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Higgs couplings combination at CMS

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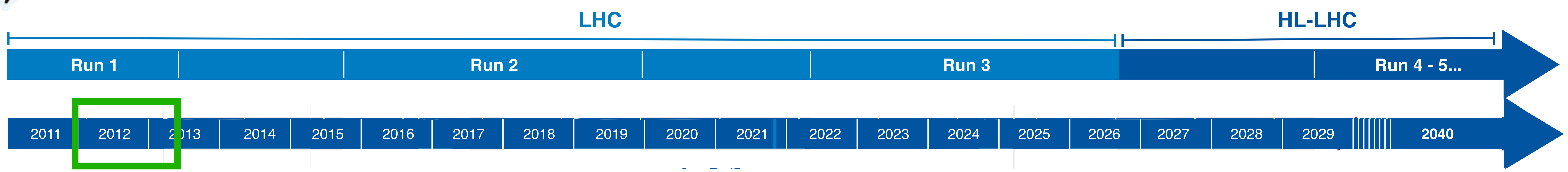
(University of Hamburg)
On behalf of the CMS Collaboration

FSP CMS
Erforschung von Universum und Materie

The Higgs boson turns 10

LHC / HL-LHC Plan



"This boson is a very profound thing we have found. ***We're reaching into the fabric of the universe*** *at a level we've never done before. [...]* ***We're*** *on the frontier now,* ***on the edge of a new exploration****. [...] we could open a whole new realm of discoveries."*

– J. Incandela

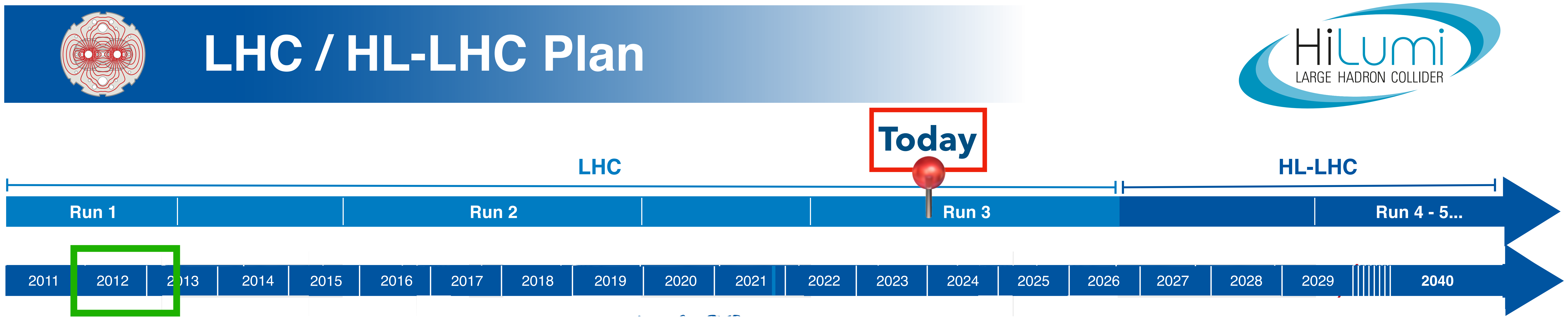
Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

The ATLAS Collaboration

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC

The CMS Collaboration

The Higgs sector at the LHC



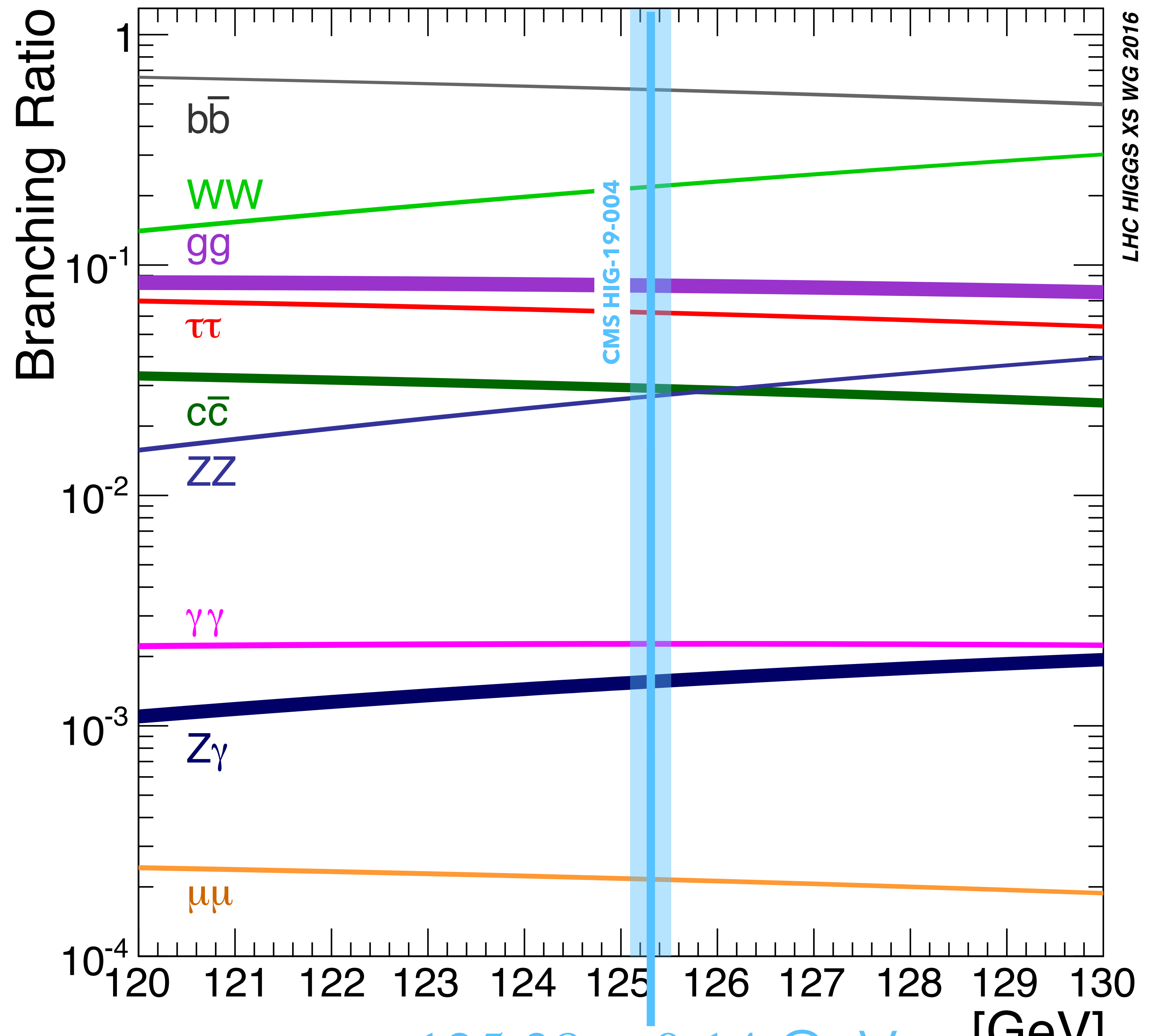
Combination of all decay channels at $\sqrt{s} = 7, 8$ *TeV*

Measured properties in agreement with SM

Mass: $m_H = 125.09 \pm 0.21$ (stat) $\pm\ 0.11$ (syst) GeV

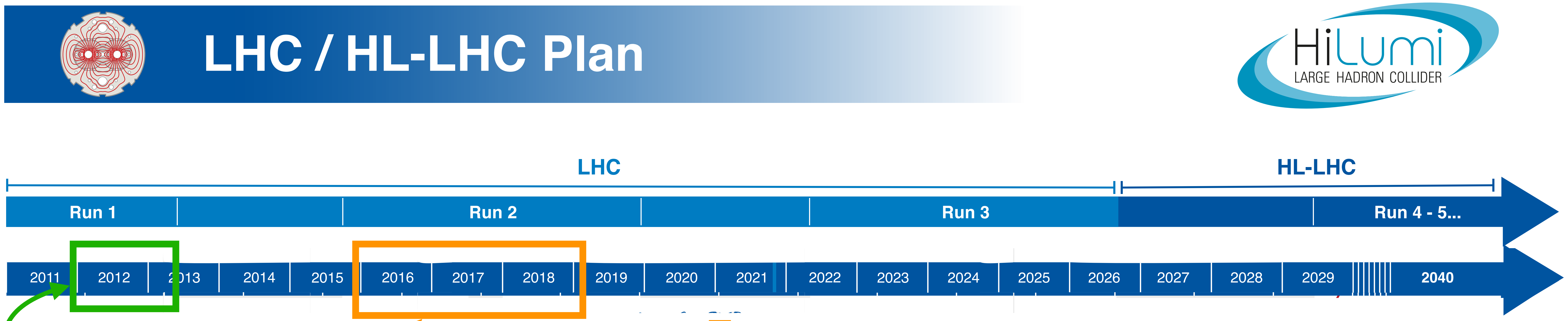
J^P: 0^+ CP-even structure

Value of m_H determines which decay channels are accessible at LHC



$m_H = 125.38 \pm 0.14$ GeV

Run-II: more data, more power

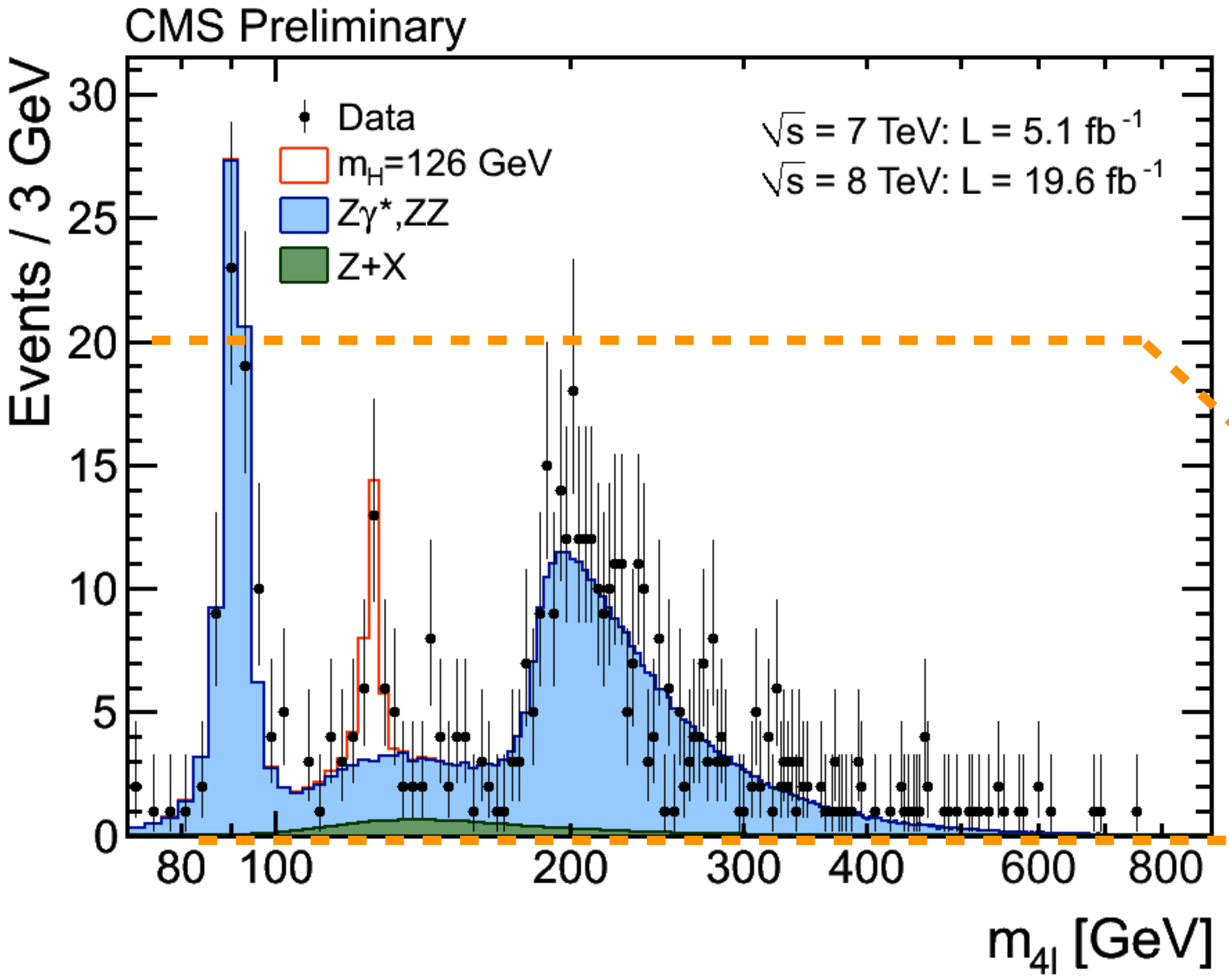


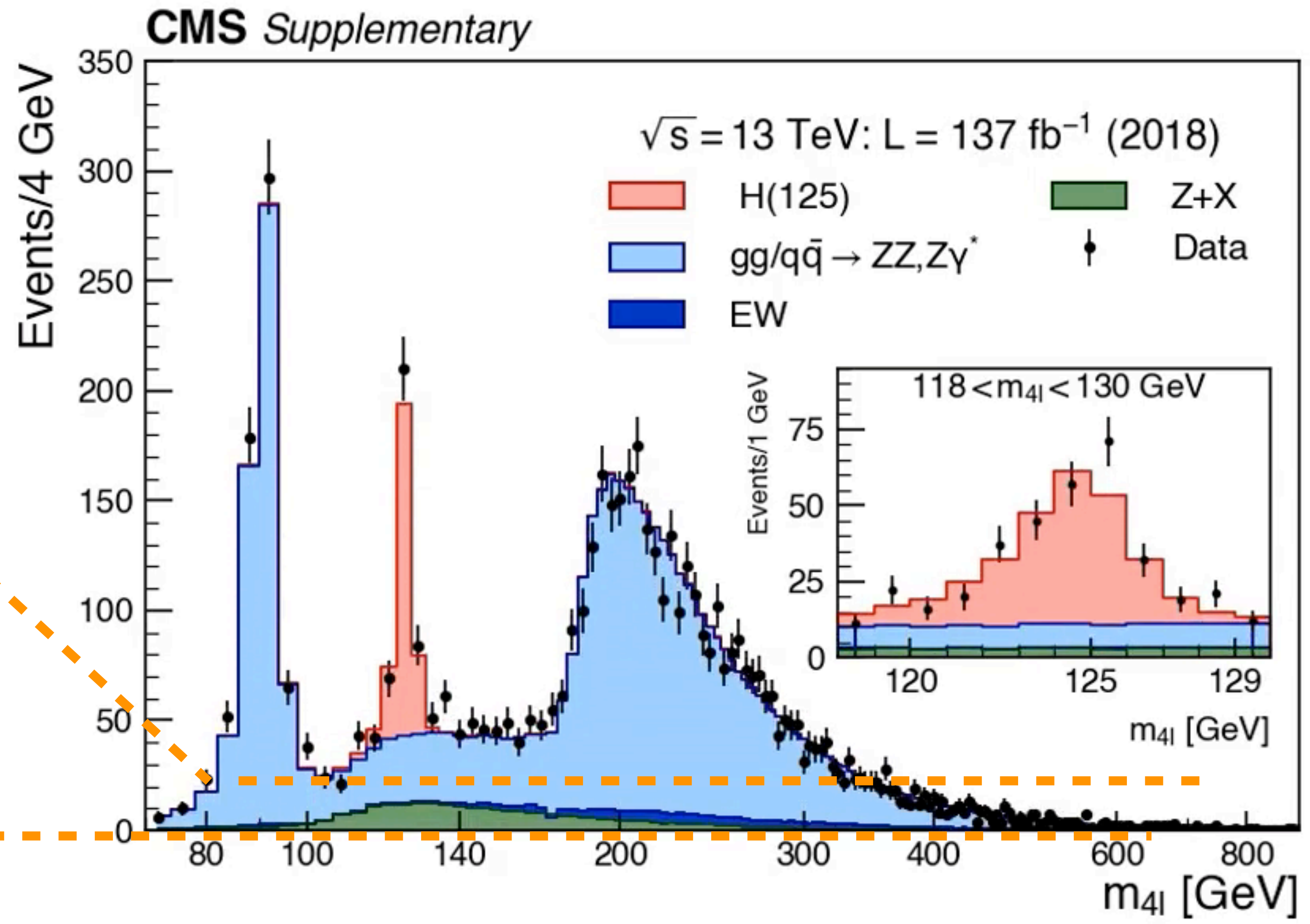
Run-I: $\sqrt{s} = 7 - 8$ TeV

Discovery & characterisation

Run-II: $\sqrt{s} = 13$ TeV

precision physics era





Production xsec x2-4 larger in Run-II

Luminosity x10 larger than Run-I

Run-II: ~ 8 million H bosons produced

One boson, many questions

Is this the SM-like H boson?

Are the production and decay rates compatible with the SM?

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Measure fermionic and bosonic couplings and probe BSM contributions

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Run-II combination: access to several final states, reduction of uncertainties, improved analysis techniques…

The input analyses

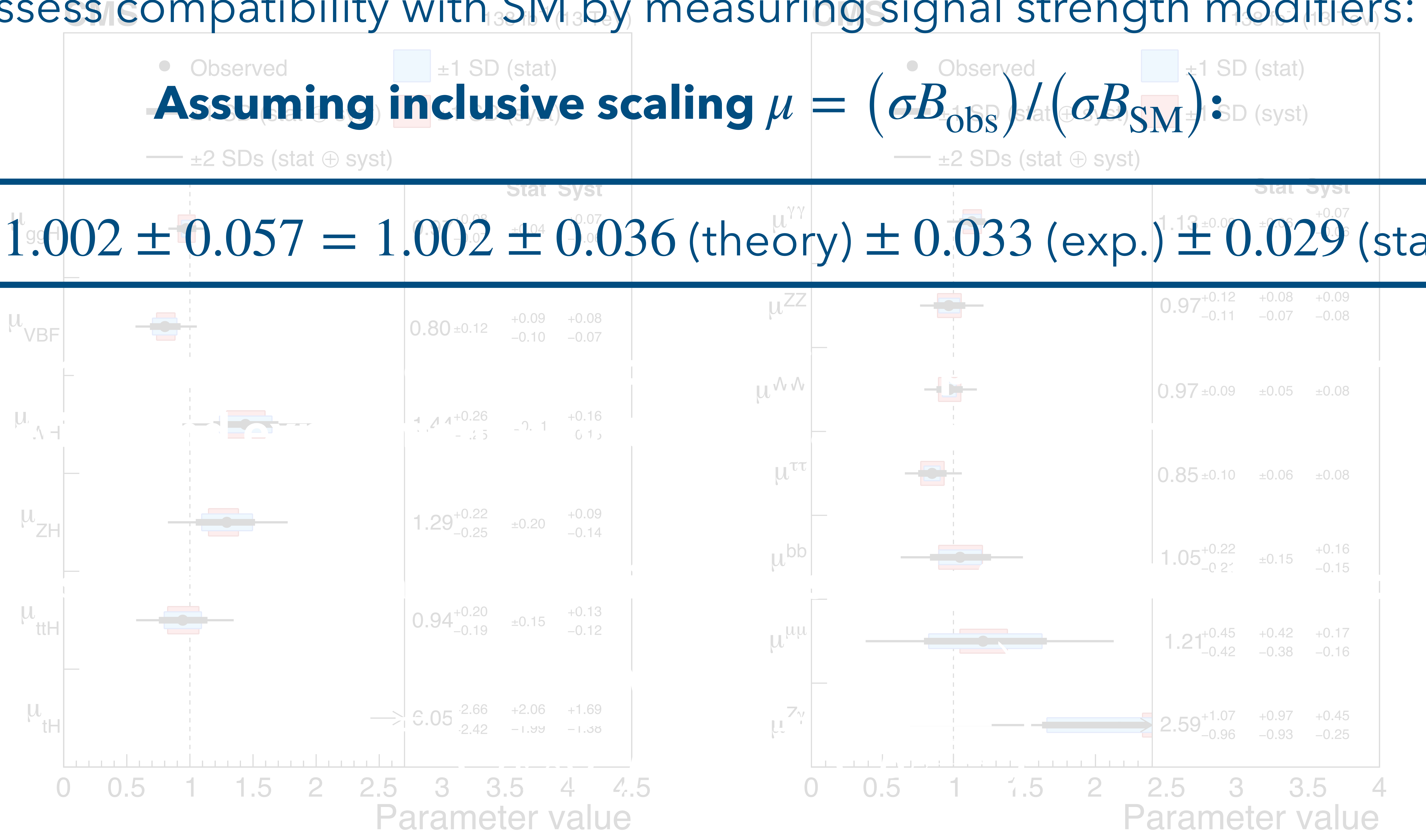
CMS HIG-22-001

Decay channel	Luminosity (fb^{-1})	ggH	VBF	VH	ttH/tH
$H \to \gamma\gamma$	138	✓	✓	✓	✓
$H \to ZZ$	138	✓	✓	✓	✓
$H \to WW$	138	✓	✓	✓	✓
$H \to bb$	36 (ttH), 77 (VH), 138 (ggH)	✓	✓	✓	✓
$H \to \tau\tau$	138	✓	✓	✓	✓
$H \to \mu\mu$	138	✓	✓	✓	✓
$H \to Z\gamma$	138	✓	✓		
$H \to inv$	138	✓	✓	✓	

Run-II combination: comprehensive characterisation of the H boson profile at LHC!

Do we observe SM yields?

Assess compatibility with SM by measuring signal strength modifiers:



Assuming inclusive scaling $\mu = (\sigma B_{\text{obs}})/(\sigma B_{\text{SM}})$:

$$\boxed{\mu = 1.002 \pm 0.057 = 1.002 \pm 0.036\,(\text{theory}) \pm 0.033\,(\text{exp.}) \pm 0.029\,(\text{stat.})}$$

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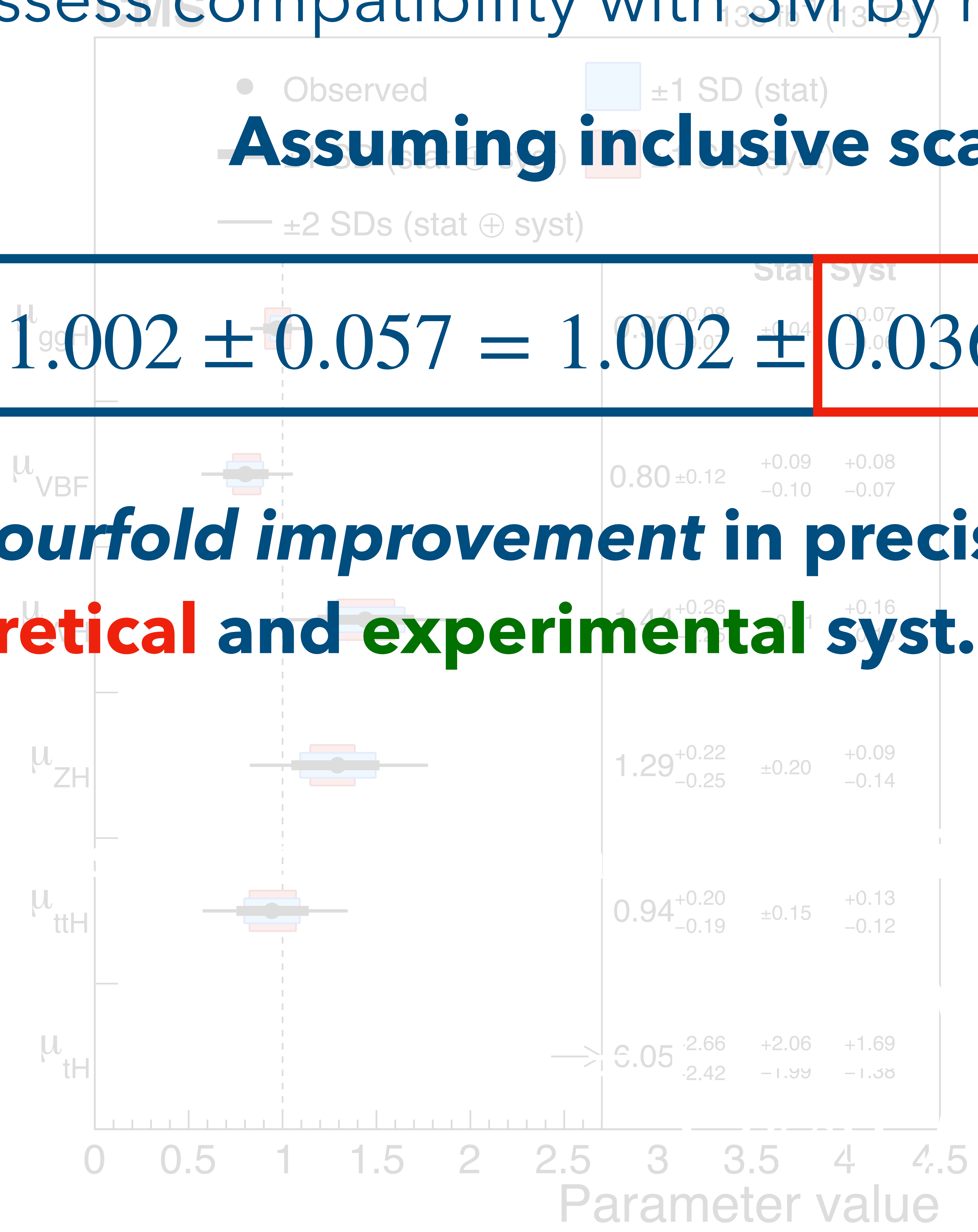

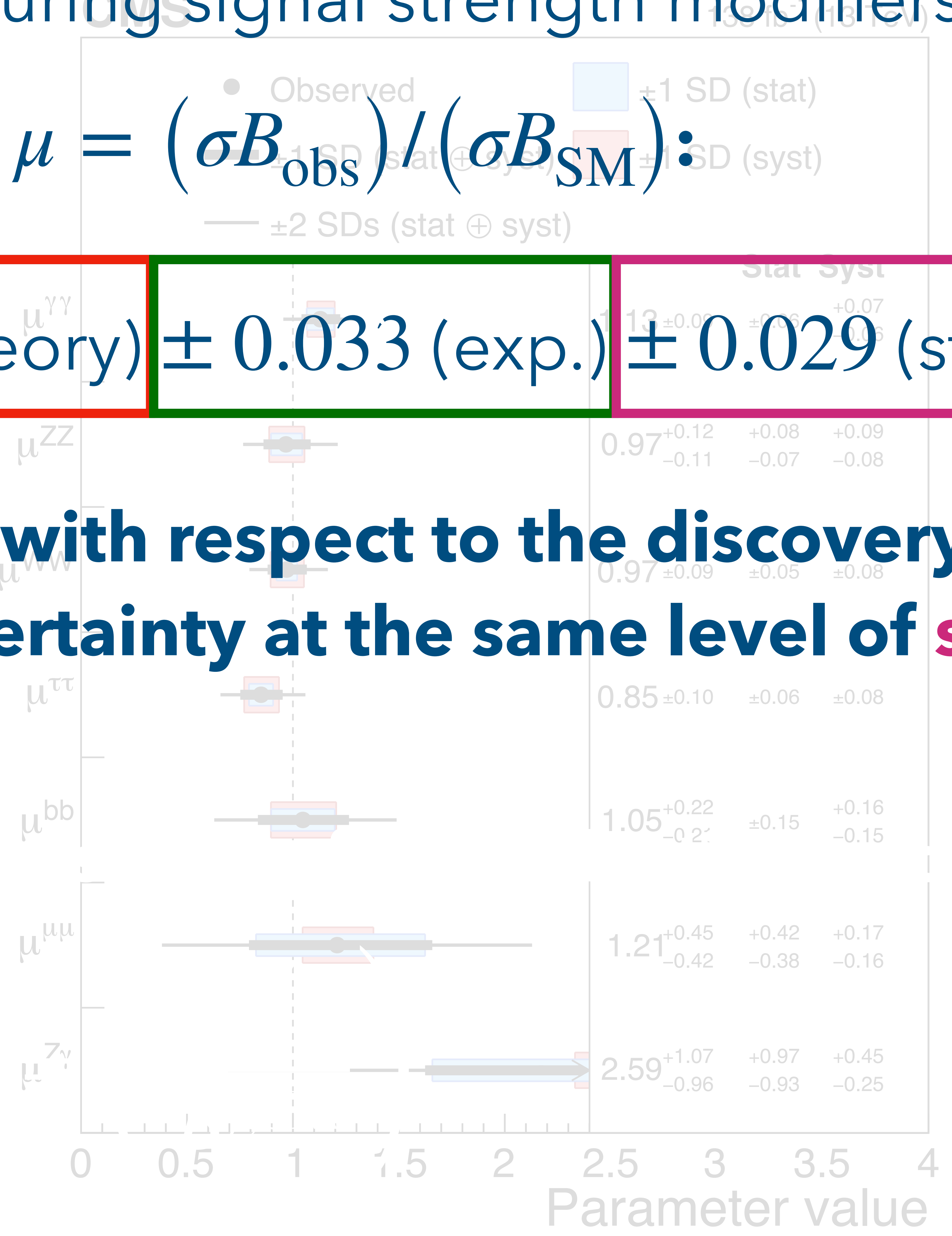

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Fourfold improvement **in precision with respect to the discovery**

Theoretical and experimental syst. uncertainty at the same level of stat.!

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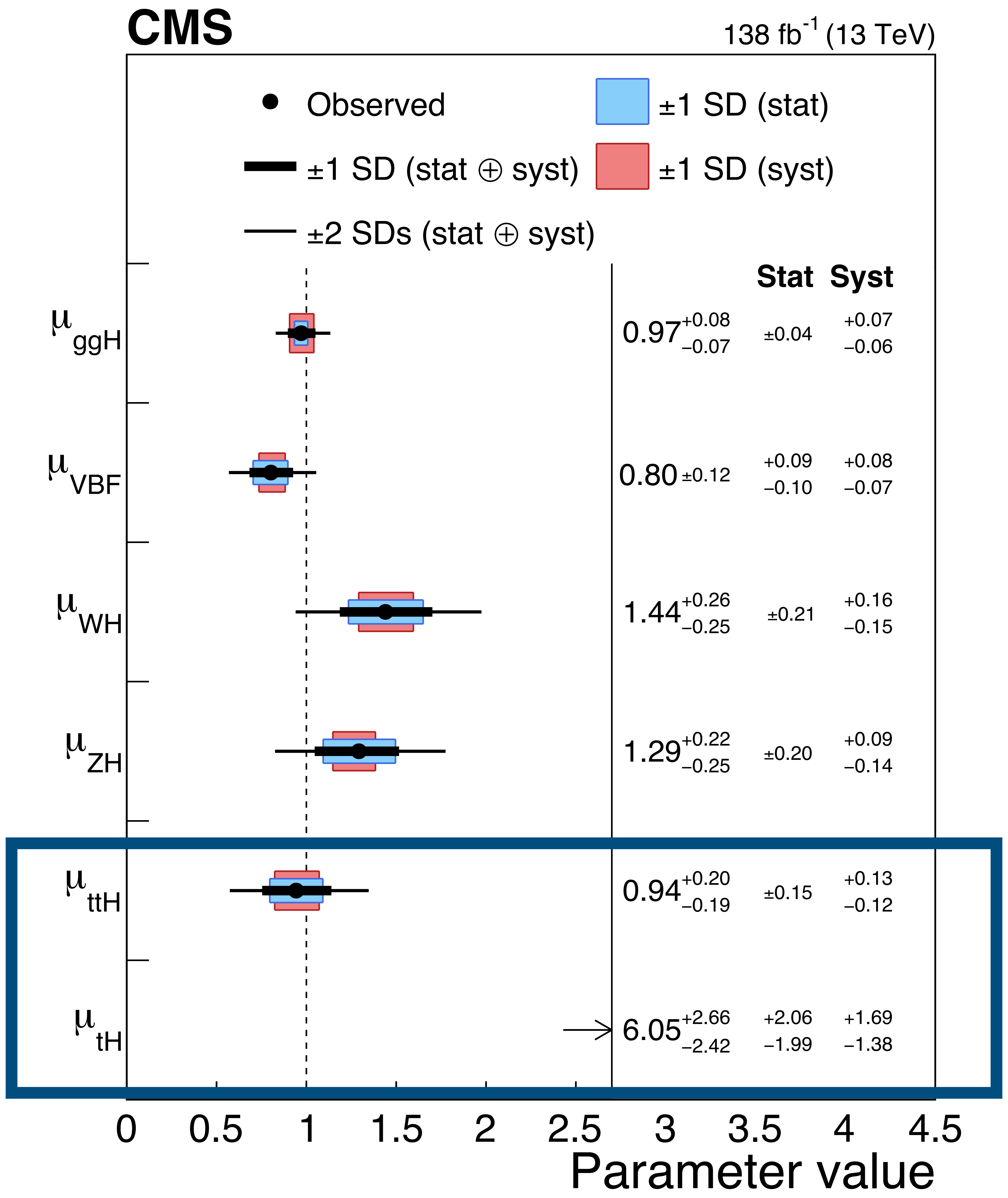
Theoretical and experimental syst. uncertainty at the same level of stat.!

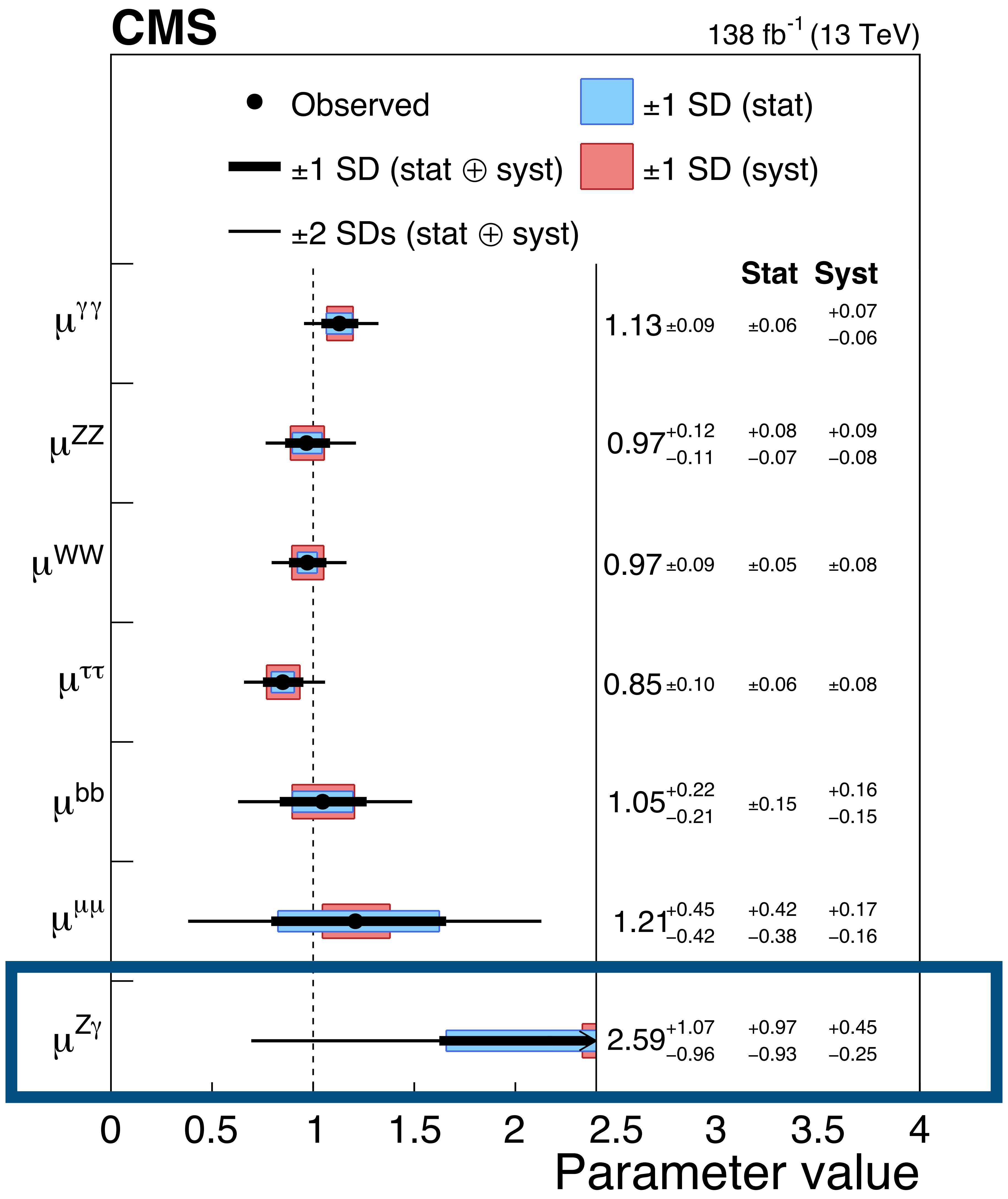
Relaxing assumptions and assuming **different scaling for production and decay:**

$$\mu_i = \left(\frac{\sigma_i}{\sigma_{i,\text{SM}}}\right) \qquad \mu_i = \left(\frac{B^f}{B^{f,\text{SM}}}\right)$$

Do we observe SM yields?



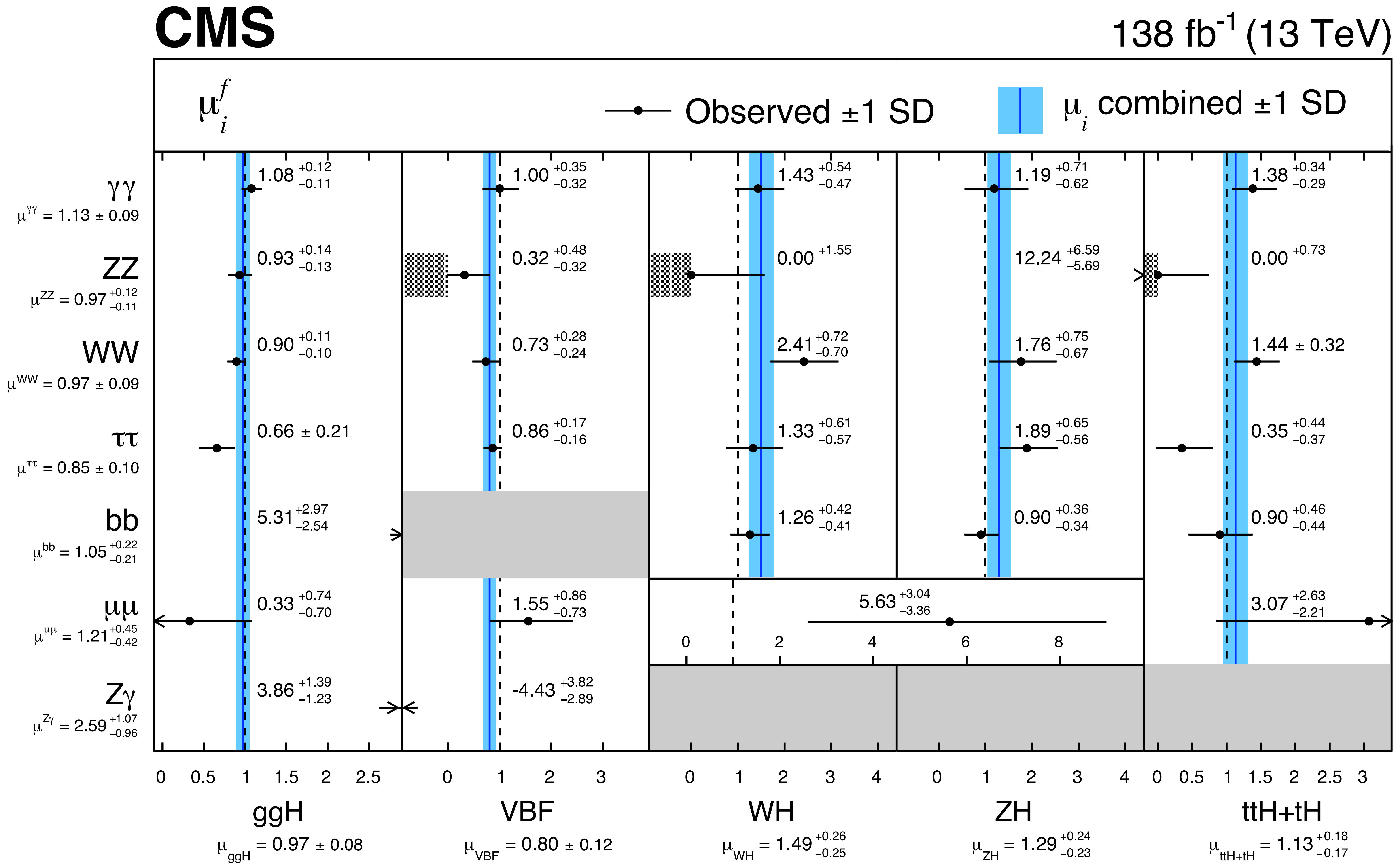
ttH and tH modes measured separately



New result!

Do we observe SM yields?

More general test of SM with **all μ_i^f independent** also shows **good agreement** with **SM** predictions



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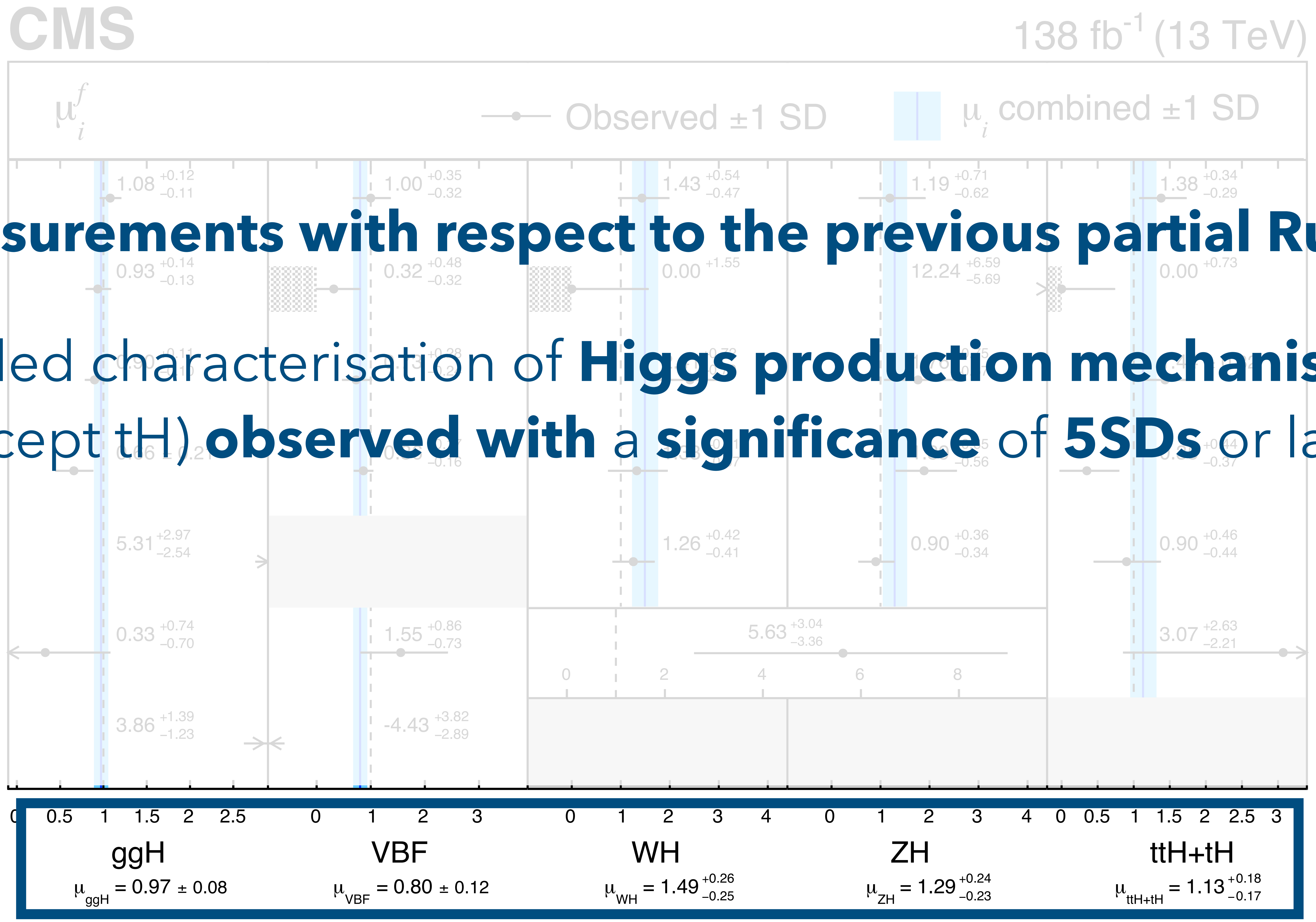
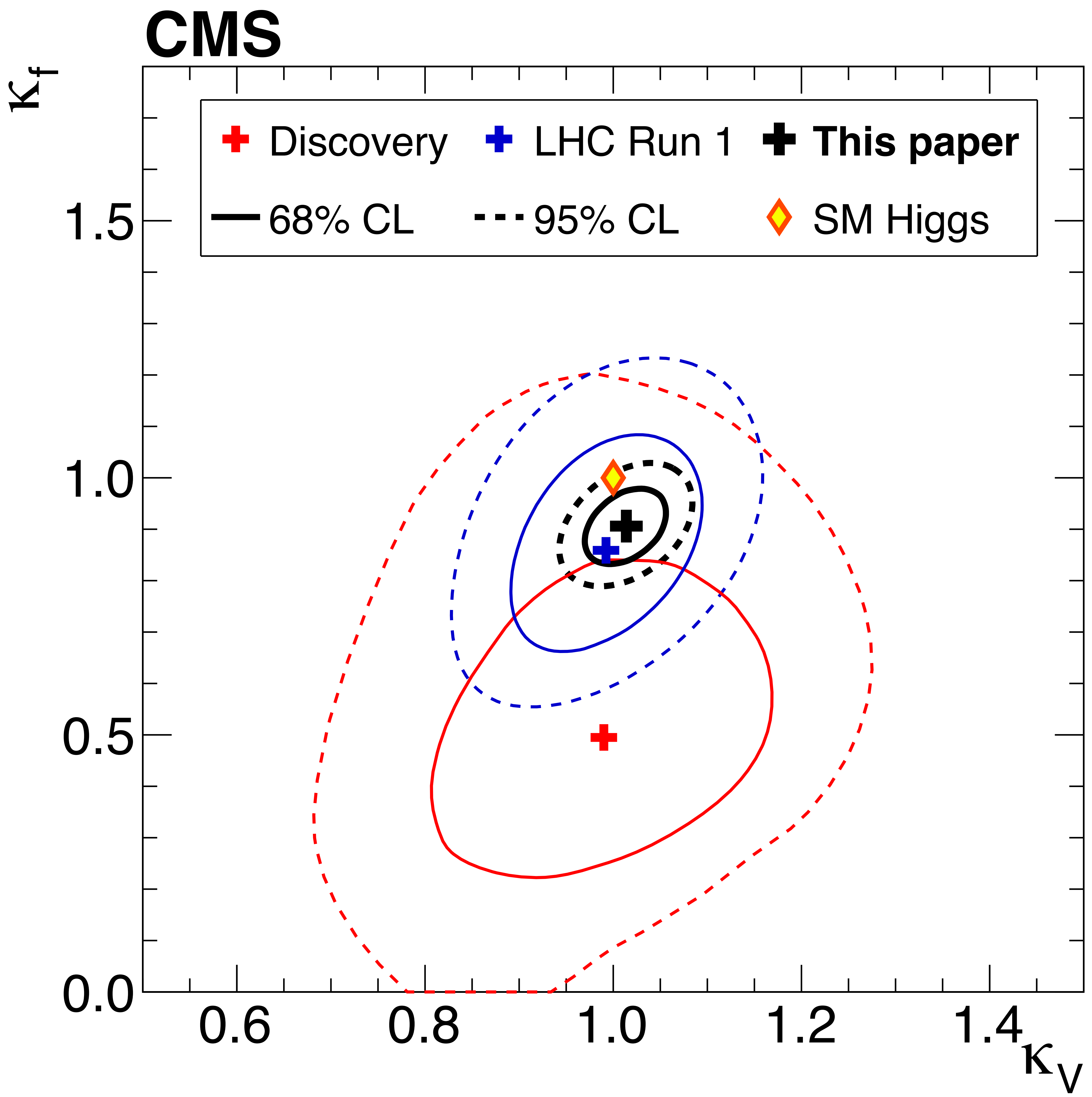


Several new measurements with respect to the previous partial Run-II combination

Detailed characterisation of **Higgs production mechanisms**, all (except tH) **observed with** a **significance** of **5SDs** or larger

Do we observe SM couplings?



Probe SM predictions by measuring coupling modifiers $\overrightarrow{\kappa}$ (=1 in SM):

$$\sigma_i B^f = \left(\frac{\sigma_i(\overrightarrow{\kappa})\Gamma^f(\overrightarrow{\kappa})}{\Gamma_H(\overrightarrow{\kappa})} \right)$$

κ_V, κ_f : bosonic- and fermionic-like coupling modifiers in agreement with SM within 10%

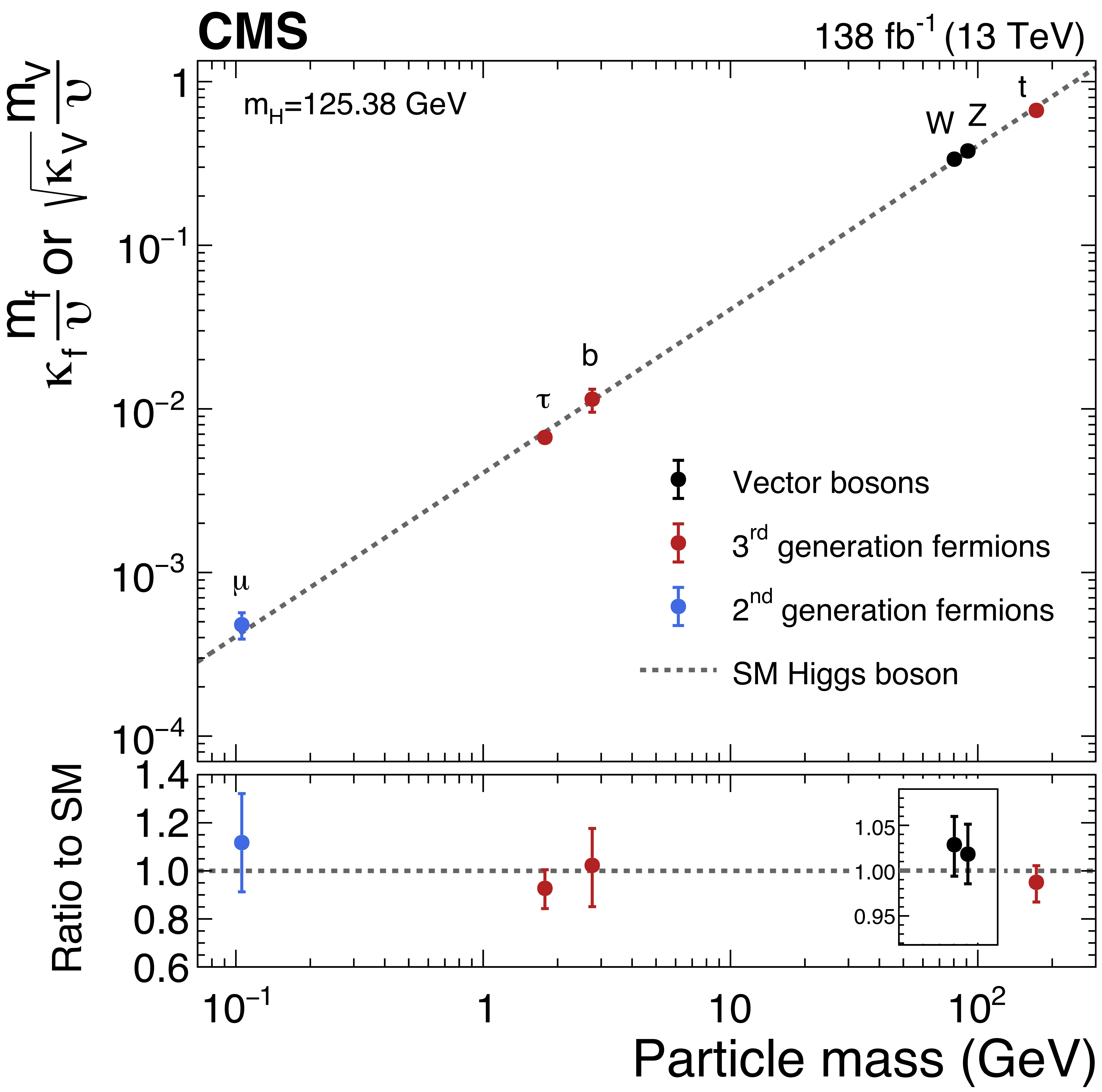
Substantial improvement in precision with respect to Discovery and Run-I

Do we observe SM couplings?

Measure κ_V, κ_f for each vector-boson and fermion to **probe expected scaling of coupling modifiers with the particle mass**

Excellent agreement with scalings predicted by the SM: $\kappa_V \propto m_V^2, \kappa_f \propto m_f$

Statistical and systematic uncertainties contribute at the same level to all measurements but κ_μ

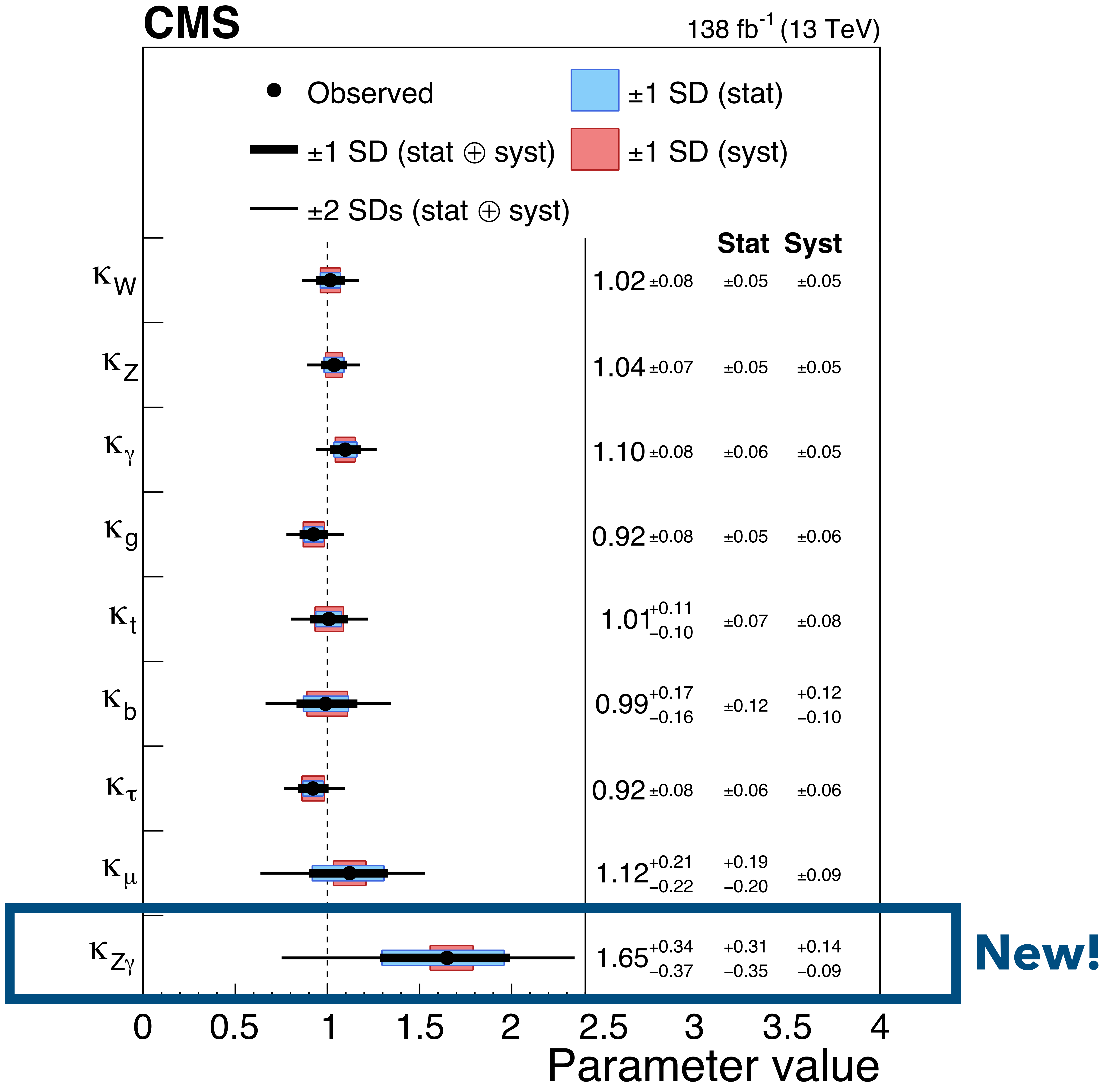


What about more couplings?

Probe extensions of the SM introducing **additional modifiers** for **gluon**, **photons**, and $Z\gamma$ **couplings**

Excellent **agreement with** the **SM, at** the **level of 10%** for most coupling modifiers

Undetected and invisible decays not included in this model



Invisible & undetected decays

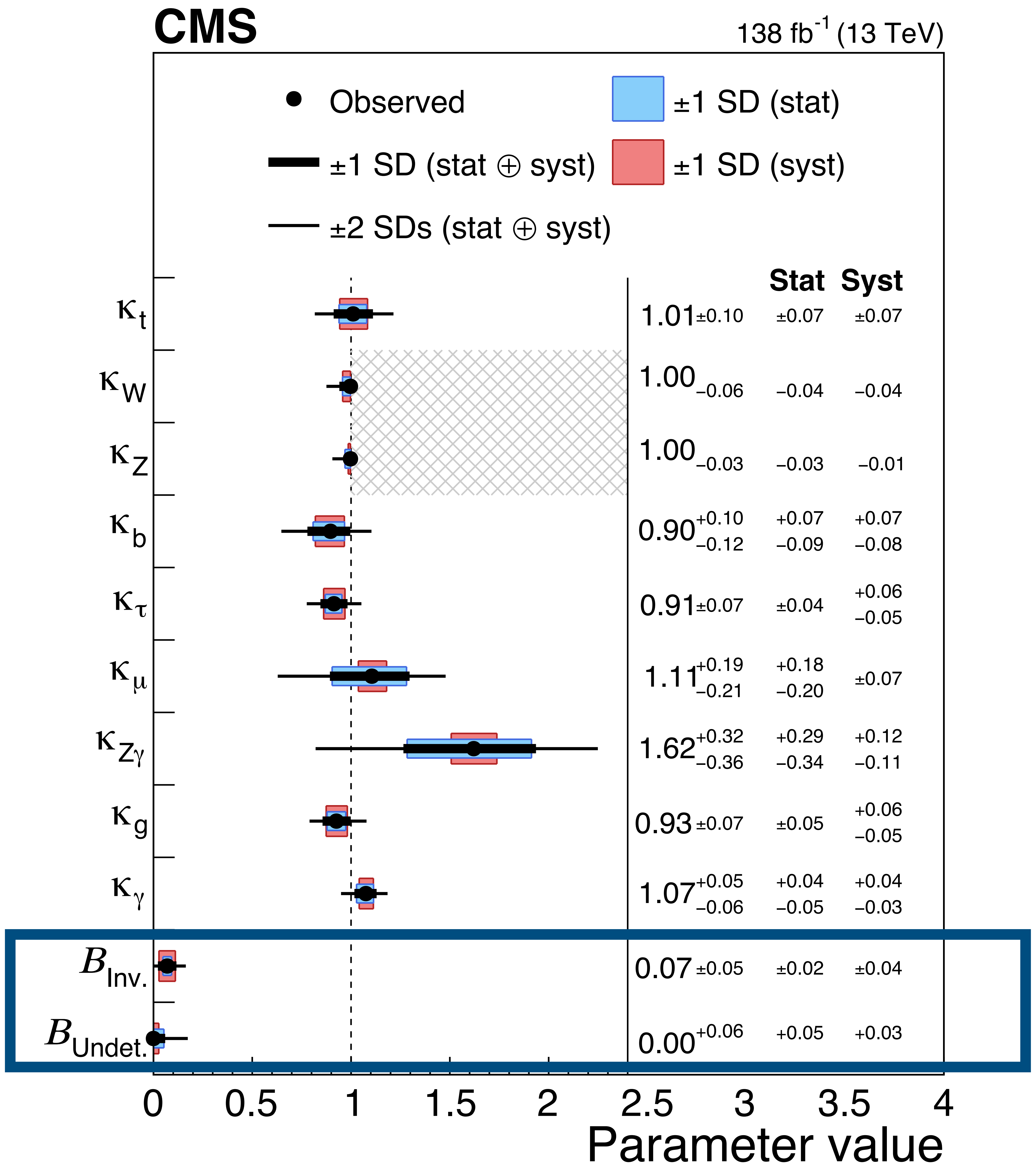
"Stress test" of SM predictions including BSM contributions to Higgs total width:

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \frac{\kappa_H^2}{(1-(B_{inv}+B_{undet.}))}$$

All κs in agreement with SM (κ=1)

Upper limits on **invisible** and **undetected BRs:**

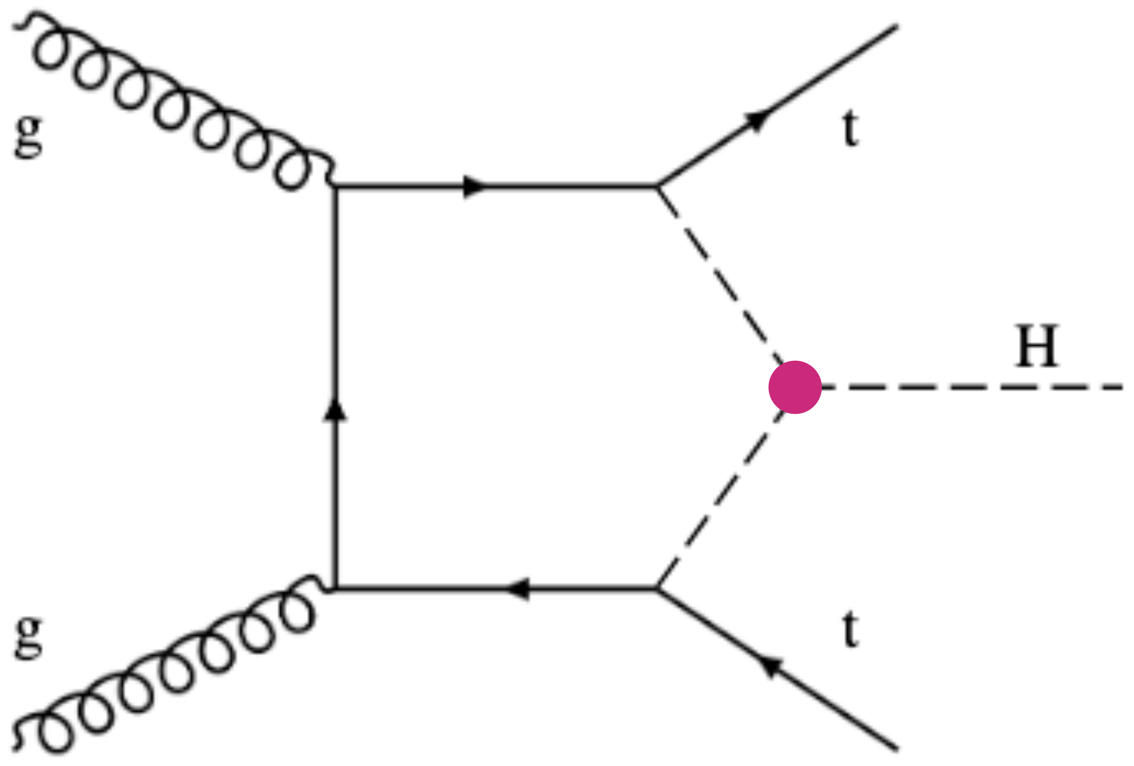
$$\mathcal{B}_{\text{Inv.}} < 0.16,\ \mathcal{B}_{\text{Undet.}} < 0.17\ @95\,\%\,\text{CL}$$

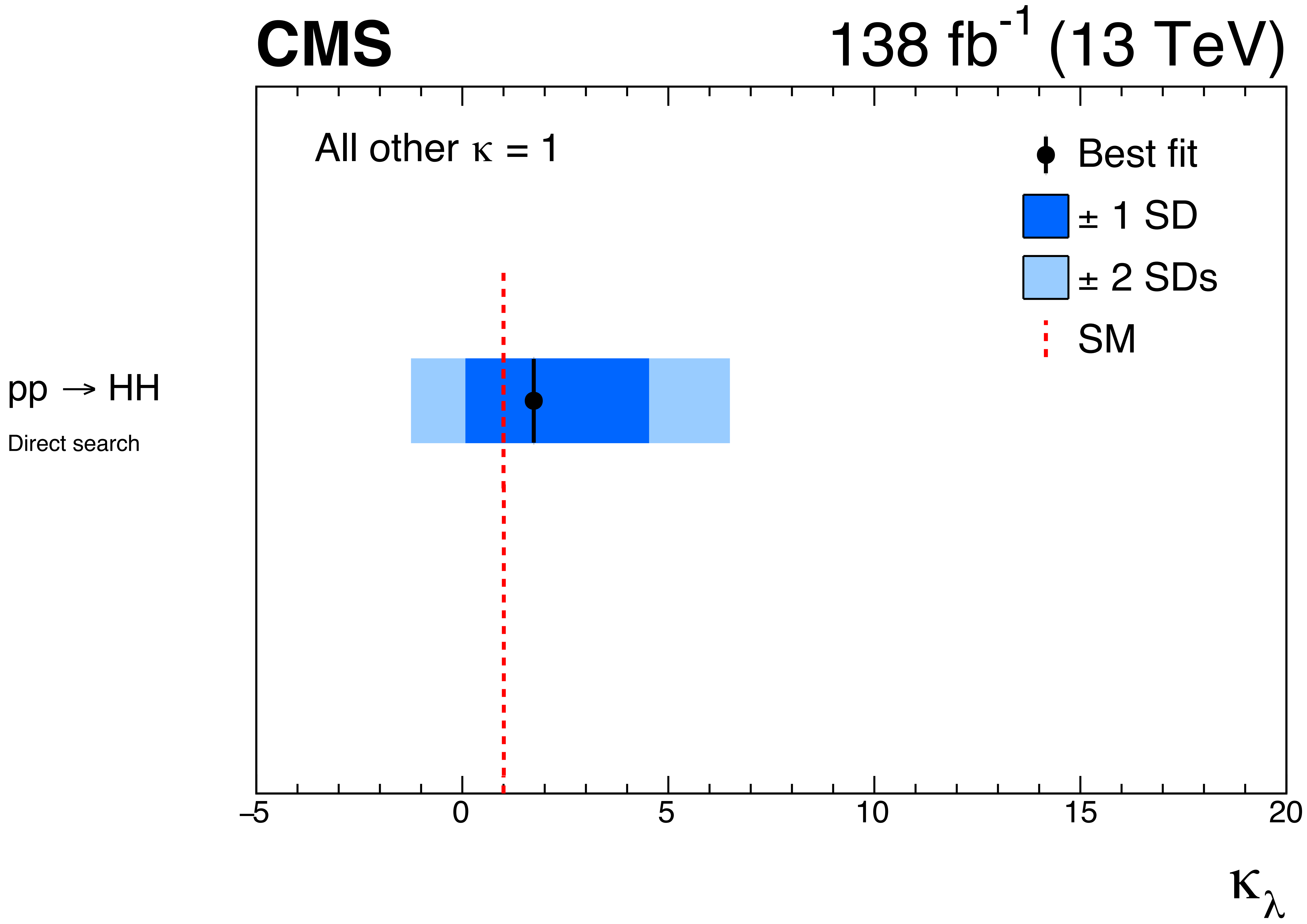


The boson self coupling

Constraint on $\kappa_\lambda = \lambda_{HHH}/\lambda_{SM}$ from single-Higgs :

NLO EW corrections to production cross sections and decay widths could cause $\kappa_\lambda \neq 1$





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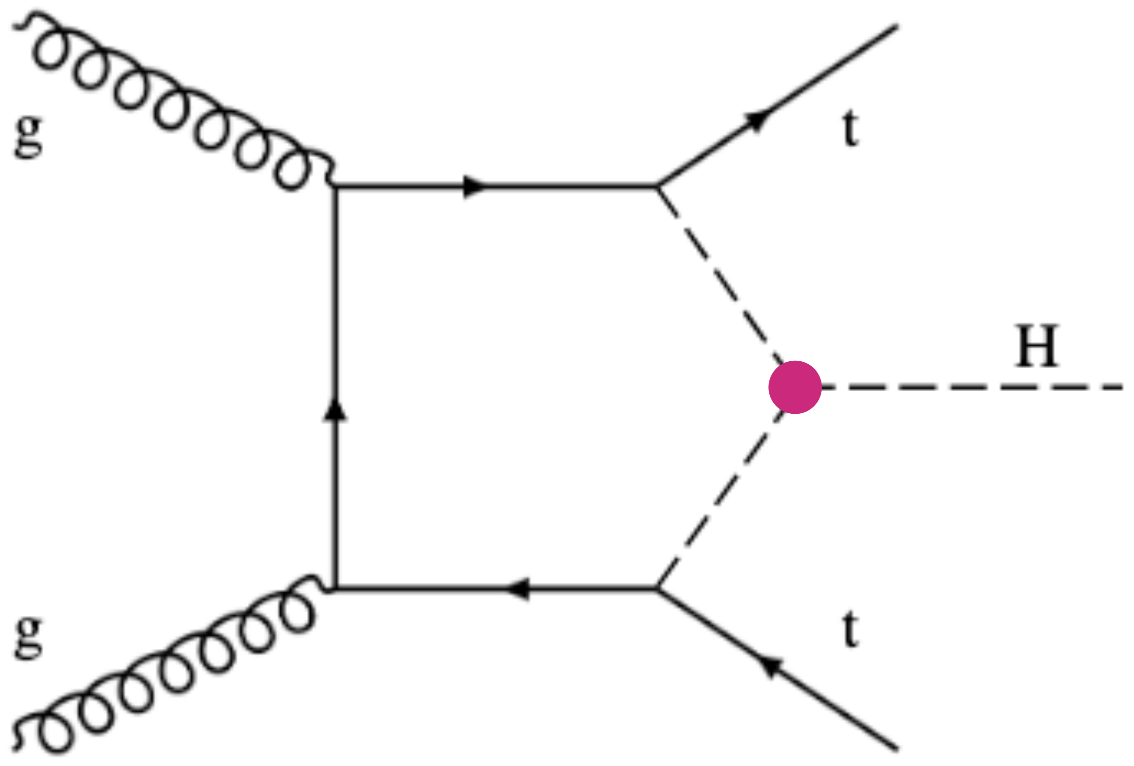
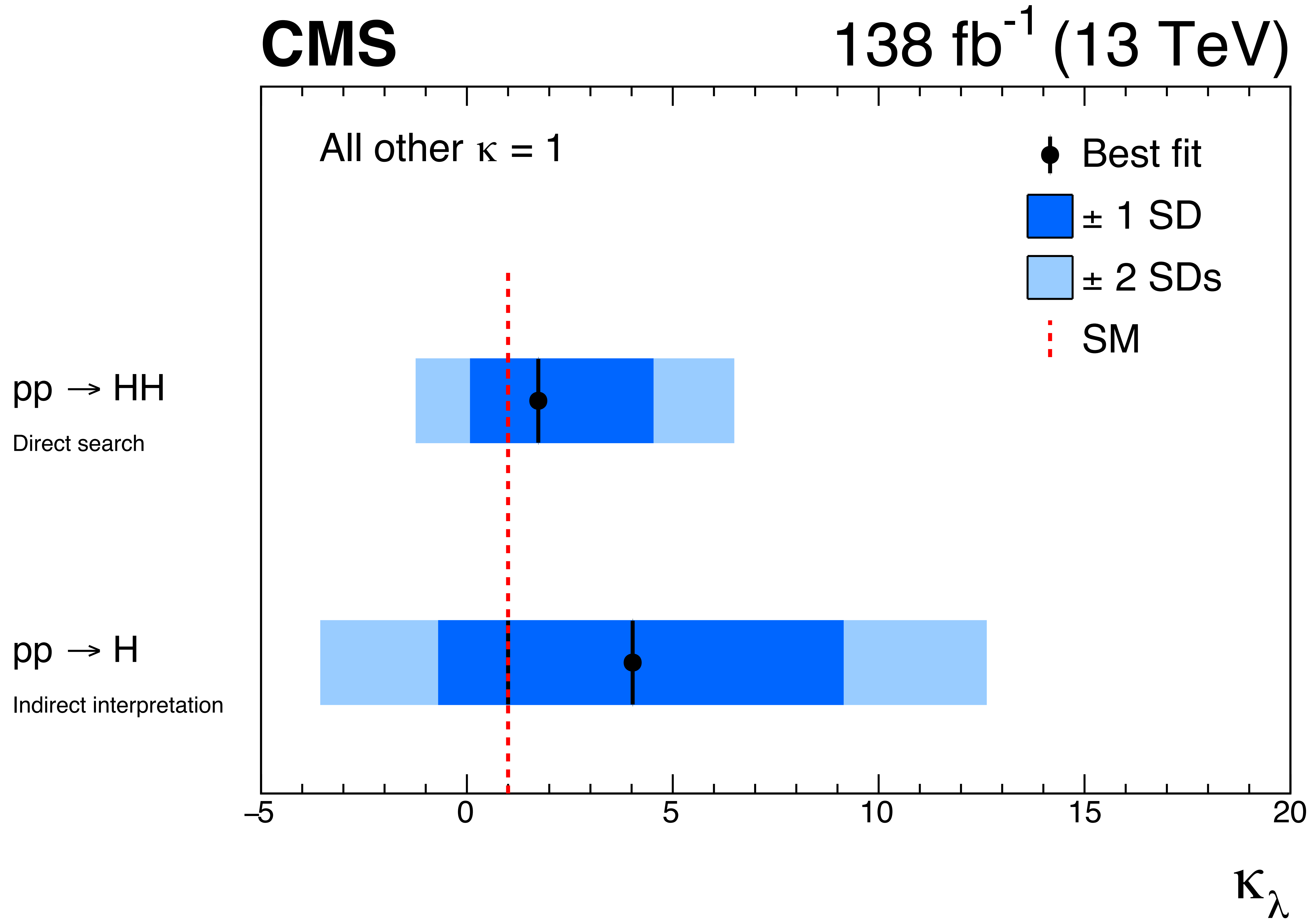


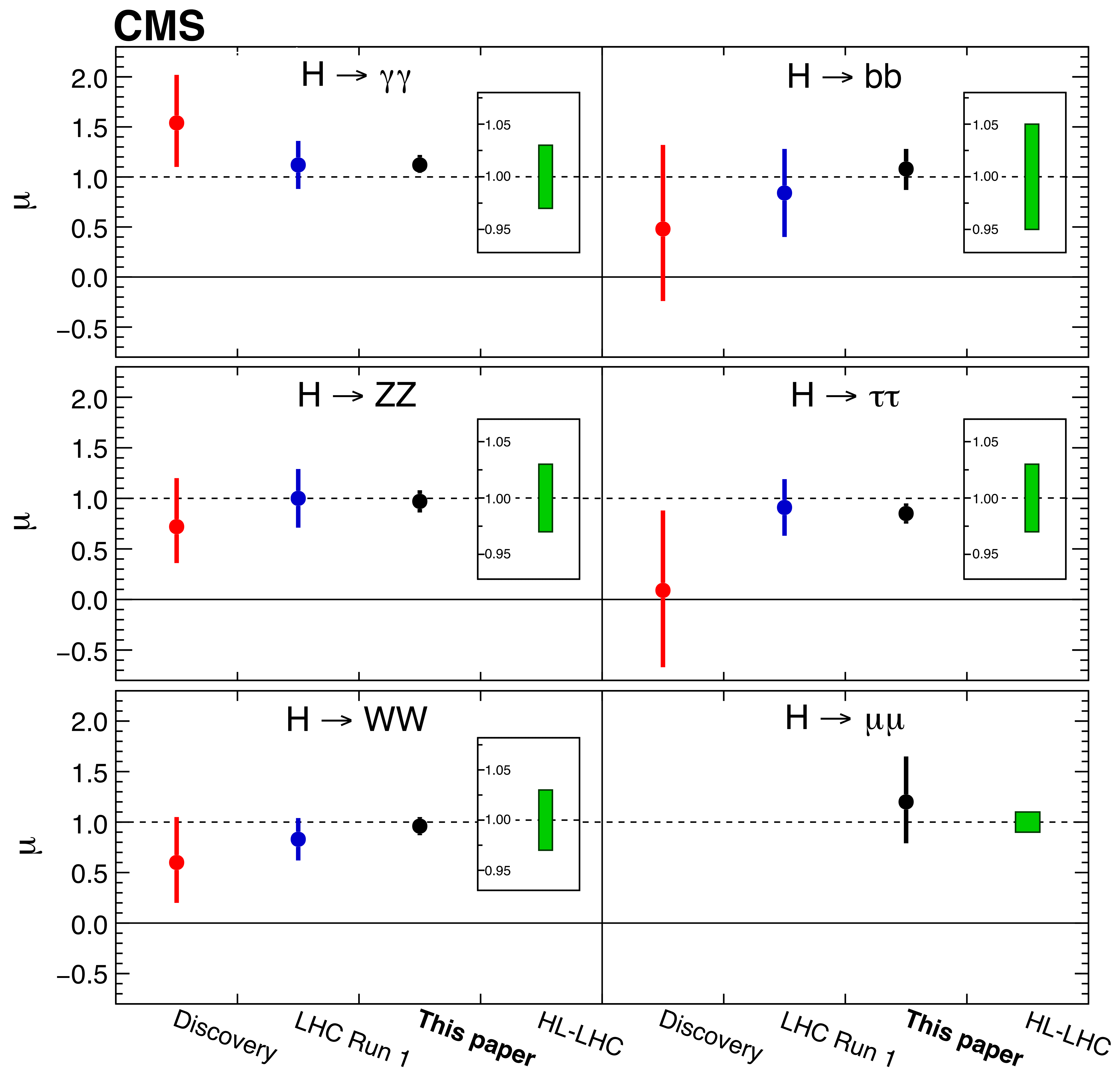
Inclusive production and decay rates scale as

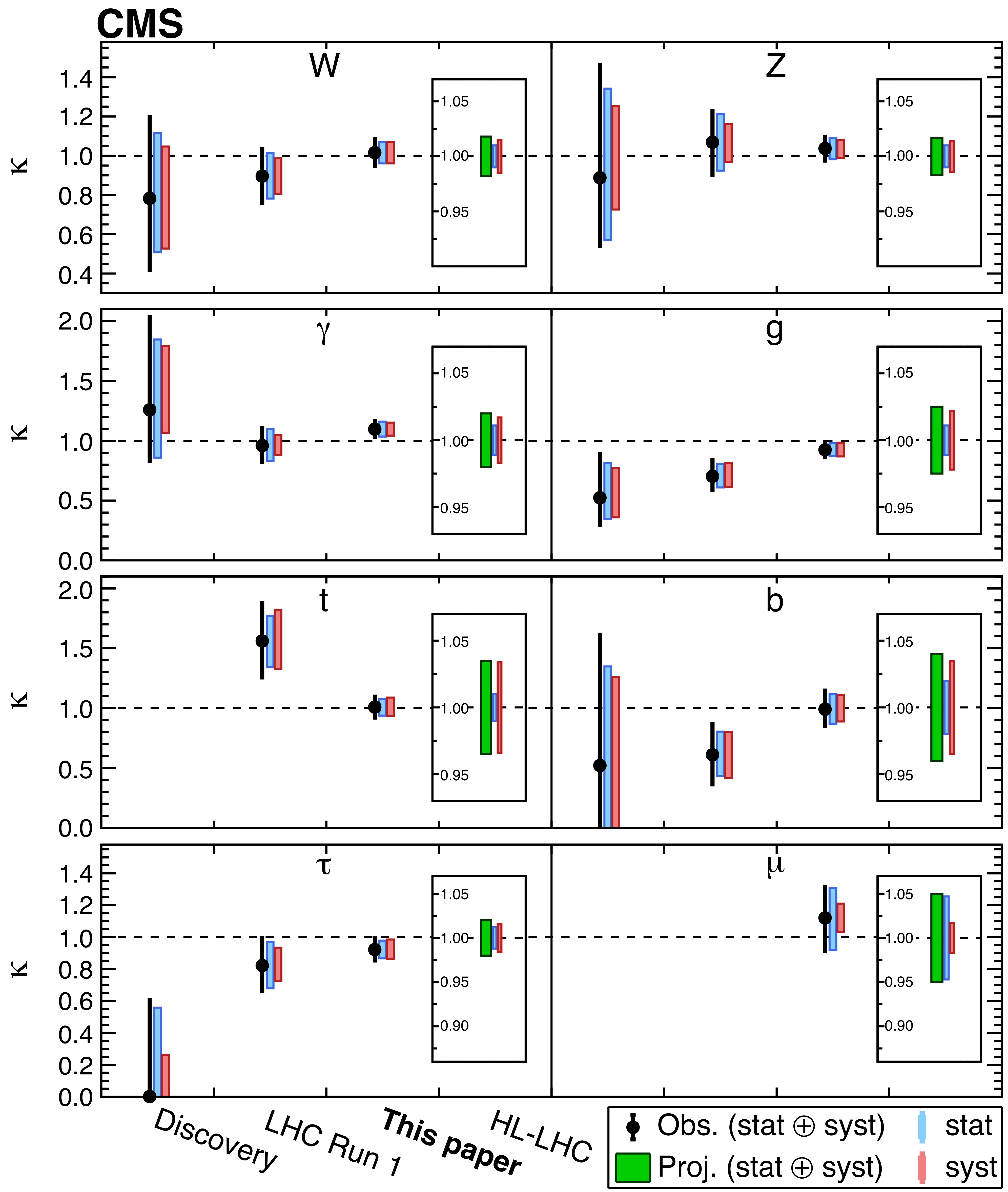
$$\mu_i(\kappa_V, \kappa_F, \kappa_\lambda) = Z_H^{BSM}(\kappa_\lambda)\left[S_i(\kappa_V, \kappa_F) + K_{BSM}(1-\kappa_\lambda)\right]$$

$$\mu^f(\kappa_V, \kappa_F, \kappa_\lambda) = \frac{S_f(\kappa_V, \kappa_F) + (\kappa_\lambda - 1)C^f}{\sum_d \Gamma_d^{SM}\left(S_d(\kappa_V, \kappa_F) + (\kappa_\lambda - 1)C^d\right)}$$

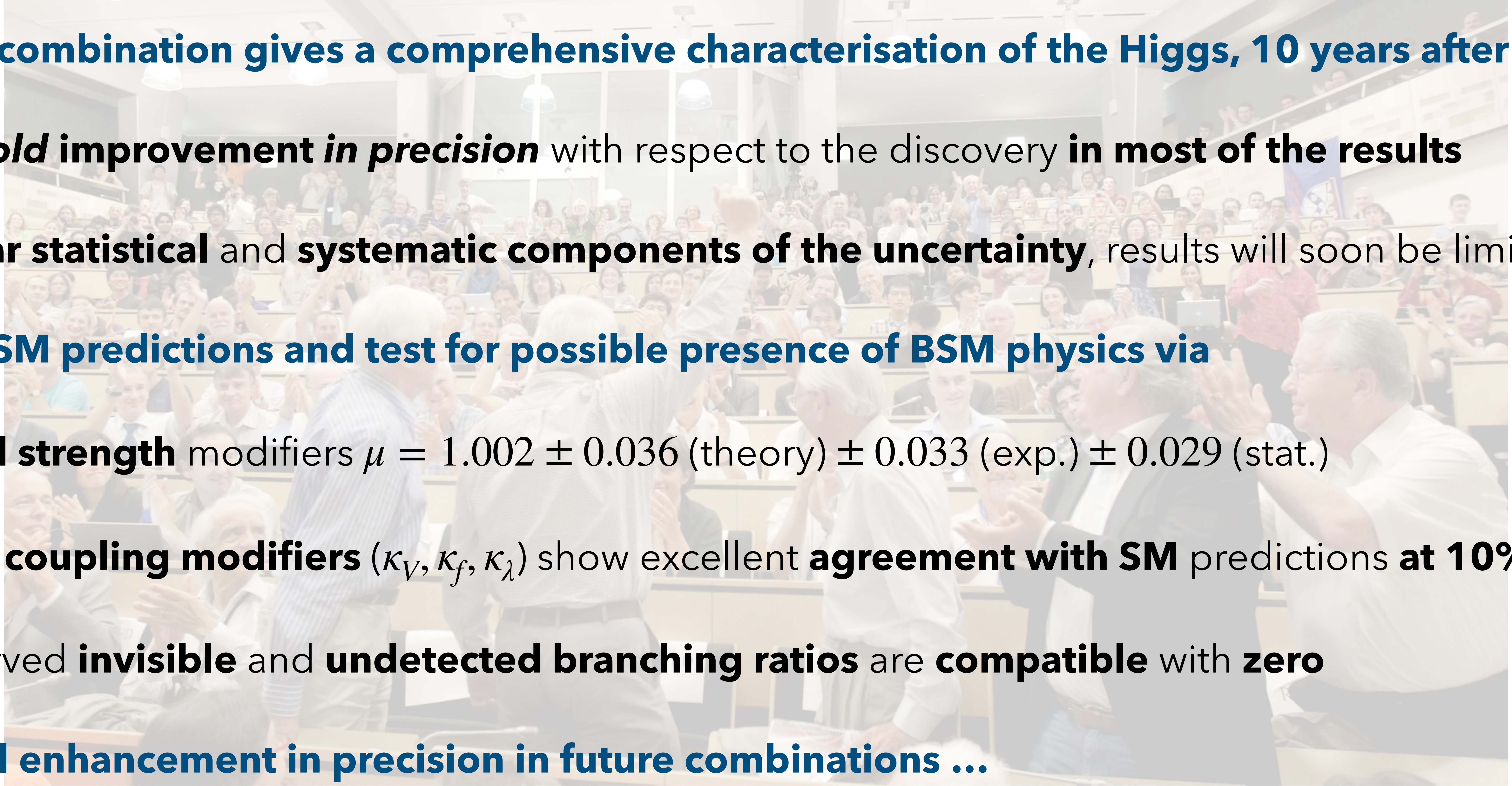


A look onto the future: @ HL-LHC





Conclusion



Full Run-II combination gives a comprehensive characterisation of the Higgs, 10 years after discovery

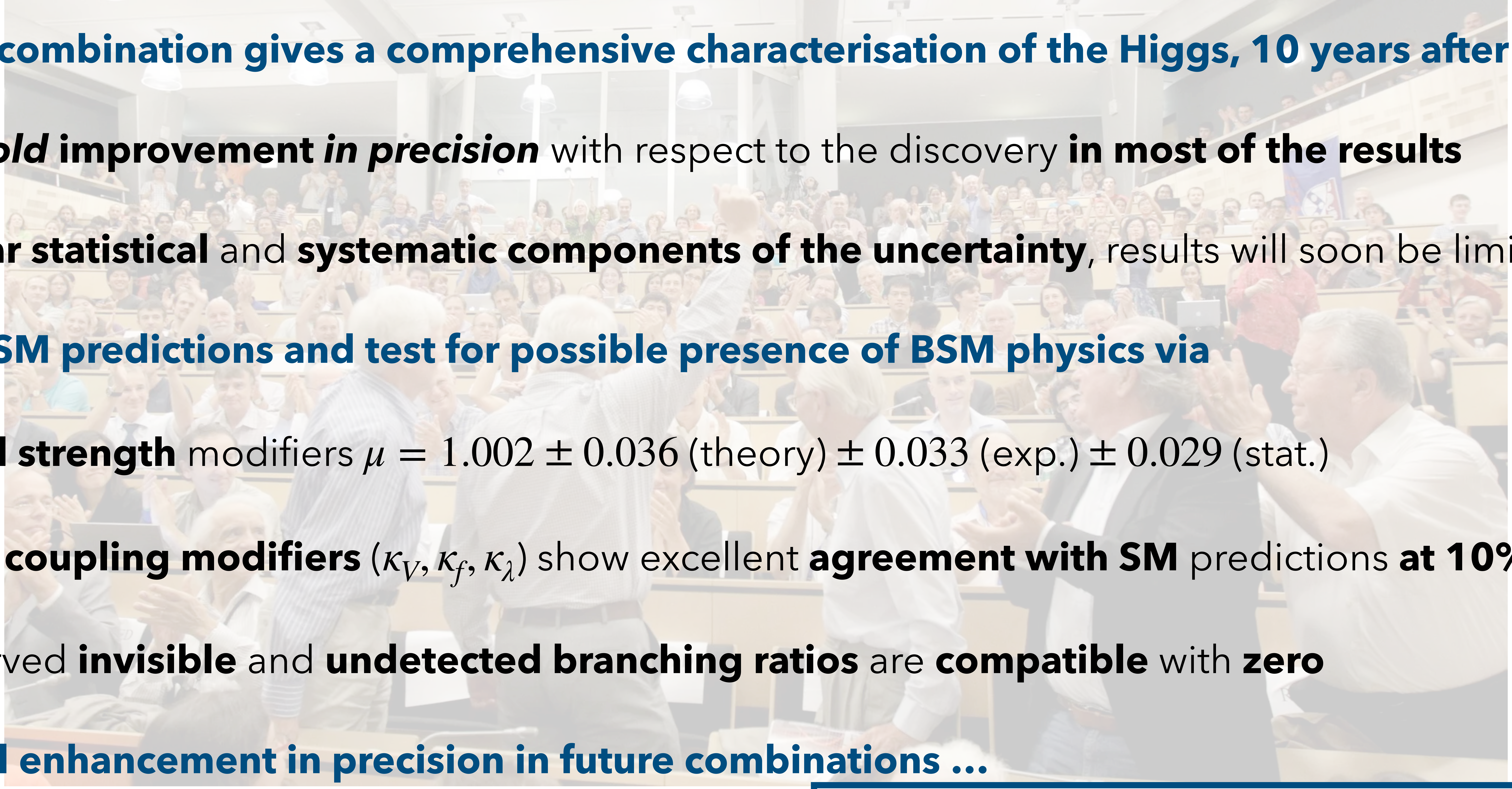
- ***Fourfold* improvement *in precision*** with respect to the discovery **in most of the results**
- **Similar statistical** and **systematic components of the uncertainty**, results will soon be limited by latter

Probe the SM predictions and test for possible presence of BSM physics via

- **Signal strength** modifiers $\mu = 1.002 \pm 0.036$ (theory) $\pm\, 0.033$ (exp.) $\pm\, 0.029$ (stat.)
- Higgs **coupling modifiers** $(\kappa_V, \kappa_f, \kappa_\lambda)$ show excellent **agreement with SM** predictions **at 10%** level
- Observed **invisible** and **undetected branching ratios** are **compatible** with **zero**

Substantial enhancement in precision in future combinations …

Conclusion



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Stay tuned for *precision physics era* at HL-LHC!