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Studying the Higgs sector with ATLAS

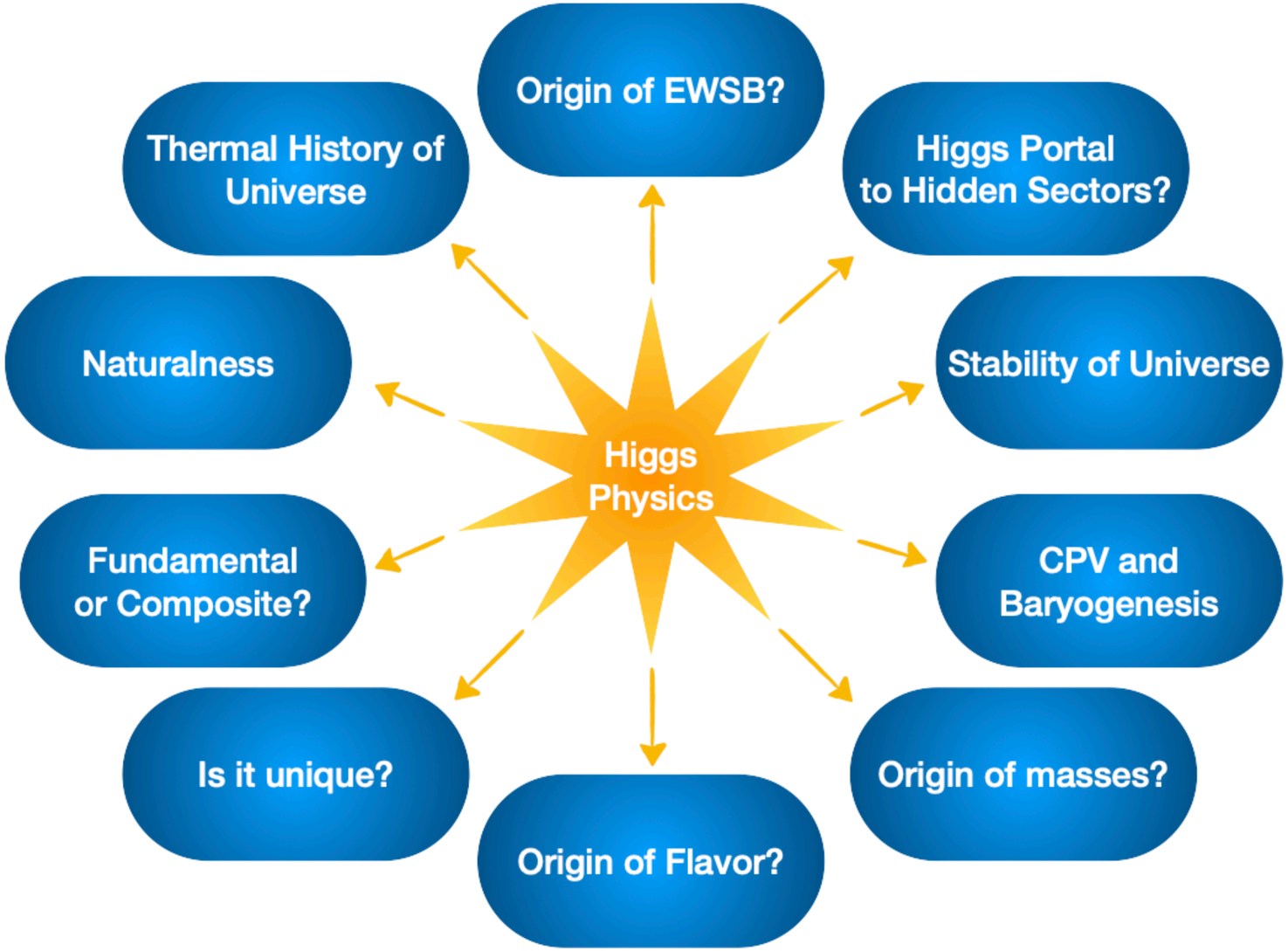
Christina Dimitriadi
on behalf of ATLAS Sweden

Partikeldagarna 2023, Stockholm
14 June 2023

ATLAS EXPERIMENT

phdcomics.com

Higgs physics



arXiv:2211.11084

Higgs mechanism and SM predictions

- Postulated to explain masses of elementary particles in the SM through electroweak symmetry breaking

Scalar: spin 0, CP even

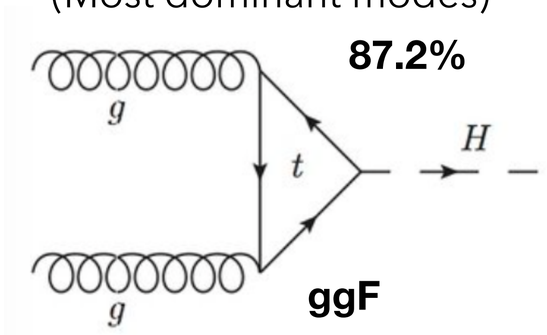
- SM predictions:

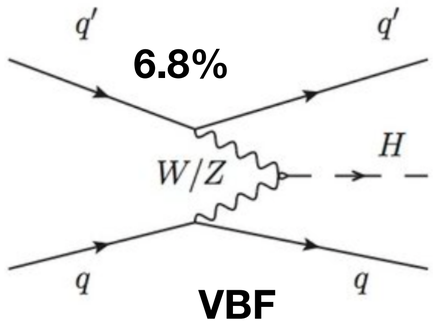
Width ~$\mathcal{O}$(MeV)

Higgs to fermion couplings ~fermion mass
Higgs to boson couplings ~boson mass^2
Higgs to itself coupling ?

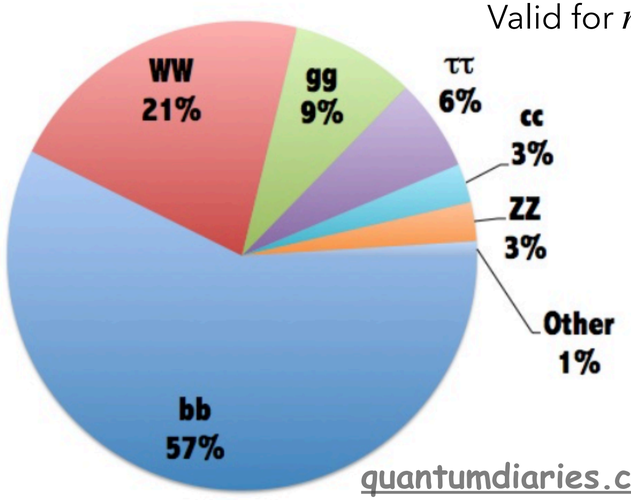
- Higgs boson production and decays at LHC

(Most dominant modes)





Valid for $m_H = 125\,\mathrm{GeV}$



July 4th: Happy Higgs day

New York Times

July 4, 2012

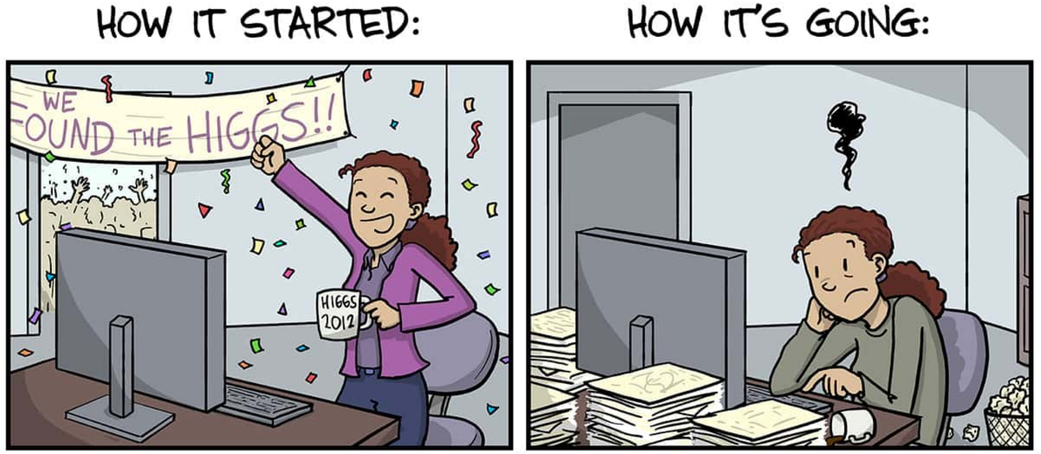
Physicists Find Elusive Particle Seen as Key to Universe

Researchers said they had discovered what looked for all the world like the Higgs boson, a long-sought particle that could lead to a new understanding of how the universe began.

By DENNIS OVERBYE

CERN

- The Higgs boson was discovered by ATLAS and CMS in 2012, $m_H \sim 125$ GeV
- Discovery driven by $\gamma\gamma, 4l, WW$ decay channels
- Nobel Prize awarded to Peter Higgs and Francois Englert in 2013



physicsworld

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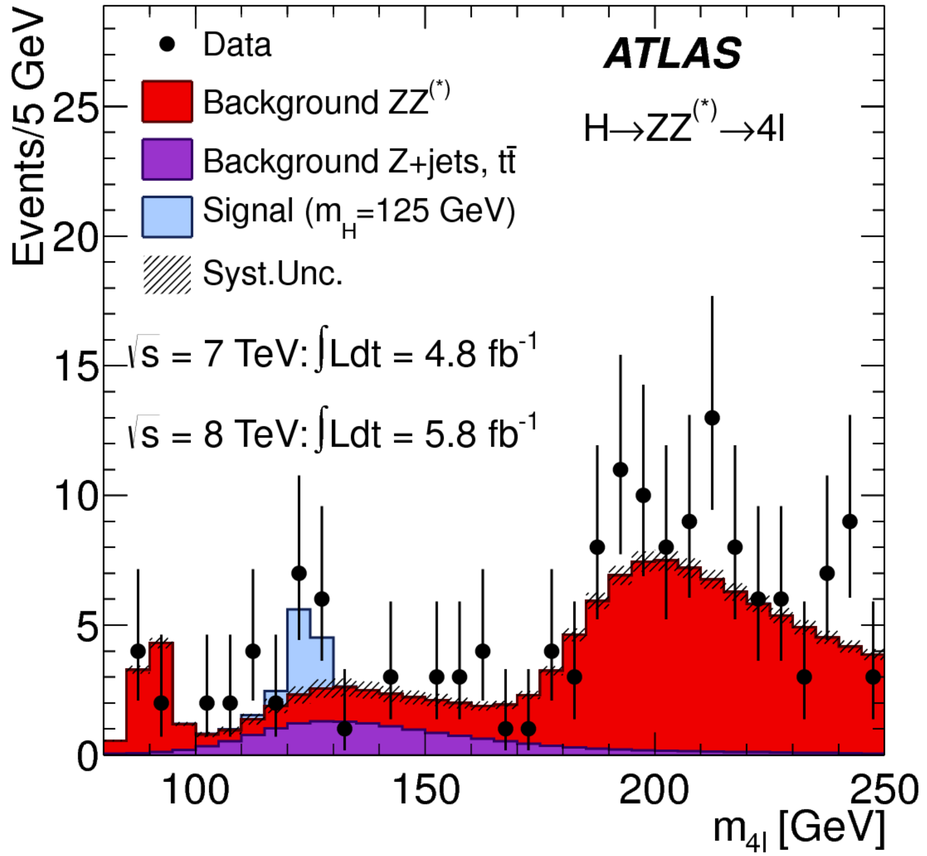
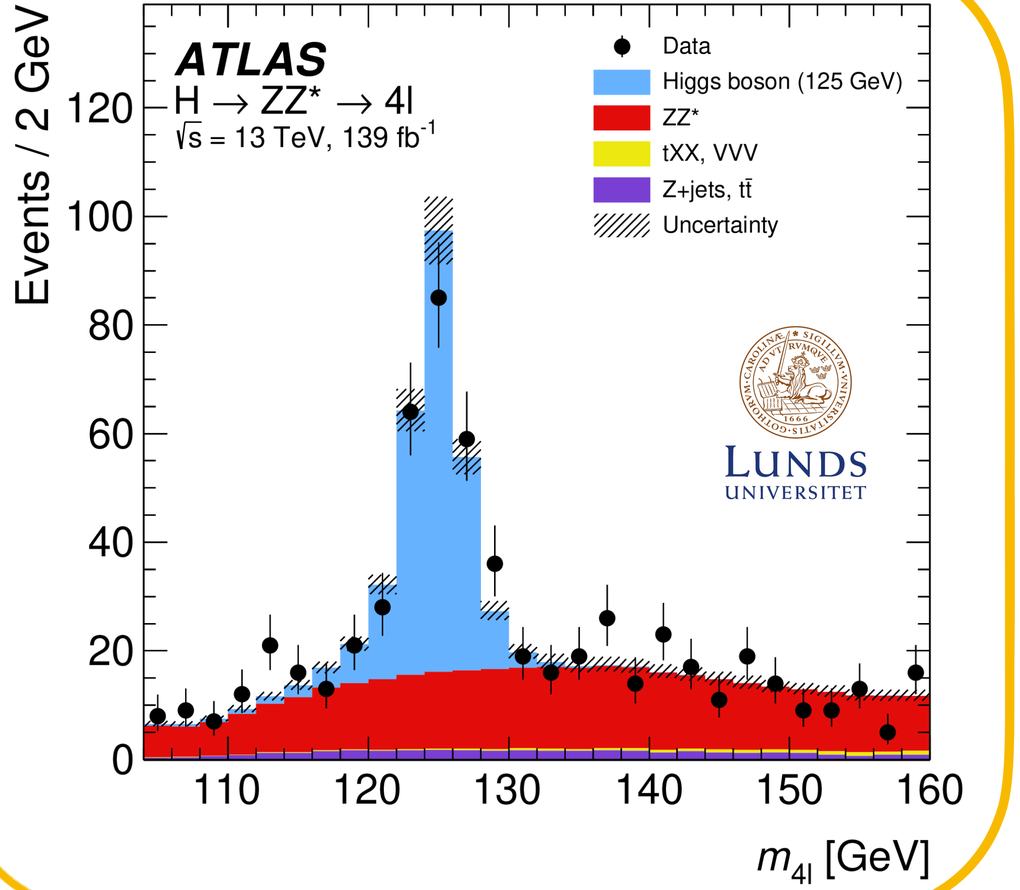
Also check: 10th anniversary of Higgs boson discovery

From discovery to precision physics

Partial Run 1 dataset



Full Run 2 dataset

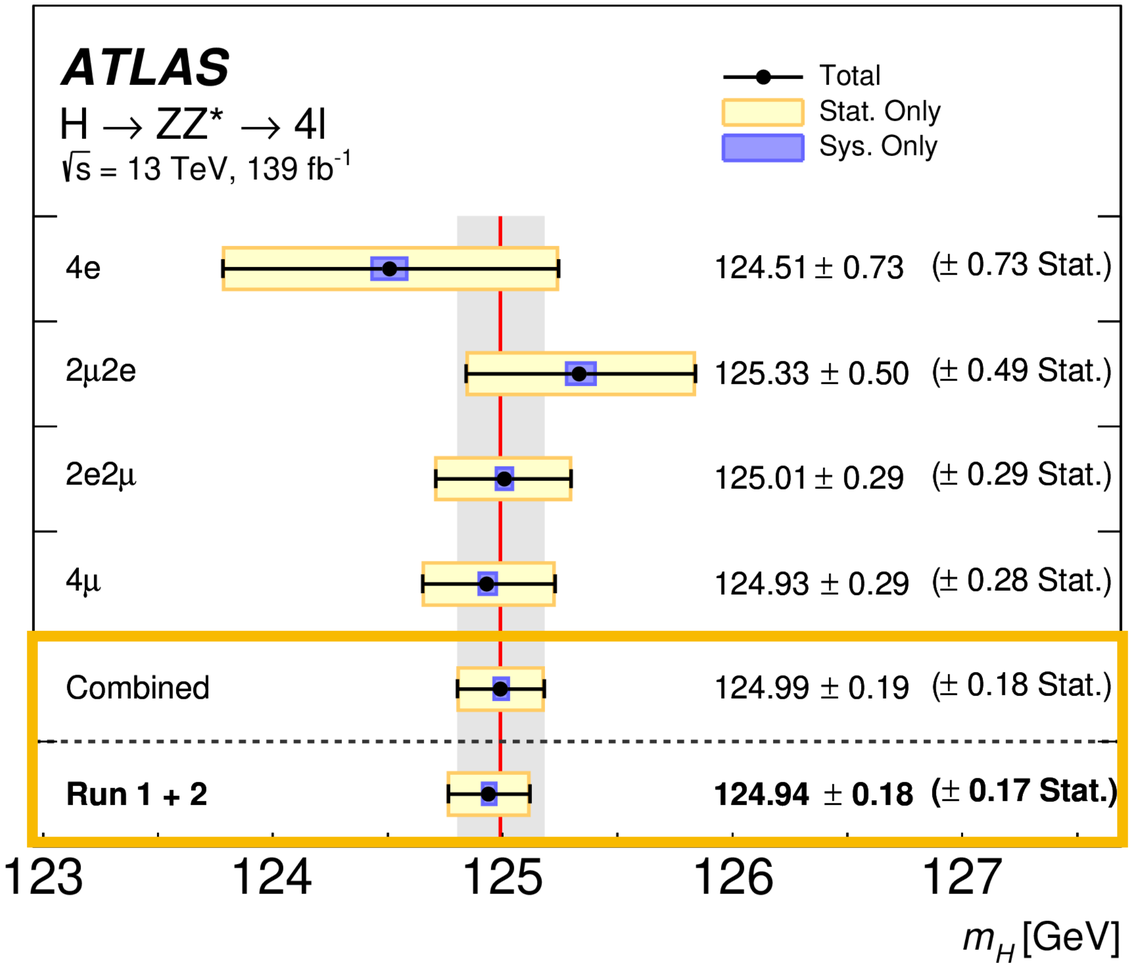


Phys. Lett. B 716 (2012) 1-29

arXiv:2207.00320 *Accepted by PLB*

Higgs boson mass

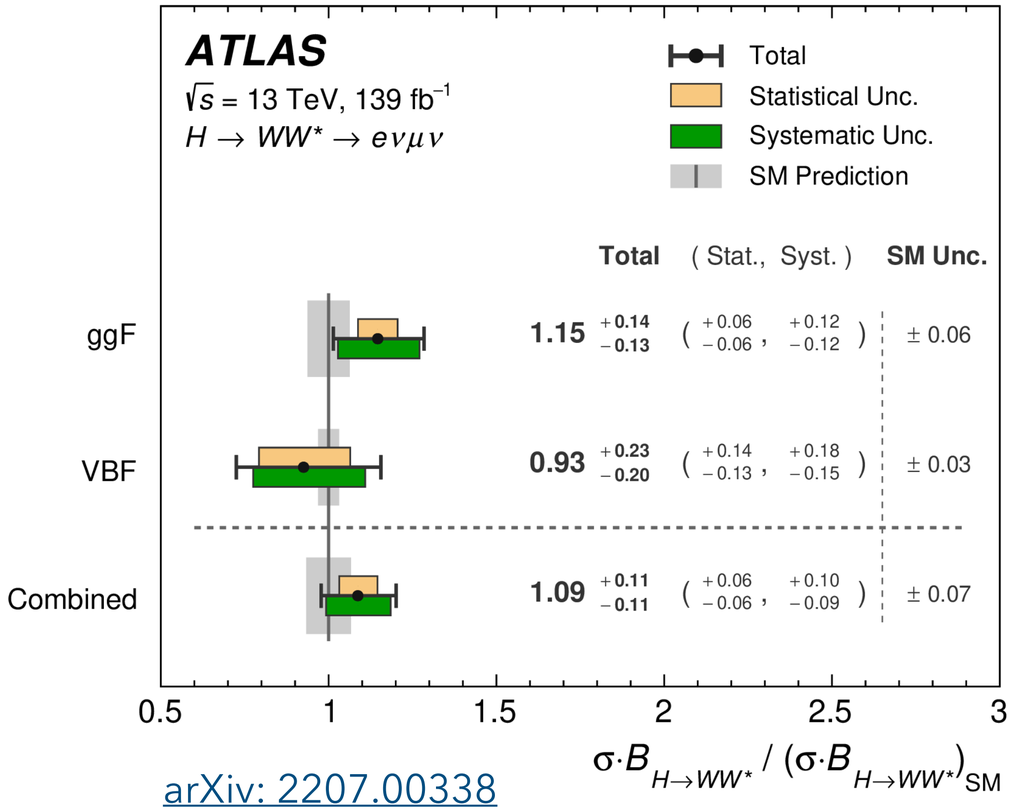
- Only free parameter in SM Higgs sector
- Latest ATLAS full Run 2 measurement
  $H \to ZZ^* \to 4l$
  - Improved momentum-scale calibration for muons arXiv:2212.07338 *Submitted to EPJC*
- Run 1+2: **0.14%** uncertainty



arXiv:2207.00320 *Accepted by PLB*

Cross-section measurements in $H \to WW^* \to e\nu\mu\nu$

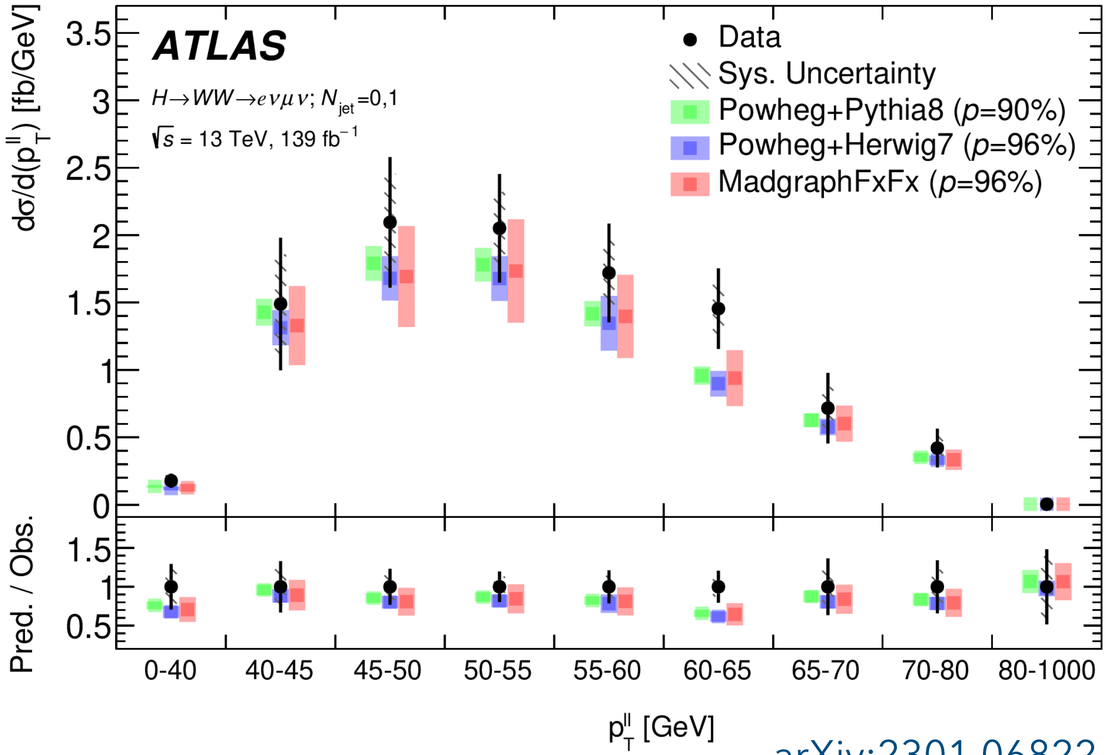
- Inclusive ggF and VBF cross-sections, and a combined measurement



arXiv: 2207.00338

Accepted by PRD

- Differential ggF cross-sections in a fiducial phase-space

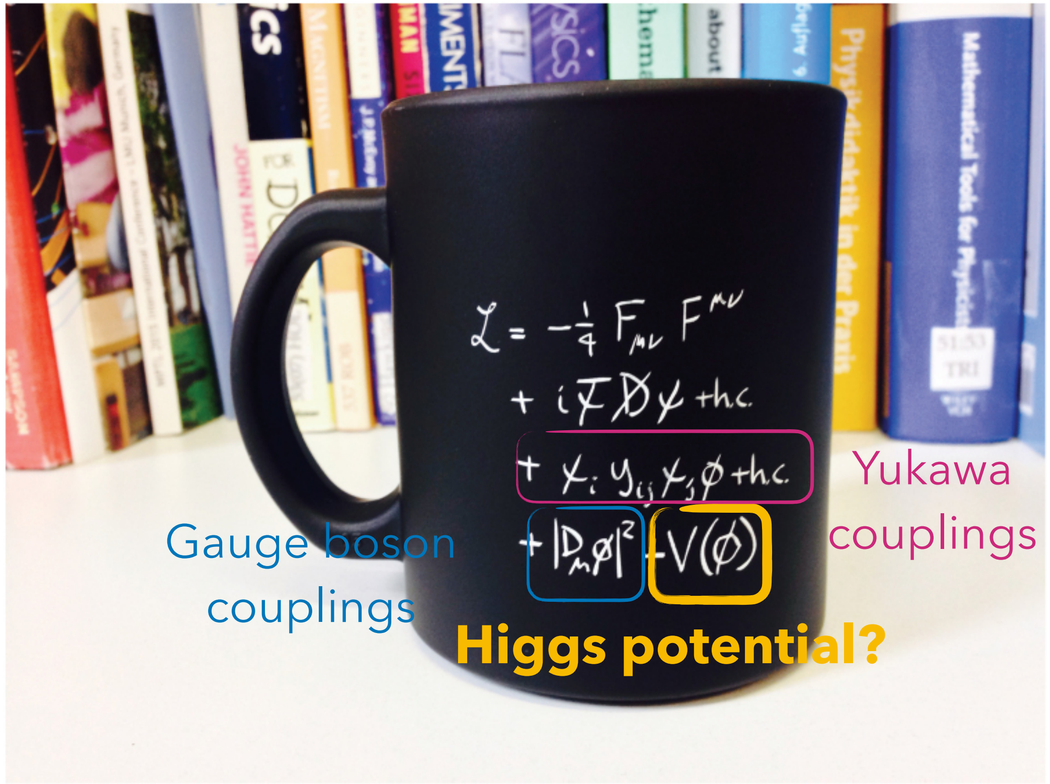


arXiv:2301.06822

Accepted by EPJC

Results consistent with SM expectations

Higgs sector in SM

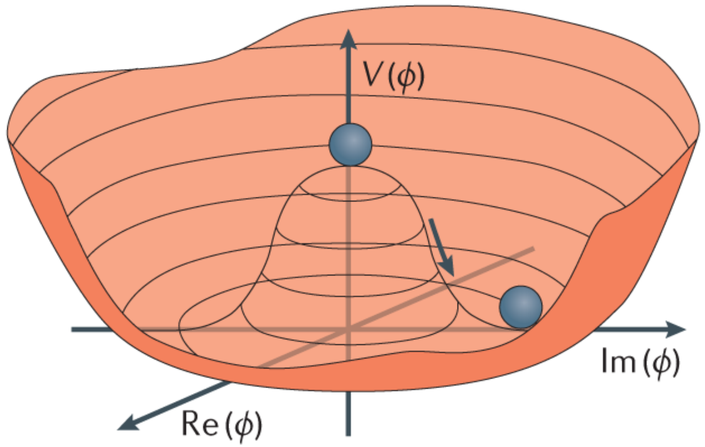


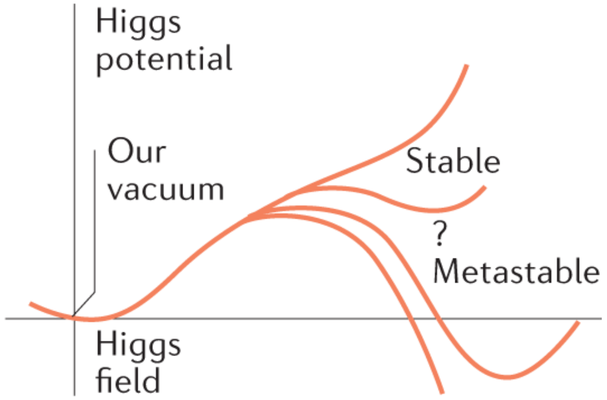
"Let's have a coffee with the Standard Model of particle physics"

- Since the Higgs boson discovery, the scalar sector has been greatly studied by the experiments
- But the Higgs potential is mostly unexplored at the LHC
- $V(H) = \frac{1}{2} m_H H^2 + \lambda v H^3 + \dots$

Self-interaction

$\lambda_{HHH} = \lambda v$





Nature (review article)

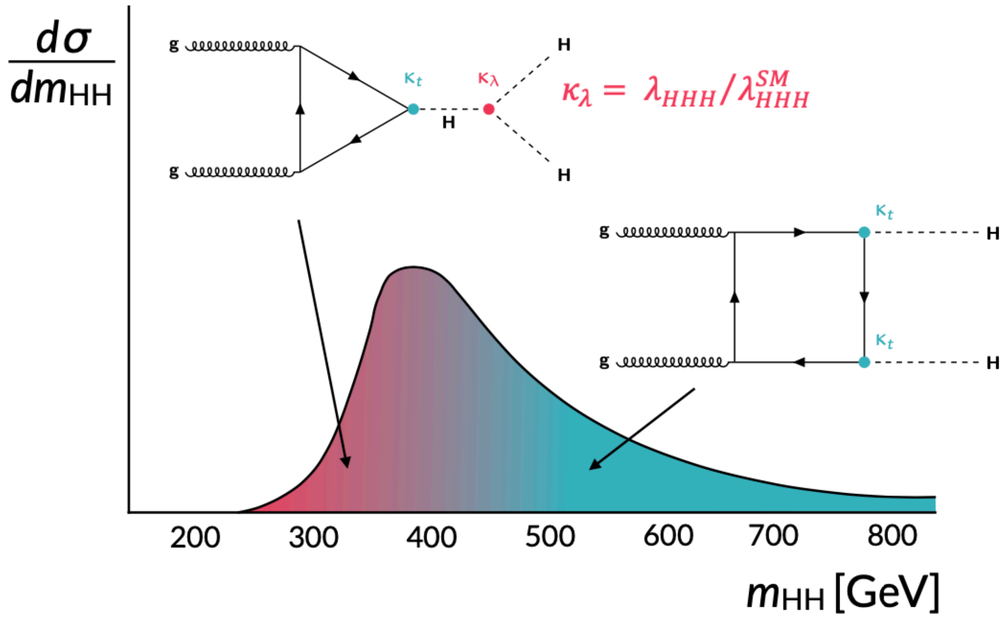
Twice the Higgs, twice the fun

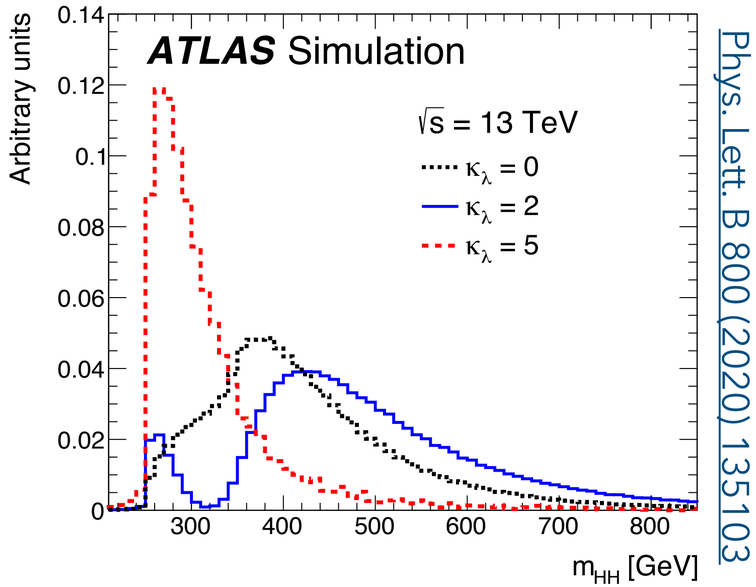
- A measurement of HH production will provide evidence of the Higgs self-coupling

  ➡ ultimate probe of the shape of the Higgs potential

- Any deviation of the self-interaction from its SM expectation is a sign of new physics!

- HH production at the LHC: very rare process, $\sigma_{\mathrm{ggF}}(pp \to HH) = 31\,\mathrm{fb}$ (at 13 TeV)





Phys. Lett. B 800 (2020) 135103

Change of HH cross-section & kinematics with κ_λ variations

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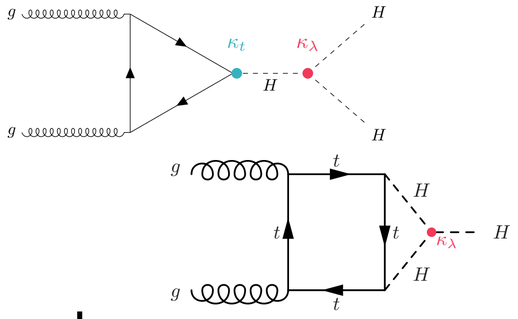
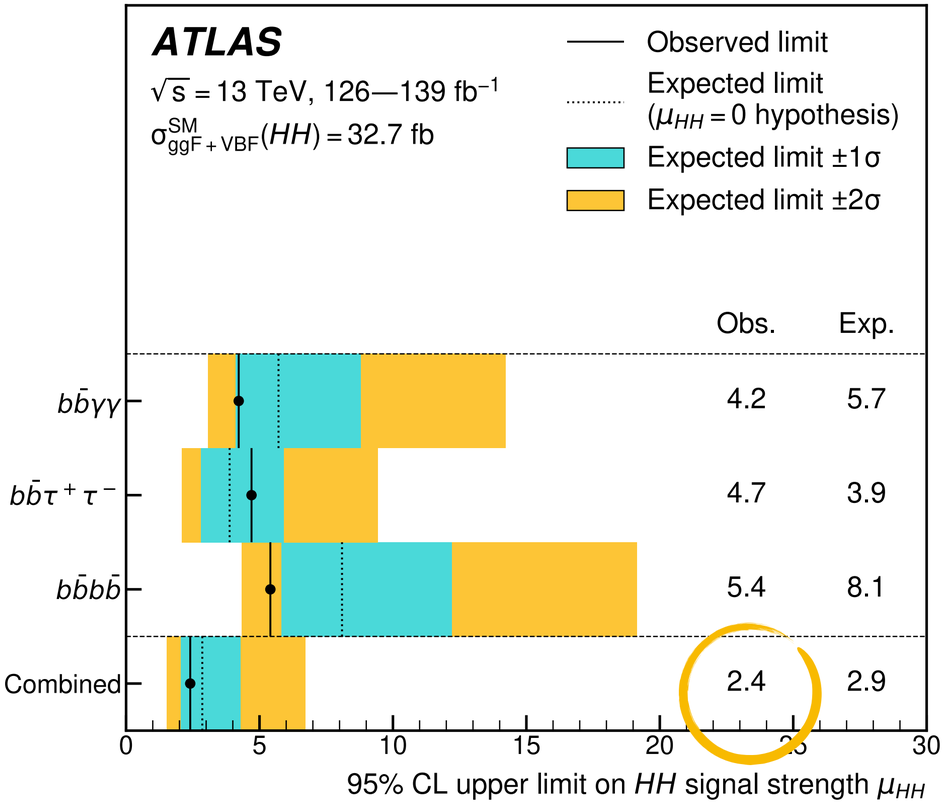
(bbττ + bbγγ)

searches



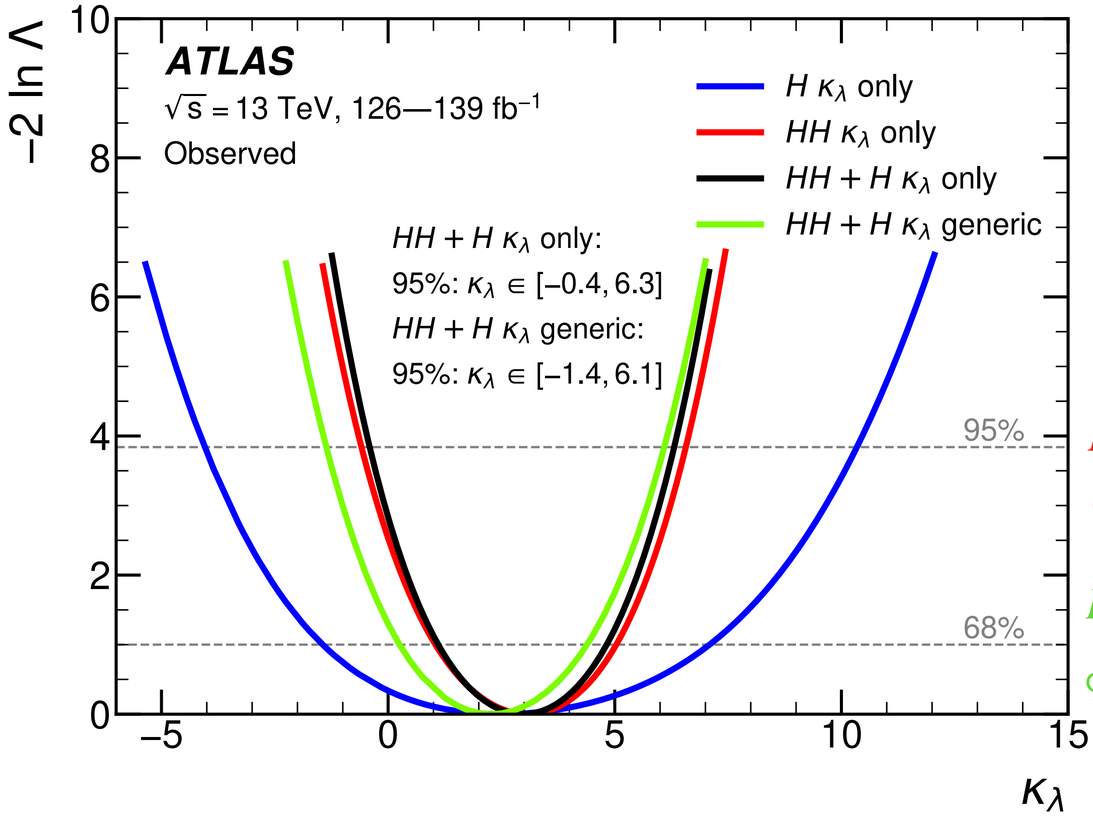
- Recent combination of the most sensitive decay channels: $bb\gamma\gamma$, $bb\tau\tau$, $bbbb$

Upper limits on HH production



Best obs. limit yet on HH production

Constraints on κ_λ from single- and di-H analyses



$HH : \kappa_\lambda \in [-0.6, 6.6]$

other κ fixed to 1

$H + HH : \kappa_\lambda \in [-1.4, 6.1]$

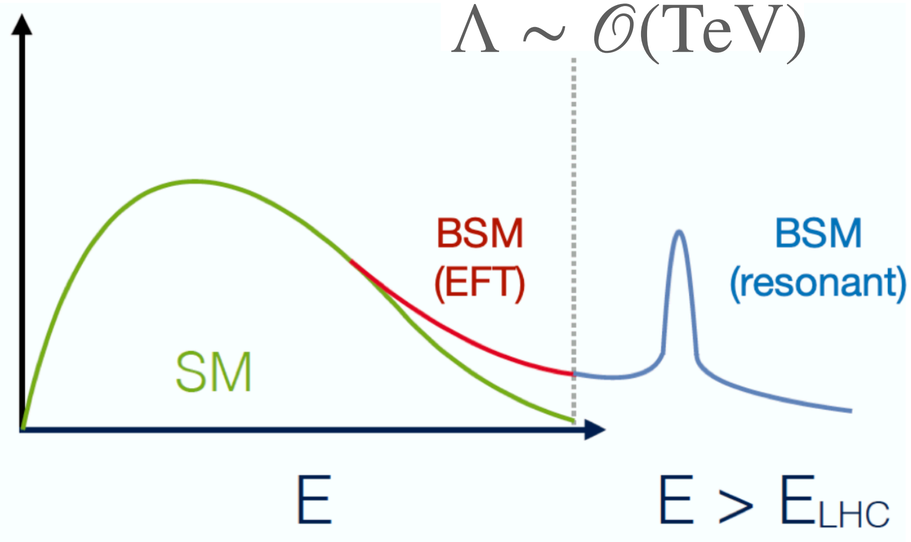
other κ floating

arXiv:2211.01216 [hep-ex] *Accepted by PLB*

New physics..

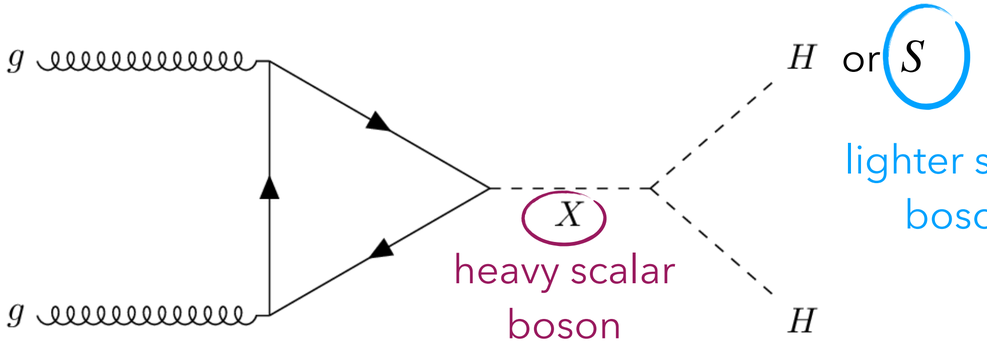
with Effective Field Theories?

- Reveal high energy physics through precise measurements at low energy
- No strong model-dependence
- Multiple efforts in the HH community

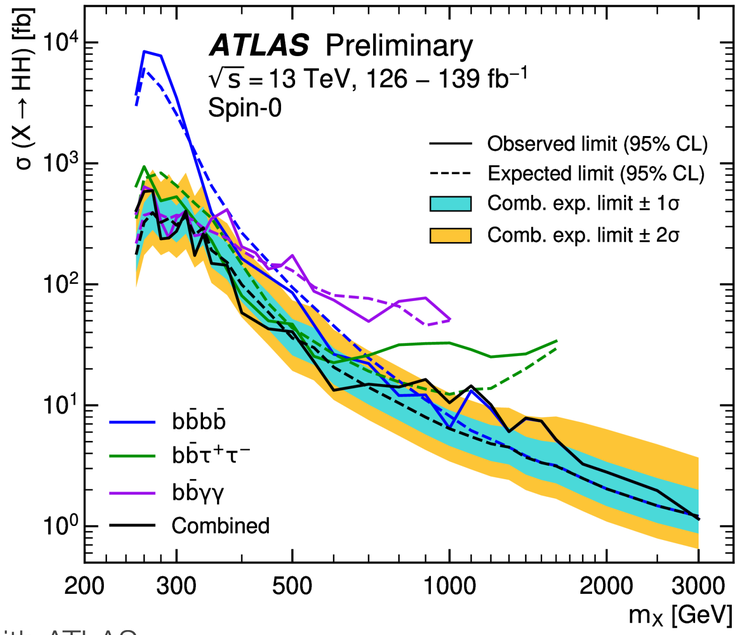


S. Kortner

testing heavy resonance hypotheses?



ATLAS-CONF-2021-052



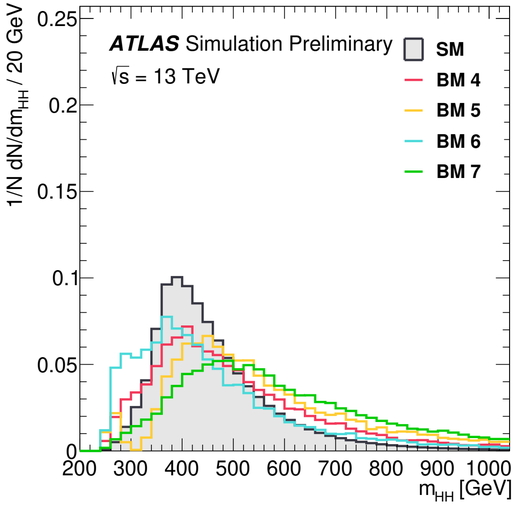
(Resonant HH / SH)

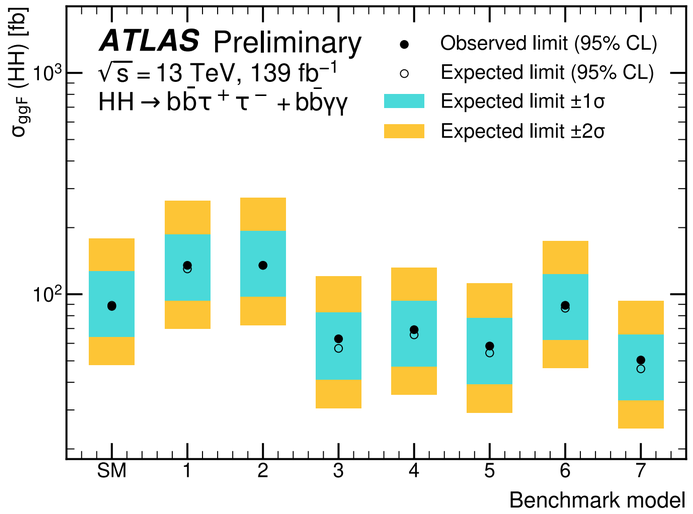
ongoing

EFT interpretations in

- Upper limits on HEFT benchmarks with characteristic m_{HH} shape features

Benchmark model	c_{hhh}	c_{tth}	c_{ggh}	c_{gghh}	c_{tthh}
SM	1	1	0	0	0
BM 1	3.94	0.94	1/2	1/3	−1/3
BM 2	6.84	0.61	0.0	−1/3	1/3
BM 3	2.21	1.05	1/2	1/2	−1/3
BM 4	2.79	0.61	−1/2	1/6	1/3
BM 5	3.95	1.17	1/6	−1/2	−1/3
BM 6	5.68	0.83	−1/2	1/3	1/3
BM 7	−0.10	0.94	1/6	−1/6	1





[ATL-PHYS-PUB-2022-019]

bbττ + bbγγ

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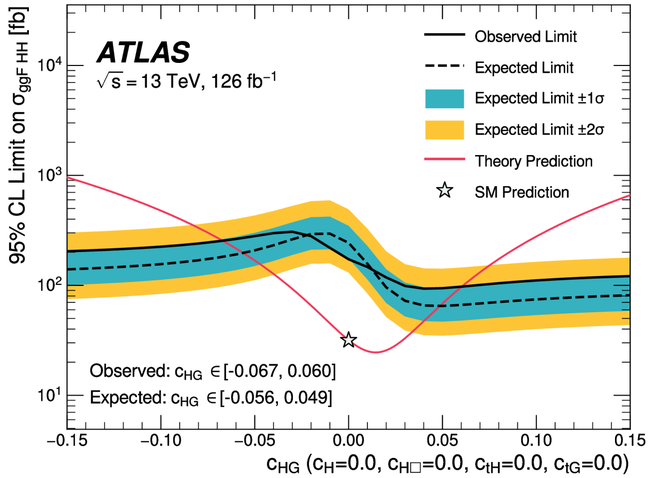
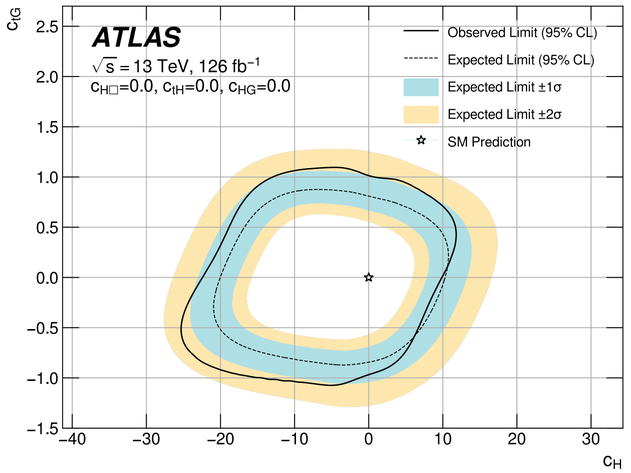
- Constraints on SMEFT Wilson coefficients





bbbb

[arXiv:2301.03212 [hep-ex]]

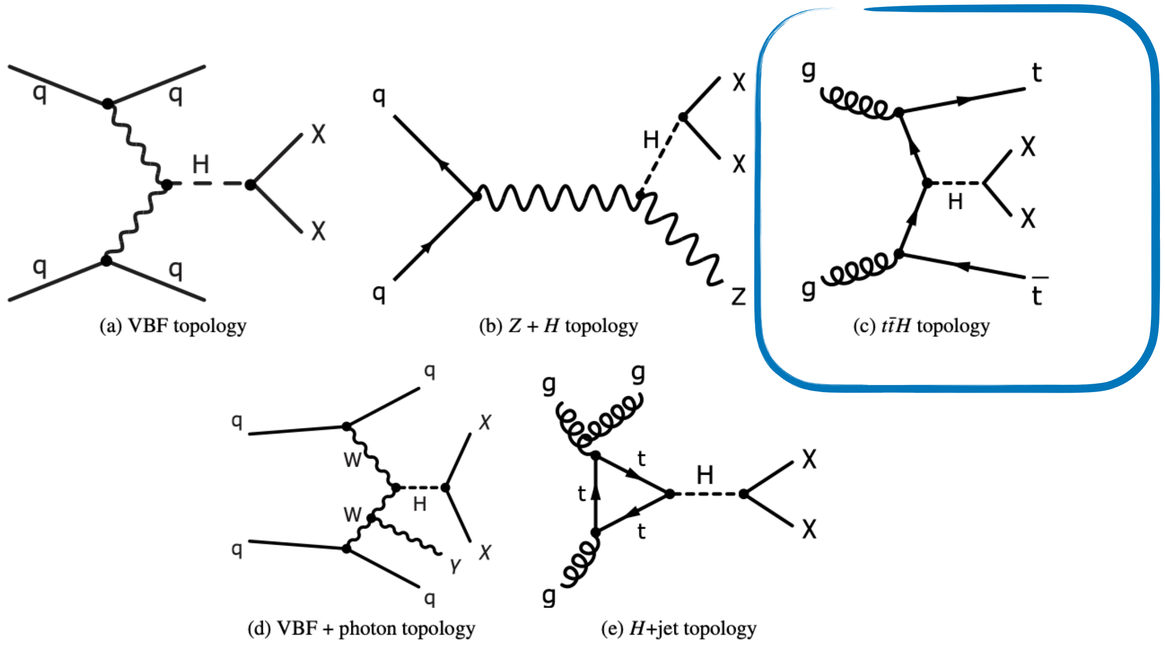
Submitted to PRD

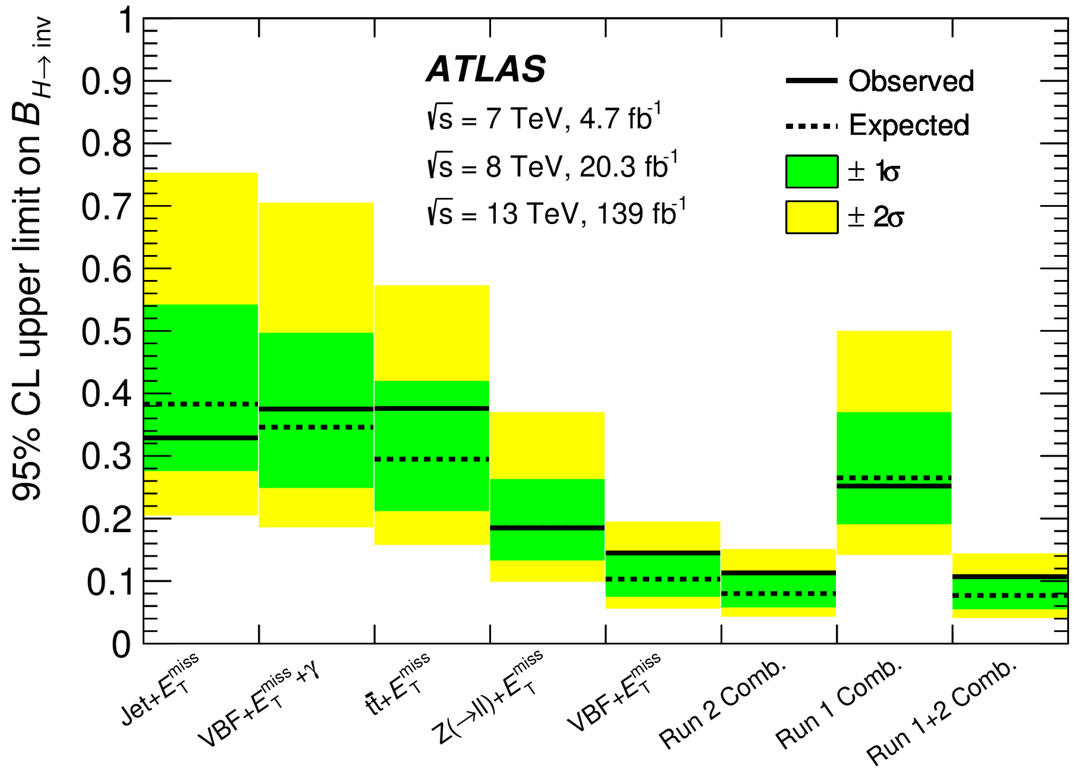
Other BSM activities

Higgs→invisible combination

Phys. Lett. B 842 (2023) 137963

- In SM, $\mathcal{B}_{H\to\text{inv}} = 0.1\,\%$, arising from the decay of Higgs boson via $ZZ^* \to 4\nu$
- **Dark matter**: Searches for invisible decays of the Higgs boson, $t\bar{t} + E_T^{\text{miss}}$ is one of them
- Observed (expected) $\mathcal{B}_{H\to\text{inv}} < 10.7\,\%\,(7.7\%)$ at 95% CL (Run 1+ Run 2 combination)





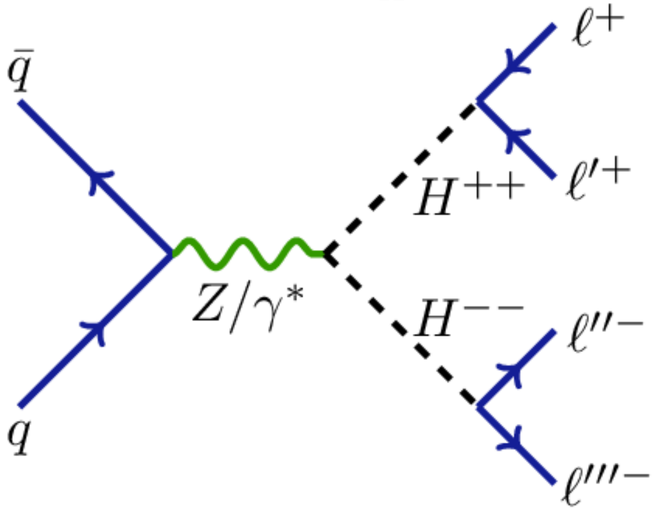
Doubly charged Higgs boson search

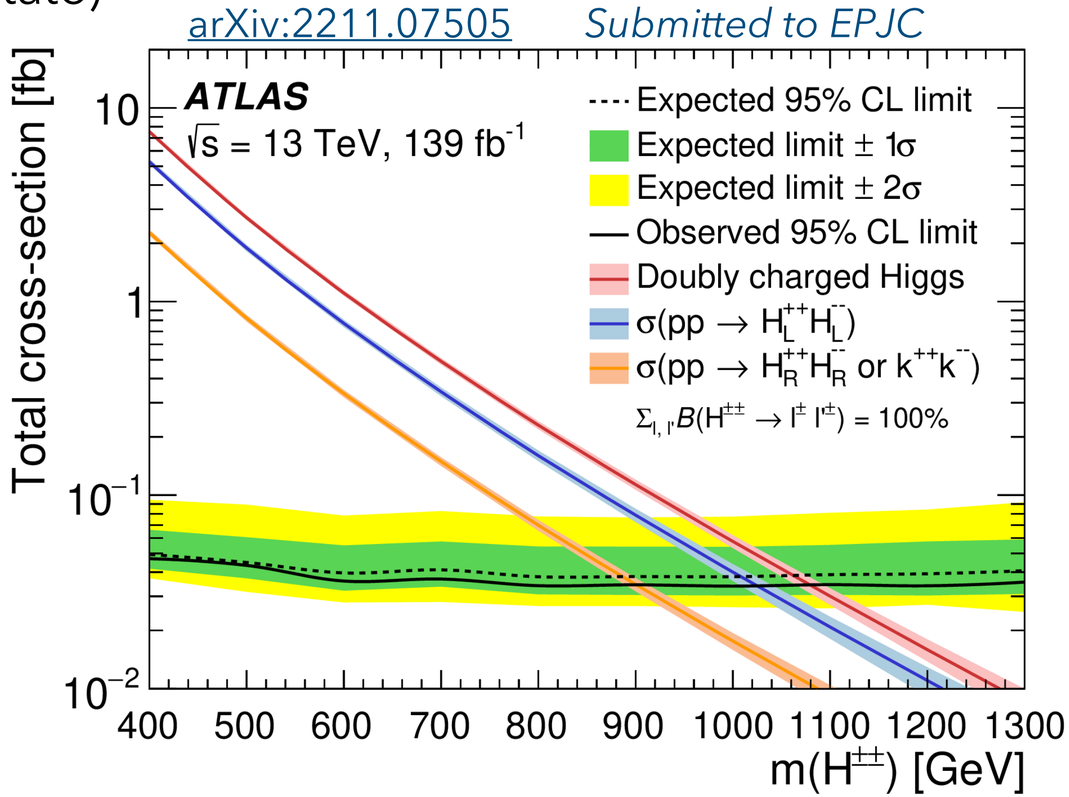
- Some theories like left-right symmetric models (LRSMs) or BSM scenarios with neutrino mass generation predict the existence of doubly charged Higgs bosons

- Search for $H^{\pm\pm}$ pair production in all lepton flavour and charge combinations, $H^{\pm\pm} \to l^{\pm}l^{\pm}$, where $l = e, \mu, \tau$ (only studies electrons or muons in the final state)

- Split in 2-, 3-, and 4-l channels

- Observed lower limit on $m_{H^{\pm\pm}}$ at 1080 GeV (95% CL)





Summary

- Many new measurements with Run 2 ATLAS data characterising the Higgs boson and further exploring the Higgs sector
- Improved precision
- Large contributions from Swedish institutes
- Looking forward to Run 3 and beyond

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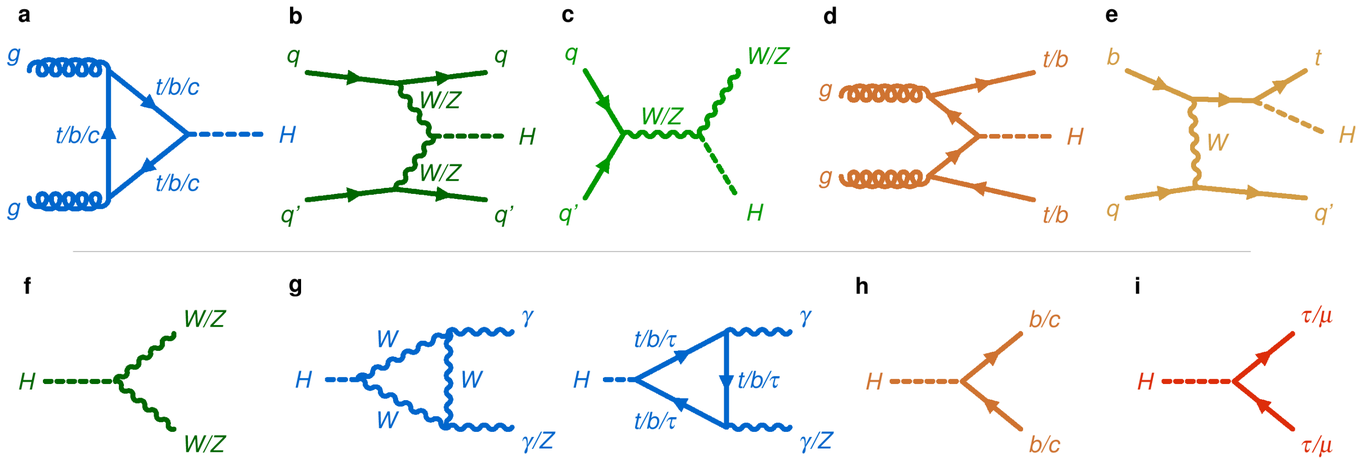
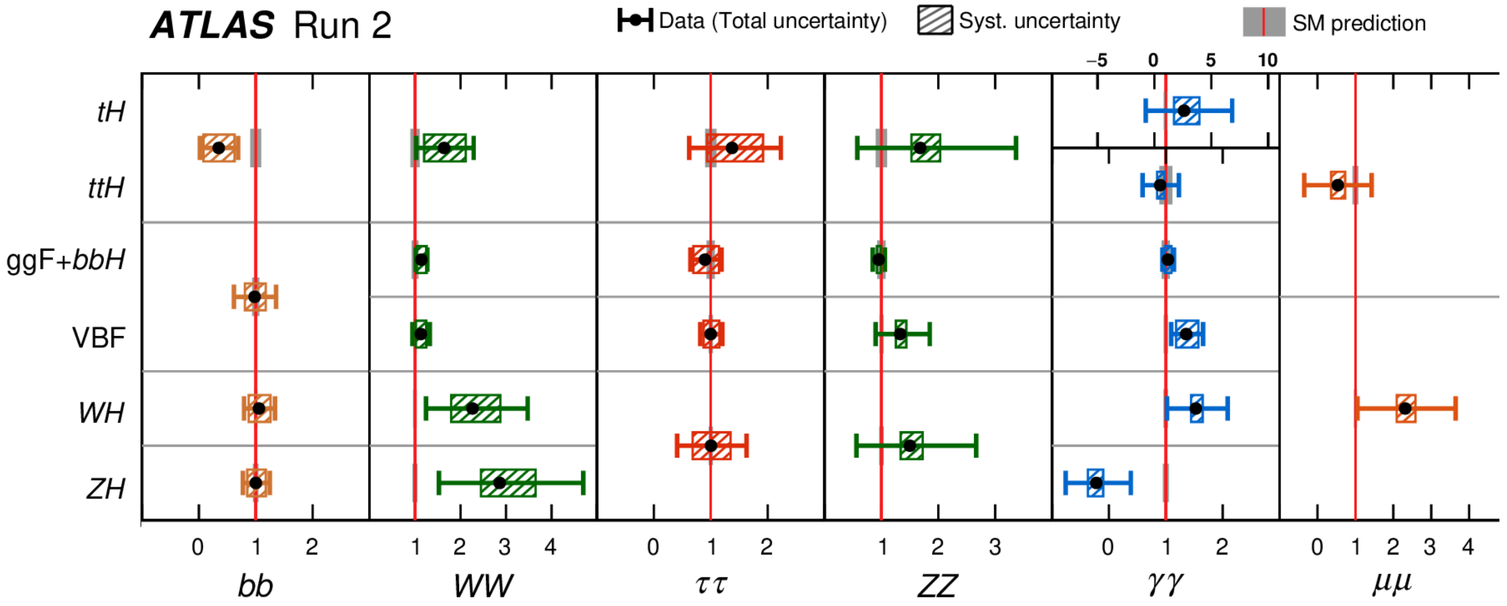
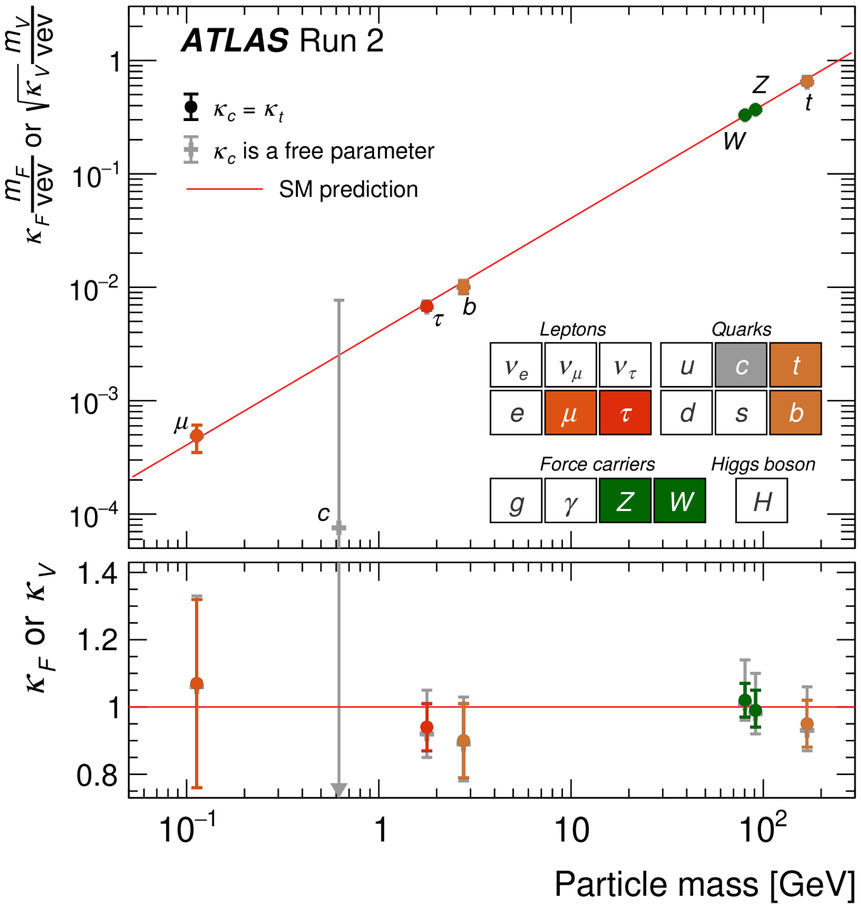
Back-up

Summary of Higgs boson couplings



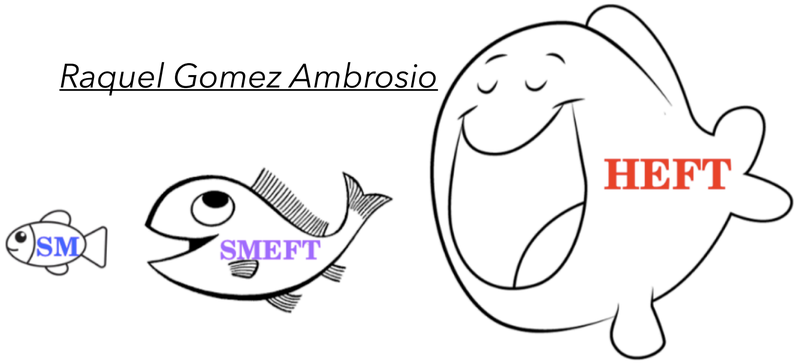


σ × B normalized to SM prediction



EFT frameworks

Raquel Gomez Ambrosio



SMEFT

- Canonical counting, expansion in $1/\Lambda$

$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{\text{SM}} + \sum_{n,i} \frac{c_i^{(n)}}{\Lambda^{n-4}} \mathcal{O}_i^{(n)}$$

- SM symmetries and fields, traditional EWSB mechanism (Higgs field: $SU(2)_L$ doublet)

- More restrictive (correlated Wilson coefficients)

HEFT

- No power-counting like in SMEFT, more similar to chiral perturbation theory

$$\mathscr{L}_{d_\chi} = \mathscr{L}_{(d_\chi=2)} + \sum_{L=1}^{\infty} \sum_i \left(\frac{1}{16\pi^2}\right)^L c_i^{(L)} O_i^{(L)}$$

- Higgs field: EW singlet

- Much more general (independent couplings)