



Measurement of the W boson mass at CMS

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Introduction

The W boson mass is a parameter of the electroweak sector of the Standard Model (SM). Its value is predicted from precise measurements of $\alpha(m_Z)$, G_μ and m_Z :

$$m_W^2 \left(1 - \frac{m_W^2}{m_Z^2}\right) = \frac{\pi \alpha(m_Z)}{\sqrt{2} G_\mu} (1 + \Delta r)$$

where Δr encodes loop corrections to the propagator (sensitive to m_H and m_T). New forces or particles may modify the value of m_W with respect to the SM prediction.

Providing a precise experimental measurement of m_W is a test of consistency of the electroweak sector of the SM. The SM prediction value of m_W is obtained by the so-called electroweak fits, the most recent being

$$m_{W,SM} = 80.353 \pm 0.006 \text{ GeV.}$$

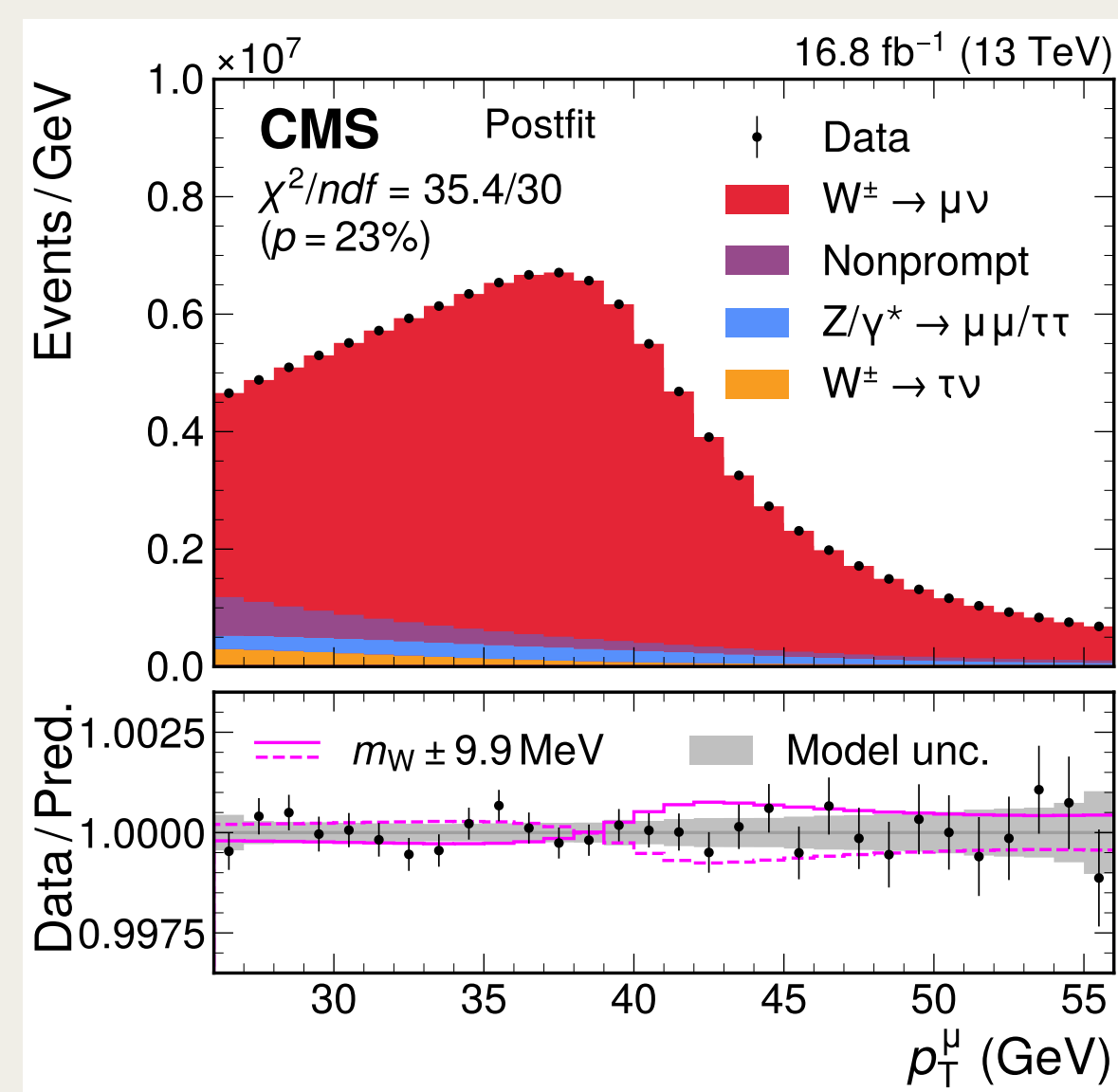
Measurement strategy

$W \rightarrow \mu\nu$ events from a subset of 2016 data (Run 2).

Value of m_W is encoded in the peak of the muon transverse momentum (p_T^μ) distribution:

- ▶ p_T^μ measurable with high precision, low dependency on pile-up collisions;
- ▶ spectrum is sensitive to the W transverse momentum p_T^W and production angular coefficients.

Goal:
reconstruct the distribution at 0.1% level to achieve $\sigma(m_W) \sim 10$ MeV.

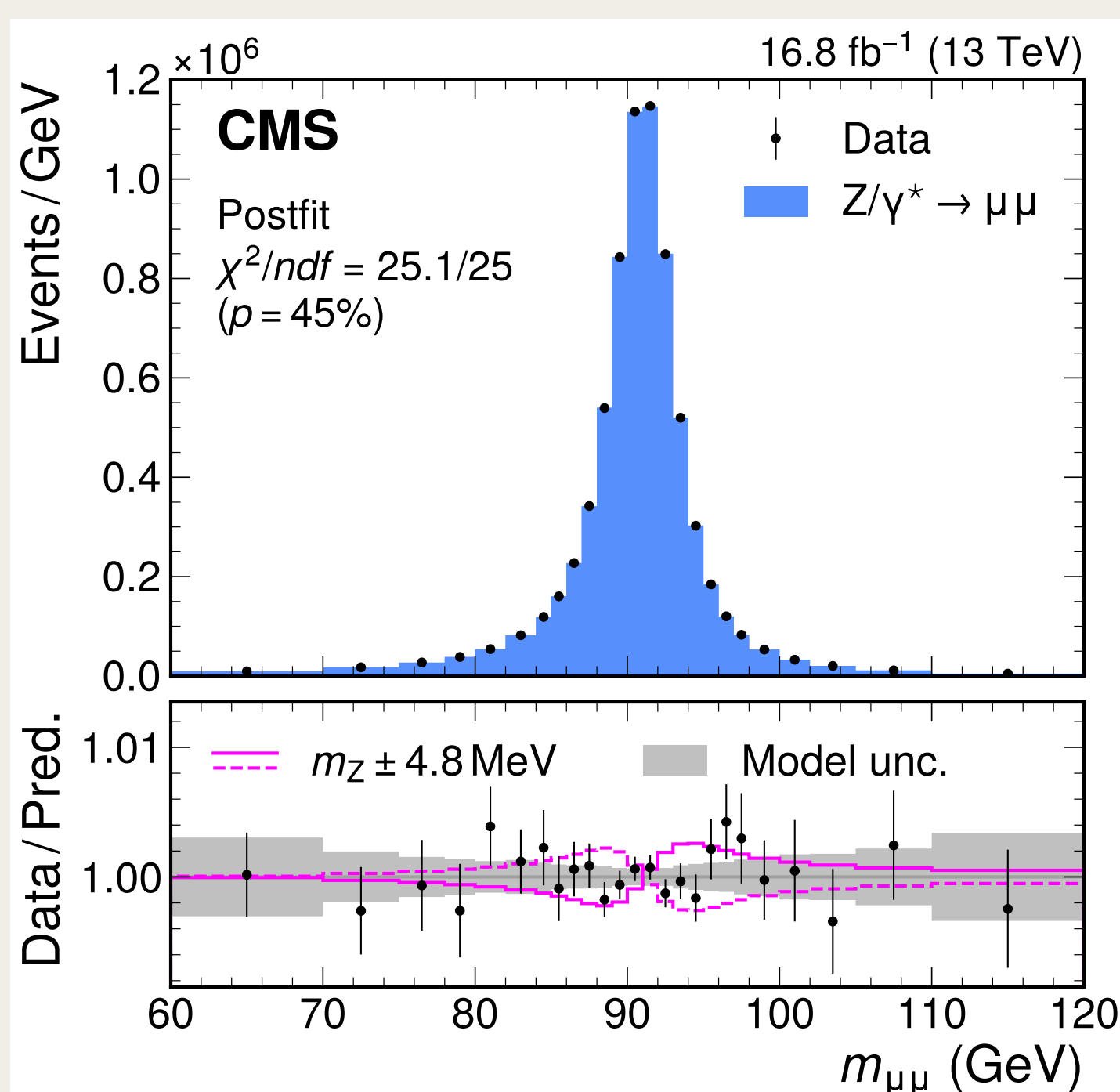


Muon momentum calibration

- ▶ A relative bias of 10^{-4} in the muon scale translates to $\Delta m_W = 8$ MeV.

Dedicated calibration of the momentum scale, based on di-muon events from J/Ψ decays:

- track refit with specialized new algorithm;
- corrections of localized detector effects;
- mass fits in $p_T^{\mu+}, \eta^{\mu+}, p_T^{\mu-}, \eta^{\mu-}$ space.



Validation on $Z \rightarrow \mu\mu$ events: "measurement" of Z mass compatible with LEP, $m_Z - m_Z^{LEP} = 2.2 \pm 4.8$ MeV.

Selection and fit strategy

- ▶ *single Global muon* [2], having $p_T^\mu \in [26, 56]$ GeV,
- ▶ *identification and isolation criteria*,
- ▶ $m_T > 40$ GeV, to suppress non-prompt background.

Analysis based on a highly granular fit to 3D distribution of p_T^μ , muon pseudorapidity η^μ and charge q^μ .

Muon reconstruction efficiencies

Local corrections to simulated templates are crucial for a precise measurement of $m_W \rightarrow$ scale factors (SF), defined as the ratio of muon reconstruction efficiency in data and in MC.

Used the **Tag-and-Probe technique** on $Z \rightarrow \mu\mu$ events, in fine bins of probe's $p_T^\mu - \eta^\mu$.

Efficiency is measured in five subsequent steps, better capture the relevant features in the reconstruction chain:

- ▶ "reconstruction": match of *standalone* muon to inner track;
- ▶ "tracking": associate a Global muon track to a standalone muon;
- ▶ "ID+IP": PF identification and loose cut on impact parameter;
- ▶ "trigger": match an object that fired the trigger to the muon;
- ▶ "isolation": no activity around the muon.

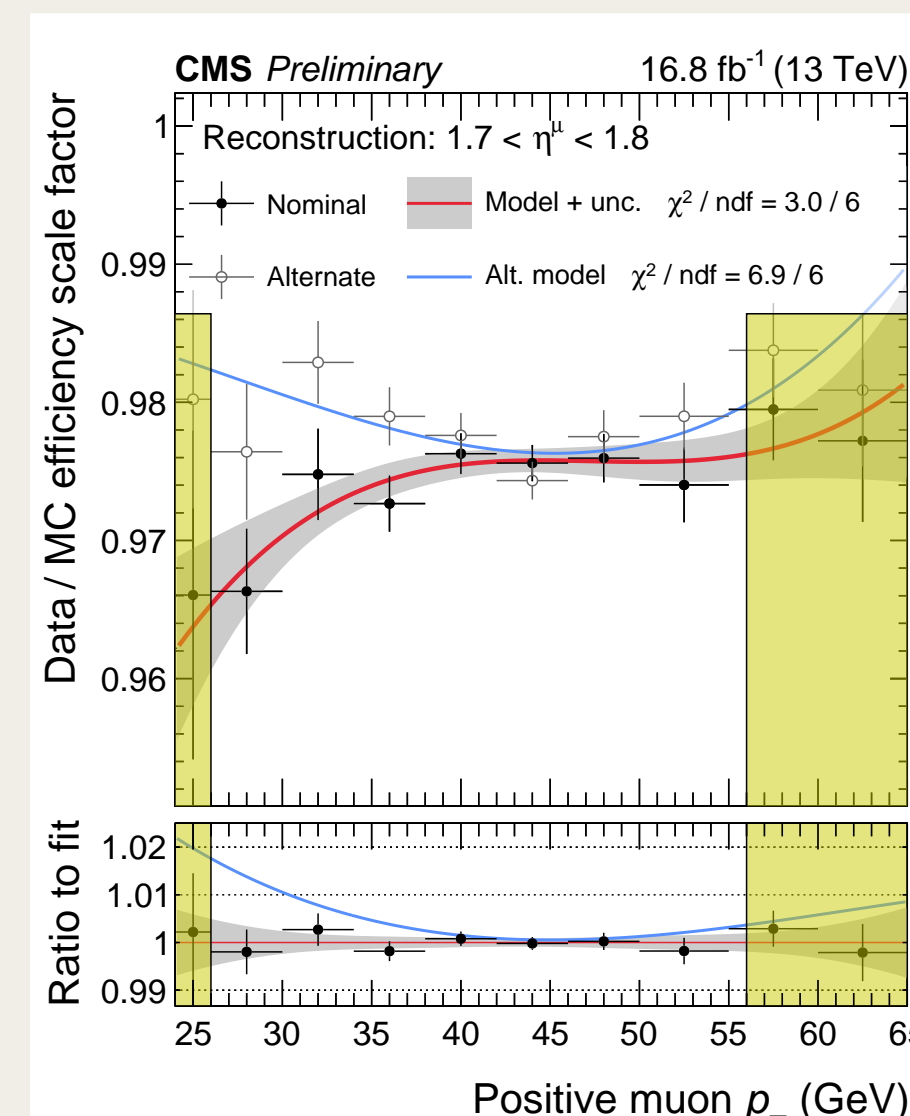
Trigger and isolation measured also in bins of Z recoil (u_T): account for different u_T spectrum between W and Z production, can modify the muon isolation.

Background subtraction on data \rightarrow likelihood fit to the tag-probe $m_{\mu\mu}$, with signal and background *pdfs*. Measurements with different models result in alternative scale factors.

Scale factors are then smoothed with respect to p_T (and u_T), to lift statistical fluctuations.

- ▶ stat. uncertainties: eigen-variations of the fit to nominal SF ;
- ▶ syst. uncertainties: ratio of smoothed alternative SF to the nominal one.

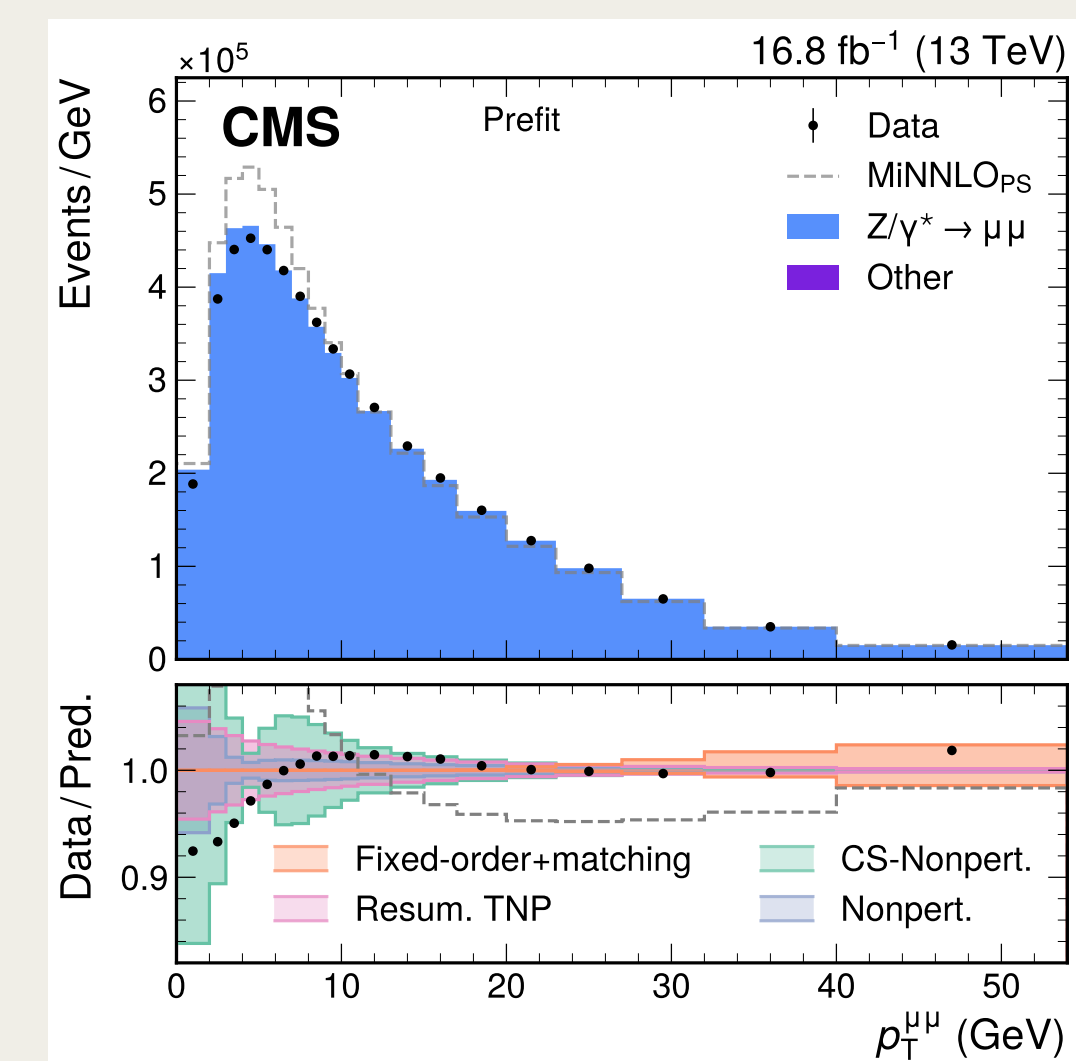
About 3000 nuisance parameters \rightarrow **impact of 3 MeV** on m_W .



W production modeling

Boson p_T distribution simulated with MiNNLO_{PS} , with corrections from advanced calculations in QCD:

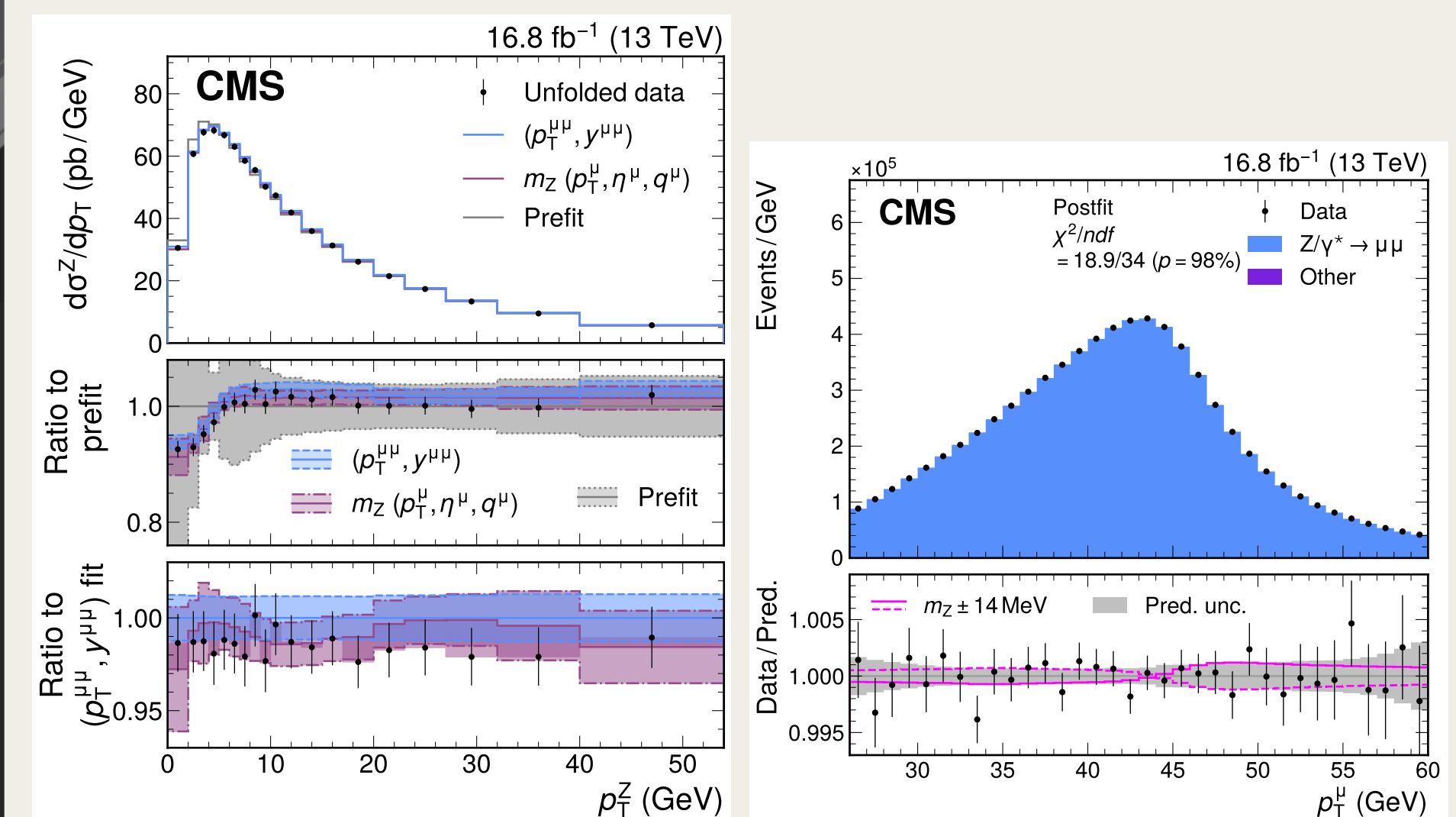
- ▶ resummation at low p_T^V/m_V with SCETlib, to achieve N^3LL order [3];
 - *Theory Nuisance Parameters* as related uncertainties [4]
- ▶ non-perturbative corrections and uncertainties;
- ▶ fixed-order corr. (NNLO) at high p_T^V , through matching with DYturbo.



Z data reserved for independent validation of uncertainty model, without tuning its parameters.

Validations

Experimental inputs and boson p_T modeling validated in the m_Z W -like measurement: on $Z \rightarrow \mu\mu$ events, one muon is treated like a neutrino \rightarrow analogue fit of m_W , in a background-free environment.

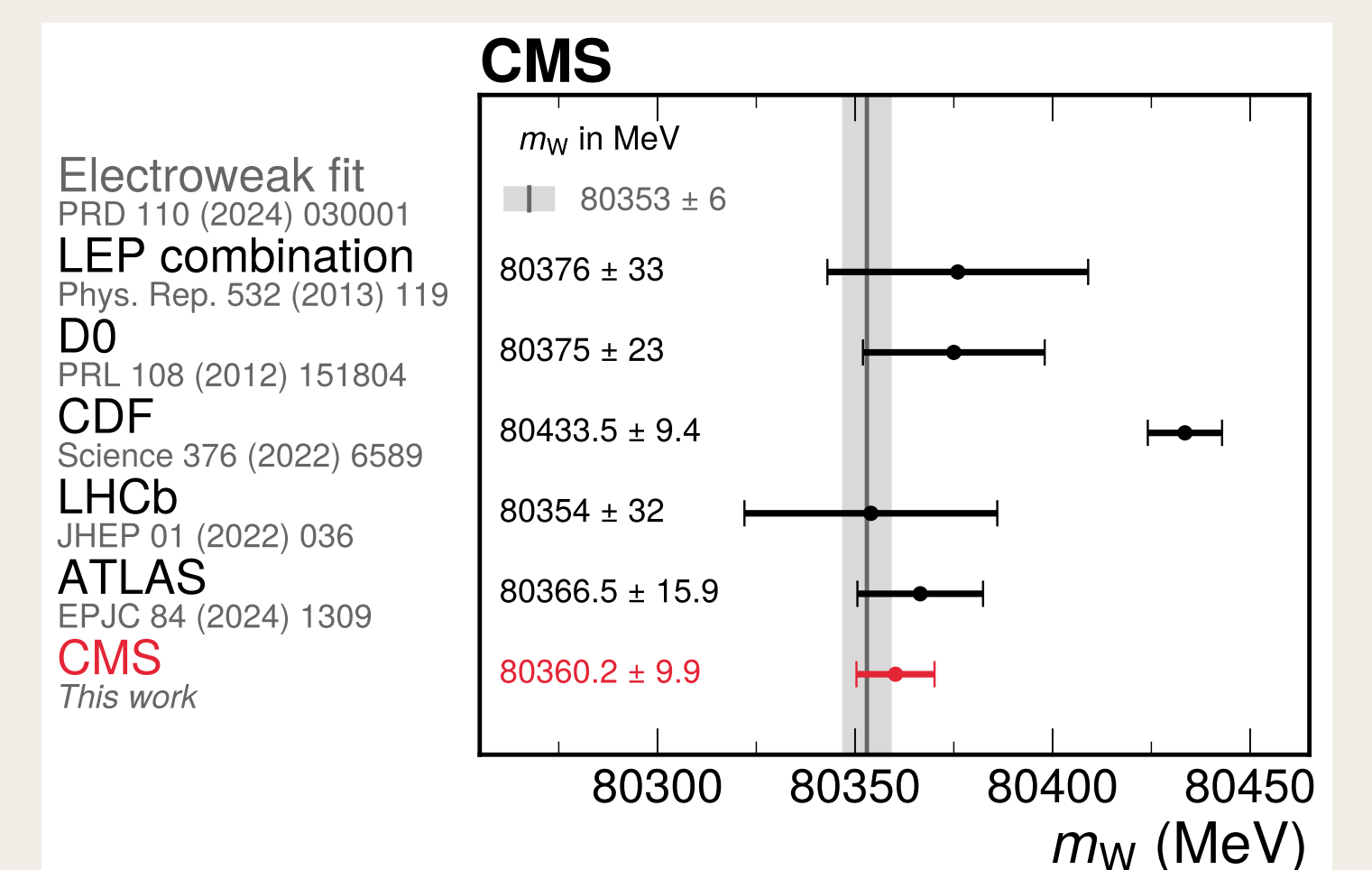


- ▶ Postfit p_T^Z spectrum from W -like fit consistent with direct fit to $p_T^{\mu\mu}$.
- ▶ Value of m_Z from W -like fit compatible with LEP value.

- ▶ Proof that p_T^W can be constrained in situ within the m_W fit, with no tuning from Z data.

Final result

$$\hat{m}_W = 80360.2 \pm 9.9 \text{ MeV}$$



Most precise measurement at the LHC, compatible with the SM prediction.

References

- [1] CMS Collaboration, *Nature* 652 (2026) 321, ARXIV:2412.13872
- [2] CMS Collaboration, *JINST* 13 (2018) P06015, ARXIV:1804.04528
- [3] Billis G., Michel J. K. L., Tackmann F. J., *JHEP* 2025 170, ARXIV:2411.16004
- [4] Tackmann F. J., ARXIV:2411.18606

Background image courtesy of CERN (CDS record 2909335)