QCD and Electroweak Physics at the Tevatron

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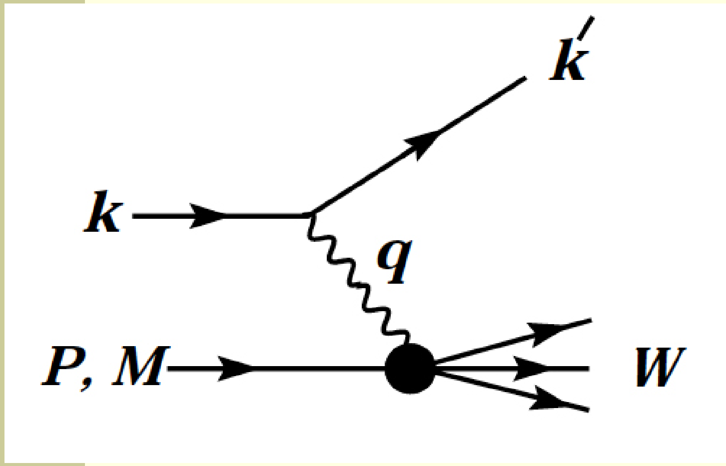
February 13, 2006

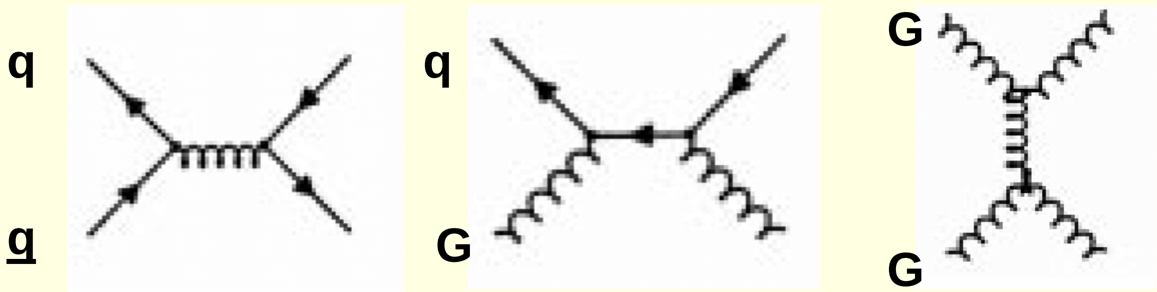
Outline

- Jet Physics
  - inclusive cross sections
  - kt algorithm
- Inclusive Boson production
  - γ
  - W/Z cross sections
  - Z rapidity
  - W asymmetry
- W/Z + jets
- W properties
- Prospects with > 1 fb-1

Gluon distributions at high x from p$\bar{p}$ scattering



$$\sigma(ep \to eX) \propto x\left[\frac{4}{9}(u + \bar{u}) + \frac{1}{9}(d + \bar{d})\right]$$

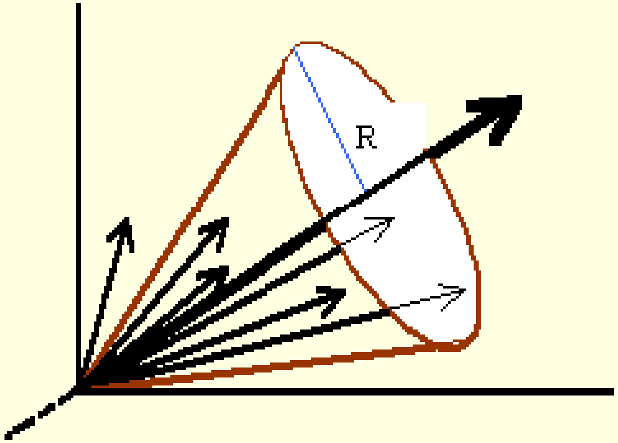


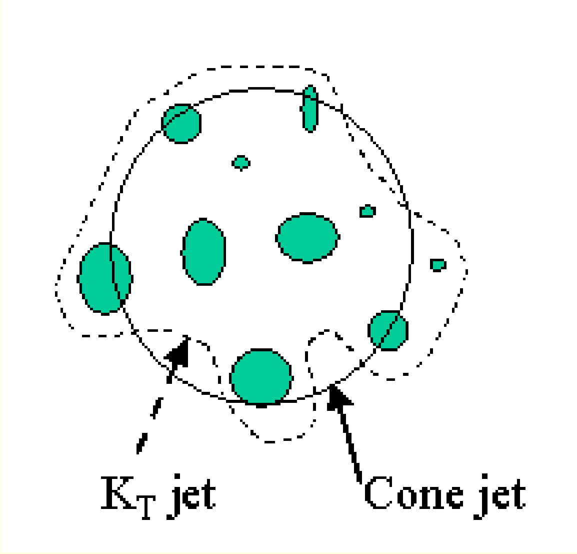
$$\sigma(p\bar{p} \to jj) \propto x_1 x_2\left[q_1 + \bar{q}_1 + \frac{9}{4}G_1\right]\left[q_2 + \bar{q}_2 + \frac{9}{4}G_2\right]$$

Inclusive jets – different algorithms

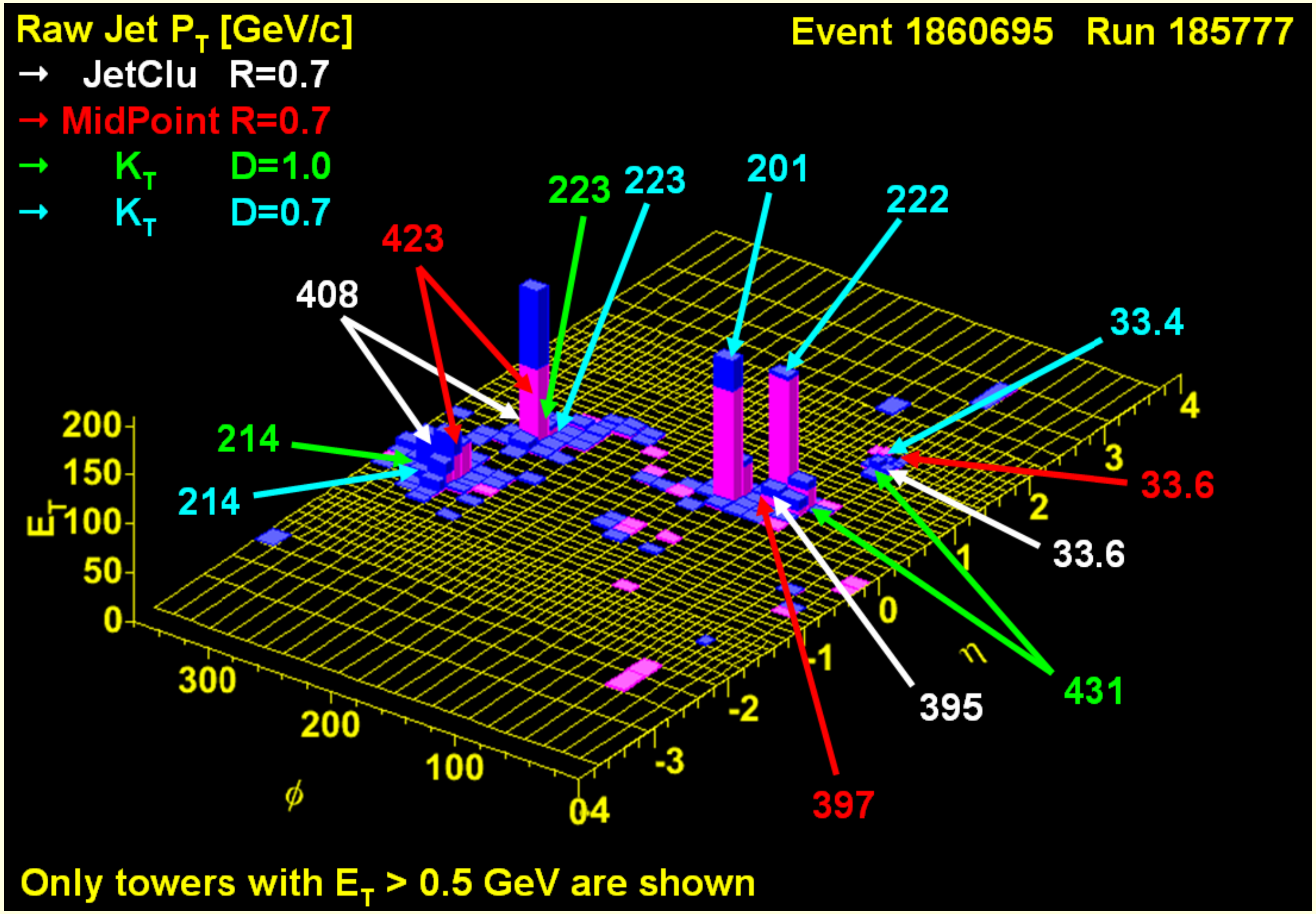
- Cone jets
  - easy to understand
  - hard to define
  - hard to calculate
  - easy to subtract multiple interactions
- kt jets
  - hard to understand
  - easy to calculate
  - but what about additional interactions at high L ?

$$d_{ij} = \min(E_{T,i}^2, E_{T,j}^2)\frac{\Delta R_{ij}^2}{D^2} \quad d_{ii} = E_{T,i}^2$$

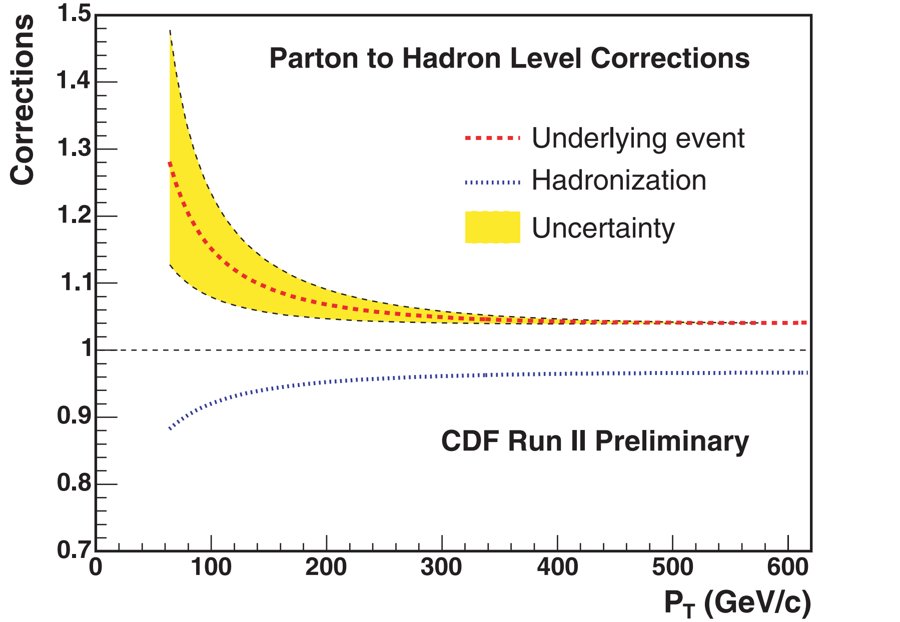


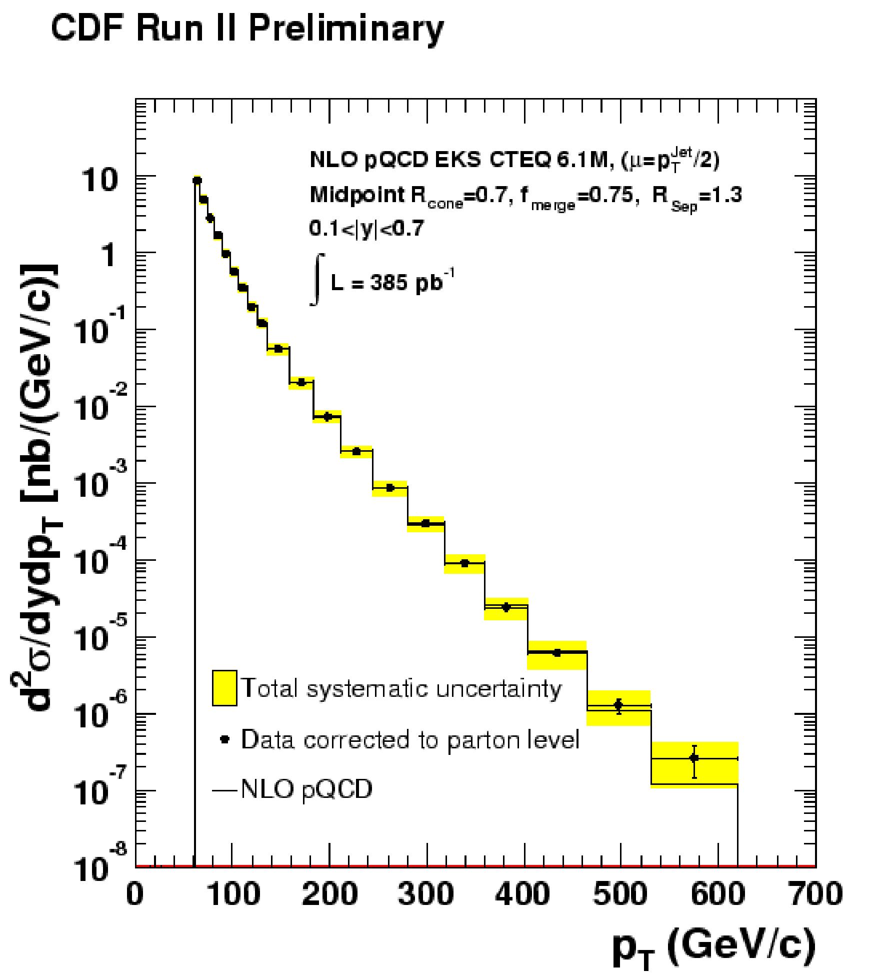


Typical event from CDF



Central jet $d\sigma/dp_T$

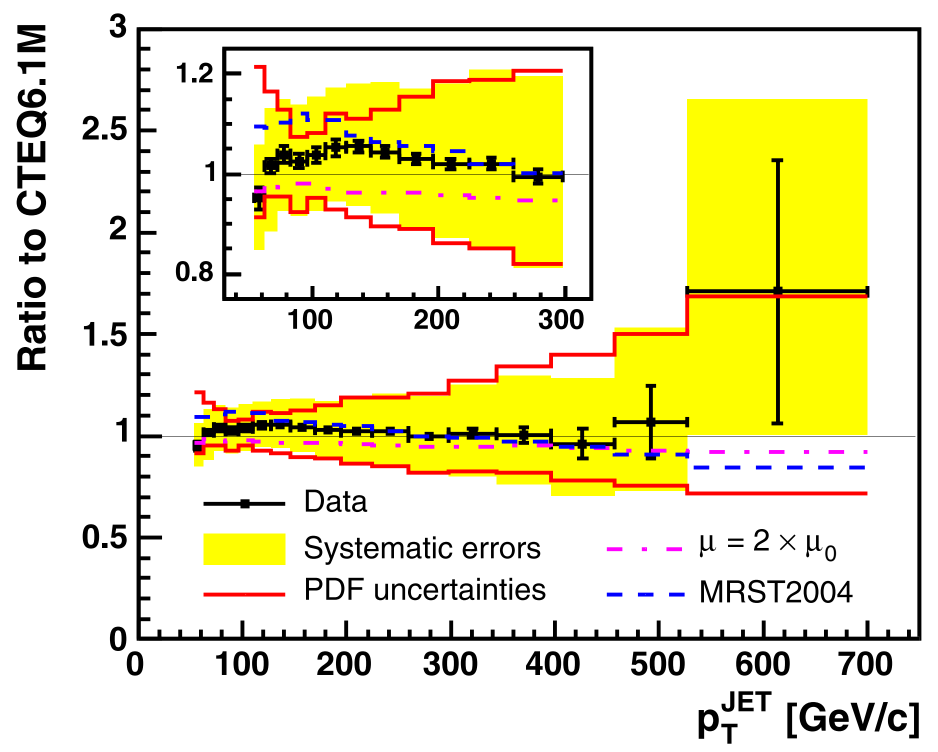




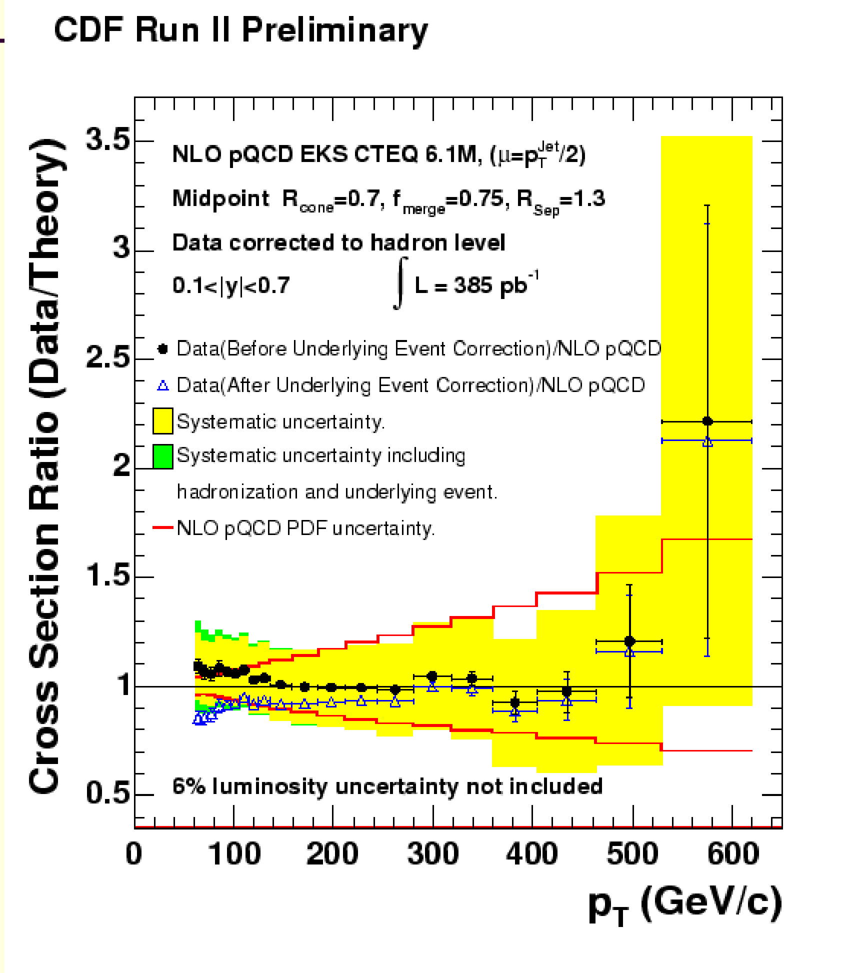
Note, an underlying event and hadronization correction of up to 20% is applied at low PT

k_T jets and cone jets

can match k_T spectra at low and high luminosity by adding ~1.6 GeV/interaction

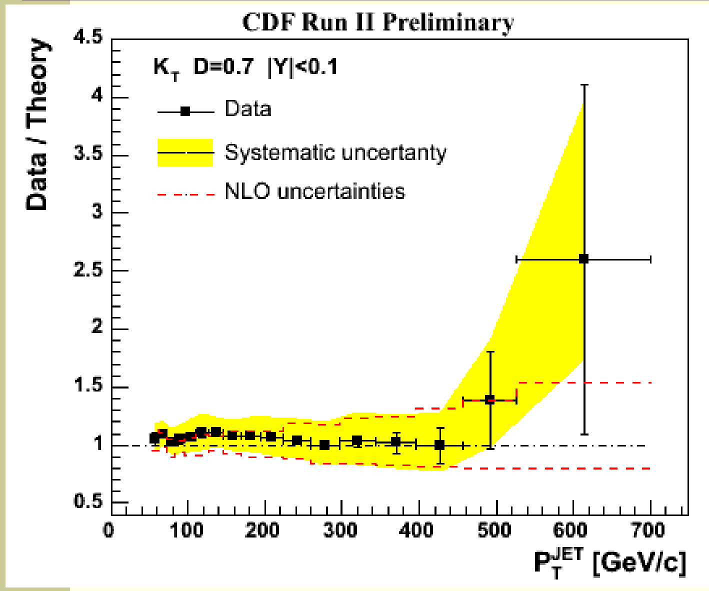


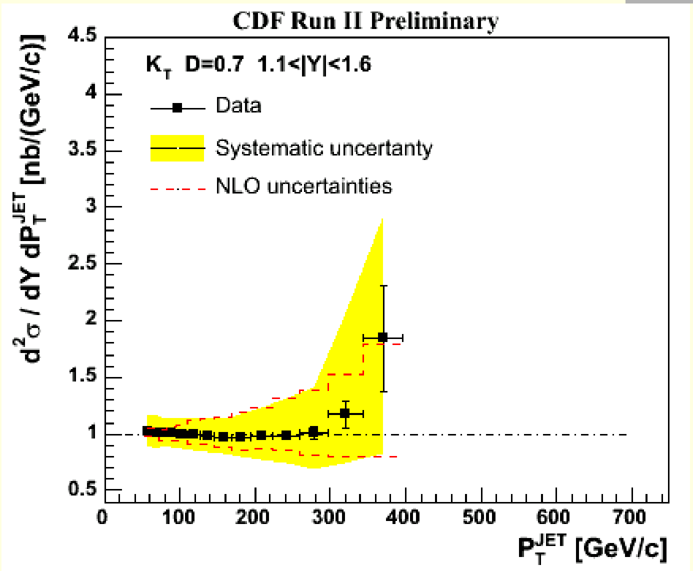
k_T algorithm

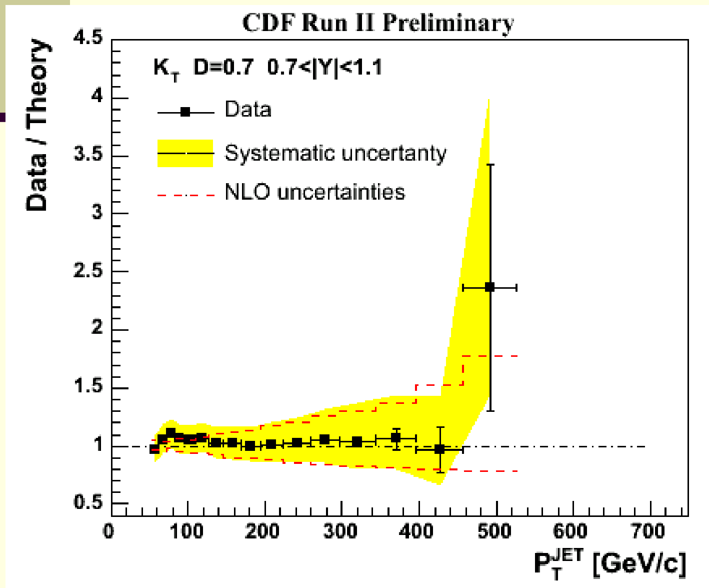


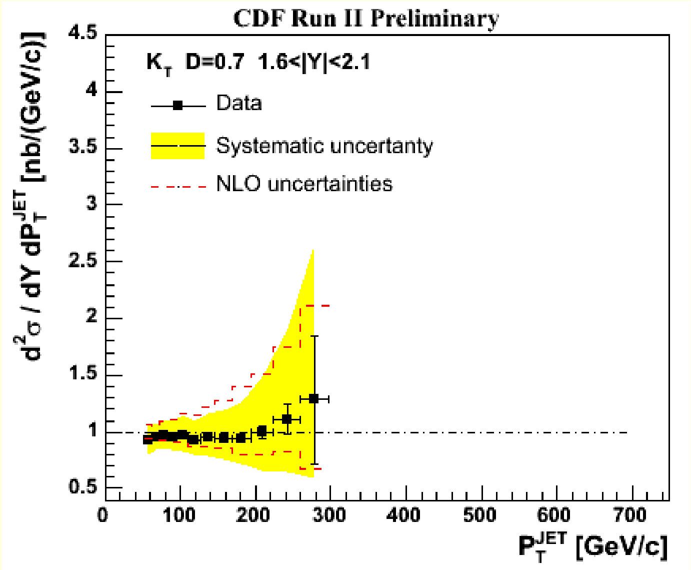
midpoint cone algorithm

kT algorithm results in 4 rapidity bins

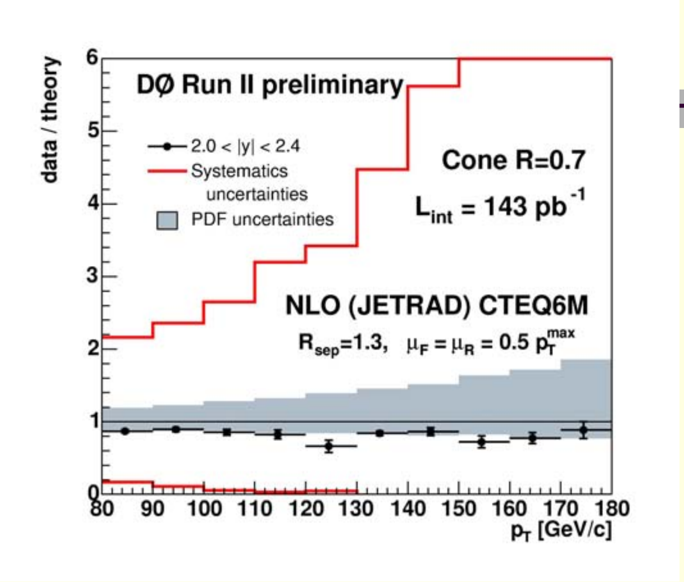


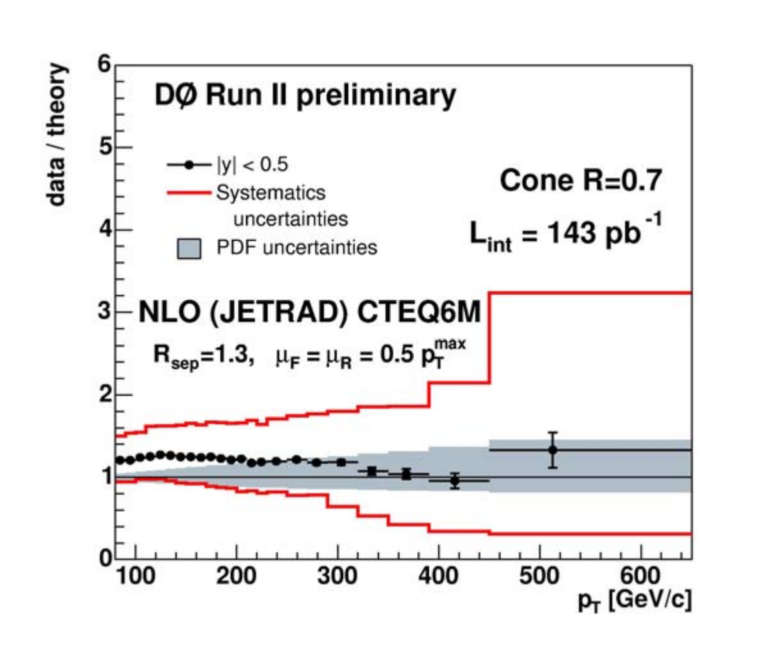


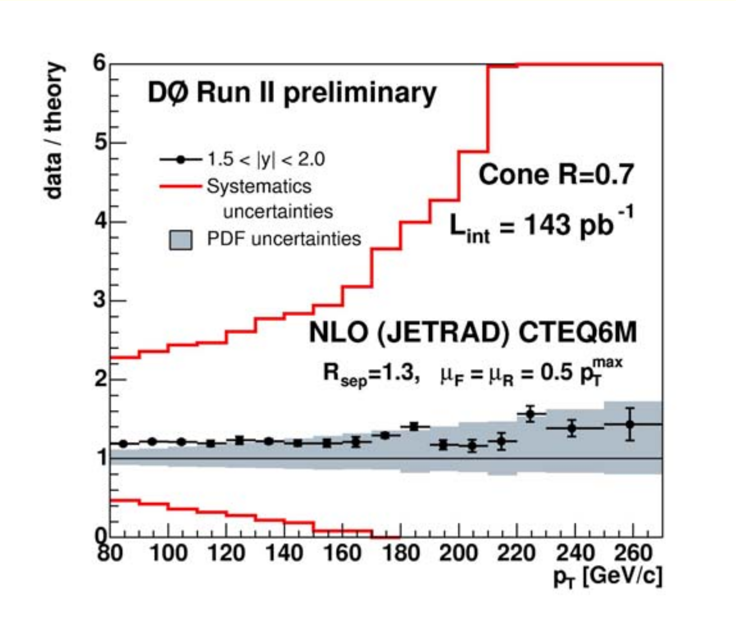




D0 2004
new energy scale
will halve the errors

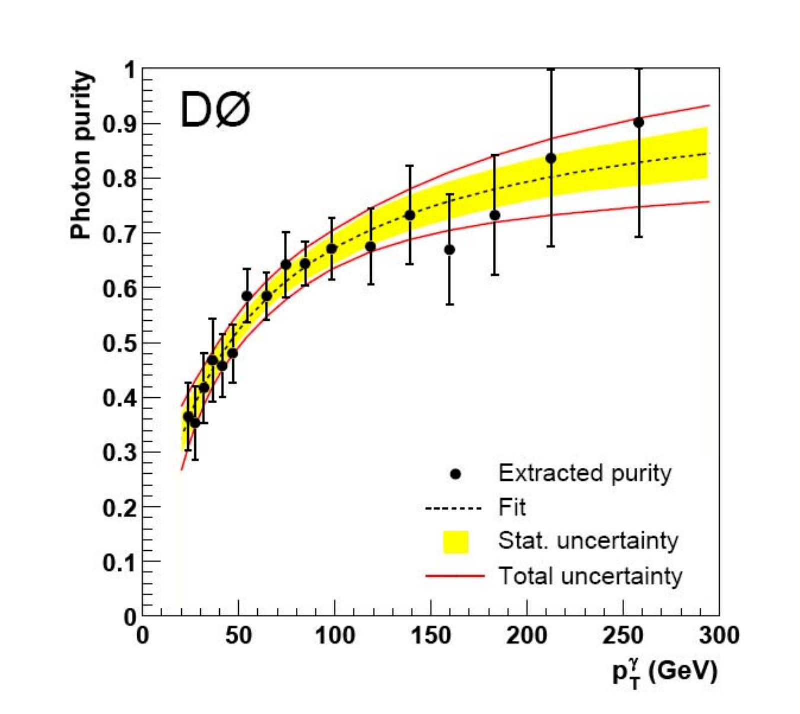




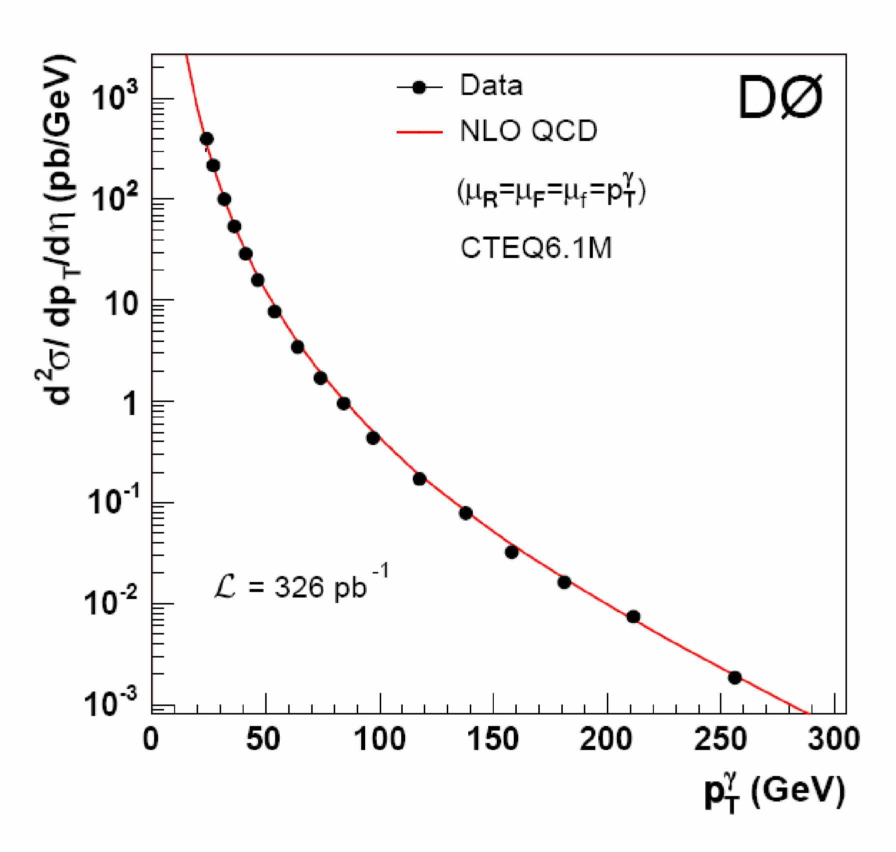


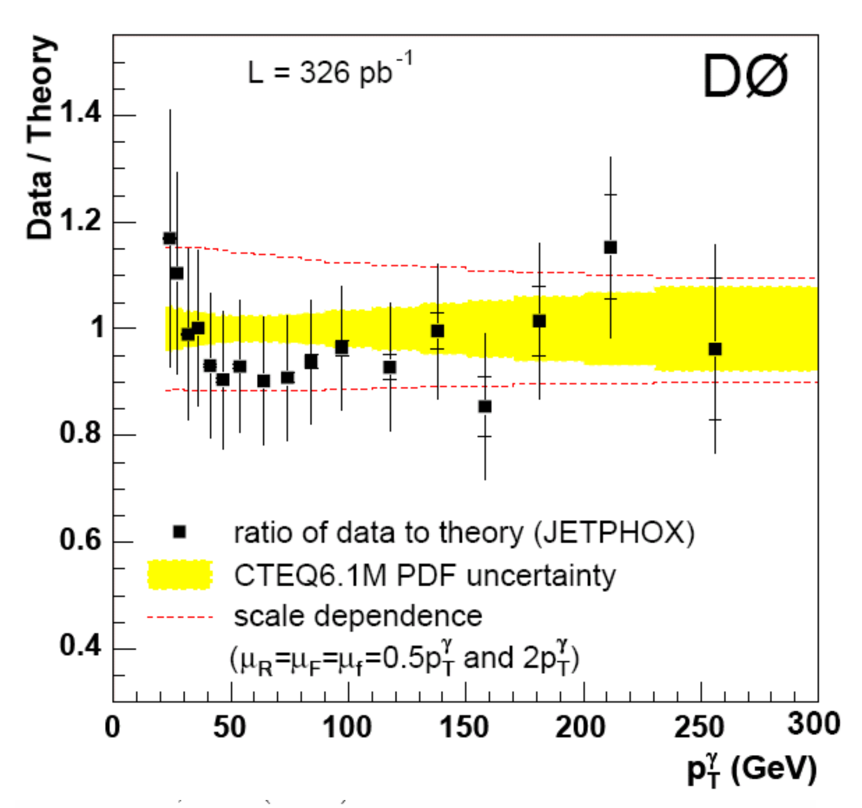
Photon production

- important for the future H->γγ
- Less energy smearing than jets
- Better understanding of energy scale
- purity is lower



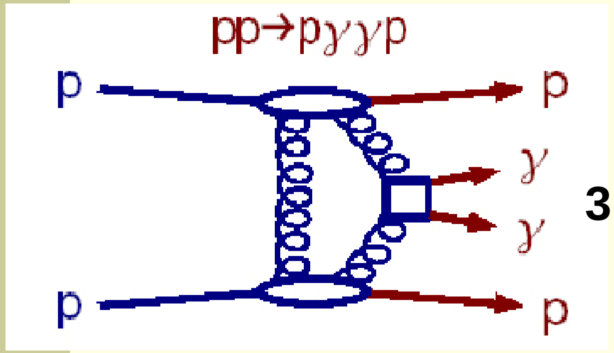
Direct photons



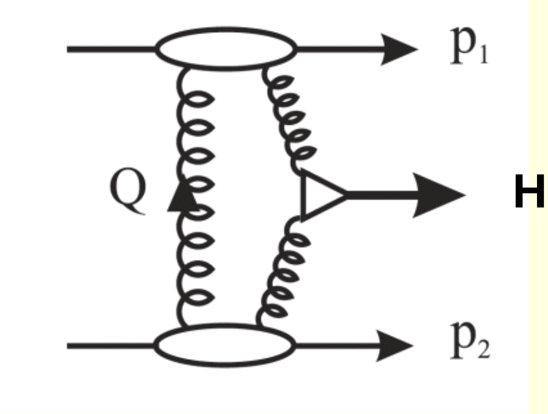


[22] T. Binoth et al., Eur. Phys. J. **C16**, 311 (2000).
[23] S. Catani et al., JHEP **05**, 028 (2002).

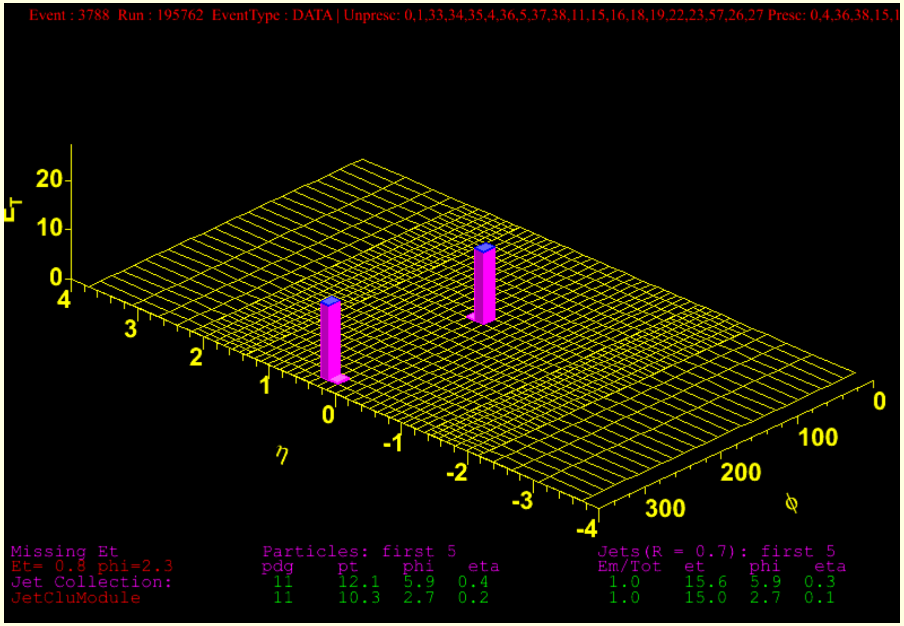
CDF Diffractive diphotons



3 events so far

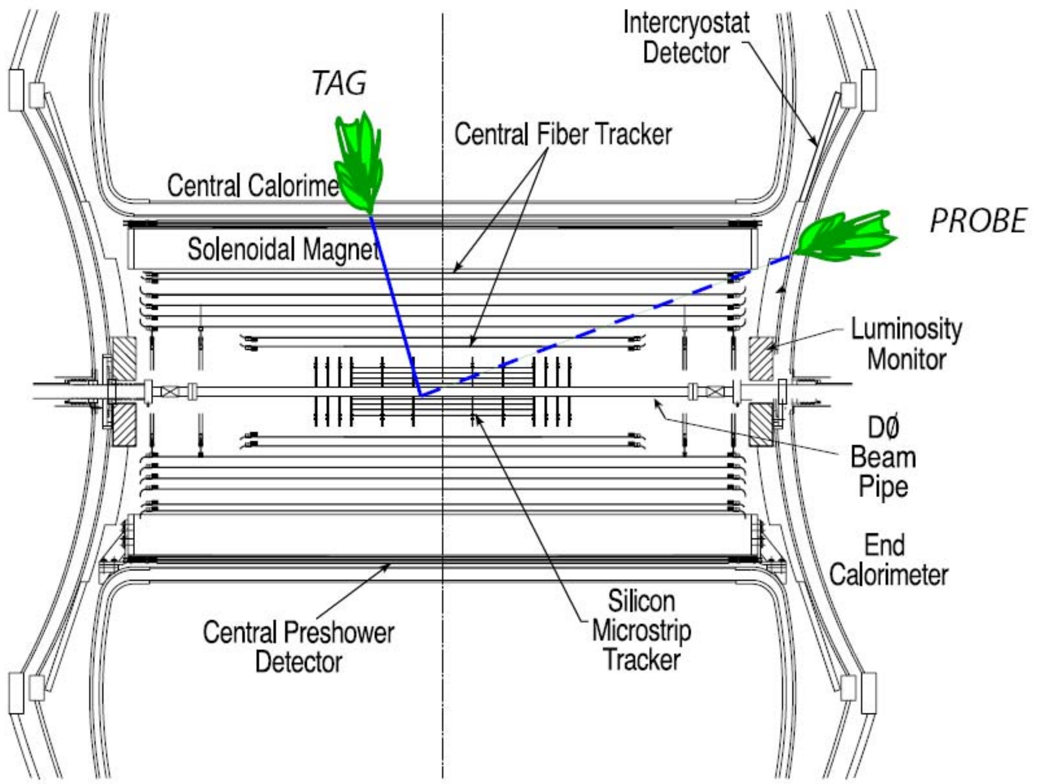


H at LHC?



V.Khoze, A.Martin, M.Ryskin & J.Stirling
hep-ph/0111078 ; hep-ph/0409037

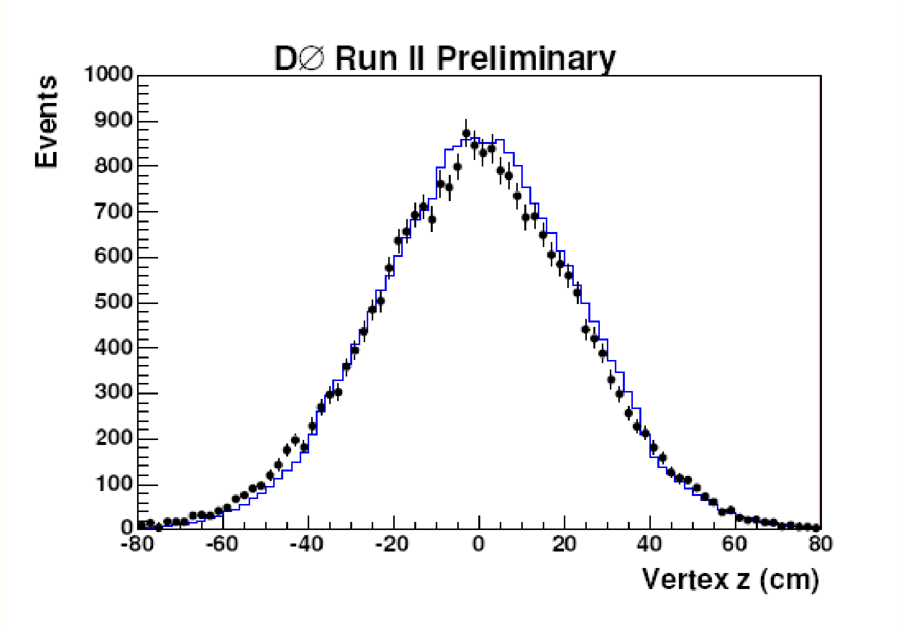
W/Z physics - Tag and Probe method



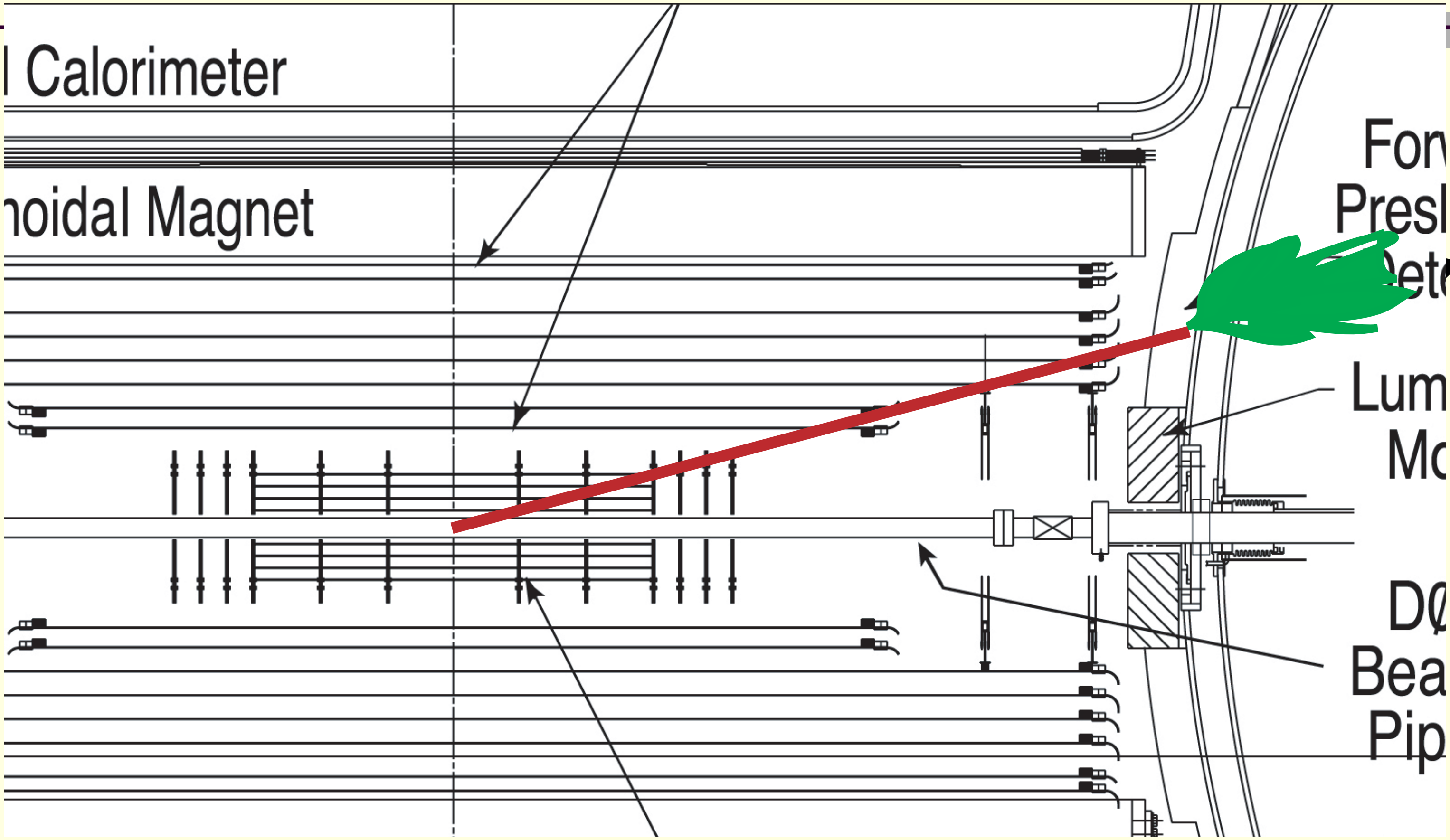
- Find a really good lepton, use as a ‘TAG’.
  - Passed trigger
  - Tight shower cuts
  - Good track match
- Use some component (track or shower) to make another PROBE lepton and from that a Z^0
- Was the PROBE efficient for trigger/tracking/shower?
- Use MC to correct for residual biases ~2%.

W/Z physics to high rapidity

- Tevatron beamspot is long compared to the detector size. Vertices far from the center along the beam axis can reach low values of polar angle not possible from the center of the detector.

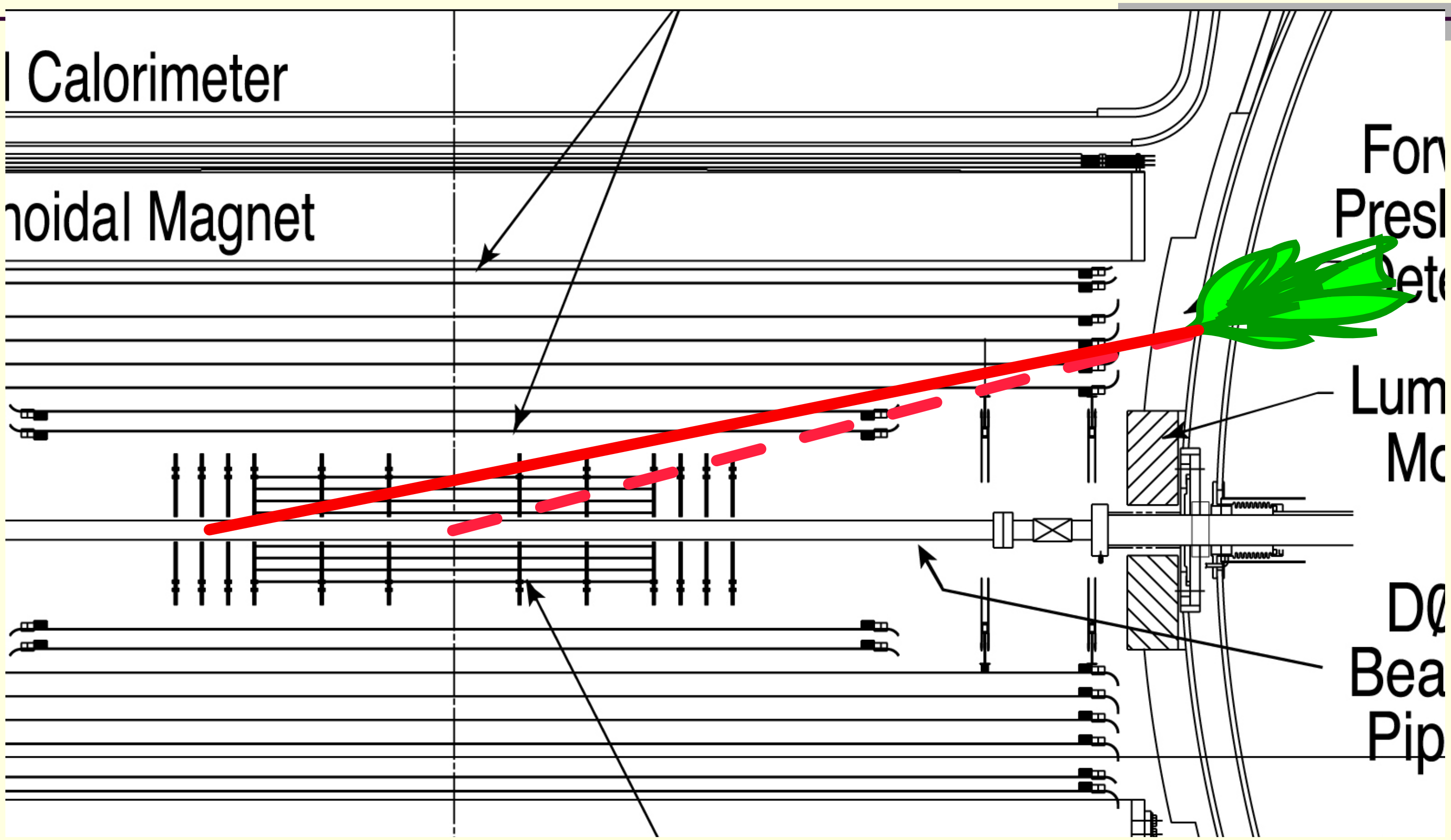


Tracking efficiency for different z_{vtx}



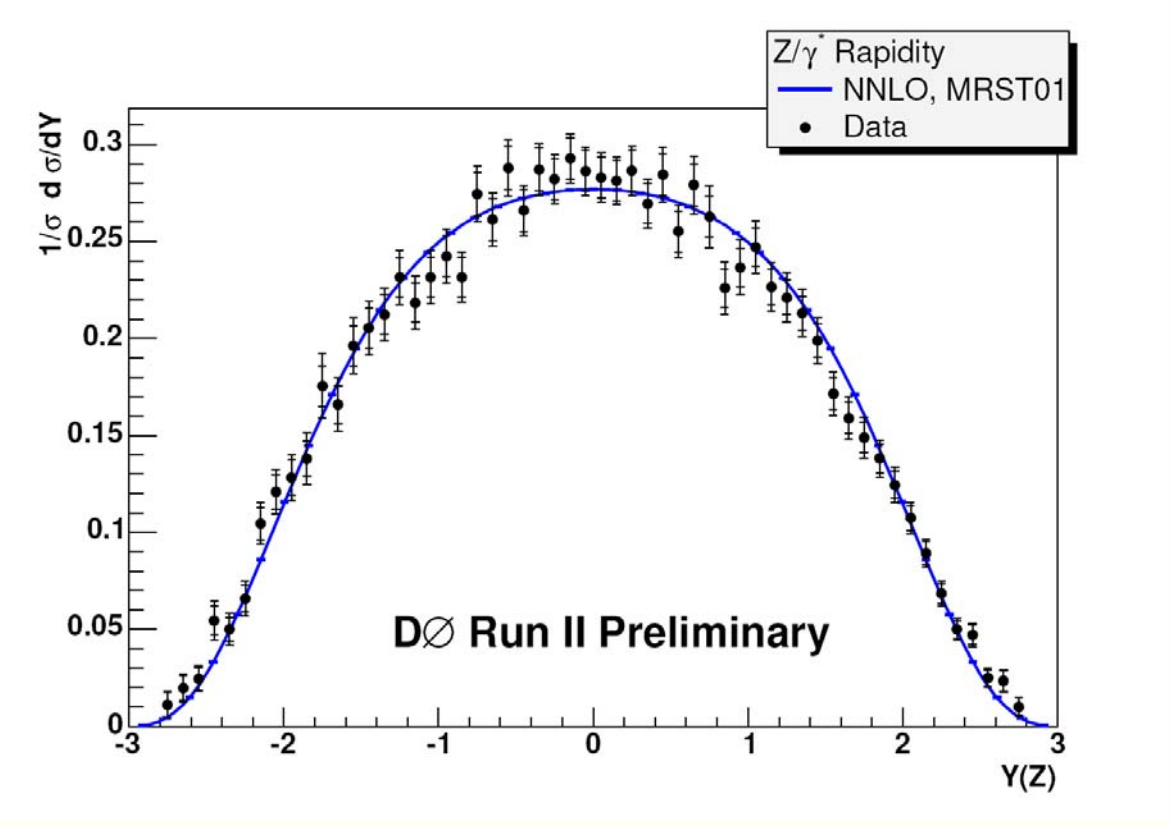
$$z_{vtx} \sim 0, \eta_{det} = 2, \eta_{phys} = 2$$

Reach rapidity not accessible at $z_{vtx}=0$



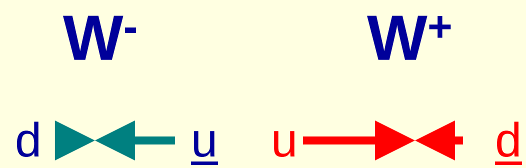
$$z_{vtx} \sim -40\ cm,\ \eta_{det} = 2,\ \eta_{phys} > 2$$

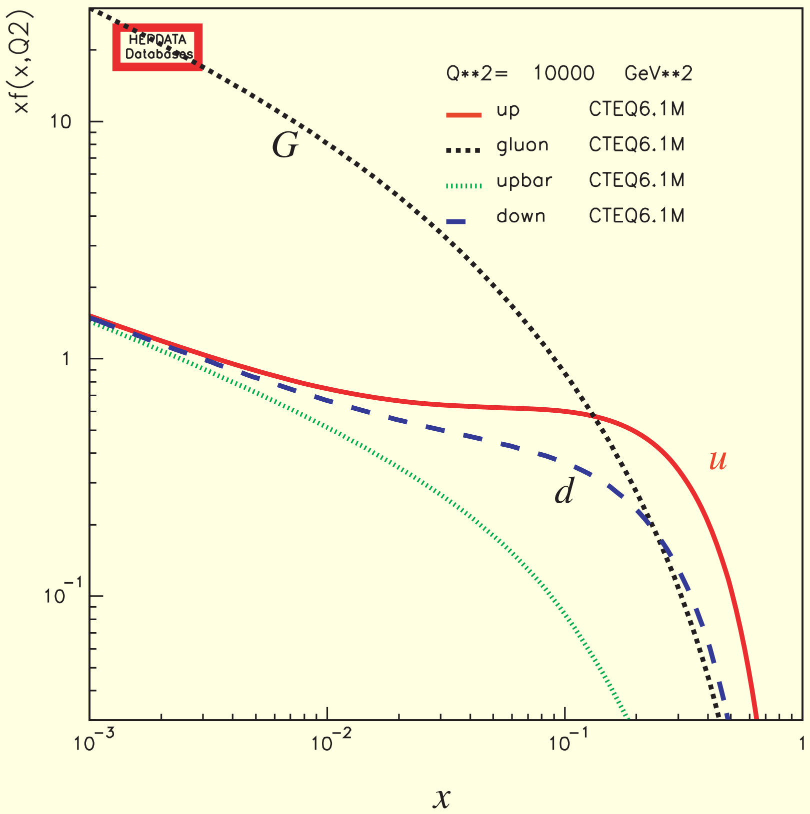
Z rapidity distribution



C. Anastasiou, L. Dixon, K. Melnikov and F. Petriello

W asymmetry





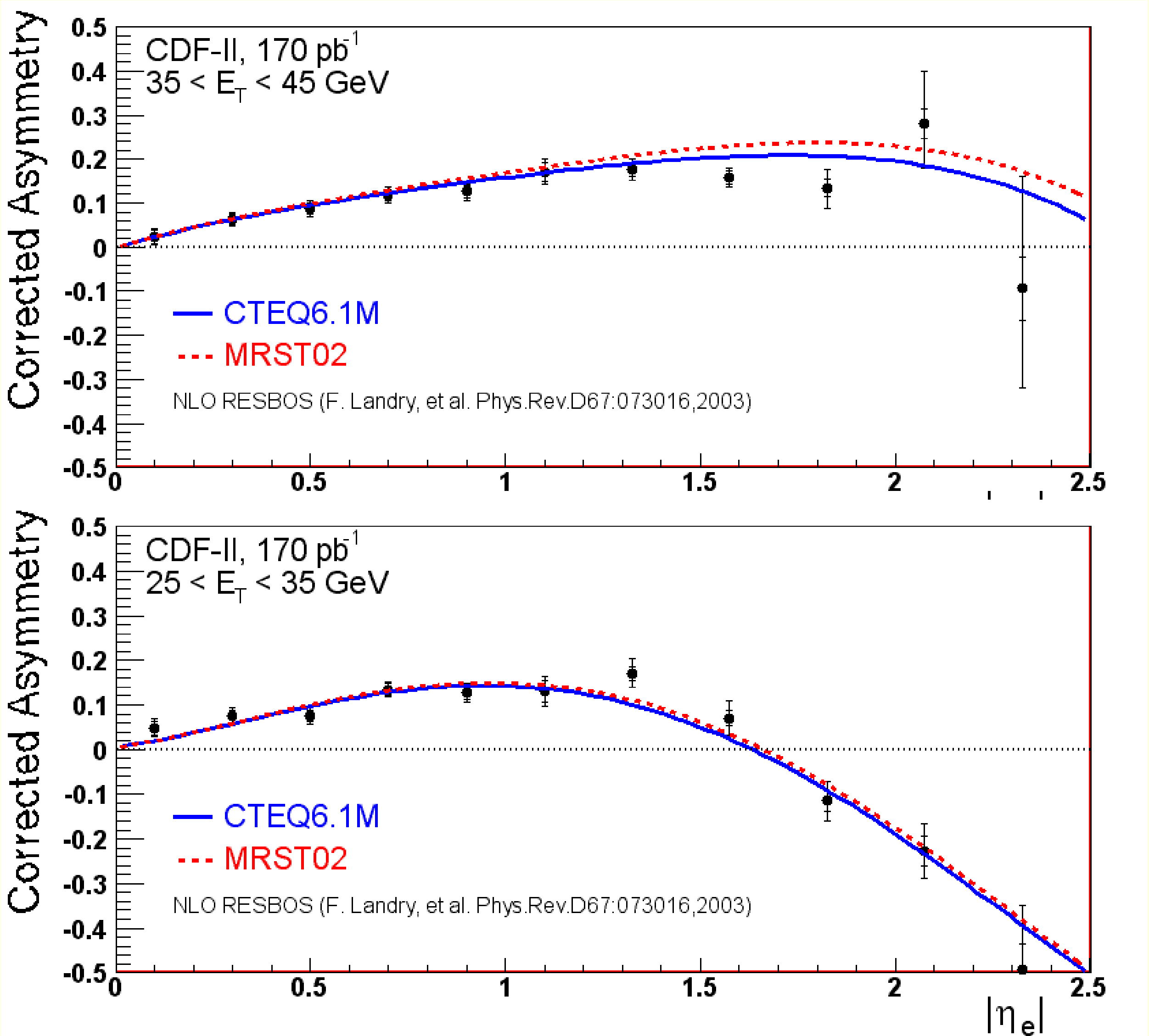
$$A(y_W) = \frac{d\sigma(W^+)/dy_W - d\sigma(W^-)/dy_W}{d\sigma(W^+)/dy_W + d\sigma(W^-)/dy_W};$$

$$A(x_1, x_2) \propto \frac{u(x_1)\bar{d}(x_2) - d(x_1)\bar{u}(x_2)}{u(x_1)\bar{d}(x_2) + d(x_1)\bar{u}(x_2)}$$

$$A(\eta_e) = \frac{d\sigma(e^+)/d\eta_e - d\sigma(e^-)/d\eta_e}{d\sigma(e^+)/d\eta_e + d\sigma(e^-)/d\eta_e};$$

$$A(\eta_e) = \frac{d\sigma(e^+)/d\eta_e - d\sigma(e^-)/d\eta_e}{d\sigma(e^+)/d\eta_e + d\sigma(e^-)/d\eta_e}$$

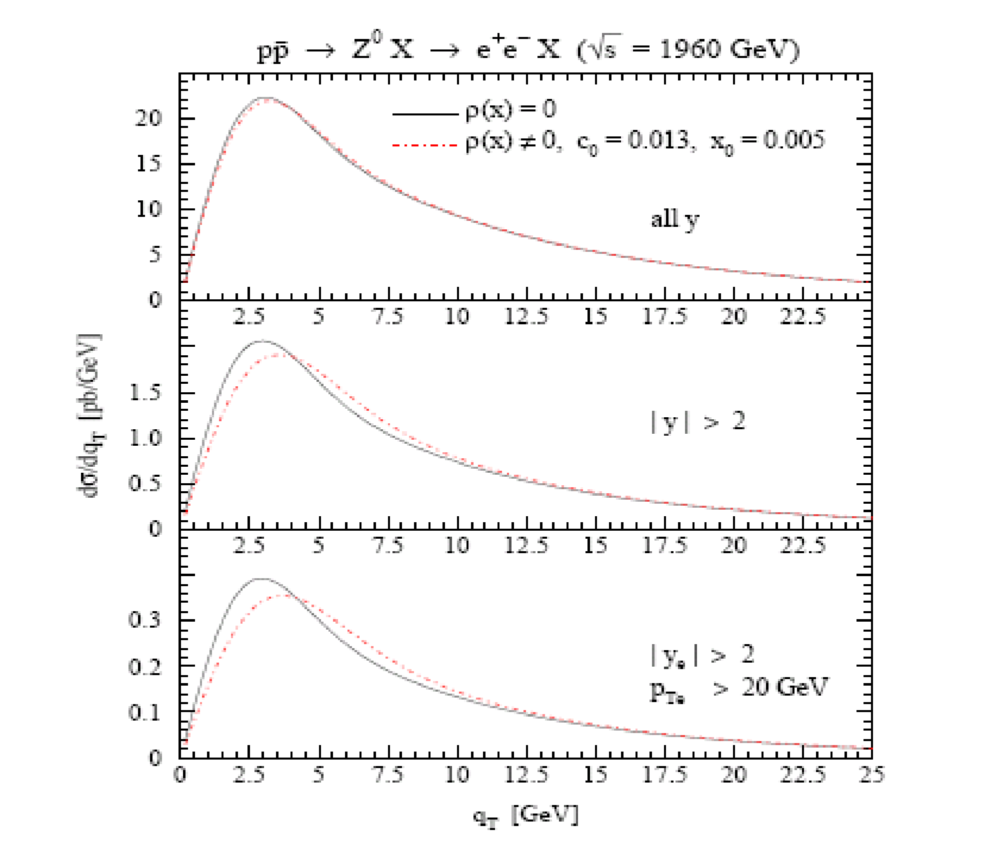
hep-ex/0501023
Phys. Rev. D.



Z pt contribution

Boson Pt tuned at low rapidity – does it work at high rapidity?

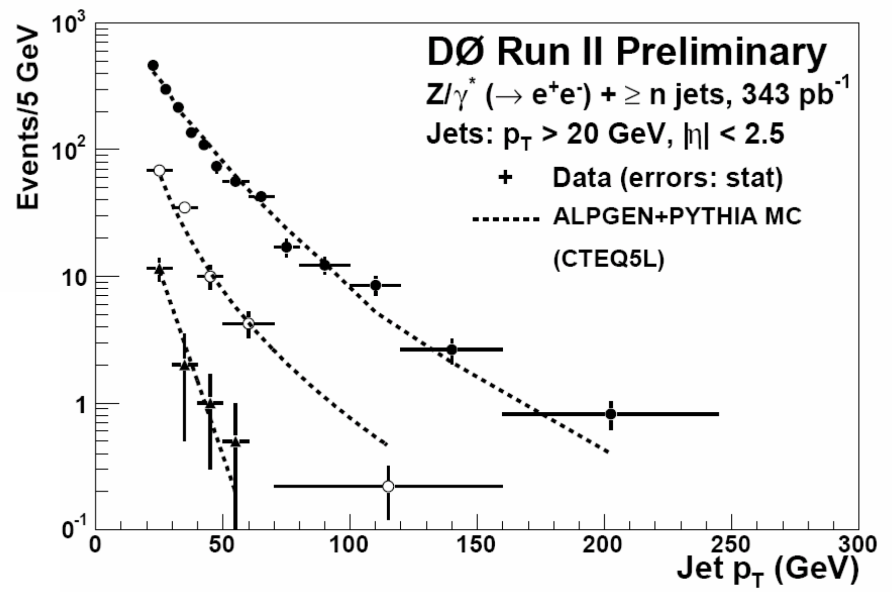
- hep-ph/0410375 **Phys.Rev.D72:033015,2005** (Berge, Nadolsky, Olness and Yuan)

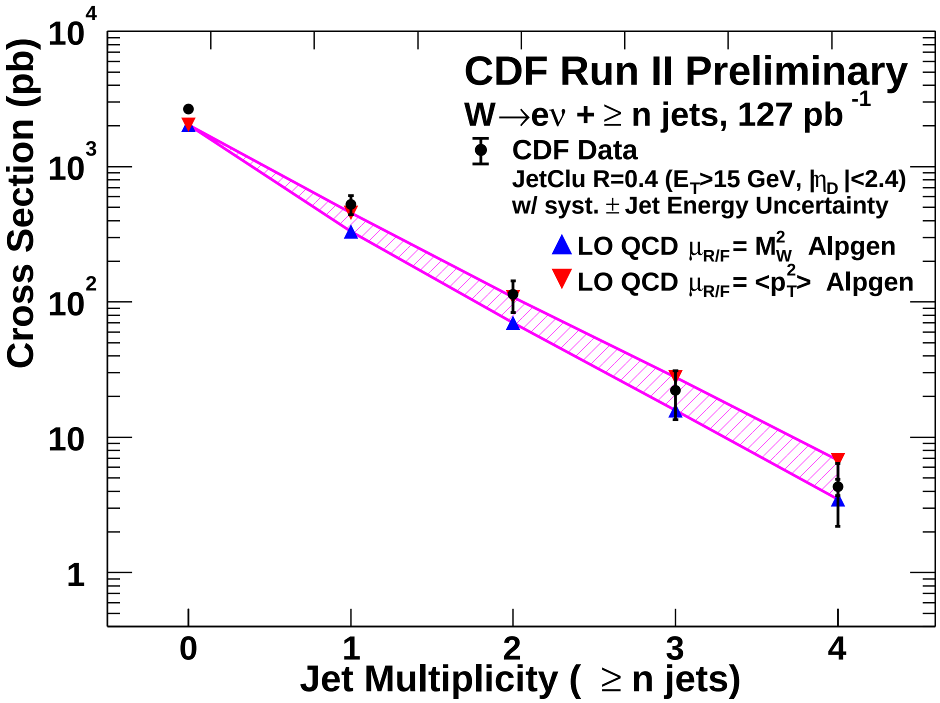


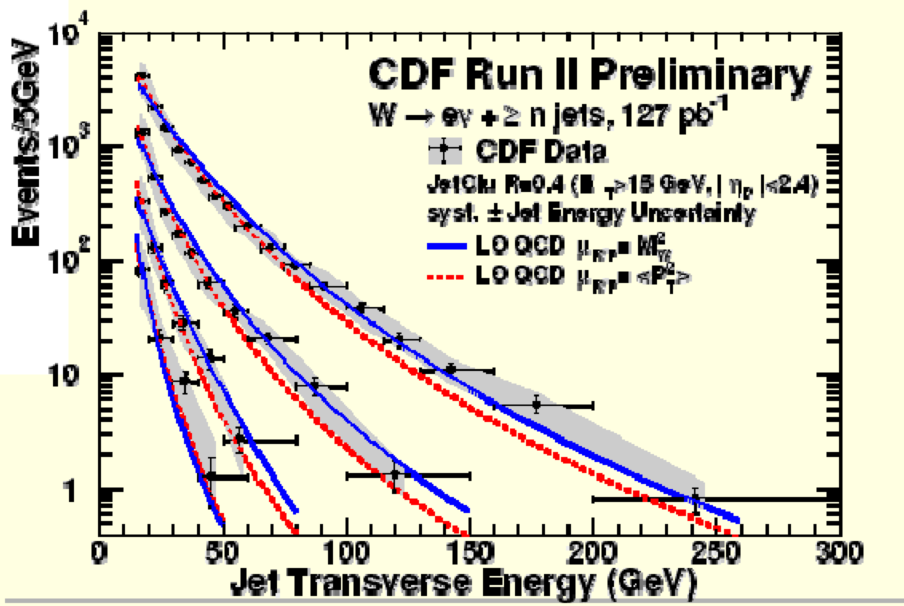
W/Z + jets

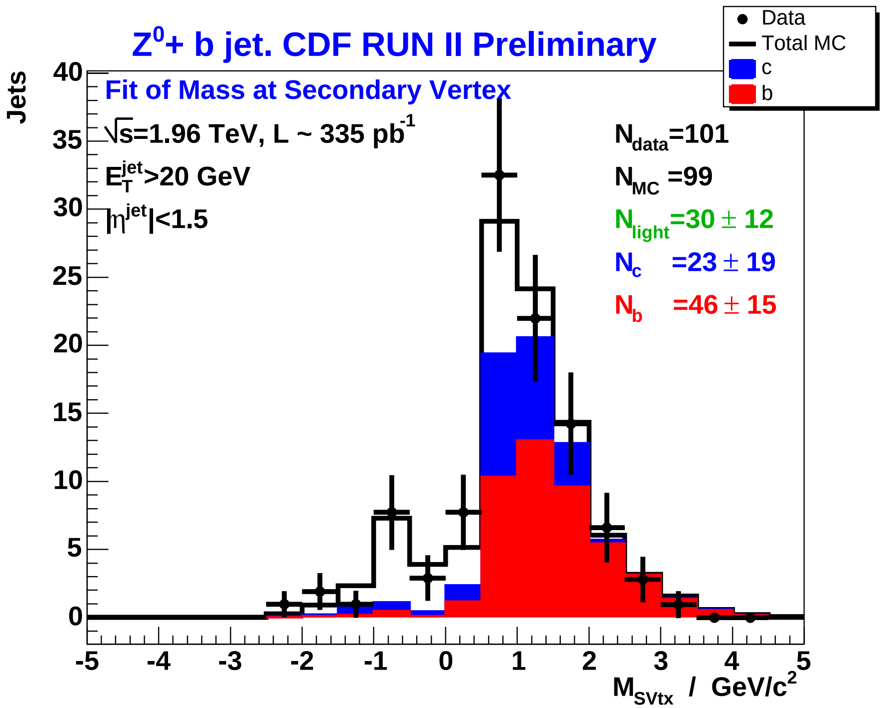
- W/Z production with jets, especially b jets is important in understanding many interesting Higgs, Top and more exotic channels

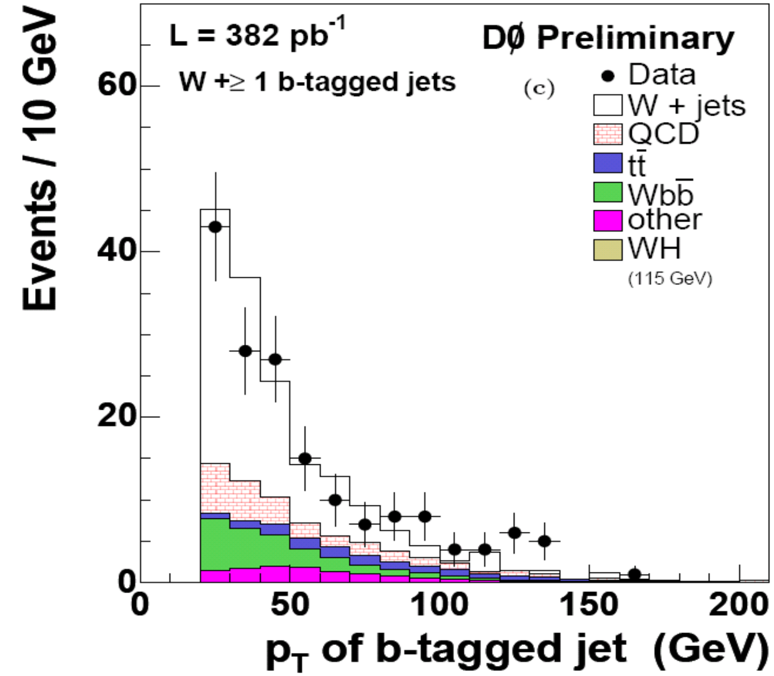
W/Z+jets

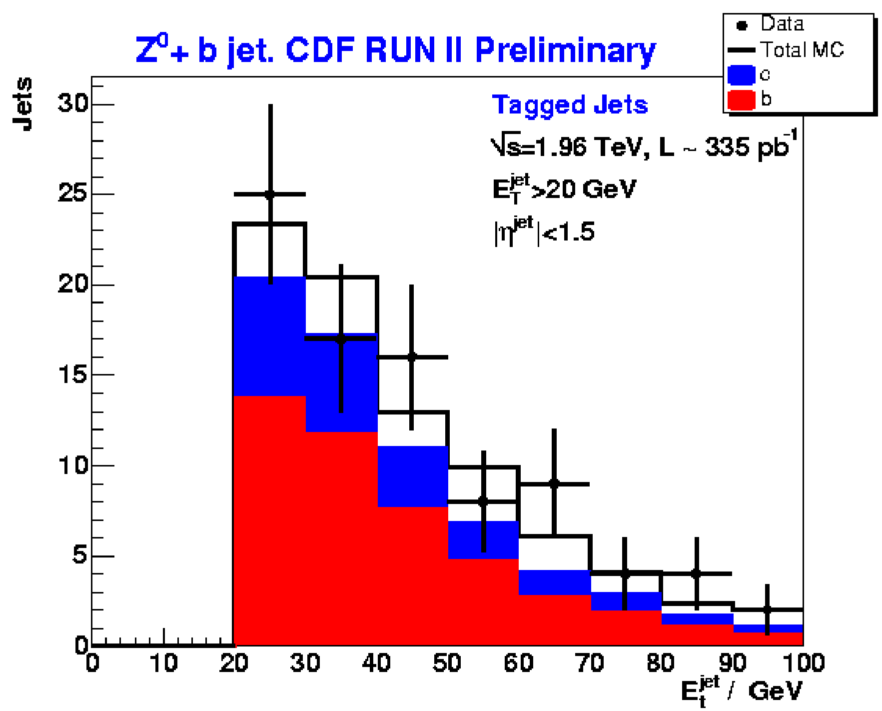

DØ Run II Preliminary
Z/γ* (→ e+e-) + ≥ n jets, 343 pb-1
Jets: pT > 20 GeV, |η| < 2.5
Data (errors: stat)
ALPGEN+PYTHIA MC
(CTEQ5L)
Events/5 GeV
Jet pT (GeV)

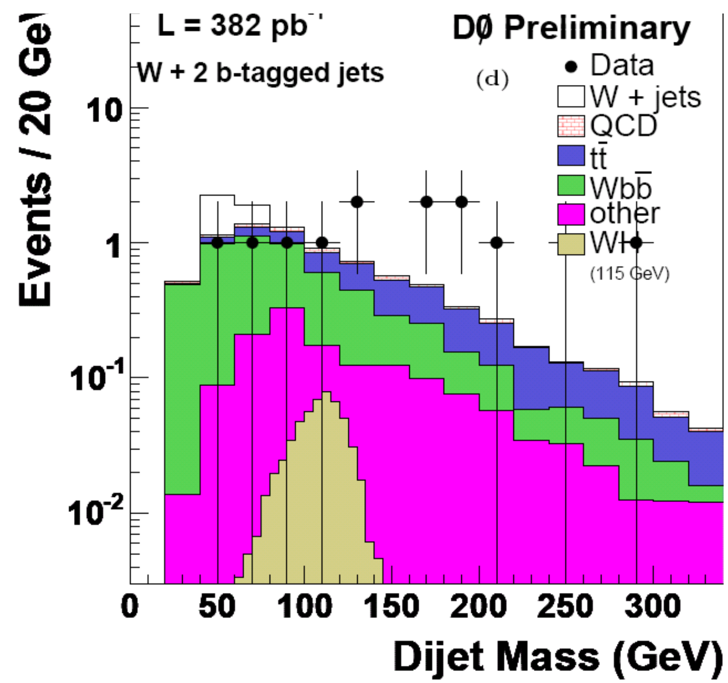

CDF Run II Preliminary
W→eν + ≥ n jets, 127 pb-1
CDF Data
JetClu R=0.4 (ET>15 GeV, |ηD|<2.4)
w/ syst. ± Jet Energy Uncertainty
LO QCD μR/F = M2W Alpgen
LO QCD μR/F = <p2T> Alpgen
Cross Section (pb)
Jet Multiplicity (≥ n jets)

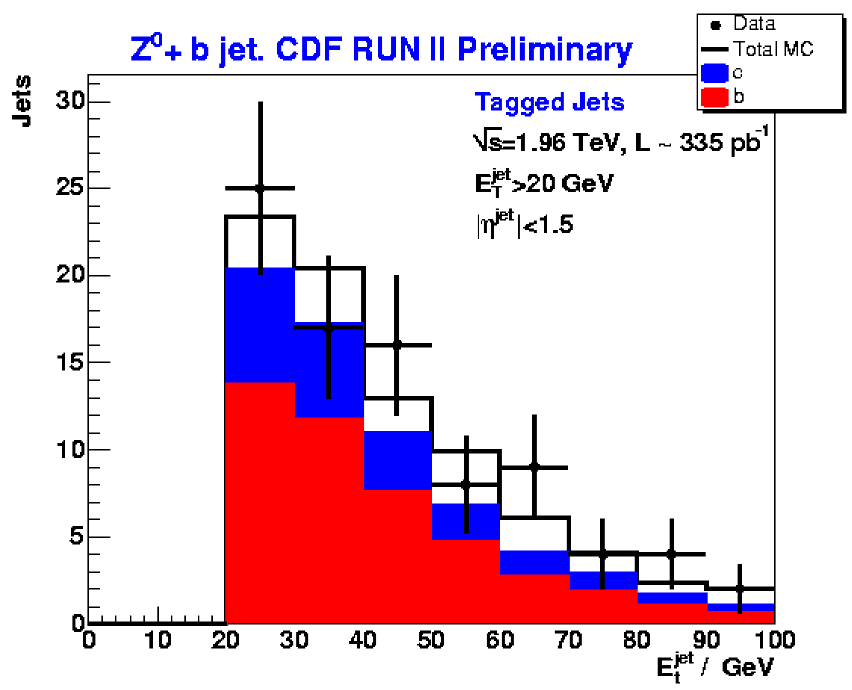

CDF Run II Preliminary
W → eν + ≥ n jets, 127 pb-1
CDF Data
Events/5GeV
Jet Transverse Energy (GeV)


Z0+ b jet. CDF RUN II Preliminary
Fit of Mass at Secondary Vertex
√s=1.96 TeV, L ~ 335 pb-1
ET jet>20 GeV
|η jet|<1.5
N data=101
N MC =99
N light=30 ± 12
N c =23 ± 19
N b =46 ± 15
Data
Total MC
c
b
Jets
M SVtx / GeV/c2

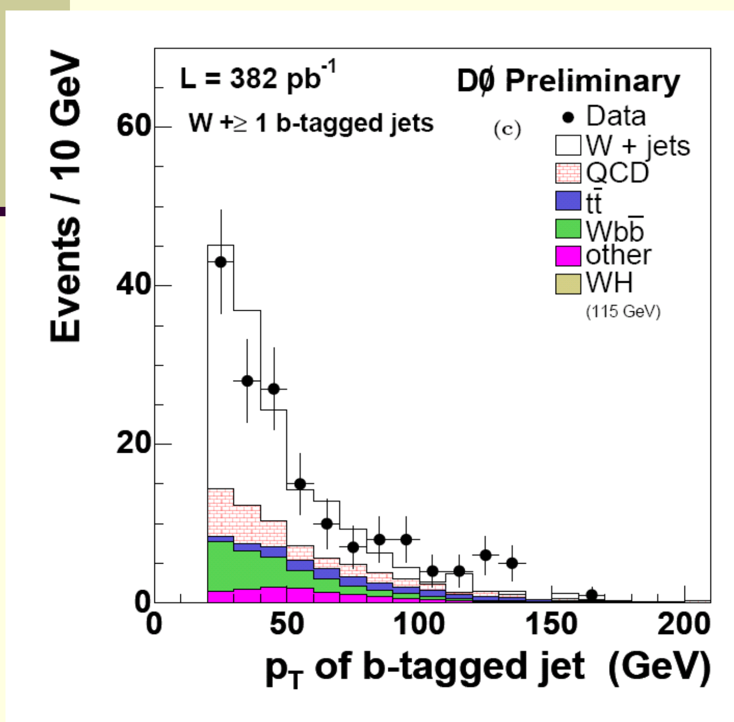

L = 382 pb-1
DØ Preliminary
W +≥ 1 b-tagged jets
(c)
Data
W + jets
QCD
tt̄
Wbb̄
other
WH
(115 GeV)
Events / 10 GeV
pT of b-tagged jet (GeV)

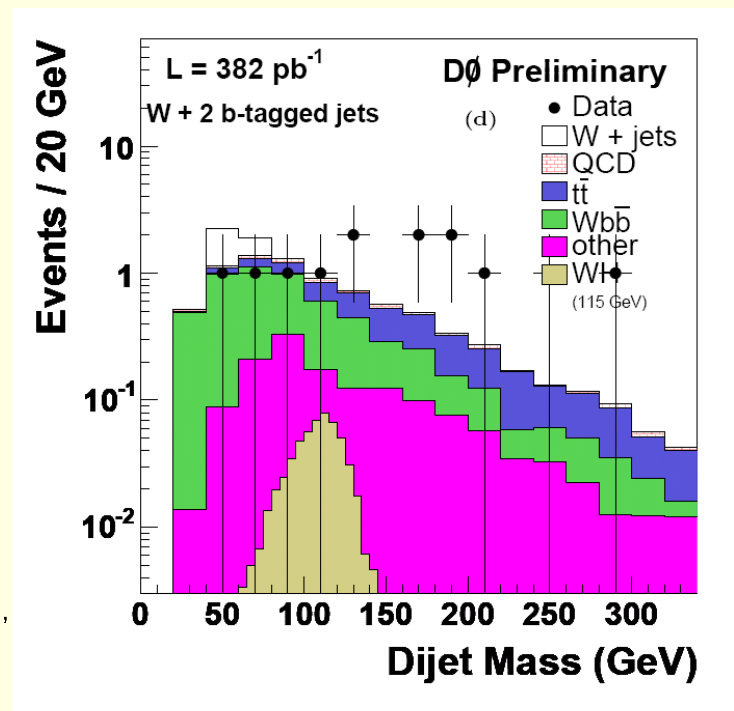

Z0+ b jet. CDF RUN II Preliminary
Tagged Jets
√s=1.96 TeV, L ~ 335 pb-1
ET jet>20 GeV
|η jet|<1.5
Data
Total MC
c
b
Jets
Et jet / GeV


L = 382 pb-1
DØ Preliminary
W + 2 b-tagged jets
(d)
Data
W + jets
QCD
tt̄
Wbb̄
other
WH
(115 GeV)
Events / 20 Ge
Dijet Mass (GeV)

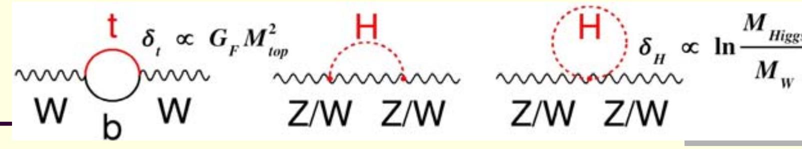

Z0+ b jet. CDF RUN II Preliminary
Data
Total MC
c
b
Tagged Jets
√s=1.96 TeV, L ~ 335 pb-1
E_T^jet>20 GeV
|η^jet|<1.5
Jets
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
90
100
E_t^jet / GeV

Z + b's


L = 382 pb-1
DØ Preliminary
W +≥ 1 b-tagged jets
(c)
Data
W + jets
QCD
tt̄
Wbb̄
other
WH
(115 GeV)
Events / 10 GeV
0
20
40
60
0
50
100
150
200
p_T of b-tagged jet (GeV)

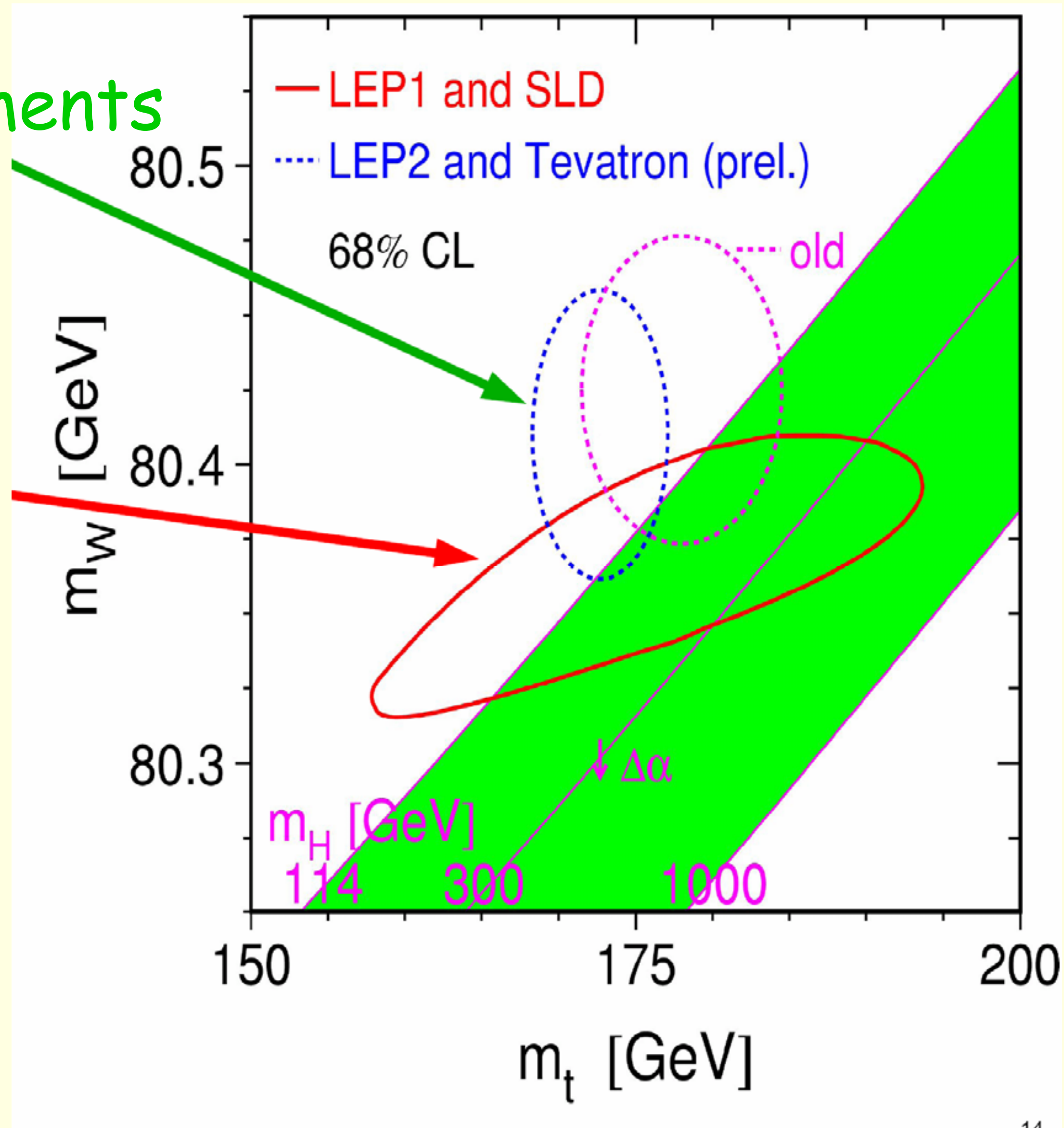

L = 382 pb-1
DØ Preliminary
W + 2 b-tagged jets
(d)
Data
W + jets
QCD
tt̄
Wbb̄
other
WH
(115 GeV)
Events / 20 GeV
10-2
10-1
1
10
0
50
100
150
200
250
300
Dijet Mass (GeV)

W mass

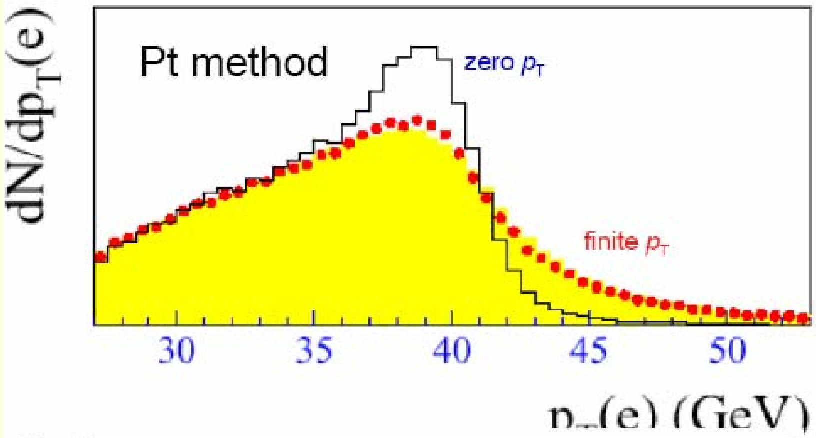


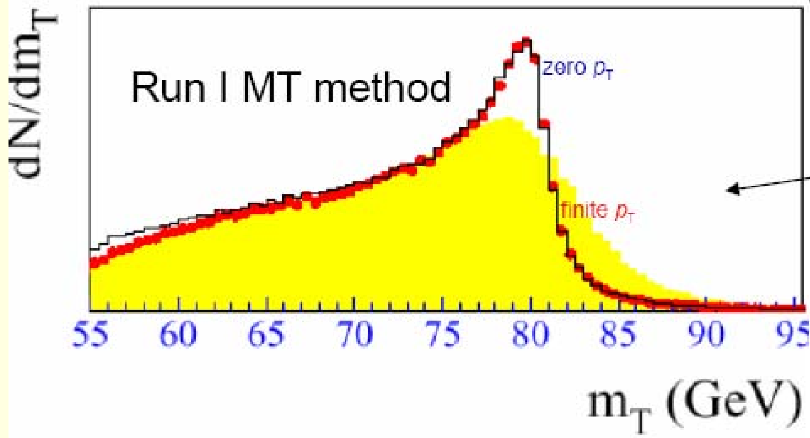
Direct measurements

From Z couplings



W mass variables





____ is LO process

● is real QCD process

▭ is real QCD with resolution

Dominated by QCD model

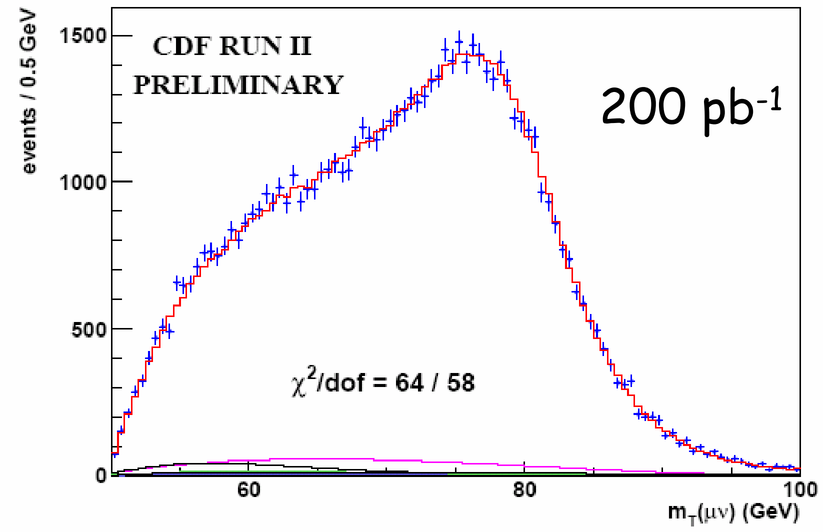
Run I MT method
Dominated by resolution

$$m_T = \sqrt{2p_T^l p_T^\nu (1 - \cos(\Delta\phi))}.$$

Plots from D0 Run II study.

CDF M_T analysis

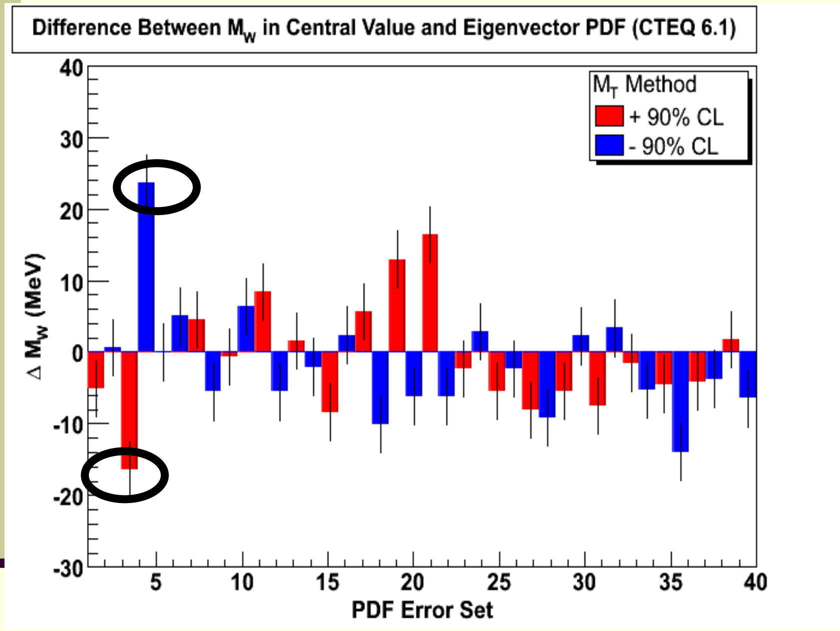
Present combined error is 76 MeV

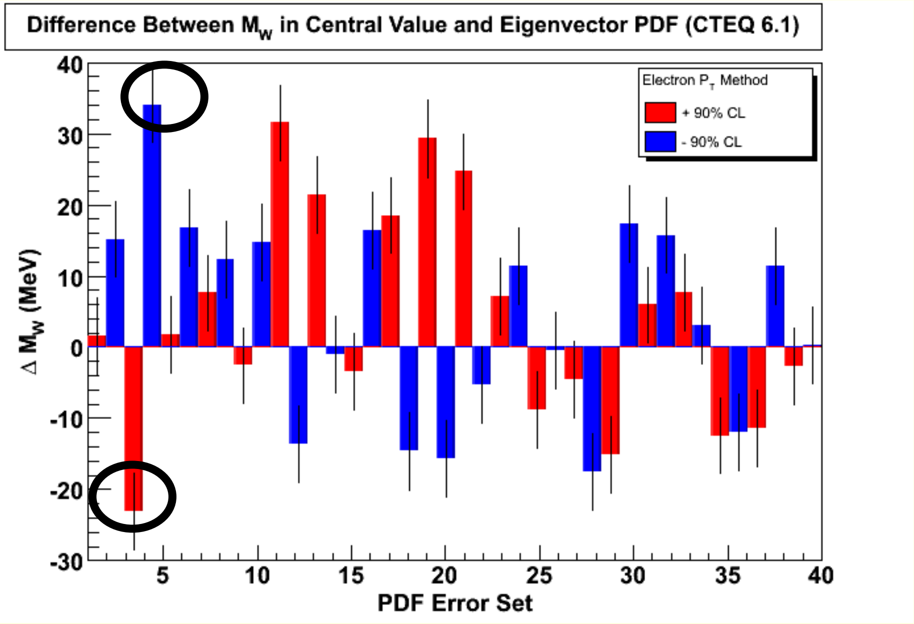


200 pb^{-1}

Systematic [MeV]	Electrons (Run 1b)	Muons (Run 1b)	Common (Run 1b)
Lepton Energy Scale and Resolution	70 (80)	30 (87)	25
Recoil Scale and Resolution	50 (37)	50 (35)	50
Backgrounds	20 (5)	20 (25)	
Production and Decay Model	30 (30)	30 (30)	25 (16)
Statistics	45 (65)	50 (100)	
Total	105 (110)	85 (140)	60 (16)

PDF uncertainties in W mass 90% CL





MT method

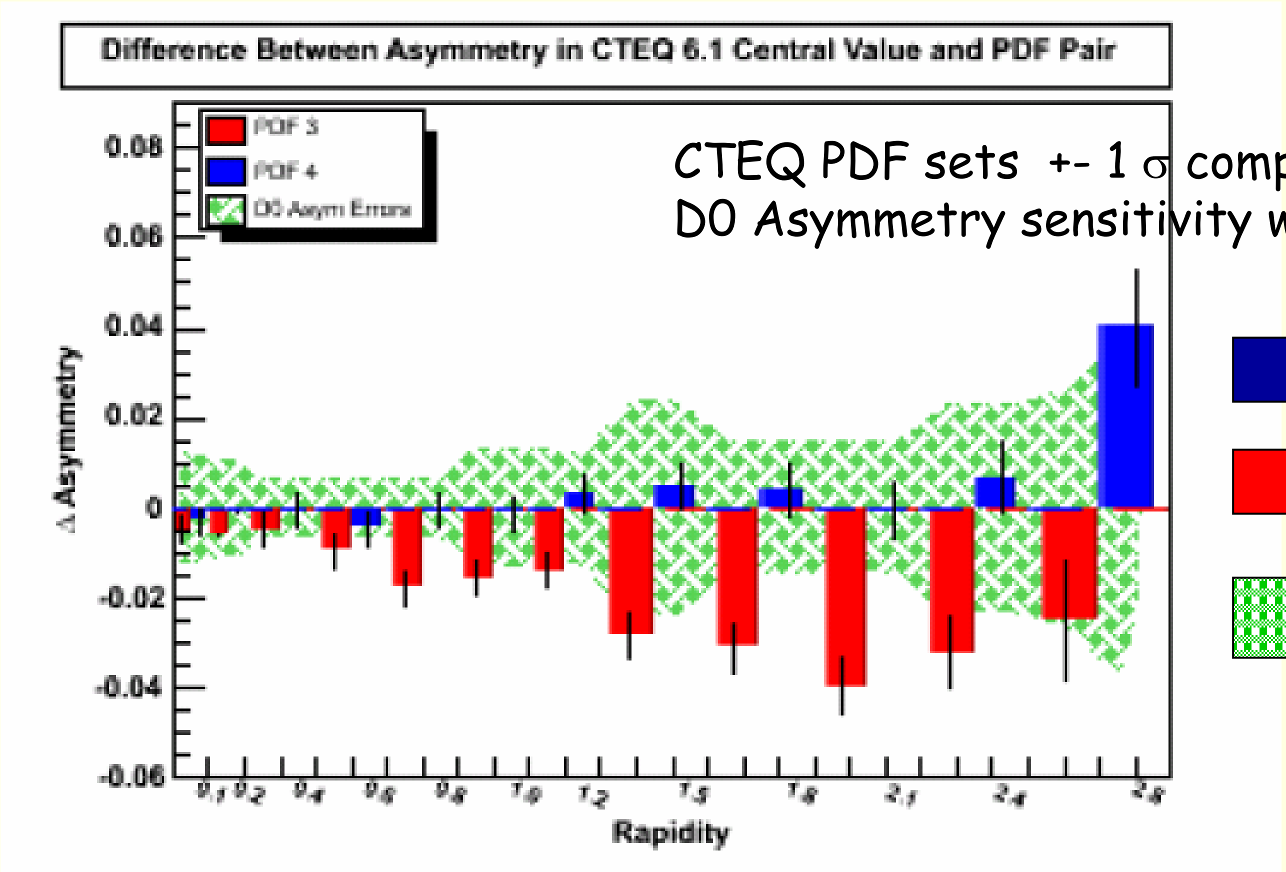
PT method

Bottom line ~ 22 MeV @ 90%

Bottom line ~ 35 MeV @ 90 %

PDF sensitivity to Asymmetry

PDF sets 3 and 4



CTEQ PDF sets +- 1 σ compared to
D0 Asymmetry sensitivity with ~400 pb^{-1}

+PDF

-PDF

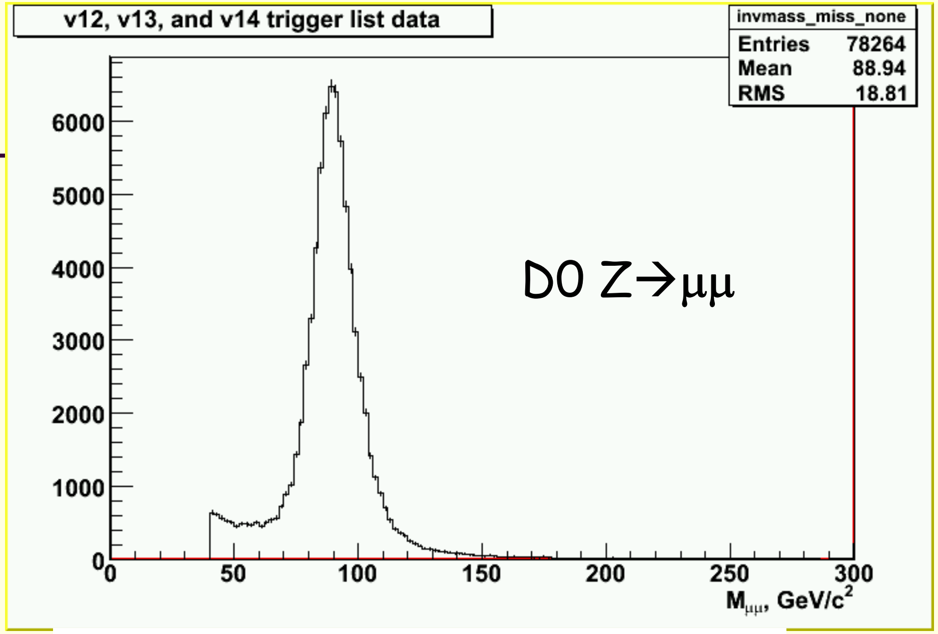
Projected errors from D0 data

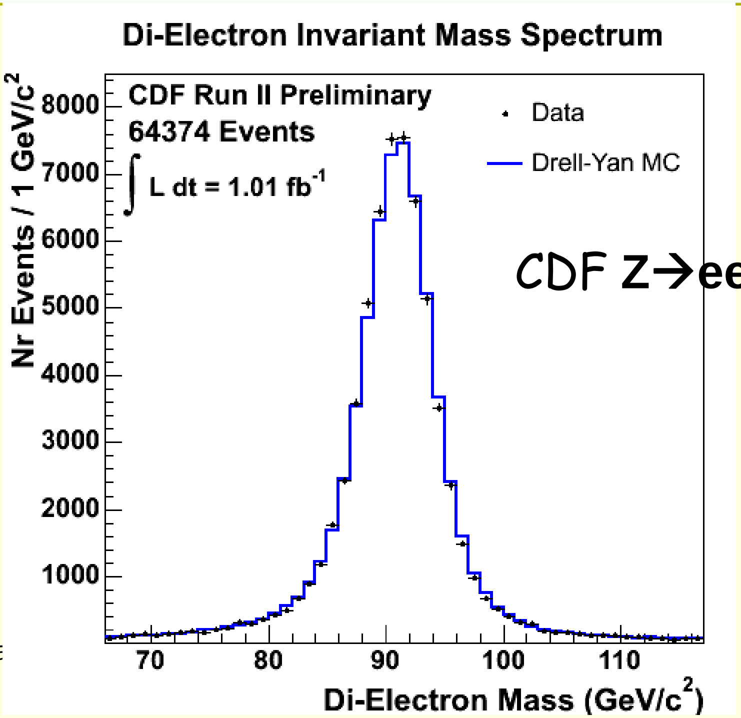
Prospects

- 1 fb^{-1} samples now available
- Calibration of charged lepton and recoil to 0.1% is very difficult at a hadron collider.
  - Use the Z but not all problems cancel in the W/Z scale ratio
- P_T becomes more powerful with more statistics. Especially if new data on $\sigma(y, p_T)$ and W asymmetry constrain the physics models.

Prospects II

- I showed nothing with more than about ½ of the data now recorded by CDF/D0.
- Higher statistics measurements will be coming out over the next year (month!).





Conclusions

- No big surprises, just improvements

More conclusions

- Inclusive jets
  - production measurements with higher energy/statistics -> better G(x)
  - kt algorithm works at high luminosity at hadron colliders
- W/Z production
  - Now measured over full rapidity range
  - NNLO predictions being tested
  - enough statistics for asymmetry, polarization, low pt behavior to refine PDF’s and nonperturbative corrections.
- Bosons + jets
  - ALPGEN/pythia models describe the observed rates for multijets and for b jets.
- W mass
  - statistics on the way
  - theoretical errors can be reduced using existing Run II data
  - calibration is hard!