Latest Jets Results from the Tevatron

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on behalf of CDF & D0 collaborations

42nd Rencontres de Moriond

QCD and High Energy Hadronic Interactions

La Thuile, Italy, March 17-24, 2007

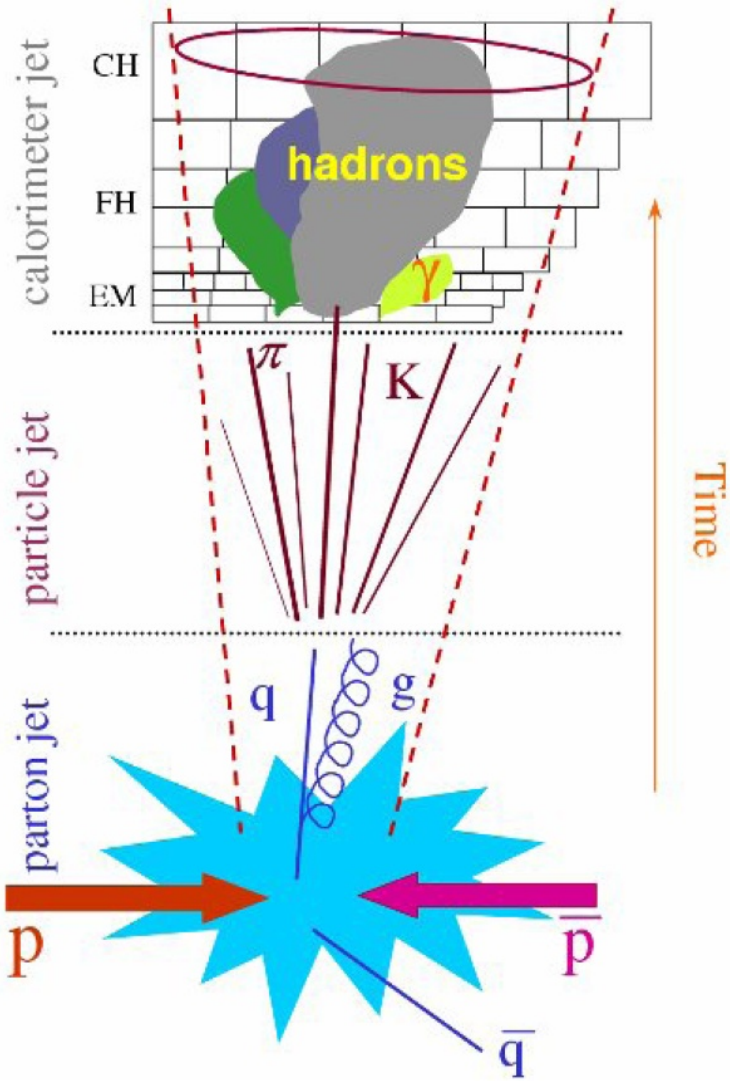
Outline

- Jets in hadronic collisions.
- CDF and D0 detectors at Fermilab.
- **Inclusive jet** production from D0.

  inclusive jets from CDF $\Rightarrow$ see next talk by Olga Norniella
- **Dijet production** cross sections from CDF $(jj, b\bar{b})$.
- **Jet + isolated γ** triple differential cross section from D0.
- **Z+jets** studies from CDF.
- Summary and outlooks.

I will talk only about recently approved analyzes, most of them are based on ~1 fb^{-1} data sample collected during Run IIa

Jets in hadronic collisions

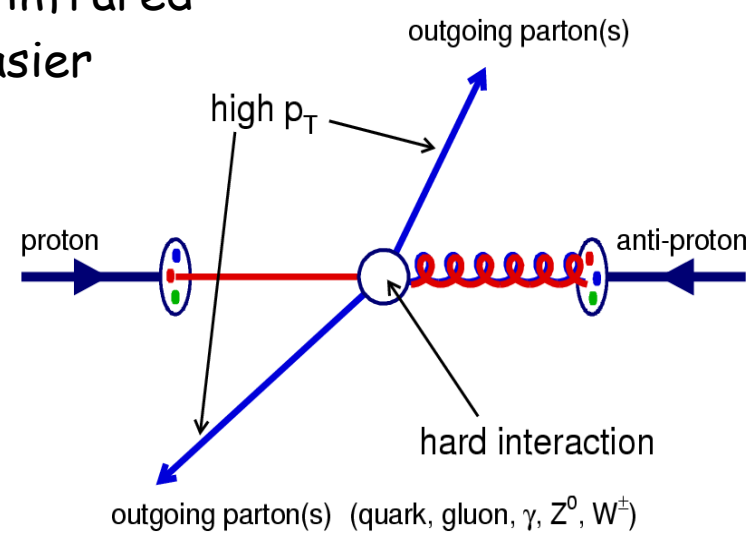


Physics in hadron-hadron collisions:

- hard interactions of 2 partons (PDFs)
- soft initial state radiation (dijet azimuthal decorrelations)
- soft final state radiation (internal jet structure)
- hard radiation (multi-jets, W/Z+jets, γ+jets)
- hadronization/fragmentation (FFs, hadronization corr.)
- multi-parton interactions (underlying event)

Directly observed: energy deposits & tracks

Jet definition relates observables defined on: parton-, particle- and detector level
Jet algorithms that are infrared and collinear safe are easier to compare with theory **(midpont cone, k_T)**

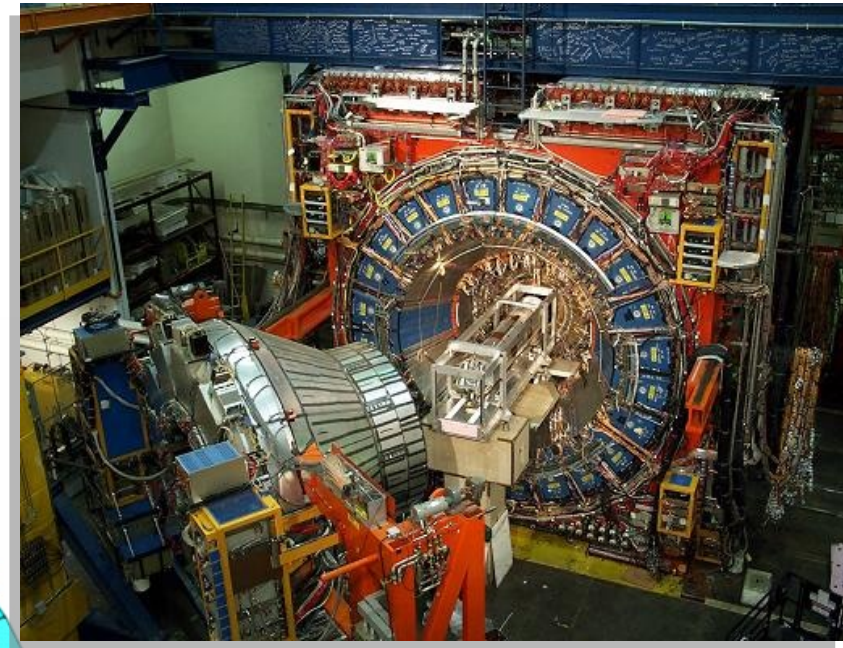


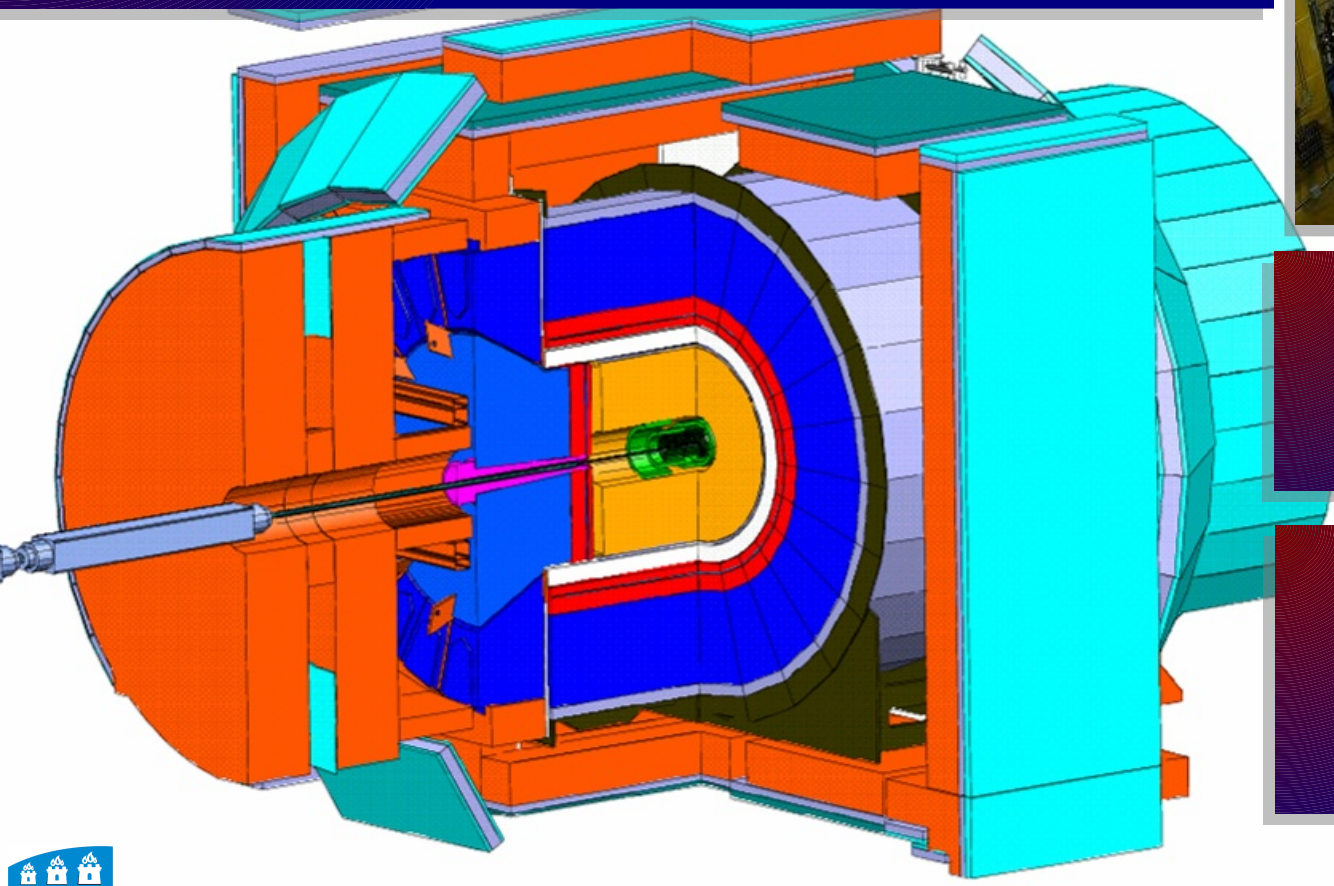
Jets not necessarily represent partons from the LO 2→n process...

CDF detector in Run II

- **Tracker**
  (Silicon Microstrips + Wire Chamber):

6 layers of inner Silicon Vertex Det: $|\eta| < 2$
Intermediate Silicon Layer: $1 < |\eta| < 2$
Central Outer Tracker: $|\eta| < 1$
1.5 T superconducting solenoid



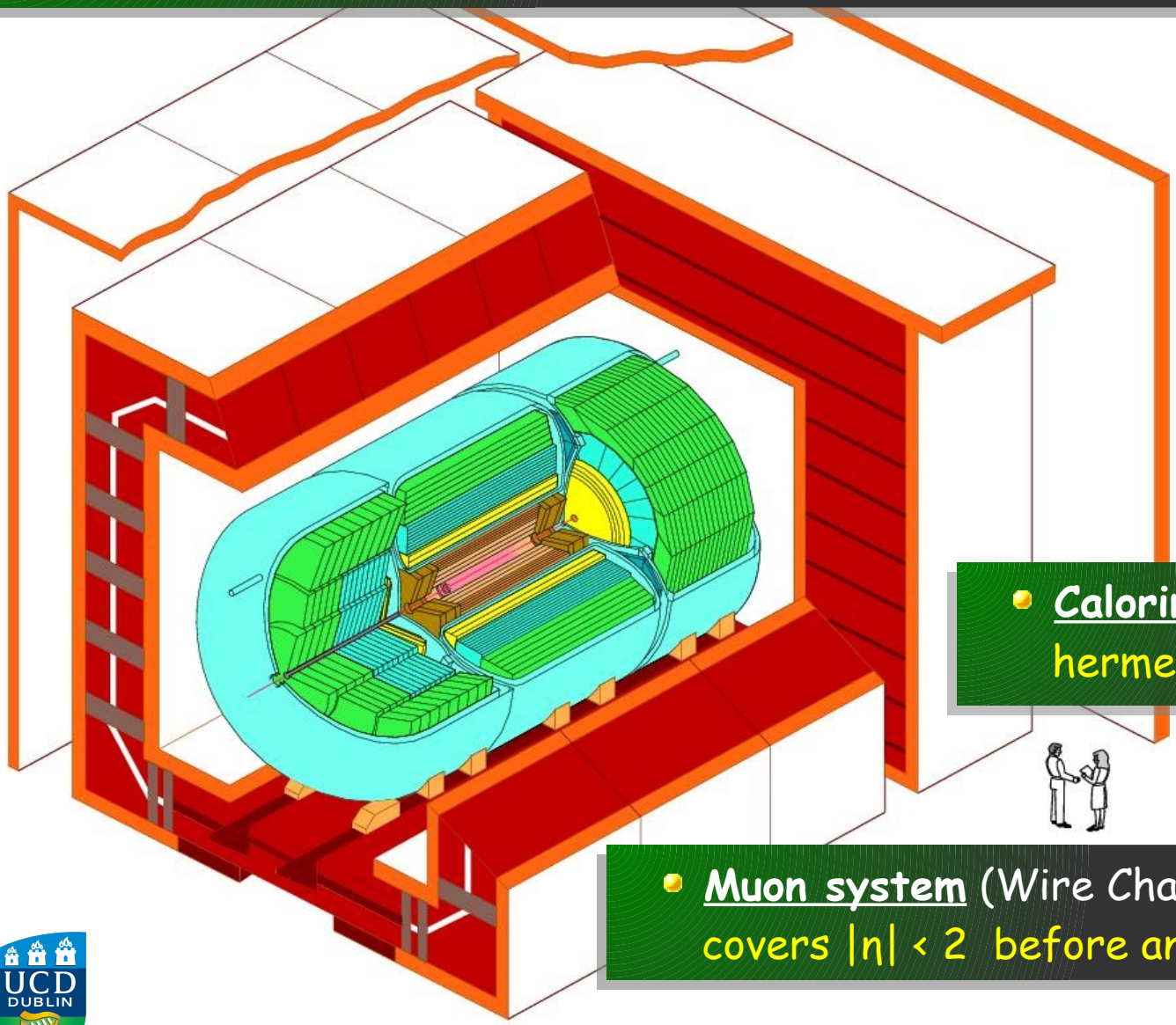


- **Calorimeter** (sampling Pb,Fe/ Scintillator,Wire Chambers):
  covers $|\eta| < 3.6$

- **Muon System** (Scintillators + Proportional Wire Chambers):
  behind steel shielding
  covers $|\eta| < 1.5$

D0 detector in Run II

- **Tracker** (Silicon Microstrips + Scintillating Fibers): covers $|\eta| < 2.5$ inside 2 T superconducting solenoid

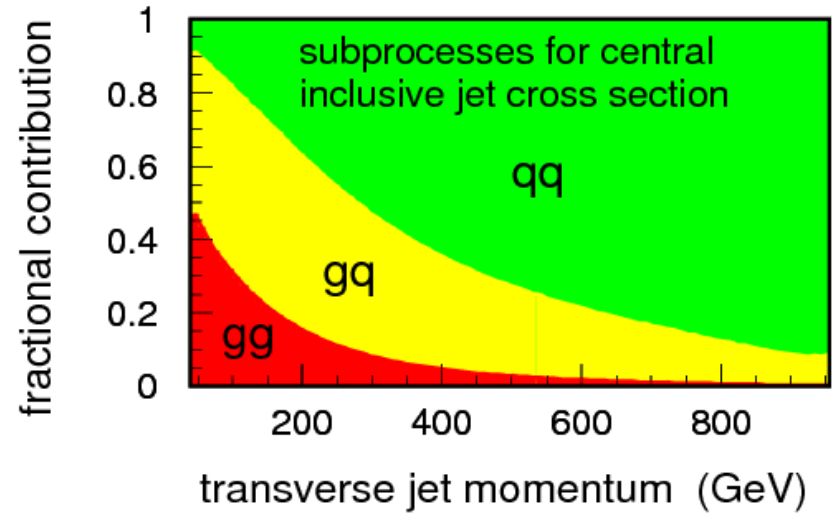


- **Calorimeter** (Sampling U/Liquid Ar): hermetic coverage: $|\eta| < 4.2$

- **Muon system** (Wire Chambers + Scintillators): covers $|\eta| < 2$ before and after toroid

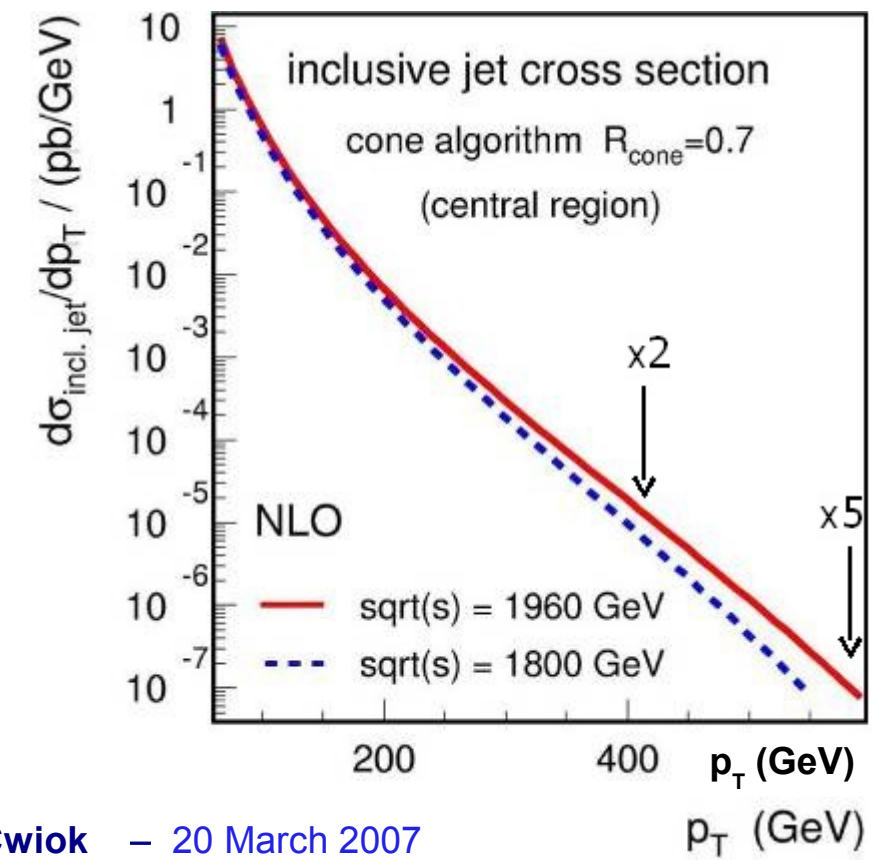
Inclusive jet cross section (D0)

Inclusive jet cross section is directly sensitive to the strong coupling constant α_s and to **PDFs** of the proton

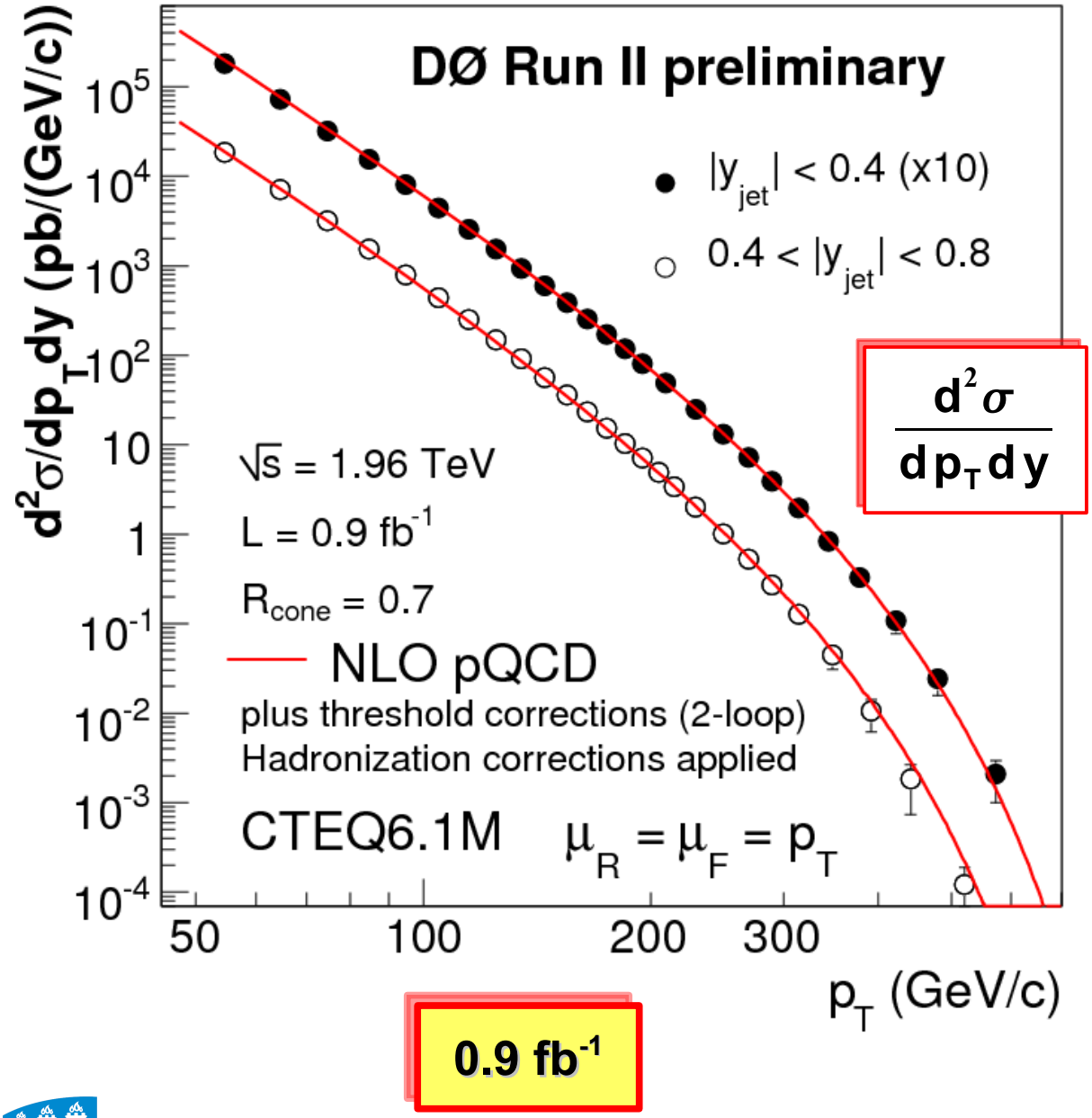


High p_T jets in Run II:

- Center-of-mass energy: $\sqrt{s}$=1.96 TeV (Run I: $\sqrt{s}$=1.8 TeV)
  ⇒ higher cross section by a factor of 5 at p_T=600 GeV ⇒ better sensitivity to NP
- Even at p_T=500 GeV quark-gluon scattering still contributes to 30% of events
  ⇒ sensitivity to gluon PDF at x~0.5 region
- Midpoint cone algorithm with cone size R=0.7 (in $\phi \times \eta$ space) is used by D0 ⇒ infrared safe
- Integrated luminosity from the ongoing Run II (~2 fb^{-1}) is already x10 larger than from Run I



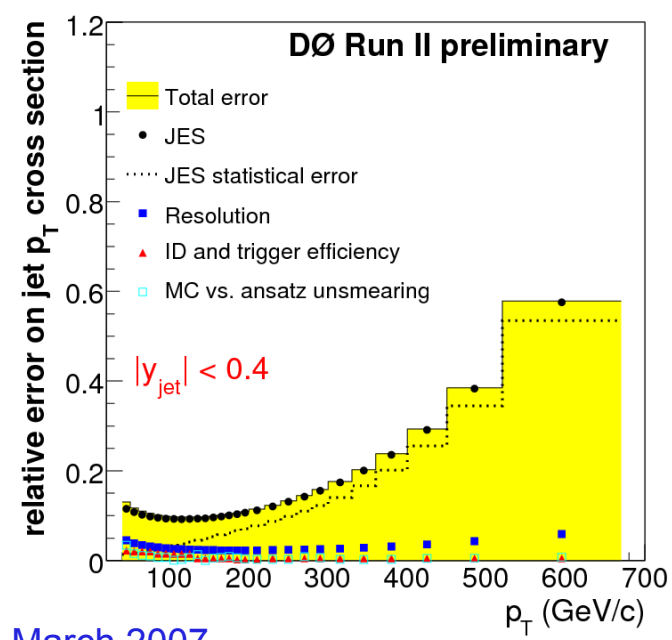
Inclusive jet cross section (D0)



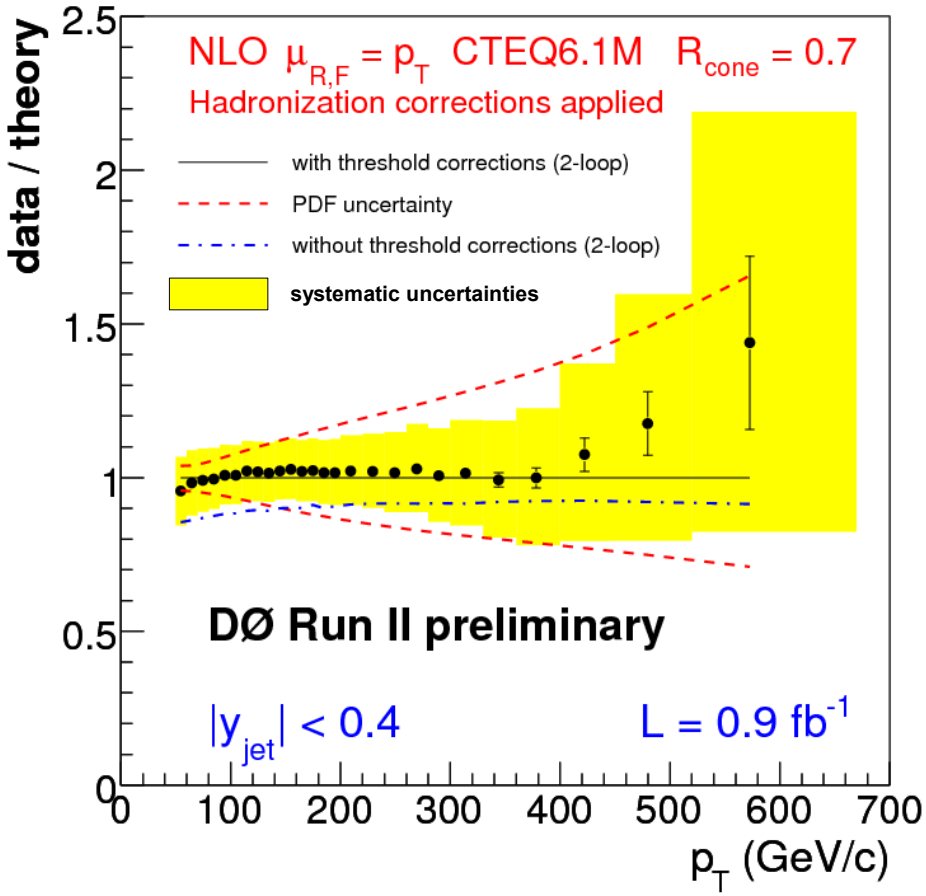
$$\frac{d^2\sigma}{dp_T\,dy}$$

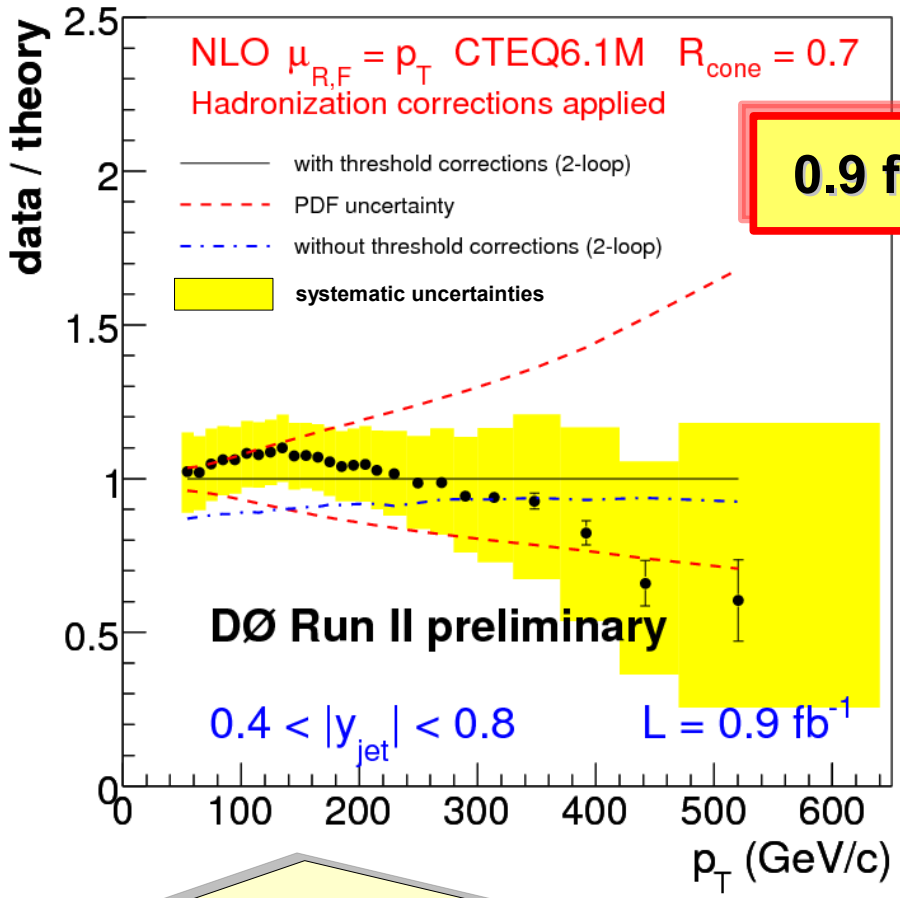
0.9 fb^{-1}

- 2 central rapidity bins
- Data compared to **NLO pQCD** prediction by **NLOJET++** (using CTEQ6.1M PDFs) with:
  - 2-loop NNLO-NNL corrections using threshold resummation techniques (Kidonakis at al.)
  - Hadronization corrections
- Syst. uncertainties dominated by Jet Energy Scale at high p_T



Inclusive jet cross section (D0)



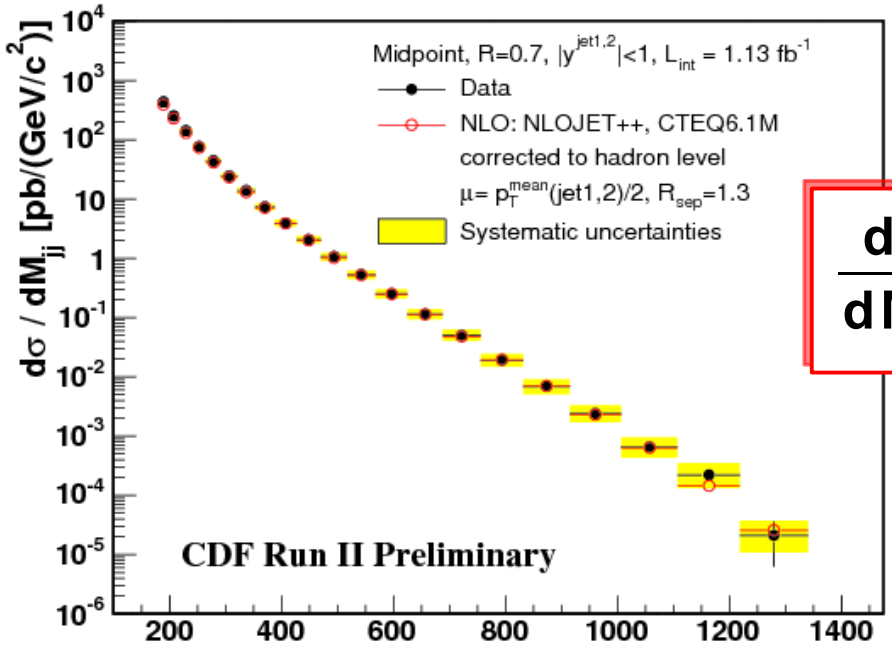


0.9 fb^{-1}

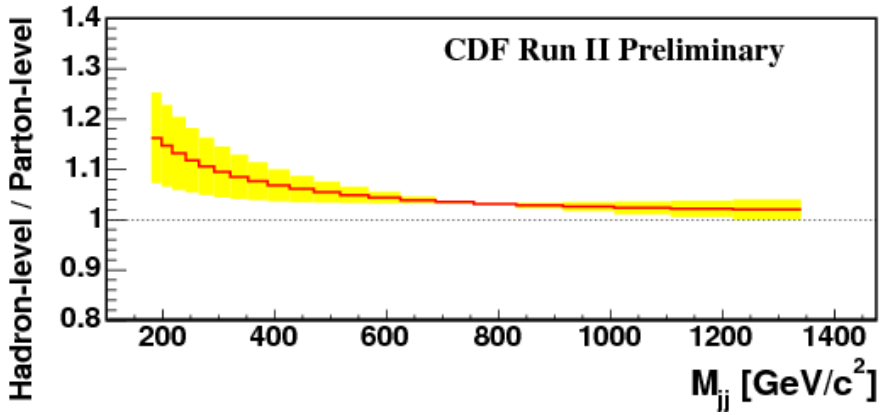
- **Experimental uncertainties comparable with that of PDFs**
- **Good agreement of theory and data over p_T range: 50-700 GeV**
- Potential sensitivity to other PDF sets: MRST 2004, Alekhin 2002
- JES systematics expected to be reduced in the near future

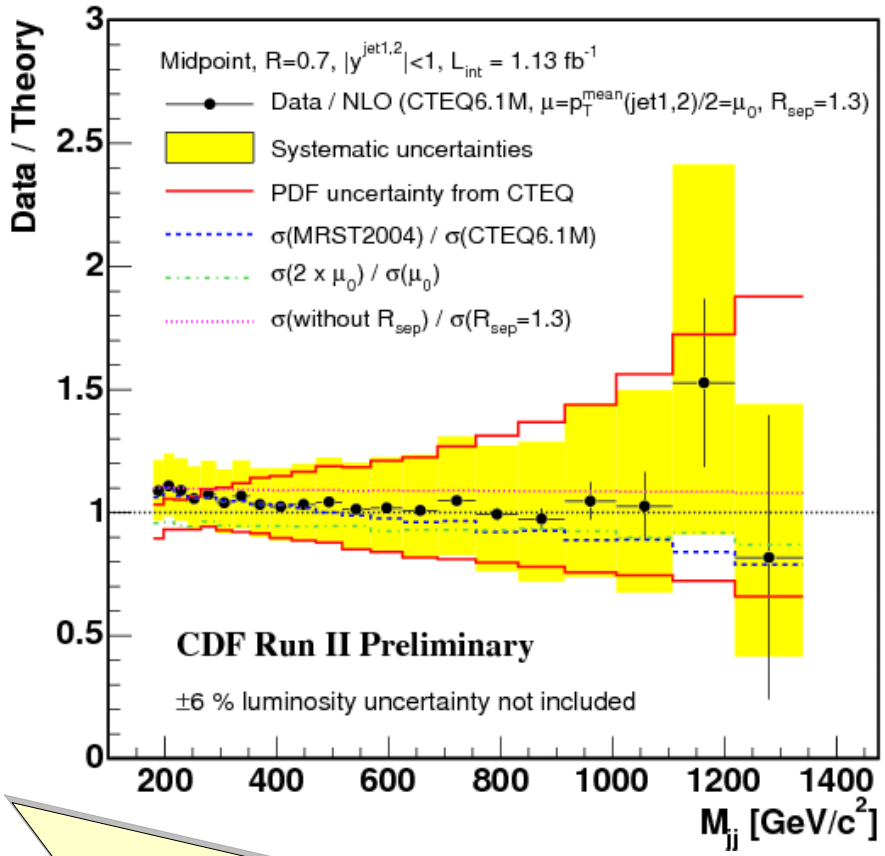
Dijet production cross section (CDF)

- Test of pQCD predictions
- Sensitive to new physics:
  decays of massive particles, compositeness



$$\frac{d\sigma}{dM_{jj}}$$



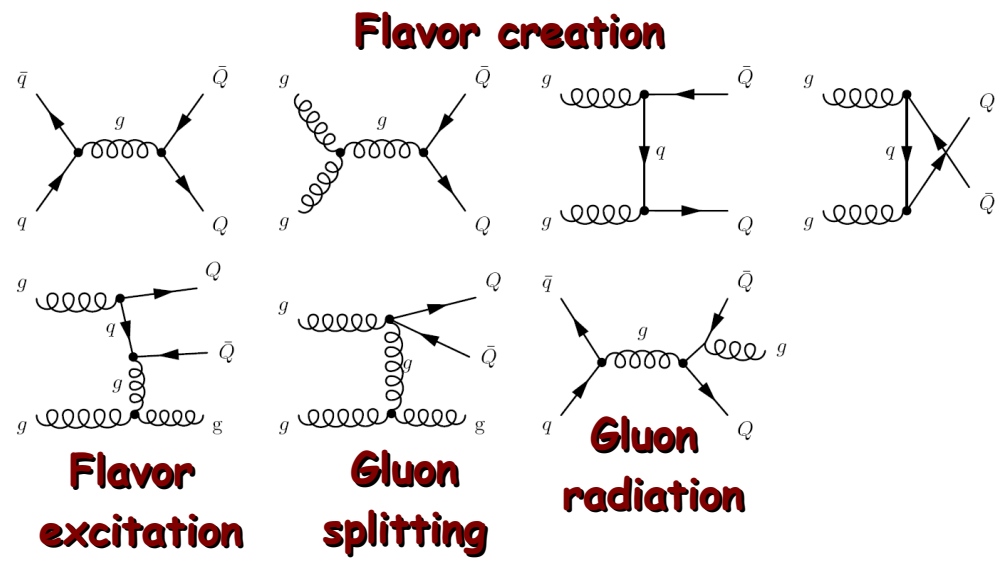


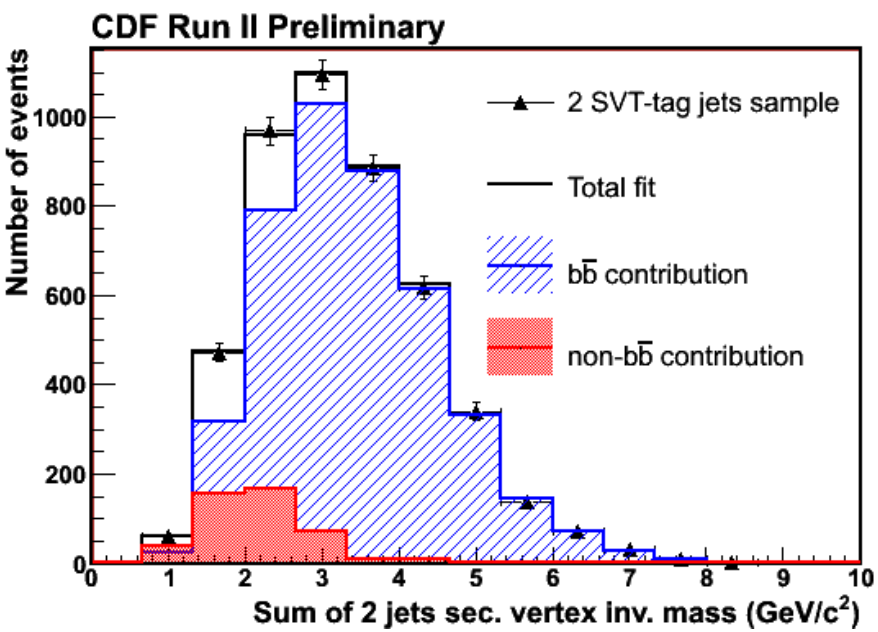
- Dijet cross section measured vs M_{jj}
- Experimental uncertainties comparable to PDF uncertainties
- Consistent with NLO pQCD predictions

1.13 fb^{-1}

Dijet b-bbar cross section (CDF)

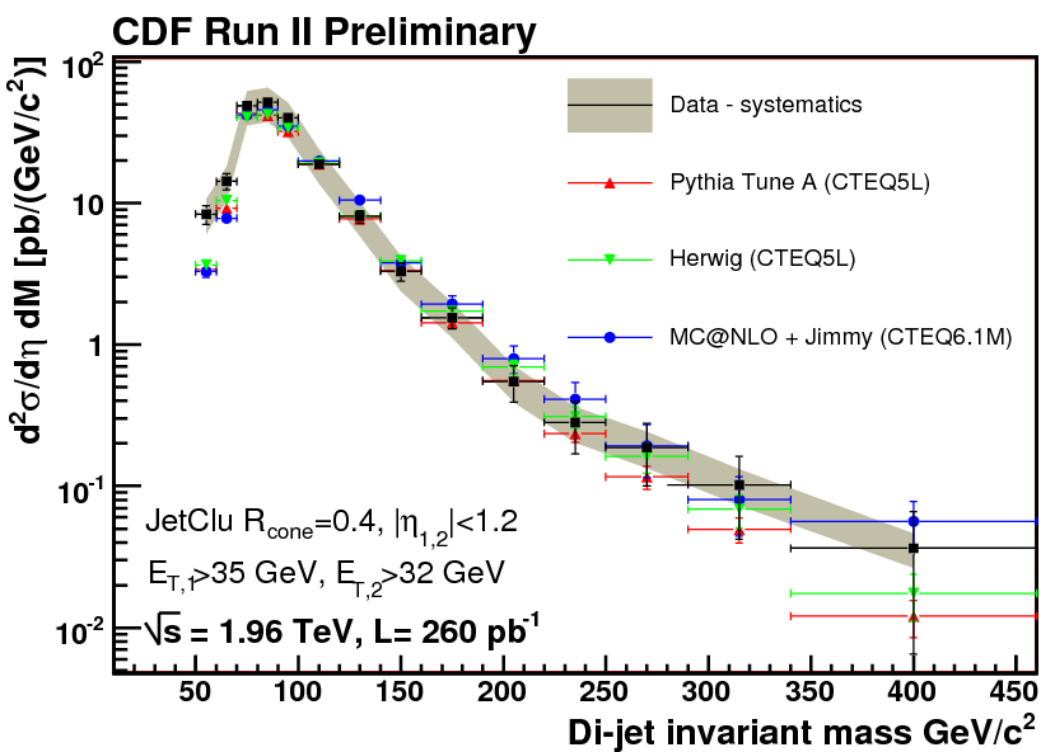
- Provides understanding of b production mechanisms: direct production, flavor excitation, gluon splitting
- Tests radiative corrections

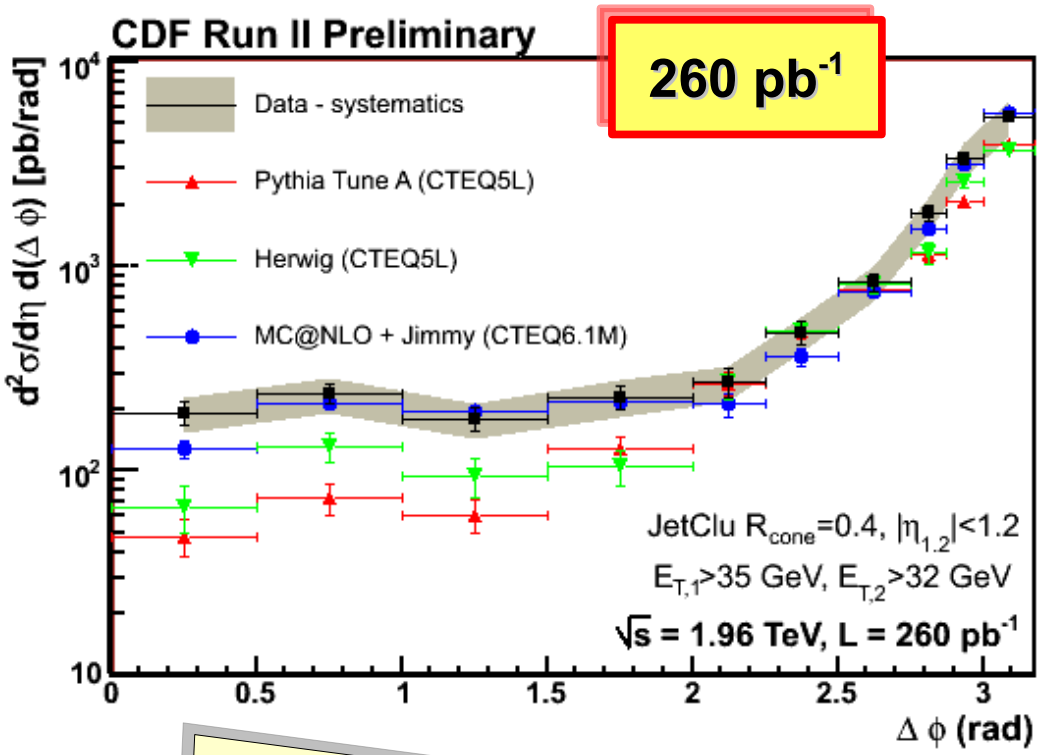




- Triggering on events having 2 displaced tracks at Level 2 (SVT)
- Offline reconstruction of secondary vertices (SV) inside the jet; b-tagging with 2D "SecVtx" algorithm
- Distribution of invariant mass of SV tracks used to separate contribution due to heavy flavor jets from light quark and gluon jets
  ⇒ fitting 2 template distributions
- Efficiency for two b-tagged jets: 2 - 4%
- Purity for two b-tagged jets: 75 – 90%

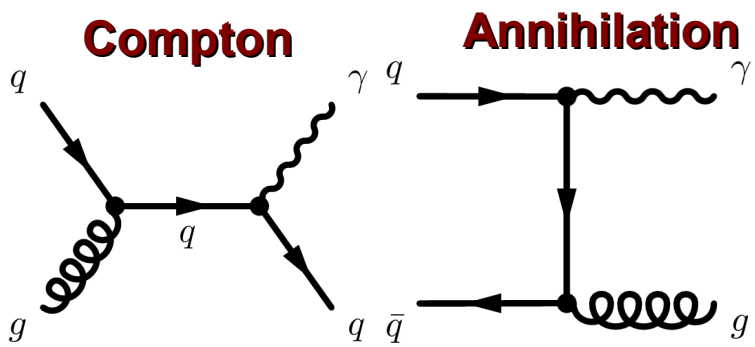
Dijet b-bbar cross section (CDF)





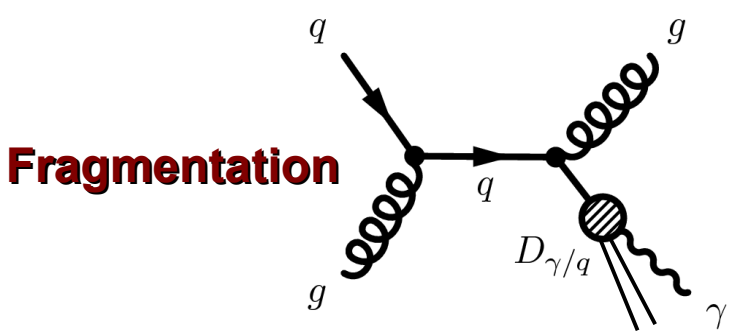
- Measured **differential dijet cross section** vs: **leading jet E_T , M_{jj} , $\Delta\phi_{jj}$**
- $\Delta\phi_{jj}$ distribution very sensitive to soft gluon radiation
- Results corrected to the hadron level
- **LO predictions** : **PYTHIA Tune A**, **HERWIG** (both using CTEQ5L PDFs)
- **NLO prediction** : **MC@NLO+Jimmy** (using CTEQ6.1M PDFs) – describes data well in a wide range of the phase space

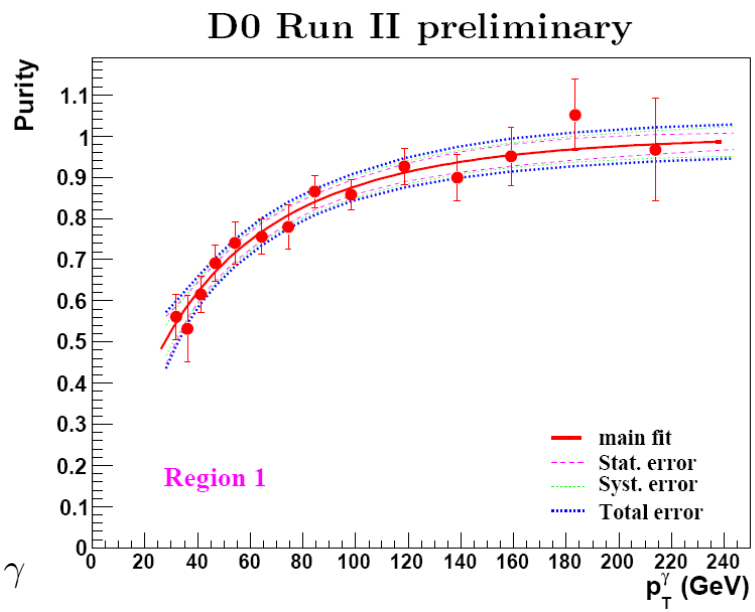
Jet + isolated photon cross section (D0)



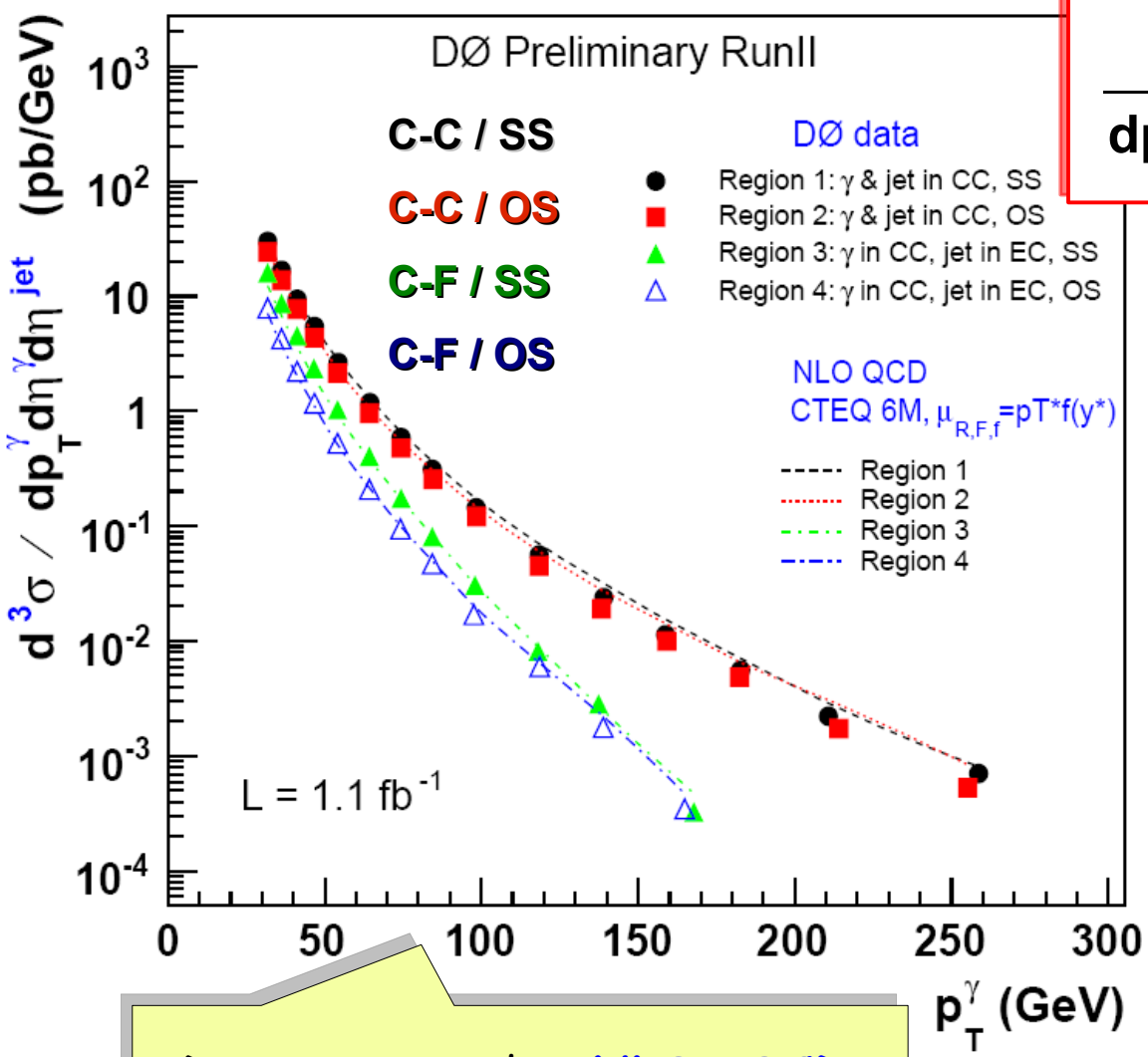
- Direct photons come unaltered from parton subprocesses to EM calorimeter
- Compton process dominates at $p_T^{\gamma} < 120$ GeV
- Cross section sensitive to gluon distribution $G(x_T,Q^2)$ inside colliding hadrons ⇒ constrain PDFs?

- $\sigma(\text{jets}) / \sigma(\gamma) \approx 10^3$ ⇒ challenging experimental measurement
- Main source of **background is caused by decays of neutral hadrons** (η, π^0, K^0_S) to photons in the final state, mainly **at low p_T^{γ}**
  ⇒ **isolation criteria** reduce this contribution
- Artificial Neural Network is used to further improve photon purity





Jet + isolated photon cross section (D0)



$$\frac{d^3\sigma}{dp_T^\gamma\, d\eta^\gamma\, d\eta^{jet}}$$

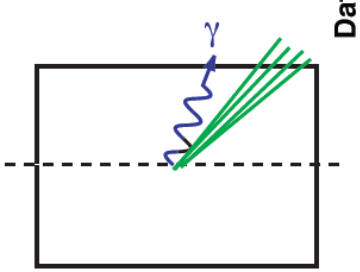
1.1 fb^{-1}

- **Measured triple differential inclusive cross section**
- **Central isolated photon**: p_T^γ>30 GeV, $|\eta^\gamma|$<0.8
- Leading **jet**: p_T^{jet}>15 GeV,
  central ($|\eta^{jet}|$<0.8) or
  forward (1.5<$|\eta^{jet}|$<2.5)
- C-C or C-F events of 2 kinds:
  (η^γ, η^{jet}) have **same** signs (SS)
  (η^γ, η^{jet}) have **opposite** signs (OS)
- 4 regions cover much larger domain than any previous γ+jets measurement (up to p_T^γ=300 and 200 GeV for C-C and C-F events, respectively)

Data compared to **NLO pQCD JETPHOX** predictions using CTEQ6.1M PDFs and BFG FFs

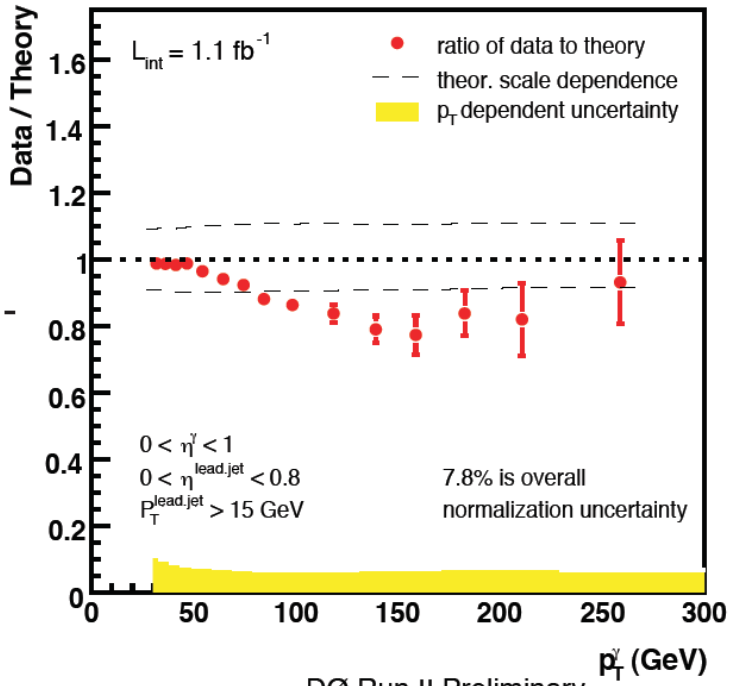
Jet + isolated photon cross section (D0)

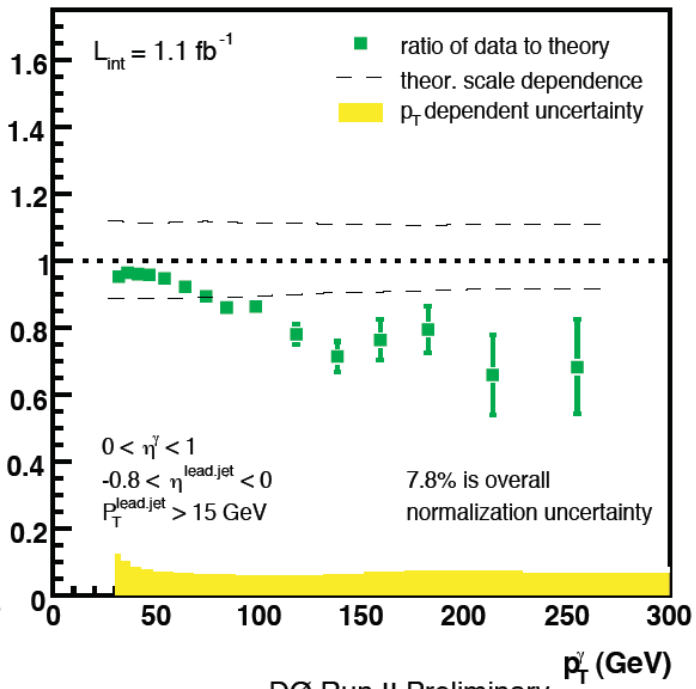
1.1 fb^{-1}

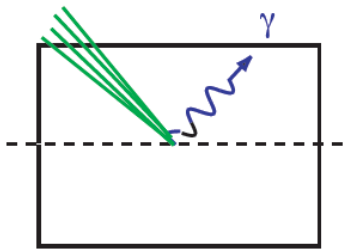


Region 1

C-C / SS



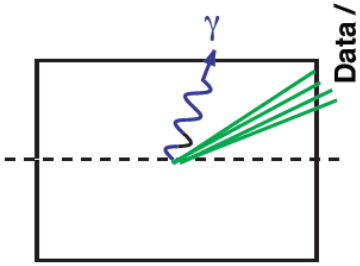




Region 2

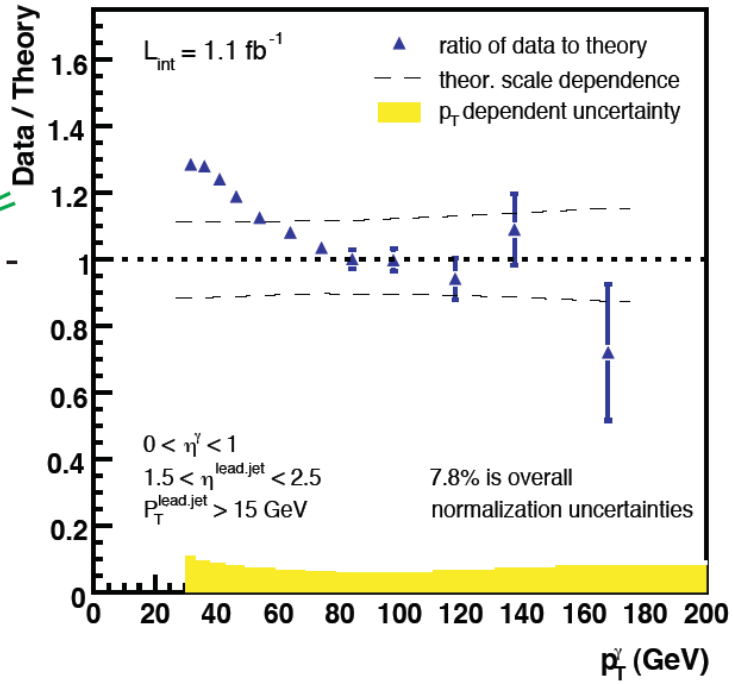
C-C / OS

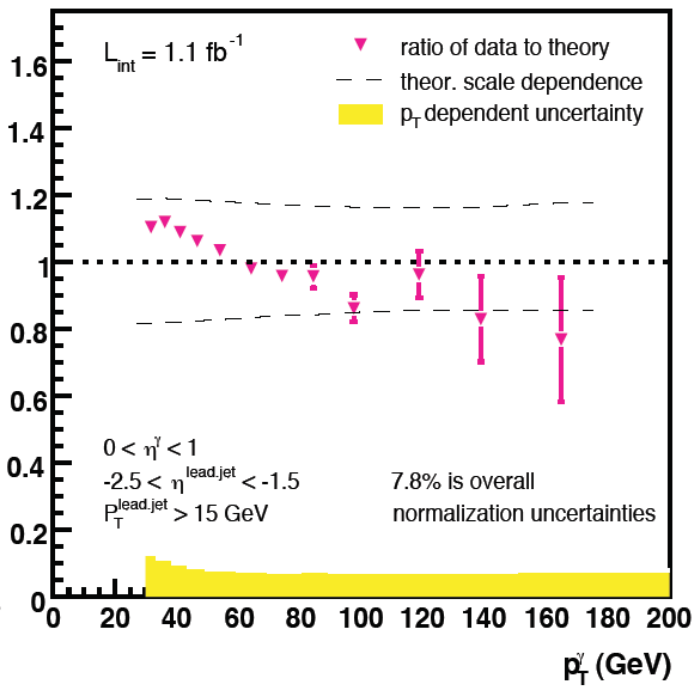
similar deviations seen before in inclusive photons (UA2, CDF, D0)

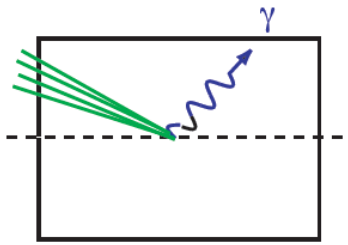


Region 3

C-F / SS







Region 4

C-F / OS

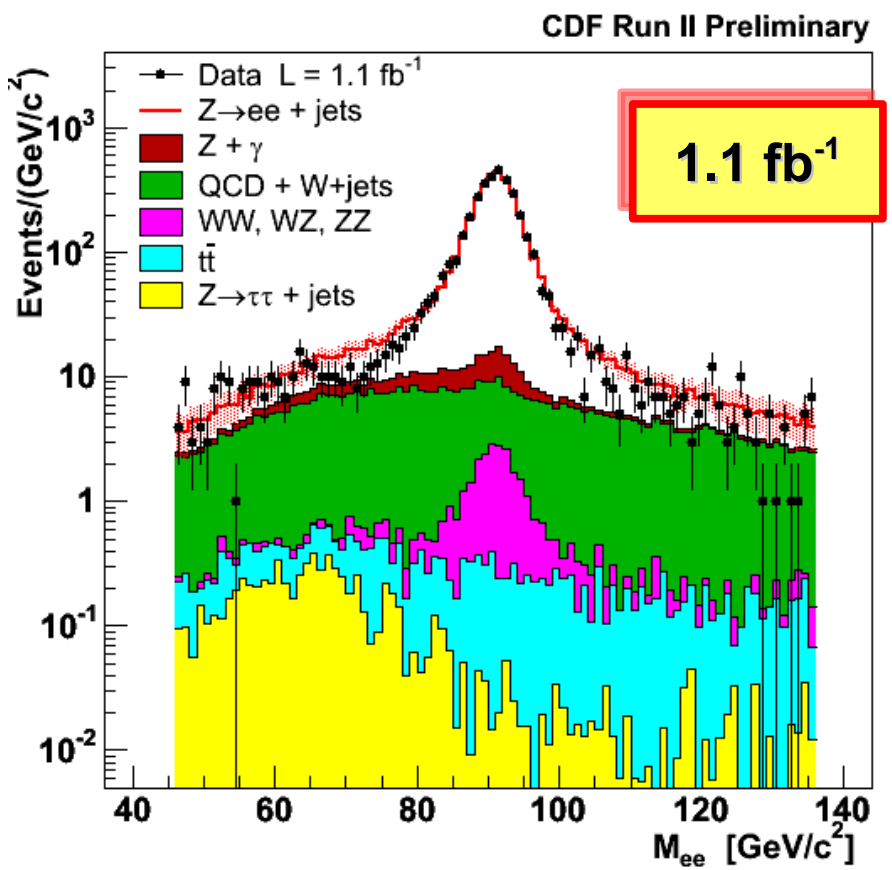
Z + jets cross section (CDF)

Vector Boson + Jets

- Testing LO, NLO perturbative QCD predictions at high momentum transfers
- Testing models of hadronization and underlying event
- Background for: Top production, Higgs, SUSY
- Useful for NP searches like: compositeness and decays of heavy particles

$p\bar{p} \to Z(\to e^+e^-)$ + jets measurement:

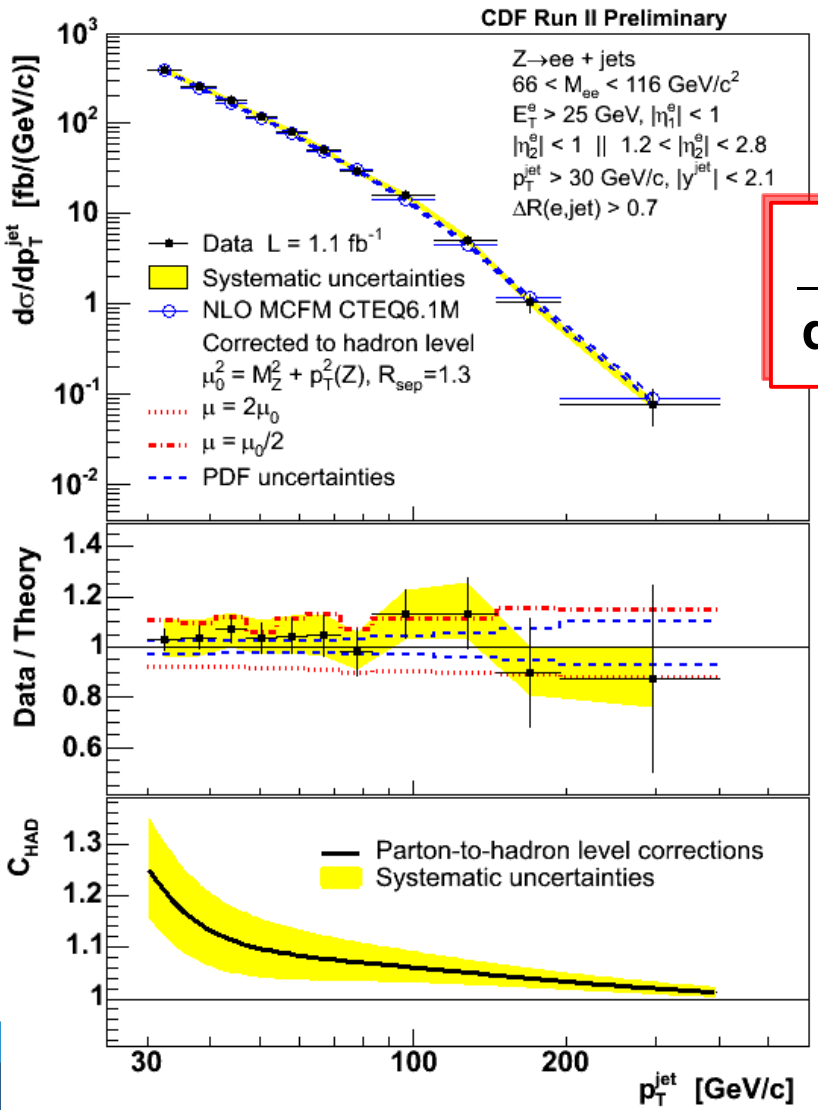
- Cleaner experimental signature than W+jets, but x10 smaller cross section
- Jets: defined using MidPoint search cone algorithm with R=0.7, hadron level jets region: $p_T^{jet} > 30$ GeV, $|y^{jet}| < 2.1$
- Electrons: $E_T > 25$ GeV, isolated from jet cones by $\Delta R > 0.7$, Central-Central or Central-Forward pairs
- Z-mass window: $66 < M_{ee} < 116$ GeV



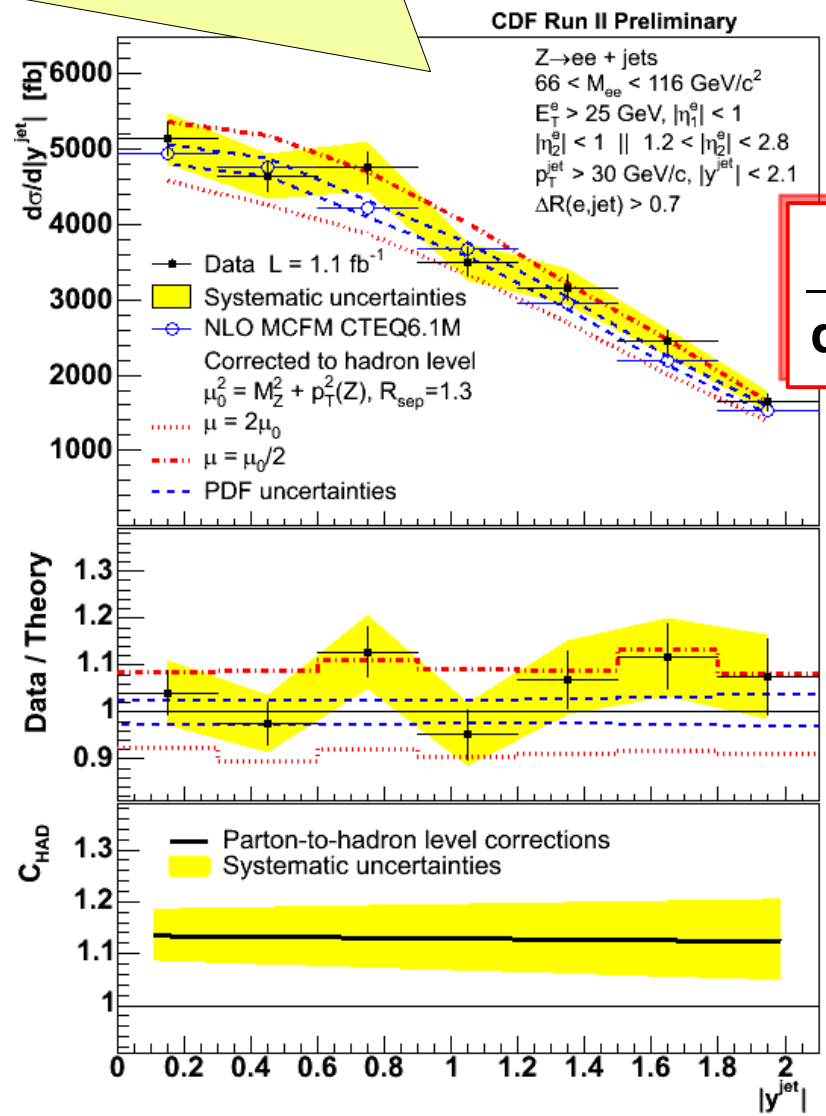
Z + jets cross section (CDF)

- Measured differential cross section vs: p_T^{jet}, $|y^{jet}|$
- Good agreement with MCFM predictions: NLO pQCD + additional C_{had} factor due to non-pQCD contributions

1.1 fb^{-1}

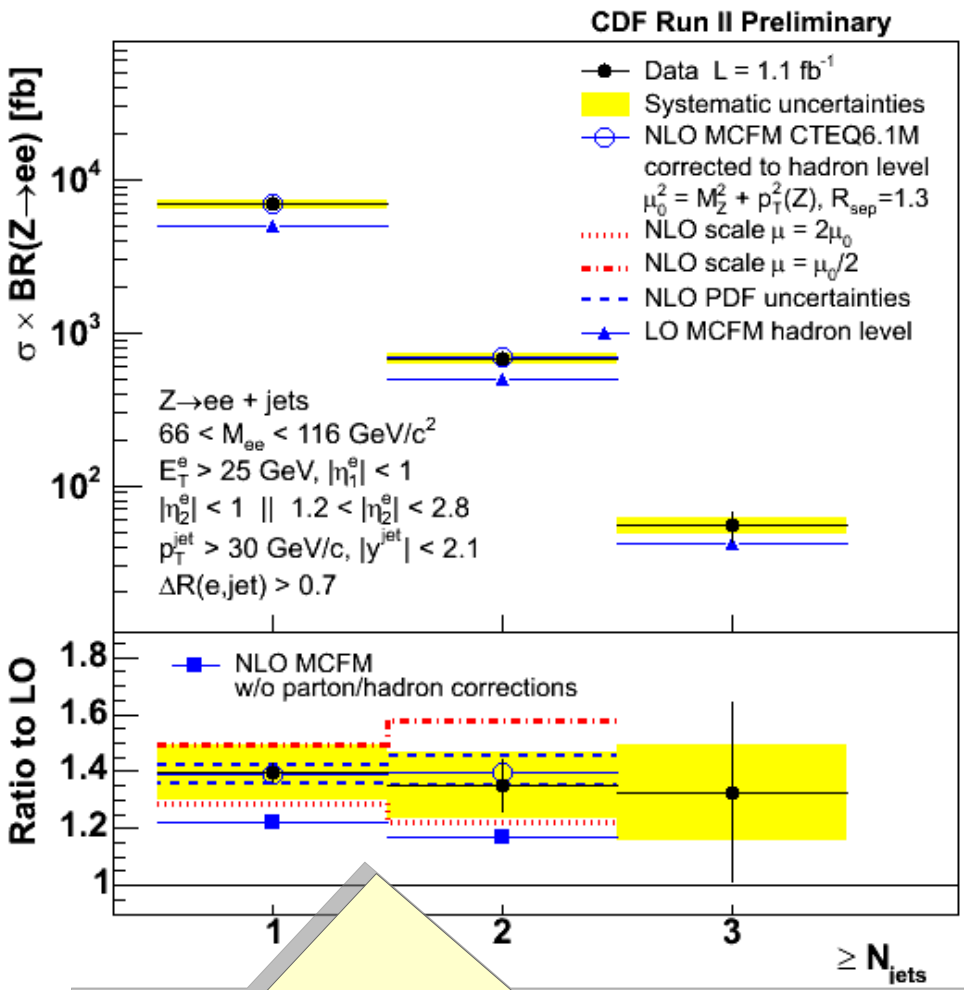


$$\frac{d\sigma}{dp_T^{jet}}$$



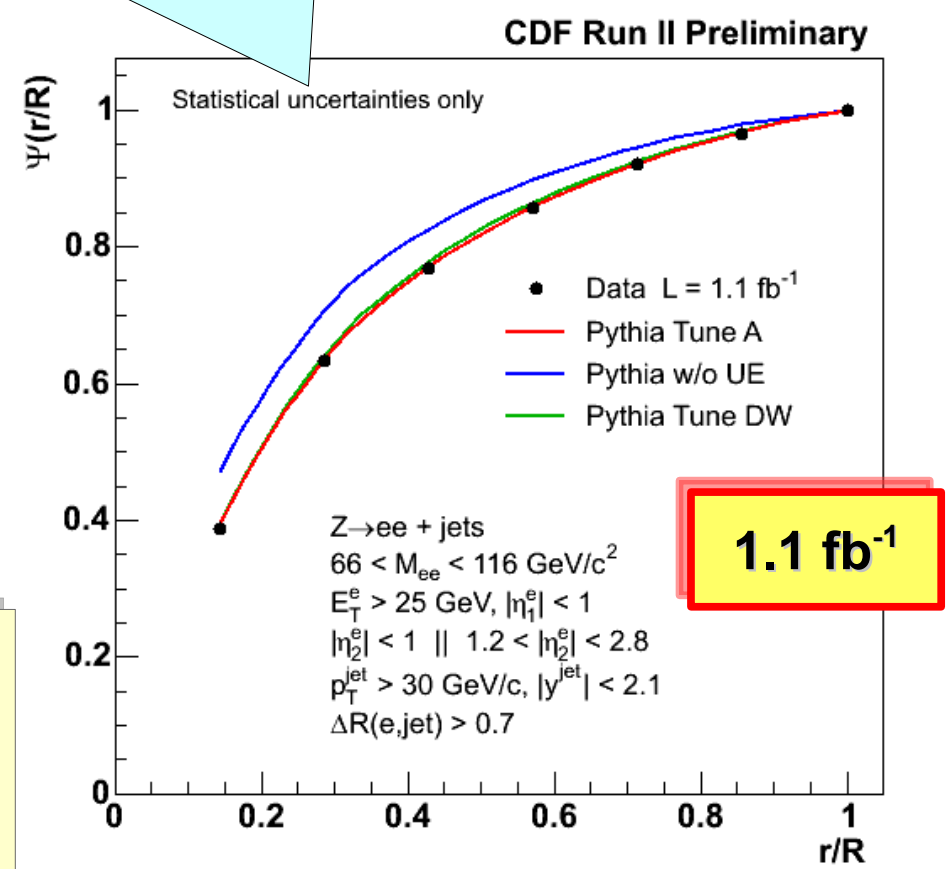
$$\frac{d\sigma}{d|y^{jet}|}$$

Z + jets cross section (CDF)



Underlying event contribution studies:

- integrated- and differential jet shapes
- transverse energy flow wrt Z-boson direction
- different PYTHIA tunes compared with data



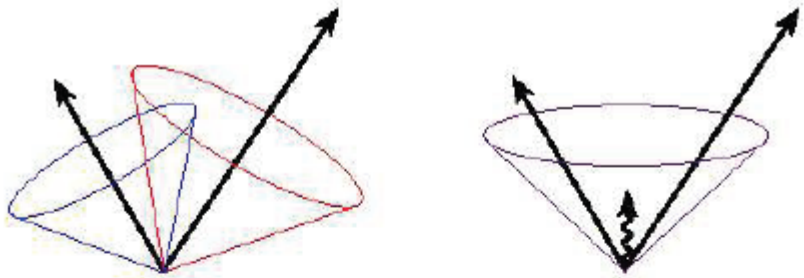
- NLO pQCD predictions for N_{jets}=1,2
- LO pQCD predictions for N_{jets}=1,2,3
- ratio NLO/LO vs $N_{jets} \approx$ const
- non-perturbative corrections to NLO ~15%

Summary and outlooks

- Next-to-Leading order QCD models describe data reasonably well over wider p_T and rapidity ranges than previous studies.
- More QCD jet analyzes from Run II are under way.
- Each experiment recorded to tape over 2 fb^{-1} of data
- Near-future anticipated increase in statistics should allow both experiments to extend their measurements over a larger kinematic region (4-8 fb^{-1} by 2009).

BACKUP slides

Jet algorithms (1)



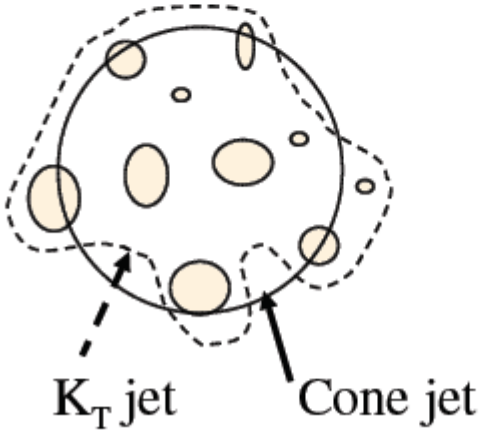
Run I Legacy Cone:

- Draw a cone of fixed size in η–ϕ space around a seed
- Compute jet axis from E_T-weighted mean and jet E_T from ΣE_T's
- Draw a new cone around the new jet axis and recalculate axis and new E_T
- Iterate until stable
- Algorithm is sensitive to soft radiation

Improved Run II Cone : "Joint Jet Working Group"

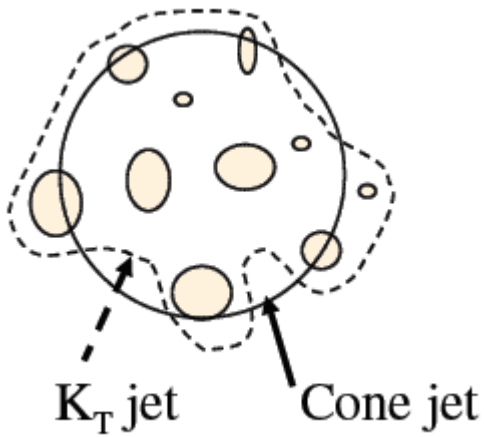
- Use 4-vectors instead of E_T
- Add additional midpoint seeds between pairs of close jets
- Split/merge after stable protojets found
- Improved infrared safety at NLO

(D0 Run II/CDF MIDPOINT)



V. O'Dell

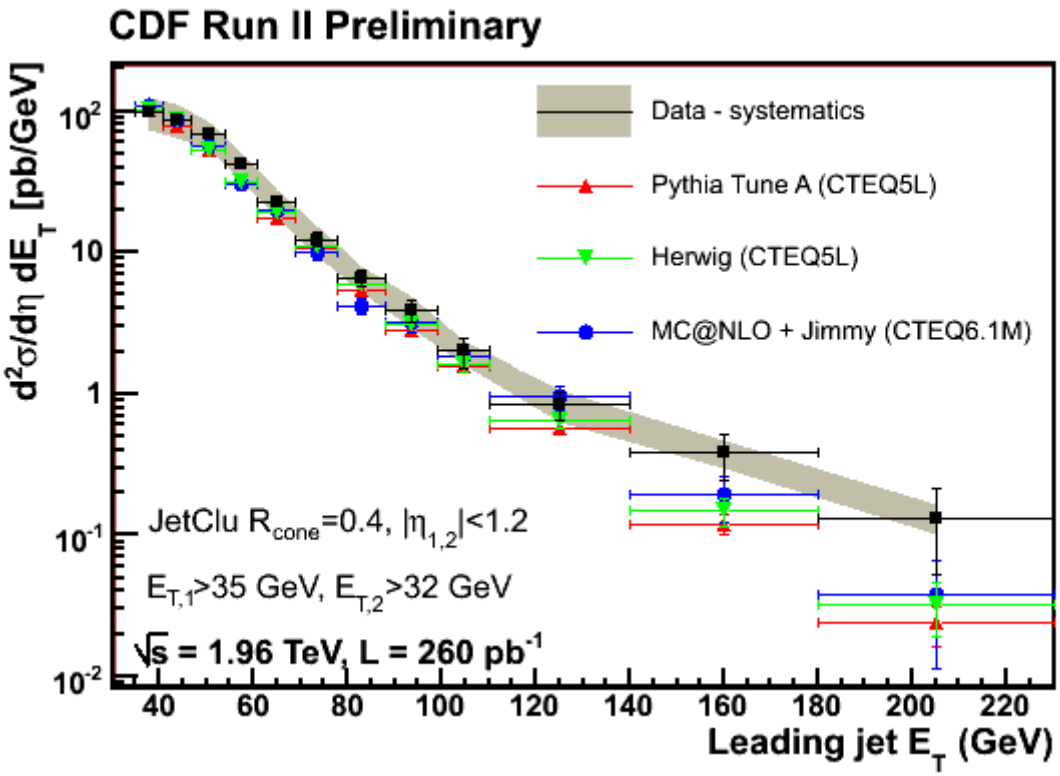
Jet algorithms (2)



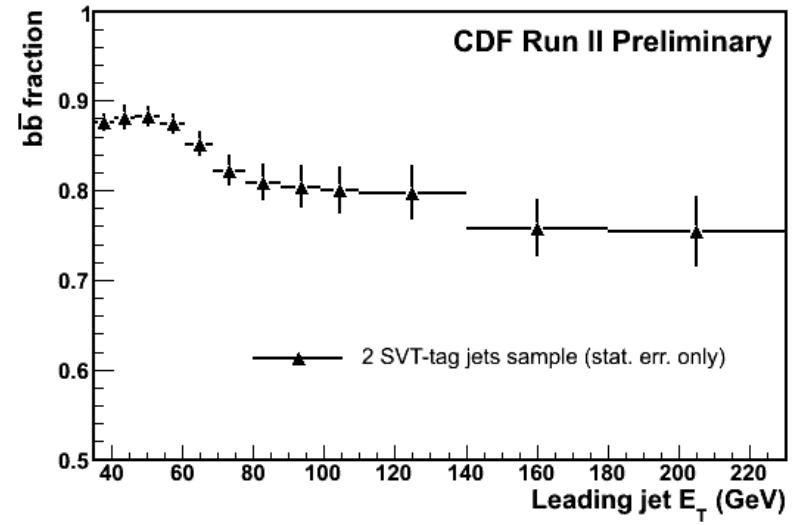
CDF k_T algorithm in Run II:

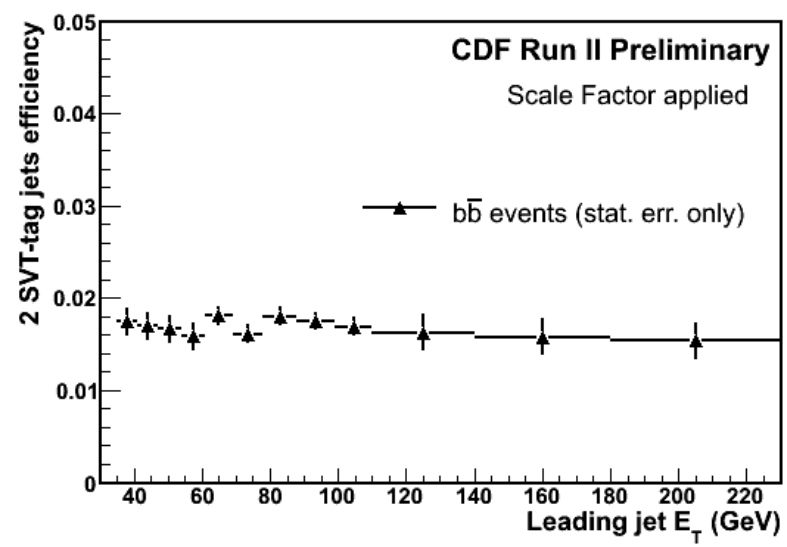
- Iterative procedure
- Closest pair are recombined into one until the mutual distance is lower then some cut
- No fixed geometrical shape
- No splitting or merging
- Infrared/collinear safe

Dijet b-bbar cross section (CDF)

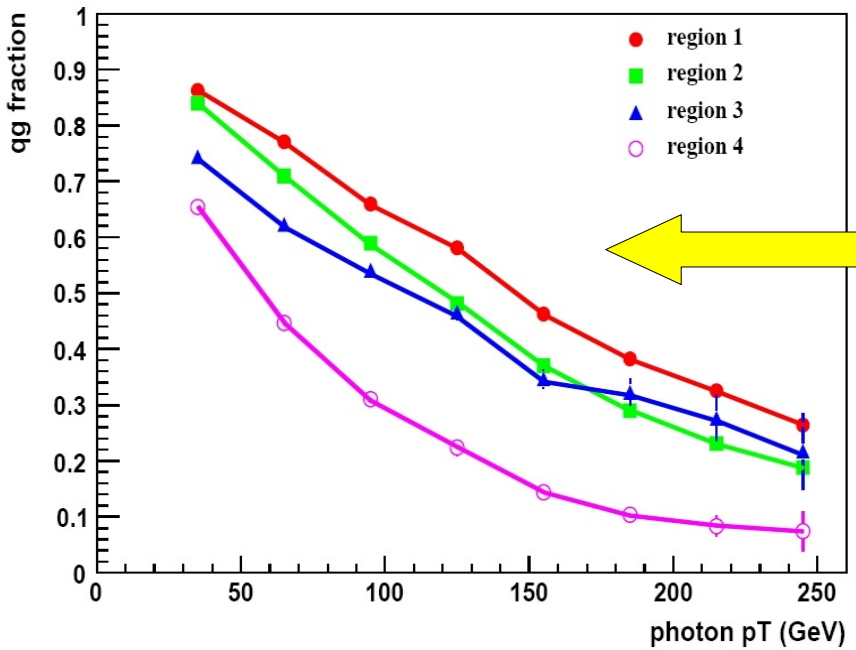


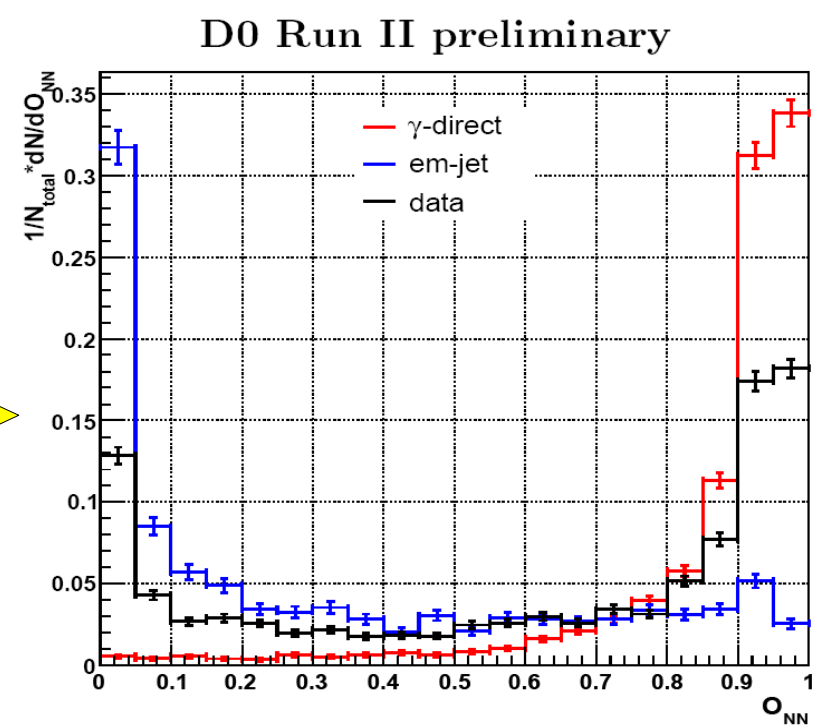
260 pb^{-1}





Jet + isolated photon cross section (D0)



- PYTHIA simulation of the fractional contributions due to **Compton (qg)** subprocesses as a function of p_T^{γ}
- Region 1 : **Central – Central, Same Sign rapidity**
- Region 2 : **Central – Central, Opposite Sign rapidity**
- Region 3 : **Central – Forward, Same Sign rapidity**
- Region 4 : **Central – Forward, Opposite Sign rapidity**

- Normalized Artificial Neural Network (ANN) outputs for **"γ+jet"** signal and **"jet+jet"** backgrounds for $40 < p_T^{\gamma} < 50$ GeV region
- O_{NN}**>0.7** cut is used
- Photon selection efficiency varies between 50% and 80% depending on p_T^{γ}