QCD results from DØ

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Outline

Introduction

- Proton Structure - motivation for the measurements
- Tevatron & DØ in RunIIa

QCD Studies at DØ

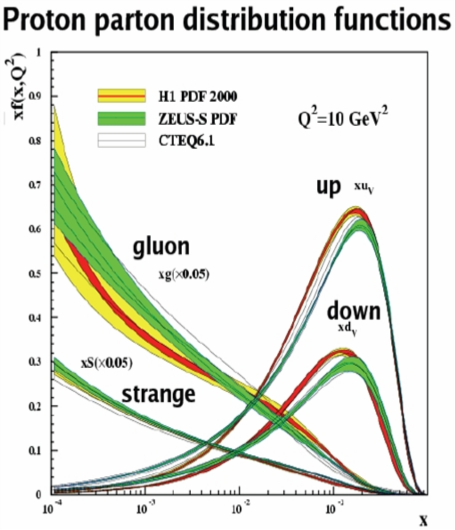
- Inclusive Jet p_{T} Cross-section
- Dijet Azimuthal Decorrelations
- Inclusive Photon p_{T} Cross-section
- W Charge Assymetry
- Z+jets

Summary

Proton Structure

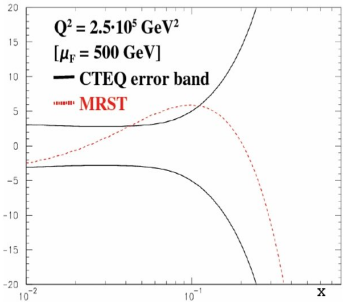
Quark and gluon content of proton described by parton distribution functions (PDF)

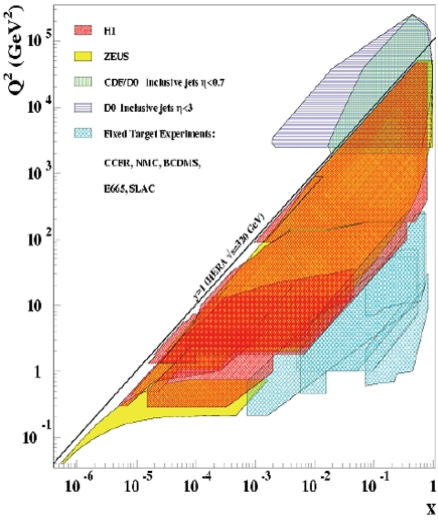
- $f(x, Q^2)$ is the probability of finding parton with momentum fraction x inside a proton at the scale Q^2.
- Measured in DIS experiments (mostly in ep collisions, but $p\bar{p}$ or pp examines different parts of x, Q^2 space)



Proton Structure - PDF at Tevatron

- Different reach than in ep - high p_{T} - high x, high Q^2
- Possible constrains on PDFs



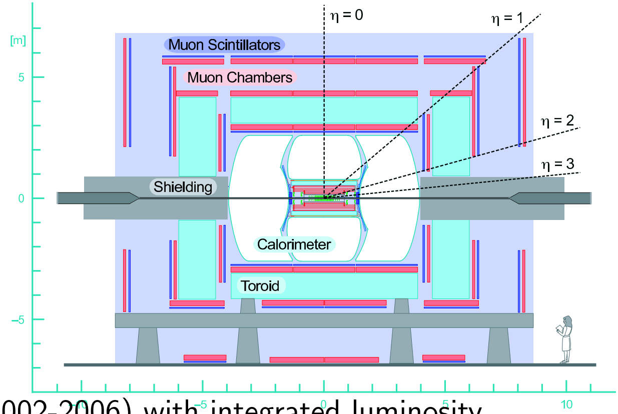


Other Motivation

Production of vector bosons with jets:

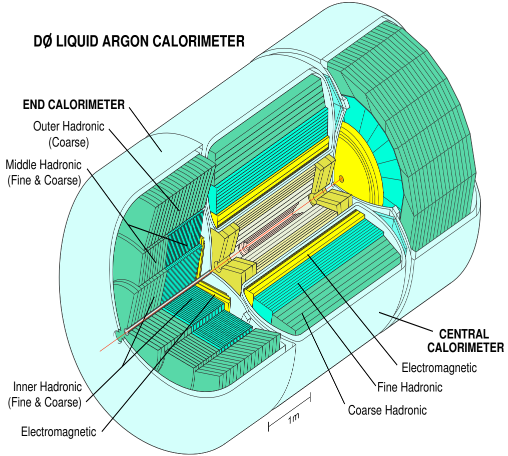
- Jet(s) balancing the vector boson in p_{T}
- QCD background to various interesting processes (top, new physics, etc ...)
- The best process at the Tevatron to find Higgs - in associated production with vector bosons $H \rightarrow WH$ and $H \rightarrow ZH$ with W, Z bosons decaying leptonically and Higgs into pair of $b\bar{b}$ jets

Tevatron and DØ Detector



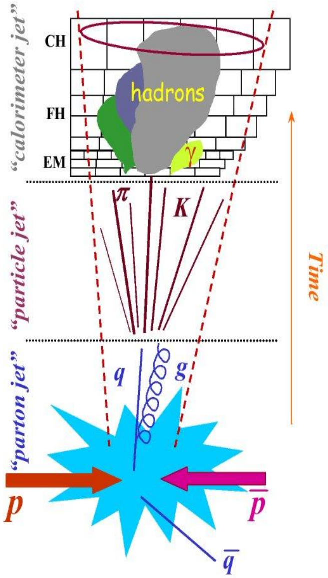
- $\sqrt{s} = 1.96\mathrm{TeV}$
- Luminosities $> 10^{32}\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$
- Finished RunIIa (2002-2006) with integrated luminosity $\sim 1.2\mathrm{fb}^{-1}$
- Starting RunIIb - aim at $4 - 8\mathrm{fb}^{-1}$

DØ Calorimeter



- Uranium-Liquid Argon Calorimeter
- Uniform hermetic coverage
  $|\ \eta\ | \leq 4.2$
  $[\eta \equiv -\ln\tan(\theta/2)]$
- Fine segmentation
  (up to $|\ \eta\ | < 3.2$)
  $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

Jets



- Calorimeter jet
  - interaction of hadrons with calorimeter
  - collection of calorimeter cell energies
- Particle jet
  - after hadronization and fragmentation
  - effect of hadronization is soft $\Rightarrow$ allows comparison between particle and parton jets
- Parton jet
  - hard scattering
  - additional showers

Run II Cone Jet Algorithm

- Uses particles as **seeds**
  - experiment - calorimeter clusters (above given threshold)
  - MC - stable particles
  - pQCD - partons
- Uses 4-vector scheme
  - p_{T} instead of E_{T}
  - rapidity $y = \frac{1}{2} \ln \frac{E+p_z}{E-p_z}$ instead of pseudorapidity η
- Combines 4-vectors within a cone of radius $R_{\mathrm{cone}} = 0.7$ in $y \times \phi$

$$\Delta R = \sqrt{(\Delta y)^2 + (\Delta \phi)^2} < R_{\mathrm{cone}}$$

- Calculates jet axis - iterates until the solution is stable
- Adds midpoints between jets as additional seeds $\Rightarrow$ infrared safe
- Removes identical solutions, and treats overlapped jets (split-merge fraction 50%, jet $p_{\mathrm{T}}^{\mathrm{min}} = 6\mathrm{GeV}$)

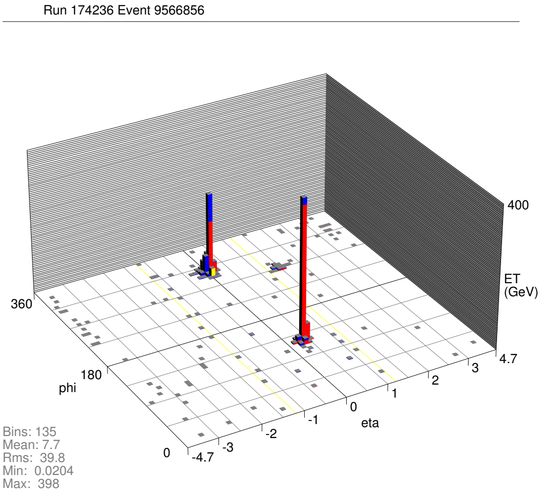
Jet Energy Scale

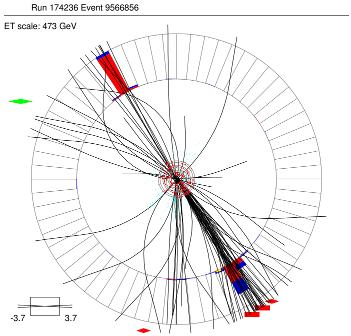
- Measured energy is corrected to particle level

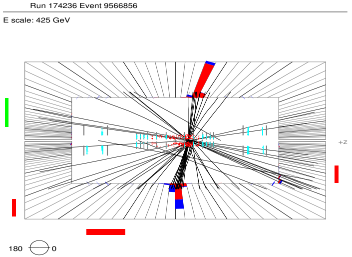
$$E^{\text{ptcl}} = \frac{E^{\text{cal}} - O}{\mathcal{F}_\eta \cdot R \cdot S}$$

  - Offset (O) is energy not associated with hard scattering
  - $\eta-$dependent corrections ($\mathcal{F}_\eta$) uniforms the response in η
  - Response (R) is the calorimeter response to jets
  - Showering (S) is the correction for fraction of energy outside the jet cone after showering in the calorimeter
- Dominant uncertainty of the measurements
- Final version to be completed by this summer (with the complete RunIIa dataset $\Rightarrow$ reduced statistical and systematical uncertainties)

Highest p_T Event





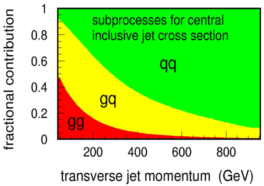


	1st jet	2nd jet
p_T	624 GeV	594 GeV
y_{jet}	0.14	-0.17
ϕ_{jet}	2.10	5.27

$M_{jj} = 1220\text{GeV}$

mE_t: 20.8
phi_t: 295 deg

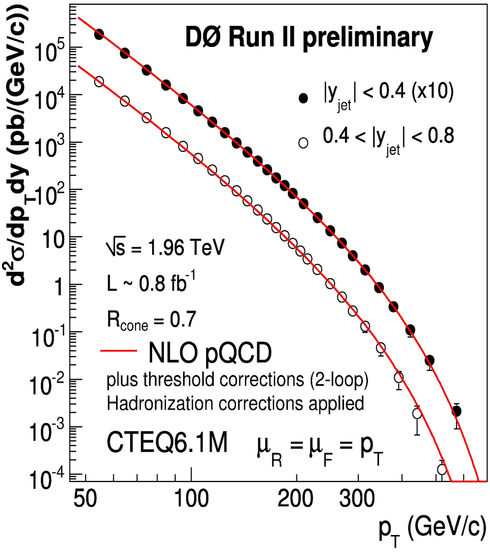
Inclusive jet pT spectrum motivation



- Curiosity of excess of high p_{T} jets by CDF in RunI
- PDF not well constrained at high x (especially gluon) - increased gluon density can explain the CDF result
- Highest energy available, largest datasample, ...
- The nature of the basic interaction between quarks and gluons
- Possible new physics - quark substructure, ...

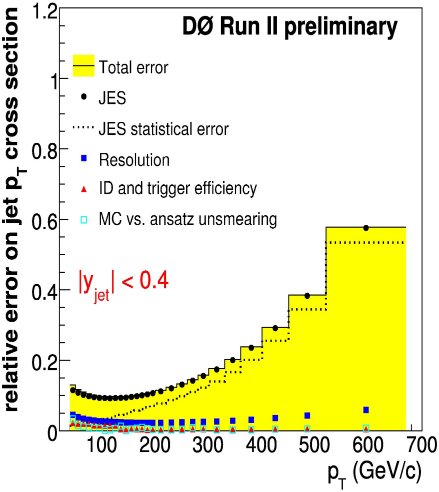
Inclusive jet pT spectrum (Results)

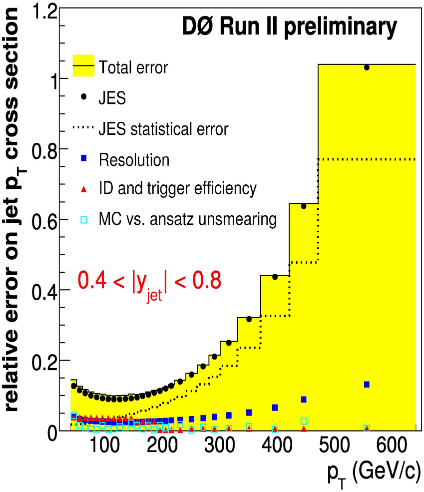
- Data scaled to NNLO-NLL theory at $p_{\mathrm{T}} = 100\mathrm{GeV}$ to remove luminosity uncertainty
- NLO predictions computed using fastNLO (based on NLOJet++, *Z. Nagy, Phys. Rev. Lett. 88, 122003,2002*) with CTEQ6.1M
- NNLO-NLL corrections computed using threshold resumation techniques (*Kidonakis et. al, Phys. Rev. D63, 054019, 2001*)



Total uncertainties

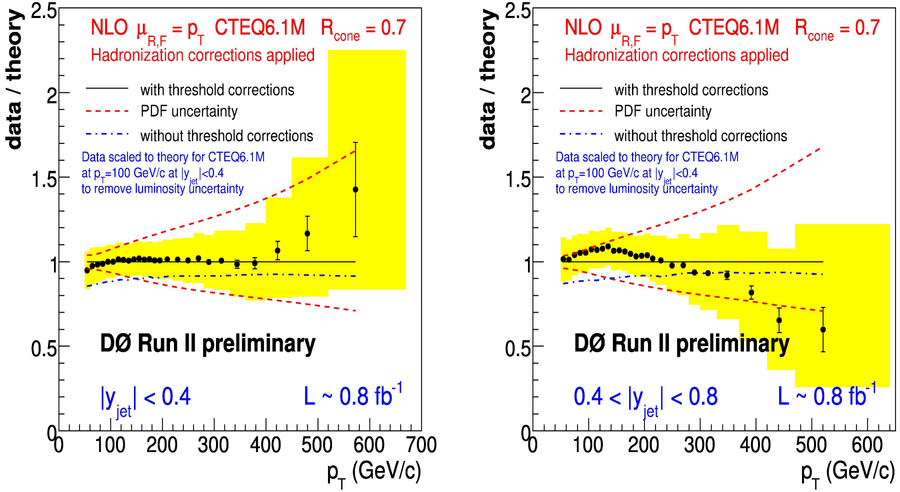
- Dominated by Jet energy scale (to be improved)





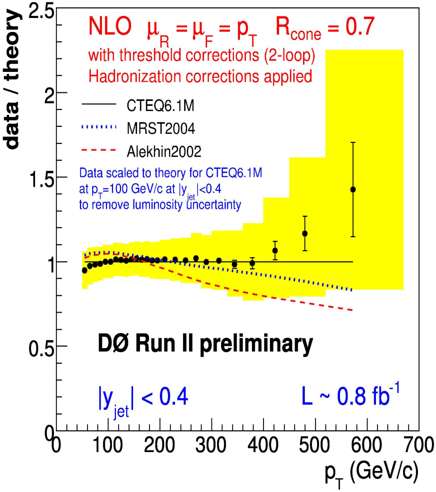
Theory comparison

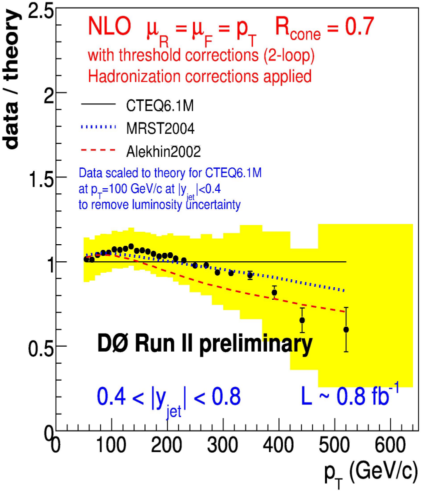
- Present JES uncertainty is large → should improve by Summer



Inclusive jets - PDF sensitivity

- Sensitive to different PDF sets





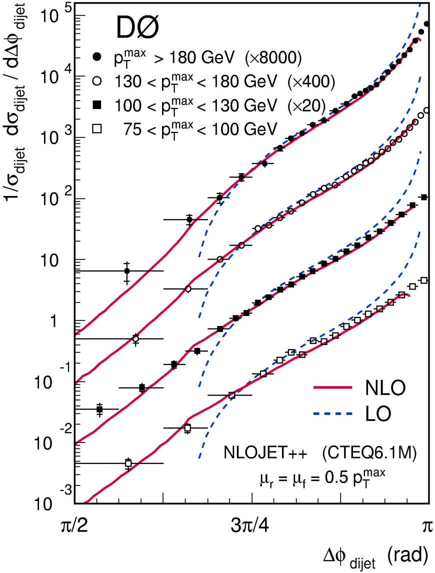
Dijet Azimuthal decorrelations

Measure $\Delta\phi$ between two leading jets

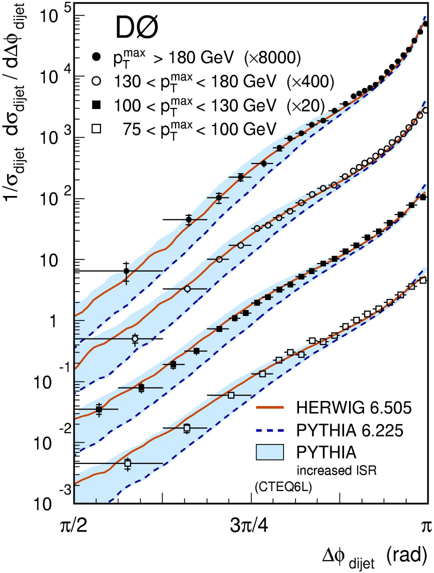
- Dijet production in lowest order pQCD
  - jets have equal p_{T} and $\Delta\phi_{\mathrm{dijet}} = \pi$
- Additional soft radiation causes small azimuthal decorrelations
  - $\Delta\phi_{\mathrm{dijet}} \sim \pi$
- Hard radiation can lead to larger decorrelations
  - $2/3\pi \leq \Delta\phi_{\mathrm{dijet}} < \pi$ for three-jet production
  - $\Delta\phi_{\mathrm{dijet}} < 2/3\pi$ for four-jet production

$\Rightarrow$ $\Delta\phi_{\mathrm{dijet}}$ is sensitive to higher order QCD radiation without explicitly measuring third and fourth jets

DeltaPhi



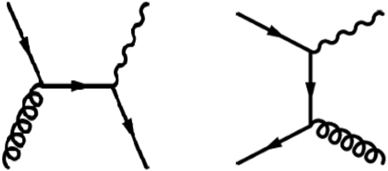
DØ
p_T^{max} > 180 GeV (×8000)
130 < p_T^{max} < 180 GeV (×400)
100 < p_T^{max} < 130 GeV (×20)
75 < p_T^{max} < 100 GeV
NLO
LO
NLOJET++ (CTEQ6.1M)
$\mu_r = \mu_f = 0.5\ p_T^{max}$
$1/\sigma_{dijet}\ d\sigma_{dijet} / d\Delta\phi_{dijet}$
$\Delta\phi_{dijet}$ (rad)
π/2
3π/4
π



DØ
p_T^{max} > 180 GeV (×8000)
130 < p_T^{max} < 180 GeV (×400)
100 < p_T^{max} < 130 GeV (×20)
75 < p_T^{max} < 100 GeV
HERWIG 6.505
PYTHIA 6.225
PYTHIA
increased ISR
(CTEQ6L)
$1/\sigma_{dijet}\ d\sigma_{dijet} / d\Delta\phi_{dijet}$
$\Delta\phi_{dijet}$ (rad)
π/2
3π/4
π

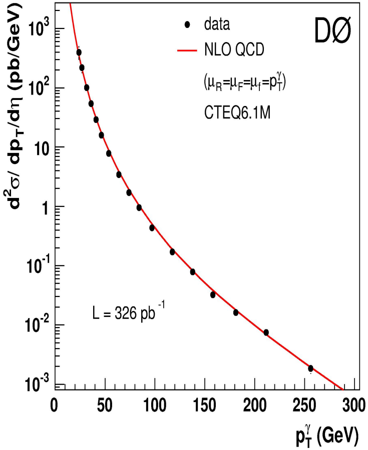
Inclusive photon cross-section (Motivation)

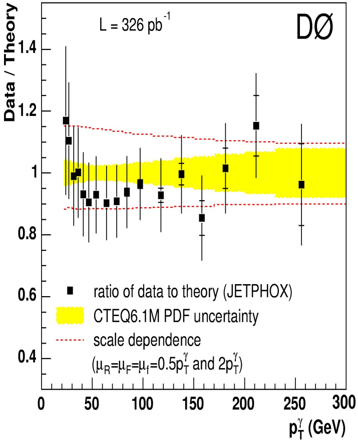
- Isolated photons produced quark-gluon Compton scattering or quark anti-quark annihilations



- Studies of production of isolated high-p_{T} photons are test of pQCD and provide information about the distribution of partons within protons, particularly about gluon (appears in LO)

Inclusive photon cross-section (Results)





W Charge Assymetry Motivation

W^+ boson is produced mostly by u quark from proton and $\bar{d}$ from antiproton. W^- by d quark from proton and $\bar{u}$ from antiproton. Most of the Ws is produced by valence-valence and valence-sea annihilations (85% at the Tevatron).

Measuring the $W^\pm$ rapidity provides useful information about the PDFs of u and d quarks.

$$x_{1(2)} = \frac{M_W}{\sqrt{s}} e^{(\pm) y_W}$$

Allowing to measure PDFs at $Q^2 \approx M_W^2$ and x between 0.005 and 0.3 (for $-2 < y_W < +2$).

W Charge Asymmetry Motivation cont'd

On average u valence quarks carry more of the proton momentum than d valence quarks, therefore W^+ is boosted along the proton beam direction (and W^- along antiproton beam direction).

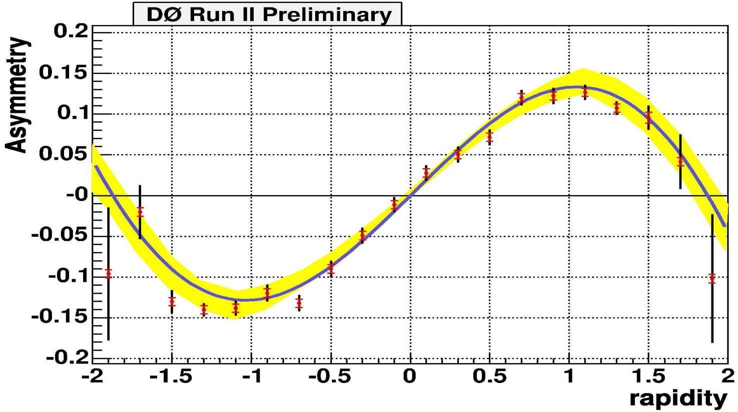
$$A(y) = \frac{\frac{\mathrm{d}\sigma(W^+)}{\mathrm{d}y} - \frac{\mathrm{d}\sigma(W^-)}{\mathrm{d}y}}{\frac{\mathrm{d}\sigma(W^+)}{\mathrm{d}y} + \frac{\mathrm{d}\sigma(W^-)}{\mathrm{d}y}} \rightarrow \frac{d(x)}{u(x)}$$

W charge assymetry is difficult to measure directly - in $W \rightarrow \ell\nu_\ell$, the longitudinal component of neutrino's momentum can't be measured. But we can measure the lepton charge asymmetry (muon it this analysis) and with the known $W \rightarrow \ell\nu$ coupling we can deduce the W charge assymetry

Muon Charge Asymmetry

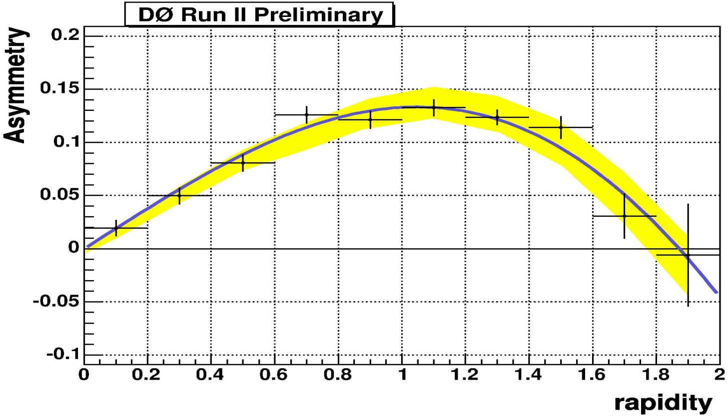
The muon charge asymmetry is defined as

$$A(y_\mu) = \frac{\frac{\mathrm{d}\sigma(\mu^+)}{\mathrm{d}y} - \frac{\mathrm{d}\sigma(\mu^-)}{\mathrm{d}y}}{\frac{\mathrm{d}\sigma(\mu^+)}{\mathrm{d}y} + \frac{\mathrm{d}\sigma(\mu^-)}{\mathrm{d}y}}$$



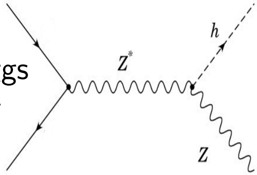
Muon Charge Asymmetry

- Corrected and CP folded muon charge asymmetry with combined statistical and systematical uncertainties
- Statistical uncertainties (only 230pb^{-1}) larger than systematic uncertainties - still place for improvement



Z+jet Motivation

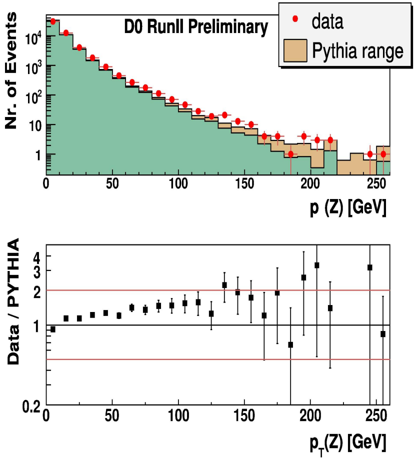
- Heavy resonance production - $qg \to q^* \to Zq \to e^+e^-q$
- MC tuning (Pythia, Sherpa)
- Important background for new physics
- Tevatron's best possibility to find (light) Higgs
  $p\bar{p} \to HZ \to b\bar{b}\nu\nu(b\bar{b}\ell\ell), H \to HW \to b\bar{b}\ell\nu$



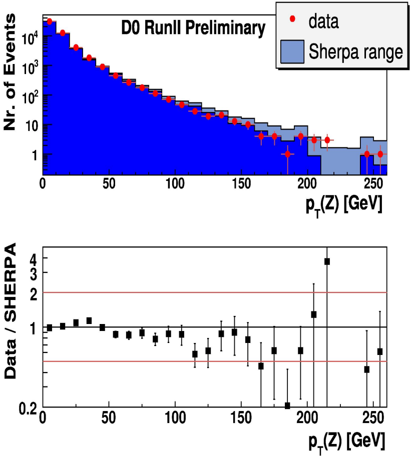
Z+jet Measurement

- Generally good agreement

Pythia

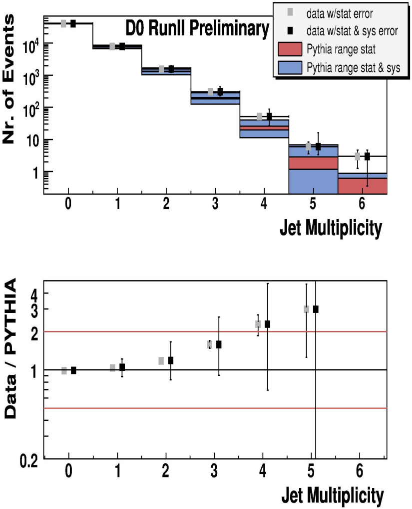


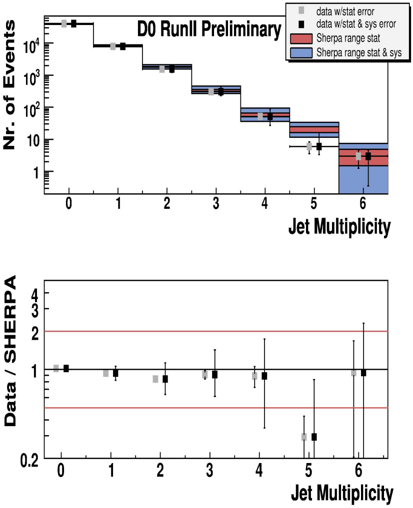
Sherpa



Z+jet Measurement cont'd

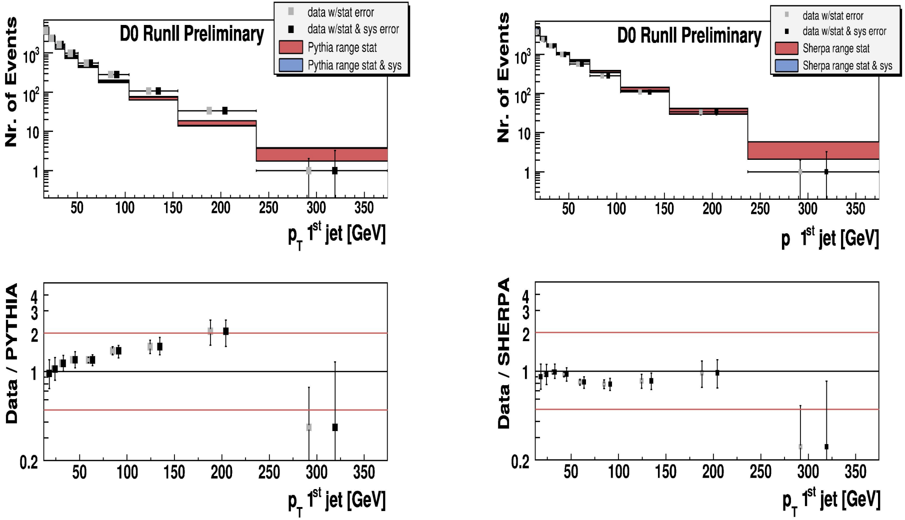
- Pythia predicts fewer hard jets than seen in data





Z+jet Measurement cont'd

- Leading jet comparison



Conclusions

- Proton structure investigated at the highest energy currently available
- Improvement in JES over the past year - uncertainties comparable to DØ RunI
- Several DØ measurements can constrain PDF and can help in tuning Monte Carlo models
- Plans for improvment
  - Final Jet Energy Scale by summer with reduced uncertainties
  - Use as large dataset for the measurements as possible