Precision Electroweak Measurements in CMS

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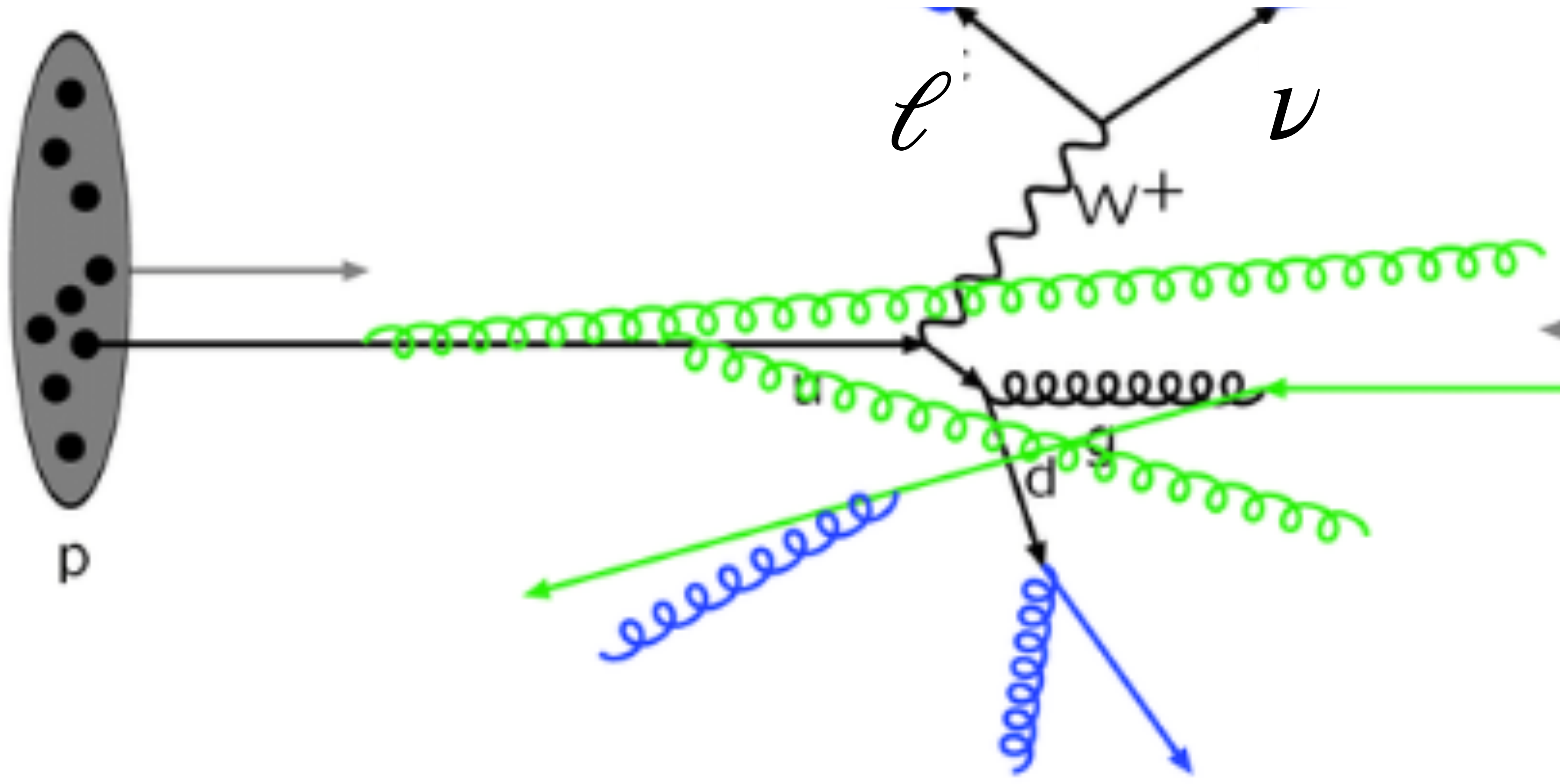
On behalf of CMS Collaboration

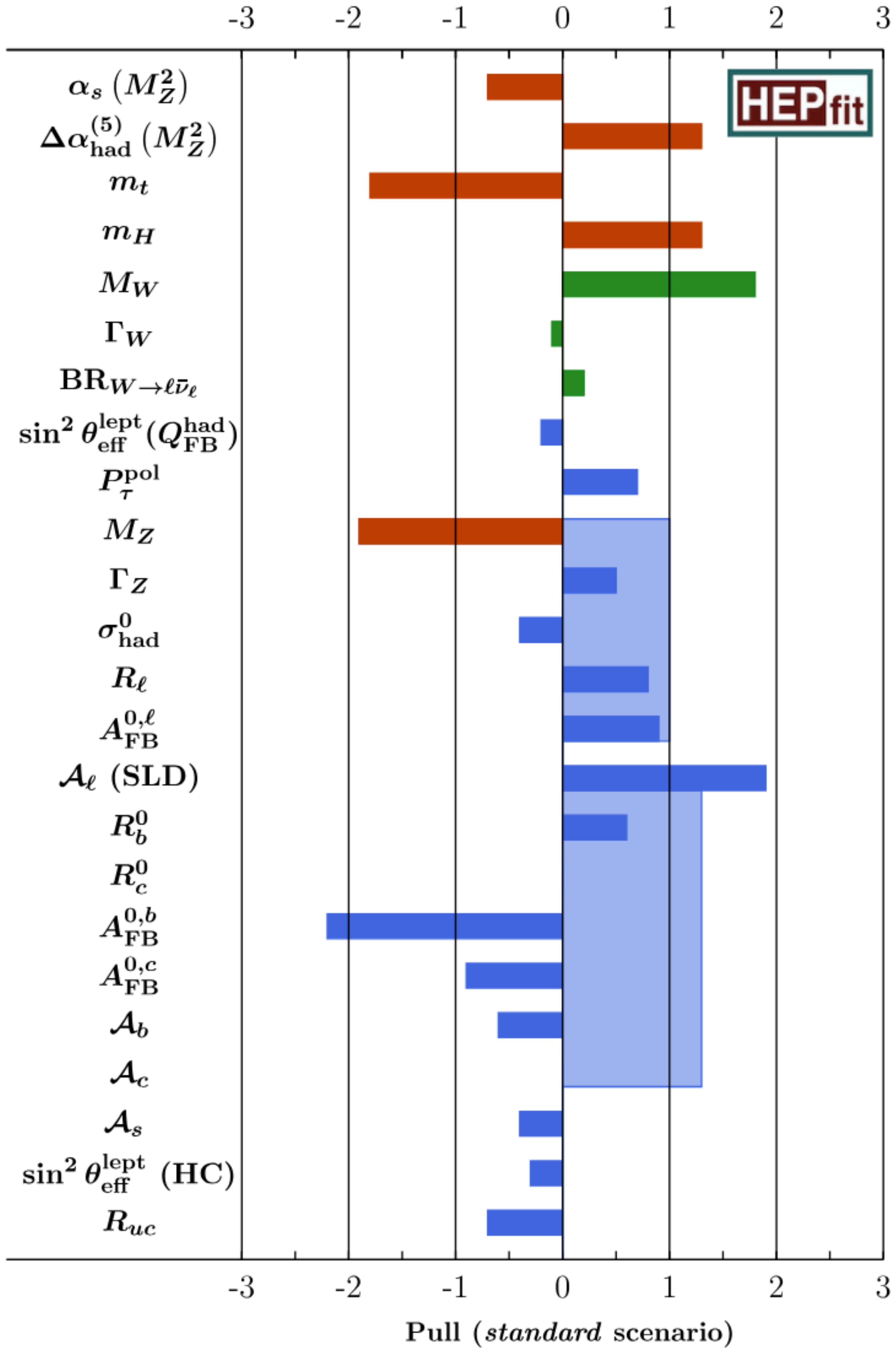
LHCP 2024 @ Boston

June 4th, 2024

Introduction

[Phys. Rev. D 106, 033003]





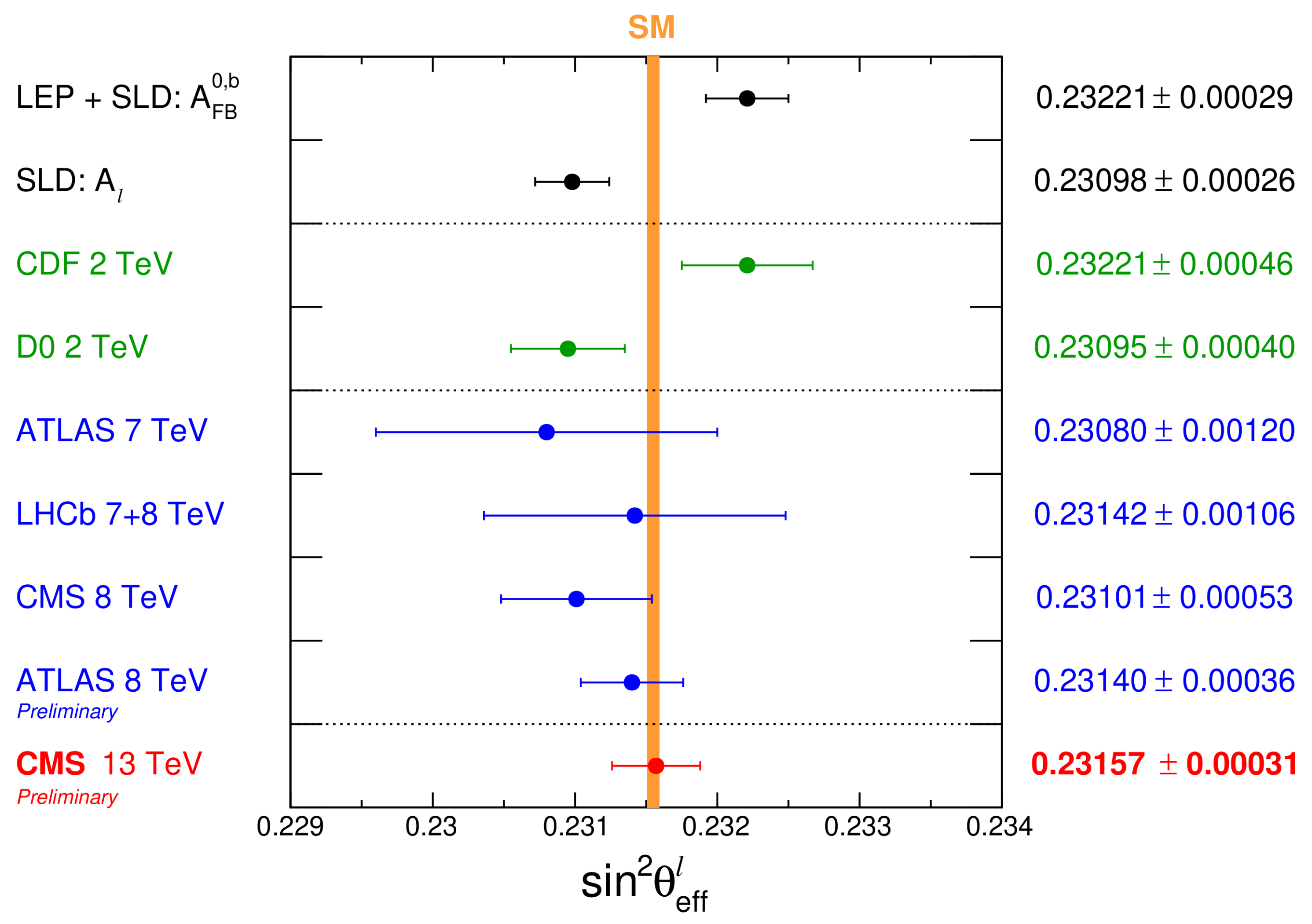
Precision standard model measurements =

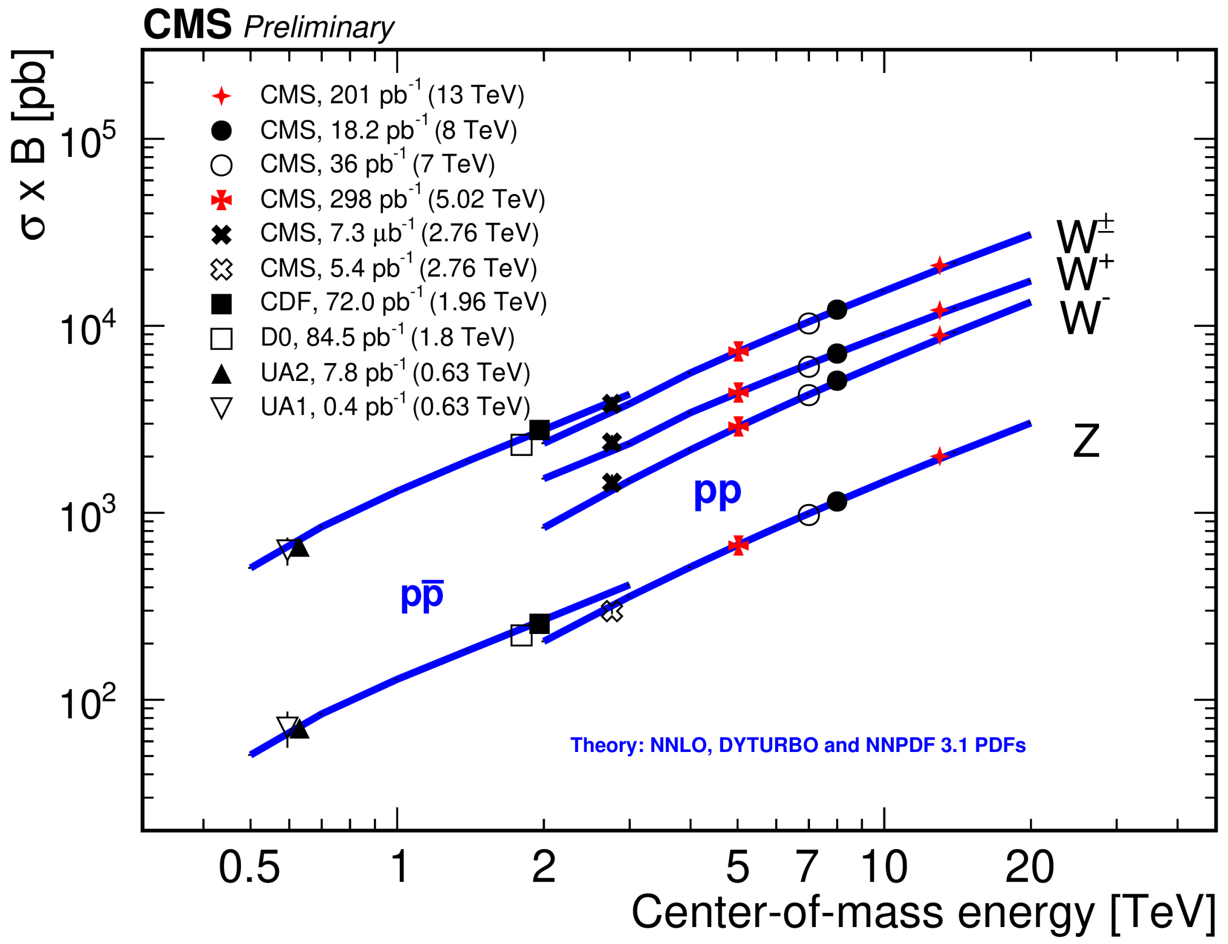
- Make full usage of the statistics collected to understand better experiment and theory
- indirect searches for new physics, with sensitivity reaches to higher energy scales better than direct new physics searches

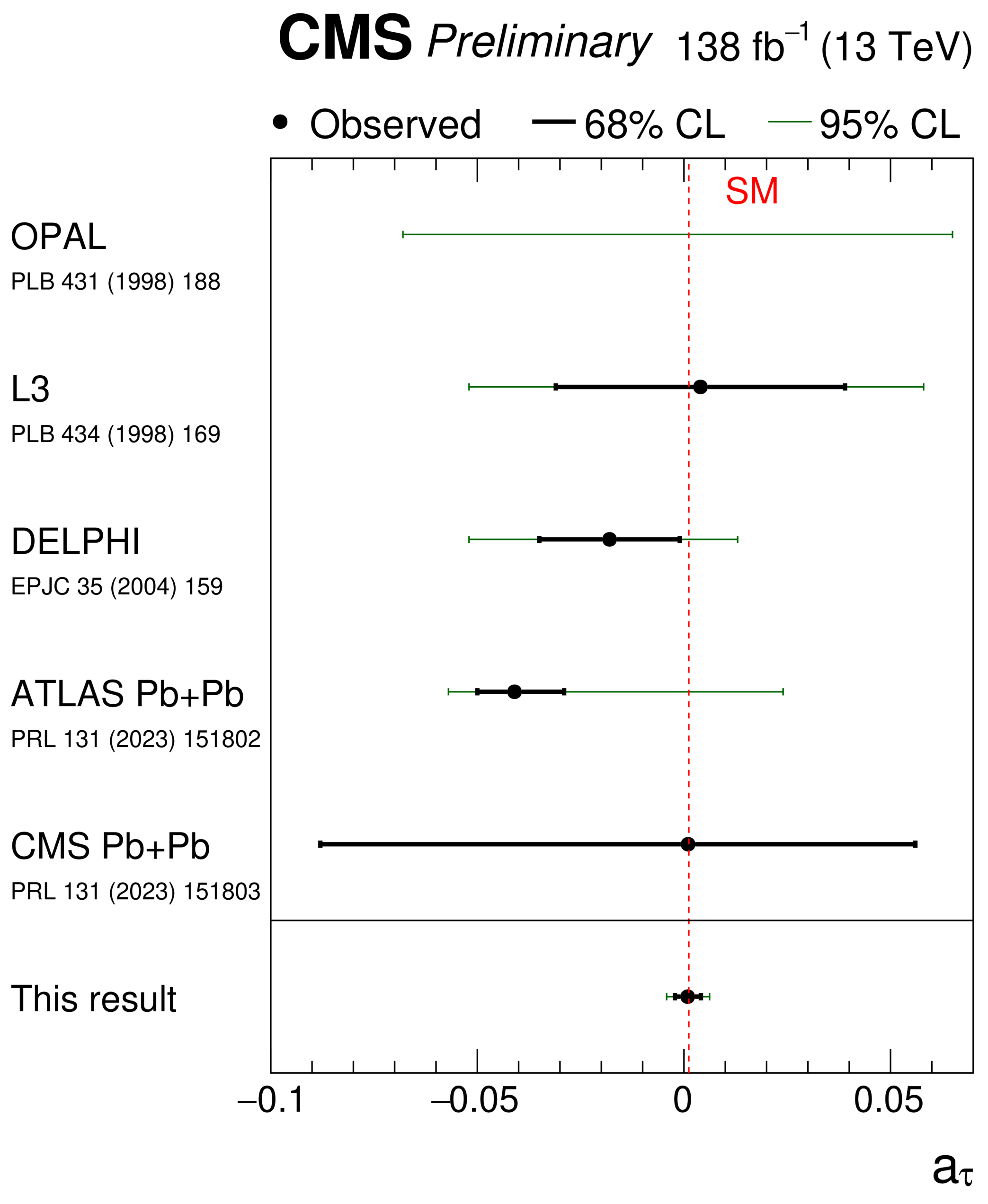
Overview

Covered in this talk:

- CMS-PAS-SMP-22-010 Drell-Yan forward-backward asymmetry and effective weak mixing angle
- CMS-PAS-SMP-20-004 W and Z production cross sections at 5.02TeV and 13TeV
- CMS-PAS-SMP-22-017 Z production cross sections at 13.6TeV
- CMS-PAS-SMP-23-005 GamGam -> TauTau and limits on tau g-2







Effective Weak Mixing Angle

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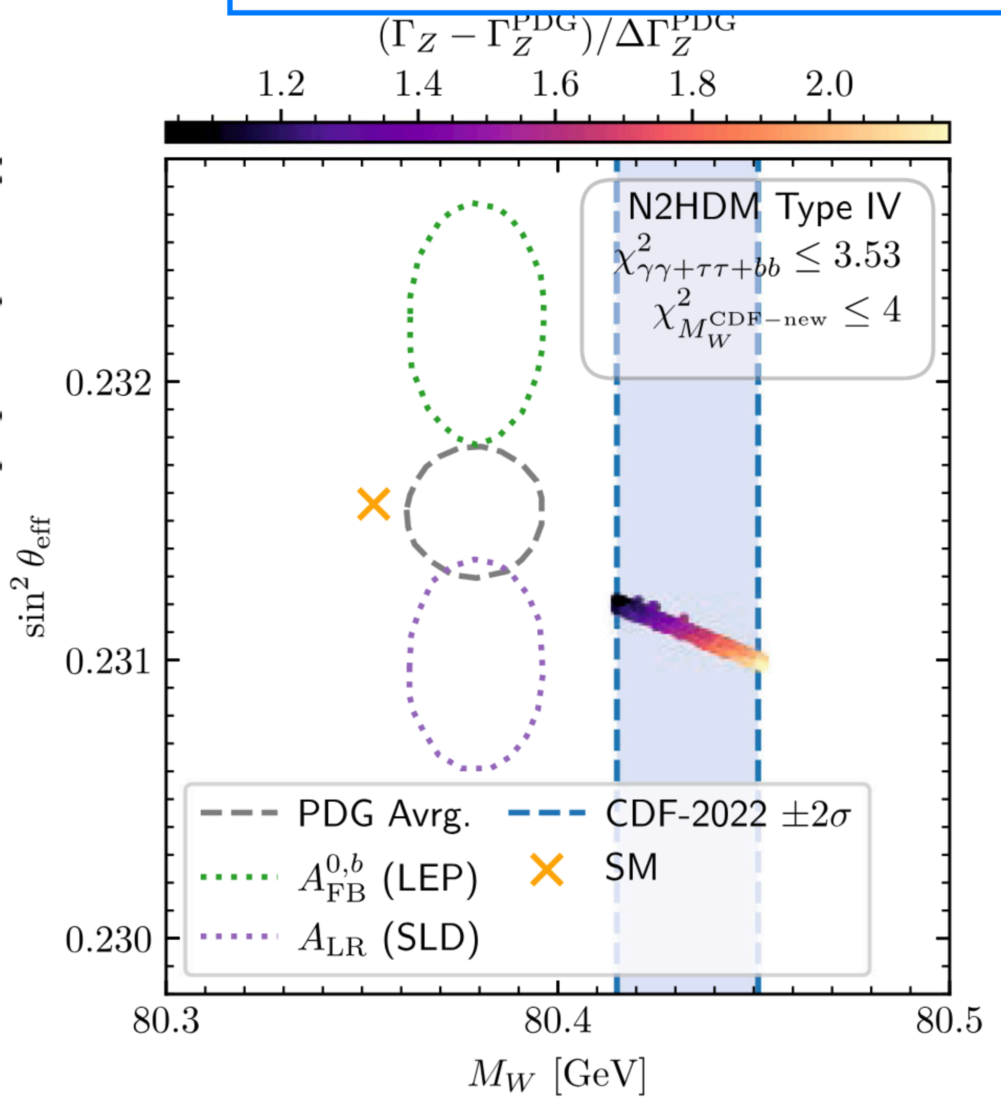
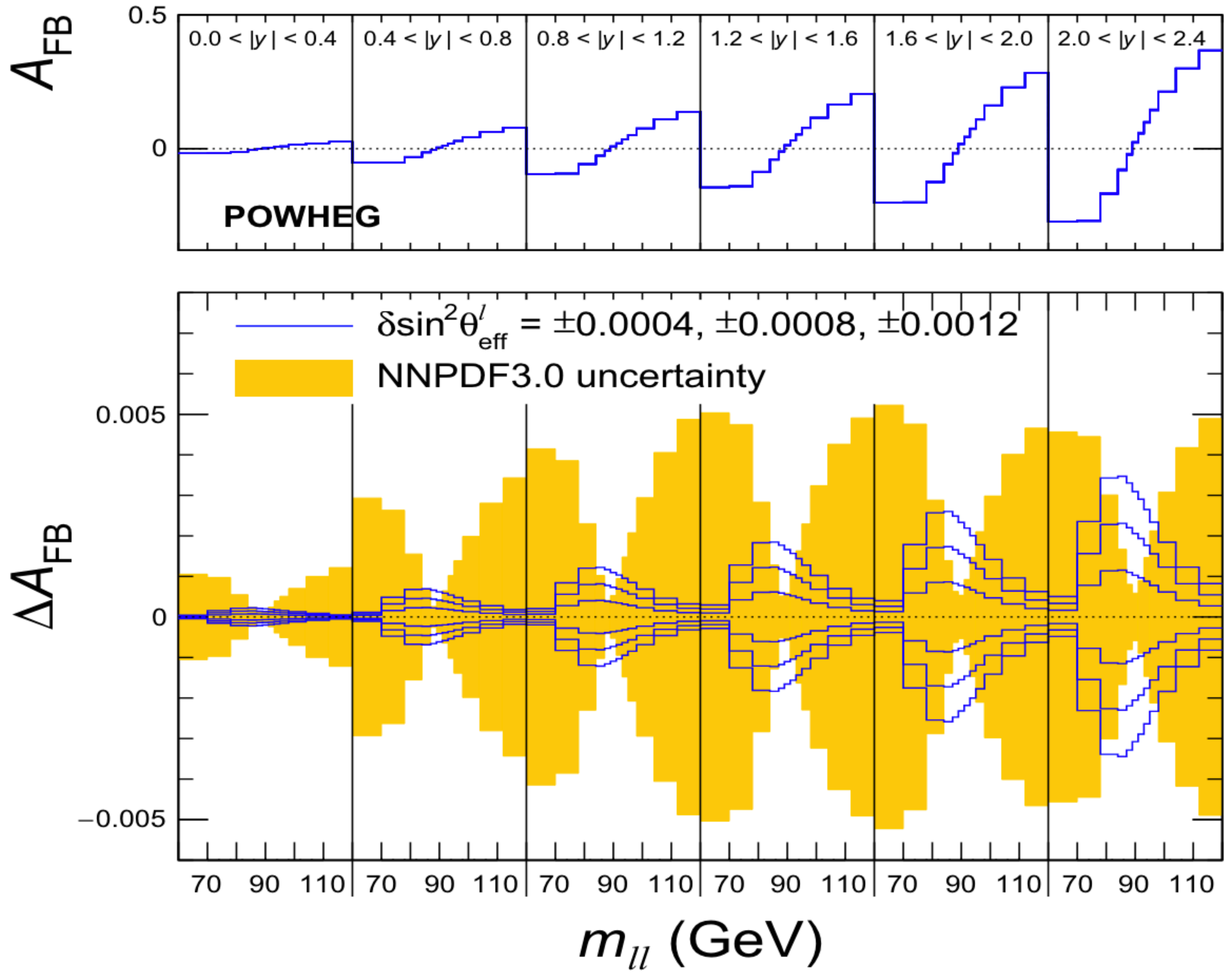
Eur. Phys. J. C 83, 450 (2023)

pulls (nD Pull) for sets of correlated observables, and are given in units of standard deviations.

Global SM EW fit (*standard* scenario)				
	Measurement	Posterior	Individual Prediction	1D Pull
$\sin^2\theta_{\rm eff}^{\rm lept}(Q_{\rm FB}^{\rm had})$	0.2324 ± 0.0012	0.231509 ± 0.000056 [0.231399, 0.231619]	0.231506 ± 0.000056 [0.231397, 0.231617]	0.7



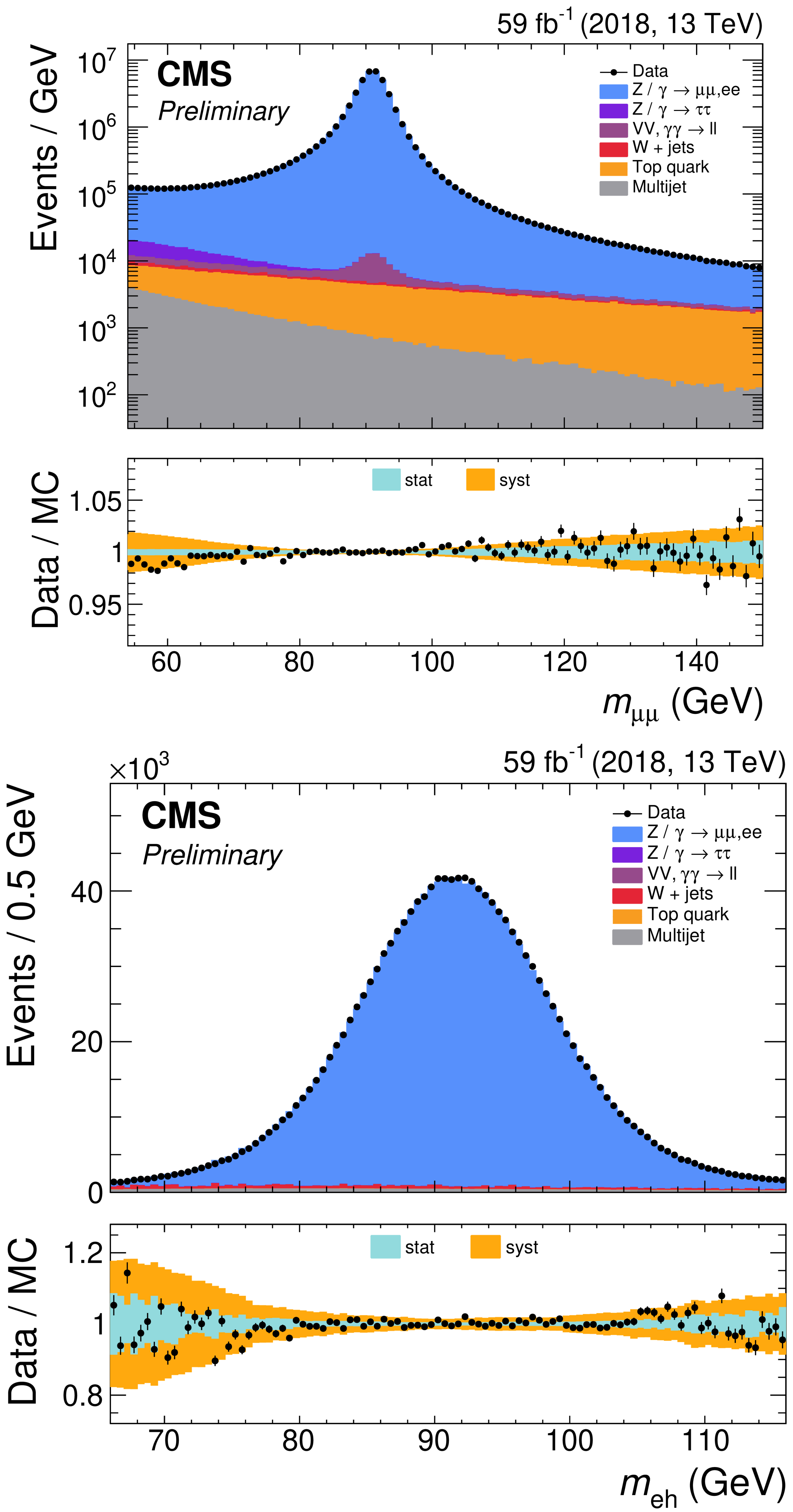
- Effective weak mixing angle is one of the key fundamental parameters in the SM.
- Its precision from theoretical predictions using other SM parameters is better than the current experimental uncertainty.
- Experimentally, it is measured using forward-backward asymmetry A_{FB} of $Z/\gamma \rightarrow \ell\ell$ events
  - A_{FB} depends on $\sin^2\theta^{\ell}_{eff}$ near m_Z
  - Strong dependence on PDF, fitting observable with $\sin^2\theta^{\ell}_{eff}$ and PDF-nuisance templates



Effective Weak Mixing Angle

CMS-PAS-SMP-22-010

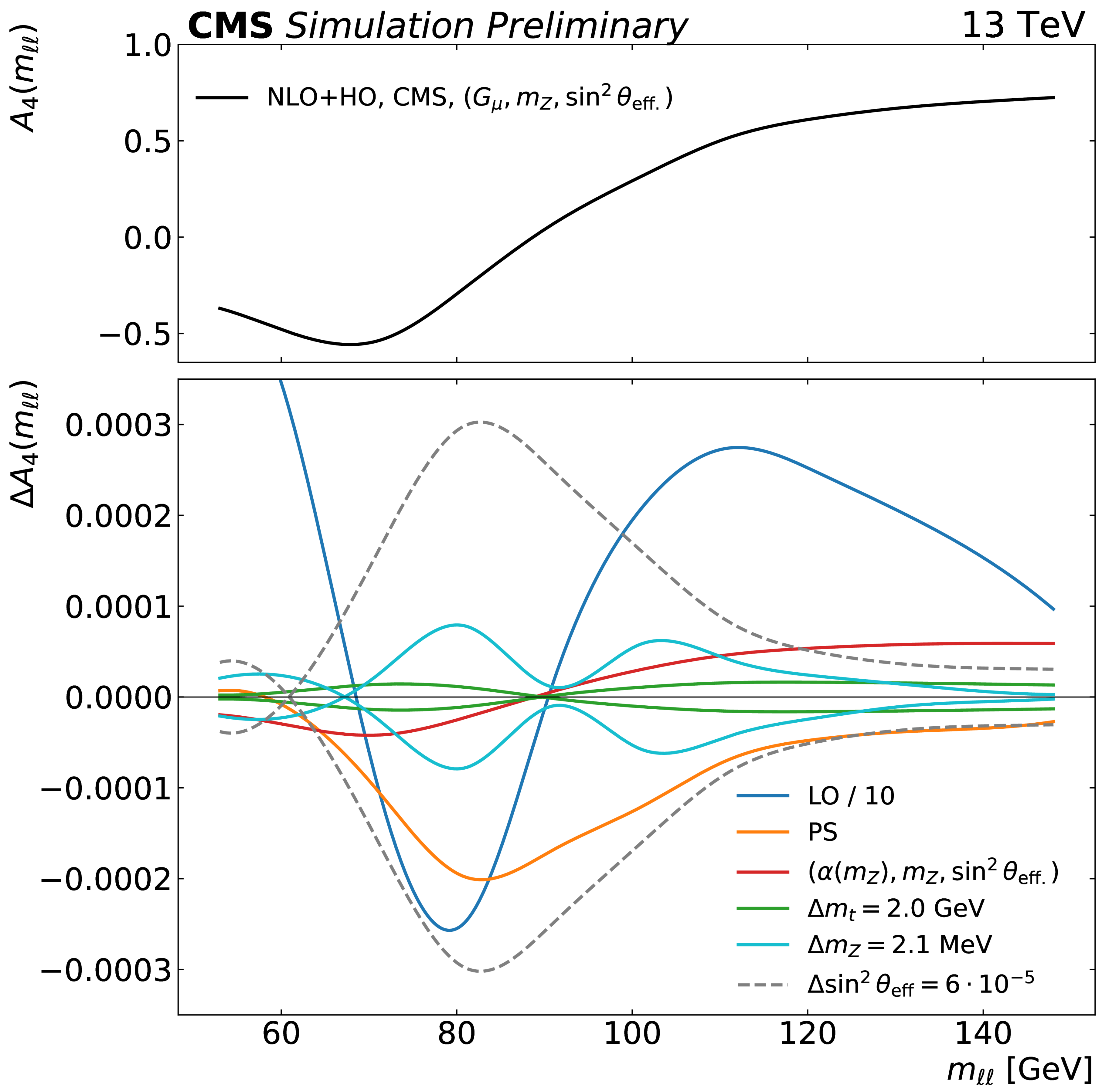
- Signal samples using POWHEG MiNNLO + Pythia8 + Photos
- Four channels considered: $\mu\mu$, ee, eg, and eh:
  - μ and e are leptons within detector acceptance, i.e, |eta|<2.4 and 2.5 respectively
  - g is for electrons in the endcap outside the tracking volume, i.e., 2.5<|eta|<2.87
  - h is for electrons in the forward calorimeter 3.14<|eta|<4.36
- Background:
  - W+jets: corrected with fake-lepton scale factors
  - Multijet background: from data sideband
  - Other EW and top background: from simulations
- Systematic uncertainties:
  - Experimental: MC stat., efficiency, momentum calibration, background, etc
  - Theory: QCD scale, $p_T^{\ell\ell}$ modeling, FSR, etc
  - PDF uncertainty

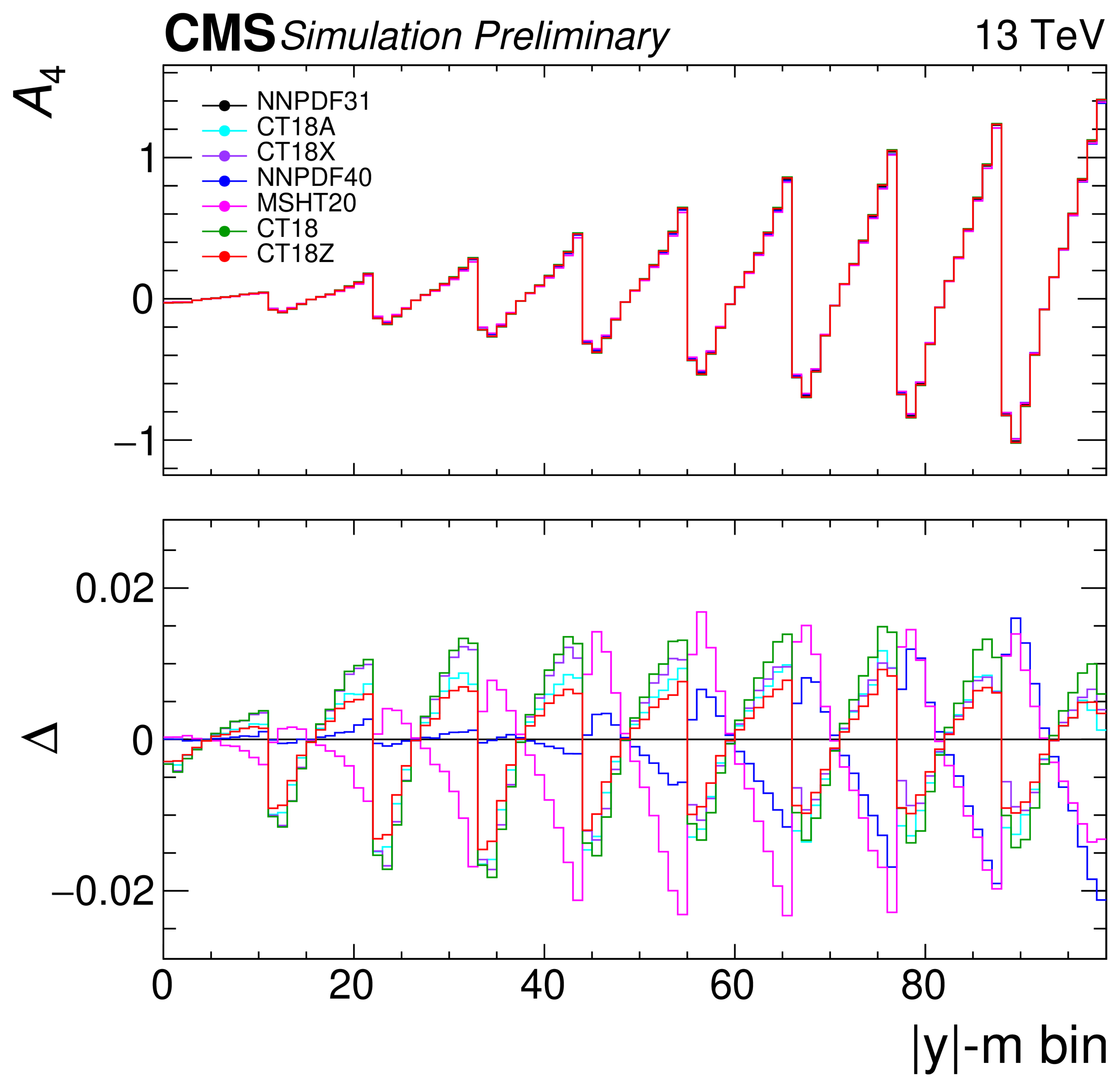


Effective Weak Mixing Angle

CMS-PAS-SMP-22-010

- Default EW configuration
  - NLO weak + universal HO corrections
  - input scheme of ($\sin^2\theta^{\ell}_{eff}$, m_Z, and G_μ)
  - Width: complex-mass scheme (CMS)
- Systematic variations:
  - Different Scheme: ($\sin^2\theta^{\ell}_{eff}$, m_Z, and α)
  - Width: pole scheme (PS)
  - Parameter values: (Δm_Z, Δm_t, ΔG_μ)

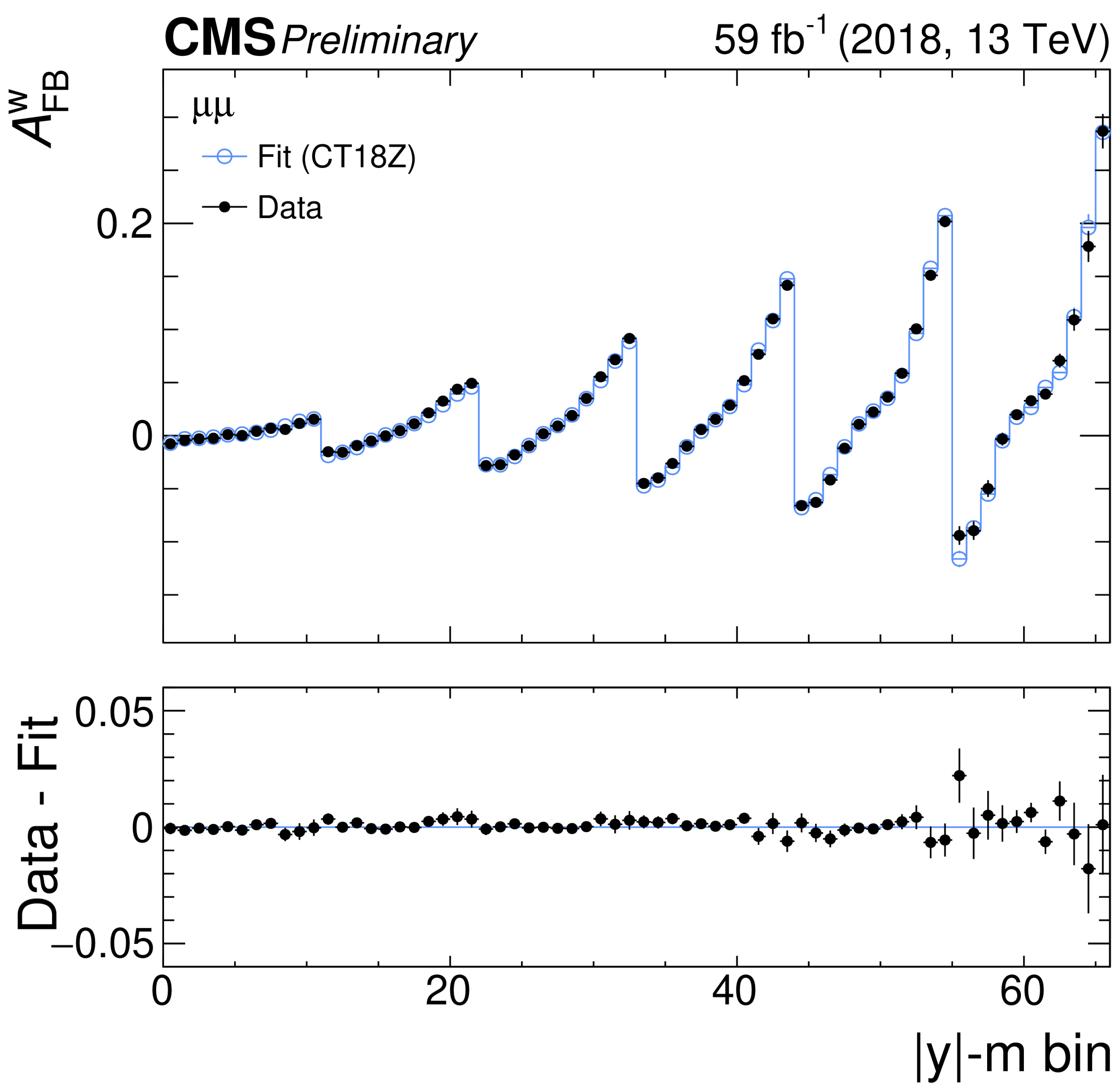


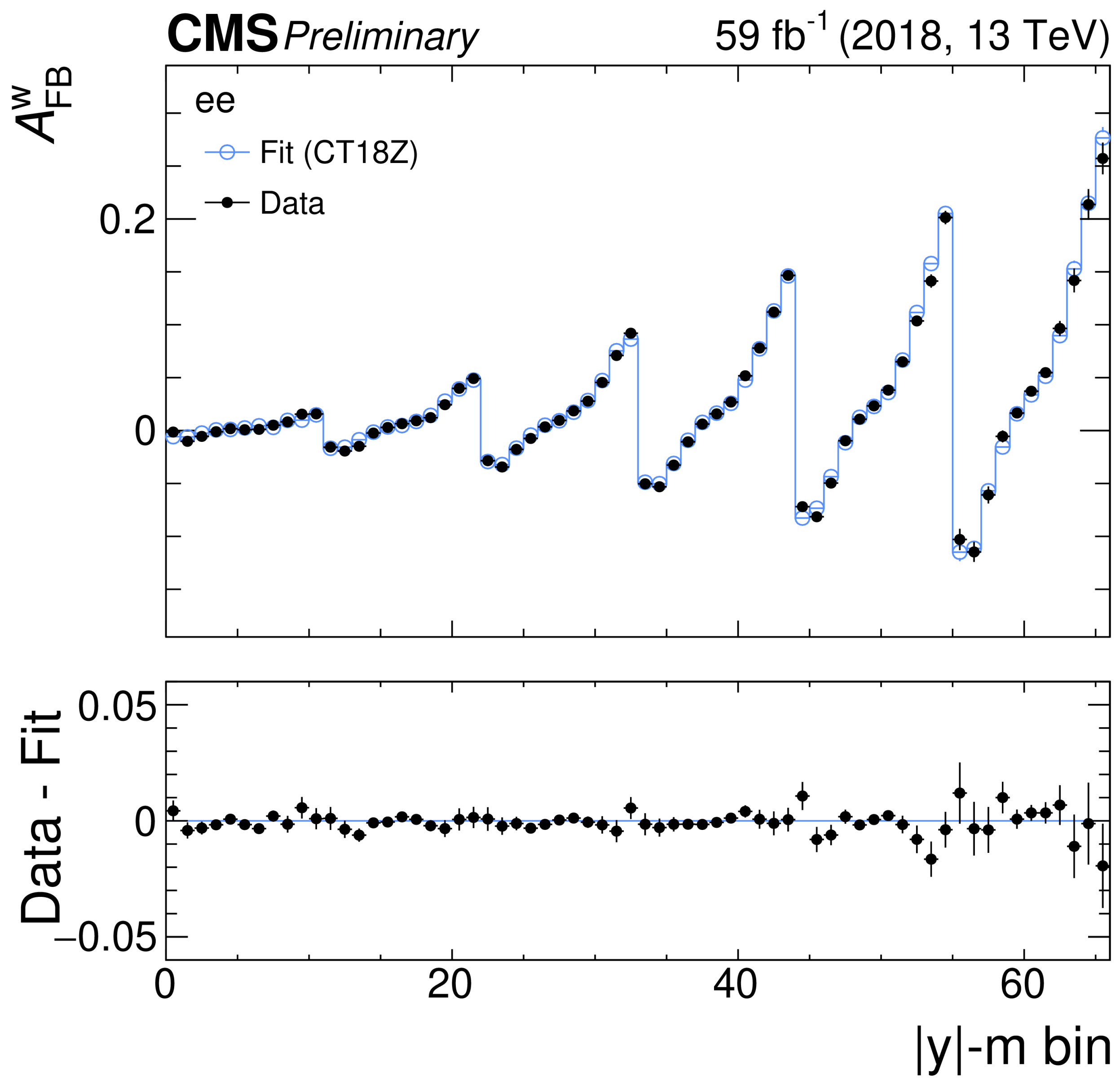


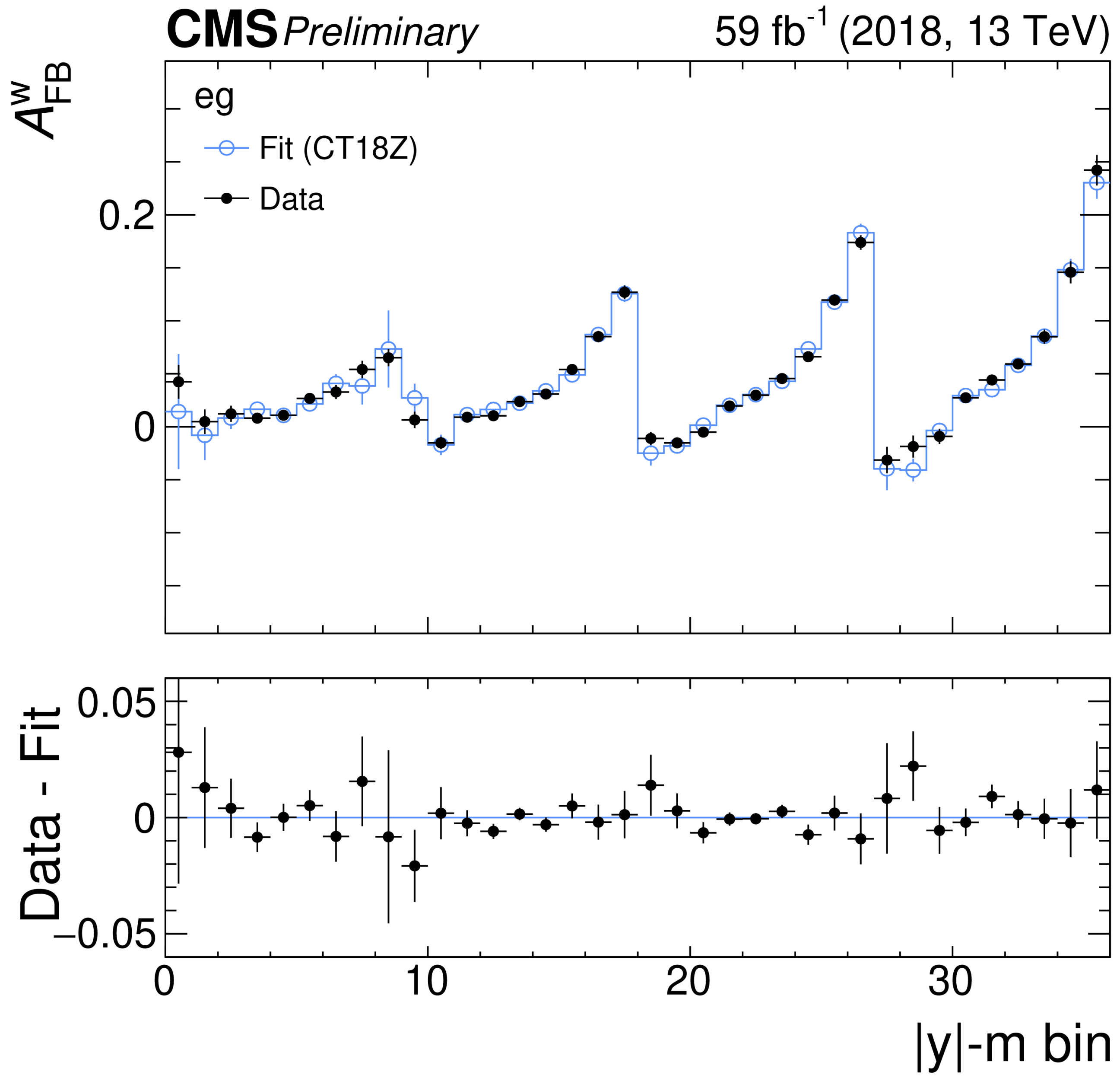
- Different NNPDFs tested. By default CT18Z is chosen, since its uncertainty covers the best the other central values

Effective Weak Mixing Angle

CMS-PAS-SMP-22-010







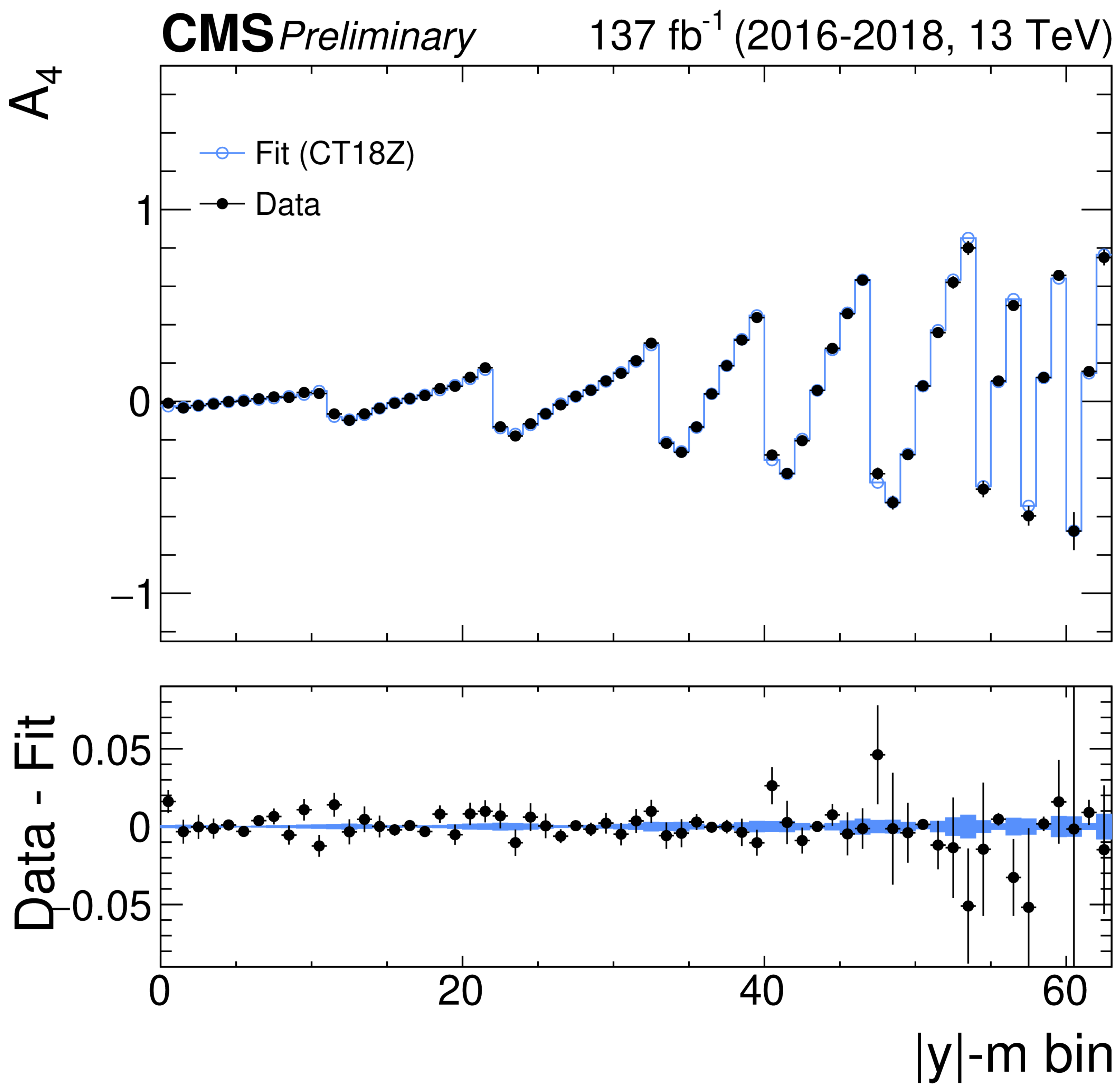
- Extract $\sin^2\theta^\ell_{eff}$ from simultaneous χ^2 fit of $A_{FB}(y,m)$ in all runs and channels

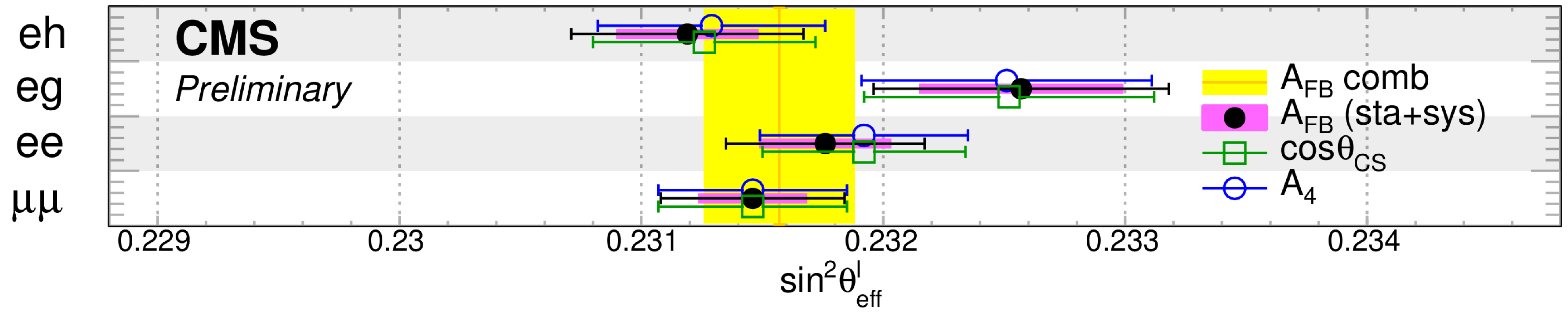
	χ^2	bins	$p(\%)$	$\sin^2\theta^\ell_{\rm eff}$	stat	exp	theo	PDF	MC	bkg	eff	calib	ot
$\mu\mu$	241.3	264	82.7	23146 ± 38	17	17	7	30	13	3	2	5	
ee	256.7	264	59.8	23176 ± 41	22	18	7	30	14	4	5	3	
eg	119.1	144	92.8	23257 ± 61	30	40	5	44	23	11	12	19	
eh	104.6	144	99.3	23119 ± 48	18	33	9	37	14	10	16	18	
$\ell\ell$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

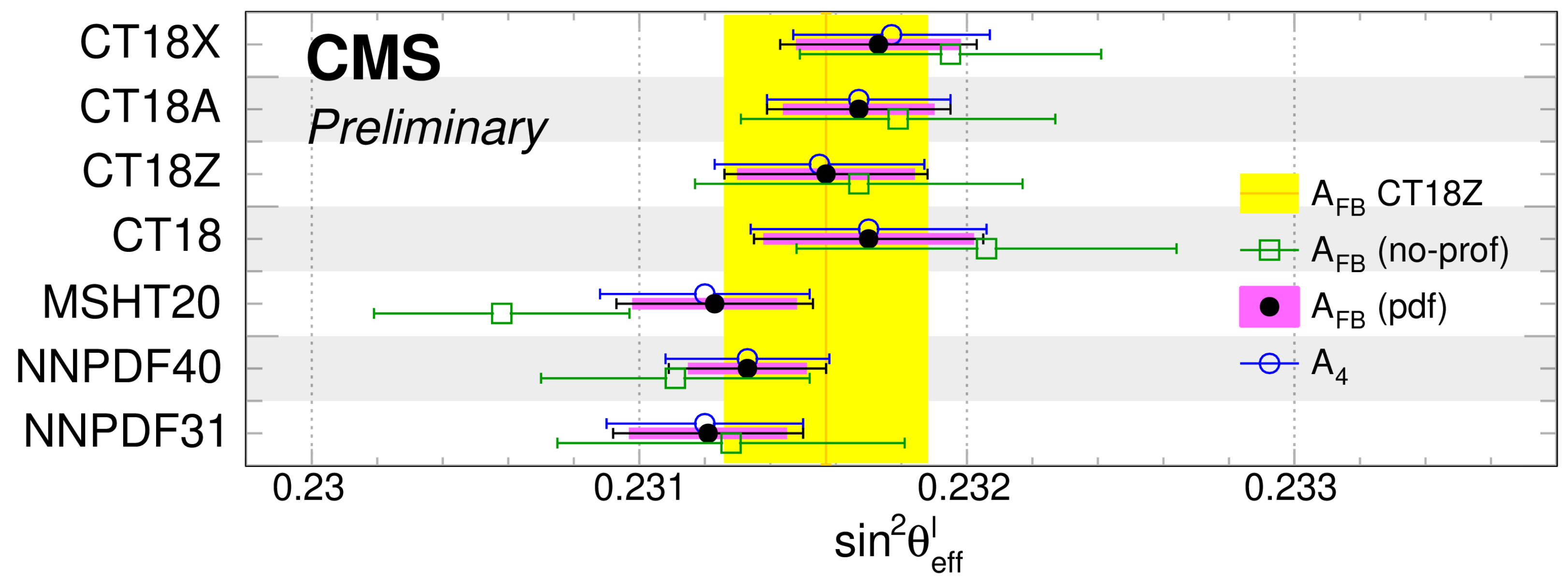
$\sin^2\theta^\ell_{\rm eff}$ x 10^5

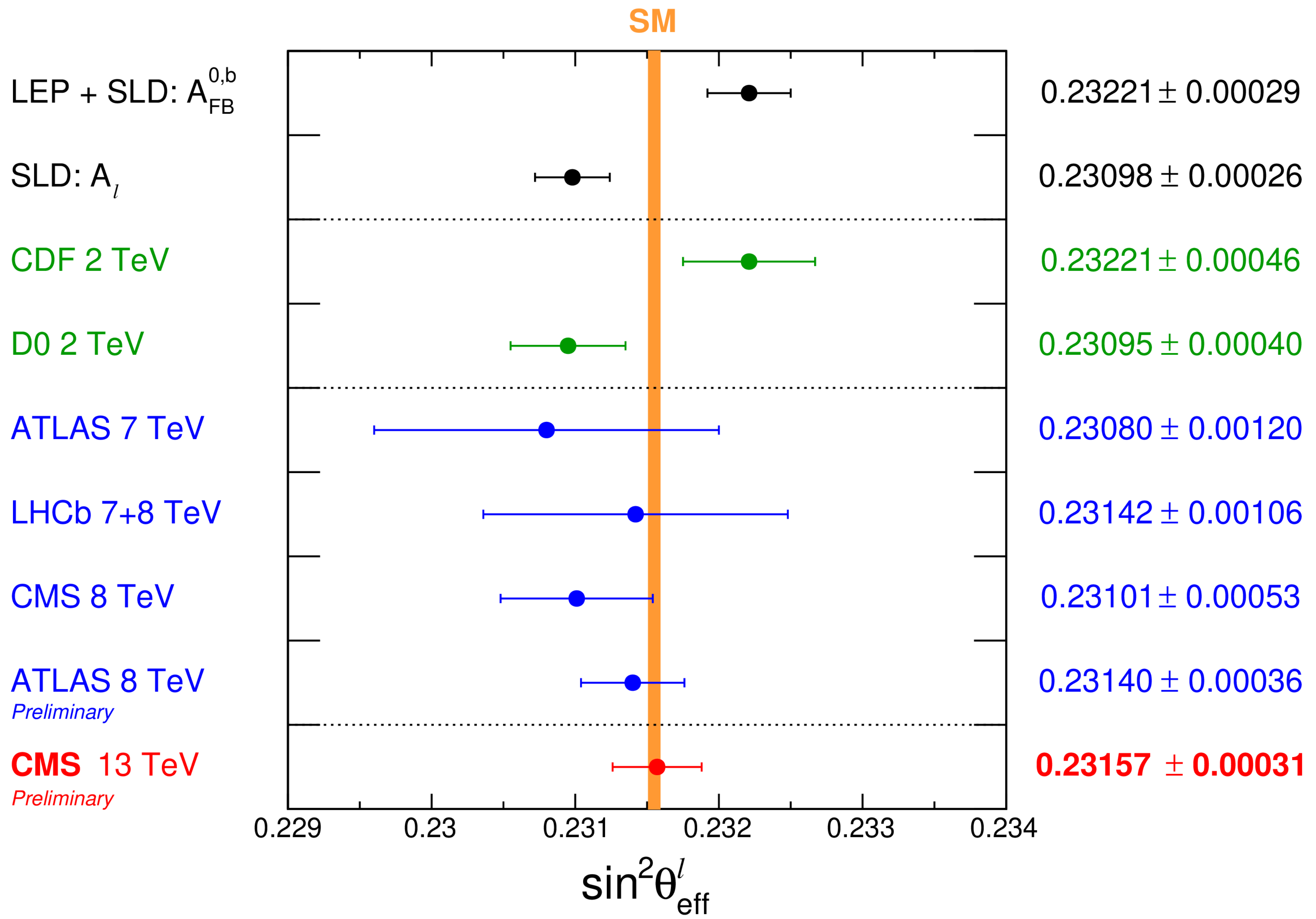
Effective Weak Mixing Angle

CMS-PAS-SMP-22-010





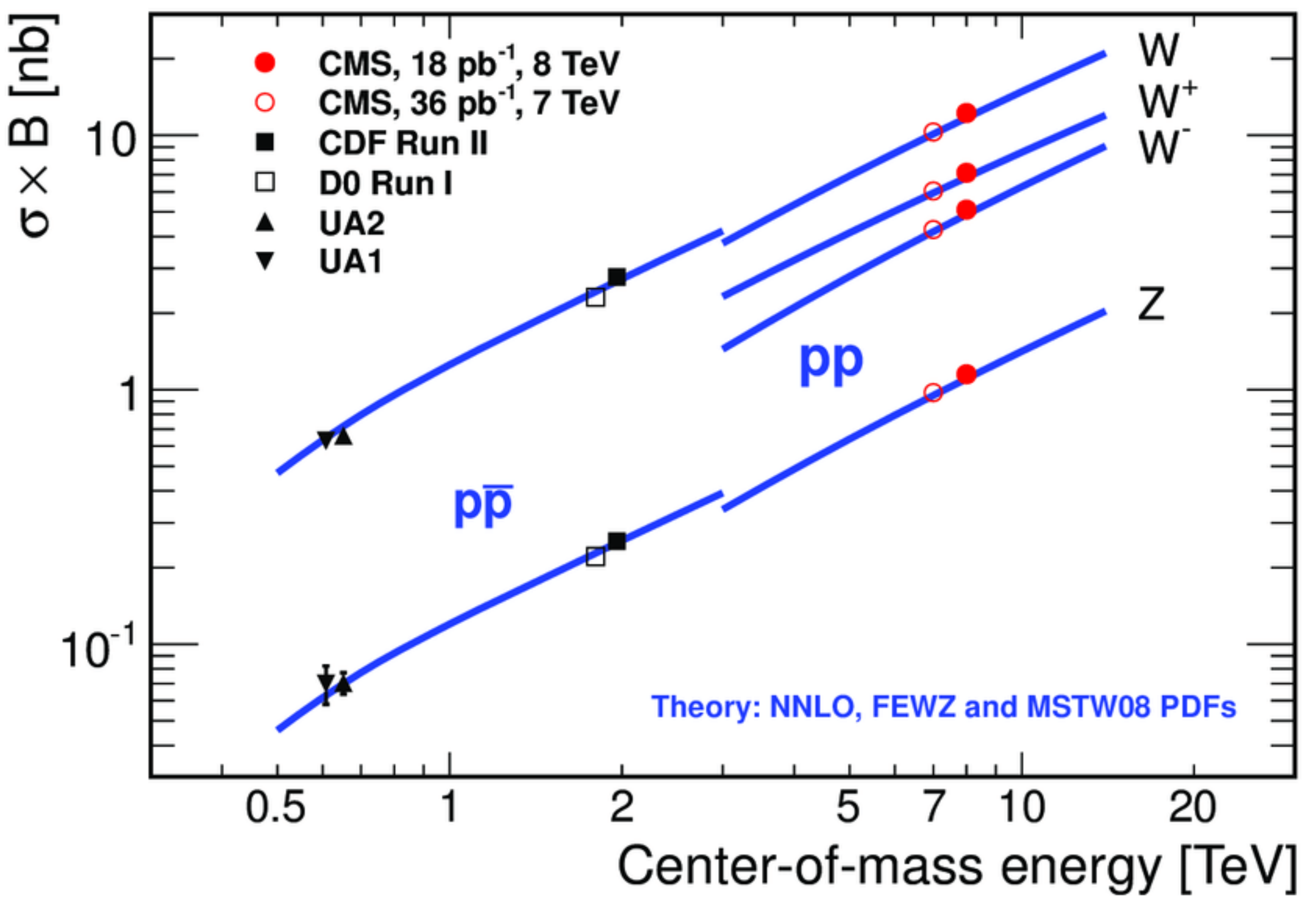


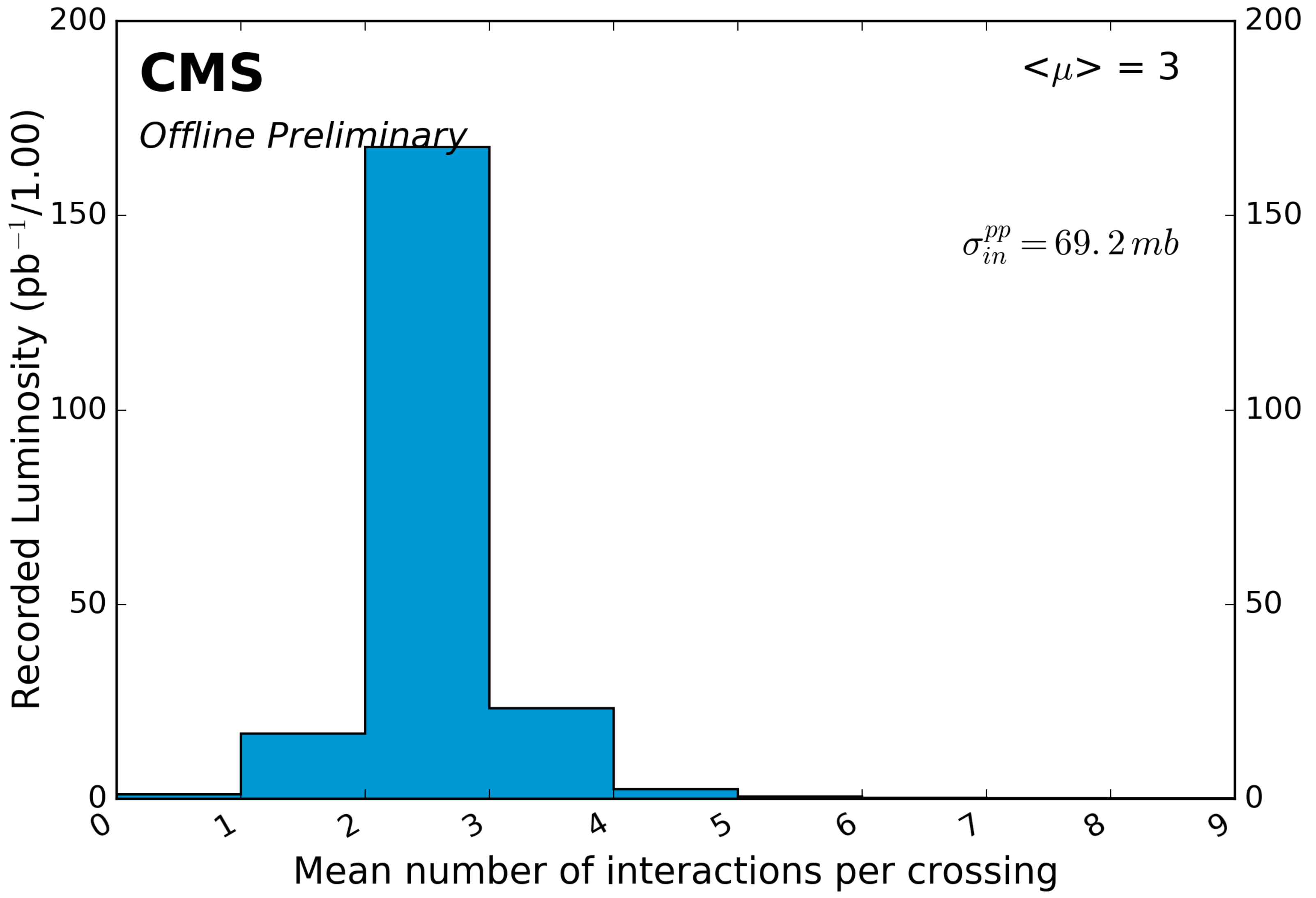


- A_4 measurements provided.
- Comparing $\sin^2\theta^{\ell}_{eff}$ using different fits: A_{FB}, A_4, and $\cos\theta_{CS}$, between different PDFs
- Good agreement with predictions and previous measurements
  - **The most precise measurement at hadron colliders**

W and Z Cross sections

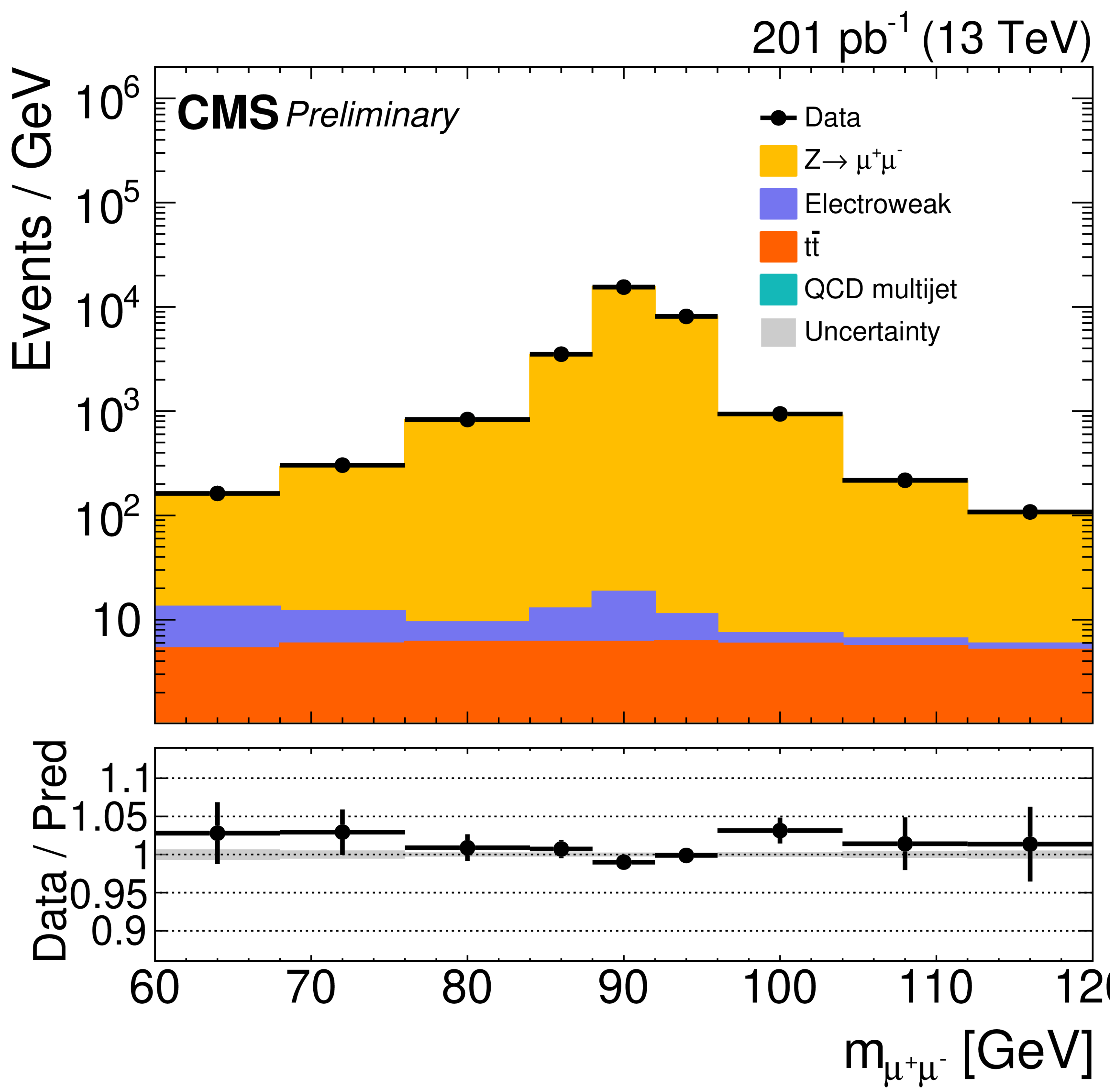
- W and Z cross sections provide precise tests of the standard model predictions:
    - Cross section ratios between W and Z, and between different center-of-mass energy, provide important inputs to the PDFs
    - Good validation on the experimental methodology and the luminosity measurements
- Dedicated low pileup runs at 5.02TeV and 13TeV provide such opportunities, to carry out such measurements with better uncertainties:
    - Low pileup - better recoil resolution and smaller uncertainty - lower QCD multijet background

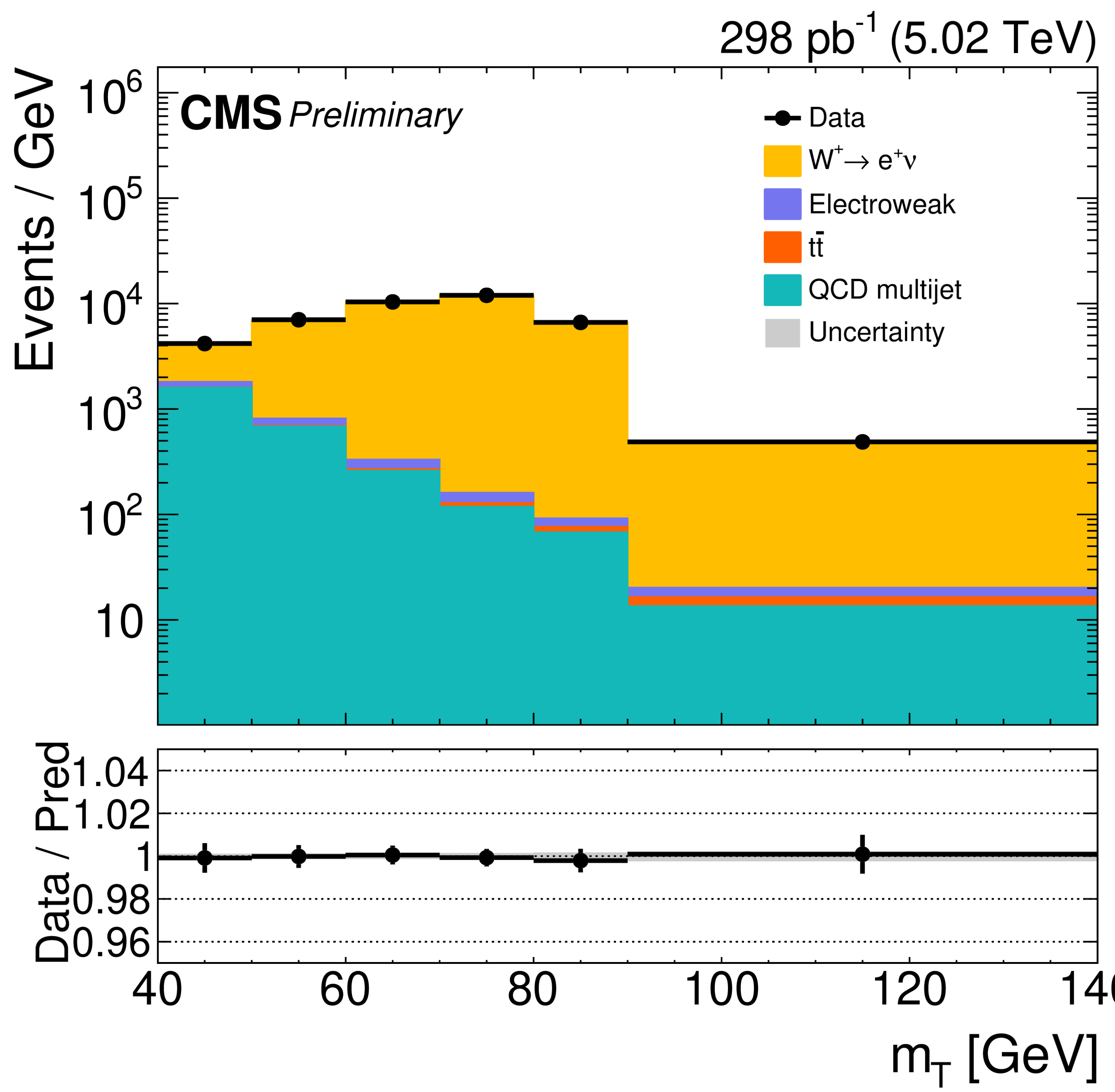


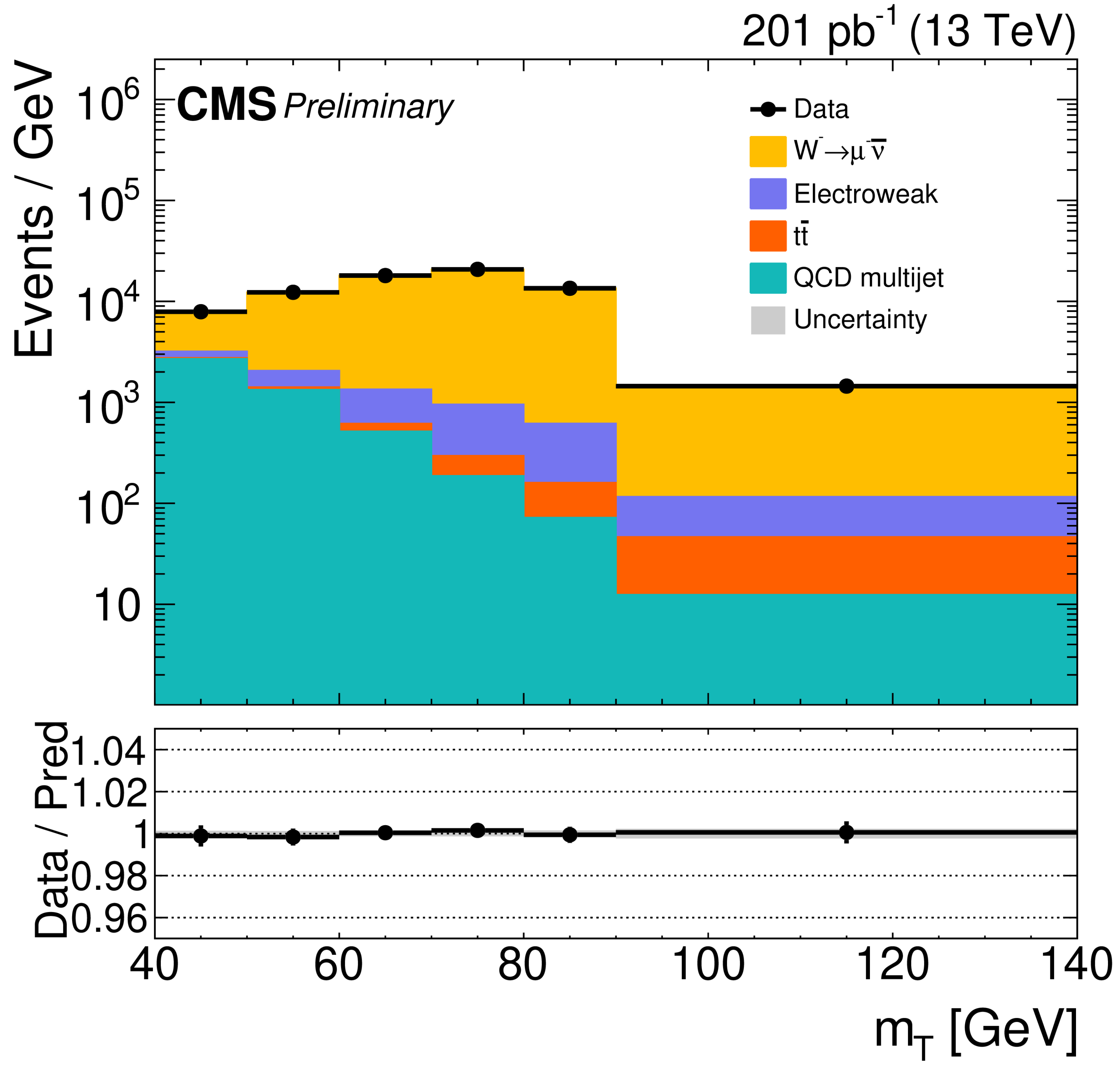


W and Z Cross sections

CMS-PAS-SMP-20-004







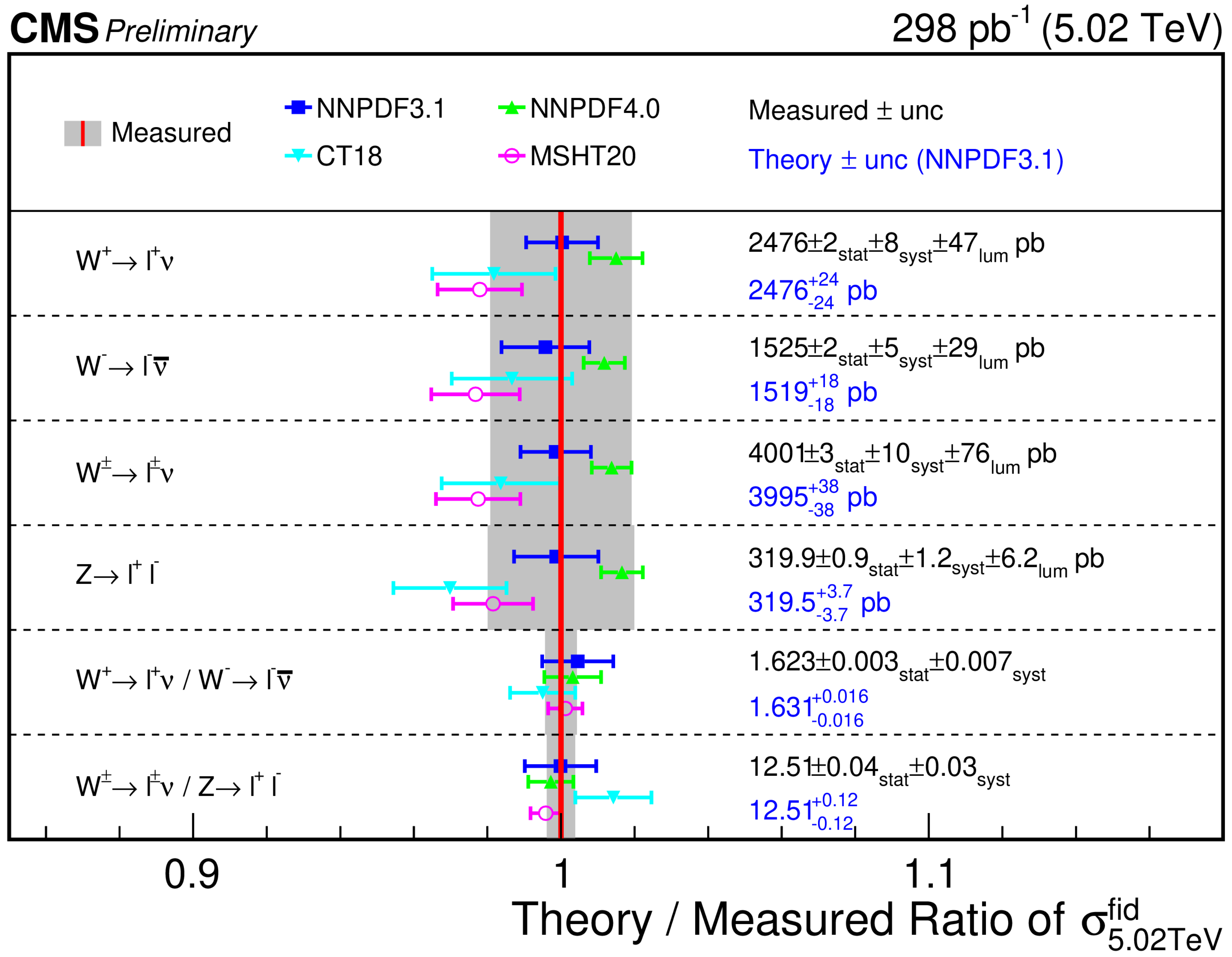
- Measurements done by fitting $m_{\ell\ell}$ and m_T distributions for Z and W
- EWK and ttbar background estimated from simulation. QCD multijet background is the dominant background for W's, estimated from data control region (inverting mT)

	$W^+ \to \mu^+\nu$	$W^- \to \mu^-\bar{\nu}$	$Z \to \mu^+\mu^-$	$W^+ \to e^+\nu$	$W^- \to e^-\bar{\nu}$	$Z \to e^+e^-$
Data	1016318	796731	128889	689131	561870	72040
Signal	924311.1	709152.6	128414.3	592682.4	467677.2	71523.5
Electroweak	37161.9	32791.4	264.1	11721.9	11045.5	154.3
$t\bar{t}$	6100.4	6117.7	347.3	4596.7	4607.9	207.9
QCD multijet	48525.4	48589.0	0.0	80367.4	78699.4	0.0

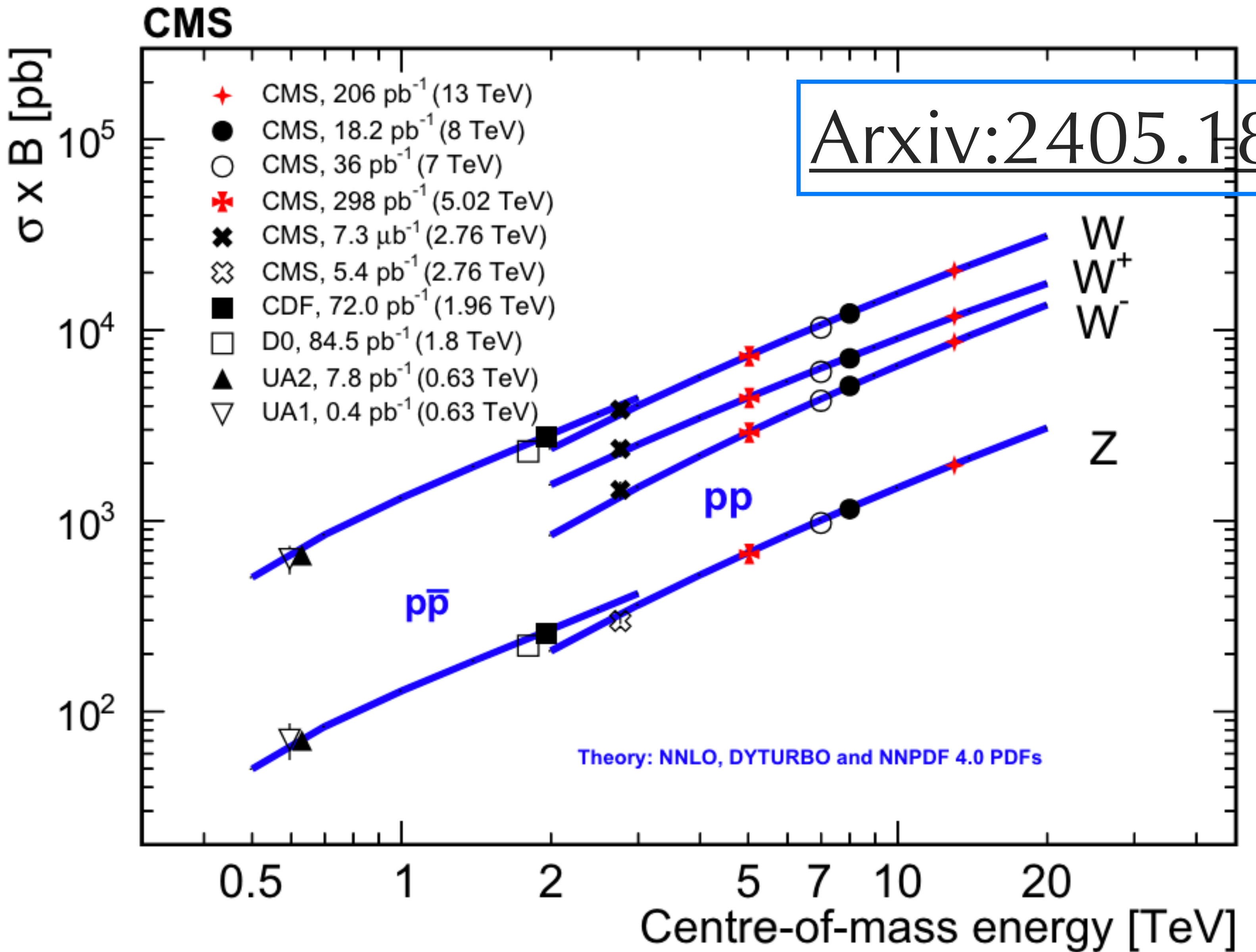
W and Z Cross sections

CMS-PAS-SMP-20-004

	$W^+ \to \ell^+\nu$	$W^- \to \ell^-\bar{\nu}$	$Z \to \ell^+\ell^-$	$W^\pm \to \ell^\pm\nu$	$W^\pm/Z$	W^+/W^-
Total	0.32	0.34	0.37	0.26	0.25	0.40
Efficiency (stat)	0.23	0.21	0.26	0.17	0.11	0.30
Trigger prefire correction	0.14	0.13	0.22	0.14	0.08	0.01
QCD multijet (syst)	0.11	0.15	0.12	0.09	0.15	0.19
MC sim. stat	0.10	0.12	0.11	0.08	0.13	0.15
EWK+$t\bar{t}$ cross section	0.08	0.10	0.02	0.09	0.07	0.03
PDF + α_S	0.05	0.07	0.03	0.05	0.05	0.07
Efficiency (syst)	0.04	0.05	0.09	0.04	0.06	0.01
QCD multijet (stat)	0.04	0.04	0.03	0.03	0.04	0.06
Hadronic recoil calibration	0.02	0.02	0.02	0.02	0.03	0.01
μ_R and μ_F scales	0.01	0.01	0.01	0.01	0.01	0.00



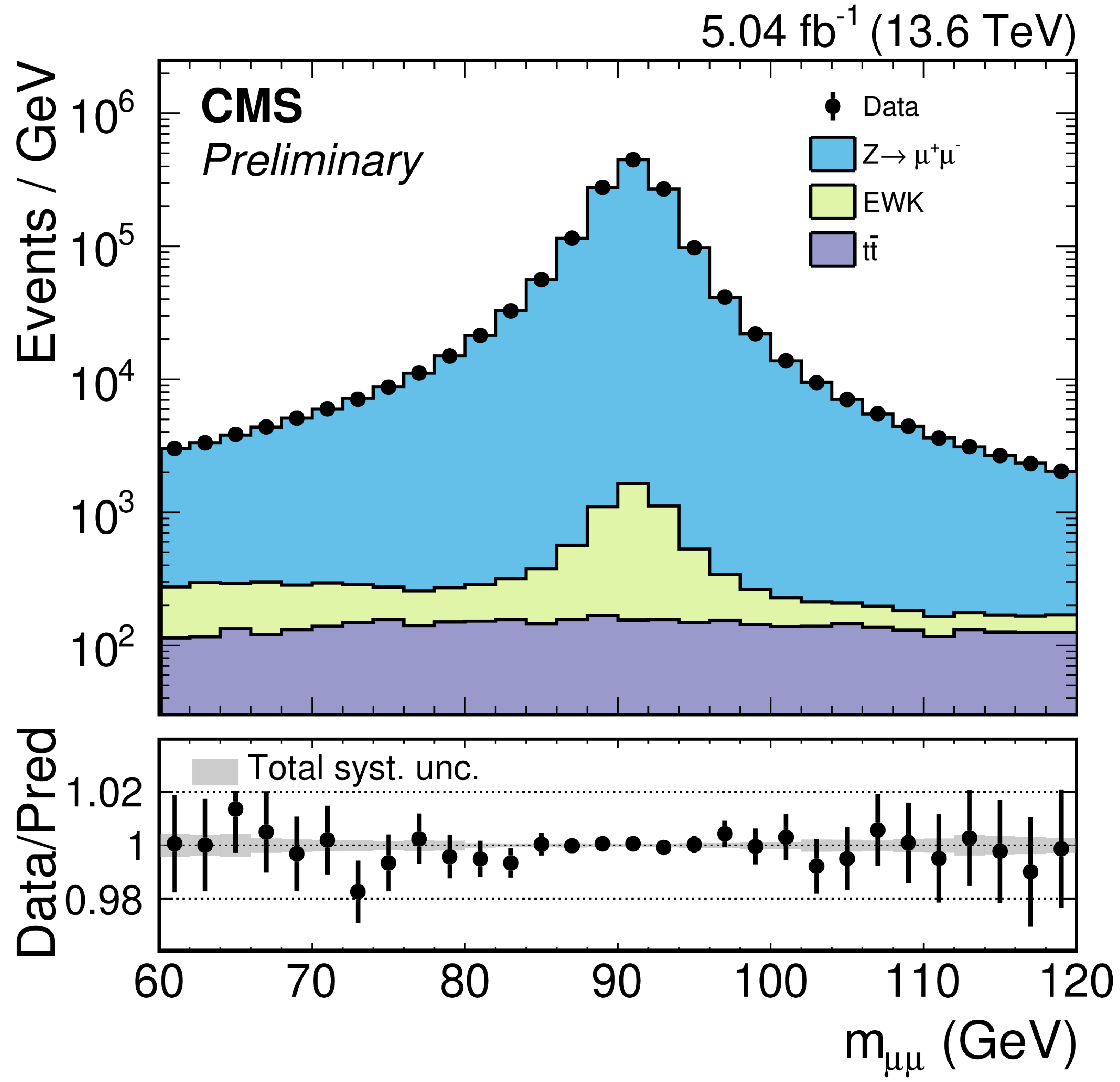
- **<2% uncertainty** (luminosity uncertainty (~1.9%) + O(0.3%) experimental uncertainty) **for fiducial cross sections**
- **<0.4% uncertainty** for fiducial cross section **ratios**
- Good agreement with predictions at different center-of-mass energy

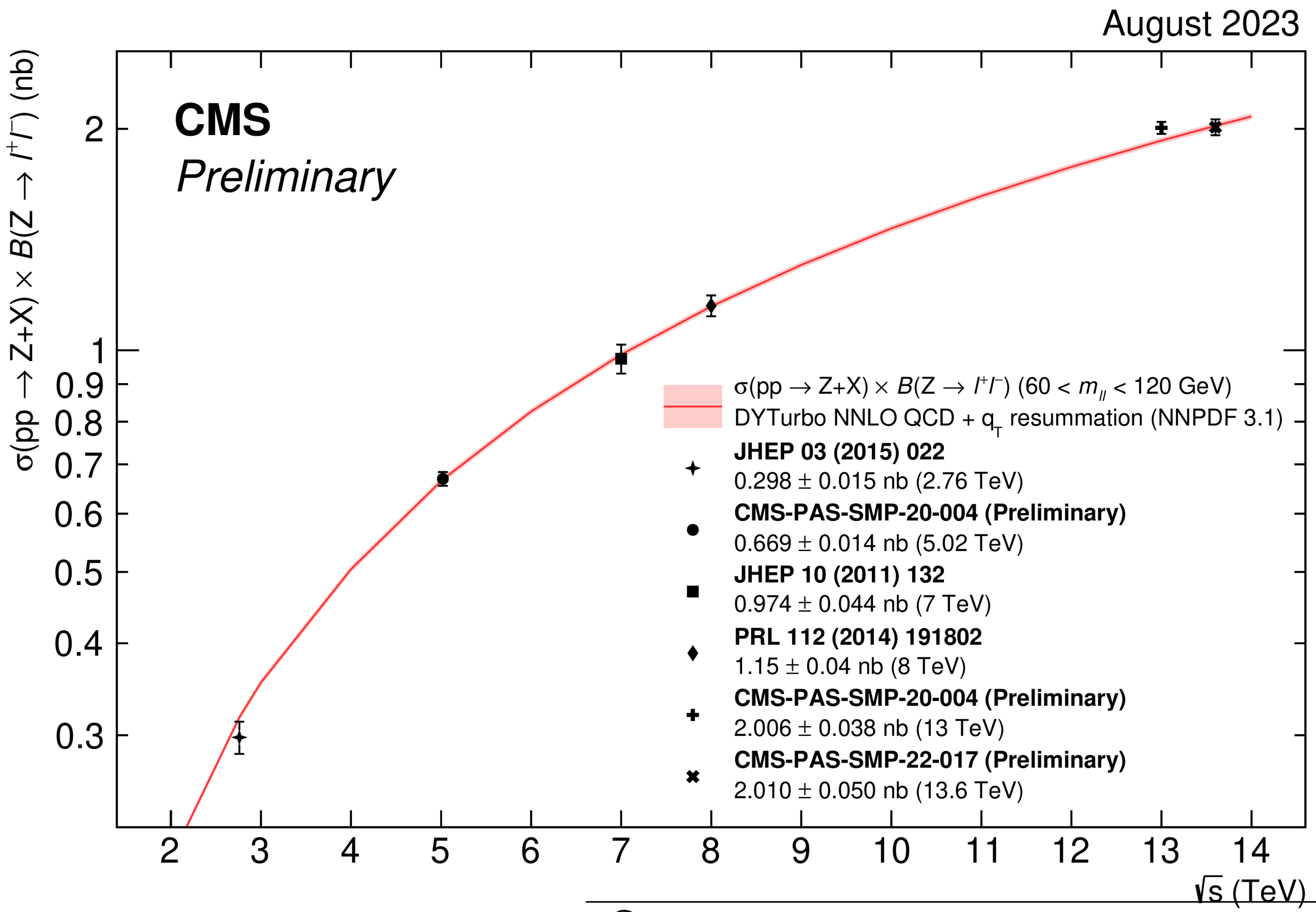


Arxiv:2405.18661

W and Z Cross sections

CMS-PAS-SMP-22-017



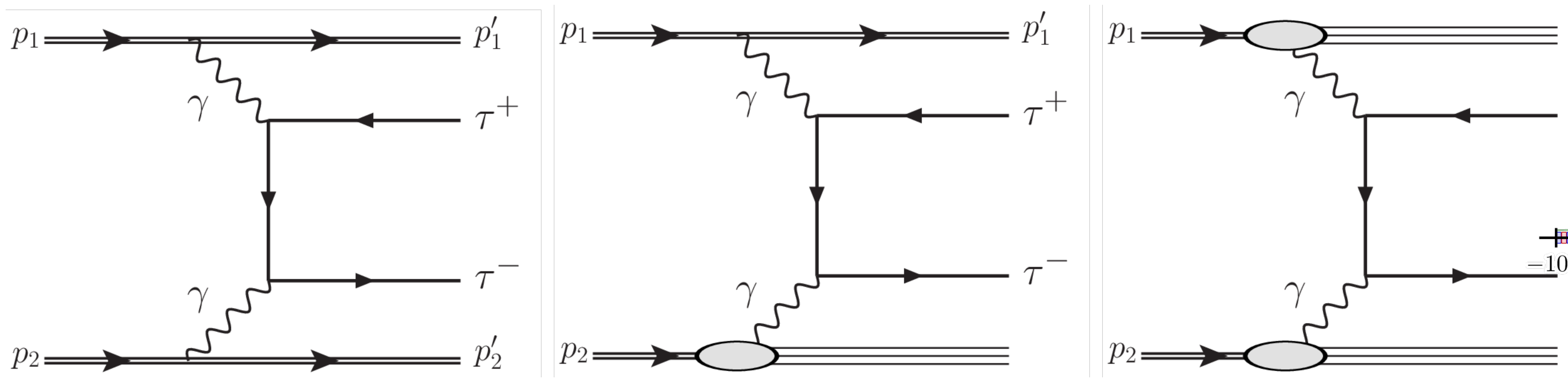


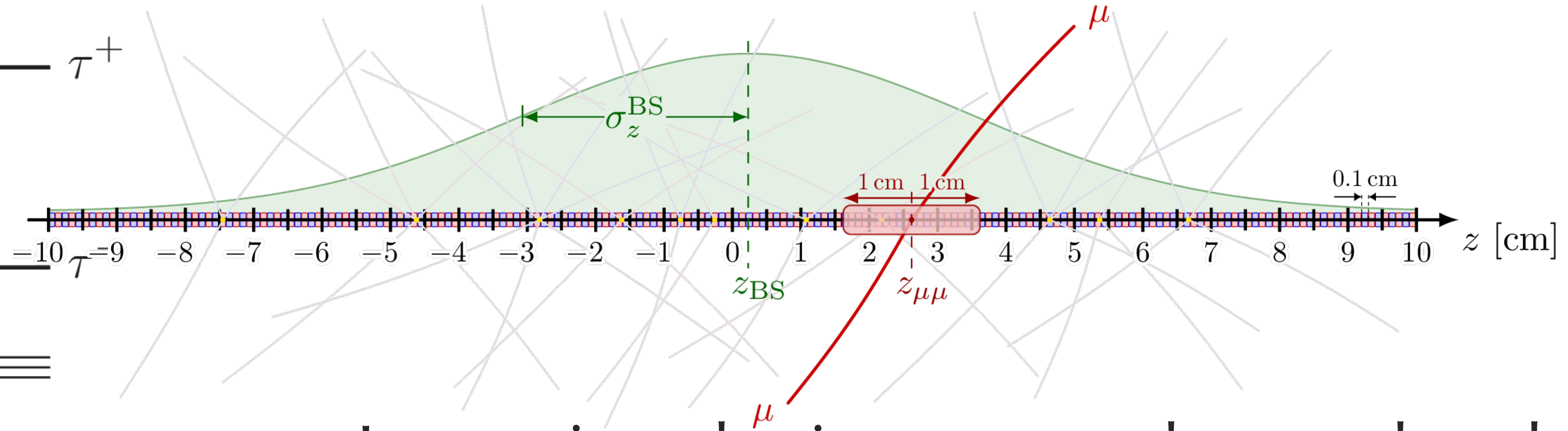
- Similar measurements carried out for the Z cross sections at 13.6TeV with Run-3 data, using similar analysis strategy
- Analysis in the dimuon channel. Subpecent uncertainty achieved + O(2%) luminosity uncertainty
- Good agreement with predictions

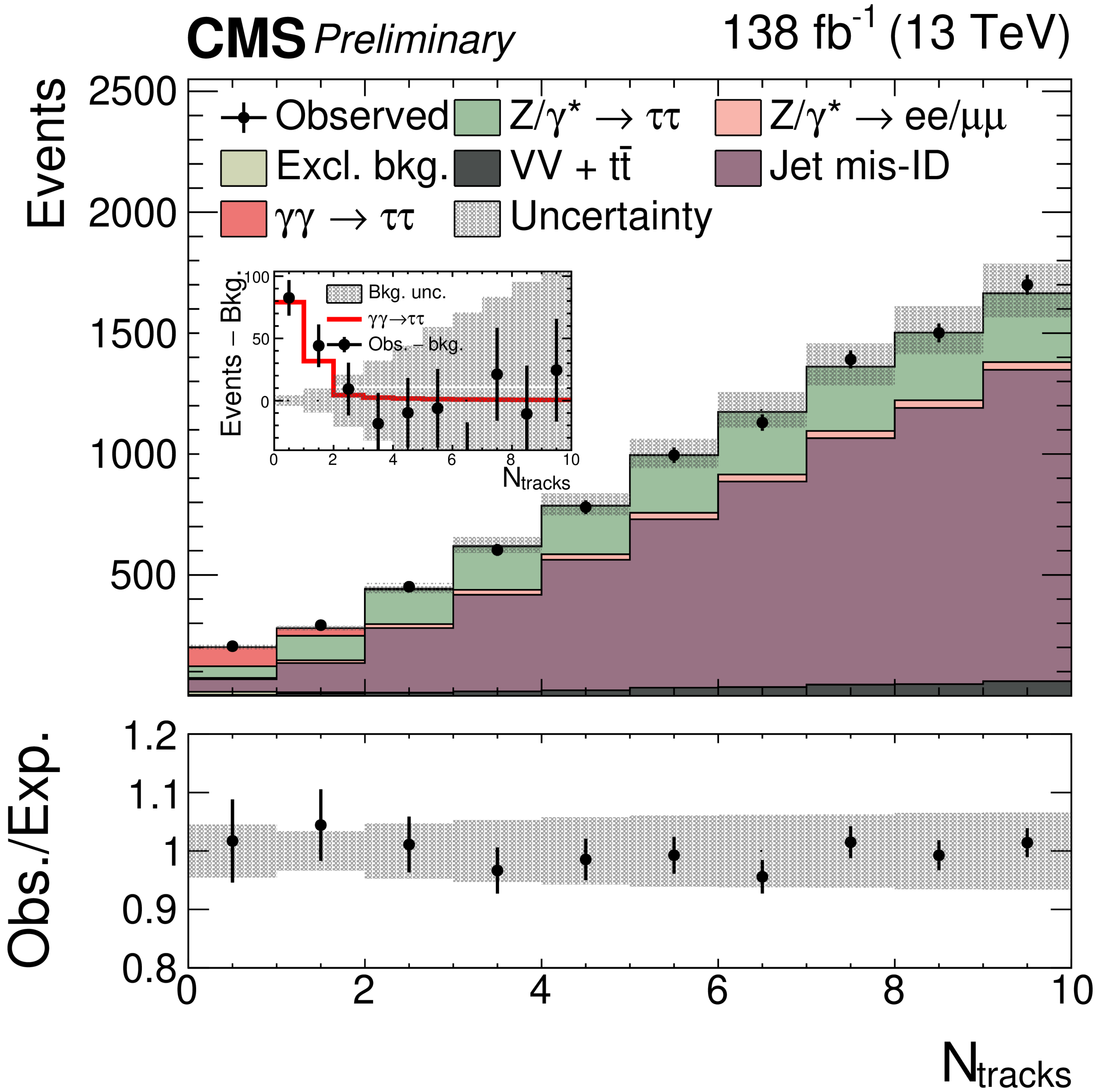
Source	Uncertainty (%)
Muon efficiencies	0.83
PDF, QCD scale and parton shower	0.53
Finite size of MC samples (bin-by-bin)	0.35
tt̄ background	0.16
EWK background	0.12
Pileup	0.08
Muon momentum correction	0.08
Combined syst. uncertainty	0.92
Luminosity	2.3
Stat. uncertainty	0.06

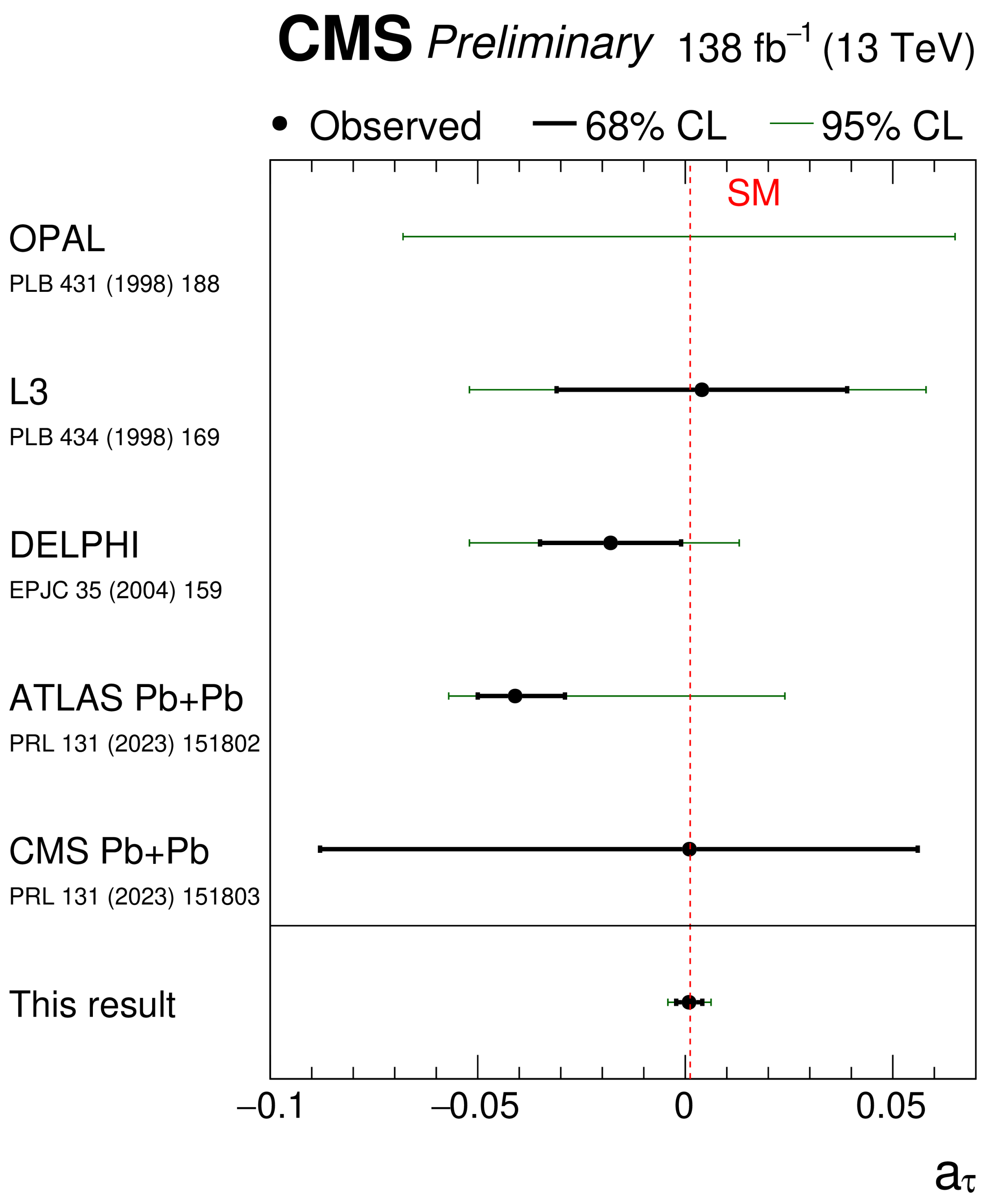
$gg \to \tau\tau$ Production

CMS-PAS-SMP-23-005









- Interesting physics process, less explored in pp collisions, but **sensitive to tau anomalous electromagnetic momenta**
- Excellent tracking performance provides the opportunity to select such process by vetoing additional tracks:
  - Veto events with nTrack > 1
- First observation of $gg \to \tau\tau$ and strongest constraint on tau $g-2$
  - More in G. Sorrentino's talk on Friday

Summary

- Our experiment has really exploited the usage of huge statistics of W and Z events to understand the systematic effects and reduce the uncertainties, with results similar to or better than the LEP precision
  - Improving precision is very challenging, but every step forward is very interesting and worth to explore

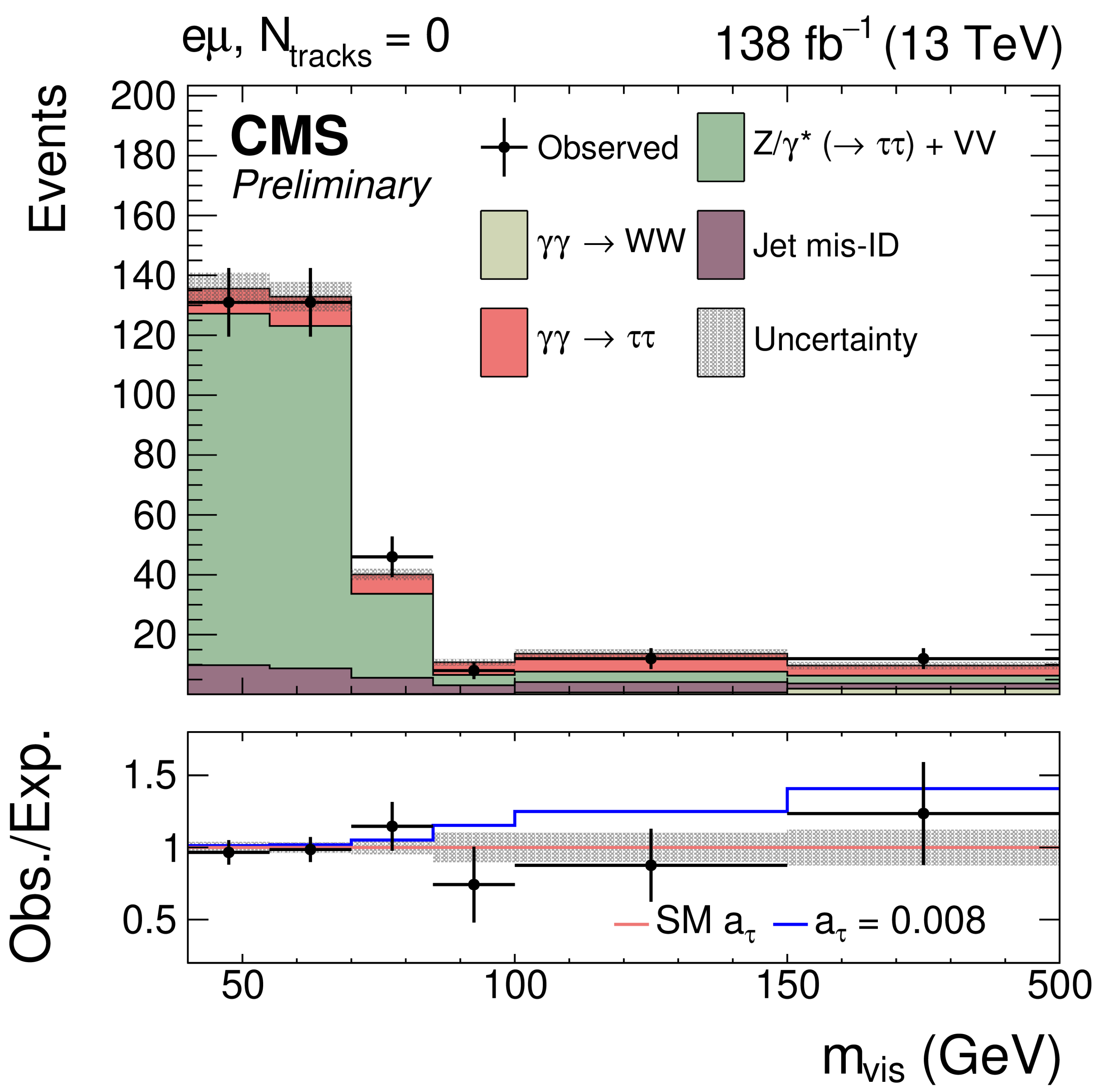
- SM predictions continue to be very successful, with no significant tensions found with the theory and experimental uncertainties.

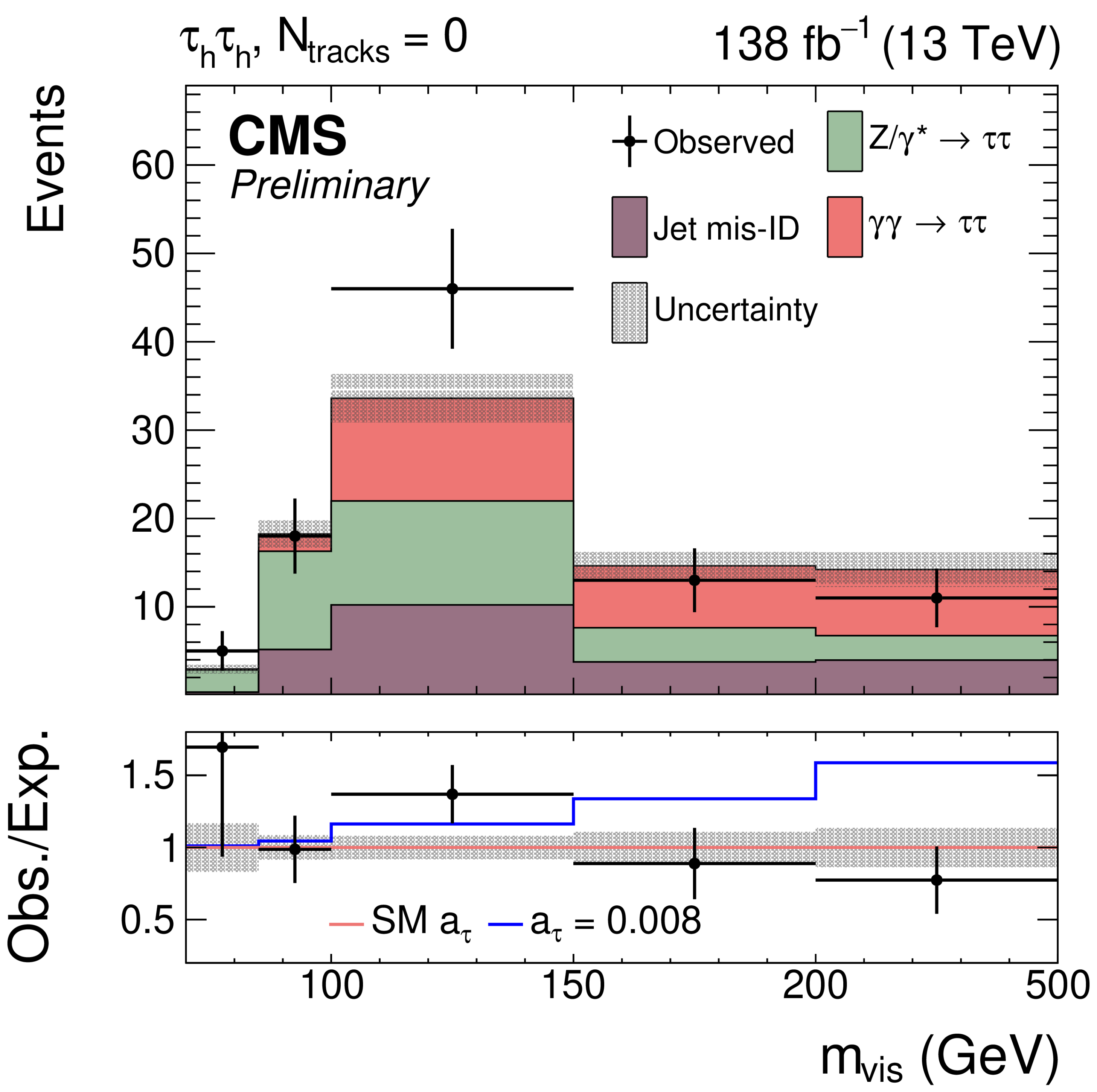
- CMS will continue to explore new ideas and test SM with more results to come out.

Back Up

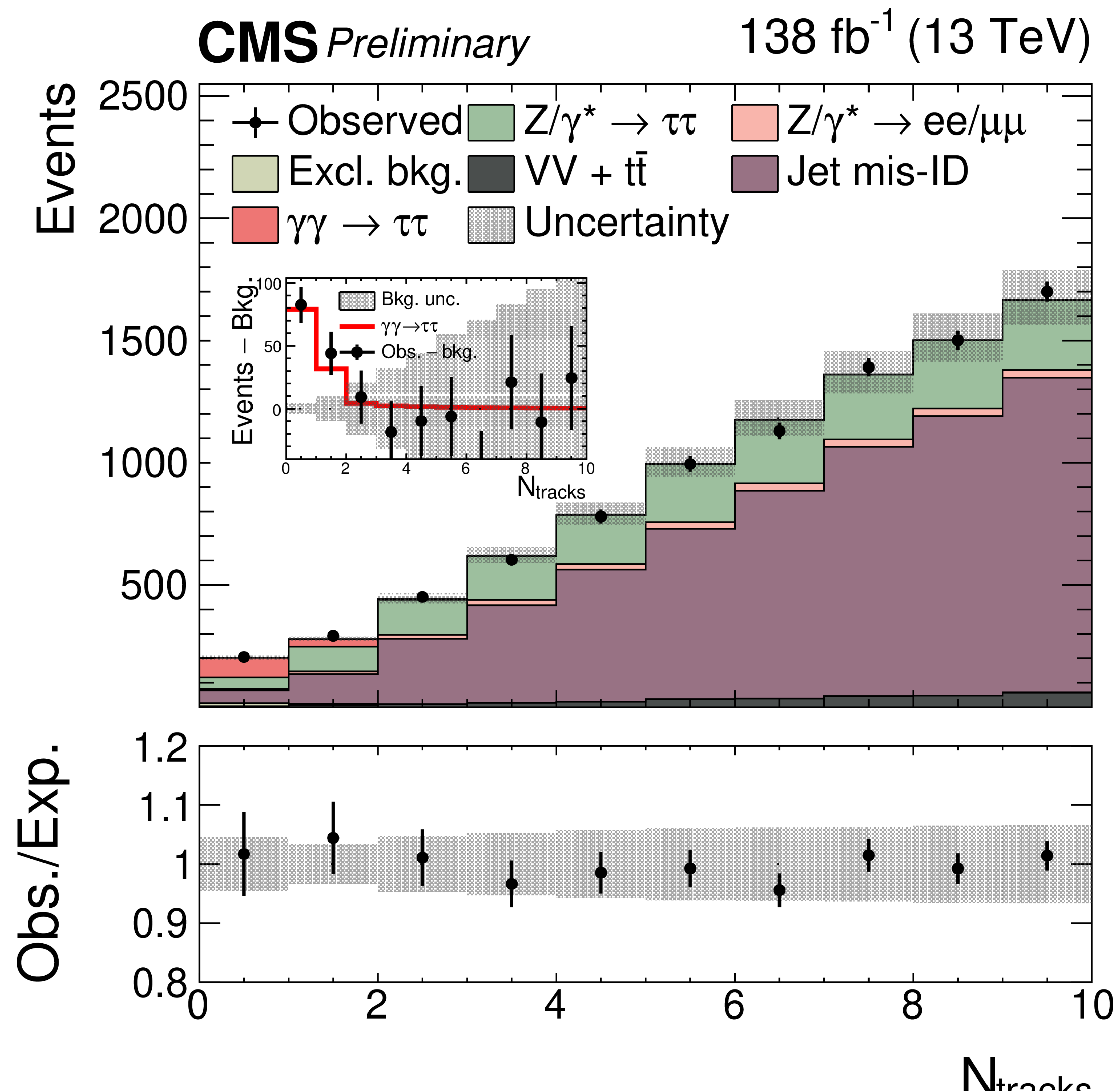
$gg \to \tau\tau$ Production

CMS-PAS-SMP-23-005





- **Clear signal in the low nTrack region**



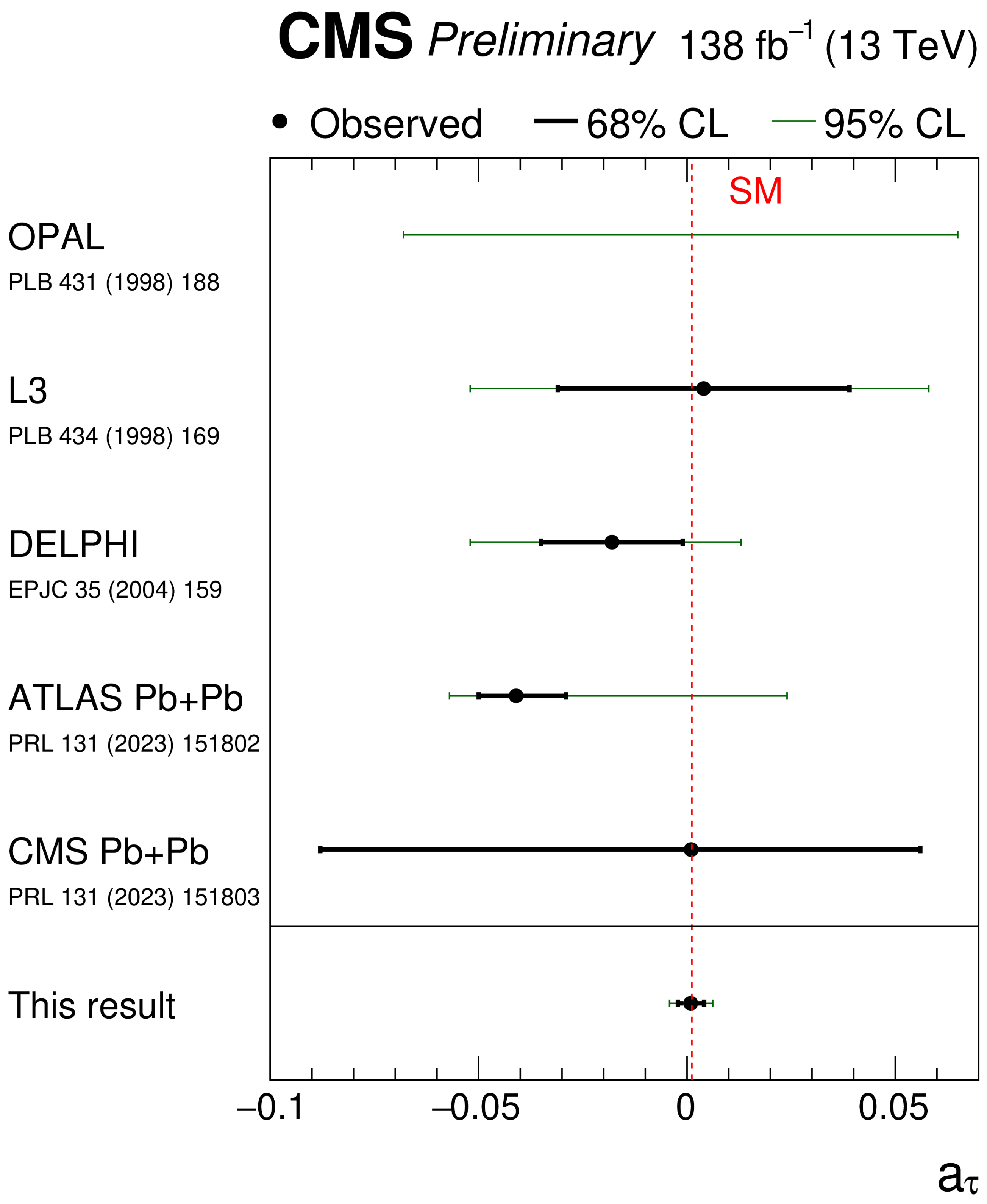
- Good agreement between data and MC in different channels
- Good sensitivity to tau anomalous electromagnetic moments

$gg \to \tau\tau$ Production

CMS-PAS-SMP-23-005

Process	$e\mu$	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$
$Z/\gamma^* \to \tau\tau$	3.6 ± 0.5	9.0 ± 1.2	18.7 ± 2.9	20.2 ± 3.1
$Z/\gamma^* \to ee/\mu\mu$	—	3.9 ± 1.2	1.6 ± 0.6	—
Jet mis-ID	5.0 ± 0.8	11.4 ± 2.9	16.5 ± 3.6	17.5 ± 2.8
Inclusive VV	3.0 ± 0.3	0.2 ± 0.0	0.4 ± 0.0	—
$\gamma\gamma \to ee/\mu\mu$	—	8.1 ± 2.3	1.4 ± 0.2	—
$\gamma\gamma \to WW$	2.5 ± 0.6	0.1 ± 0.0	0.4 ± 0.1	—
Total bkg.	14.1 ± 1.3	32.8 ± 4.8	38.9 ± 4.4	37.7 ± 4.2
Signal	11.9 ± 4.2	15.8 ± 5.7	40.3 ± 14.2	33.4 ± 11.2
Total	26.0 ± 3.8	48.5 ± 4.7	79.2 ± 13.6	71.1 ± 9.3
Observed	24	54	57	70

- Observed number of events agree with expected signal + estimated background
- **First Observation of $gg \to \tau\tau$ observation in pp collisions**



- Much better sensitivity to the anomalous electromagnetic momenta
- Set the most stringent limit on a_τ