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Single Higgs recent highlights and summary

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Roadmap of the Higgs boson discoveries (2012 - 2023)

LHC HL-LHC

Run 1 | Run 2 | Run 3 | Run 4 - 5...

LS1 | EYETS | LS2 | EYETS | LS3

7 TeV | 8 TeV | 13 TeV | 13.6 TeV | 13.6 - 14 TeV energy

splice consolidation
button collimators
R2E project

cryolimit interaction regions

Diodes Consolidation
LIU Installation
Civil Eng. P1-P5

pilot beam

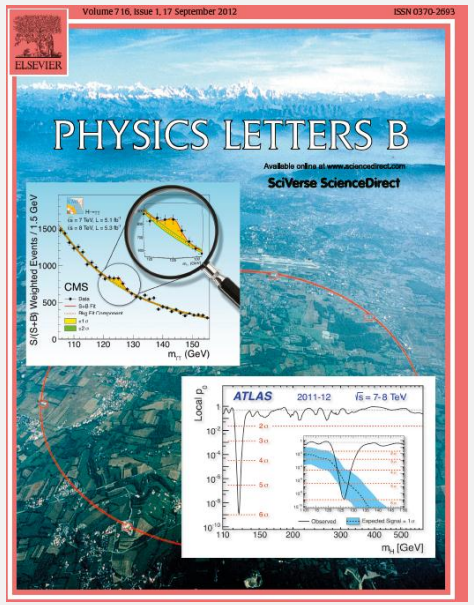
inner triplet radiation limit

HL-LHC installation

High Luminosity LHC

2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2040

SM-like Higgs discovery (ggF H→$\gamma\gamma$ + ZZ + WW)



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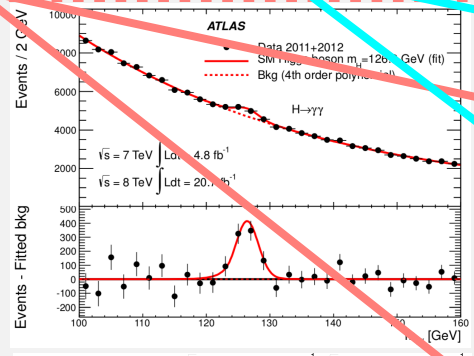
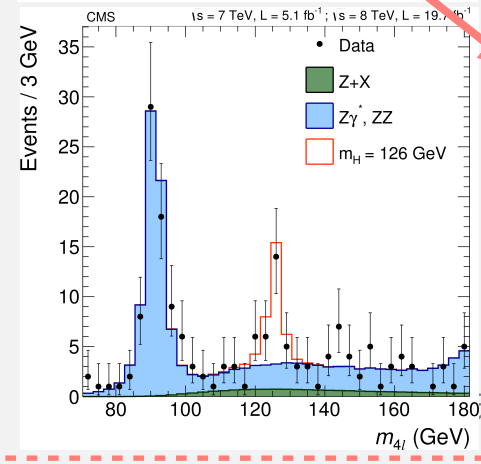
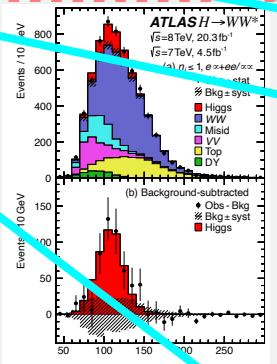
H→$\gamma\gamma$, ZZ→4l observation (0+)

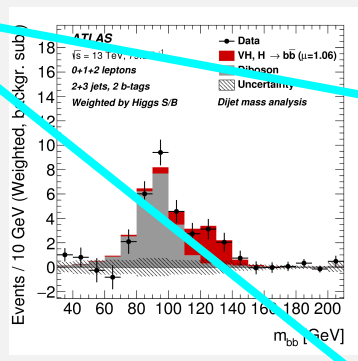




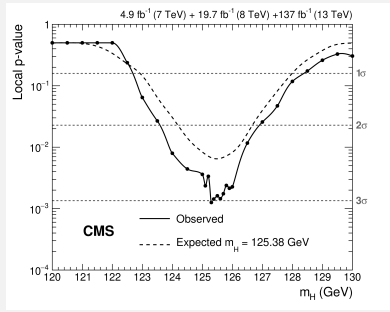
H→WW observation



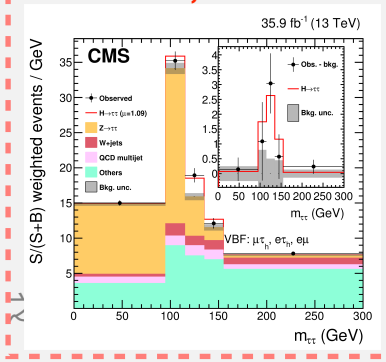
VH, H→bb obs.



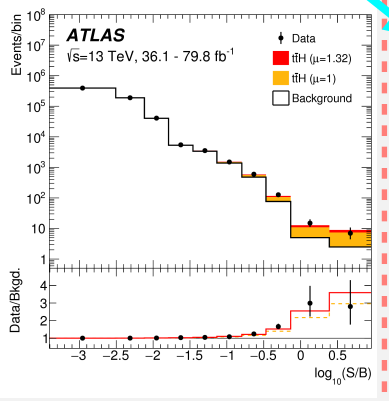
H→$\mu\mu$ evidence



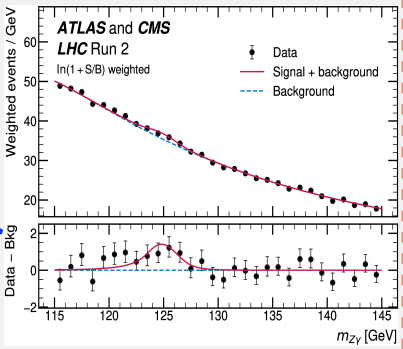
VBF H obs., H→$\tau\tau$ obs.



ttH observation



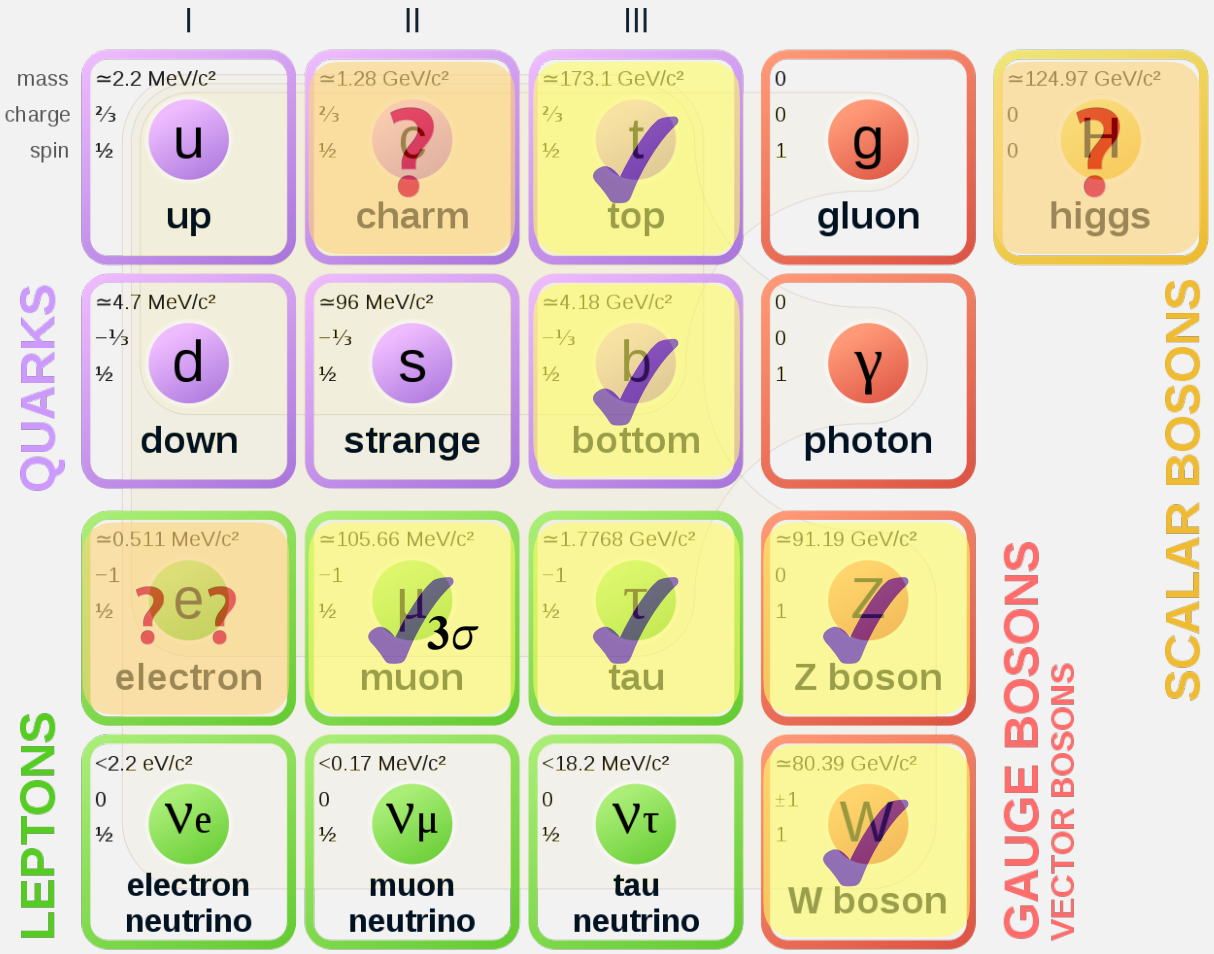
H→Zγ evidence



Eras of precision measurements of the Higgs boson

- **Discoveries for dominant Higgs production and decay channels**
  - ✓ productions: *ggF, VBF, WH, ZH, ttH*
  - ✓ decays: *H→bb, WW, ττ, ZZ, γγ*
  - ✓ evidence for *H→Zγ, H→μμ*

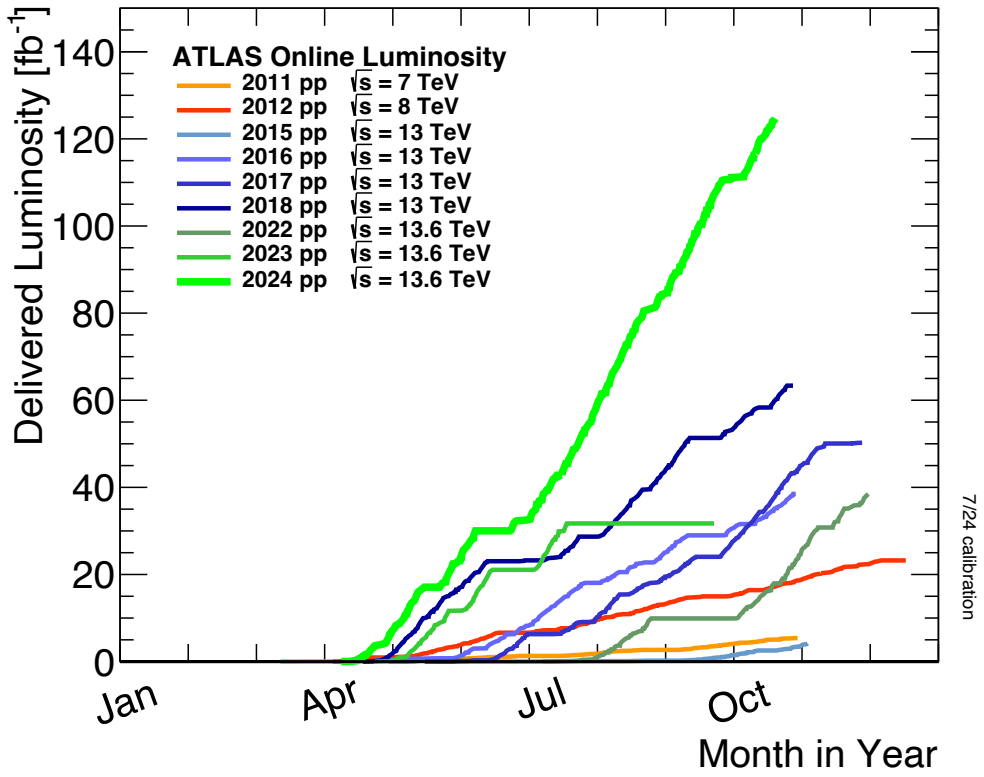
- **Measurement precision of couplings**
  - *to W/Z vector bosons: ~ 5%*
  - *to the 3rd gen. fermions (t, b, τ): 7% ~ 12%*

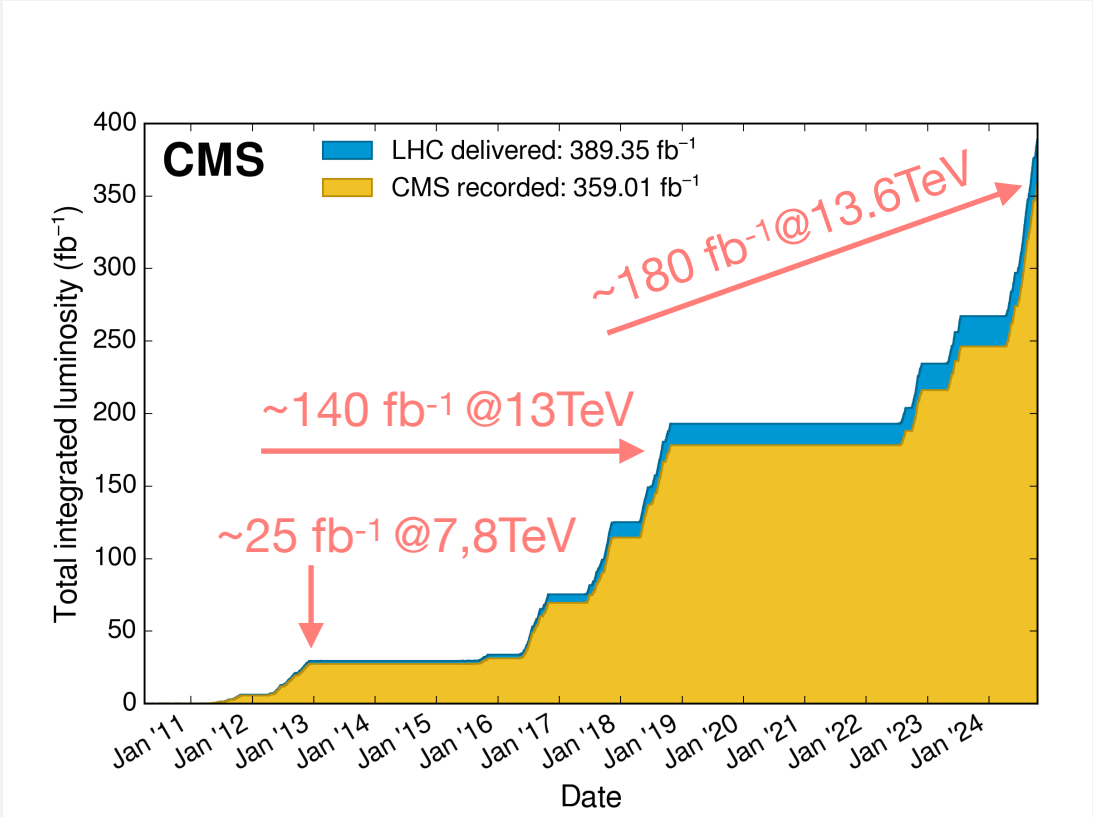


Outline of this talk

- **Higgs cross section measurement at 13.6 TeV**
- **Higgs boson mass measurement updates**
- **Constraints on the Higgs boson width**
  - *from on-shell Higgs mass measurement*
  - *from on-shell Higgs production plus 4-tops process*
- **Cross section measurement from VH, H→bb channel**
- **Cross section measurement from ttH/tH, H→bb channel**
- **Updates on ttH, H→multi-leptons channel**
- **Differential cross section measurement in H→ττ channel**
- **Direct constraints on Higgs-charm Yukawa coupling**
  - *searching for VH, H→cc process*
  - *searching for cH, H→γγ process*
- **Constraints on anomalous Higgs couplings in H→WW channel**

ATLAS and CMS Run 2 and Run 3 datasets



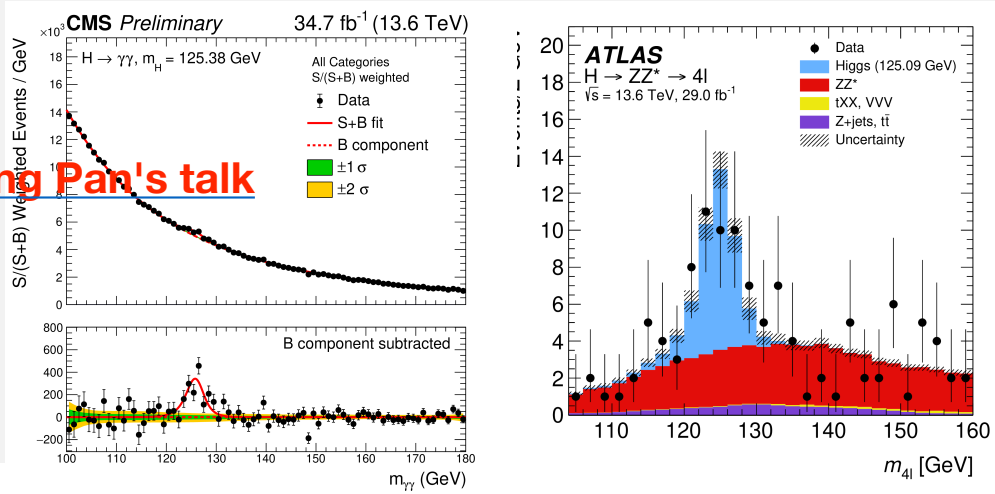


- **Both experiments have collected**
  - ~ 140 fb^{-1} luminosity at 13 TeV in full Run 2
  - already recorded ~ 180 fb^{-1} luminosity at 13.6 TeV til now in Run 3
- **Thanks to the CERN accelerator and technical teams for excellent LHC performance!**

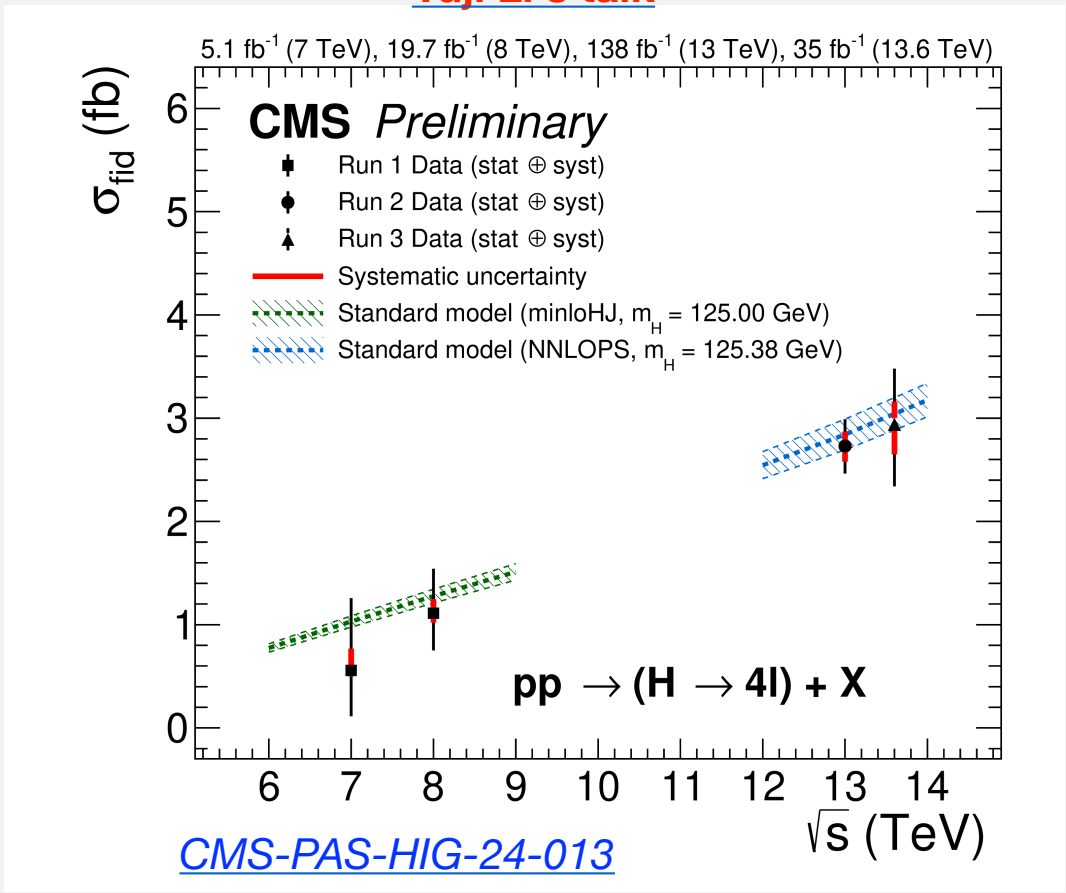
Rediscovery the Higgs boson at 13.6 TeV

- **The Higgs cross sections measurement at 13.6 TeV ➔ in good agreement with the SM.**

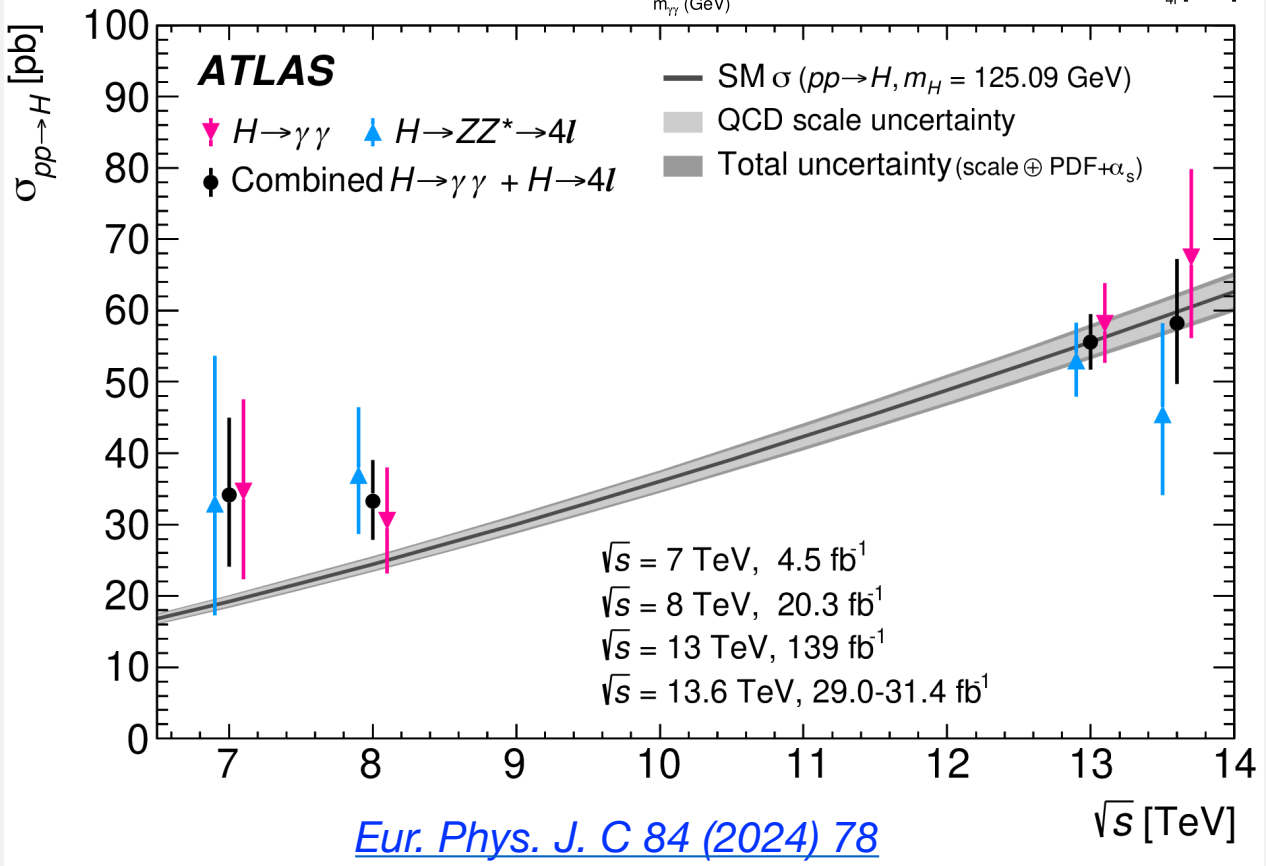
Chengyang Pan's talk



Yuji Li's talk



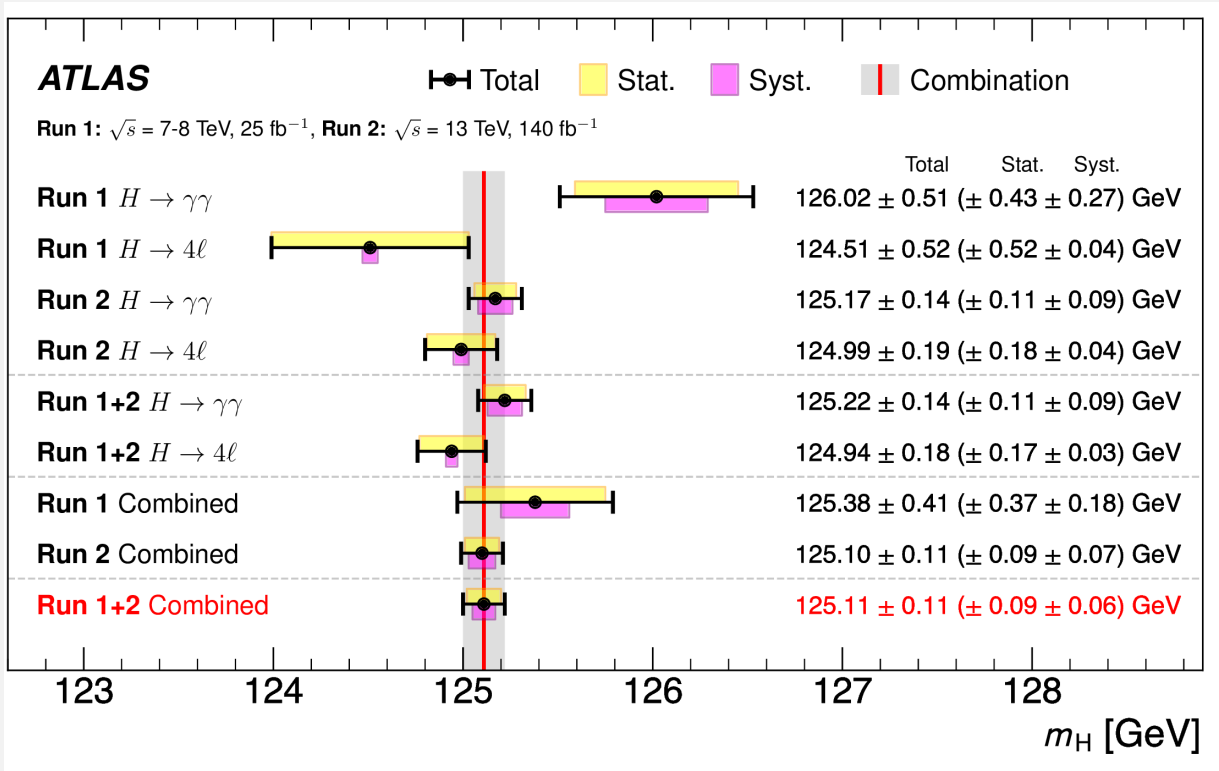
CMS-PAS-HIG-24-013



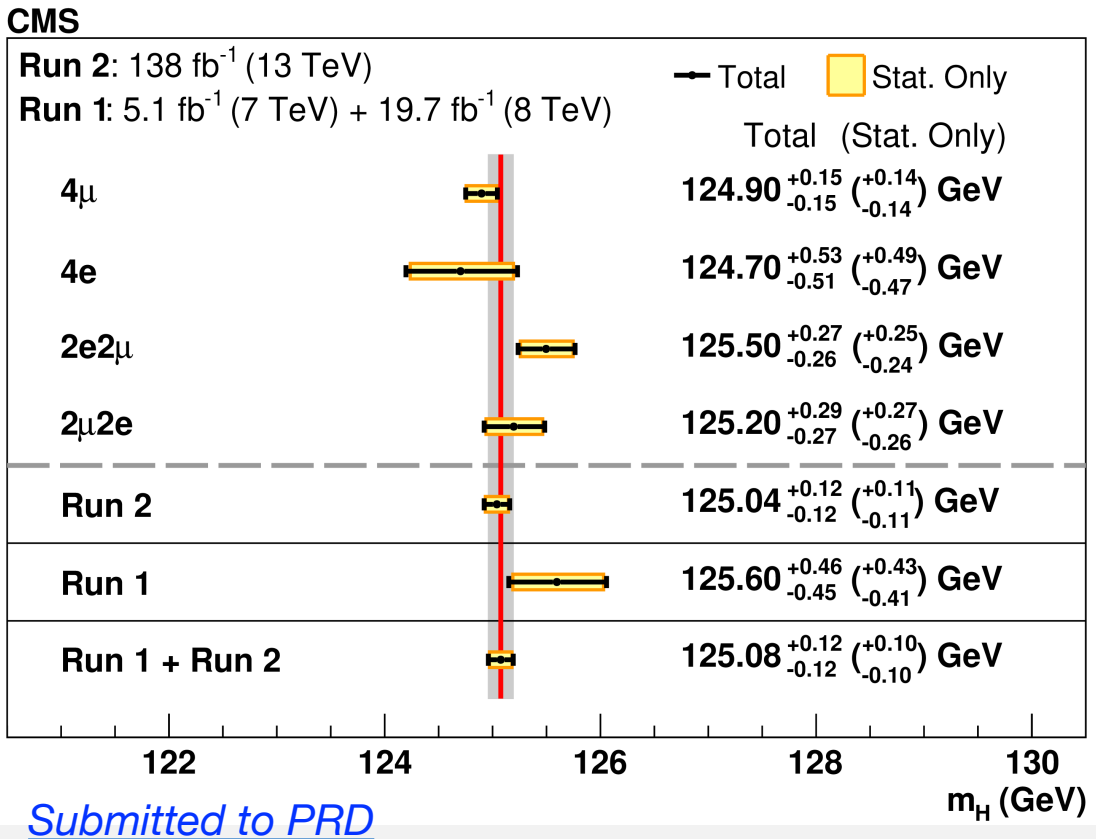
Eur. Phys. J. C 84 (2024) 78

The Higgs boson mass measurement at < 0.1% precision

- **ATLAS Run 2+Run 1 combination:** $125.11 \pm 0.09(stat.) \pm 0.06(syst.)\ GeV$.
- **CMS $H \to ZZ \to 4l$ has most precise single measurement:** $125.04 \pm 0.12\ GeV$.



[Phys. Rev. Lett. 131 (2023) 251802]

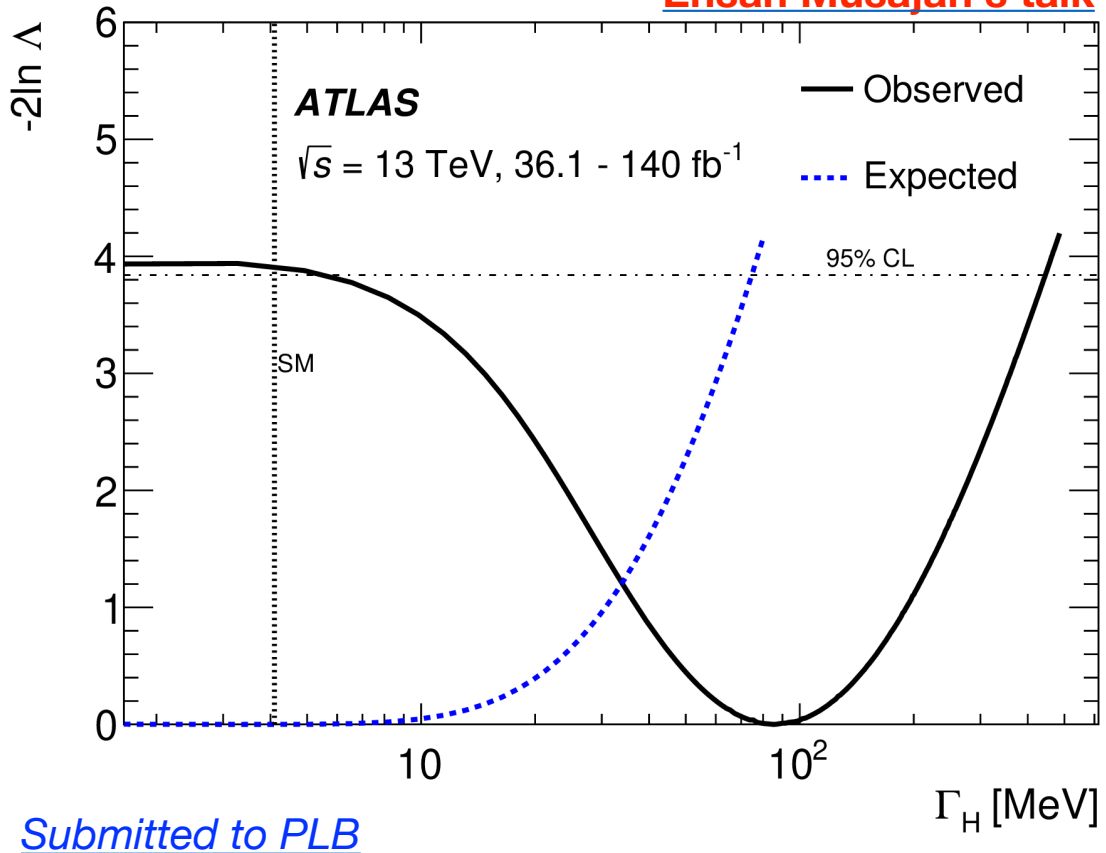


[Submitted to PRD]

Updates on the Higgs boson width constraints

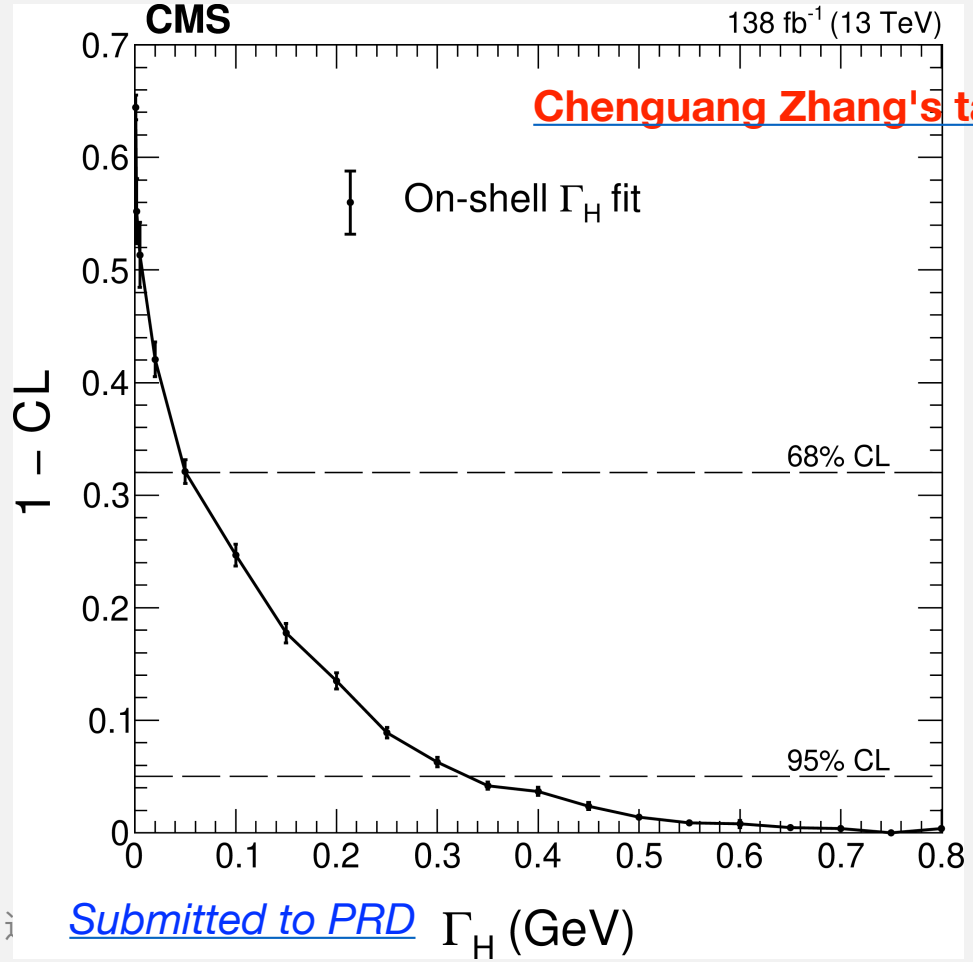
- **CMS, ATLAS observed** $\Gamma_H = 3.2^{+2.0}_{-1.5}\ MeV,\ 4.5^{+3.3}_{-2.5}\ MeV$**, in agreement with SM** $4.1\ MeV$**.**
- **ATLAS on-shell Higgs production & 4-top obs.(exp.) set limit at 95% CL:** $450\ MeV\ (75\ MeV)$**.**
- **CMS on-shell Higgs mass measurement in** $H \to ZZ \to 4l$ **set limit at 95% CL:** $330\ MeV$**.**

Ehsan Musajan's talk



Submitted to PLB

Chenguang Zhang's talk

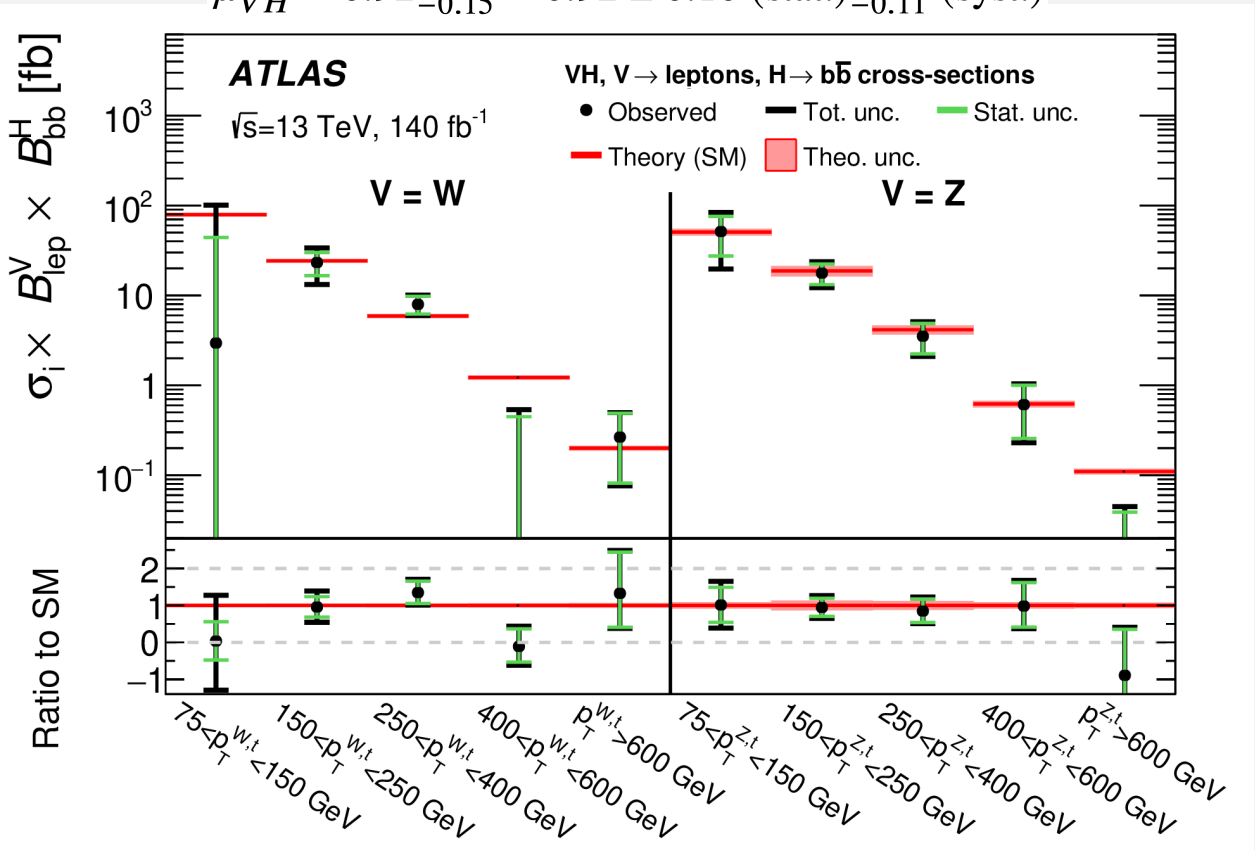


Submitted to PRD

VH, H→bb Simplified Template Cross Section measurement

- **The measurement of cross section times branching ratio in vector boson p_T bins.**
- **Measurements are in good agreement with the predictions within uncertainty.**

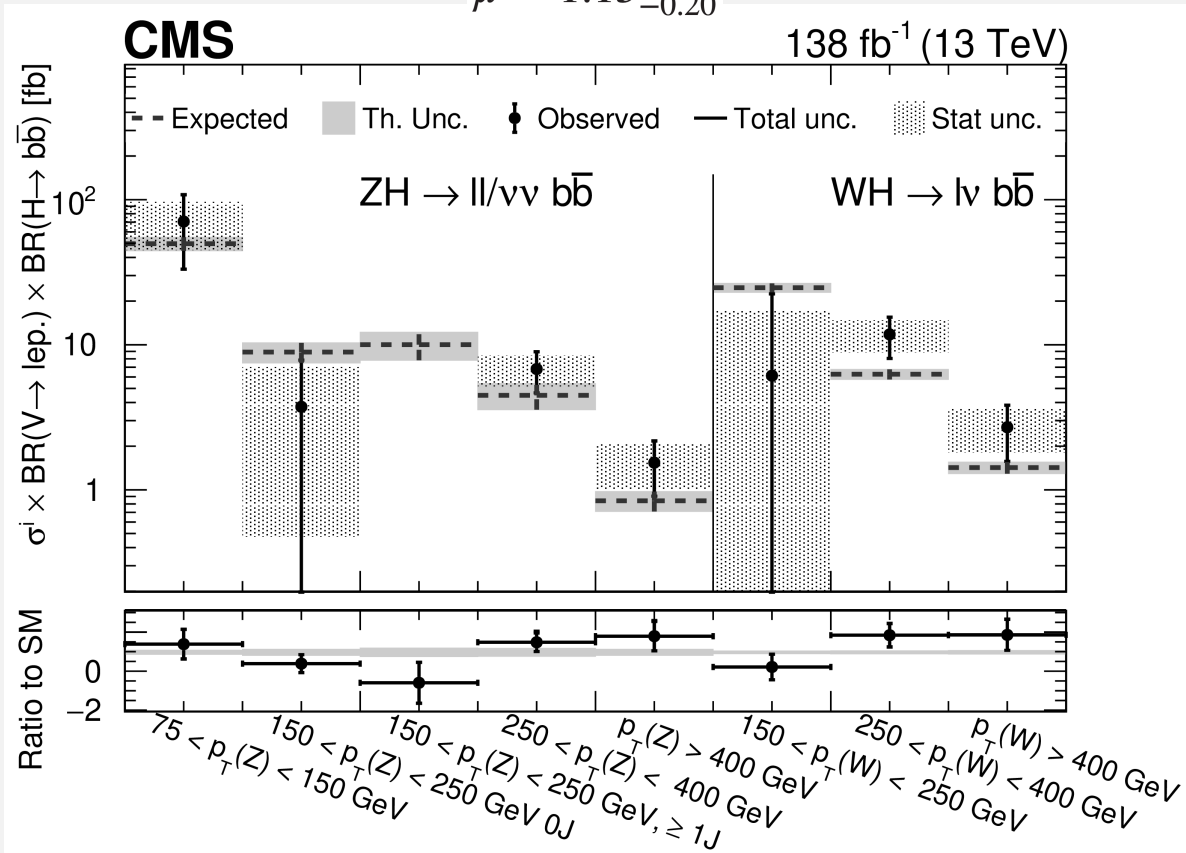
$$\mu_{VH}^{bb} = 0.92^{+0.16}_{-0.15} = 0.92 \pm 0.10\,(\text{stat.})^{+0.13}_{-0.11}\,(\text{syst.})$$



[Submitted to P.R.D](#)

[Yuhao Wang's talk](#)

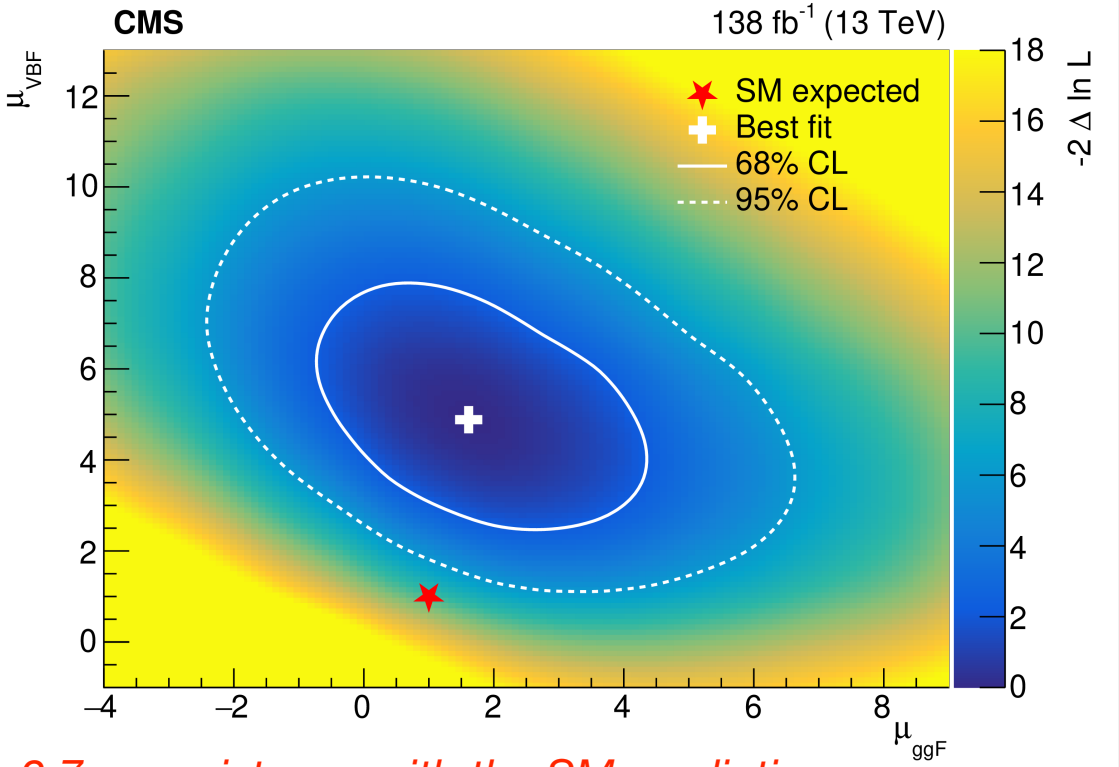
$$\mu = 1.15^{+0.22}_{-0.20}$$



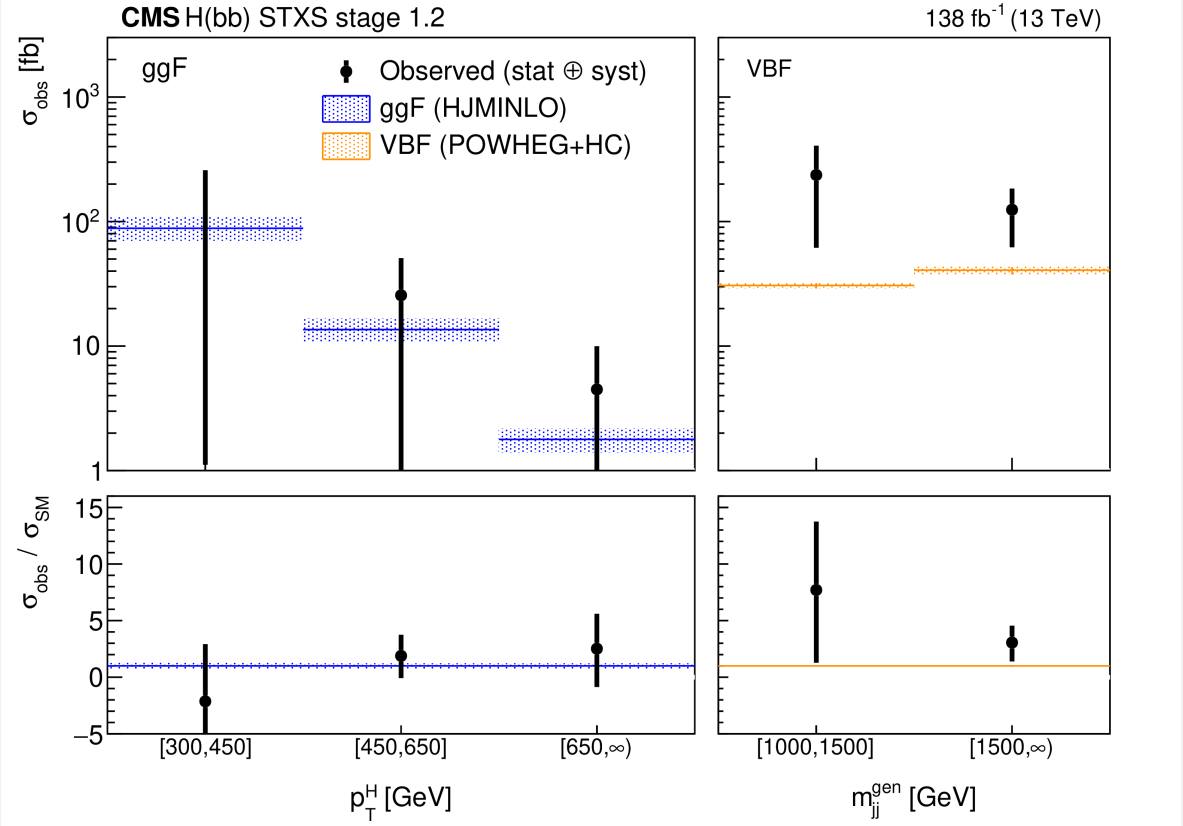
[Phys. Rev. D 109 (2024) 092011](#)

ggF and VBF processes, H→bb for boosted Higgs production

- Large-radius jets signature, employing jet substructure and heavy-flavor tagger.
- The observed signal strength for VBF and ggF, H→bb: $4.9^{+4.9}_{-1.6}$ and $1.6^{+1.7}_{-1.5}$.



2.7σ consistency with the SM prediction

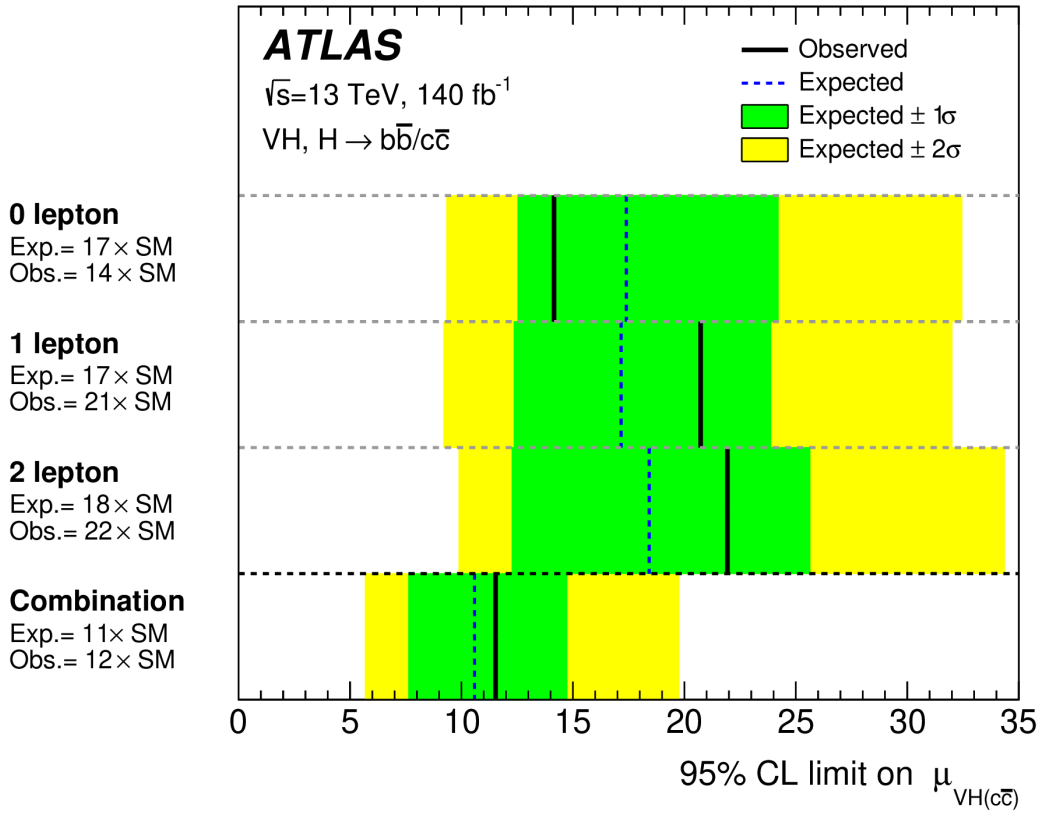


[Submitted to JHEP]

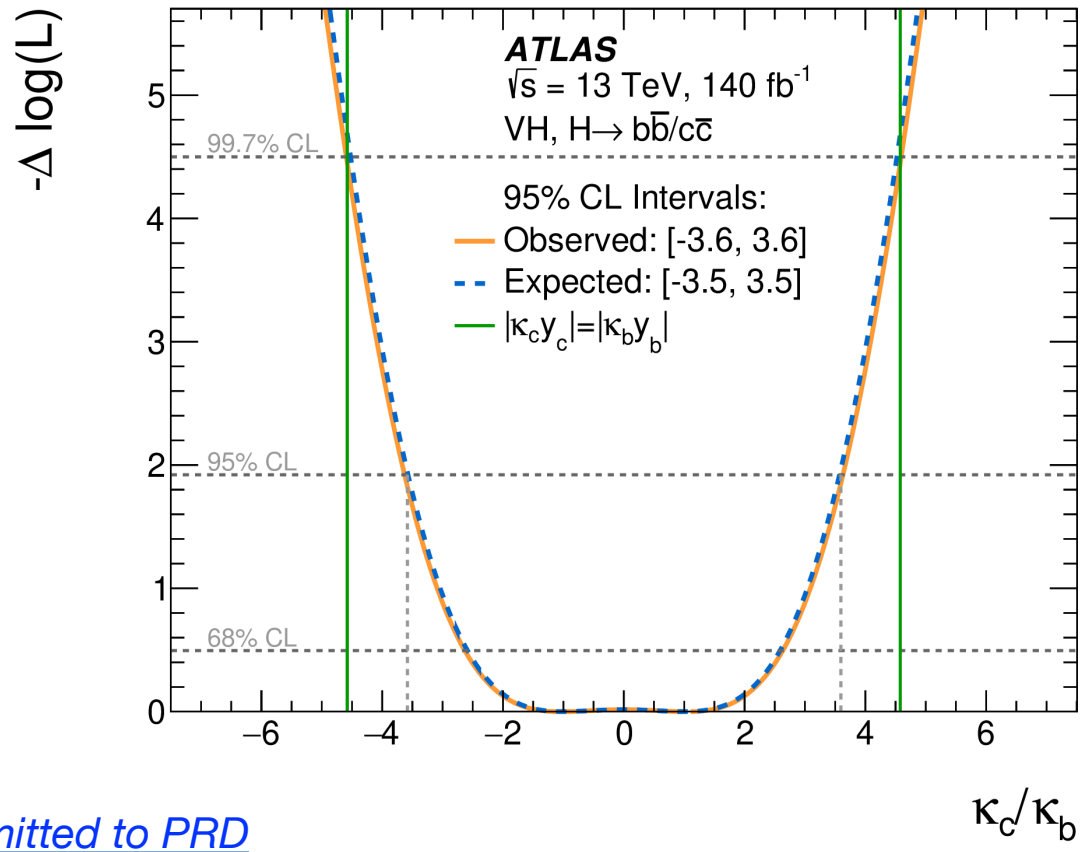
VH, H→cc direct constraints on the charm Yukawa coupling

- **95% CL upper limit on signal strength 11.5 and on coupling modifier $|\kappa_c| < 4.2$.**
- **Combination of H→bb and H→cc, setting 95% CL upper limit on: $|\kappa_c/\kappa_b| < 3.6$. ➔ less than b- and c-quark mass ratio 4.578, confirming Higgs coupling to charm is weaker than coupling to bottom.**

Stat. and sys. effect at a similar level !



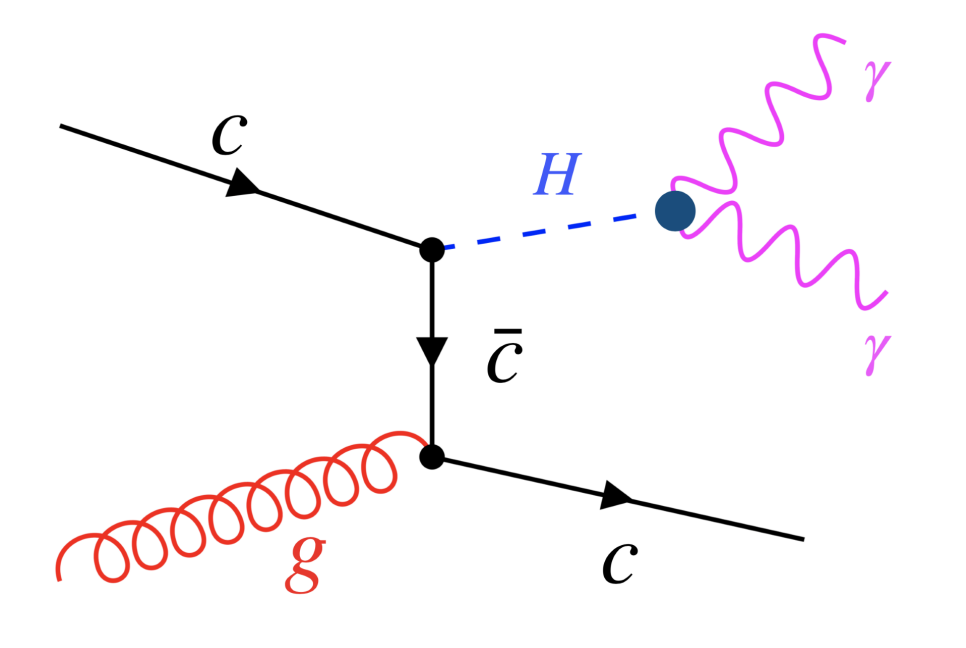
Yuhao Wang's talk

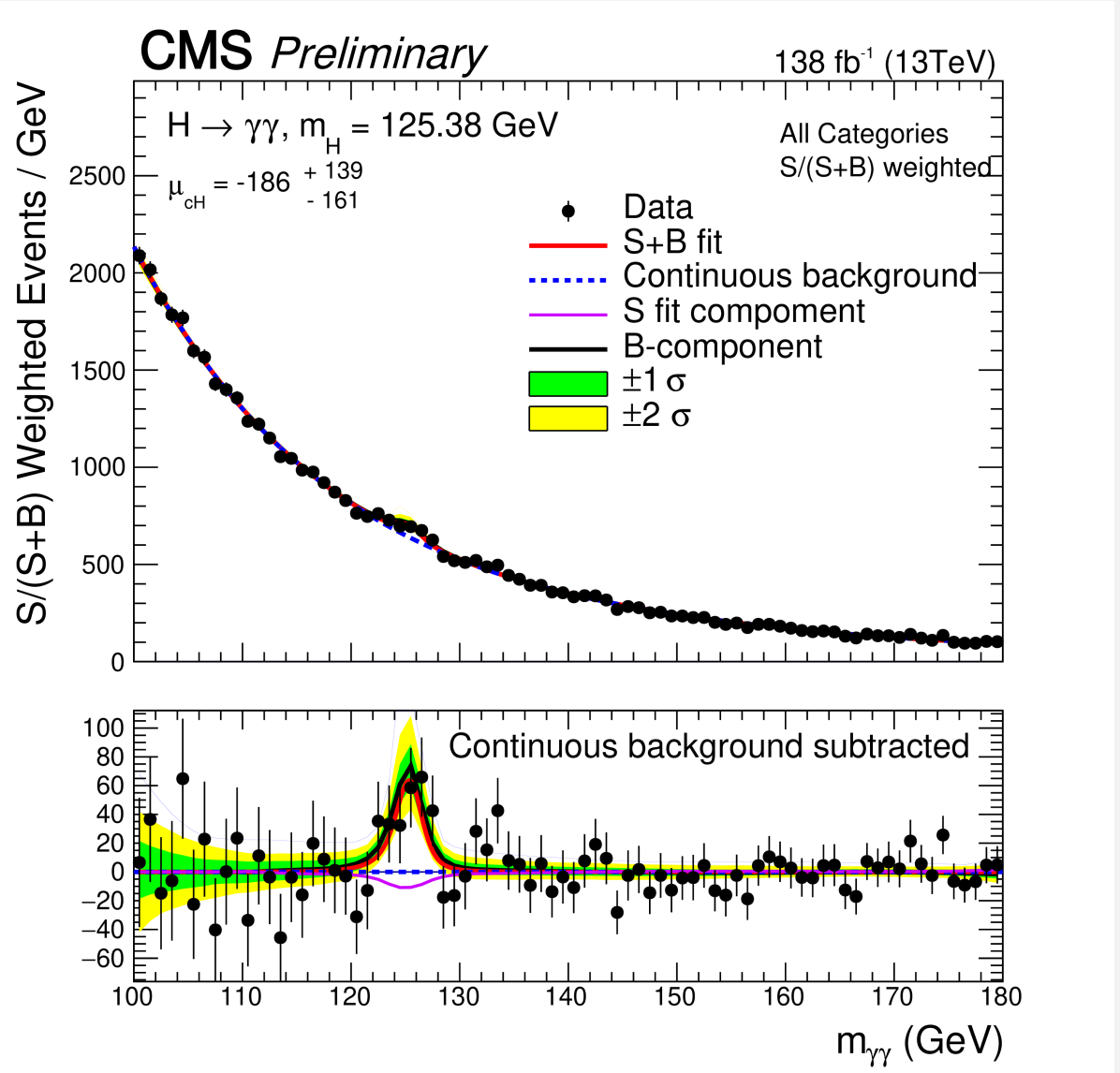


Submitted to PRD

Direct constraints on charm Yukawa coupling from cH, H→γγ

- **Searching for signature of H→γγ plus one hadronic jet.**
- **The observed (expected) limit at 95% CL on cH signal strength: 243 (355), on coupling strength: $|\kappa_c| < 38.1 (|\kappa_c| < 72.5)$.**

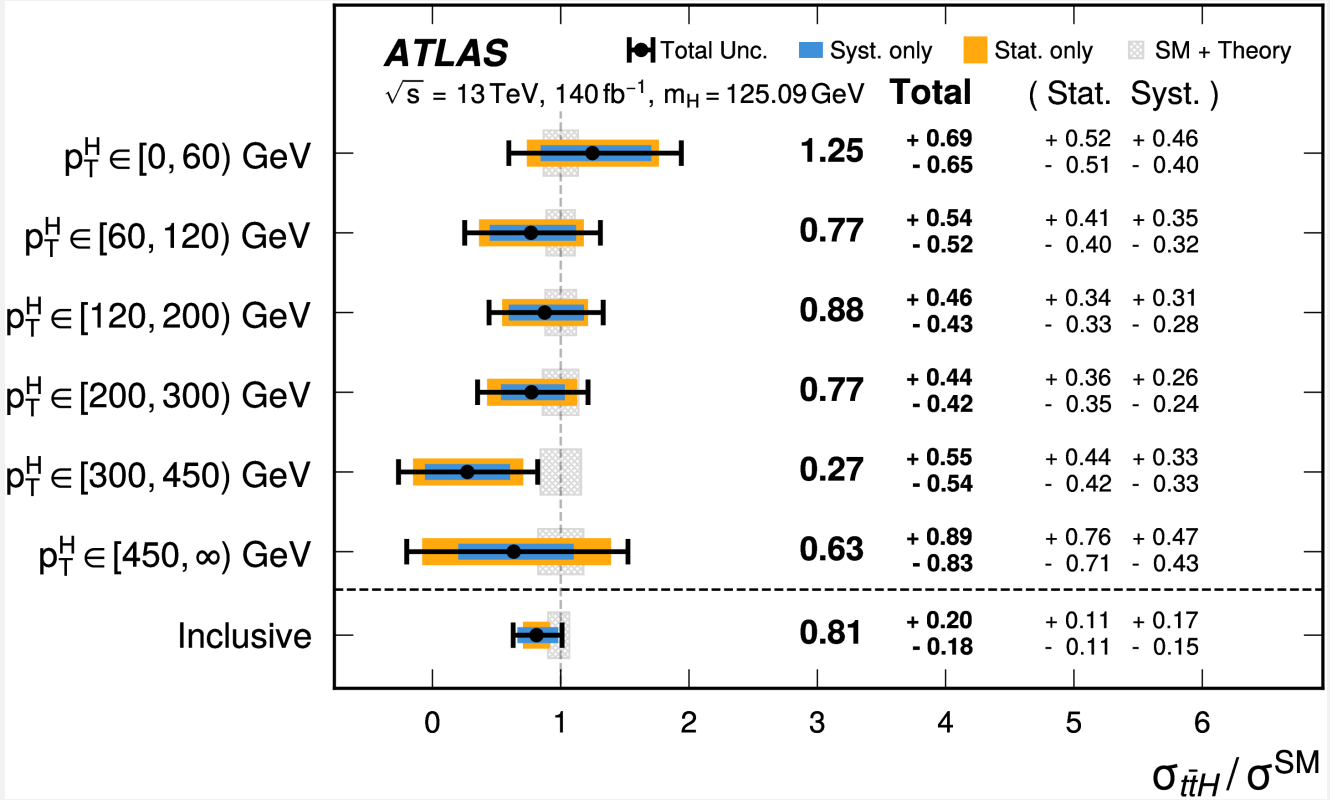


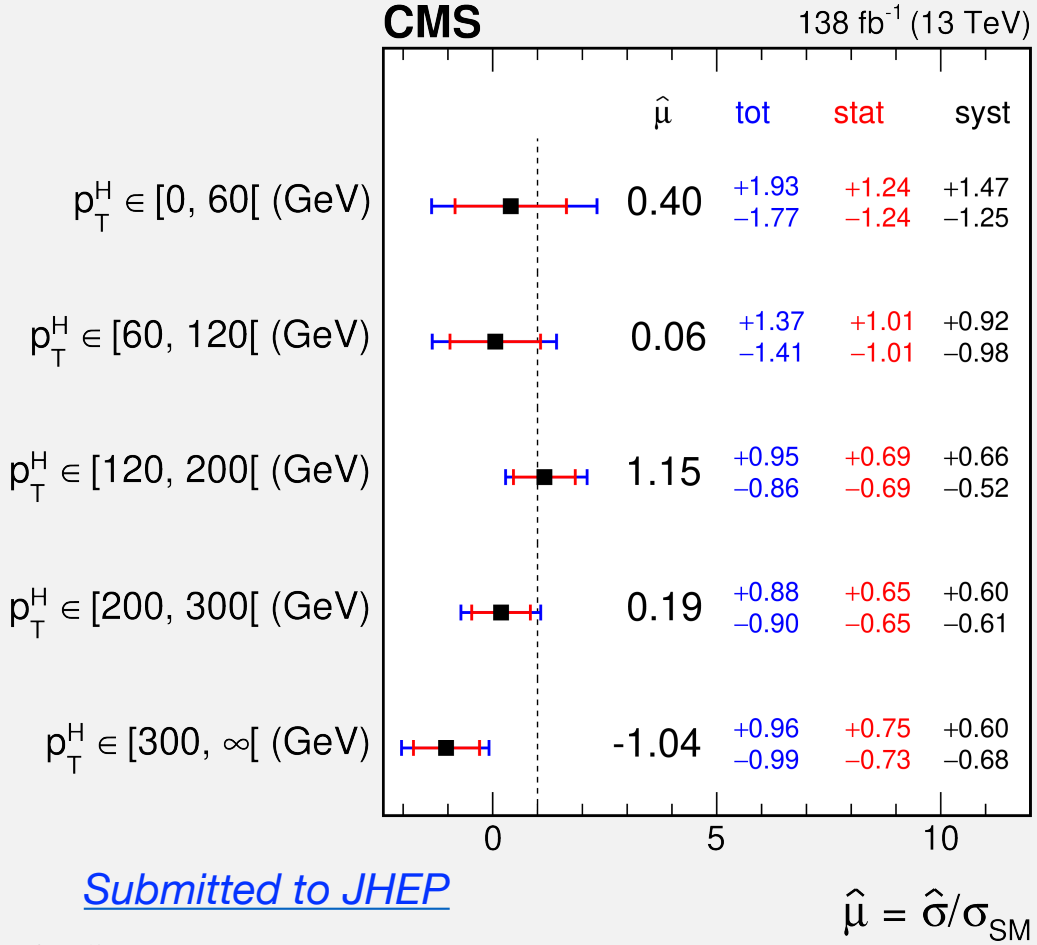


CMS-PAS-HIG-23-010

ttH, H→bb cross section measurement in Higgs p_T bins

- **ATLAS measured ttH cross section** $\sigma_{t\bar{t}H} = 411^{+101}_{-92}\,\text{fb} = 411 \pm 54(\text{stat.})^{+85}_{-75}(\text{syst.})\,\text{fb}$
- **CMS measured ttH signal strength:** $\mu_{t\bar{t}H} = 0.33 \pm 0.17(stat.) \pm 0.21(syst.)$



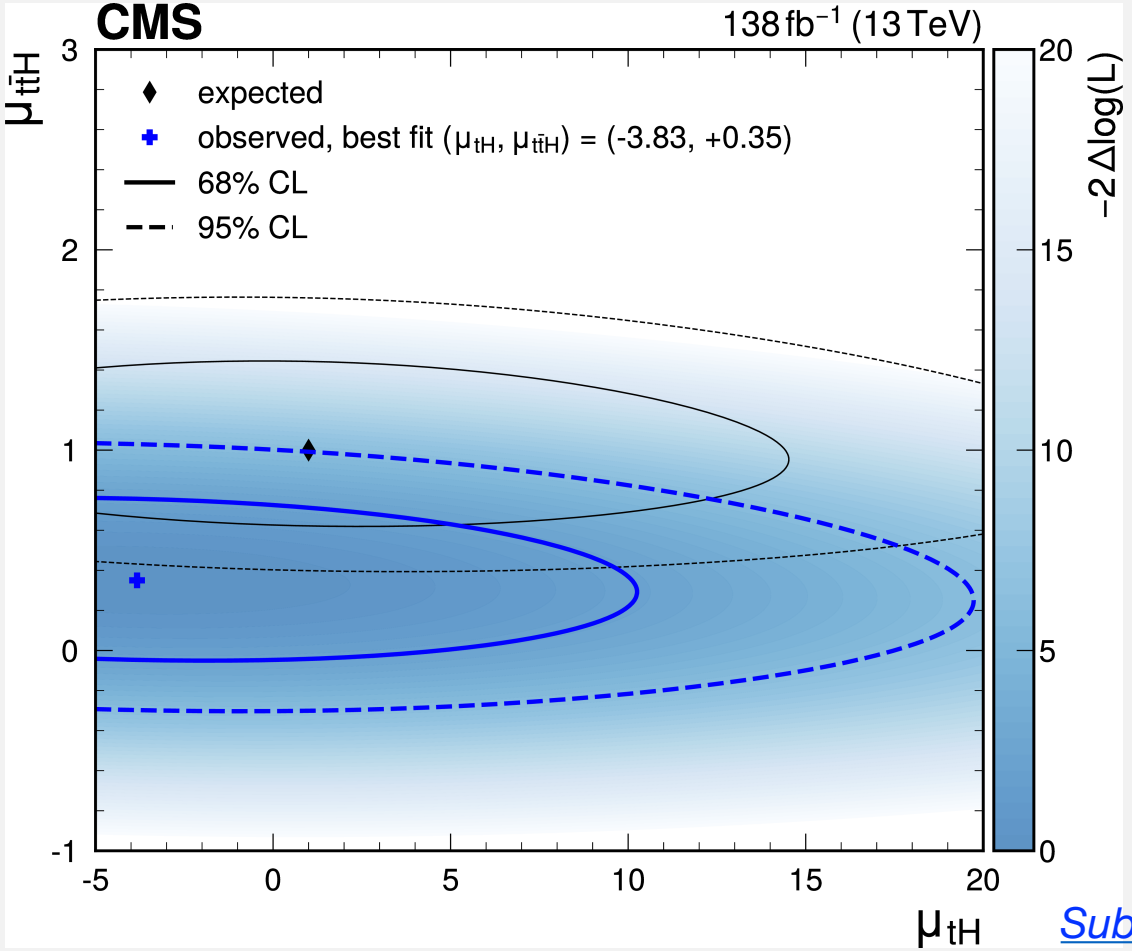


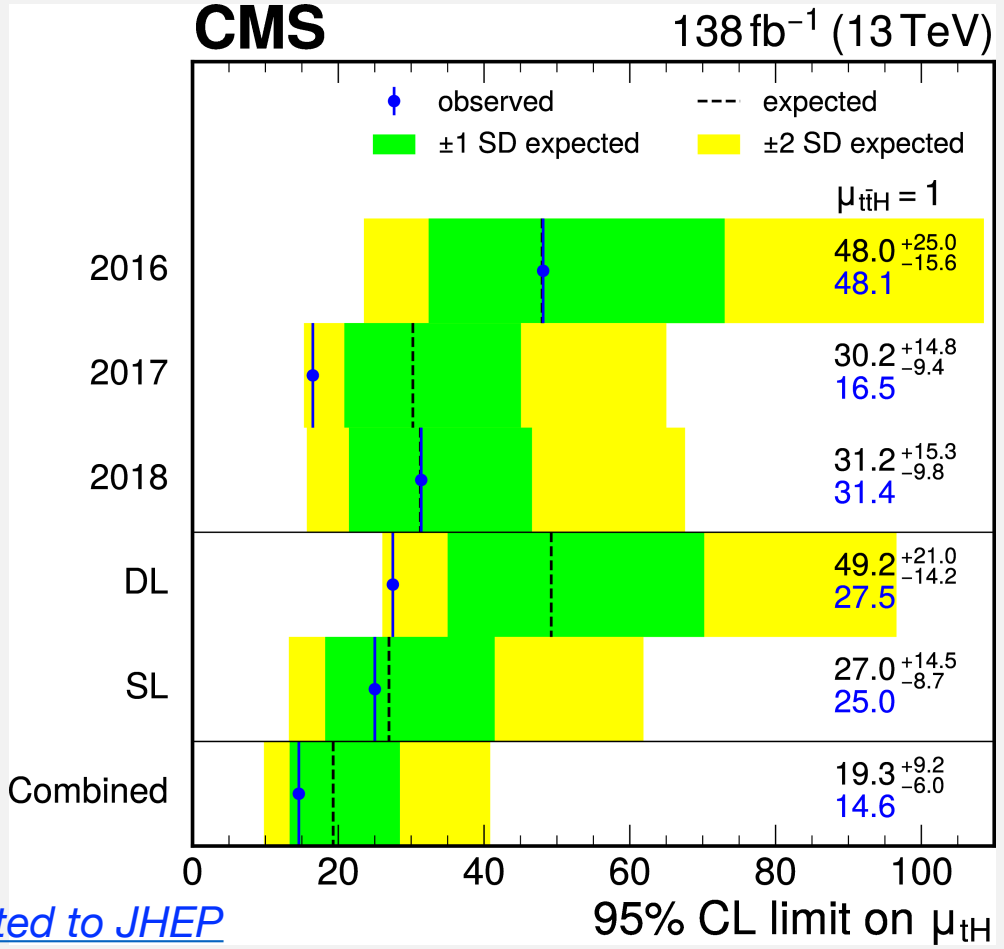
Submitted to EPJC

Submitted to JHEP

Searching for tH, H→bb process

- **95% CL upper limit on tH production rate: 14.6 times the SM prediction.**



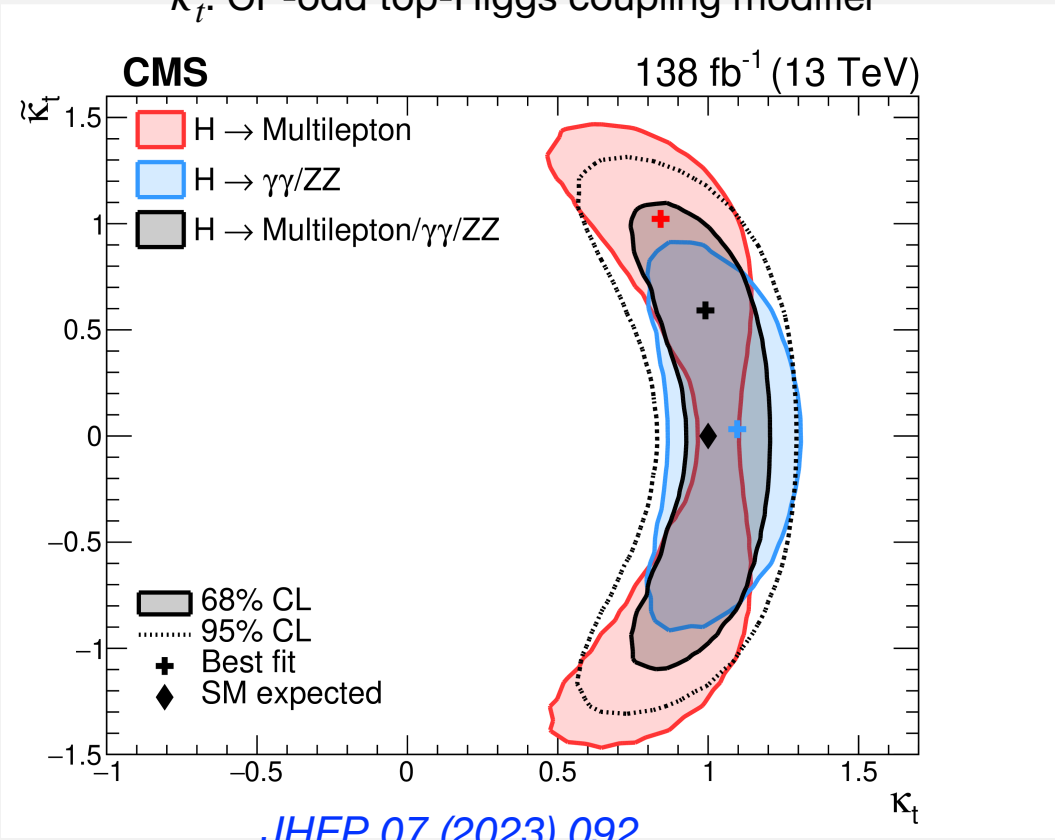


Submitted to JHEP

ttH, H→multi-leptons channel status

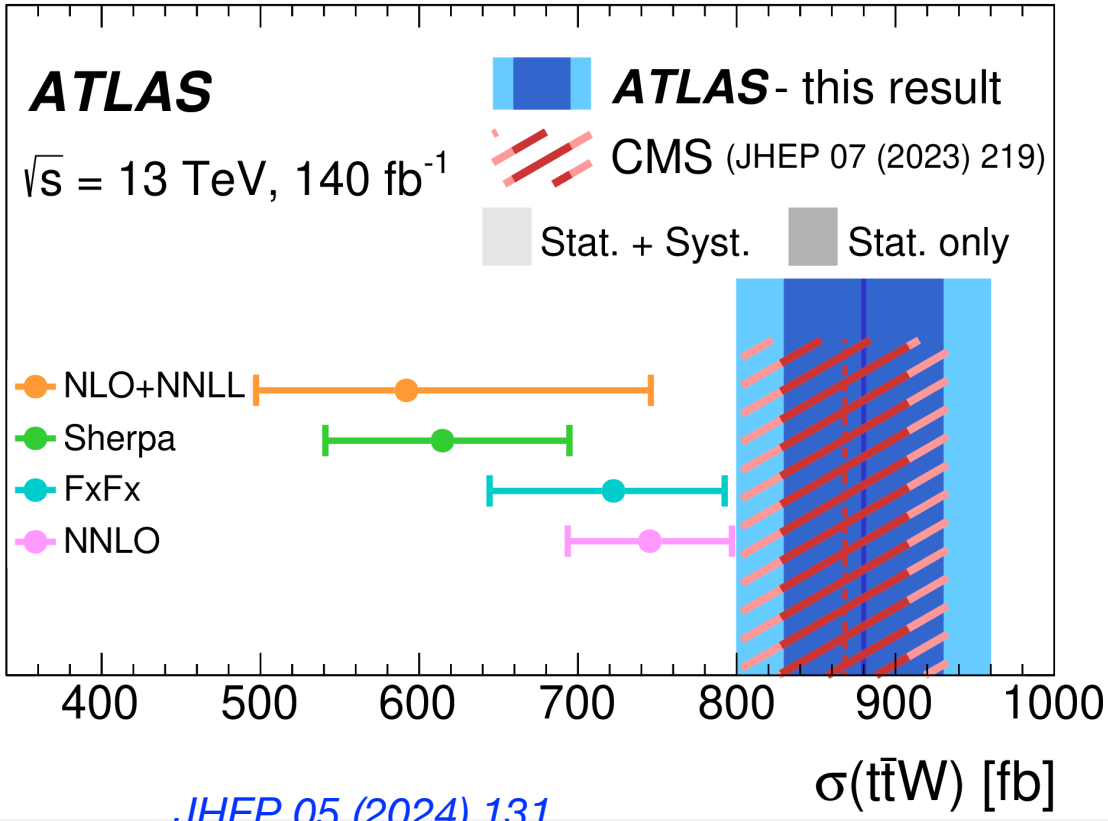
- **CMS set constraints on top-Higgs coupling CP property using full Run 2 dataset.**
- **ATLAS updated on the ttW (main irreducible bkg.) cross section measurement.**

κ_t: CP-even top-Higgs coupling modifier
$\tilde{\kappa}_t$: CP-odd top-Higgs coupling modifier



JHEP 07 (2023) 092

Physics briefing: ttW production mild tension



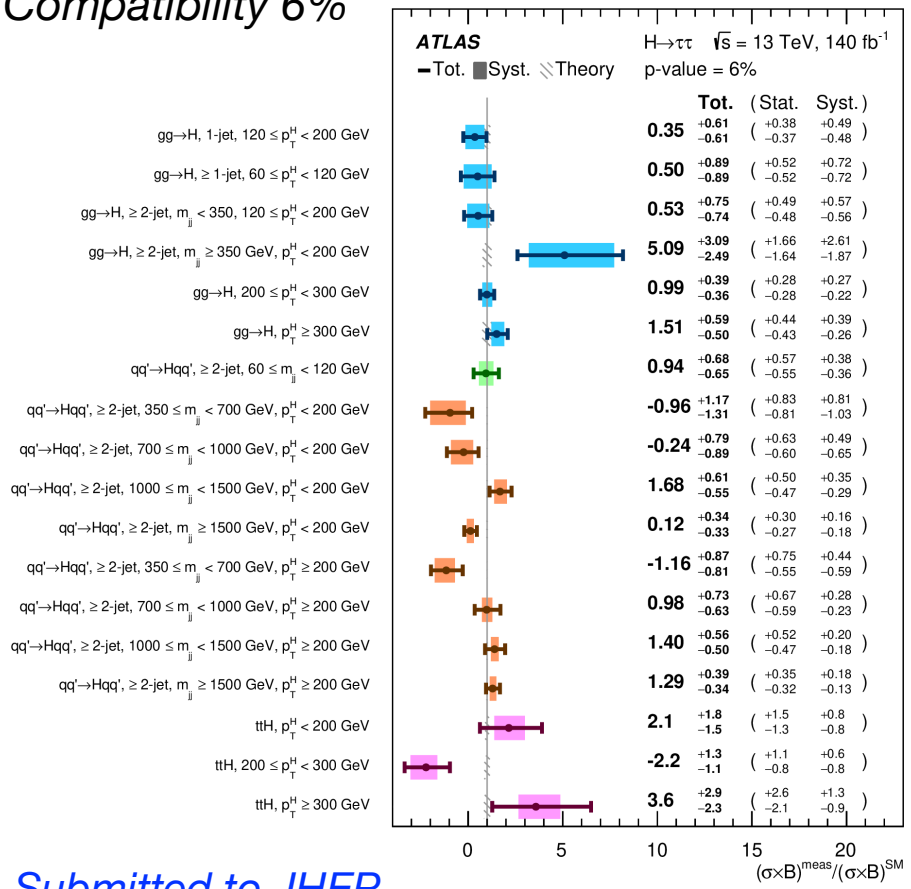
JHEP 05 (2024) 131

Jialin Li's talk

H→ττ channel cross section measurement

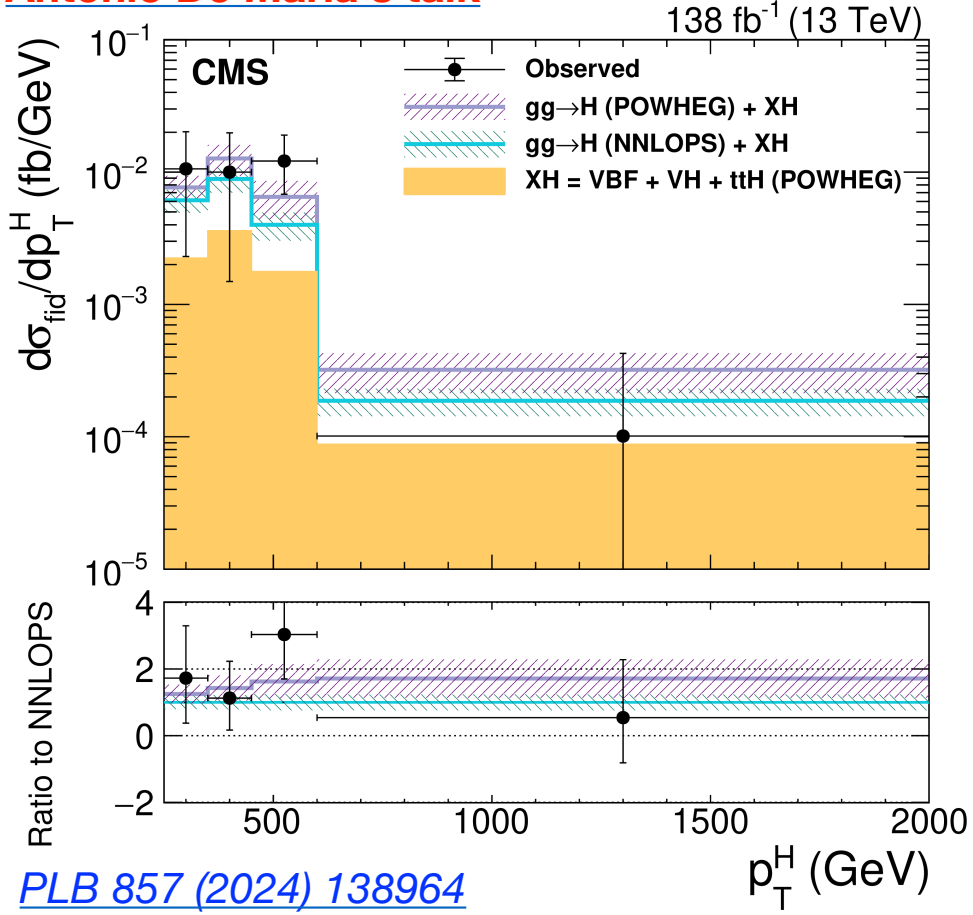
- **ATLAS has most precise single measurement on VBF production: $\mu_{VBF} = 0.93^{+0.17}_{-0.15}$.**
- **CMS extended Higgs transverse momentum measurement beyond 600 GeV.**

Compatibility 6%



Submitted to JHEP

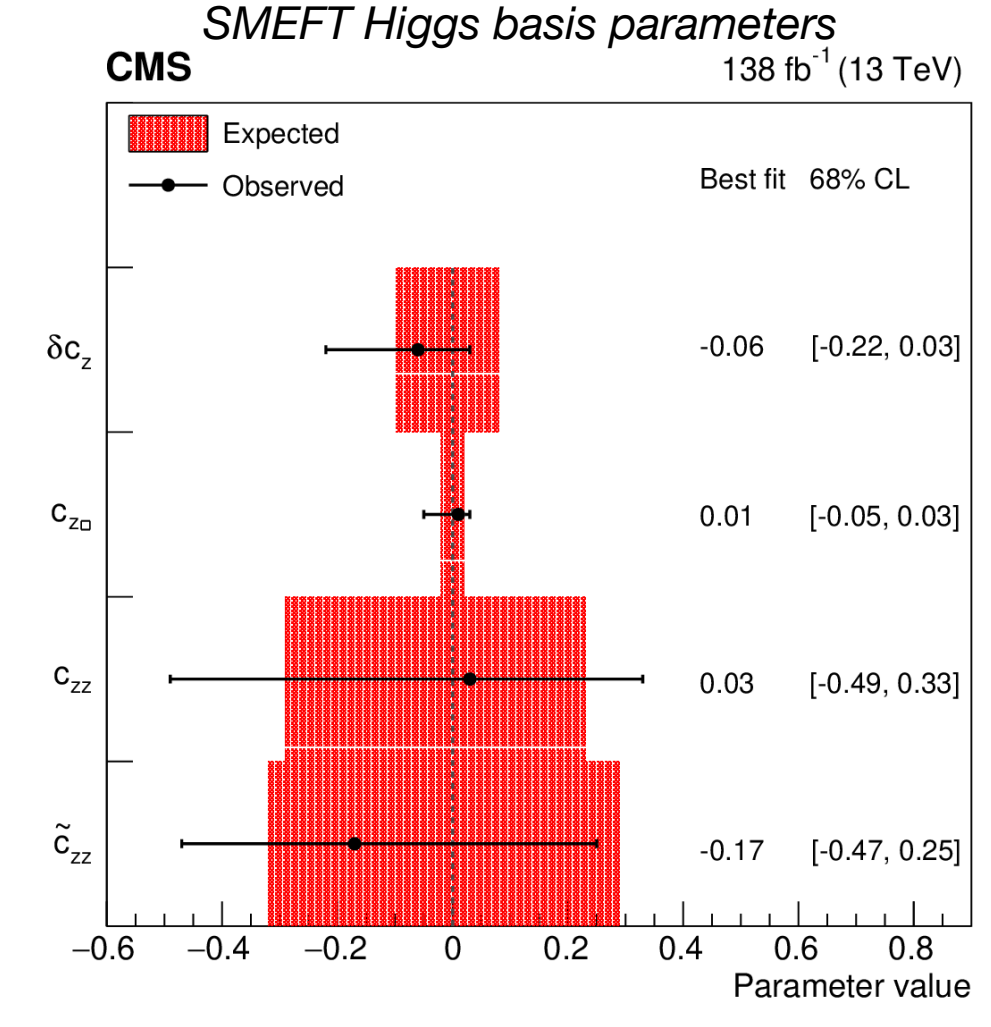
Antonio De Maria's talk

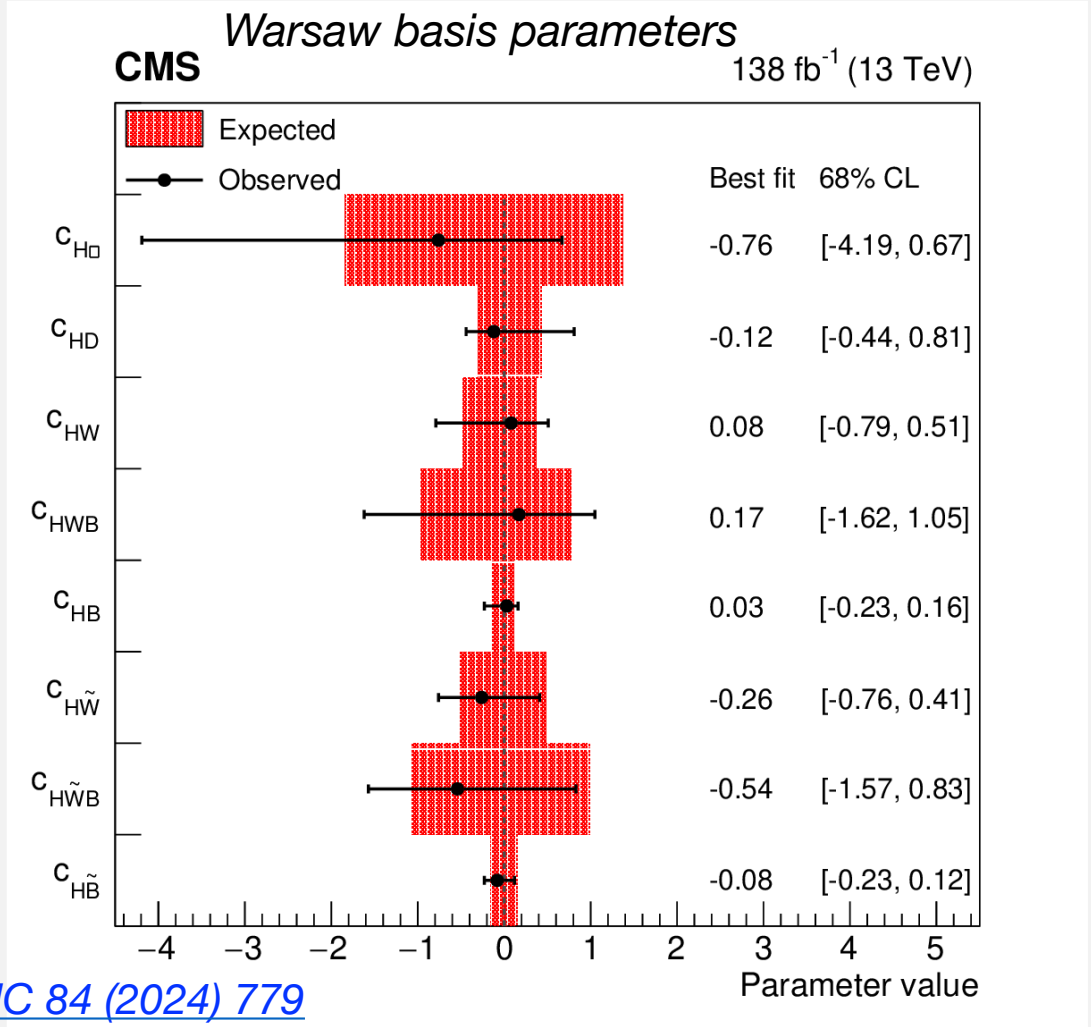


PLB 857 (2024) 138964

Constraints on anomalous Higgs couplings in H→WW channel

- **In H→WW→eμ channel, all measurements are consistent with the SM predictions.**



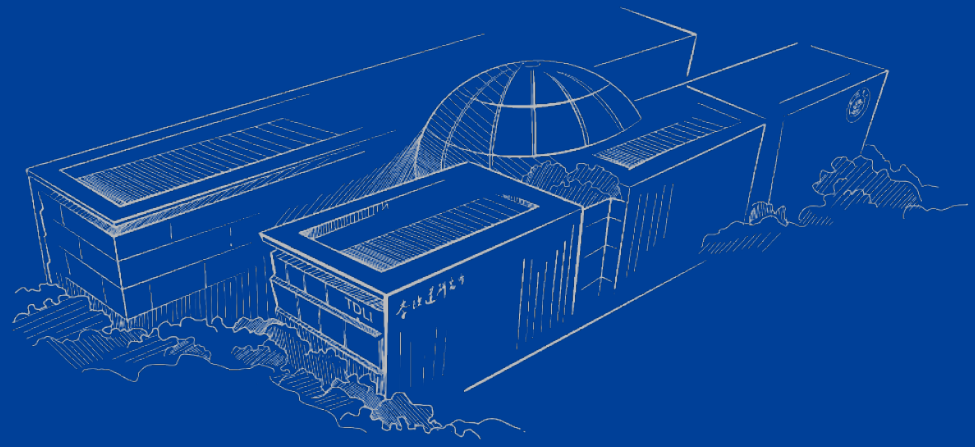


EPJC 84 (2024) 779

Conclusion

- **Rediscovery of the SM Higgs boson at 13.6 TeV in both experiments!**
- **Run 2 legacy analyses are being finalized, more challenge analysis channels come later!**
  - VH, H→bb updated STXS cross sections ➔ in good agreement with the SM
  - ttH, H→bb updated STXS cross sections ➔ CMS has 2.4σ inconsistency with the SM
  - H→$\tau\tau$ channel provides STXS and differential cross section measurements
- **New ideas/approaches have been studied for Higgs properties measurement**
  - Constraints on Higgs width using on-shell Higgs production and mass measurement
  - Constraints on charm-Higgs Yukawa coupling via cH, H→$\gamma\gamma$ channel: $|\kappa_c| < 38.1$
  - Combination of VH, H→bb and H→cc channels set limit on $|\kappa_c/\kappa_b| < 3.6$
- **Run 3 already recorded more statistics than Run 2 + Run1, please stay tuned!**

Thanks

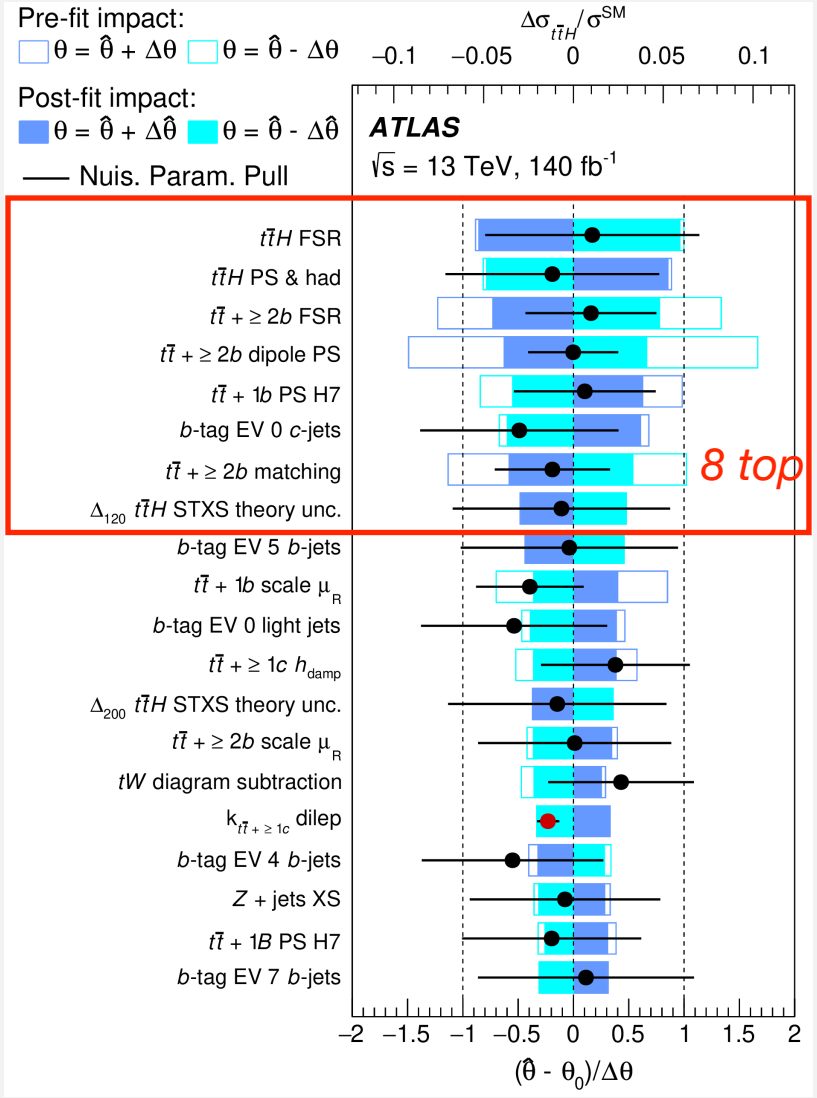


Systematics ranking in VH and ttH, H→bb analysis

ATLAS VH, H→bb/cc channels systematics ranking

Source of uncertainty	σ_μ			
	$VH,\ H \to b\bar{b}$	$WH,\ H \to b\bar{b}$	$ZH,\ H \to b\bar{b}$	$VH,\ H \to c\bar{c}$
Total	0.153	0.204	0.216	5.31
Statistical	0.097	0.139	0.153	3.94
Systematic	0.118	0.149	0.153	3.57
Statistical uncertainties				
Data statistical	0.090	0.129	0.139	3.67
$t\bar{t}$ $e\mu$ control region	0.009	0.014	0.027	0.08
Background floating normalisations	0.034	0.049	0.042	1.24
Other VH floating normalisation	0.007	0.018	0.014	0.33
Simulation samples size	0.023	0.033	0.030	1.62
Experimental uncertainties				
Jets	0.027	0.035	0.030	1.02
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.010	0.005	0.021	0.23
Leptons	0.003	0.002	0.010	0.25
b-tagging b-jets	0.020	0.018	0.026	0.29
b-tagging c-jets	0.013	0.017	0.012	0.73
b-tagging light-flavour jets	0.005	0.008	0.008	0.66
Pile-up	0.008	0.017	0.002	0.23
Luminosity	0.006	0.007	0.006	0.08
Theoretical and modelling uncertainties				
Signal	0.076	0.074	0.101	0.72
Z + jets	0.042	0.018	0.081	1.77
W + jets	0.054	0.087	0.026	1.42
$t\bar{t}$ and Wt	0.018	0.033	0.018	1.02
Single top-quark (s-, t-ch.)	0.010	0.018	0.002	0.16
Diboson	0.033	0.039	0.049	0.52
Multijet	0.005	0.010	0.005	0.55

ttH, H→bb channel systematics ranking



8 top systs.!

Systematics breakdown of the CMS H→ττ analysis

Production mode	ggF	ttH	VBF	VH
Best-fit value	0.94	0.77	0.93	0.91
Total uncertainty	±0.30	±0.97	±0.16	±0.62
Statistical uncertainty	±0.15	±0.82	±0.12	±0.52
Total systematic uncertainty	±0.26	±0.51	±0.11	±0.34
Samples size	±0.09	±0.32	±0.03	±0.25
Theoretical uncertainty in signal	±0.19	±0.14	±0.10	±0.13
Jet and $E_{\mathrm{T}}^{\mathrm{miss}}$	±0.12	±0.14	±0.03	±0.11
Hadronic τ-lepton decays	±0.05	±0.09	±0.01	±0.04
Misidentified τ-lepton background	±0.05	±0.05	±0.02	±0.11
Luminosity	±0.01	±0.01	±0.01	±0.02
Theoretical uncertainty in top-quark processes	±0.01	±0.30	–	±0.02
Theoretical uncertainty in Z + jets processes	±0.03	±0.07	–	±0.02
Flavour tagging	±0.02	±0.05	±0.01	±0.01
Electrons and muons	±0.02	±0.01	±0.01	±0.02