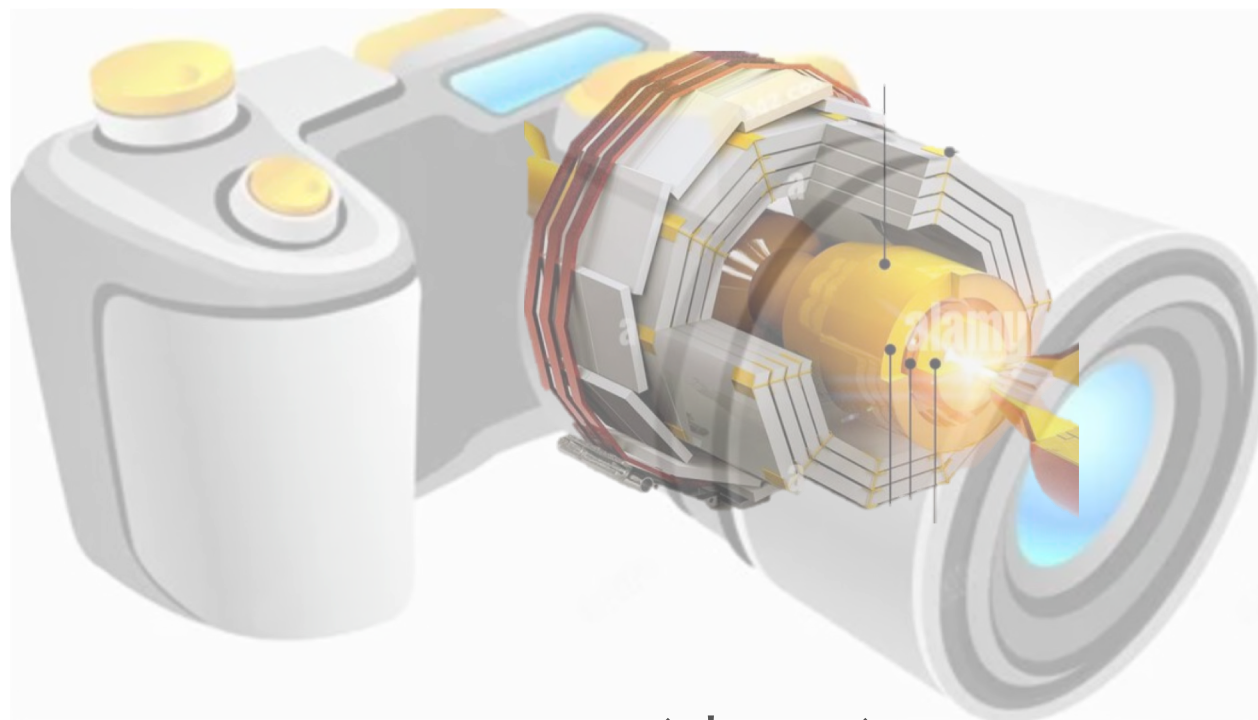


Recent results on Higgs Property Measurements in CMS



Li Yuan (袁 丽)

北京航空航天大学

味物理讲座， 2026年6月18日



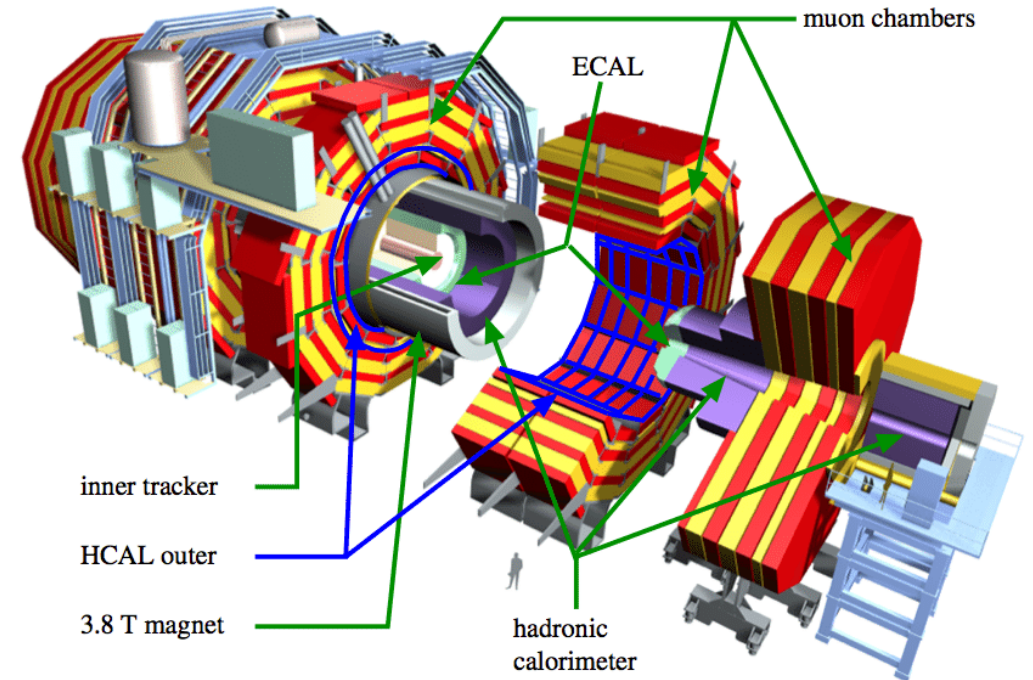
CMS experiment at the LHC

LHC tunnel: underground 100 m, circumference 27 km



CMS detector

diameter 15 m, length 22 m, weight 14000 ton

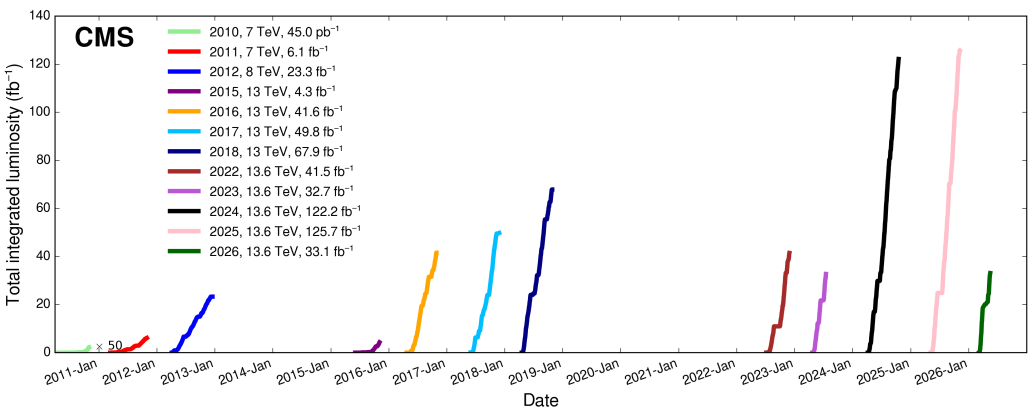
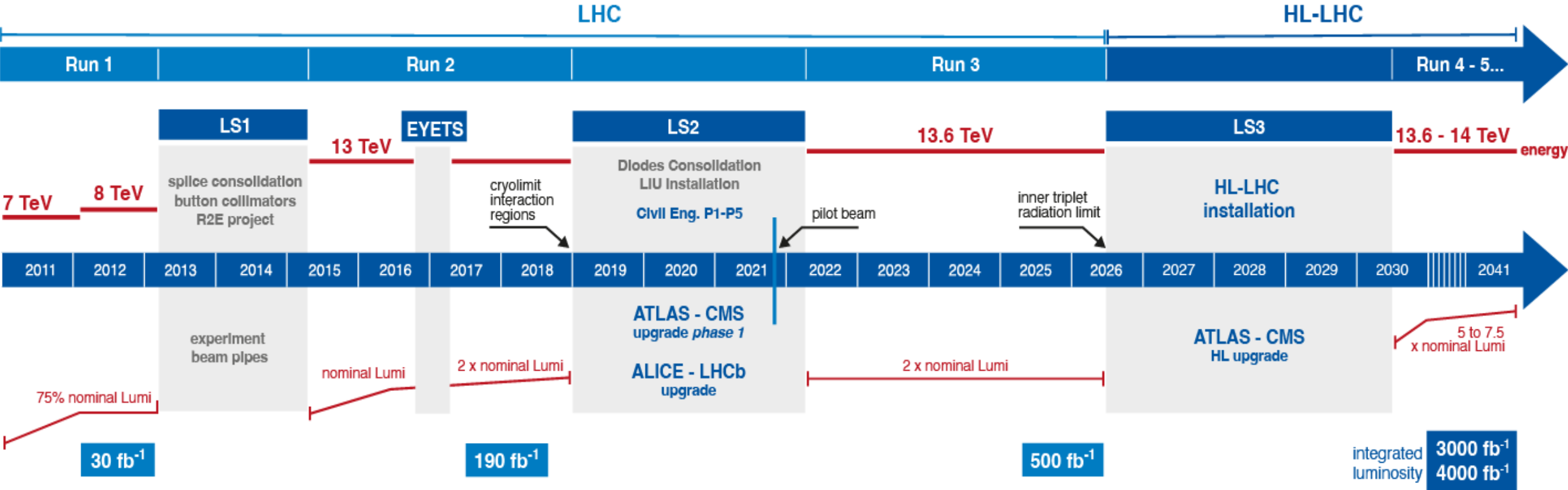


CMS collaboration consists of > 6000 people from 246 institutions in 58 countries.

CMS China group consists of > 240 people from 11 institutions:

高能所、北大、北航、中山、清华、浙大、复旦、科大、华南师大、山大、南师大

LHC/HL-LHC data-taking schedule

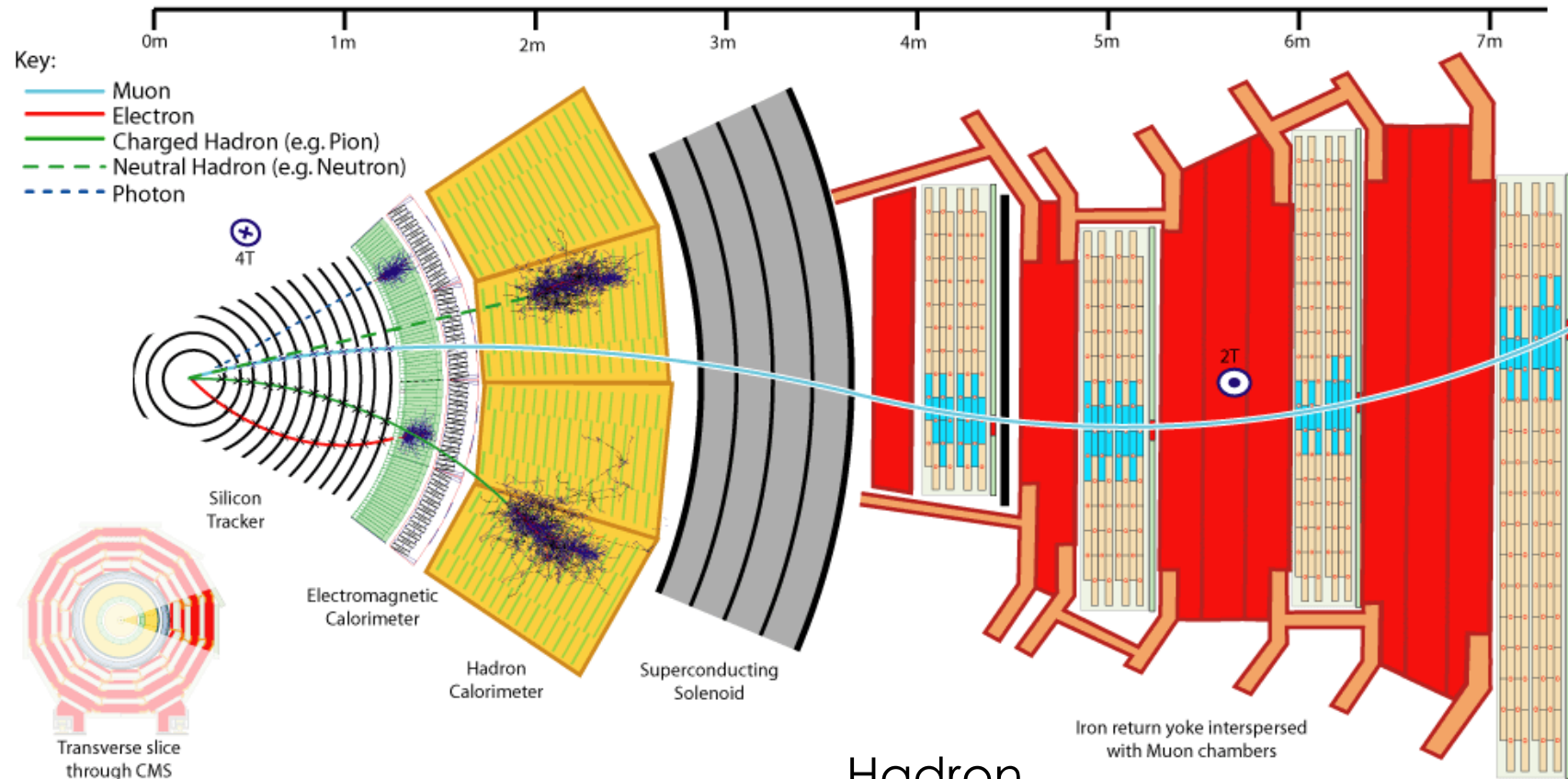


CMS p-p collision data

	time	vs	luminosity
Run 1	2011-2012	7-8 TeV	~25 fb ⁻¹
Run 2	2015-2018	13 TeV	~150 fb ⁻¹
Run 3	2022-2026	13.6 TeV	~260 fb ⁻¹

Particles detected at CMS

Muon
Electron
Photon
Jets
MET

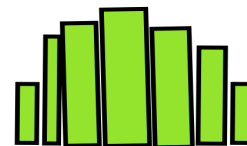
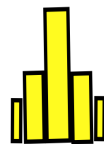


Inner tracker

EM calorimeter

Hadron
calorimeter

Muon Chamber



Appro. Precision

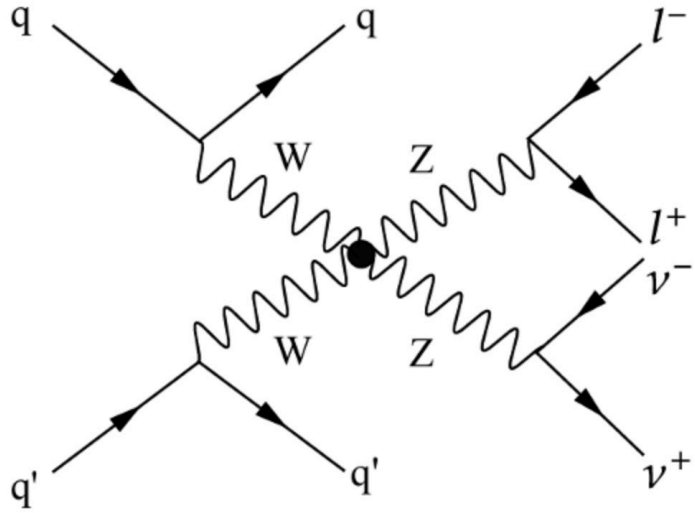
<1%

~1-2%

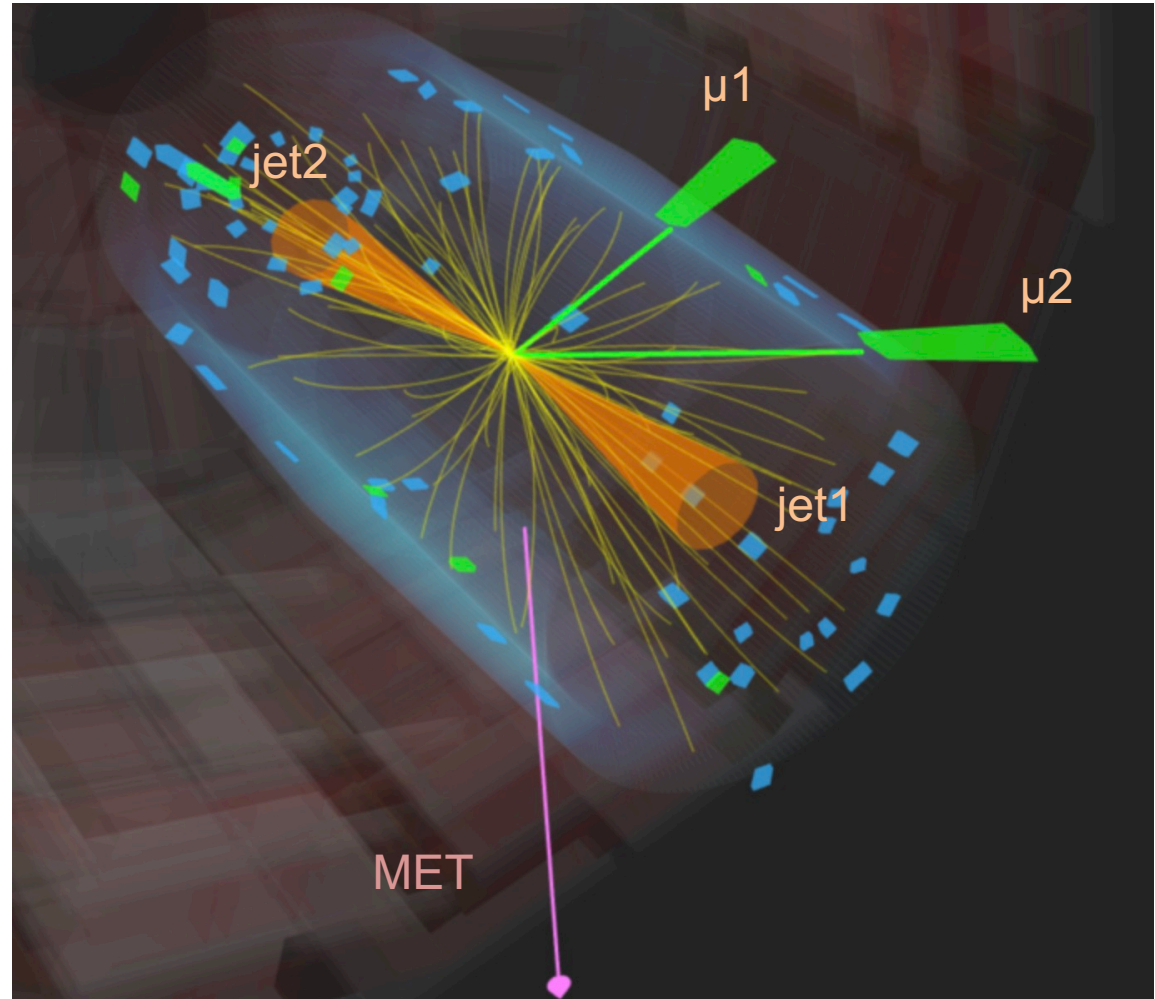
~10-20%

~1%

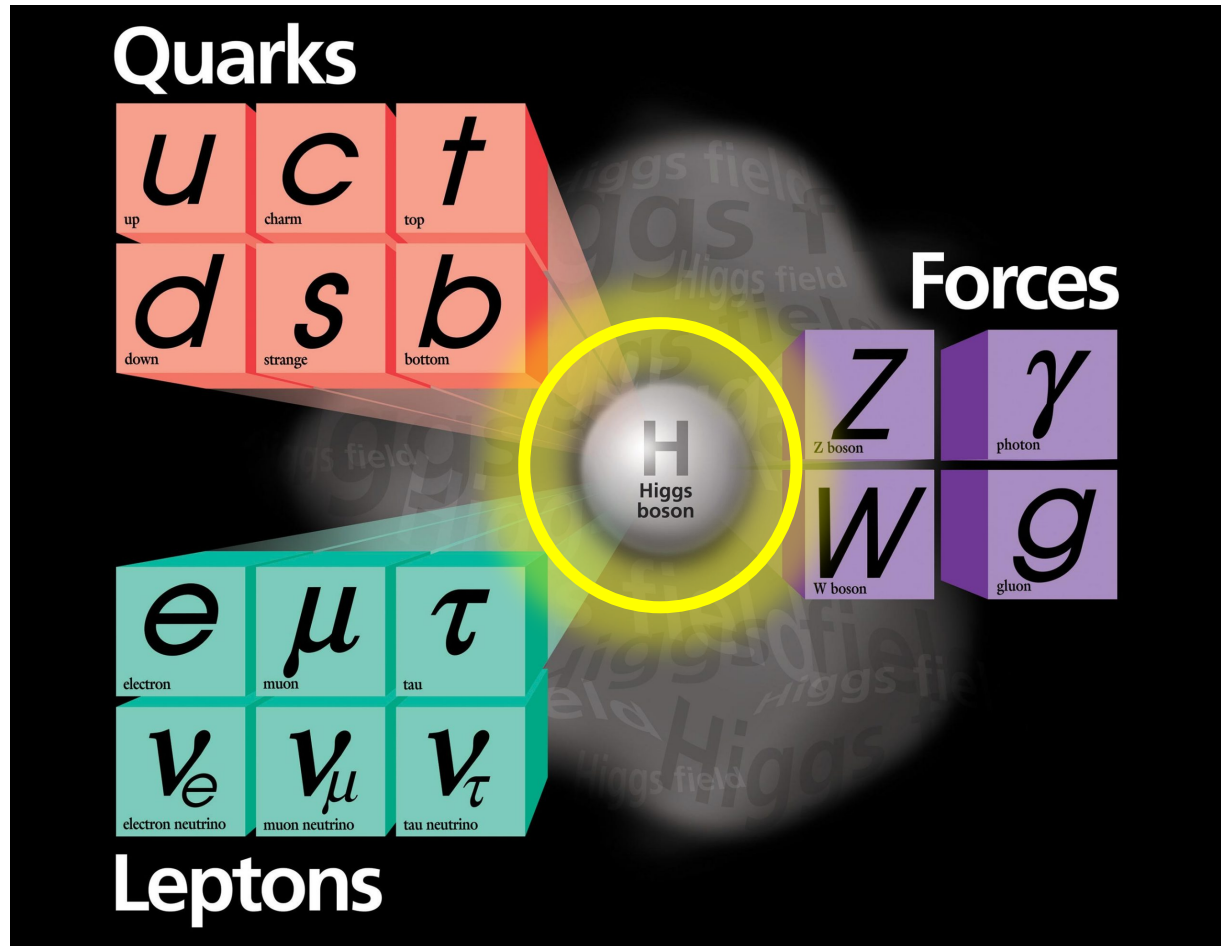
Event Reconstruction in CMS



- Track/Vertex/Cluster reconstruction
- Objects reconstruction (μ , e , γ , jets)
- Calculate MET
- Event selection

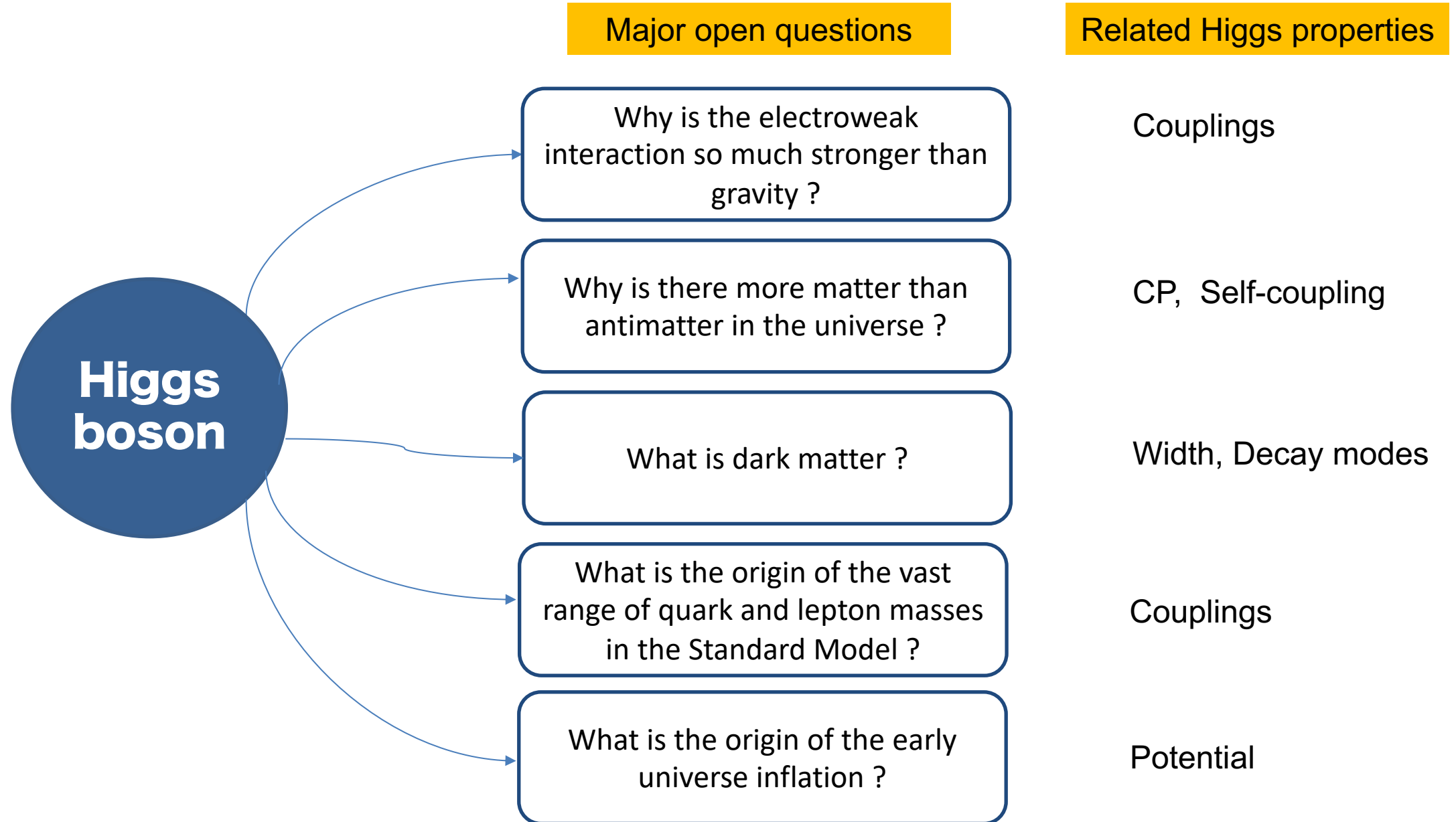


Higgs is so peculiar

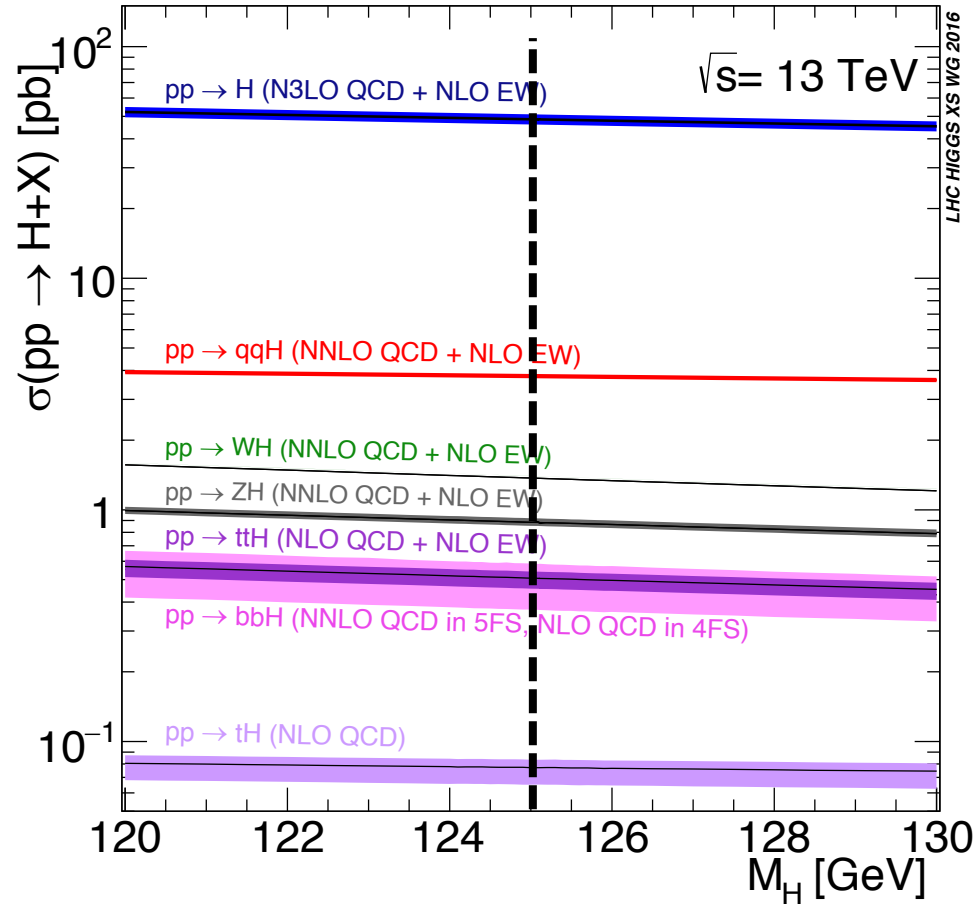
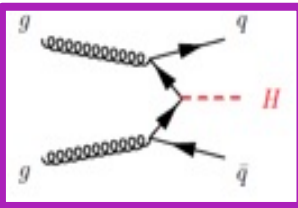
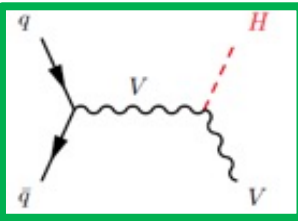
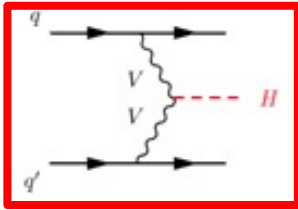
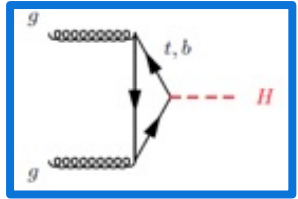


- ❖ The only scalar in fundamental particles
- ❖ Responsible for Electroweak Symmetry Breaking and explain the origin of mass
- ❖ Its mass is at EW scale $O(100\text{GeV})$
- ❖ Its special mass lineshape

Probe Key Science Questions

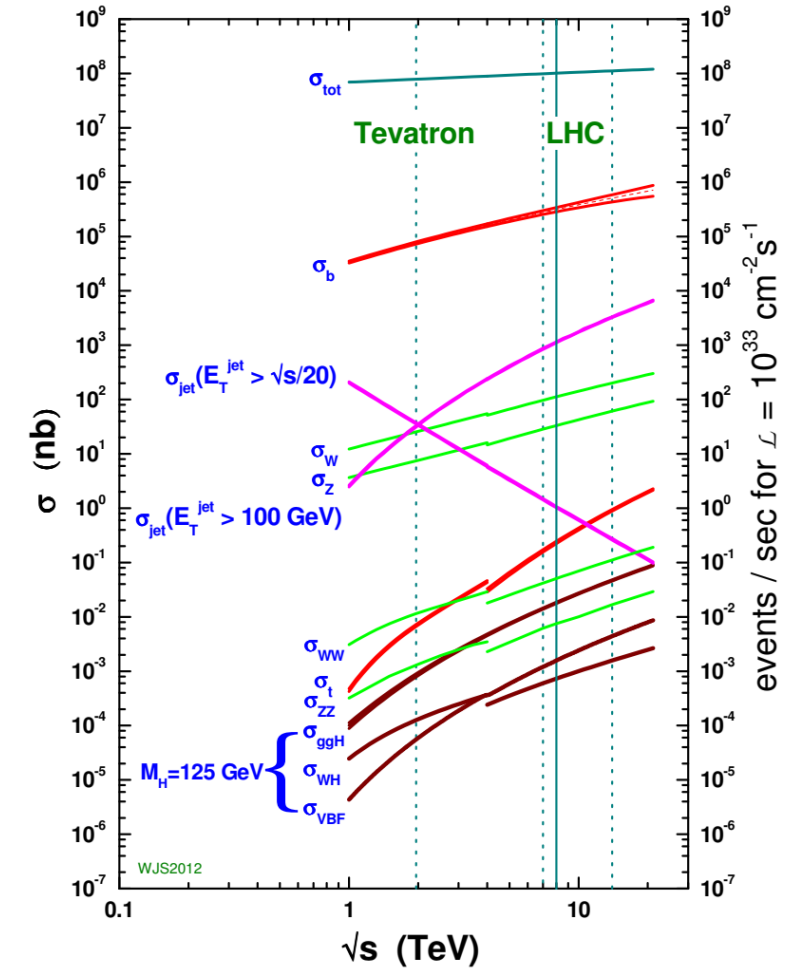


Higgs Production



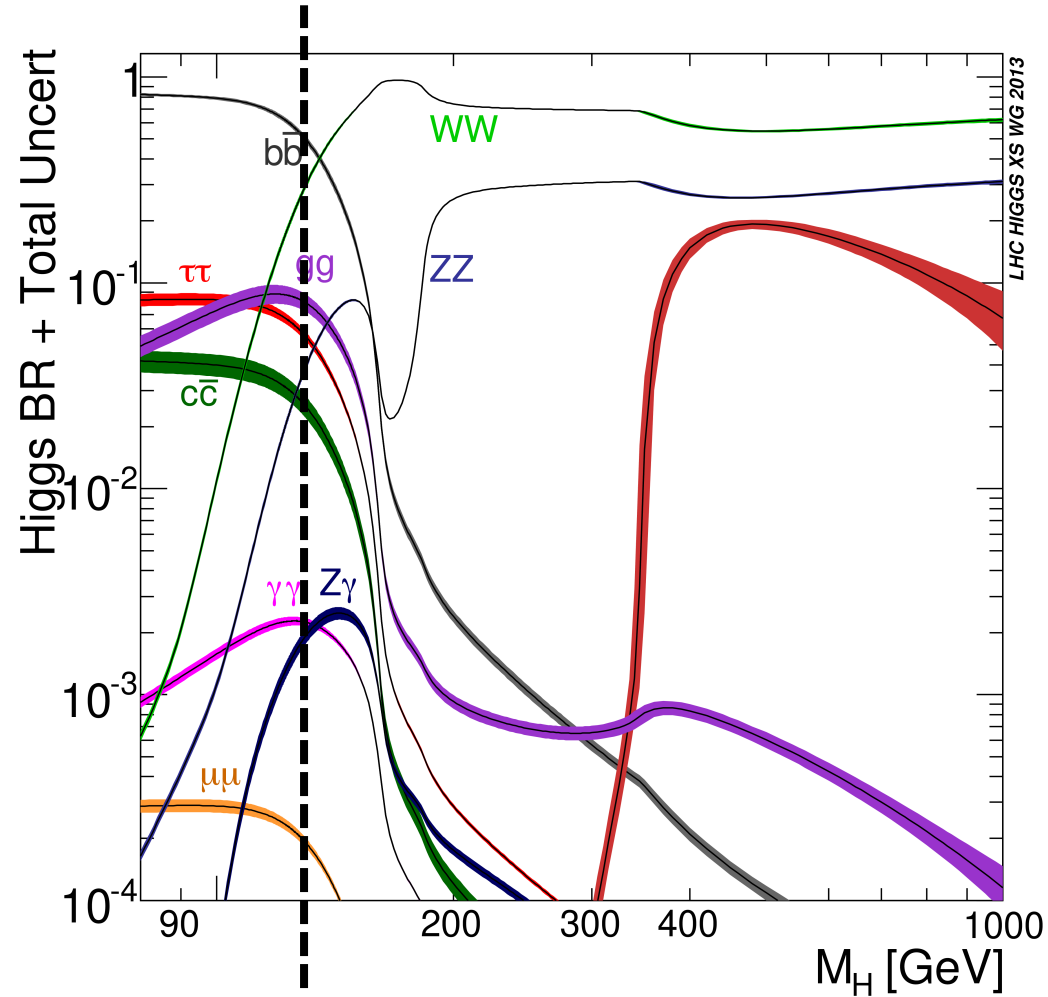
$$\sigma_{ggF} = 48.58 \text{ pb}, \quad \sigma_{VBF} = 3.782 \text{ pb}, \quad \sigma_{VH} = 2.257 \text{ pb}, \quad \sigma_{ttH} = 0.507 \text{ pb}$$

proton - (anti)proton cross sections

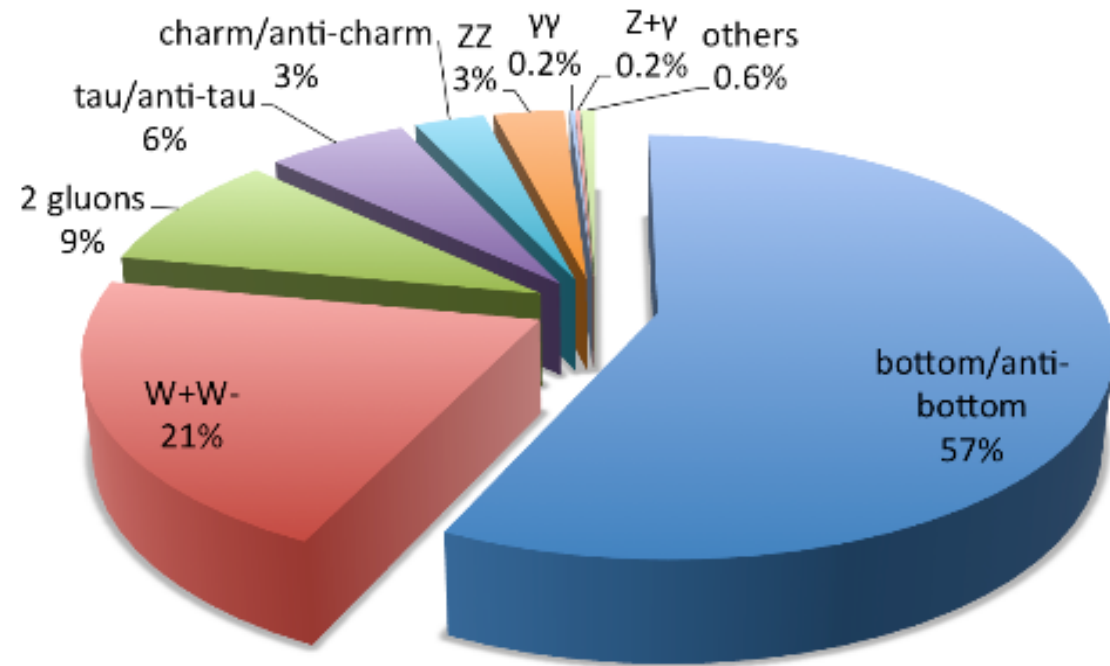


10^{10} Physics events
contain 1 Higgs

Higgs Decay



Decays of a 125 GeV Standard-Model Higgs boson



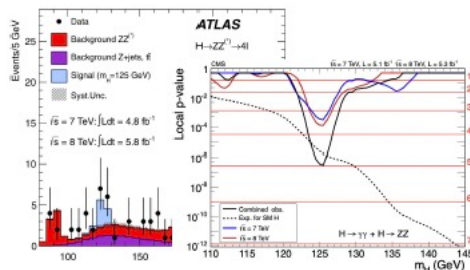
A long journey for exploring the Higgs boson

2010



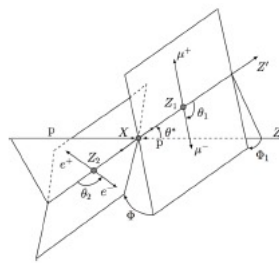
First Higgs boson searches begin

2012



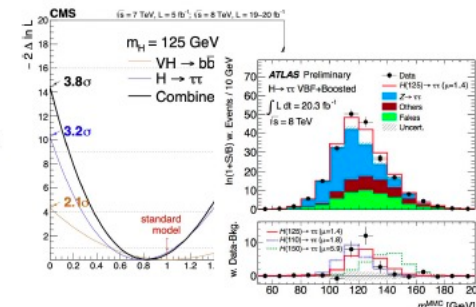
Discovery of the Higgs boson

2013



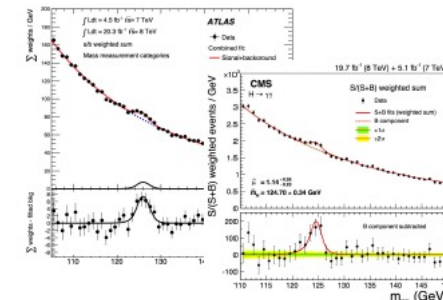
$J^P = 0^+$

2014



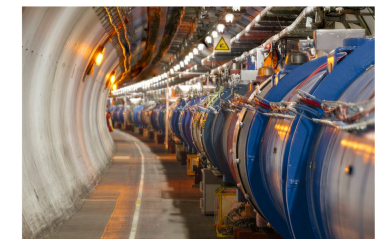
Evidence of $H \rightarrow f\bar{f}$

2014



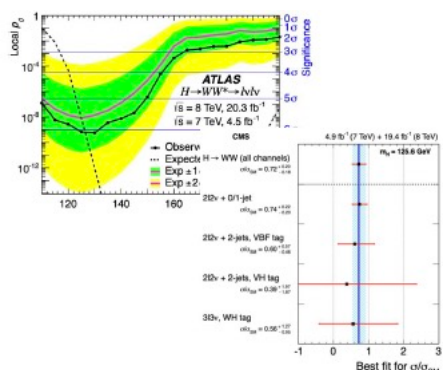
Higgs boson mass measurement

2015



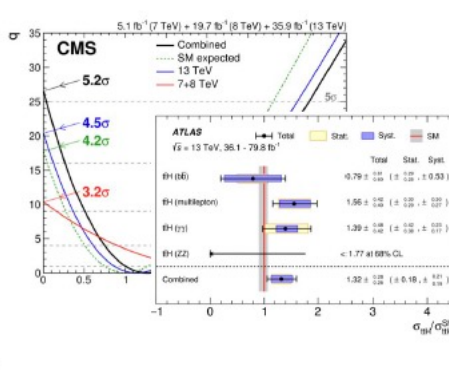
LHC@13TeV, start of precision measurement era

2015



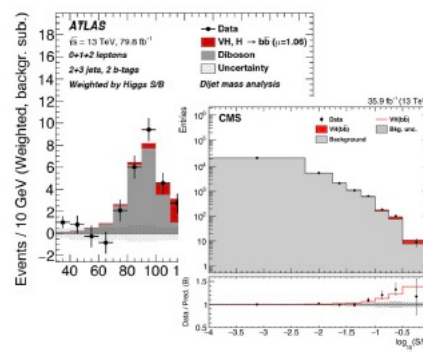
Observation of $H \rightarrow WW$

2018



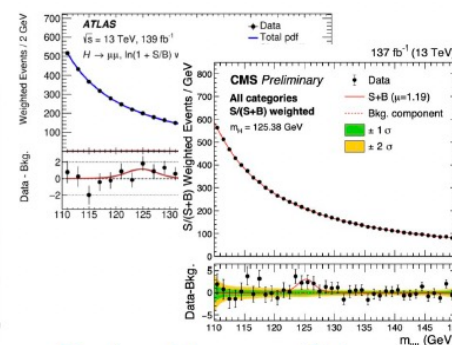
Observation of $t\bar{t}H$

2018



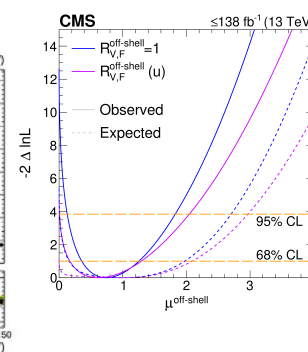
Observation of $H \rightarrow b\bar{b}$

2020



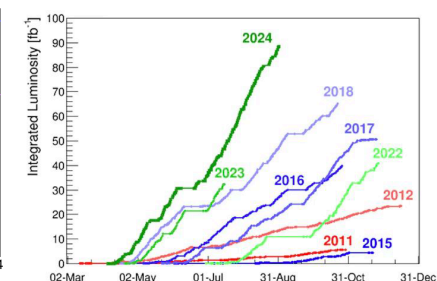
Evidence of $H \rightarrow \mu\mu$

2022



Evidence of offshell H

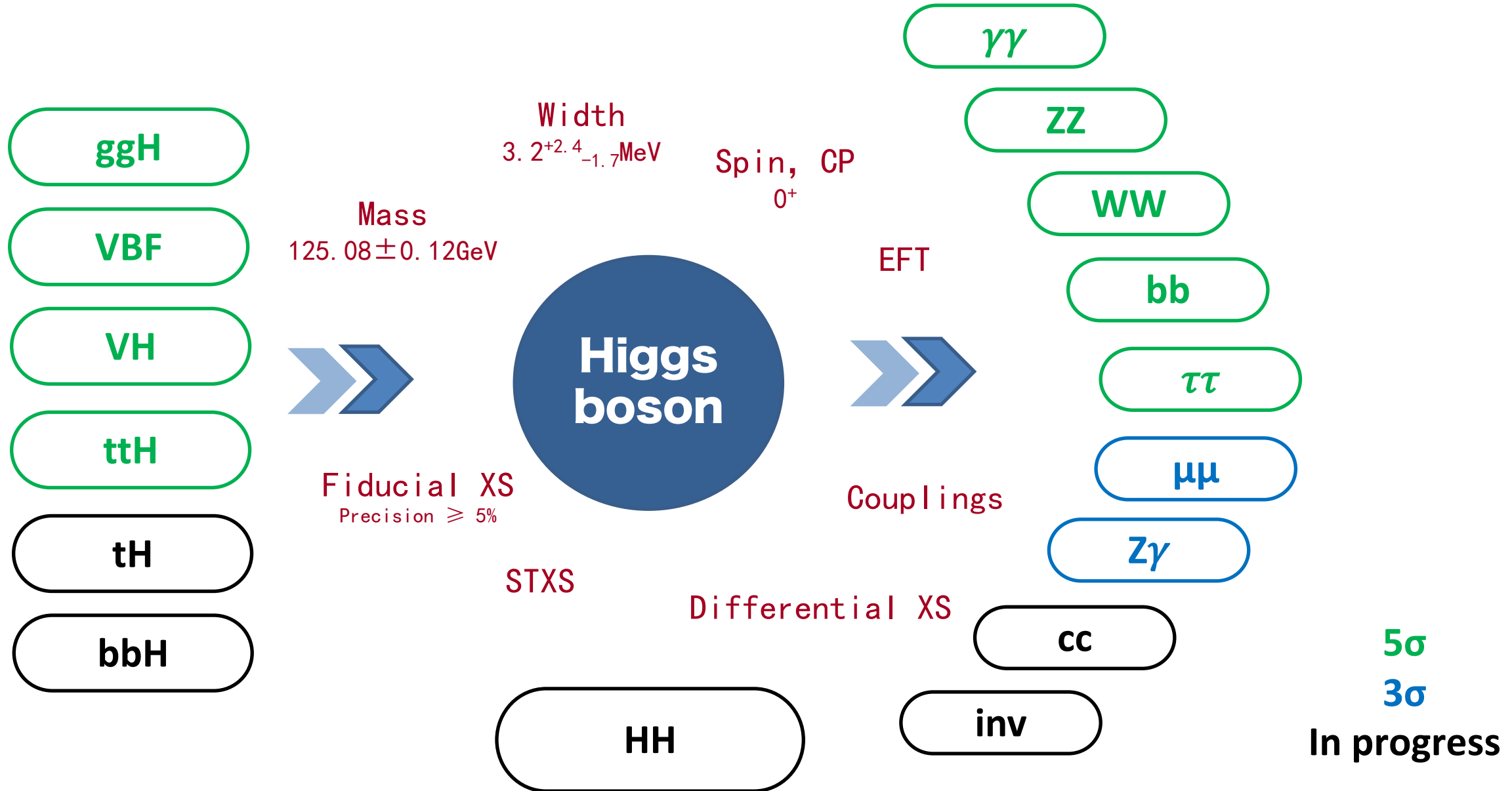
2022-2026



LHC@13.6TeV

A non-exhaustive list of results representing tremendous efforts for exploring the Higgs boson

Overview of Higgs Property Measurements in CMS



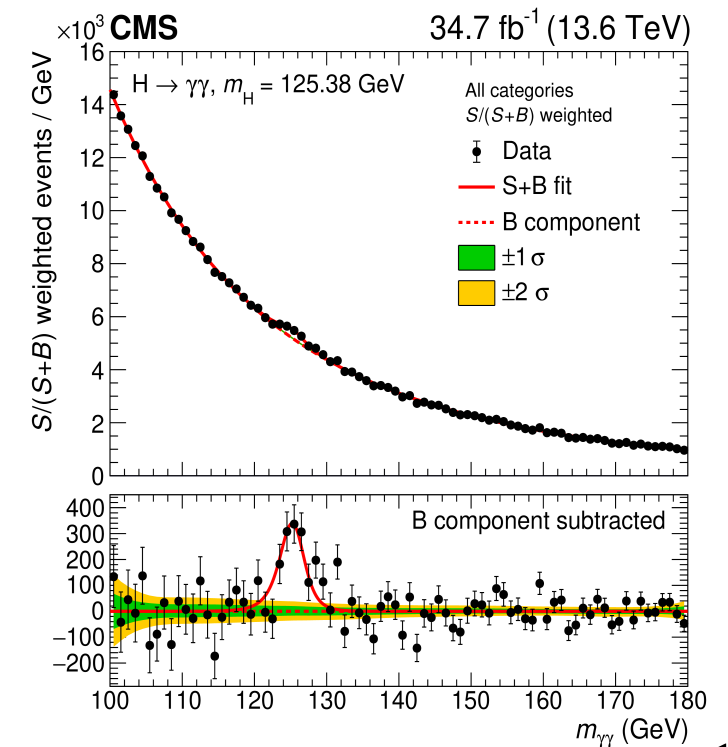
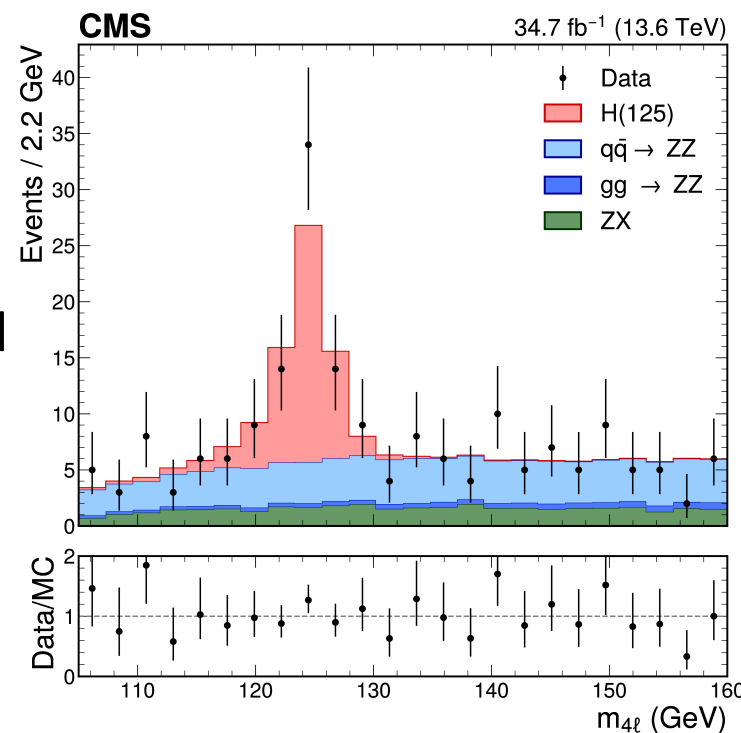
Cross sections and couplings measurements

Higgs Cross section measurement

- Test the electroweak symmetry spontaneous breaking mechanism
- Connect to the coupling measurement between Higgs and other particles
- Probe the Higgs dynamics and possible new physics phenomenon

Two golden channels:

- $H \rightarrow ZZ \rightarrow 4\ell$
 - Very small BRs ($\sim 0.026\%$)
 - Narrow peak over low background
- $H \rightarrow \gamma\gamma$
 - Small BRs ($\sim 0.26\%$)
 - Narrow peak over exponential background

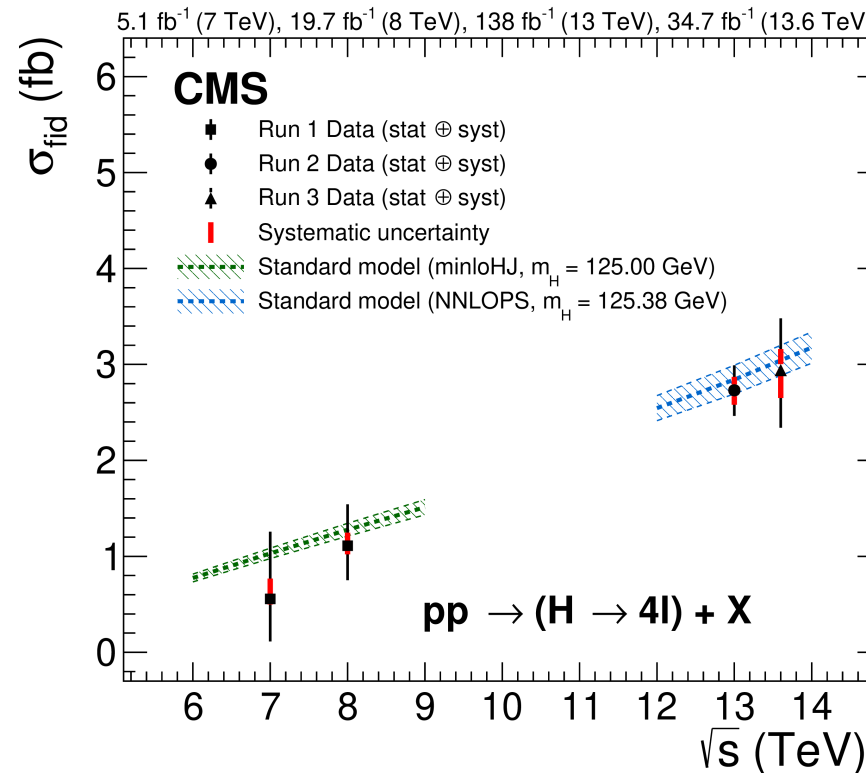


Higgs Cross section measurement

- Test the electroweak symmetry spontaneous breaking mechanism
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- Probe the Higgs dynamics and possible new physics phenomenon

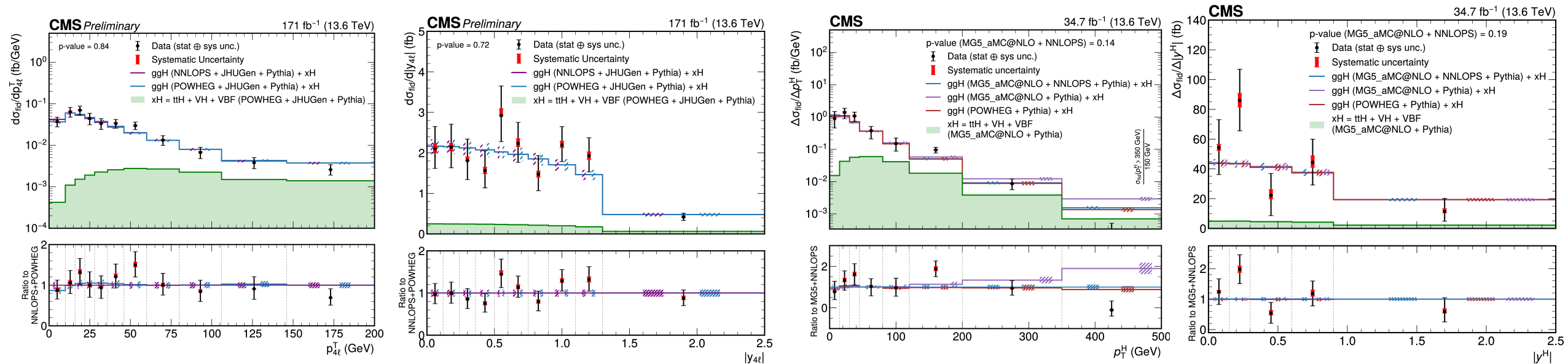
Two golden channels:

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 - Very small BRs ($\sim 0.026\%$)
 - Narrow peak over low background
- $H \rightarrow \gamma\gamma$
 - Small BRs ($\sim 0.26\%$)
 - Narrow peak over exponential background

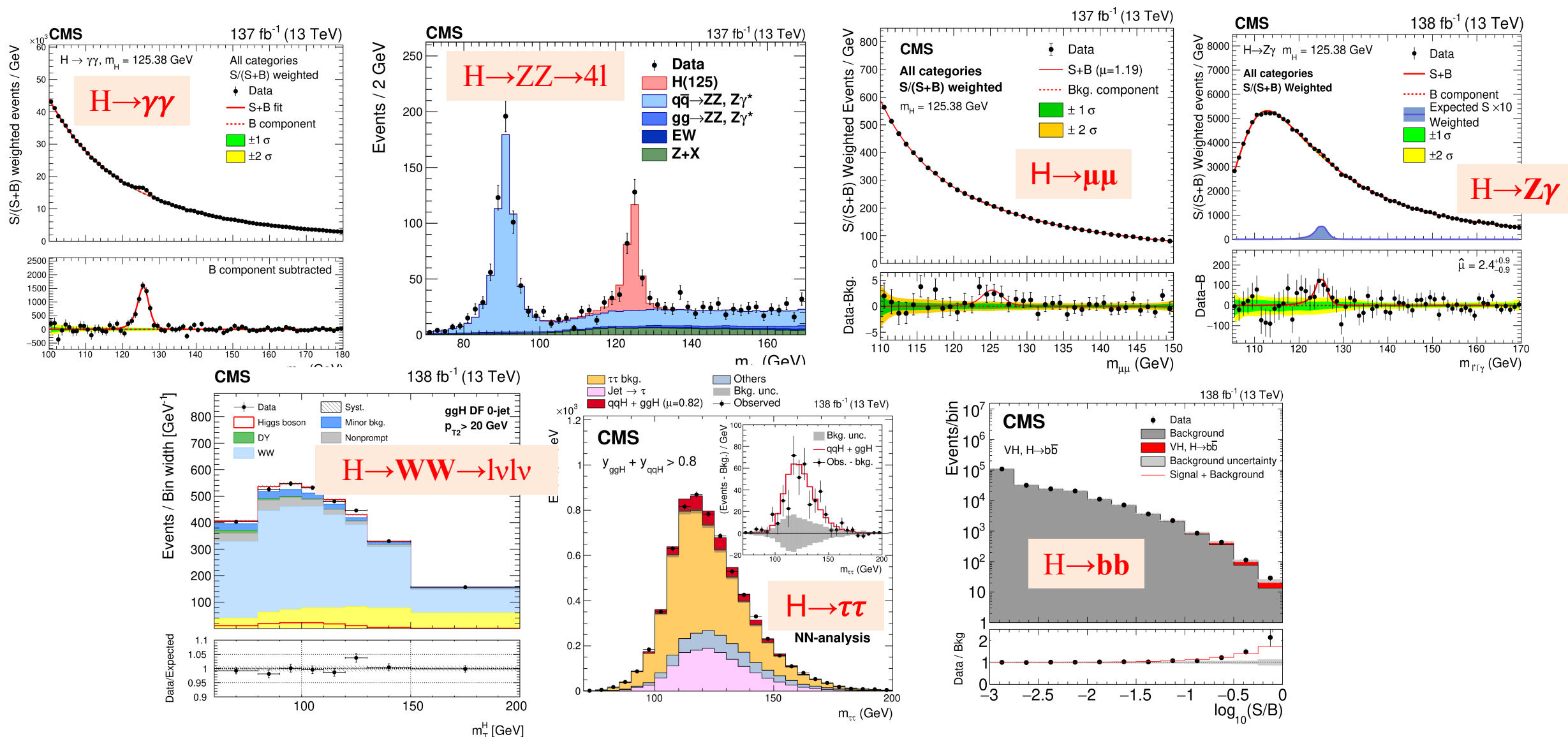


Differential cross section measurement

- Measuring differential cross section is a portal to unveiling the fundamental aspects of how nature works, probing couplings, inspecting the process kinematics and isolate BSM effects
- Fully differential cross sections measured in a fiducial phase space defined to match as closely as possible experimental selections to attain maximal model-independence



Global combination among the channels



Detailed study in each channel with Run 2 data.

Global combination among the channels

arXiv: 2602.18611

Signal strength: $\mu = \frac{N_{\text{measured}}}{N_{\text{SM}}}$

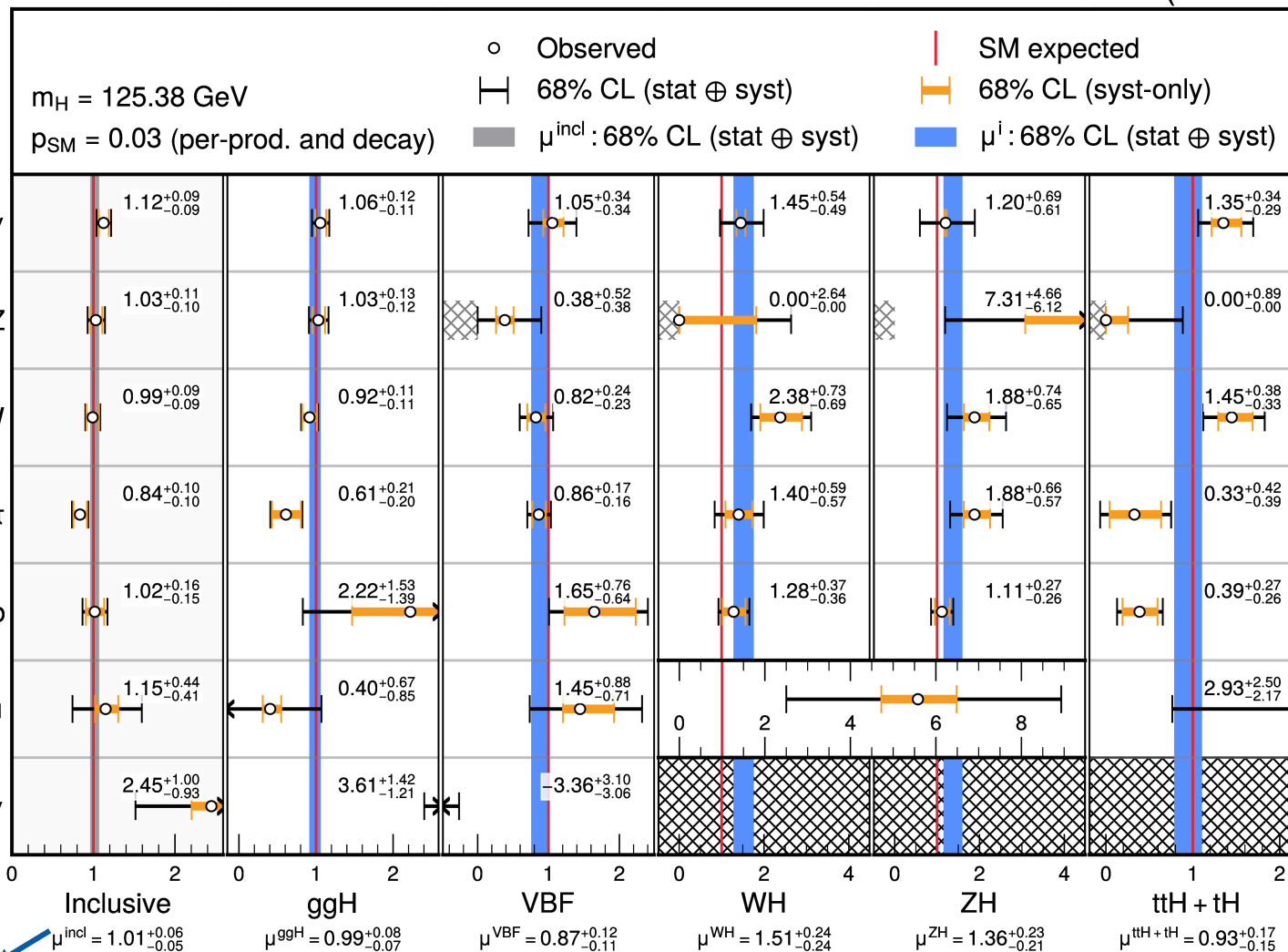
High-resolution channels

More challenging channels

Rare decay modes

CMS

138 fb⁻¹ (13 TeV)

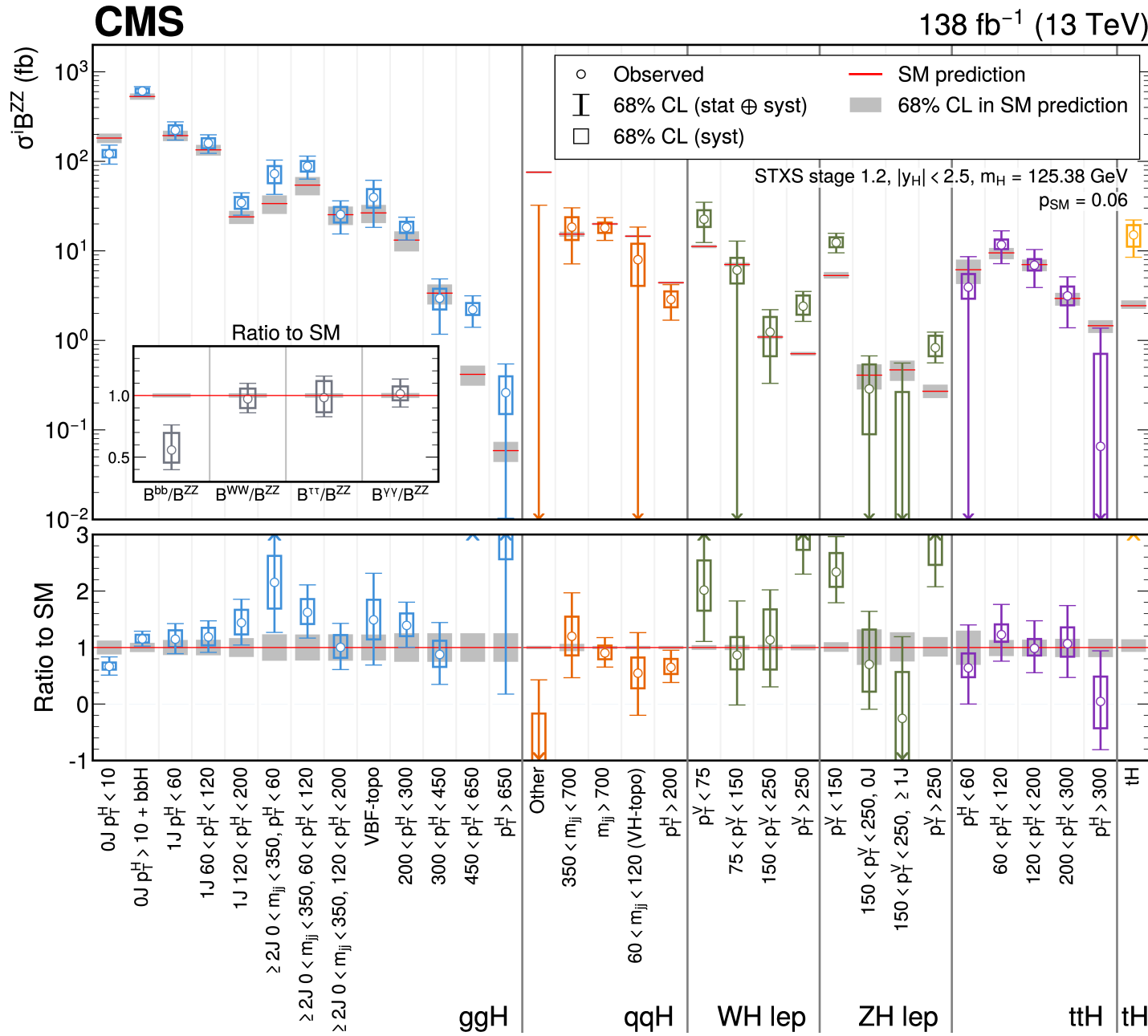


$$\mu^{\text{incl}} = 1.01^{+0.06}_{-0.05} = 1.014^{+0.040}_{-0.039}(\text{theo})^{+0.025}_{-0.024}(\text{exp}) \pm 0.028(\text{stat})$$

Precision of 5%

Synergy among the decay channels to maximize the measurement precision.

Simplified Template Cross Section Measurement

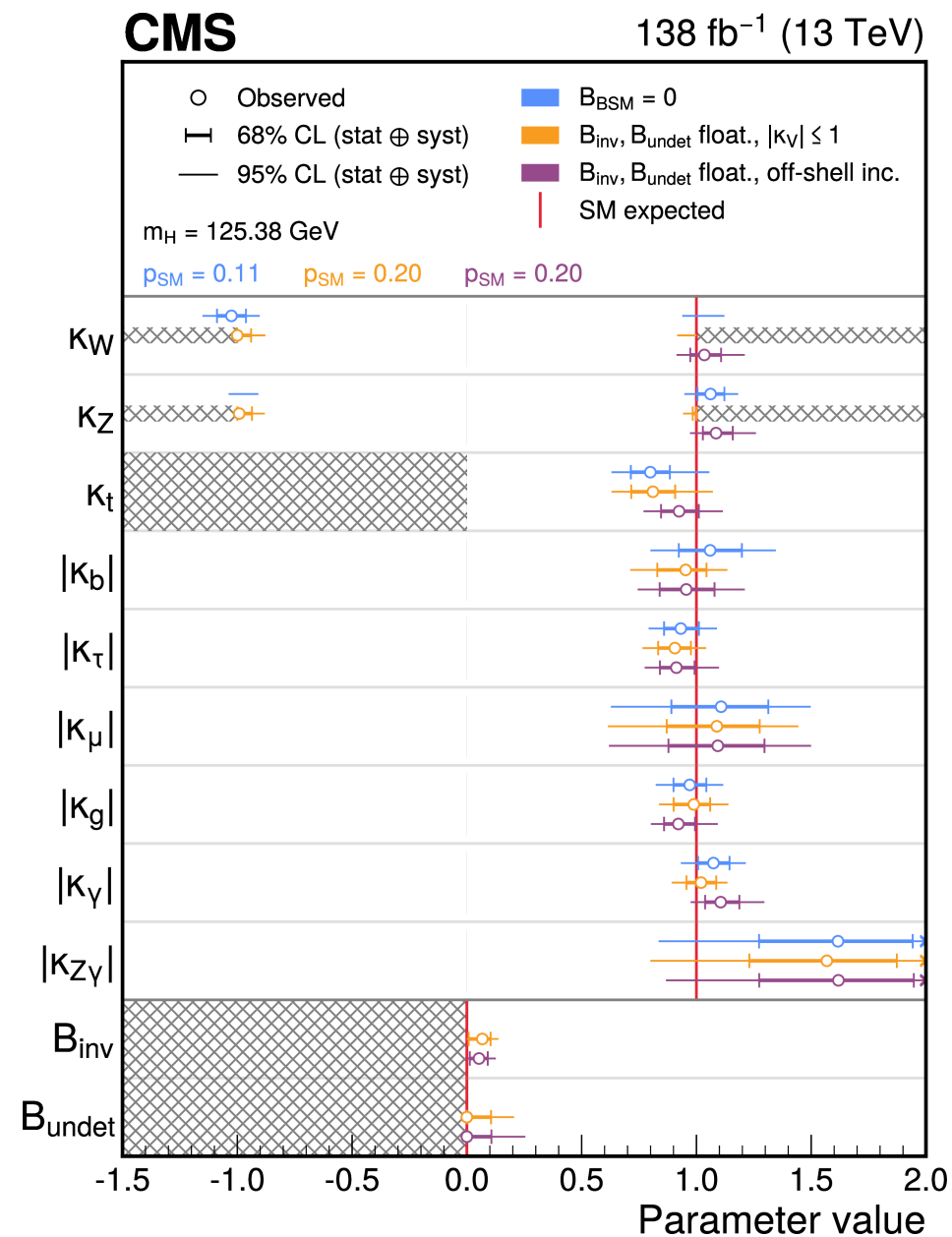
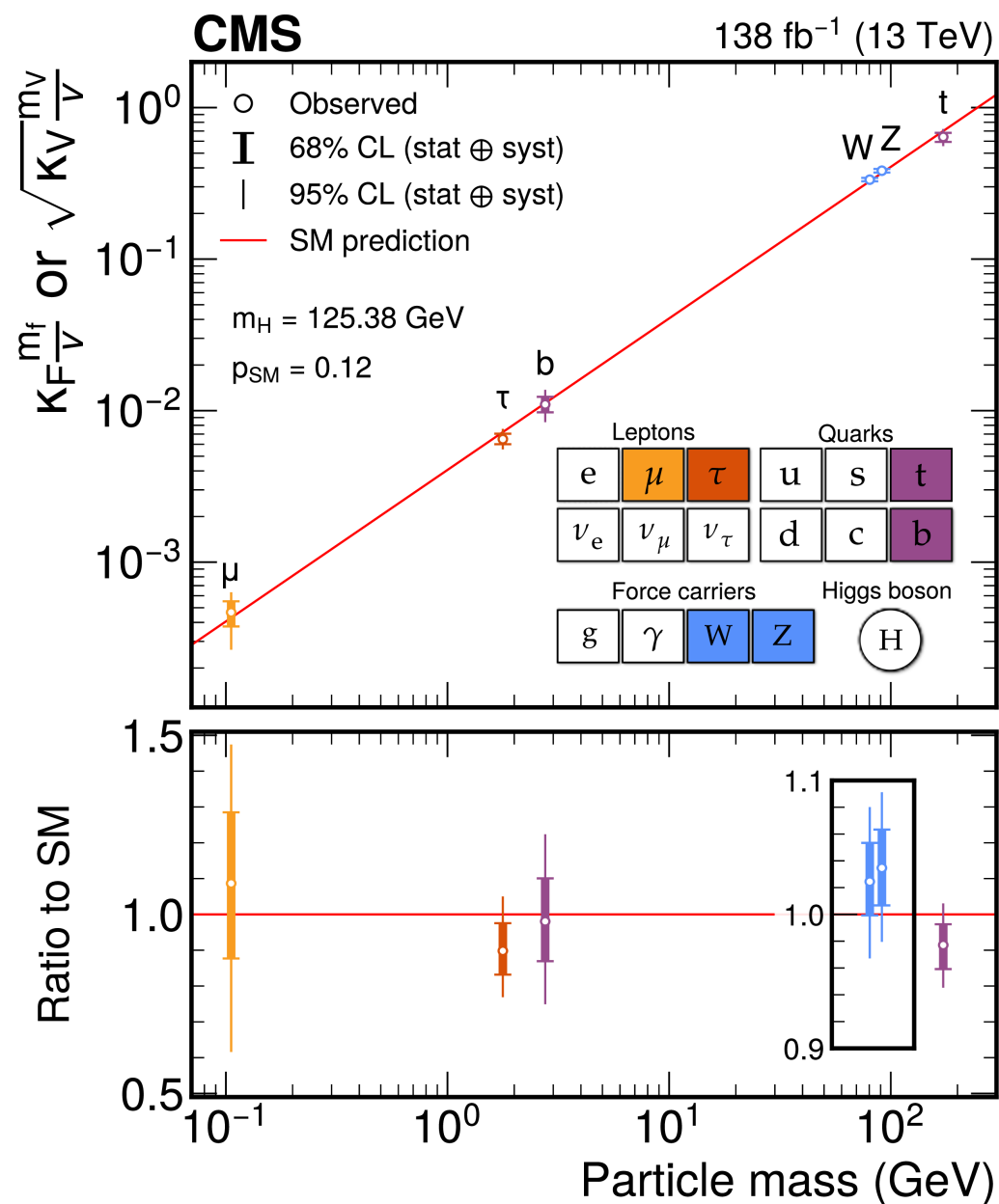


[arXiv: 2602.18611](https://arxiv.org/abs/2602.18611)

- Measure the XS in intervals of H p_T or V p_T for each production channel
- Probe the potential new physics in some specific H p_T region

Couplings Measurement

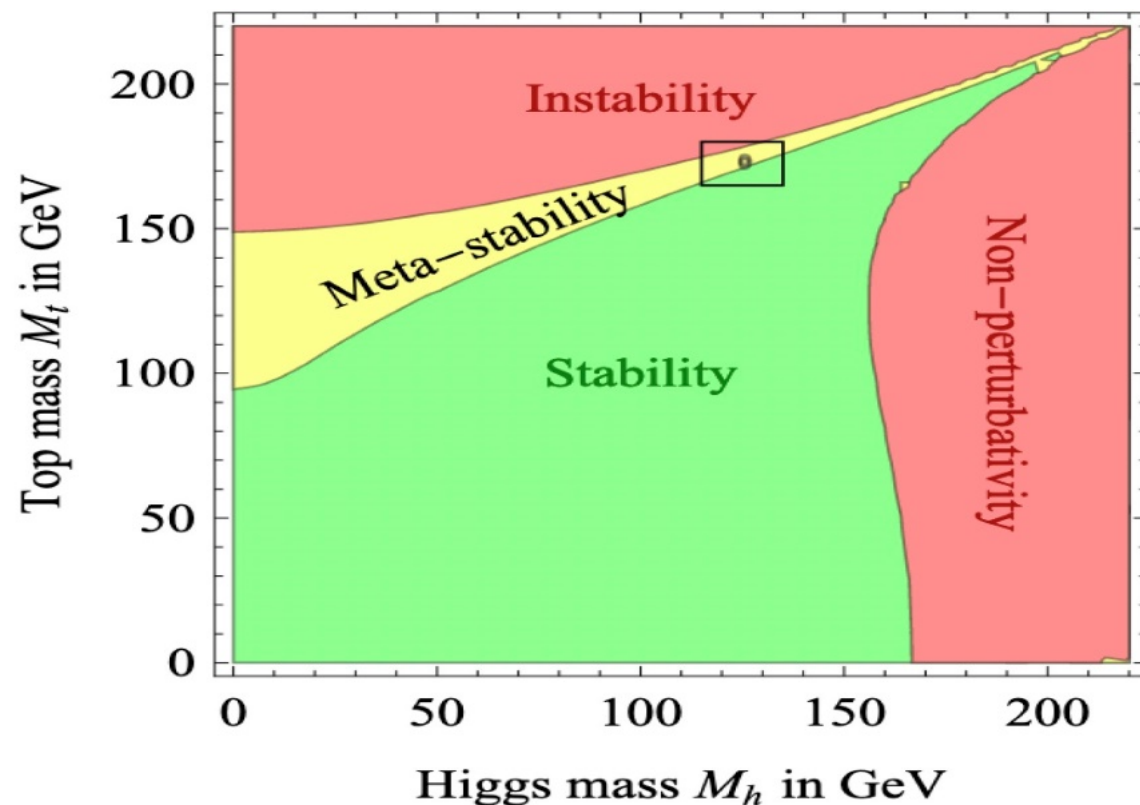
[arXiv: 2602.18611](https://arxiv.org/abs/2602.18611)



Mass measurements

The Higgs boson mass

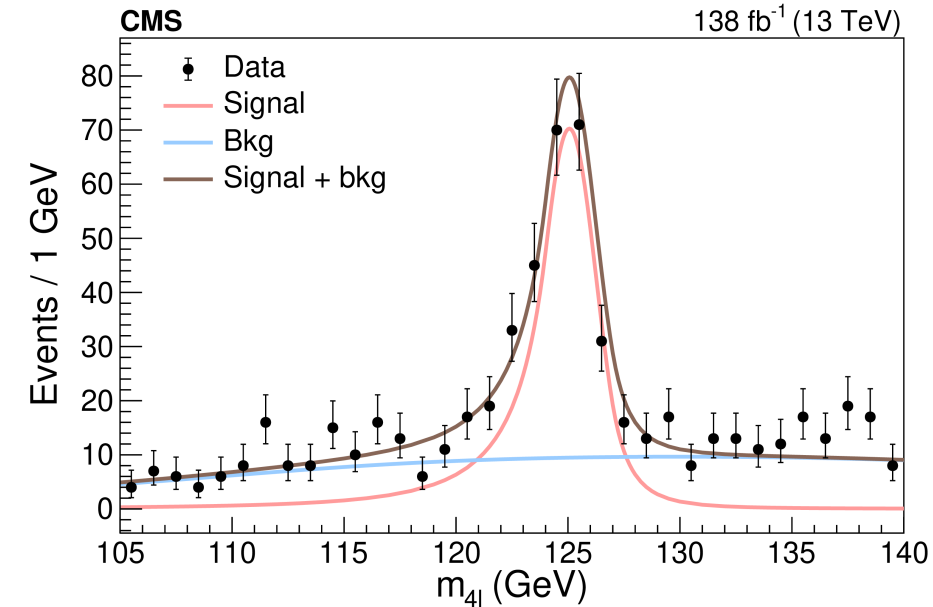
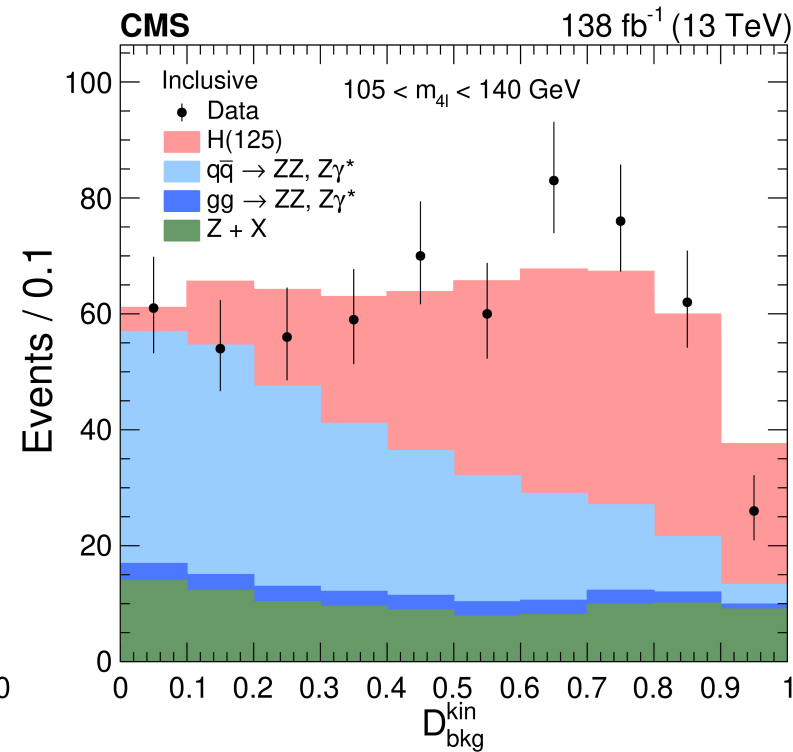
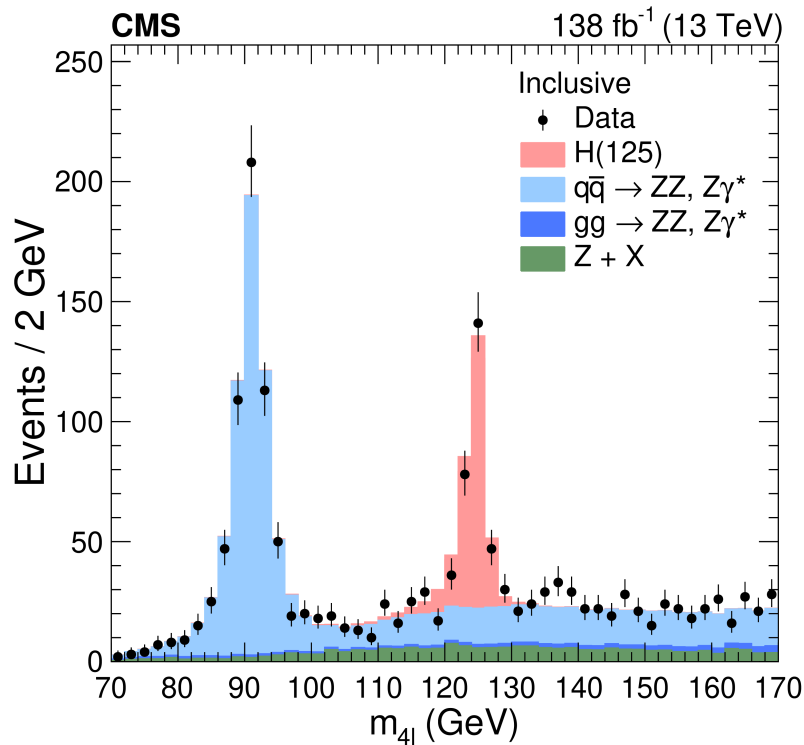
- A free parameter in SM
- The Higgs boson mass is not a test of the SM but it is an important ingredient in SM predictions of many “ m_H -dependent” observables
 - Higgs boson observables: couplings, BRs ...
 - Electroweak observables: mass of the W boson, mass of the top quark, effective weak mixing angle ...
- The Higgs boson mass value is connected to the nature of the stability of electroweak vacuum, with deep cosmological implications



m_H measurement: $H \rightarrow ZZ \rightarrow 4l$

Phys. Rev. D 111(2025)092014

Full reconstruction of m_{4l} from the final state four leptons.

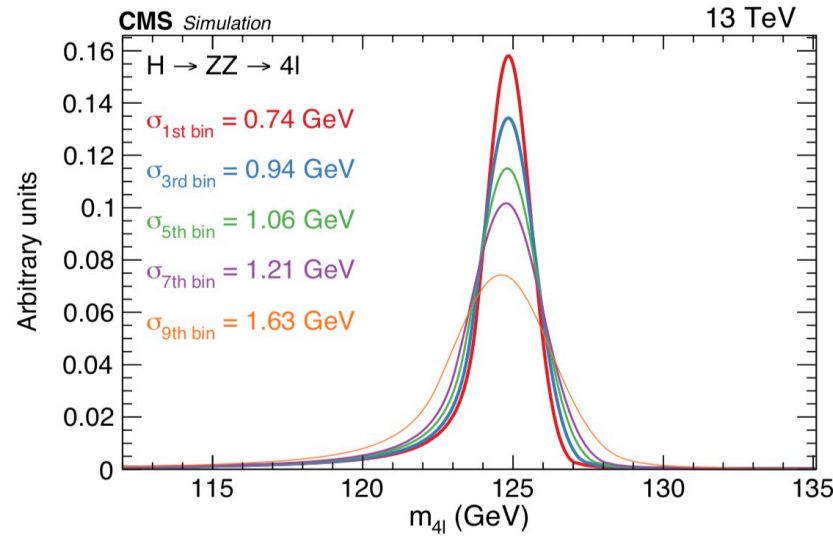
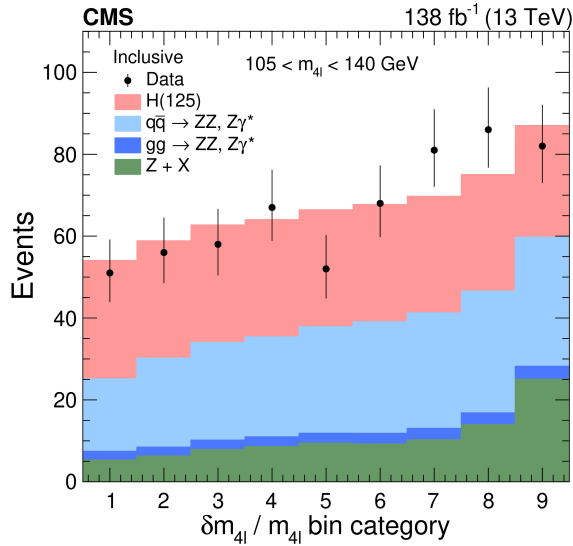


m_{4l} fit functions:

- Sig: Double-Sided CB (+ Landau)
- Bkg: Bernstein (ZZ), Landau (Z+X)

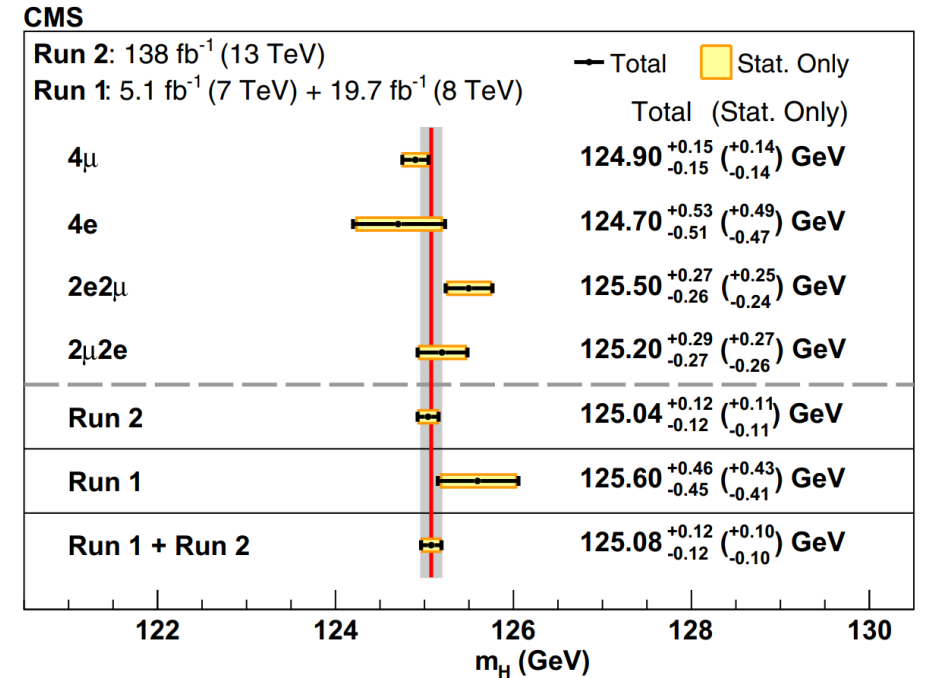
m_H measurement: $H \rightarrow ZZ \rightarrow 4l$

Phys. Rev. D 111(2025)092014



Run 2 improvements:

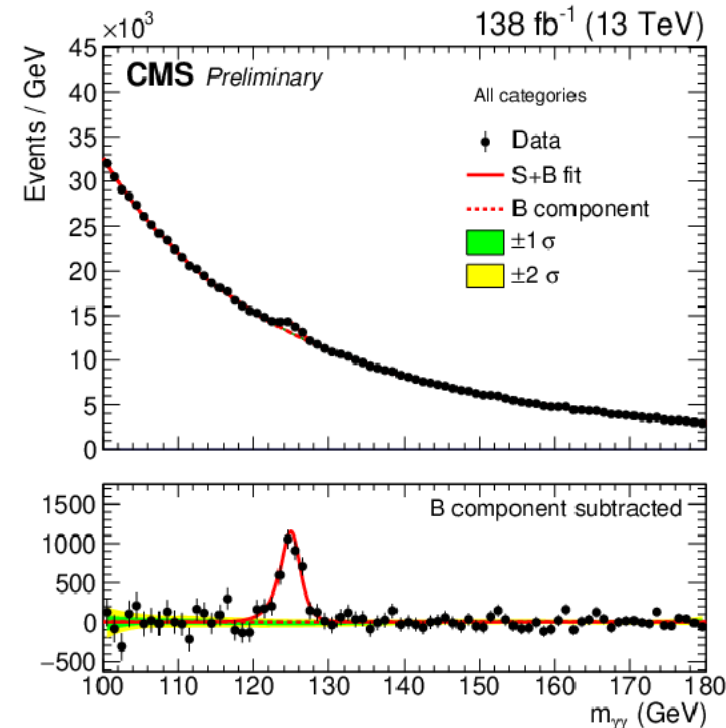
- muon p_T recalculated with the constraint of beam spot: 3~8%
- events are categorized by the relative event-by-event mass uncertainty ($\delta m_{4l}/m_{4l}$)
- kinematic fit is performed using the mass constraint from the on-shell Z



The best precision with a single channel (Run 1 + Run 2):

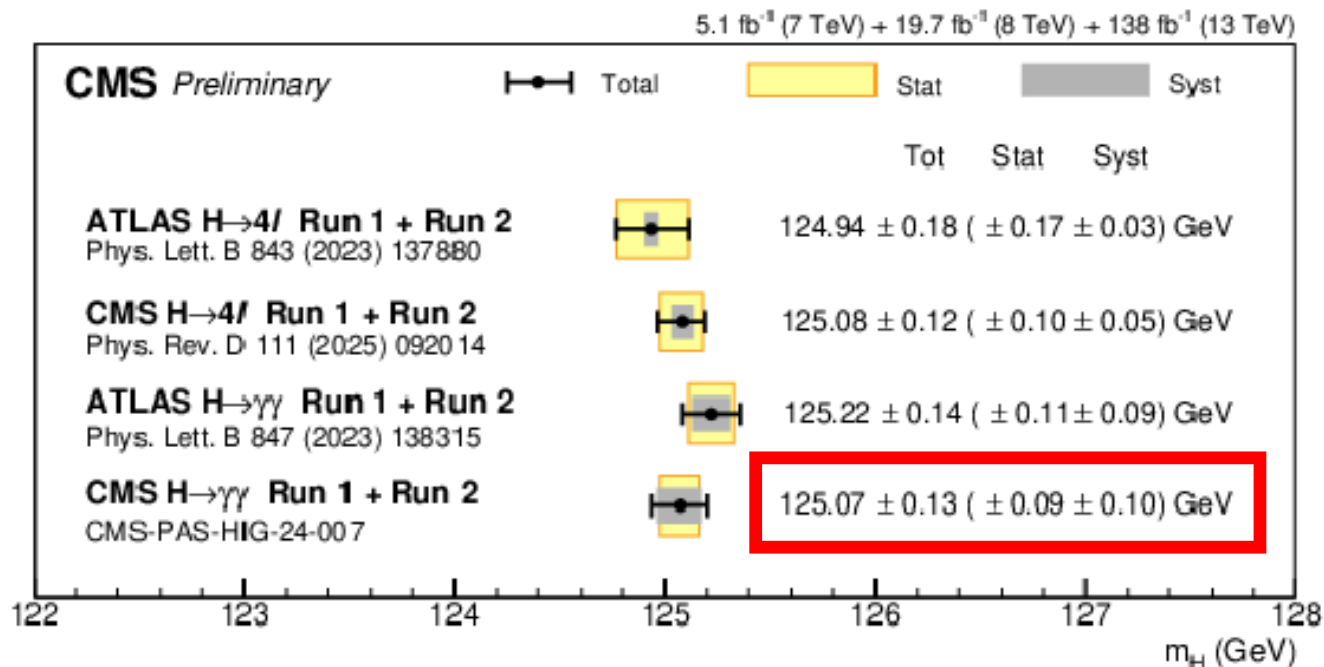
$$125.08 \pm 0.12 \text{ GeV} \left\{ \begin{array}{l} \pm 0.10 \text{ stat} \\ \pm 0.05 \text{ syst} \end{array} \right.$$

m_H measurement: $H \rightarrow \gamma\gamma$



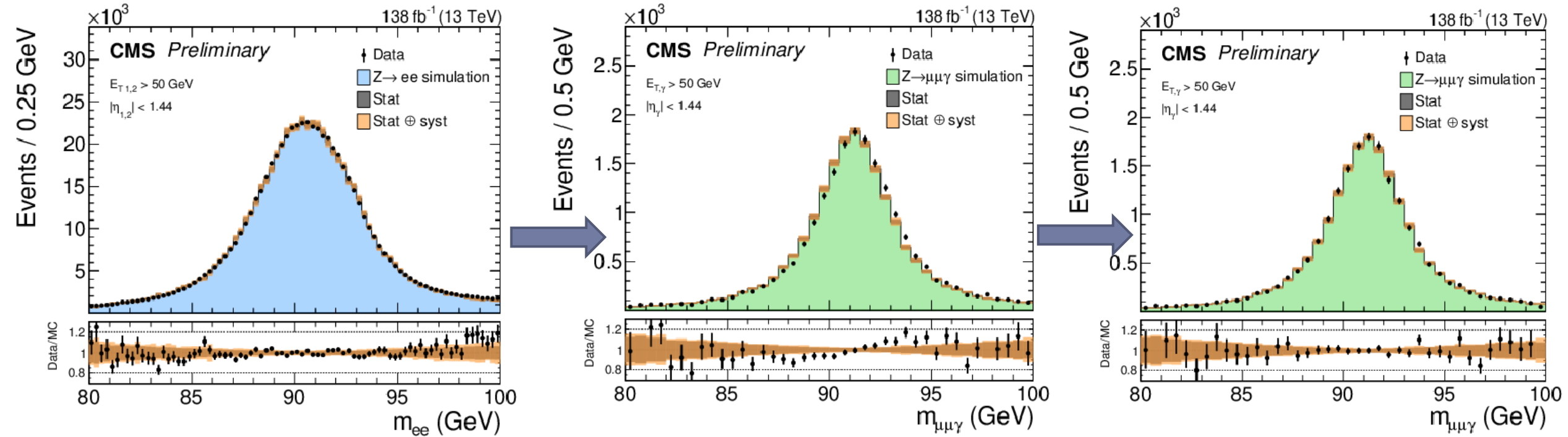
- Events categorized on photon η and diphoton BDT
- 1D fit on $m_{\gamma\gamma}$
 - sig: voigtian functions
 - bkg: a family of functions

Source	Contribution (MeV)
Photon energy scale	
Statistical uncertainty of muon sample	75
Residual non-linearity	64
Muon momentum	38
Electromagnetic shower	23
Photon energy resolution	7
Interference between ggH signal and background	27
Other sources	13
Statistical uncertainty	100
Total uncertainty	150



m_H measurement: $H \rightarrow \gamma\gamma$

The most important component in this analysis is the photon energy calibration.



Run 2 improvements:

- After energy calibration for ECAL cluster with $Z \rightarrow ee$ data/MC events, residual electron-photon scale differences is derived with FSR photons in $Z \rightarrow \mu\mu\gamma$ data/MC events

Width measurements

The Higgs boson width

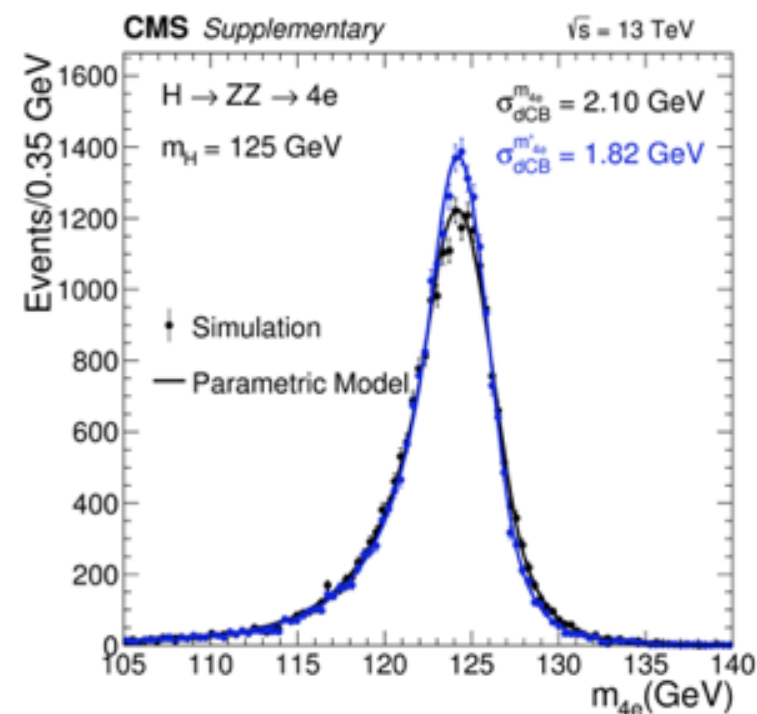
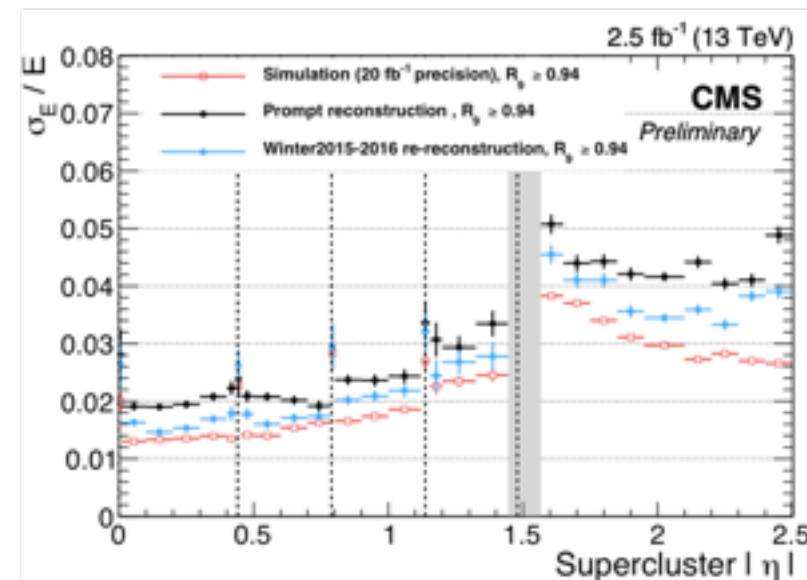
- Predicted width in SM: $\Gamma_H = 4.1\text{MeV}$
- Due to detector response, the mass of Higgs is smeared $\sigma \sim 1\text{-}2\text{GeV}$

e.g for an electron $E_e \sim 50\text{ GeV}$, $\sigma_e \sim 1\text{GeV}$

$$m_H = \sqrt{(E_{e1} + E_{e2} + E_{e3} + E_{e4})^2 - (\vec{p}_{4e})^2}$$

$$\sigma_{mH} = 2 \times \sigma_e = 2\text{GeV}$$

Unable to measure Higgs width
through on-shell pole



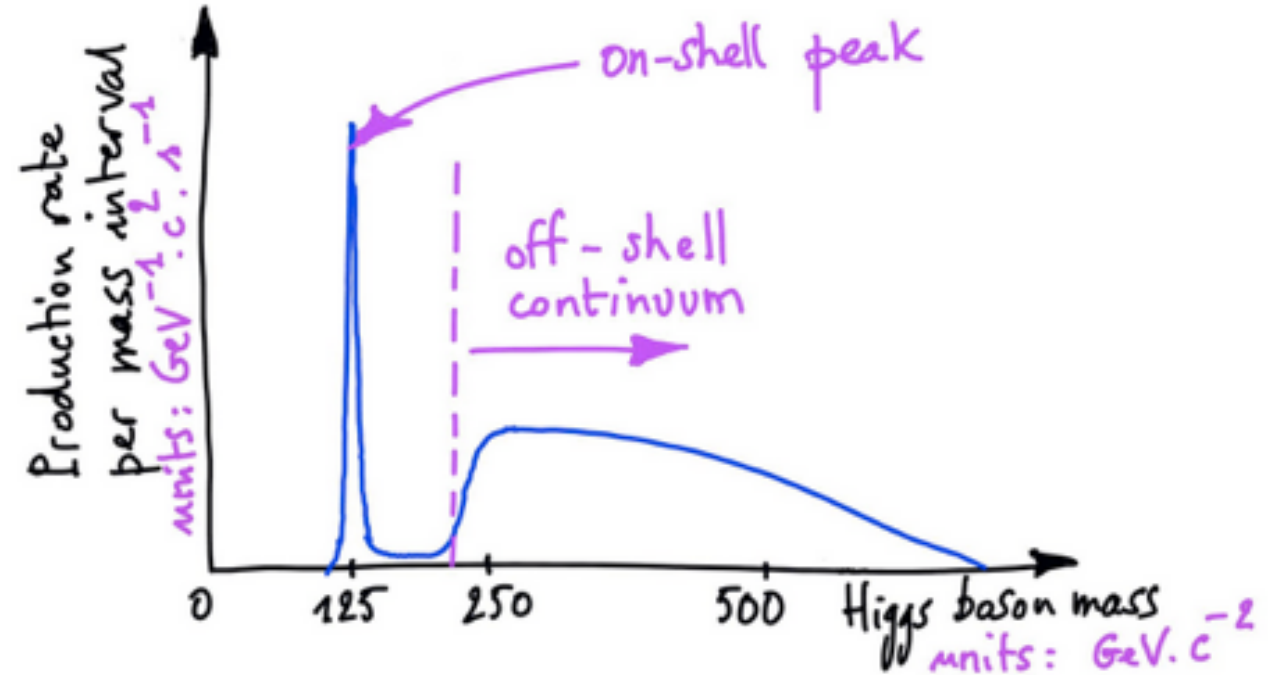
Indirect way to measure Γ_H

- Higgs production rate:

$$d\sigma \propto \frac{g_{\text{prod}}^2 g_{\text{dec}}^2}{(q_H^2 - m_H^2)^2 + m_H^2 \Gamma_H^2} dq_H^2$$

$$\sigma^{\text{on-shell}} \propto \frac{g_{\text{prod}}^2 g_{\text{dec}}^2}{\Gamma_H} \propto \mu_{\text{on-shell}}$$

$$\sigma^{\text{off-shell}} \propto \int \frac{g_{\text{prod}}^2 g_{\text{dec}}^2}{(q_H^2 - m_H^2)^2} dq_H^2 \propto \mu_{\text{off-shell}} \propto \mu_{\text{on-shell}} \times \Gamma_H / \Gamma_{SM}$$

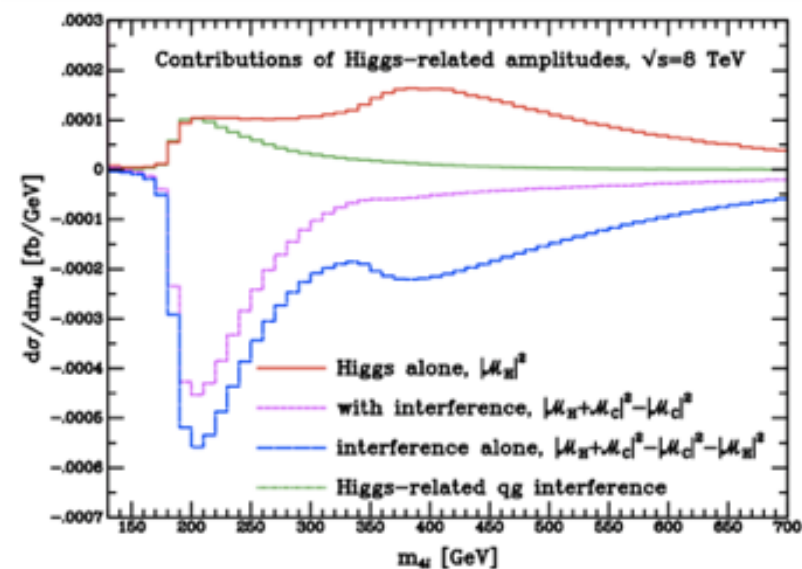
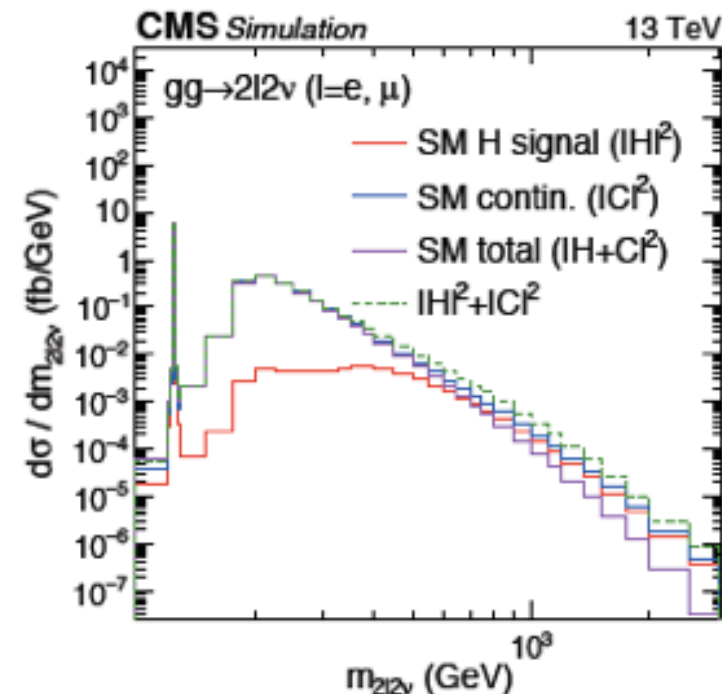
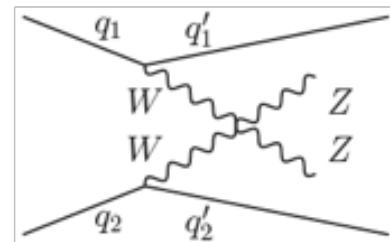
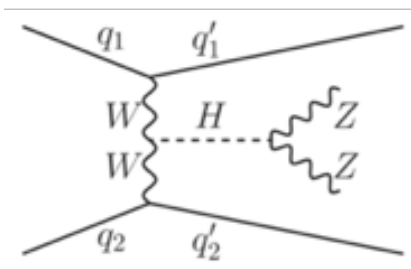
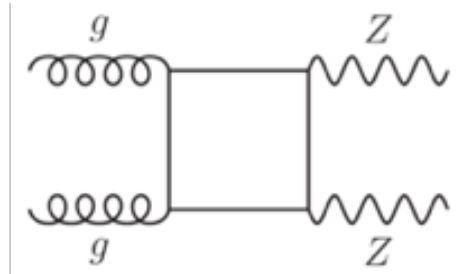
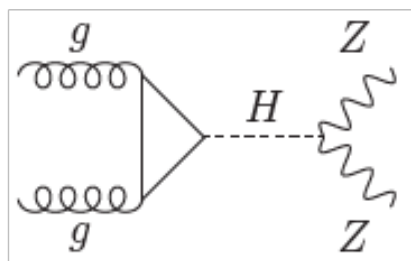


- By measuring the signal strengths in the on-shell and off-shell, and take their ratio, we could measure Γ_H

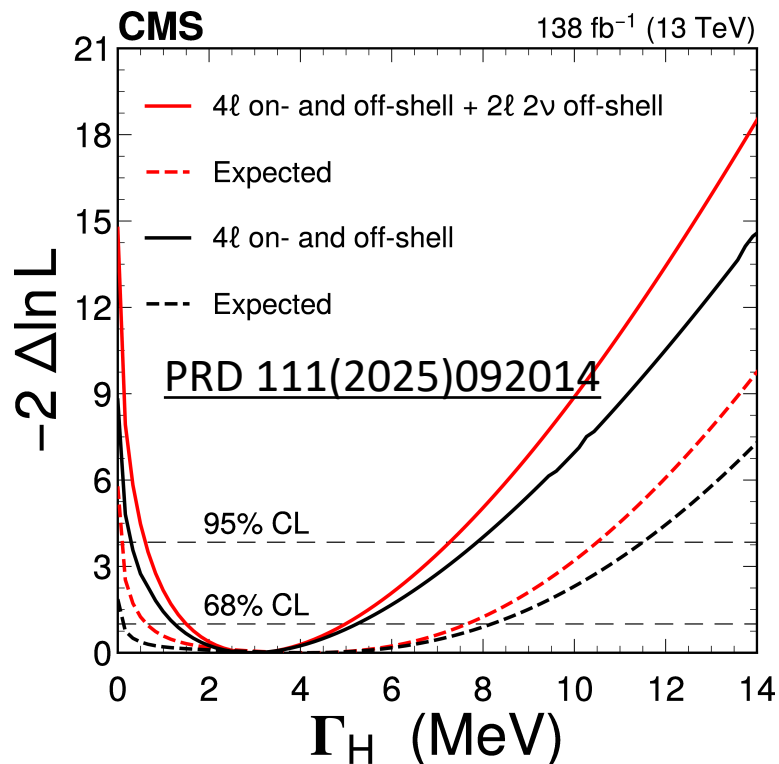
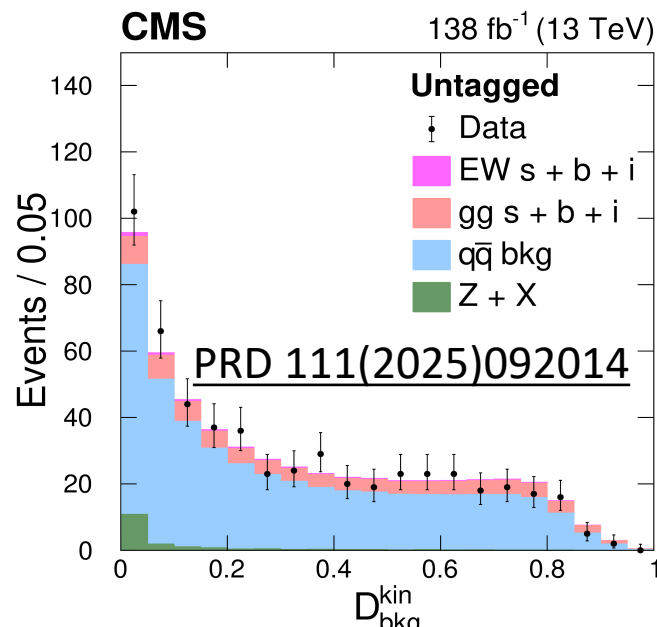
$$\Gamma_H / \Gamma_{SM} = \frac{\mu_{\text{off-shell}}}{\mu_{\text{on-shell}}}$$

Off-shell Higgs

- Difficulties for probing off-shell Higgs:
 - Low production rate: $\sim 10\%$ of total XS
 - Large destructive interference with continuum background

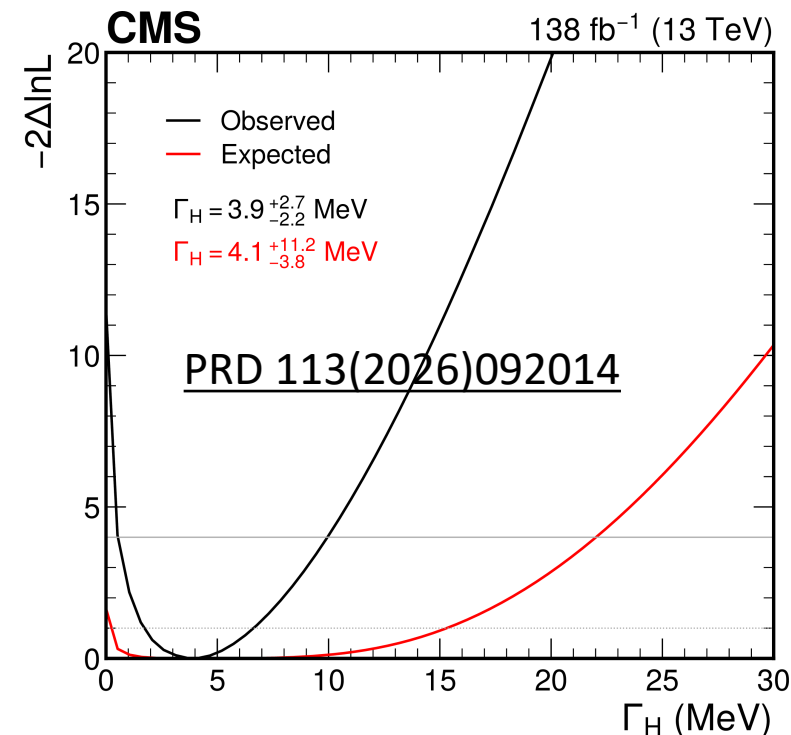


Evidence for off-shell Higgs and measured width



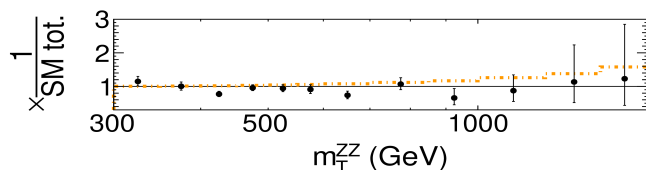
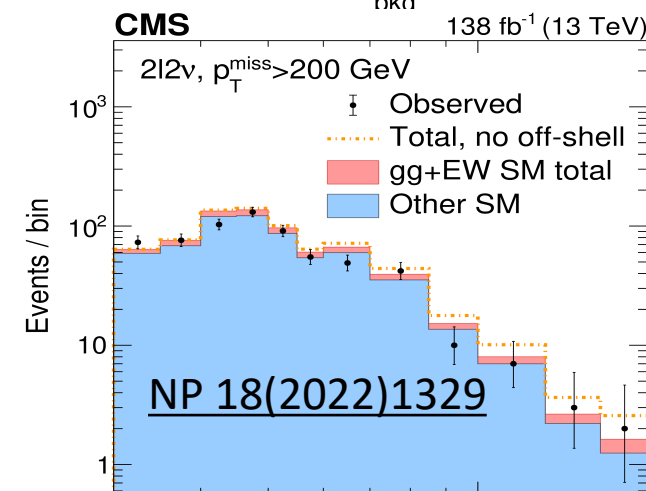
$H \rightarrow ZZ \rightarrow 4l$ and $H \rightarrow ZZ \rightarrow 2l2\nu$

$$\Gamma_H = 3.0_{-1.5}^{+2.0} \text{ MeV}$$



$H \rightarrow WW \rightarrow e\nu\mu\nu$

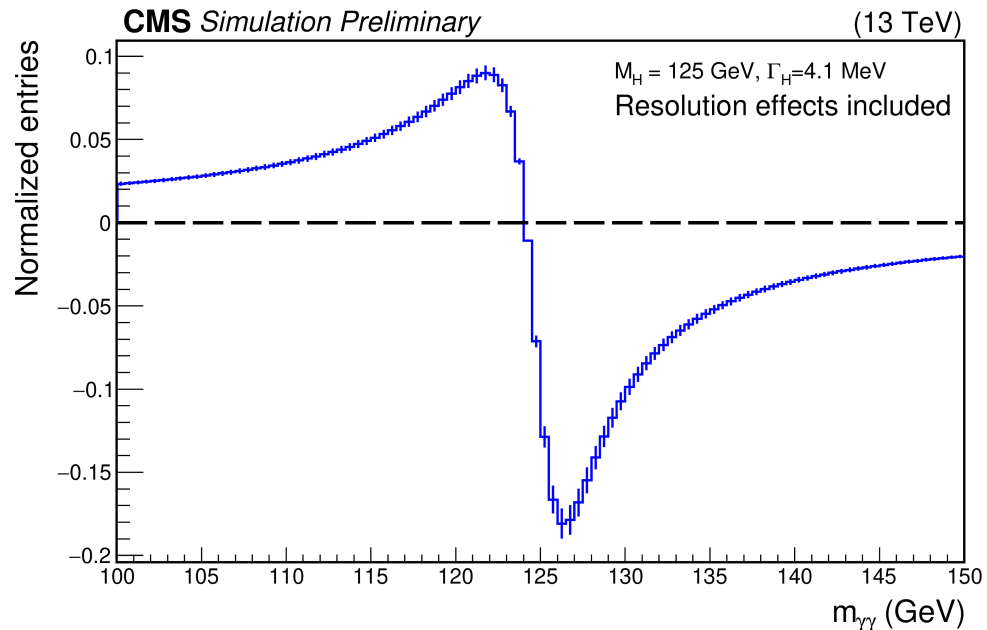
$$\Gamma_H = 3.9_{-2.2}^{+2.7} \text{ MeV}$$



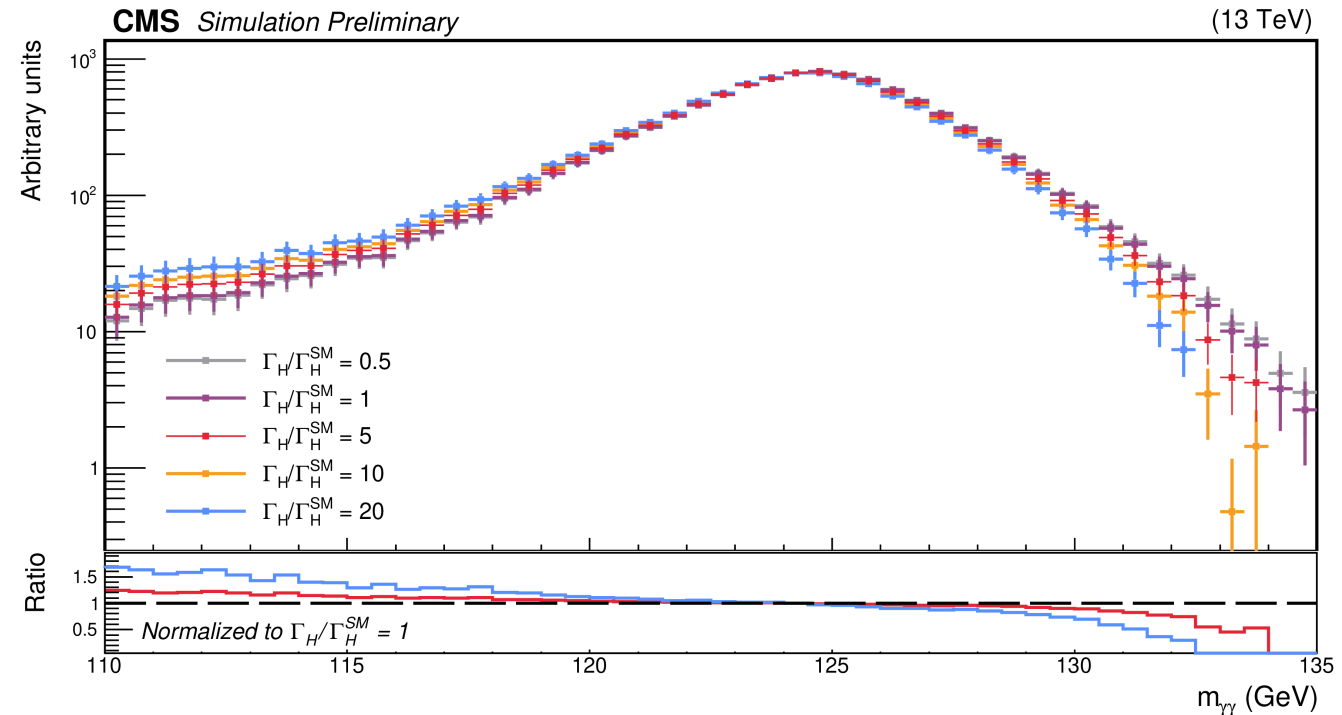
Higgs width measurement with on-shell interference

Interference between $gg \rightarrow H \rightarrow \gamma\gamma$ and continuum $gg \rightarrow \gamma\gamma$ around the on-shell pole

$$d\sigma_i/dm_{\gamma\gamma} = c_{g\gamma} \frac{(m_{\gamma\gamma}^2 - m_H^2)R + m_H \Gamma_H I}{(m_{\gamma\gamma}^2 - m_H^2)^2 + m_H^2 \Gamma_H^2}$$



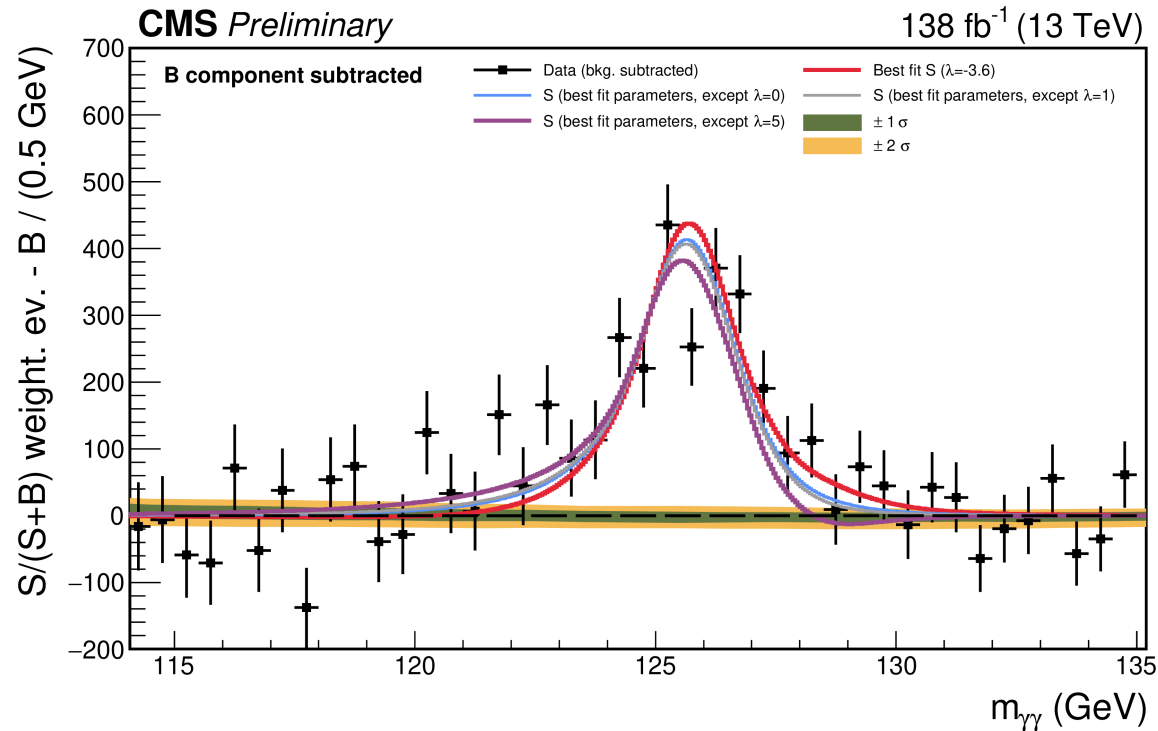
CMS-PAS-HIG-25-004



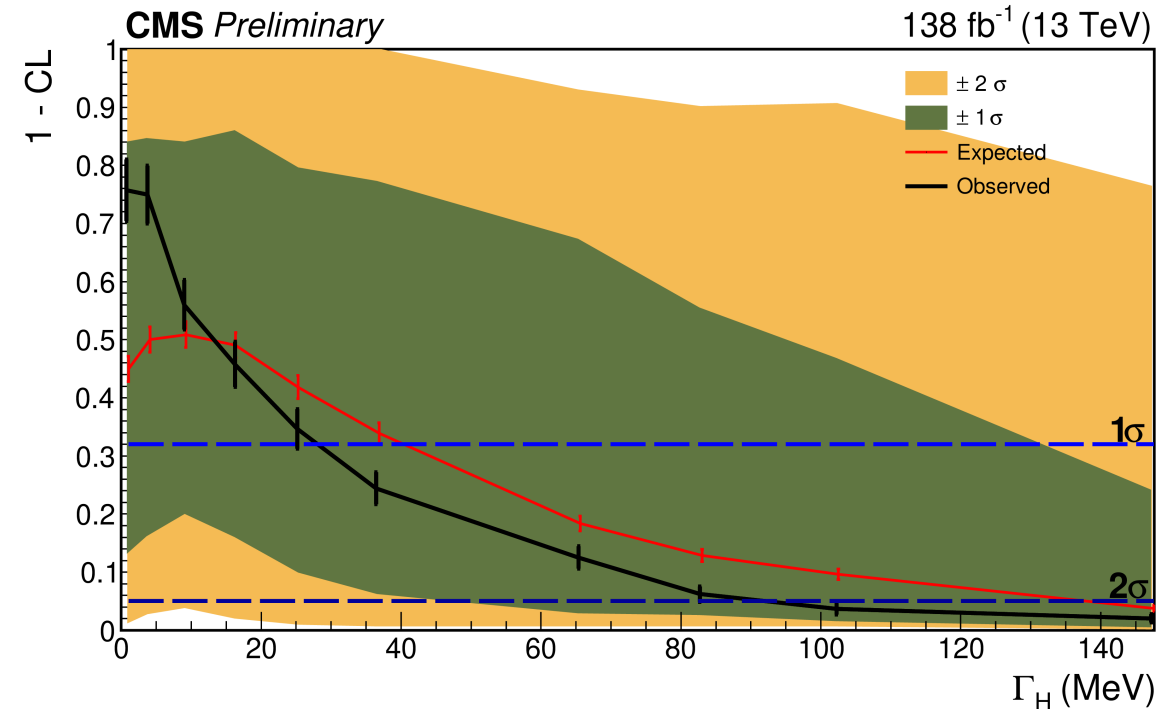
The larger Γ_H , the bigger deviation from the SM Higgs $m_{\gamma\gamma}$ lineshape.

Higgs width measurement with on-shell interference

CMS-PAS-HIG-25-004



Measure Higgs $m_{\gamma\gamma}$ lineshape to
constrain Γ_H

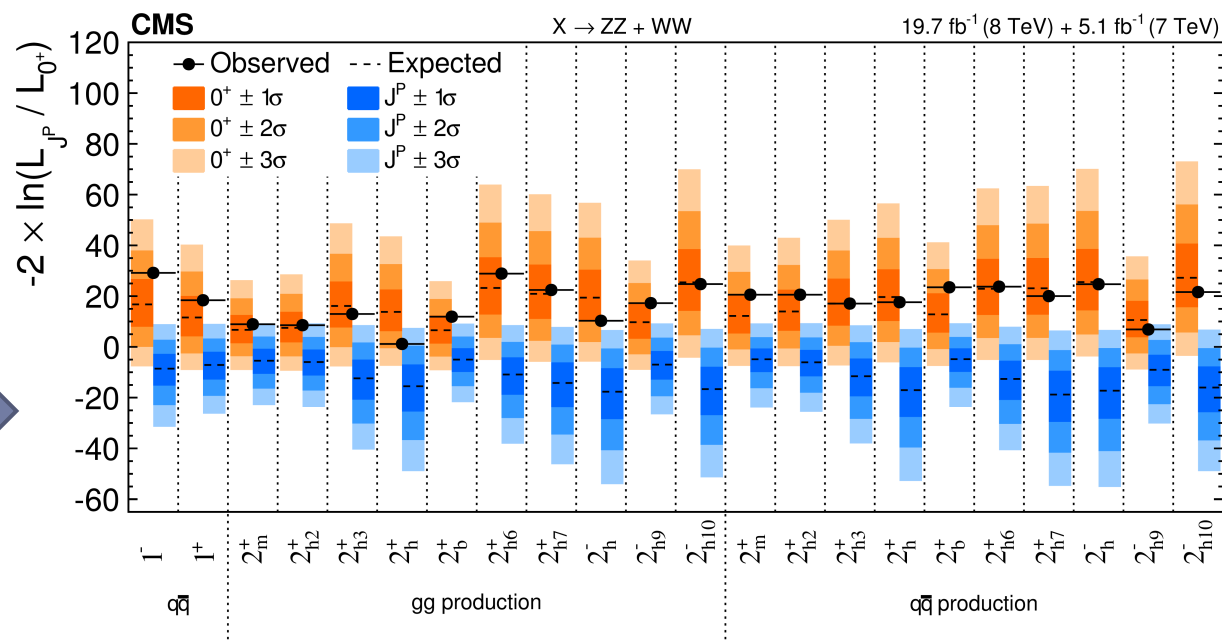


Obs (Exp) upper limit :
 $\Gamma_H < 91.8$ (138.2) MeV at 95%CL

CP structure measurements

Higgs CP structure

- Higgs is CP even scalar in SM: $J^P = 0^+$
- In couplings of Higgs and bosons, data favors SM hypothesis, alternative J^P hypothesis mostly excluded by $> 99.9\%$ CL at Run 1
- Strong theoretical motivation to search for CP-violating effects in couplings of Higgs and fermions



Probing process		Scale of CP-odd contribution
Fermion	$H\tau\tau$, $H\tau\tau$	$O(1)$: tree level
Boson	$H\tau\tau$, $H\tau\tau$, $H\tau\tau$, $H\tau\tau$	$O(1/\Lambda^2)$

Λ is the scale of BSM physics in effective field theory

Probe CP violation in $H\tau\tau$

- Lagrangian for τ Yukawa coupling parameterized with

$$\mathcal{L}_Y = -\frac{m_\tau}{v} H (\kappa_\tau \bar{\tau} \tau + \tilde{\kappa}_\tau \bar{\tau} i \gamma_5 \tau)$$

CP even CP odd

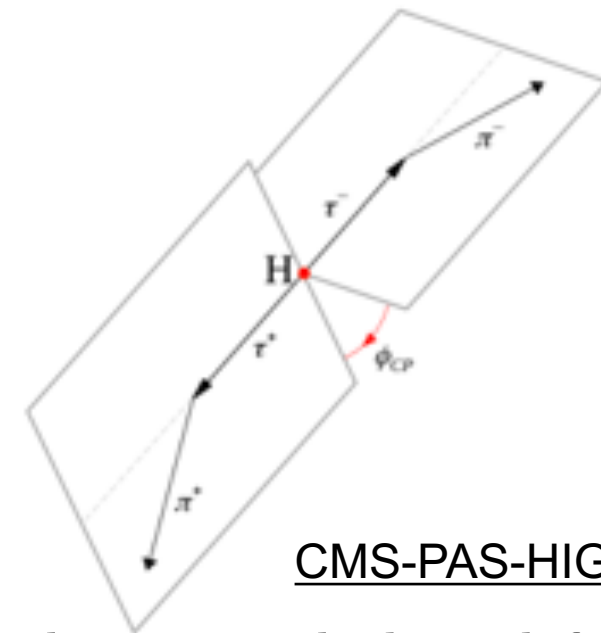
$$\tan(\alpha^{H\tau\tau}) = \frac{\tilde{\kappa}_\tau}{\kappa_\tau}$$

CP even: $\alpha^{H\tau\tau} = 0^\circ$ (SM)

CP odd: $\alpha^{H\tau\tau} = 90^\circ$

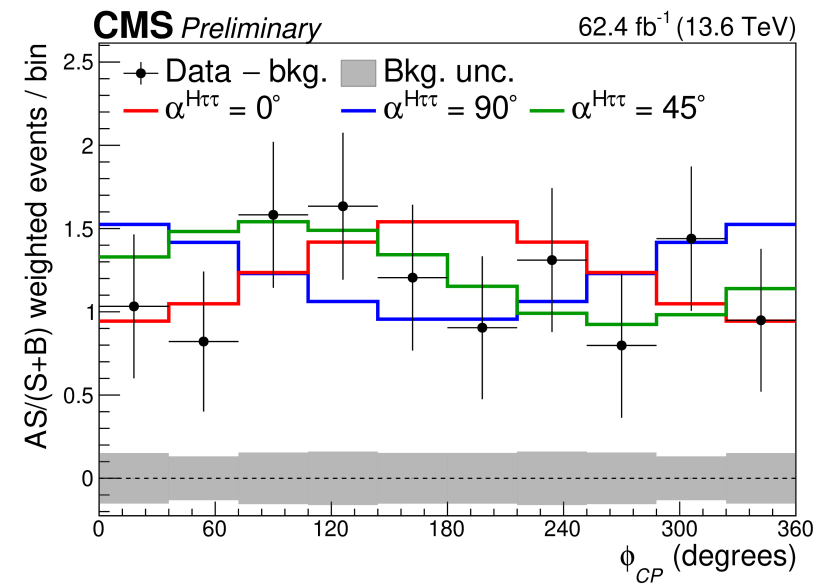
CP mixed: $0^\circ < |\alpha^{H\tau\tau}| < 90^\circ$

If $5^\circ < |\alpha^{H\tau\tau}| < 15^\circ$, it could explain baryon asymmetry whilst remaining compatible with current experimental constraints



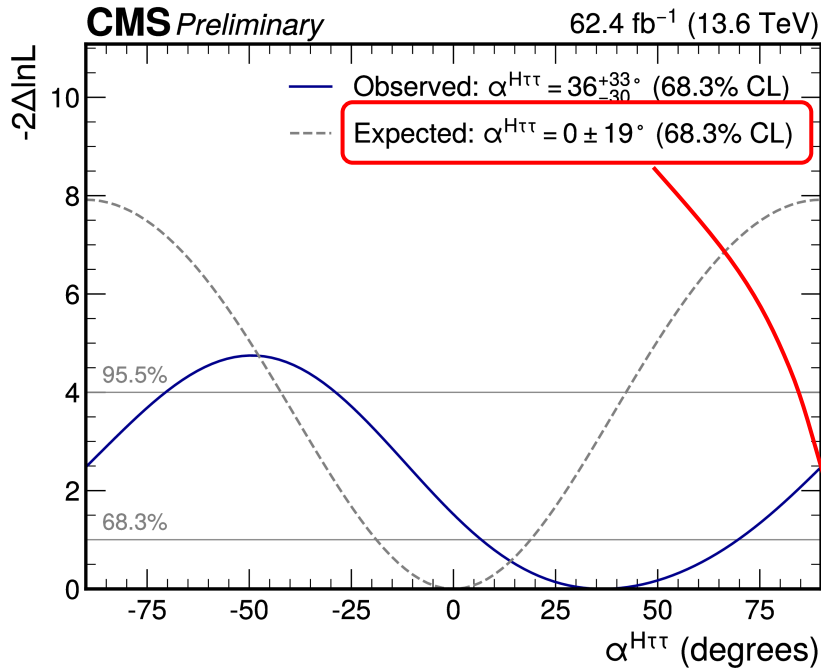
CMS-PAS-HIG-25-012

The acoplanarity angle ϕ_{CP} is defined as the angle between the two τ lepton decay planes in the H rest frame.



Probe CP violation in $H\tau\tau$

2022+2023 (Run 3)

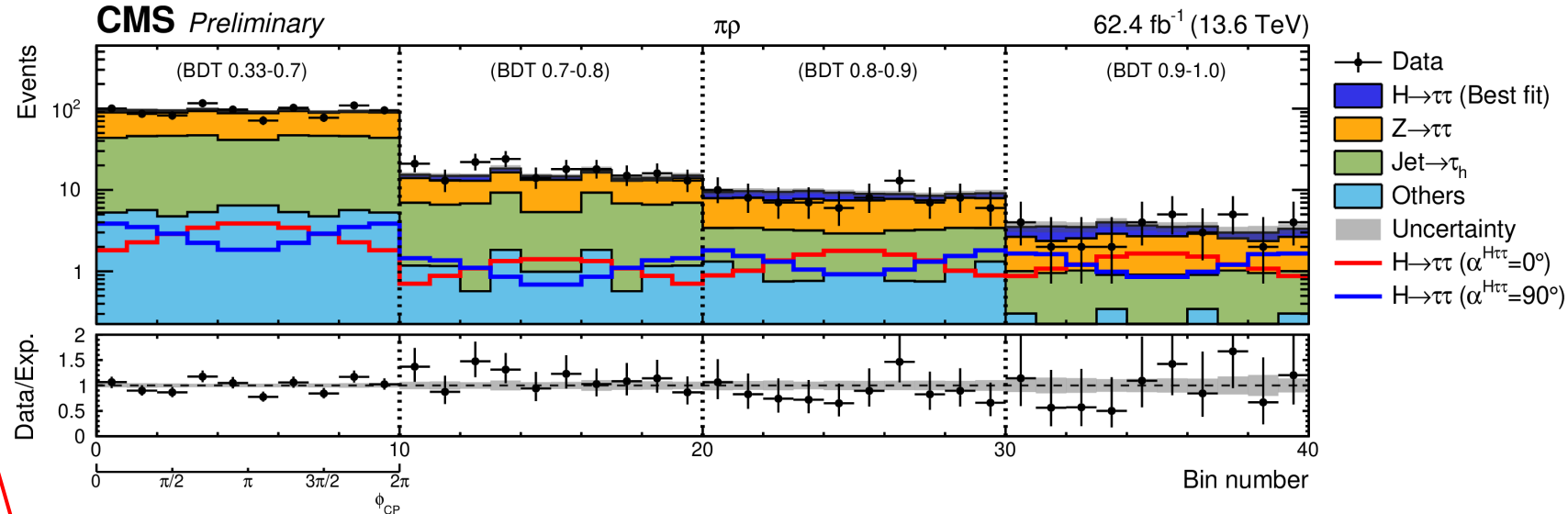


Larger sensitivity of Run 3 analysis

Expected Run 2 result: $\alpha^{H\tau\tau} = 0 \pm 21^\circ$

The expected exclusion of pure CP-odd scenario ($\alpha^{H\tau\tau} = 90^\circ$) is 2.8σ

CMS-PAS-HIG-25-012



Three channels ($\tau_h\tau_h$, $\tau_h\tau_\mu$, $\tau_h\tau_e$) are considered. Dedicated BDT is trained for each channel to separate S and B.

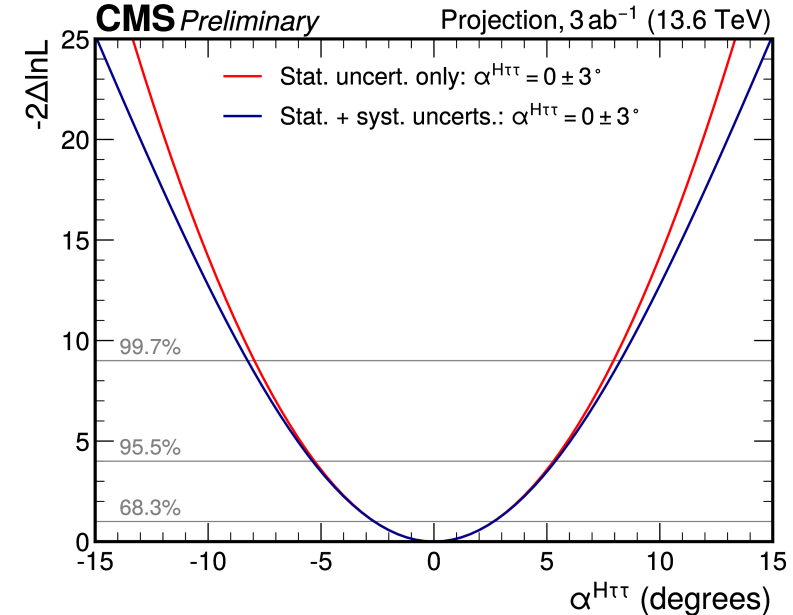
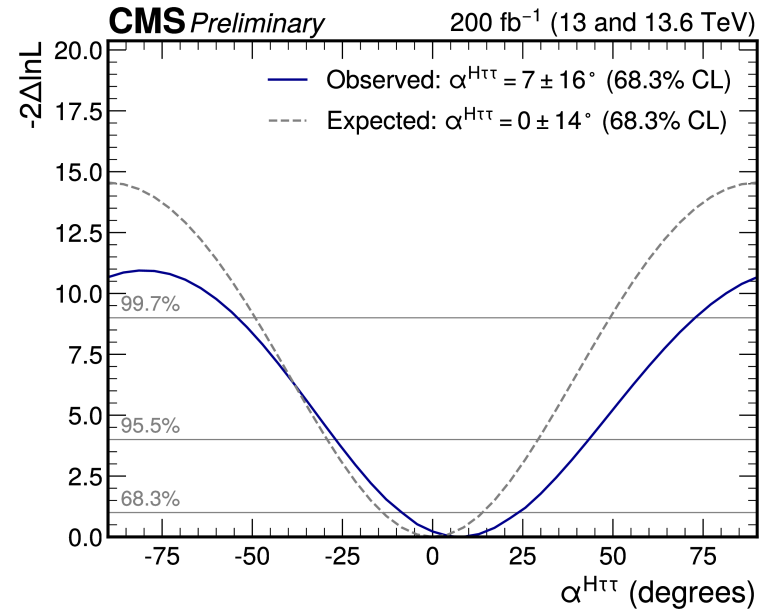
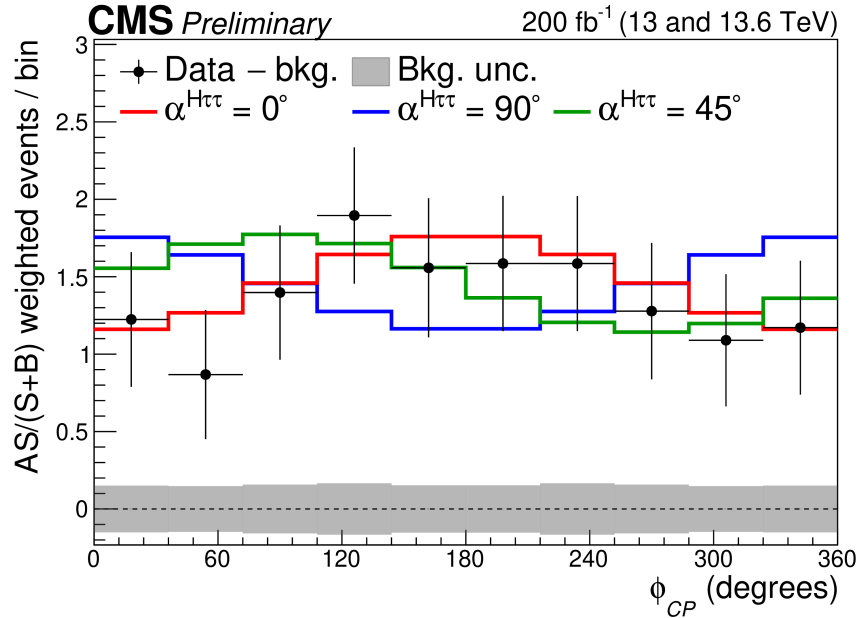
Run 3 improvements:

- better hadronic tau identification (DeepTau)
- better decay mode classification (ParticleNet)
- new triggers and optimized cuts

Probe CP violation in $H\tau\tau$

Run 2 + Run 3: 2016-2023

CMS-PAS-HIG-25-012



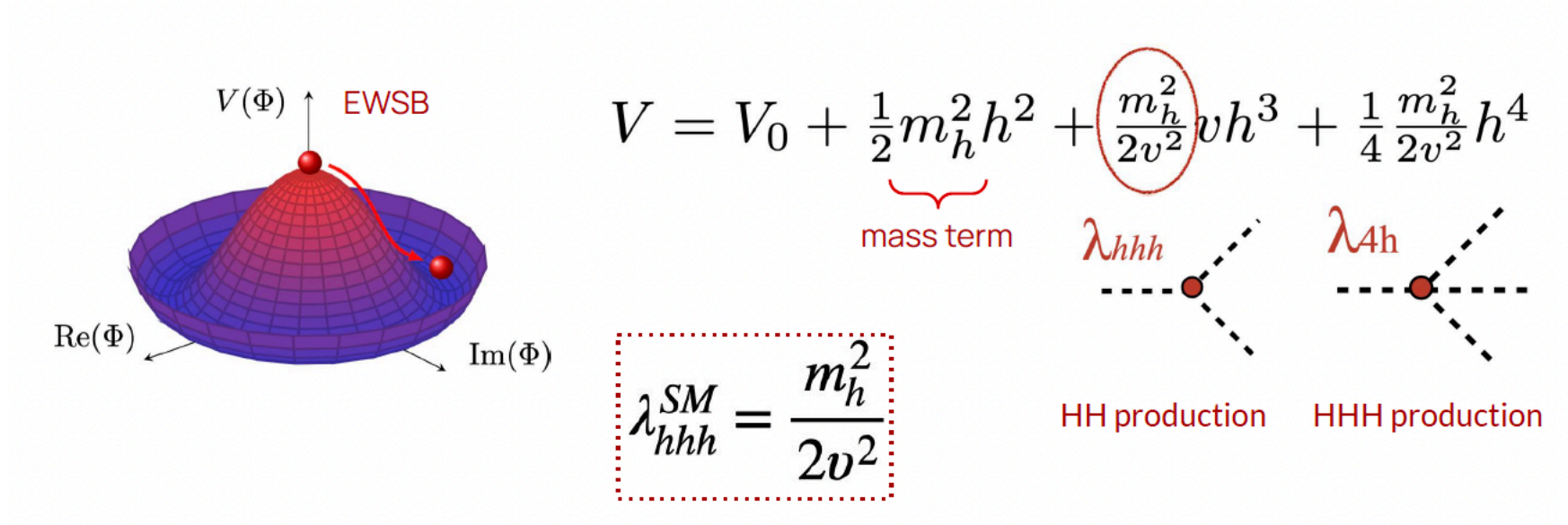
Observed result: $\alpha^{H\tau\tau} = 7 \pm 16^\circ$
Expected result: $\alpha^{H\tau\tau} = 0 \pm 14^\circ$

- Most precise measurement by CMS of the CP nature of the Higgs boson couplings to tau leptons
- Projection to HL-LHC ($\pm 3^\circ$), even better sensitivity than at future e^+e^- colliders ($\pm 6^\circ$)

Higgs self-coupling measurements

Higgs self-coupling

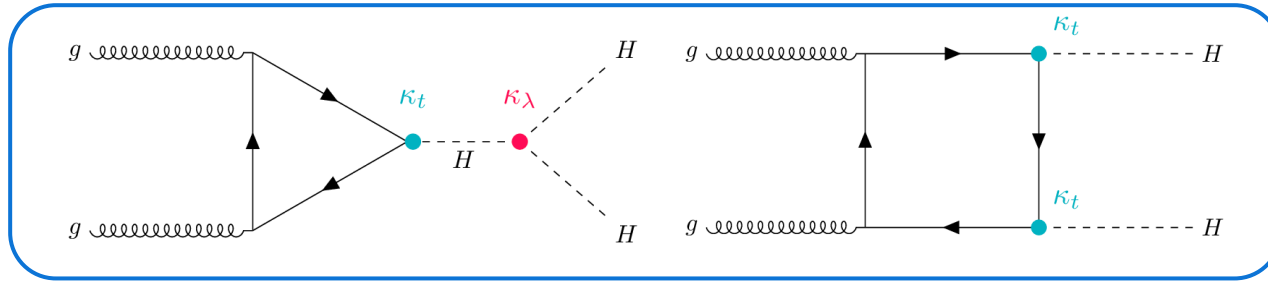
- It validates (or invalidates) the EWSB
- It is a direct probe of the “shape” of the Higgs Potential
- It determines the fate of our universe (Vacuum Stability)



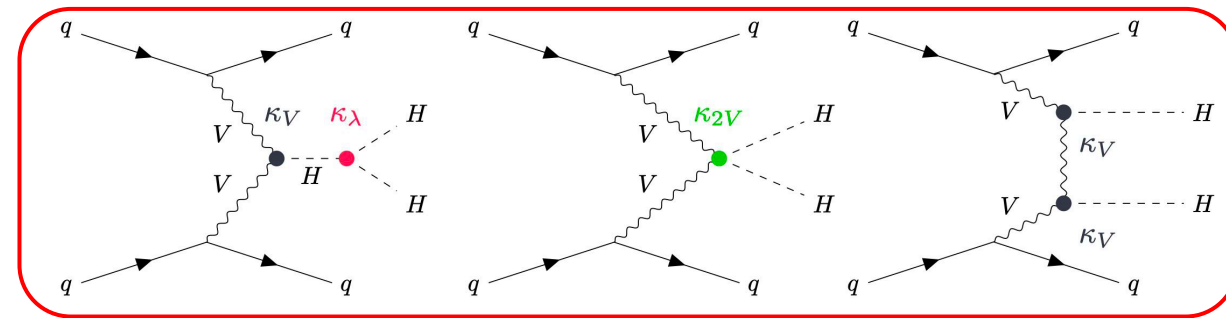
λ_{hhh} shapes the Higgs potential & governs the dynamics of EWSB

HH production

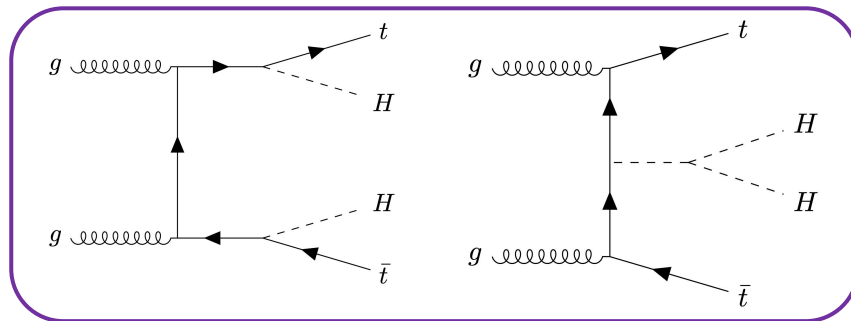
- HH searches provide the only direct way to probe the λ_{hhh}



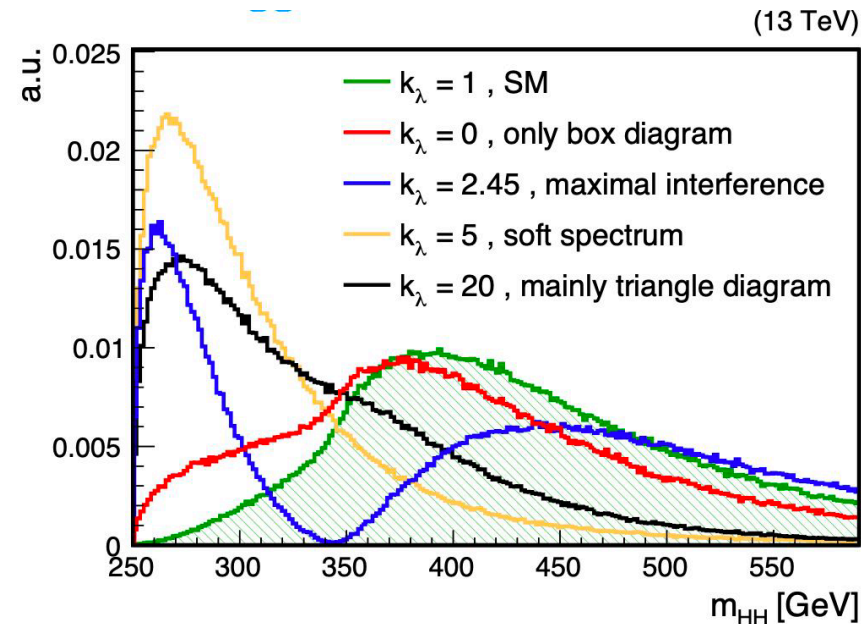
$\sigma_{ggHH} = 31.1 \text{ fb @ 13 TeV (34.1 fb @ 13.6 TeV)}$
 $\sim 1000\times$ smaller than single H production



$\sigma_{VBF HH} = 1.726 \text{ fb @ 13 TeV (1.874 fb @ 13.6 TeV)}$



$\sigma_{ttHH} = 0.756 \text{ fb @ 13 TeV (0.86 fb @ 13.6 TeV)}$



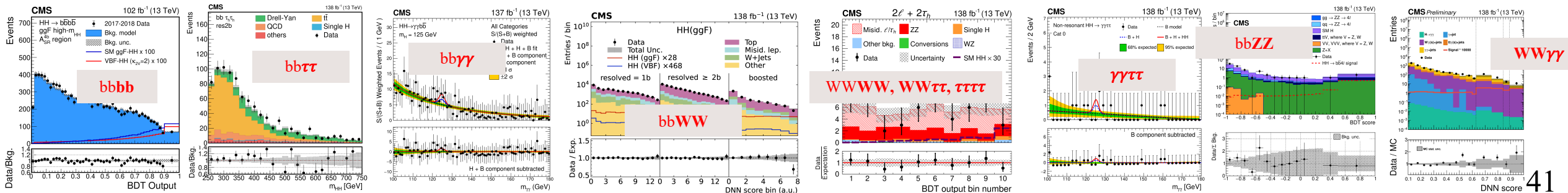
$$\kappa_\lambda = \frac{\lambda}{\lambda_{SM}}$$

BSM modification to κ_λ could lead to much higher cross sections

HH decay channels

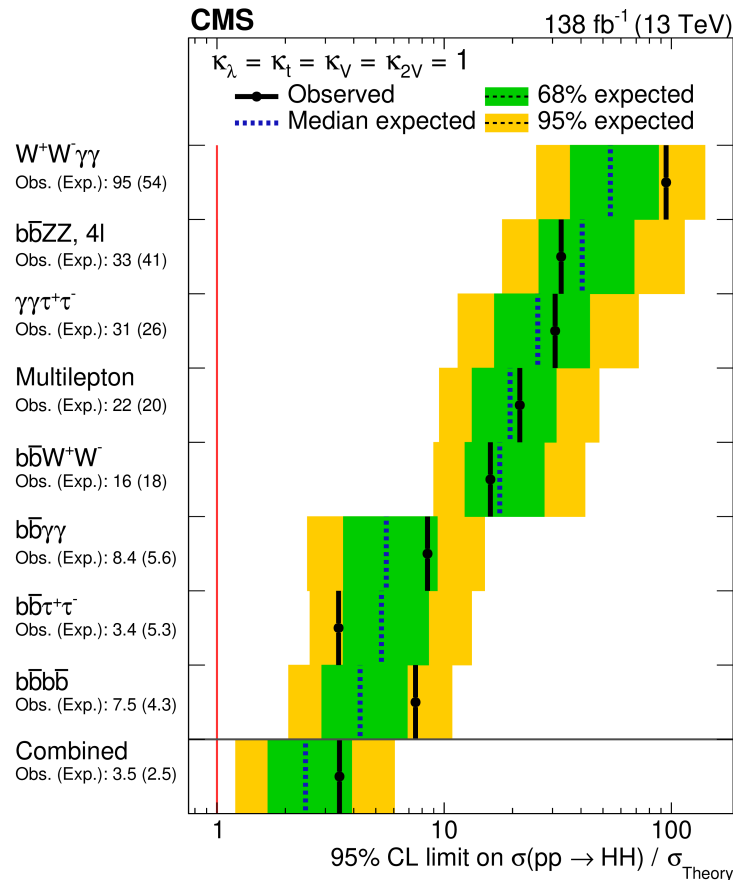
- Channels with large BRs often suffer from challenging signatures and large backgrounds
- Highest sensitivity channels:
 - bbbb**: highest BR, fully reconstruction, low purity
 - bb $\tau\tau$** : modest BR, higher purity
 - bb $\gamma\gamma$** : small BR, fully reconstruction, good $m_{\gamma\gamma}$ resolution
- CMS has a broad program of HH searches with most decay channels covered

Decays	$h \rightarrow b\bar{b}$	$h \rightarrow W\bar{W}$	$h \rightarrow \tau\bar{\tau}$	$h \rightarrow Z\bar{Z}$	$h \rightarrow \gamma\gamma$
$h \rightarrow b\bar{b}$	34%				
$h \rightarrow W\bar{W}$	25%	4.6%			
$h \rightarrow \tau\bar{\tau}$	7.3%	2.7%	0.39%		
$h \rightarrow Z\bar{Z}$	3.1%	1.1%	0.33%	0.069%	
$h \rightarrow \gamma\gamma$	0.26%	0.10%	0.028%	0.012%	0.0005%

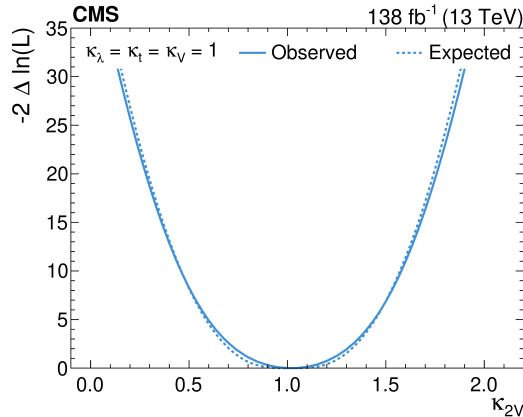


Combination of Non resonant HH searches

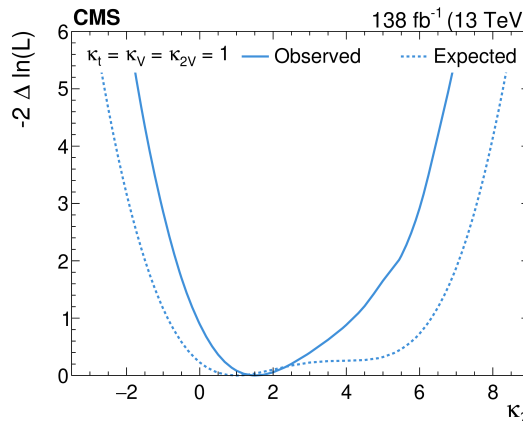
- Combine $bbbb$, $bb\tau\tau$, $bb\gamma\gamma$, multilepton ($WWWW$, $WW\tau\tau$, $\tau\tau\tau\tau$), $bbWW$, $\gamma\gamma\tau\tau$, $bbZZ$, $WW\gamma\gamma$
- Based on full Run 2 dataset, extrapolated to HL-LHC



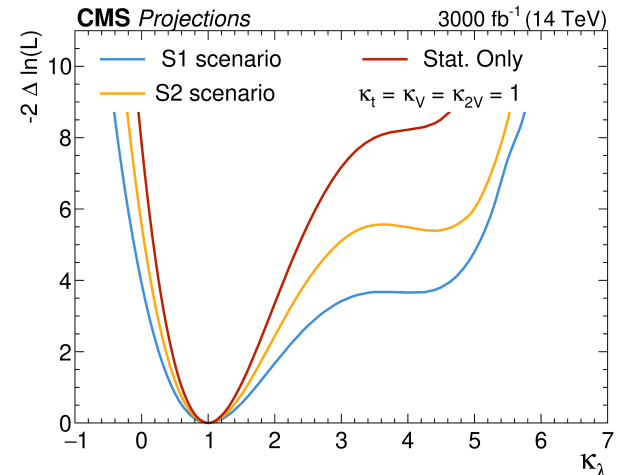
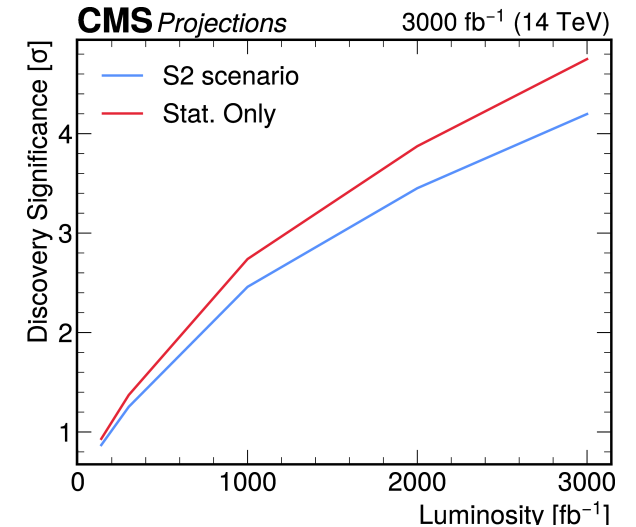
$$\sigma_{HH} < 3.5 (2.5) \times \sigma_{SM}$$



$\kappa_{2V} = 0$ excluded at more than 5σ



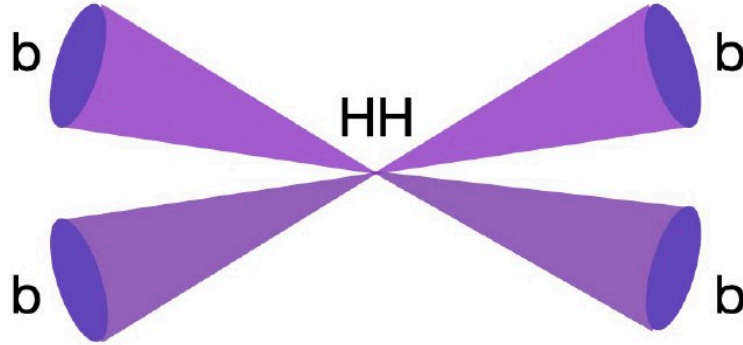
$$-1.35 < \kappa_\lambda < 6.35$$



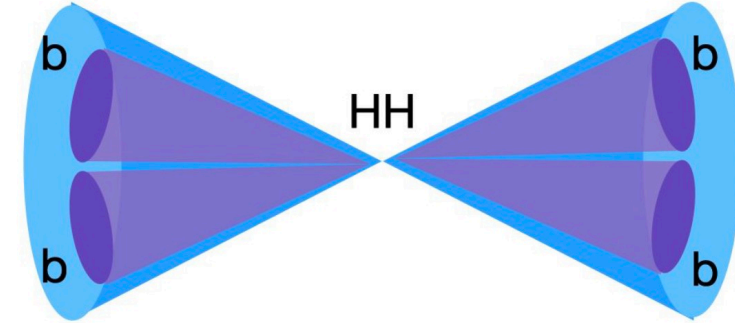
Search for $HH \rightarrow bbbb$

- Include two topologies for the analysis:

Resolved: Higgs decay products reconstructed as small radius jets



Merged: both Higgs reconstructed as large radius jets



Event selection in 2022 and 2023:

- Online selection with 4j2b triggers
- ≥ 4 AK4 PUPPI jets ($p_T > 70, 50, 40, 35$ (30) GeV, $|\eta| < 2.5$, TightID)
- ≥ 2 b jets (ParticleNet Medium WP)
- HH jets: Four leading in b-tag score jets
- Pairing assignment done as in [Run-2 \$HH \rightarrow 4b\$ analysis](#)
- VBF candidate jets: $p_T > 30$ GeV with $|\eta| < 4.7$, not b-tagged

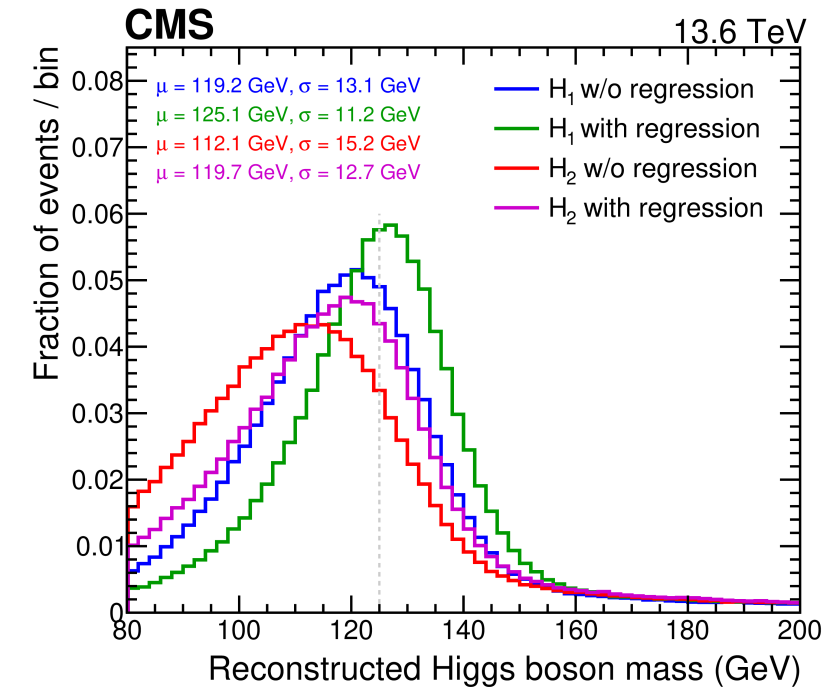
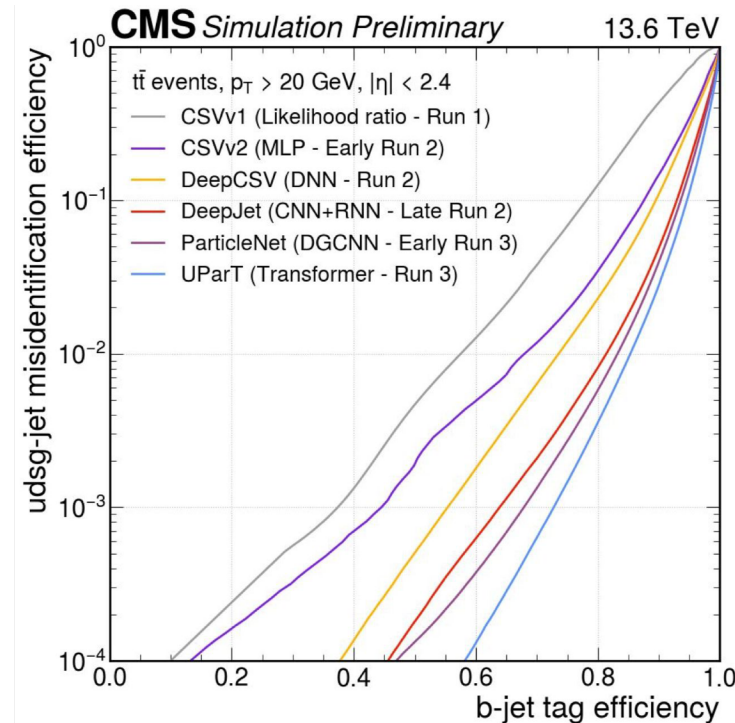
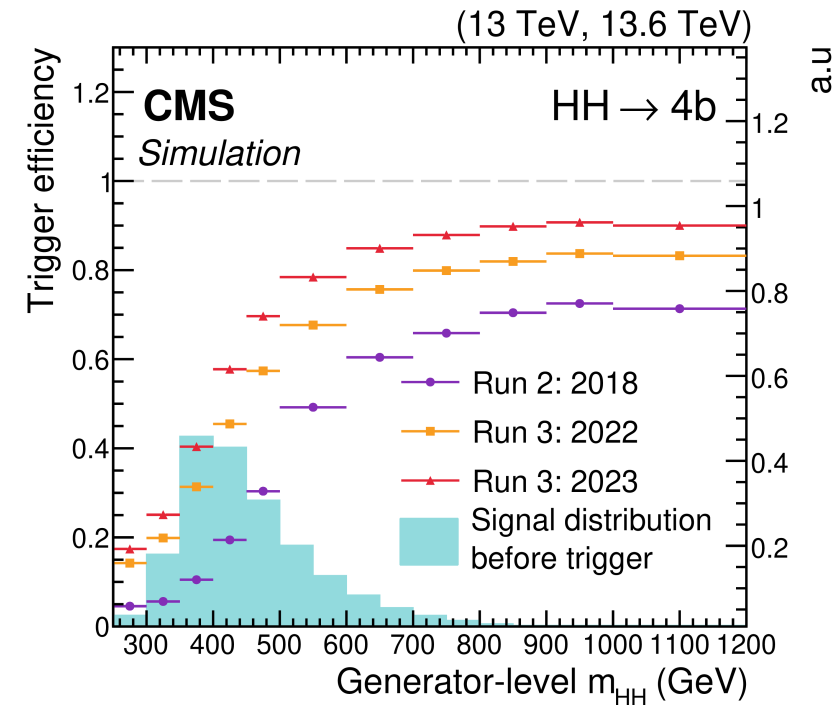
Event selection:

- ≥ 2 AK8 jets ordered in GloParT $T_{x_{bb}}$ score, with $T_{x_{bb}}(H_1) > 0.3$
- BDT multi-classifier:
Separates $ggHH \rightarrow 4b$ and $qqHH \rightarrow 4b$ from QCD-multijet and $t\bar{t}b\bar{b}$ backgrounds
Includes $T_{x_{bb}}(H_1)$

Search for $HH \rightarrow bbbb$: resolved topology

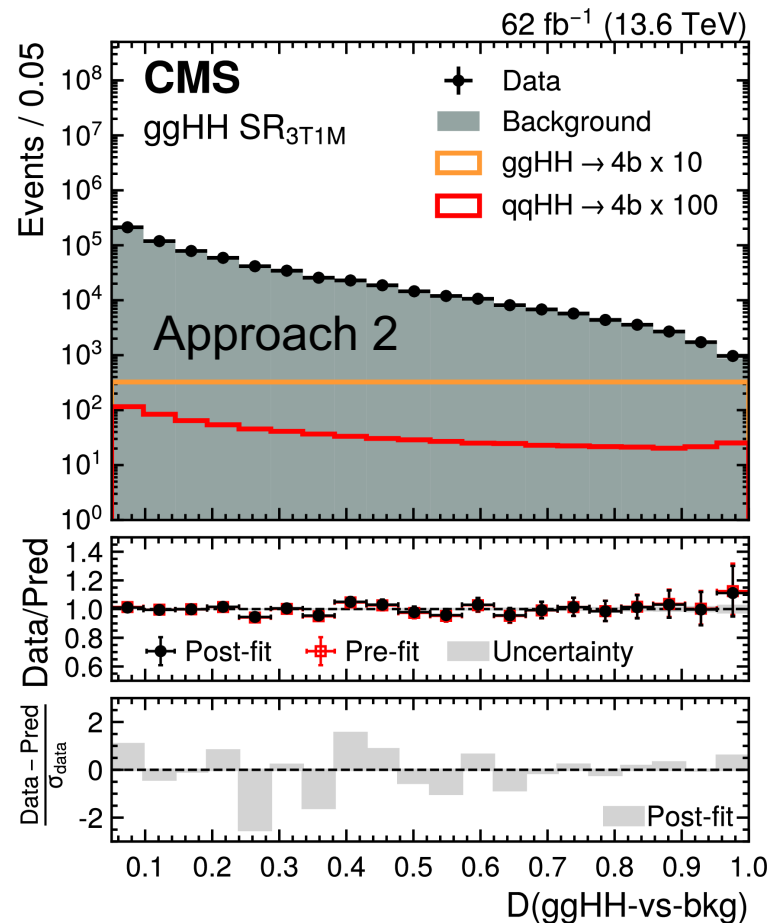
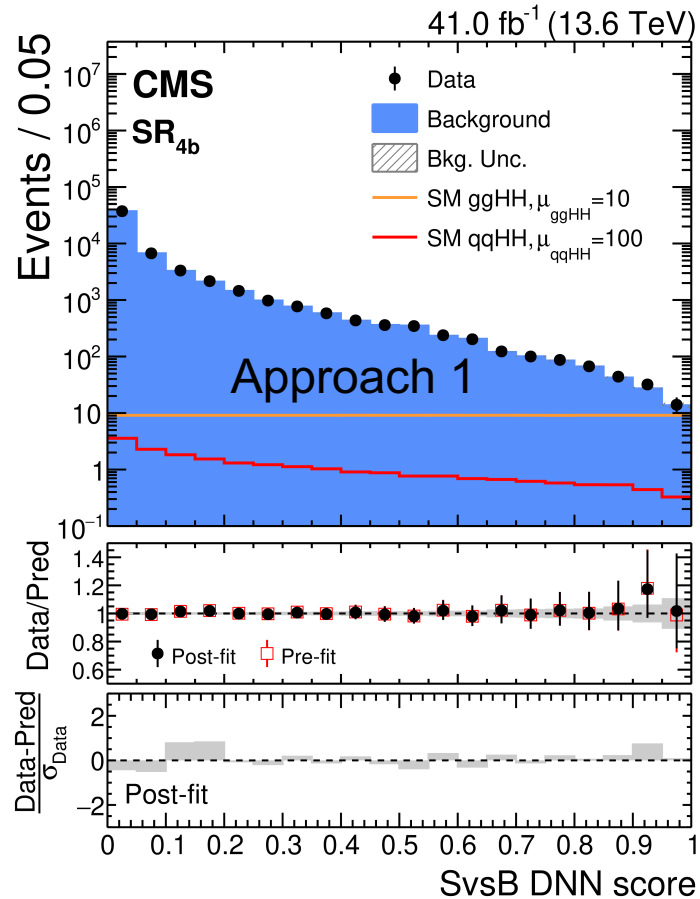
Run 3 improvements:

- new triggers, graph-based algorithm (ParticleNet) for b-tagging, bjet p_T regression



Search for $HH \rightarrow bbbb$: resolved topology

- background estimated from 2b CR, validated in 3b and 4b sideband region.
- Fit on ML-based discriminant to extract HH signal



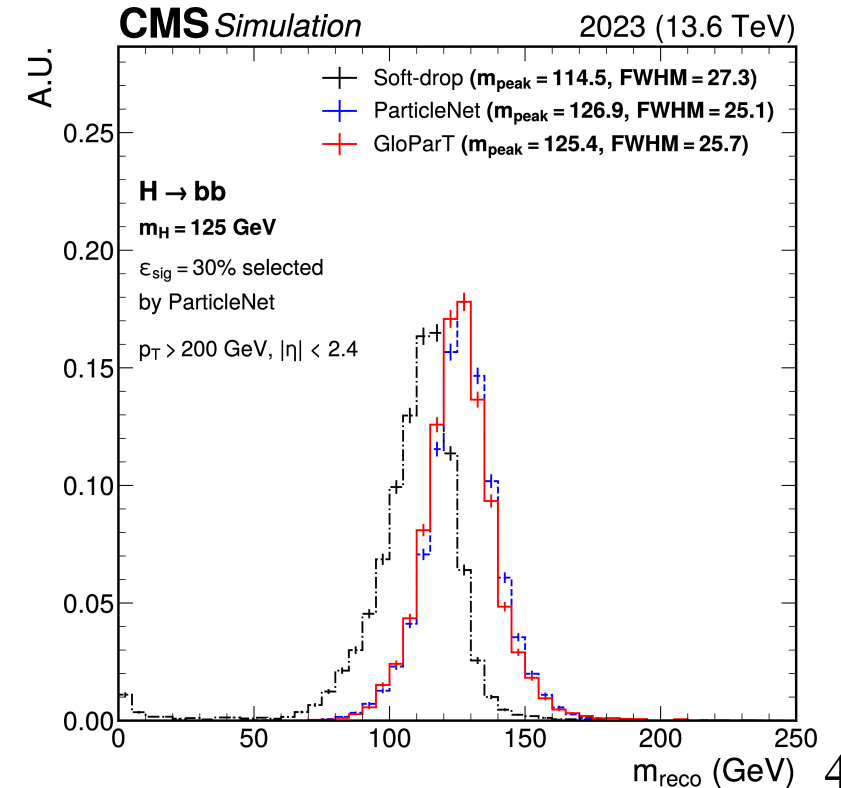
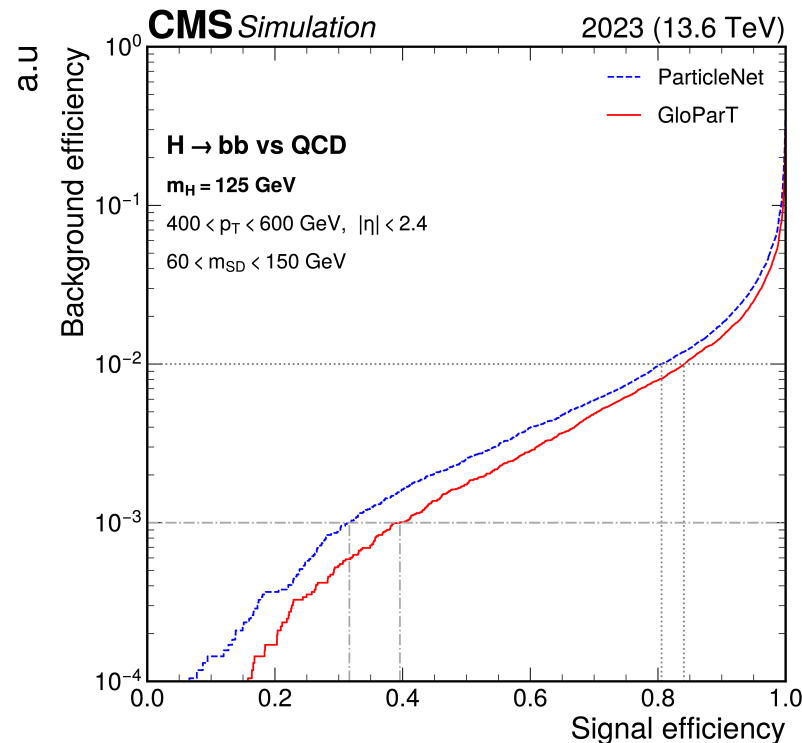
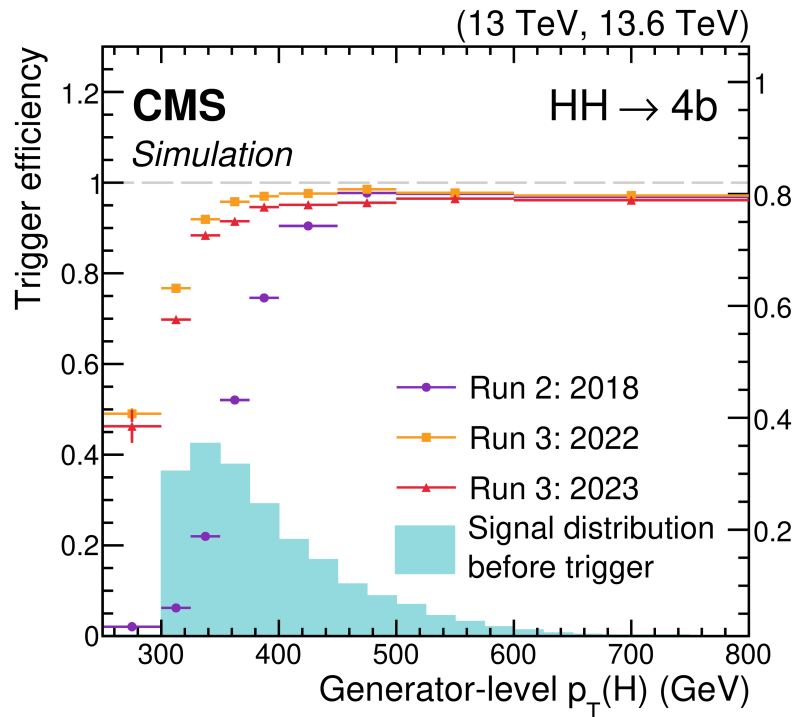
Obs(Exp) upper limits on μ_{HH} :

- Approach 1: 6.3(5.3) $\Rightarrow$ used in combination with Run 2.
- Approach 2: 5.0(6.1) $\Rightarrow$ Includes ZZ&ZH as standard candles
- Scaling to Run 2 luminosity (138 fb⁻¹) : $\times 2$ improvement!

Search for $HH \rightarrow bbbb$: merged topology

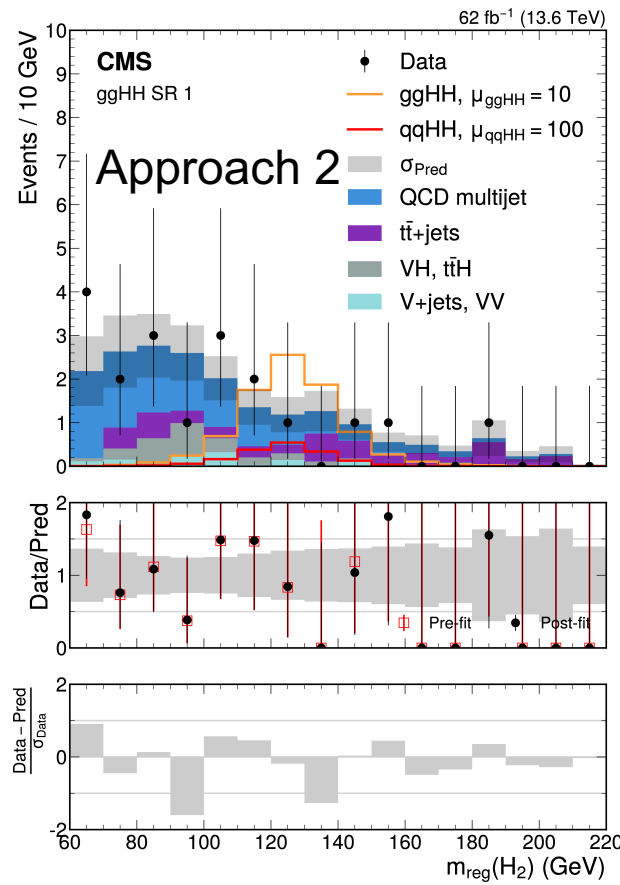
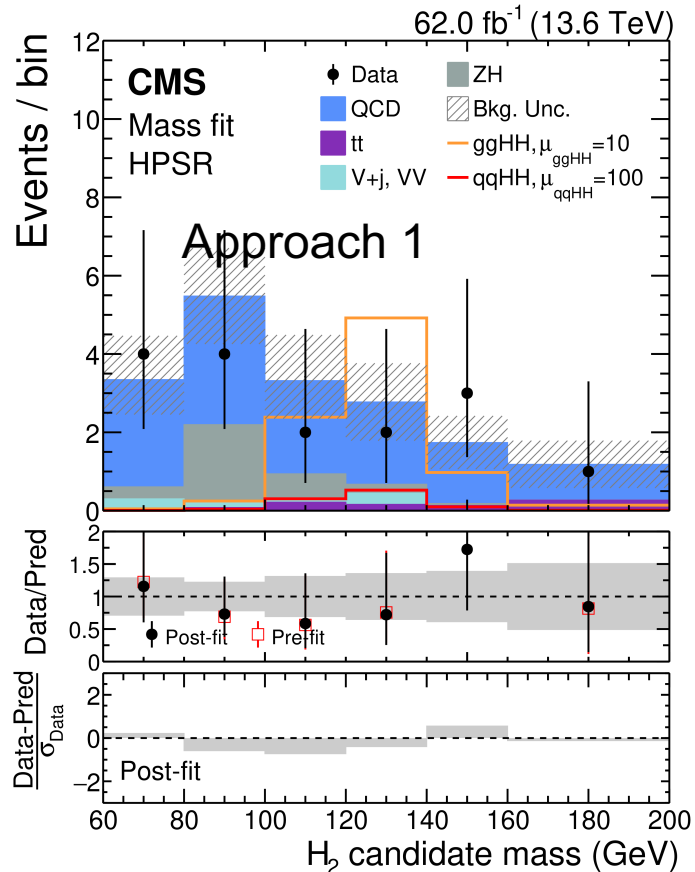
Run 3 improvements:

- new triggers, transformer-based algorithm for $H \rightarrow bb$ tagging, improved mass resolution with GloParT regression



Search for $HH \rightarrow bbbb$: merged topology

- QCD-multijet background derived from data, $t\bar{t}$ background from simulation with data-driven corrections
- Signal extraction: fit on the mass of the subleading-in- p_T Higgs

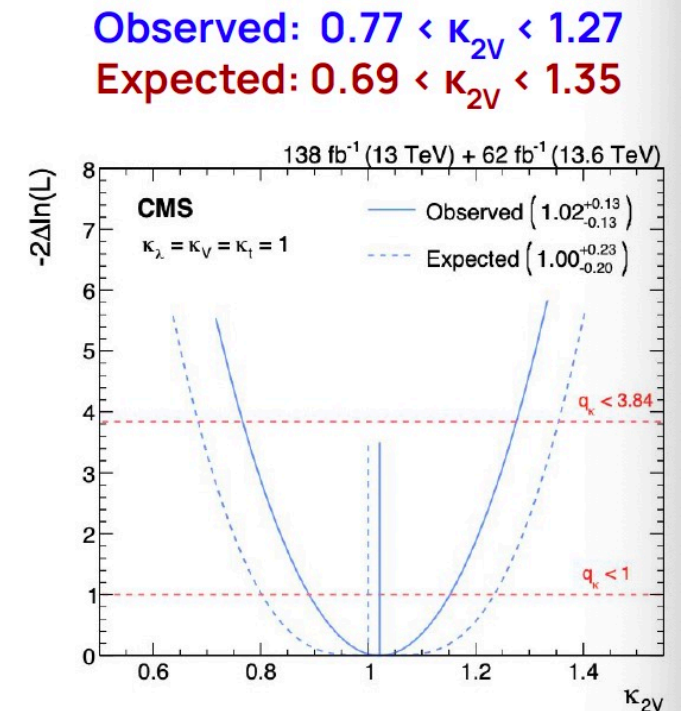
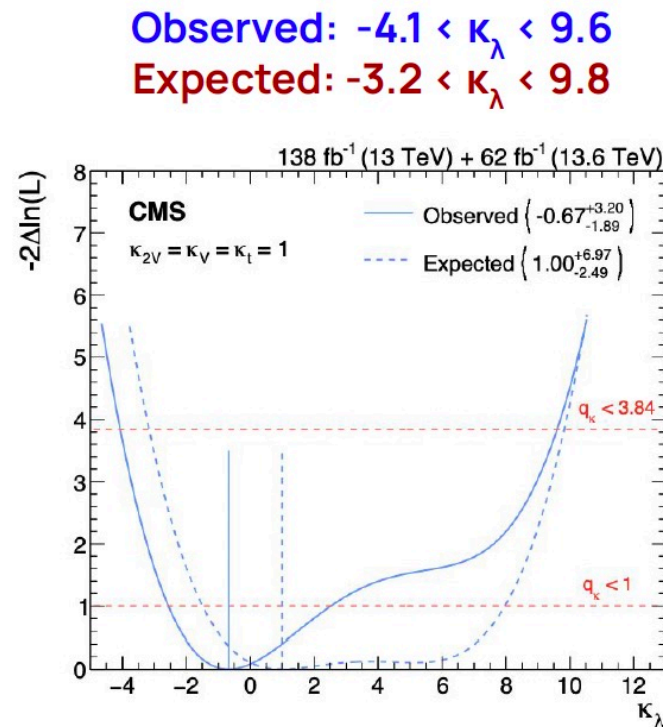
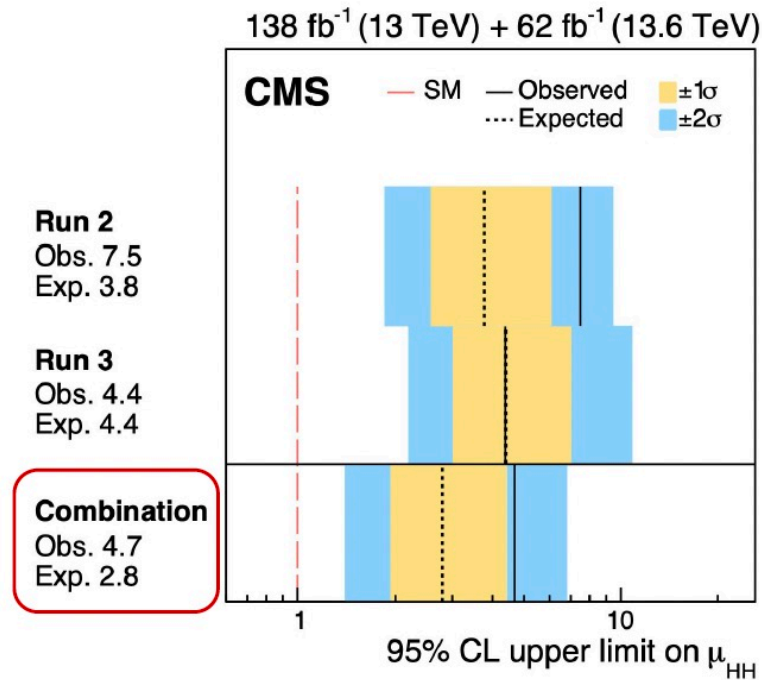


Obs(Exp) upper limits on μ_{HH} :

- Approach 1: 5.3(6.6)
⇒ used in combination with Run 2
- Approach 2: 11.1(8.1)
- Dominant systematic uncertainties related to the background estimation & uncertainty on the HH XS

Search for $HH \rightarrow bbbb$: combination

- $HH \rightarrow bbbb$ search targets **ggF and VBF** HH production using:
 - resolved and merged topologies with Run 3 data (2 approaches each)
 - reanalysis of Run 2 resolved analysis $\rightarrow$ **25% improvement**
 - **combination of the above with Run 2 merged analysis**



Most stringent constraints achieved in the $HH \rightarrow bbbb$ final state to date.

Most stringent constraints on κ_{2V} to date!

Conclusion and Outlook

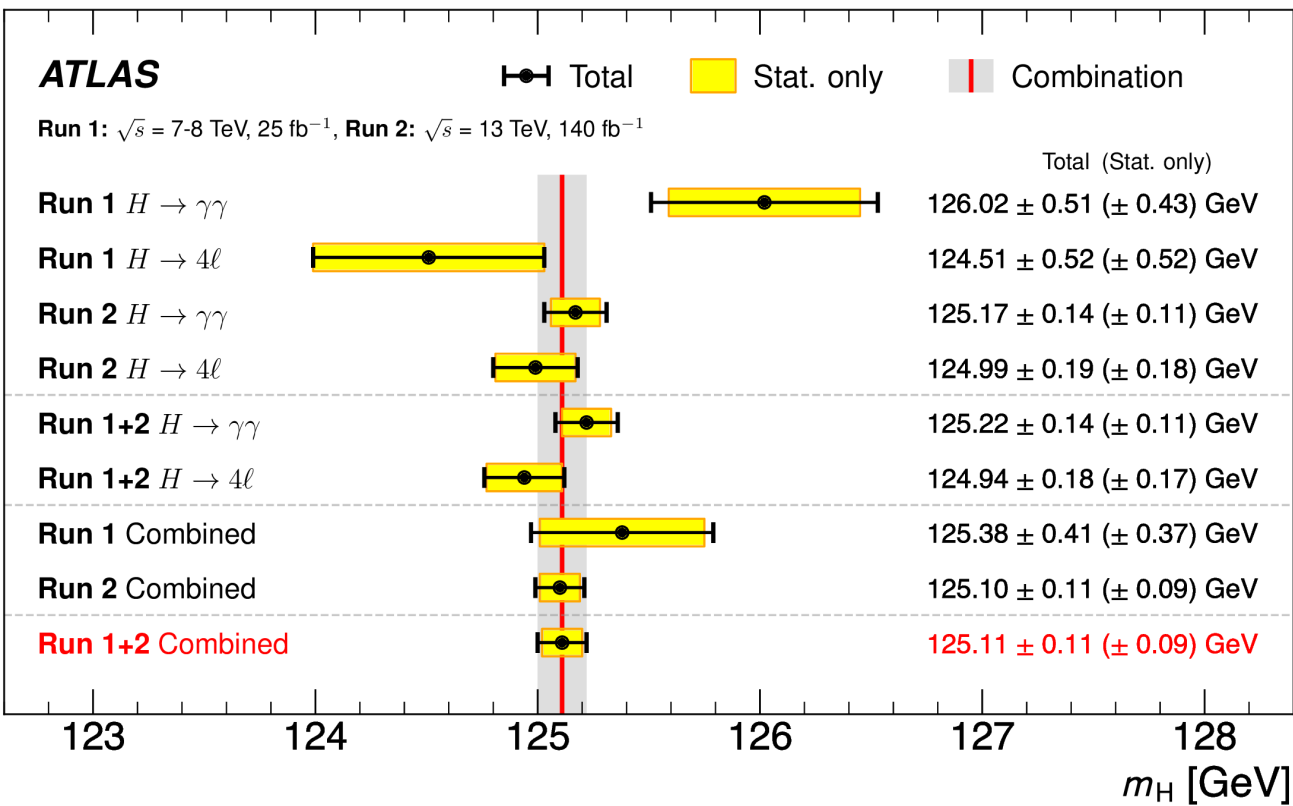
- We are at the dawn of precision Higgs physics
 - Signal strength: $\mu^{incl} = 1.01^{+0.06}_{-0.05}$ (precision of 5%)
 - Mass: (H→ZZ→4l) $125.08 \pm 0.12 \text{ GeV}$, (H→γγ) $125.07 \pm 0.13 \text{ GeV}$
 - Width: (H→ZZ→4l & 2l2ν) $\Gamma_H = 3.0^{+2.0}_{-1.5} \text{ MeV}$, (H→WW→eνμν) $\Gamma_H = 3.9^{+2.7}_{-2.2} \text{ MeV}$
 - CP violating effect probed in fermion section, pure CP odd coupling excluded by $> 3\sigma$
- Tremendous work on HH searches:
 - Several improvements in heavy-flavor tagging, trigger, analysis techniques using ML provide sensitivity boosts
 - Searches remain statistically limited
- Prospect at the end of HL-LHC
 - Observation of H→μμ and H→Zγ and determine their couplings with precision of 3% and 7% respectively
 - Observation of HH with significance $> 5\sigma$ at 2ab^{-1}

Stay Tuned



谢谢！

ATLAS实验Higgs质量测量结果： Run1+Run2



Source	Systematic uncertainty on m_H [MeV]
e/γ E_T -independent $Z \rightarrow ee$ calibration	44
e/γ E_T -dependent electron energy scale	28
$H \rightarrow \gamma\gamma$ interference bias	17
e/γ photon lateral shower shape	16
e/γ photon conversion reconstruction	15
e/γ energy resolution	11
$H \rightarrow \gamma\gamma$ background modelling	10
Muon momentum scale	8
All other systematic uncertainties	7

<u>衰变道</u>	ATLAS <u>obs (exp)</u>	<u>CMS</u> <u>obs (exp)</u>
<u>bbbb</u>	$5.4 (8.1) \times \sigma_{\text{SM}} [13\text{TeV}, 126/\text{fb}]$	$3.9 (7.8) \times \sigma_{\text{SM}} [13\text{TeV}, 138/\text{fb}]$
<u>bb$\gamma\gamma$</u>	$4.2 (5.7) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$	$7.7 (5.2) \times \sigma_{\text{SM}} [13\text{TeV}, 137/\text{fb}]$
<u>bb$\tau\tau$</u>	$4.6 (3.9) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$	$3.3 (5.2) \times \sigma_{\text{SM}} [13\text{TeV}, 138/\text{fb}]$
<u>WWWW, WW$\tau\tau$, $\tau\tau\tau\tau$</u>	$160 (120) \times \sigma_{\text{SM}} [13\text{TeV}, 36/\text{fb}]$	$21.3 (19.4) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$
<u>bbWW$\rightarrow$bblvlv</u>	$40 (29) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$	$79 (89) \times \sigma_{\text{SM}} [13\text{TeV}, 36/\text{fb}]$
<u>bbWW$\rightarrow$bblvqq</u>	$300 (300) \times \sigma_{\text{SM}} [13\text{TeV}, 36/\text{fb}]$	–
<u>bbZZ$\rightarrow$bblll'</u>	–	$32.4 (39.6) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$
<u>bbbb, bb$\tau\tau$, bb$\gamma\gamma$. etc</u>	$2.4 (2.9) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$	$3.4 (2.5) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$

<u>衰变道</u>	ATLAS <u>obs (exp)</u>	ATLAS <u>NEW obs (exp)</u>
<u>bbbb</u>	$5.4(8.1) \times \sigma_{\text{SM}} [13\text{TeV}, 126/\text{fb}]$	$5.3(8.1) \times \sigma_{\text{SM}} [13\text{TeV}, 138/\text{fb}]$
<u>bbγγ</u>	$4.2(5.7) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$	$4.0(5.0) \times \sigma_{\text{SM}} [13\text{TeV}, 137/\text{fb}]$
<u>bbττ</u>	$4.7(3.9) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$	$5.9(3.3) \times \sigma_{\text{SM}} [13\text{TeV}, 138/\text{fb}]$
<u>WWWW, WWττ, ττττ...</u>	$160(\underline{120}) \times \sigma_{\text{SM}} [13\text{TeV}, 36/\text{fb}]$	$17(\underline{11}) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$
<u>bbWW/ZZ/ττ → bbl̄l̄νν</u>	$40(\underline{29}) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$	$10(\underline{14}) \times \sigma_{\text{SM}} [13\text{TeV}, 36/\text{fb}]$
<u>bbWW → bbl̄l̄νq̄q̄</u>	$300(\underline{300}) \times \sigma_{\text{SM}} [13\text{TeV}, 36/\text{fb}]$	–
<u>bbZZ → bbl̄l̄l̄l̄</u>	–	$39(35) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$
<u>bbbb, bbττ, bbγγ. etc</u>	<u>bbbb, bbττ, bbγγ</u> $2.4(2.9) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$	<u>bbbb, bbττ, bbγγ, bbl̄l̄νν, multilepton</u> $2.9(2.4) \times \sigma_{\text{SM}} [13\text{TeV}, 139/\text{fb}]$

ATLAS

$\sqrt{s} = 13 \text{ TeV}, 126\text{--}140 \text{ fb}^{-1}$

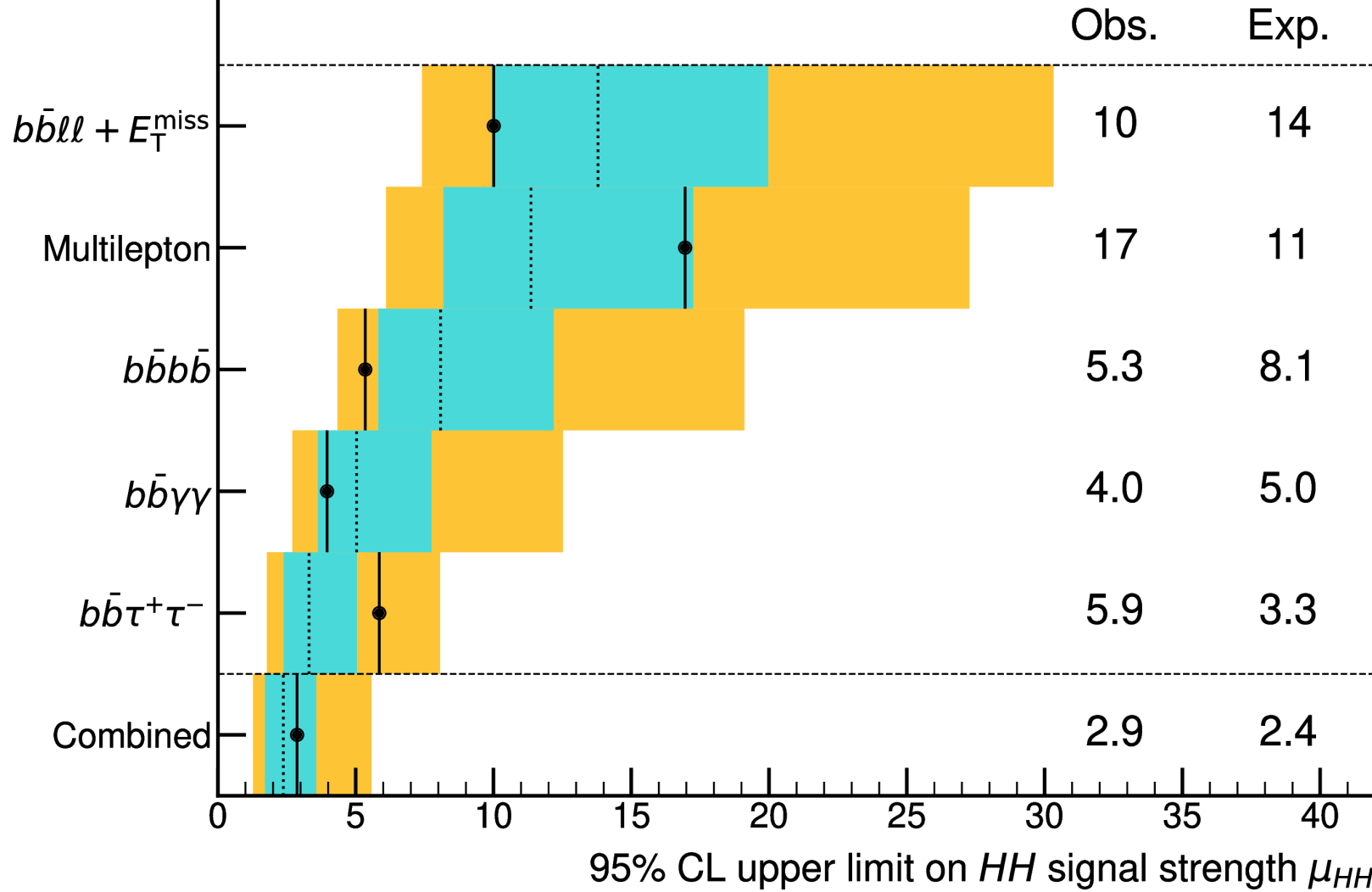
$\sigma_{\text{ggF} + \text{VBF}}^{\text{SM}}(HH) = 32.8 \text{ fb}$

—●— Observed limit (95% CL)

⋯ Expected limit (95% CL)
($\mu_{HH} = 0$ hypothesis)

Expected limit $\pm 1\sigma$

Expected limit $\pm 2\sigma$



CMS Run 3 HH analyses

channel	Result
bbbb	$4.4 (4.4) \times \sigma_{\text{SM}} \quad 13.6\text{TeV} \quad 62 \text{ fb}^{-1}$
bbbb	$4.7(2.8) \times \sigma_{\text{SM}} \quad 13.6\text{TeV} \quad 62 \text{ fb}^{-1} + 13\text{TeV} \quad 138 \text{ fb}^{-1}$
bb $\gamma\gamma$	$11.0 (7.3) \times \sigma_{\text{SM}} \quad 13.6\text{TeV} \quad 62 \text{ fb}^{-1}$
bbWW (fully leptonic)	$12 (18.5) \times \sigma_{\text{SM}} \quad 13.6\text{TeV} \quad 62 \text{ fb}^{-1}$