ATLAS EXPERIMENT

Nikhef

Properties of the Higgs boson

Measurements of the **mass**, **width** and coupling **CP structure** of the Higgs-boson with the ATLAS detector

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On behalf of the ATLAS collaboration

CIPANP 2022

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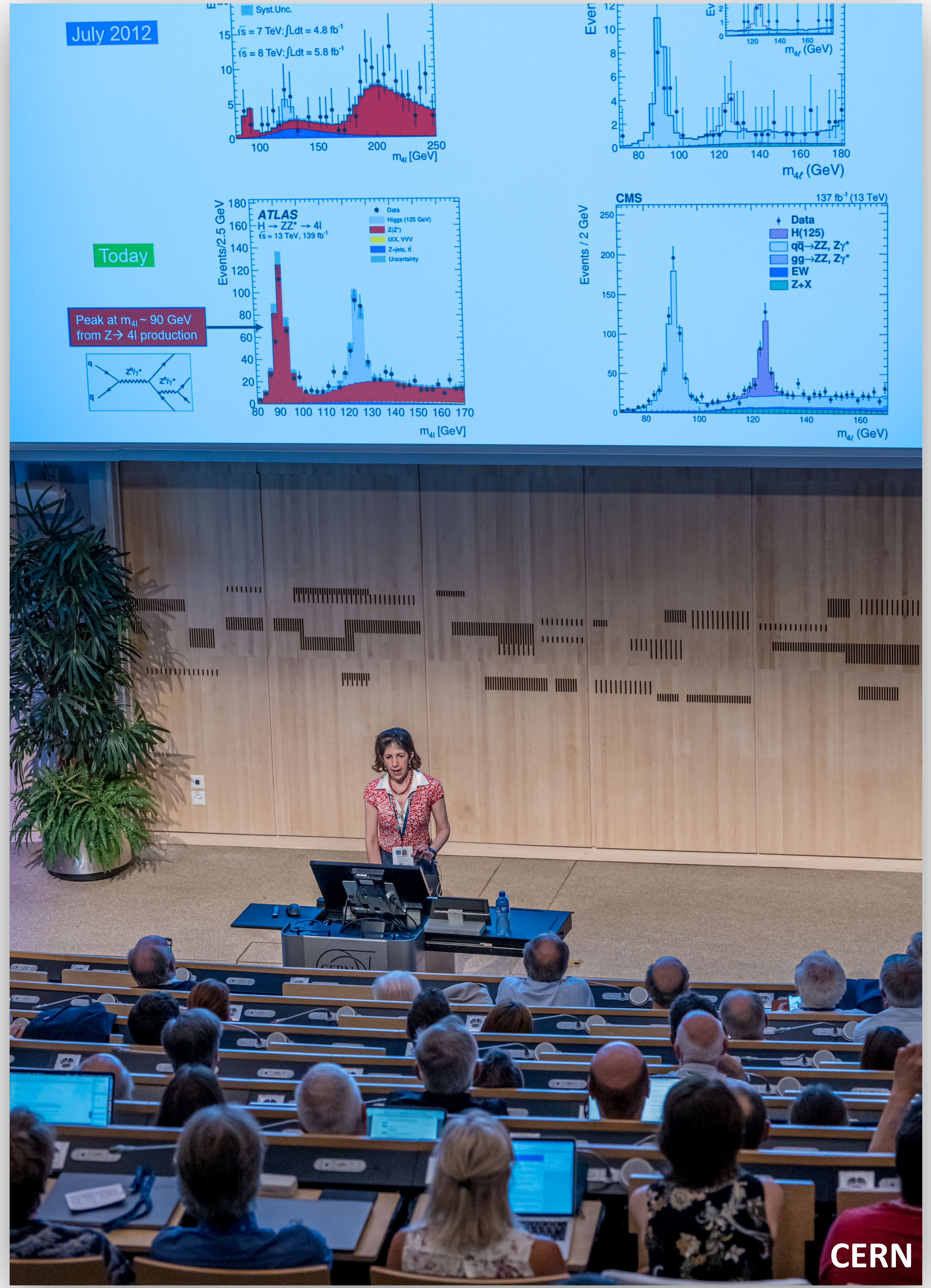
10 years of Higgs property measurements:

04 July 2022: CERN celebrated its **10th anniversary** of the Higgs boson discovery announcement.

From J. Ellis et. al. 1976 [paper] on the phenomenological profile of the Higgs boson:

> small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

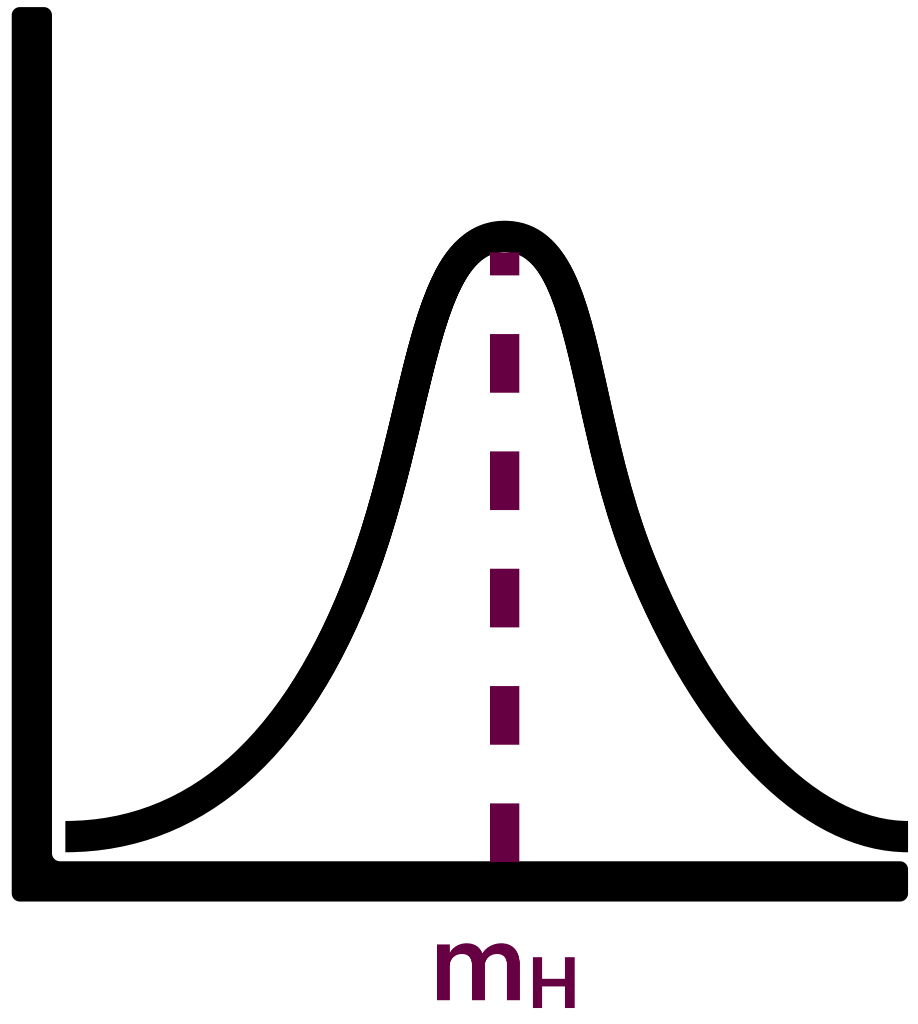


Today: Overview of current Higgs property measurements:

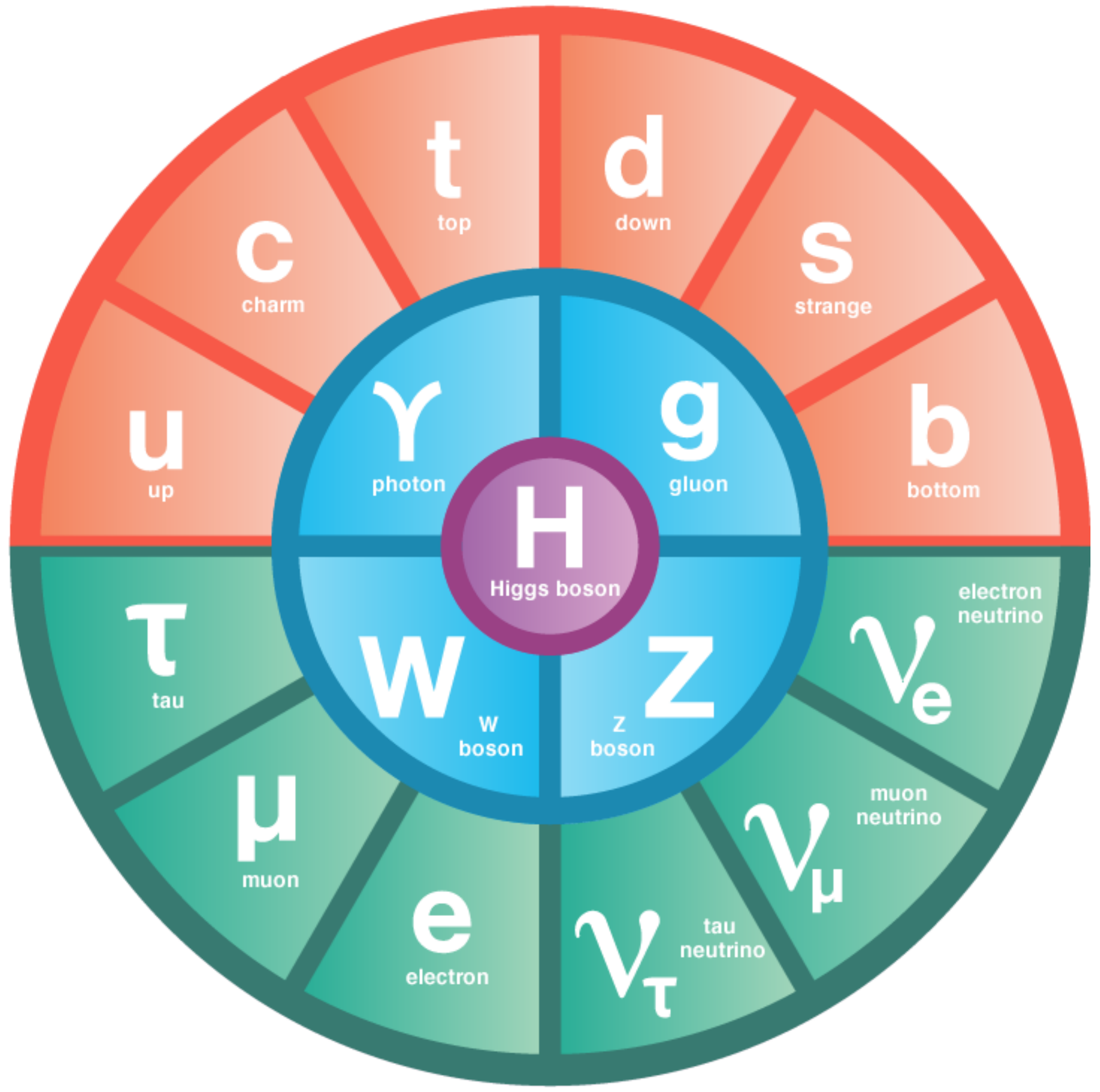
1. Mass of the Higgs boson
2. Width of the Higgs
3. Spin and Charge-Parity (CP) state of the Higgs

1.

MASS



The missing piece of the puzzle:



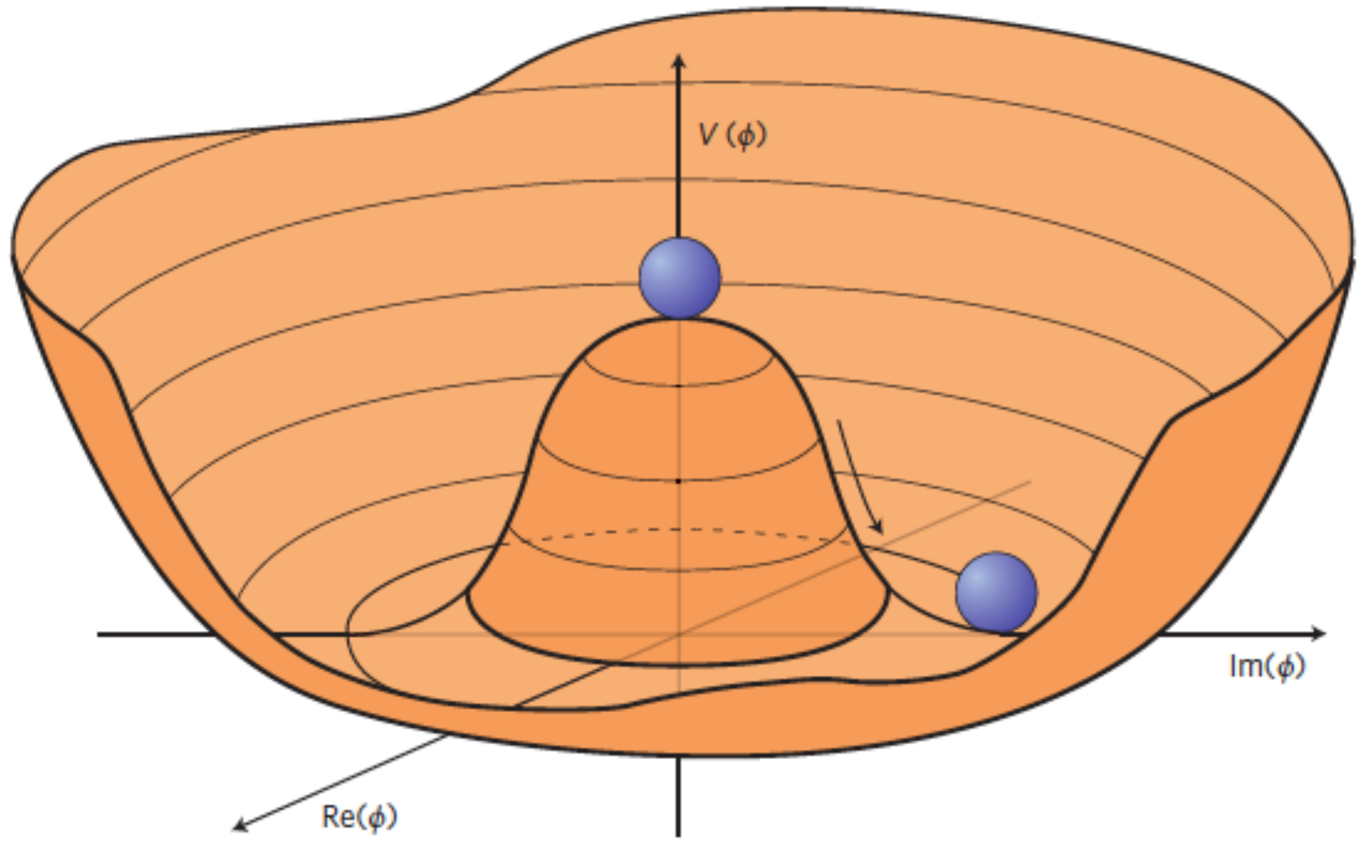
Does the Higgs behave as expected by the SM?

<u>Why measure the Higgs mass?</u>

Not predicted by the theory!

- Higgs couplings to SM particles are completely defined by the mass.
- **Shape of the Higgs potential fully known in the theory**, once the vev and m_H have been determined.

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



<u>How to measure the mass:</u>

Precision: $H \to ZZ^* \to 4\ell$ and $H \to \gamma\gamma$, ℓ = electron (e) or muon (μ)

Despite low BR for each, profit from clean detector signature.

Precision greatly impacted by both statistics and experimental systematics.

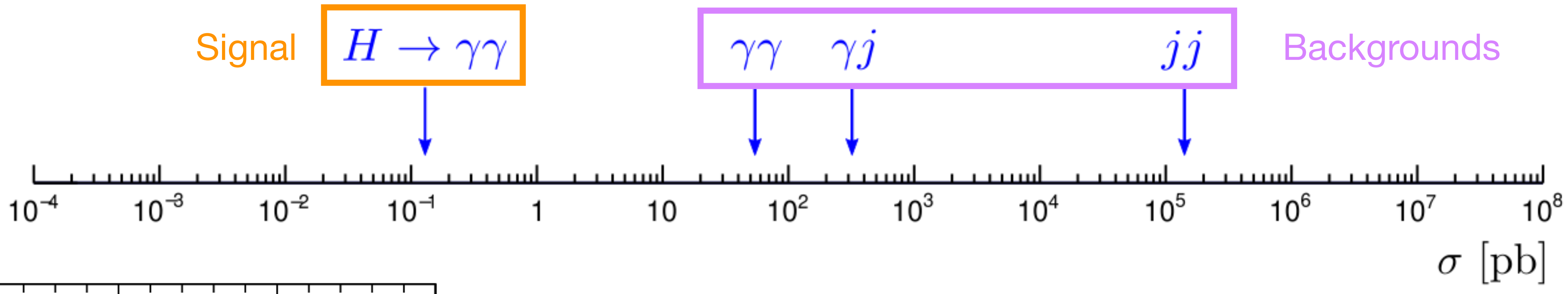
-> Require extremely good calibration of γ energy scale, γ energy resolution, e energy scale, μ momentum scale, etc.

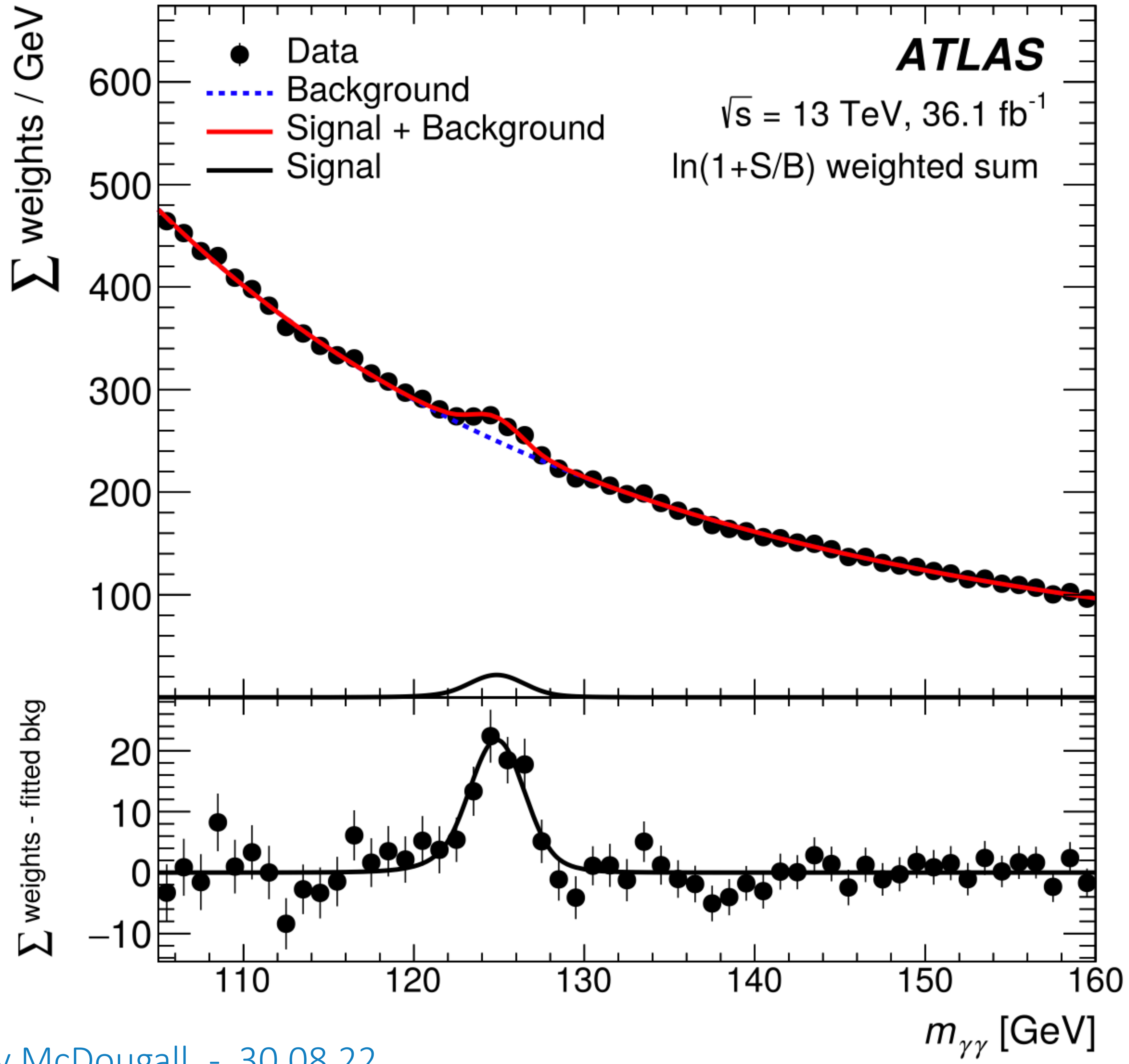
Latest $H \to \gamma\gamma$ mass measurement:

Phys. Lett. B 784 (2018) 345

$\gamma\gamma$ decay channel: extremely low cross-section, but very clean signature.

Dominant backgrounds: SM $\gamma\gamma$ production, γ+jet, di-jet.

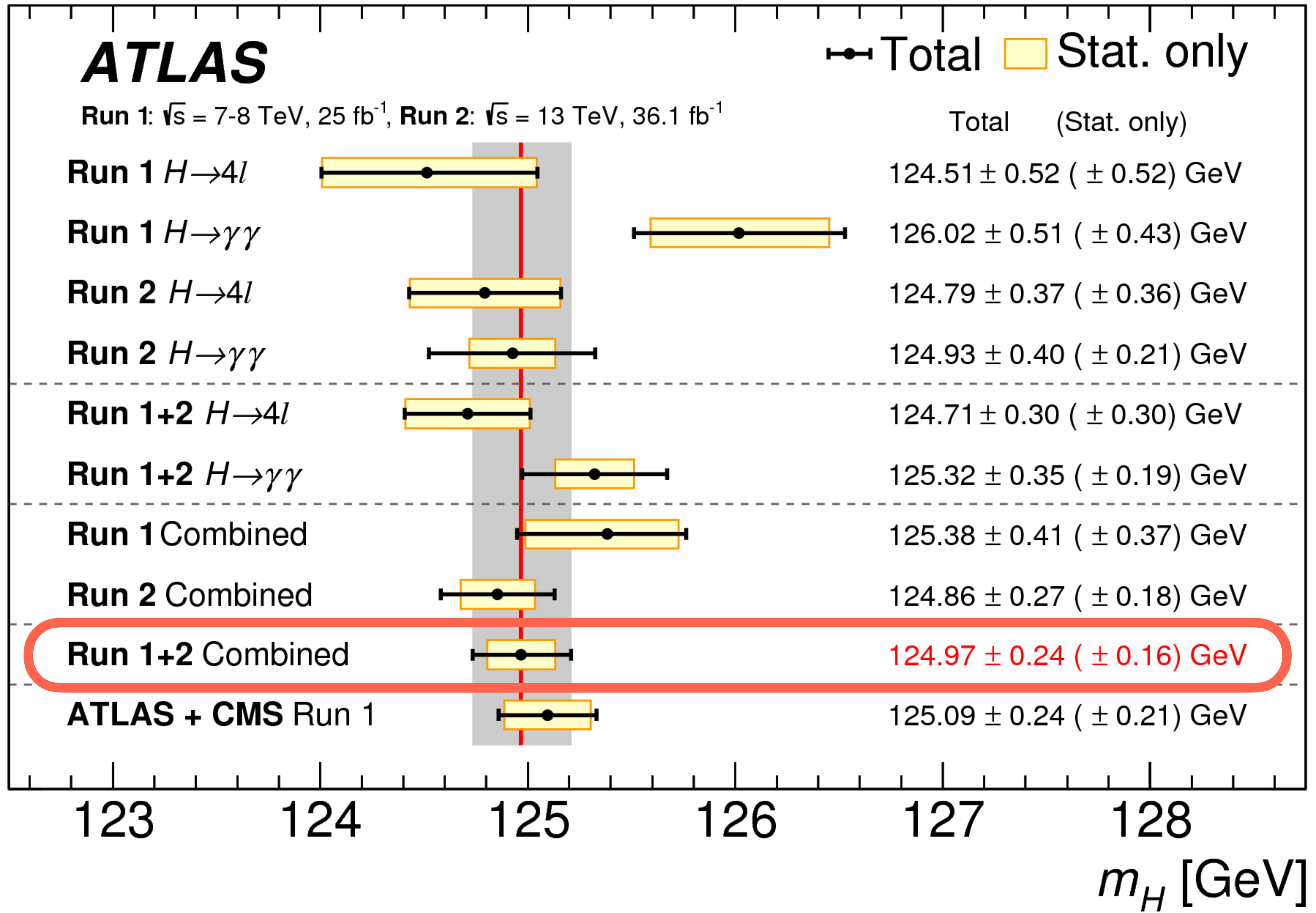




$H \to \gamma\gamma$ (36.1 fb^{-1}):

$$m_H^{\gamma\gamma} = 124.93 \pm 0.21 \text{ (stat)} \pm 0.40 \text{ (sys) GeV}$$

- Uncertainty dominated by experimental systematics.
- Two leading sources of experimental systematics are related to calibrating the EM calorimeter: $\mathcal{O}(250)$ MeV

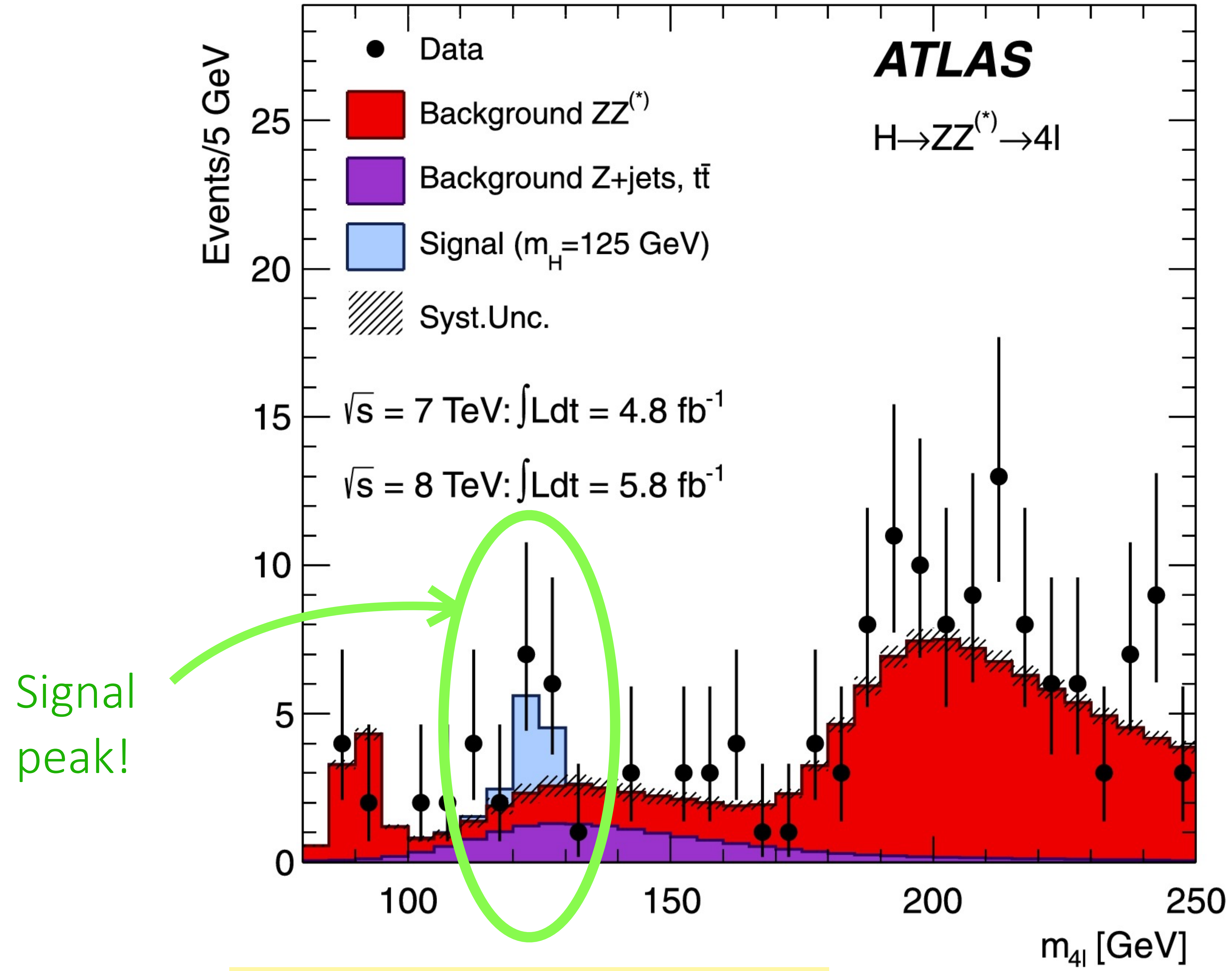


Evolution of mass measurement:

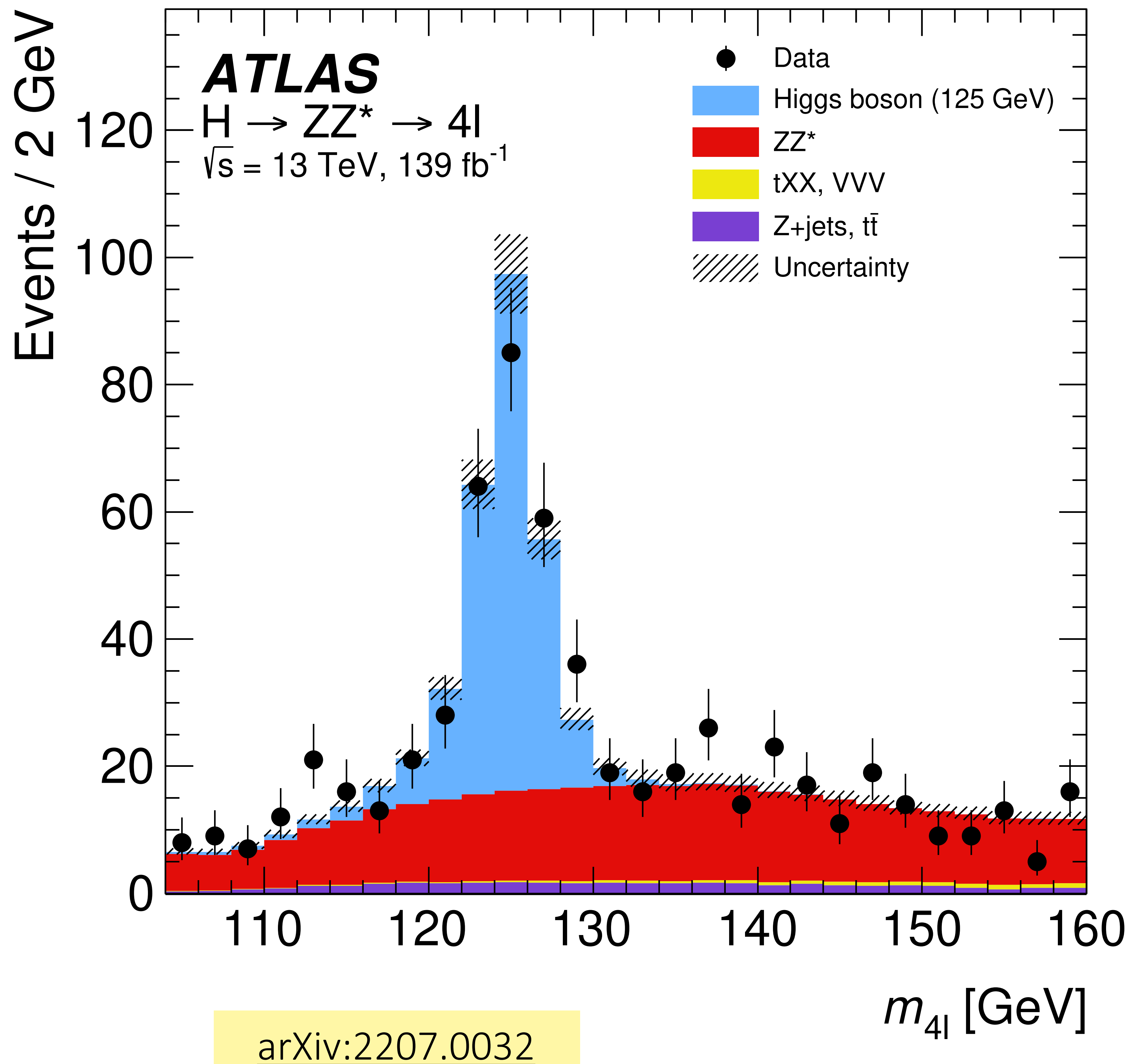
NEW

Measurement of the Higgs Boson mass has come a long way since the 2012 Higgs discovery!

- ✓ More statistics (30x)
- ✓ Better understanding of the dominant backgrounds.
- ✓ Significant reduction in systematic uncertainties.
- ✓ Improved analysis techniques.



Physics Letters B 716 1 (2012) 1-29



arXiv:2207.0032

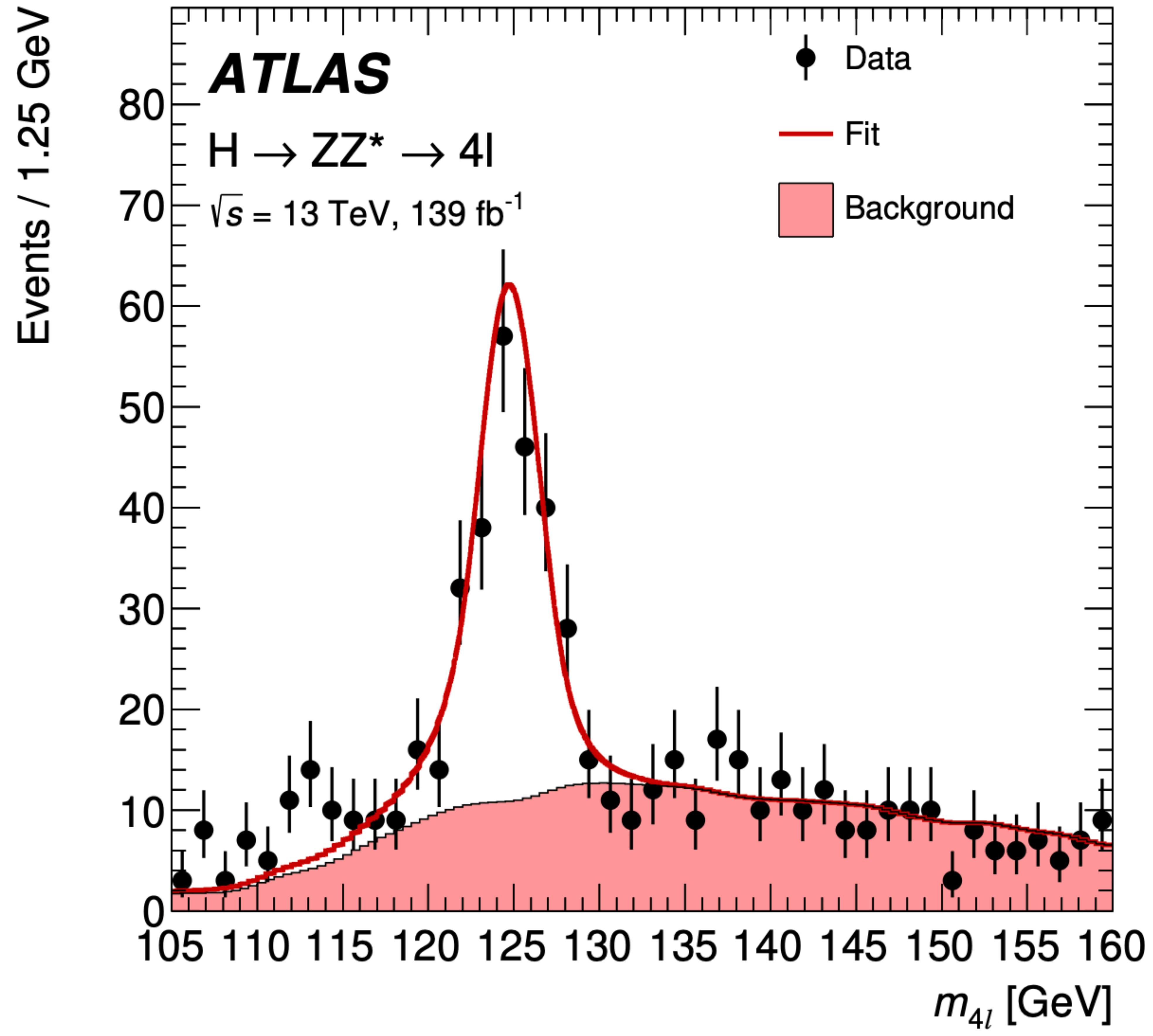
NEW

Latest $H \to ZZ^* \to 4\ell$ mass result:

arXiv:2207.0032

In this channel: larger dataset + improved experimental techniques + more precise lepton calibration.
Improvements since 36 fb^{-1} analysis:

- ⇒ Factor 2 reduction in statistical uncertainty
- ⇒ $\sim$ 20% reduction on systematic uncertainty relative to previous Run 2 publication



Size of leading systematics:

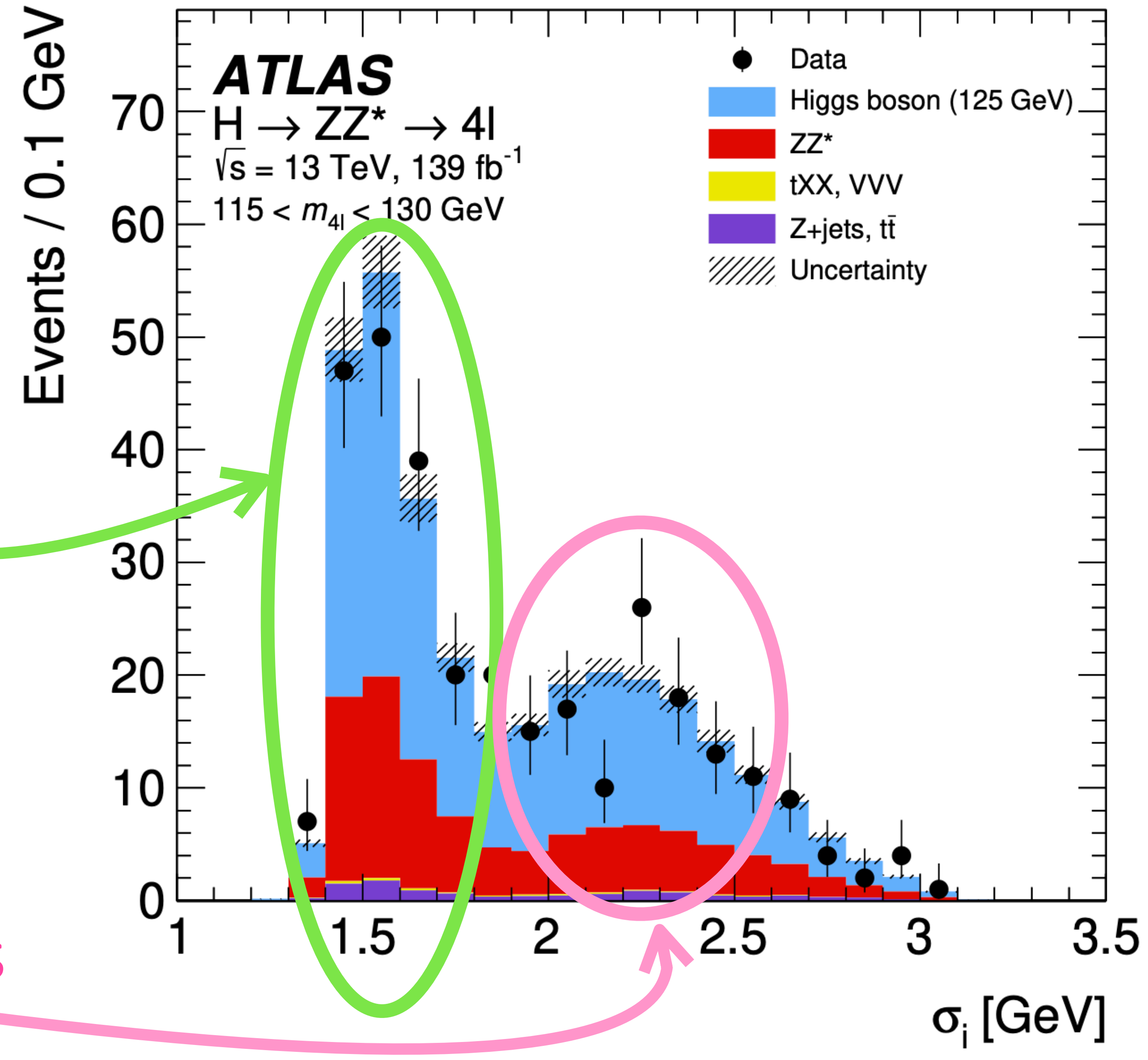
Systematic Uncertainty	Contribution [MeV]
Muon momentum scale	±28
Electron energy scale	±19
Signal-process theory	±14

Analysis improvements:

1. New deep neural network (DNN) for S/B discrimination
2. Improved p_T^μ calibration.
3. **Per event, σ_i,** resolution estimate!

$\sigma_i \sim$ 1.5 GeV for 4μ and 2μ2e events

$\sigma_i \sim$ 2.1 GeV for 2e2μ and 4e events

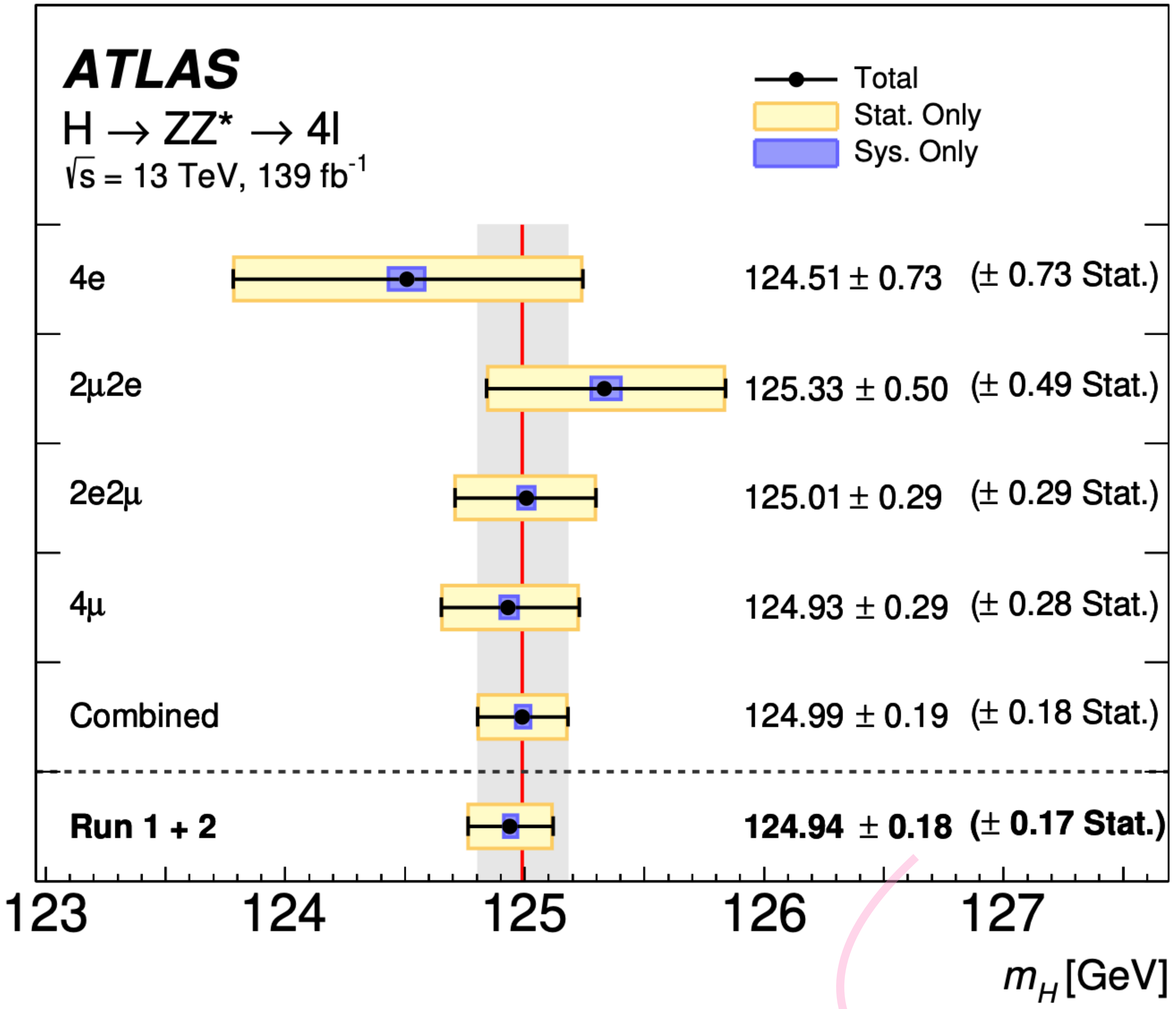


Latest $H \to ZZ^* \to 4\ell$ mass result:

NEW

arXiv:2207.0032

Simultaneous fit for all decay channels.



0.14% uncertainty on m_H!

Strongly **stat error limited**

$\sim$ 88% improvement compared to $m_H^{H\to ZZ}$, RunI

$H \to ZZ^* \to 4\ell$ full Run 2 dataset (139 fb^{-1}):

$$m_H^{ZZ} = 124.99 \pm 0.18\ (\text{stat}) \pm 0.04\ (\text{sys})\ \text{GeV}$$

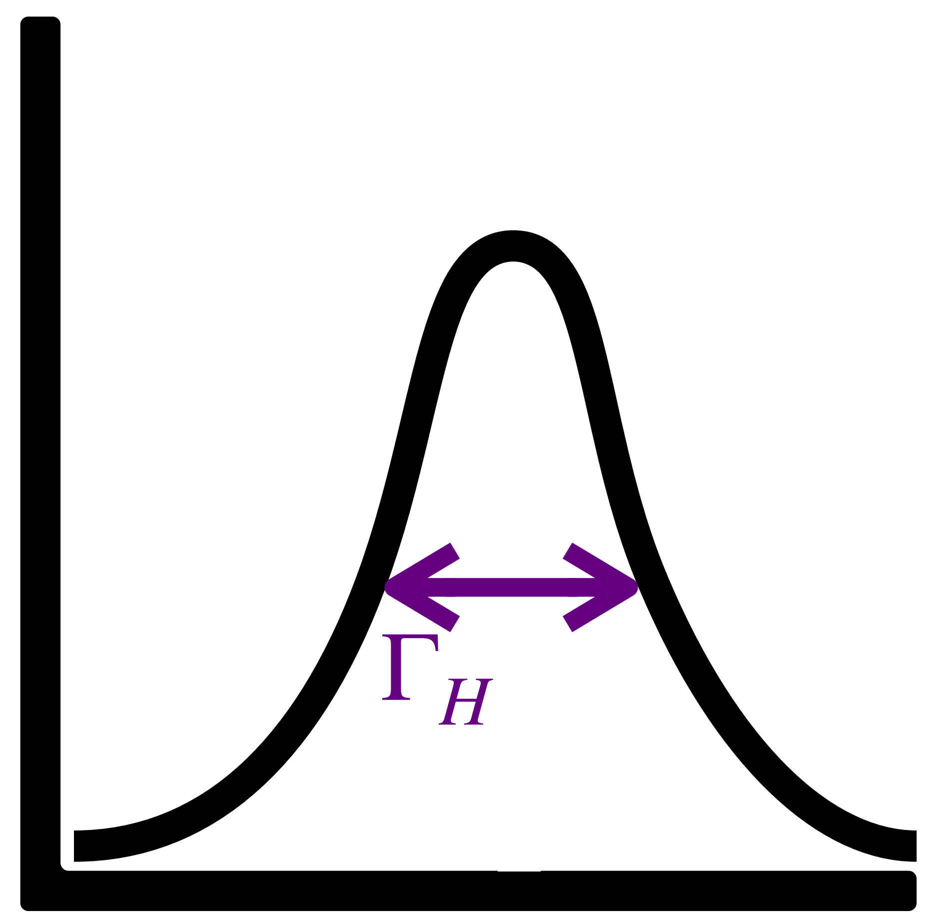
$H \to ZZ^* \to 4\ell$ combination of Run 1 and Run 2 datasets:

$$m_H^{ZZ} = 124.94 \pm 0.17\ (\text{stat}) \pm 0.03\ (\text{sys})\ \text{GeV}$$

This m_H result is one of **the most precise** measurements of the LHC scientific program!

2.

WIDTH



The Higgs width: a difficult measurement!

Contains information about the interactions of the Higgs with all other fundamental particles.
Since width value depends on Higgs couplings to SM particles-> very important to measure it precisely!
If theory $\neq$ measurement $\Rightarrow$ new particles that also couple to the Higgs? New physics?

The SM predicts the total Higgs width to be:

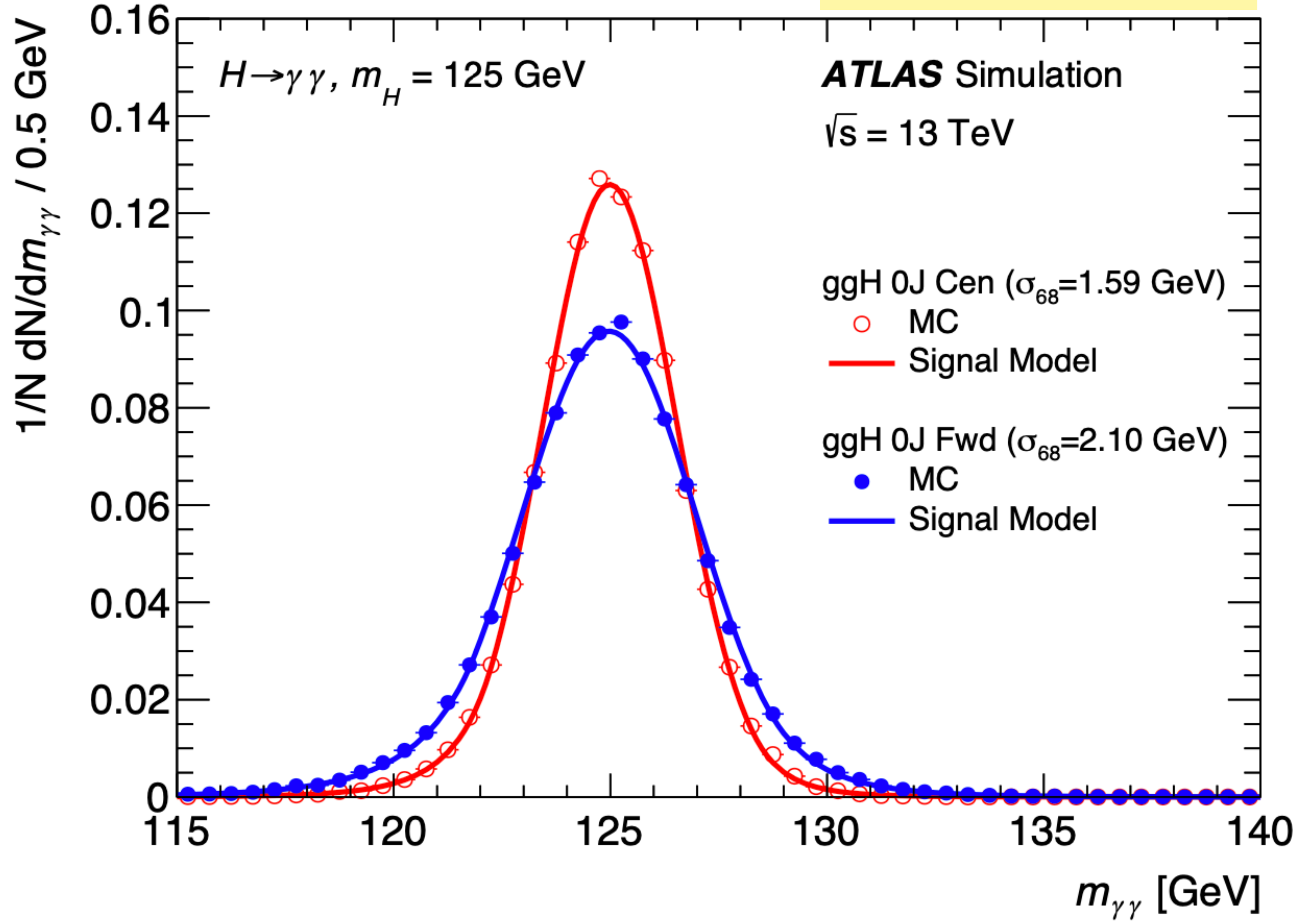
$$\Gamma_H^{SM} = 4.07 \text{ MeV}$$

Direct measurement:
Technique: Scan over invariant mass profile of the Higgs decay products, in peak on-shell region.

Feasibility: Possible for other particles with larger width - the Z boson ($\Gamma_Z^{SM} = 2.09$ GeV).

Limitation: Restricted by *experimental resolution* $\Gamma_H < 1 - 2$ GeV.

ATLAS-CONF-2020-026



Indirect determination of the Higgs width:

Across m_H invariant mass distribution can define two regions of interest.

On-shell: region **close** to Higgs resonant peak, defined by $s \sim m_H^2$

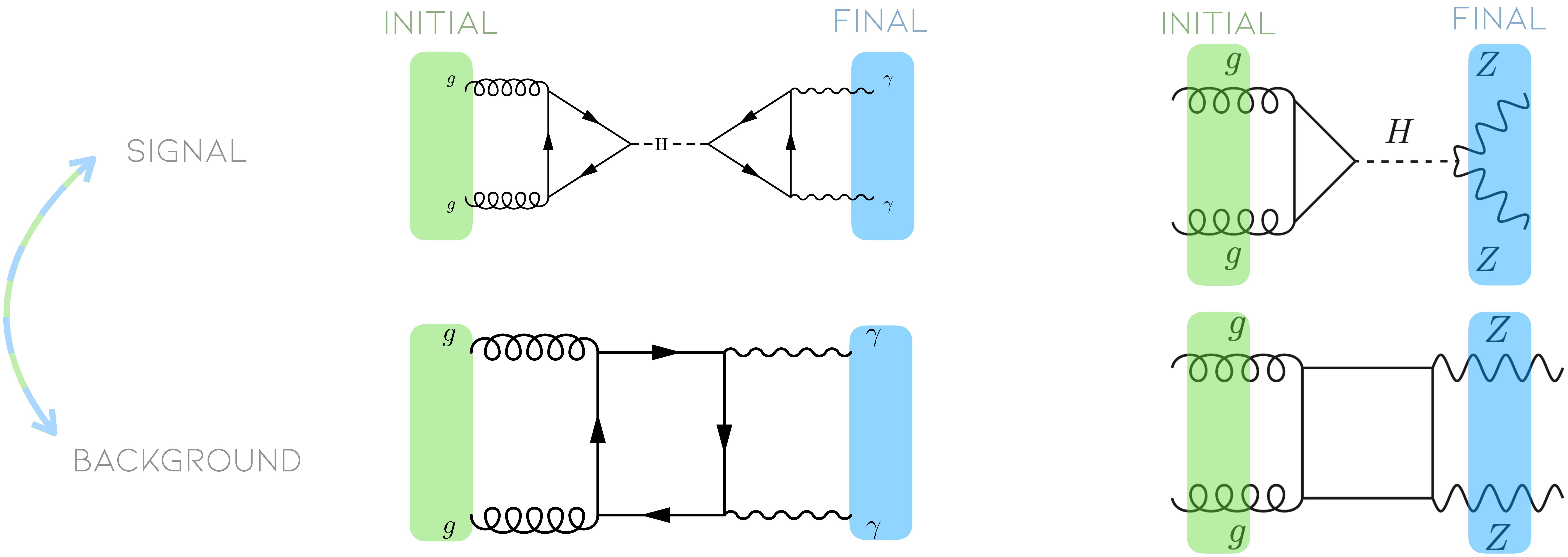
Off-shell: region **far** from peak of distribution, defined as $s >> m_H^2$

Indirect measurement techniques:

1. Interferometry (in on-shell region)
2. Off-shell method

Interference occurs between processes with the same initial and final state particles.

Interference impacts both the total cross-section, and the invariant mass line-shape.



Indirect determination of the Higgs width:

Off-shell region: [Phys. Rev. D 90, 053003], [arXiv:1307.4935v3], [Phys. Rev. D 89, 053011]:

Combine on-shell and off-shell information.

- Particularly interesting in HVV (V = W or Z) decays - strongly enhanced at high energies => far from resonant mH peak.
- **Off-shell Higgs production enhanced** at $\sim$ 350 GeV because of top-quark loops in ggF.
- $\sim$15% of Higgs cross-section is for masses > $2 \times m_Z$ due to increased phase space of on-shell Z production.

Cross-section given the Higgs propagator:

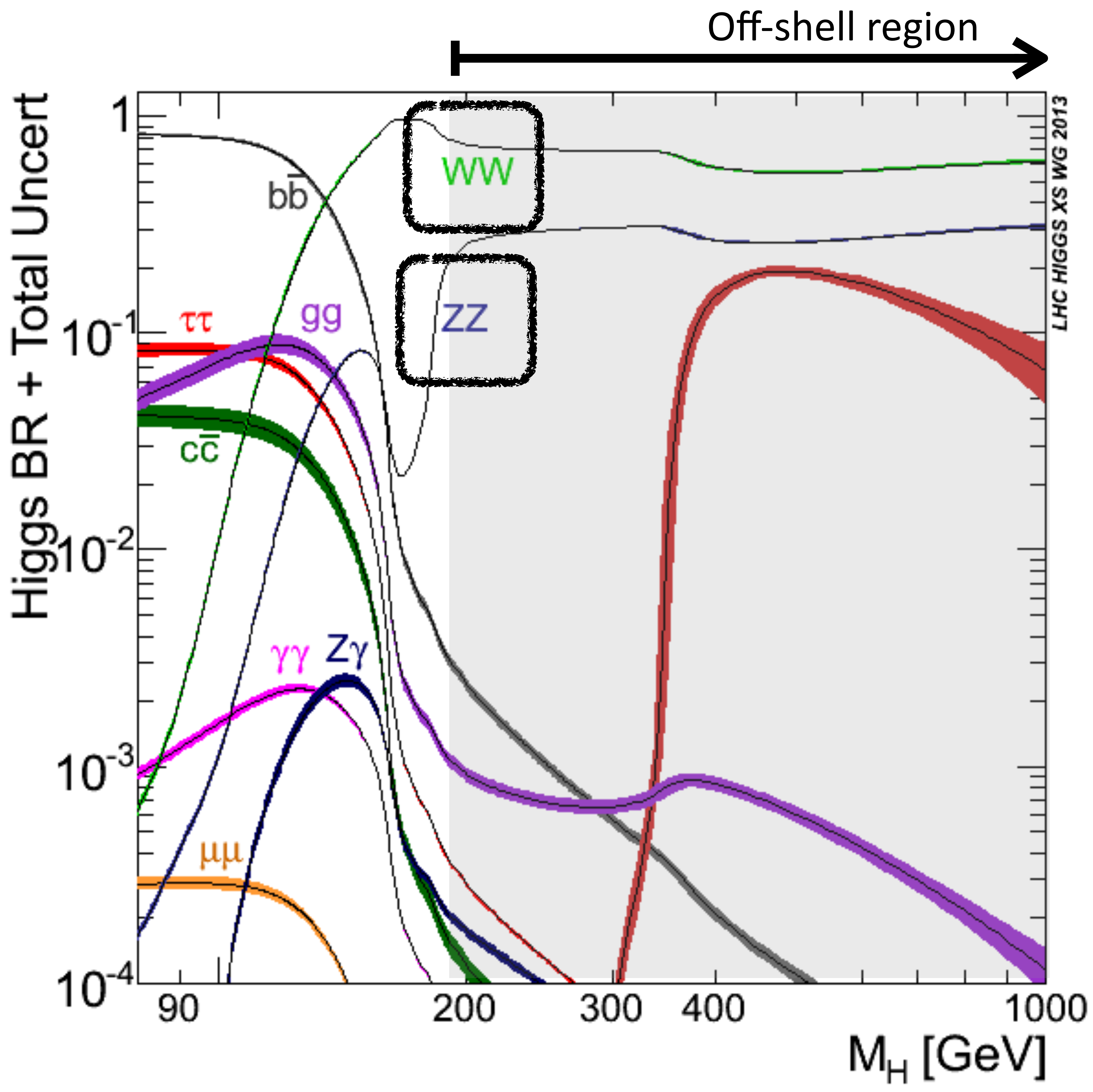
$$\sigma \sim \frac{g^2_{\text{prod}} \times g^2_{\text{decay}}}{(s - m_H^2)^2 + m_H^2 \Gamma_H^2}$$

On-shell limit: $s \sim m_H^2$

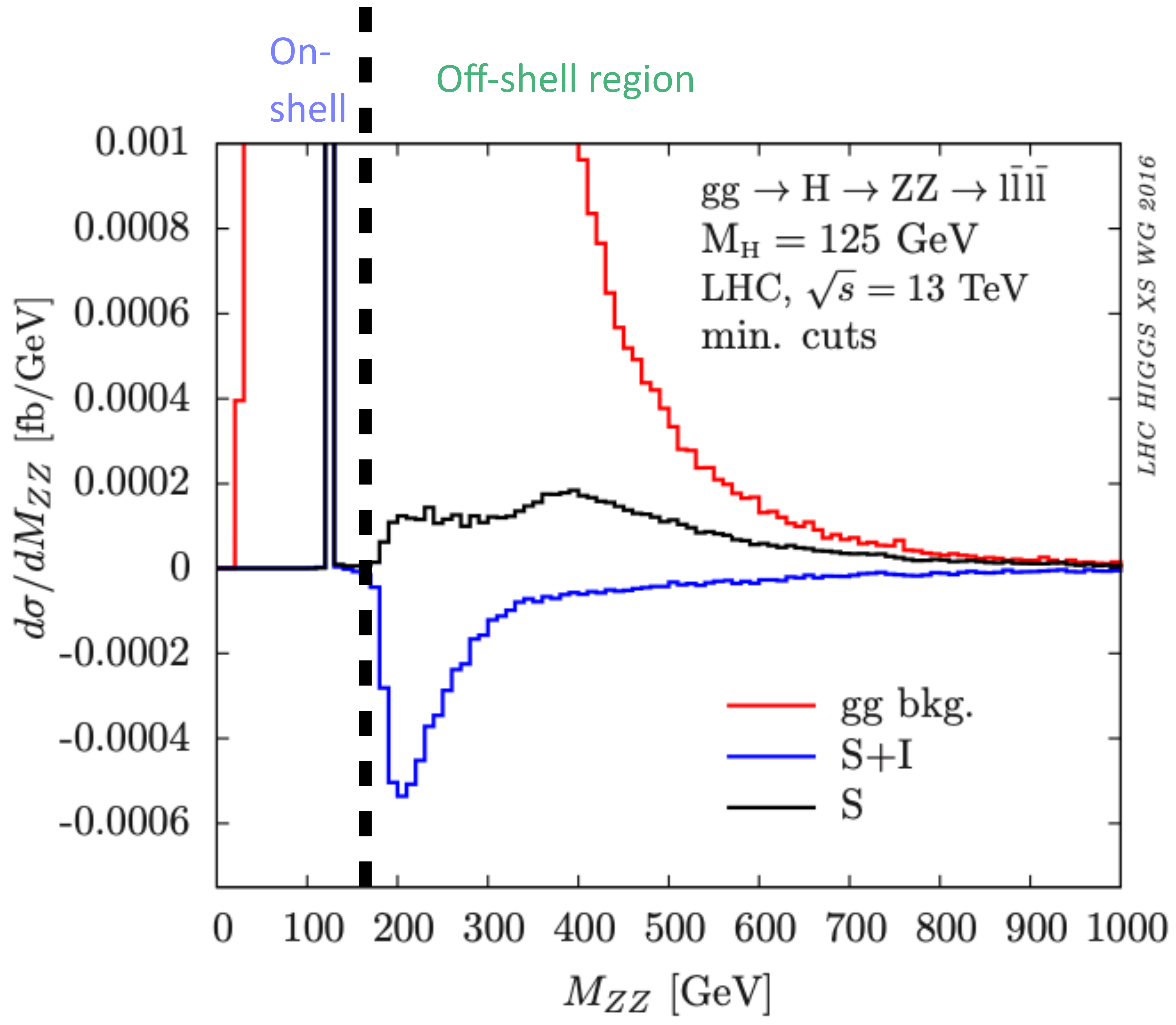
$$\sigma_{\text{on-shell}} \sim \frac{g^2_{\text{prod}} \times g^2_{\text{decay}}}{\Gamma_H}$$

Off-shell limit $s >> m_H^2$:

$$\sigma_{\text{off-shell}} \sim g^2_{\text{prod}} \times g^2_{\text{decay}}$$



Indirect determination of the Higgs width:



Interference effects = sizeable and destructive.

Determination of Higgs width, Γ_H :

take ratio between off-shell and on-shell event yields:

$$\frac{\mu_{\text{off-shell}}}{\mu_{\text{on-shell}}} = \frac{\Gamma_H}{\Gamma_H^{SM}}$$

WARNING: Method relies on the couplings cancellation.

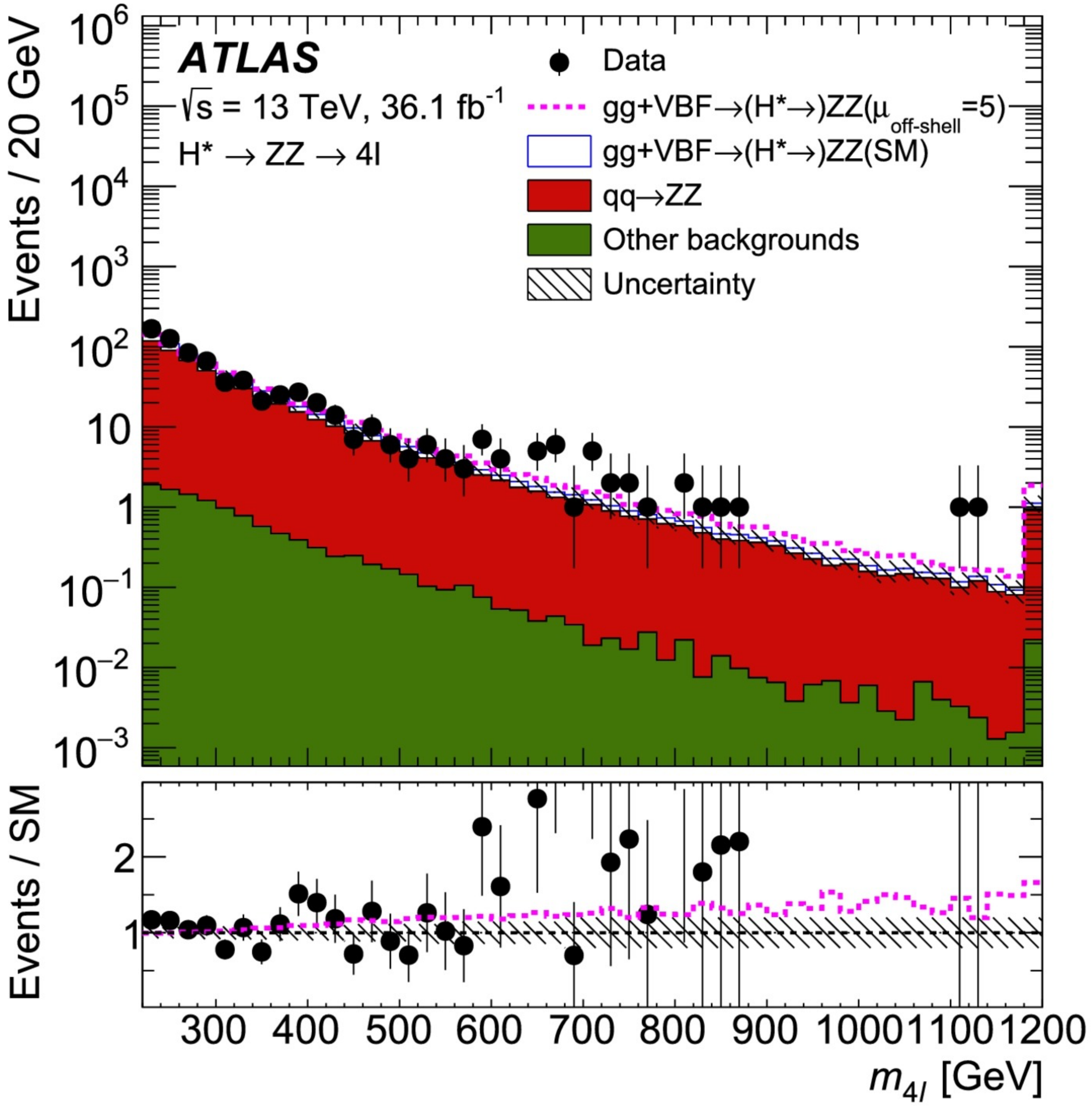
- **Assumes**: on-shell and off-shell couplings are the same, despite very different energies.
- Theoretical model dependance not present in on-shell only methods.
- Several BSM effects could de-correlate on- and off-shell couplings, e.g. additional Higgs states [PhysRevD.92.075038].

Measurements of the Higgs width from off-shell production:

Physics Letters B 786 (2018) 223–244

Latest results use 36 fb^{-1} of data.

Measurements use $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow ZZ^* \rightarrow 2\ell 2\nu$ decays.



Discriminating variables:

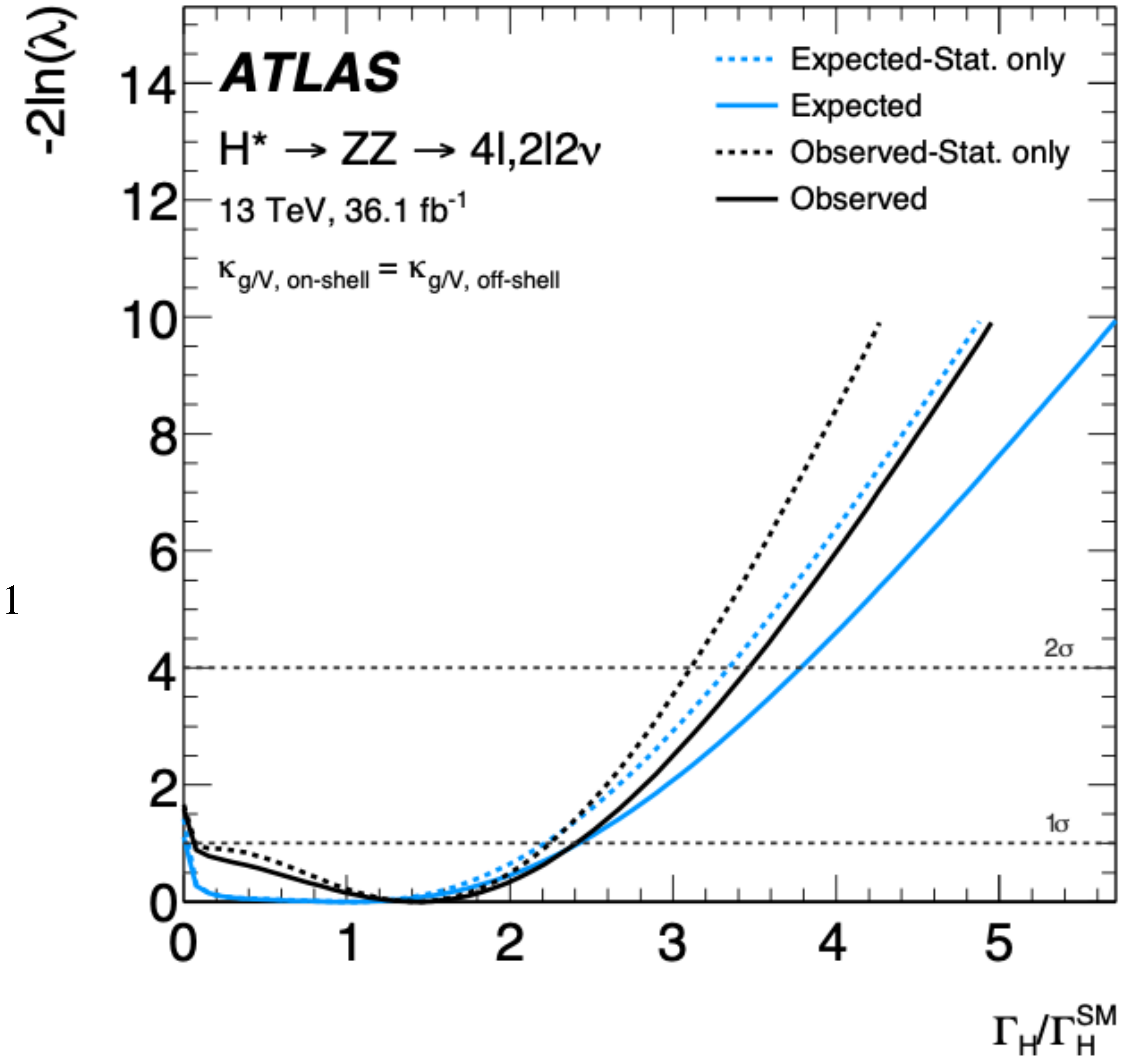
4ℓ channel: $m_{4\ell}$ and D_{ME}

$2\ell 2\nu$ channel: m_T^{ZZ}

On-shell rates from 36 fb^{-1} analysis:

$\mu_{\text{on-shell}} = 1.28^{0.21}_{0.19}$

[arXiv:1712.02304]



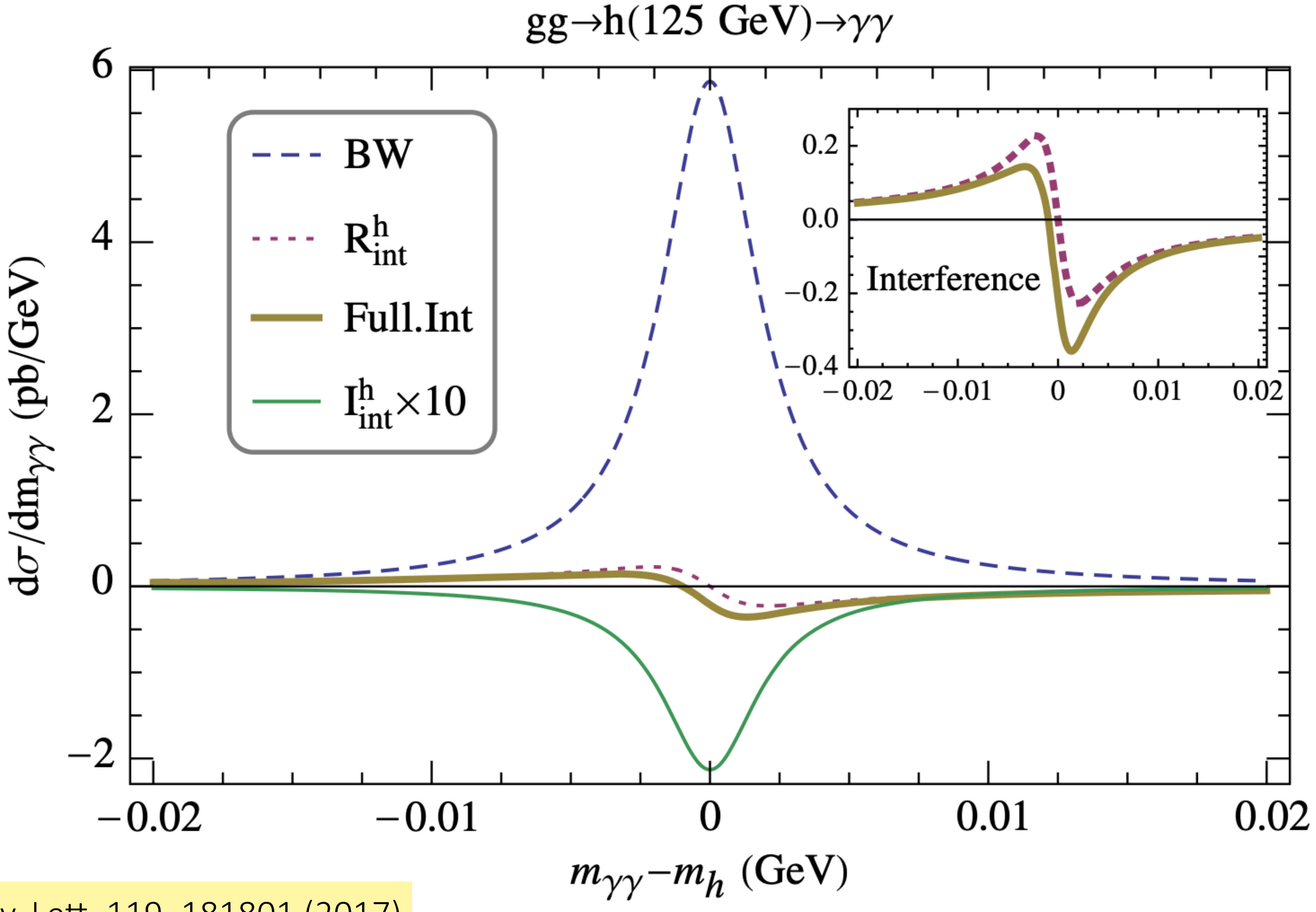
Observed results for the Higgs boson total width:

$\Gamma_H < 14.4$ MeV @ 95% CL

Indirect determination of the Higgs width:

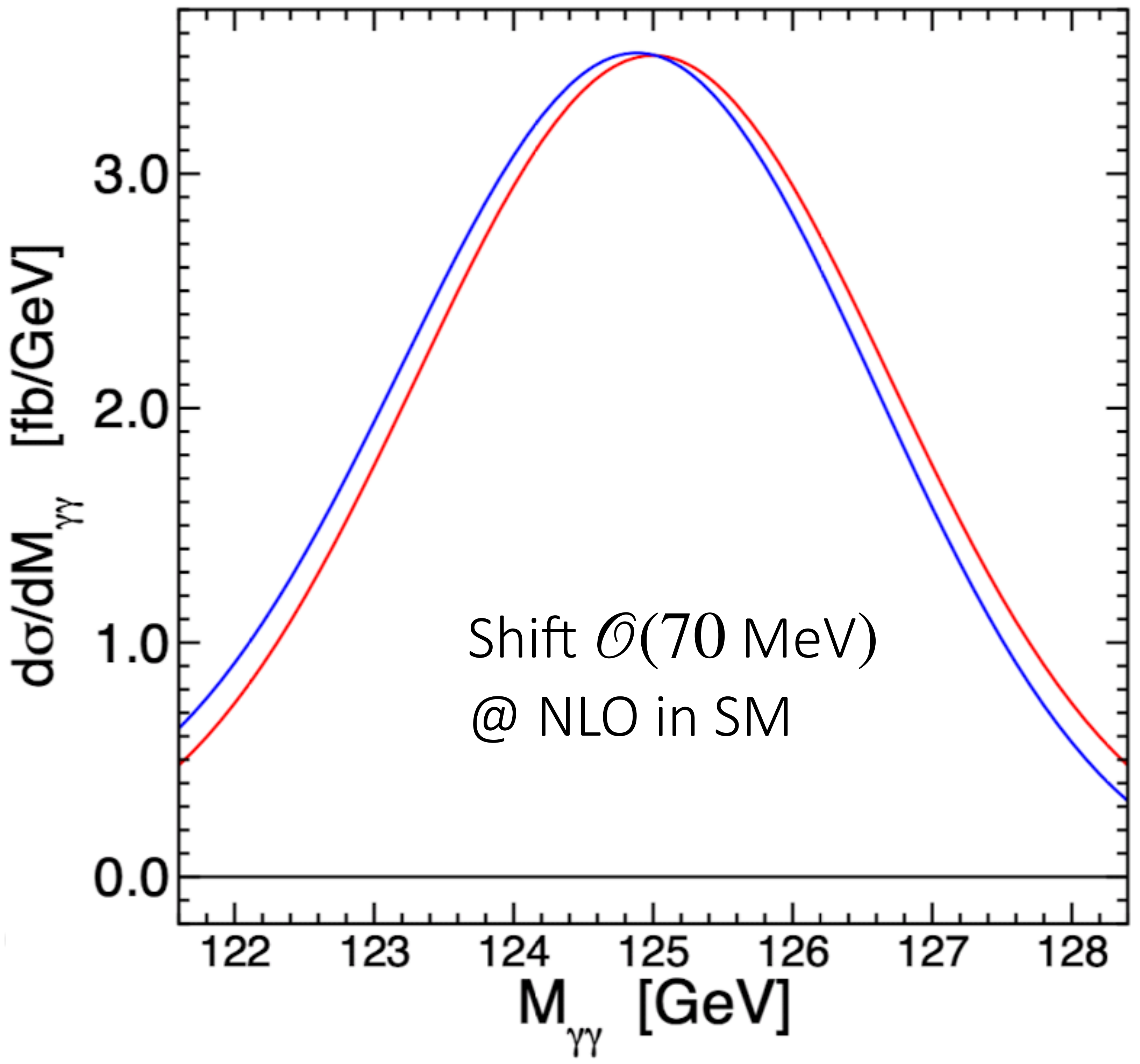
Interferometry - on-shell region: [Phys. Rev. Lett. 111, 111802], [Phys. Rev. Lett. 119, 181801], [Phys. Rev. D 86, 073016]

1. Apparent shift in mass distribution (due to antisymmetric shape effects)
2. Overall reduction in the total yield $\mathcal{O}(2\%)$.
   - Measured mass shift is proportional to the Higgs boson width: $\Delta m_H \propto \sqrt{\Gamma_H/\Gamma_H^{SM}}$
   - No constraints made on the couplings.



Phys. Rev. Lett. 119, 181801 (2017)

arXiv:1208.1533



With the HL-LHC dataset, and subsequent theoretical improvements, expect bounds on the order of $\Gamma_H \sim \mathcal{O}(10) \times \Gamma_H^{SM}$ [CERN-LPCC-2018-04].

3.

CP + SPIN

Phys Lett B 726 (2013) 120-144

The Higgs boson spin and CP quantum numbers:

The SM predicts the Higgs to be spin 0 (only SM particle), and have positive parity (CP even): $J^{CP} = 0^{++}$

Measuring the spin:

Run I: Evidence for spin 0 nature of the Higgs.

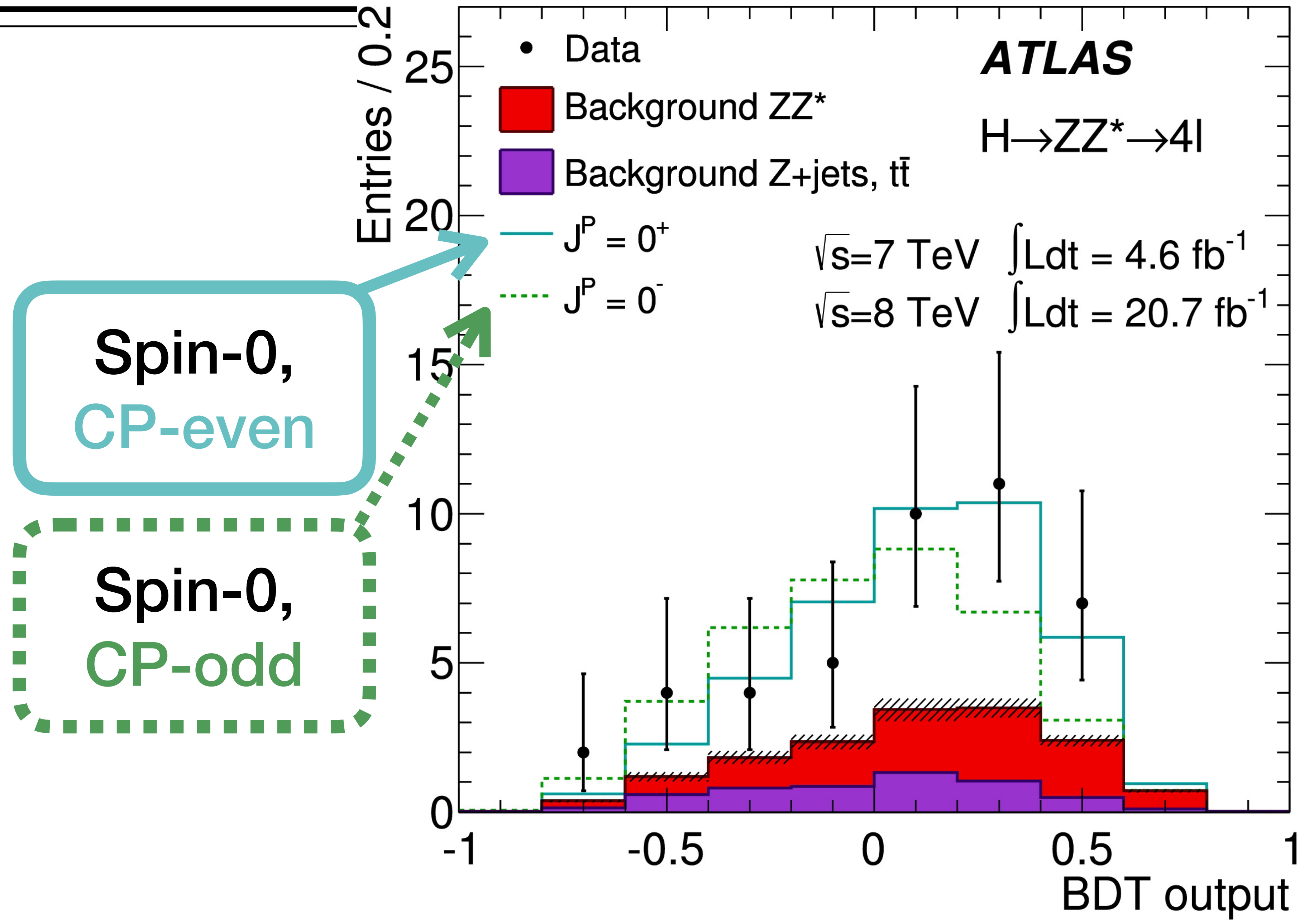
Spin 1 and 2 hypotheses excluded at > 99.9% CL using $H \to \gamma\gamma$, $H \to WW^*$, $H \to ZZ^*$.

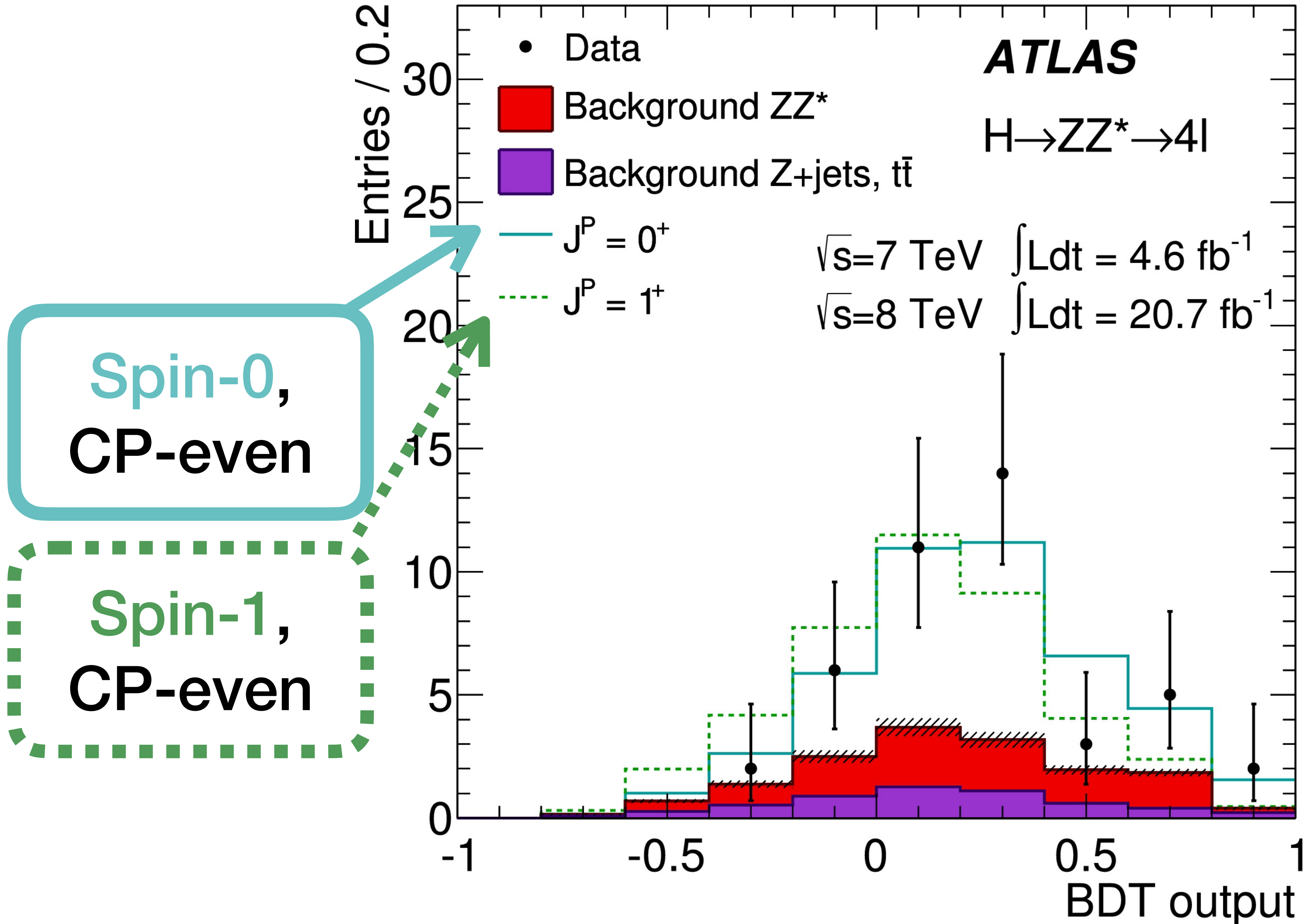
Higgs purely CP-even? Possibility of CP-violation in Higgs sector?

Presence of a CP-odd (pseudo-scalar) admixture has not yet been excluded.

Measured CP-odd contribution = new physics

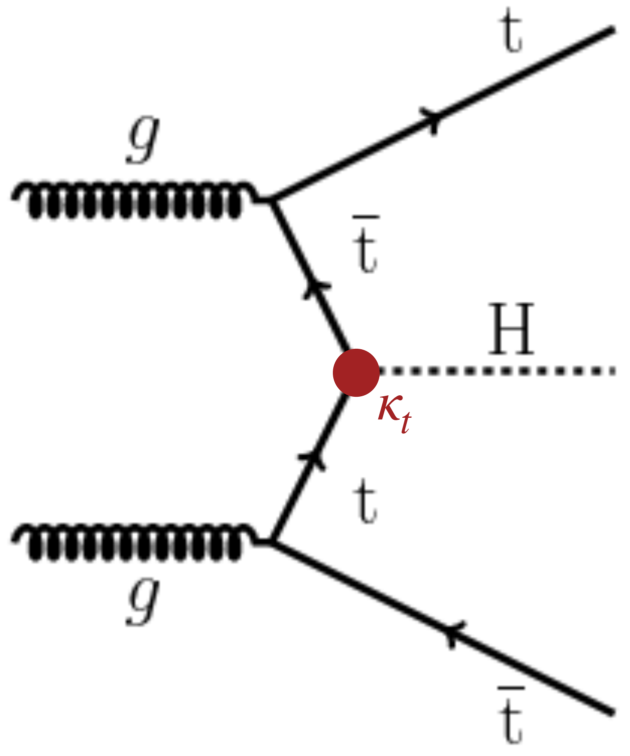
⇒ contribute to the observed baryon asymmetry of the universe.

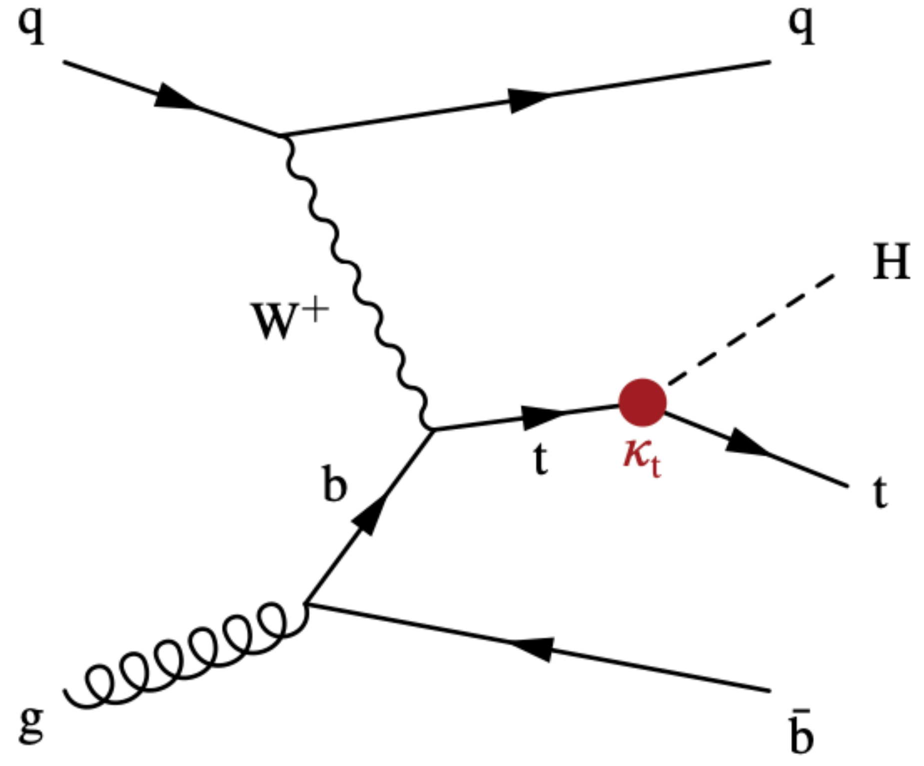




Probing CP properties of the top-Higgs Yukawa coupling:

CP properties of the top-Higgs Yukawa coupling studied directly using Higgs Boson production in association with top quarks, e.g. top quark pair, $t\bar{t}H$ or single top tH processes.



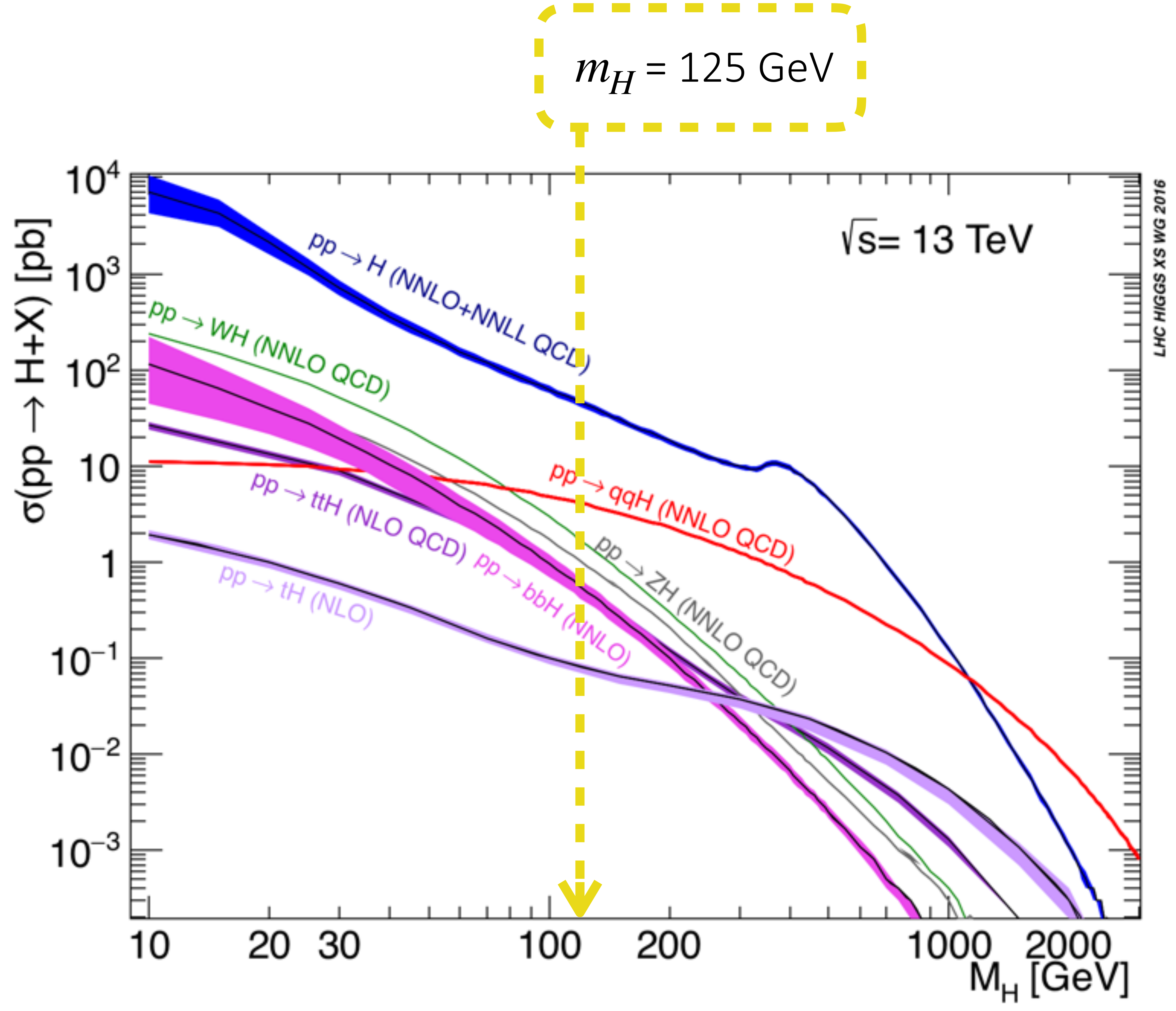


$$\mathscr{L}_{eff} = -\frac{m_t}{v}\{\bar{\psi}_t\kappa_t\left[\cos(\alpha) + i\sin(\alpha)\gamma_5\right]\psi_t\}H$$

κ_t (> 0) is the top Yukawa coupling parameter (=1) for SM

α is the CP mixing angle
SM: Pure CP-even, α=0°

Pure CP-odd
$\alpha = \pm 90°$



Any other α value → new source of CP violation in SM!

Latest ATLAS results, using 139 fb^{-1} collected at 13 TeV consider $H \to \gamma\gamma$ and $H \to b\bar{b}$.

Probing CP properties of the top-Higgs Yukawa in $H \to \gamma\gamma$:

Phys. Rev. Lett. 125 (2020) 061802

Measured rates:

$\sigma_{t\bar{t}H} \times B_{\gamma\gamma} = 1.64^{+0.38}_{-0.36}$ (stat)$^{+0.17}_{-0.14}$ (sys) fb

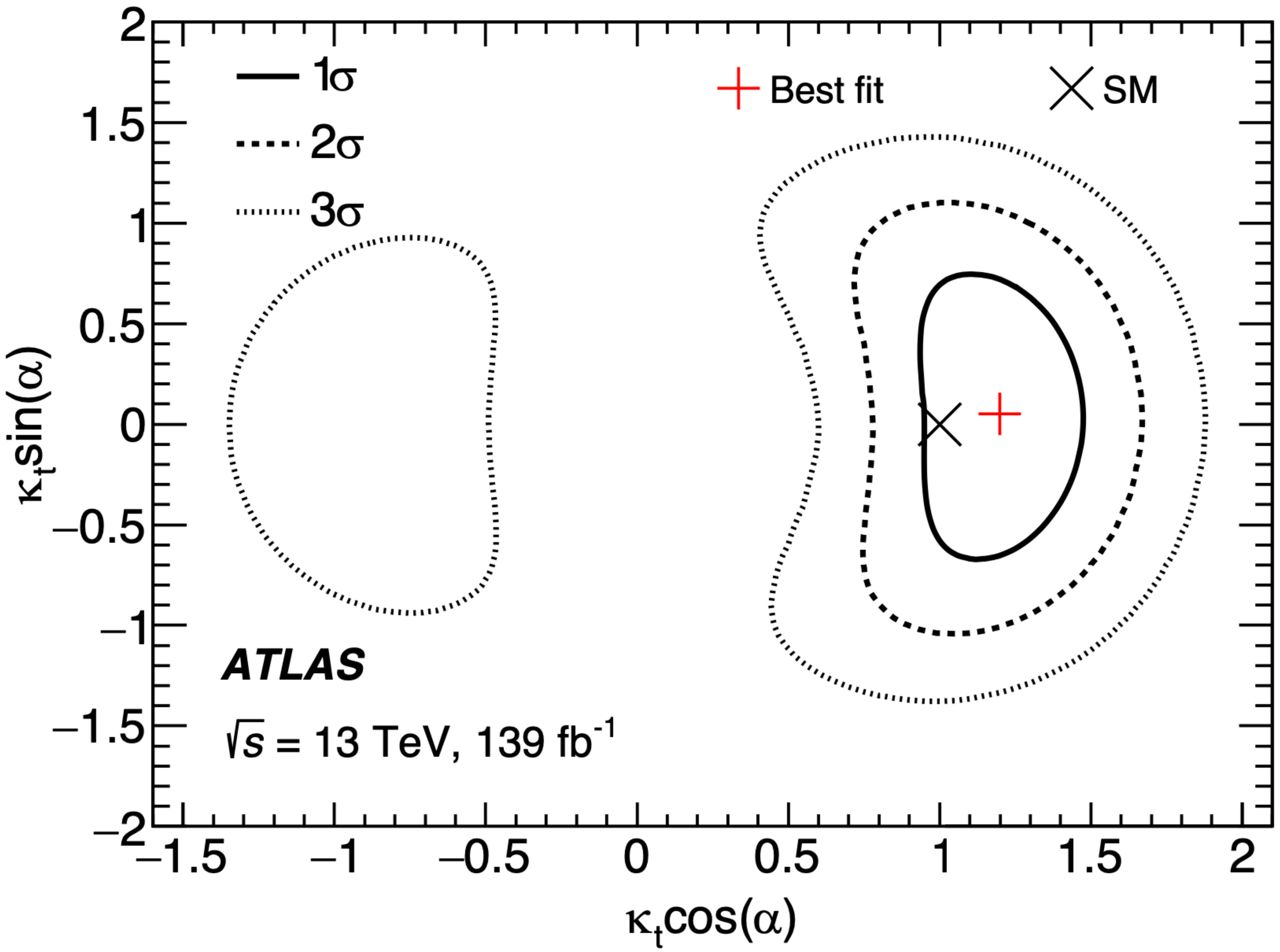
Assuming a CP-even coupling and constraining all non-$t\bar{t}H$ Higgs processes to SM predictions.

Measured rate for $t\bar{t}H$:

$1.43^{+0.33}_{-0.31}$ (stat)$^{+0.21}_{-0.15}$ (sys) $\times$ $SM_{\text{expectation}}$

Pure CP-odd coupling excluded at 3.9σ
→ *Severely* constrained!

Limit set on CP mixing angle:
$|\alpha| > 43°$ excluded @ 95% CL



All measurements are consistent with SM expectations.

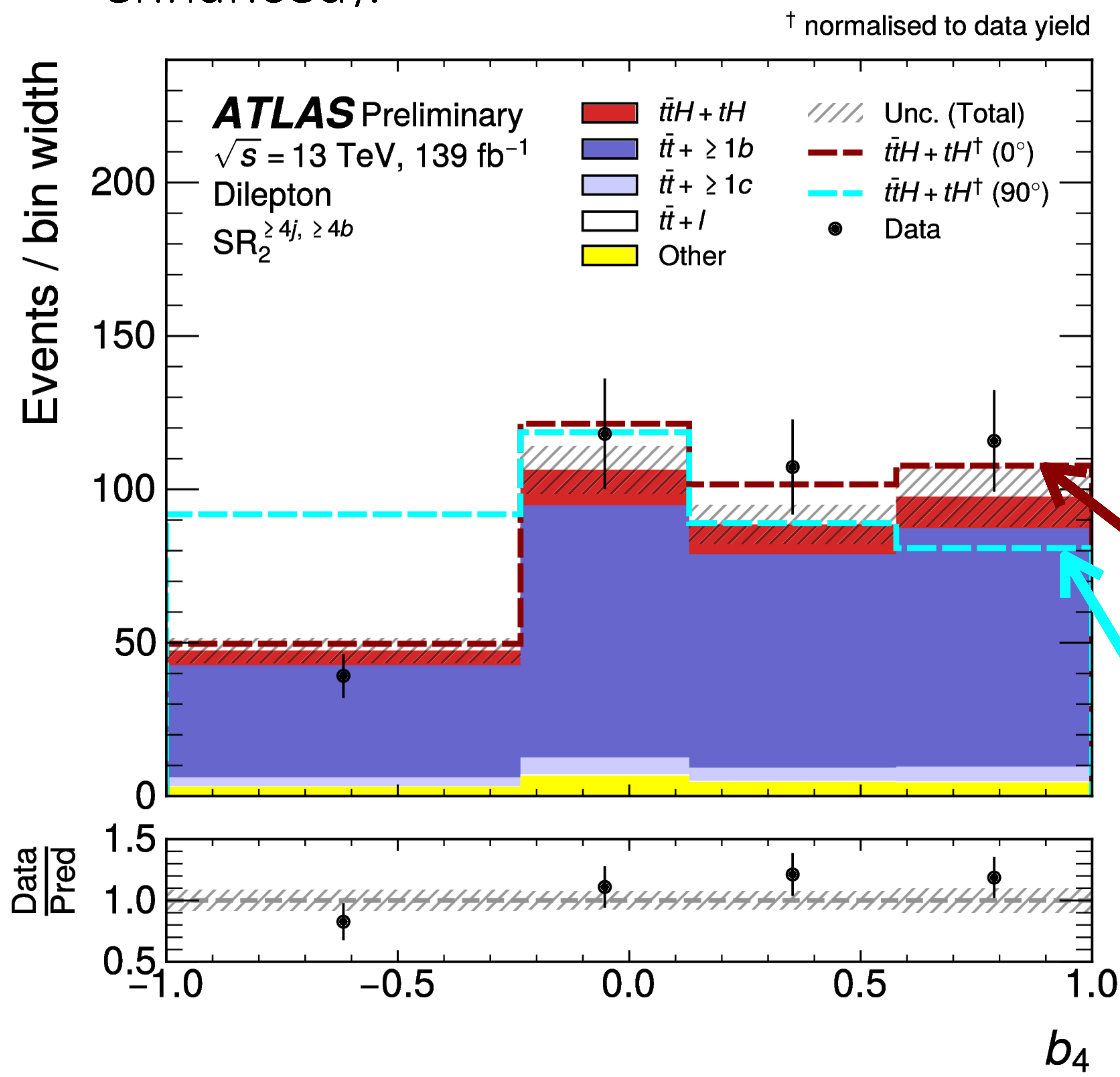
Probing CP properties of the top-Higgs Yukawa in $H \rightarrow b\bar{b}$:

NEW

ATLAS-CONF-2022-016

Channel: $H \rightarrow b\bar{b}$ produced in association with top quarks ($t\bar{t}H$ or tH).
Target final states where ≥ 1 top decays semi-leptonically to e or μ.

Analysis optimised for $t\bar{t}H(\rightarrow b\bar{b})$, not the tH signal -> small yield, due to destructive interference.
Higgs pT sensitive to CP -> exploited by considering boosted region (tH enhanced).

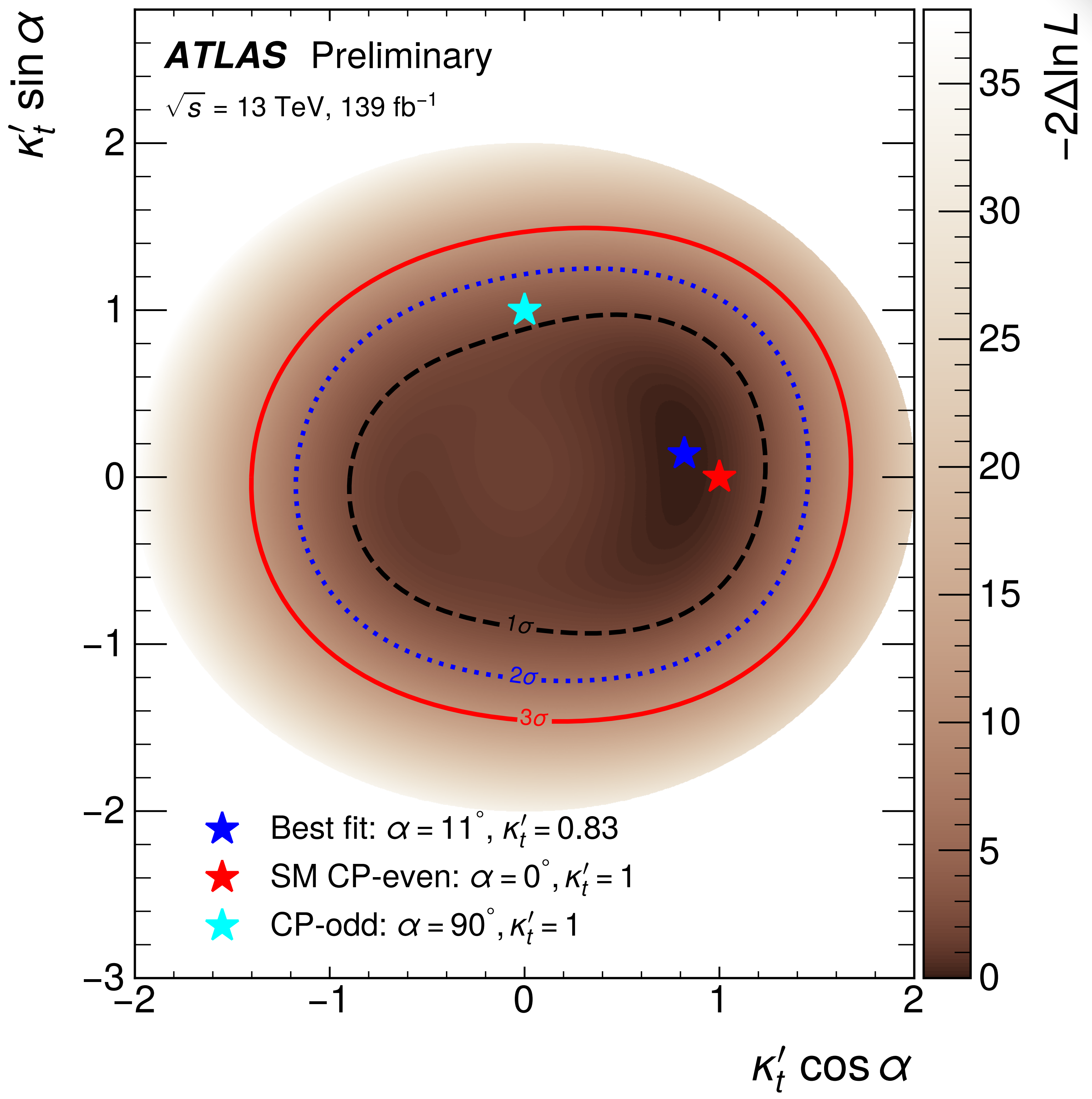


CP sensitive observable: b4 exploits enhanced t production close to beam pipe and in opposite directions, for CP-odd $t\bar{t}H$ production.

$$b_4 = \frac{p_1^z p_2^z}{|\vec{p_1}||\vec{p_2}|}$$

α = 0°, CP-even

α = 90°, CP-odd



Values of α and κ_t determined simultaneously using a binned profile likelihood fit.

Pure CP-odd coupling excluded at 1.2 σ

Best fit values: CP-mixing angle, $\alpha = 11^{\circ}{}^{+55^{\circ}}_{-77^{\circ}}$

Coupling strength $\kappa_t = 0.83^{+0.30}_{-0.46}$

NEW

Defining a CP sensitive observable in $H \to \tau\tau$:

ATLAS-CONF-2022-032

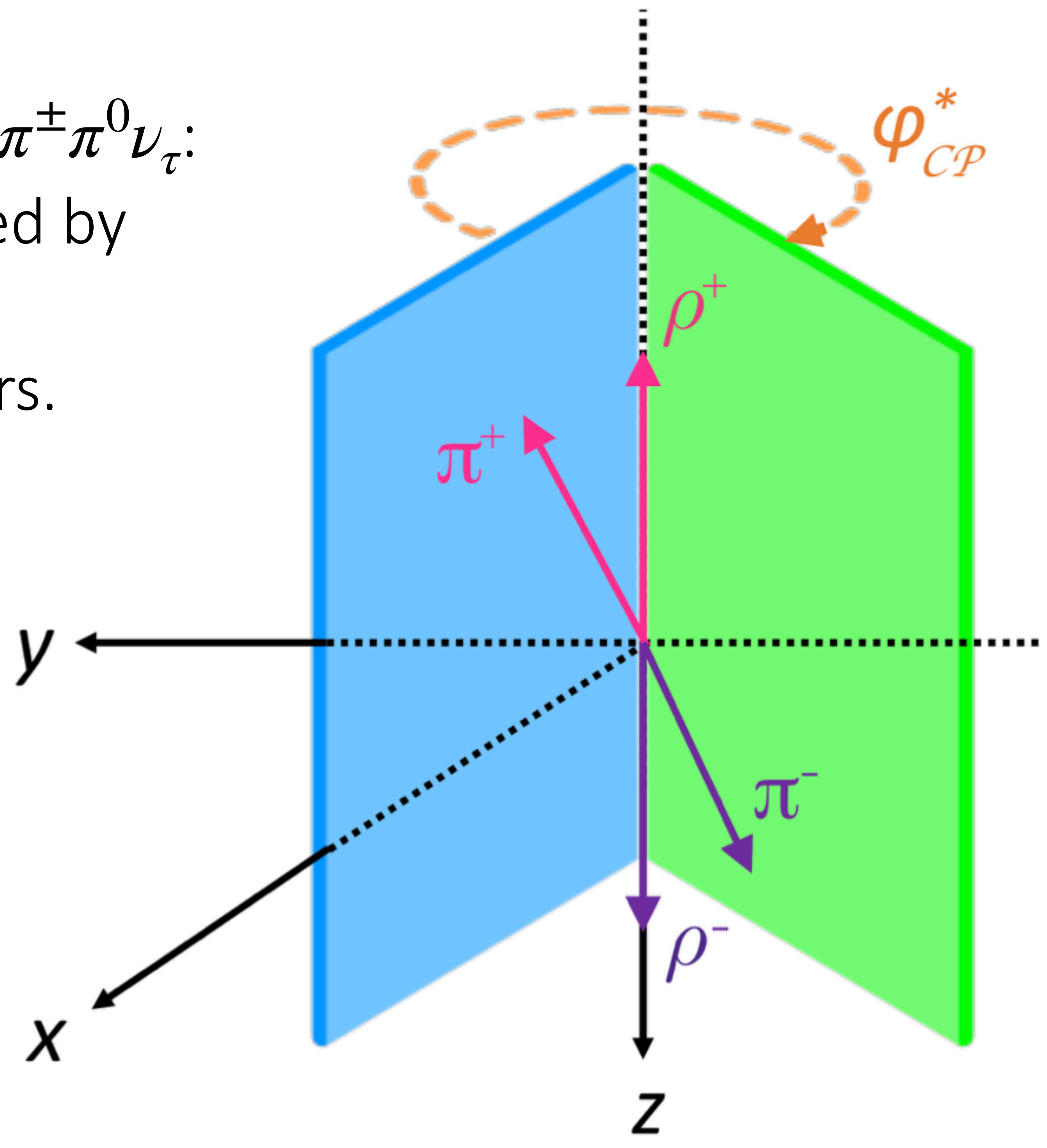
Higgs decays to τ lepton pairs allow for direct probe of the CP properties of the Higgs to τ Yukawa coupling.

CP-mixing angle, ϕ_τ information encoded in correlations between transverse spin components of τ leptons.

CP sensitive observable: acoplanarity angle, φ^*_{CP} between the decay planes.

⇒ Constructed based on visible decay products, where method is different for each decay channel.

For $\tau^\pm \to \rho^\pm \nu_\tau \to \pi^\pm \pi^0 \nu_\tau$: decay plane formed by the pion four-momentum vectors.



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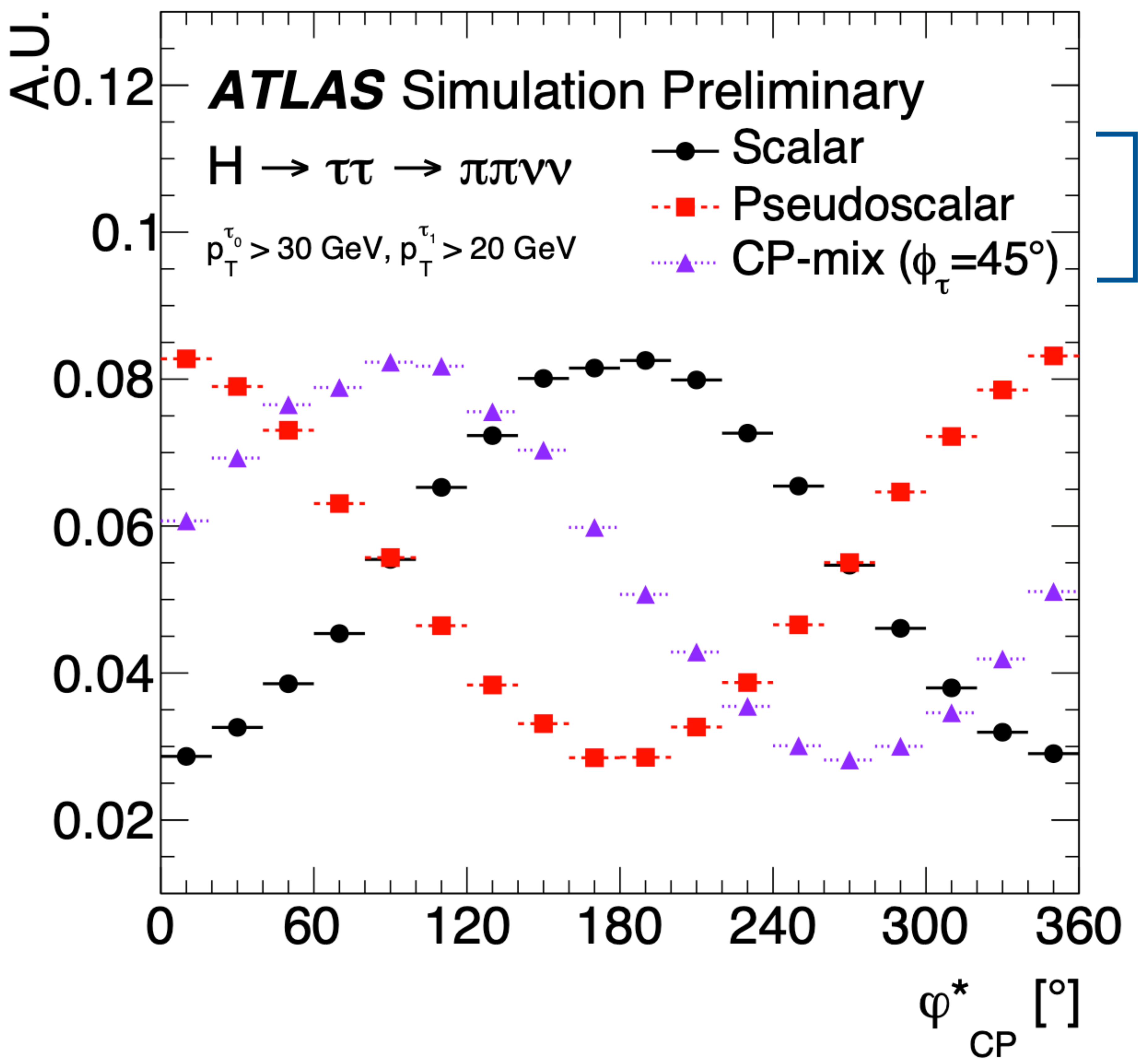


Shape of φ^*_{CP} distribution under different Higgs CP hypotheses.

NEW

Determination of the Higgs CP state in $H \rightarrow \tau\tau$:

ATLAS-CONF-2022-032

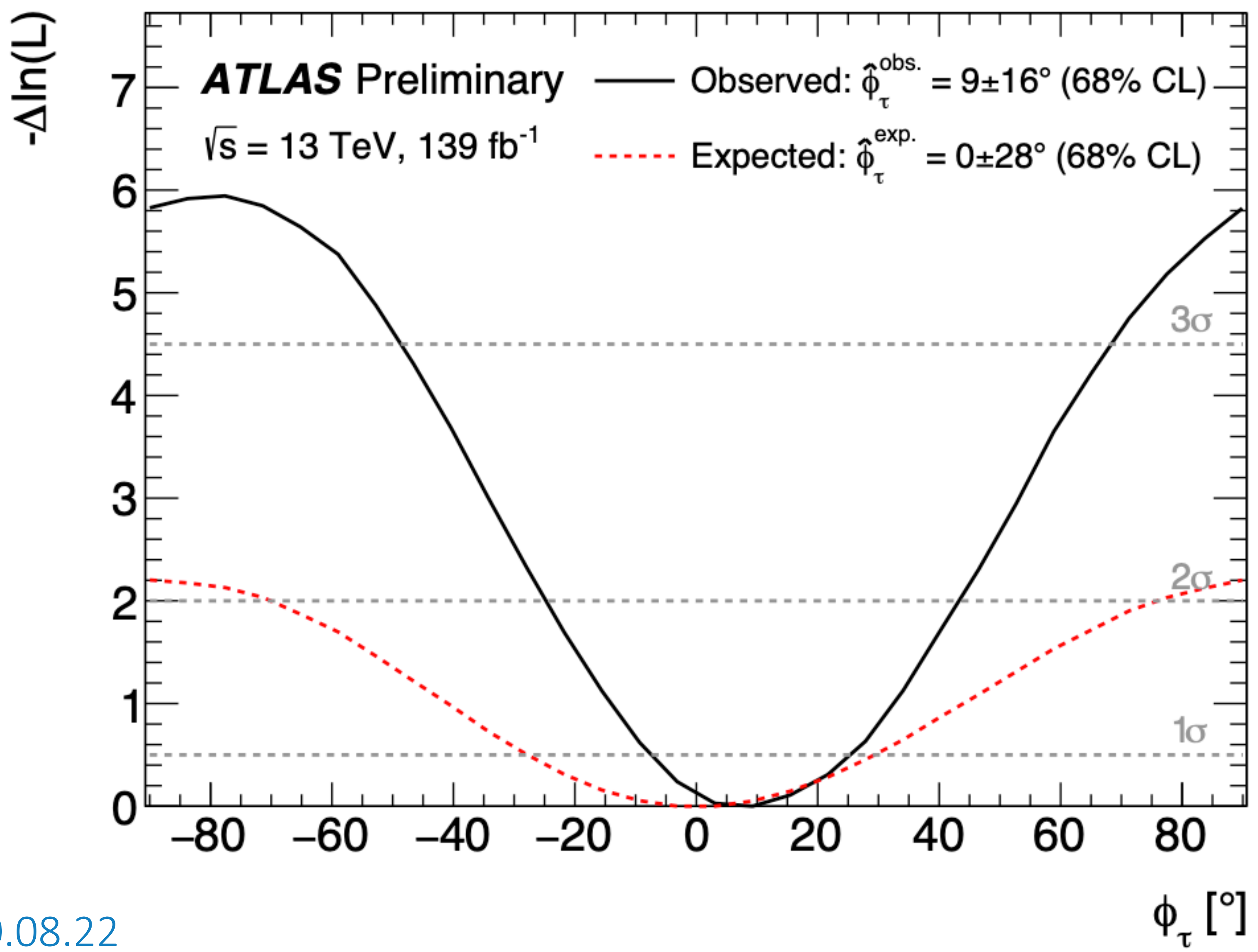
ATLAS measurement using 139 fb^{-1} of data, collected at 13 TeV.

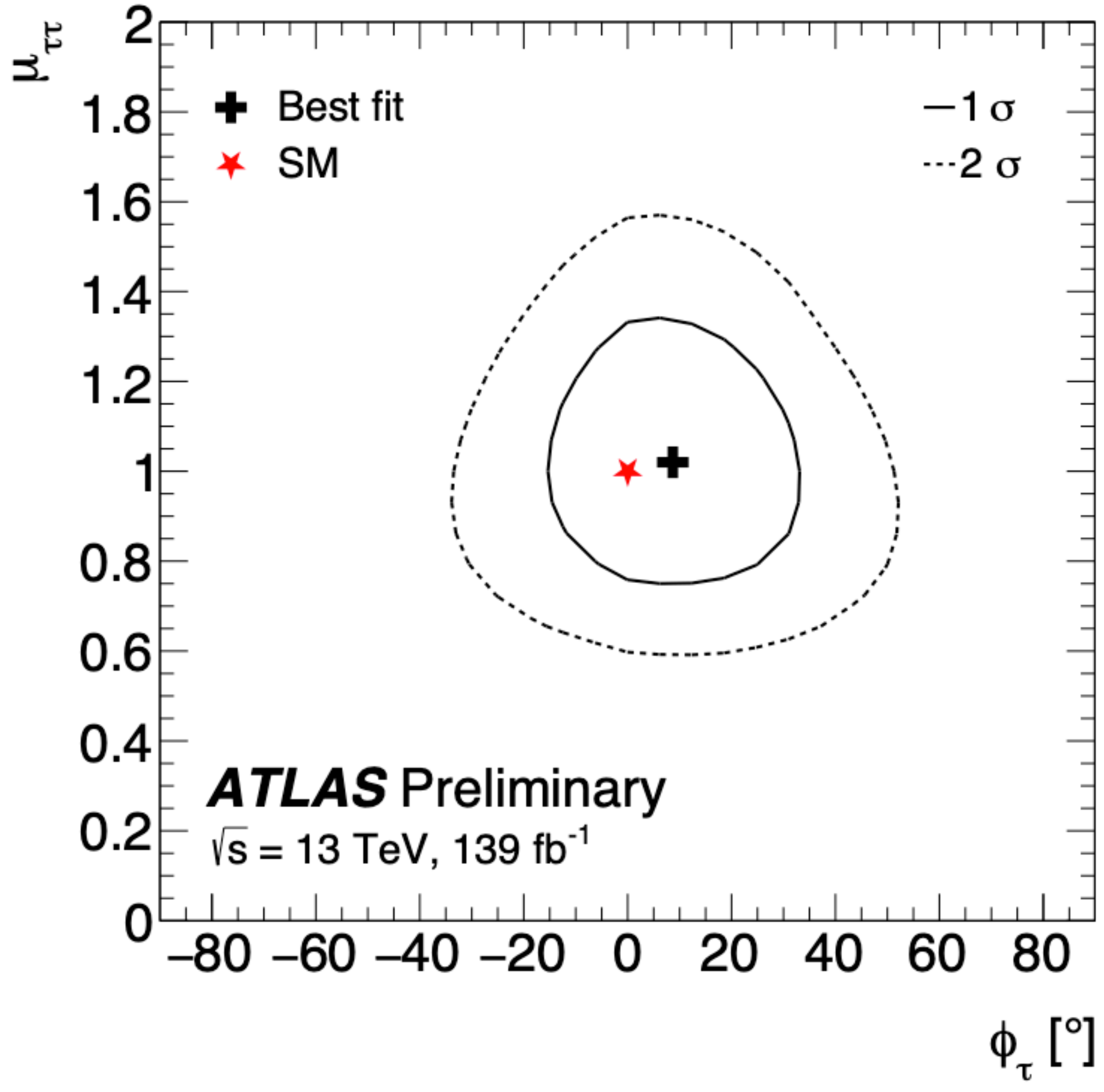
Observed value of ϕ_τ is: 9 ± 16°

Total uncertainty dominated by **statistical** uncertainties.
Leading systematic uncertainties:

- jets (4.3° impact)
- theory uncertainties on $H \rightarrow \tau\tau$ (1.5°)

Uncertainties on the τ decay reconstruction < 1° on ϕ_τ.





Pure CP-odd hypothesis is excluded at 3.4σ!

Compatible with the SM expectation within the measurement uncertainties.

NEW

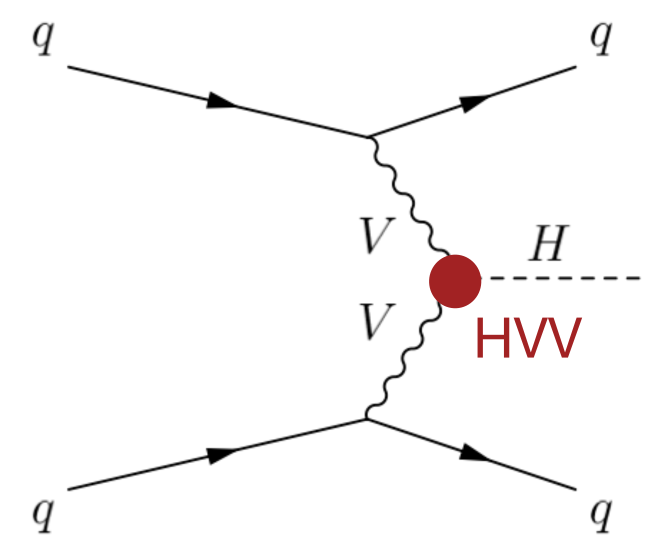
CP properties of HVV couplings in VBF $H \to \gamma\gamma$:

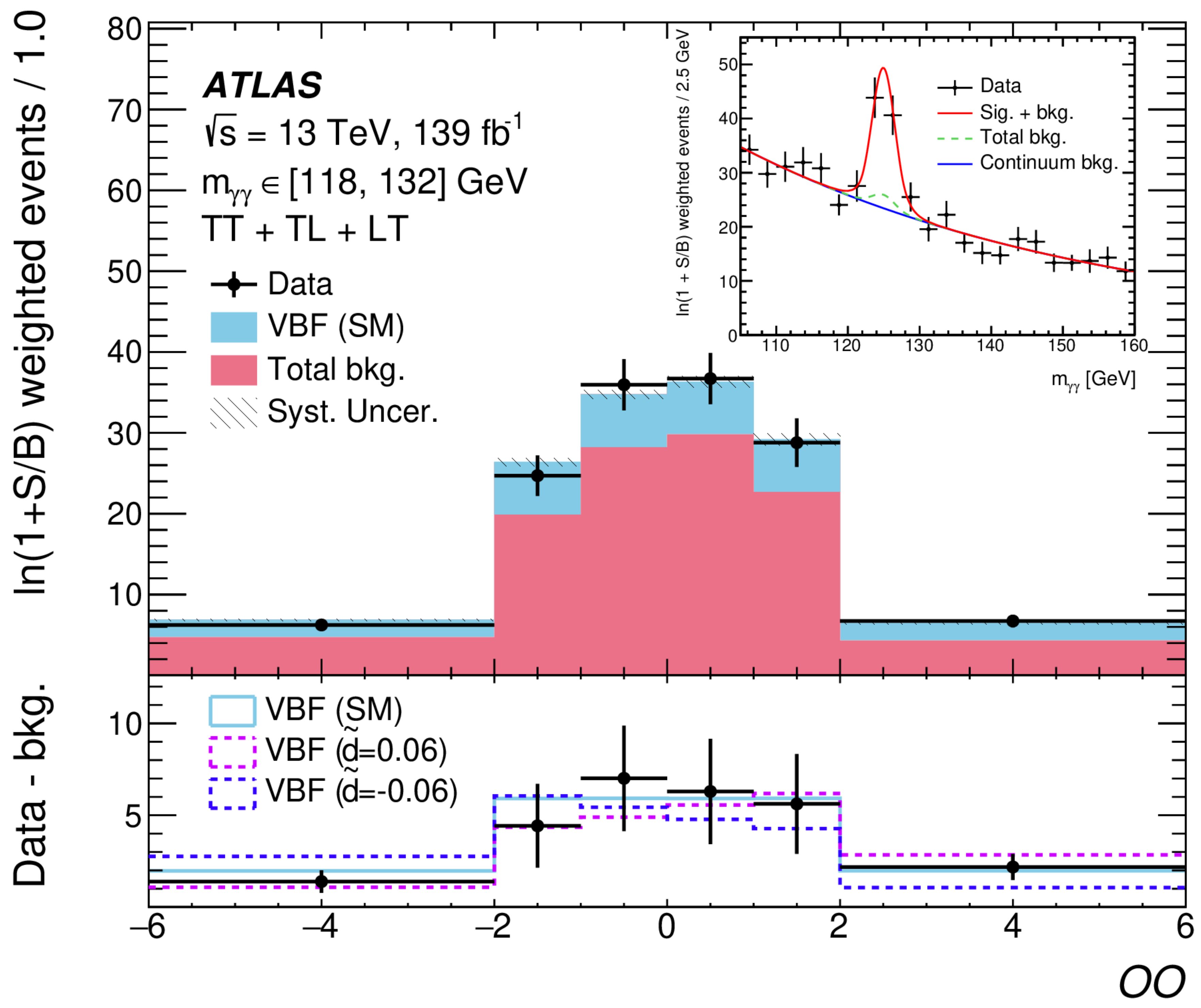
CERN-EP-2022-134

CP-odd component in HVV decays described by adding dim-6 operators to the SM Lagrangian, using an effective field theory (EFT) approach:

$$|\mathcal{M}|^2 = |\mathcal{M}_{\text{SM}}|^2 + \tilde{d} \cdot 2Re(\mathcal{M}^*_{\text{SM}}\mathcal{M}_{\text{CP-odd}}) + \tilde{d}^2 \cdot |\mathcal{M}_{\text{CP-odd}}|^2$$

Test CP invariance of the HVV coupling - Optimal Observable (OO) method: $OO = 2 \cdot Re(\mathcal{M}^*_{\text{SM}} \cdot \mathcal{M}_{\text{CP-odd}})/|\mathcal{M}_{\text{SM}}|^2$





SM: symmetric, and mean = 0.

Wilson coefficients multiplying CP-odd operators describe CP-odd couplings.

1. HISZ [Phys. Rev. D 48, 2182]: constrain $\tilde{d}$
2. Warsaw [arXiv:1008.4884v3]: constrain $c_{H\tilde{W}}$

All CP-even operator coefficients ⇒ zero

MOST STRINGENT!

	68% (exp.)	95% (exp.)	68% (obs.)	95% (obs.)
$\tilde{d}$ (inter. only)	[−0.027, 0.027]	[−0.055, 0.055]	[−0.011, 0.036]	[−0.032, 0.059]
$\tilde{d}$ (inter.+quad.)	[−0.028, 0.028]	[−0.061, 0.060]	[−0.010, 0.040]	[−0.034, 0.071]
$\tilde{d}$ from $H \to \tau\tau$	[−0.038, 0.036]	–	[−0.090, 0.035]	-
Combined $\tilde{d}$	[−0.022, 0.021]	[−0.046, 0.045]	[−0.012, 0.030]	[−0.034, 0.057]
$c_{H\tilde{W}}$ (inter. only)	[−0.48, 0.48]	[−0.94, 0.94]	[−0.16, 0.64]	[−0.53, 1.02]
$c_{H\tilde{W}}$ (inter.+quad.)	[−0.48, 0.48]	[−0.95, 0.95]	[−0.15, 0.67]	[−0.55, 1.07]

Results all compatible with SM!

The future of Higgs measurements:

Successful and interesting 10 years of Higgs properties measurements.

1. Combined Run I+II Higgs mass measurement in $H \rightarrow ZZ^* \rightarrow 4\ell$ with precision of **0.14%** !
2. Higgs width has been constrained to:

$$\Gamma_H < 14.4 \text{ MeV @ 95\% CL}$$

3. Pure CP odd Higgs excluded at 3.9σ (3.4σ) with $H \rightarrow \gamma\gamma$ ($H \rightarrow \tau\tau$) decays. **CP mixing not yet ruled out.**

13.6 TeV collisions started in July 2022.
Early Run3 analyses have begun.

Run3 + the HL-LHC will bring very interesting new results.

Full set of public ATLAS results:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults

More questions or comments?
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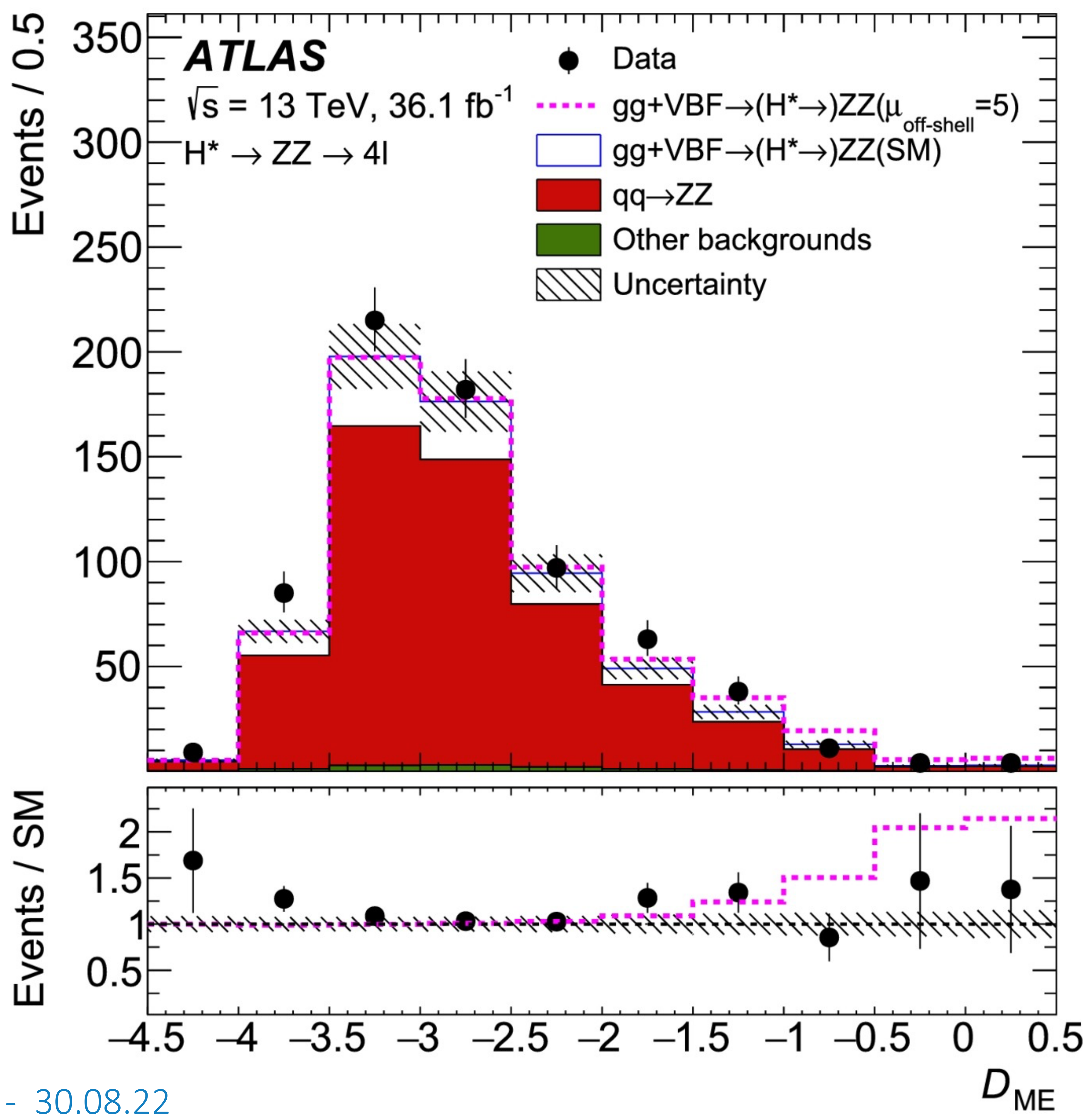
EXTRA MATERIAL

Measurements of the Higgs width from off-shell production:

Physics Letters B 786 (2018) 223–244

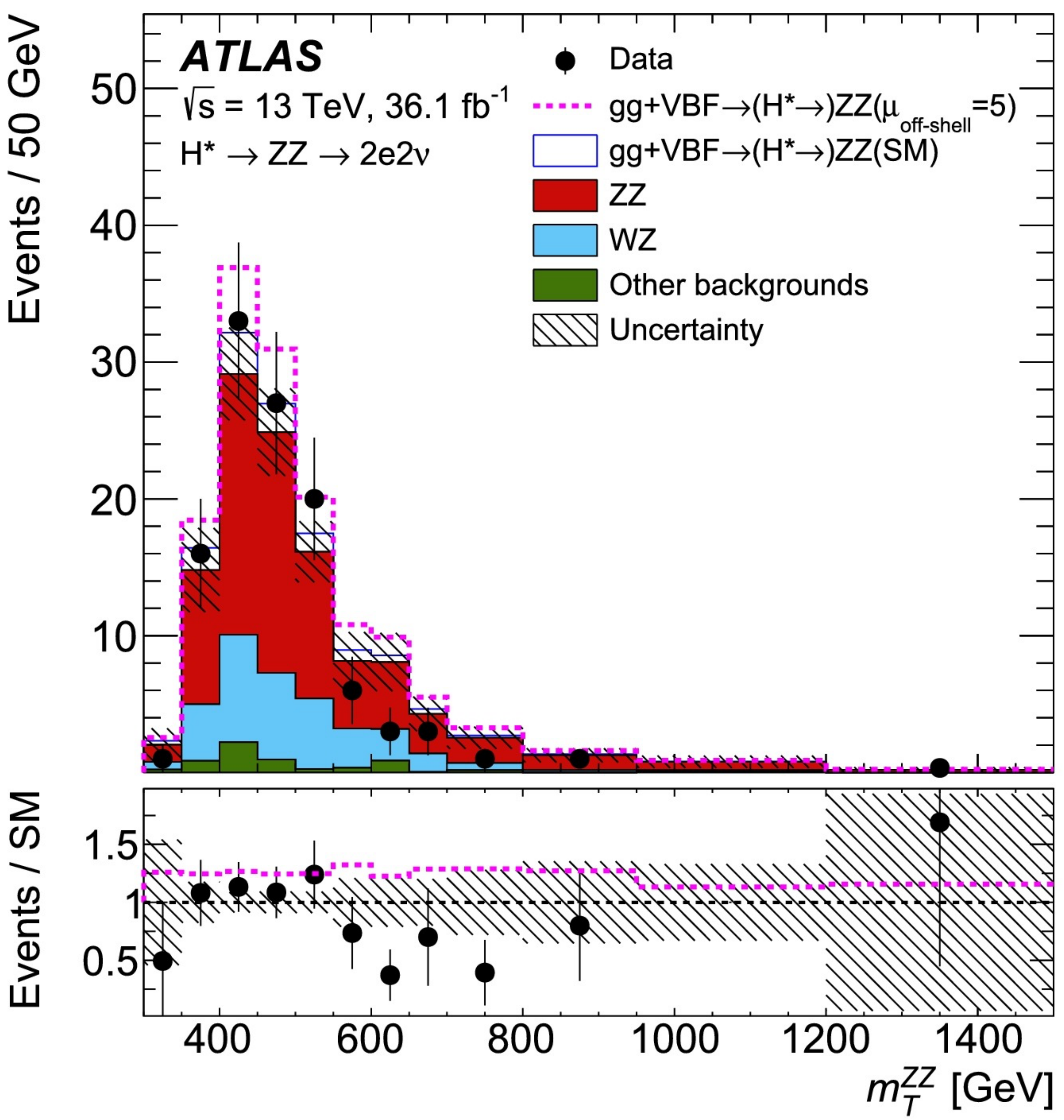
ME-based discriminant used in the 4l channel is defined as per XXXX:

$$D_{\mathrm{ME}} = \log_{10}\left(\frac{P_H}{P_{gg}+c\cdot P_{q\bar{q}}}\right)$$



Observable of interest in $2\ell 2\nu$ channel: transverse mass of the ZZ system, m_T^{ZZ}:

$$m_{\mathrm{T}}^{ZZ} \equiv \sqrt{\left[\sqrt{m_Z^2+\left(p_{\mathrm{T}}^{\ell\ell}\right)^2}+\sqrt{m_Z^2+\left(E_{\mathrm{T}}^{\mathrm{miss}}\right)^2}\right]^2-\left|\vec{p}_{\mathrm{T}}^{\,\ell\ell}+\vec{E}_{\mathrm{T}}^{\mathrm{miss}}\right|^2}$$



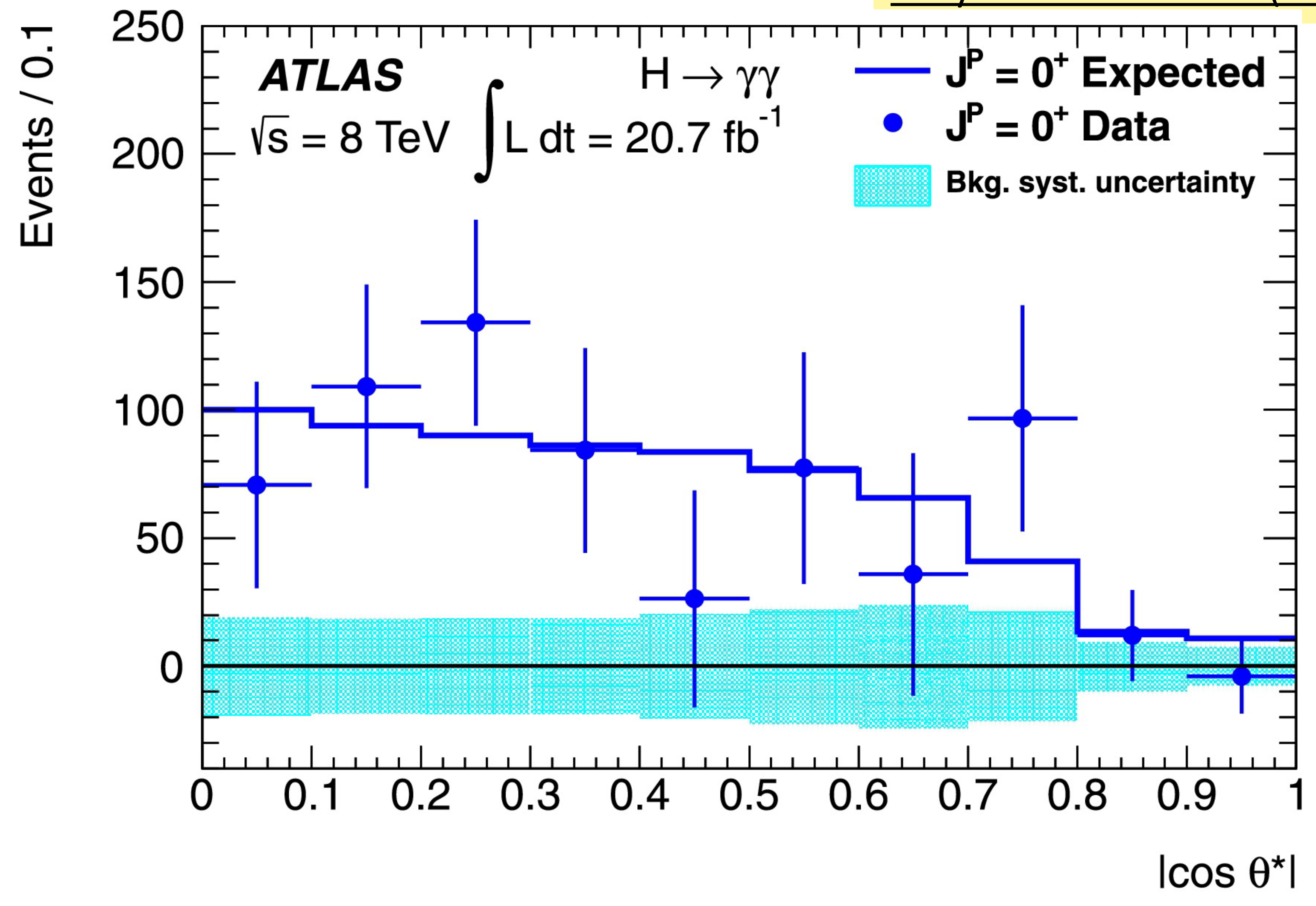
The Higgs boson spin and CP quantum numbers:

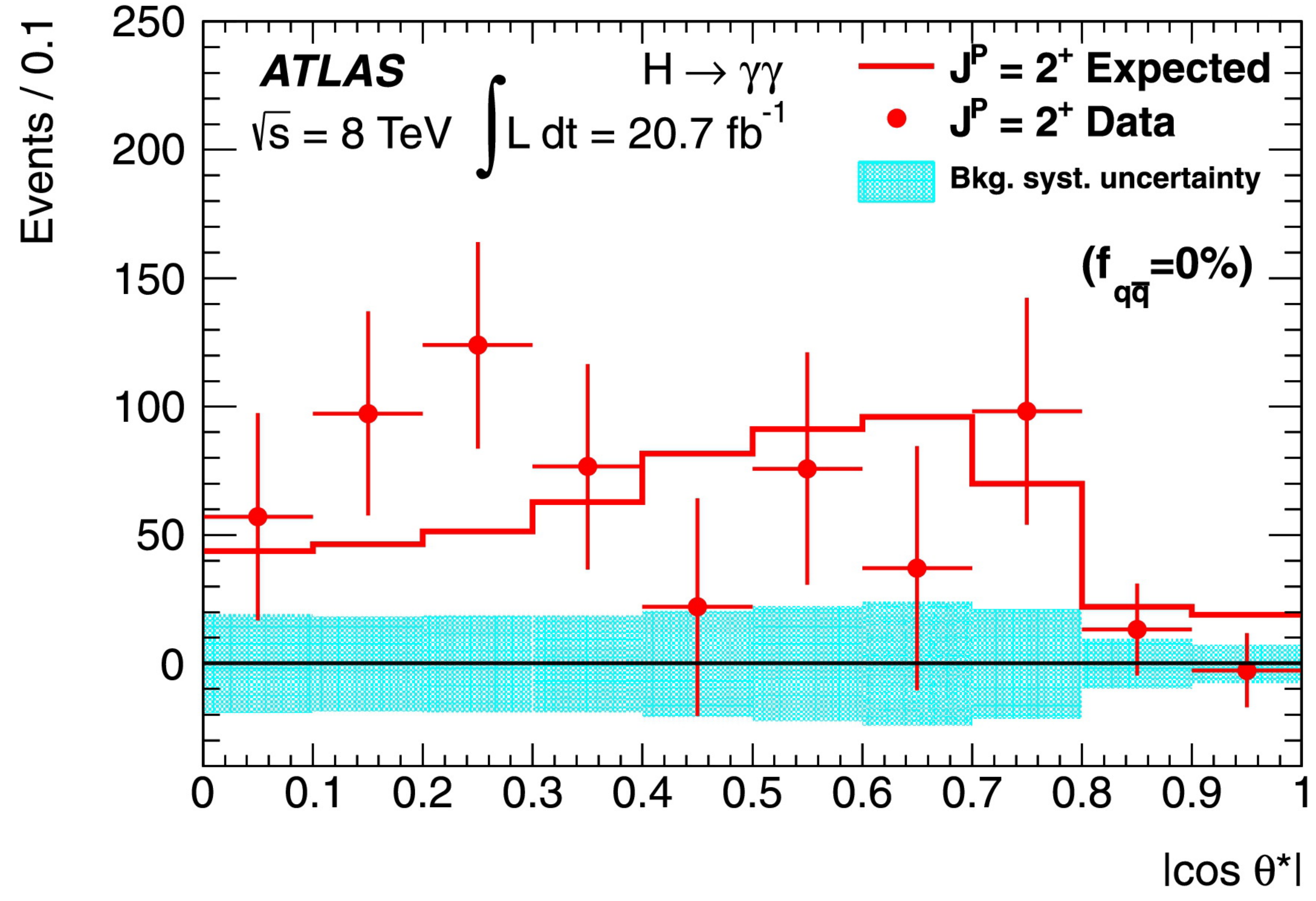
[Phys Lett B 726 (2013) 120-144]

Spin is a property of the particle, where as Charge-Parity (CP) of the couplings.

$H \rightarrow \gamma\gamma$ analysis: sensitive observable, $|cos\theta^*|$ = polar angular distribution of the photons in the resonance rest frame, defined by:

$$|\cos\theta^*| = \frac{|\sinh(\Delta\eta^{\gamma\gamma})|}{\sqrt{1+(p_T^{\gamma\gamma}/m_{\gamma\gamma})^2}}\frac{2p_T^{\gamma 1}p_T^{\gamma 2}}{m_{\gamma\gamma}^2},$$





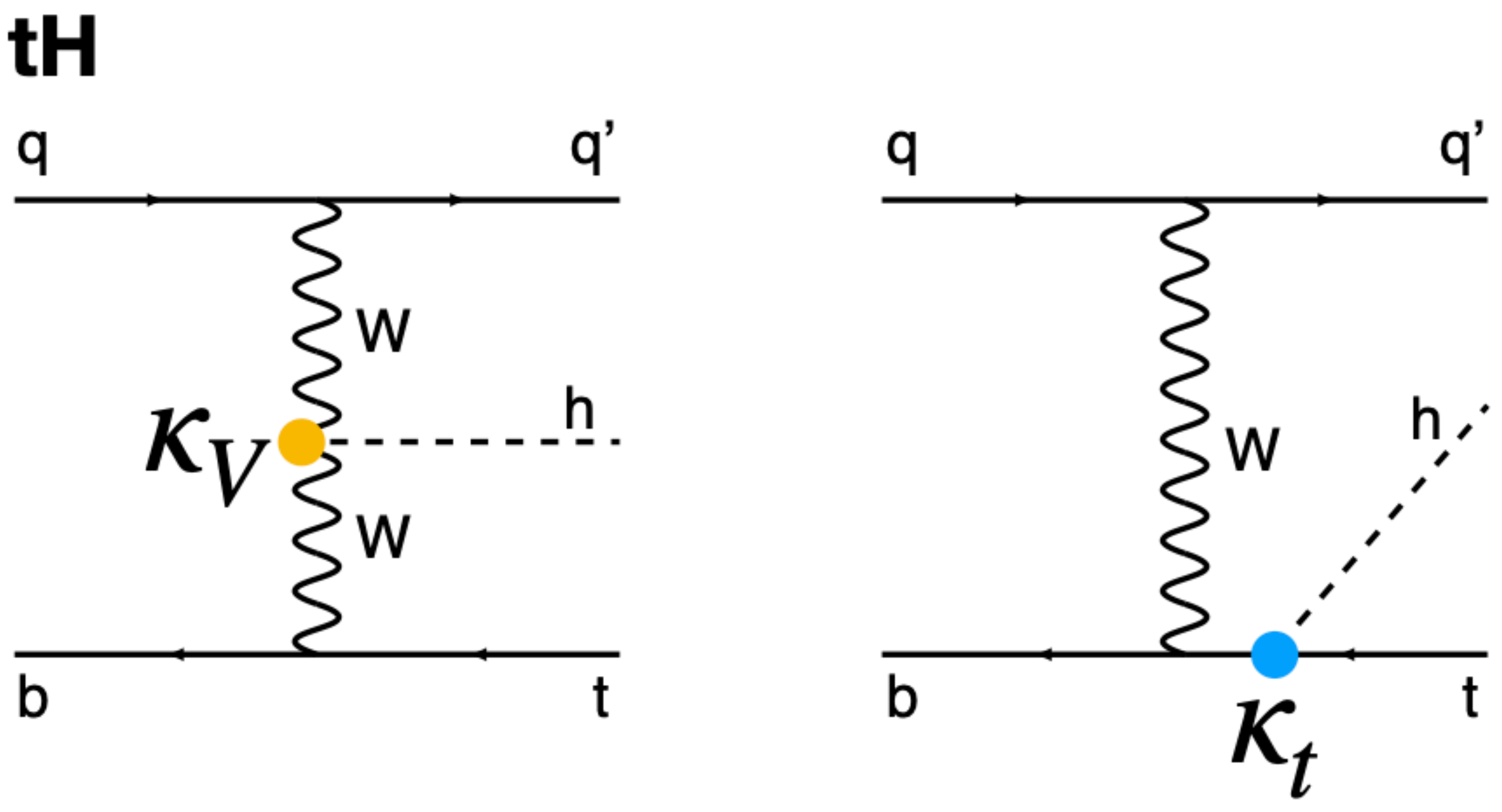
Spin information can be extracted from the distribution of the absolute value of the cosine of the polar angle θ^* of the photons with respect to the z-axis of the Collins–Soper frame [ref].

Distributions show are background subtracted.
In this analysis, only J=0 and J=2 hypothesis were considered.
Normalised to fitted number of signal events.

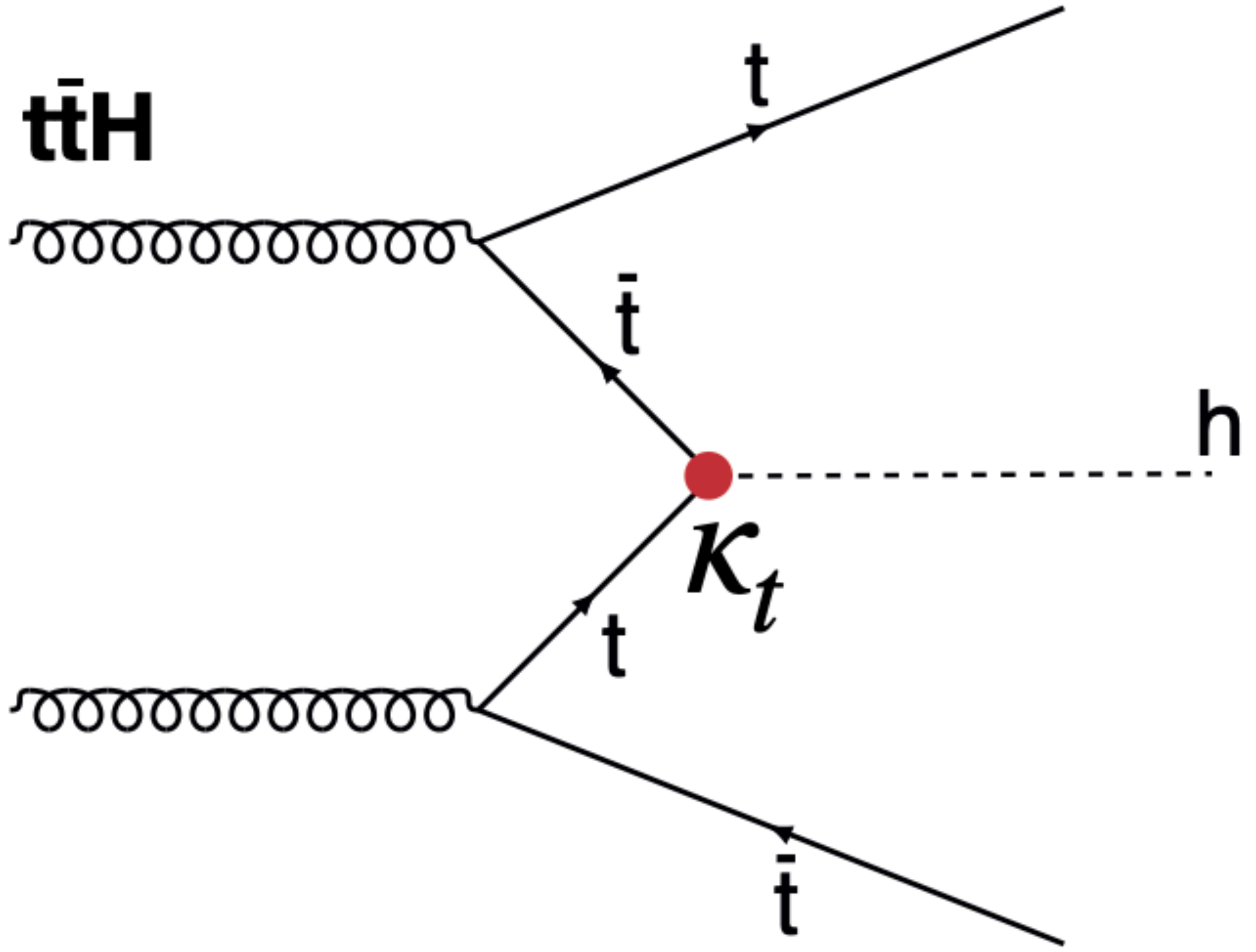
Probing CP properties of the top-Higgs Yukawa in $H \to \gamma\gamma$:

Phys. Rev. Lett. 125 (2020) 061802

- tH is sensitive to the sign of the top Yukawa coupling, as opposed to $t\bar{t}H$
- Sensitivity comes from interference between possible diagrams.
- Use process to directly exclude κ_t in ATLAS.



$$\sigma_{tH}/\sigma_{tH}^{SM} = 2.63\kappa_t^2 - 5.25\kappa_t\kappa_V + 3.58\kappa_V^2$$



$$\sigma_{t\bar{t}H}/\sigma_{t\bar{t}H}^{SM} = \kappa_t^2$$

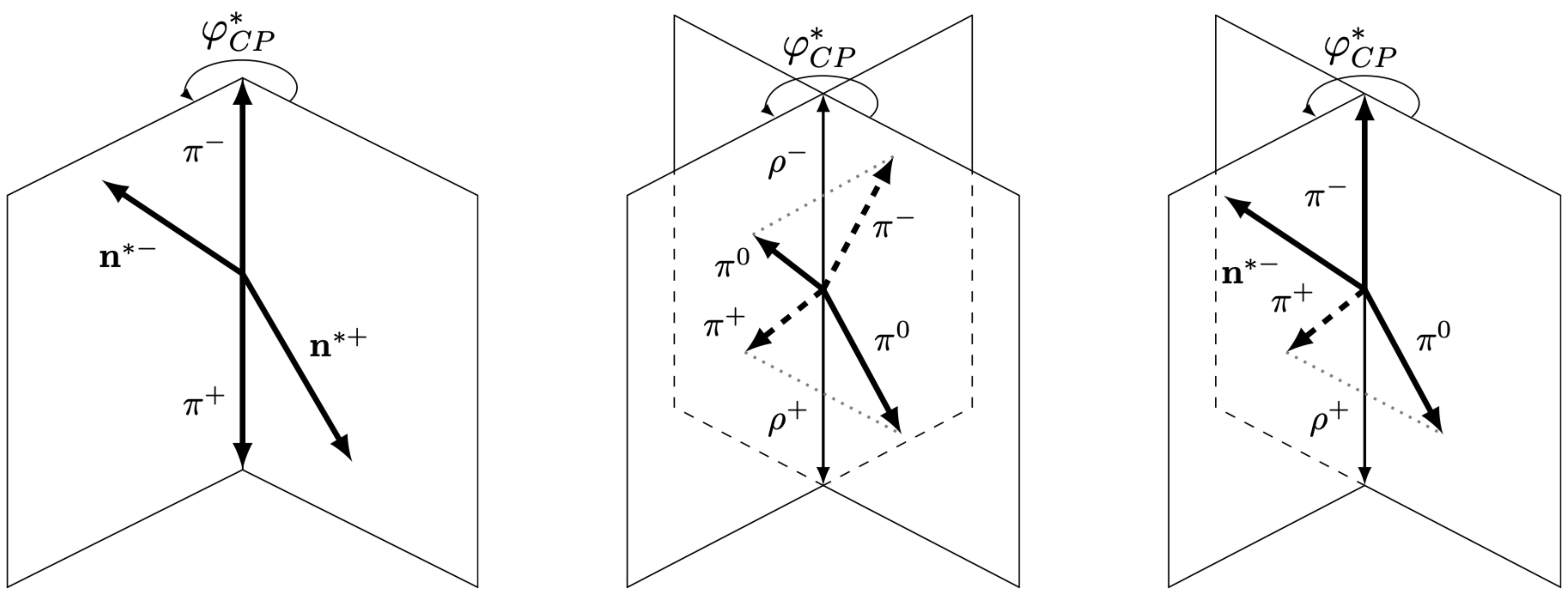
Defining a CP sensitive observable:

ATLAS-CONF-2022-032

ϕ_τ information encoded in correlations between transverse spin components of τ leptons (passed down to τ decay products as consequence of parity violation in weak interactions).

Define **CP sensitive observable: acoplanarity angle, φ^*_{CP}** between the decay planes.

⇒ Constructed based on visible decay products, where method is different for each decay channel.



(a) $H \to \tau^+\tau^- \to \pi^+\pi^- + 2\nu$ (b) $H \to \tau^+\tau^- \to \pi^+\pi^0\nu\pi^-\pi^0\nu$ (c) $H \to \tau^+\tau^- \to \pi^+\pi^0\nu\pi^-\nu$

Figure 1: Illustration of the τ lepton decay planes for constructing the φ^*_{CP} observable in (a) $H \to \tau^+\tau^- \to \pi^+\pi^- + 2\nu$ decay using the impact parameter method, (b) $H \to \tau^+\tau^- \to \pi^+\pi^0\nu\pi^-\pi^0\nu$ using the ρ-decay plane method, and (c) $H \to \tau^+\tau^- \to \pi^+\pi^0\nu\pi^-\nu$ using the combined impact parameter and ρ-decay plane method. The decay planes are spanned by the spatial momentum vector of the charged decay particle of the τ lepton ($\pi^\pm$) and either its impact parameter $\mathbf{n}^{*\pm}$ or the spatial momentum vector of the neutral decay particle of the τ lepton (π^0).

Impact parameter method:

$$\varphi^* = \arccos(\hat{\mathbf{n}}^{*+}_\perp \cdot \hat{\mathbf{n}}^{*-}_\perp) \quad \text{and} \quad \mathcal{O}^*_{CP} = \hat{\mathbf{q}}^{*-} \cdot (\hat{\mathbf{n}}^{*+}_\perp \times \hat{\mathbf{n}}^{*-}_\perp),$$

$$\varphi^*_{CP} = \begin{cases} \varphi^* & \text{if } \mathcal{O}^*_{CP} \geq 0 \\ 360^\circ - \varphi^* & \text{if } \mathcal{O}^*_{CP} < 0, \end{cases}$$

ρ-decay plane method:

$$\varphi^* = \arccos(\hat{\mathbf{q}}^{*0+}_\perp \cdot \hat{\mathbf{q}}^{*0-}_\perp) \quad \text{and} \quad \mathcal{O}^*_{CP} = \hat{\mathbf{q}}^{*-} \cdot (\hat{\mathbf{q}}^{*0+}_\perp \times \hat{\mathbf{q}}^{*0-}_\perp),$$

$$\varphi^{*\prime} = \begin{cases} \varphi^* & \text{if } \mathcal{O}^*_{CP} \geq 0 \\ 360^\circ - \varphi^* & \text{if } \mathcal{O}^*_{CP} < 0. \end{cases} \qquad \varphi^*_{CP} = \begin{cases} \varphi^{*\prime} & \text{if } y^\rho_+ y^\rho_- \geq 0 \\ \varphi^{*\prime} + 180^\circ & \text{if } y^\rho_+ y^\rho_- < 0. \end{cases}$$

$$y^\rho_\pm = \frac{E_{\pi^\pm} - E_{\pi^0}}{E_{\pi^\pm} + E_{\pi^0}}$$

Combined IP and ρ method:

$$\varphi^*_{CP} = \begin{cases} \varphi^{*\prime} & \text{if } y^\rho \geq 0 \\ \varphi^{*\prime} + 180^\circ & \text{if } y^\rho < 0, \end{cases}$$

NEW

Studying CP properties of HVV couplings in VBF $H \rightarrow \gamma\gamma$:

CERN-EP-2022-134

	68% (exp.)	95% (exp.)	68% (obs.)	95% (obs.)
$\tilde{d}$ (inter. only)	[−0.027, 0.027]	[−0.055, 0.055]	[−0.011, 0.036]	[−0.032, 0.059]
$\tilde{d}$ (inter.+quad.)	[−0.028, 0.028]	[−0.061, 0.060]	[−0.010, 0.040]	[−0.034, 0.071]
$\tilde{d}$ from $H \rightarrow \tau\tau$	[−0.038, 0.036]	–	[−0.090, 0.035]	-
Combined $\tilde{d}$	[−0.022, 0.021]	[−0.046, 0.045]	[−0.012, 0.030]	[−0.034, 0.057]
$c_{H\tilde{W}}$ (inter. only)	[−0.48, 0.48]	[−0.94, 0.94]	[−0.16, 0.64]	[−0.53, 1.02]
$c_{H\tilde{W}}$ (inter.+quad.)	[−0.48, 0.48]	[−0.95, 0.95]	[−0.15, 0.67]	[−0.55, 1.07]

Results are compatible with the SM