Highlights from Moriond 2024

Higgs, SM, BSM, Flavour

Fabrice Balli, IRFU/DPhP

DPhP Seminar, April 22nd, 2024

https://moriond.in2p3.fr/

Disclaimer

- Large amount of new results
  - Will go through several of them but not all
- Not an expert in each topic!
- Interesting Young Scientist Forum presentations !
- Very good level of skiing

Outline

- Higgs
- Standard Model (SM)
- Beyond SM
- Flavour

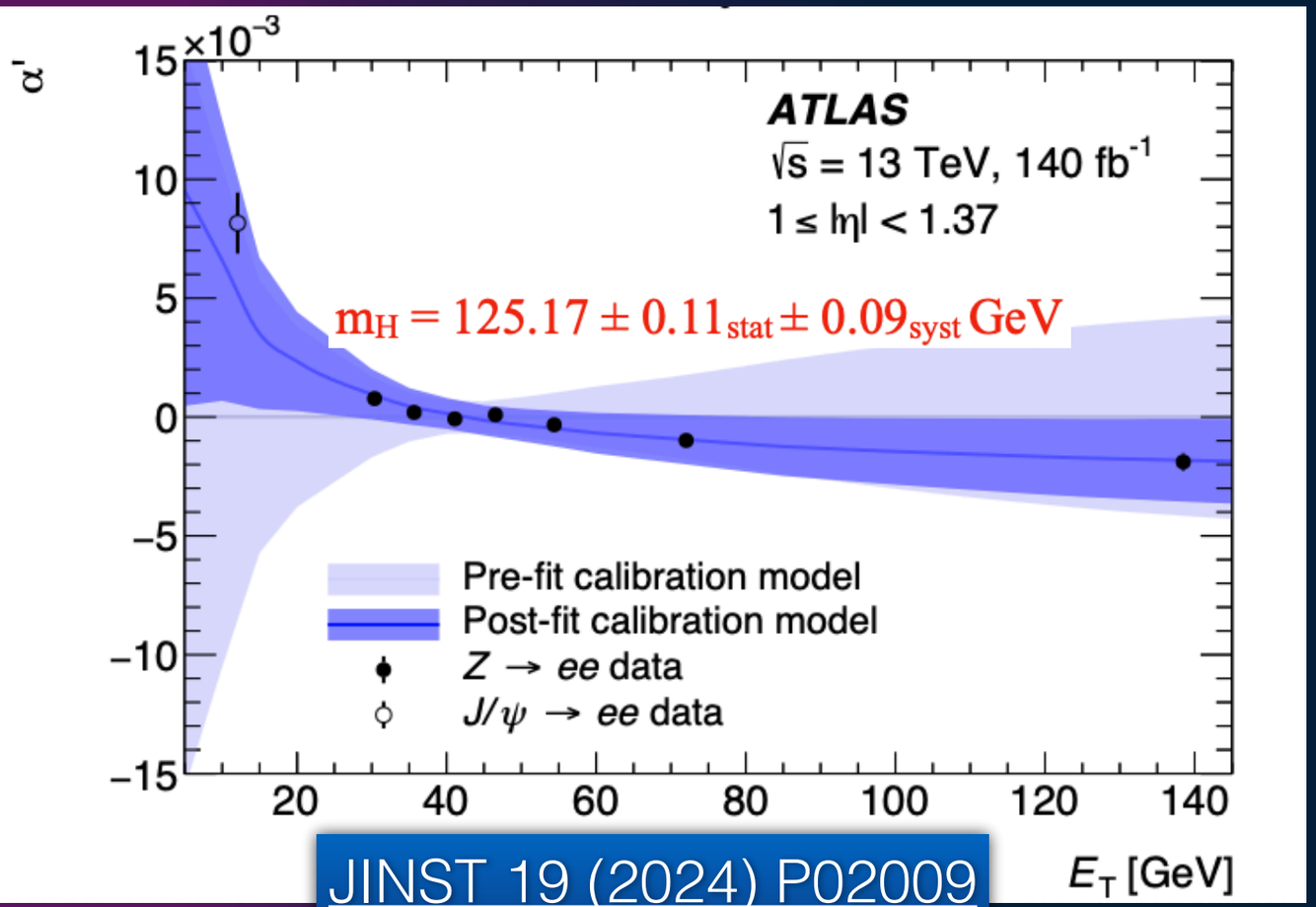
Higgs

Higgs mass and width

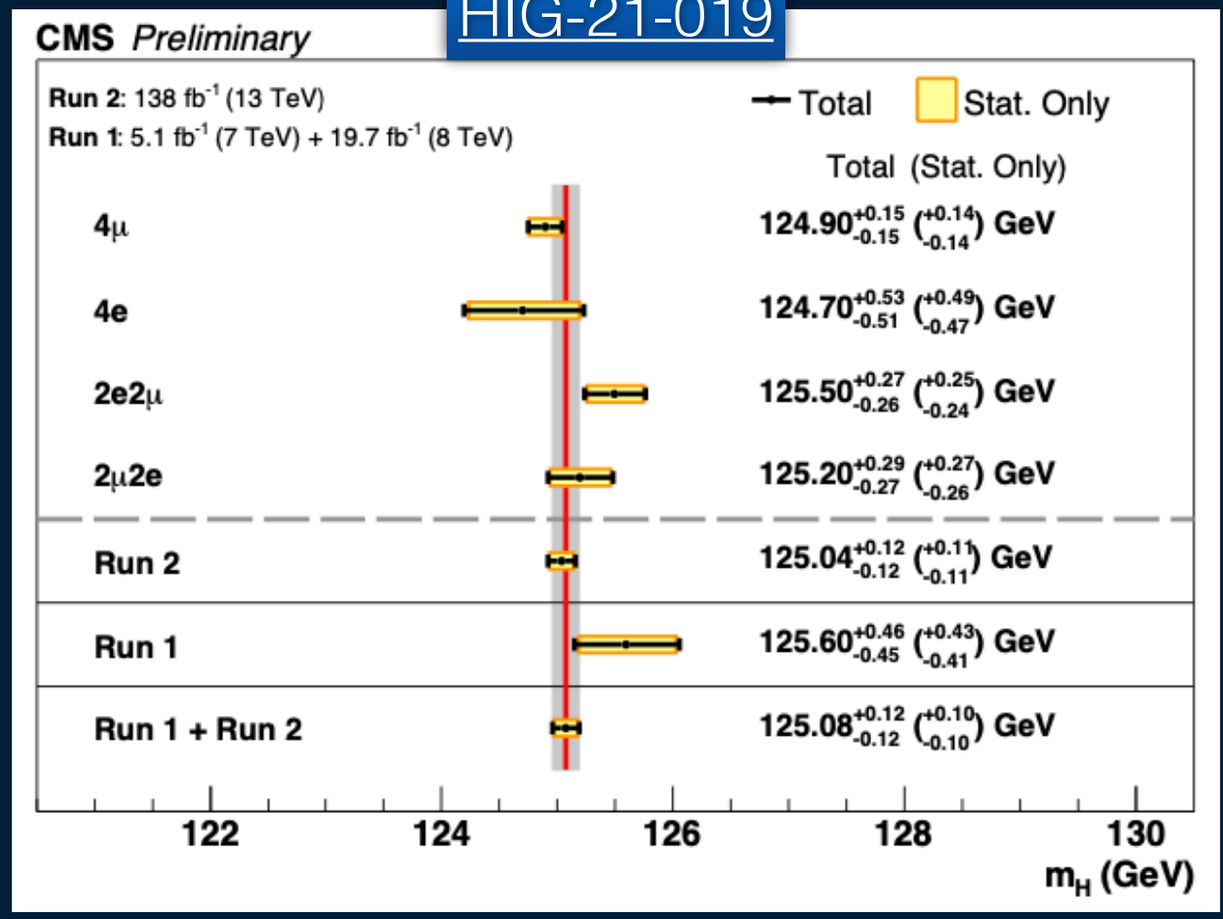
Higgs mass : fundamental parameter of the SM

- Measured in 4ℓ and γγ channels
  - ATLAS: improvement of photon energy scale —> keep systematic below statistical uncertainty!
  - CMS: most precise single measurement (4 ℓ), several improvements (beam spot constraint, per-event uncertainty) **m_H = 125.08 ± 0.10 ± 0.05 GeV**

- Higgs width sensitive to BSM scenarios
  - CMS (NEW):
    - Γ = (2.9+1.9-1.4) MeV, ∈ [0.6, 7.0] MeV @ 95% CL
  - ATLAS :
    - Γ = (4.5+3.0-2.5) MeV, <10.2 MeV @ 95% CL



JINST 19 (2024) P02009

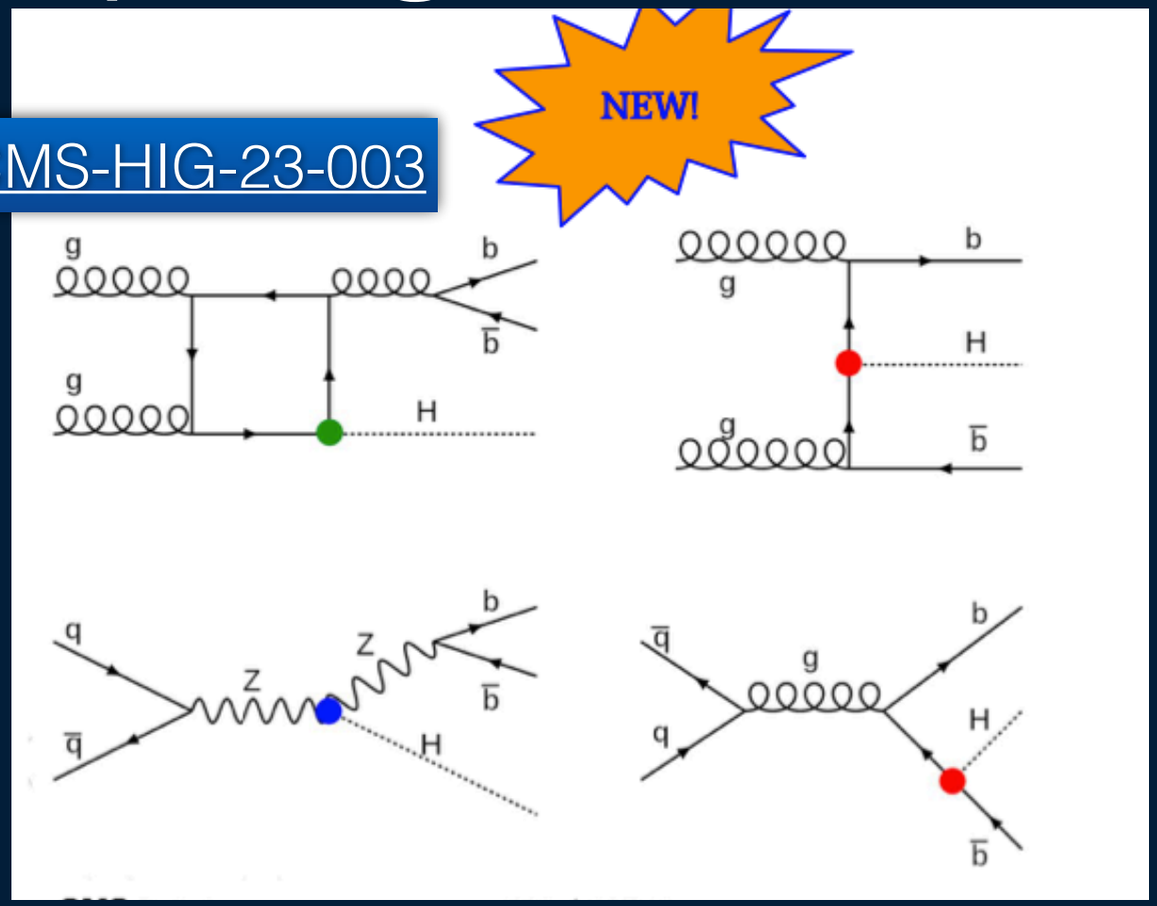


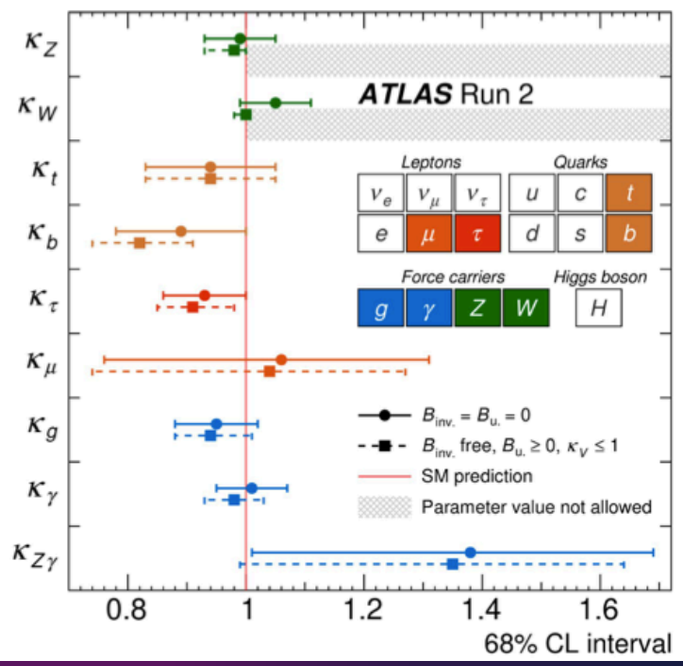
Higgs couplings

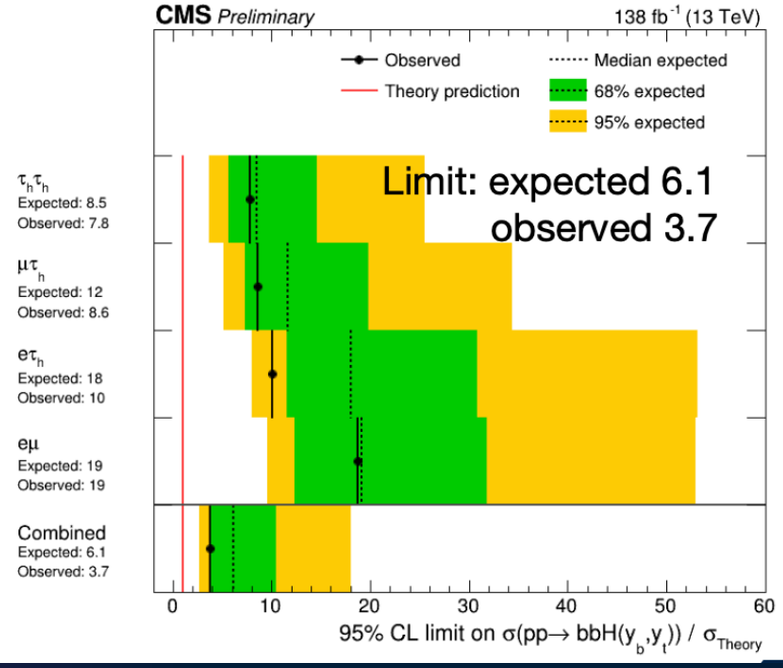
- Higgs couplings fundamental to measure
  - 2nd generation of fermions
  - Probe CP structure and test SM predictions
- New CMS measurement of H+bb associated production, sensitive to κ_t, κ_Z, and κ_b
  - Cross-section 0.48 pb, similar to ttH
  - Challenging backgrounds (multijet), use leptonic decays of the WW and $\tau\tau$ final states to fight it
- Compatible with the SM within 2sigma

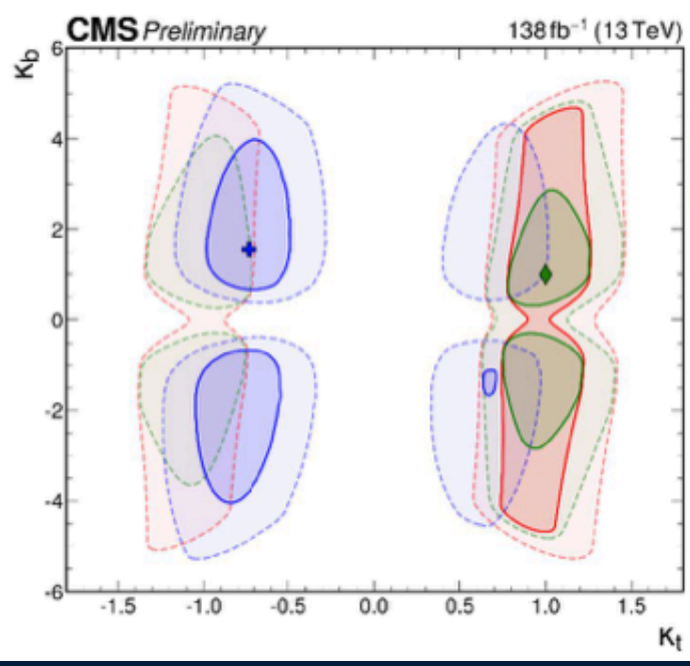
CMS-HIG-23-003

NEW!

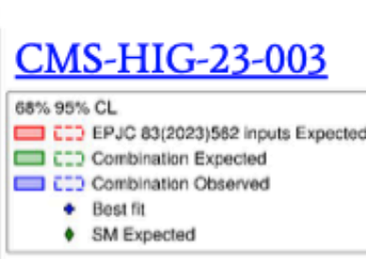








CMS-HIG-23-003

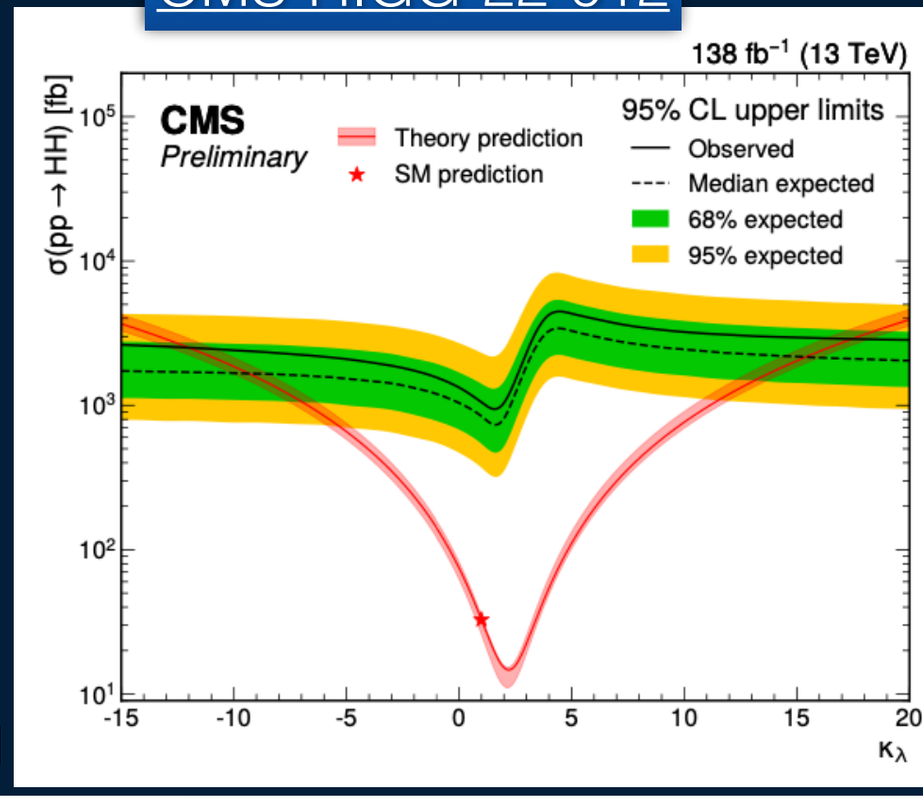


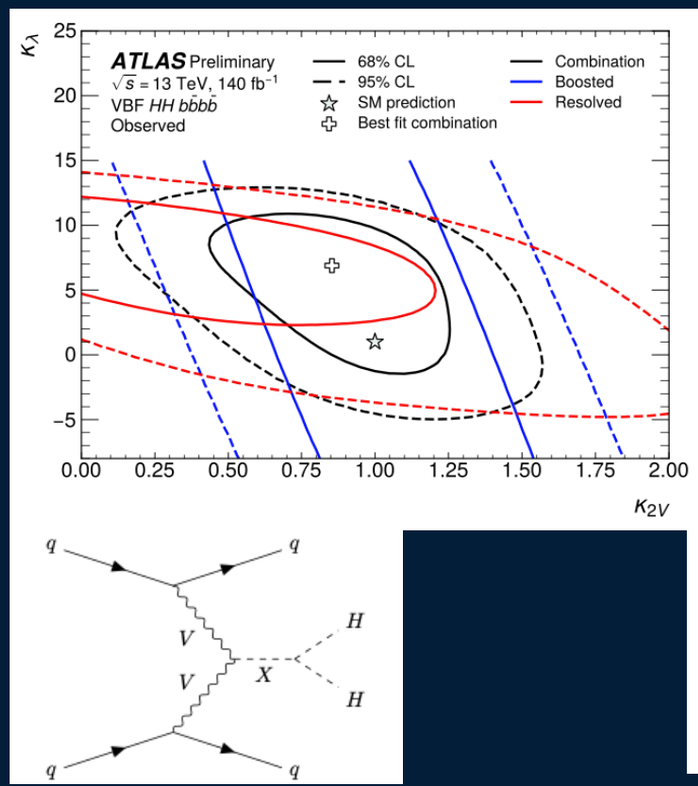
HH searches

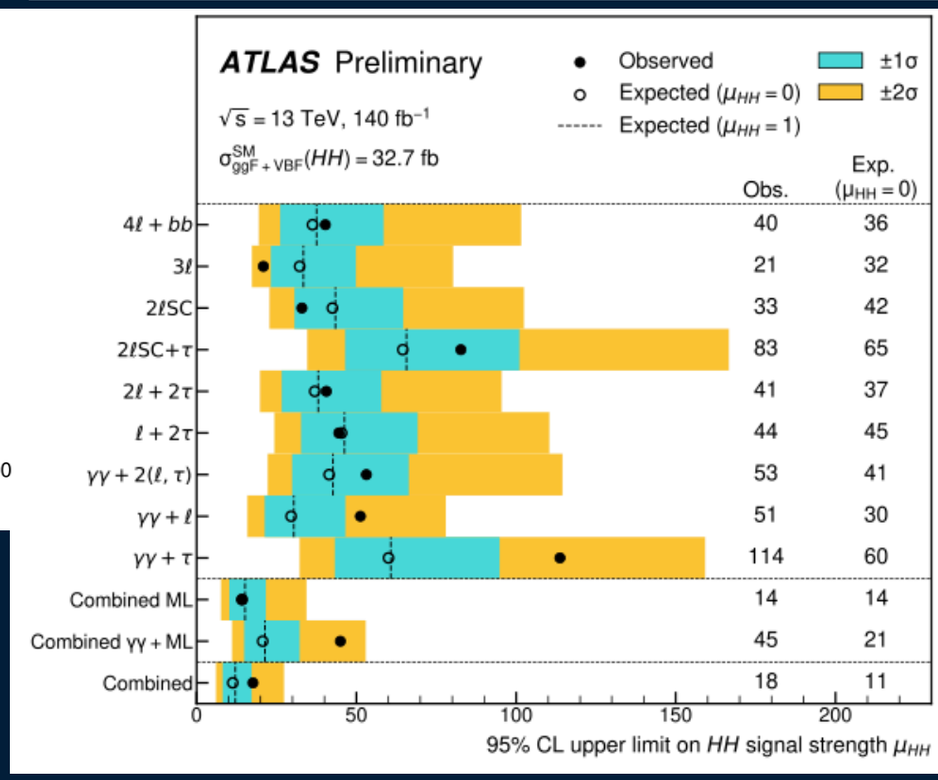
- HH—>$\gamma\gamma\tau\tau$: First dedicated search, observed limit of 33 (26) times the SM
  - Observed (expected) constraint on κ_λ rejects values outside of the interval [–12, 17] ([–9.4, 15]).
  - Also interpreted in new physics models
- ATLAS multilepton [ATLAS-CONF-2024-005]
  - First global search in the multi-lepton channels with combined observed (expected) limit of 18 (11) times the SM
- ATLAS VBF 4b
  - constraints on κ_{2V} greatly improved, with exclusion of $\kappa_{2V} = 0$ with a observed (expected) significance of 3.4σ (2.9σ).
  - Also set limit to resonant VBF models

[ATLAS-CONF-2024-003]

CMS-HIGG-22-012

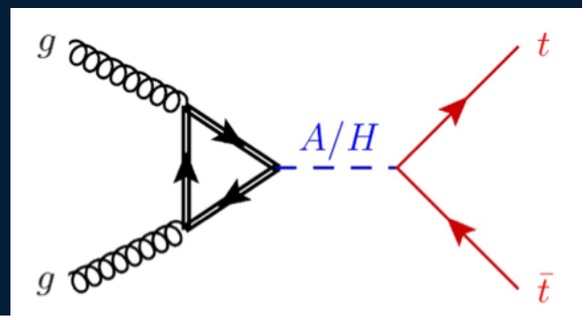




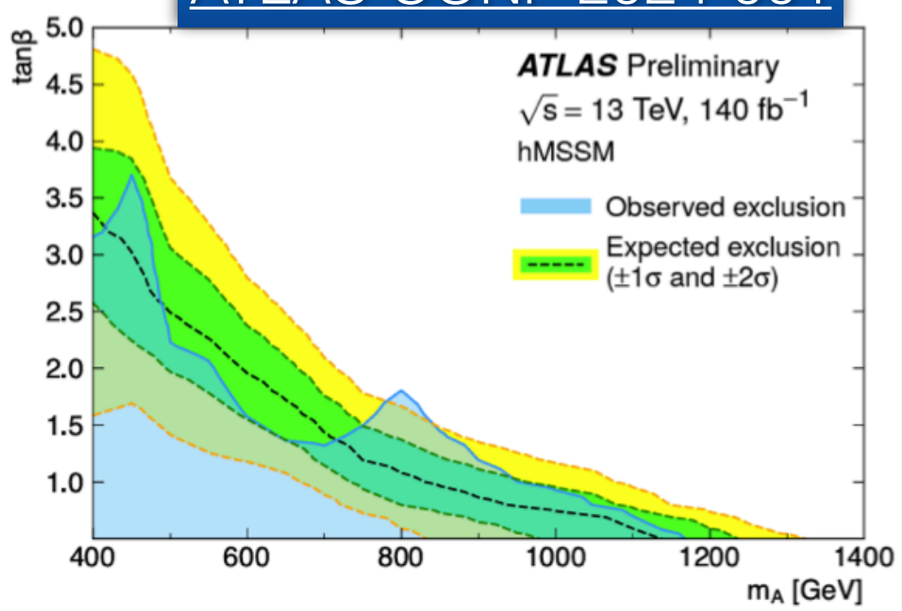


BSM and rare decays of H

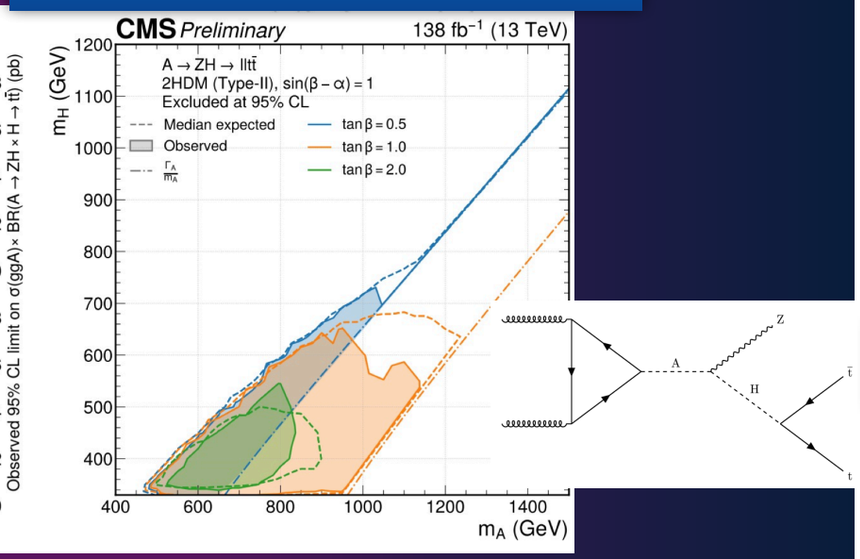
- NEW (CMS) : search for aa—> μμμμ
  - 2017+18 dataset, improves over previous 2016 measurement
  - Also interpreted in BSM scenarios: NMSSM, vector dark portal and dark SUSY
- NEW (ATLAS) : H/A —> ttbar
  - Motivated by 2HDM
  - Small deviation observed at 800 GeV, local significance 2.3σ
- NEW (CMS) : $A \rightarrow ZH \rightarrow llt\bar{t}$
  - No deviation from SM

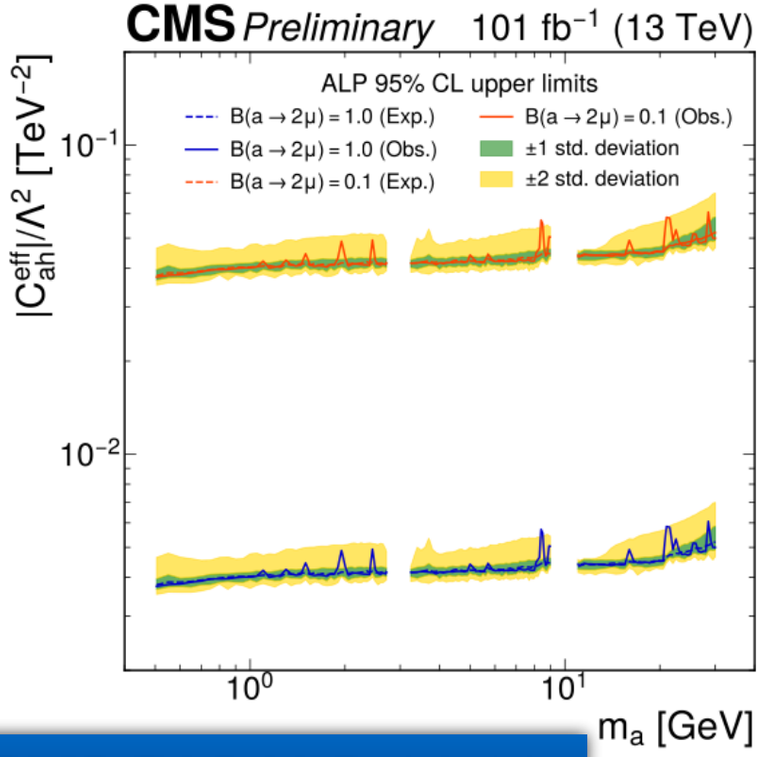


ATLAS-CONF-2024-001



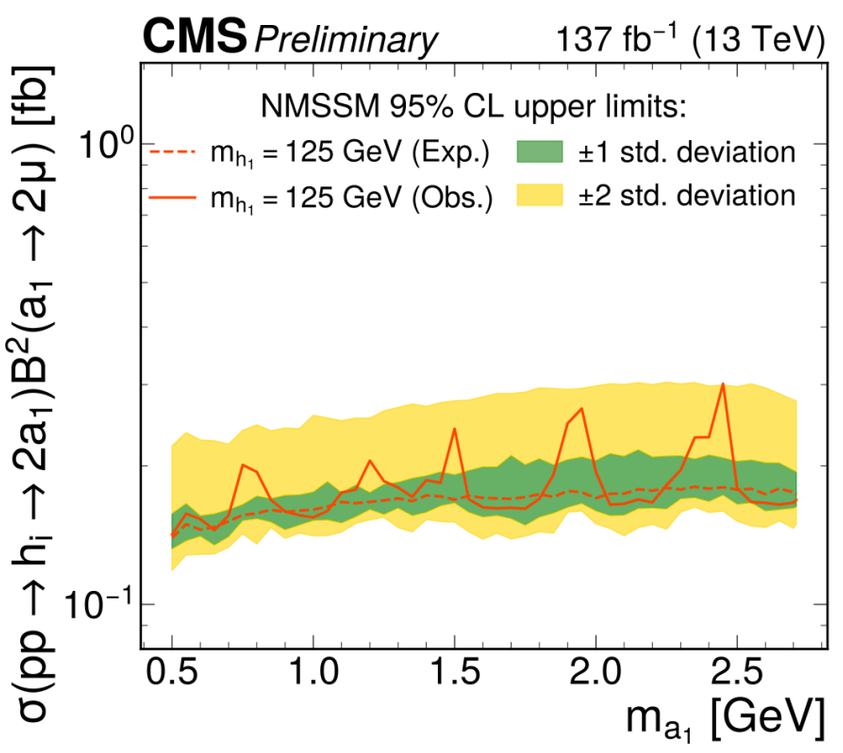
CMS-PAS-B2G-23-006





CMS-PAS-HIG-21-004

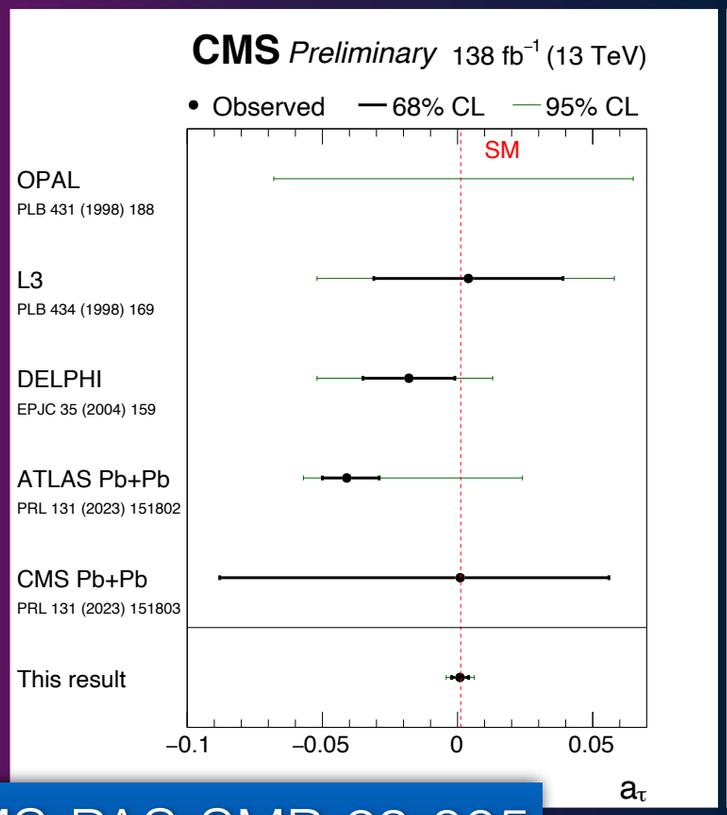
↑ Constraints on the effective coupling of an axion-like particle to the Higgs boson

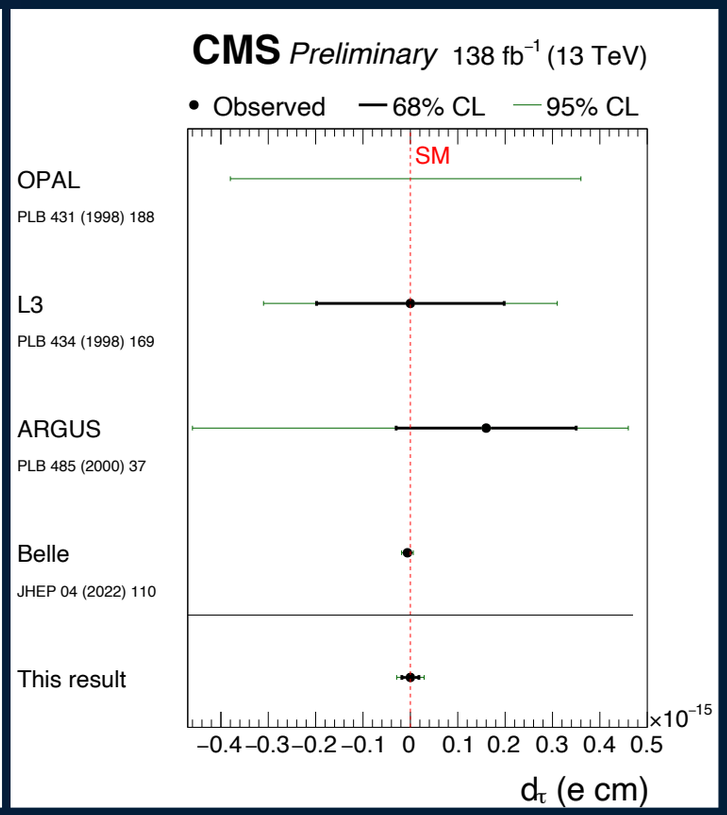


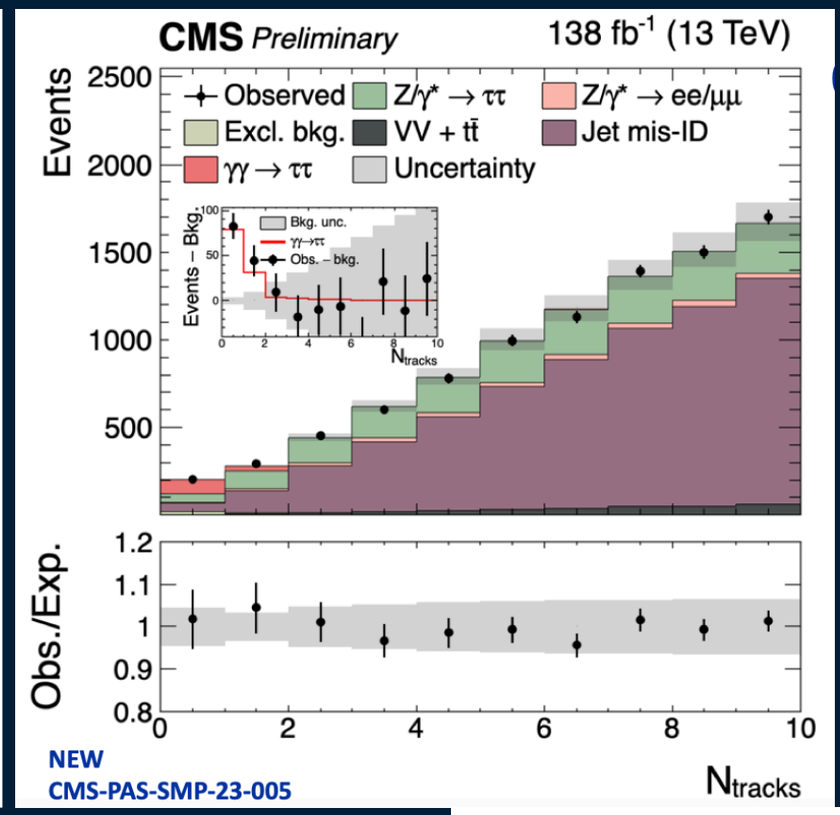
↑ Cross-section times branching fraction constraints in NMSSM interpretation with $m_{h_1} = 125$ GeV

Standard Model

CMS : first observation of $\gamma\gamma \to \tau\tau$ in *pp*



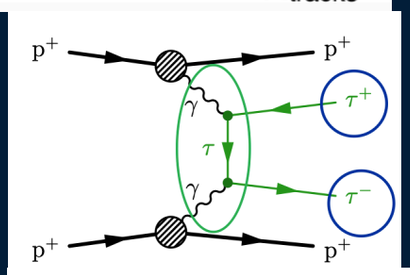


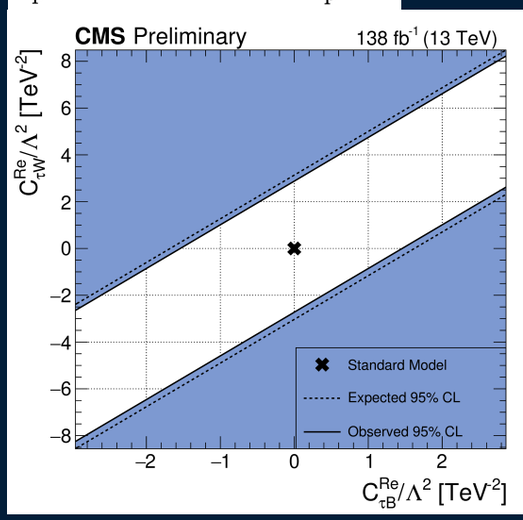


CMS-PAS-SMP-23-005

- 5.3σ observed, 6.5σ expected
- Measuring the photon-lepton interaction is a key way to access the anomalous electromagnetic moment (a_τ : magnetic moment of the spin, d_τ electric dipole moment)
- Extraction of a_τ (τ g-2)
  - Most stringent limit set on both a_τ and d_τ to date: 1σ uncertainty on a_τ is only 3 times the one loop contribution
    - BSM physics parameterized in SMEFT

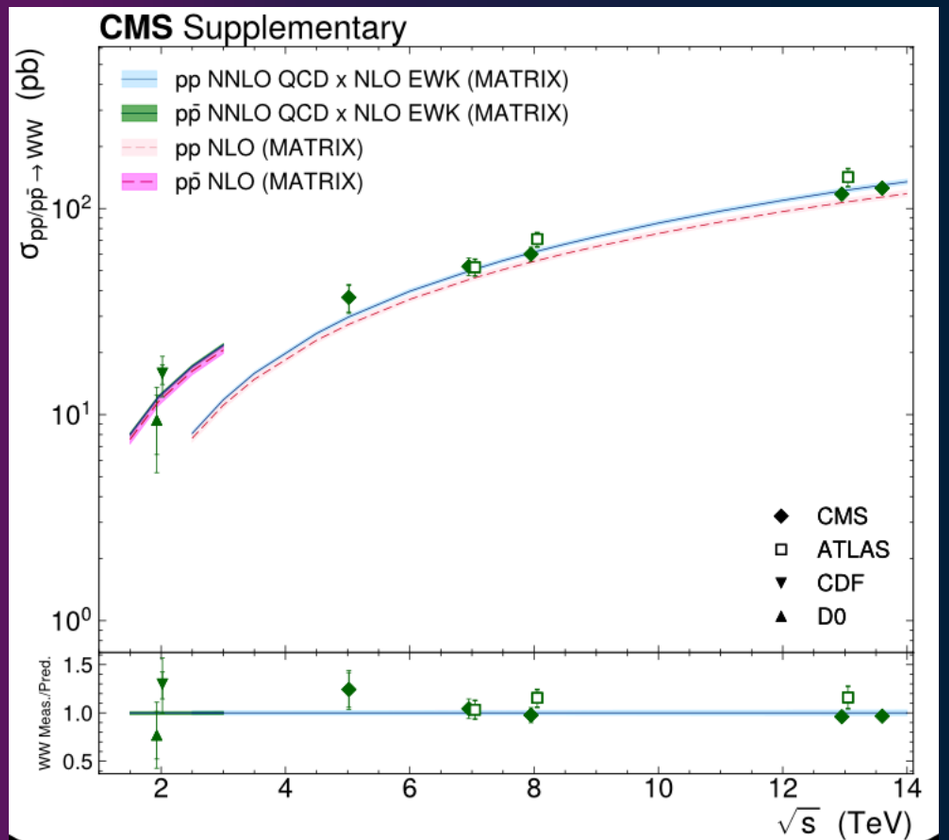
$$\delta a_\tau = \frac{2m_\tau}{e}\frac{\sqrt{2}v}{\Lambda^2}\,\mathrm{Re}\left[C_{\tau\gamma}\right]$$

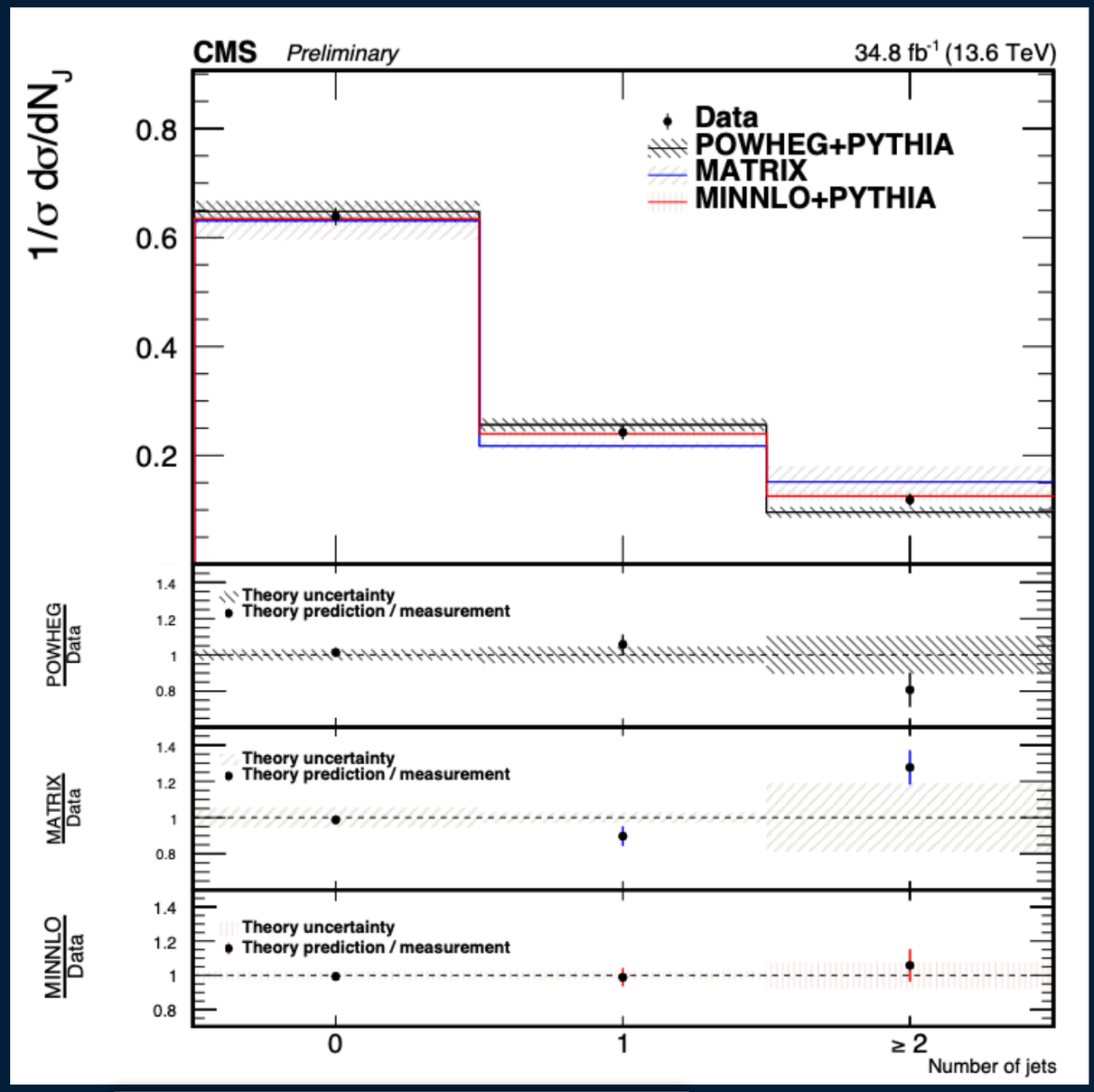




CMS : WW cross-sections at 13.6 TeV

- First measurement of W^+W^- at 13.6 TeV
- • Used data collected in 2022 → 34.8 fb^{-1}
- Event category: 1 muon and 1 electron of opposite charge
- The measured inclusive cross section is 125.7 ± 5.6 pb, in agreement with predictions



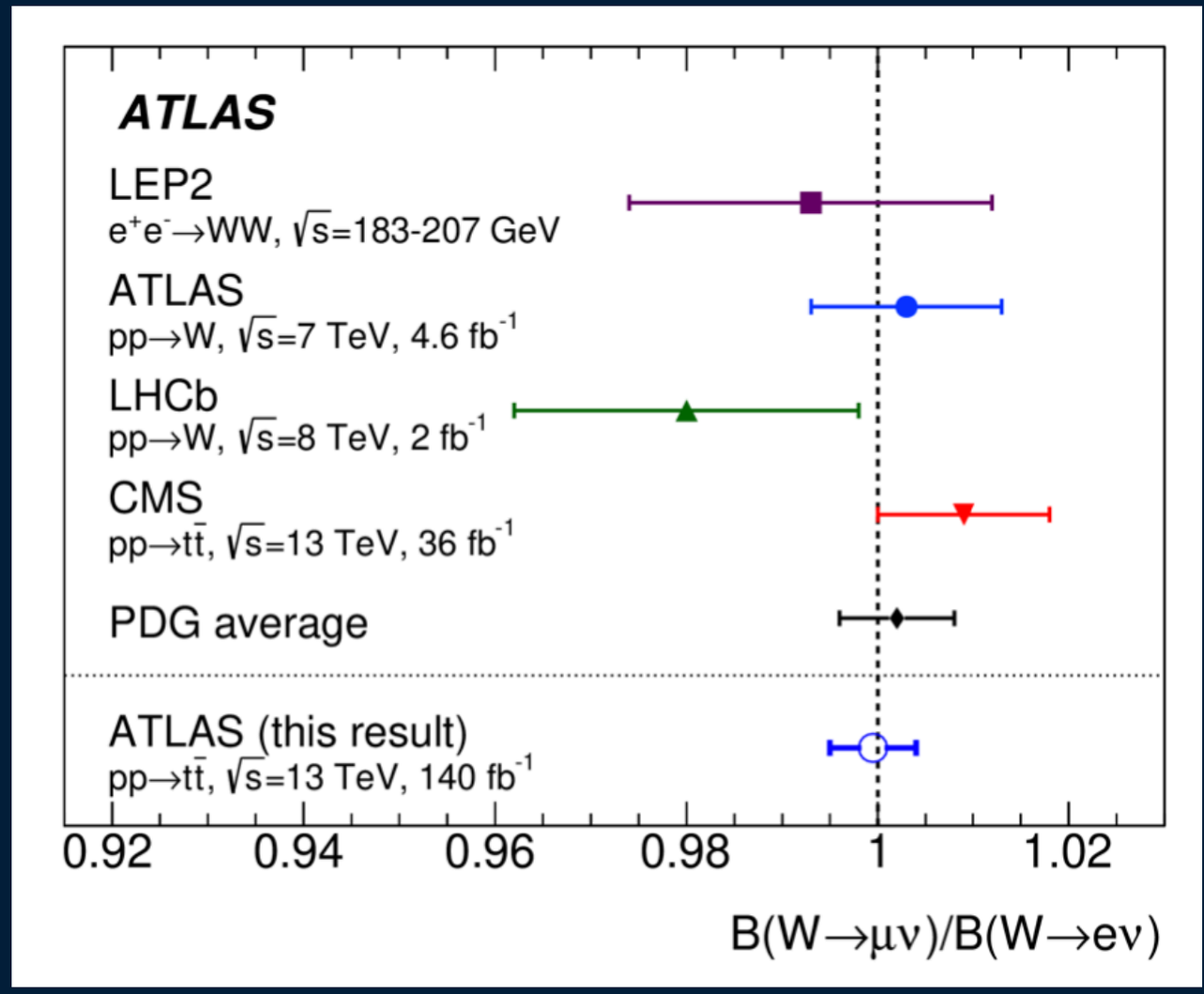


CMS-PAS-SMP-24-001

- First comparison with MiNNLOPS
- Very good agreement with theory

Lepton flavour universality - ATLAS

- W/Z couplings assumed to be independent of mass
  - Violation of lepton flavor universality —> sign of BSM physics
  - Measured through ratio of W-> ℓν decay rates (ℓ = e, μ) in ttbar events
- Experimental measurement uses ratio of W to Z cross-sections to allow better cancellation of uncertainties
  - W in ttbar decays (2 dileptonic decay channels)
  - Z events (same flavour)
  - Likelihood fit to extract the ratio
  - Leading uncertainties : PDF, fake leptons, lepton uncertainties and Z modelling
- Multiply by precise LEP/SLD Z cross-section



$$R_W^{\mu/e}(\mathrm{ATLAS}) = R_{WZ}^{\mu/e}(\mathrm{ATLAS}) \cdot \sqrt{R_Z^{\mu\mu/ee}(\mathrm{LEP+SLD})}$$

arXiv:2403.02133

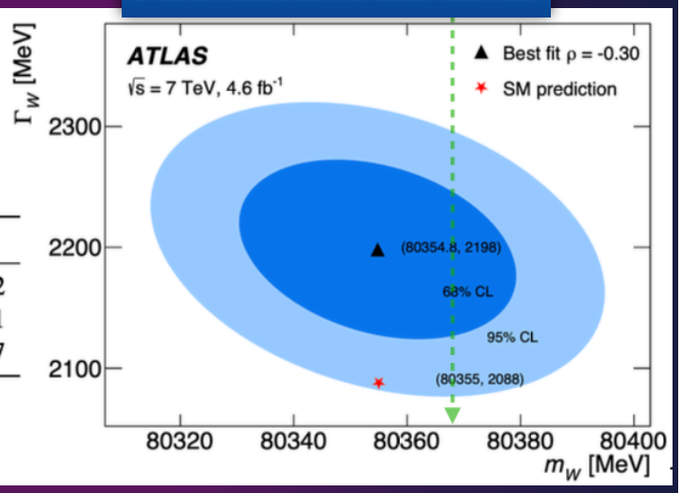
- relative uncertainty of 0.45 %
- most precise single measurement to date, also more precise than previous PDG average

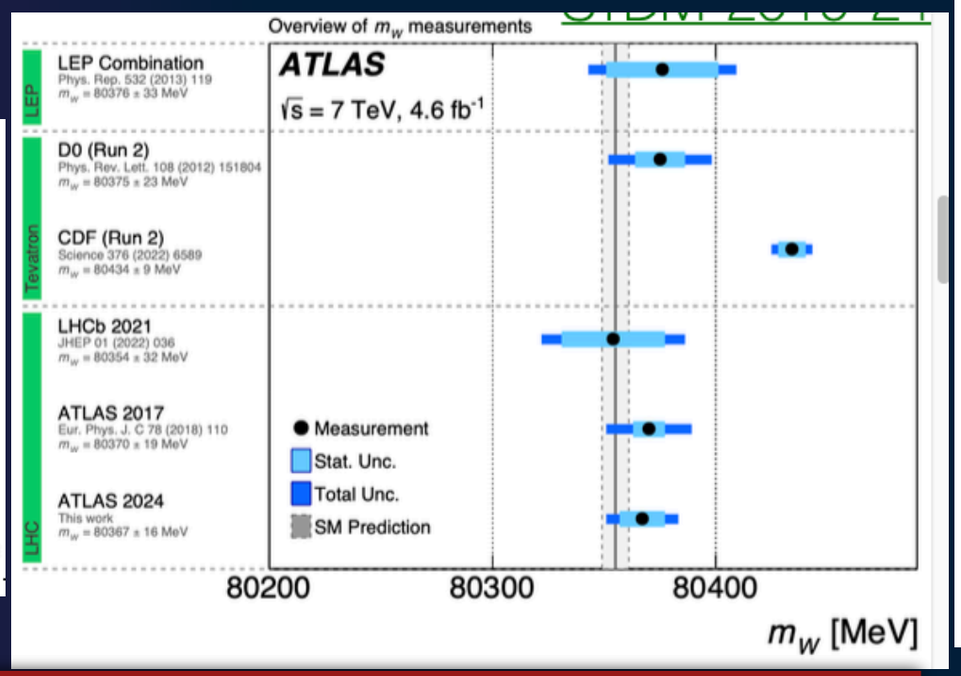
Rμ/e (ATLAS) = 0.9995 ± 0.0022 (stat.) ± 0.0036 (syst.) ± 0.0014 (LEP+SLD)

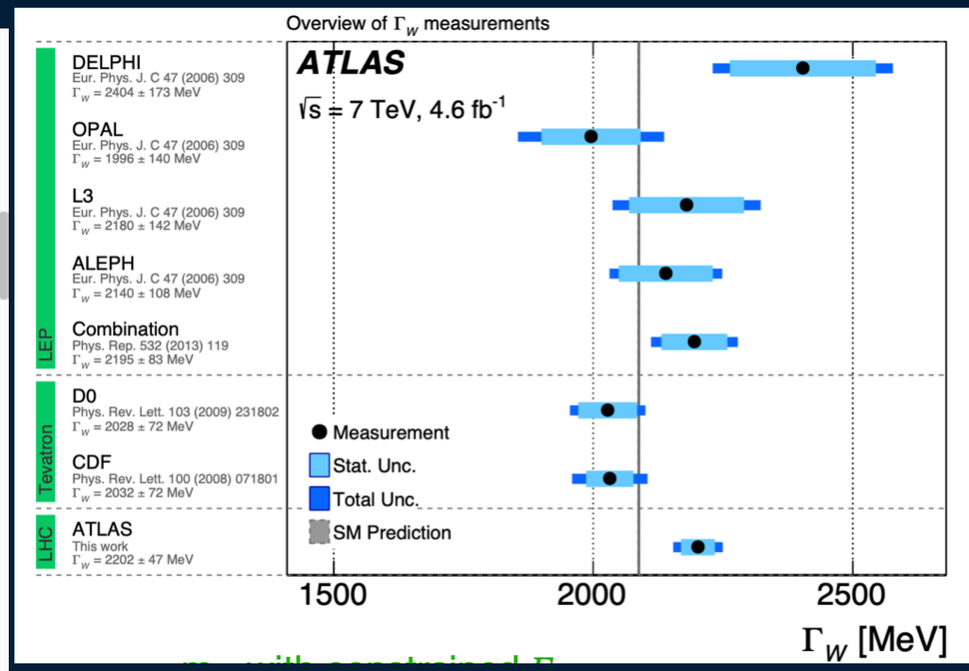
m_W and Γ_W - ATLAS

- Fundamental parameter of SM limiting in precision for the comparison to theory predictions (global EW fit)
- Also need to understand the disturbing tension with latest CDF measurement —> more precision is needed by other experiments
- Result was preliminary for LHCP 2023, now submitted, re-analysis of 2018 result, using 2011 Run1 data taken at 7 TeV

STDM-2019-24







$$\Gamma_W = 2202 \pm 32\ (\text{stat.}) \pm 34\ (\text{syst.})\ \text{MeV} = 2202 \pm 47\ \text{MeV}$$

$$m_W = 80366.5 \pm 15.9\ \text{MeV}$$

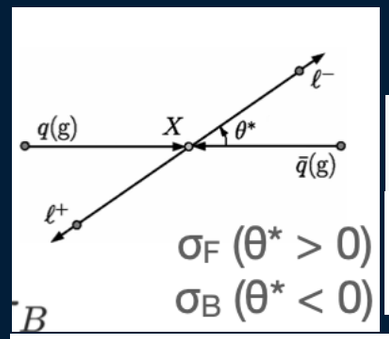
Uncertainties on Γ_W

Unc. [MeV]	Total	Stat.	Syst.	PDF	A_i	Backg.	EW	e	μ	u_T	Lumi	m_W	PS
p_T^ℓ	71.8	27.3	66.4	21.2	13.9	10.4	4.9	13.2	11.5	12.0	9.6	6.3	55.2
m_T	47.5	35.5	31.6	4.9	6.6	9.6	3.3	13.2	9.2	17.6	9.1	5.5	12.1
Combined	46.8	32.0	34.1	6.7	7.5	9.4	3.3	13.1	9.4	16.7	9.1	5.6	17.7

- Improvements on several fronts, mainly
  - **Updated PDFs**
  - **Use of profile likelihood fit**
- Also includes measurement of **W width, first at LHC**

$\sin^2\theta_W$ - CMS

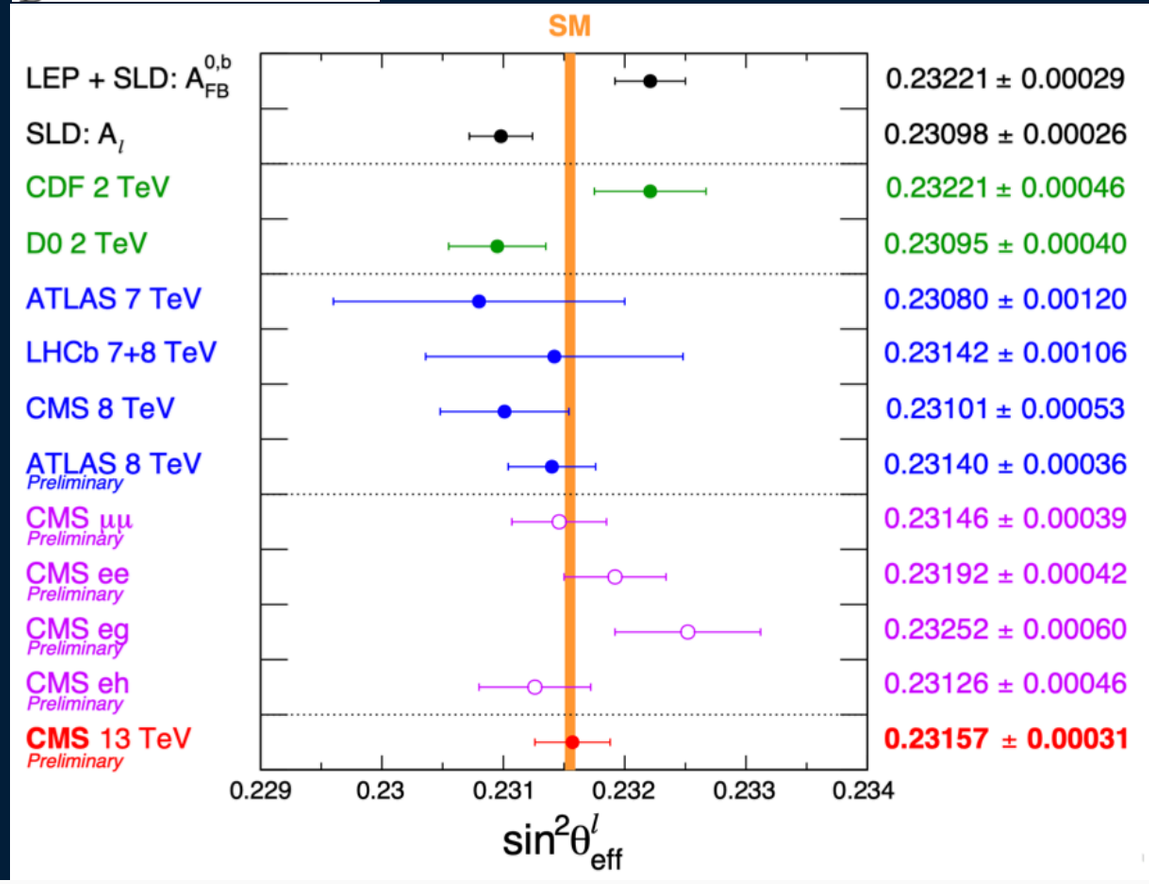
- Weak mixing angle is an SM parameter of paramount importance
- Best (preliminary) result of WMA in a hadron collider !!
  - Measure $\sin^2\theta_{\ell,\,\mathrm{eff}}$ through forward-backward asymmetry (A_{FB}) of leptons in Z events, in mass and rapidity bins
- Includes electrons outside of tracking/only in forward calorimeter (h)
  - |η| acceptance up to 4.36, increase sensitivity to AFB
- PDF uncertainty dominates
- Four ℓℓ channels : μμ, ee, eg, eh
  - μ : |eta| < 2.4
  - e : |eta| < 2.5
  - g : EF electron 2.5 < |eta| < 2.87
  - h : HF electron 3.14 < |eta| < 4.36

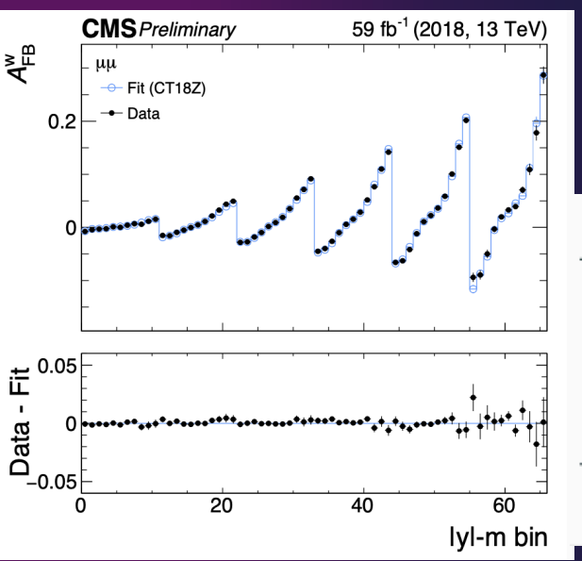


CMS-SMP-22-010

$$\sin^2\theta^{\ell}_{\mathrm{eff}} = (1 - m^2_{\mathrm{W}}/m^2_{\mathrm{Z}})\kappa^{\ell}$$

$$A_{\mathrm{FB}} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$



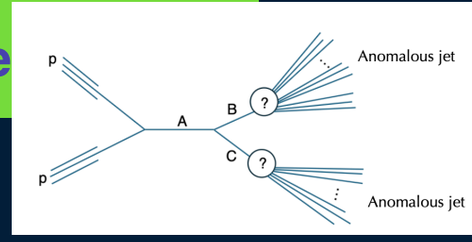


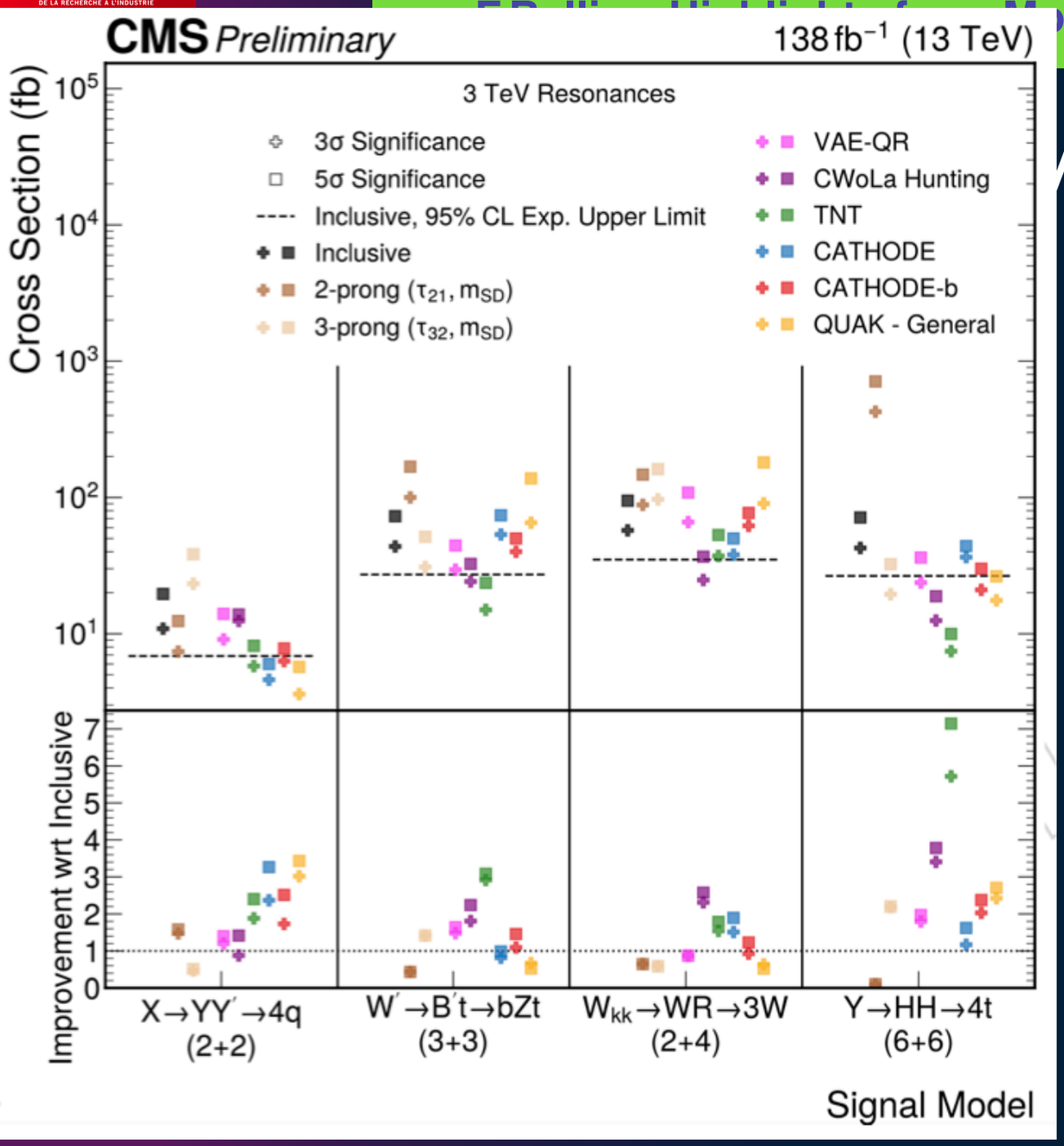
ch	χ^2	nbin	p(%)	$\sin^2\theta^{\ell}_{\mathrm{eff}}$	±	σ	stat	exp	theo	pdf	mc	bkg	eff	calib	other
$\mu\mu$	241.3	264	82.7	23146	±	38	17	17	7	30	13	3	2	5	4
ee	256.7	264	59.8	23176	±	41	22	18	7	30	14	4	5	3	7
eg	119.1	144	92.8	23257	±	61	30	40	5	44	23	11	12	19	9
eh	104.6	144	99.3	23119	±	48	18	33	9	37	14	10	16	18	6
$\ell\ell$	730.7	816	98.4	23157	±	31	10	15	9	27	8	4	6	6	3

BSM

CMS-PAS-EXO-22-026

...y detection



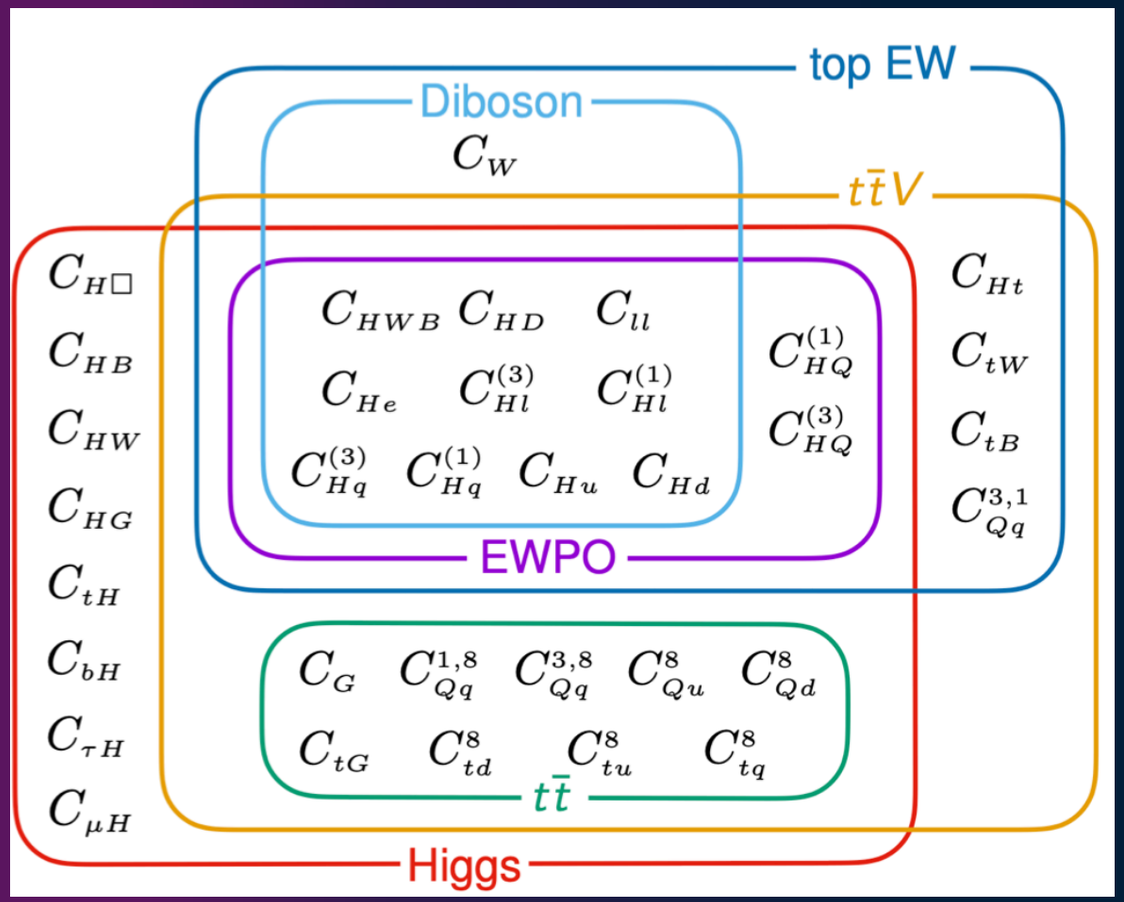


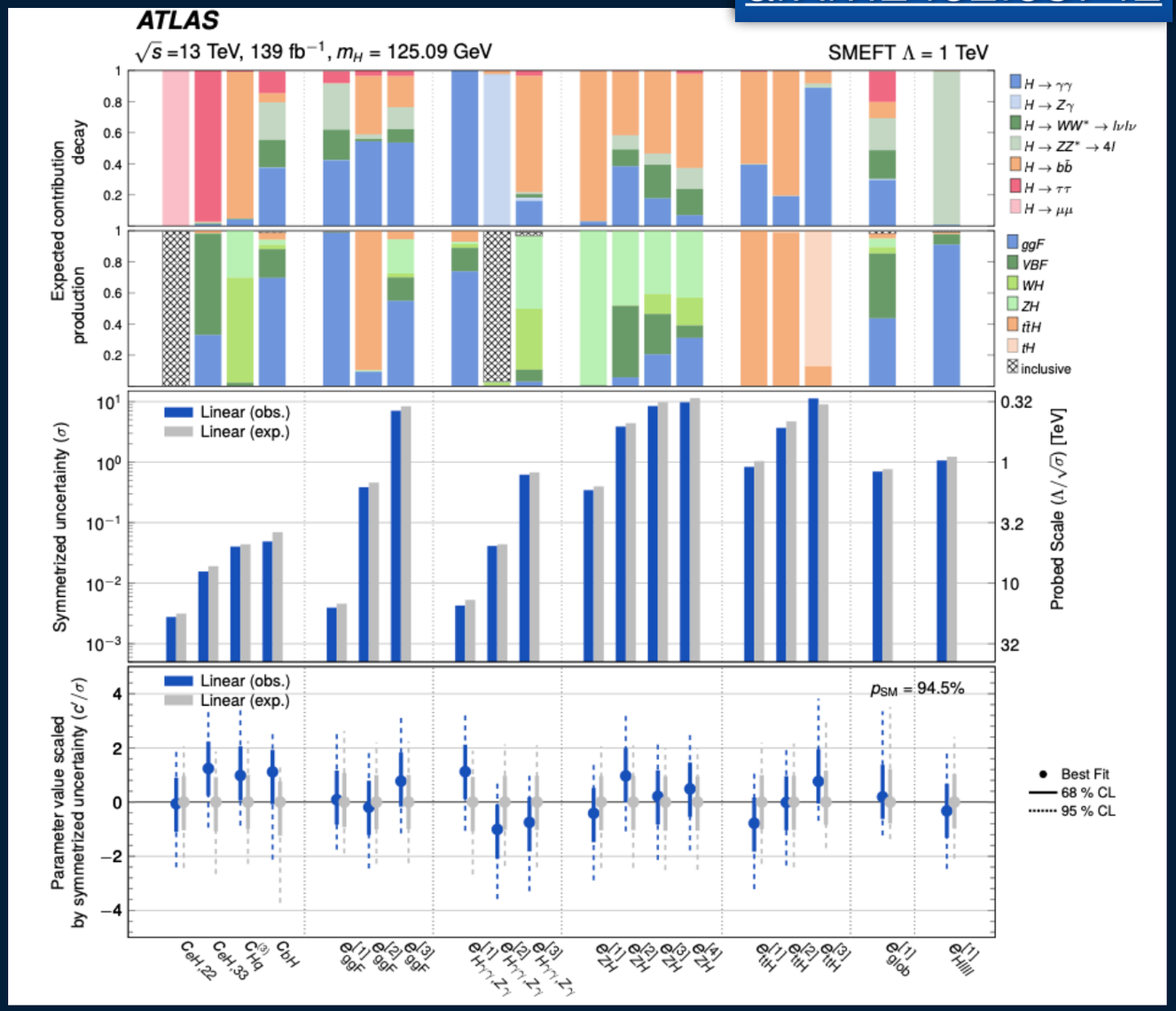
- The ranking metric is defined as the minimal value of the cross section of the injected signal to cross the 3/5 σ significance.
- All methods almost always better than inclusive / traditional search strategy!

Model dependence

- **Unsupervised**: learn to understand regular jets → look for outliers
  - Auto-Encoders (VAE with Quantile Regression).
- **Weakly supervised**: try to separate 2 groups of jets → learn to identify signals
  - Classification Without Labels (CWoLa)
  - Tag N' Train (TNT)
  - Classifying Anomalies Through Outer Density Estimation (CATHODE)
- **Semi-supervised**: encode a 'prior' of potential signals → look for similar
  - Quasi Anomalous Knowledge (QUAK).
- Obtain comparison of sensitivity of different methods against more classical methods
  - inclusive search (i.e. no jets selection)
  - selection on jet 2-prong observable
  - selection on jet 3-prong observable

EFT in ATLAS and CMS





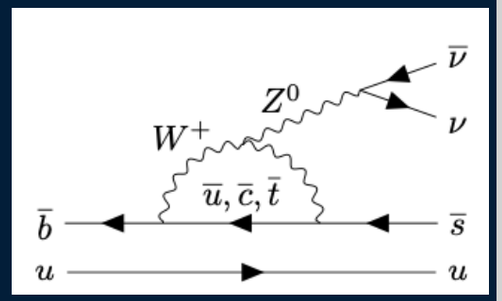
arXiv:2402.05742

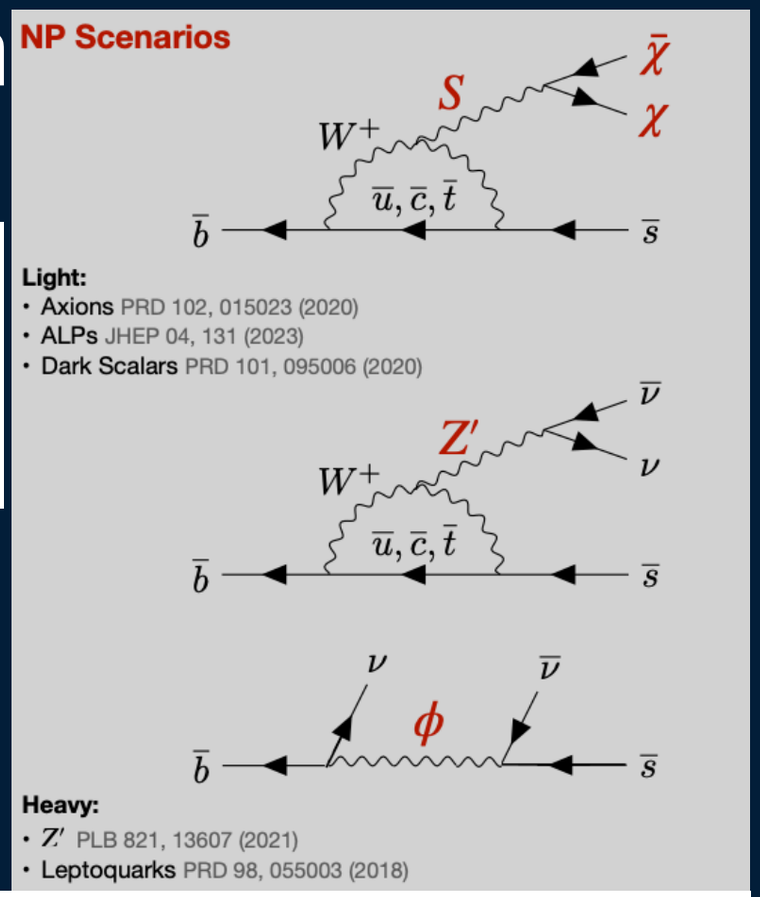
- Try to constrain higher dimensional operators from all available data
  - New physics could be at such a high energy scale that we cannot see the new resonances at the LHC, but still impact observables at lower energies —> Parametrise with operators of dimension n, Wilson coefficients and energy scale of NP
- Example : Combined Higgs fit
  - p-value of compatibility between data and SM is 94.5%
- Other recent measurements interpreted in EFT —> no deviation from SM

Flavour

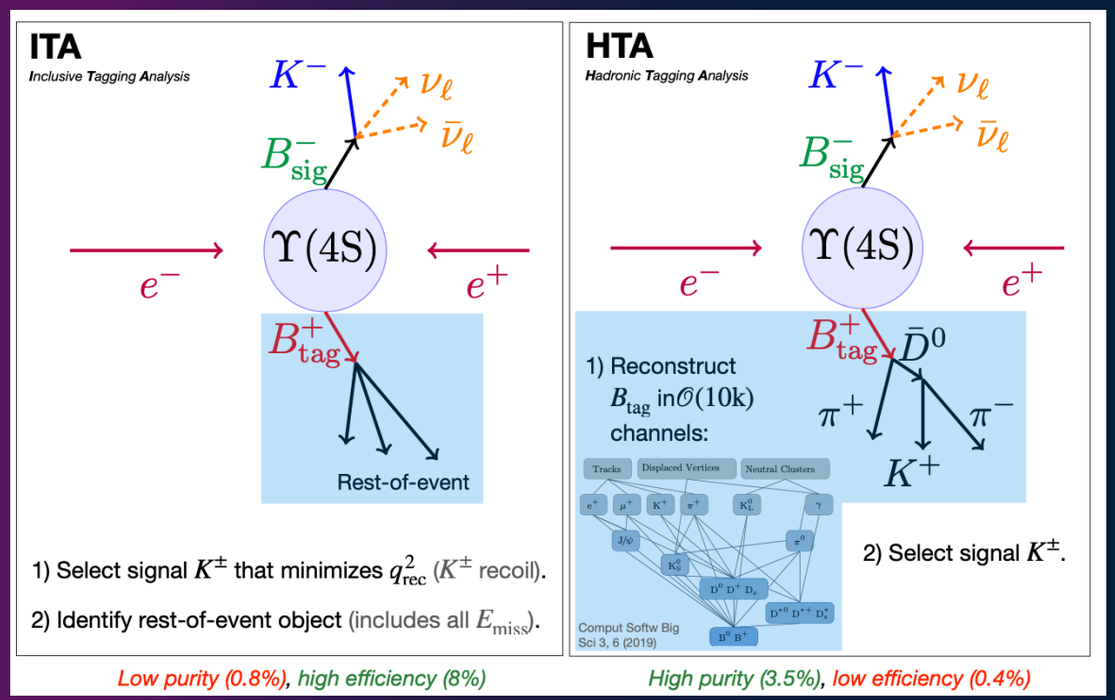
Radiative and electroweak penguin (Belle/Belle II)

- Search for the rare decay $B^+ \to K^+ \nu\bar{\nu}$
  - b-> sll suppressed by GIM mechanism
- Combine 2 complementary analyses (ITA/HTA)
  - Combined: 2.7σ deviation from SM



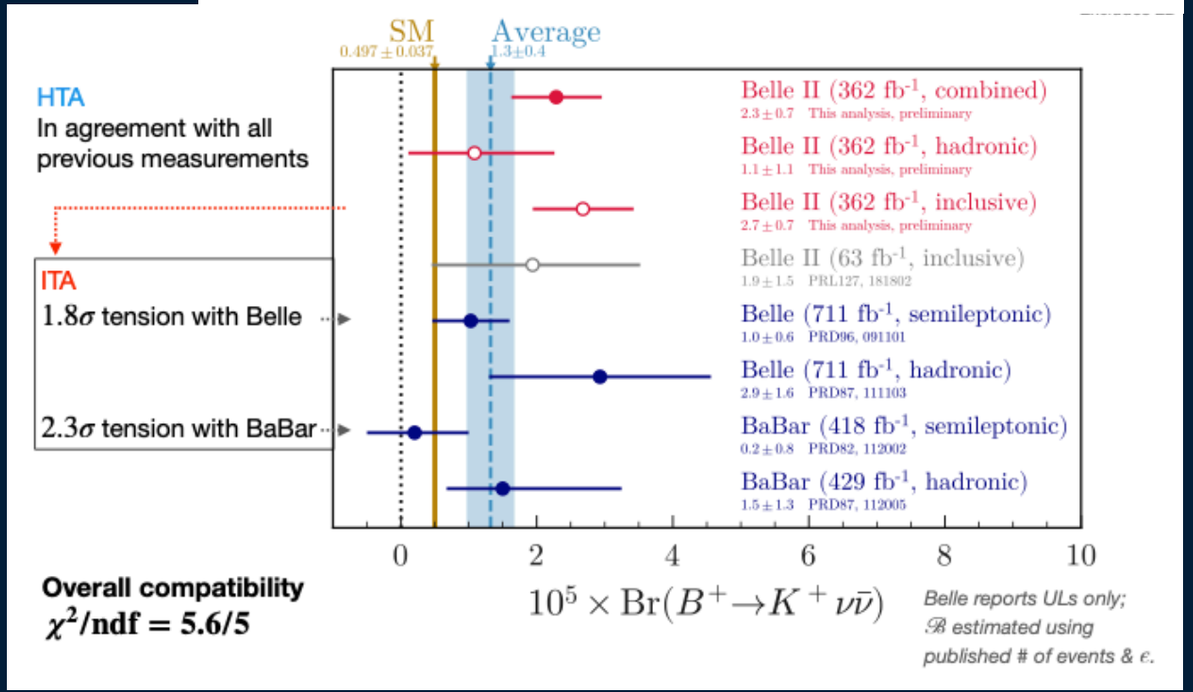


- Very active effort within Belle II to provide results for other channels
- Also plan to use of Belle data (large statistics)



ITA
- $\mathcal{B} = [2.7 \pm 0.5 \pm 0.5] \times 10^{-5}$
- Significance of the excess 3.5σ
- 2.9σ deviation from SM

HTA
- $\mathcal{B} = [1.1^{+0.9+0.8}_{-0.8-0.5}] \times 10^{-5}$
- Significance of the excess 1.1σ
- 0.6σ deviation from SM



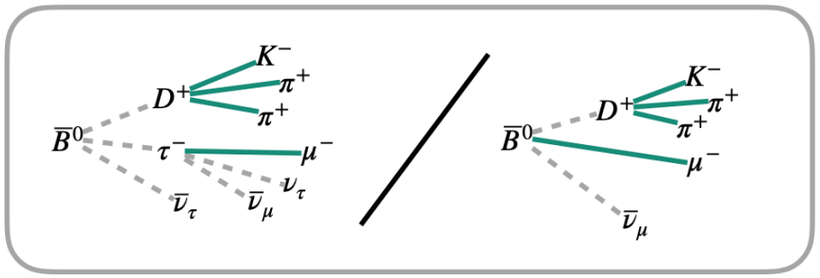
R(D+) & R(D*+) in LHCb

- Lepton flavour universality ratios : test consists in well defined experimental and theoretical set of measurements that shows some tensions between the tau and muonic decays of B-hadrons
  - Analyses are focusing on D-mesons as a 3.34σ tension with SM exists
- Potential physics beyond the Standard Model (BSM) affecting semi-tauonic decays
- LHCb introduced a new analysis focussing on the D^+ ground state:
  - First time that this state is probed !
  - Only relying on 2 fb^{-1} at the moment
  - Tension with SM goes down to 3.17σ

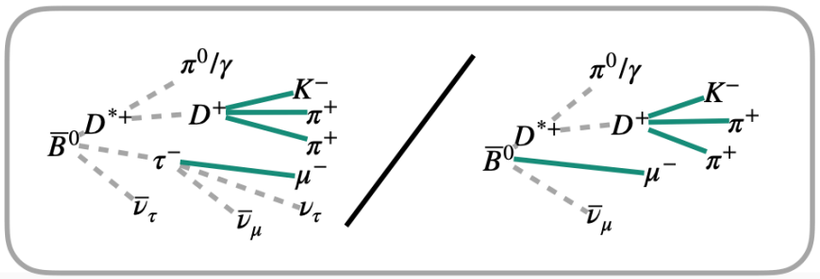
[LHCb preliminary]

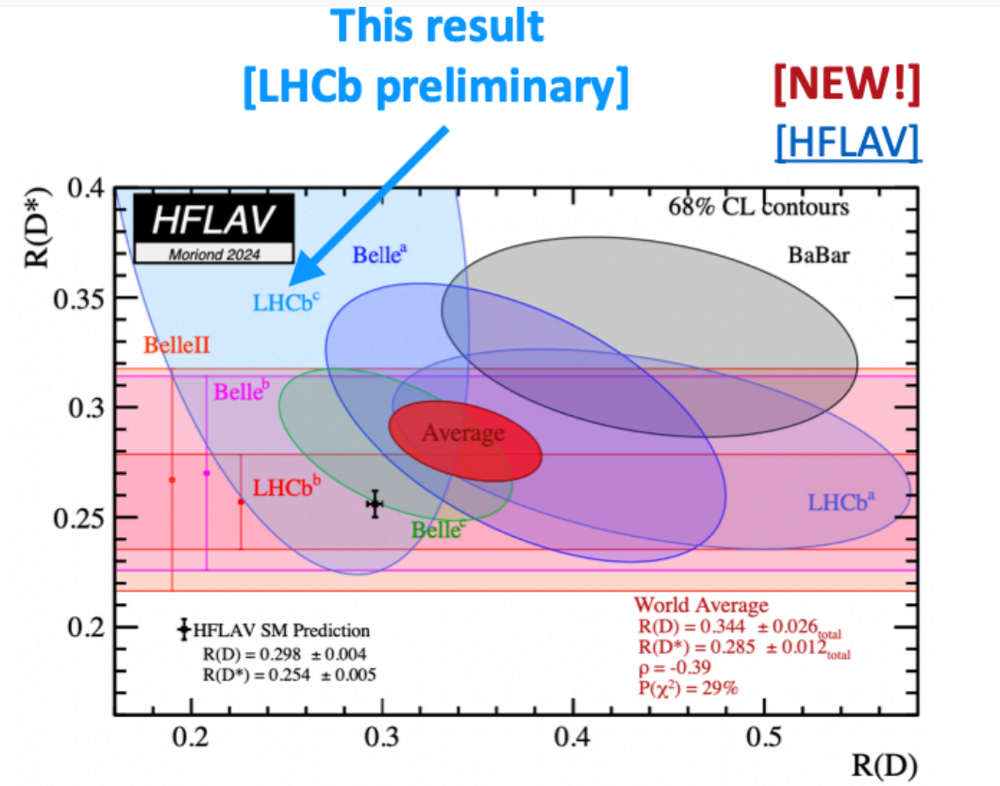
$$R(D^+) = 0.249 \pm 0.043(stat) \pm 0.047(syst)$$
$$R(D^{*+}) = 0.402 \pm 0.081(stat) \pm 0.085(syst)$$
$$\rho = -0.39$$

R(D+) =



R(D*+) =



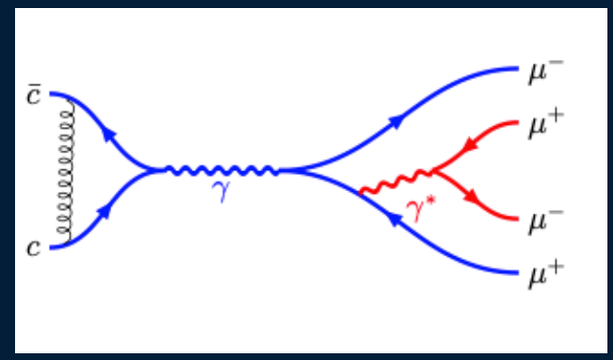


New World Average.

Tension with SM at the level of **3.17 σ**.

LHCb-PAPER-2024-007 (in preparation)

Observation of J/$\psi \rightarrow 4\mu$

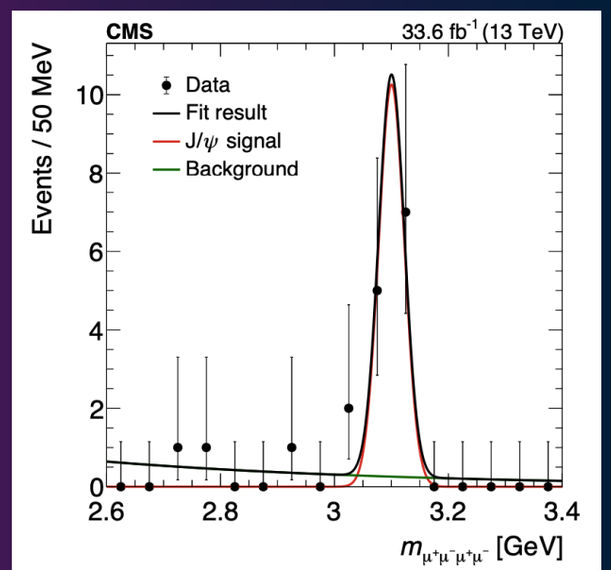


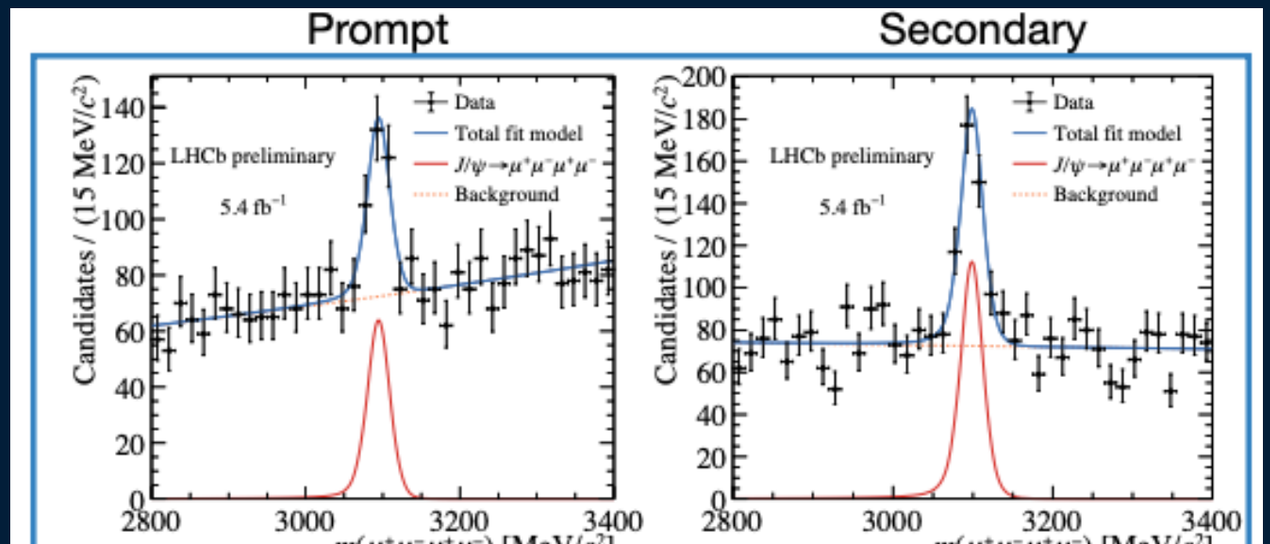
- The study of J/ψ into 4 leptons is a unique test of EW physics with heavy quarks:
  - The SM prediction is rather small: $\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-) = (9.74 \pm 0.05) \times 10^{-7}$
  - It could involve some new physics to enhance this ratio
  - A first result from BESIII (PRD 109, 052006 (2024)) already measured the final states in 4 e and 2 e / 2 μ
    - An upper limit was set on $\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-) < 16 \times 10^{-7}$
  - At Moriond EW, CMS showed the first observation, fitting simultaneously the 2 μ and 4 μ decays:
    - Significance > 7 σ
    - $\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-) = (10.1^{+3.3}_{-2.7} \pm 0.4) \times 10^{-7}$

CMS-BPH-22-006

- Less than a week later LHCb also showed its result at Moriond QCD. Similar strategy as CMS but also exploits secondary decays from B-hadrons :
  - Significance >> 5 σ
  - $\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-\mu^+\mu^-) = (11.3 \pm 1.0 \pm 0.5 \pm 0.1) \times 10^{-7}$

LHCb-CONF-2024-001





Summary

- Large amount of new results
  - Unfortunately no strong sign of deviation w.r.t. SM predictions
    - ‘The chase is better than the catch’ (Motörhead)
- Very interesting theory talks, sometimes accessible to experimentalists
  - e.g. Asymptotic unification of gauge and Yukawa couplings, A. De Andrea
- See full programmes at:
  - EW: https://indico.in2p3.fr/event/32664/timetable/?view=standard_numbered
  - QCD: https://moriond.in2p3.fr/2024/QCD/Program.html