Measurement of the Drell-Yan cross section at 7 TeV

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Outline

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- The CMS detector
- Analysis Strategy and Procedure
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  - Background Estimation
  - Detector Resolution
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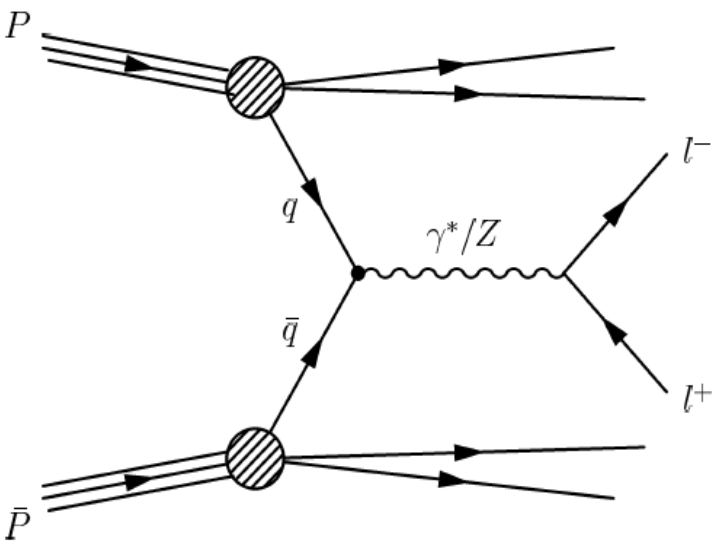
  - $d^2\sigma/dMdY$
- Summary

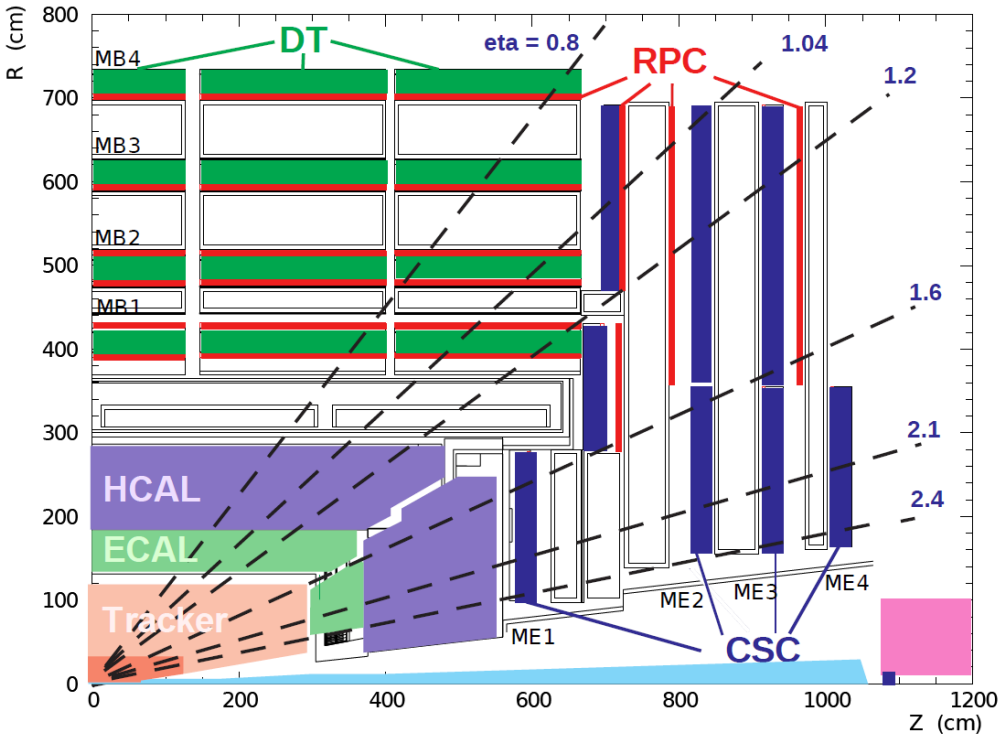
Motivation

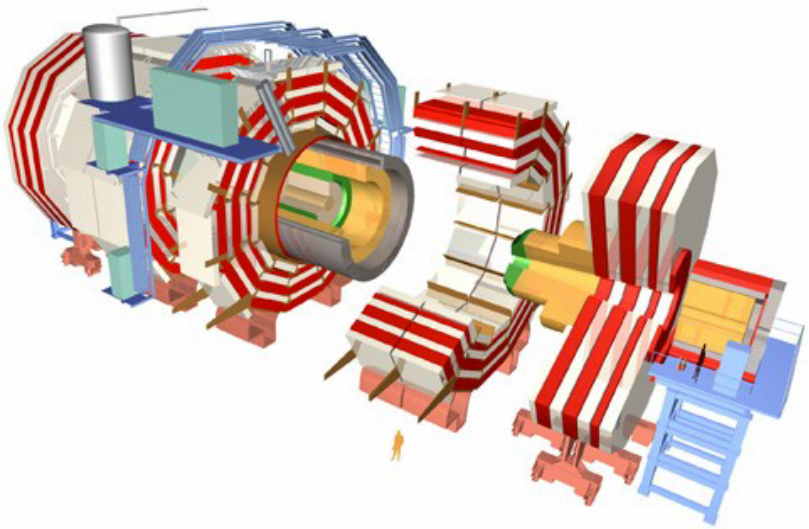
- Drell-Yan process
  - Is an important Standard Model benchmark channel
  - Theoretical cross section calculated up to NNLO
    - allowing tests of perturbative QCD
  - Differential cross section $d\sigma/dM$ depends on parton density functions (PDFs)
    - can be used to constrain PDFs
  - Drell-Yan is an important background for searches for physics beyond the Standard Model



- Measure the differential cross section $(1/\sigma_Z)d\sigma/dM$
  - normalize differential cross sections to the cross section at the Z peak
  - performed in muon and electron channel
- Measure the double differential cross section $(1/\sigma_Z)d^2\sigma/dMdY$
  - measurement directly usable to constraint PDFs
  - performed in muon channel $|Y| < 2.4$

The CMS Detector



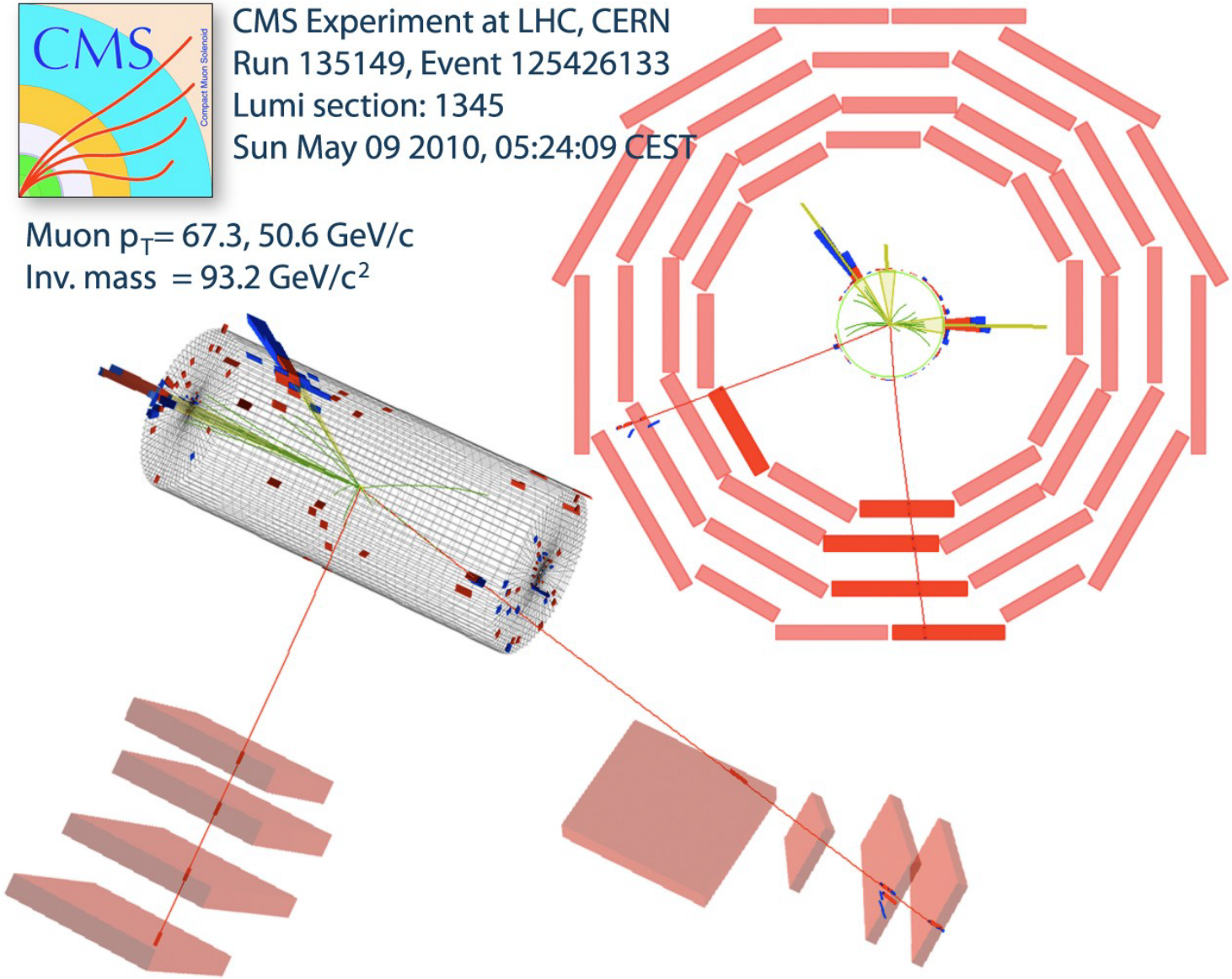


CMS can detect leptons (μ and e) up to 2.4, 2.5 in pseudorapidity and, effectively, in di-lepton rapidity (Y)

Drell-Yan Event

CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST

Muon p_T= 67.3, 50.6 GeV/c
Inv. mass = 93.2 GeV/c^2



Analysis Overview

- Full 2011 CMS dataset, containing 4.5 fb^{-1} of proton collision data is used
- Drell-Yan samples are produced with POWHEG MC generator
  - Rescaled to NNLO cross section from FEWZ
- Analysis procedure is the same for muon and electron channel
  - Event selection
  - Subtraction of Backgrounds
  - Momentum scale and resolution correction
  - Acceptance and Efficiency correction using MC
  - Efficiency correction using data-driven methods
  - Correction for Final State Radiation (FSR) effects based on MC
  - Systematic uncertainty estimation
  - Normalization to Z peak cross section
  - Comparison with theoretical predictions

Cross Section Measurement

- To measure the cross section per bin, we use the following formula:

$$\sigma_{i,j} = \frac{N^{u}_{i,j}}{A_{i,j} \cdot \varepsilon_{i,j} \cdot C_{i,j} \cdot L_{\text{int}}} \qquad R_i = \frac{1}{\sigma_Z}\frac{d\sigma}{dM}$$

i – mass bin
j – absolute rapidity bin
N^U – unfolded, background subtracted yield
A – acceptance
ε – efficiency
C – efficiency and FSR correction
L_{int} – integrated luminosity

- Note: the acceptance correction is not applied for the 2D measurement

- Binning
  - 1D: 40 mass bins (15-1500 GeV)
  - 2D: 6 mass slices
    - 20, 30, 60, 120, 200, 15000 GeV
  - |Y| < 2.4
  - 24 rapidity bins up to 200 GeV
  - 12 rapidity bins in 200-1500 GeV

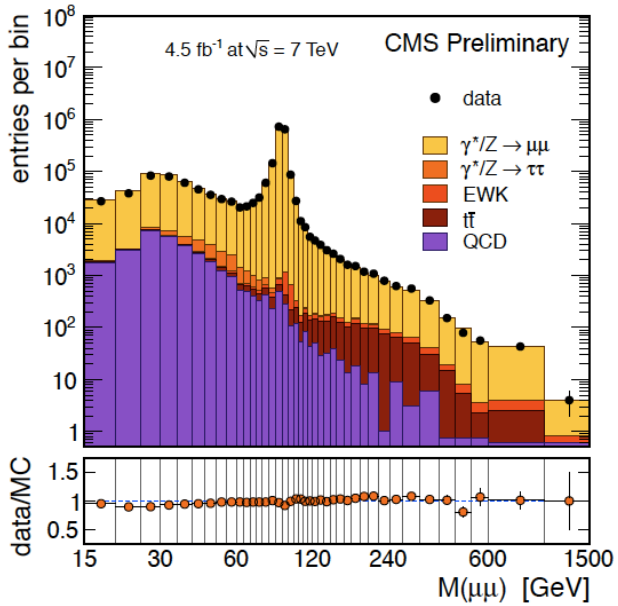
We take advantage of the CMS detector's capabilities to measure very low mass DY

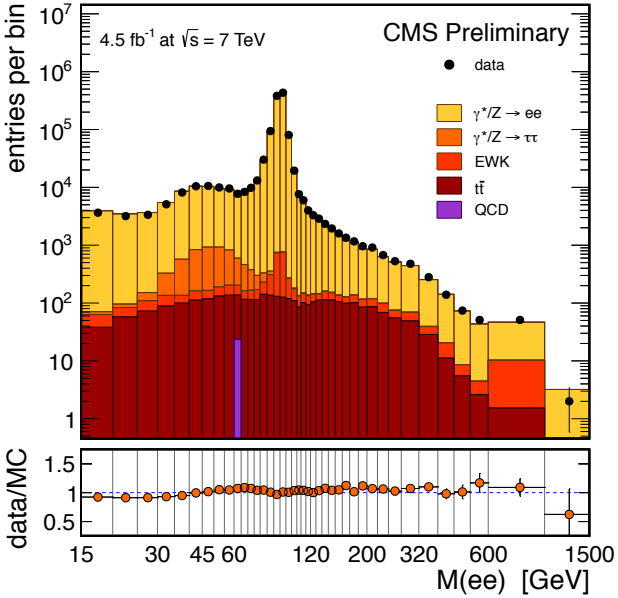
Event Selection

- Muon channel:
  - Un-prescaled double muon trigger with no isolation requirement on the level of HLT is used (online muon p_T > 13, 8 GeV)
  - 2 muons with opposite charge, p_T > 14, 9 GeV, $|\eta| < 2.4$
  - Muon track quality cuts
  - Relative combined particle-flow isolation with electrons and photons excluded
  - Select the highest vertex probability muon pair
    - cut on di-muon vertex probability and 3D angle to reject cosmics and muons not coming from the same collision/process
- Electron channel:
  - Un-prescaled di-electron trigger (E_T > 8, 13 GeV)
  - 2 particle-flow electrons, E_T > 20, 10 GeV, $|\eta| < 2.5$
    - Exclude ECAL gap
  - Apply electron ID cuts
  - Conversion rejection using vertexing method
    - No missing inner hits allowed
  - Particle-flow isolation

Background Estimation (I)

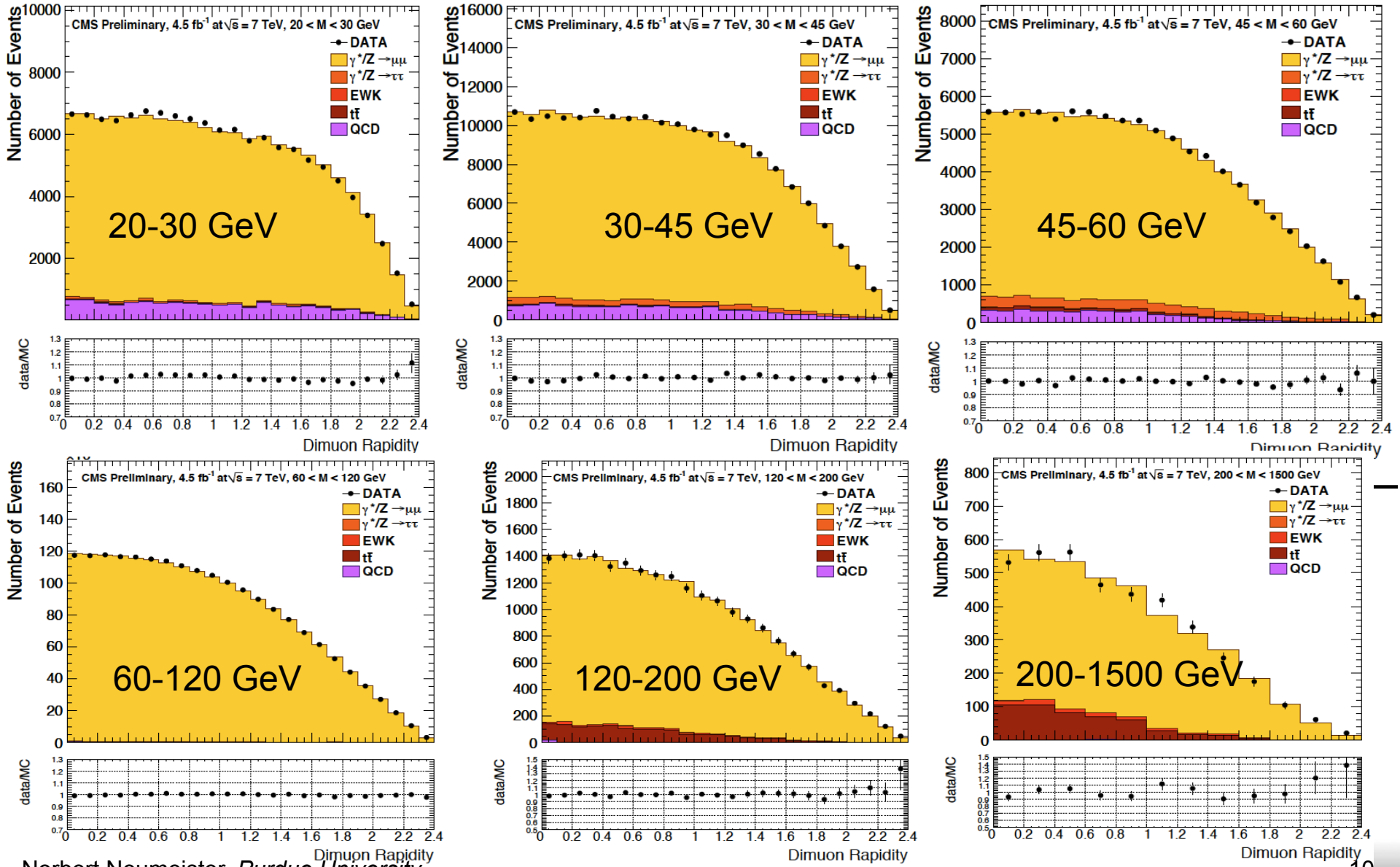
- Muon channel:
  - Low-mass region: QCD multi-jets
  - Peak region: Drell-Yan → $\tau^+\tau^-$, W → l + ν, dibosons
  - High-mass region: top pair production, dibosons
  - QCD background determination using the data-driven ABCD method
  - All other backgrounds are estimated from MC
- Electron channel:
  - Data-driven technique to estimate backgrounds
  - e-μ method: Drell-Yan → $\tau^+\tau^-$, ttbar, WW, single top
  - Fake rate: QCD, W+jets





Mass spectrum in the detector acceptance for data and MC events. The signal is normalized to the NNLO cross section.

Background Estimation (II)



Detector Resolution (I)

- The mass spectrum is corrected for resolution effects by using the response matrix unfolding technique
- The "true" spectrum is obtained by constructing the response matrix T where:

$$N_i^{obs} = \sum_k T_{ik} N_k^{true}$$

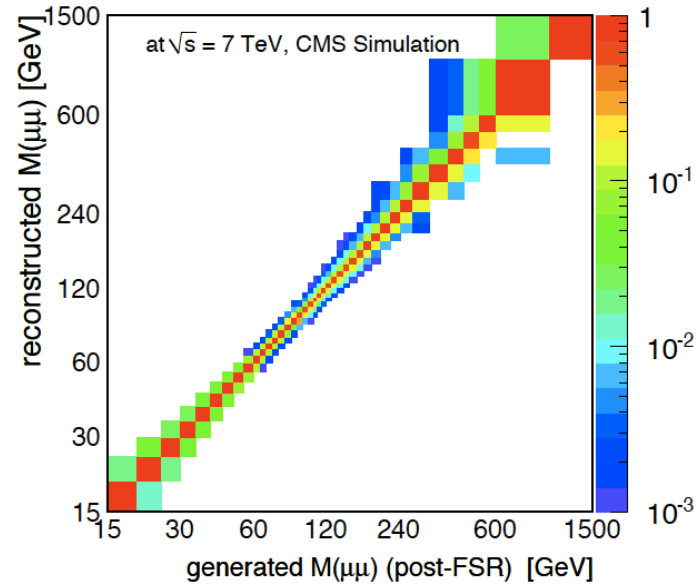
  - T_{ik} is the probability that an event belonging in mass bin k is reconstructed in mass bin i
  - T_{ik} is extracted from MC simulation
  - The momentum scale correction, taking into account the effects of detector misalignment, is applied
- By inverting T, the corrected spectrum can be obtained
  - We use the technique of matrix inversion to unfold the spectrum

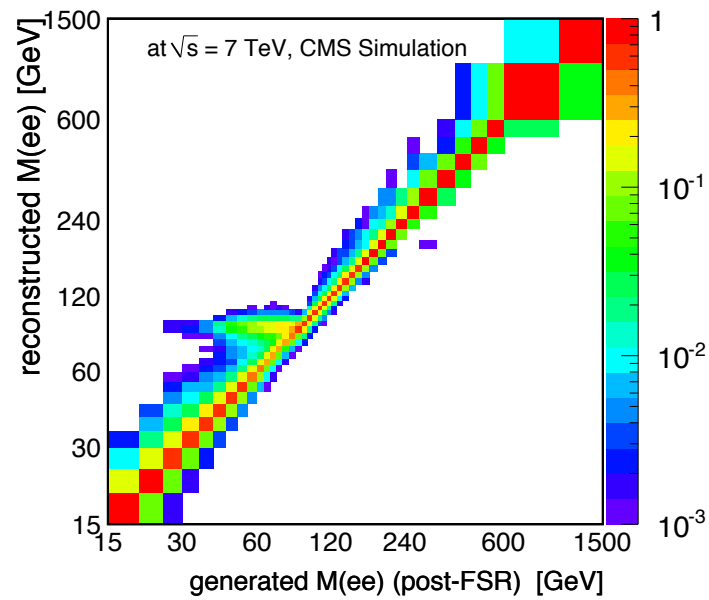
$$N_i^{true} = \sum_k (T_{ik})^{-1} N_k^{obs}$$

- FSR correction is performed as a separate step

Detector Resolution (II)

- The unfolding procedure corrects the effects of the detector resolution on the mass spectrum
- Muons:
  - Response matrix is nearly diagonal
  - Off-diagonal elements located adjacent: < 0.1
- Electrons:
  - Large effects below Z peak due to FSR photons in response matrix



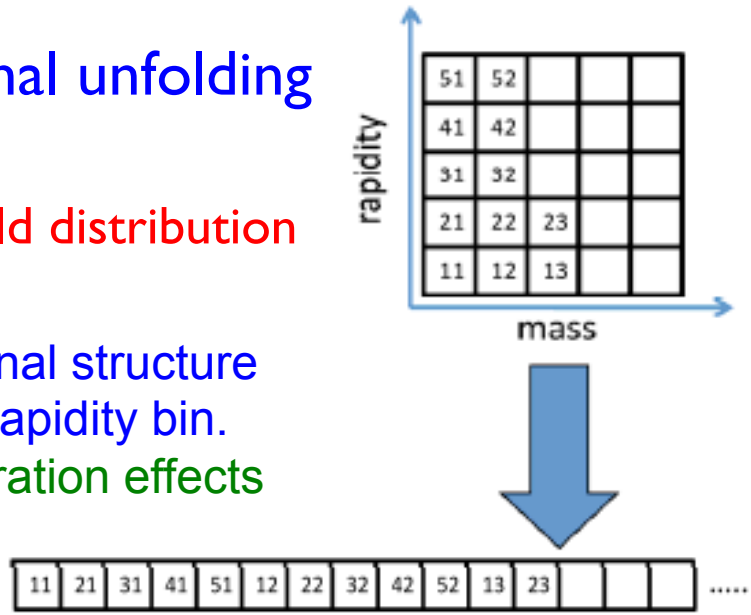


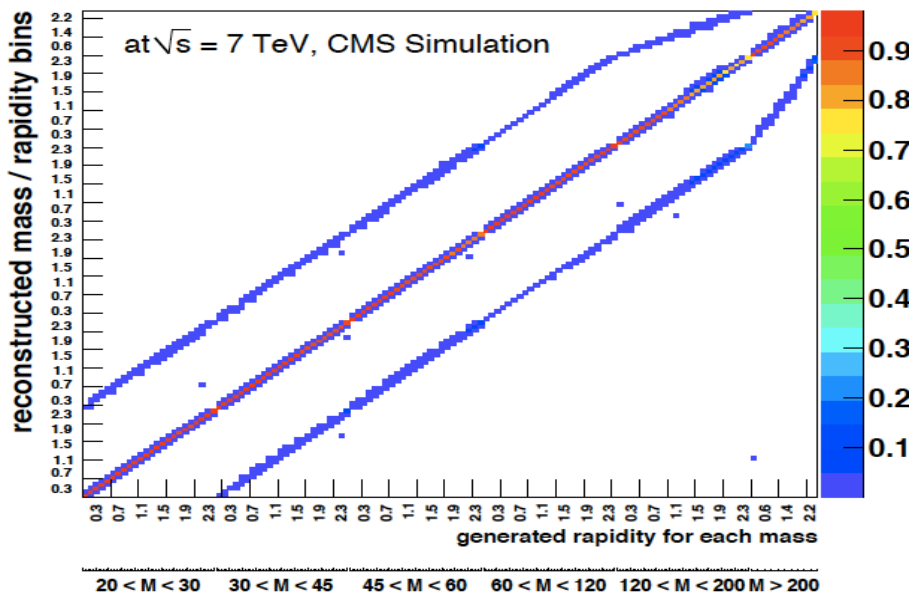
Detector Resolution (III)

- For the 2D measurement, the conventional unfolding method is used
  - Convert 2D rapidity-mass into a 1D mass yield distribution
  - Apply the usual 1D unfolding procedure

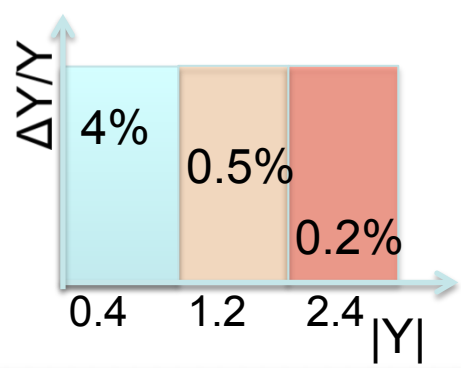
The resulting response matrix has a block-diagonal structure with each block corresponding to a given mass-rapidity bin.

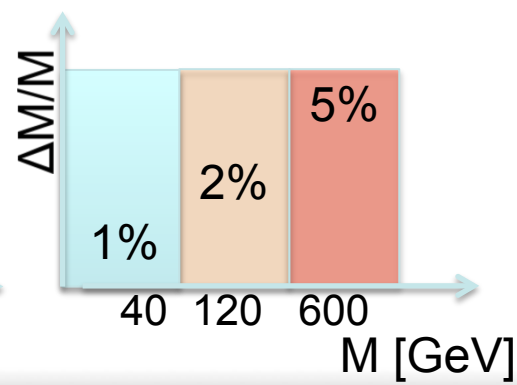
The entries off the main diagonal are due to migration effects





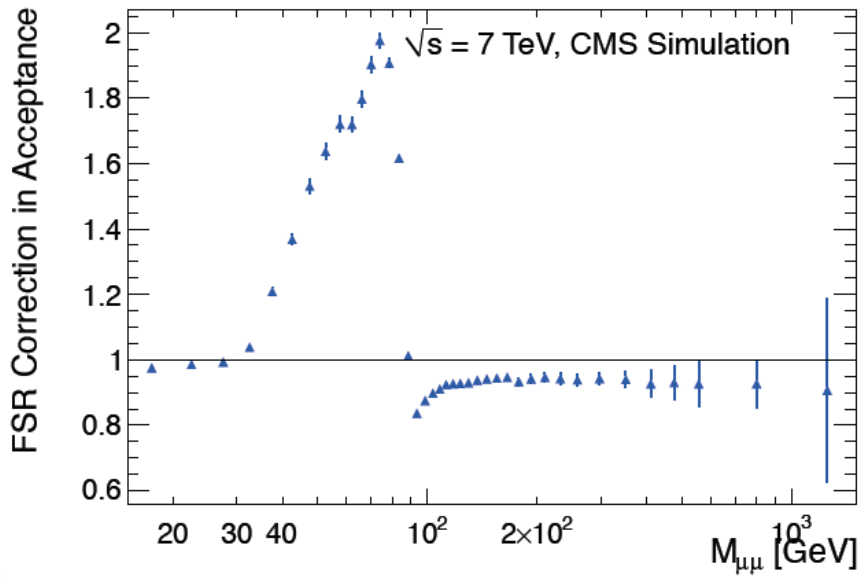
132 × 132 unfolding matrix

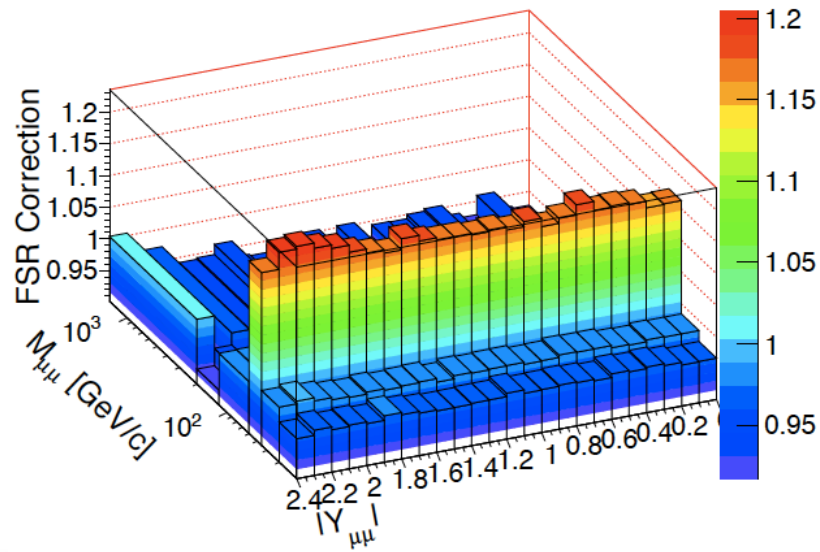




Final State Radiation Correction

- FSR corrections are determined from simulation
  - The FSR modeling in the POWHEG signal sample is used to derive the corrections bin by bin
  - FSR effects are very well modeled in MC
- FSR-correction factors are derived bin-by-bin
- Correction is applied in order to compare the measurement to the theoretical calculations which don't include FSR





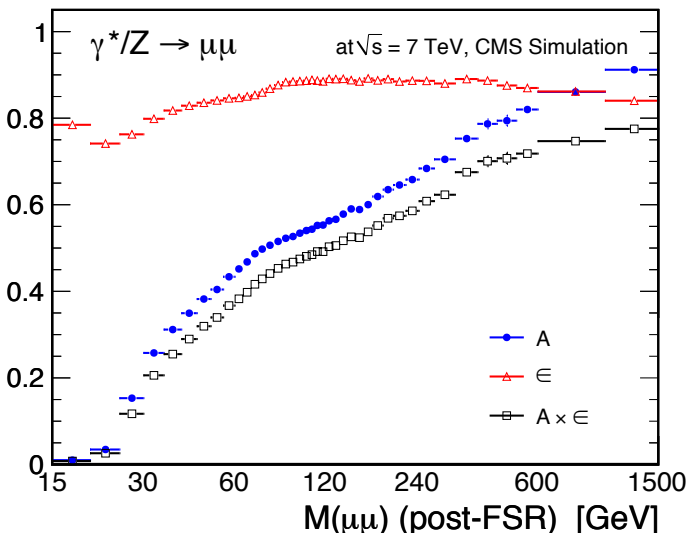
Acceptance and Efficiency (I)

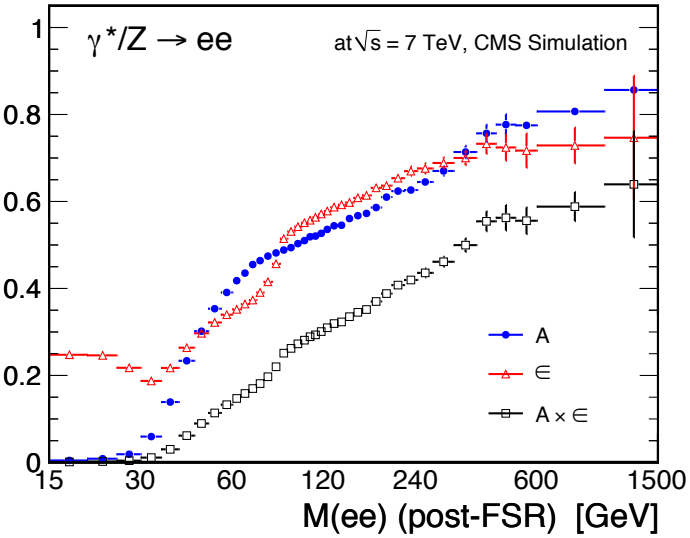
- Acceptance*efficiency is derived from MC according to:

$$A \cdot \varepsilon = \frac{N^{Acc}}{N^{GEN}} \cdot \frac{N^{RECO}}{N^{Acc}} = \frac{N^{RECO}}{N^{GEN}}$$

N_X – number of generated events, with X:
GEN – initial
ACC – in the acceptance
SEL – (RECO) selected

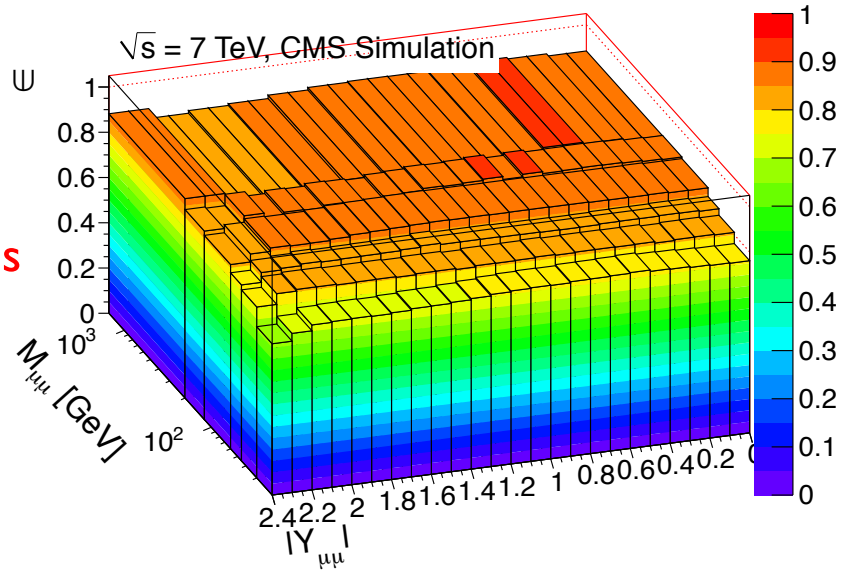
- The acceptance accounts for the lepton p_T and η cuts, the efficiency reflects the full selection
- Efficiencies for leptons are measured using data driven techniques
  - MC efficiencies are corrected to match data
- FEWZ NNLO reweighting procedure is applied to correct for model dependence
- At low invariant masses, the two high-p_T leptons in the analysis, indirectly impose the existence of a hard gluon in the process (➔NLO)
- The lepton kinematic distributions in this region are very sensitive to the exact description (especially for very low invariant mass)
  - Thus for proper description of the low invariant mass region NNLO is mandatory!





Acceptance and Efficiency (II)

- For the 2D measurement, only efficiency correction is applied
  - No acceptance correction is applied
  - 2D measurement is model independent
- Efficiency corrections
  - Data-driven efficiency scale factors are applied to correct for systematic deviations between data and MC
  - Single lepton efficiencies are estimated using the data-driven *Tag-and-Probe* technique
  - The efficiency correction tables are determined for each individual efficiency as
    - $\rho = \rho(p_T,\eta) = \varepsilon_{Data}(p_T, \eta)/\varepsilon_{MC}(p_T, \eta)$
    - The efficiency corrections are applied per lepton and are used to weight the MC events



Systematic Uncertainties

- Muon channel
  - Unfolding & momentum scale correction: 0.5% at low mass; 28% at high mass
  - Estimation of backgrounds: about 0.5% at low masses; up to 23% at high mass
  - Efficiency estimation: about 0.5% at low masses; up to 3.5% at high masses
- Electron channel
  - Energy scale correction: 1-6% (in low and high mass regions) to 10% (Z peak region)
  - Unfolding: 1-5% (in low and high mass regions) to 10% (Z peak region); highest mass bin: 34%
  - Estimation of backgrounds: about 0.5% (low mass) to 6% (high mass)
  - Efficiency estimation: ~1% (Z peak region) to 6% (in low and high mass regions); highest mass bin: 19%
- PDF uncertainties: 3% in low mass region to 1% in high mass region
- The modeling uncertainty on acceptance for the $d\sigma/dM$ measurement is largest at low mass: up to 10%
- The luminosity uncertainty cancels out due to the normalization to the Z peak cross section

dσ/dM Results (I)

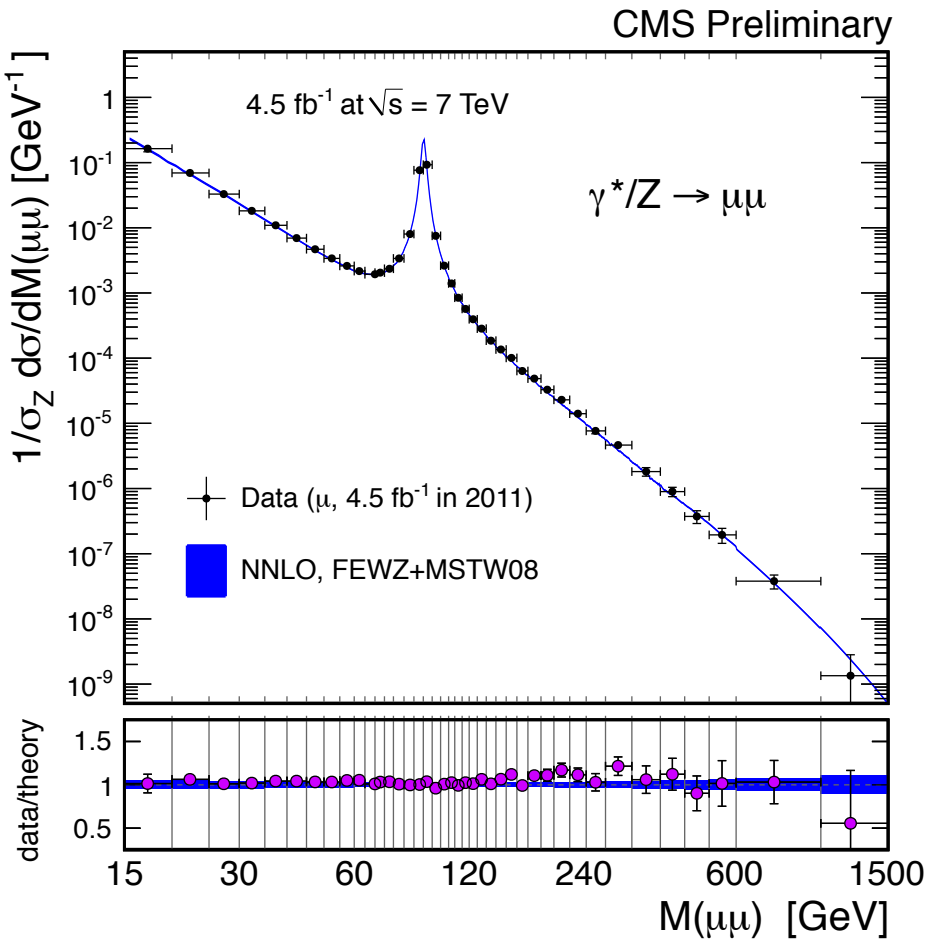
- Normalized cross-section is calculated as:

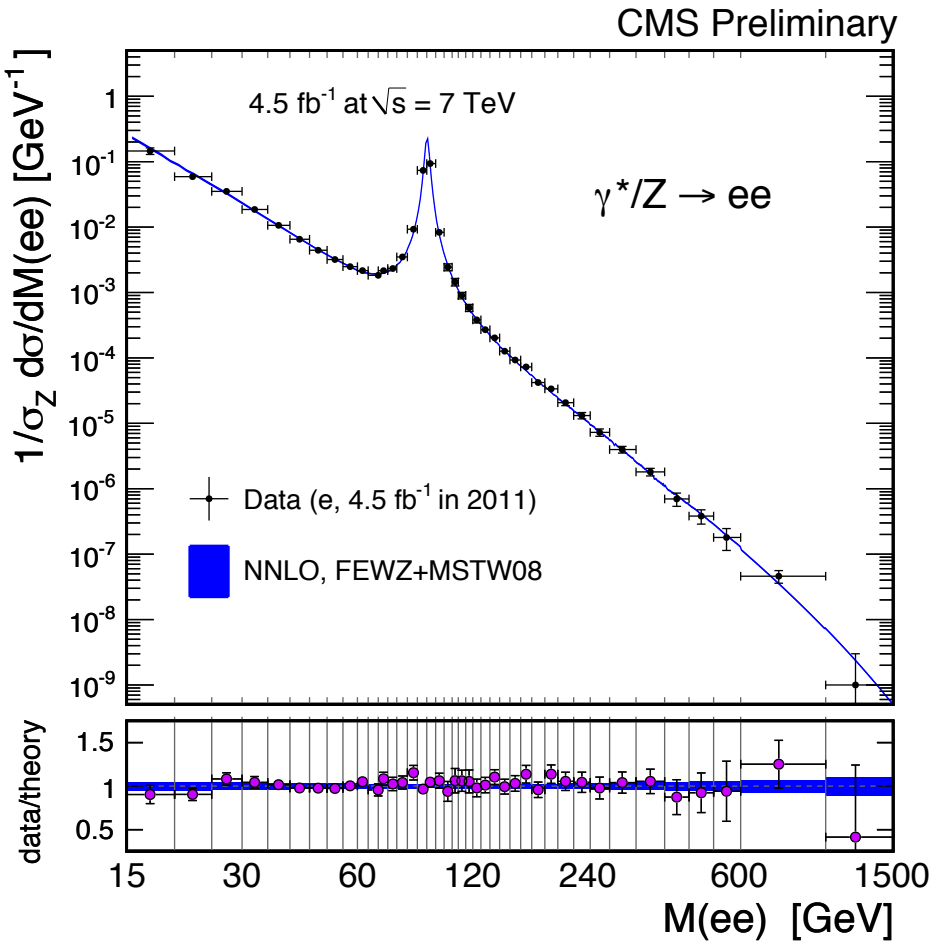
$$R^{i}_{pre\ FSR} = \frac{N^{i}_{u}}{A_i \epsilon_i \rho_i} / \frac{N_{u,norm}}{A_{norm} \epsilon_{norm} \rho_{norm}}$$

i - mass bin index

  - Where 'norm' refers to the measurement in the normalization region (Z peak: 60 < M < 120 GeV)
  - 40 mass bins covering the range from 15 to 1500 GeV are used
- The Drell-Yan cross section normalized to the Z peak is calculated for both muons and electrons in the full phase space
  - will be available in the acceptance region as well

dσ/dM Results (II)





The data distribution is well described by NNLO. At low invariant masses it is difficult to control the “modeling” uncertainty, at high invariant masses statistics plays a major role.

$d^2\sigma/dMdY$ Results (I)

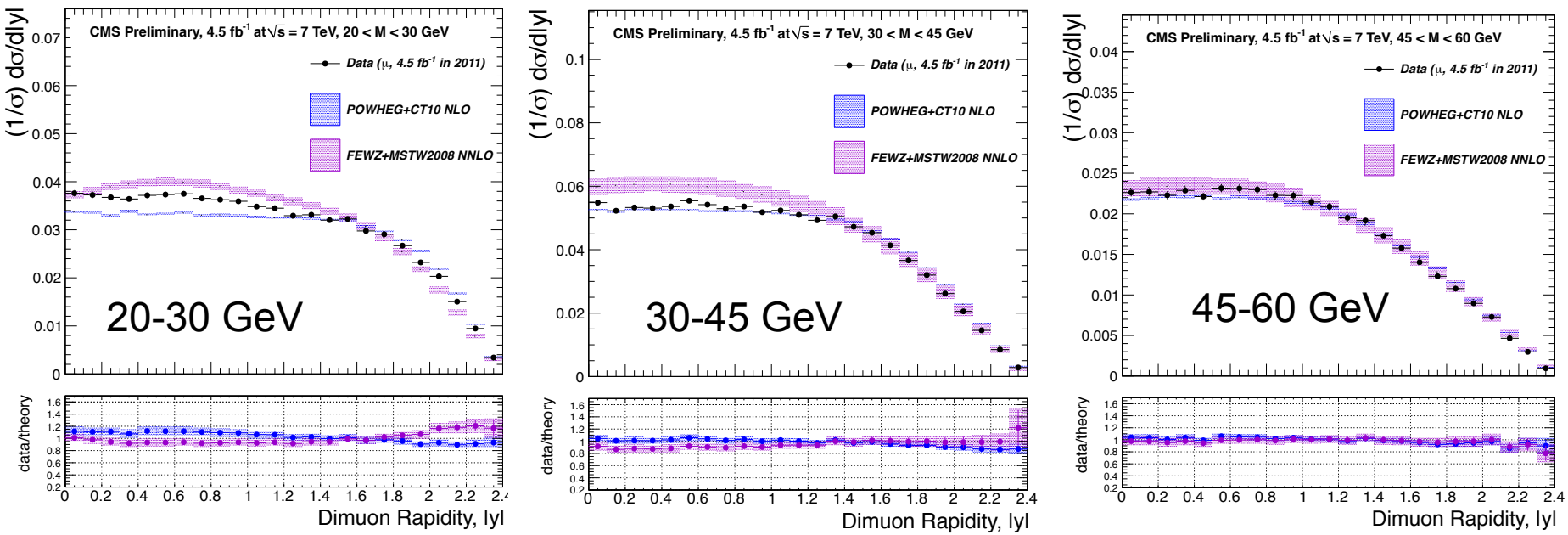
- The 2D measurement is performed within the detector acceptance, to reduce the model dependence
- The result of the double differential cross section measurement is presented as the following ratio per absolute rapidity bin *i* within the invariant mass slice *j*:

$$R^{i,j}_{pre\ FSR} = \frac{N_u^{i,j}}{\epsilon^{i,j}\rho^{i,j}} / \frac{N_u^{norm}}{\epsilon^{norm}\rho^{norm}}$$

  - *j* – rapidity index, *i* –mass index
  - Where 'norm' refers to the measurement in the normalization region (Z peak: 60 < M < 120 GeV) within |Y| < 2.4
- Performed in 24 rapidity bins between 0 and 2.4 (12 Y-bins for the highest mass bin) and
- 6 mass ranges: (20-30), (30,45), (45,60), **(60,120)**, (120, 200), (200,1500) GeV

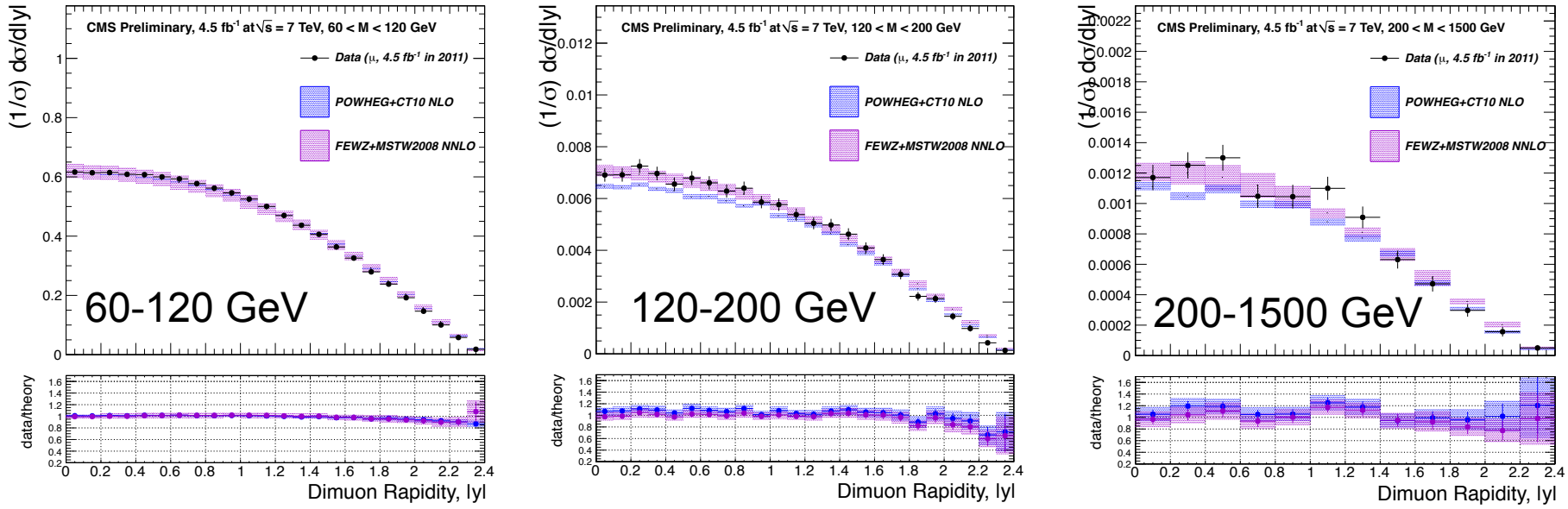
$d^2\sigma/dMdY$ Results (II)

- Currently we compare to FEWZ + MSTW2008@NNLO and POWHEG + CT10@NLO
- Moving away from the Z peak we gain discrimination power
- The full covariance matrix is to be included in the paper being finalized. Studies in the electron channel are also being finalized and are part of the paper in preparation.
  - At this point we can test the influence of our measurement on global PDF fits



$d^2\sigma/dMdY$ Results (III)

Within the detector acceptance



- Good agreement observed for most mass bins
- Low mass region is very sensitive to PDF uncertainties
- To properly take into account the PDF uncertainty, the comparisons with various NNLO PDF sets are being performed
  - including NNPDF2.1, JR09VFNS, ABKM and CT10W NNLO PDF sets

Summary

- The Drell-Yan differential cross-section normalized to the Z peak was measured in the muon and electron channel with 40 mass bins, covering the mass range 15–1500 GeV
  - The full 2011 dataset was used: 4.5 fb^{-1}
  - The results agree with NNLO theory calculations
  - The precision makes the measurement sensitive to the NNLO theoretical predictions
- The double-differential cross section was measured in the muon channel. The measurement was performed in 6 invariant mass bin covering the mass range of 20-1500 GeV and absolute rapidity range of $|Y| < 2.4$
  - The measurement is performed within the detector acceptance to reduce the model dependence of the result
  - The $d^2\sigma/dMdY$ measurement results can be directly used to constrain PDFs