UNIVERSIDAD DE OVIEDO

Precision electroweak results at CMS

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On behalf of the CMS Collaboration

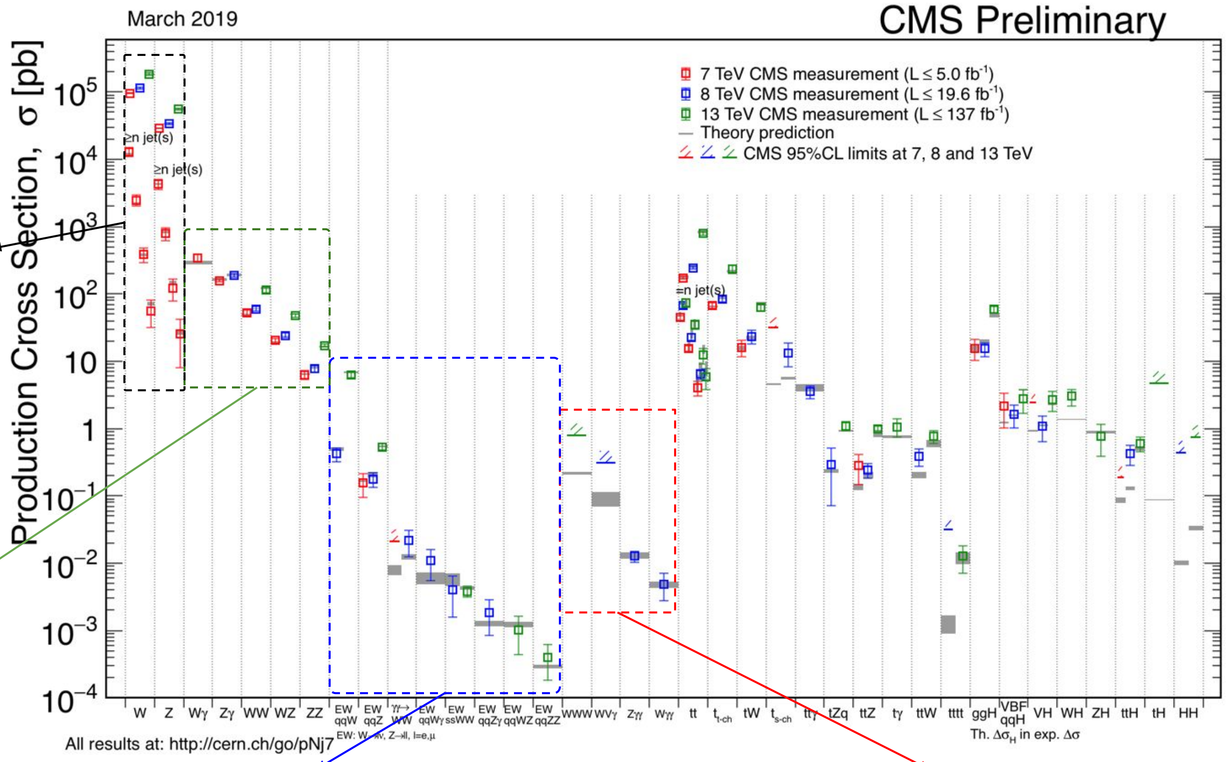
Why precision electroweak physics?

- Interesting sector for consistency checks of the standard model:
  - Multiple interdependent parameters can be measured separately.

- Very high cross-section processes (Z+jets, W+jets):
  - Can be used as a handle to calibrate our objects/MC.
  - Need a deep understanding of them to do so!

- Complementarity to direct Beyond-the-standard-model searches:
  - Precision searches work as an additional handle to search for new phenomena through deviations from SM.

Global picture



Single boson production

- Very high cross sections.
- Inclusive / differential cross-section measurements of high precision.
- Handles for the measurement of the standard model electroweak parameters.
- Focus of this talk.

Diboson production (inclusive)

- High cross-sections.
- Era of **precision measurements** for the inclusive cross sections.
- Discussed in dedicated talk.

VBS/VBF production

- Very low cross sections.
- First **observations** at 13 TeV.
- Discussed in dedicated talks.

Triboson production

- Very rare processes.
- Starting to see **observations/ evidences**.
- Discussed in dedicated talks.

Diboson measurements

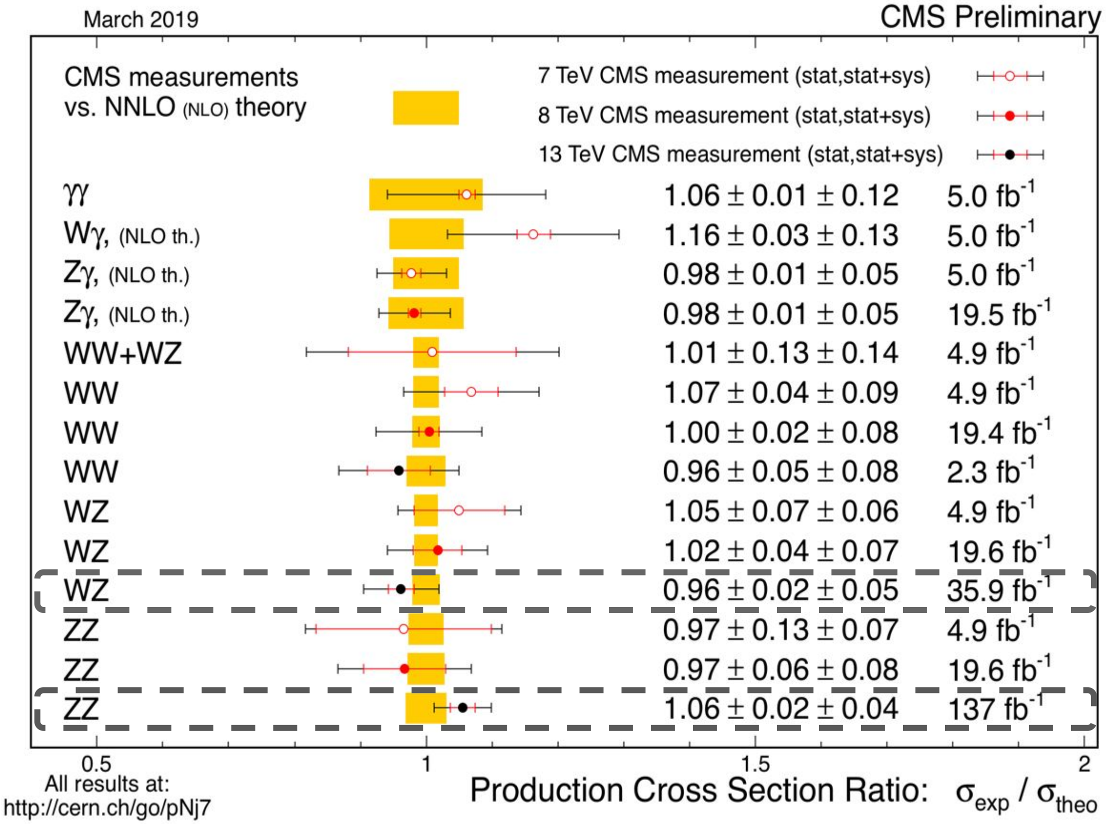
arXiv:1901.03428

CMS-PAS-SMP-19-001

⇢ Higher statistical power (36-150 fb^{-1}) for 13 TeV data. Diboson analyses no longer limited by statistical power.

⇢ Measurements benefit from new dedicated analyses focusing in systematic reduction .

⇢ Now able to provide differential measurements with high precision.



See the dedicated multiboson talk

qqV and qqVV ("VBS") measurements

⇢ Very extensive effort to study VBS processes in detail at 13 TeV. A lot of new results these last two years!

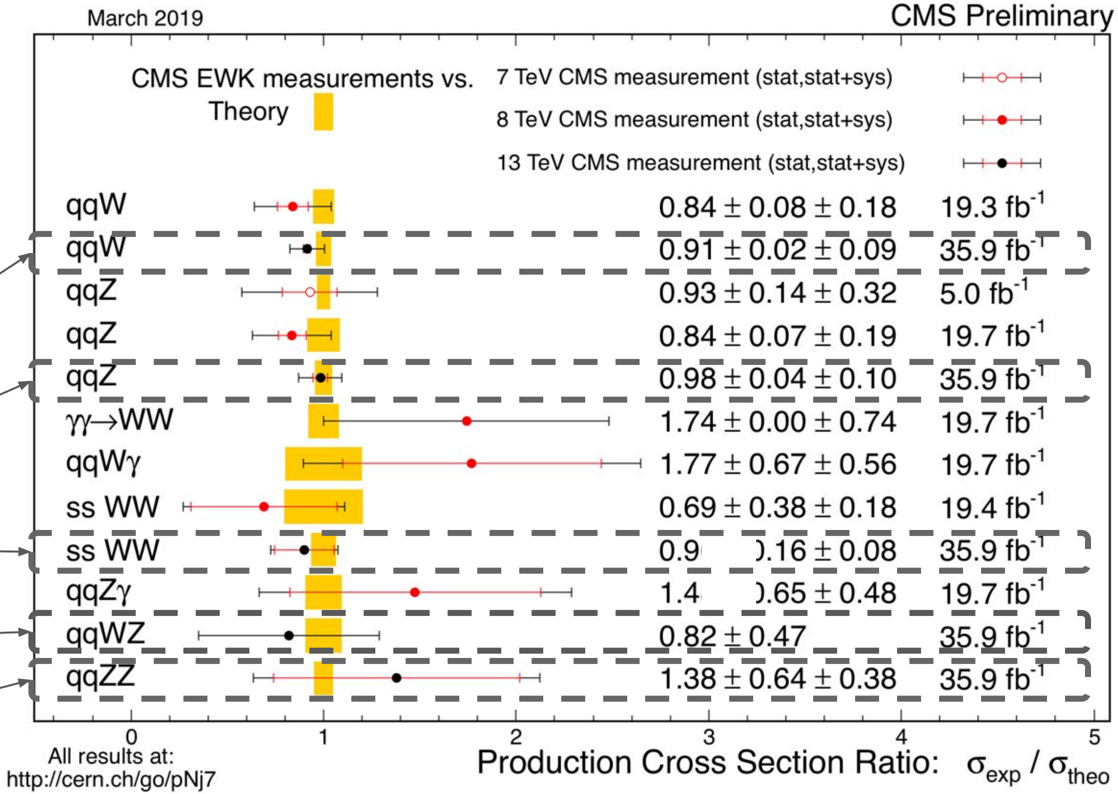
arXiv:1903.04040

arXiv:1712.09814

arXiv:1709.05822

arXiv:1901.04060

arXiv:1806.11073



See the dedicated VBS/VBF talk(s)

Drell-Yan differential cross sections - Mass

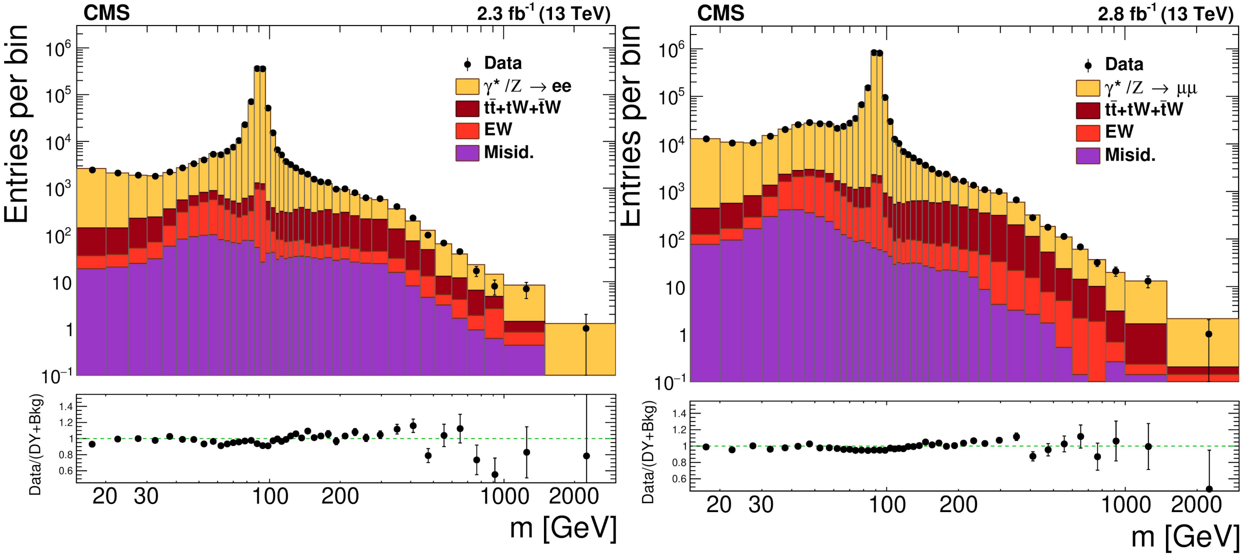
arXiv:1812.10529

⇢ Analysis dedicated to the study m_{ll} variable in $Z/\gamma^* \to ll$ production.

⇢ ~2.8-2.3 fb^{-1} of 13 TeV data (depending on the lepton flavor channel).

⇢ Selection requires a pair of opposite-sign same-flavor light leptons with p_T requirements mimicking trigger ones.

⇢ Extend the reach of previous analysis up to masses between 15 GeV and 3 TeV.



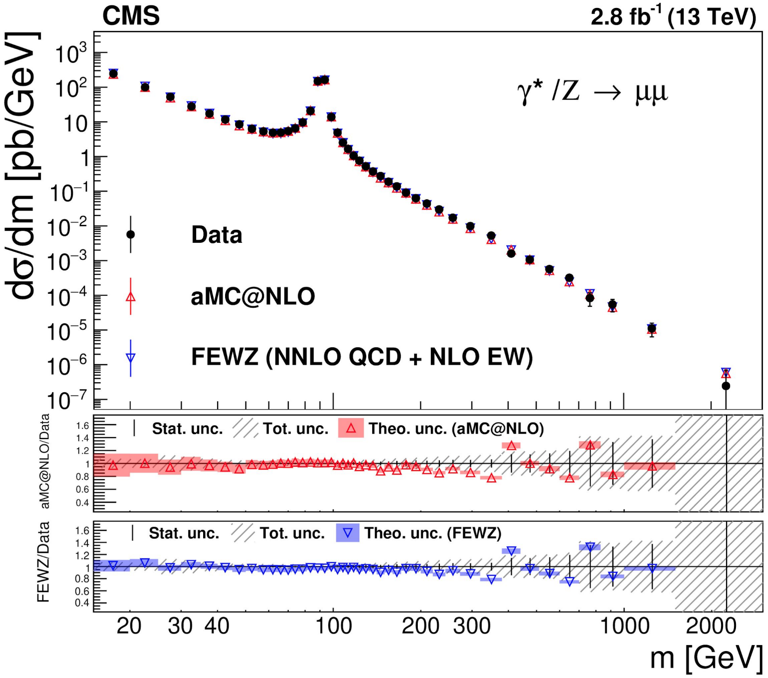
⇢ Non resonant backgrounds estimated from eμ channel.

⇢ QCD “misID” background estimated with matrix method.

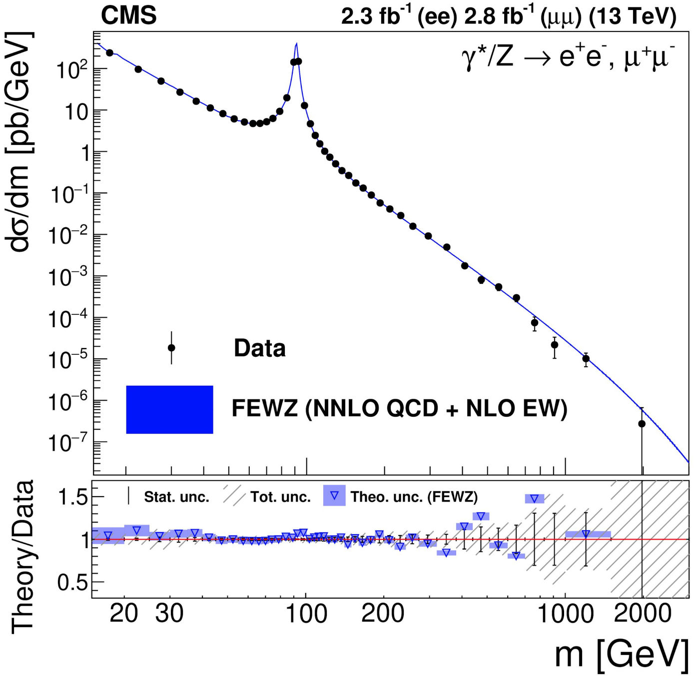
Drell-Yan differential cross sections - Mass

arXiv:1812.10529

Fiducial, μμ



Fiducial, all



⇢ Unfolding procedure (iterative “d’Agostini” method) to obtain results in the fiducial region:

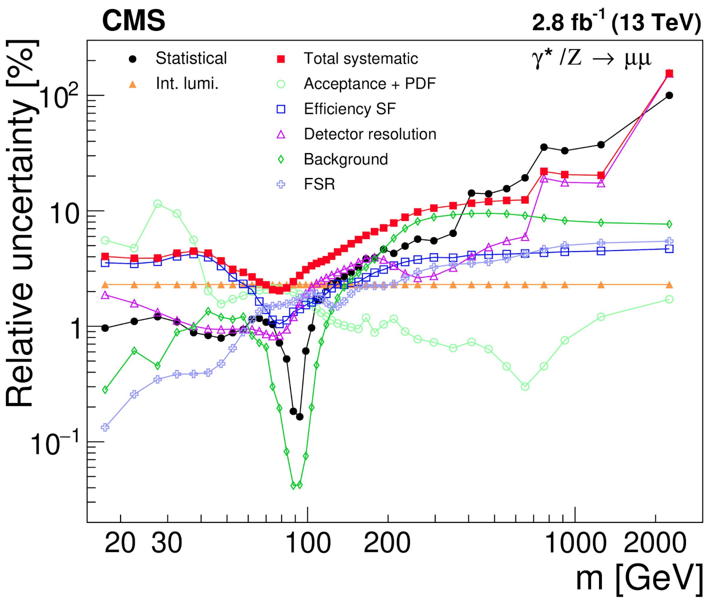
$p_T^{l1} > 30$ (22) GeV for μ(e) --- $p_T^{l2} > 10$ GeV --- $|\eta^\mu| < 2.4$ --- $|\eta^e| < 2.5$, $|\eta^e| \notin [1.44, 1.57]$

⇢ Good agreement observed with both the NLO and NNLO predictions.

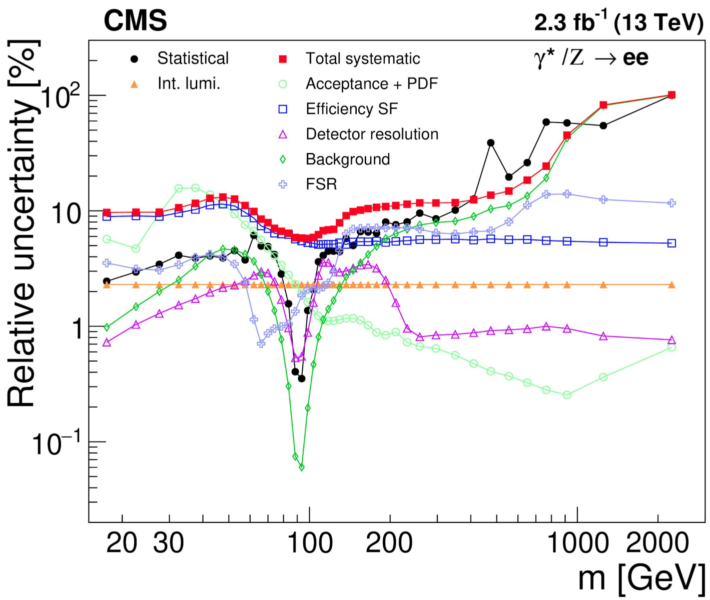
Drell-Yan differential cross sections - Mass

arXiv:1812.10529

⇢ Bulk of the distribution at the limit imposed by luminosity uncertainty (μμ)/lepton efficiency (ee). We can still profit from higher statistical power in the high mass region.



Muon channel uncertainties



Electron channel uncertainties

Z differential cross sections - Kinematics

CMS-PAS-SMP-17-010

⇢ Analyzed 36 fb^{-1} (2016 dataset) of 13 TeV data. Including double-differential measurements.

⇢ Similar selection criteria: pair of opposite-sign same-flavor light leptons, $|m_{ll} - m_Z| < 15$ GeV.

⇢ Measurements in terms of p_T^{ll}, $|y^{ll}|$ and ϕ^*:

$$\phi^* = \tan\left(\frac{\pi - |\phi_{l_-} - \phi_{l_+}|}{2}\right)\sqrt{1 - \tanh^2\left(\frac{\eta_{l_-} - \eta_{l_+}}{2}\right)} \sim \boxed{\frac{p_T^{ll}}{m_{ll}}}$$

Reduce uncertainties affecting lepton p_T

⇢ Extremely precise fiducial cross-section measurement in:

$p_T^{l1} > 25$ GeV --- $p_T^{l2} > 25$ GeV --- $|\eta| < 2.4$ --- $|m_{ll} - 91.2 \text{ GeV}| < 15$ GeV

⇢ Final value close to theoretical predictions:

$\sigma_{aMC@NLO}$(NLO QCD) = 682 ± 55 pb

σ_{FEWZ} (NNLO QCD) = 719 ± 8 pb

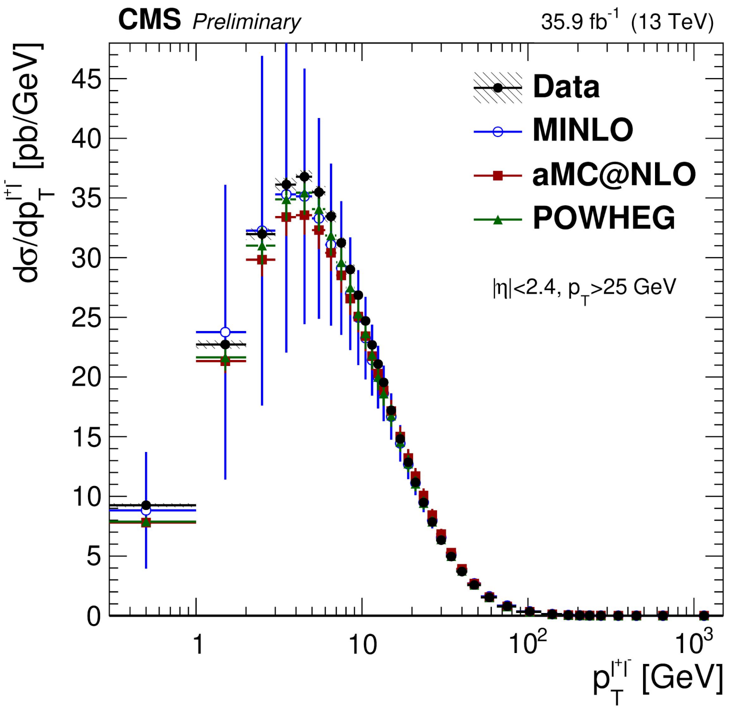
Cross section	$\sigma\,\mathcal{B}$ [pb]
$\sigma_{Z\to\mu\mu}$	$694 \pm 6\,(\text{syst}) \pm 17\,(\text{lumi})$
$\sigma_{Z\to ee}$	$712 \pm 10\,(\text{syst}) \pm 18\,(\text{lumi})$
$\sigma_{Z\to\ell\ell}$	$699 \pm 5\,(\text{syst}) \pm 17\,(\text{lumi})$

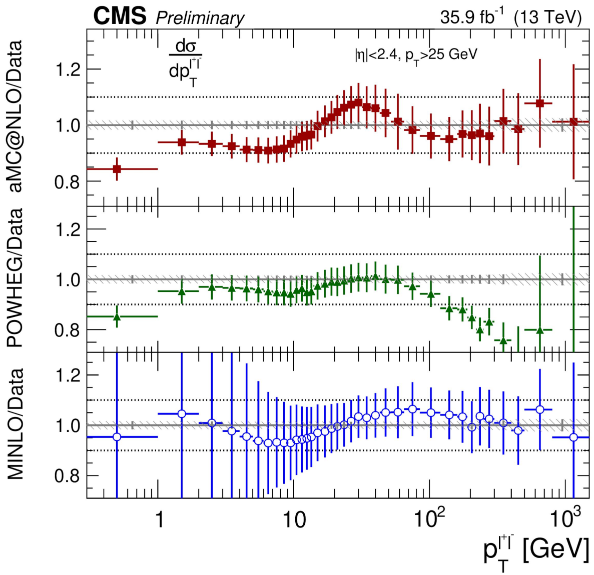
Z differential cross sections - $|p_T^Z|$

[CMS-PAS-SMP-17-010]

⇢ Unfolding procedure (iterative "d'Agostini" method) to obtain results at the fiducial region level:

$p_T^{l1} > 25$ GeV --- $p_T^{l2} > 25$ GeV --- $|\eta| < 2.4$ --- $|m_{ll} - 91.2 \text{ GeV}| < 15$ GeV





⇢ Comparisons show agreement with all of:

MiNLO (*) (NLO QCD + NLO EWK)

aMC@NLO (NLO QCD + NLO EWK)

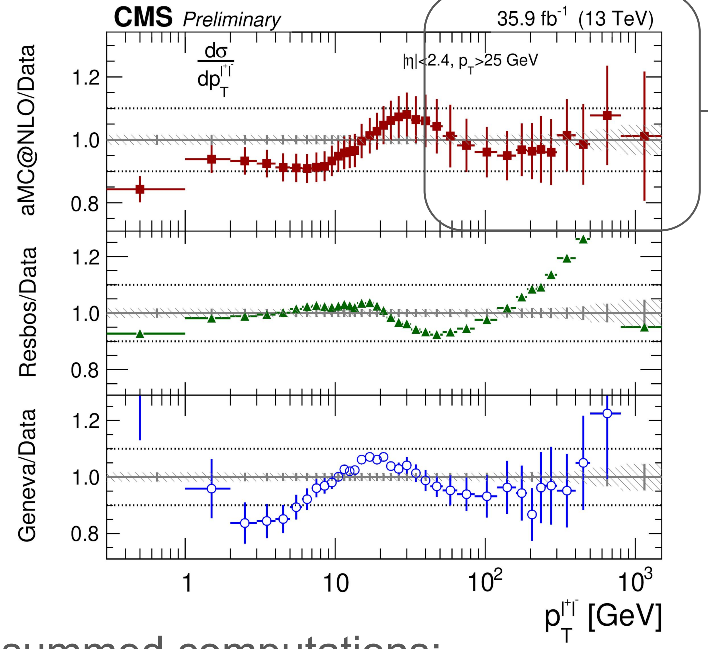
(*) POWHEG with the MiNLO prescription

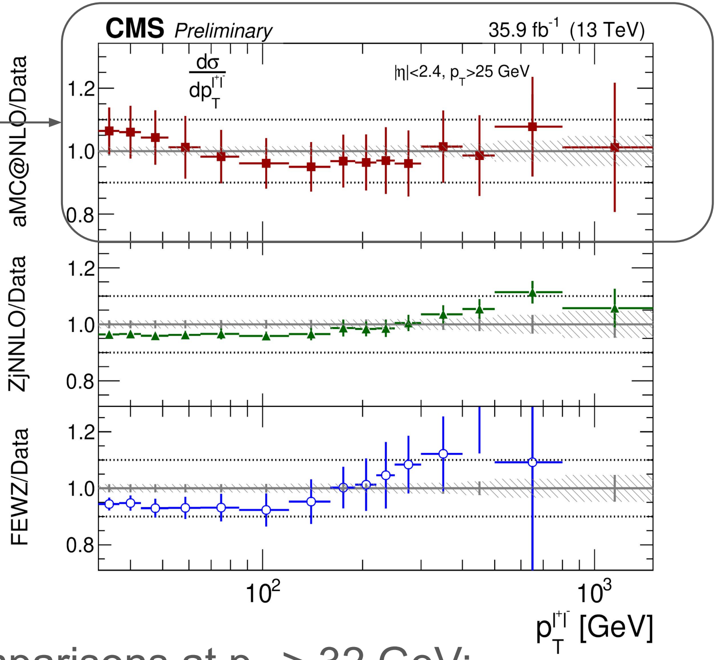
⇢POWHEG shows high p_T discrepancies.

Z differential cross sections - $|p_T^Z|$

CMS-PAS-SMP-17-010

⇢ Additional detailed comparisons to other prediction:





⇢ Resummed computations:

RESBOS (NNLL accuracy)

GENEVA (NNLL accuracy)

⇢ Comparisons at p_T > 32 GeV:

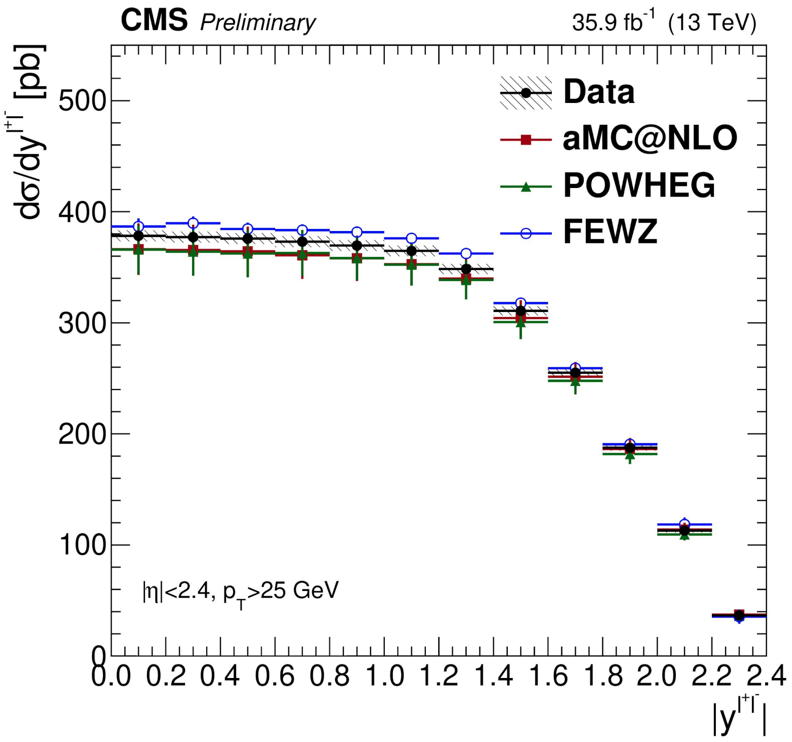
Total Z+j NNLO accuracy computation

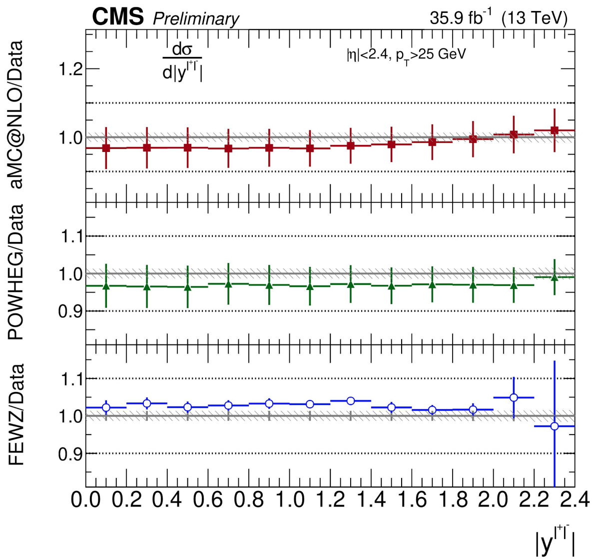
FEWZ (NNLO accuracy)

Z differential cross sections - $|y^Z|$

CMS-PAS-SMP-17-010

⇢ Unfolding procedure (iterative “d’Agostini” method) to obtain results at the fiducial region level:





⇢ Comparisons show good agreement for:

FEWZ (NNLO QCD + NLO EWK)

POWHEG (NLO QCD + NLO EWK)

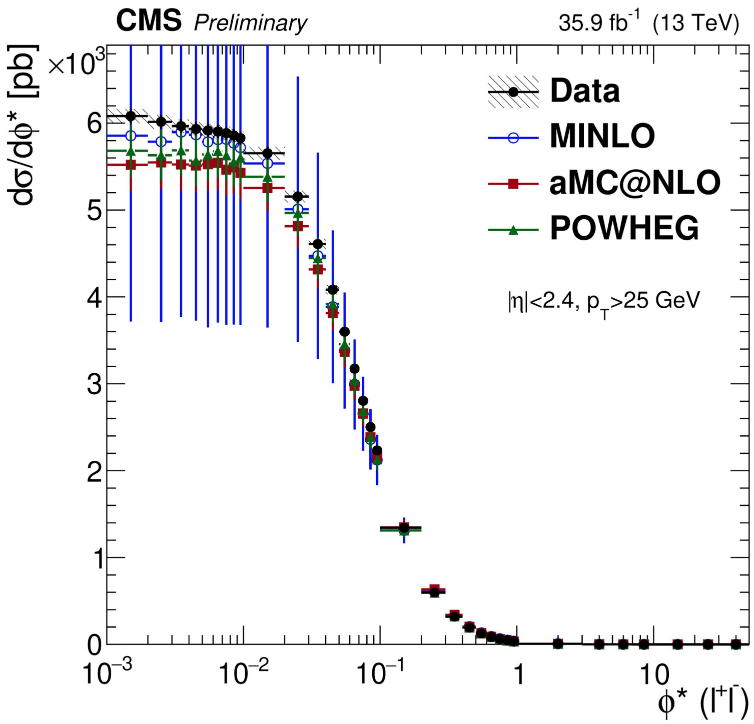
⇢ Small slope observed with respect to:

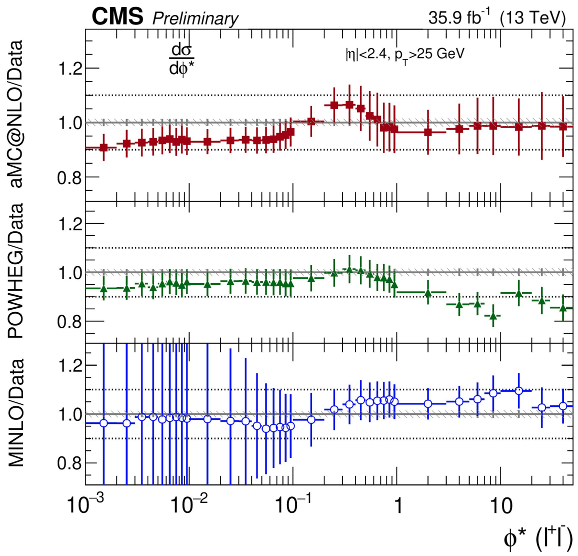
aMC@NLO (NLO QCD + NLO EWK)

Z differential cross sections - $|\phi^*|$

CMS-PAS-SMP-17-010

⇢ Unfolding procedure (iterative "d'Agostini" method) to obtain results at the fiducial region level:





⇢ Comparisons show agreement with all of:

MiNLO (*) (NLO QCD + NLO EWK)

POWHEG (NLO QCD + NLO EWK)

aMC@NLO (NLO QCD + NLO EWK)

(*) POWHEG with the MiNLO prescription

Effective leptonic weak mixing angle

arXiv:1806.00863

⇢ Measured with 8 TeV (~19 fb^{-1}) data. Use forward-backward asymmetry A_{FB} in $Z \to ll$ events:

Axial/V-Axial couplings

$$\frac{v_f}{a_f} = 1 - 4|Q_f|\sin^2(\theta^l_{eff}) \quad A_{FB}(v_l, a_l, v_f, a_f) \leftrightarrow A_{FB}(m_{ll}, y_{ll})$$

Dilepton invariant mass and rapidity

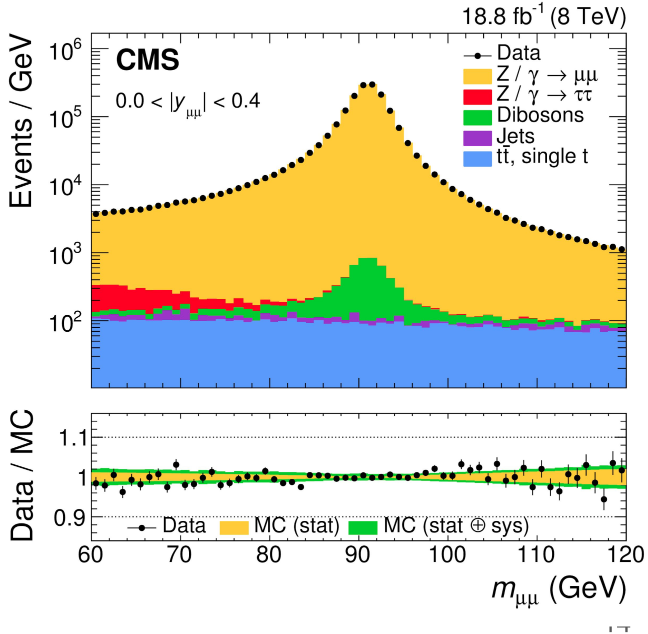
⇢ Selected events with an opposite sign ee/μμ pair.

⇢ Define 72 measurement bins classified by m_{ll} (12) times $|y_{ll}|$ (6).

⇢ For each bin: compute A_{FB} based on lepton-Z angle in the Collins-Soper frame using the reweighting method.

⇢ Templates of $A_{FB}(m_{ll}, |y_{ll}|)$ (different θ_{eff}^{l}) from POWHEG.

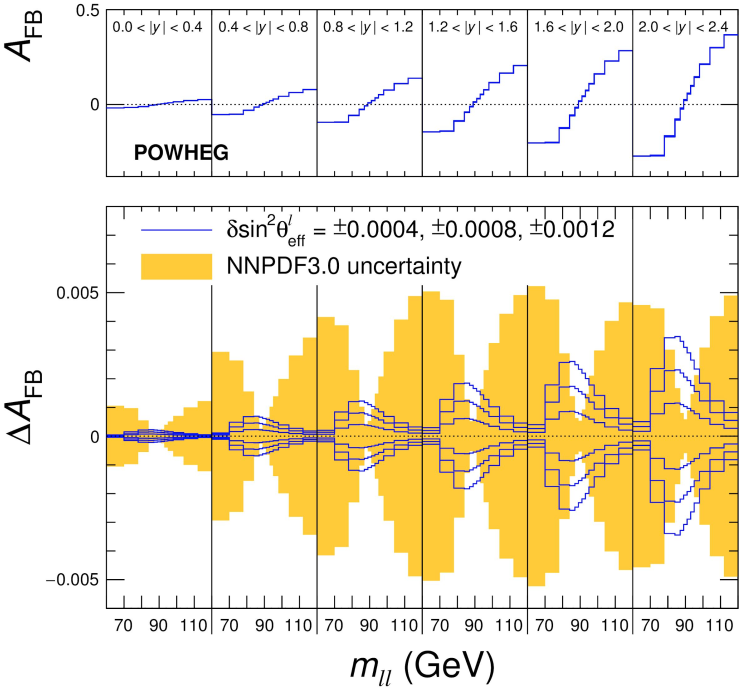
⇢ Templated fit to the best value of θ_{eff}^{l}.



Weak mixing angle measurement - PDFs

arXiv:1806.00863

⇢PDF ($\sin^2(\theta_{eff}^{l})$) variations induce high differences in A_{FB} outside (inside) the Z peak.

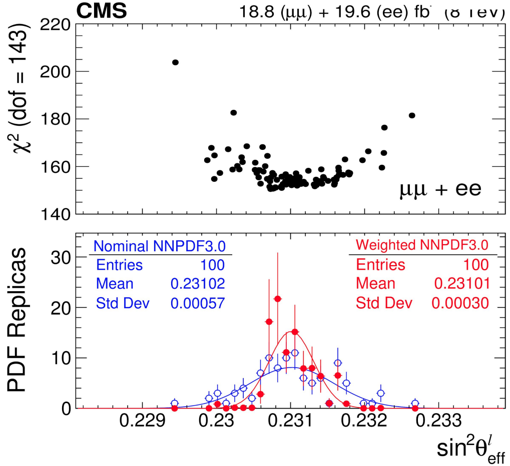


⇢ Try to constrain them along with $\sin^2(\theta_{eff}^{l})$.

⇢ Introduce a Bayesian reweighting technique to reduce the PDF uncertainty.

⇢ For each replica, fit the best value θ_{eff}^{l} and reweight it by:

$$w_i = \frac{e^{-\frac{\chi^2_{\min,i}}{2}}}{\frac{1}{N}\sum_{i=1}^{N} e^{-\frac{\chi^2_{\min,i}}{2}}}$$



⇢ Nominally used for the NNPDF3.0 set, cross-checked with CT10, CT14, MMHT2014.

arXiv:1806.00863

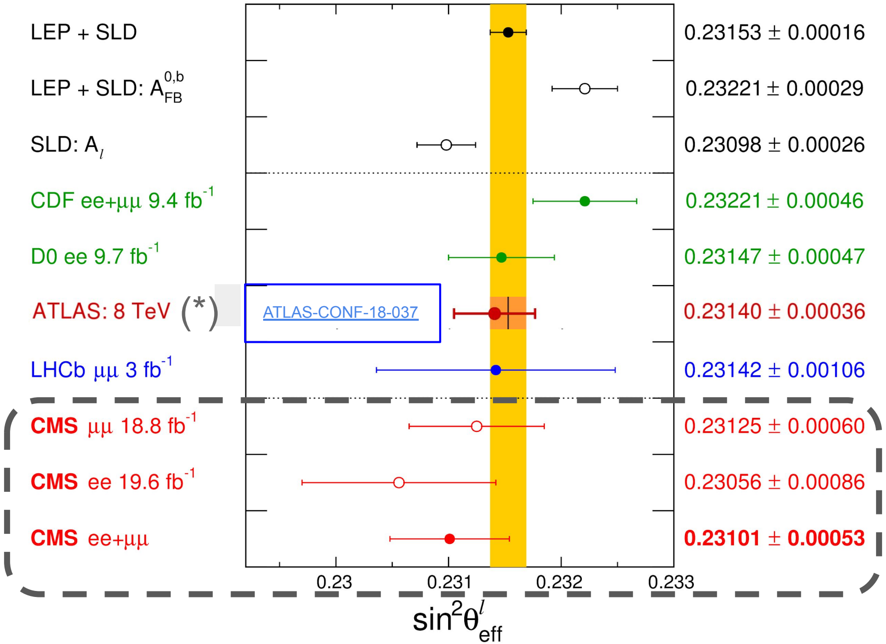
Weak mixing angle measurement - Results

⇢ Closing the precision gap with TEVATRON/LEP's results.

⇢ Noticeable improvement with the application of the PDF's χ^2 reweighting.

⇢ Uncertainties dominated by statistical variations of both data and MC.

Uncertainty source (greater)	Muons	Electrons
Size of MC event sample	0.00015	0.00033
Lepton selection efficiency	0.00005	0.00004
Lepton momentum calibration	0.00008	0.00019
μ_R and μ_F scales	0.00011	0.00013
POWHEG MINLO Z+j *vs.* Z at NLO	0.00009	0.00009
MC statistics	0.00044	0.00060



(*) New result (after the CMS one was public)

Channel	Not constraining PDFs	Constraining PDFs
Muons	0.23125 ± 0.00054	0.23125 ± 0.00032
Electrons	0.23054 ± 0.00064	0.23056 ± 0.00045
Combined	0.23102 ± 0.00057	0.23101 ± 0.00030

Conclusions

⇢ Latest results in Drell-Yan cross-sections show increasingly higher precisions:

⇢ Detector-related and modelling effects already very small. Currently limited by our understanding of total luminosity. Can we go even lower?

⇢ Experimental results more precise than theoretical predictions.

⇢ Electroweak (effective) mixing angle measurements already closing the gap with ee collider results.

⇢ Can we solve the 3σ tension between LEP and SLD results?

⇢ More and more precision results coming from single, double and (now) triple boson production.

⇢ A very exciting time to work in electroweak physics!

Back-Up