Measurement of the Drell-Yan differential cross section at 7 TeV

Norbert Neumeister

Department of Physics

Purdue University

on behalf of the the CMS Collaboration

DIS2011: XIX International Workshop on Deep-Inelastic Scattering and Related Subjects, 11-15 Apr 2011, Newport News, VA

Outline

Outline

- Motivation

Outline

- Motivation
- Analysis Strategy and Procedure

Outline

- Motivation
- Analysis Strategy and Procedure
- Event Selection

Outline

- Motivation
- Analysis Strategy and Procedure
- Event Selection
- Background Estimation
  - Comparisons with Simulation
  - Data based estimations

Outline

- Motivation
- Analysis Strategy and Procedure
- Event Selection
- Background Estimation
  - Comparisons with Simulation
  - Data based estimations
- Acceptance and Efficiencies

Outline

- Motivation
- Analysis Strategy and Procedure
- Event Selection
- Background Estimation
  - Comparisons with Simulation
  - Data based estimations
- Acceptance and Efficiencies
- Unfolding

Outline

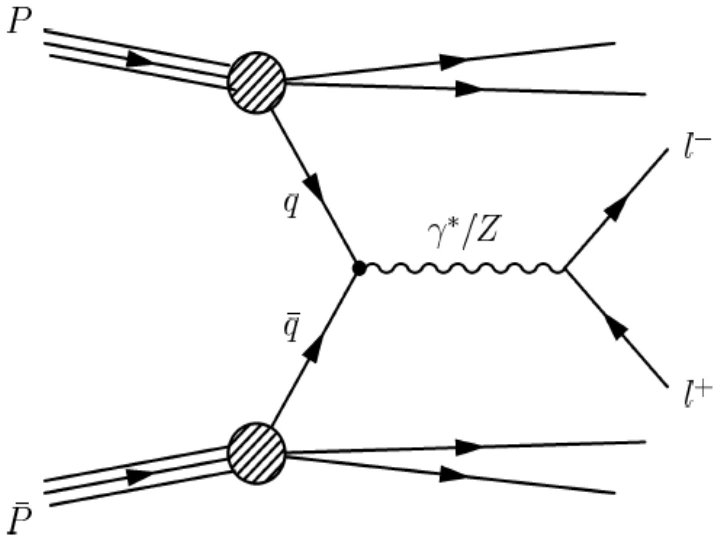
- Motivation
- Analysis Strategy and Procedure
- Event Selection
- Background Estimation
  - Comparisons with Simulation
  - Data based estimations
- Acceptance and Efficiencies
- Unfolding
- Systematic Uncertainties

Outline

- Motivation
- Analysis Strategy and Procedure
- Event Selection
- Background Estimation
  - Comparisons with Simulation
  - Data based estimations
- Acceptance and Efficiencies
- Unfolding
- Systematic Uncertainties
- Results

Motivation

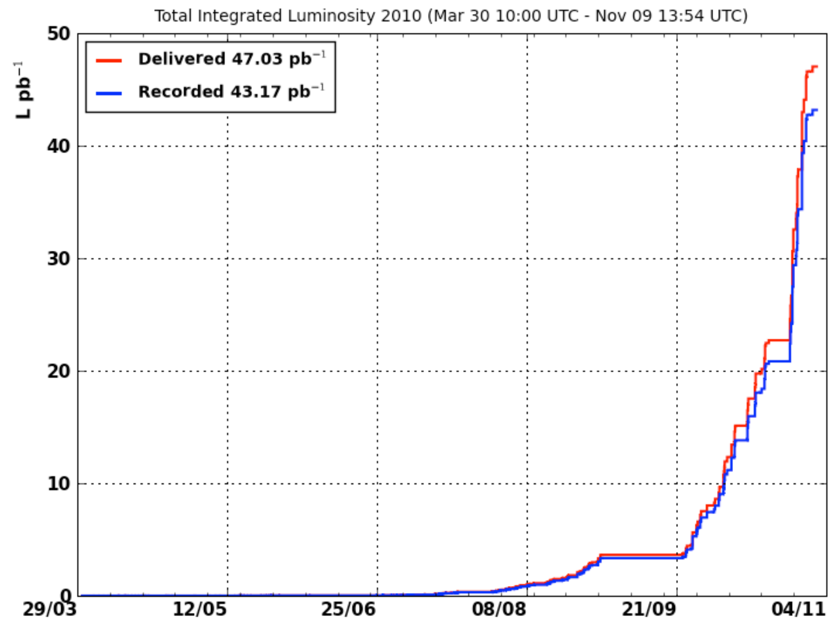
- Drell-Yan process
  - Is an important Standard Model benchmark channel
  - Theoretical cross section calculated up to NNLO
    - allowing tests of perturbative QCD
  - Differential cross section dσ/dM depends on parton density functions (PDFs)
    - can be used to constrain PDFs
  - Drell-Yan is an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

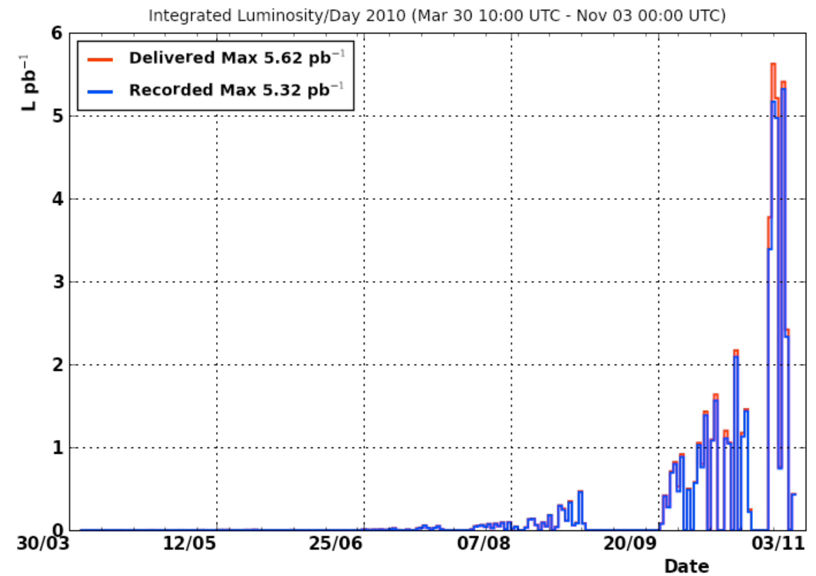


- Goal
  - Measure the differential cross section $(1/\sigma_Z)d\sigma/dM$
    - normalize differential cross sections to the cross section at the Z peak (60 – 120 GeV)
    - cancels out most systematic uncertainties including luminosity

Data

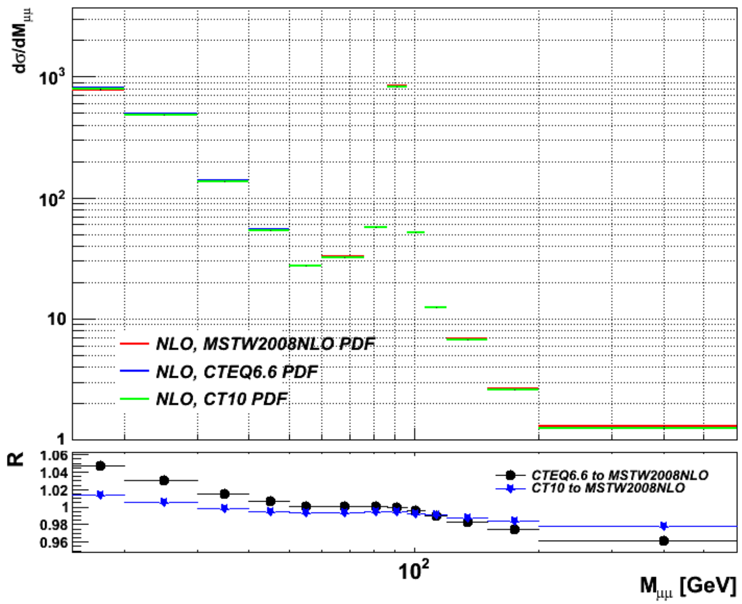
- CMS recorded 43.17 pb^{-1} at $\sqrt{s}$ = 7 TeV in 2010
- Data recording efficiency exceeded 90%
- Only highest quality data used for physics analyses
- Analysis based on entire 2010 Data Sample
  - 36.4 ± 1.5 pb^{-1}

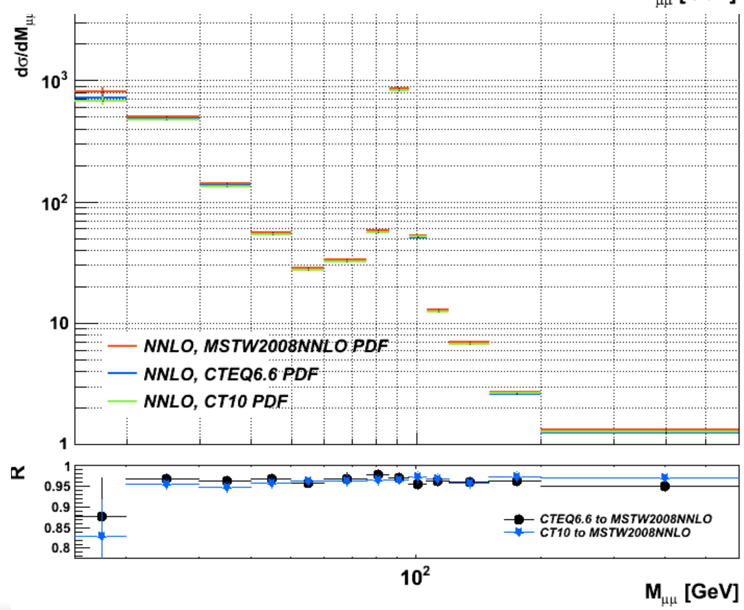




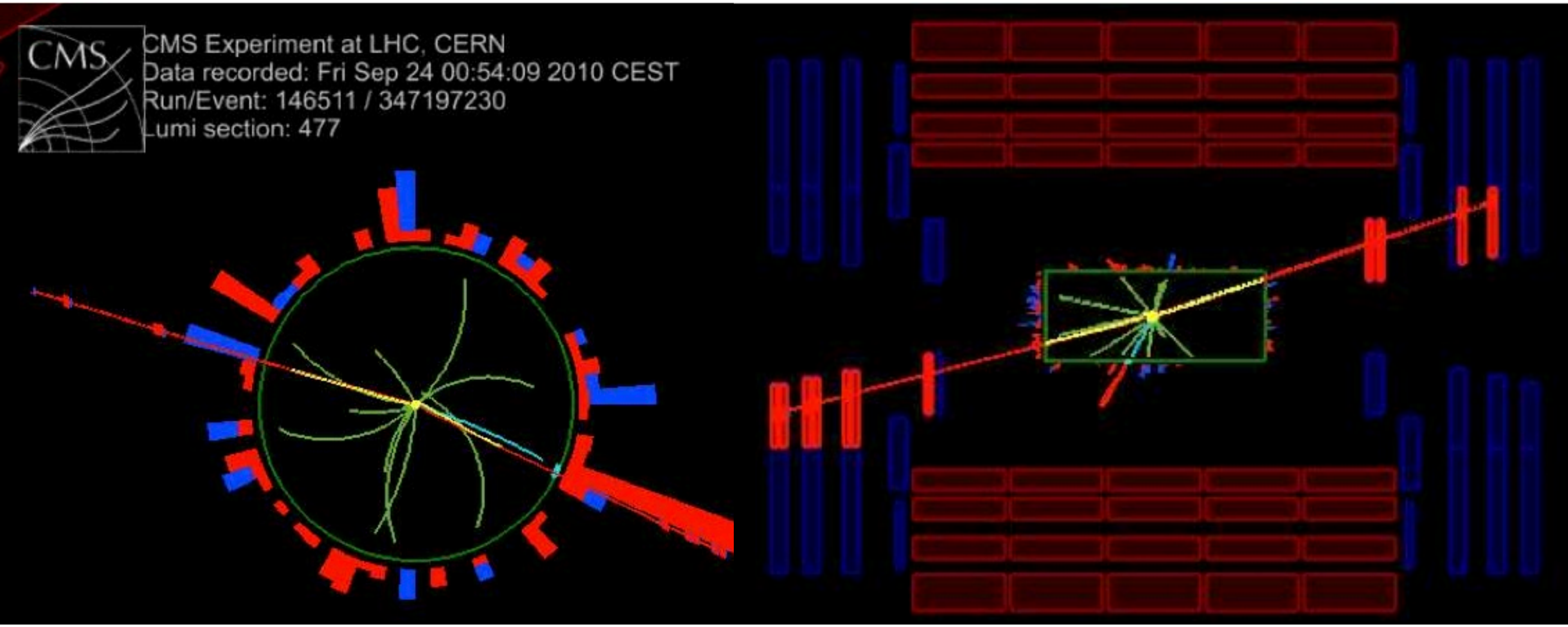
Theoretical Predictions

- Signal simulated using POWHEG + Pythia6
  - CT10 PDF and Z2 Tune
- Compare result with theoretical prediction obtained with FEWZ 2.0.1 at NLO and NNLO
  - arXiv:1011.3540v1
- Various PDF sets are used
  - MSTW2008, Eur. Phys. J. C63 (2009)
  - CTEQ66, Phys. Rev. D78:013004 (2008)
  - CT10, arXiv:1007.2241 (2010)
  - Use to evaluate PDF uncertainties
- Theoretical cross section is calculated pre-FSR





Drell-Yan Event



Analysis Overview

- Analysis procedure and method are same for muon and electron channel
  - Event selection
  - Acceptance and efficiency calculation using MC
  - Data–driven efficiency correction using Tag & Probe
  - Background estimation
    - Dominant background estimation using various data-driven methods
    - Other backgrounds estimation using MC
  - Unfolding correction to remove detector resolution effects
  - Correction of Final State Radiation (FSR) based on MC
  - Calculate shape R: normalization to Z peak cross section
  - Comparison with theoretical predictions
- Analysis performed for both muon and electron final state
  - Only muon results will be presented

Cross Section Measurement

- We measured the normalized differential cross section $(1/\sigma_Z)d\sigma/dM$ in 13 mass bins:

$$\sigma_i = \frac{N_i^u}{A_i \cdot \varepsilon_i \cdot C_i \cdot L_{\text{int}}} \qquad r_i = \frac{\dfrac{N_i^u}{A_i \cdot \varepsilon_i \cdot C_i \cdot \Delta M_i}}{\dfrac{N_u^{norm}}{A^{norm} \cdot \varepsilon^{norm} \cdot C^{norm} \cdot \Delta M^{norm}}}$$

i – mass bin
N^U – unfolded, background correct yield
A – pre-FSR acceptance
ε – efficiency
C – efficiency and FSR correction
L_{int} – integrated luminosity

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

Mass binning
15-20 GeV
20-30 GeV
30-40 GeV
40-50 GeV
50-60 GeV
60-76 GeV
76-86 GeV
86-96 GeV
96-106 GeV
106-120 GeV
120-150 GeV
150-200 GeV
200-600 GeV

Trigger Selection

- Muons:
  - **Single muon trigger:** a combination of lowest p_T threshold un-prescaled triggers with no isolation requirement on the level of HLT is used for a given run to maximize the yields
    - combination of Mu9+11+15 in different run ranges to maximize the yield with the un-prescaled lowest p_T (single) trigger
  - **Di-muon trigger:** an un-prescaled low-p_T threshold double muon trigger with no isolation requirement on the level of HLT is used
    - HLT_DoubleMu3, un-prescaled lowest p_T (double) trigger
- Electrons: **Single Electron HLT Trigger**

Trigger Name	L1 P_t	HLT P_t	Run Range	Int. Lumi.
HLT_Photon10_L1R	5 GeV	10 GeV	136033 – 137028	0.005 pb^{-1}
HLT_Photon15_Cleaned_L1R	5 GeV	15 GeV	138564 – 140401	0.25 pb^{-1}
HLT_Ele15_SW_CaloEleId_L1R	8 GeV	15 GeV	141956 – 144114	2.90 pb^{-1}
HLT_Ele17_SW_CaloEleId_L1R	8 GeV	17 GeV	144115 – 147145	5.06 pb^{-1}
HLT_Ele17_SW_TightEleId_L1R	8 GeV	17 GeV	147146 – 148058	9.47 pb^{-1}
HLT_Ele17_SW_TighterEleIdIsol_L1R*	8 GeV	17 GeV	148819 – 149422	18.44 pb^{-1}

Event Selection (Muons)

- Trigger Selection
  - Event must trigger a single muon HLT path
  - Analysis also performed with double muon HLT trigger
- Kinematic Selection
  - 2 muons with opposite charge
  - 1 muon p_T > 16 GeV, $|\eta|$ < 2.1
  - 1 muon p_T > 7 GeV, $|\eta|$ < 2.4
- Muon Identification
  - Both muons reconstructed as "Tracker Muons" (inside-out) and "Global Muons" (outside-in)
  - Minimum number of hits in Tracker/Pixel detector
  - Minimum number matched muon system hits
  - Global track fit must have $\chi^2/ndf < 10$
  - Track transverse impact parameter (w.r.t. beam spot) < 0.2 cm
- Isolation
  - Relative Isolation not including ECAL

$$I_{rel} = \left(\sum p_T(tracks) + \sum E_T(HCAL)\right) / p_T(\mu) < 0.15$$

Electromagnetic Calorimeter not included in isolation requirement due to loss in efficiency below Z peak caused by Final State Radiation

- Di-muon vertex probability and 3D angle to reject cosmics and muons not coming from the same collision/process
- Trigger matching
  - Require trigger matching by ΔR and $\Delta p_T/p_T$

Backgrounds

- Common backgrounds to both muons and electrons
  - QCD multijets
    - Leptons inside of jets
    - "punch through" for muons
    - Electrons faked by jets
    - Dominant background in the low mass region for muons
  - Top pair production
    - Dominant background at **high mass** for muons, and at **low mass** for electrons
  - Drell-Yan → $\tau^+\tau^-$
    - Dominant in "mid-range" masses
  - W → l + ν
  - Di-Boson production
    - decays to two real leptons in the final state
- For muons, also need to worry about
  - Cosmic Rays
    - removed by 3D angle and impact parameter cuts
  - Upsilons
    - dimuon resonance in low mass region

Background Estimation

- Template method
  - Isolation variable has distinct shape for signal and background
  - Create templates for shapes using data
    - Same sign events for background
    - Signal from opposite sign events in the Z peak region with one muon highly isolated (shape taken from second muon)
  - Extract estimate of background contamination in signal region using the fit results
- Opposite Sign (OS) / Same Sign (SS) Method
  - Divide events into samples based on number of isolated muons and whether muons are OS or SS
  - Take ratio of OS/SS events for categories of 0, 1, or 2 isolated muons
  - Estimate background based on these ratios

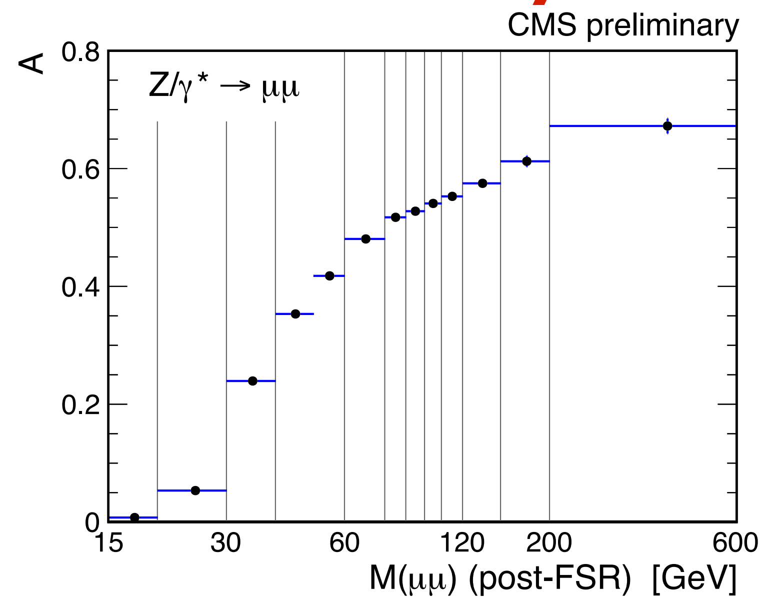
$$N(2|OS) = N(2|SS)\frac{N(1|OS)}{N(1|SS)}$$

Acceptance and Efficiency

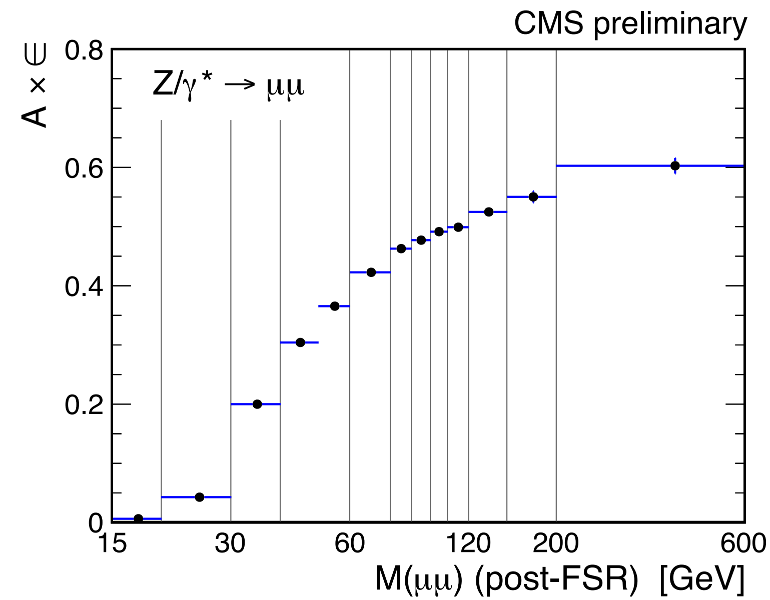
- Acceptance*efficiency is derived from MC simulation

$$A*\epsilon = \frac{N_{ACC}}{N_{GEN}} \frac{N_{SEL}}{N_{ACC}} = \frac{N_{SEL}}{N_{GEN}} \quad (\leq 1)$$

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



- In this definition:
  - Acceptance (A) accounts for p_T and η cuts
  - Efficiency (ε) reflects the full selection (lepton ID, reconstruction, isolation, trigger)
- Efficiencies for leptons are measured using data driven techniques
  - MC efficiencies are corrected to match data
- For calculation of acceptance, we consider simulated leptons *after* Final State Radiation



Efficiencies

- For both muons and electrons, efficiencies are estimated using data driven techniques
  - Muon isolation efficiency by the "Random Cone" method
  - All others using Tag and Probe technique
- MC is corrected to match results from these measurements using weights
- Efficiency estimation methods
  - The muon efficiencies (except for isolation) are estimated by the T&P method
    - Obtained for data and MC and used to extract data-driven corrections to MC
    - Using Z and Upsilon events
    - The measurements are performed in (p_T,η) bins
  - For the isolation efficiency the LKTC ("random cone") algorithm is applied
  - The track efficiency is above 99.5% efficient and well described by MC

Unfolding

- 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:

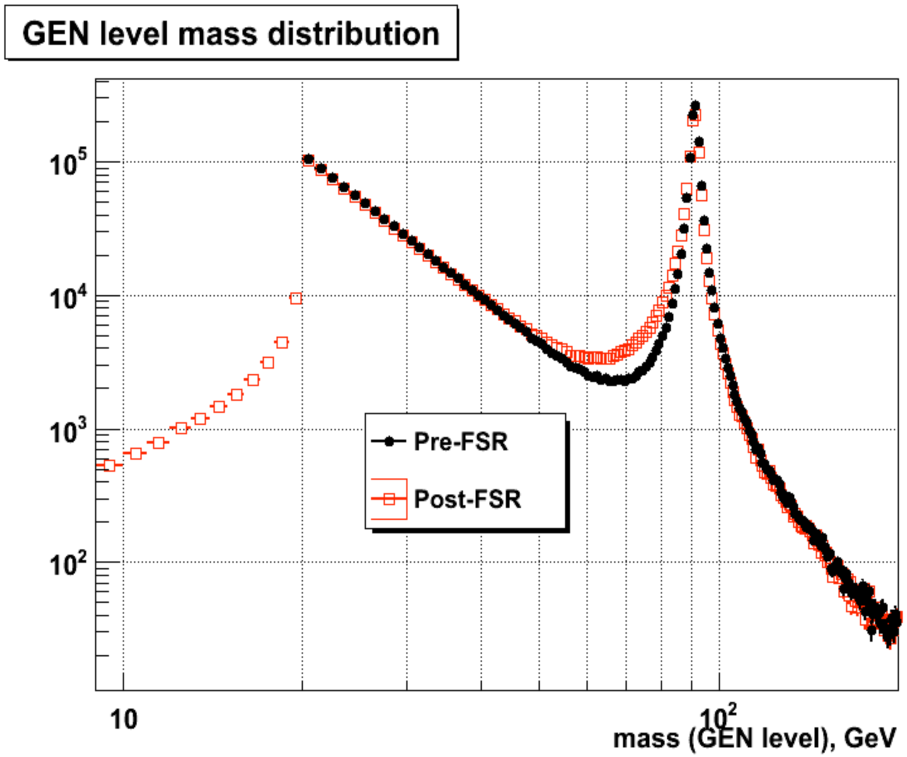
$$N_i^{obs} = \sum_k T_{ik} N_k^{true}$$

  - 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
- 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 done as a separate step

Final State Radiation Correction



- Measurement in the acceptance is for post FSR muons/electrons
- Correction made in order to compare to theoretical calculations which don't include FSR
  - Example: FEWZ
- The FSR modeling in the POWHEG signal sample is used to derive the corrections bin by bin

Systematic Uncertainties (I)

- Luminosity uncertainty: ~4%, cancels out in the ratio
- Efficiency: up to 2%
  - The uncertainty per mass bin is estimated by the RMS of trials varying the correction factors obtained (assuming Gaussian behavior). The mean gives the nominal value for the correction.
- Backgrounds: ~3% and up to 10% at high masses
  - Statistical uncertainties propagated as systematics
  - QCD estimation uncertainties at low masses added in quadrature
  - Uncertainty on yield at low masses < 4%
- Pile-Up: ~0.5%
  - Analysis is based on simulated events without pile-up
  - Pile-up effects mostly the isolation efficiency
  - Comparisons between pile-up and no pileup MCs show ~0.5% variation in each bin in the cross-section ratio
- Di-muon vertex selection
  - No signs of data/MC differences
  - Efficiency of selection > 98% with < 0.3% variation per mass bin

Systematic Uncertainties (II)

- Unfolding: less than 2%
  - Bias in response matrix is simulated using pseudo-experiment ensembles but holding the response matrix fixed
  - Uncertainty on possible distortion of mass spectrum is tested by smearing of muon curvature and then unfolding
  - The small shift in the Z peak position between MC and data is taken into account
- PDFs: up to 3%
  - Use standard re-weighting techniques, taking into account correlations between bins
- QCD corrections: current estimate < 1% effect excluding low mass region
- Variations of the normalization scale
- Higher order effects are crucial in the low mass range
  - Extracted from FEWZ and applied as a correction to POWHEG
- EWK corrections: effect around Z peak shown to be less than 1%

Results (I)

- The measurement is normalized to the Z peak Region

$$R_i = \frac{N_i^U}{A_i \epsilon_i C_i} / \frac{N_{NORM}^U}{A_{NORM} \epsilon_{NORM} C_{NORM}}$$

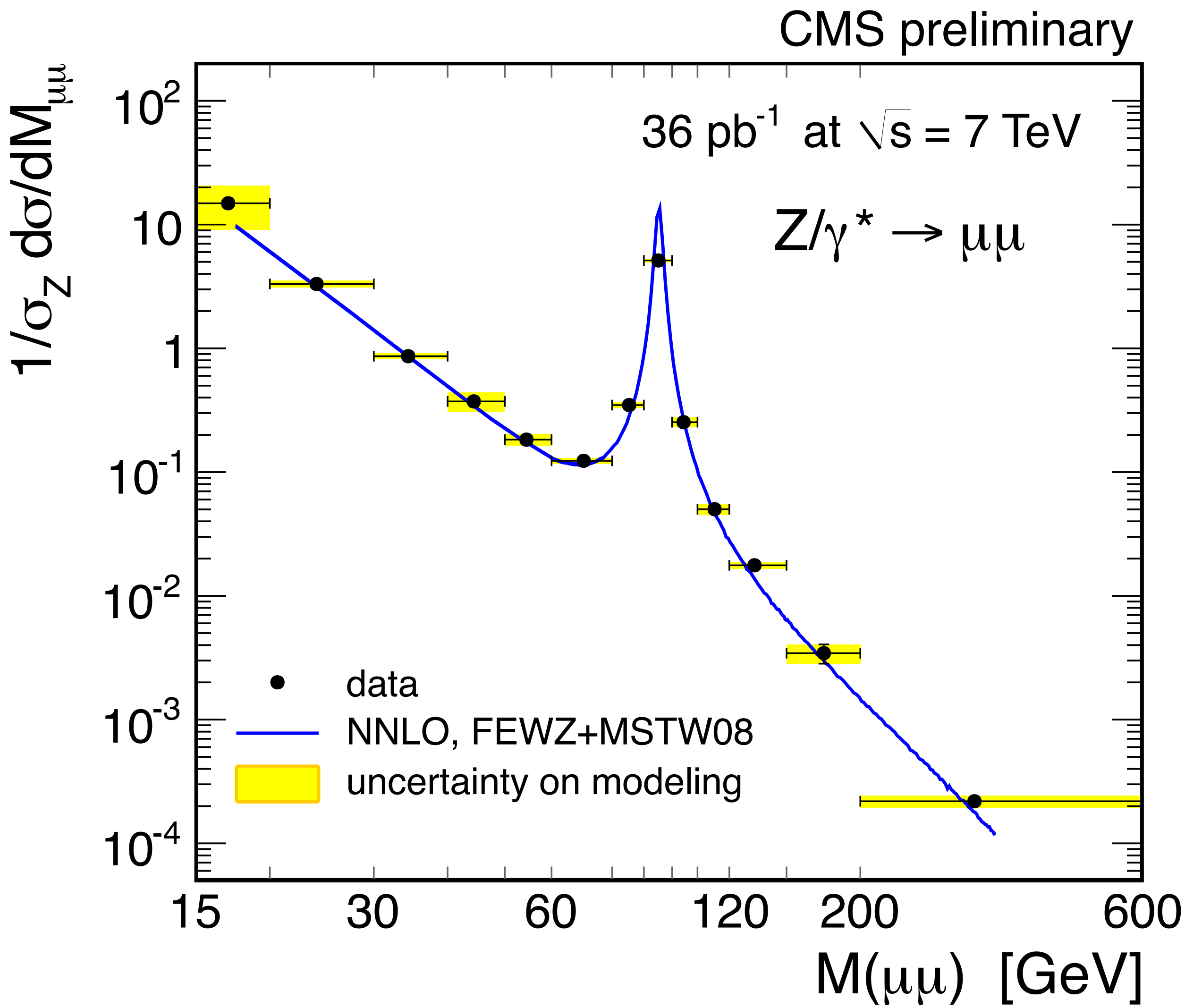
  – 60 GeV < M_{ll} < 120 GeV, as for the CMS Z cross section measurement

- We cross check our result for the absolute cross section in the Z peak region against the published CMS result

$$\sigma_{\mu\mu} = 926 \pm 8_{stat} \pm 8_{syst} \ {}^{+14}_{-23} \ {}_{PDF} \pm 37_{lum}$$

Results (II)

CMS-PAS-EWK-10-007



$$r_i = \frac{R_i}{\Delta M_i} / \frac{1}{\Delta M_{NORM}}$$

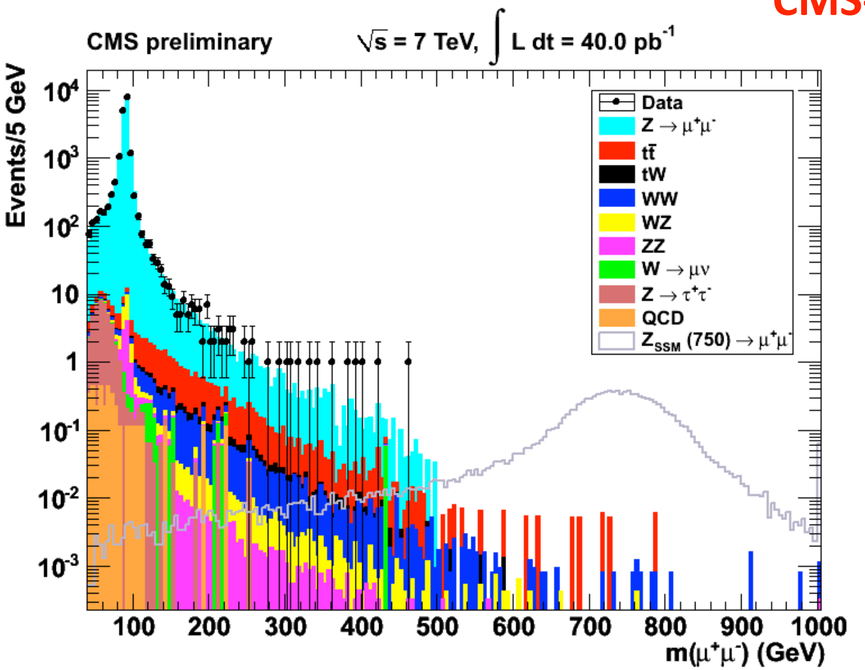
Modeling uncertainty accounts for acceptance differences between POWHEG and FEWZ

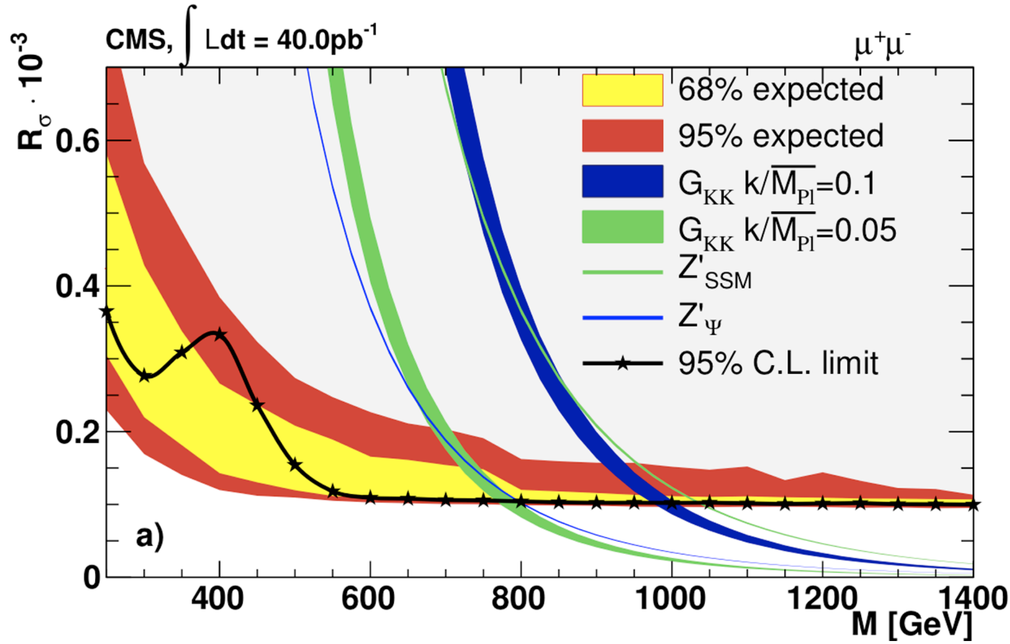
The theoretical prediction is obtained with FEWZ at NNLO, and it agrees well with our measurements

Limits on New Resonances

- Calculate limits on new physics resonances decaying to di-muons in the high-mass tail of the Drell-Yan continuum
- The search is model independent
  - Z' and Kaluza-Klein Graviton models are represented for limits on new physics

CMS-PAS-EXO-10-013





Summary

- The Drell-Yan differential cross-section normalized to the Z peak was measured in the muon channel with 13 mass bins
  - good agreement between single and double muon trigger based selection
- A similar measurement in the di-electron channel is in progress
  - preliminary results are consistent with the di-muon results
- Comparison with theoretical predictions at NNLO
  - good agreement with data if modeling uncertainty is taken into account

Compact Muon Solenoid Detector

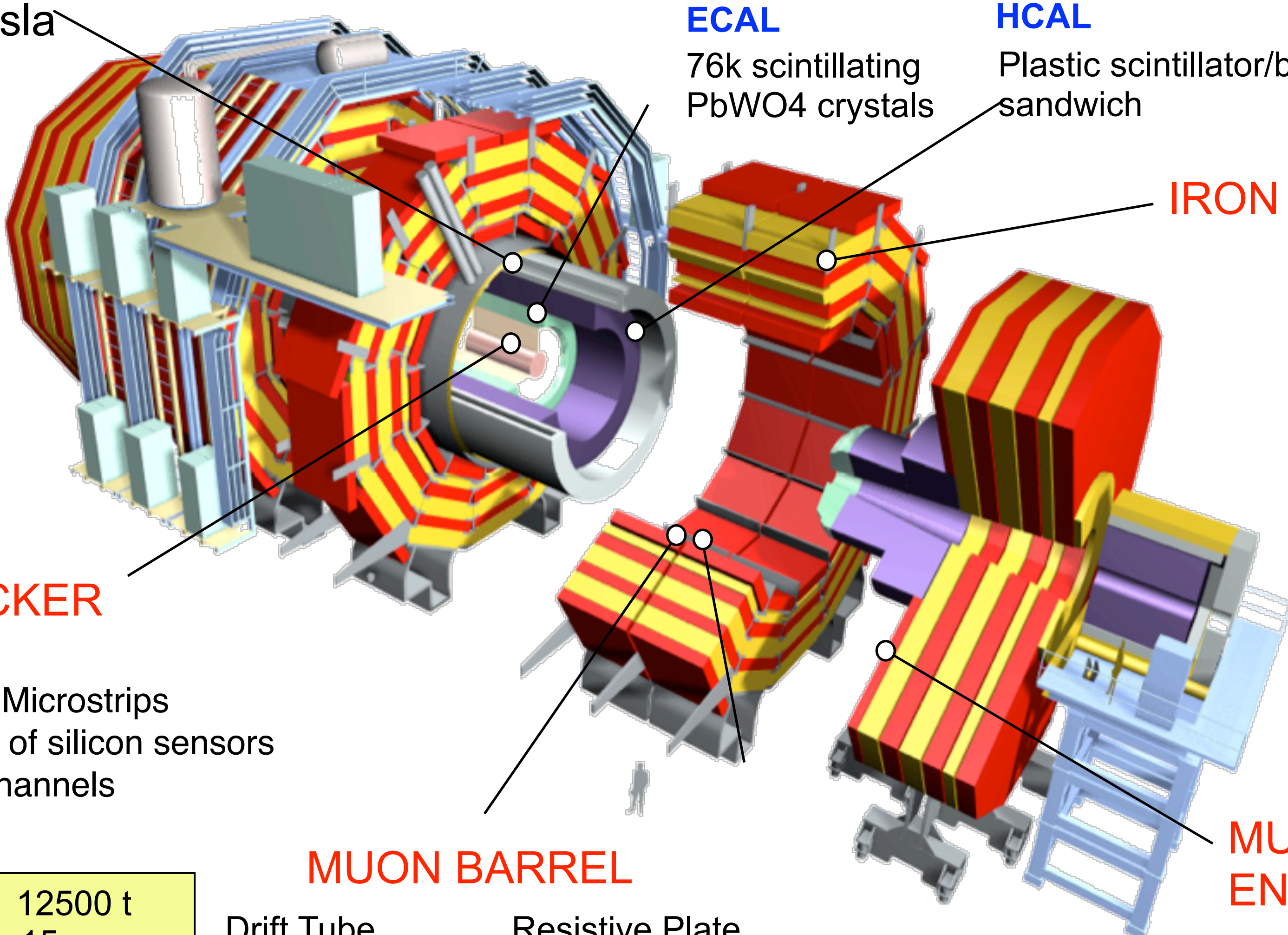
Superconducting Coil, 3.8 Tesla

CALORIMETERS

ECAL
76k scintillating PbWO4 crystals

HCAL
Plastic scintillator/brass sandwich

IRON YOKE



TRACKER

Pixels
Silicon Microstrips
210 m^2 of silicon sensors
9.6M channels

MUON BARREL

Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)

MUON ENDCAPS

Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

Total weight	12500 t
Overall diameter	15 m
Overall length	21.6 m

Event Selection (Electrons)

- Single Electron HLT Trigger
- Kinematic Selection
  - 2 ECAL driven electrons
  - Leading Electron E_T > 20 GeV
  - Second Electron E_T > 10 GeV
  - $|\eta| < 2.5$ excluding small gap in ecal barrel/endcap transition region (1.442-1.566)
- Electron Identification
  - Transverse impact parameter (w.r.t. primary vertex) < 0.02 cm
  - Longitudinal impact parameter (w.r.t. primary vertex) < 1.0 cm
  - Electron conversion rejection
  - Quality cuts on ECAL superclusters
- Isolation
  - Combined tracker/ECAL/HCAL relative isolation < 0.1 for both barrel and endcap
- Energy scale corrections applied

Background Estimation Techniques

- Muons:
  - QCD backgrounds estimated with various data-driven techniques
    - OS/SS and template method
  - All other backgrounds estimated from MC simulation
- Electrons:
  - For backgrounds which give two real electrons (not from Z), use data-driven e-μ method
  - For Z backgrounds and QCD, estimate using MC simulation
- Dominant electron channel backgrounds also give e-μ final state
  - Can use this to estimate e + e background
  - e + μ events are essentially signal free
  - Can use the same trigger to select events as signal
- MC and data estimation agree well