Experimental highlights

Giacinto Piacquadio, Sep 14th, 2022

Stony Brook University

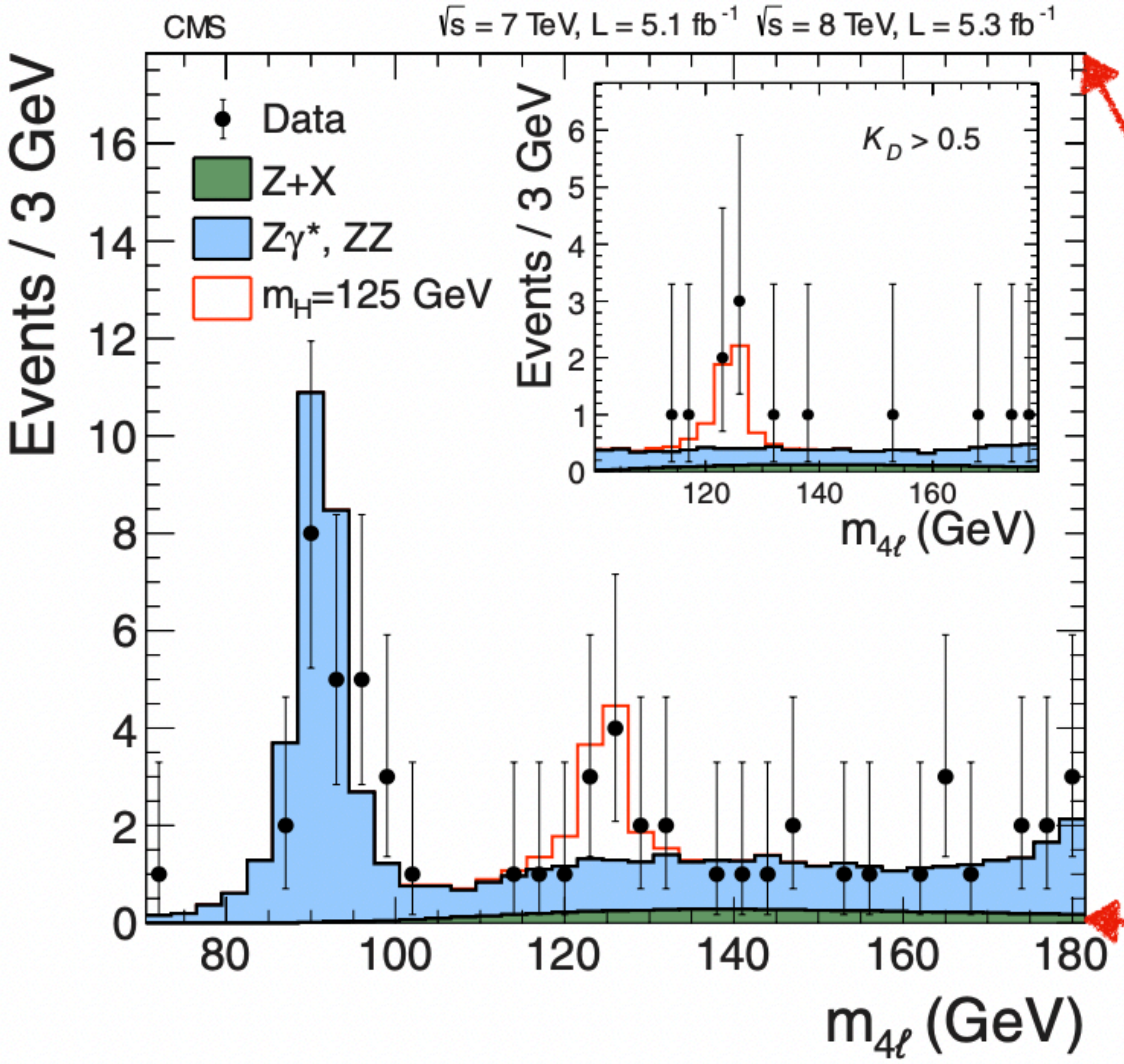
NSF

A few introductory remarks

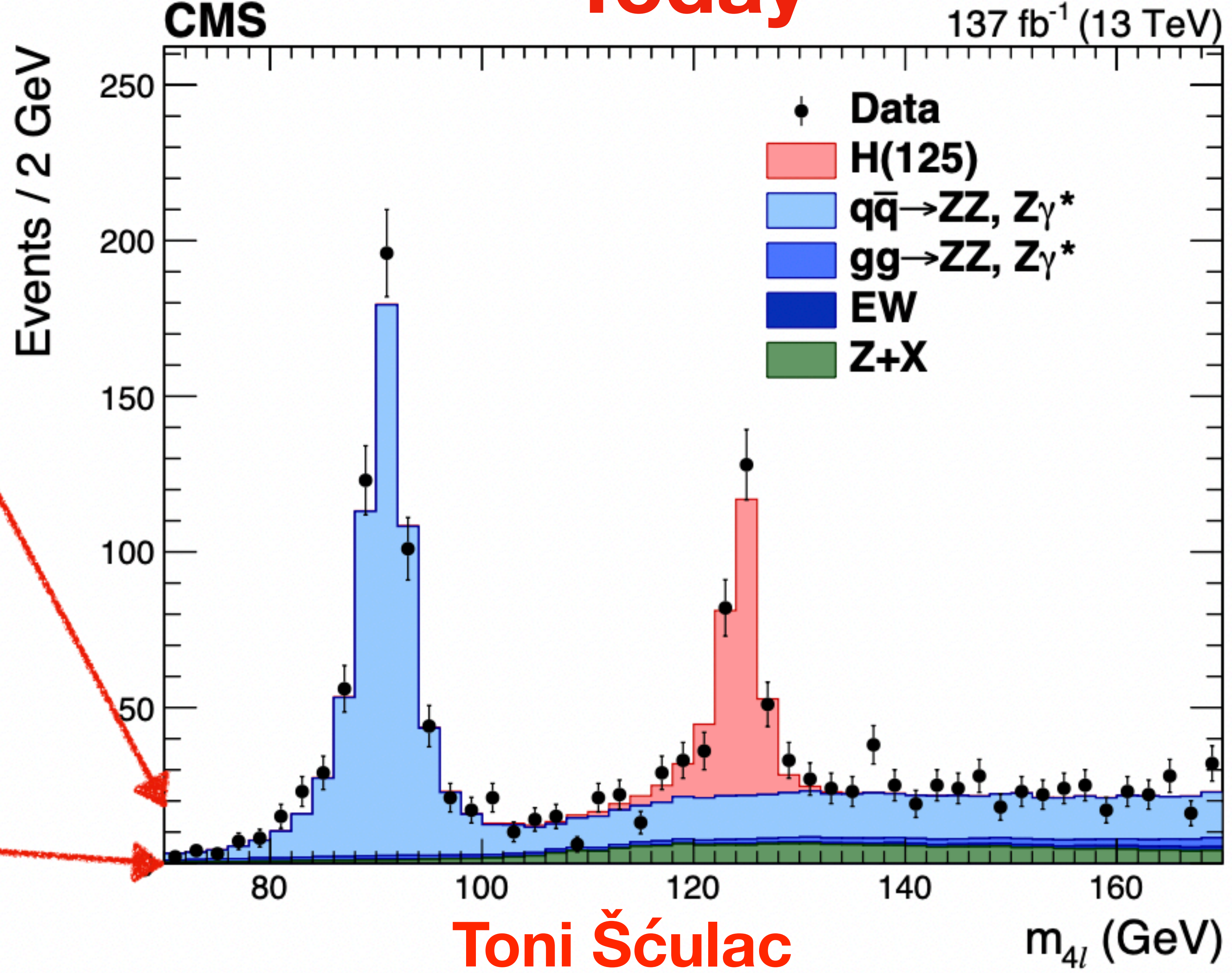
- Thanks to the organizers for the wonderful conference!
  - It has been a pleasure to finally meet everybody again in person
  - and even more on such a special year as the 10th anniversary year of the Higgs Boson discovery
- Excellent talks, YSF talks especially impressive, great discussion sessions…
- Cannot make justice of all talks, but will pick-up topics/highlights that either
  - *triggered discussion* (***controversial?***), or
  - *caught my attention* (and thus a ***likely biased*** selection)
- Apologies to all speakers that I will not properly represent in my talk…

Status of Higgs physics 10-years after discovery

- Today >30 times more statistical power
- Better detector performance in almost all areas despite significantly more challenging conditions

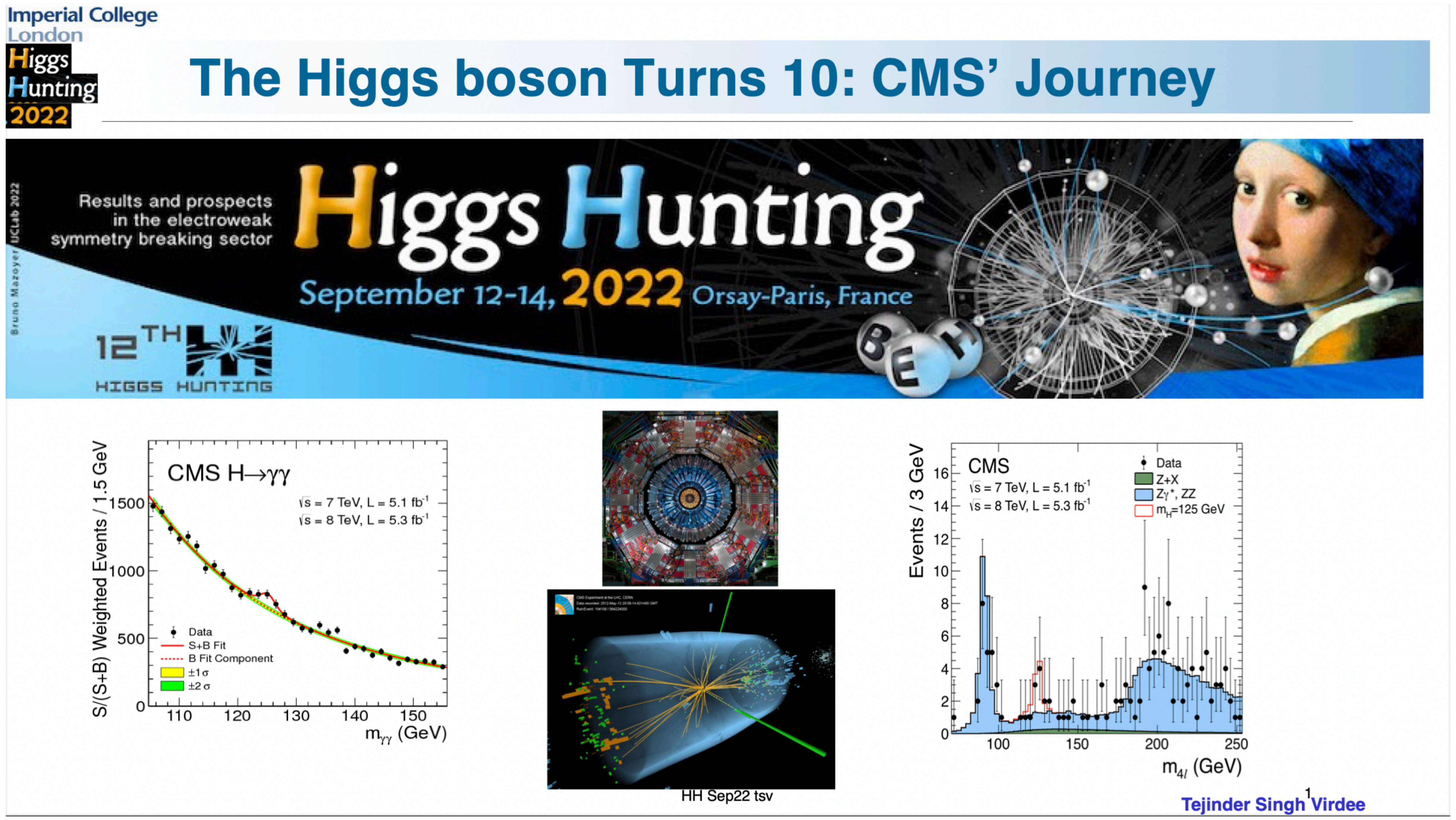


Today



Toni Šćulac

We also had two truly inspiring "historical perspective" talks!



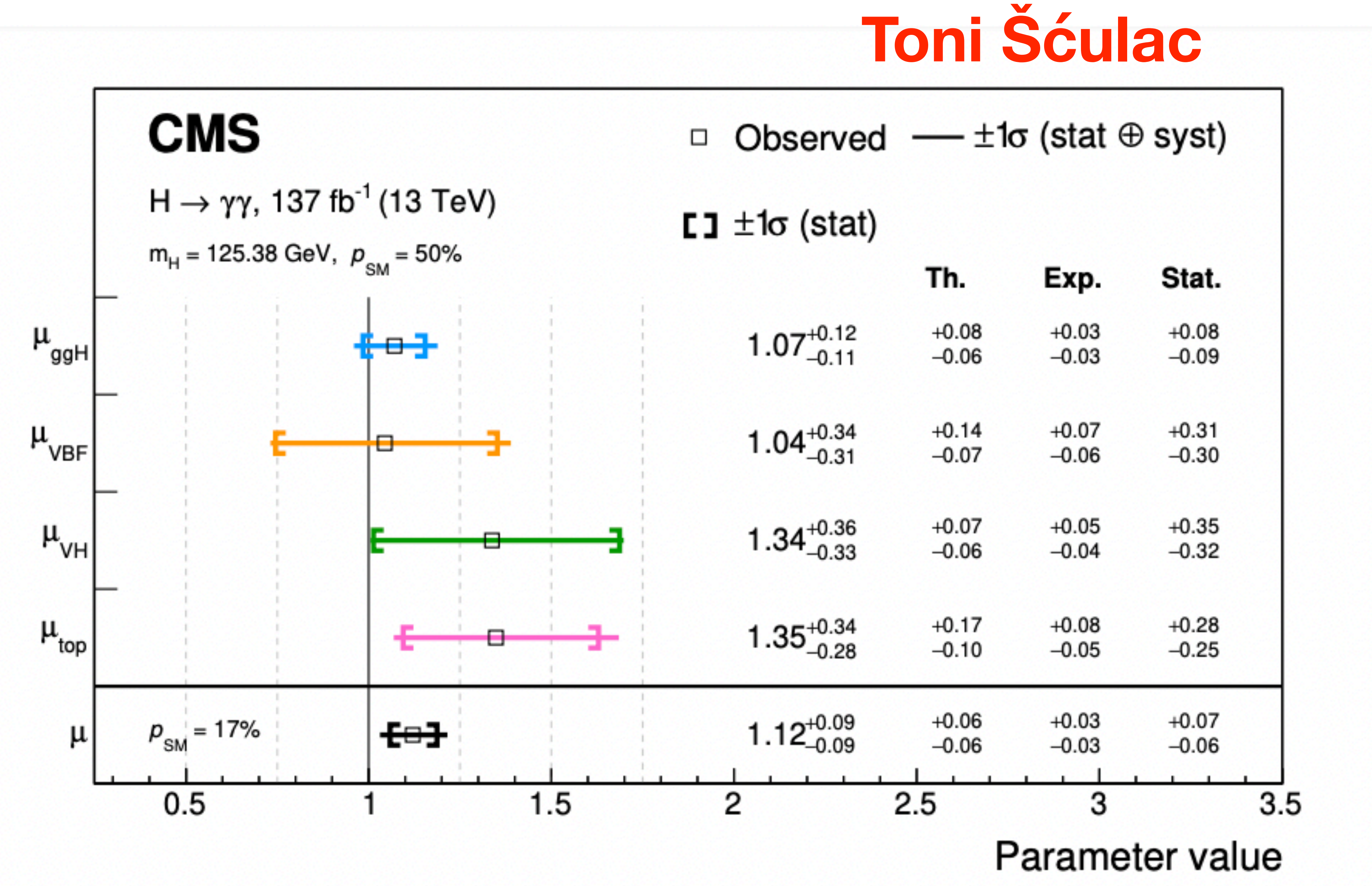
translating freely **Peter Jenni**:
"These are difficult times, but you have to fight if you want to reach your objective"

translating freely **Tejinder Virdee**:
"Not everything will go according to plans, you need to be ready for the unexpected and adapt your plans"

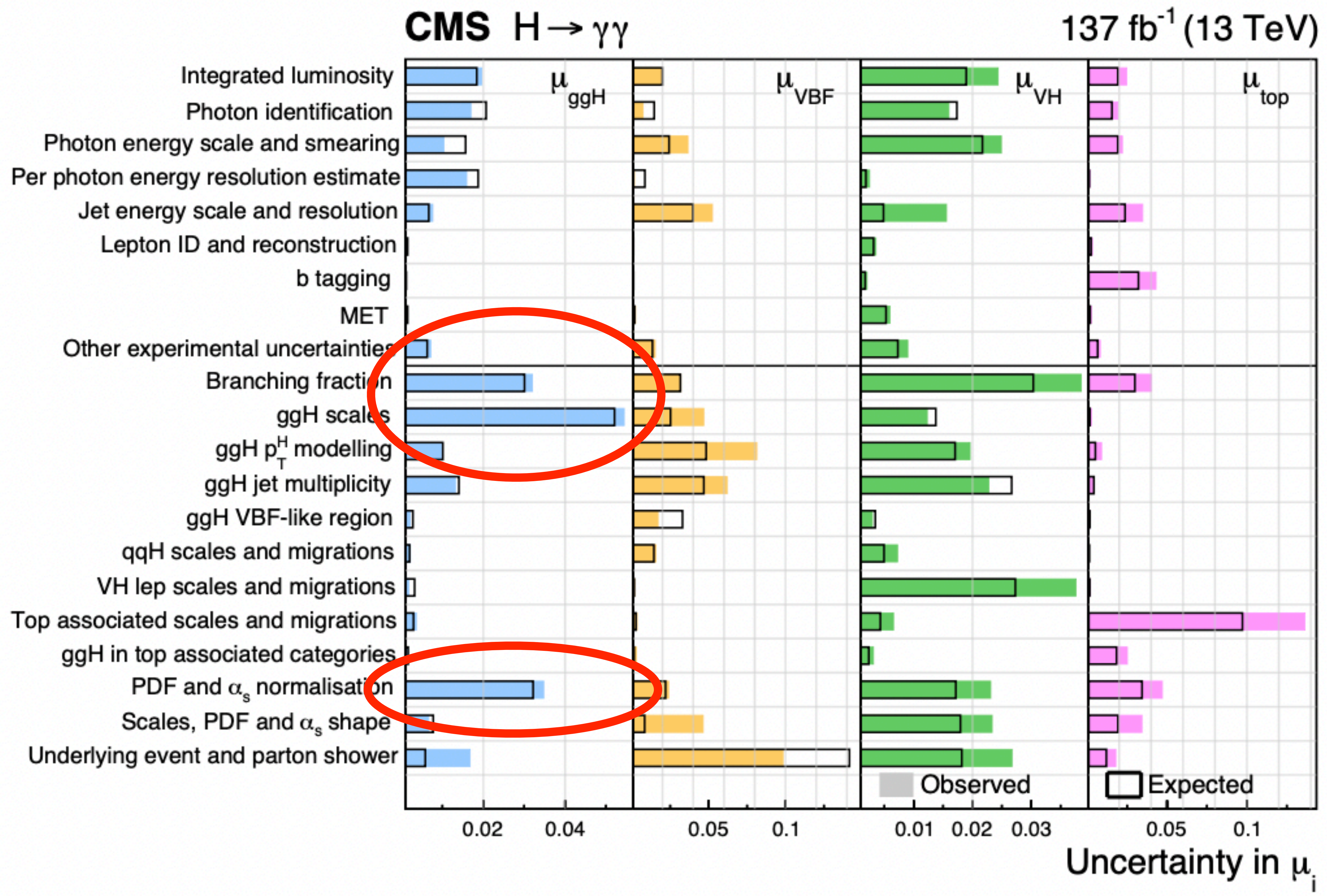
- We are deeply indebted to Peter and Tejinder's leaderships, who made two marvelous detectors such as ATLAS and CMS become a reality.
- And we should remember these words when we will be fighting for the next collider!

Higgs decays to bosons - highlights

H → γγ



- Better than 10% uncertainty on gluon fusion
- Theory uncertainties start to really matter in ggH:

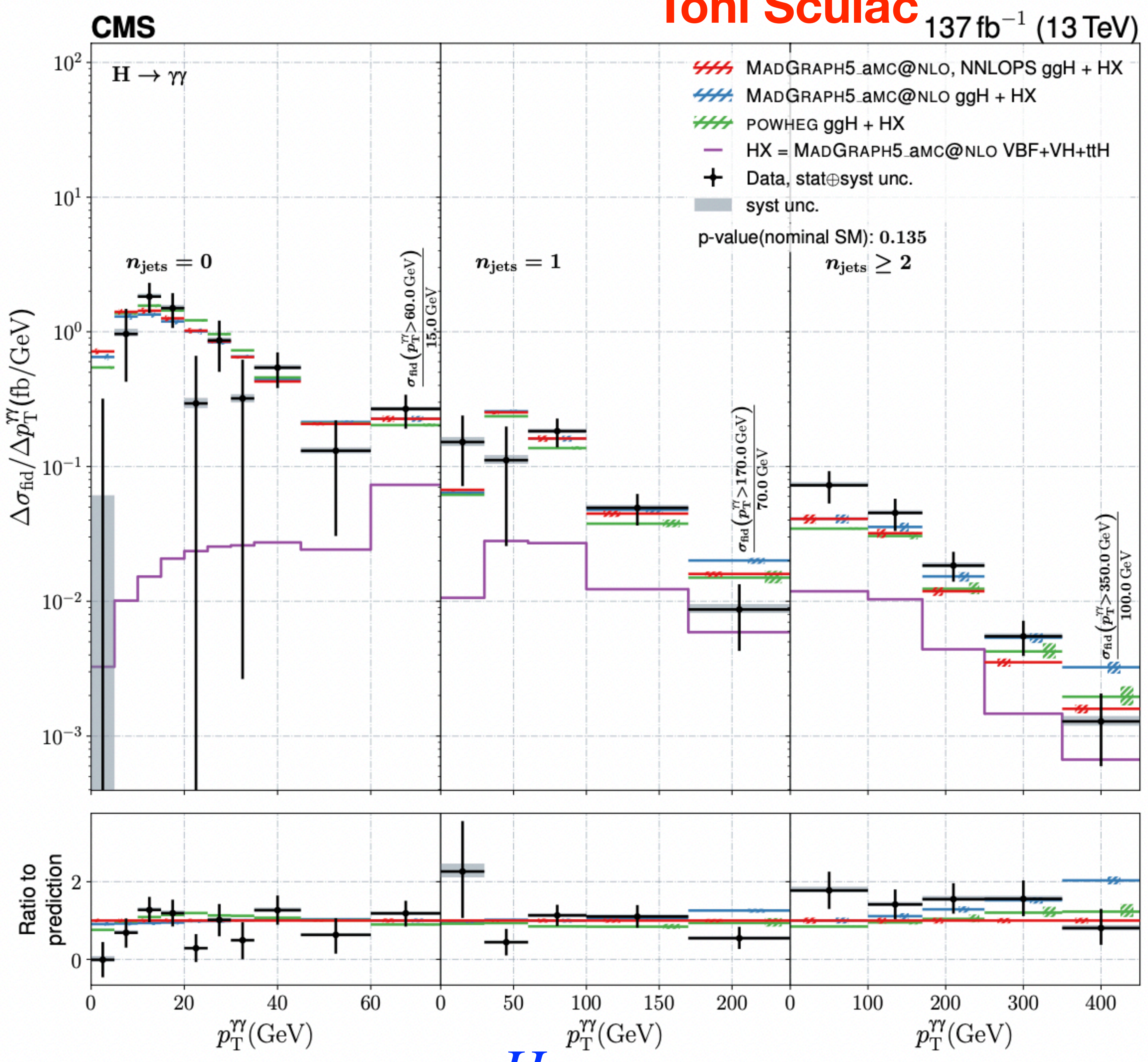


- Inclusive signal uncertainty smaller: time to start optimizing analysis to minimize theory error?
  - Any theorist starting to scream? :-)

H → γγ

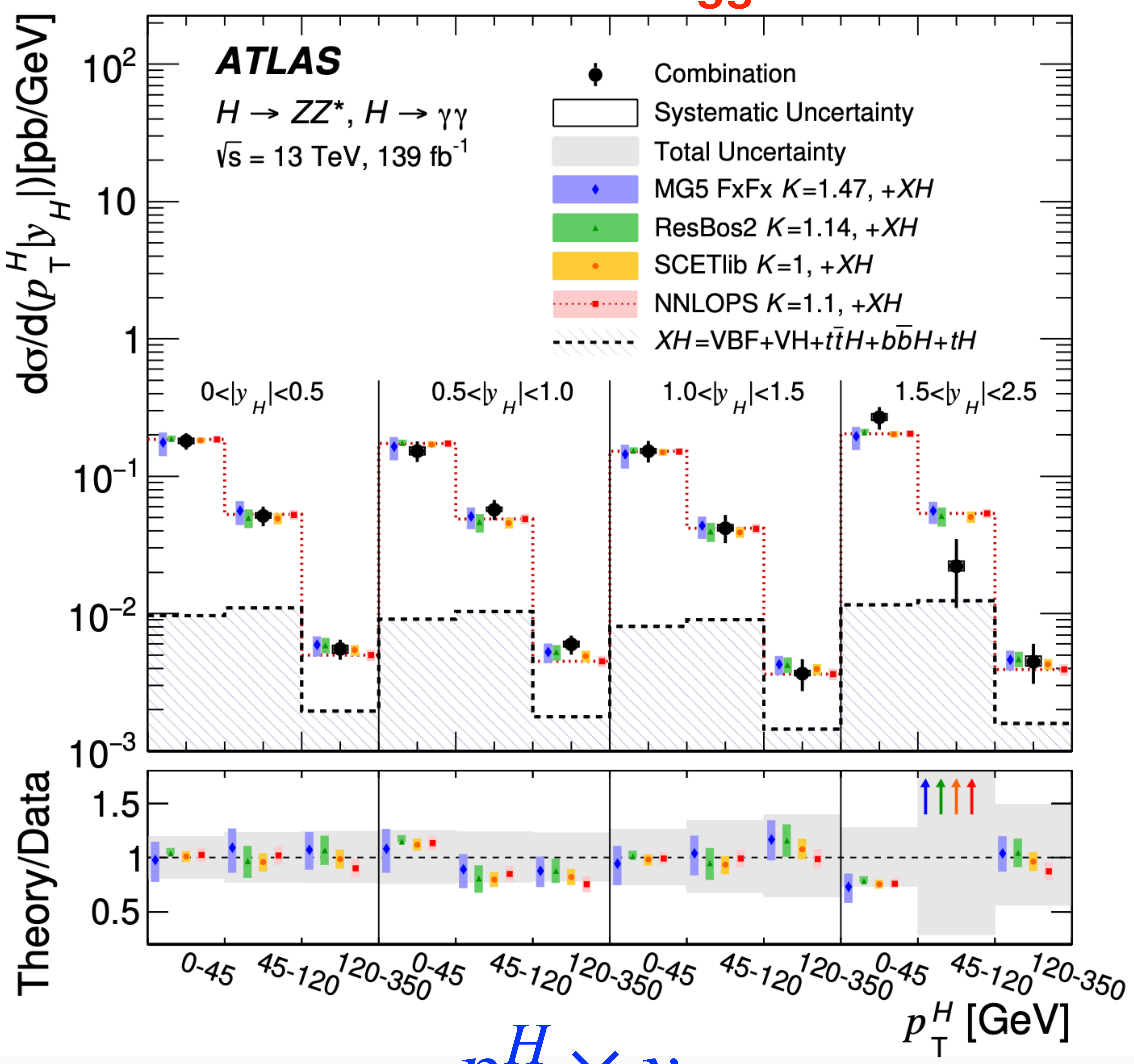
- Many more differential distributions, including double differential:

Toni Šćulac



$p_T^H \times n_{jet}$

Ruggero Turra

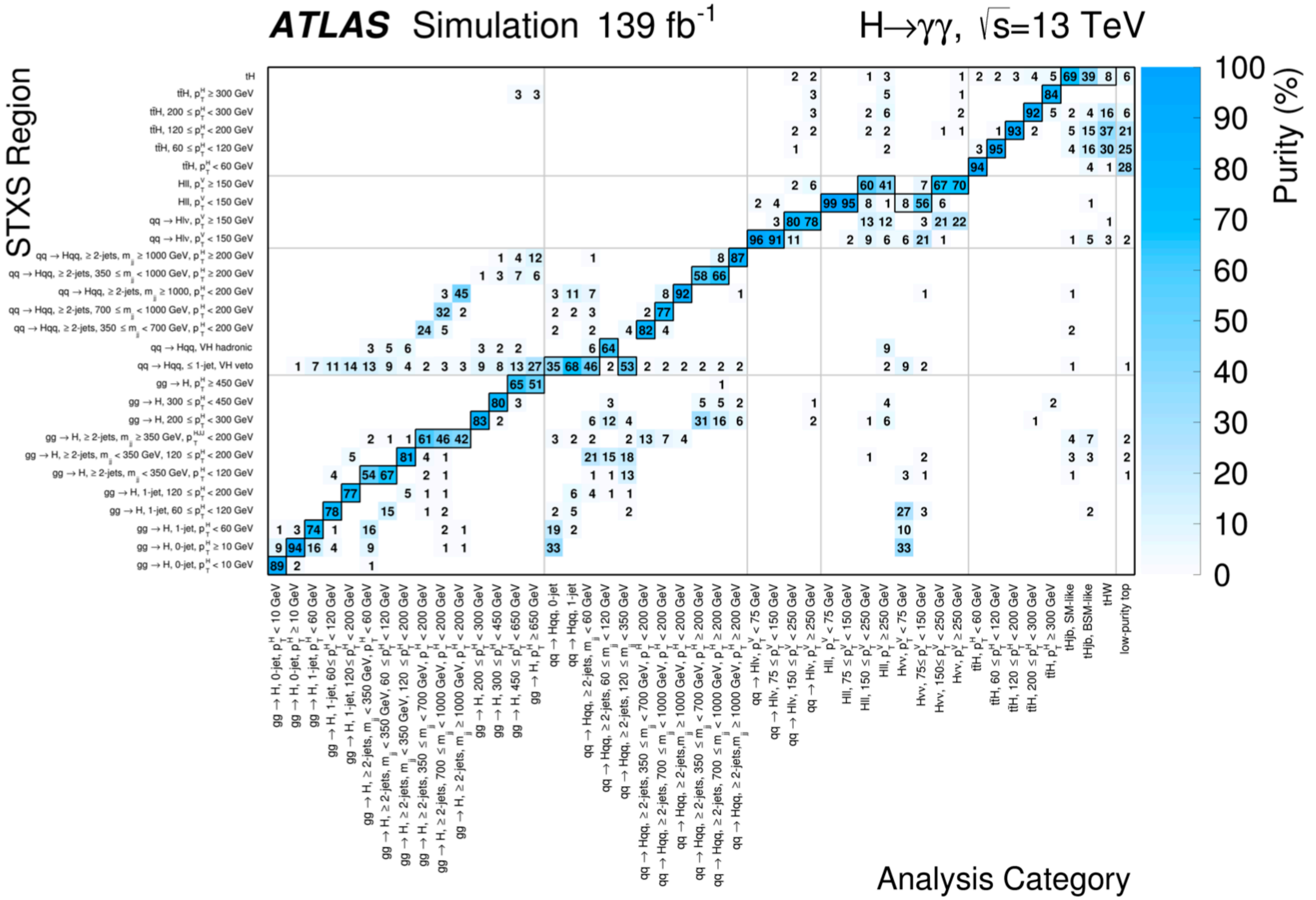


$p_T^H \times y_H$

H → γγ

- ATLAS and CMS analyses went already through a lot of optimization

Ruggero Turra



- And still: every iteration brings improvements beyond statistics.
- E.g. use of "D-optimality" in ATLAS:
  - Categorization of events in STXS regions based on multi-score BDT (choose category with highest score)
  - Drawback: not optimal
  - Solution: iteratively apply weights to each BDT output, based on minimizing determinant of final measurement covariance matrix.

$H \rightarrow ZZ \rightarrow 4l$

Siyuan Yan

- Updated ATLAS mass measurement

  - Goal: capturing dependencies between m_{4l}, D_{NN} and σ_i into a 2D likelihood function

  For signal:

$$P_s = P_s(m_{4l} | D_{NN}, \sigma_i, m_H) \cdot P_s(D_{NN} | m_H) \cdot P_s(\sigma_i)$$

$$\approx P_s(m_{4l} | D_{NN}, \sigma_i, m_H) \cdot P_s(D_{NN} | m_H)$$

$$P_b = P_b(m_{4l}, D_{NN})$$

Leading uncertainties	Impact (MeV)
Statistical	**±186**
Muon momentum scale	±28
Electron energy scale	±19
Signal-process theory	±14

- 50% reduction in muon momentum scale systematics, but negligible impact since measurement still dominated by statistical uncertainties:

$$m_H = 124.99 \pm 0.18\ (stat) \pm 0.04\ (sys)\ GeV$$

(0.14% uncertainty)

Currently most precise measurement: 0.11% (CMS Run-1 + partial Run-2, $H \rightarrow \gamma\gamma$ + $H \rightarrow ZZ$)

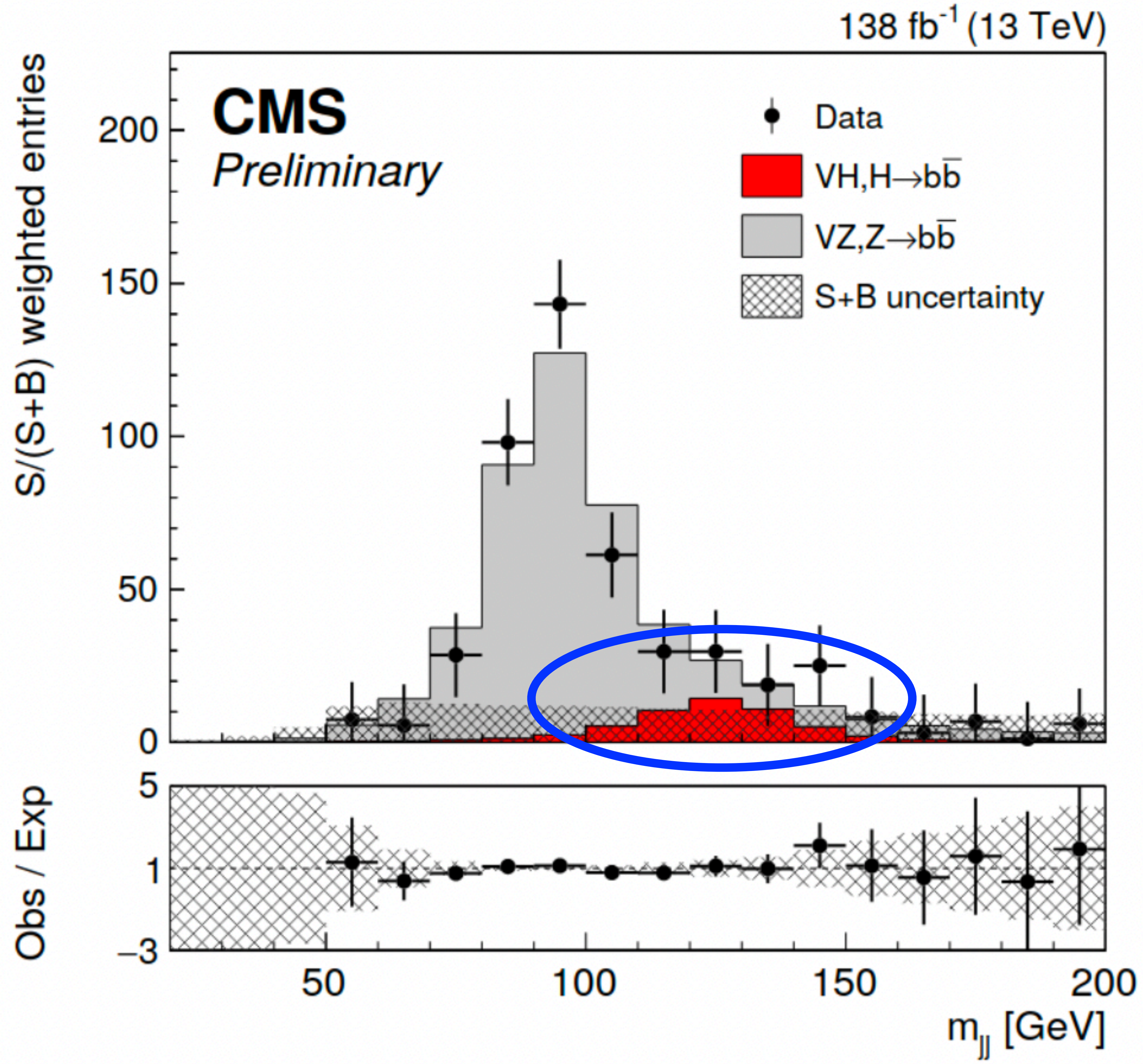
Higgs decays to fermions or ttH production - highlights

VH, H → bb

New results from CMS

Christina Reissel

- **inclusive signal strength**:
  $\mu = 0.58^{+0.19}_{-0.18}$ with observed (expected) significance of 3.3σ (5.2σ)
- **cross check analysis**:
  - direct visualization of excess using dijet invariant mass: $\mu = 0.34 \pm 0.34$ (mass-decorrelated DNN for event categorization)
  - VZ analysis: $\mu = 1.16 \pm 0.13$

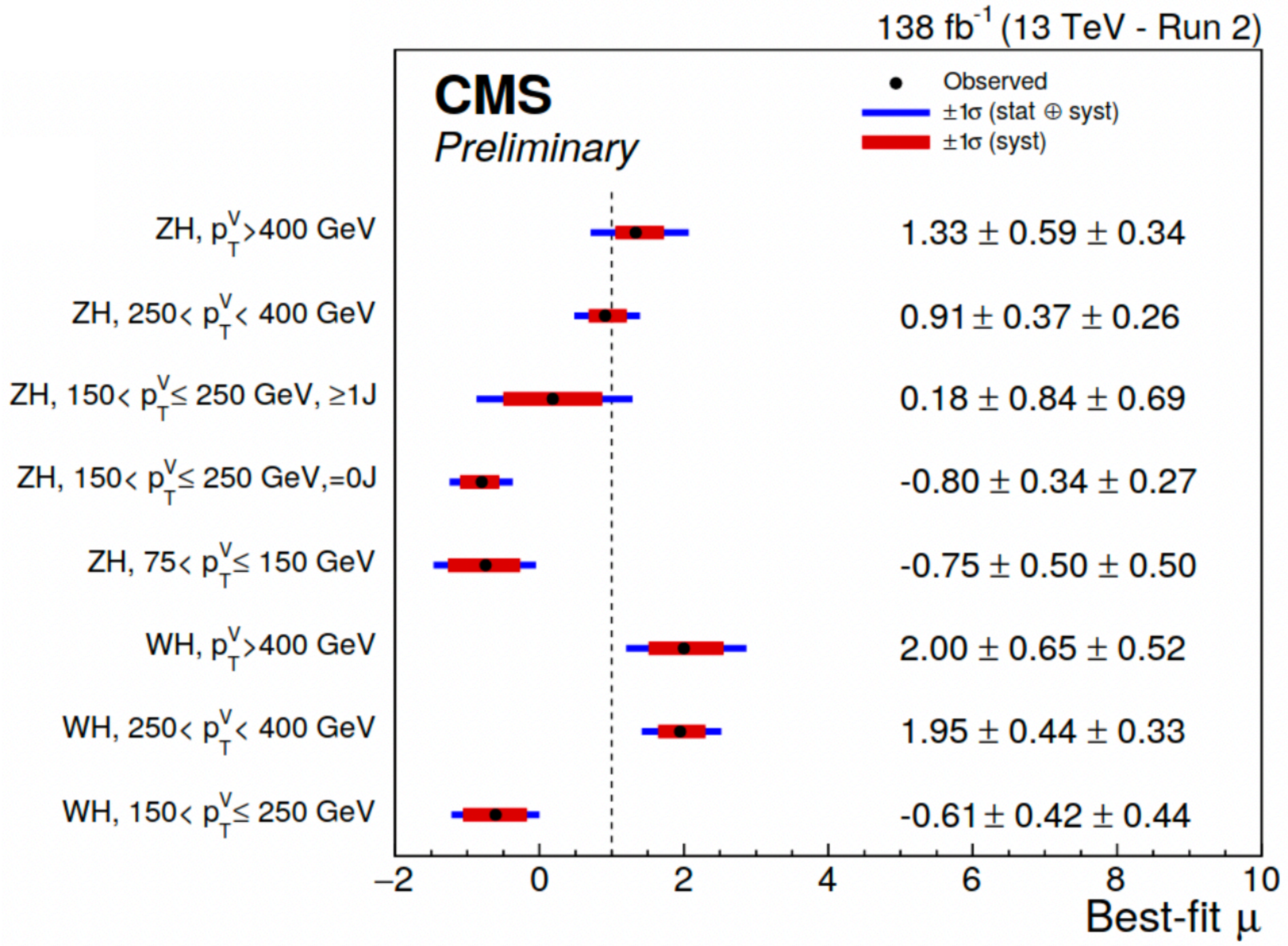


(background subtracted)

VH, H → bb
New results from CMS

Christina Reissel

- **inclusive signal strength**:
  $\mu = 0.58^{+0.19}_{-0.18}$ with observed (expected) significance of 3.3σ (5.2σ)
  - This will matters! Kappas would be significantly increased if used in Higgs combination.
  - Quite some discussion on Monday: many cross-checks (e.g. diboson) already performed.
    - Same taggers as previous result, boosted region added pT(H)>250 GeV



- Some trend vs pT?
- Not seen in the ATLAS result
- Combination of ATLAS and CMS will take time!
  - May need common bkg systematic samples

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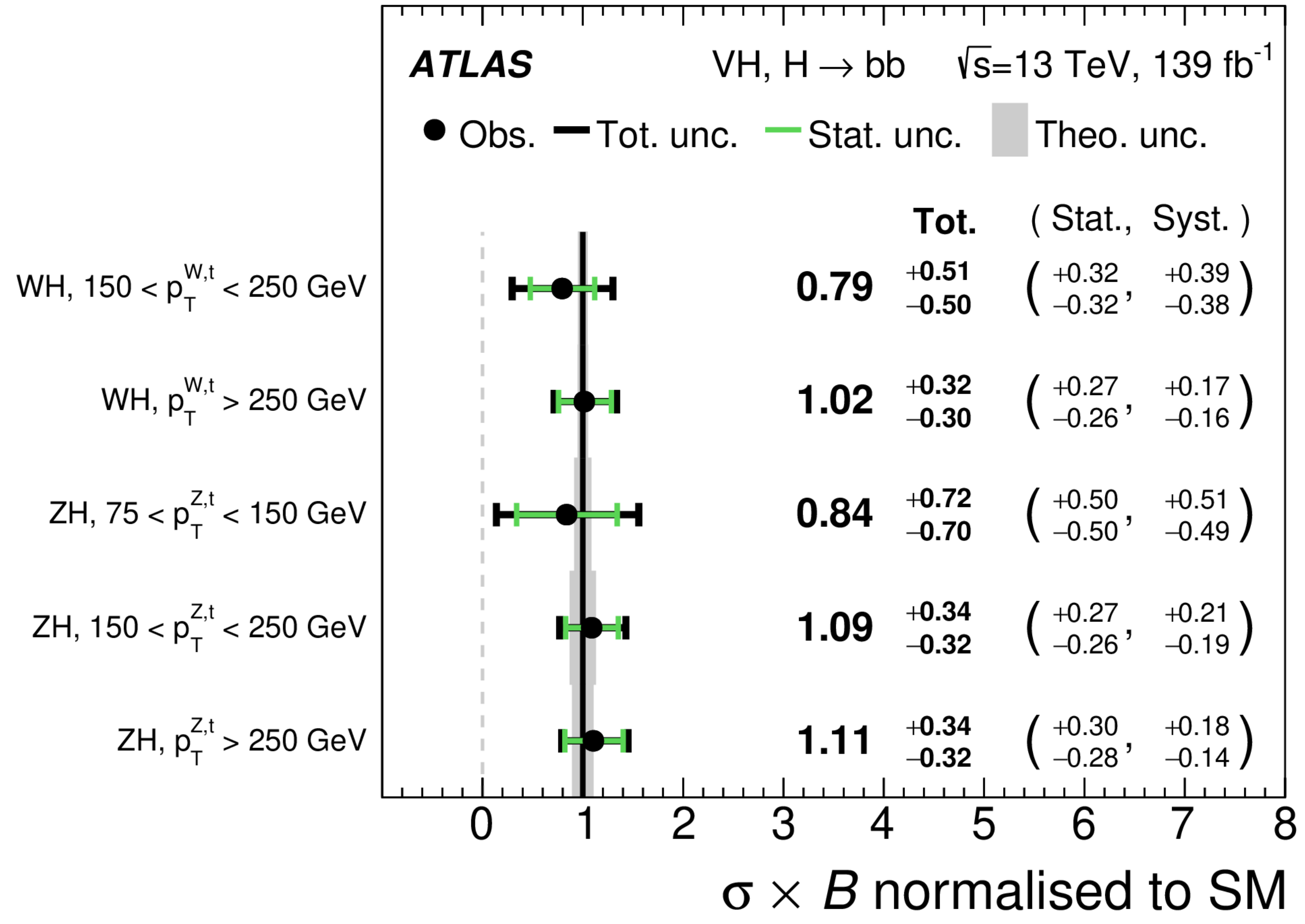
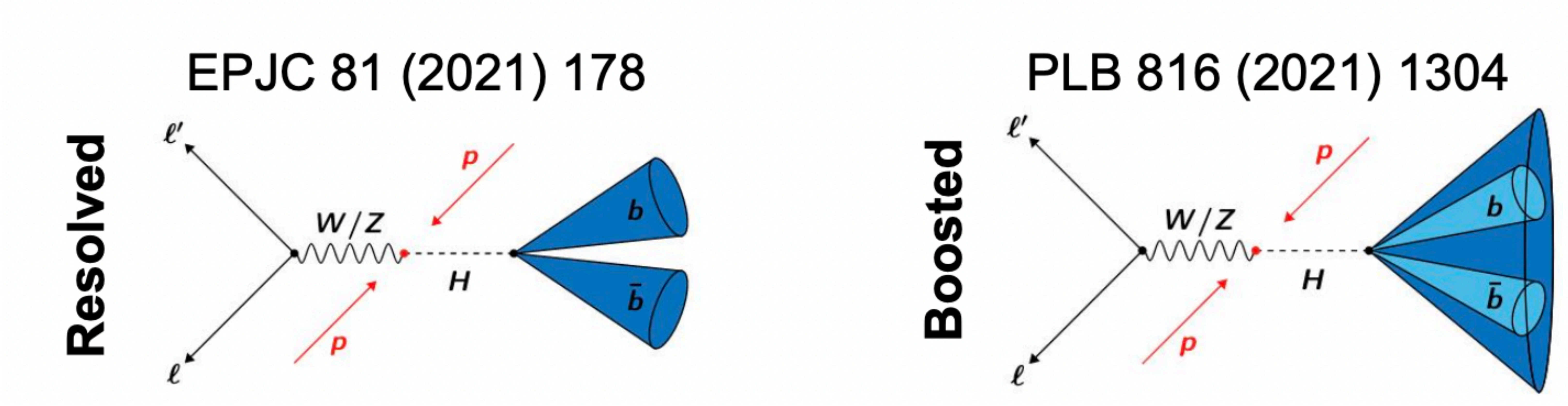


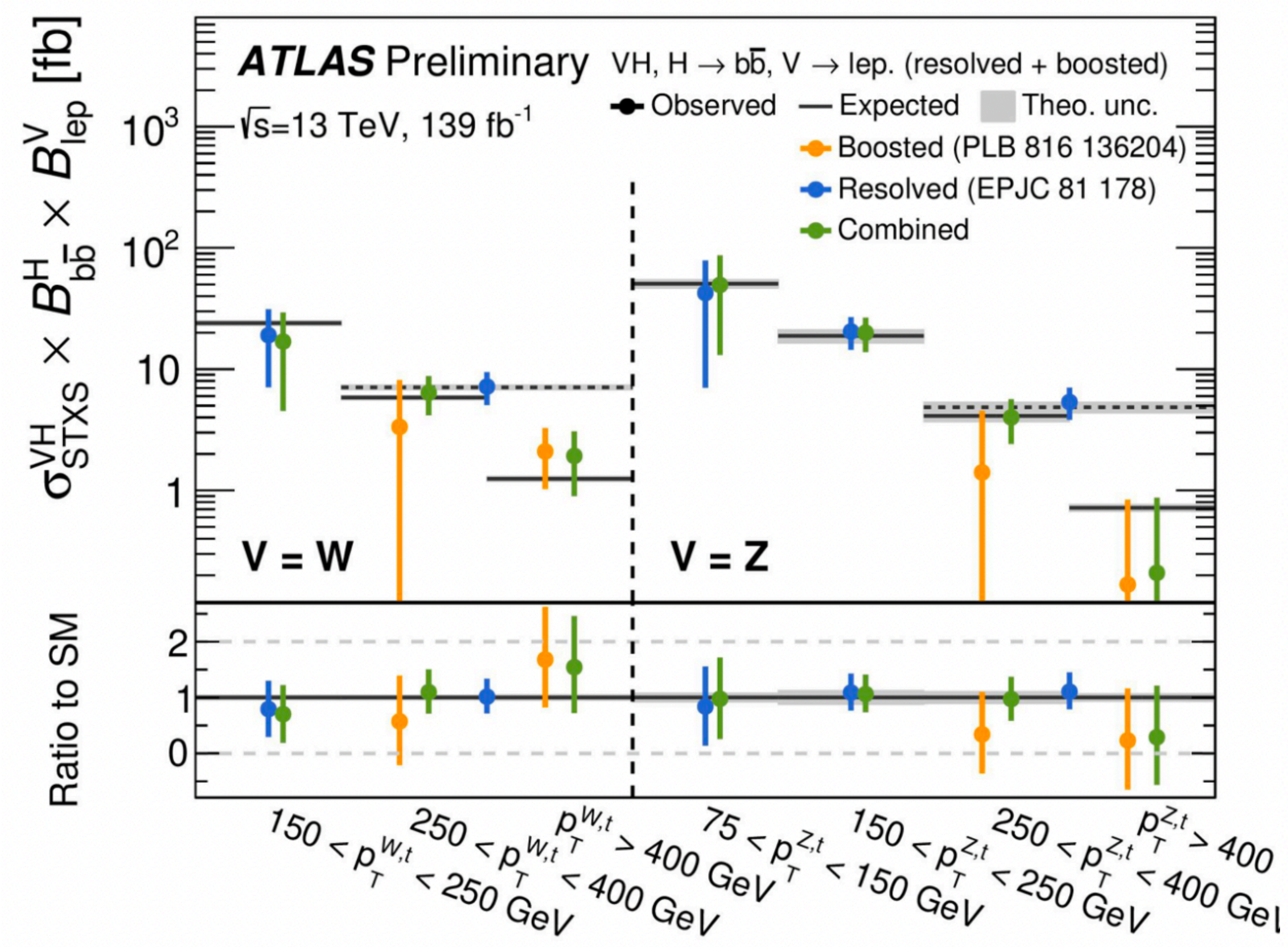
VH, H → bb

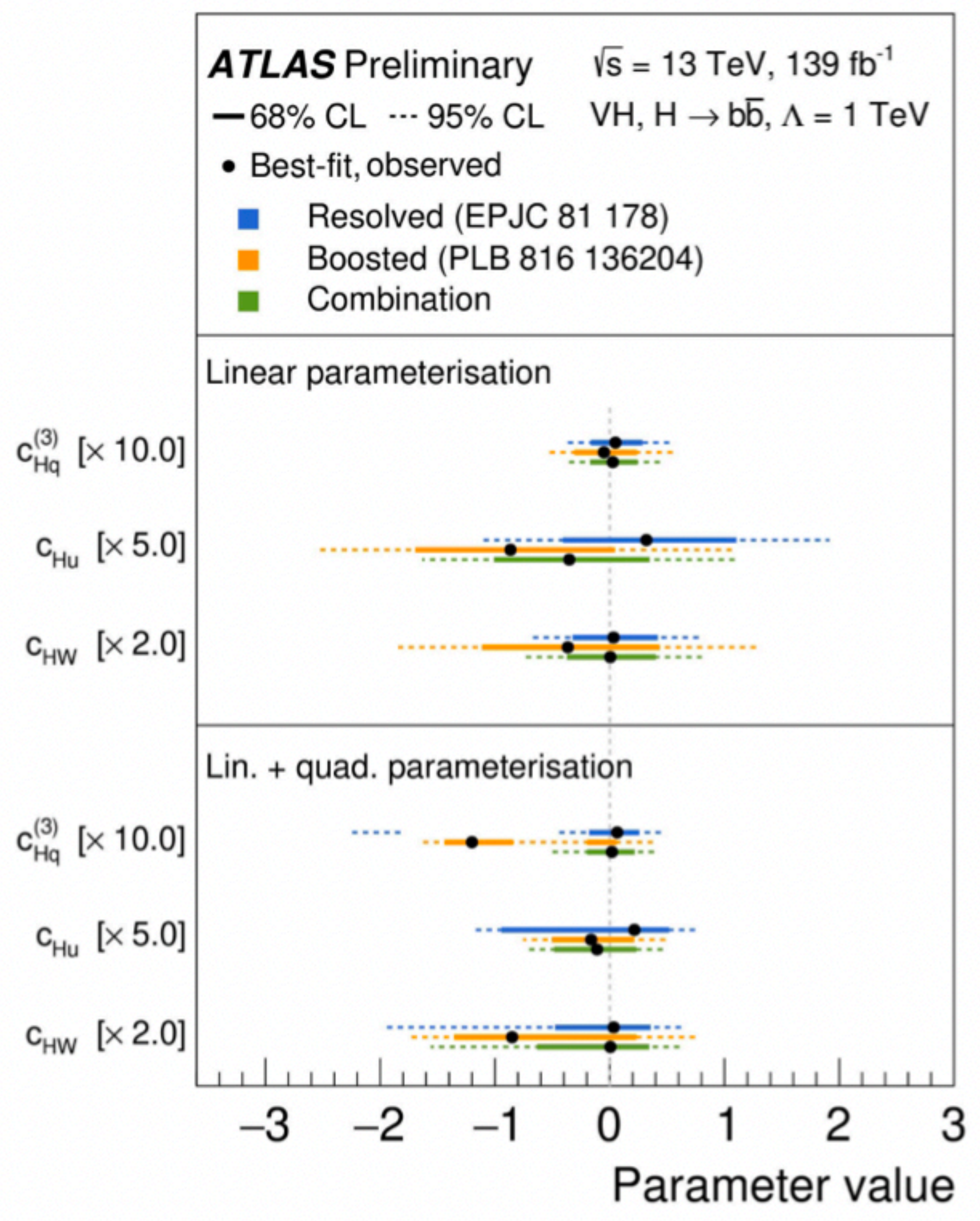
ATLAS combination of resolved and boosted



Giuseppe Callea

- Overlap removed by considering boosted-only for pT(V)>400 GeV ('simplest' combination)
- Negligible impact on overall cross-section
- Helps improve measurement at high pT(V) & constraints on EFT parameters.



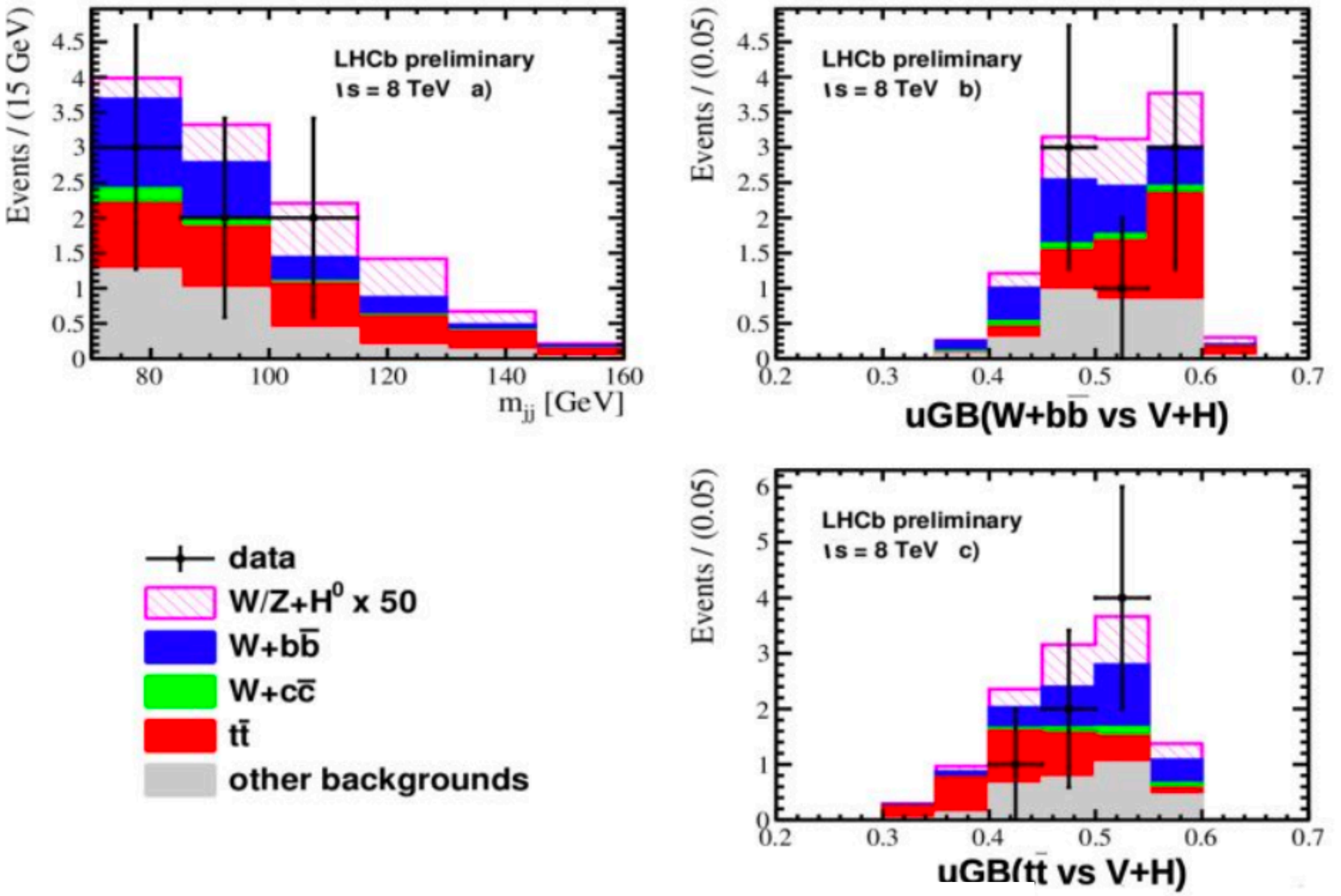


VH, H → bb(/cc)

LHCb results

- Main limitation for LHCb: limited acceptance / non-hermetic coverage
- But:
  - Access to complementary region of phase space
  - Excellent vertex reconstruction/PID
- B-tagging performance currently comparable to ATLAS/CMS, state-of-the-art Machine Learning tools being currently implemented

Laura Buonincontri

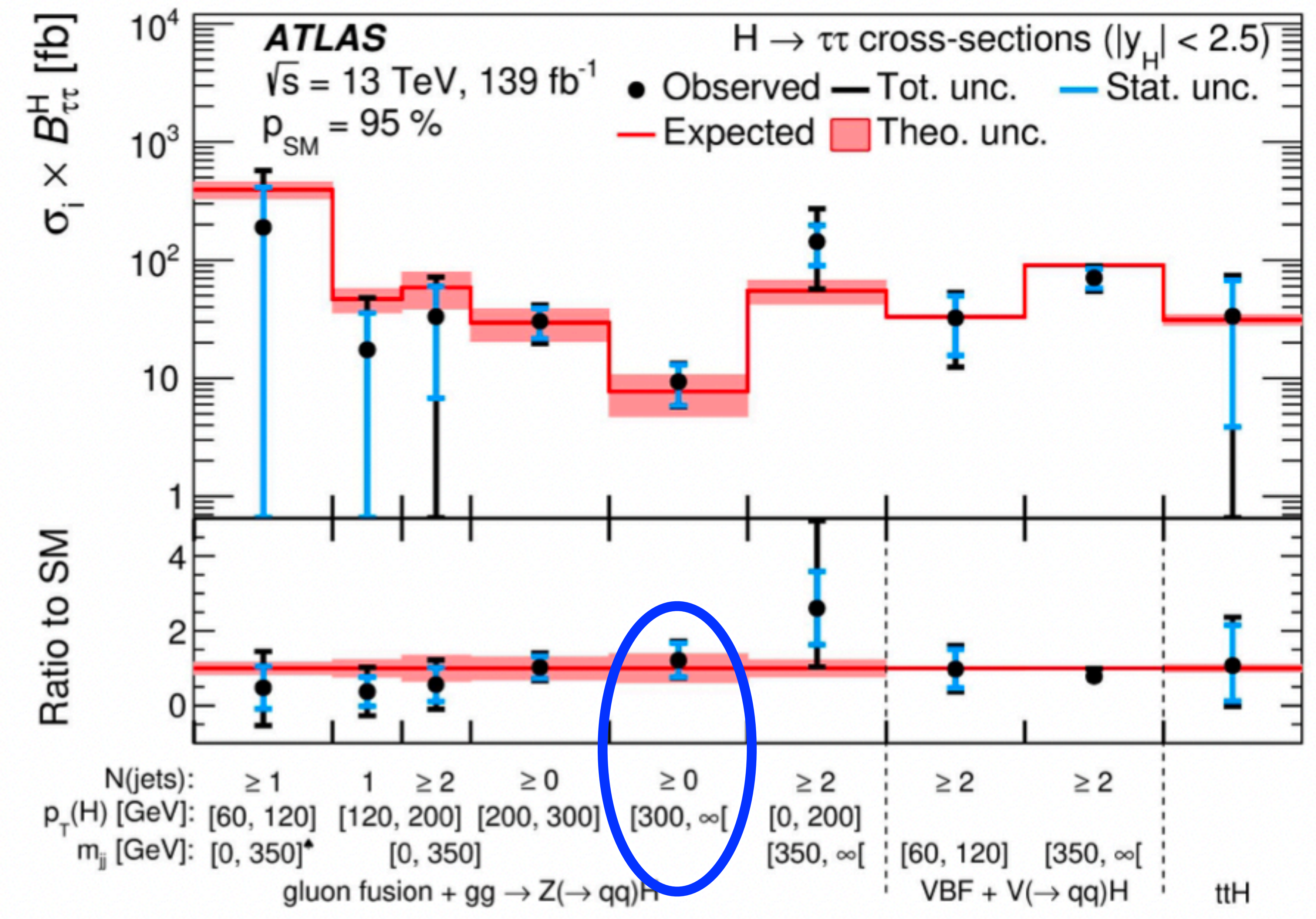


Upper limits on Yukawa couplings: $y^b < 7\, y^b_{SM}$, $y^c < 80\, y^c_{SM}$

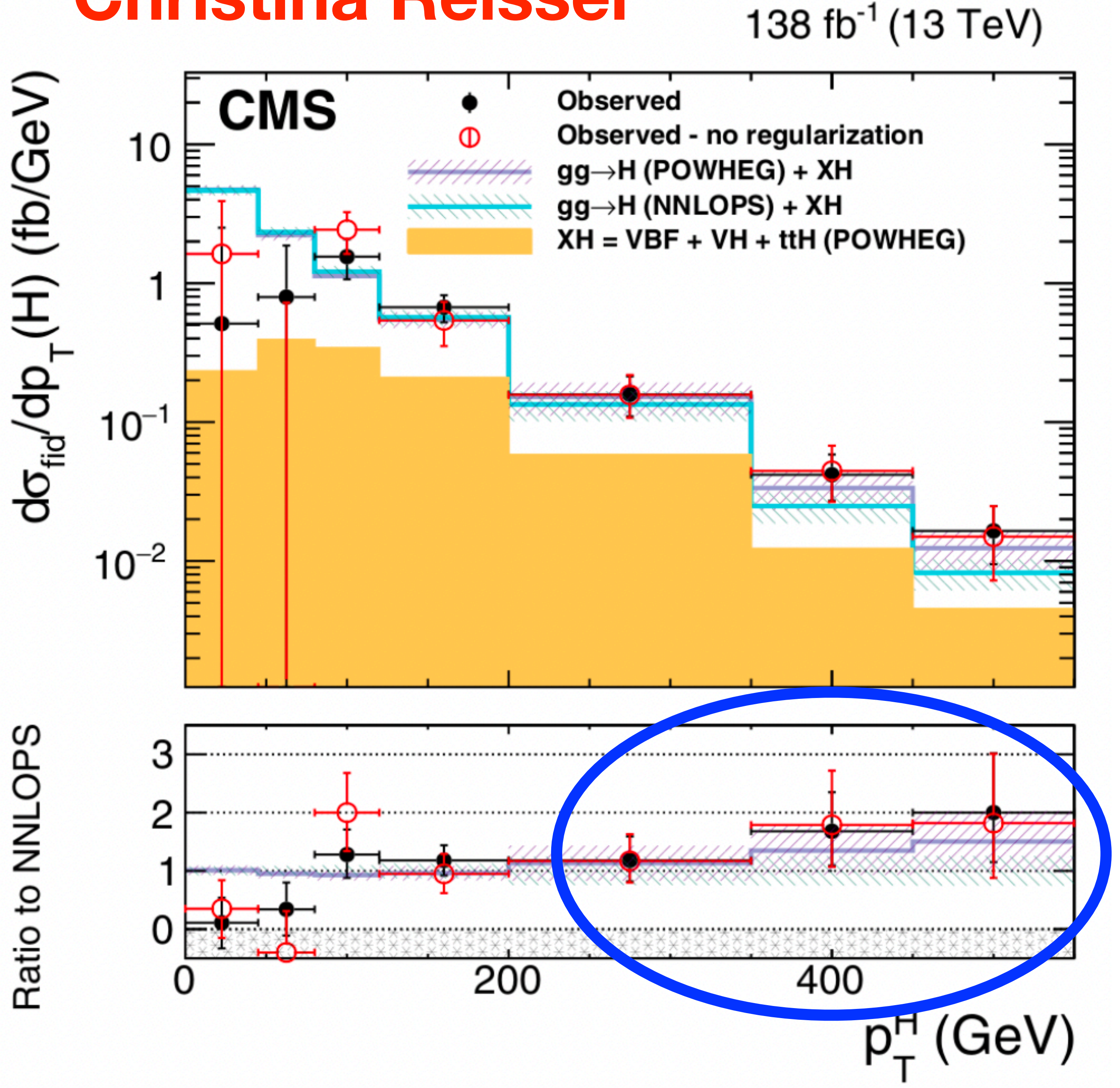
H → ττ

- Measurements in 9 STXS bins for both ATLAS and CMS:
- First ever unfolded differential measurement in this channel by CMS for several observables:

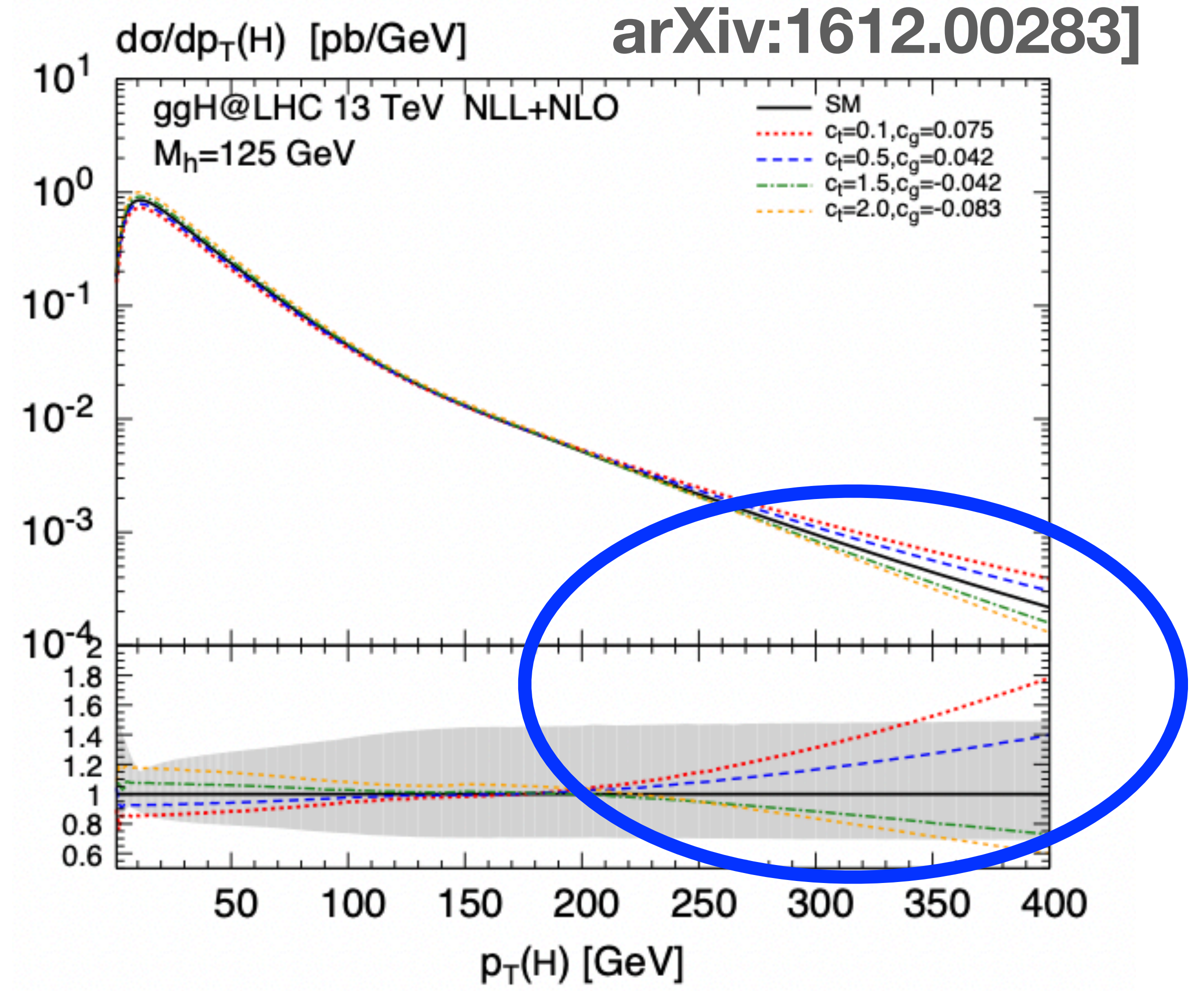
Giuseppe Callea



Christina Reissel



[Grazzini et al., arXiv:1612.00283]



- Provides one of the most precise measurements at pT(H) ~ 300-400 GeV.
- This is a region particularly sensitive to BSM. However, requires careful evaluation of SM prediction (M. Spira, e.g. mtop dependence)

ttH, H → multi leptons

Brendon Bullard

- CMS result updated to full Run-2, ATLAS still partial Run-2 (36 fb^{-1})

NLO+NNLL	592^{+155}_{-97} fb	2001.03031
NLO+FxFx	722^{+71}_{-78} fb	2108.07826
ATLAS (36 fb^{-1})	870 ± 190 fb	1901.03584
CMS (36 fb^{-1})	770^{+180}_{-160} fb	1711.02547
CMS (138 fb^{-1})	868 ± 65 fb	2208.06485

- ttW modeling problems:
  - cross-section underestimated by MC
  - ATLAS observes some mismodeling in differential prediction, and charge asymmetry
- Strong effort by ATLAS, CMS and theory in LHC Higgs WG to improve description of ttW (and ttbb) background(s) (e.g. see comparisons in LHCHWG-2022-003)
- ATLAS presented a first measurement of charge asymmetry in ttW events

$$A_c^\ell = \frac{N(\Delta_y^\ell > 0) - N(\Delta_y^\ell < 0)}{N(\Delta_y^\ell > 0) + N(\Delta_y^\ell < 0)}, \quad \Delta_y^\ell = |y_{\ell^+}| - |y_{\ell^-}|$$

Detector-level

$$A_c^\ell(t\bar{t}W) = -0.123 \pm 0.136\,(\text{stat.}) \pm 0.051\,(\text{syst.})$$

Expected: $A_c^\ell(t\bar{t}W)_{\text{MC}} = -0.084\,^{+0.005}_{-0.003}\,(\text{scale}) \pm 0.006\,(\text{MC stat.})$

Particle-level

$$A_c^\ell(t\bar{t}W)_{\text{PL}} = -0.112 \pm 0.170\,(\text{stat.}) \pm 0.055\,(\text{syst.})$$

Expected: $A_c^\ell(t\bar{t}W)_{\text{MC}} = -0.063\,^{+0.007}_{-0.004}\,(\text{scale}) \pm 0.004\,(\text{MC stat.})$

- No discrepancy with MC prediction found.

Higgs combination

Most channels are included in the combination

	ggH	qqH	VH	ttH/tH
H→γγ	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS
H→ZZ	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS
H→WW	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS
H→ττ	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS
H→bb	ATLAS, CMS	ATLAS	ATLAS, CMS	ATLAS, CMS
H→μμ	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS
H→cc			ATLAS	
H→Zγ	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS	ATLAS, CMS
H→inv	CMS	ATLAS, CMS	ATLAS, CMS	

Adinda de Wit
(CERN Symposium for 10th anniversary)

But which channels are *not yet* included?

- CMS

Analyses	Integrated lumi (fb^{-1})	ggH	qqH	VH	ttH & tH
H(γγ)	138	X	X	X	X
H(ZZ→4l)	138	X	X	X	X
H(WW)	138	X	X	X	X
H(Zγ)	138	X	X		
H(bb)	36(ttH) 77(VH) 138(ggH)	X	X	X	X
H(ττ)	138	X	X	X	X
ttH multilepton(ττ, WW, and ZZ)	138				X
H(μμ)	138	X	X		X
H(invisible)	138	X	X	X	

Fabio Monti, Bob Cousins

- Main missing channels:
  - VH, H → bb with full Run-2 (*NEW* but not included in combination yet)
  - ttH, H → bb will full Run-2

But which channels are *not yet* included?

- ATLAS

	ttH	tH	ggF	VBF	WH	ZH
γγ	139	139	139	139	139	139
ZZ* (4l)	139		139	139	139	
WW*			139	139	36.1	36.1
bb	139		incl. boost: 139	126	139	139
ττ	139		139	139	139	
ttH multilept	80					
cc					139	
μμ		139			139	
Zγ			(inclusive) 139			
inv				139		Z(ll)H: 139
	(purple)		Not in Kinematic (NO STXS)			
	(yellow)		Only for Kinematic (ONLY STX			
	(green)		Only for floating kc			
	(red)		K models with Binv & Bu			

Paolo Francavilla

- Main missing channels:
  - VH, H → WW with full Run-2
  - ttH, H → multi lepton [performing ttW measurement program]
  - Additional modes for H → invisible

But which channels are *not yet* included?

- ATLAS

	ttH	tH	ggF	VBF	WH	ZH
γγ	139	139	139	139	139	139
ZZ* (4l)	139		139	139	139	
WW*			139	139	36.1	36.1
bb	139		incl. boost: 139	126	139	139
ττ	139		139	139	139	
ttH multilept	36.1					
cc					139	
μμ		139			139	
Zγ			(inclusive) 139			
inv				139		Z(ll)H: 139
			Not in Kinematic (NO STXS)			
			Only for Kinematic (ONLY STX			
			Only for floating kc			
			K models with Binv & Bu			

Paolo Francavilla

- *In most cases there are “good” reasons why CMS or ATLAS may be late??*

- Main missing channels:
  - VH, H → WW with full Run-2
  - ttH, H → multi lepton [performing ttW measurement program]
  - Additional modes for H → invisible

Overall signal strength

H Discovery (up to 10.4 fb^{-1} at 7-8 TeV)
$\mu = 0.87 \pm 0.23$ [dominated by stat.]

Run 1 comb (up to 24.8 fb^{-1} at 7-8 TeV)
$\mu = 1.00 \pm 0.13$ [+0.08/-0.07 (theory) ± 0.07 (exp.) ± 0.09 (stat.)]

This combination (up to 138 fb^{-1} at 13 TeV)
$\mu = 1.002 \pm 0.057$ [± 0.036 (theory) ± 0.033 (exp.) ± 0.029 (stat.)]

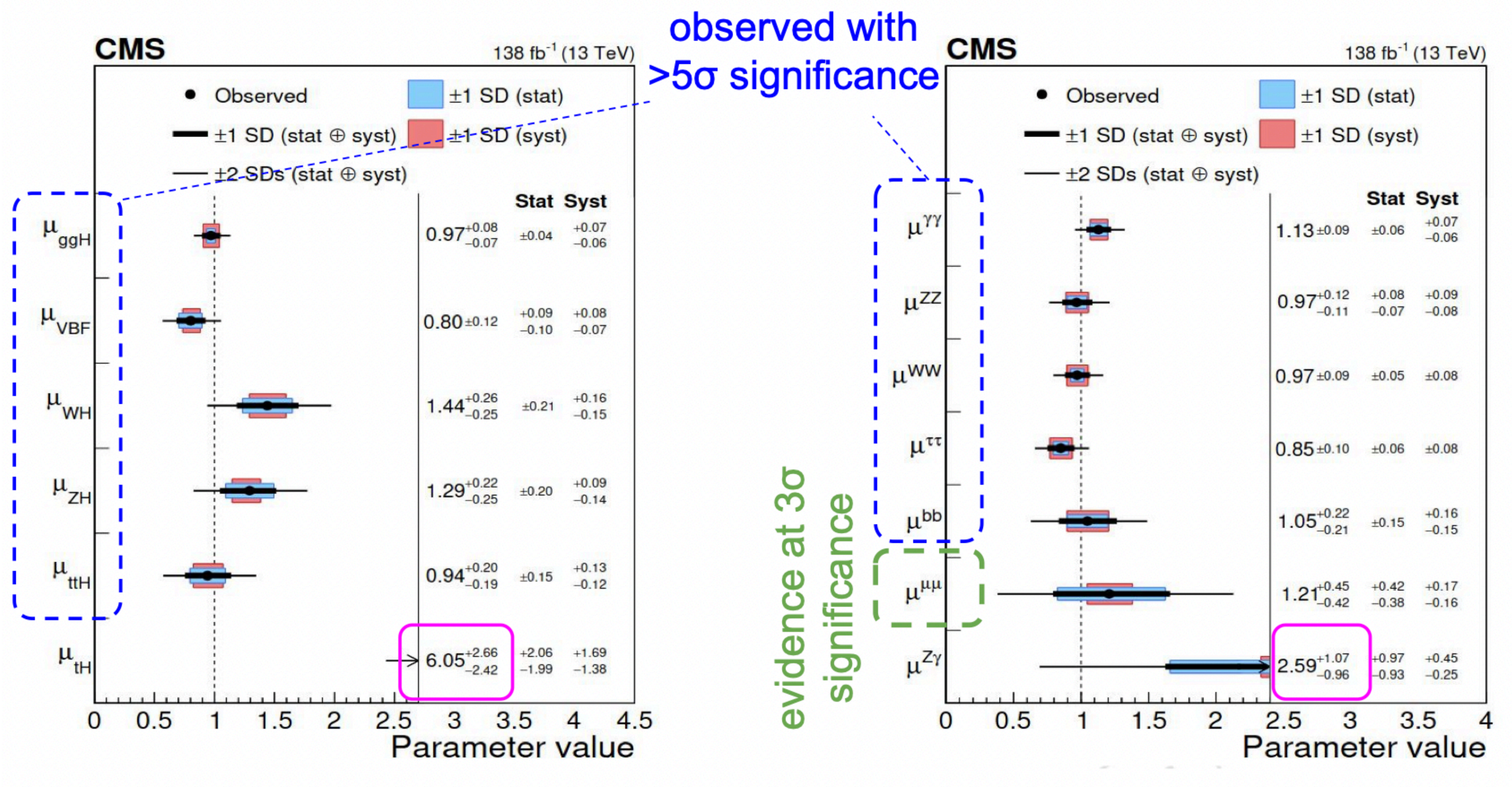
CMS
Fabio Monti

$$\mu = 1.05 \pm 0.06 = 1.05 \pm 0.03\,(\text{stat.}) \pm 0.03\,(\text{exp.}) \pm 0.04\,(\text{sig. th.}) \pm 0.02\,(\text{bkg. th.}).$$

ATLAS
Paolo Francavilla

- Both ATLAS and CMS measure 1 within an uncertainty of 6%.
- Notice also exp and theory sys errors went down by ~x2 since Run-1

Production and decay modes



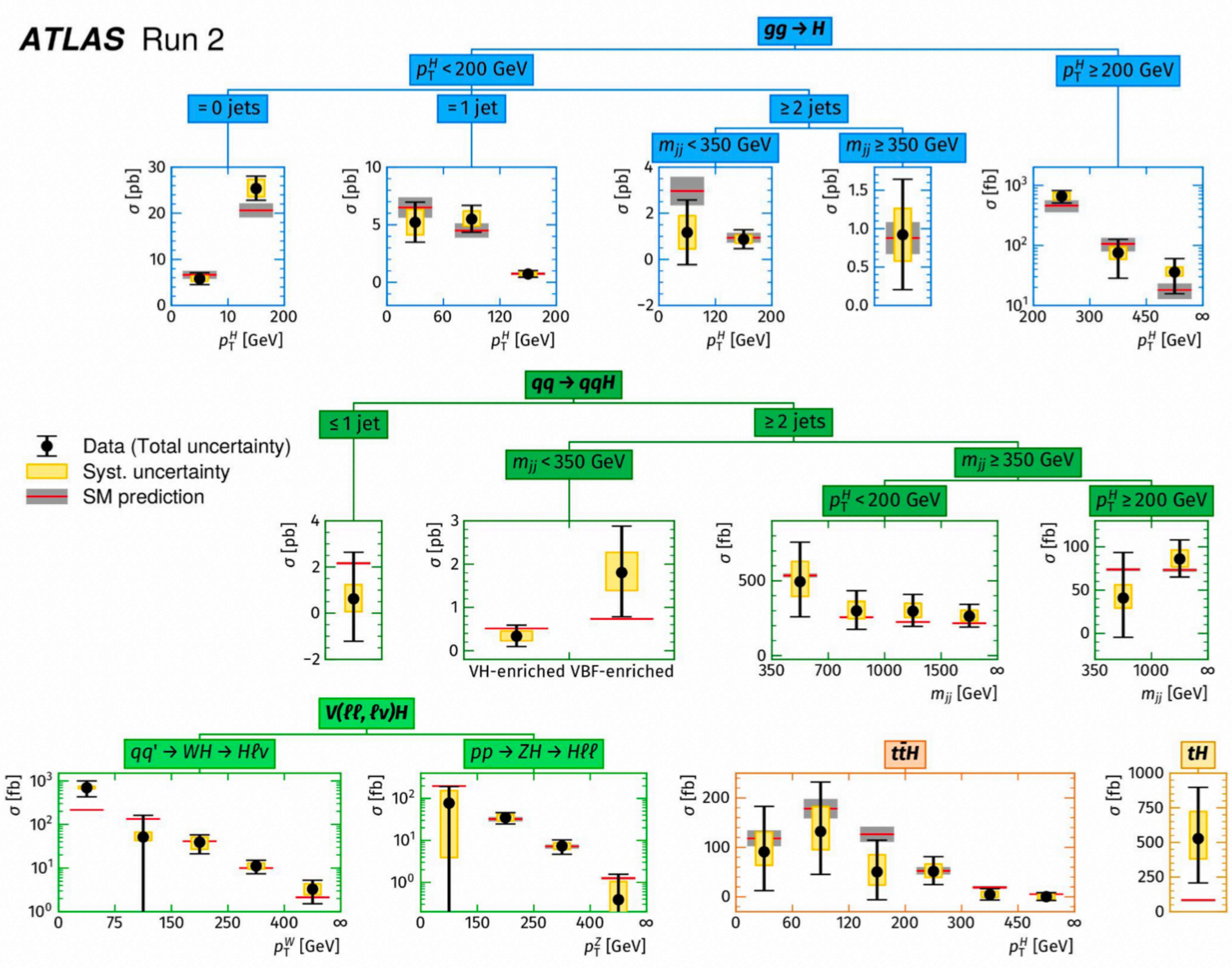
Fabio Monti

- All measurements by ATLAS and CMS compatible with SM prediction.
- Both ATLAS and CMS see a first hint of Zγ (CMS: 2.7σ, ATLAS: 2.2σ), compatible with SM expectations at the 1-1.5σ level.

Maxime Gouzevitch

Simplified Template Cross Sections (STXS)

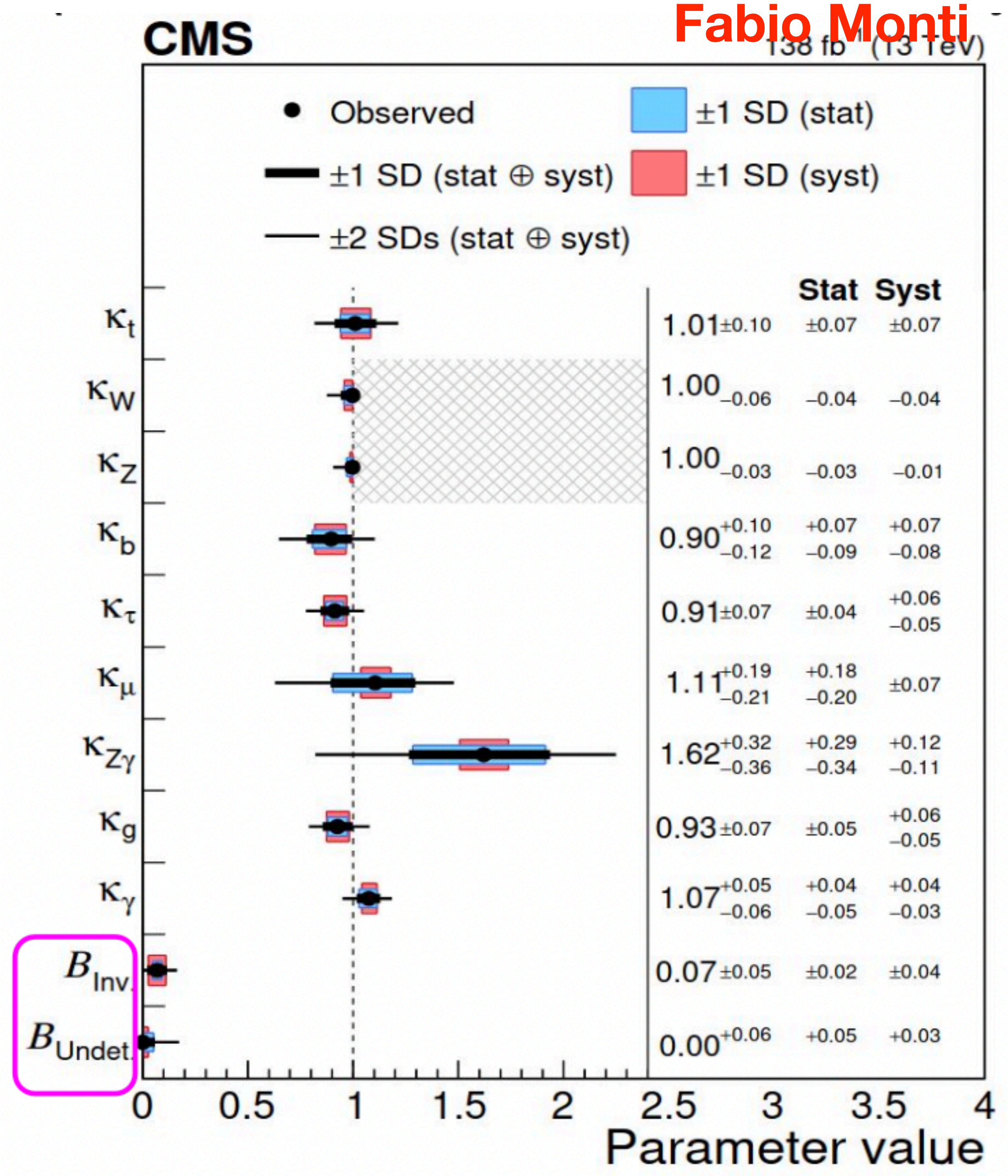
Paolo Francavilla



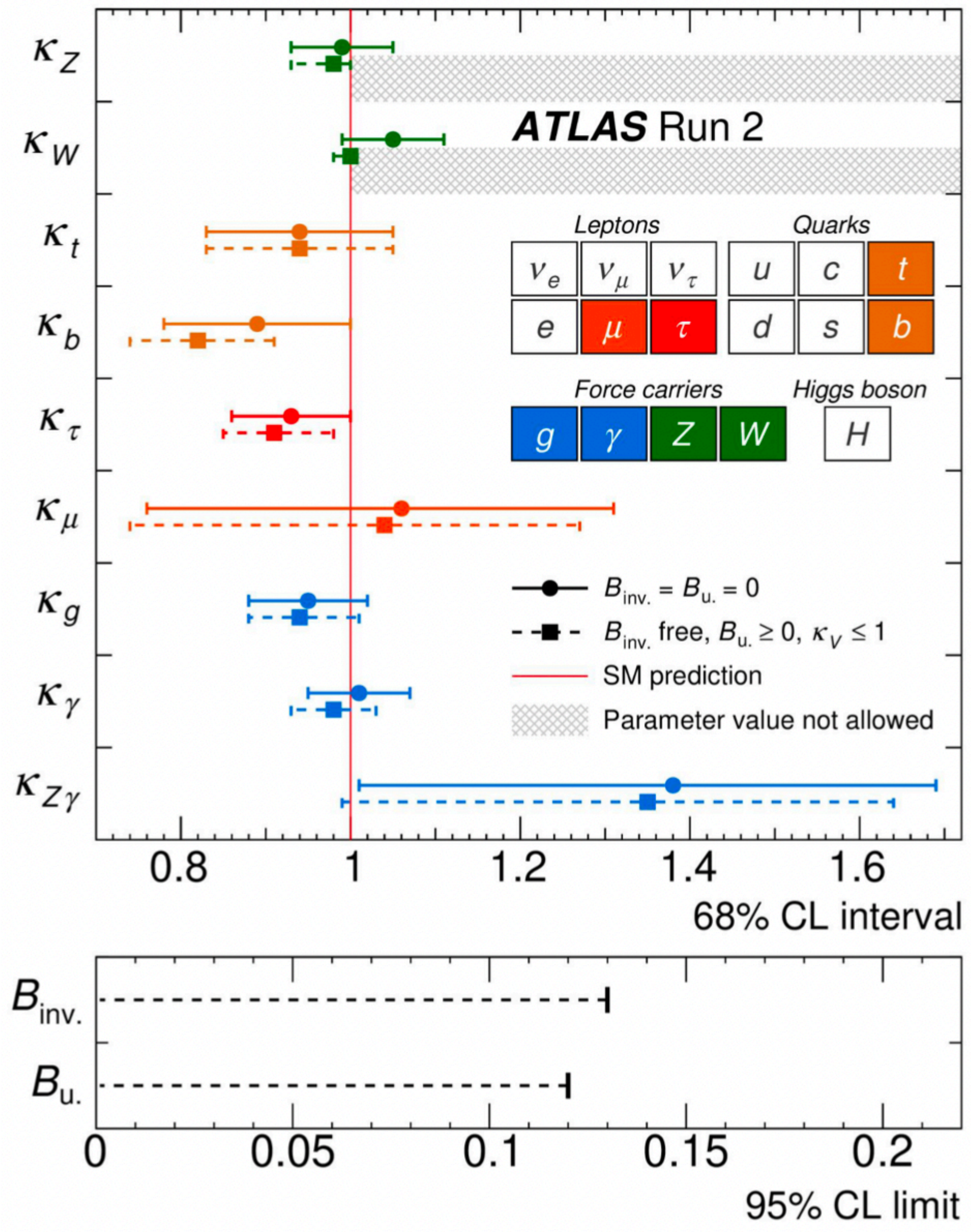
- Combined results differential in STXS granularity shows impressive progress.
- But again, no sign of a discrepancy with the SM.

Couplings in kappa framework and $BR_{inv,und}$

Fabio Monti



Paolo Francavilla



- Full Run-2 precision (with most channels):
  - $\kappa_Z, \kappa_W \approx 5\,\%$
  - $\kappa_\tau \approx 8\,\%$
  - $\kappa_b, \kappa_t \approx 10\,\%$
  - $BR_{inv/und} < 10-15\,\%$ @ 95% CL
- Combination of ATLAS and CMS will improve this!

- Reminder: we cannot directly measure the total width at the LHC, thus we need an additional assumption to determine BR_{und}, e.g. $|\kappa_V| < 1$.

EFT interpretation in STXS framework

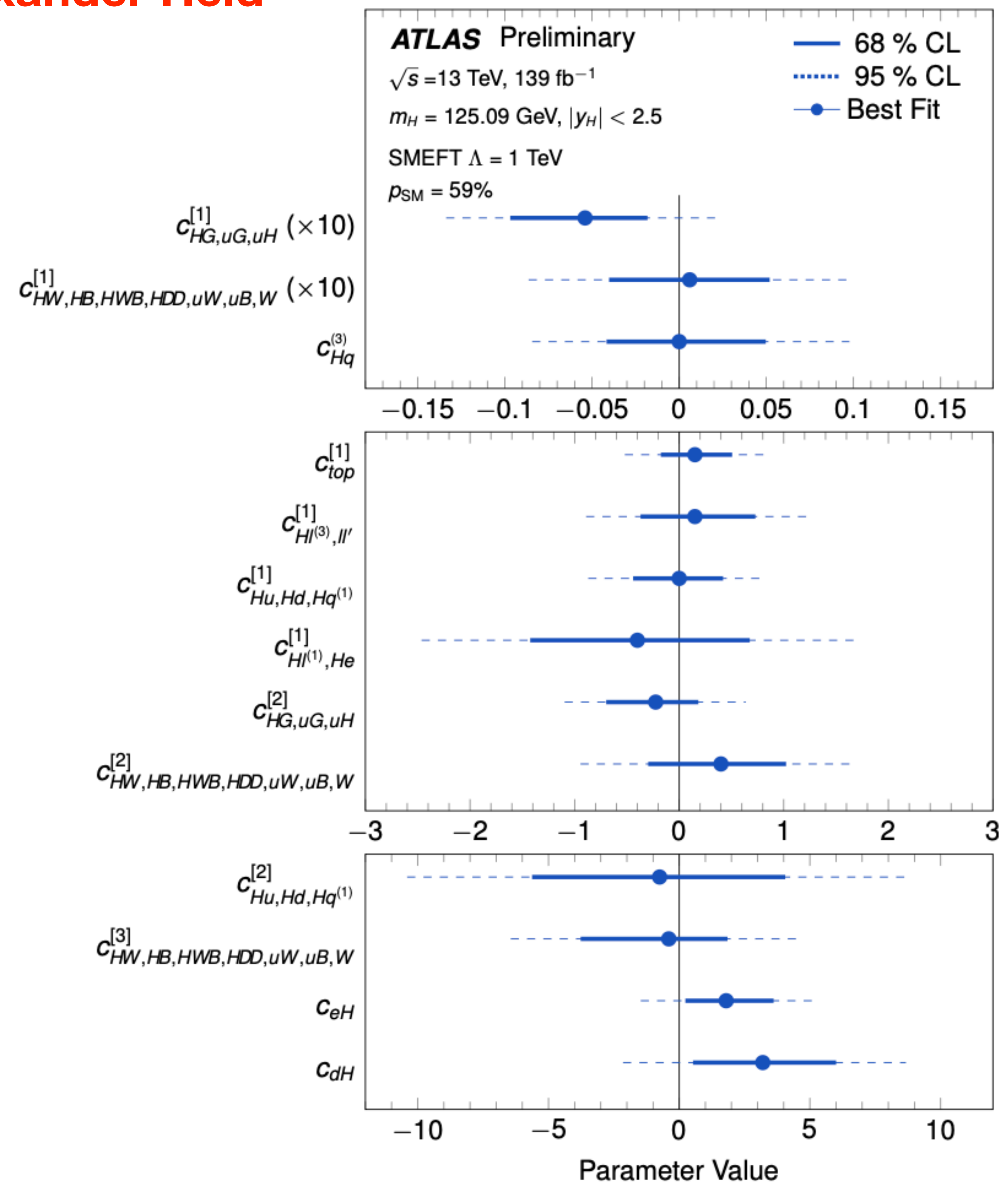
Alexander Held

- Beyond kappa framework (SMEFT):

$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum \frac{c_i}{\Lambda^2} \mathcal{O}_i^{d=6} + \ldots$$

- Down to 32 parameters with flavor + CP assumptions.
- Signal strength per STXS bin parameterized as function of Wilson coefficients (SMEFT, Warsaw basis)
- 28 (linear) combinations of parameters are found to which the data are sensitive
  - No significant impact from other parameters

results (using linear model)



Search for additional scalar bosons

Search for additional scalar bosons

A whole suite of new results by ATLAS and CMS

CMS (Yiwen Wen)

Model	Channel	Reference
2HDM	$H^+ \to H\, W^+$	arXiv:2207.01046
MSSM	$\phi \to \tau\tau$	arXiv:2208.02717
2HDM/MSSM	Heavy $H \to W^+W^-$	CMS-PAS-HIG-20-016
NMSSM + TRSM	$X \to YH \to bb\gamma\gamma$	CMS-PAS-HIG-21-011
	$X \to YH \to bbbb$	arXiv:2204.12413
Singlet scalar	$V\phi$, $tt\phi$, $\phi \to ll/\tau\tau$	CMS-PAS-EXO-21-018

ATLAS (Xiaotong Chu)

$X \to \gamma\gamma$ ✓

✓ $H^{++}H^{--} \to 4l$

★ $H^{\pm} \to ZW \to 3l+\nu$

$ttH/A \to 4top$ ✓

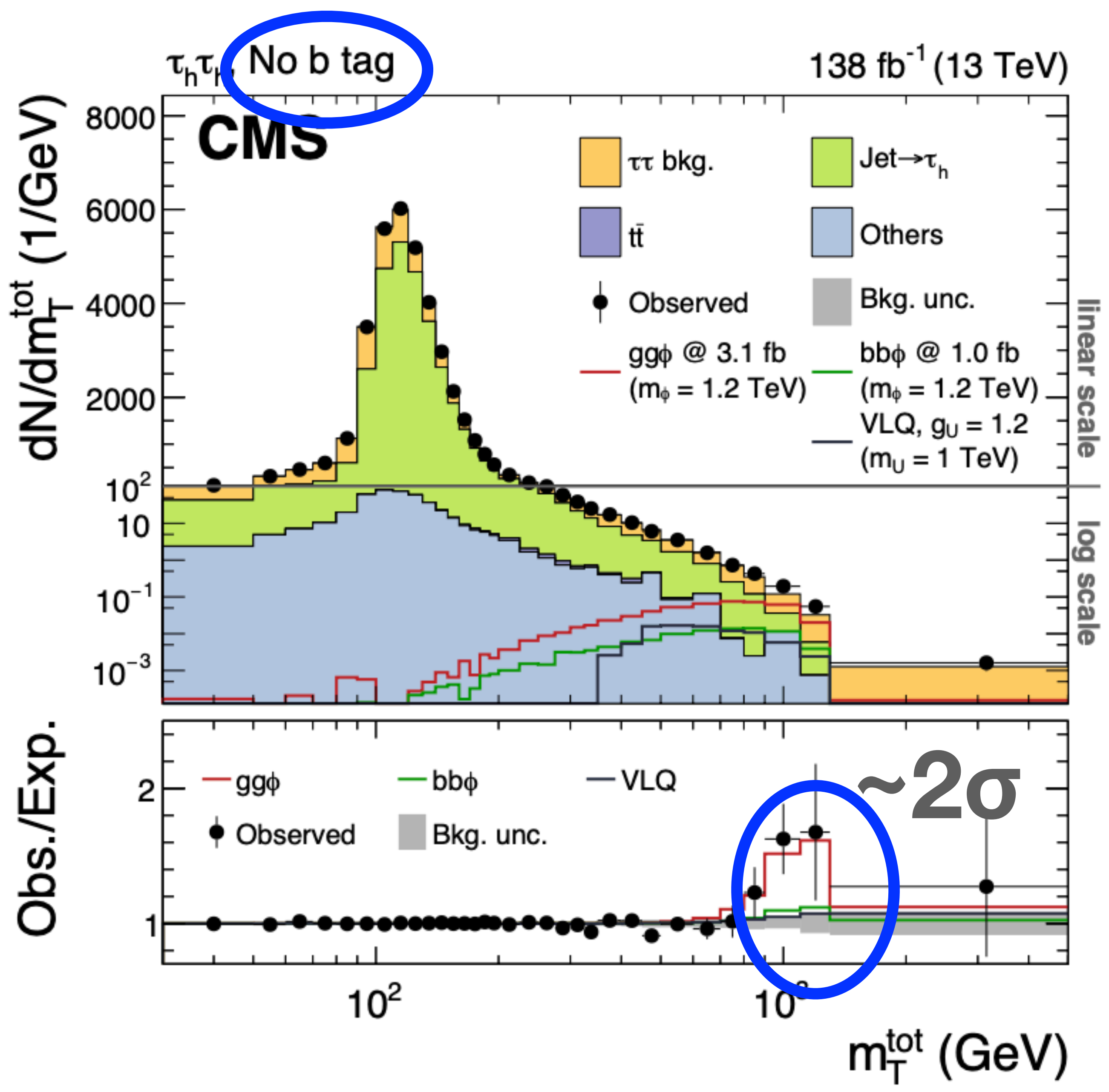
$t \to qX(\to bb)$ ✓

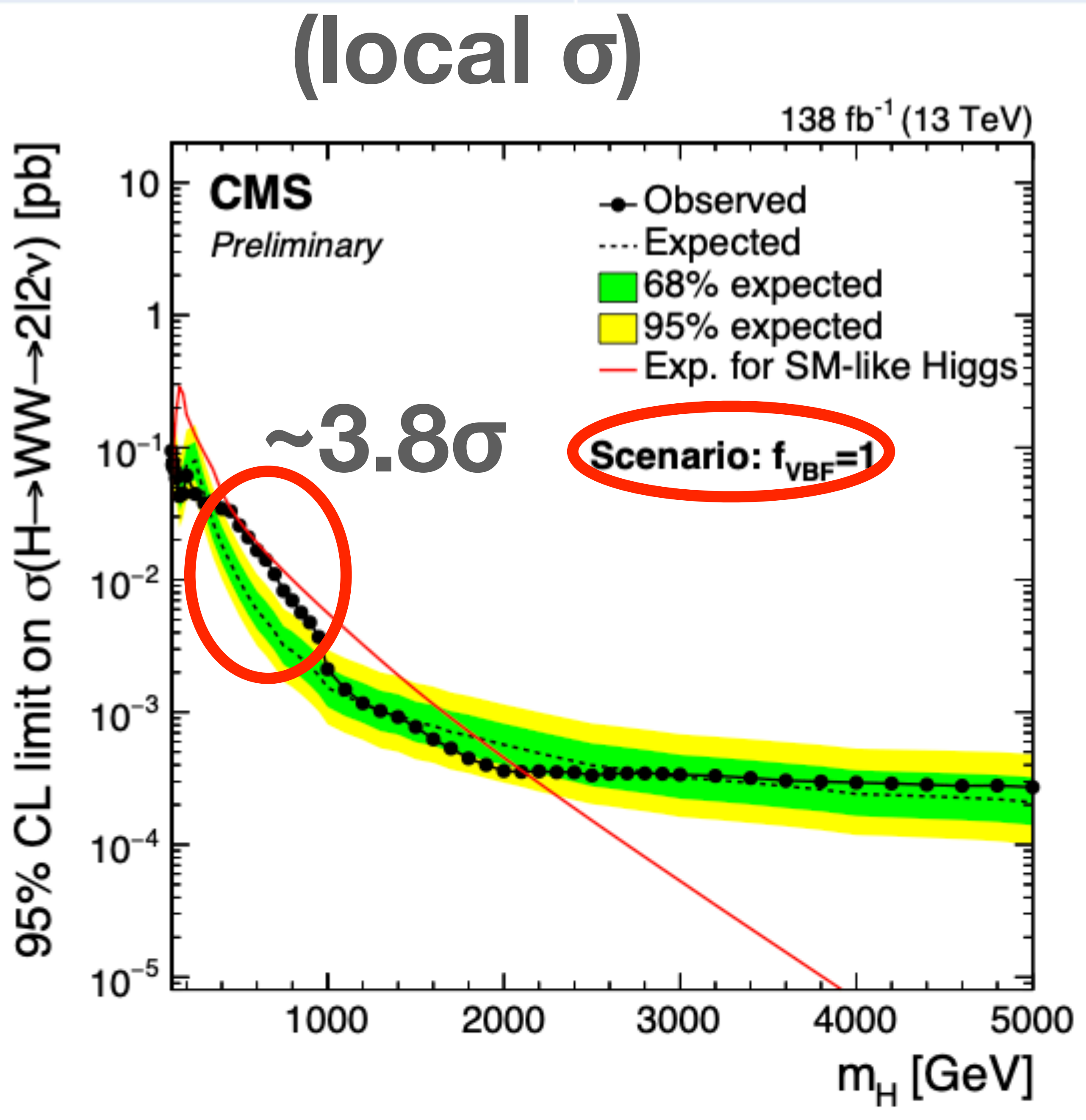
$WH(\to WW)$ ✓

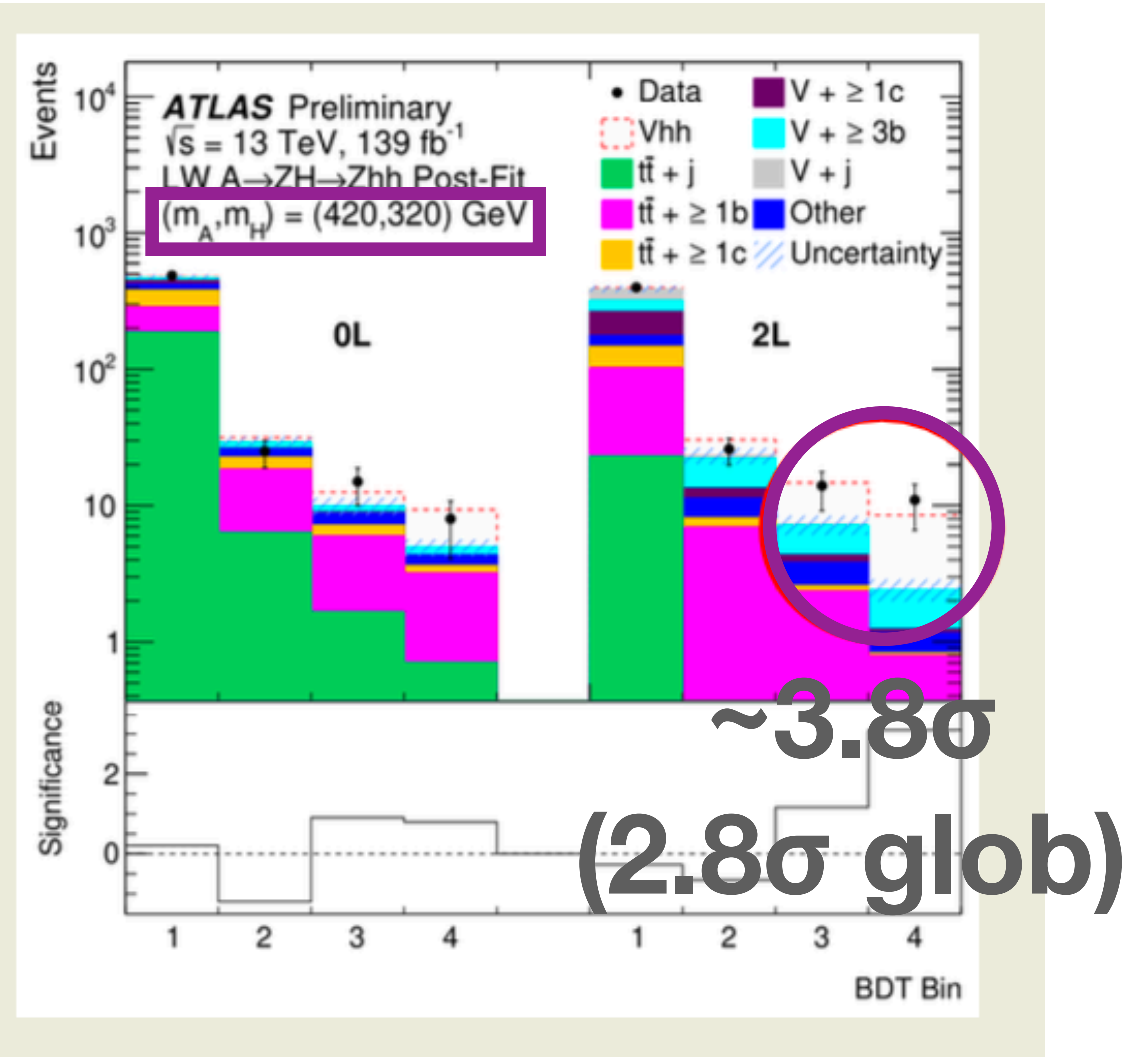
$H \to$ leptons+b-jets ✓

$A \to ZH(\to bb)$ ✓

$VH(\to hh)$ ★







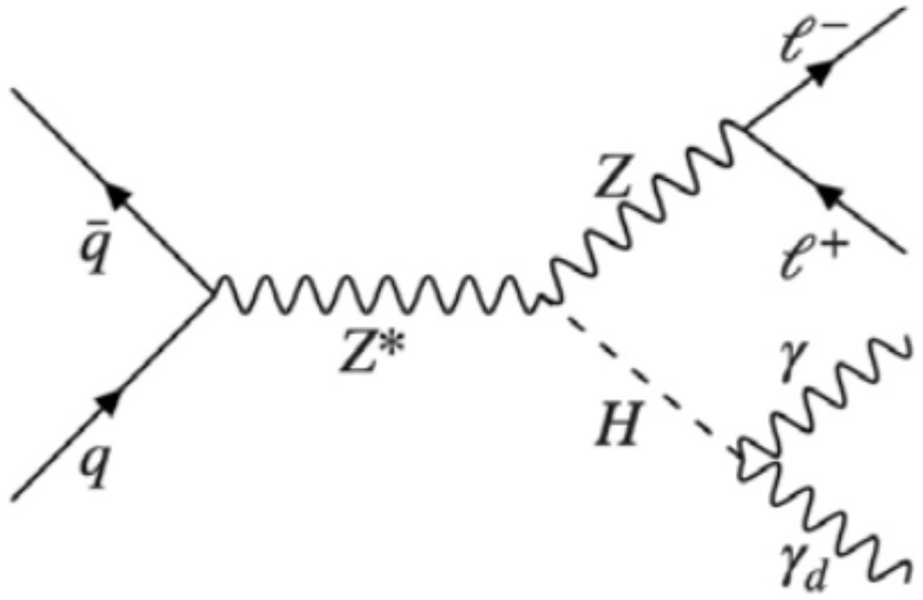
- Tantalizing hints got our theory colleagues excited!
  - Discussion about LEE [Bob Cousins]
- Run-3 may tell if anything behind

Search for rare and BSM decays

Search for rare decays - new results

Yuan-Tang Chou

$H \to \gamma \gamma_d$ (ATLAS)

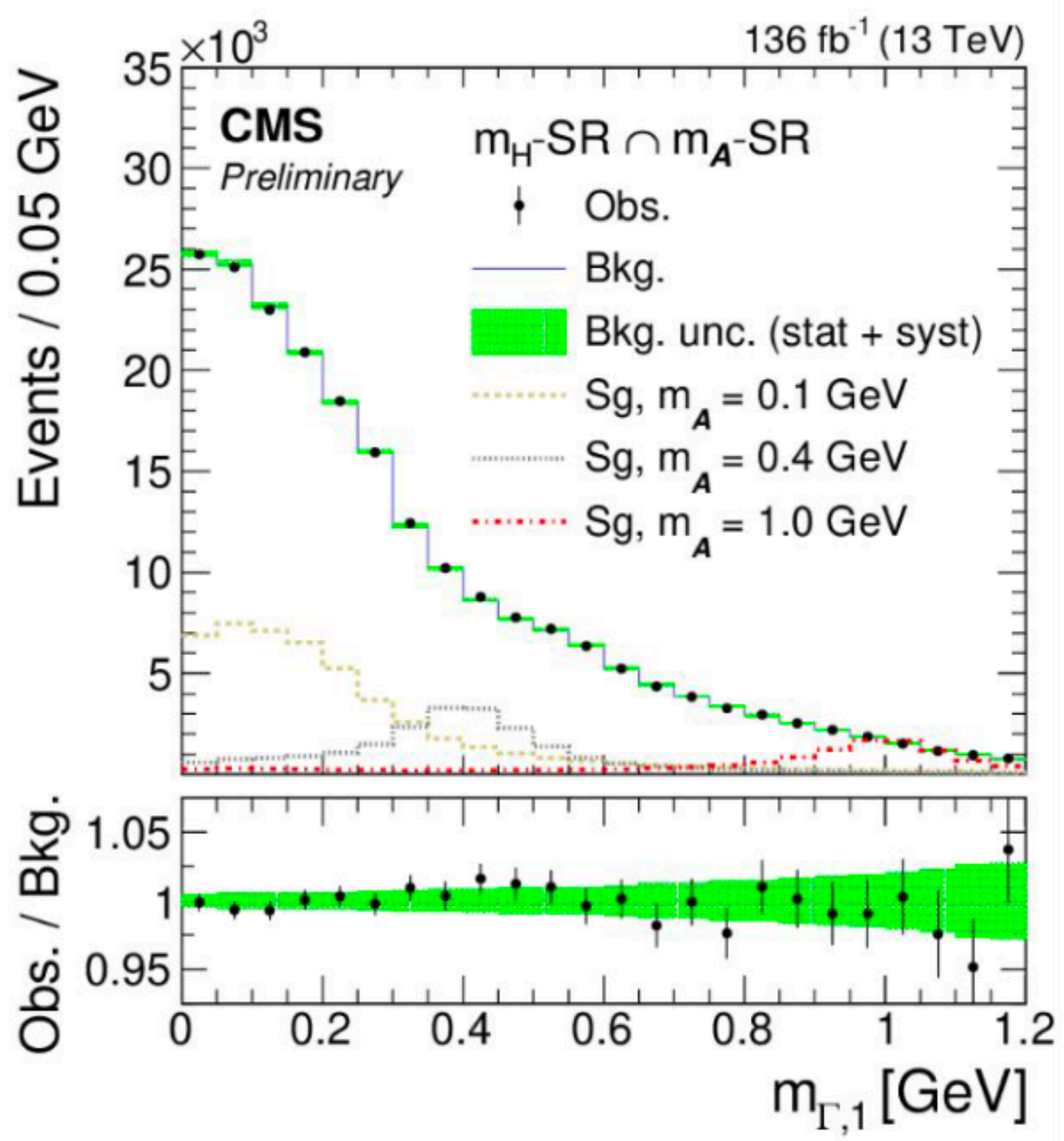


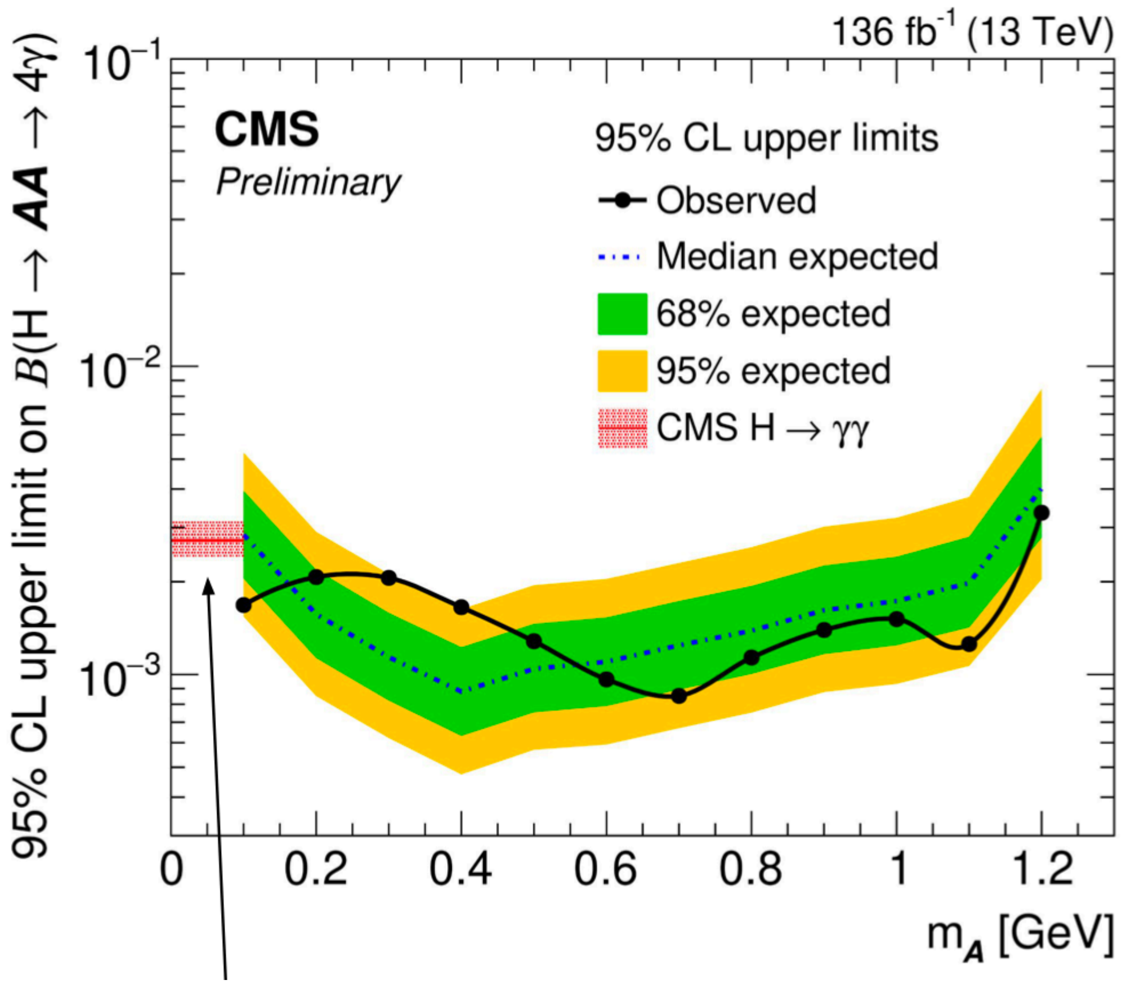
- Search for dark photons with mass 0-40 GeV
- No excess. Limit:
  - BR($\gamma \gamma_d$)<2.3% @ 95% CL

Maxime Gouzevitch

$H \to AA \to 4\gamma$ (CMS)

- Analysis made possible by novel DNN based reconstruction of merged photons (arXiv:2204.12313)
- Probe m_A<1.2 GeV (merged) or m_A>15 GeV (resolved)





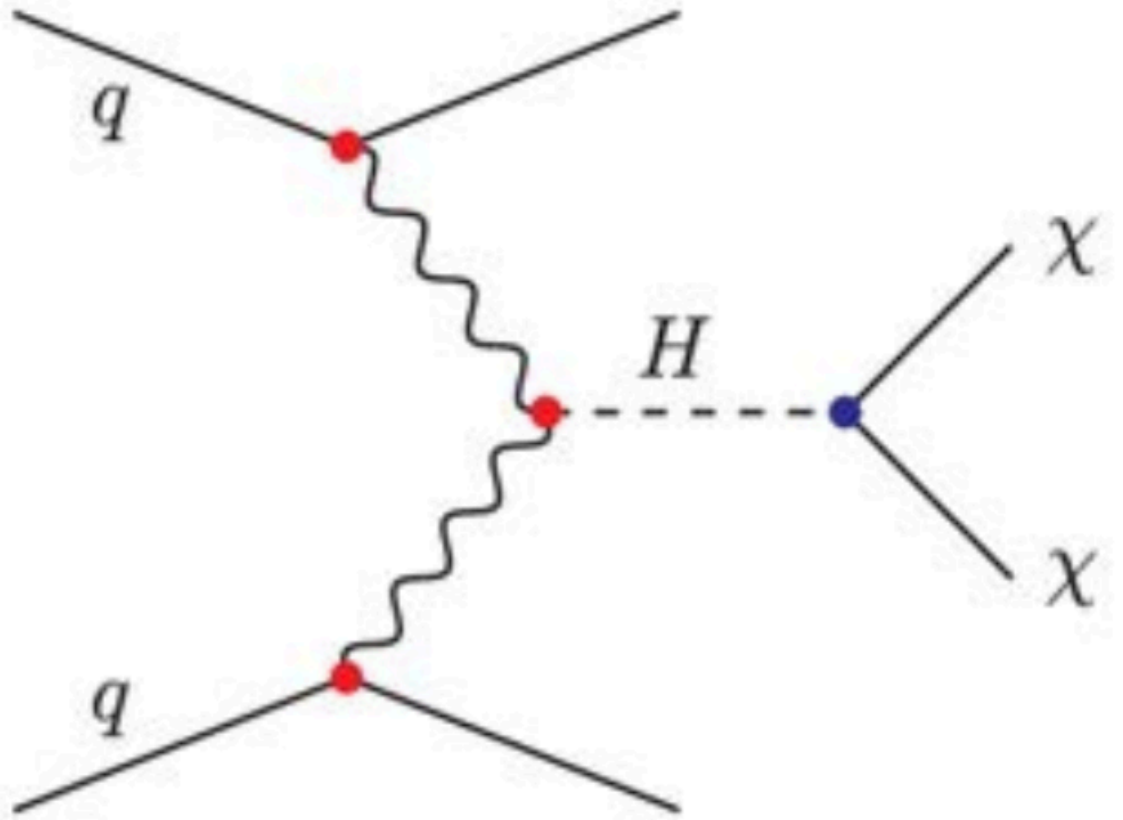
Limit from $H \to \gamma \gamma$

- Exclude BR < 0.9-3.3 10^{-3} @ 95% CL

Search for rare decays - new results (II)

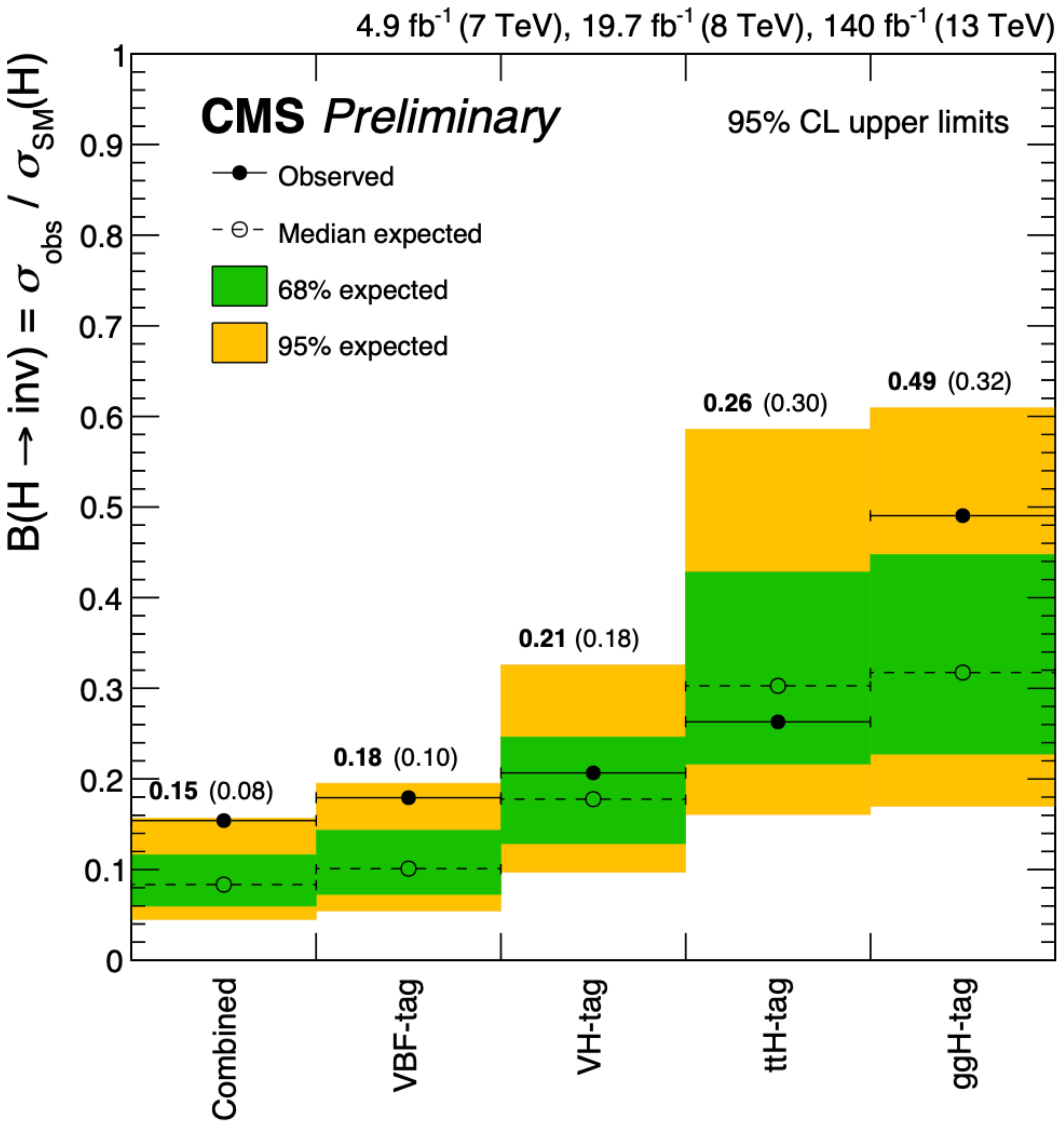
Olivier Davignon

H → invisible (CMS)



- VBF most sensitive mode
- Updated with combination of VBF and MET triggers, and improved bkg estimate
- Limit: BR<18% (10% exp) (ATLAS: <15% (10% exp))

- New combination with all main production modes:



VH(had)+ttH(had) NEW

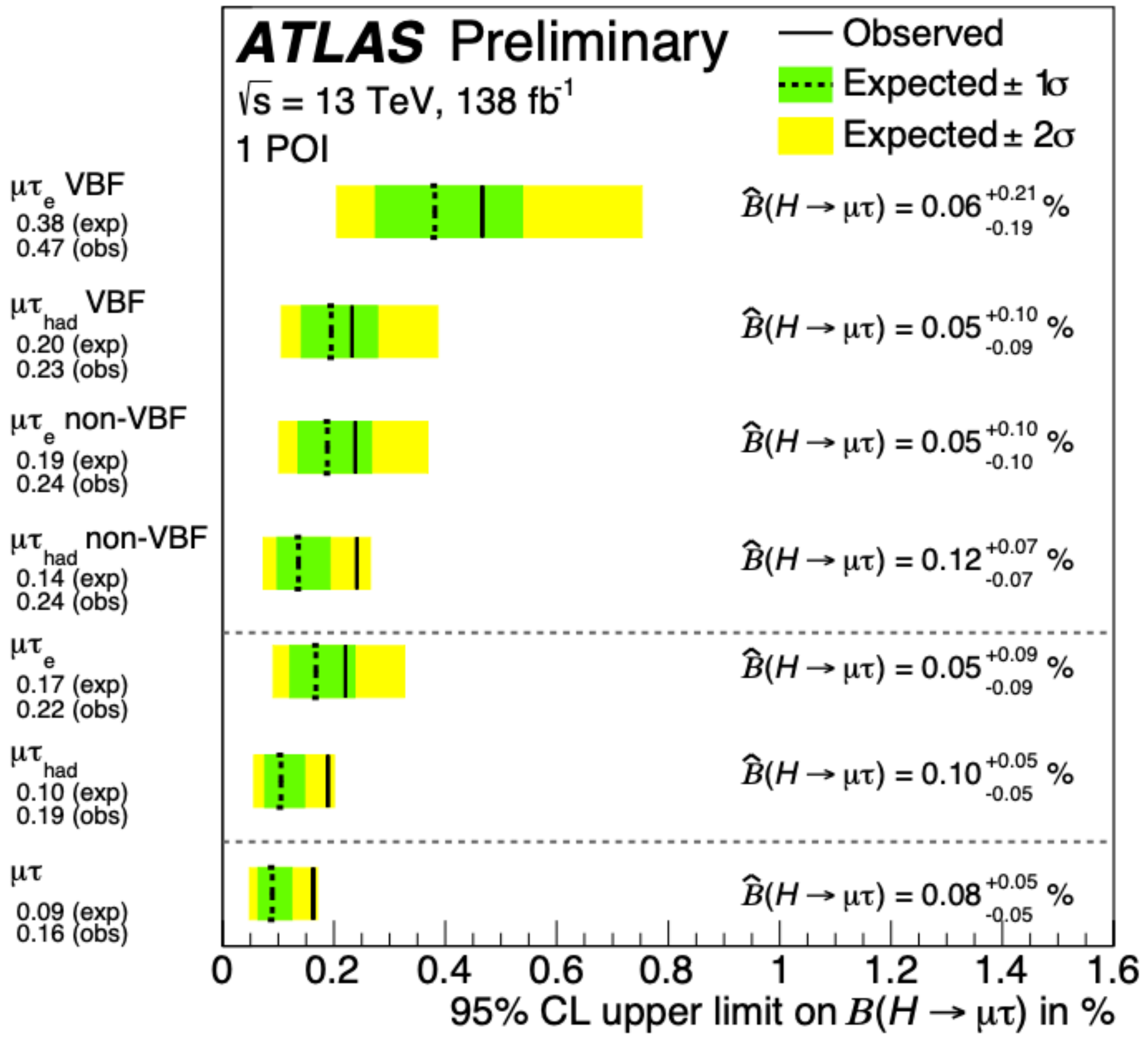
- Combined limit: BR<15% @ 95%CL (8% expected!!)
- Both ATLAS and CMS have slight excesses in the VBF analysis.

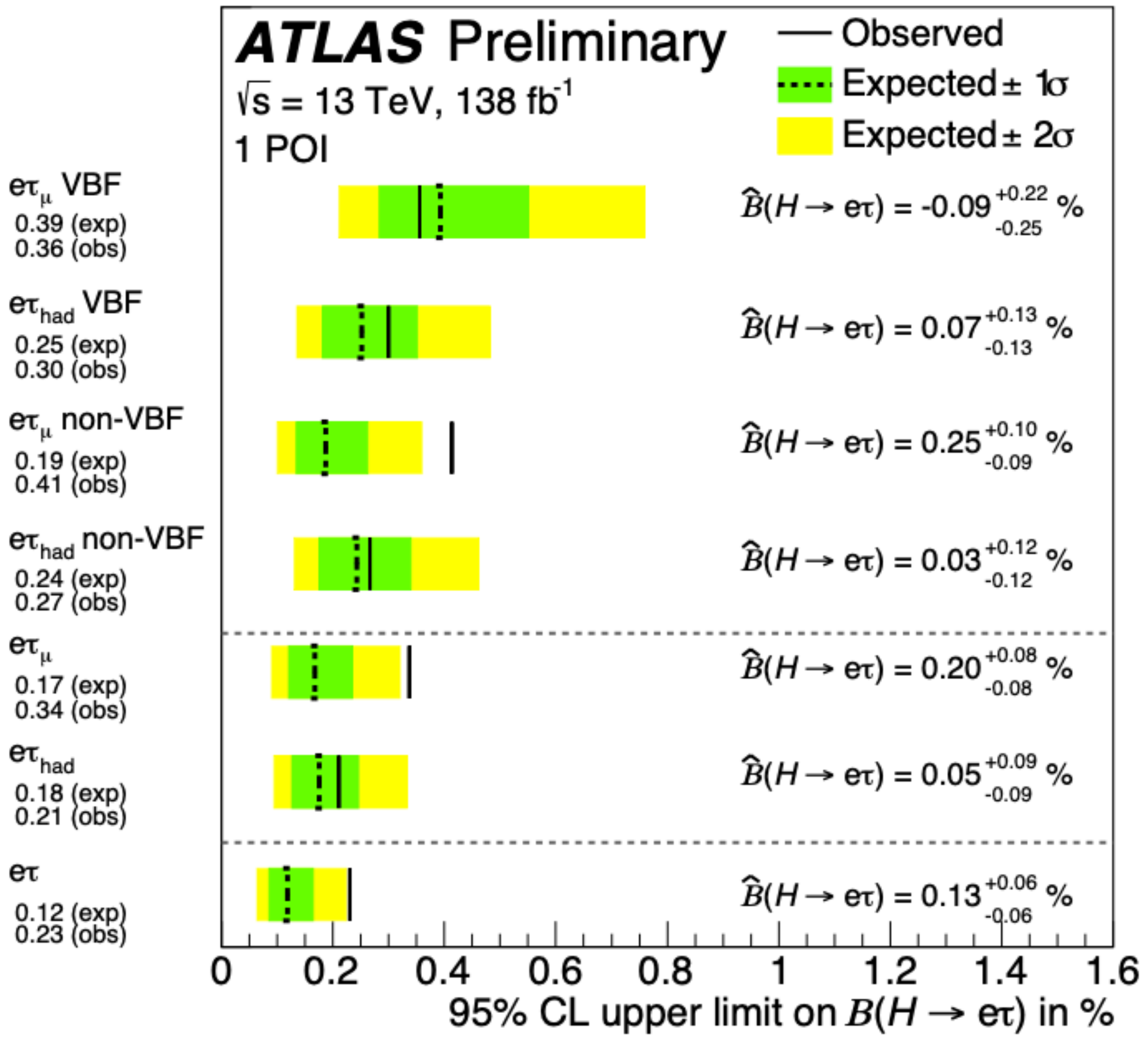
Search for rare decays - new results (III)

Antonio De Maria

H → eτ / μτ (ATLAS)

- Just released for Higgs Hunting!





$\text{BR}(e\tau) < \mathbf{0.19}\,\%\ (\mathbf{0.11}\,\%\ \text{exp.})$

$\text{BR}(\mu\tau) < \mathbf{0.18}\,\%\ (\mathbf{0.09}\,\%\ \text{exp.})$

Maxime Gouzevitch

(CMS)

- Limits comparable to full Run-2 CMS results:

$\text{BR}(e\tau) < \mathbf{0.22}\,\%\ (\mathbf{0.16}\,\%\ \text{exp.})$

$\text{BR}(\mu\tau) < \mathbf{0.15}\,\%\ (\mathbf{0.15}\,\%\ \text{exp.})$

CP-structure of Higgs couplings

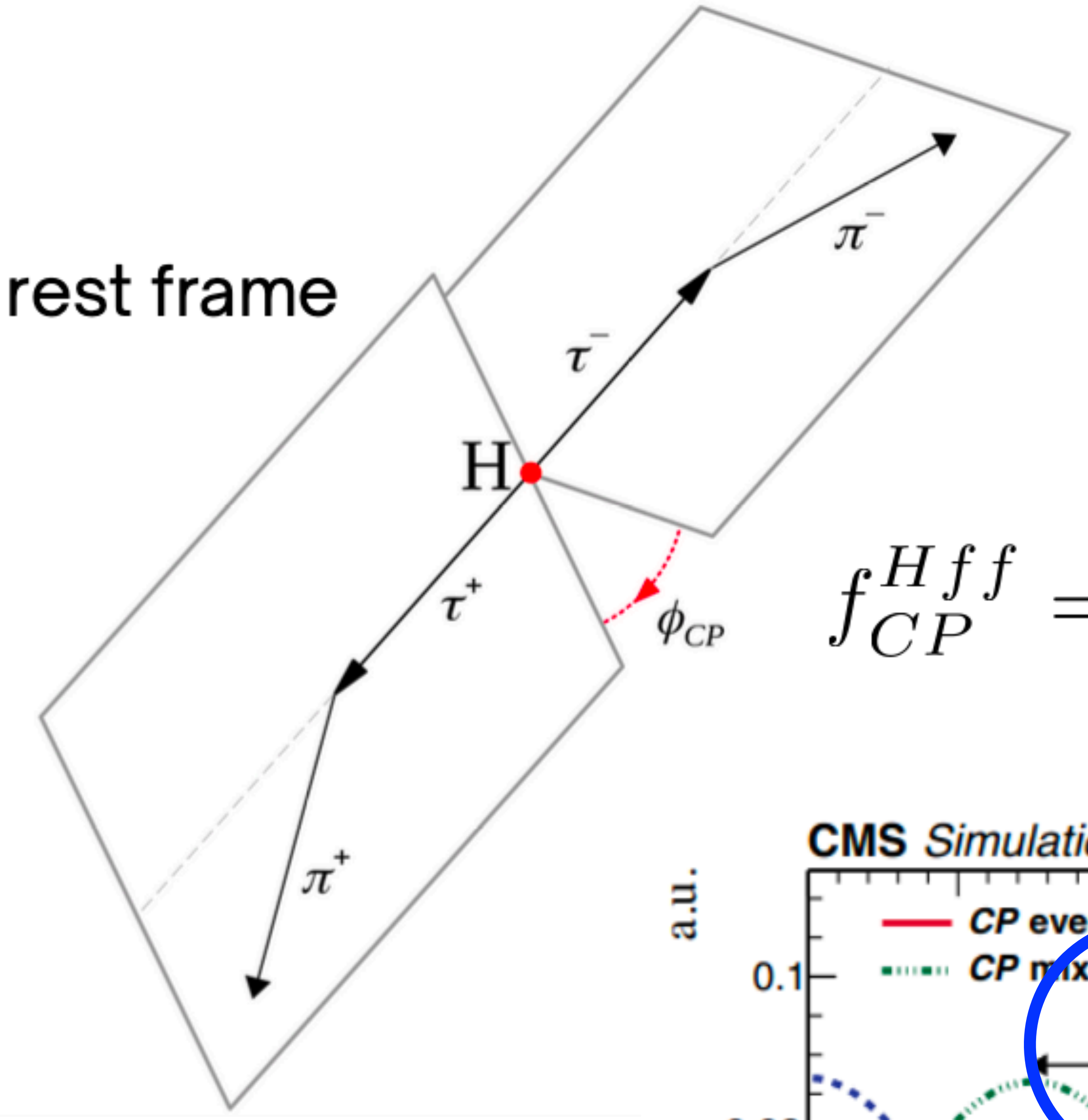
- Sakharov conditions require C and CP violation as necessary (but not sufficient) condition for baryogenesis
- CP violation in CKM sector is very small! (talk by M. Carena)
- Due to lack of time, will focus on coupling to fermions:

$$L_Y = -\frac{m_f \phi}{v}(\kappa_f \overline{\psi_f}\psi_f + \tilde{\kappa}_f \overline{\psi_f} i\gamma_5 \psi_f)$$

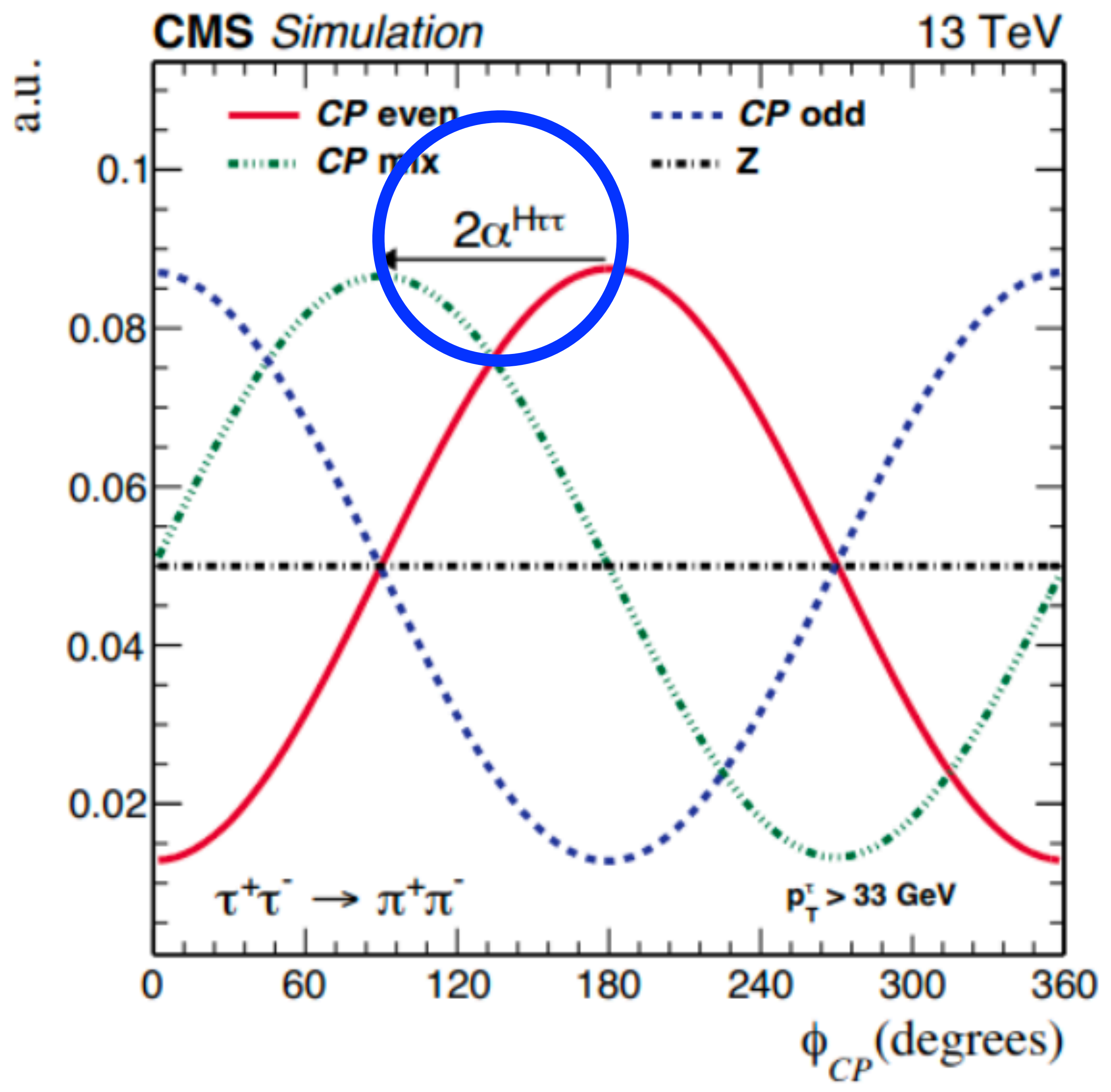
Measuring CP in H → ττ decay

- Measure angle between decay planes

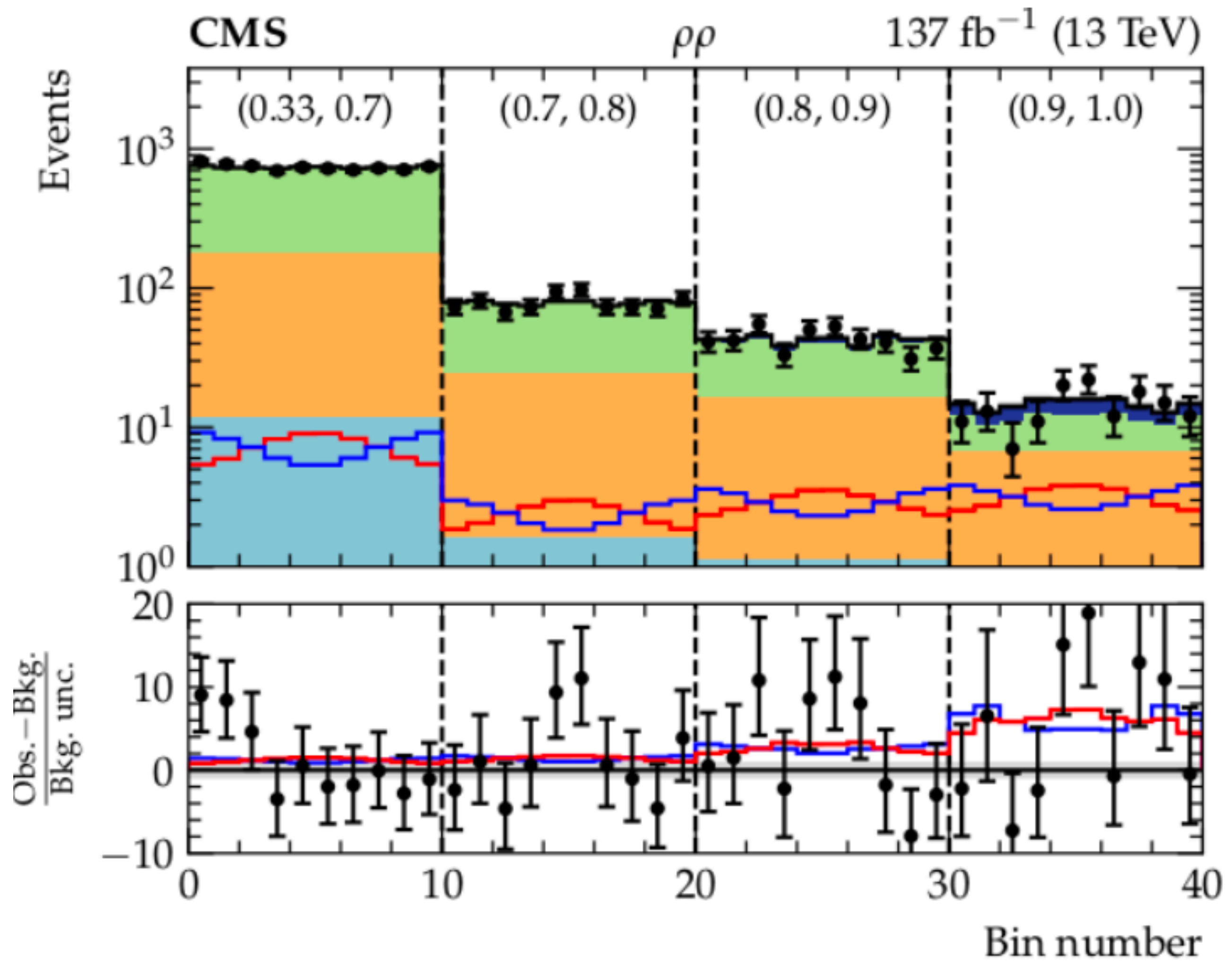
Higgs rest frame



$$f_{CP}^{Hff} = \frac{|\tilde{\kappa}_f|^2}{|\kappa_f|^2 + |\tilde{\kappa}_f|^2} = \sin^2(\alpha^{Hff})$$



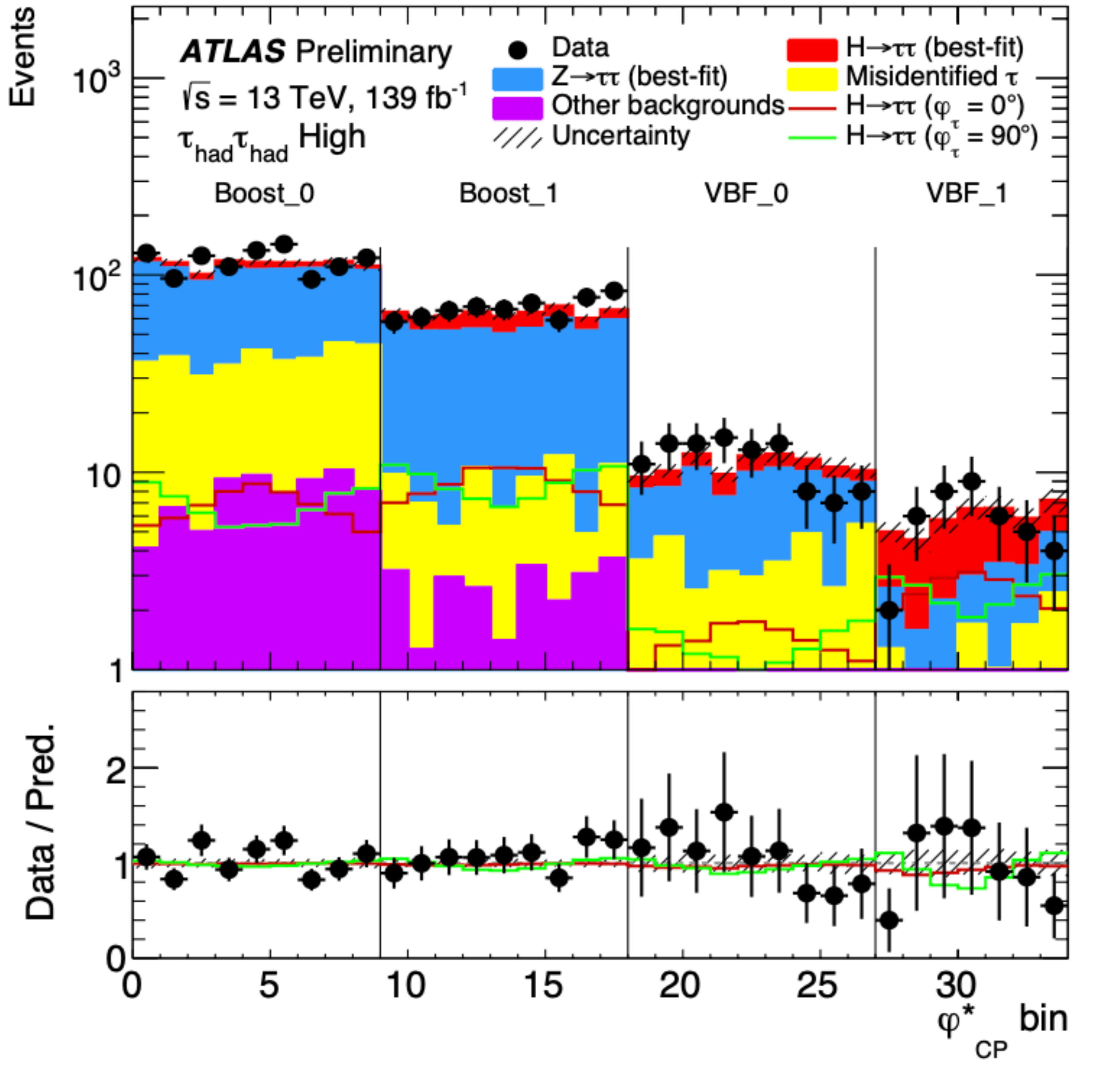
Marco Sessini, Andrea Cardini



α(Hττ) = 9 ± 16°

CP-odd hypothesis excl. at 3.4σ (2.1σ exp)

Ricardo Gonçalo



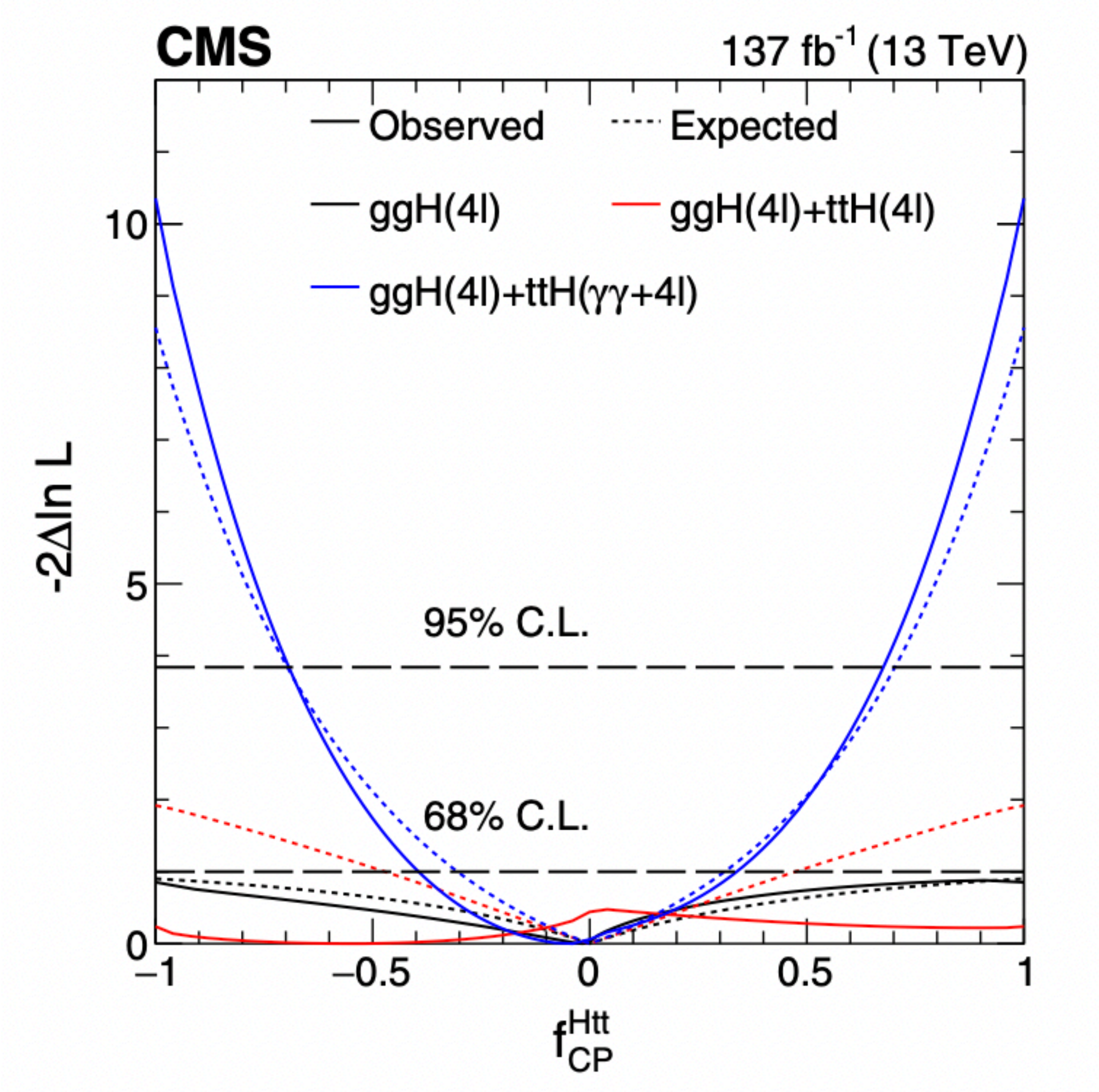
α(Hττ) = -1 ± 19°

CP-odd hypothesis excl. at 3.4σ (2.1σ exp)

Measuring CP in ttH/tH production

Andrea Cardini

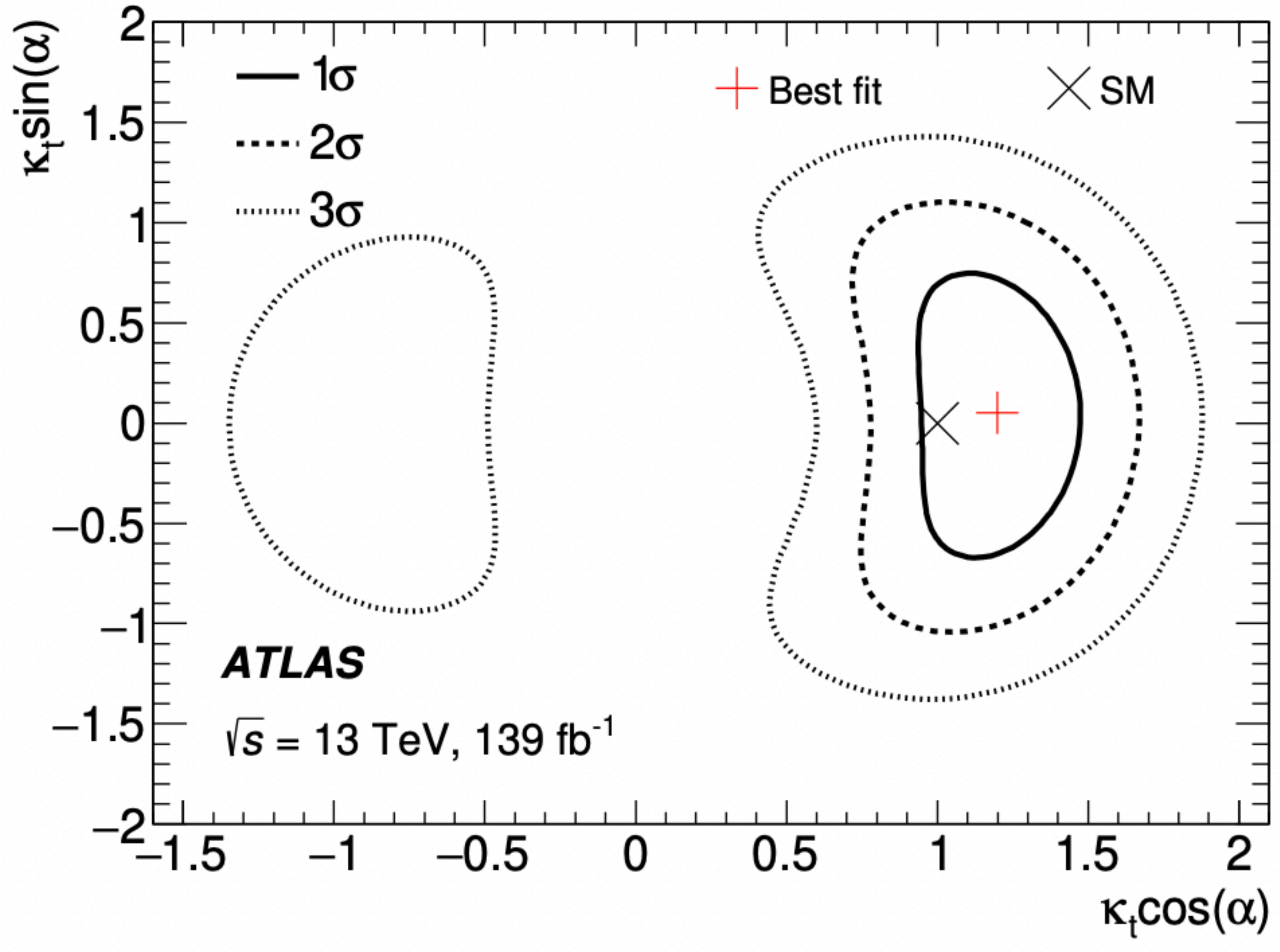
- H → γγ and ZZ



- CP-odd excluded at 3.2σ (2.7σ exp.)
- Simultaneous fit also with CP-even and CP-odd ggF

Ricardo Gonçalo

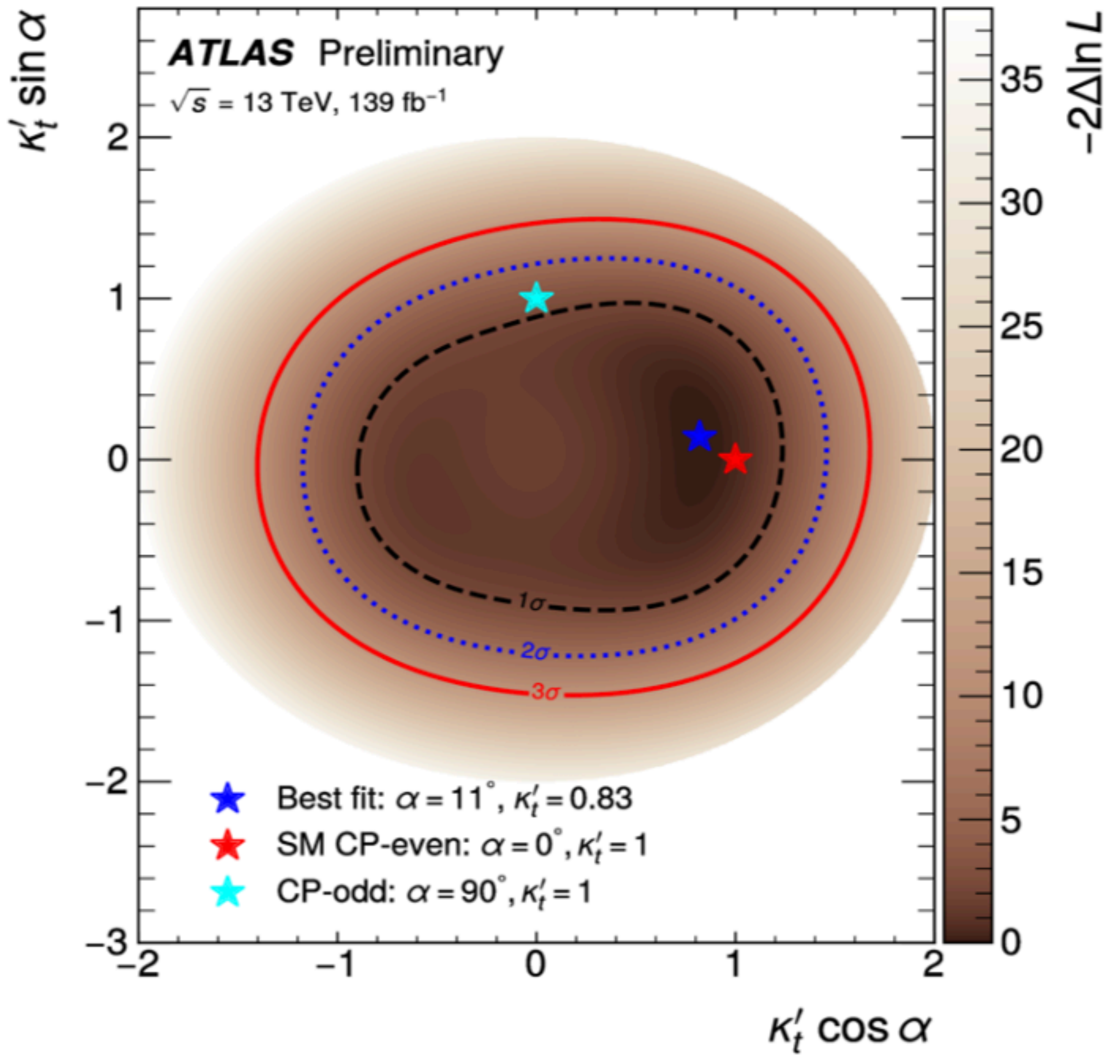
- H → γγ



- CP-odd excluded at 3.9σ (2.5σ exp.)

Neelam Kumari

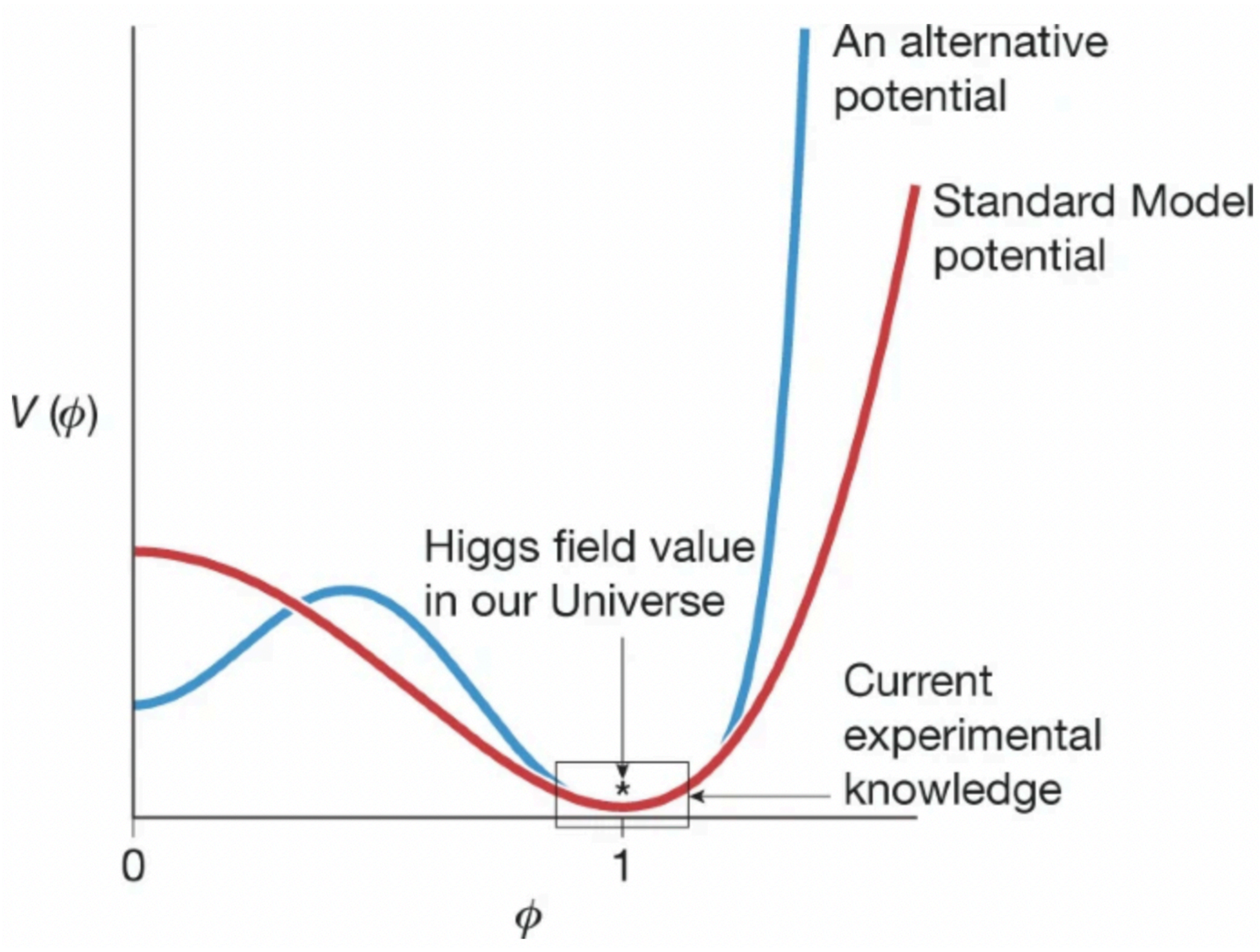
- H → bb



- New CP sensitive variables defined
- ttbb background modelling challenging! (e.g. 4F vs 5F)

Probing the Higgs boson self-coupling

[G. Salam, Nature 607, 41–47 (2022)]



$$V(\phi) = V_0 + \frac{1}{2} m_H^2 + \lambda \nu H^3 + \frac{1}{4} \lambda H^4$$

- Shape of Higgs potential crucial e.g. to understand whether EW baryogengesis may explain matter anti-matter asymmetry in our Universe [talk by M. Carena]

Search for HH - latest combinations

- Main search modes:

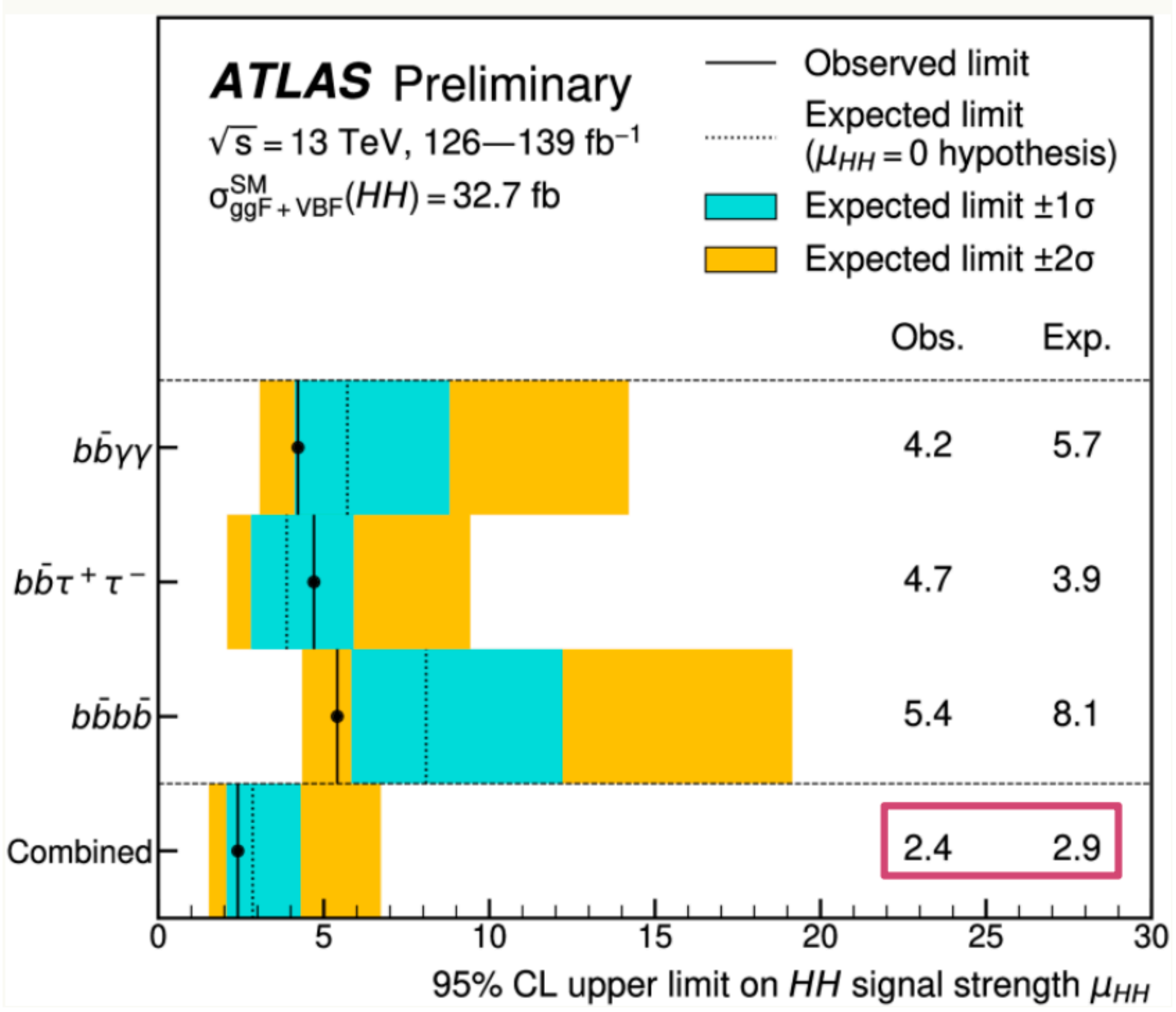
	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

[K. Leney]

- Full Run-2 results from both ATLAS and CMS

Zhe Yang

ATLAS

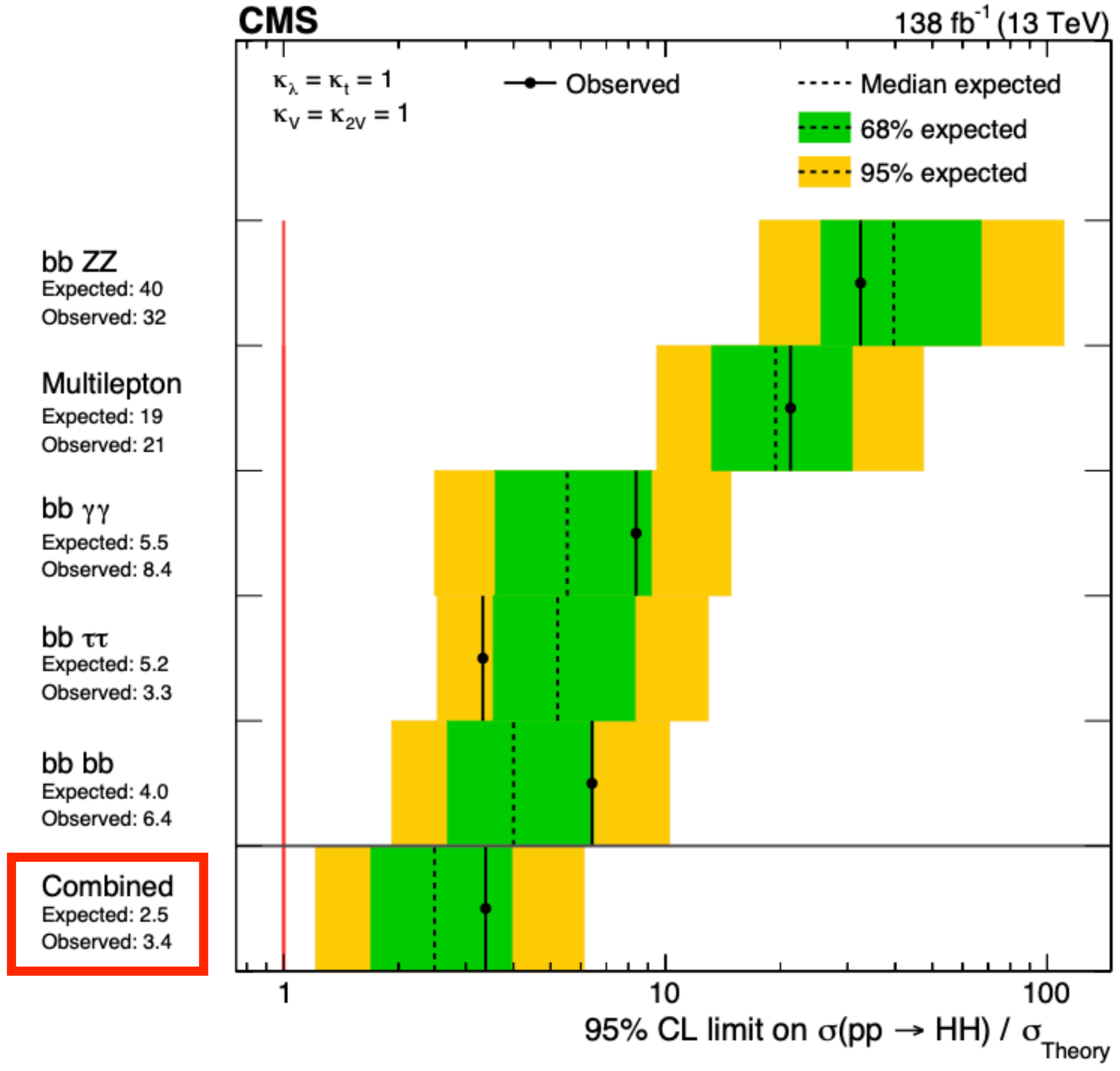


ATLAS: σ/σ_{SM} < 2.4 (2.9), obs (exp)

Marcel Rieger

CMS

Nature 607 (2022) 60



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[K. Leney]

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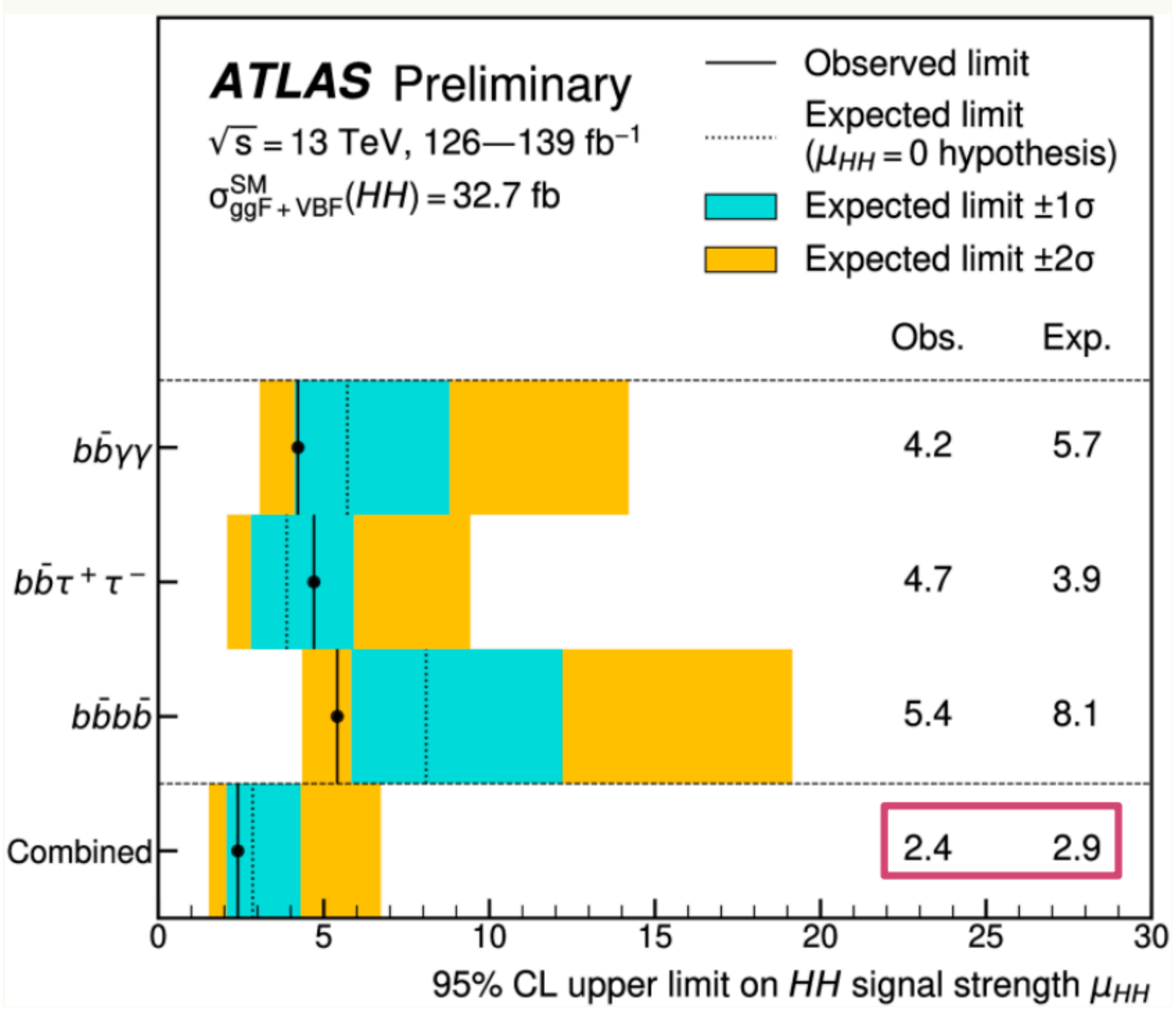


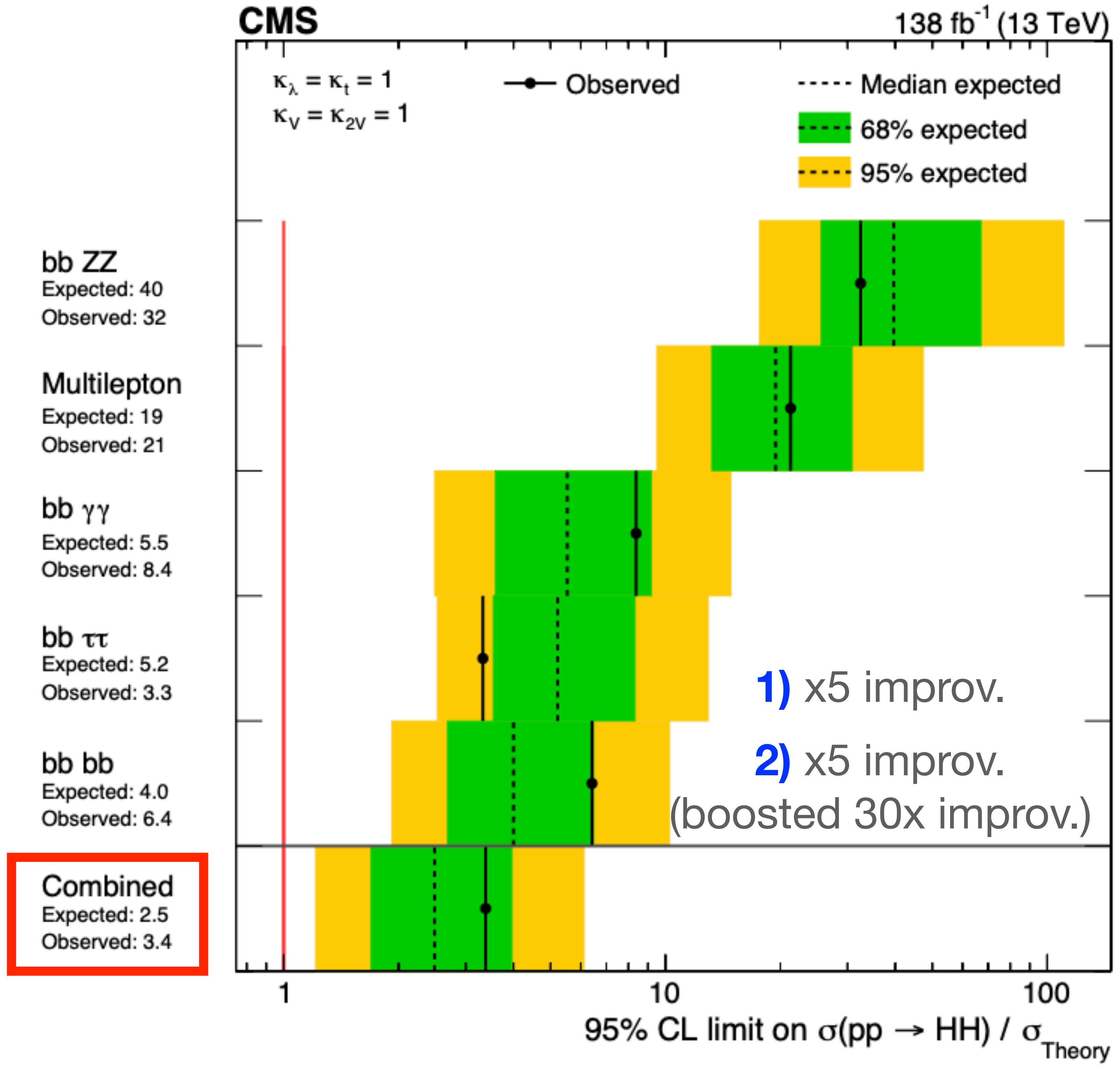
ATLAS: σ/σ_{SM} < 2.4 (2.9), obs (exp)

3) combination with single-H

Marcel Rieger

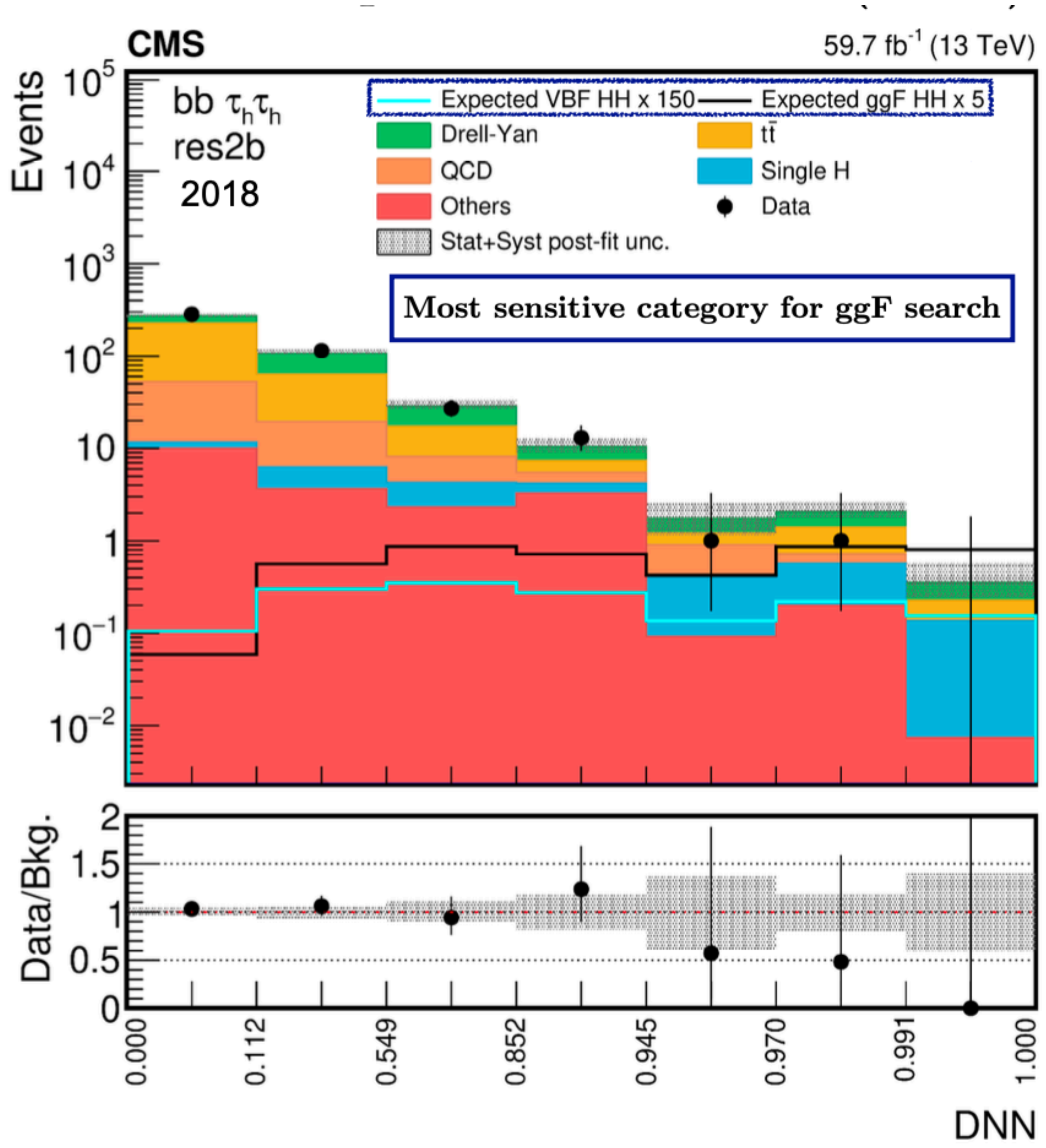
CMS

Nature 607 (2022) 60

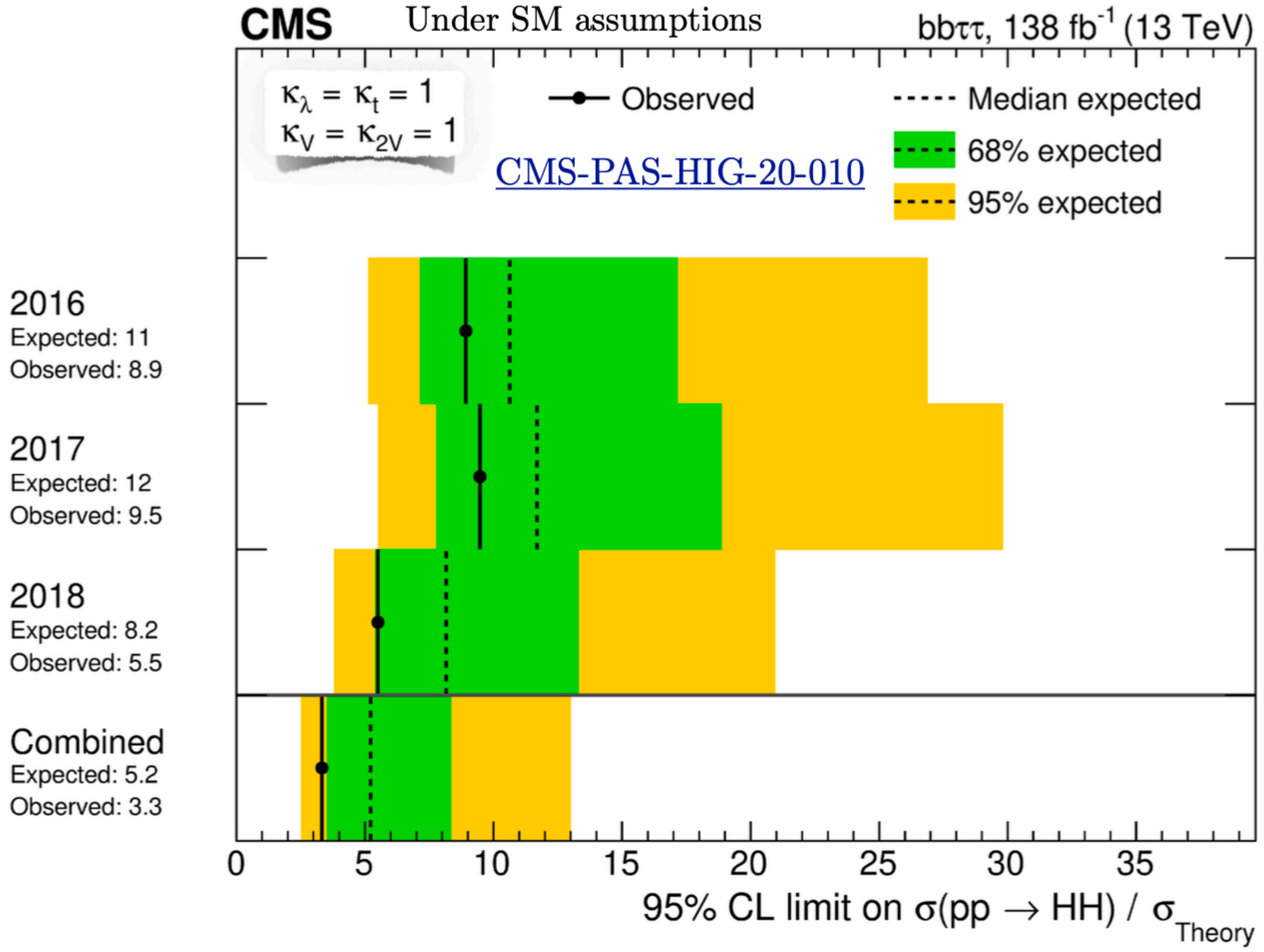


CMS: σ/σ_{SM} < 3.4 (2.5), obs (exp)

HH → bbττ



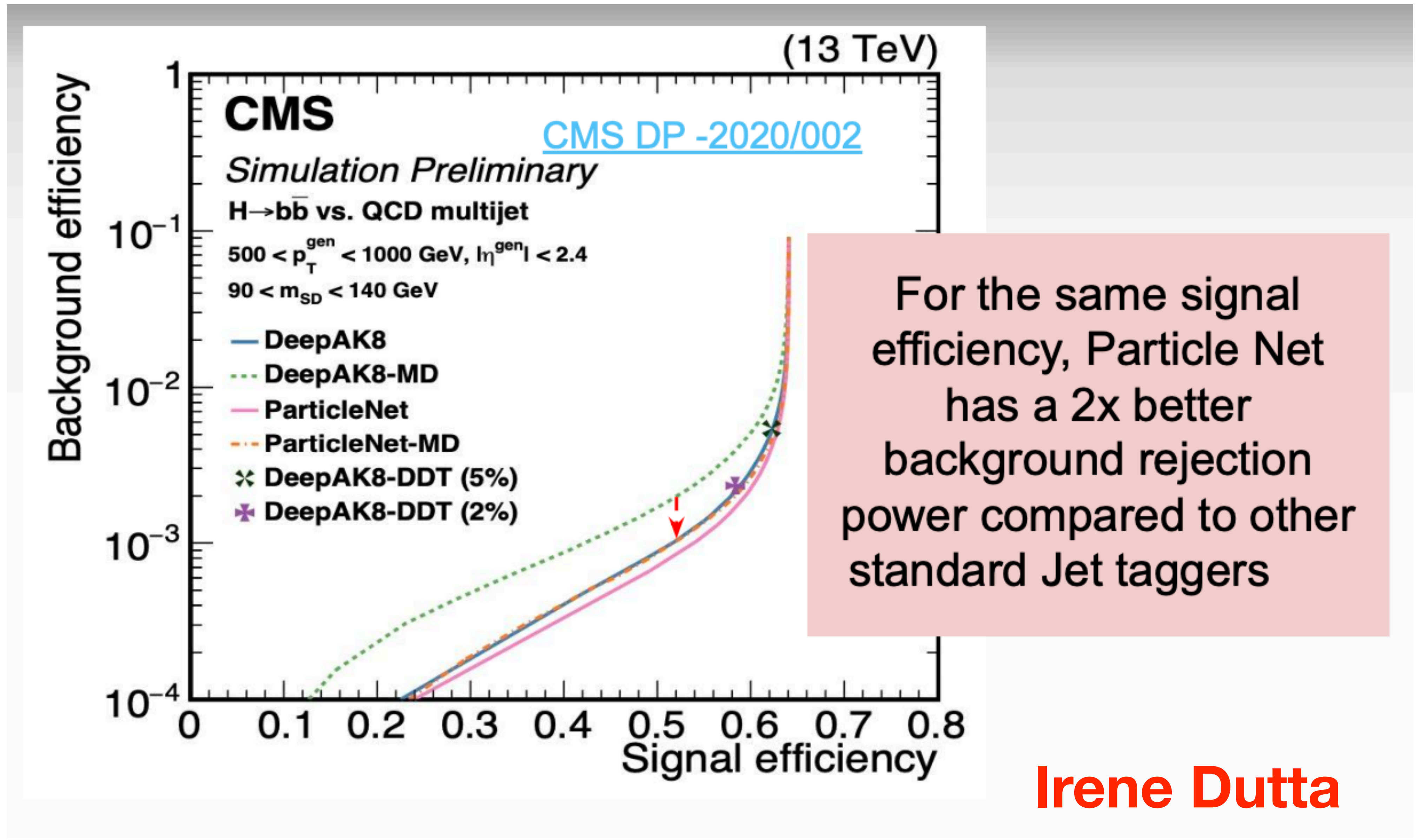
Valeria d'Amante



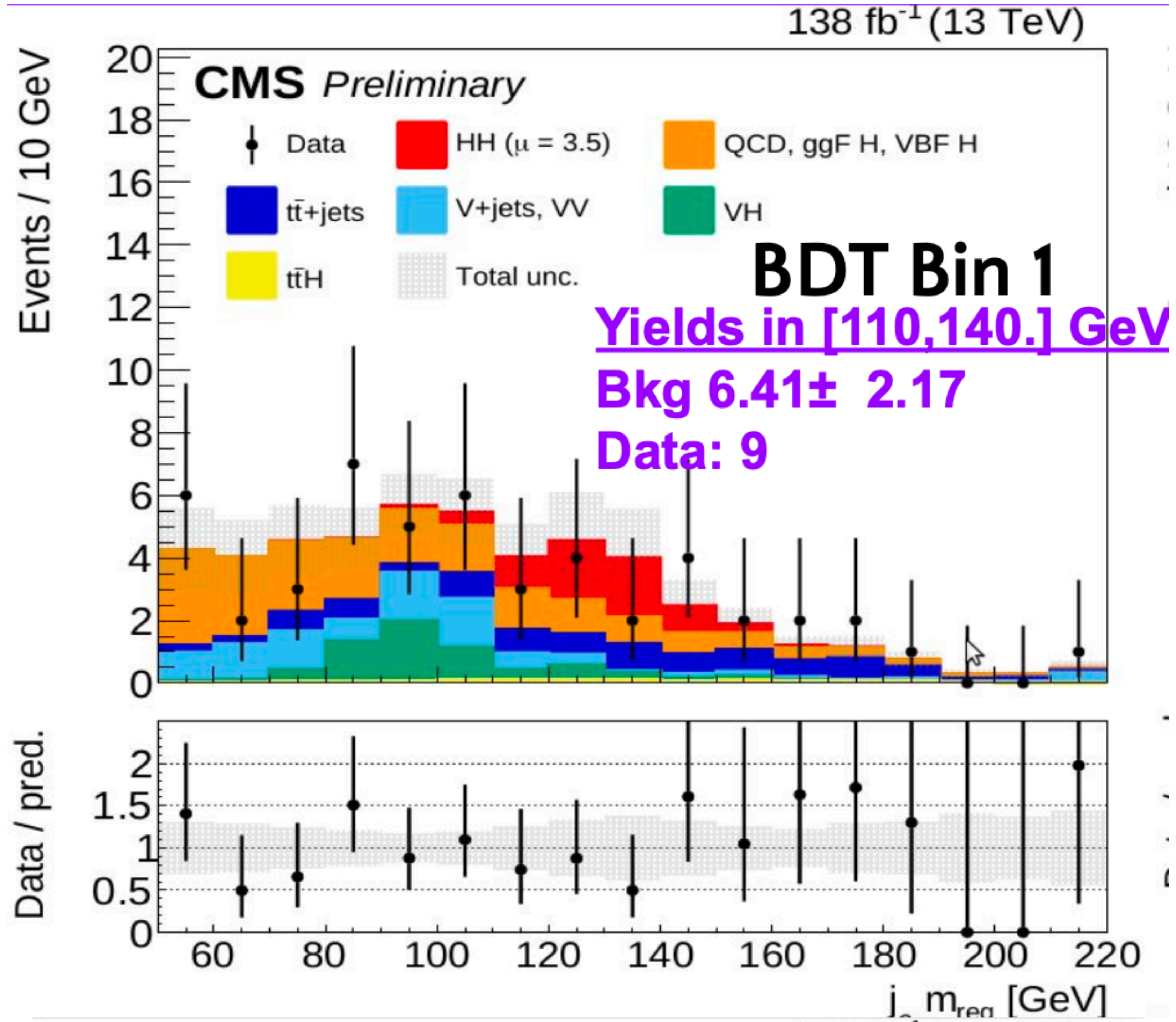
- New result: $\sigma/\sigma_{SM} < 5.2$ *(3.3 exp.)*
- ATLAS: $\sigma/\sigma_{SM} < 4.7$ *(3.9 exp.)*

- New trigger strategy, new DNN, New Flavor and Tau Tagging (DeepTau, DeepFlavor)
- Factor 5 improvements with respect to the previous result (factor ~2.5 beyond statistics)

HH → bbbb boosted



- New ParticleNet tagger to separate merged jets from H to bb from QCD
  - GNN (Graph Neural Network) based on low level PFlow/b-tagging info
  - New method to avoid mass distortion (X to bb sample with flat mass)
  - But very challenging calibration! (docum.)



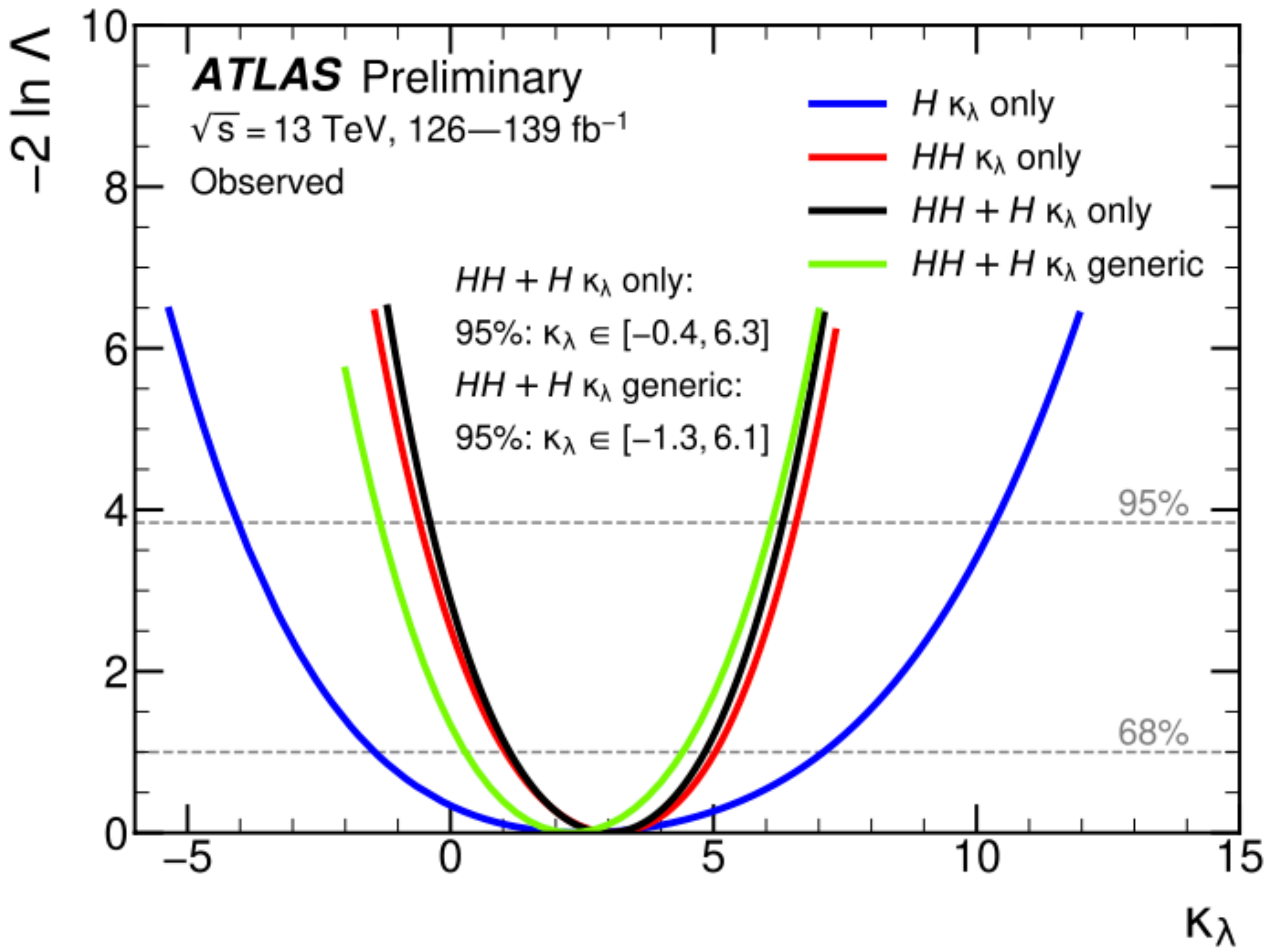
- Fit to merged jet mass (in bins of BDT of HH vs ttbar and multijet)
- Result:
  $\sigma/\sigma_{SM} < 9.9$ (5.1 exp.)
  (~1.4σ excess over SM)

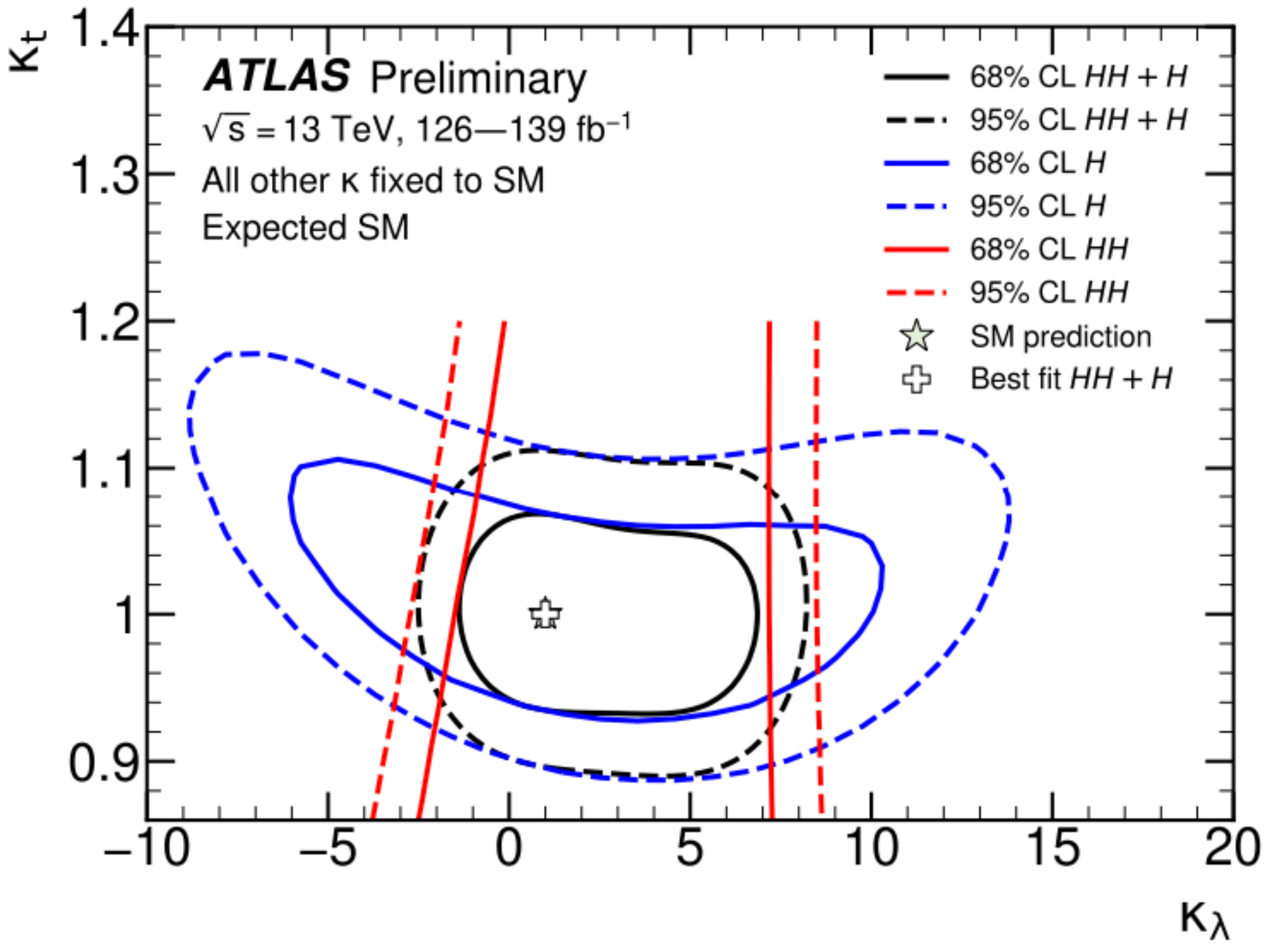
Determination of κλ from single Higgs

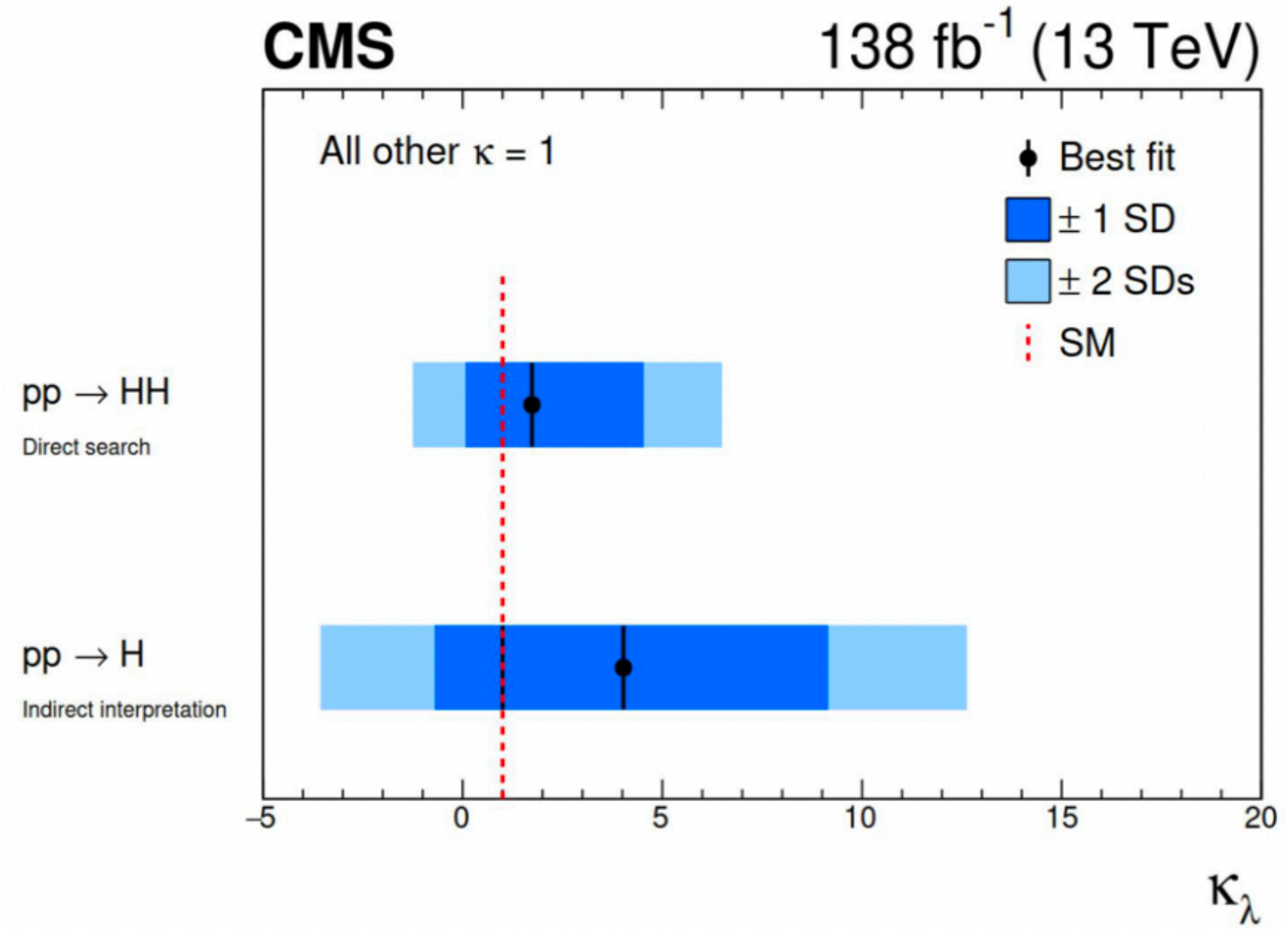
- Dependence of single-Higgs production on κλ through EW corrections recently derived in STXS binning, except for ggH (LHCHWG-2022-002)
- Both ATLAS and CMS applied it to their latest combination:

Alkaid Cheng

Fabio Monti







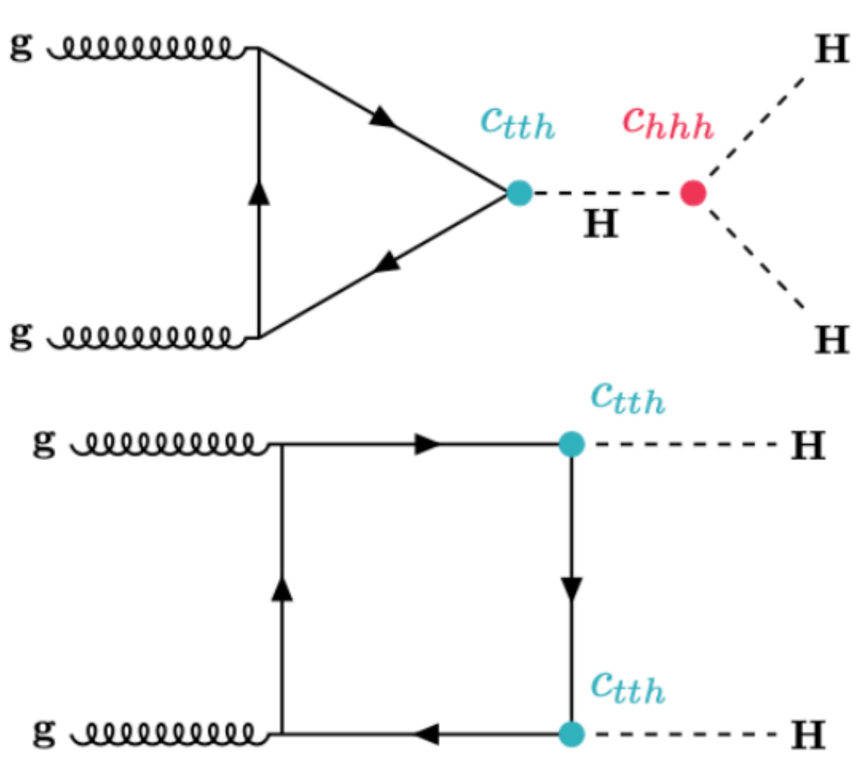
- Only small improvements, but allows determination of κλ with other kappas.
- Single-Higgs constraint dominated by ggH rate, i.e. theory uncertainty important!

Interpretation using HEFT EFT

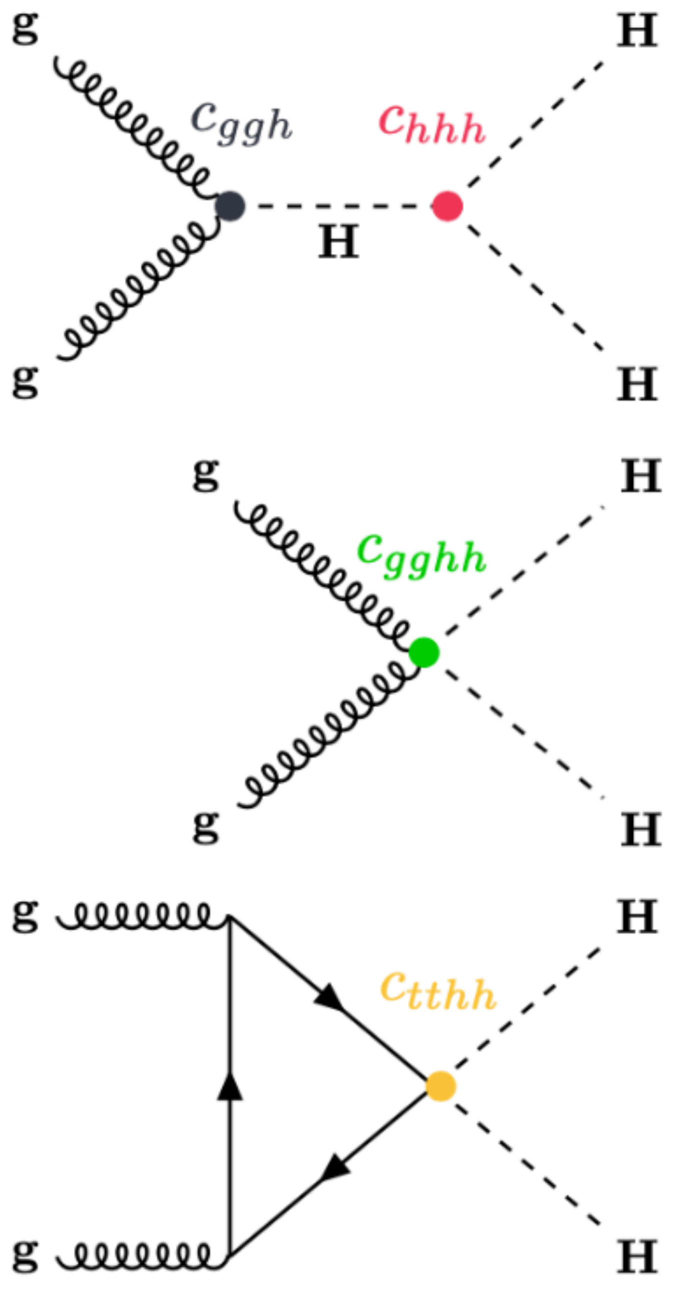
Alexander Held

- Several additional non-SM diagrams:

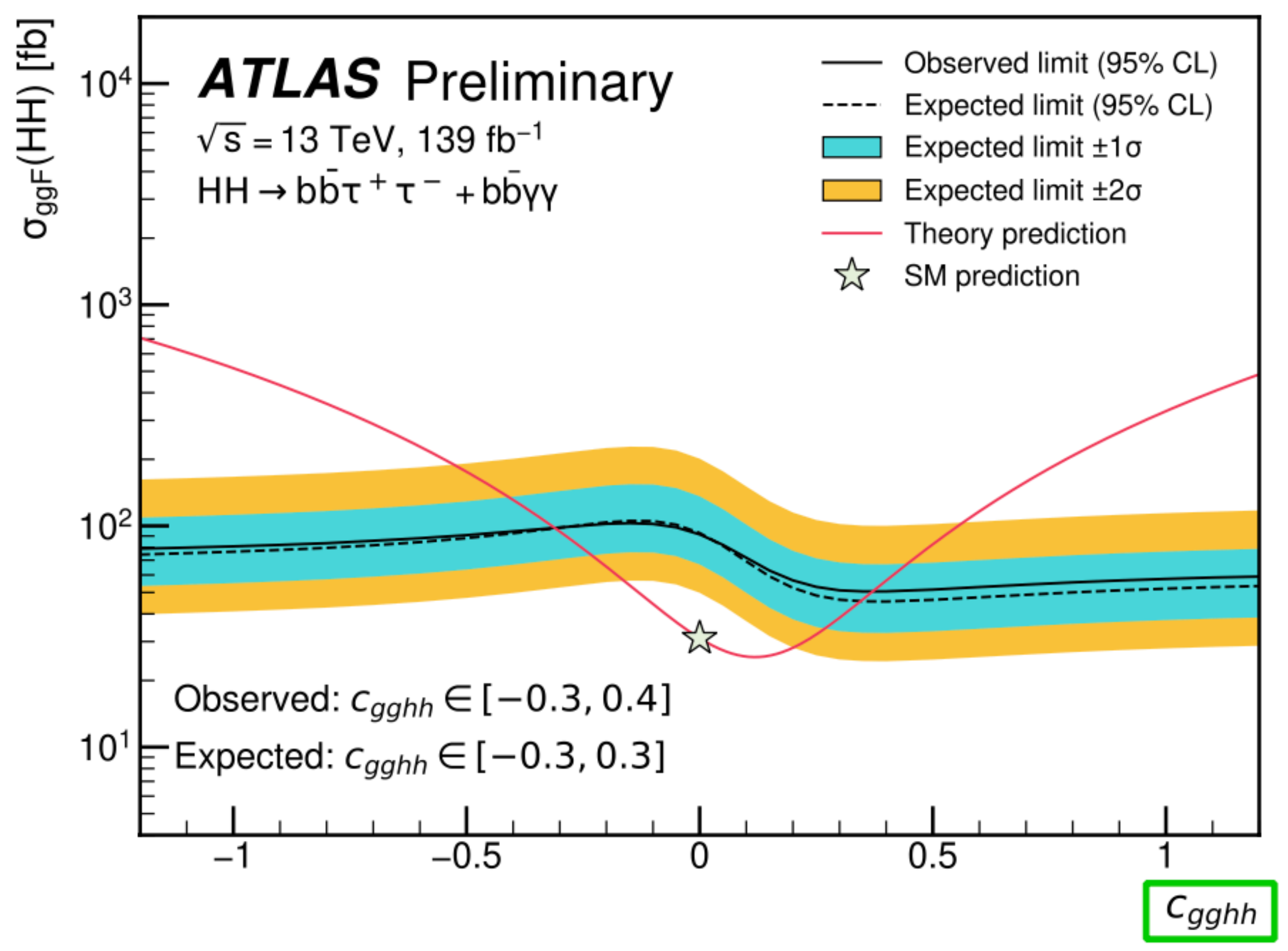
SM-like HH production

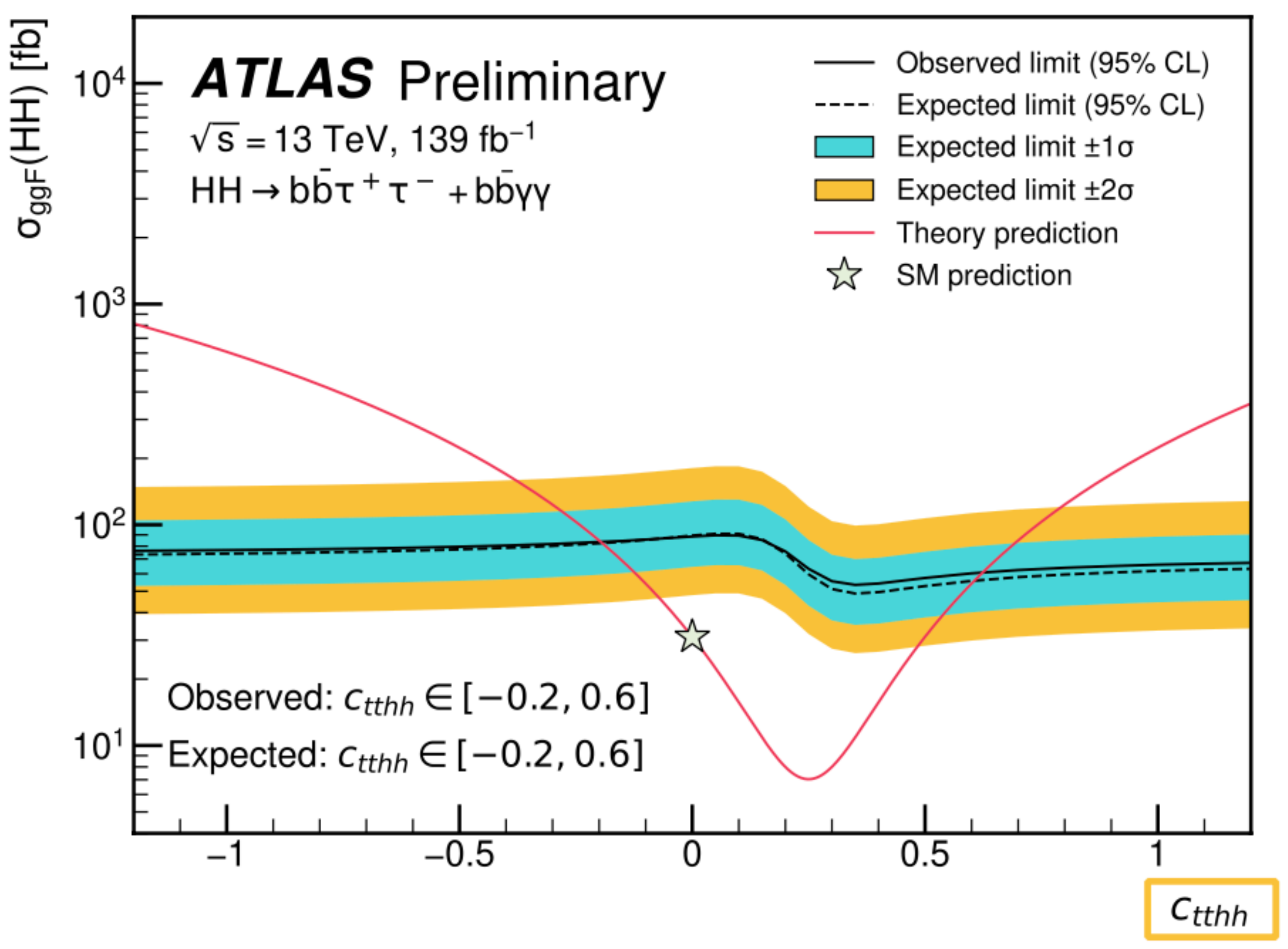


additional ggF diagrams in HEFT



- Constrained using combination of HH → bbττ and HH → bbγγ

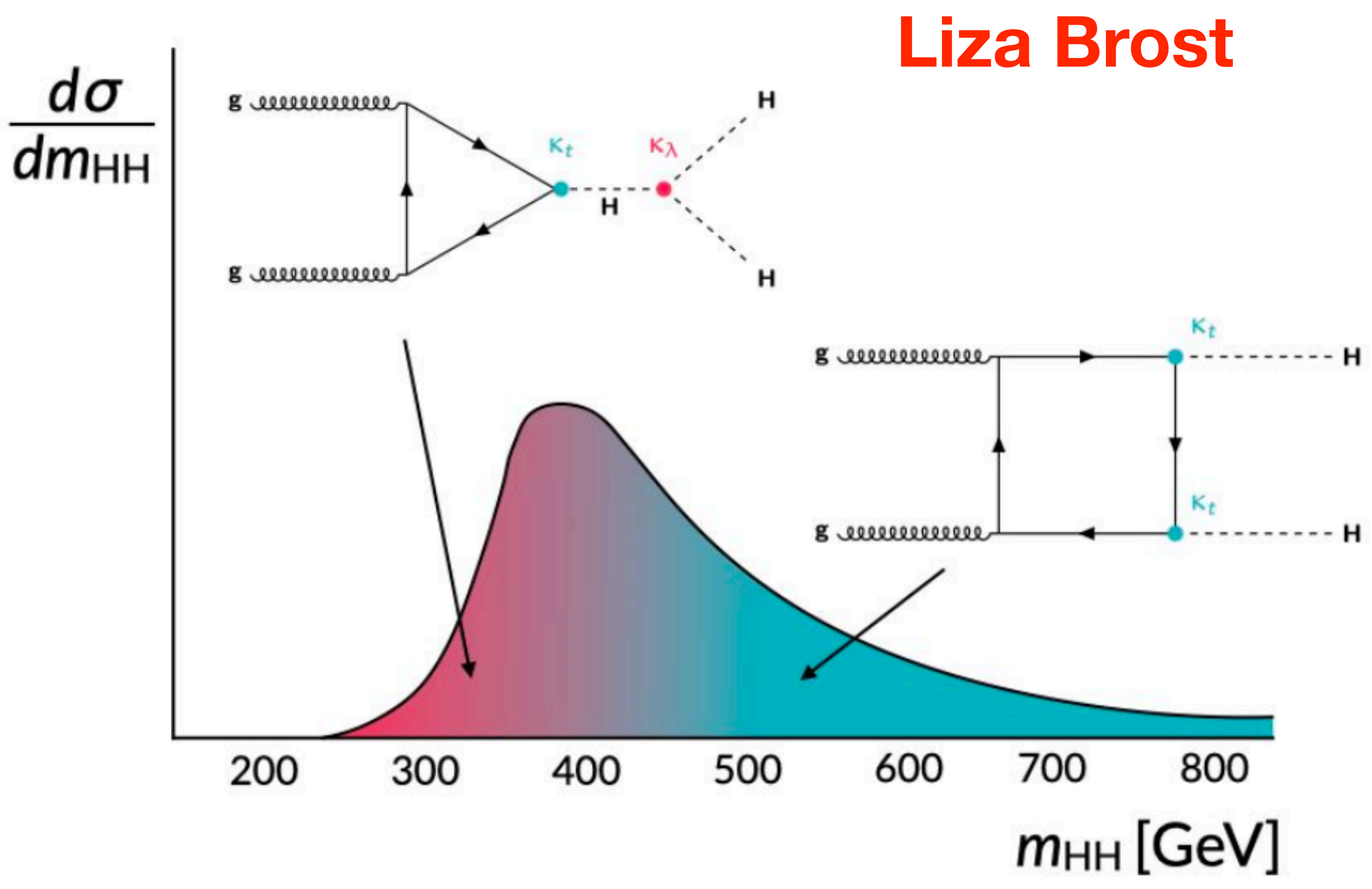




Wilson coefficient	$b\bar{b}\gamma\gamma$ Obs.	$b\bar{b}\gamma\gamma$ Exp.	$b\bar{b}\tau^+\tau^-$ Obs.	$b\bar{b}\tau^+\tau^-$ Exp.	Combination Obs.	Combination Exp.
c_{gghh}	$[-0.4, 0.5]$	$[-0.5, 0.7]$	$[-0.4, 0.4]$	$[-0.4, 0.4]$	$[-0.3, 0.4]$	$[-0.3, 0.3]$
c_{tthh}	$[-0.3, 0.8]$	$[-0.4, 0.9]$	$[-0.3, 0.7]$	$[-0.2, 0.6]$	$[-0.2, 0.6]$	$[-0.2, 0.6]$

- Different approach: use of 18 HEFT benchmarks in CMS [Ram Krishna Sharma]

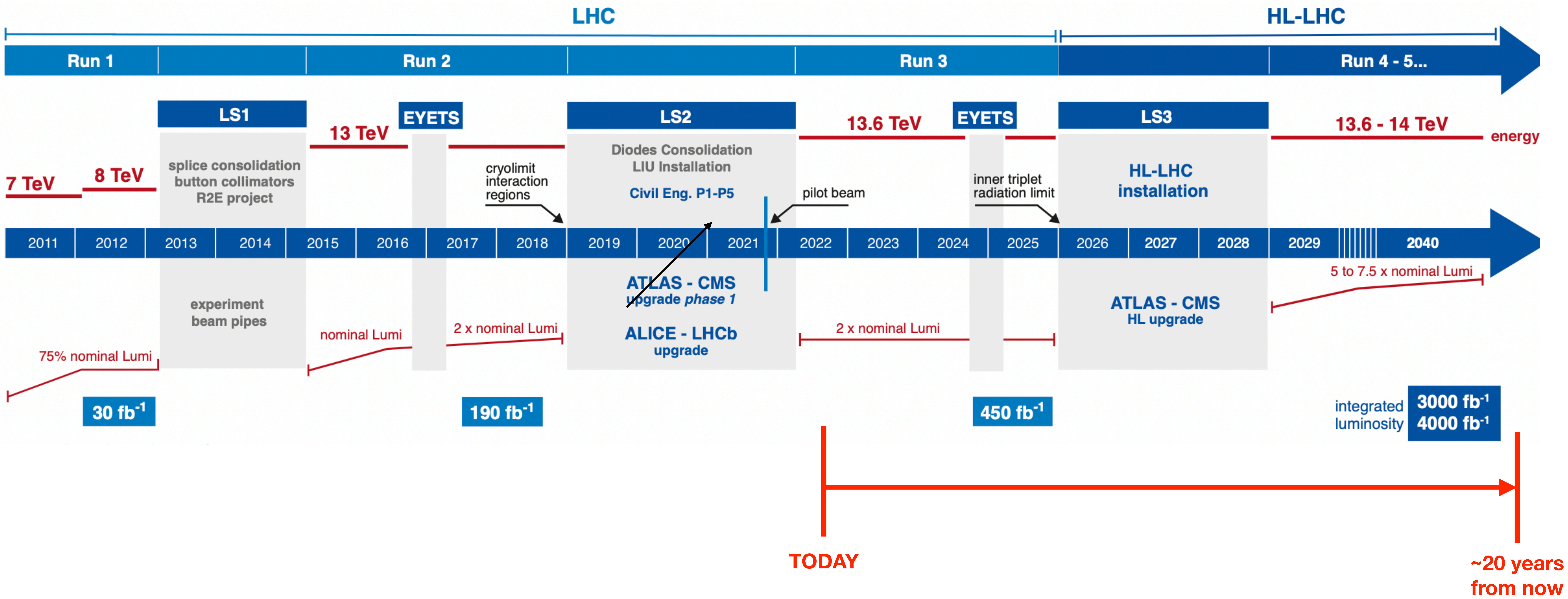
Biggest challenge ahead?



- Low mHH events drive sensitivity to k_λ
- Reduce trigger/reconstruction thresholds / maximize efficiency to increase low m_{HH} efficiency
- Especially challenging towards HL-LHC!

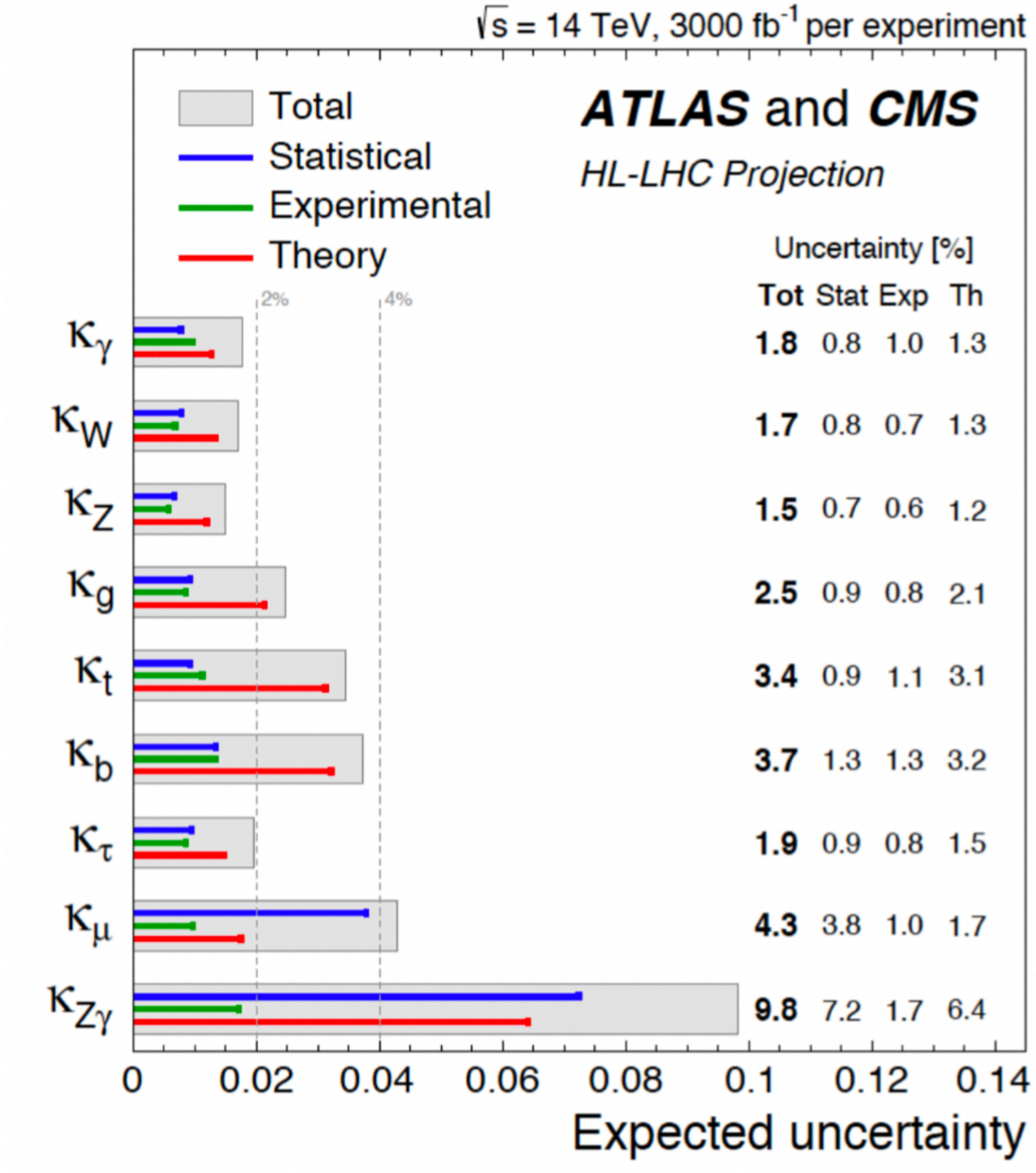
Prospects for future

Schedule towards High-Lumi LHC



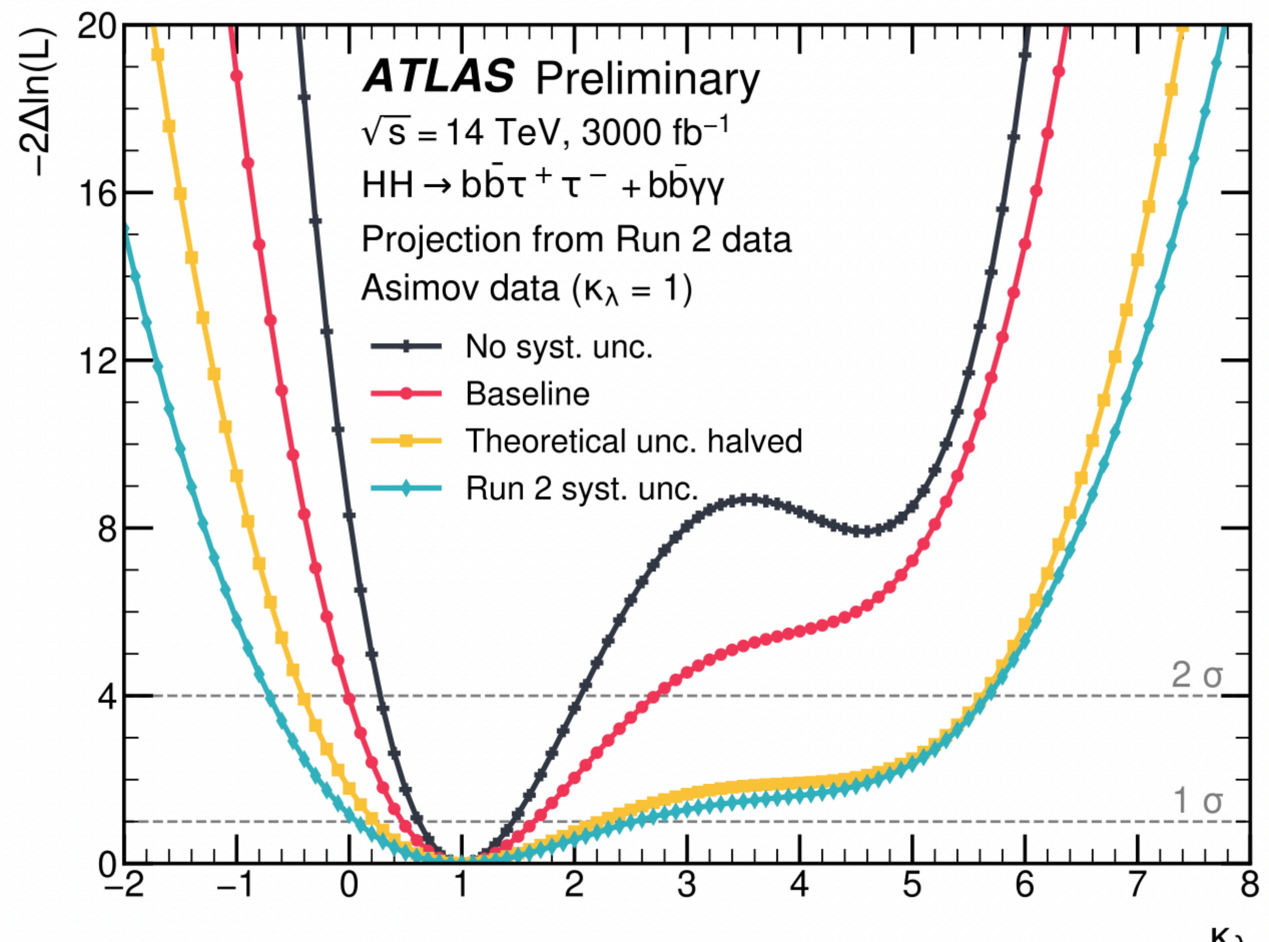
- Seems like a long time, but building the next collider may well require more than 20 years! We need to start now… (and, with Peter Jenni's words, "fight for it"!)

Emmanuel Perez, Suat Donertas

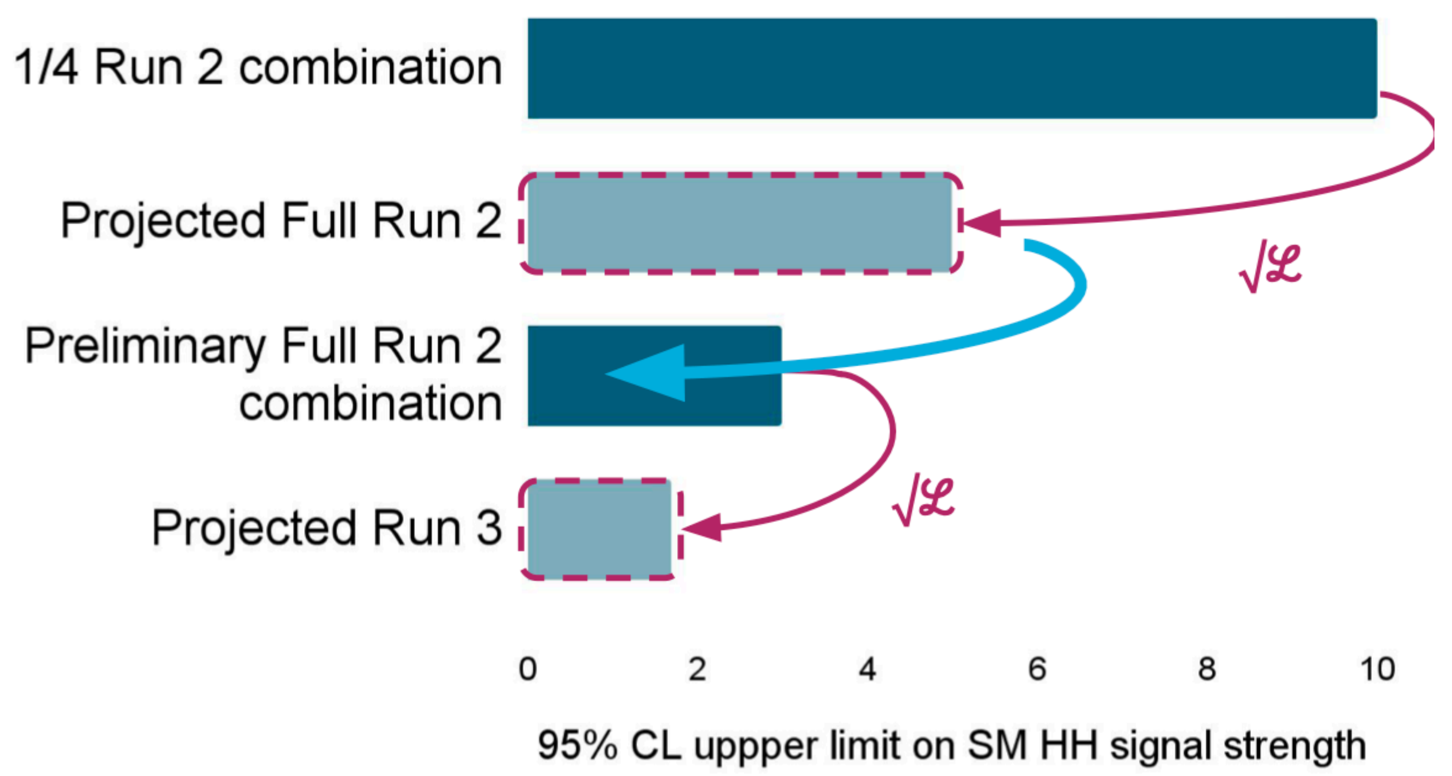


- What can HL-LHC achieve?
  - Single-Higgs couplings
    - 1.5-4% percent precision on most couplings (depends crucially on our theory colleagues!)
  - Trilinear Higgs couplings
    - First bounds on Higgs self-coupling
    - Things are improving while we speak :-)

[ATL-PHYS-PUB-2022-005]



Liza Brost, HH discussion session



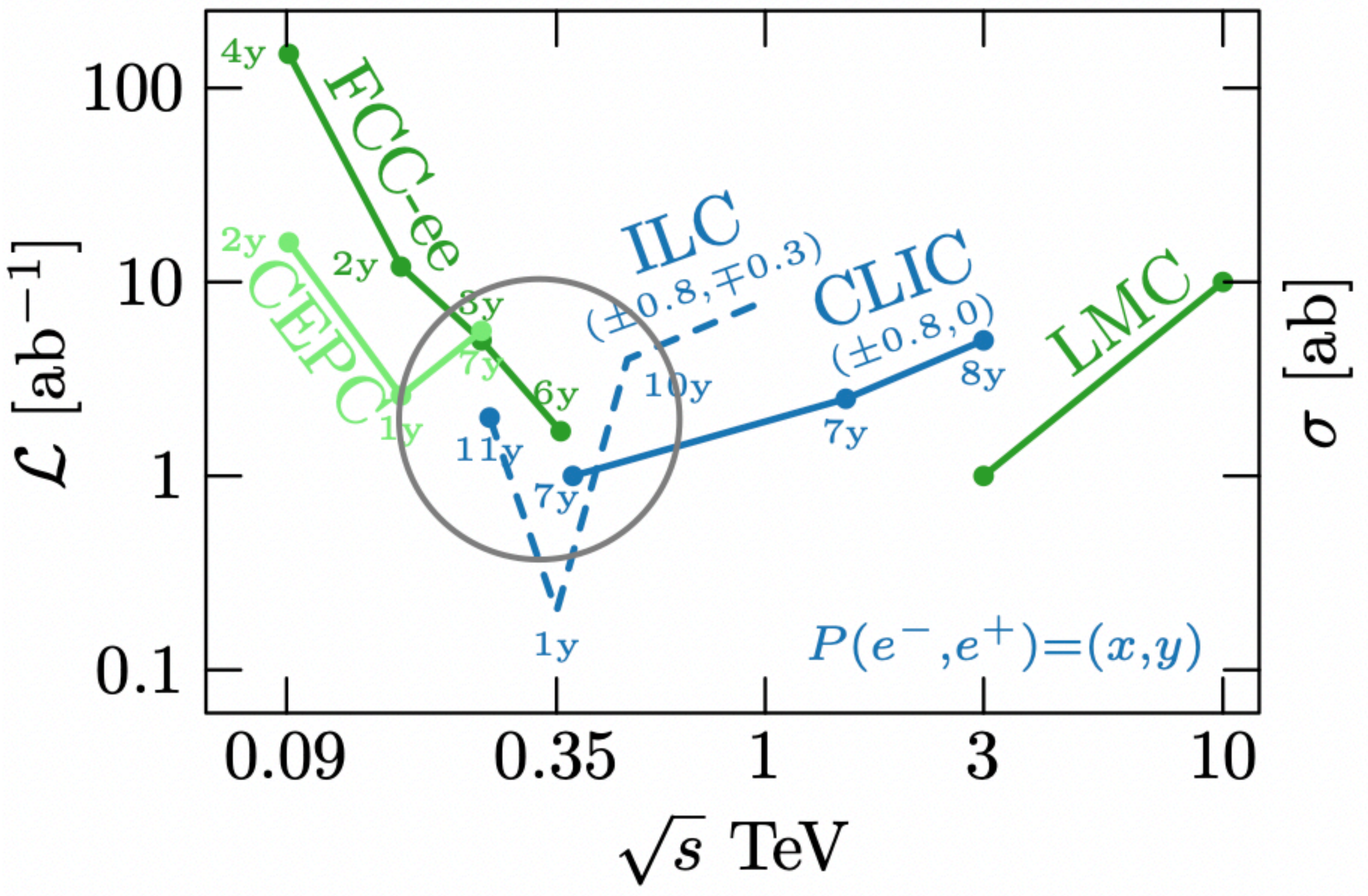
Beyond HL-LHC

- Many possible colliders, community needs to converge on 1 (2?) options
- Lepton collider provide lower cross-sections, but a very clean environment and excellent resolutions / particle identifications
- European Strategy Update 2020

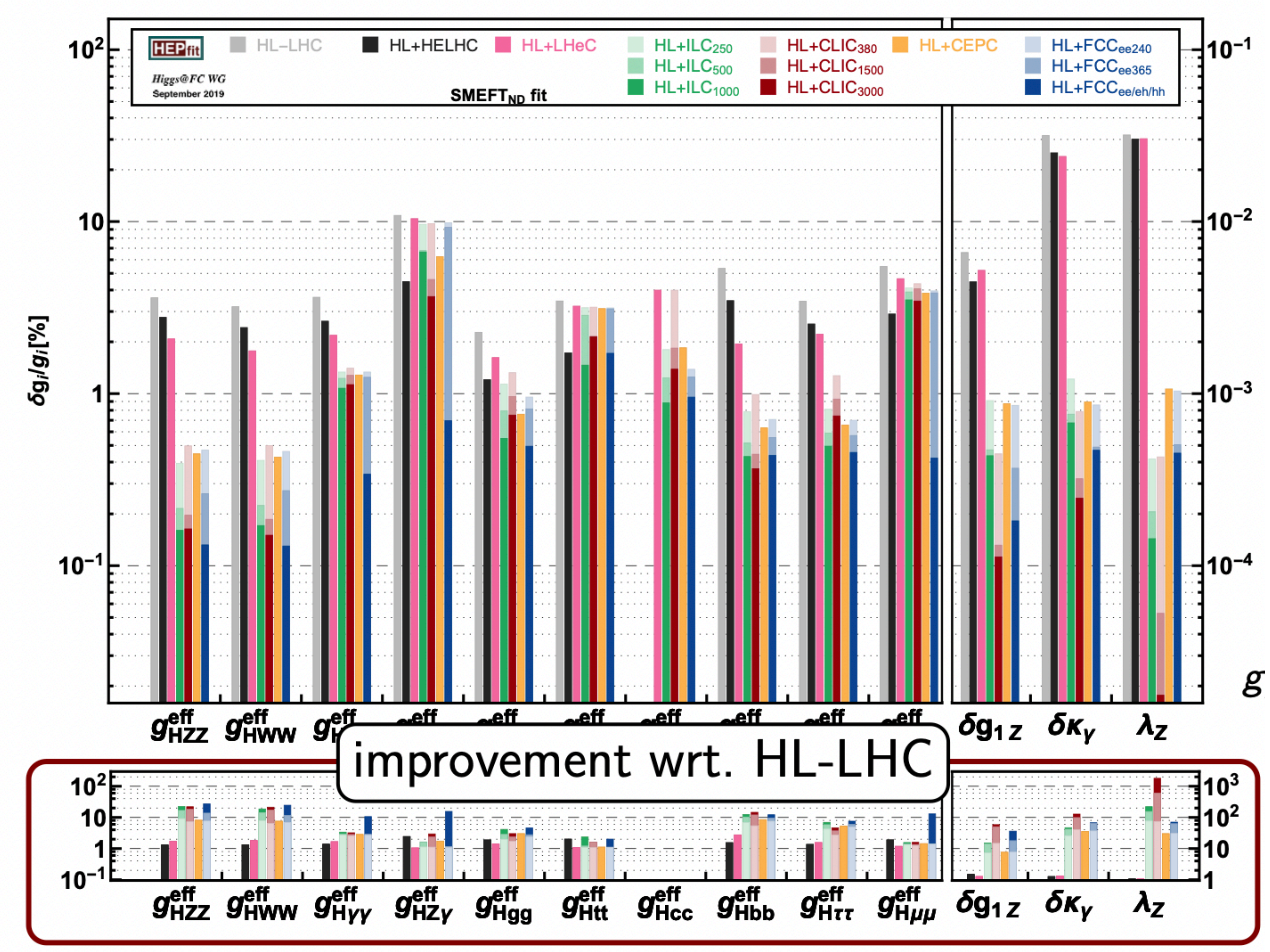
> a) An **electron-positron Higgs factory** is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. (...)

- But many options available for a lepton collider

Gauthier Durieux



Prospects at future colliders - single-Higgs



- Large improvements everywhere except where stat. unc. Dominates
- Improvement not only quantitative
  - e.g. e+e- colliders allow for model independent access to couplings

$$\sigma_{\rm ZH} \times \mathcal{B}(\rm H \to X\overline{X}) \propto \frac{g^2_{\rm HZZ} \times g^2_{\rm HXX}}{\Gamma_{\rm H}}$$

H → ZZ* provides Γ_H
H → XX provides g_{HXX}

Gauthier Durieux

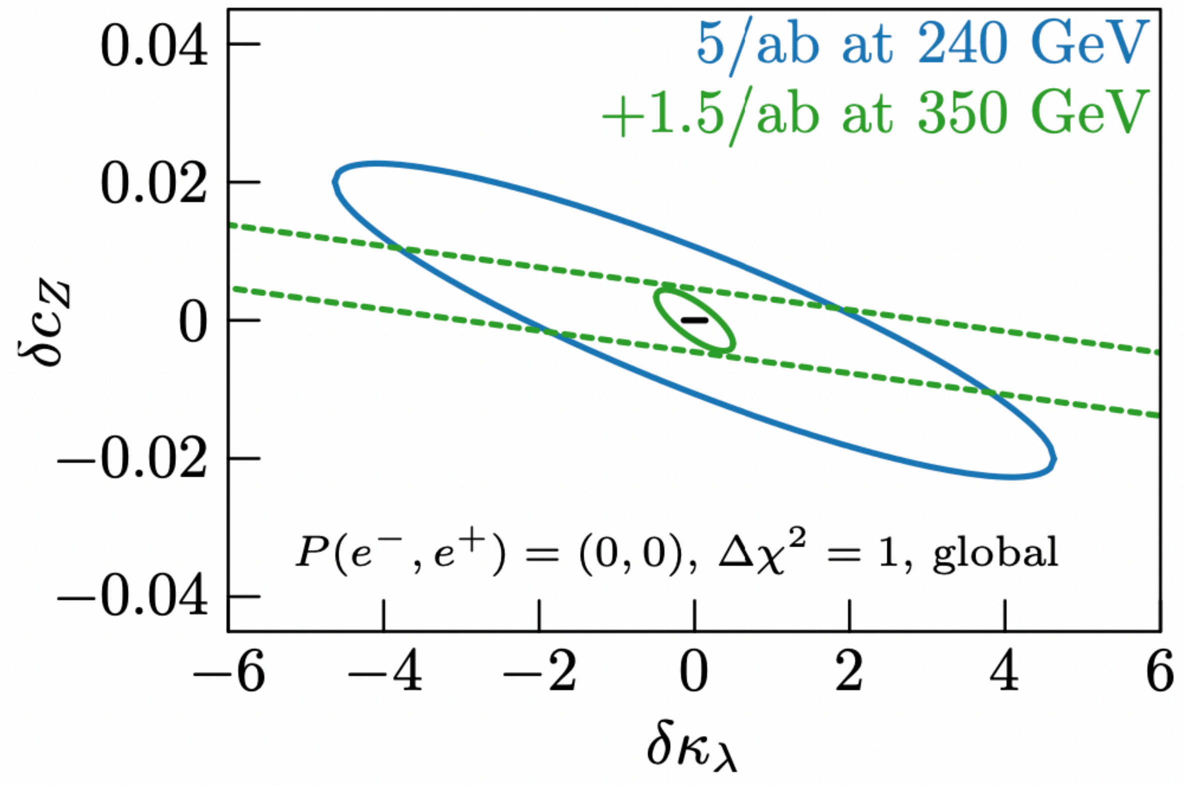
Prospects at future colliders - self-coupling

Snowmass, Meenakshi Narain

collider	Indirect-h_{SM}	$h_{SM}h_{SM}$	combined
HL-LHC [24]	100-200%	50%	50%
ILC_{250}/C^3-250 [14, 17]	49%	–	49%
ILC_{500}/C^3-550 [14, 17]	38%	20%	20%
ILC_{100}/C^3-1000 [14, 17]	36%	10%	10%
$CLIC_{380}$ [19]	50%	–	50%
$CLIC_{1500}$ [19]	49%	36%	29%
$CLIC_{3000}$ [19]	49%	9%	9%
FCC-ee [20]	33%	–	33%
FCC-ee (4 IPs) [20]	24%	–	24%
FCC-hh [25]	-	3.4-7.8%	3.4-7.8%
μ(3 TeV) [23]	-	15-30%	15-30%
μ(10 TeV) [23]	-	4%	4%

- Generally, high-energy options favored (rate!)
- At e^+e^- determination through single-Higgs EW corrections becomes feasible (~10% prec.)
  - Requires two C.o.M. energies to disentangle from σ_H

Gauthier Durieux



Prospects at future colliders - self-coupling

Snowmass, Meenakshi Narain

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Muon Collider option studied in detail at Snowmass!

- Generally, high-energy options favored (rate!)
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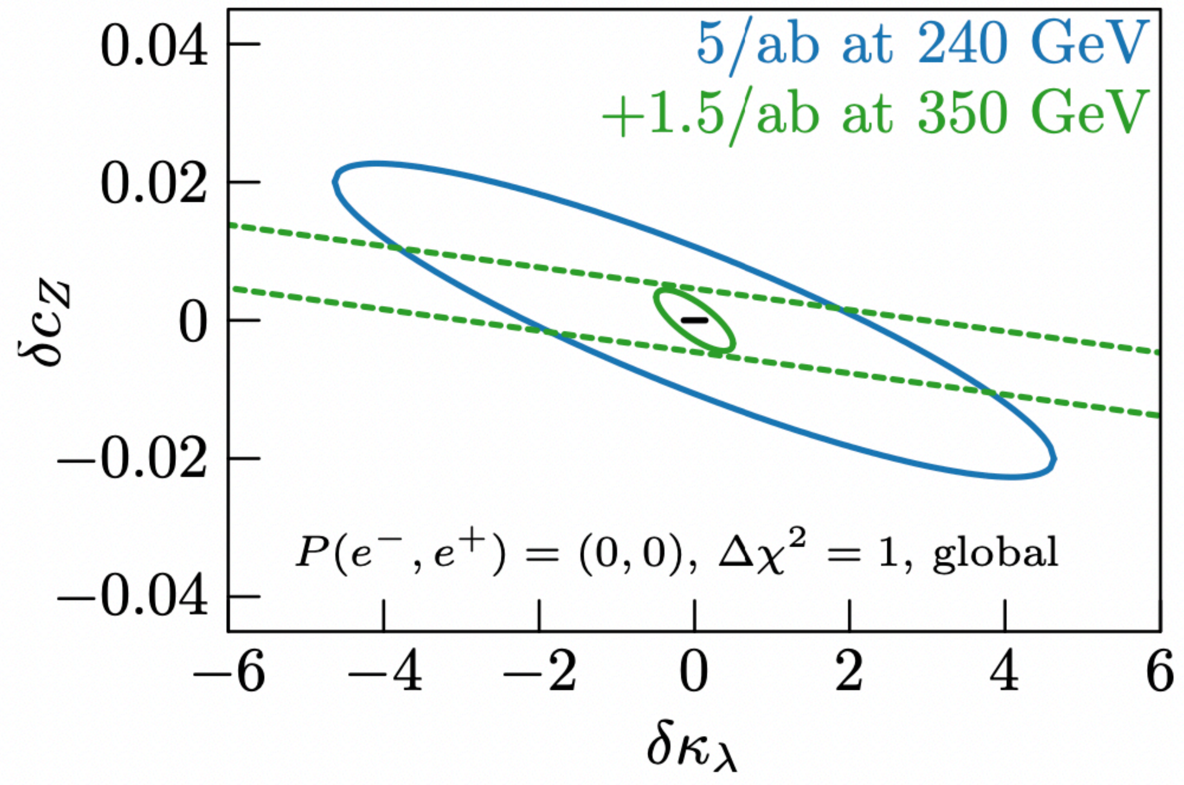
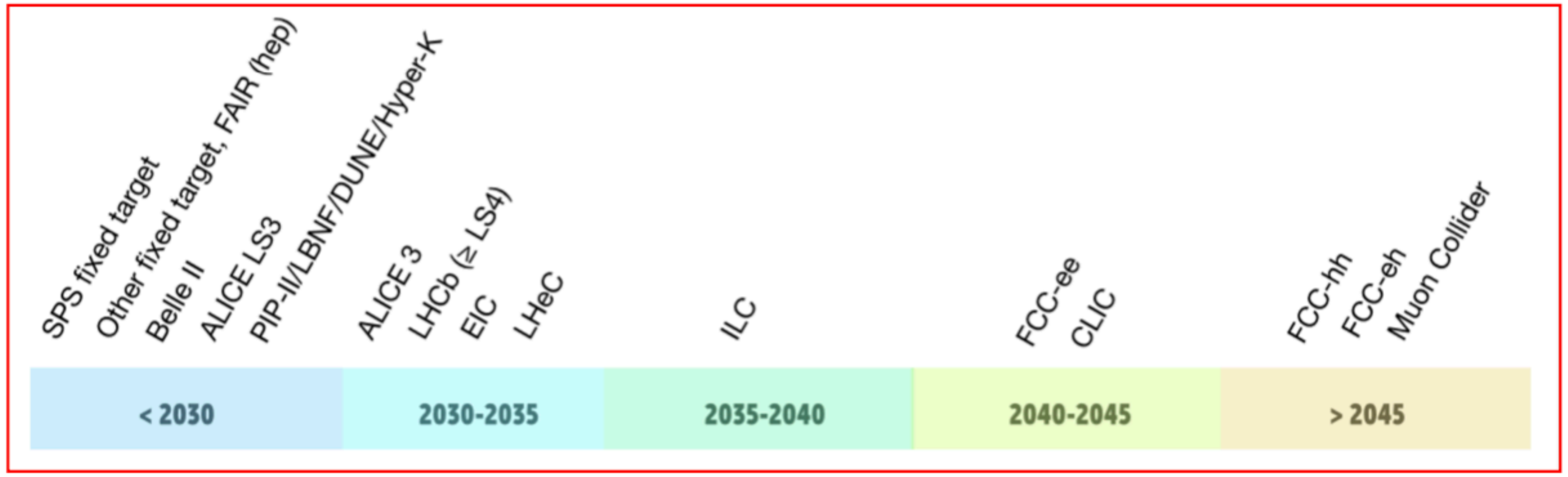
  - Requires two C.o.M. energies to disentangle from σ_H

Gauthier Durieux



R&D roadmap towards future

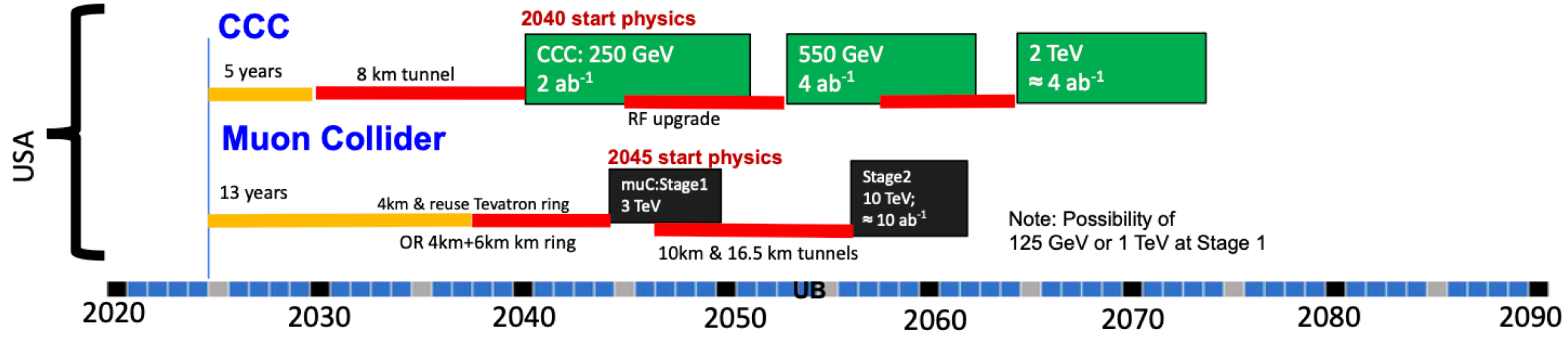
Karl Jakobs



- ECFA Roadmap Document approved and presented to CERN Council in Dec 2021 (seek approval by end-2022)
- Roadmap includes R&D for both accelerators and detectors

Meenakshi Narain

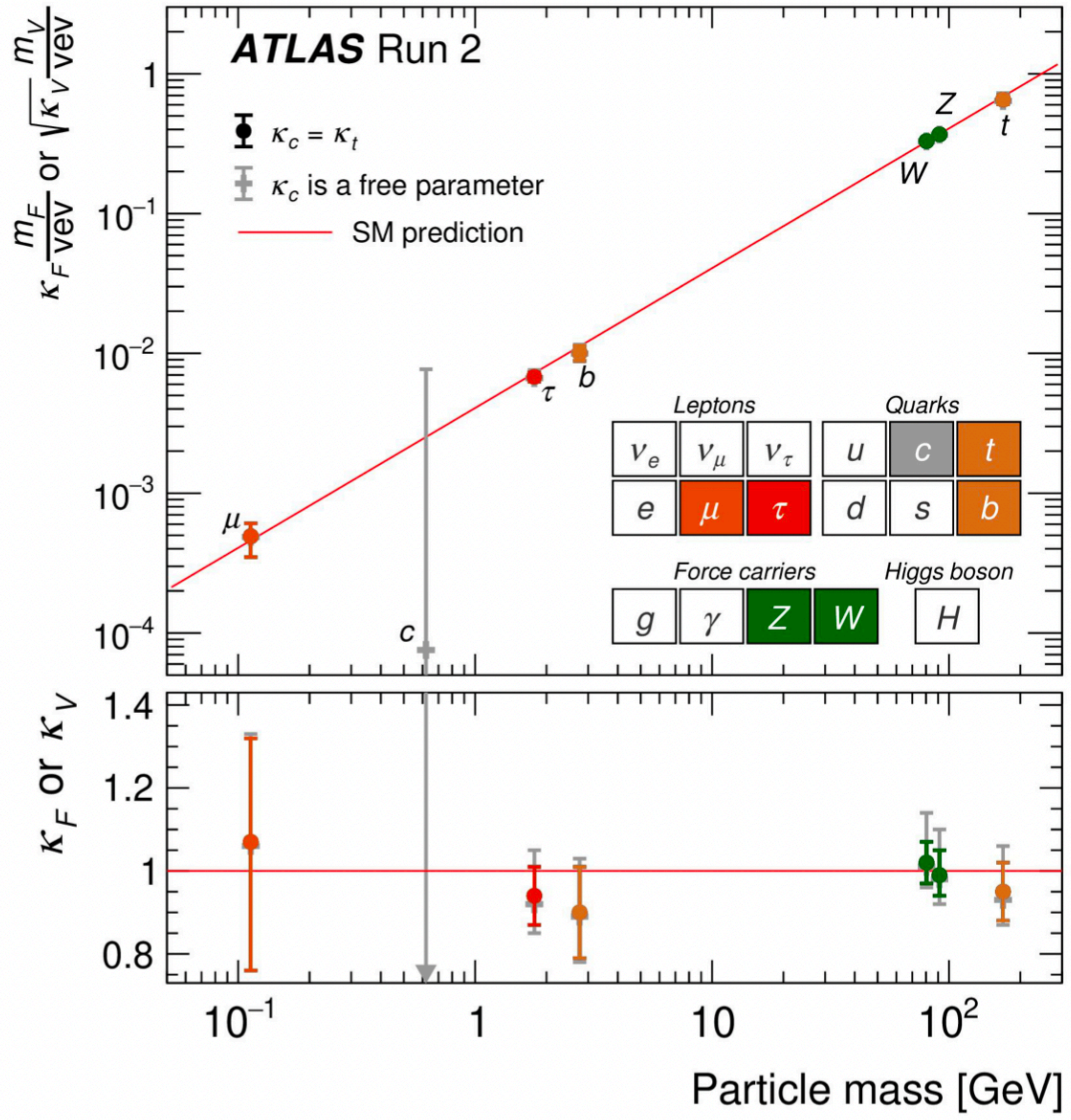
- US Snowmass process just ending
  - P5 will now meet and define priorities on US side



  - Proposals emerged to host CCC or Muon Collider in the US (and consider hosting ILC)

Concluding…

- We have come a very long way since the Higgs Boson discovery
- Impressive suite of results presented at Higgs Hunting 2022
    - Analyses routinely exceed expectations from simple luminosity scaling
- Community working or actively engaged in preparing for the future
    - HL-LHC to be ready in a few years
    - Discussion and R&D activities ongoing to define the next collider



…and yes: the “hunt” is indeed not fully over yet…

[K. Leney, L. Brost]

Thank you!

-to the organizers
-to the talk presenters
-to the session conveners
-to all participants