Latest results on inclusive W/Z production at CMS

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on behalf of the CMS Collaboration

Warsaw
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2014

Overview

Focus on a recent publication and a new preliminary result:

- Inclusive W and Z boson cross-sections at 8 TeV
- Double differential $\frac{\mathrm{d}^2\sigma}{\mathrm{dP_T dY}}$ Drell-Yan to muons cross-section at 8 TeV

Motivation: Inclusive W and Z boson cross-section

- W and Z boson production is a prominent hard scattering process at hadron colliders
- Important background for Higgs and BSM searches
- Theoretical predictions are available at NNLO in perturbative QCD
- Calculations are limited by PDFs, missing higher order QCD effects and electroweak radiative corrections available at NLO.
- Better constraints on PDFs by differential measurements

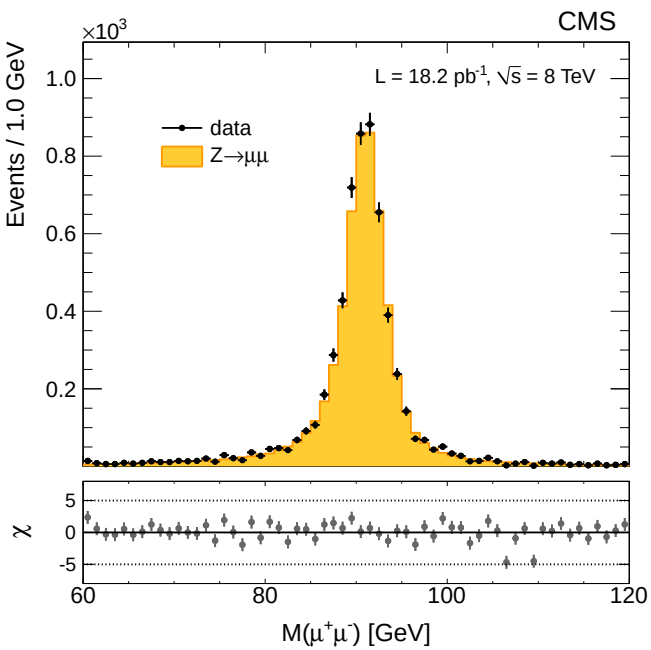
Measurement of inclusive W and Z boson cross-sections at 8 TeV:

- CERN-PH-EP-2013-217, acc. PRL
- Uses $18.2\,\mathrm{pb}^{-1}$ of 2012 data collected with low pile up ($\sim$5 interactions/ bunch crossing)
- Significant improvement in luminosity determination w.r.t preliminary result shown last year
- Both electron and muon channels are analyzed $\rightsquigarrow$ clean final states

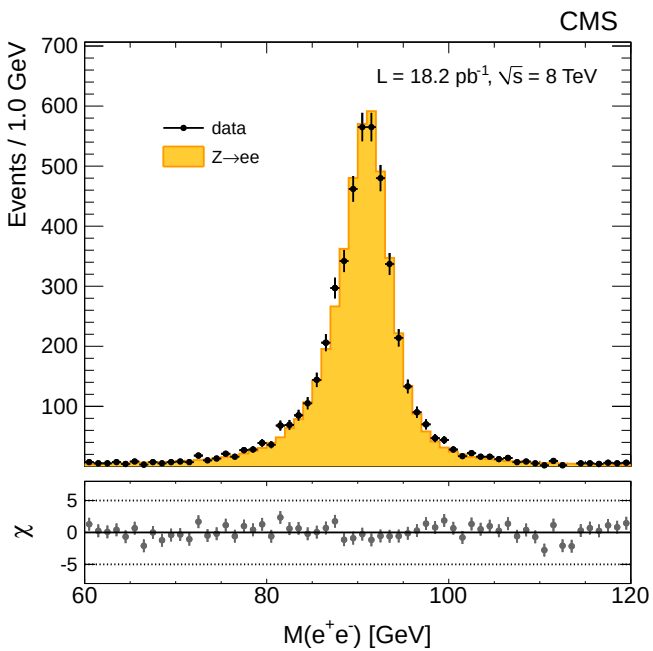
Inclusive Z boson cross-section at 8 TeV

- $Z \to \ell\ell$:
  - Signature of 2 isolated leptons
  - Mass range; $60 < M_{\ell\ell} < 120$ GeV
  - Small background contamination

$Z \to \mu\mu$:
- $p_T > 25$ GeV, $|\eta(\mu)| < 2.1$
- $\sim$ 6K candidates



$Z \to ee$:
- $p_T > 25$ GeV, $|\eta(\mu)| < 2.5$
- $\sim$ 5K candidates



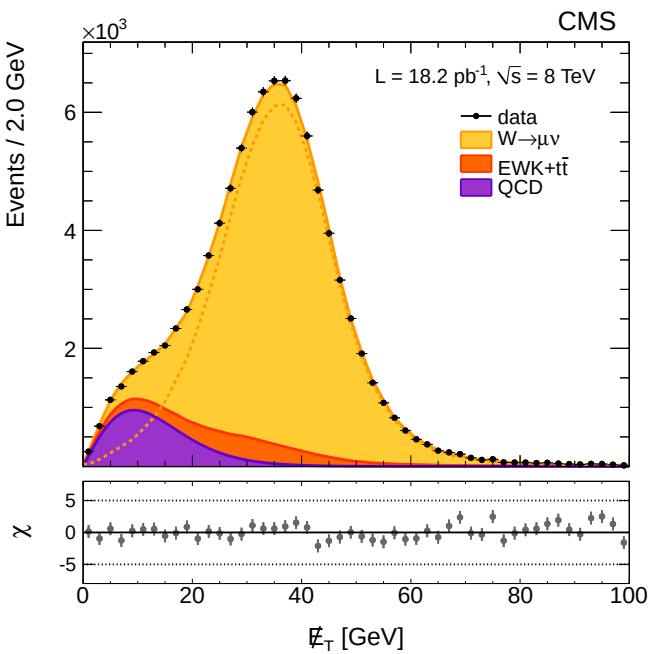
Inclusive W boson cross-section at 8 TeV

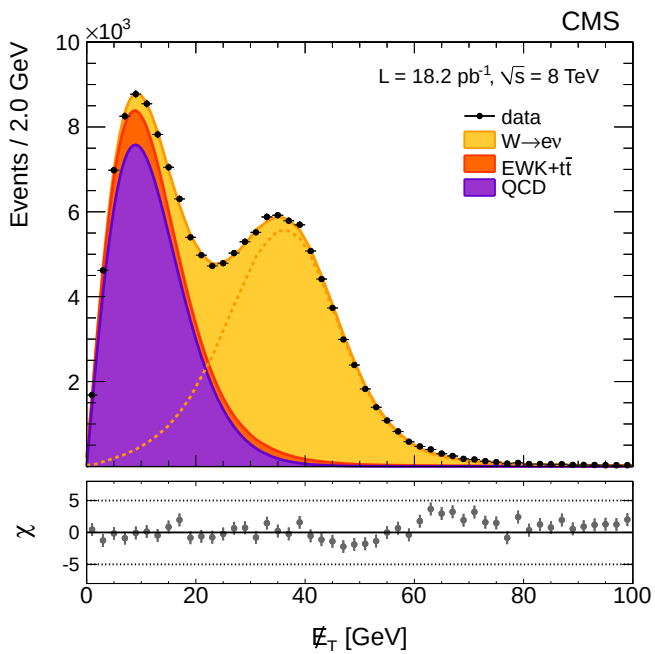
- $W \to \ell\nu$:
  - Signature of 1 isolated lepton and significant missing transverse energy (MET)
  - Signal extracted with fit to MET distributions:

    analytic function for QCD, templates for signal and EWK backgrounds

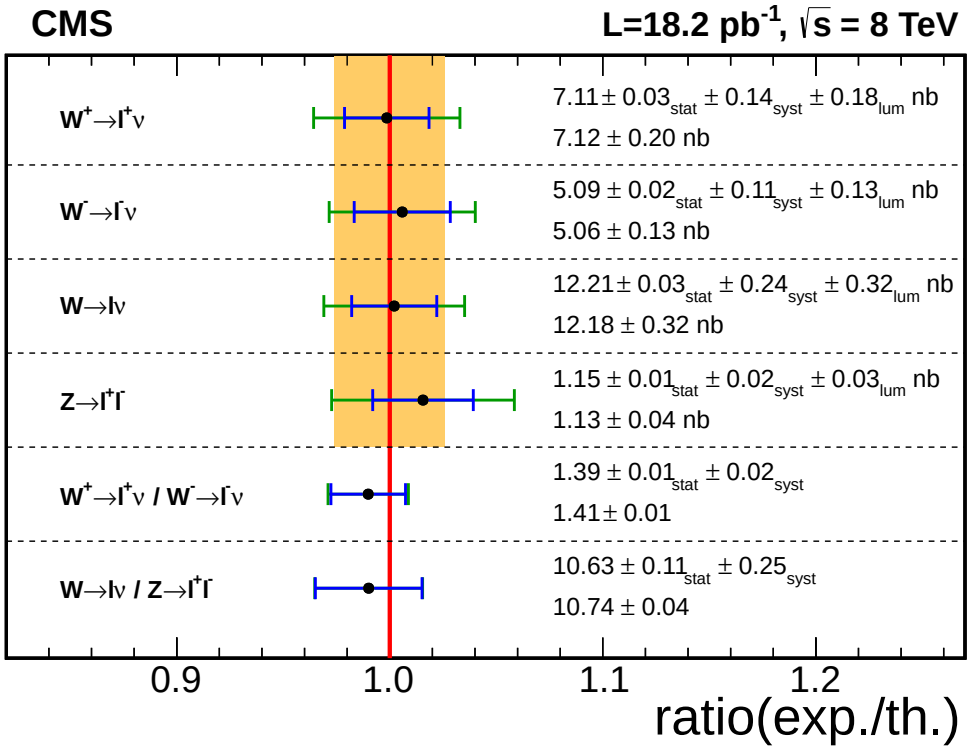
$W \to \mu\nu$:
- $p_T > 25\,\text{GeV}$, $|\eta(\mu)| < 2.1$
- $\sim$ 81K candidates

$W \to e\nu$:
- $p_T > 25\,\text{GeV}$, $|\eta(\mu)| < 2.5$
- $\sim$ 75K candidates





Ratio of inclusive W and Z boson cross-sections at 8 TeV



Lumi uncertainty of 2.6 % indicated by yellow area

Inner error bars include experimental uncertainties only
- dominated by efficiency

Outer error bars also include theoretical uncertainties

- Shown are the combined results of the total inclusive cross-sections
- Measurements in electron and muon channel are consistent
- Good agreement with theoretical prediction: NNLO FEWZ+MSTW2008

Motivation: Double differential $\frac{d^2\sigma}{dP_T dY}$ Drell-Yan cross-section

- Double differential $\frac{d^2\sigma}{dP_T dY}$ Drell-Yan cross-section measurement allows to test QCD dynamics over a large kinematic range at high granularity and precision

- Non zero boson P_T due to quark/gluon initial state radiation
  - Low P_T: dominated by multiple soft gluon radiation (perturbative effects)
  - High P_T: dominated by hard gluon radiation (matrix element)

$\Rightarrow$ Excellent benchmark to test and tune generators

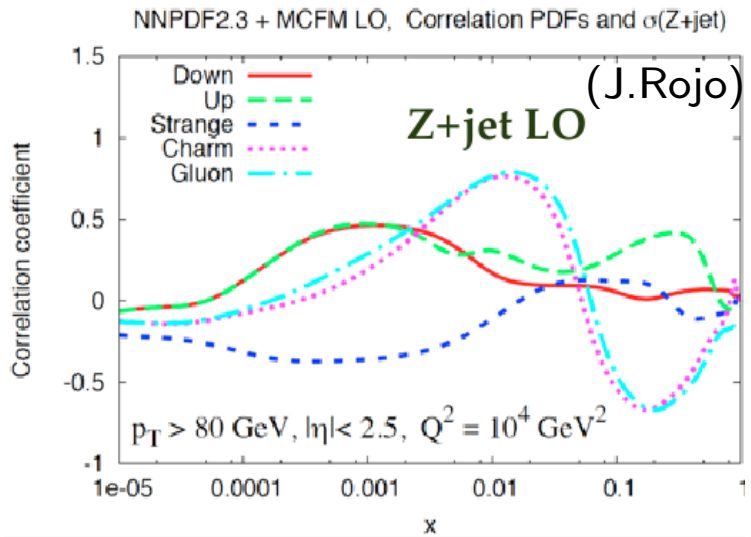
Motivation: Double differential $\frac{d^2\sigma}{dP_T dY}$ Drell-Yan cross-section

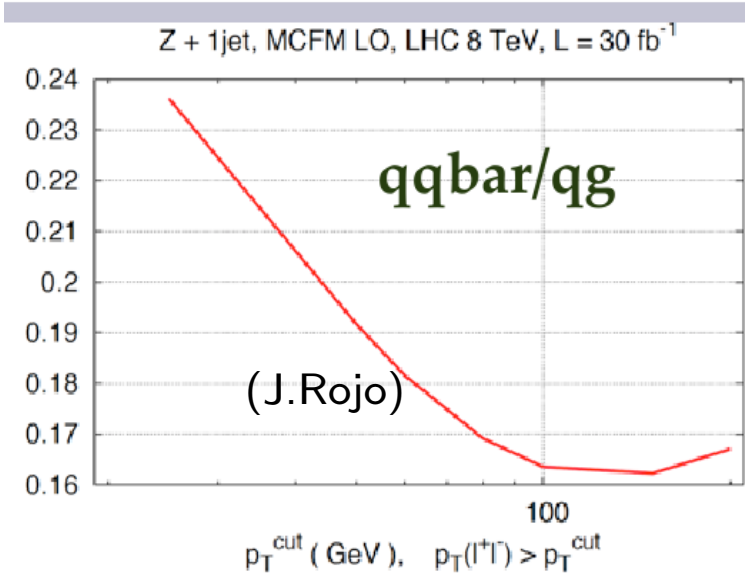
- Z boson production at large P_T is sensitive to gluons

$\rightsquigarrow$ Potential to constrain gluon PDFs

- Sensitive in kinematical region relevant for Higgs production in gluon fusion
- Complementary result to other measurements e.g. direct photon and top pair production
  - uncorrelated systematics $\rightsquigarrow$ easy to combine
- Requirements on the measurement (for potential impact on gluon PDFs):
  - Precision $\sim 1\,\%$ in the P_T tail

    $\rightsquigarrow$ Statistically not limited, but very good control of systematics is needed
  - Full covariance matrix of uncertainties





Double differential $\frac{d^2\sigma}{dP_T dY}$ Drell-Yan cross-section at 8 TeV

- Analysis documented in CMS-PAS-SMP-13-013
- Details of the measurement:
  - Complete 8 TeV data-set is used ($\int \mathcal{L} dt = 19.7\,\text{fb}^{-1}$)
  - Analysis of muon channel: isolated single muon trigger with $p_T(\mu) > 24\,\text{GeV}$ and $|\eta(\mu)| < 2.1$
  - Determine cross-section in fiducial volume (inside muon acceptance)

    $\rightsquigarrow$ reduce uncertainties of acceptance
  - Determine fiducial cross-section normalized to inclusive fiducial cross-section

    $\rightsquigarrow$ Shape measurement

    $\Rightarrow$ global systematic uncertainties (i.e. lumi) cancels

Data Selection

Compromise between minimizing background and maximizing acceptance:

1. Leading muon trigger matched to single muon trigger
2. leading muon: $p_T > 25\,\text{GeV}$, $|\eta| < 2.1$, rel. isolation < 0.12
3. sub-leading muon: $p_T > 10\,\text{GeV}$, $|\eta| < 2.4$, rel. isolation < 0.5

   $\rightsquigarrow$ looser isolation required for sub-leading muon, since for larger $P_T(Z)$ it tends to go into the hadronic recoil
4. $\mu^{\pm}$ is tight: reconstructed in muon chambers and inner tracker layers, and requirements on quality of track fit and primary vertex
5. $81 < M(\mu\mu) < 101\,\text{GeV}$
6. $|Y(\mu\mu)| < 2$

Used binning in $P_T(Z) - |Y(Z)|$:

- $P_T(Z)$: 0, 20, 40, 60, 80, 100, 120, 140, 170, 200, inf GeV
- $|Y(Z)|$: 0, 0.4, 0.8, 1.2, 1.6, 2.0

Measurement

The data and simulation is corrected for:

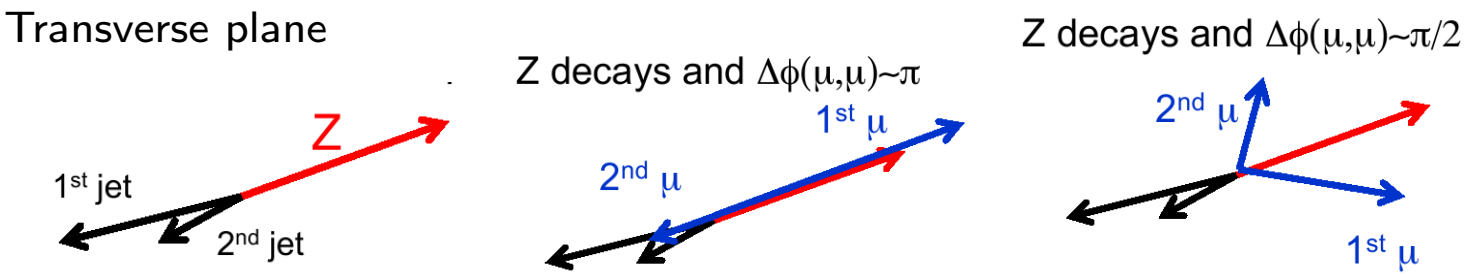
- Efficiencies: Tracking, trigger, identification and isolation
- Muon momentum scale and resolution (correction of mis alignment)
- Simulation is weighted in $P_T(Z)$ and $Y(Z)$ to match data shape
- Background is subtracted

Measurement

Special treatment of the efficiency corrections (using a tag and probe method):

- With increasing $P_T(Z)$, sub-leading muon tends to go into hadronic recoil

  $\rightsquigarrow$ Isolation efficiencies for leading and sub-leading muon are different



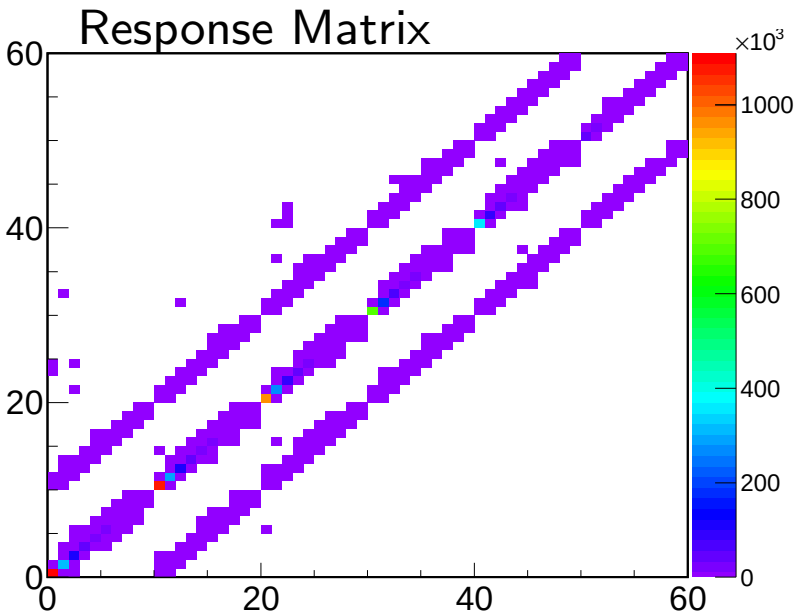
$\Rightarrow$ The sub-leading muon might have in both cases the same p_T,
but the isolation efficiency is very different.

$\rightsquigarrow$ Efficiency in $p_T(\mu)$-$\eta(\mu)$ is not sufficient.

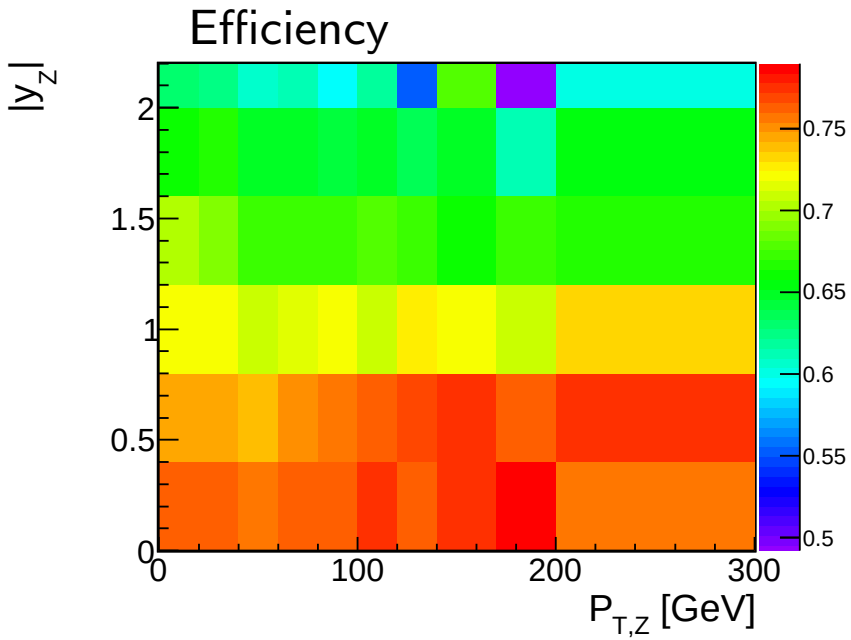
$\Rightarrow$ Efficiency measured in $P_T(Z)$-$\cos\theta^*$-$|\phi^*|$ to take into account the event kinematics
(θ^* and ϕ^* are the polar and the azimuthal angles in the helicity frame)

Unfolding

- Detector resolution is unfolded using the 'iterative Bayesian' method implemented in the RooUnfold package
- Response matrix and efficiencies are derived from MadGraph+PYHTIA6 Z2* tune

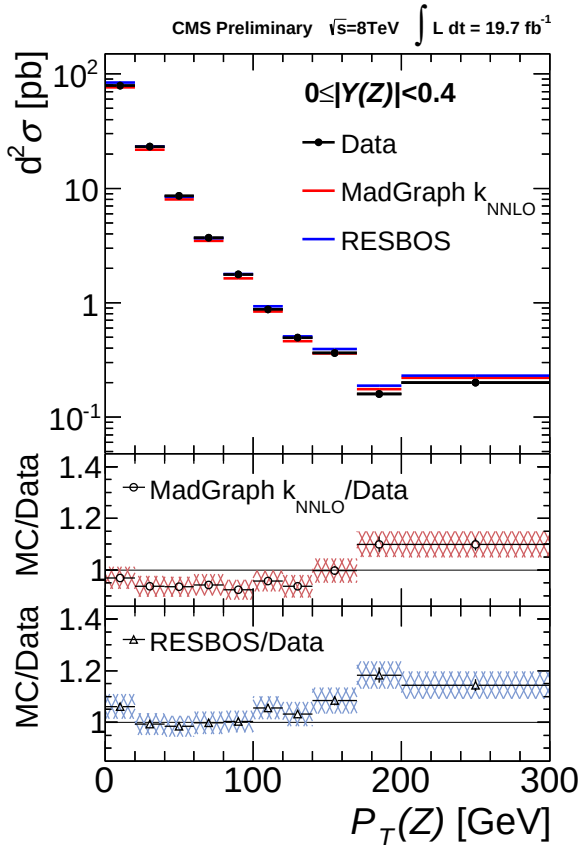


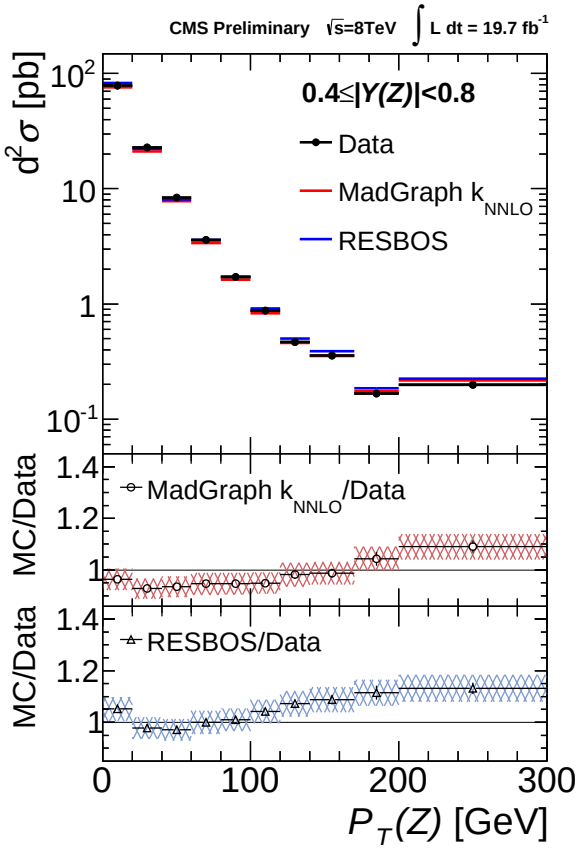
Bin number: $P_T(Z)_i + 10 \cdot |Y(Z)|_j$

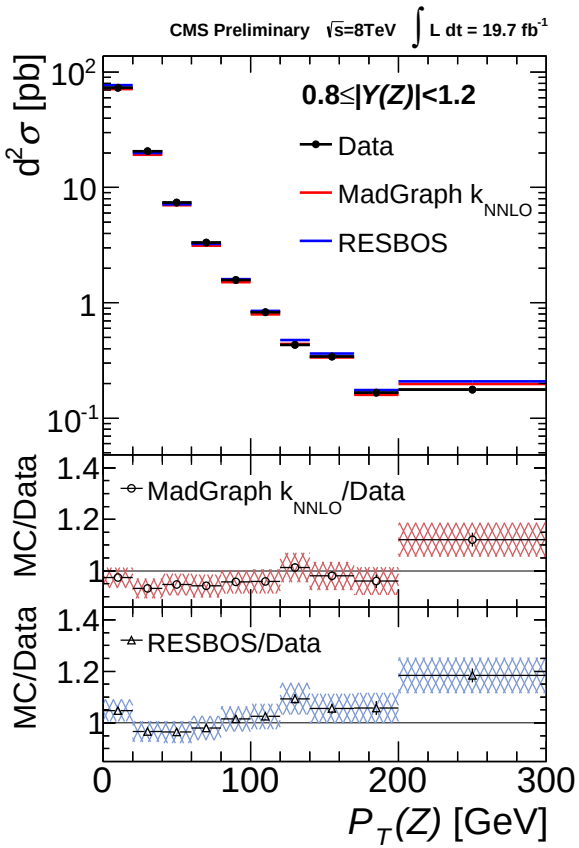


Response matrix almost diagonal $\Rightarrow$ Very small fraction of bin migration

Results: Absolute Fiducial Cross-Section (1)

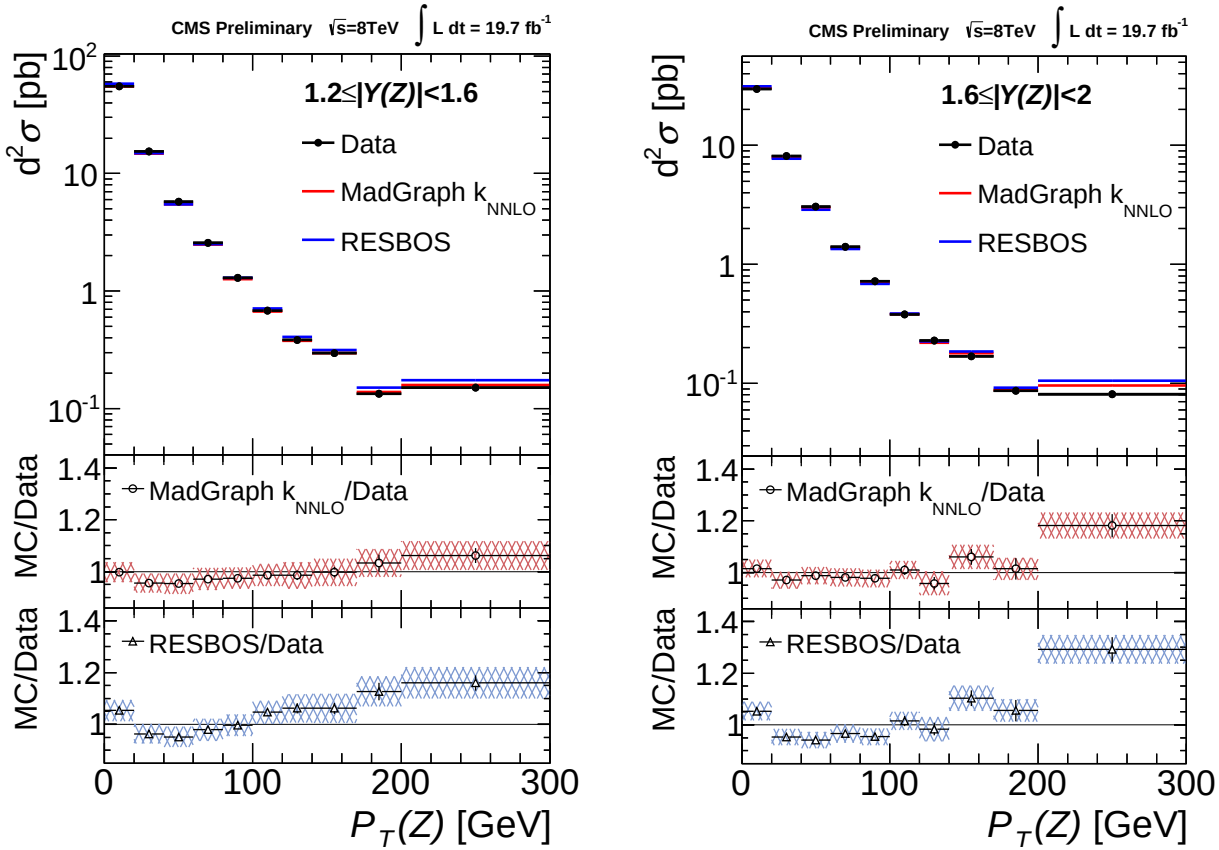






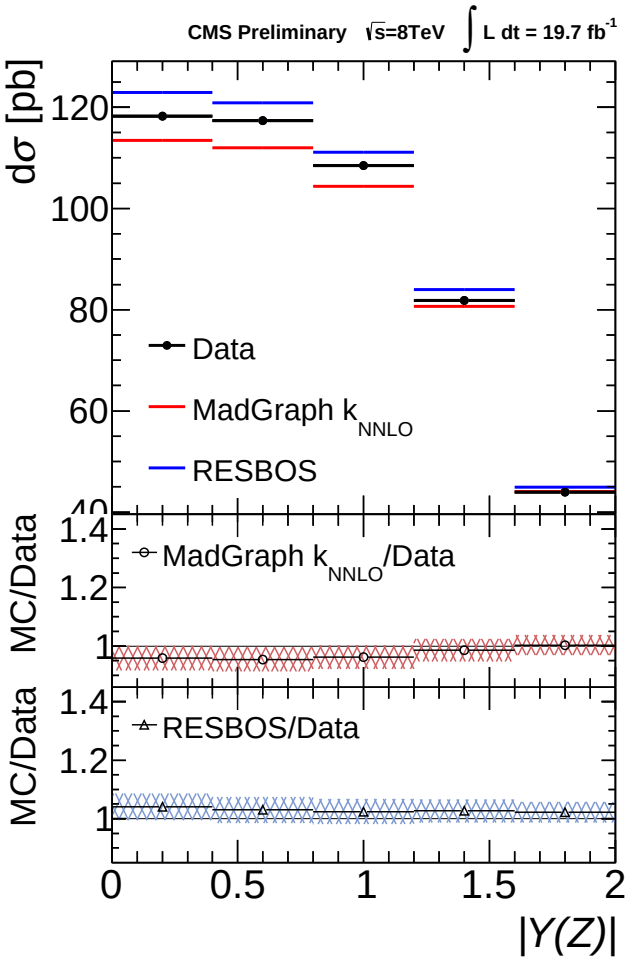
- MadGraph+PYTHIA6 Z2* tune, with CTEQ6L1 PDF set
- RESBOS, with CT10nnlo PDF set
- Vertical error bars show statistical errors of data and simulation
- Hatched bands show systematic uncertainties of data only (dominated by efficiency and lumi)
- Shape in P_T not well predicted by theory

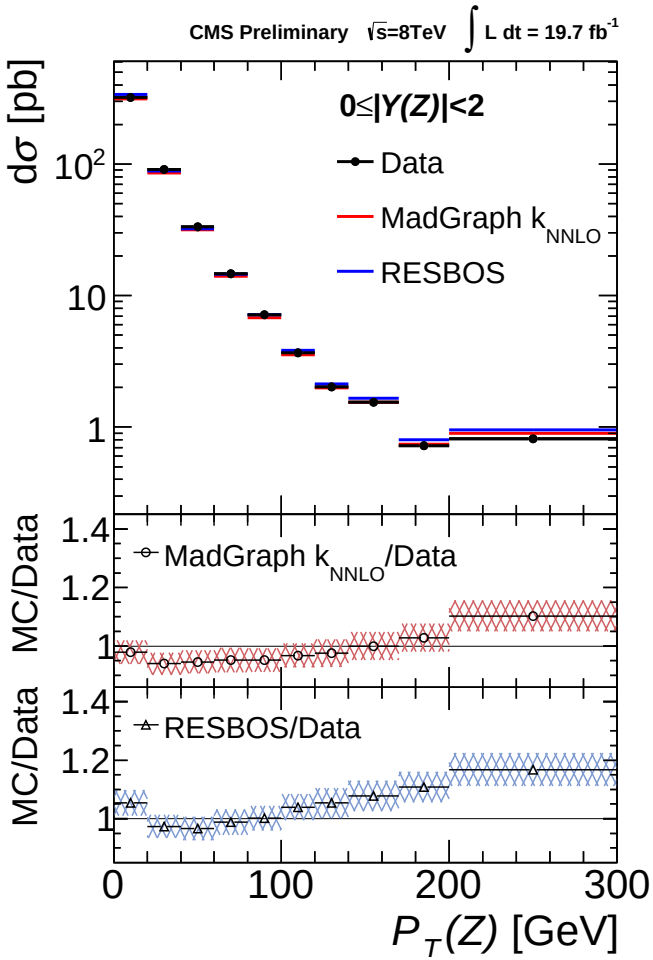
Results: Absolute Fiducial Cross-Section (2)



- Shape in P_T not well predicted by theory

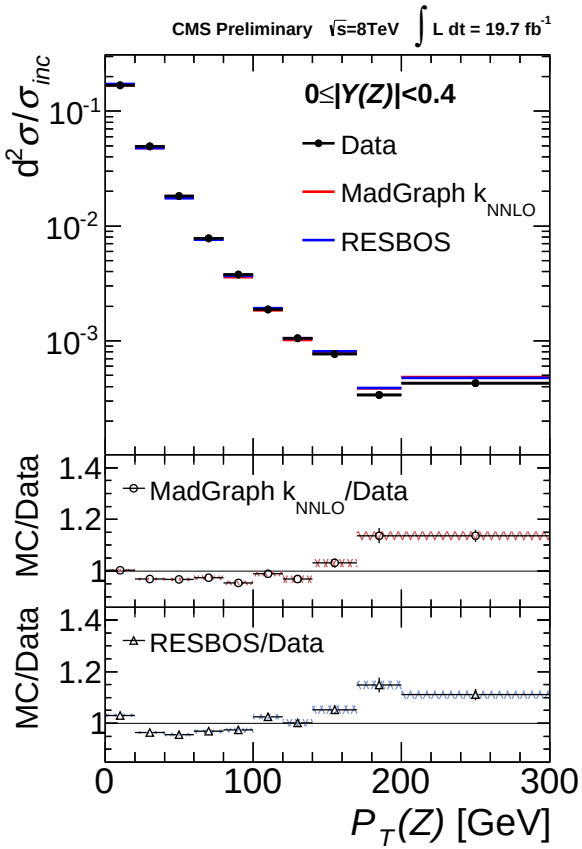
Results: Absolute Fiducial Cross-Section (3)

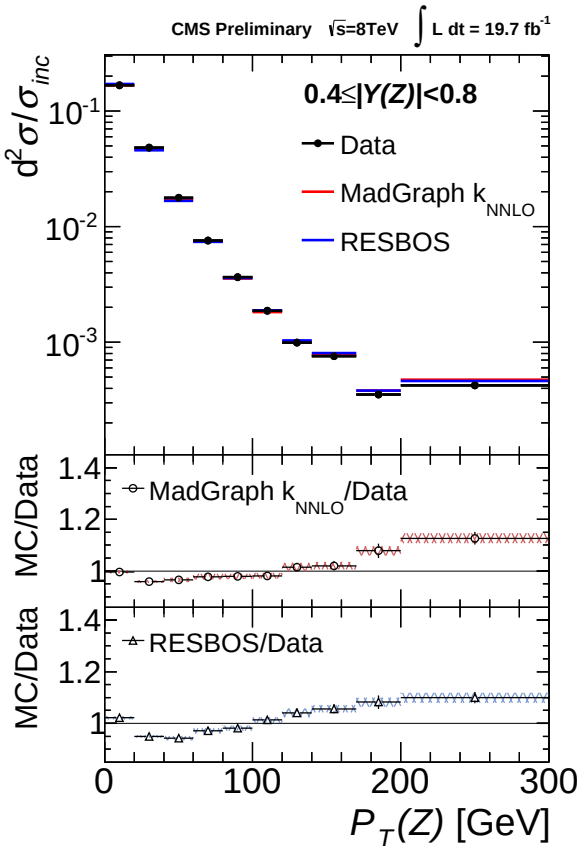


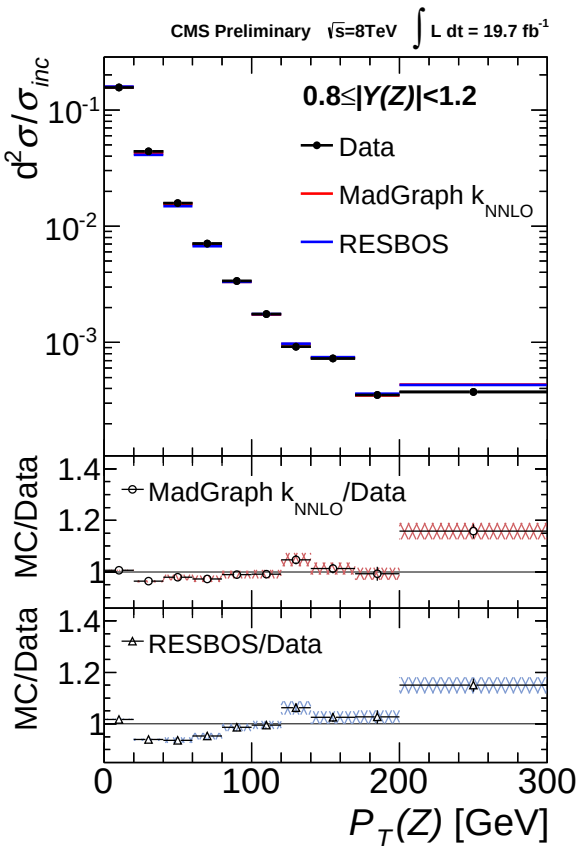


- MadGraph and RESBOS agree with data within experimental uncertainties
- Shape in P_T not well predicted by theory

Results: Normalized Fiducial Cross-Section (1)

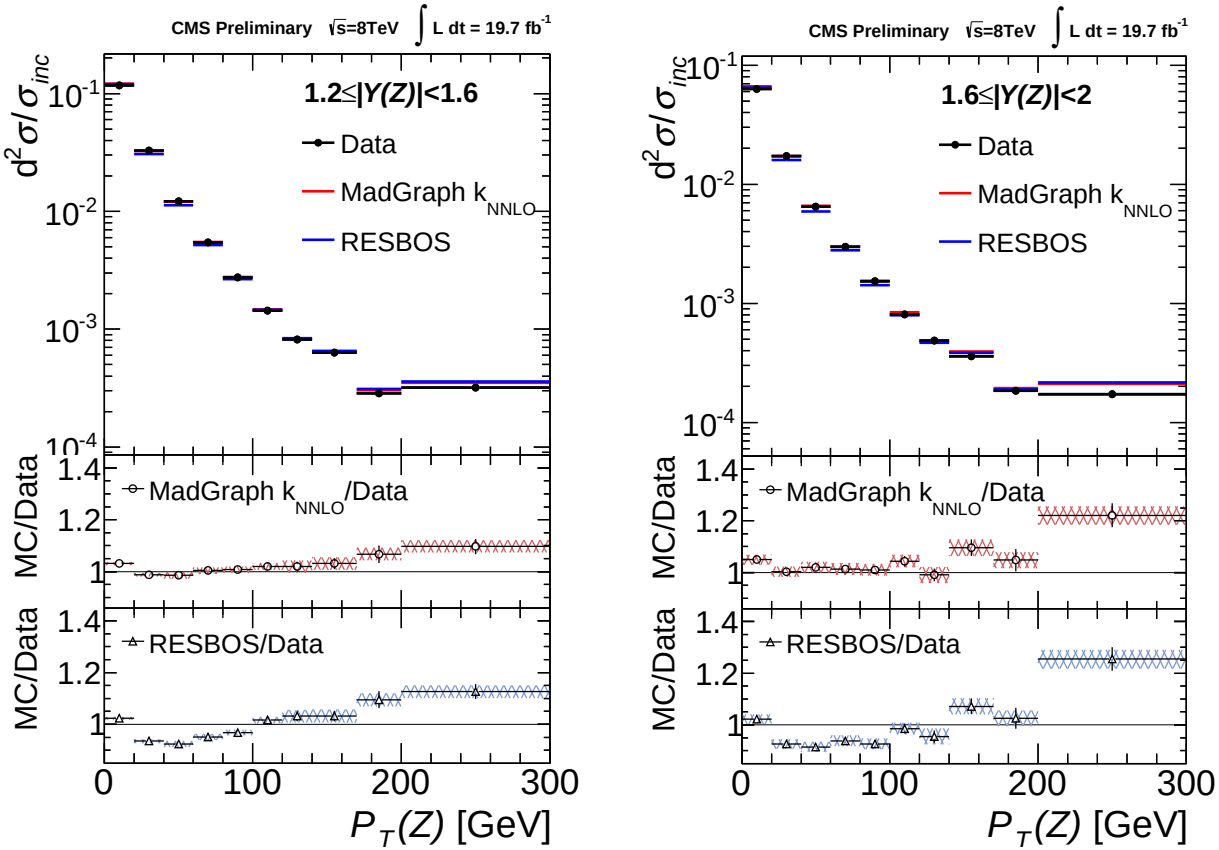






- Shape measurement $\rightsquigarrow$ global systematics cancel
- Shape in P_T not well predicted by theory

Results: Normalized Fiducial Cross-Section (2)



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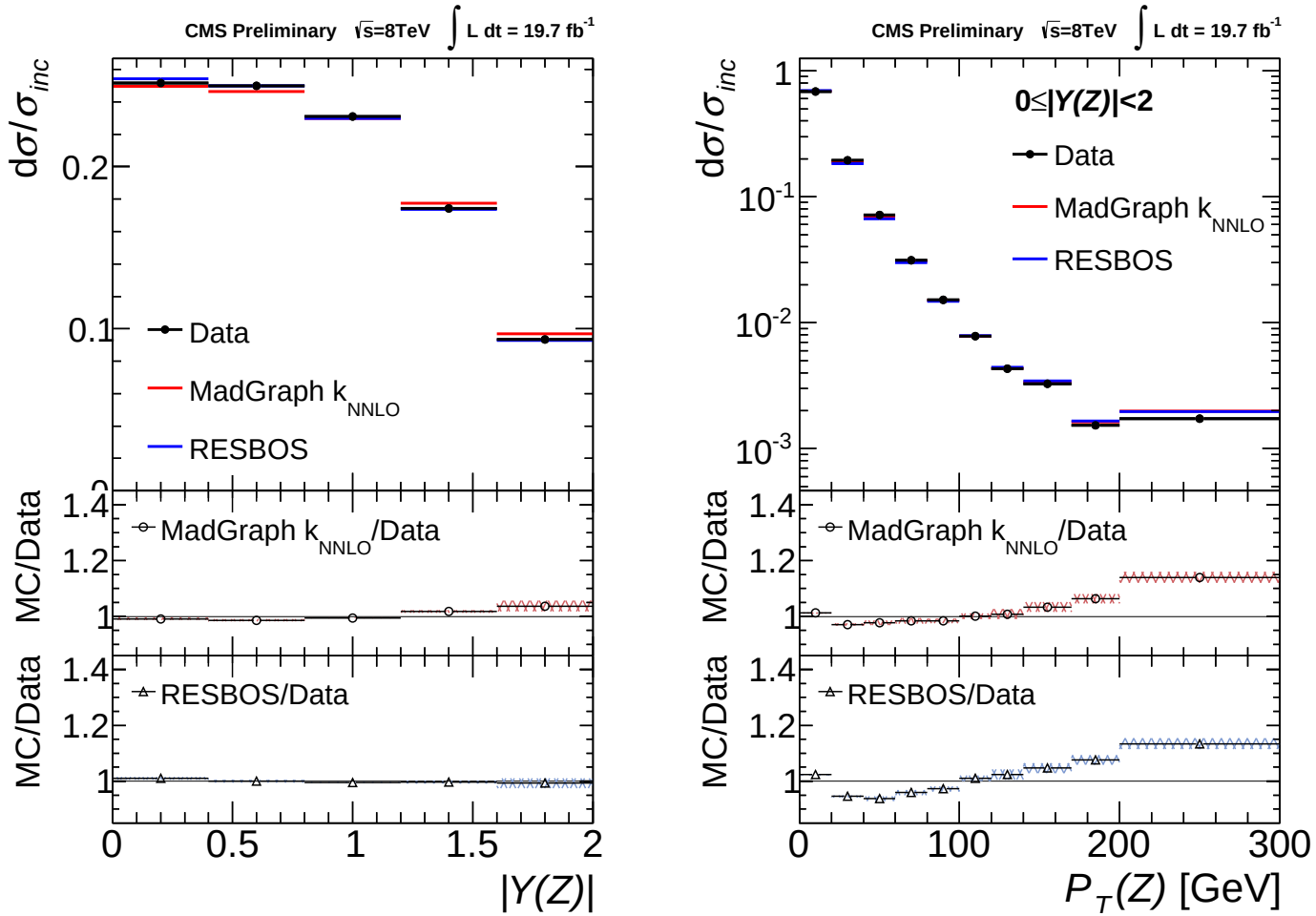
Results: Normalized Fiducial Cross-Section (3)



- Shape measurement $\rightsquigarrow$ global systematics cancel
- Both show similar trends for $P_T(Z) > 80\,\text{GeV}$
- Shape in P_T not well predicted by theory

Summary

- Presented:
  - Inclusive W and Z cross-sections at 8 TeV
  - Preliminary double differential $\frac{\mathrm{d}^2\sigma}{\mathrm{dP_T dY}}$ Drell-Yan cross-section at 8 TeV
- Results allow precise test of the Standard Model at the TeV scale
- Test of NLO and NNLO calculations
- Probe and constrain PDFs in a new kinematic regime

Thank You

Muon charge asymmetry in inclusive W production at 7 TeV

- Asymmetry between W^+ and W^- bosons as function of boson rapidity provides constraints on PDFs. Dominant production: $u\bar{d}(\bar{u}d) \to W^{+(-)}$
  $\rightsquigarrow$ d/u ratio and sea antiquark densities in Bjorken x range: $10^{-3} < x < 10^{-1}$
- Experimentally measured is lepton charge asymmetry:

$$\mathcal{A}(\eta) = \frac{\mathrm{d}\sigma/\mathrm{d}\eta(\mathrm{W}^+ \to \ell^+\nu) - \mathrm{d}\sigma/\mathrm{d}\eta(\mathrm{W}^- \to \ell^-\nu)}{\mathrm{d}\sigma/\mathrm{d}\eta(\mathrm{W}^+ \to \ell^+\nu) + \mathrm{d}\sigma/\mathrm{d}\eta(\mathrm{W}^- \to \ell^-\nu)}$$

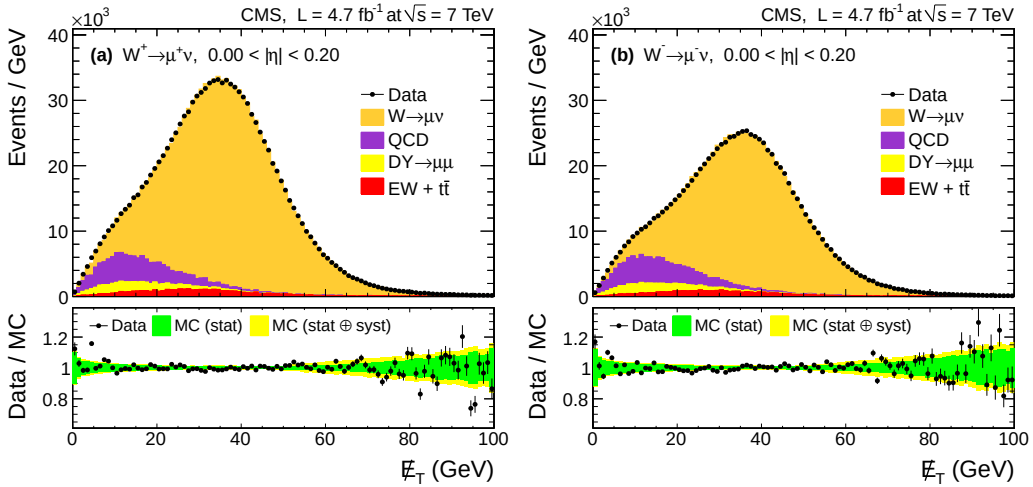
- Precise measurement, many systematics cancel out in asymmetry

Muon channel measured with 4.7 fb^{-1} of 2011 data at 7 TeV

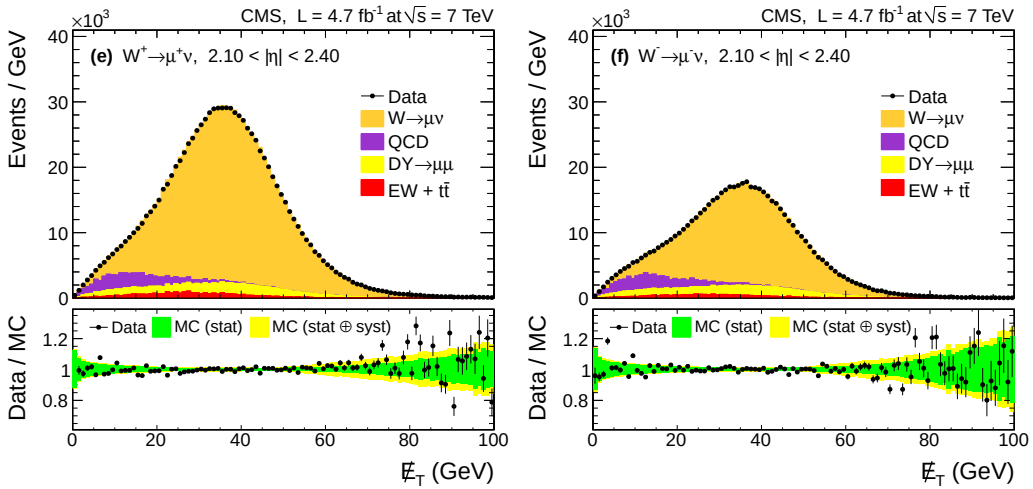
- CERN-PH-EP-2013-232, submitted to PRD

Muon charge asymmetry in inclusive W production at 7 TeV

MET distributions for $0 < |\eta(\mu)| < 0.2$

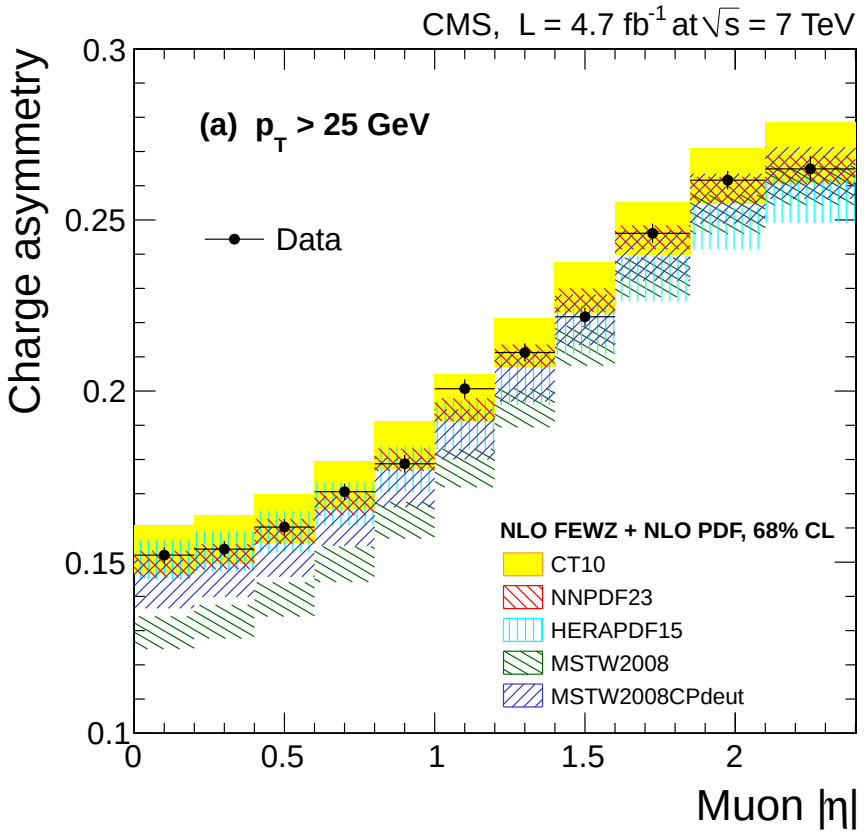


MET distributions for $2.1 < |\eta(\mu)| < 2.4$



- Similar event selection as for inclusive W cross-section measurement
- Data and simulation are corrected for:
  - efficiencies
  - muon momentum scale and resolution
- $W \to \mu\nu$ signal extracted from fits to the MET distributions
  - Background shape depends on $\eta(\mu)$
- Full covariance matrix provided

Muon charge asymmetry in inclusive W production at 7 TeV



vertical error bars include both statistical and systematic uncertainties

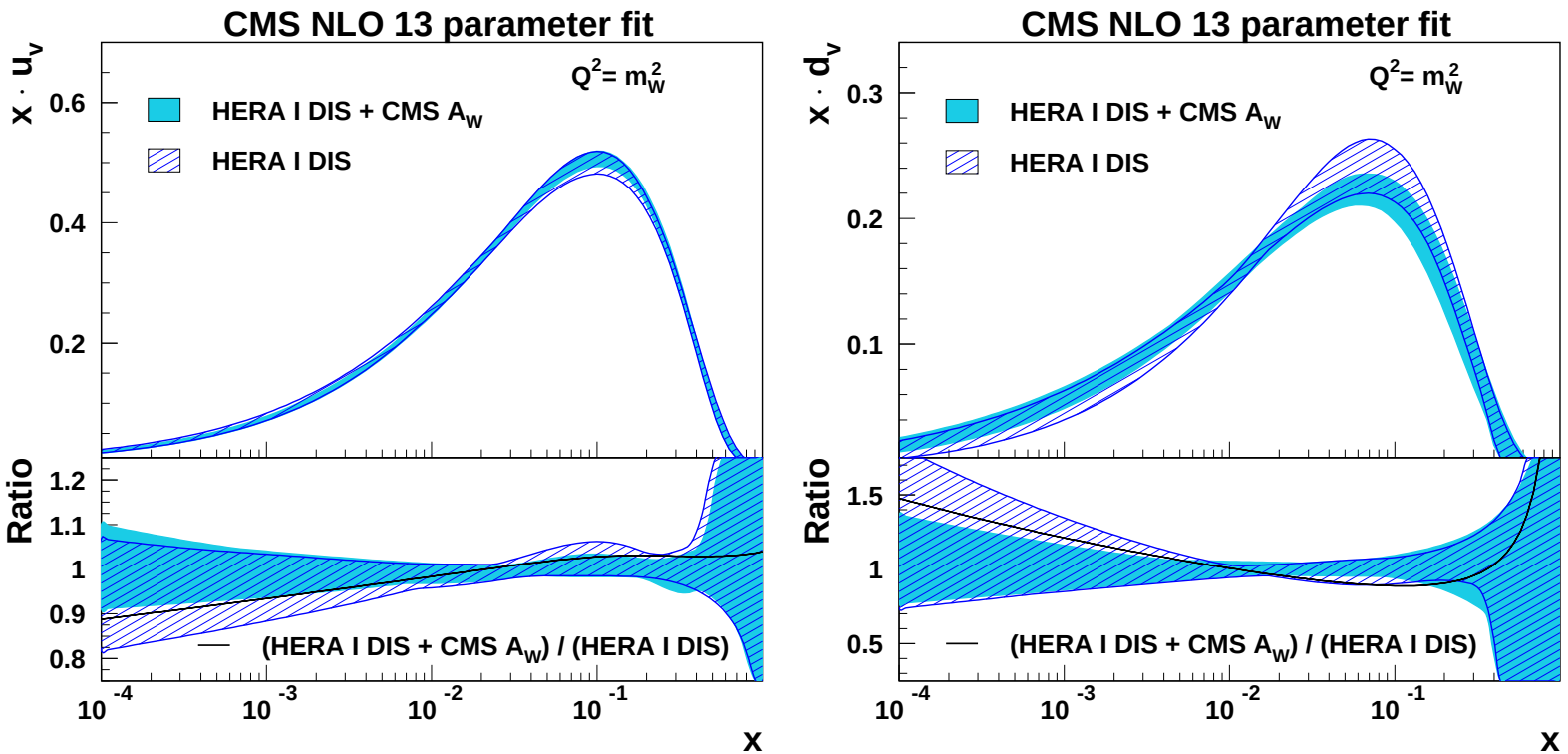
systematics dominated by:

- efficiency
- QCD background
- muon momentum correction

shaded areas indicate PDF uncertainties of corresponding PDF set

- Good agreement with NLO prediction, except for PDF set MSTW2008
- NLO prediction is consistent within NNLO prediction at the 1 % level

Muon charge asymmetry in inclusive W production at 7 TeV



- Change of shape within total uncertainties observed
- Uncertainties get significantly smaller
- In combination with $W + charme$ put constraints on strange PDF

  $\rightsquigarrow$ See Ringaile's presentation (WG1: Wed. 11:50)