Sensitivity of Tevatron Measurements to Parton Distribution Functions

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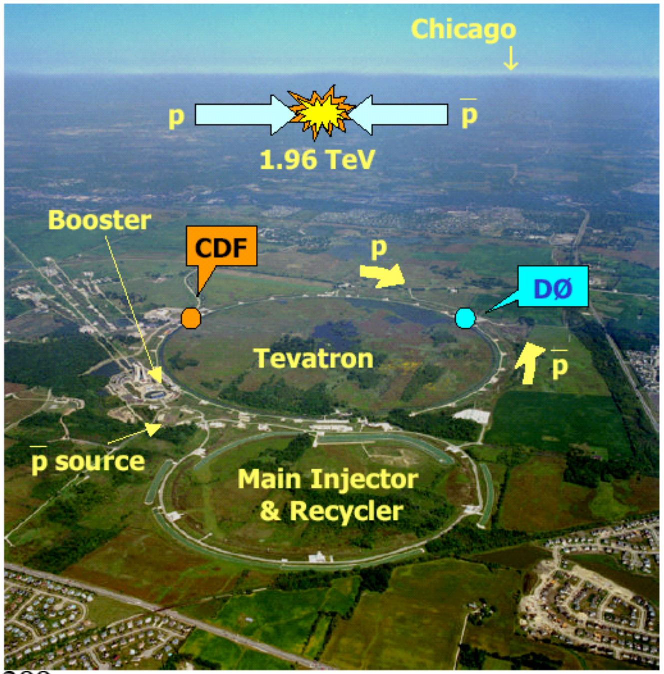
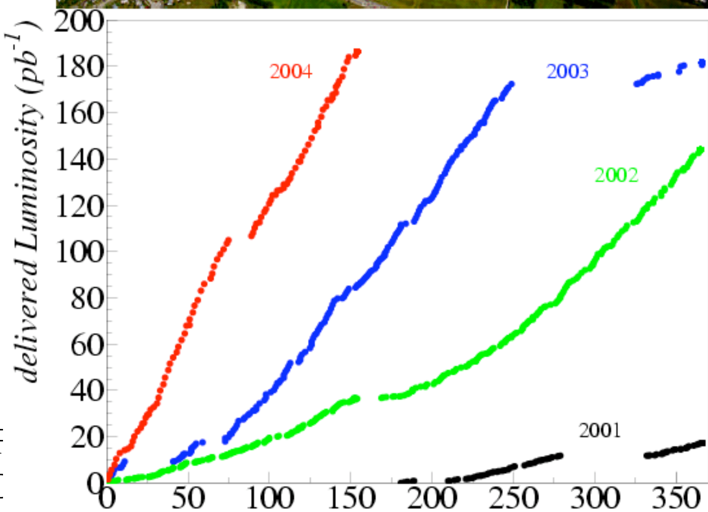
The Tevatron in Run 2





- Tevatron is a proton-antiproton collider operating with E_{beam}=980 GeV

$$\sqrt{s} = 1.96\text{TeV} \ \ \text{RunII (1.8TeV RunI)}$$

- 36 p and p bunches → 396 ns between bunch crossing.

- Increased instantaneous luminosity:
- Record: ~7.2 x 10^{31} cm^{-2} s^{-1}
- Tevatron has delivered in total ~500 pb–_
- Medium term: FY2003
  - Base goal: 230 pb^{-1} Design: 310 pb^{-1}
  - so far: 180 pb^{-1}
- Long term, by the end of FY09
  - Base goal: 4.4 fb^{-1} Design: 8.5 fb^{-1}

Outline

- Inclusive Jet Cross Section
- W Charge Asymmetry
- W and Z cross sections
- W mass
- Conclusions

P.S.: will mostly cover CDF since personally much more familiar with them, D0 has also made many nice measurements along the same lines

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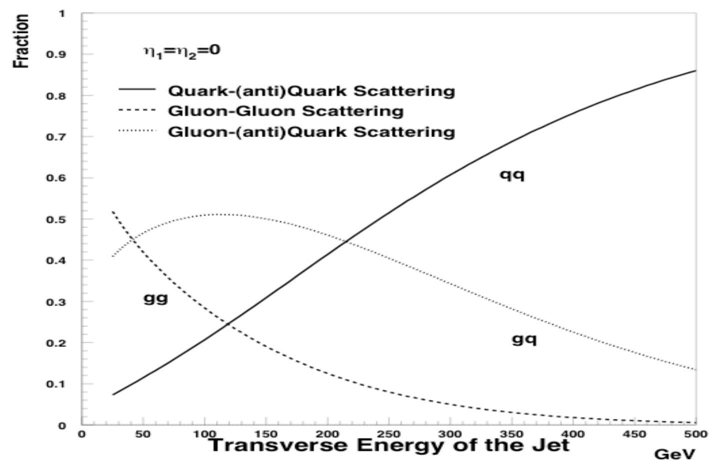
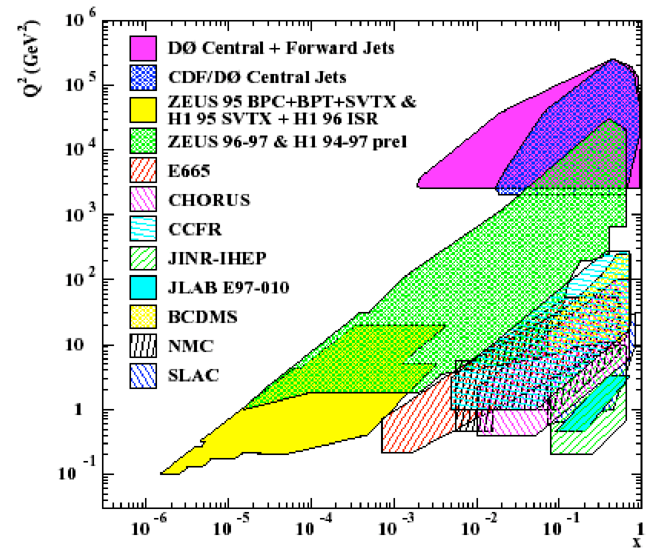
Jet Cross Section: Sensitivty

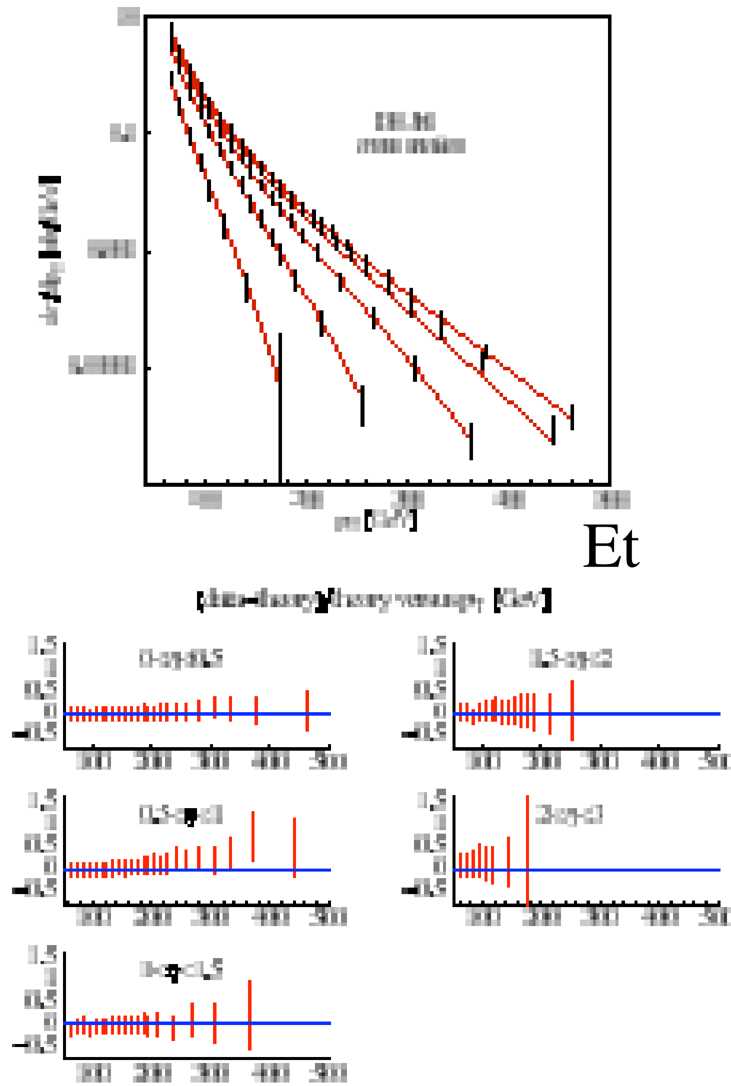
- At low and medium Et dominated by gluon induced processes
- Complementary to HERA: probing
  - lower x at same Q^2
  - same x and Q^2
  - higher Q^2 at high x
- Going forward (large η) means increasing/decreasing x at fixed Q^2:
  - Disentangle x- and Q^2-dependence





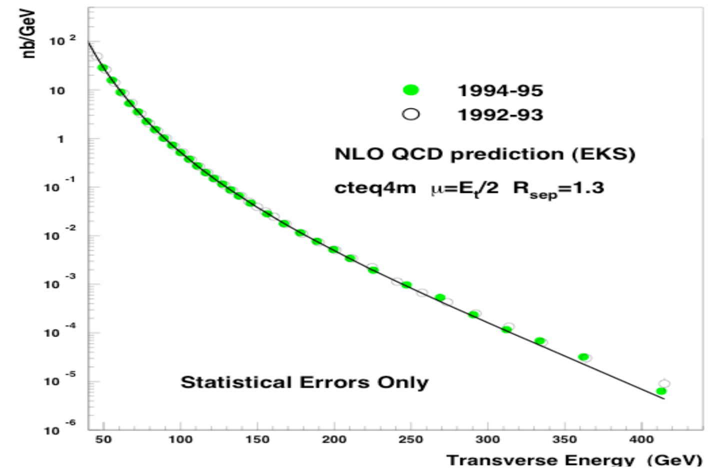
D0 Run 1: Jet Cross Section at high η

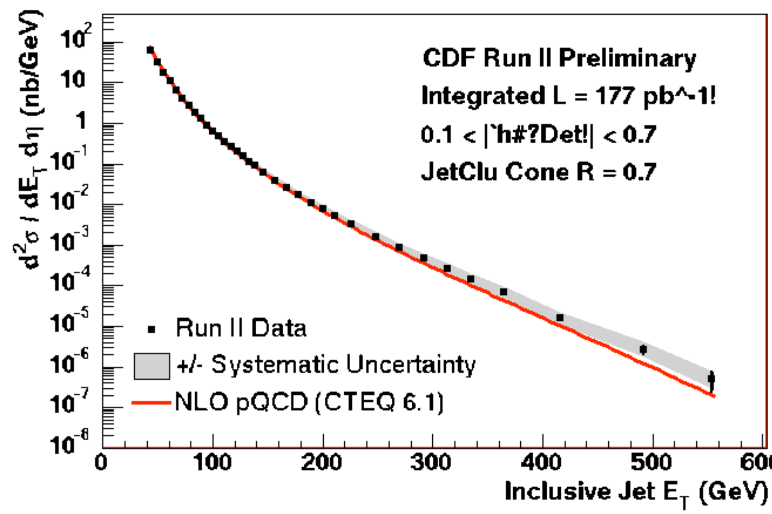
- Inclusive cross sections in Run 1 measured:
  - In wide η-range
- Significant impact on PDF's
  - The famous CTEQxHJ fit now natural (before achieved by giving large weight to data): hep/ph-0201195
- Overlaps with HERA highest x and Q2 data:
  - How do HERA fits compare?

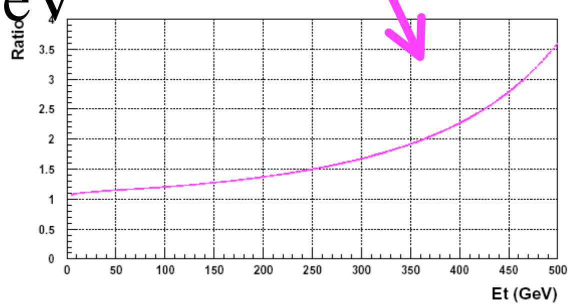


Jet Cross Section: Run 1 and Run 2

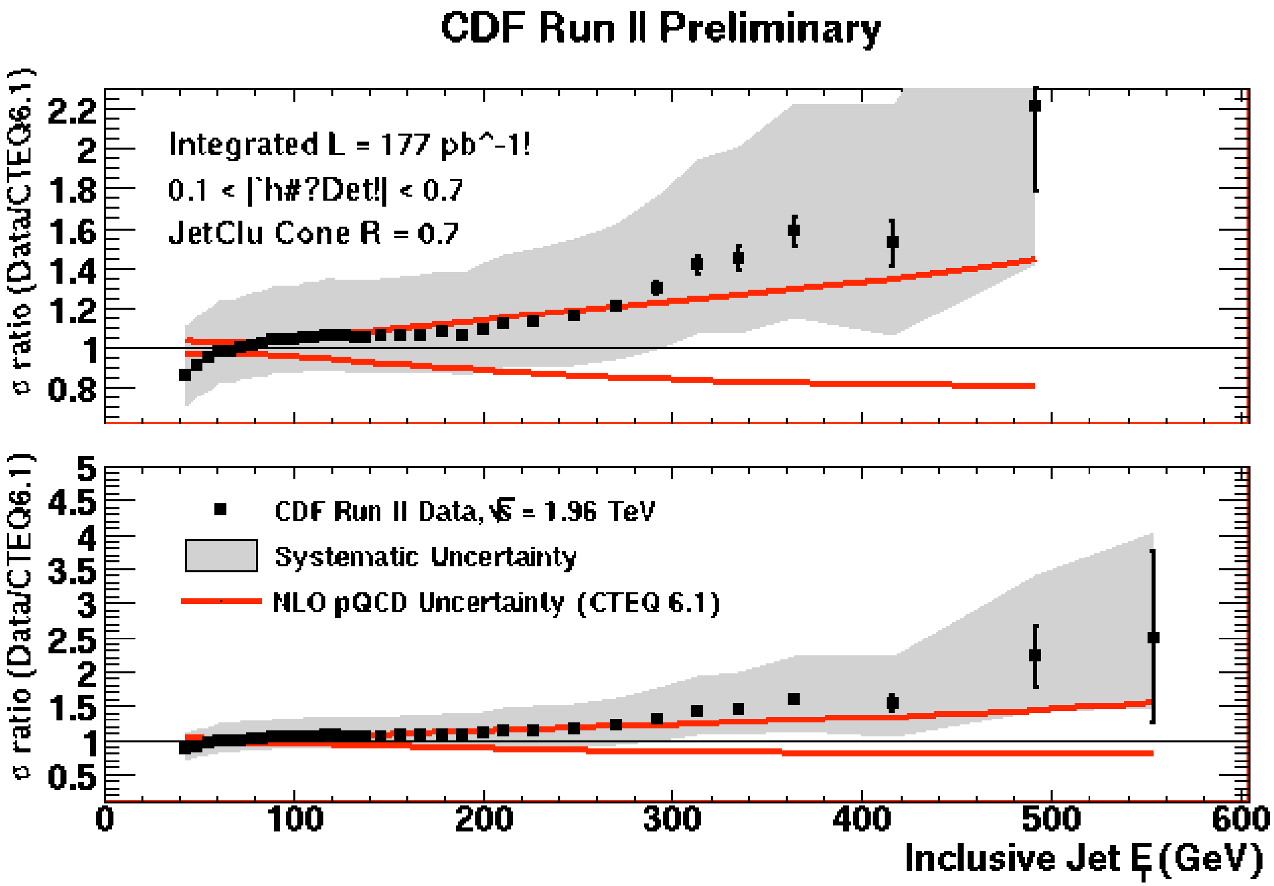
- Steeply falling:
  - 9 orders of magnitude
  - Very sensitive to energy scales and resolutions
- Higher CM-energy in Run2 (1.8 ->1.96 TeV)
  - Cross section factor 3 higher at highest Et
  - Measurement extends up to 550 GeV







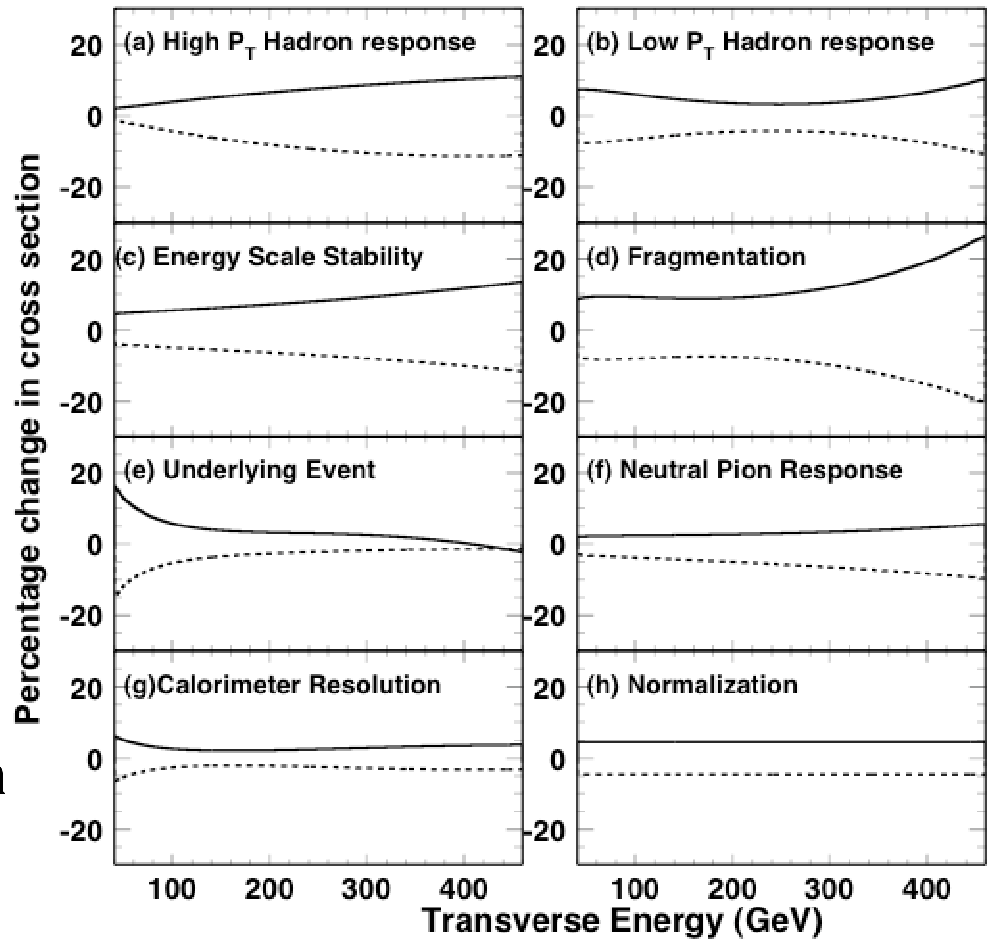
Data Over Theory: Run 2



Systematic Error dominates at all Et ⇒ important to understand uncertainties and their correlations

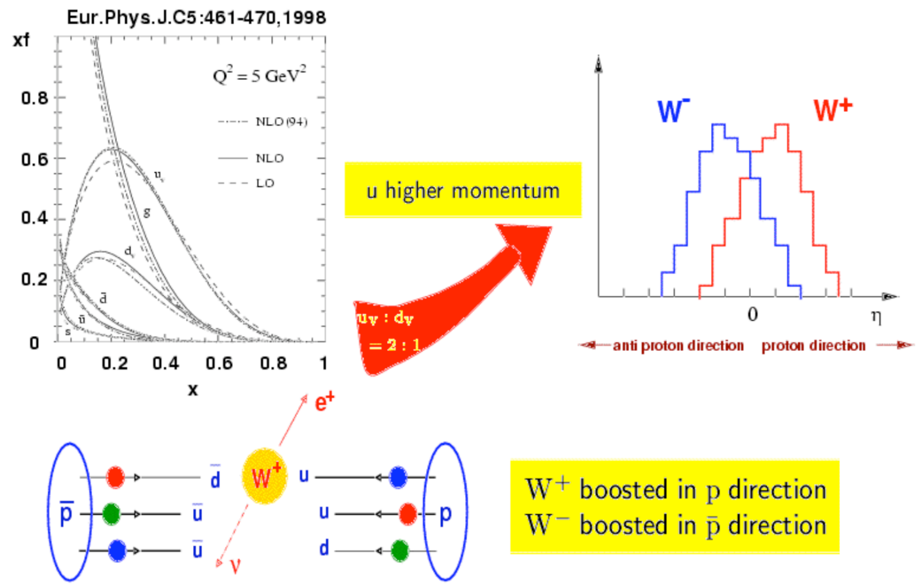
Jets: Run 1 Systematic Errors

- Identified 8 independent sources:
  a) $\pi^{\pm}$ response: test beam energy scale
  b) $\pi^{\pm}$ response: in situ tuning
  c) Time dependent variations
  d) How well does MC describe fragmentation
  e) Underlying event
  f) π^{0} energy scale
  g) Resolution
  h) Luminosity
- No calibration process at high Et (γ-jet "stops" at 100-150 GeV)=> relying on MC



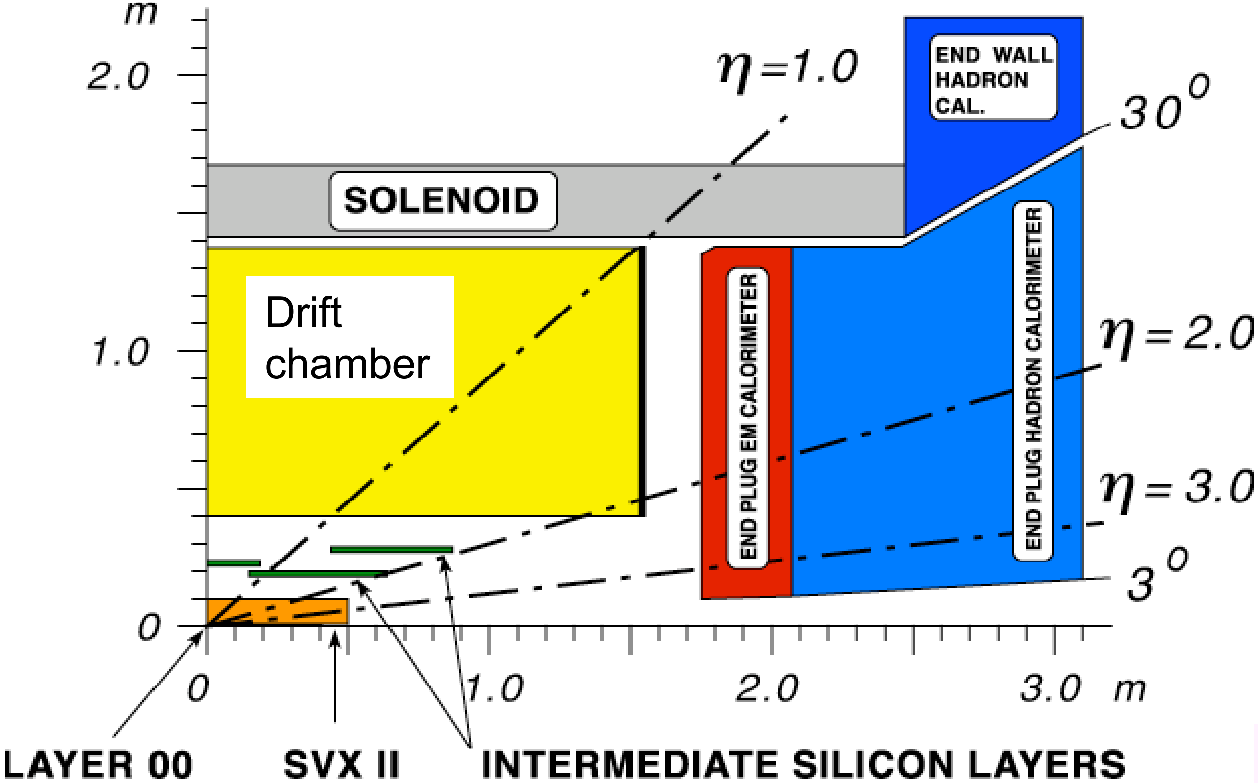
W Charge Asymmetry

- Sensitive to derivative of d/u at x≈0.1
- Used by CTEQ and MRST
- Complementary to HERA Charged Current measurements which measure d directly
- Experimentally:
  - Using new forward silicon and calorimeters
  - Precision measurement, i.e. good understanding of systematic errors required



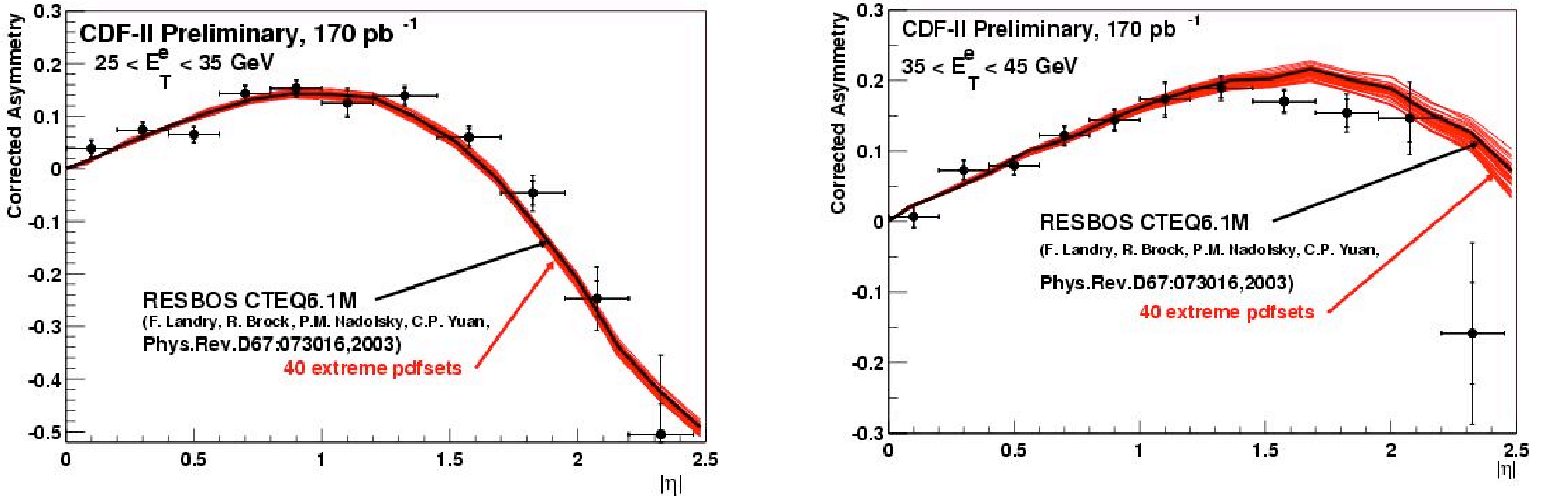
$$A_l(\eta) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta} \simeq \frac{\mathrm{d(x)}}{\mathrm{u(x)}}$$

CDF Run II Detector: forward region



- forward region better instrumented in Run2
- extend lepton coverage for W and Z measurements
- Silicon track found by extrapolating back from EM shower in Plug calorimeter:
  - Go as forward as possible…

Brand New Run 2 data: two Pt bins



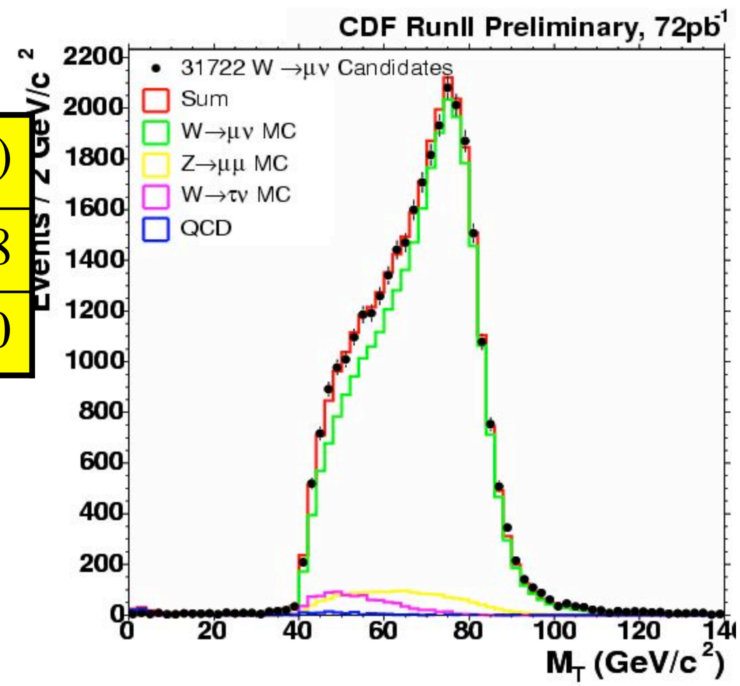
- Et dependence of asymmetry not well modelled by CTEQ6 PDF's (they were fit to the average)
- Data provides new PDF constraints

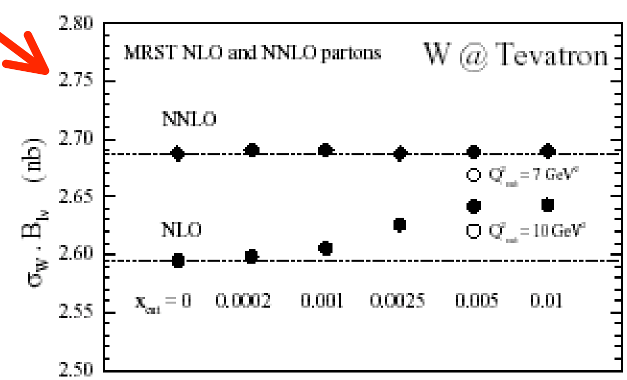
W and Z cross sections: Luminosity Monitor for LHC/Tevatron?

- CDF 2 measurements: 2% precision

	CDF (pb)	NNLO(pb)
Z	254.3±3.3(st.)±4.3(sys.)±15.3(lum.)	250.5±3.8
W	2777±10(st.)± 52(sys.)± 167(lum.)	2687±40

- NNLO uncertainty also better than 2% (MRST+ L. Dixon): NLO not good enough: 4% lower
- Impressive agreement between data and theory: can we use this to measure lumi now to 3%?
- Dominant exp. Error due to W/Z rapidity distribution: PDF's…





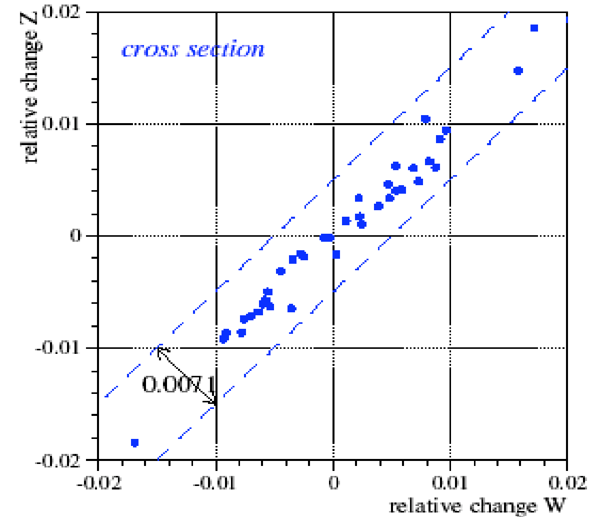
hep-ph/0308087

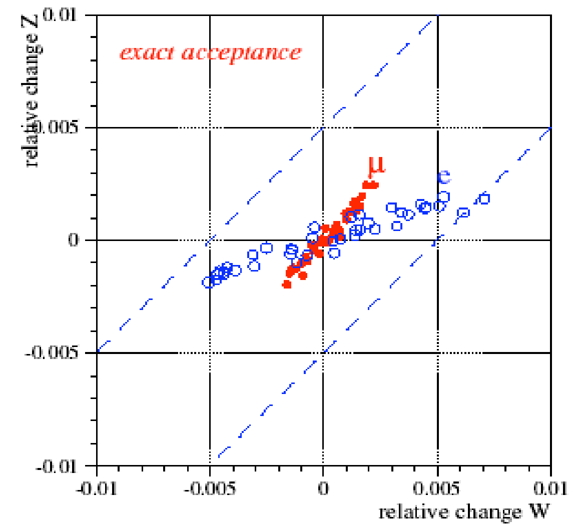
PDF errors in W/Z Production

- Cross section error factor 5 larger than acceptance errors
- W and Z highly correlated:
  - Achieving better precision (1%) on ratio σ(W)/σ(Z):

$$R = \frac{\sigma(p\bar{p} \to W \to l\nu)}{\sigma(p\bar{p} \to Z \to ll)} = 10.93 \pm 0.15(stat) \pm 0.13(sys)$$

- electron channel better than muon channel:
  - Larger acceptance due to usage of forward calorimeter





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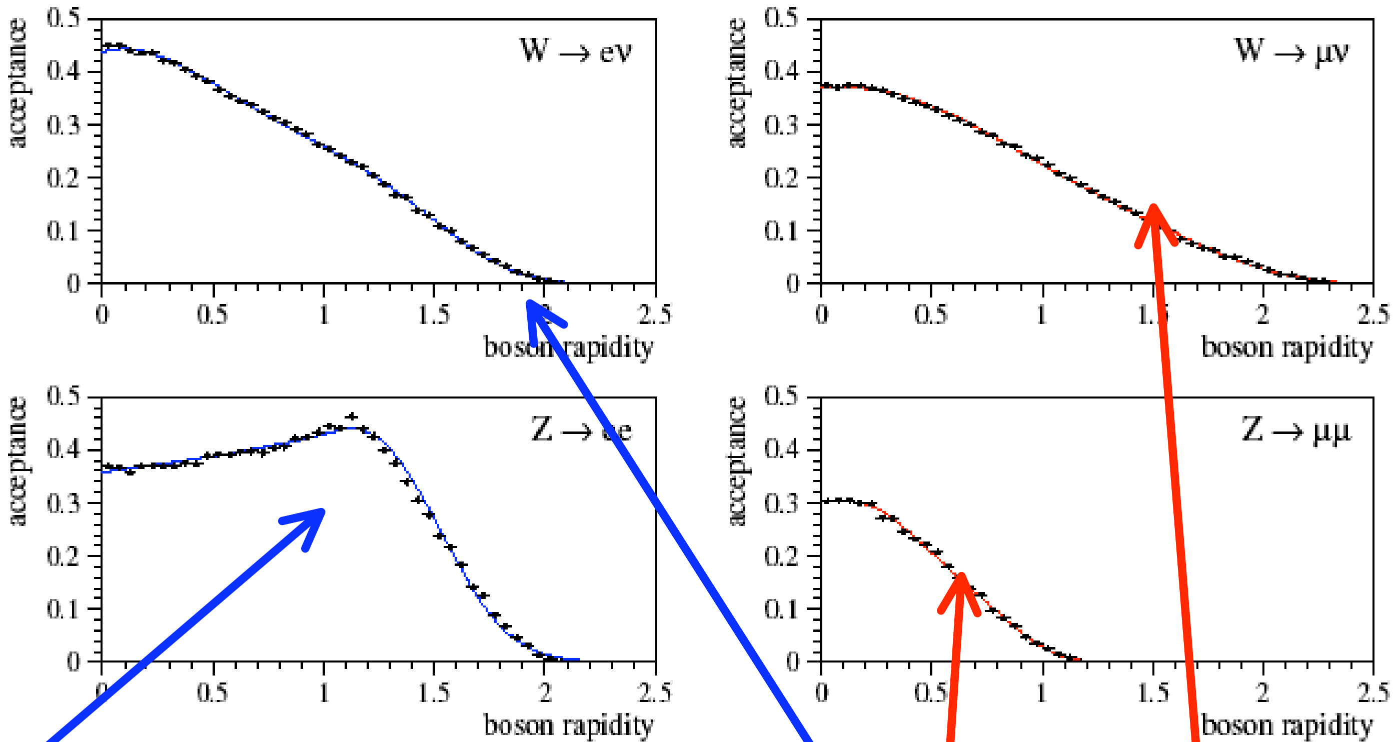
Acceptance versus Rapidity



Uses leptons up to η=2.6

Use leptons up to η=1

Reducing syst. Error by extending measurements to forward region (or restricting rapidity range?)

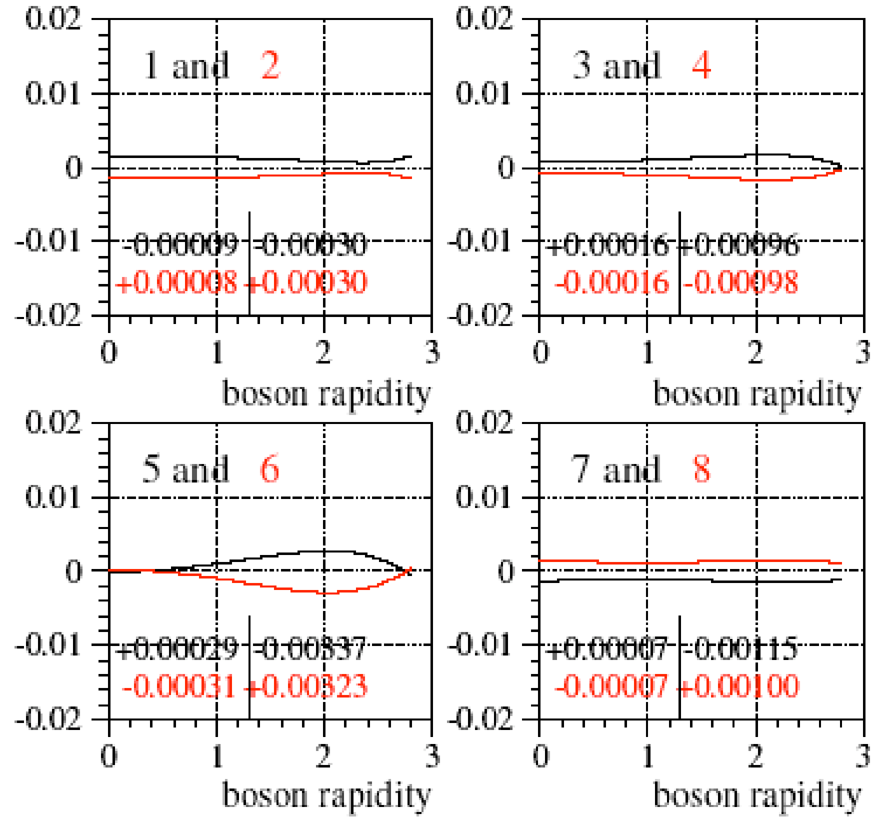
Frc
DE

PDF error estimate using CTEQ6

- Use analytical cross section expression (LO) to calculate dσ/dy:

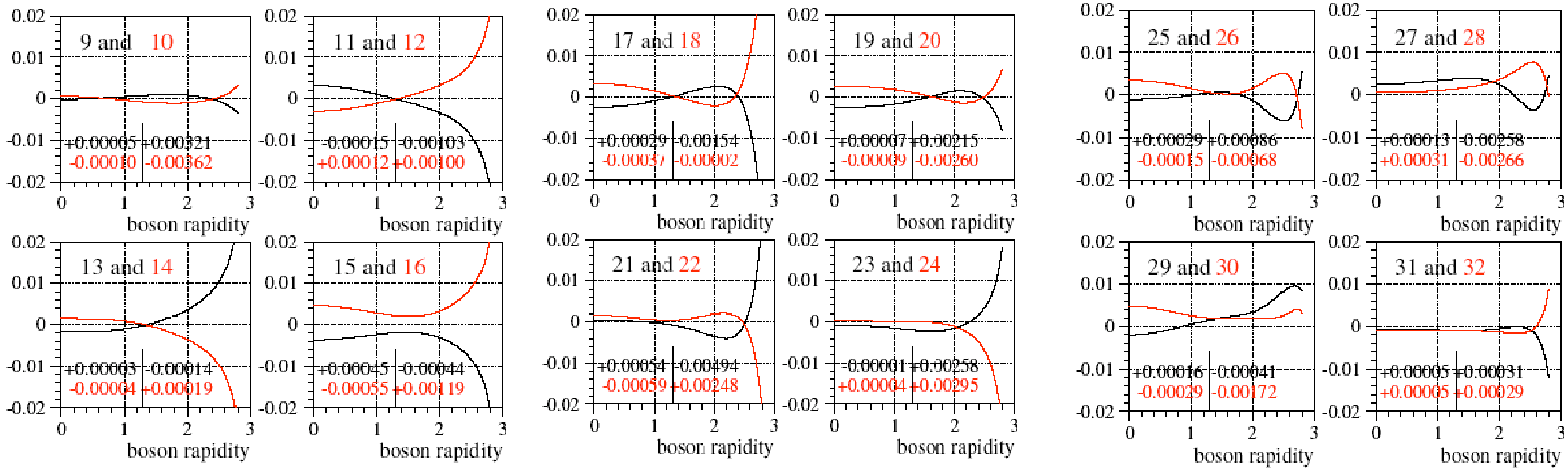
$$\frac{d\sigma_W}{dy} = K\frac{2\pi G_F}{3\sqrt{2}}\, x_a\, x_b\, u(x_a)\, d(x_b)$$

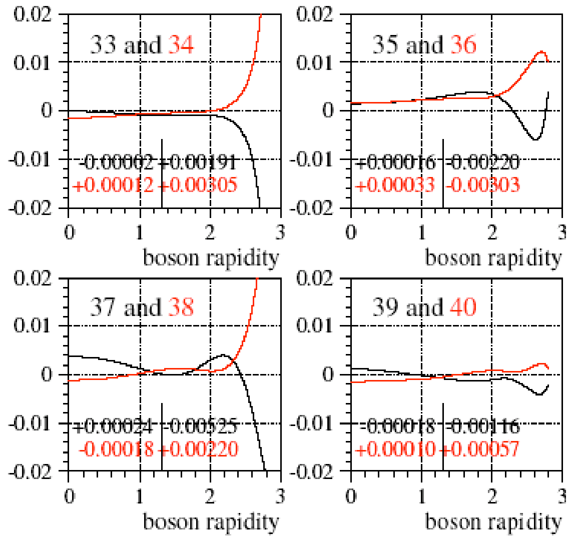
with $x_{a,b} = \frac{M_W}{\sqrt{s}} \exp(\pm y).$



- Integrate for 40 eigenvectors from CTEQ and fold in parametrised experimental acceptance
- Compare also to MRST central fit (MRST error sets give factor 2 smaller uncertainty)
- Plot versus boson rapidity

More CTEQ6 PDF errors



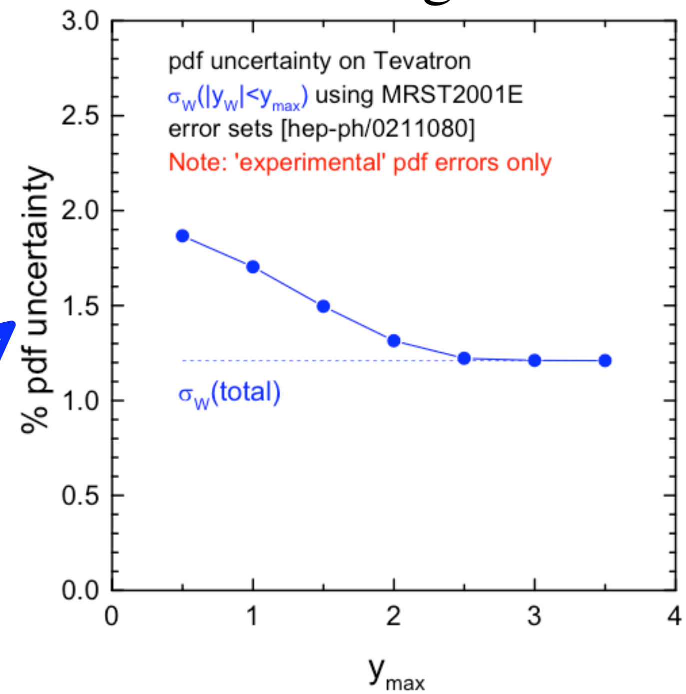


- ➢11-16 seem most important: can they be constrained better?
- ➢Some are not symmetric…what does that mean?
- ➢Excellent tool setup to understand real behaviour (not limited by MC statistics)

Other thoughts on W/Z cross sections

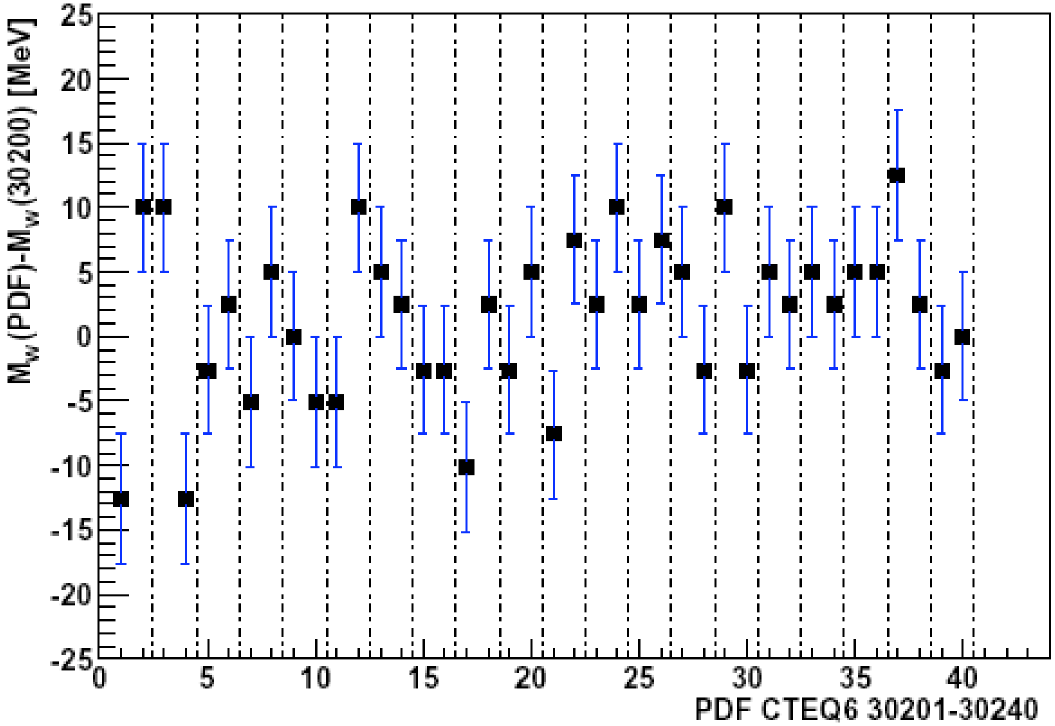
- Reduce rapidity range to |y|<1.5 or so:
  - PDF's go funny in forward region: low and high x partons…
  - J. Stirling tried on the theory side and concludes that the error will be similar:
    - "experimental" increases slightly
    - "theoretical" should be similar (and dominates anyway).
  - Should check for Tevatron and LHC using error PDF's?
- Is there a danger to spoil Lumi measurement due to New Physics, e.g. cascade decays of squarks etc. into W's, Z's???
  - Probably more suppressed in Z than W due to smaller BR into leptons?

J. Stirling



Syst. Error on W mass due to PDF's

40 eigenvectors of CTEQ6 give "90% CL" (J. Huston), i.e. 1.64 σ



Error calculation: =1/2 $\sqrt{\Sigma(\Delta M_W(+) - \Delta M_W(-))^2}$ /1.64=15 MeV

Precision Measurements: e.g. CDF W mass

	Run 1 (e/μ)	200 /pb	2/fb
statistical	65/100	50	15
E/p scale (Z)	75/85	60	18
Recoil model	37/35	25	14
background	5/25	18	5
PDF	15	15	15
QED	11	11	11
Pt(W) model	15/20	15/20	15/20
Sum	100/140	90	40

Scale with sqrt(Lumi): W and Z statistics

Production Model: independent of Lumi

Production Model errors becoming important: 1 sigma errors?

Summary

- Understanding correlated and uncorrelated errors in jet cross-section measurements:
  - Constrain gluon at high x, particularly with forward jet data
- Brand new measurement of W charge asymmetry provides new constraints (publish in roughly 3 months)
- W/Z cross sections measured and predicted to 2% precision:
  - Promising as luminosity monitor for LHC
  - PDF uncertainties result in largest experimental error
- Precision EWK mearuements, e.g. W mass will be limited by PDF's with 2/fb
  - Can they be constrained better by e.g. HERA data?
- Need to make an honest estimate of 1 sigma error and not overestimate systematics

Backup Slides

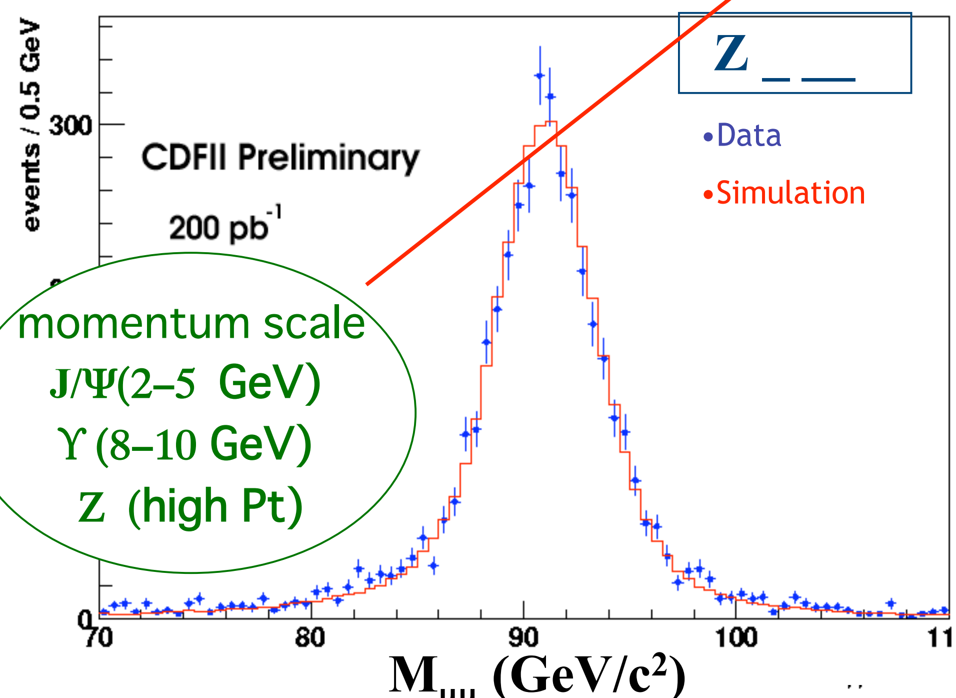
W mass prospects

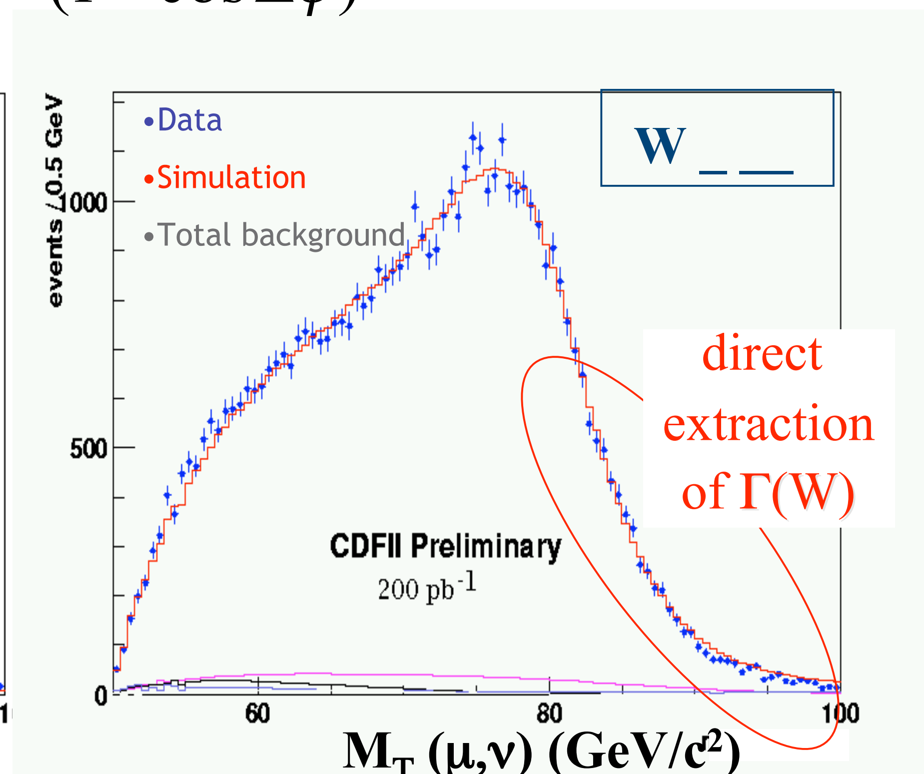
- CDF Run I (_) $m_W = 80.465 \pm 100(\text{stat}) \pm 103(\text{sys})$ MeV
- CDF Run II for 250/pb estimate (_): = X ± 55(stat) ± 80(sys) MeV

Calorimeter:
right energy scale
and resolution

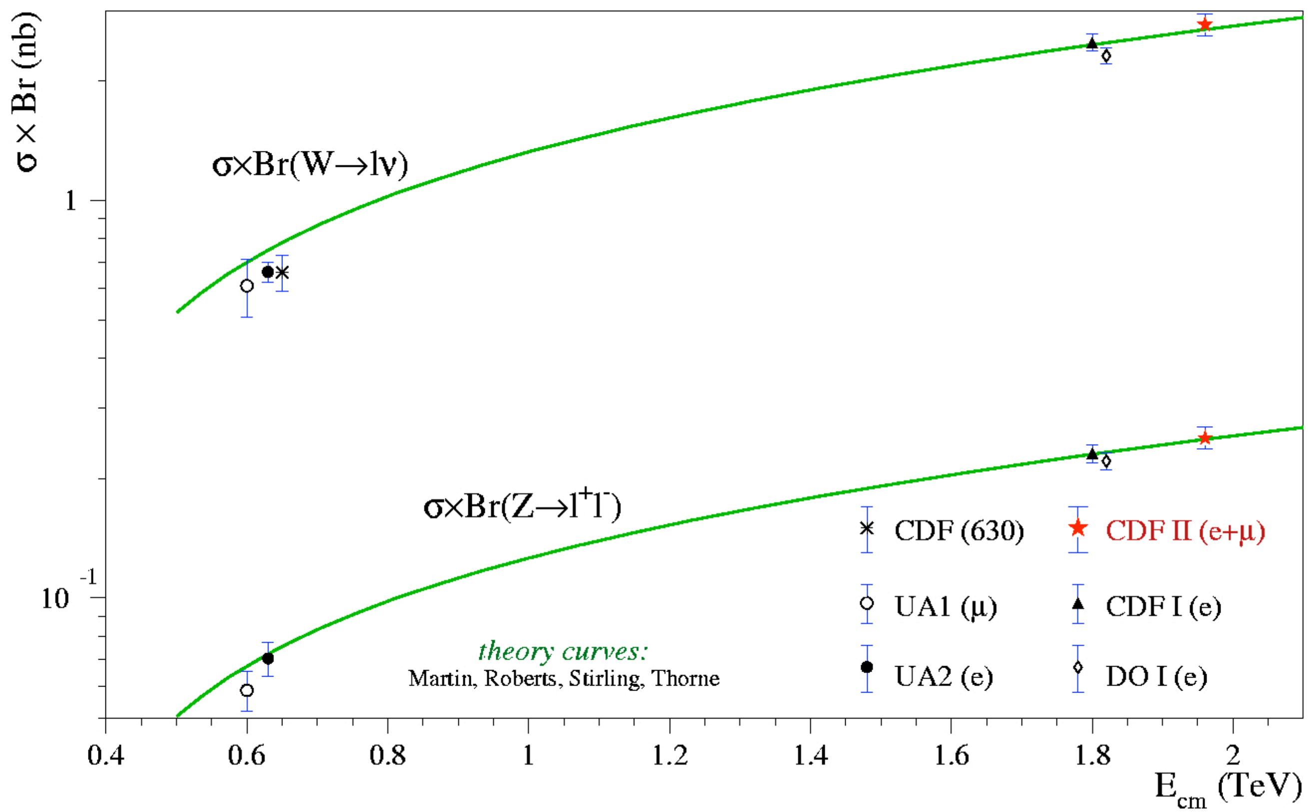
$$M_T = \sqrt{2 p_t E_T^{miss} (1 - \cos \Delta\phi)}$$

momentum scale
J/Ψ(2–5 GeV)
ϒ (8–10 GeV)
Z (high Pt)





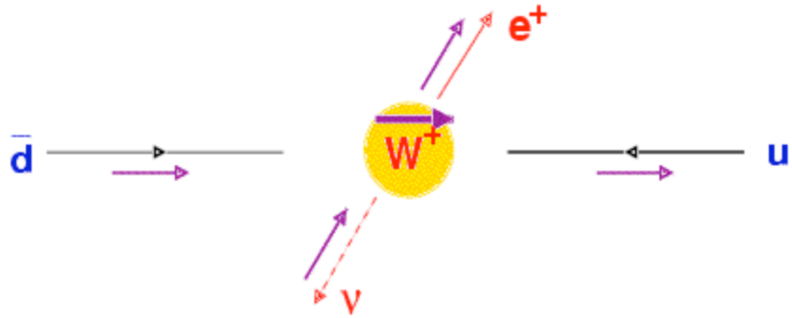
Summary of W/Z Cross sections



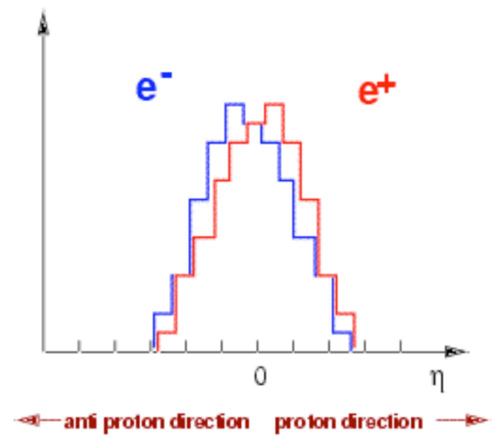
$$\sigma(p\bar{p} \rightarrow Z/\gamma^* \rightarrow ll) = 254.3 \pm 3.3(stat) \pm 4.3(syst) \pm 15.3(lum)\,\text{pb}$$

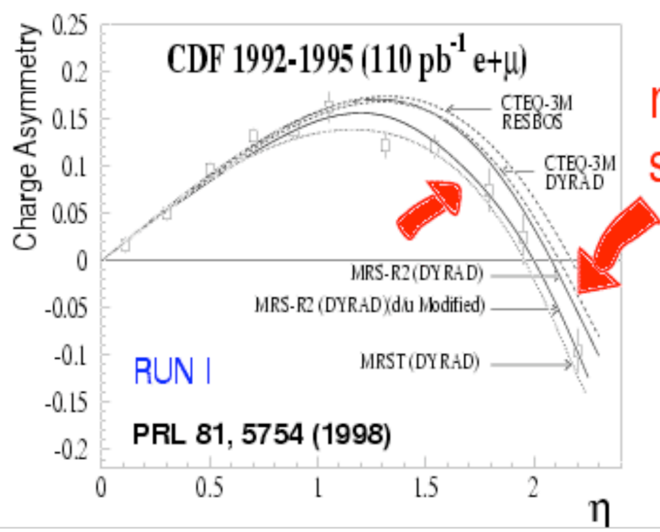
$$\sigma(p\bar{p} \rightarrow W \rightarrow l\nu) = 2777 \pm 10(stat) \pm 52(syst) \pm 167(lum)\,\text{pb}$$

W Charge Asymmetry



$$A_l(\eta) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta} \simeq \frac{\mathrm{d(x)}}{\mathrm{u(x)}}$$





most sensitive

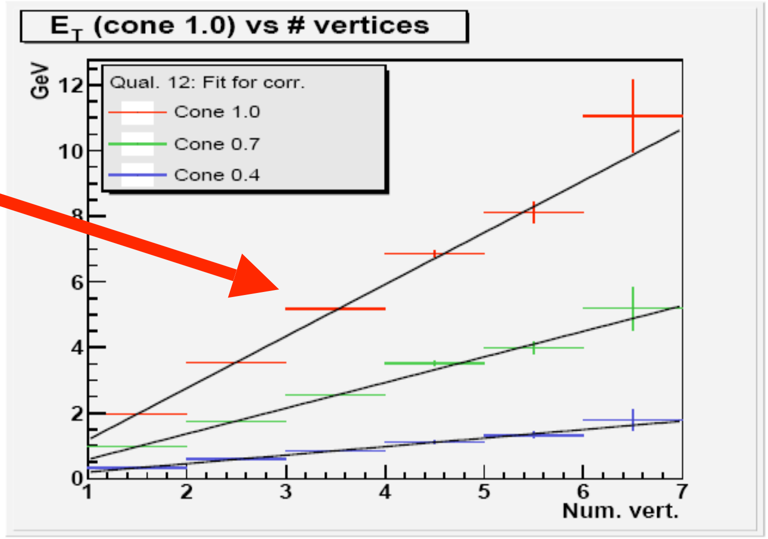
Lepton and Charge ID up to high $|\eta|$

Other (Random) Points

- High tanβ SUSY couples strongly to b-quarks:
  - Currently estimate 10% errors for MSSM higgs
  - How well do we understand b-quark DF?
- NNLO effect probably important for high Et jets
- Accurate MC modelling of e.g. fragmentation vital for understanding jets: Ariadne, Pythia, Herwig
- Understand meaning of PDF errors: 1 sigma in e.g. "blue-band fit" for W and top mass?
  - How do "40 eigenvectors" relate to measurements? What constrains what? More obvious in MRST fits
  - What are the theoretical errors?
  - Are the HERA systematic errors "true" or "safe"? (My F2 measurement was "safe" I think)

Why not kt Algorithm?

- Multiple pp interactions spoil jet Et measurement
- Subtracting "average Et" from extra interactions:
  - In cone algorithms this is easy: average Et in random cones in MinBias events
  - In kt there is a bias towards clustering as much as possible from extra interactions
  - More difficult to estimate this bias in kt algorithms
- Theoretically more attractive to use kt but experimentally not
- CDF have never seen advantage in terms of resolution: does HERA or LHC?



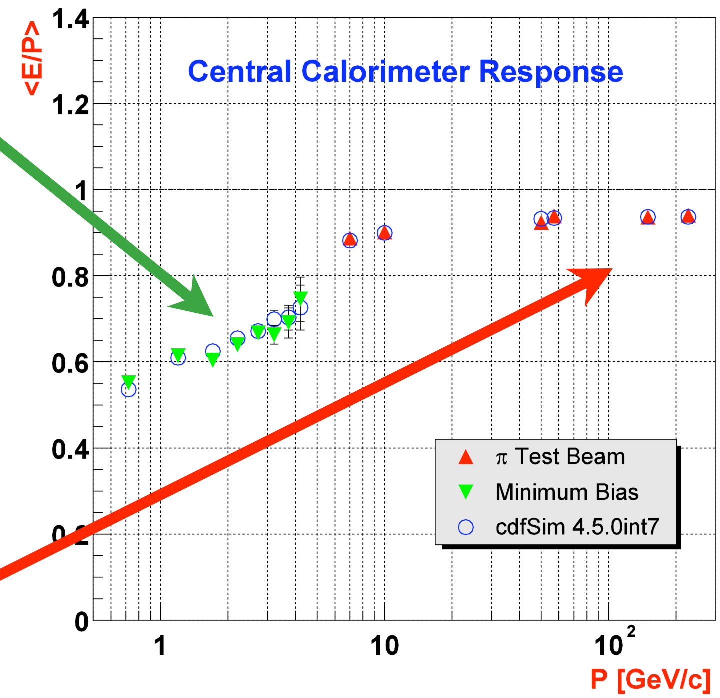
Correct Measured Jets to Particle Level Jets

- Cannot use data (e.g. γ-jet balancing) since no high statistics calibration processes at high Et>100 GeV
- Extracted from MC ➔ MC needs to
  1. Simulate accurately the response of detector to single particles (pions, protons, neutrons, etc.):
     CALORIMETER SIMULATION
  2. Describe particle spectra and densities at all jet Et:
     FRAGMENTATION
  - Measure fragmentation and single particle response in data and tune MC to describe it
  - Use MC to determine correction function to go from observed to "true"/most likely Et:

$$E^{true} = f\,(\,E^{obs}, \eta, \text{conesize})$$

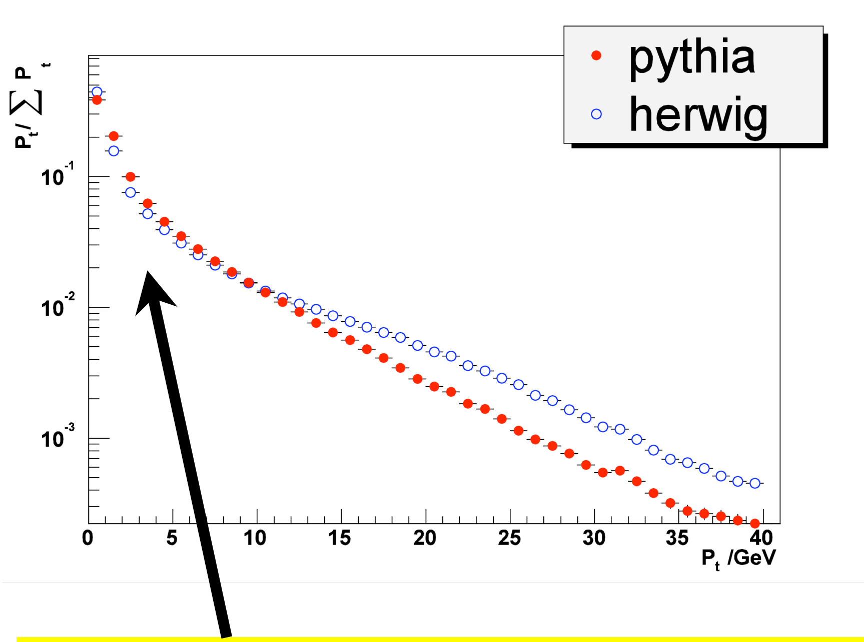
E.g. Single Particle Response

- Low Pt (1-10 GeV) in situ calibration:
  - Select "isolated" tracks and measure energy in tower behind them
  - Dedicated trigger
  - Perform average BG subtraction
  - Tune GFlash to describe E/p distributions at eack p (use π/p/K average mixture in MC)
- High Pt (>8 GeV) uses test beam
- Independent systematic errors



Fragmentation

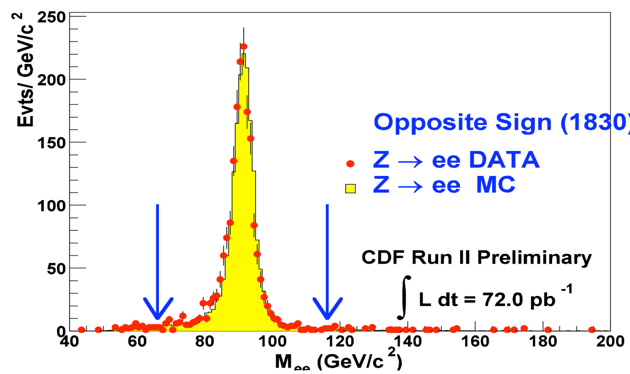
- Due to non-linearity of CDF calorimeter big difference between e.g.
  - 1 10 GeV pion
  - 10 1 GeV pions
- Measure number of and Pt spectra of particles in jets at different Et values as function of track Pt:
  - Requires understanding track efficiency inside jets
  - Ideally done for each particle type (π, p, K)

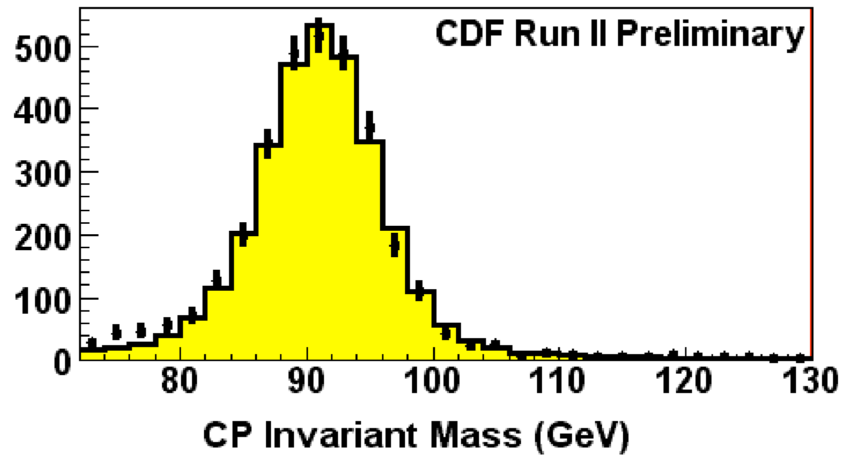


E.g. difference in fragmentation between Herwig and Pythia may result in different response

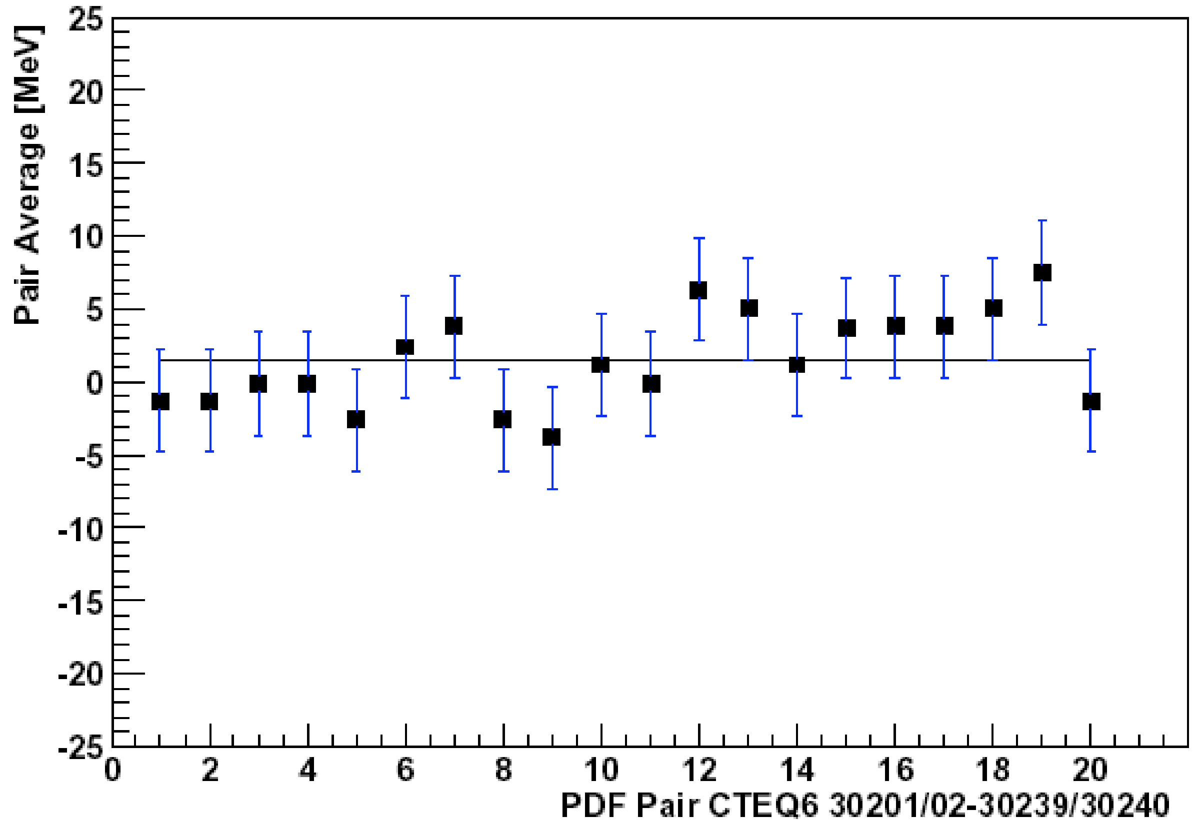
In Situ Calorimeter Calibration II

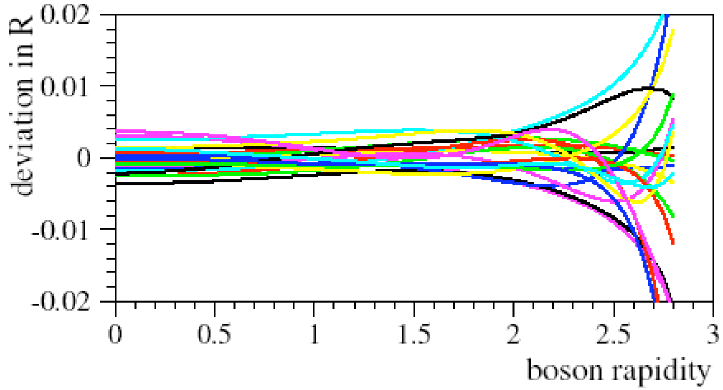
- Z_ ee peak:
  - Set absolute EM scale in central and plug
  - Compare data and MC: mean and resolution
  - Applied in Central and Plug
- MinBias events:
  - Occupancy above some threshold: e.g. 500 MeV
  - Time stability
  - Phi dependent calibrations: resolution





Average Shift of PDF Pair




deviation in R
0.02
0.01
0
-0.01
-0.02
0
0.5
1
1.5
2
2.5
3
boson rapidity