Higgs physics at the LHC

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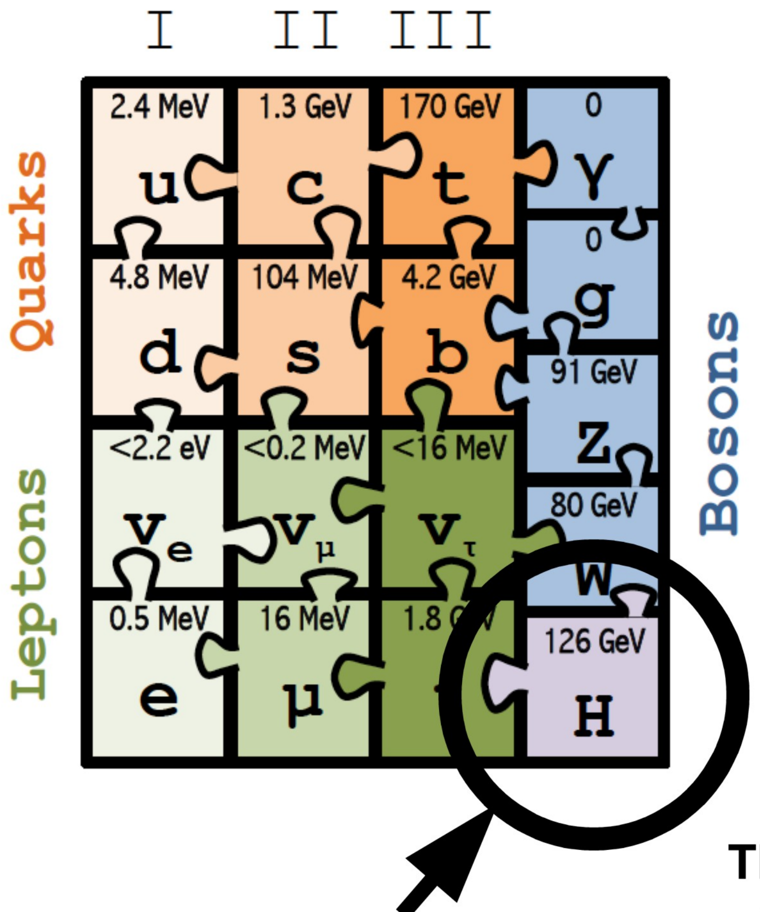
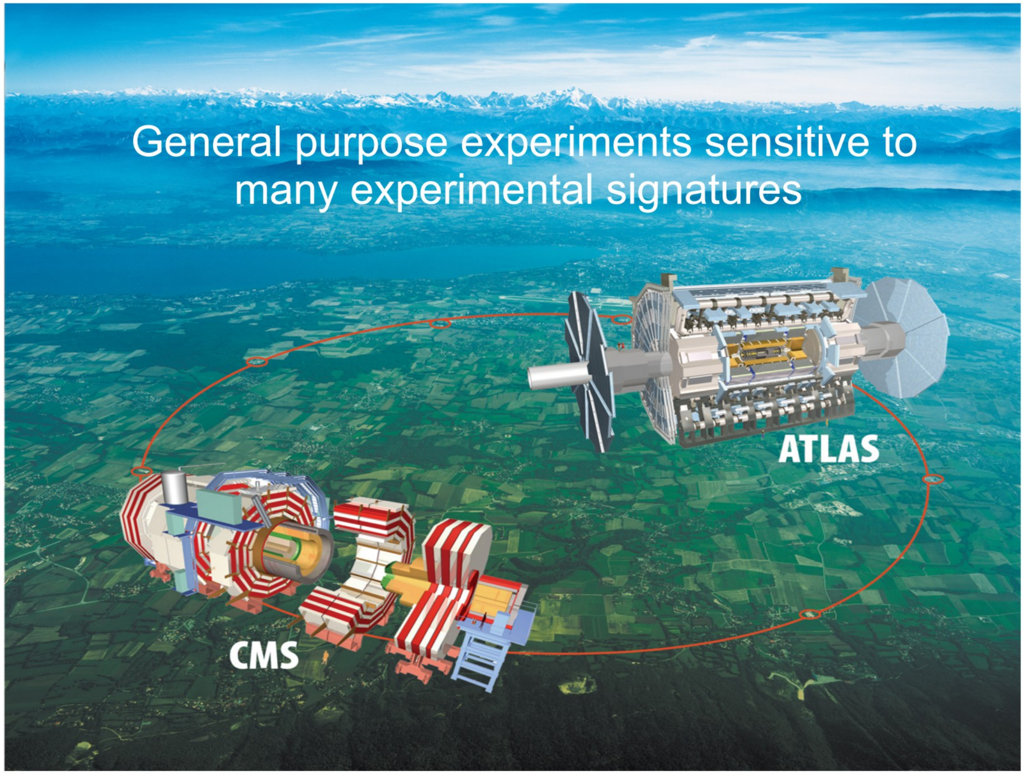
A biased selection of latest public results from the ATLAS and CMS collaborations
For a complete list of results I invite you to check here for ATLAS and CMS

SILAFAE 2024
Cinvestav, Mexico City, Mexico
November 4-8, 2024

In this talk



The main actor



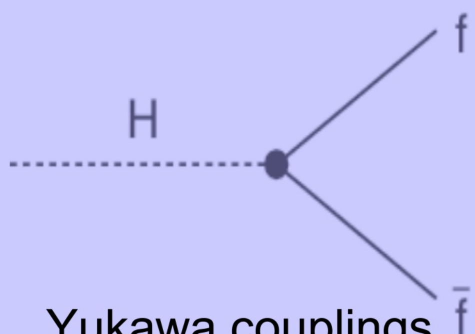
The main stage will be the center of the ATLAS and CMS detectors at the Large Hadron Collider (LHC) at CERN

We will touch on the following topics

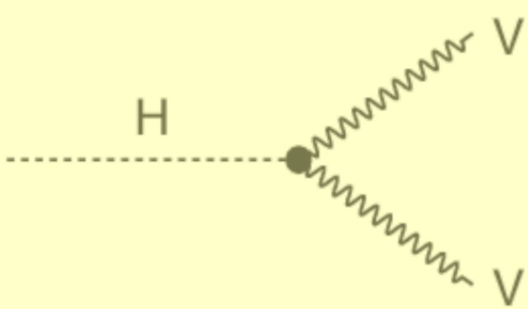
- Brief summary: What do we know today about this particle? State of the art
- Latest results: precise measurements, search for new physics at high energies
- What could the future bring?

How well do we know the Standard Model?

- The SM is a huge success from the experimental point of view that predicts and the Higgs is one of the main actors in that context
  - 15 out of the 19 free parameters of the SM are connected to the Higgs boson
  - And once the mass is known, several predicted properties of this particle can be tested



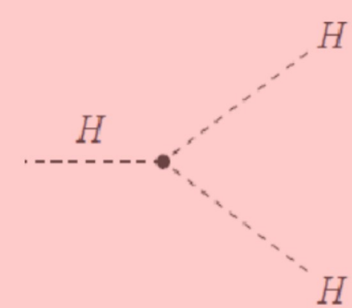
Yukawa couplings



Vector boson couplings

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \bar{\psi} \not{D} \psi + \bar{\psi}_i y_{ij} \psi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$

July 4th 2012:
"Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC"

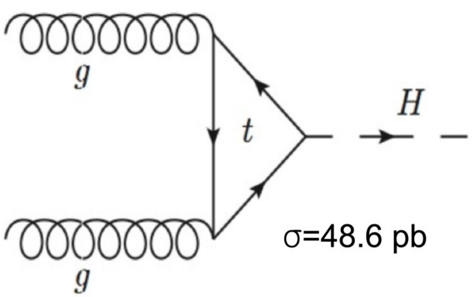


Higgs self-coupling

Identifying the Higgs boson at the LHC: production

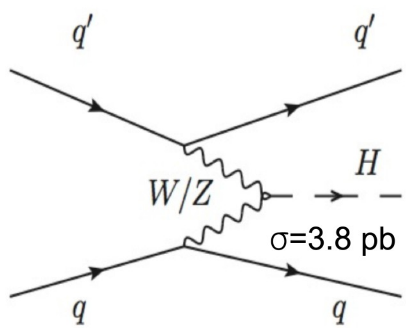
Different analyses performed by LHC experiments, depending on the Higgs production mode:

Gluon fusion (ggF)



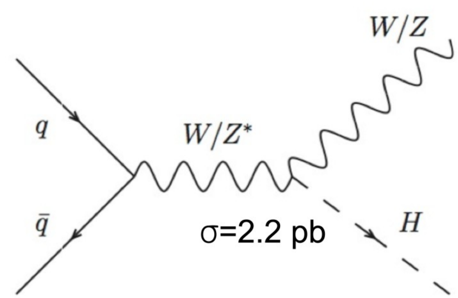
- Main production mode at the LHC
- Large backgrounds

Vector Boson Fusion (VBF)



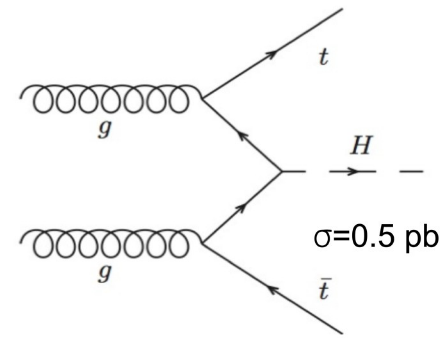
- The two jets with high rapidity separation improve triggering and bkg rejection
- Accessibility to gauge coupling

W/Z associated production (VH)



- Mostly triggered by leptonic decay of W/Z boson
- Accessibility to gauge coupling

$t\bar{t}$ associated production (ttH)



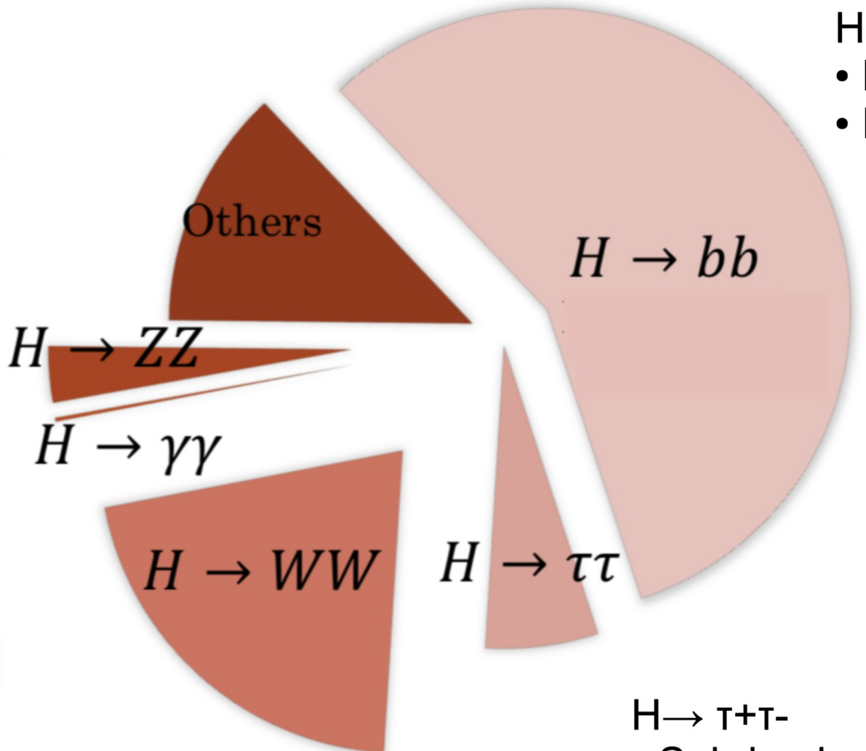
- Semileptonic and hadronic top decays
- Accessibility to the top Yukawa coupling

Identifying the Higgs boson at the LHC: decays

Which production mode or/and decay is the best?

H→ bb
- Dominant decay (~58% BR)
- Huge backgrounds from QCD jets

H→ Z(*)Z
- Penalty from Z→l+l-
- BR very clean, fully reconstructed



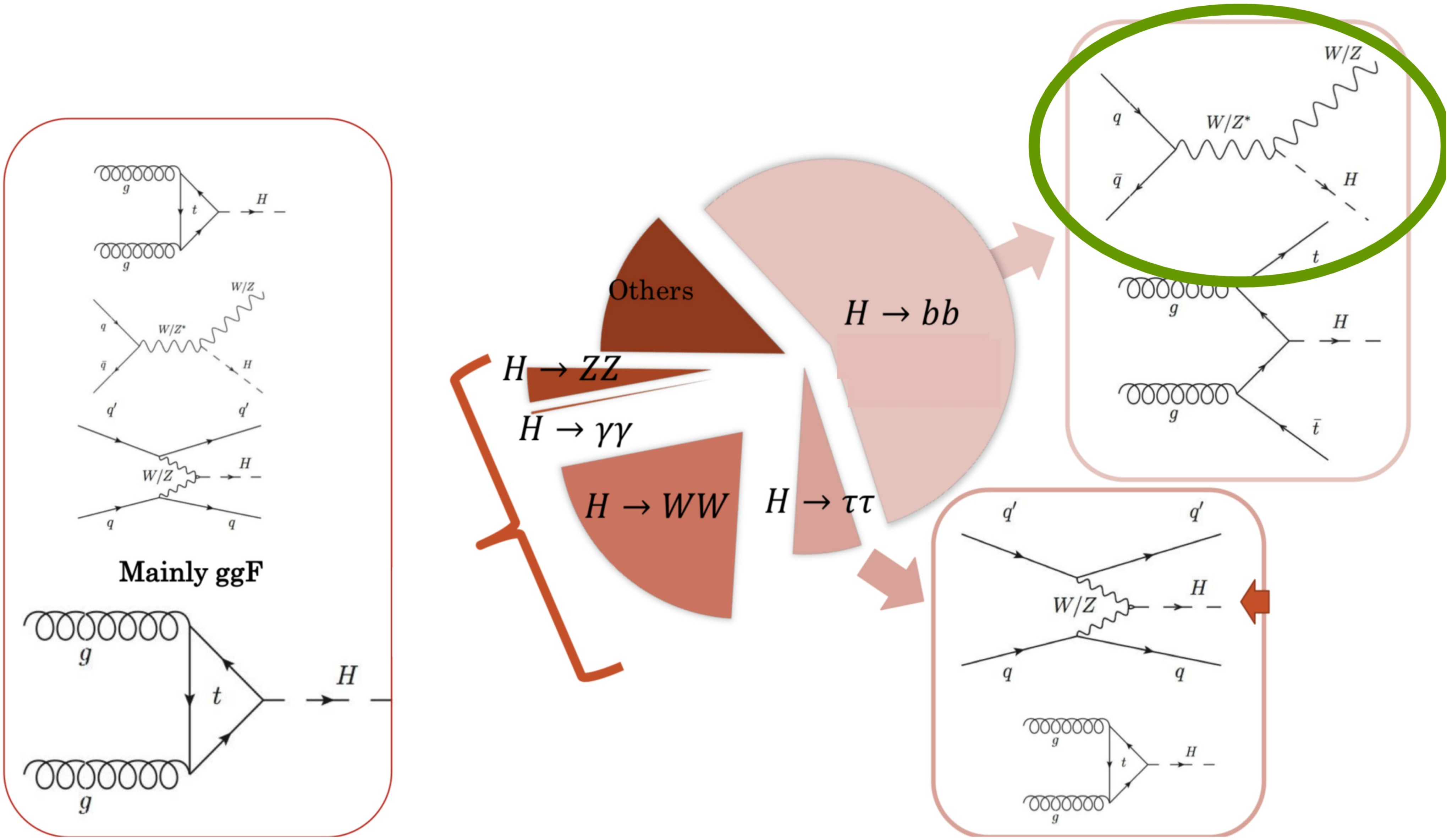
H→ γγ :
- Very small BR
- Huge bkgs. from QCD photons and jets
- Fully reconstructed, clean mass measurement

H→ W+W-
- Subdominant (~22%)
- Incomplete reconstruction

H→ τ+τ-
- Subdominant (~6%)
- Incomplete reconstruction

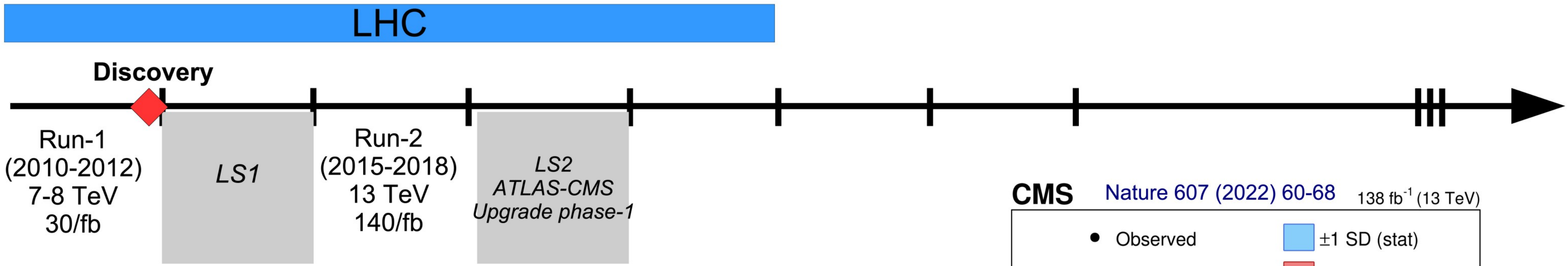
There is an interplay between production and decay based on the backgrounds

Identifying the Higgs boson at the LHC: Interplay between production and decay



• *Slide from George Aad's JRJC 2014 talk*

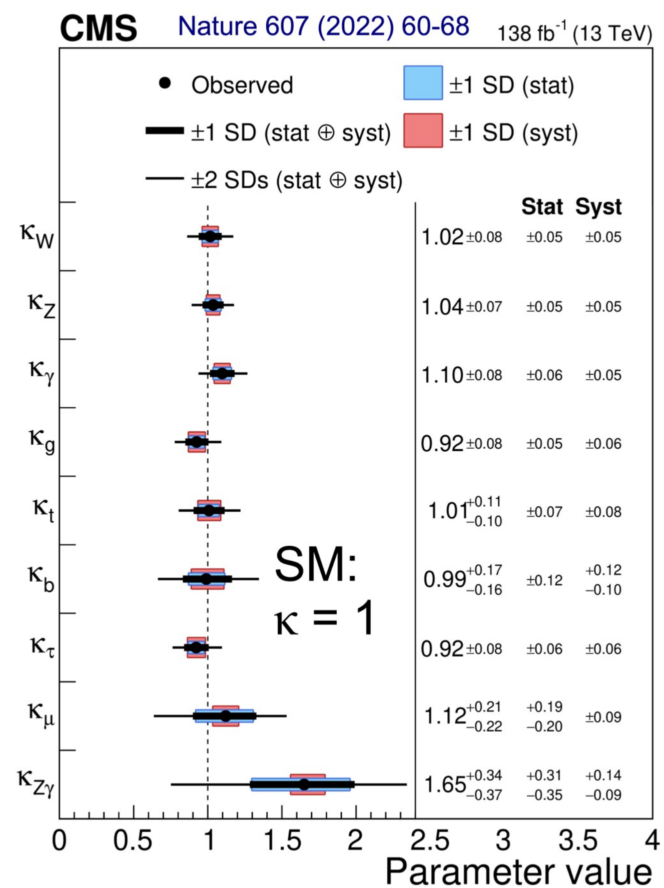
What we managed with Run-2 data?



- **ZZ, WW and γγ were the first ones to be observed!** *Now we are doing precision measurements with them!*

- ***Major breakthroughs in recent years:***
  - Observation of H→ττ using 2016 data
  - Observation of H→bb decay in 2018
  - Observation of ttH production combining different decay modes
  - Evidence for decay of H→μμ and Zγ decay
  - Ongoing searches (e.g. cc, di-Higgs)
  - Precision measurements of Higgs properties

- **Spoiler alert: so far high consistency with SM!**



Most precise measurements of (most) Higgs couplings to-date from combinations of Run-2 data: from 8% (to weak bosons) to 10-20% (for third generation fermions)

Do we really know everything about the Standard Model?

- There are still many open questions in this puzzle, that the Higgs boson can help addressing (?)

Keep measuring Higgs couplings

Including Higgs self-coupling

As well as its properties: mass, CP, total decay width

Looking for decays not predicted in the SM (direct searches)

With the best precision possible, probing the SM in extreme corners

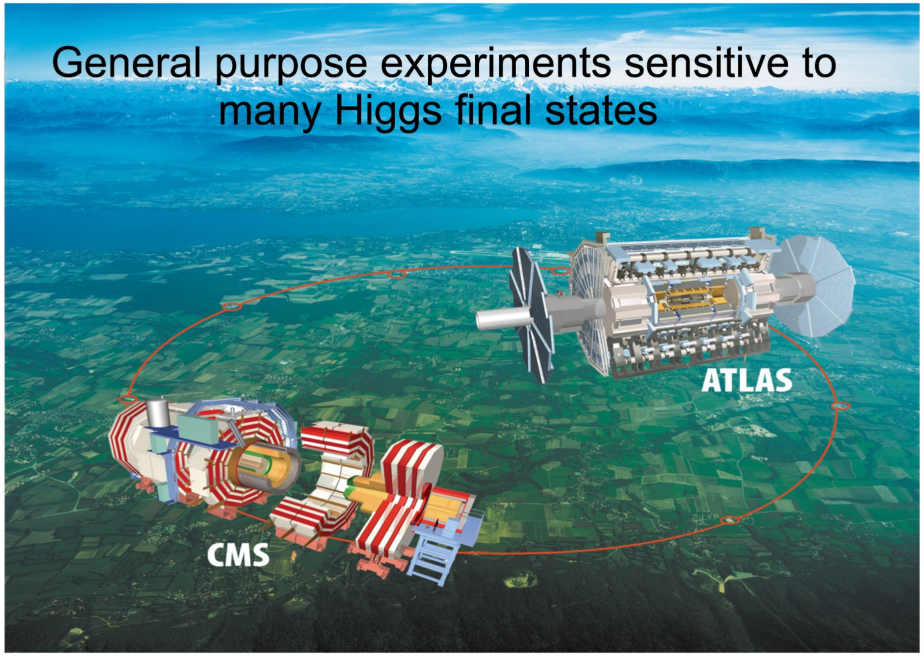
- What is behind the large range of particle masses in the SM?
  - **Fermion flavor violating Higgs boson decays?**
  - **Are there modified Higgs couplings to other particles?**
- Why is the electroweak interaction so much stronger than gravity?
  - Is the Higgs boson an elemental particle?
  - **Are there anomalies in the interaction between Higgs and W/Z bosons?**
- Matter-antimatter differences?
  - Are there **CP violating Higgs boson decays?**
  - Are there multiple Higgs sectors?
  - Due to **anomalies in the Higgs self-coupling?**
- What is dark matter?
  - Can the Higgs boson provide a portal to dark matter?
  - **New decay modes of the Higgs boson?**
  - **Higgs lifetime consistent with the SM?**

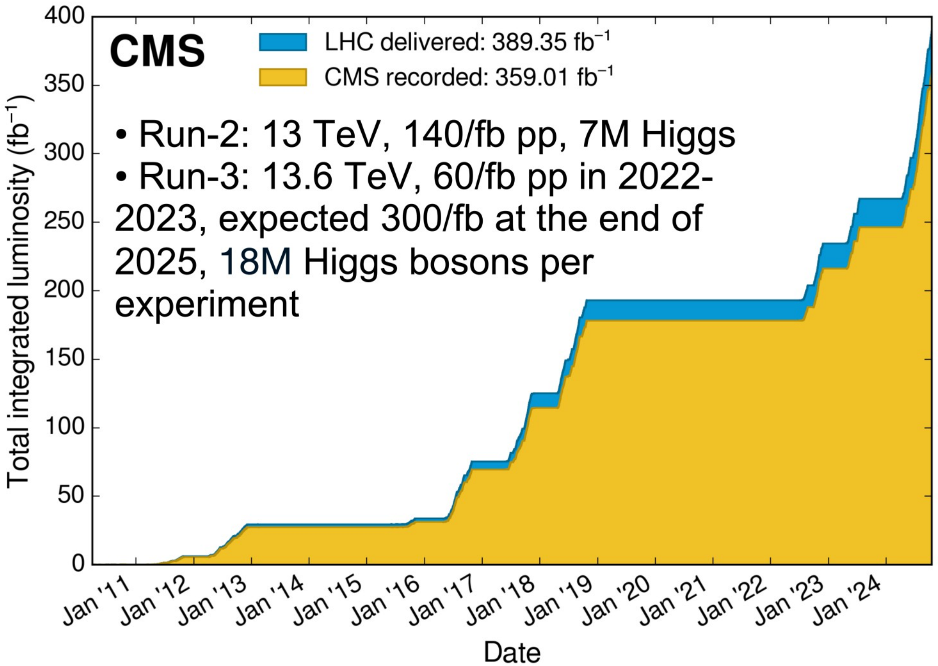
From N. Berger @ICHEP2024

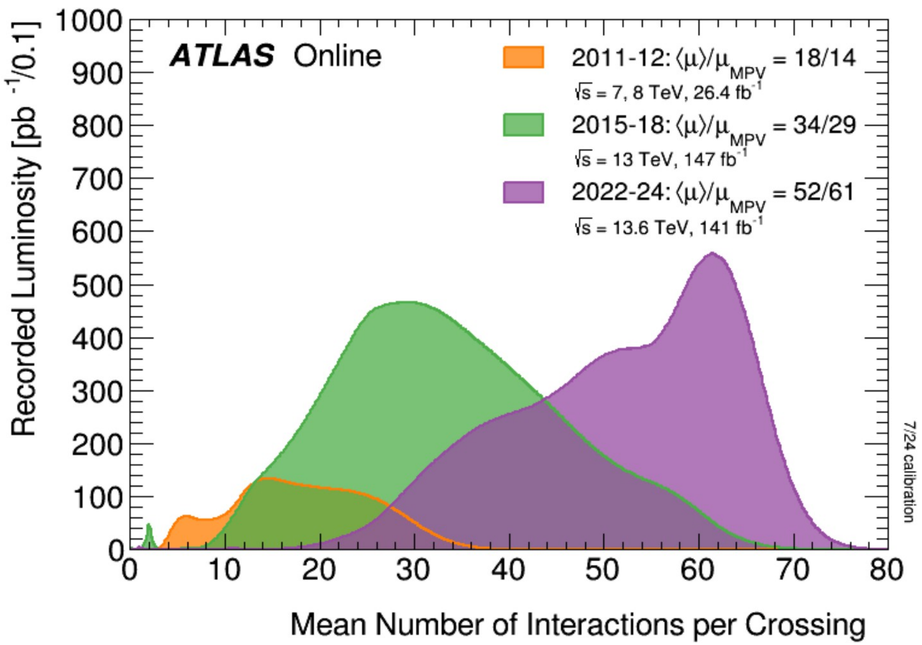
Our tools

The ATLAS and CMS experiments and the LHC

- Large **increase in integrated luminosity** vs time: >30x the amount of data available at the moment of the discovery but conditions are more challenging
- **Improvements in performance and analysis methodologies**
- And a **good understanding of the detector** and data quality





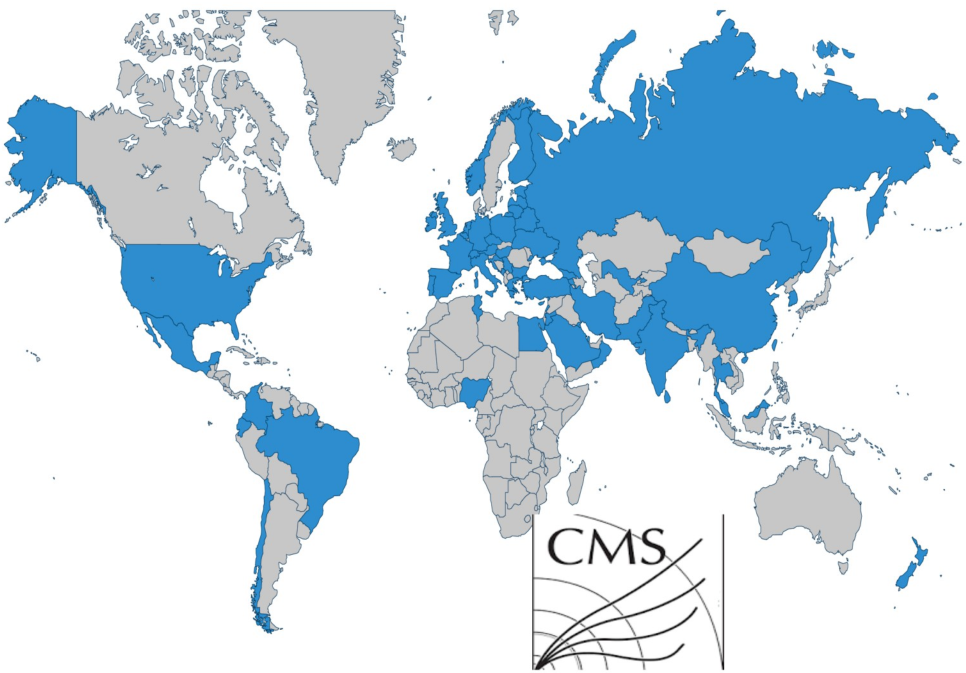


Our tools

The ATLAS and CMS experiments and the LHC

- Latin American participation in these collaborations
  - Key contributions in data analysis, instrumentation and detector performance

Reference



247 Institutions from 57 countries, 6288 active people (2022)

ATLAS-PHOTO-2019-001

251 institutes from 41 countries, 6003 members (2024)

Before presenting the latest results: clarifications

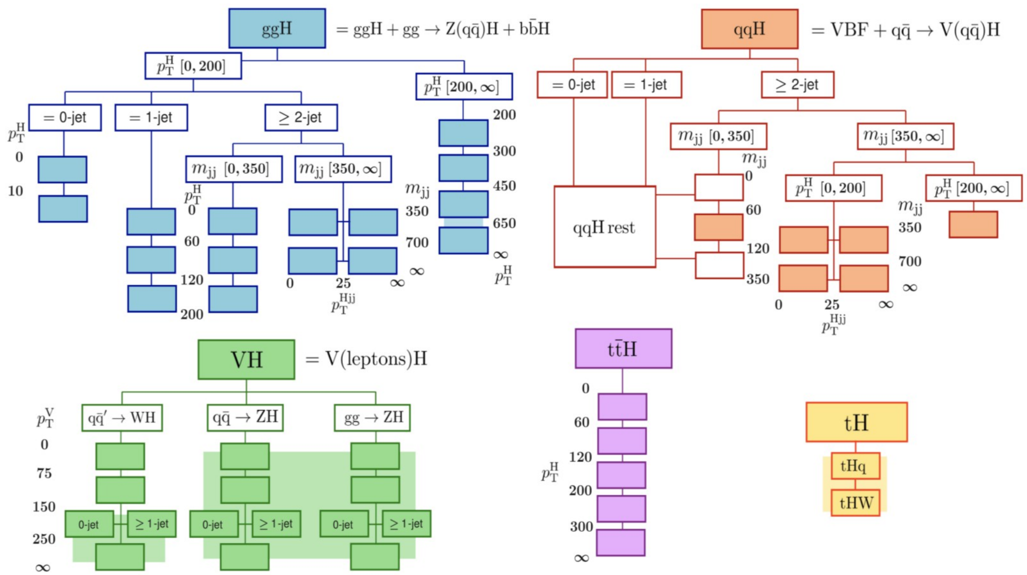
- **I will present latest results using full Run-2 dataset and some with Run-3**
  - Major improvements in performance and analysis methodologies (a lot of ML)
  - Every measurement consists of one or more signal regions, designed to selected target Higgs production/decay
  - Analyses use profile likelihood fits to constrain systematics and bkg using the data

***κ framework:** κ parameters act as linear modifiers to H coupling strengths without altering any kinematic distributions*

$$\sigma \cdot \mathcal{B}\,(i \to H \to f) = \kappa_i^2 \cdot \kappa_f^2 \cdot \sigma_i^{\mathrm{SM}} \cdot \frac{\Gamma_f^{\mathrm{SM}}}{\Gamma_H(\kappa_i^2, \kappa_f^2)}$$

$$\kappa_i^2 = \frac{\sigma_i}{\sigma_i^{\mathrm{SM}}} \quad \text{and} \quad \kappa_f^2 = \frac{\Gamma_f}{\Gamma_f^{\mathrm{SM}}}$$

***STXS regions** defined per production mode, optimized for sensitivity while reducing theory dependence*



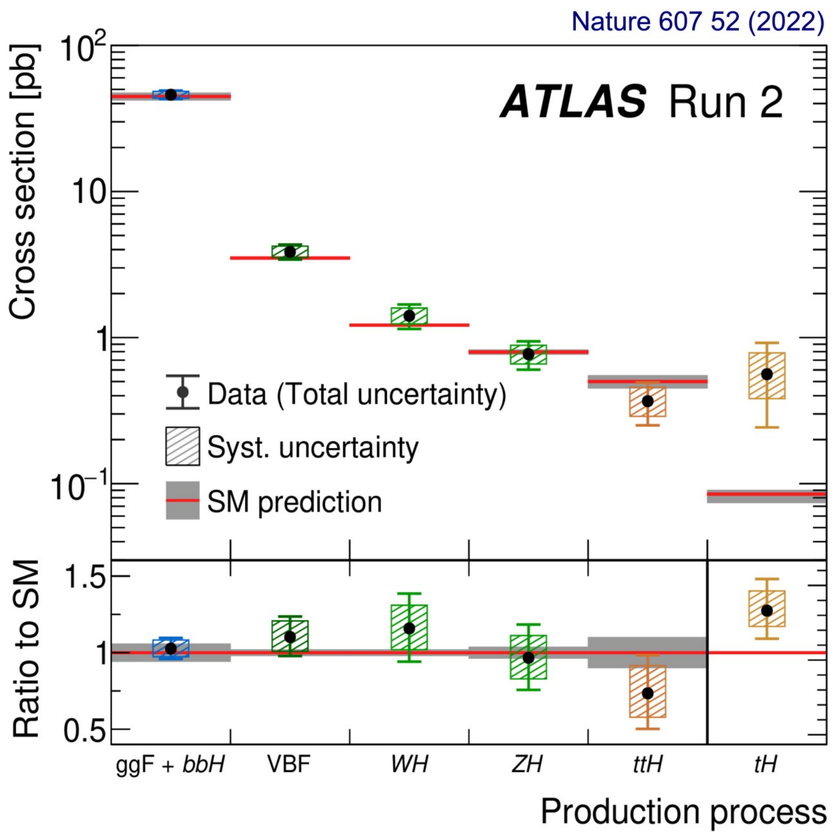
Analyses trying to provide more granular information on the Higgs:

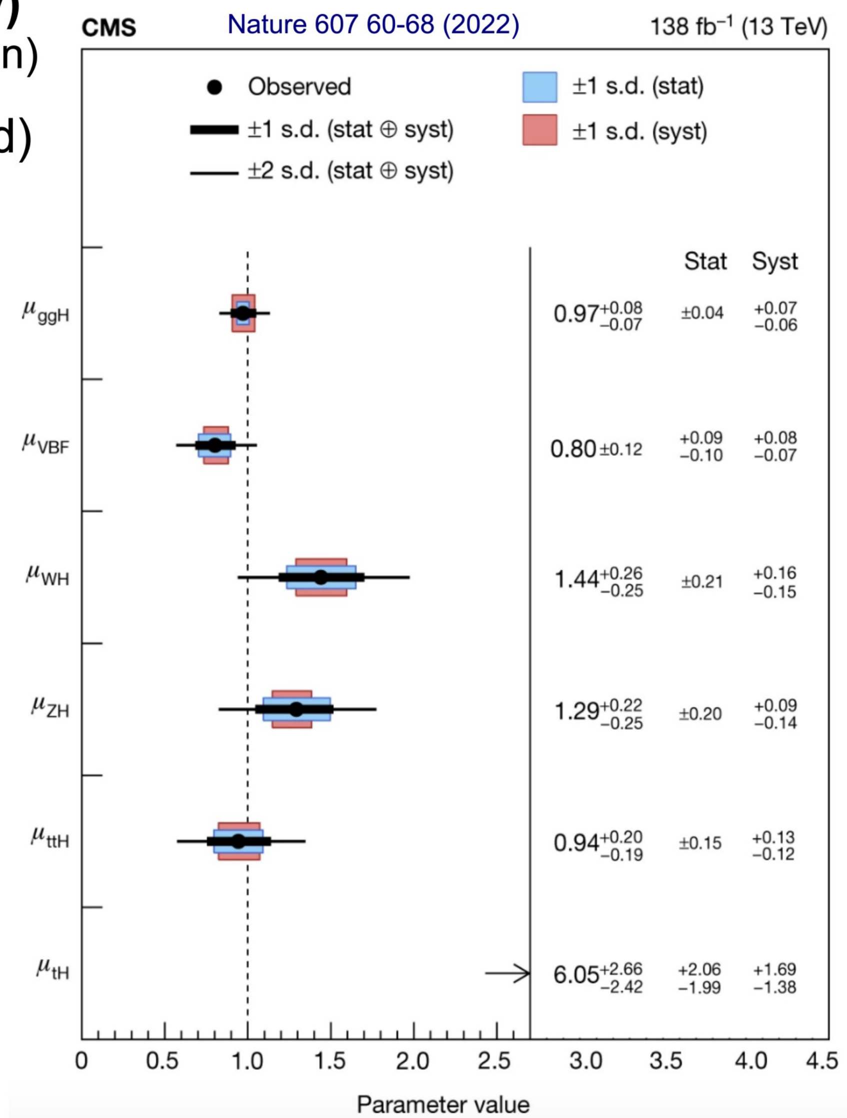
- **Inclusive measurements:**
  - Cross sections (σ)
  - Signal strengths ($\mu = \sigma \cdot BR / \sigma \cdot BR_{SM}$)
  - Coupling strength scale factor relative to SM (κ framework, κ = 1 for SM)
- **Differential measurements**
- **Or semi-differential:** Simplified Template Cross Section (STXS) framework

Latest results on:
Higgs boson couplings to other particles

Let's about its production

- **Most dominant production modes observed (updated in 2022, 10^{th} Higgs discovery anniversary)**
  - Results agree with SM prediction (no significant deviation)
- Upper limit on tH production 7xSM (15xSM expected)
- Let's also take a look at more recents results



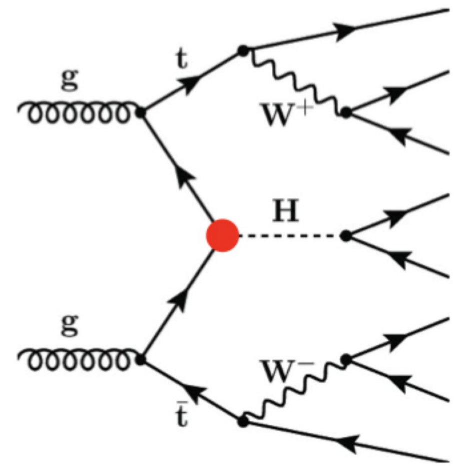


ATLAS final ttH (H→bb) measurement

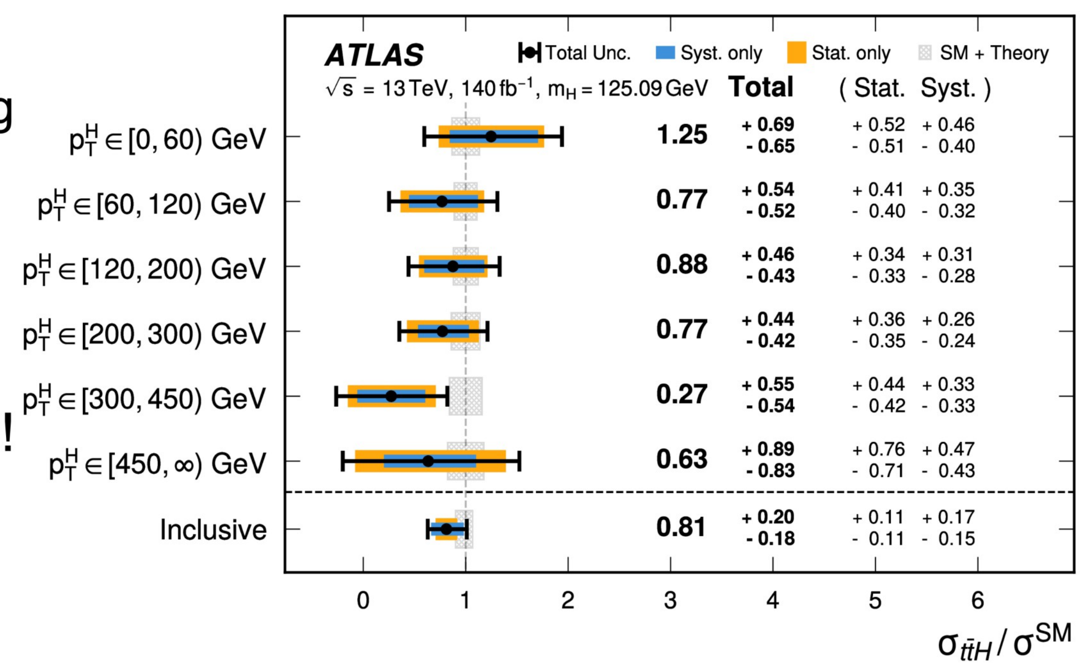
- **Direct access the top-quark Yukawa coupling! A 3rd generation quark**

- **Analysis strategy:**
  - Very rich/complex topology: 1 or 2 leptons, (b-)jets, MET
  - **Improvements with respect to previous analysis** (JHEP 06 (2022) 97): improved b-tagging, transformer-based ML to reconstruct and classify events, modelling of backgrounds (ttb(b)..)
    - **Overall uncertainty improved by factor 1.8, 4.6σ observed, x3 signal yield on the same dataset**

- Most precise single ttH channel to date!
  - CMS Results with similar sensitivity: HIG-19-011

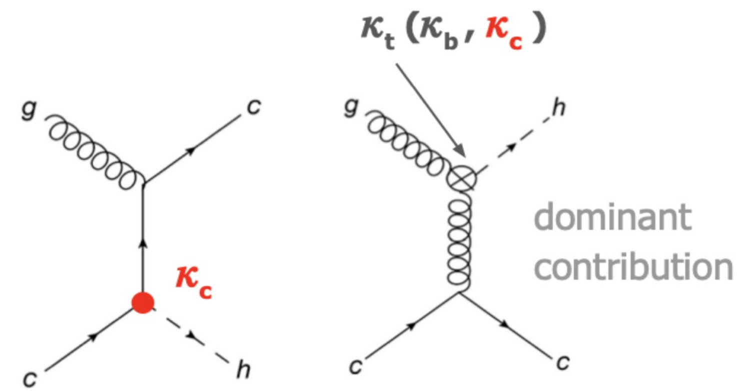


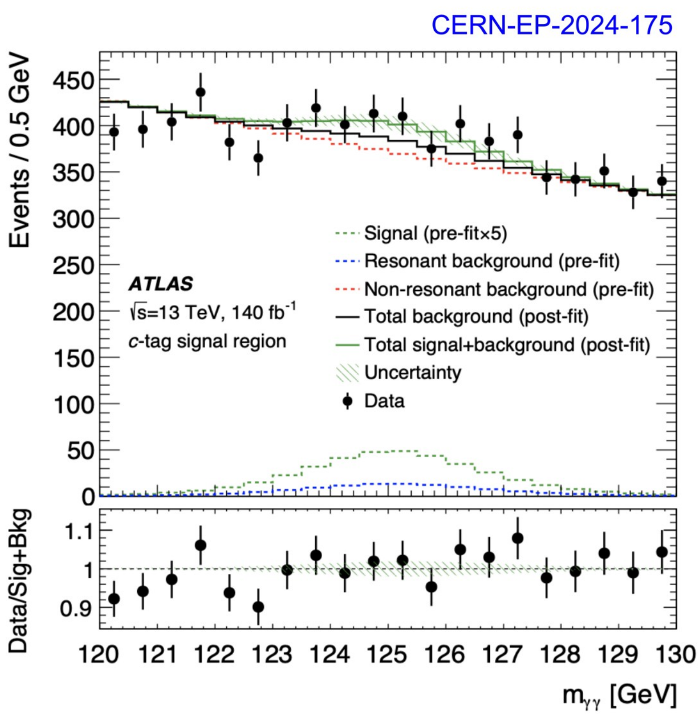
arXiv:2407.10904

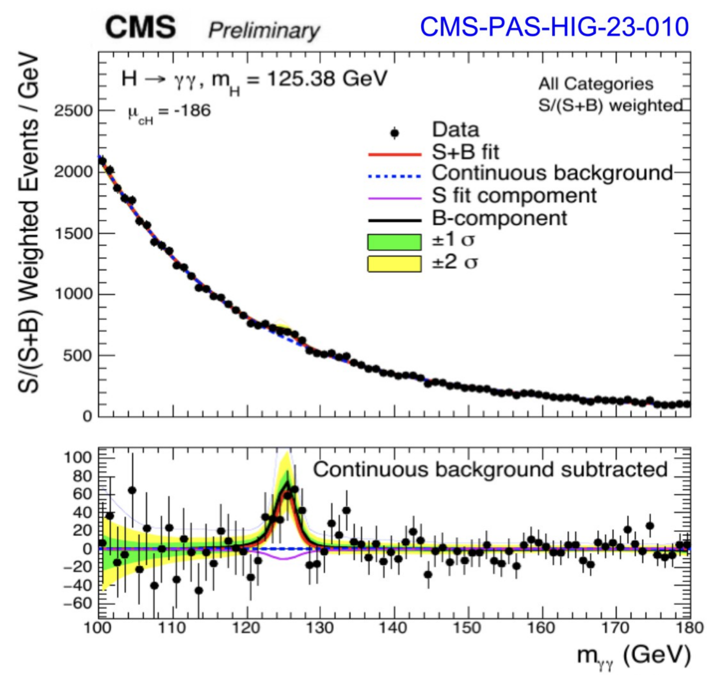


Very rare production processes: H(→γγ)+c

- **Proving the c-coupling via the production**
- **Analysis strategy:**
  - Exploits the clean decay of H →γγ
  - Challenges: c-tagging, dominant contributions not sensitive to κ_c (~99%) in particular ggH backgrounds
  - Non-resonant bkg $pp \rightarrow \gamma\gamma + n$ is data-driven estimated





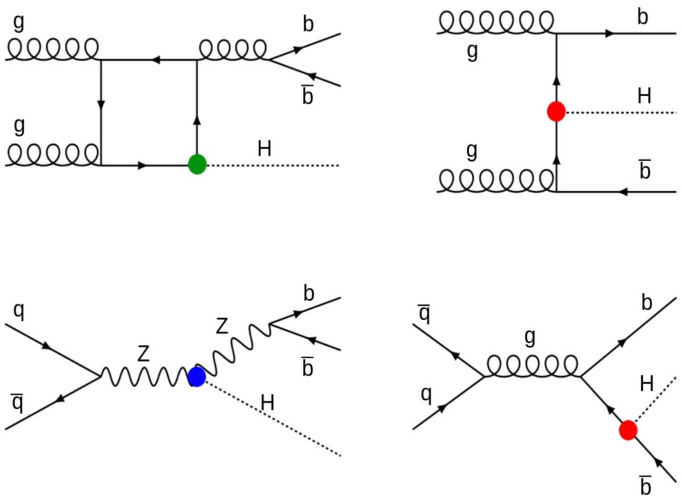


- ATLAS target inclusive H+c
- σ(H+c) = 5.2 ± 3.0 pb (SM: 2.9 pb), < 10.4 pb @ 95% CL

- CMS target κ_c-dependent part
- μ < 243 (355) ⇒ $|\kappa_c|$ < 38.1 (72.5) @ 95% CL

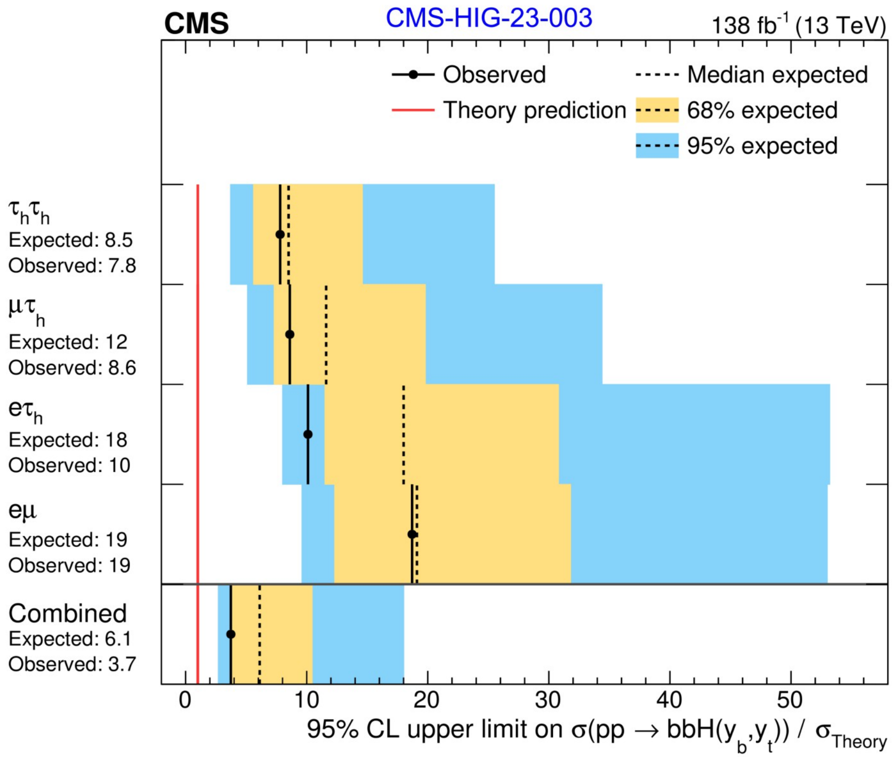
Very rare production processes: bbH(→ττ/WW)

- **bbH cross-section ~ ttH cross-section**
- Sensitive to Higgs-b-quark and Higgs-top coupling
  - Quark loop dominates cross-section +destructive interference



- **Analysis strategy:**
  - Decays to pairs of tau leptons and pairs of leptonically decaying W bosons are considered
  - BDT classifiers used in each of the studied channels
  - **Main challenges:** large backgrounds from Z+jets, tt, jet →τhad mis-ID

- μ <3.7 at 95% CL (exp. 6.1)

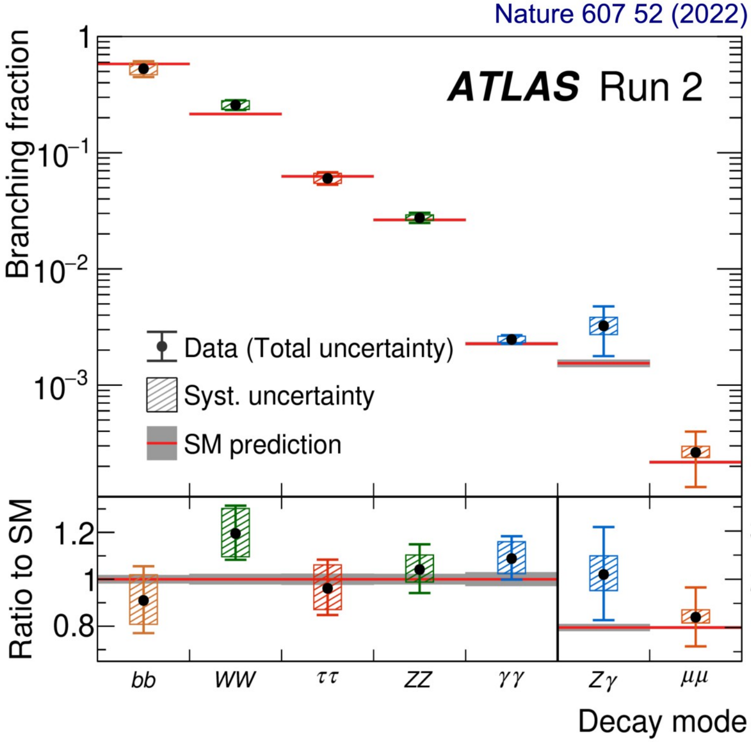


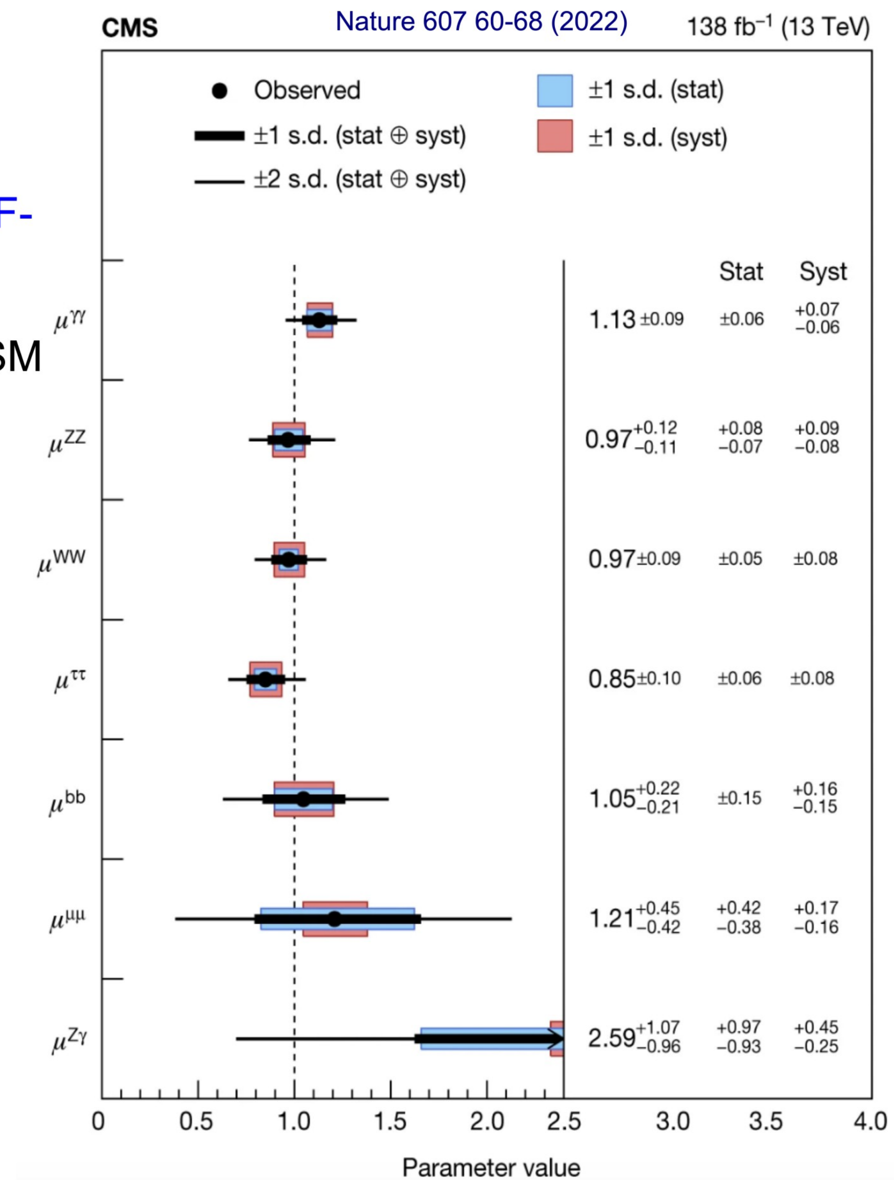
Let's talk about its decays

- **> 88% of potential SM decays observed and measured with < 10-20% precision (updated in 2022, 10th Higgs discovery anniversary)**
  - No observation of H→μμ, cc, gg...

- Some recent results:
  - VH, H→ bb/cc, ATLAS Run-2 legacy [ATLAS-CONF-2024-010]
  - H→$\tau\tau$, ATLAS Run 2 legacy [HIGG-2022-07]. Total cross-section values computed and agreeing with SM

Nature 607 52 (2022)

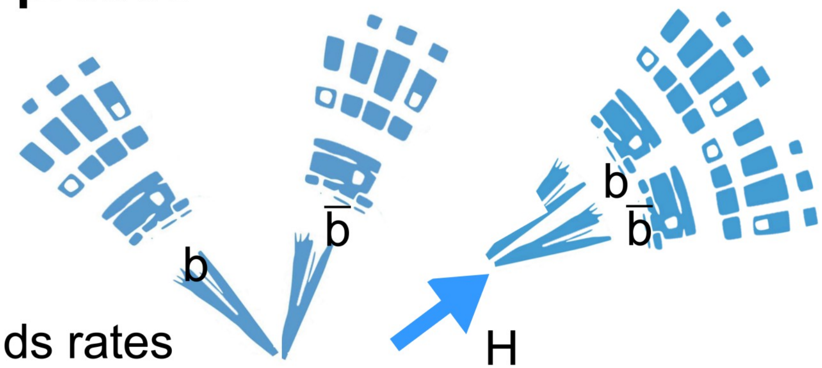




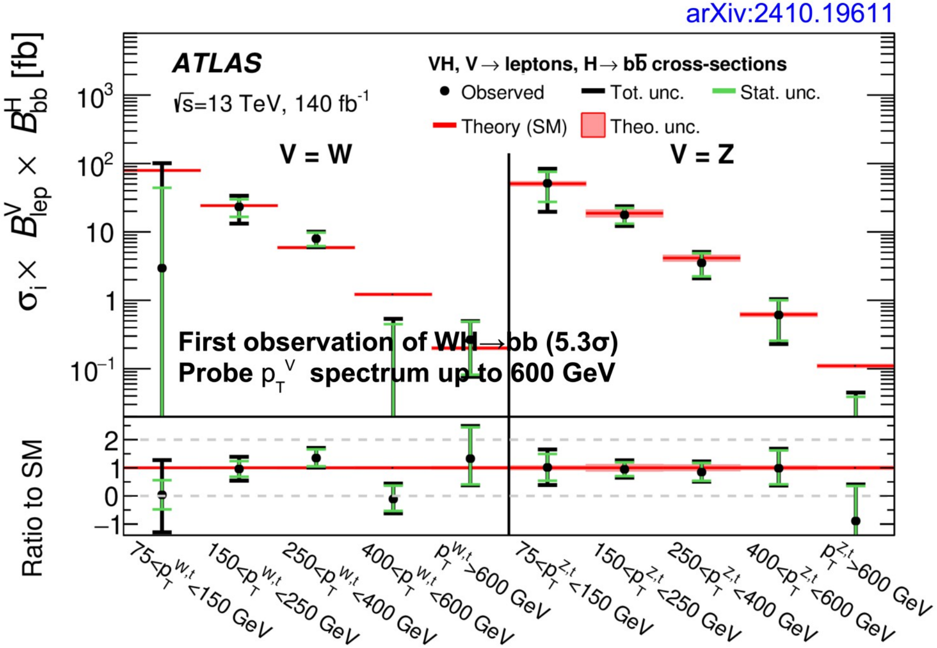
Run-2 VH (H→ bb|cc) measurement (1/2)

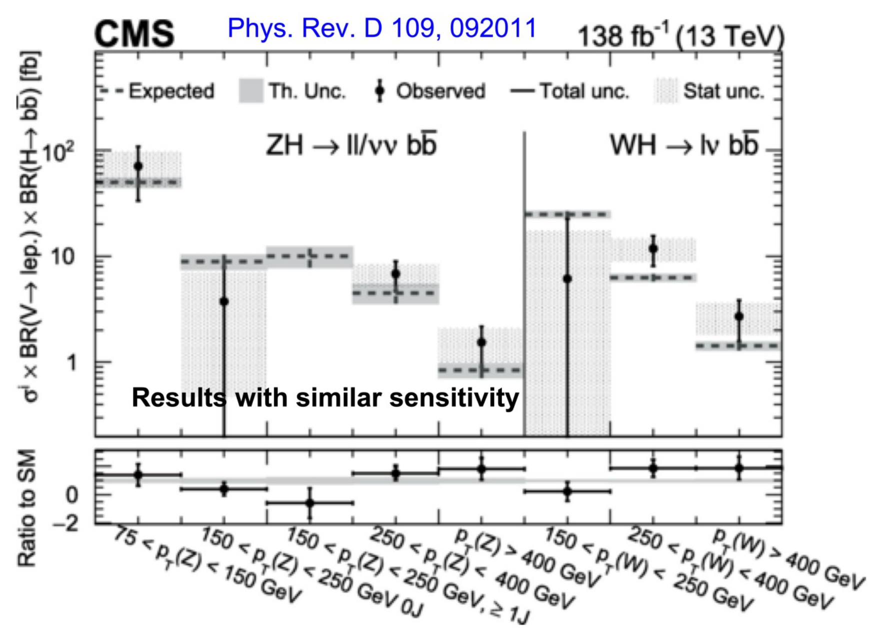
- **H → bb largest Higgs decay BR (58%) and H→cc probes coupling to 2nd generation quark**

- **Analysis strategy for VH, H→bb:**
  - Boosted (p_T^V > 250 GeV) and resolved topologies
  - Split signal according to number of leptons
  - **Challenges**: poor kinematic resolution, high backgrounds rates (V+jets and top) and requires excellent performance for the b-jets ID



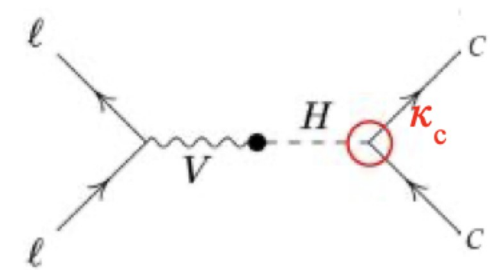
- Observation of H→bb in 2018, now in full differential measurements mode. Results compatible with SM!



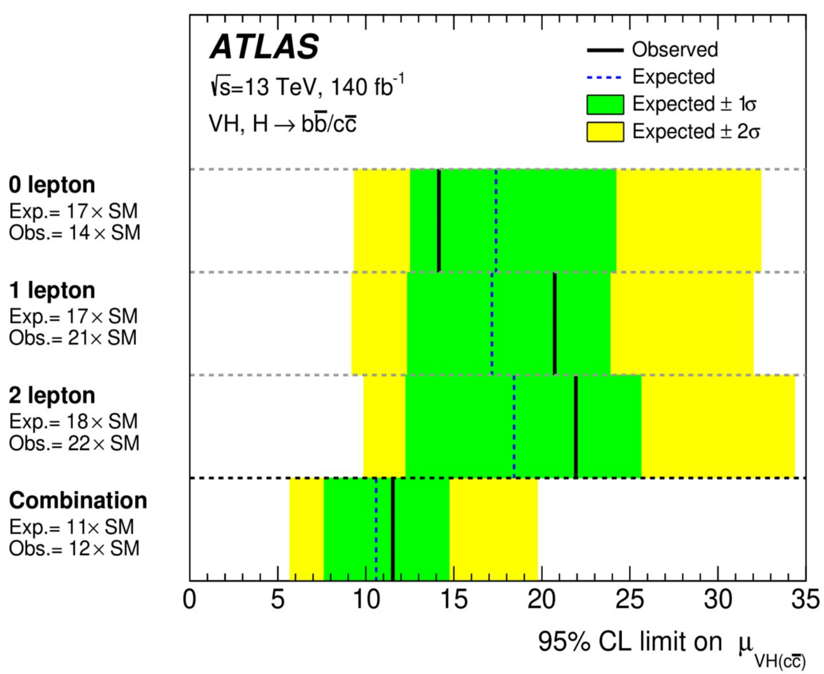


Run-2 VH ($H \to$ bb|cc) measurement (2/2)

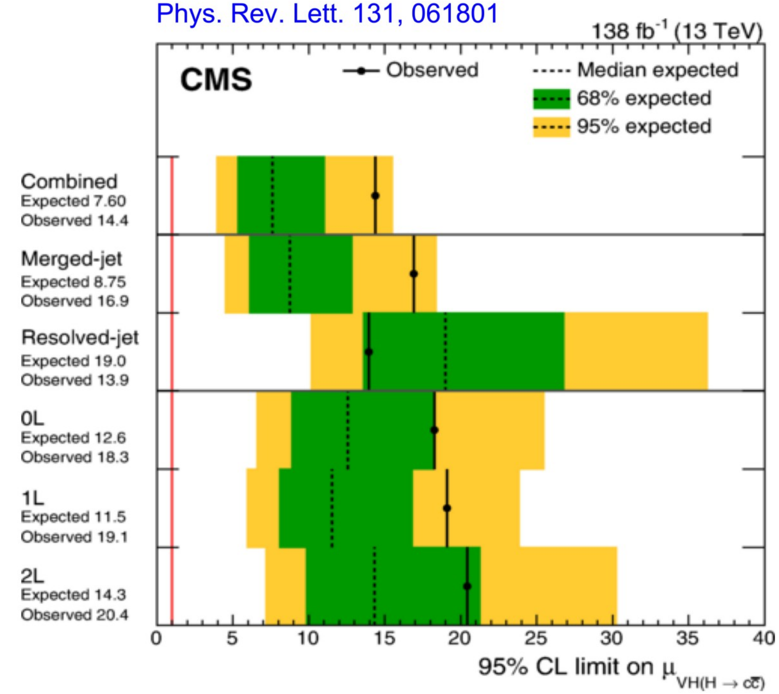
- **Let's focus on the $H \to cc$ results: proving the coupling via the decay**
- **Improvements wrt previous analysis**: improved b-/c-tagging, ML for signal vs background separation



arXiv:2410.19611



Phys. Rev. Lett. 131, 061801



- ATLAS does a simultaneous fit with $VH \to bb$
- The analysis method is validated with the measurement of VZ, 5.2σ observed
- μ<11.3xSM obs.(exp.) and $|\kappa_c| < 4.2$ @95% CL
- Best limit to date. Improvements 2-3x wrt previous limits

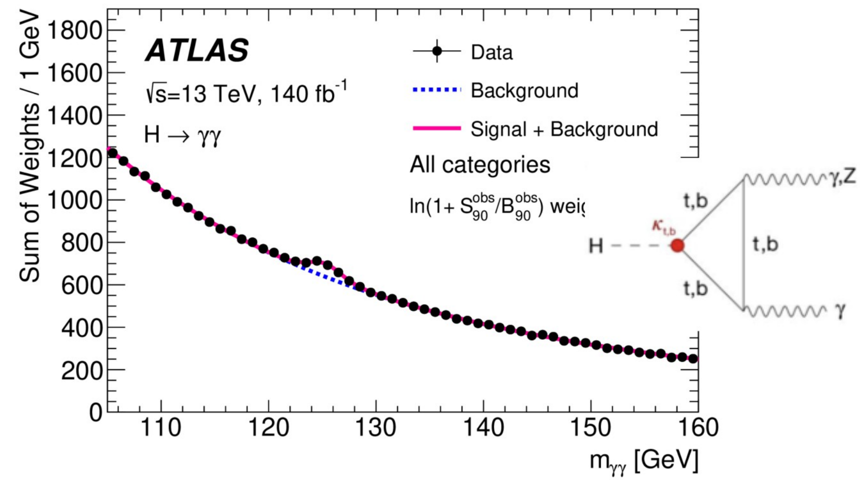
- Includes boosted $H \to cc$ ($p_T^H > 300$ GeV)
- μ<14(8)xSM obs.(exp.) @95% CL and $1.1 < |\kappa_c| < 5.5$
- First observation of $Z \to cc$ in hadronic collisions

Latest results on:
Other Higgs boson properties

Its mass

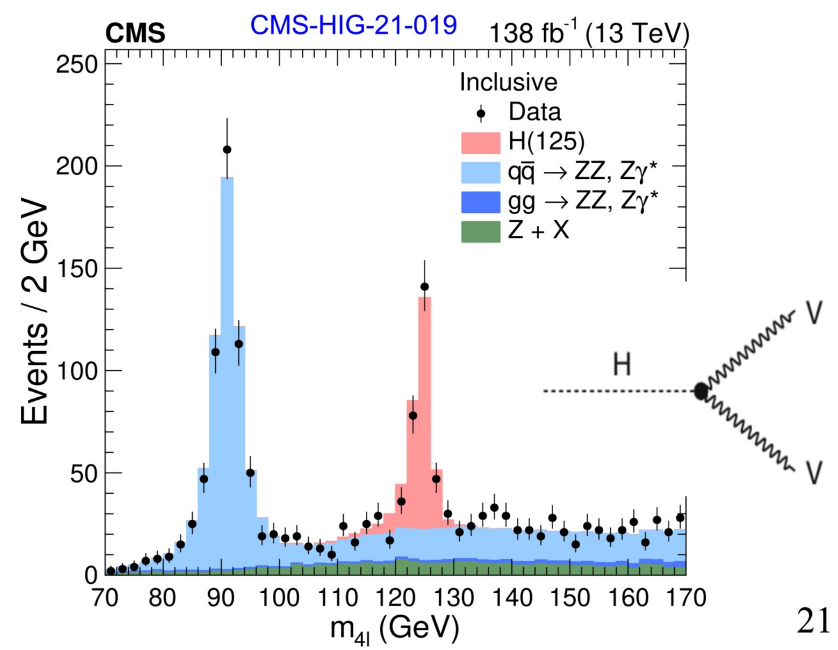
Phys. Lett. B 847 (2023) 138315
Phys. Lett. B 843 (2023) 137880

- Leading precision channels for mass measurements:
  - **H→ZZ→4l (e/μ):** Low statistics but clean final state, high signal/bkg. Still dominated by statistical uncertainties
  - **H→γγ:** High statistics and good $m_{\gamma\gamma}$ resolution. Smoothly falling background in $m_{\gamma\gamma}$. Large effort put to reduce uncertainties on photon energy calibration.



- **ATLAS uses a combination of both channels**
  - m_H = 125.08 ± 0.10 (stat.) ± 0.05 (syst.) GeV
  - Most precise measurement to date

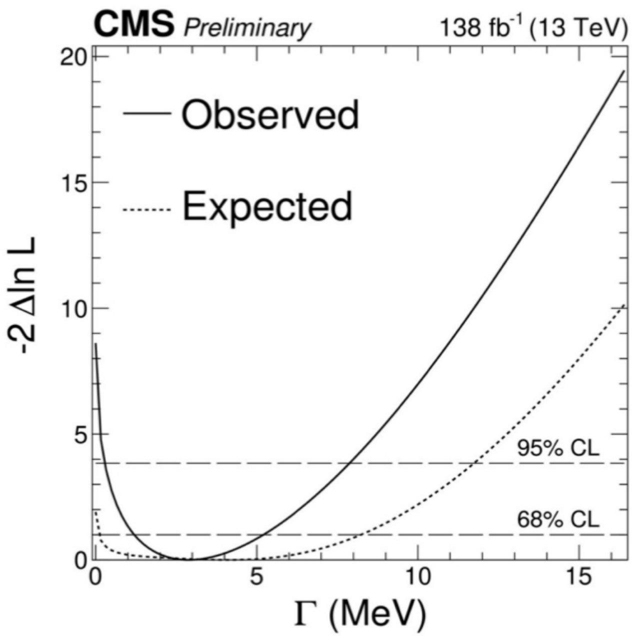
- **CMS results comes from H→ZZ→4l**
  - M_H = 125.04 ± 0.11 (stat.) ± 0.12 (syst.) GeV
  - Most precise single measurement (< 1%)



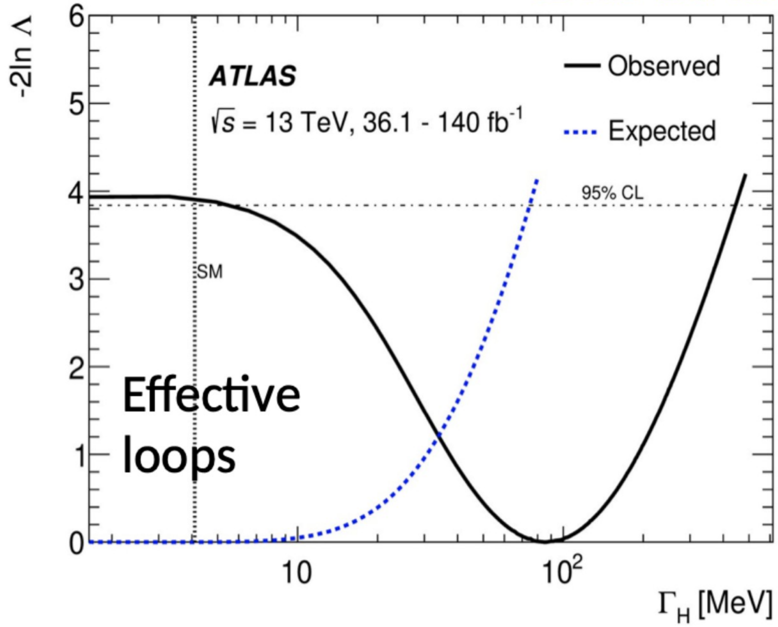
Its total decay width

- **SM predicts Higgs width: ~ 4.1 MeV for m_H~125 GeV**
  - Can be altered through BSM Higgs-boson decays
  - Can not be measured directly at LHC due to limited detector resolution

CMS-PAS-HIG-21-019



CERN-EP-2024-190



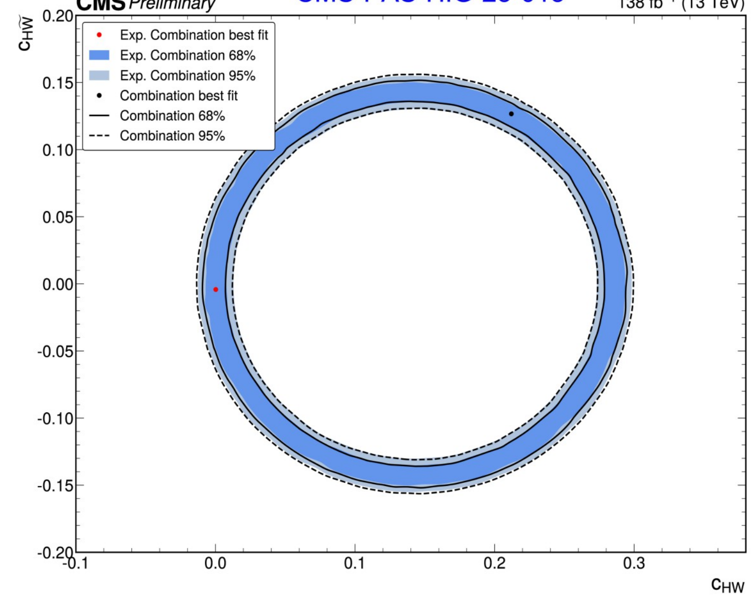
- **Higgs width from H→ZZ→4l** relies on on- and off-shell couplings being the same, and no BSM contributions to ggH loop
  - ATLAS: $\Gamma_H = 4.5^{+3.3}_{-2.5}$ MeV (PLB 846 (2023) 138223)
  - CMS: $\Gamma_H = 2.9^{+2.3}_{-1.7}$ MeV (CMS-PAS-HIG-21-019)
- **First attempt to constraint it using 4-top production cross-section** and Higgs on-shell measurements. Assumes on- and off-shell couplings to top are the same
  - CMS: Γ_H<110×SM (expected 18×SM)

Higgs CP and CP violation

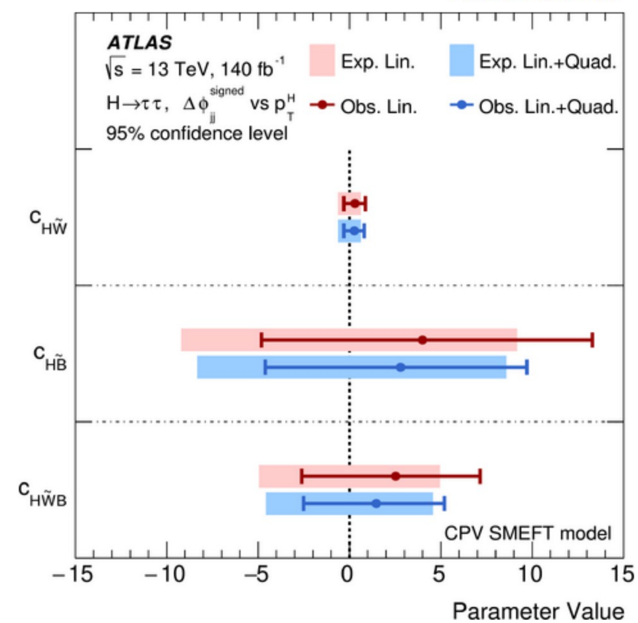
- **Could a violating Higgs-boson production or decay explain (partially) the matter-antimatter asymmetry?**
  - The SM Higgs boson is a CP-even scalar (0+)
  - ATLAS and CMS excluded pure spin-parity states 0− , 1+ , 1− , 2+ and 2− @> 99% CL based on the observed Higgs boson decays ($\gamma\gamma$, ZZ, WW)
  - But, could the Higgs boson be a mixture of CP-even and CP-odd states?

- CP-odd effects in Higgs boson couplings being tested in different ways, e.g.
  - SMEFT interpretation of the p_T^H spectrum in Combination of fiducial differential cross-section measurements in H→γγ / $\tau\tau$ / WW / ZZ final states [CMS-PAS-HIG-23-013]
  - Fiducial differential cross-sections for VBF/ttH, H→$\tau\tau$, e.g. $\Delta\varphi_{jj}$, sensitive to Higgs CP [HIGG-2022-07]
  - **All results compatible with the SM**

CMS-PAS-HIG-23-013



HIGG-2022-07

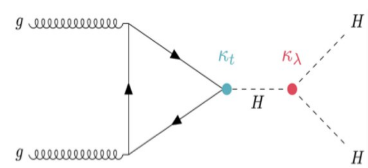


2D and 1D scan of pairs of CP-even and CP-odd operators

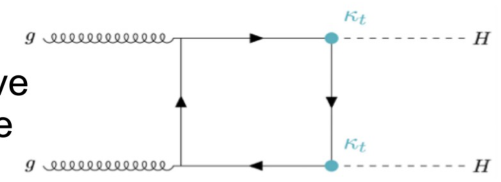
Latest results on:
Higgs self couplings

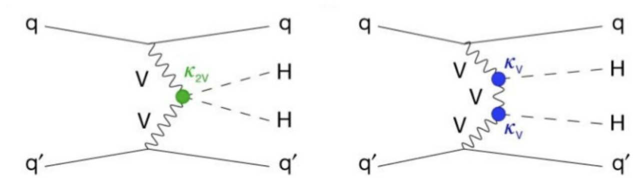
On the search side: HH production

- Another way of probing the EWSB mechanism: making progress towards **testing the shape of the Higgs potential through the Higgs self-coupling**
  - Rare process in SM: σ(gg→HH) ≈0.1%*σ(gg→H)
  - LHC has generated ~7.5 million Higgs boson but only 4500 Higgs-boson pairs in Run-2



+ destructive interference

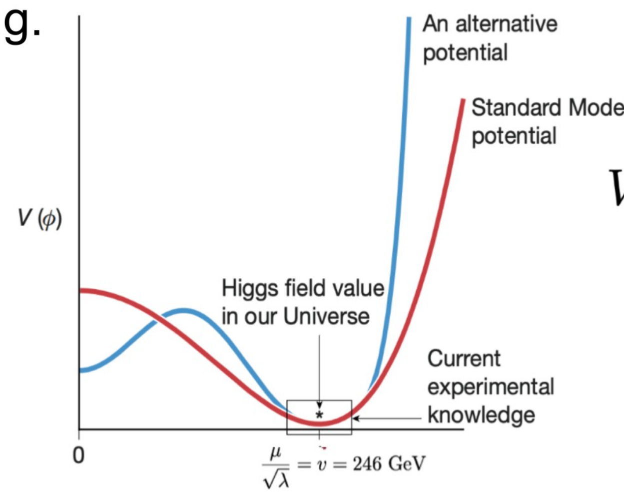




- Access the triple Higgs boson coupling (κ_λ)
  - Probe the shape of the Higgs potential
- Also access to other interactions, e.g. VVHH (κ_{2V})

	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%

= Existing results



$$V = V_0 + \frac{1}{2} m_H^2 h^2 + \frac{m_H^2}{2v^2} v h^3 + \ldots$$

Higgs boson mass: *know to 0.2%*

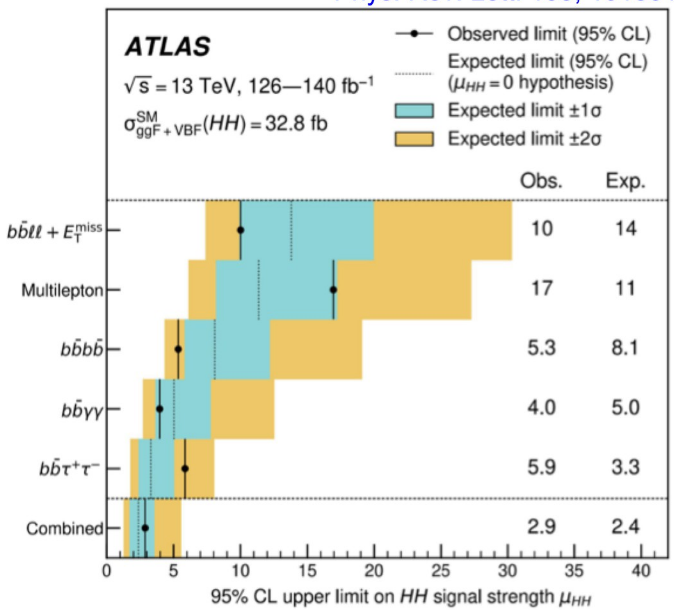
Higgs boson self interaction

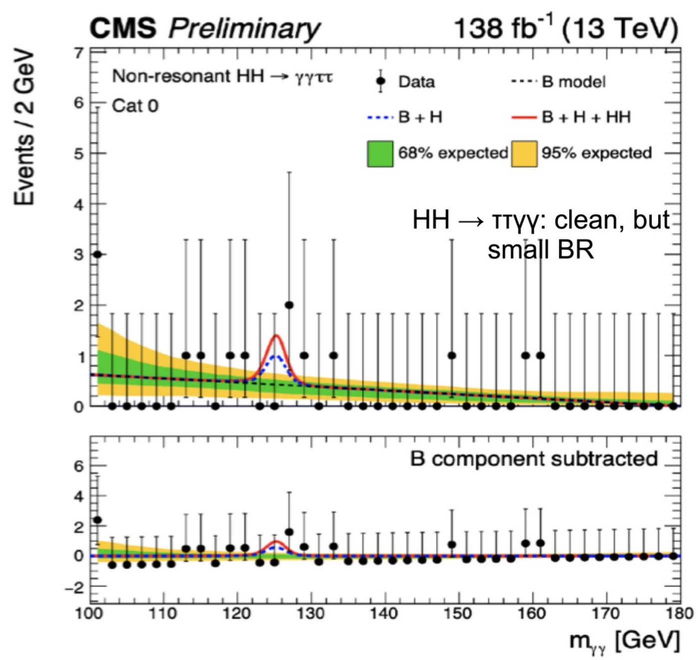
- No golden channel, therefore a combination is important to increase sensitivity!

News on κ_λ

- **ATLAS Run-2 HH combination (bbττ + bbγγ + bbbb + multileptons + bbll+MET)**
  - Best (exp.) upper limit on σ(ggF HH): < 2.9 (2.4) × SM @95% CL
- **Similar result obtained by CMS** [Nature 607 (2022) 60] with same channels
- Observed limits on κ_λ:
  - ATLAS: [-1.2, 7.2]
  - CMS: [-1.24, 6.49]
- Hierarchy of channels depends on many things → not the same in ATLAS/CMS
- The following aspects are key to progress towards HH evidence:
  - Good detector performance
  - Improvements of analysis and object performance technique
  - Exploring new channels

Phys. Rev. Lett. 133, 101801



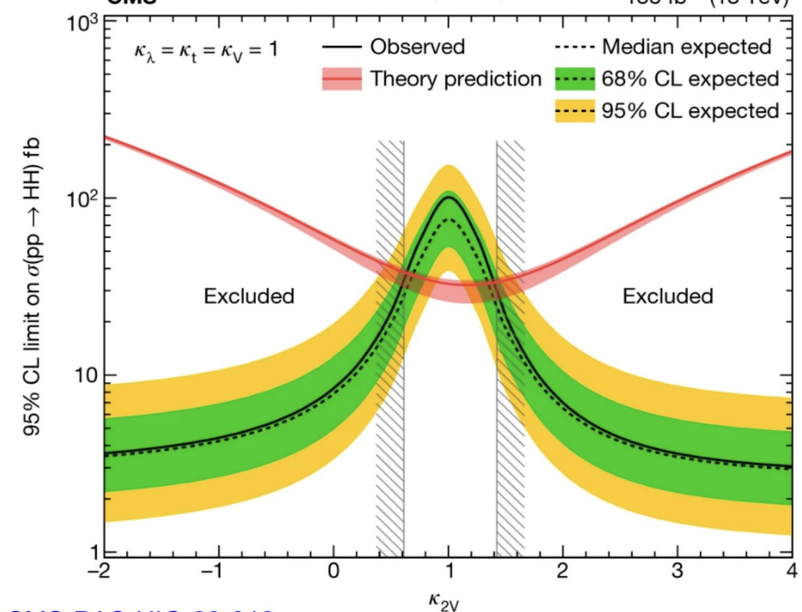


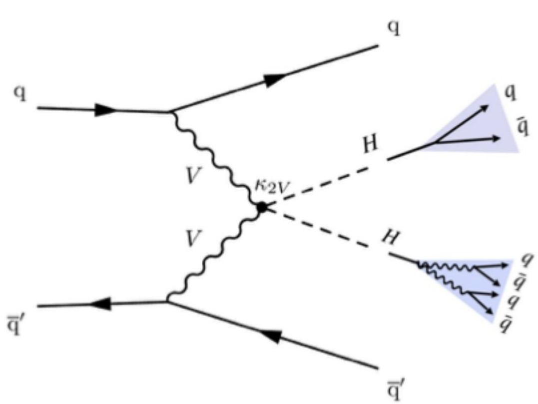
News on κ_{2V}

- **Current constraints on κ_{2V}:**
  - ATLAS: [0.6, 1.5] Phys. Rev. Lett. 133, 101801
  - CMS: [0.67, 1.38] Nature 607 (2022) 60
  - Dominated by bbbb

- **Exploration of new channels also important in this case**, e.g. CMS first search for all-hadronic bbVV in boosted topology
  - $-0.04 < \kappa_{2V} < 2.05$ @95% CL ($0.05 < \kappa_{2V} < 1.98$ exp.)

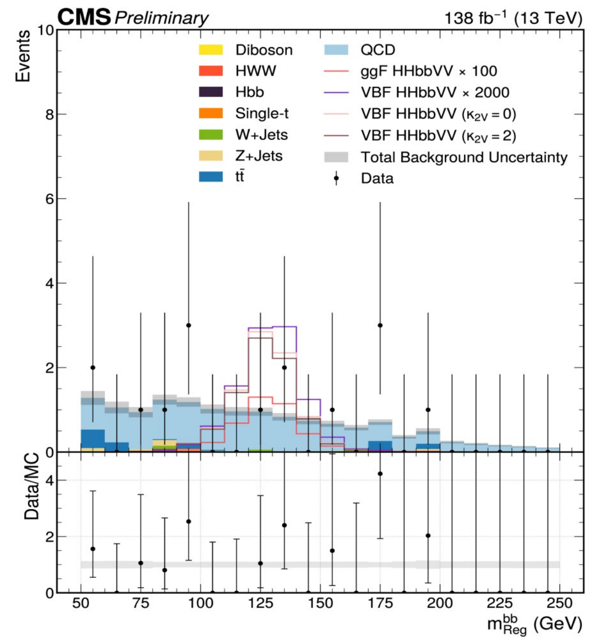
Nature 607 (2022) 60



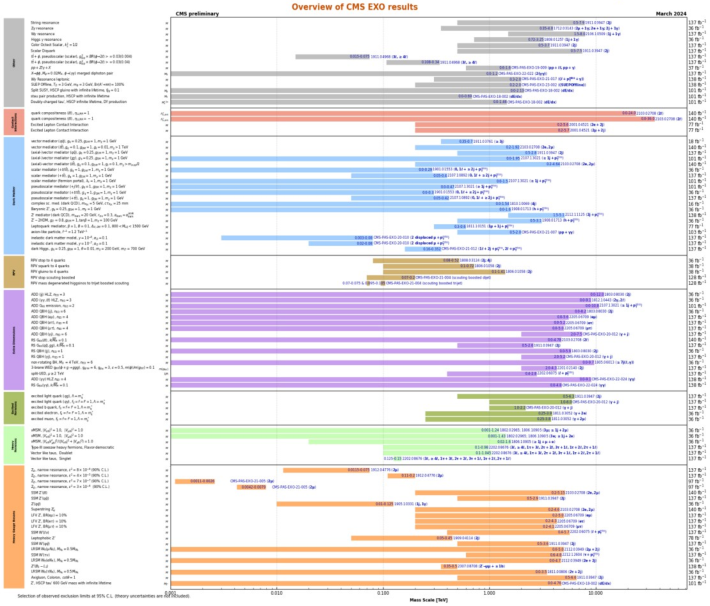


CMS-PAS-HIG-23-012

B-only Post-Fit VBF Region

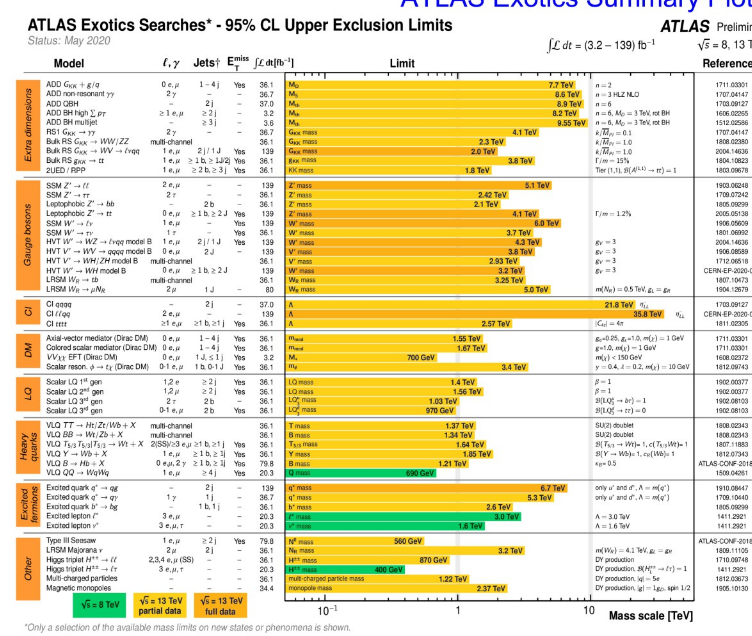


CMS Exotica Summary Plots



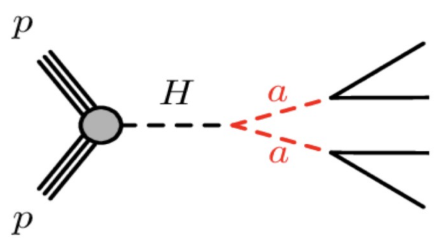
A huge BSM program at LHC: Higgs as a portal for new physics?

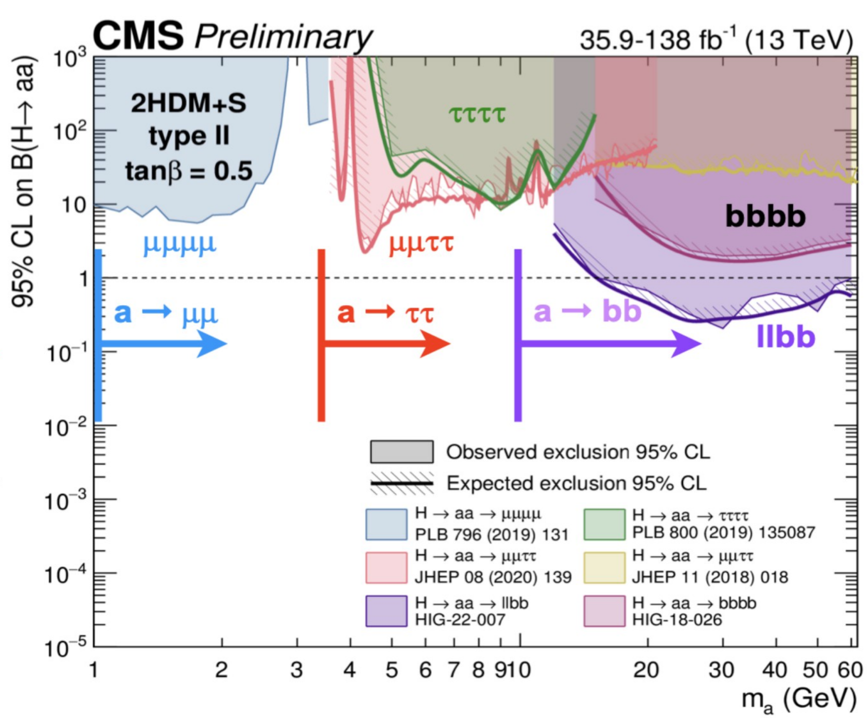
ATLAS Exotics Summary Plots



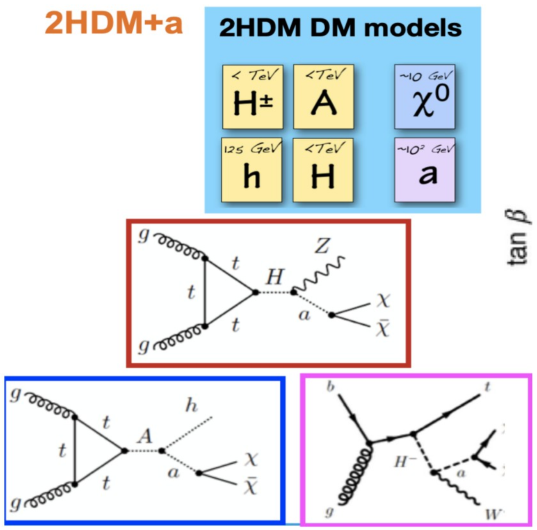
BSM in the Higgs sector (a couple of examples)

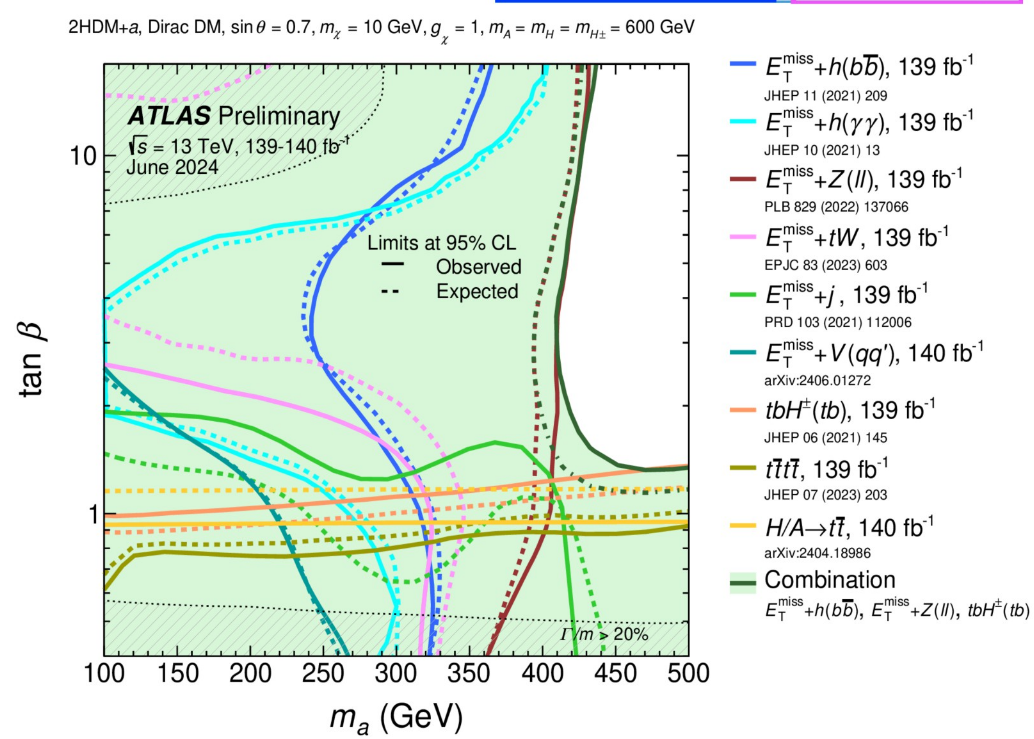
- Pseudoscalars (a) via Higgs decays





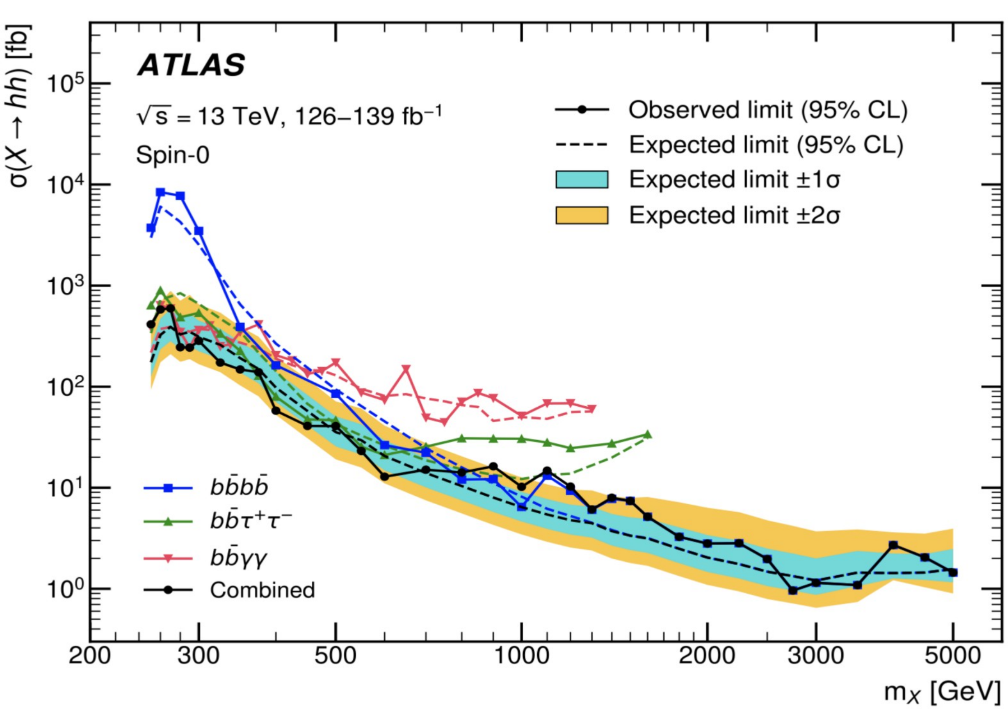
- Higgs and dark matter: 2HDM+a models



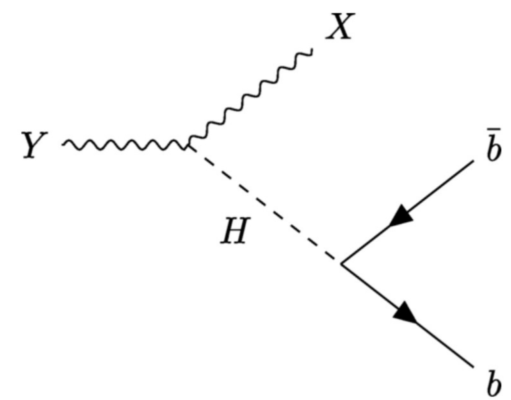


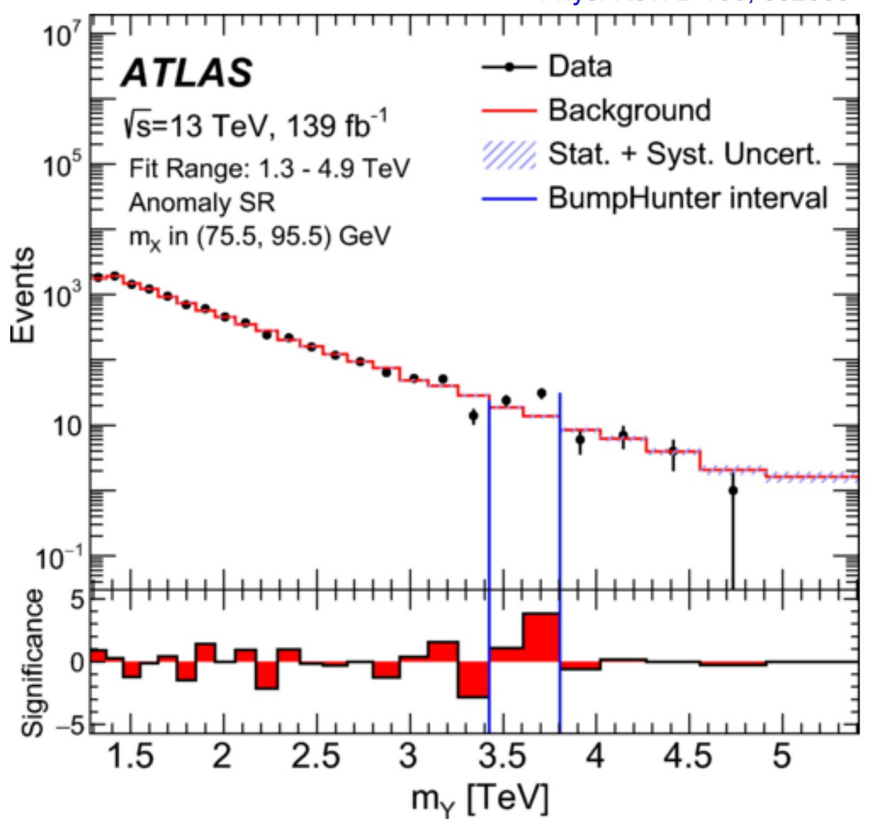
BSM in the Higgs sector (a couple of examples)

- Resonances decaying to Higgs bosons: X → HH combining bbbb , bbγγ and bbττ final states



- Anomaly detection based resonance search in fully hadronic states



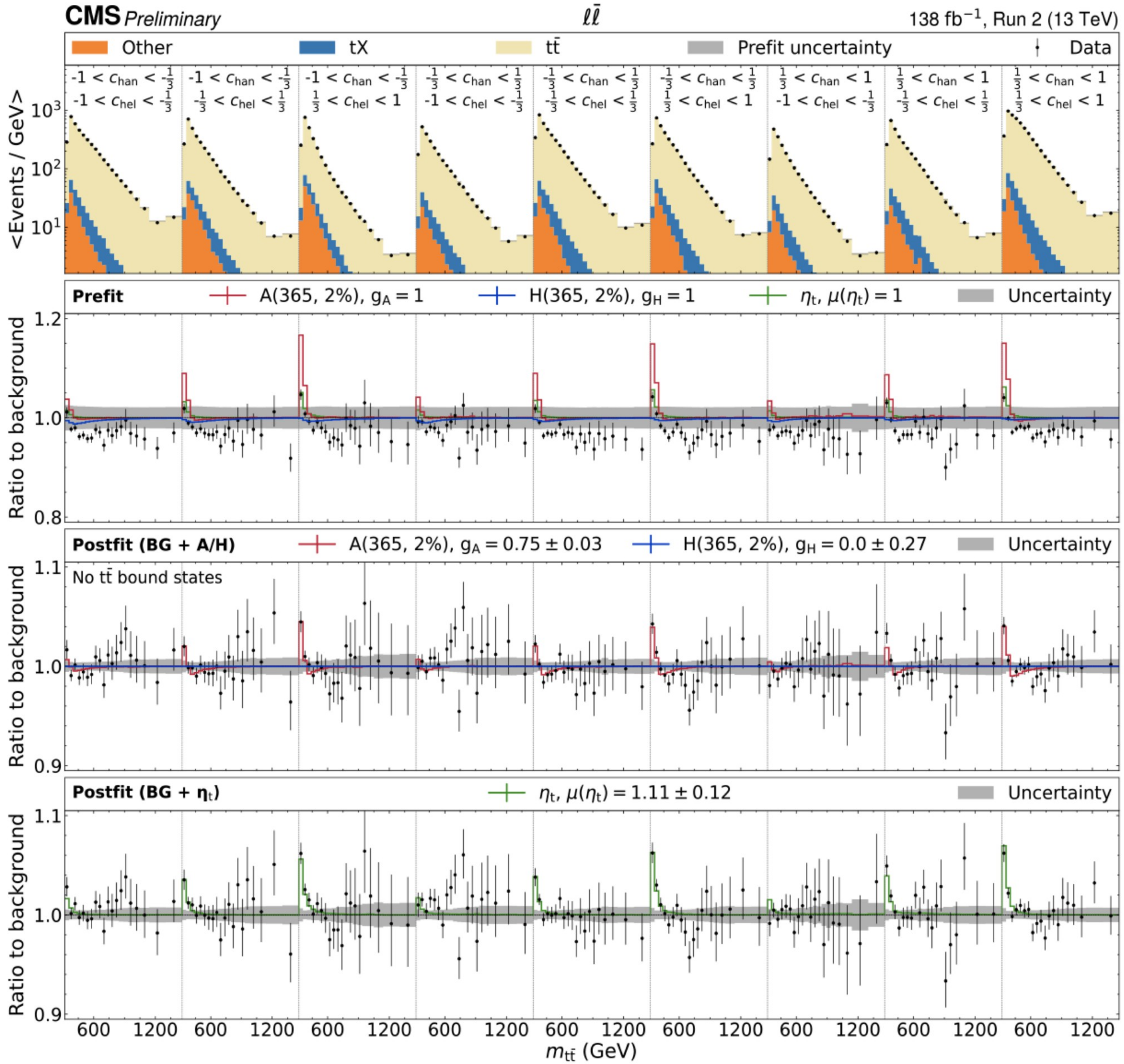


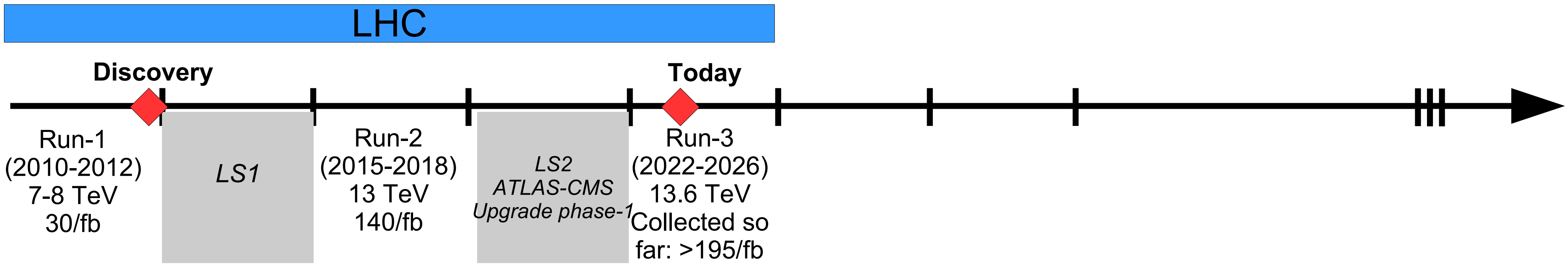
BSM in the Higgs sector (a couple of examples)

- Looking for scalar fields beyond the minimum prescribed in the SM. They might be neutral, charged, light, heavy, CP-even (H), CP-odd (A), etc

- E.g. search for A/H decaying to top-antitop pairs
    - Excess of >5 σ (local) close to threshold, fitted equally well by A and by color-singlet top-antitop bound state
    - Important to see what Run-3 data shows for these small excesses

CMS-PAS-HIG-22-013





Latest results using Run-3 data at 13.6 TeV!

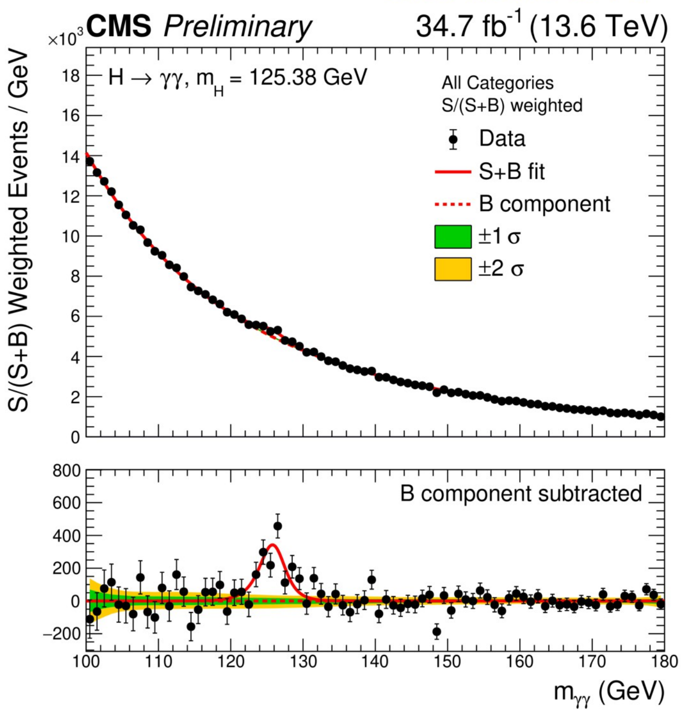
Cross-section measurements at 13.6 TeV (1/3)

- Given strong sensitivity of $H\to\gamma\gamma$ and $H\to 4l$ channels, ATLAS and CMS performed analyses using early Run 3 datasets (34.7 fb^{-1} collected in 2022)

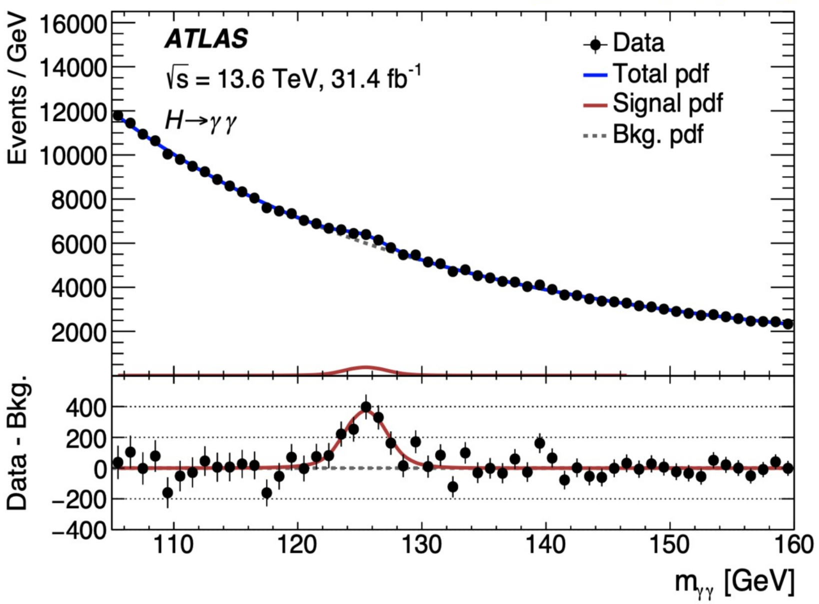
- Good agreement with SM predictions!

- Measured fiducial cross-sections:
  - 4l: 2.8 ± 0.74 fb (ATLAS), $2.94^{+0.53}_{-0.49}$(stat)$^{+0.29}_{-0.22}$(syst) fb (CMS), $3.09^{+0.39}_{-0.31}$ fb(SM)
  - $\gamma\gamma$: 76^{+14}_{-13} fb (ATLAS), 78 ± 11(stat)$^{+6}_{-5}$(sys) fb (CMS), 67.8 ± 3.4 fb

CMS-PAS-HIG-23-014



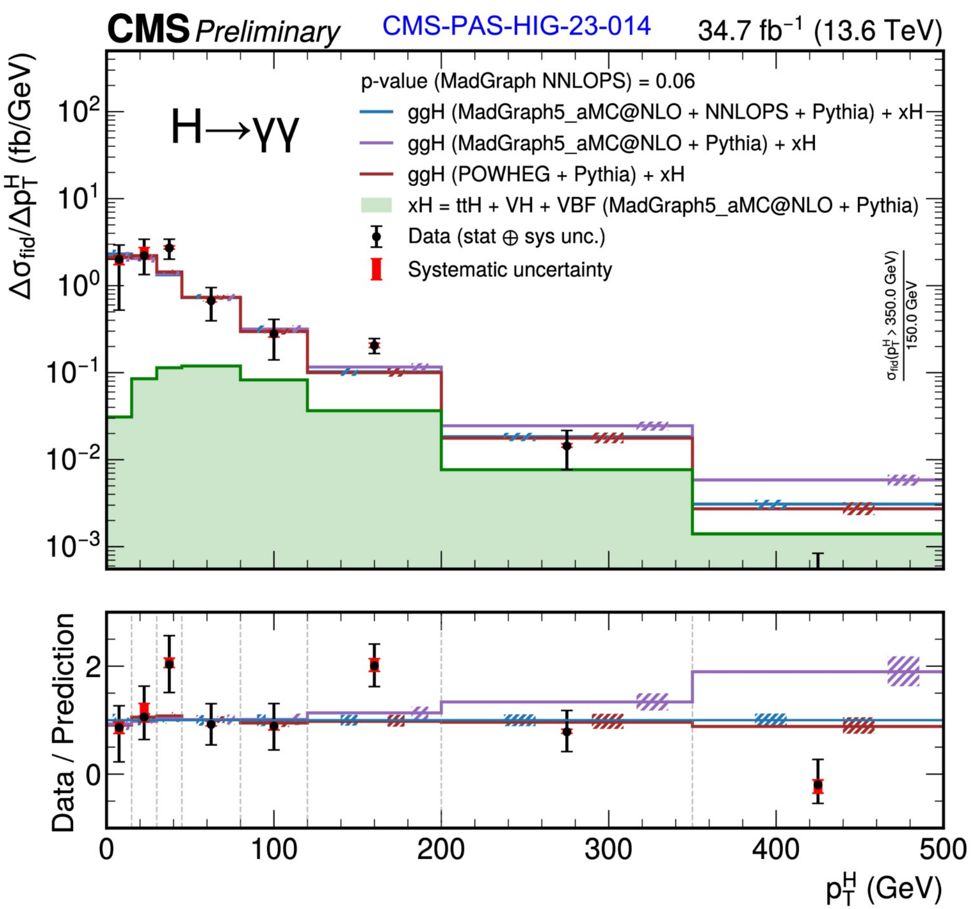
Eur. Phys. J. C 84, 78 (2024)

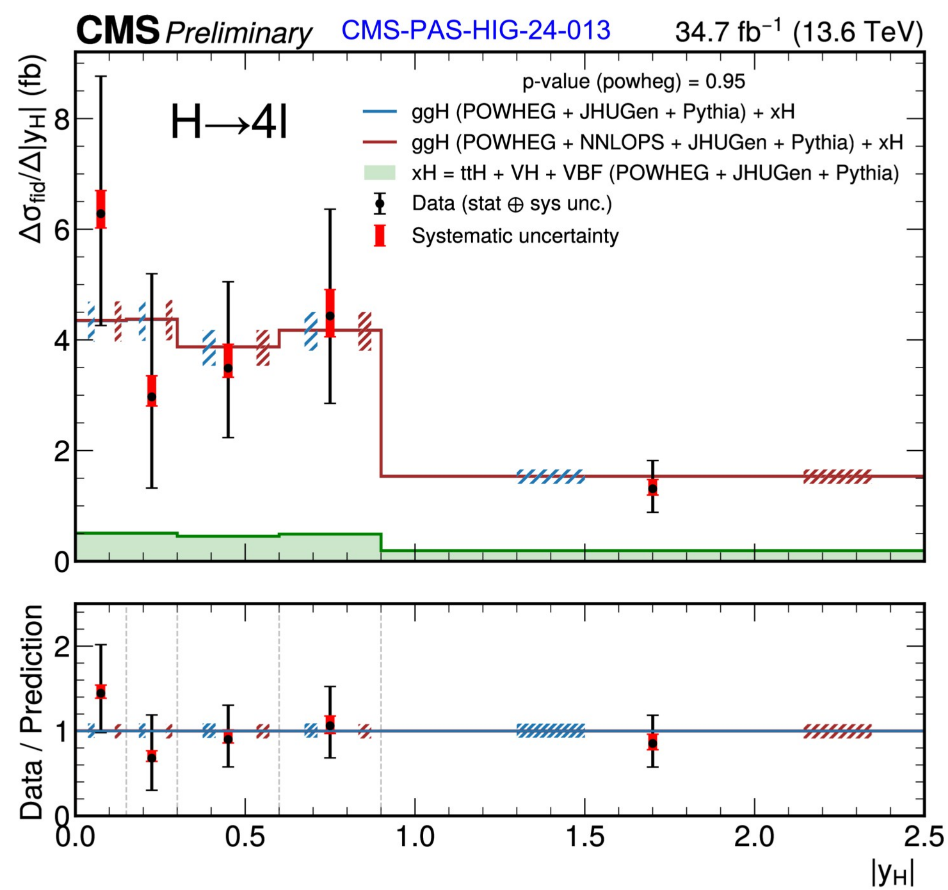


Cross-section measurements at 13.6 TeV (2/3)

- Given strong sensitivity of H→$\gamma\gamma$ and H→4l channels, ATLAS and CMS performed analyses using early Run 3 datasets (34.7 fb−1 collected in 2022)

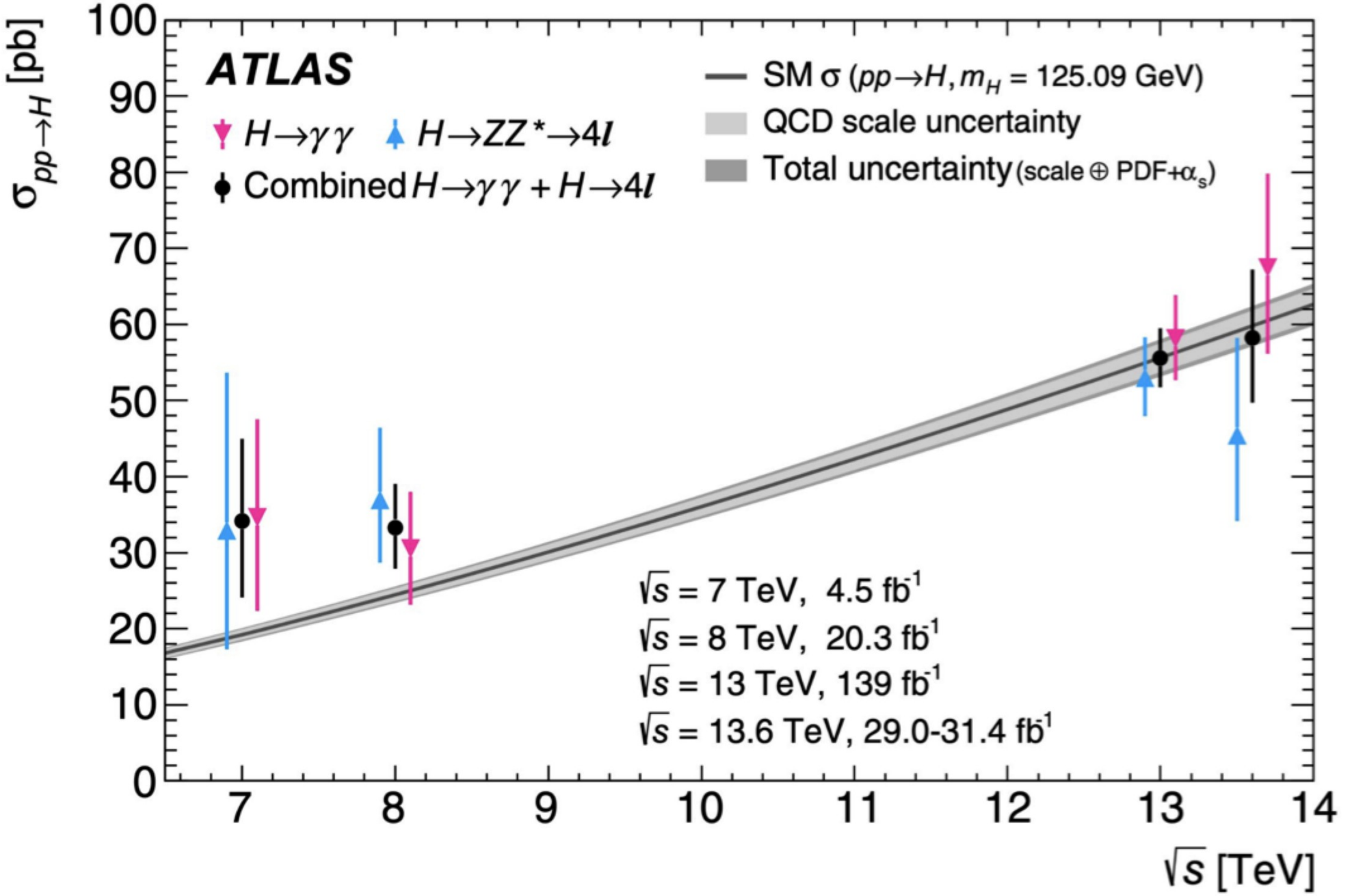
- Good agreement with SM predictions!

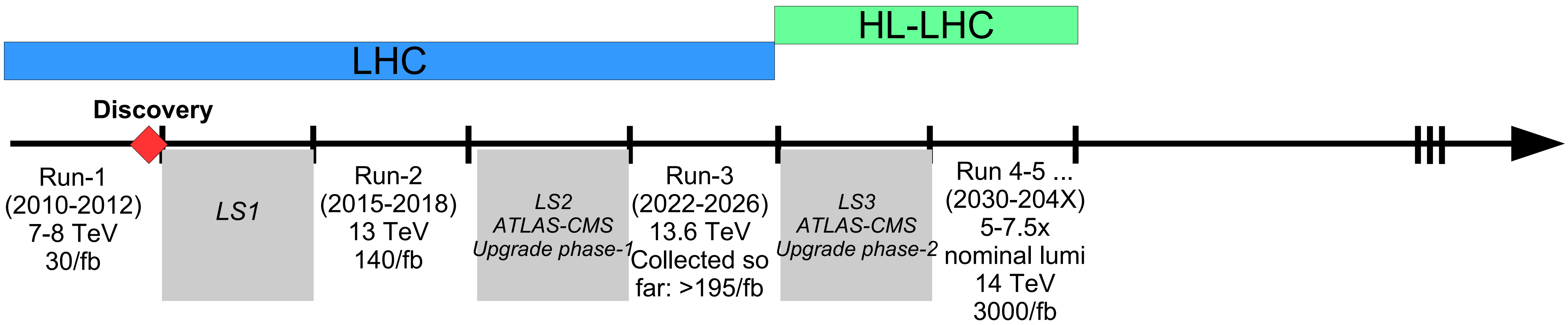




Cross-section measurements at 13.6 TeV (3/3)

- Comparing 13.6 TeV measurements with Run 1 and Run 2 results
  - Good agreement with SM predictions! expected trend predicted by the SM

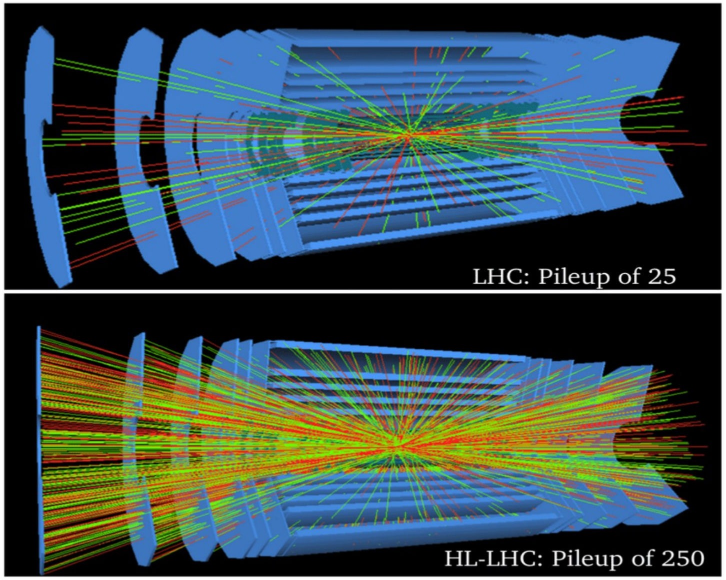


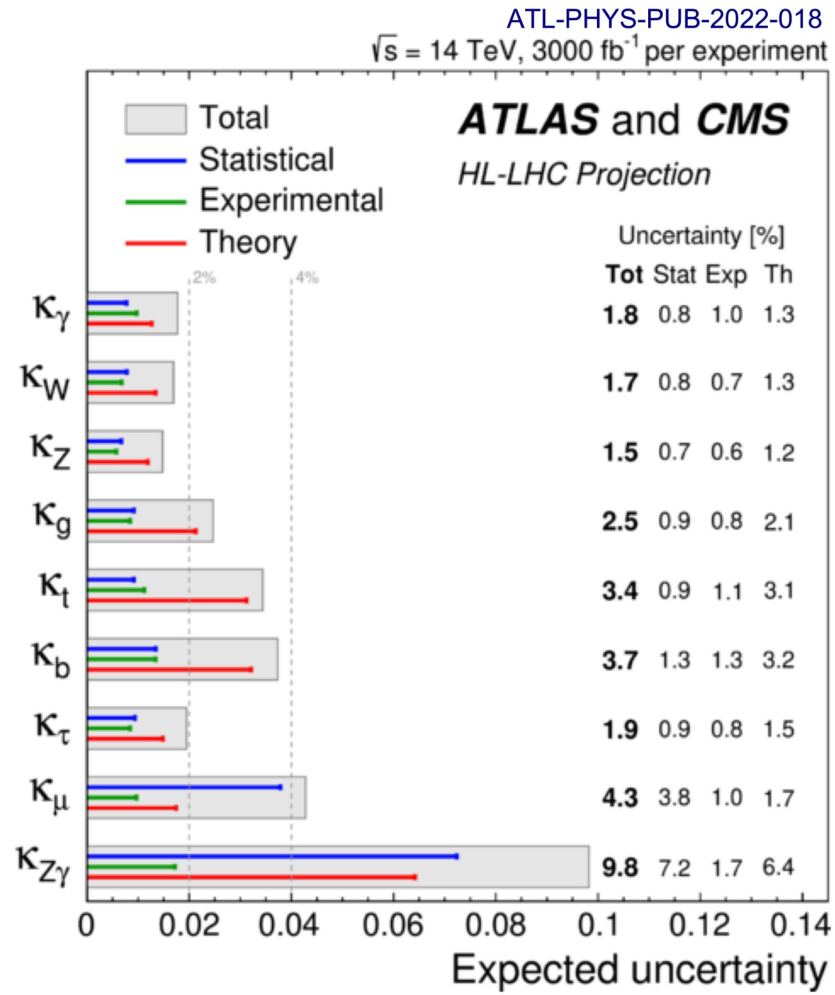


Looking towards the (not so far) future

High Luminosity LHC (HL-LHC)

- **HL-LHC will dramatically expand the Higgs physics reach**
  - 170M Higgs bosons - 120k HH pairs for 3000/fb
- **But also challenging!**
  - More pile-up, beam induced cavern background, radiation to detectors
  - Big challenges for computing and data storage given the larger dataset
- **Requires improvements for experiments in all areas**
  - Detectors, trigger, software and computing





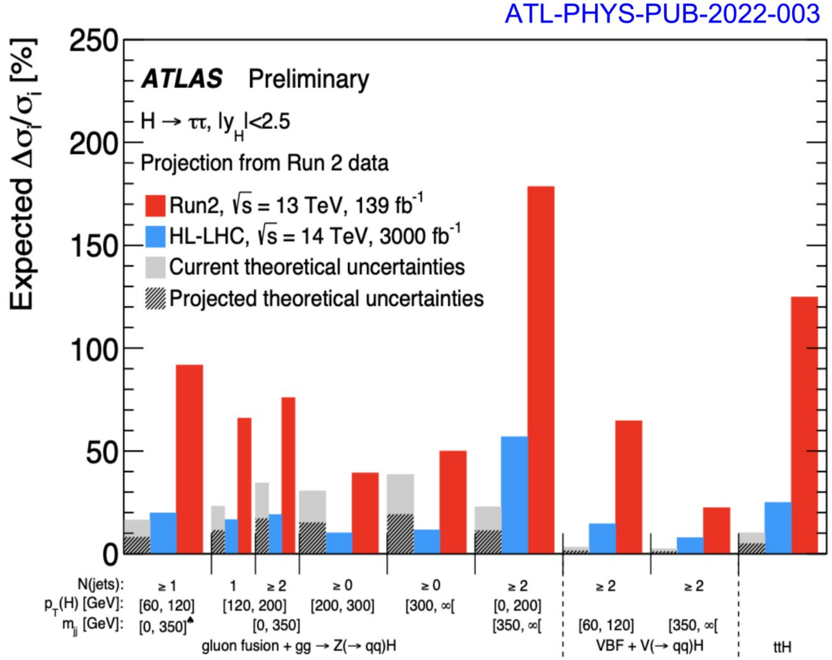
- 2-4% precision for many of the Higgs couplings. Theory uncertainty remains the largest component for most measurements
- Different uncertainties scenarios considered in these studies

High Luminosity LHC (HL-LHC)

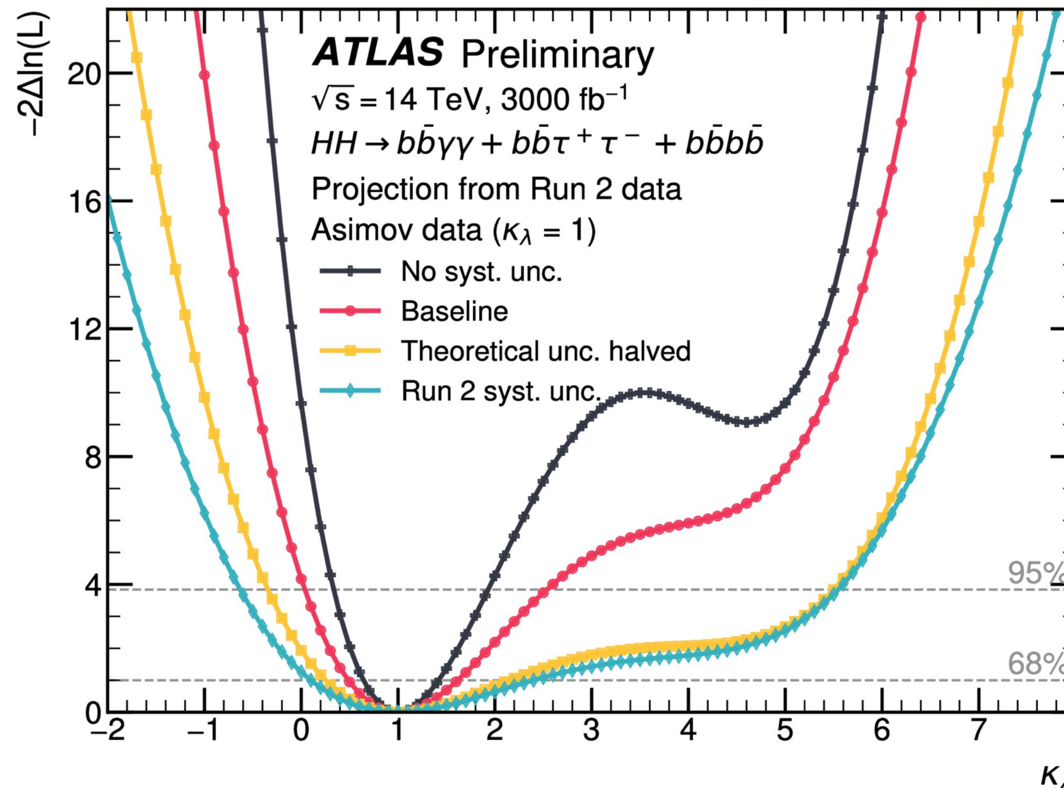
- **HL-LHC will dramatically expand the Higgs physics reach**

- Differential cross-sections: theory uncertainty dominates in many bins

ATL-PHYS-PUB-2022-003



ATL-PHYS-PUB-2022-053



- Significance of HH signal at the 5σ level (considering both experiments)
- 50% uncertainty on the self-coupling
- Several times CMS and ATLAS have exceeded their extrapolations (R&D, e.g. ATL-PHYS-PUB-2024-016 $bb\tau\tau$)

To conclude...

- **Major advances in Higgs boson physics since its discovery**. Impressive results thanks to collaborations, available data, improved algorithms and theoretical predictions
  - With increasing complexity of the analyses in terms of statistical model and analysis definition

- The Higgs is a **tool in the search for new physics**: direct and indirect way
  - So far good agreement with SM prediction given current accuracy
  - Still room for new physics, unfortunately no roadmap available

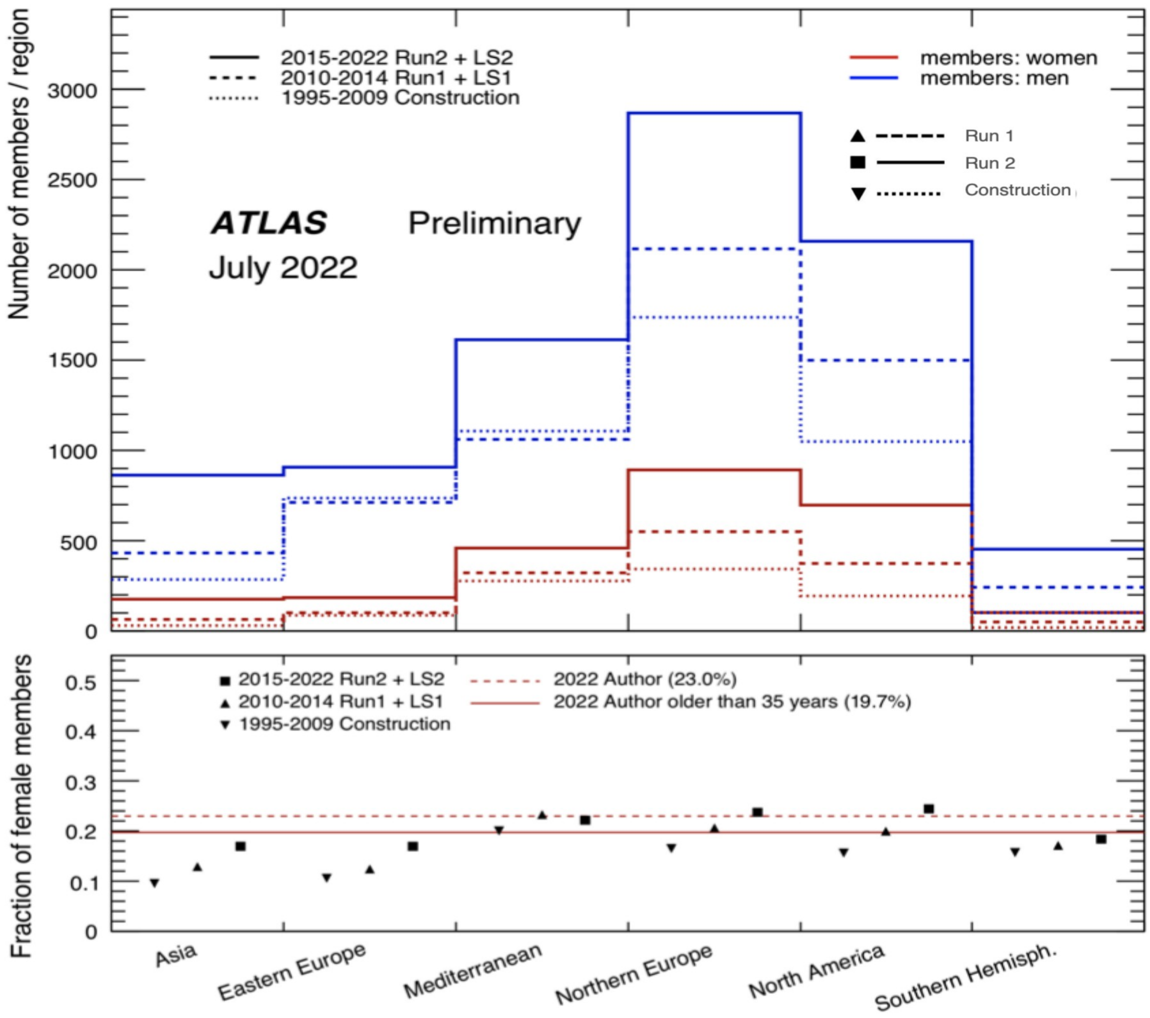
- A contextualised glimpse of the current state of the art for Higgs physics provided in this talk. More details will be provided in the following talks: Luke Baines, Gregory Douglas Penn, Sergei Shmatov

- Further analysis is being performed using the full Run-2 statistics and first results for Run-3 start to arrive as well
  - But already ~5× more data collected already in Run-3!
  - More combined measurements are expected in the coming months

BACKUP

ATLAS members by home institution

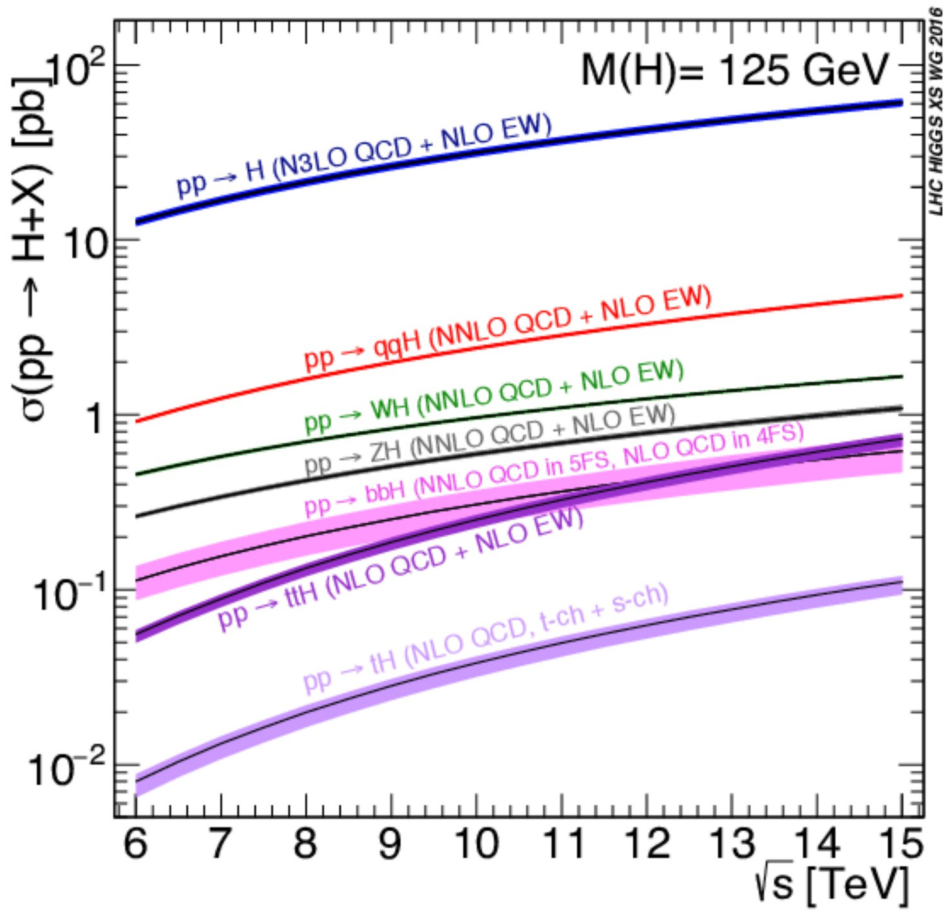
ATL-OREACH-PUB-2023-001

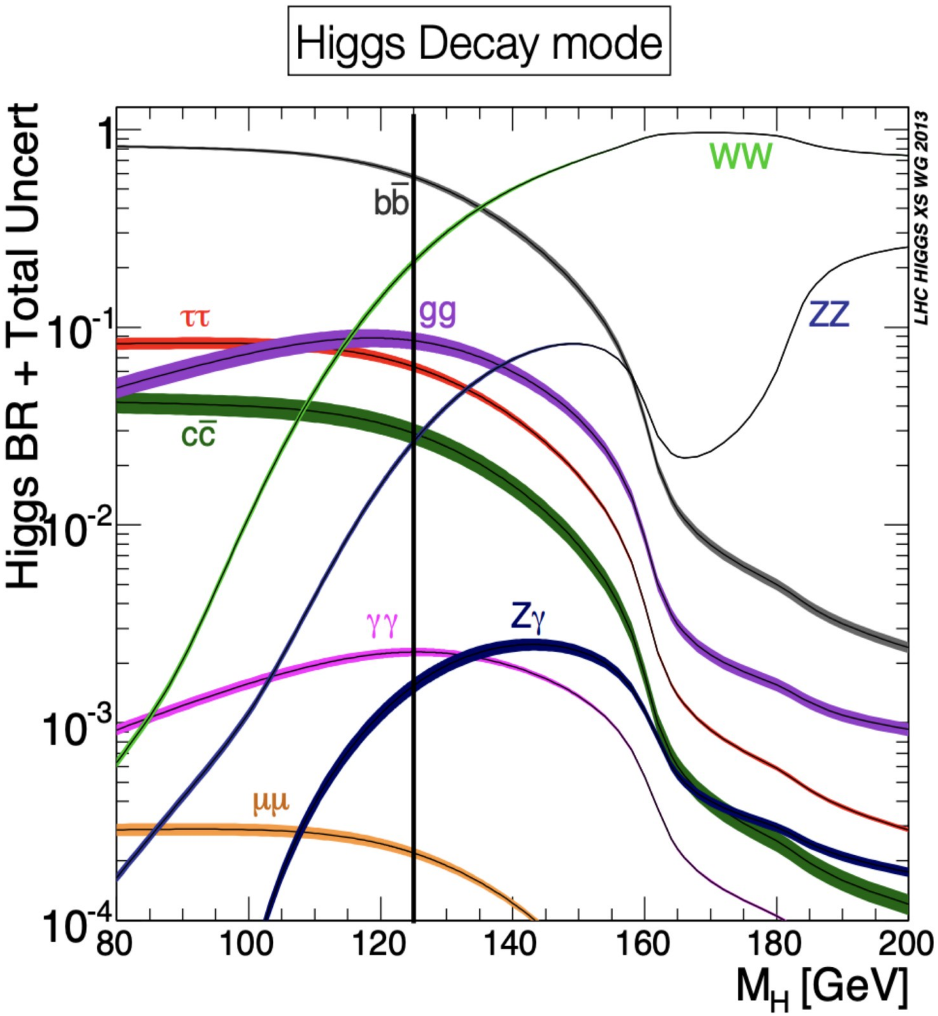


Number of ATLAS members by home institution (2022)

Asia: Armenia, Azerbaijan, China, Georgia, Japan, Taiwan
Eastern Europe: Belarus, Czech Republic, Poland, Romania, Russia (including JINR Dubna), Serbia, Slovakia, Slovenia
Mediterranean: France, Greece, Israel, Italy, Portugal, Spain, Turkey, Morocco
North America: Canada, USA
Northern Europe: Austria, Denmark, Germany, the Netherlands, Norway, Sweden, Switzerland (including CERN), UK
Southern Hemisphere: Argentina, Australia, Brazil, Chile, Colombia, South Africa

Higgs production and decay modes at LHC





Why is important to study couplings?

- Couplings are a **powerful test of nature of Higgs** : SM, or subtly different?
- Interpretations **evolving from coupling strength to full coupling structure** (EFT)
- Two main frameworks used for interpretations:

  - **κ framework:**
    - κ parameters act as linear modifiers to H coupling strengths
    - **SM-like → κ = 1**
    - Testing with and without BSM contributions in decays (B_i invisible rate, B_u undetected rate)

$$\sigma \cdot \mathcal{B}(i \to H \to f) = \kappa_i^2 \cdot \kappa_f^2 \cdot \sigma_i^{\mathrm{SM}} \cdot \frac{\Gamma_f^{\mathrm{SM}}}{\Gamma_H(\kappa_i^2, \kappa_f^2)}$$

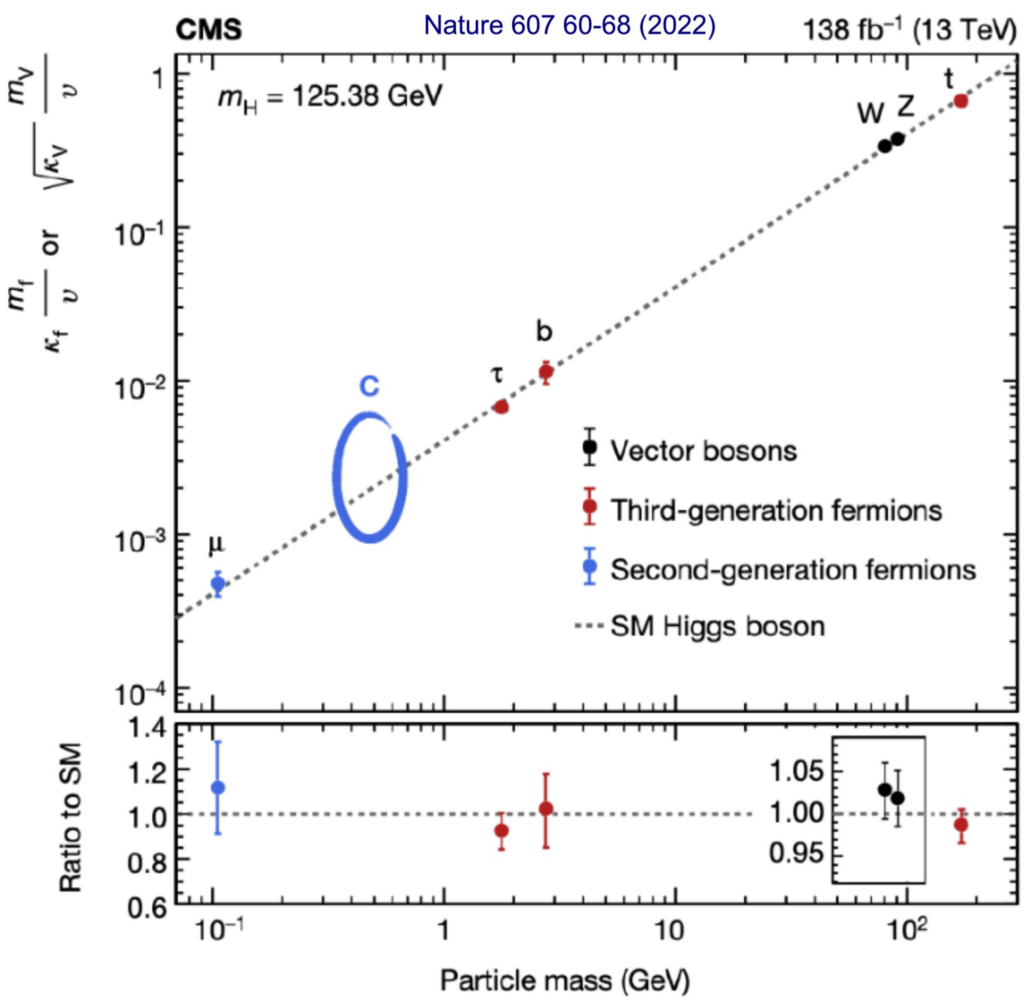
$$\kappa_i^2 = \frac{\sigma_i}{\sigma_i^{\mathrm{SM}}} \quad \text{and} \quad \kappa_f^2 = \frac{\Gamma_f}{\Gamma_f^{\mathrm{SM}}}$$

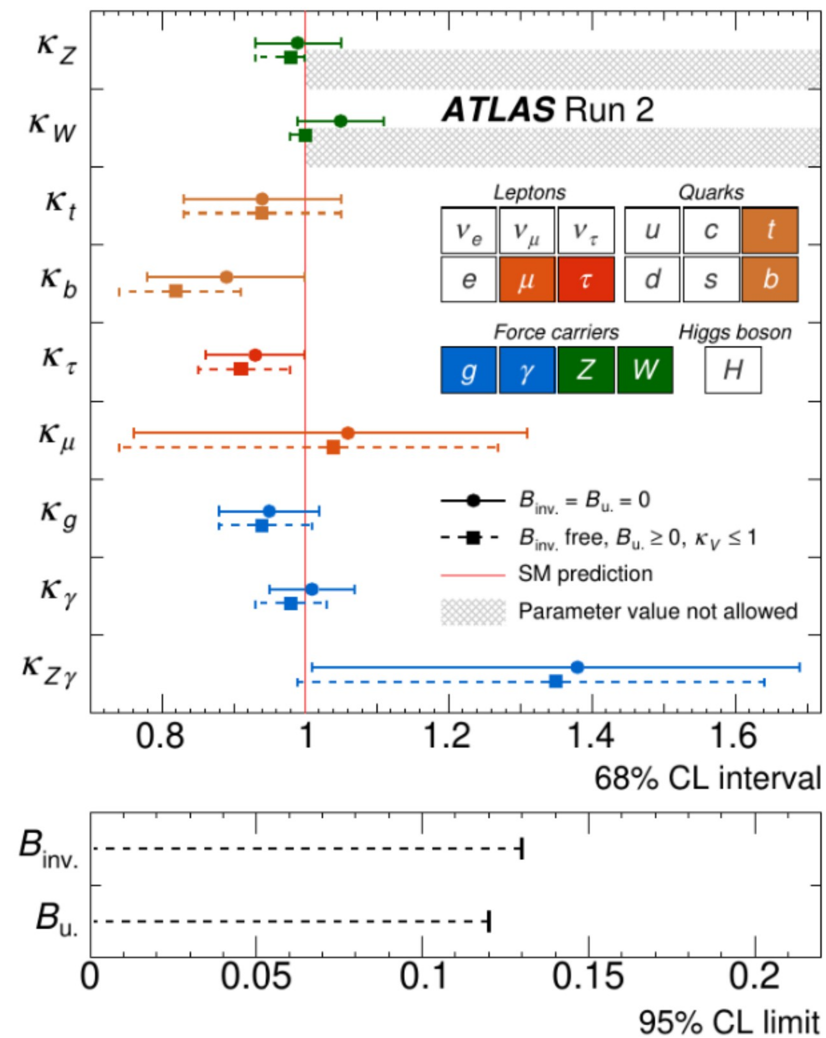
  - **EFT framework:**
    - One Wilson coefficient c_i introduced per BSM coupling
    - Measured in combination of multiple final states, targeting CP-even operators
    - **SM-like → c_i = 0**

$$\mathscr{L}_{\mathrm{SMEFT}} = \mathscr{L}_{\mathrm{SM}} + \sum_i \frac{c_i^{(5)}}{\Lambda_i} \mathcal{O}_i^{(5)} + \boxed{\sum_i \frac{c_i^{(6)}}{\Lambda_i^2} \mathcal{O}_i^{(6)}} + \ldots$$

Combined couplings measurements

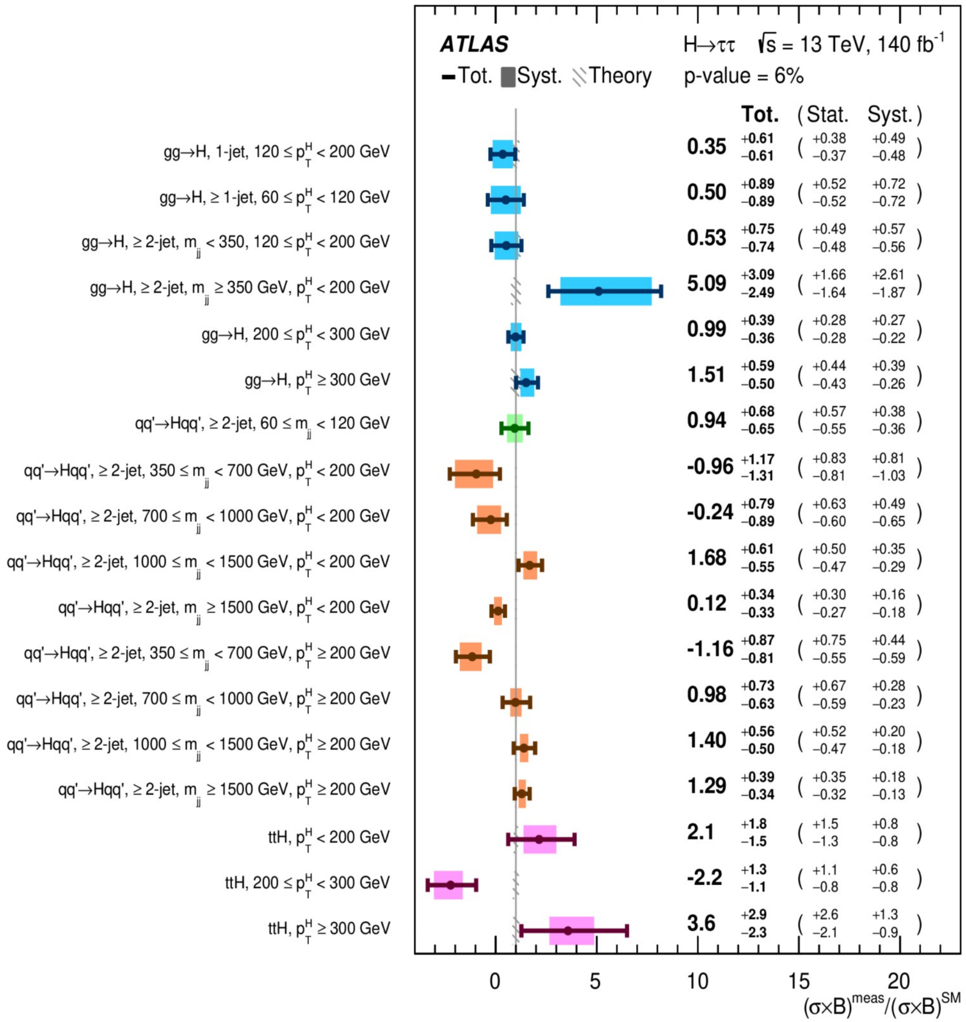
Nature 607 52 (2022)

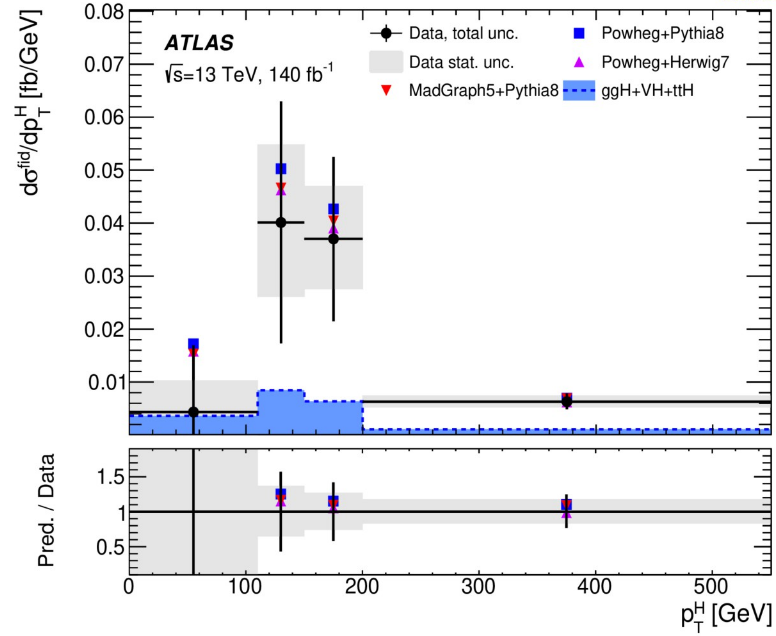


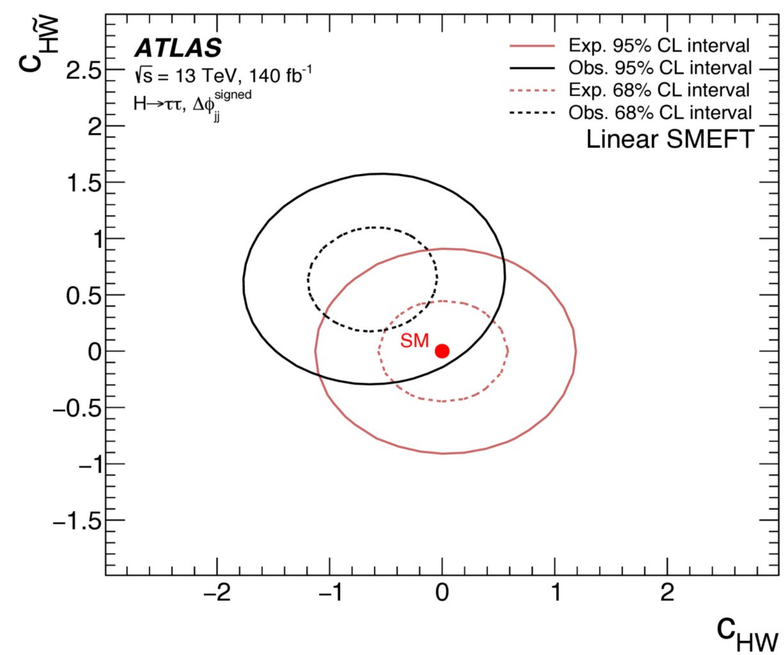


ATLAS H→ττ analysis

arXiv:2407.16320

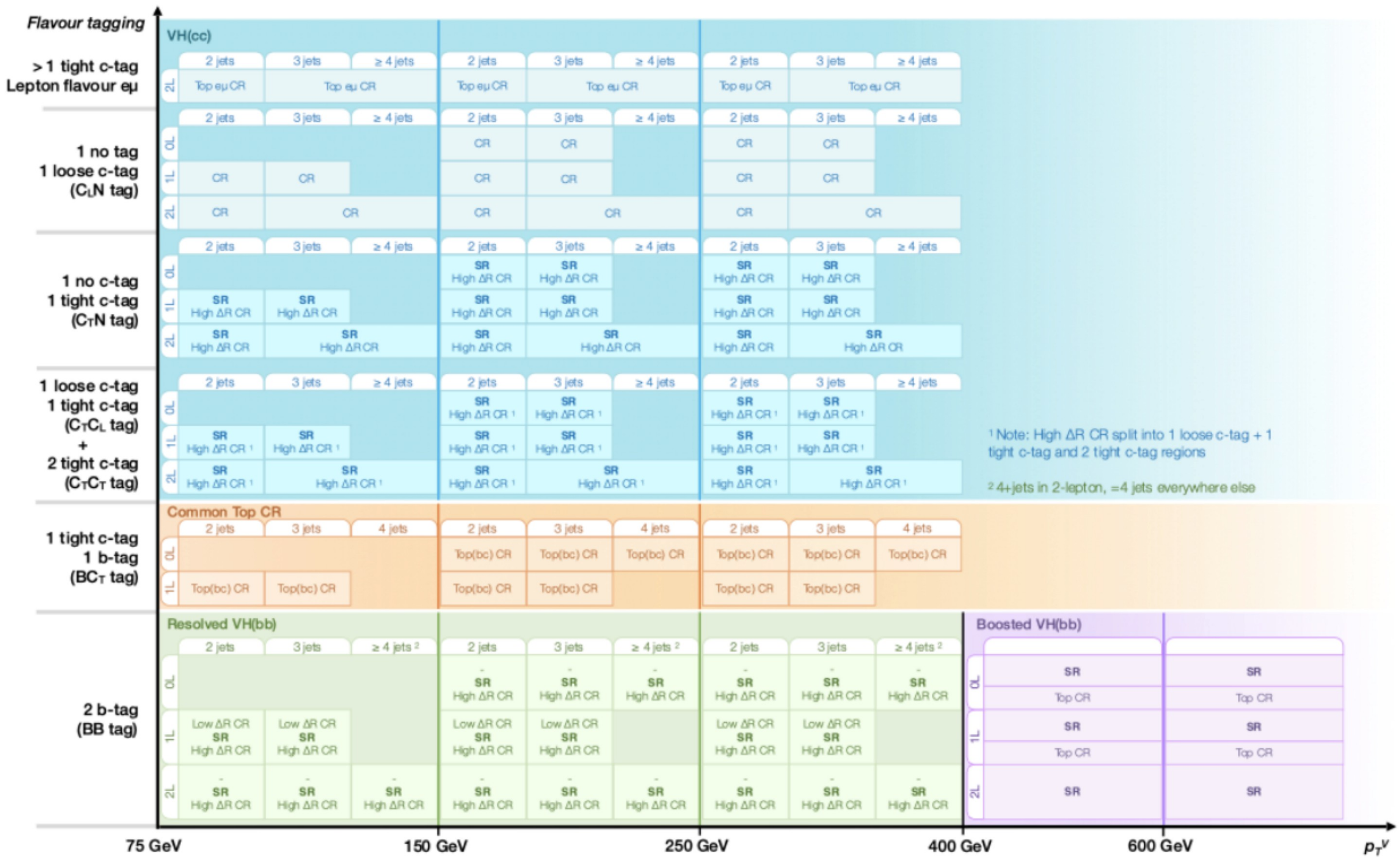






ATLAS Final Run 2 VH→bb measurement

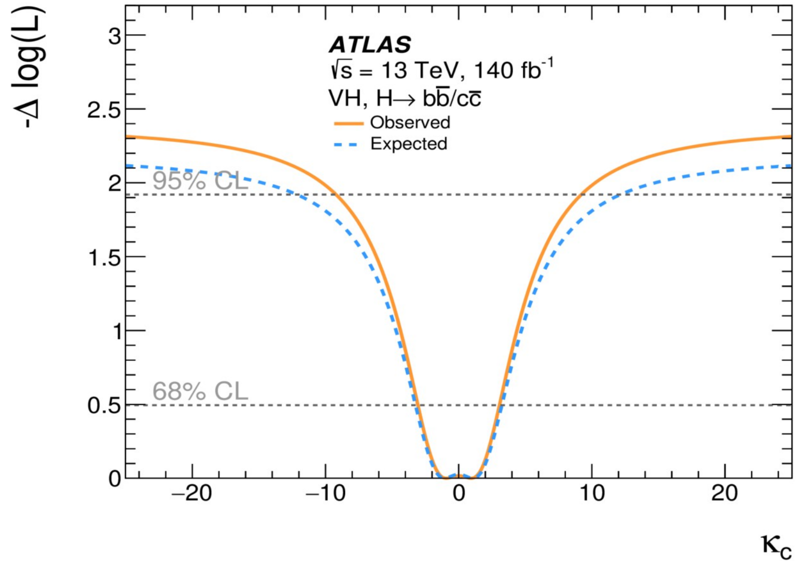
arXiv:2410.19611

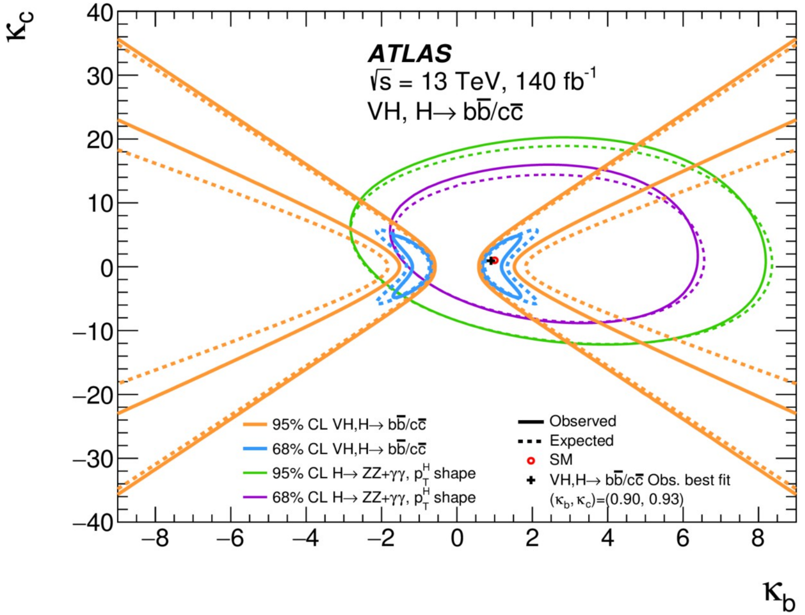


ATLAS Final Run 2 VH→bb measurement

arXiv:2410.19611

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

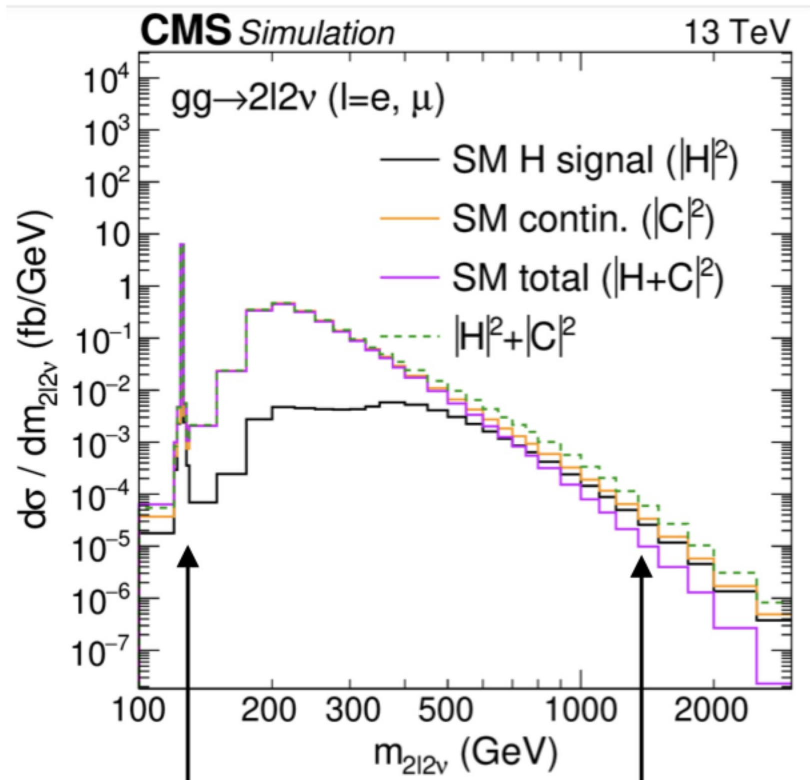




Higgs total width

- At the LHC, SM Γ_H inaccessible via direct measurements of the Higgs boson line shape or flight distance, due to limited detector resolution

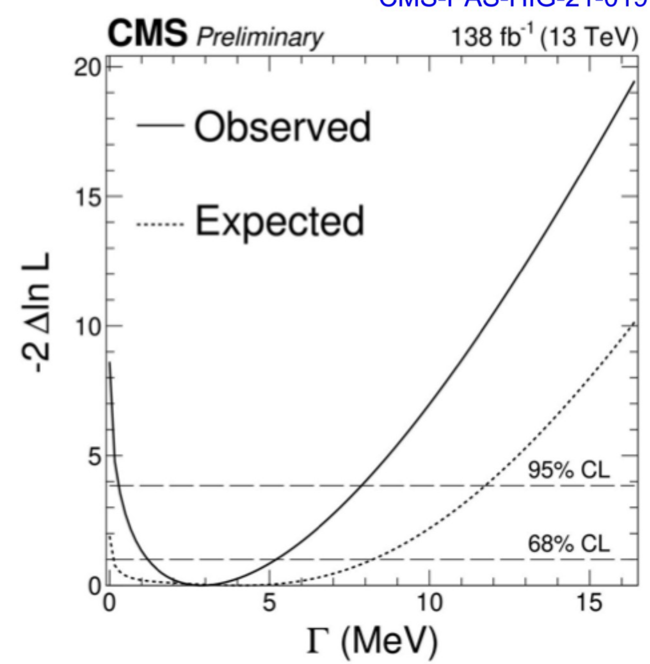
Constraint via $\Gamma_H \propto$ σ(off-shell) / σ(on-shell)
e.g. in ggF $H \rightarrow ZZ(*) \rightarrow 4l$, assuming the effective couplings are the same



on-shell ~ $\frac{\sigma_{pp\rightarrow H}\Gamma_{4l}}{\Gamma_H}$

off-shell ~ $\frac{\sigma_{pp\rightarrow H}\Gamma_{4l}}{(m_{4l}^2 - m_H^2)^2}$

CMS-PAS-HIG-21-019



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