Introduction to Higgs+BSM session

Anne-Catherine Le Bihan (CNRS)

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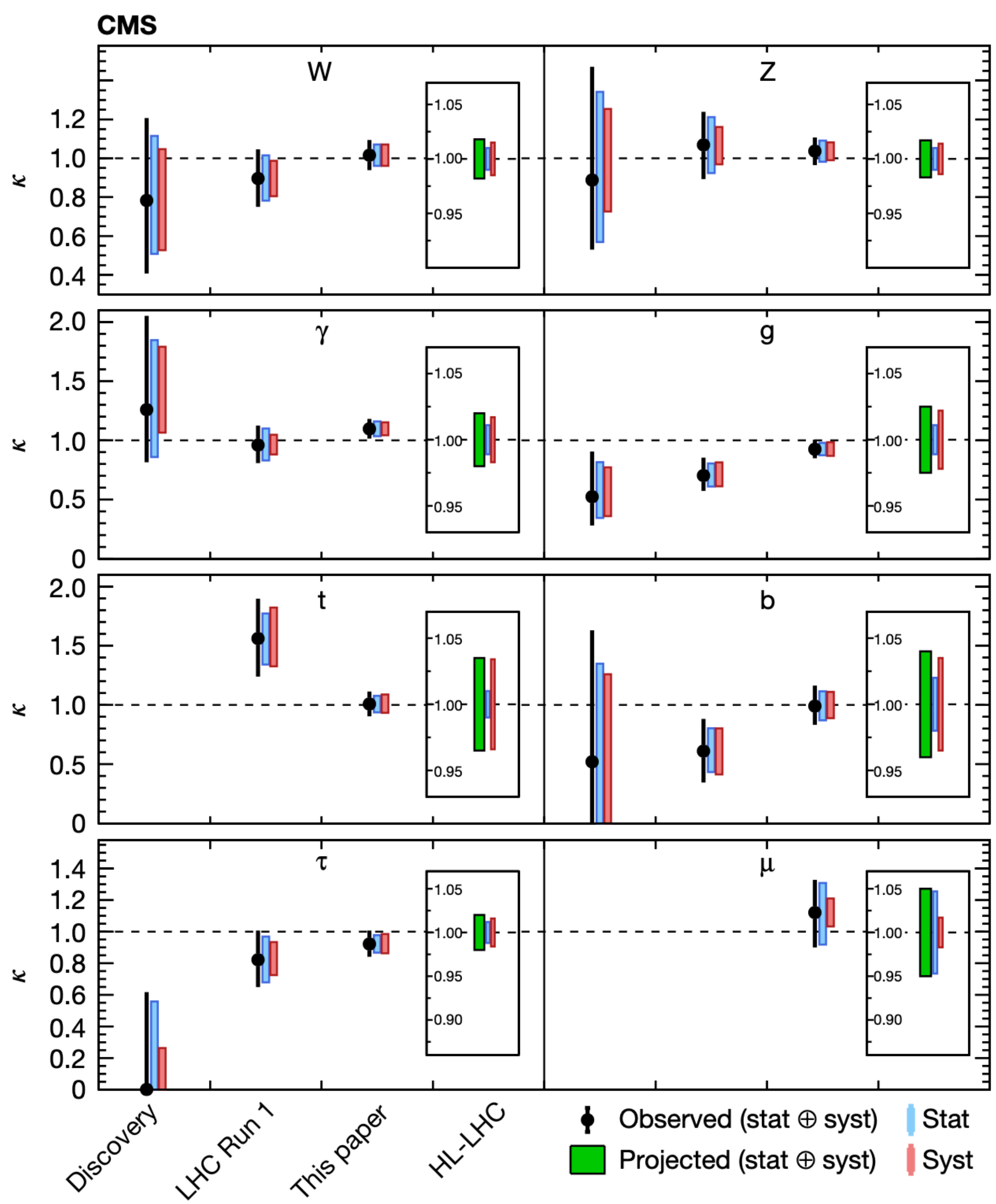
Higgs boson decays

Couplings to **bosons** and **3rd generation fermions** are known with a precision of ~**10%**

Evidence only for H → $\mu\mu$ and H → $Z\gamma$

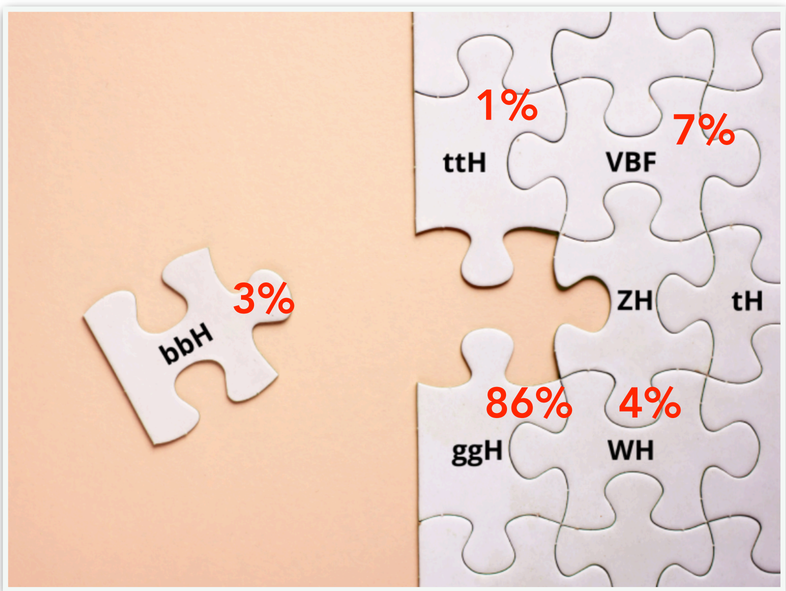
1.1 < |κ| < 5.5… thanks to improvements on machine learning side…

BR(H→ee) < 3.0-3.6.10^{-4}… SM predicts BR(H→ee) ~5.10^{-9}



We don't know yet how the Higgs boson couples to the **first generation of fermions** which constitutes **ordinary matter**…

Higgs boson production modes



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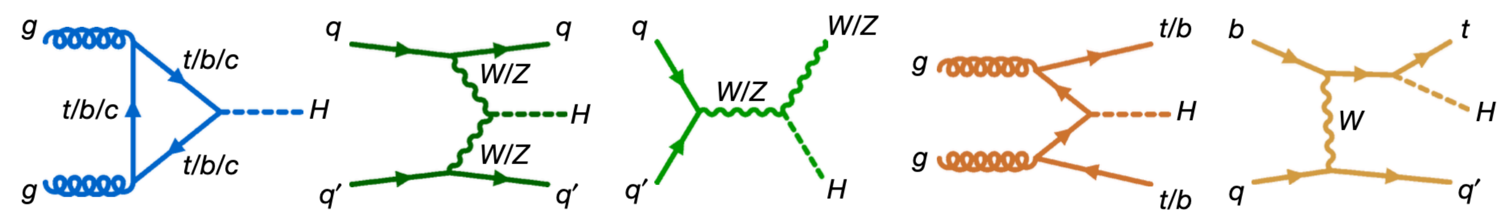


Global signal strength modifiers

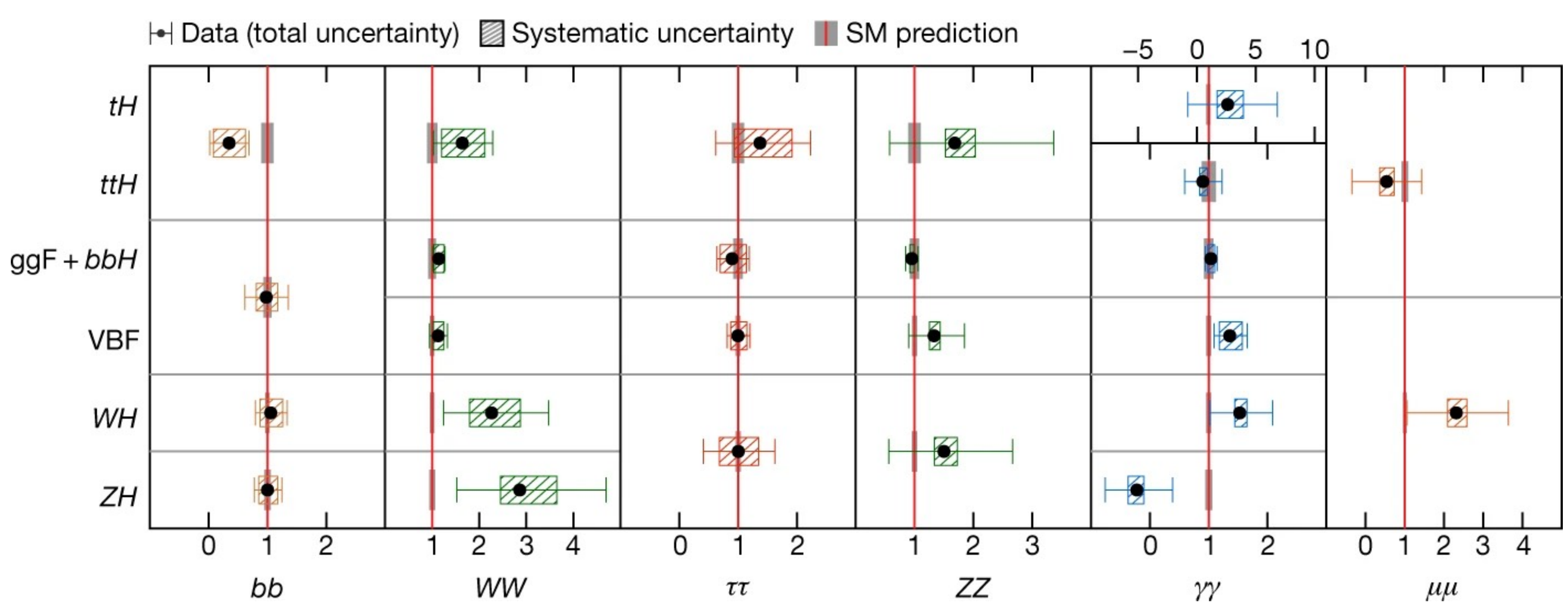
μ = 1.05 ± 0.06 (ATLAS)

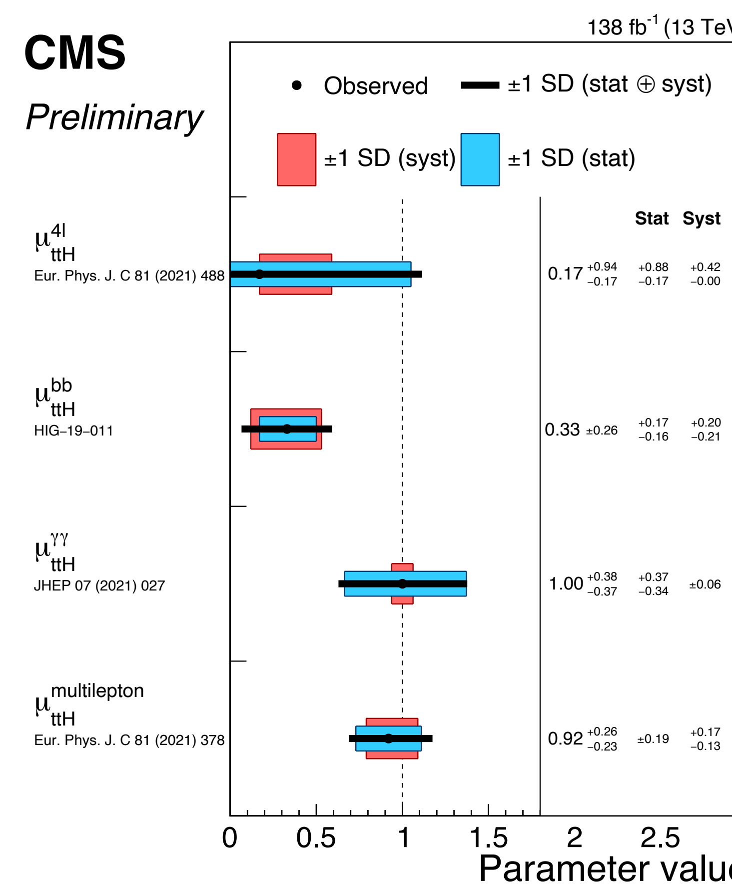
μ = 1.002 ± 0.057 (CMS)

Observation of the usual production modes ggH, VBF, VH, ttH

bbH and tH still to be seen

ttH to be better understood

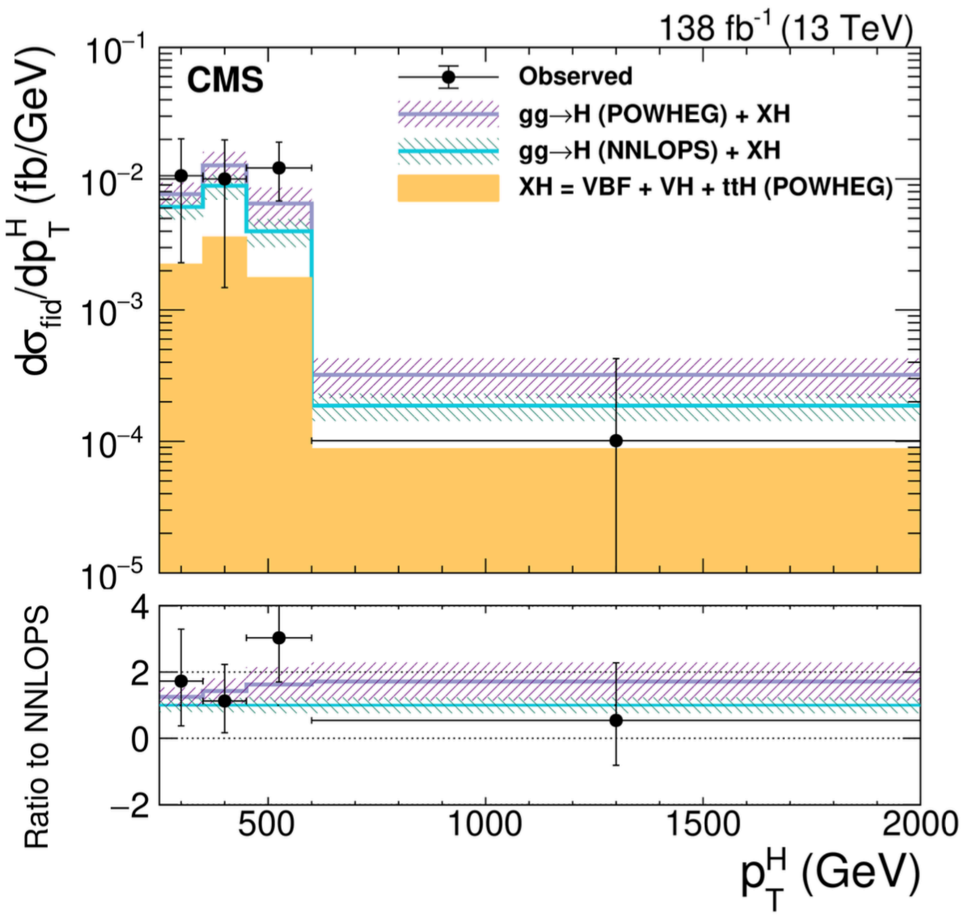




Higgs production and decay modes

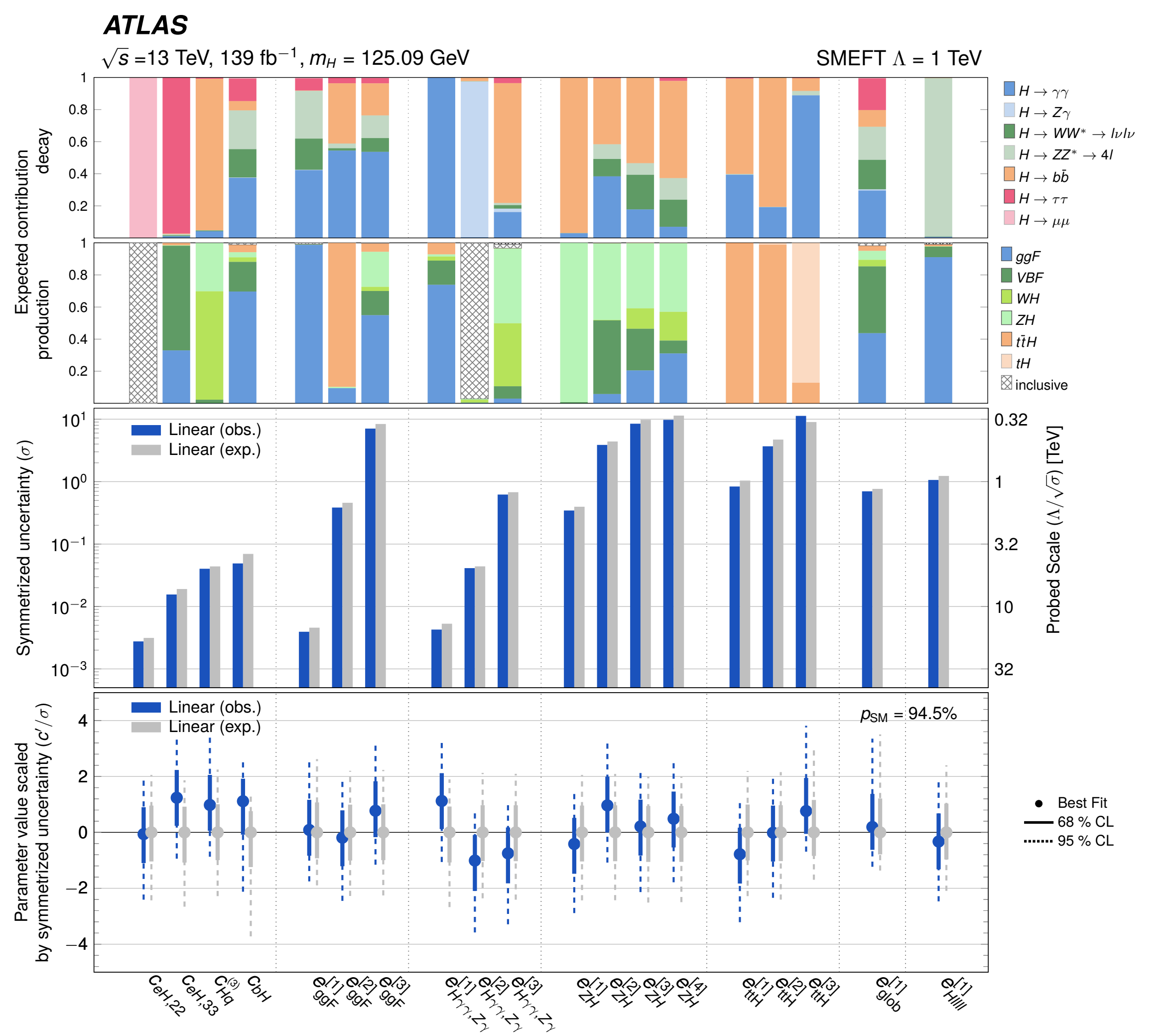
More precision in STXS and differential measurements needed

Higgs pT scrutinised for deviations…
How far can we go?
More precision needed..



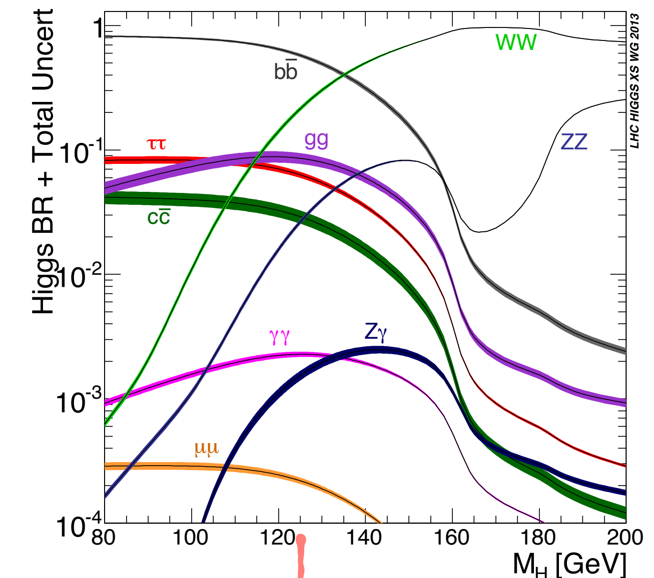
STXS measurements reinterpreted with EFT approach

Input measurements don't allow to constrain all Wilson coefficients simultaneously
→ 19 linear combinations in rotated basis

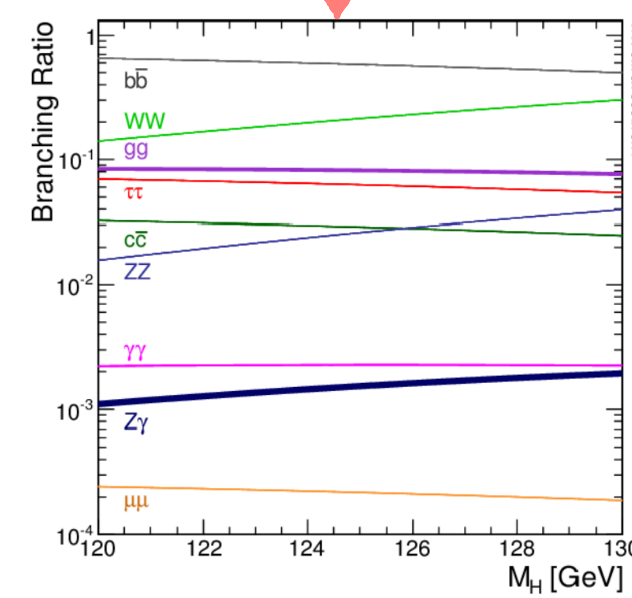


Higgs boson mass

Higgs boson mass not predicted by the SM but yet known with 1 permille precision (**0.1 GeV**)!
It was **0.6 GeV at discovery**…

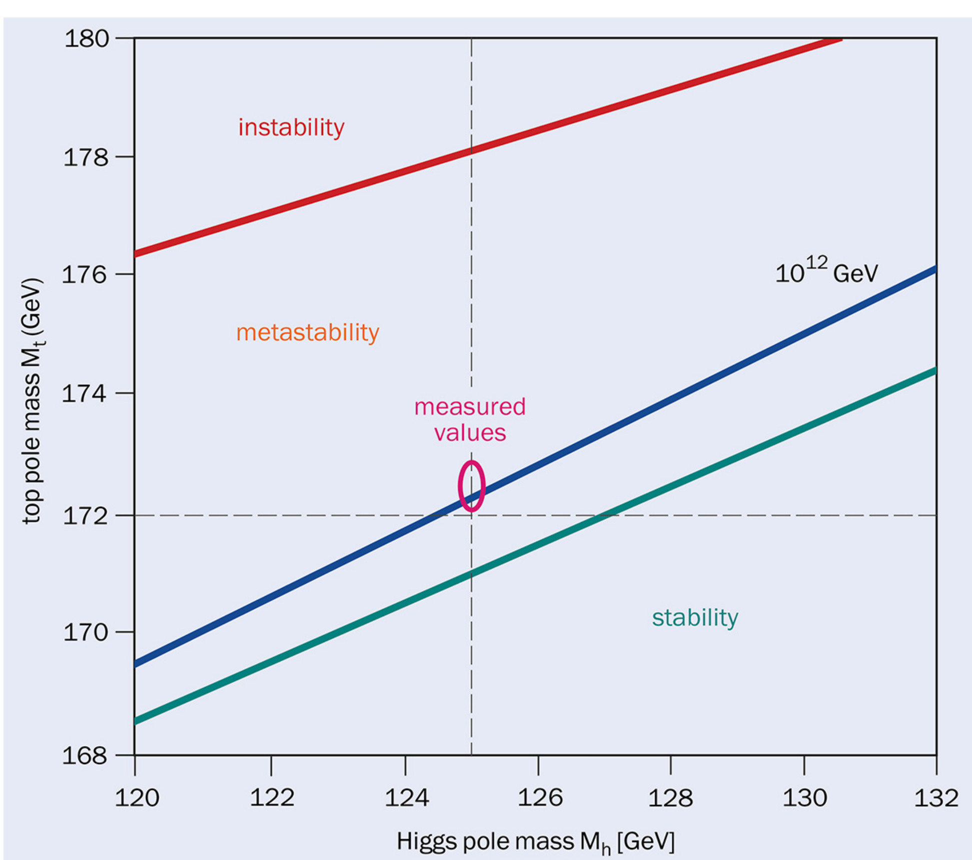


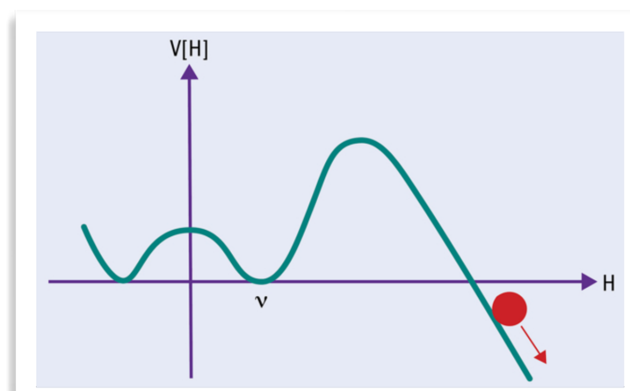
Since 2012…



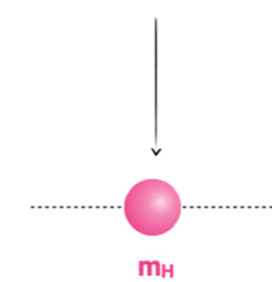
One of the fundamental parameters of the SM

- It fixes the Higgs BRs and production cross sections
- It allows consistency tests of the SM
- It fixes the Higgs self-coupling value, metastable universe or not? New physics needed to stabilise the EW vacuum?





$$V(h) \simeq \frac{1}{2} m_H^2 h^2 + \lambda v h^3 + \frac{1}{4}\lambda h^4 + \ldots$$



Minimum of the potential

$$m_H = \sqrt{2\lambda} v \approx 125 \text{ GeV}$$

Higgs boson width

Direct measurements performed with H $\rightarrow ZZ^* \rightarrow 4\ell$ mass
but with limited resolution…

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$\Gamma_H <$ 330 MeV @ 95% CL

VBF production allows to set constraints of invisible BRs thanks to distinctive 2 jets signature:
BR($H \rightarrow inv$)< 15% for ATLAS, <18% for CMS

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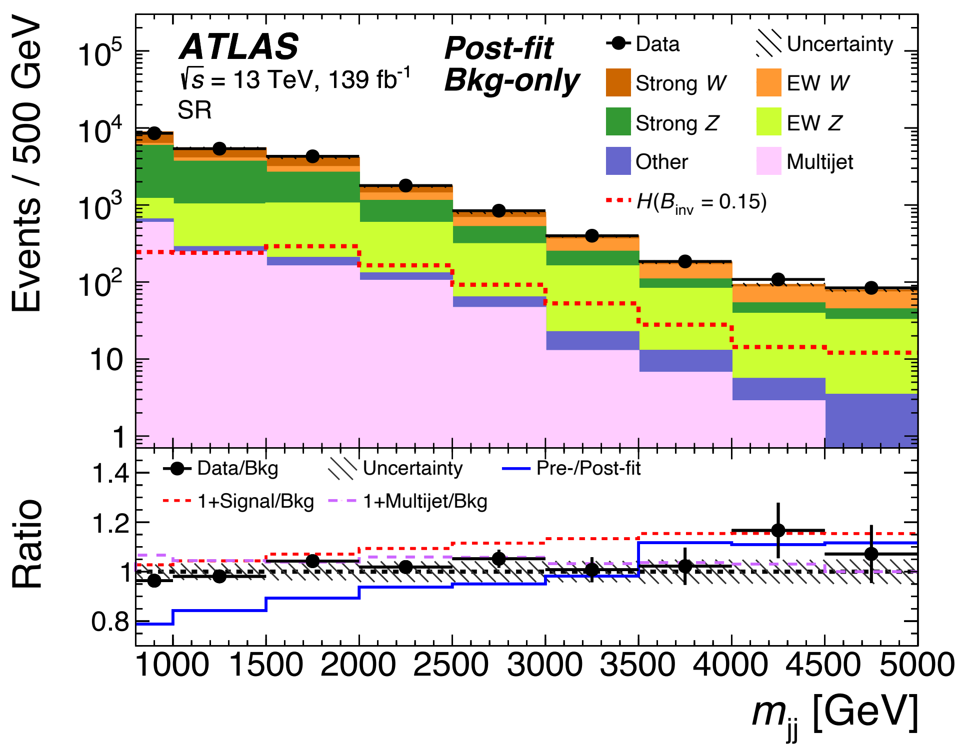

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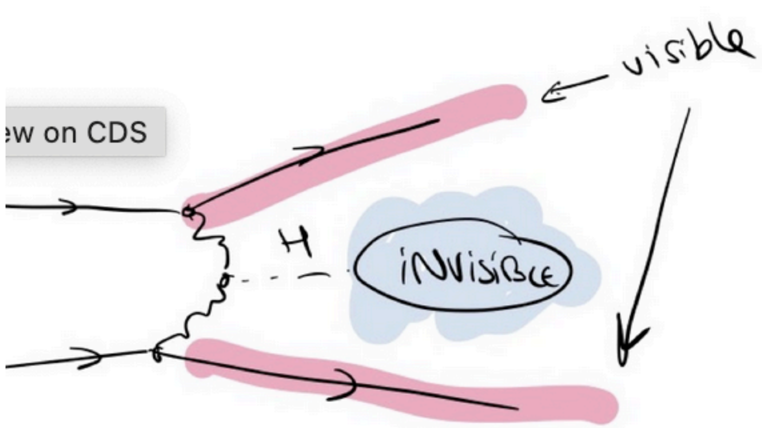
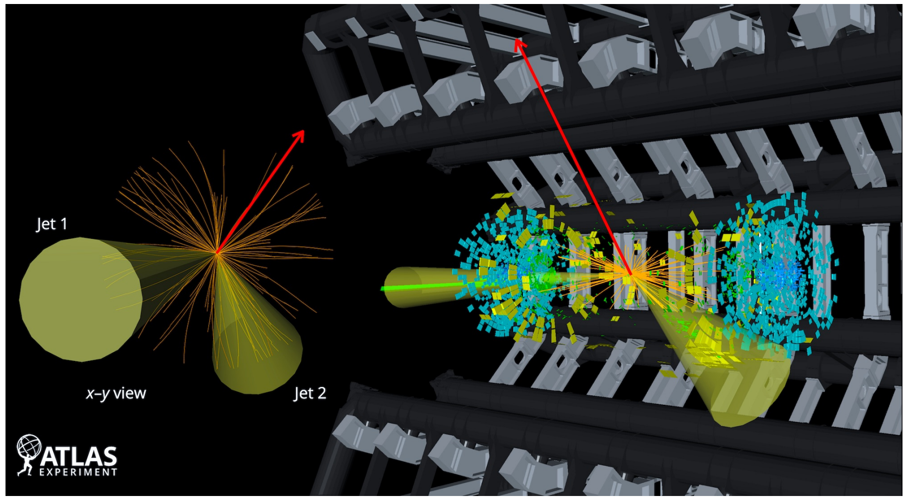


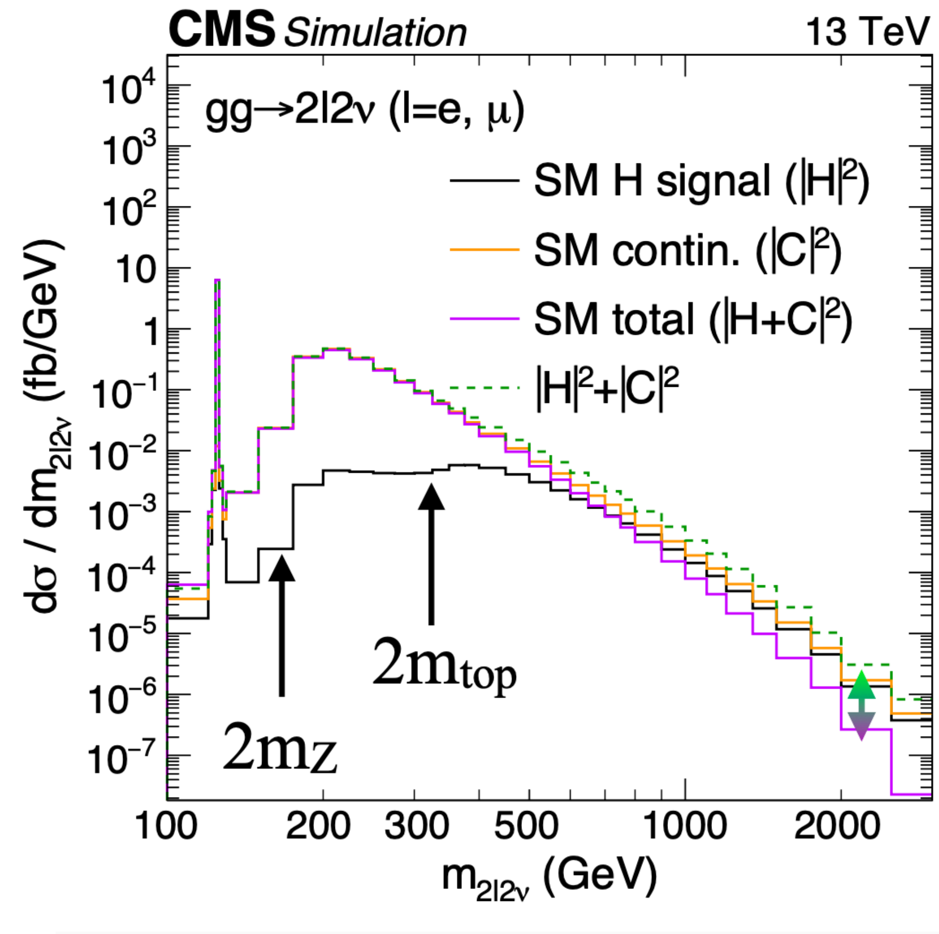


Higgs boson width

On- & off-shell ratio gives access to the Higgs boson width
Assuming **same couplings to on- and off-shell Higgs**
And that no new particles couples to the Higgs

$$\mu_{ZZ}^{\text{on}} \equiv \frac{\sigma_h \times \text{BR}(h \to ZZ \to 4\ell)}{[\sigma_h \times \text{BR}(h \to ZZ \to 4\ell)]_{\text{SM}}} \sim \frac{\kappa_{ggh}^2\, \kappa_{hZZ}^2}{\Gamma_h/\Gamma_h^{\text{SM}}}$$

$$\mu_{ZZ}^{\text{off}} \equiv \frac{\mathrm{d}\overline{\sigma}_h}{[\mathrm{d}\overline{\sigma}_h]_{\text{SM}}} \sim \kappa_{ggh}^2(\hat{s})\, \kappa_{hZZ}^2(\hat{s})$$



ZZ* is the interesting channel: non-negligible off-shell Higgs contribution thanks to **longitudinal polarisation of W/Z at high energy**

JHEP 08 (2023) 040

$\Gamma_H = 2.9^{+1.9}_{-1.4}$ @ 68% CL

PLB 846 (2023) 138223

$\Gamma_H = 4.5^{+3.3}_{-2.5}$ @ 68% CL

Measurement is statistically limited!

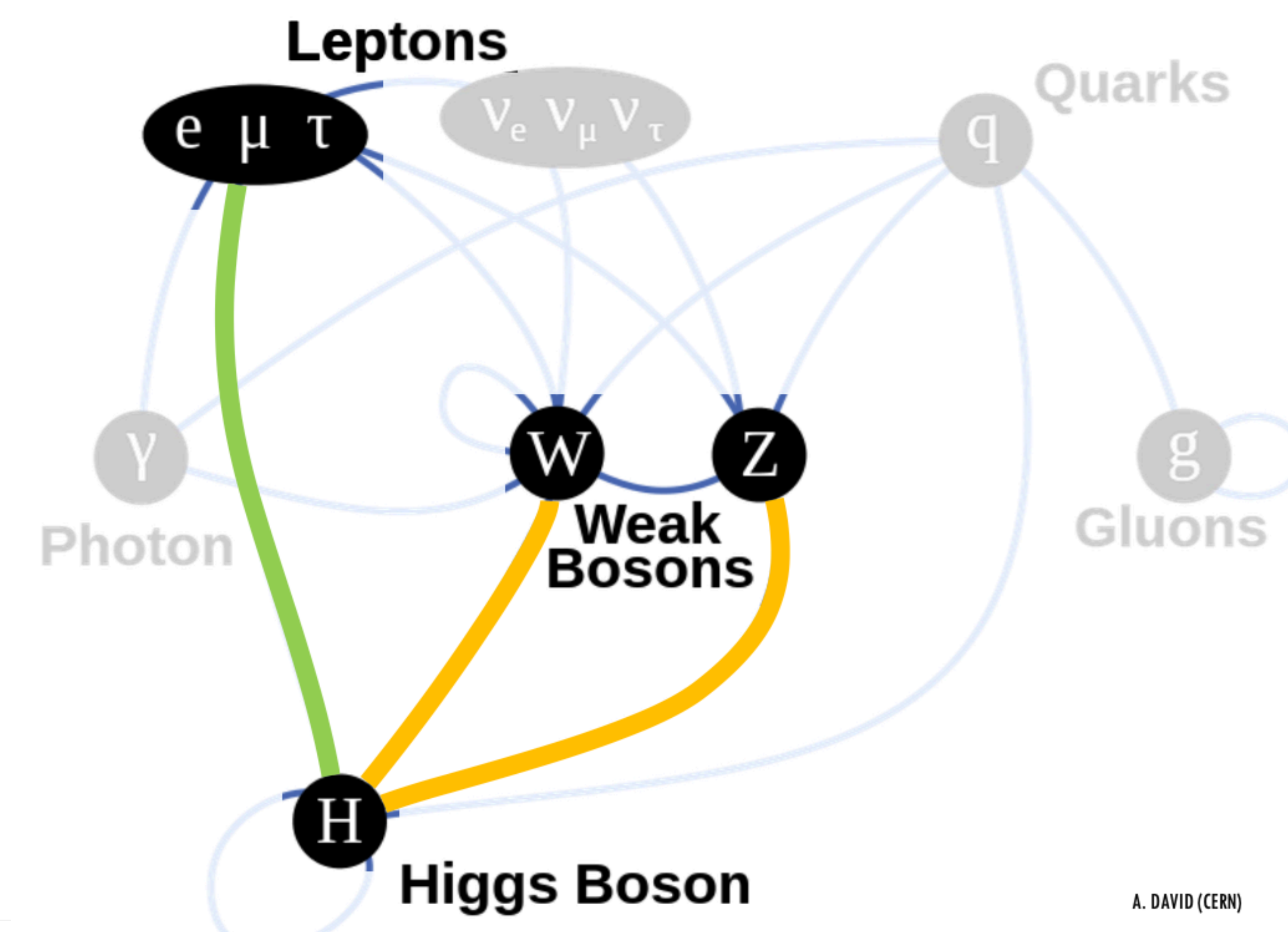
But very good modelling of gg→VV background and interference with Higgs needed (that depends on $\sqrt{(\mu_{off-shell})\ldots}$) needed

Higgs boson Charge-Parity

Higgs boson charge (C) known since it's discovery in $H \rightarrow \gamma\gamma$

Higgs boson spin (J) known to be 0 since Run 1

CP violation needed to explain the **matter-antimatter asymmetry** observed in the Universe… !



Anomalous couplings to vector bosons

Tree level CP-even coupling (=0 if absent in SM)

CP-even anomalous higher order couplings

$$\mathscr{A}(HVV) \simeq \left[a_1^{VV} + \frac{k_1^{VV} q_1^2 + k_2^{VV} q_2^2}{(\Lambda_1^{VV})^2} + \frac{k_3^{VV}(q_1+q_2)^2}{(\Lambda_Q^{VV})^2} \right] m_V^2 \varepsilon_{V1}^* \varepsilon_{V2}^* + a_2^{VV} f_{\mu\nu}^{*(1)} f^{*(2)\mu\nu} + a_3^{VV} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2)\mu\nu} ,$$

CP-even anomalous coupling

CP-odd anomalous coupling

Yukawa couplings: couplings to fermions

$$L_Y = \frac{m_\tau}{v} \bar{\tau}(\kappa_\tau + i\gamma^5 \widetilde{\kappa_\tau})\tau H$$

$$\tan(\alpha^{H\tau\tau}) = \widetilde{\kappa_\tau}/\kappa_\tau$$

CP even (SM)

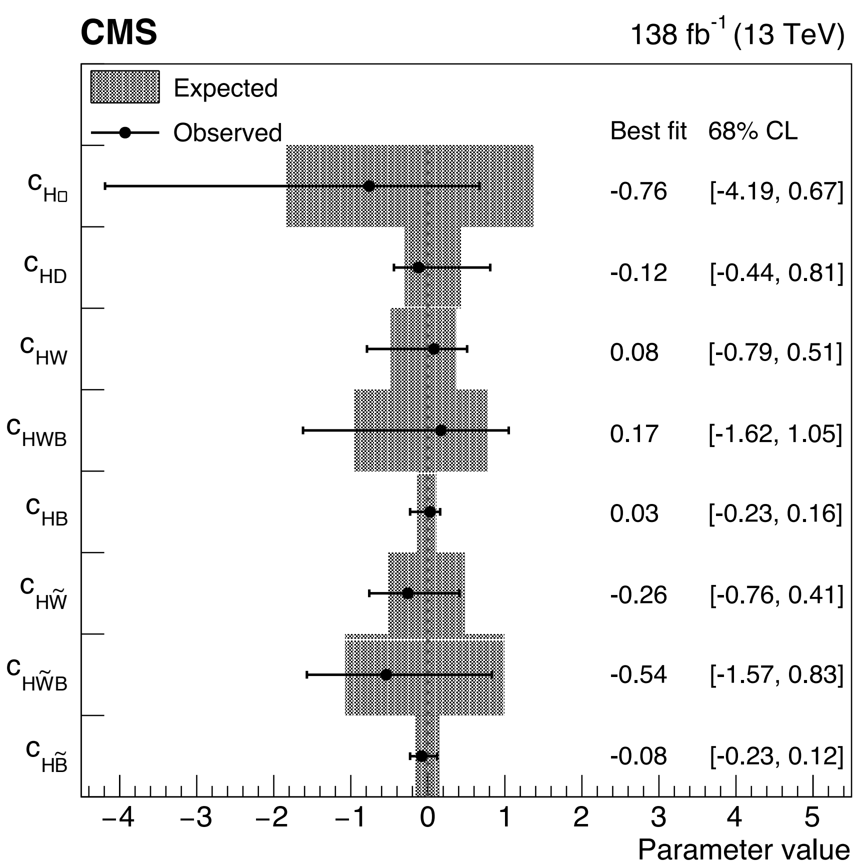
CP odd

Higgs boson Charge-Parity

Bosonic couplings

EFTs interpretation

No deviations seen…

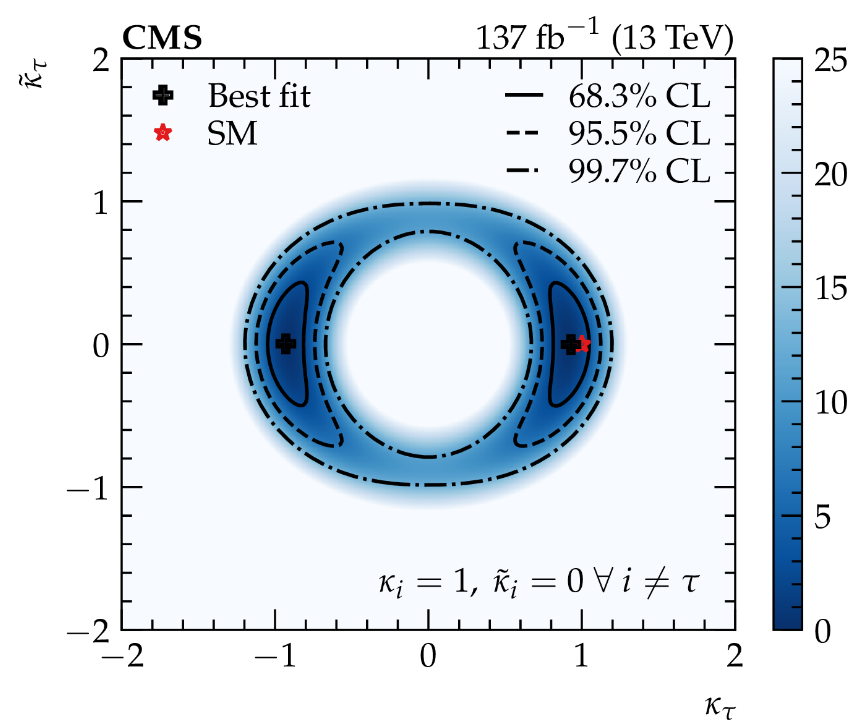


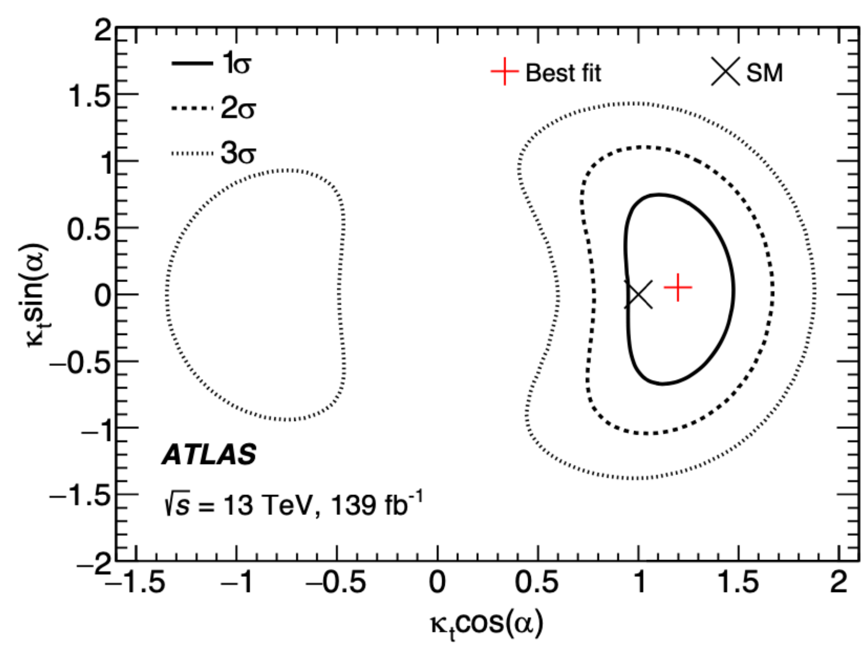
CMS-PAS-HIG-22-008 acc. JHEP

Fermionic couplings: top and tau experimentally accessible

Pure CP-odd excluded for both at **3σ level only**

Still room for the Higgs boson to be in a mixed state…!





JHEP 06 (2022) 012

Eur. Phys. J. C 83 (2023) 563

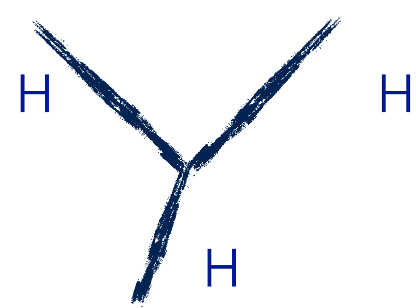
Phys. Rev. lett. 125 (2020) 061802

Phys. Rev. D 104 (2021) 052004

Higgs boson self-coupling

A self-interacting Higgs would be unlike anything yet seen in nature: all other interactions change particle identity!

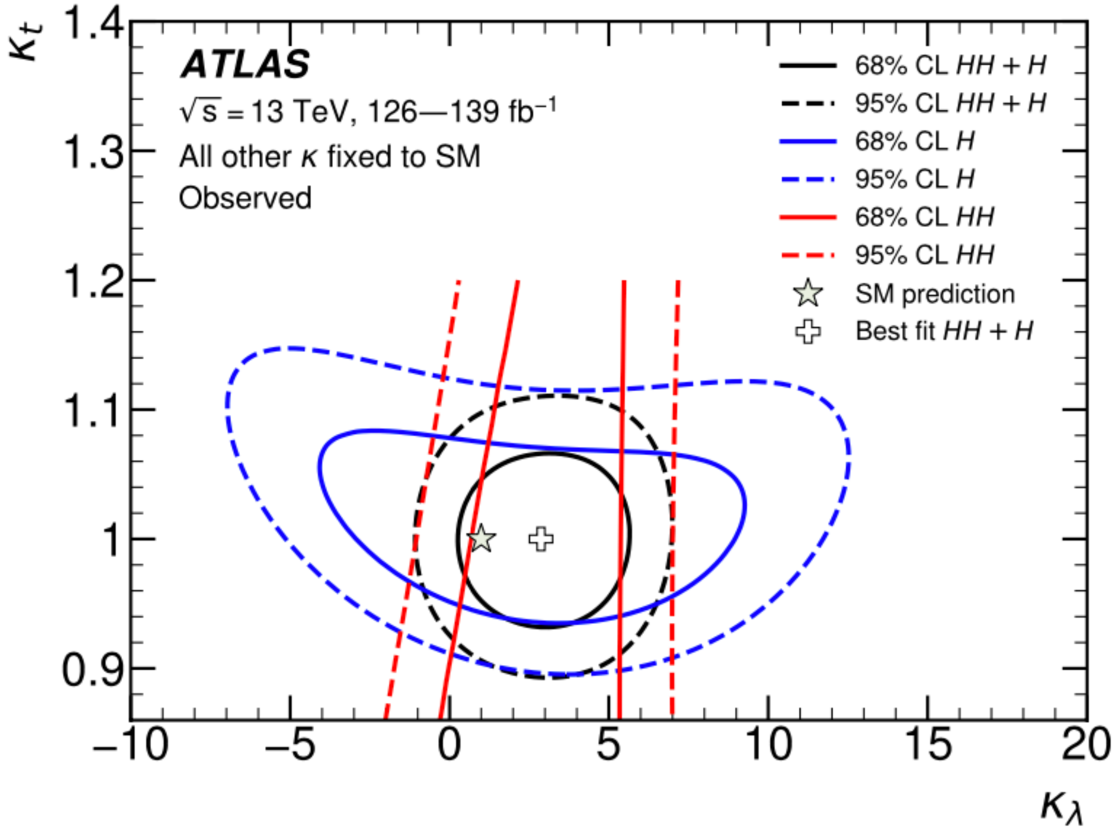
Fundamental test of the Higgs mechanism!



Current status (di-Higgs + single-Higgs)

ATLAS: $-1.4<\kappa_\lambda<6.1$ ($-2.2<\kappa_\lambda<7.7$)
CMS: $-2.3<\kappa_\lambda<7.8$ ($-1.4<\kappa_\lambda<7.8$)

More precision and data needed!



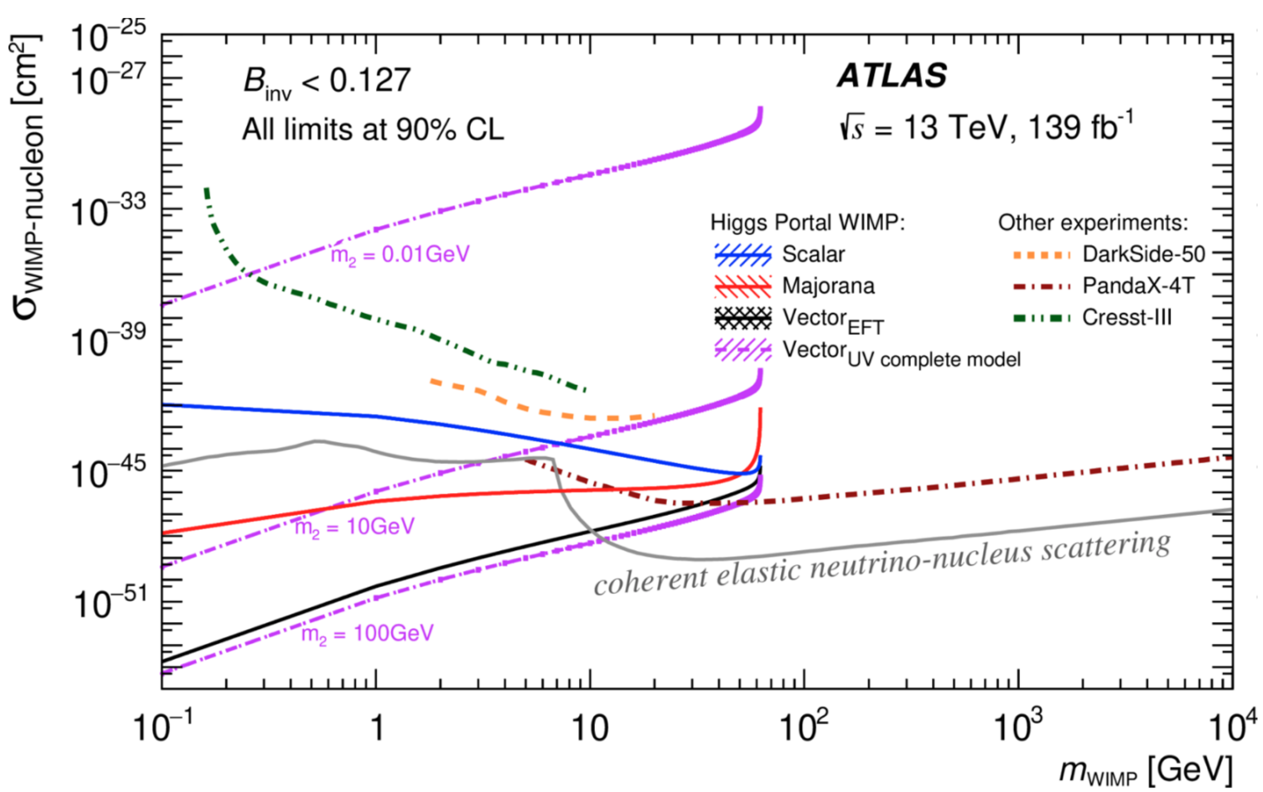
Single Higgs measurements (sensitive to λ through NLO EW corrections)
Important to eliminate the degeneracy between κ_λ and κ_t
And cross section is ˜3 time higher than di-Higgs one! VBF di-Higgs needed as well, other couplings involved!

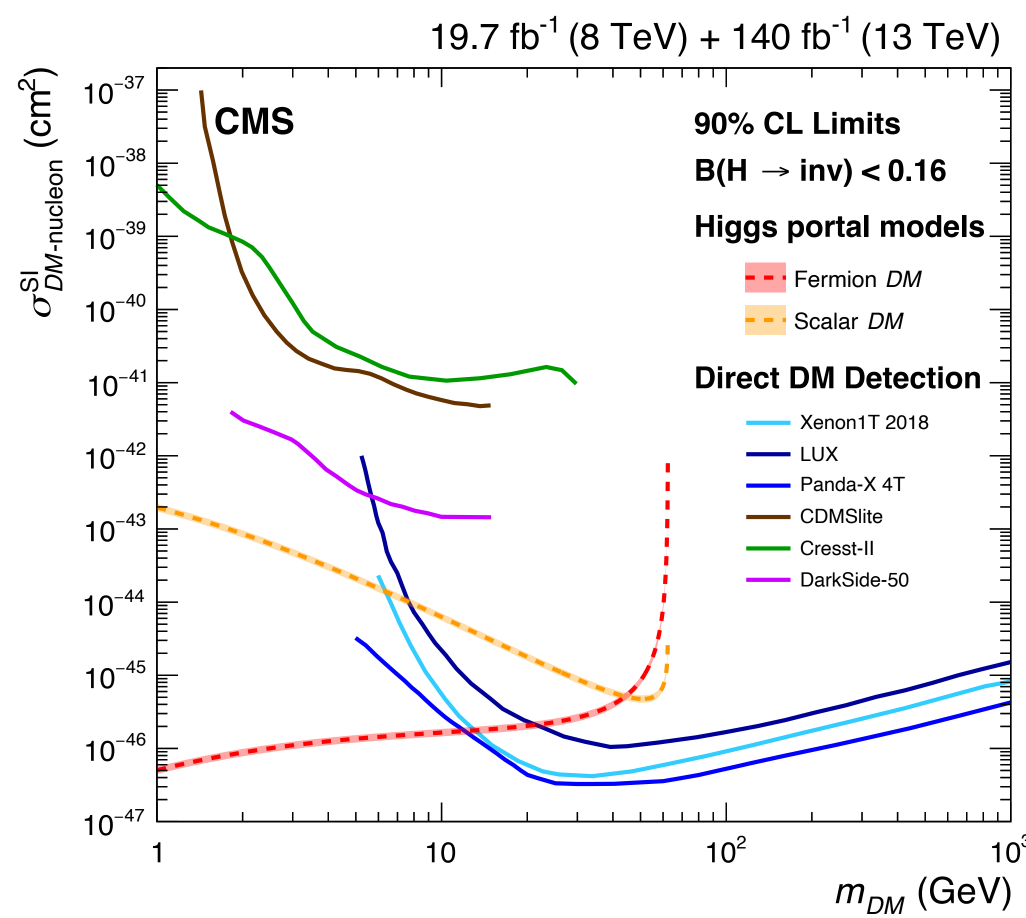
What is the nature of dark matter?

The Higgs mechanism gives mass to particles…
Does it give mass to dark matter?

No sign of new particles in direct searches, but competitive limits from Higgs portal below 10 GeV from LHC

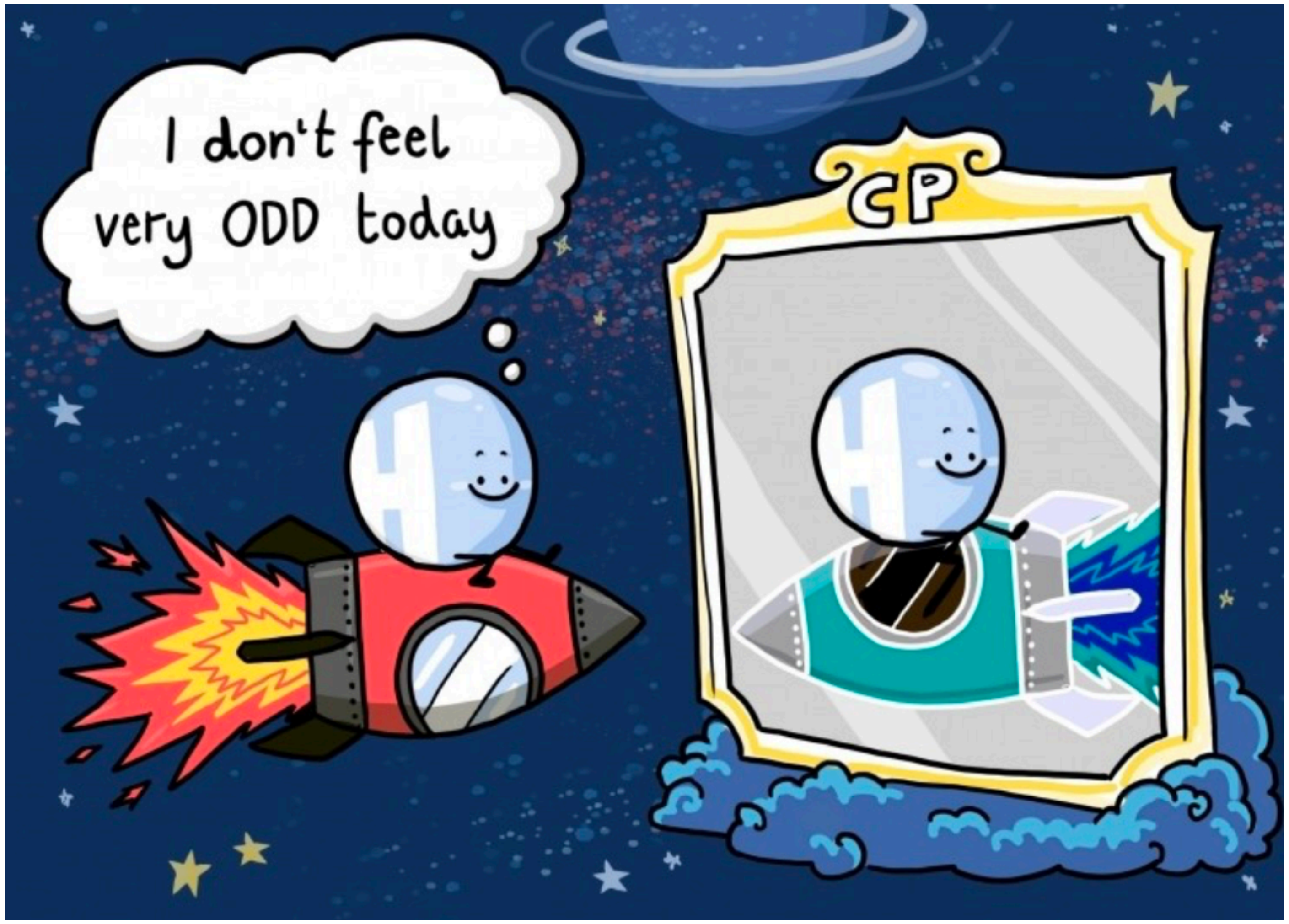
Can we do better? With machine learning? More data? New data? New resonance hunting strategy?





No sign of new physics so far…

Nor in the Higgs sector nor with direct searches



T1P1
LHC - Higgs+BSM
(Room 1)

Room 1: T1P1 LHC - Higgs+BSM

Chairperson: Anne-Catherine Le Bihan (IPHC, Strasbourg)

(20' talks = 15'+5' d

(15'+5')	**Introduction** Anne-Catherine Le Bihan (IPHC, Strasbourg)
(15'+5')	**Higgs Mass and width measurements at ATLAS** Laura Nasella (University of Milan)
(15'+5')	**Rare (SM) Higgs boson decays and rare Higgs production modes at CMS** Jae-Bak Kim (University of California at Santa Barbara)
(15'+5')	**Higgs self-coupling at CMS (including di-Higgs resonnant searches)** Oguz Guzel (Université Catholique de Louvain)
(15'+5')	**Resonances all over the place?** Gilbert Moultaka (LUPM, Montpellier)
(15'+5')	**Search for Dark Matter in ATLAS** Qibin Liu (Tsung-Dao Lee Institute, Shanghai Jiao Tong University)
(15'+5')	**Model Agnostic searches in final states with jets at ATLAS** Antonio D'Avanzo (Università degli Studi di Napoli Federico II)