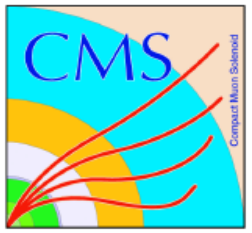


Latest results on single electroweak boson production from CMS experiment

Marco Cipriani

Sapienza Università di Roma e INFN Roma1

On behalf of the CMS collaboration

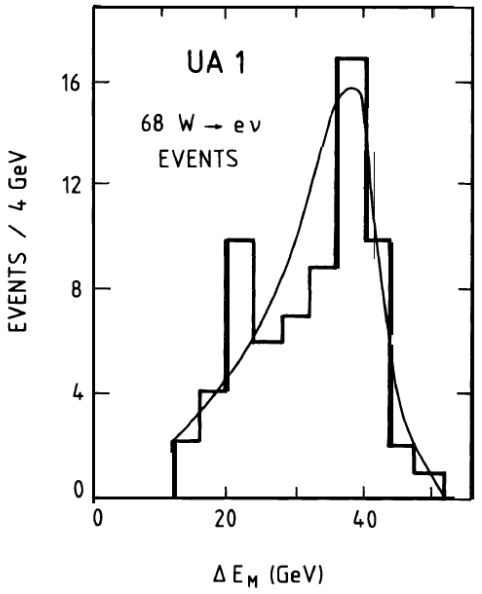
LHCP2018:

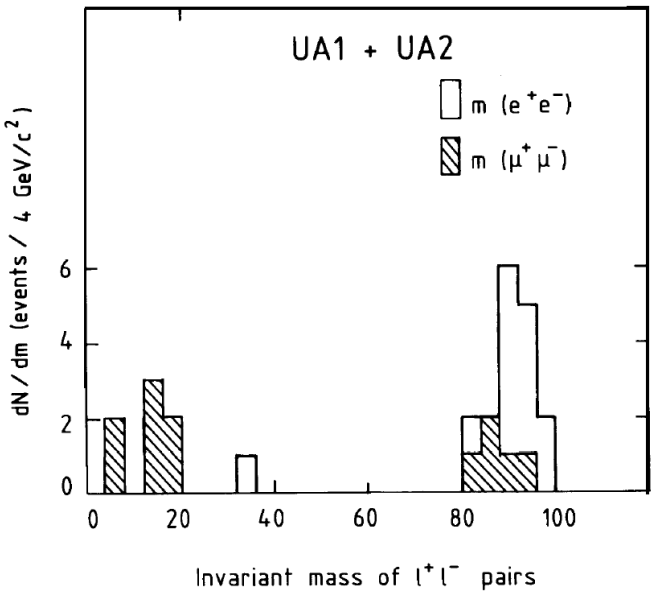
Sixth Annual Conference on Large Hadron Collider Physics

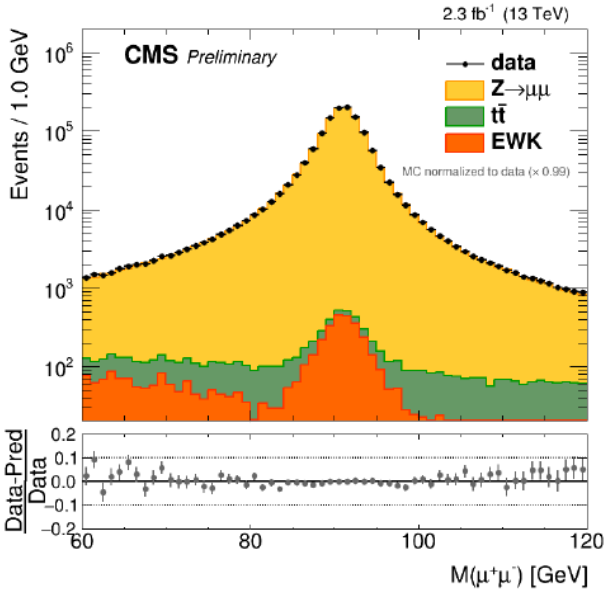
04-09 June 2018, Bologna (Italy)

35 years of electroweak bosons!

- **W and Z bosons discovered at CERN in 1983 (predicted ≈ 20 years before)**
  - properties more deeply studied later at LEP and Tevatron in 90'
- **Still on the front line of the LHC physics programme**
  - Z bosons extensively used **for e/μ energy scale calibration**
  - inclusive and differential cross-section measurements provide stringent **tests of perturbative QCD calculation and parton distribution functions** (PDF)

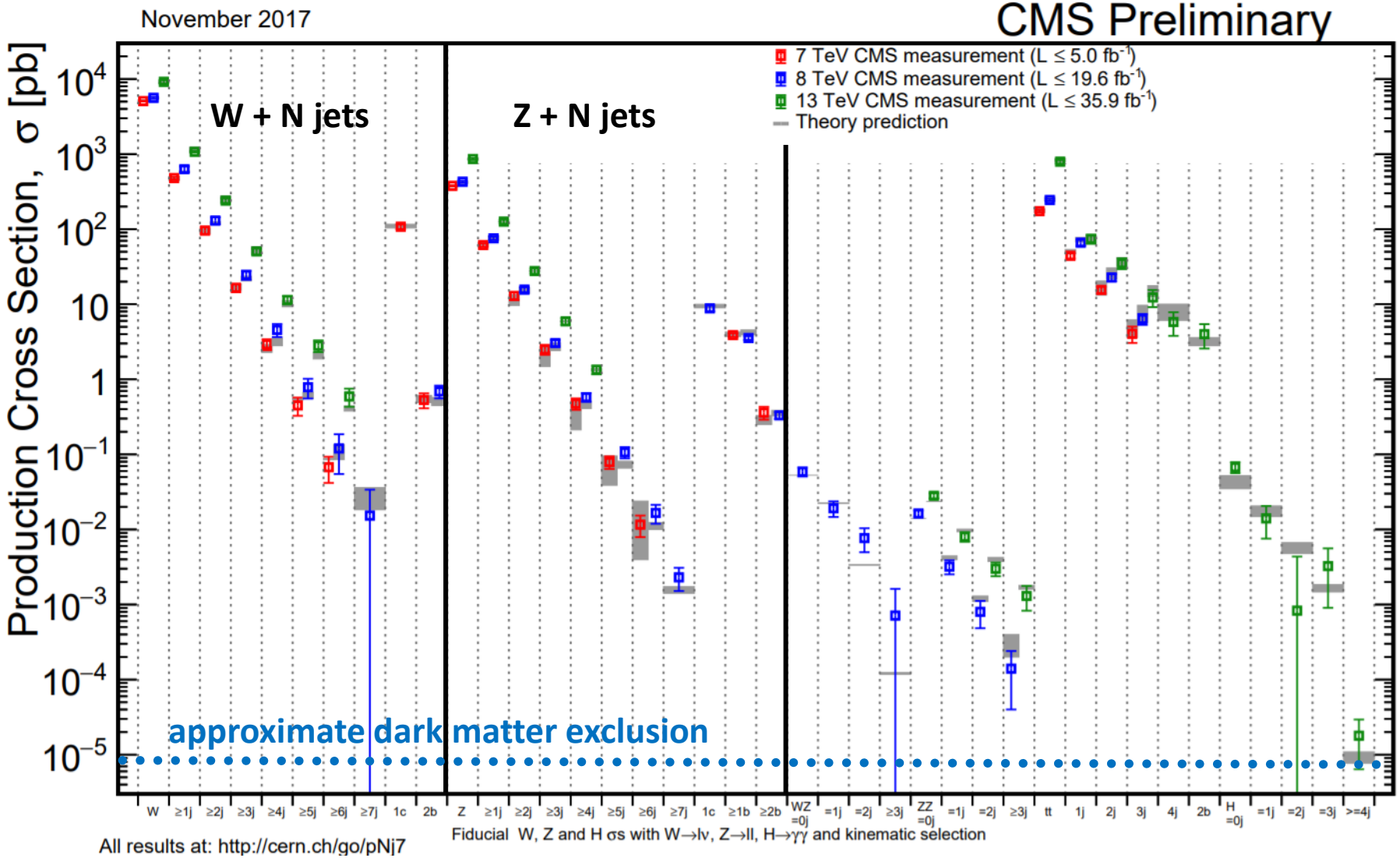






The success of the Standard Model

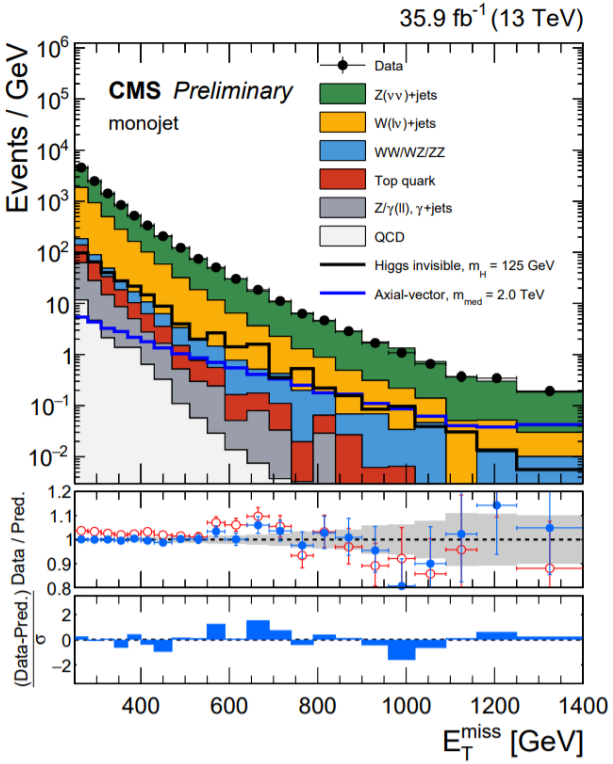
- **Experimental cross section measurements span over > 7 orders of magnitude**
  - very good agreement with theoretical predictions at different energy scales

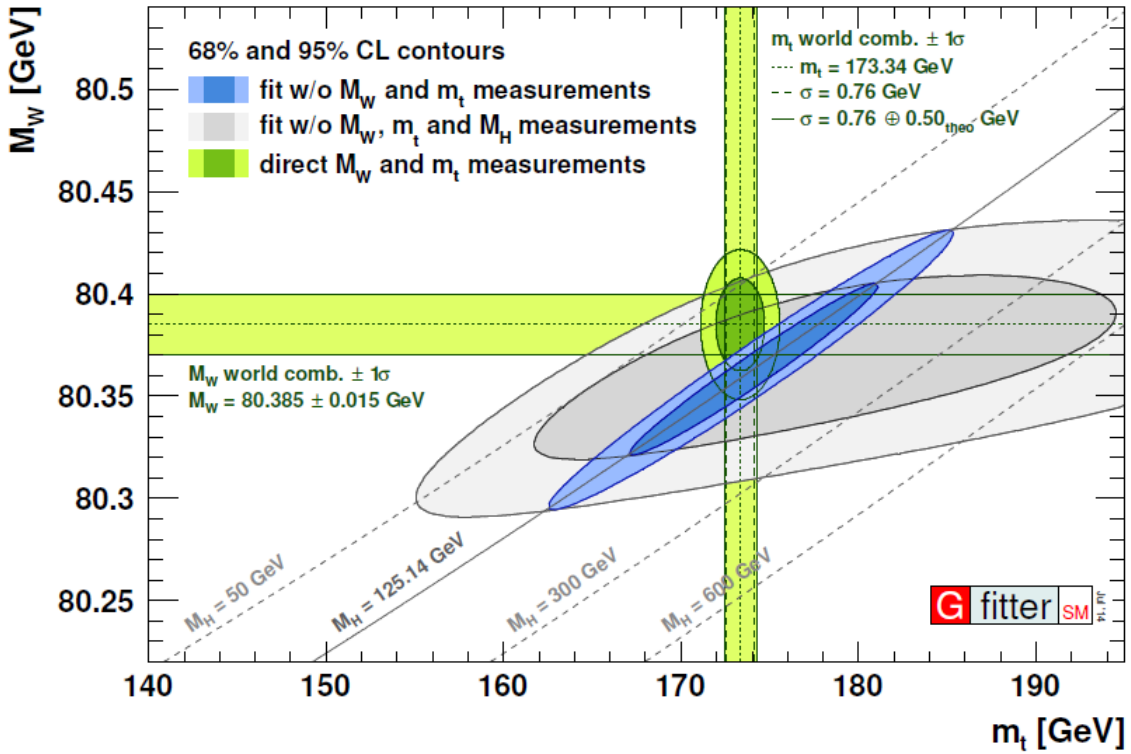


Still of paramount interest

- **Z/W production is a constant presence in any analysis at LHC**
  - main source of background in searches for dark matter
  - precise experimental knowledge of kinematic spectra, supported by robust theoretical calculation, fundamental for searches for new physics

- **Key role for other Standard Model measurements as well**
  - $d\sigma/dp_T^Z$ and $d\sigma/dp_T^W$ crucial to reach O(10) MeV precision on W-boson mass





Main features of Z/W analyses

- **Latest CMS public results mostly based on 8 TeV or early 13 TeV data**
  - unlike searches for new physics, **details (and systematics) matter a lot**
  - analysis with recent data ongoing/under approval

- **Cross-sections measured (double-)differentially in many kinematic variables**
  - boson or lepton p_T, η, number of jets or other suitable variables
  - often **normalized to total cross-section**: some uncertainties cancel out

- **Results compared with predictions from several MC generators**
  - **test different approaches to model parton shower and/or hard scattering**
  - theoretical calculations often available at NNLO(+NNLL) at few % precision

For each bin i of given observable

$$\left[\frac{d\sigma}{dx}\right]_i = \frac{N_{evt}^i - B^i}{L \cdot (\varepsilon \cdot A)^i \cdot \Delta x^i}$$

N_{evt}: observed events in i-th bin
B : background events
L : integrated luminosity
$\varepsilon \cdot A$: efficiency times accceptance

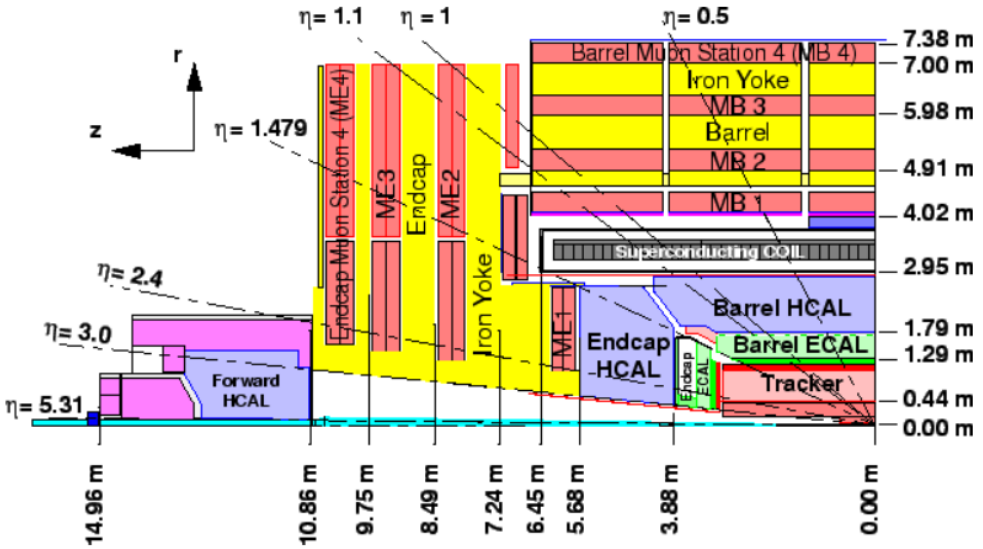
Common experimental details

- **Clean signatures due to leptonic decay (especially for Z bosons)**
  - isolated high p_T leptons
  - main backgrounds: top quark production, DiBosons, τ (from Z/W), QCD

- **Measurements performed in fiducial regions**
  - **e/μ p_T thresholds dictated by trigger** (depend on $\sqrt{s}$)
  - **η limited by tracker acceptance**

- **Unfolding techniques to allow for direct comparison with predictions**
  - efficiency and **detector resolution**

Typical kinematic requirements		
Flavour	**p_T [GeV]**	**$\lvert\eta\rvert$ (<)**
Electron	25	2.5
Muon	20	2.4

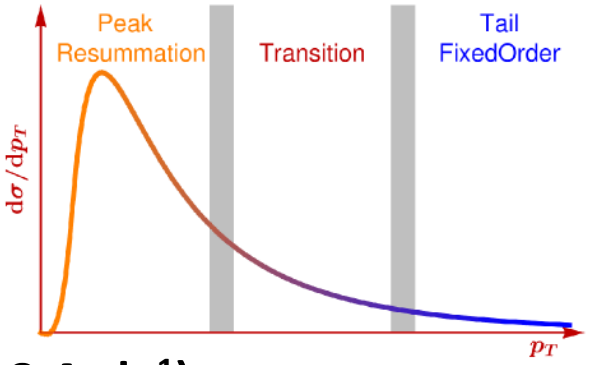


8 TeV data

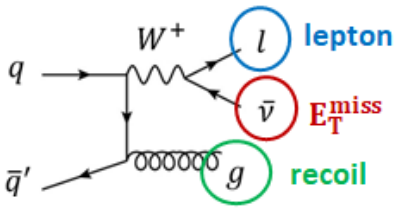
W and Z-boson $d\sigma/dp_T$

published in JHEP

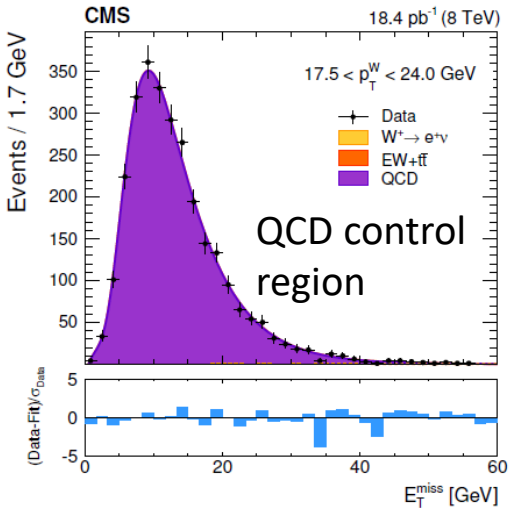
- **Fixed order perturbative QCD calculations works for $p_T \gtrsim m_{Z,W}$**
  - large logarithmic terms for $p_T \ll m_{Z,W}$ due to soft gluon radiation, resummation needed
  - measurements at $p_T \lesssim 10$ GeV are precious

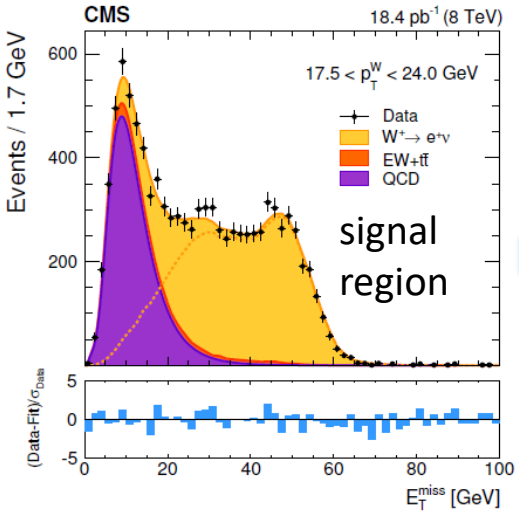


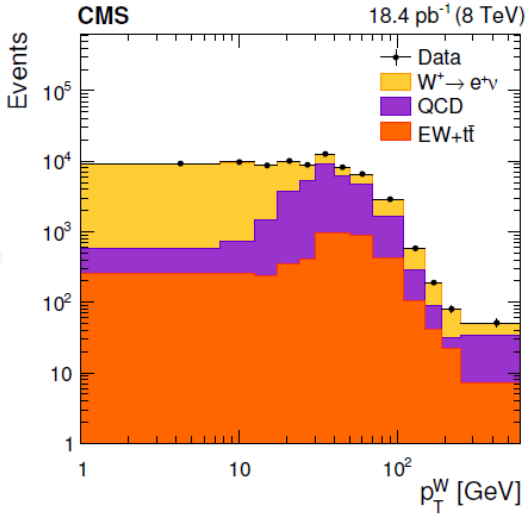
- **Data collected during special low-luminosity run (18.4 pb^{-1})**
  - less background, improved recoil resolution (mainly for W)



- **Signal extraction**
  - W: fit to E_T^{miss}, QCD shape from control region (inverted lepton ID/isolation)
  - Z: count events within selected mass window





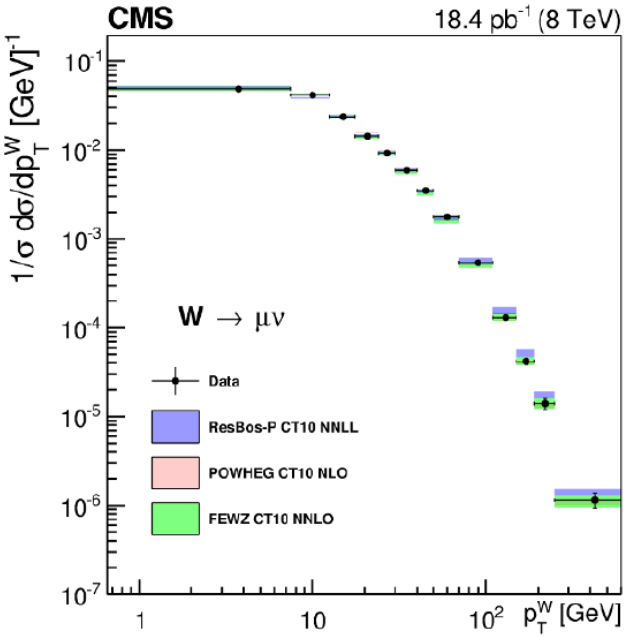


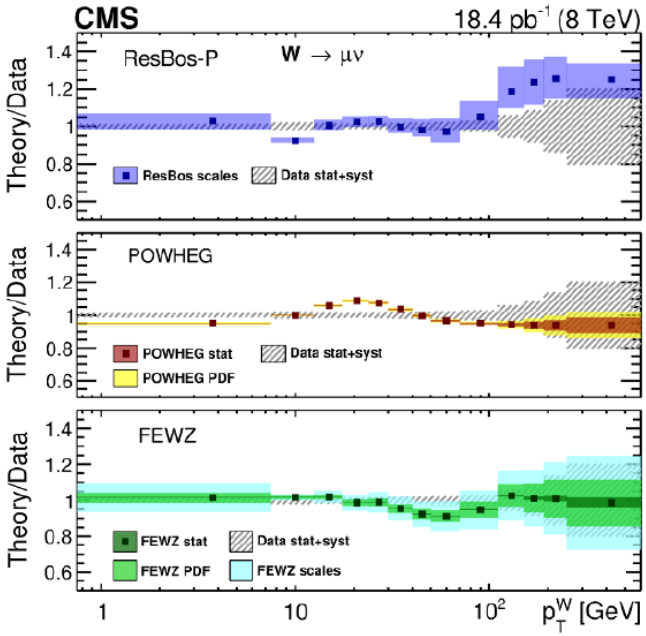
Comparison with theory

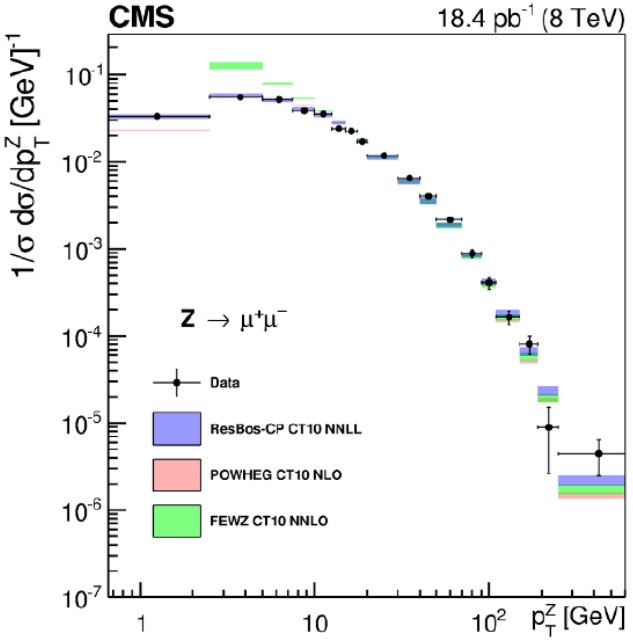
published in JHEP

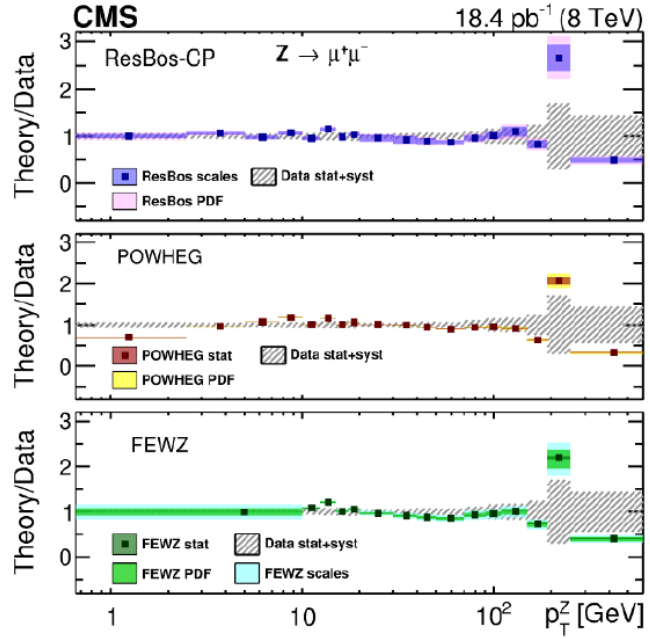
Comparison with **ResBos**, **POWHEG** and **FEWZ** with CT10 PFDs

Different predictions have some level of disagreement in different p_T regions







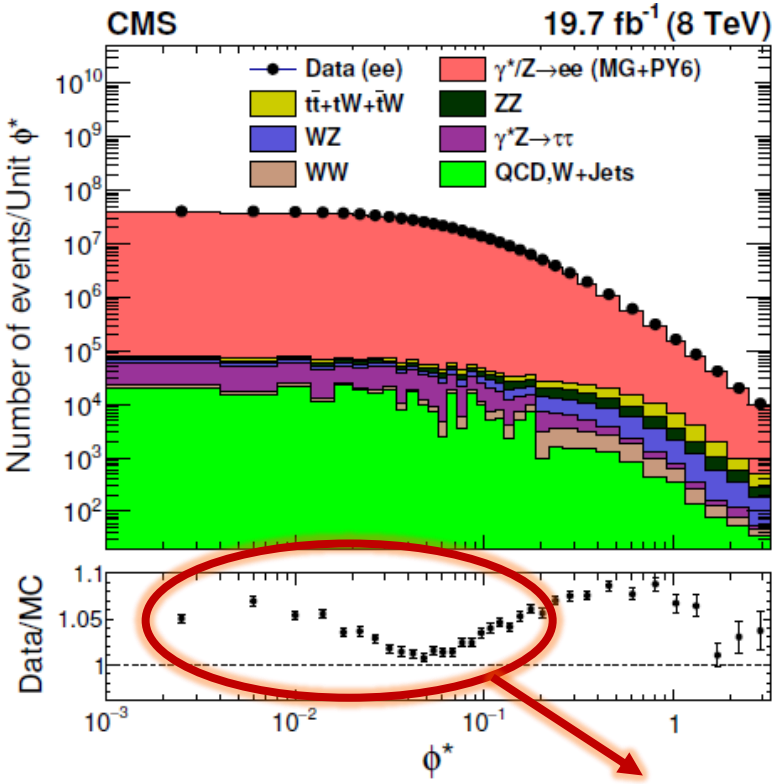


Z-boson dσ/dϕ*

- **ϕ^* correlated with p_T^Z, but better resolution**
  - depends only on angular variables

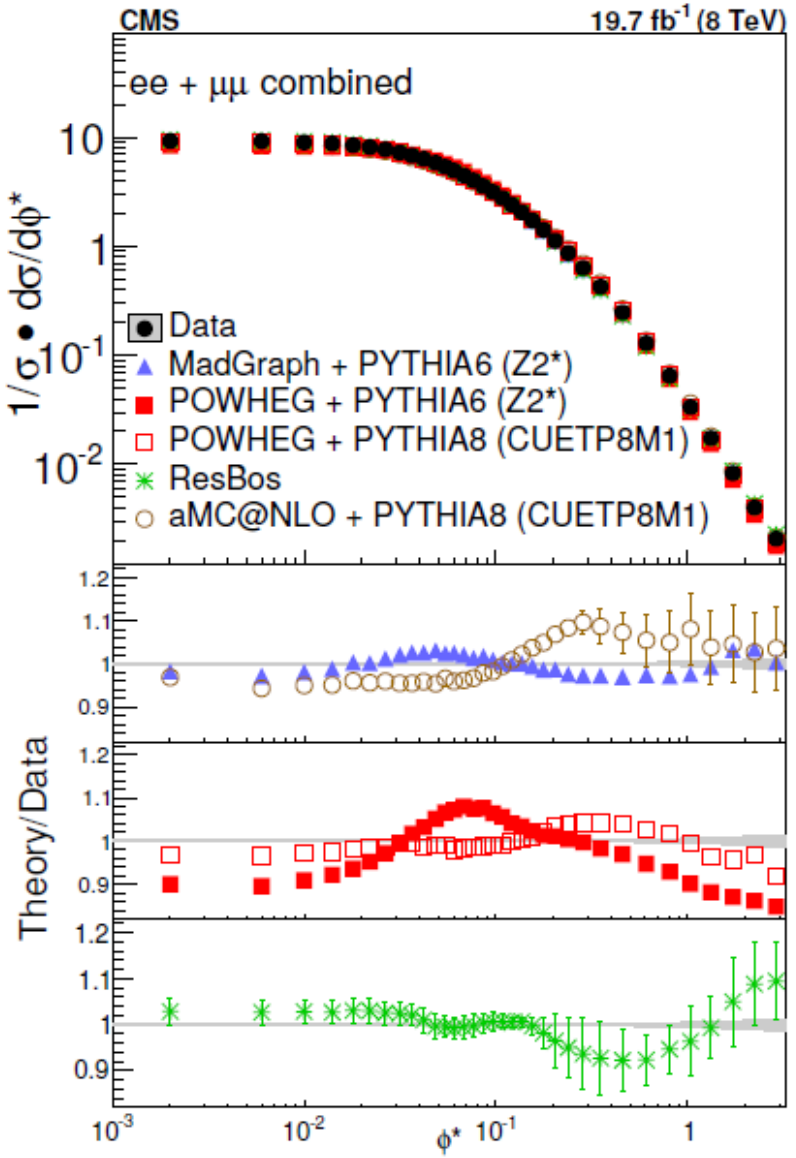
$$\phi^* = \tan\left(\frac{\pi - \Delta\phi}{2}\right)\sin(\theta_\eta^*) \qquad \phi^* \approx p_T^Z/m_{ll}$$

$$\cos(\theta_\eta^*) = \tanh(\Delta\eta/2)$$

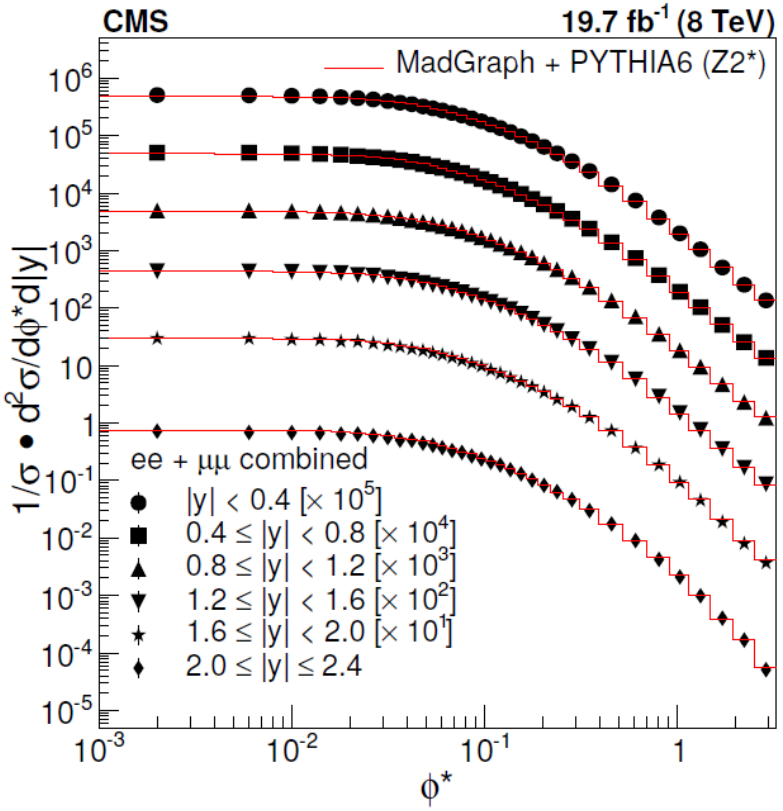


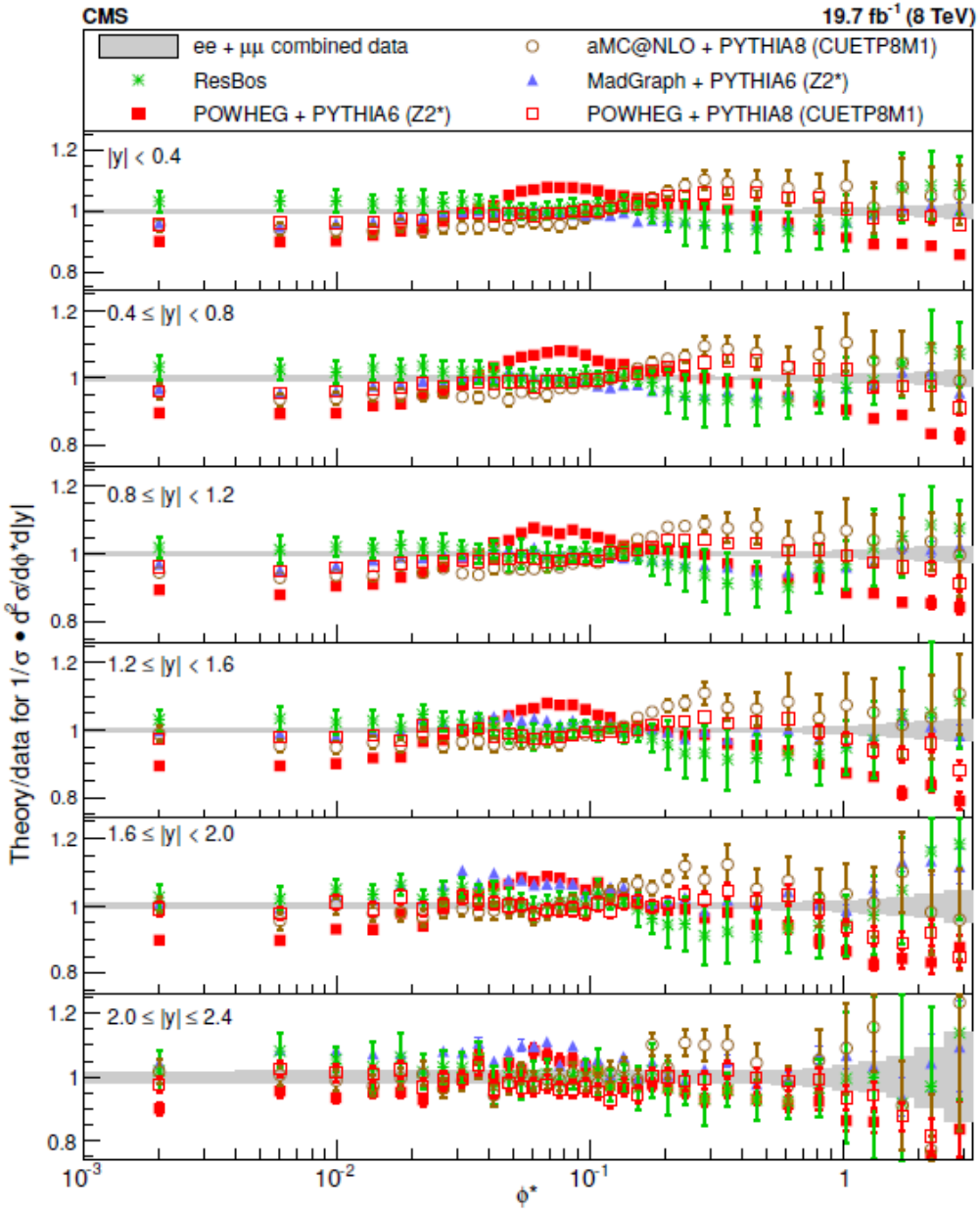
$p_T^Z \lesssim 10$ GeV

SMP-17-002, published in JHEP



Z-boson $d^2\sigma/d\phi^* d|y|$





Compare with different predictions

- more advanced calculations of hard scattering better reproduce data
- showering method and non perturbative effects are important

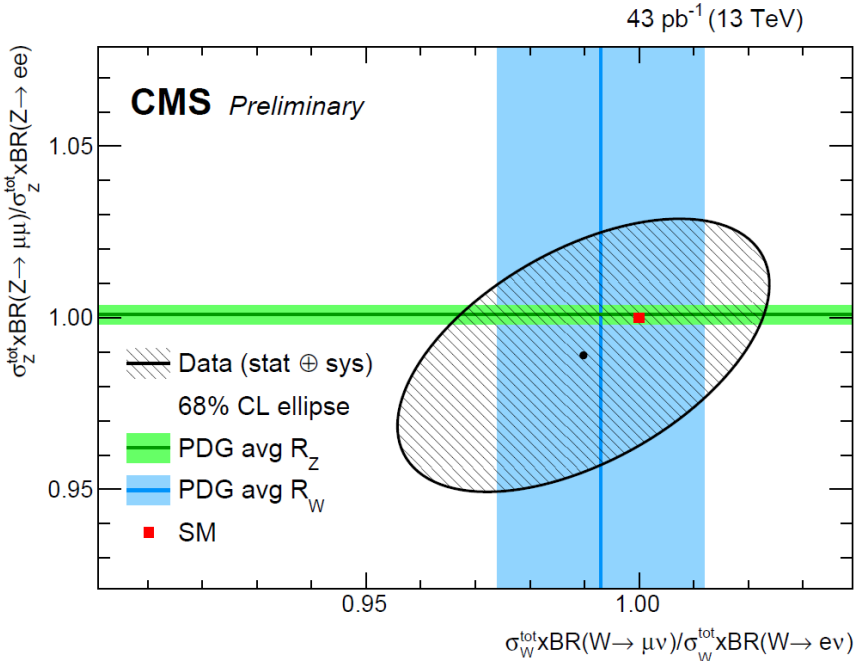
13 TeV data

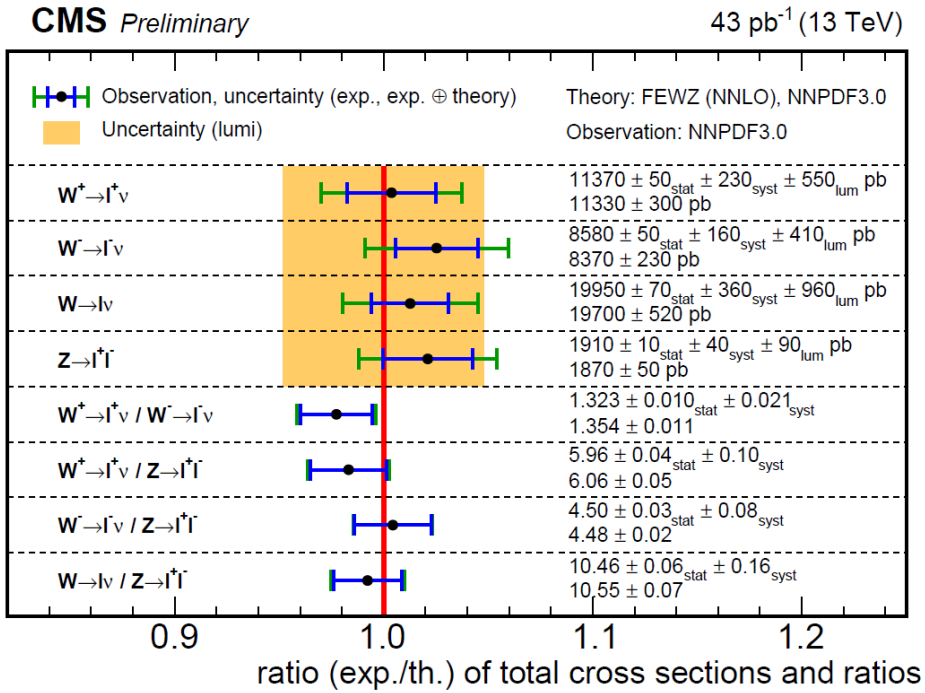
Inclusive W and Z production cross sections

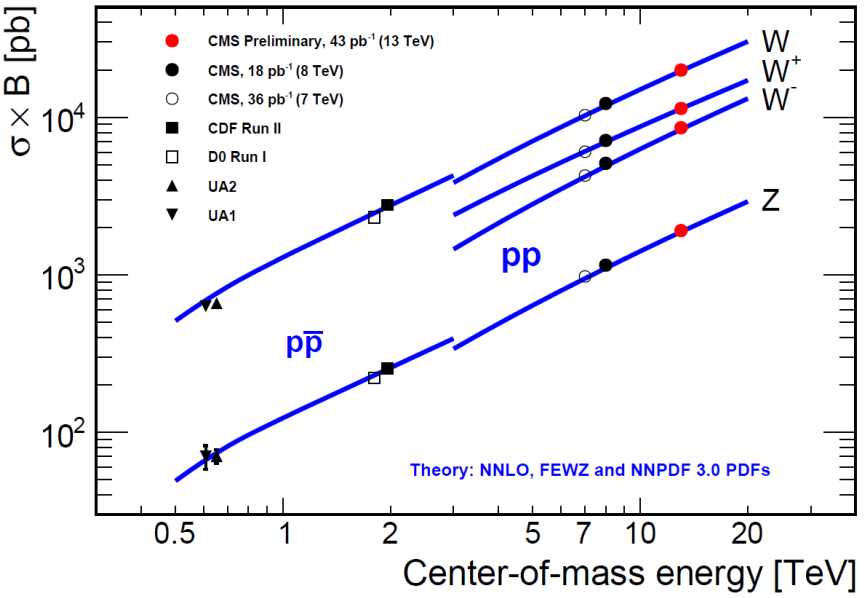
CMS-PAS SMP-15-004 (2015 data)

simple measurement
→ but a lot of information

measurements by CMS at 7 and 8 TeV
→ validate theory at different $\sqrt{s}$







Inclusive and differential Z production cross sections

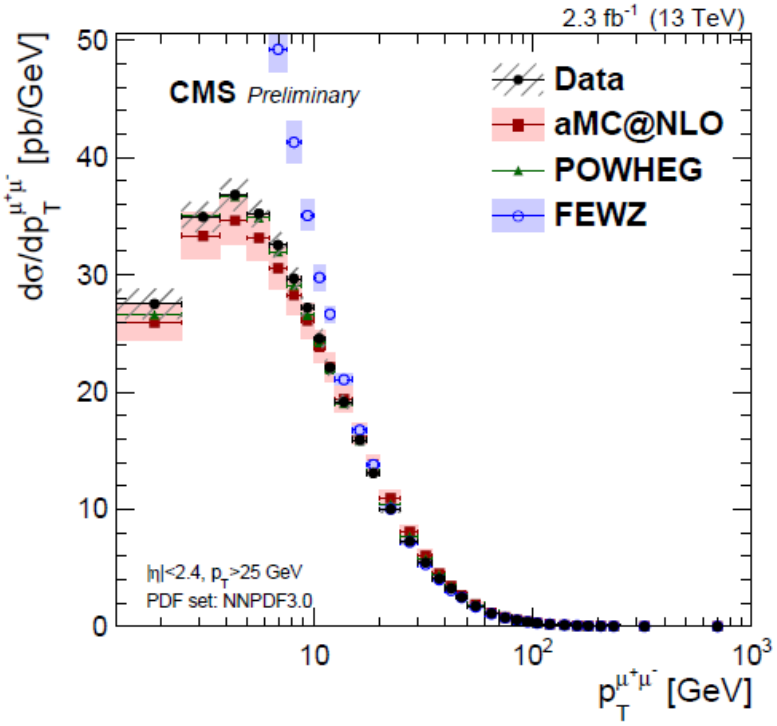
Measurement on **full 2015 dataset with Z→ μμ**

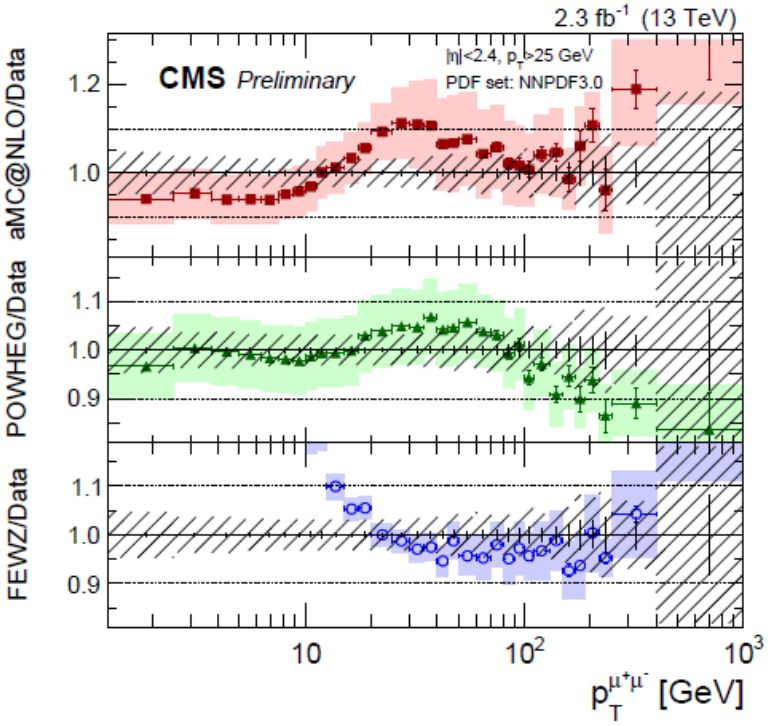
- Inclusive and differential in $p_T^{\mu\mu}$, ϕ^*, $|Y^{\mu\mu}|$, p_T^{μ}

Inclusive measurement: 1870 ± 2 (stat) ± 35 (syst) ± 51 (lumi) pb

- good agreement with theory (NNLO QCD + NLO EWK)

For differential measurements, **no generator describes data in all phase-space**



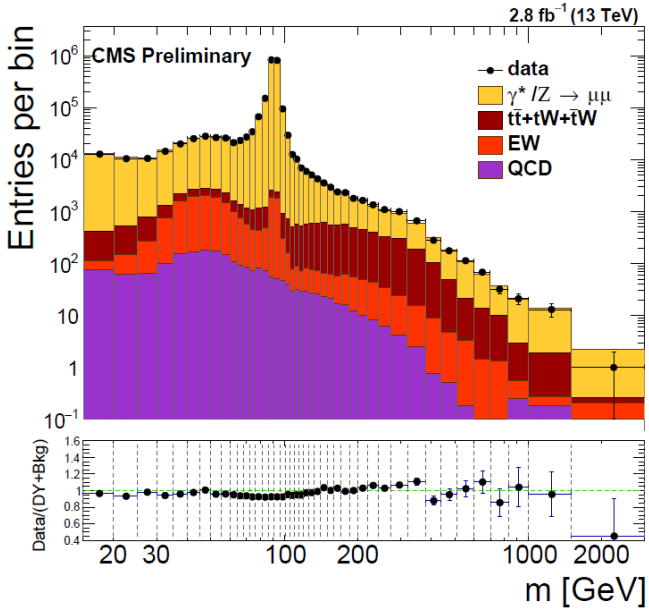


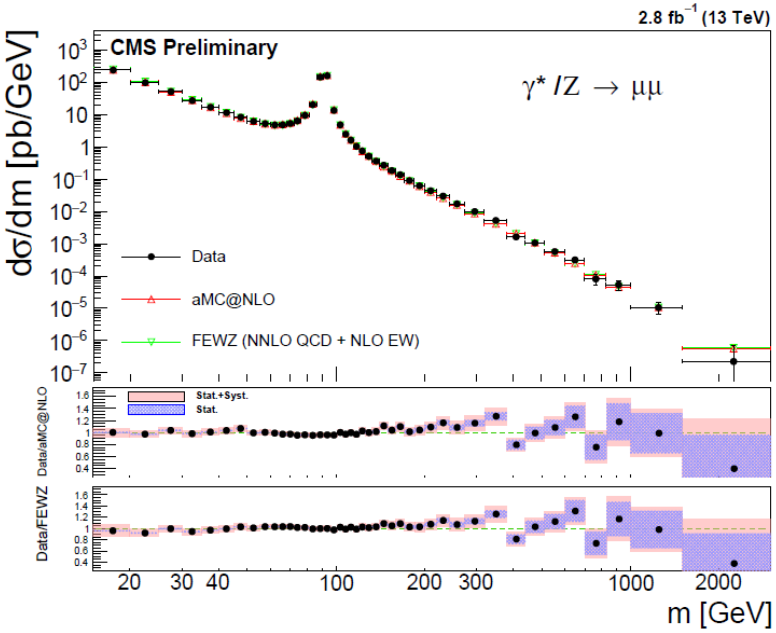
CMS PAS SMP-15-011

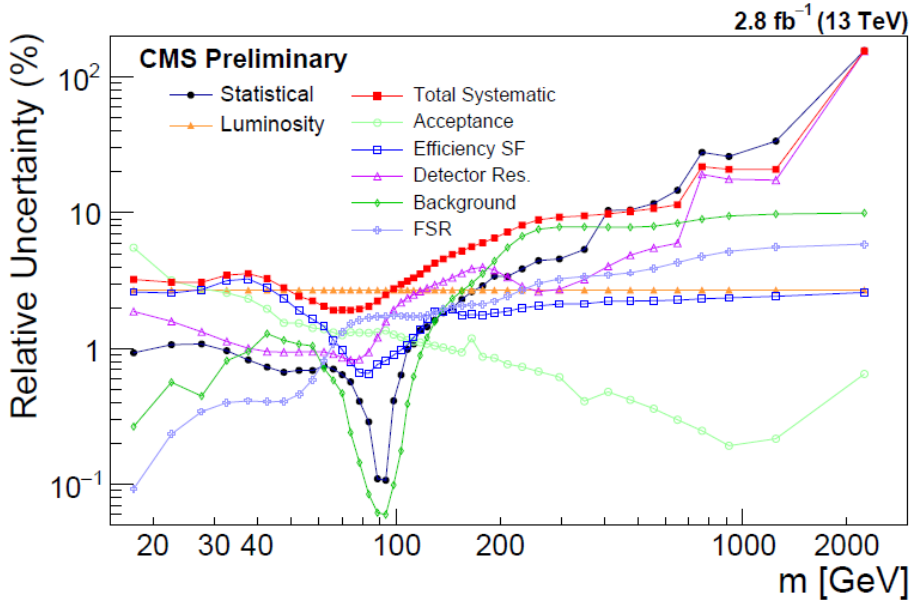
Differential Drell-Yan cross section

CMS-PAS SMP-16-009

- **paramount for searches for new resonances** decaying into lepton pairs
- **statistical uncertainty dominates at high mass**
  - improve with more data
- **limited by muon p_T resolution at high mass**
  - improve adding electron channel (on its way)



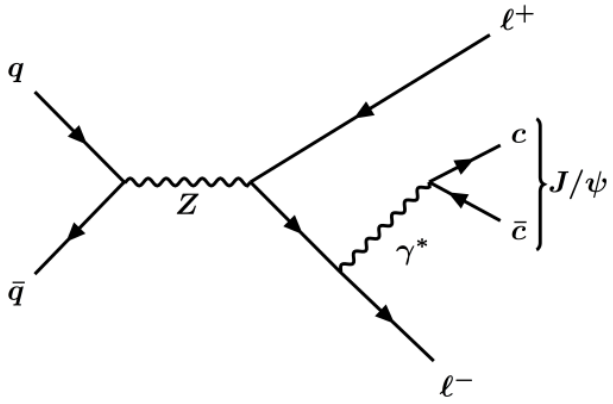




Rare decays: $Z \to J/\psi\, l^+ l^-$

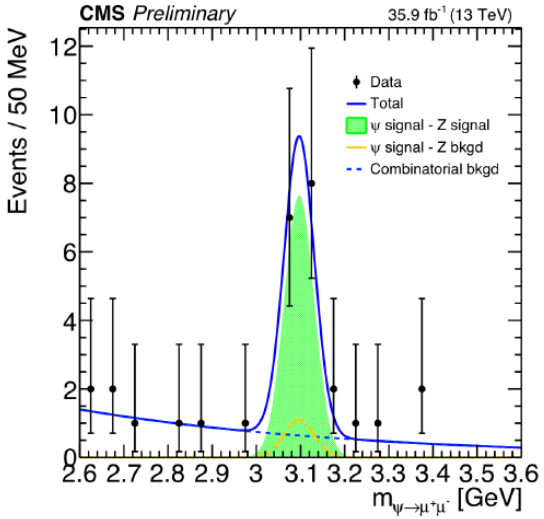
- **$Z \to ee/\mu\mu,\ J/\psi \to \mu\mu$**
  - predicted branching ratio: $\approx 7 \cdot 10^{-7}$
  - **first observation of this process**

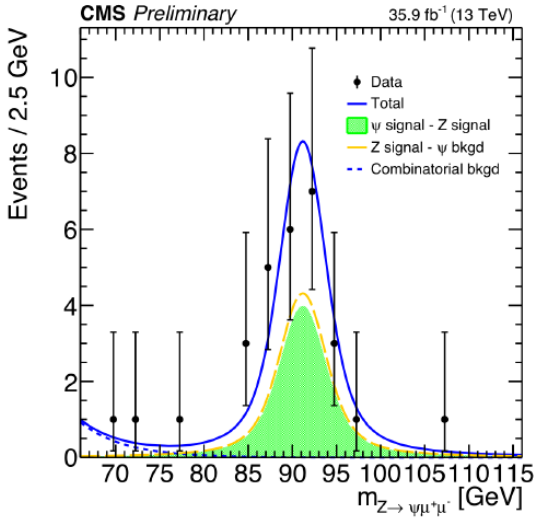
CMS-PAS SMP-16-001

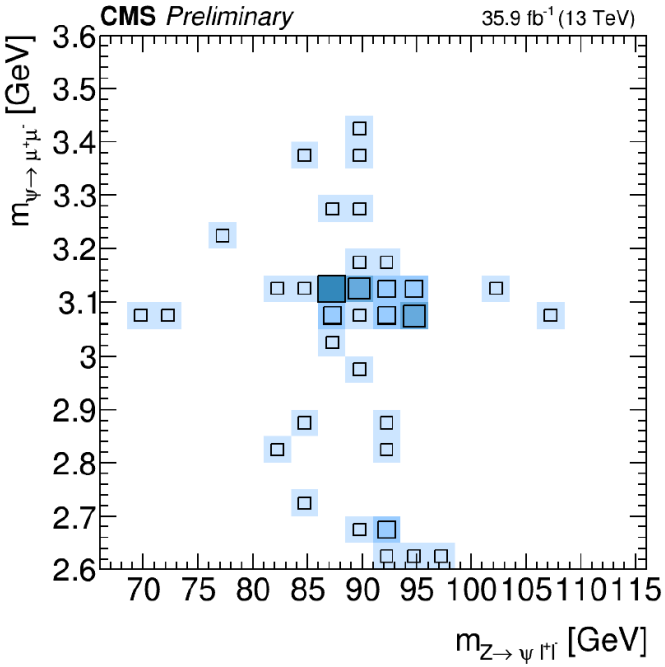


- **Branching ratio presented as ratio to $Z \to 4\mu$**
  - $R_{J/\psi l^+ l^-} = 0.70 \pm 0.18\ (\text{stat}) \pm 0.05\ (\text{syst})$
  - assume unpolarized J/ψ (extreme polarization scenarios imply $\approx$ 20% variation)

- **Full 2016 dataset used**
  - polarization study requires more data







Summary

- **Some latest CMS result about Z/W production presented**
  - mostly on **8 and early 13 TeV data** (many new results will become public soon)
  - still a lot of space for improvements with larger 13 TeV dataset

- **Measurements of paramount importance for searches for new physics**
  - help consolidate our current knowledge of the electroweak sector
  - lead to **more accurate background predictions** for other rare processes

- **Cross-sections measured (double-)differentially in many kinematic variables**
  - valuable inputs to **test theoretical calculations** at higher orders

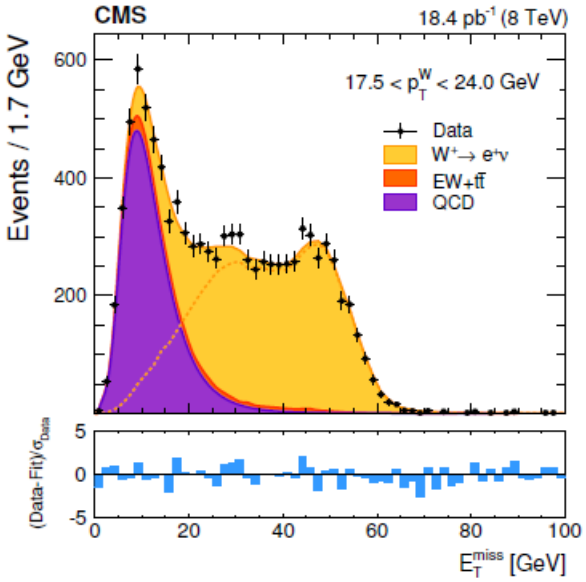
- **Results compared with predictions from many generators**
  - **test different approaches to model parton shower and/or hard scattering**
  - level of agreement depends on considered phase-space, but generally good

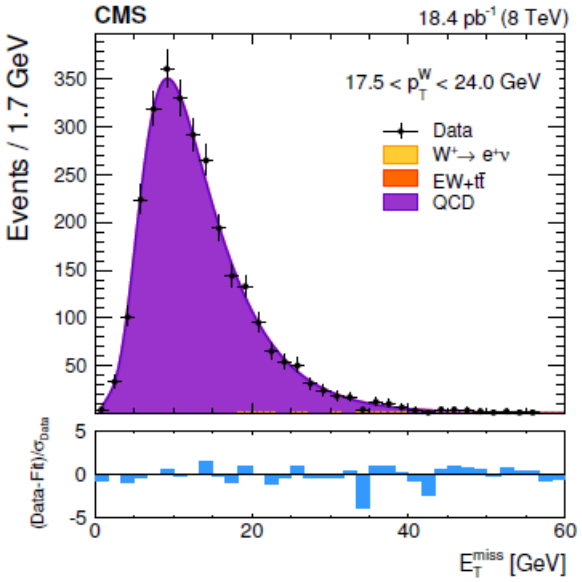
BACKUP

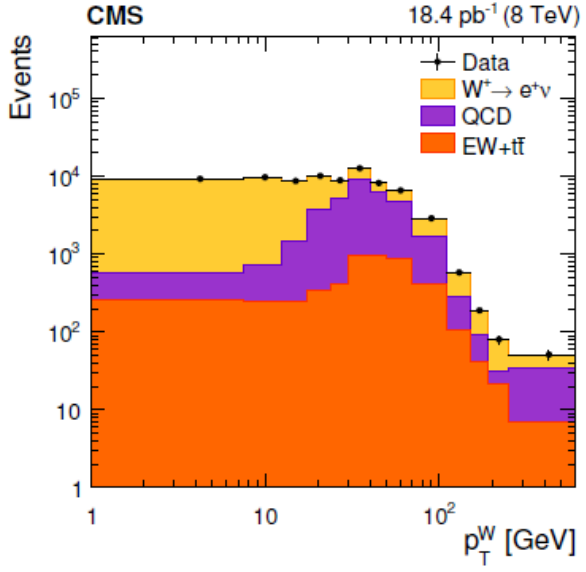
W and Z-boson $d\sigma/dp_T$

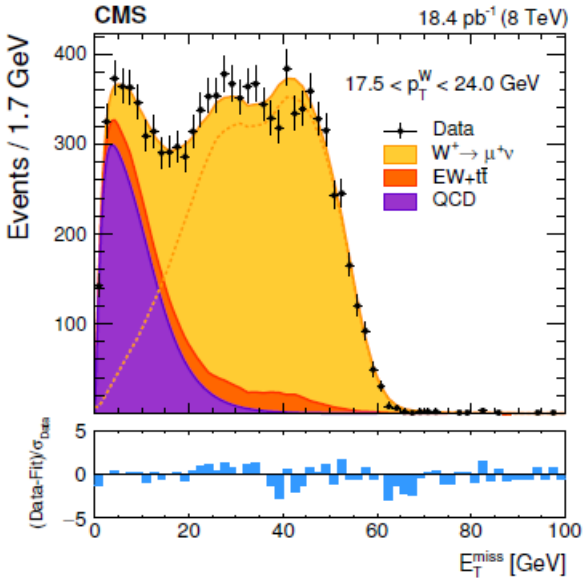
signal region

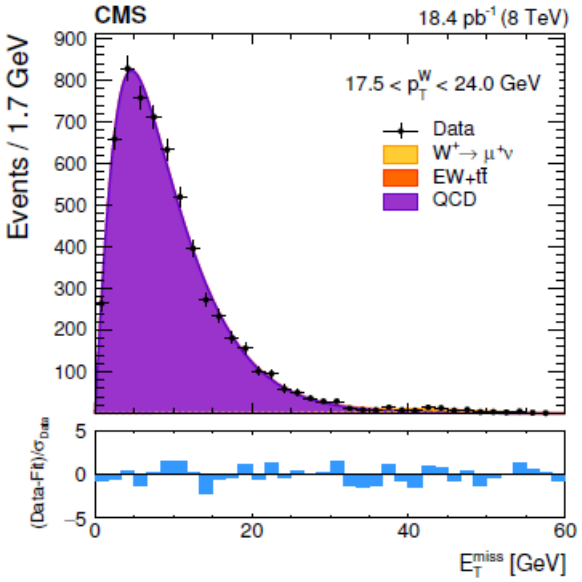
QCD control region

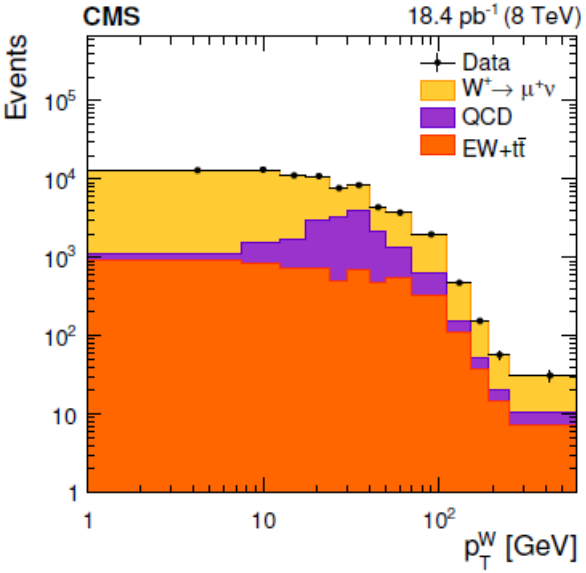






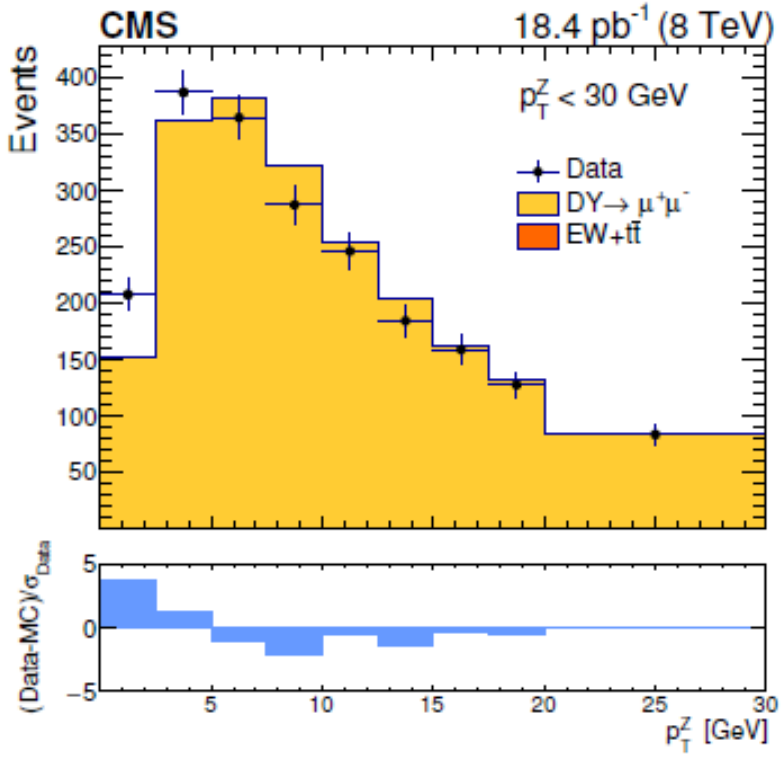


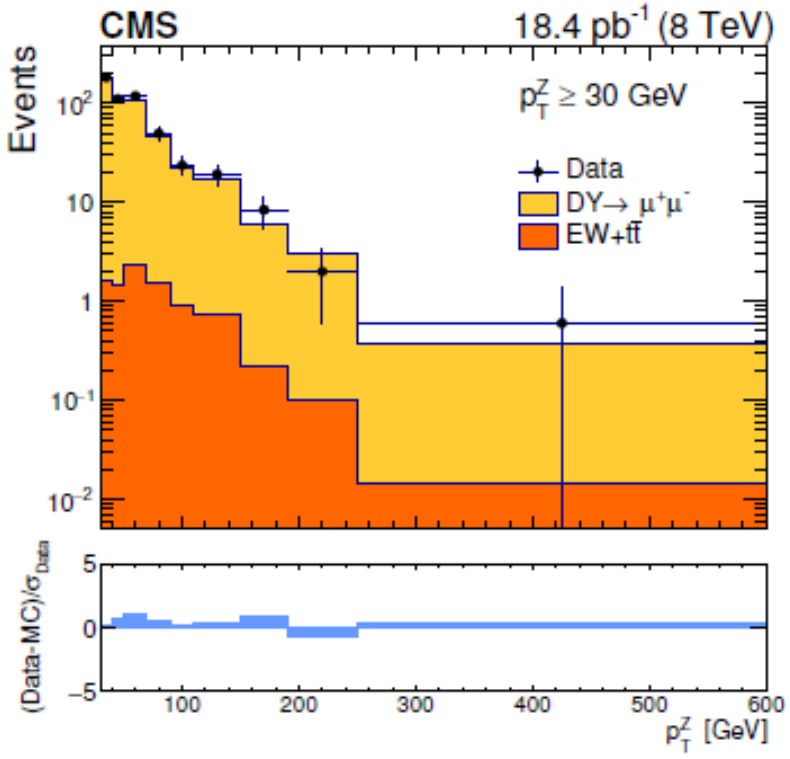




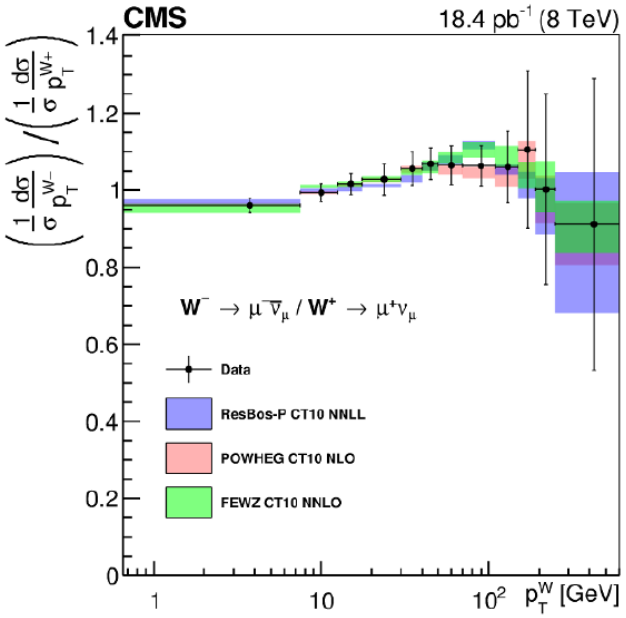
W and Z-boson $d\sigma/dp_T$

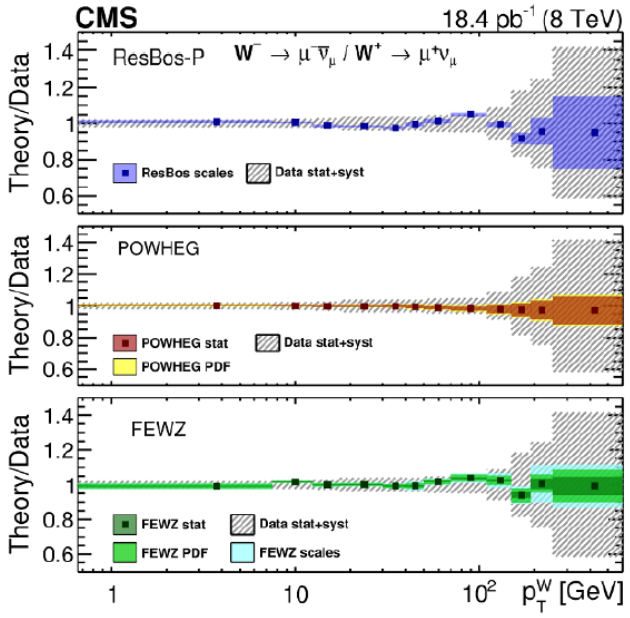
- **QCD background negligible in the Z channel**
  - data-driven estimate
  - compute probability that a QCD object is identified as a lepton (pass ID/isolation)
  - use this probability to reweight events in a sample with non-isolated leptons

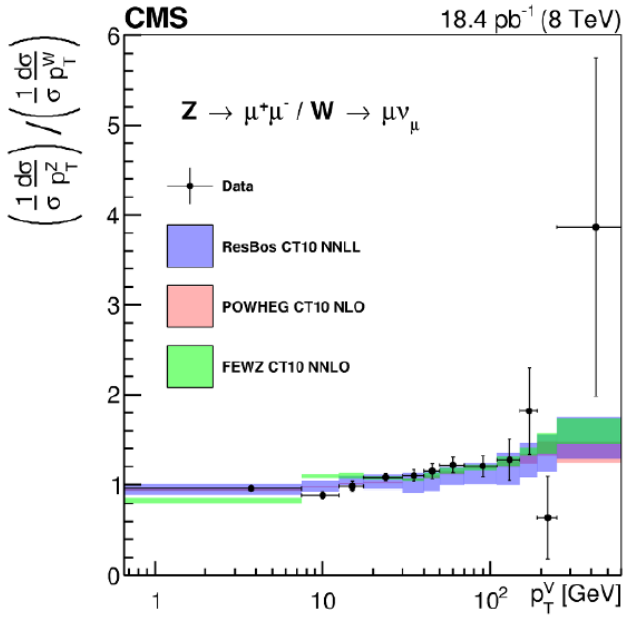


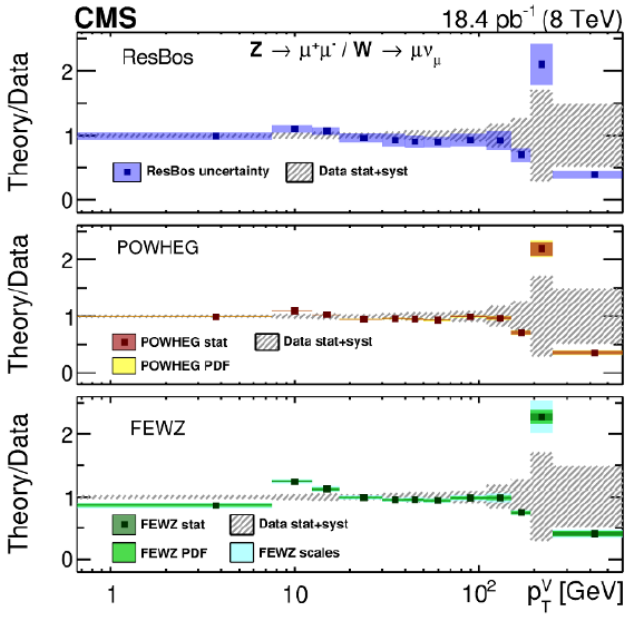


W and Z-boson $d\sigma/dp_T$





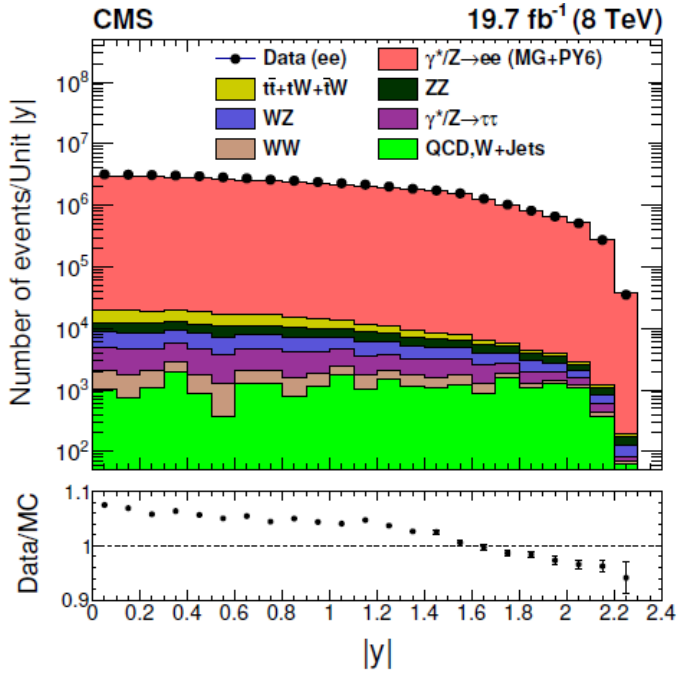


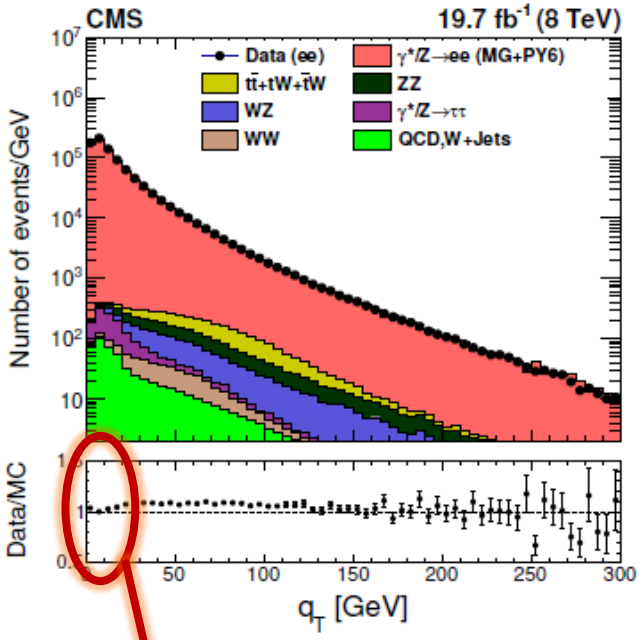


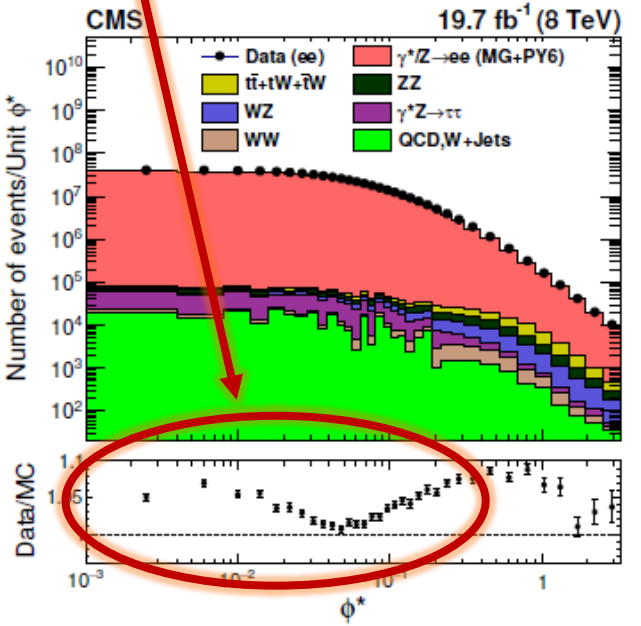
Z-boson $d^2\sigma/d\phi^* d|y|$

- **measurement performed in fiducial region**
  - p_T^l> 30 GeV, $|\eta_l|$ < 2.1 for first lepton
  - p_T^l> 20 GeV, $|\eta_l|$ < 2.4 for second lepton
  - leptons defined before final-state radiation

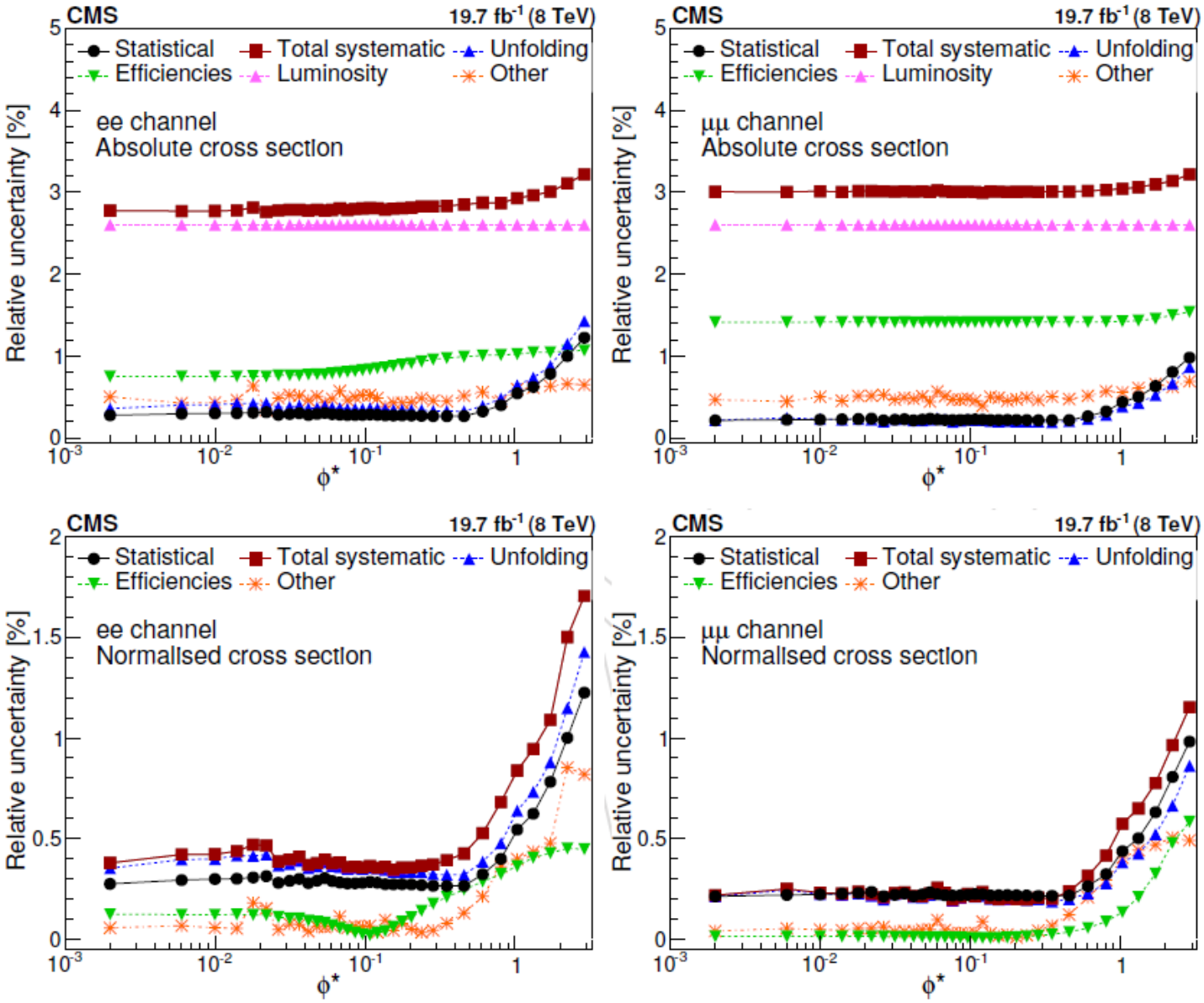
- **observed distributions unfolded to pre-FSR**
  - using D'Agostini method with 4 iterations





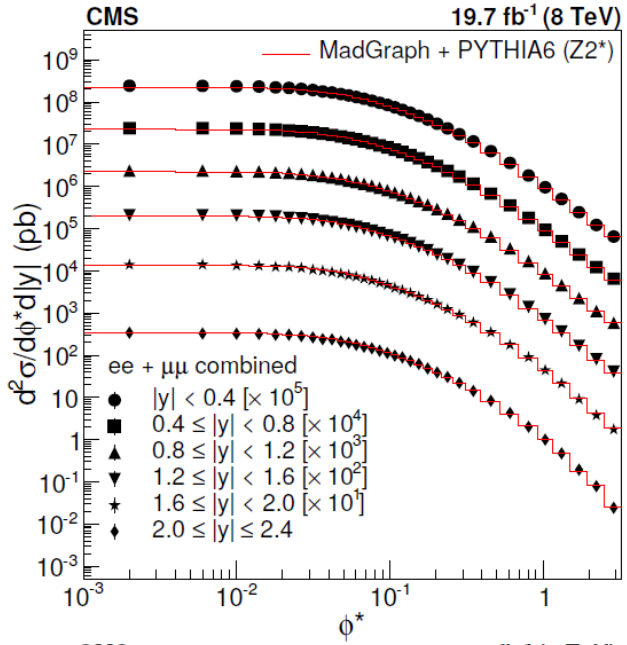


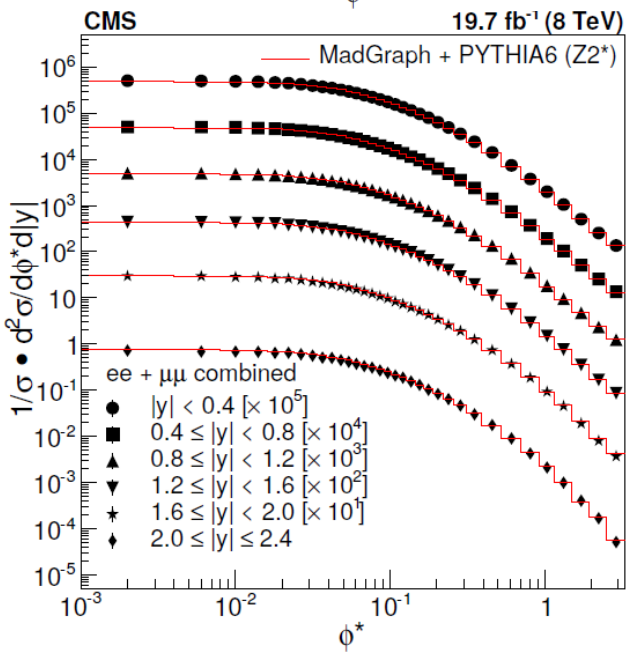
Z-boson $d^2\sigma/d\phi^* d|y|$

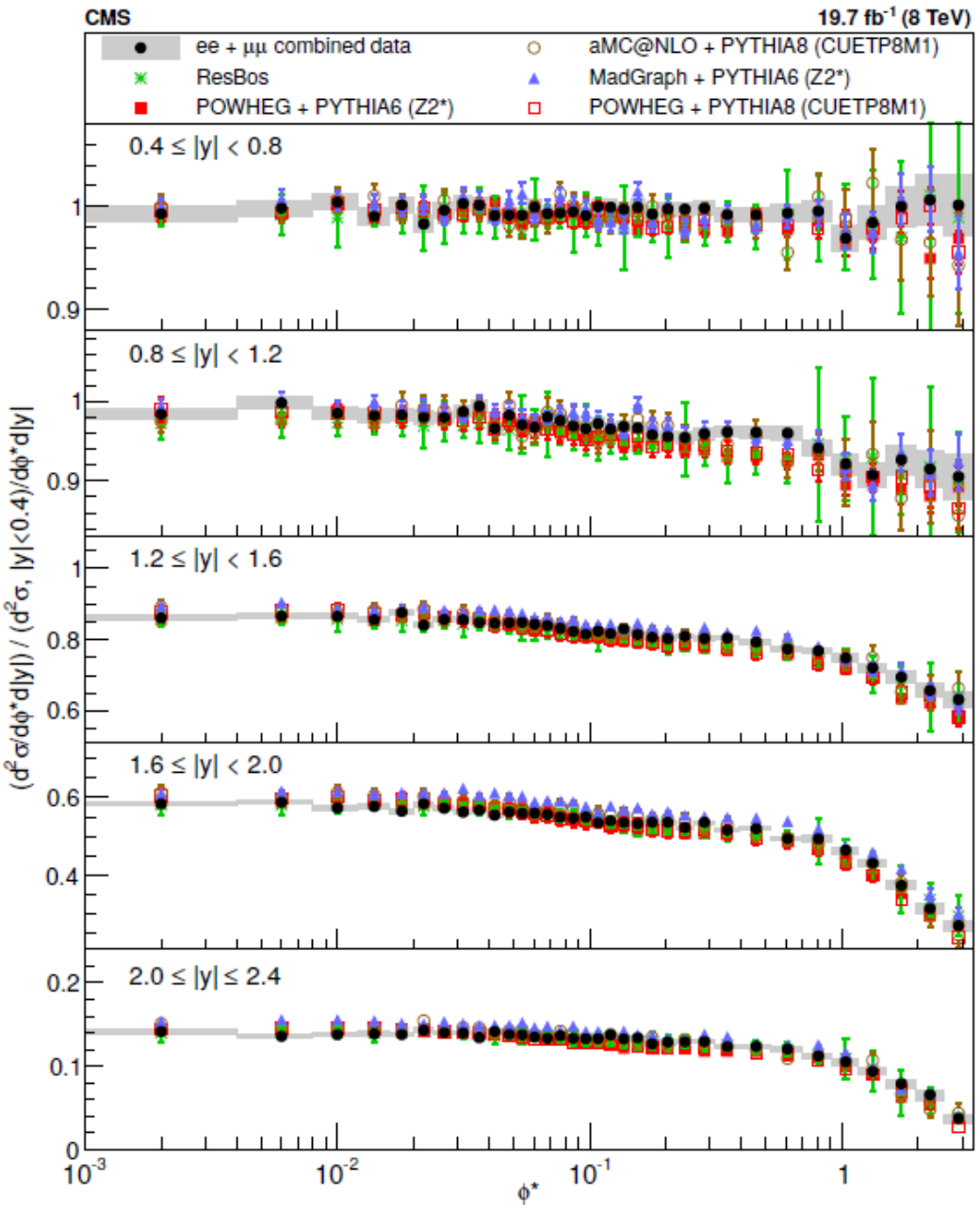


‘‘other’’ includes: background, pileup, electron energy scale or muon pT resolution, QED-FSR

Z-boson $d^2\sigma/d\phi^* d|y|$

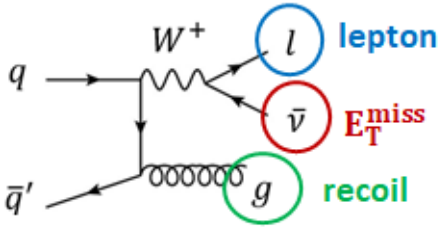


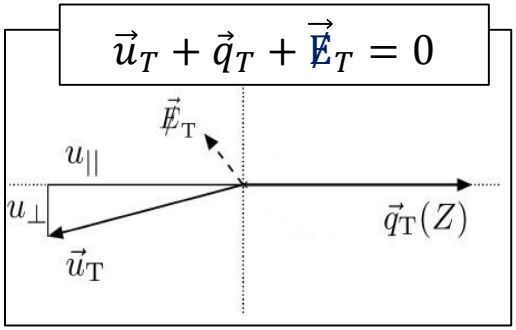


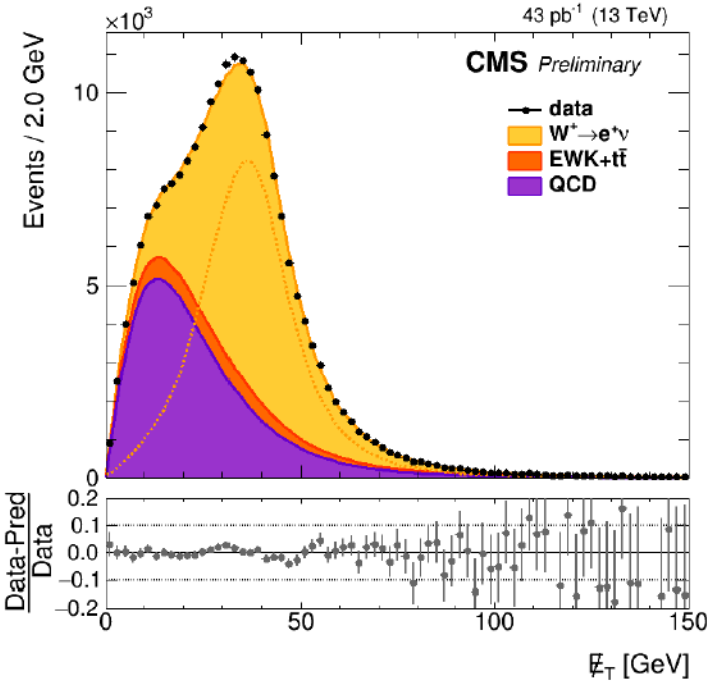


Inclusive W and Z production cross sections

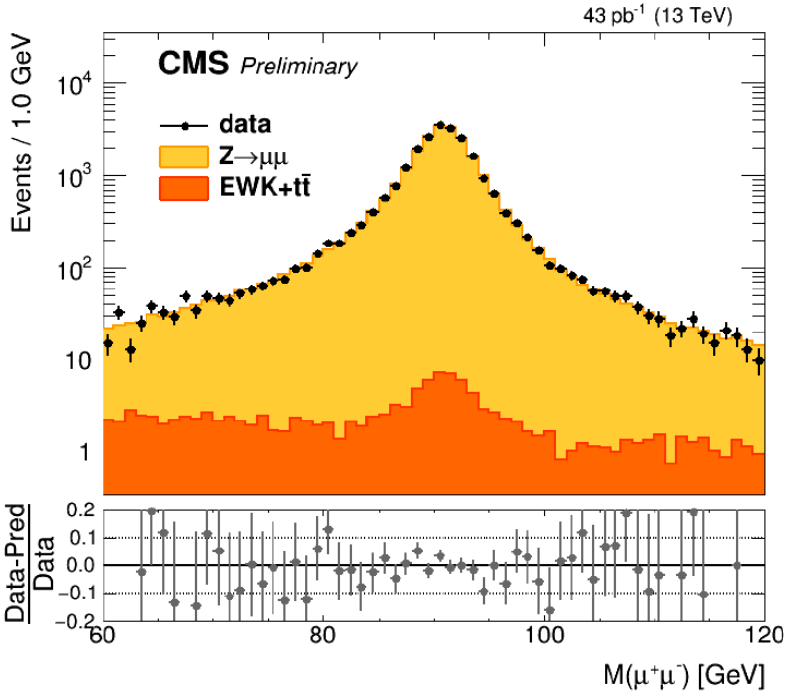
- **W-boson signal extracted from fit to E_T^{miss}**
  - QCD modelled with analytic function
  - signal and EWK background from simulations
- **accurate description of E_T^{miss} response and resolution**
  - derived from dedicated recoil calibration in Z events
- **Z yield counting events within selected mass window**



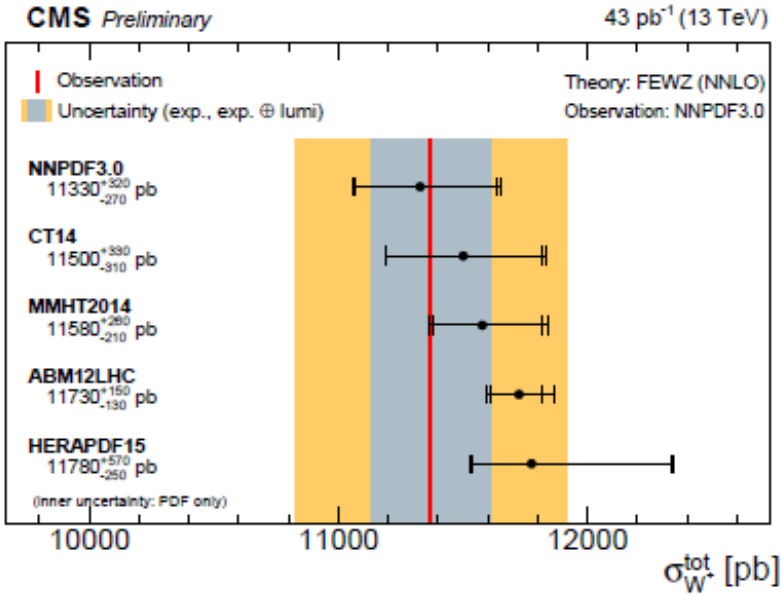


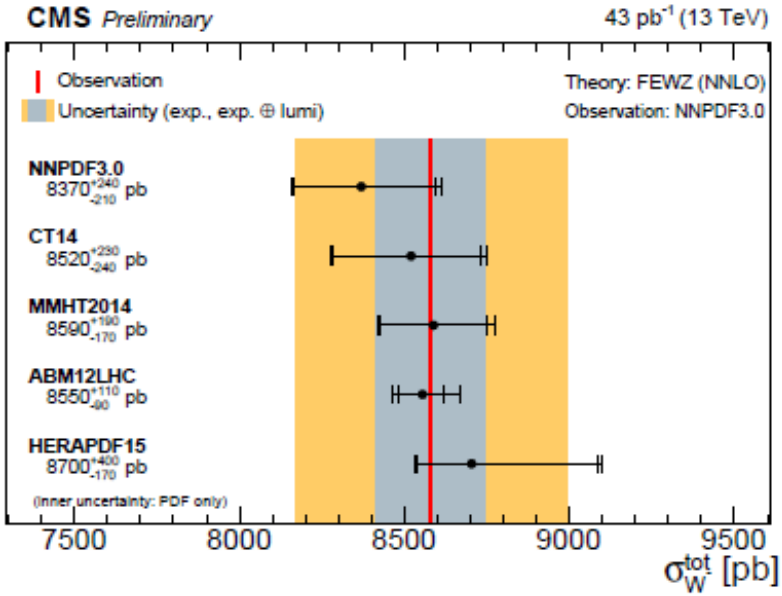


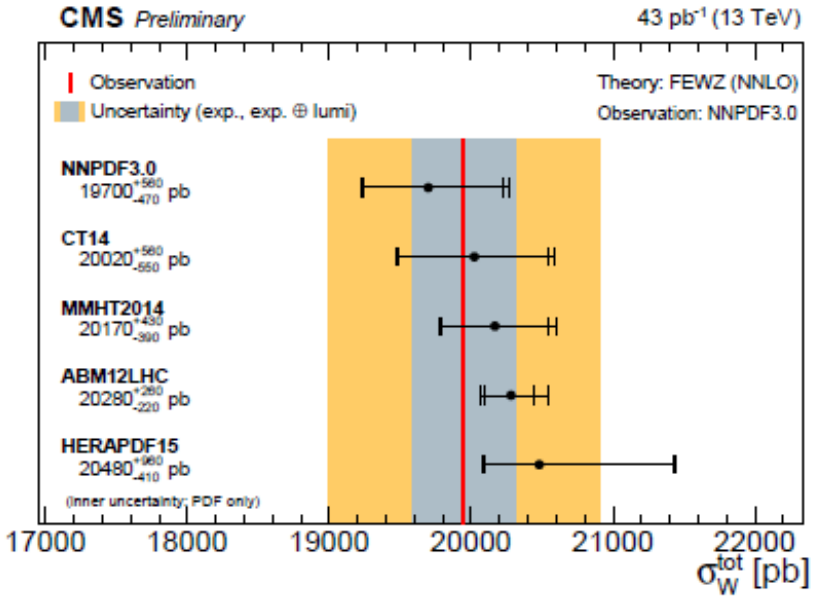
CMS-PAS
SMP-15-004

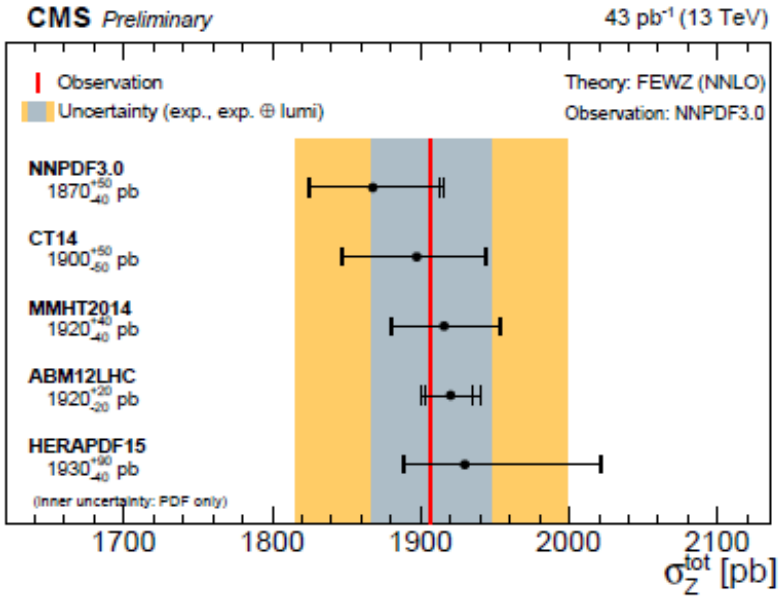


Inclusive W and Z production cross sections







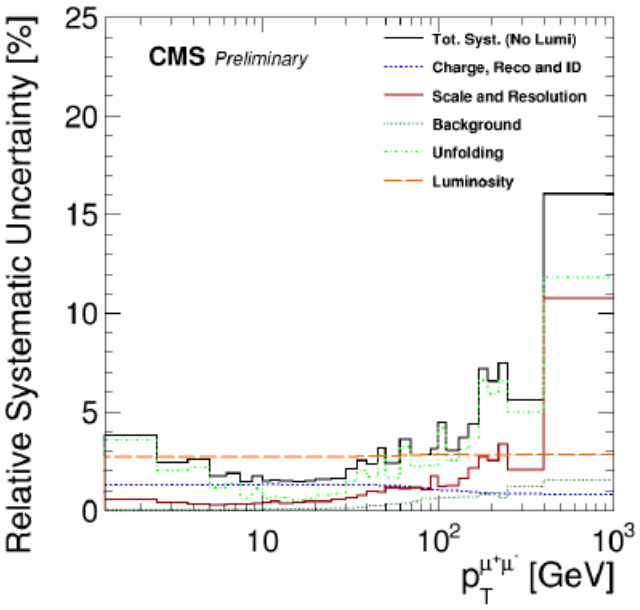


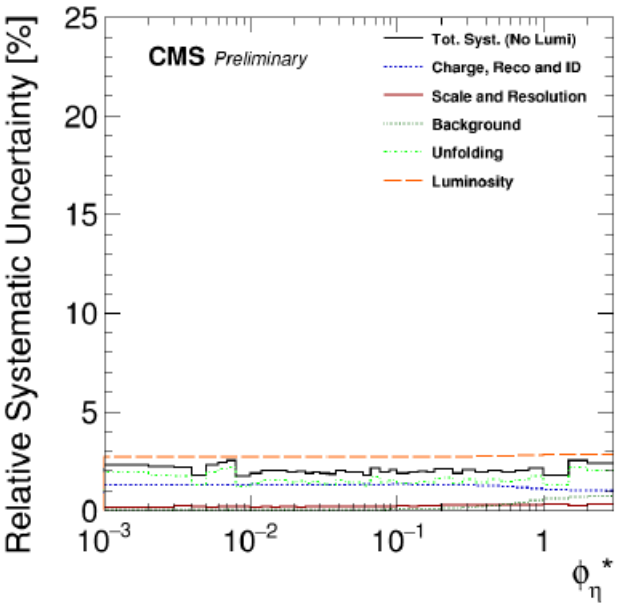
Inclusive and differential Z production cross sections

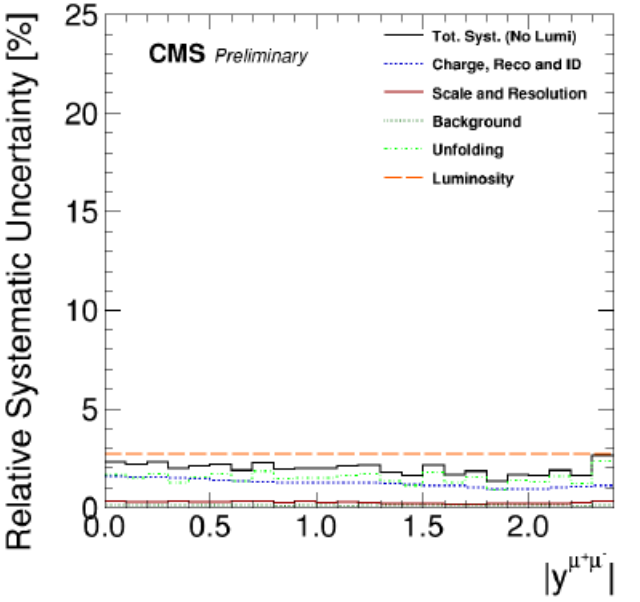
Unfolding uncertainty generally the largest (MC statistics, since no p_T dependent MC was used at the time)

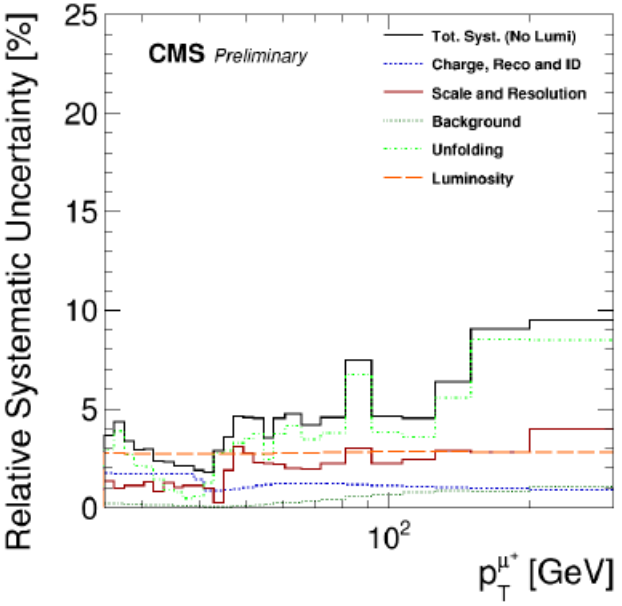
scale and resolution uncertainty on momentum-based variables important at **at high p_T**

scale and resolution uncertainty on angular variables flat









Inclusive and differential Z production cross sections