Jet Production Measurements at DØ

Jochen Cammin

University of Rochester

for the DØ Collaboration

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- Introduction
- Inclusive jet cross section
- High p_T μ-tagged cross section
- Z+jets measurement
- Summary

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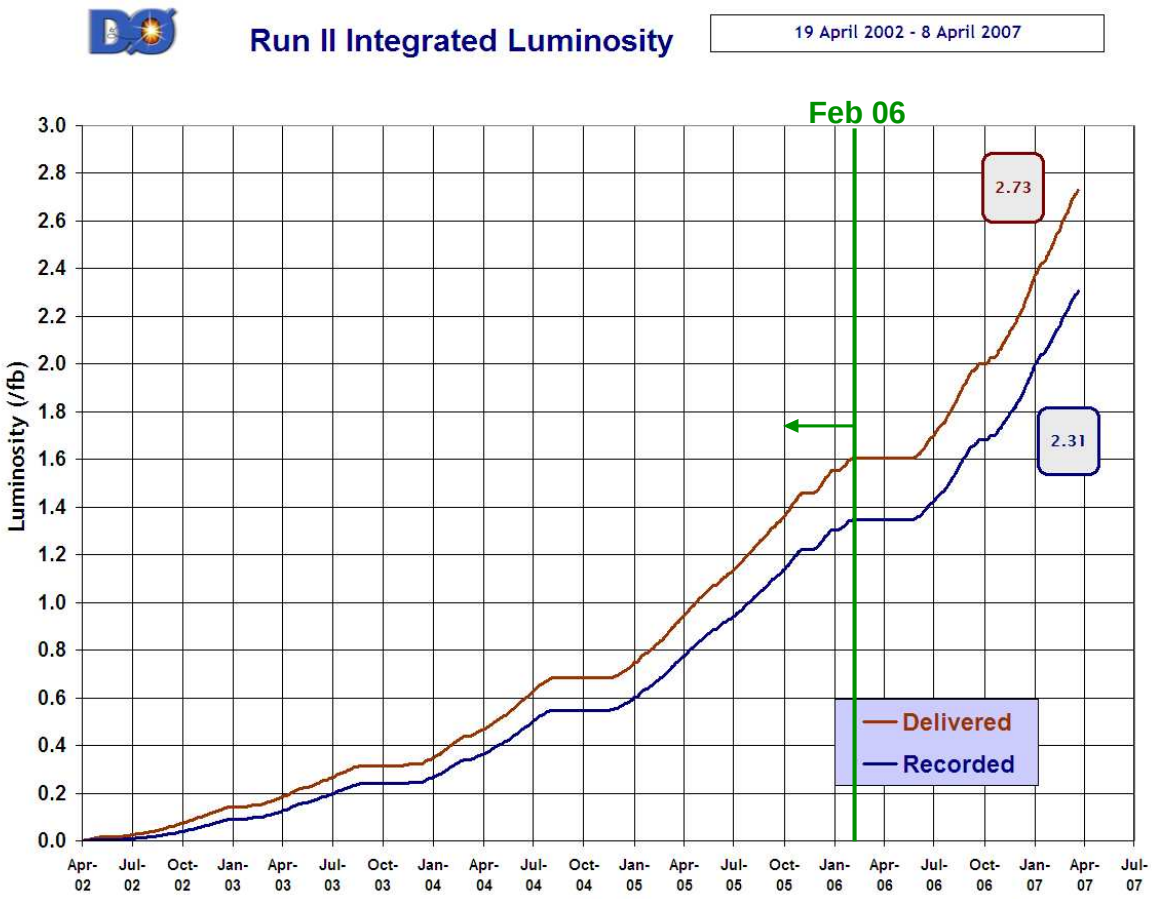
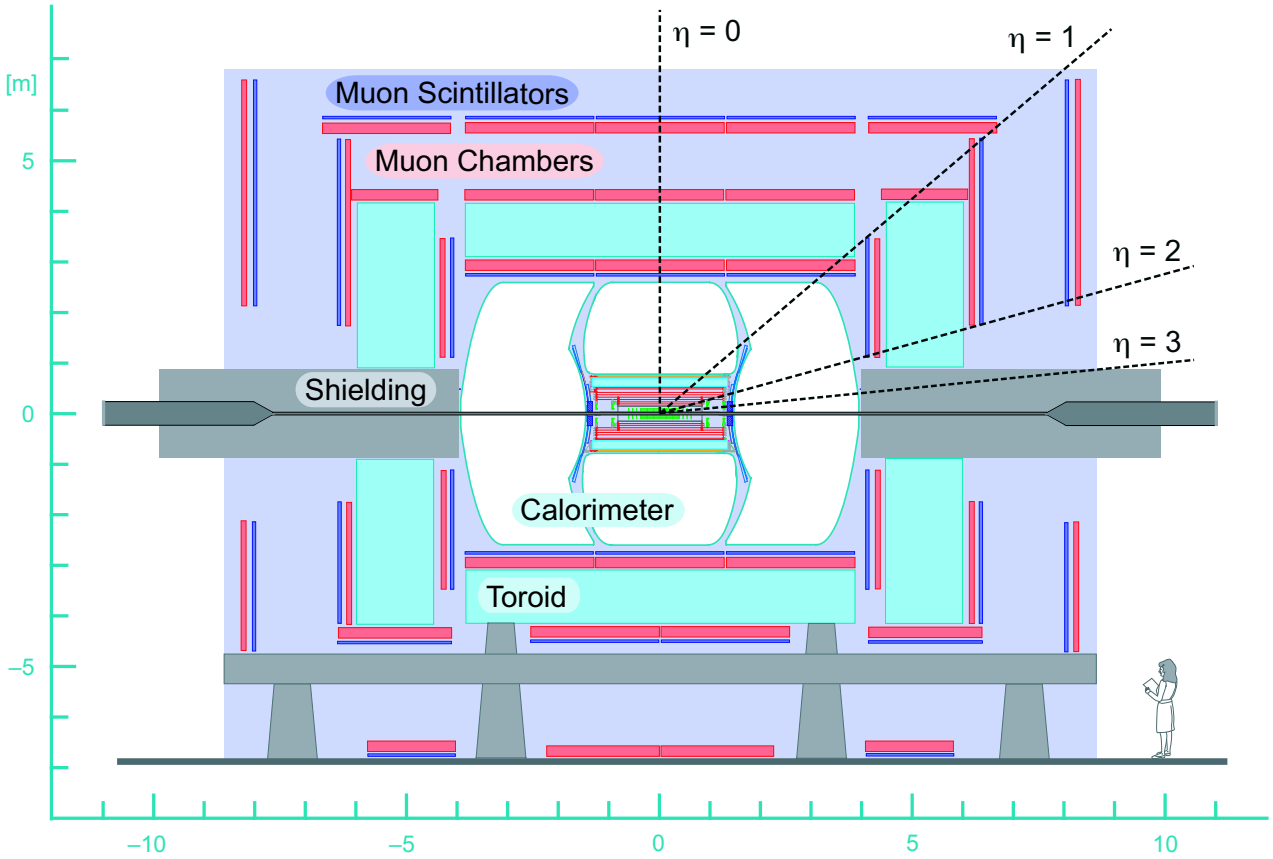
The Tevatron

- $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV (Run II).
- Delivered integrated luminosity: 2.73 fb^{-1}.
  Recorded integrated luminosity: 2.31 fb^{-1} (as of Apr 08, 2007).
- Presented analyses use up to the full Run II A dataset.

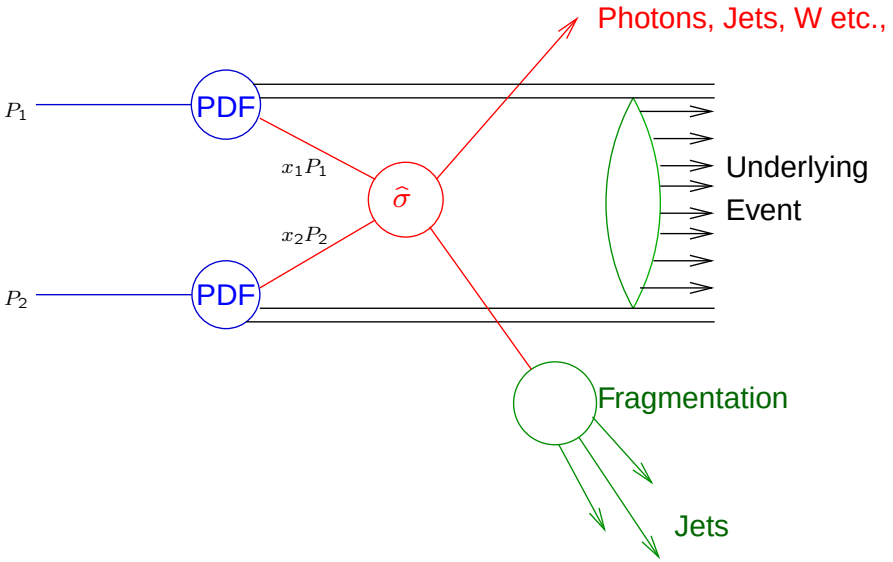


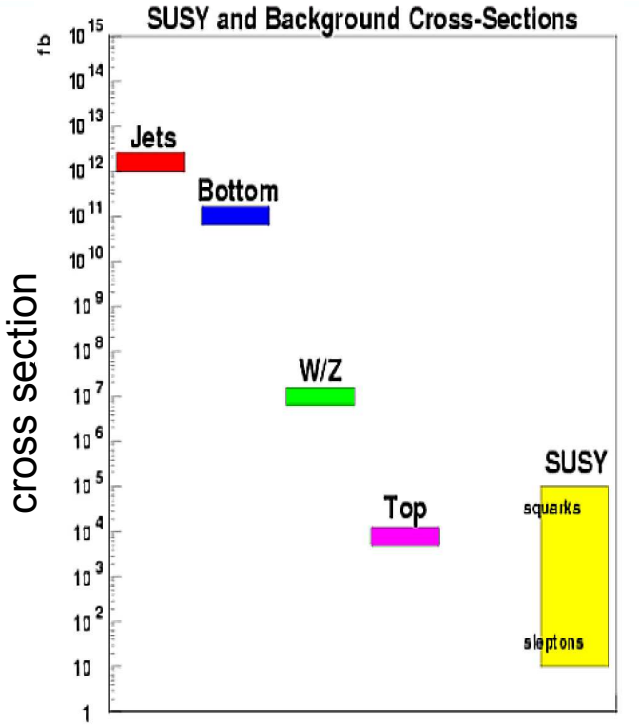
The DØ Detector



- **Tracking**
  Silicon microstrip and scintillating fiber tracker / 2T magnetic field / Central and forward preshower detectors / Coverage: $|\eta| < 3$.
- **Calorimeter**
  Liquid Argon Uranium / 4 EM and 7 hadronic layers / Coverage: $|\eta| < 4.2$.
- **Muon Detector**
  Drift tubes and scintillators / 1.8T toroid / coverage: $|\eta| < 2$.

Cross sections predictions require PDF inputs





$$\sigma = \Sigma \int dx_1 dx_2 f(x_1, p_T) f(x_2, p_T) \hat{\sigma}$$

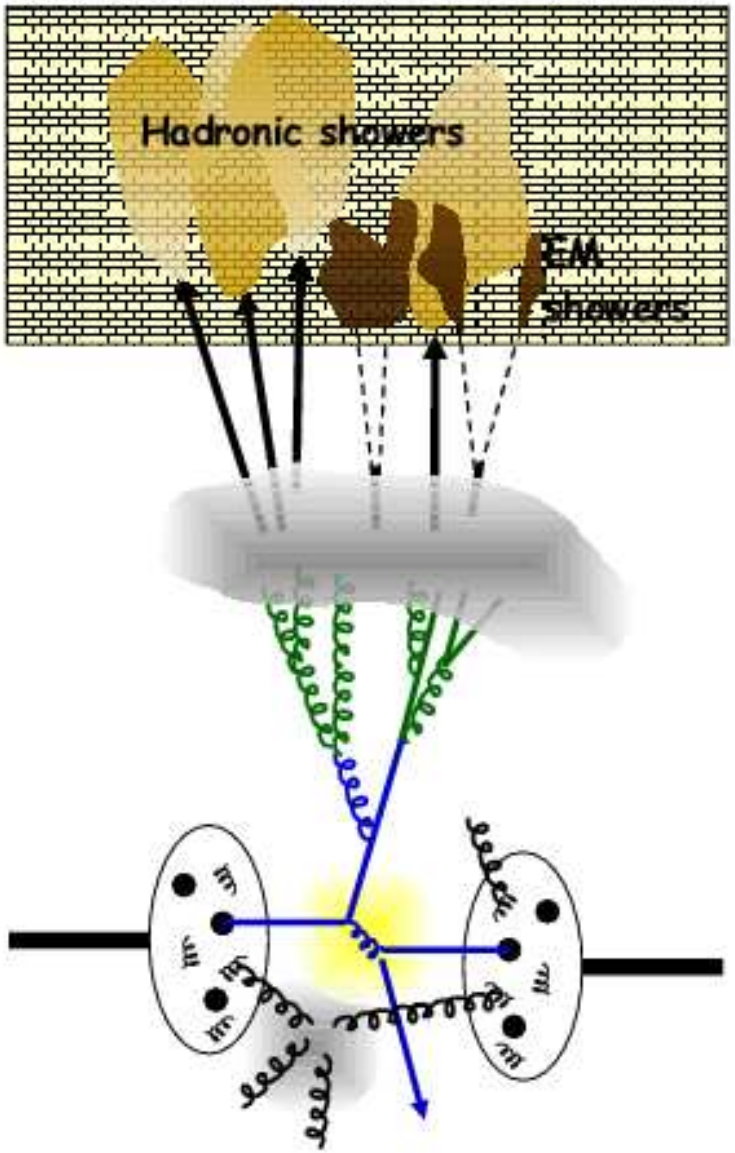
$x_{1,2}$: Momentum fraction of proton carried by struck parton

p_T: Jet transverse momentum

Measurements of jet production important for...

- determination of parton density functions (PDFs),
- tests of perturbative QCD, fragmentation, higher-order calculations,
- sensitivity to new physics at highest energies, not reached by other processes
- understanding of background for other analyses (top, Higgs, W/Z, ...)

Jets: Relating Measurement and Prediction

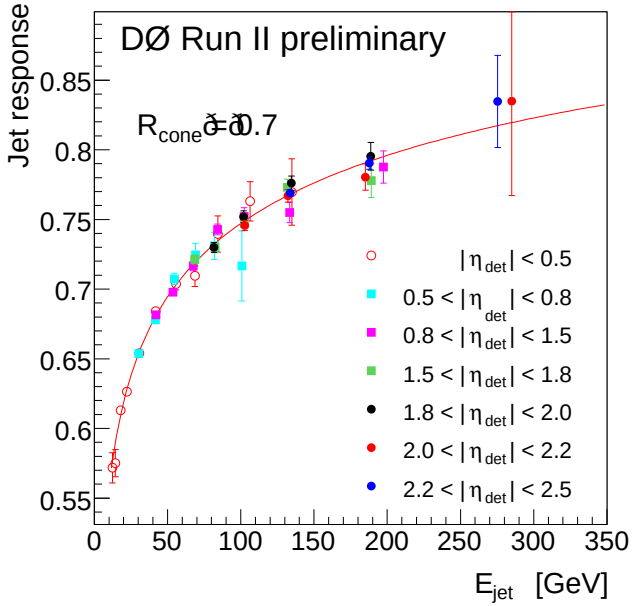


- **Detector level**
  - Energy depositions in calorimeter.
  - Jet algorithms to combine clusters into jets (DØ uses Run II Midpoint Cone algorithm).
  - Corrections for resolution and efficiency, energy offset (minimum bias, pile-up, noise).
- **Particle level**
  - Simulation: apply jet algorithms to stable particles.
  - Data: correct for differences between particle jets and calorimeter jets.
- **Parton level**
  - Model hard and soft interactions (PDFs, initial and final state radiation, fragmentation, hadronization, underlying event, beam interactions, . . .)

Jet Energy Scale

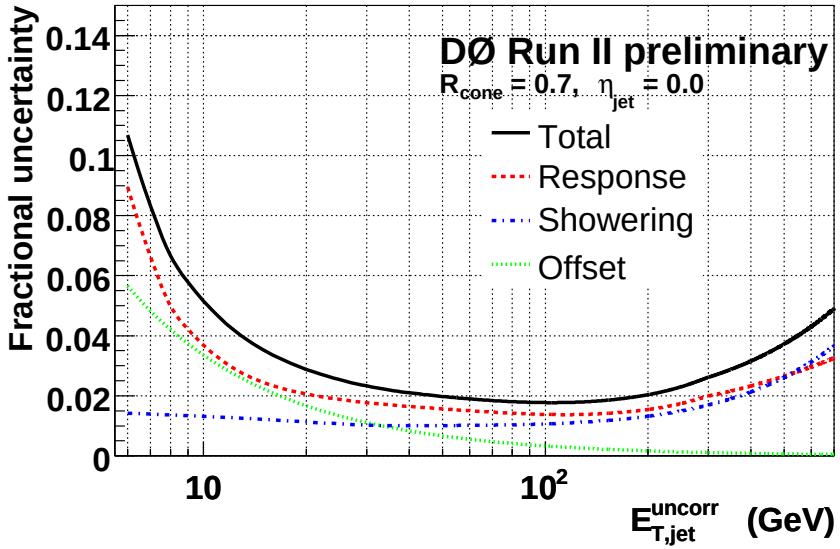
Jet energy scale corrects measured energy back to particle level.

$$E_{ptcl} = \frac{E_{cal} - \text{Offset}}{\text{Response} \times \text{Showering}}$$



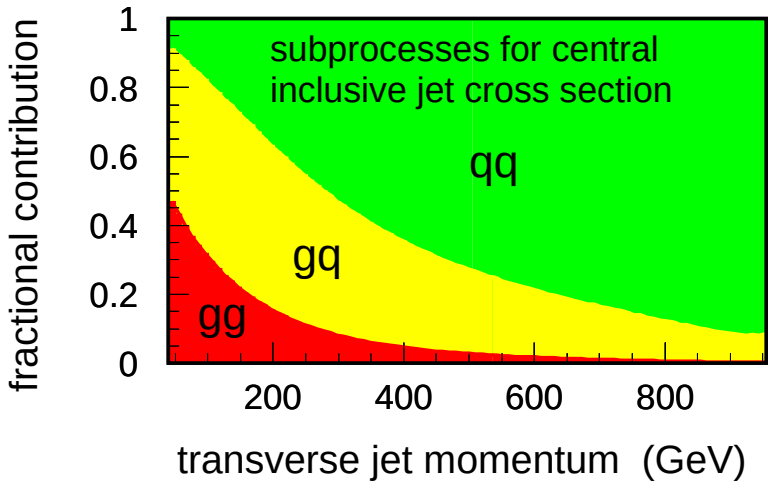
- Offset: energy not originating from hard process (underlying event, pile-up, noise).
- Response: absolute $R_j(E)$ and relative $R_j(\eta)$.
- Showering: energy leaking inside/outside jet cone (detector effects only).

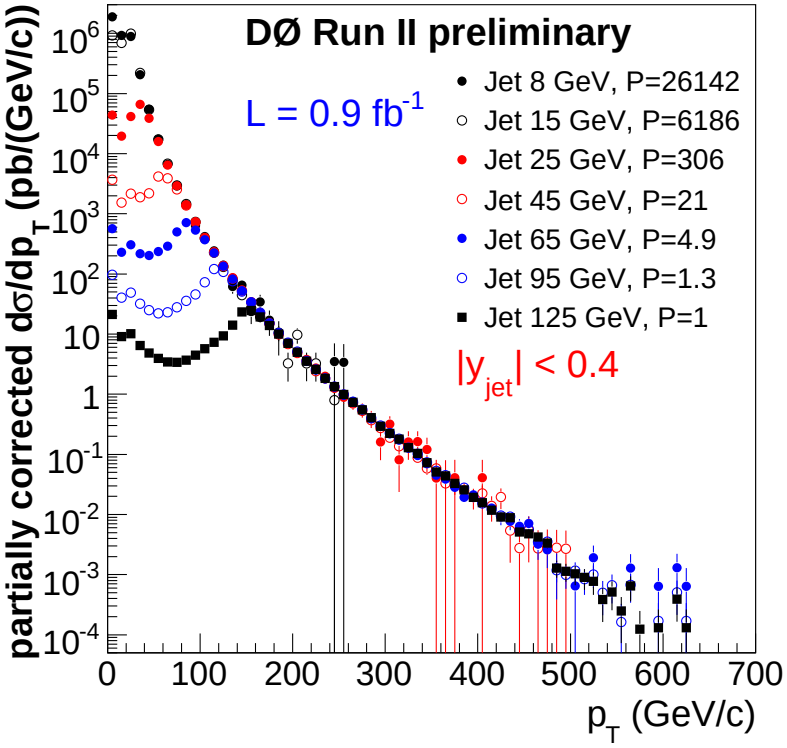
JES uncertainties



Inclusive Jet Production

- Inclusive jet cross section: count all jets in event. $\mathcal{L} = 0.9$ fb^{-1}.
- High-p_T cross section dominated by $q\bar{q}$ interaction.



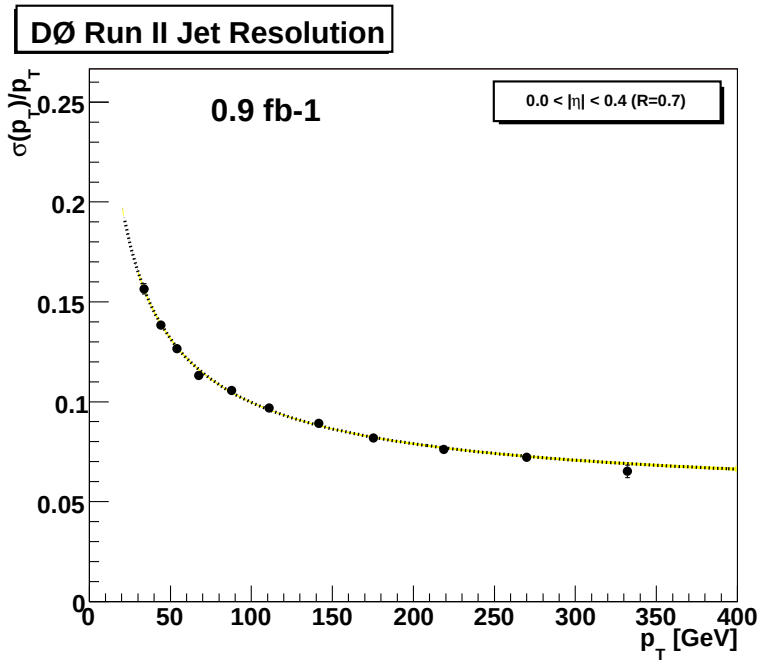


- Use single jet triggers with different p_T threshold to cover large range.
- Sensitive to new physics at high p_T.

Corrections

Jet p_T resolution

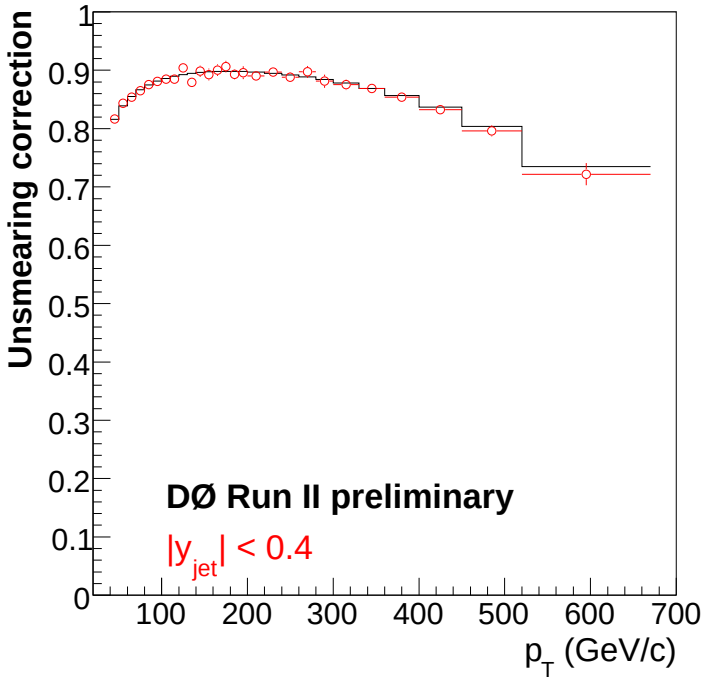
- Measured in dijet data events.
- $A = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$.
- $\frac{\sigma_{p_T}}{p_T} = \sqrt{2}\,\sigma_A$.
- Additional corrections for soft radiation and particle level imbalance.



Unsmearing

- Use ansatz function smeared with Gaussian p_T resolution.
- Correct data by ratio of original to smeared ansatz function.
- Cross check with Pythia jets smeared by p_T resolution.

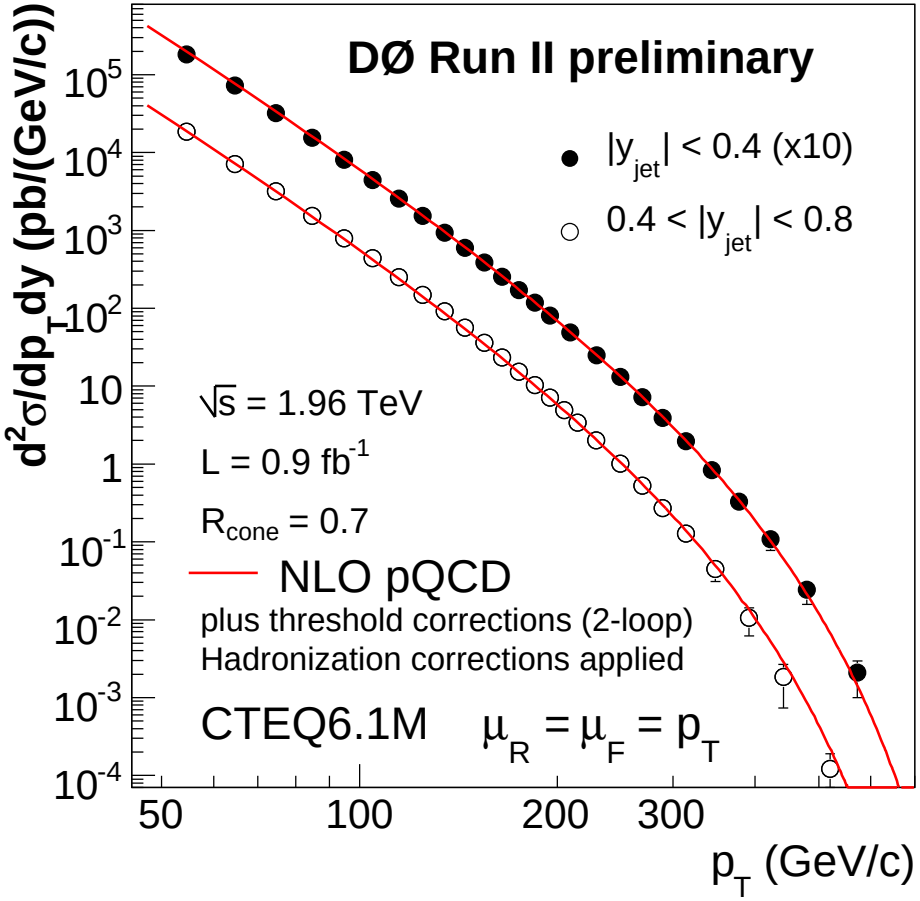
line : ansatz, circles: smeared Pythia



Results on Inclusive Jet Cross Section

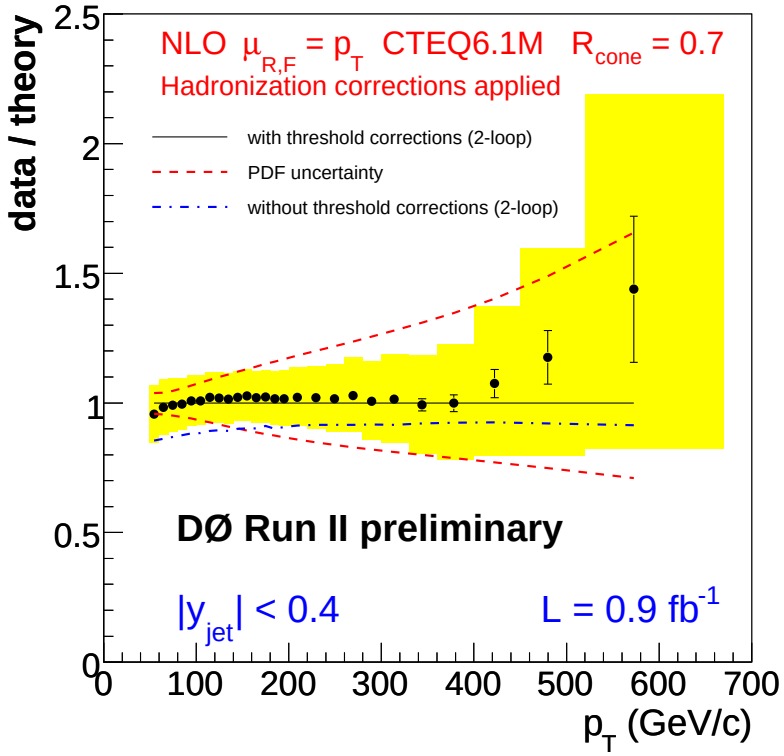
- After unsmearing.
- Data and NLO theory.
- Normalized to DØ luminosity.
- Good agreement with theory over large p_T range

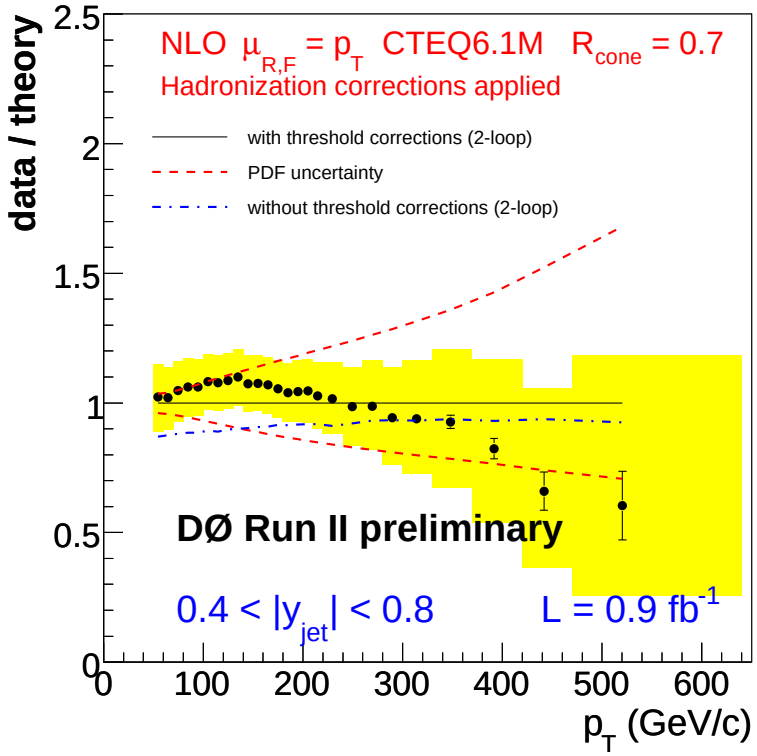
fastNLO based on NLOJet++ (Z. Nagy, Phys. Rev. Lett. 88, 122003, 2002) with CTEQ6.1M, threshold resummation (Kidonakis, Owens, Phys. Rev. D63, 054019, 2001).



Results and Theory Prediction

- Data / theory (CTEQ6.1M PDFs).
- Red lines: up/down variations of PDF parameters.
- Blue line: NLO cross section w/o threshold corrections.



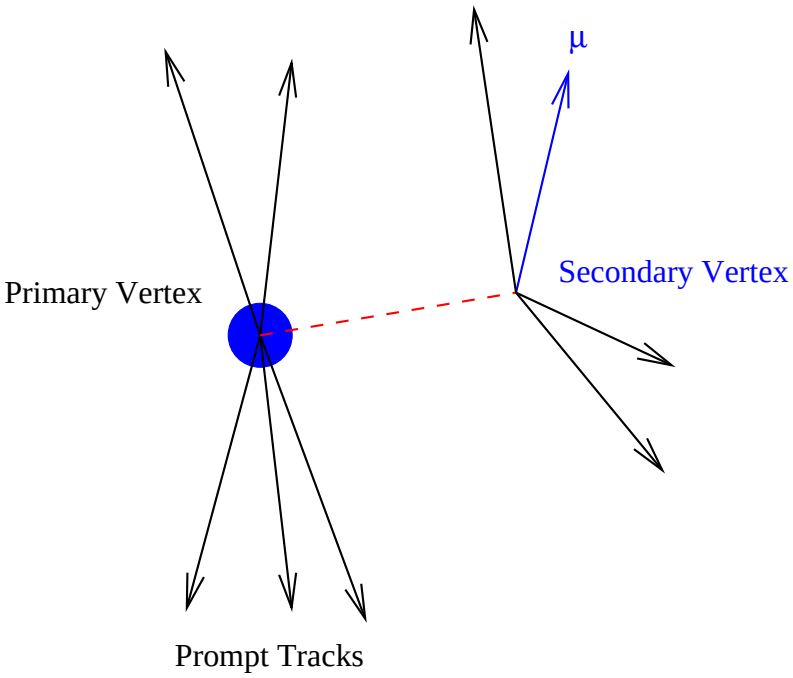


Systematic uncertainties dominated by jet energy scale.
Significant reduction expected from JES based on 1 fb^{-1} data set.

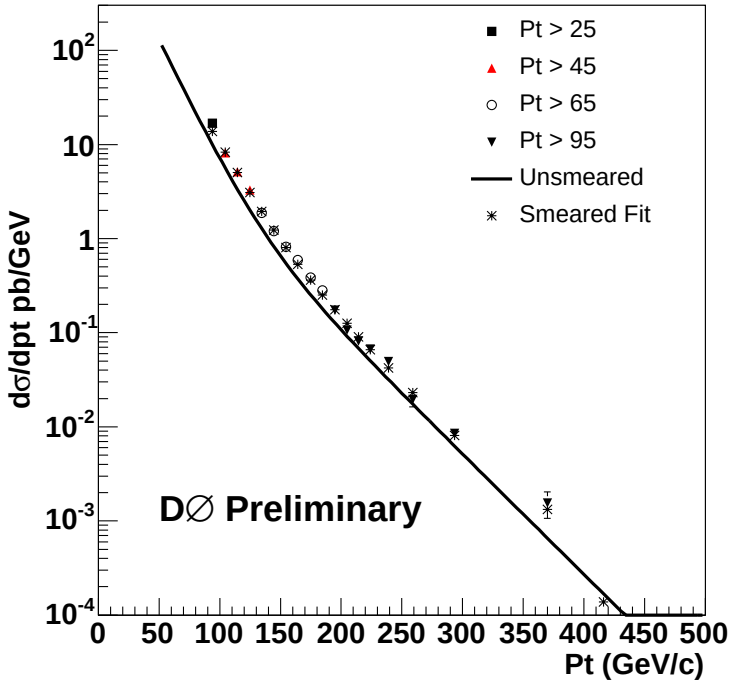
High p_T μ-tagged Cross Section

- Heavy flavor QCD production important background to many other analysis → needs to be understood well
- Possible to detect signs of new physics
- Identify ("tag") b jets by *soft lepton* in jet
- Based on $\mathcal{L} = 300$ pb^{-1}, $|y| < 0.5$, Run II Midpoint cone ($\Delta R = 0.5$)

Soft lepton tag

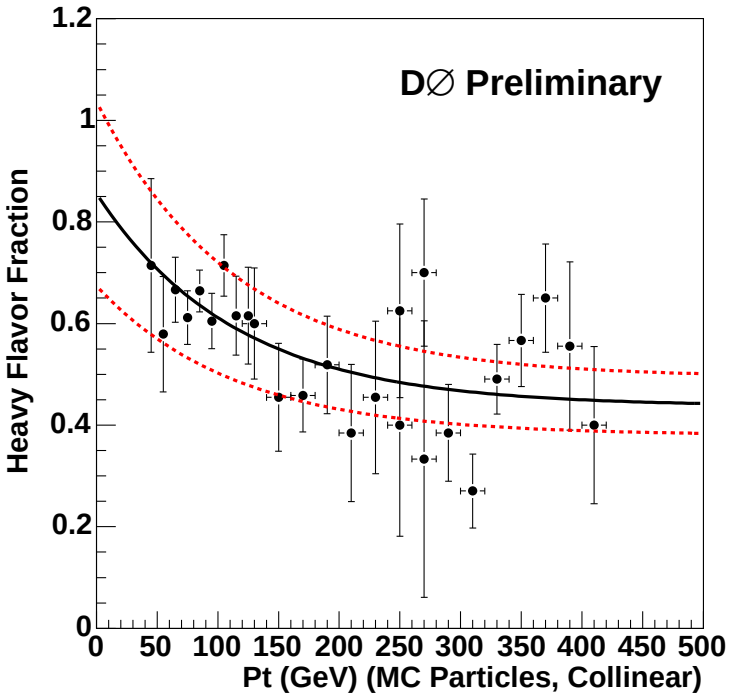


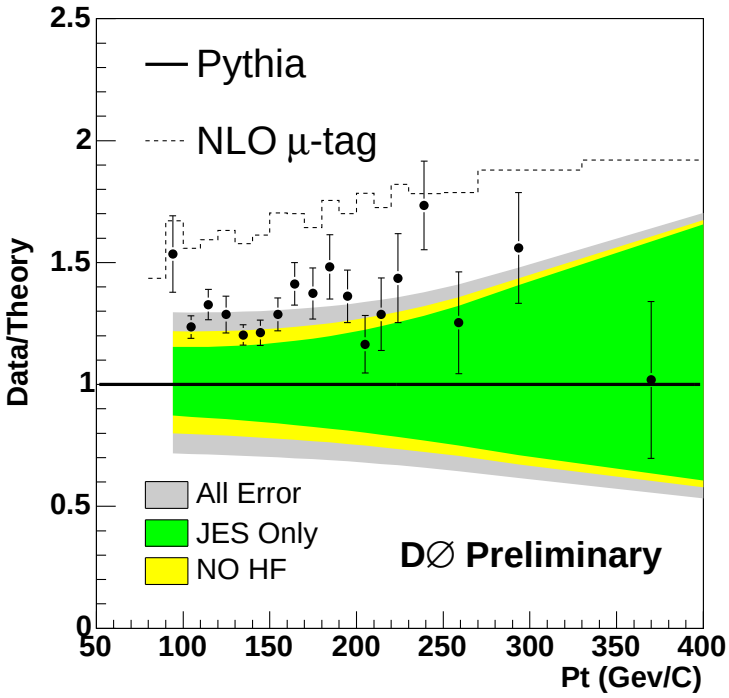
Need to unsmear to get to "true" jet p_T



High p_T μ-tagged Cross Section

- Flavor fraction estimation from simulation (20% uncertainty assigned).



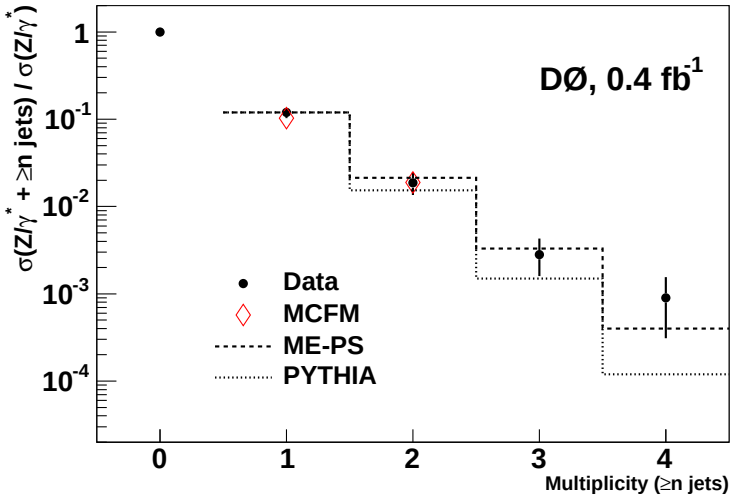


"NLO μ-tag": NLOJET++ and k-factor from Pythia for fraction of μ-tagged jets.

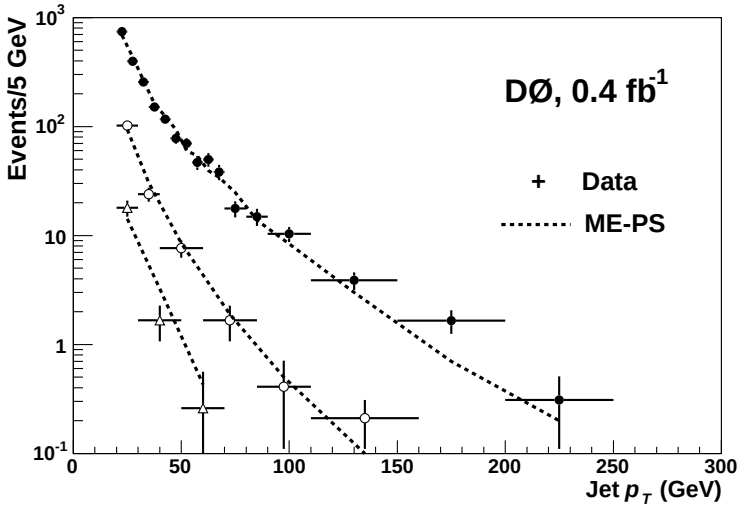
Z+jets Production

- Measure $Z/\gamma^* \to e^+e^- +$ jets ($\mathcal{L} = 400$ pb^{-1}).
- Smaller cross section than W+jets, but cleaner sample.
- $p_T^e > 25$ GeV, $|\eta_{det}^e| < 1.1$, $p_T^{jet} > 20$ GeV, $|\eta_{det}^{jet}| < 2.5$
- Mass constraint 75 GeV $< M_{ee} <$ 105 GeV.
- Compare to NLO/PS predictions.

Jet multiplicity



Jet p_T

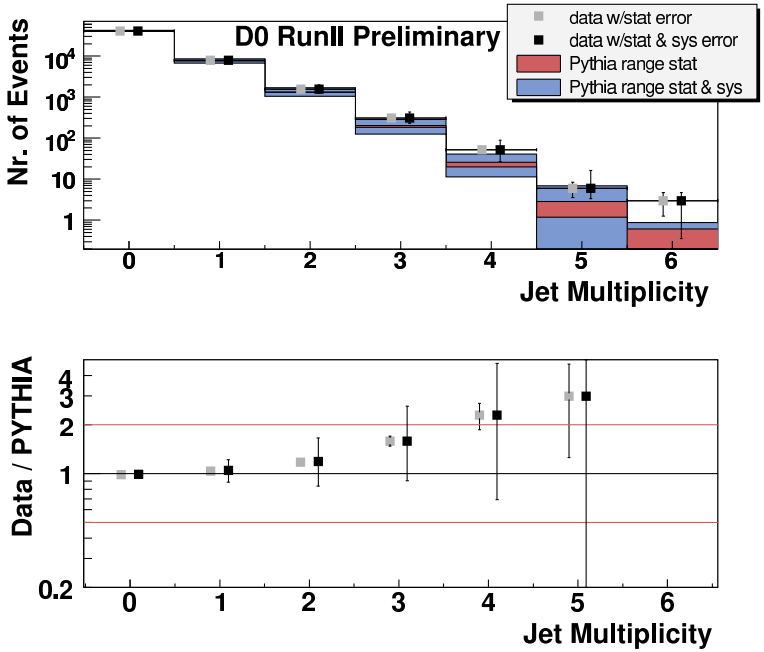


Z+jets: Comparison with Theory

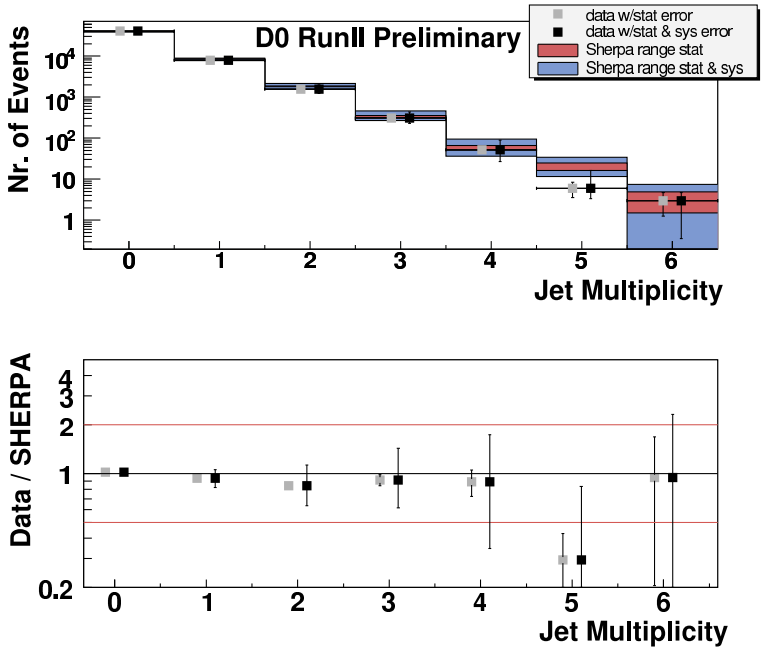
- $Z/\gamma^* \to e^+e^- +$ jets ($\mathcal{L} = 950$ pb^{-1}), compare data to predictions from Pythia and Sherpa.

- **Jet multiplicities**
- Pythia: too few jets at high multiplicity.

Pythia



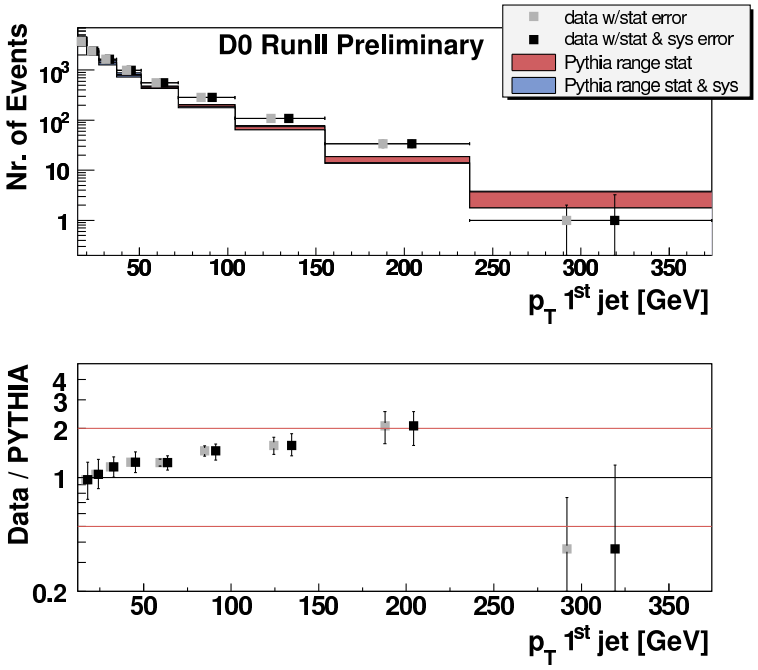
Sherpa



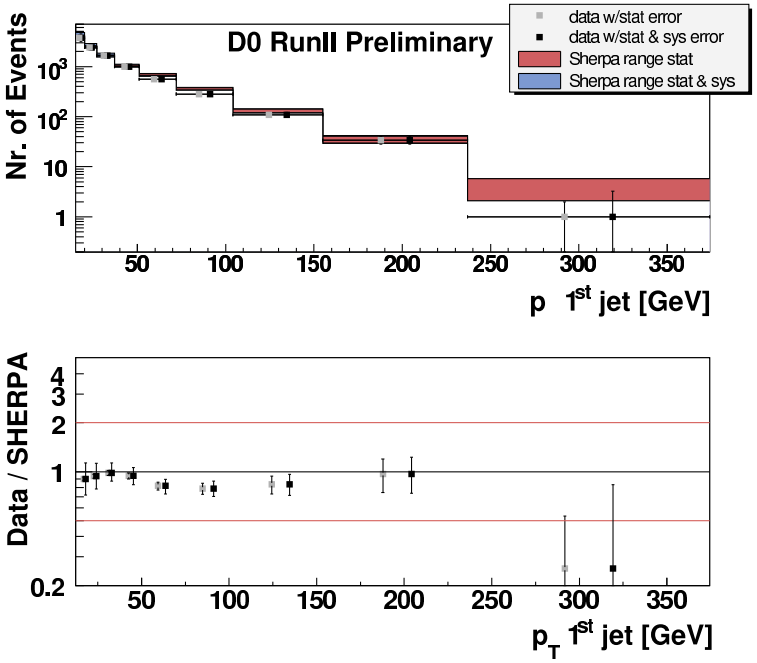
Z+jets: Comparison with Theory

- **p_T of leading jet**
- Pythia: spectrum too soft.

Pythia



Sherpa



More comparisons in backup slides.

Summary

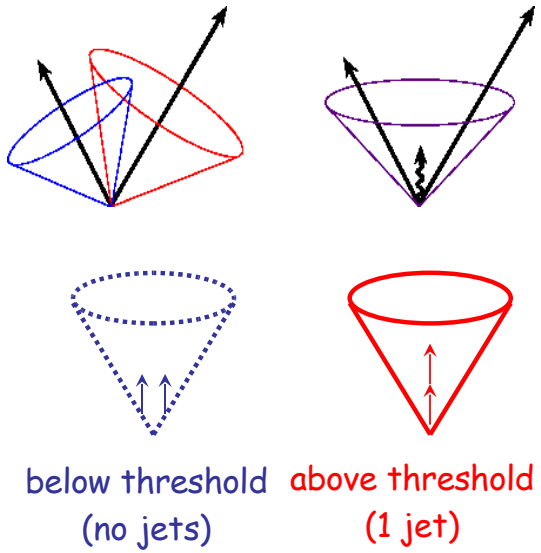
- Jet production measurements in Run II test the Standard Model and QCD in new kinematic energy domain.
- Big success in constraining theoretical models (for example gluon and quark PDFs).
- Updated inclusive jet cross section (DØ luminosity correction).
- Higher precision will be achieved soon with much improved jet energy scale.

BACKUP

Jet Algorithms

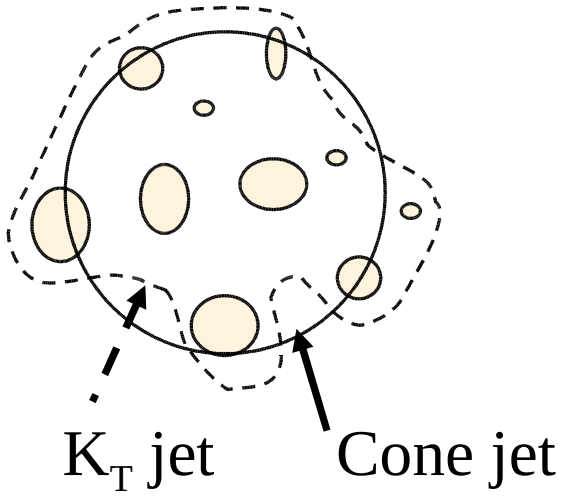
DØ uses Run II Midpoint (cone) algorithm

- Cluster seeds in $y - \phi$ space with fixed cone size (adding four-vectors).
- Use midpoints between jets (infrared safety).
- Iterate until stable.
- Merging/Splitting of jets.



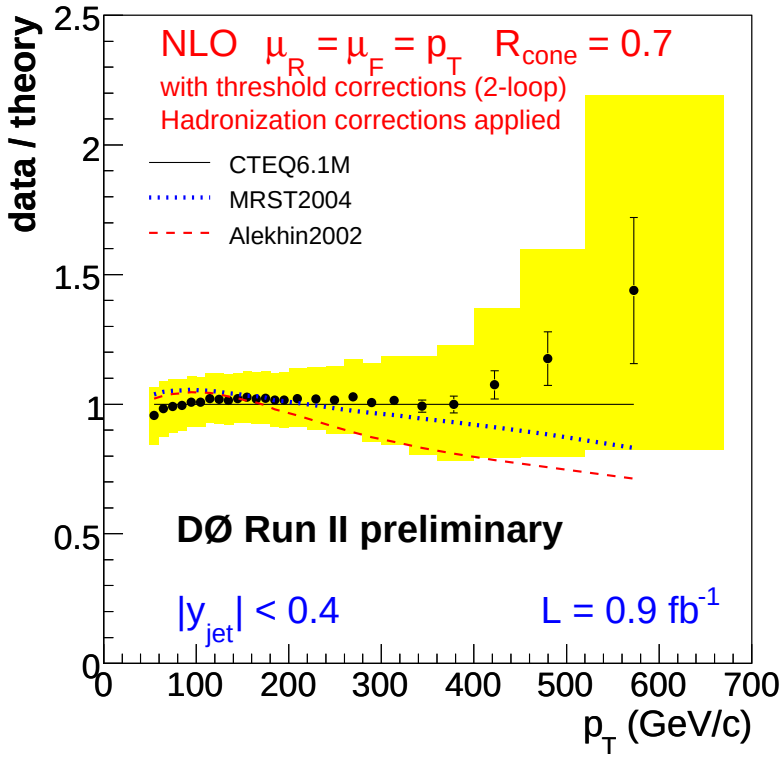
K_T algorithm

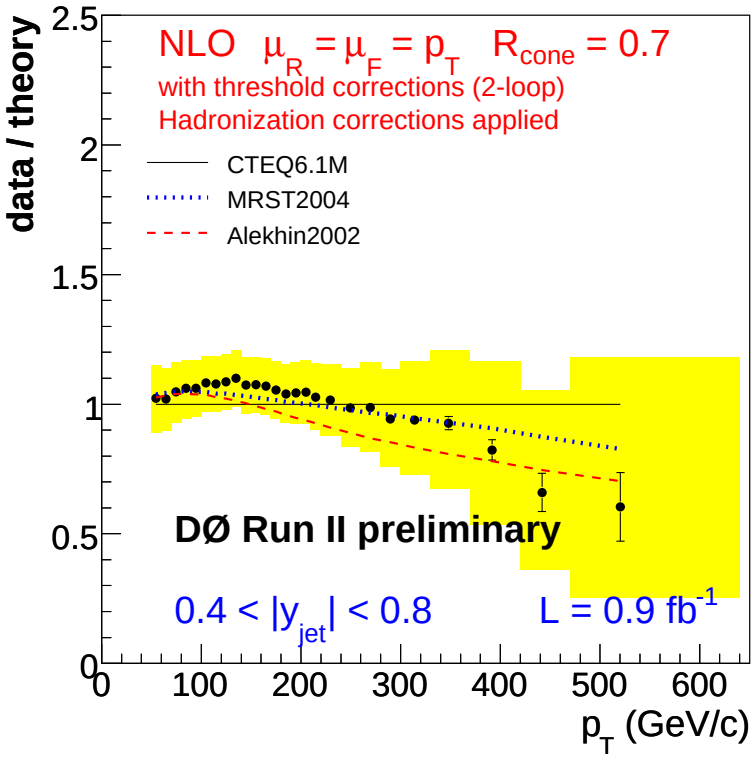
- Combine clusters based on relative p_T.
- Collinear + infrared safe.
- No split/merge.



Inclusive Jet Cross Section

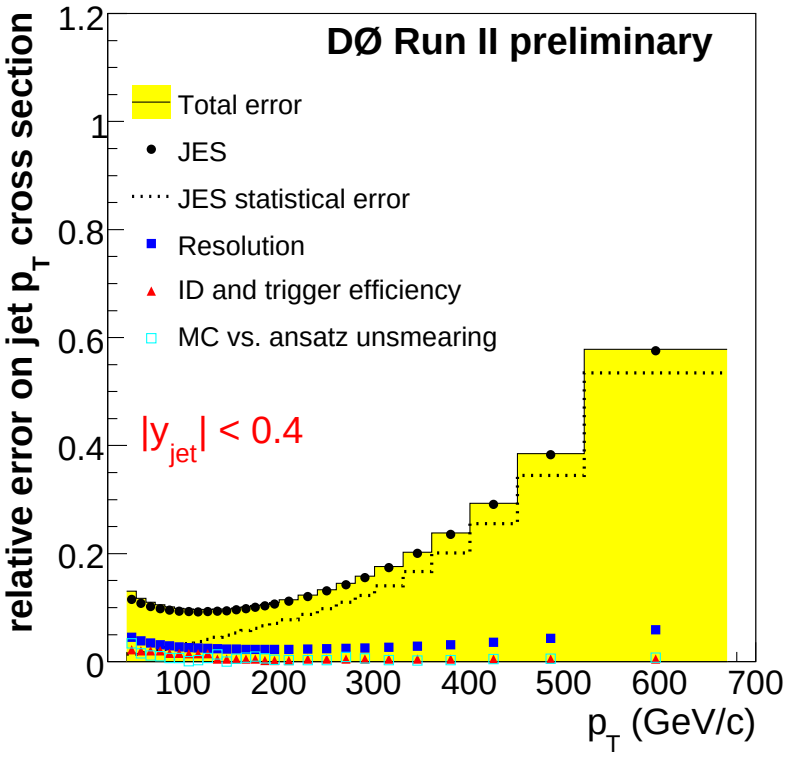
- Compare data to predictions with different PDFs.

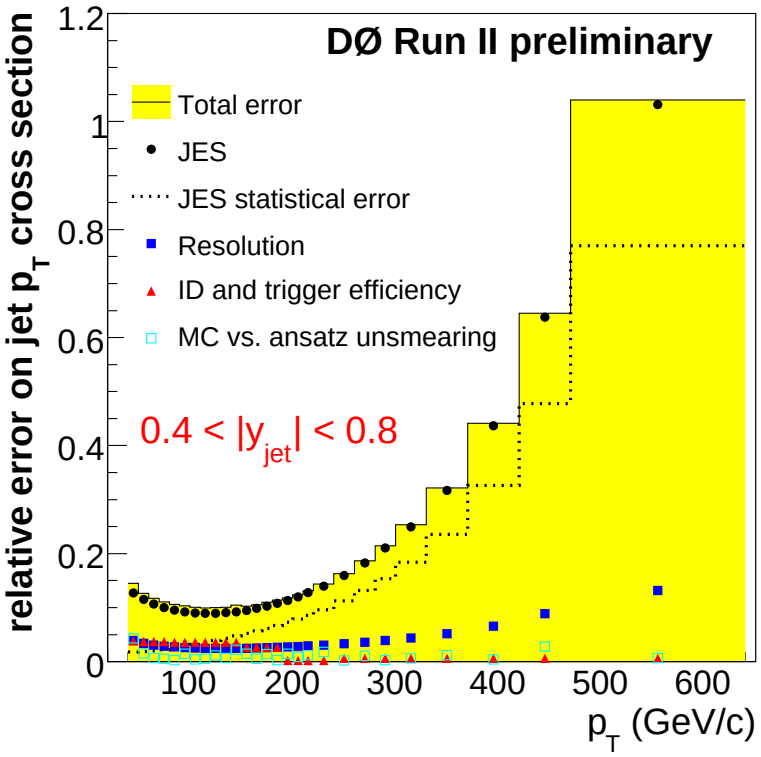




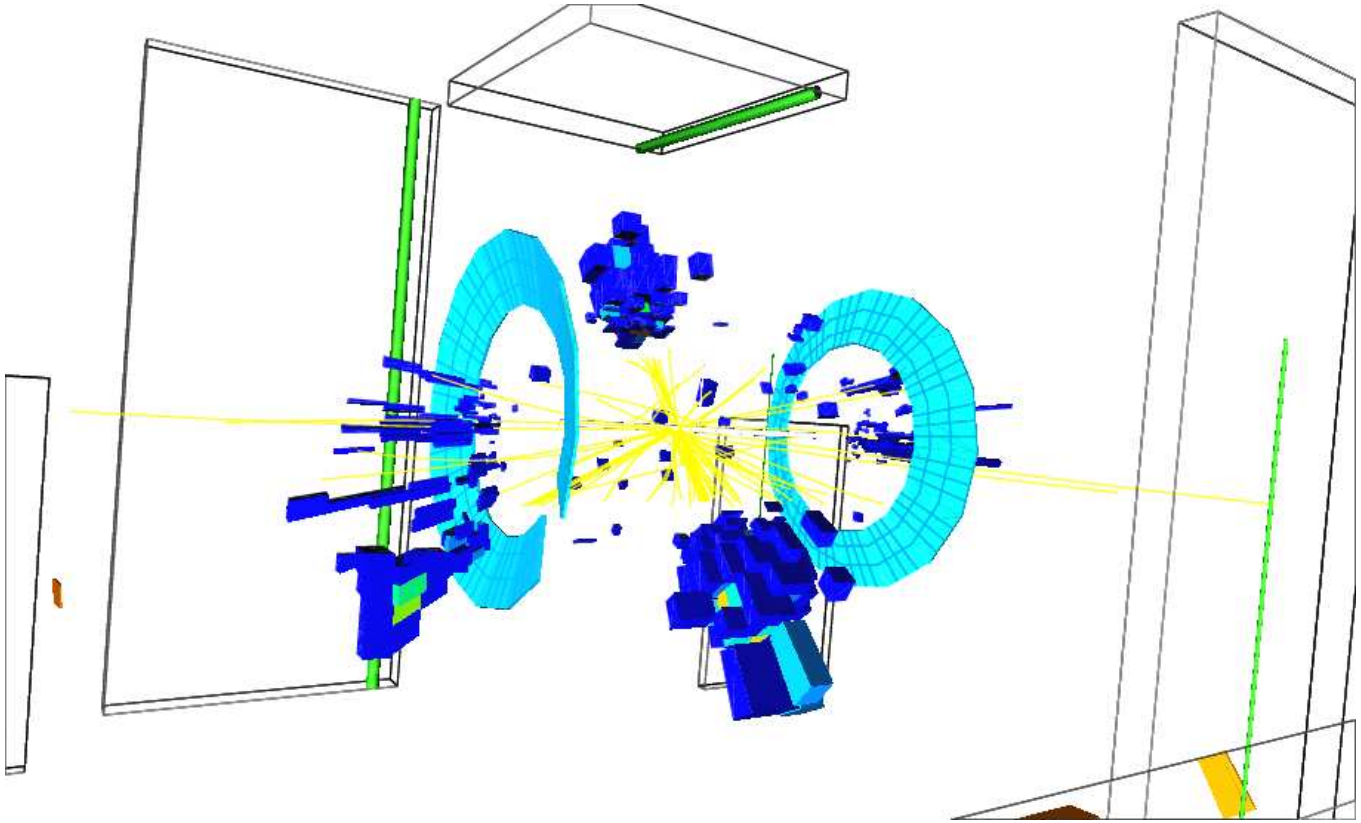
Inclusive Jet Cross Section: Total Systematics

- Jet energy scale is dominant uncertainty.
- Significant reduction expected from new JES (soon).





High p_T Dijet Event Display

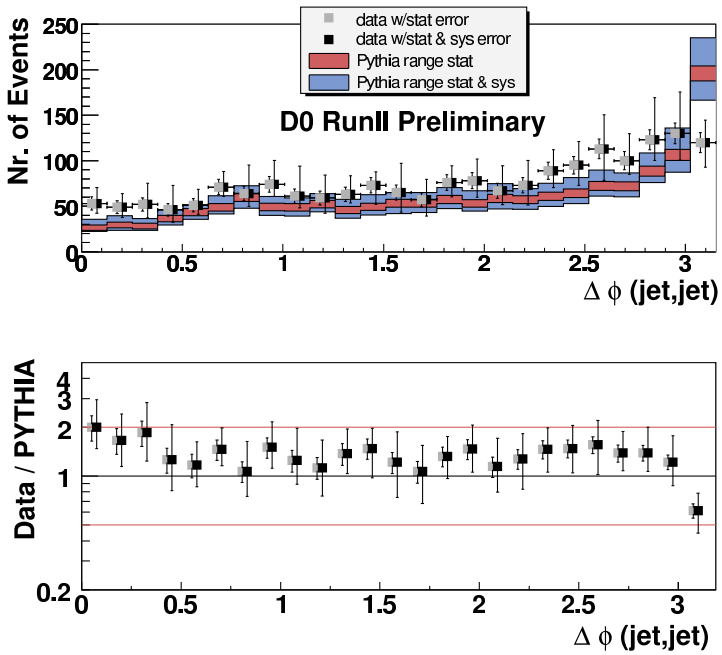
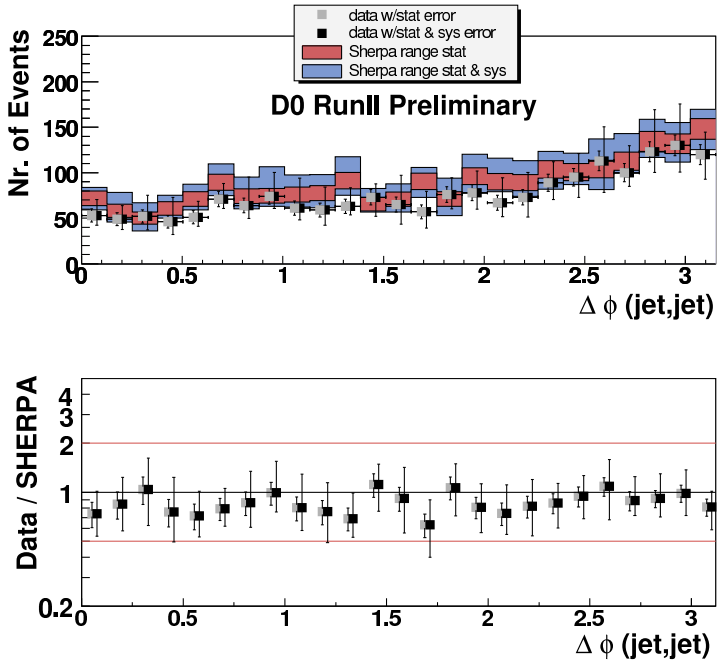


Jet 1	Jet 2
p_T =624 GeV	p_T =594 GeV
$\eta = 0.14$	$\eta = -0.17$
$\phi = 2.10$	$\phi = 5.27$
$M_{jj} = 1.22$ TeV	

Z+jets: Comparison with Theory

- **$\Delta\phi$(jet, jet)**
- Pythia: predicts peak at π, which is not seen in data.

Pythia



Sherpa