zh (h=125 GeV Higgs)
Zh → llbb and ννbb from ggF.
Good sensitivity for small tanβ.
h → bb could be resolved (2 small-R jets) or merged (1 large-R jet).
Dominant background: tt and Z+jets, constrained from data.
ννbb
llbb
ATLAS Preliminary
Largest excess is at 500 GeV (llbb channel) with a local significance of 1.6σ.
-CONF-2020-043/
5
Howard Haber
ctiver
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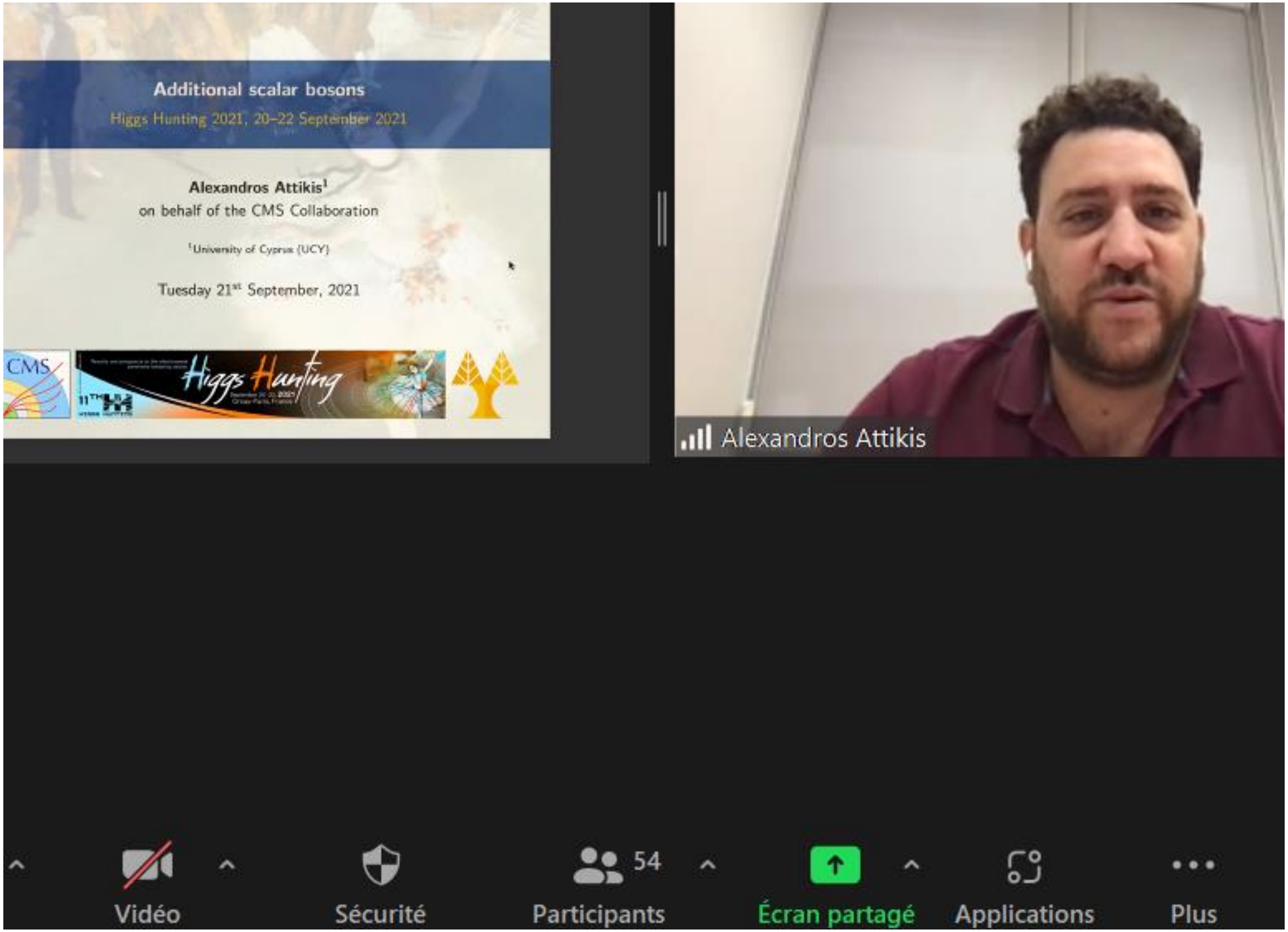
Additional scalar bosons
Higgs Hunting 2021, 20–22 September 2021
Alexandros Attikis[1]
on behalf of the CMS Collaboration
[1]University of Cyprus (UCY)
Tuesday 21st September, 2021
CMS
Higgs Hunting
Alexandros Attikis
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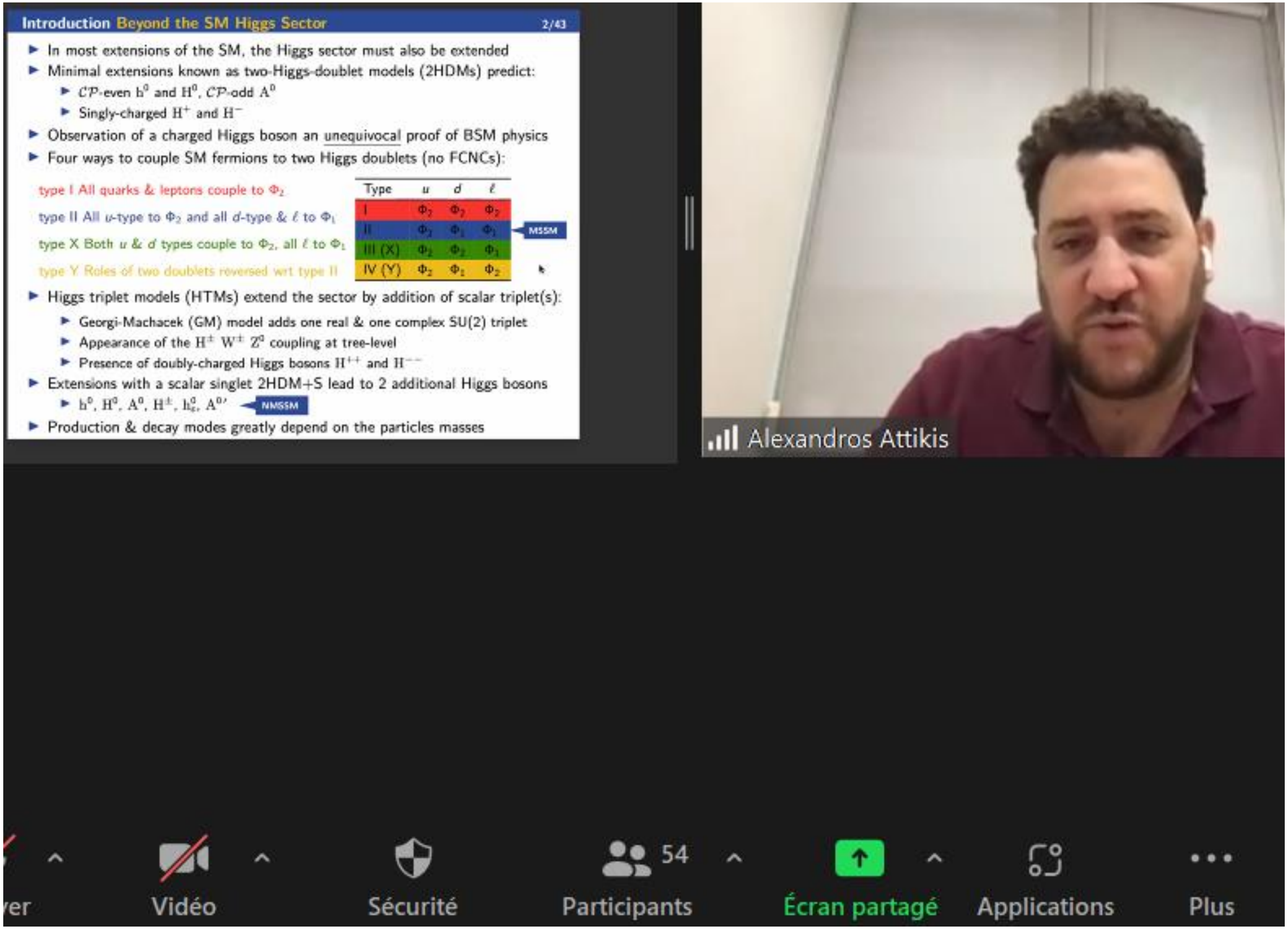
Introduction Beyond the SM Higgs Sector
2/43
In most extensions of the SM, the Higgs sector must also be extended
Minimal extensions known as two-Higgs-doublet models (2HDMs) predict:
$\mathcal{CP}$-even h^0 and H^0, $\mathcal{CP}$-odd A^0
Singly-charged H^+ and H^-
Observation of a charged Higgs boson an unequivocal proof of BSM physics
Four ways to couple SM fermions to two Higgs doublets (no FCNCs):
type I All quarks & leptons couple to Φ_2
type II All u-type to Φ_2 and all d-type & ℓ to Φ_1
type X Both u & d types couple to Φ_2, all ℓ to Φ_1
type Y Roles of two doublets reversed wrt type II
Type u d ℓ
I Φ_2 Φ_2 Φ_2
II Φ_2 Φ_1 Φ_1
III (X) Φ_2 Φ_2 Φ_1
IV (Y) Φ_2 Φ_1 Φ_2
MSSM
Higgs triplet models (HTMs) extend the sector by addition of scalar triplet(s):
Georgi-Machacek (GM) model adds one real & one complex SU(2) triplet
Appearance of the $H^{\pm}W^{\mp}Z^0$ coupling at tree-level
Presence of doubly-charged Higgs bosons H^{++} and H^{--}
Extensions with a scalar singlet 2HDM+S lead to 2 additional Higgs bosons
h^0, H^0, A^0, $H^{\pm}$, h^0_s, $A^{0\prime}$
NMSSM
Production & decay modes greatly depend on the particles masses
Alexandros Attikis
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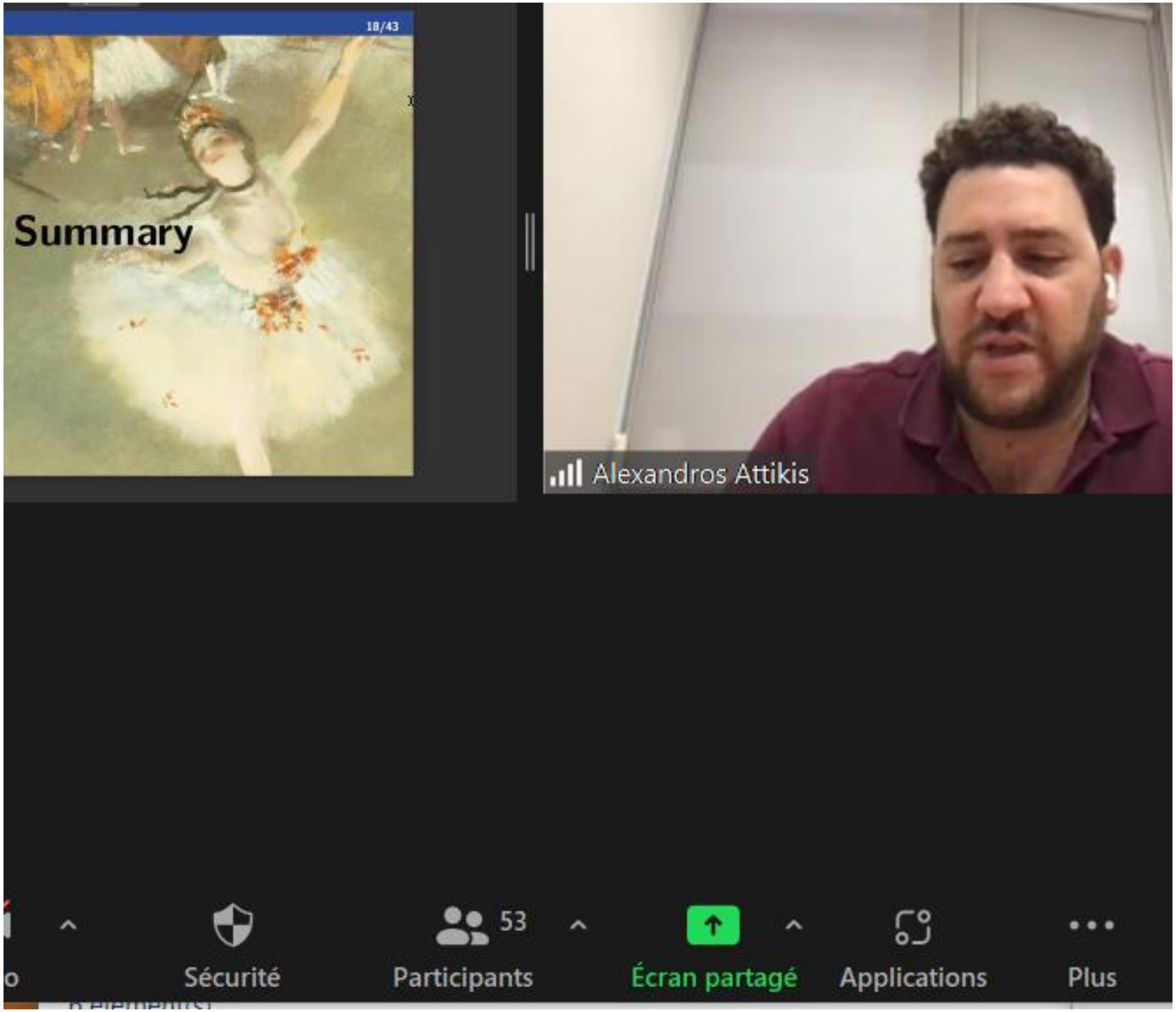
18/43
Summary
Alexandros Attikis
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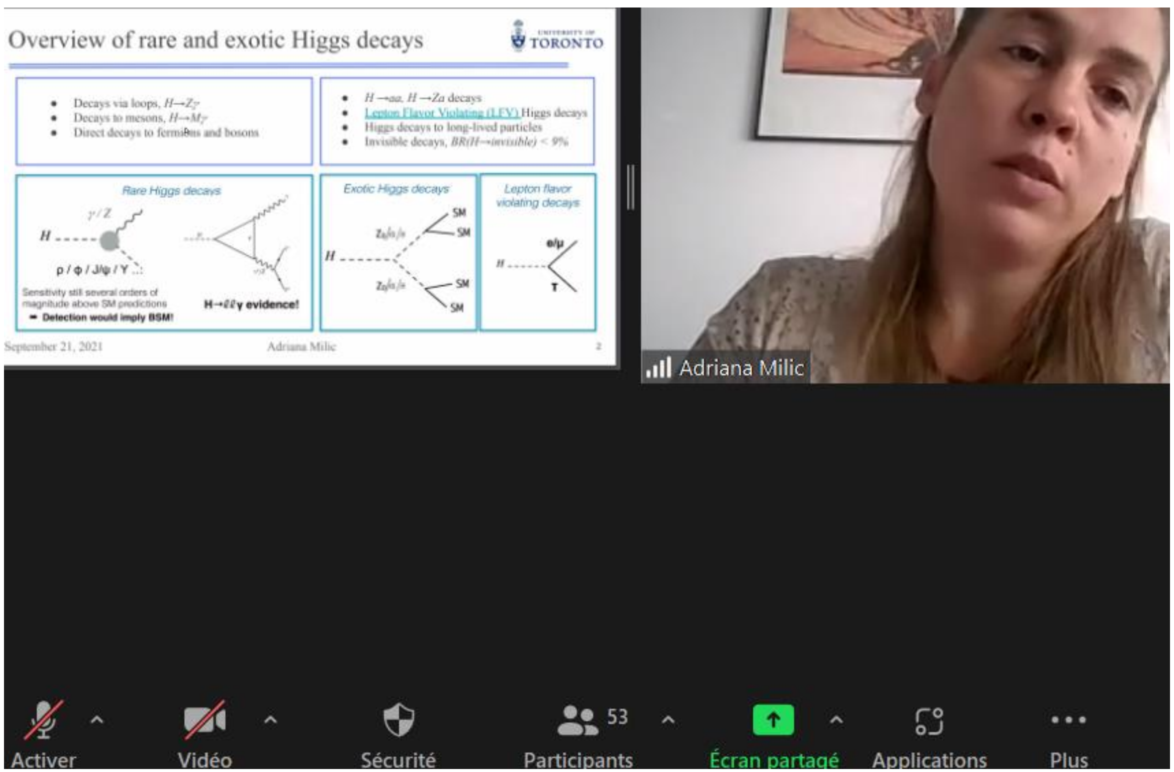
Searches for rare SM and BSM Higgs decays in ATLAS
Adriana Milic
September 20-22, 2021
Higgs Hunting 2021 - Paris, France
On behalf of the ATLAS collaboration
ATLAS EXPERIMENT
UNIVERSITY OF TORONTO
CERN
Adriana Milic


Overview of rare and exotic Higgs decays
UNIVERSITY OF TORONTO
Decays via loops, H→Zγ
Decays to mesons, H→Mγ
Direct decays to fermions and bosons
H→aa, H→Za decays
Lepton Flavor Violating (LFV) Higgs decays
Higgs decays to long-lived particles
Invisible decays, BR(H→invisible) < 9%
Rare Higgs decays
γ / Z
H
ρ / ϕ / J/ψ / Υ ...
Sensitivity still several orders of magnitude above SM predictions
➡ Detection would imply BSM!
H→ℓℓγ evidence!
Exotic Higgs decays
SM
Lepton flavor violating decays
e/μ
τ
September 21, 2021
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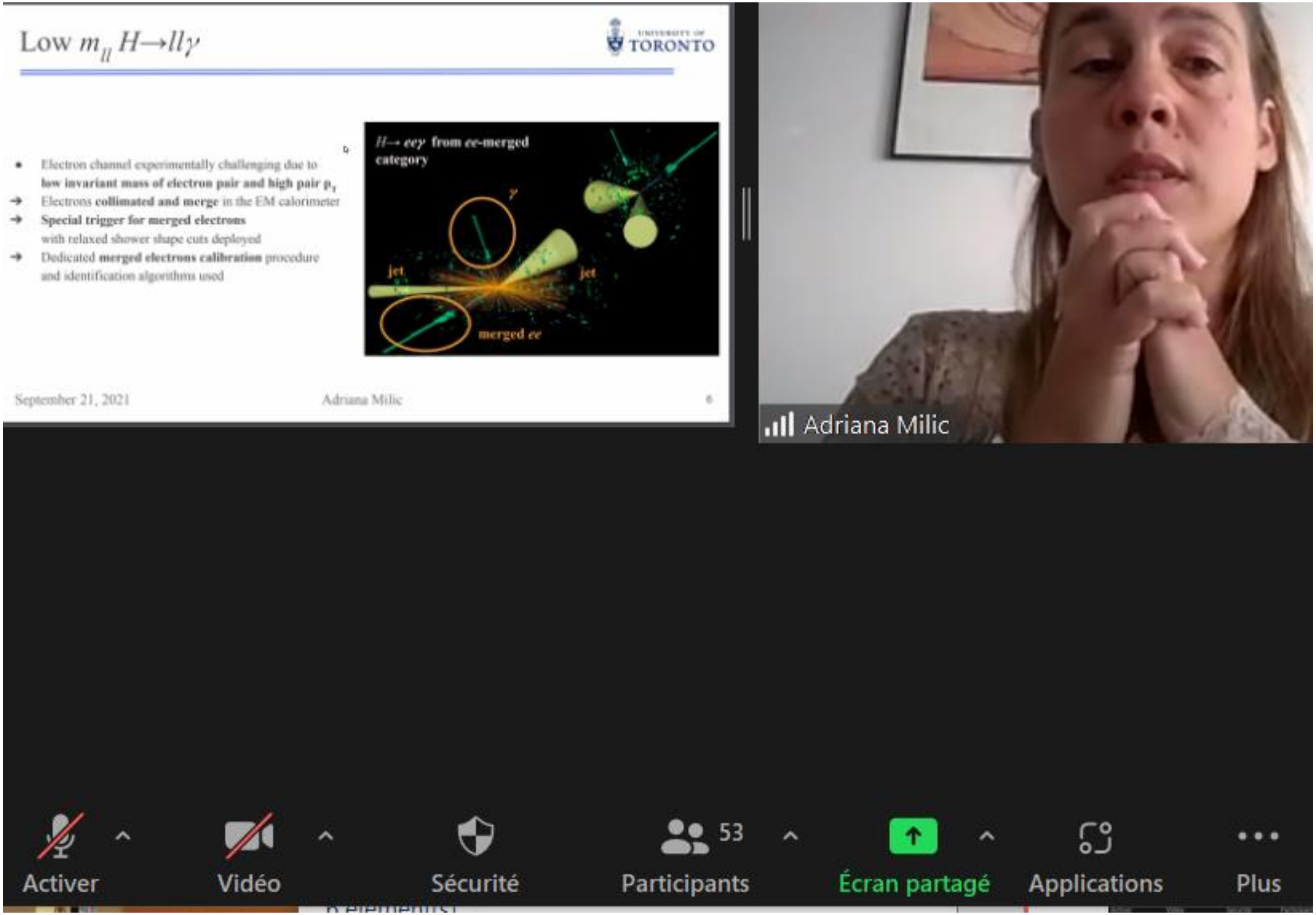
Low m_{ll} $H \rightarrow ll\gamma$
UNIVERSITY OF TORONTO
Electron channel experimentally challenging due to low invariant mass of electron pair and high pair p_T
→ Electrons collimated and merge in the EM calorimeter
→ Special trigger for merged electrons with relaxed shower shape cuts deployed
→ Dedicated merged electrons calibration procedure and identification algorithms used
$H \rightarrow ee\gamma$ from ee-merged category
γ
jet
jet
merged ee
September 21, 2021
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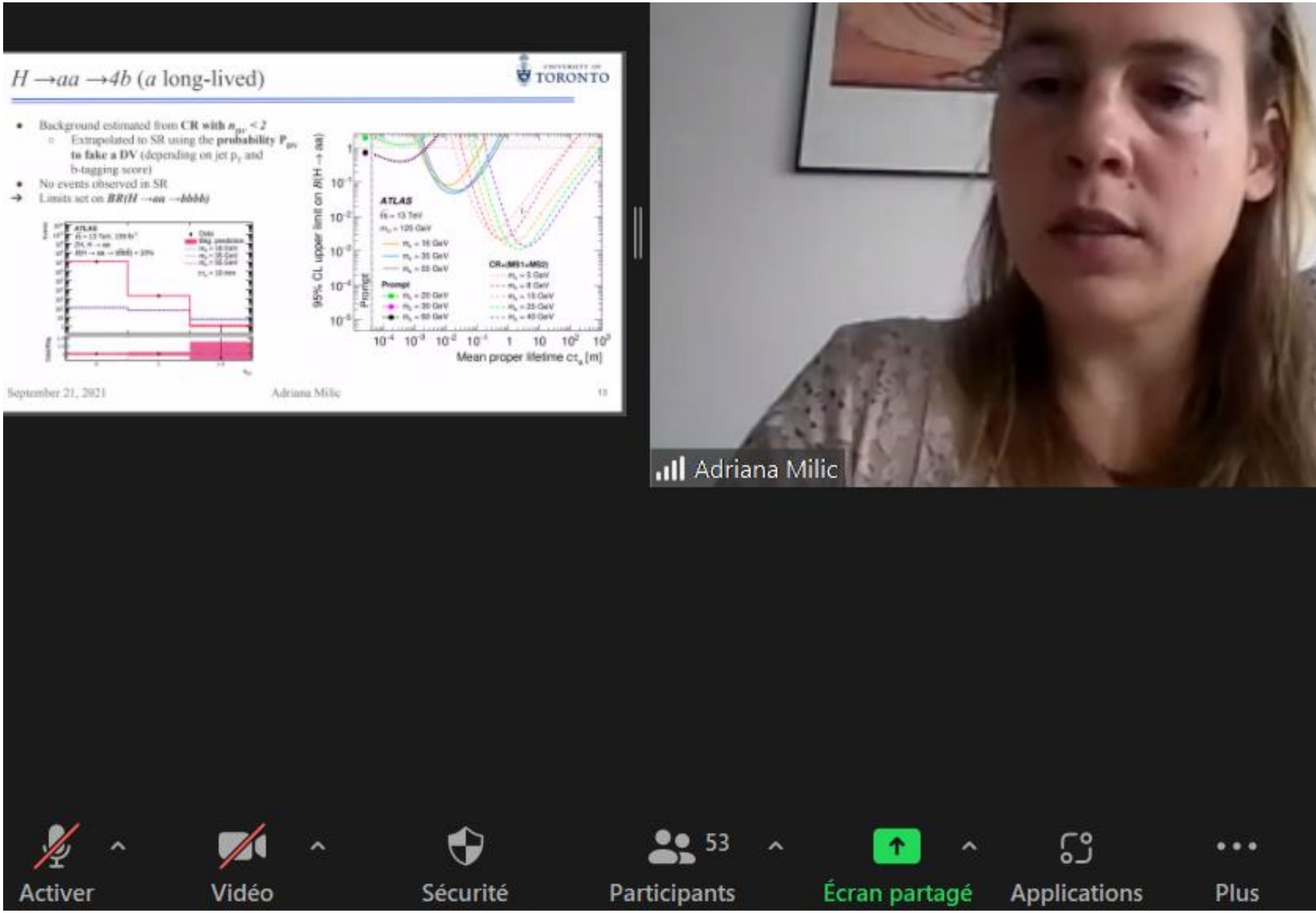

H →aa →4b (a long-lived)
TORONTO
Background estimated from CR with n_DV < 2
Extrapolated to SR using the probability P_DV to fake a DV (depending on jet p_T and b-tagging score)
No events observed in SR
→ Limits set on BR(H →aa →bbbb)
ATLAS
95% CL upper limit on B(H → aa)
Prompt
Mean proper lifetime cτ_a [m]
September 21, 2021
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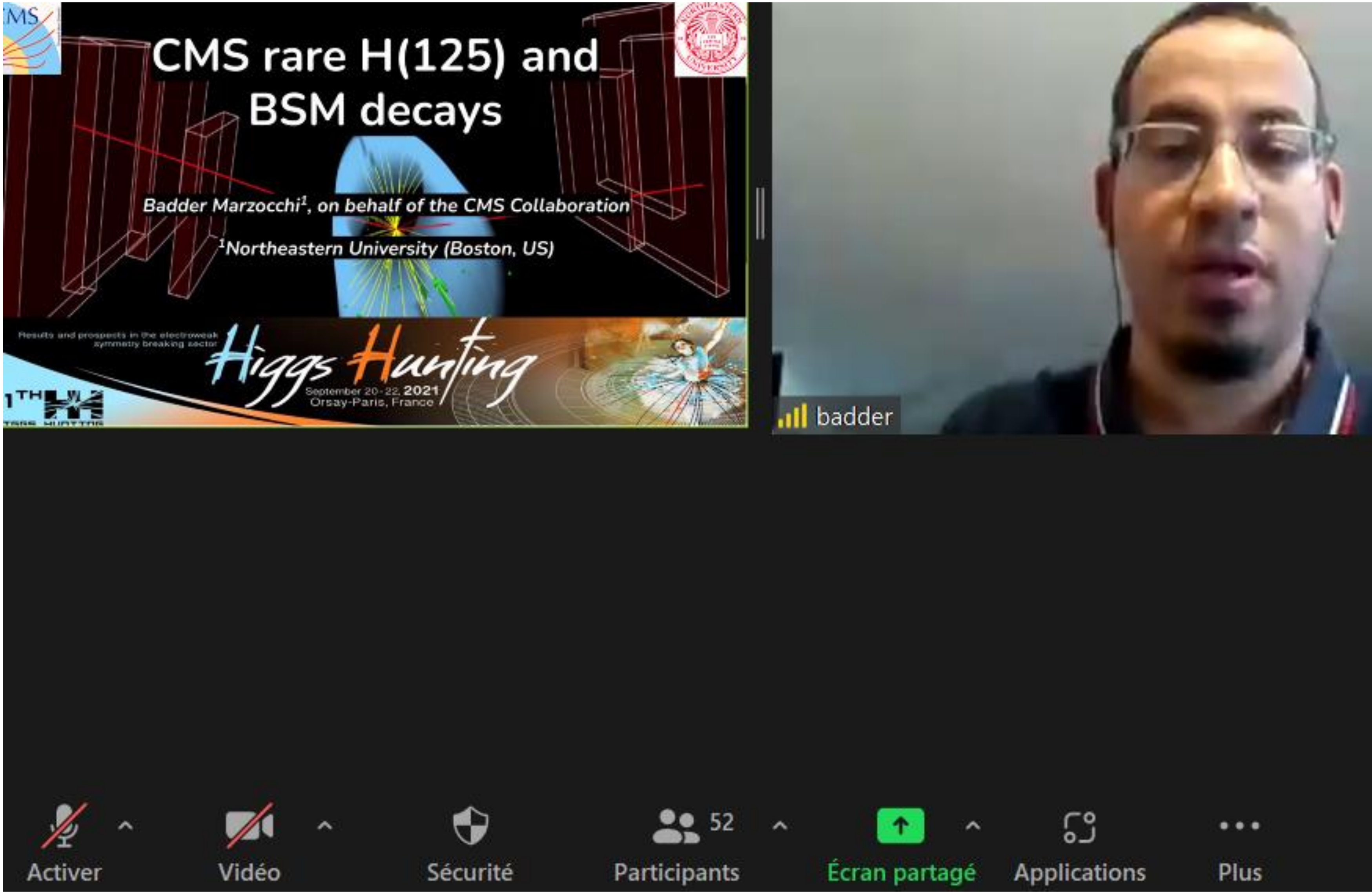
CMS rare H(125) and BSM decays
Badder Marzocchi[1], on behalf of the CMS Collaboration
[1]Northeastern University (Boston, US)
Results and prospects in the electroweak symmetry breaking sector
Higgs Hunting
September 20-22, 2021
Orsay-Paris, France
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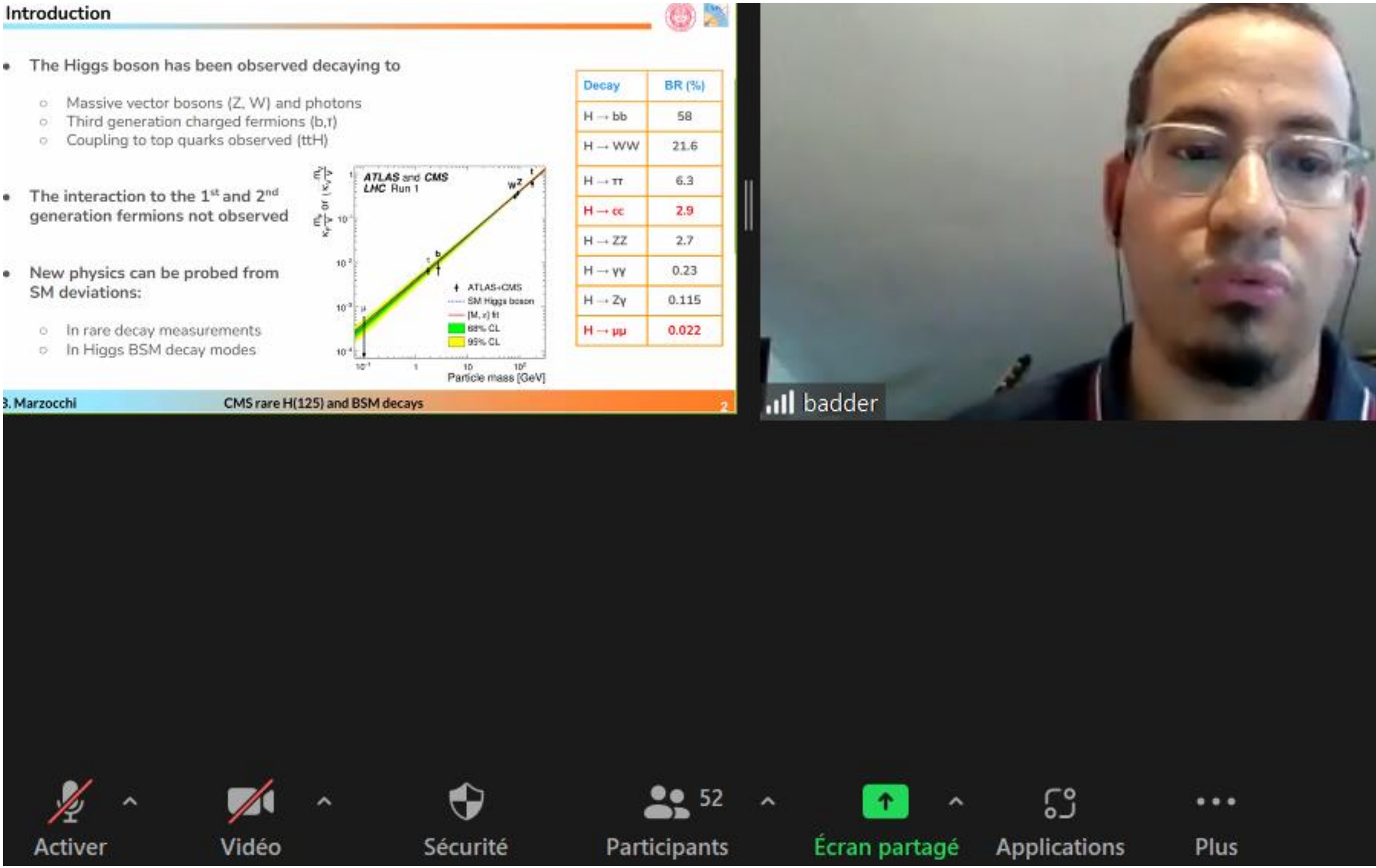
Introduction
The Higgs boson has been observed decaying to
Massive vector bosons (Z, W) and photons
Third generation charged fermions (b,τ)
Coupling to top quarks observed (ttH)
The interaction to the 1st and 2nd generation fermions not observed
New physics can be probed from SM deviations:
In rare decay measurements
In Higgs BSM decay modes
ATLAS and CMS
LHC Run 1
ATLAS+CMS
SM Higgs boson
[M, ε] fit
68% CL
95% CL
Particle mass [GeV]

Decay	BR (%)
H → bb	58
H → WW	21.6
H → ττ	6.3
H → cc	2.9
H → ZZ	2.7
H → γγ	0.23
H → Zγ	0.115
H → μμ	0.022

B. Marzocchi
CMS rare H(125) and BSM decays
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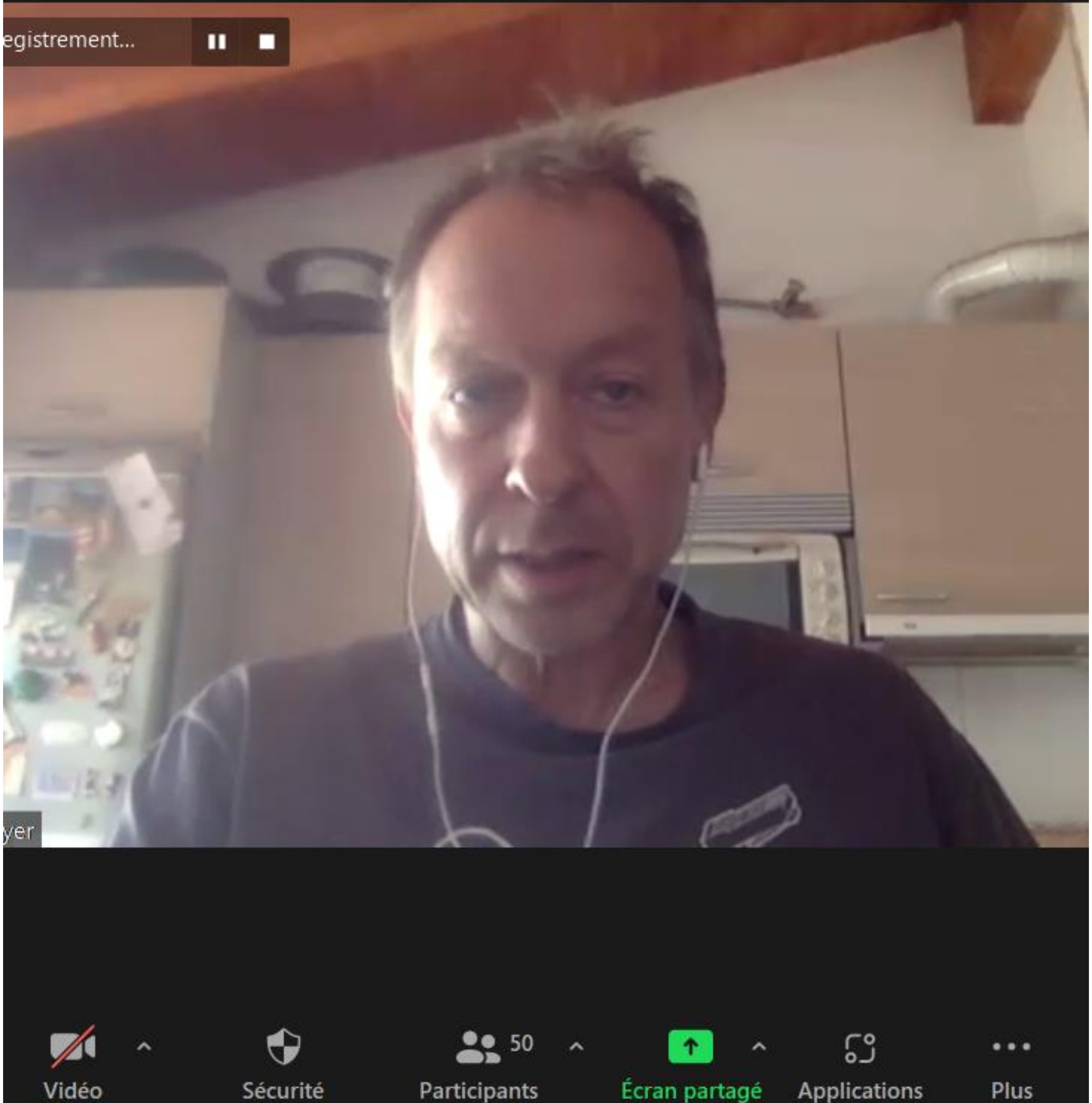
Applications
Plus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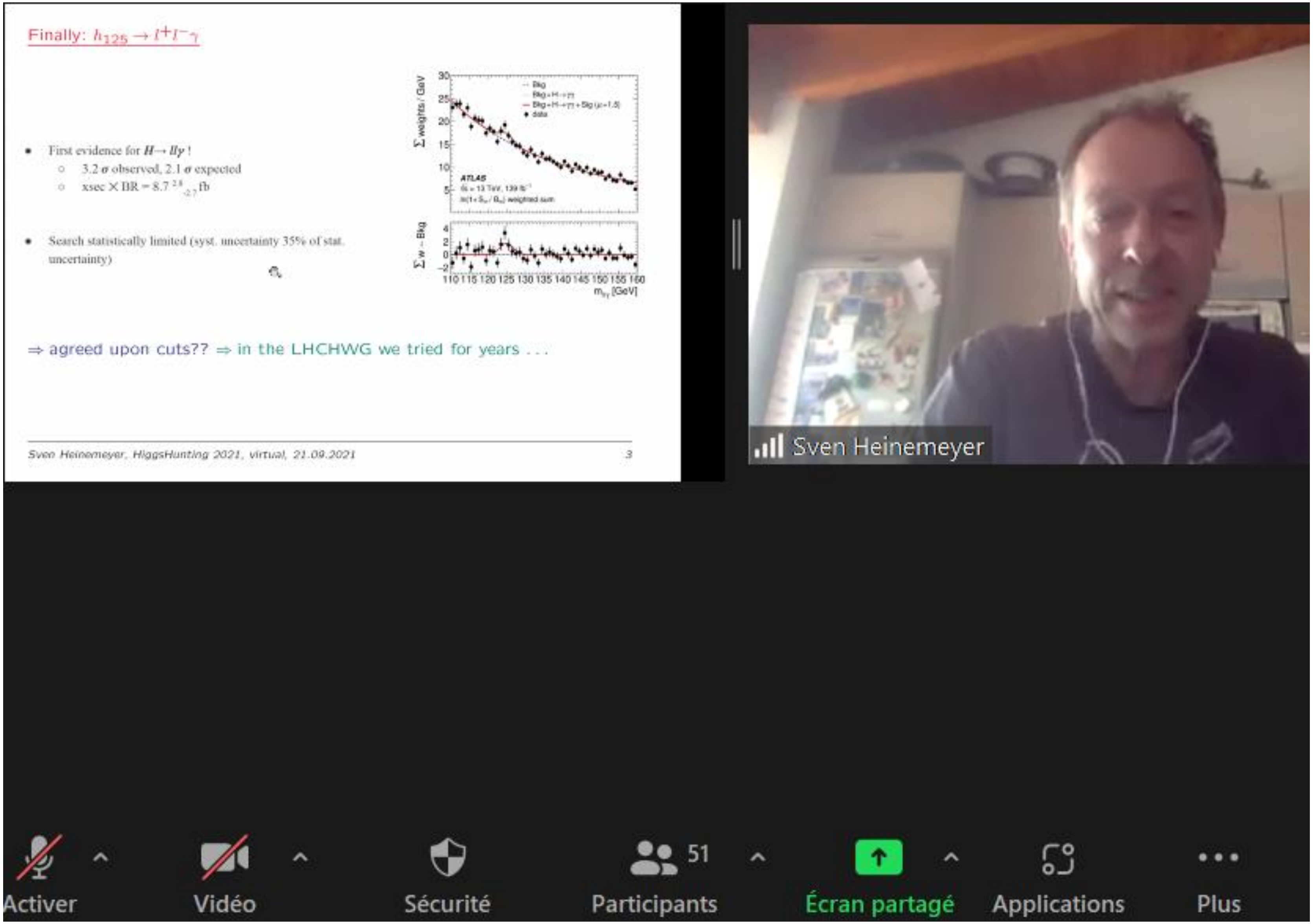
Plus



Finally: $h_{125} \to l^+l^-\gamma$
First evidence for $H \to ll\gamma$!
3.2 σ observed, 2.1 σ expected
xsec × BR = $8.7^{2.8}_{-2.7}$ fb
Search statistically limited (syst. uncertainty 35% of stat. uncertainty)
⇒ agreed upon cuts?? ⇒ in the LHCHWG we tried for years . . .
ATLAS
Σ weights / GeV
Σ w − Bkg
110 115 120 125 130 135 140 145 150 155 160
$m_{\gamma\gamma}$ [GeV]
Sven Heinemeyer, HiggsHunting 2021, virtual, 21.09.2021
3
Sven Heinemeyer
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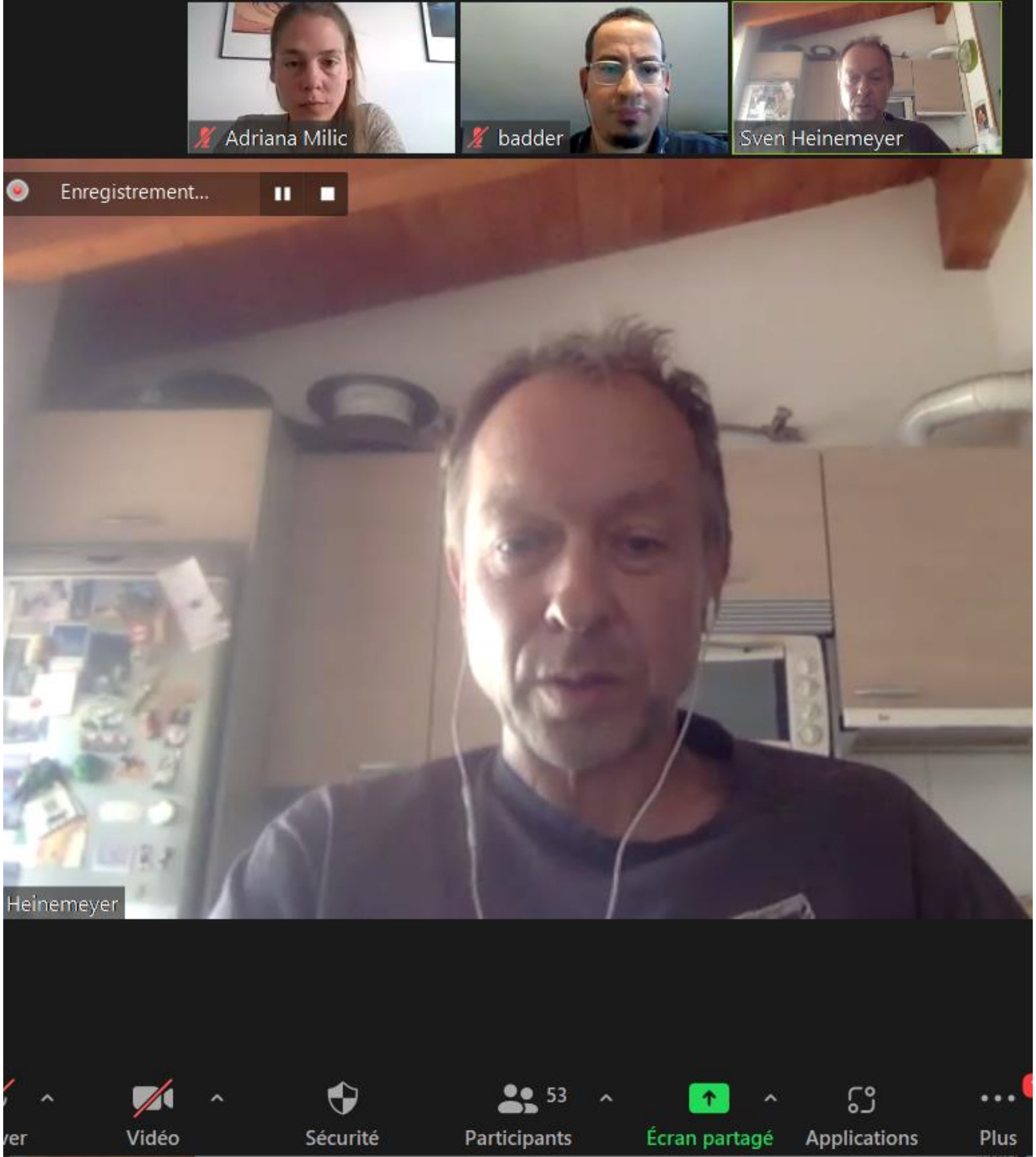

Adriana Milic
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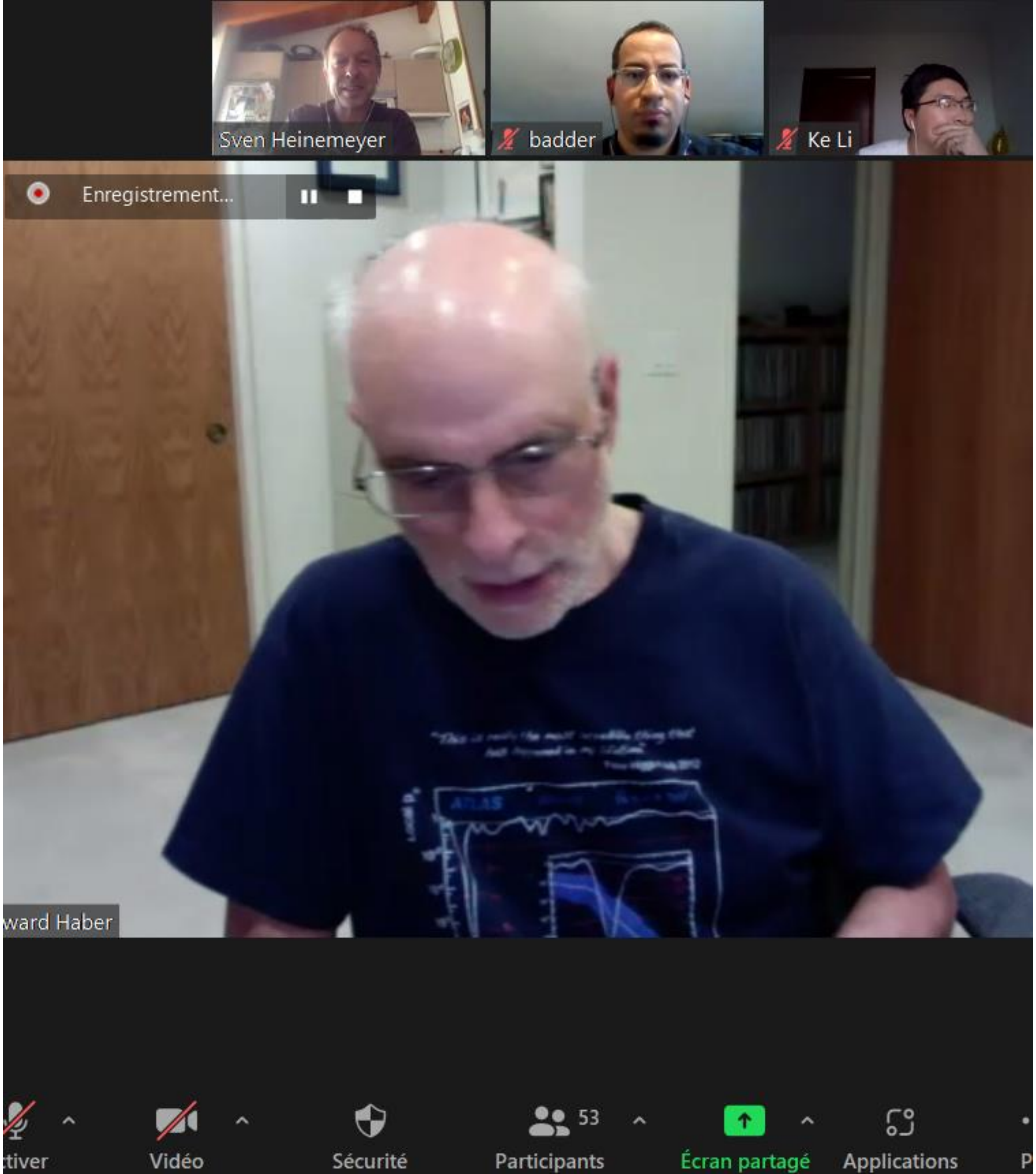
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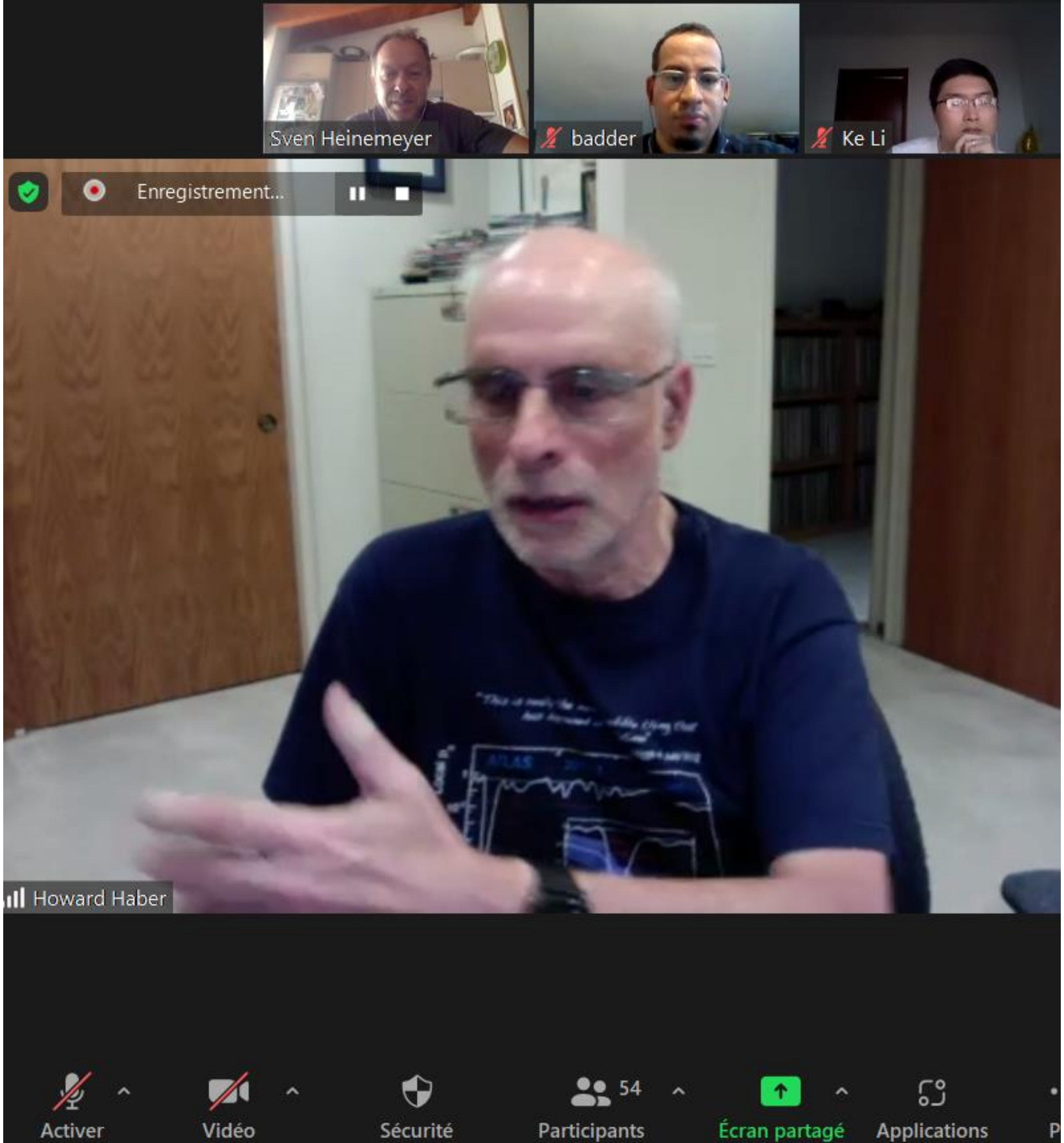
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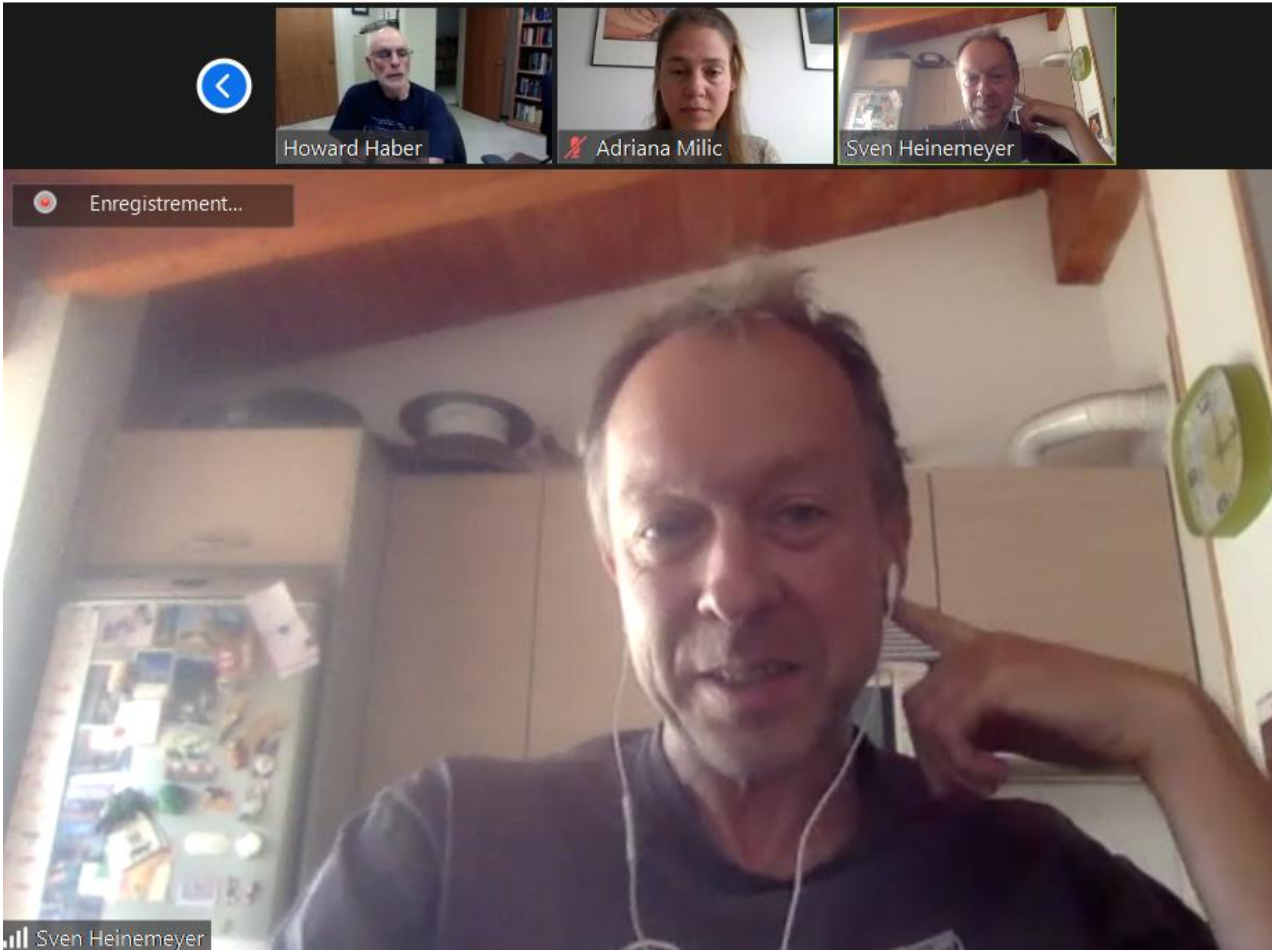
Howard Haber
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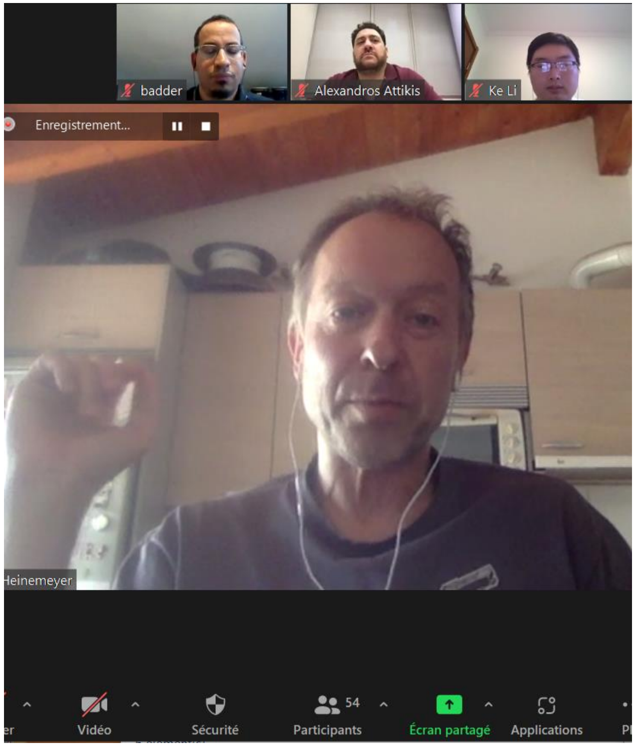
Sven Heinemeyer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Ke Li
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Heinemeyer
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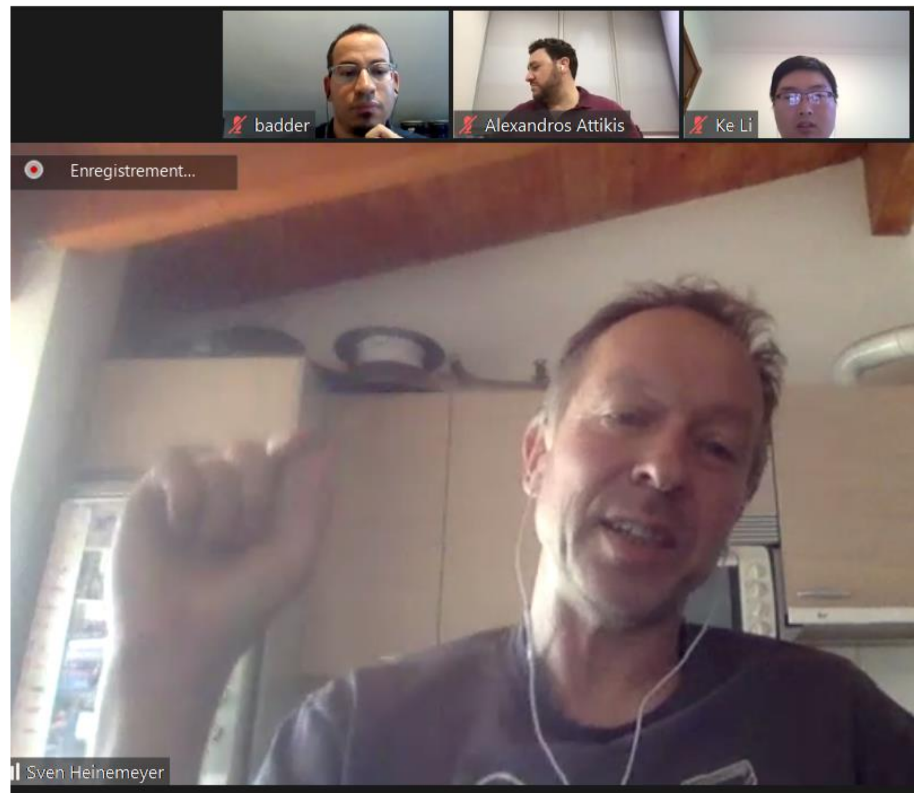
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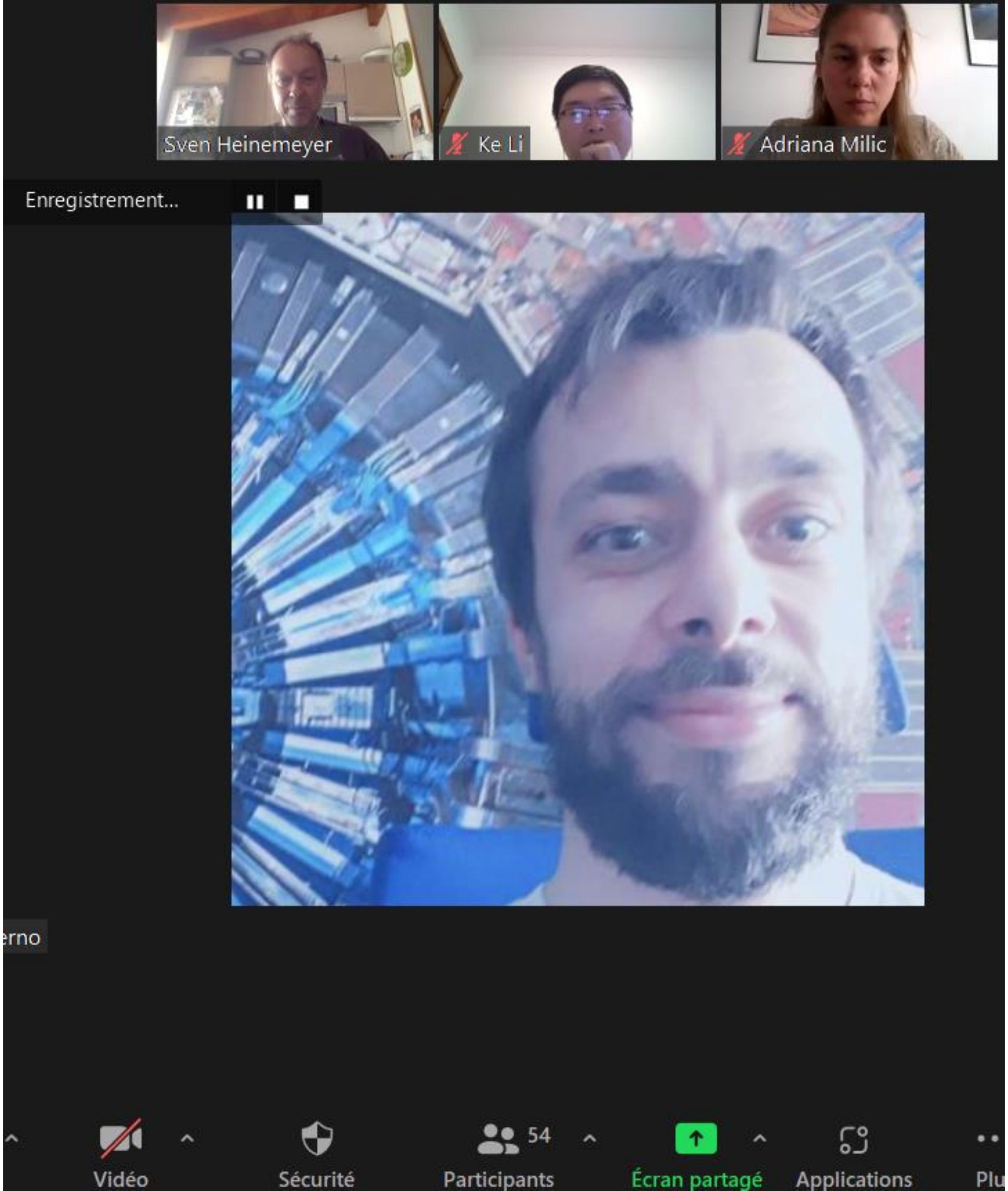

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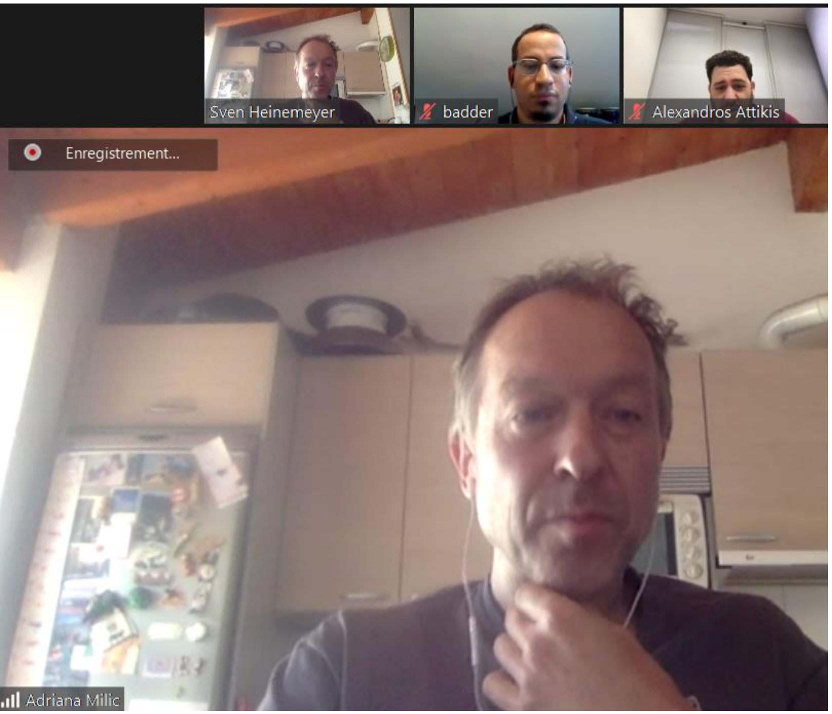
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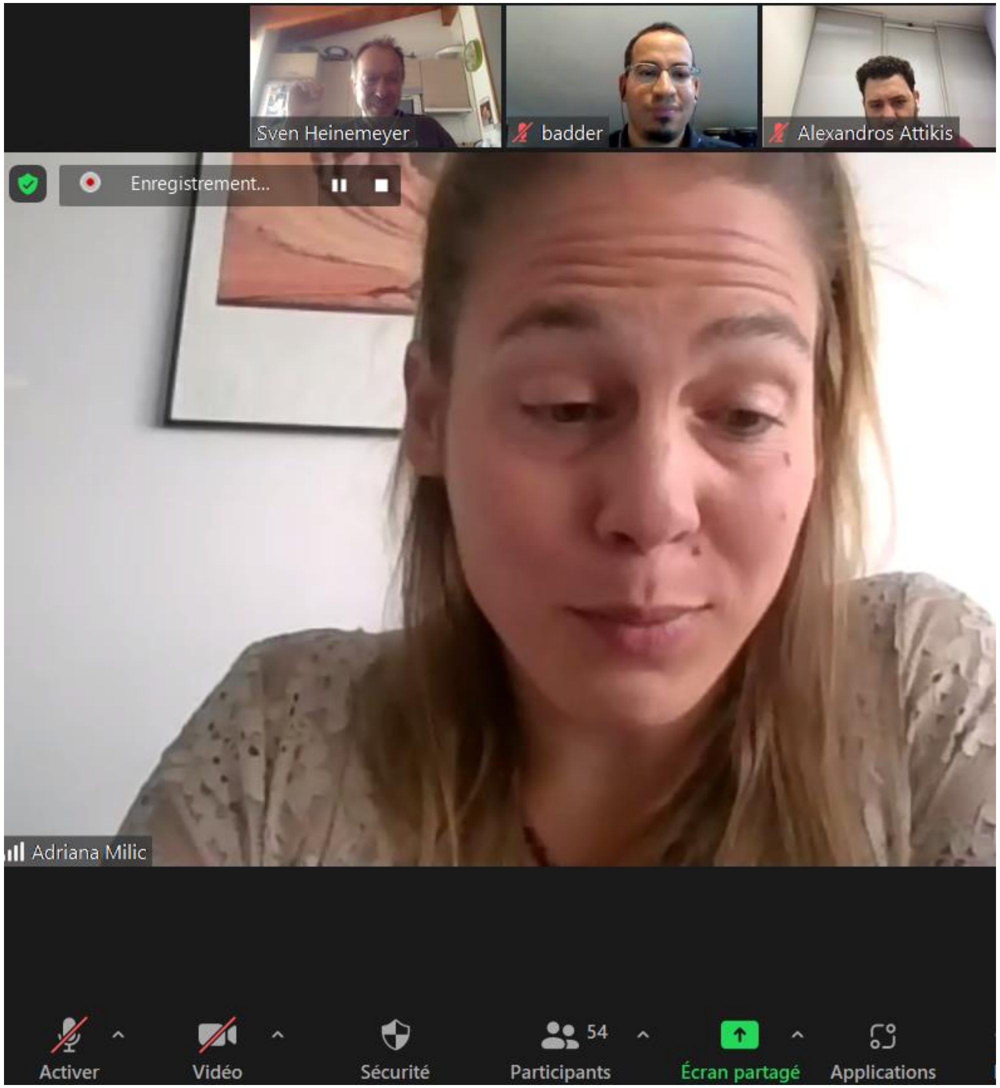
Adriana Milic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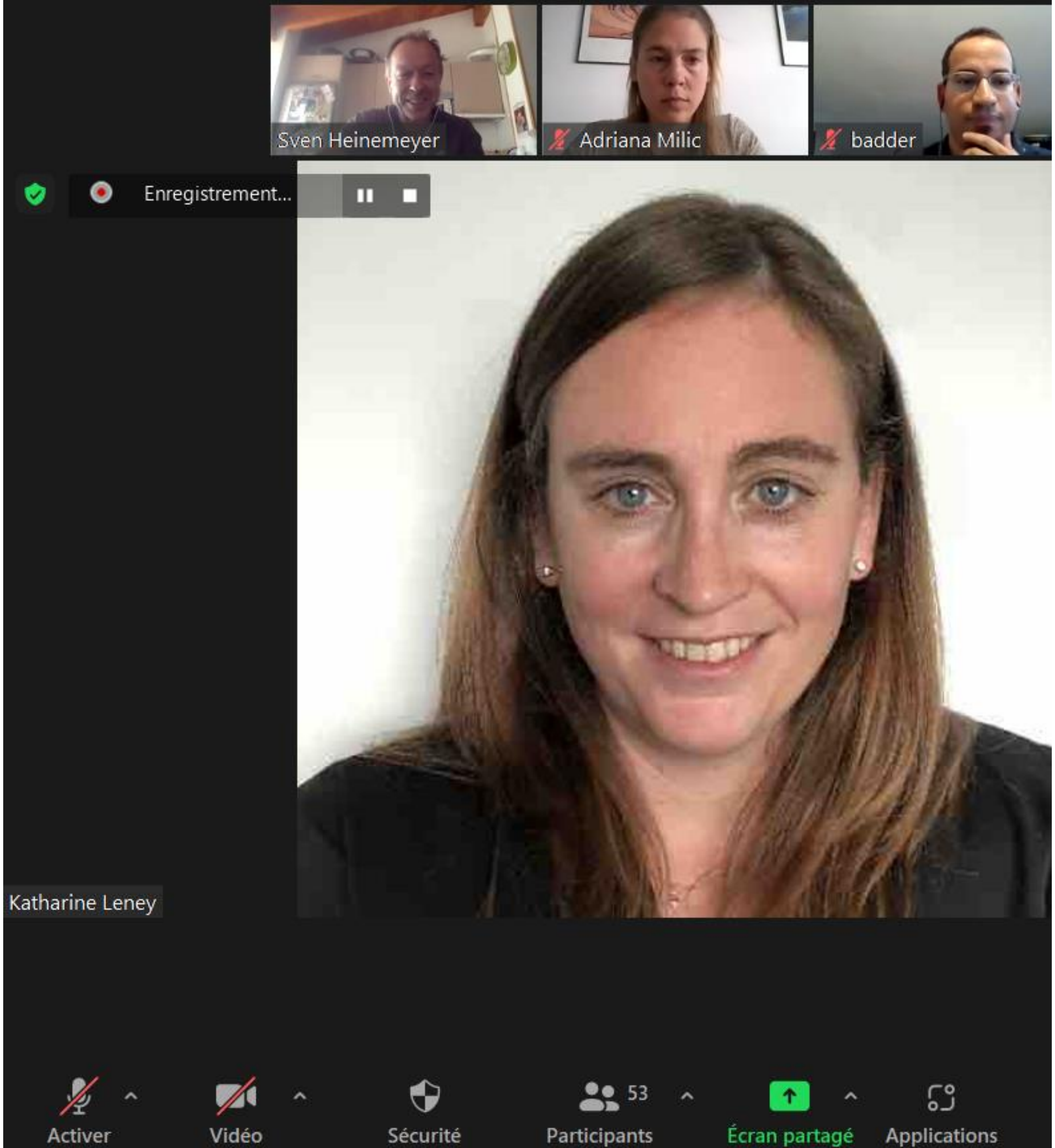
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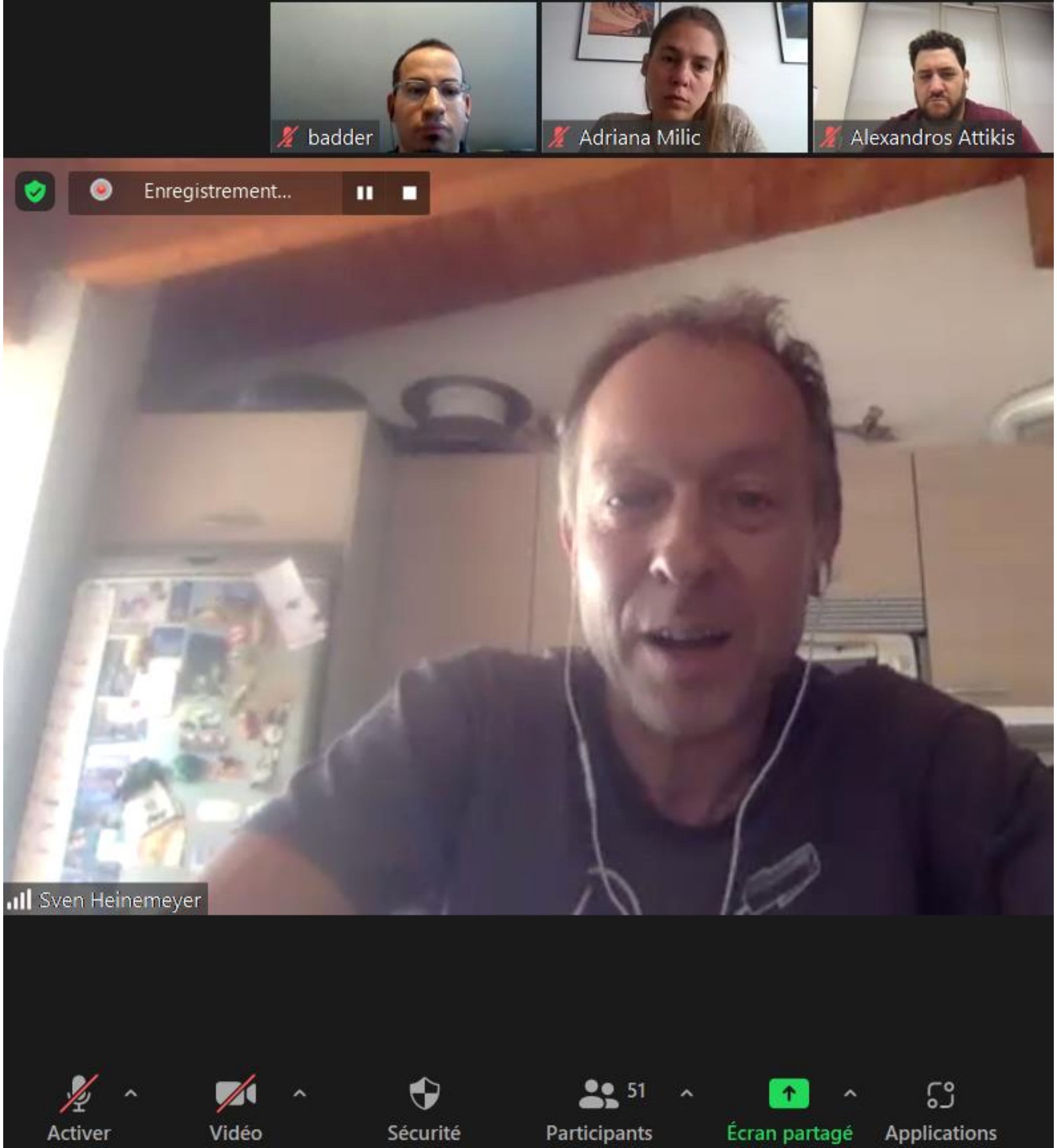
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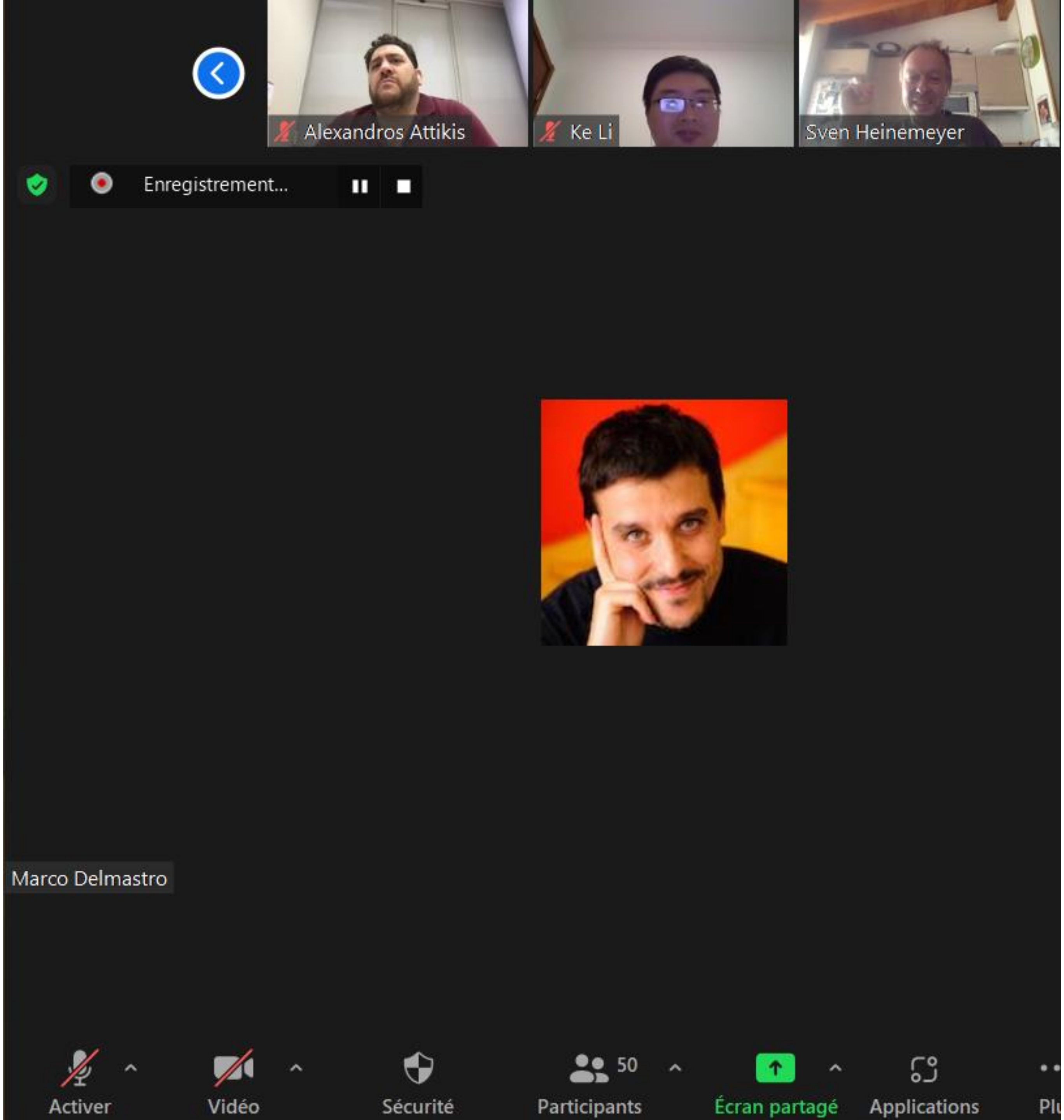
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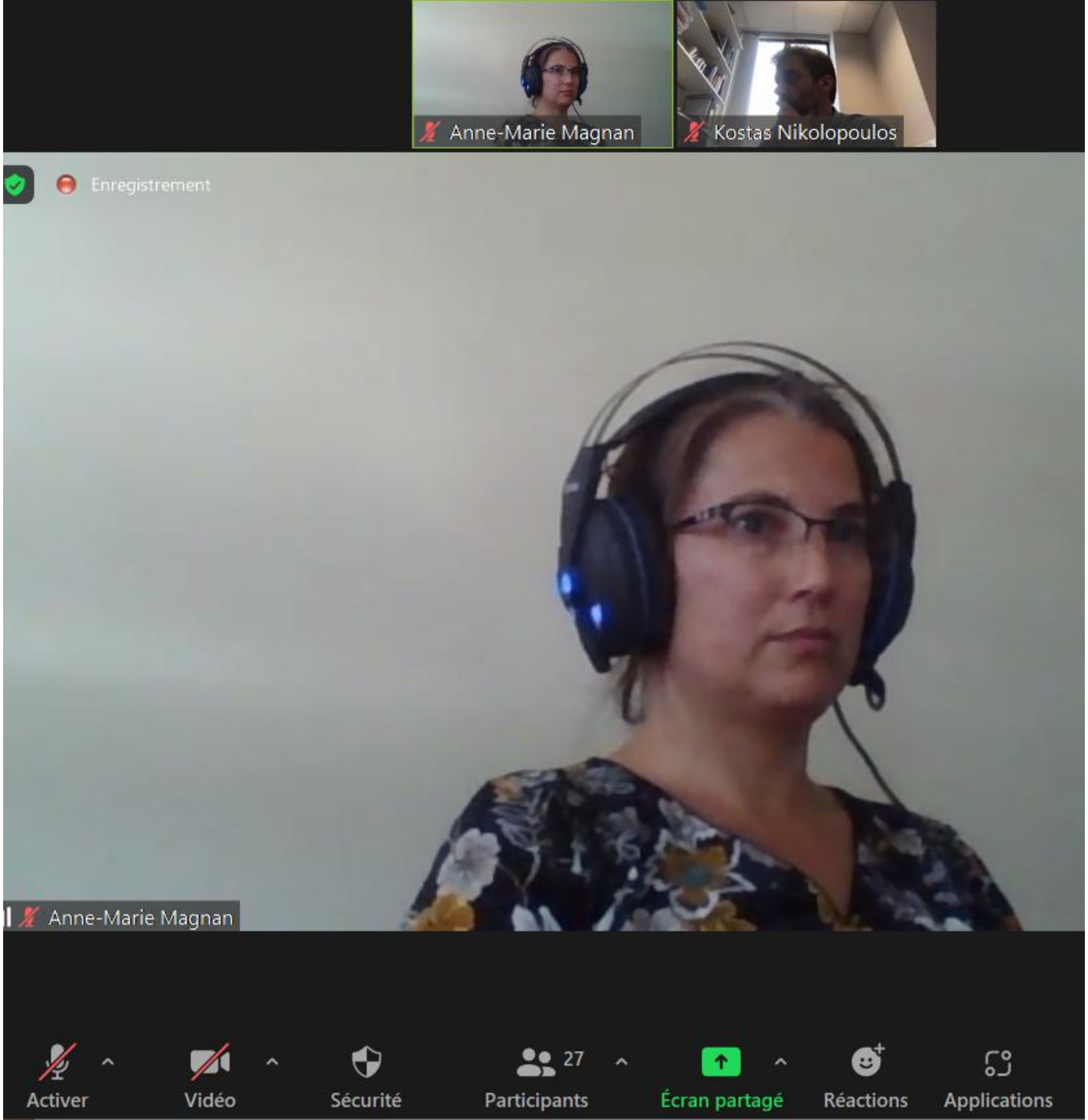
Anne-Marie Magnan
Kostas Nikolopoulos
Enregistrement
Anne-Marie Magnan
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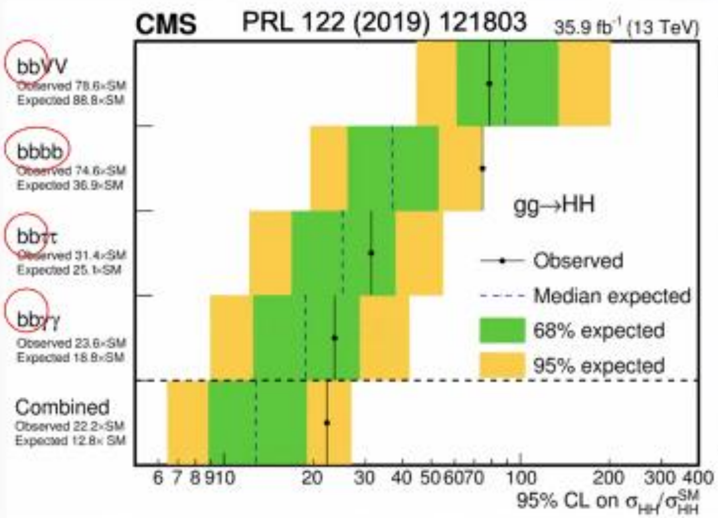
Set the scene

CMS

- Searches with b quarks play an important role in the LHC physics program



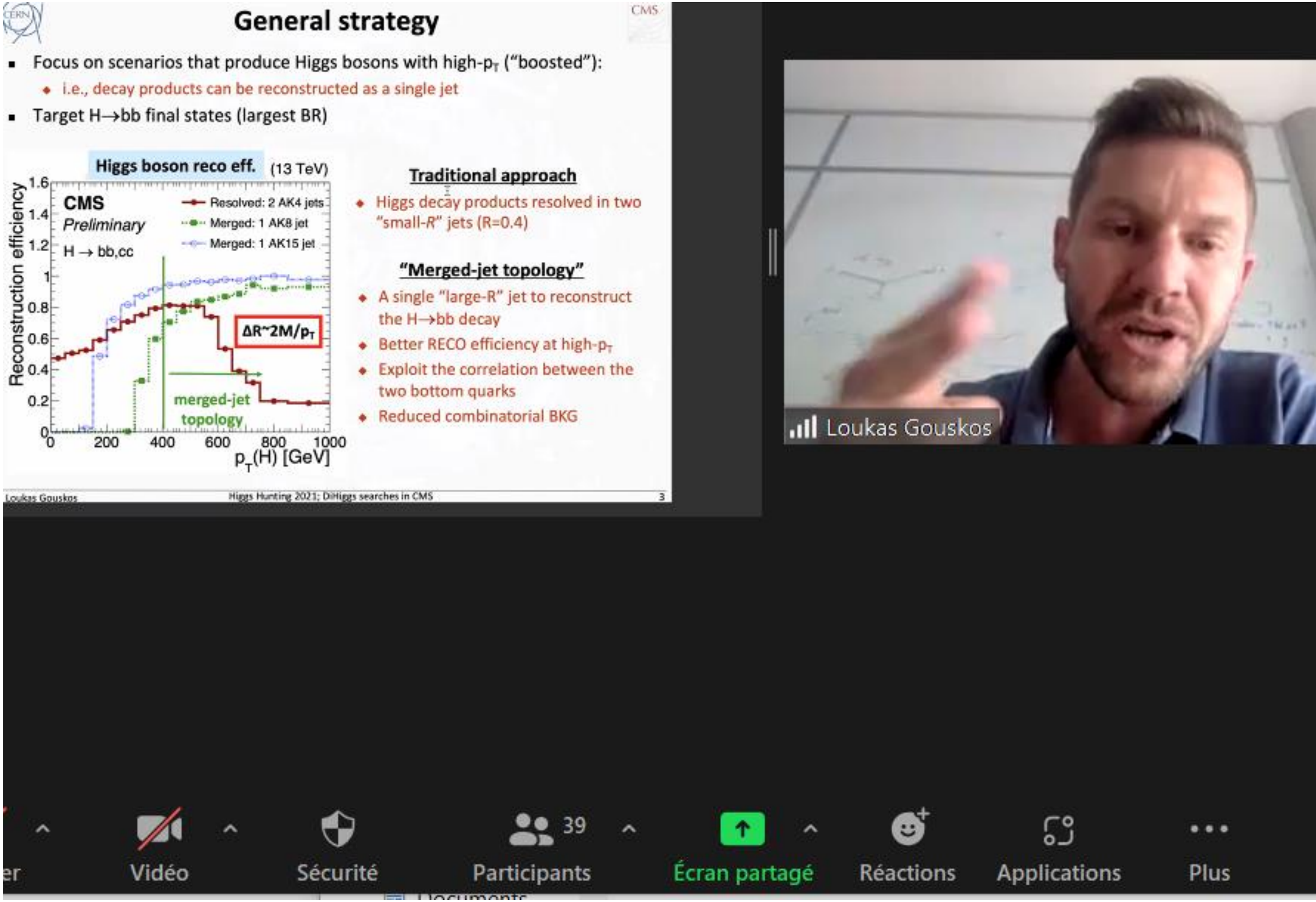
Characteristic case:
Searches with Higgs boson(s)

- H→bb: largest BR
- **but:** large QCD backgrounds

Key for success:

- Advanced b-jet identification algorithms
- Sophisticated analysis techniques

- Today's talk: Recent CMS results w/ **boosted** Higgs bosons decaying to b quarks
  - Particularly focus on the latest tools and techniques developed to enhance sensitivity
    - e.g., jet identification ("tagging"), jet mass regression, search design
- Full suite of results: CMS-B2G-analyses , CMS-HIG-analyses


General strategy
CMS
Focus on scenarios that produce Higgs bosons with high-pT ("boosted"):
i.e., decay products can be reconstructed as a single jet
Target H→bb final states (largest BR)
Higgs boson reco eff. (13 TeV)
CMS
Preliminary
H → bb,cc
Resolved: 2 AK4 jets
Merged: 1 AK8 jet
Merged: 1 AK15 jet
ΔR~2M/pT
merged-jet
topology
Reconstruction efficiency
pT(H) [GeV]
Traditional approach
Higgs decay products resolved in two "small-R" jets (R=0.4)
"Merged-jet topology"
A single "large-R" jet to reconstruct the H→bb decay
Better RECO efficiency at high-pT
Exploit the correlation between the two bottom quarks
Reduced combinatorial BKG
Loukas Gouskos
Higgs Hunting 2021: DiHiggs searches in CMS
3
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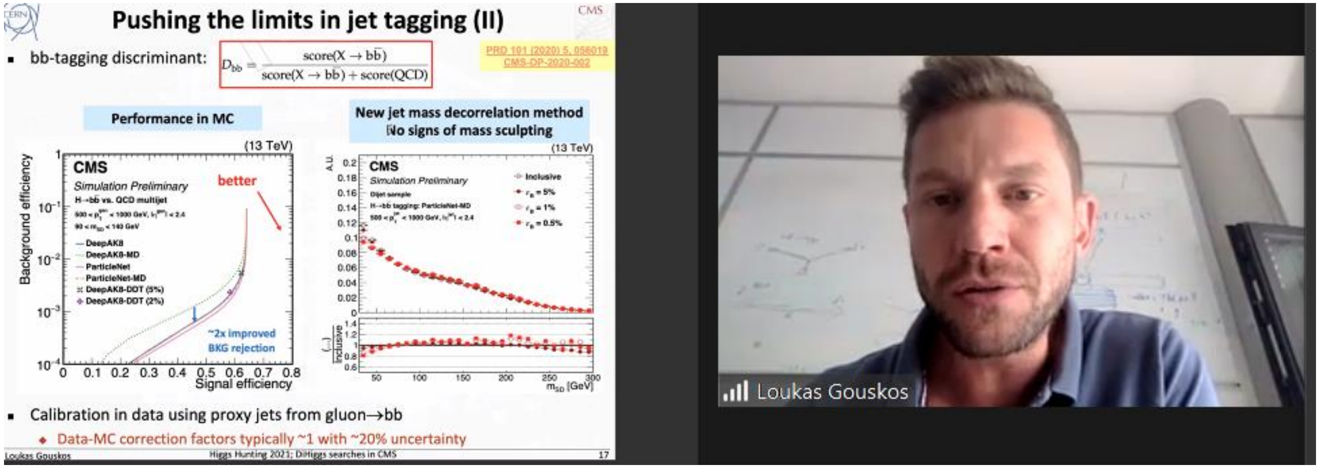
Plus



Pushing the limits in jet tagging (II)
bb-tagging discriminant:
$D_{bb} = \frac{score(X \to b\bar{b})}{score(X \to b\bar{b}) + score(QCD)}$
PRD 101 (2020) 5, 056019
CMS-DP-2020-002
Performance in MC
New jet mass decorrelation method
No signs of mass sculpting
better
~2x improved BKG rejection
Background efficiency
Signal efficiency
Calibration in data using proxy jets from gluon→bb
Data-MC correction factors typically ~1 with ~20% uncertainty
Higgs Hunting 2021; DiHiggs searches in CMS
17
Loukas Gouskos

Large-R jet mass regression
Large-R jet
Jet mass: powerful observable to discriminate signal (e.g., H→bb jets) from BKGs [e.g., QCD jets]
but very sensitive to soft radiation, pileup, ...
Grooming techniques [e.g., SoftDrop] have been developed to mitigate this effect:
Iteratively decluster the jet and remove constituents that are:
soft and/or wide angle
Pros: simple and well tested in data
Cons: some inefficiency
e.g., some two prong jet identified as 1-prong
Decays to bb/cc:
additional energy loss via the (undetected) neutrinos from semileptonic decays
Over-subtraction
Additional radiation
QCD multijet
W boson
Z boson
Higgs boson
Higgs Hunting 2021; DiHiggs searches in CMS
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Plus

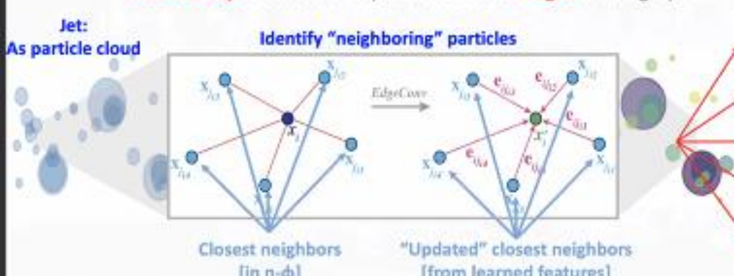
Pushing the limits in jet tagging

CMS

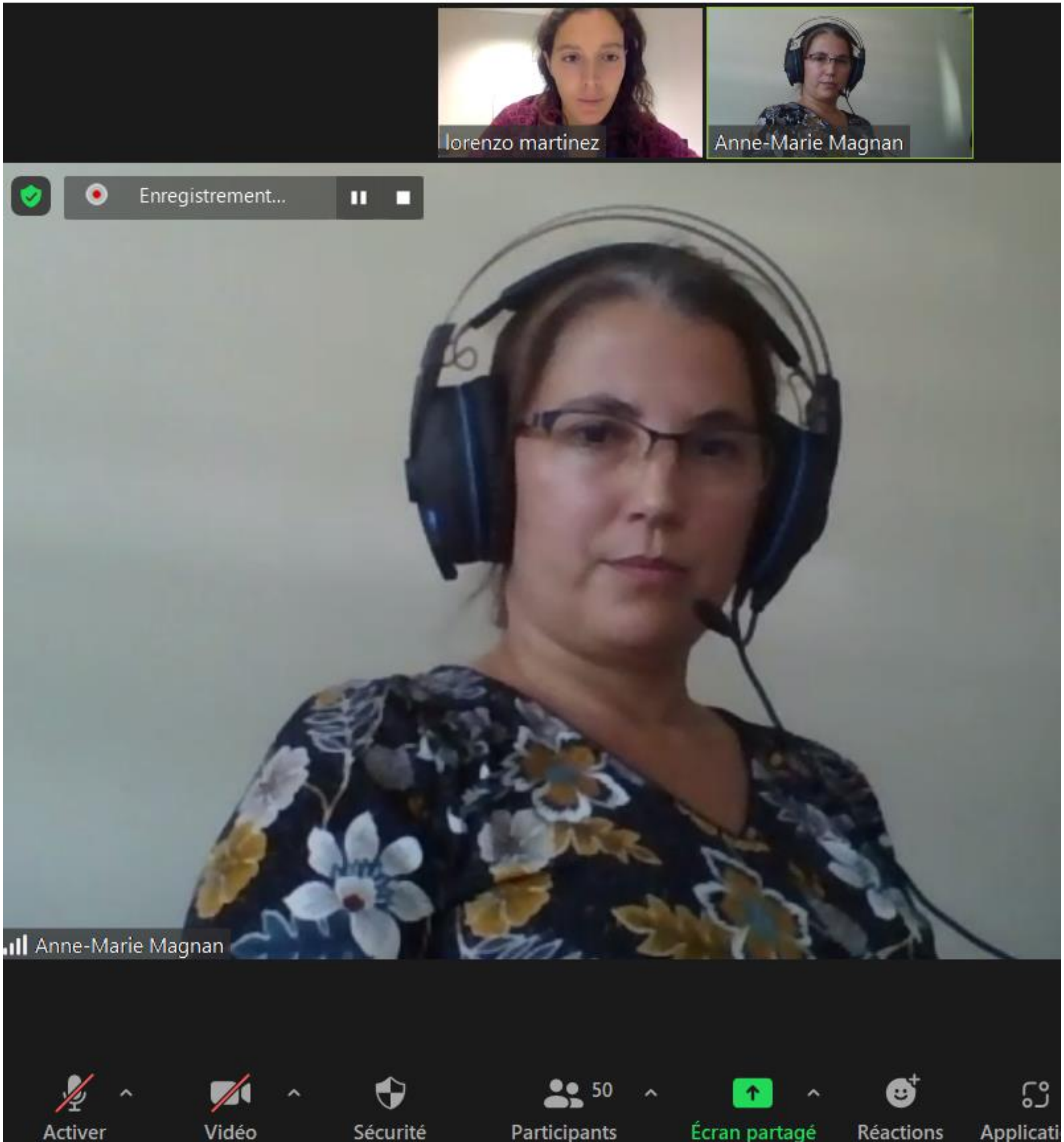
- **ParticleNet**: Novel algorithm w/ improved **jet representation** & **network arch.**
  - Jet represented as a "particle cloud"
  - Architecture: Graph Neural Networks [i.e., DGCNN – add ref]
  - **Input:** PFcands & SV, **Output:** W/Z/H/top/QCD + decays; [same as DeepAK15]

PRD 101 (2020) 5, 056019
CMS-DP-2020-002

- Follow a hierarchical learning approach
  - **First:** Learn "local" structures; **Then:** move to more "global" features
  - Treat the particle cloud as a graph
    - Particles are the vertices of the graph
      Relationships between the particles are the **edges** of the graph



Category	Label
Top	bcq bqq bq cq
Higgs	bb cc VV*→qqqq
Z	bb cc qq
W	cq qq
QCD	g→bb g→cc b c others


lorenzo martinez
Anne-Marie Magnan
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Réactions


ATLAS EXPERIMENT
LAPP
cnrs
ATLAS measurements of Vector Boson Scattering
Narei Lorenzo Martinez (LAPP-Annecy, France)
on behalf of the ATLAS collaboration
September 21st, 2021 - Higgs Hunting 2021
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lorenzo martinez
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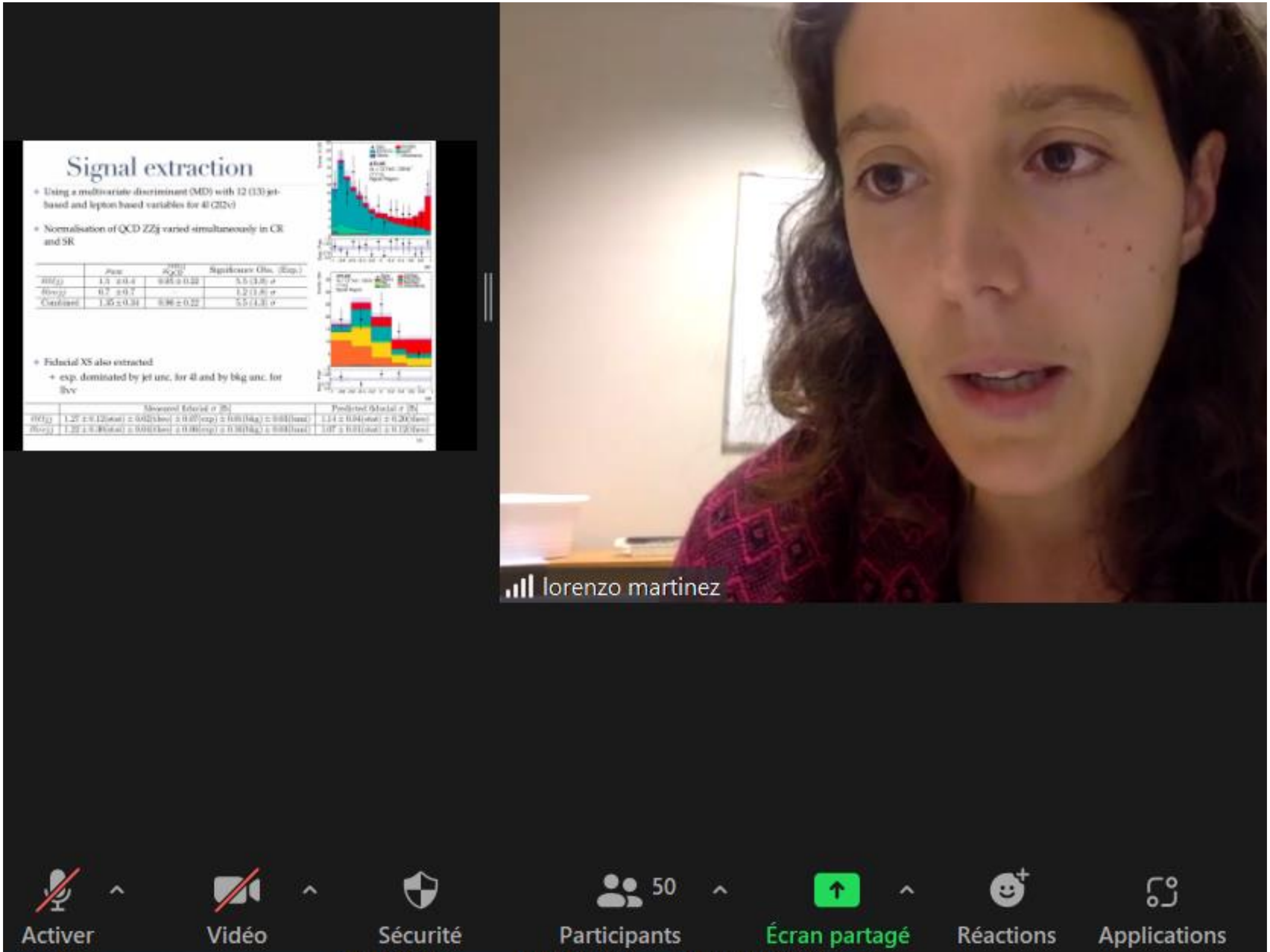
Réactions
Applications
Plus


lorenzo martinez


Signal extraction
Normalisation of QCD ZZjj varied simultaneously in CR and SR
Fiducial XS also extracted
lorenzo martinez
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Réactions
Applications

Outline

- This is a **VBS summary talk** of the most recent **CMS measurements**
  - only **results** obtained with the **full Run 2 data** are included
- **Several final states** presented:
  - **fully-leptonic** : $W^{\pm}W^{\pm} \to 2l2\nu$; $WZ \to 3l\nu$; $ZZ \to 4l$
  - **semi-leptonic**: $WW/WZ \to l\nu jj$;
  - **with photons**: $Z\gamma \to 2l\gamma$;
- Inclusive/differential **cross-section measurements**
- **EFT interpretation** and constraints on anomalous **quartic gauge couplings**
  - **VBS** targets **explicit models** e.g. VBF $H^{\pm}$ and $H^{\pm\pm}$, see talk by Attikis
- **Prospects** for VV scattering measurements **at the HL-LHC** with the CMS detector

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Activer Vidéo Sécurité Participants 47 Écran partagé Réactions Applications Plus

Outline
This is a VBS summary talk of the most recent CMS measurements
only results obtained with the full Run 2 data are included
Several final states presented:
fully-leptonic : W±W±→2l2ν; WZ→3lν; ZZ→4l
semi-leptonic: WW/WZ→lνjj;
with photons: Zγ →2lγ;
Inclusive/differential cross-section measurements
EFT interpretation and constraints on anomalous quartic gauge couplings
VBS targets explicit models e.g. VBF H± and H±±, see talk by Attikis
Prospects for VV scattering measurements at the HL-LHC with the CMS detector
Antonio Vagnerini
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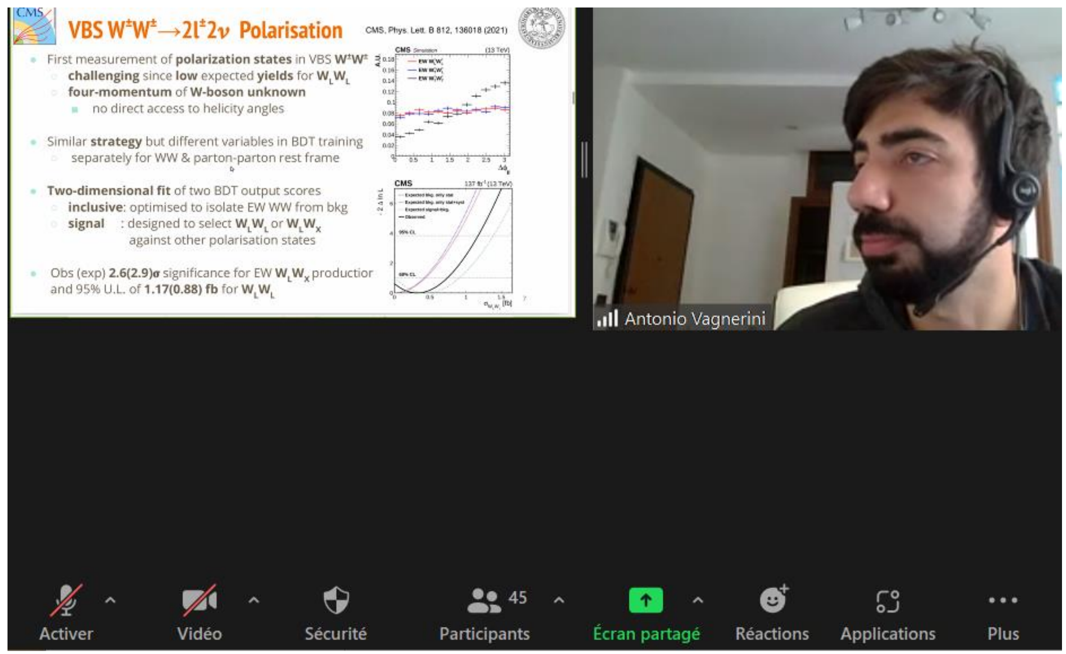
Fin



VBS W±W±→2l±2ν Polarisation
CMS, Phys. Lett. B 812, 136018 (2021)
First measurement of polarization states in VBS W±W±
challenging since low expected yields for W_LW_L
four-momentum of W-boson unknown
no direct access to helicity angles
Similar strategy but different variables in BDT training
separately for WW & parton-parton rest frame
Two-dimensional fit of two BDT output scores
inclusive: optimised to isolate EW WW from bkg
signal : designed to select W_LW_L or W_LW_X
against other polarisation states
Obs (exp) 2.6(2.9)σ significance for EW W_LW_X production
and 95% U.L. of 1.17(0.88) fb for W_LW_L
CMS
Antonio Vagnerini
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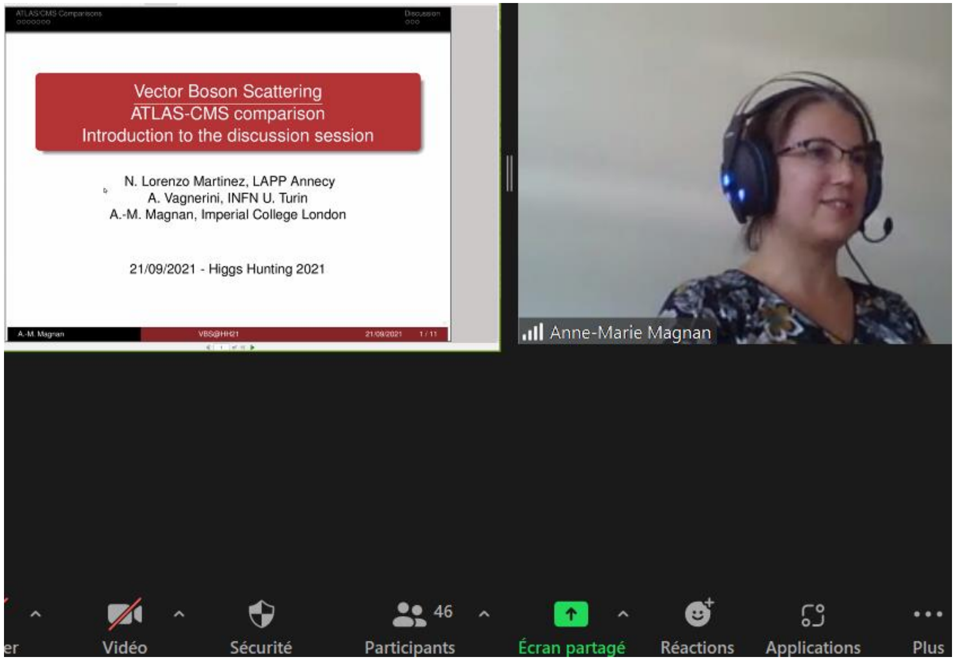
ATLAS/CMS Comparisons
Discussion
Vector Boson Scattering
ATLAS-CMS comparison
Introduction to the discussion session
N. Lorenzo Martinez, LAPP Annecy
A. Vagnerini, INFN U. Turin
A.-M. Magnan, Imperial College London
21/09/2021 - Higgs Hunting 2021
A.-M. Magnan
VBS@HH21
21/09/2021
1 / 11
Anne-Marie Magnan
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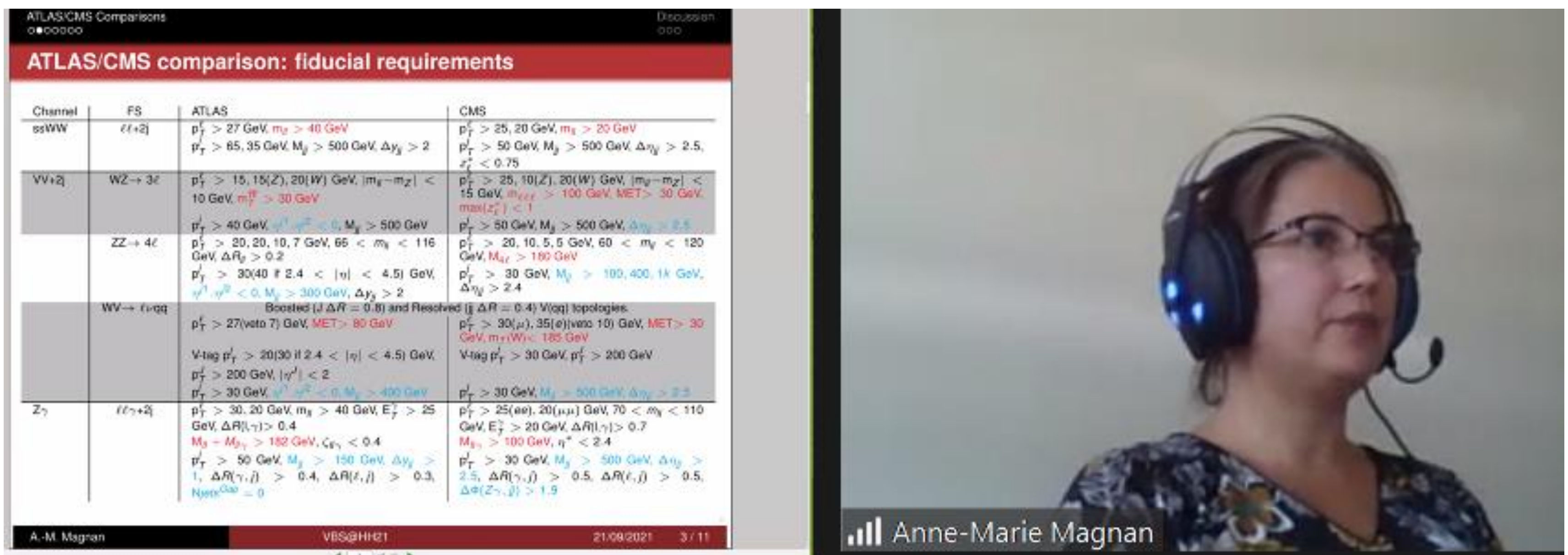
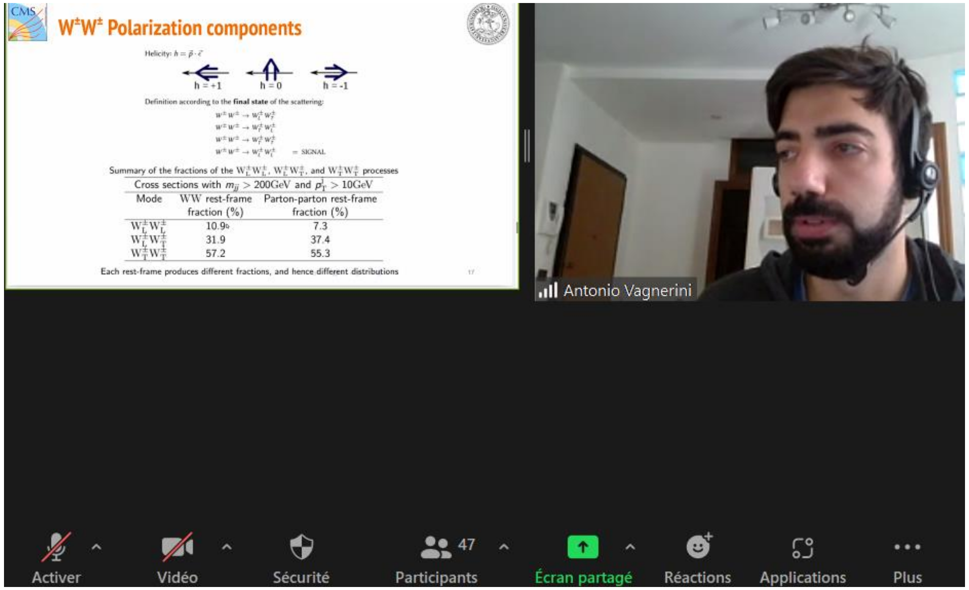

ATLAS/CMS Comparisons
Discussion
ATLAS/CMS comparison: fiducial requirements
Channel
FS
ATLAS
CMS
ssWW
VV+2j
WZ→ 3ℓ
ZZ→ 4ℓ
WV→ ℓνqq
Boosted (J ΔR = 0.8) and Resolved (jj ΔR = 0.4) V(qq) topologies.
Zγ
A.-M. Magnan
VBS@HH21
21/09/2021
3 / 11
Anne-Marie Magnan



$W^{\pm}W^{\pm}$ Polarization components
Helicity: $h = \vec{p} \cdot \vec{\epsilon}$
h = +1
h = 0
h = -1
Definition according to the **final state** of the scattering:
$w^{\pm}w^{\pm} \rightarrow w_L^{\pm}w_T^{\pm}$
$w^{\pm}w^{\pm} \rightarrow w_T^{\pm}w_L^{\pm}$
$w^{\pm}w^{\pm} \rightarrow w_T^{\pm}w_T^{\pm}$
$w^{\pm}w^{\pm} \rightarrow w_L^{\pm}w_L^{\pm}$ = SIGNAL
Summary of the fractions of the $W_L^{\pm}W_L^{\pm}$, $W_L^{\pm}W_T^{\pm}$, and $W_T^{\pm}W_T^{\pm}$ processes
Cross sections with $m_{jj} > 200\text{GeV}$ and $p_T^j > 10\text{GeV}$
Mode | WW rest-frame fraction (%) | Parton-parton rest-frame fraction (%)
$W_L^{\pm}W_L^{\pm}$ | 10.9 | 7.3
$W_L^{\pm}W_T^{\pm}$ | 31.9 | 37.4
$W_T^{\pm}W_T^{\pm}$ | 57.2 | 55.3
Each rest-frame produces different fractions, and hence different distributions
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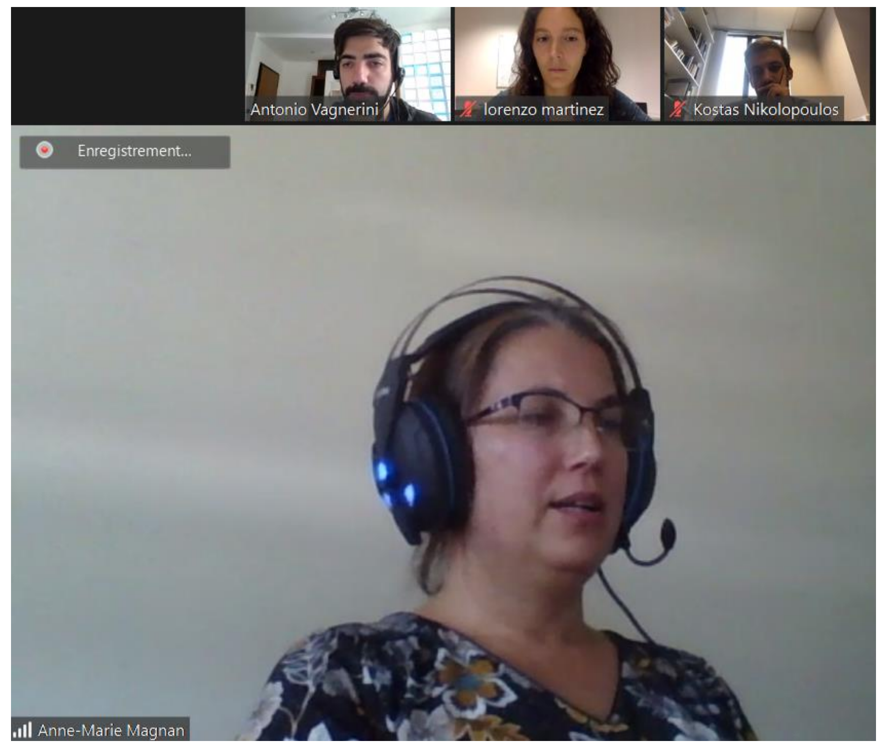

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lorenzo martinez
Kostas Nikolopoulos
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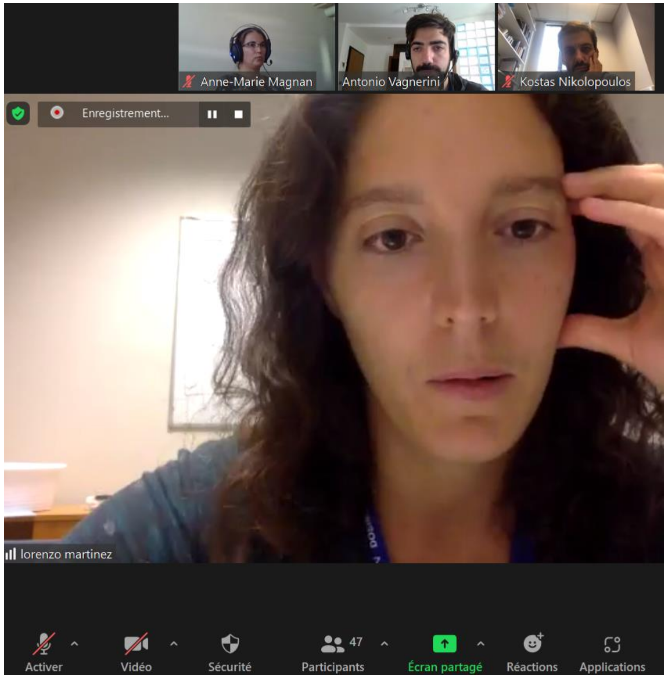
Anne-Marie Magnan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Antonio Vagnerini
Kostas Nikolopoulos
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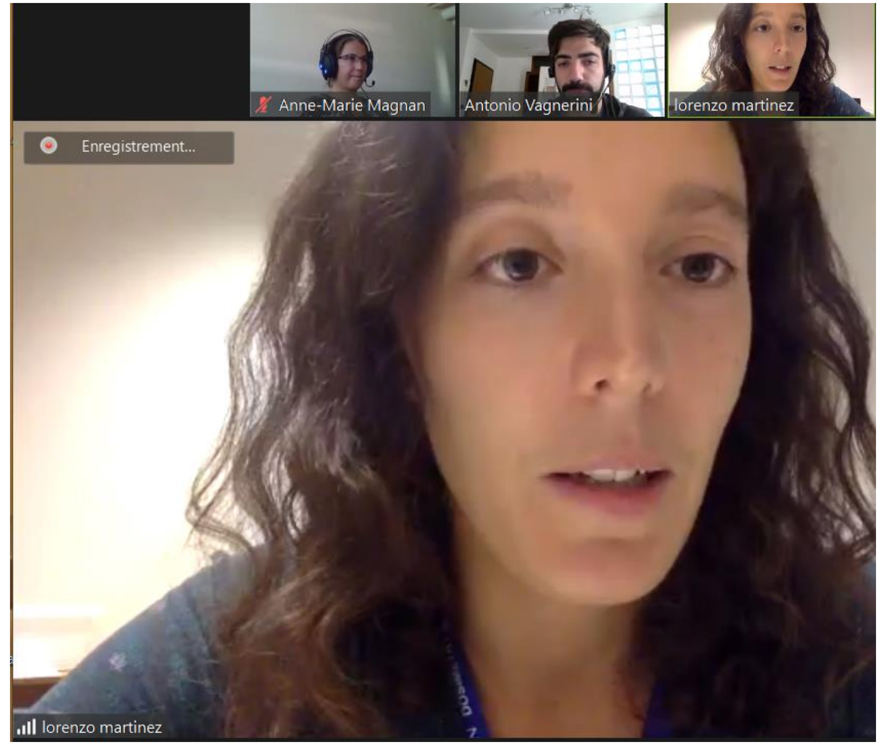
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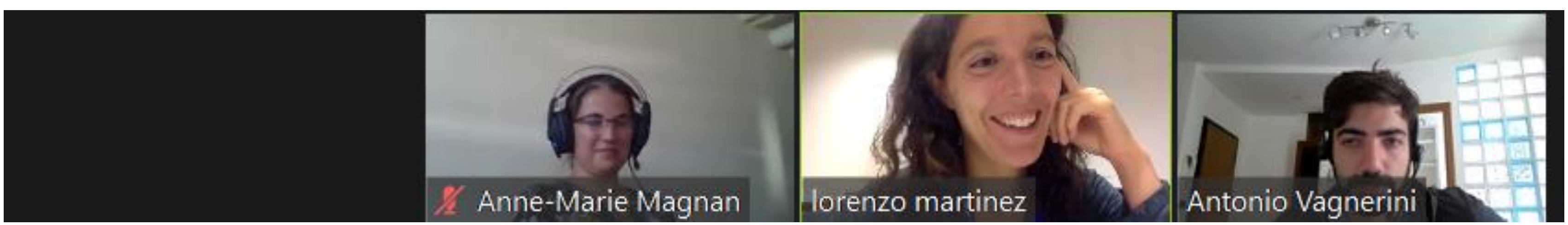
lorenzo martinez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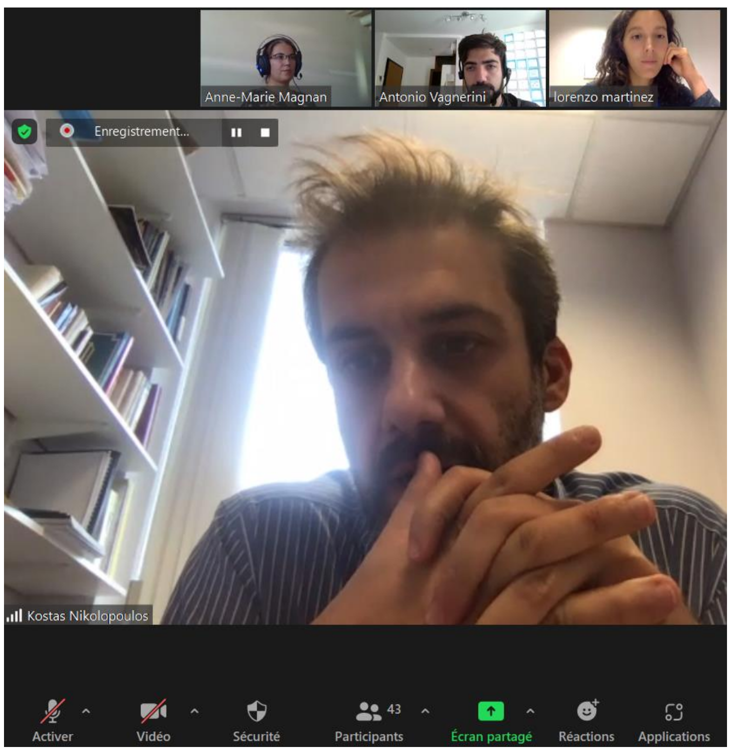
Antonio Vagnerini


Anne-Marie Magnan
Antonio Vagnerini
lorenzo martinez
Enregistrement...
lorenzo martinez


Antonio Vagnerini
lorenzo martinez
Kostas Nikolopoulos
Enregistrement...
Anne-Marie Magnan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Antonio Vagnerini
lorenzo martinez
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Kostas Nikolopoulos
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Vidéo
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lorenzo martinez
Antonio Vagnerini
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Antonio Vagnerini
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Applications
Plus


Karsten Koeneke
Emilian Dudas
Enregistrement
Emilian Dudas
Activer
Vidéo
Sécurité
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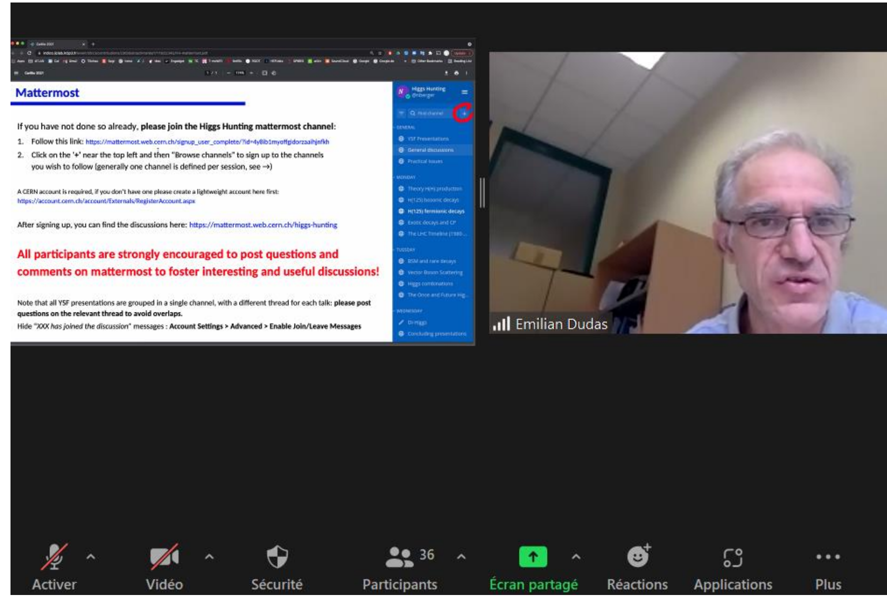
Partager (Alt+S)
Applications
Plus


Mattermost
If you have not done so already, please join the Higgs Hunting mattermost channel:
1. Follow this link: https://mattermost.web.cern.ch/signup_user_complete/?id=4y8ib1myoffgidorzaaihjnfkh
2. Click on the '+' near the top left and then "Browse channels" to sign up to the channels you wish to follow (generally one channel is defined per session, see →)
A CERN account is required, if you don't have one please create a lightweight account here first:
https://account.cern.ch/account/Externals/RegisterAccount.aspx
After signing up, you can find the discussions here: https://mattermost.web.cern.ch/higgs-hunting
All participants are strongly encouraged to post questions and comments on mattermost to foster interesting and useful discussions!
Note that all YSF presentations are grouped in a single channel, with a different thread for each talk: please post questions on the relevant thread to avoid overlaps.
Hide "XXX has joined the discussion" messages : Account Settings > Advanced > Enable Join/Leave Messages
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Activer
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Réactions
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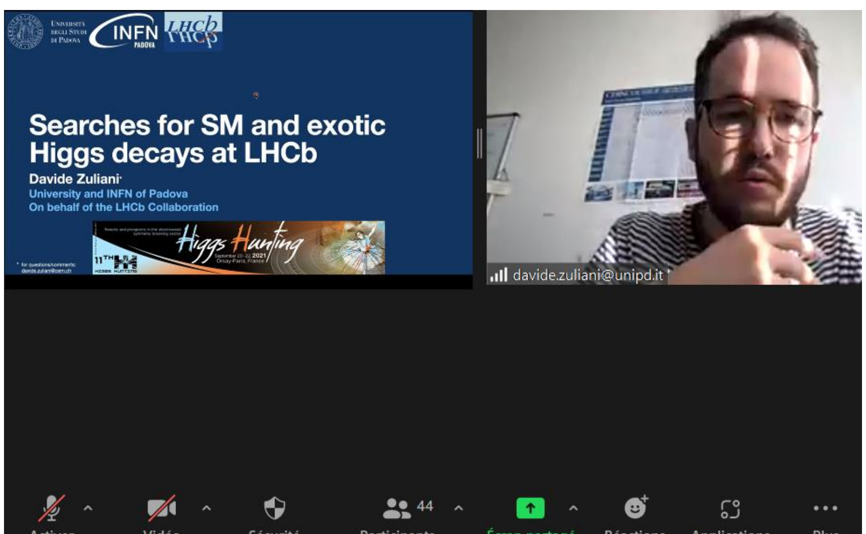
Plus


Karsten Koeneke
Christophe Grojean (DESY...
Emilian Dudas


INFN
PADOVA
LHCb
Searches for SM and exotic Higgs decays at LHCb
Davide Zuliani
University and INFN of Padova
On behalf of the LHCb Collaboration
Higgs Hunting
davide.zuliani@unipd.it
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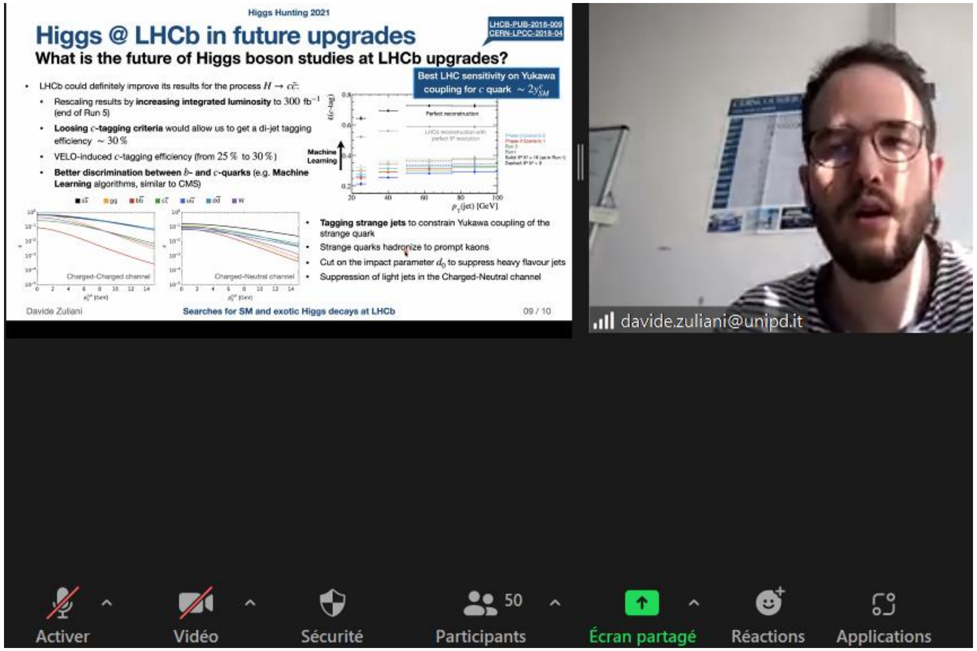
Applications
Plus


Higgs Hunting 2021
Higgs @ LHCb in future upgrades
LHCB-PUB-2018-009
CERN-LPCC-2018-04
What is the future of Higgs boson studies at LHCb upgrades?
Best LHC sensitivity on Yukawa coupling for c quark ~ 2y_SM^c
LHCb could definitely improve its results for the process H → cc̄:
Rescaling results by increasing integrated luminosity to 300 fb⁻¹ (end of Run 5)
Loosing c-tagging criteria would allow us to get a di-jet tagging efficiency ~ 30 %
VELO-induced c-tagging efficiency (from 25 % to 30 %)
Better discrimination between b- and c-quarks (e.g. Machine Learning algorithms, similar to CMS)
Machine Learning
Perfect reconstruction
Tagging strange jets to constrain Yukawa coupling of the strange quark
Strange quarks hadronize to prompt kaons
Cut on the impact parameter d0 to suppress heavy flavour jets
Suppression of light jets in the Charged-Neutral channel
Charged-Charged channel
Charged-Neutral channel
Davide Zuliani
Searches for SM and exotic Higgs decays at LHCb
09 / 10
davide.zuliani@unipd.it
Activer
Vidéo
Sécurité
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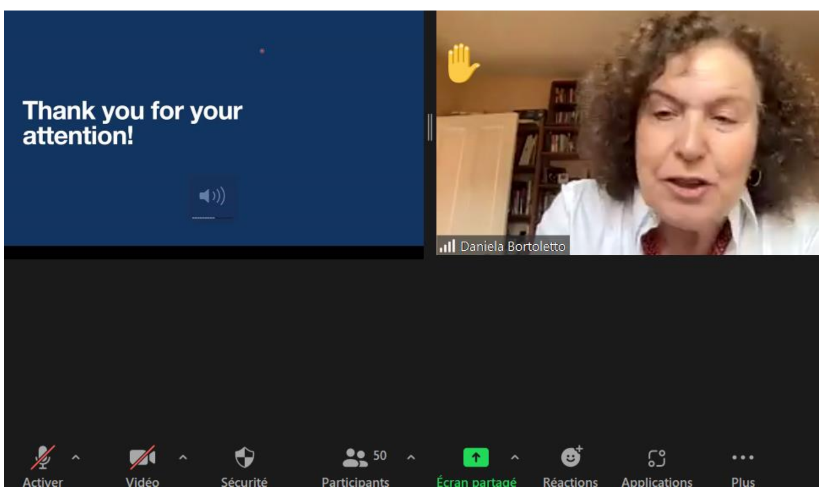
Participants
Écran partagé
Réactions
Applications


Thank you for your attention!
Daniela Bortoletto
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Vidéo
Sécurité
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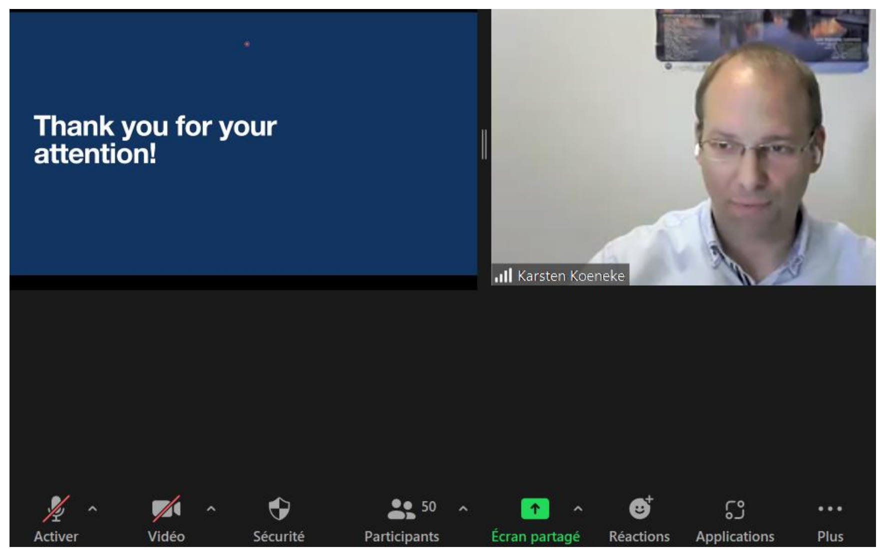
Participants
Écran partagé
Réactions
Applications
Plus


Thank you for your attention!
Karsten Koeneke
Activer
Vidéo
Sécurité
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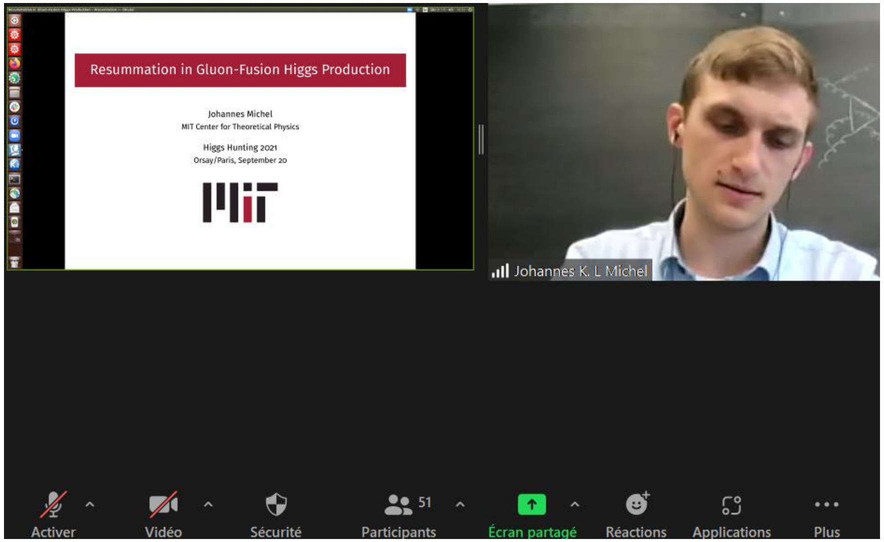
Participants
Écran partagé
Réactions
Applications
Plus


Resummation in Gluon-Fusion Higgs Production
Johannes Michel
MIT Center for Theoretical Physics
Higgs Hunting 2021
Orsay/Paris, September 20
Johannes K. L Michel
Activer
Vidéo
Sécurité
Participants
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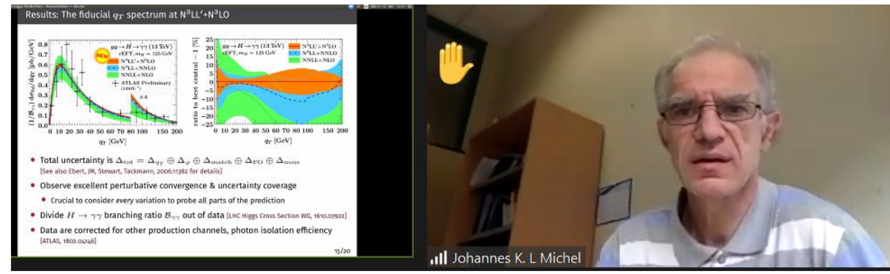
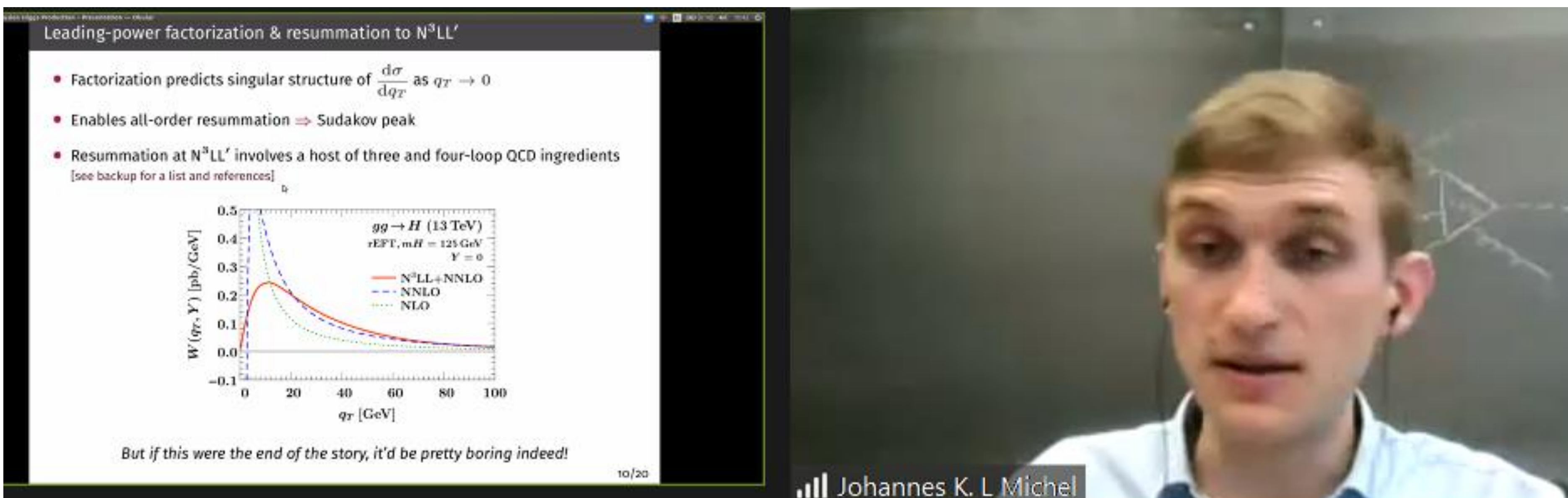
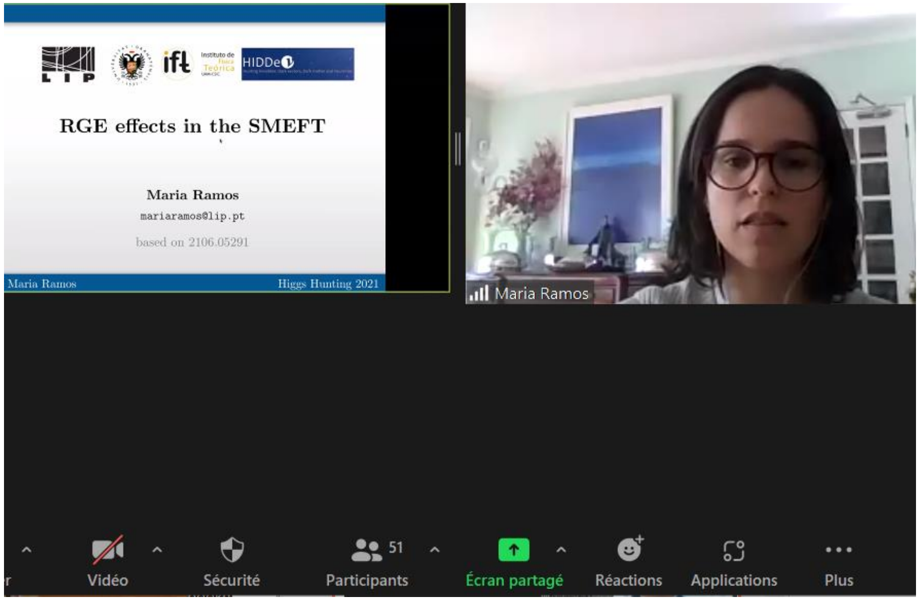
Écran partagé
Réactions
Applications
Plus


Results: The fiducial q_T spectrum at N^{3}LL'+N^{3}LO
Total uncertainty is $\Delta_{tot} = \Delta_{q_T} \oplus \Delta_{\varphi} \oplus \Delta_{match} \oplus \Delta_{FO} \oplus \Delta_{nons}$
Observe excellent perturbative convergence & uncertainty coverage
Crucial to consider every variation to probe all parts of the prediction
Divide $H \to \gamma\gamma$ branching ratio $B_{\gamma\gamma}$ out of data
Data are corrected for other production channels, photon isolation efficiency
Johannes K. L Michel


Leading-power factorization & resummation to N^{3}LL'
Factorization predicts singular structure of $\frac{d\sigma}{dq_T}$ as $q_T \to 0$
Enables all-order resummation ⇒ Sudakov peak
Resummation at N^{3}LL' involves a host of three and four-loop QCD ingredients
[see backup for a list and references]
$gg \to H$ (13 TeV)
rEFT, mH = 125 GeV
Y = 0
N^{3}LL+NNLO
NNLO
NLO
$W(q_T, Y)$ [pb/GeV]
q_T [GeV]
But if this were the end of the story, it'd be pretty boring indeed!
10/20
Johannes K. L Michel


RGE effects in the SMEFT
Maria Ramos
mariaramos@lip.pt
based on 2106.05291
Maria Ramos
Higgs Hunting 2021
Maria Ramos
Vidéo
Sécurité
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Participants
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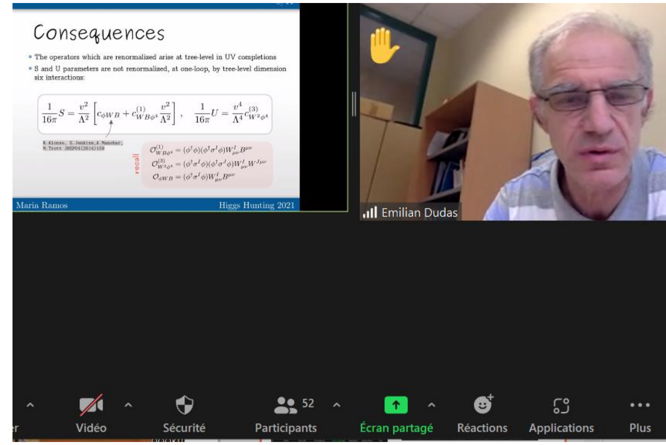
Applications
Plus


Consequences
The operators which are renormalized arise at tree-level in UV completions
S and U parameters are not renormalized, at one-loop, by tree-level dimension six interactions:
Maria Ramos
Higgs Hunting 2021
Emilian Dudas
Vidéo
Sécurité
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Participants
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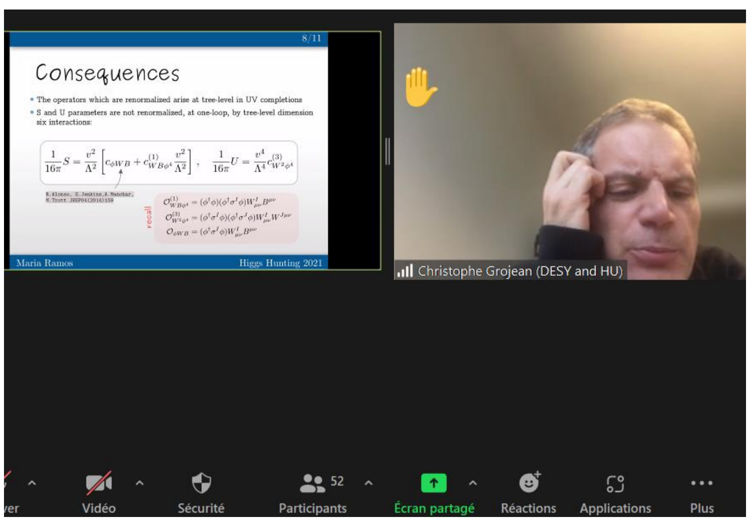
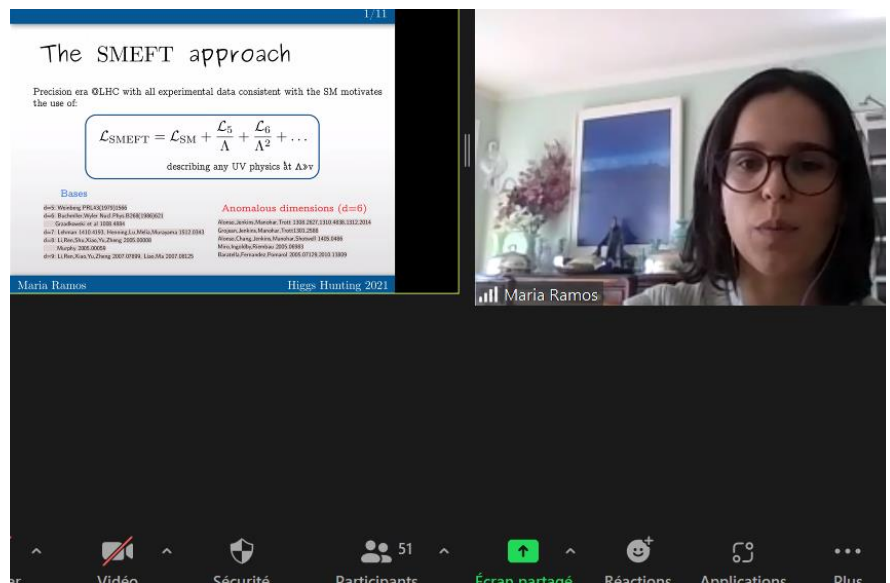
Réactions
Applications
Plus


8/11
Consequences
The operators which are renormalized arise at tree-level in UV completions
S and U parameters are not renormalized, at one-loop, by tree-level dimension six interactions:
Maria Ramos
Higgs Hunting 2021
Christophe Grojean (DESY and HU)
Vidéo
Sécurité
52
Participants
Écran partagé
Réactions
Applications
Plus


1/11
The SMEFT approach
Precision era @LHC with all experimental data consistent with the SM motivates the use of:
describing any UV physics at Λ≫v
Bases
Anomalous dimensions (d=6)
Maria Ramos
Higgs Hunting 2021
Maria Ramos
Vidéo
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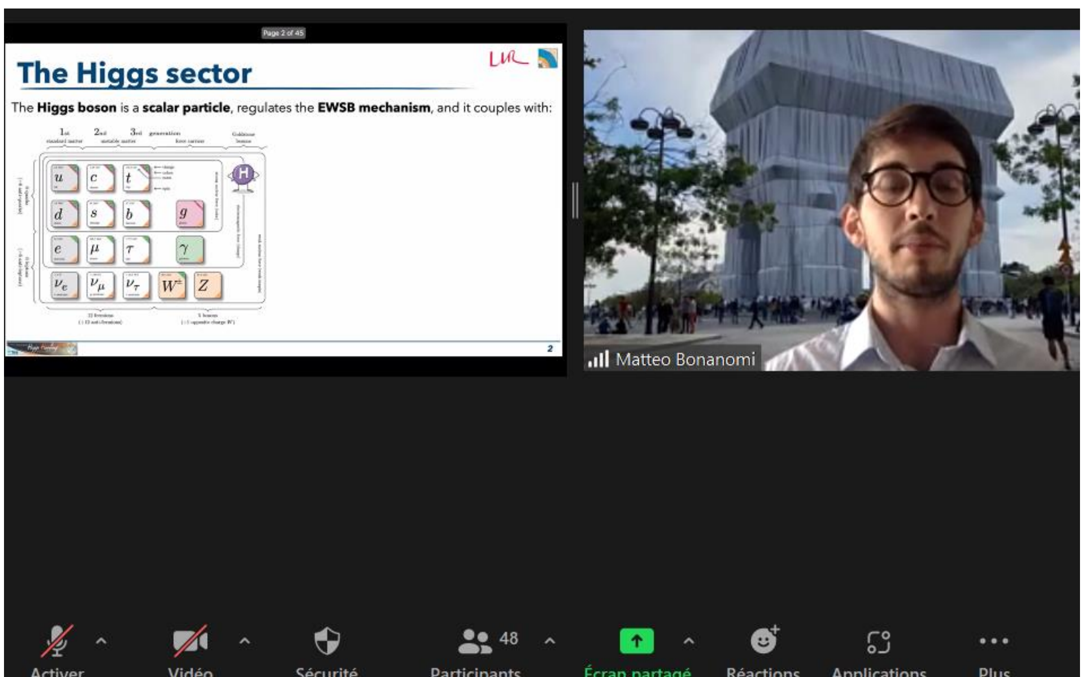
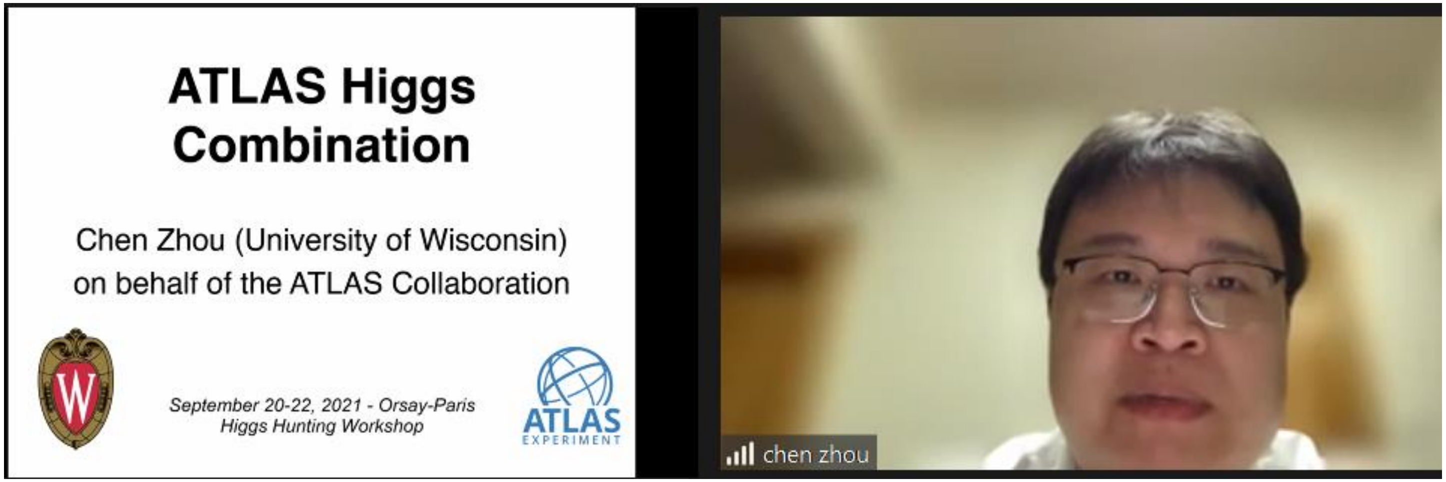
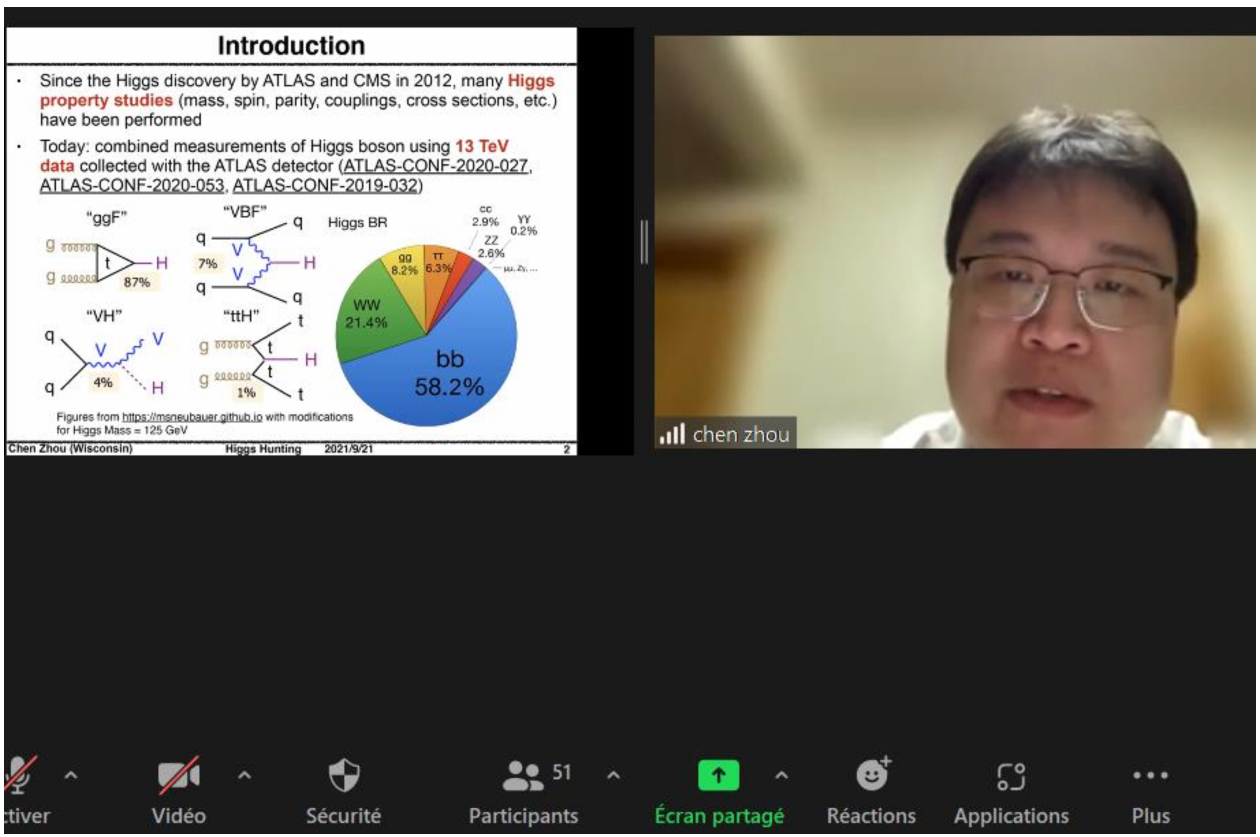
Higgs Hunting
21/09/2021
CMS Higgs Combination
Matteo Bonanomi
Matteo Bonanomi


Page 2 of 45
The Higgs sector
The **Higgs boson** is a **scalar particle**, regulates the **EWSB mechanism**, and it couples with:
Matteo Bonanomi
Activer
Vidéo
Sécurité
48
Participants
Écran partagé
Réactions
Applications
Plus


ATLAS Higgs
Combination
Chen Zhou (University of Wisconsin)
on behalf of the ATLAS Collaboration
September 20-22, 2021 - Orsay-Paris
Higgs Hunting Workshop
ATLAS
EXPERIMENT
chen zhou


Introduction
Since the Higgs discovery by ATLAS and CMS in 2012, many Higgs property studies (mass, spin, parity, couplings, cross sections, etc.) have been performed
Today: combined measurements of Higgs boson using 13 TeV data collected with the ATLAS detector (ATLAS-CONF-2020-027, ATLAS-CONF-2020-053, ATLAS-CONF-2019-032)
"ggF"
87%
"VBF"
7%
"VH"
4%
"ttH"
1%
Higgs BR
cc 2.9%
γγ 0.2%
ZZ 2.6%
gg 8.2%
ττ 6.3%
WW 21.4%
bb 58.2%
Figures from https://msneubauer.github.io with modifications for Higgs Mass = 125 GeV
Chen Zhou (Wisconsin)
Higgs Hunting
2021/9/21
2
chen zhou
Vidéo
Sécurité
51
Participants
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Réactions
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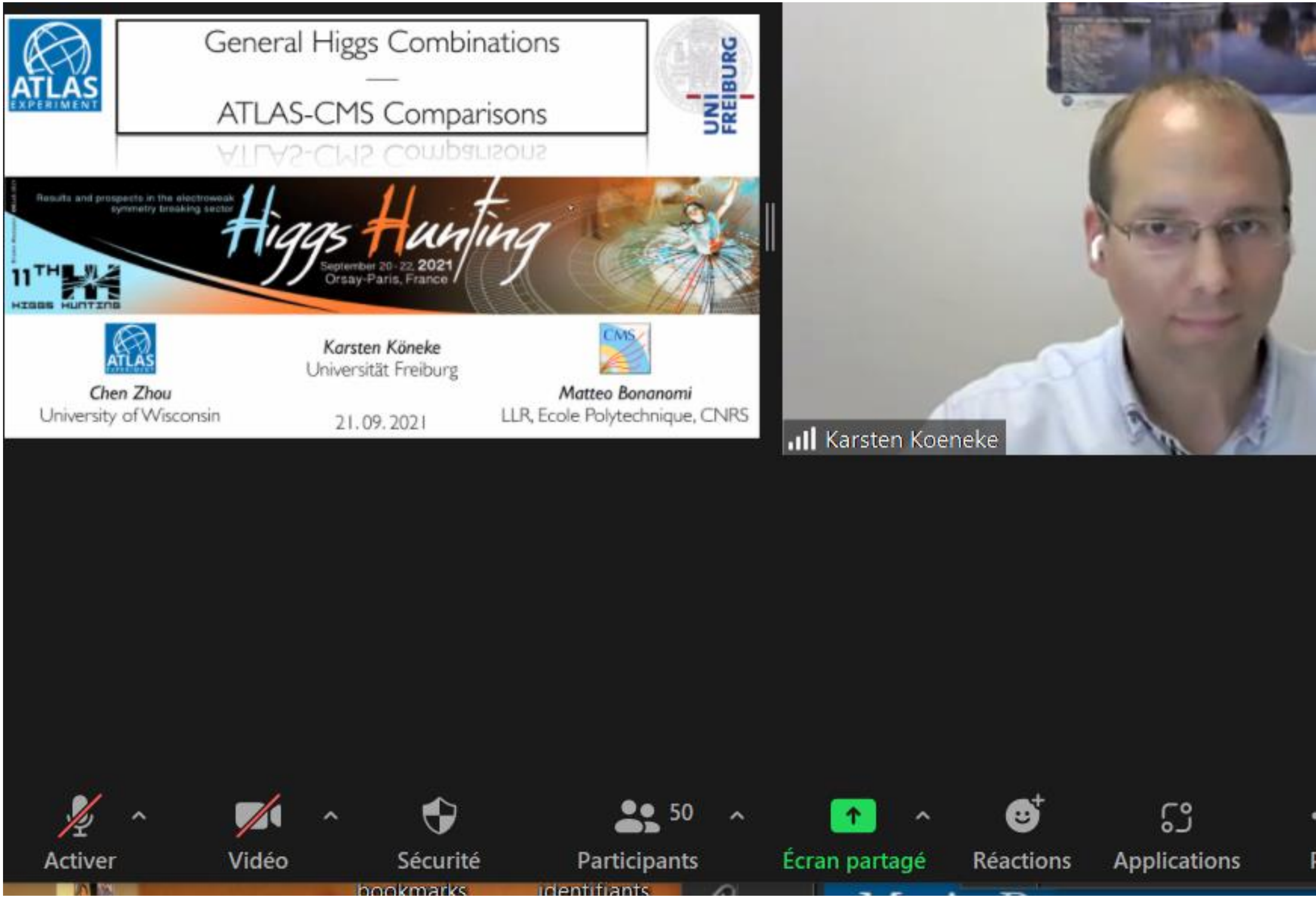
Plus


ATLAS EXPERIMENT
General Higgs Combinations
—
ATLAS-CMS Comparisons
UNI FREIBURG
Results and prospects in the electroweak symmetry breaking sector
Higgs Hunting
September 20 - 22, 2021
Orsay-Paris, France
11TH HIGGS HUNTING
ATLAS
Chen Zhou
University of Wisconsin
Karsten Köneke
Universität Freiburg
21.09.2021
CMS
Matteo Bonanomi
LLR, Ecole Polytechnique, CNRS
Karsten Koeneke
Activer
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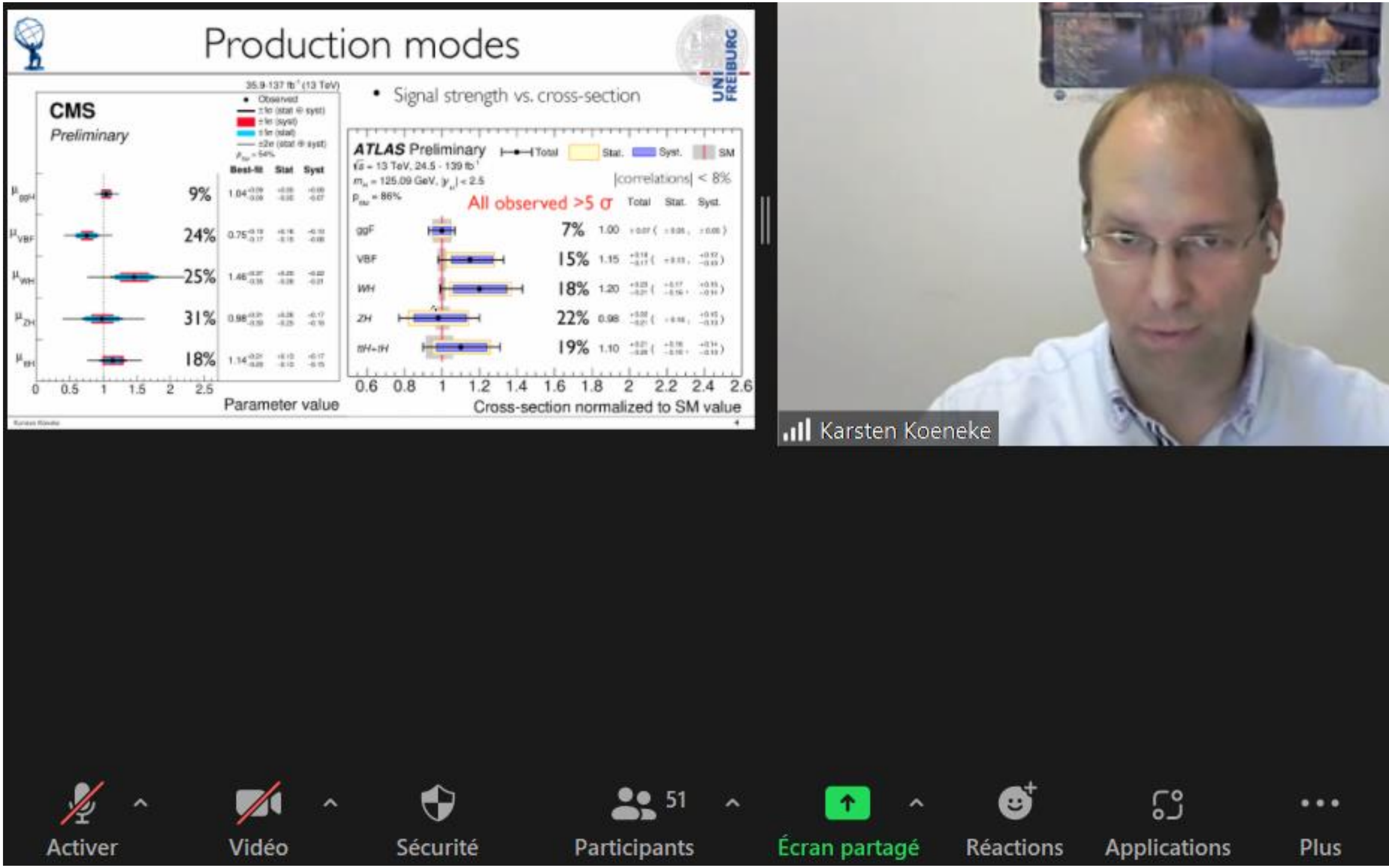

Production modes
CMS
Preliminary
Observed
Best-fit
Stat
Syst
9%
24%
25%
31%
18%
Parameter value
Signal strength vs. cross-section
ATLAS Preliminary
Total
Stat.
Syst.
SM
|correlations| < 8%
All observed >5 σ
ggF
VBF
WH
ZH
7%
15%
18%
22%
19%
Cross-section normalized to SM value
UNI FREIBURG
Karsten Koeneke
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Vidéo
Sécurité
Participants
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Réactions
Applications
Plus

Inputs and Global μ

Decay channel	ggF		VBF		VH		ttH+tH	
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
$H \to \gamma\gamma$	139	77 ◉	139	77 ◉	139	◉	139	77 ◉
$H \to ZZ^* \to 4\ell$	139	137 ◉	139	137 ◉	139	137 ◉	139	137 ◉
$H \to WW^*$	36[1] ◉	36	36[1] ◉	36		36 ◉		
$H \to bb$	◉	36 ◉	<31[1] ◉		139	77	36[1] ◉	77
$H \to \tau\tau$	36[1] ◉	77 ◉	36[1] ◉	77 ◉	◉	77	◉	
ttH multilepton							36[1] ◉	77 ◉
$H \to \mu\mu$	139[1]	36 ◉	139[1]	36 ◉	139[1]	◉	139[1]	◉
$H \to$ invisible		◉	139[1]		◉	◉	◉	

Full Run 2

◉ Updated result available; not yet in main public combination

[1] Not used in STXS fit

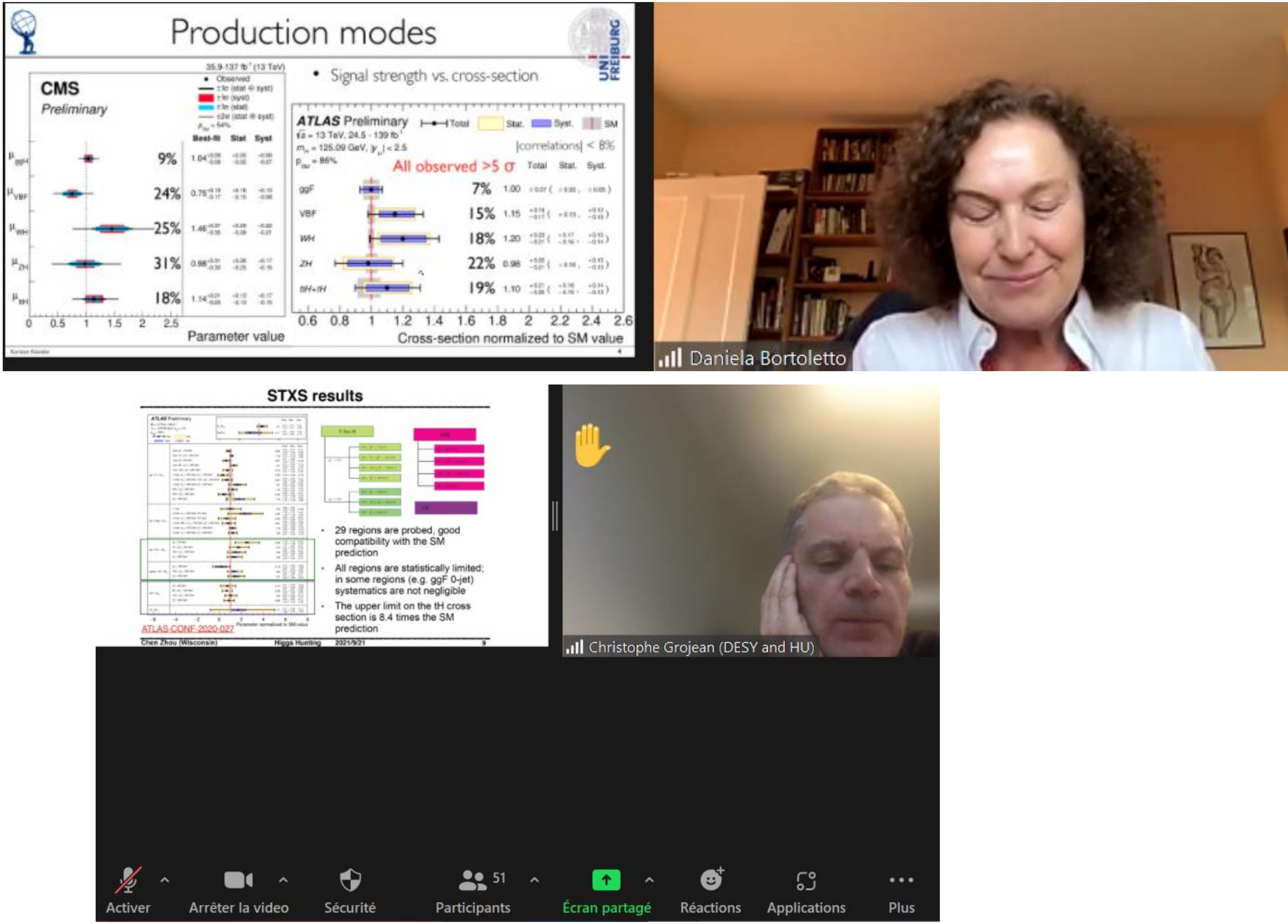
Global signal strength:

- ATLAS: $\mu = 1.06 \pm 0.07 = 1.06 \pm 0.04(\text{stat.}) \pm 0.03(\text{exp.})^{+0.05}_{-0.04}(\text{sig. th.}) \pm 0.02(\text{bkg. th.})$
- CMS: $\mu = 1.02^{+0.07}_{-0.06} = 1.02 \pm 0.04(\text{stat}) \pm 0.04(\text{exp}) \pm 0.04(\text{theo})$

Daniela Bortoletto

Daniela Bortoletto a levé la main

Activer Vidéo Sécurité 51 Participants Écran partagé Réactions Applications Plus


Production modes
Signal strength vs. cross-section
CMS
Preliminary
ATLAS Preliminary
All observed >5 σ
|correlations| < 8%
Total
Stat.
Syst.
SM
ggF
VBF
WH
ZH
ttH+tH
7%
15%
18%
22%
19%
9%
24%
25%
31%
18%
Parameter value
Cross-section normalized to SM value
UNI FREIBURG
Daniela Bortoletto
STXS results
29 regions are probed, good compatibility with the SM prediction
All regions are statistically limited; in some regions (e.g. ggF 0-jet) systematics are not negligible
The upper limit on the tH cross section is 8.4 times the SM prediction
ATLAS-CONF-2020-027
Chen Zhou (Wisconsin)
Higgs Hunting
2021/9/21
9
Christophe Grojean (DESY and HU)
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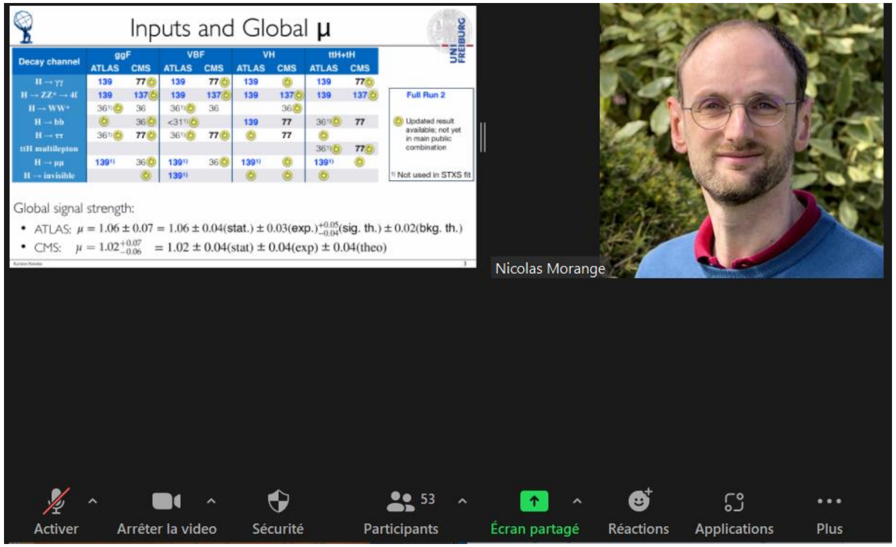
Inputs and Global μ
Global signal strength:
ATLAS: μ = 1.06 ± 0.07 = 1.06 ± 0.04(stat.) ± 0.03(exp.) (sig. th.) ± 0.02(bkg. th.)
CMS: μ = 1.02 = 1.02 ± 0.04(stat) ± 0.04(exp) ± 0.04(theo)
Nicolas Morange
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Participants
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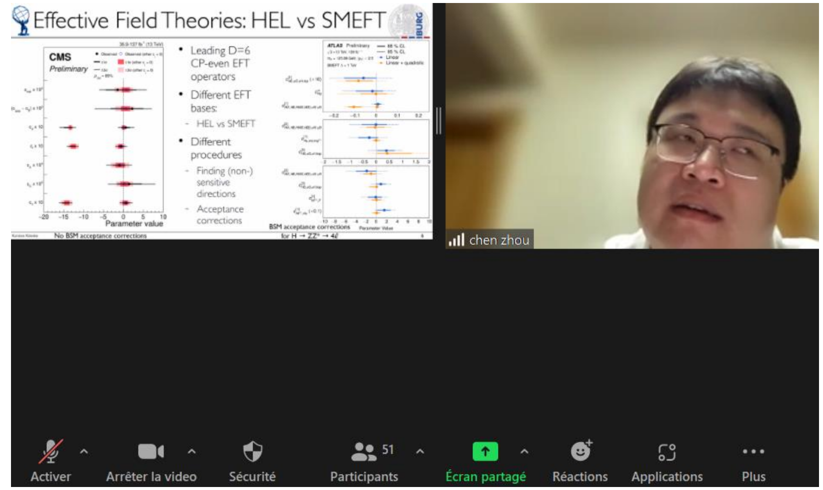
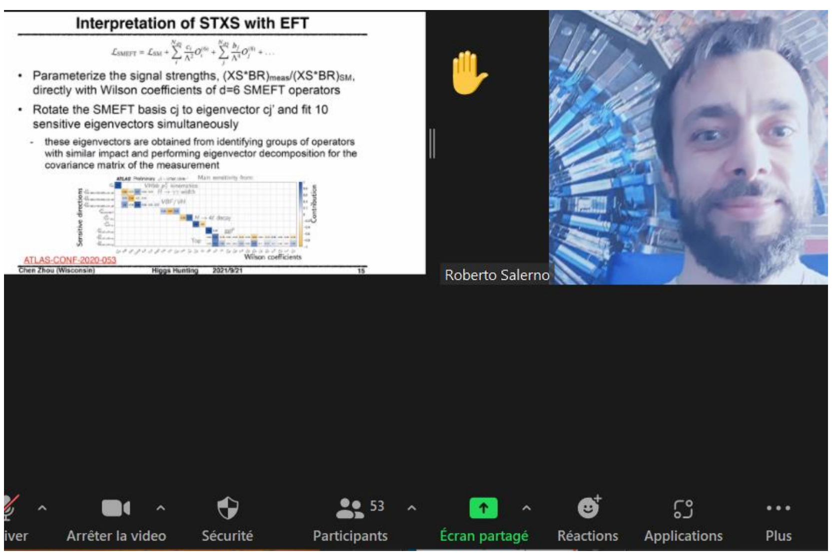
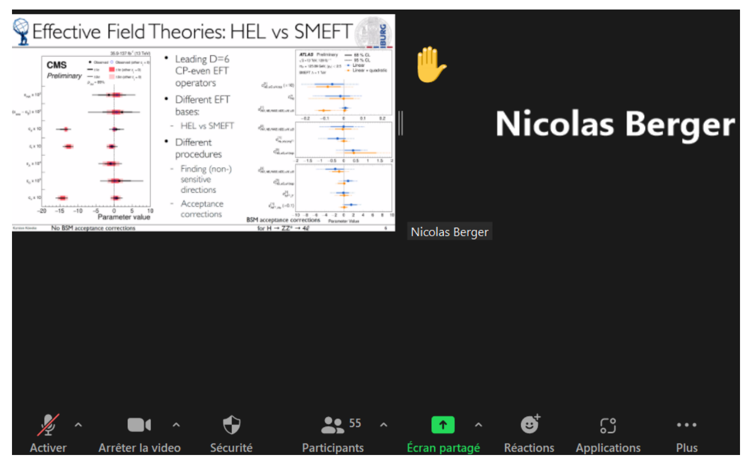
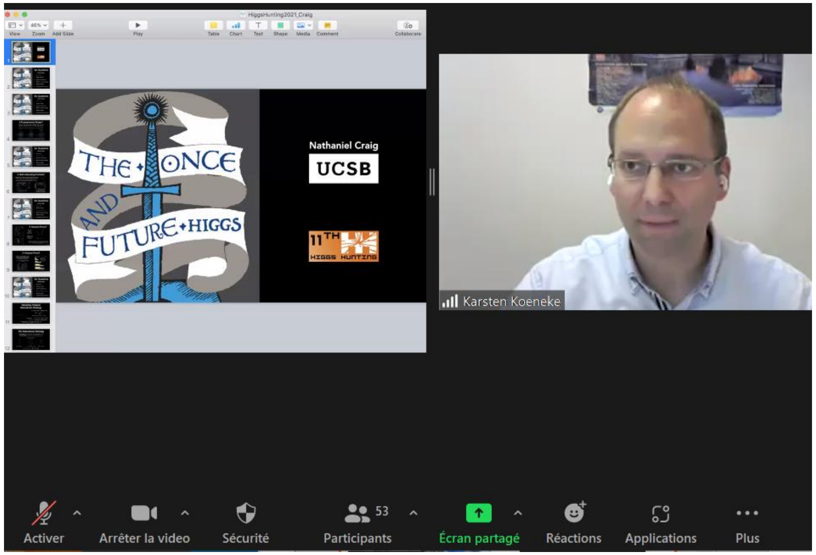

Effective Field Theories: HEL vs SMEFT
Leading D=6 CP-even EFT operators
Different EFT bases:
HEL vs SMEFT
Different procedures
Finding (non-) sensitive directions
Acceptance corrections
chen zhou
Activer
Arrêter la video
Sécurité
51
Participants
Écran partagé
Réactions
Applications
Plus


Interpretation of STXS with EFT
Parameterize the signal strengths, (XS*BR)meas/(XS*BR)SM, directly with Wilson coefficients of d=6 SMEFT operators
Rotate the SMEFT basis cj to eigenvector cj' and fit 10 sensitive eigenvectors simultaneously
these eigenvectors are obtained from identifying groups of operators with similar impact and performing eigenvector decomposition for the covariance matrix of the measurement
ATLAS-CONF-2020-053
Chen Zhou (Wisconsin)
Higgs Hunting
2021/9/21
15
Roberto Salerno
Arrêter la video
Sécurité
53
Participants
Écran partagé
Réactions
Applications
Plus


Effective Field Theories: HEL vs SMEFT
Leading D=6 CP-even EFT operators
Different EFT bases:
HEL vs SMEFT
Different procedures
Finding (non-) sensitive directions
Acceptance corrections
Nicolas Berger
Nicolas Berger
Activer
Arrêter la video
Sécurité
55
Participants
Écran partagé
Réactions
Applications
Plus



THE ONCE AND FUTURE HIGGS
Nathaniel Craig
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11TH HIGGS HUNTING
Karsten Koeneke
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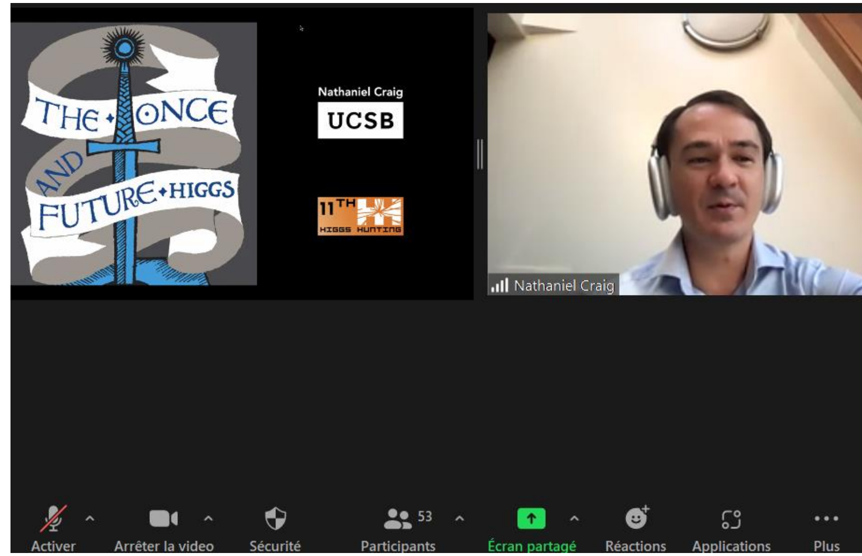
Applications
Plus



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Nathaniel Craig
Activer
Arrêter la video
Sécurité
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Écran partagé
Réactions
Applications
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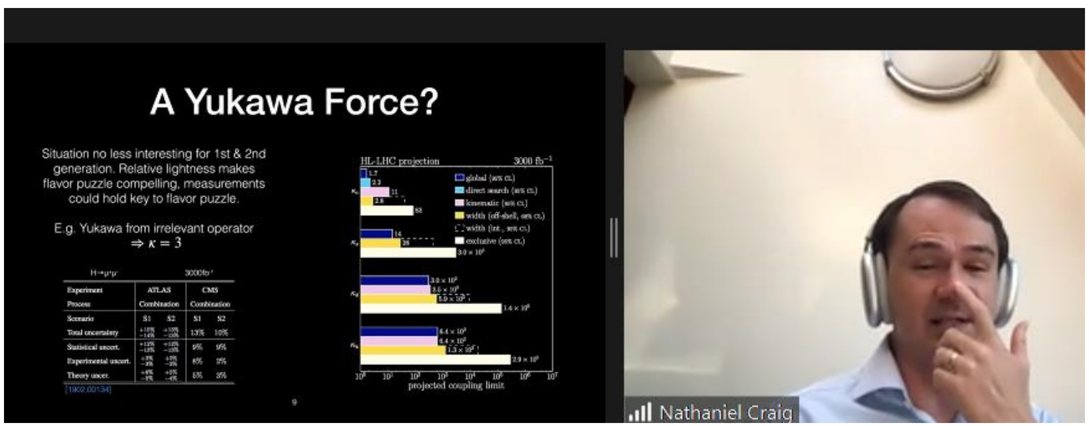

A Yukawa Force?
Situation no less interesting for 1st & 2nd generation. Relative lightness makes flavor puzzle compelling, measurements could hold key to flavor puzzle.
E.g. Yukawa from irrelevant operator ⇒ κ = 3
HL-LHC projection
projected coupling limit
Nathaniel Craig

A Yukawa Force?
Situation no less interesting for 1st & 2nd generation. Relative lightness makes flavor puzzle compelling, measurements could hold key to flavor puzzle.
E.g. Yukawa from irrelevant operator
$\Rightarrow \kappa = 3$
Experiment
ATLAS
CMS
Process
Combination
Combination
Scenario
S1
S2
S1
S2
Total uncertainty
Statistical uncert.
Experimental uncert.
Theory uncer.
HL-LHC projection
3000 fb^{-1}
global (95% CL)
direct search (95% CL)
kinematic (95% CL)
width (off-shell, 95% CL)
width (int., 95% CL)
exclusive (95% CL)
projected coupling limit
Nathaniel Craig
Activer
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Participants
Écran partagé
Réactions
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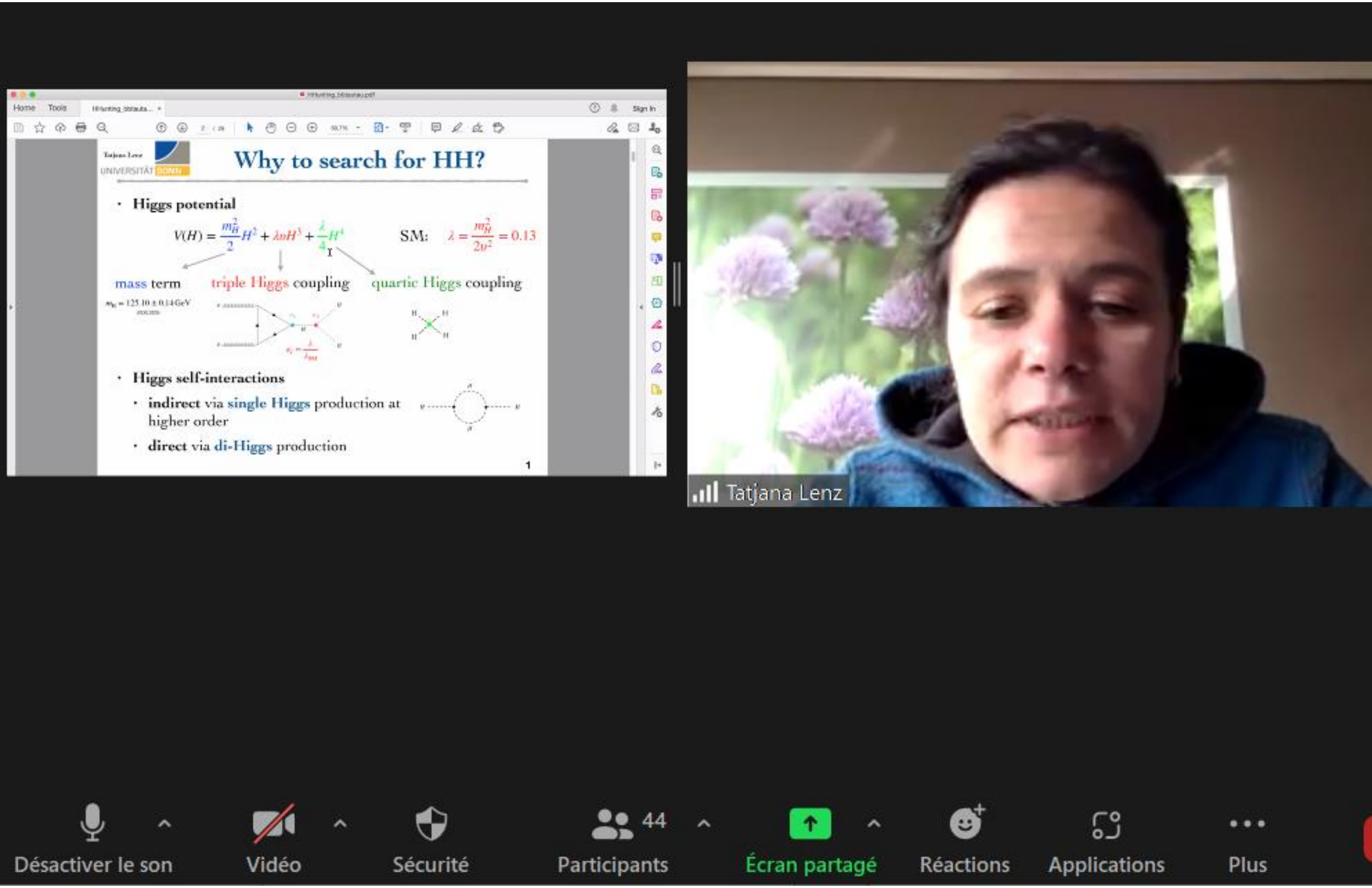
Plus


UNIVERSITÄT BONN
Why to search for HH?
Higgs potential
$V(H) = \frac{m_H^2}{2}H^2 + \lambda v H^3 + \frac{\lambda}{4}H^4$
SM: $\lambda = \frac{m_H^2}{2v^2} = 0.13$
mass term
triple Higgs coupling
quartic Higgs coupling
Higgs self-interactions
indirect via single Higgs production at higher order
direct via di-Higgs production
1
Tatjana Lenz
Désactiver le son
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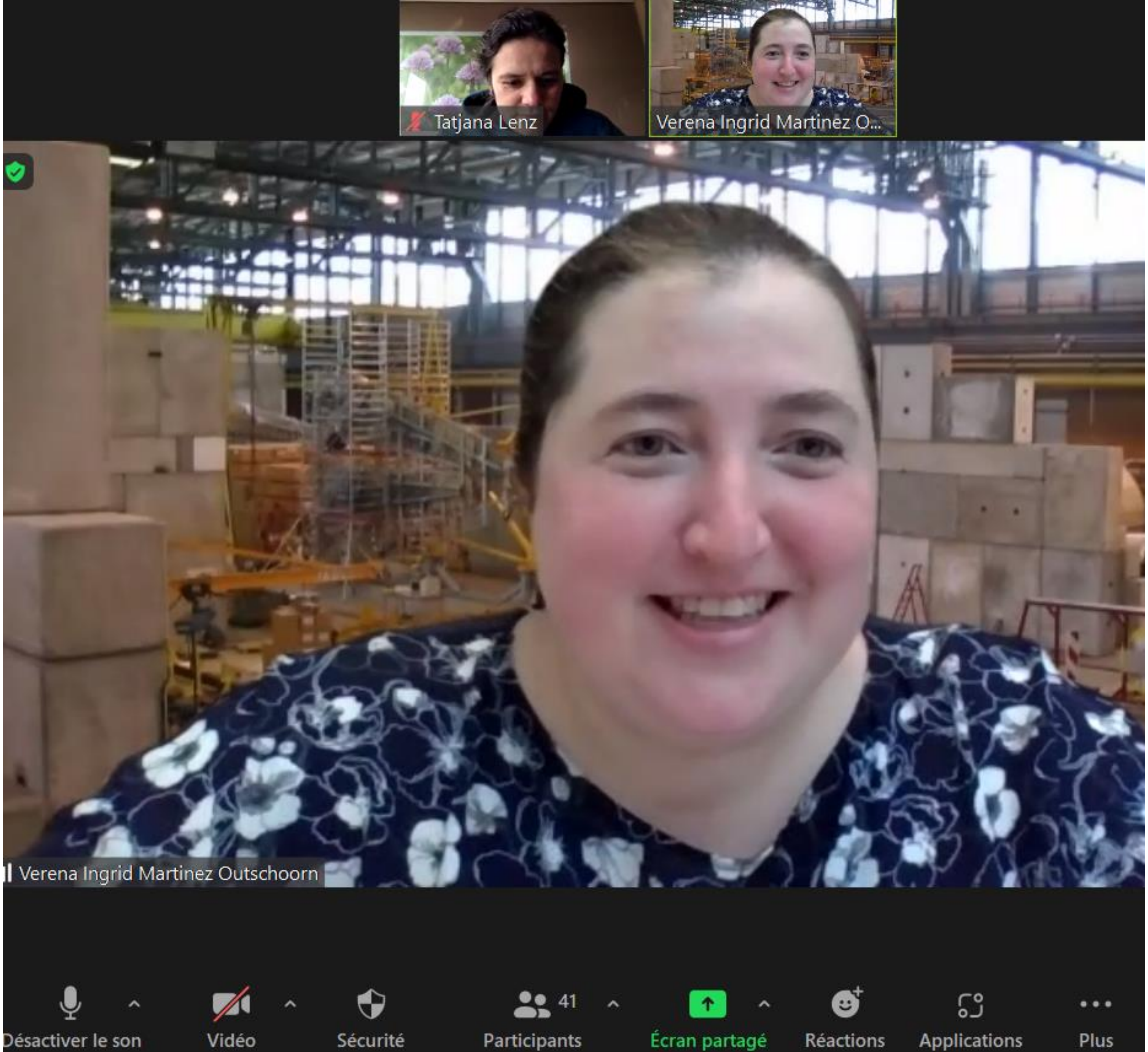
Tatjana Lenz
Verena Ingrid Martinez O...
Verena Ingrid Martinez Outschoorn
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Tools
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Tatjana Lenz
UNIVERSITÄT BONN
HH Production ggF & VBF
HH production → non-resonant via ggF and VBF
"triangle"
non-resonant ggF
non-resonant VBF
VBF production is sub-dominant ~ 1.7 fb @ 13 TeV
3
Tatjana Lenz
48
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Sécurité
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Réactions
Applications
Plus

Tatjana Lenz
UNIVERSITÄT BONN

HH bbττ: Systematics

- Relative contribution to the uncertainty in the extracted signal cross-sections (sum in quadrature)

Uncertainty source	Non-resonant HH	Resonant $X \to HH$ 300 GeV	500 GeV	1000 GeV
Data statistical	81%	75%	89%	88%
Systematic	59%	66%	46%	48%
$t\bar{t}$ and Z + HF normalisations	4%	15%	3%	5%
MC statistical	28%	44%	33%	18%
Experimental				
Jet and E_T^{miss}	7%	28%	5%	3%
b-jet tagging	3%	6%	3%	3%
$\tau_{had-vis}$	5%	13%	3%	7%
Electrons and muons	2%	3%	2%	1%
Luminosity and pileup	3%	2%	2%	5%
Theoretical and modelling				
Fake-$\tau_{had-vis}$	9%	22%	8%	7%
Top-quark	24%	17%	15%	8%
$Z(\to \tau\tau)$ + HF	9%	17%	9%	15%
Single Higgs boson	29%	2%	13%	14%
Other backgrounds	3%	2%	5%	3%
Signal	5%	10%	13%	34%

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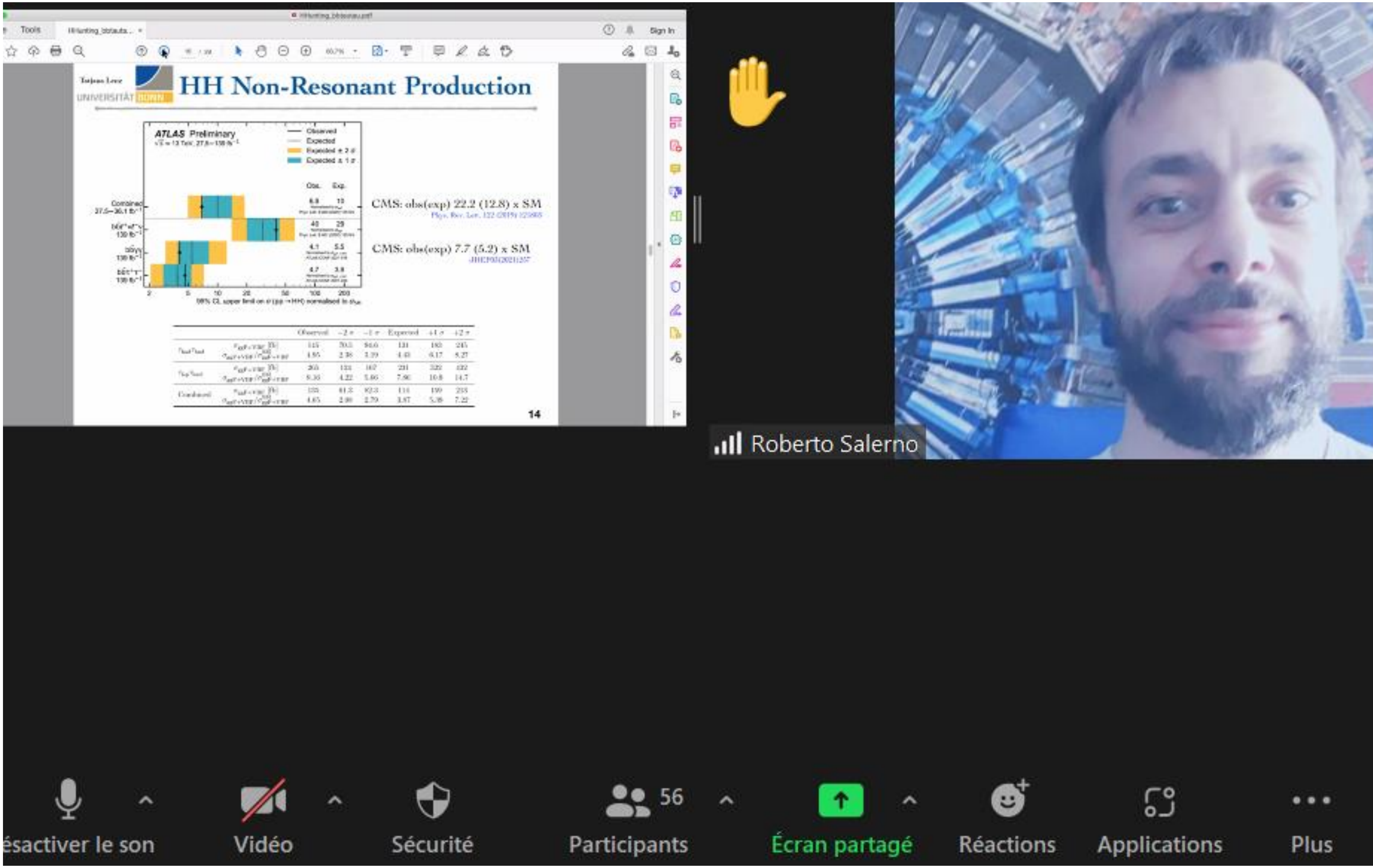
iver le son Vidéo Sécurité Participants 55 Écran partagé Réactions Applications


Tools
Sign In
HH Non-Resonant Production
UNIVERSITÄT BONN
ATLAS Preliminary
Observed
Expected
Expected ± 2 σ
Expected ± 1 σ
Obs. Exp.
Combined
CMS: obs(exp) 22.2 (12.8) x SM
CMS: obs(exp) 7.7 (5.2) x SM
14
Roberto Salerno
56
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Sécurité
Participants
Écran partagé
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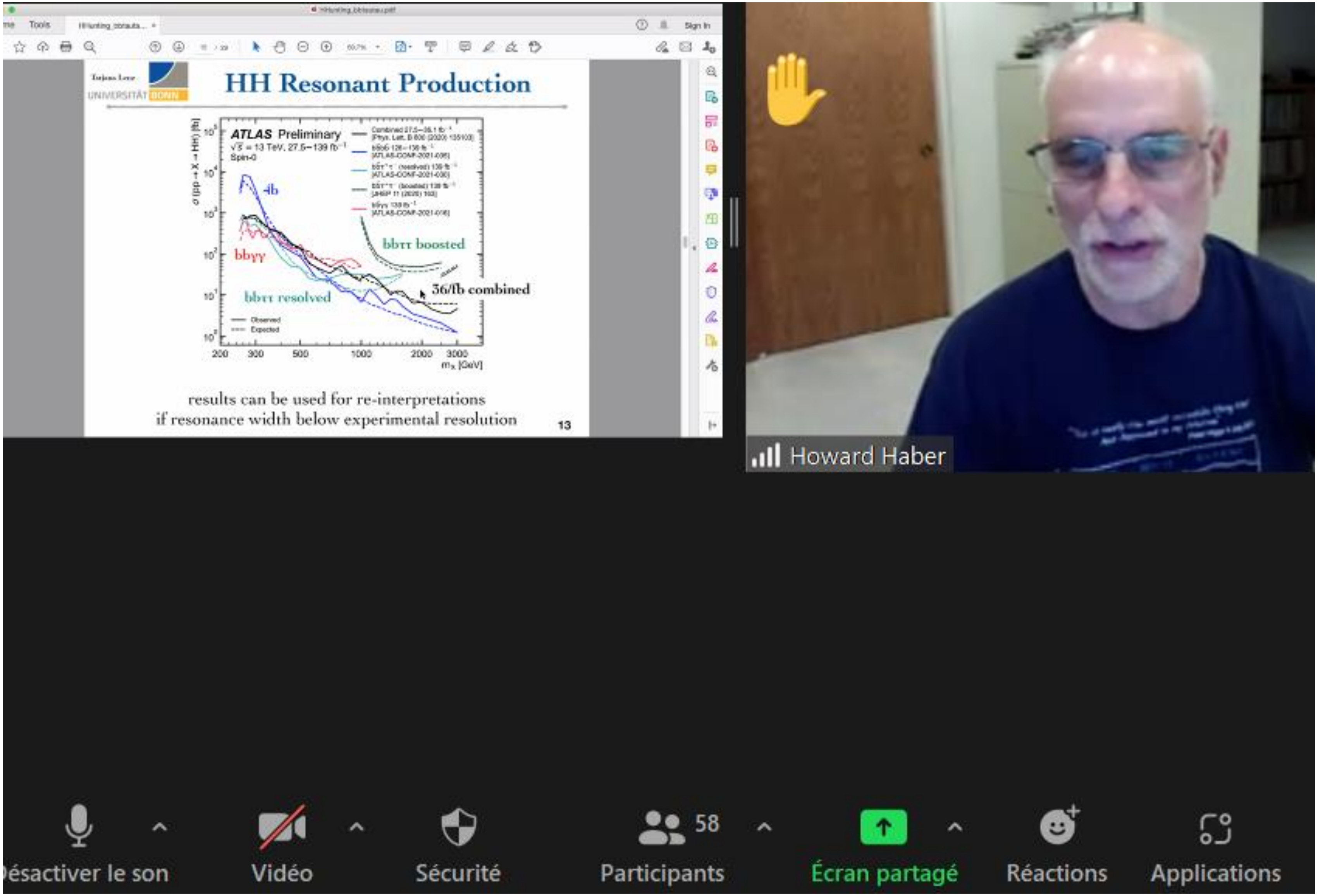
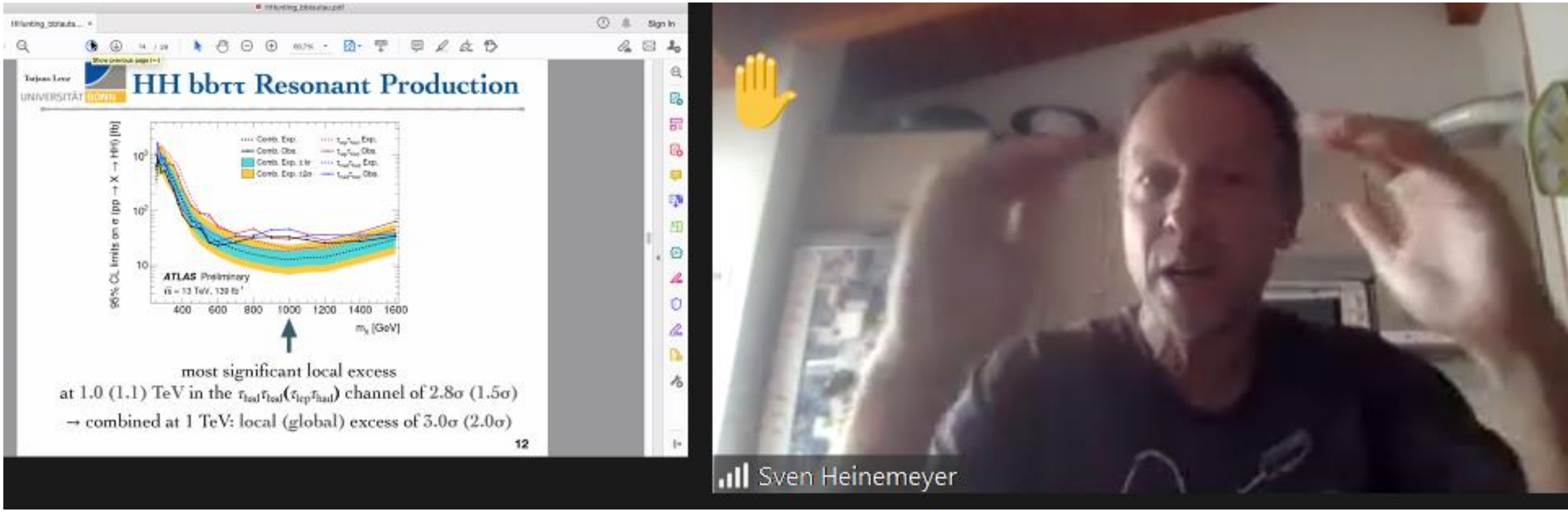
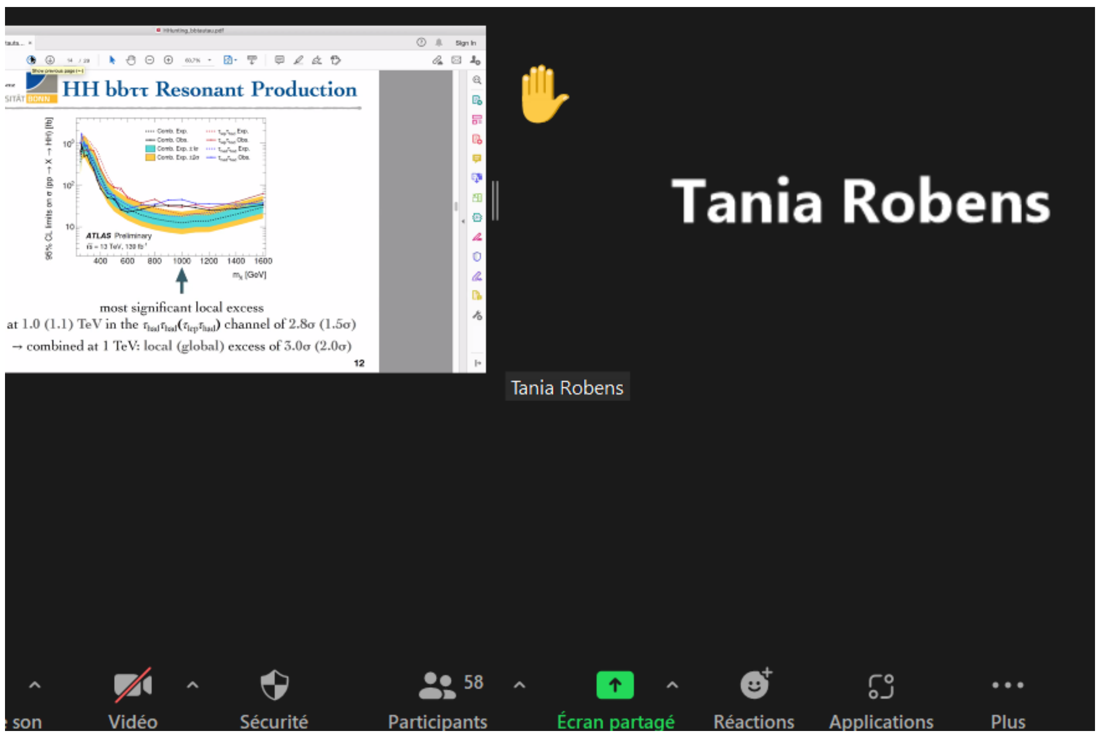
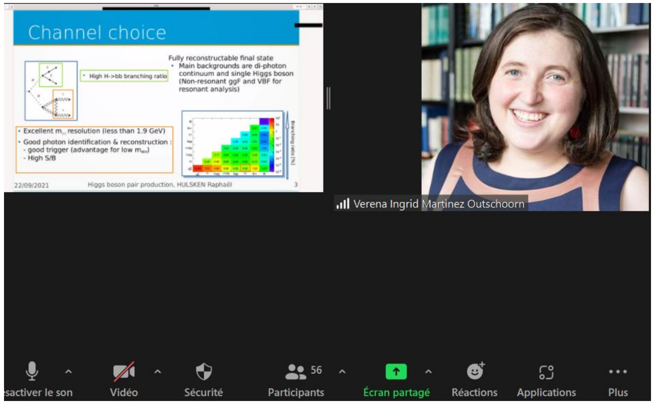
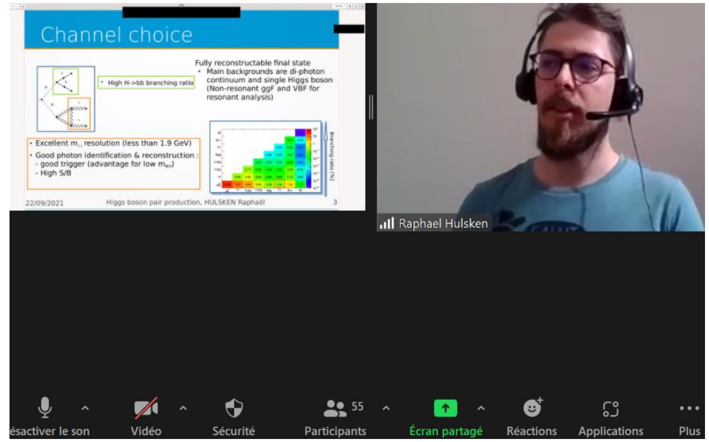
Plus

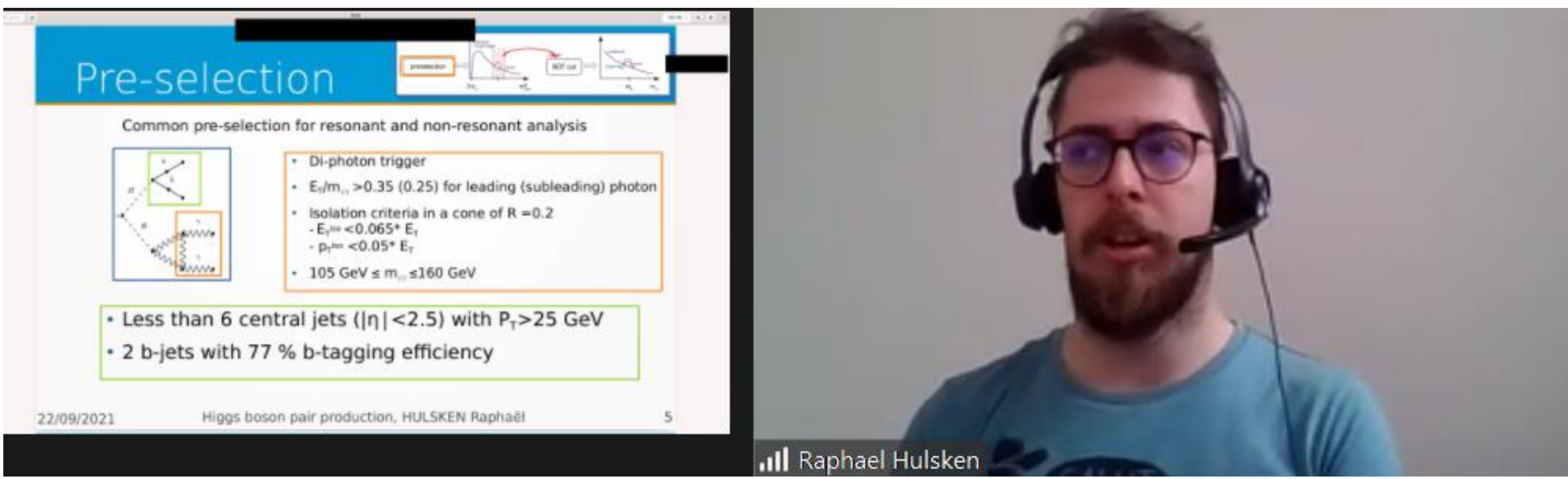

HH Resonant Production
UNIVERSITÄT BONN
ATLAS Preliminary
Spin-0
bbγγ
bbττ boosted
bbττ resolved
36/fb combined
Observed
Expected
200 300 500 1000 2000 3000
results can be used for re-interpretations
if resonance width below experimental resolution
13
Howard Haber
ésactiver le son
Vidéo
Sécurité
58
Participants
Écran partagé
Réactions
Applications

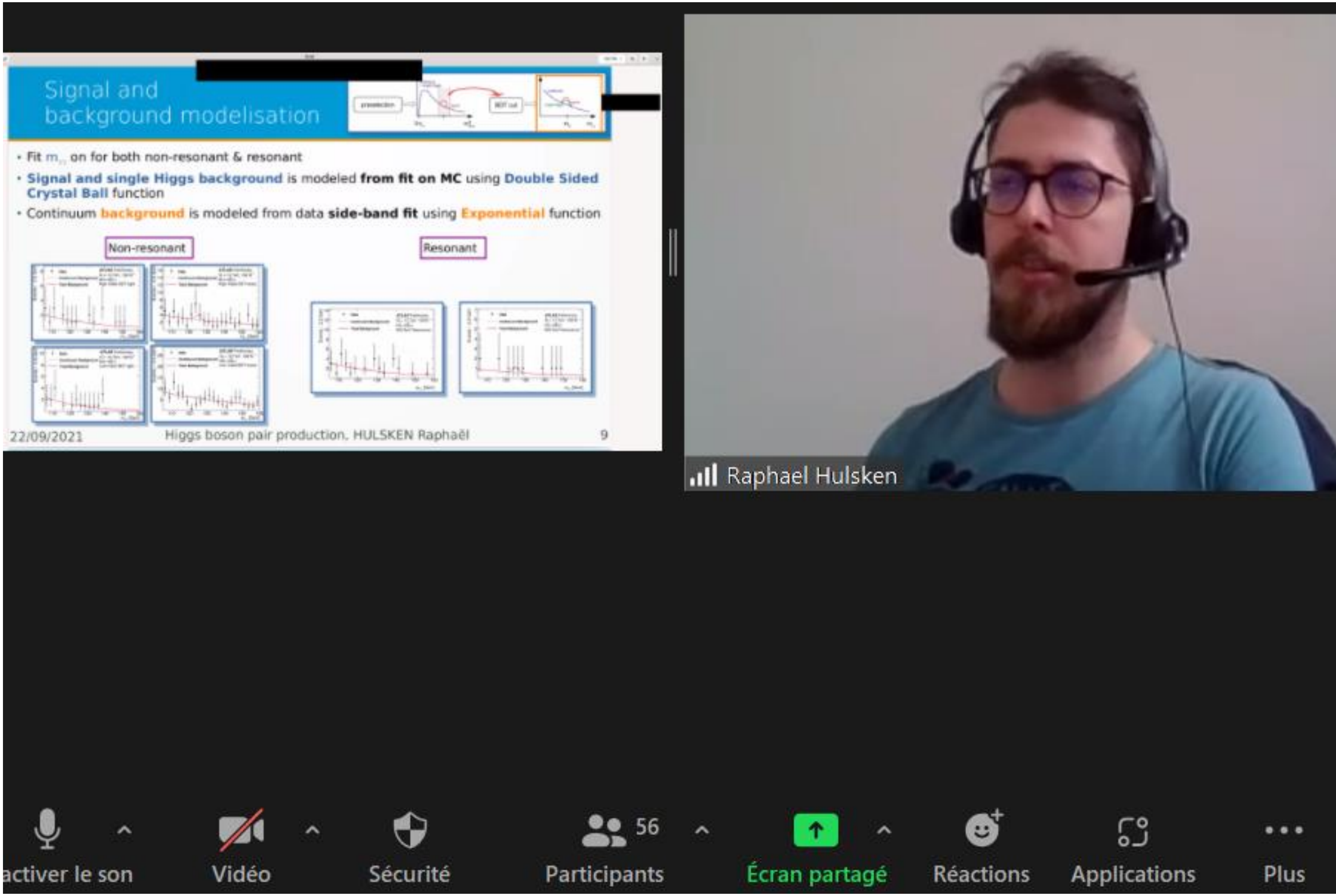

HH bbττ Resonant Production
UNIVERSITÄT BONN
ATLAS Preliminary
m_X [GeV]
most significant local excess
at 1.0 (1.1) TeV in the $\tau_{had}\tau_{had}(\tau_{lep}\tau_{had})$ channel of 2.8σ (1.5σ)
→ combined at 1 TeV: local (global) excess of 3.0σ (2.0σ)
12
Sven Heinemeyer

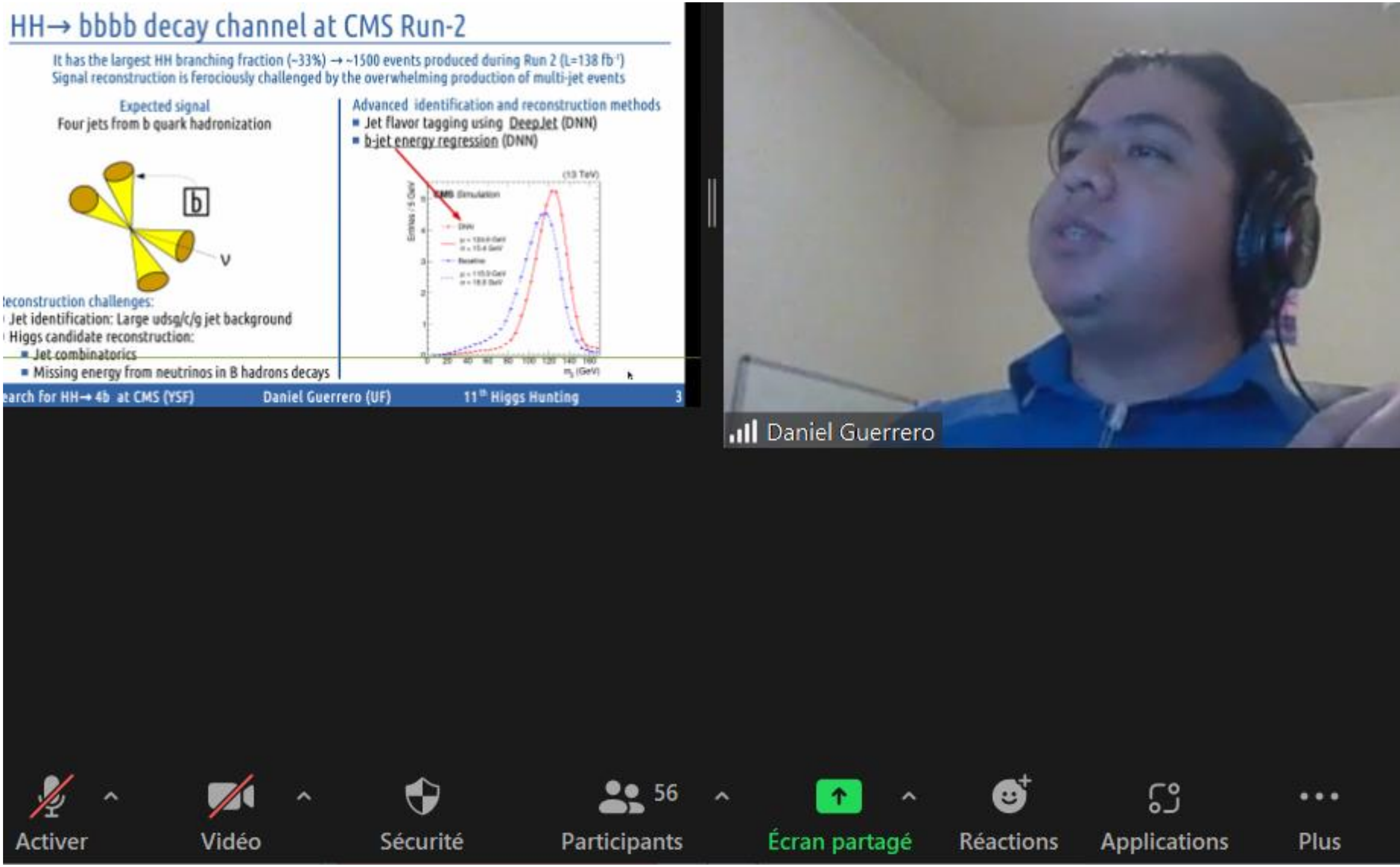

HH bbττ Resonant Production
most significant local excess
at 1.0 (1.1) TeV in the $\tau_{had}\tau_{had}(\tau_{lep}\tau_{had})$ channel of 2.8σ (1.5σ)
→ combined at 1 TeV: local (global) excess of 3.0σ (2.0σ)
Tania Robens
Tania Robens
son
Vidéo
Sécurité
58
Participants
Écran partagé
Réactions
Applications
Plus

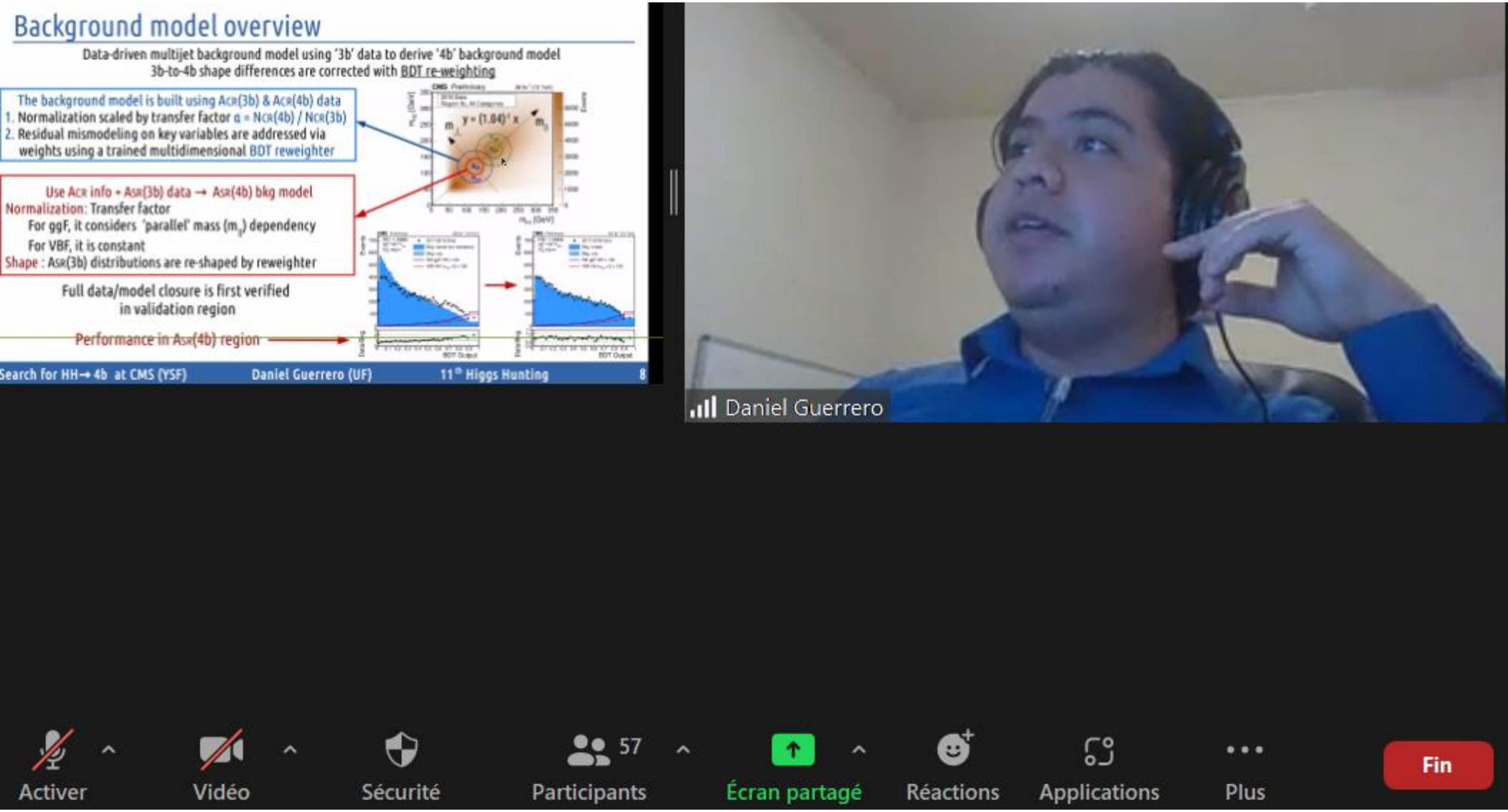

Channel choice
Verena Ingrid Martinez Outschoorn
56
Vidéo
Sécurité
Participants
Écran partagé
Réactions
Applications
Plus

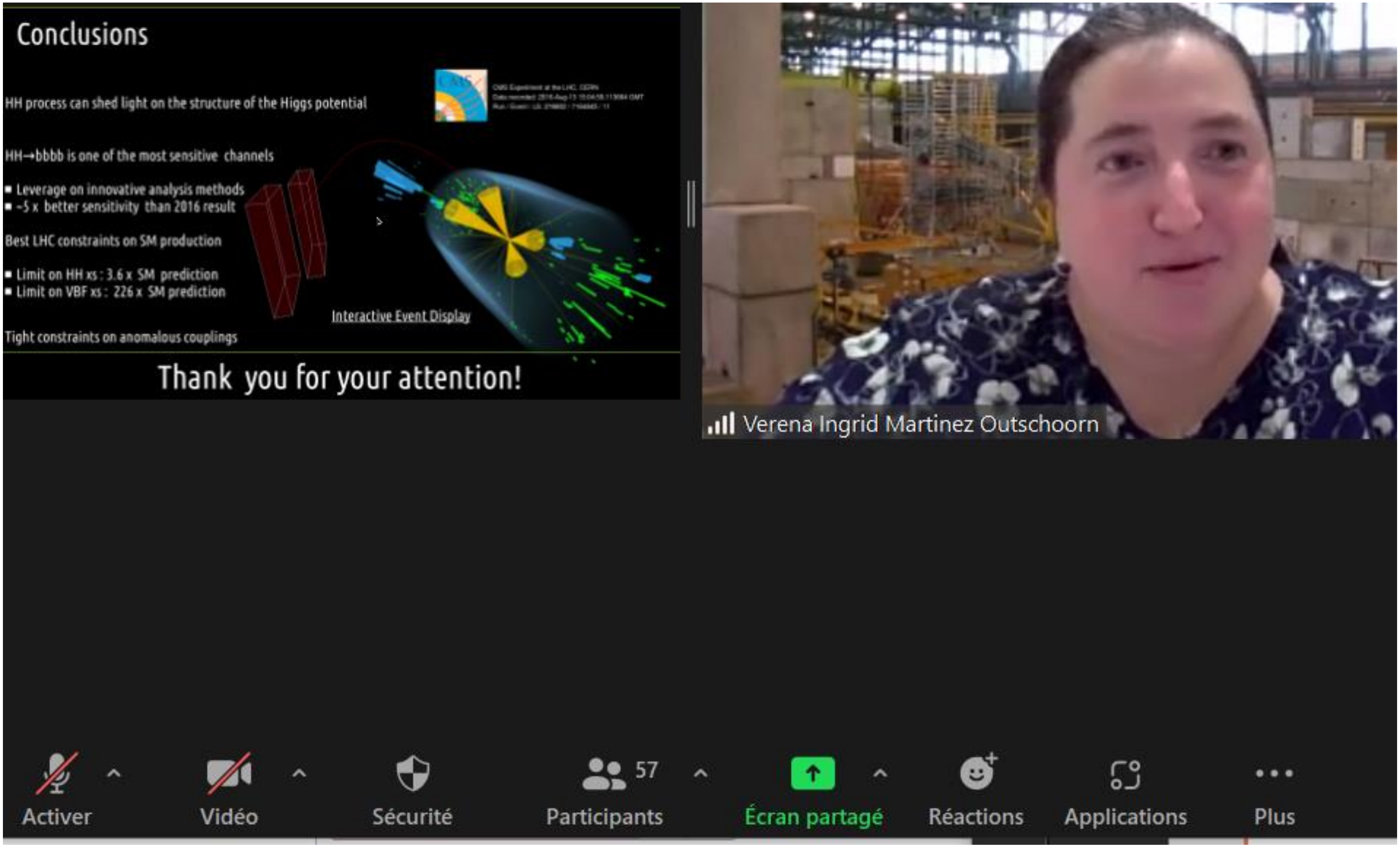

Channel choice
Raphael Hulsken
55
ésactiver le son
Vidéo
Sécurité
Participants
Écran partagé
Réactions
Applications
Plus

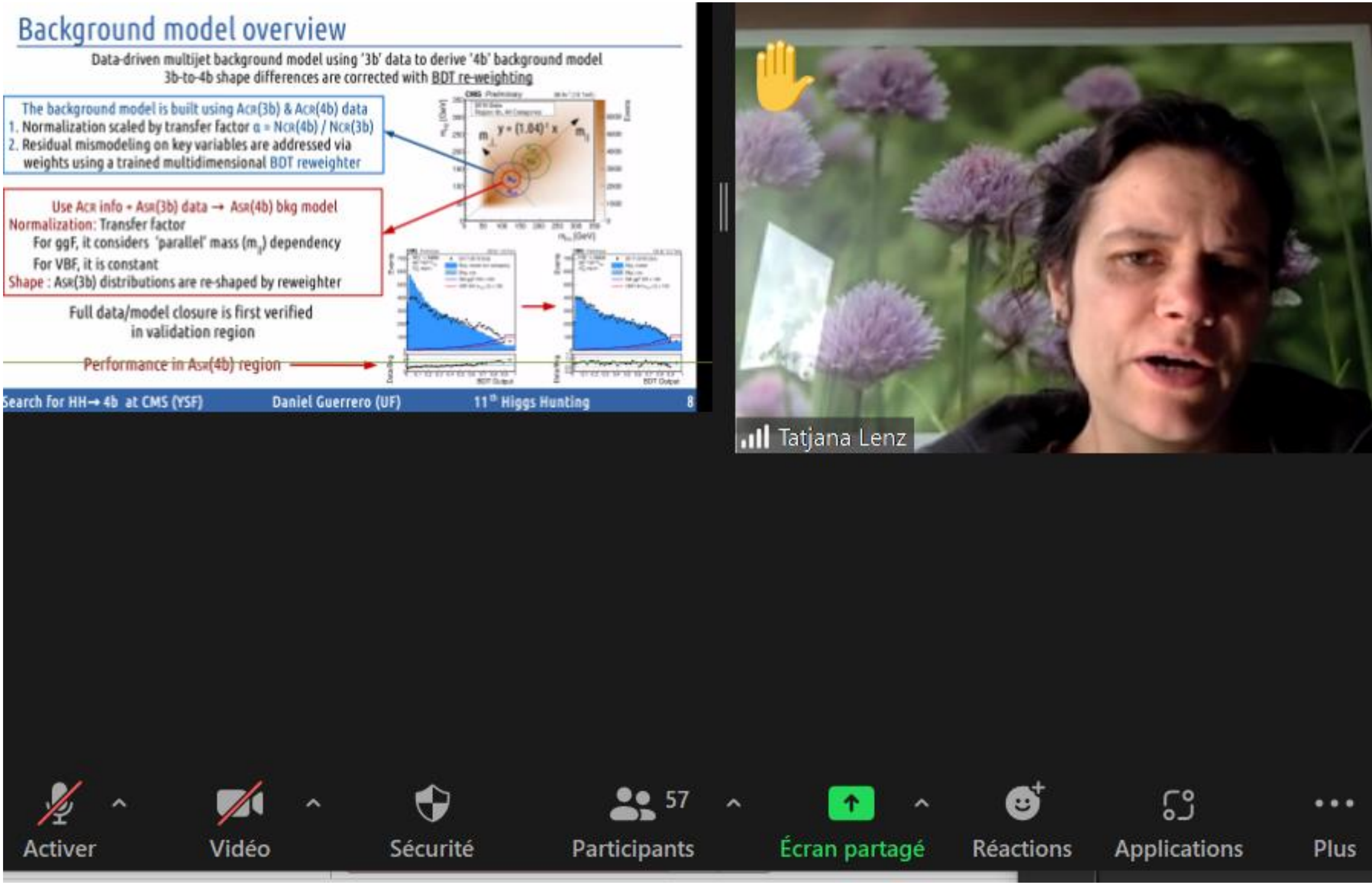

Pre-selection
Common pre-selection for resonant and non-resonant analysis
Di-photon trigger
E_T/m_γγ >0.35 (0.25) for leading (subleading) photon
Isolation criteria in a cone of R =0.2
105 GeV ≤ m_γγ ≤160 GeV
Less than 6 central jets (|η|<2.5) with P_T>25 GeV
2 b-jets with 77 % b-tagging efficiency
22/09/2021
Higgs boson pair production, HULSKEN Raphaël
5
Raphael Hulsken


[redacted]
Signal and background modelisation
[redacted]
• Fit $m_{\gamma\gamma}$ on for both non-resonant & resonant
• Signal and single Higgs background is modeled from fit on MC using Double Sided Crystal Ball function
• Continuum background is modeled from data side-band fit using Exponential function
Non-resonant
Resonant
22/09/2021
Higgs boson pair production, HULSKEN Raphaël
9
Raphael Hulsken
activer le son
Vidéo
Sécurité
56
Participants
Écran partagé
Réactions
Applications
Plus


HH→ bbbb decay channel at CMS Run-2
It has the largest HH branching fraction (~33%) → ~1500 events produced during Run 2 (L=138 fb-1)
Signal reconstruction is ferociously challenged by the overwhelming production of multi-jet events
Expected signal
Four jets from b quark hadronization
b
ν
Advanced identification and reconstruction methods
Jet flavor tagging using DeepJet (DNN)
b-jet energy regression (DNN)
econstruction challenges:
Jet identification: Large udsg/c/g jet background
Higgs candidate reconstruction:
Jet combinatorics
Missing energy from neutrinos in B hadrons decays
earch for HH→4b at CMS (YSF)
Daniel Guerrero (UF)
11th Higgs Hunting
3
Daniel Guerrero
56
Activer
Vidéo
Sécurité
Participants
Écran partagé
Réactions
Applications
Plus


Background model overview
Data-driven multijet background model using '3b' data to derive '4b' background model
3b-to-4b shape differences are corrected with BDT re-weighting
The background model is built using ACR(3b) & ACR(4b) data
1. Normalization scaled by transfer factor α = NCR(4b) / NCR(3b)
2. Residual mismodeling on key variables are addressed via weights using a trained multidimensional BDT reweighter
Use ACR info + ASR(3b) data → ASR(4b) bkg model
Normalization: Transfer factor
For ggF, it considers 'parallel' mass (m∥) dependency
For VBF, it is constant
Shape : ASR(3b) distributions are re-shaped by reweighter
Full data/model closure is first verified in validation region
Performance in ASR(4b) region
CMS Preliminary
y = (1.04)^x
Search for HH→4b at CMS (YSF)
Daniel Guerrero (UF)
11th Higgs Hunting
8
Daniel Guerrero
Activer
Vidéo
Sécurité
57
Participants
Écran partagé
Réactions
Applications
Plus
Fin


Conclusions
HH process can shed light on the structure of the Higgs potential
HH→bbbb is one of the most sensitive channels
▪ Leverage on innovative analysis methods
▪ ~5 x better sensitivity than 2016 result
Best LHC constraints on SM production
▪ Limit on HH xs : 3.6 x SM prediction
▪ Limit on VBF xs : 226 x SM prediction
Tight constraints on anomalous couplings
Interactive Event Display
Thank you for your attention!
Verena Ingrid Martinez Outschoorn
Activer
Vidéo
Sécurité
57
Participants
Écran partagé
Réactions
Applications
Plus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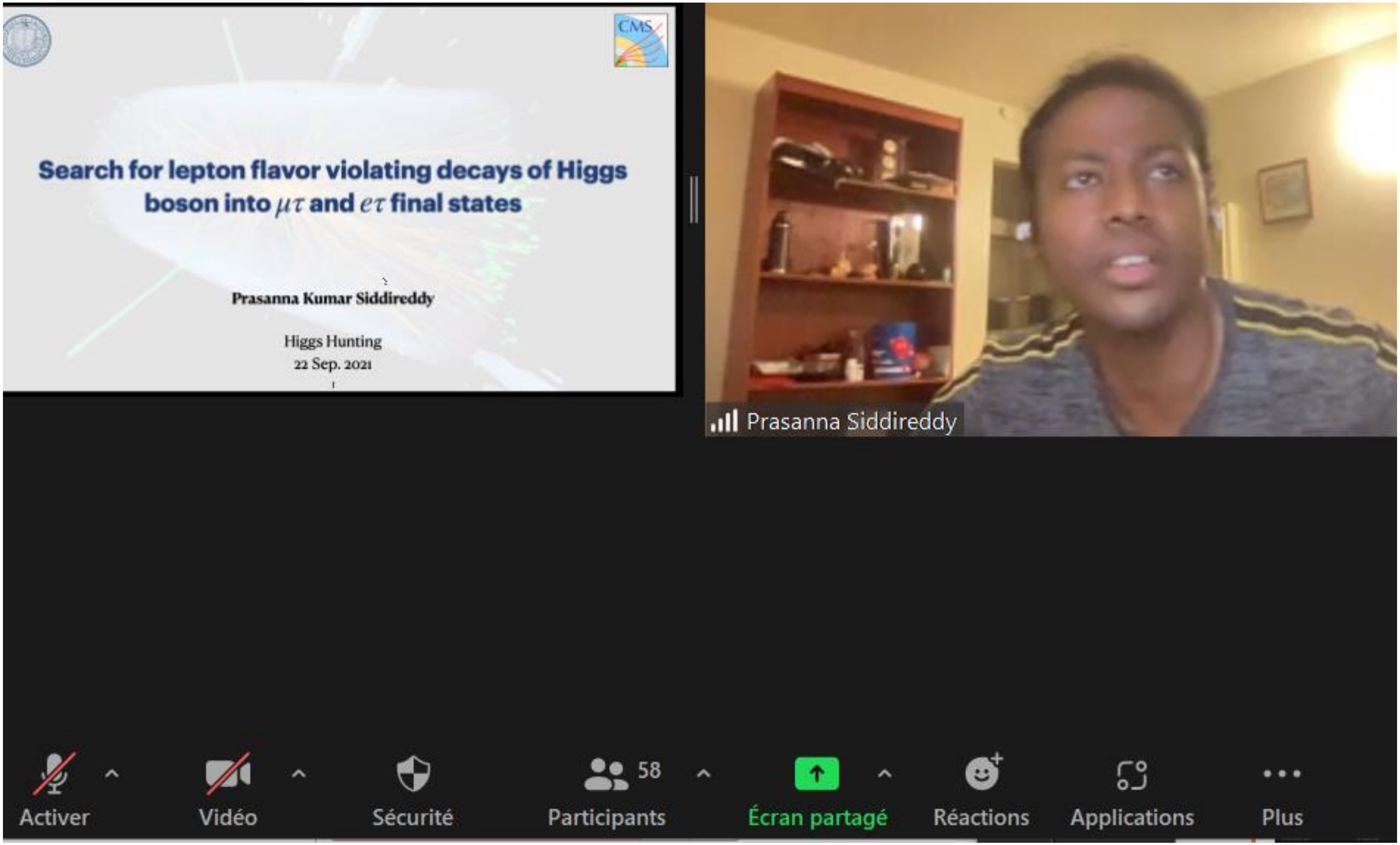
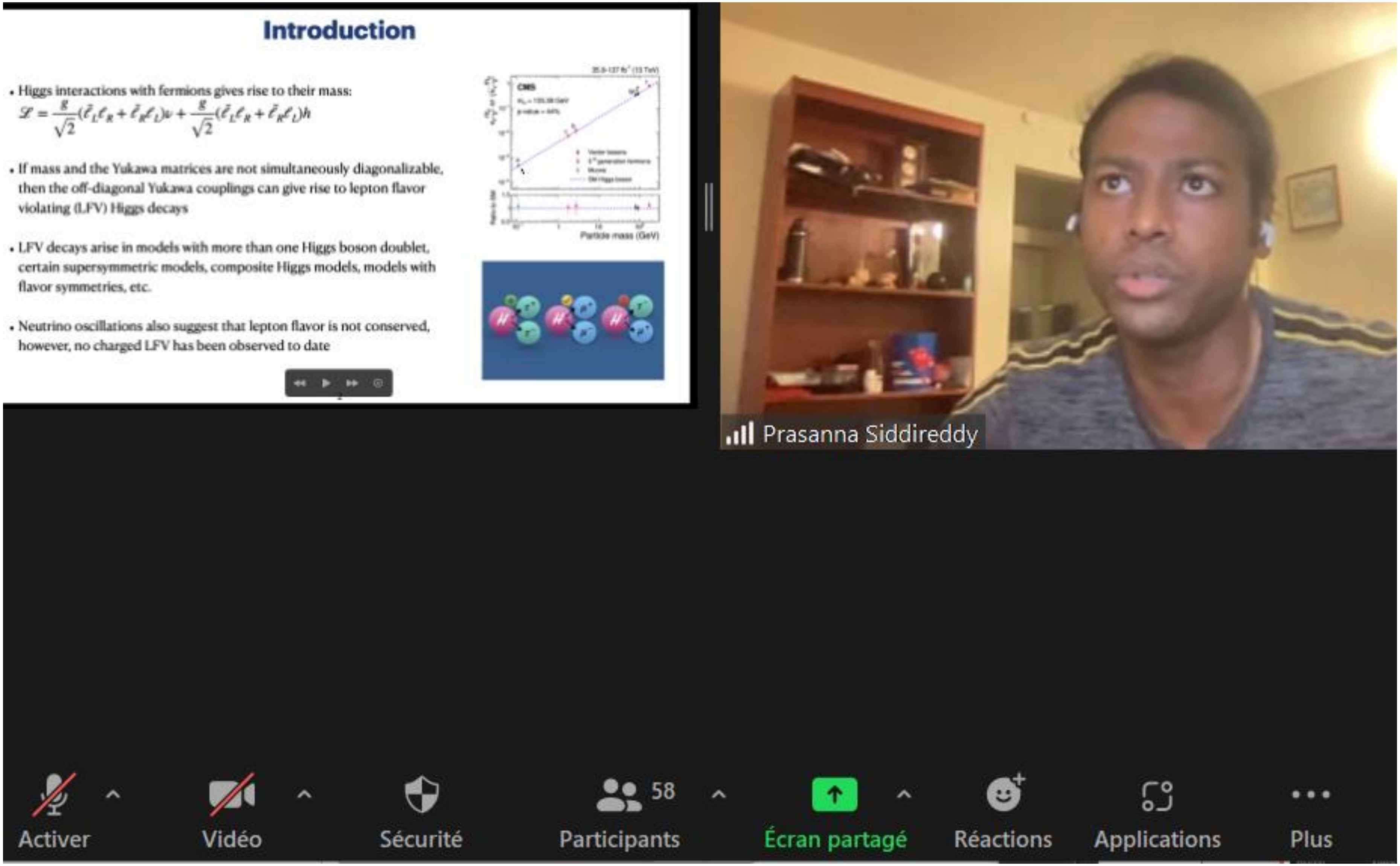
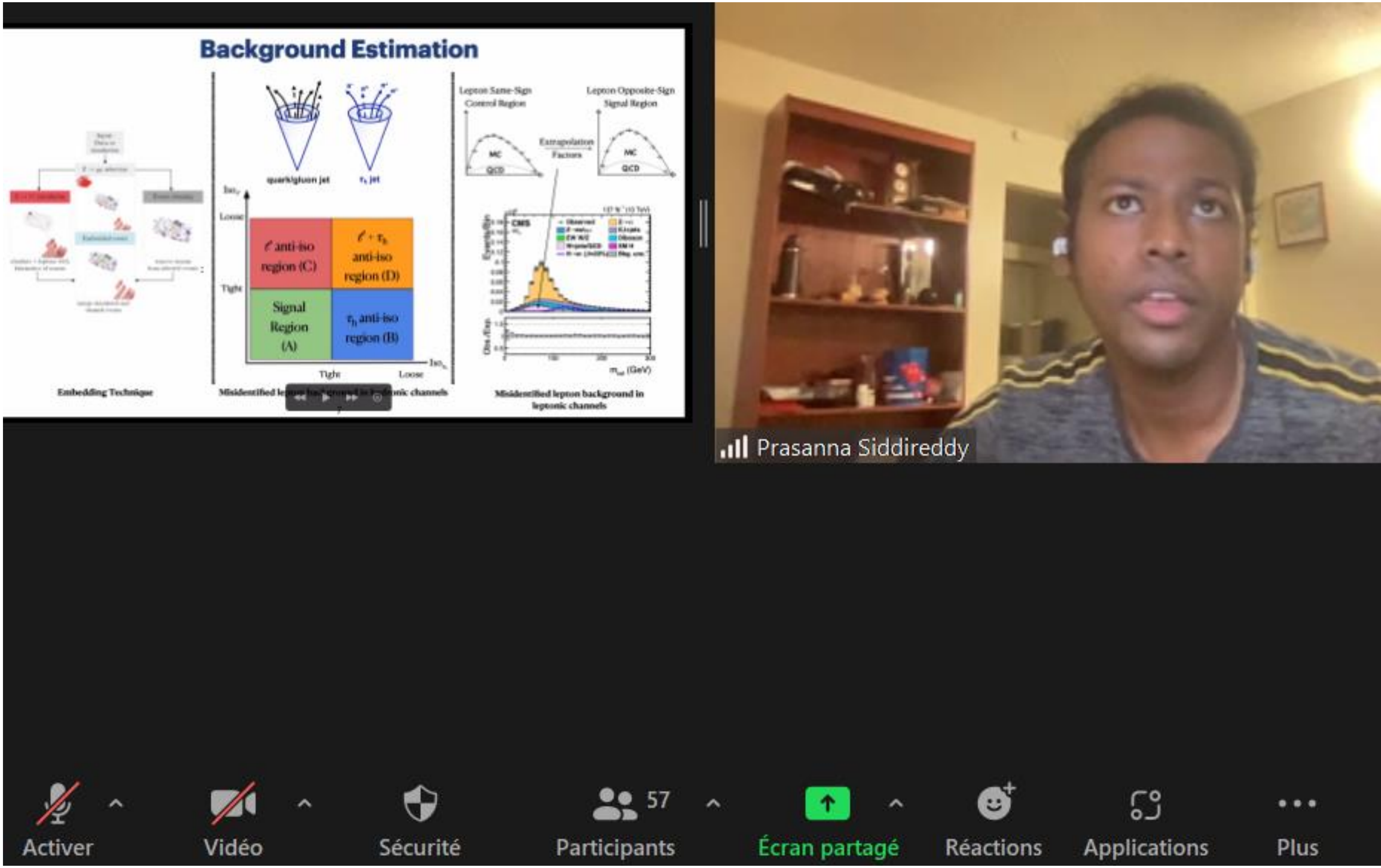
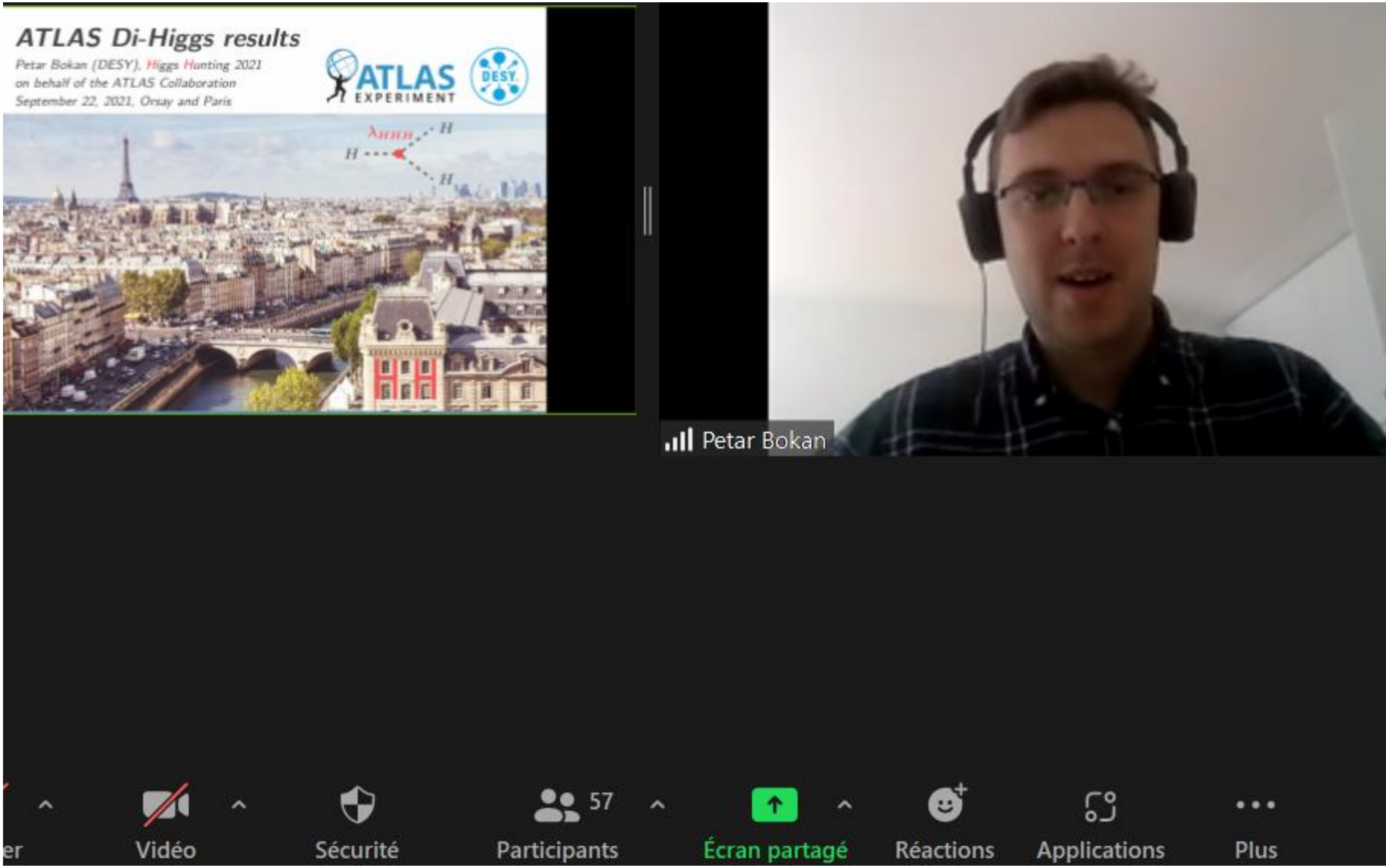
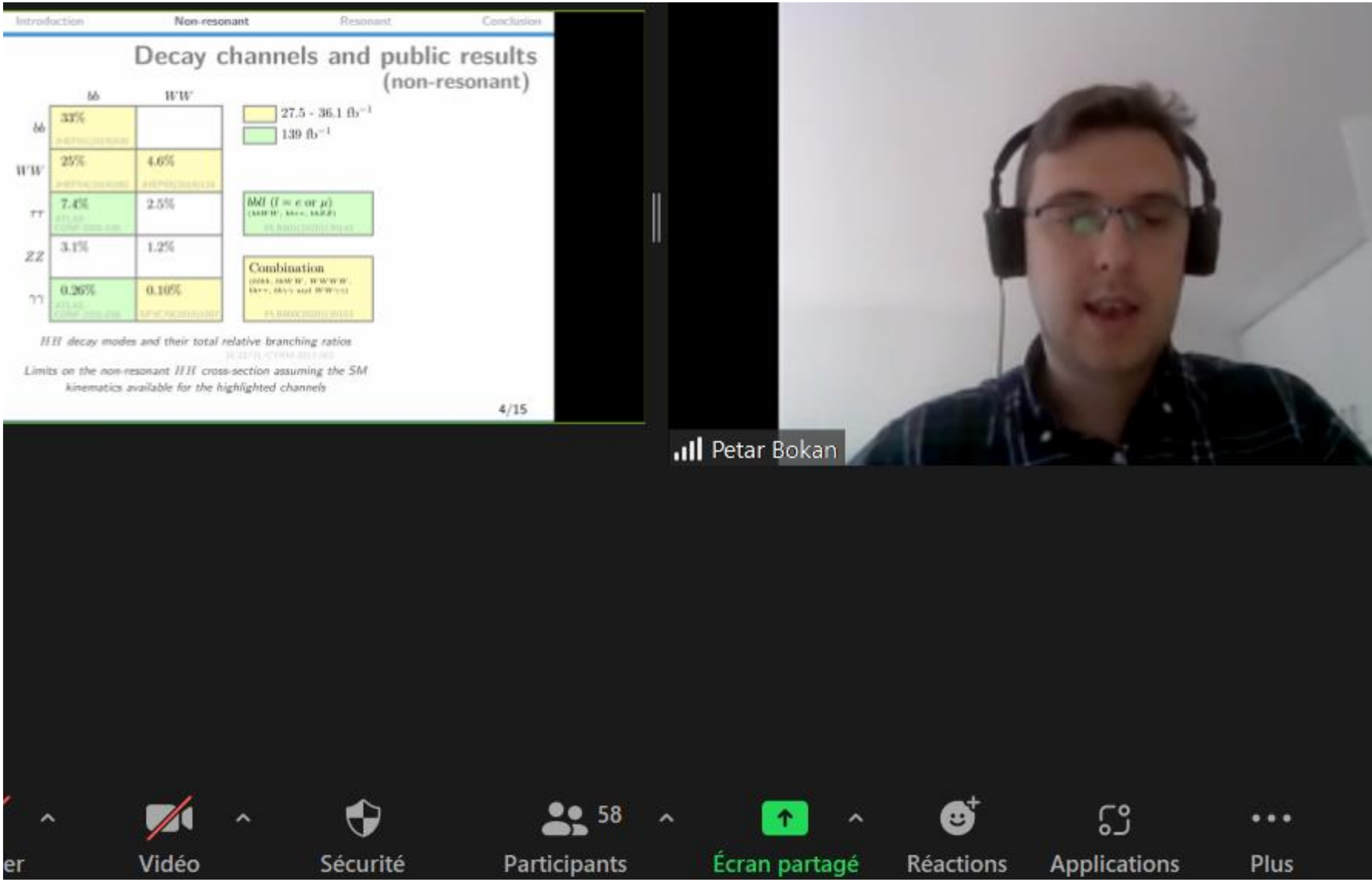
Full data/model closure is first verified in validation region
Performance in ASR(4b) region
y = (1.04)² x
Search for HH→4b at CMS (YSF)
Daniel Guerrero (UF)
11th Higgs Hunting
8
Tatjana Lenz
Activer
Vidéo
Sécurité
57
Participants
Écran partagé
Réactions
Applications
Plus

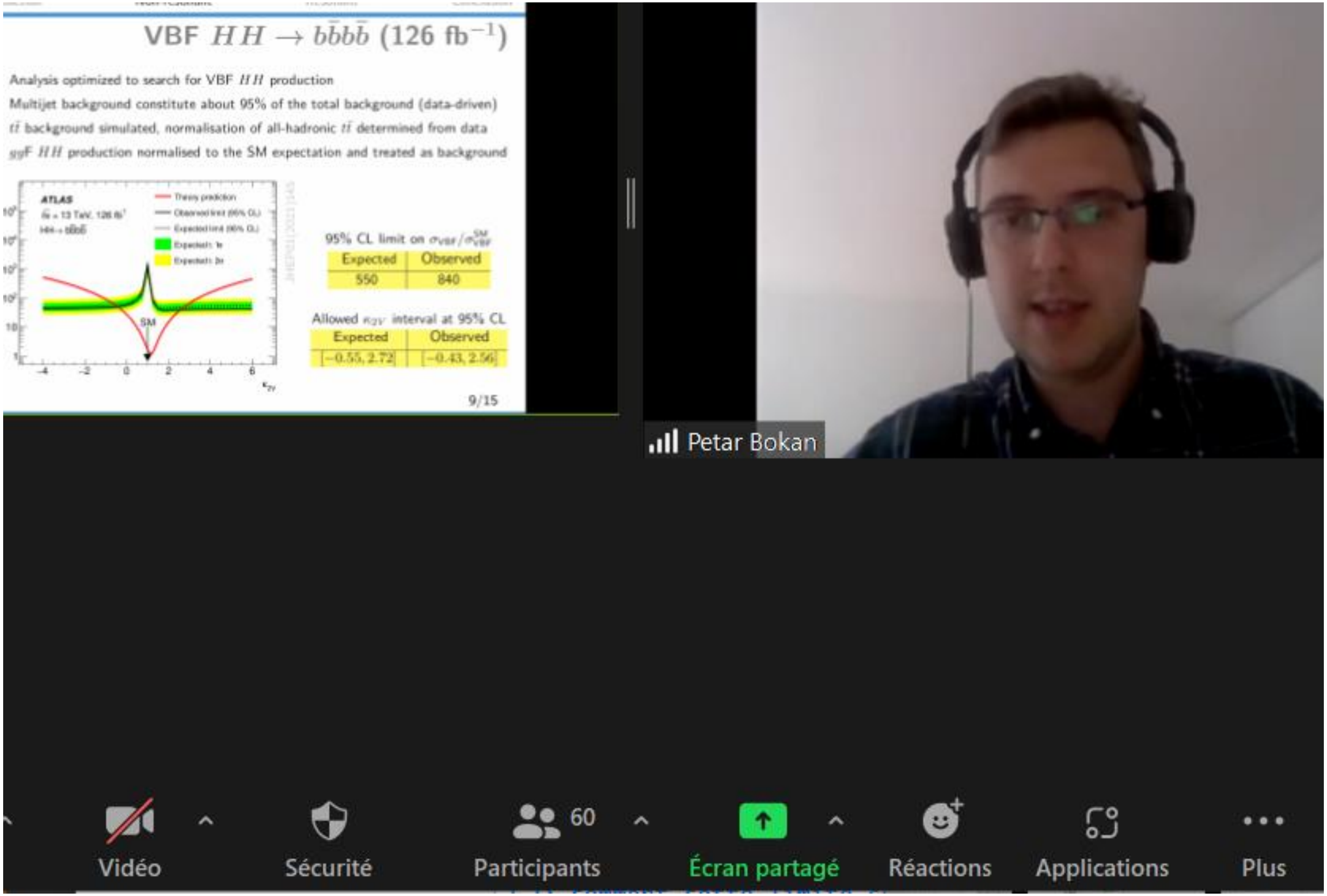

Search for lepton flavor violating decays of Higgs boson into $\mu\tau$ and $e\tau$ final states
Prasanna Kumar Siddireddy
Higgs Hunting
22 Sep. 2021
CMS
Prasanna Siddireddy
Activer
Vidéo
Sécurité
58
Participants
Écran partagé
Réactions
Applications
Plus


Introduction
• Higgs interactions with fermions gives rise to their mass:
$\mathcal{L} = \frac{g}{\sqrt{2}}(\bar{\ell}_L \ell_R + \bar{\ell}_R \ell_L)v + \frac{g}{\sqrt{2}}(\bar{\ell}_L \ell_R + \bar{\ell}_R \ell_L)h$
• If mass and the Yukawa matrices are not simultaneously diagonalizable, then the off-diagonal Yukawa couplings can give rise to lepton flavor violating (LFV) Higgs decays
• LFV decays arise in models with more than one Higgs boson doublet, certain supersymmetric models, composite Higgs models, models with flavor symmetries, etc.
• Neutrino oscillations also suggest that lepton flavor is not conserved, however, no charged LFV has been observed to date
CMS
Particle mass (GeV)
Prasanna Siddireddy
Activer
Vidéo
Sécurité
Participants 58
Écran partagé
Réactions
Applications
Plus


Background Estimation
Lepton Same-Sign Control Region
Lepton Opposite-Sign Signal Region
Extrapolation Factors
MC
QCD
quark/gluon jet
τ_h jet
ℓ anti-iso region (C)
$\ell+\tau_h$ anti-iso region (D)
Signal Region (A)
τ_h anti-iso region (B)
Loose
Tight
Embedding Technique
Misidentified lepton background in leptonic channels
Prasanna Siddireddy
Activer
Vidéo
Sécurité
57
Participants
Écran partagé
Réactions
Applications
Plus


ATLAS Di-Higgs results
Petar Bokan (DESY), Higgs Hunting 2021
on behalf of the ATLAS Collaboration
September 22, 2021, Orsay and Paris
ATLAS
EXPERIMENT
DESY.
Petar Bokan
Vidéo
Sécurité
57
Participants
Écran partagé
Réactions
Applications
Plus


Introduction
Non-resonant
Resonant
Conclusion
Decay channels and public results
(non-resonant)
bb
WW
27.5 - 36.1 fb⁻¹
139 fb⁻¹
bb
33%
WW
25%
4.6%
ττ
7.4%
2.5%
ZZ
3.1%
1.2%
γγ
0.26%
0.10%
bbll (l = e or μ)
Combination
HH decay modes and their total relative branching ratios
Limits on the non-resonant HH cross-section assuming the SM kinematics available for the highlighted channels
4/15
Petar Bokan
Vidéo
Sécurité
58
Participants
Écran partagé
Réactions
Applications
Plus


VBF $HH \to b\bar{b}b\bar{b}$ (126 fb^{-1})
Analysis optimized to search for VBF HH production
Multijet background constitute about 95% of the total background (data-driven)
$t\bar{t}$ background simulated, normalisation of all-hadronic $t\bar{t}$ determined from data
ggF HH production normalised to the SM expectation and treated as background
ATLAS
SM
95% CL limit on $\sigma_{VBF}/\sigma_{VBF}^{SM}$
Expected | Observed
550 | 840
Allowed κ_{2V} interval at 95% CL
Expected | Observed
$[-0.55, 2.72]$ | $[-0.43, 2.56]$
9/15
Petar Bokan
Vidéo
Sécurité
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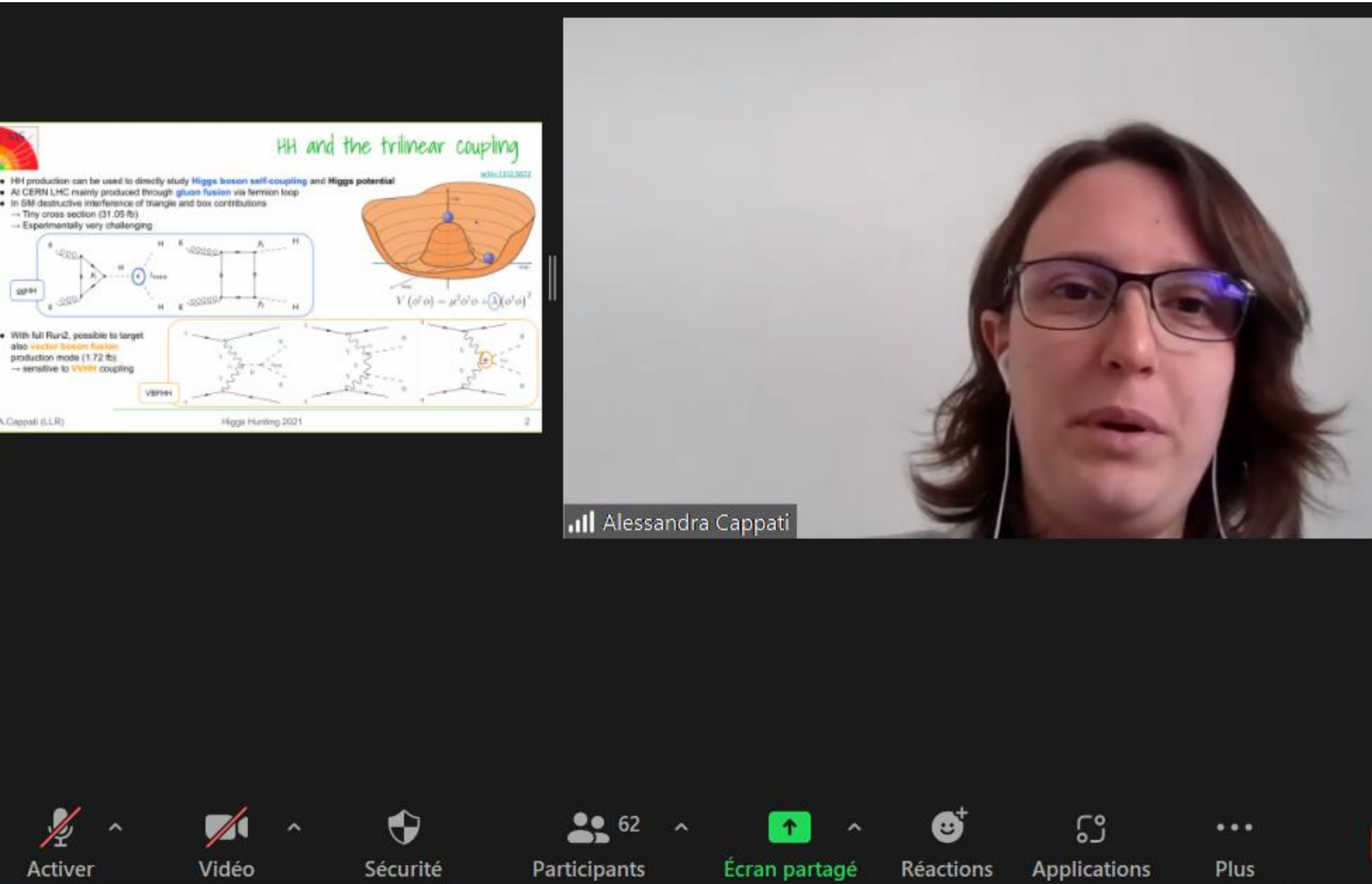
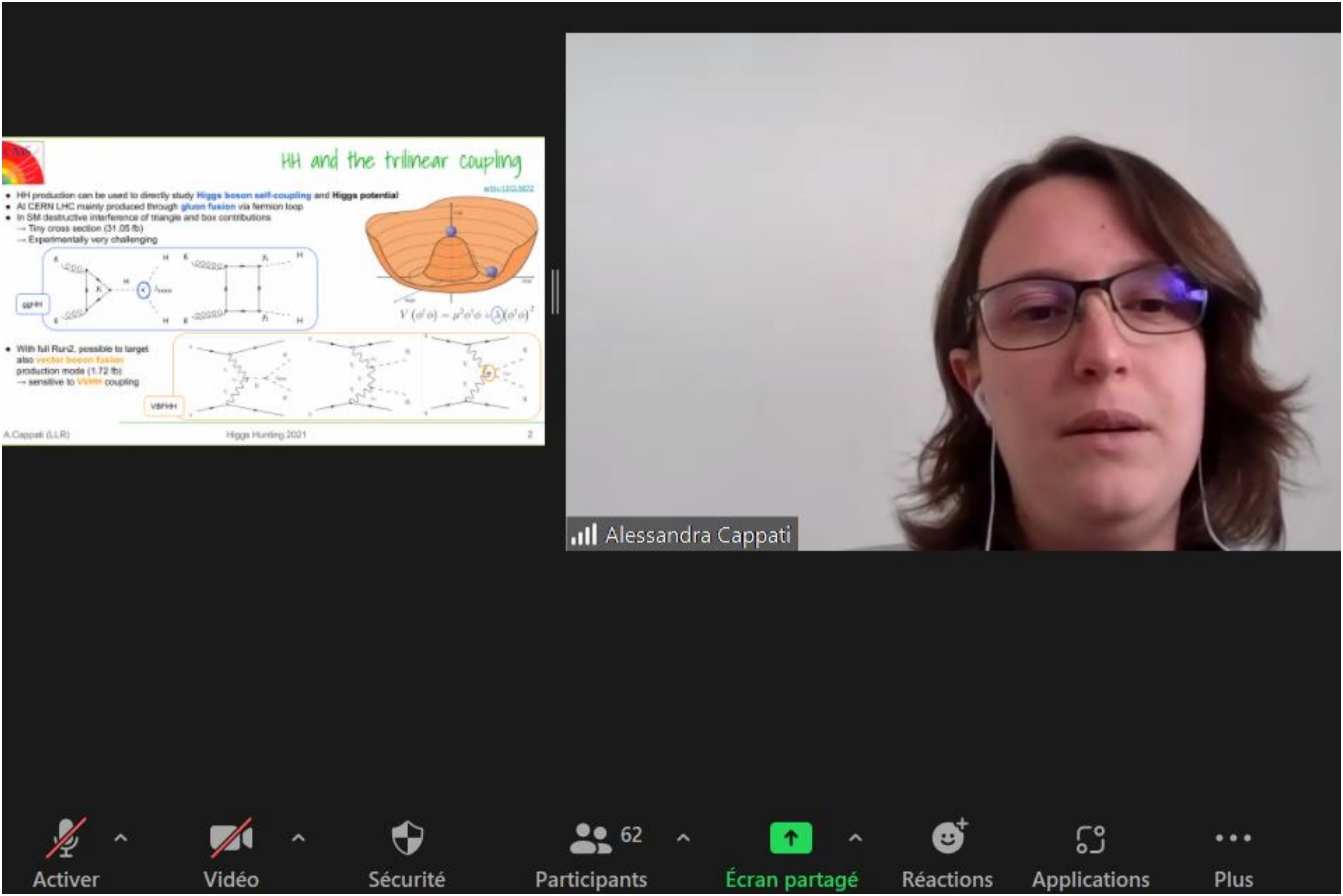
Participants
Écran partagé
Réactions
Applications
Plus


HH and the trilinear coupling
HH production can be used to directly study Higgs boson self-coupling and Higgs potential
At CERN LHC mainly produced through gluon fusion via fermion loop
In SM destructive interference of triangle and box contributions
→ Tiny cross section (31.05 fb)
→ Experimentally very challenging
ggHH
With full Run2, possible to target also vector boson fusion production mode (1.72 fb)
→ sensitive to VVHH coupling
VBFHH
A.Cappati (LLR)
Higgs Hunting 2021
2
Alessandra Cappati
Activer
Vidéo
Sécurité
62
Participants
Écran partagé
Réactions
Applications
Plus


HH and the trilinear coupling
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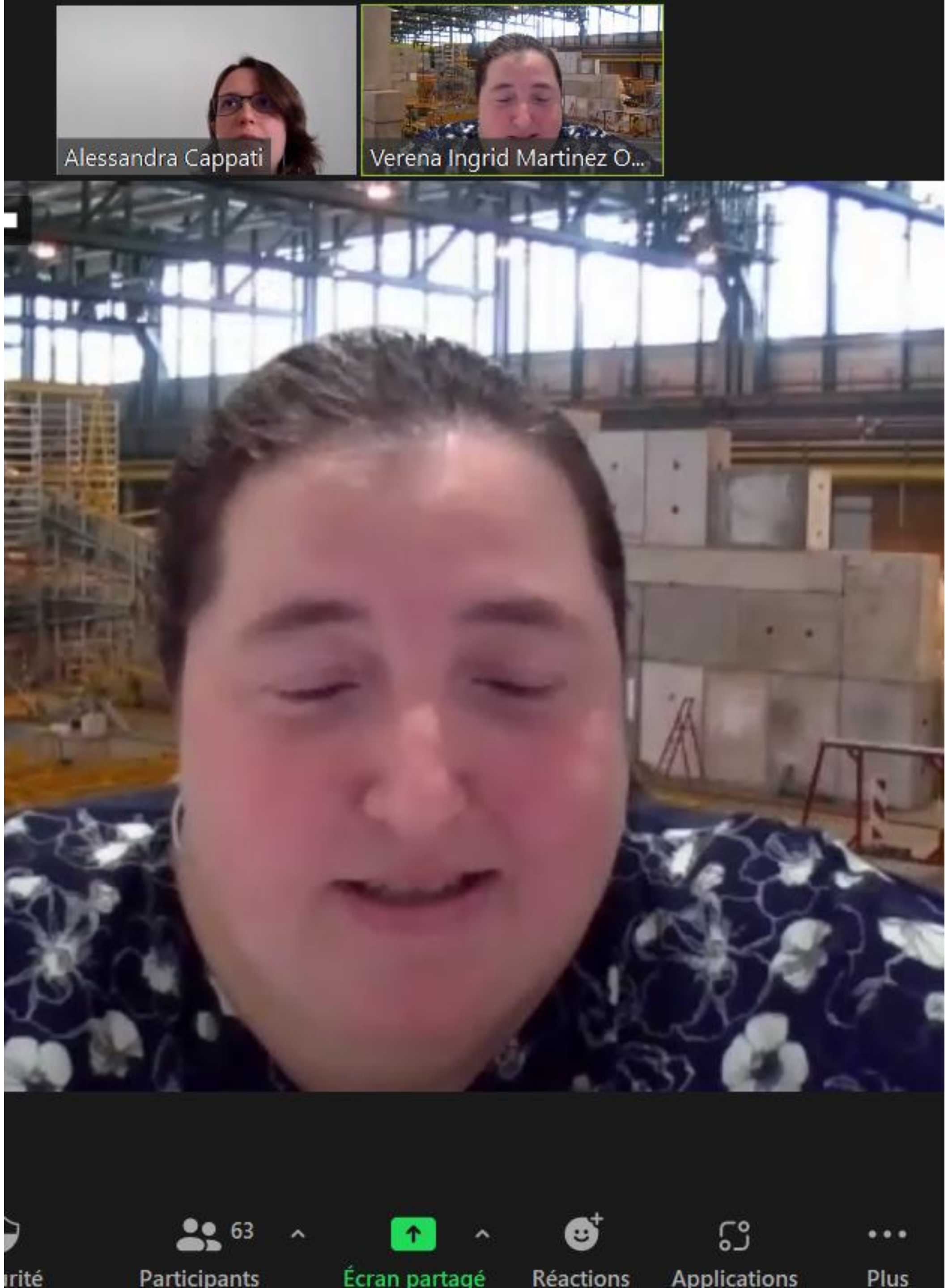
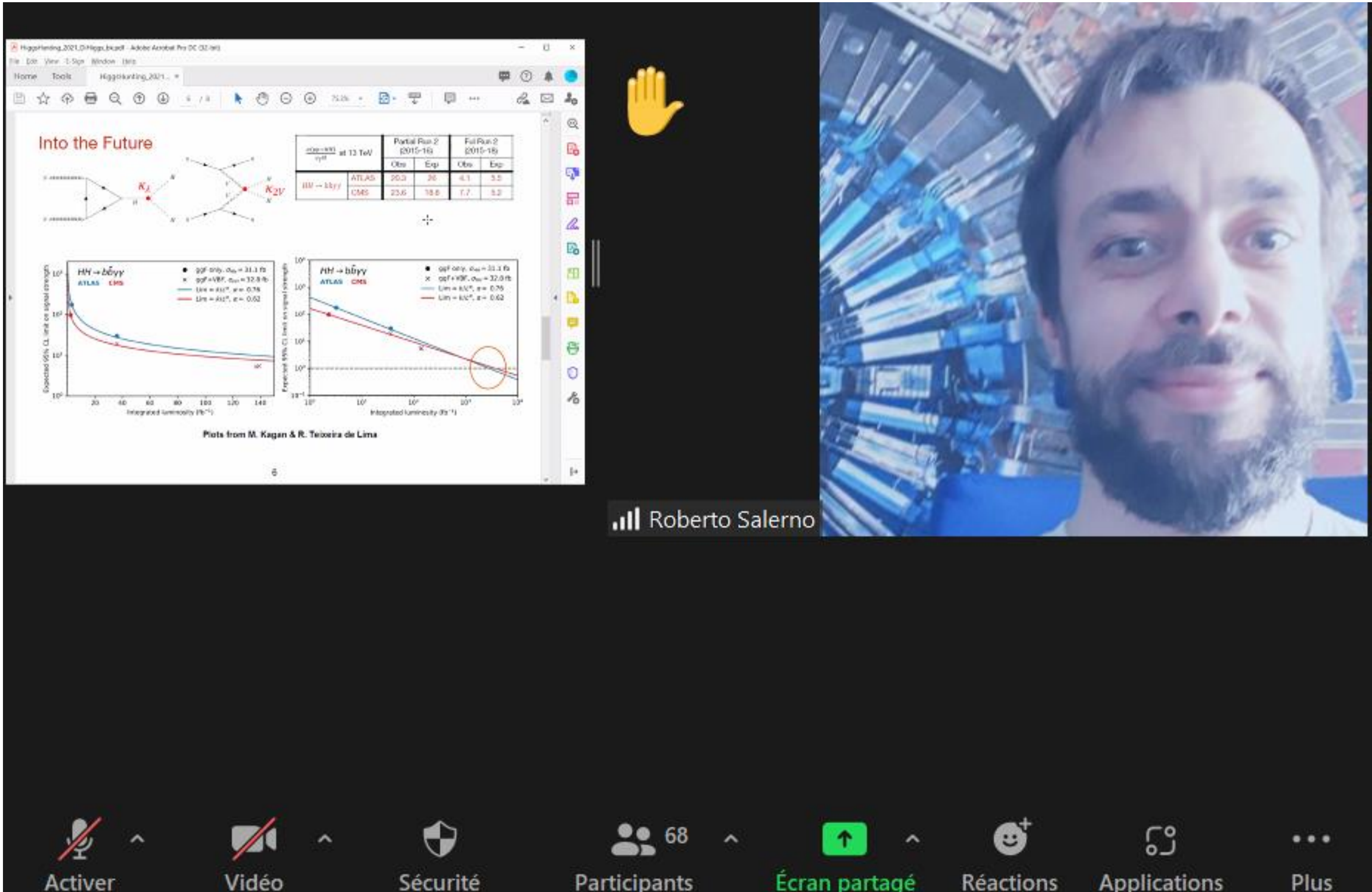
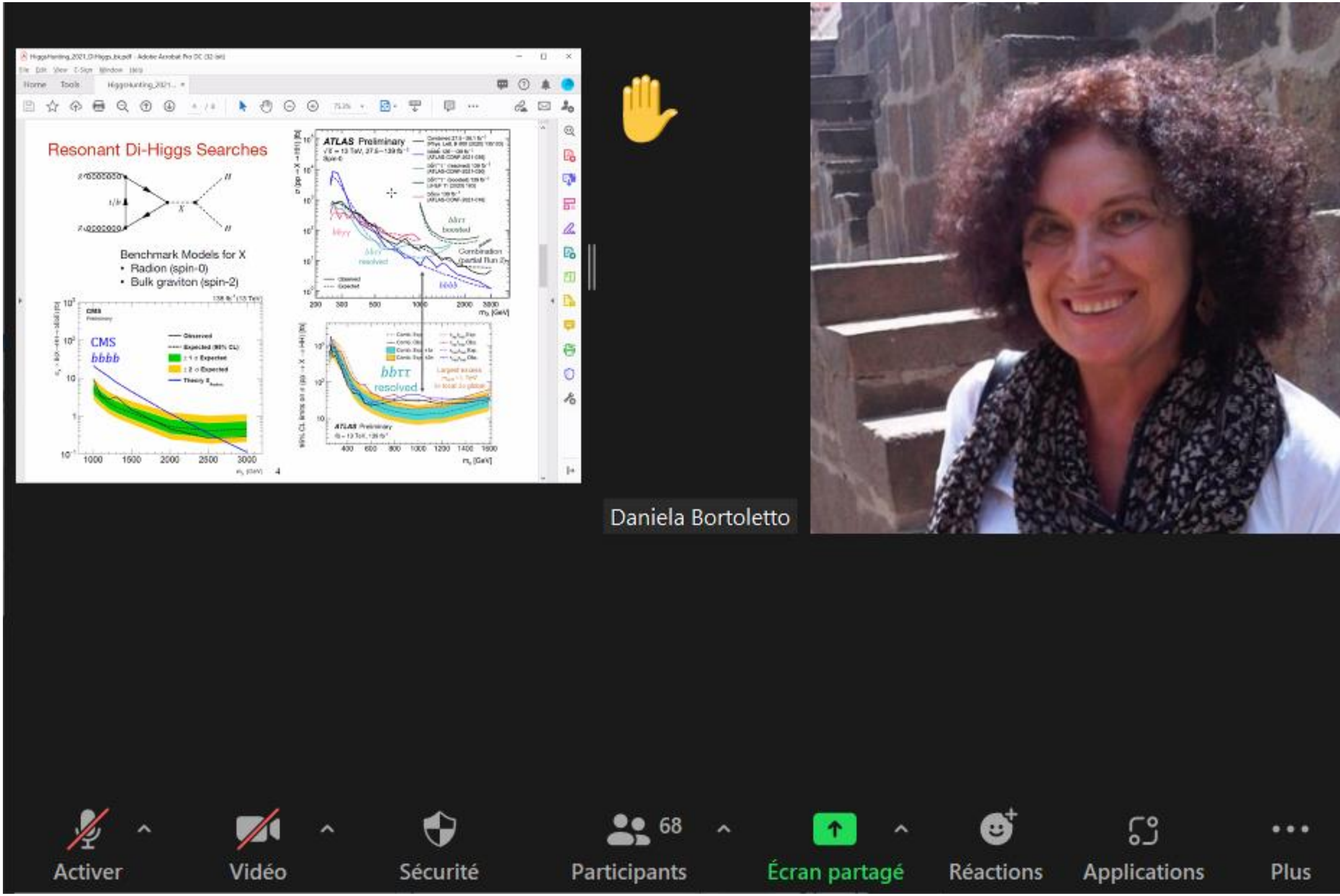
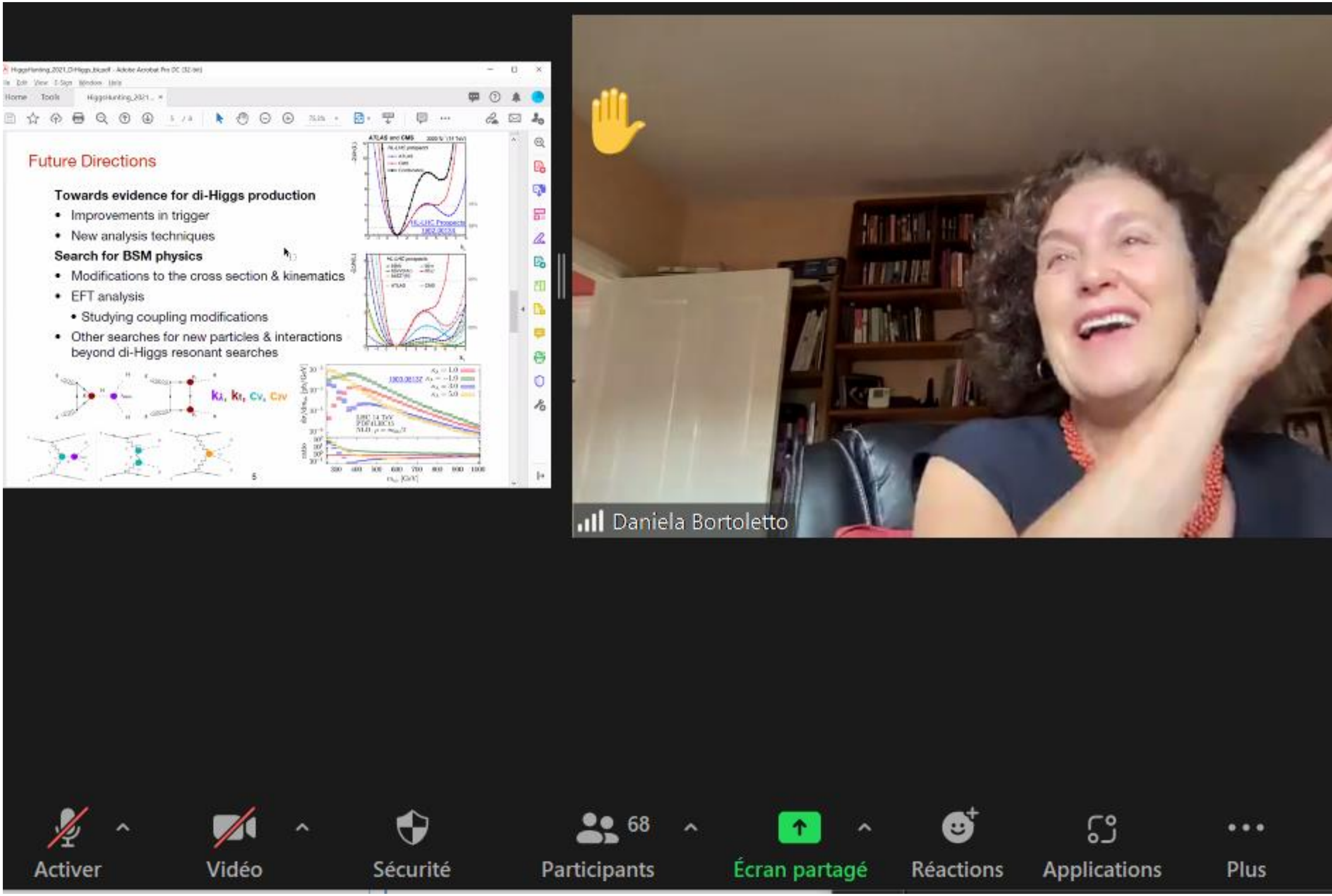
ggHH
With full Run2, possible to target also vector boson fusion production mode (1.72 fb)
→ sensitive to VVHH coupling
VBFHH
A.Cappati (LLR)
Higgs Hunting 2021
2
Alessandra Cappati
Activer
Vidéo
Sécurité
62
Participants
Écran partagé
Réactions
Applications
Plus


Alessandra Cappati
Verena Ingrid Martinez O...
63
Participants
Écran partagé
Réactions
Applications
Plus



Into the Future
Plots from M. Kagan & R. Teixeira de Lima
Roberto Salerno
68
Activer
Vidéo
Sécurité
Participants
Écran partagé
Réactions
Applications
Plus


Resonant Di-Higgs Searches
Benchmark Models for X
• Radion (spin-0)
• Bulk graviton (spin-2)
CMS
bbbb
ATLAS Preliminary
bbττ
resolved
Daniela Bortoletto
68
Activer
Vidéo
Sécurité
Participants
Écran partagé
Réactions
Applications
Plus


Future Directions
Towards evidence for di-Higgs production
• Improvements in trigger
• New analysis techniques
Search for BSM physics
• Modifications to the cross section & kinematics
• EFT analysis
• Studying coupling modifications
• Other searches for new particles & interactions beyond di-Higgs resonant searches
kλ, kt, cV, c2V
5
Daniela Bortoletto
Activer
Vidéo
Sécurité
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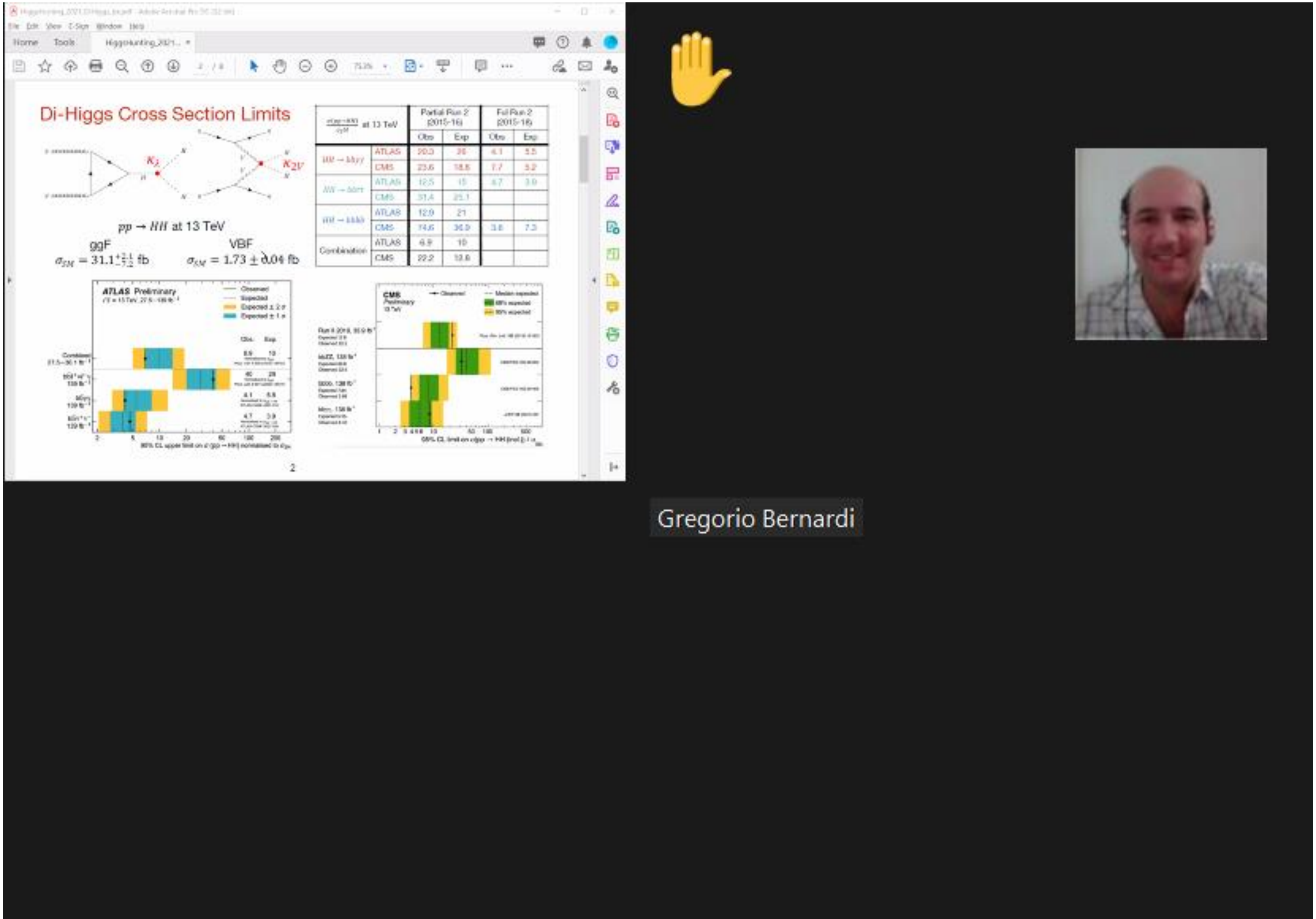
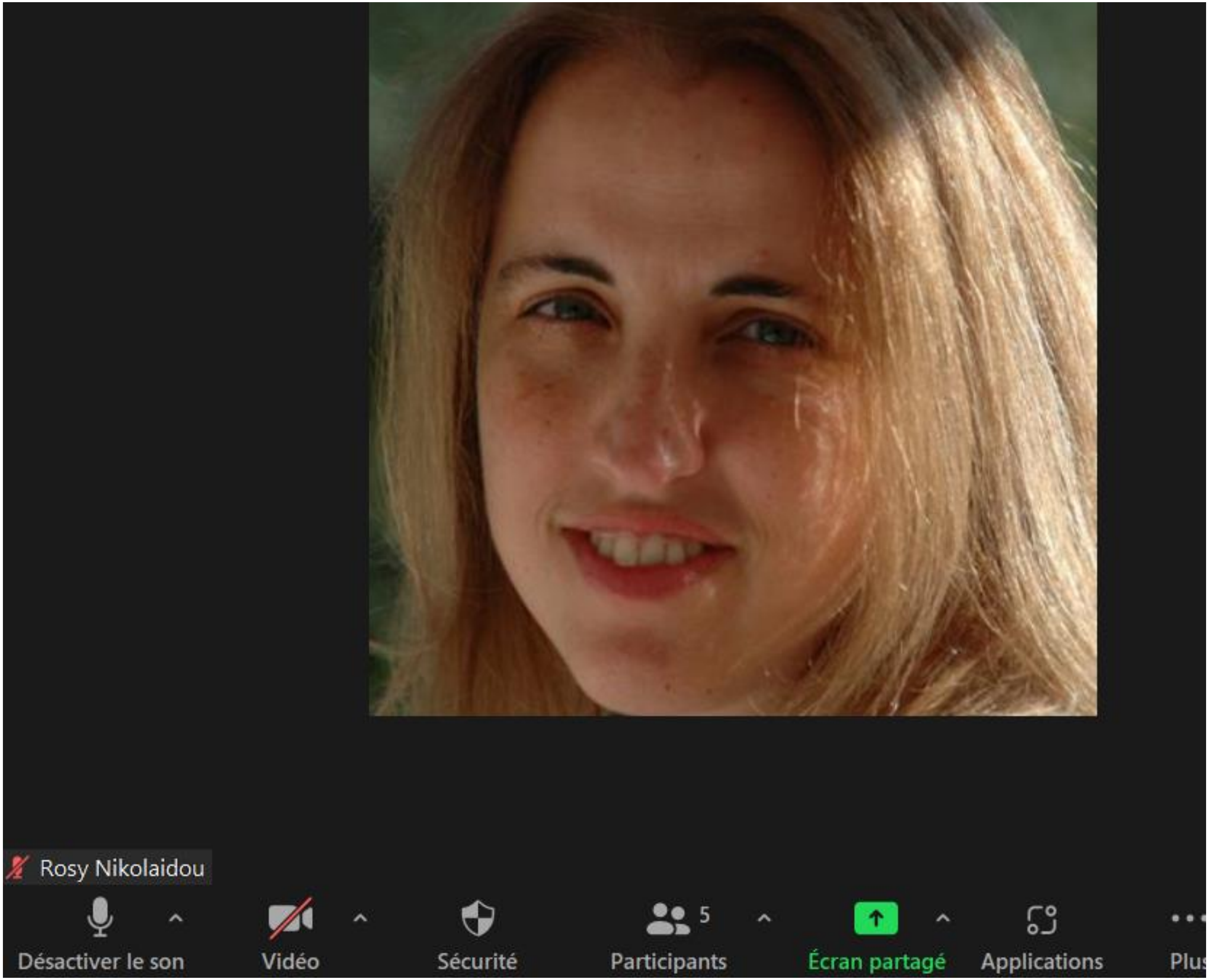
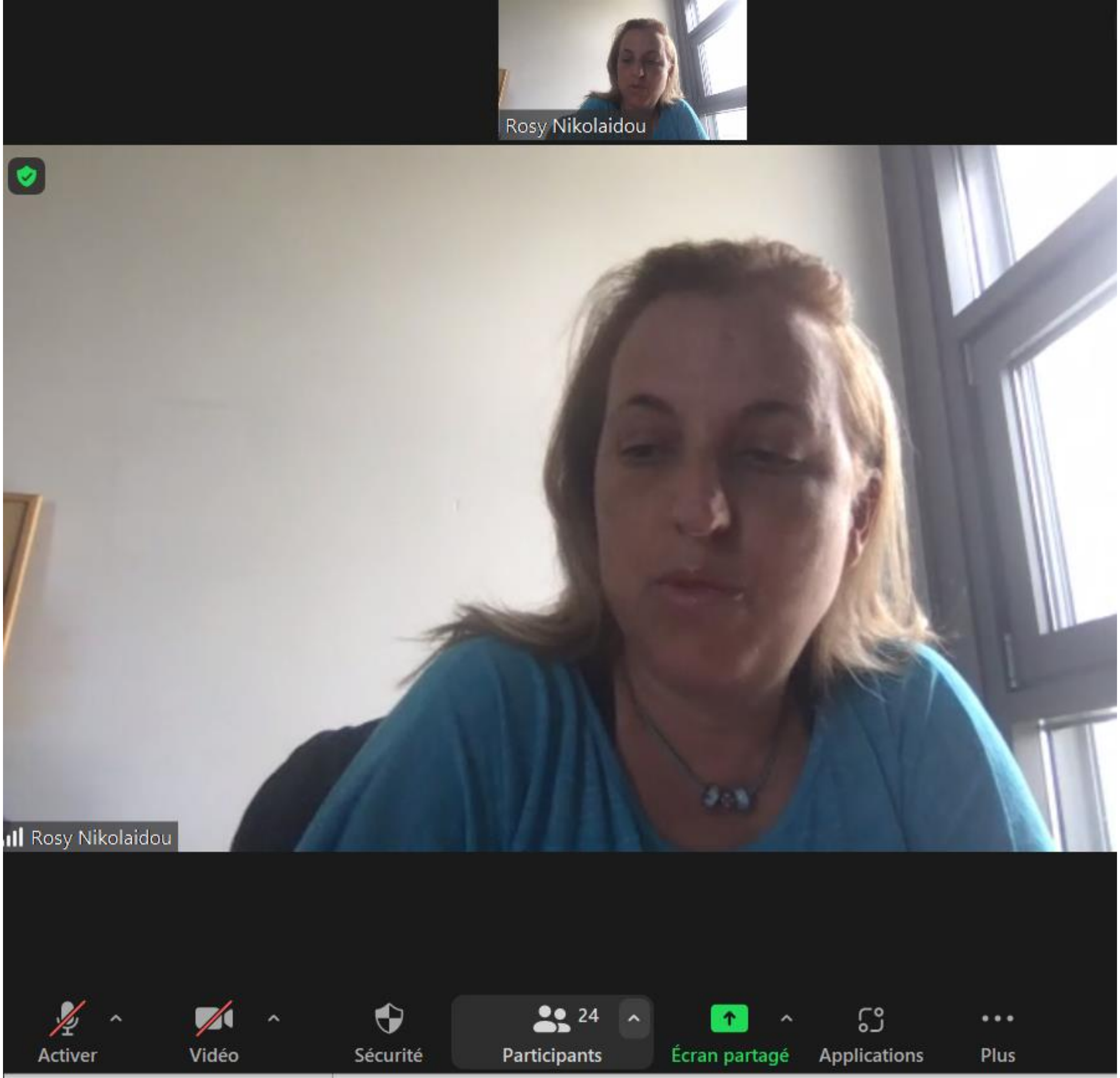
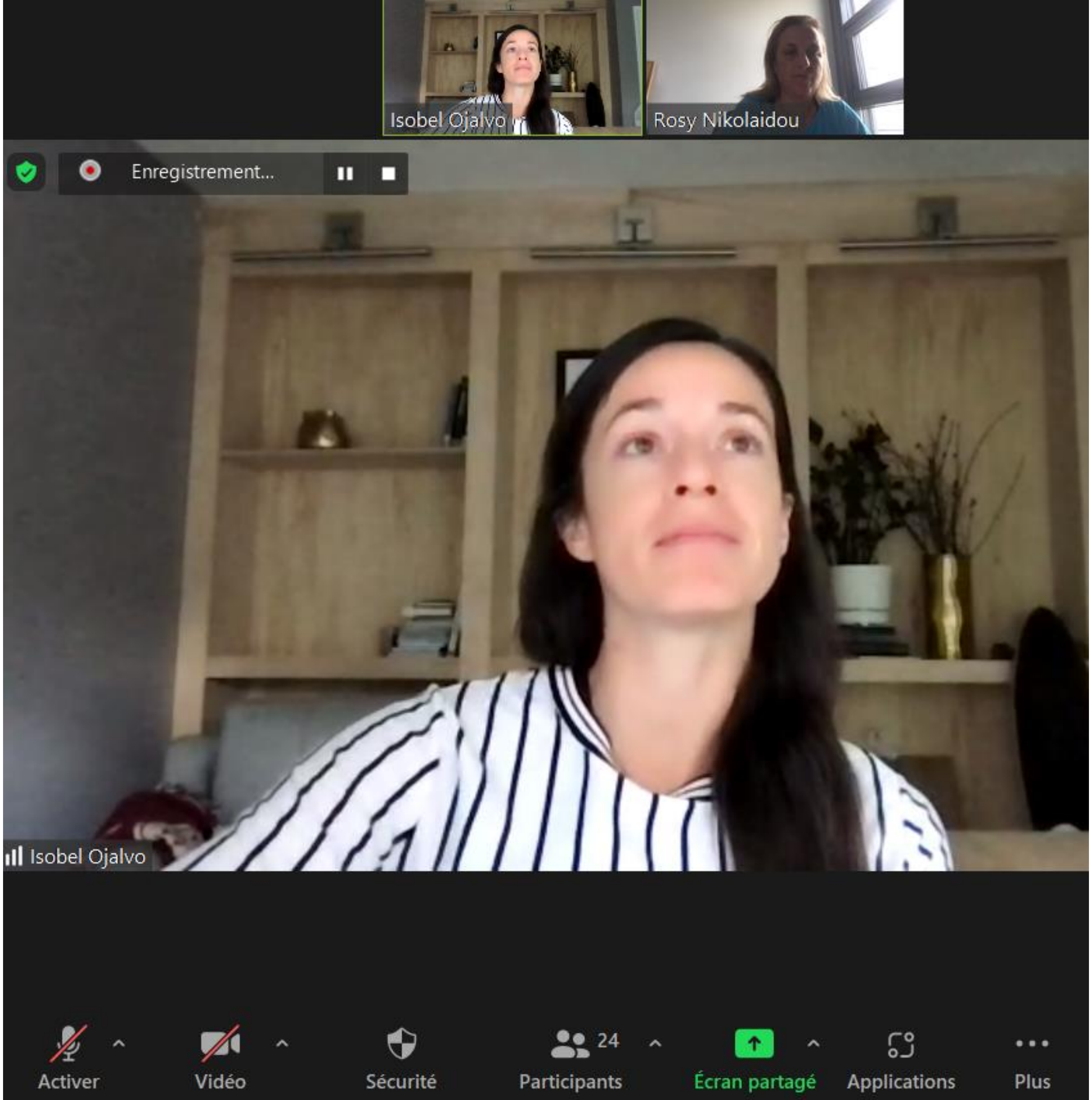
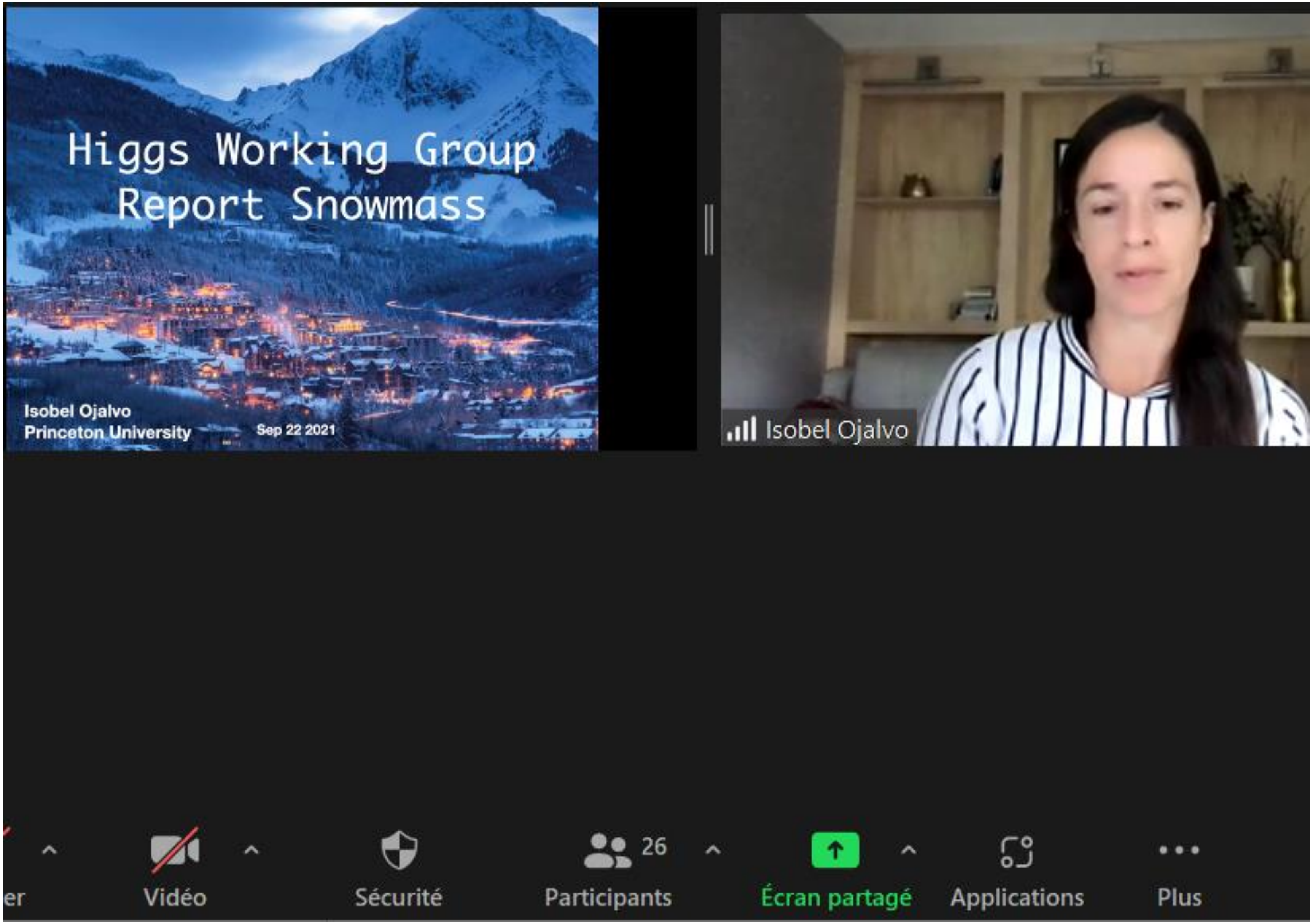
Participants
Écran partagé
Réactions
Applications
Plus


Di-Higgs Cross Section Limits
$pp \to HH$ at 13 TeV
ggF
$\sigma_{SM} = 31.1^{+2.1}_{-7.2}$ fb
VBF
$\sigma_{SM} = 1.73 \pm 0.04$ fb
at 13 TeV
Partial Run 2 (2015-16)
Full Run 2 (2015-18)
Obs
Exp
ATLAS
CMS
Combination
ATLAS Preliminary
CMS Preliminary
2
Gregorio Bernardi


Rosy Nikolaidou
Désactiver le son
Vidéo
Sécurité
5
Participants
Écran partagé
Applications
Plus


Rosy Nikolaidou
Rosy Nikolaidou
Activer
Vidéo
Sécurité
24
Participants
Écran partagé
Applications
Plus


Isobel Ojalvo
Rosy Nikolaidou
Enregistrement...
Isobel Ojalvo
Activer
Vidéo
Sécurité
24
Participants
Écran partagé
Applications
Plus



Higgs Working Group
Report Snowmass
Isobel Ojalvo
Princeton University
Sep 22 2021
Isobel Ojalvo
er
Vidéo
Sécurité
26
Participants
Écran partagé
Applications
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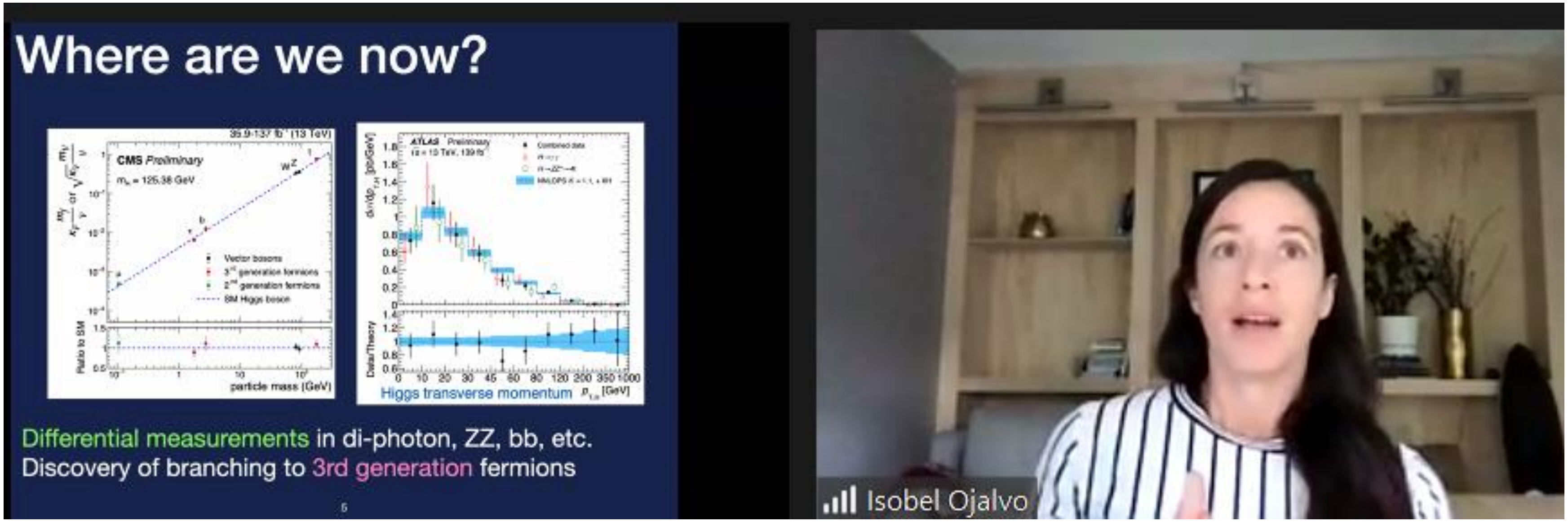
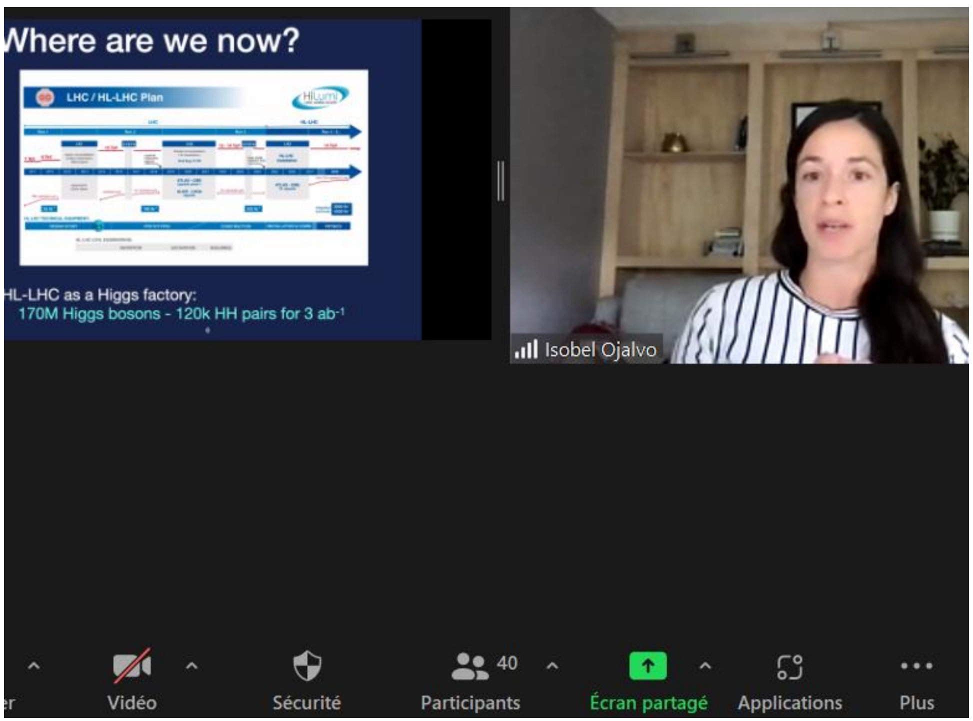

Where are we now?
CMS Preliminary
particle mass (GeV)
Higgs transverse momentum
Differential measurements in di-photon, ZZ, bb, etc.
Discovery of branching to 3rd generation fermions
Isobel Ojalvo


Vhere are we now?
LHC / HL-LHC Plan
HL-LHC as a Higgs factory:
170M Higgs bosons - 120k HH pairs for 3 ab-1
Isobel Ojalvo
Vidéo
Sécurité
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Participants
Écran partagé
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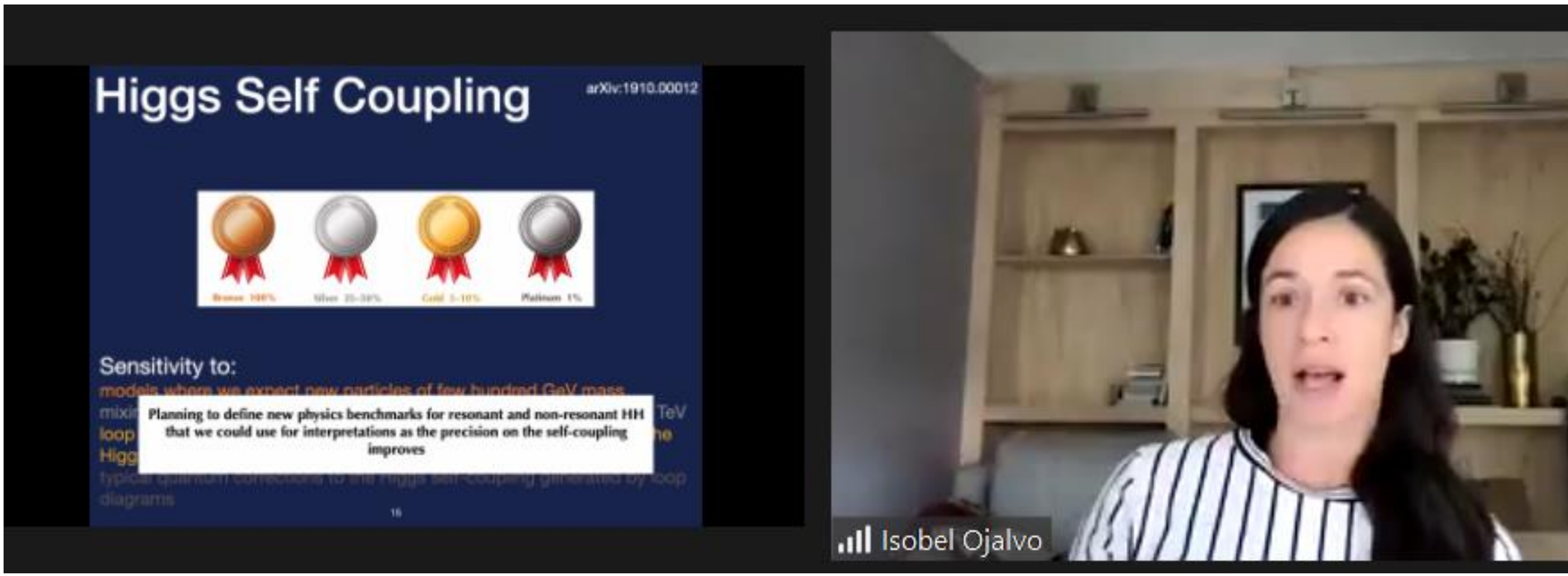
Plus


Isobel Ojalvo


Higgs Self Coupling
arXiv:1910.00012
Platinum 1%
Sensitivity to:
Planning to define new physics benchmarks for resonant and non-resonant HH that we could use for interpretations as the precision on the self-coupling improves
Isobel Ojalvo


Higgs Couplings: Muon Collider
Renewed (or continued) Interest in Muon Colliders
High energy muon colliders actually collider a mix of EWK states
Combination with other machines to improve precision measurements
2005.10289
2103.14043
and more
Isobel Ojalvo
ctiver
Vidéo
Sécurité
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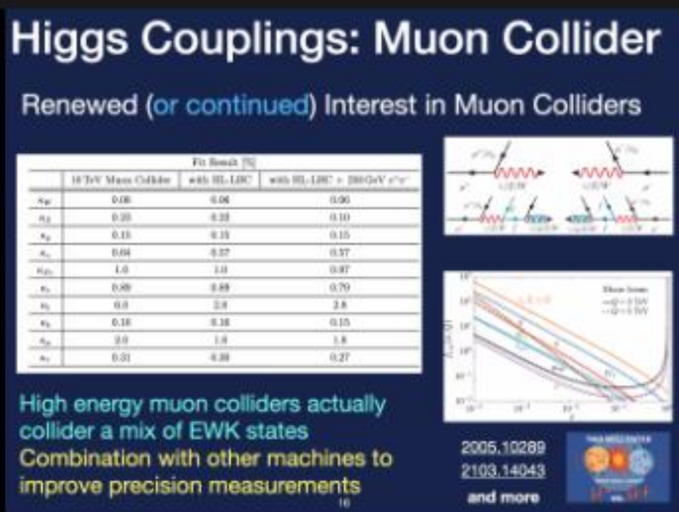
Participants
Écran partagé
Applications
Plus


Higgs Couplings: Muon Collider
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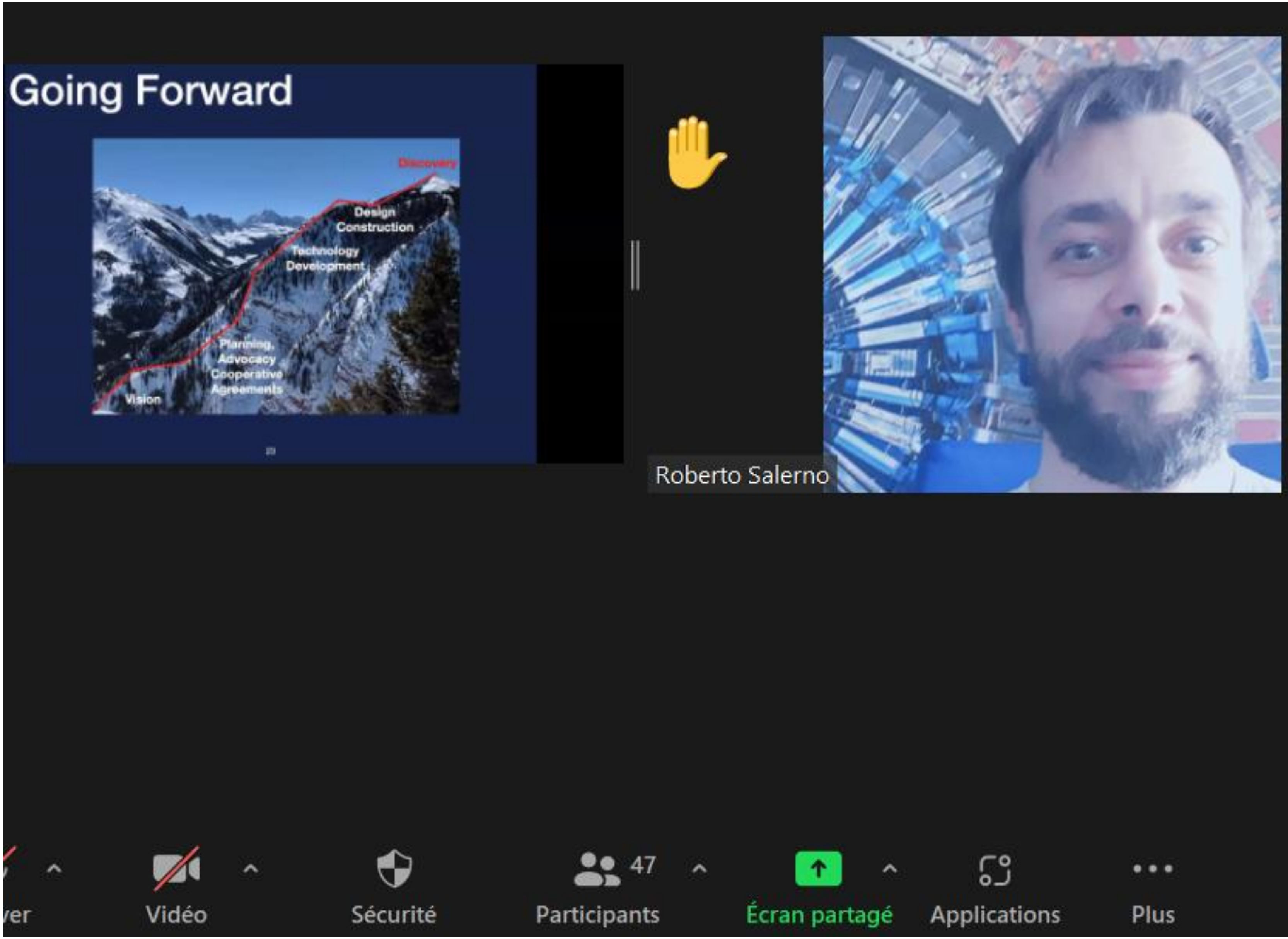
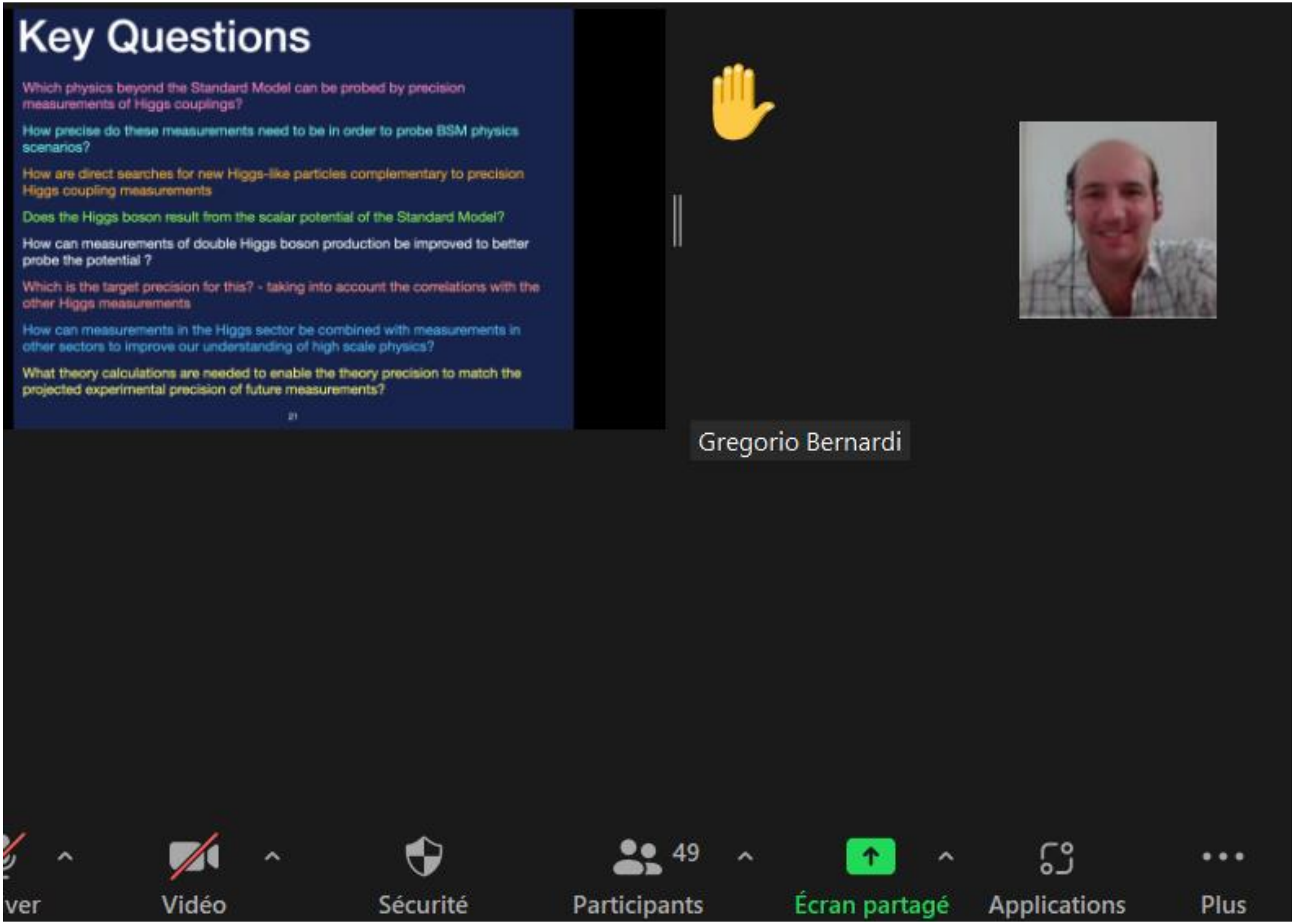
2005.10289
2103.14043
and more


Isobel Ojalvo


Going Forward
Discovery
Design
Construction
Technology
Development
Planning,
Advocacy
Cooperative
Agreements
Vision
Roberto Salerno
Vidéo
Sécurité
47
Participants
Écran partagé
Applications
Plus


Key Questions
Which physics beyond the Standard Model can be probed by precision measurements of Higgs couplings?
How precise do these measurements need to be in order to probe BSM physics scenarios?
How are direct searches for new Higgs-like particles complementary to precision Higgs coupling measurements
Does the Higgs boson result from the scalar potential of the Standard Model?
How can measurements of double Higgs boson production be improved to better probe the potential ?
Which is the target precision for this? - taking into account the correlations with the other Higgs measurements
How can measurements in the Higgs sector be combined with measurements in other sectors to improve our understanding of high scale physics?
What theory calculations are needed to enable the theory precision to match the projected experimental precision of future measurements?
21
Gregorio Bernardi
ver
Vidéo
Sécurité
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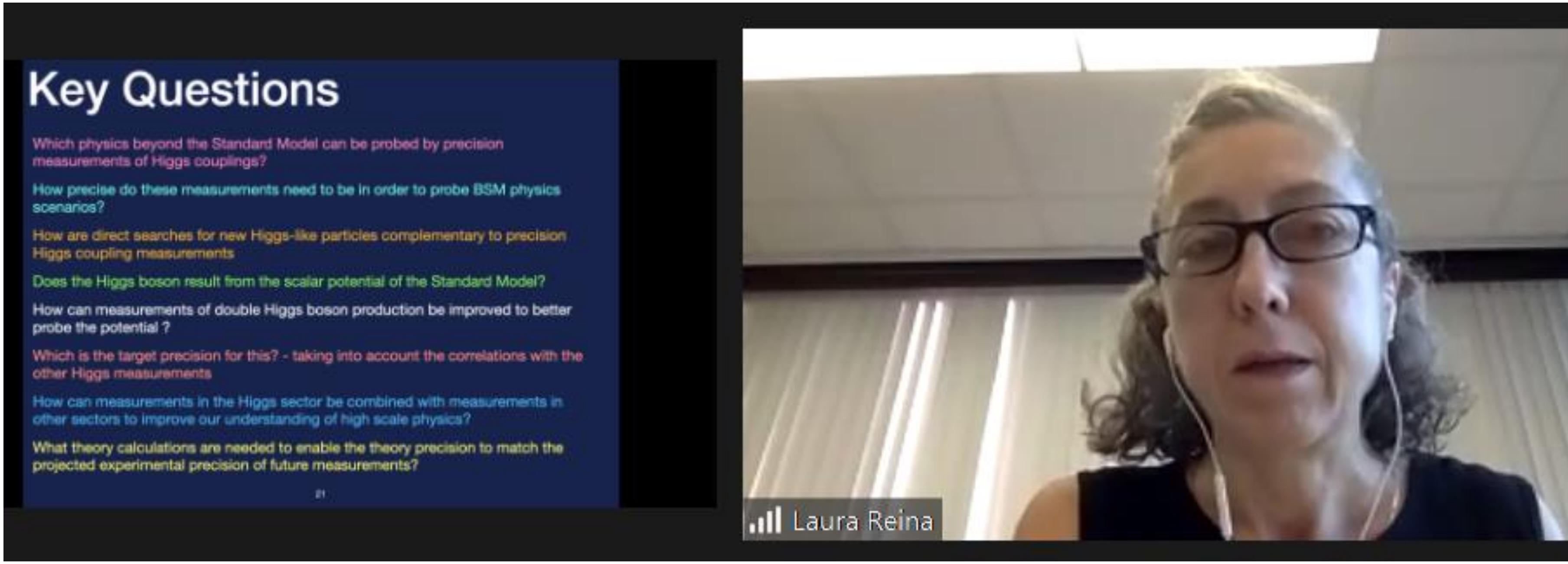
Participants
Écran partagé
Applications
Plus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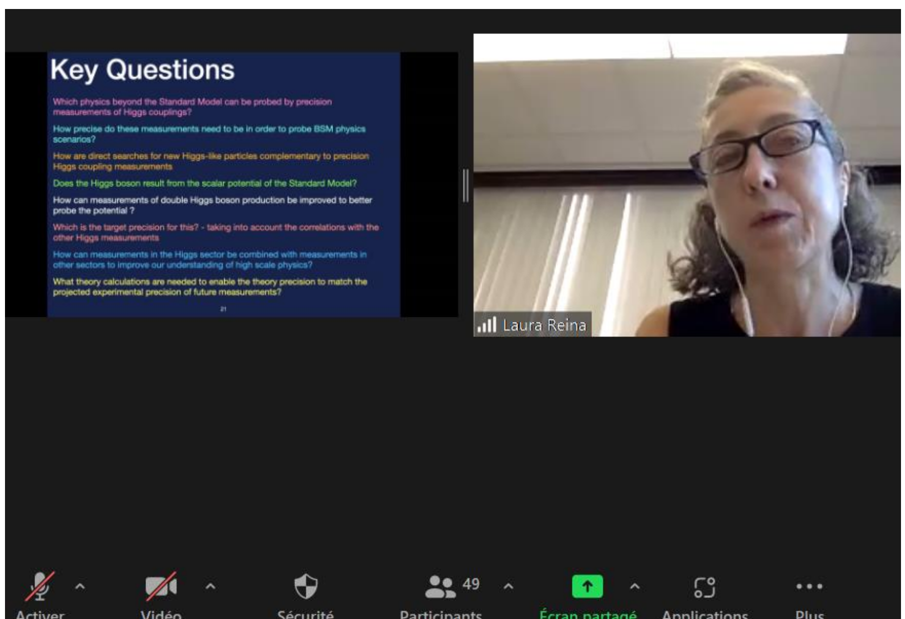
21
Laura Reina


Key Questions
Laura Reina
Activer
Vidéo
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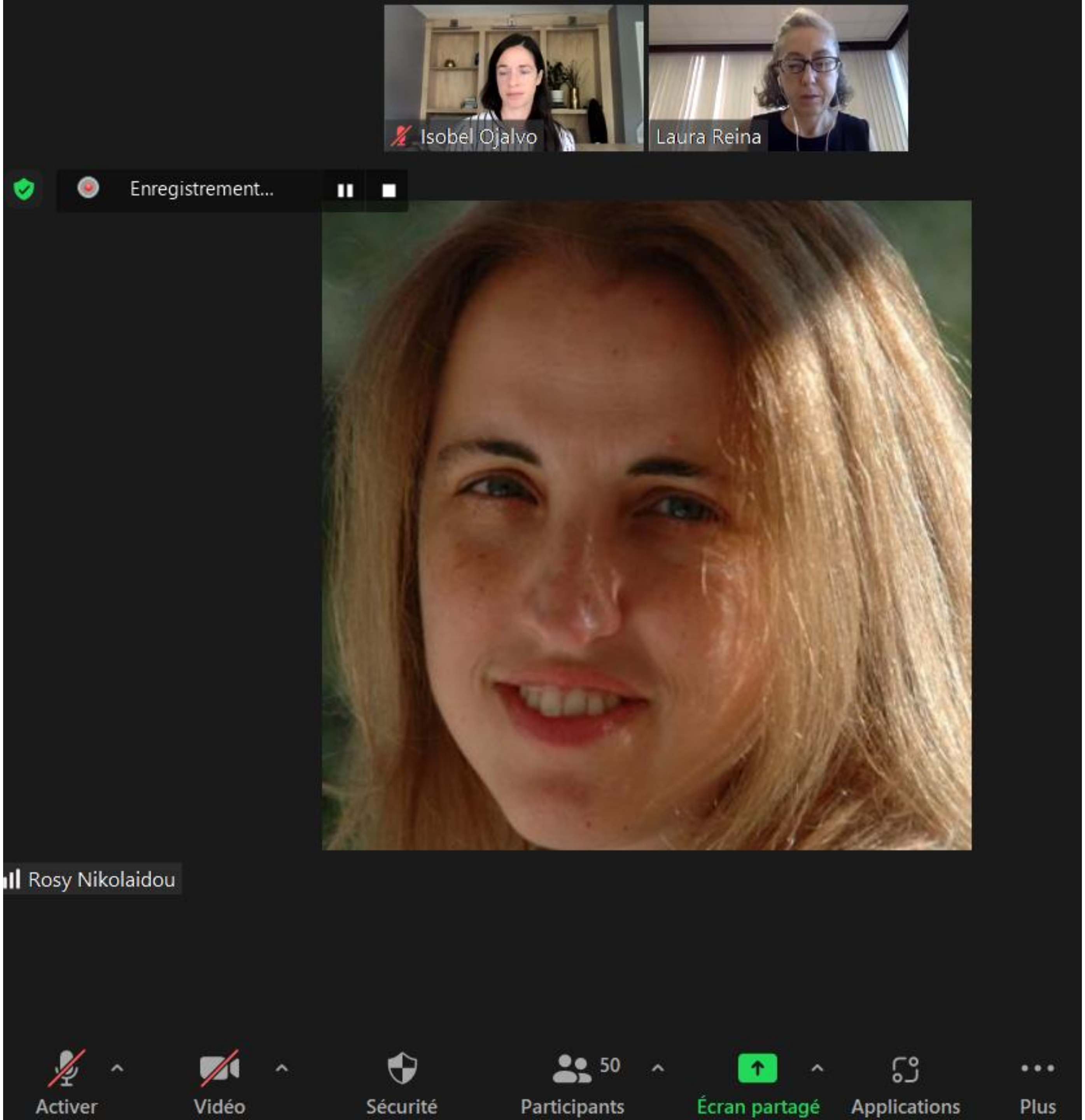
Isobel Ojalvo
Laura Reina
Enregistrement...
Rosy Nikolaidou
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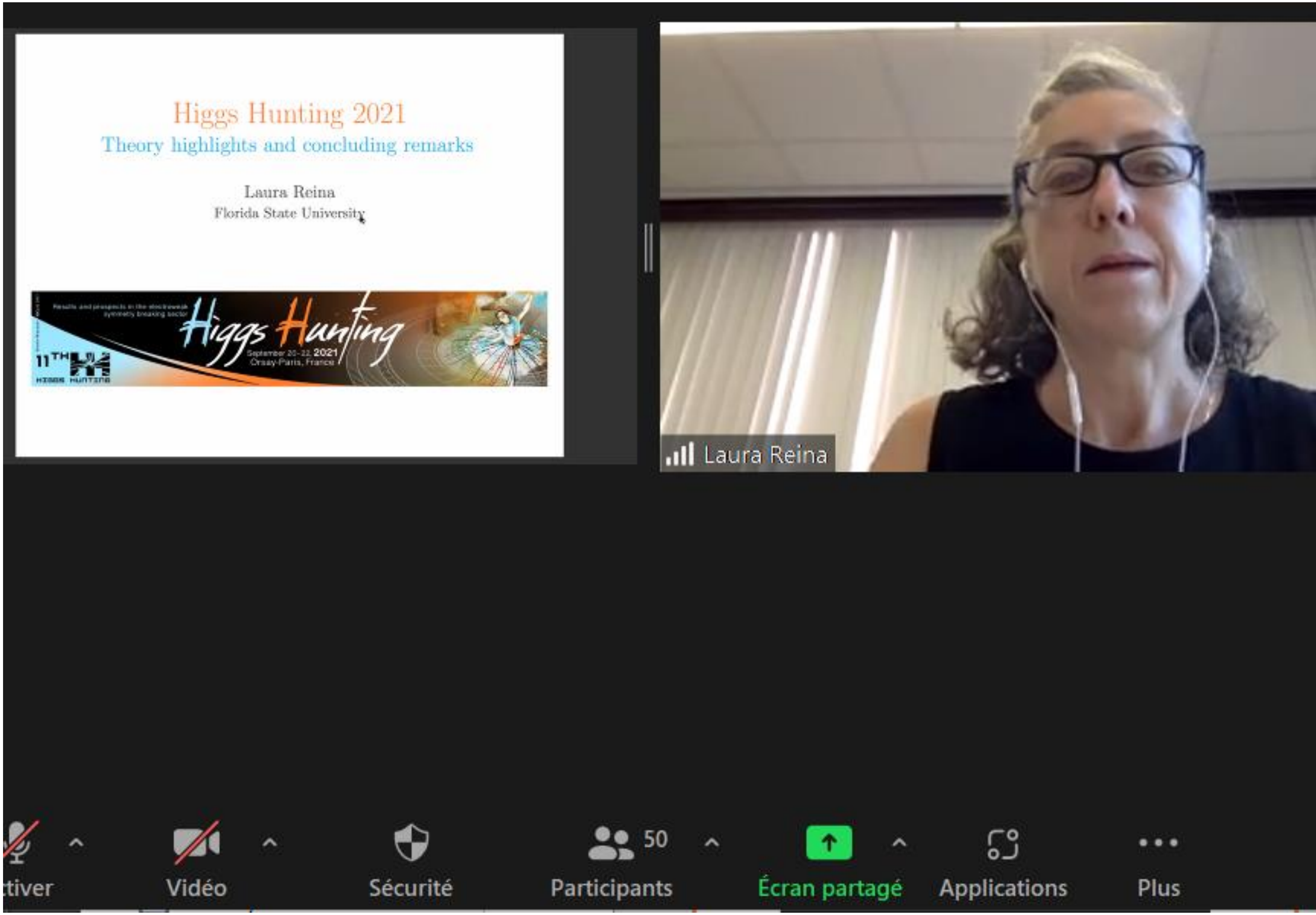
Higgs Hunting 2021
Theory highlights and concluding remarks
Laura Reina
Florida State University
Higgs Hunting
September 20-22, 2021
Orsay-Paris, France
11TH
Laura Reina
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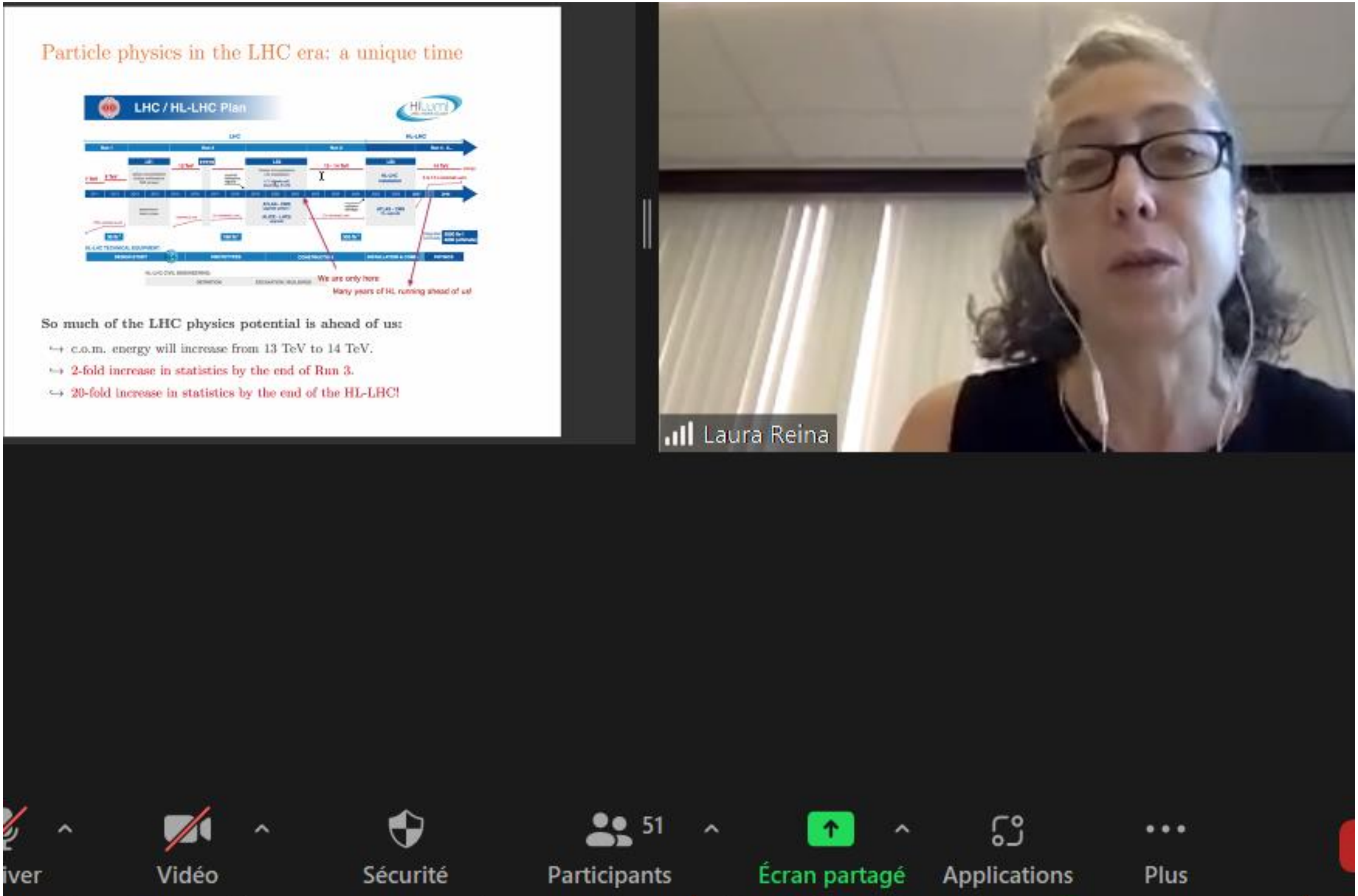
Particle physics in the LHC era: a unique time
LHC / HL-LHC Plan
We are only here
Many years of HL running ahead of us!
So much of the LHC physics potential is ahead of us:
↪ c.o.m. energy will increase from 13 TeV to 14 TeV.
↪ 2-fold increase in statistics by the end of Run 3.
↪ 20-fold increase in statistics by the end of the HL-LHC!
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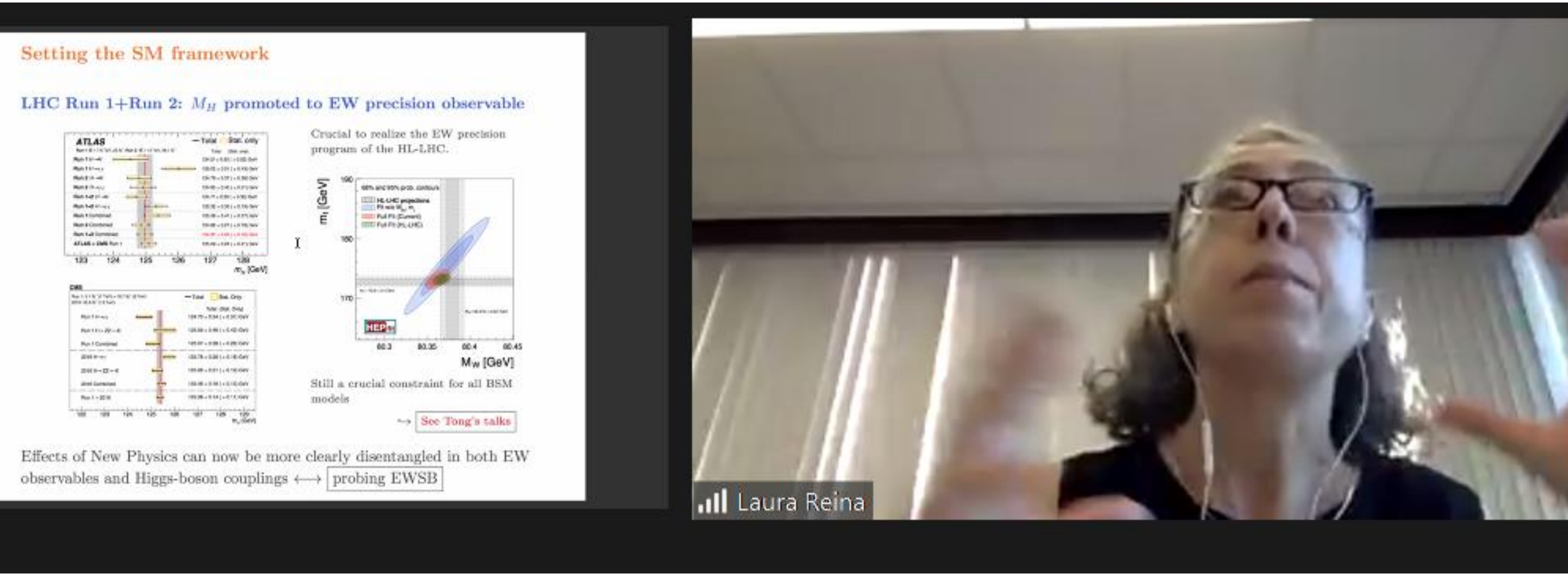
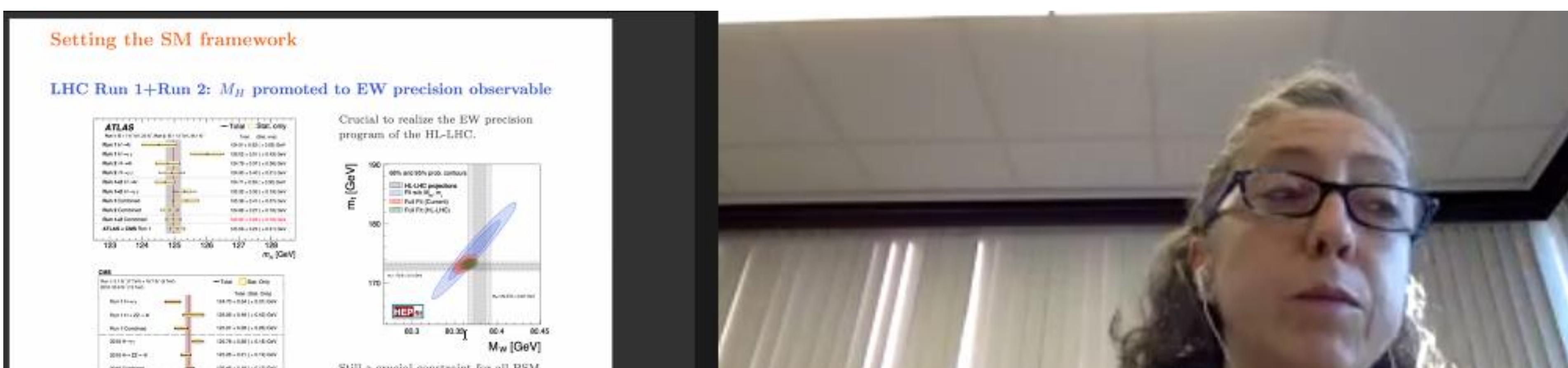

Setting the SM framework
LHC Run 1+Run 2: M_H promoted to EW precision observable
Crucial to realize the EW precision program of the HL-LHC.
ATLAS
CMS
m_t [GeV]
M_W [GeV]
Still a crucial constraint for all BSM models
→ See Tong's talks
Effects of New Physics can now be more clearly disentangled in both EW observables and Higgs-boson couplings ⟷ probing EWSB
Laura Reina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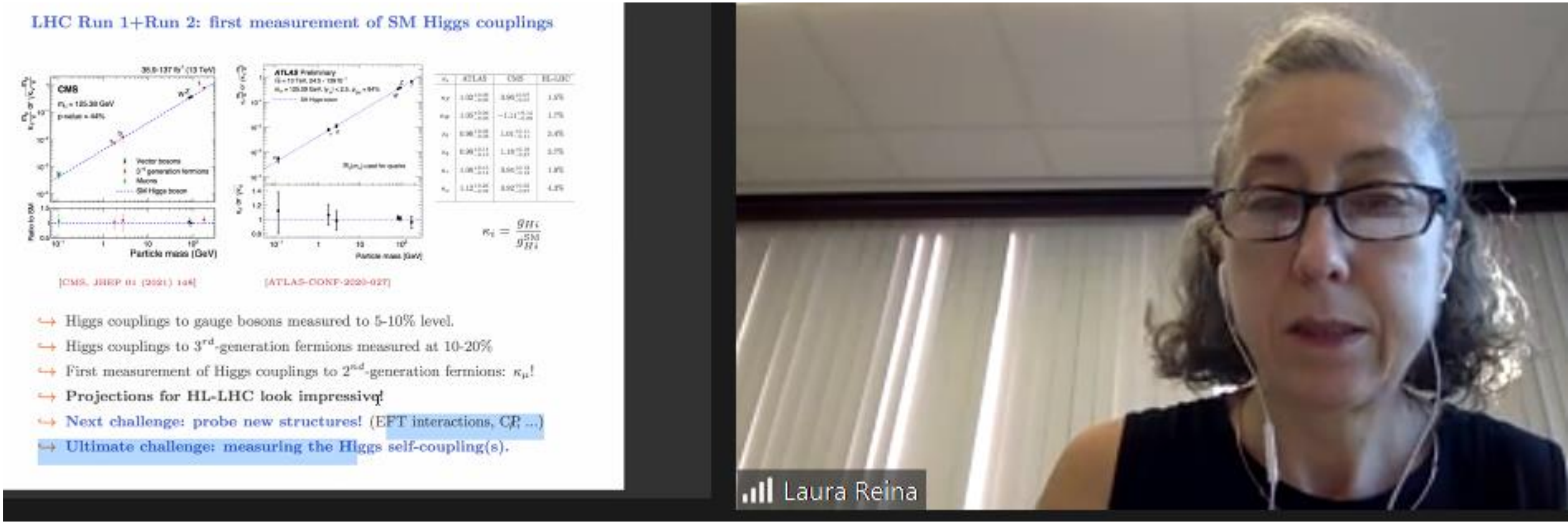
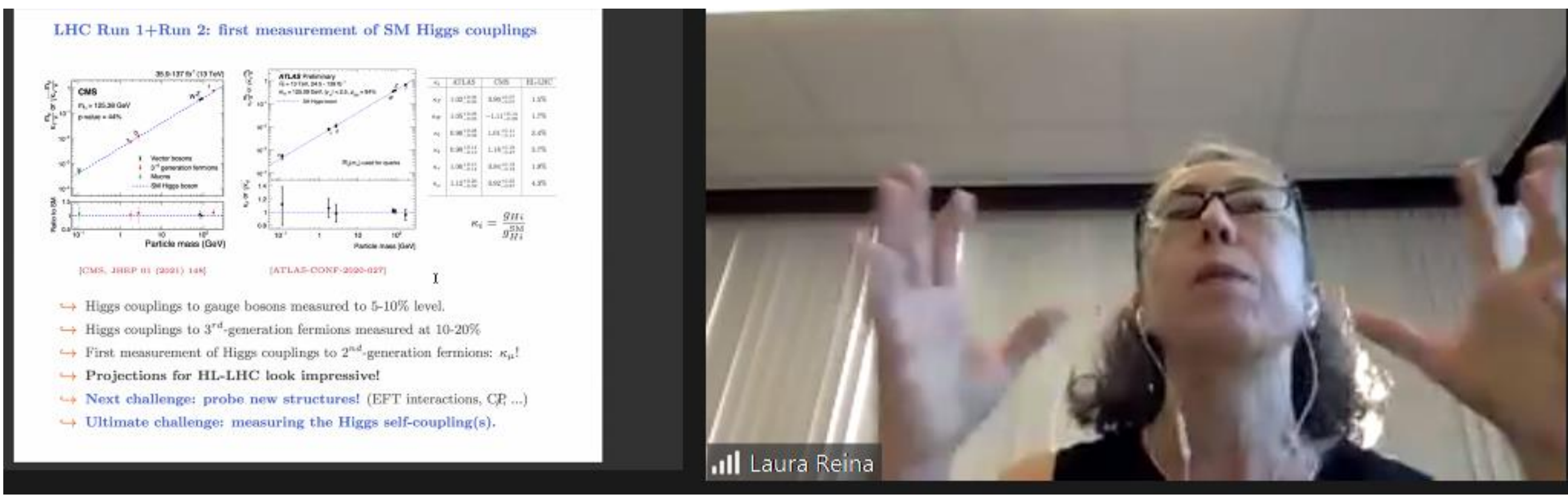

LHC Run 1+Run 2: first measurement of SM Higgs couplings
CMS
Vector bosons
3rd generation fermions
Muons
SM Higgs boson
Particle mass [GeV]
ATLAS Preliminary
Particle mass [GeV]
ATLAS
CMS
HL-LHC
$\kappa_i = \frac{g_{Hi}}{g_{Hi}^{SM}}$
[CMS, JHEP 01 (2021) 148]
[ATLAS-CONF-2020-027]
↪ Higgs couplings to gauge bosons measured to 5-10% level.
↪ Higgs couplings to 3rd-generation fermions measured at 10-20%
↪ First measurement of Higgs couplings to 2nd-generation fermions: κ_μ!
↪ Projections for HL-LHC look impressive!
↪ Next challenge: probe new structures! (EFT interactions, CP, ...)
↪ Ultimate challenge: measuring the Higgs self-coupling(s).
Laura Reina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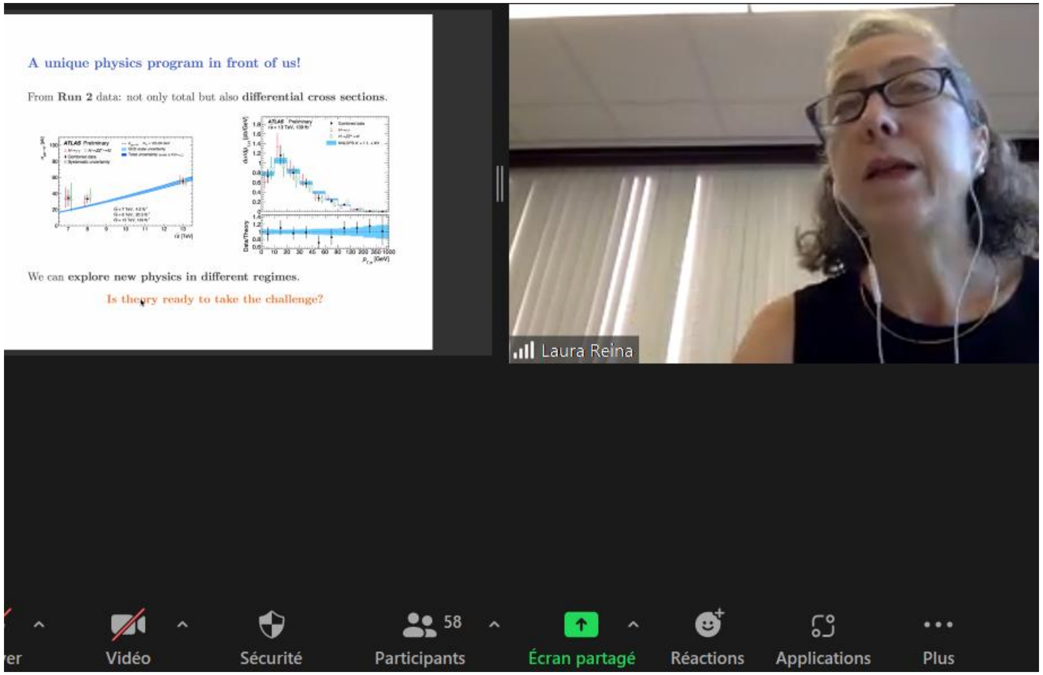
A unique physics program in front of us!
From Run 2 data: not only total but also differential cross sections.
ATLAS Preliminary
We can explore new physics in different regimes.
Is theory ready to take the challenge?
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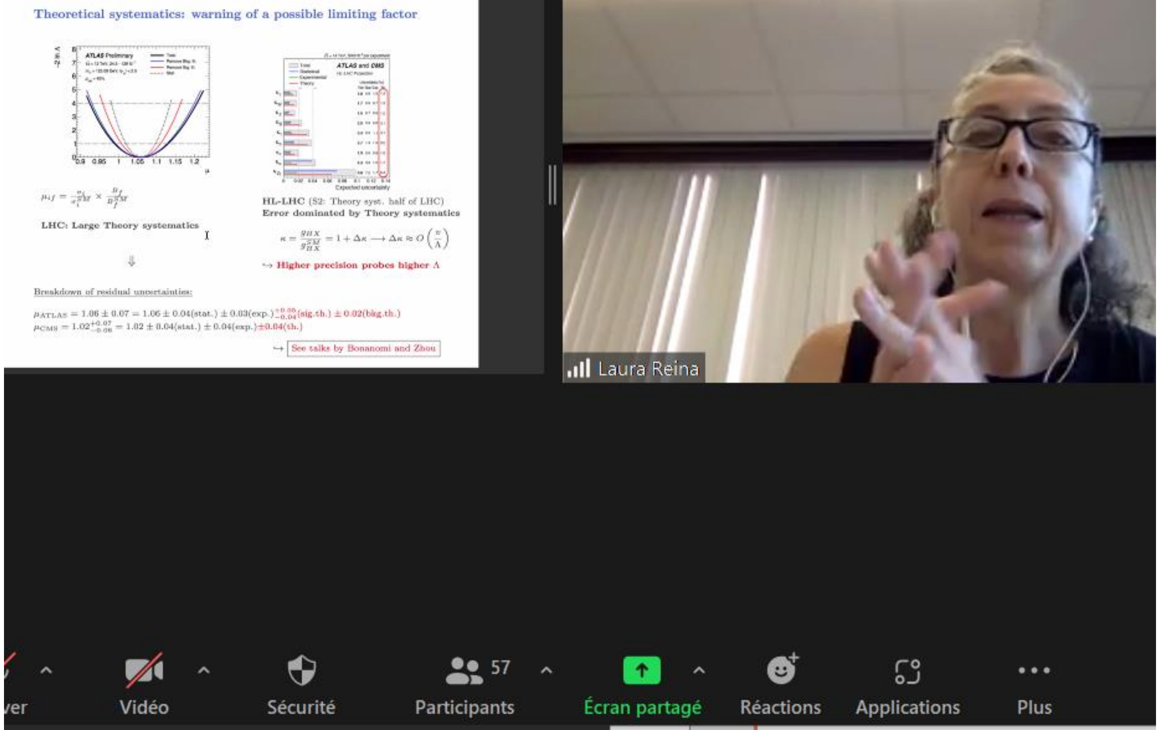
Laura Reina


Laura Reina


Theoretical systematics: warning of a possible limiting factor
LHC: Large Theory systematics
HL-LHC (S2: Theory syst. half of LHC)
Error dominated by Theory systematics
Higher precision probes higher Λ
Breakdown of residual uncertainties:
See talks by Bonanomi and Zhou
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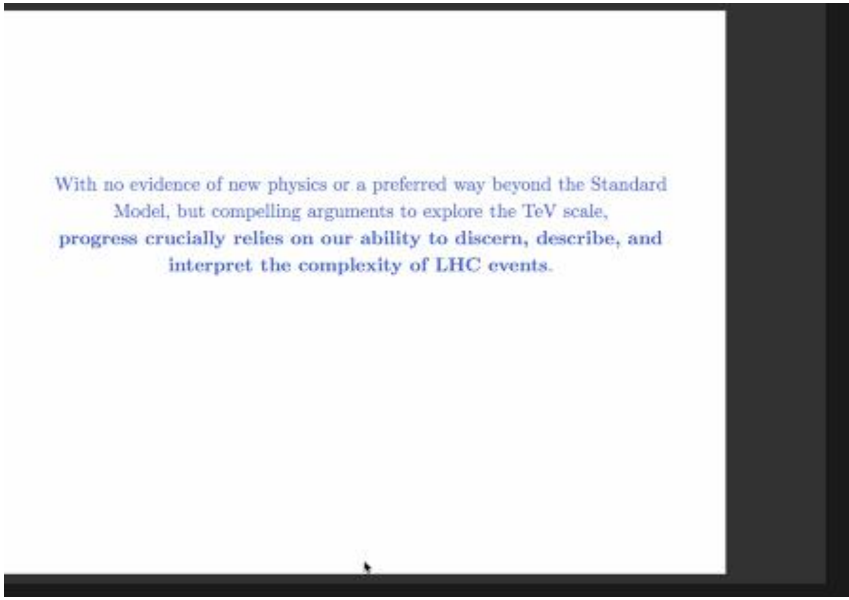
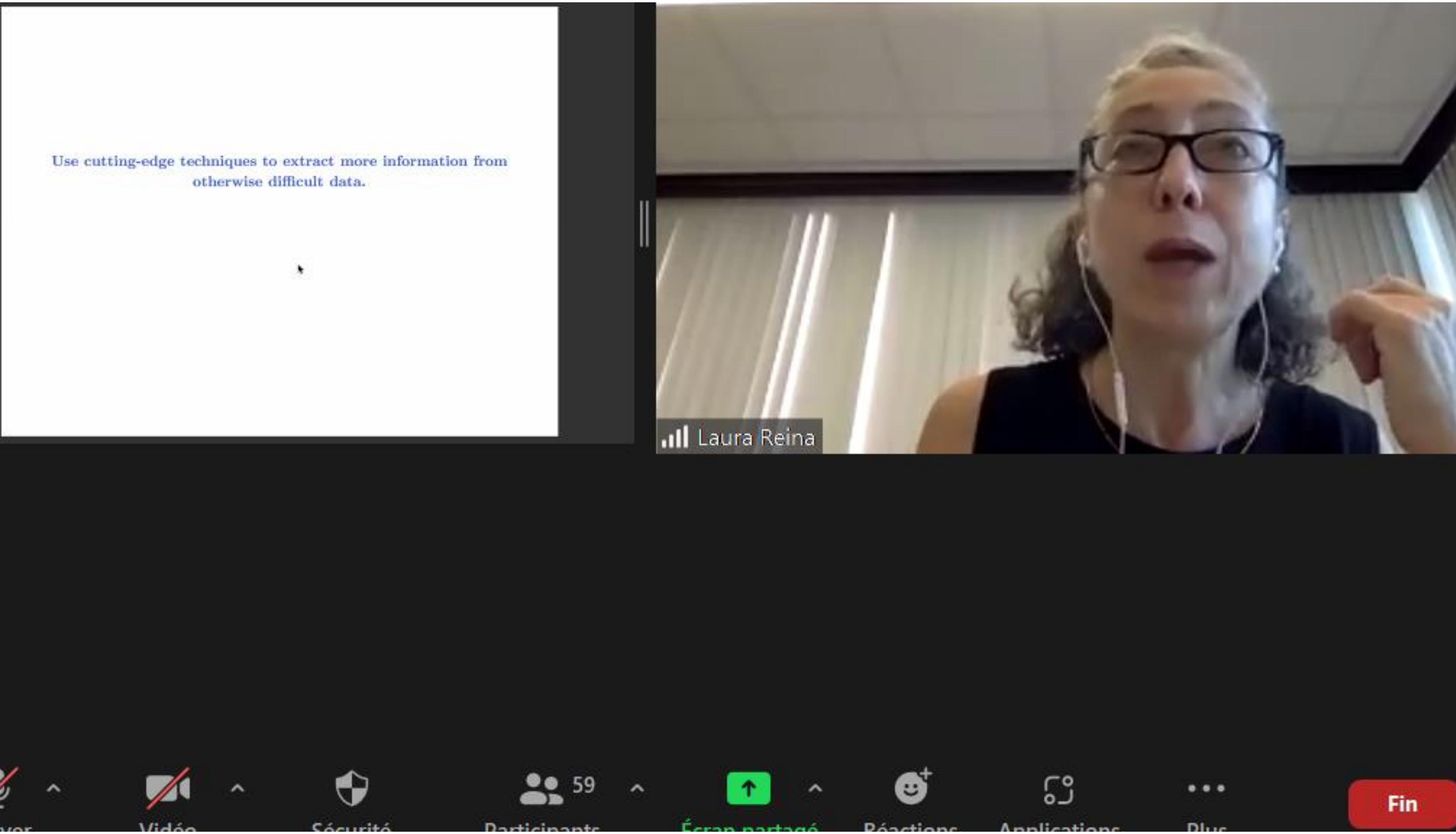

With no evidence of new physics or a preferred way beyond the Standard Model, but compelling arguments to explore the TeV scale,
progress crucially relies on our ability to discern, describe, and interpret the complexity of LHC events.


Laura Reina


Laura Reina


Laura Reina


Use cutting-edge techniques to extract more information from otherwise difficult data.
Laura Reina
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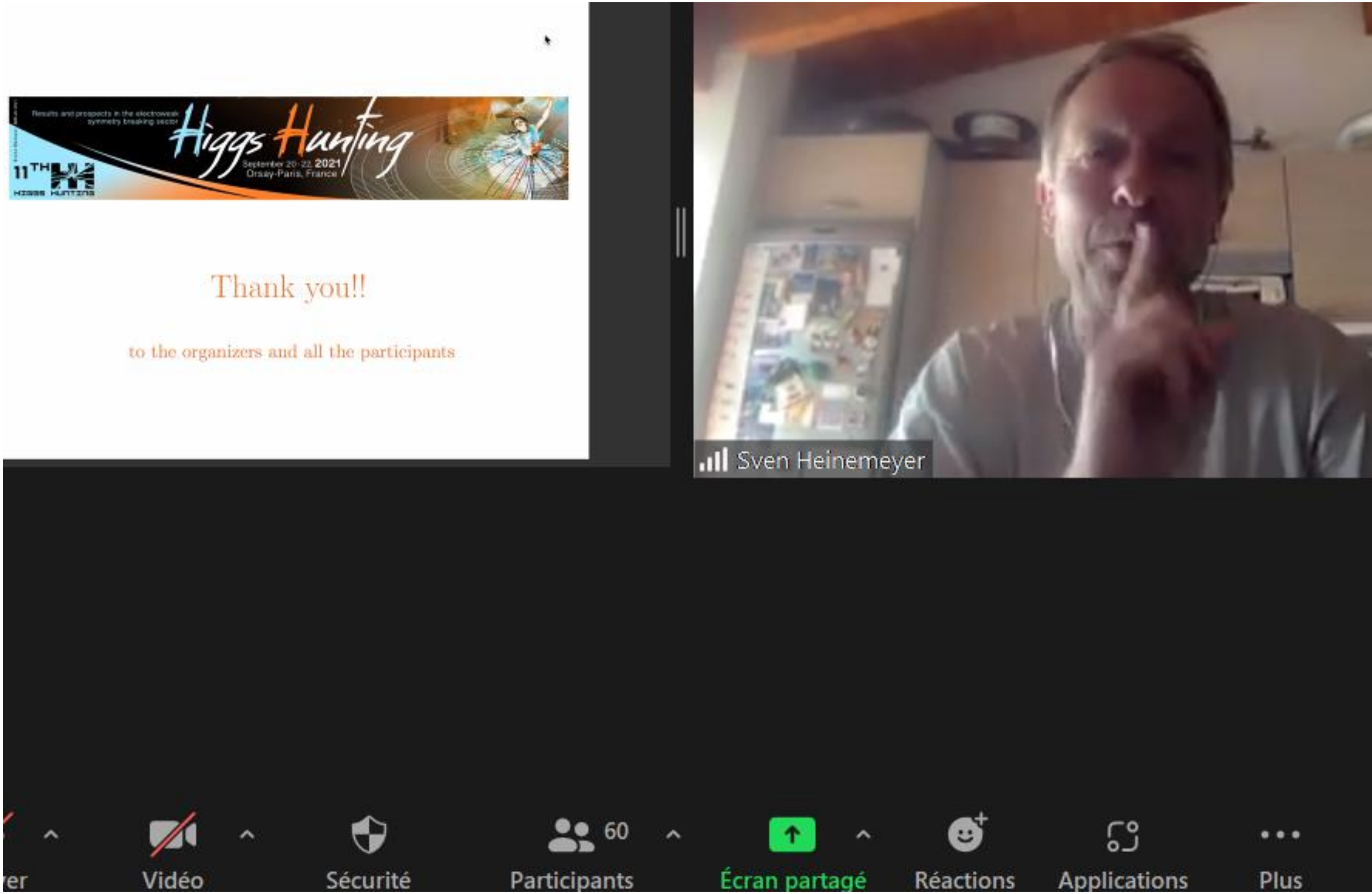
Fin


Results and prospects in the electroweak symmetry breaking sector
Higgs Hunting
September 20-22, 2021
Orsay-Paris, France
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Thank you!!
to the organizers and all the participants
Sven Heinemeyer
Vidéo
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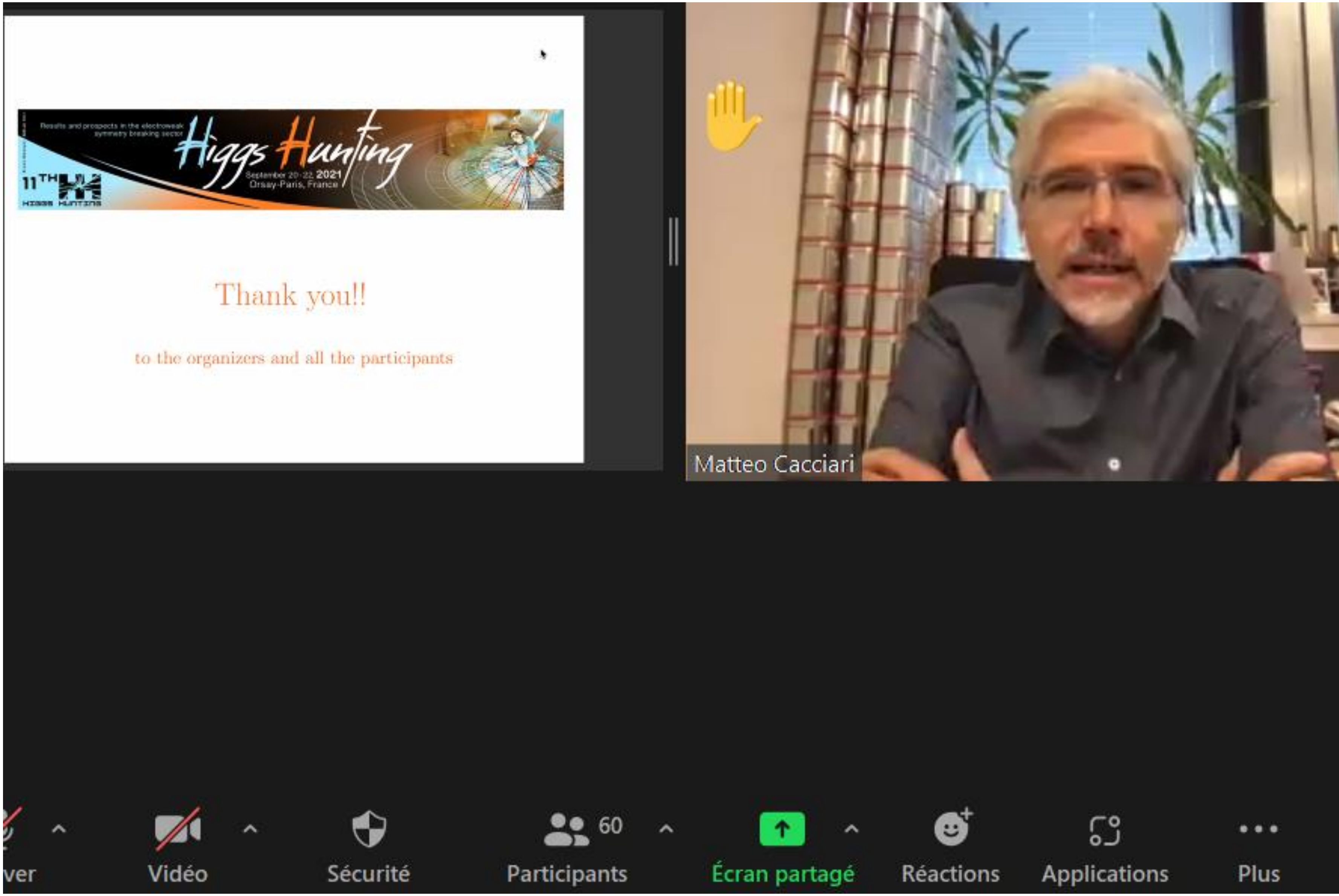
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Matteo Cacciari
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Matteo Cacciari

INTRODUCTION

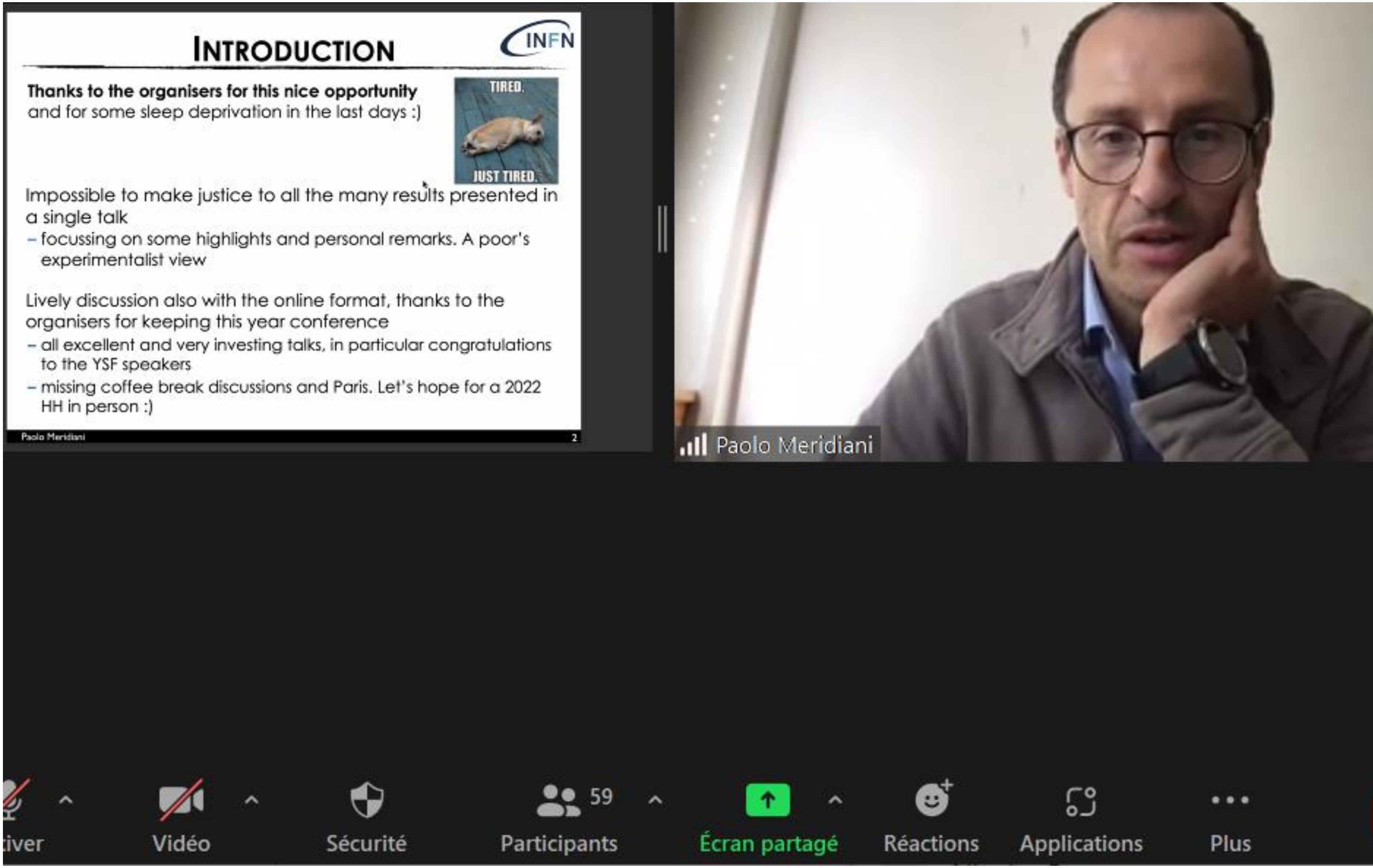
Thanks to the organisers for this nice opportunity
and for some sleep deprivation in the last days :)

Impossible to make justice to all the many results presented in a single talk

- focussing on some highlights and personal remarks. A poor's experimentalist view

Lively discussion also with the online format, thanks to the organisers for keeping this year conference

- all excellent and very investing talks, in particular congratulations to the YSF speakers
- missing coffee break discussions and Paris. Let's hope for a 2022 HH in person :)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TIRED.
JUST TIRED.
Impossible to make justice to all the many results presented in a single talk
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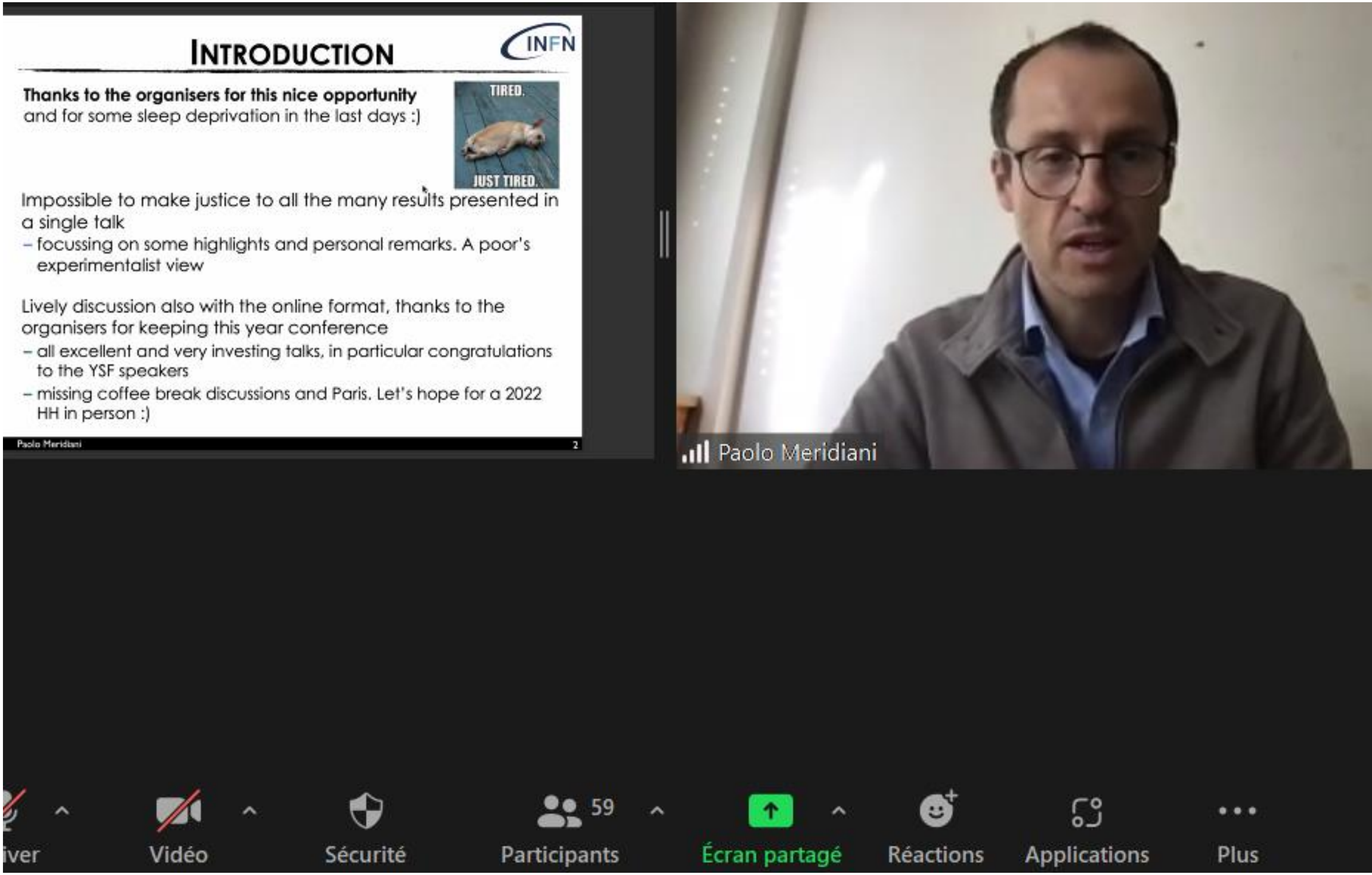
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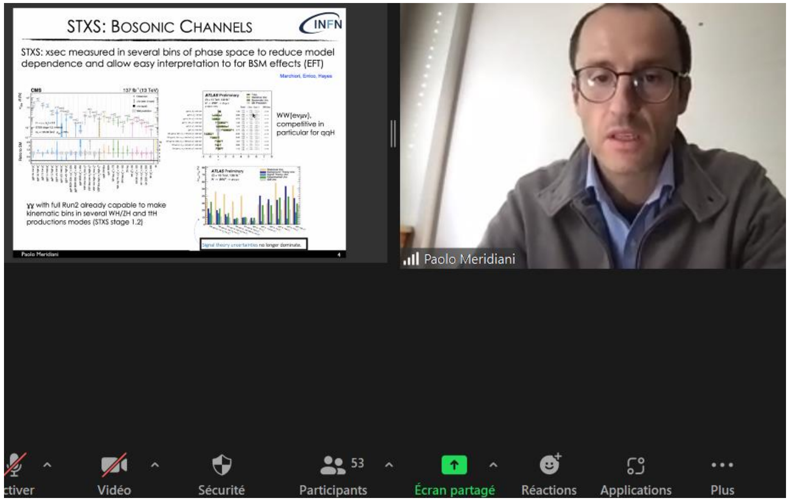
STXS: Bosonic Channels
STXS: xsec measured in several bins of phase space to reduce model dependence and allow easy interpretation to for BSM effects (EFT)
WW(eνμν), competitive in particular for qqH
γγ with full Run2 already capable to make kinematic bins in several WH/ZH and ttH productions modes (STXS stage 1.2)
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3rd Gen Coupling: ttH
Run2 legacy: discovery of the Yukawa mechanism for all 3rd gen fermions (t,b,τ)
ttH: 5σ from combination in 2018, now with full Run2 probing ttH @ ~ 20-30% in single channels
CMS ttH
First dedicated measurements for tH (multi lepton, γγ)
ATLAS ttH→bb: xsec also in pt(H) bins
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3rd Gen Coupling: VH(bb)
VH(→bb): new analysis from ATLAS combining resolved and boosted topology in STXS bins pT(V)
Sensitivity in EFT improved
A potential application for Run3: more granular 2D measurement (pT(W) vs mT) guarantees better EFT constraints for VH
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VBF H(bb)
Another "unforeseen" channel. Combining 2 channels: full hadronic (bbjj) with bbjj+γ
3σ for VBF in H→bb alone
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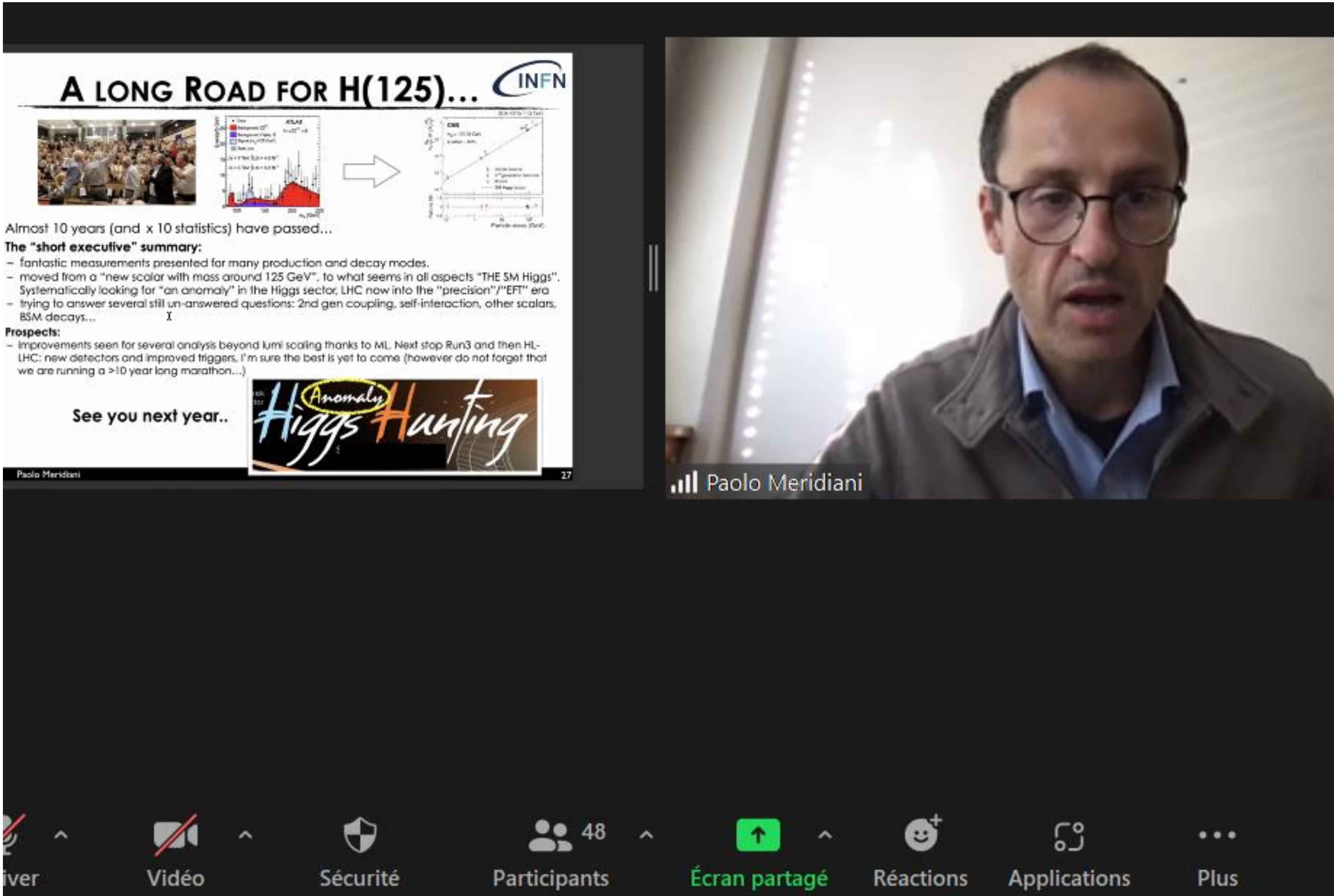
A LONG ROAD FOR H(125)…
INFN
Almost 10 years (and x 10 statistics) have passed…
The "short executive" summary:
– fantastic measurements presented for many production and decay modes.
– moved from a "new scalar with mass around 125 GeV", to what seems in all aspects "THE SM Higgs". Systematically looking for "an anomaly" in the Higgs sector, LHC now into the "precision"/"EFT" era
– trying to answer several still un-answered questions: 2nd gen coupling, self-interaction, other scalars, BSM decays…
Prospects:
– Improvements seen for several analysis beyond lumi scaling thanks to ML. Next stop Run3 and then HL-LHC: new detectors and improved triggers. I'm sure the best is yet to come (however do not forget that we are running a >10 year long marathon…)
See you next year..
Anomaly
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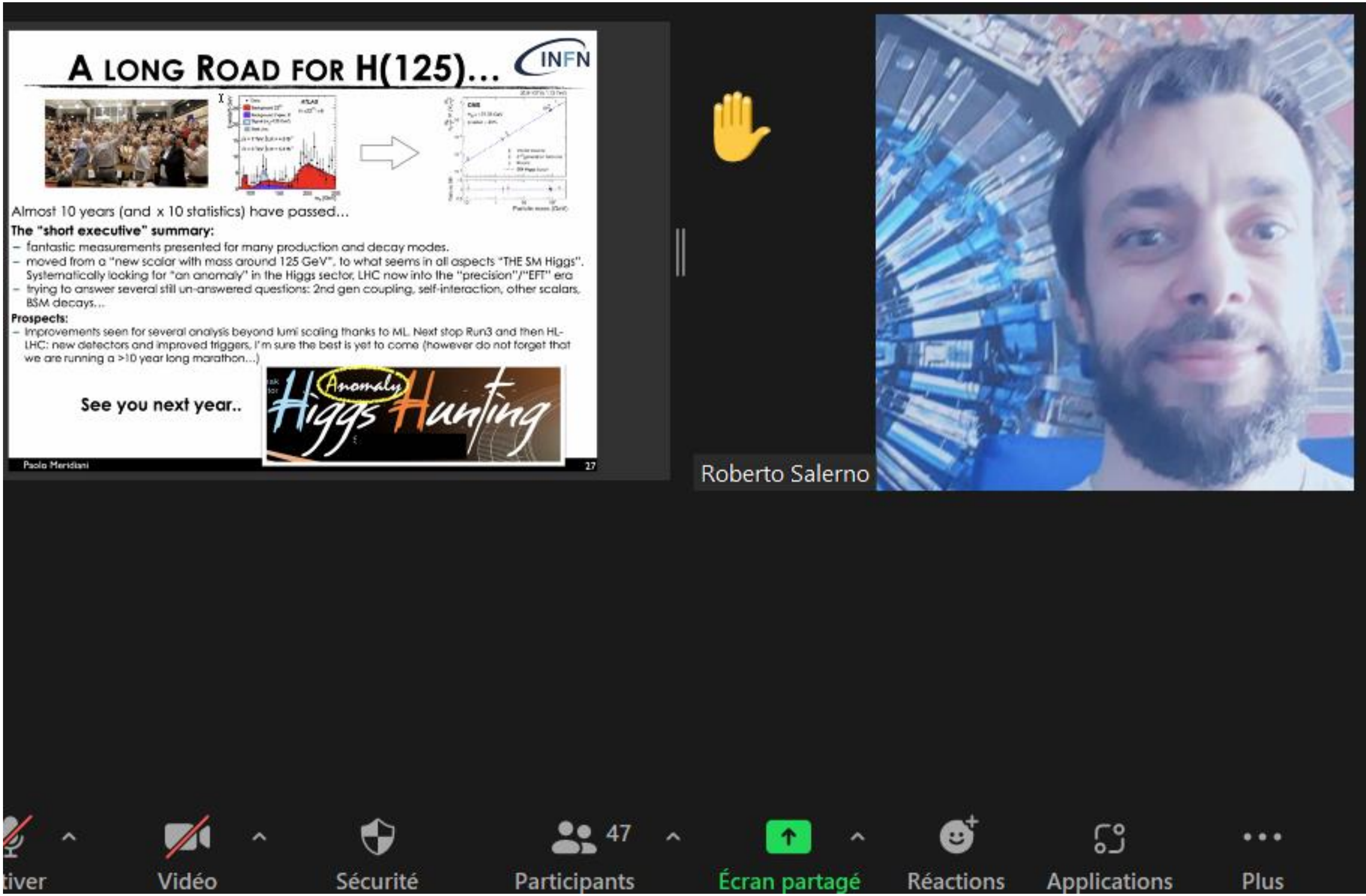
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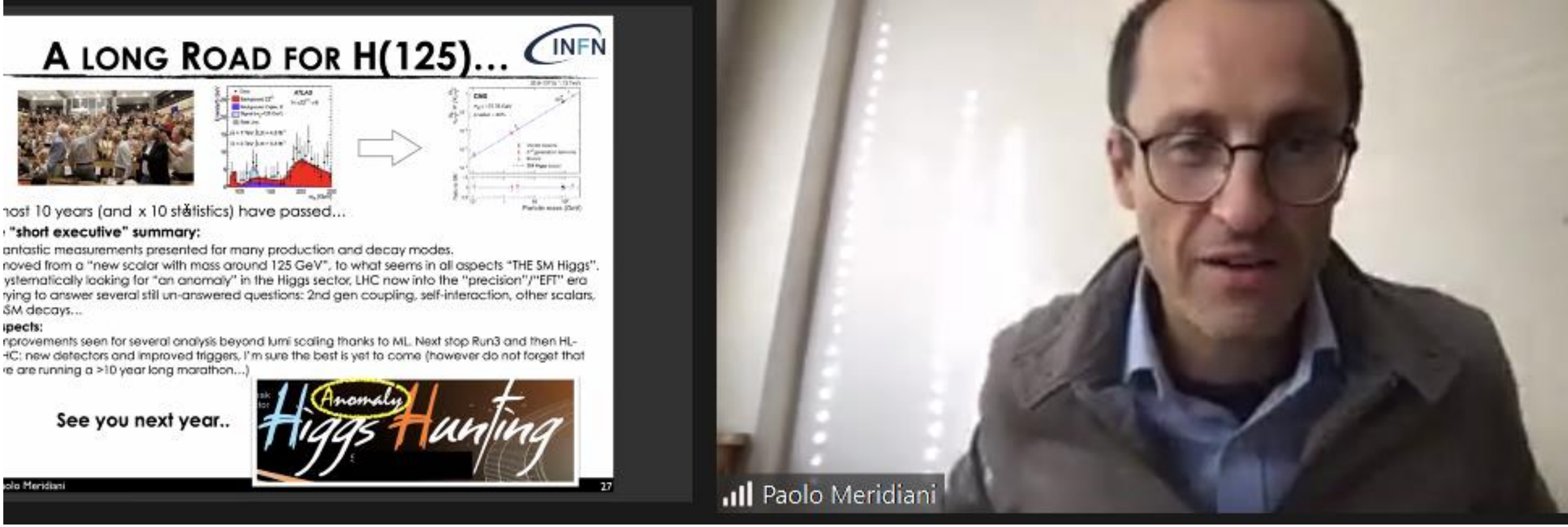
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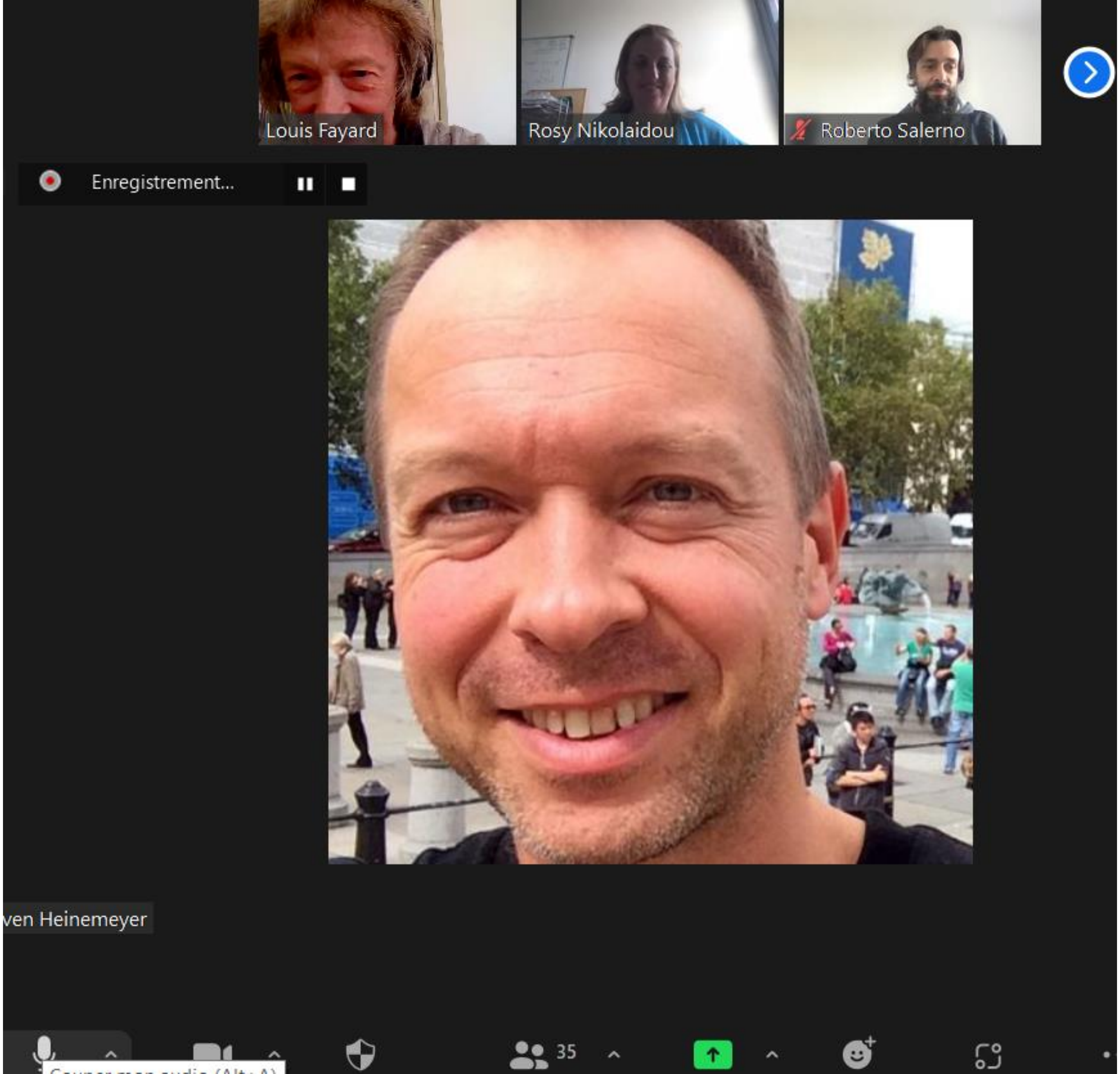
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