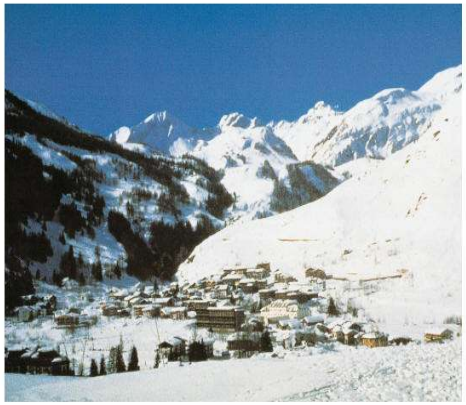
QCD Studies at the Tevatron



Oriol Saltó

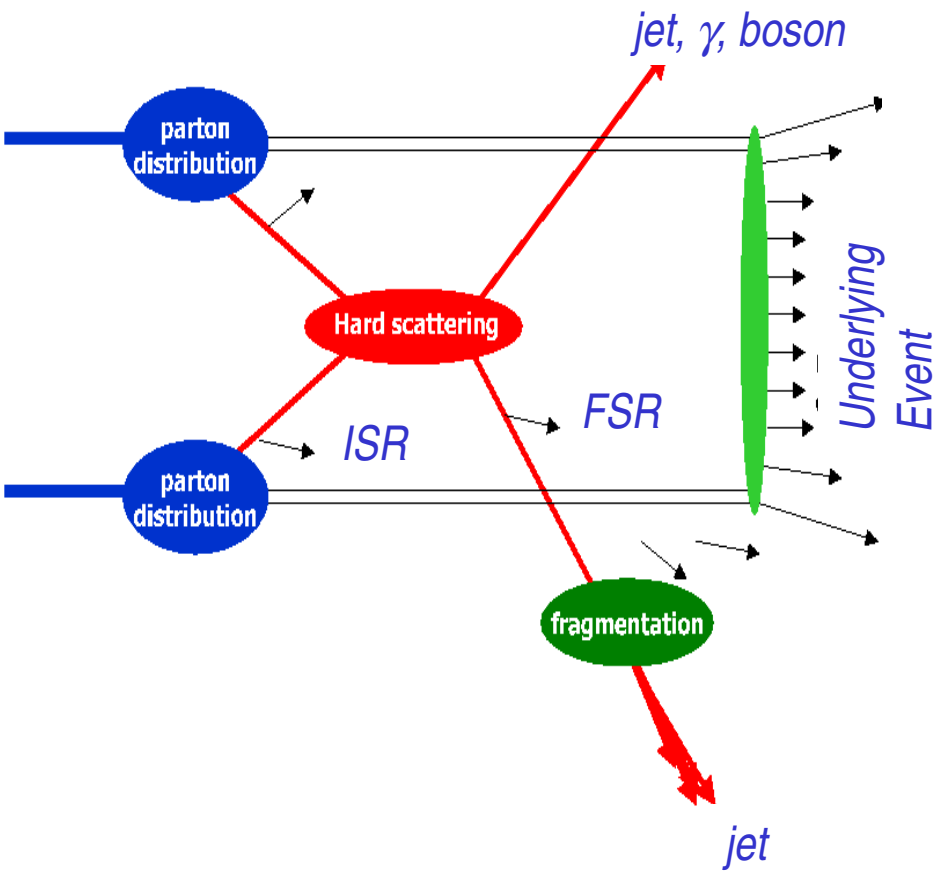
IFAE – Barcelona

for the CDF and DØ Collaborations

Les Rencontres de Physique de la Vallee d'Aoste 2007

Outline

- Tevatron, CDF and DØ
- Inclusive jet production
- Inclusive Photon Production
- Boson+jets
- Heavy flavor jets
- Summary

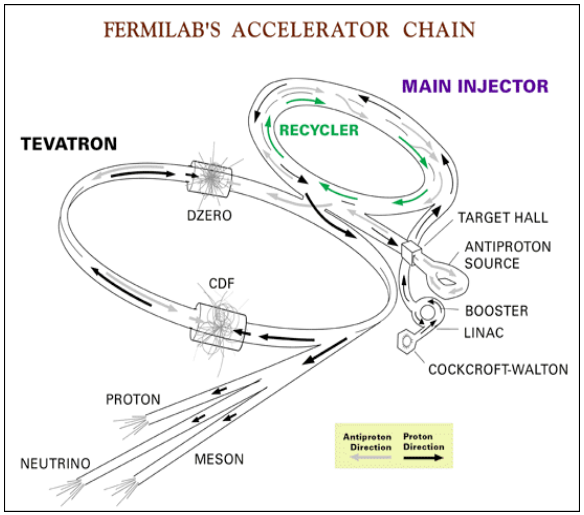


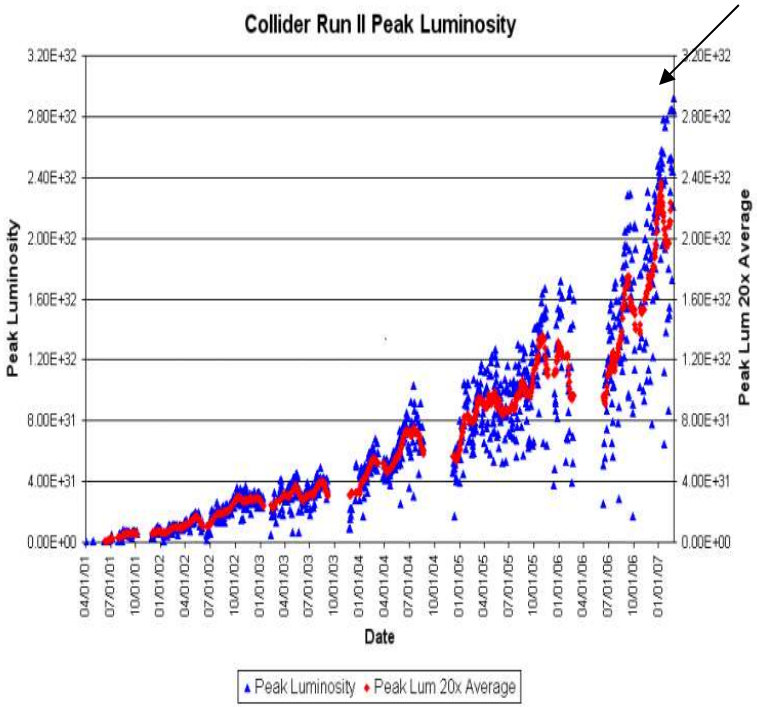
There are many more results, not covered in this talk

Tevatron

***p-p*bar** collider at $\sqrt{s}$ = **1.96 TeV**

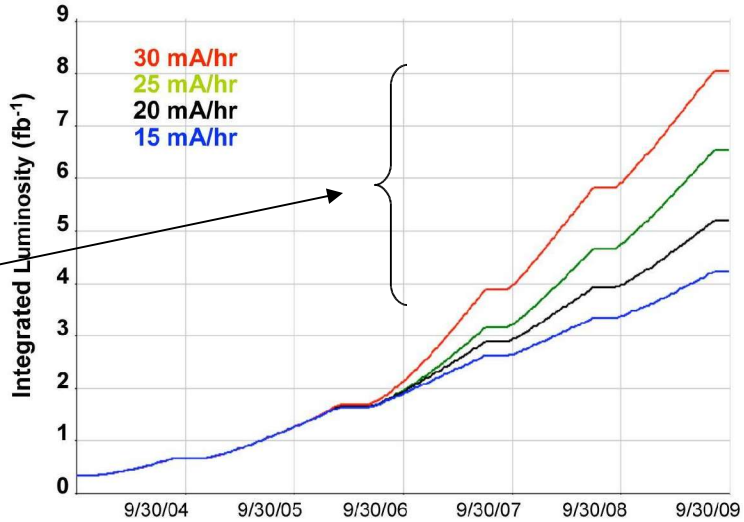
- Tevatron has delivered **2.5 fb^{-1}**
- CDF and DØ have ~**2.0 fb^{-1}** on tape
- Analysis shown here using up to **1.1 fb^{-1}**





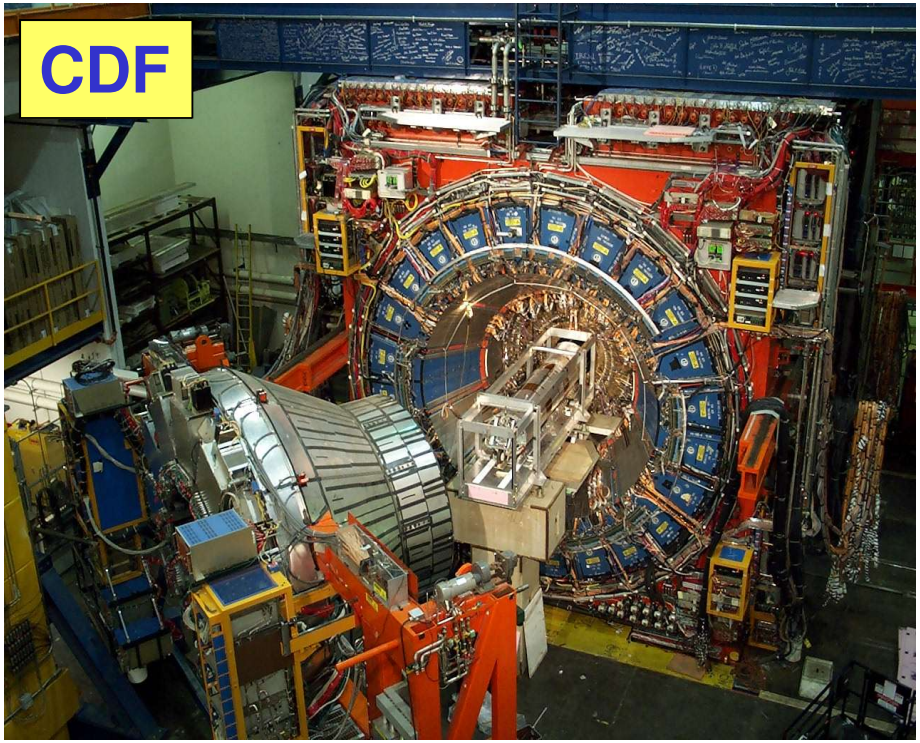
Instantaneous luminosities close to **3E32**

Projections: 4 to 8 fb^{-1} by 2009



CDF and DØ

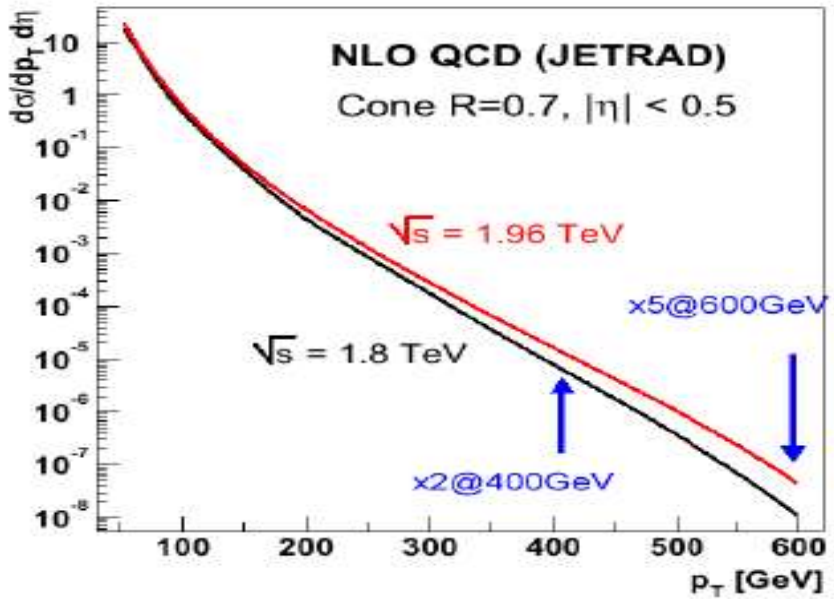
Both experiments recording data with high **efficiency** (80-85%) and making full use of their capabilities.

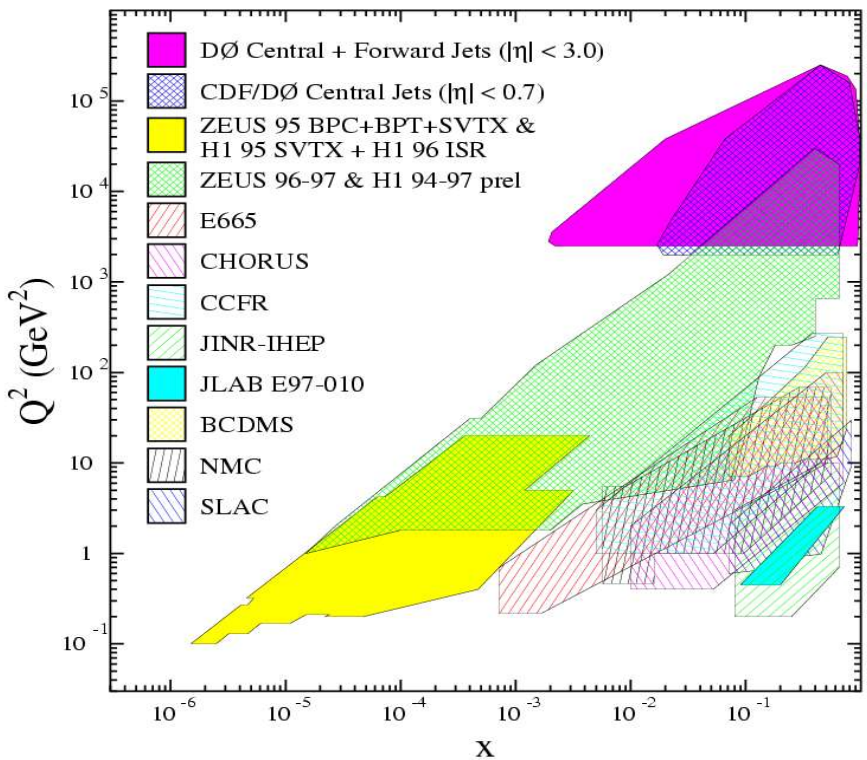


Jet Physics at the Tevatron

In **Run II**:

- Increased $\sqrt{s}$ → increase in the **jet production** cross section
- Increased the $\mathbf{p_T^{jet}}$ range up to 600-700 GeV/c
- Explored the use of new jet algorithms: **MidPoint, $\mathbf{k_T}$**
- Measurements in a wide **rapidity** region



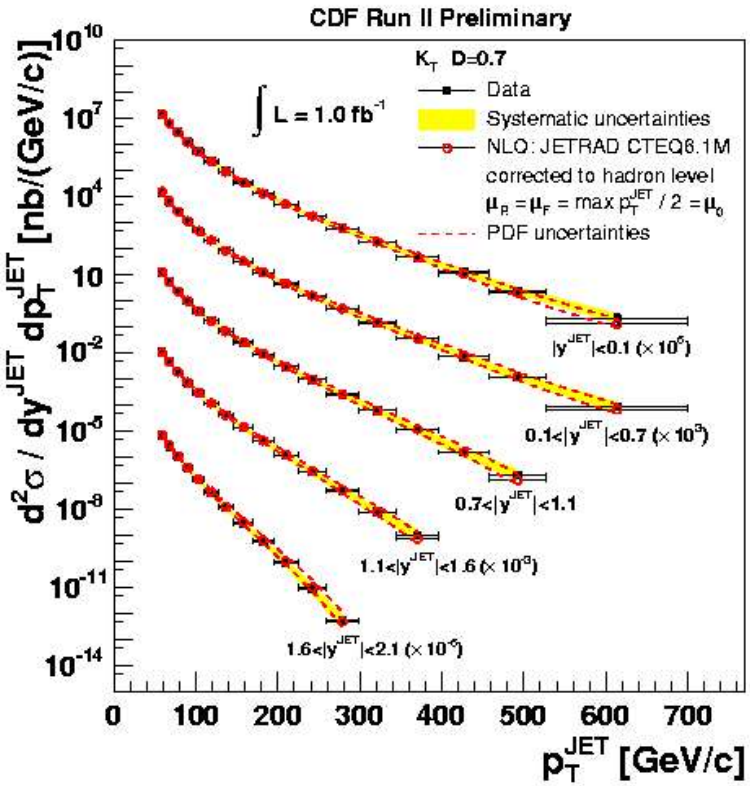


Measurements of **hadronic collisions** must take into account:

- **PDF** of the partons in the protons
- **Non-pQCD** contributions
  - **Underlying Event**
  - **Fragmentation** of the partons

Inclusive Jet Cross Section (CDF)

1.0 fb^{-1}

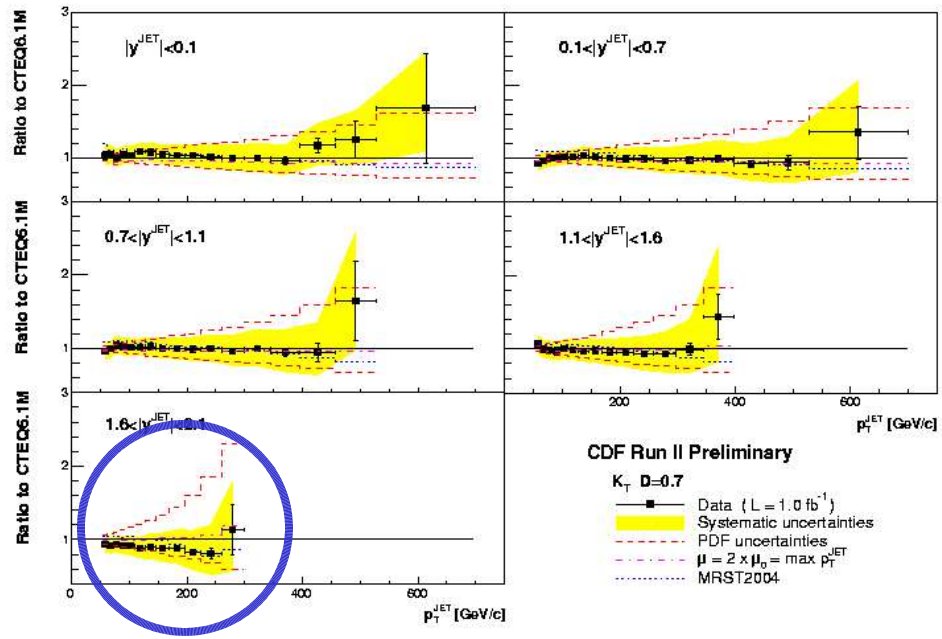


k_T algorithm (D=0.7)

$$d_{ij} = \min(P^{2}_{T,i}, P^{2}_{T,j}) \frac{\Delta R^2}{D^2} \qquad d_i = (P_{T,i})^2$$

- Five rapidity regions up to **$|y^{jet}| < 2.1$**
- Compared to pQCD **NLO** prediction corrected for non-perturbative contributions

- **Good agreement** in the five rapidity regions

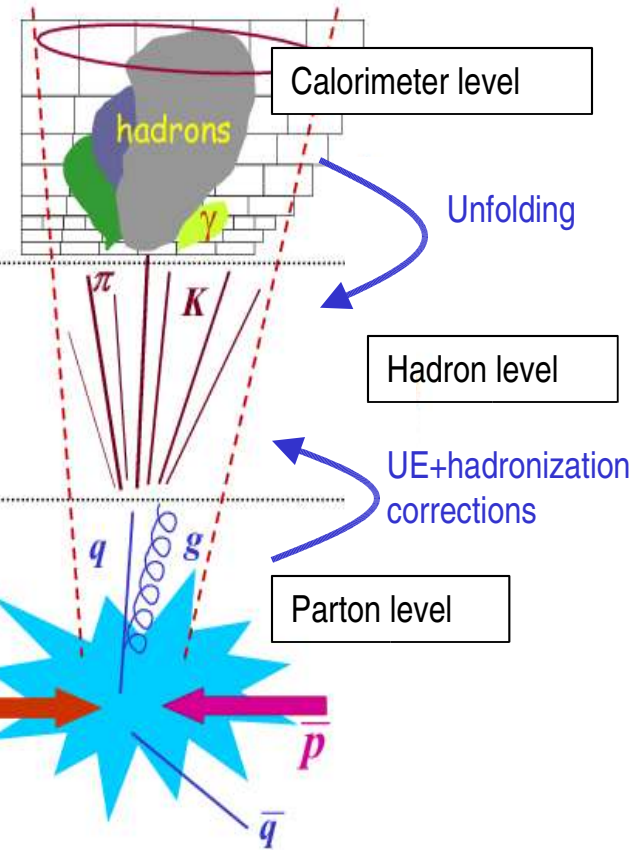


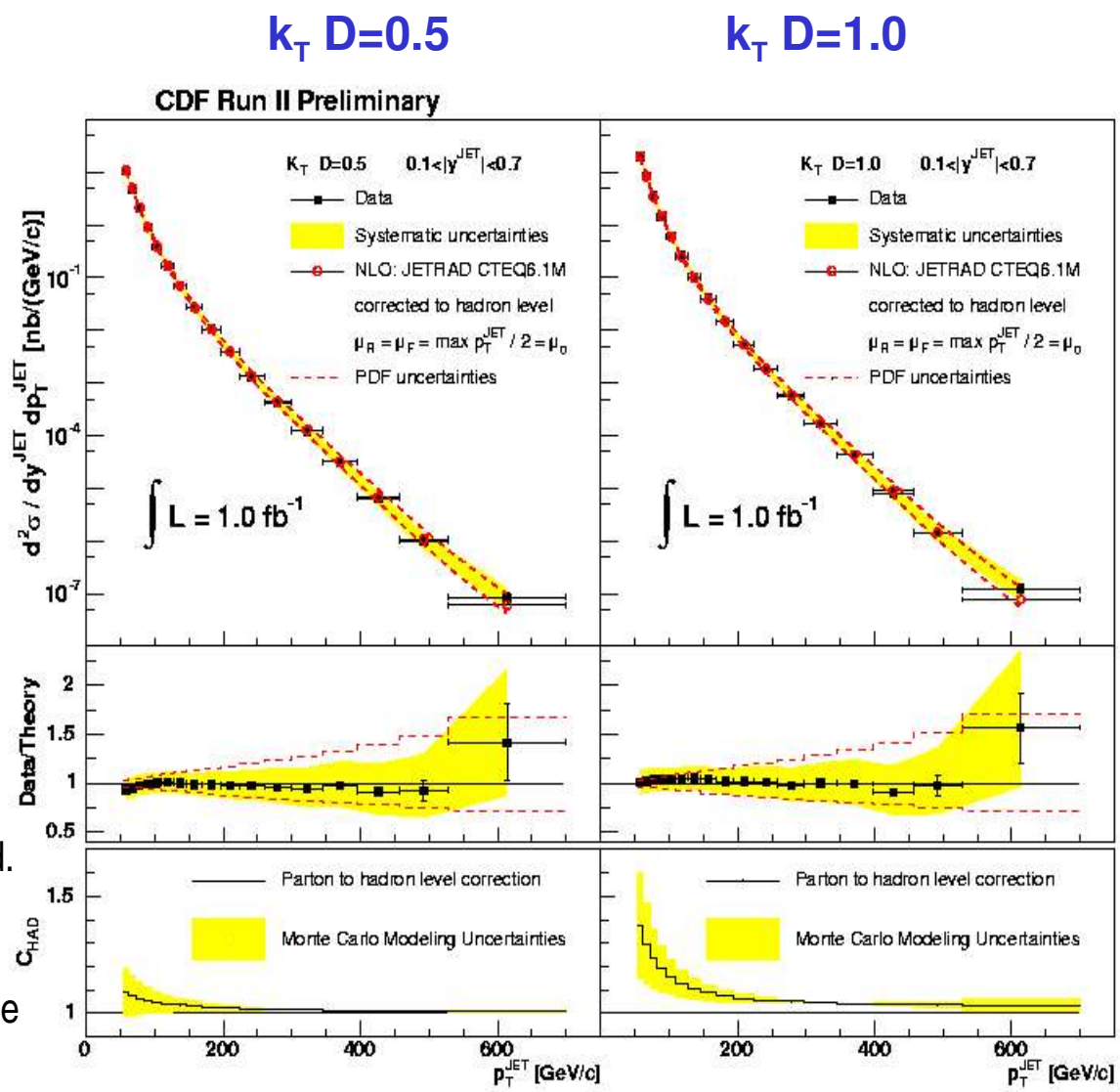
- Uncertainties on the data are comparable to the uncertainties on the theoretical prediction
  - Measurement should contribute to increase the **PDF** knowledge.

- CDF and DØ has similar results using the **MidPoint** algorithm

PRL 96, 122001 (2006) Submitted to PRD

Non-pQCD contributions



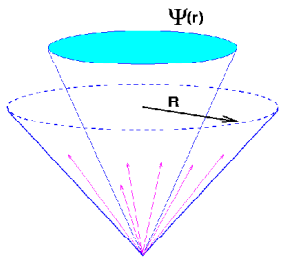


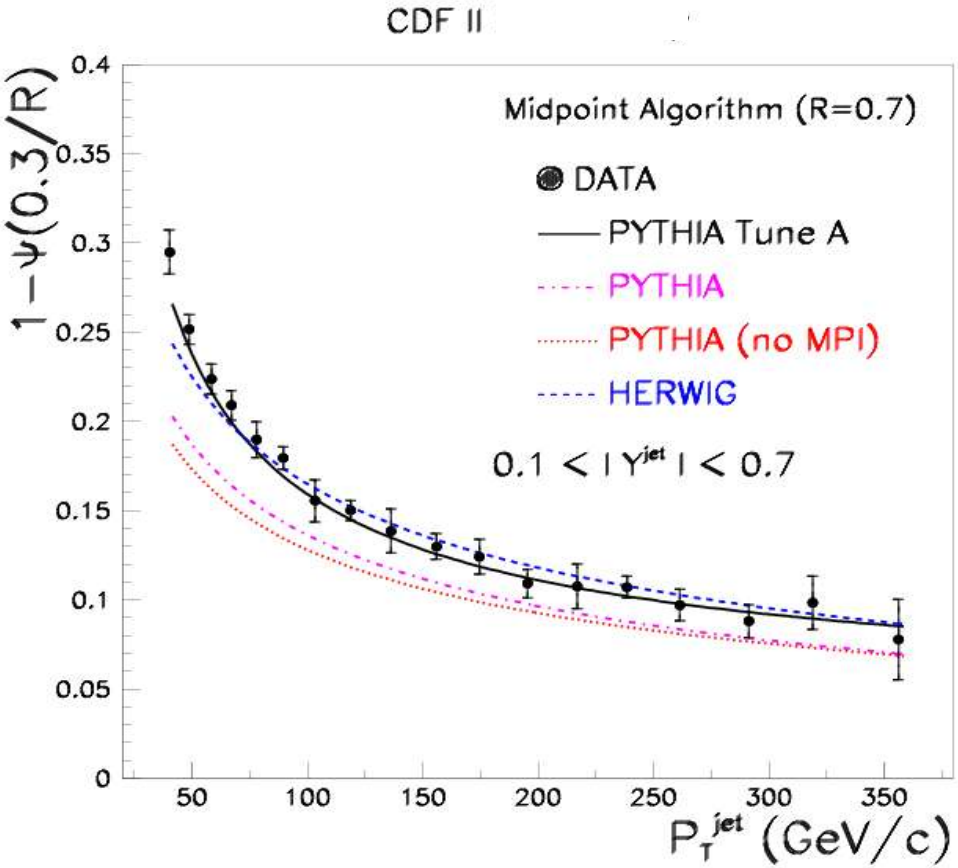
- **Non-pQCD** contributions are understood.
- Checked with different **jet sizes**
- They are extracted from the MC
  - Dedicated measurements to validate the MC simulation

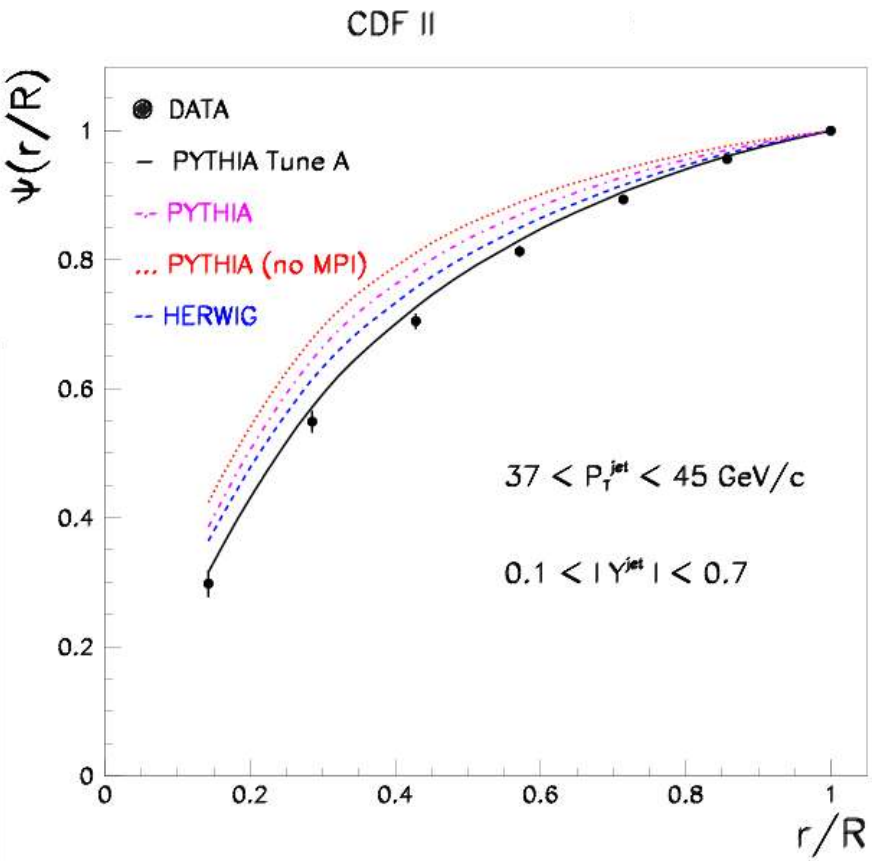
Jet Shapes (CDF)

PRD 71, 112002 (2005)

$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{p_T(0,r)}{p_T(0,R)}$$



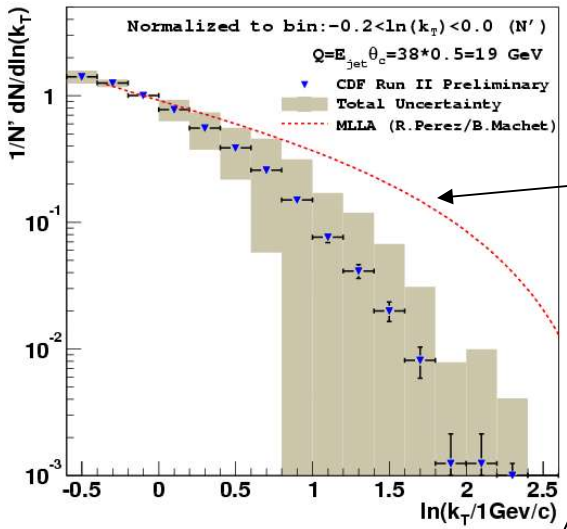




- The observable is sensitive to the **fragmentation** of the partons.
- Also sensitive to the simulation of the contributions from the **underlying event**.
- Underlying event and fragmentation are understood in all the p_T^{jet} range.

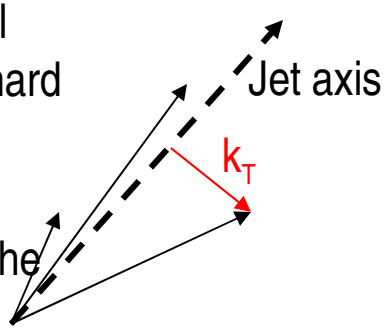
k_T distribution of particle inside jets (CDF)

385 pb^{-1}

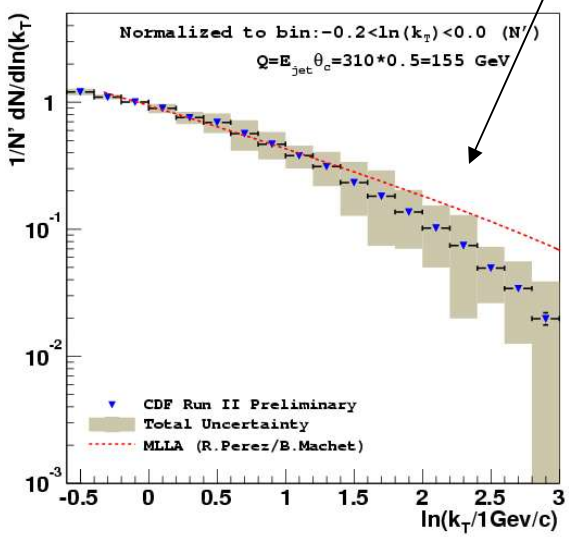


Process in the limit of the perturbative calculations:

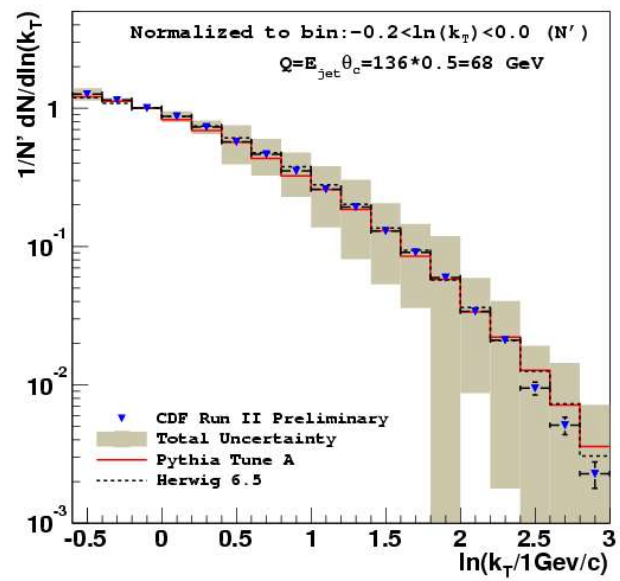
- **MLLA next-to-leading log** theoretical prediction do not describe large k_T's at low hard scales



- Larger hard scales are better described by the perturbative predictions



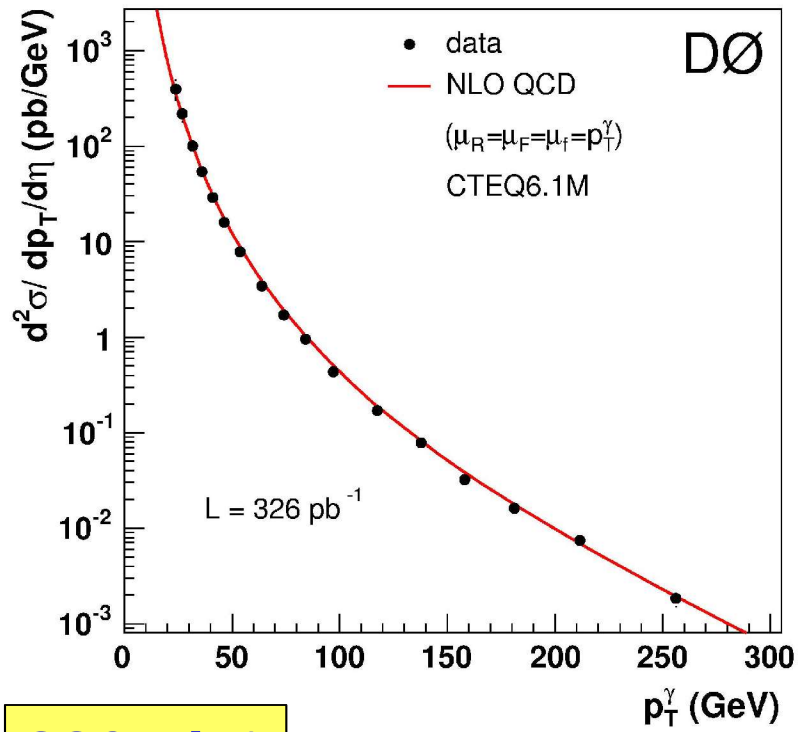
Pythia Tune A describes well the k_T distribution of the particles even at low scales



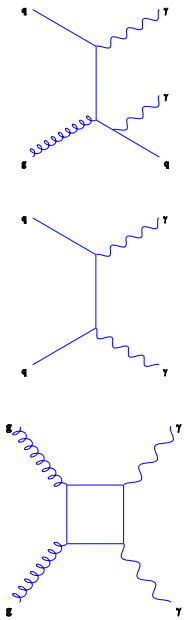
Inclusive Photon Cross Section (DØ)

Direct photon production can be used to precisely study **QCD** dynamics:

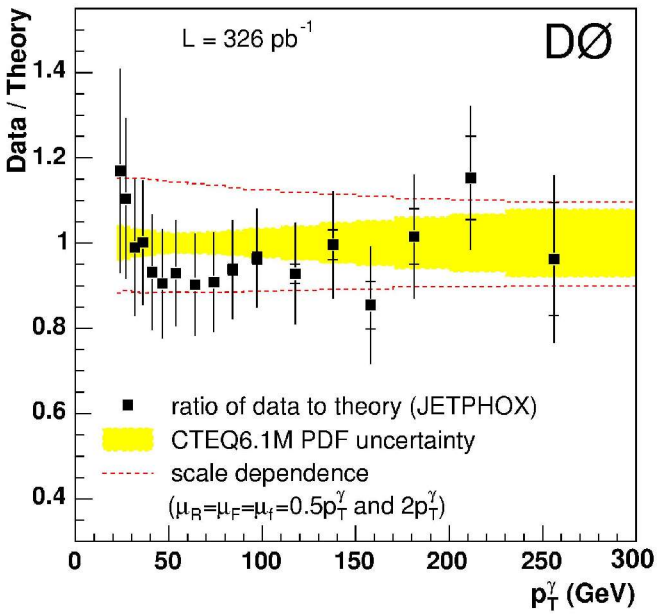
- **Cleaner signal**: no definition of "jet" is needed
- Lower p_T's can be accessed
- Sensitive to **gluon PDF**



330 pb^{-1}



Central photons |y|<0.9
Photons up to 442 GeV/c of p_T

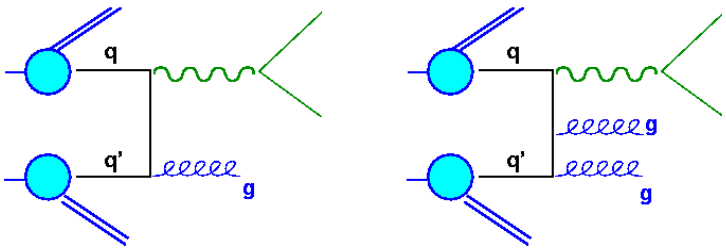


Good agreement with NLO predictions.

With more data (1-2 fb^{-1}), p_T range can be expanded and **uncertainties** can be reduced yo level of **PDF uncertainties.**

Boson+jets

- They are important backgrounds to:
  - **top** production
  - **Higgs** searches
  - **SUSY** searches



- Could be used in searches for **compositeness**, **heavy objects** decays, etc.

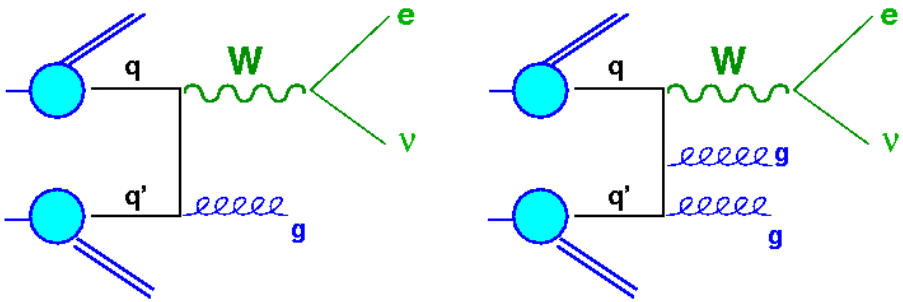
- Test of **pQCD** at high momentum transfer and **NLO** predictions are available in some cases

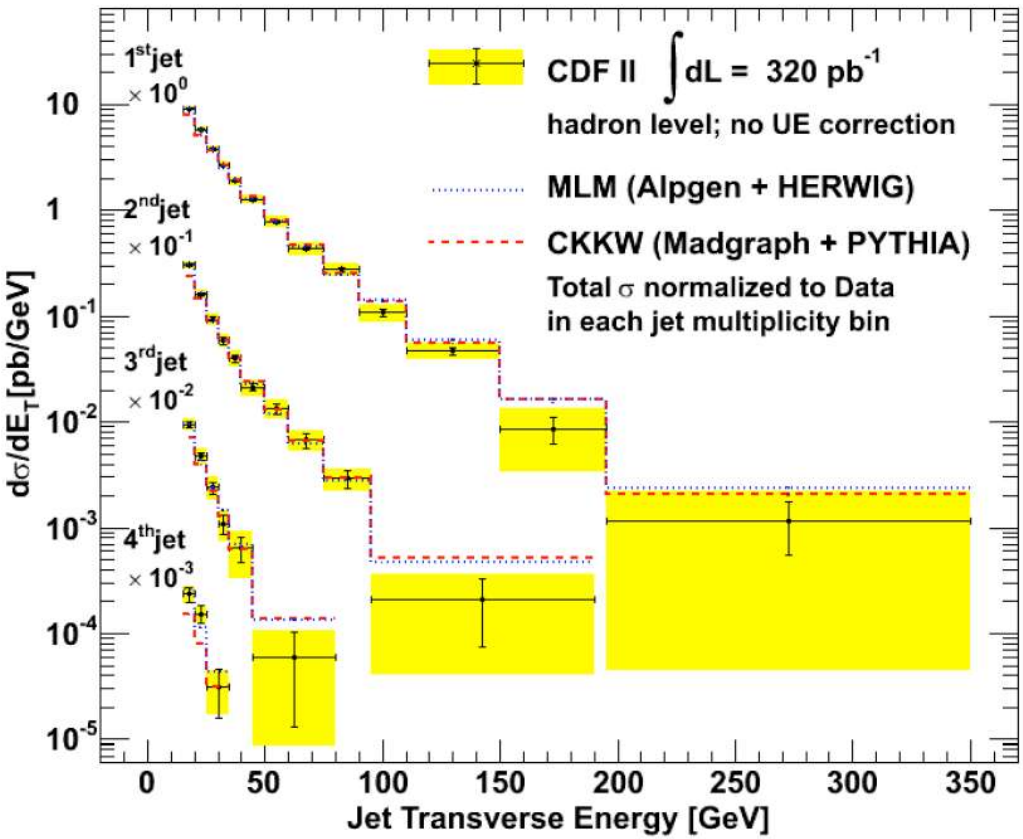
- The measurements are also sensitive to **Underlying Evens** and **hadronization** modeling.

- Efforts are being made on producing **LO matrix elements** (ME) with different parton multiplicities and **matching** them with **parton showers** (PS) without double counting the contributions to a given jet mutiplicity.

W+jets (CDF)

320 pb^{-1}





W → eν + jets

Jets reconstructed with CDF Run I cone based algorithm (**JetClu**)

R = 0.4

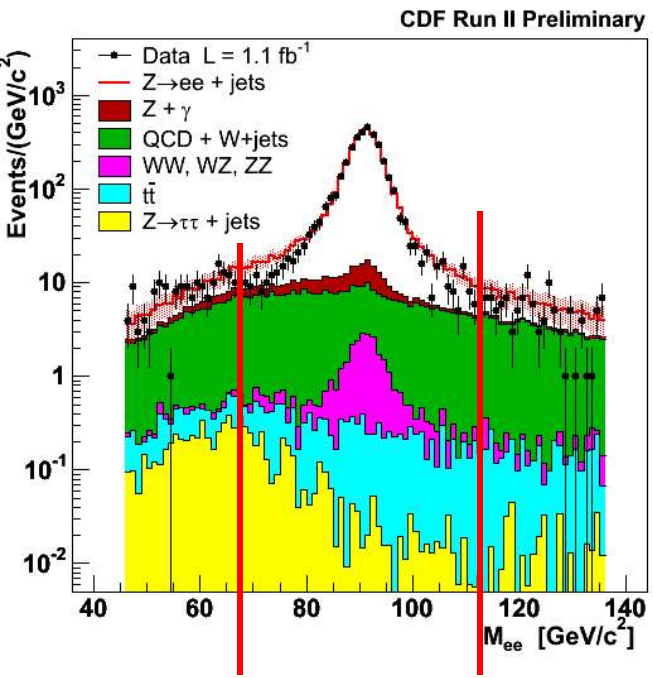
$E_T^{jet} > 15$ GeV, $|\eta^{jet}| < 2$

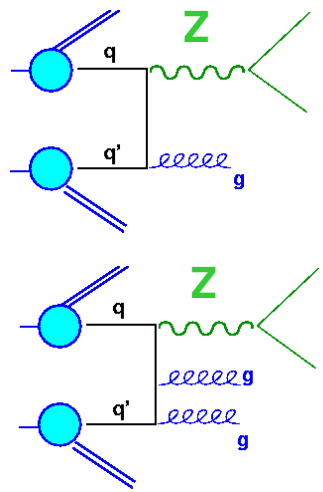
Stringent test of **pQCD** calculations. Important to test ME+PS matching techniques (MLM, CKKW…)

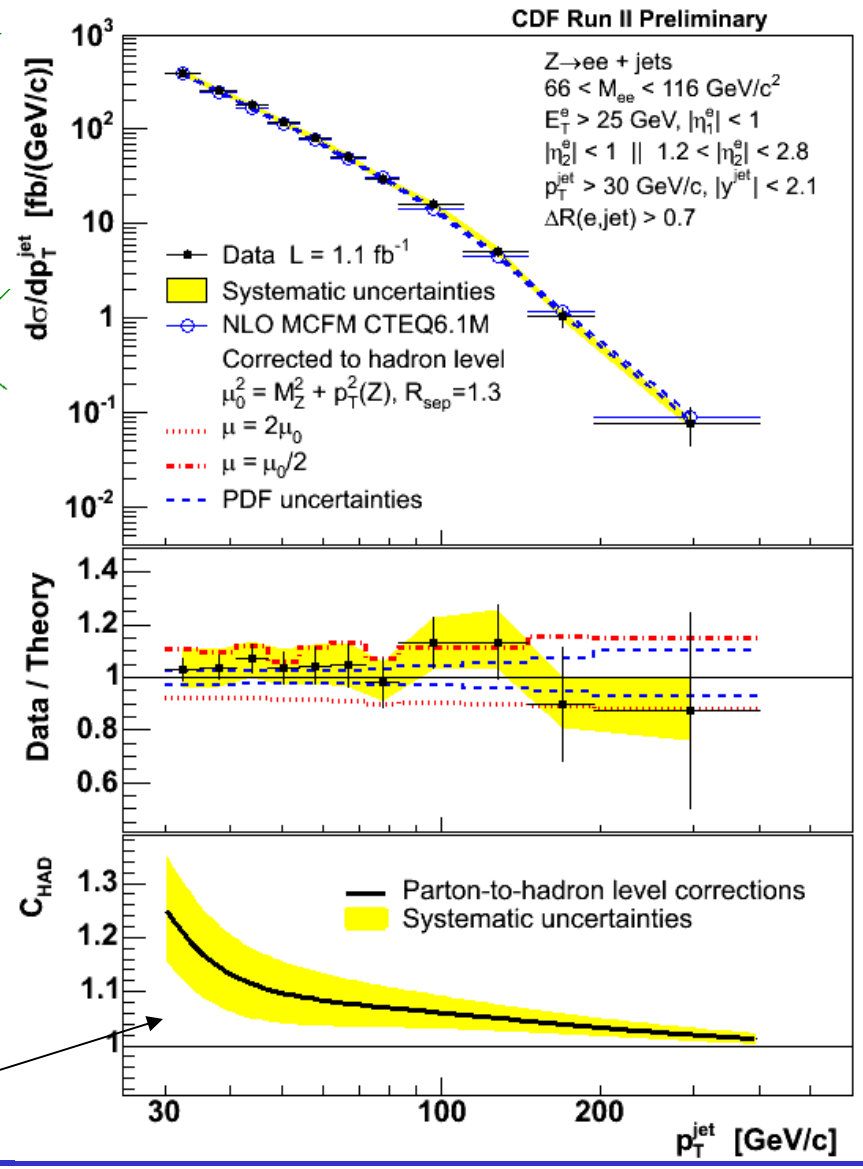
Shape comparison to different LO **ME+PS** predictions with different matching techniques.

Z+jets (CDF)

1.1 fb^{-1}







Ten times smaller cross section than **W+jets**, but **Z→ee** is a cleaner sample almost background free below the Z mass peak

p_T^{jet} > 30 GeV/c $|y^{jet}|$ < 2.1

Data corrected to hadron level.
Good agreement with **NLO predictions** with **non-perturbative** contributions.

Z+jets (CDF)

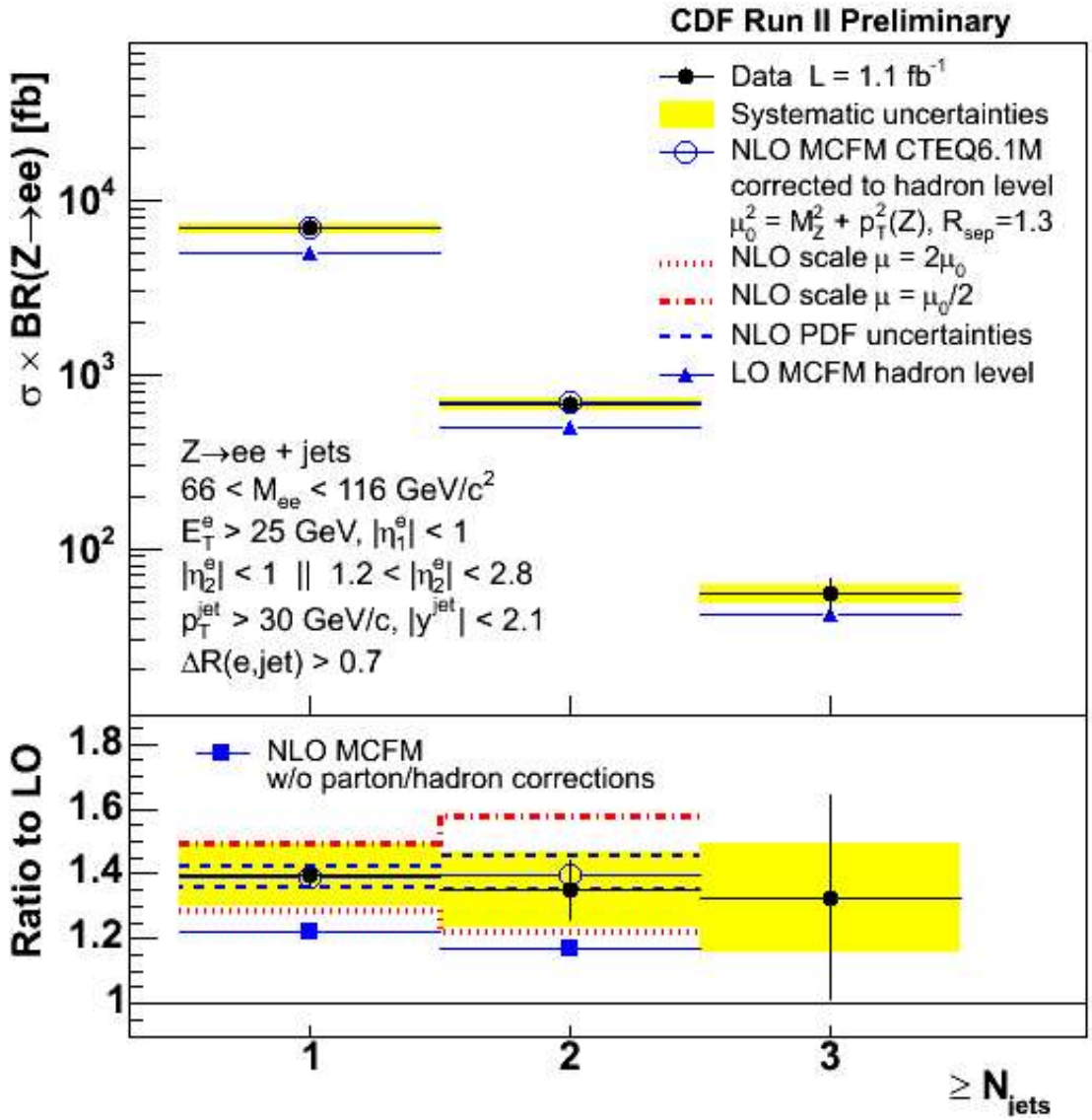
1.1 fb^{-1}

NLO predictions up to **2 jets** in the final state.

3 jets for the **LO**.

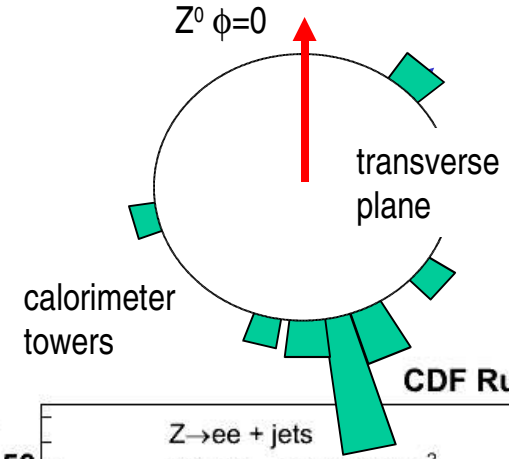
Constant **k-factor** NLO/LO with the jet rapidity.

Size of the **non-perturbative** contributions: ~10%

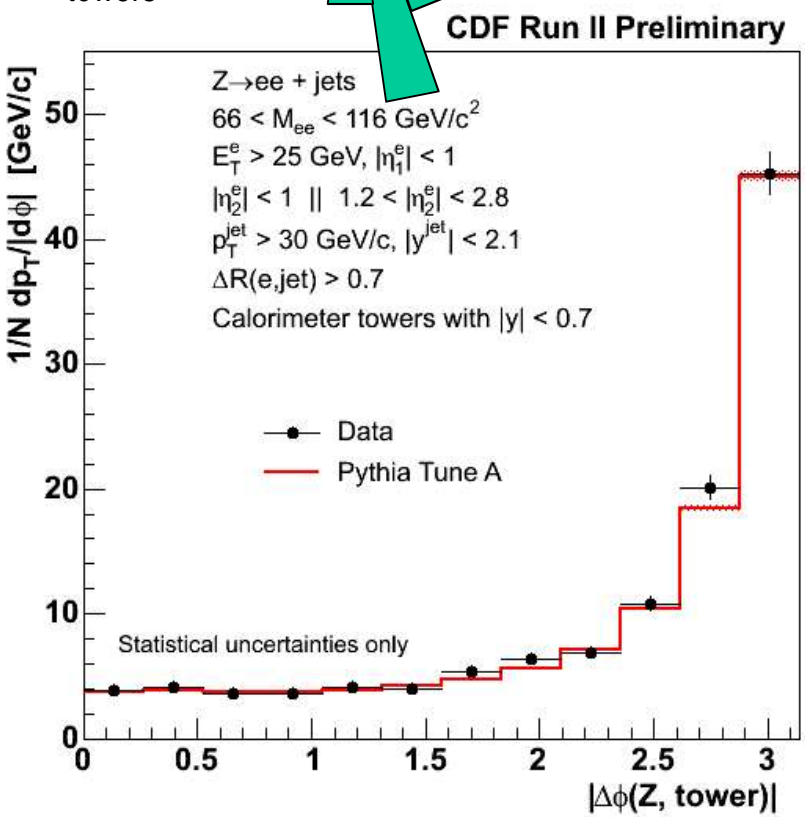


Underlying Events in Z+jets (CDF)

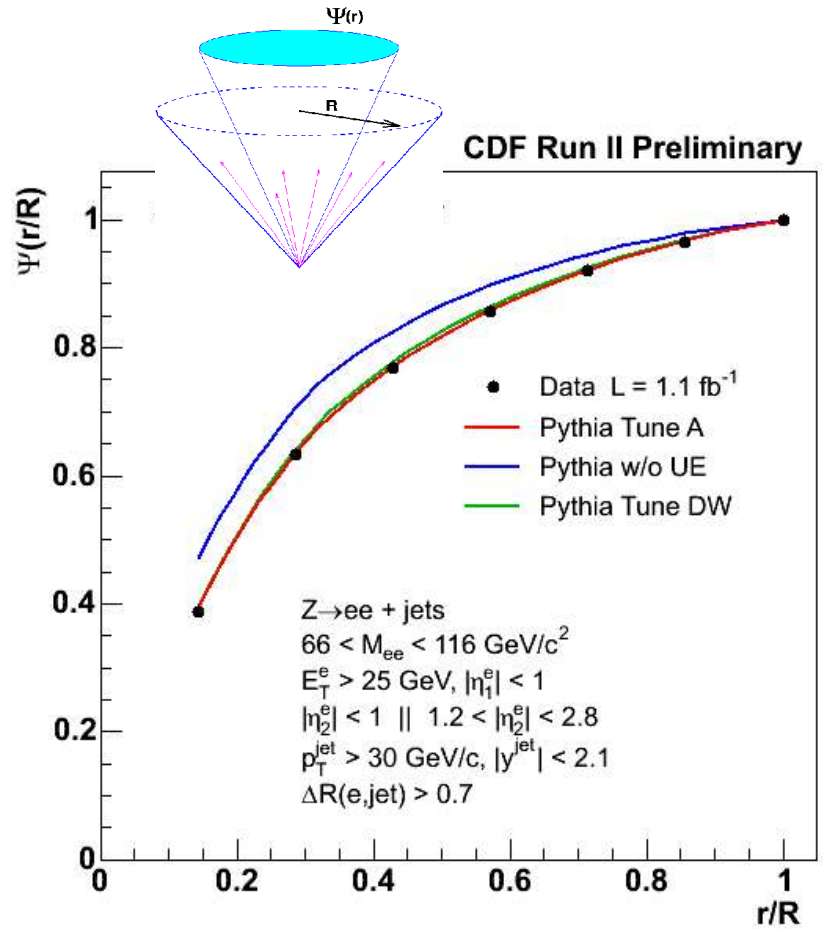
1.1 fb^{-1}



Energy flow



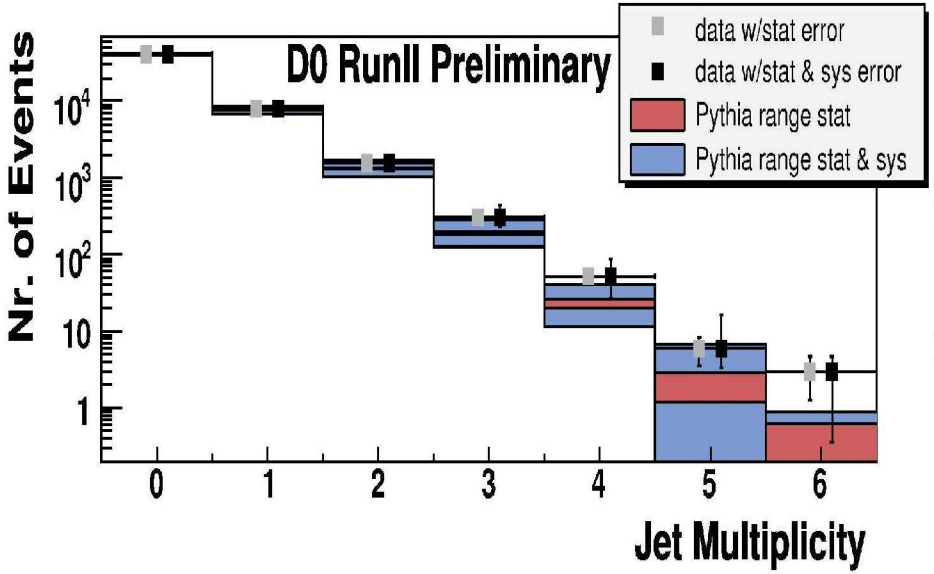
Jet Shapes

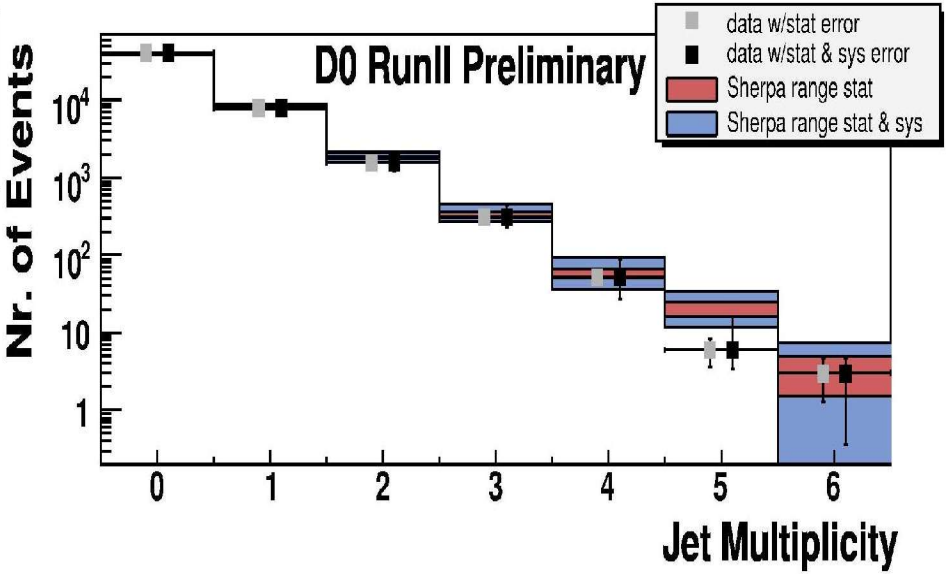


Z+jets in different MC (DØ)

0.95 fb^{-1}

Comparing the prediction of **Z+jets** done by **different MCs**:
(p_T^{jet} > 15 GeV/c)





Pythia Z inclusive

Jets are created from the PS

It describes up to the 2nd jet

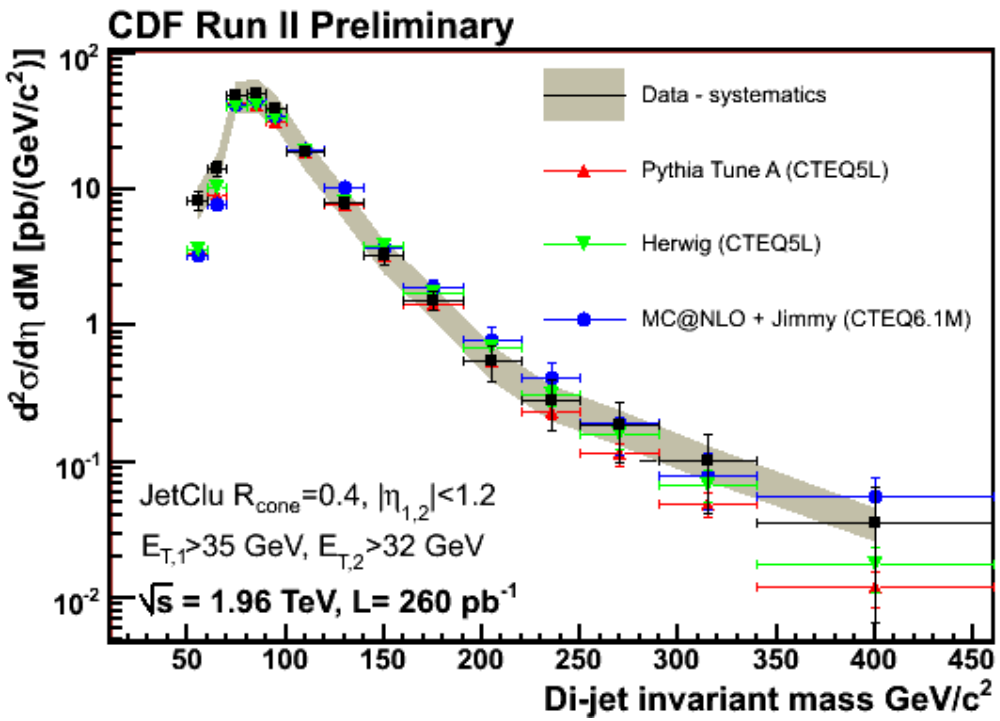
Sherpa Z+0…3p

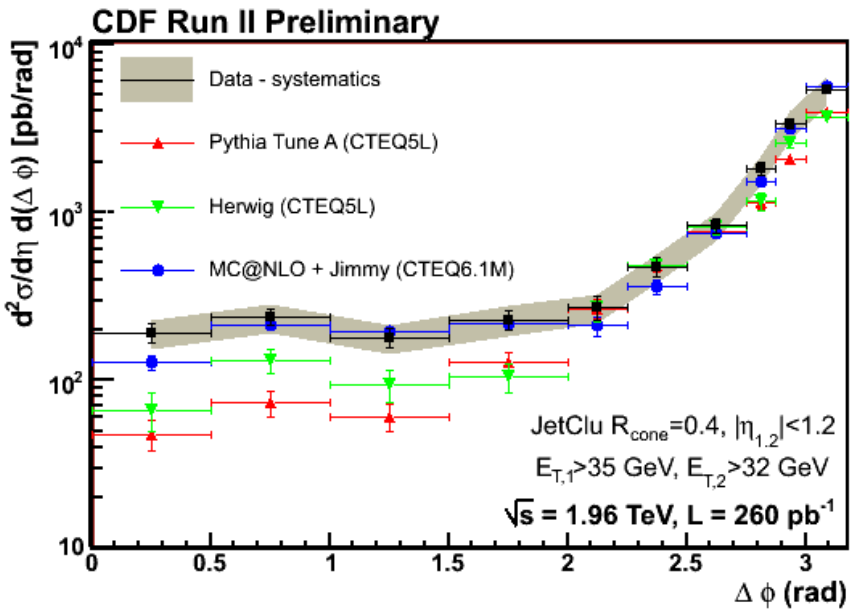
ME+PS matched for every parton/jet mutiplicity

Describes better higher jet multiplicities.

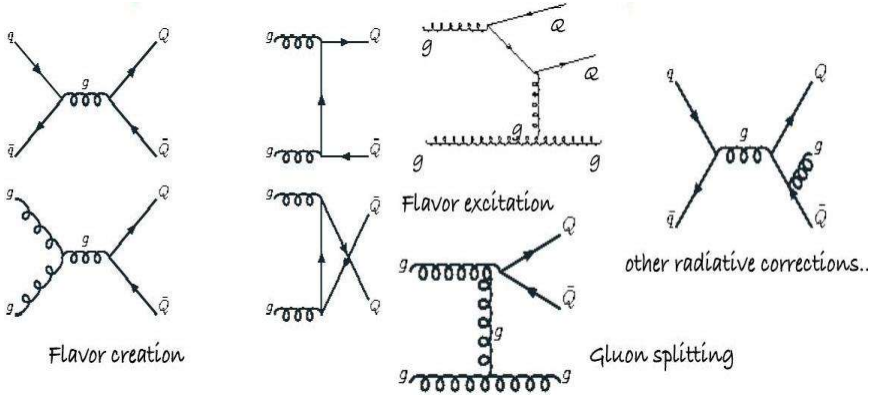
b-bbar dijet production (CDF)

260 pb^{-1}





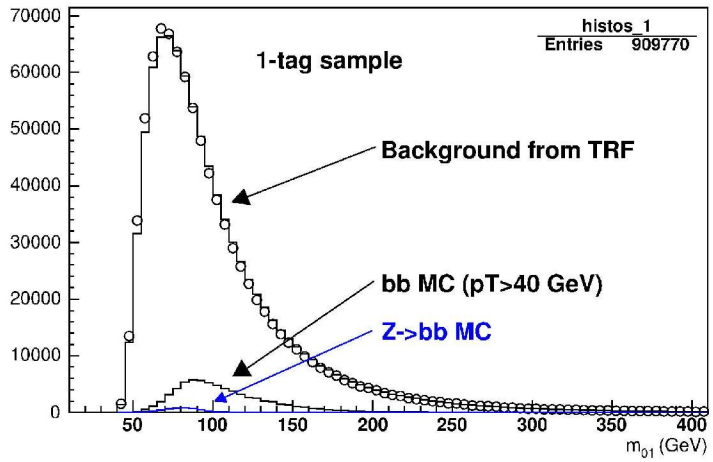
$\Delta\phi$ distribution is very sensitive to the soft gluon radiation

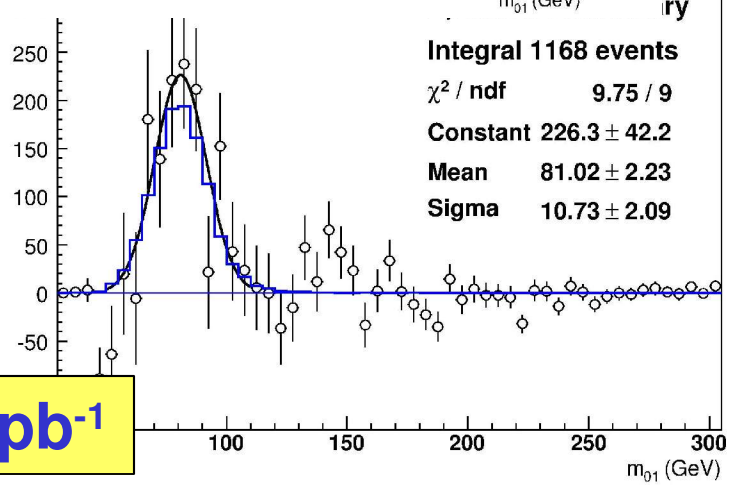


Provides understanding of the **b production** mechanisms : **direct** production, flavor **excitation**, **gluon splitting**.

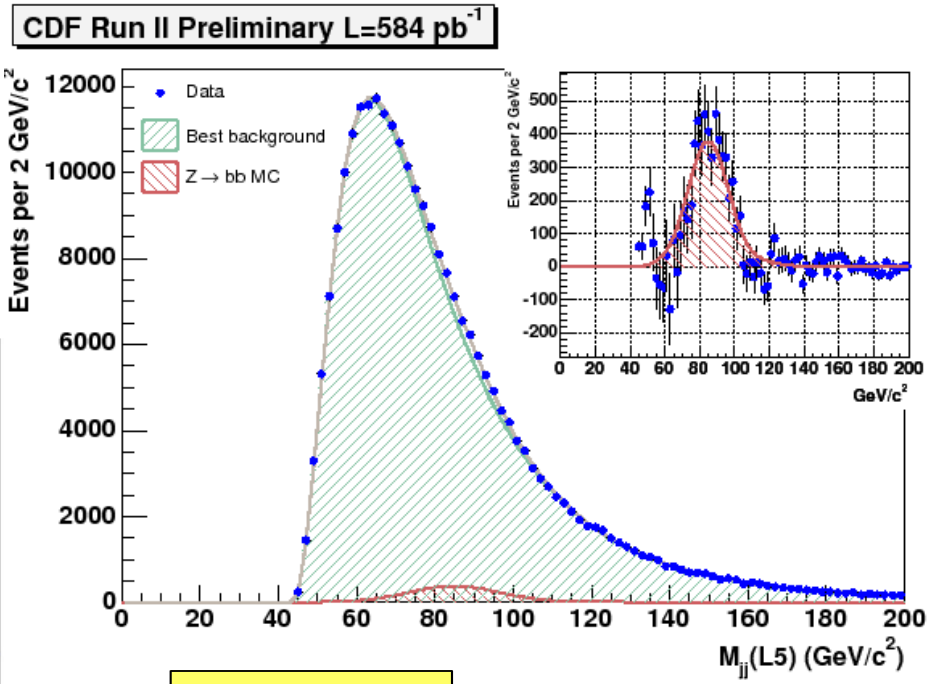
$Z \rightarrow bb$ (DØ & CDF)

Challenging due to the very **large background** from *b*-*b*bar production and mis-tagged jets.
Important to establish the **b energy scale**.





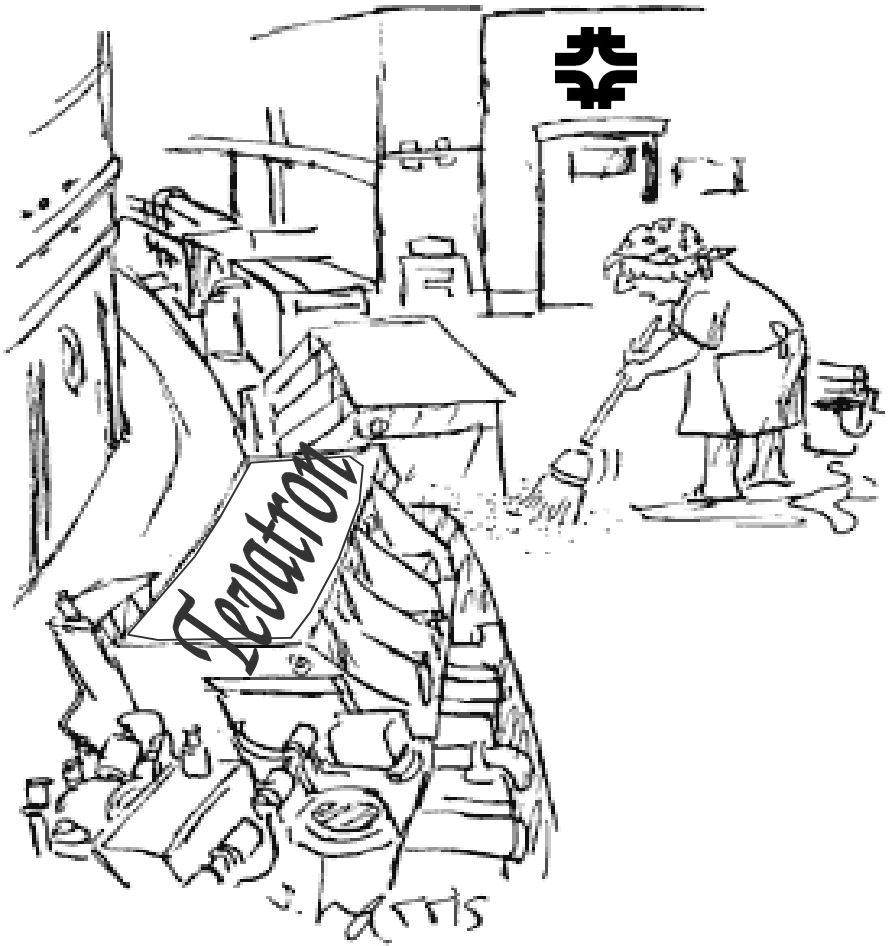
300 pb^{-1}



584 pb^{-1}

Summary

- **Tevatron** and the experiments are performing very well and more than 4 fb^{-1} of data are expected by 2009.
- **CDF** and **DØ** are carrying out a coherent set of QCD measurements.
- Measurements cover a large range of p_T and rapidities.
- All these measurements will provide at good ground for the **LHC**.



"Particles, particles, particles."

Backup slides

Inclusive Jet Cross Section (DØ)

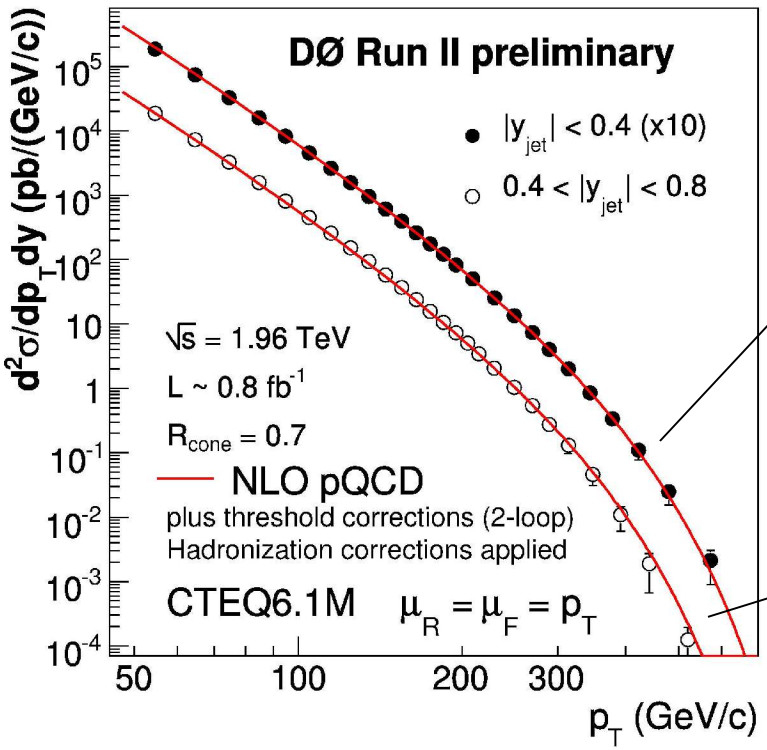
MidPoint cone algorithm (R=0.7)

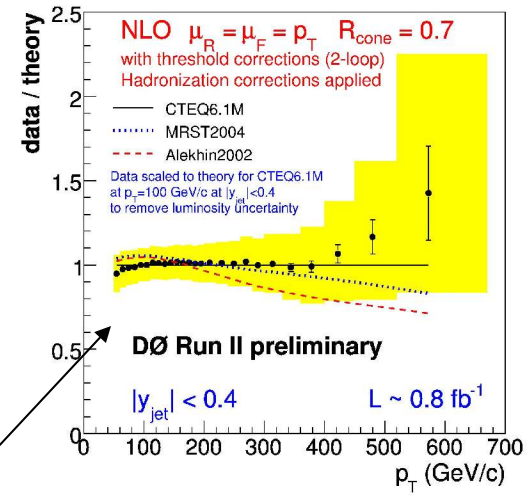
Two rapidity regions:

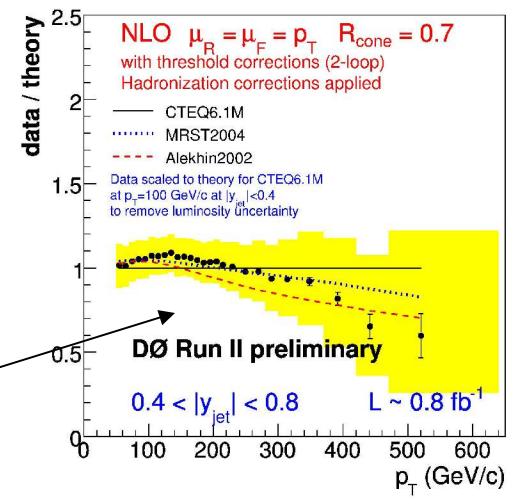
- $|y^{jet}| < 0.4$
- $0.4 < |y^{jet}| < 0.8$

Shape comparison with the **pQCD NLO** prediction

0.8 fb^{-1}



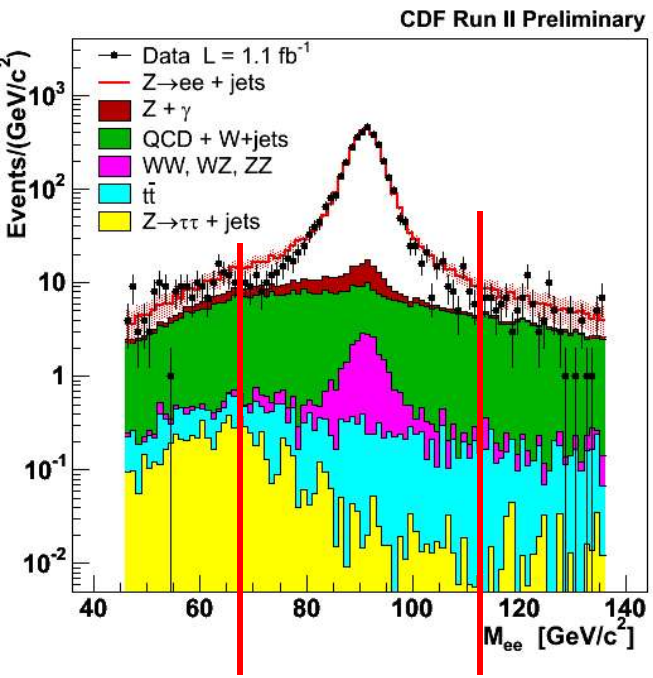


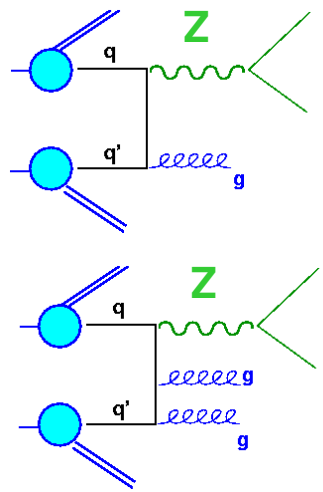


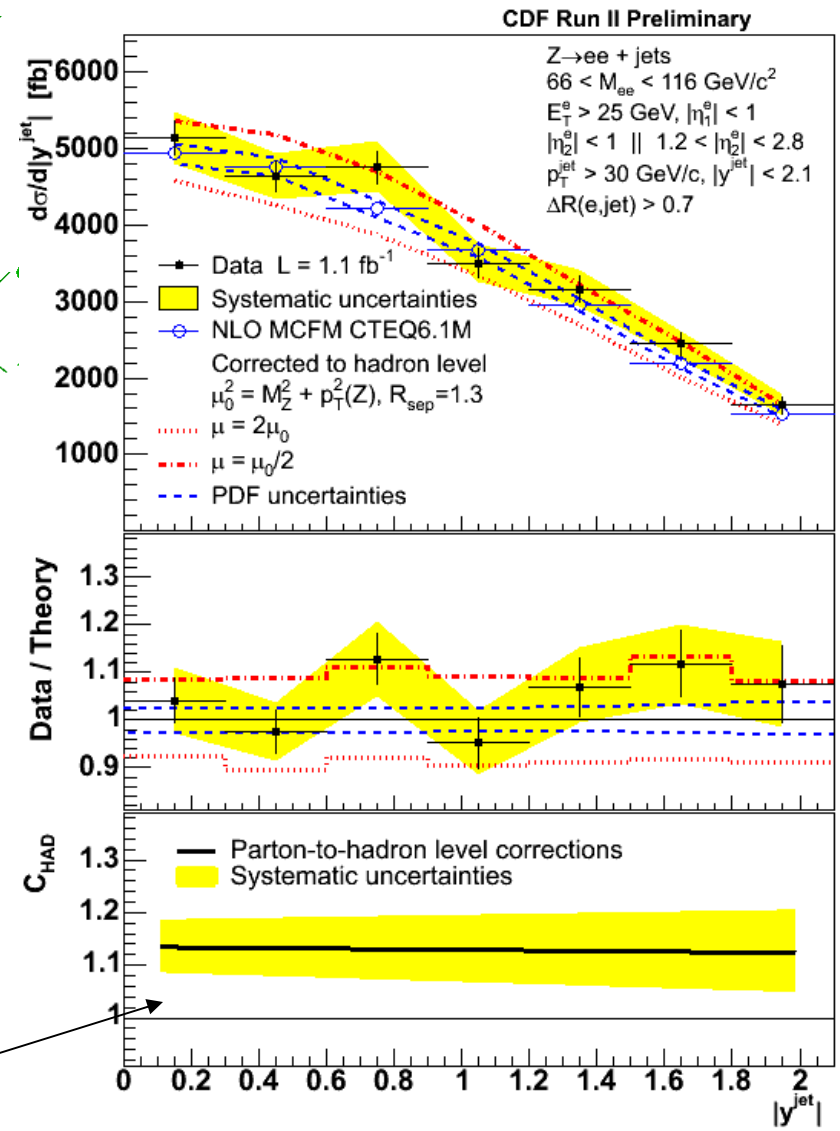
Shape is consistent with **NLO prediction**

Z+jets (CDF)

1.1 fb^{-1}







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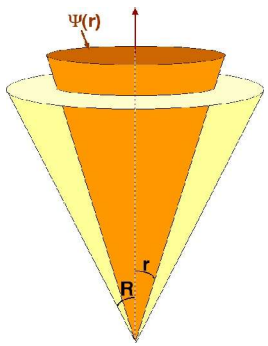
p_T^{jet} > 30 GeV/c $|y^{jet}|$ < 2.1

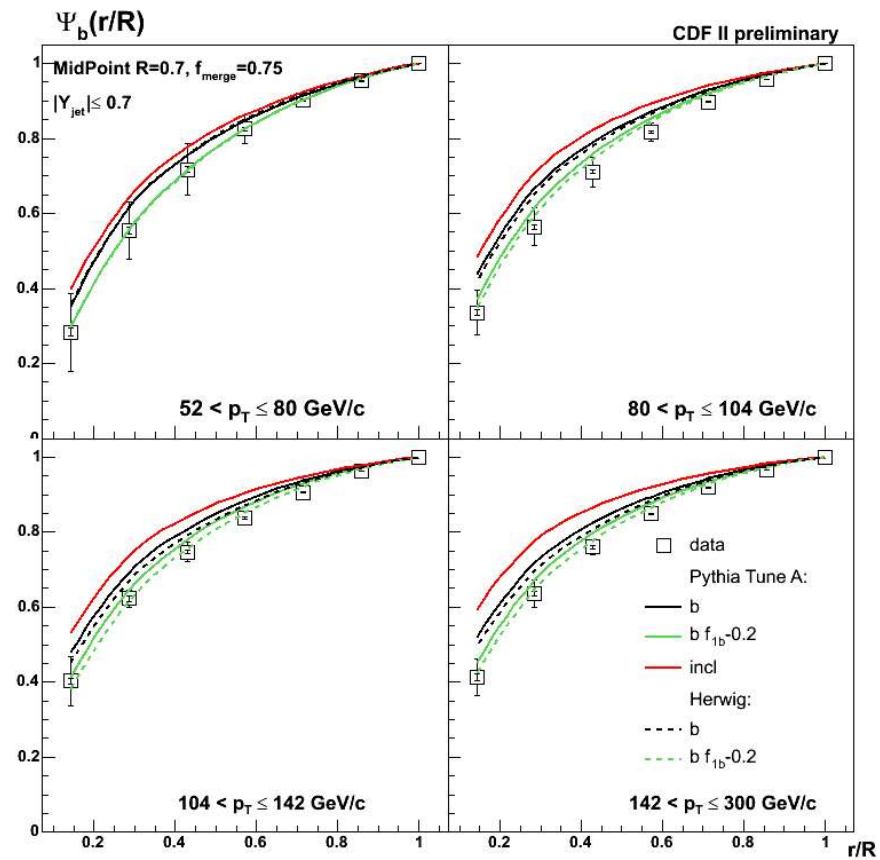
Data corrected to hadron level.
Good agreement with **NLO predictions** with **non-perturbative** contributions.

b-jet Shapes (CDF)

300 pb^{-1}



$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{p_T(0,r)}{p_T(0,R)}$$



First attemps to measure the shapes in heavy flavor jets.

Showing the jet shapes in the **data** compared to **Pythia Tune A** and **Herwig.**

Shape in **b jets** are sensitive to the **b content** of the jet (fraction of 1b/2b jets: $\mathbf{f_{1b}}$).