Studies of DY $\to \mu\mu$ process
in pp collisions at 7 TeV with CMS Experiment

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Drell-Yan Scattering and the Structure of Hadrons
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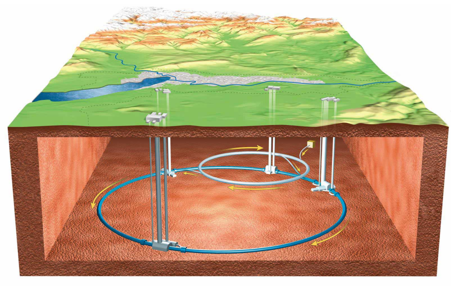
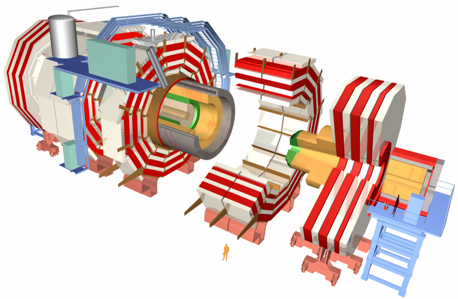
Outline

- CMS experiment at LHC
- Analysis
  - Events selection
  - Backgrounds
  - Performance
  - Uncertainties
- Results
  - $d\sigma/dM$ differential cross section measurement
  - $d^2\sigma/dMdY$ double-differential cross section measurement
  - A_{FB}
  - Weak-mixing Angle

CMS@LHC: a heavy gauge boson factory & detector





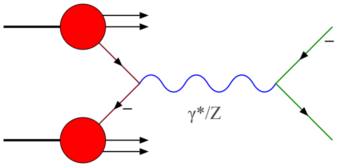
LHC:

- Beam energy: 2x3.5 TeV
- Super-conducting magnets
- 1232 dipole magnets (bending)
- 500 quadrupole magnets (focus)

CMS:

- Overall diameter 15 m,length 28.7 m
- Solenoid magnet 3.8 T
- Tracker: $|\eta| < 2.5$, Muon: $|\eta| < 2.4$, ECAL: $|\eta| < 3$
- Muons p_T resolution $\approx$ 2%, electrons E resolution $\approx$ 3% for energies relevant for this analysis
- 2011 run: 5.28 fb^{-1} delivered, 4.98 fb^{-1} is "golden" data
- Instantaneous luminosity reached 3.5×10^{33}
- Pile-up: factor 1-15 (increased with luminocity) multiple interactions

DY pairs production at LHC



- The production of lepton pairs in hadron-hadron collisions via the Drell–Yan (DY) process is described in the Standard Model
- DY lepton pairs constitutes a major source of background for various searches, including searches for new physics, such as production of high mass dilepton resonances.

- Theoretical calculations of the differential cross section $d\sigma/dM$ are well established up to next-to-next-to-leading order (NNLO)

  MC samples are produced using a variety of generators. The signal is generated with POWHEG interfaced with the PYTHIA parton-shower generator at the next-to-leading order (NLO). A $t\bar{t}$ is produced with the MadGraph generator interfaced with the TAUOLA generator used to simulate fragmentation at the leading order. Rest is PYTHIA generator. The detector simulation is performed using GEANT4.
- Comparisons between calculations and precise experimental measurements provide stringent tests of perturbative QCD and significant constraints on the evaluation of the PDFs.
- DY advantages:
  - High event rates at the LHC
  - Leptonic decays $Z \to l + l$ to electrons and muons provide clean signals
  - Help to understand and calibrate the detector response: trigger, identification, resolution, efficiencies

DY crossection calculation

In this analysis cross sections are calculated as:

$$\sigma = \frac{N_{\mathrm{u}}}{A \varepsilon C \mathscr{L}},$$

- where N_{u} is the unfolded background-subtracted yield, corrected for detector resolution,
- values of the acceptance A and the efficiency ε are estimated from simulation,
- C - FSR correction (from MC)

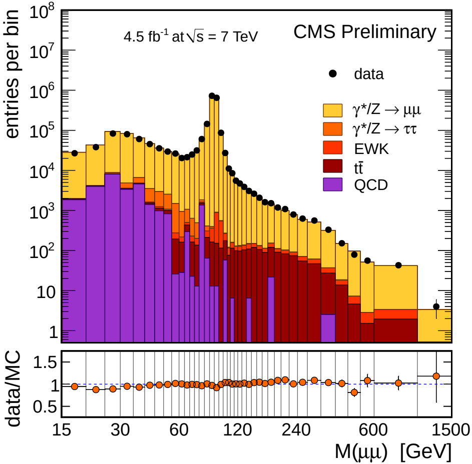
Selection

- Trigger: unprescaled double muon trigger with no isolation requirement ($p_T > 13 GeV$ and $p_T > 8 GeV$)
- Dimuon candidate: 2 muons with opposite charge and highest vertex probability
- Offline kinematic selection: $p_T > 14 GeV$ and $p_T > 9 GeV$, $|\eta| < 2.4$
- each muon reconstructed as ”tracker” AND ”global” + quality cuts
- cosmics rejection:
  impact parameter $< 2mm$,
  opening angle differs from π by $> 5mrad$
- isolation requirements

Analysis details: background estimation

Background sources:

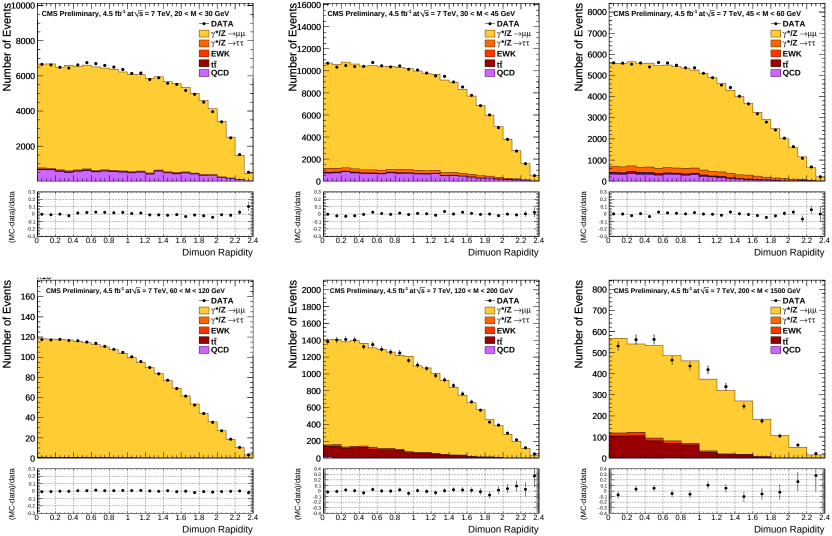
- Low masses: QCD events with multiple jets
- Z^0 *region*: Drell-Yan $\to \tau^+\tau^-$, $W \to l + \nu$, dibosons
- High masses: $t\bar{t}$ and diboson leptonic decays



The observed dimuon invariant mass spectra within the detector acceptance for data and Monte Carlo events and corresponding data to MC ratio of yields. The FEWZ-POWHEG correction is applied to the Monte Carlo signal events.

Analysis details: background estimation

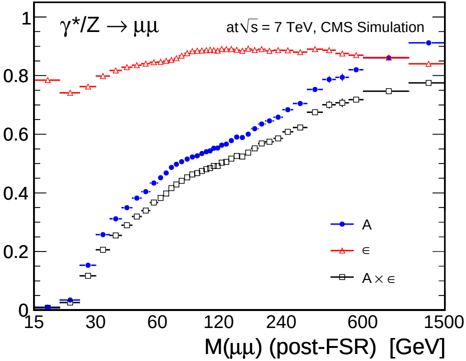
The expected shapes and relative dimuon yields from data and Monte Carlo events in bins of dimuon rapidity per invariant mass slice:



Analysis details: efficiencies and acceptance

POWHEG MC is used to estimate acceptance. POWHEG does not properly describe the low mass region since it is based on NLO. An additional acceptance correction has to be applied to take the NNLO effects into account. The POWHEG distributions are modified according to the FEWZ at NNLO predictions.

- The acceptance accounts for the muon p_T and η cuts, the efficiency reflects the full selection
- Post-FSR muon quantities are used to calculate the dimuon invariant mass
- FEWZ NNLO reweighting procedure is applied to correct for model dependence
- Efficiency is almost independent of invariant mass (0.8-0.9), but the acceptance is increasing with mass from very low values (0.007) to about 0.9



Analysis details: Systematic Uncertainties

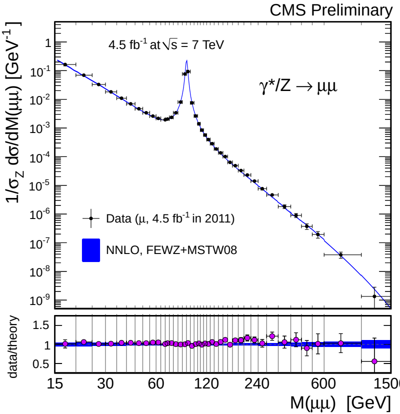
- the systematic uncertainty from the background estimation is 1% on average in the low mass and peak regions increasing with mass to about 20%,
- the systematic uncertainty on the muon momentum-scale and resolution is small (below 1%) at low and intermediate masses and becomes dominant in the highest invariant mass bin (25%),
- the efficiency estimation uncertainty is below 1% in the low mass and peak regions, increasing to about 3% at high invariant masses.

$d\sigma/dM$ differential cross section measurement

In order to reduce systematic uncertainties, the Drell-Yan $d\sigma/dM$ differential cross section is normalized to the cross section in the Z peak region ($60 < M < 120$ GeV). The result of the measurement is calculated as the ratio:

$$R^i_{pre\ FSR} = \frac{N^i_u}{A^i \varepsilon^i \rho^i} \Big/ \frac{N^{norm}_u}{A^{norm} \varepsilon^{norm} \rho^{norm}} \quad (1)$$

where N^i_u is the number of events after the unfolding procedure and background subtraction, the acceptances A^i, the efficiencies ε^i, and the corrections estimated from data ρ^i, in a given invariant mass bin i are defined earlier in the text. For both lepton channels the cross sections in the Z region measured in this analysis are in a very good agreement with the previous CMS measurement. The results are normalized to the invariant mass bin widths, ΔM^i, defining shape $r^i = R^i/\Delta M^i$.



The Drell-Yan invariant mass spectrum, normalized to the Z resonance region, as measured and as predicted by NNLO calculations, for the full phase space.

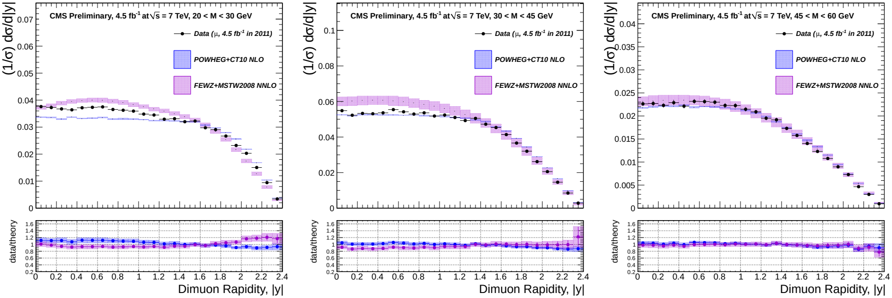
https://cdsweb.cern.ch/record/1439026
CMS-PAS-EWK-11-007, Drell-Yan Double Differential Cross Section

$d^2\sigma/dMdY$ double-differential X-section: low masses

The result of the is presented as the following ratio

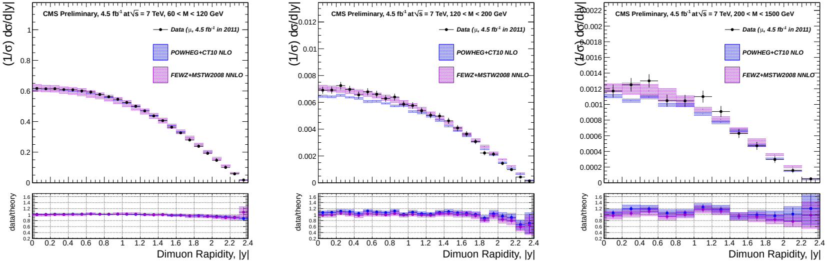
$$R^{i,j}_{pre\ FSR} = \frac{N_u^{i,j}}{\varepsilon^{i,j}\rho^{i,j}} / \frac{N_u^{norm}}{\varepsilon^{norm}\rho^{norm}}. \quad (2)$$

The quantities $N_u^{i,j}$, $\varepsilon^{i,j}$, $\rho^{i,j}$ are defined in a given bin (i, j), with i corresponding to the binning in invariant mass, and j corresponding to the binning in absolute rapidity. The N_u^{norm}, ε^{norm}, and ρ^{norm} refer to the Z peak region within $|Y| < 2.4$. The results are normalized to the dimuon absolute rapidity bin widths, ΔY^j, defining shape $r^{i,j} = R^{i,j}/(\Delta Y^j)$.



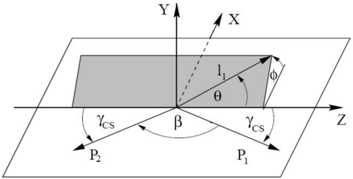
https://cdsweb.cern.ch/record/1439026
CMS-PAS-EWK-11-007, Drell-Yan Double Differential Cross Section

$d^2\sigma/dMdY$ double-differential X-section: mid & high masses



Good agreement observed for high mass bins

https://cdsweb.cern.ch/record/1439026
CMS-PAS-EWK-11-007, Drell-Yan Double Differential Cross Section



"Dilution" of asymmetry measurements:

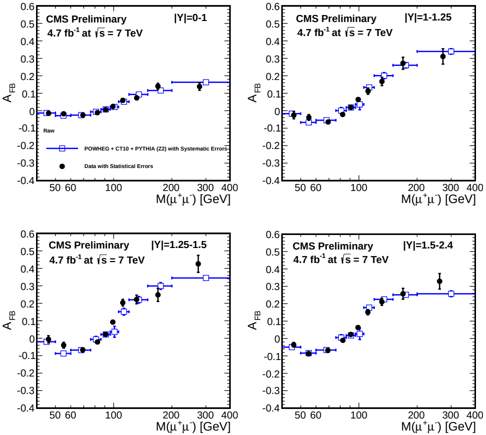
- bin-to-bin migration due to finite detector resolution
- Final-State-Radiation (FRS)
- acceptance cuts
- unknown quark/antiquark direction for the LHC

Collins-Soper frame is used in which the angle θ^*_{CS} is defined as the angle between the lepton momentum and an axis that bisects the angle between the quark and opposite to the anti-quark direction. Use of this frame reduces the uncertainties due to the transverse momentum of the incoming quarks. The angle θ^*_{CS} can be calculated using quantities measured in the lab frame as

$$\cos\theta^*_{\mathrm{CS}} = \frac{Q_z}{|Q_z|} \frac{2(P_1^+ P_2^- - P_1^- P_2^+)}{|Q|\sqrt{Q^2 + Q_T^2}} \quad (3)$$

https://cdsweb.cern.ch/record/1430637
CMS EWK-11-004 PAS: Forward-backward asymmetry of Drell-Yan pairs

The measured and expected raw A_{FB} distribution for each M-Y bin are shown with the associated statistical and systematical uncertainties.The raw A_{FB} distributions are calculated using the efficiency corrected, pile-up re-weighted and background-subtracted data.

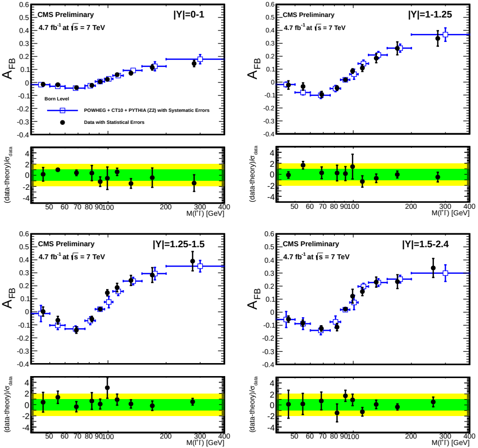


https://cdsweb.cern.ch/record/1430637

CMS EWK-11-004 PAS: Forward-backward asymmetry of Drell-Yan pairs

A_{FB}: muons + electrons

Efficiency corrected, pile-up re-weighted, background-subtracted data + unfolidng

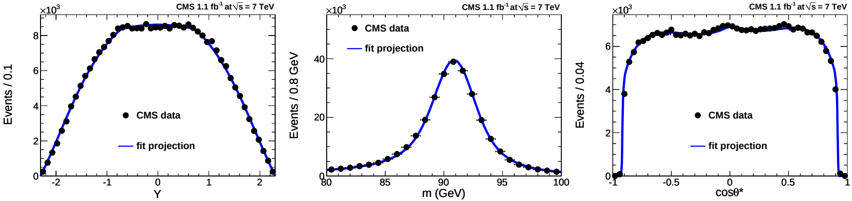


The dilution due to the unknown quark direction is largest for small rapidity values and decreases with increasing rapidity. The first rapidity bin, $|Y| = 0.00 - 1.00$ is the bin with the largest dilution effect due to the unknown quark direction but with the smallest acceptance effect. The next two bins, $|Y| = 1.00 - 1.25$ and $|Y| = 1.25 - 1.50$, have the largest asymmetry. The highest rapidity bin, $|Y| = 1.5 - 2.4$, is affected the least by dilution but suffers a large acceptance reduction resulting in a smaller asymmetry compared to the adjacent Y bin.

https://cdsweb.cern.ch/record/1430637

CMS EWK-11-004 PAS: Forward-backward asymmetry of Drell-Yan pairs

$$\frac{d\sigma_{pp}(Y,\hat{s},\cos\theta^*;\theta_{\mathrm{W}})}{dY\,d\hat{s}\,d\cos\theta^*} \propto \sum_{q=\mathrm{u,d,s,c,b}} \Big[\hat{\sigma}^{\mathrm{even}}_{q\bar{q}}(\hat{s},\cos^2\theta^*;\theta_{\mathrm{W}}) + D_{q\bar{q}}(\hat{s},Y)\times\hat{\sigma}^{\mathrm{odd}}_{q\bar{q}}(\hat{s},\cos\theta^*;\theta_{\mathrm{W}})\Big]\times F_{q\bar{q}}(\hat{s},Y) \quad (4)$$



$$\sin^2\theta_{\mathrm{eff}} = 0.2287 \pm 0.0020\ (\mathrm{stat.}) \pm 0.0025\ (\mathrm{syst.})\,.$$

http://prd.aps.org/abstract/PRD/v84/i11/e112002

Phys. Rev. D 84, 112002 (2011) Measurement of the weak mixing angle with the Drell-Yan process in proton-proton collisions at the LHC

Summary

- Normalized cross section of the Drell-Yan process in the muon channel covering the mass range of 15-1500 GeV has been measured using the full 2011 dataset (integrated luminosity 4.5 fb^{-1})
- The results agree with NNLO theory calculations as computed with FEWZ using the MSTW2008 PDFs
- The precision makes the measurement sensitive to the NNLO theoretical predictions
- We have also measured the double-differential cross section in 6 invariant mass bins 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
- CMS detector measured A_{FB} up to 400 GeV mass bin with 4.7 fb^{-1} of data
- $sin^2\Theta_W$ and A_{FB} measurement to be consistent with the Standard Model predictions within uncertainties