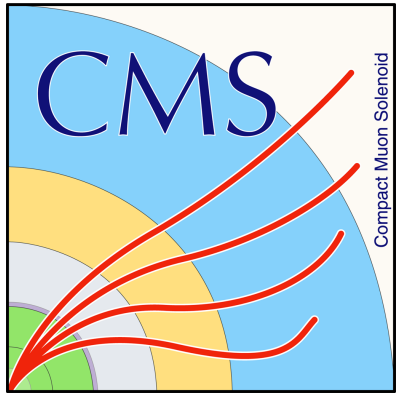
Higgs boson combination and coupling measurements at CMS



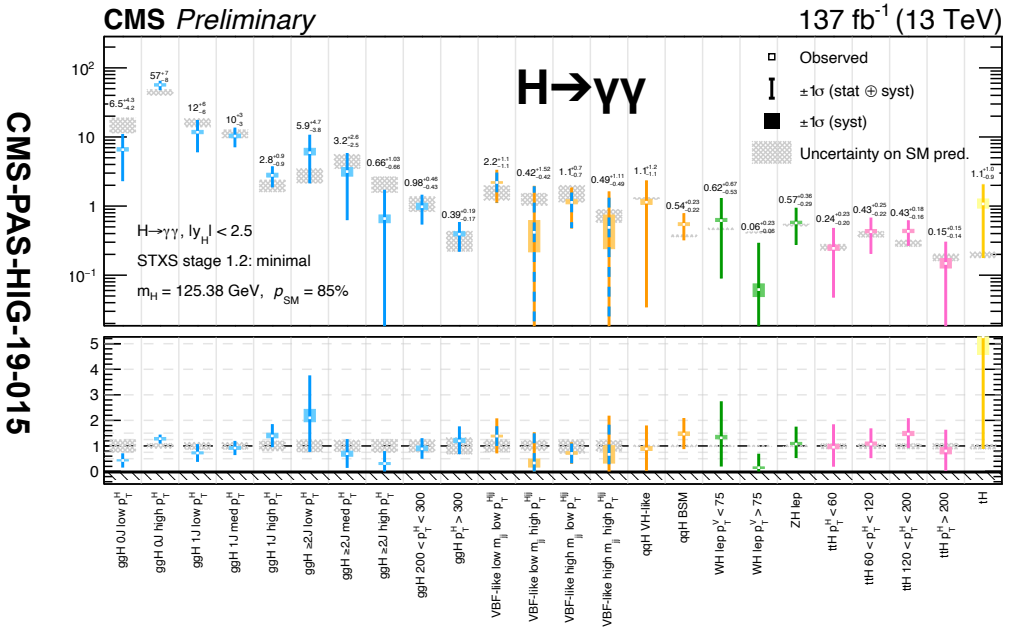
A. de Wit (DESY) on behalf of the CMS collaboration

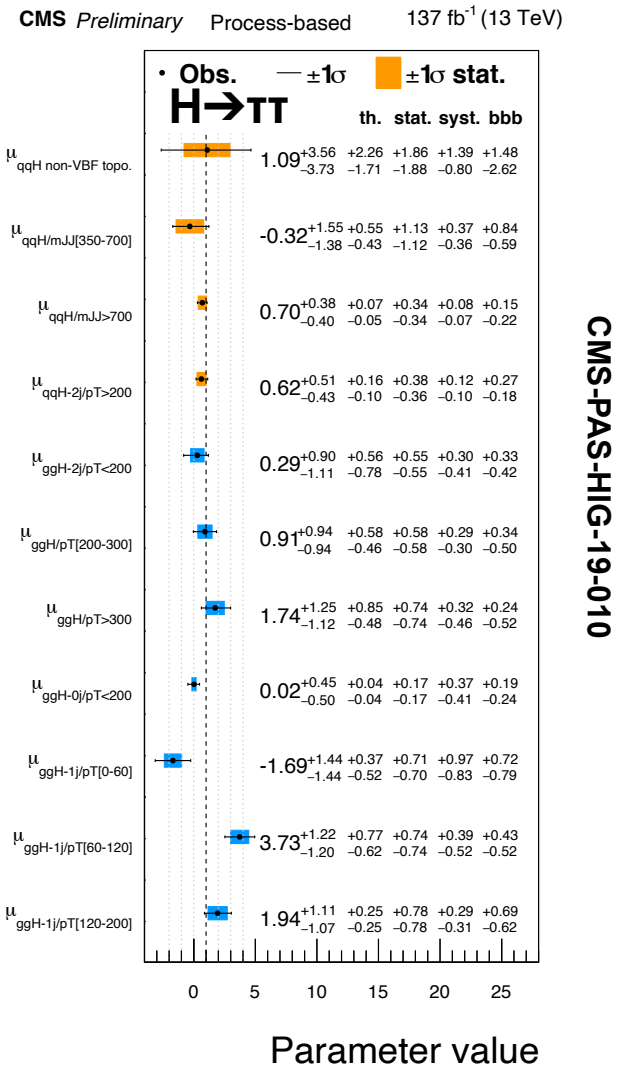
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Higgs physics in LHC Run 2

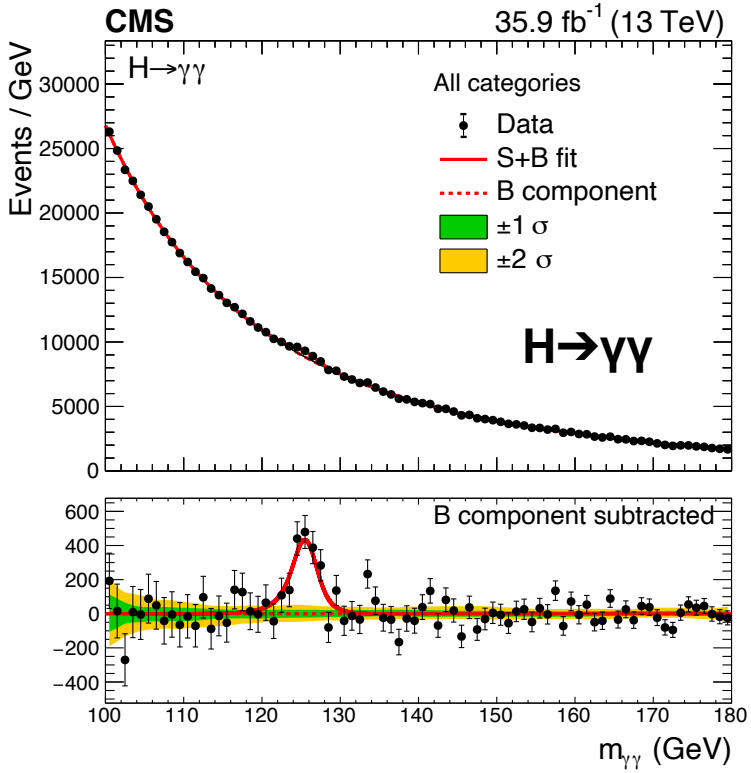
- Focus for Higgs physics in LHC Run 2: **precision; going beyond inclusive measurements**
- A lot of information in measurements of individual production- and decay modes ➔ **Combined measurements give ultimate precision**
- In this presentation, using partial Run 2 dataset:
  - Combined mass measurement
  - (inclusive) coupling combination
  - EFT interpretation based on simplified template cross section measurements





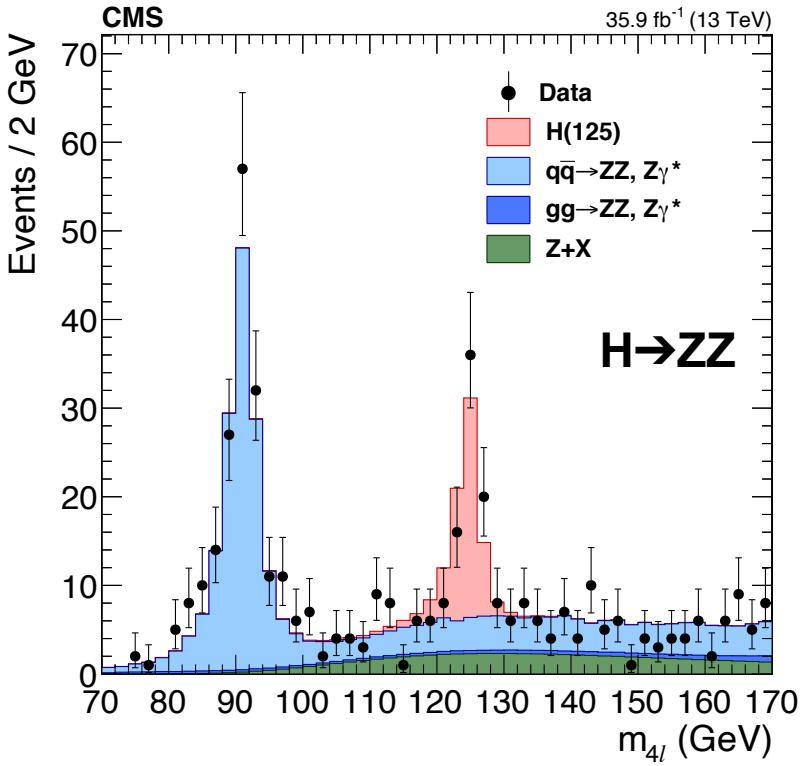
Combined Higgs boson mass measurement: ingredients

- **Mass measurement in H→γγ and H→ZZ→4l channels**
  - Using data from 2016 (35.9 fb^{-1} @13 TeV) and Run 1 (5.1 fb^{-1} @ 7 TeV and 19.7 fb^{-1} @ 8 TeV)
- H→γγ mass measurement relies on precise photon energy scale calibration



Phys. Lett. B 805 (2020) 135425

m_H = 125.78 ± 0.18 (stat) ± 0.18 (syst) GeV



JHEP 11 (2017) 047

m_H = 125.26 ± 0.20 (stat) ± 0.08 (syst) GeV

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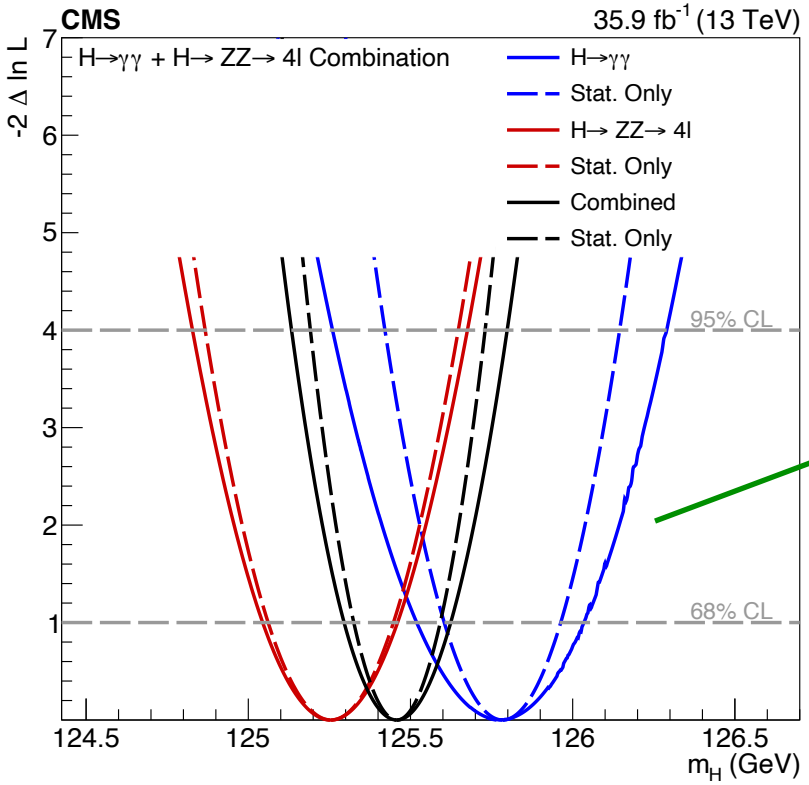
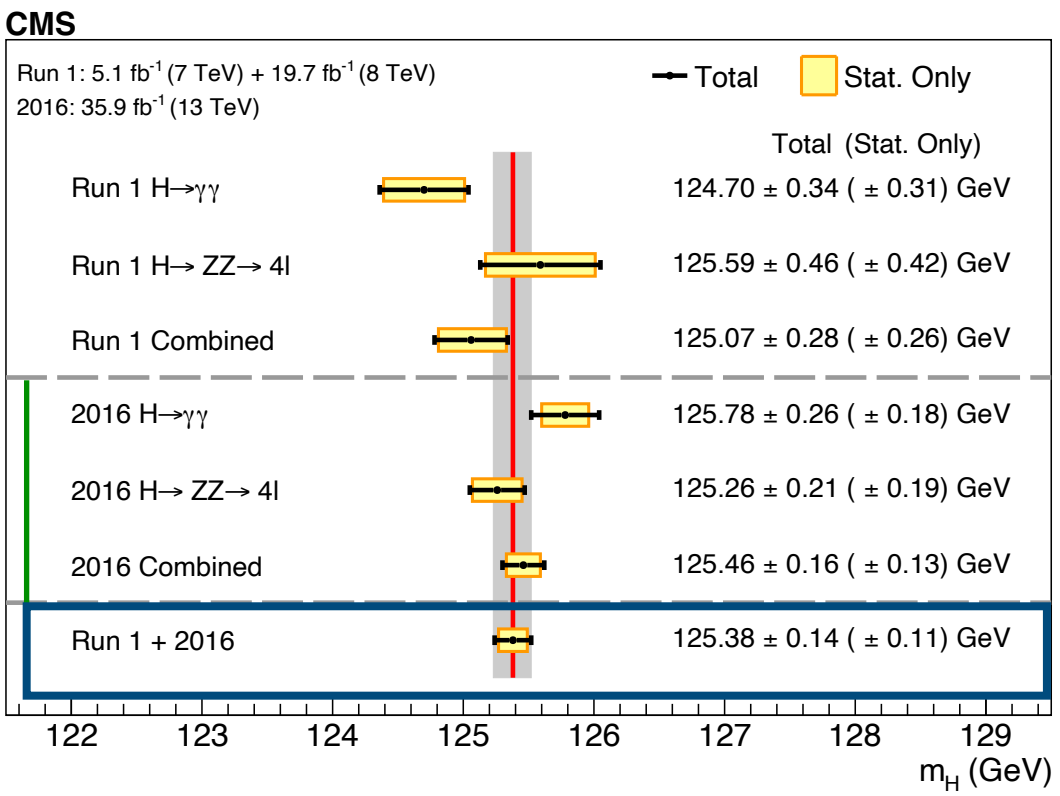
Higgs boson mass measurement





Combination of H➔ZZ and H➔γγ with 2016 data

Combining Run 1 & 2016 data:
m_H = 125.38 ± 0.14 GeV

0.11% precision (compare with previous most sensitive measurement: 0.2% precision)

Coupling combination: ingredients

- Combination of dedicated analyses of main production and decay channels
  - Most production x decay channels included
- Using partial Run 2 data set
  - 137 fb^{-1} = 2016, 2017 and 2018 (full Run 2)
  - 77.4 fb^{-1} = 2016+2017
  - 35.9 fb^{-1} = 2016

	H→γγ	H→ZZ	H→WW	H→ττ	H→bb	H→μμ
ggH	77.4 fb^{-1}	137 fb^{-1}	35.9 fb^{-1}	77.4 fb^{-1}	35.9 fb^{-1}	35.9 fb^{-1}
qqH	77.4 fb^{-1}	137 fb^{-1}	35.9 fb^{-1}	77.4 fb^{-1}	-	35.9 fb^{-1}
VH	-	137 fb^{-1}	35.9 fb^{-1}	35.9 - 77.4 fb^{-1}	77.4 fb^{-1}	-
ttH	77.4 fb^{-1}	77.4 fb^{-1}	77.4 fb^{-1}	77.4 fb^{-1}	77.4 fb^{-1}	-

Signal strength measurements

- Signal strength modifiers μ scale cross sections and branching ratios relative to the SM:

$$\mu_i = \frac{\sigma_i}{\sigma_i^{\mathrm{SM}}} \qquad \mu^f = \frac{\mathrm{BR}^f}{\mathrm{BR}^f_{\mathrm{SM}}} \qquad \mu_i^f = \frac{\sigma_i \cdot \mathrm{BR}^f}{(\sigma_i \cdot \mathrm{BR}^f)_{\mathrm{SM}}} = \mu_i \times \mu^f$$

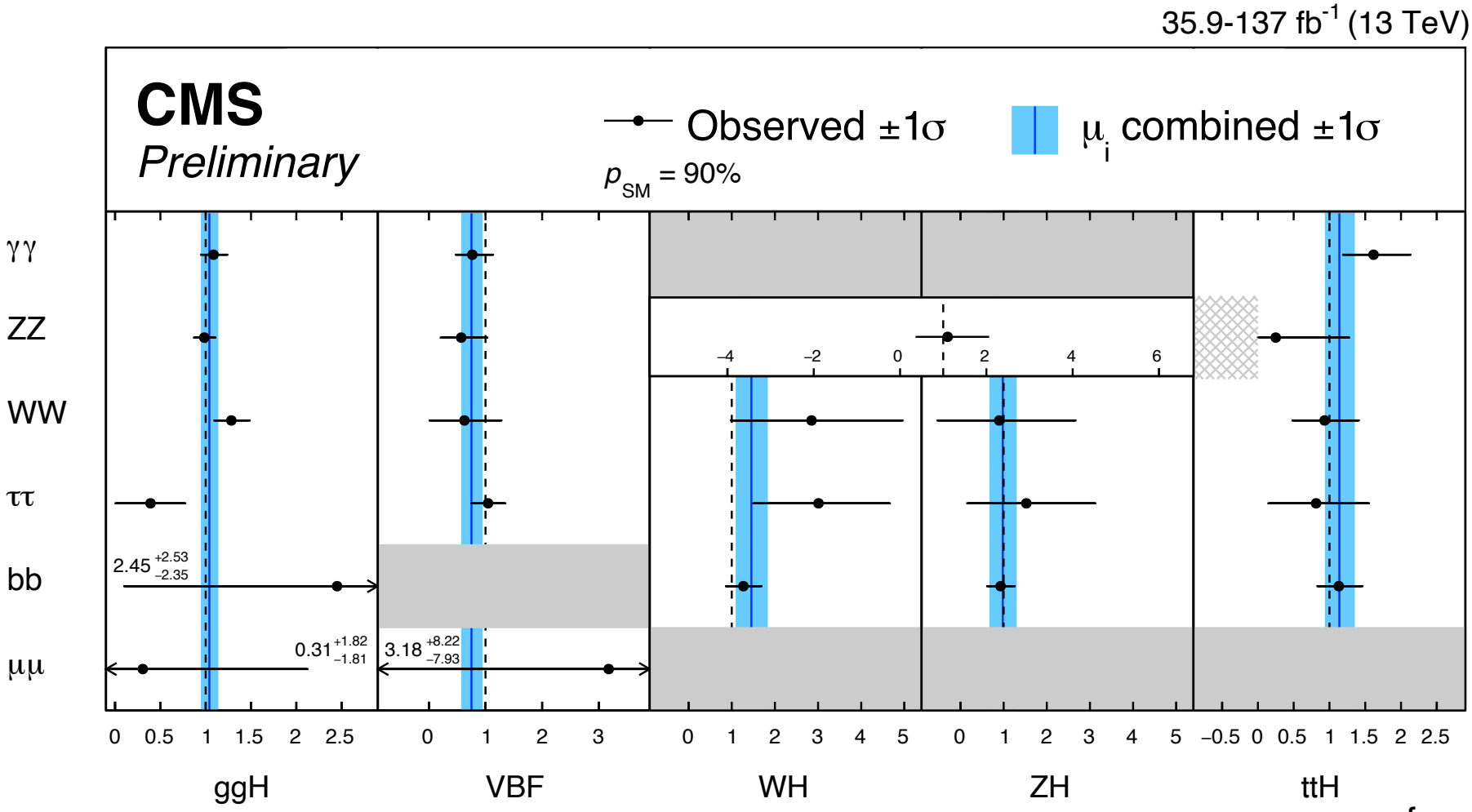
- Defining a signal strength modifier for all production processes and decay modes together:

$$\mu = 1.02^{+0.07}_{-0.06} = 1.02 \pm 0.04\ (\text{theory}) \pm 0.04\ (\text{exp.}) \pm 0.04\ (\text{stat.})$$

  - **~25% improvement in relative precision compared to the 2016-only CMS combination**

$$\mu = 1.17^{+0.10}_{-0.10} = 1.17^{+0.06}_{-0.06}\ (\text{stat.})\ ^{+0.06}_{-0.05}\ (\text{sig. th.})\ ^{+0.06}_{-0.06}\ (\text{other syst.})$$

Signal strength per production and decay mode



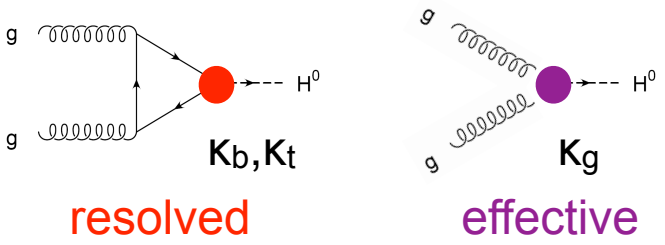
Good agreement with SM expectation; already have very precise measurements in some (production x decay channels)

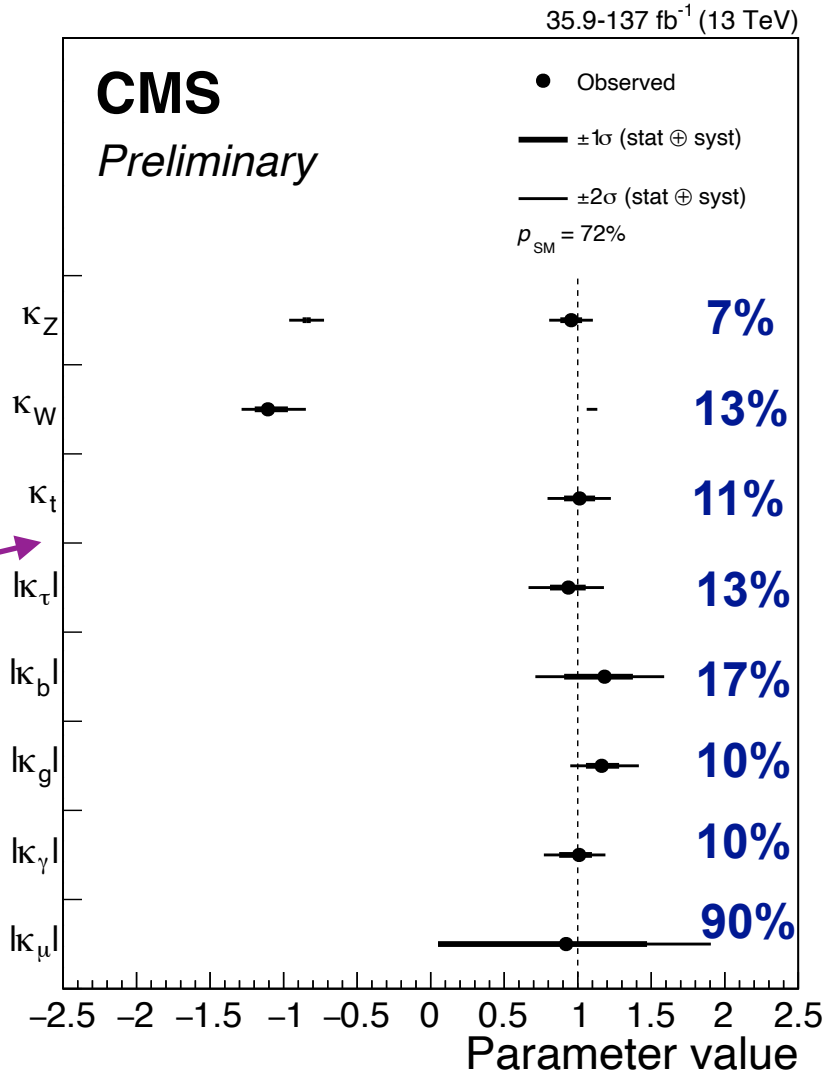
Coupling modifiers (κ)

- Coupling modifiers ➔ parameterisation of inclusive production and decay rates

$$\kappa_j^2 = \frac{\sigma_j}{\sigma_j^{SM}} \qquad \kappa_j^2 = \frac{\Gamma^j}{\Gamma_{SM}^j}$$

- Effective vertices or resolving the loops in production & decay modes, e.g.:





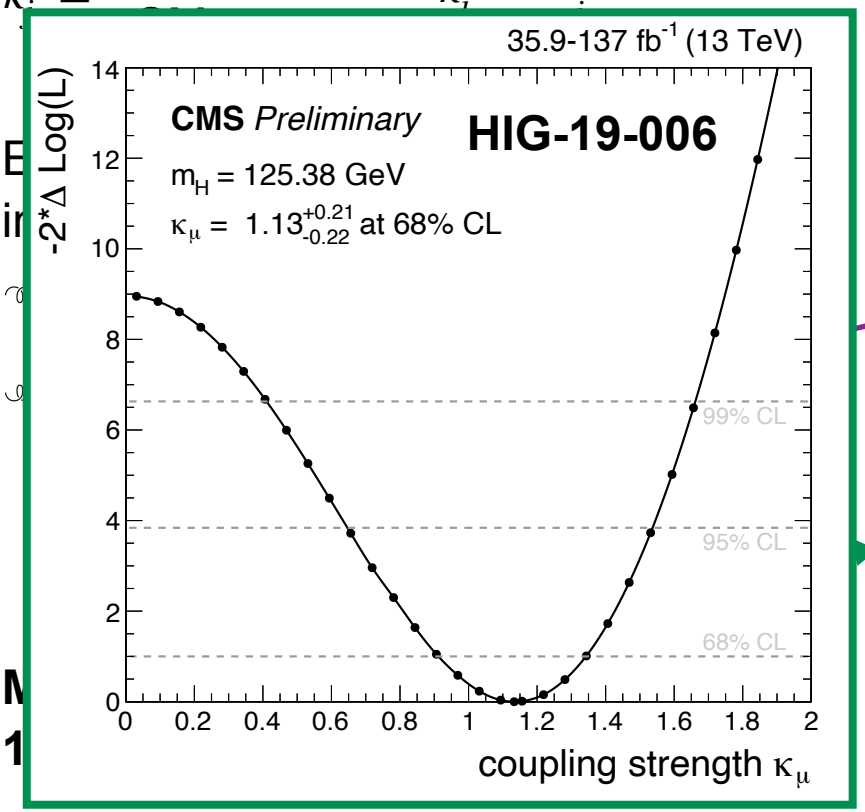
- **Measure most couplings to 10-20% precision**

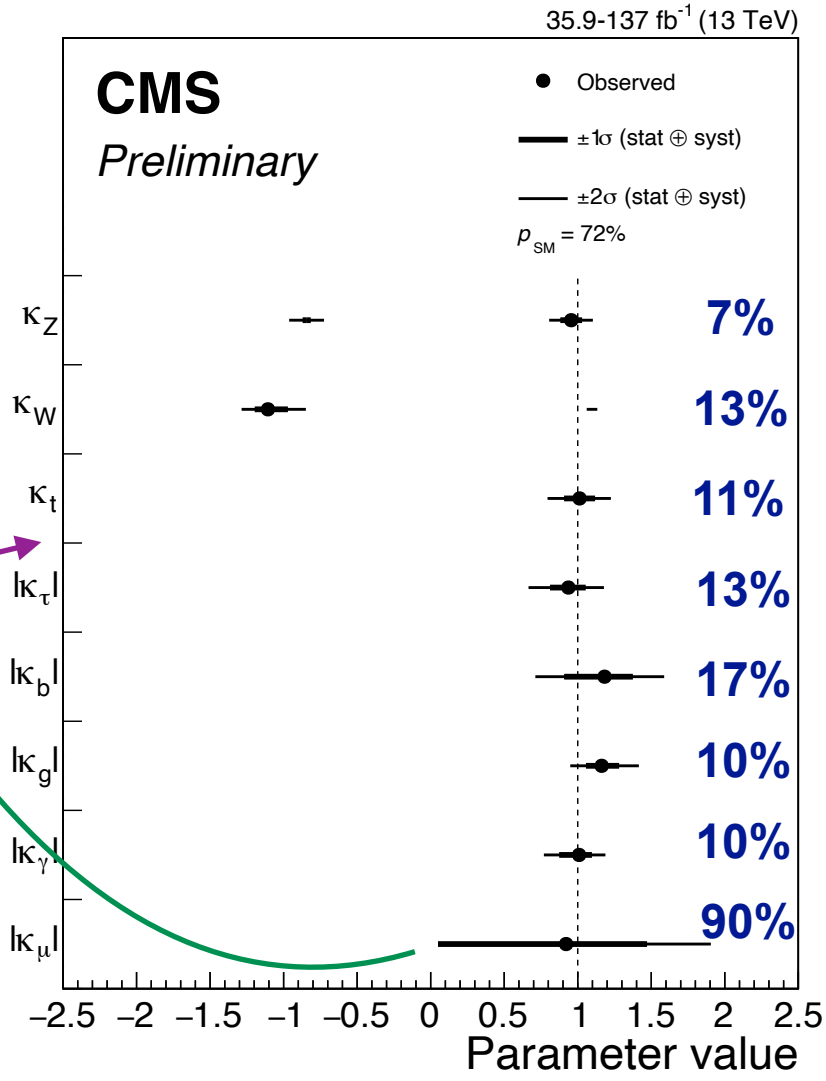
Coupling modifiers (κ)

- Coupling modifiers ➔ parameterisation of inclusive production and decay rates

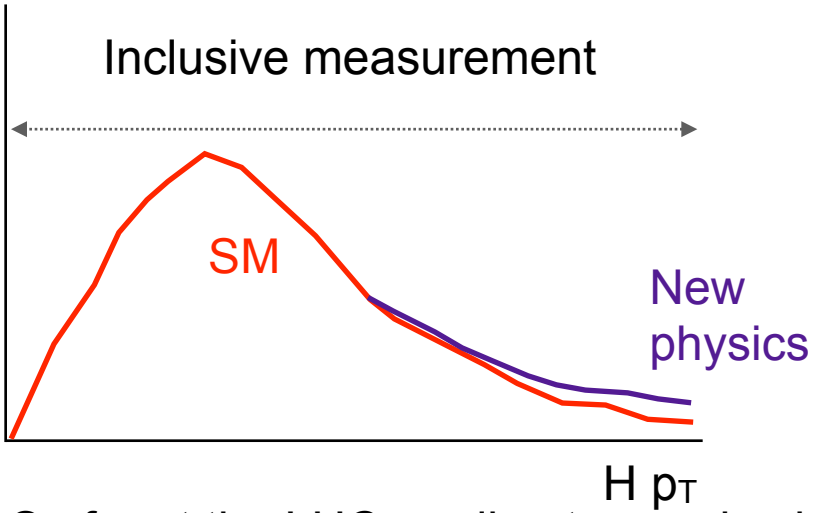
$$\kappa_j^2 = \frac{\sigma_j}{\sigma_j^{SM}} \qquad \kappa_j^2 = \frac{\Gamma^j}{\Gamma^{j\,SM}}$$

- E
- M





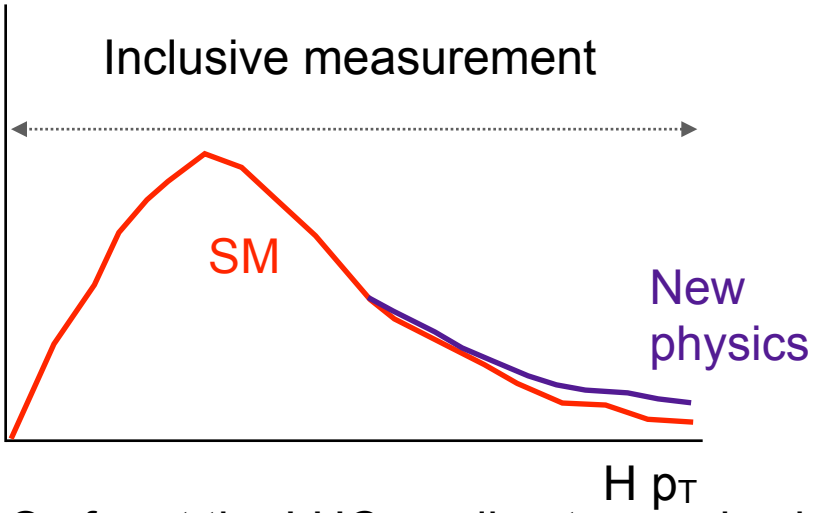
Effective field theory in Higgs physics

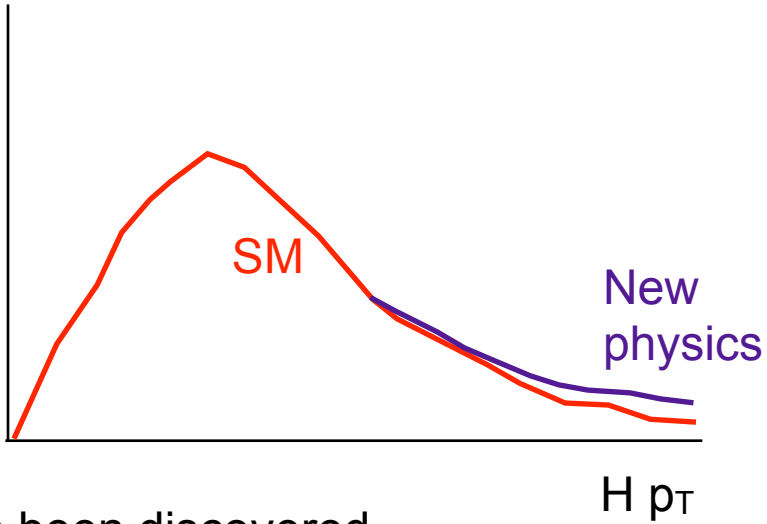


- So far at the LHC no direct new physics has been discovered
- Using SM particles to learn about new physics at very high energy scales? ➔ Effective field theory:

$$\mathcal{L}_{\mathrm{HEL}} = \mathcal{L}_{\mathrm{SM}} + \sum_j \mathcal{O}_j f_j / \Lambda^2$$

Effective field theory in Higgs physics





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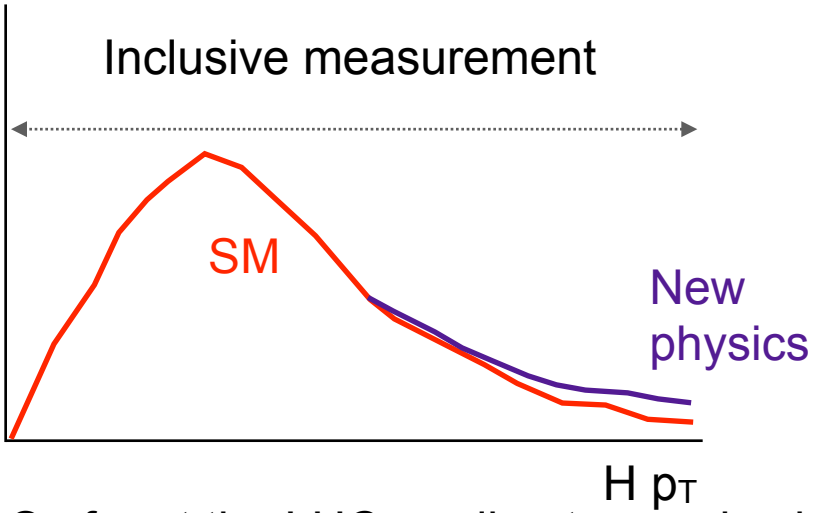

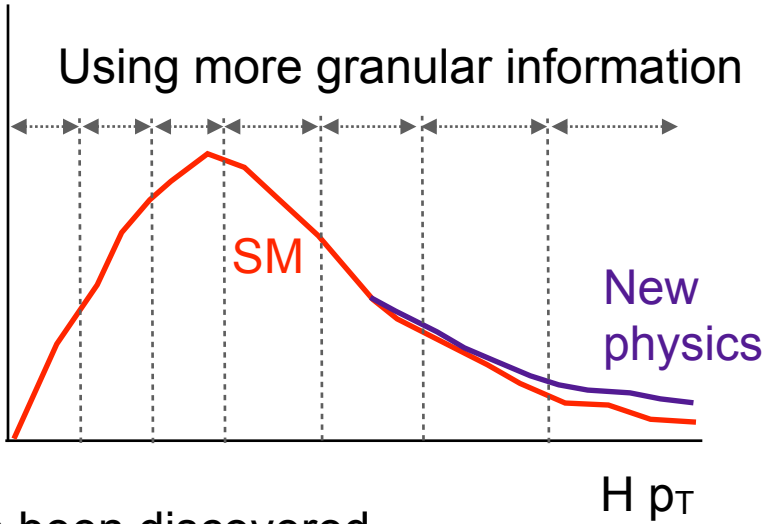

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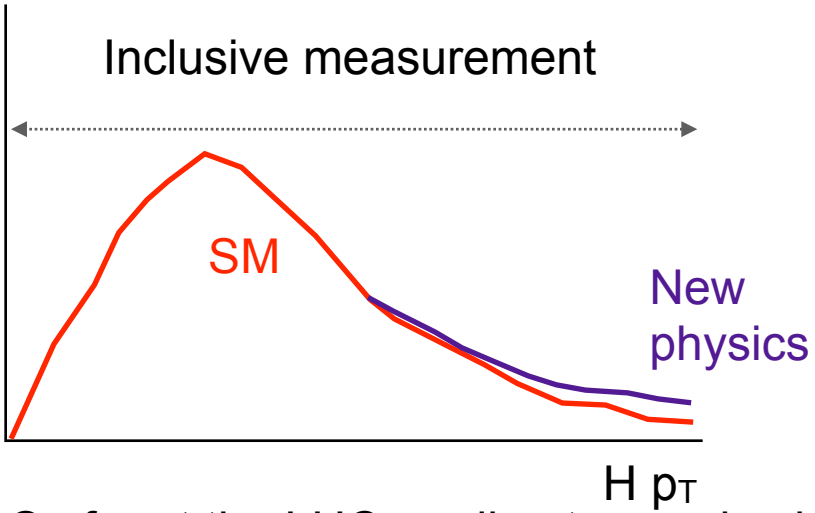
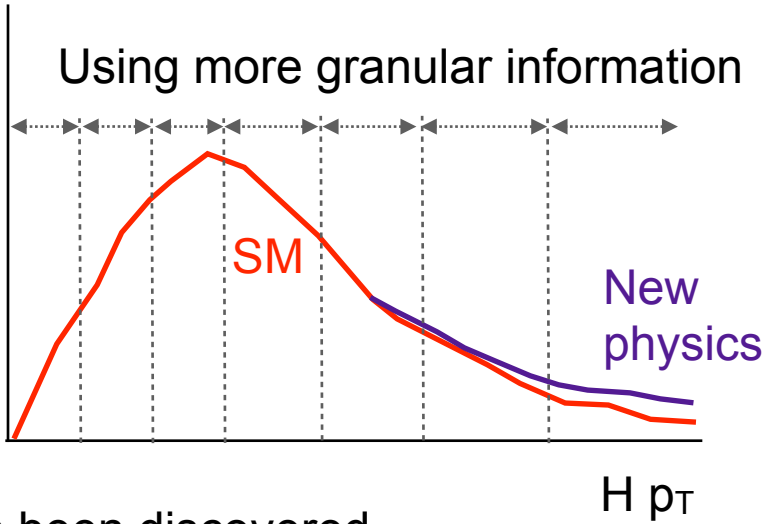
Effective field theory in Higgs physics





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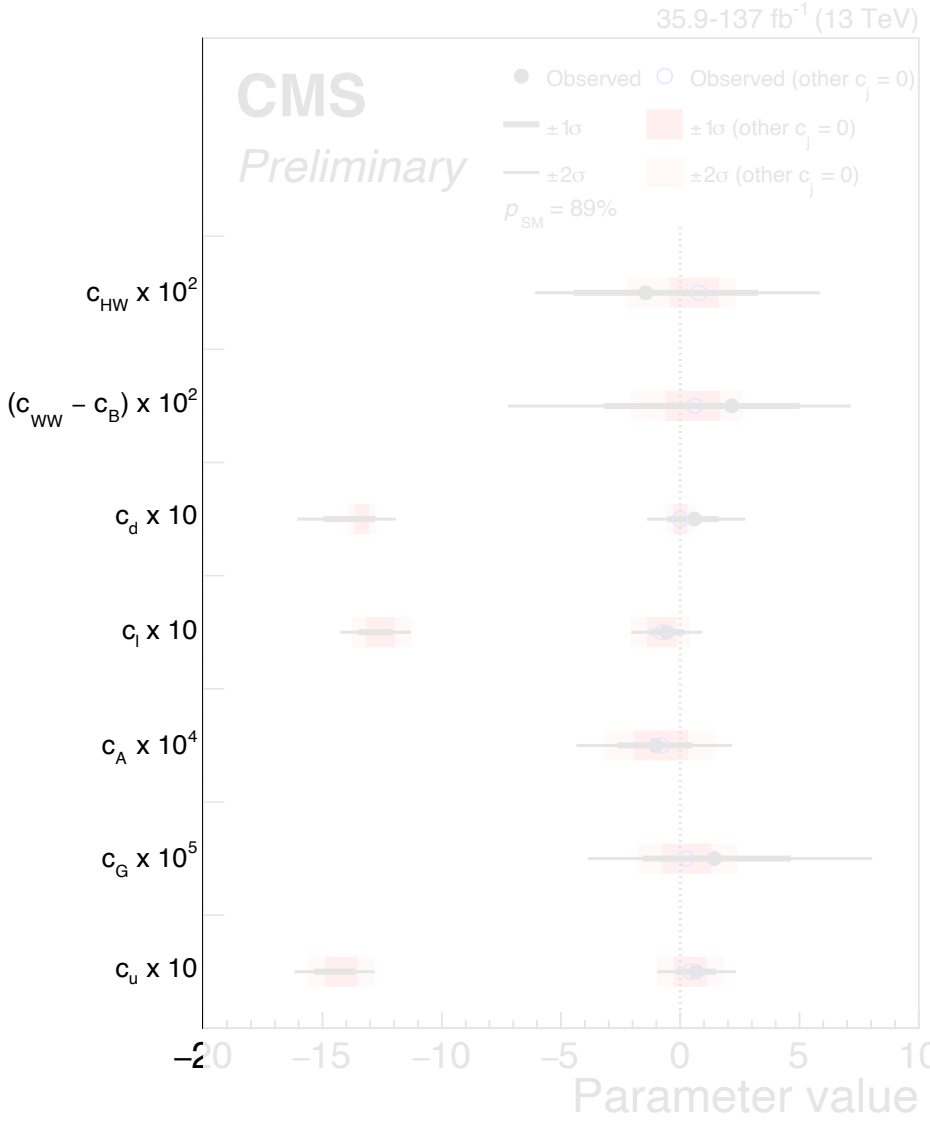
For interpretation presented here : use more granular information in form of STXS categorisation [*] (mix of STXS stage 0, 1, 1.1). See talk by Savvas (after this) for a direct approach.

[*] Method as described in https://cds.cern.ch/record/2673969

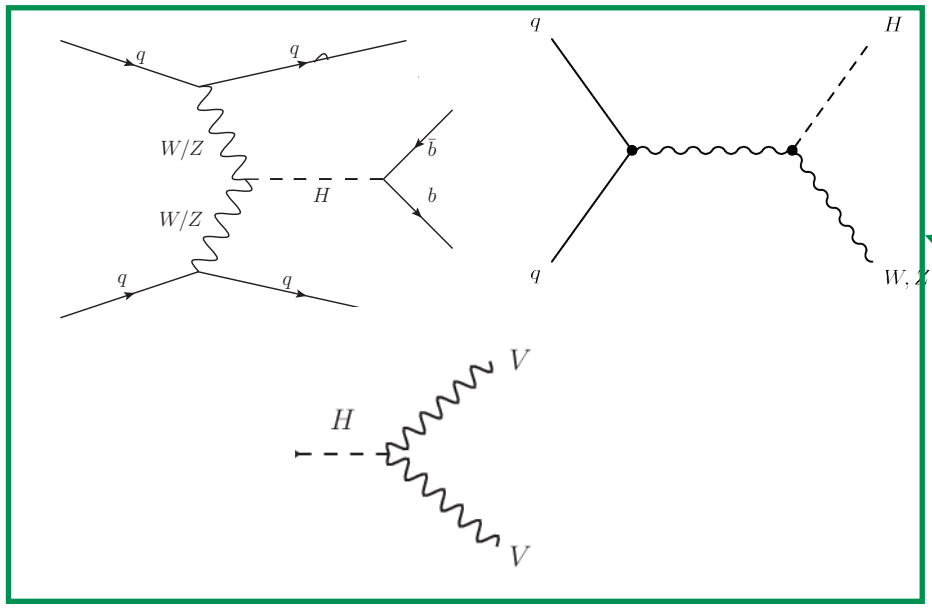
STXS → EFT

$$\sigma_i^{\text{EFT}} = \sigma_i^{\text{SM}} + \sigma_i^{\text{int}} + \sigma_i^{\text{BSM}}$$

$$\text{scaling}_i(c_j) = \frac{\sigma_i^{\text{EFT}}}{\sigma_i^{\text{SM}}} = 1 + \Sigma_j A_j c_j + \Sigma_{jk} B_{jk} c_j c_k$$



STXS → EFT



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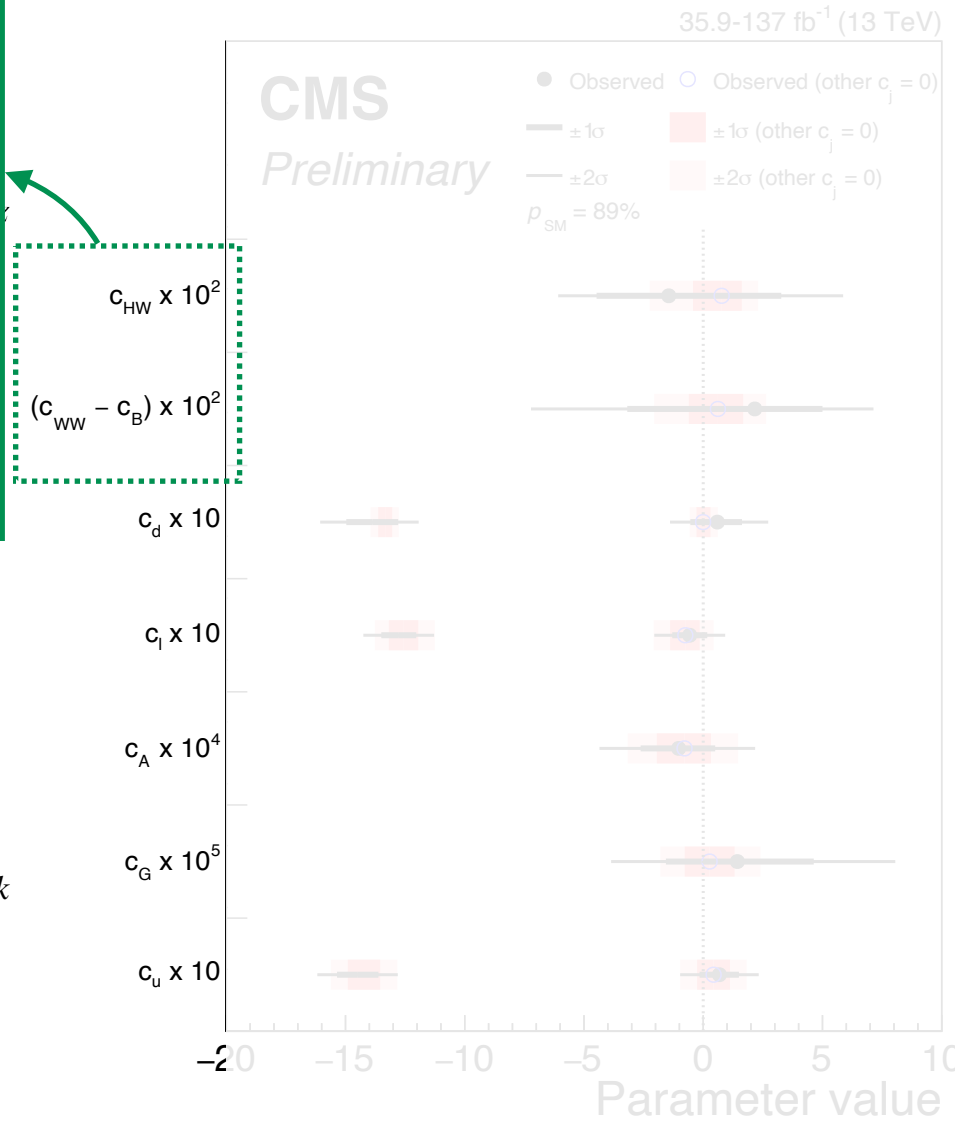
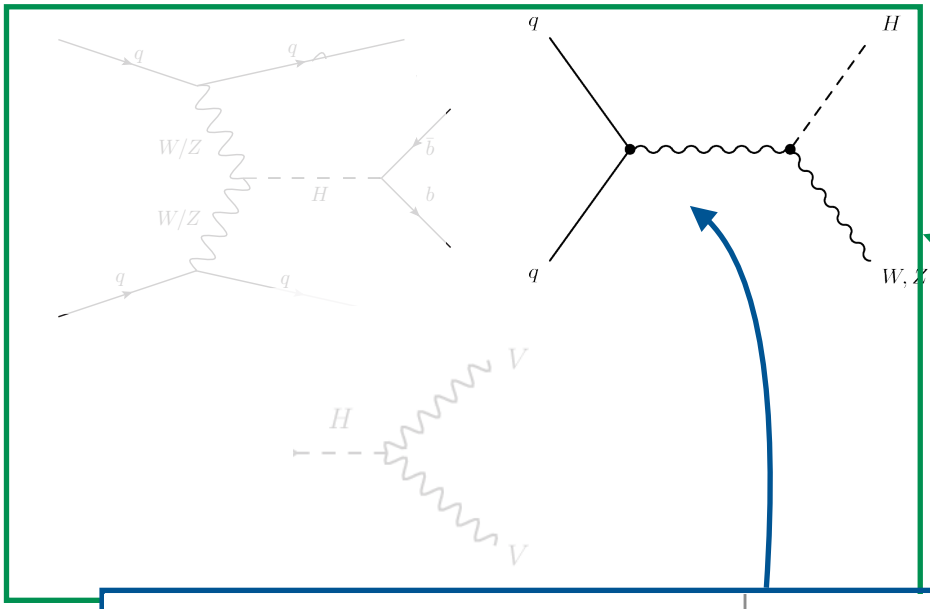
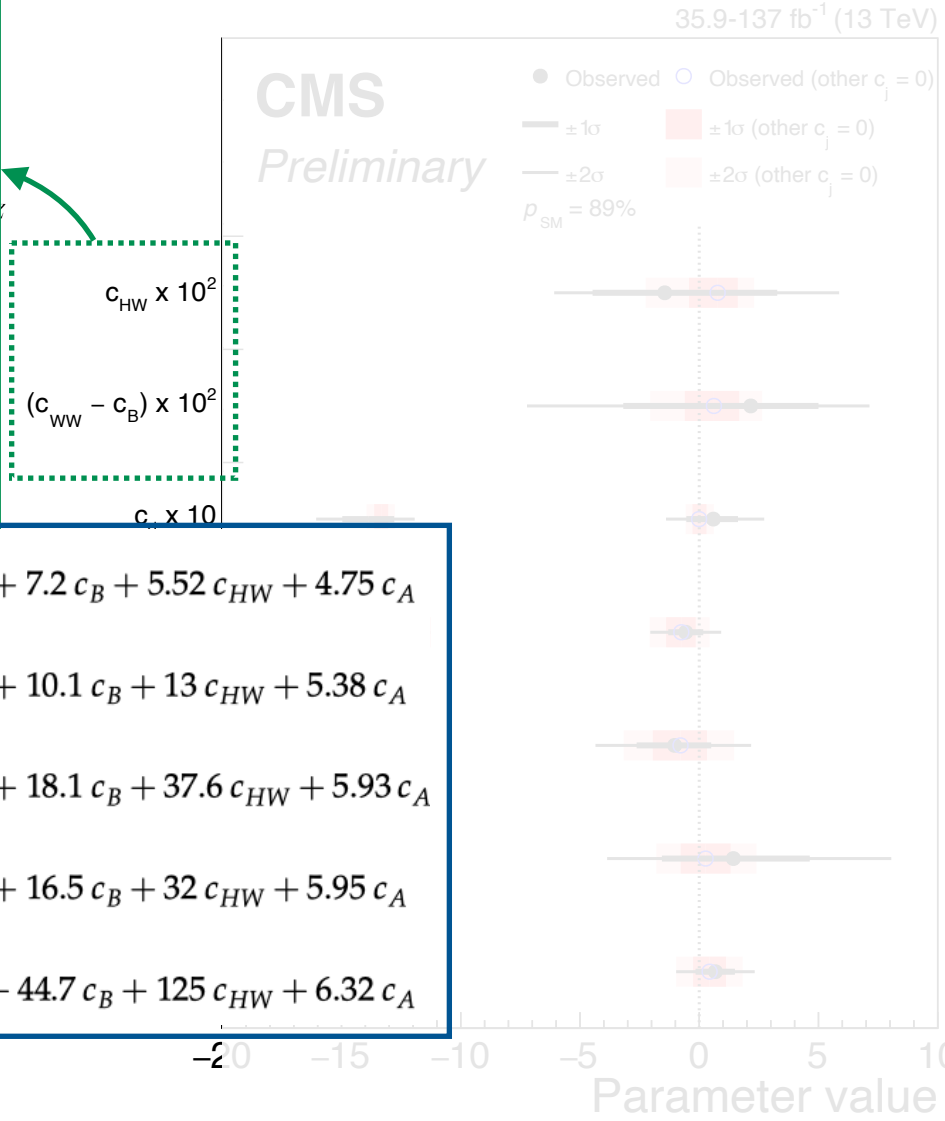


STXS → EFT



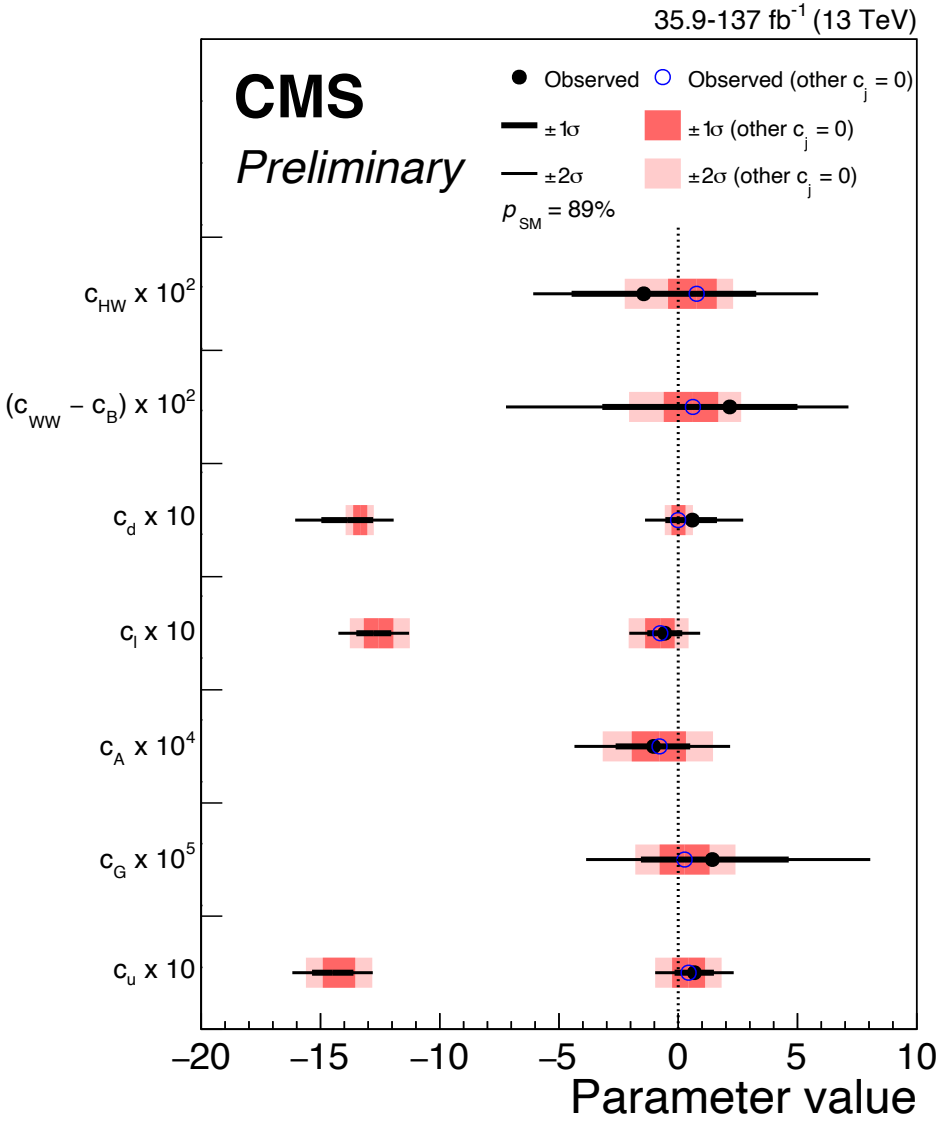


$qq \to H\ell\ell$ ($p_T^V < 75$ GeV)	$25.7\, c_{WW} + 7.2\, c_B + 5.52\, c_{HW} + 4.75\, c_A$
$qq \to H\ell\ell$ ($75 \le p_T^V < 150$ GeV)	$35.5\, c_{WW} + 10.1\, c_B + 13\, c_{HW} + 5.38\, c_A$
$qq \to H\ell\ell$ (0-jet, $150 \le p_T^V < 250$ GeV)	$62.2\, c_{WW} + 18.1\, c_B + 37.6\, c_{HW} + 5.93\, c_A$
$qq \to H\ell\ell$ (≥1-jet, $150 \le p_T^V < 250$ GeV)	$56.9\, c_{WW} + 16.5\, c_B + 32\, c_{HW} + 5.95\, c_A$
$qq \to H\ell\ell$ ($p_T^V \ge 250$ GeV)	$151\, c_{WW} + 44.7\, c_B + 125\, c_{HW} + 6.32\, c_A$

sca

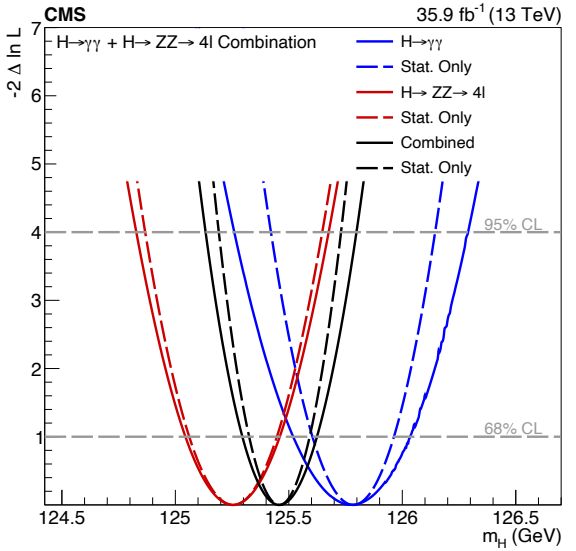
EFT interpretation

- Consider 7 coefficients of HEL affecting the Higgs sector
  - CP-violating operators ignored
- SM expectation: coefficients are 0
- **Good agreement** with the SM expectation

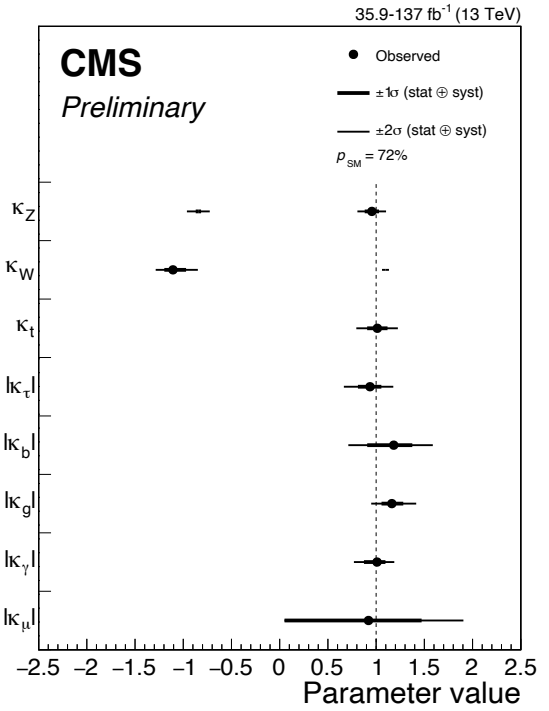


Summary and outlook

- Presented results on combined measurements of Higgs boson properties from CMS:
  - Higgs boson mass measured to **0.11% precision**
  - Signal strength measurements & coupling modifiers
  - Interpretation of STXS measurements in the EFT framework



- **Combined coupling measurements in agreement with SM expectation so far**
  - Very precise measurements already available in some channels

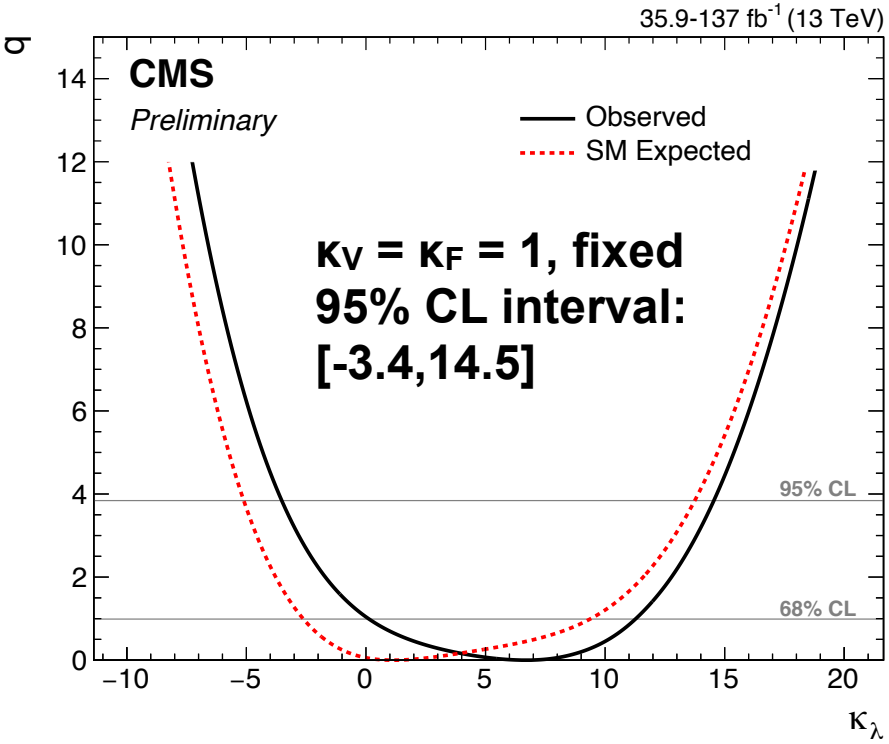


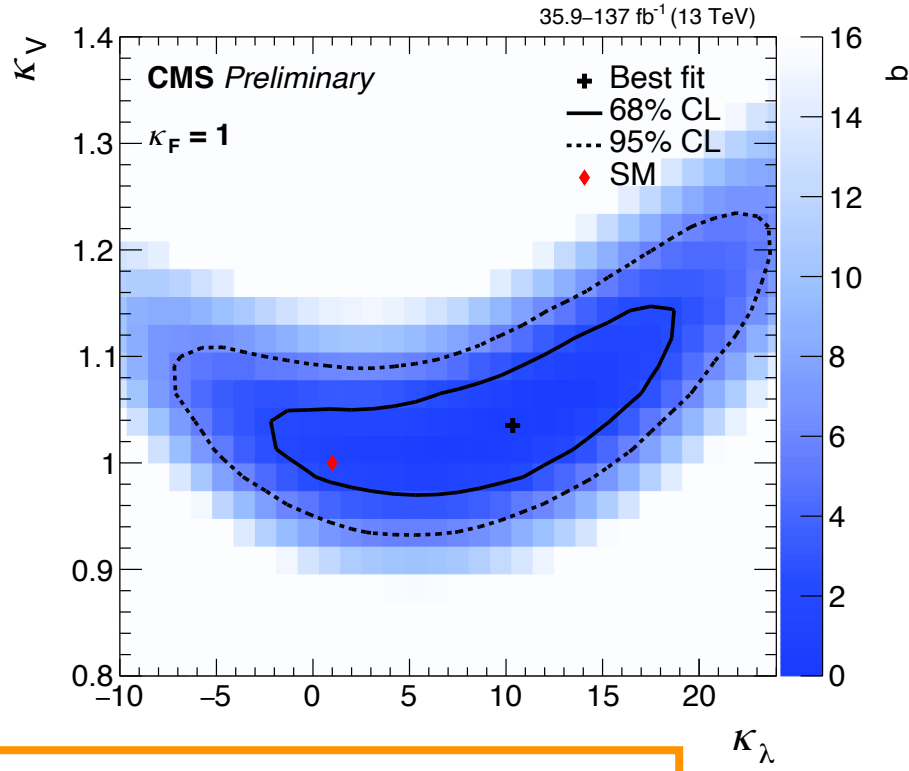
- Expect even more precise results from full Run 2 combination and later a combination with ATLAS results: **stay tuned!**

Backup

Constraints on Higgs boson self-coupling

- Higgs boson self-coupling: $\kappa_\lambda = \lambda_{HHH}/\lambda_{SM}$. Can construct a three parameter model to parameterise deviations in the production- and decay rates from the SM expectation that depends on κ_λ, κ_V, κ_F (arXiv:1607.04251, arXiv:1709.08649)
- This model modifies **only** inclusive production- and decay rates

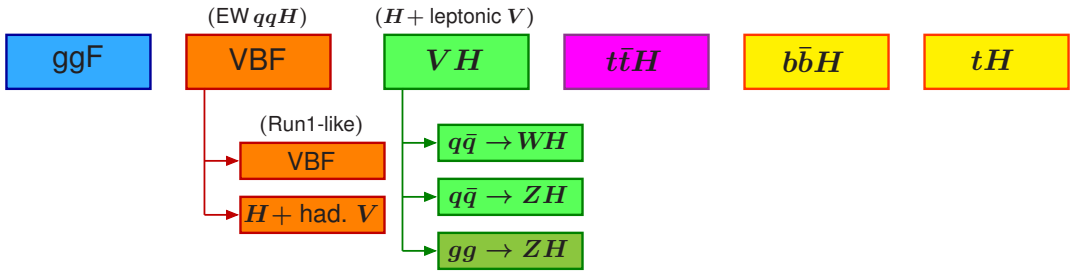




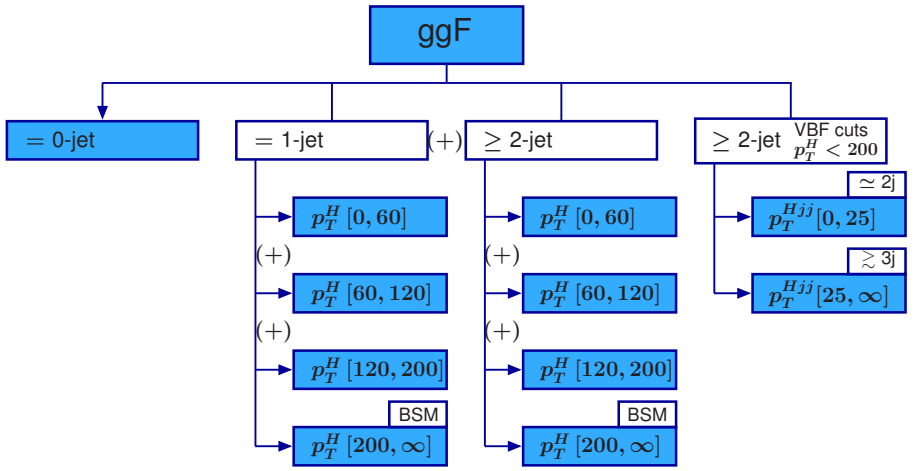
Sensitivity only with <u>stringent assumptions</u>
➔ **We will continue to need HH measurements**

STXS inputs

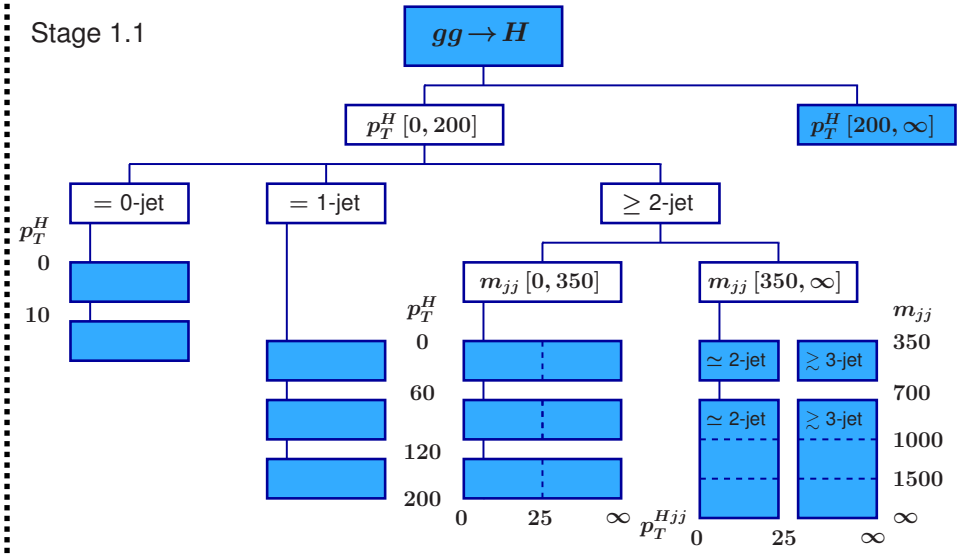
Mixture of data sets and ages = mixture of STXS stages



Stage 0
H➔WW, H➔bb, H➔μμ



Stage 1
H➔ZZ



Stage 1.1
H➔γγ H➔ττ