Study of the Drell-Yan process with CMS.

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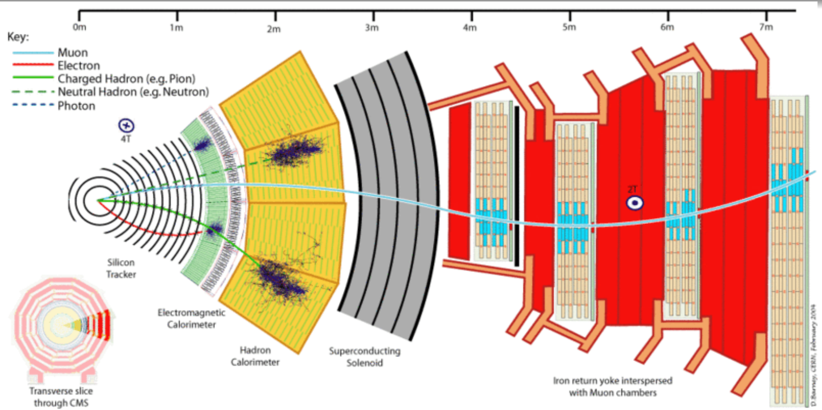
August 26, 2013

CMS Detector



Global muon momentum resolution:

$dp_T/p_T = 1 - 1.5\%$ at $p_T = 10\ GeV$, $dp_T/p_T = 6 - 17\%$ at $p_T = 1\ TeV$

Electron energy resolution:

$dE/E < 0.5\%$ fro $E > 100\ GeV$

Measurement of the Drell-Yan Cross Section in pp Collisions at $\sqrt{s} = 7\ TeV$

Based On: CMS-PAS-SMP-13-003

Available on the CERN CDS information server CMS PAS SMP-13-003

CMS Physics Analysis Summary

Contact: cms-pag-conveners-smp@cern.ch

2013/04/23

Measurement of the differential and double-differential Drell-Yan cross sections in proton-proton collisions at $\sqrt{s} = 7$ TeV

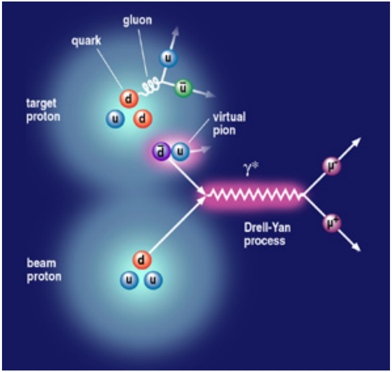
The CMS Collaboration

Abstract

Measurements are presented for the measurements of the differential and double differential Drell-Yan cross section using an integrated luminosity of 4.5 fb^{-1} (dimuon) and 4.8 fb^{-1} (dielectron) of proton-proton collision data recorded with the CMS detector at the LHC at $\sqrt{s} = 7$ TeV. The cross sections $d\sigma/dM$ are measured in the mass range 15 GeV to 1500 GeV for the dimuon, dielectron, and combined channels. Results are also presented on the measurement of the double-differential cross section $d^2\sigma/dMdY$ in the dimuon channel. The double-differential cross section measure-

The Drell-Yan process

- The production of lepton pairs in pp-collisions is described by the s-channel exchange of $\gamma^{\star} Z$
- Theoretical calculations of $d\sigma/dM(ll)$ and $d^2\sigma/dM(ll)Y$ ($M(ll)$ - dilepton invariant mass, Y - dilepton rapidity) established up to NNLO order
- Comparison of Data and MC provide stringent tests of QCD and significant constraints on the evaluation PDFs
- DY is a mojor background for $t\bar{t}$ and diboson measurements as well as for searches for new physics (high mass dilepton resonances)



Measurements are done at $\sqrt{s} = 7\ TeV$ on CMS data correstponding to $L = 4.5\ fb^{-1}$ (dimuon) and $L = 4.8\ fb^{-1}$ (dielectron) in $20 < M(ll) < 1500\ GeV$ range, results are normalized to the cross section in the Z region ($60 < M(ll) < 120\ GeV$)

DY Cross Section

Cross sections are calculated as

$$\sigma = \frac{N_u}{A\epsilon\rho L'} \qquad (1)$$

where N_u is the unfolded background-subtracted yield and A - acceptance, ϵ - efficiency (estimated from simulation). ρ - factor that accounts for differences in the efficiency between data and simulation. L is not required for the measurements since the cross sections are normalized to the Z region.

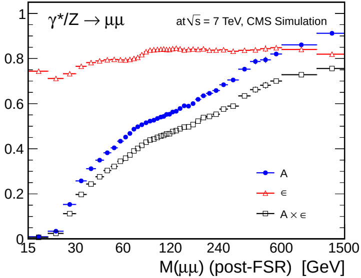
Muon Selection

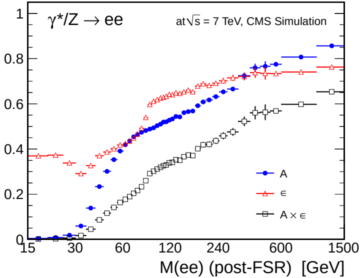
- Dimuon trigger with minimum p_T threshold
- One muon with $|\eta| < 2.4$ and $p_T > 14$ GeV and one with $p_T > 9$ GeV
- Standart CMS muon identification and quality criteria (number of hits etc.)
- Impact parameter in the transverse plane less then 2mm
- Angle between the two muons must differ from π by more than 5 mrad
- Dimuon vertex χ^2 probability smaller than 2%.
- Isolation of both muons $I_{rel} = (\sum p_T(tracks) + \sum E_T(had))/p_T(\mu) < 0.15$, where $\sum E_T(had)$ - sum of the E_T of hadronic deposits and $\sum p_T(tracks)$ sum of the p_T of the additional tracker tracks in cone $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.3$

Electron Selection

- Dielectron trigger with E_T threshold 17 GeV for one of the electrons and 8 GeV for the other
- Candidate is required to be consistent with a particle originating from the primary vertex
- Electron identification criteria based on shower shape and track-cluster matching are applied
- No missing hits in the pixel detector
- Eliminating those electrons for which a partner track consistent with a conversion hypothesis is found
- Isolation $(\sum p_T(tracks) + \sum E_T(had) + \sum E_T(em))/p_T(e) < 0.15$, where $\sum E_T(em)$ is the sum of the E_T of electromagnetic deposits, except for electrons with $E_T < 20\ GeV$ where requirement is less than 0.1
- $|\eta| < 1.44$ or $1.57 < |\eta| < 2.5$
- Electron $E_T > 10\ GeV$

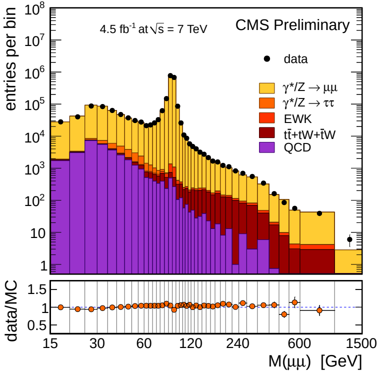
Acceptance and Efficiency

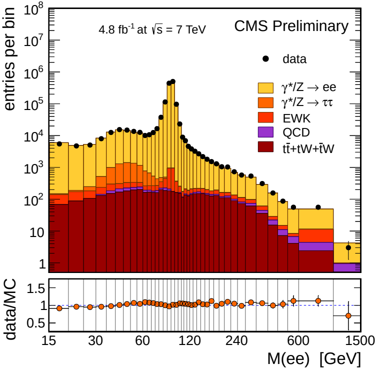




DY acceptance (blue, filled circles), efficiency (red, open triangles), and their product (black, open squares) per invariant mass bin, for the mu^+mu^- (left) and e^+e^- (right) channels

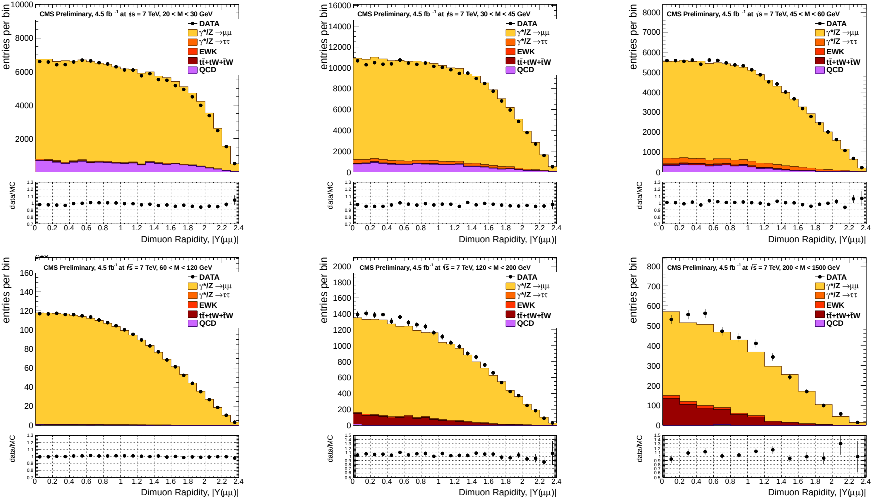
Background 1





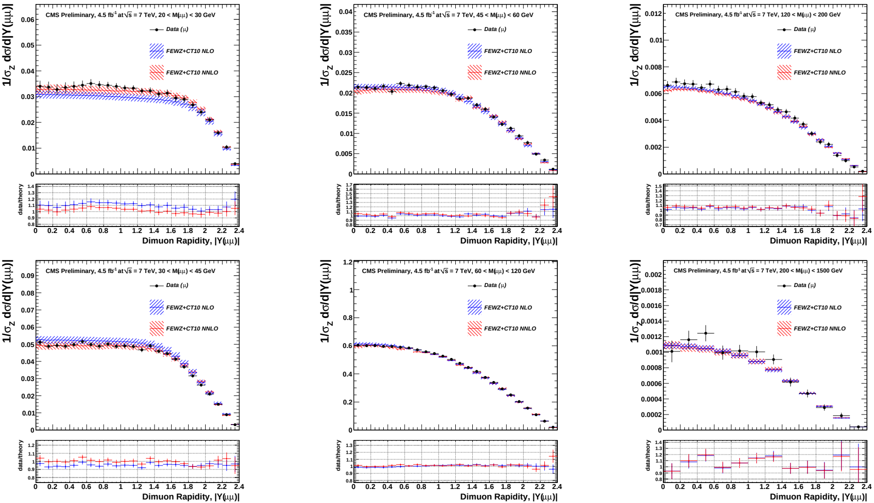
The observed dimuon (left) and dielectron (right) invariant mass spectra within the detector acceptance for data and Monte Carlo events and corresponding data to MC ratio of yields. The FEWZ-POWHEG correction is applied to the Monte Carlo signal events. Electron energy correction is applied to data and simulated events. QCD and ttbar background yields as predicted by data-driven methods.

Background 2



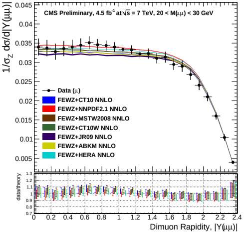
The observed dimuon rapidity spectra per invariant mass slice for data and Monte Carlo events.

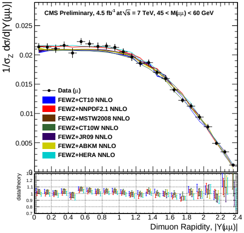
Normalized rapidity-invariant mass spectrum

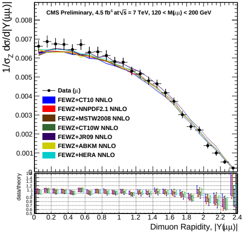


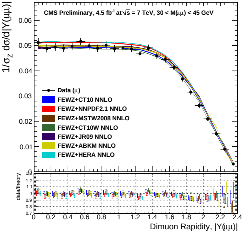
The Drell-Yan rapidity-invariant mass spectrum in detector acceptance, normalized to the Z resonance region, $r = 1/\sigma_Z * d^2\sigma/dMdY$.

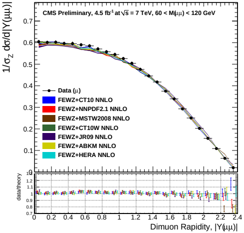
Comparison with theory expectations

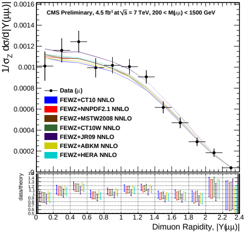






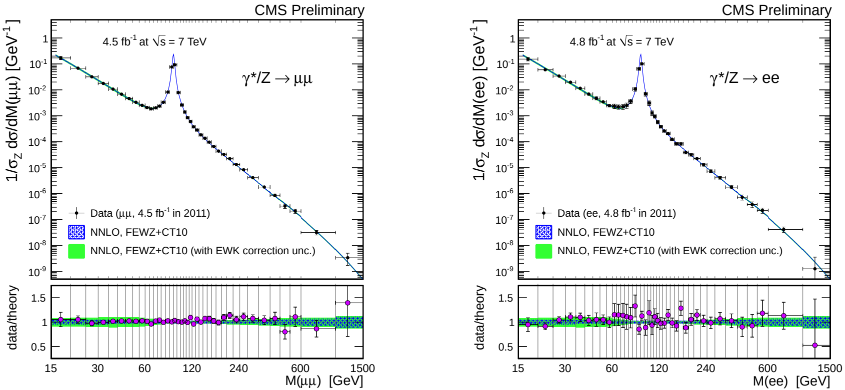






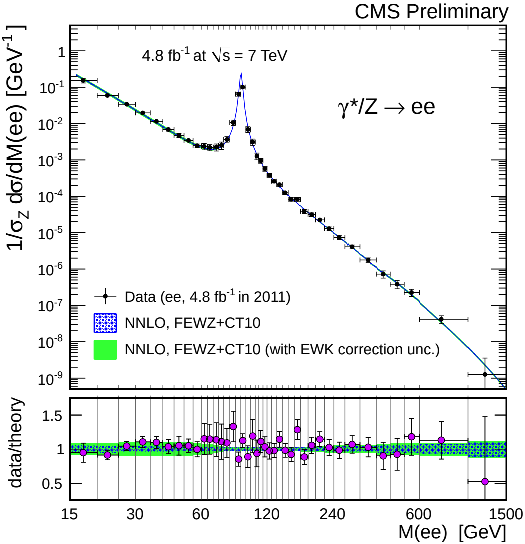
Comparison with theory expectations with various NNLO PDF sets: CT10, HERA, NNPDF2.1, MSTW08, CT10W, JR09, ABKM.

Normalized invariant mass spectrum



The Drell-Yan invariant mass spectrum in the dimuon (left) and dielectron (right) channel, normalized to the Z region, $r = 1/\sigma_Z * d\sigma/dM$, as measured and as predicted by NNLO, for the full phase space.

Combined DY invariant mass



The Drell-Yan invariant mass spectrum in the combined channel, normalized to the Z region, $r = 1/\sigma_Z * d\sigma/dM$ (NNLO).

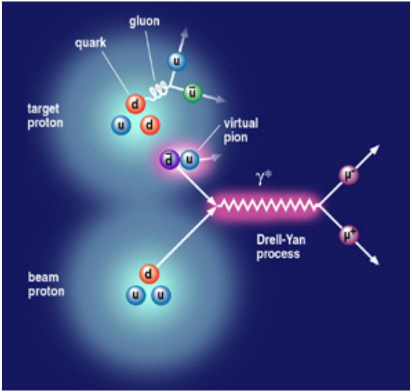
A_{FB} and the Drell-Yan process

Vector and axial-vector currents in the process $q\bar{q} \to Z/\gamma^{\star} \to l^{+}l^{-}$ lead to P-symmetry breaking and forward-backward asymmetry (A_{FB}) in the number of Drell-Yan lepton pairs:

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} \qquad (2)$$

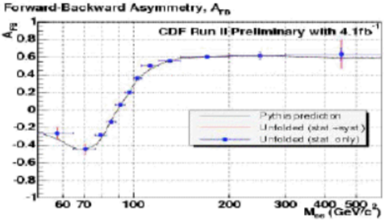
$$\sigma_F = \int_0^1 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta) \qquad (3)$$

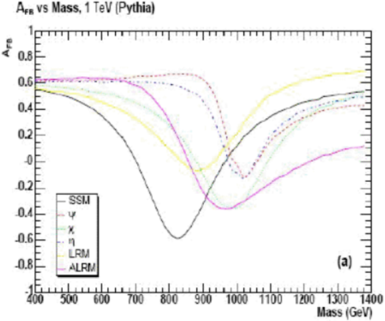
$$\sigma_B = \int_{-1}^0 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta) \qquad (4)$$



Where θ - is the angle between μ^{-} and quark momentum in dimuon center of mass frame.

Application of A_{FB}





Measurement of the A_{FB} can provide:

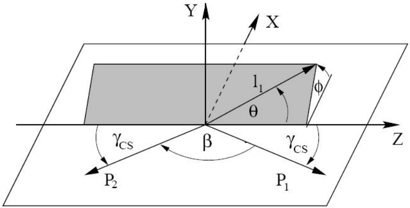
- Test of the SM in the new energy region
- Provide at the Z-pole a precise measurement of $\sin^2\theta_W$

Deviations from the SM predictions for A_{FB} may indicate the existence of:

- A new neutral gauge boson
- Quark-lepton compositeness
- Existence of supersymmetric particles
- Extra dimensions, etc.

In case of BSM physics A_{FB} can help to determine it's nature

Reference System



- On *pp* colliders quark and antiquark directions are unknown
- Dimuon boost direction is assumed to be the quark direction

The Collins-Soper frame where the angle $\theta^\star$ is defined to be the angle between the lepton momentum and a z-axis that bisects the angle between q and $\bar{q}$ directions is used. This frame reduces the uncertainties due to the transverse momentum of quarks.

$$\frac{d\sigma}{d\cos\theta^\star} = A(1+\cos^2\theta^\star)+B\cos\theta \quad (5)$$

Background and Uncertainties

Main sources of background:

- For low masses
  - $Z \rightarrow \tau\tau$
  - QCD dijets
- $t\bar{t}$ for high masses

A_{FB} measurement lead to a large systematic uncertainty and thus requires correction on the following effects:

- Finite detector resolution and alignment
- QED FSR
- Acceptance
- Unknown quark antiquark direction at the LHC

Selection Cuts for Muon Candidates

Kinematics:

- Oppositely charged global and tracker muons
- $|\eta| < 2.4$ and $p_T > 20\ GeV$

Quality requirements:

- > 10 tracker hits, > 1 pixel hits, > 1 muon hits
- > 2 muon stations
- $\chi^2 < 10$ for the global fit
- Small impact parameter $d_0 < 0.2$
- Remove back-to-back dimuons $\alpha > 2.5$ mrad

Isolation:

- Tracker+HCAL isolation
  $(\sum p_T(tracks) + \sum E_T(had))/p_T(\mu) < 0.15$

Selection Cuts for Electron Candidates

Kinematics:

- Oppositely charged electrons
- $|\eta| < 1.444$ or $1.566 < |\eta| < 2.5$
- HLT ECAL L1-trigger requiring an ECAL cluster with minimum E_T between 10 to 17 GeV

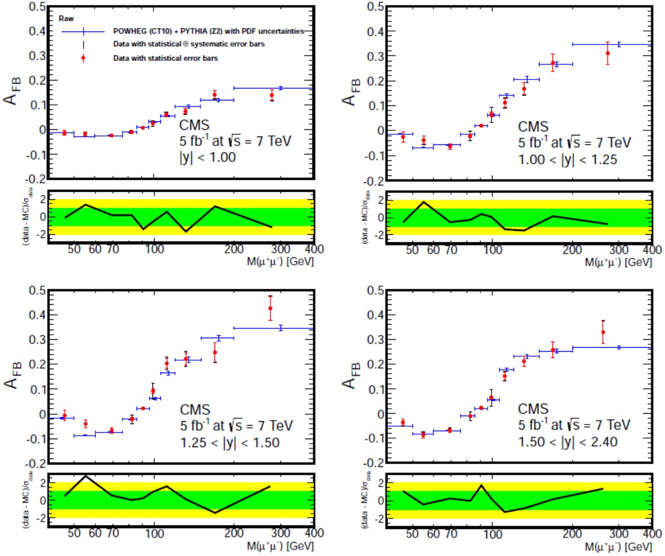
Quality requirements:

- Minimum supercluster E_T of 20 GeV
- No missing Tracker hits before the first one
- Reject when a conversion partner track close to the electron
- Using shower shape variables

Isolation:

- Isolation using the Tracker and calorimeters

CMS Results with 5 fb^{-1}



arXiv:1207.3973 ; CMS-EWK-11-004 ; CERN-PH-EP-2012-187. - 2012. - 29 p.

CMS Results ($\sin^2\theta_W$)

$$\frac{d\sigma_{pp\to l^+l^-X}(Y,s,\cos\theta^\star)}{dYdsd\cos\theta^\star} \propto \sum_{q=u,d,s,c,b} [\hat{\sigma}^{even}_{qq}(s,\cos^2\theta^\star,\sin^2\theta_W)+D_{q\bar{q}}(s,Y)\times\hat{\sigma}^{odd}_{q\bar{q}}(s,\cos\theta^\star,\sin^2\theta_W]F_{q\bar{q}}(s,Y) \quad (6)$$

$$\sin^2\theta_W = 0.2287 \pm 0.0020(stat.) \pm 0.0025(syst.) \quad (7)$$

Systematic uncertainties in the measurement of $\sin^2\theta_W$:

Source	Correction	Uncertaintie
PDF	-	± 0.0013
FSR	-	± 0.0011
LO model (EWK)	-	± 0.0002
LO model (QCD)	$+0.0012$	± 0.0012
Resolution/alignment	$+0.0007$	± 0.0013
Acceptance and Efficiency	-	± 0.0003
Background	-	± 0.0001
Total	$+0.0019$	± 0.0025

Phys. Rev. D 84, 112002 (2011)

Conclusion

- Drell-Yan process is a good probe for new physics
- $\sin^2 \theta_W$, A_{FB} and DY cross section measurements are consistent with the Standard Model predictions within uncertainties