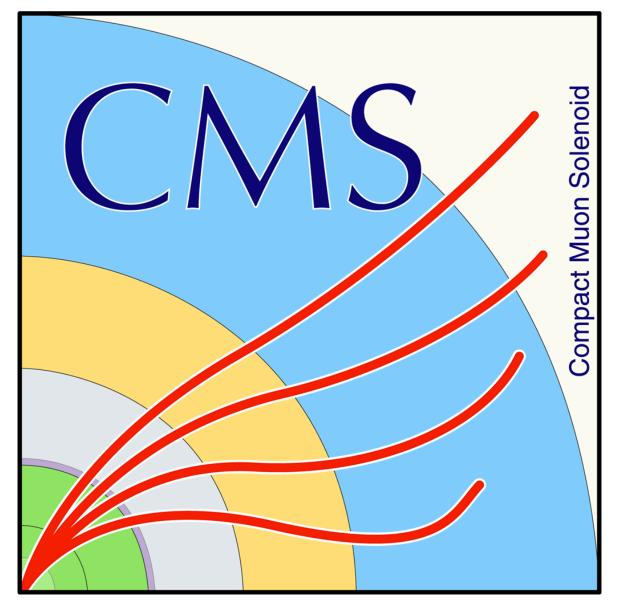
Link to ATLAS Slides













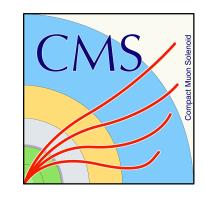
Chen Zhou University of Wisconsin



ATLAS-CMS Comparisons

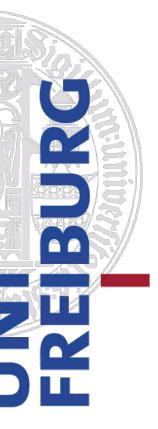
AILAS-UMS Comparisons

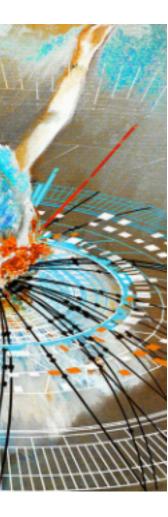
Karsten Köneke Universität Freiburg



Matteo Bonanomi LLR, Ecole Polytechnique, CNRS

21.09.2021









Inputs and Global µ

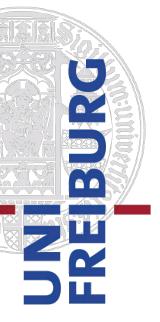
| Decey obernel | gg | F | VE | 3F | V | - | ttH- | нtН |
|---|--------------------------|-----|--------------------------|-----|--------------------------|-----|--------------------------|-----|
| Decay channel | ATLAS | CMS | ATLAS | CMS | ATLAS | CMS | ATLAS | CMS |
| $H \rightarrow \gamma \gamma$ | 139 | 77 | 139 | 77 | 139 | | 139 | 77 |
| $H \rightarrow ZZ^* \rightarrow 4\ell$ | 139 | 137 | 139 | 137 | 139 | 137 | 139 | 137 |
| $H \rightarrow WW^*$ | 361) | 36 | 361) | 36 | | 36 | | |
| $\mathbf{H} \rightarrow \mathbf{b}\mathbf{b}$ | | 36 | <311) | | 139 | 77 | 361) | 77 |
| $H \rightarrow \tau \tau$ | 361) | 77 | 361) | 77 | | 77 | | |
| ttH multilepton | | | | | | | 361) | 77 |
| $H \rightarrow \mu \mu$ | 139 ¹⁾ | 36 | 139 ¹⁾ | 36 | 139 ¹⁾ | | 139 ¹⁾ | |
| $H \rightarrow invisible$ | | | 139 ¹⁾ | | | | | |

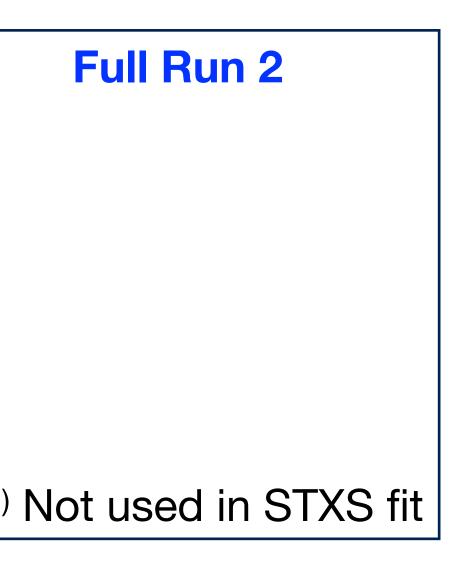
Global signal strength:

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

• ATLAS: $\mu = 1.06 \pm 0.07 = 1.06 \pm 0.04(\text{stat.}) \pm 0.03(\text{exp.})^{+0.05}_{-0.04}(\text{sig. th.}) \pm 0.02(\text{bkg. th.})$

Ligas Lupting 2021/0/15







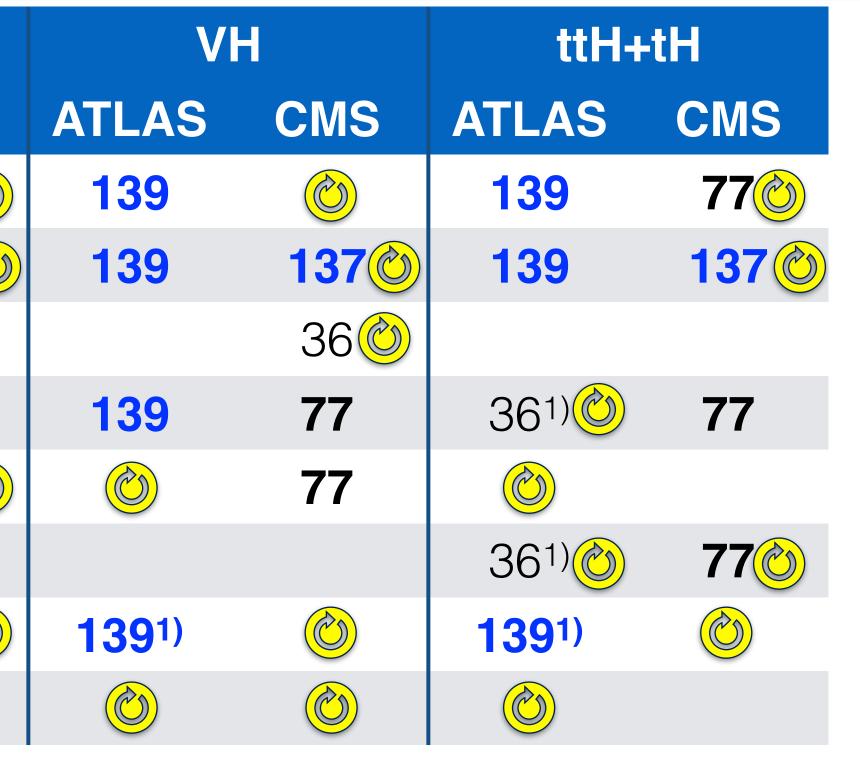


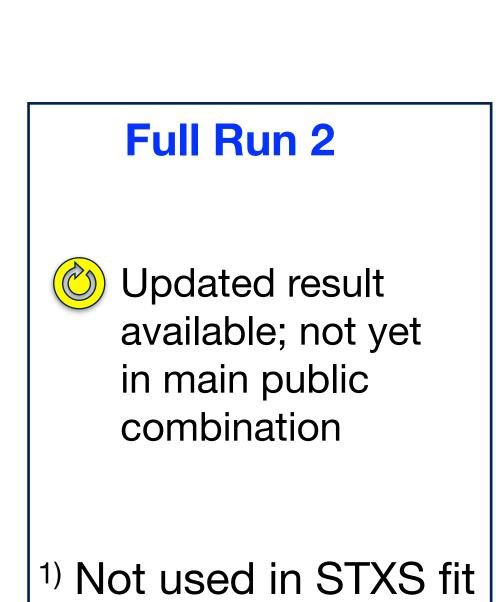
Inputs and Global µ

| Doooy oboppol | gg | F | VBF | | |
|---|--------------------------|------|--------------------------|------|--|
| Decay channel | ATLAS | CMS | ATLAS | CMS | |
| $H \rightarrow \gamma \gamma$ | 139 | 77 ⊘ | 139 | 77 ⊘ | |
| $H \rightarrow ZZ^* \rightarrow 4\ell$ | 139 | 137⊘ | 139 | 137⊘ | |
| $H \rightarrow WW^*$ | 36 ¹⁾ | 36 | 361) | 36 | |
| $\mathbf{H} \rightarrow \mathbf{b}\mathbf{b}$ | | 36 🙆 | <311) | | |
| $H \rightarrow \tau \tau$ | 36 ¹⁾ | 77 ⊘ | 36 ¹⁾ | 77 ⊘ | |
| ttH multilepton | | | | | |
| $H \rightarrow \mu \mu$ | 139 ¹⁾ | 36🙆 | 139 ¹⁾ | 36 🙆 | |
| $H \rightarrow invisible$ | | Ì | 139 ¹⁾ | | |

Global signal strength:

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





• ATLAS: $\mu = 1.06 \pm 0.07 = 1.06 \pm 0.04(\text{stat.}) \pm 0.03(\text{exp.})^{+0.05}_{-0.04}(\text{sig. th.}) \pm 0.02(\text{bkg. th.})$

Liggo Lupting 2021/0/15

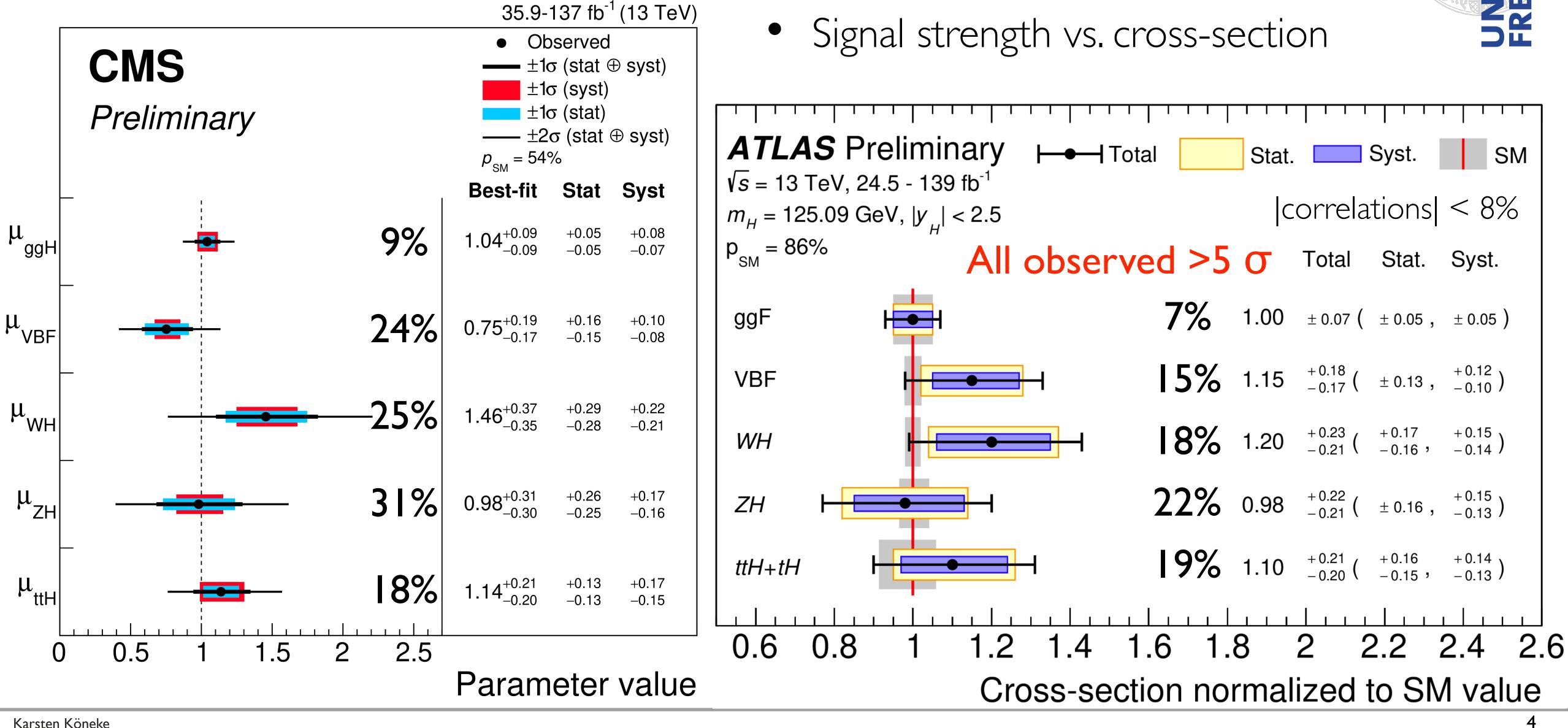






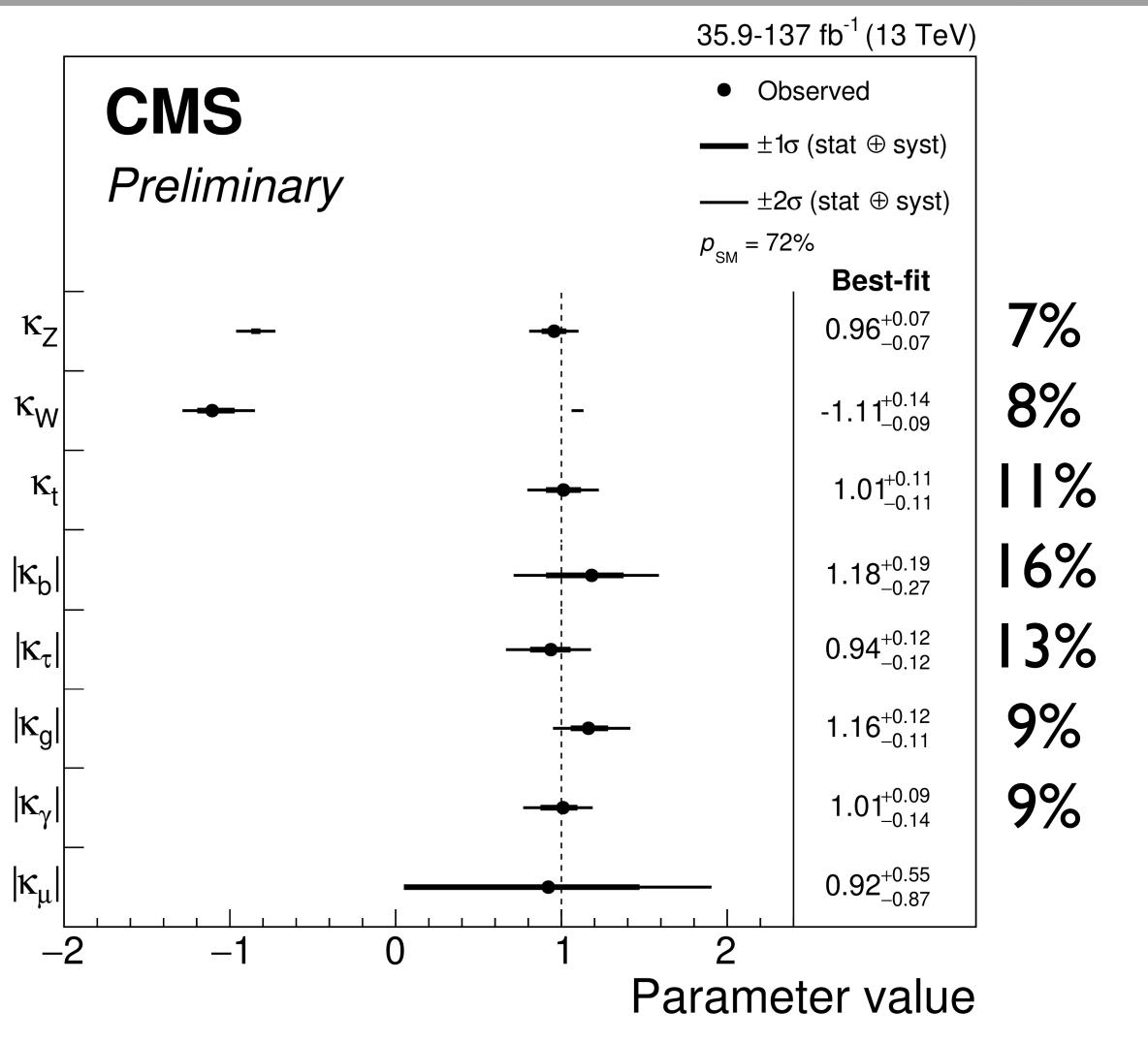


Production modes

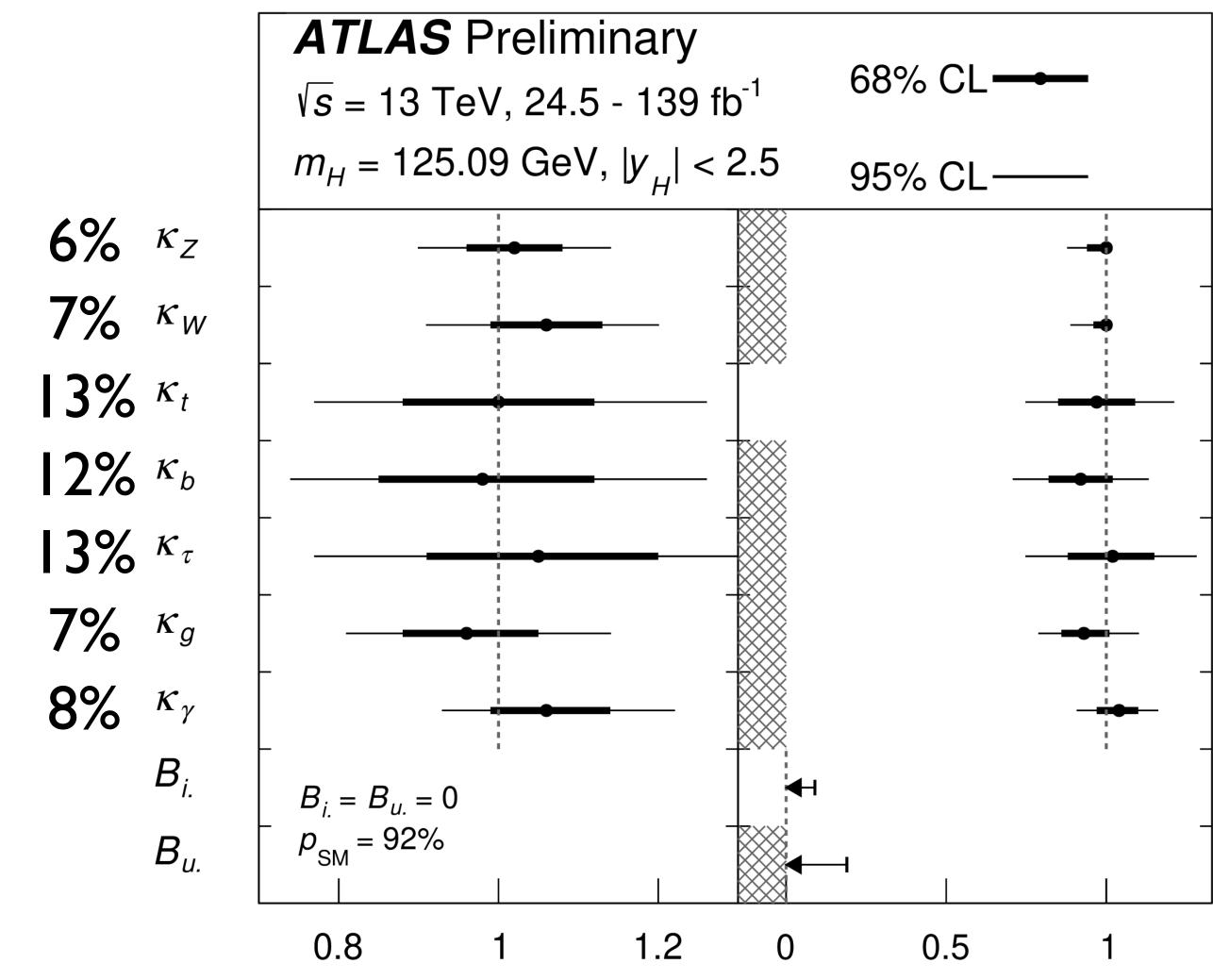






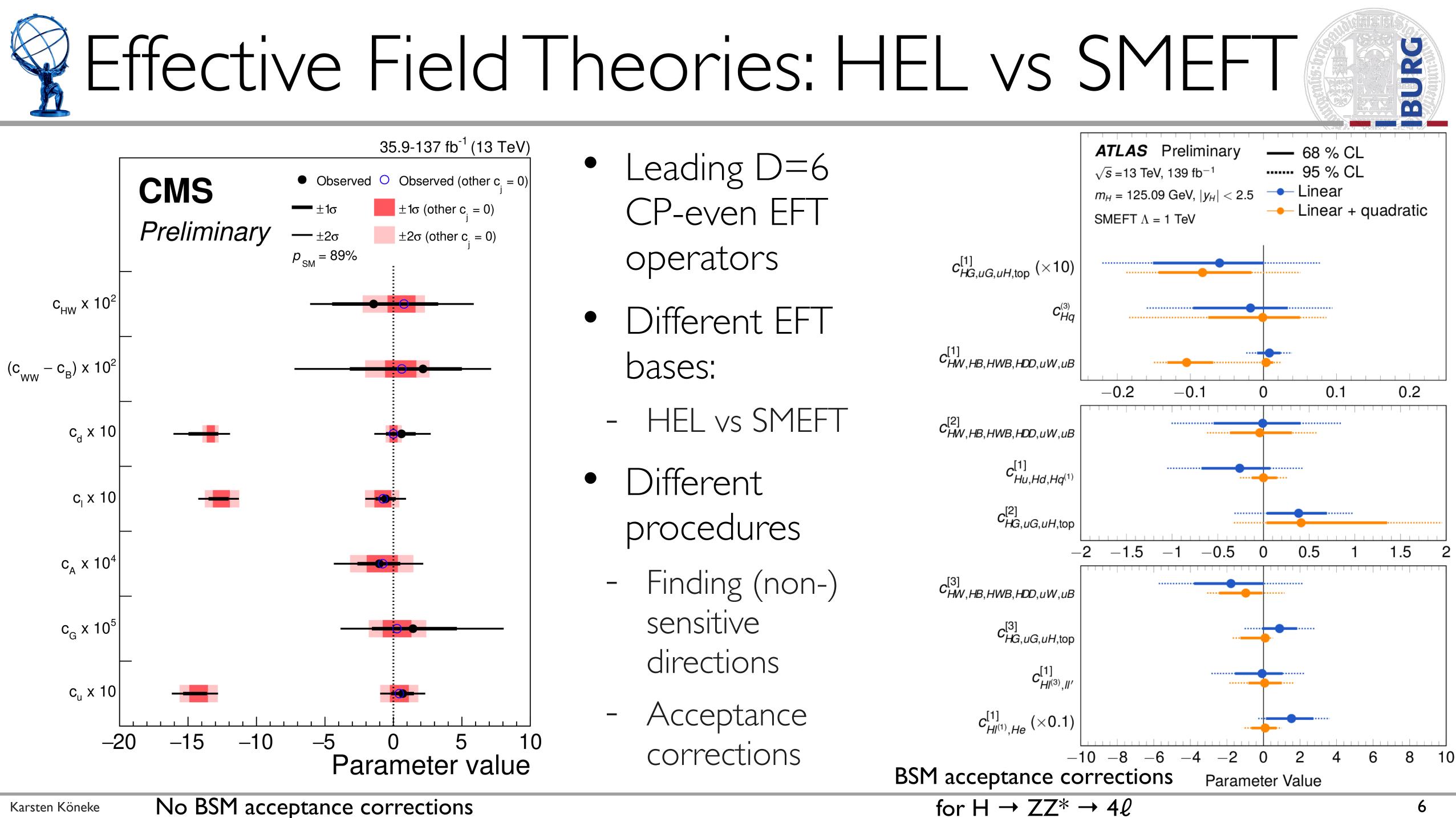


K Framework





5

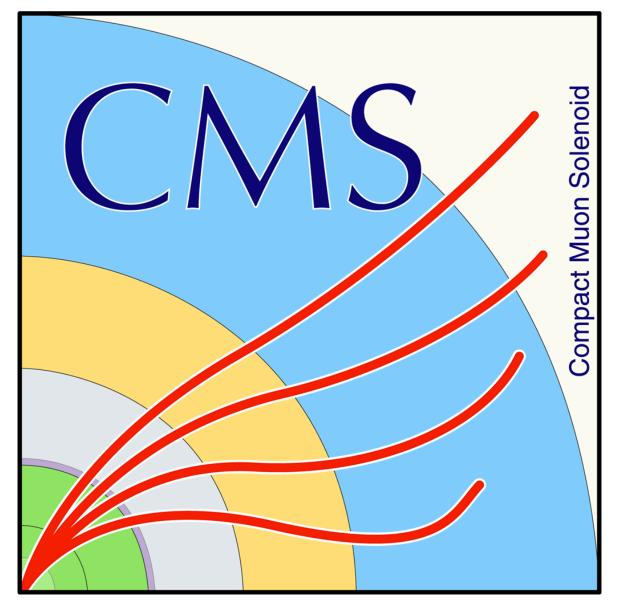


No BSM acceptance corrections

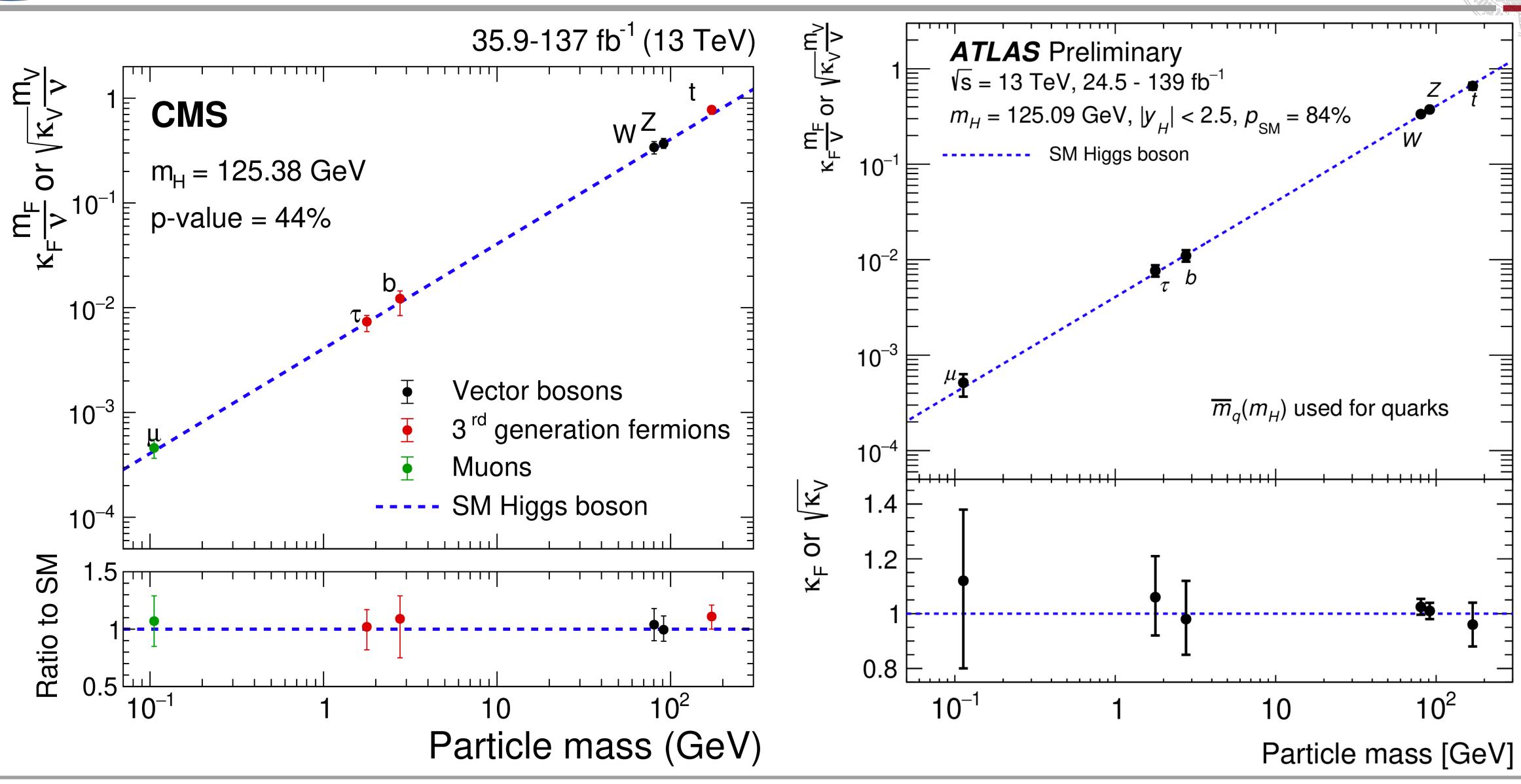
Link to ATLAS Slides











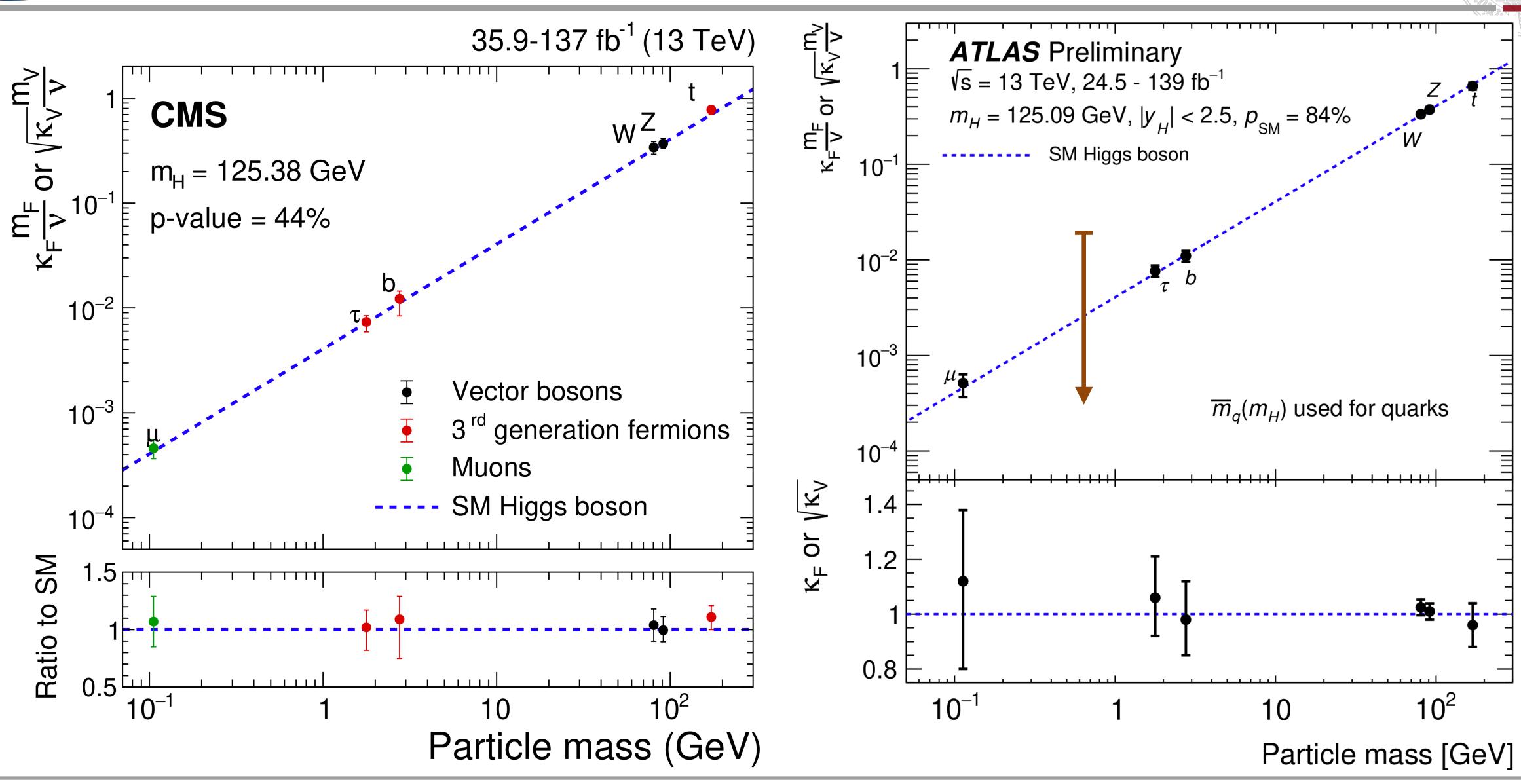
Karsten Köneke

K Framework









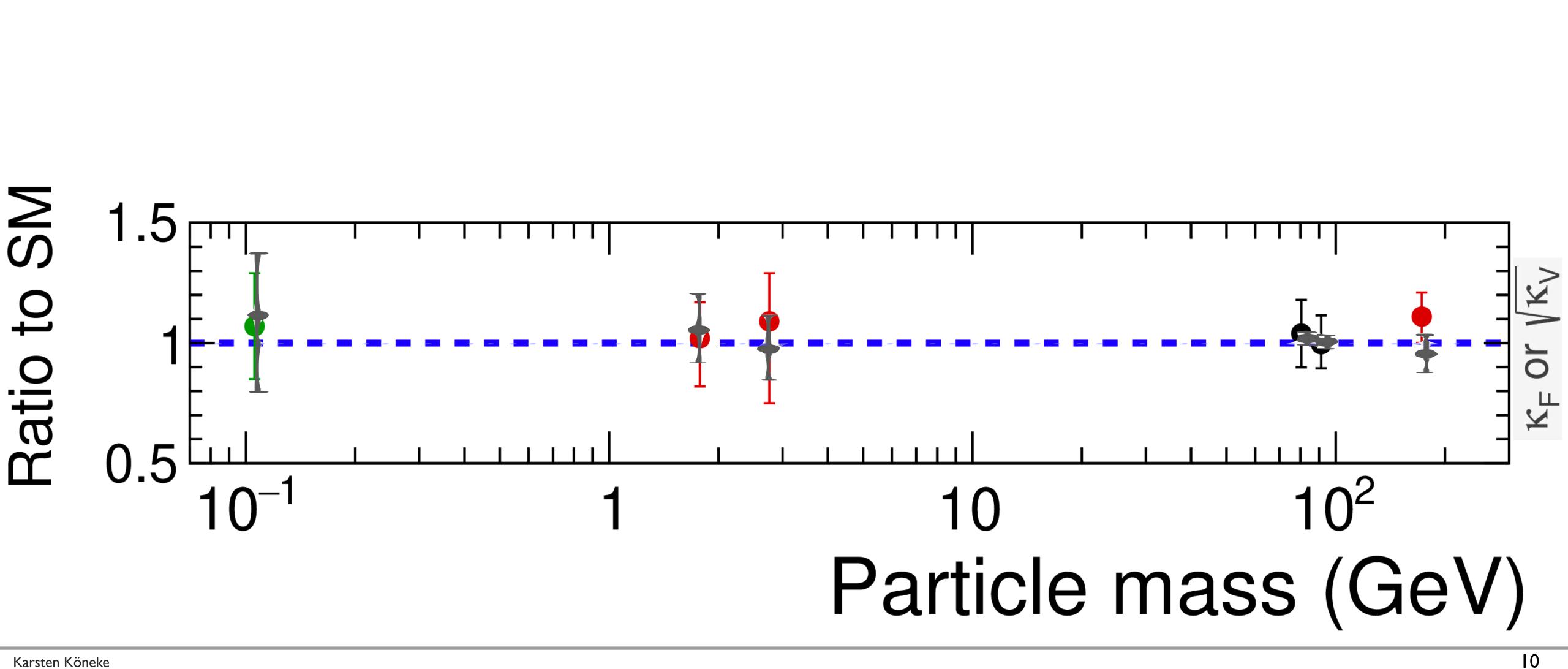
Karsten Köneke

K Framework

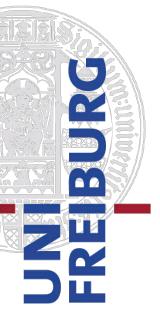








K Framework



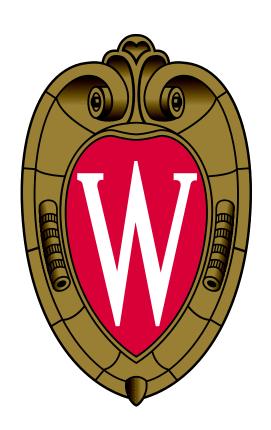




ATLAS Slides

ATLAS Higgs Combination

Chen Zhou (University of Wisconsin) on behalf of the ATLAS Collaboration

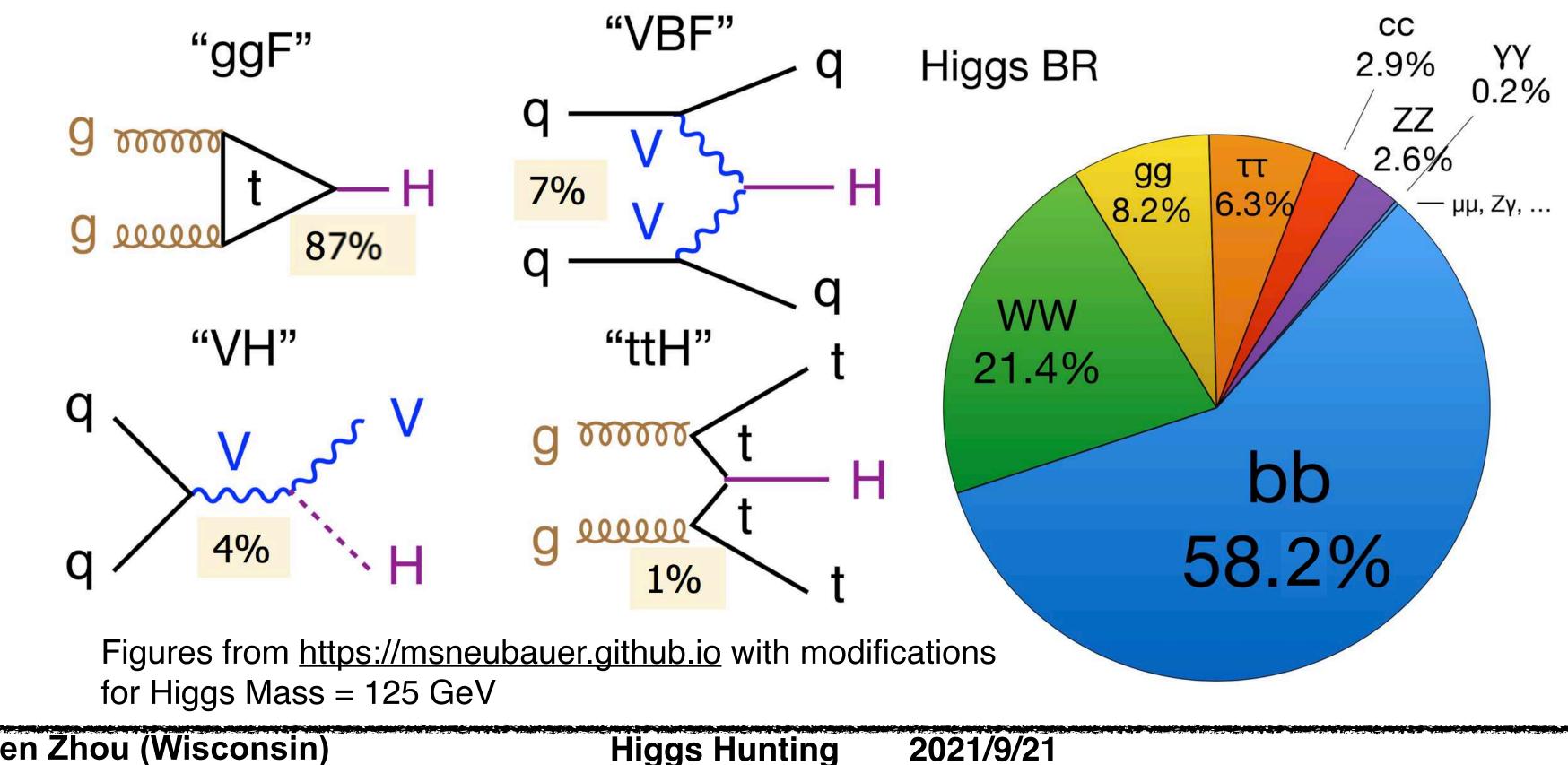


September 20-22, 2021 - Orsay-Paris Higgs Hunting Workshop



Introduction

- ullethave been performed
- ulletATLAS-CONF-2020-053, ATLAS-CONF-2019-032)



Chen Zhou (Wisconsin)

Higgs Hunting

Since the Higgs discovery by ATLAS and CMS in 2012, many Higgs property studies (mass, spin, parity, couplings, cross sections, etc.)

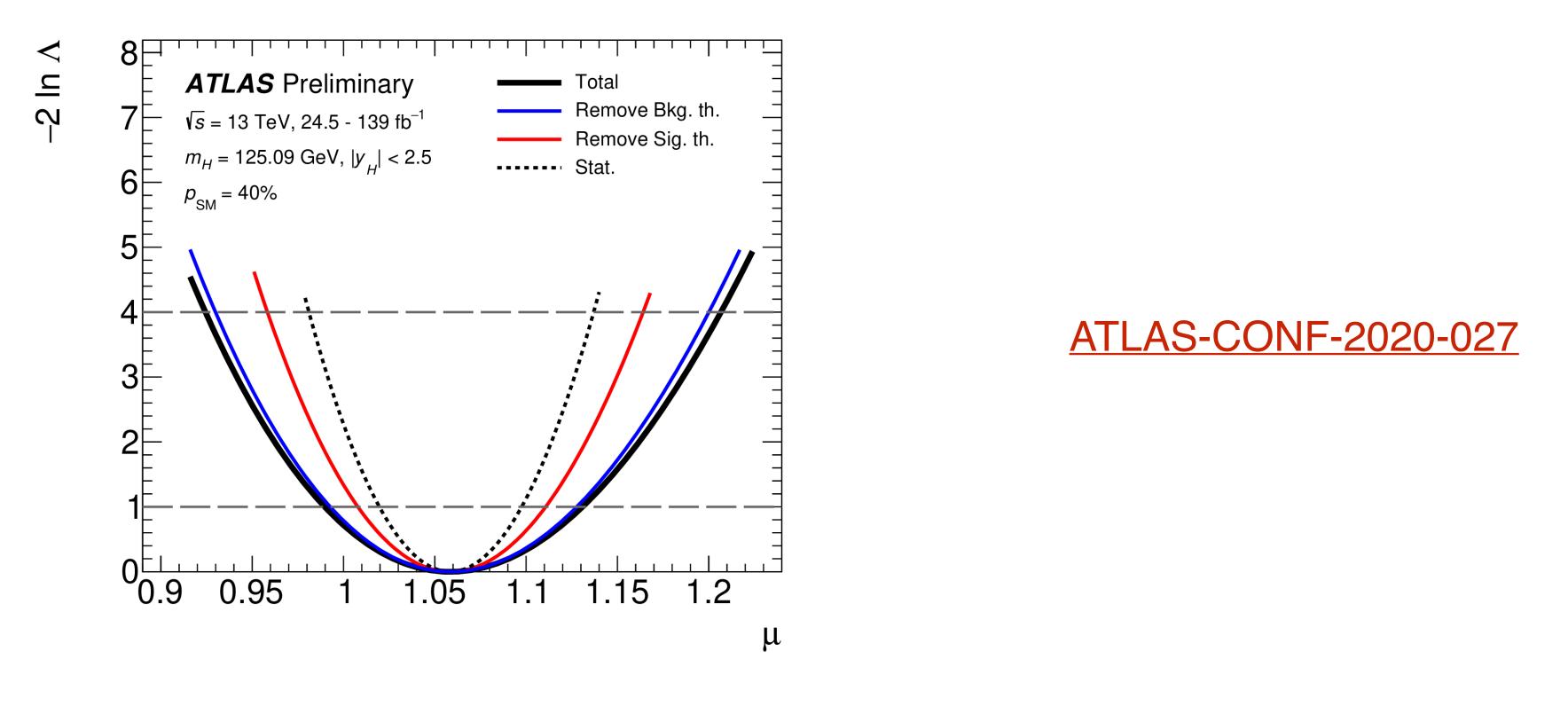
Today: combined measurements of Higgs boson using 13 TeV data collected with the ATLAS detector (ATLAS-CONF-2020-027,

Signal strength & production cross-section measurements

| | ggF | VBF | VH | ttH+tH |
|------|---------------------------|-----------------------------|---------------------------|------------------------------|
| Η→γγ | ✔ (139 fb ⁻¹) | ✔ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) |
| H→ZZ | ✓ (139 fb⁻¹) | ✓ (139 fb⁻¹) | ✓ (139 fb ⁻¹) | |
| H→WW | ✓ (36 fb ⁻¹) | ✓ (36 fb ⁻¹) | | ✓ (36-139 fb ⁻¹) |
| Н→тт | ✓ (36 fb ⁻¹) | ✓ (36 fb ⁻¹) | | |
| H→bb | | ✓ (25-31 fb ⁻¹) | ✓ (139 fb ⁻¹) | ✓ (36 fb⁻¹) |

✓: channel included in the combination

Inclusive signal strength

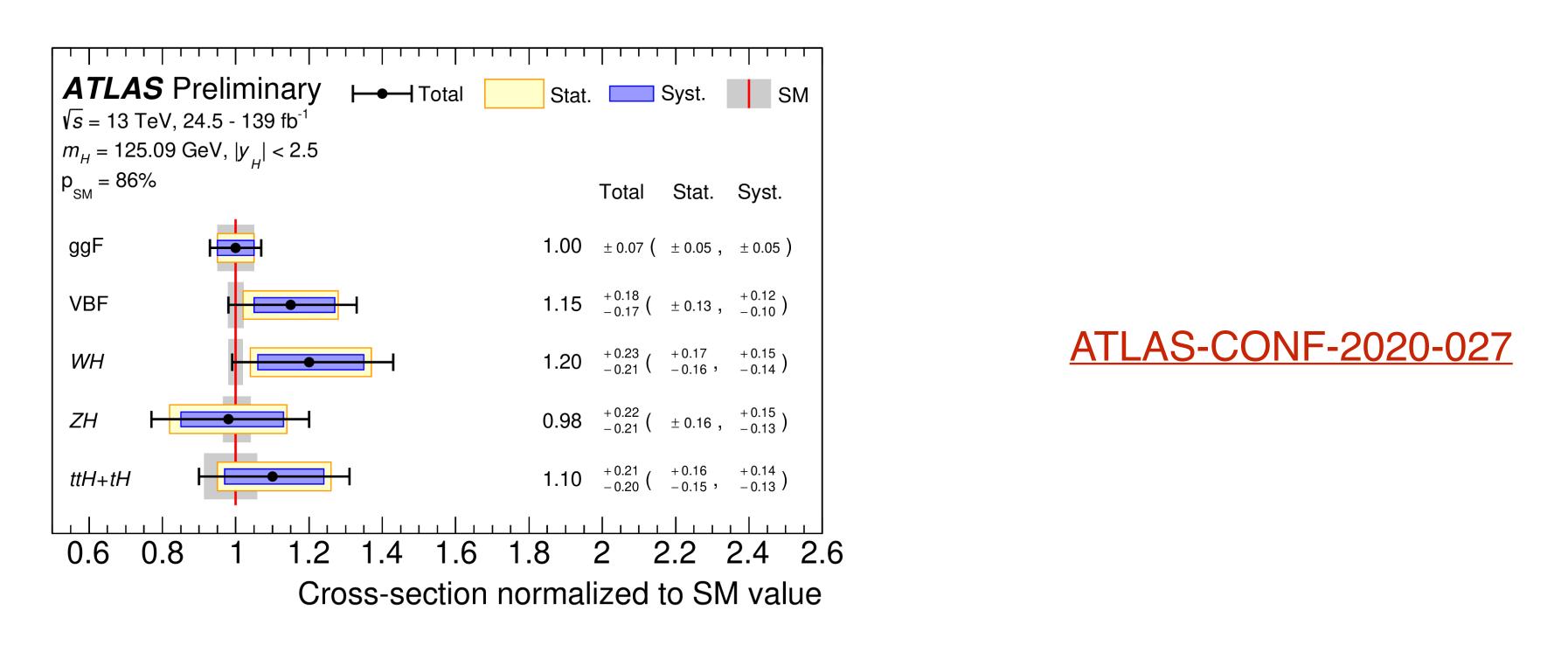


This measurement is systematically limited Chen Zhou (Wisconsin)

Inclusive signal strength, defined as the measured Higgs boson signal yield normalized to its SM prediction, is determined to be

 $\mu = 1.06 \pm 0.07 = 1.06 \pm 0.04(\text{stat.}) \pm 0.03(\text{exp.})^{+0.05}_{-0.04}(\text{sig. th.}) \pm 0.02(\text{bkg. th.})$

Production mode cross sections (assuming the SM decays)



- ggF cross section is now measured with 7% precision
 - Precision of N3LO cross section prediction: 5% \bullet
- - WH: 6.3σ, ZH: 5.0σ

All major production modes (ggF, VBF, WH, ZH, ttH) are observed!

Simplified template cross section (STXS) measurements

| | ggF | VBF | VH | ttH+tH |
|------|---------------------------|---------------------------|---------------------------|---------------------------|
| Η→γγ | ✔ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) |
| H→ZZ | ✔ (139 fb⁻¹) | ✓ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) |
| H→bb | | | ✓ (139 fb ⁻¹) | |

: channel included in the combination

Simplified template cross sections

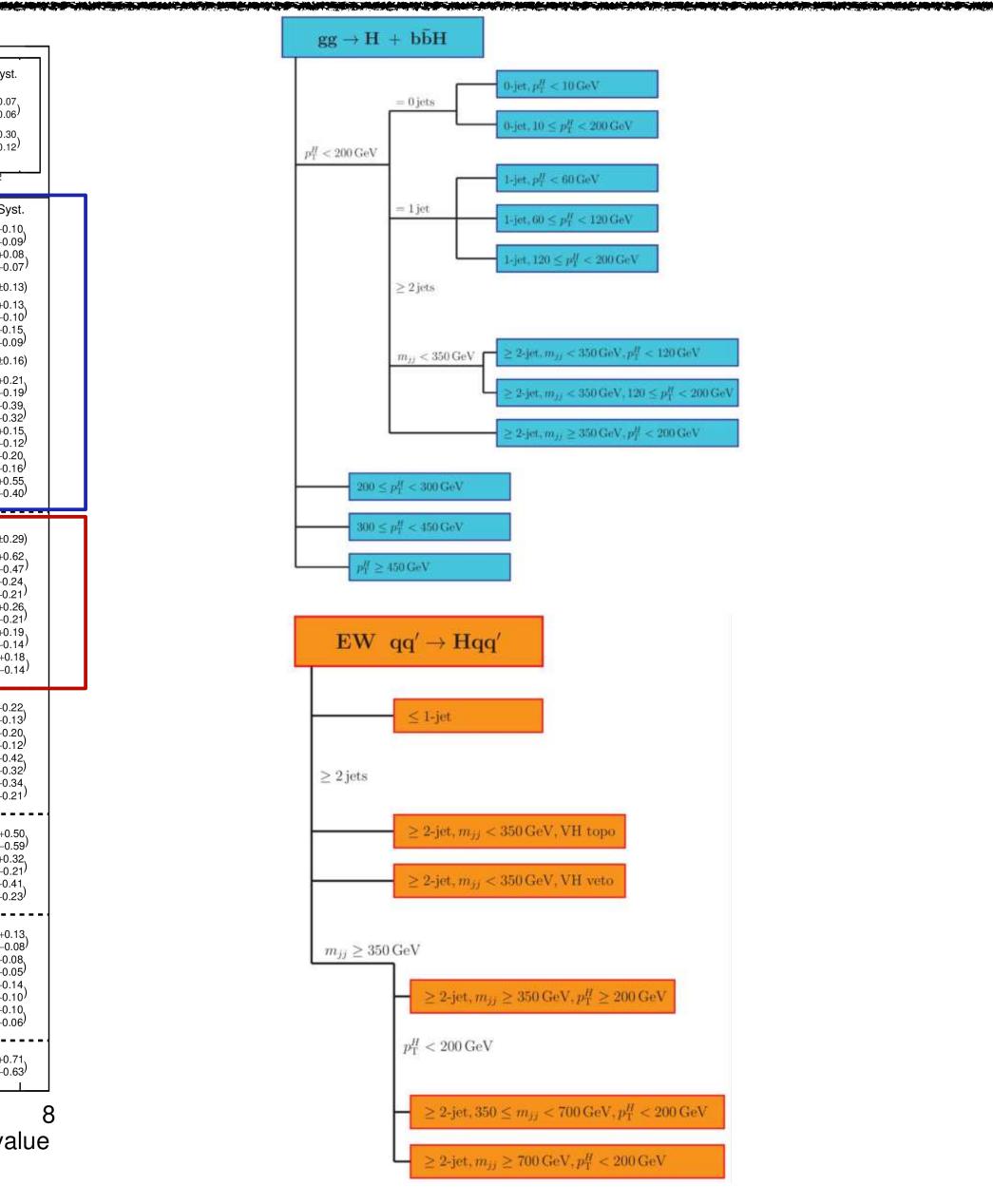
- Measure production mode cross-sections in various phase-space regions, which are chosen according to
 - sensitivity to BSM effects
 - avoidance of large theory uncertainties
 - matching to experimental selections
- Within each region, use the SM predicted signal templates to fit data
 - Can still exploit powerful analysis techniques (e.g. MVA)
- STXS are measured granularly in this combination
 - without assuming the SM decays of Higgs boson

STXS results

| $m_H = 125.09 \text{ Ge}$ $p_{SM} = 95\%$ Tota | $\sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1}$ $m_H = 125.09 \text{ GeV}, y_H < 2.5$ $p_{SM} = 95\%$ \int | | | 1.07 | Total +0.14 -0.12 +0.57 -0.28 | (+0.1 -0.1 |
|--|---|---------------------|-------------------|--|---|---|
| gg→H × B _{zz} . | 0-jet, $p_{T}^{H} < 10 \text{ GeV}$ 0-jet, $10 \le p_{T}^{H} < 200 \text{ GeV}$ 1-jet, $p_{T}^{H} < 60 \text{ GeV}$ 1-jet, $60 \le p_{T}^{H} < 120 \text{ GeV}$ 1-jet, $120 \le p_{T}^{H} < 200 \text{ GeV}$ ≥ 2 -jet, $m_{jj} < 350 \text{ GeV}, p_{T}^{H} < 120 \text{ GeV}$ ≥ 2 -jet, $m_{jj} < 350 \text{ GeV}, 120 \le p_{T}^{H} < 200 \text{ GeV}$ ≥ 2 -jet, $m_{jj} \ge 350 \text{ GeV}, p_{T}^{H} < 200 \text{ GeV}$ $200 \le p_{T}^{H} < 300 \text{ GeV}$ $300 \le p_{T}^{H} < 450 \text{ GeV}$ | 00 GeV | { ●{ ● | 0.82 1.12 0.61 1.31 0.72 0.30 0.67 1.61 1.19 0.39 1.76 | $\begin{array}{c} +0.22\\ -0.20\\ +0.15\\ -0.14\\ +0.31\\ -0.29\\ +0.45\\ -0.41\\ \pm 0.45\\ +0.46\\ -0.44\\ +0.83\\ -0.76\\ +0.40\\ -0.36\\ +0.56\\ -0.44\\ \end{array}$ | $\begin{pmatrix} +0.4\\ -0.3\\ (-0.5\\ (-0.6\\ -0.6\\ (-0.3\\ (-0.5\\ (-0.4\\ -0.4\\ -0.4\\ (-0.4\\ -0.4\\ (-0.4\\ -0.4\\ -0.4\\ (-0.4\\ -0.4\\ -0.4\\ (-0.4\\ -0.4\\ -0.4\\ (-0.4\\ -0.4\\ -0.4\\ (-0.4\\ -0.4\\ -0.4\\ (-0.4\\ -0.4\\ -0.4\\ (-0.4\\ -0.4\\ -0.4\\ -0.4\\ (-0.4\\ -0.4\\ -0.4\\ -0.4\\ (-0.4\\ -0.4\\ -0.4\\ -0.4\\ -0.4\\ (-0.4\\ -0.4$ |
| qq→Hqq × B _{zz*} | $\leq 1 \text{-jet}$ $\geq 2 \text{-jet}, \ m_{jj} < 350 \text{ GeV}, \ VH \text{ veto}$ $\geq 2 \text{-jet}, \ m_{jj} < 350 \text{ GeV}, \ VH \text{ topo}$ $\geq 2 \text{-jet}, \ 350 \leq m_{jj} < 700 \text{ GeV}, \ p_{T}^{H} < 200$ $\geq 2 \text{-jet}, \ m_{jj} \geq 700 \text{ GeV}, \ p_{T}^{H} < 200 \text{ GeV}$ $\geq 2 \text{-jet}, \ m_{jj} \geq 350 \text{ GeV}, \ p_{T}^{H} \geq 200 \text{ GeV}$ | / F | ⊣ ■■■■ | 1.00 2.29 0.65 0.81 1.16 1.20 | +1.66 -1.52 +0.83 -0.73 +0.64 -0.56 +0.34 -0.29 +0.44 | $ \begin{pmatrix} +0.9\\ -0.8\\ +1.5\\ (-1.2\\ +0.7\\ (-0.6\\ +0.9\\ (-0.8\\ (-0.2\\ +0.2\\ (-0.2\\ +0.2\\ (-0.3\\ +0.2\\ ($ |
| $qq \rightarrow HIv \times B_{ZZ^*}$ | $p_{\tau}^{v} < 75 \text{ GeV}$ $75 \le p_{\tau}^{v} < 150 \text{ GeV}$ $150 \le p_{\tau}^{v} < 250 \text{ GeV}$ $p_{\tau}^{v} \ge 250 \text{ GeV}$ | | | 2.46 1.70 1.46 1.28 | -1.02 +1.01 -0.82 +0.93 -0.72 | (+1.7) (-1.0) (-0.8) (-0.8) (-0.8) (-0.8) |
| $gg/qq \rightarrow Hll \times B_{ZZ^*}$ | $p_T^V < 150 \text{ GeV}$ $150 \le p_T^V < 250 \text{ GeV}$ $p_T^V \ge 250 \text{ GeV}$ | ┝╼═╾╢ ┝╤═ ┝╤═ | ■──H | 0.19 1.30 1.41 | -0.82 +0.77 -0.56 +0.91 | $\begin{pmatrix} +0.8\\ -0.8\\ -0.8\\ (-0.8\\ -0.8\\ (-0.8\\ -0.5 \end{pmatrix}$ |
| tītH × B _{zz} . | $p_T^H < 60 \text{ GeV}$ $60 \le p_T^H < 120 \text{ GeV}$ $120 \le p_T^H < 200 \text{ GeV}$ $p_T^H \ge 200 \text{ GeV}$ | | 1 | 0.72 0.66 1.00 0.86 | -0.64 +0.51 -0.43 +0.60 -0.51 +0.53 | $\begin{pmatrix} +0.7\\ -0.6\\ -0.2\\ \end{pmatrix}$ |
| <i>tH</i> × <i>B</i> _{ZZ*} −6 | | | 2 4 | 1.71 │ | +3.31 -2.52 6 | (+3.2 (2.4 |

Chen Zhou (Wisconsin)

Higgs Hunting



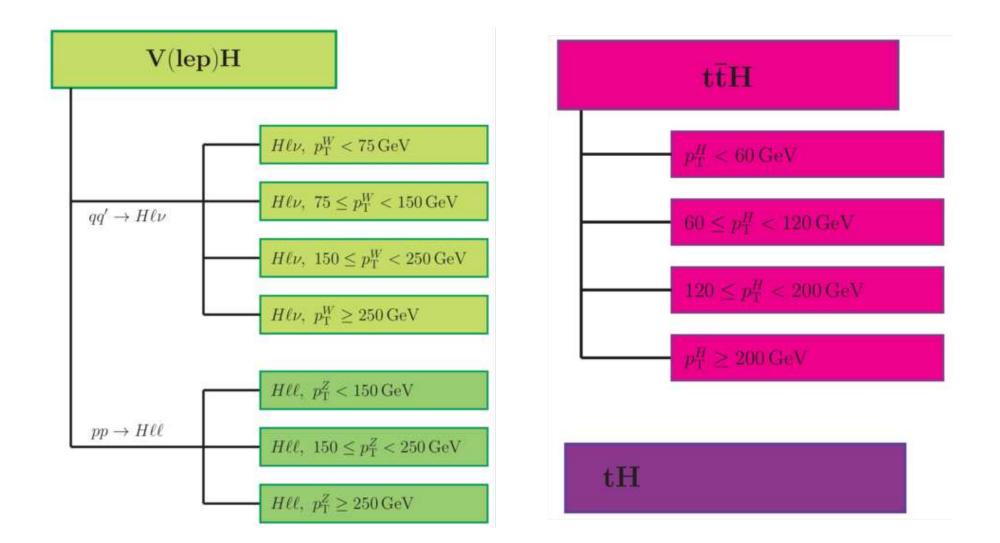
2021/9/21

STXS results

| \sqrt{s} = 13 TeV, 13 m_H = 125.09 Ge | | $B_{\gamma\gamma}/B_{ZZ^*}$ | | ¢ ee l | 1.07 | +0.14 +0.12 -0.12 (_0.11, | +0.07 0.06 |
|--|---|------------------------------------|-----|---------------|--|---|--|
| р _{зм} = 95% | | $B_{b\overline{b}}/B_{ZZ^{\star}}$ | | | 0.77 | +0.57 (^{+0.48} -0.28 (^{-0.25} , | +0.30 0.12 |
| Tota | | <u> </u> | 0.5 | •••• | 1.5 | | 2 |
| $gg \rightarrow H \times B_{ZZ^*}$ | 0-jet, $p_{\tau}^{H} < 10 \text{ GeV}$ 0-jet, $10 \le p_{\tau}^{H} < 200 \text{ GeV}$ 1-jet, $p_{\tau}^{H} < 60 \text{ GeV}$ 1-jet, $60 \le p_{\tau}^{H} < 120 \text{ GeV}$ 1-jet, $120 \le p_{\tau}^{H} < 200 \text{ GeV}$ ≥ 2 -jet, $m_{jj} < 350 \text{ GeV}, p_{\tau}^{H} < 120 \text{ GeV}$ ≥ 2 -jet, $m_{jj} < 350 \text{ GeV}, 120 \le p_{\tau}^{H} < 200 \text{ GeV}$ ≥ 2 -jet, $m_{jj} < 350 \text{ GeV}, p_{\tau}^{H} < 200 \text{ GeV}$ ≥ 2 -jet, $m_{jj} < 350 \text{ GeV}, p_{\tau}^{H} < 200 \text{ GeV}$ $200 \le p_{\tau}^{H} < 300 \text{ GeV}$ $300 \le p_{\tau}^{H} < 450 \text{ GeV}$ | | | | 0.82 1.12 0.61 1.31 0.72 | Total Stat. +0.22 ($+0.19-0.20$ (-0.18 , +0.15 ($+0.13-0.14$ (-0.12 , +0.31 ($+0.28-0.30$ (-0.27 , +0.31 ($+0.28-0.29$ (-0.27 , +0.45 ($+0.42-0.41$ (-0.40 , ± 0.45 (± 0.42 , $+0.45$ (± 0.42 , +0.46 ($+0.41-0.40$, ± 0.73 -0.76 (-0.69 , +0.37 -0.36 ($+0.52-0.49$ (-0.46 , +0.52 -0.49 (-0.46 , +0.52 | $\begin{array}{c} +0.7\\ -0.0\\ +0.\\ -0.\\ \pm 0.\\ +0.\\ -0.\\ \pm 0.\\ \pm 0$ |
| qq→Hqq × B _{zz} . | $p_{\tau}^{H} \ge 450 \text{ GeV}$ $\le 1 \text{-jet}$ $\ge 2 \text{-jet}, m_{jj} < 350 \text{ GeV}, VH \text{ veto}$ $\ge 2 \text{-jet}, m_{jj} < 350 \text{ GeV}, VH \text{ topo}$ $\ge 2 \text{-jet}, 350 \le m_{jj} < 700 \text{ GeV}, p_{\tau}^{H} < 200$ $\ge 2 \text{-jet}, m_{jj} \ge 700 \text{ GeV}, p_{\tau}^{H} < 200 \text{ GeV}$ $\ge 2 \text{-jet}, m_{jj} \ge 350 \text{ GeV}, p_{\tau}^{H} \ge 200 \text{ GeV}$ | | | ■ | 1.76 1.00 2.29 0.65 0.81 1.16 1.20 | $\begin{array}{c} +1.44\\ -1.22\\ -0.89\\ -0.89\\ -0.89\\ -0.84\\ +1.66\\ +1.54\\ -1.52\\ -1.45\\ -1.45\\ -1.52\\ -1.45\\ -1.45\\ -1.45\\ -1.54\\ -1$ | -0 ±0.: +0.: +0.: +0.: +0.: +0.: +0.: +0.: + |
| qq→HIv×B _{zz*} | $p_{\tau}^{v} < 75 \text{ GeV}$ $75 \le p_{\tau}^{v} < 150 \text{ GeV}$ $150 \le p_{\tau}^{v} < 250 \text{ GeV}$ $p_{\tau}^{v} \ge 250 \text{ GeV}$ | | | | 2.46 1.70 1.46 1.28 | $\begin{array}{c} +1.18\\ -1.02\\ +1.01\\ +0.99\\ -0.82\\ -0.82\\ -0.81\\ +0.93\\ -0.72\\ +0.79\\ +0.71\\ -0.56\end{array} + \begin{array}{c} +1.16\\ -1.02\\ -0.81\\ -0.83\\ -0.65, \\ +0.71\\ -0.52, \end{array}$ | +0.2 -0.7 +0.4 -0.3 |
| gg/qq→Hll × B _{zz*} | $p_{\tau}^{V} < 150 \text{ GeV}$ $150 \le p_{\tau}^{V} < 250 \text{ GeV}$ $p_{\tau}^{V} \ge 250 \text{ GeV}$ | | | | 0.19 1.30 1.41 | $\begin{array}{c} +0.74 \\ -0.82 \\ +0.77 \\ +0.77 \\ -0.56 \\ +0.91 \\ -0.63 \end{array} \begin{pmatrix} +0.54 \\ -0.57 \\ +0.70 \\ -0.52 \\ +0.81 \\ -0.59 \\ \end{array}$ | · -0. +0. -0. |
| tī̃H×B _{zz} . | $p_{\tau}^{H} < 60 \text{ GeV}$ $60 \le p_{\tau}^{H} < 120 \text{ GeV}$ $120 \le p_{\tau}^{H} < 200 \text{ GeV}$ $p_{\tau}^{H} \ge 200 \text{ GeV}$ | | | | 0.72 0.66 1.00 0.86 | $\begin{array}{c} +0.77\\ -0.64\\ +0.51\\ -0.43\\ +0.51\\ -0.43\\ +0.60\\ +0.59\\ -0.51\\ -0.50\\ +0.52\\ -0.45\\ \end{array}$ | -0. +0.0 -0.0 +0. -0.1 +0.1 |
| $tH \times B_{ZZ^*}$ | <u> </u> | | | | 1.71 | +3.31 (+3.23 -2.52 (-2.44, | +0. -0. |
| -6 | -4 -2 | 0 | 2 | 4 | | 6 | |

Chen Zhou (Wisconsin)

Higgs Hunting



- 29 regions are probed, good • compatibility with the SM prediction
 - All regions are statistically limited; in some regions (e.g. ggF 0-jet) systematics are not negligible
- The upper limit on the tH cross section is 8.4 times the SM prediction

2021/9/21

•

Coupling modifier ("kappa") interpretation

| | ggF | VBF | VH | ttH+tH |
|------|---------------------------|---------------------------|---------------------------|------------------------------|
| Η→γγ | ✔ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) | ✓ (139 fb⁻¹) |
| H→ZZ | ✓ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) | ✓ (139 fb ⁻¹) | |
| H→WW | ✓ (36 fb ⁻¹) | ✓ (36 fb⁻¹) | | ✓ (36-139 fb ⁻¹) |
| Н→тт | ✓ (36 fb ⁻¹) | ✓ (36 fb⁻¹) | | |
| H→bb | | ✓ (25-31 fb⁻¹) | ✓ (139 fb⁻¹) | ✓ (36 fb⁻¹) |

✓: channel included in the combination

Analyses of $H \rightarrow \mu \mu$ (139 fb⁻¹) and $H \rightarrow invisible$ (139 fb⁻¹) are also included in relevant studies

Higgs Hunting

Chen Zhou (Wisconsin)

Coupling modifier ("kappa")

- Leading order motivated framework: assign coupling modifier to each (effective) interaction vertex (e.g. κ_W, κ_t...)
- In this framework, production cross section times decay branch fraction of i→H→f can be parameterized as

 $\sigma_i \times B_f =$

- (this allows for a consistent treatment of production and decay)
- Total width of Higgs boson can be expressed as

 $\Gamma_H(\boldsymbol{\kappa}, B_{\mathrm{i.}}, B_{\mathrm{u.}})$

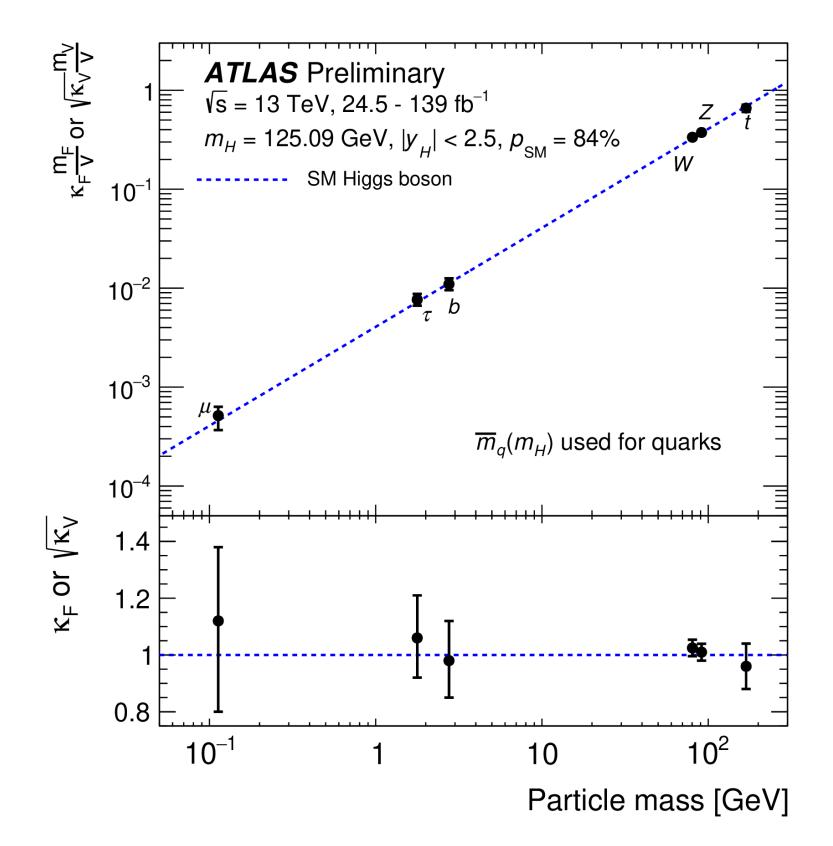
B_{i.}= BSM contribution to BR of invisible decays which are identified through a missing transverse momentum signature B_{u.}= BSM contribution to BR of undetected decays to which none of the analyses in the combination are sensitive

$$=\frac{\sigma_i(\boldsymbol{\kappa})\times\Gamma_f(\boldsymbol{\kappa})}{\Gamma_H},$$

$$= \kappa_H^2(\boldsymbol{\kappa}, B_{\mathrm{i.}}, B_{\mathrm{u.}}) \Gamma_H^{\mathrm{SM}}$$

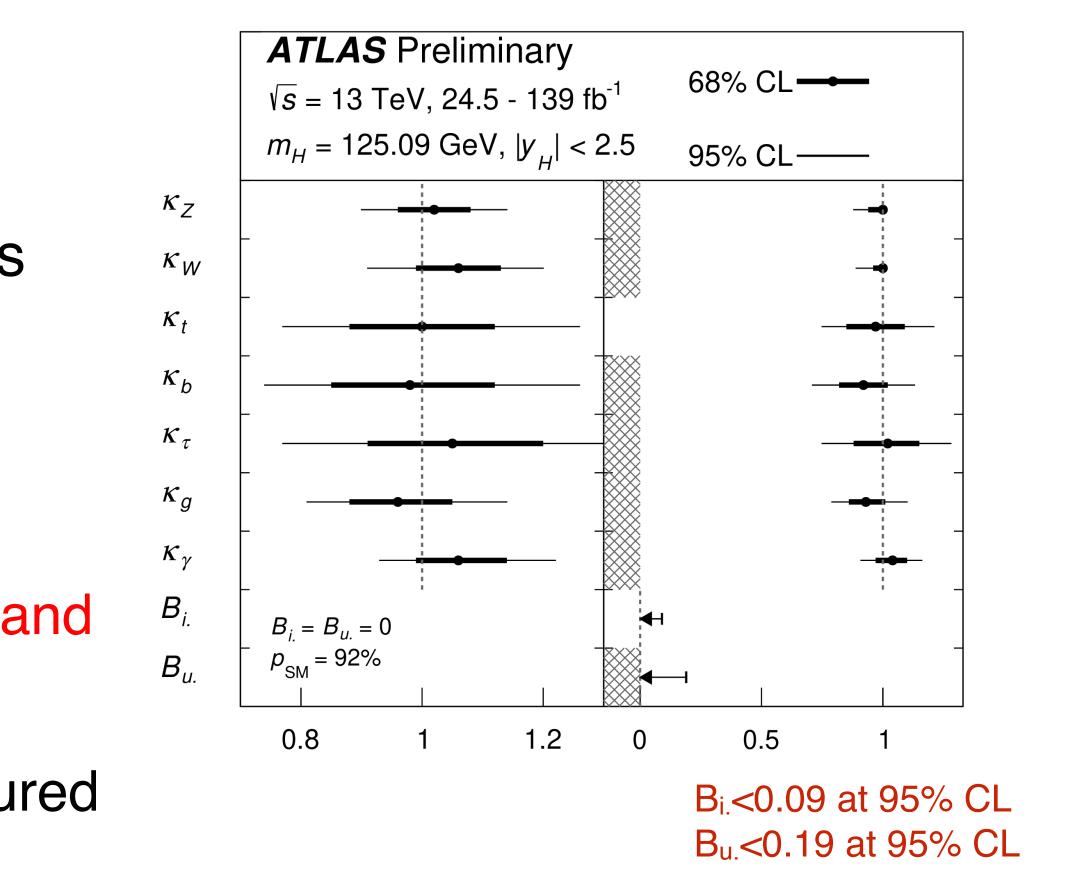
Coupling modifier vs. particle mass

- Assume no BSM contribution in loopinduced processes (ggF, H→γγ etc.) or total width. Resolve ggF and Hγγ effective vertices
- Good agreement with the SM across 3 orders of magnitude of particle mass!



Coupling modifier: different scenarios

- Not resolving ggF and Hγγ effective vertices (and introducing corresponding coupling modifiers κ_g, κ_γ), explore two different scenarios for total width:
 - Left: assume B_{i.}=B_{u.}=0
 - **Right**: constrain $B_{i.}$ and $B_{u.}$ using H→invisible analysis and $\kappa_V < 1$
- All coupling modifiers are measured to be compatible with the SM

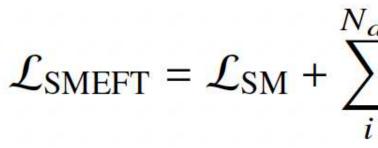


Interpretation of STXS measurements with Effective Field Theory (EFT)

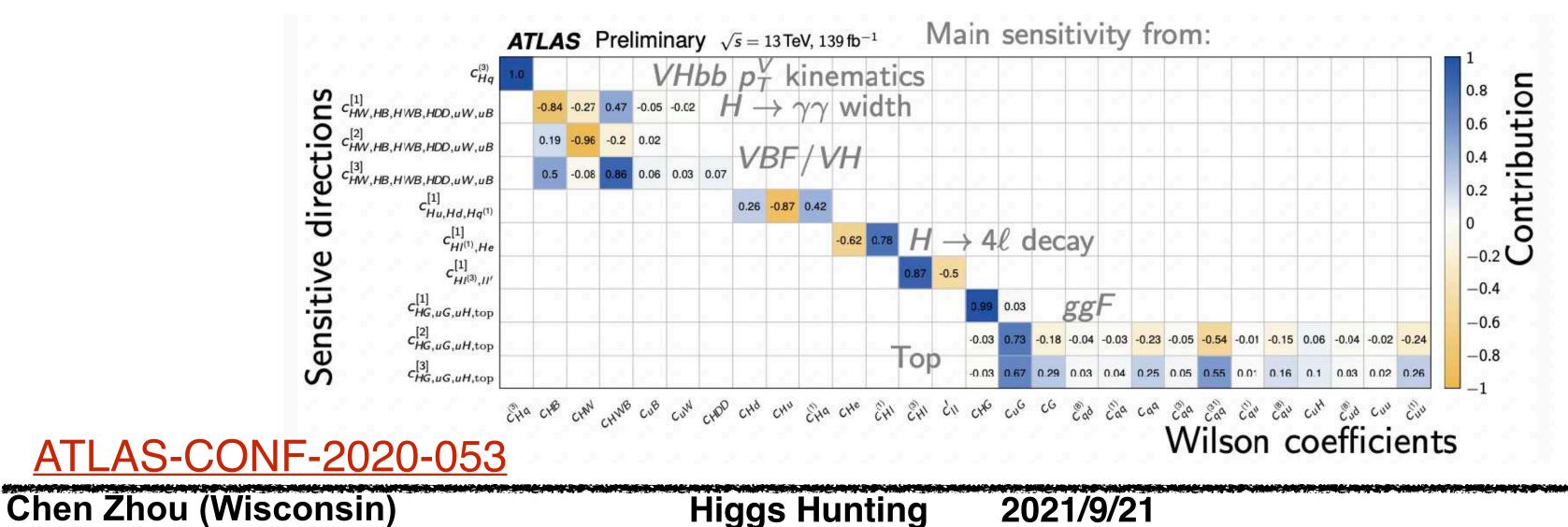
| | ggF | VBF | VH | ttH+tH |
|------|---------------------------|---------------------------|---------------------------|---------------------------|
| Η→γγ | ✓ (139 fb ⁻¹) |
| H→ZZ | ✓ (139 fb ⁻¹) |
| H→bb | | | ✔ (139 fb⁻¹) | |

: channel included in the combination

Interpretation of STXS with EFT



- Parameterize the signal strengths, (XS*BR)_{meas}/(XS*BR)_{SM} directly with Wilson coefficients of d=6 SMEFT operators
- Rotate the SMEFT basis cj to eigenvector cj' and fit 10 sensitive eigenvectors simultaneously
 - these eigenvectors are obtained from identifying groups of operators with similar impact and performing eigenvector decomposition for the covariance matrix of the measurement

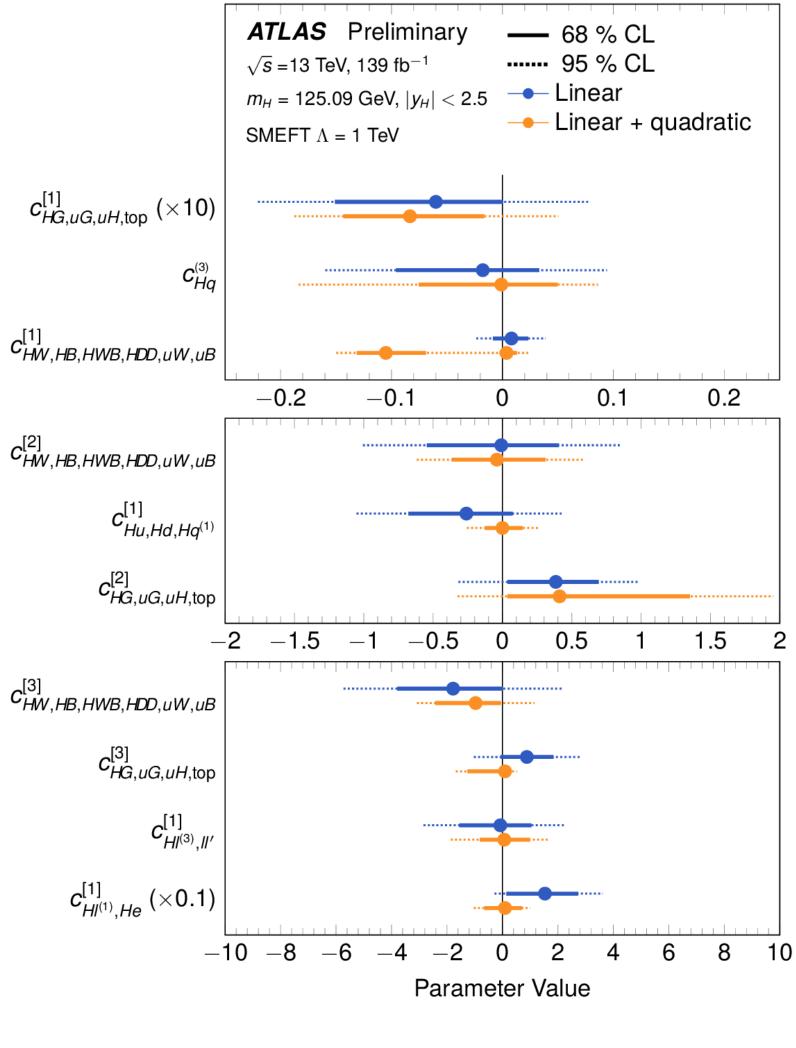


 $\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{i}^{N_{d6}} \frac{c_i}{\Lambda^2} O_i^{(6)} + \sum_{i}^{N_{d8}} \frac{b_j}{\Lambda^4} O_j^{(8)} + \dots$

Interpretation of STXS with EFT

- All measured parameters are consistent with the SM expectation within their uncertainties
- Comparison of the linear model and the linear+quadratic model shows sizeable sensitivity to operators suppressed by Λ^4

From a simultaneous fit

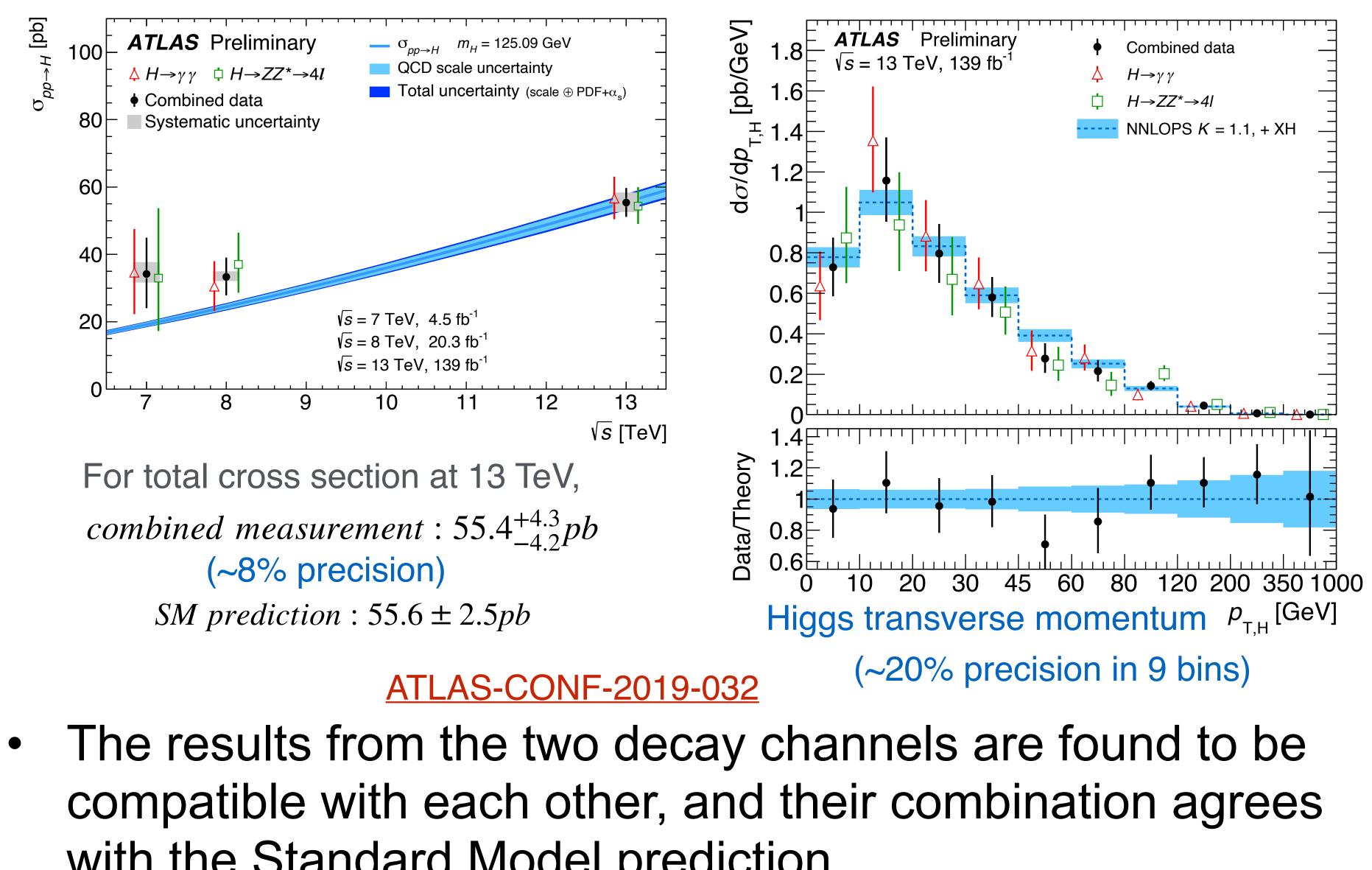


of Higgs boson production

Including the $H \rightarrow \gamma \gamma$ and $H \rightarrow ZZ^* \rightarrow 4$ -lepton decay channels Using the full Run-2 dataset recorded by ATLAS, corresponding to 139 fb⁻¹

Combined measurements of the total and differential cross sections

Total and differential cross sections



with the Standard Model prediction

Chen Zhou (Wisconsin)

- measurements of Higgs boson production and decays:
 - inclusive signal strength
 - production cross sections
 - simplified template cross sections
- Based on 139 fb⁻¹ of full Run 2 data, ATLAS performed combined measurements of total and differential Higgs boson cross sections
- All major production modes (ggF, VBF, WH, ZH, ttH) are observed
- All measurements are in agreement with the SM within the improved uncertainties

Based on up to **139 fb**⁻¹ of Run 2 data, ATLAS performed combined

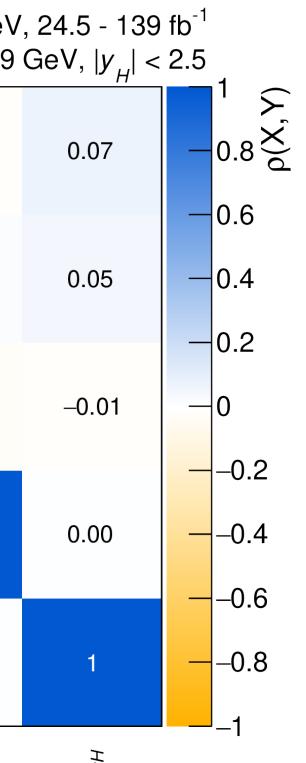
• Results can be interpreted using "kappa", EFT and BSM models

Backup slides

Chen Zhou (Wisconsin)

Production mode cross sections (assuming the SM decays)

| | $\sqrt{s} = 13 \text{ TeV}$ $m_H = 125.09$ | | | |
|----------------------------------|---|----------------|---------------|---------------|
| σ_{ggF} | 1 | -0.08 | -0.02 | -0.02 |
| σ_{VBF} | -0.08 | 1 | 0.01 | 0.02 |
| $\sigma_{_{WH}}$ | -0.02 | 0.01 | 1 | -0.03 |
| $\sigma_{_{ZH}}$ | -0.02 | 0.02 | -0.03 | 1 |
| σ _t τ _{H+tH} | 0.07 | 0.05 | -0.01 | 0.00 |
| | σ_{ggF} | σ_{VBF} | σ_{WH} | σ_{ZH} |

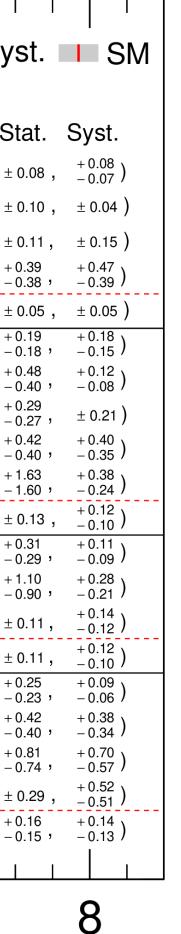


σ_{tīH+tH}

Production mode cross sections in each decay channel

| ATLAS Droliminory | | ' ' | | ' |
|--|------------------|--------|--------------|--------------------|
| ATLAS Preliminary $\sqrt{s} = 13 \text{ TeV}, 24.5 - 139 \text{ fb}^{-1}$ $m_H = 125.09 \text{ GeV}, y_H < 2.5$ | ⊢⊷⊣⊤(| otal 💻 | Stat | - |
| p _{SM} = 87% | | | | Total |
| ggF үү 🙀 | | | 1.03 | ± 0.11 (|
| ggF ZZ 🙀 | | | 0.94 | +0.11 -0.10 (|
| ggF WW 📥 | | | 1.08 | +0.19 -0.18 (|
| ggF ττ μ📫 μ | | | 1.02 | + 0.60 - 0.55 (|
| ggF comb. 🛛 🙀 | | | 1.00 | ± 0.07 (|
| VBF γγ 📕 | | | 1.31 | +0.26 -0.23 (|
| VBF ZZ | | | 1.25 | +0.50 -0.41 (|
| VBF WW | | | 0.60 | +0.36 -0.34 (|
| VBF ττ μ | | | 1.15 | + 0.57 - 0.53 (|
| VBF bb | | } | 3 .03 | + 1.67 - 1.62 (|
| VBF comb. 🔤 | | | 1.15 | + 0.18 - 0.17 (|
| VH γγ 🗧 🛏 | | | 1.32 | + 0.33 - 0.30 (|
| VH ZZ | | | 1.53 | +1.13 -0.92 (|
| VH bb 🖷 | | | 1.02 | +0.18 -0.17 (|
| VH comb. 🗖 | | | 1.10 | +0.16 -0.15 (|
| ttH+tH γγ 📫 | | | 0.90 | +0.27 -0.24 (|
| ttH+tH VV | - - | | 1.72 | + 0.56 - 0.53 (|
| ttH+tH ττ ι |] - 1 | | 1.20 | + 1.07 - 0.93 (|
| ttH+tH bb ⊨=== | | | 0.79 | + 0.60 - 0.59 (|
| <i>ttH+tH</i> comb. ≢ | | | 1.10 | +0.21 -0.20 (|
| | | | | |
| 2 0 5 | 2 | Λ | | 6 |

 $\sigma \times B$ normalized to SM

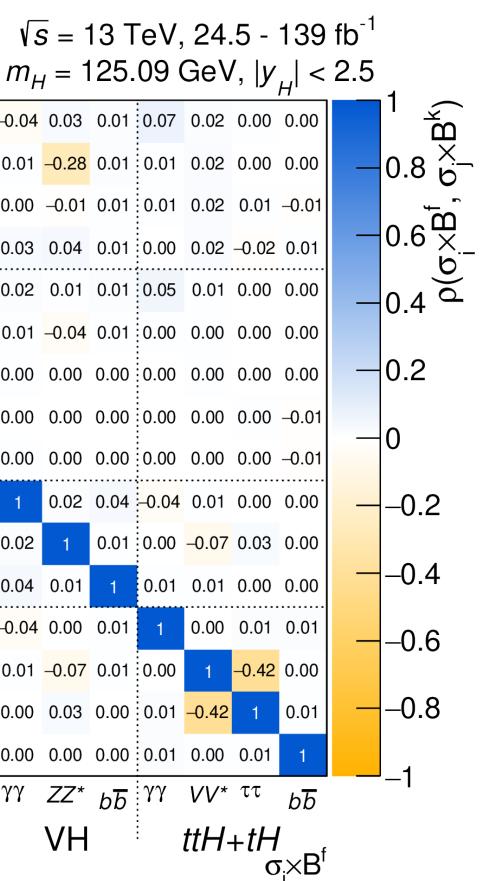


2021/9/21

Production mode cross sections in each decay channel

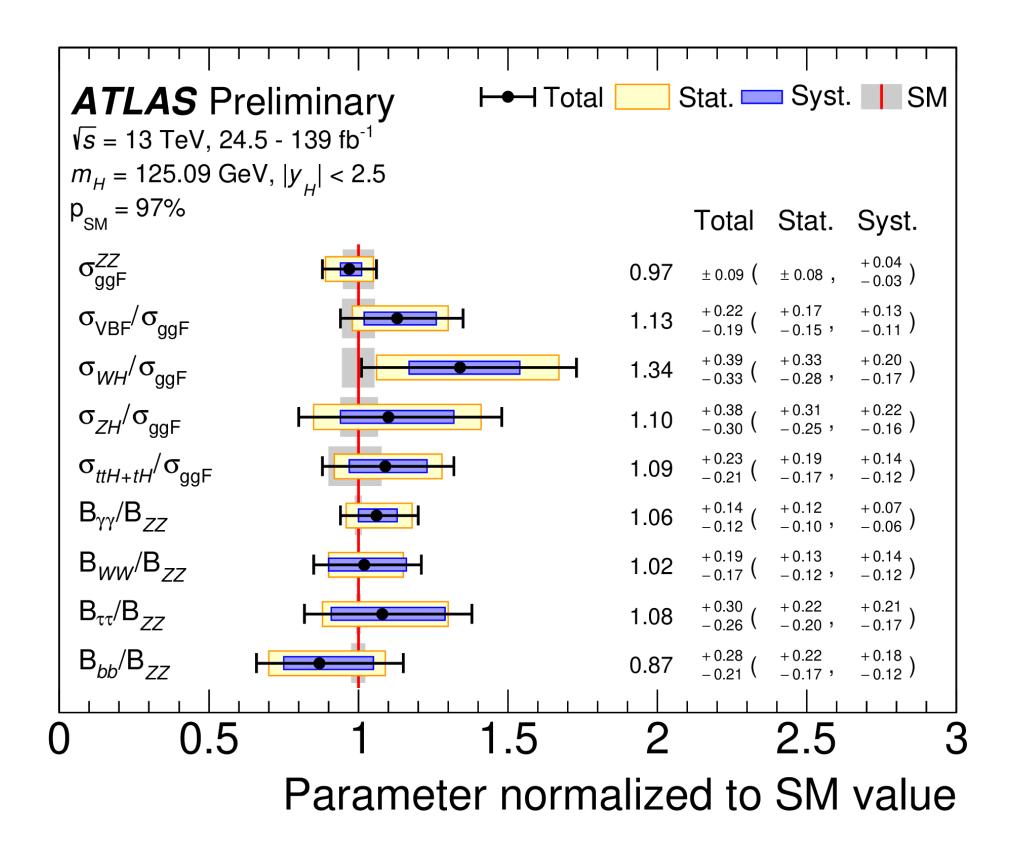
| ATLAS Preliminary | |
|--------------------------|---|
| | r |

| | | | γγ <i>ZZ*WW</i> * ττ ggF | | | | γγ ZZ*WW* ττ bδ VBF | | | ממ | | VH | ממ | 1 | ĺ | |
|-----------|--------------|-----|-----------------------------|-------|-------|-------|------------------------|-------|-------|-------|-----------------|-------|-------|-----------------|-------|---|
| | | | γγ | ZZ* | WW* | ττ | γγ | ZZ* | WW* | ττ | $b\overline{b}$ | γγ | ZZ* | $b\overline{b}$ | γγ | - |
| | | bb | 0.00 | 0.00 | -0.01 | 0.01 | 0.00 | 0.00 | 0.00 | -0.01 | -0.01 | 0.00 | 0.00 | 0.00 | 0.01 | |
| | ttH4 | ττ | 0.00 | 0.00 | 0.01 | -0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.01 | - |
| | + <i>t</i> / | VV* | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | -0.07 | 0.01 | 0.00 | |
| | - | γγ | 0.07 | 0.01 | 0.01 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | -0.04 | 0.00 | 0.01 | 1 | |
| | | bb | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.04 | 0.01 | 1 | 0.01 | |
| | \leq | ZZ* | 0.03 | -0.28 | -0.01 | 0.04 | 0.01 | -0.04 | 0.00 | 0.00 | 0.00 | 0.02 | 1 | 0.01 | 0.00 | - |
| _ | | γγ | -0.04 | 0.01 | 0.00 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 1 | 0.02 | 0.04 | -0.04 | |
| | | bЪ | 0.01 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | _ |
| - | | ττ | 0.00 | 0.01 | 0.01 | -0.45 | 0.00 | 0.00 | -0.01 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| ĺ | /BI | WW* | 0.01 | 0.00 | -0.08 | 0.03 | 0.01 | 0.01 | 1 | -0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| I | | ZZ* | 0.01 | -0.21 | 0.00 | 0.03 | 0.07 | 1 | 0.01 | 0.00 | 0.00 | 0.01 | -0.04 | 0.01 | 0.00 | |
| | | γγ | -0.11 | 0.00 | 0.01 | 0.04 | 1 | 0.07 | 0.01 | 0.00 | 0.01 | 0.02 | 0.01 | 0.01 | 0.05 | |
| | | ττ | 0.06 | 0.00 | 0.00 | 1 | 0.04 | 0.03 | 0.03 | -0.45 | 0.00 | 0.03 | 0.04 | 0.01 | 0.00 | |
| | 00 | WW* | 0.01 | 0.02 | 1 | 0.00 | 0.01 | 0.00 | -0.08 | 0.01 | 0.01 | 0.00 | -0.01 | 0.01 | 0.01 | |
| 6 | Ш | ZZ* | 0.02 | 1 | 0.02 | 0.00 | 0.00 | -0.21 | 0.00 | 0.01 | 0.00 | 0.01 | -0.28 | 0.01 | 0.01 | |
| ا م ×B | | γγ | 1 | 0.02 | 0.01 | 0.06 | -0.11 | 0.01 | 0.01 | 0.00 | 0.01 | -0.04 | 0.03 | 0.01 | 0.07 | |
| | | | | | | | | | | | | 1 | | | | |



Production mode cross sections and decay branch ratios





| | | | <i>F</i> | 1 | | H' |
|----------------------------------|---|--|--|---|---|---|
| | 0-jet, <i>p</i> ^{<i>H</i>} _{<i>T</i>} < 10 GeV | 1 0.04 0.02 0.07 0.03 0.03 0.02 0.07 0.07 0.01 0.03 0.00 | 0.04 0.03 0.02 0.11 0.09 0 | 07 0.06 0.06 0.06 | 0.01 0.07 0.06 0.03 | 0.05 0.05 0.06 0.02 <mark>-0.27</mark> -0.06 |
| | 0-jet, 10 ≤ <i>p</i> ^{<i>H</i>} / _{<i>T</i>} < 200 GeV | 0.04 1 - <mark>0.28</mark> 0.26 0.14-0.060.13 0.03 0.22 0.06 0.08 -0.05 | • | | • | |
| | | 0.02- <mark>0.28</mark> 1 0.13 0.12-0.04-0.02 0.03 0.05 0.02 0.02 <mark>-0.3</mark> | - | | | |
| | | 0.07 0.26 0.13 1 0.29 <mark>-0.21</mark> 0.10 0.02 0.24 0.08 0.08 <mark>-0.46</mark> | | | | |
| T | 1 | 0.03 0.14 0.12 0.29 1 -0.03-0.07 0.01 0.14 0.05 0.05 -0.44 | | | | |
| $gg ightarrow H 	imes B_{ZZ^*}$ | | 0.03-0.06-0.04-0.21-0.03 1 0.17 0.01 0.13 0.11 0.06 0.01 | | | | |
| $gg \times E$ | | 0.02 0.13-0.020.10-0.07 0.17 1 0.00 0.23 0.15 0.11 0.01 | | | | |
| | | 0.07 0.03 0.03 0.02 0.01 0.01 0.00 1 0.08 0.05 0.06 0.03 | | | | |
| | | 0.07 0.22 0.05 0.24 0.14 0.13 0.23 0.08 1 0.10 0.12 0.15 | | | | |
| | | 0.07 0.22 0.03 0.24 0.14 0.13 0.23 0.08 11 0.10 0.12 0.13 0.01 0.06 0.02 0.08 0.05 0.11 0.15 0.05 0.10 1 0.05 0.07 | | | - | |
| | | 0.03 0.08 0.02 0.08 0.05 0.06 0.11 0.06 0.12 0.05 1 0.04 | | | | |
| | | | | | | |
| | - | 0.00-0.05 <mark>-0.310.46-0.44</mark> 0.01 0.01-0.03-0.15-0.07-0.04 | | | | |
| dd Z* | | 0.04 0.02 0.04 0.02 0.00 <mark>-0.46 0.48</mark> -0.05 <mark>-0.26 0.20</mark> -0.11-0.0 | | | | |
| $ ightarrow Hqq 	imes B_{ZZ^*}$ | | 0.03 0.02 0.03 0.02 0.02 <mark>-0.18 0.28</mark> 0.04 <mark>-0.17 0.10</mark> -0.01 -0.0 | | | | |
| -bt | | 0.02 0.09 0.04 0.08 0.04 0.01 0.04 <mark>-0.46</mark> 0.06 0.01 0.02 <mark>-0.04</mark> | | | | |
| Ũ | \geq 2-jet, $m_{jj} \geq$ 700 GeV, $p_{T_{ij}}^{\prime \prime} <$ 200 GeV | 0.11 0.18 0.11 0.18 0.09 0.00 0.02 <mark>-0.20</mark> 0.13 0.01 0.06 <mark>-0.12</mark> | 0.14 0.04 0.21 1 0.22 0. | 10 0.08 0.08 0.08 | 0.02 0.09 0.08 0.05 | 0.07 0.08 0.09 0.02 0.38 0.09 |
| | | 0.09 0.13 0.06 0.11 0.05–0.010.01 0.04–0.05 <mark>-0.09</mark> –0.01 0.02 | | | | |
| 2 | | 0.07 0.10 0.01 0.07 0.03 0.01 0.03 0.05 0.08 0.01 0.03 0.01 | | | | |
| $\rightarrow HIv$ B_{ZI^*} | $75 \le p_{T}^{V} < 150 \text{ GeV}$ | 0.06 0.10 0.02 0.06 0.02 0.01 0.03 0.04 0.08 0.02 0.03 0.01 | 0.02 0.02 0.03 0.08 0.07 0 | <mark>.16</mark> 1 <mark>-0.12</mark> -0.03 | <mark>0.12</mark> -0.03-0.040.03 | 0.04 0.04 0.06+0.05+0.20 0.05 |
| - bb | | 0.06 0.10 0.02 0.07 0.02 0.01 0.04 0.04 0.06 0.01 0.03 0.01 | | | | |
| | | 0.06 0.11 0.01 0.08 0.03 0.01 0.04 0.04 0.07 0.01 0.04 0.01 | | | | |
| HH ZZ* | p_{τ}^{V} < 150 GeV | 0.01–0.010.02–0.010.00 0.00–0.010.01 0.01 0.00 0.00 0 | 0.01 0.01 0.01 0.02 0.01 | .04-0.12 <mark>-0.27-0.24</mark> | 1 - <mark>0.26-0.25</mark> 0.00 | 0.00 0.01 0.01 0.01 <mark>-0.02</mark> 0.30 |
| gg/qq $→$ H $\times B_{ZZ^*}$ | $150 \le p_{\tau}^{V} < 250 \text{ GeV}$ | 0.07 0.10 0.02 0.08 0.03 0.01 0.03 0.05 0.07 0.01 0.04 0.01 | 0.03 0.02 0.03 0.09 0.08 0 | .08-0.03 0.60 0.67 | <mark>0.26</mark> 1 0.690.03 | 0.04 0.04 0.04 0.03 0.22 0.79 |
|) X | $p_{\tau}^{\dot{V}} \ge 250 \text{ GeV}$ | 0.06 0.10 0.02 0.07 0.02 0.01 0.04 0.04 0.06 0.01 0.04 0.01 | 0.02 0.02 0.03 0.08 0.07 0 | .08- <mark>0.04</mark> 0.65 0.68 | 0.25 0.69 1 0.03 | 0.04 0.03 0.03 0.03 0.21 0.84 |
| 0 | ρ ^H _τ < 60 GeV | 0.03 0.04 0.01 0.03 0.01 0.01 0.02 0.03 0.04 0.02 0.02 0.01 | 0.01 0.01 0.01 0.05 0.04 0 | .03 0.03 0.03 0.03 | 0.00 0.03 0.03 1 | -0.010.04 0.06 <mark>- 0.11-0.10</mark> -0.03 |
| *22 | $60 \le p_{\tau}^{H} < 120 \text{ GeV}$ | 0.05 0.06 0.02 0.05 0.02 0.01 0.03 0.05 0.06 0.02 0.03 0.01 | 0.01 0.02 0.02 0.07 0.06 0. | 04 0.04 0.04 0.04 | 0.00 0.04 0.04 0.01 | 1 0.03 0.11 -0.20-0.15-0.04 |
| tt × B | $120 \le p_{\tau}^{H} < 200 \text{ GeV}$ | 0.05 0.08 0.02 0.05 0.02 0.02 0.03 0.06 0.07 0.06 0.05 0.02 | 0.03 0.01 0.02 0.08 0.06 0 | 05 0.04 0.02 0.03 | 0.01 0.04 0.03 0.04 | 0.03 1 0.11 0.21 0.17 0.03 |
| | $p_{\tau}^{H} \ge 200 \text{ GeV}$ | 0.06 0.08 0.02 0.05 0.02 0.03 0.04 0.08 0.07 0.01 0.03 0.02 | 0.02 0.02 0.02 0.09 0.08 0. | 07 0.06 0.04 0.04 | 0.01 0.04 0.03 0.06 | 0.11 0.11 1 -0.41-0.20-0.04 |
| | $^{\prime}tH \times B_{77^{*}}$ | 0.02 0.02 0.01 0.01 0.00 <mark>-0.02-0.01-0.06-</mark> 0.03-0.03-0.01 0.02 | 0.00 0.00 0.02 0.02 0.01+0 | .03-0.05-0.04-0.03 | 0.01 <u>-0.03-</u> 0.03 <mark>-0.11</mark> | 0.20-0.21-0.41 1 0.050.03 |
| | | 0.27-0.38-0.09-0.28-0.12-0.05-0.15-0.17-0.32-0.04-0.14-0.06 | | | | |
| | | 0.06-0.10-0.01-0.08-0.03-0.01-0.04-0.05-0.07-0.01-0.04-0.0 | | | | |
| | | GeV GeV GeV GeV GeV GeV GeV GeV | | | > > > >:> | |
| | |) GeV) GeV | GeV, VH veto GeV, VH topo $p_T^H < 200$ GeV $p_T^H < 200$ GeV $p_T^H \ge 200$ GeV | < / 5 GeV < 150 GeV < 250 GeV ≥ 250 GeV | < 150 GeV < 250 GeV > 250 GeV < 4 < 60 GeV | <pre>< 120 GeV < 200 GeV < 200 GeV $fH \times B_{ZZ^*}$ </pre> $B_{b\overline{b}} B_{ZZ^*}$ |
| | | < 10 2000 200 < 60 < 600 < 200 200 200 200 200 300 300 450 | V, VH V, VH < 200 < 200 < 200 | < /5 < 150 < 250 ≥ 250 | 150 250 250 < 60 | $\frac{120}{200}$ $\frac{200}{B_{bb}}$ |
| | | $\begin{array}{c} \mathcal{A} \\ $ | $\begin{array}{c} \text{GeV} \\ \text{GeV} \\ \mu_{1}^{H} \\ \mu_{1}^{H} \\ \mu_{1}^{H} \end{array}$ | 0 > L > L > L > L | $^{>}$ $^{+}$ $^{-}$ | $\begin{array}{c} \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} \mathcal{L} L$ |
| | | | ' | | VI | |
| | | 0-jet 1. 10 ≤ 1.jet 1.60 ≤ 120 ≤ 120 ≤ 120 ≤ 200 ≤ 300 ≤ | < 350 < 350 < 350 GeV, GeV, | 75 150 | 150 | 60 ≤ 120 ≤ |
| | | 0-jet 0-jet, 10 ≤ 1-jet, 120 ≤ 1-jet, 120 ≤ < 350 GeV, 200 ≤ 300 ≤ 300 ≤ | | | | |
| | | | 2-jet, m_{ji} 2-jet, m_{ji} $m_{ji} < 700$ $m_{ji} \ge 700$ $m_{ji} \ge 350$ | | | |
| | | , m _{jj} 350 | | | | |
| | | 2-jet, ^{jj} < 2-jet, | ≥ 350 ≤ 2-jet, | • | • | |
| | | ≥ 2-j- 2-jet, <i>m_{ji}</i> ≥ 2-j- | t, 35 ≥ 2 ≥ 2 | | | |
| | | | 2-je | | | |
| | | \wedge | | | | .= |
| | | $gg \rightarrow H \\ \times B_{ZZ^*}$ | $qq \rightarrow Hqq$ | $qq \rightarrow Hlv$ | gg/qq→Hll × B _{zz*} | tīH V B |
| | | × D ZZ* | $\times B_{ZZ^*}$ | $\times B_{ZZ^*}$ | ^ D _{ZZ*} | $\times B_{ZZ^*}$ |

STXS results

ATLAS Preliminary $m_H = 125.09 \text{ GeV}, |y_H| < 2.5$ $\sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1}$

 $\mathbf{\Sigma}$ 0.8× \mathbf{O} -0.6 -0.4-0.2-0-0.2 -0.4 -0.6 --0.8

_1

ATLAS-CONF-2020-027

Parametrizations using coupling modifier ("kappa")

| Production | Loops | Main | Effective | Resolved modifier |
|-------------------------|------------------|--------------|------------------------|--|
| Froduction | Loops | interference | modifier | Resolved modifier |
| $\sigma(\rm ggF)$ | \checkmark | t–b | κ_g^2 | $1.040 \kappa_t^2 + 0.002 \kappa_b^2$ - |
| $\sigma(\text{VBF})$ | - | - | - | $0.733 \kappa_W^2 + 0.267 \kappa_Z^2$ |
| $\sigma(qq/qg \to ZH)$ | - | - | - | κ_Z^2 |
| $\sigma(qg \to ZH)$ | | t–Z | K(ZII) | $2.456 \kappa_Z^2 + 0.456 \kappa_t^2$ |
| 0(99 / 211) | · | 0 2 | $\kappa_{(ggZH)}$ | $-0.011 \kappa_Z \kappa_b + 0.00$ |
| $\sigma(WH)$ | - | - | - | κ_W^2 |
| $\sigma(t\bar{t}H)$ | - | - | - | κ_t^2 |
| $\sigma(tHW)$ | - | t–W | - | $2.909\kappa_t^2 + 2.310\kappa_W^2$ |
| $\sigma(tHq)$ | - | t–W | - | $2.633 \kappa_t^2 + 3.578 \kappa_W^2$ |
| $\sigma(b\bar{b}H)$ | - | - | - | κ_b^2 |
| Partial decay wid | $^{\mathrm{th}}$ | | | |
| Γ^{bb} | - | - | - | κ_b^2 |
| Γ^{WW} | - | - | - | κ_W^2 |
| Γ^{gg} | \checkmark | t–b | κ_g^2 | $1.111 \kappa_t^2 + 0.012 \kappa_b^2$ |
| $\Gamma^{	au	au}$ | - | - | - | $\kappa_{	au}^2$ |
| Γ^{ZZ} | - | - | - | κ_Z^2 |
| Γ^{cc} | - | - | - | $\kappa_c^2 \ (= \kappa_t^2)$ |
| | | | | $1.589 \kappa_W^2 + 0.072 \kappa_t^2$ |
| $\Gamma^{\gamma\gamma}$ | \checkmark | t–W | κ_γ^2 | $+0.009 \kappa_W \kappa_\tau + 0.0$ |
| | | | | $-0.002 \kappa_t \kappa_b - 0.00$ |
| $\Gamma^{Z\gamma}$ | \checkmark | t–W | $\kappa^2_{(Z\gamma)}$ | $1.118\kappa_W^2 - 0.125\kappa_W$ |
| Γ^{ss} | - | - | - | $\kappa_s^2 \ (= \kappa_b^2)$ |
| $\Gamma^{\mu\mu}$ | - | - | - | κ^2_μ |
| Total width $(B_{i.} =$ | $= B_{u.} = 0$ |)) | | |
| | | | | $0.581 \kappa_b^2 + 0.215 \kappa_W^2$ |
| | | | | $+0.063 \kappa_{	au}^2 + 0.026 \kappa_{	au}^2$ |
| Γ_H | \checkmark | - | κ_{H}^{2} | $+0.0023 \kappa_{\gamma}^2 + 0.001$ |
| | | | | $+0.0004 \kappa_{s}^{2} + 0.000$ |

Chen Zhou (Wisconsin)

Higgs Hunting

 $-0.038 \,\kappa_t \kappa_b - 0.005 \,\kappa_t \kappa_c$ $\hat{\mathfrak{c}}_Z^2$

 $-1.903 \kappa_Z \kappa_t$ $003 \kappa_t \kappa_b$

 $\kappa_W - 4.220 \kappa_t \kappa_W$ $k_W^2 - 5.211 \kappa_t \kappa_W$

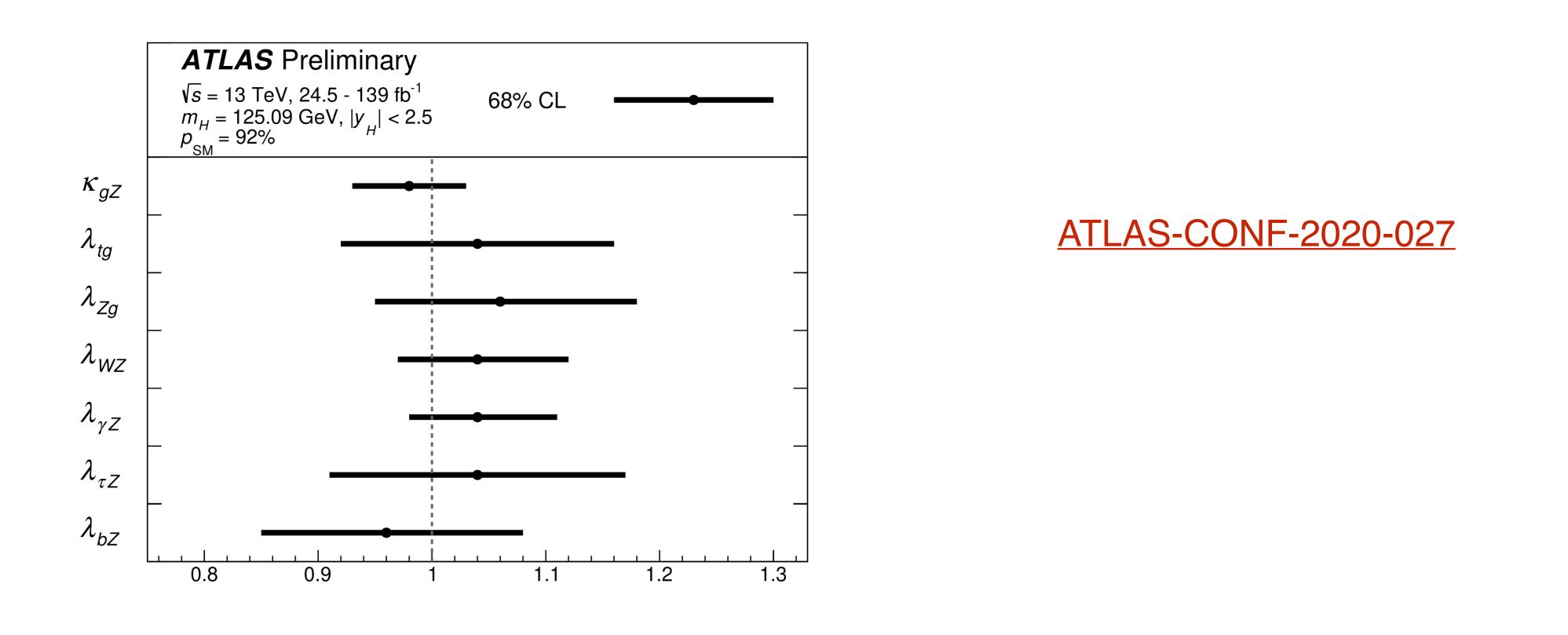
ATLAS-CONF-2020-027

 $-0.123 \kappa_t \kappa_b$

 $\kappa_t^2 - 0.674 \,\kappa_W \kappa_t$ $.008 \kappa_W \kappa_b$ $02 \kappa_t \kappa_\tau$ $\kappa_W \kappa_t + 0.004 \kappa_t^2 + 0.003 \kappa_W \kappa_b$

 $k_W^2 + 0.082 \kappa_g^2$ $\frac{6 \kappa_Z^2 + 0.029 \kappa_c^2}{015 \kappa_{(Z\gamma)}^2} \\
\frac{0022 \kappa_\mu^2}{0022 \kappa_\mu^2}$

Coupling modifier interpretation: no assumption on total width



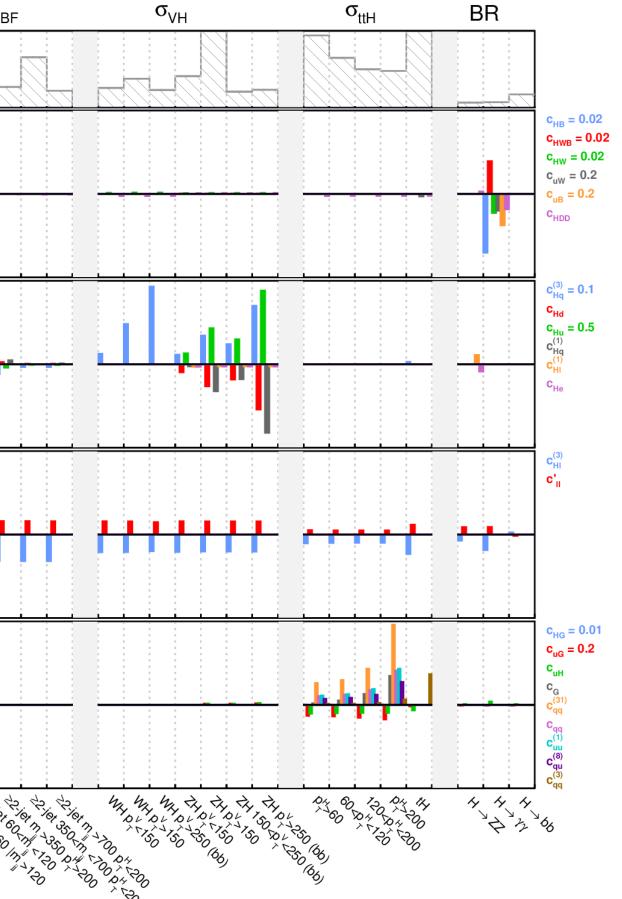
Wilson coefficients

| Wilson coefficient | Operator | Wilson coefficient | Operator |
|-----------------------------------|---|--|---|
| $c_{H\square}$ | $(H^{\dagger}H)\Box(H^{\dagger}H)$ | c_{uG} | $(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{H} G^A_{\mu\nu}$ |
| c_{HDD} | $\left(H^{\dagger}D^{\mu}H\right)^{*}\left(H^{\dagger}D_{\mu}H\right)$ | c_{uW} | $(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{H} W^I_{\mu\nu}$ |
| c_{HG} | $H^{\dagger}HG^{A}_{\mu\nu}G^{A\mu\nu}$ | c_{uB} | $(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{H} B_{\mu\nu}$ |
| c_{HB} | $H^{\dagger}H B_{\mu\nu}B^{\mu\nu}$ | c_{ll}' | $(\bar{l}_p \gamma_\mu l_t) (\bar{l}_r \gamma^\mu l_s)$ |
| c_{HW} | $H^{\dagger}H W^{I}_{\mu\nu}W^{I\mu\nu}$ | $c_{qq}^{\scriptscriptstyle (1)}$ | $(\bar{q}_p \gamma_\mu q_t) (\bar{q}_r \gamma^\mu q_s)$ |
| c_{HWB} | $H^{\dagger}\tau^{I}H W^{I}_{\mu\nu}B^{\mu\nu}$ | $c^{(3)}_{qq}$ | $(\bar{q}_p \gamma_\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$ |
| c_{eH} | $(H^{\dagger}H)(\bar{l}_{p}e_{r}H)$ | c_{qq} | $(\bar{q}_p \gamma_\mu q_t) (\bar{q}_r \gamma^\mu q_s)$ |
| c_{uH} | $(H^{\dagger}H)(\bar{q}_{p}u_{r}H)$ | $c^{(31)}_{qq}$ | $(\bar{q}_p \gamma_\mu \tau^I q_t) (\bar{q}_r \gamma^\mu \tau^I q_s)$ |
| c_{dH} | $(H^{\dagger}H)(\bar{q}_{p}d_{r}\tilde{H})$ | c_{uu} | $(\bar{u}_p \gamma_\mu u_r)(\bar{u}_s \gamma^\mu u_t)$ |
| $c_{Hl}^{\scriptscriptstyle (1)}$ | $(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{l}_{p}\gamma^{\mu}l_{r})$ | $c^{\scriptscriptstyle(1)}_{oldsymbol{u}oldsymbol{u}}$ | $(\bar{u}_p \gamma_\mu u_t)(\bar{u}_r \gamma^\mu u_s)$ |
| $c_{Hl}^{\scriptscriptstyle (3)}$ | $(H^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}H)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$ | $c_{qu}^{\scriptscriptstyle (1)}$ | $(\bar{q}_p \gamma_\mu q_t) (\bar{u}_r \gamma^\mu u_s)$ |
| c_{He} | $(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{e}_{p}\gamma^{\mu}e_{r})$ | $c_{ud}^{\scriptscriptstyle (8)}$ | $(\bar{u}_p \gamma_\mu T^A u_r) (\bar{d}_s \gamma^\mu T^A d_t)$ |
| $c_{Hq}^{\scriptscriptstyle (1)}$ | $(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{q}_{p}\gamma^{\mu}q_{r})$ | $c_{qu}^{\scriptscriptstyle{(8)}}$ | $(\bar{q}_p \gamma_\mu T^A q_r)(\bar{u}_s \gamma^\mu T^A u_t)$ |
| $c_{Hq}^{\scriptscriptstyle (3)}$ | $(H^{\dagger}i\overleftrightarrow{D}^{I}_{\mu}H)(\bar{q}_{p}\tau^{I}\gamma^{\mu}q_{r})$ | $c_{qd}^{\scriptscriptstyle (8)}$ | $(\bar{q}_p \gamma_\mu T^A q_r) (\bar{d}_s \gamma^\mu T^A d_t)$ |
| c_{Hu} | $(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{u}_{p}\gamma^{\mu}u_{r})$ | c_W | $\epsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$ |
| c_{Hd} | $(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)(\bar{d}_{p}\gamma^{\mu}d_{r})$ | c_G | $f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$ |

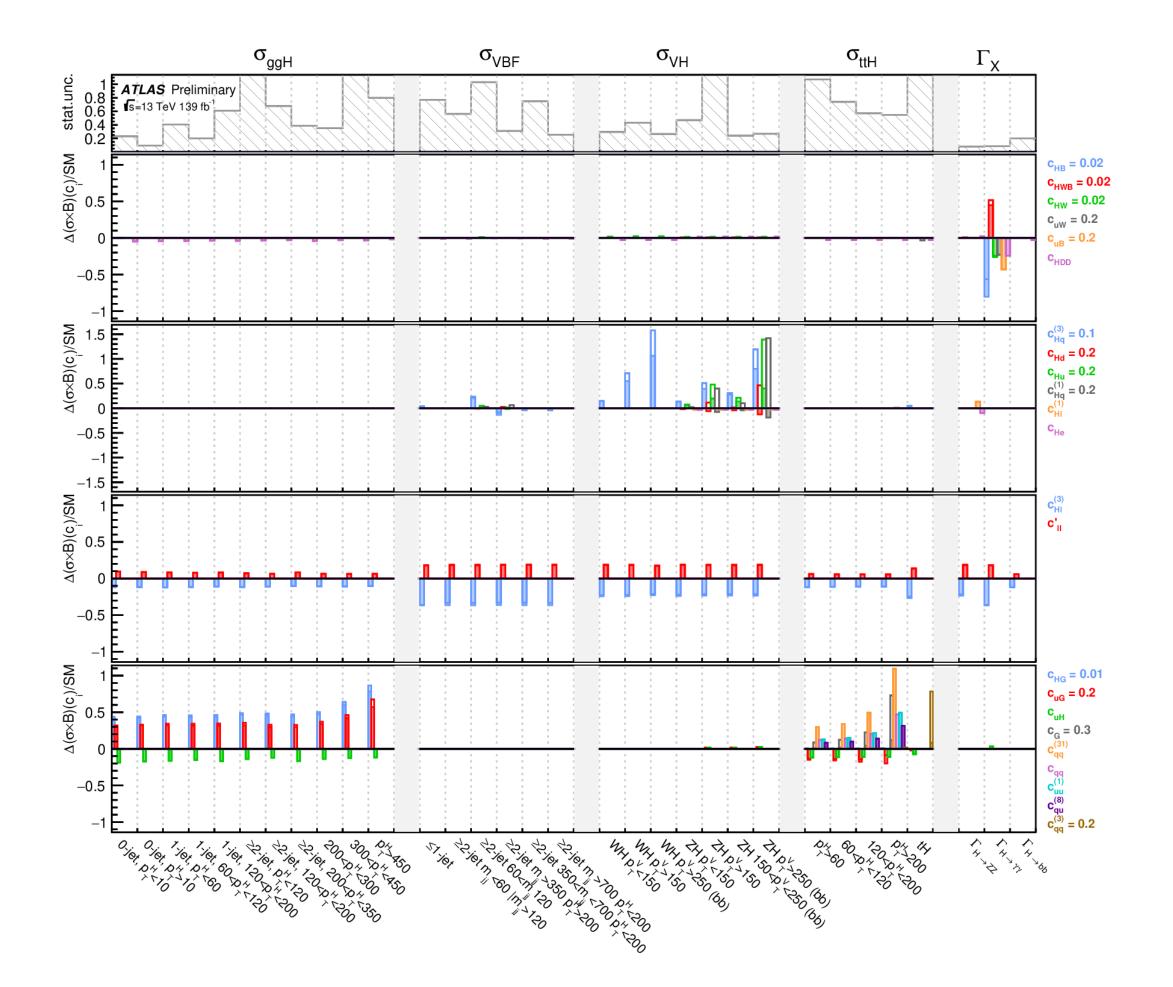
<u>ATL-PHYS-CONF-2020-053</u>

unting 2021/9/21

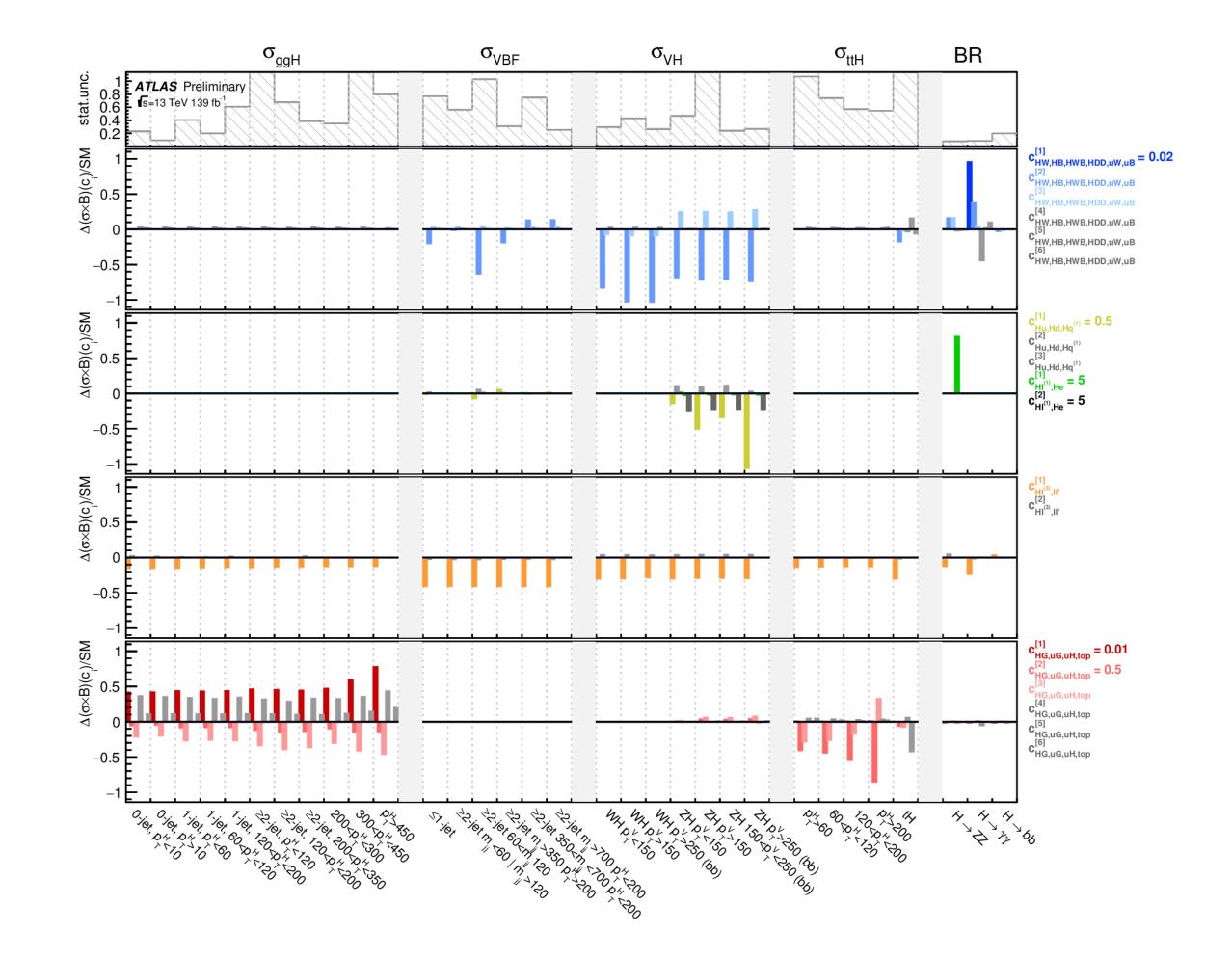
 σ_{ggH} σ_{VBF} ATLAS Preliminary s=13 TeV 139 fb⁻¹ stat. Õ 0.4 0.2 $\Delta(\sigma \times B)(c_i)/SM$ -0.5 ∆(σ×B)(c₁)/SM 0.5 -0.5 ∆(σ×B)(c,)/SM -0.5 ∆(σ×B)(c)/SM -0.5



<u>ATL-PHYS-CONF-2020-053</u>



<u>ATL-PHYS-CONF-2020-053</u>



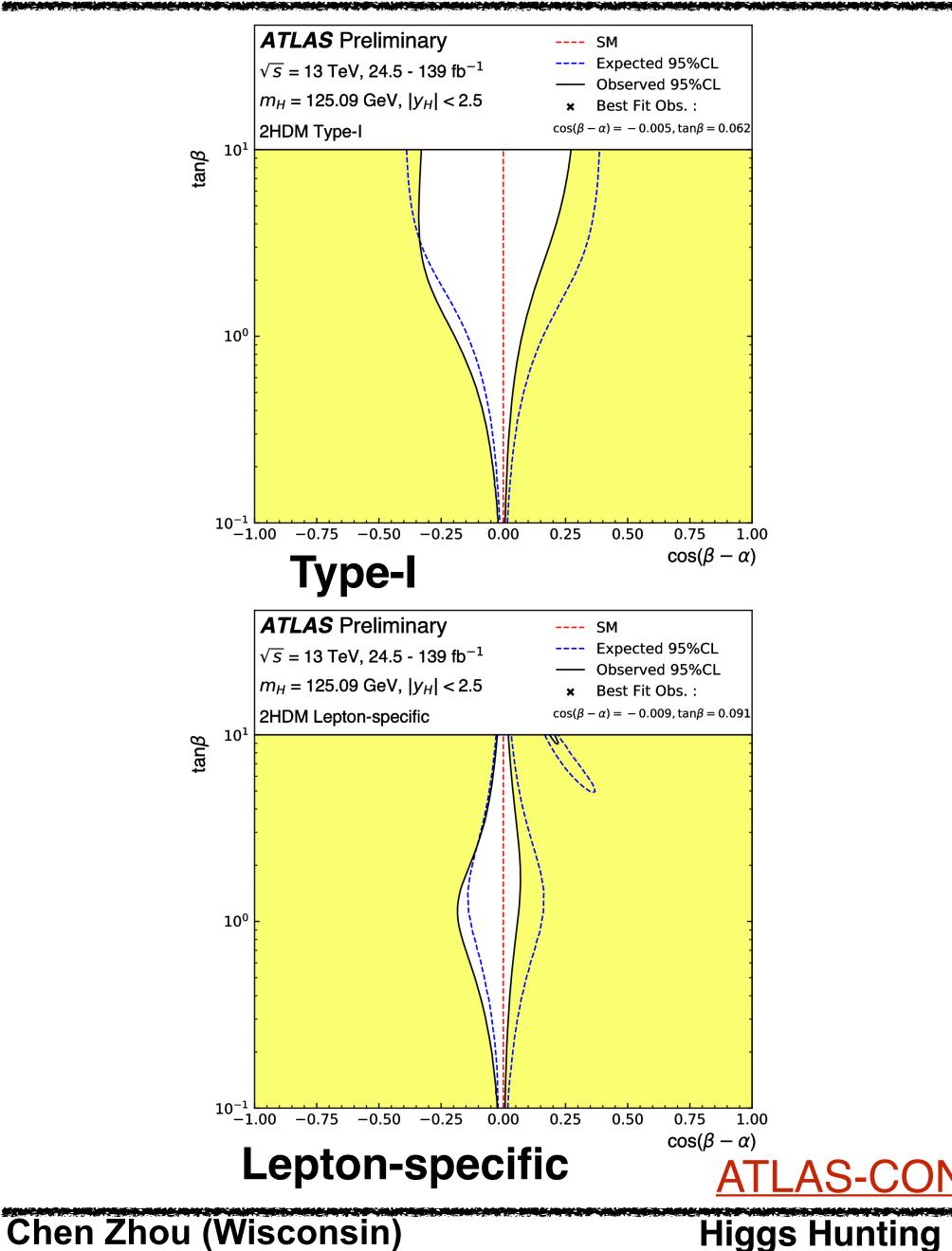
<u>ATL-PHYS-CONF-2020-053</u>

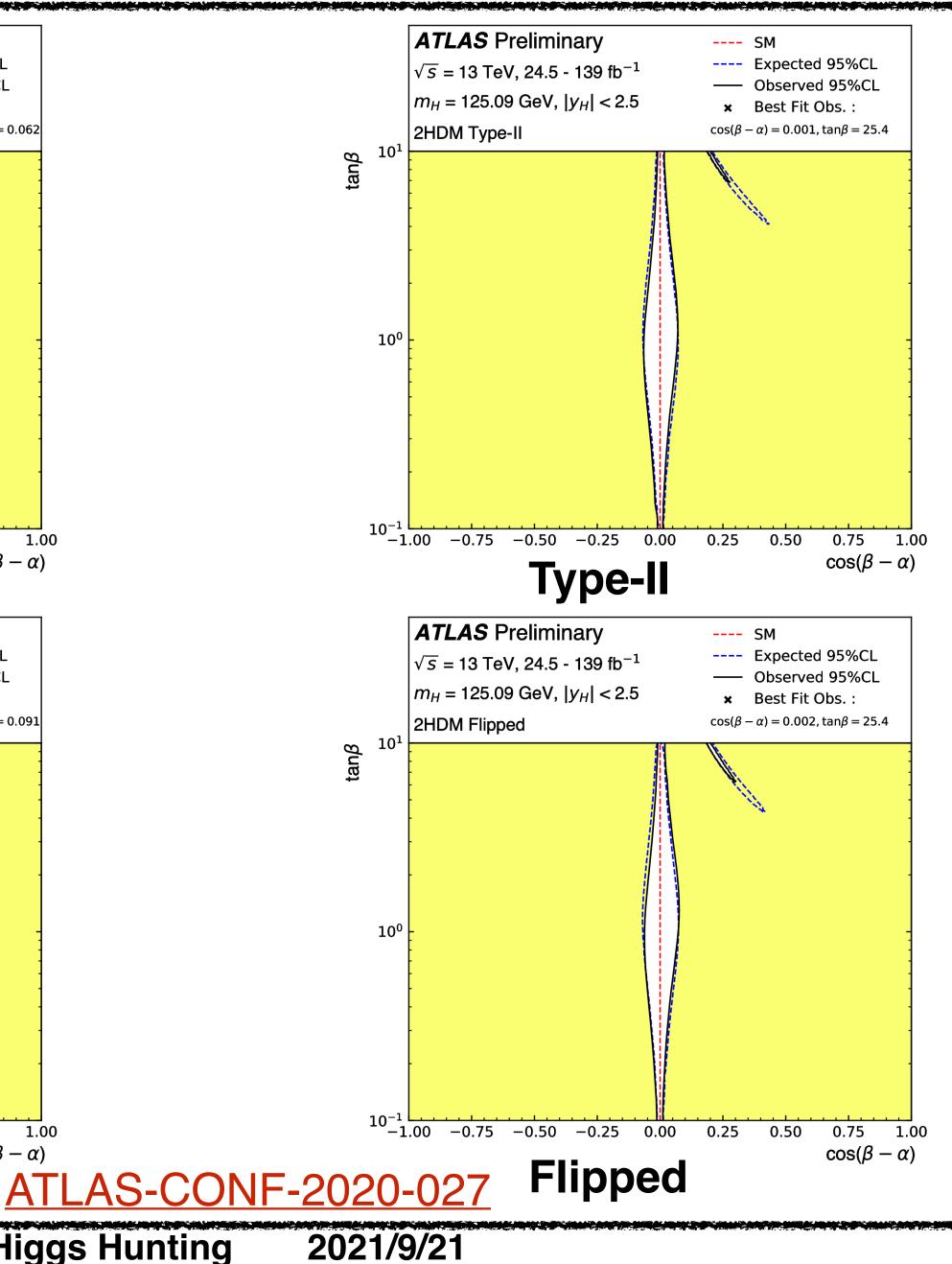
| | ATI | LAS | S Pre | | | | | | 2.52 | 139 _H < | |
|--|-------------------------------------|-----------------------|------------------------|----------------------------|--------------------------|---|--------------------------|--|--|--|---------------|
| $m{c}_{Hq}^{(3)}$ | 1 | -0.74 | 0.28 | 0.75 | -0.38 | 0.24 | 0.07 | 0.12 | 0.64 | 0.70 | $-0.8 \times$ |
| С ^[1] НІ ⁽¹⁾ ,Не | -0.74 | 1 | -0.19 | -0.91 | 0.19 | -0.05 | 0.05 | 0.00 | -0.44 | -0.95 | d d |
| $m{c}_{HI^{(3)},II'}^{[1]}$ | 0.28 | -0.19 | 1 | 0.25 | -0.54 | 0.47 | 0.05 | 0.95 | -0.40 | 0.44 | -0.6 |
| $C^{I J}_{Hd,Hq^{(1)},Hu}$ | 0.75 | -0.91 | 0.25 | 1 | -0.24 | 0.12 | 0.06 | 0.09 | 0.30 | 0.90 | -0.4 -0.2 |
| С ^[1] НG,иG,иH,top | -0.38 | 0.19 | -0.54 | -0.24 | 1 | -0.69 | -0.20 | -0.66 | -0.09 | -0.33 | |
| с [2] НG,иG,иH,top | 0.24 | -0.05 | 0.47 | 0.12 | -0.69 | 1 | 0.19 | 0.58 | 0.00 | 0.18 | -0 -0.2 |
| $m{c}^{[3]}_{HG, uG, uH, top}$ | 0.07 | 0.05 | 0.05 | 0.06 | -0.20 | 0.19 | 1 | 0.11 | 0.09 | -0.03 | -0.2 |
| C ^[1] HW,HB,HWB,HDD,uB,uW | 0.12 | 0.00 | 0.95 | 0.09 | -0.66 | 0.58 | 0.11 | 1 | -0.49 | 0.27 | -0.4 |
| С ^[2] HW,HB,HWB,HDD,uB,uW | 0.64 | -0.44 | -0.40 | 0.30 | -0.09 | 0.00 | 0.09 | -0.49 | 1 | 0.21 | -0.8 |
| С ^[3] HW,HB,HWB,HDD,uB,uW | 0.70 | -0.95 | 0.44 | 0.90 | -0.33 | 0.18 | -0.03 | 0.27 | 0.21 | 1 | 1 |
| | C ⁽³⁾ C _{Hq} | С ^[1] , He | C ^[1] , II' | $c^{[1]}_{Hd,Hq^{(1)},Hu}$ | $c^{[1]}_{HG,uG,uH,top}$ | <mark>С</mark> ^[2] НG,uG,uH,top | $c^{[3]}_{HG,uG,uH,top}$ | С ^[1] СНW,НВ,НWВ,НDD,иВ,иW | С ^[2] СНW,НВ,НWВ,НDD,иВ,иW | С ^[3] СНW,НВ,НWВ,НDD,uB,uW | |

| С ⁽³⁾ С Нд | С ^[1] , HI ⁽¹⁾ , He | C ^[1] _{HI⁽³⁾,II'} | С ^[1] С Нd, Нq ⁽¹⁾ , Ни | [1] HG,uG,uH,top |
|---------------------------------|---|--|--|---------------------|
| | | | S | EH |

<u>ATL-PHYS-CONF-2020-053</u>

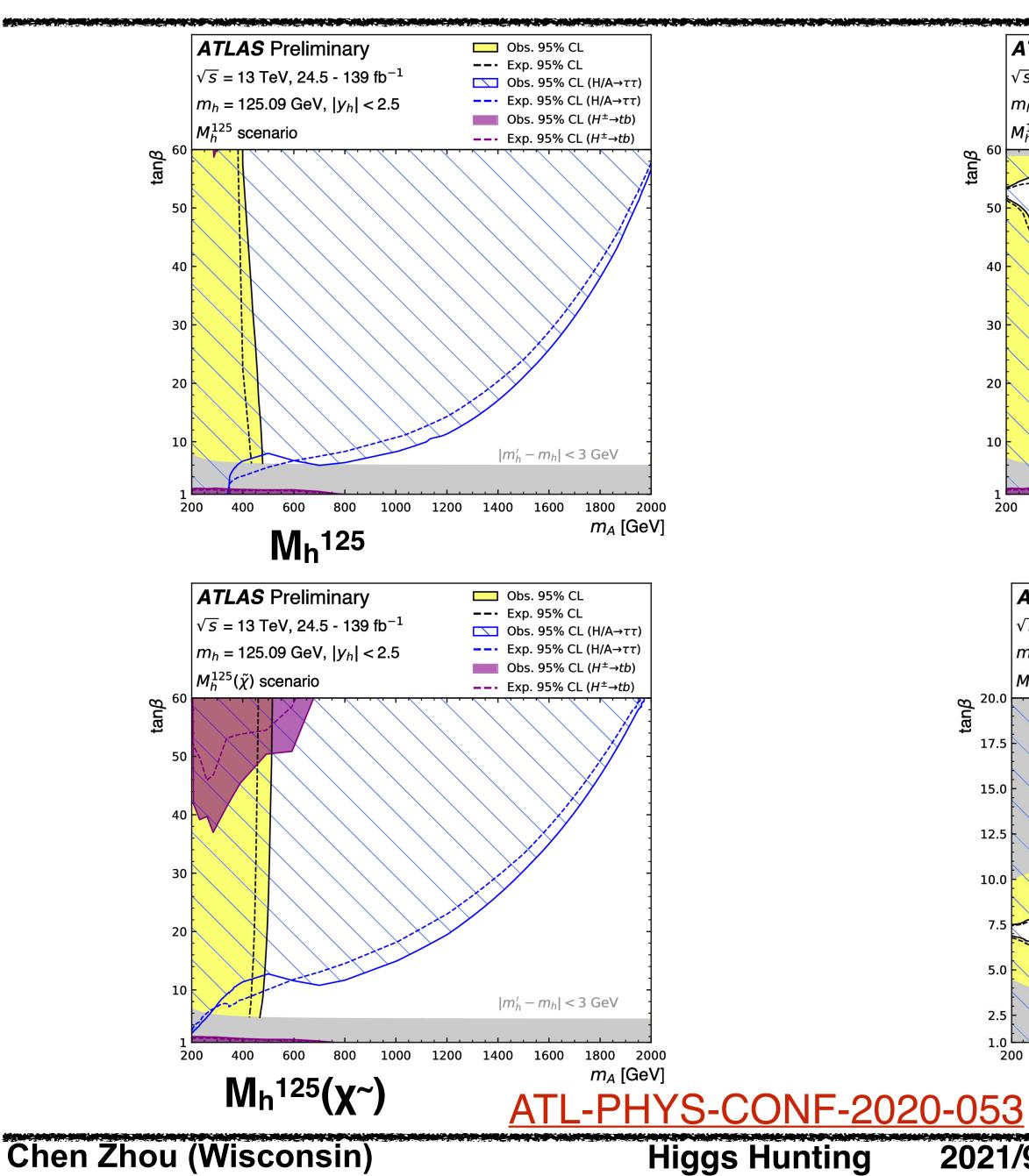
Constraints on Two Higgs Doublet Model (2HDM)

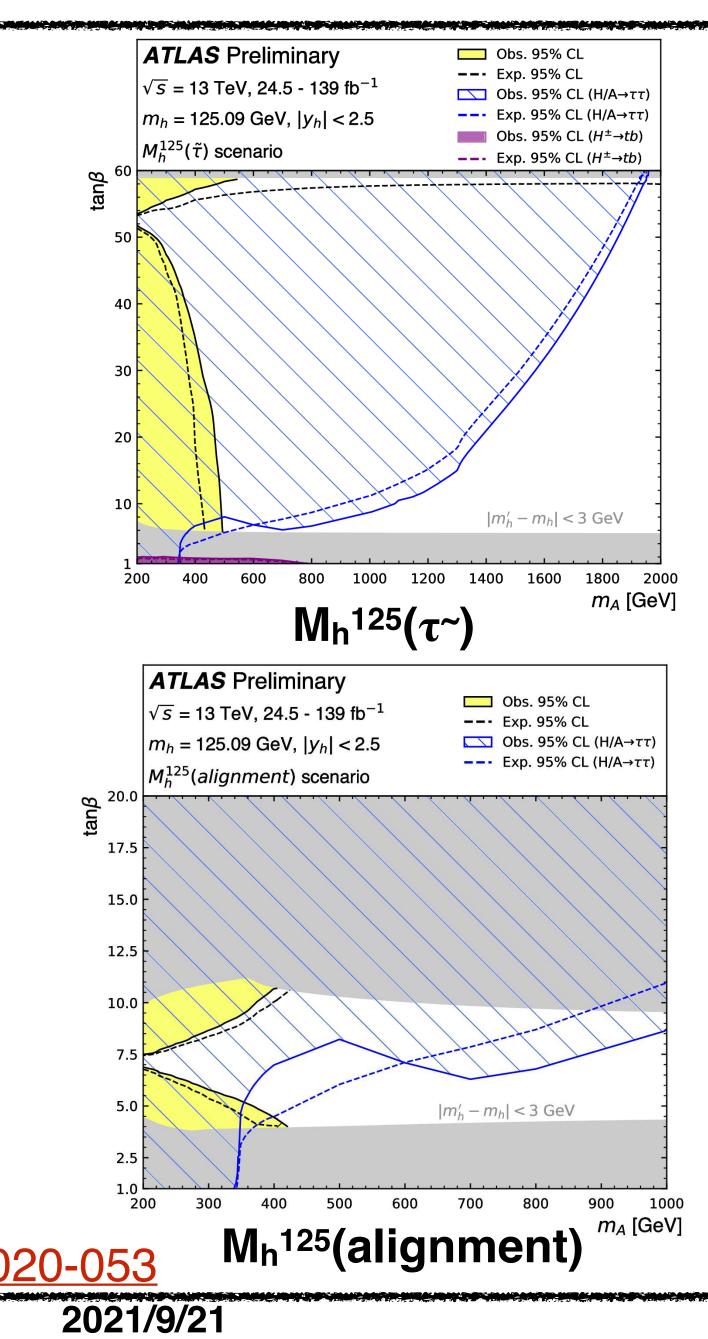




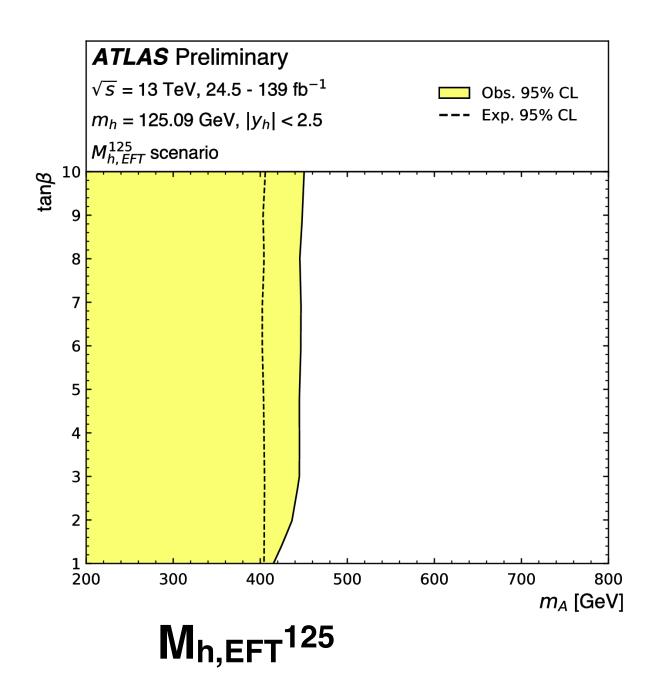
33

Constraints on Minimal Supersymmetric Standard Model (MSSM)





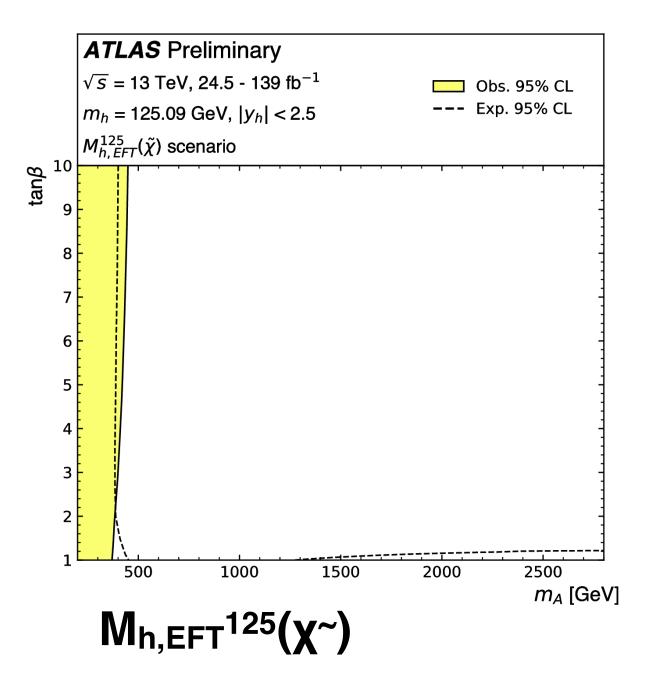
Constraints on Minimal Supersymmetric Standard Model (MSSM)

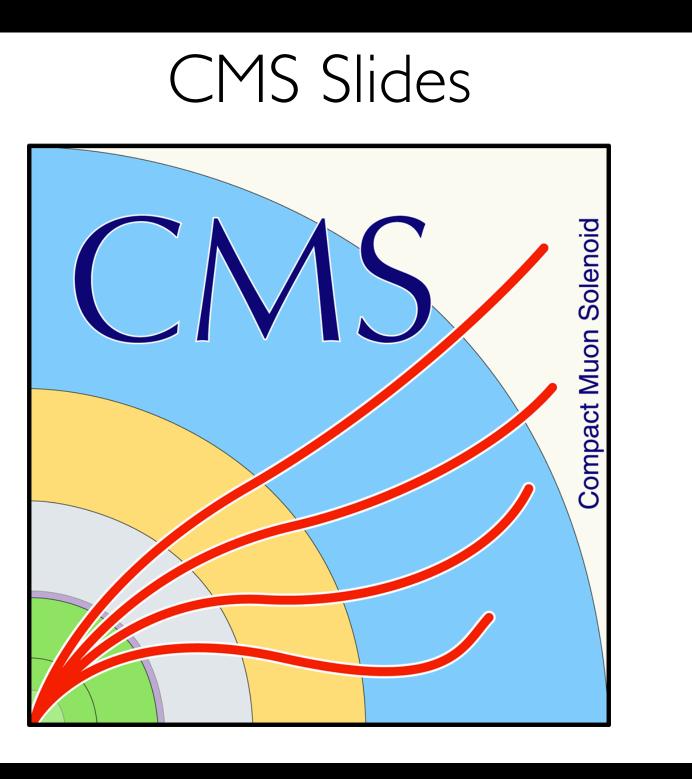


ATL-PHYS-CONF-2020-053

Chen Zhou (Wisconsin)

Higgs Hunting







(LLR, Ecole Polytechnique, CNRS) On behalf of the CMS Collaboration

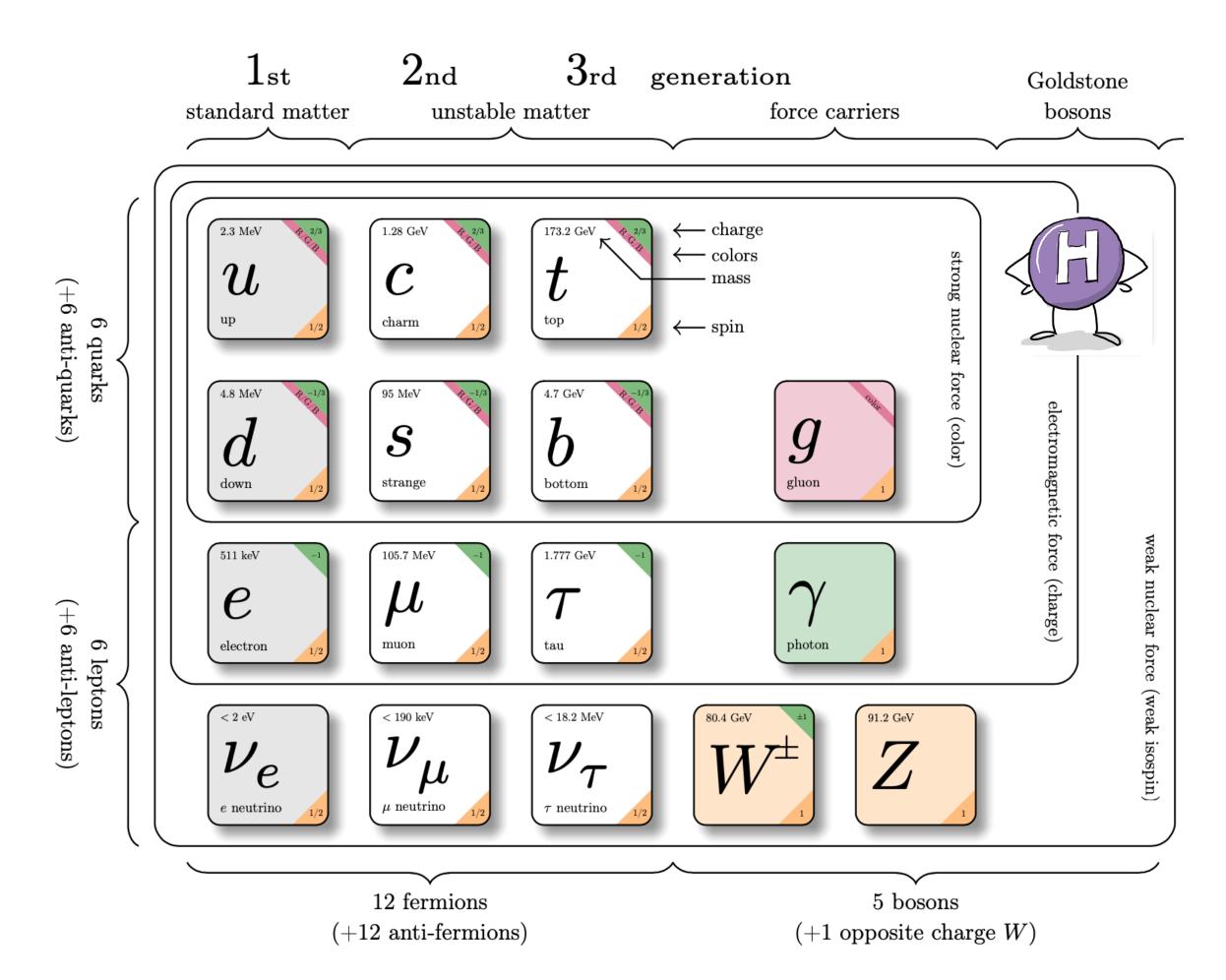
Higgs Hunting 21/09/2021

CMS Higgs Combination

Matteo Bonanomi



The Higgs boson is a scalar particle, regulates the EWSB mechanism, and it couples with:

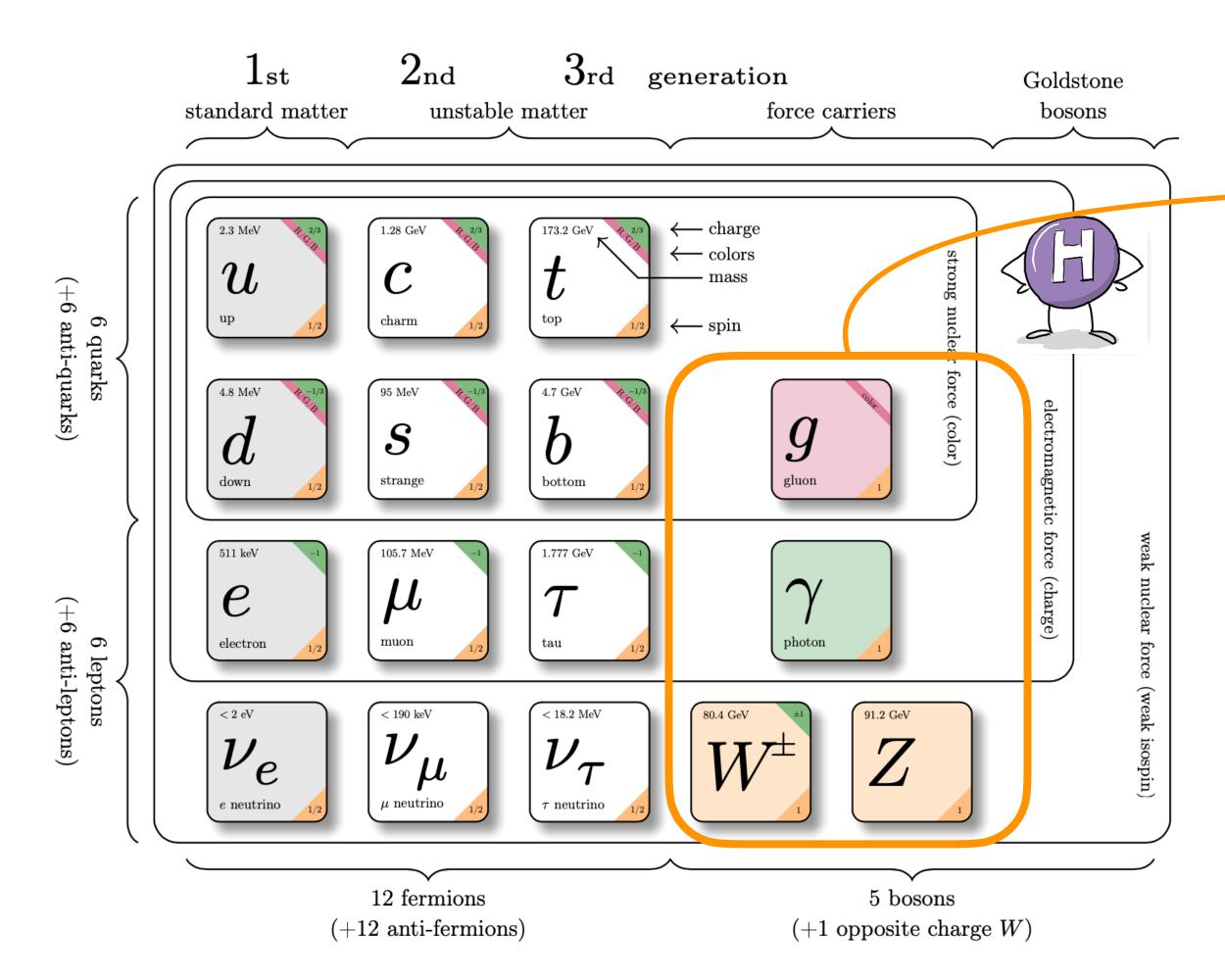






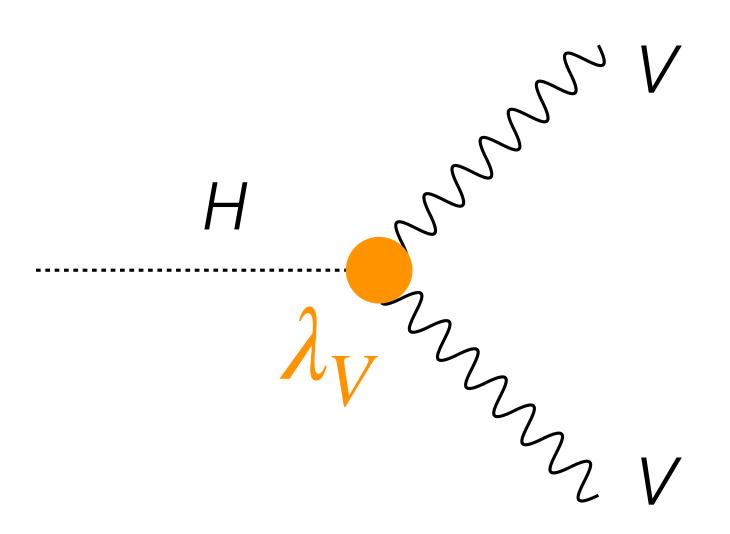


The Higgs boson is a scalar particle, regulates the EWSB mechanism, and it couples with:



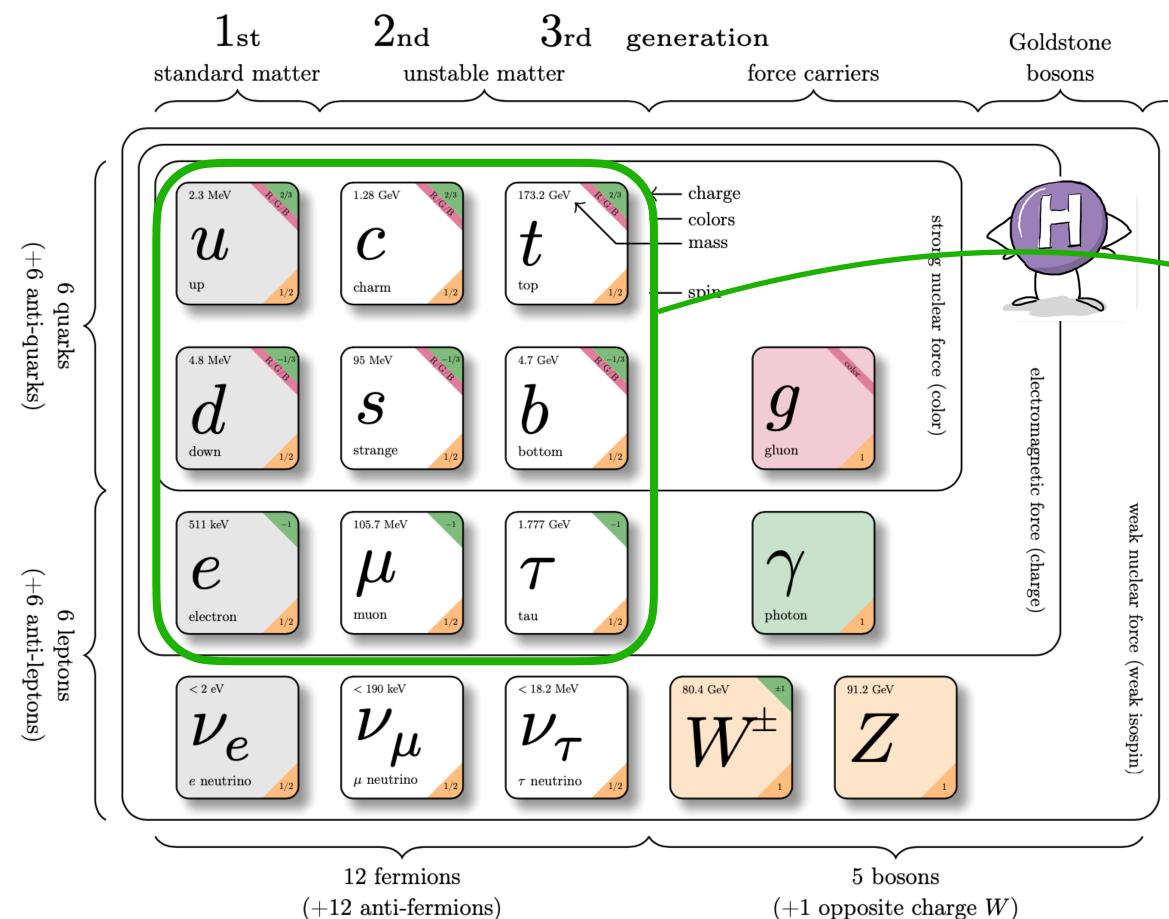














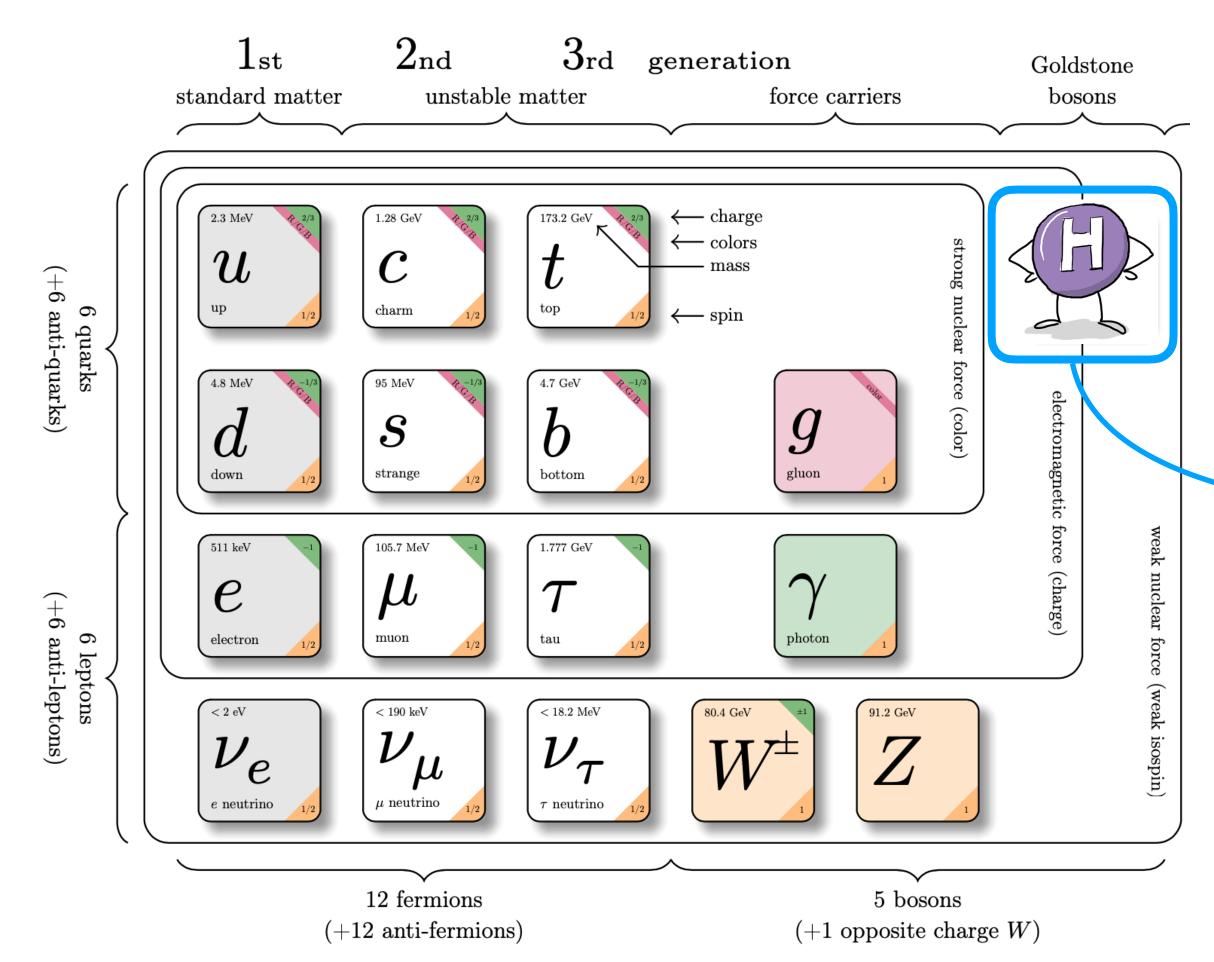
The Higgs boson is a scalar particle, regulates the EWSB mechanism, and it couples with:

Couplings to gauge bosons: $\lambda_V = -m_V^2$ Couplings to fermions: $\lambda_f = \frac{\sqrt{2}}{m_f}$ Н











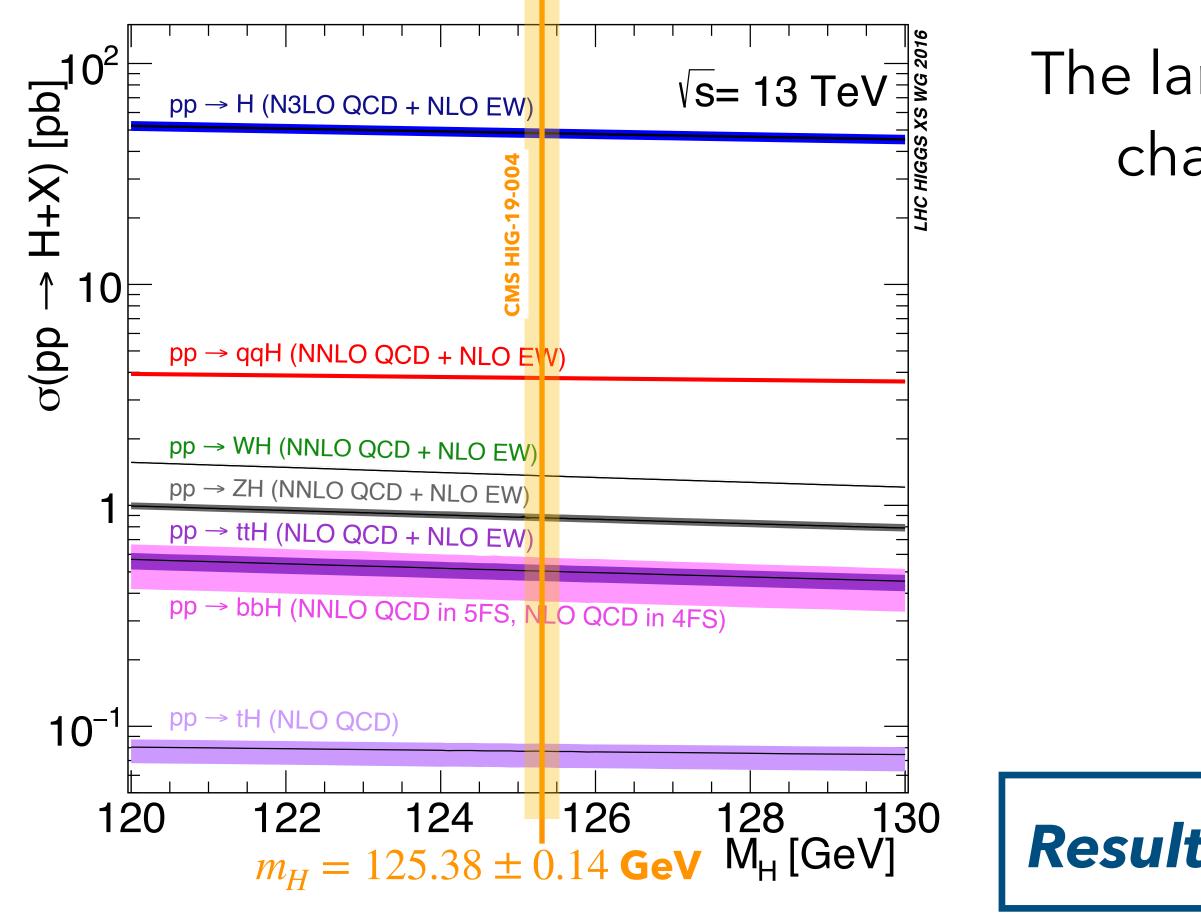
The Higgs boson is a scalar particle, regulates the EWSB mechanism, and it couples with:

Couplings to gauge bosons: $\lambda_V = -m_V^2$ Couplings to fermions: $\lambda_f = \frac{\sqrt{2}}{m_f}$ Higgs boson self-coupling: $\lambda_H =$ $\frac{m_H^2}{v^2}$ Н





The Higgs sector at the LHC



Higgs Hunling

In 2015 LHC started the Run II phase, opening the doors for the precision physics era, with the goal of precision measurements of the Higgs boson couplings

> The large statistics and combination of different decay channels provide comprehensive assessment of H boson properties:

Production and decay rates

Higgs boson self coupling

EFT interpretations in STXS

Results from partial Run-II CMS Combination shown









The input analyses

Higgs Hunting

| Decay channel | Luminosity (fb ⁻¹) | ggH | VBF | VH | ttH |
|--|--------------------------------|--------------|--------------|--------------|--------------|
| $H \rightarrow \gamma \gamma$ | 77 | \checkmark | \checkmark | | \checkmark |
| $H \rightarrow ZZ^* \rightarrow 4\ell$ | 137 | \checkmark | \checkmark | \checkmark | \checkmark |
| $H \rightarrow WW$ | 36 | \checkmark | \checkmark | \checkmark | |
| $H \rightarrow bb$ | 36 (ggH) - 77 (others) | \checkmark | | \checkmark | \checkmark |
| $H \rightarrow \tau \tau$ | 77 | \checkmark | \checkmark | | |
| ttH multilepton | 77 | | | | \checkmark |
| $H \rightarrow \mu\mu$ | 36 | | | | |







References in Backup

CMS-HIG-19-005



7

The input analyses

Higgs Hunting

| Decay channel | Luminosity (fb ⁻¹) | ggH | | | | | |
|-------------------------------|--------------------------------|-----|---------|--------------------------------------|--------------------------------------|--|--|
| $H \rightarrow \gamma \gamma$ | 77 | | | | | | |
| $H \to ZZ^* \to 4\ell$ | 137 | | Doutiol | | | | |
| $H \rightarrow WW$ | 36 | | | | -II dataset(s), sive study of the | | |
| $H \rightarrow bb$ | 36 (ggH) - 77 (others) | | Hbo | son prop | erties. | | |
| $H \rightarrow \tau \tau$ | 77 | | | ntly work n-II comb | | | |
| ttH multilepton | 77 | | | | | | |
| $H \rightarrow \mu\mu$ | 36 | | | | | | |







References in Backup

CMS-HIG-19-005









Scaling of production (i) or decay (f) of the SM Higgs boson as:

$$\mu_i = \frac{\sigma_i}{\left(\sigma_i\right)_{\rm SM}}$$

The combined signal strength modifier is measured to be



$$\mu^f = \frac{B^f}{\left(B^f\right)_{\rm SM}}$$

 $\mu = 1.02 \pm 0.04$ (th) ± 0.04 (exp) ± 0.04 (stat)









Scaling of production (i) or decay (f) of the SM Higgs boson as:

$$\mu_i = \frac{\sigma_i}{\left(\sigma_i\right)_{\rm SM}}$$

$$\mu = 1.02 \pm 0.04$$
(th) ± 0.04 (exp) ± 0.04 (stat)

With the increasing statistics available from Run-II, the systematic uncertainties are becoming the limiting factor for the ultimate precision of the measurements, while statistical uncertainties are substantially reduced in many decay channels



$$\mu^f = \frac{B^f}{\left(B^f\right)_{\rm SM}}$$

The combined signal strength modifier is measured to be



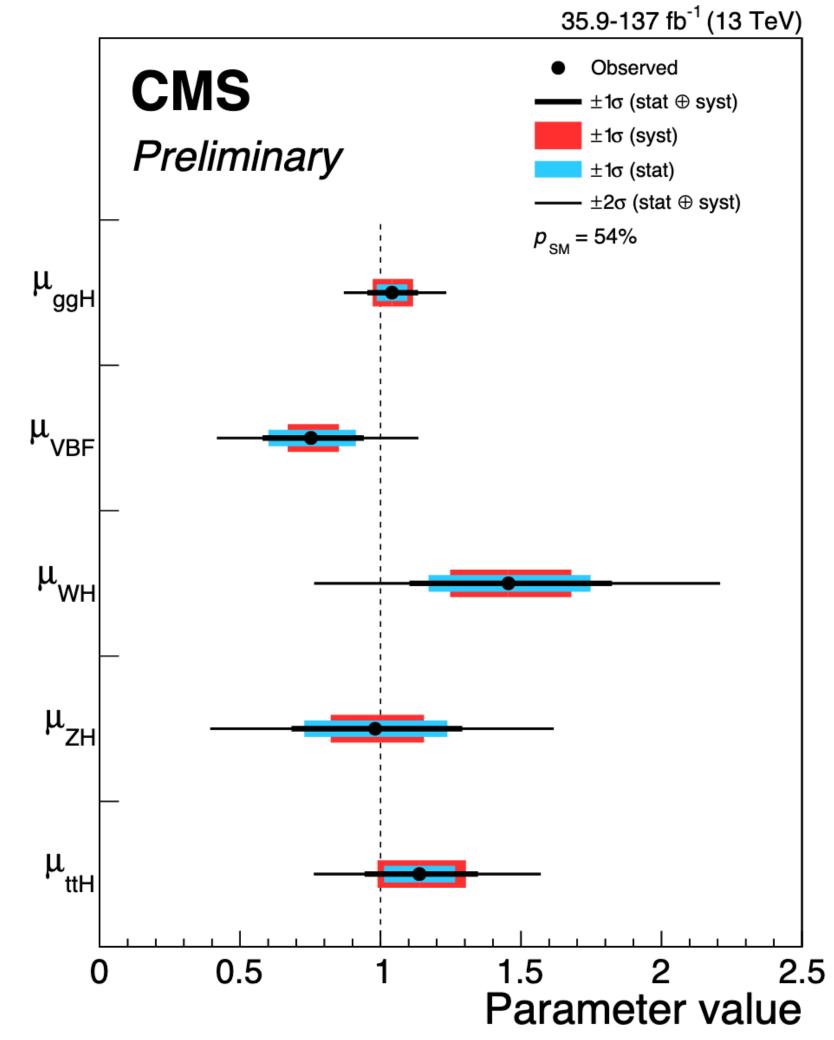


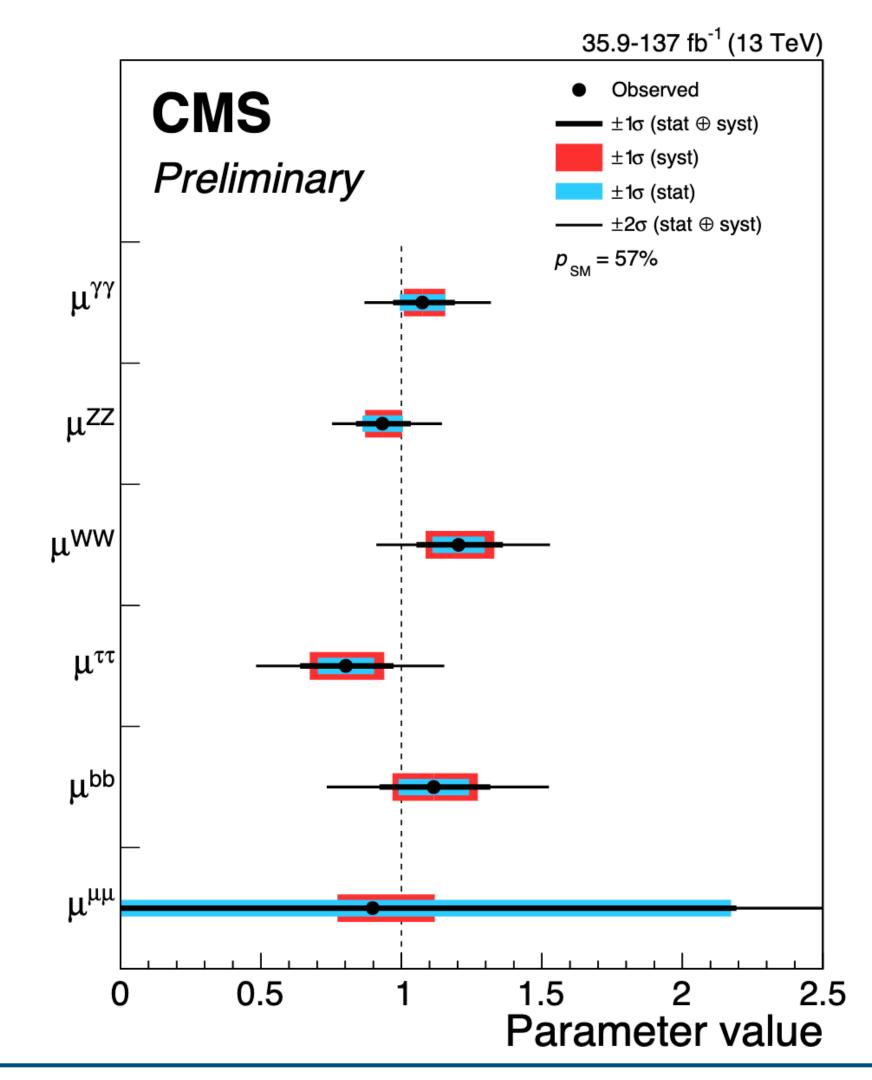






Simultaneous measurement of all the production and decay signal strengths



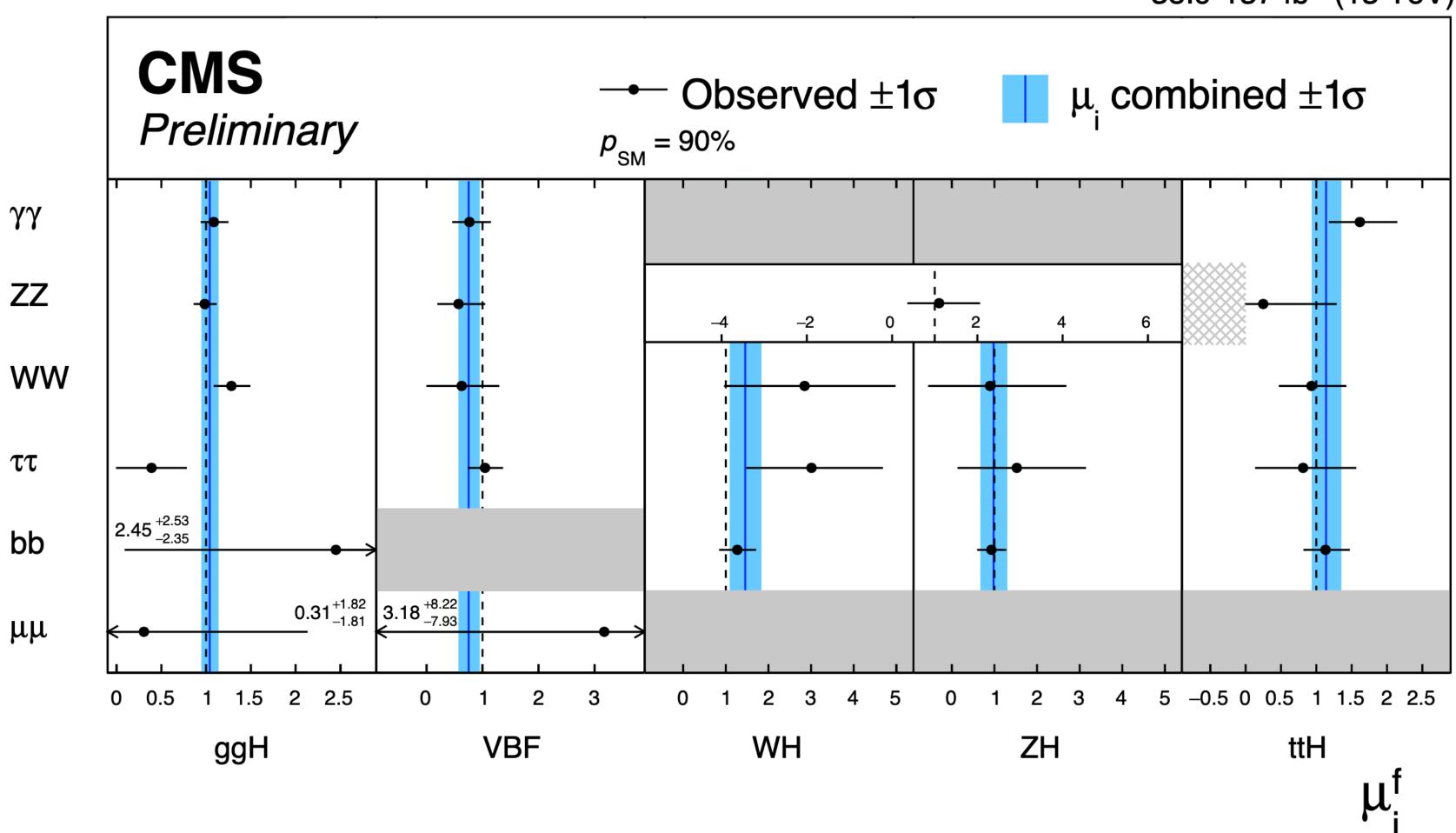














Measurement of **production times decay** μ_i^f from combination across decay channels

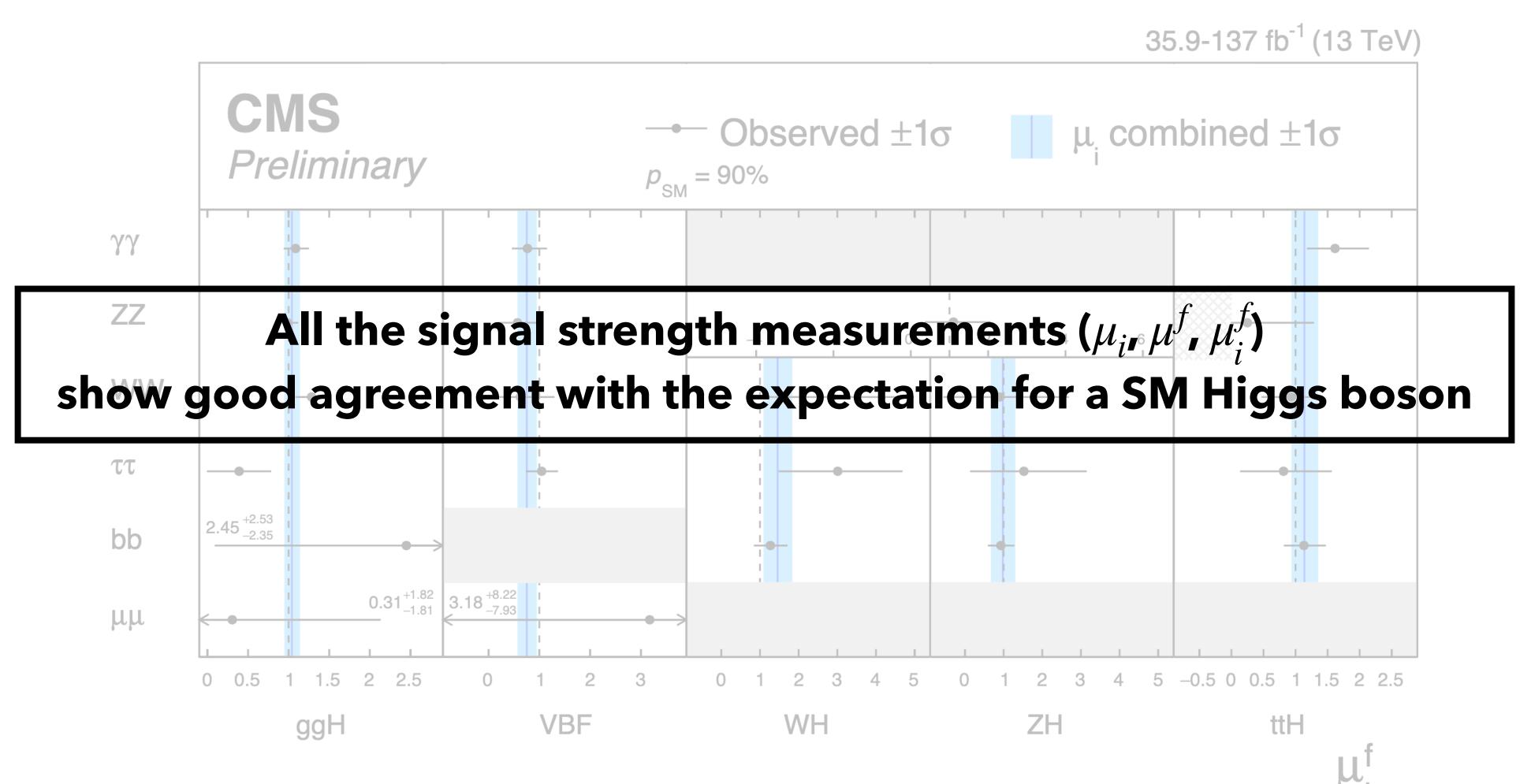
35.9-137 fb⁻¹ (13 TeV)













Measurement of **production times decay** μ_i^f from combination across decay channels

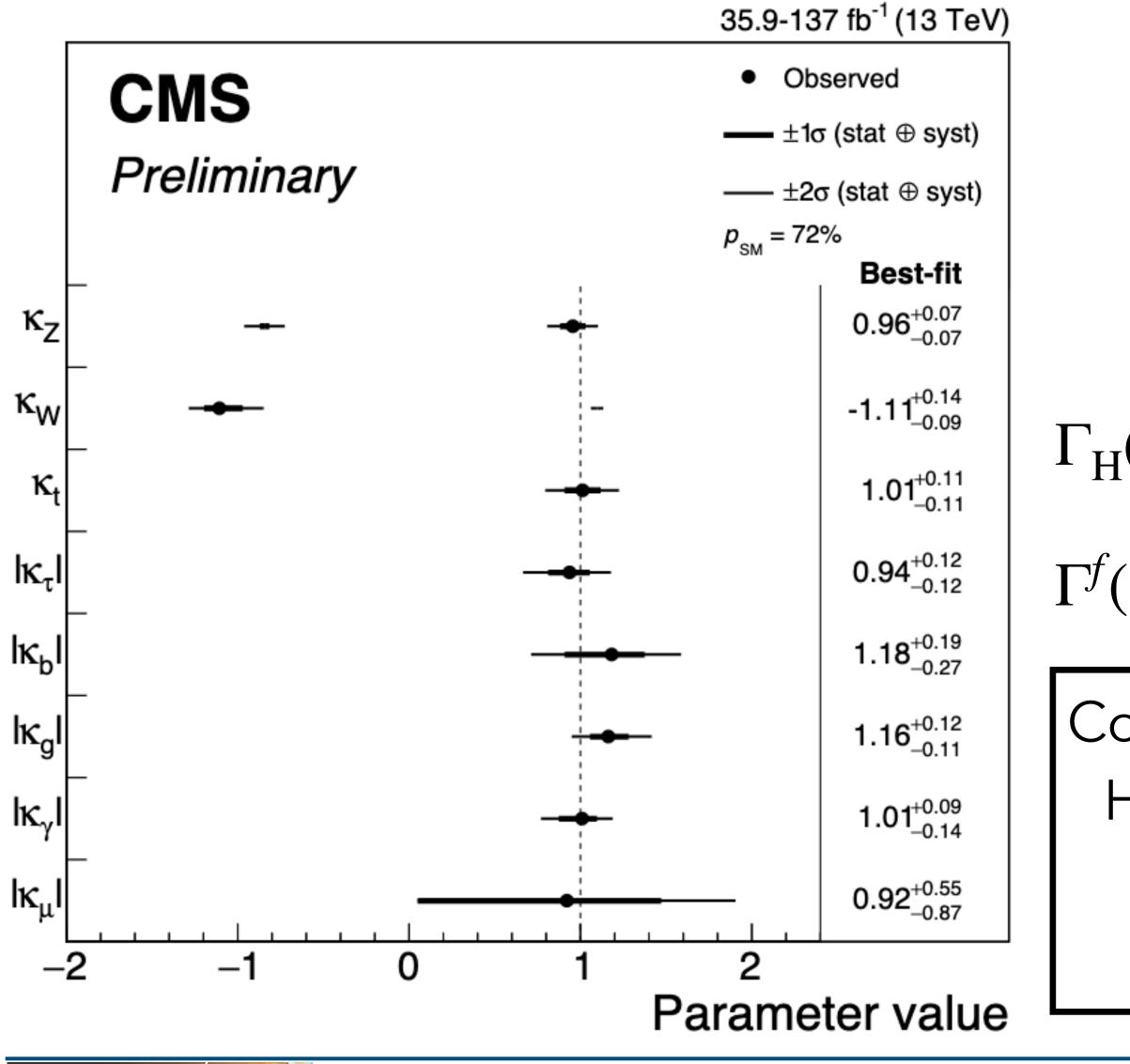








H boson couplings: *k*-framework



Higgs Hunting



Assuming only SM Higgs boson decays:

$$\sigma_i B^f = \frac{\sigma_i(\vec{\kappa}) \Gamma^f(\vec{\kappa})}{\Gamma_{\rm H}(\vec{\kappa})}$$

 $\Gamma_{\rm H}(\vec{\kappa})$: total width of the Higgs boson

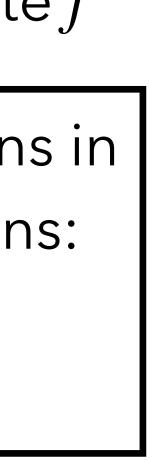
 $\Gamma^{f}(\vec{\kappa})$: partial width of the decay to the final state f

Coupling modifiers $\vec{\kappa}$ to parametrize deviations in HVV and Hff couplings from the SM predictions:

$$\kappa_j^2 = \sigma_j / \sigma_j^{\text{SM}}$$
 or $\kappa_j^2 = \Gamma^j / \Gamma_{\text{SM}}^j$

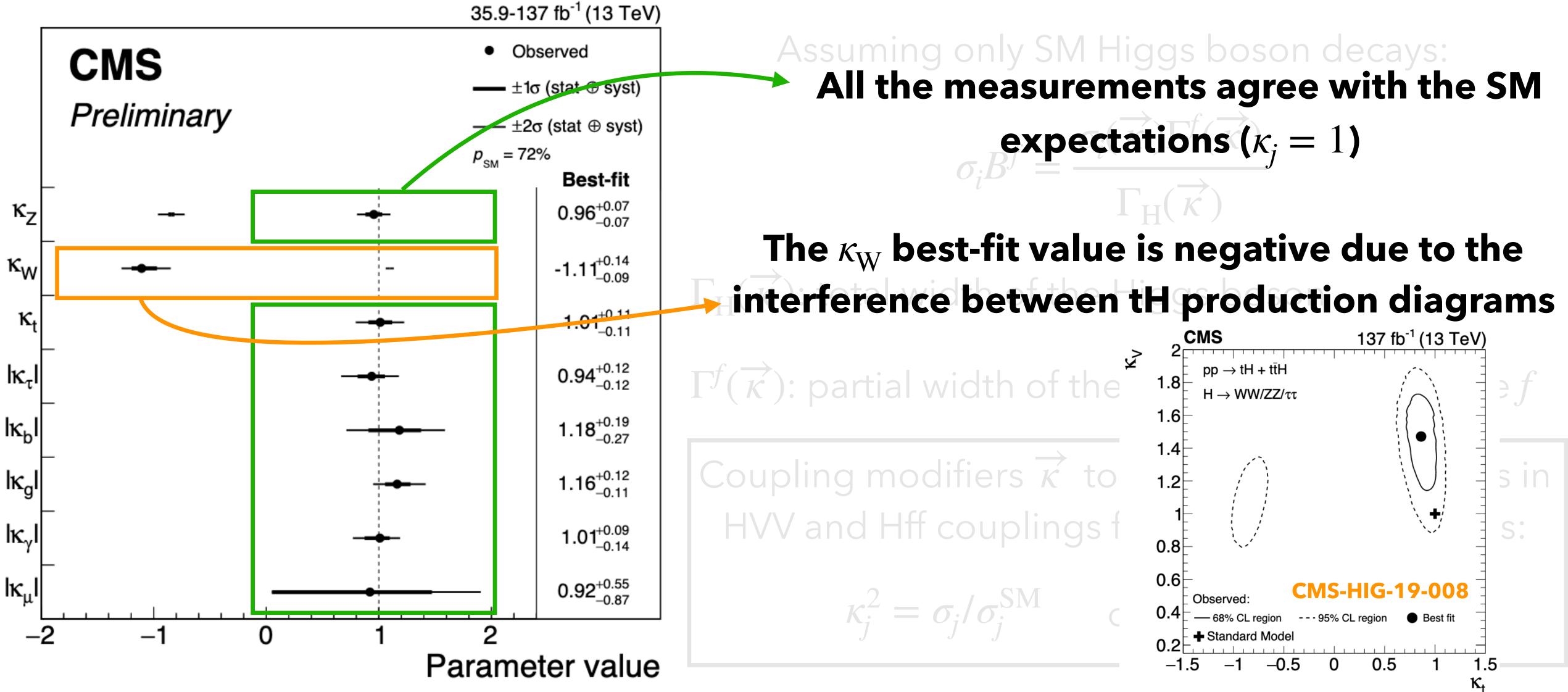








H boson couplings: *k*-framework



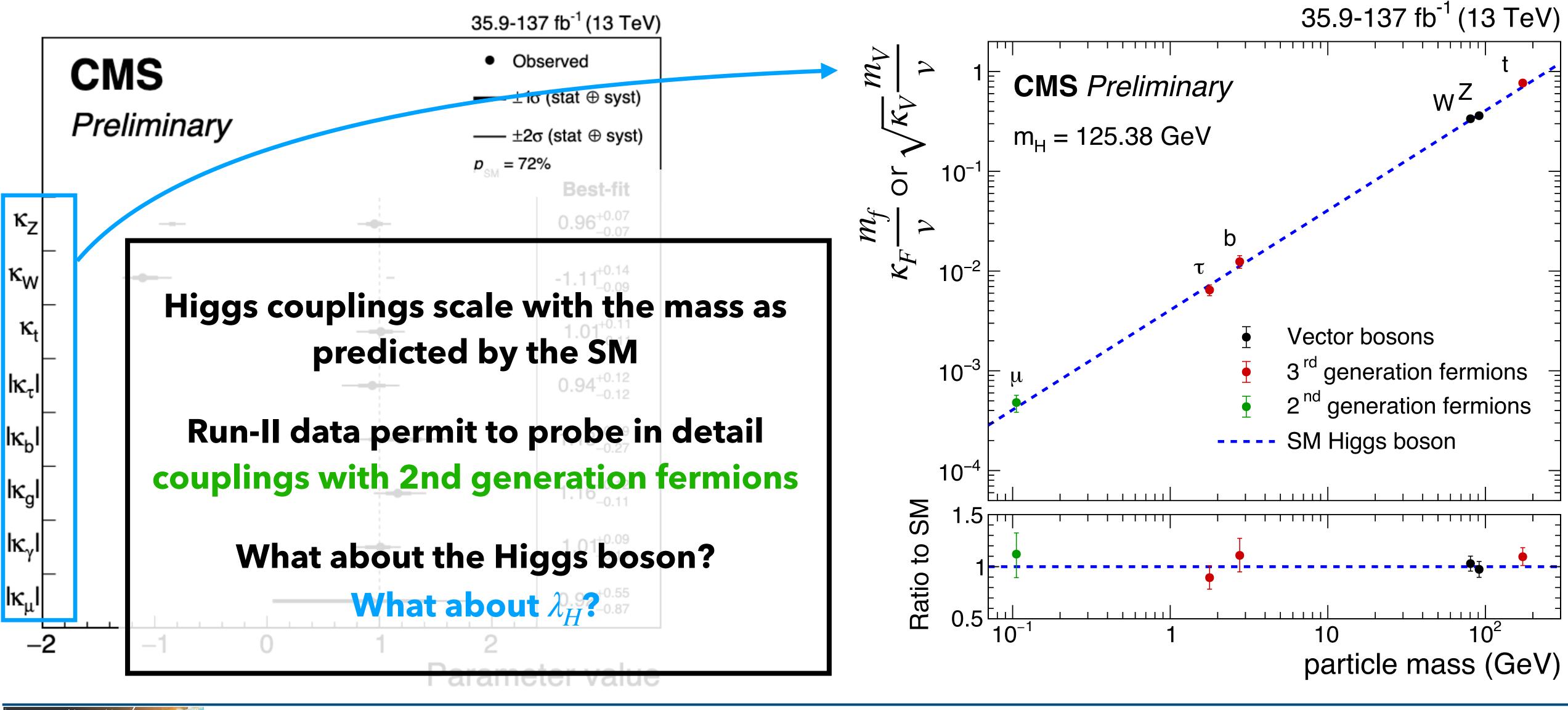








H boson couplings: *k*-framework







16

H boson self-coupling

Constraint on $\kappa_{\lambda} = \lambda_{HHH} / \lambda_{SM}$ from single-Higgs decay channels via modifications of the production cross sections and decay widths from NLO electroweak corrections

Inclusive production and decay rates scale as¹

$$\mu_i(\kappa_{\rm V},\kappa_{\rm F},\kappa_{\lambda}) = Z_{\rm H}^{\rm BSM}(\kappa_{\lambda}) \left[S_i(\kappa_{\rm V},\kappa_{\rm F}) + K_{\rm BSM}(1 + \kappa_{\lambda})\right]$$

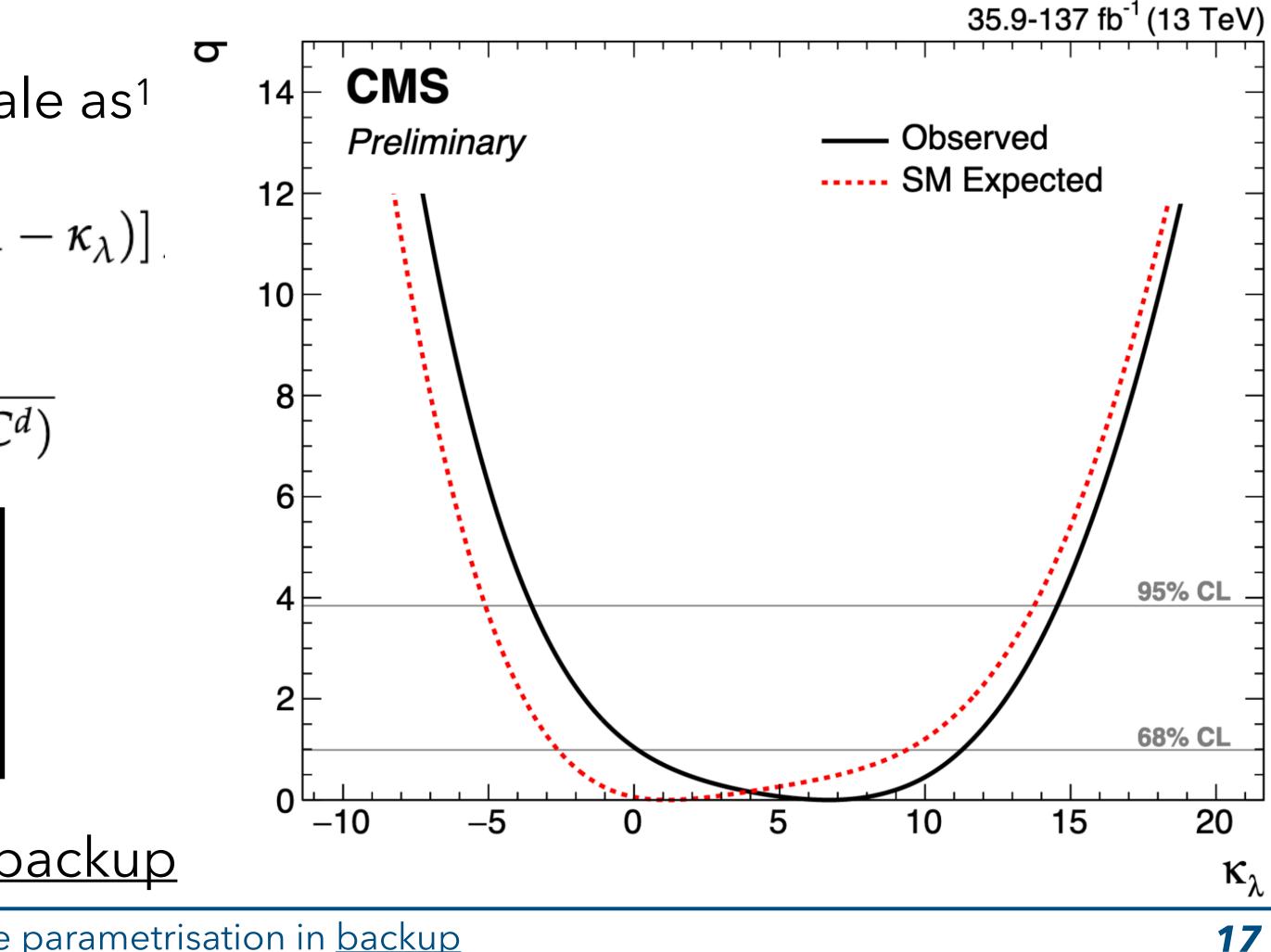
$$\mu^{f}(\kappa_{\rm V},\kappa_{\rm F},\kappa_{\lambda}) = \frac{S_{f}(\kappa_{\rm V},\kappa_{\rm F}) + (\kappa_{\lambda}-1)C^{f}}{\sum_{d}\Gamma_{d}^{\rm SM}\left(S_{d}(\kappa_{\rm V},\kappa_{\rm F}) + (\kappa_{\lambda}-1)C^{d}\right)}$$

Limits on κ_{λ} with $\kappa_V = \kappa_F = 1$: [-3.5,14.5] ([-5.1,13.7])

Additional scans with κ_V or κ_F floating in <u>backup</u>







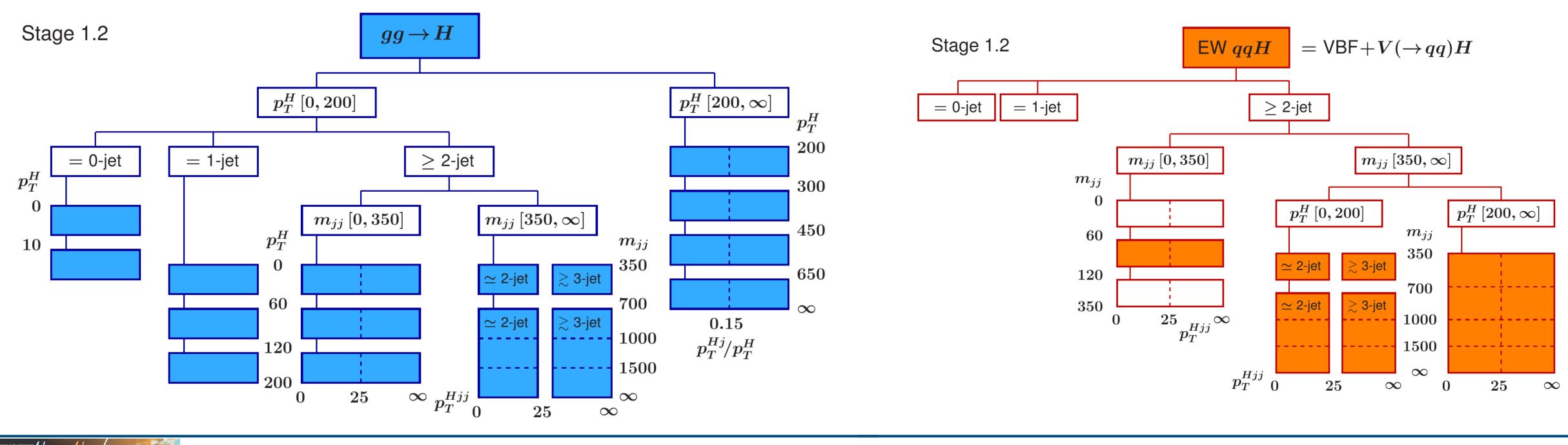
¹: Details on the parametrisation in <u>backup</u>



Simplified Template Cross Section framework

The primary goal of STXS framework is to minimise the measurement dependence on theory predictions without losing sensitivity

In this analysis STXS bins used to set constraints on Effective Field Theory (EFT) operators





Coverage of the entire phase space and **specific regions** designed **to detect BSM effects**







EFT couplings

Extend SM Lagrangian with higher-dim operators in the **HEL¹ model:**

$$\mathcal{L}_{\text{HEL}} = \mathcal{L}_{\text{SM}} + \sum_{j} \mathcal{O}_{j} f_{j} / I$$
$$\bigvee^{j}$$
$$\sigma_{i}^{\text{EFT}} = \sigma_{i}^{\text{SM}} + \sigma_{i}^{\text{int}} + \sigma_{i}^{\text{BSM}}$$

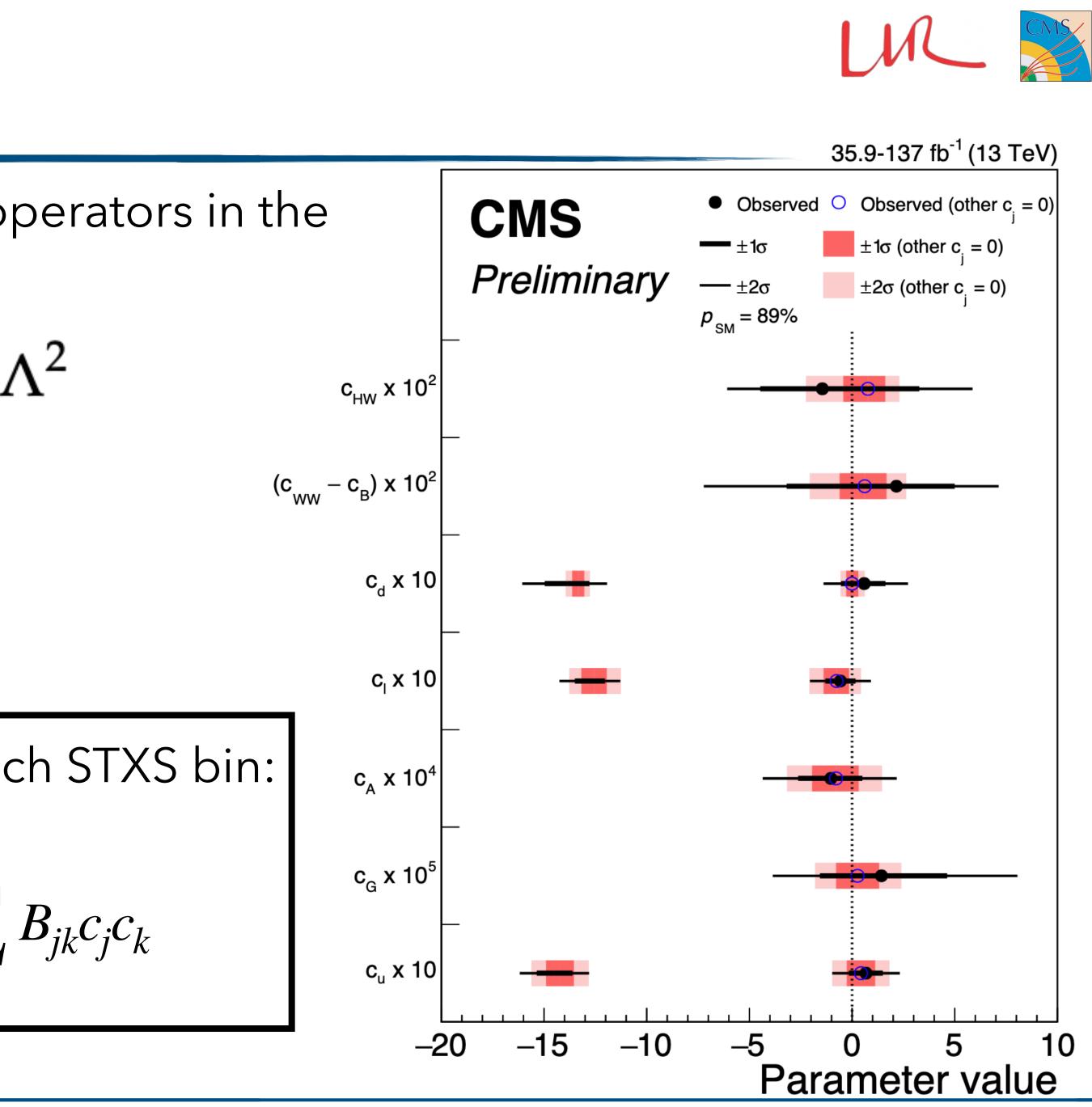
Scaling depending on $c_i = f_i / \Lambda^2$ for each STXS bin:

$$\mu_i(c_j) = \frac{\sigma_i^{\text{EFT}}}{\sigma_i^{\text{SM}}} = 1 + \sum_j A_j c_j + \sum_{jk} A_j c$$

¹: Higgs Effective Lagrangian

Higgs Hunting

 $H \rightarrow ZZ, H \rightarrow \gamma\gamma$ combined to set limits on CP-even(odd) anomalous couplings (cf. backup)





EFT couplings

Extend SM Lagrangian with higher-dim operators in the HEL¹ model:

$\mathcal{L}_{\rm HEL} = \mathcal{L}_{\rm SM} + \sum \mathcal{O}_i f_i / \Lambda^2$

 $H \rightarrow \mu\mu$ and boosted $H \rightarrow bb$ analyses not considered

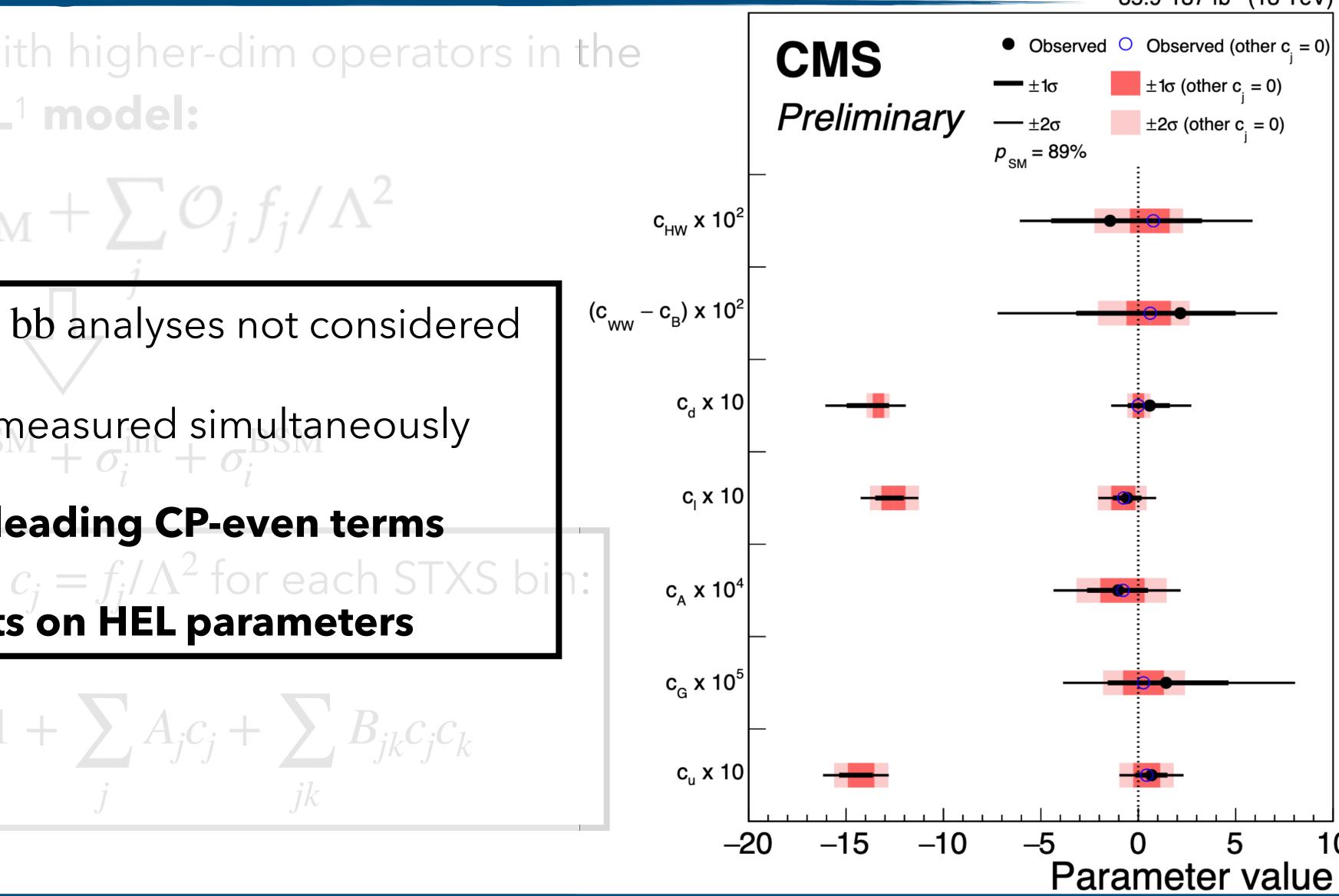
Eight EFT parameters measured simultaneously $\sigma_i = \sigma_i + \sigma_i + \sigma_i$

Parameters related to leading CP-even terms Scaling depending on $c_i = f_i / \Lambda^2$ for each STXS bin: **Stringent constraints on HEL parameters**

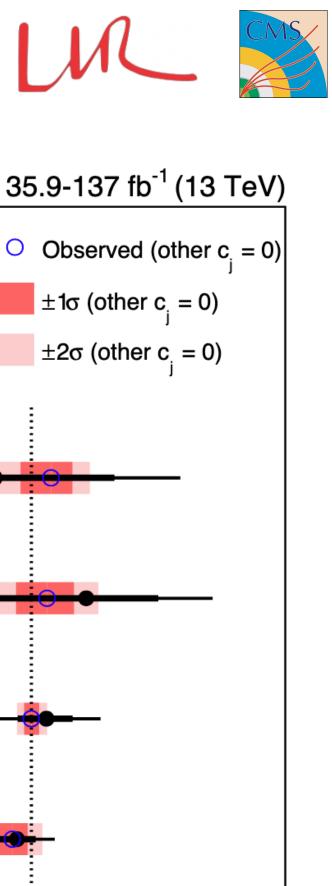
Higgs Hunting



ik



 $H \rightarrow ZZ, H \rightarrow \gamma\gamma$ combined to set limits on CP-even(odd) anomalous couplings (cf. backup)





10



The large statistics collected during Run-II opens the doors to precision measurements era

Comprehensive characterization of the Higgs boson properties from combination of all decay channels

- Signal strength modifiers $\mu = 1.02 \pm 0.04$ (th) ± 0.04 (exp) ± 0.04 (stat)
- Study Higgs couplings from *k*-framework measurements and expected scaling with the mass is observed

Full Run-II combination (from CMS and ATLAS+CMS) will enhance the precision of these results...





• Partial Run-II datasets used here, full Run-II analyses are ongoing and will be included in a future study

• Similar statistical and systematic components of the uncertainty, results will soon be limited by latter

• Interpretation of STXS measurements in EFT: most powerful constraints on HEL parameters to date











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- observed





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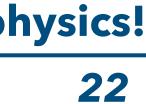
Full Run-II combination (from CMS and ATLAS+CMS) will enhance the precision of these results...

... and possibly unveil new physics!





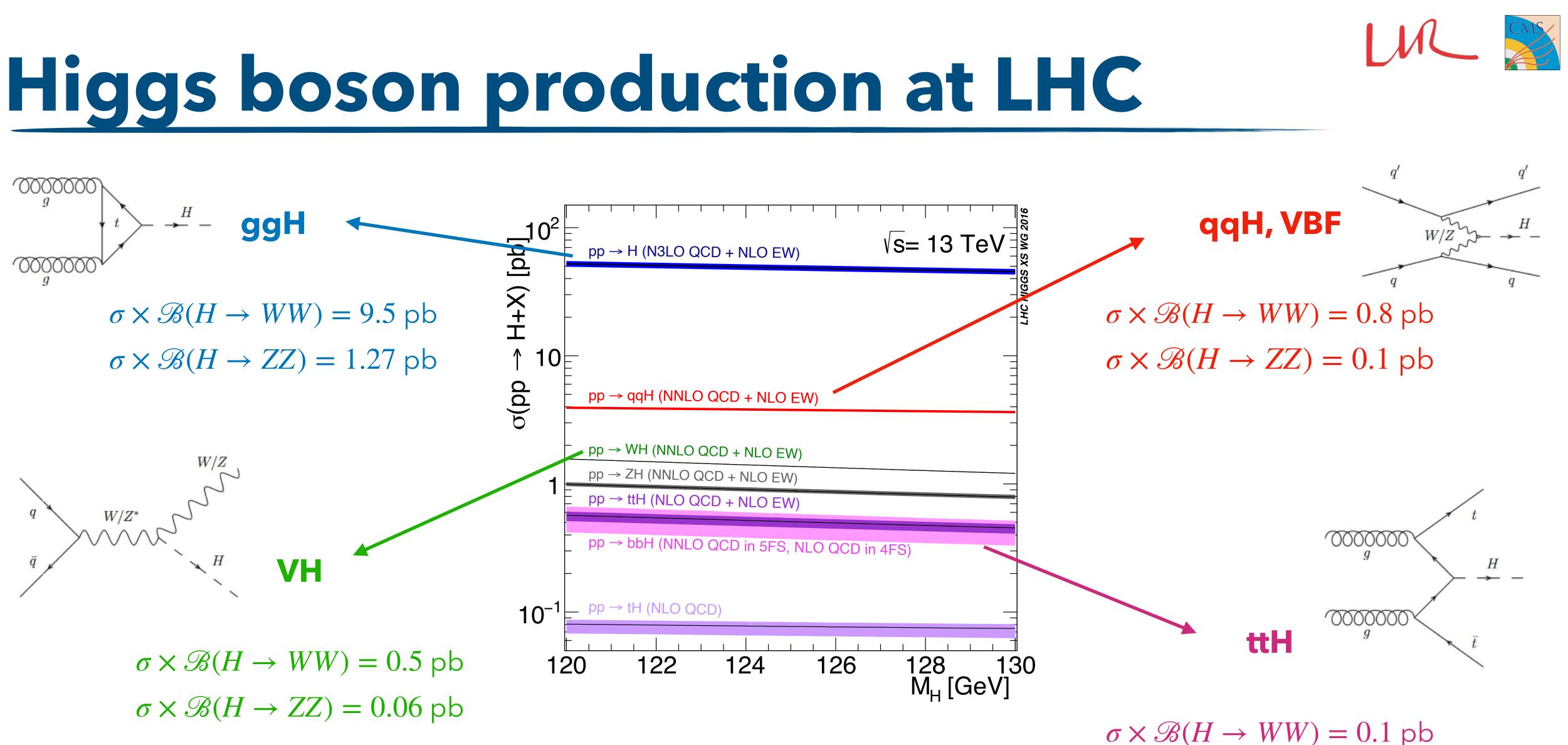














 $\sigma \times \mathscr{B}(H \to ZZ) = 0.01 \text{ pb}$



The input analyses & categories

| Analysis | Decay tags | Production tags | Luminosity (fb $^{-1}$) | References |
|---|---|---|--------------------------|------------|
| ${ m H} ightarrow \gamma \gamma$ | $\gamma\gamma$ | ggH, $p_T(H) \times N$ -jet bins VBF, $p_T(H jj)$ bins | 77.4 | [53] |
| | | ttH | 35.9, 41.5 | [54], [55] |
| | | ggH, $p_T(H) \times N$ -jet bins VBF, m_{jj} bins | | |
| ${ m H} ightarrow { m ZZ}^{(*)} ightarrow 4\ell$ | 4µ,2e2µ/2µ2e,4e | VH hadronic | 137 | [56] |
| | | VH leptonic, $p_{T}(V)$ bins ttH | | |
| | eμ/μe | $ggH \le 2$ -jets VBF | | |
| $\mathrm{H} \rightarrow \mathrm{W}\mathrm{W}^{(*)} \rightarrow \ell \nu \ell \nu$ | ee+µµ | $ggH \le 1$ -jet | 35.9 | [57] |
| | eµ+jj | VH hadronic | 00.7 | |
| | 3ℓ | WH leptonic | | |
| | 4ℓ | ZH leptonic | | |
| ${ m H} ightarrow 	au 	au$ | | ggH, $p_T(H) \times N$ -jet bins VH hadronic | 77.4 | [58] |
| | $e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$ | VBF VH, high- $p_{\rm T}({\rm V})$ | 35.9 | [59] |
| $H \rightarrow bb$ | $W(\ell\nu)H(bb)$ $Z(\nu\nu)H(bb), Z(\ell\ell)H(bb)$ | WH leptonic ZH leptonic | 35.9, 41.5 | [60], [61] |
| $11 \rightarrow 00$ | bb | ttH, t $\overline{t} \rightarrow 0$, 1, 2 ℓ + jets | 77.4 | [62] |
| | | ggH, high- $p_{\rm T}({\rm H})$ bins | 35.9 | [63] |
| ttH production with H \rightarrow leptons | $\begin{array}{c} 2\ell \mathrm{ss}, 3\ell, 4\ell, \\ 1\ell + 2\tau_{\mathrm{h}}, 2\ell \mathrm{ss} + 1\tau_{\mathrm{h}}, 3\ell + 1\tau_{\mathrm{h}} \end{array}$ | ttH | 35.9, 41.5 | [64], [65] |
| $H \rightarrow \mu \mu$ | μμ | ggH VBF | 35.9 | [66] |

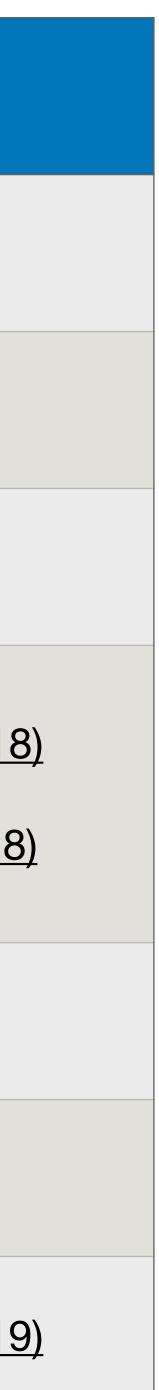


References in Backup





| | Luminosity (fb ⁻¹) | References |
|--|--------------------------------|--|
| $H \rightarrow \gamma \gamma$ | 77 | <u>CMS-PAS-HIG-18-029</u> <u>CMS-PAS-HIG-18-018</u> |
| $H \rightarrow ZZ^* \rightarrow 4\ell$ | 137 | <u>CMS-PAS-HIG-19-001</u> |
| $H \rightarrow WW$ | 36 | <u>Phys. Lett. B 791 (2019) 96</u> |
| $H \rightarrow bb$ | 36 (ggH) - 77 (others) | <u>Phys. Rev. Lett. 121, 121801 (2018</u> <u>CMS-PAS-HIG-18-030</u> <u>Phys.Rev. Lett. 120, 071802 (2018</u>) |
| $H \rightarrow \tau \tau$ | 77 | <u>CMS-PAS-HIG-18-032</u> JHEP 06 (2019) 093 |
| ttH multilepton | 77 | <u>CMS-PAS-HIG-18-019</u> |
| $H \rightarrow \mu\mu$ | 36 | <u>Phys. Rev. Lett. 122, 021801 (2019</u> |



Signal strength modifiers

| Production μ_i | | | | | | |
|---------------------------|---|---|--|--|--|--|
| | | Uncert | tainty | | | |
| Parameters | Best-fit | Stat. | Syst. | | | |
| μ_{ggH} | $1.04\substack{+0.09\\-0.09}$ | +0.05 -0.05 | $+0.08 \\ -0.07$ | | | |
| rggII | $\begin{pmatrix} +0.09\\ -0.08 \end{pmatrix}$ | $\begin{pmatrix} +0.05\\ -0.05 \end{pmatrix}$ | $\begin{pmatrix} +0.07\\ -0.07 \end{pmatrix}$ | | | |
| $\mu_{ m VBF}$ | $0.75^{+0.19}_{-0.17}$ | +0.16 -0.15 | $+0.10 \\ -0.08$ | | | |
| | $\begin{pmatrix} +0.20\\ -0.19 \end{pmatrix}$ | $\begin{pmatrix} +0.17\\ -0.16 \end{pmatrix}$ | $\begin{pmatrix} +0.11 \\ -0.10 \end{pmatrix}$ | | | |
| $\mu_{ m WH}$ | $1.46^{+0.37}_{-0.35}$ | +0.29 -0.28 | +0.22 -0.21 | | | |
| | $\begin{pmatrix} +0.35\\ -0.34 \end{pmatrix}$ | $\begin{pmatrix} +0.29 \\ -0.28 \end{pmatrix}$ | $\begin{pmatrix} +0.20 \\ -0.19 \end{pmatrix}$ | | | |
| $\mu_{ m ZH}$ | $0.98^{+0.31}_{-0.30}$ | +0.26 -0.25 | +0.17 -0.16 | | | |
| | $\begin{pmatrix} +0.30\\ -0.29 \end{pmatrix}$ | $\left(\begin{smallmatrix}+0.25\\-0.25\end{smallmatrix}\right)$ | $\begin{pmatrix} +0.17 \\ -0.15 \end{pmatrix}$ | | | |
| $\mu_{ m ttH}$ | $1.14^{+0.21}_{-0.20}$ | +0.13 -0.13 | +0.17 -0.15 | | | |
| , | $\begin{pmatrix} +0.20\\ -0.18 \end{pmatrix}$ | $\begin{pmatrix} +0.12\\ -0.12 \end{pmatrix}$ | $\begin{pmatrix} +0.15 \\ -0.13 \end{pmatrix}$ | | | |

| R | |
|---|--|
| | |

| Decay μ^f | | | | | | |
|----------------------|--|--|---|--|--|--|
| Uncertainty | | | | | | |
| Parameters | Best-fit | Stat. | Syst. | | | |
| $\gamma\gamma\gamma$ | $1.07\substack{+0.12 \\ -0.10}$ | $^{+0.08}_{-0.08}$ | $^{+0.08}_{-0.07}$ | | | |
| $\mu^{\gamma\gamma}$ | $\begin{pmatrix} +0.10 \\ -0.10 \end{pmatrix}$ | (+0.08) | (+0.07) | | | |
| | | (-0.08) | (-0.06) | | | |
| μ^{ZZ} | $0.93\substack{+0.10 \\ -0.09}$ | $+0.07 \\ -0.07$ | $+0.07 \\ -0.06$ | | | |
| μ | $\begin{pmatrix} +0.11\\ -0.10 \end{pmatrix}$ | (+0.08) | (+0.07) | | | |
| | | (-0.07) +0.09 | (-0.06) +0.13 | | | |
| μ^{WW} | $1.20\substack{+0.16 \\ -0.15}$ | -0.09 | +0.13 -0.12 | | | |
| r. | $\begin{pmatrix} +0.14\\ -0.13 \end{pmatrix}$ | $\begin{pmatrix} +0.09 \\ -0.09 \end{pmatrix}$ | $\binom{+0.11}{-0.10}$ | | | |
| | 0.80+0.17 | $+0.10^{-1}$ | +0.14 | | | |
| $\mu^{	au	au}$ | , 0.10 | -0.10 | -0.13 | | | |
| | $\begin{pmatrix} +0.18\\ -0.17 \end{pmatrix}$ | $\left(\substack{+0.10\\-0.10}\right)$ | $\begin{pmatrix} +0.15\\ -0.14 \end{bmatrix}$ | | | |
| hh | $1.11\substack{+0.20\\-0.19}$ | $+0.13 \\ -0.13$ | $+0.16 \\ -0.15$ | | | |
| μ^{bb} | , 0.17 | (+0.12) | (+0.15) | | | |
| | $\begin{pmatrix} +0.20\\ -0.19 \end{pmatrix}$ | (-0.12) | (-0.14) | | | |
| 1.UU | $0.90\substack{+1.29 \\ -1.28}$ | $+1.28 \\ -1.27$ | $+0.22 \\ -0.13$ | | | |
| $\mu^{\mu\mu}$ | $\begin{pmatrix} +1.20\\ -1.26 \end{pmatrix}$ | (+1.25) | (+0.24) | | | |
| | (-1.26) | (-1.26) | (-0.06 | | | |







Signal strength modifiers

| Decay | Production Process | | | | | | | | | | | | | | | | |
|---------------------------------------|--|---------------------------|--------------------------------|--|---|---------------------------|--|---|--|------------------------|---------------------------|------------------------|------------------------|------|---------------------|---------------------------------|---------------------------|
| mode | e e | gН | | | VBF | | | WH | | ZH | | | | ttH | | | |
| | | Uncer | rtainty | | Unce | rtainty | | Unce | rtainty | | | Uncer | rtainty | | | Uncer | rtainty |
| | Best-fit | Stat. | Syst. | Best-f | fit Stat. | Syst. | Best-fi | t Stat. | Syst. | Best | -fit | Stat. | Syst. | Best | t-fit | Stat. | Syst. |
| $H \to bb$ | $2.45 \begin{array}{c} +2.53 \\ -2.35 \end{array}$ | $\substack{+2.04\\-2.01}$ | $^{+1.51}_{-1.22}$ | | — | | $\begin{vmatrix} 1.27 & +0.\\ -0. \end{vmatrix}$ | $\begin{array}{rrr} 42 & +0.32 \\ 40 & -0.31 \end{array}$ | $^{+0.27}_{-0.25}$ | 0.93 | $^{+0.33}_{-0.31}$ | $^{+0.27}_{-0.26}$ | $^{+0.19}_{-0.17}$ | | $+0.33 \\ -0.30$ | $^{+0.16}_{-0.16}$ | $^{+0.29}_{-0.25}$ |
| | $\binom{+2.11}{-1.95}$ | $\binom{+1.92}{-1.91}$ | $(^{+0.86}_{-0.34})$ | | — | | $(^{+0.}_{-0.}$ | $\binom{42}{41}\binom{+0.33}{-0.32}$ | $) \left({+0.27 \atop -0.26} \right)$ | (| $(^{+0.32}_{-0.31})$ | $\binom{+0.26}{-0.26}$ | $\binom{+0.19}{-0.17}$ | () | $^{+0.32}_{-0.30})$ | $(^{+0.16}_{-0.16})$ | $(^{+0.28}_{-0.25})$ |
| $\mathrm{H} \to \tau \tau$ | $0.39 \ \ {}^{+0.38}_{-0.39}$ | $\substack{+0.16\\-0.16}$ | $^{+0.35}_{-0.35}$ | $ 1.05 + 0 \\ -0$ | $\begin{array}{ccc} 0.30 & +0.25 \\ 0.29 & -0.24 \end{array}$ | $\substack{+0.18\\-0.17}$ | $3.01 \begin{array}{c} +1.\\ -1. \end{array}$ | $\begin{array}{ccc} 65 & +1.37 \\ 51 & -1.27 \end{array}$ | $\substack{+0.92\\-0.81}$ | 1.53 | $^{+1.60}_{-1.37}$ | $^{+1.41}_{-1.25}$ | $^{+0.75}_{-0.55}$ | 0.81 | $+0.74 \\ -0.67$ | $^{+0.57}_{-0.53}$ | $\substack{+0.46\\-0.40}$ |
| | $\binom{+0.39}{-0.36}$ | $\binom{+0.16}{-0.16}$ | $\left(^{+0.36}_{-0.33} ight)$ | $(^{+0}_{-0})$ | $\binom{0.31}{0.30}\binom{+0.25}{-0.25}$ | $(^{+0.18}_{-0.17})$ | $(^{+1}_{-1}$ | $\binom{52}{40}\binom{+1.27}{-1.16}$ |) $\binom{+0.82}{-0.78}$ | (| $(^{+1.45}_{-1.25})$ | $\binom{+1.32}{-1.17}$ | $\binom{+0.59}{-0.46}$ | (1 | $^{+0.72}_{-0.64})$ | $\binom{+0.57}{-0.53}$ | $\binom{+0.43}{-0.36}$ |
| $\mathrm{H} \to \mathrm{W}\mathrm{W}$ | $1.28 \begin{array}{c} +0.20 \\ -0.19 \end{array}$ | $\substack{+0.11\\-0.11}$ | $^{+0.17}_{-0.15}$ | $0.63 \ ^{+0}_{-0}$ | $\begin{array}{ccc} 0.65 & +0.58 \\ 0.61 & -0.54 \end{array}$ | $^{+0.30}_{-0.29}$ | 2.85 $^{+2.}_{-1.}$ | | $\substack{+1.13\\-0.96}$ | 0.90 | $\substack{+1.77\\-1.43}$ | $^{+1.70}_{-1.41}$ | $^{+0.50}_{-0.24}$ | 0.93 | $^{+0.48}_{-0.45}$ | $^{+0.37}_{-0.36}$ | $^{+0.30}_{-0.26}$ |
| | $(^{+0.17}_{-0.16})$ | $(^{+0.11}_{-0.10})$ | $(^{+0.14}_{-0.12})$ | $ (^{+0}_{-0})$ | $\binom{0.61}{0.58}$ $\binom{+0.55}{-0.52}$ | $\binom{+0.27}{-0.26}$ | $(^{+1.}_{-1.})$ | $\binom{48}{20}\binom{+1.33}{-1.09}$ |) $\binom{+0.64}{-0.51}$ | (| $(^{+1.67}_{-1.37})$ | $\binom{+1.61}{-1.36}$ | $(^{+0.43}_{-0.21})$ | (1 | $^{+0.45}_{-0.41})$ | $\left(^{+0.35}_{-0.35}\right)$ | $\binom{+0.27}{-0.22}$ |
| $\mathrm{H} ightarrow \mathrm{ZZ}$ | $0.98 \begin{array}{c} +0.12 \\ -0.11 \end{array}$ | $^{+0.09}_{-0.09}$ | $^{+0.08}_{-0.07}$ | $0.57 \begin{array}{c} +0 \\ -0 \end{array}$ | $0.46 + 0.44 \\ -0.36 - 0.35$ | $^{+0.15}_{-0.09}$ | | 1.10 | $^{+0.96}_{-0.74}$ | | $^{+0.19}_{-0.10}$ | | | 0.25 | $^{+1.03}_{-0.25}$ | $^{+1.00}_{-0.25}$ | $^{+0.21}_{-0.00}$ |
| | $(^{+0.13}_{-0.12})$ | $(^{+0.10}_{-0.09})$ | $(^{+0.08}_{-0.07})$ | $(^{+0}_{-0})$ | $(^{+0.52}_{-0.47})$ $(^{+0.52}_{-0.44})$ | $(^{+0.23}_{-0.14})$ | | | $(^{+0.99}_{-0.73})$ | $(^{+0.96}_{-0.72})$ (| $(^{+0.21}_{-0.11})$ | | | (1 | $^{+1.12}_{-0.67})$ | $(^{+1.10}_{-0.67})$ | $(^{+0.22}_{-0.06})$ |
| ${ m H} ightarrow \gamma \gamma$ | $1.09 \begin{array}{c} +0.15 \\ -0.14 \end{array}$ | $^{+0.11}_{-0.11}$ | $\substack{+0.10\\-0.08}$ | $0.77 \ ^{+0}_{-0}$ | 0.37 + 0.32 + 0.27 - 0.27 | $^{+0.18}_{-0.09}$ | | _ | | | - | | | 1.62 | $+0.52 \\ -0.43$ | $\substack{+0.44\\-0.40}$ | $^{+0.27}_{-0.14}$ |
| | $(^{+0.14}_{-0.13})$ | $(^{+0.11}_{-0.11})$ | $(^{+0.09}_{-0.07})$ | $(^{+0}_{-0})$ | $(^{+0.33}_{-0.36})$ $(^{+0.33}_{-0.32})$ | $(^{+0.25}_{-0.18})$ | | _ | | | - | _ | | (1 | $^{+0.41}_{-0.35})$ | $(^{+0.39}_{-0.35})$ | $(^{+0.15}_{-0.07})$ |
| $H \rightarrow \mu \mu$ | $0.31 \begin{array}{c} +1.82 \\ -1.81 \end{array}$ | $\substack{+1.80\\-1.80}$ | $^{+0.22}_{-0.22}$ | 3.18 + 8 - 7 | 8.22 +7.99 7.93 -7.90 | $^{+1.93}_{-0.76}$ | | _ | | | - | _ | | | | _ | |
| | $\Big \begin{pmatrix} +1.78 \\ -1.79 \end{pmatrix} \\$ | $\binom{+1.76}{-1.79}$ | $(^{+0.28}_{-0.07})$ | $ (^{+8}_{-7})$ | $\binom{3.13}{7.95}\binom{+8.01}{-7.88}$ | $(^{+1.41}_{-1.05})$ | | — | | | - | _ | | | | — | |



| 1 | N | |
|---|---|--|
| | | |







H boson couplings: *k*-framework

| Coupling modifiers κ_i | | | | | |
|--------------------------------------|--|--|--|--|--|
| | | Uncert | tainty | | |
| Parameters | Best-fit | Stat. | Syst. | | |
| K_ | $0.96\substack{+0.07 \\ -0.07}$ | $^{+0.06}_{-0.06}$ | $^{+0.04}_{-0.05}$ | | |
| κ _Z | $\begin{pmatrix} +0.08 \\ -0.08 \end{pmatrix}$ | $\begin{pmatrix} +0.06 \\ -0.06 \end{pmatrix}$ | $\begin{pmatrix} +0.05 \\ -0.05 \end{pmatrix}$ | | |
| KxAz | $-1.11\substack{+0.14\\-0.09}$ | $+0.13 \\ -0.07$ | $+0.05 \\ -0.06$ | | |
| $\kappa_{ m W}$ | $\begin{pmatrix} +0.09 \\ -0.09 \end{pmatrix}$ | $\begin{pmatrix} +0.07 \\ -0.07 \end{pmatrix}$ | $\begin{pmatrix} +0.06\\ -0.06 \end{pmatrix}$ | | |
| $\kappa_{ m t}$ | $1.01\substack{+0.11\-0.11}$ | $+0.06 \\ -0.06$ | $+0.09\\-0.08$ | | |
| "t | $\begin{pmatrix} +0.10\\ -0.10 \end{pmatrix}$ | $\begin{pmatrix} +0.06 \\ -0.06 \end{pmatrix}$ | $\left(\substack{+0.08\\-0.08}\right)$ | | |
| $\kappa_{	au}$ | $0.94^{+0.12}_{-0.12}$ | +0.08 -0.11 | +0.09 -0.06 | | |
| ~τ | $\begin{pmatrix} +0.12\\ -0.11 \end{pmatrix}$ | $\begin{pmatrix} +0.08\\ -0.07 \end{pmatrix}$ | $\begin{pmatrix} +0.09\\ -0.08 \end{pmatrix}$ | | |
| $\kappa_{ m b}$ | $1.18\substack{+0.19 \\ -0.27}$ | $+0.14 \\ -0.13$ | +0.13 -0.24 | | |
| | $\begin{pmatrix} +0.17\\ -0.16 \end{pmatrix}$ | $\begin{pmatrix} +0.13\\ -0.12 \end{pmatrix}$ | $\begin{pmatrix} +0.11 \\ -0.11 \end{pmatrix}$ | | |
| κ _g | $1.16\substack{+0.12\\-0.11}$ | $+0.08 \\ -0.08$ | $+0.08 \\ -0.08$ | | |
| 8 | $\begin{pmatrix} +0.11 \\ -0.10 \end{pmatrix}$ | $\begin{pmatrix} +0.07\\ -0.07 \end{pmatrix}$ | $\begin{pmatrix} +0.08\\ -0.07 \end{pmatrix}$ | | |
| κ_{γ} | $1.01\substack{+0.09\\-0.14}$ | +0.07 -0.07 | +0.06 -0.12 | | |
| Ĩ | $\begin{pmatrix} +0.09\\ -0.08 \end{pmatrix}$ | $\begin{pmatrix} +0.07\\ -0.07 \end{pmatrix}$ | $\begin{pmatrix} +0.05\\ -0.05 \end{pmatrix}$ | | |
| κ_{μ} | $0.92^{+0.55}_{-0.87}$ | +0.54 -0.87 | +0.10 -0.01 | | |
| μ | $\begin{pmatrix} +0.52\\ -0.96 \end{pmatrix}$ | $\left(\substack{+0.51\\-0.95}\right)$ | $\begin{pmatrix} +0.08\\ -0.08 \end{pmatrix}$ | | |



Assuming only SM Higgs boson decays:

$$\sigma_i B^f = \frac{\sigma_i(\vec{\kappa}) \Gamma^f(\vec{\kappa})}{\Gamma_{\rm H}(\vec{\kappa})}$$

 $\Gamma_{\rm H}(\vec{\kappa})$: total width of the Higgs boson

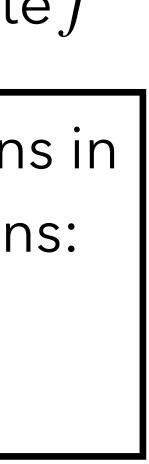
 $\Gamma^{f}(\vec{\kappa})$: partial width of the decay to the final state f

Coupling modifiers $\vec{\kappa}$ to parametrize deviations in HVV and Hff couplings from the SM predictions:

$$\kappa_j^2 = \sigma_j / \sigma_j^{\text{SM}}$$
 or $\kappa_j^2 = \Gamma^j / \Gamma_{\text{SM}}^j$

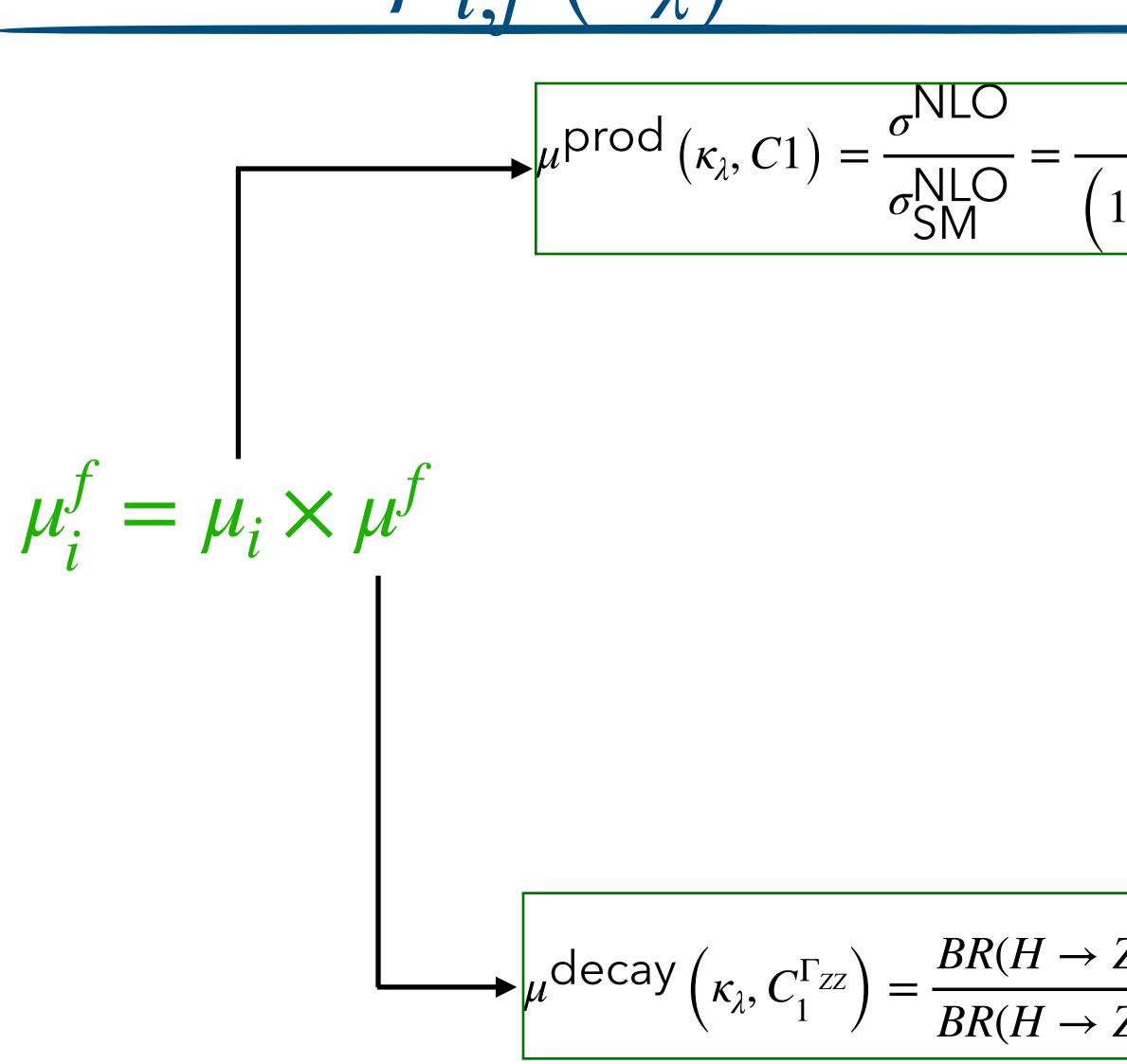








Extract $\mu_{i,i}(\kappa_{\lambda})$





$$\frac{1 + \kappa_{\lambda}C_{1} + \delta Z_{H}}{\left(1 - \left(\kappa_{\lambda}^{2} - 1\right)\delta Z_{H}\right)\left(1 + C_{1} + \delta Z_{H}\right)}$$

$$\frac{\rightarrow ZZ}{\rightarrow ZZ} = 1 + \frac{\left(\kappa_{\lambda} - 1\right)\left(C_{1}^{\Gamma_{ZZ}} - C_{1}^{\Gamma_{tot}}\right)}{1 + \left(\kappa_{\lambda} - 1\right)C_{1}^{\Gamma_{tot}}}$$







Extract
$$\mu_{i,j}\left(\kappa_{\lambda}\right)$$

$$\mu^{\text{prod}\left(\kappa_{\lambda},C1\right)} = \frac{\sigma^{\text{NLO}}}{\sigma^{\text{NLO}}_{\text{SM}}} = \frac{1 + \kappa_{\lambda}C_{1} + \delta Z_{H}}{\left(1 - \left(\kappa_{\lambda}^{2} - 1\right)\delta Z_{H}\right)\left(1 + C_{1} + \delta Z_{H}\right)}$$

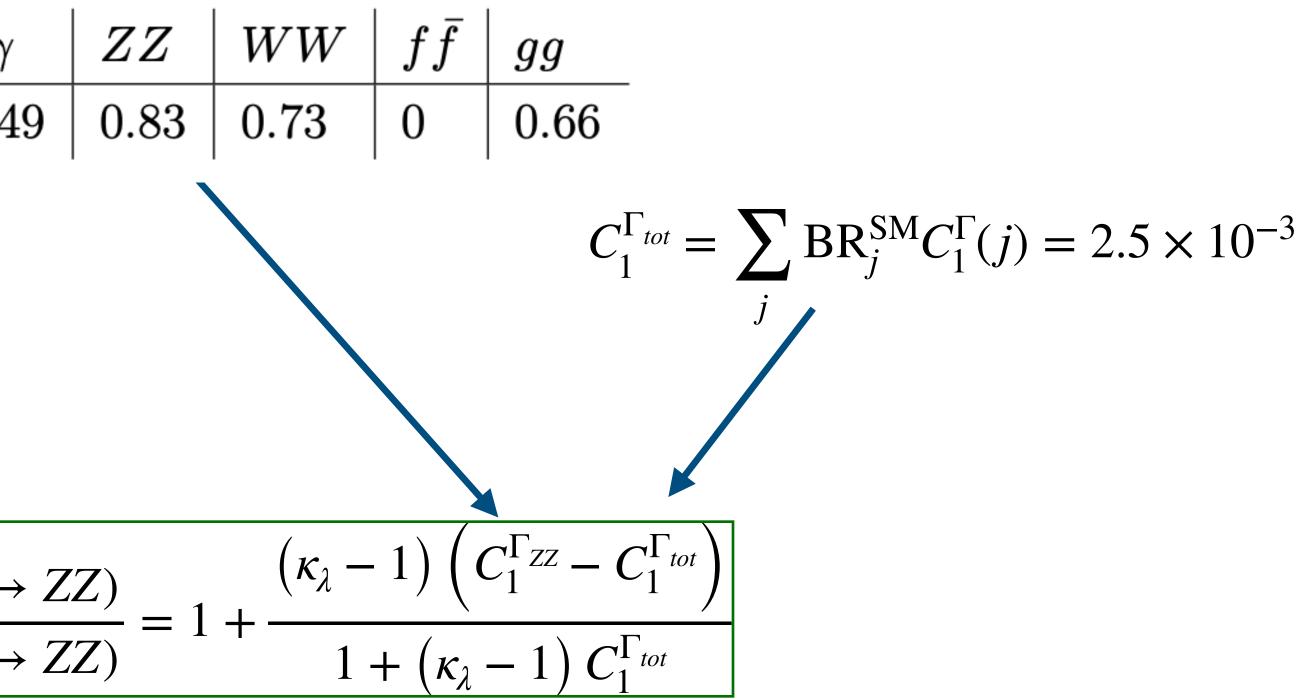
$$\mu_{i}^{f} = \mu_{i} \times \mu^{f}$$

$$\frac{C_{1}^{\Gamma}[\%]}{\text{on-shell } H \mid 0.49 \mid 0.83 \mid 0.73 \mid 0 \mid 0.66}$$

$$C_{1}^{\Gamma_{ort}} = \mu_{i}^{\text{odecay}}\left(\kappa_{\lambda},C_{1}^{\Gamma_{ZZ}}\right) = \frac{BR(H \to ZZ)}{BR(H \to ZZ)} = 1 + \frac{\left(\kappa_{\lambda} - 1\right)\left(C_{1}^{\Gamma_{ZZ}} - C_{1}^{\Gamma_{ort}}\right)}{1 + \left(\kappa_{\lambda} - 1\right)C_{1}^{\Gamma_{ort}}}$$





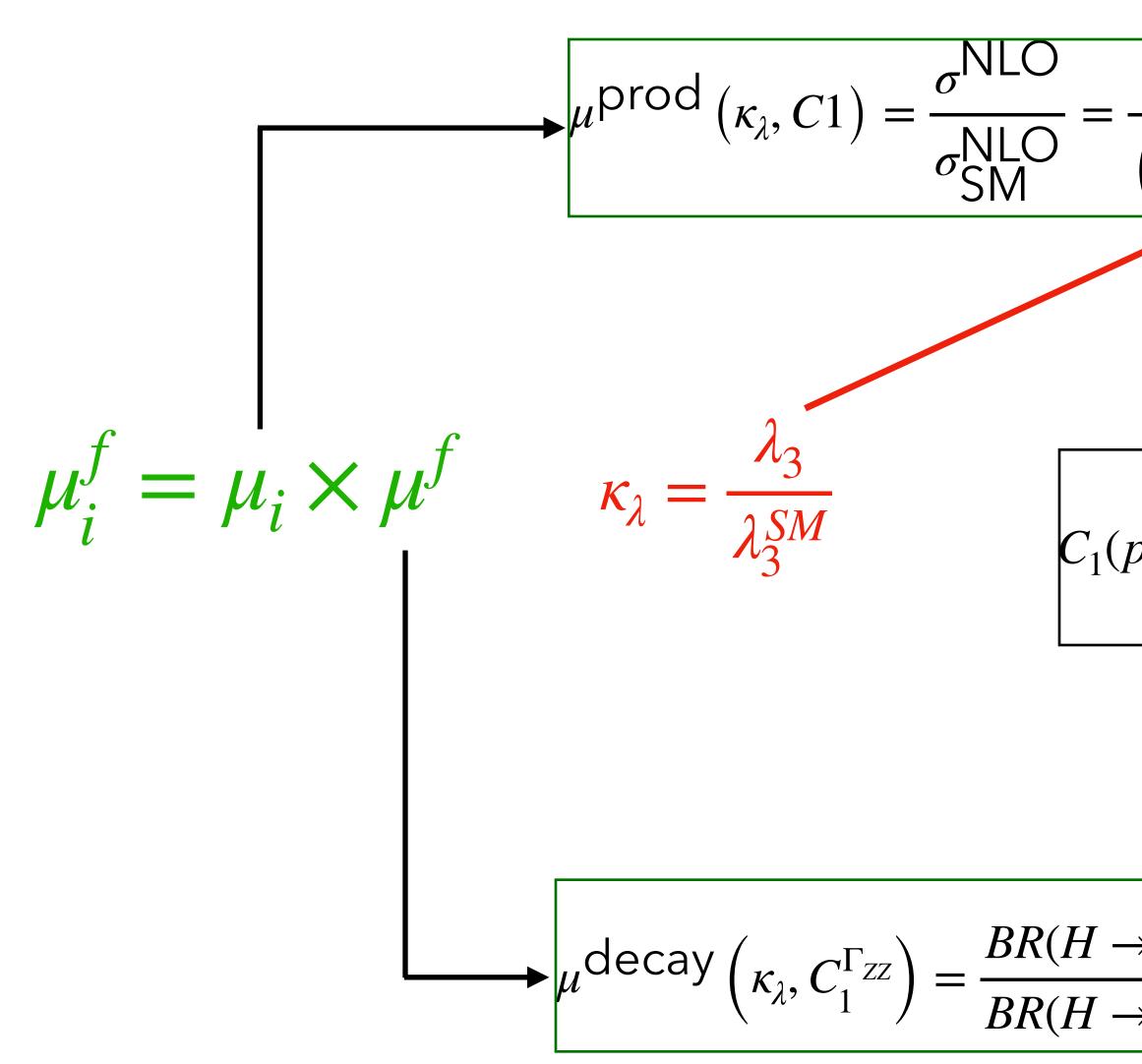








Extract $\mu_{i,i}(\kappa_{\lambda})$







$$\frac{1 + \kappa_{\lambda}C_{1} + \delta Z_{H}}{\left(1 - \left(\kappa_{\lambda}^{2} - 1\right)\delta Z_{H}\right)\left(1 + C_{1} + \delta Z_{H}\right)}$$

$$\delta Z_{H} = -1.536 \times 10^{-3}$$

$$\delta Z_{H} = -1.536 \times 10^{-3}$$
Depends both on the boson production means on the kinematic set of the set

$$\frac{2}{2} \frac{ZZ}{Z} = 1 + \frac{(\kappa_{\lambda} - 1)(C_1 - C_1)}{1 + (\kappa_{\lambda} - 1)C_1^{\Gamma_{tot}}}$$





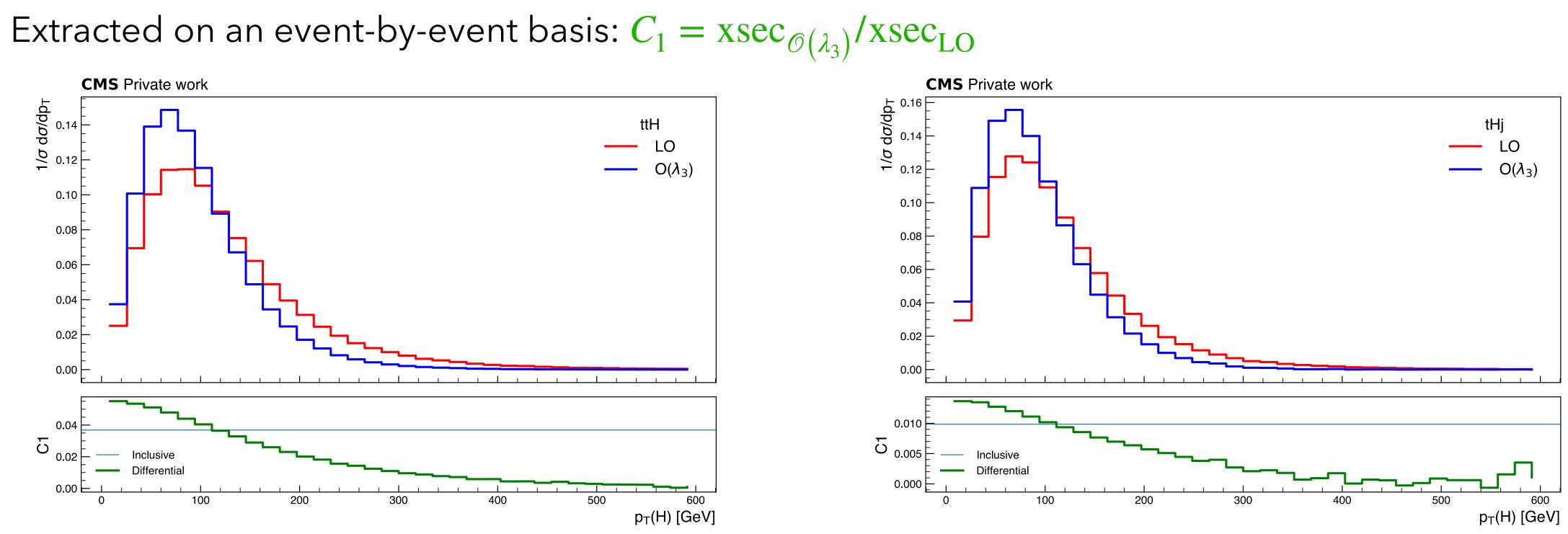
e H ode cs



Compute $C_1(p_n)$

While δZ_H is a universal quantity, $C_1(p_n)$ is process and kinematics dependent

- MadGraph5 dedicated hhh-model and reweighing tool available
- Generate LO events (for each prod. mode) and reweigh to take into account NLO EW corrections





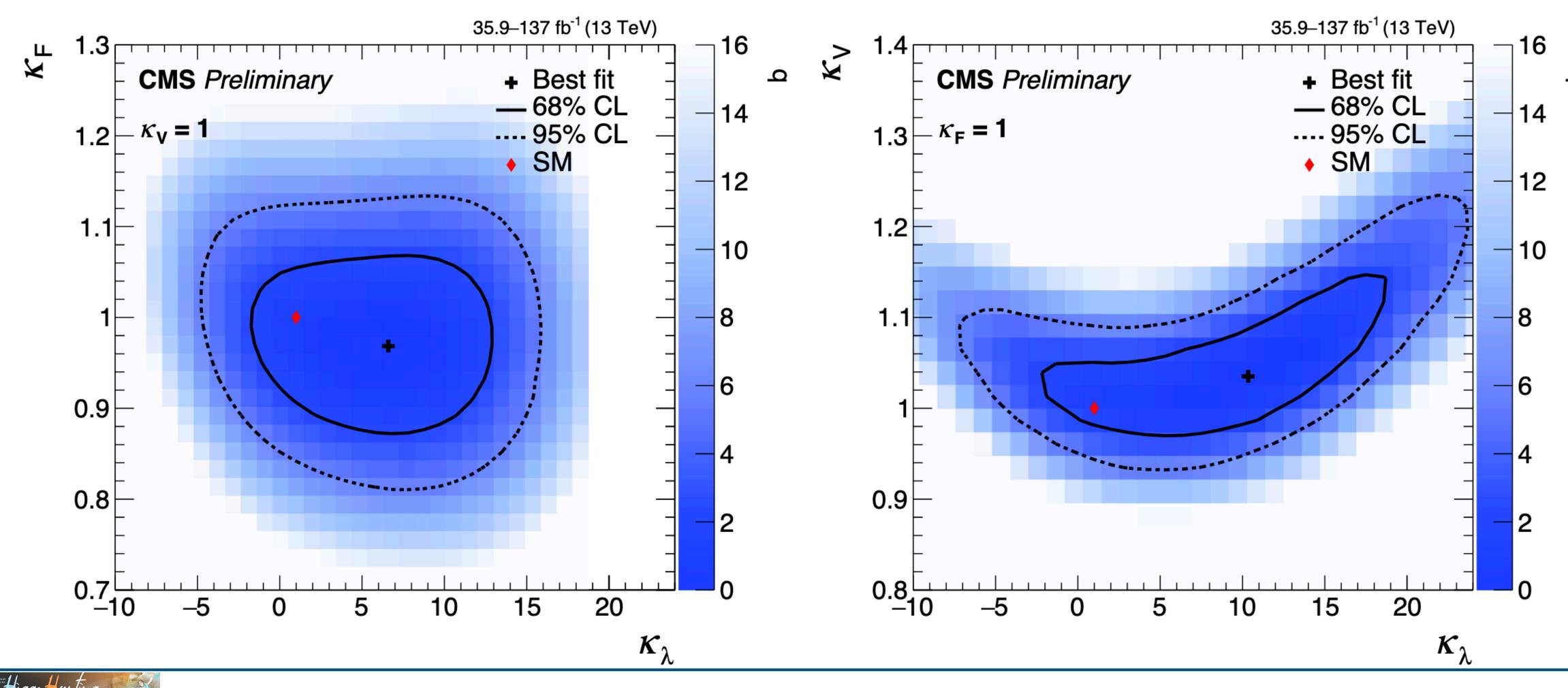






H boson self-coupling

Constraint on $\kappa_{\lambda} = \lambda_{HHH} / \lambda_{SM}$ from single-Higgs decay channels via modifications of the production cross sections and decay widths from NLO electroweak corrections





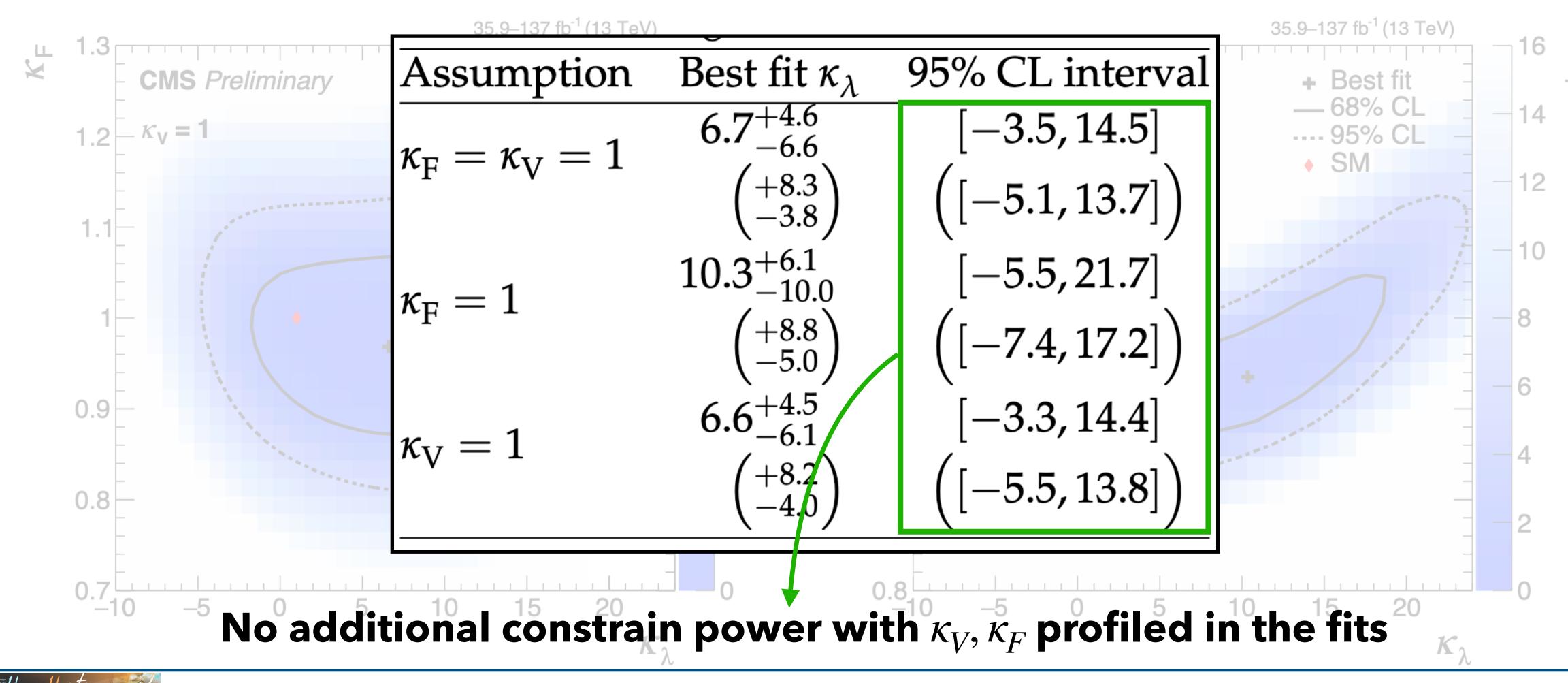






H boson self-coupling

Constraint on $\kappa_{\lambda} = \lambda_{HHH} / \lambda_{SM}$ from single-Higgs decay channels via modifications of the production cross sections and decay widths from NLO electroweak corrections





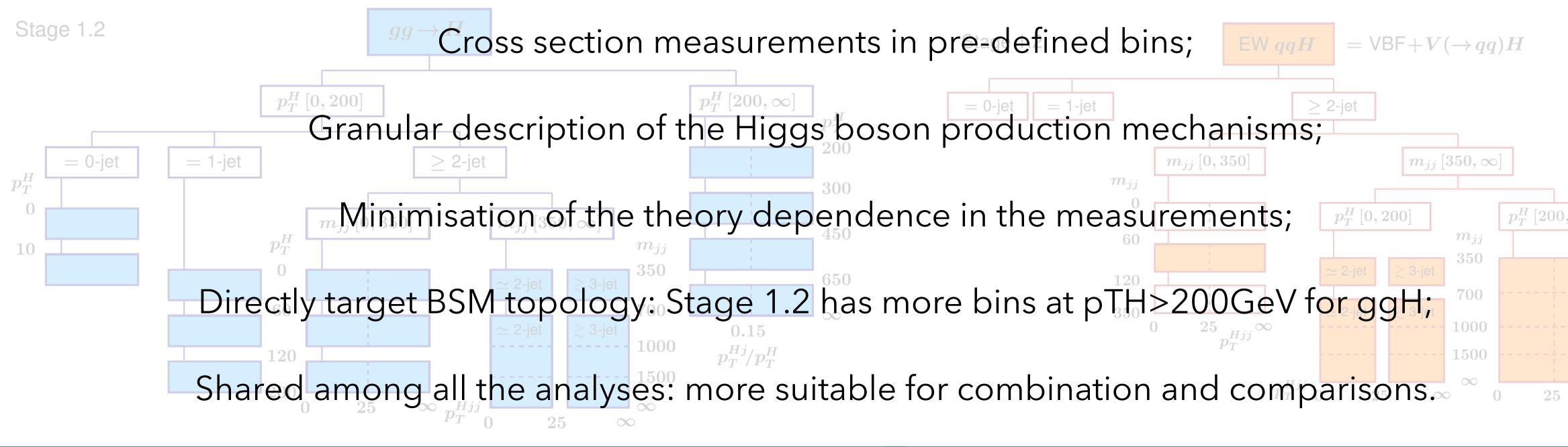


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Simplified Template Cross Section framework

The primary goal of STXS framework is to minimise the measurement dependence on theory predictions without losing sensitivity





Coverage of the entire phase space and **specific regions** designed **to detect BSM effects**







EFT parametrization of STXS bins

| STXS region (stage 0) | A_j |
|-------------------------|--|
| gg ightarrow H | $8.73 \times 10^3 c_G$ |
| qq ightarrow Hqq | $9.02c_{WW} + 0.6c_B - 0.797c_{HW} + 0.399c_A$ |
| $qq \to H\ell\nu$ | $42.5 c_{WW} + 19.9 c_{HW}$ |
| $qq \to H\ell\ell$ | $36.6c_{WW} + 10.5c_B + 15c_{HW} + 5.14c_A$ |
| $gg/qq \rightarrow ttH$ | $2.95 c_u + 115 c_G$ |

STXS Stage 1.0 and Stage 1.1 parametrizations in CMS-HIG-19-005

| STXS region (stage 0) | B_{jk} |
|-----------------------|---|
| $gg \to H$ | $1.95 \times 10^7 c_G^2$ |
| qq ightarrow Hqq | $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ |
| $qq \to H\ell\nu$ | 912 c_{WW}^2 + 558 c_{HW}^2 + 1.3 × 10 ³ $c_{WW} c_{HW}$ |
| $qq \to H\ell\ell$ | $602 \ c_{WW}^2 + 51.7 \ c_B^2 + 321 \ c_{HW}^2 + 10.7 \ c_A^2 + 350 \ c_{WW} \ c_{WW}^2 + 102 \ c_{WW} \ c_A + 227 \ c_B \ c_{HW} + 31.4 \ c_B \ c_A + 29.7 \ c_H^2$ |
| gg/qq → ttH | $2.14 \ c_u^2 + 6.13 \ c_{WW}^2 + 1 \ c_B^2 + 5.87 \ c_{HW}^2 + 2.97 \times 10^4 \ c_G^2 + 167 \ c_u^2 \ c_G^2 - 0.31 \ c_{WW}^2 \ c_B^2 + 11.9 \ c_{WW}^2 \ c_{HW}^2 - 0.318 \ c_B^2 \ c_{HW}^2$ |









Limits on EFT parameters

| HEL Parameters | Definition |
|--------------------------|---|
| $c_A 	imes 10^4$ | $c_A = \frac{m_W^2}{g'^2} \frac{f_A}{\Lambda^2}$ |
| $c_G 	imes 10^5$ | $c_G = \frac{m_W^2}{g_s^2} \frac{f_G}{\Lambda^2}$ |
| $c_u \times 10$ | $c_u = -v^2 \frac{f_u}{\Lambda^2}$ |
| $c_d 	imes 10$ | $c_d = -v^2 \frac{f_d}{\Lambda^2}$ |
| $c_\ell 	imes 10$ | $c_\ell = -v^2 rac{f_\ell}{\Lambda^2}$ |
| $c_{HW} 	imes 10^2$ | $c_{HW} = rac{m_W^2}{2g} rac{f_{HW}}{\Lambda^2}$ |
| $(c_{WW}-c_B)	imes 10^2$ | $c_{WW} = rac{m_W^2}{g} rac{f_{WW}}{\Lambda^2}$, $c_B =$ |

| | Others profiled | Fix others to SM |
|---|--|--|
| | $-1.03^{+1.53}_{-1.59}$ | $-0.78^{+1.11}_{-1.16}$ |
| | $\begin{pmatrix} +1.59 \\ -1.56 \end{pmatrix}$ | $\begin{pmatrix} +1.10 \\ -1.11 \end{pmatrix}$ |
| | $1.43^{+3.20}_{-3.00}$ | $0.27^{+1.05}_{-1.05}$ |
| | $\begin{pmatrix} +3.13 \\ -2.74 \end{pmatrix}$ | $\begin{pmatrix} +1.03 \\ -1.01 \end{pmatrix}$ |
| | $0.68^{+0.82}_{-0.83}$ | $0.43^{+0.69}_{-0.69}$ |
| | $\begin{pmatrix} +0.83 \\ -0.79 \end{pmatrix}$ | $\begin{pmatrix} +0.68 \\ -0.67 \end{pmatrix}$ |
| | $0.59^{+1.03}_{-1.13}$ | $-0.01\substack{+0.31\\-0.28}$ |
| | $\begin{pmatrix} +1.08\\ -1.05 \end{pmatrix}$ | $\begin{pmatrix} +0.30 \\ -0.28 \end{pmatrix}$ |
| | $-0.57^{+0.74}_{-0.73}$ | $-0.75^{+0.60}_{-0.64}$ |
| | $\begin{pmatrix} +0.72 \\ -0.77 \end{pmatrix}$ | $\begin{pmatrix} +0.58 \\ -0.60 \end{pmatrix}$ |
| | $-1.45^{+4.72}_{-3.03}$ | $0.77^{+0.84}_{-1.20}$ |
| | $\begin{pmatrix} +3.93 \\ -3.27 \end{pmatrix}$ | $\begin{pmatrix} +1.04\\ -1.38 \end{pmatrix}$ |
| $= \frac{2m_W^2}{g'} \frac{f_B}{\Lambda^2}$ | $2.16^{+2.84}_{-5.35}$ | $0.62^{+1.06}_{-1.22}$ |
| g' Λ ² | $\begin{pmatrix} +3.46\\ -5.00 \end{pmatrix}$ | $\begin{pmatrix} +1.09\\ -1.23 \end{pmatrix}$ |







Correlations of EFT parameters

| CMS Preliminary 35.9-137 fb ⁻¹ (13 TeV) | | | | | | | - | |
|---|---------|----------------------------------|----------------------------------|---------|---------------------|---|-----------------------------------|--------------|
| c _u x 10 | 1.00 | 0.42 | 0.03 | -0.02 | 0.37 | 0.29 | -0.30 | -0.8 |
| с _д х 10 ⁵ | 0.42 | 1.00 | -0.01 | 0.08 | 0.85 | 0.50 | -0.54 | -0.6 |
| c _A x 10 ⁴ | 0.03 | -0.01 | 1.00 | -0.32 | -0.32 | -0.09 | -0.03 | -0.4 -0.2 |
| c _i x 10 | -0.02 | 0.08 | -0.32 | 1.00 | 0.19 | -0.15 | 0.23 | -0 |
| c _d x 10 | 0.37 | 0.85 | -0.32 | 0.19 | 1.00 | 0.64 | -0.60 | 0.2 0.4 |
| (c _{ww} – c _B) x 10 ² | 0.29 | 0.50 | -0.09 | -0.15 | 0.64 | 1.00 | -0.94 | 0.6 |
| c _{HW} x 10 ² | -0.30 | -0.54 | -0.03 | 0.23 | -0.60 | -0.94 | 1.00 | 0.8 |
| | c, x 10 | с _G х 10 ⁵ | c _A x 10 ⁴ | c, x 10 | с _d х 10 | (c _{ww} – c _B) x 10 ² | с _{НW} х 10 ² | 1 |
| | | | | | | 0 | | |







Correlations of EFT parameters

| CMS <i>Preliminary</i> 35.9-137 fb ⁻¹ (13 TeV) | | | | | | | | |
|--|---------------------|----------------------------------|----------------------------------|---------|---------------------|------------------------------------|-----------------------------------|--------------|
| c _u x 10 Large correlations due to | 1.00 | 0.42 | 0.03 | -0.02 | 0.37 | 0.29 | -0.30 | - 0.8 |
| the limited differential | 0.42 | 1.00 | -0.01 | 0.08 | 0.85 | 0.50 | -0.54 | - 0.6 |
| information for VH c _A x 10 ⁴ | 0.03 | -0.01 | 1.00 | -0.32 | -0.32 | -0.09 | -0.03 | -0.4 -0.2 |
| production q x 10 | -0.02 | 0.08 | -0.32 | 1.00 | 0.19 | -0.15 | 0.23 | -0 |
| c _d x 10 | 0.37 | 0.85 | -0.32 | 0.19 | 1.00 | 0.64 | -0.60 | 0.2 0.4 |
| (c _{ww} – c _B) x 10 ² | 9.29 | 0.50 | -0.09 | -0.15 | 0.64 | 1.00 | -0.94 | 0.6 |
| с _{нw} х 10 ² | -0.30 | -0.54 | -0.03 | 0.23 | -0.60 | -0.94 | 1.00 | 0.8 |
| | c _u x 10 | с _G х 10 ⁵ | с _A х 10 ⁴ | c, x 10 | c _d x 10 | c _B) x 10 ² | с _{НW} х 10 ² | 1 |
| | | | | | | (c _{ww} – (| S | |

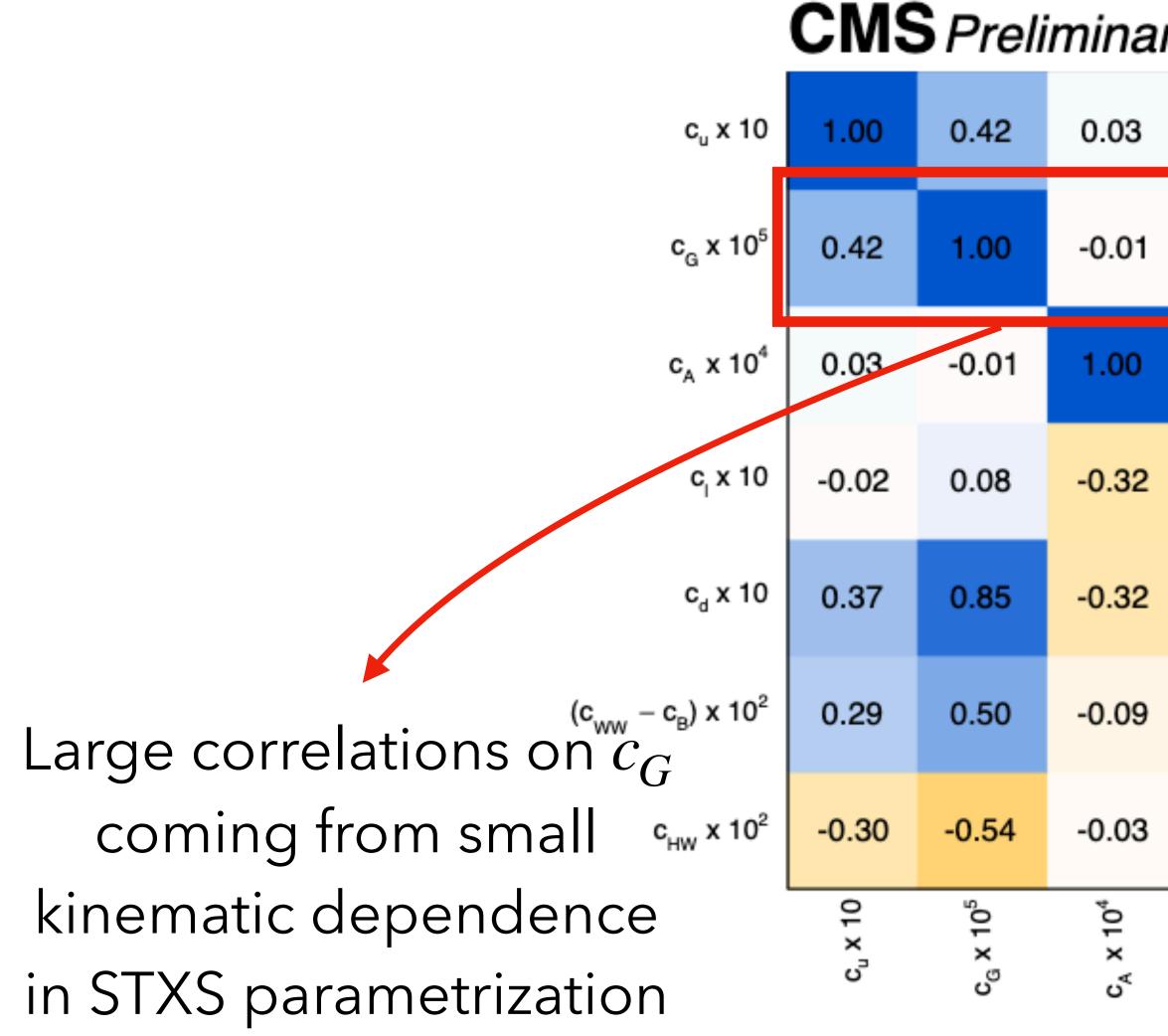








Correlations of EFT parameters





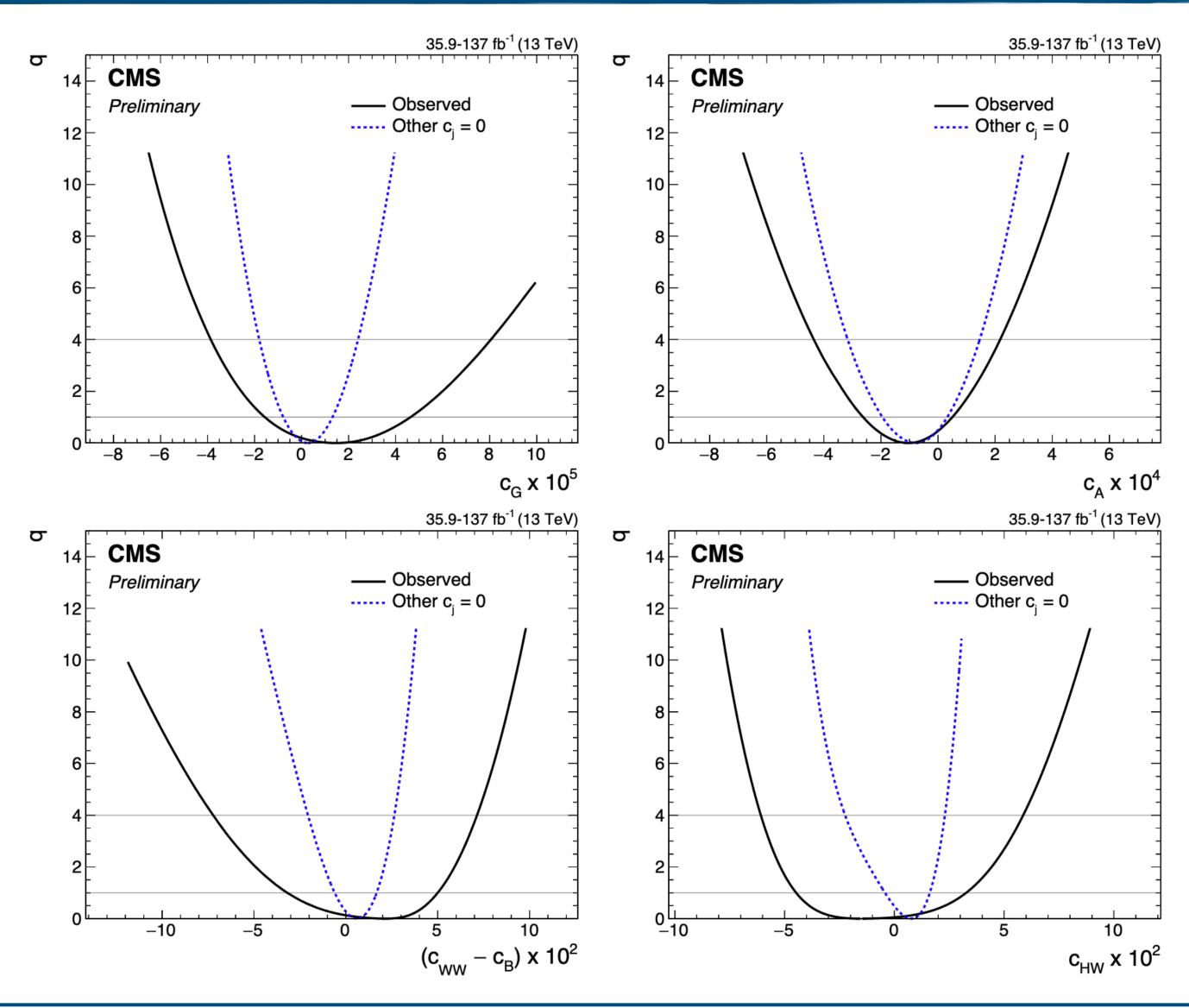
| ŗ | y a | - 1 | | | |
|---|---------|---------------------|---------------------------|-----------------------|---------------------|
| | -0.02 | 0.37 | 0.29 | -0.30 | 1 <u>-</u> - 0.8 |
| | 0.08 | 0.85 | 0.50 | -0.54 | -0.6 |
| | -0.32 | -0.32 | -0.09 | -0.03 | -0.4 -0.2 |
| | 1.00 | 0.19 | -0.15 | 0.23 | - 0 |
| | 0.19 | 1.00 | 0.64 | -0.60 | 0.2 |
| | -0.15 | 0.64 | 1.00 | -0.94 | 0.4 0.6 |
| | 0.23 | -0.60 | -0.94 | 1.00 | 0.8 |
| | c, x 10 | c _d x 10 | $(c_{ww} - c_B) \ge 10^2$ | с _{нw} х 10² | |







EFT parameters: likelihood scans



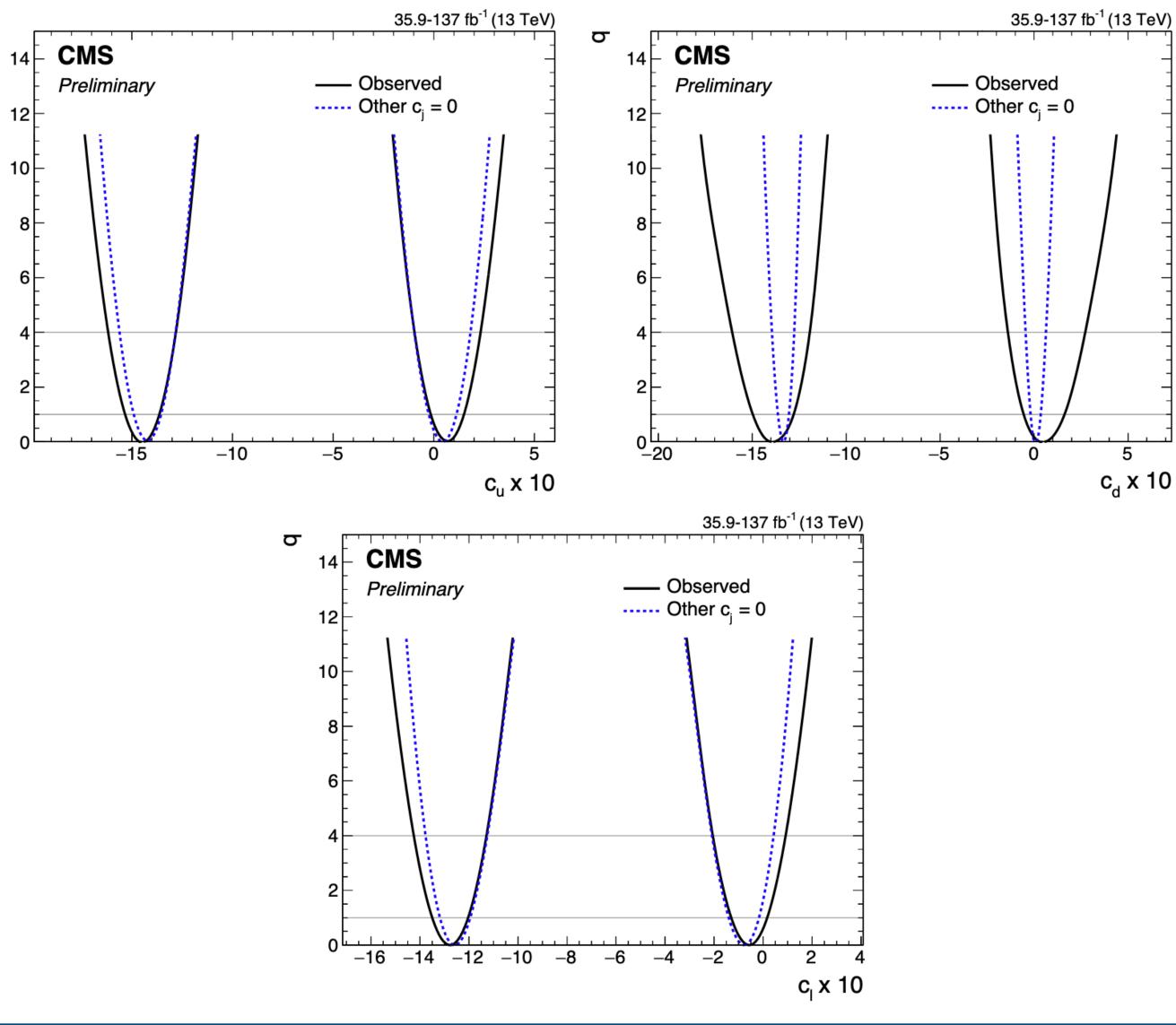


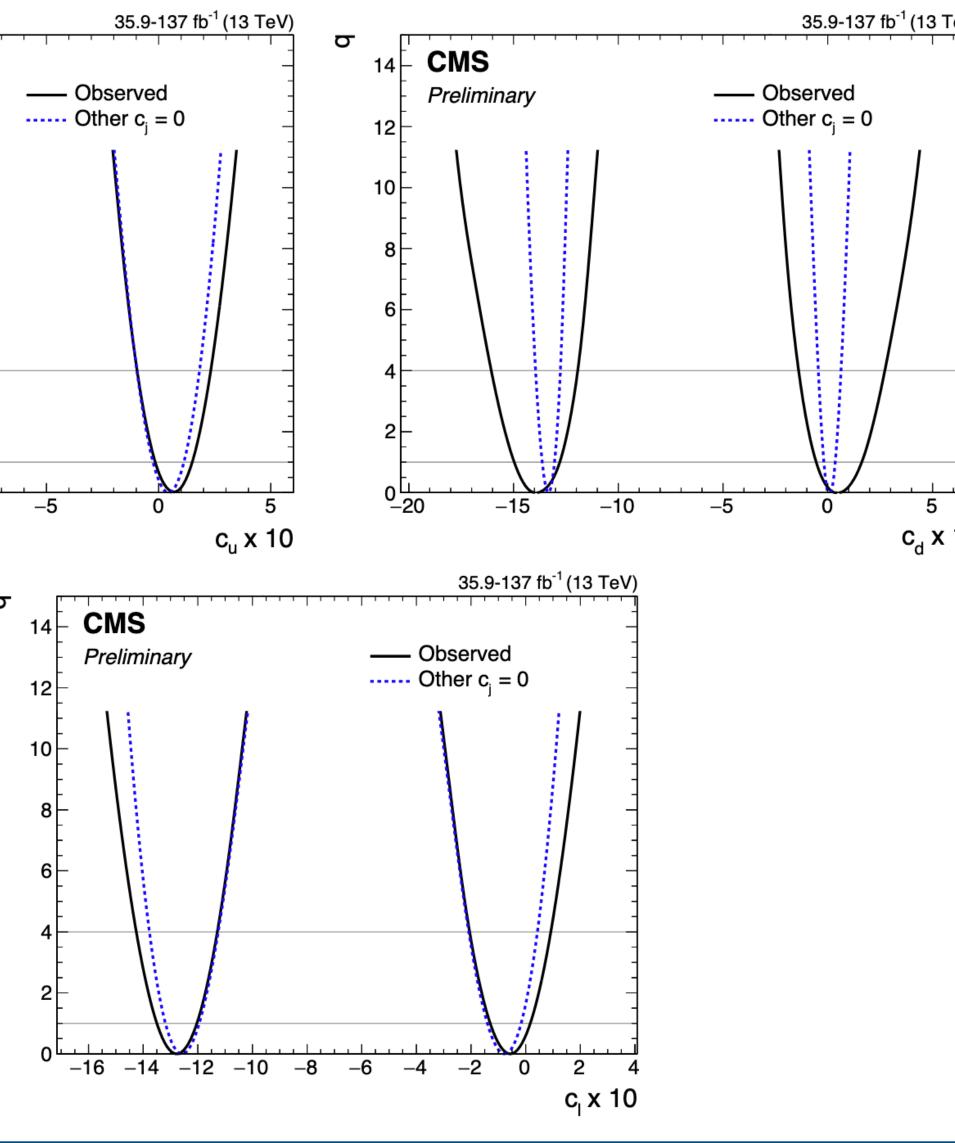




EFT parameters: likelihood scans

σ







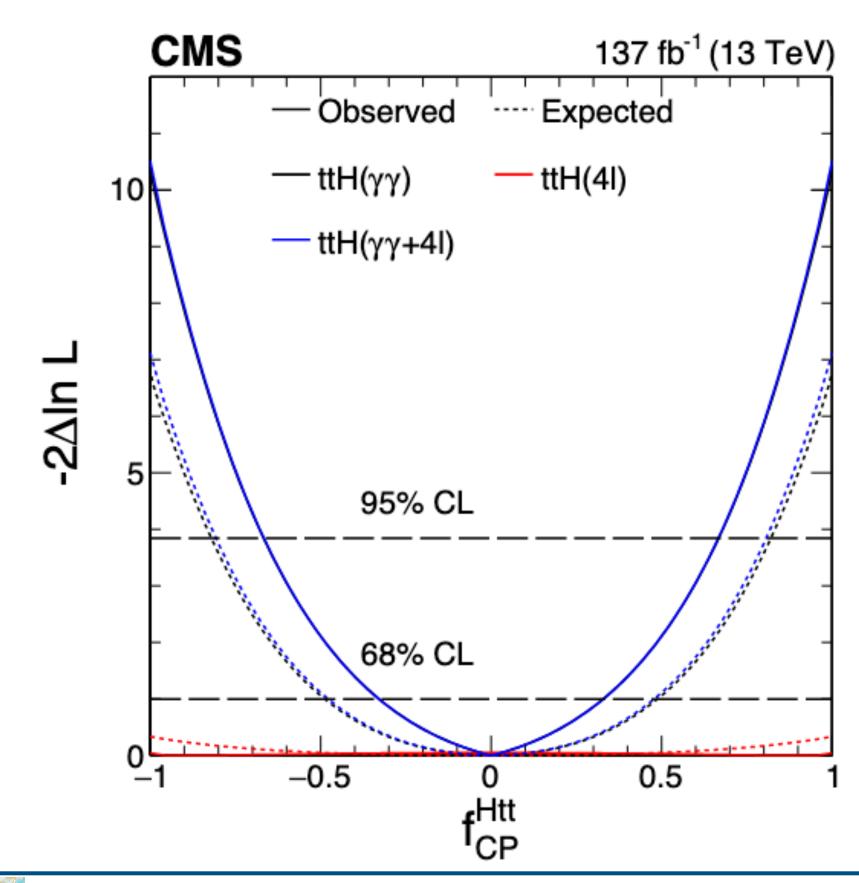






Htt couplings & EFT interpretation

 $f_{\rm CP}^{\rm Hff} = \frac{1}{|\kappa|}$

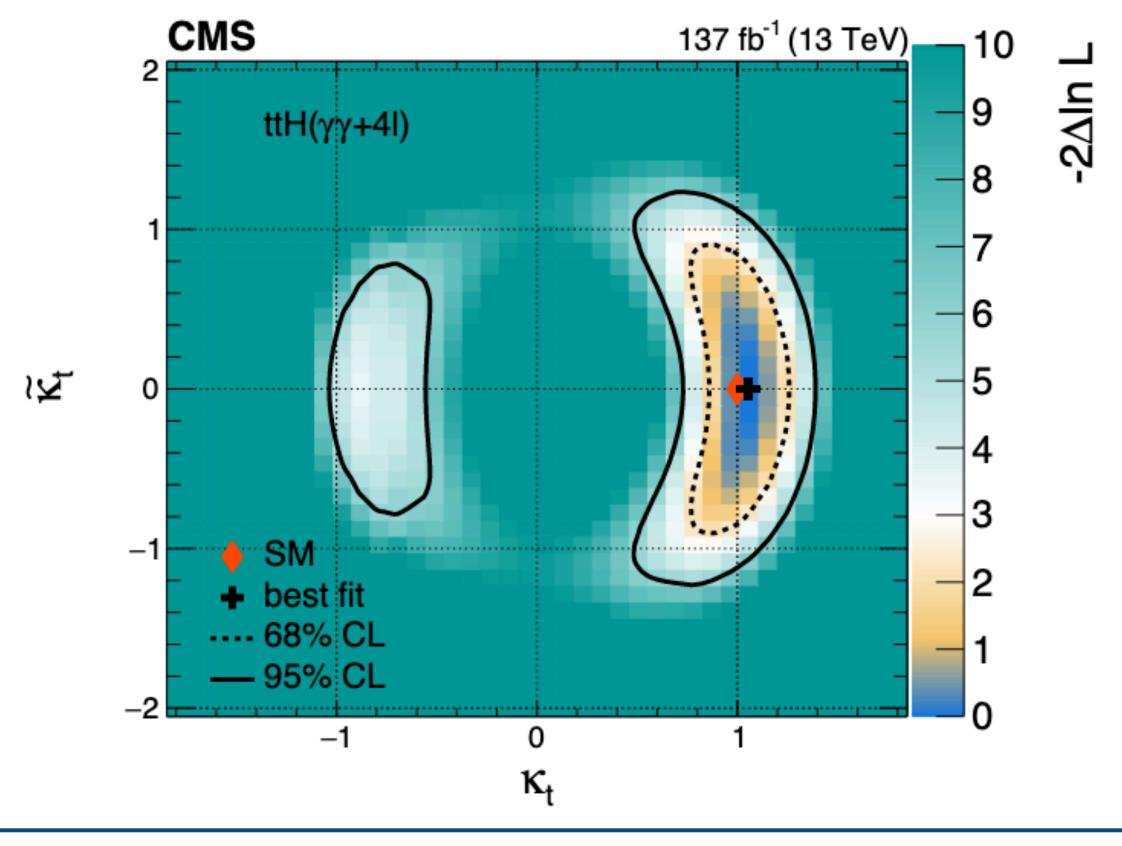




Higgs Hunting



$$\frac{|\tilde{\kappa}_{\rm f}|^2}{|\tilde{\kappa}_{\rm f}|^2 + |\tilde{\kappa}_{\rm f}|^2} \operatorname{sign}\left(\frac{\tilde{\kappa}_{\rm f}}{\kappa_{\rm f}}\right)$$



CMS-HIG-19-009

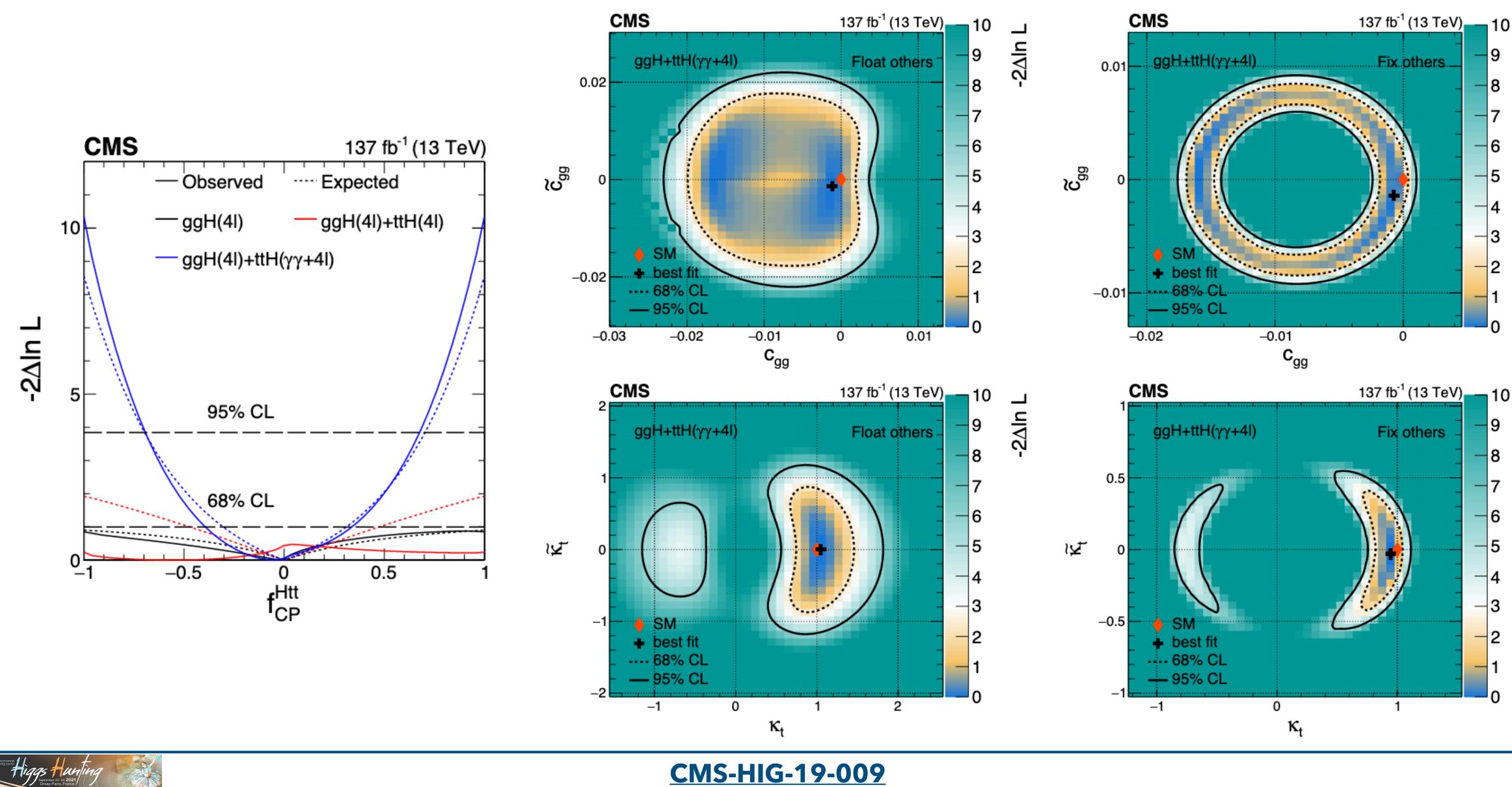


IR





Htt couplings & EFT interpretation





CMS-HIG-19-009











Link to ATLAS Slides





