Measurement of the p_T and y Differential Cross Sections for Z bosons at $\sqrt{s} = 7$ TeV

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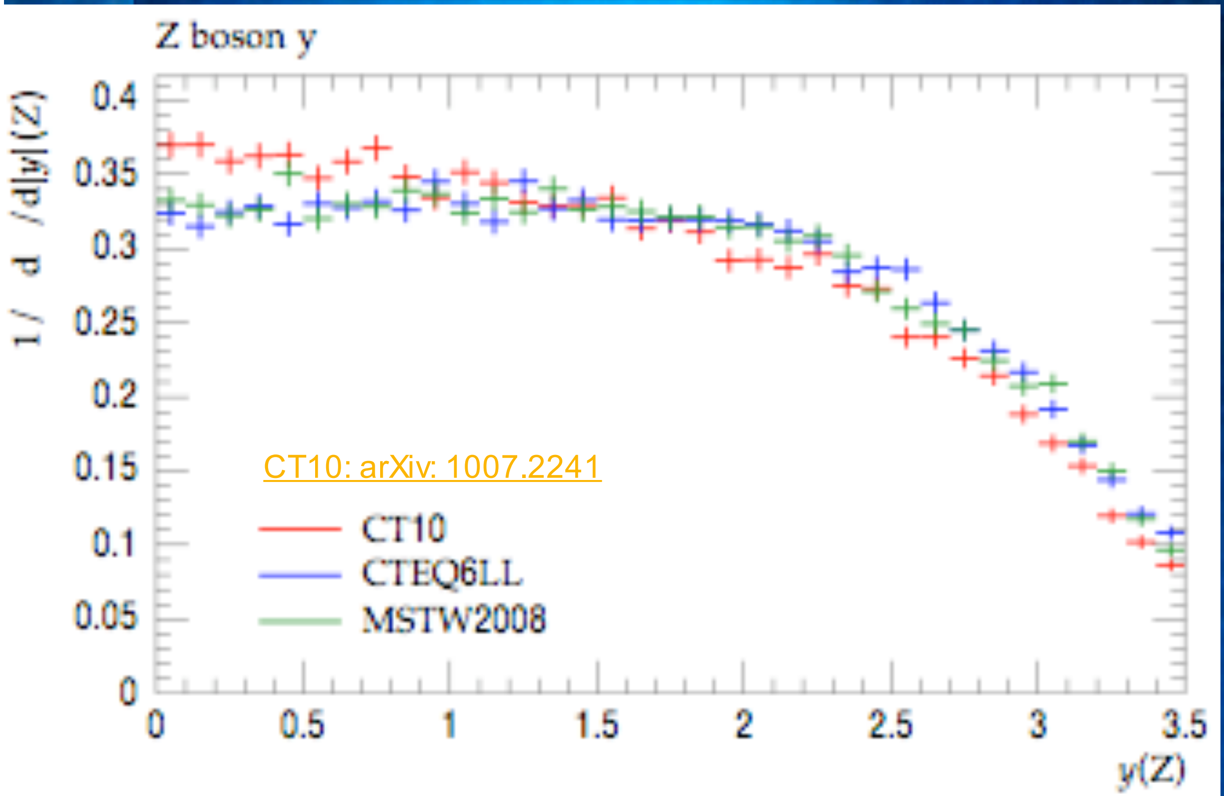
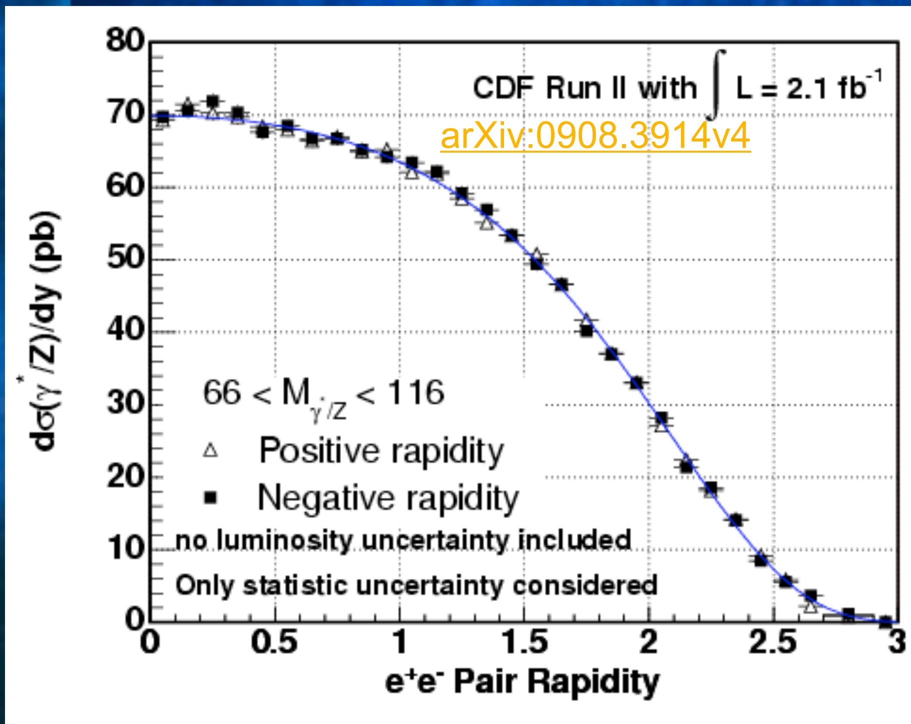
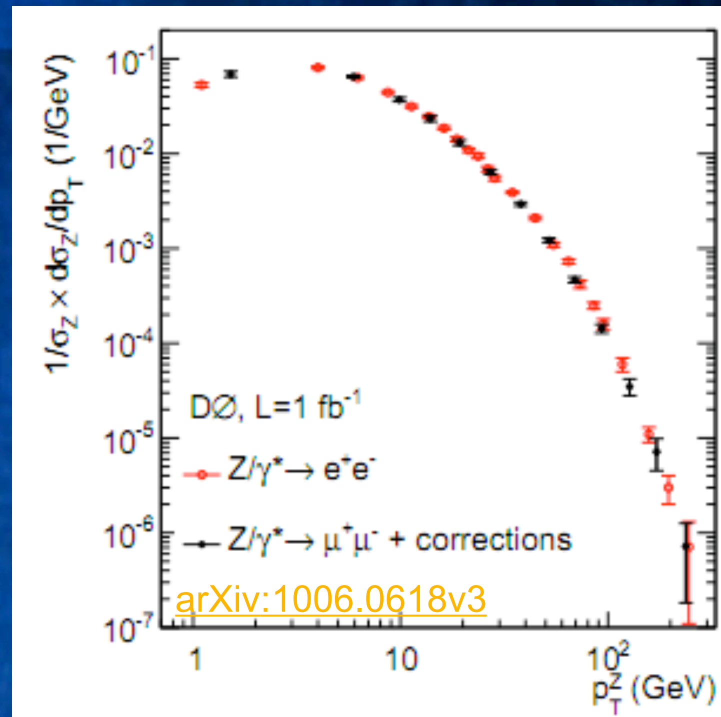
Theoretical Motivation



- Imperfect knowledge of parton density functions shape the rapidity distribution
  - Left, simulation of Z boson y from different pdf tunes.
- Initial state gluon radiation greatly effects the high p_T spectrum
- The low p_T spectrum is dominated by effects attributed to the underlying event.

Previous Studies





- Multiple studies of Z boson differential cross sections were performed at the Tevatron
- We aim to extend the effective η reach of the rapidity analysis, as well as the range in p_T reviewed.

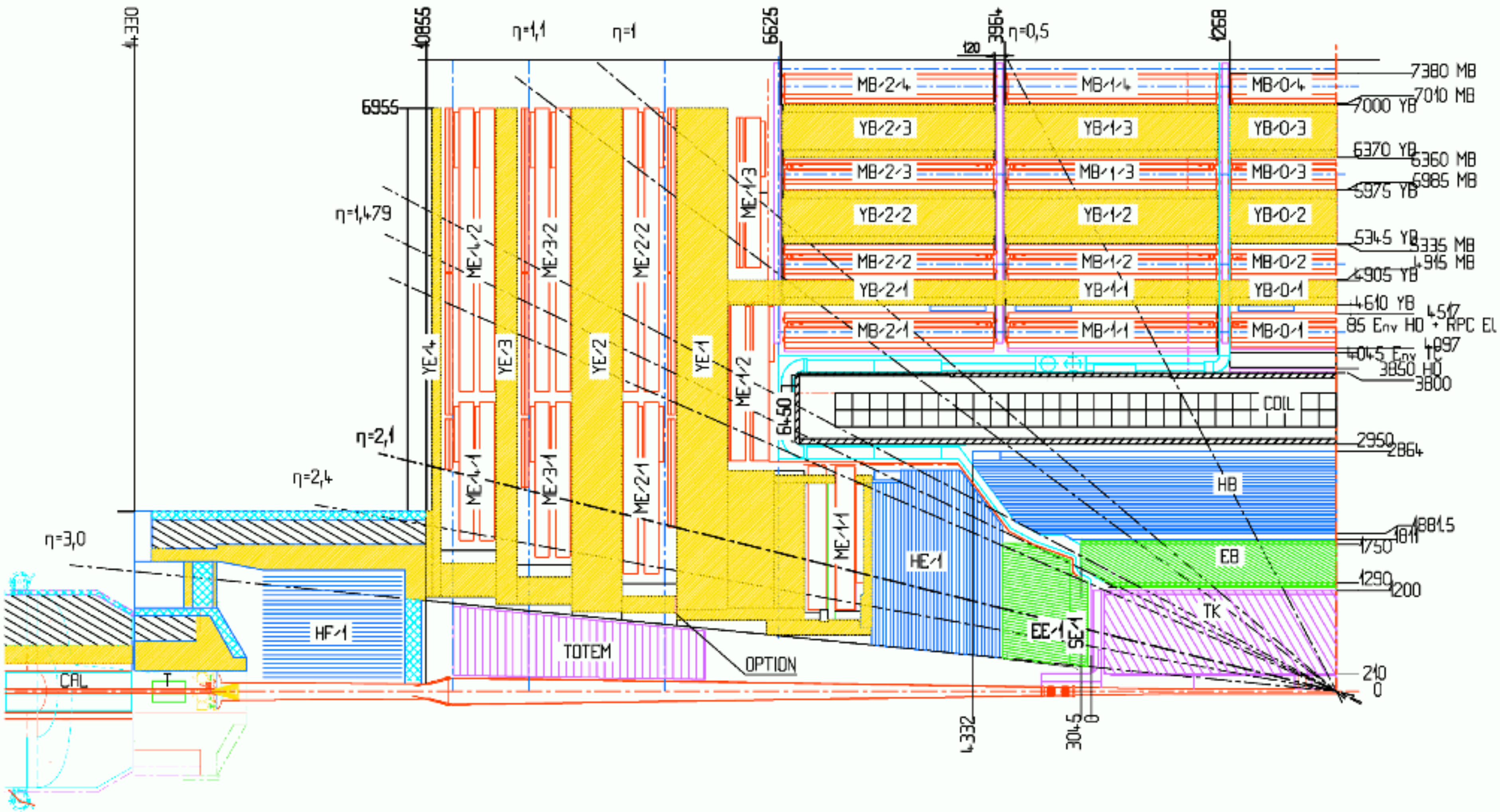
Analysis Overview

$$\frac{1}{\sigma}\frac{d\sigma}{dX}(Z/\gamma^* \to \mu^+\mu^-) = \frac{\bar{A}\times\bar{\epsilon}}{N_{Tot} - B_{Tot}} \times \frac{\sum_k R_{ik}(N_k - B_k)}{\Delta_i \cdot (A\times\epsilon)_i}$$

- We perform an analysis which measures the shape normalized to the total cross section
  - The Z is defined as lepton pairs in the range of $60 < M_{\ell\ell} < 120$
  - The Analysis is performed on the first 36 pb^{-1} of LHC, pp data

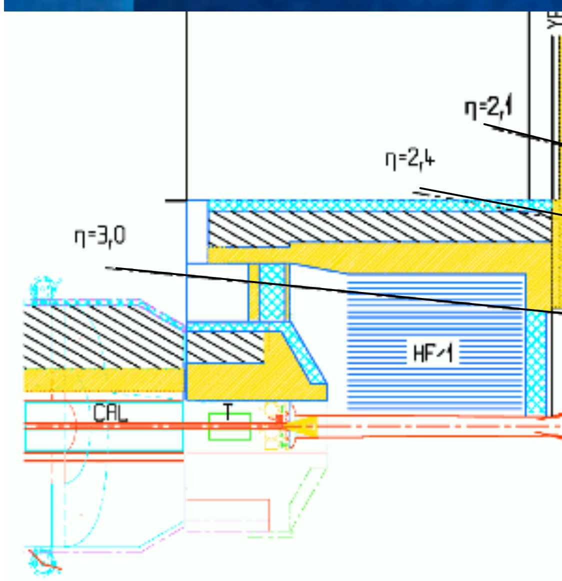
- The above formula completely encodes the analysis procedure.
  1. Perform a bin by bin correction for estimated background (B_k)
  2. Unfold the spectrum for the effects of detector resolution and final state radiation ($\Sigma_k R_{ik}$)
  3. Correct the unfolded spectrum for detector inefficiency and acceptance ($\Delta_i \cdot (A x \varepsilon)_i$)
  4. Normalize to the total cross section

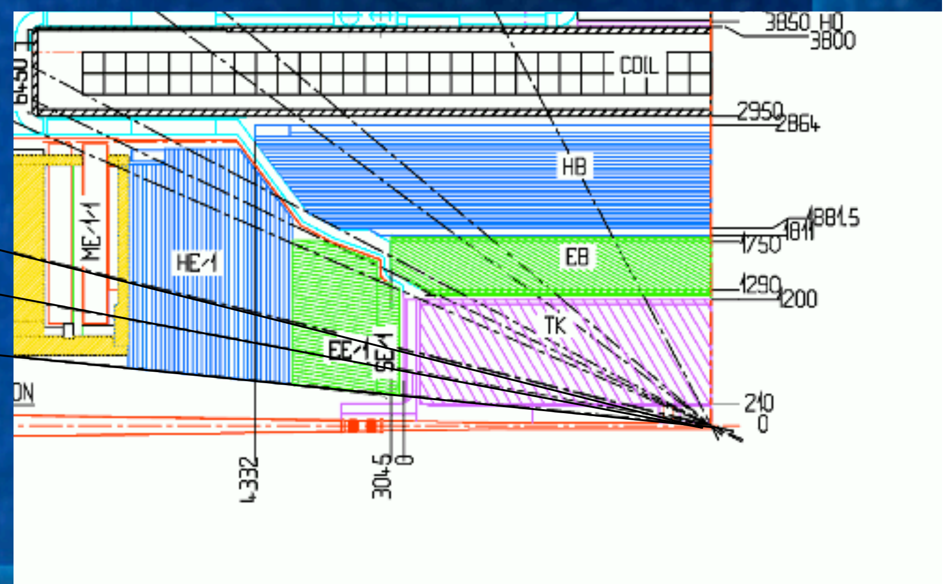
The Compact Muon Solenoid



The Compact Muon Solenoid

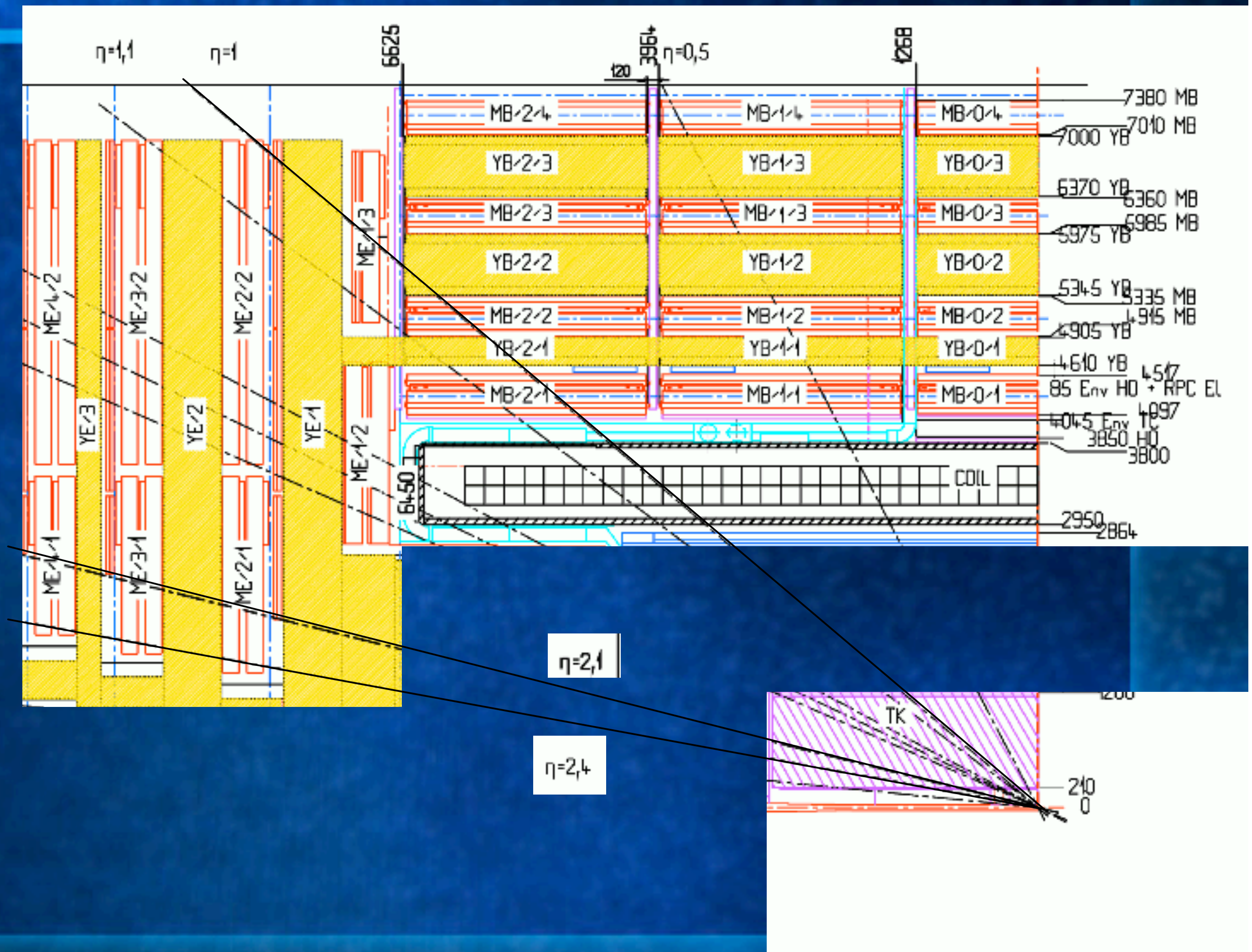
- For the Detection of electrons, CMS features a lead-tungstate electromagnetic calorimeter combined with the inner silicon tracker for electrons with $|\eta| < 3.0$, and is capable of energy resolution to ~1%
- The forward hadronic calorimeter supplements the electron endcap in the high η region, allowing the measurement to extend to $3.0 < |\eta| < 5.0$
  - By using short and long quartz fibers, the forward HCAL is able to identify electrons
- Both channels use the barrel and endcap hadronic calorimeter for isolation





The Compact Muon Solenoid

- For the Identification of muons, CMS features a gas ionization chambers embedded in iron
- The inner tracker is used for the determination of p_T, accurate to 1-3%
- The 3.8 T magnetic field is provided by the superconducting solenoid (for which the detector is named)



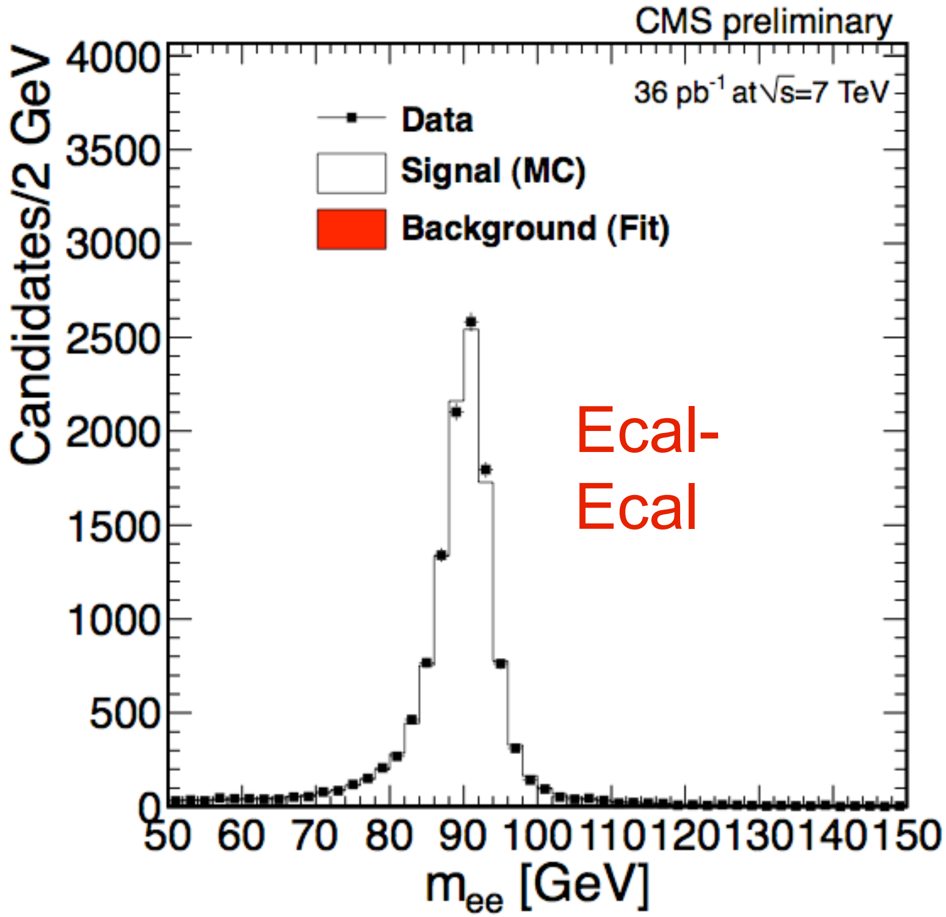
Triggers and Event Selection

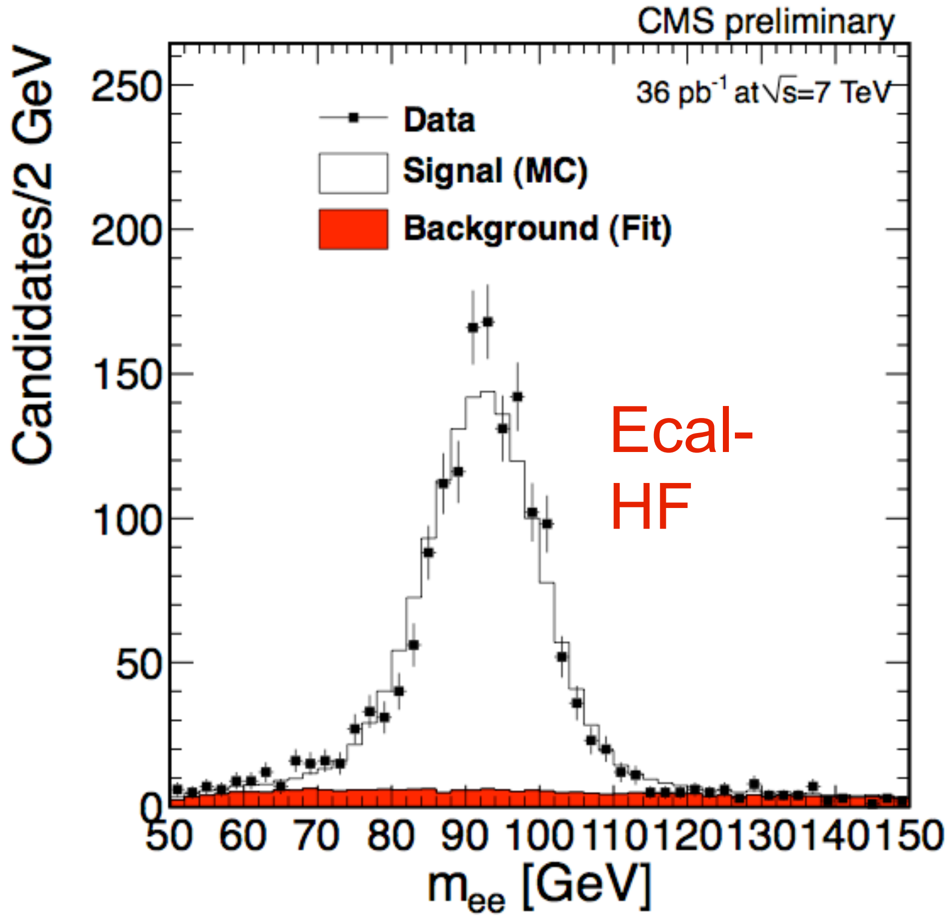
- CMS employs a 2 tier trigger scheme, with data reduction as illustrated above
- Muons: 15 GeV trigger threshold, and a 20 GeV offline cut.
- Electrons: electron and photon triggers were use with a threshold of 17 GeV, again a 20 GeV offline cut.

Further Event Selection

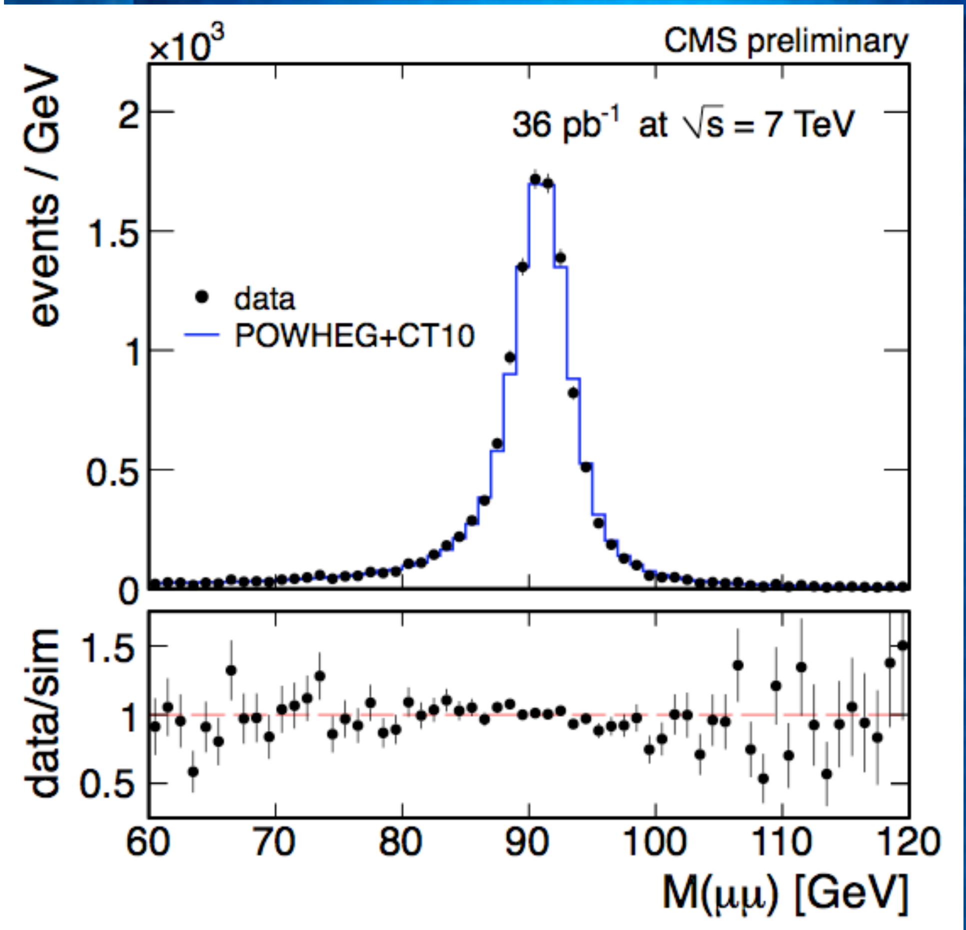
- The $d\sigma/dp_T$ measurement requires leptons to have $|\eta| < 2.1$
- For the $d\sigma/dy$ analysis, muons are restricted to have $|\eta| < 2.1$
- For the electron rapidity analysis we require 1 electron to be in the ECAL barrel or endcap ($|\eta| < 3.0$), with the second allowed to be in either the ECAL or HF ($3.1 < |\eta| < 4.6$).
- In both instances we require the leptons be isolated.
- Further details are listed in the supporting slides.

Dielectron Mass



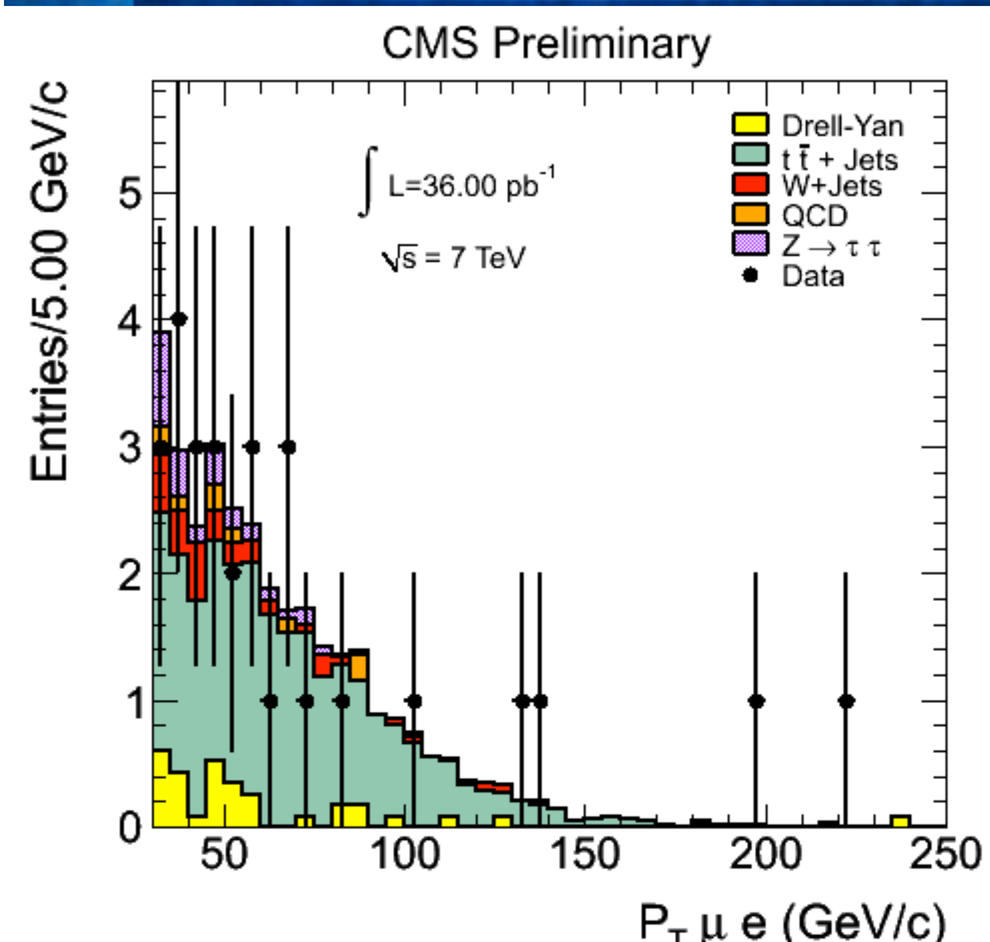


Dimuon Mass



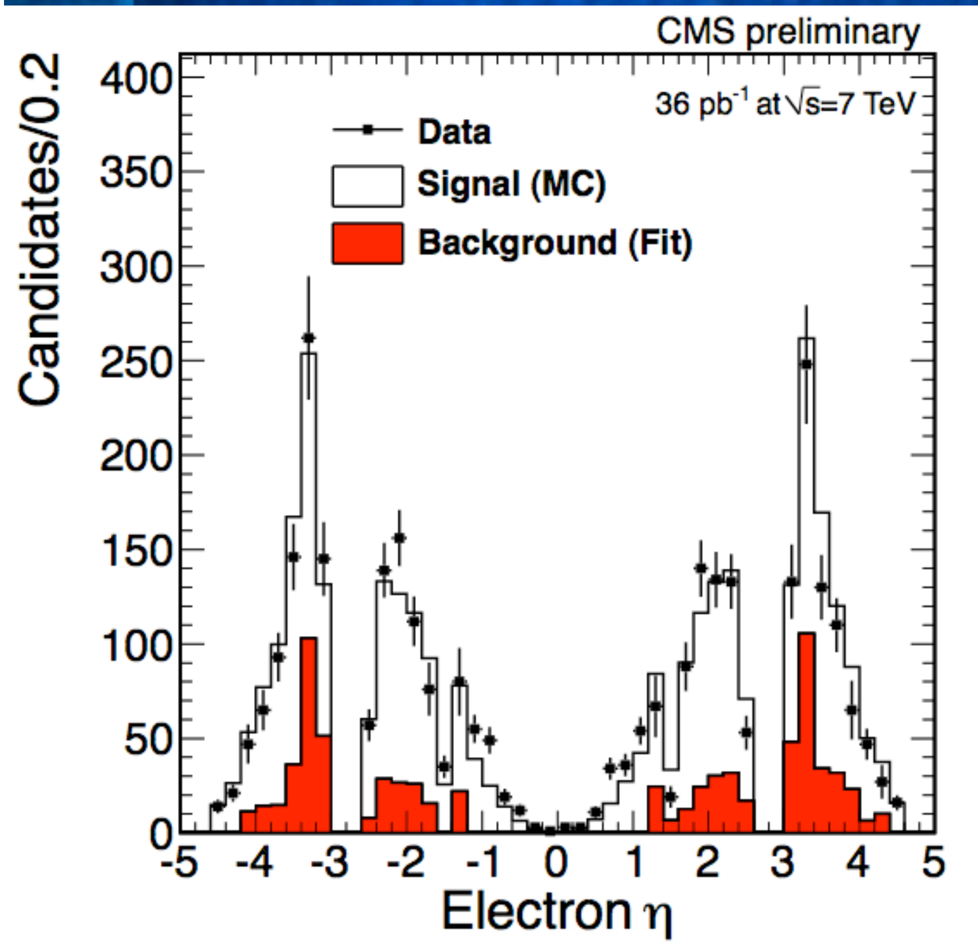
Muons	
Barrel-Barrel	~3,900
Barrel-Endcap	~5,900
Endcap-Endcap	~2,500
Electrons	
ECAL-ECAL	~10,000
ECAL-HF	~2,000

Background Estimation



- As good agreement is found, all backgrounds levels are taken from Monte Carlo
- Background are checked from data driven techniques
  - $t\bar{t}$ control region of the electron-muon p_T spectrum is inspected (shown)
  - Background contribution from QCD is estimated using several techniques

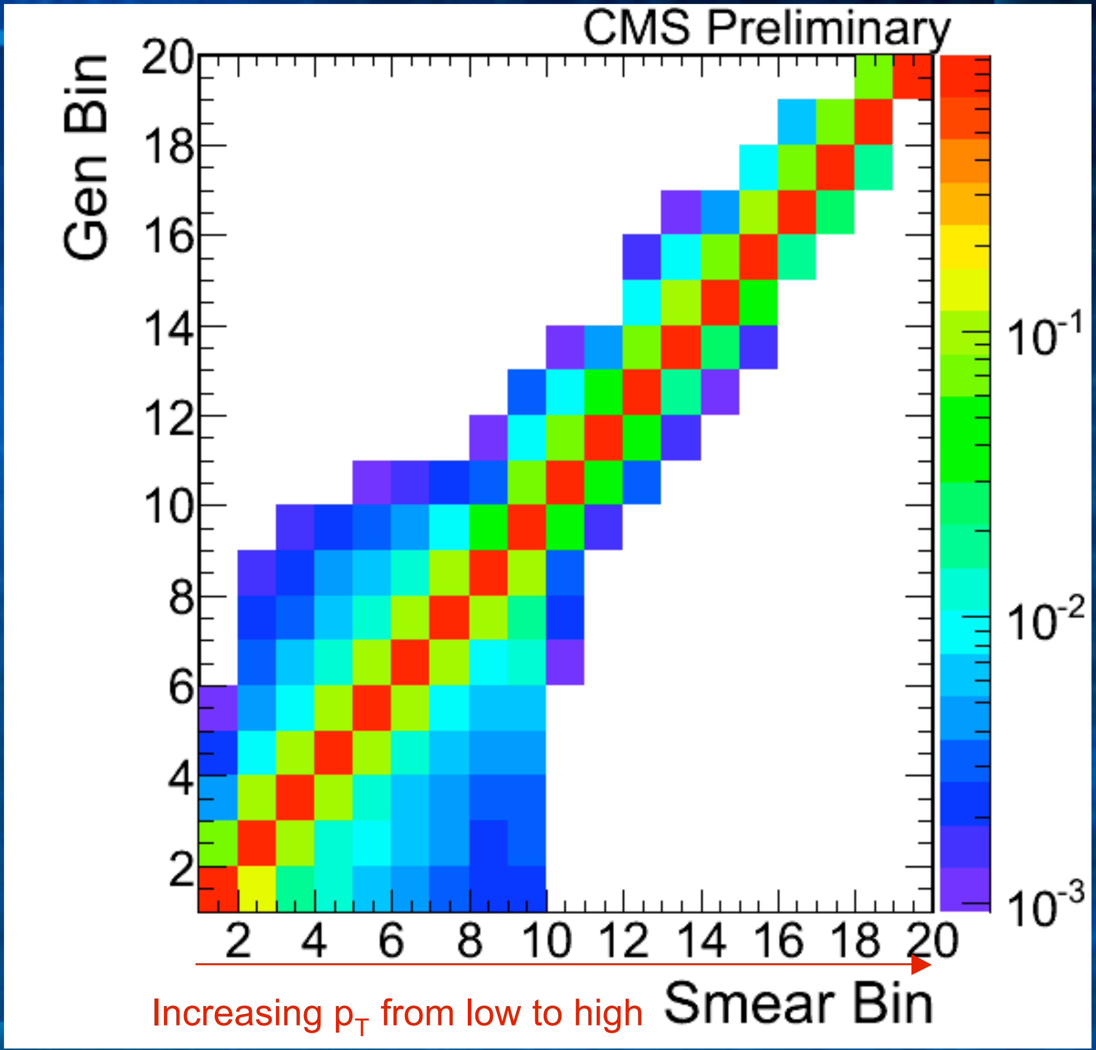
Acceptance & Efficiency



- For the $d\sigma/dp_T$ analysis, leptons with $|\eta| < 2.1$ are used, as well as limiting phase space of lepton $p_T > 20$ GeV
- For $d\sigma/dy$, corrections are made such that all phase space of η and p_T are considered
- Efficiency is measured via tag and probe for both triggers and offline selection.
  - Muon: trigger ~99%, selection ~90%
  - Electron: trigger ~97%, selection ~80%

Unfolding Detector Resolution

- We unfold the data using the unregularized matrix inversion technique
- For detector resolution, matrices are trained on data tuned resolution functions
- For FSR, we rely on pythia simulation.
- We include efficiency & acceptance s.t. all non-BG corrections are performed in a single step.
- We report uncertainties and a corresponding covariance matrix.



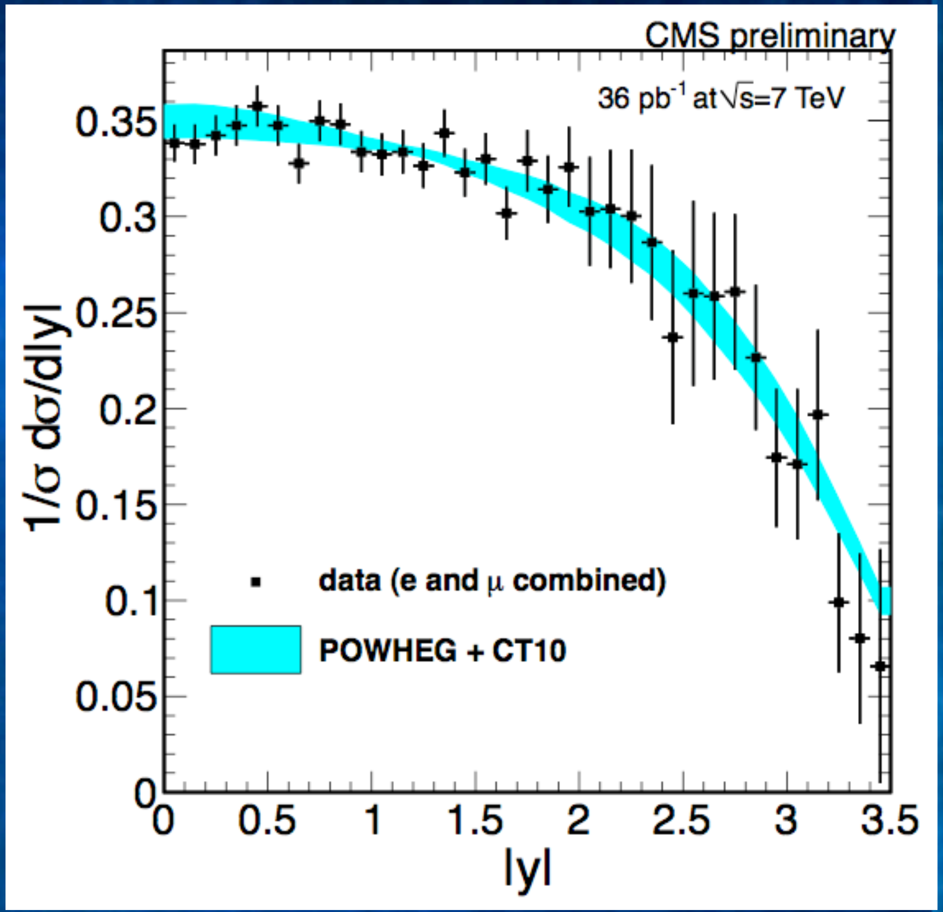
Sources of Systematic Error

- For electrons:
  - The inclusion of HF makes systematics from QCD significant
  - Imperfect knowledge of HF electromagnetic energy scales
- For muons:
  - The largest systematic uncertainties come from variation of the detector resolution

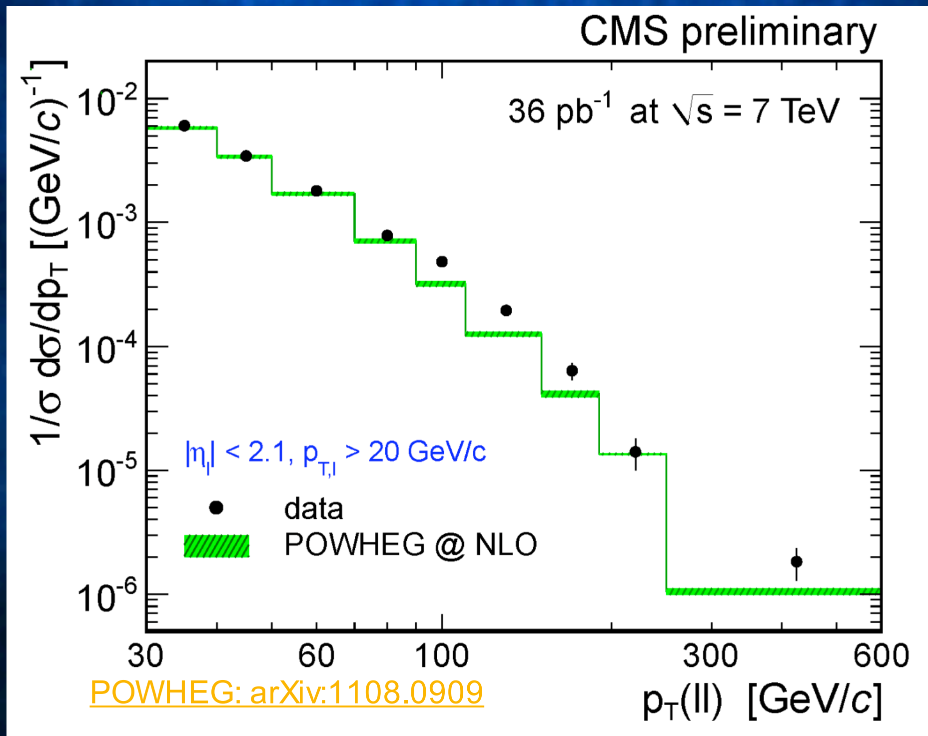
- For rapidity, acceptance corrections in regions where coverage is lacking causes uncertainties
- Uncertainty induced by dependencies to PDF shapes effect estimation of efficiency, acceptance, and unfolding
- Uncertainty arising from the sample size is largest effect

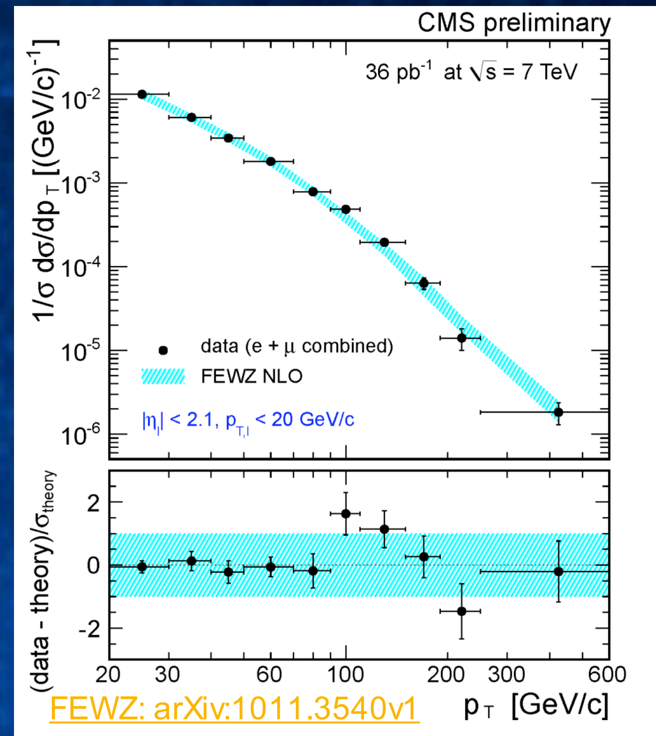
Results - Rapidity

- The rapidity is a direct probe of the PDFs
- A bin size of $\Delta y = 0.1$ are used
- As the distribution is symmetric about 0, |y| is measured
- The results are consistent with the CT10 pdf, and should provide feedback for improved tuning, particularly in the high y region.



Results - Transverse Momentum

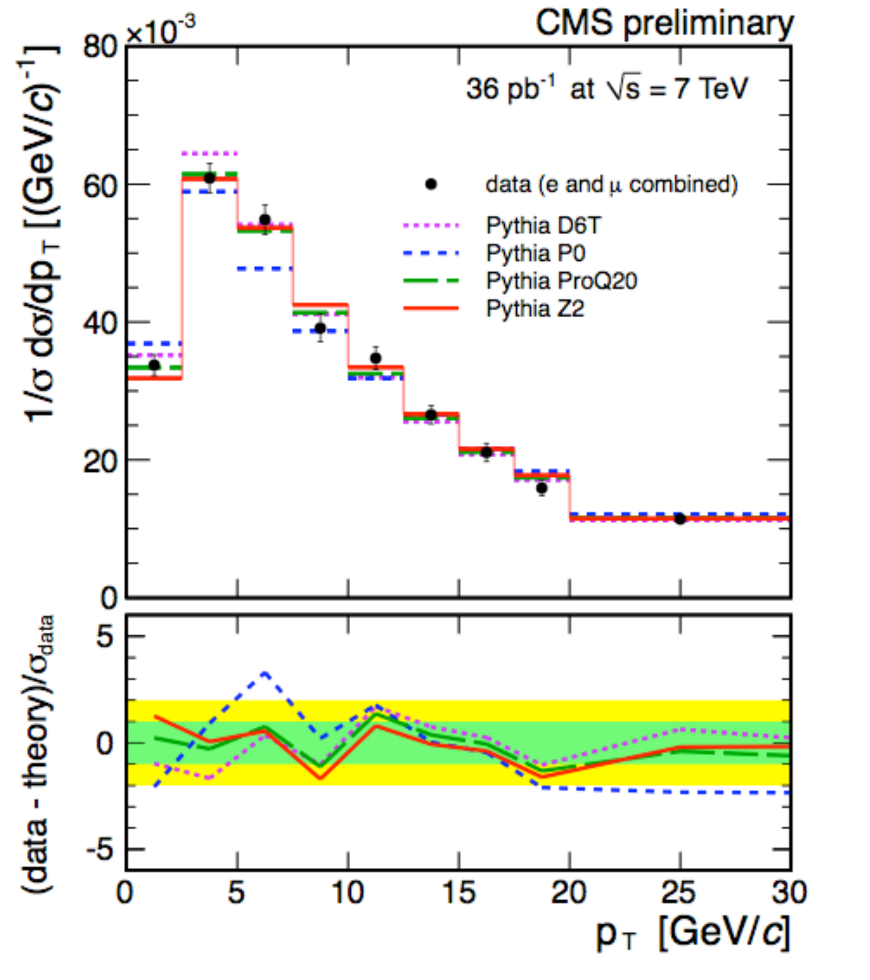




- We compare POWHEG @ NLO using the Z2 UE tune to combined e + mu data, finding disagreement in both the high (shown) and low p_T regions
- Additionally, the FEWZ NLO calculator is compared to data, showing improved agreement at the highest p_T

Results - Transverse Momentum (2)

- The low end of the transverse momentum spectrum is dominated by non-perturbative effects, generally attributed to the underlying event
- Several models are checked, with ProQ20 having the best agreement (p = 66%)



Conclusions

- We report a measurement of both the y and p_T distributions for the first 36 pb^{-1} of LHC pp data at $\sqrt{s}$ = 7 TeV
- The CT10 PDF is compared to data, showing good agreement extending to high regions of y
- The predictions of the POWHEG and FEWZ NLO calculator are compared to the perturbative regime of data, with good agreement to FEWZ
- Several Tunes of the UE are tested in the non-perturbative region, showing the best agreement for the ProQ20 tune

- The Analysis Summary can be found by searching for CMS-PAS-EWK-10-010 located on the CERN document server
- Additional comparisons to FEWZ at NNLO and variations on the PDF are to be included in the paper from this study, coming soon
- An ATLAS study of the Z p_T Spectrum has been released as well, and can be found for comparison on arXiv:1107.2381v1

Supporting Slides

Triggers and Event Selection

- We select the mass window of 60 GeV < $M_{\ell\ell}$ <120 GeV
- Muons
  - Muons are required to have 11 or more tracker hits, at least one of which is in the in in the inner pixel tracker.
  - Reconstructed using both an inside out and outside in extrapolation
  - The χ^2/NDF < 10 for the fit of the track to the tracker/muon system hits.
  - Muons required to have opposite charge.
  - Transverse impact parameter w.r.t. the beam spot is less than 0.2.
- Electrons
  - Electrons reconstructed in the electromagnetic calorimeters must have associated with it a track which extrapolates to the deposit.
  - Combinations considered are either 2 in the ecal+track region, or 1 in the ecal+ track region and 1 in the HF region.