Summary of Moriond EW 2022 - Collider Results

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Slides: https://moriond.in2p3.fr/2022/EW/ewprgm2022.html

Experimental summary talk by Monica Pepe-Altarelli

W/Z physics at ATLAS & CMS

- W/Z boson production well understood
  - Clean experimental final state, measurement of EWK SM parameters and QCD effects
  - Very precise measurements, search for rare decay channels

Drell-Yan forward-backward asymmetry

$$\frac{d\sigma}{d\cos\theta} \propto \frac{3}{8}\left[1+\cos^2\theta+\frac{A_0}{2}\left(1-3\cos^2\theta\right)+A_4\cos\theta\right]$$

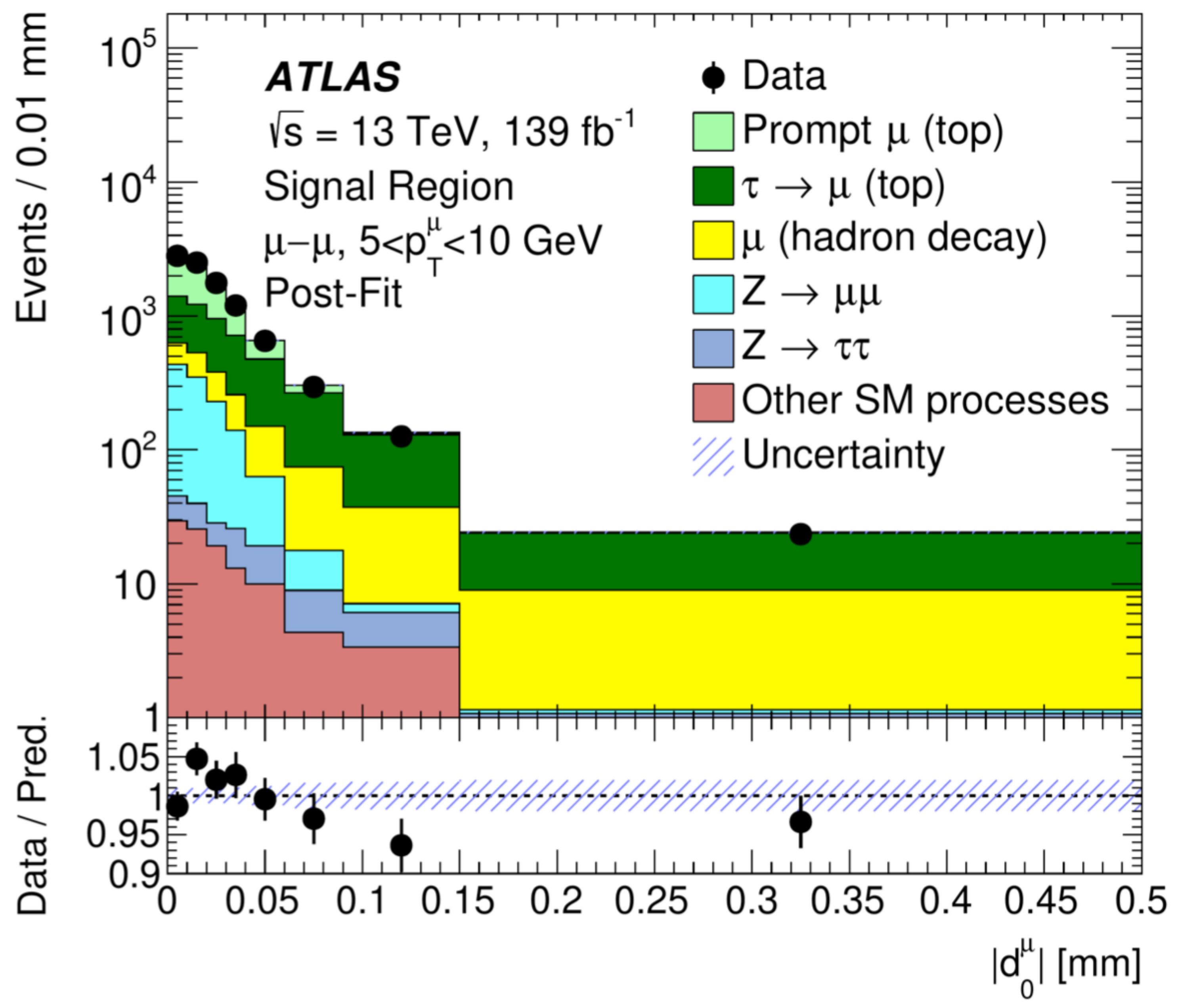
$$A_{FB}=\frac{\sigma_F-\sigma_B}{\sigma_F+\sigma_B} \qquad \frac{3}{8}A_4 = A_{FB}$$

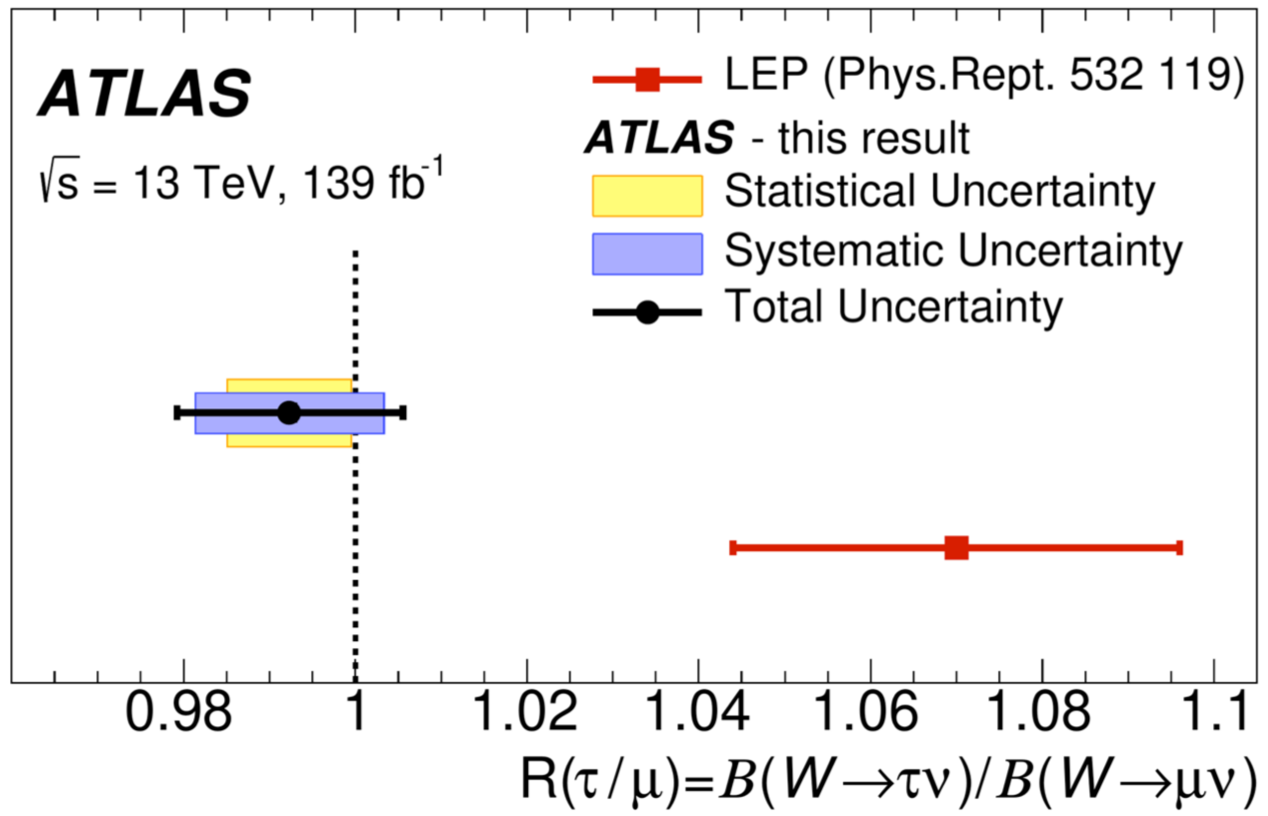
Checking lepton flavour universality

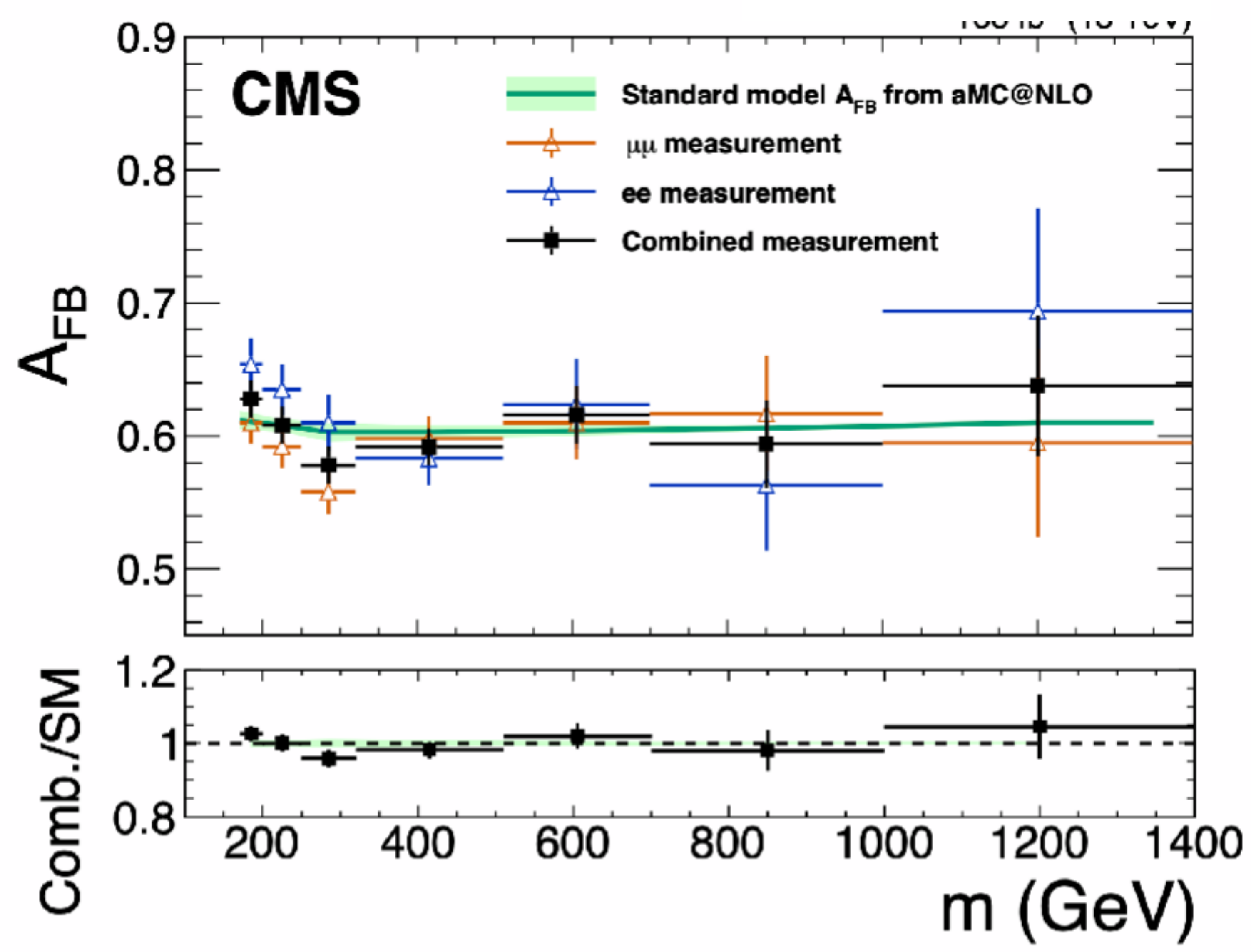
W branching fractions

$R(\tau/\mu)=B(W\to\tau\nu)/B(W\to\mu\nu)$

Use pT and d0 to distinguish the muonic τ decays from the prompt decay







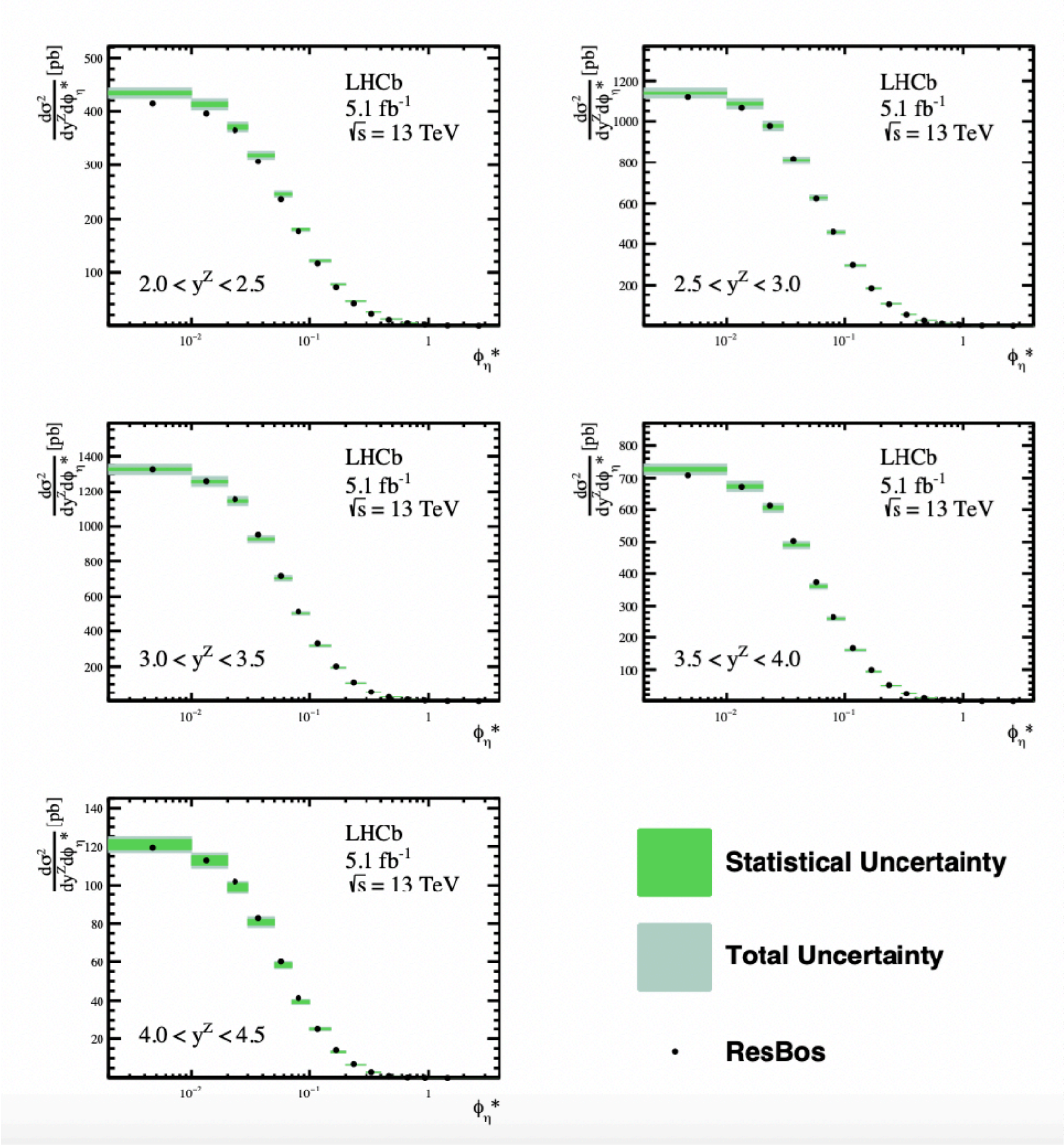
- Differential measurements of AFB and A0 are performed by fitting each mass bin independently
- Set limits on the presence of additional gauge bosons

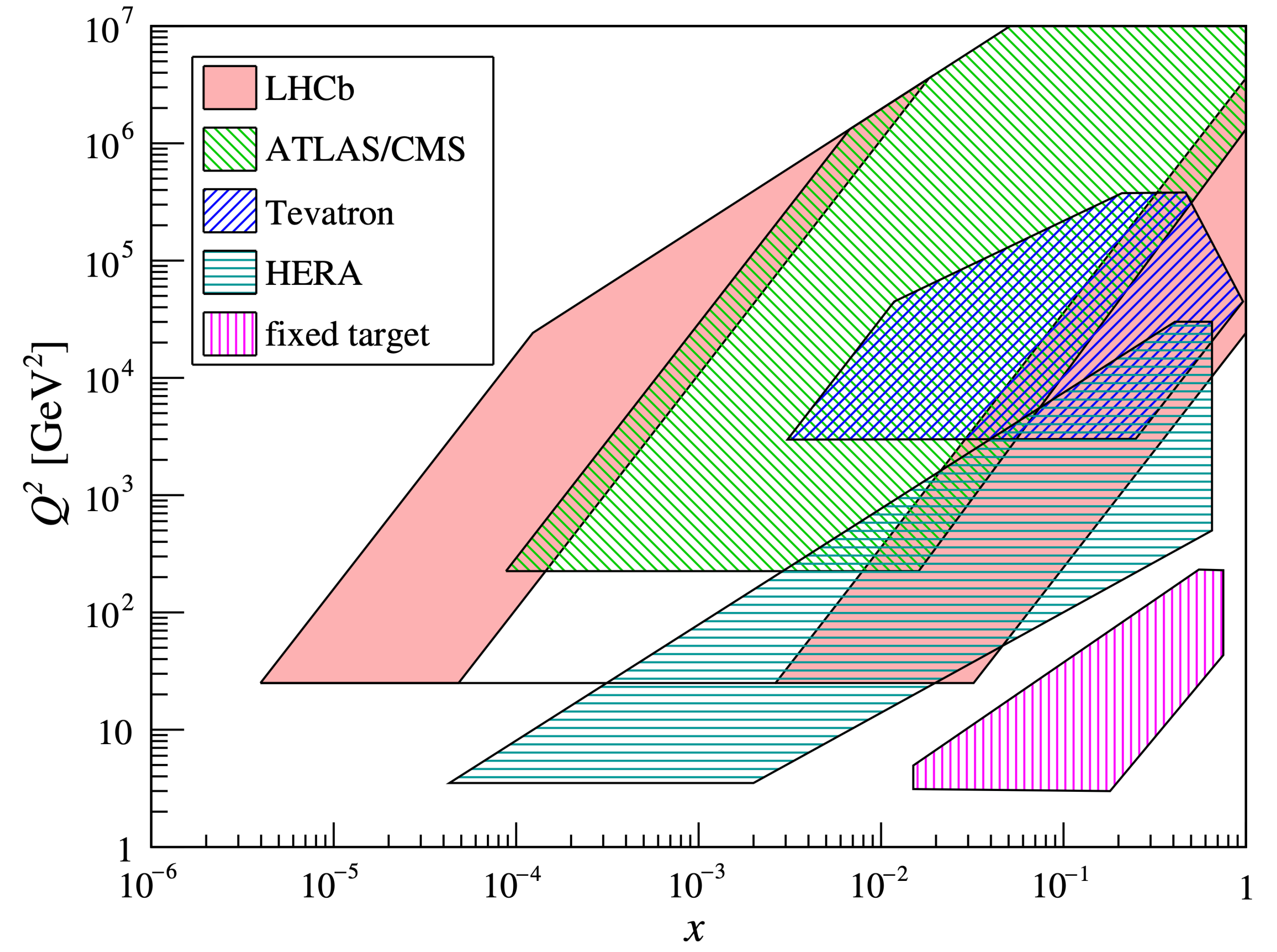
W/Z physics at LHCb

- LHCb
  - LHCb sensitive to high and low Bjorken-x
  - Complementary phase space with ATLAS & CMS

First double differential Z cross section in the forward region

provide important information for the PDF determination

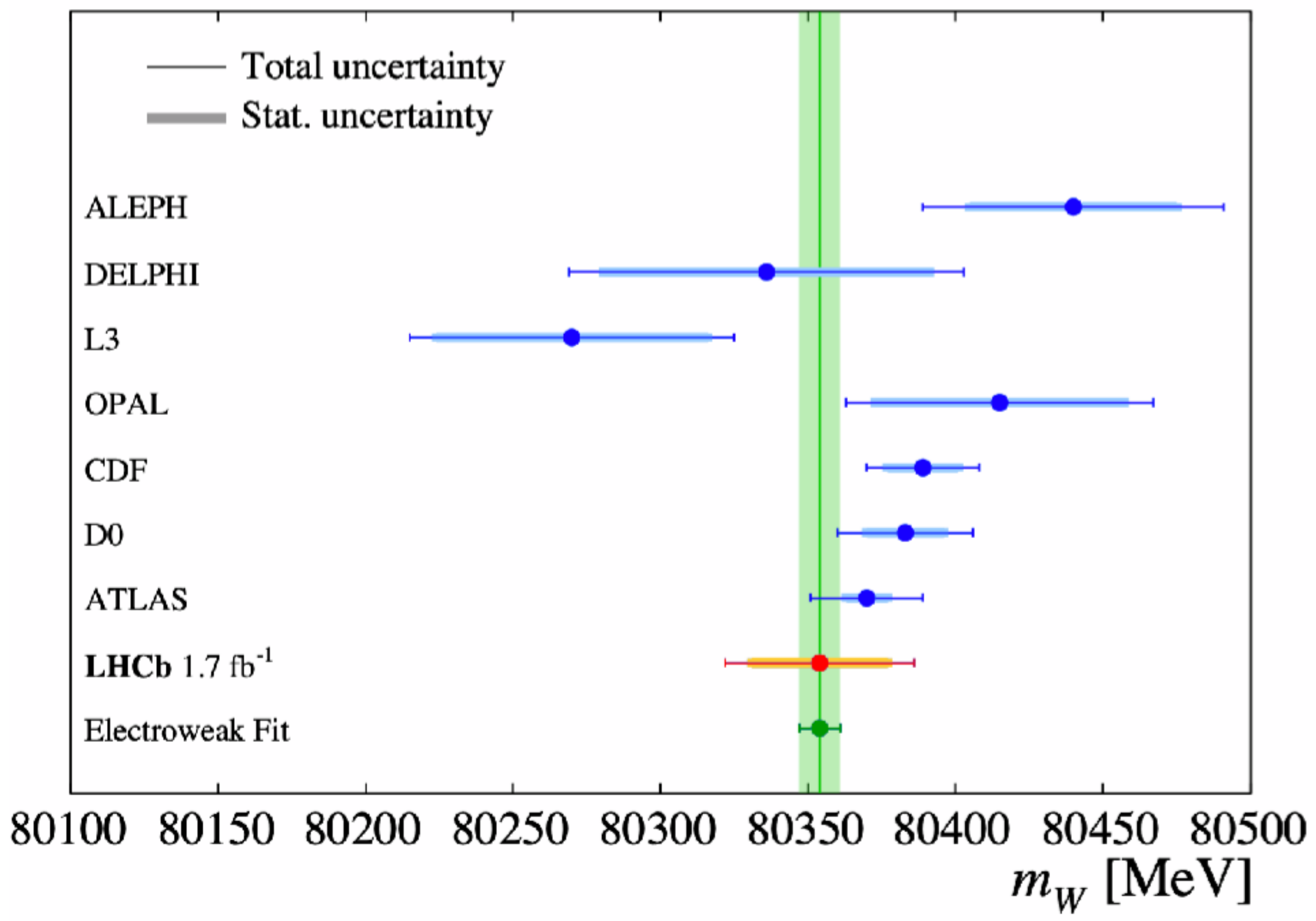




mW measurement

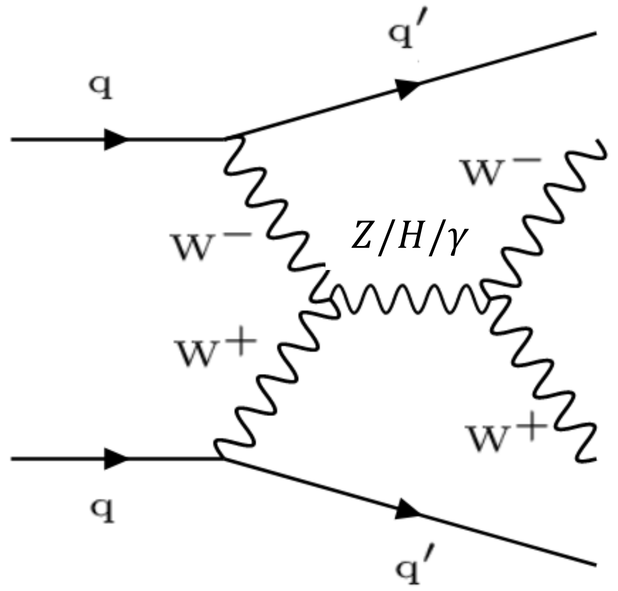
$$m_W = 80354 \pm 23_{\text{stat}} \pm 10_{\text{exp}} \pm 17_{\text{theory}} \pm 9_{\text{PDF}}\ \text{MeV}$$

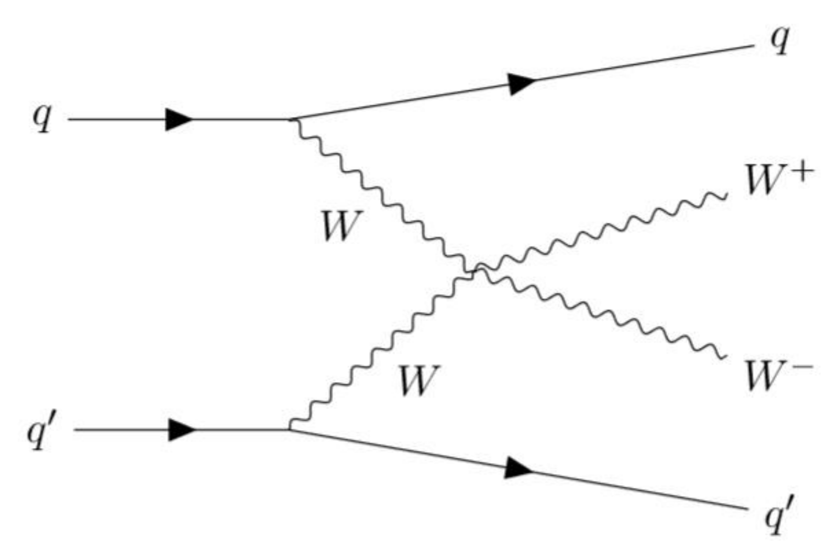
Source	Size [MeV]
Parton distribution functions	9
Theory (excl. PDFs) total	17
Transverse momentum model	11
Angular coefficients	10
QED FSR model	7
Additional electroweak corrections	5
Experimental total	10
Momentum scale and resolution modelling	7
Muon ID, trigger and tracking efficiency	6
Isolation efficiency	4
QCD background	2
Statistical	23
Total	32



Multiboson physics

- Multiboson production
  - Direct test of SM gauge boson self-interactions, deviations would hint at new physics
  - Rare process, need to be carefully understood
  - Interpretation in terms of Effective Field Theory





Observation of Vector Boson Scattering Production of W+W-

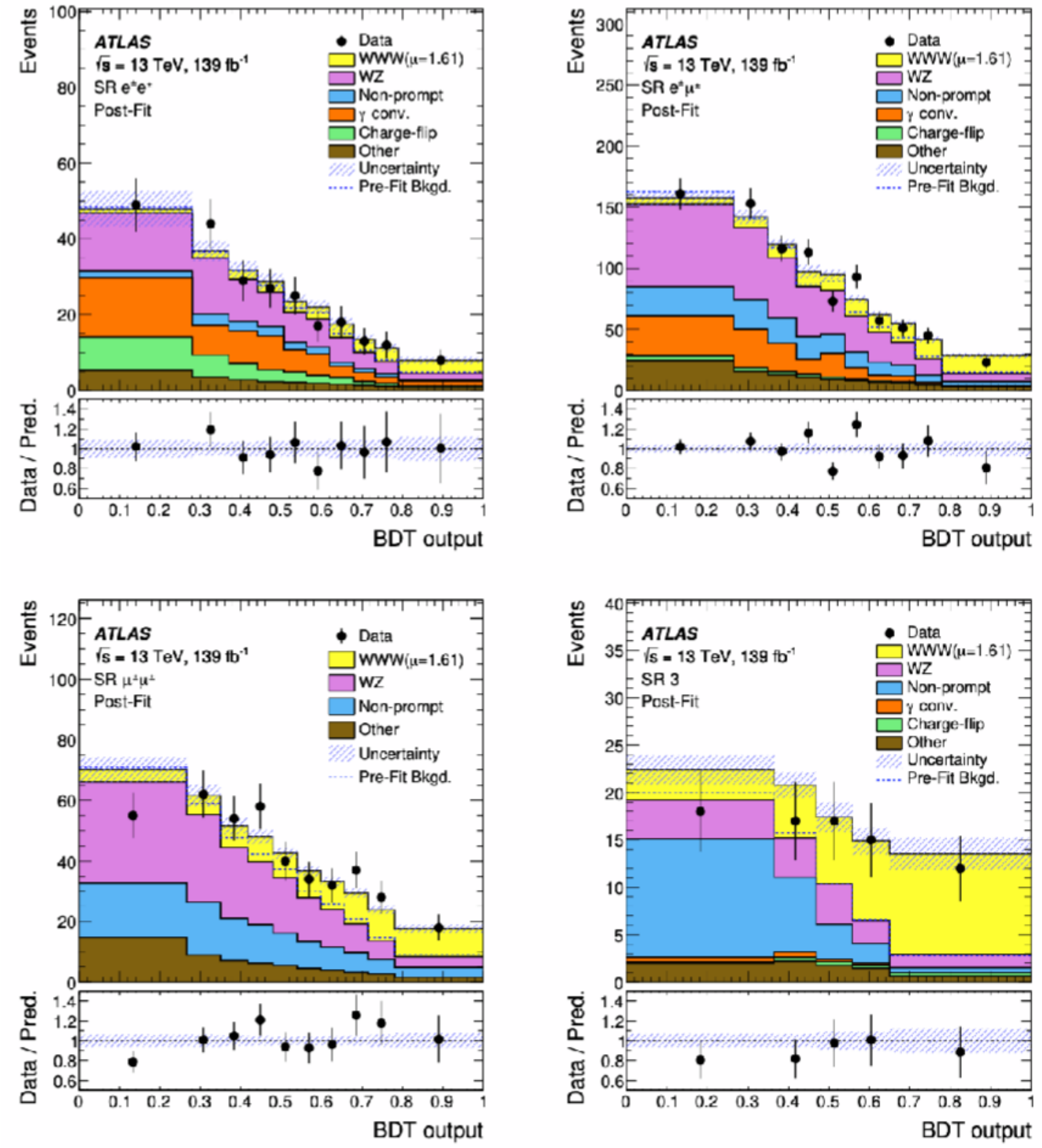
Regularized by the Higgs

$$\sigma_{EW}^{obs} = 99 \pm 20 \text{ fb}$$

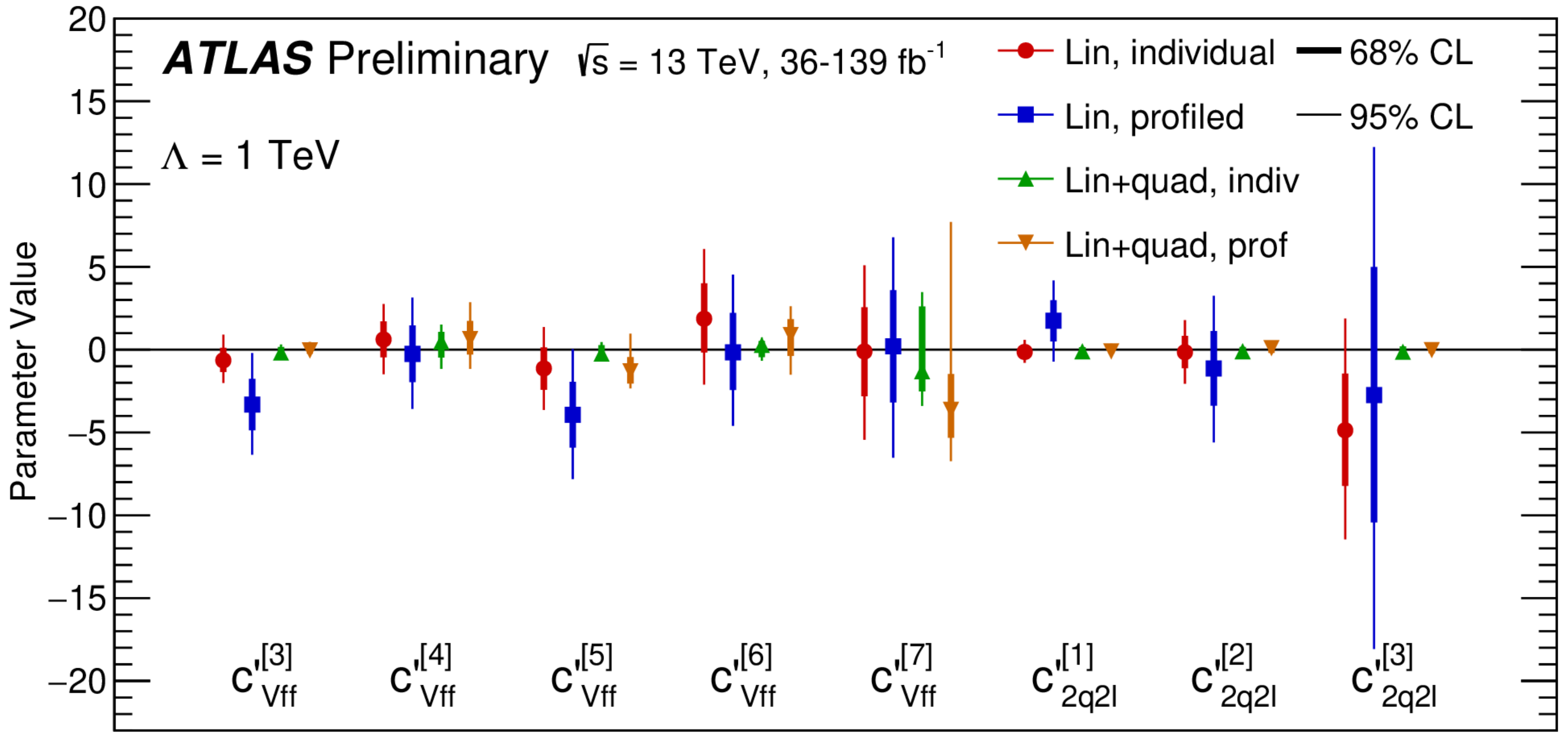
$$\sigma_{EW}^{theo} = 89 \pm 5 \text{ (scale) fb}$$

Observation of WWW production

Fit	$\mu(WWW)$	Significance observed (expected)
$e^{\pm}e^{\pm}$	1.54 ± 0.76	$2.2\ (1.4)\ \sigma$
$e^{\pm}\mu^{\pm}$	1.44 ± 0.39	$4.1\ (3.0)\ \sigma$
$\mu^{\pm}\mu^{\pm}$	2.23 ± 0.46	$5.6\ (2.7)\ \sigma$
2ℓ	1.75 ± 0.30	$6.6\ (4.0)\ \sigma$
3ℓ	1.32 ± 0.37	$4.8\ (3.8)\ \sigma$
Combined	$\mathbf{1.61 \pm 0.25}$	$\mathbf{8.0\ (5.4)\ \sigma}$



$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(5)}}{\Lambda} O_i^{(5)} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \ldots$$



$c'^{[3]}_{Vff} \approx -0.19c^{(1)}_{Hl} - 0.14c^{(3)}_{Hl} + 0.86c^{(1)}_{Hq} + 0.41c_{Hu} - 0.17c_{Hd}$

$c'^{[4]}_{Vff} \approx -0.35c_{HWB} + 0.49c_{HD} + 0.26c^{(1)}_{Hl} + 0.35c^{(3)}_{Hl} + 0.51c_{He} + 0.38c^{(1)}_{ll} + 0.18c^{(1)}_{Hq}$

$c'^{[5]}_{Vff} \approx 0.25c_{HD} + 0.33c^{(1)}_{Hl} - 0.22c^{(3)}_{Hl} + 0.18c_{He} - 0.35c^{(1)}_{ll} - 0.3c^{(1)}_{Hq} + 0.71c_{Hu} - 0.16c_{Hd}$

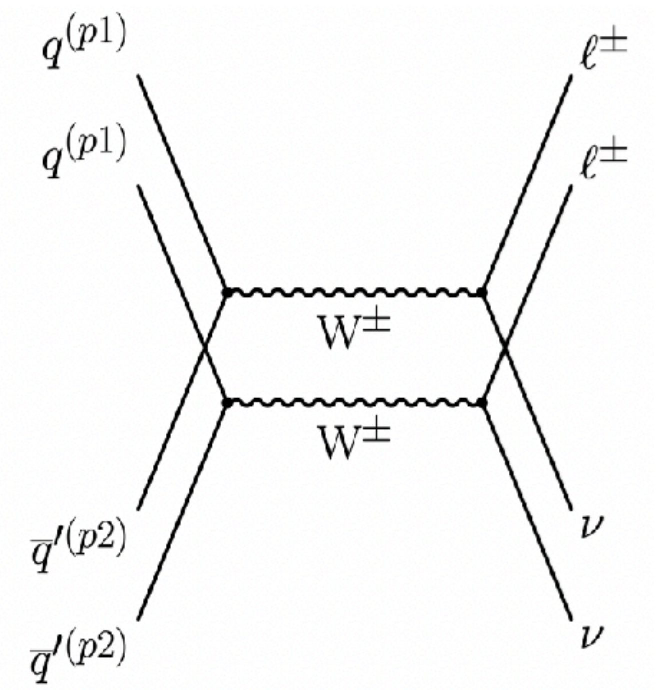
$c'^{[6]}_{Vff} \approx -0.22c^{(1)}_{Hl} + 0.52c^{(3)}_{Hl} - 0.39c_{He} + 0.44c^{(1)}_{ll} - 0.22c^{(1)}_{Hq} + 0.52c_{Hu}$

$c'^{[7]}_{Vff} \approx -0.28c_{HWB} + 0.71c_{HD} - 0.31c^{(1)}_{Hl} - 0.21c^{(3)}_{Hl} - 0.5c_{He} - 0.14c^{(1)}_{ll}$

$c'^{[1]}_{2q2l} \approx 0.56c^{(1)}_{lq} + 0.44c^{(3)}_{lq} + 0.61c_{eu} - 0.1c_{ed} + 0.34c_{qe}$

$c'^{[2]}_{2q2l} \approx 0.68c^{(1)}_{lq} + 0.15c^{(3)}_{lq} + 0.33c_{lu} - 0.51c_{eu} + 0.13c_{ed} - 0.37c_{qe}$

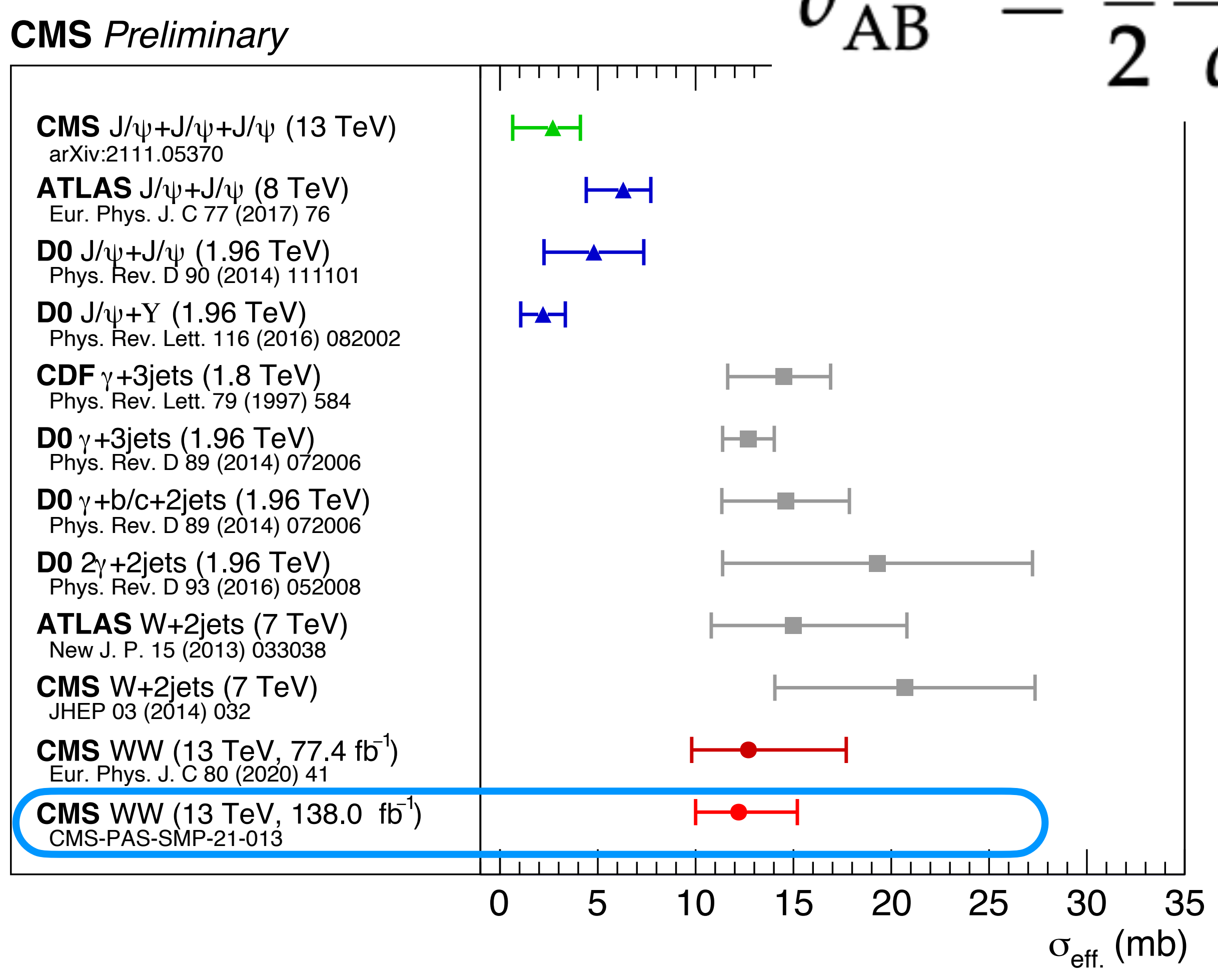
$c'^{[3]}_{2q2l} \approx -0.27c^{(1)}_{lq} + 0.79c_{lu} - 0.39c_{ld} + 0.26c_{eu} - 0.22c_{ed} - 0.16c_{qe}$



Observation of WW from double parton scattering

- Check the simple factorisation picture
- Learn the correlations of partons within the protons

$$\sigma_{AB}^{DPS} = \frac{n}{2} \frac{\sigma_A \sigma_B}{\sigma_{\text{eff}}}$$



$$\sigma_{DPS}^{WW} = 0.16 \pm 0.02_{\text{stat}} \pm 0.02_{\text{syst}} \pm 0.02_{\text{model}} \text{ pb}$$

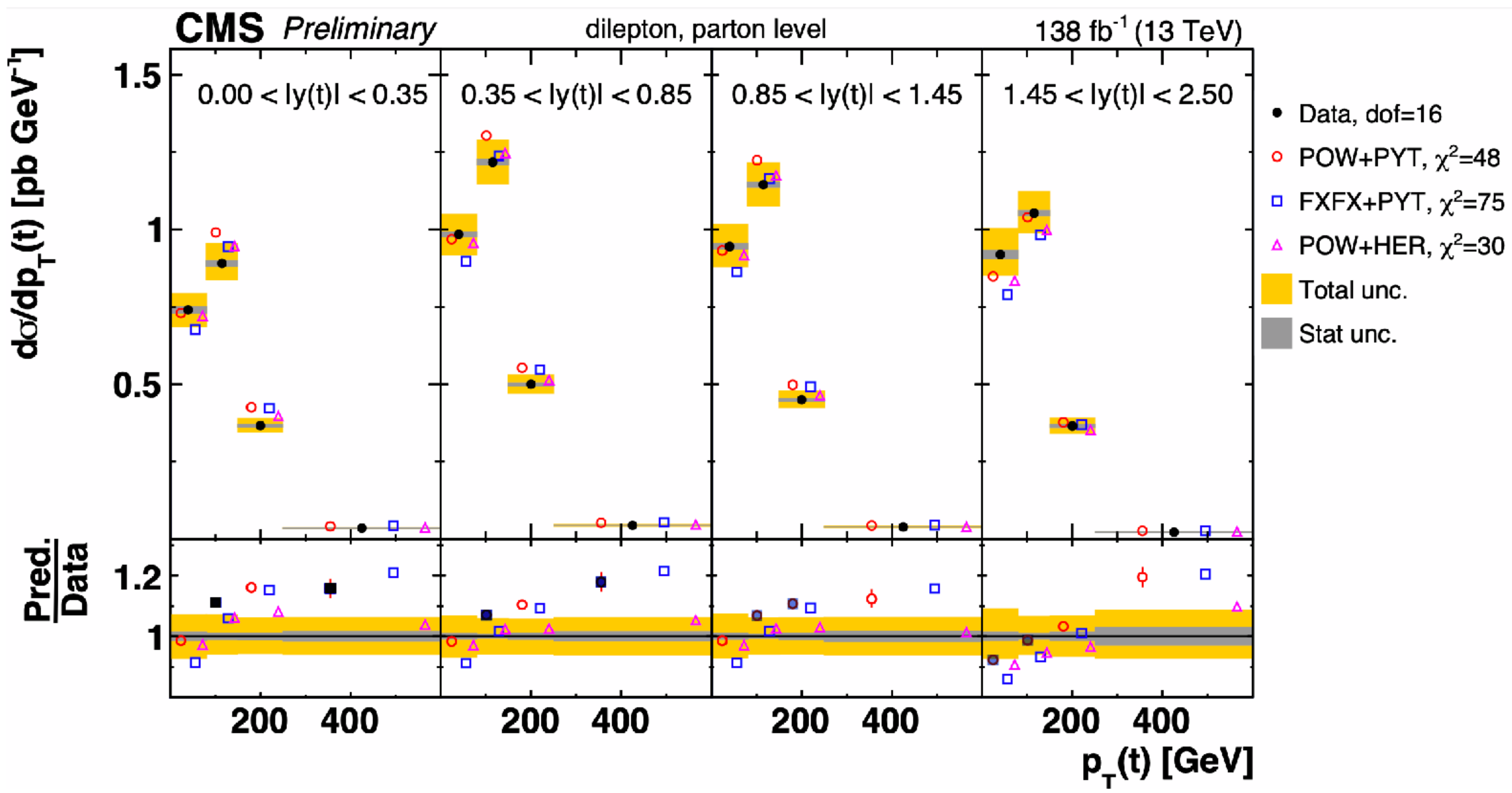
significance of 6.7σ

top physics

- LHC is a top factory
  - Precision measurements to test the SM and improve the modelling
  - Rare process and search for new physics
  - EFT interpretation in term of new physics

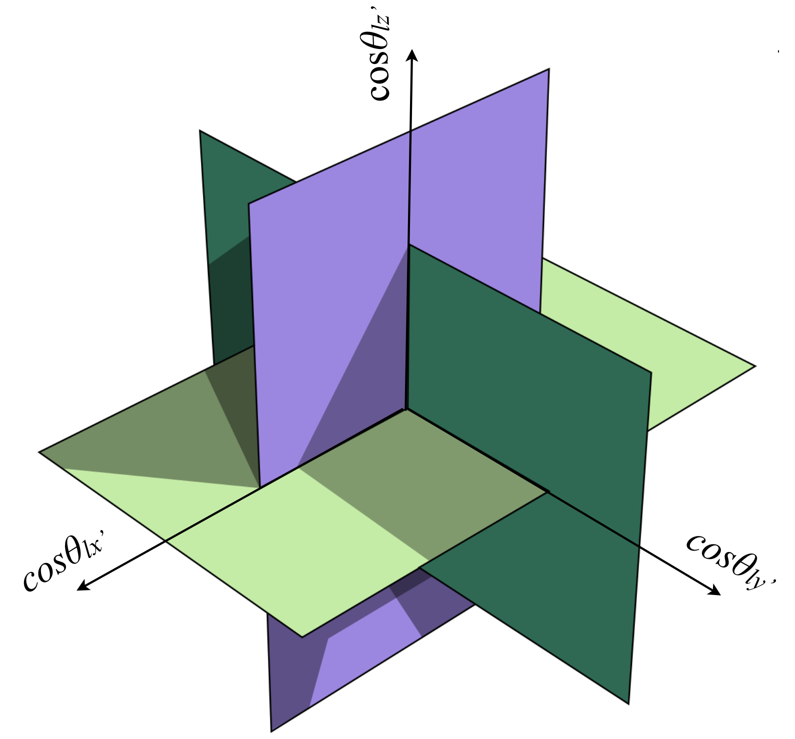
tt multi-differential cross section

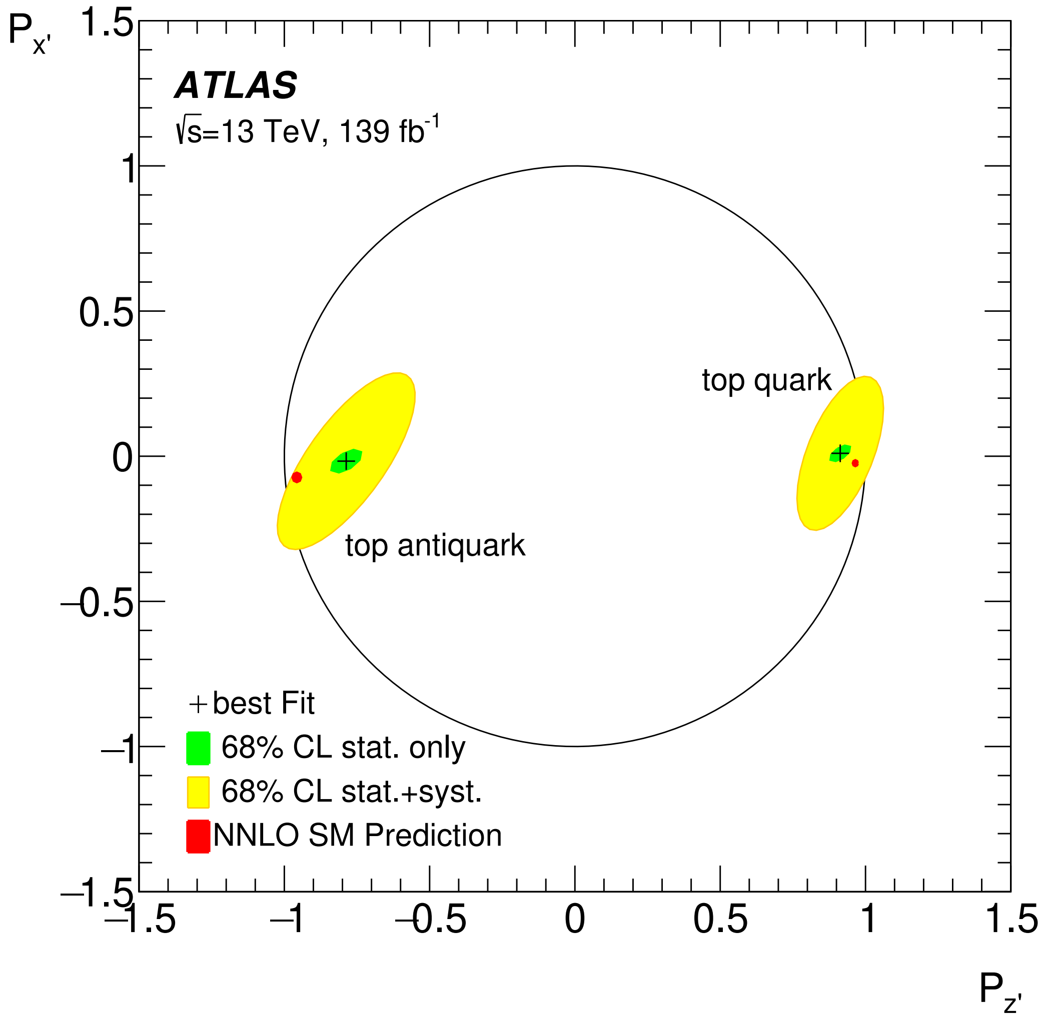
Sensitive to SM parameters mt, αs
Largest deviations from prediction for multi-differential cross sections



Polarisation in single top

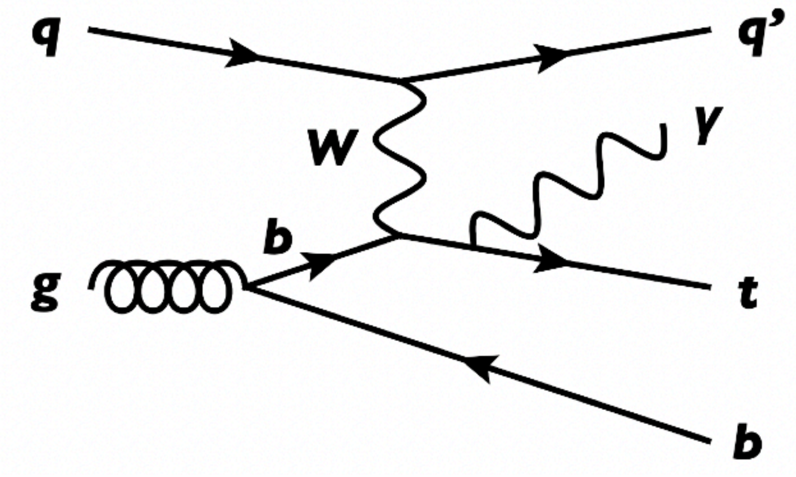
constrains on EFT operators

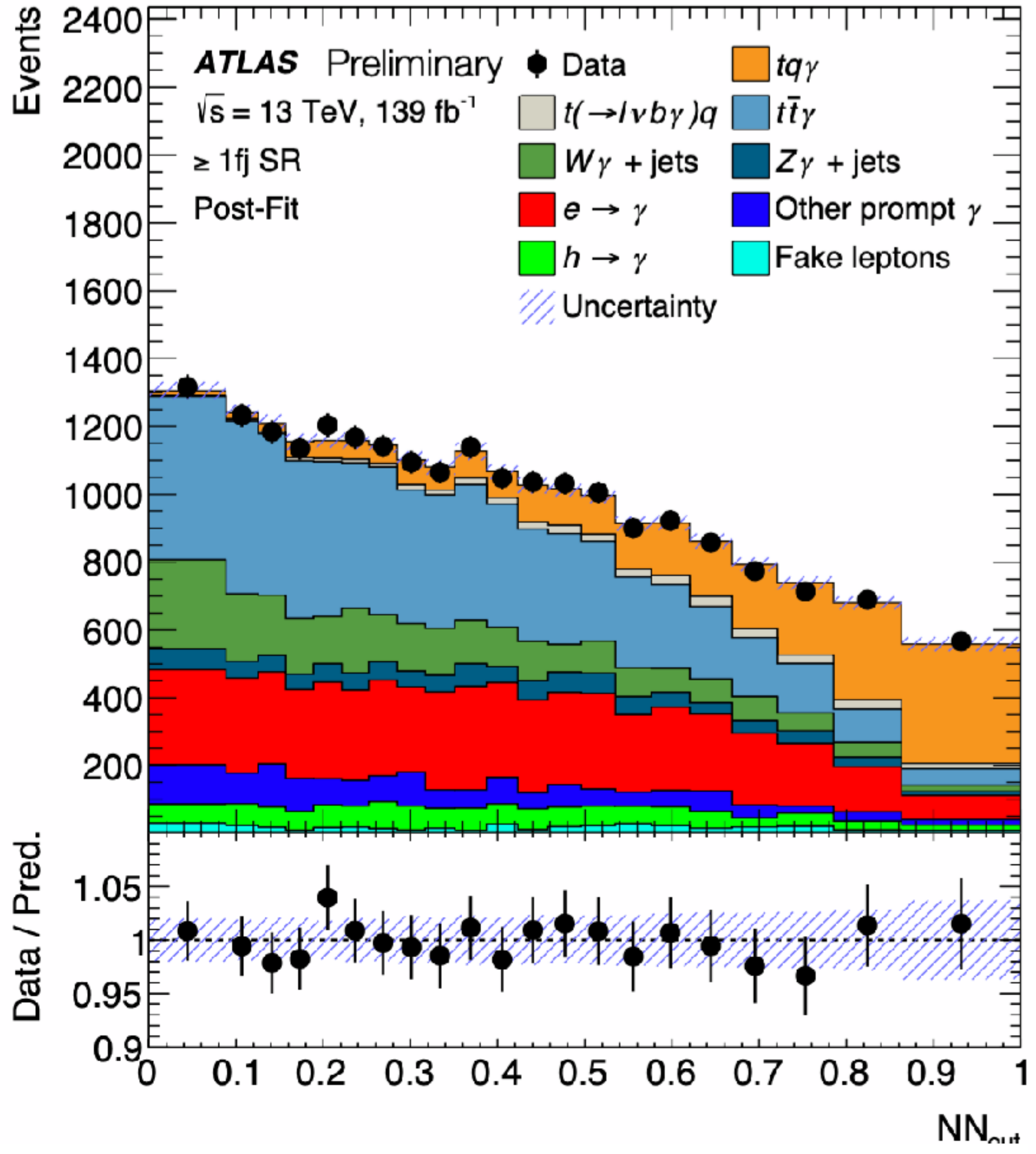




Observation of single top + photon

fundamental for probing the top-quark electroweak couplings





Observed significance of $9.1\,\sigma$ ($6.6\,\sigma$ expected)

$$\sigma_{tq\gamma} \times B(t \rightarrow \ell\nu b) = 406^{+25}_{-32}\ \text{fb}$$

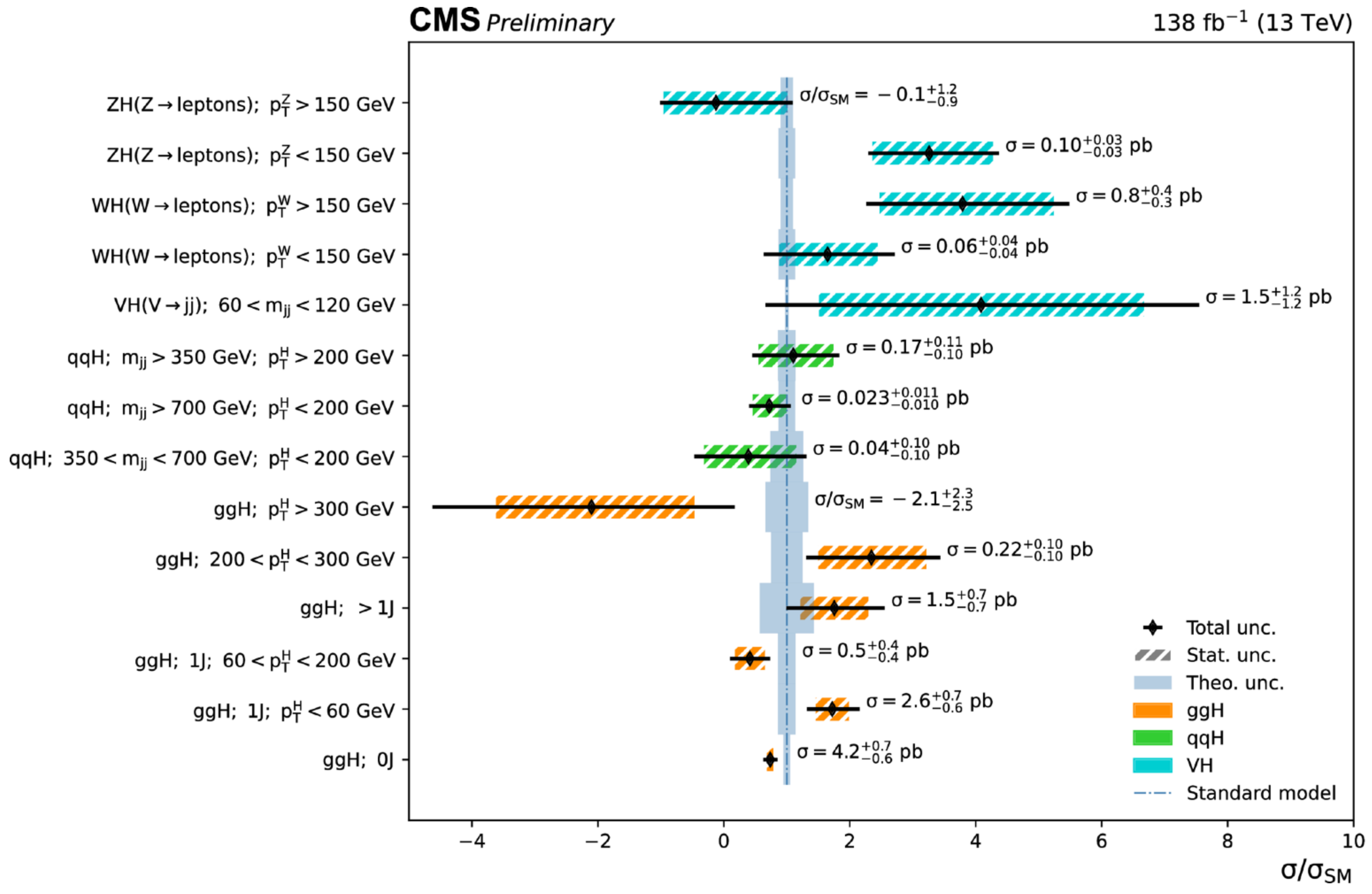
Compatible with SM at $2.5\,\sigma$

Higgs production

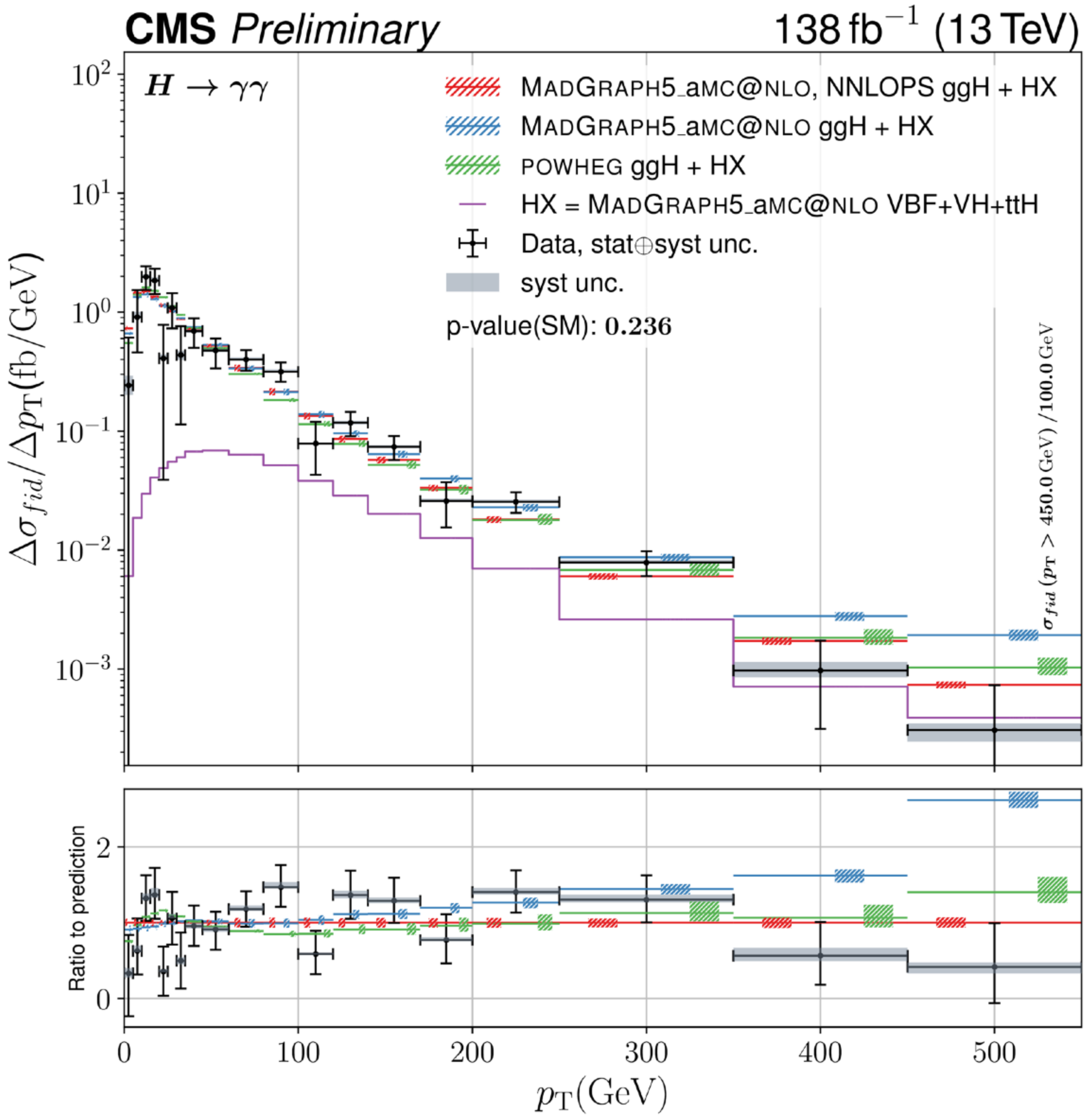
- Higgs cross section measurements
  - all the main Higgs boson production modes observed
  - 2 complementary approaches to go beyond inclusive measurements: Simplified Template Cross Sections (pre-defined template bins) or differential measurements in fiducial phase space

H→WW STXS measurement

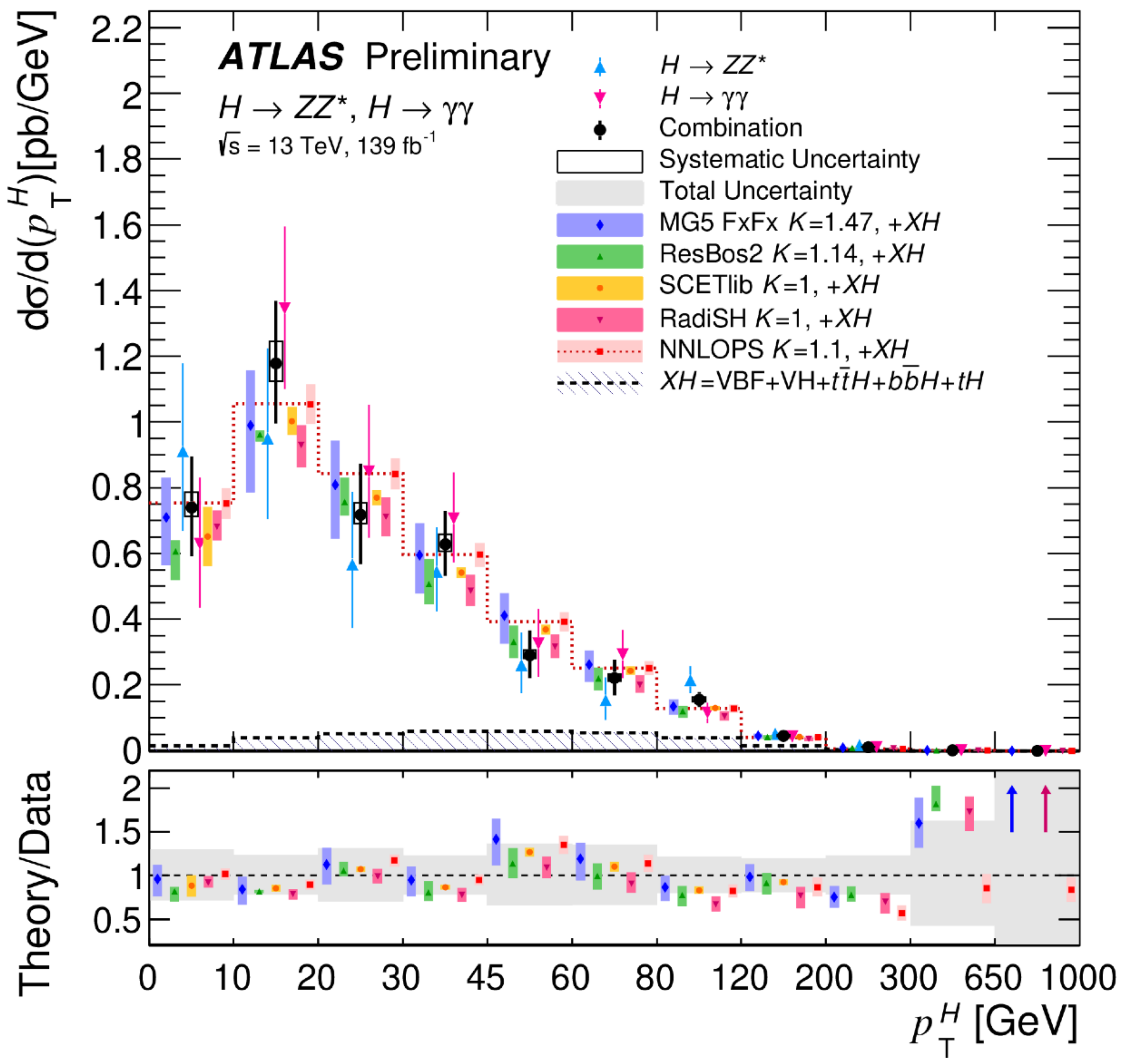
The current LHC dataset allowed the simultaneous measurement of 14 STXS cross sections



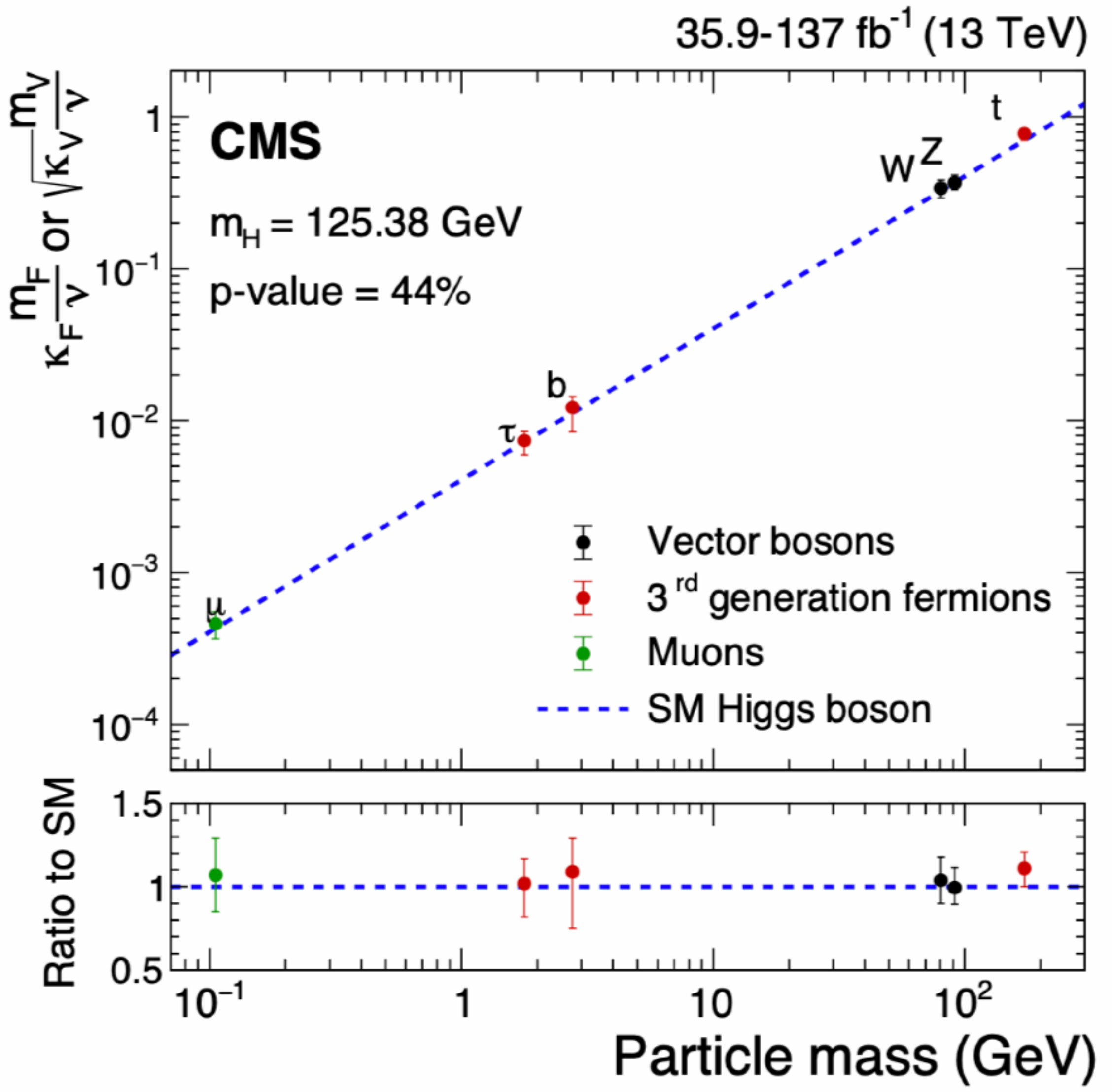
H→γγ differential measurement



Combination of H→γγ and H→ZZ differential measurement



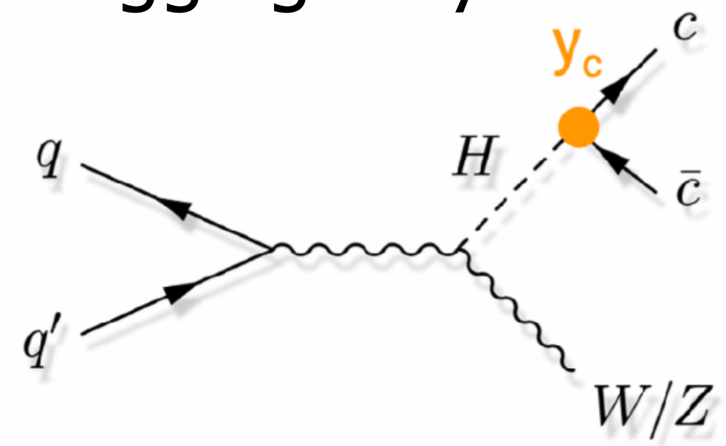
Higgs couplings



- **Key tests of the SM**
  - Higgs couplings are powerful test for the nature of the Higgs boson
  - Search for Higgs to invisible decays
- **Interpretations**
  - Within the κ-framewok or within EFT

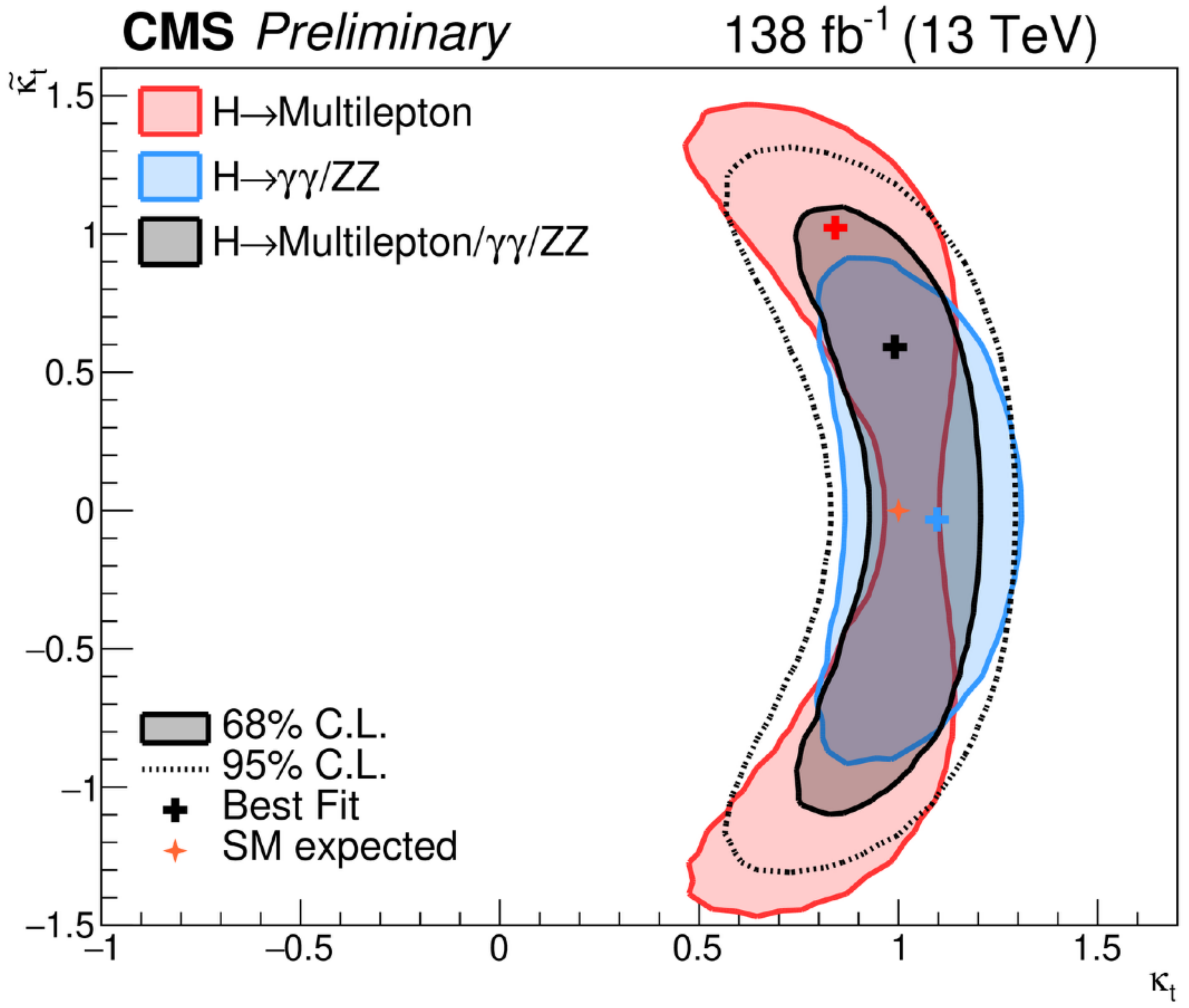
Higgs coupling to the c-quark

Very challenging: multijet background larger by 9 orders of magnitude and charm-jet tagging very difficult

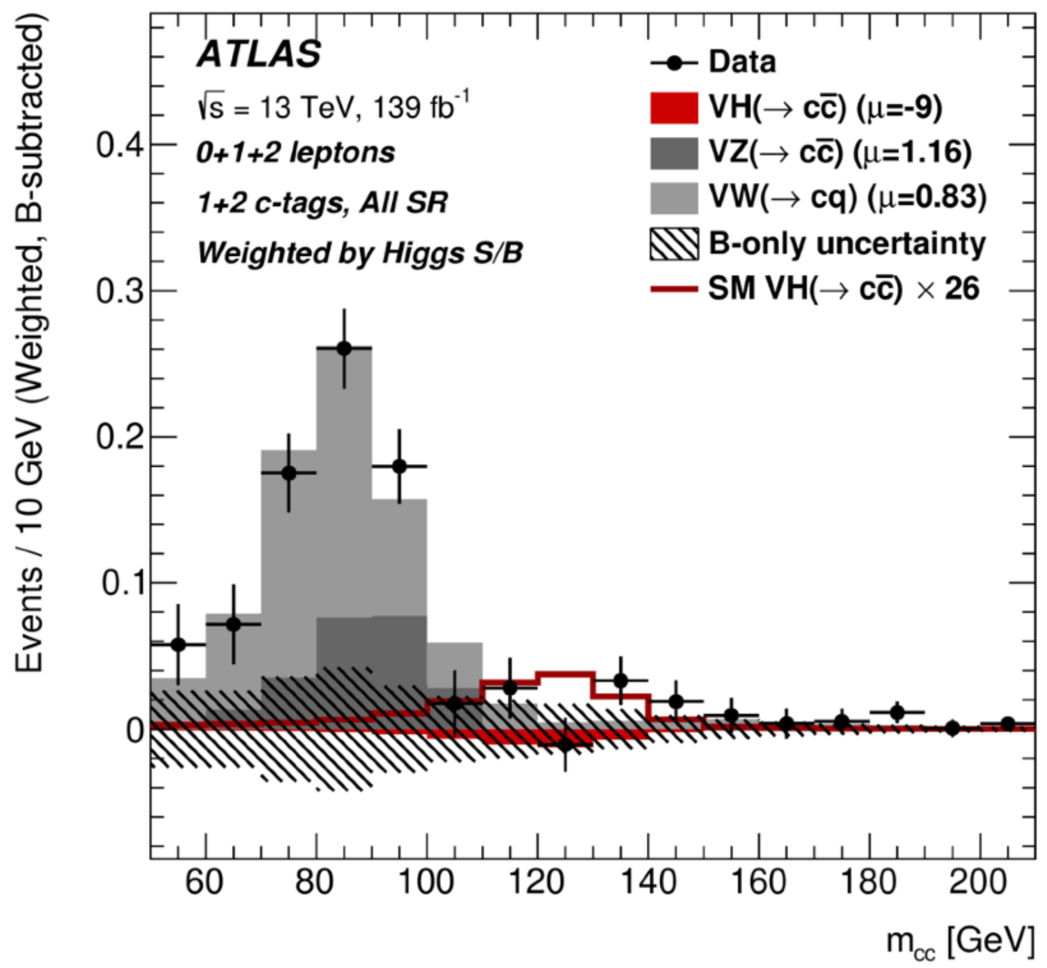


Higgs coupling to the top: ttH

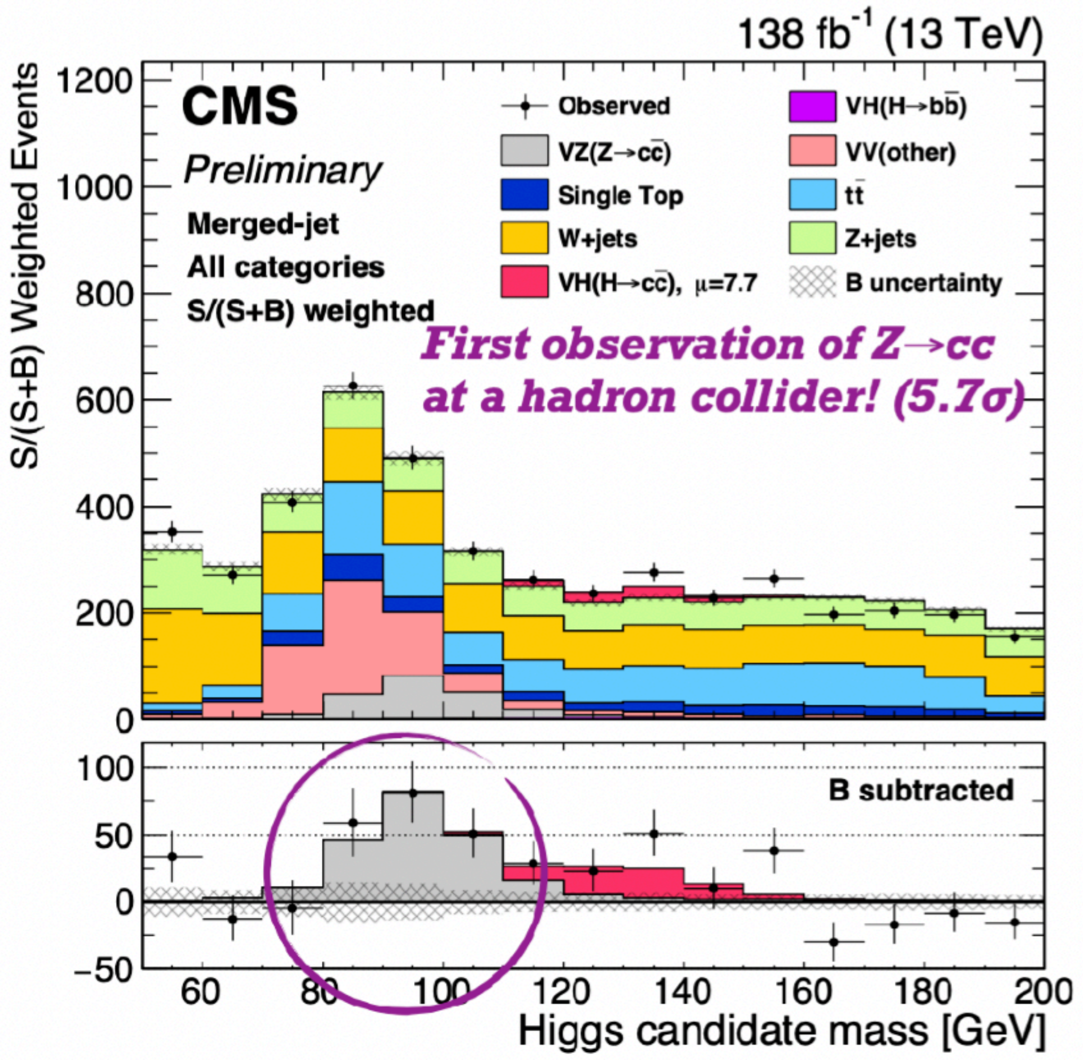
measurement in the multilepton channel
Interpretation in term of CP-odd search

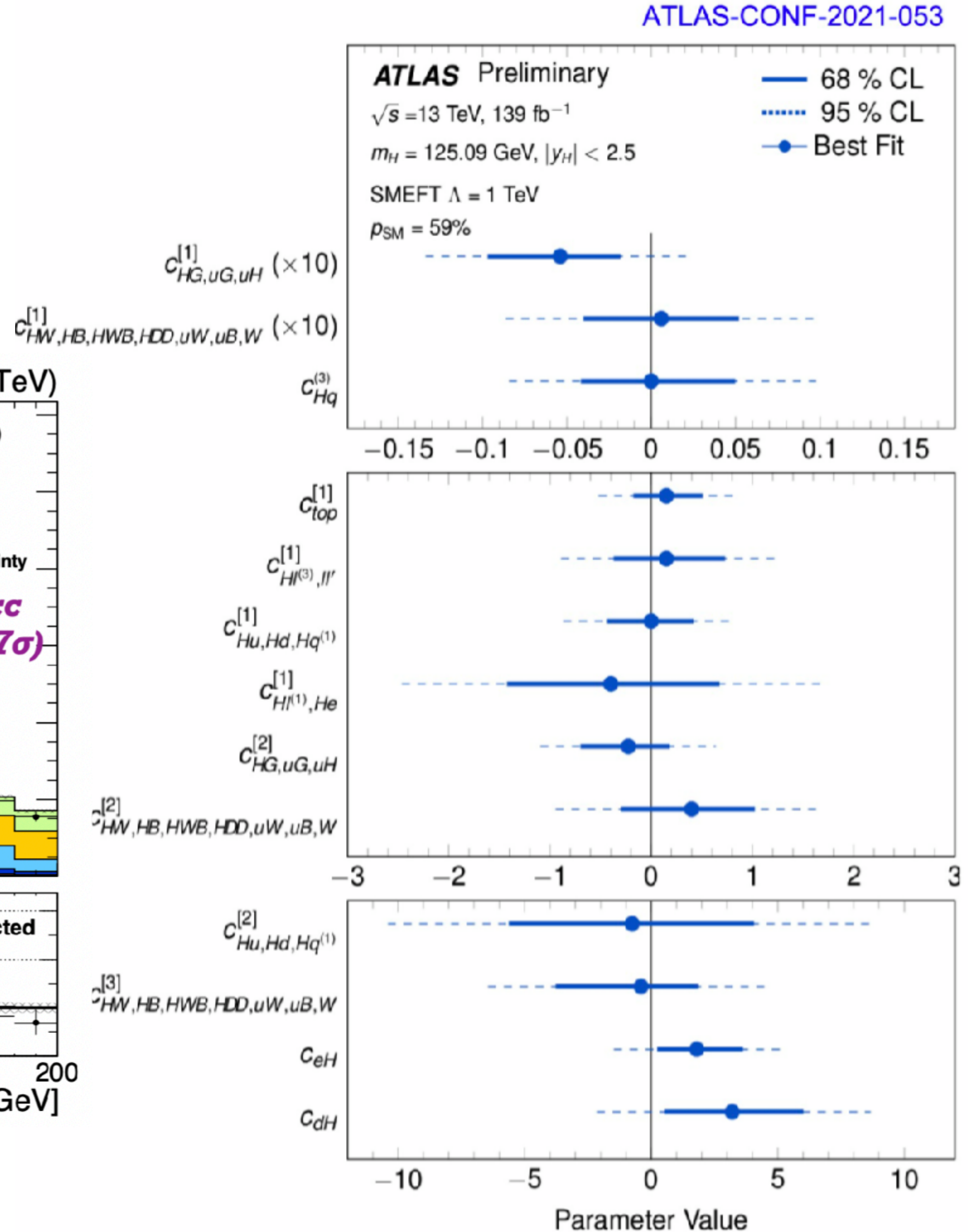


$|k_c| < 8.5$ (exp 12.4)



$1.1 < k_c < 5.5$ (exp 3.8)

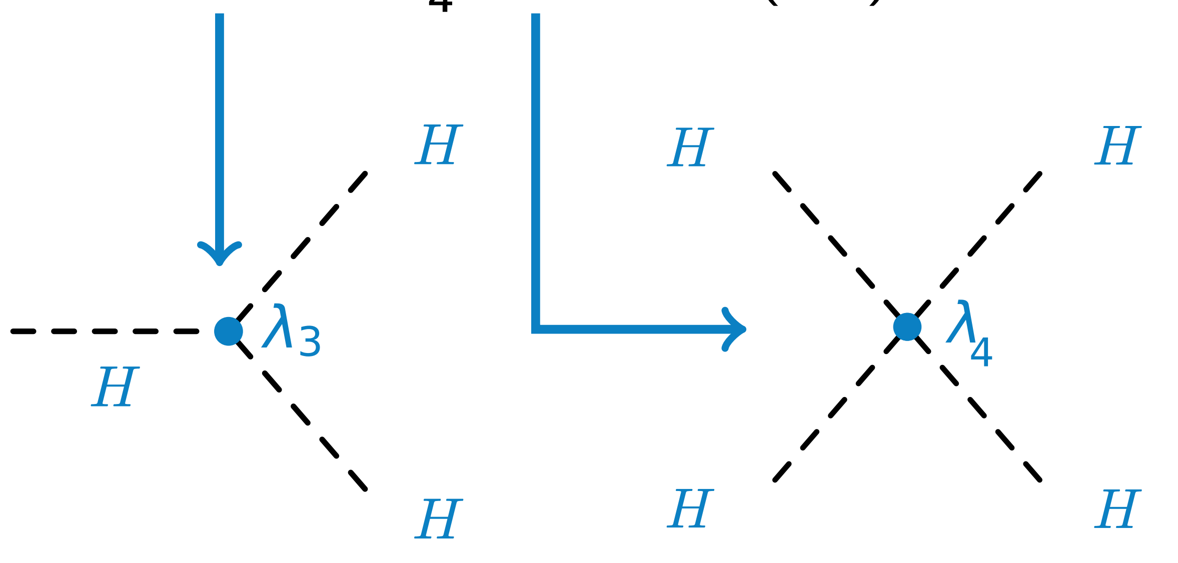


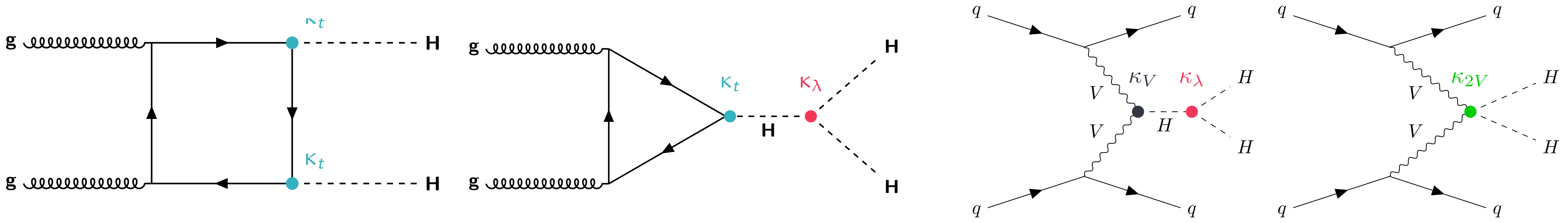


Double Higgs production

- Measurement the Higgs self coupling is a corner stone of the SM
  - Within the SM $\lambda_3 = \lambda_4$
  - λ_4 is out of reach of the LHC

$$V(H) = \frac{1}{2} m_H^2 H^2 + \lambda_3 v H^3 + \frac{1}{4} \lambda_4 H^4 + O(H^5)$$

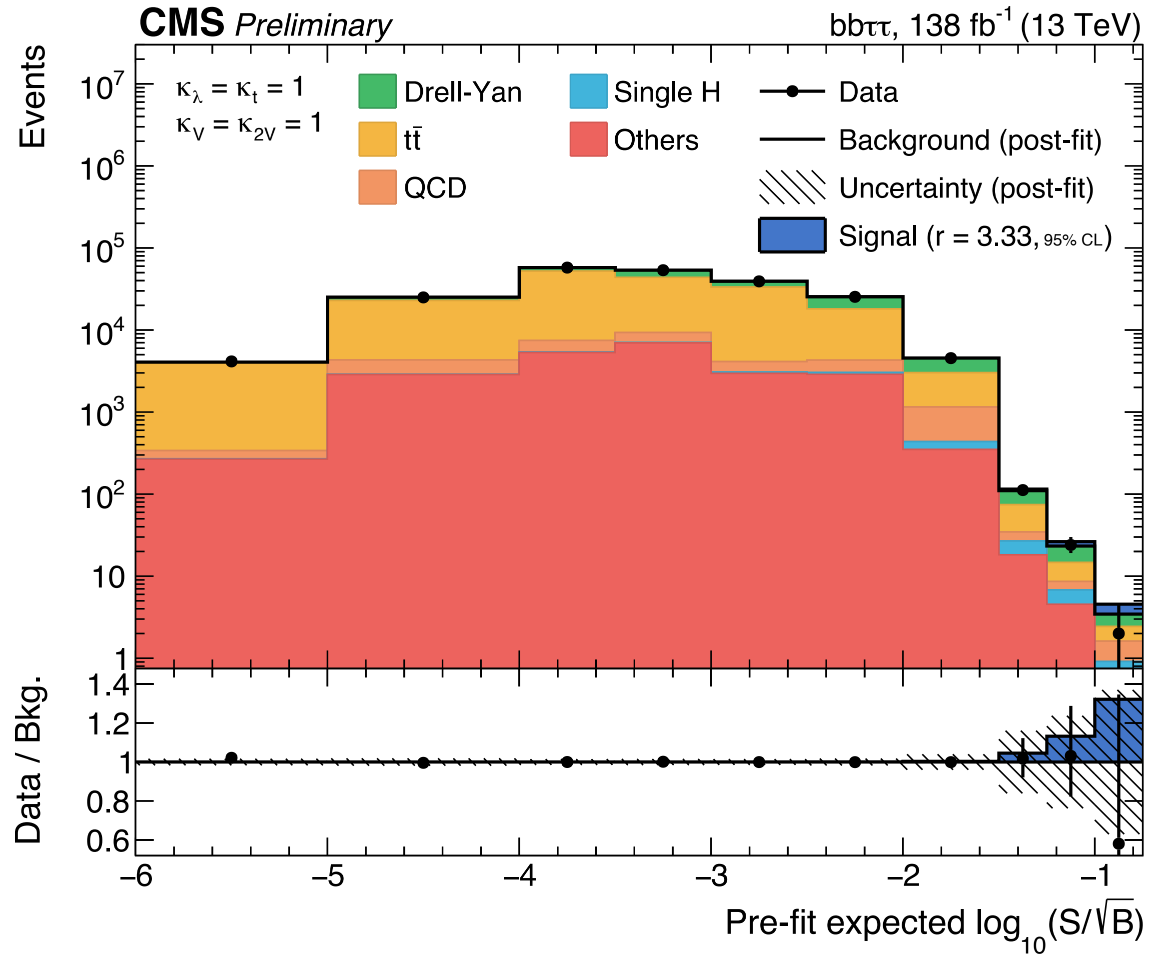




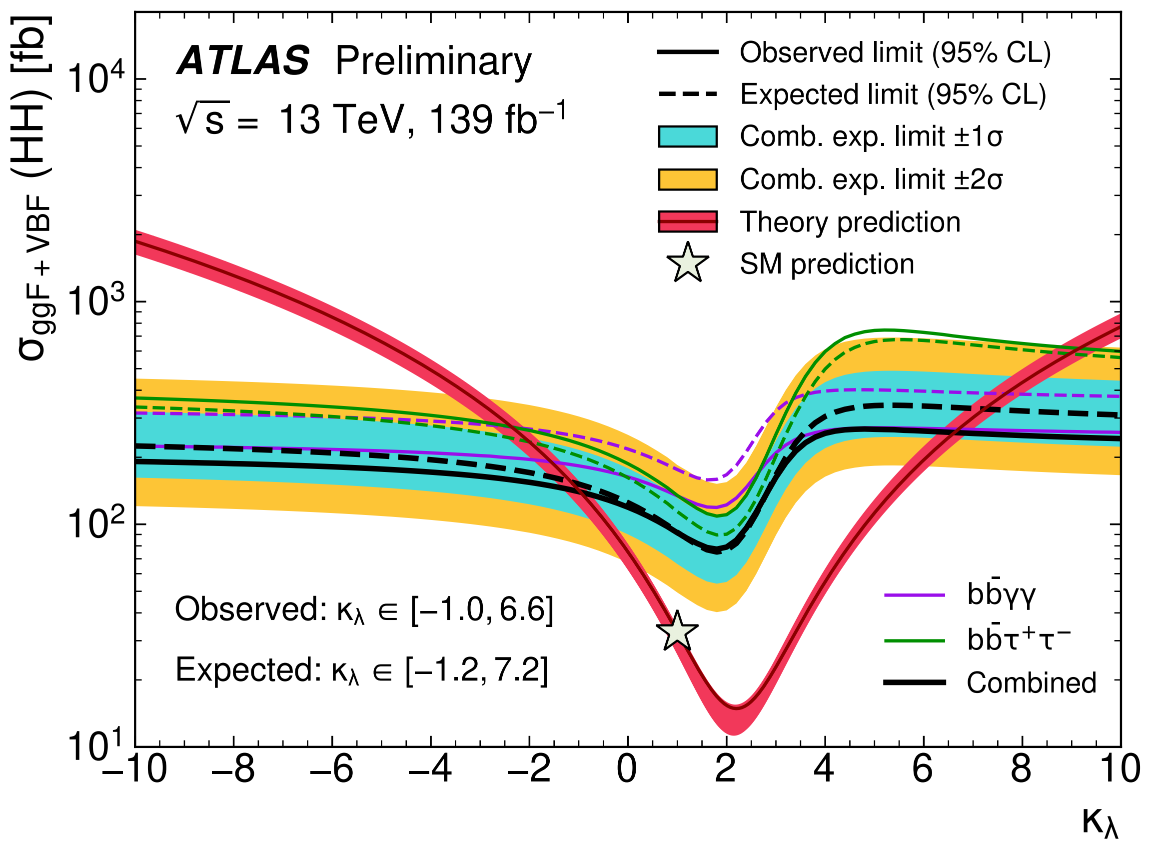
Summary of non resonant searches

		$\sigma_{HH}/\sigma_{HH}^{SM}$ 95% CL Obs.	Exp.	Improvement wrt. 36 fb^{-1} tot. (w/o lumi)	κ_λ 95% CL Obs.	Exp.
$HH \to bb\gamma\gamma$	ATLAS	4.2	5.7	×4.6 (2.3)	[-1.5, 6.7]	[-2.4, 7.7]
	CMS	7.7	5.2	×3.6 (1.9)	[-3.3, 8.5]	[-2.5, 8.2]
$HH \to bb\tau\tau$	ATLAS	4.7	3.9	×3.8 (2)	[-2.4, 9.2]	[-2.0, 9.0]
	CMS	3.3	5.2	×4.8 (2.5)	[-1.8, 8.8]	[-3.0, 9.9]
$HH \to bbbb$	ATLAS	–	–	–	–	–
	CMS	3.9	7.8	×4.7 (2.4)	[-2.3, 9.4]	[-5.0, 12.0]
boosted	CMS	9.9	5.1	-	[-9.9, 16.9]	[-5.1, 12.1]
$HH \to bbZZ$	ATLAS	–	–	–	–	–
	CMS	30	37	–	[-9.0, 14.0]	[-10.5, 15.5]
Multilepton	ATLAS	–	–	–	–	–
	CMS	21.8	19.6	–	[-7.0, 11.7]	[-7.0, 11.2]
Combination ($bb\gamma\gamma$+$bb\tau\tau$)	ATLAS	3.1	3.1	×3.2 (1.6)[a]	[-1.0, 6.6]	[-1.2, 7.2]
	CMS	–	–	–	–	–

Search for bbττ in gg fusion and VBF



Combination of bbγγ and bbττ

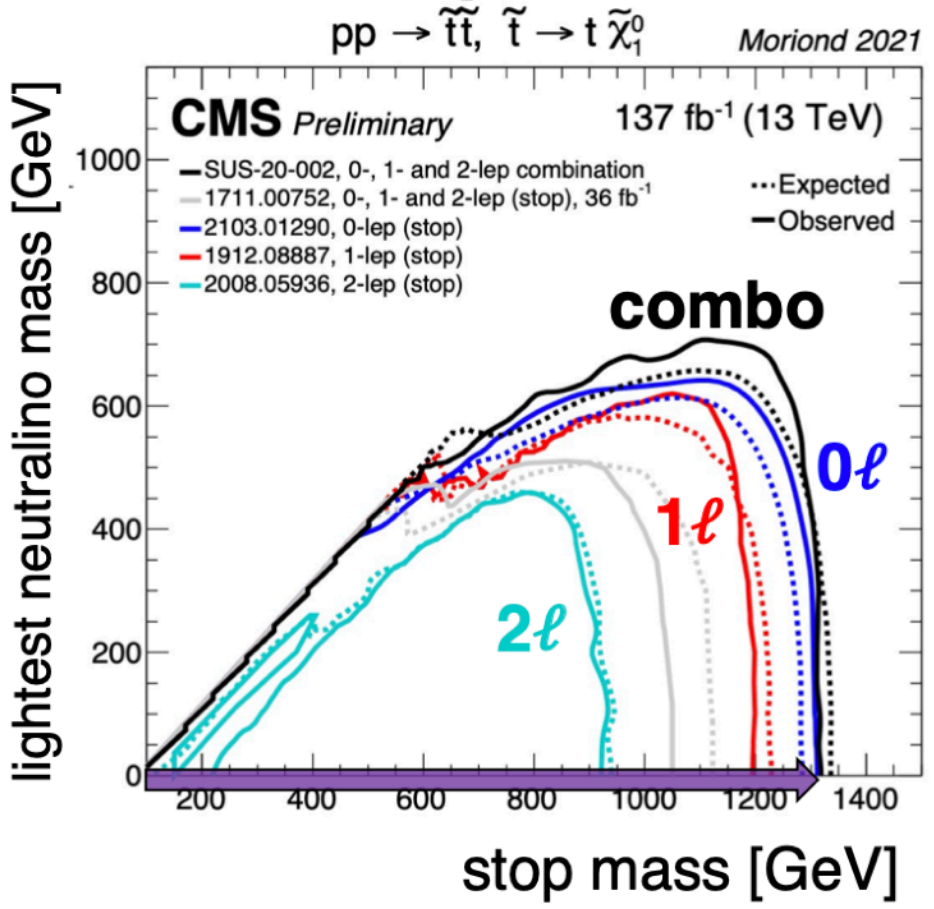


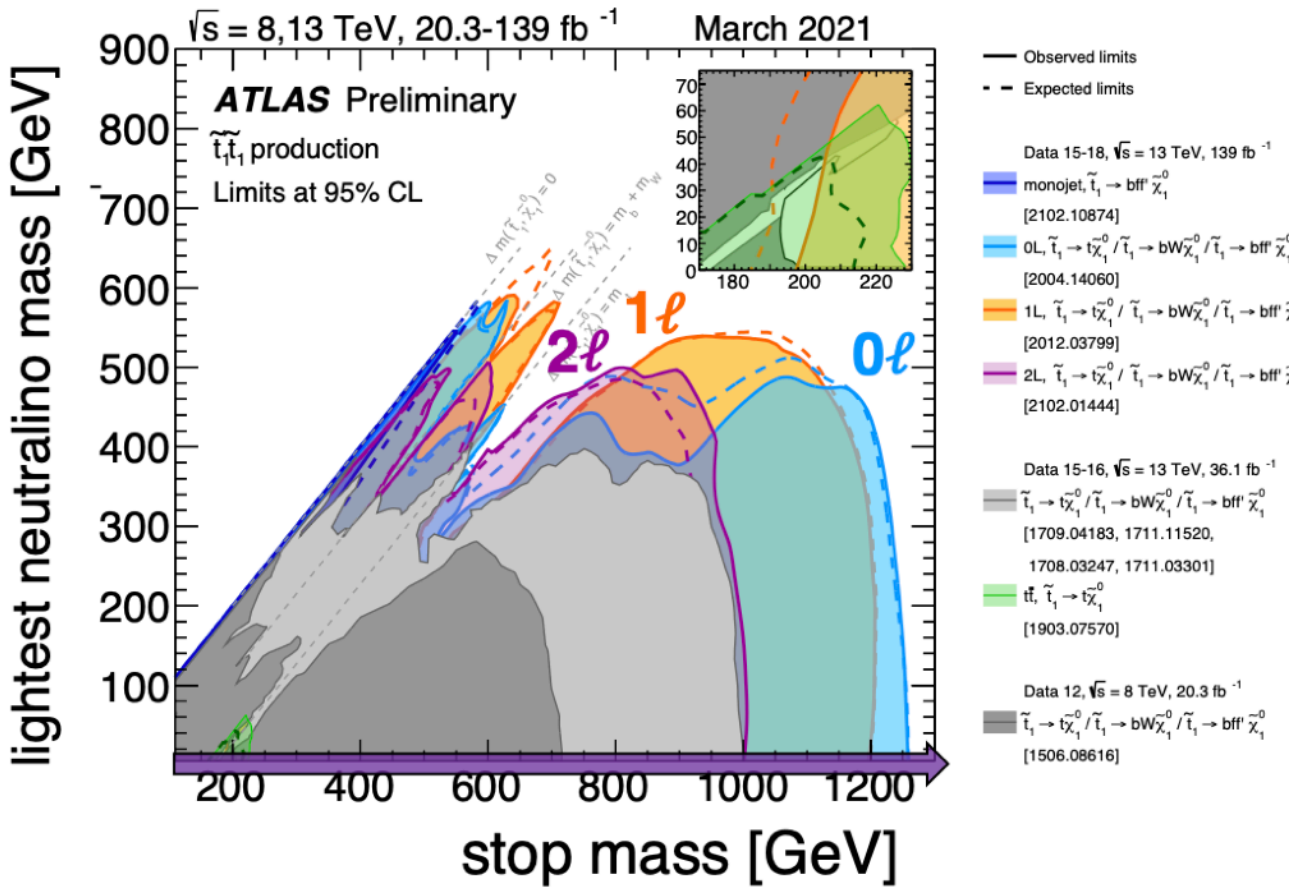
Direct searches for new physics

- Standard searches: SUSY, VLQ
- More exotic searches:
  - Long lived particles
  - Vector like leptons : model addressing the b flavour anomalies

SUSY searches

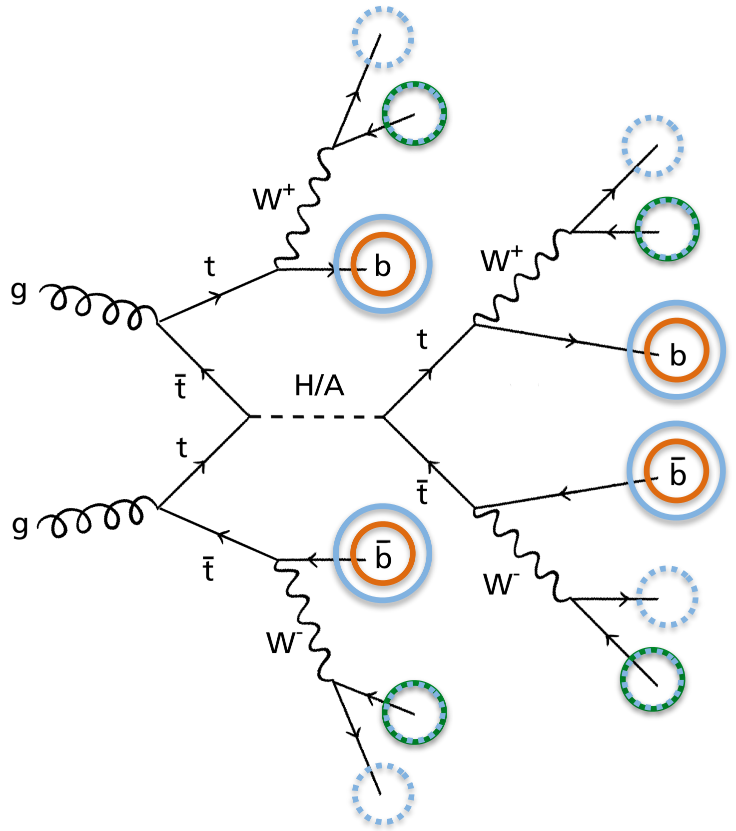
Constraints on stop

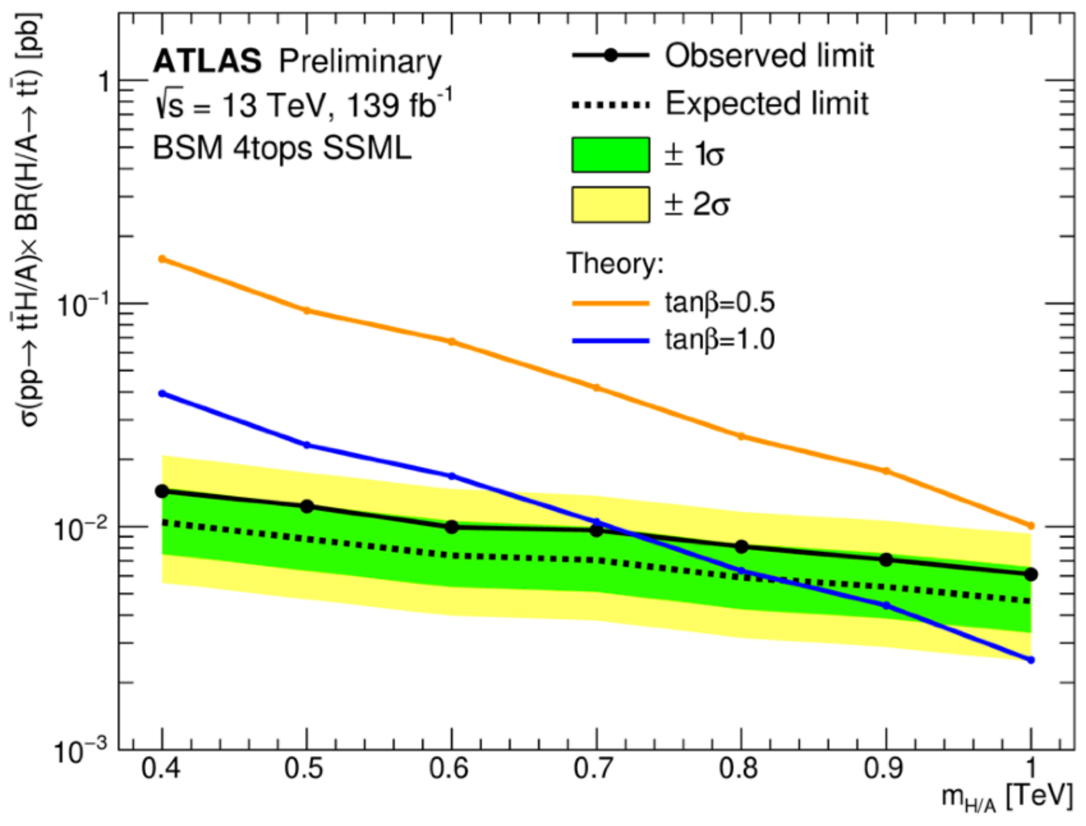




Search in the 4top final state

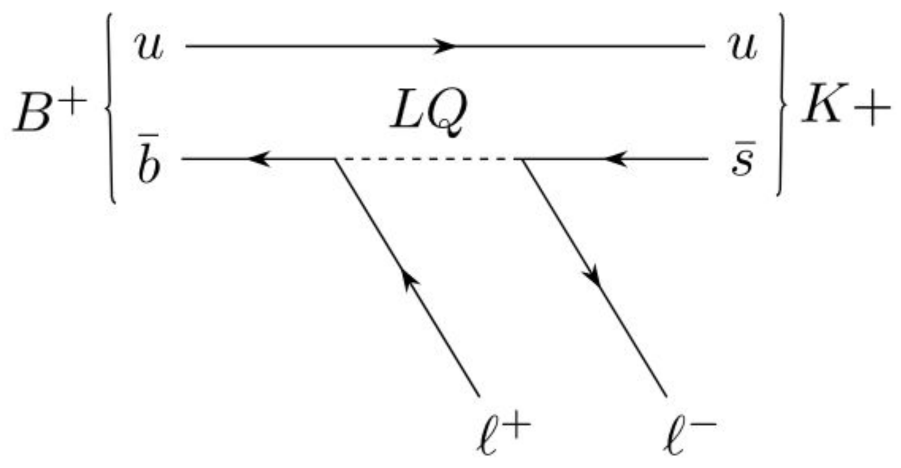
Build on SM 4top measurement

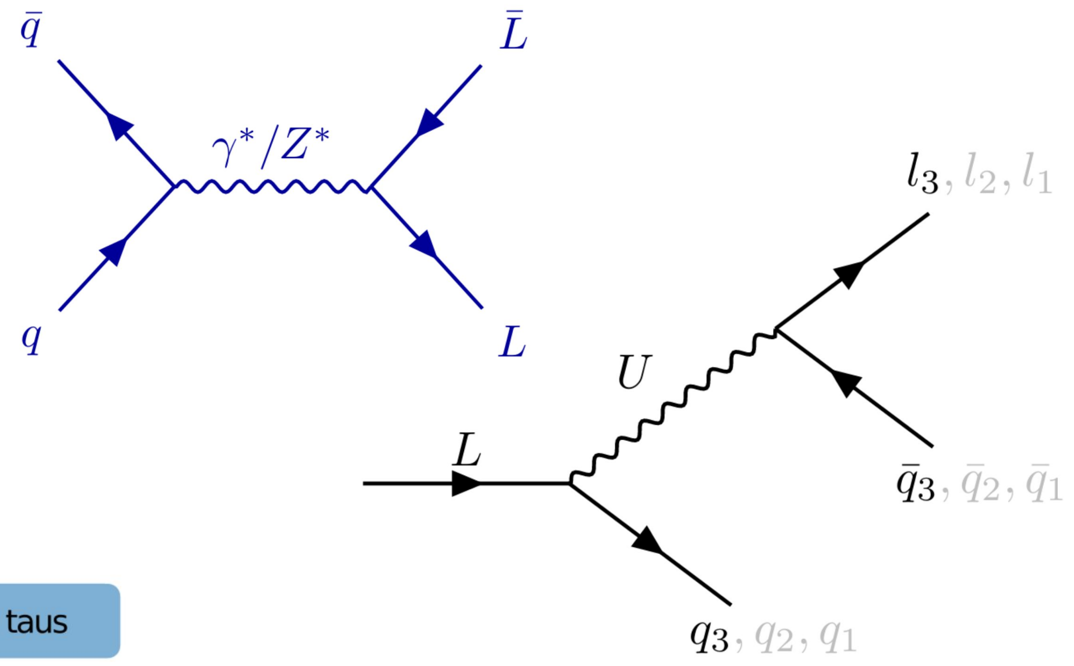


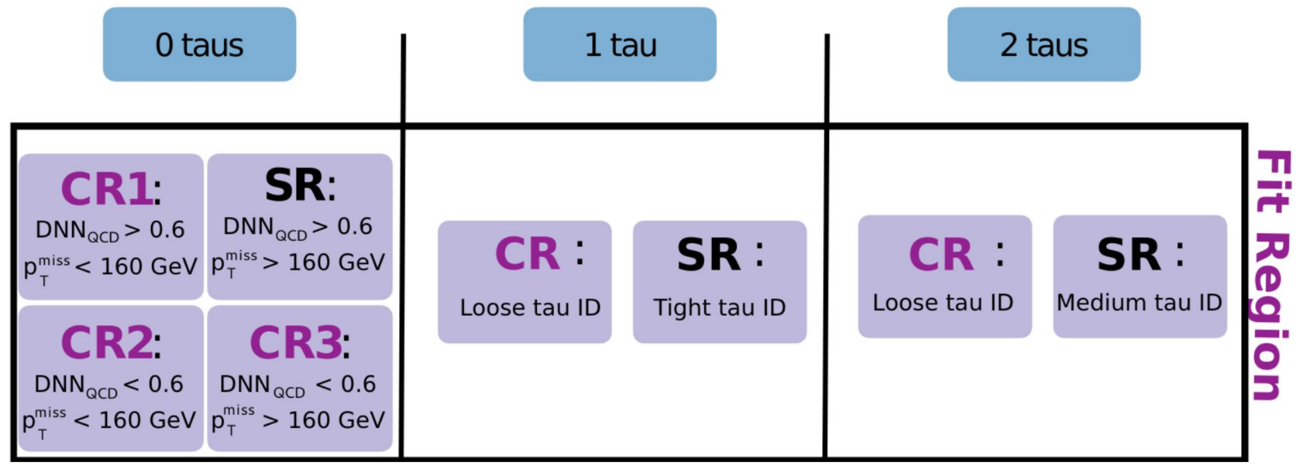


Search for vector-like leptons the 4321 model

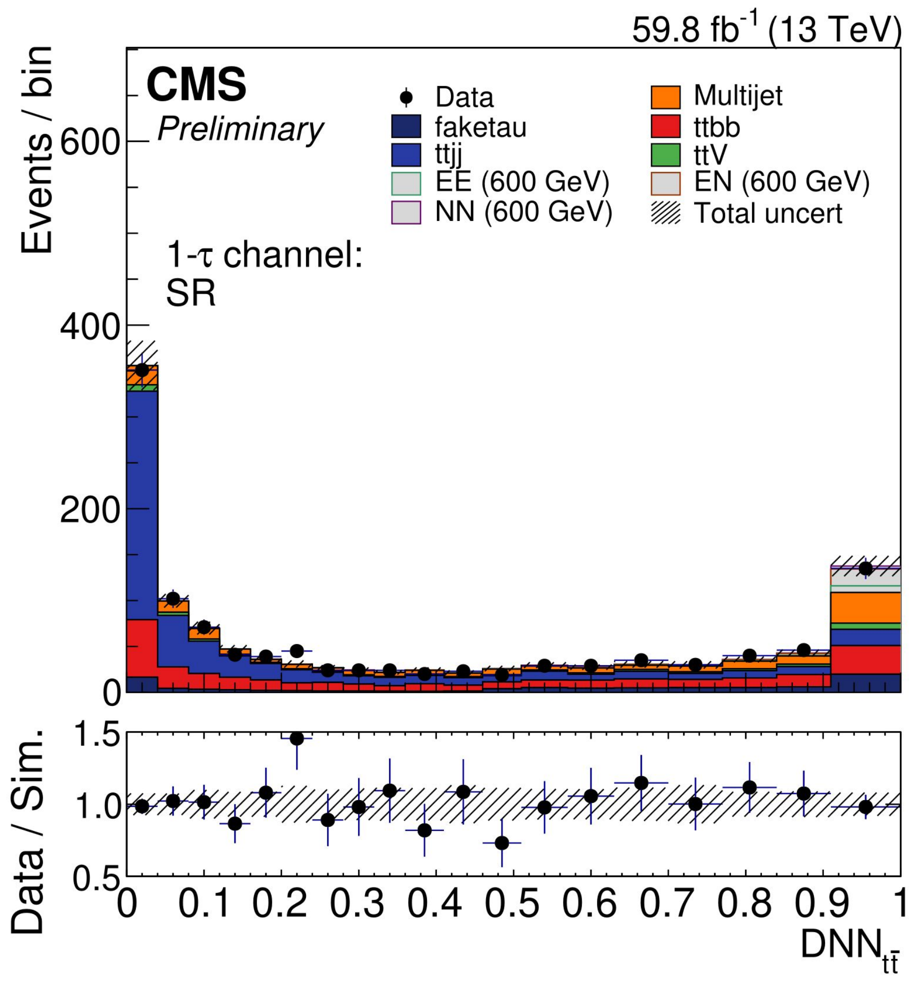
extending the SM sector to SU(4)xSU(3)’xSU(2)LxU(1)’

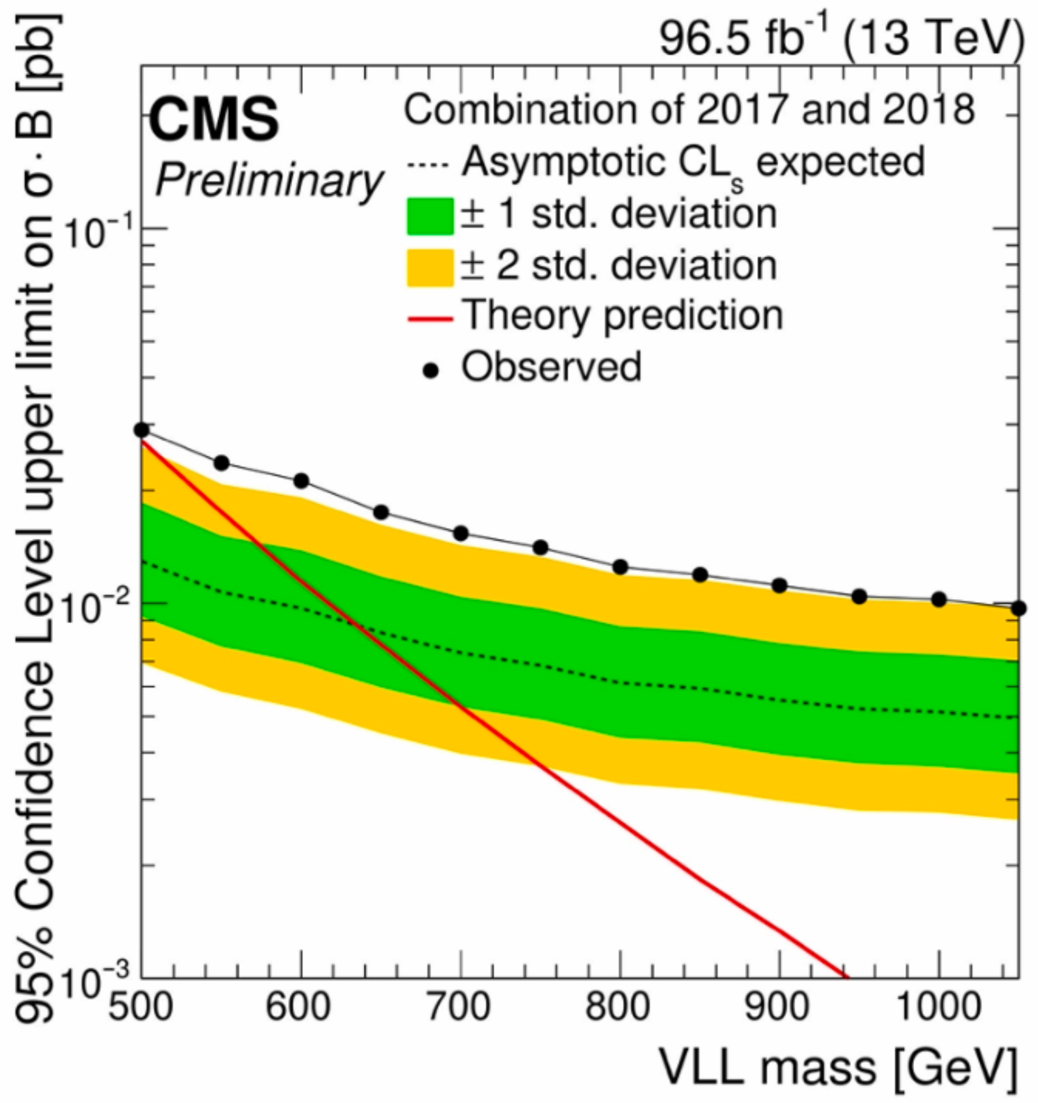






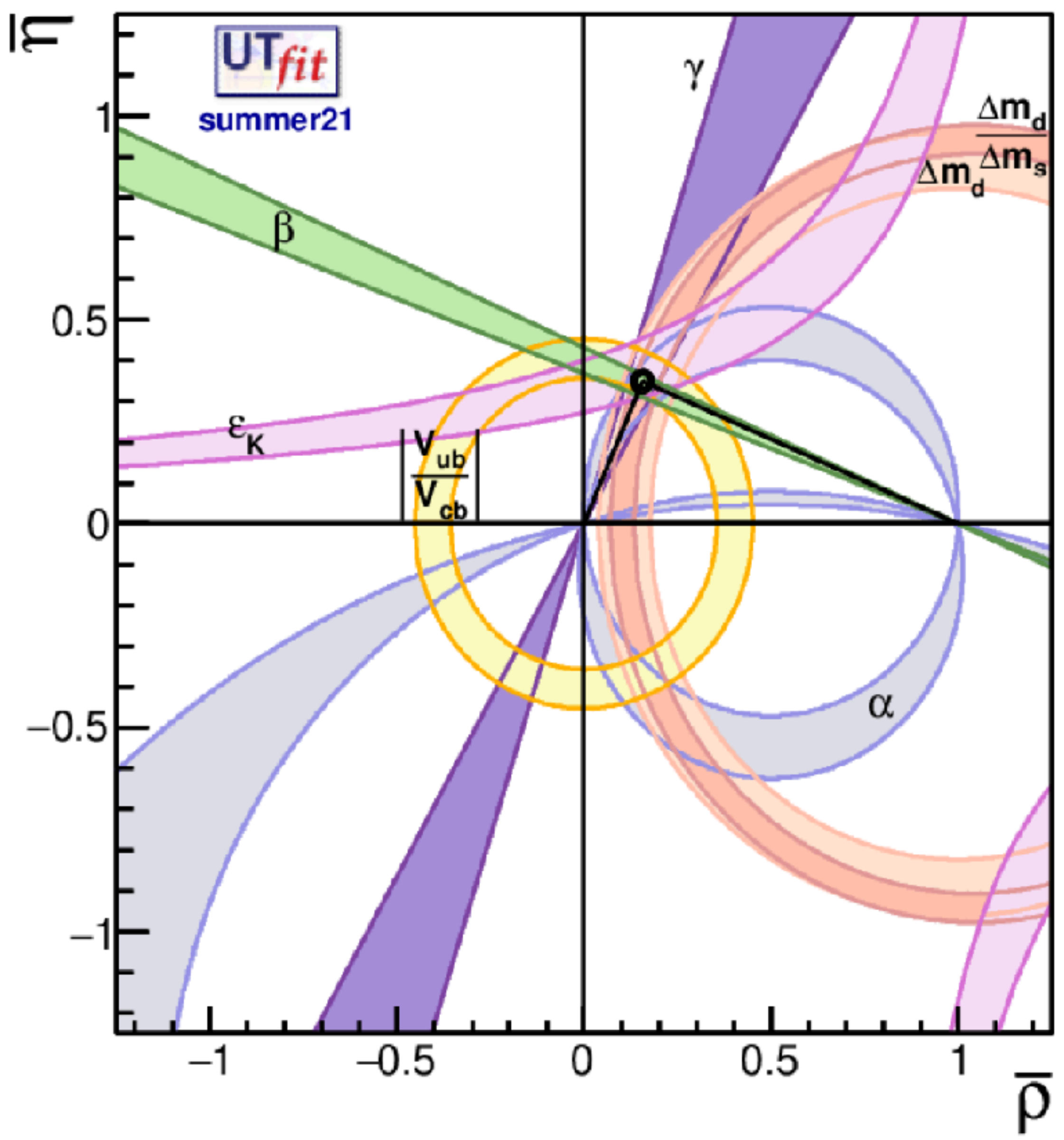
Mild excess over background-only hypothesis (2.8 σ)





Precision tests with flavour

- CKM measurements
  - Impressive precisions of the measurements
  - At the current level of precision, all measurements are consistent
  - New physics effects are small

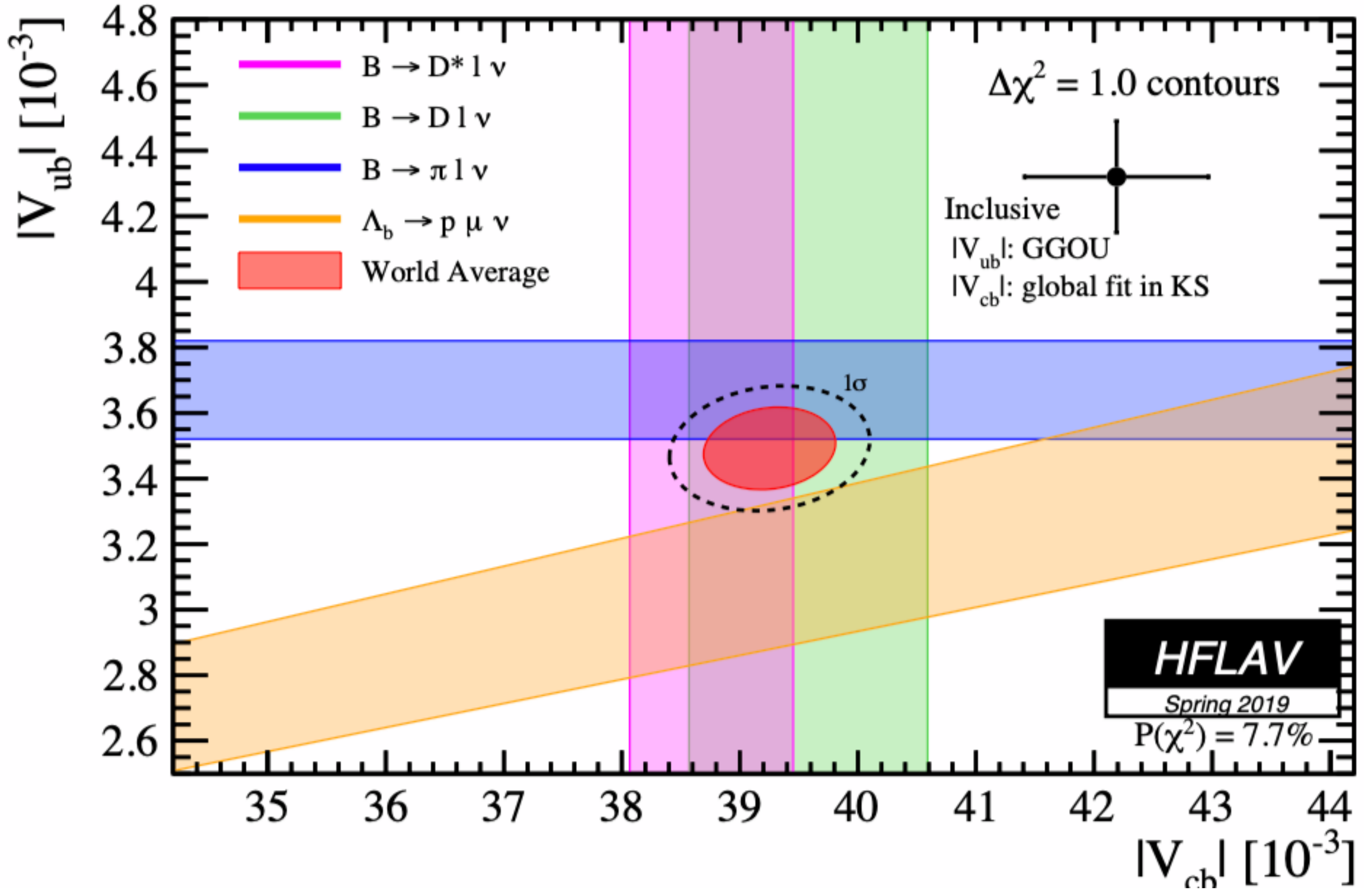


$$\bar{\rho} = 0.157 \pm 0.012 \quad \sim 8\%$$

$$\bar{\eta} = 0.350 \pm 0.010 \quad \sim 3\%$$

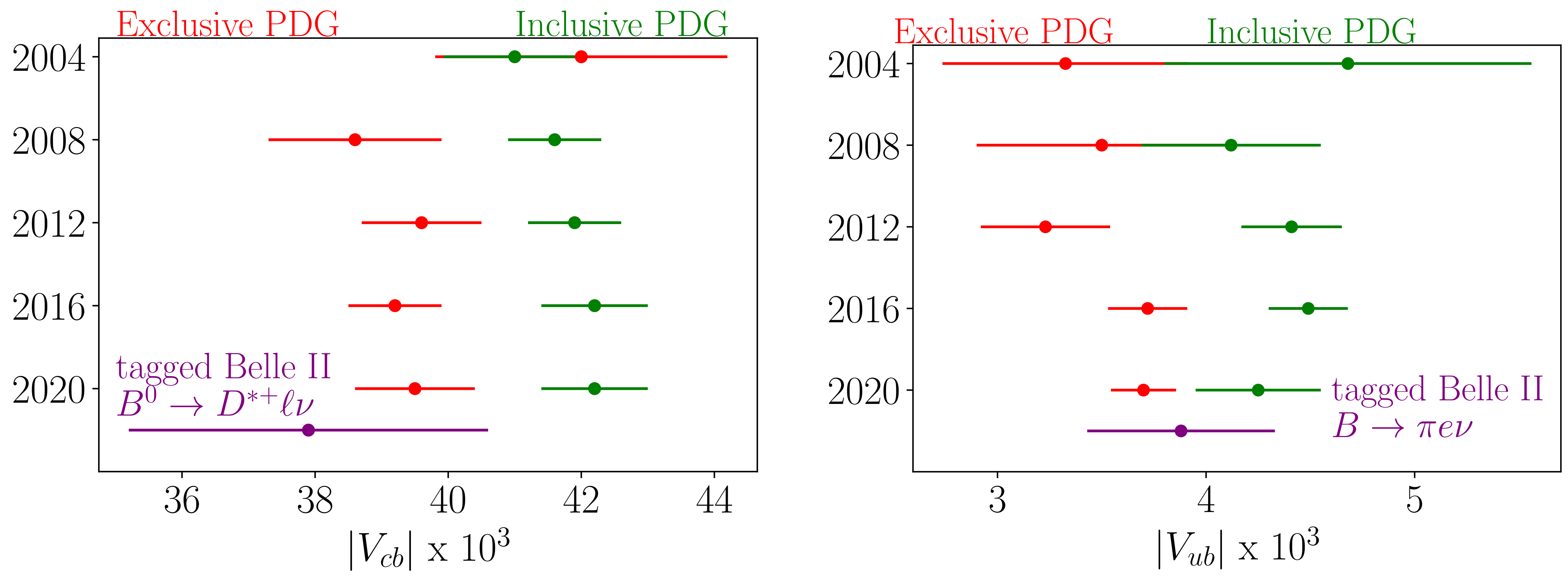
$$\gamma = (65.8 \pm 2.2)^{\circ}$$

Longstanding discrepancy between inclusive and exclusive for |Vub|,|Vcb|



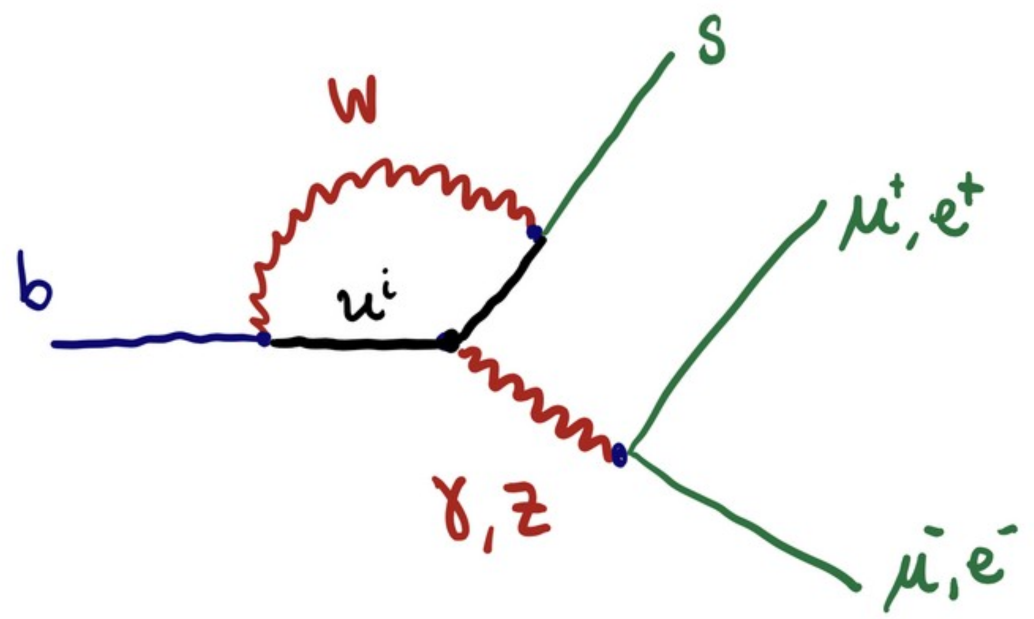
new Belle2 results

Stat limited, expected better results soon



Tests of lepton flavour universality

- In the SM only the lepton masses are flavour non-universal
  - Flavour universality could be a low energy 'accident'
  - Might have different behaviours at high energy
  - Could be discovered by comparing classes of rare decays involving different lepton pairs (e.g. μ/e or μ/τ)

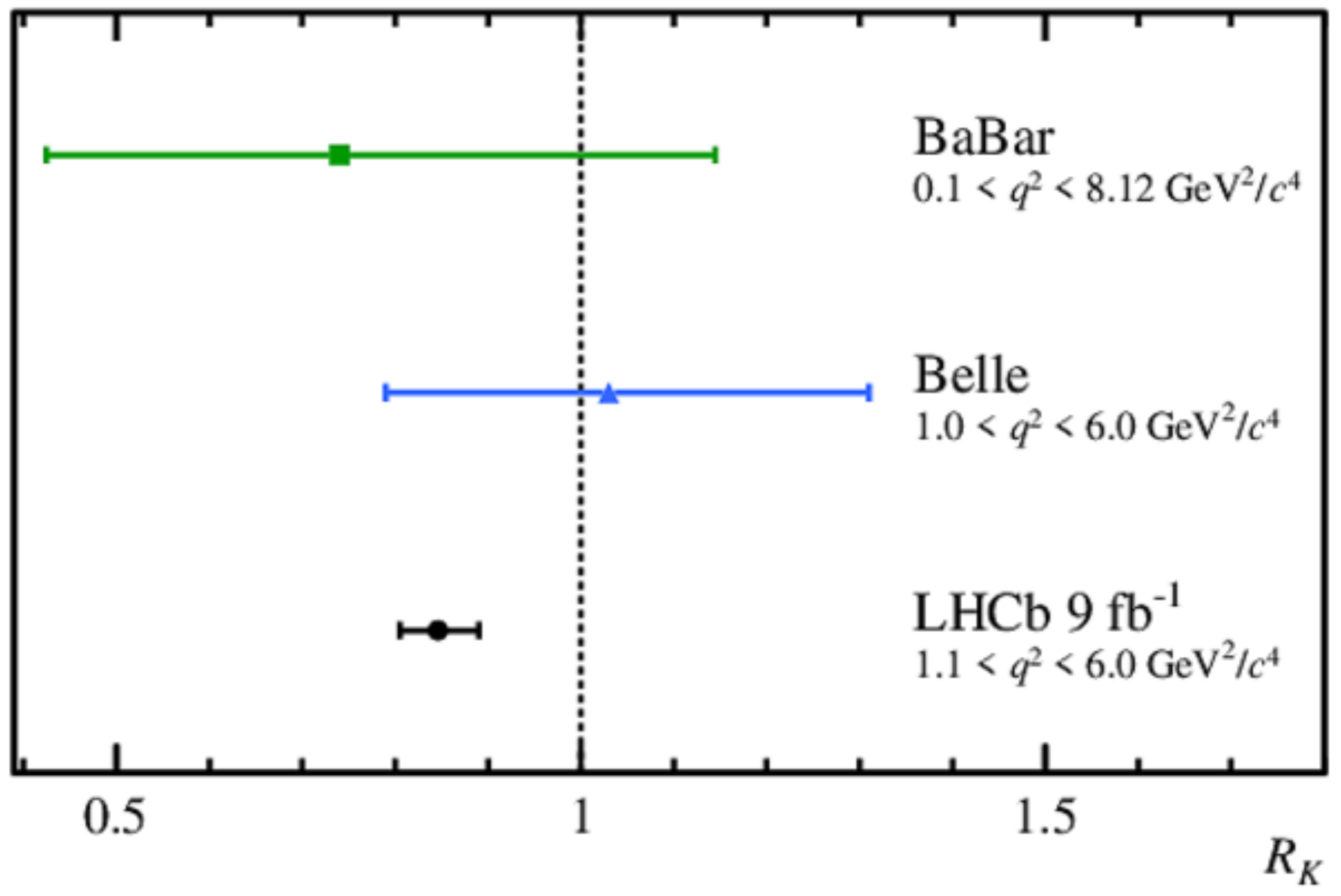


$b \to s$

$$R_{K^{(*)}} = \frac{\mathrm{Br}(B \to K^{(*)}\mu\bar{\mu})}{\mathrm{Br}(B \to K^{(*)}e\bar{e})}$$

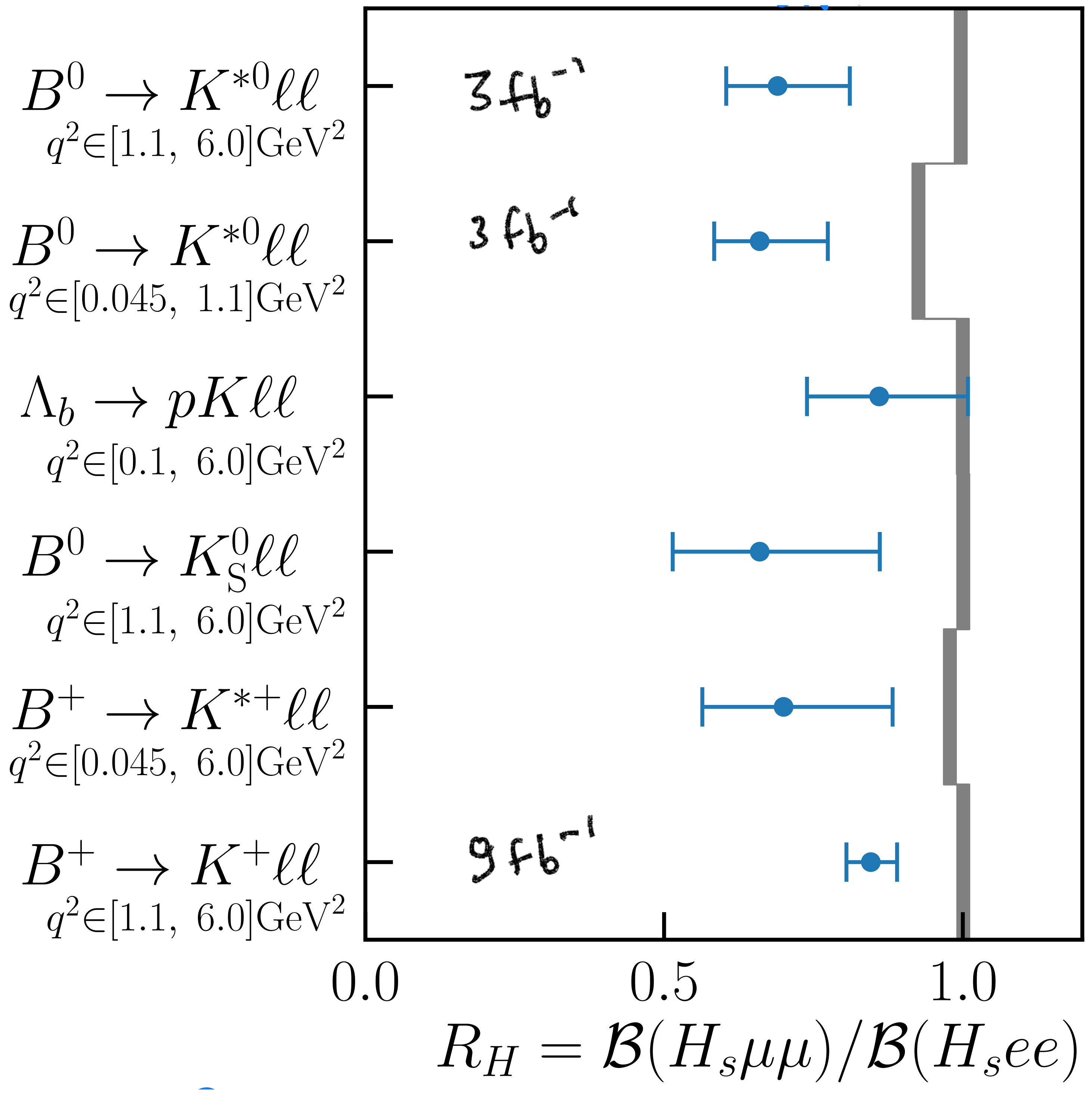
$\sim 3\sigma$ deficit

R_K ($B^+ \to K^+ l^+ l^-$)



$$R_K(1.1 < q^2 < 6.0\,\mathrm{GeV}^2) = 0.846^{+0.042}_{-0.039}\,(\mathrm{stat})\,^{+0.013}_{-0.012}\,(\mathrm{syst})$$

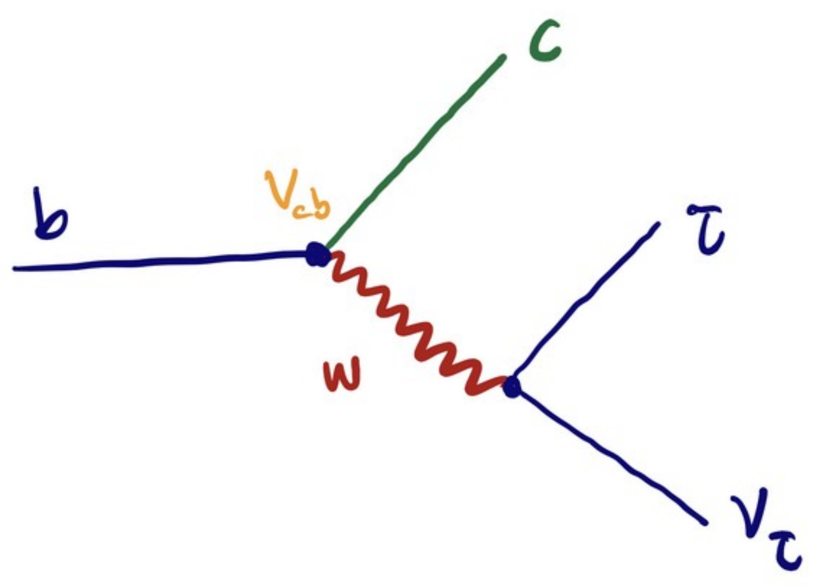
an infringing pattern



also seen in angular analysis

Tests of lepton flavour universality (2)

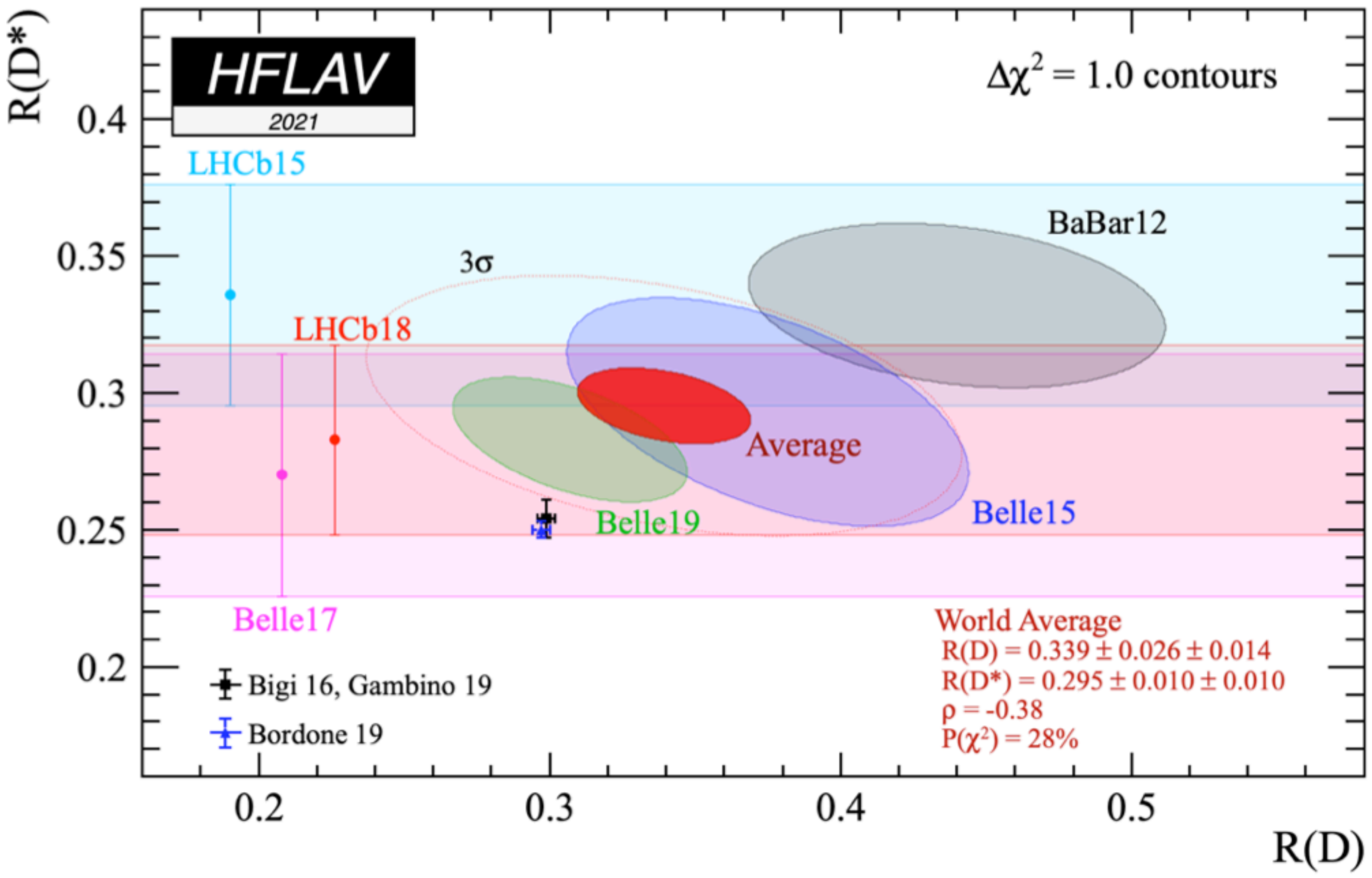
- In the SM only the lepton masses are flavour non-universal
  - Flavour universality could be a low energy 'accident'
  - Might have different behaviours at high energy
  - Could be discovered by comparing classes of rare decays involving different lepton pairs (e.g. μ/e or μ/τ)



$b \to c$

$$R_{D^{(*)}} = \frac{\mathrm{Br}(B \to D^{(*)}\,\tau\bar{\nu})}{\mathrm{Br}(B \to D^{(*)}\,\ell\bar{\nu})}\Bigg|_{\ell=e,\mu}$$

$\sim 3\sigma$ excess



All experiments see an excess wrt SM predictions

intriguing as it occurs in a tree-level SM process ($\Lambda_{NP} \lessapprox 3$ TeV)