$W \to \mu\nu$ Charge Asymmetry with the ATLAS Detector

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PDF4LHC
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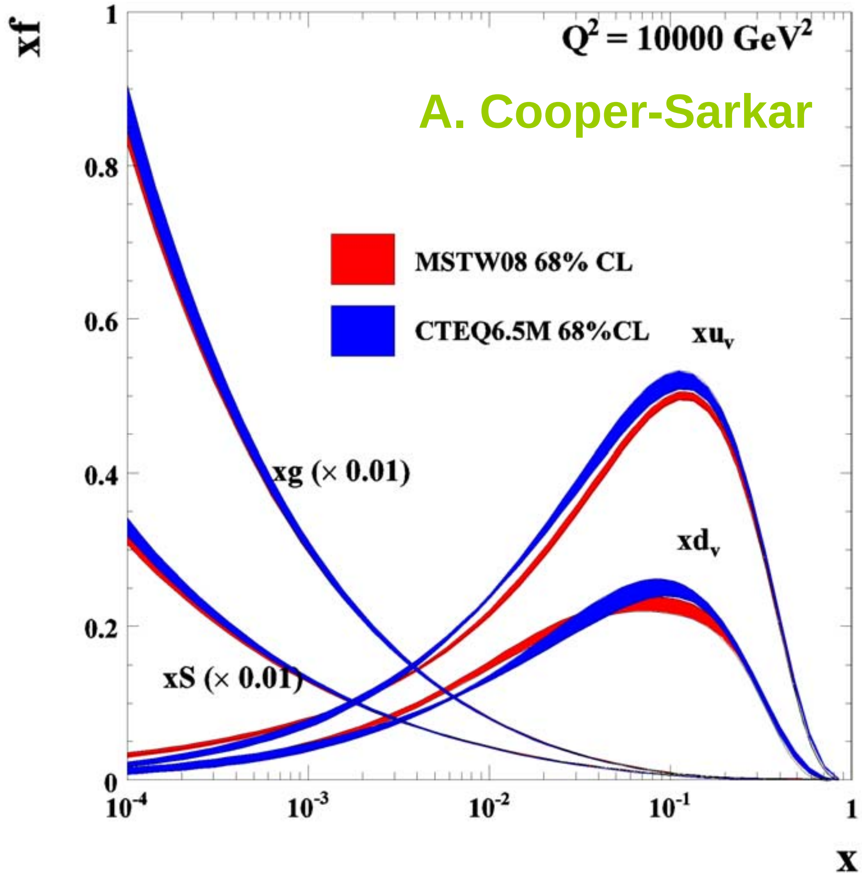
Motivation

- Interesting early precision measurement at pp collider
  - Twice as many valence *u* than *d* quarks
    - Integrated asymmetry $\neq 0$
  - W-rapidity dependency sensitive to differences between *u* and *d* PDFs
    - Asymmetry expected to rise at higher |y|, where partons with higher *x* are selected
  - Difficult to reconstruct W rapidity, use decay lepton pseudo-rapidity η

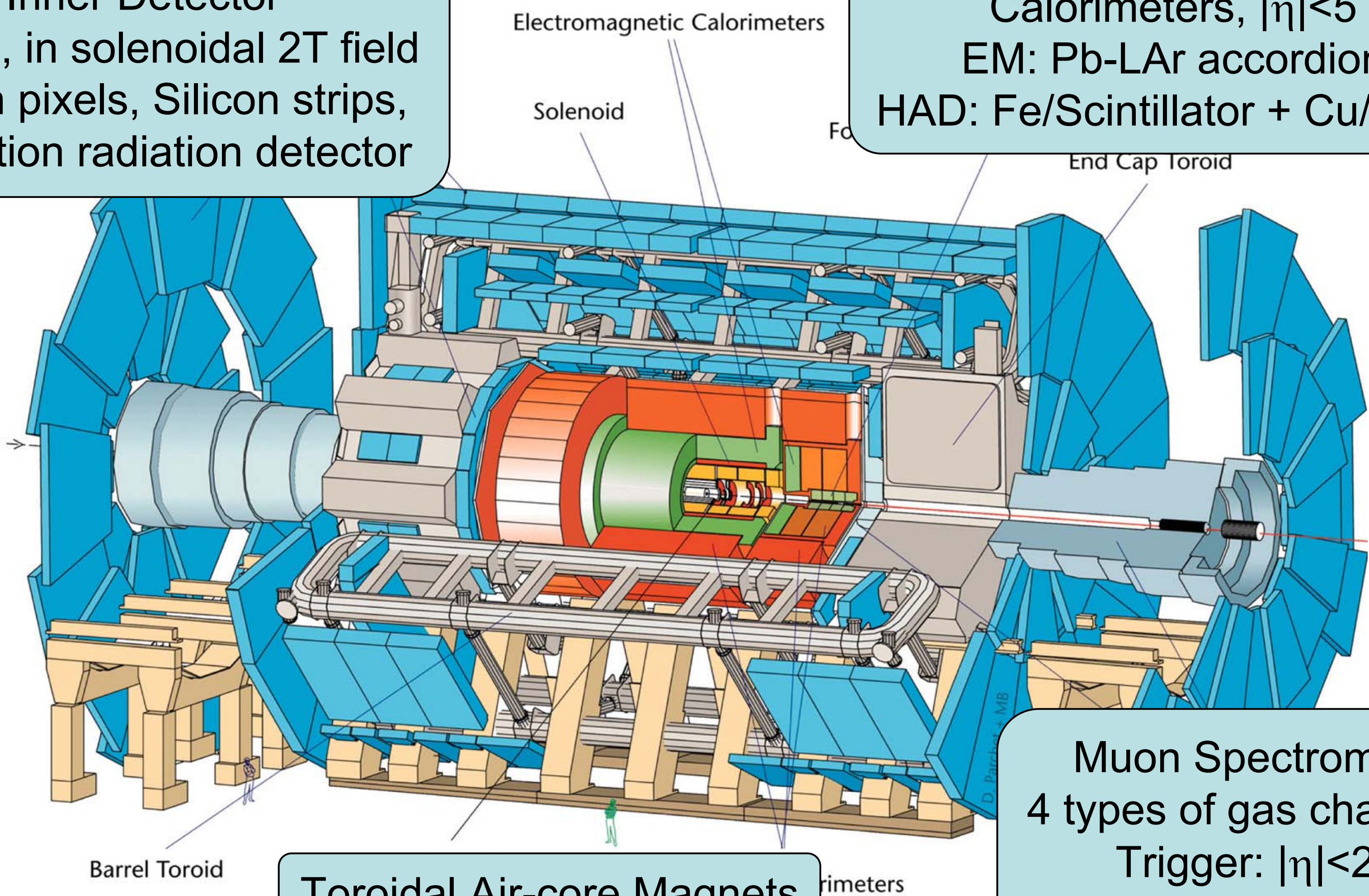


$$x_{1,2} = \frac{m_W}{\sqrt{s}} \cdot e^{\pm y}, y \simeq \eta$$

The ATLAS Detector

Inner Detector
|η|<2.5, in solenoidal 2T field
Silicon pixels, Silicon strips,
Transition radiation detector

Calorimeters, |η|<5
EM: Pb-LAr accordion
HAD: Fe/Scintillator + Cu/W-Ar



Toroidal Air-core Magnets

Muon Spectrometer
4 types of gas chambers
Trigger: |η|<2.4
Reconstruction: |η|<2.7

Methodology

- The Asymmetry Master Formula:

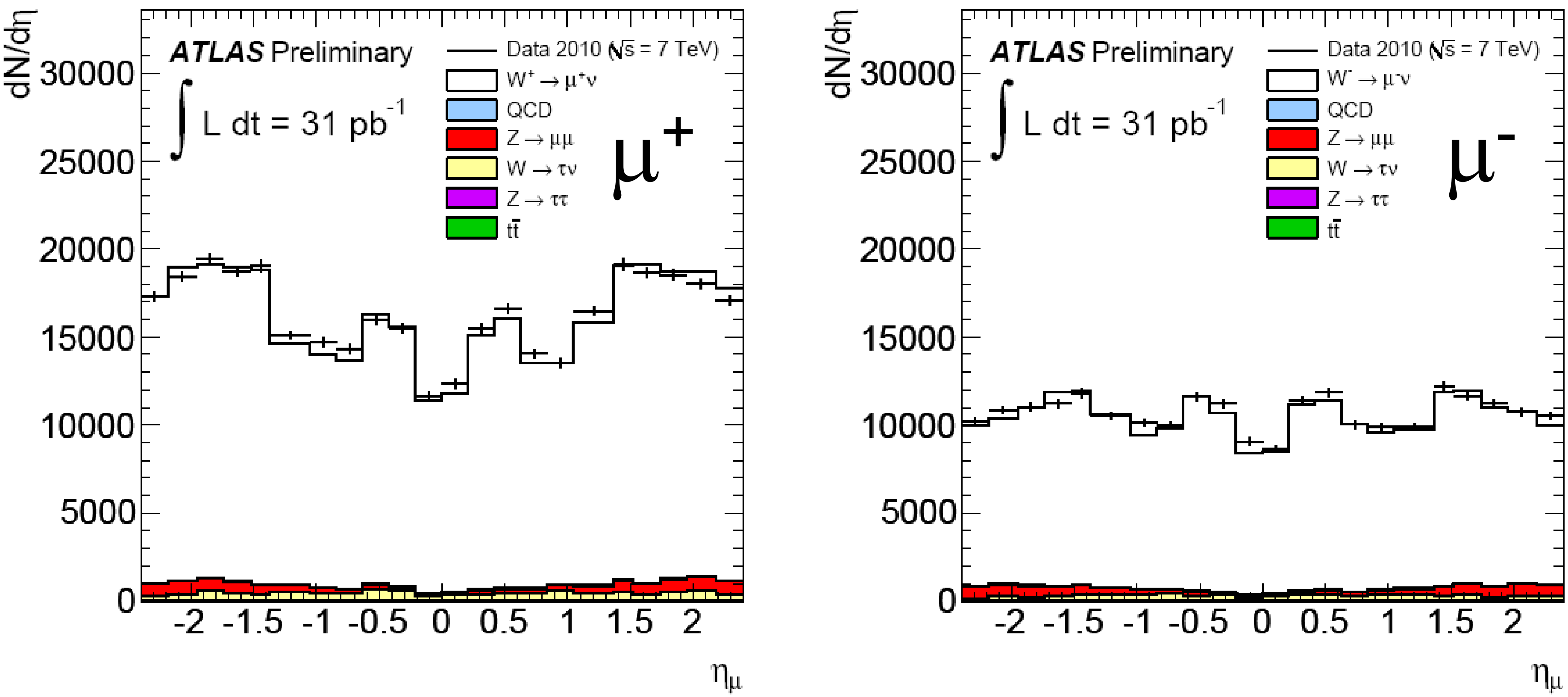
$$\mathcal{A}(\eta_\mu) = \frac{d\sigma^{\rm fid}_{W^+}/d\eta_\mu - d\sigma^{\rm fid}_{W^-}/d\eta_\mu}{\sigma^{\rm fid}_{W^+}/d\eta_\mu + d\sigma^{\rm fid}_{W^-}/d\eta_\mu}$$

$$\sigma_{\rm fid} = \frac{N_{\rm obs} - N_{\rm bkg}}{C_{\rm W} \cdot \mathcal{L}_{\rm int}}$$

- C_W: trigger, reconstruction, identification efficiency for W bosons falling within acceptance
  - N_{reco}/N_{truth}, analysis cuts applied to MC reco/truth quantities
    - Phase space: $|\eta|<2.4$, $p_T(\nu)>25$GeV, $p_T(\mu)>20$GeV
  - Correction for data/MC differences in trigger and reconstruction efficiencies

$$C_{\rm W} = \frac{N_{\rm reco}}{N_{\rm truth}} \cdot \frac{\epsilon^{\rm data}_{\rm trigger}}{\epsilon^{\rm MC}_{\rm trigger}} \cdot \frac{\epsilon^{\rm data}_{\rm reco}}{\epsilon^{\rm MC}_{\rm reco}}$$

Muon Pseudo-rapidity



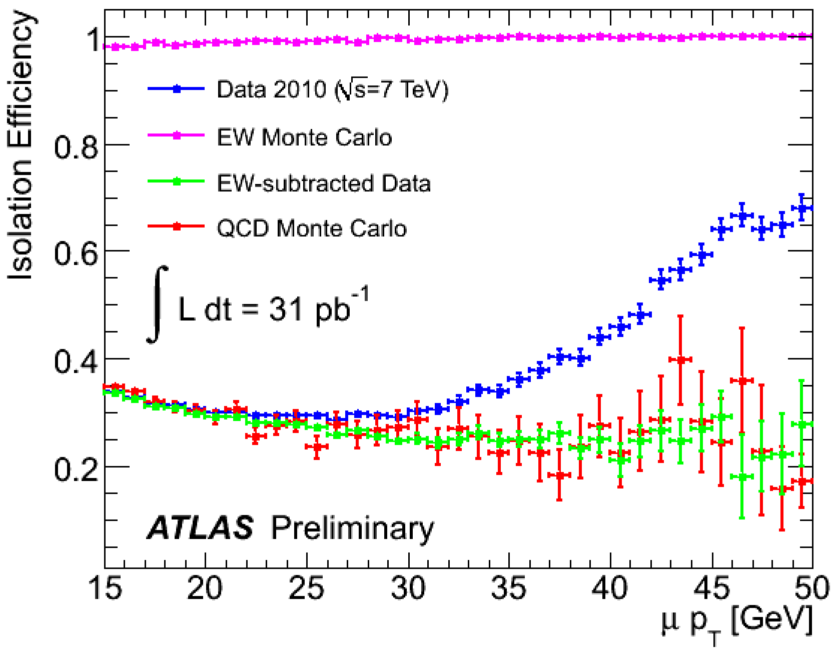
- Muon pseudo-rapidity distribution of W candidates, after all selection cuts
  - Counting experiment: muon quality cuts, isolation, $p_T(\mu)$>20GeV, E_T^{miss}>25GeV, m_T>40GeV

$$m_{\mathrm{T}} = \sqrt{2 \cdot p_{\mathrm{T}} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos(\phi_\mu - \phi_{E_{\mathrm{T}}^{\mathrm{miss}}})\right)}$$

Background Estimation

$$\sigma \propto N_{\mathrm{obs}} - N_{\mathrm{bkg}}$$

- Z→μμ/ττ, W→τν and top backgrounds estimated using Monte Carlo
  - Both shape and normalization
- "QCD" background estimation used *matrix method*
  - Release track-isolation cut to build a "loose" sample
  - Difference in efficiency of isolation cut for QCD and non-QCD samples allows one to separate the two components in data



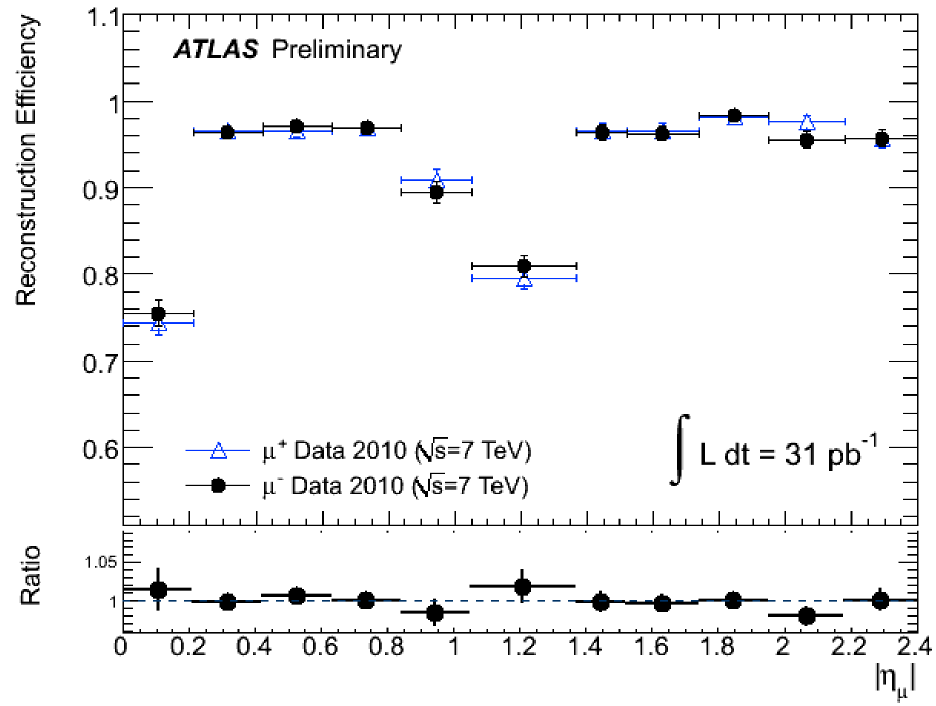
$$N_{\mathrm{QCD}} = \frac{N_{\mathrm{loose}}\epsilon_{\mathrm{non-QCD}} - N_{\mathrm{tight}}}{\epsilon_{\mathrm{non-QCD}} - \epsilon_{\mathrm{QCD}}} \cdot \epsilon_{\mathrm{QCD}}$$

- N_{bkg} ~ 7% N_{obs}
  - Clean W sample after selection

Correction to Truth Level

- Use W Monte Carlo to correct for trigger, reconstruction, and identification efficiencies of W candidates
  - C_W corrects for efficiencies and geometric acceptance
    - Robust against usage of different MC samples

$$\sigma \propto 1/C_W$$



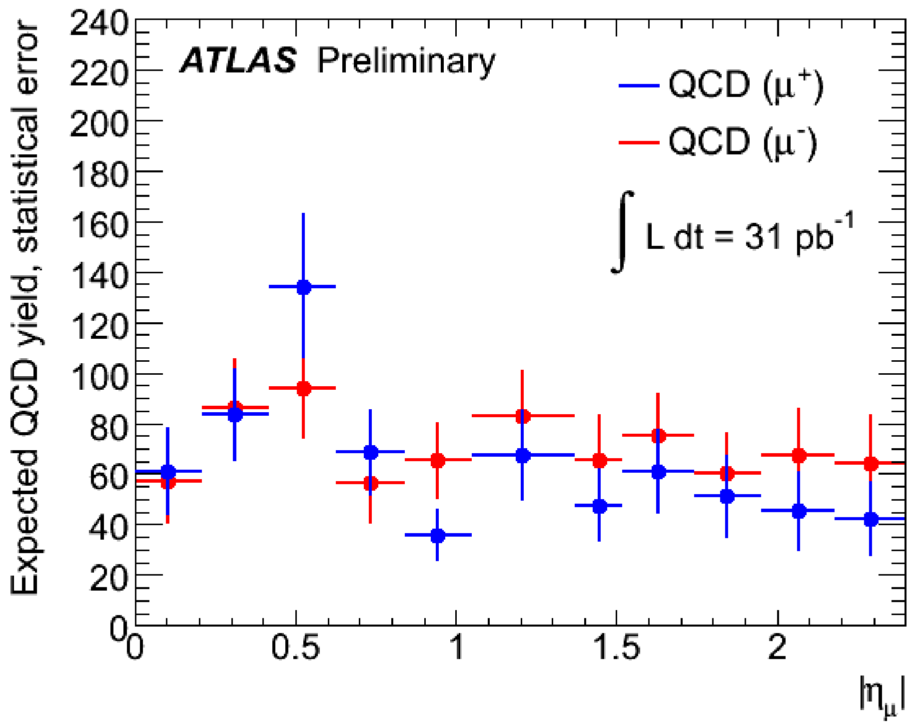
#MC W, analysis cuts on reconstructed quantities

#MC W, analysis cuts on truth quantities

$$C_W = \frac{N_{\mathrm{reco}}}{N_{\mathrm{truth}}} \cdot \frac{\epsilon^{\mathrm{data}}_{\mathrm{trigger}}}{\epsilon^{\mathrm{MC}}_{\mathrm{trigger}}} \cdot \frac{\epsilon^{\mathrm{data}}_{\mathrm{reco}}}{\epsilon^{\mathrm{MC}}_{\mathrm{reco}}}$$

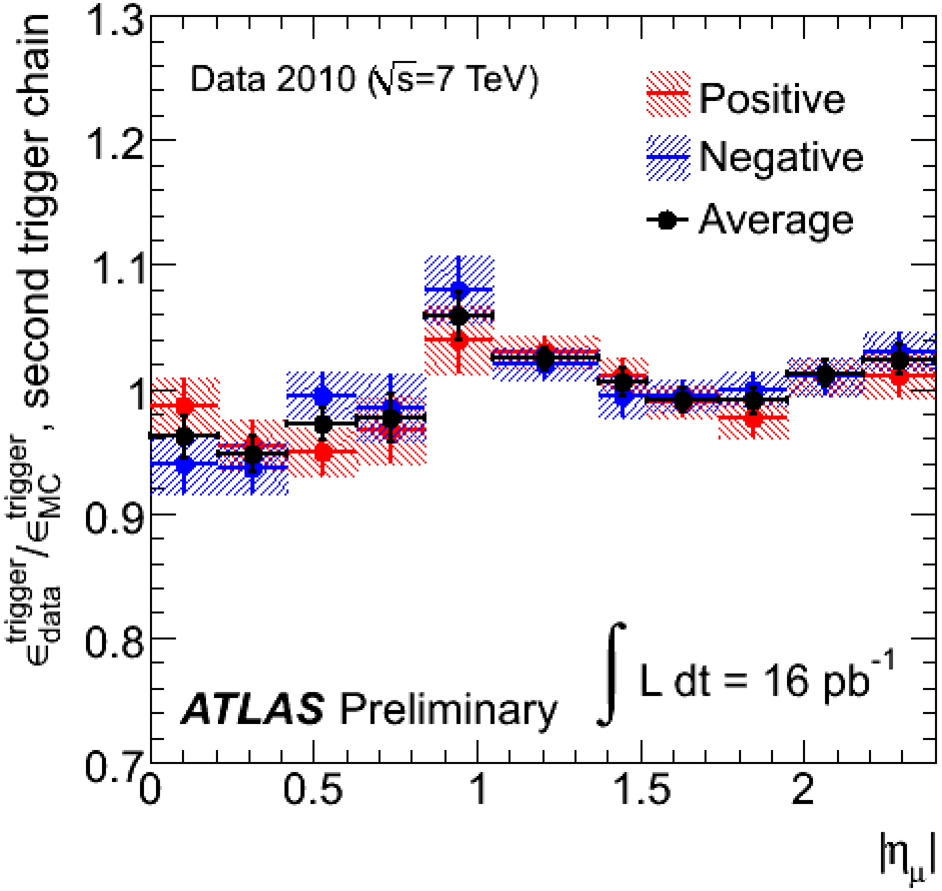
Systematics - Background

- Electro-weak and top backgrounds
  - 5% W/Z cross-section measurement; 6% ttbar
  - 3% PDF error, theory
  - 11% luminosity
    - All uncertainties bin-by-bin correlated
- QCD backgrounds
  - Statistical component (uncorrelated)
  - Error from isolation efficiencies (bin-by-bin correlated)



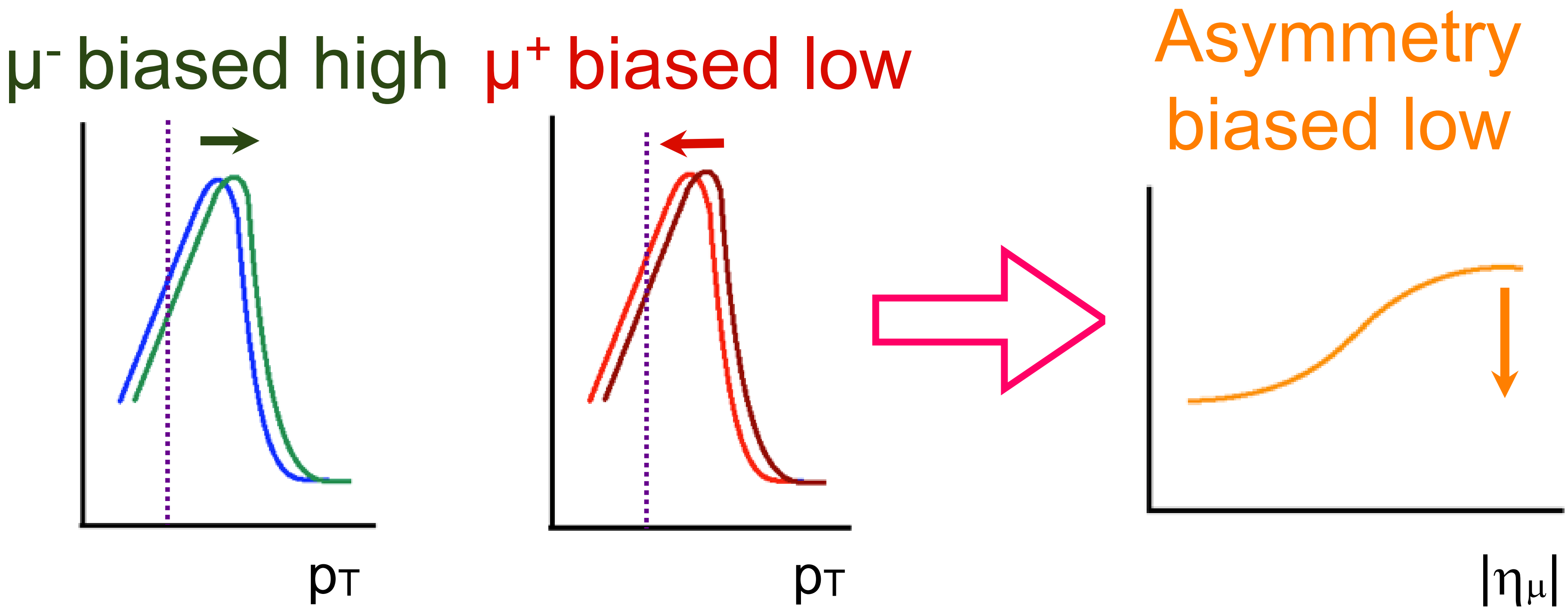
Systematics – Data/MC Scale

- Trigger Scale Factor
  - Statistical component (uncorrelated)
    - Binomial error on data and MC efficiencies
  - Systematic components cancel (10 times smaller than statistical)
    - Relative systematic variations consistent for positive and negative muons
- Reconstruction Scale Factor
  - Mostly statistical; no evidence for difference in μ^+/μ^- ε_{reco}

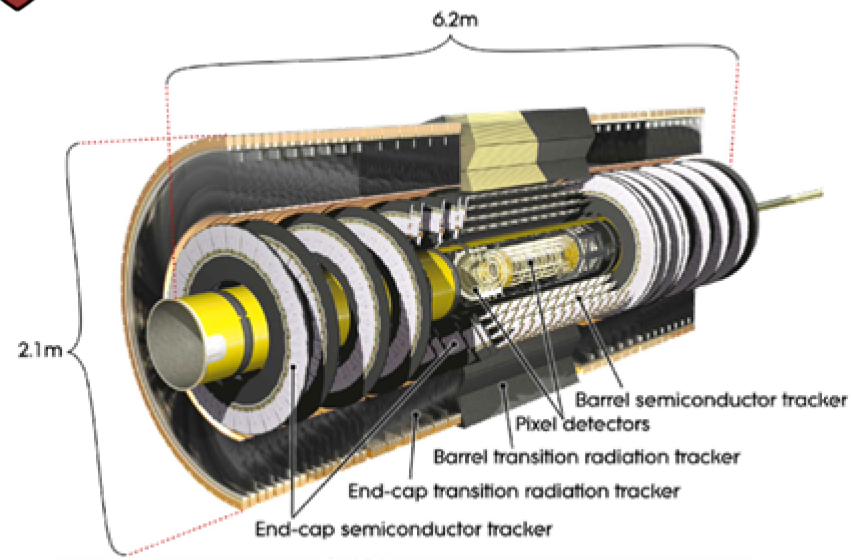


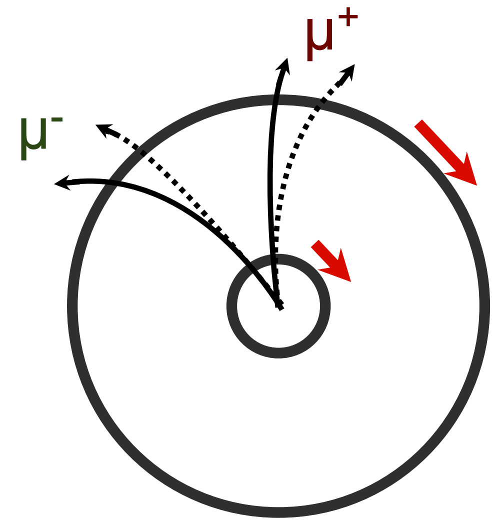
Muon Momentum Scale

- Correct measurement of muon momenta is an important challenge
  - Detector misalignments can introduce charge-dependent mis-measurements
  - The charge asymmetry measurement can be biased because the muon acceptance is modified differently for μ^+ and μ^-

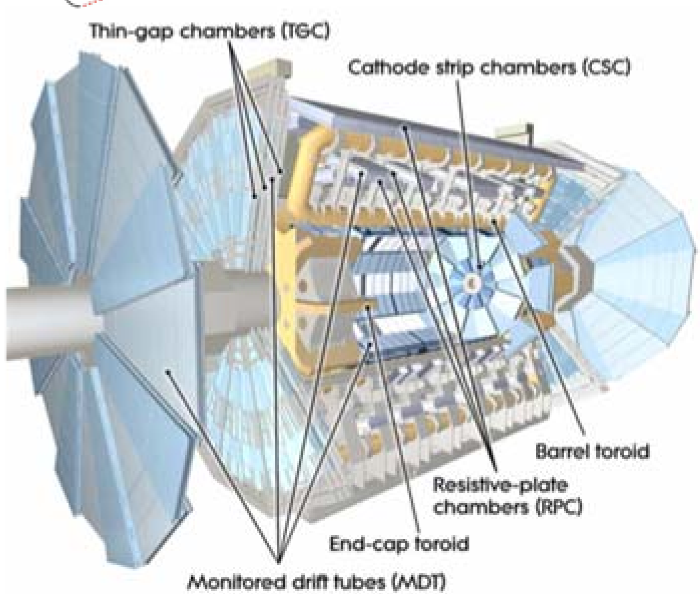


Mis-alignment Examples

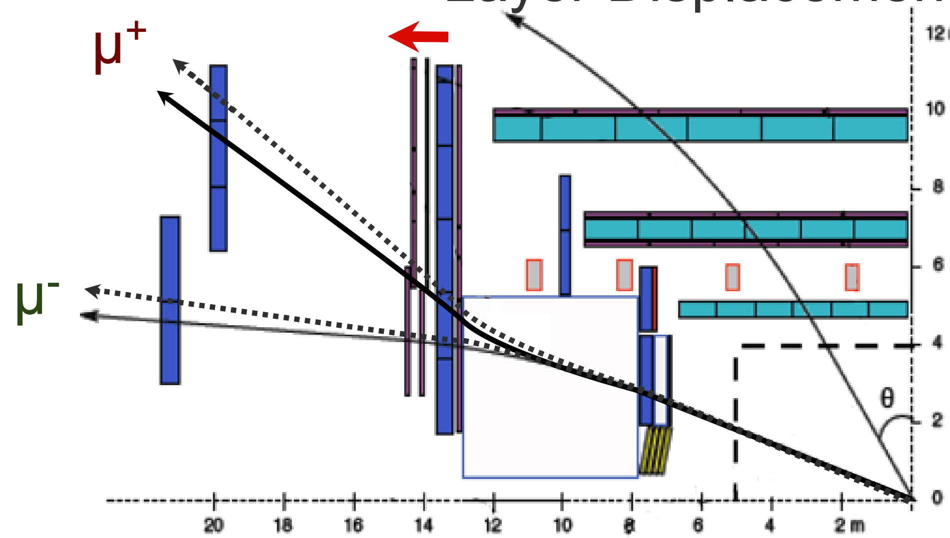




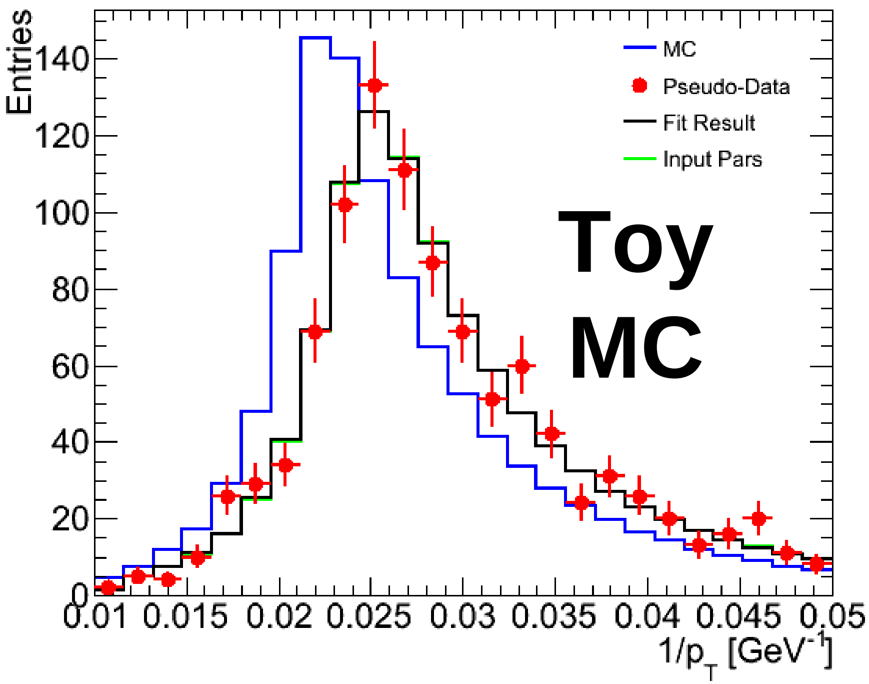
Disk Curl



Layer Displacement



Correcting Momentum Scale



$$(1/p_T)_s = 1/C_1 \times (1/p_T)_{MC} \times (1 + x \times C_2)$$

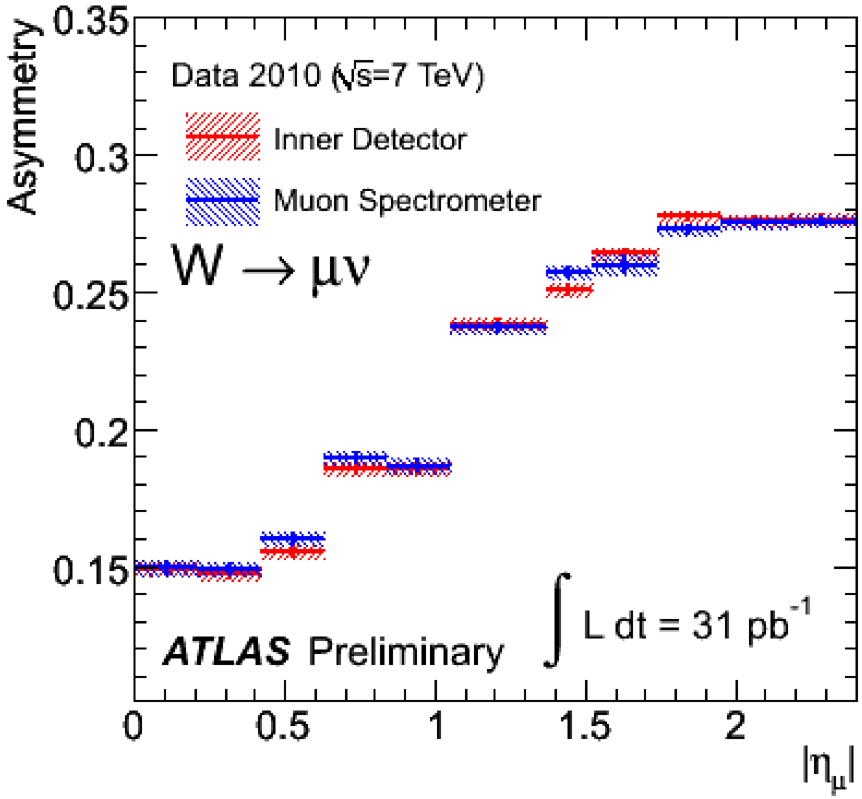
Scale **Resolution**

x is random number Gaus(0,1)

- Measure correction comparing data and simulation
  - Fit for scale in muons from W candidate
    - Obtain scale correction that correspond to best data-MC agreement
  - Measure correction scale separately for μ^+ and μ^-, in bins of muon pseudo-rapidity
  - Correct MC for detector response

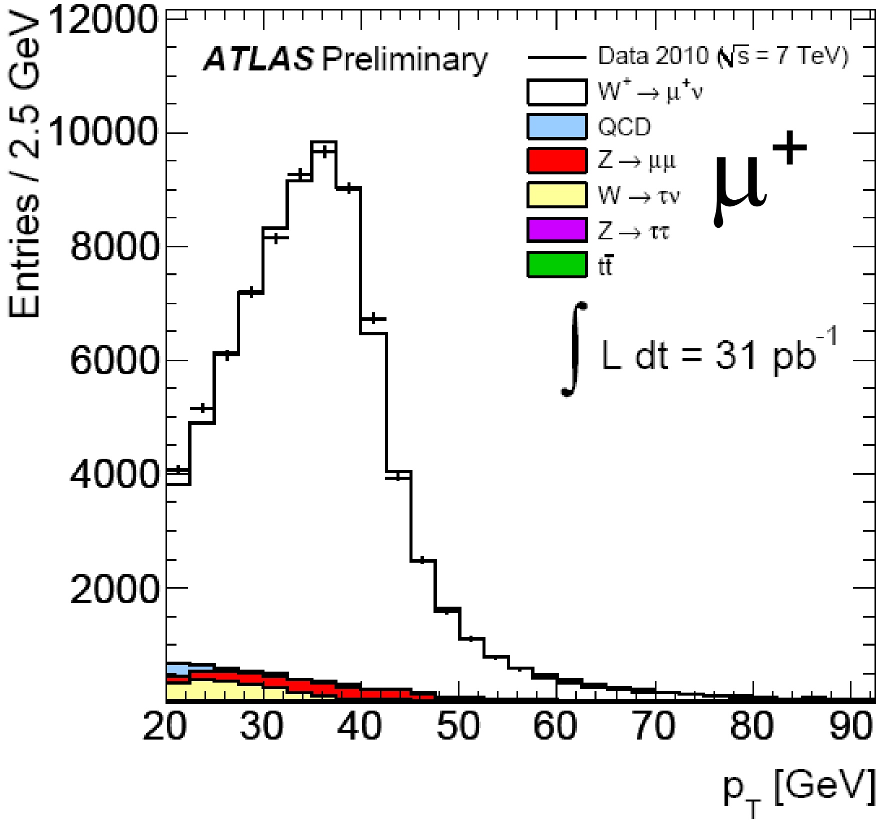
Muon p_T Scale Correction

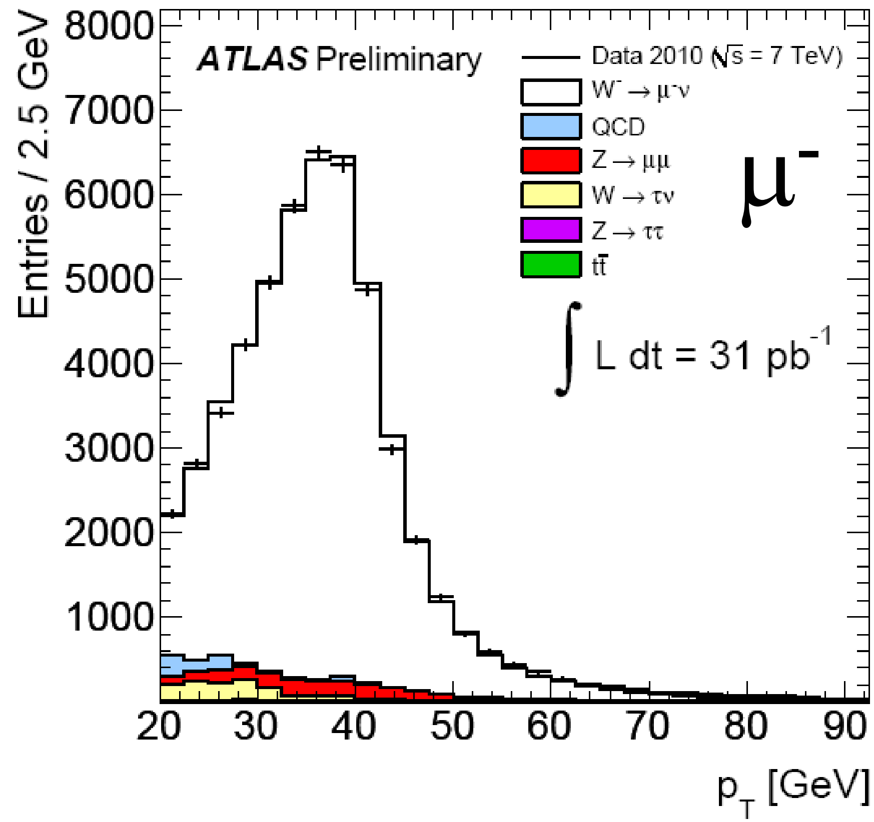
- Muon momentum separately measured by Muon Spectrometer and Inner Detector
- Test procedure by independently correcting the muon momenta measured in the Muon Spectrometer and in the Inner Detector
  - Procedure works! MS and ID measurements are compatible within the systematic uncertainty associated with correction
    - Statistical errors are not plotted (largely correlated)



Discrepancies up to 10% before correction!

Muon Transverse Momentum

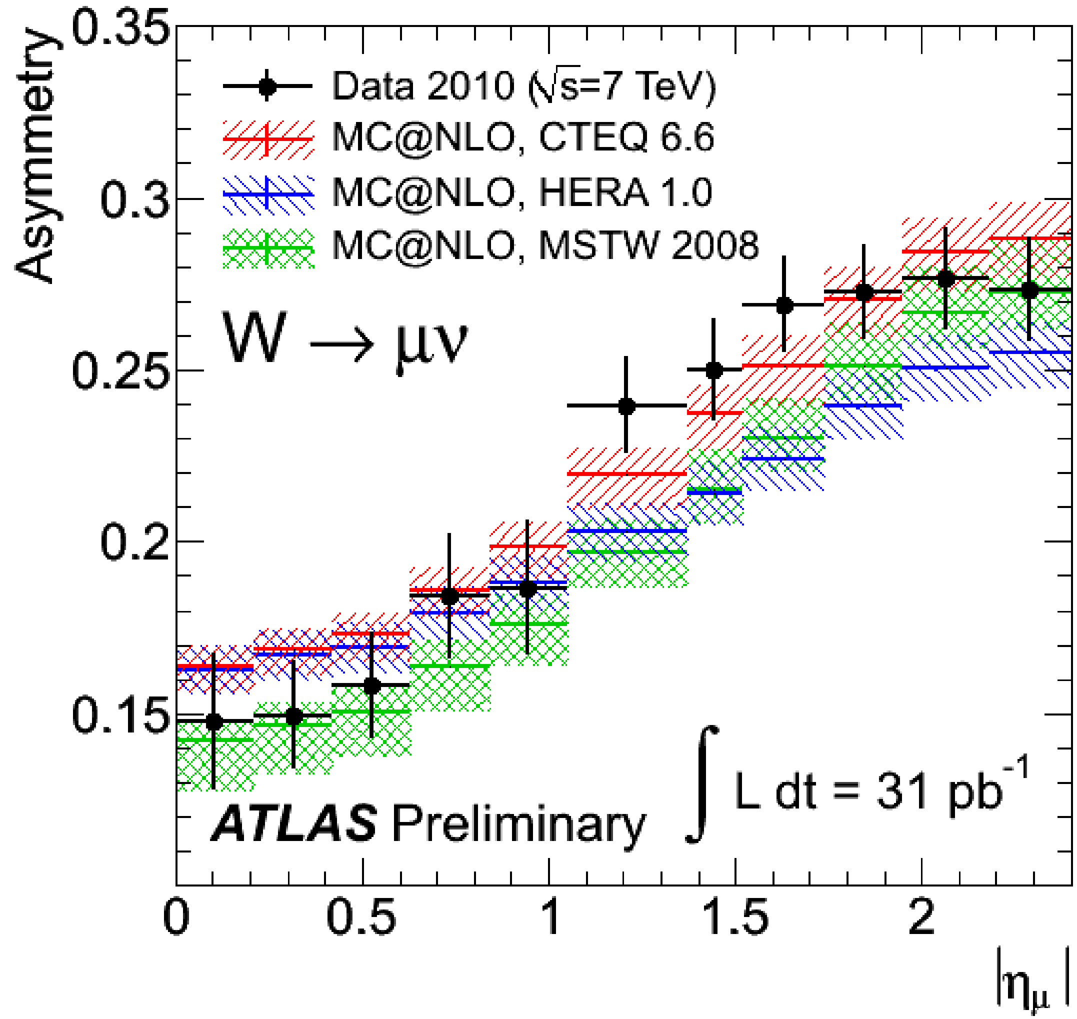




- Improved data-MC agreement after scale and resolution correction

Results

- Compared χ^2 with PDF predictions central values (n.d.f.=11)
  - CTEQ: 9.16
  - HERA: 35.81
  - MSTW: 27.31
- Measurement is <u>input</u> to PDF fits

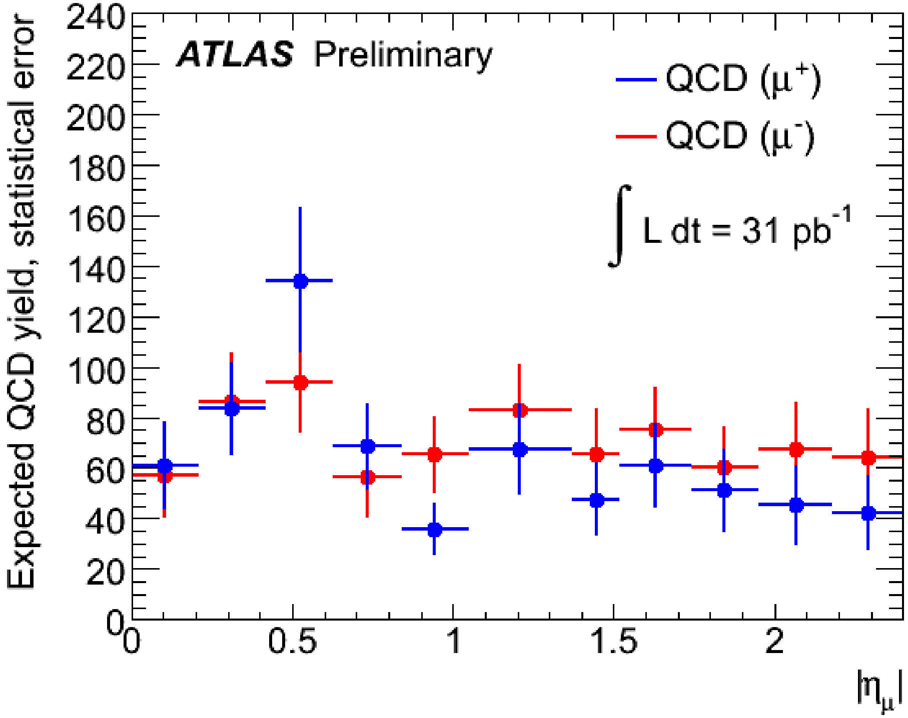


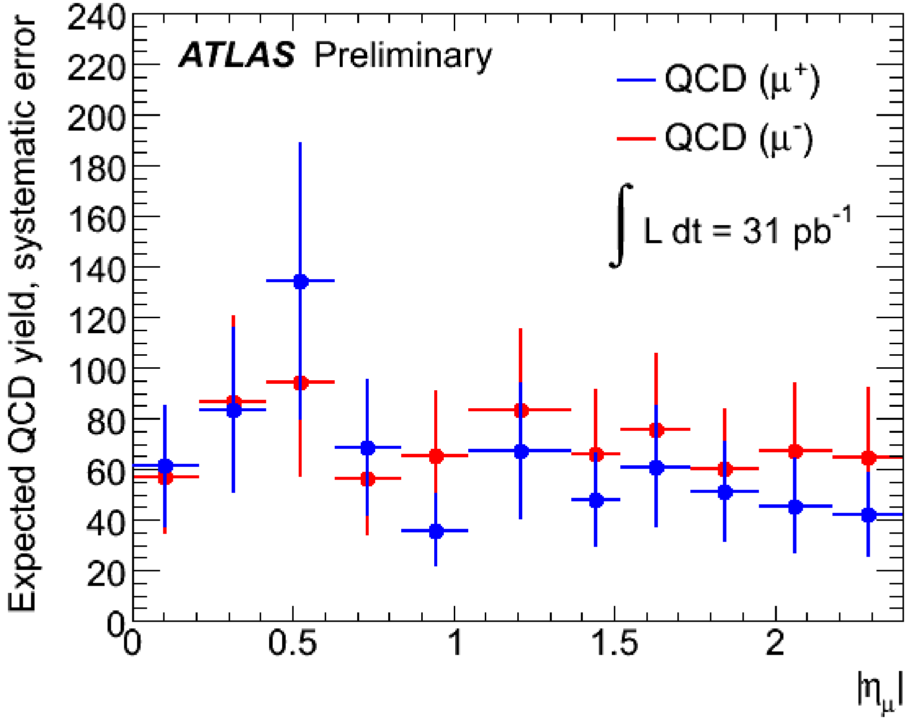
Final Remarks

- Precision measurements are already possible
  - Good understanding of detector
    - Important step before launching towards unknown
- Asymmetry measurement can provide interesting input to PDF fits
  - LHC experiments could coordinate strategies to combine results
    - Numbers presented today not directly comparable, asymmetry depends on fiducial cuts: $p_T(\mu)$, $p_T(\nu)$, …

Backup

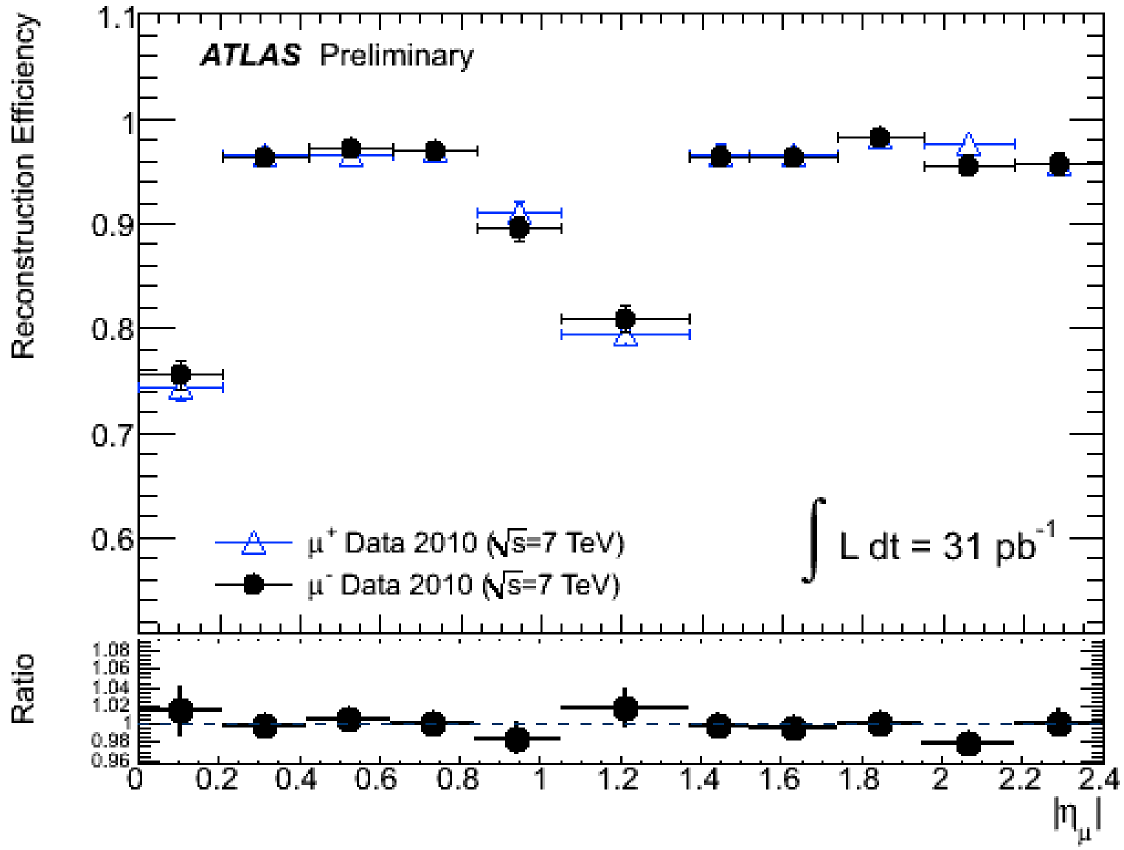
QCD Estimates





- QCD estimates: stat. (left) and syst. uncertainties (right)

Reconstruction Efficiency



- Reconstruction efficiency for μ^+ and μ^-, data T & P
  - No evidence for charge differences; reconstruction efficiency does not introduce asymmetry bias

W Sample Selection

- Muon Selection 2
  - $|z_{vertex}-z_{\mu}|<1cm$
  - $|p_T^{ID}-p_T^{MS}|/p_T^{ID}<0.5$
  - $p_T^{MS}>10GeV$
  - $p_T>20GeV$
  - $|\eta|<2.4$
  - $\Sigma p_T(\Delta R<0.4)/p_T(\mu)<0.2$
  - if $|\eta|<1.9$: #TRT hits ≥ 6 and fraction of outliers <0.9
  - if $|\eta|\geq 1.9$ and #TRT hits ≥ 6: fraction of outliers <0.9
  - #SCT hits ≥ 6
  - #Pixel hits ≥ 1

- Common Cuts 1
  - Lower-threshold unprescaled trigger
  - Good Run List
  - Jet Cleaning
    - Timing, quality-based cuts
  - Collision Event
    - Vertex with 3 tracks
    - $|z_{vertex}|<15cm$

- <u>W Candidates</u> 3
  - $E_T^{miss}>25GeV$
  - $m_T>40GeV$