Decoding the Higgs Boson: New Clues from the LHC

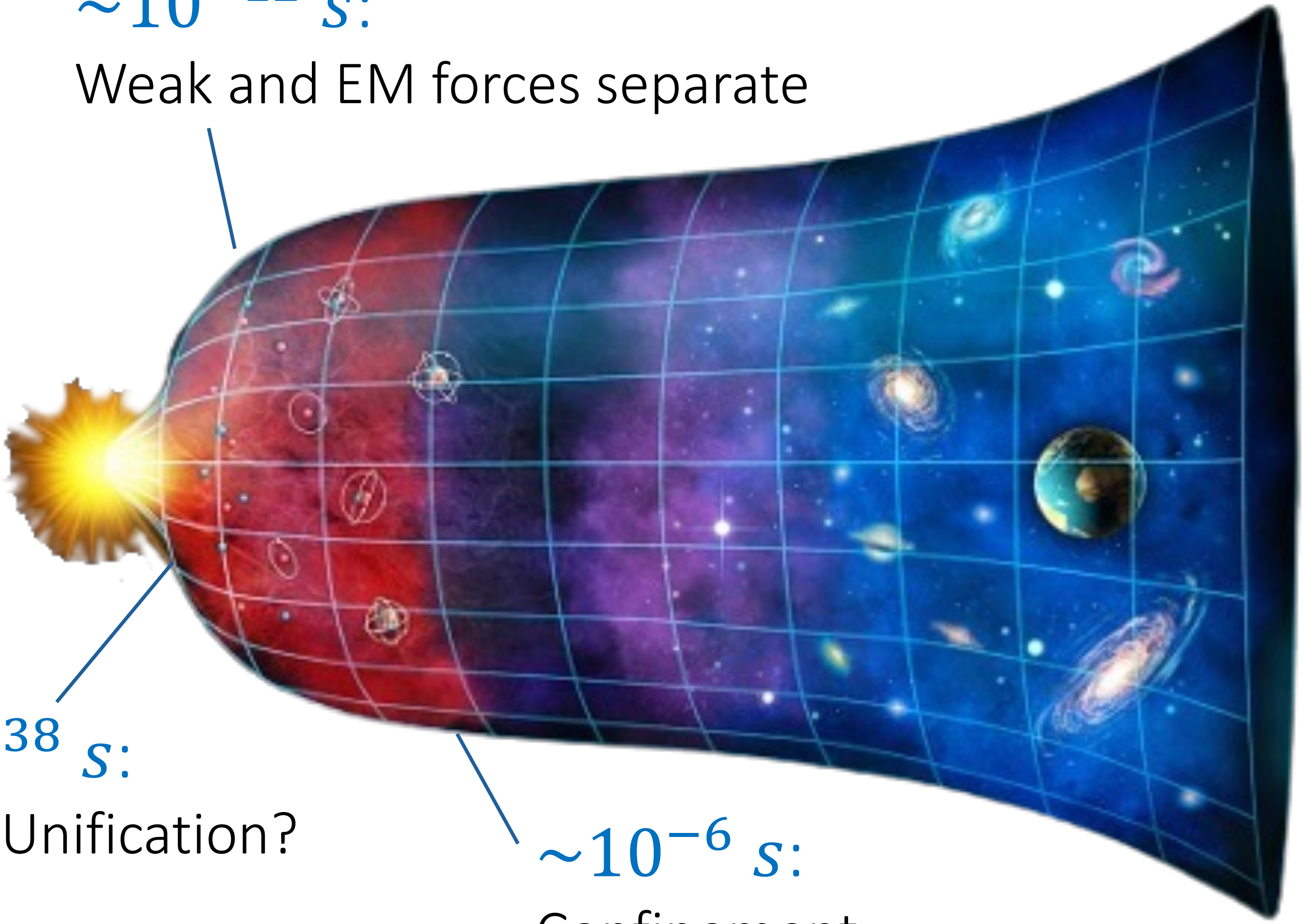
Robin Hayes

QMUL Seminar
May 21, 2025

Looking Back in Time

$\sim 10^{-12}\ s$:

Weak and EM forces separate



$\sim 10^{-38}\ s$:

Grand Unification?

$\sim 10^{-6}\ s$:

Confinement

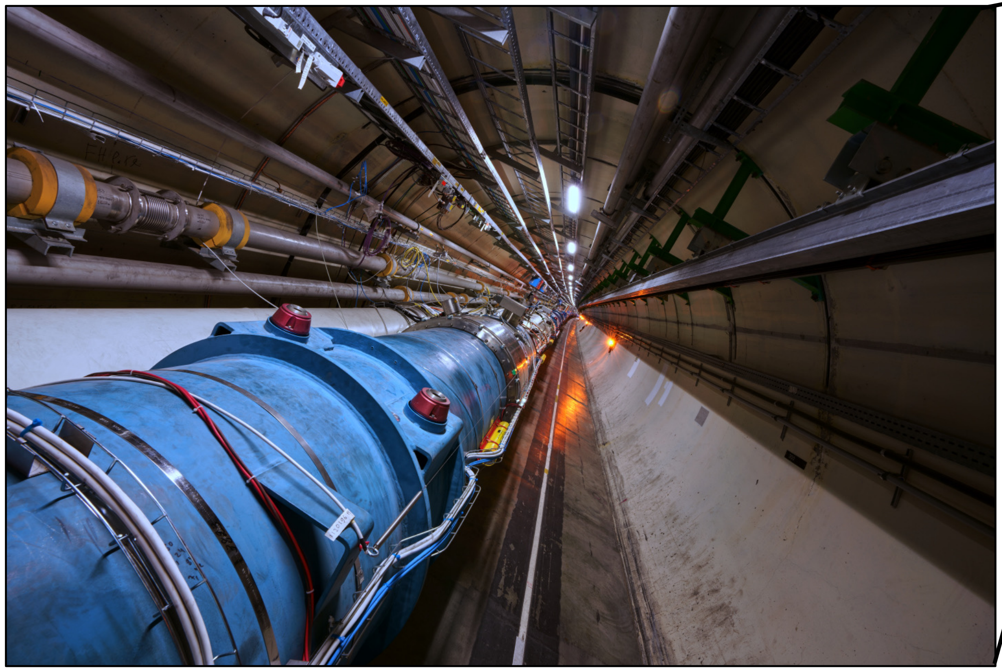
Now:

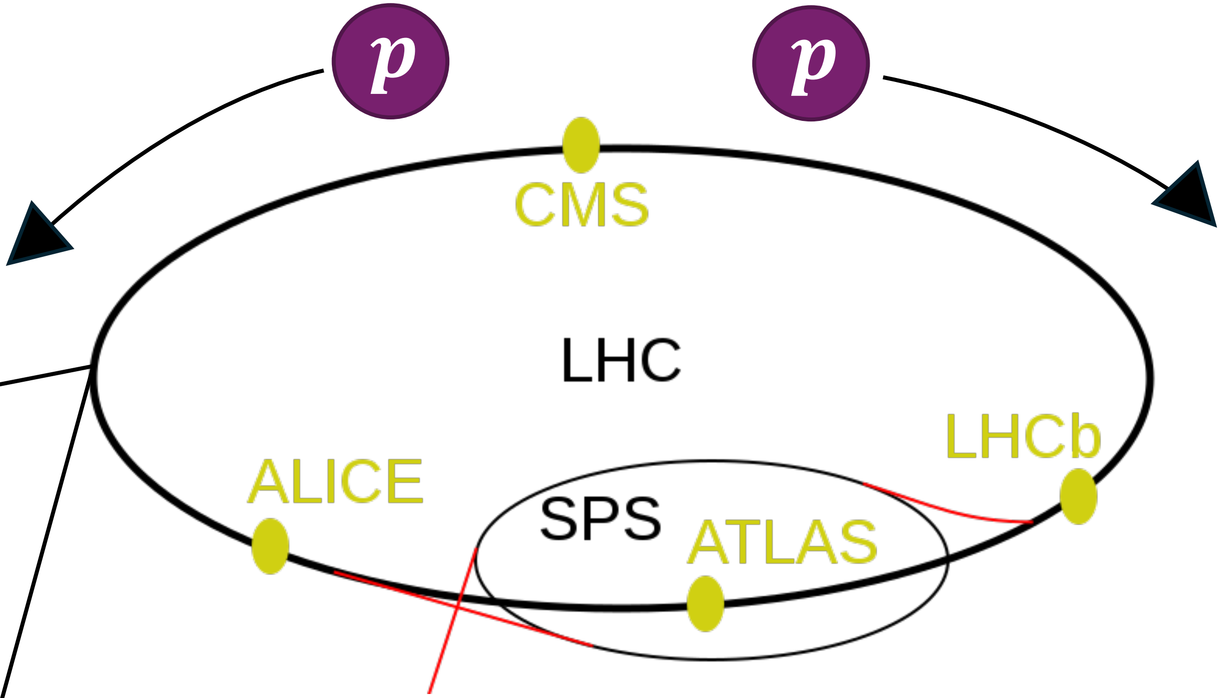
13.77 billion years after the start

The Large Hadron Collider

A tool to see back in time!

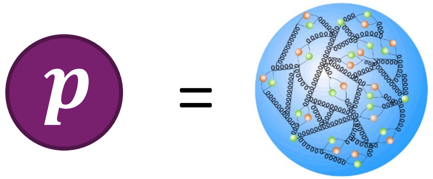
Collides beams of protons at high energies (currently: 13.6 TeV).



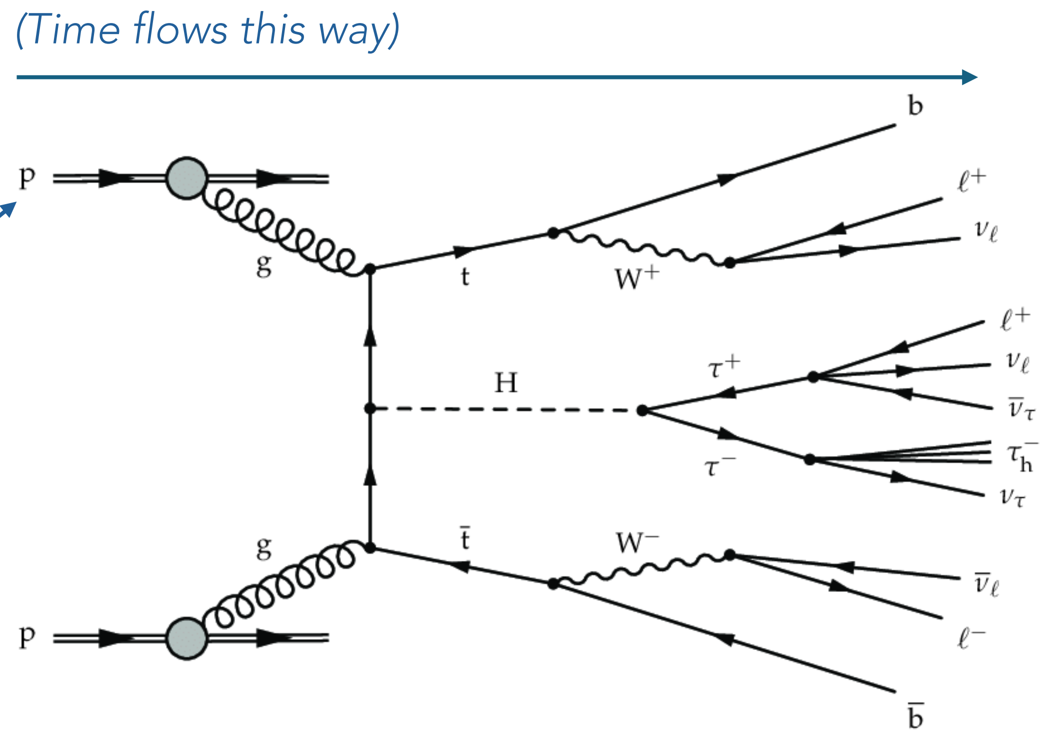


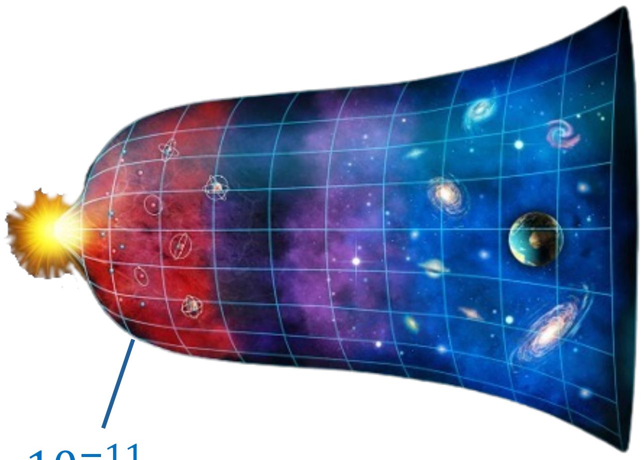
The Large Hadron Collider

Protons consist of quarks and gluons.



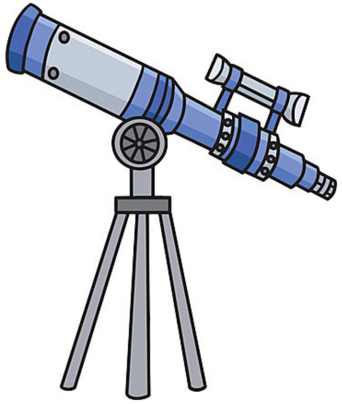
Interactions of quarks and gluons produce other particles.





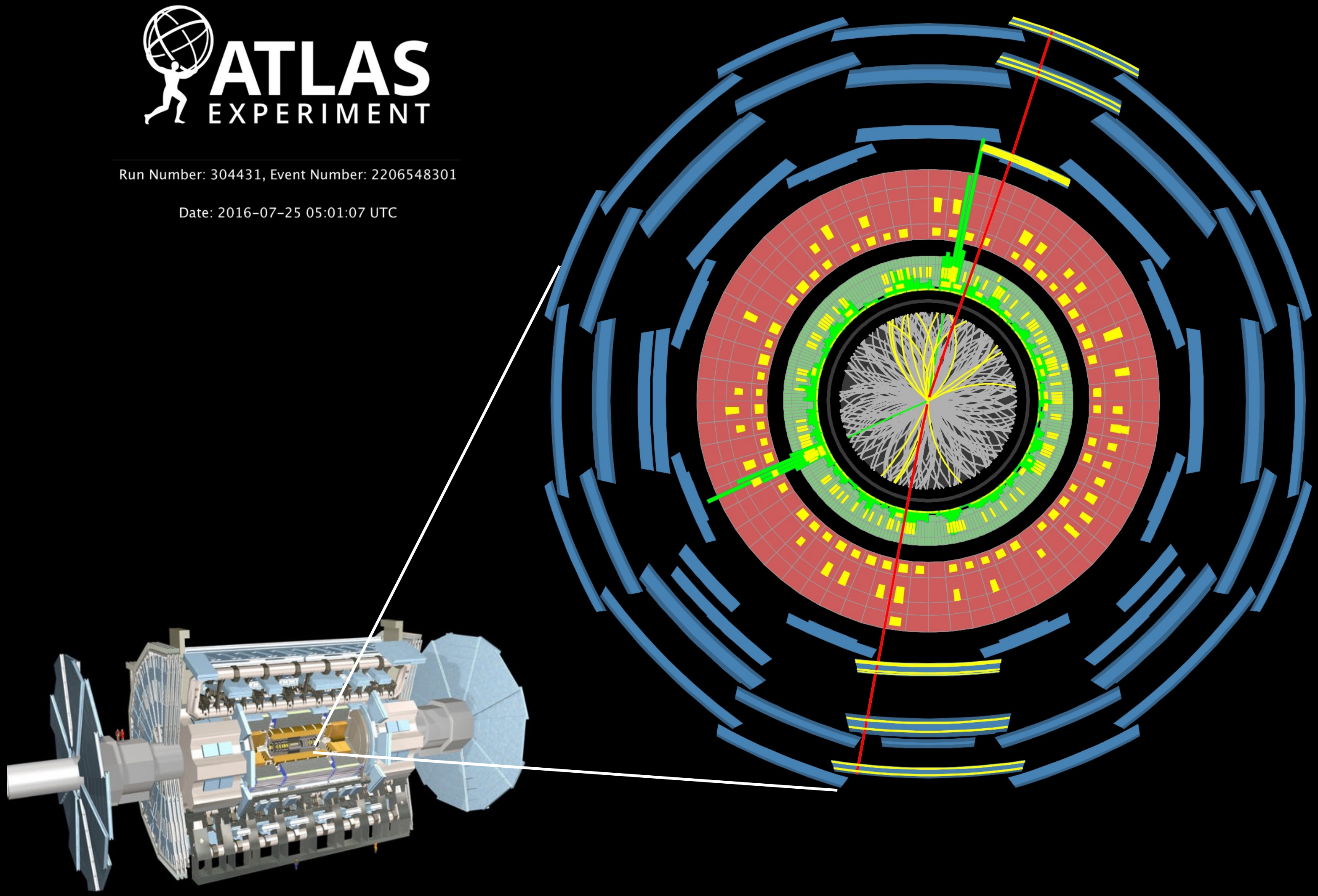
Now:
13.77 billion years after the start

$\sim 10^{-11}\ s$:
Collider energies



Recreates conditions in the universe shortly after the Big Bang!

The ATLAS Detector



ATLAS detector registers signals from the particles produced.

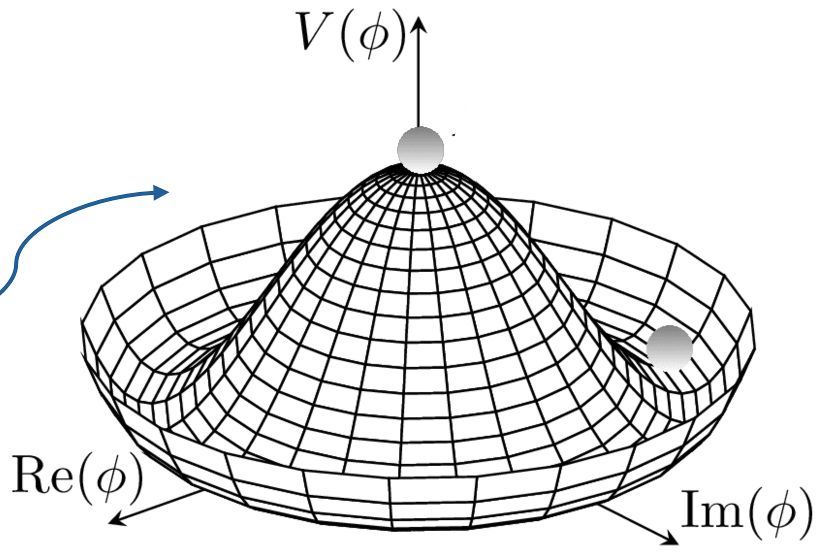
Opportunity to study conditions that existed a fraction of a second after the Big Bang.

The Large Hadron Collider

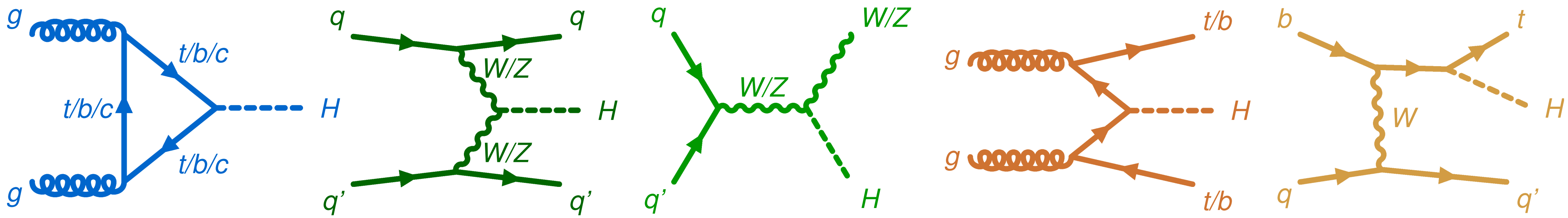
What can we do with these energies?

One example: study **the Higgs boson.**

In the Standard Model, the shape of Higgs potential leads to electroweak symmetry breaking.
→ masses for the W and Z bosons, EM/weak forces split



Interaction of quarks and gluons can make Higgs bosons at the LHC:



87% 7% 4% 1% 1%

The Higgs Boson: Discovery

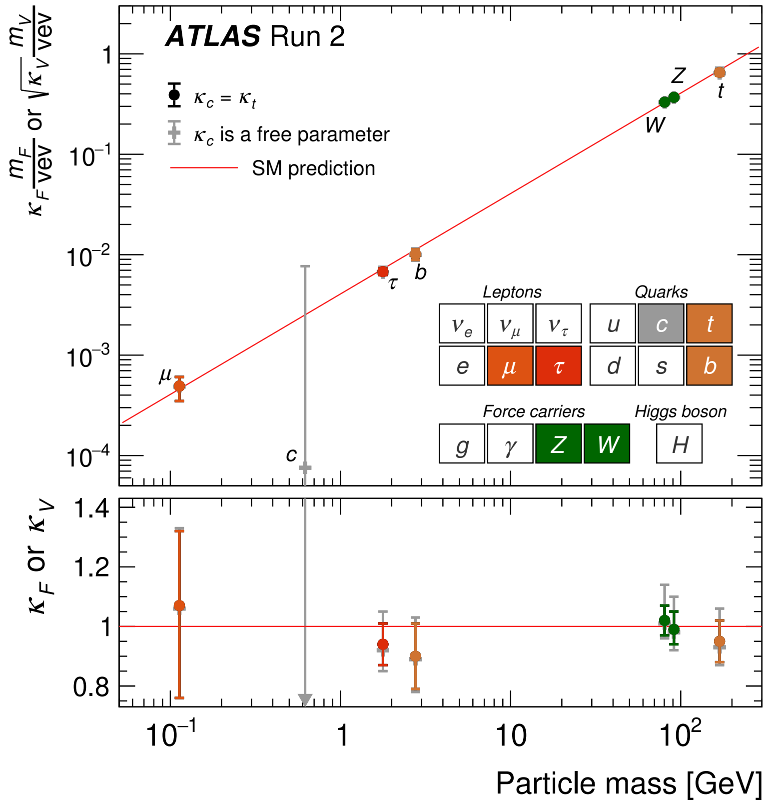
2012

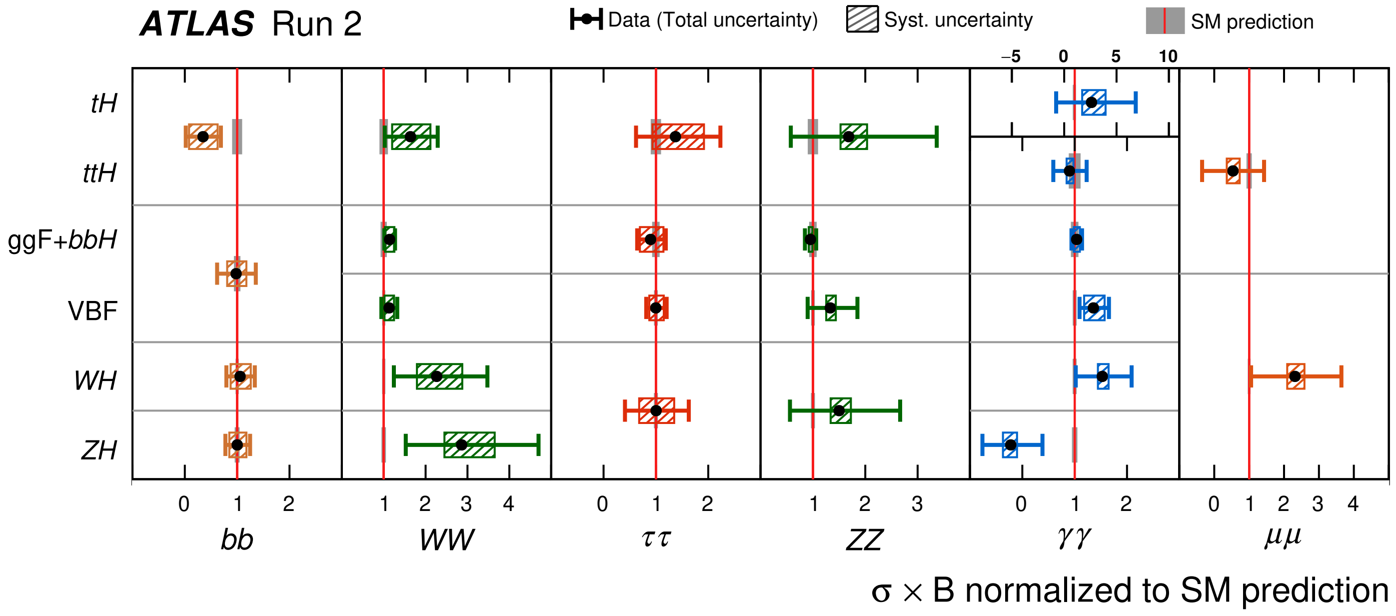
Discovery of the Higgs Boson at the Large Hadron Collider

The Higgs Boson: Since 2012

2012 - Now

Properties so far confirmed with remarkable precision...





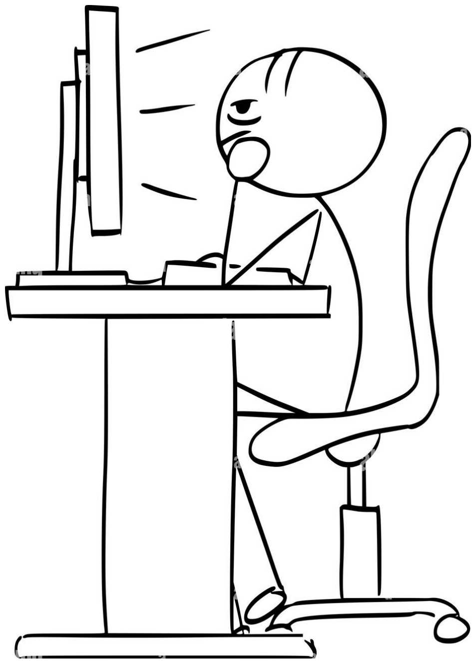
HIGG-2021-23

✓ couplings scale with mass

✓ cross-sections and branching ratios as predicted

What Now?

Have we exhausted all we can currently learn from the Higgs boson?



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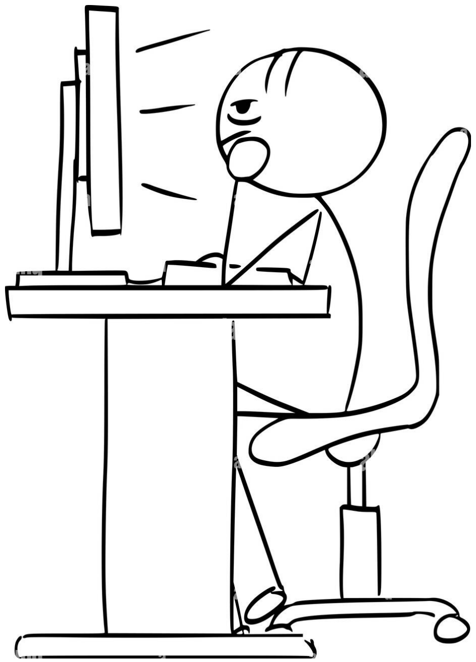


No way!

Will look at how we are going further with LHC data:

- ✓ Improved precision
- ✓ New interpretations

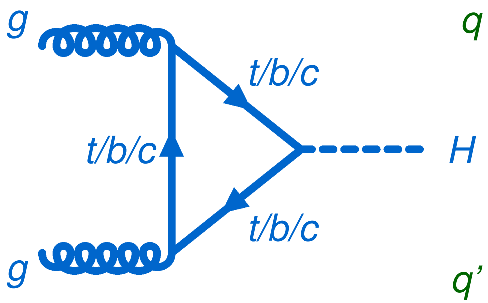
Recently at the LHC

Cross-Section Measurements

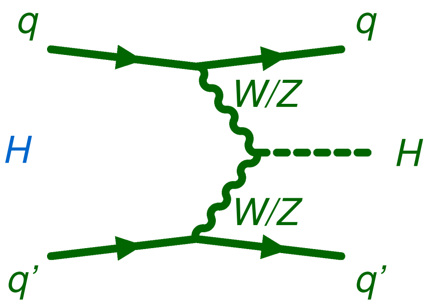
Bread and butter of the Higgs physics programme: cross-section measurements.

How often is the Higgs boson produced?

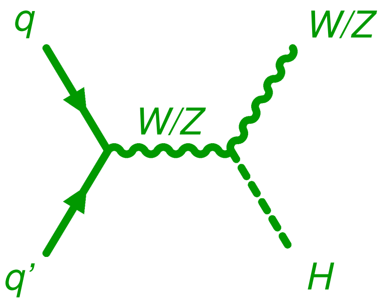
Main production modes at the LHC:



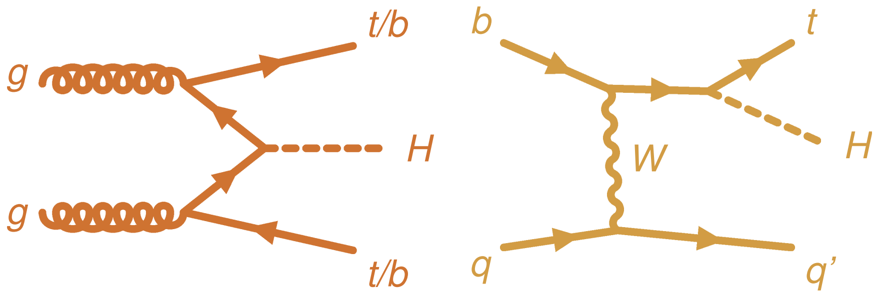
Gluon fusion (ggF)
(87%)



Vector boson fusion (VBF) (7%)



Vector boson associated production (VH)
(4%)



Top- and bottom-associated production, single-top production
(2%)

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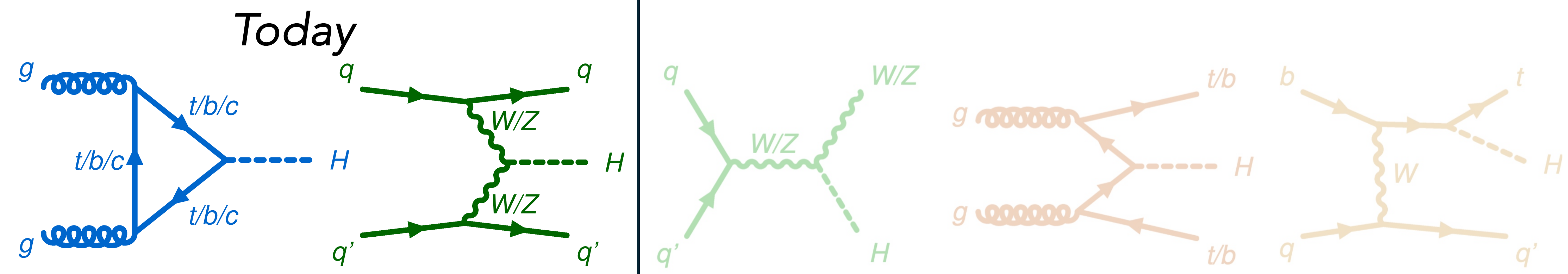


Gluon fusion (ggF) (87%)

↑ *Probes H coupling to heavy quarks and gluons*

Vector boson fusion (VBF) (7%)

↑ *Probes H coupling to vector bosons*

Vector boson associated production (VH) (4%)

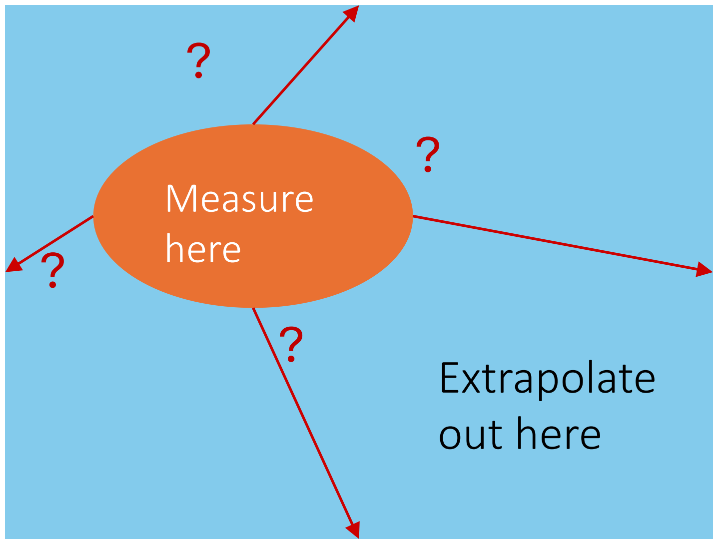
Top- and bottom-associated production, single-top production (2%)

Cross-Section Measurements

Can be measured inclusively or differentially:

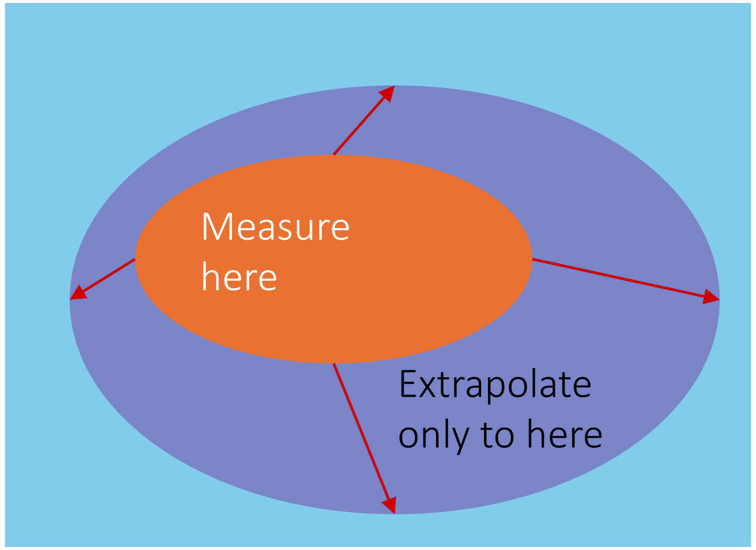
Inclusive measurements

- One number covering the total phase space
- More extrapolation = more uncertainty



Fiducial Differential measurements

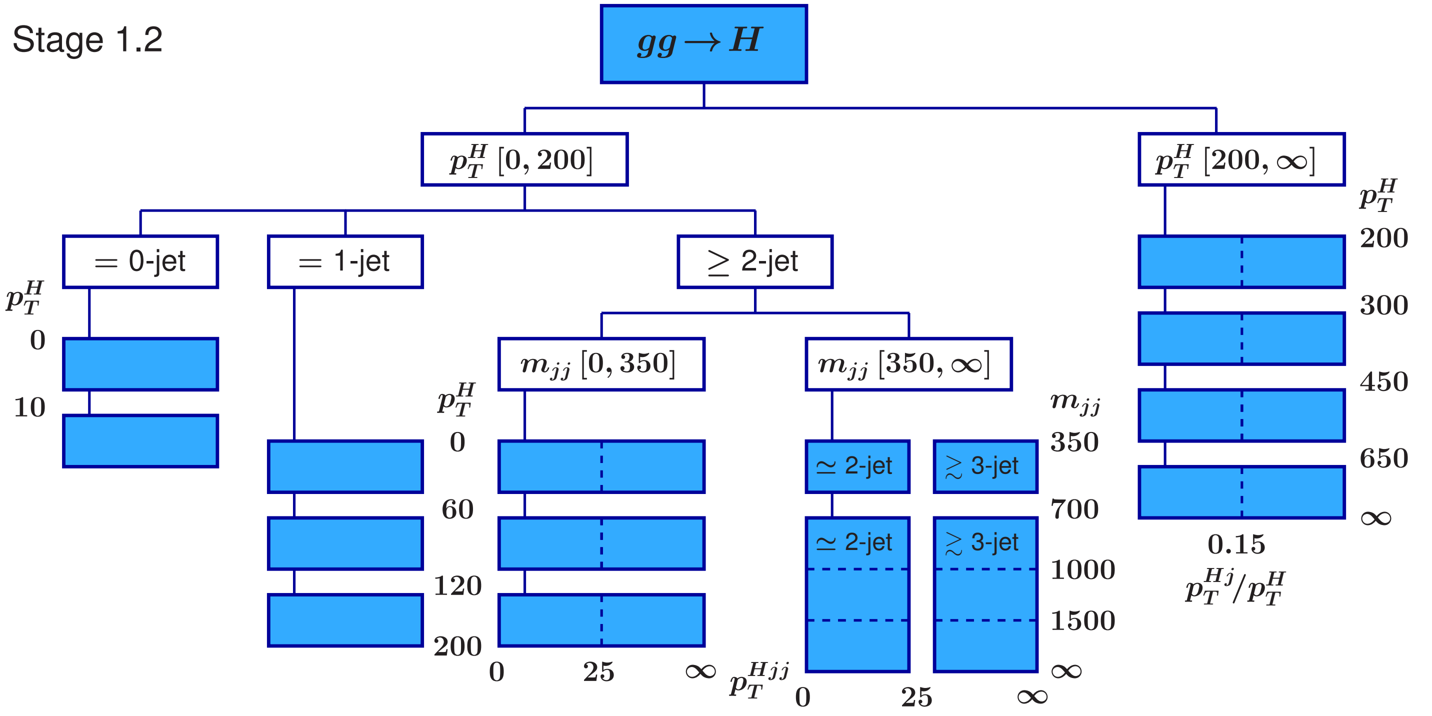
- Split total phase space into kinematic “bins”
- Less extrapolation = less uncertainty



Cross-Section Measurements: STXS

Common framework for differential (fiducial) cross-section measurements at the LHC: **Simplified Template Cross-Section (STXS)**

Current STXS binning scheme for ggF

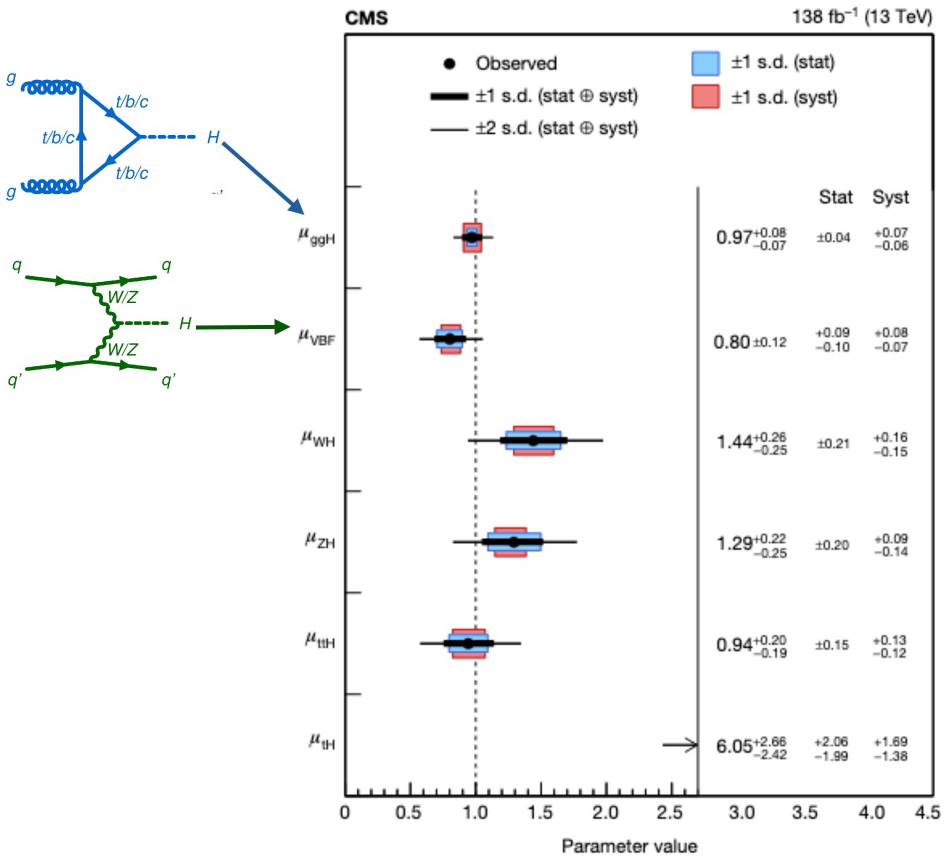


- Split total production mode cross-section (eg. σ_{ggF}) into various bins
- Isolates BSM-sensitive regions
- Reduces theory uncertainties

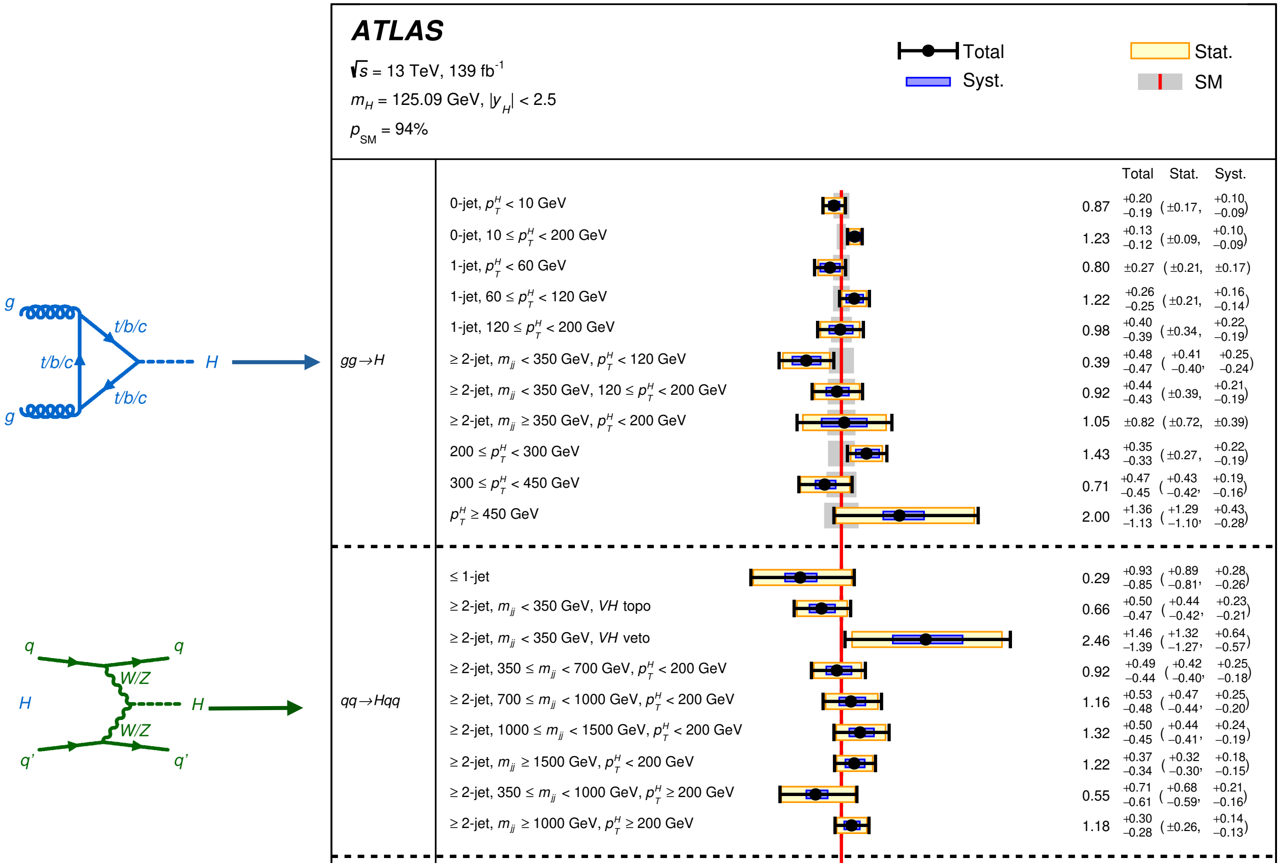
Cross-Section Measurements: Where We Stand

Recently: consistent with the Standard Model (SM), but not all measured precisely.

eg. CMS [Nature, 2022]:



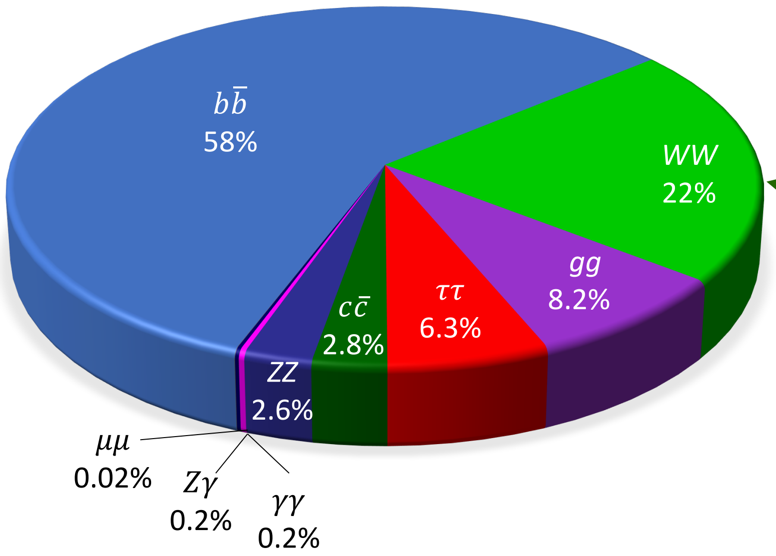
eg. ATLAS [Nature, 2022]:

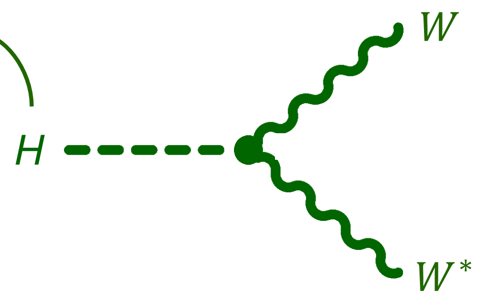


The $H \to WW^*$ Channel

Why $H \to WW^*$?

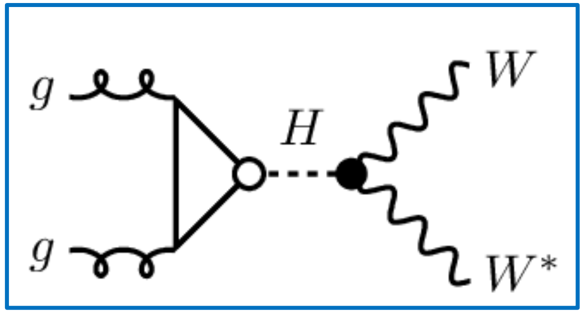
- 2nd-largest Higgs boson branching ratio: probe rarer production modes/phase spaces.
- Clean leptonic decay channel.

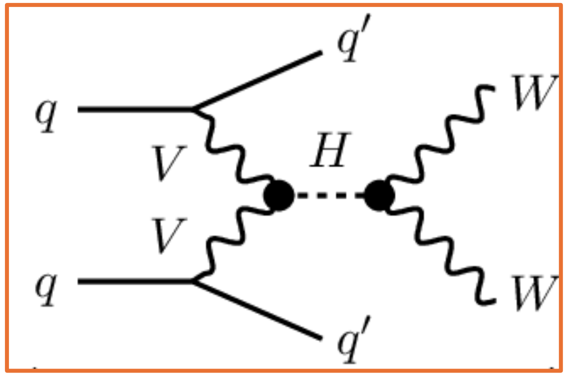




Recent ATLAS publication (HIGP-2024-07):

- Target ggF and VBF total and STXS cross-section measurements, using LHC full Run 2 dataset (2015-2018).
- Second measurement on the same dataset → aiming for improvement from analysis strategy.





ggF and VBF $H \rightarrow WW^*$

HIGP-2024-07

Challenge:

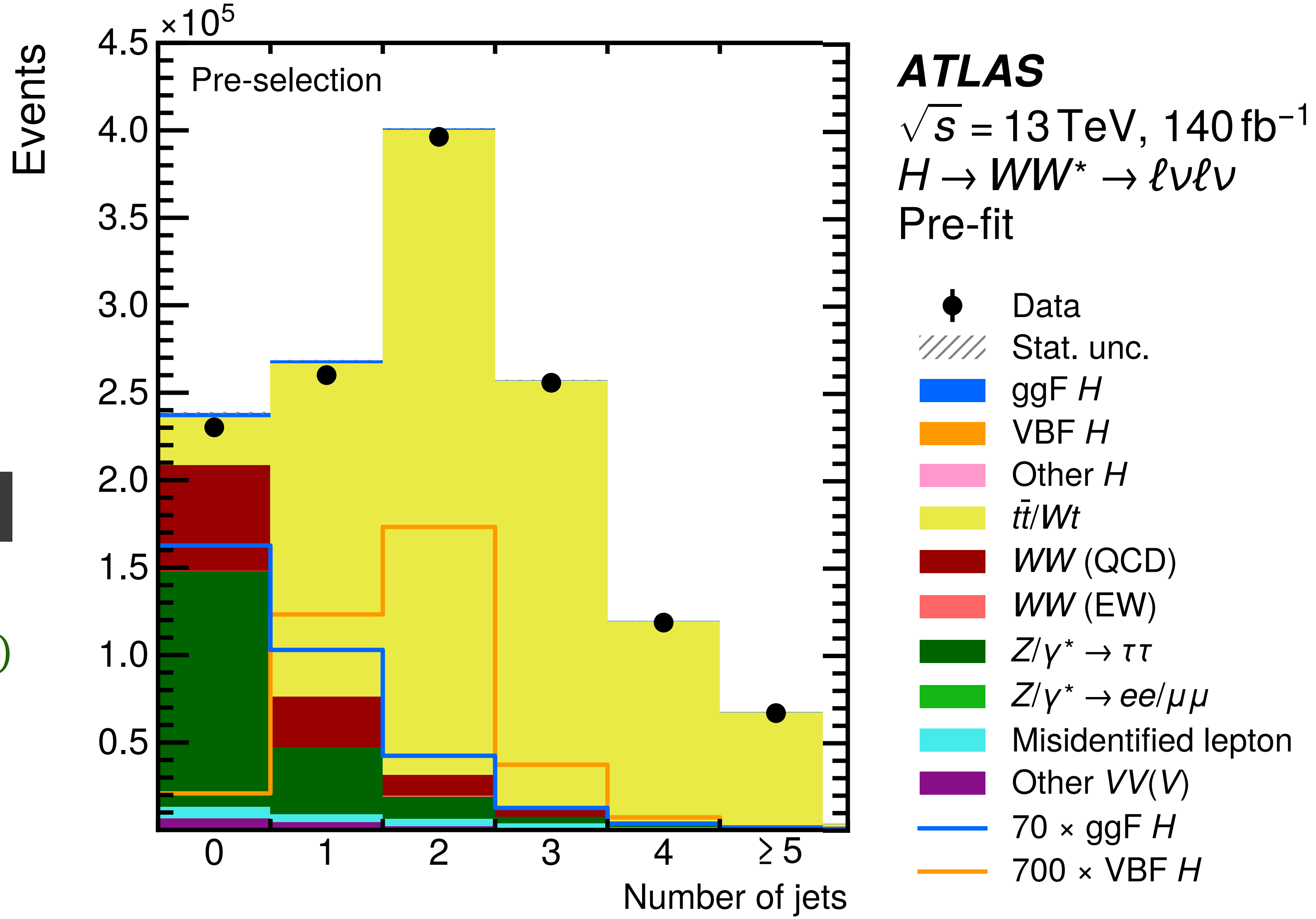
- Many processes other than $H \rightarrow WW^*$!

Processes with top quarks

Continuum WW production

Drell-Yan ($Z/\gamma^* \rightarrow \tau\tau/ee/\mu\mu$)

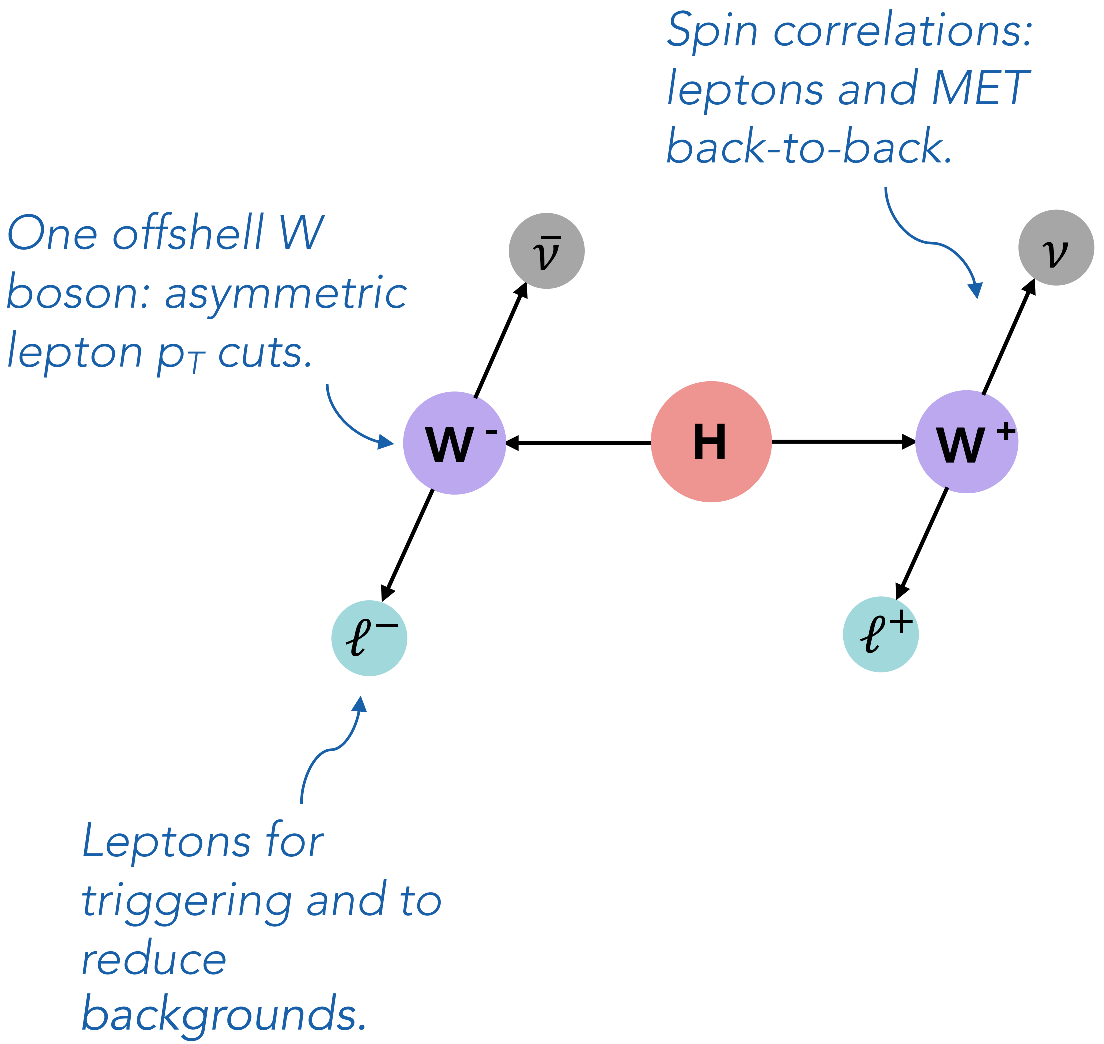
Jets faking leptons

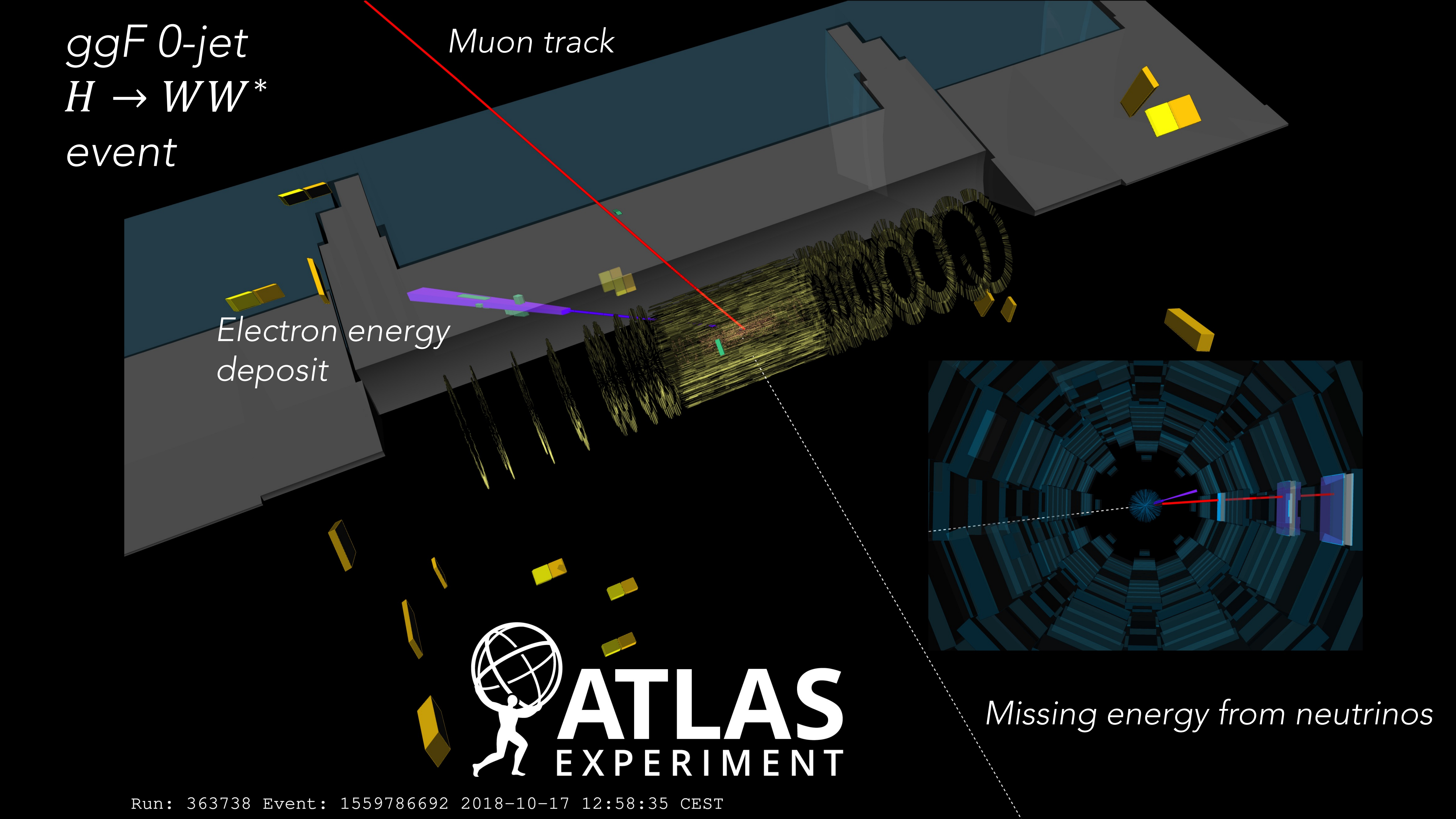


ggF and VBF $H \to WW^*$

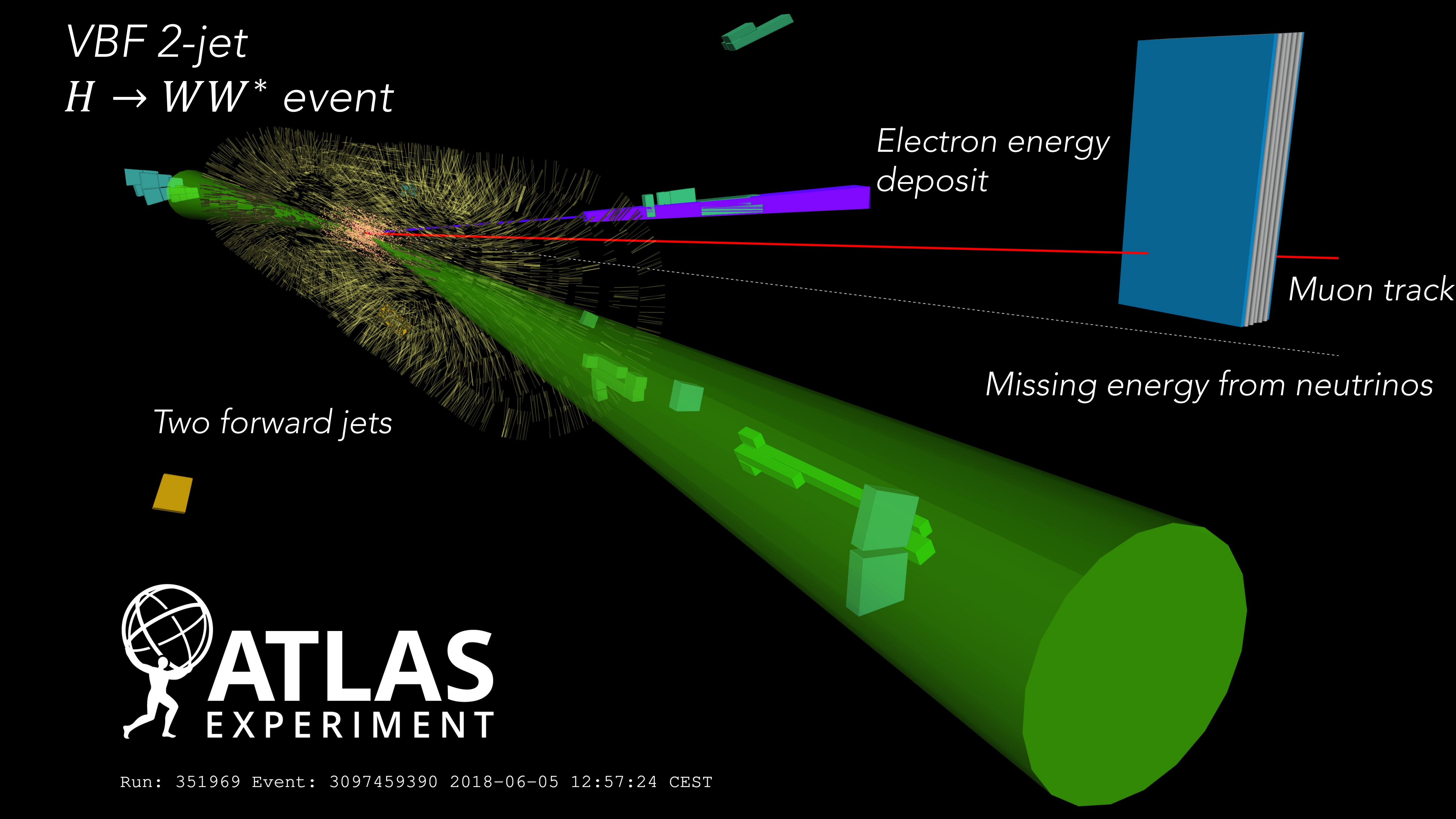
Strategy:

- Use clean leptonic decay, $H \to WW^* \to \ell\nu\ell\nu$
  - Characteristic features from spin correlations
- Different-flavour (DF, $e\nu\mu\nu$) and same-flavour (SF $e\nu e\nu/\mu\nu\mu\nu$) final states
- Suppress backgrounds with cuts on leptons and jets, and machine learning (deep neural networks).





ggF 0-jet
$H \to WW^*$
event
Muon track
Electron energy
deposit
Missing energy from neutrinos
ATLAS
EXPERIMENT
Run: 363738 Event: 1559786692 2018-10-17 12:58:35 CEST

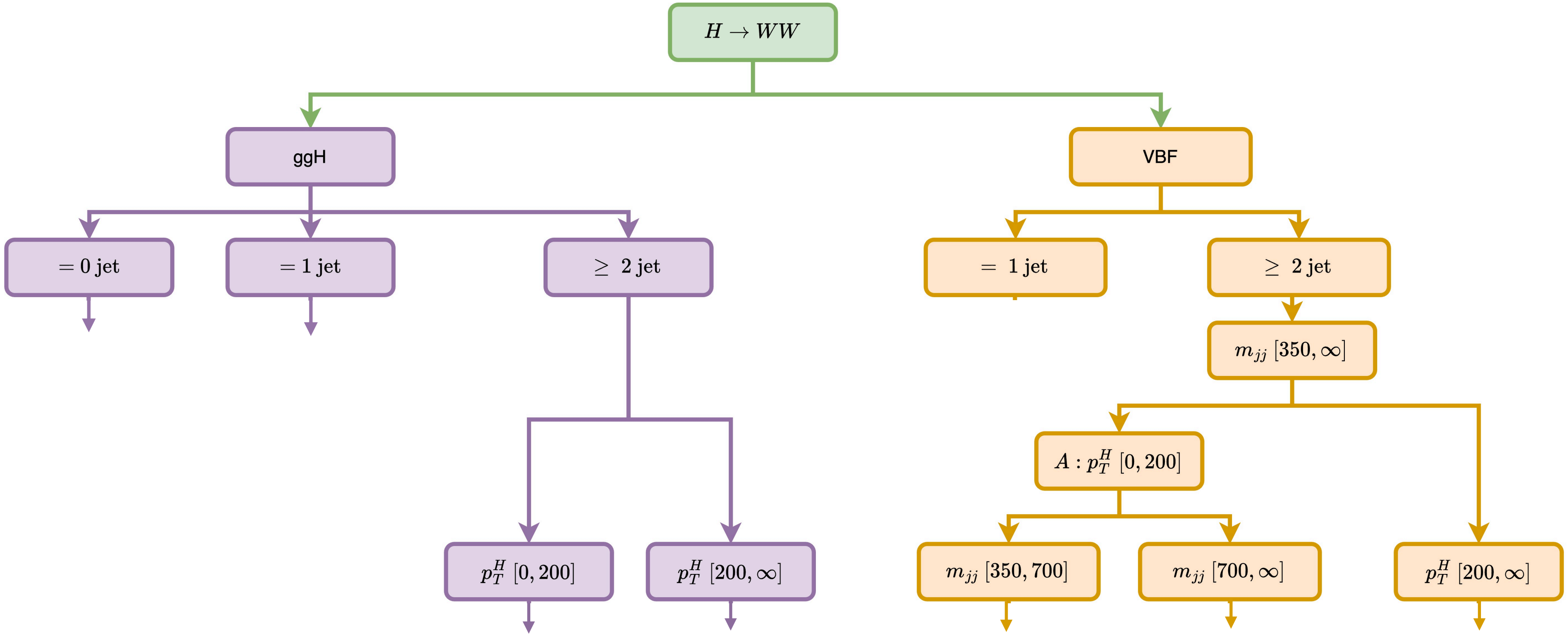

VBF 2-jet
$H \rightarrow WW^*$ event
Electron energy deposit
Muon track
Missing energy from neutrinos
Two forward jets
ATLAS
EXPERIMENT
Run: 351969 Event: 3097459390 2018-06-05 12:57:24 CEST

ggF and VBF $H \to WW^*$

HIGP-2024-07

Strategy:

- Categorize events by production mode, SF/DF, $p_{\mathrm{T}}^{H}, m_{jj}, N_{\mathrm{jets}}$ → 22 signal regions.



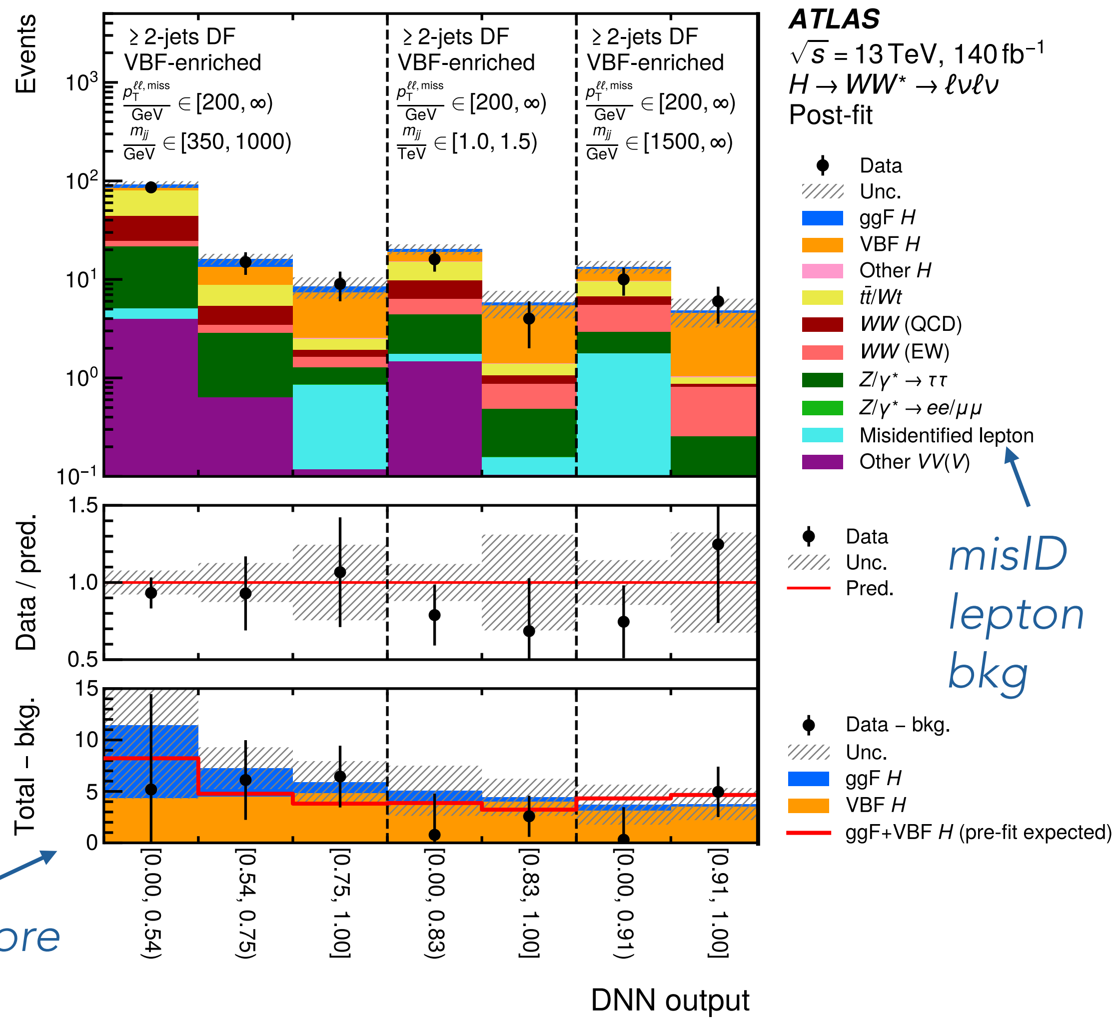
ggF and VBF $H \to WW^*$

HIGP-2024-07

Strategy:

- Deep Neural Networks in all SRs
- Multiple improvements since previous analysis address these:
  - Use of SF channel in stats-limited high-p_T^H regions
  - Machine learning applied more widely
  - Better lepton isolation → smaller misID lepton background.

DF SRs covering highest-p_T^H VBF bins

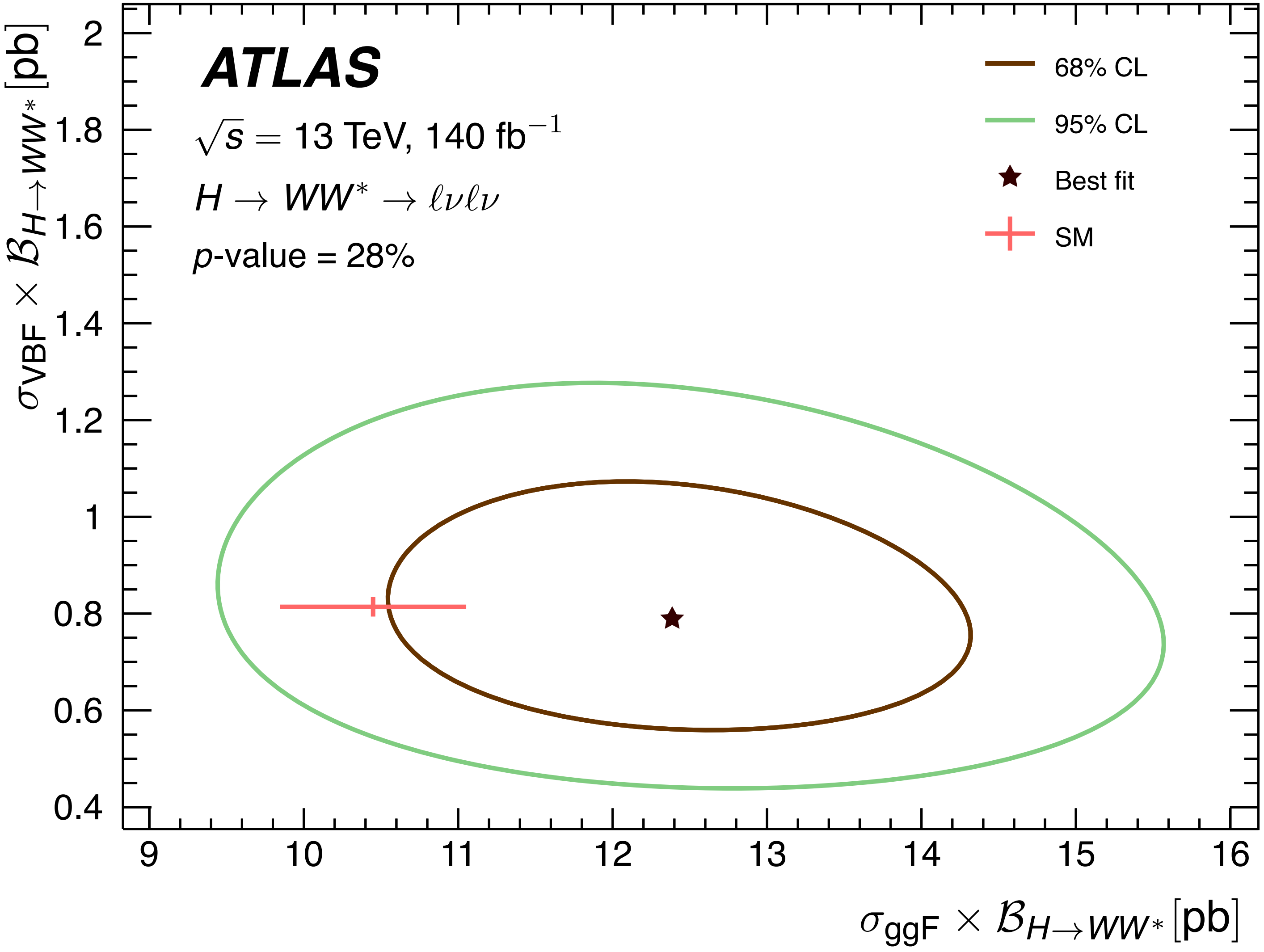


ggF and VBF $H \rightarrow WW^*$

HIGP-2024-07

Results:

- Measure σ_{ggF} and σ_{VBF}, and STXS cross-sections
- Compared to first 13 TeV paper:
  - 11% more precise for σ_{ggF} and σ_{VBF}.



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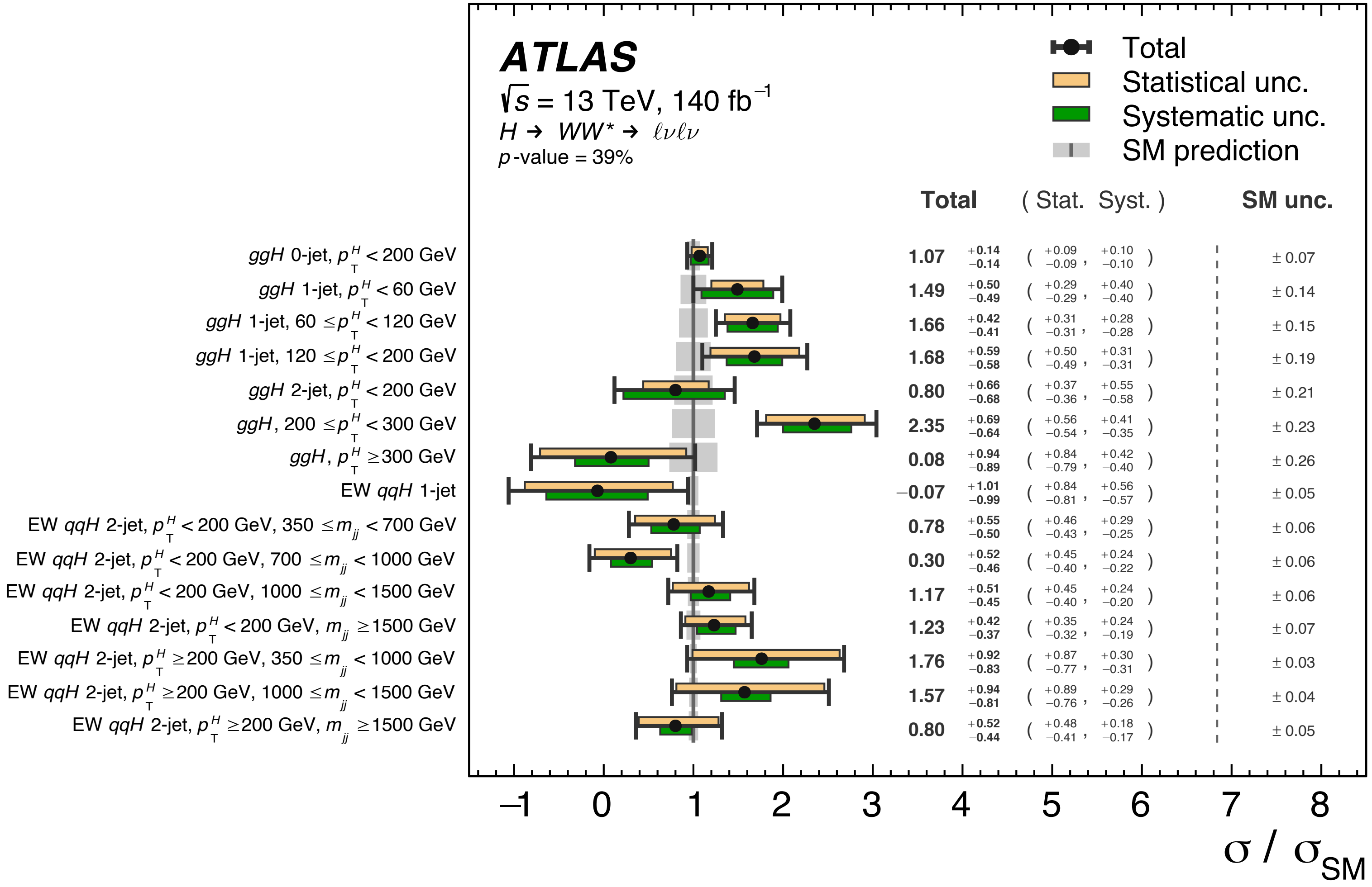

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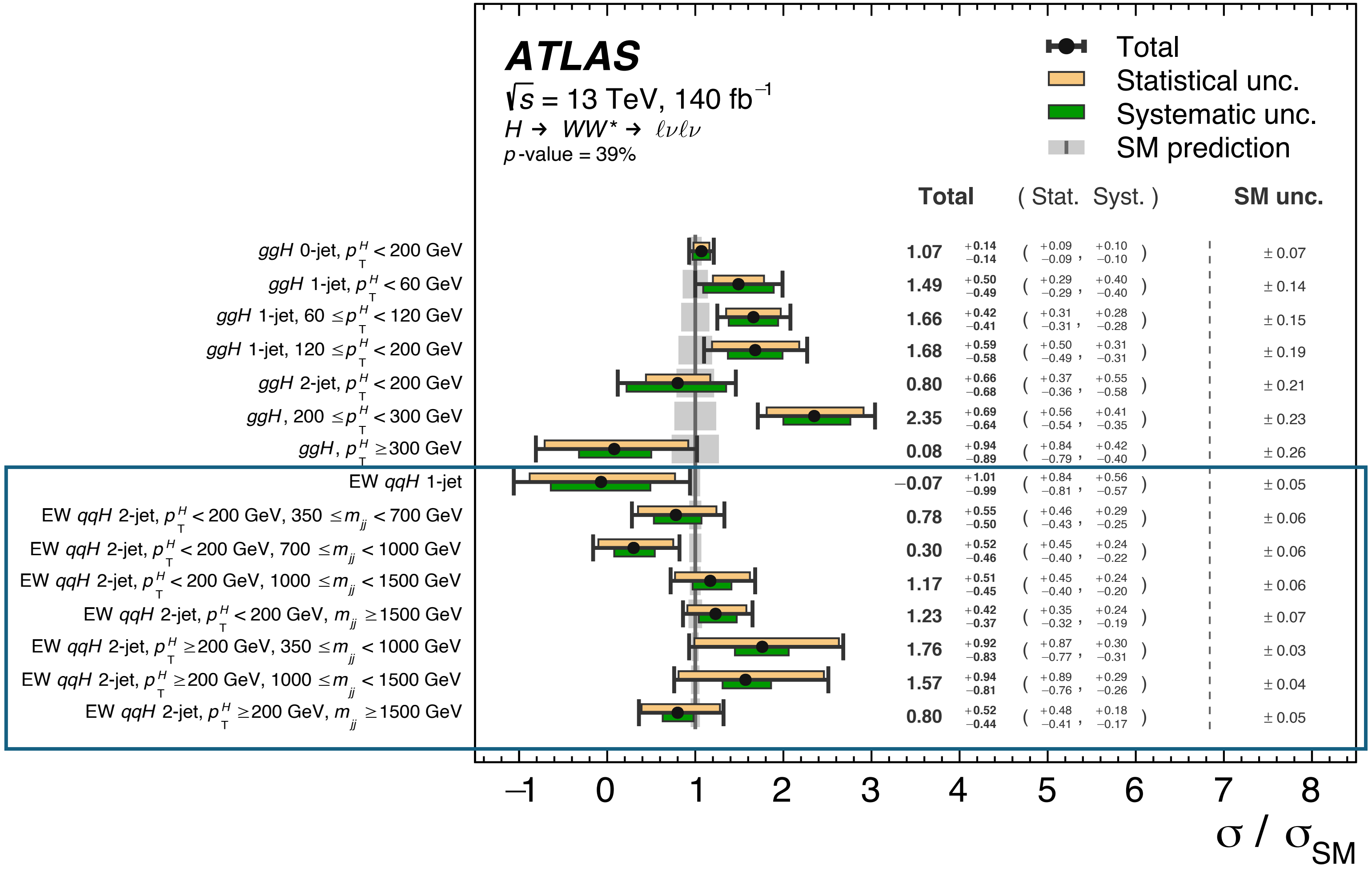
  - 10-20% more precise for VBF STXS categories.



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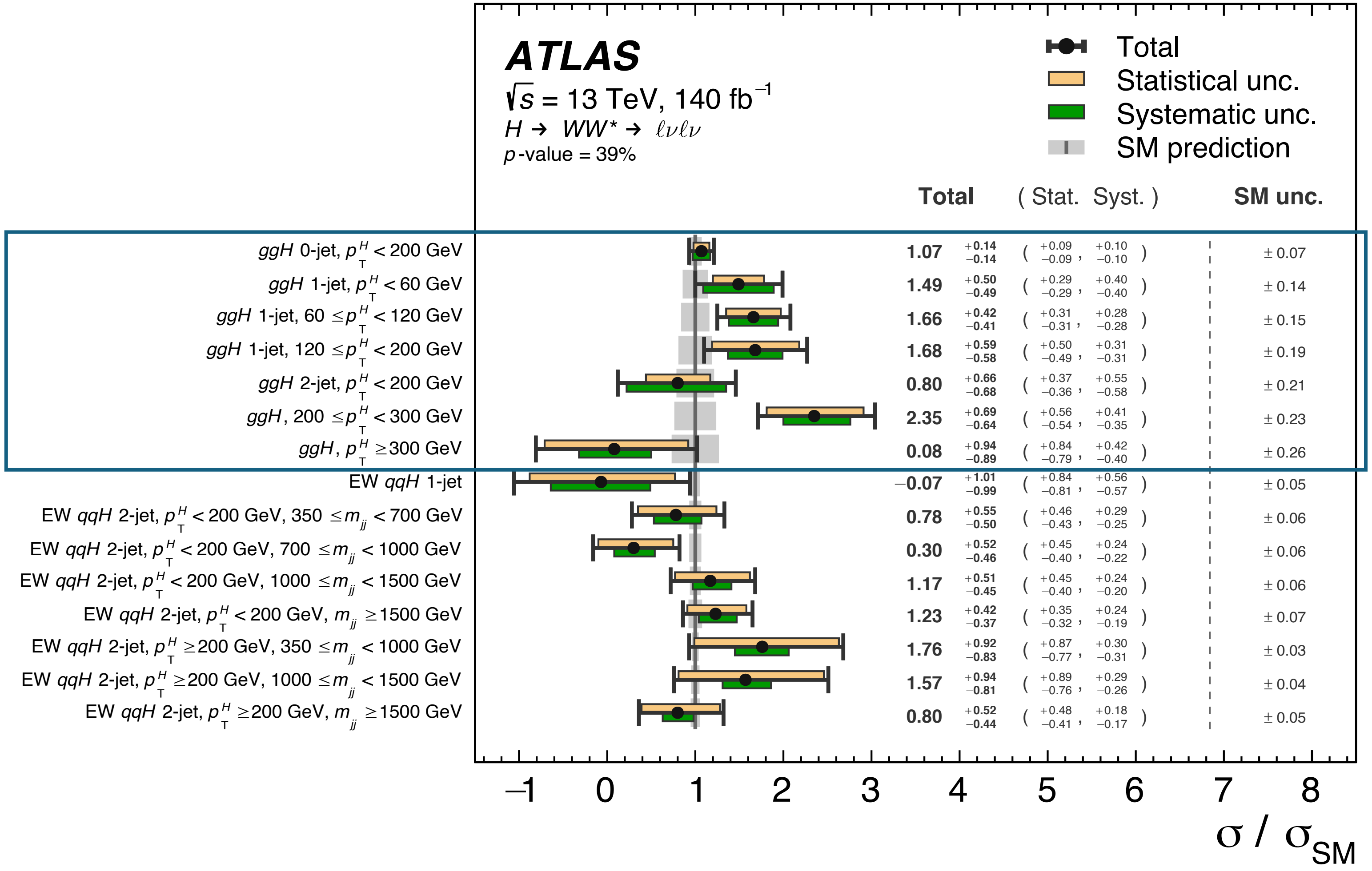
  - up to 35% improvement for ggF STXS categories.



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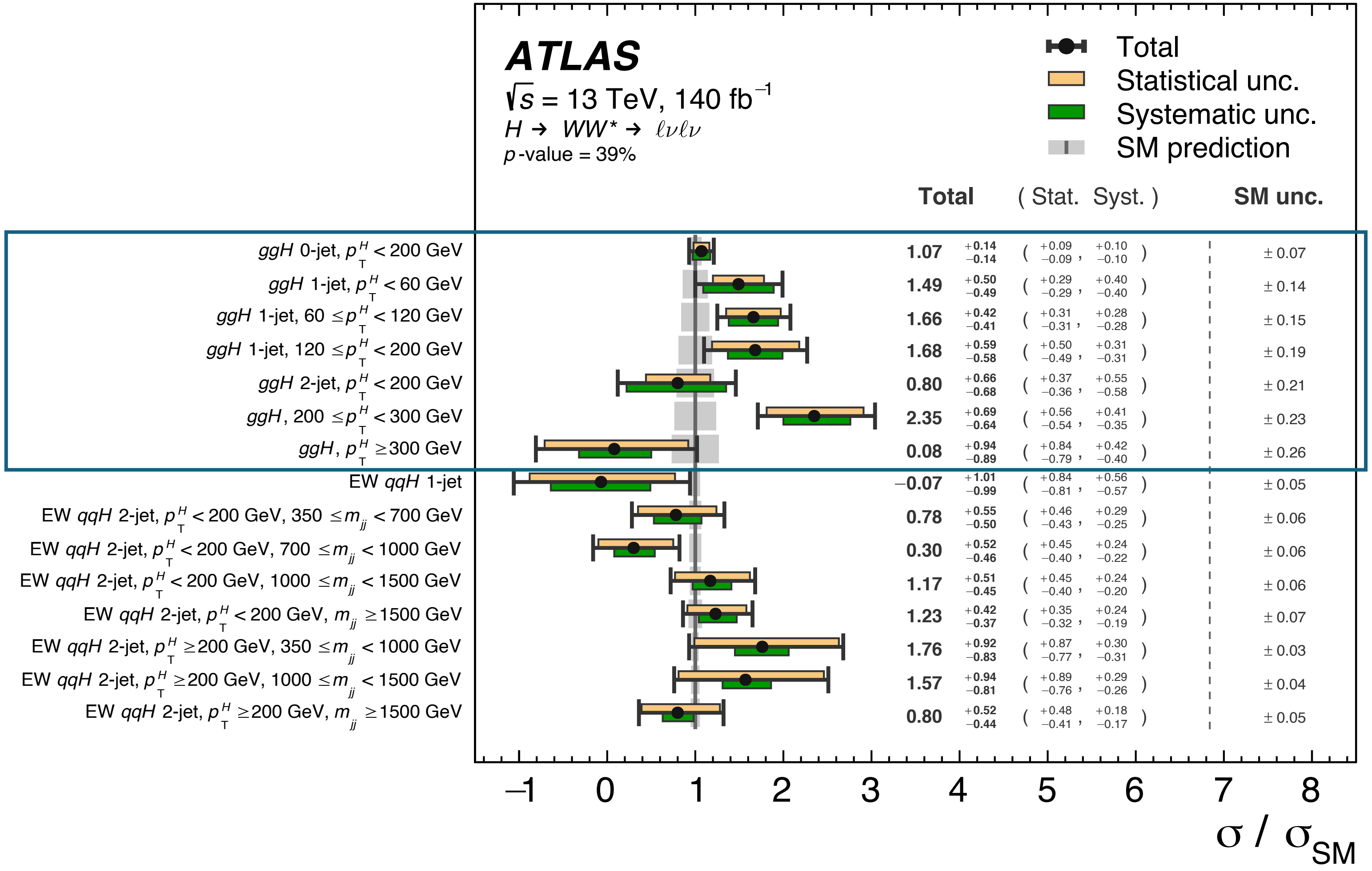


Going still further: what does this say about physics *beyond* our current energy reach?

Physics at Higher Energies: Effective Field Theory

Effective Field Theory: extend the SM Lagrangian with BSM physics operators:

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} \vartheta_i^{(6)} + \ \ldots$$

Wilson coefficients

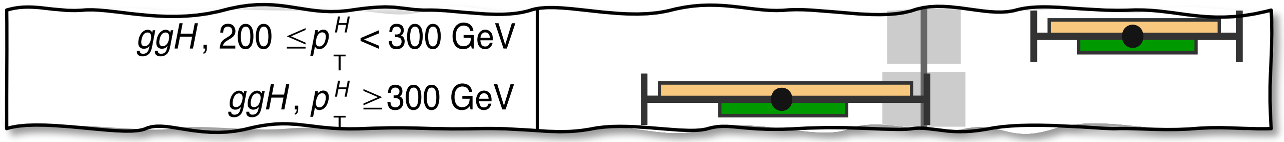
Higher-dimensional operators neglected

Operators $\vartheta_i^{(6)}$ = new heavy physics.

The presence of any $\vartheta_i^{(6)}$ operators cause measurements of **observables** like the **rate** and **distribution** of Higgs boson production to differ from the SM prediction.

→ Interpret cross-section measurements in EFT framework.

What do these deviations from the SM say about the possibility of new heavy physics?

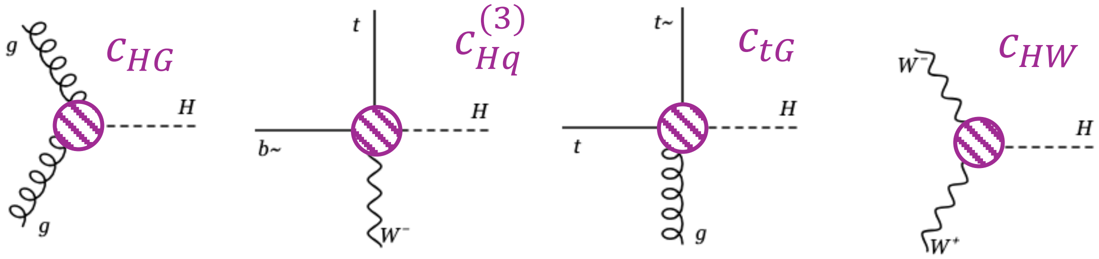


ggF and VBF $H \rightarrow WW^*$: EFT Interpretation

Strategy:

- Re-parameterize measured STXS signal strengths → constrain dim-6 EFT operators.
- Focus on linear combinations of operators to which analysis has sensitivity.

Most contributing operators:



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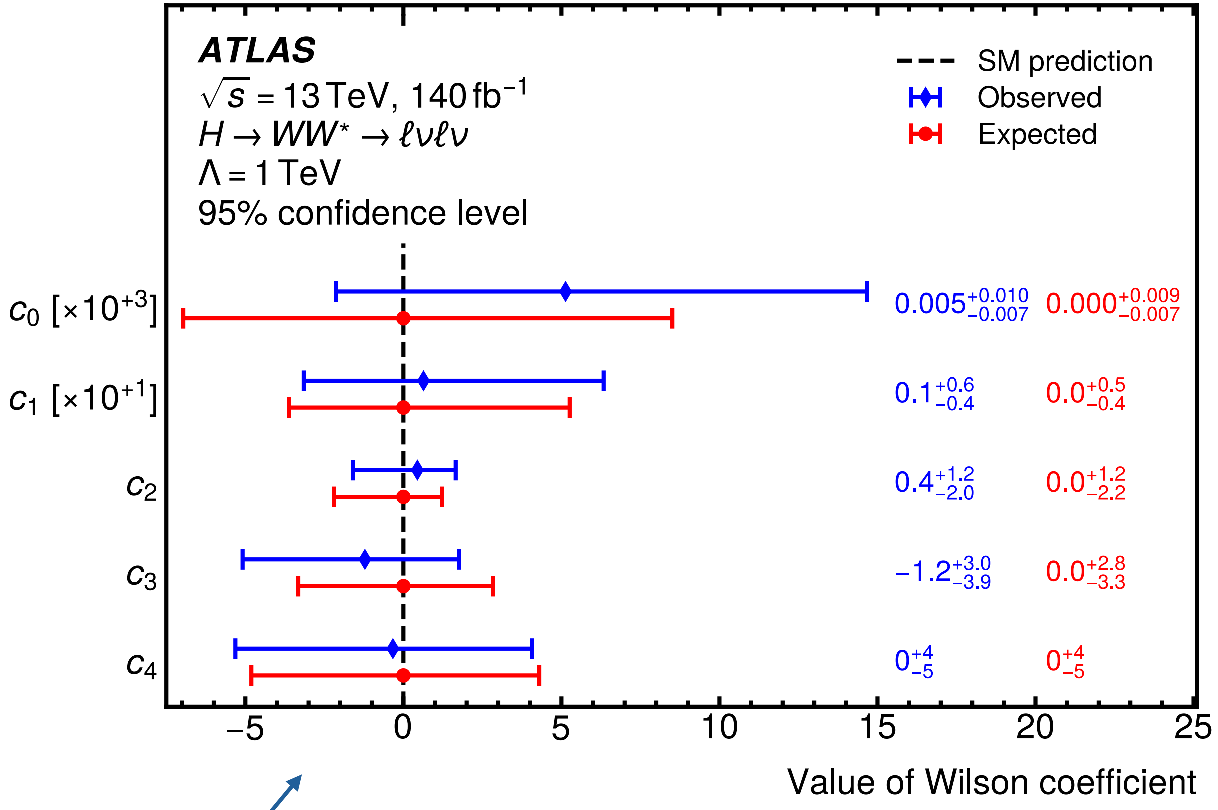

Simultaneous constraints on 5 linear combinations of EFT operators.

Closer Look at EFT

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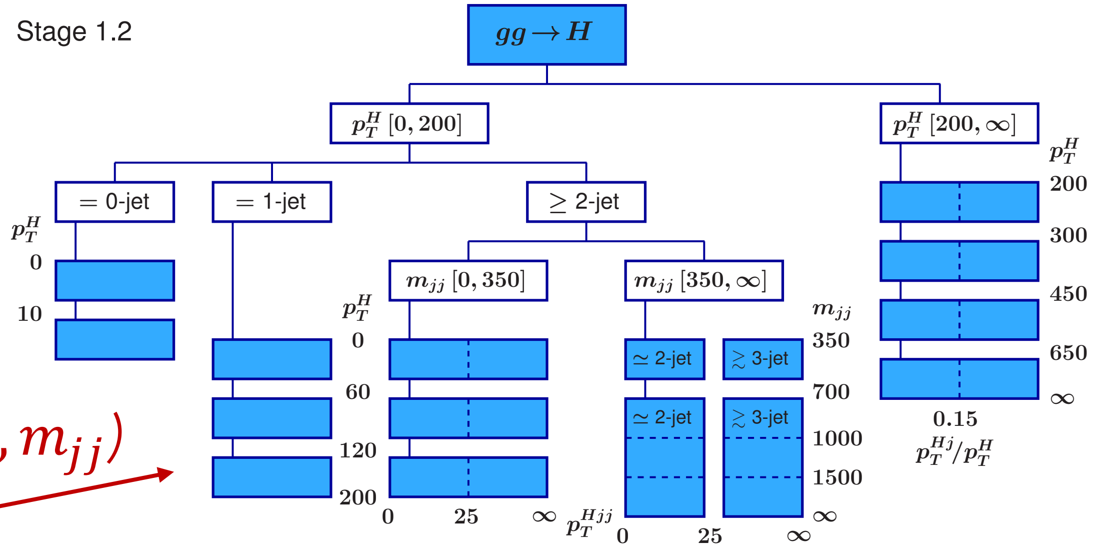
Wilson coefficients

Higher-dimensional operators neglected

Operators $\vartheta_i^{(6)}$ = new heavy physics.

- Can be characterized by their behaviour under charge-parity (CP) transformations: **even** or **odd**.

STXS measurement is only sensitive to CP-even operators!



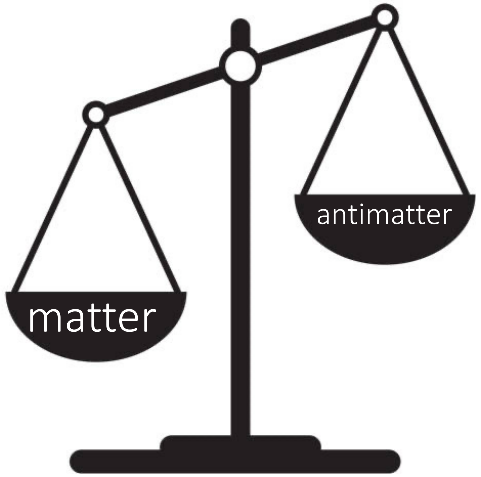
Variables ($n_{\text{Jets}}, p_{\text{T}}^H, m_{jj}$) are all CP-even.

Why Does CP Matter?

There is an imbalance in the universe!

Following the Big Bang: for every 10^8 **matter particles**, there were $10^8 - 1$ anti-matter particles.

This **imbalance** requires three ingredients:



The Sakharov Conditions:

1. Baryon number violation
2. Charge (C) and charge parity (CP) violation
3. Reactions out of thermal equilibrium

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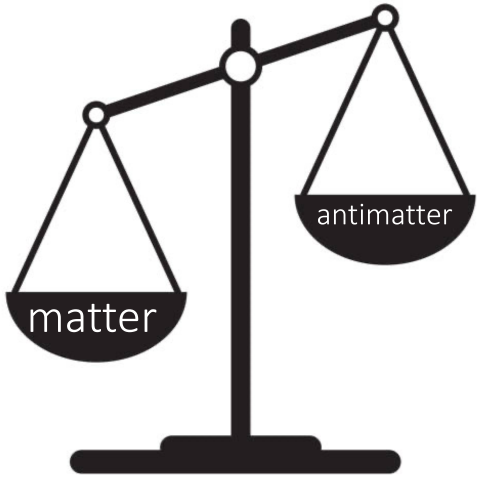


The Sakharov Conditions:

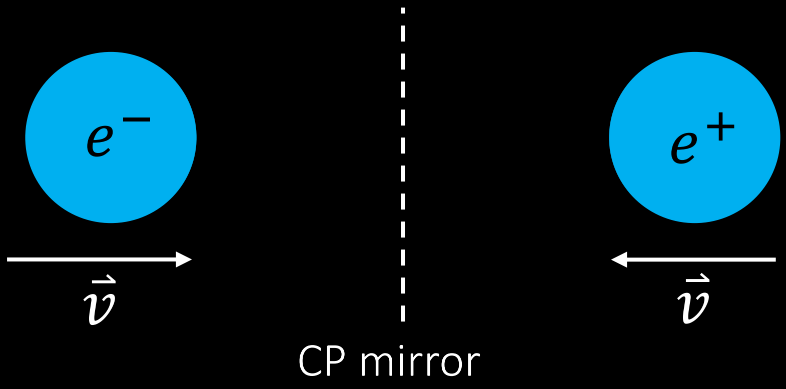
1. Baryon number violation
2. Charge (C) and **charge parity (CP) violation** → *What we can investigate*
3. Reactions out of thermal equilibrium

What is CP Violation?

Consider a **CP transformation**:

Invert **charge** and **parity** (spatial coordinates).

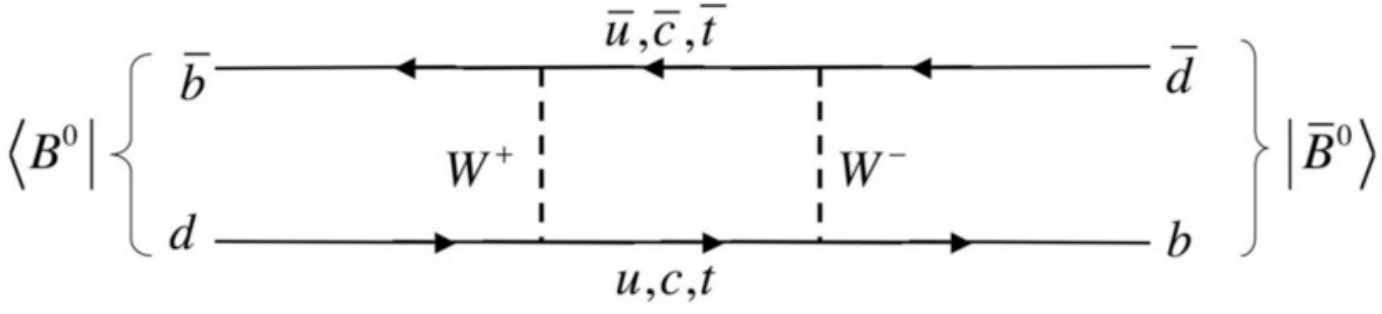
Creates **anti-particle** from **particle.**



CP violation: the charge-inverted mirror image does not follow the same laws of nature!

CP Violation in the Standard Model

In the Standard Model of particle physics, CP violation is present in weak interactions.



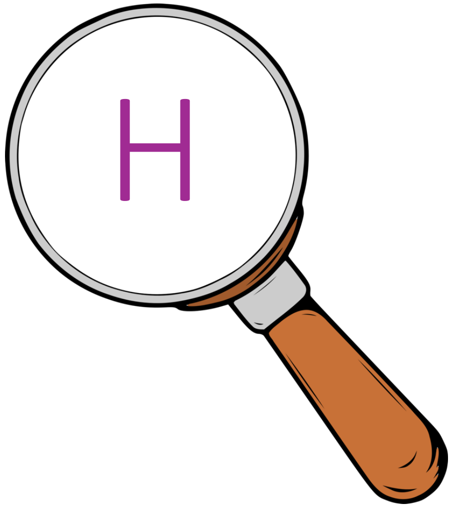
eg. B-meson decay

But it is several orders of magnitude short of what is needed to explain the universe's observed matter-antimatter asymmetry.

→ There must be other sources.

Where to look?

Good candidate: the Higgs boson.



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Higher-dimensional operators neglected

Operators $\vartheta_i^{(6)}$ = new heavy physics.

- Can be characterized by their behaviour under charge-parity (CP) transformations: **even** or **odd**.
    - CP-even operators → no CP violation
    - CP-odd operators → can cause **CP violation**.

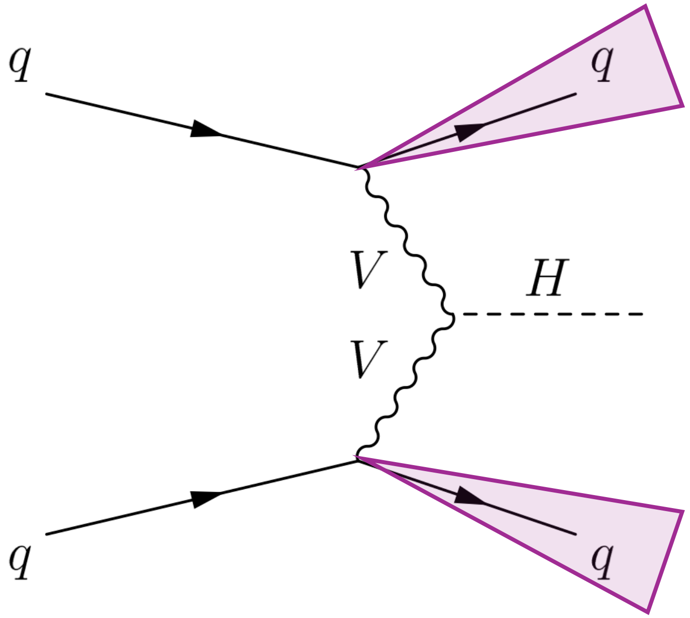
We would like sensitivity to CP-odd physics → need a suitable observable.

Adding Sensitivity to CP Violation

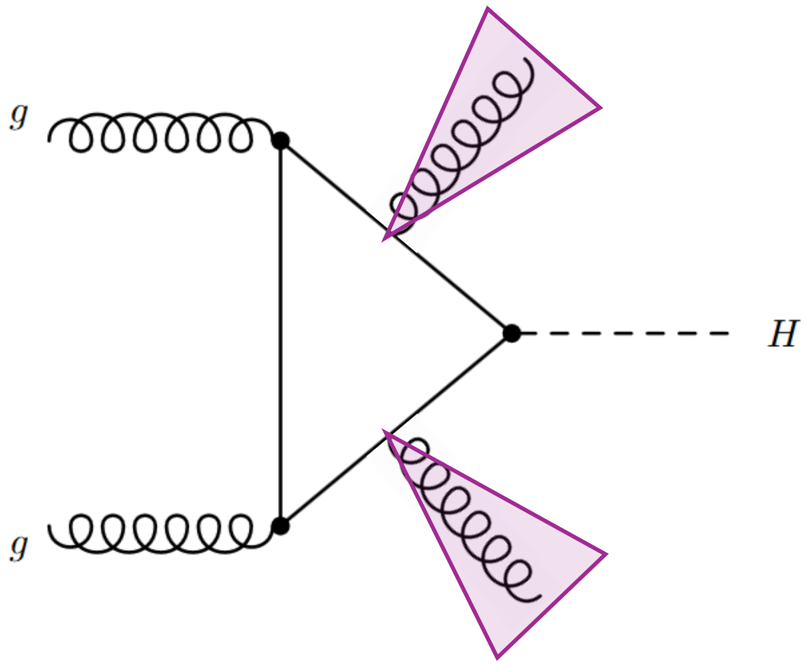
Such an observable: $\Delta\Phi_{jj}$

collimated cones of particles

- Defined for Higgs boson production with two accompanying jets:



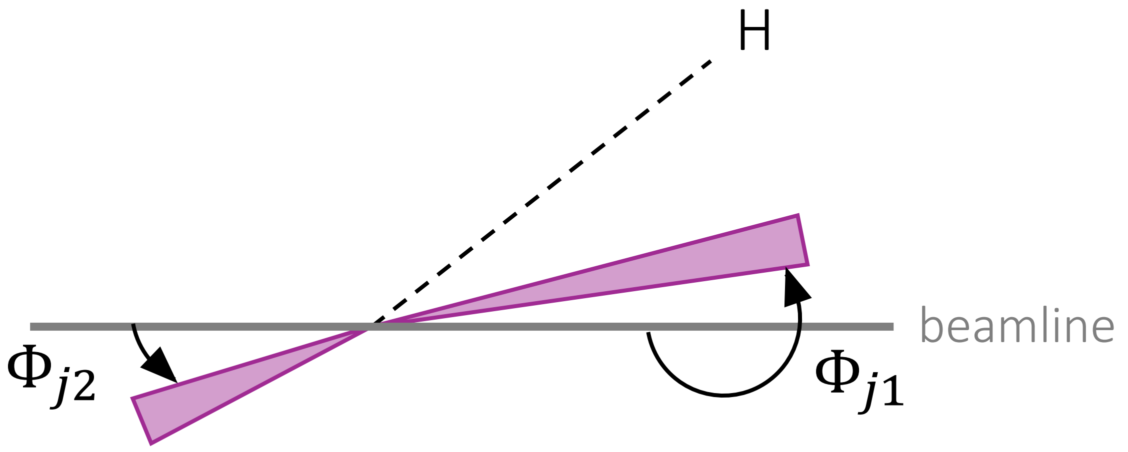
vector boson fusion (VBF)



gluon fusion (ggF)

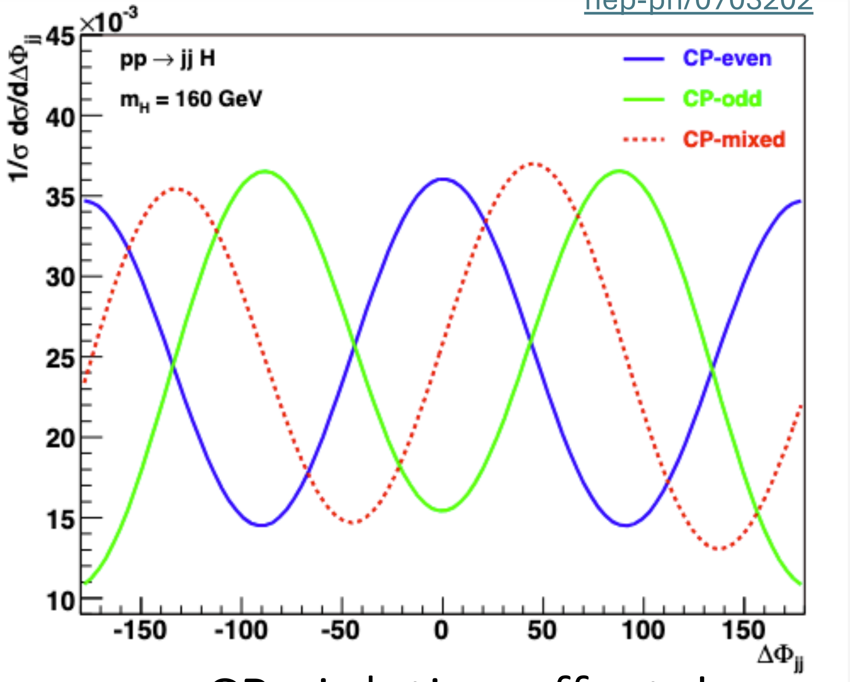
Creating $\Delta\Phi_{jj}$

- Order the jets by their angle wrt the beamline, η
- Take the difference of the azimuthal angle Φ between the jet of higher and lower η.



SM and CP-even symmetric
Pure CP-odd terms symmetric w/phase shift
Mixed SM-CP-odd terms asymmetric

hep-ph/0703202



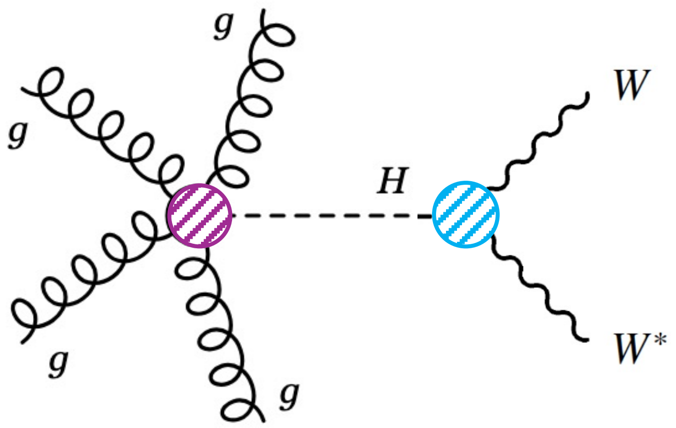
This variable is:
- symmetric around 0 for SM and CP-even operators
- asymmetric around 0 for SM/CP-odd interference

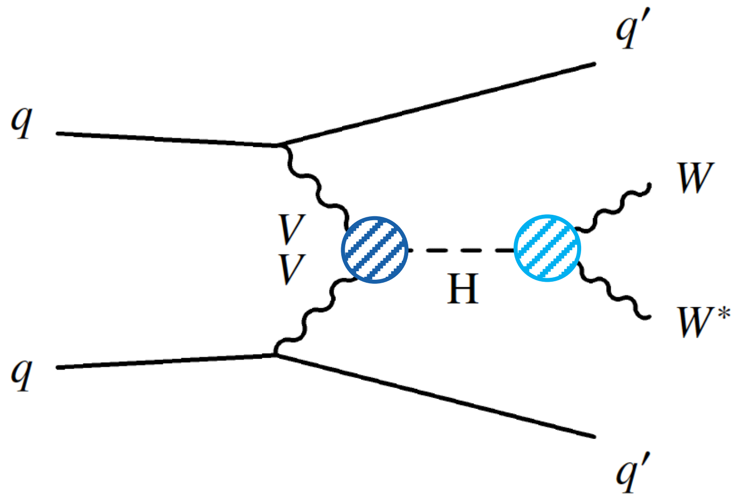
→ We can use this to distinguish **CP-violating** from non-CP-violating effects!

Using $\Delta\Phi_{jj}$ in the $H \rightarrow WW^*$ Measurement

Strategy:

- Attempt to measure four dim-6 EFT operators corresponding to four coefficients:
  - CP-even: c_{HG}, c_{HW} → symmetric $\Delta\Phi_{jj}$
  - CP-odd: $c_{H\tilde{G}}, c_{H\tilde{W}}$ → asymmetric $\Delta\Phi_{jj}$





Affect Higgs production via ggF: $c_{HG}, c_{H\tilde{G}}$

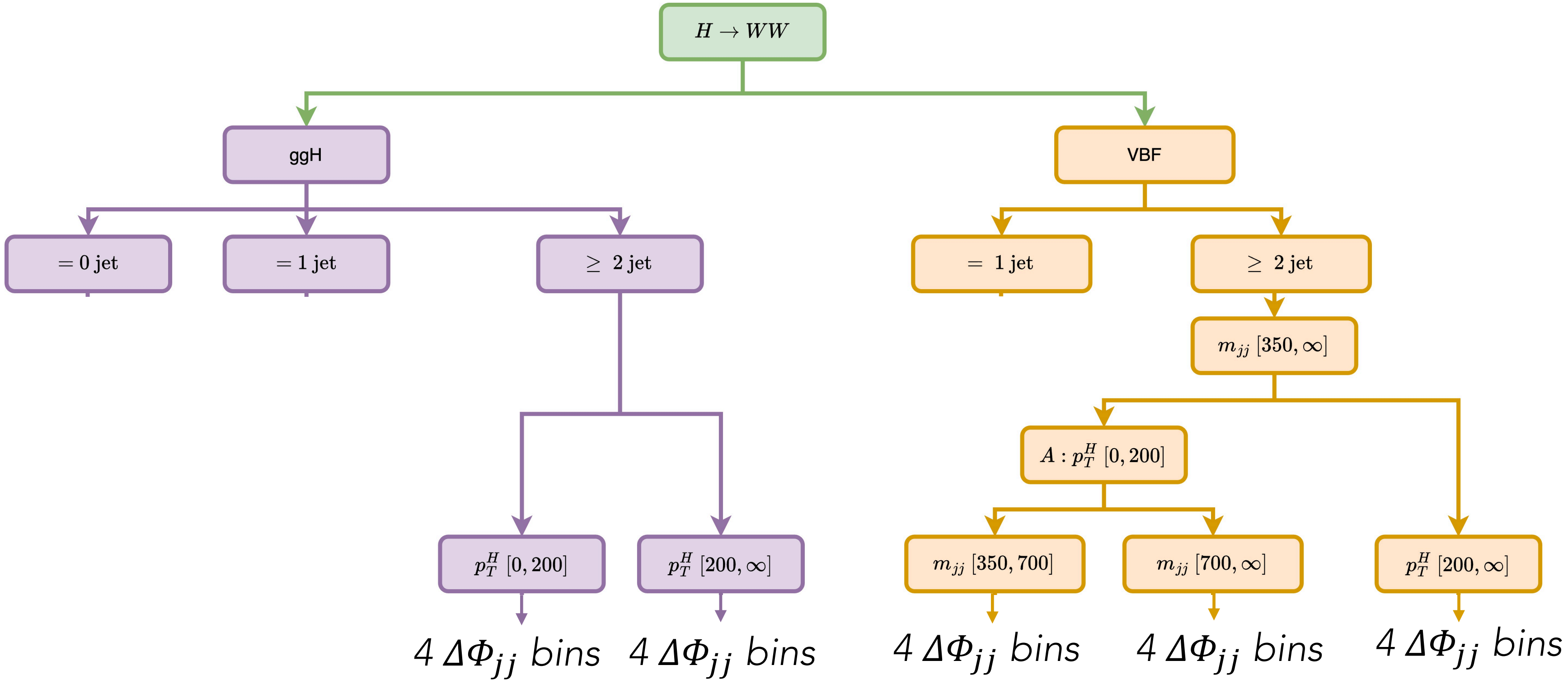
Affect Higgs production via VBF: $c_{H\tilde{W}}$

Affect Higgs production via VBF and decay via WW: c_{HW}

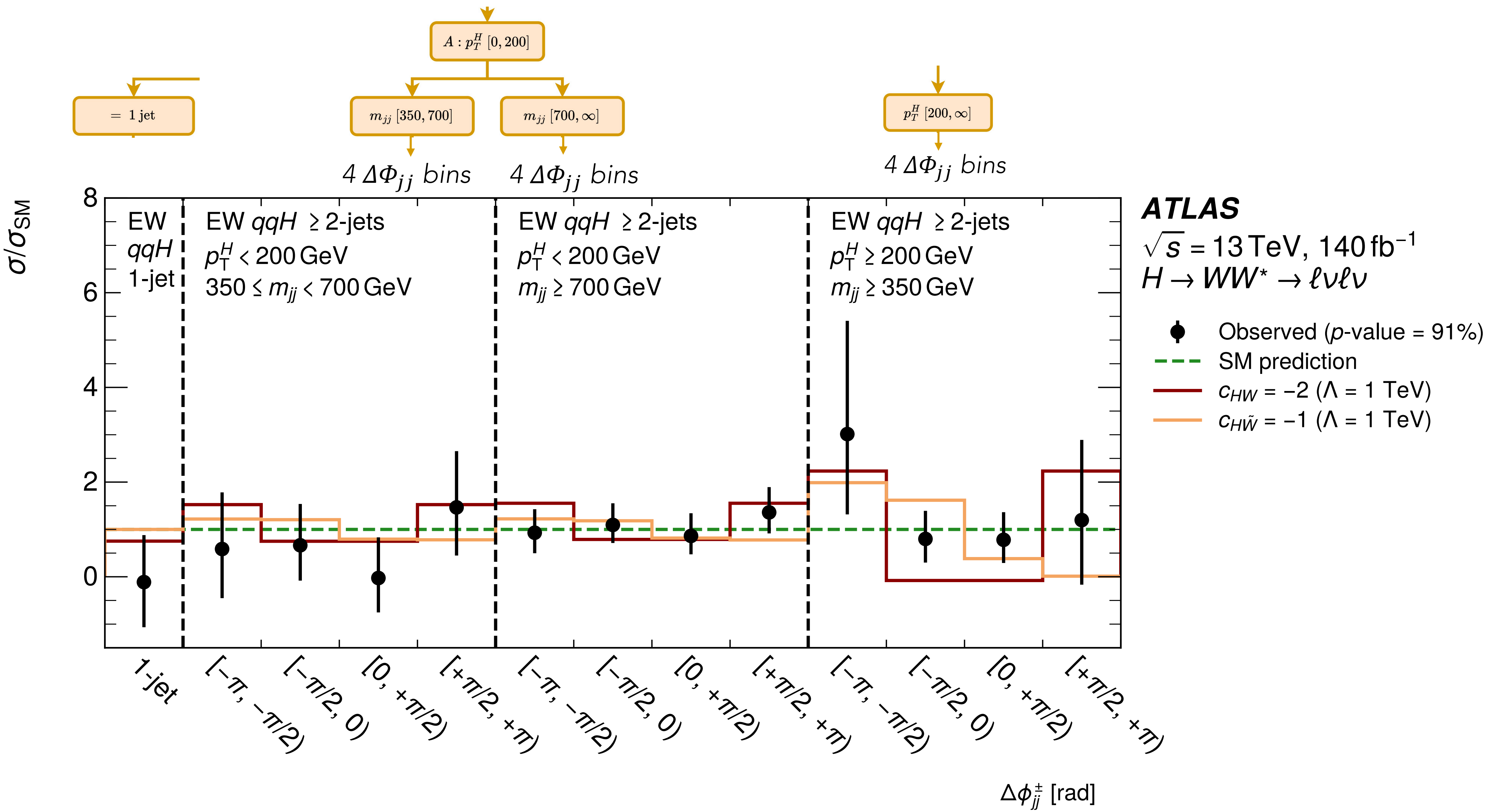
Using $\Delta\Phi_{jj}$ in the $H \to WW^*$ Measurement

Strategy:

- 2-jet STXS categories split into four $\Delta\phi^{\pm}_{jj}$ bins → target $c_{H\widetilde{W}}, c_{H\widetilde{G}}$
- 0- and 1-jet STXS categories split as usual → target c_{HG}, c_{HW}.

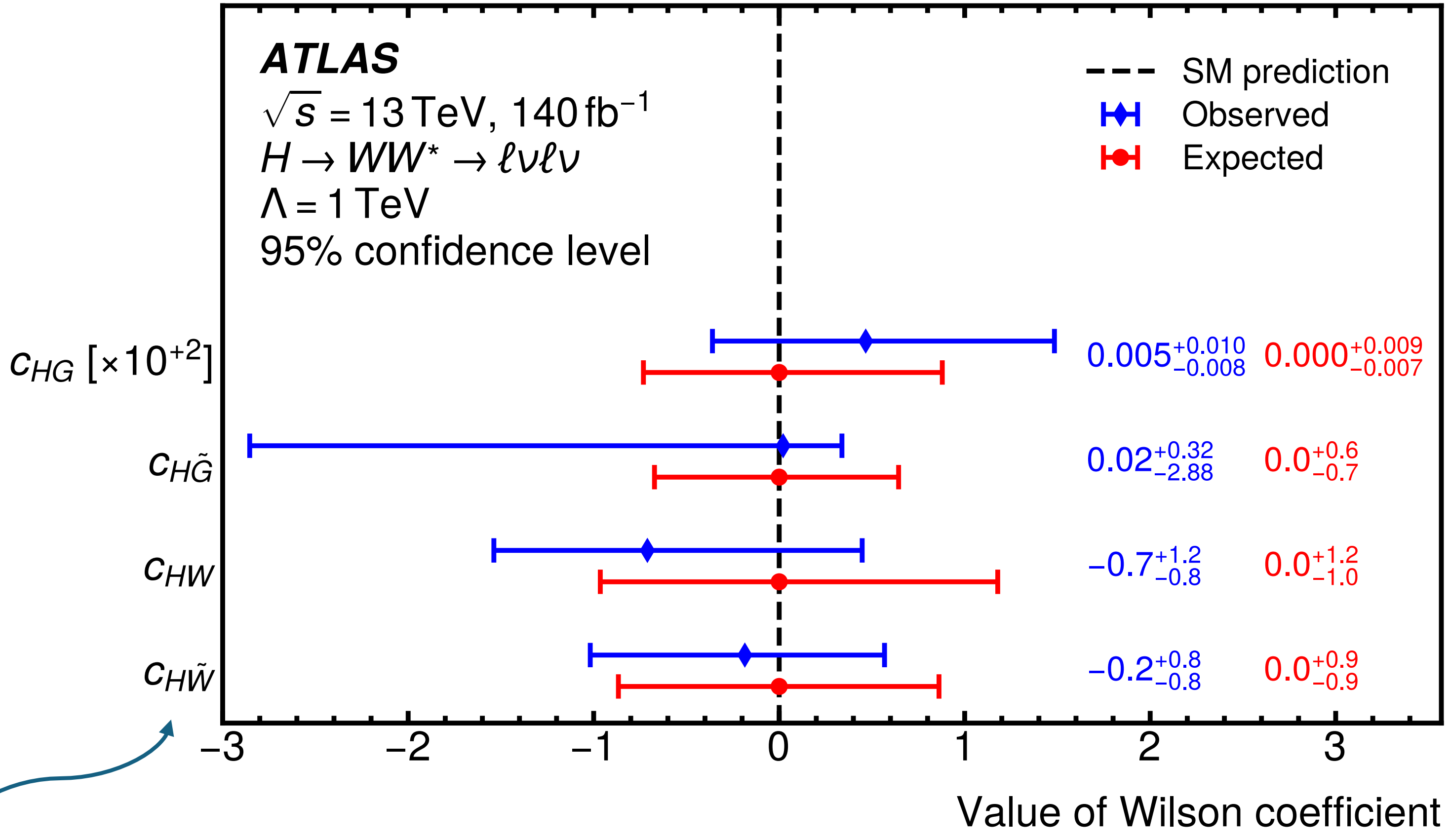


$\Delta\Phi_{jj}$ Measurements (VBF $H \rightarrow WW^*$)



ggF and VBF $H \to WW^*$: CP-Sensitive EFT Interpretation

Results:



Advantages of this result: multi-POI fit, ~no correlation with CP-even effects, $\Delta\phi_{jj}^{\pm}$ is decay-agnostic.

This result:

$c_{H\widetilde{W}}$ = [-1.0, 0.6] obs. at 95% C.L.

Compare to world-leading limits on $c_{H\widetilde{W}}$ from other ATLAS analyses: :

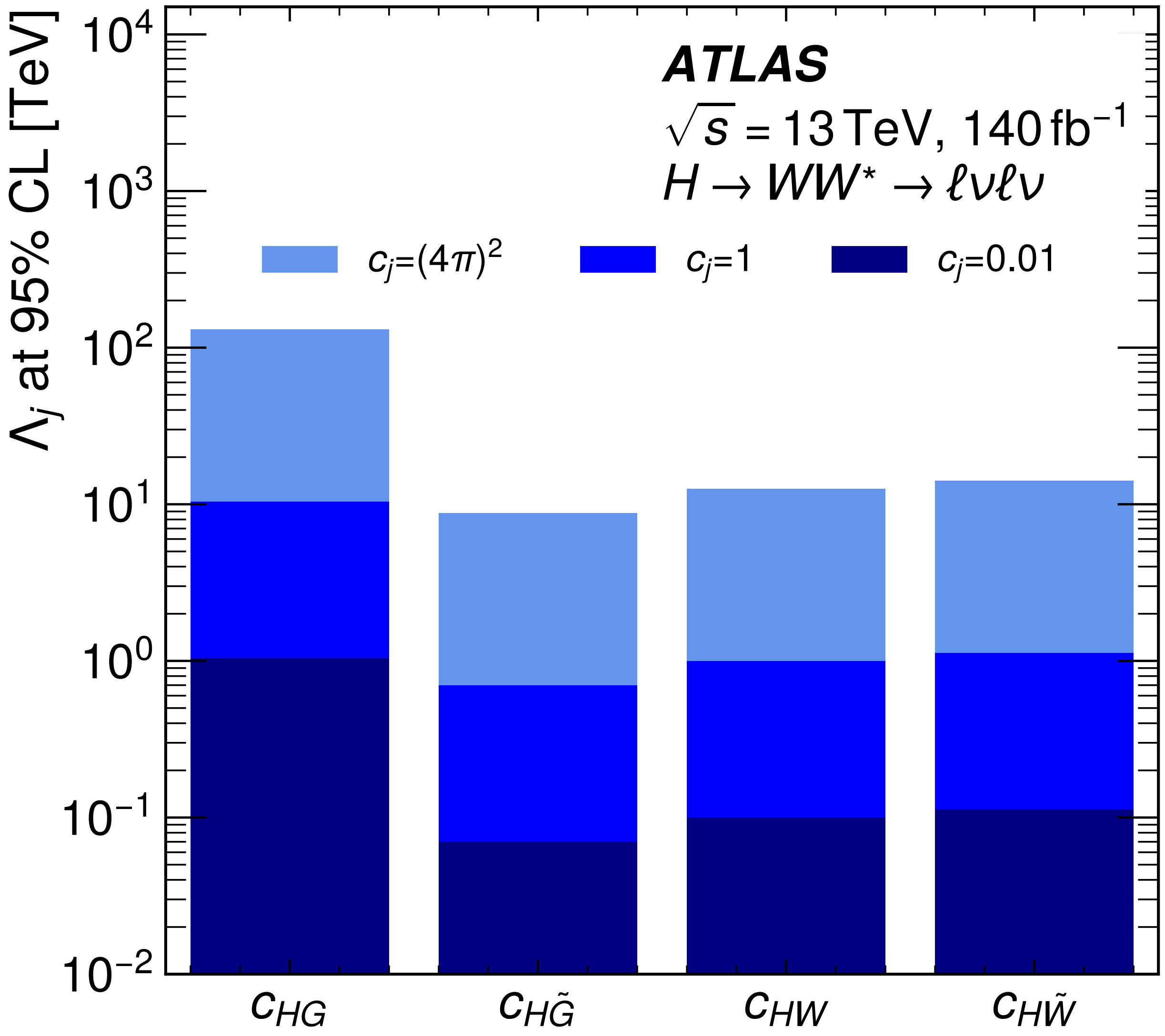
- VBF $H \to \tau\tau$ [HIGG-2022-07]:
  [−0.31, +0.88] obs at 95% C.L.
- WH $H \to b\bar{b}$ [ATL-PHYS-PUB-2025-022]:
  [−0.62, +0.85] obs at 95% C.L.

ggF and VBF $H \rightarrow WW^*$: CP-Sensitive EFT Interpretation

Results:

What does this mean?

→ Translate to limit on energy scale of new physics.



Implications and Looking Ahead

Cross-Sections → Couplings

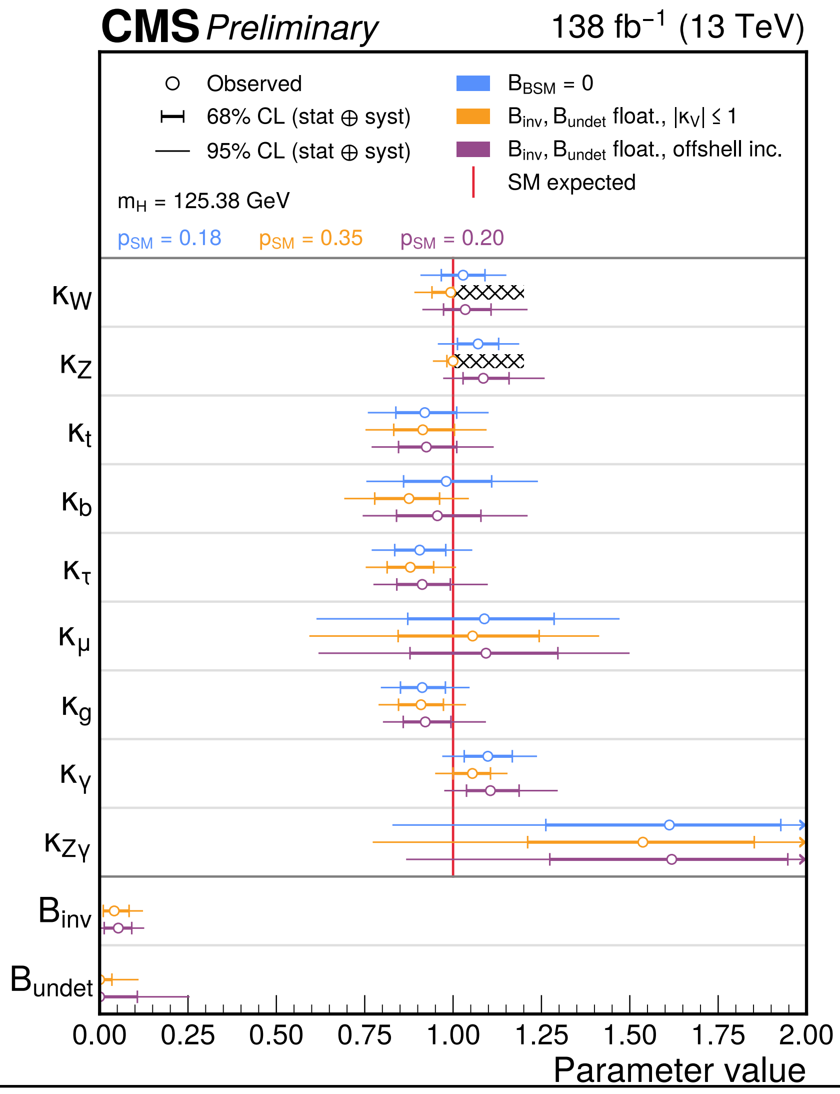
- Cross-section can be translated into Higgs boson couplings modifiers, κ.

$$\kappa_i^2 = \frac{\sigma_{i\to H}}{\sigma_{i\to H}^{\mathrm{SM}}}$$

Current precision:

- Couplings to gauge bosons (Z, W, γ) and 3rd generation fermions (t, τ): ~10%
- Coupling to b-quark: ~17%
- Large uncertainty on couplings to 2nd generation fermions, eg. κ_μ, κ_c

Latest CMS Combination [HIG-21-018]



Is This Enough?

Couplings:

- Several models predict deviations *smaller* than our current precision.

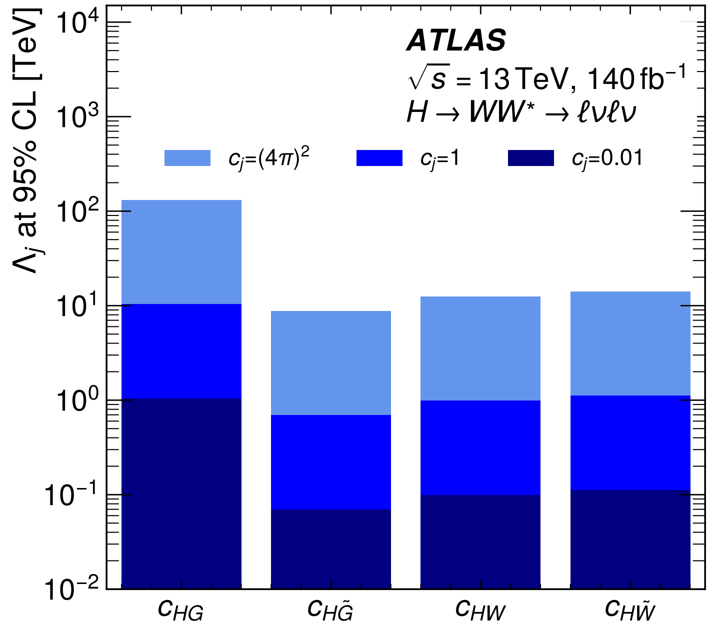
Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$\sim -.4\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

arXiv:1310.8361

~10% now ~17% now ~10% now

EFT:

- New physics could be anywhere up to the Planck scale (10^{16} TeV).



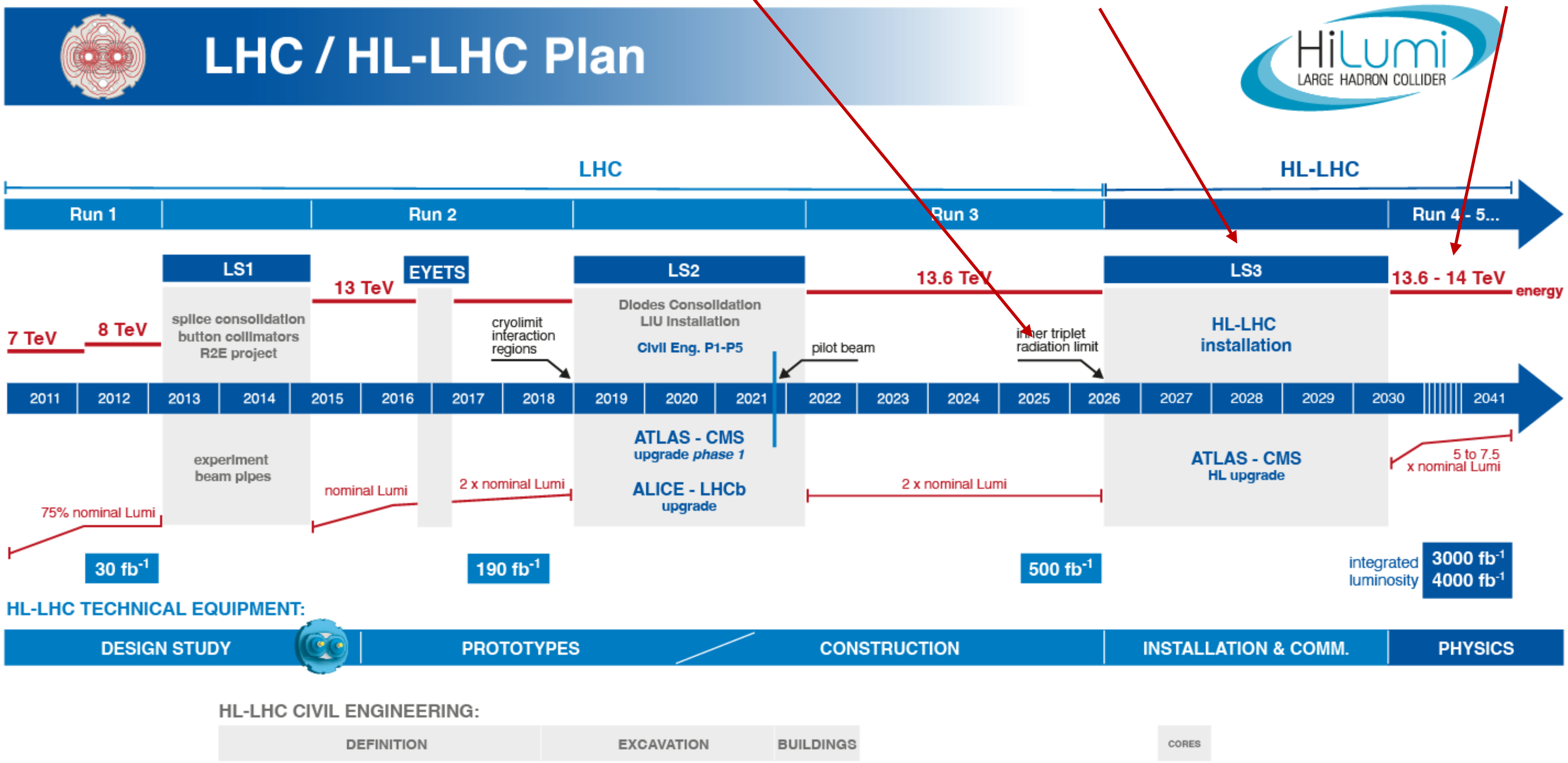
- Analysis techniques can refine results → proven earlier in this talk!
- But many results are limited by statistical uncertainty → just need more data.

The LHC in the Coming Years

2025: Run 3 ongoing

2026-2030: Long Shutdown

2030-2041: High-Luminosity LHC



High-Luminosity LHC

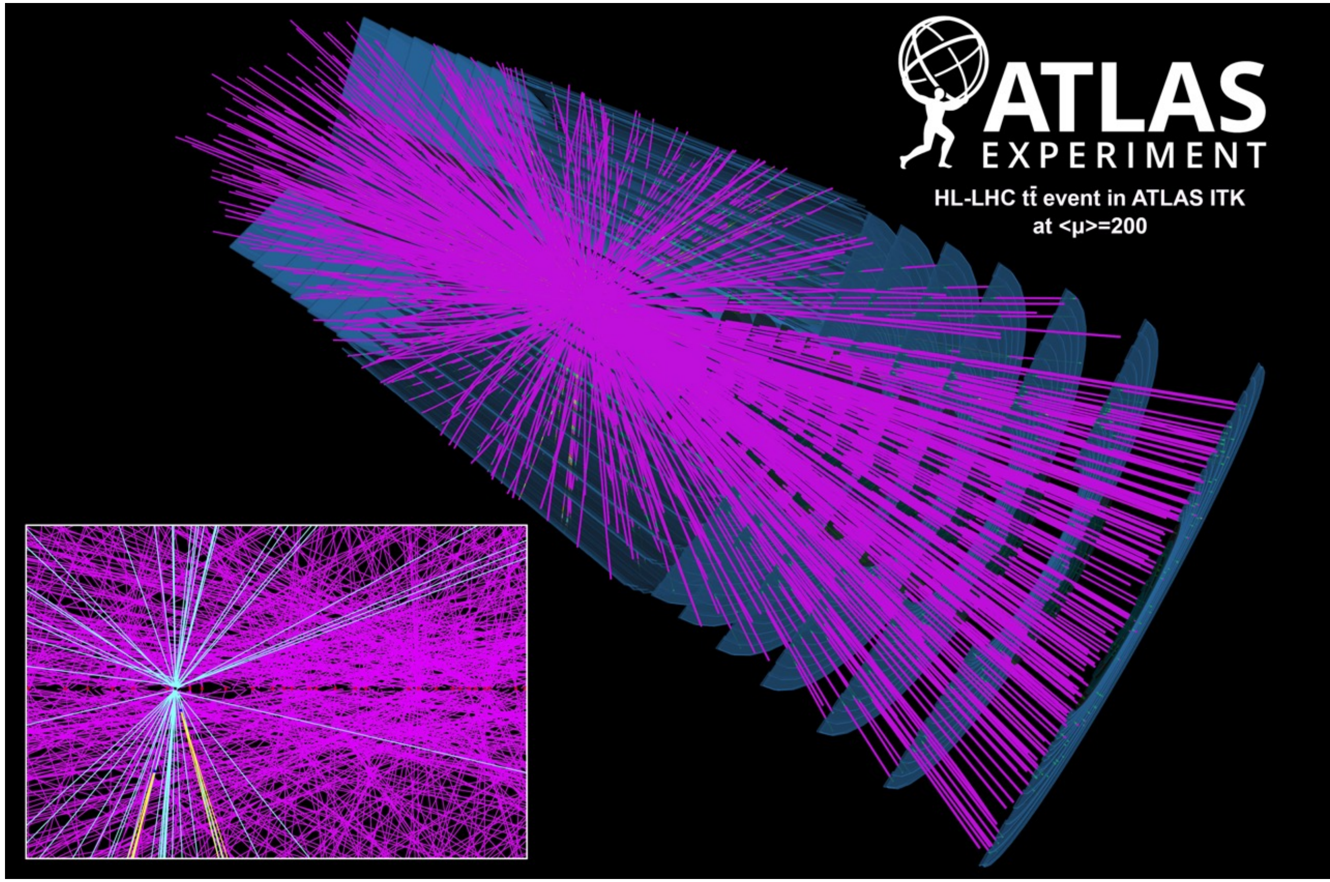
Luminosity:

- Higher luminosity = more collisions per time interval
- **Challenging**: more collisions = more unwanted information every time protons collide.

If we can surmount the challenge:

- HL-LHC will increase the size of our dataset by nearly a factor of 10!
- Can look at expected impact on our measurements.

Simulated $t\bar{t}$ event with pileup = 140 [ATLAS]



cyan tracks = what we want to detect

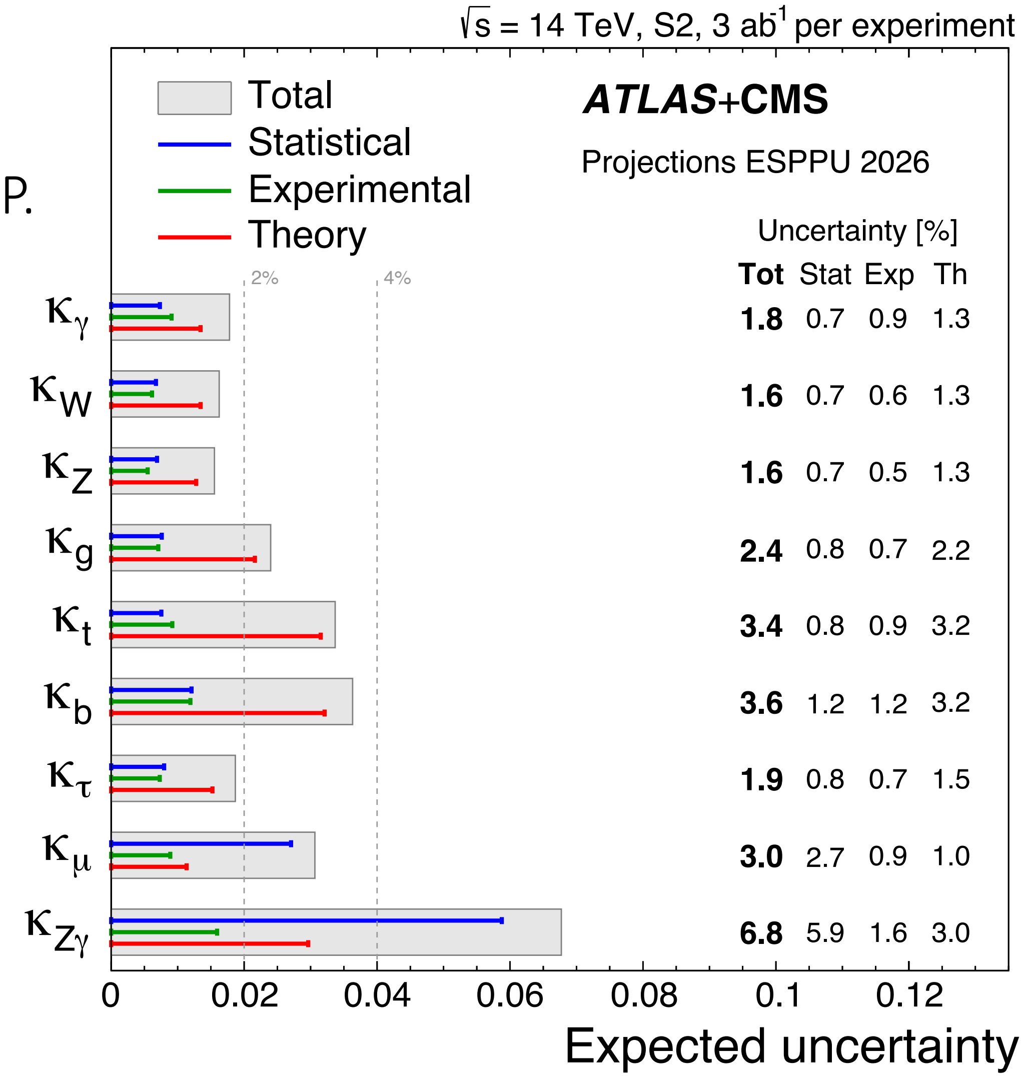
Higgs at HL-LHC

HL-LHC Projections:

- Prepared by ATLAS and CMS as input to the ESPP.
- Assume:
  - 3 ab^{-1} HL-LHC dataset
  - No impact from different running conditions
  - Systematic uncertainties reduced

Results:

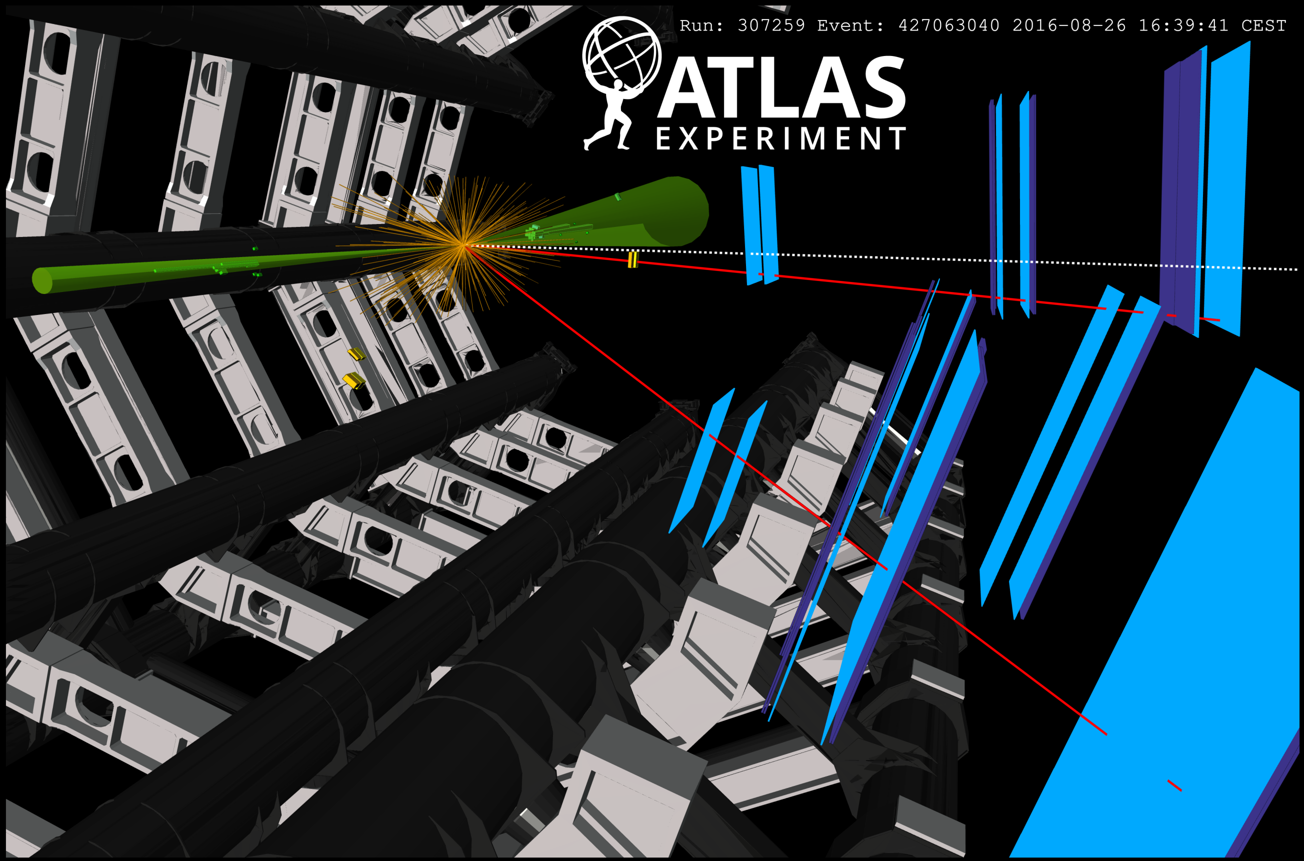
- Observation of $H \to \mu\mu$, $H \to Z\gamma$
- Limit of $|\kappa_c| < 1.5$ at 95% C.L.
- Other couplings measured with 1.6-3.6% unc.
- Higgs width measured with 17% unc.



ATL-PHYS-PUB-2025-018

Conclusions

- Presented recent progress from the LHC.
- Some big improvement over existing Run 2 results, with same dataset → shows power of innovative analysis techniques.
- The next years of the (HL-) LHC bring more promise for discovery.



Backup

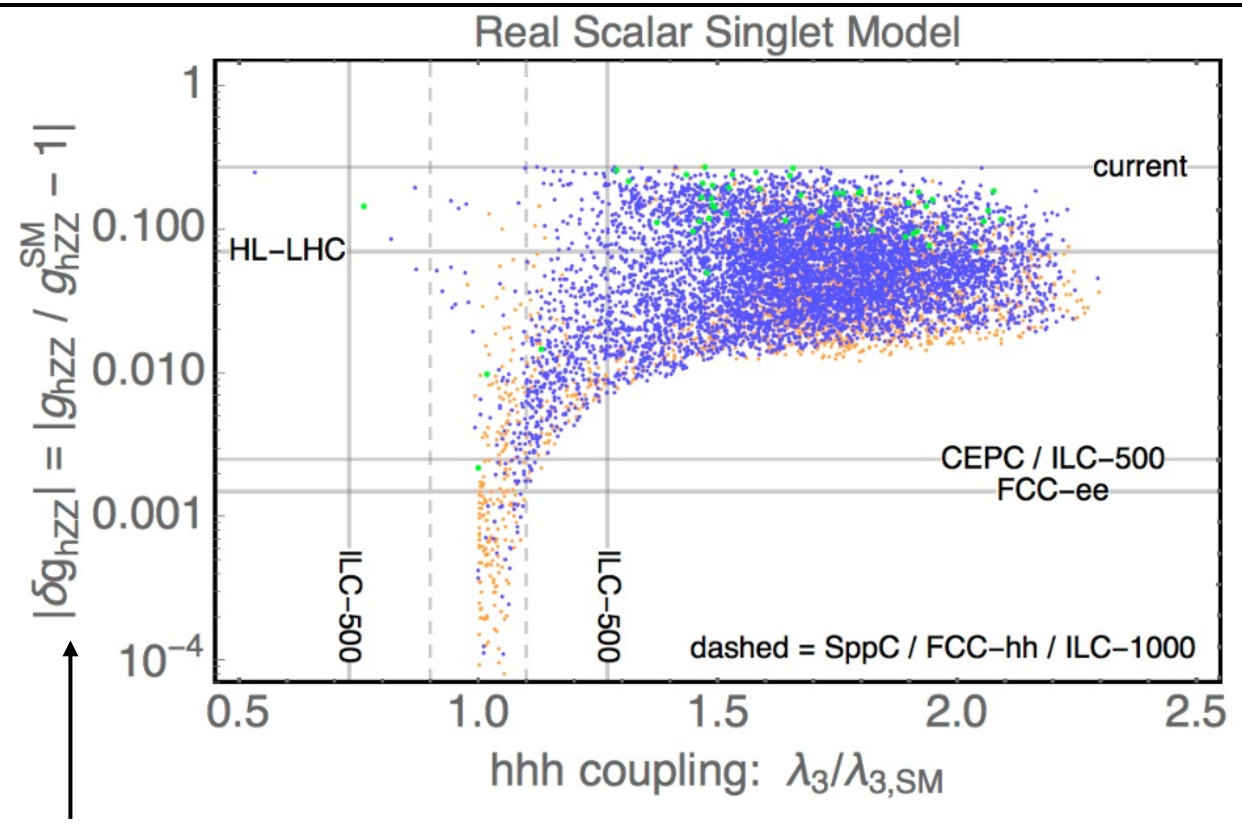
Why *HVV* Couplings?

arXiv:1608.06619

Simple model: a new singlet scalar particle exists and interacts with the Higgs boson.

Effect on Higgs interactions: *HWW* and *HZZ* interaction strengths suppressed (1-30%).

> "The most model independent effect of such new physics is the induced deviation in the Higgs couplings."



Modification to *HVV* interaction strength

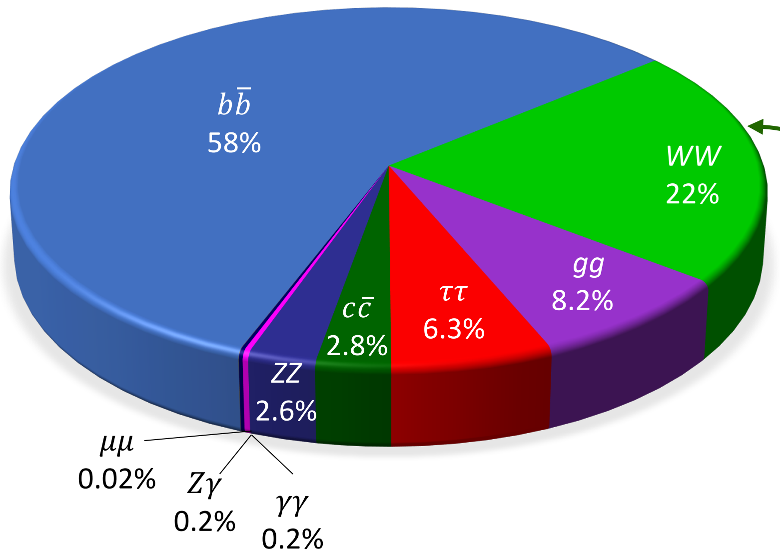
blue, orange, green points: different versions of EWSB

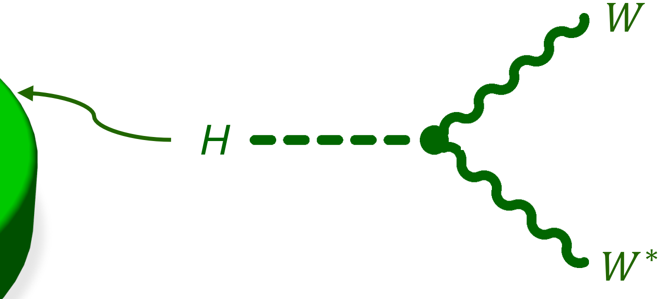
Consequences for early universe:

- Changes electroweak symmetry breaking: potential energy barrier → first-order phase transition.
- Provides a mechanism for the matter-antimatter asymmetry we observe today.

The $H \to WW^*$ Channel

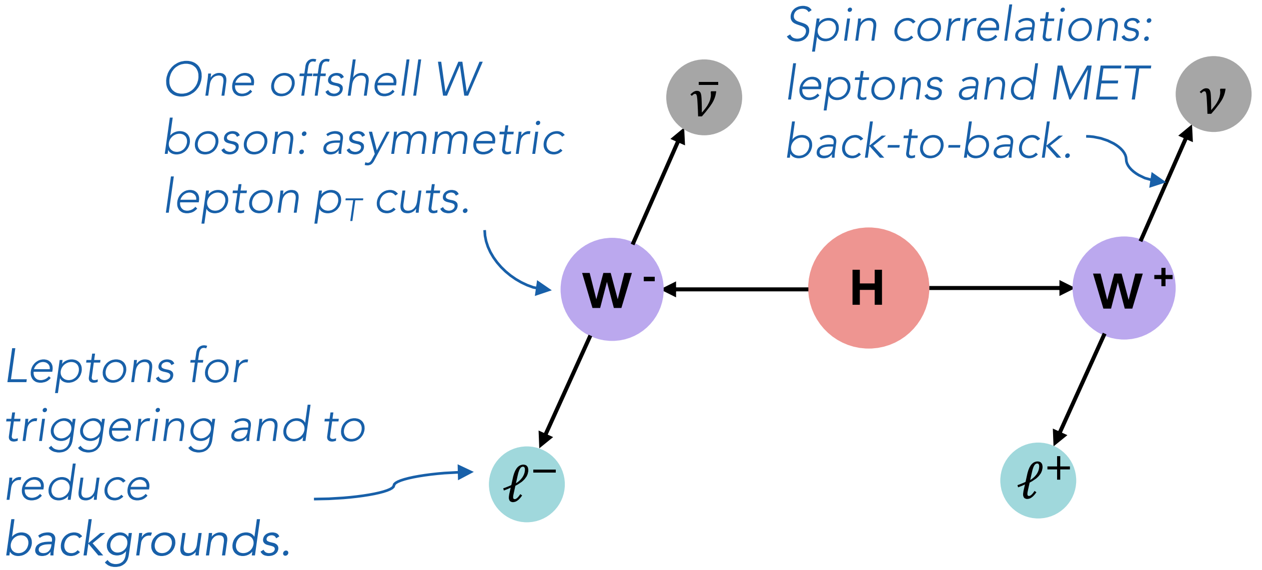
✓ Second-largest Higgs boson branching ratio: can investigate rarer production modes.





✓ Clean leptonic $H \to WW^* \to \ell\nu\ell\nu$ decay, with characteristic features

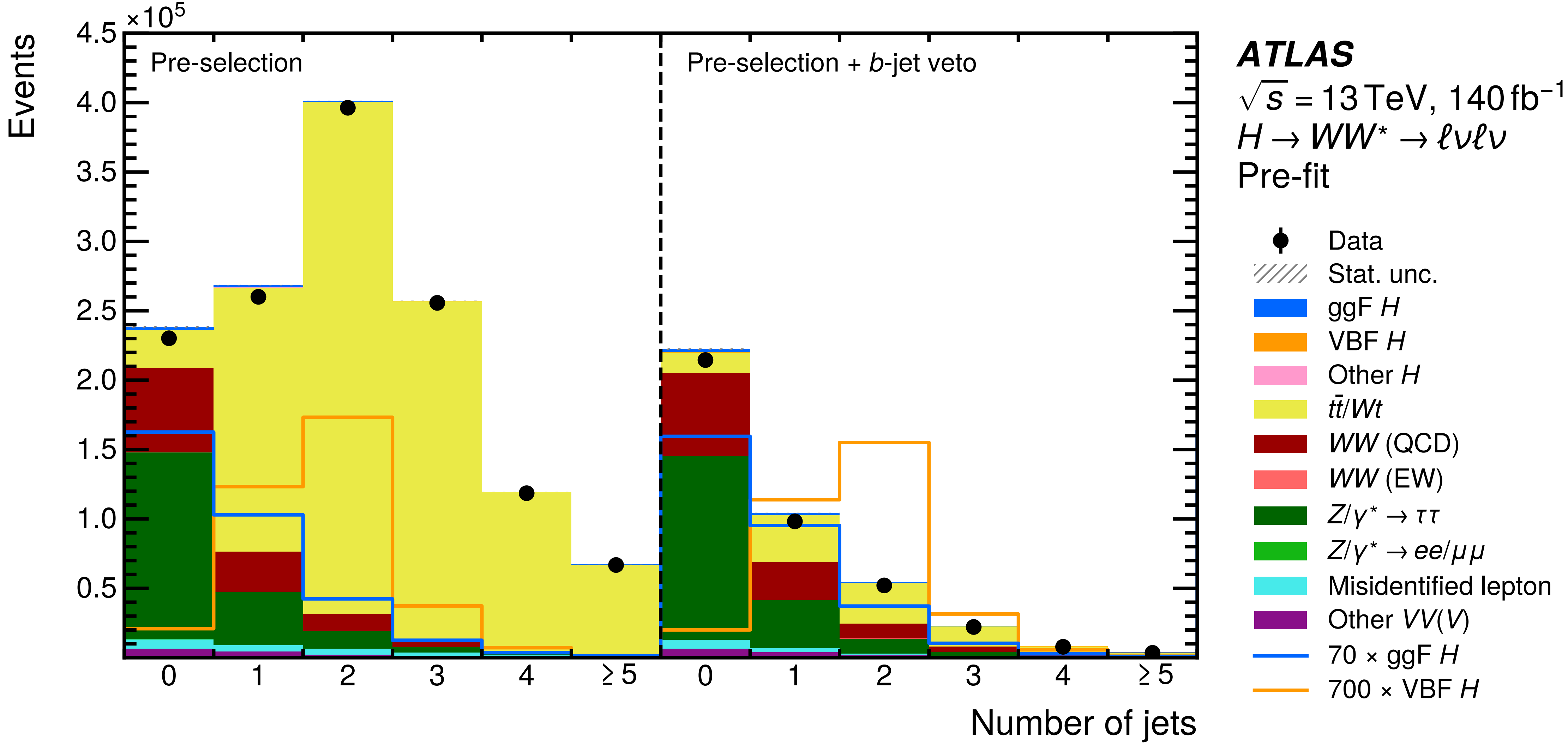
X Many background processes



ggF + VBF $H \to WW^*$

Purpose	Event class: $N_{\text{jets}} = 0$	$N_{\text{jets}} = 1$	$N_{\text{jets}} \geq 2$ ggF-enriched	$N_{\text{jets}} \geq 2$ VBF-enriched
Preselection	Two isolated, different-flavour (same-flavour) leptons with opposite charge			
	$p_{\text{T}}^{\ell_0} > 22$ GeV and $p_{\text{T}}^{\ell_1} > 15$ GeV			
	$m_{\ell\ell} > 10$ GeV (12 GeV)			
	Different-flavour leptons		($\mathcal{S}_{\text{miss}} > 4$ and $p_{\text{T}}^{\ell\ell} > 40$ GeV) Different- or same-flavour leptons	
Background suppression	$N_{b\text{-jets}}\,[p_{\text{T}} > 20\text{ GeV}] = 0$			
	$E_{\text{T}}^{\text{miss}} > 20$ GeV	$m_{\tau\tau} < m_Z - 25$ GeV		
	$\Delta\phi_{\ell\ell} < 2.0$ rad		$\Delta\phi_{\ell\ell} < 1.8$ rad	–
	$m_{\ell\ell} < 55$ GeV		$m_{\ell\ell} < 55$ GeV	$m_{\ell\ell} < 70$ GeV
	$\Delta R_{\ell\ell} > 0.6$			
Signal topology	$\Delta\phi_{\ell\ell,\text{miss}} > 1.57$ rad	–	VH orthogonality Fail CJV or Fail OLV	$m_{jj} > 350$ GeV Pass CJV and Pass OLV

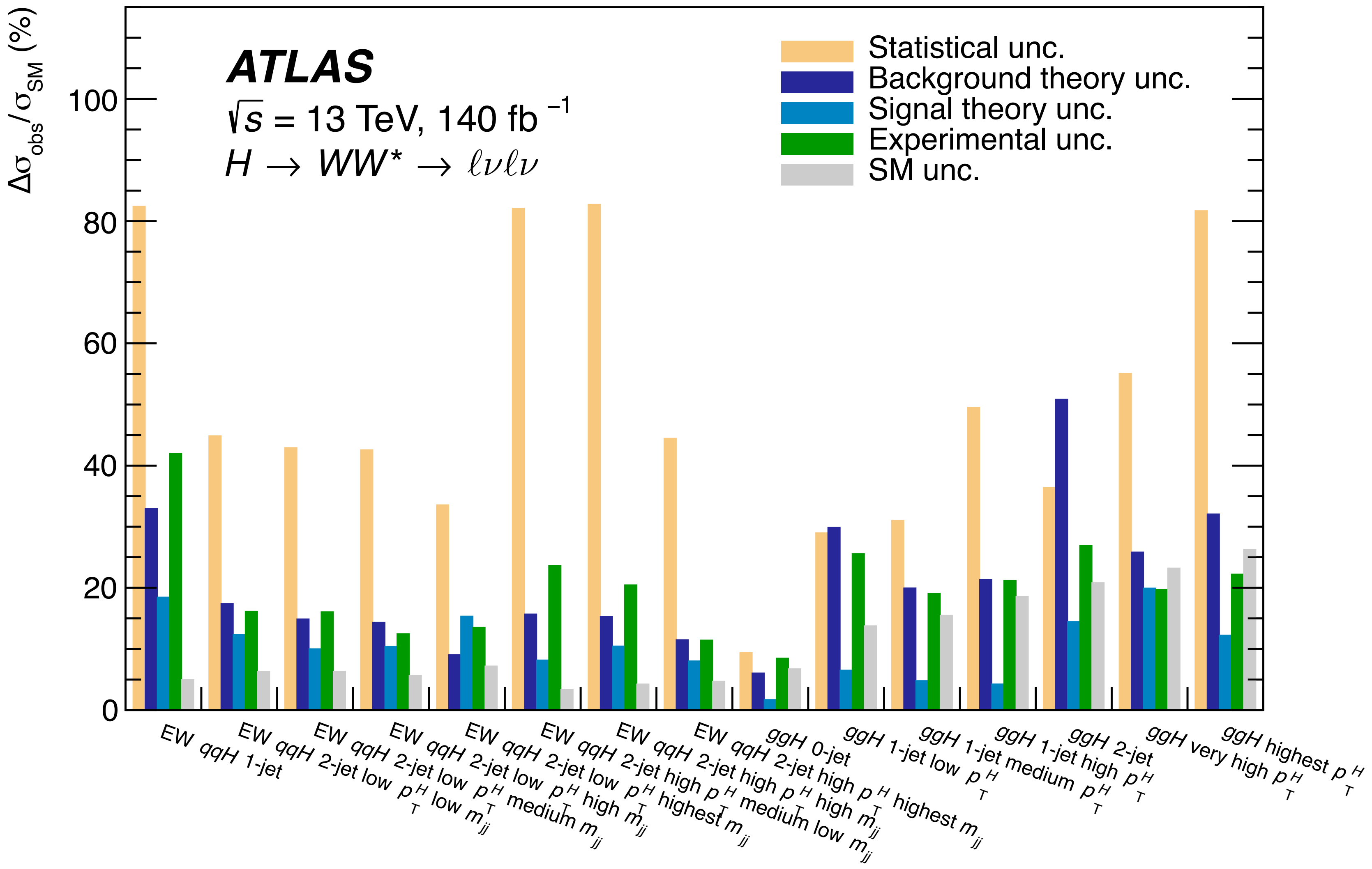
ggF + VBF $H \to WW^*$



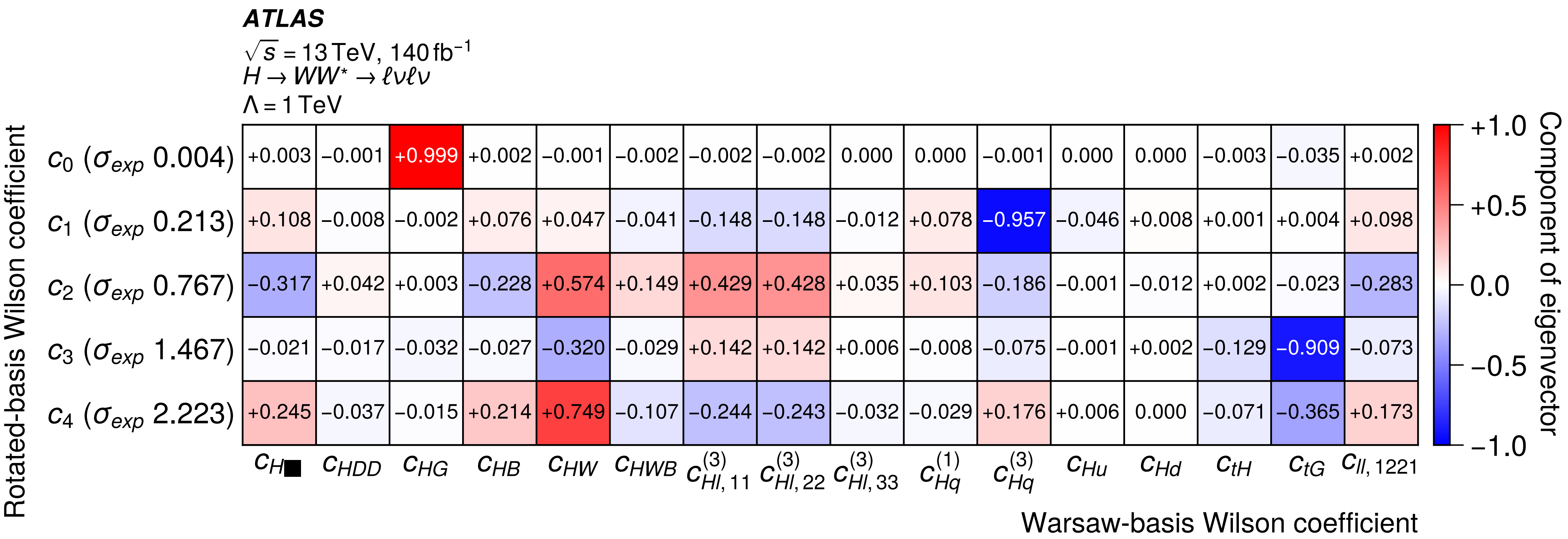
ggF + VBF $H \to WW^*$

Purpose	Variable(s)
VBF topology	η-centralities of the leading and subleading leptons, $\eta_{\ell_0}^{\text{centrality}}$ and $\eta_{\ell_1}^{\text{centrality}}$ Transverse momenta of the leading, subleading, and (if present; otherwise 0 GeV) third jets Dijet invariant mass, m_{jj} Dijet rapidity separation, Δy_{jj} Lepton-jet invariant mass combinations, $m_{\ell_0 j_0}$, $m_{\ell_0 j_1}$, $m_{\ell_1 j_0}$, and $m_{\ell_1 j_1}$ Lepton-jet angular separation combinations, $\Delta R_{\ell_0 j_0}$, $\Delta R_{\ell_0 j_1}$, $\Delta R_{\ell_1 j_0}$, and $\Delta R_{\ell_1 j_1}$
$H \to WW^* \to \ell\nu\ell\nu$ decay	Dilepton invariant mass, $m_{\ell\ell}$ Dilepton aziumuthal separation, $\Delta\phi_{\ell\ell}$ Transverse mass, m_{T}
Top quark suppression	Magnitude of the vectorial sum of the p_{T} of all leptons, jets, and $E_{\mathrm{T}}^{\text{miss}}$, $p_{\mathrm{T}}^{\text{tot}}$ Object-based $E_{\mathrm{T}}^{\text{miss}}$ significance, $\mathcal{S}_{\text{miss}}$

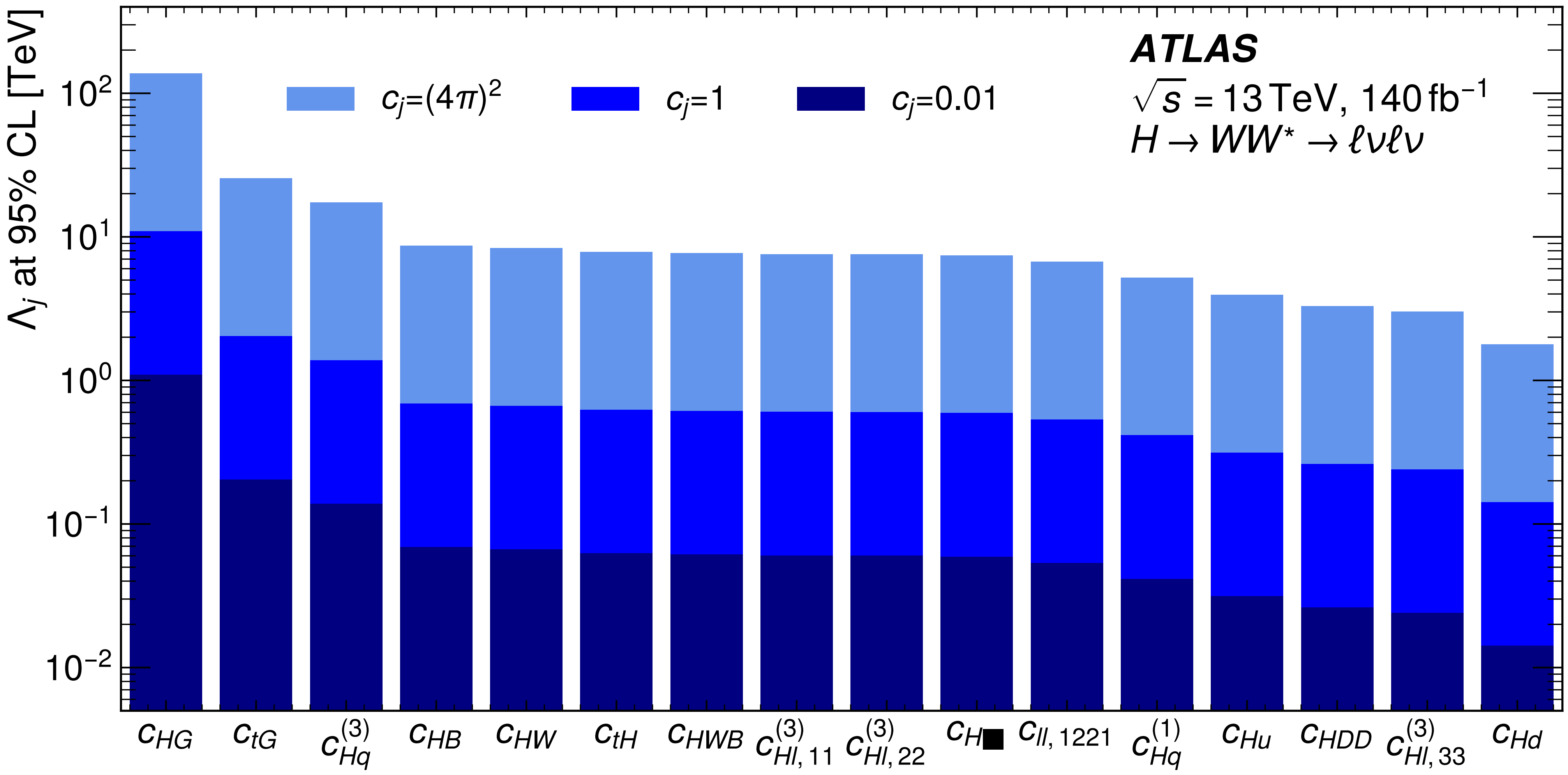
ggF + VBF $H \to WW^*$



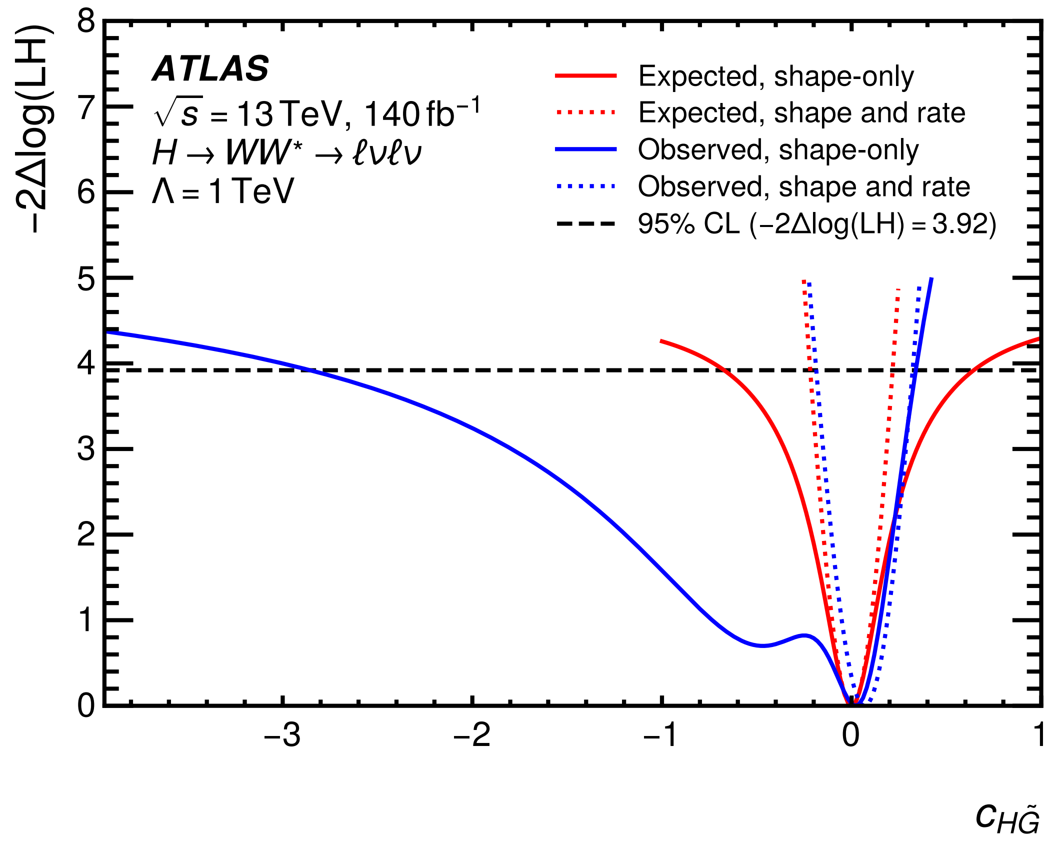
ggF + VBF $H \to WW^*$

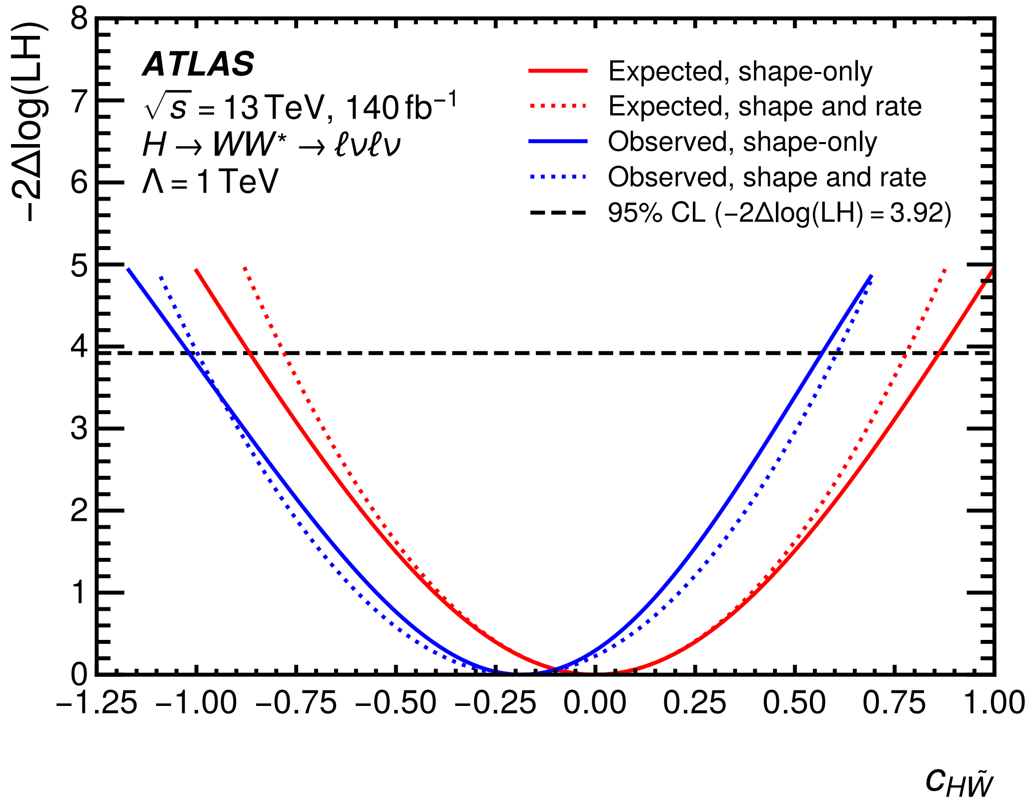


ggF + VBF $H \rightarrow WW^*$



ggF + VBF $H \to WW^*$



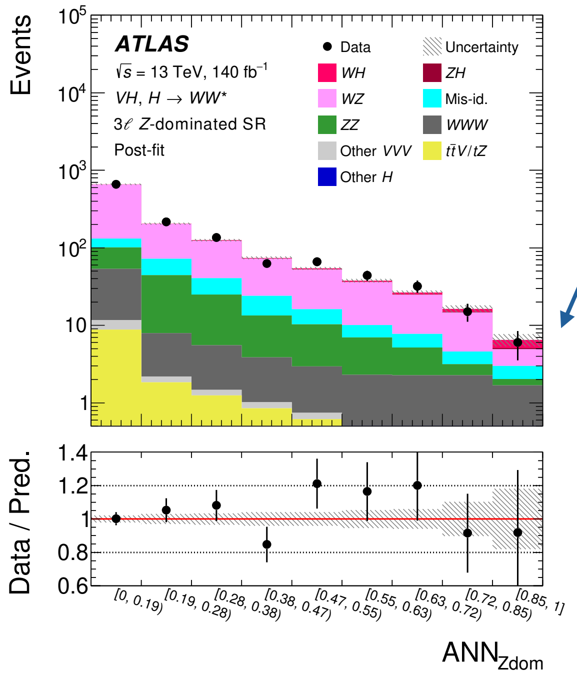


VH $H \to WW^*$

HIGG-2023-09

Strategy:

- Target inclusive measurement (previously published) and VH STXS Stage 1.2 bins (new!)
- Channels for leptonic and hadronic V decays: same-sign (SS) 2ℓ, opposite-sign (OS) 2ℓ, 3ℓ and 4ℓ final states.
- Multivariate discriminants used in every channel.

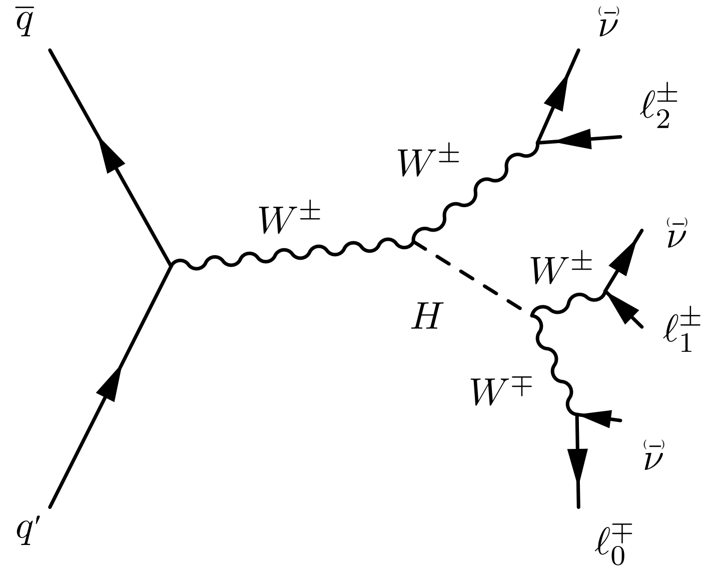


ANNs with nodes for signal and main bkgs for 2ℓ (OS) and 3ℓ

RNN for 2ℓ (SS) due to varying jet multiplicities

BDT for 4ℓ (mainly ZZ bkg)

eg. 3ℓ channel:

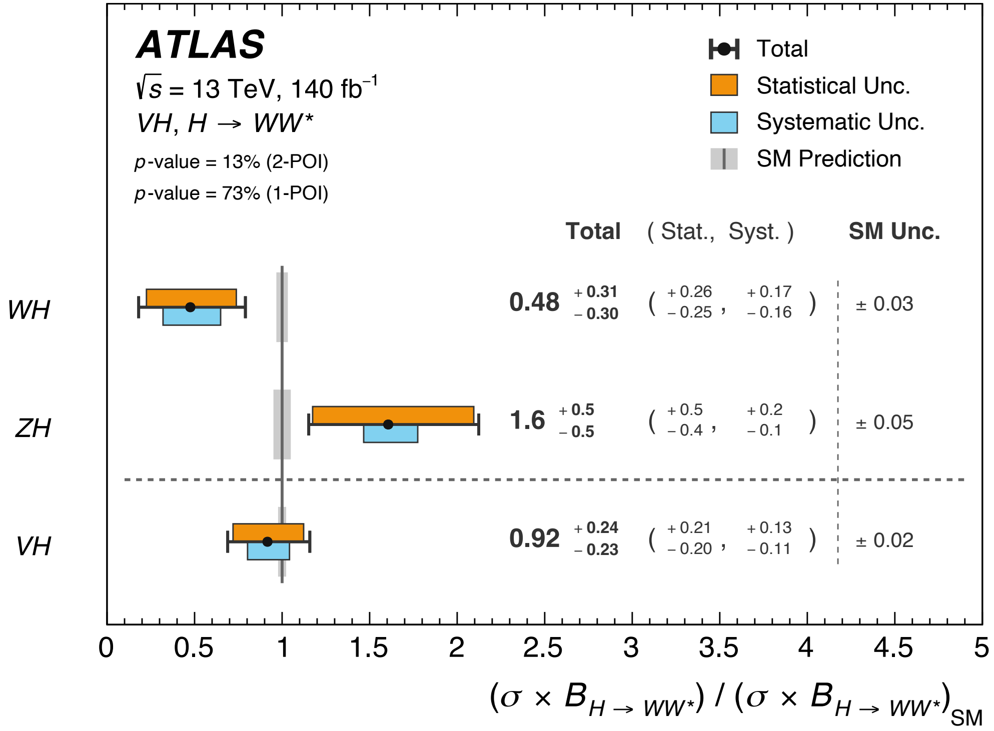


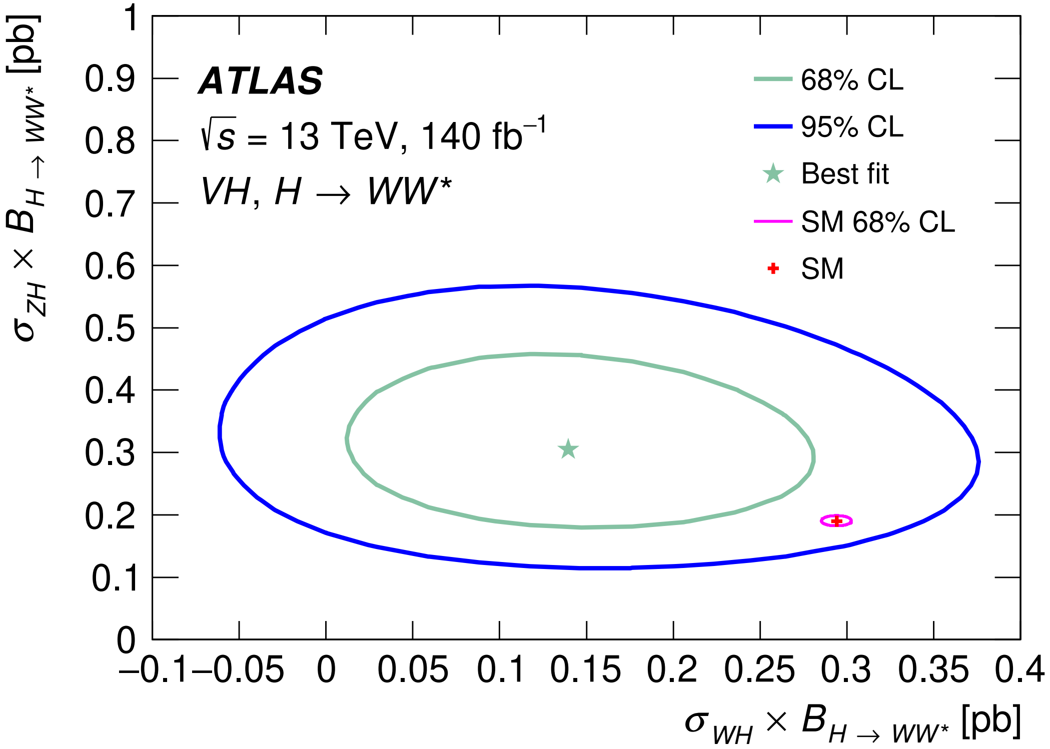
VH $H \to WW^*$

HIGG-2023-09

Results (Inclusive):

- Measurements of WH and ZH cross-sections compatible with SM within 95% C.L:

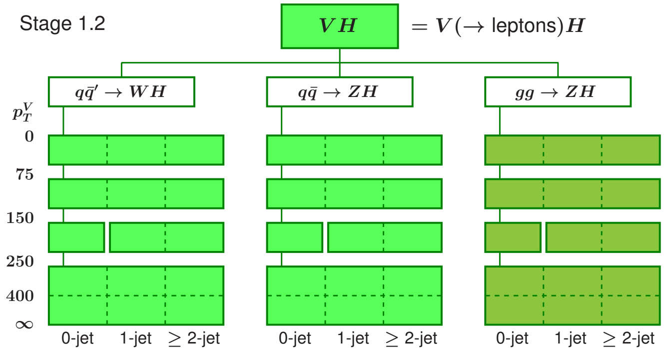




- Dominant uncertainties are statistical; 3ℓ and 4ℓ channels dominate sensitivity.

VH $H \to WW^*$

HIGG-2023-09



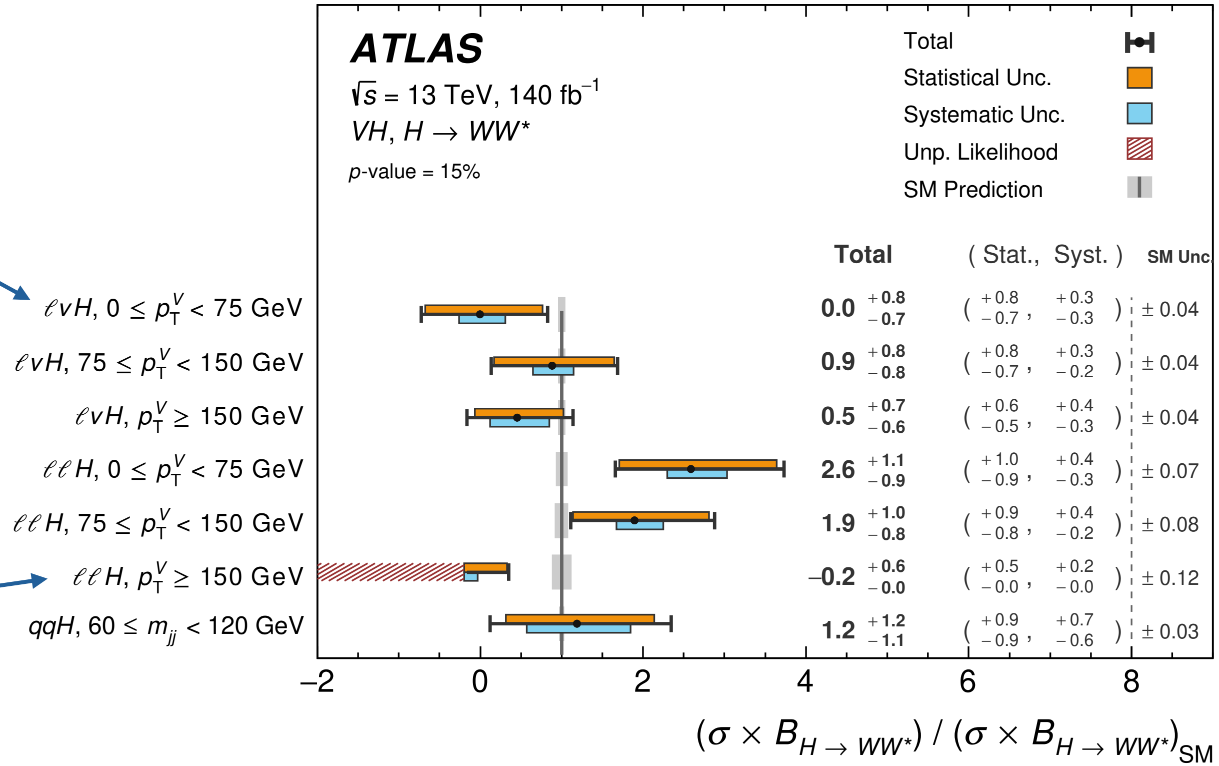
Strategy (STXS):

- Signal regions split by p_{T}^{V} proxy for STXS measurement:
  - 2ℓ, 4ℓ: sums of lepton & jet p_{T} and missing energy
  - 3ℓ: Regression ANN

Results (STXS):

WH, ZH and EW qqH split according to STXS 1.2 scheme

Lower cut-off: LH becomes unphysical (negative S+B)

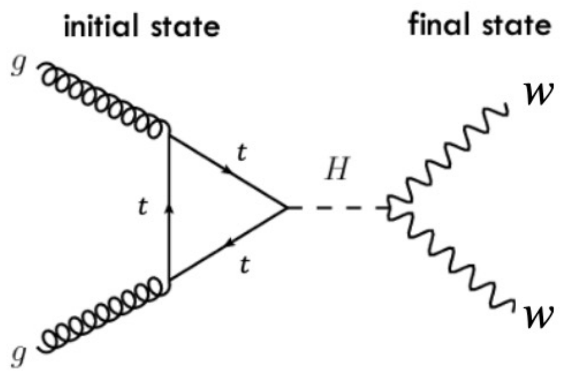


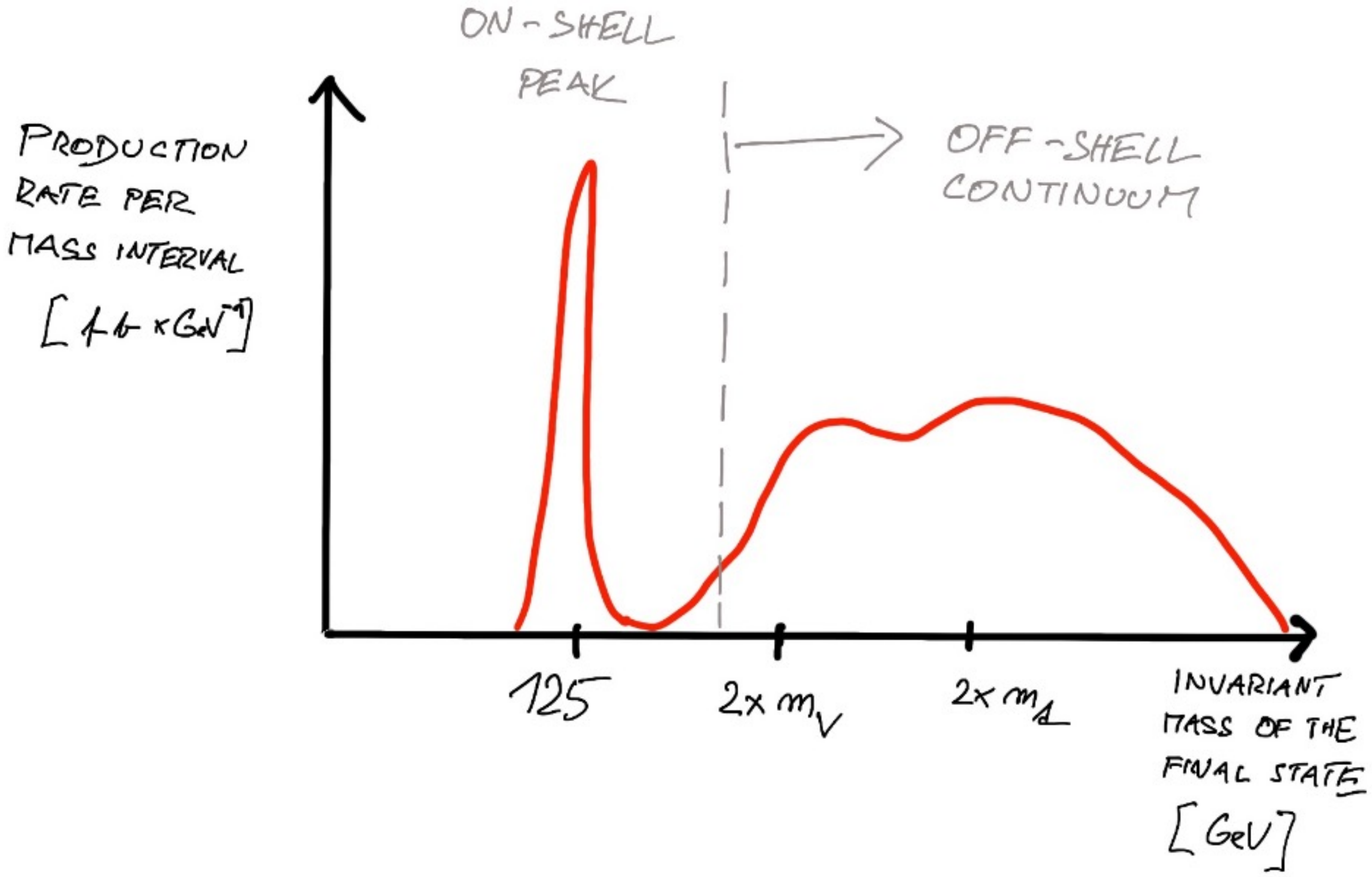
Excellent $p_{\mathrm{T}}^{V} < 150$ GeV sensitivity (competitive with combination!)

Above 125 GeV: Offshell Higgs

Image credits to HWW offshell team

Moving away from the Higgs mass peak...





$$\frac{d\sigma_{i\to H\to f}}{dM_f^2} \sim \frac{g_i^2 g_f^2}{m_H^2\Gamma_H^2 + (M_f^2 - m_H^2)^2}$$

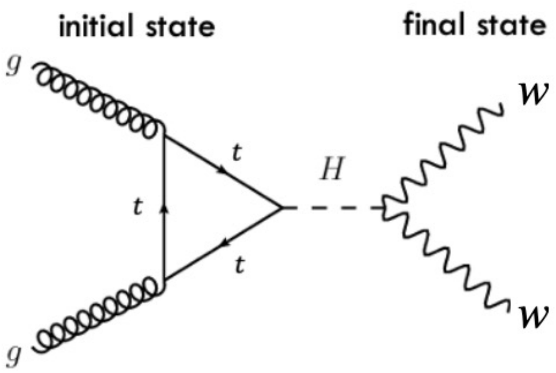
Dominant term for the on-shell region

Dominant term for the off-shell region

Above 125 GeV: Offshell Higgs

Image credits to HWW offshell team

Moving away from the Higgs mass peak...



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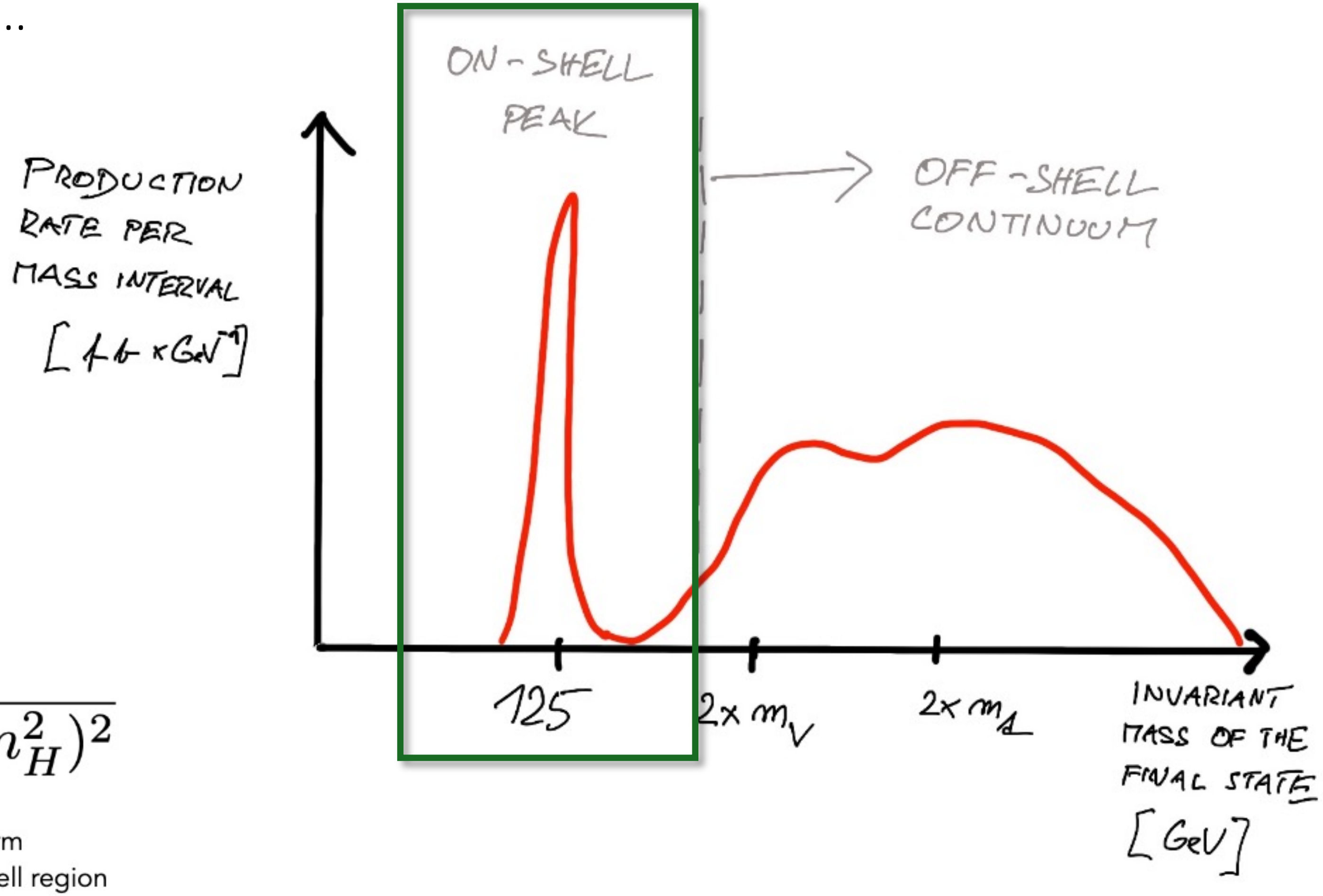
Dominant term for the on-shell region

Dominant term for the off-shell region



Above 125 GeV: Offshell Higgs

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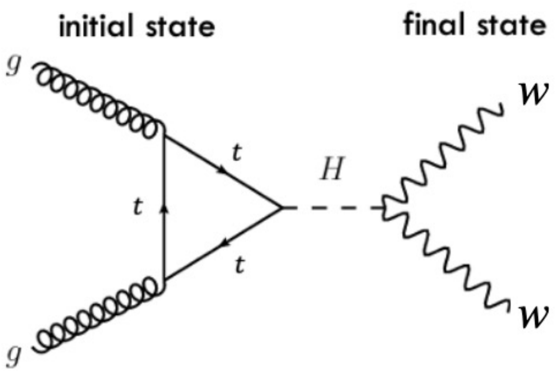
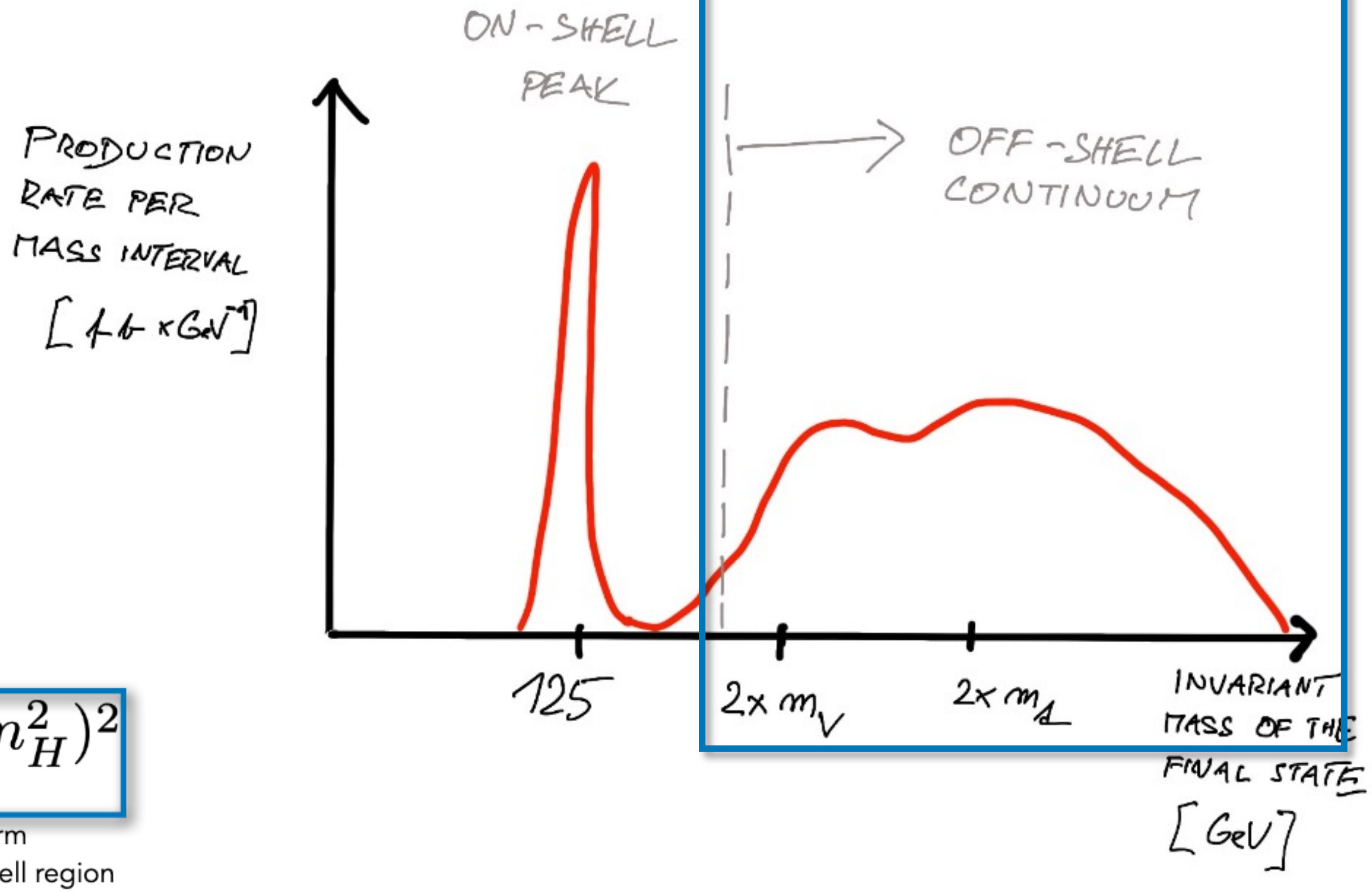
Moving away from the Higgs mass peak...





$$\frac{d\sigma_{i\to H\to f}}{dM_f^2} \sim \frac{g_i^2 g_f^2}{m_H^2\Gamma_H^2 + (M_f^2 - m_H^2)^2}$$

Dominant term for the on-shell region

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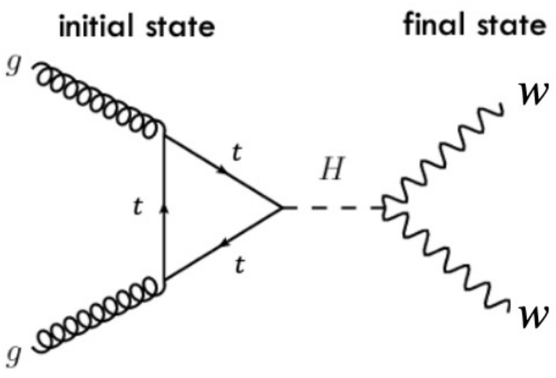
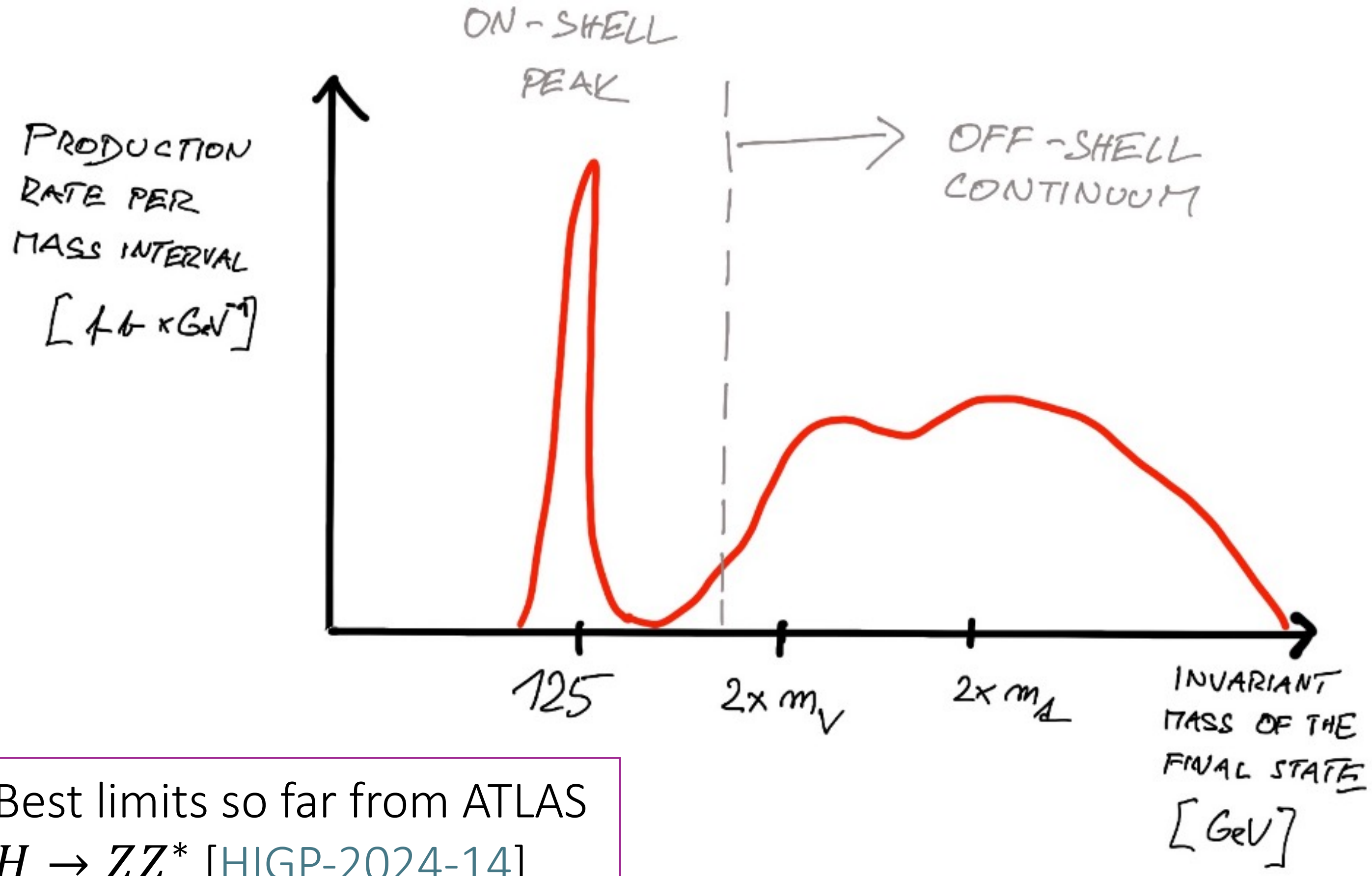
Above 125 GeV: Offshell Higgs

Image credits to HWW offshell team

Moving away from the Higgs mass peak...





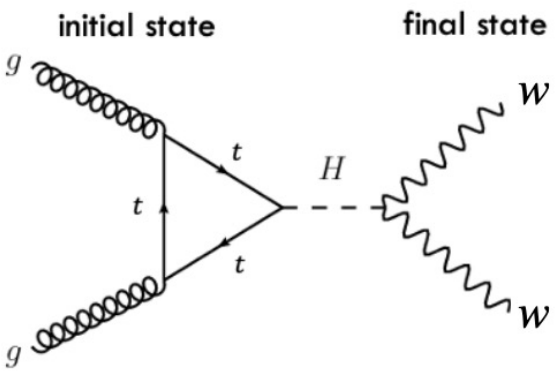
$$\Gamma_H \propto \frac{\sigma^{off-shell}_{i\to H\to f}}{\sigma^{on-shell}_{i\to H\to f}}$$

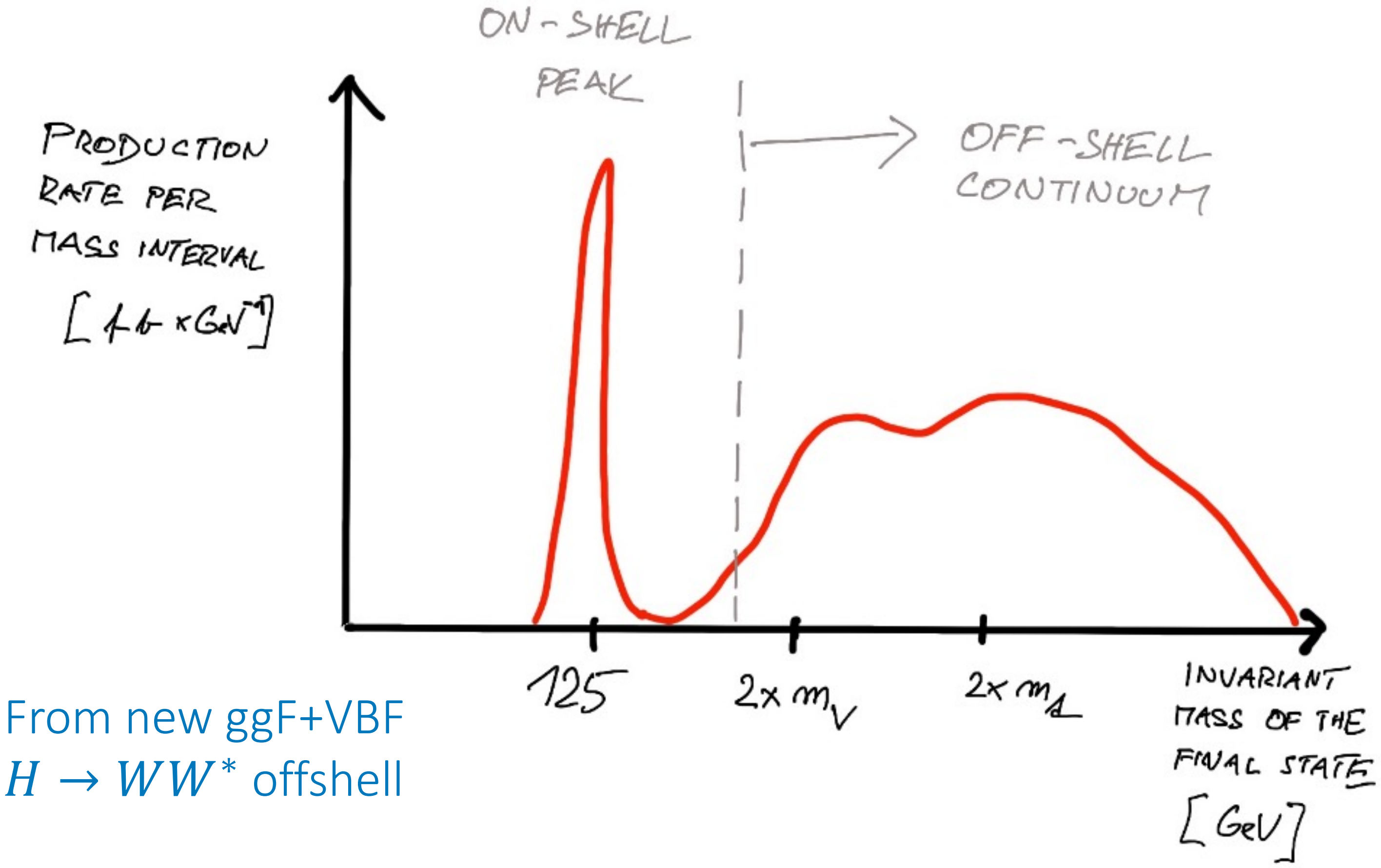
Best limits so far from ATLAS $H \to ZZ^*$ [HIGP-2024-14]

Above 125 GeV: Offshell Higgs

Image credits to HWW offshell team

Moving away from the Higgs mass peak...





$$\Gamma_H \propto \frac{\sigma^{off-shell}_{i\to H\to f}}{\sigma^{on-shell}_{i\to H\to f}}$$

From new ggF+VBF $H \to WW^*$ offshell

From ggF+VBF $H \to WW^*$ onshell (discussed earlier)

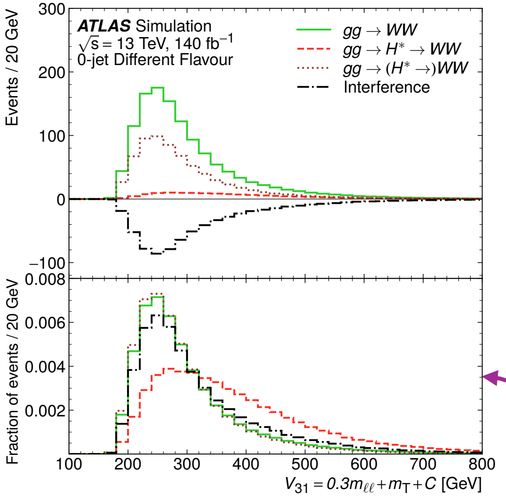
$H \to WW$ Offshell

HIGP-2024-05

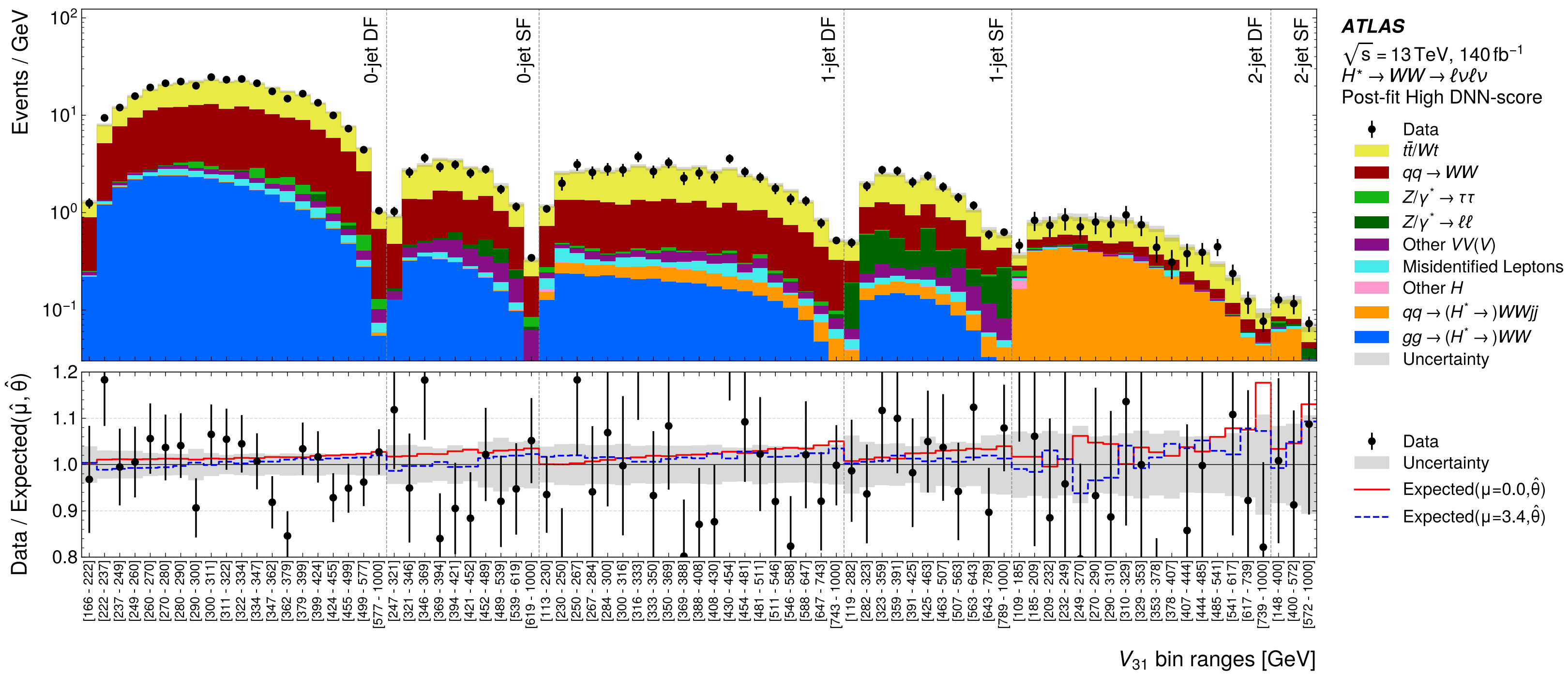
Strategy:

- Target ggF and VBF.
- DNN for sig. vs bkg. discrimination.
- m_{WW} proxy, V_{31}, to separate signal, interfering background and interference.

$$V_{31} = 0.3m_{ll} + m_{\mathrm{T}}$$



Highest DNN bin of each SR: events further binned in V_{31}



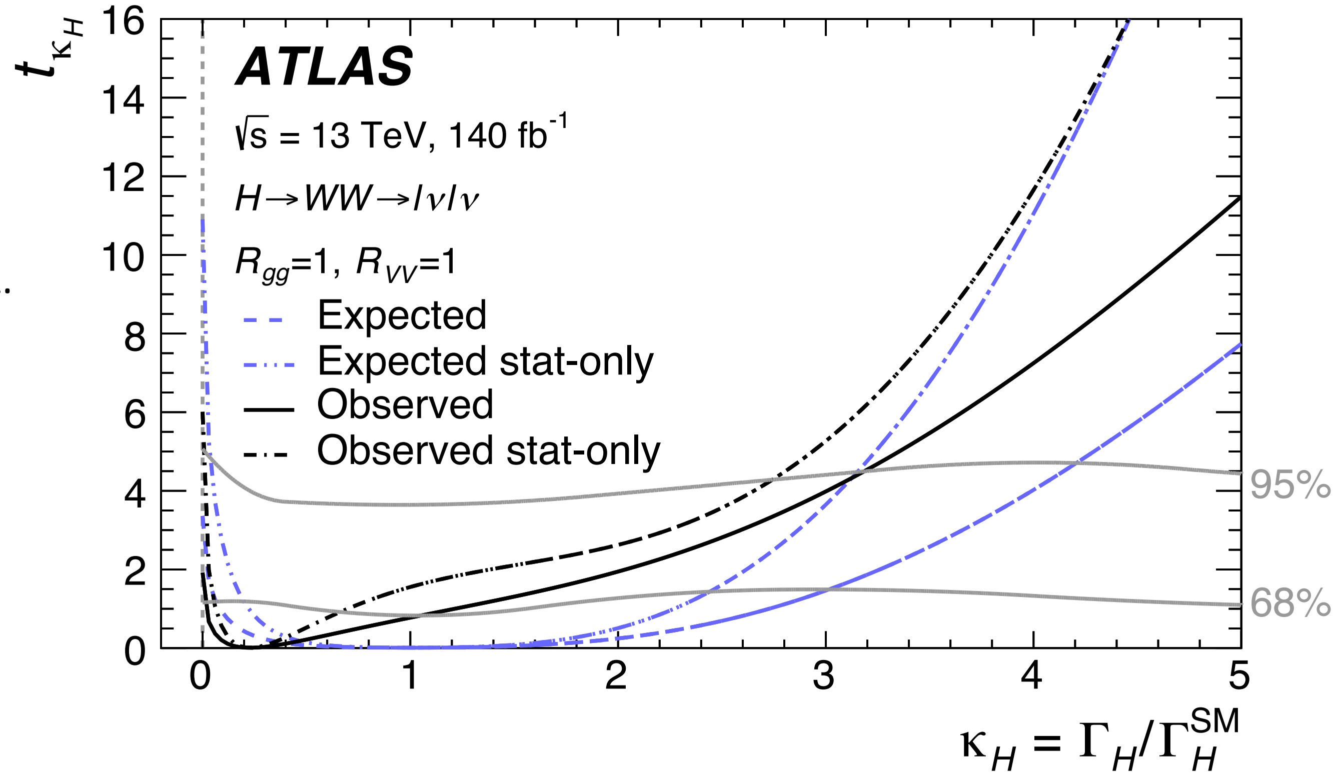
m_{WW} separates S, B and interference effectively; reco complicated by neutrinos!

$H \rightarrow WW$ Offshell

HIGP-2024-05

Sensitivity:

- μ_{offshell}: [0.0, 1.2] at 68% C.L.
  HZZ SBI: [0.33, 1.62] at 68% C.L.
- Γ_H (with onshell): [0, 4.1] MeV at 68% C.L.
  - HZZ SBI: [2.4, 7.0] MeV at 68% C.L.



95% C.L. upper limit on the Higgs width: 13.1 (17.3) MeV