Measurement of Triple Differential Photon+Jet Cross Section by DØ

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On behalf of the DØ Collaboration

European Physical Society
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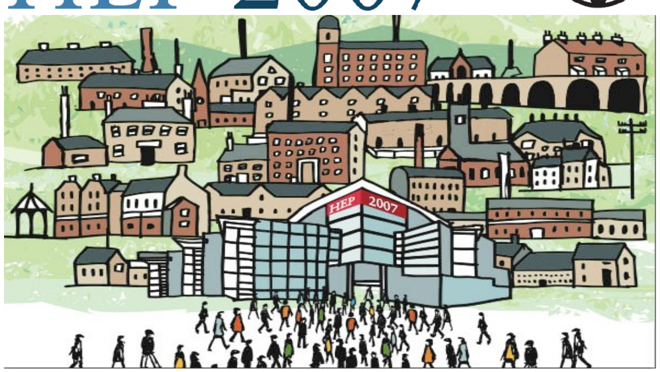

University at Buffalo
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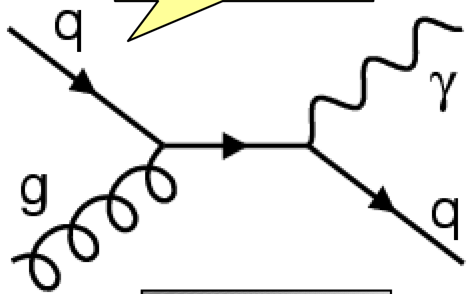
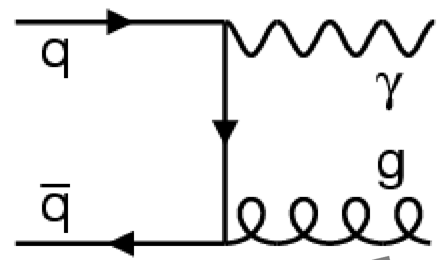
Motivation

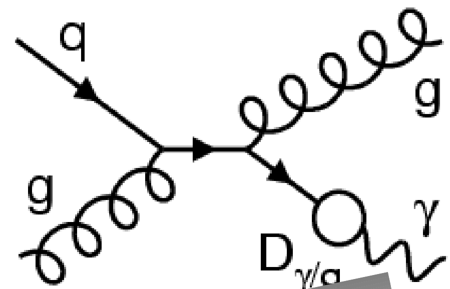
Dominant



Compton



Annihilation



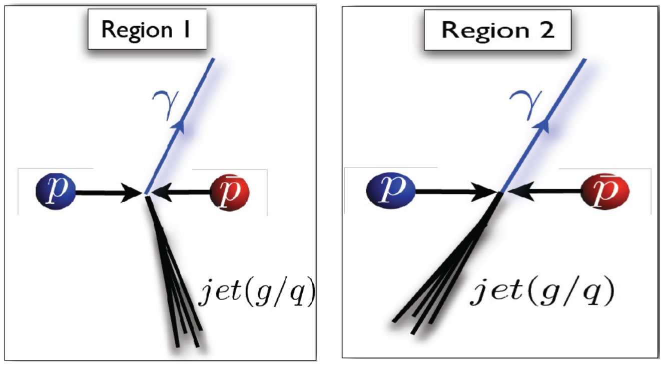
Fragmentation

Advantage: Mostly **direct photons** emerging unaltered from the hard interaction
⇒**direct probe** of the hard scattering dynamics
⇒**clean probe** w/o complication from jet fragmentation & systematics
⇒**More abundant** than Z/W+jets (a few millions at 1 fb^{-1})

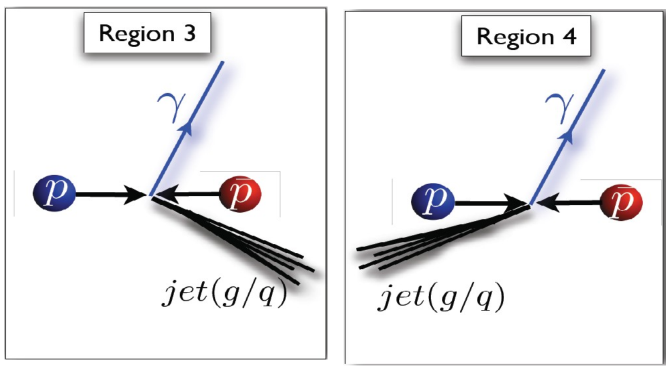
- **Precision test** of pQCD
- Sensitive to PDF's, esp. **gluon density**
- More detailed test of the underlying processes than inclusive γ measurement
- Understanding the QCD production mechanisms of photons is prerequisite to searches for new physics (esp. LHC).

γ+jet Production

γ & jet in CC (SS, OS)



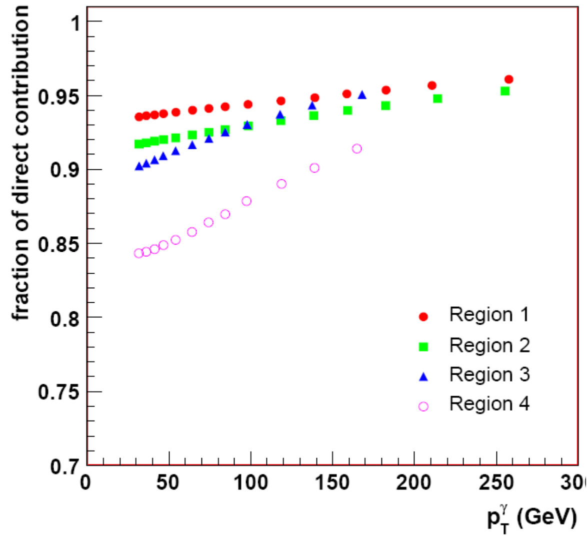
γ in CC & jet in EC (SS,OS)



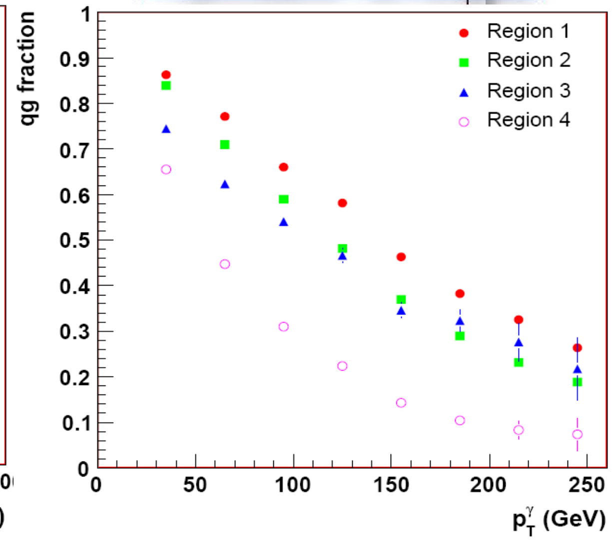
$$x_{1,2}^{LO} \approx p_T^{\gamma}/\sqrt{s}\,(e^{\pm\eta^{\gamma}} + e^{\pm\eta^{jet}})$$

Region 1: $x_{1,2}$ cover adjacent intervals
Region 2: $x_{1,2}$ almost identical
Region 3: $x_{1,2}$ cover very different intervals, very small and very large x

JETPHOX



Pythia6.3+CTEQ6L



γ^{frag} contribution decreases with p_T^{γ}

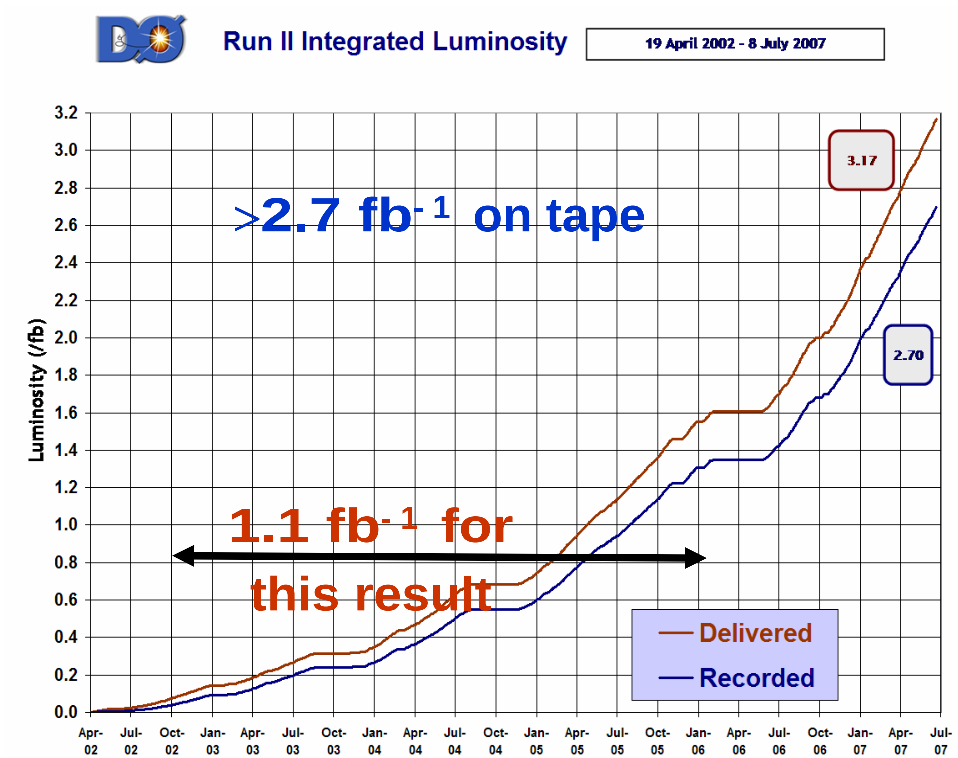
$qg \rightarrow \gamma q$ dominates in the wide kinematic range
$\Rightarrow$probe $F(x,Q^2)$ in a new window
0.007< **x** <**0.8** & $9.10^2 < Q^2 < 8.10^4$ ($Q = p_T^{\gamma}$)

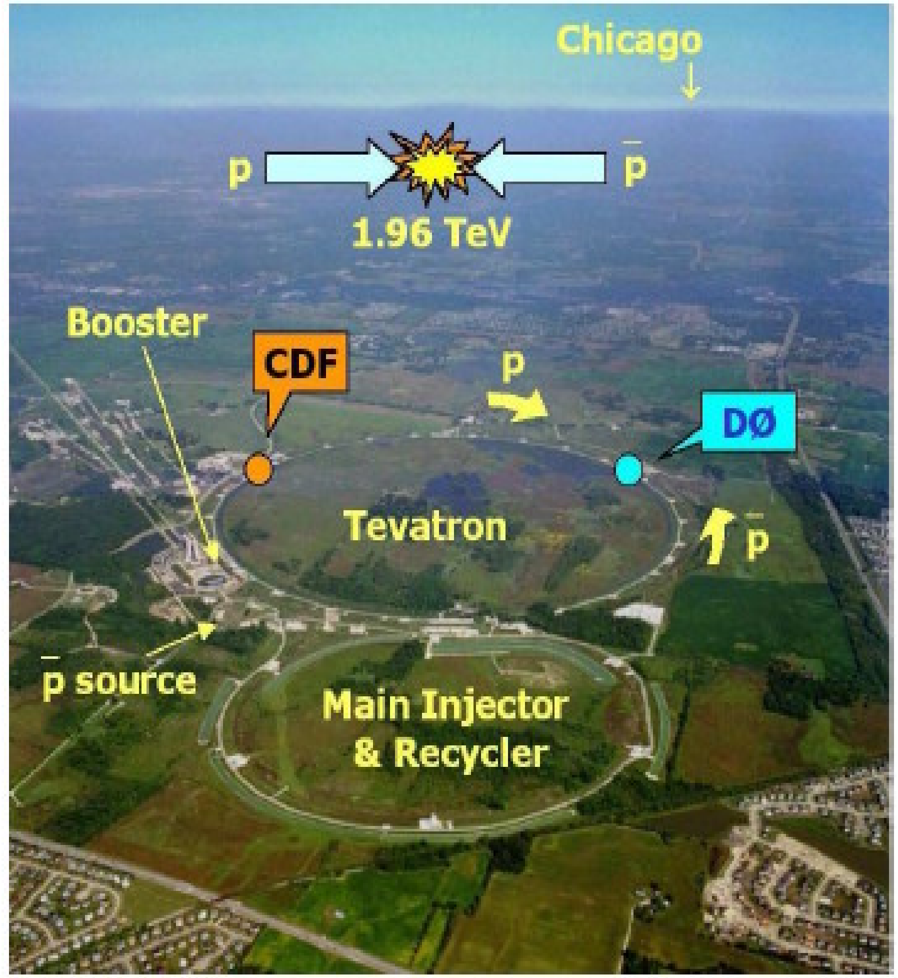
Extremely challenging!
$\sigma(jets)/\sigma(\gamma) \approx 10^3 \Rightarrow$ **severe background** from jet fragmenting into a leading π^0 (or η), particularly at small p_T^{γ}

Tevatron p$\bar{p}$-collider

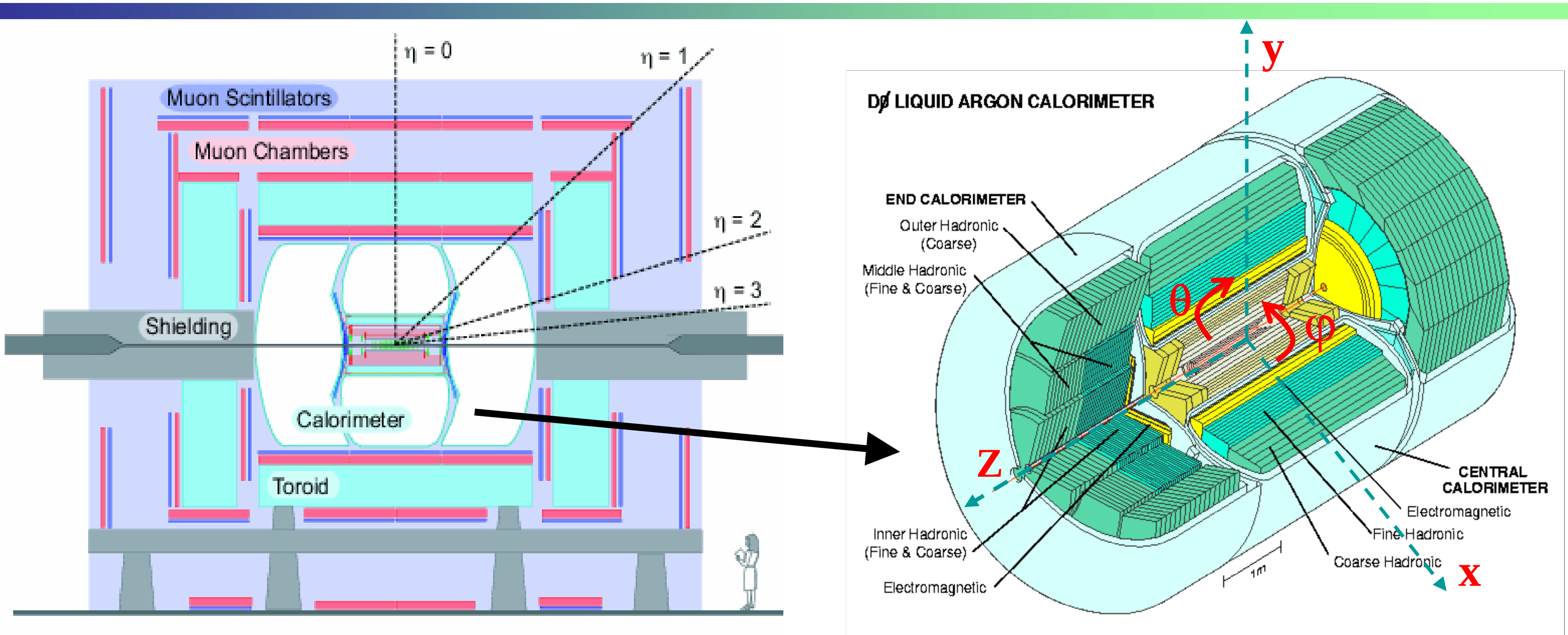
Highest energy collider √s=1.96 TeV
36x36 bunches colliding per 396 ns

Excellent Tevatron performance!
- Peak Luminosities of ~3×10^{32} $cm^{-2}s^{-1}$
- Delivered >3 fb^{-1}
- Goal : 8 fb^{-1} by 2009





The DØ Detector

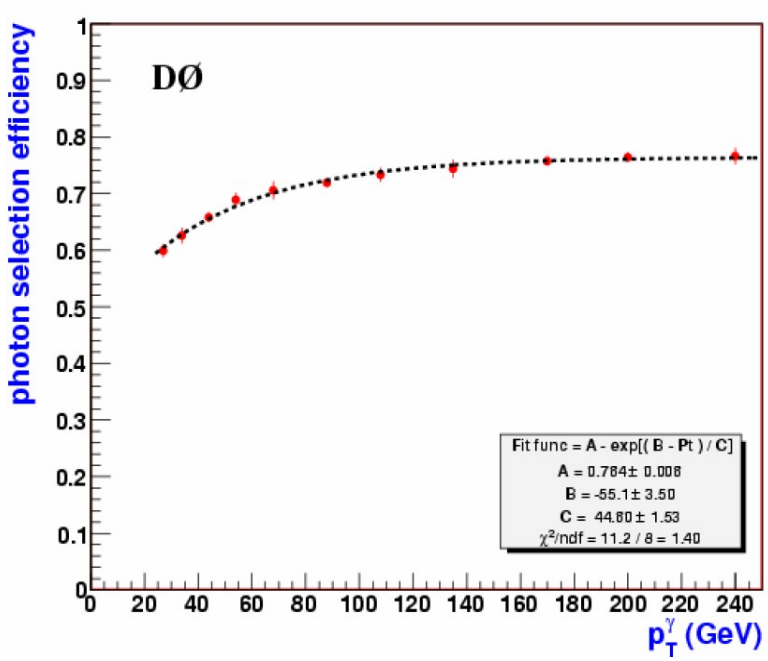


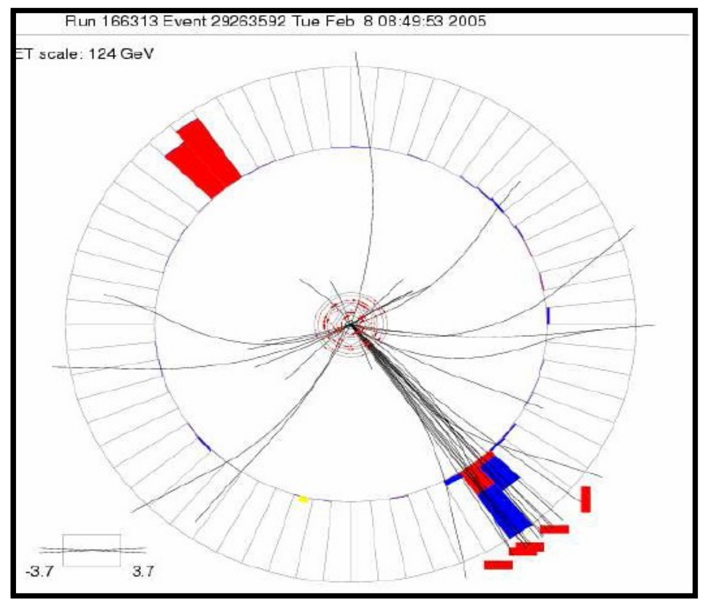
- ❑Inner tracker (silicon mictrostrips and scintillating fibers) inside 2T superconducting solenoid : |η|<2.5 ⇒**precise vertexing and tracking**
- ❑Wire tracking and scintillating muon system: |η|<2

- ❑Liquid Ar sampling & U absorber
- ❑Hermetic with full coverage (|η|<4.2)
- ❑4 EM Layers : shower-max EM3
- ❑**Fine transverse segmentation** $\Delta\eta \times \Delta\phi$ = 0.1x0.1 (0.05x0.05 in EM3)
- ❑ Good energy resolution

Event Selection

- Events selected with single high p_T EM calorimeter triggers
- Isolated photon : $p_T^{\gamma} > 30$ GeV, & central ($|\eta^{\gamma}| < 1.0$)
- Leading jet : $p_T^{jet} > 15$ GeV, central ($|\eta^{jet}| < 0.8$) or forward ($1.5 < |\eta| < 2.5$)
- γ-jet separation in η-Φ, dR(γ,jet) = 0.7
- Small missing $E_T < 12.5 + 0.36.p_T^{\gamma}$ to suppress W's & cosmic events.
- Additional cut on NN output, $O_{NN} > 0.7$

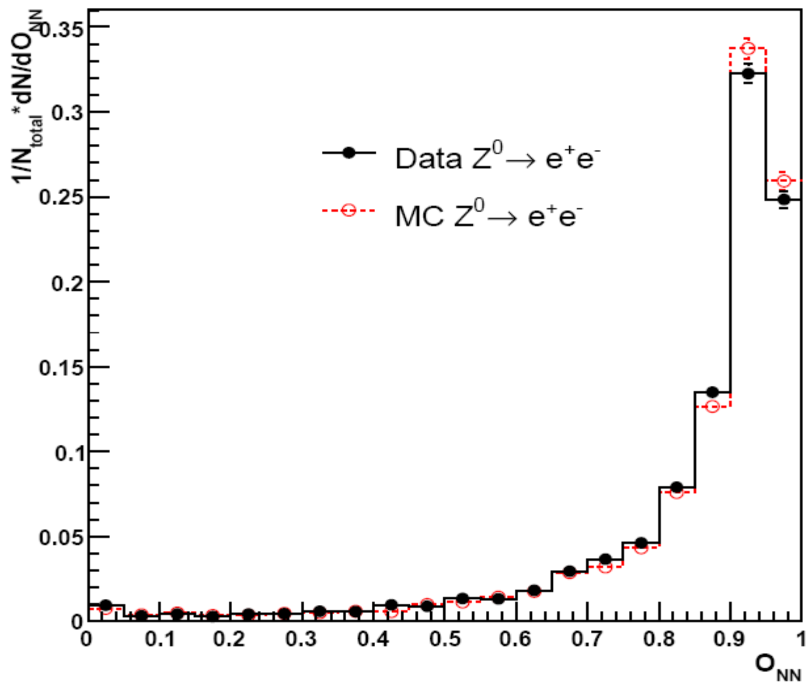


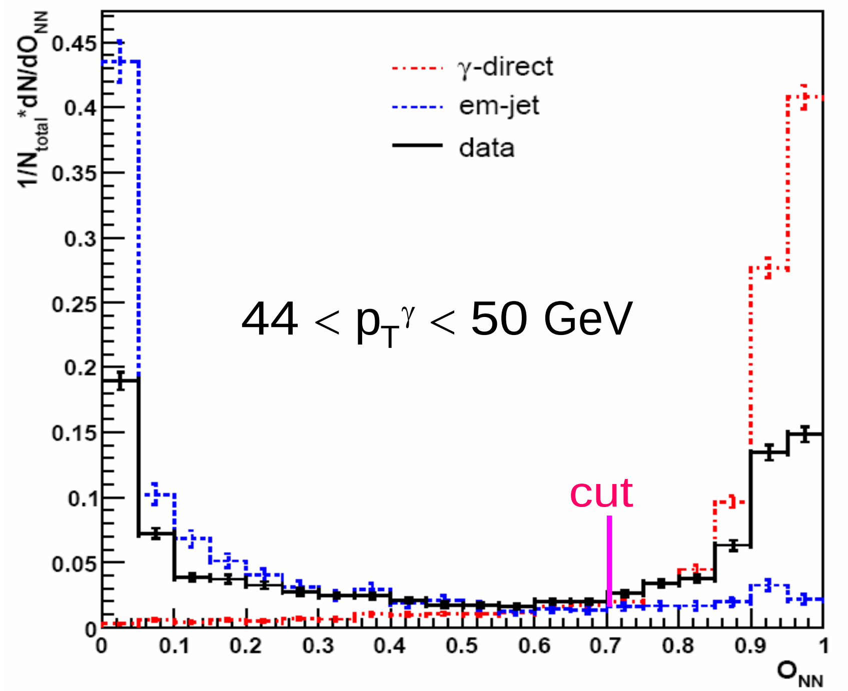


Overall systematic uncertainty on $\varepsilon^{\gamma+jet}$ of 4.5 - 5.2%

Neural Network Selection

Substantial background from dijet events to the γ+jets sample
⇒Design a NN with 3 discriminating variables between real γ's & em-jets.
⇒NN trained on fully simulated γ+jets & dijet samples from Pythia.
⇒Tested on $e^{\pm}$ from Z^0 decay (data & MC)





Apply NN to separate γ+jet signal from QCD dijet background

Content of real photons, i.e. purity is determined from fitting the NN output in data with the mixture of profiles from MC (α.γj+β.jj).

γ+jet Cross Sections

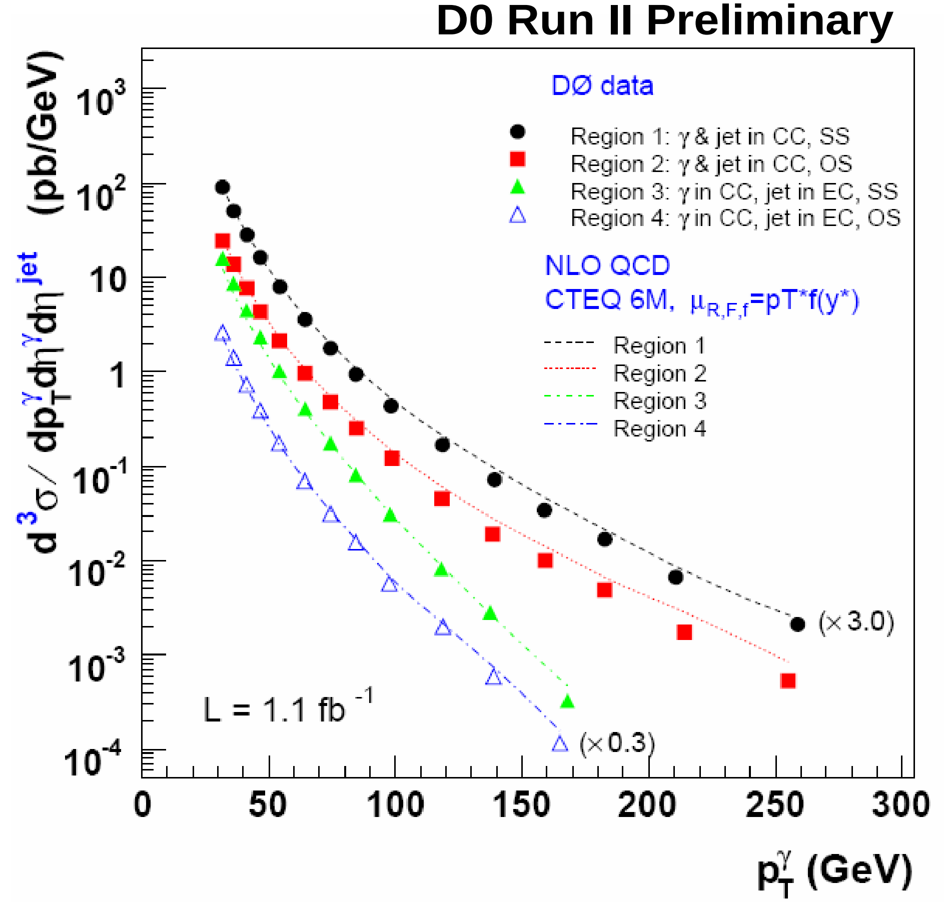
$$\frac{d^3\sigma}{dp_T^\gamma\ d\eta^\gamma\ d\eta^{jet}} = \frac{N\ \mathcal{P}\ f_{unsm}}{L_{int}\ \Delta p_T^\gamma\ \Delta\eta^\gamma\ \Delta\eta^{jet}\ A\ \epsilon_t\ \epsilon_s^\gamma\ \epsilon_s^{jet}}$$

Total γ+jet candidate events : 2.4 M
--34.4% (1), 30.2% (2), 20.3% (3), 15.1% (4)

Results include stat. ⊕ syst. errors.
-- stat. 0.1 – 8% for R1 & R2,
up to 20% in R3 & R4.
-- syst. 10 – 15% depending on regions

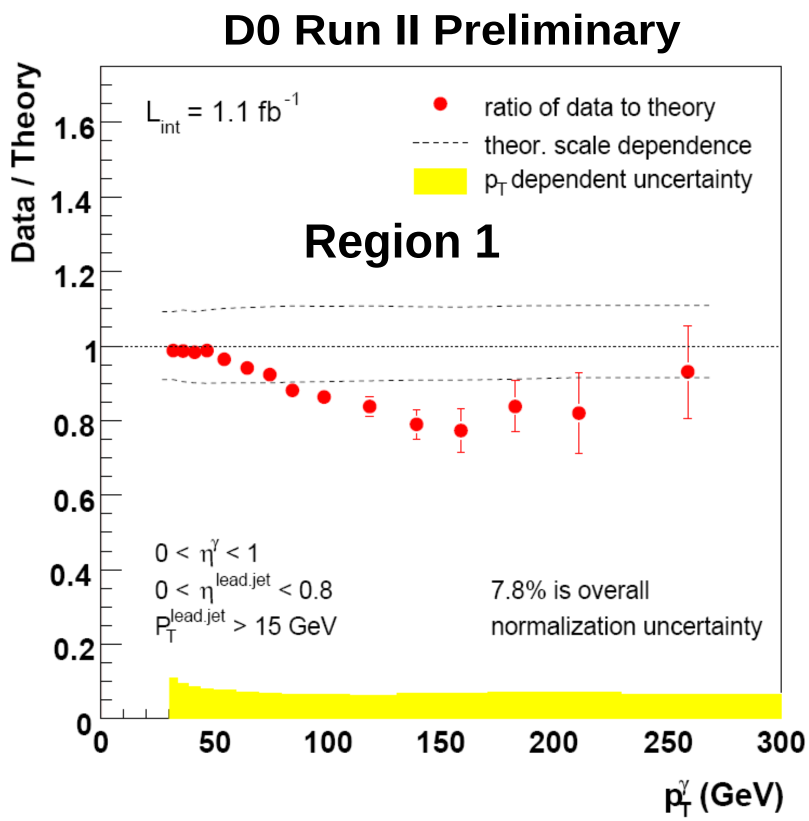
Major syst. uncertainties from purity estimation, γ and jet selections and luminosity.

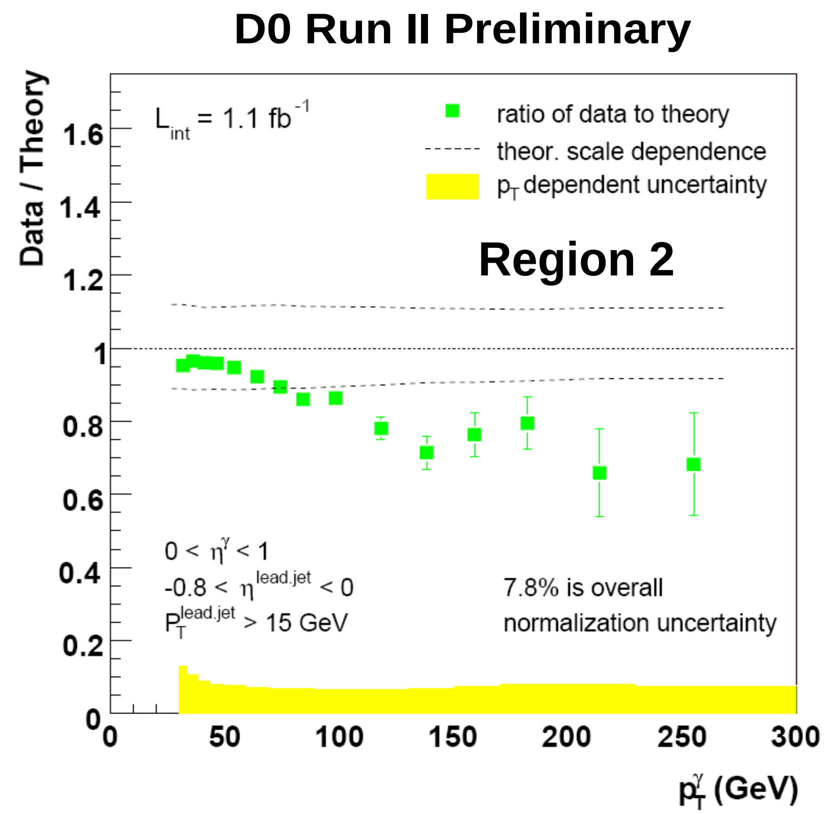
Theory : NLO pQCD calculation from JETPHOX (P. Aurenche et. al.) using CTEQ6.1M PDFs & BFG FFs.



$$\mu_R = \mu_F = \mu_f = p_T^\gamma f(y^\star) \text{ with } f(y^\star) = ([1 + exp(-2|y^\star|)]/2)^{1/2} \text{ and } y^\star = 0.5(\eta^\gamma - \eta^{jet})$$

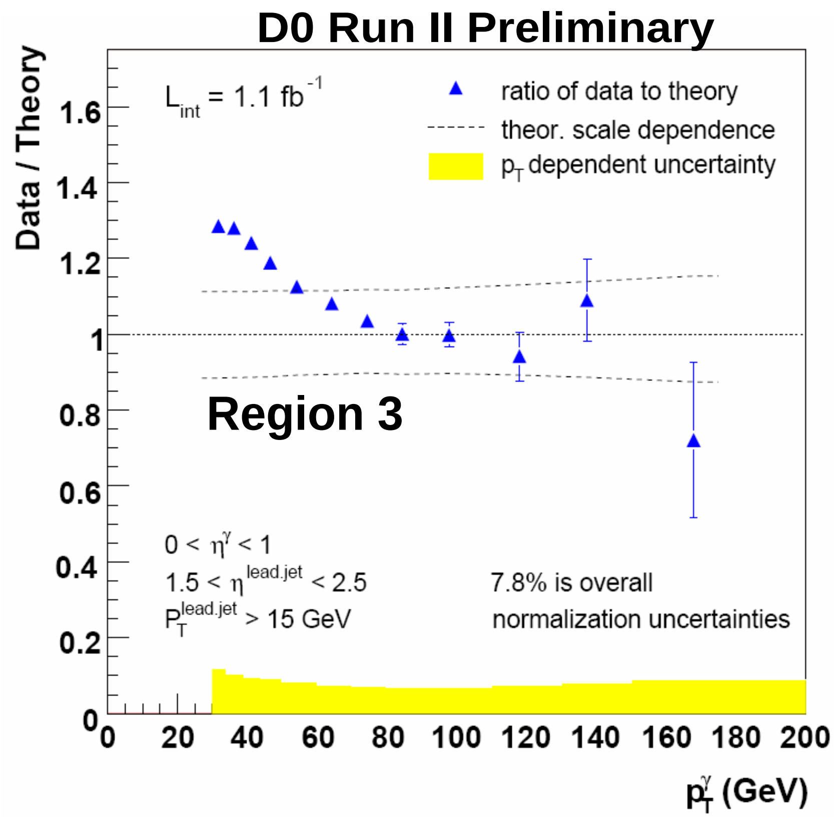
Comparison with Theory

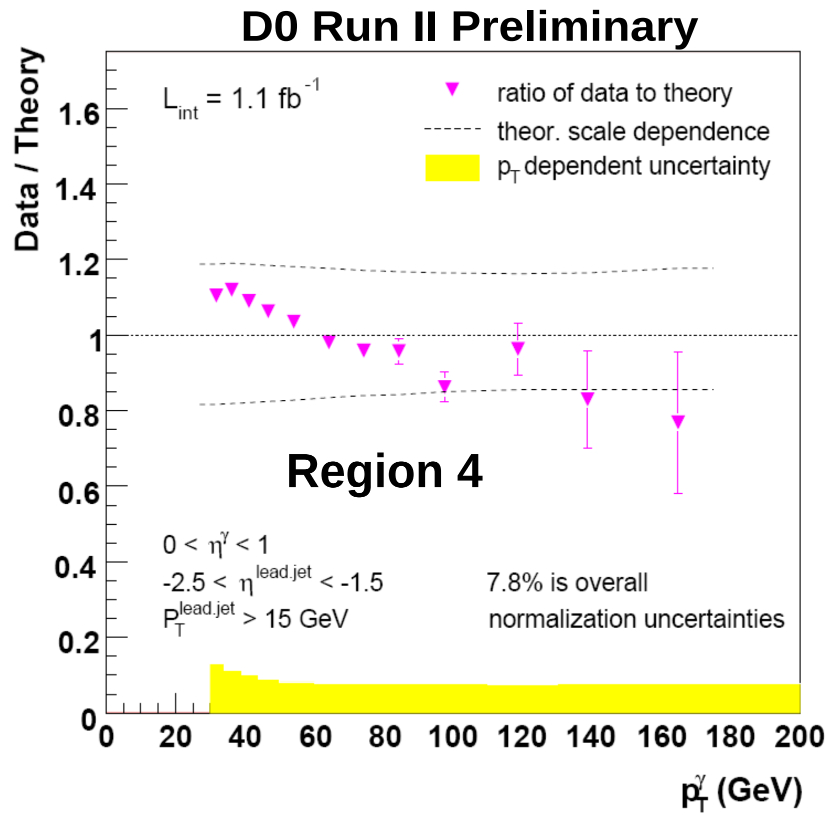




Deviation from the predictions for $p_T^\gamma > 100$ GeV for the two kinematic regions with photon and jets both in the central η regions. Shape of the Data/Theory similar to the structure observed previously by UA2, CDF and D0 Run II inclusive photon measurements.

Comparison with Theory





Shape of data/theory same for region 3 and 4. Scale dependence is biggest in region 4.
Deviation from the predictions for $p_T^\gamma < 50$ GeV for the kinematic region with photon in the central and jet in the forward η regions with the same sign of their η's.

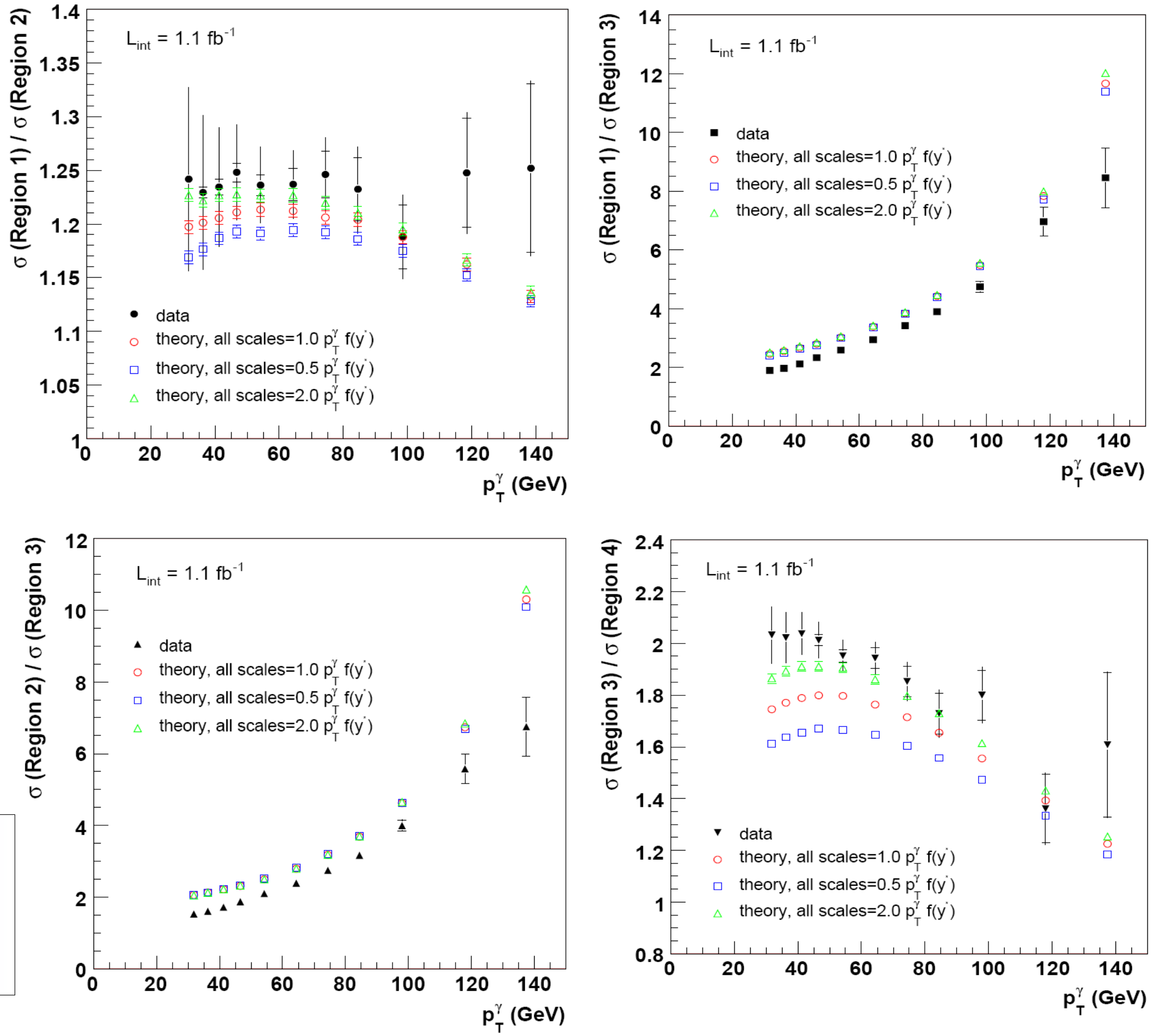
σ(Region a)/σ(Region b)

Most syst. uncertainties related to photon id are cancelled in the ratios.

Except for those related to purity and jet id when dealing with the ratio of central and forward jets.

Overall expt. unc.of 3.5 – 9% for $44<p_T^\gamma<110$ GeV and gets larger for small p_T^γ (due to syst) and larger p_T^γ (due to stat).

Significant reduction in scale uncertainty : 1-3% for R1-R3 and 3-8% for R4



Summary

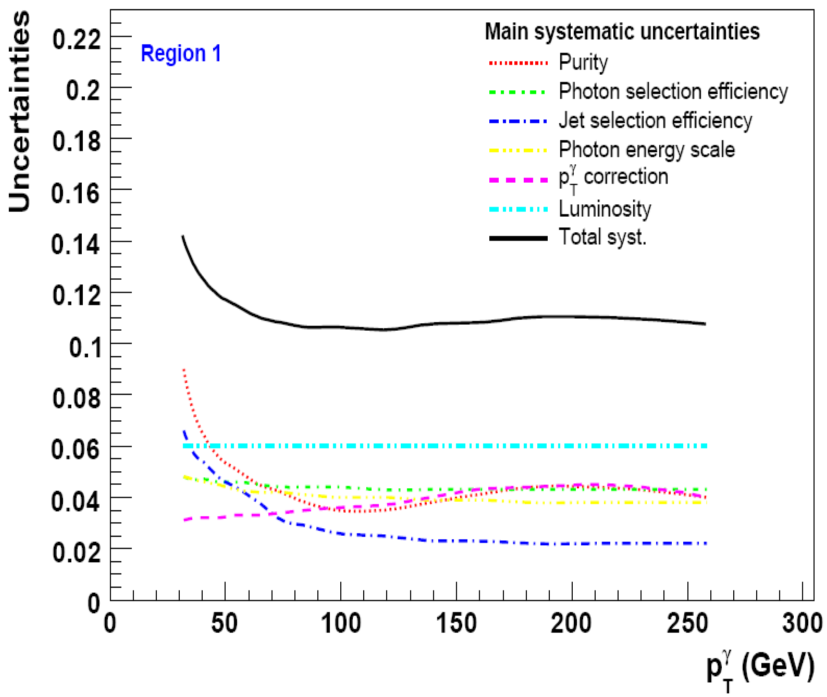
Performed a measurement of triple diff. x-section of γ+jet production.

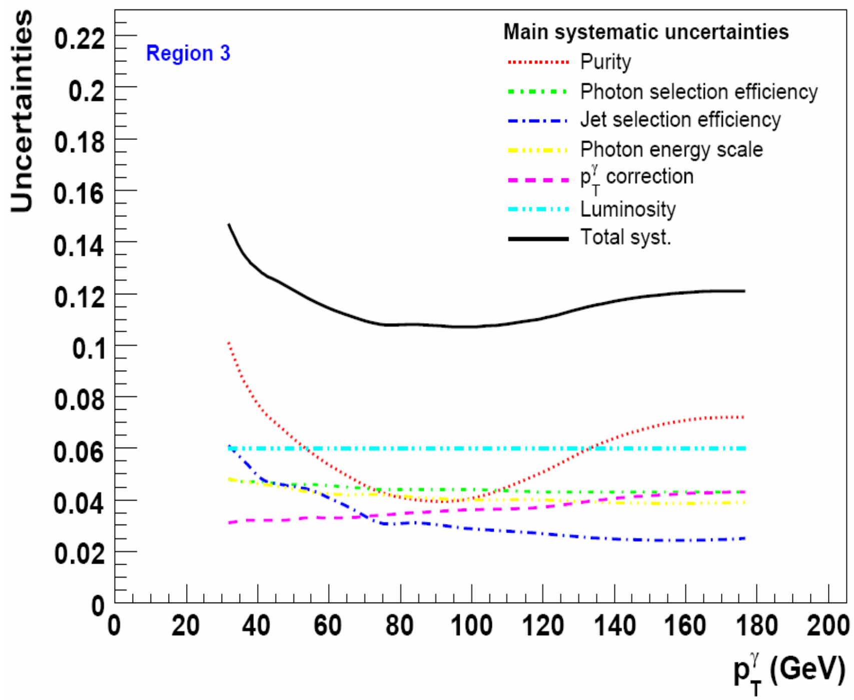
Considered γ+jet topologies open a new window to study PDF's, gluons in particular.

By taking ratios of cross sections significantly reduced effect of experimental and theoretical uncertainties

Shape of the measured x-sections, in general, qualitativey reproduced by the theory but observe a quantitative deviation from predictions for some kinematic regions.

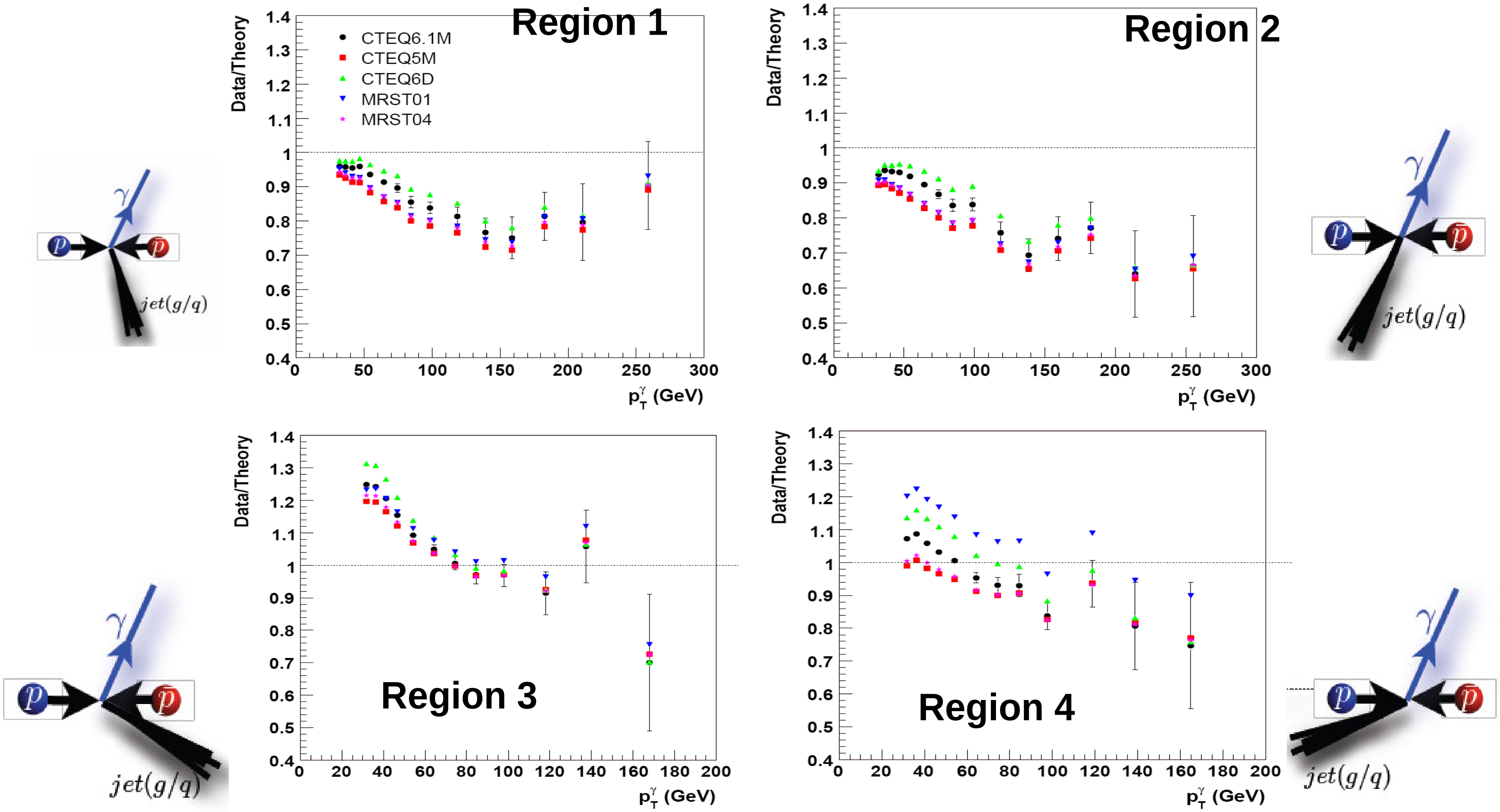
Systematic Uncertainties





The major source of uncertainties are caused by purity estimation, photon and jet selections and luminosity.

Data/Theory: PDF Dependence



Change in PDFs lead to variations in the data/theory up to ~10% for Regions 1-3 and up to ~20% for Region 4.

Neural Network Selection

Use 3 variables in NN to discriminate between γs & em-jets.

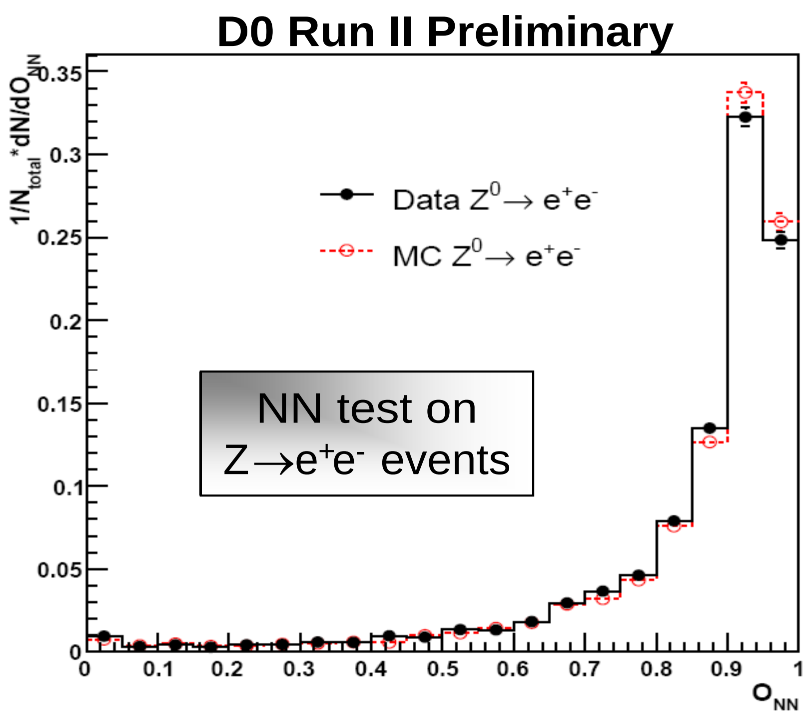
$N_{EM1\ Cells}^{E_T^{cell} > 0.4\,GeV}$

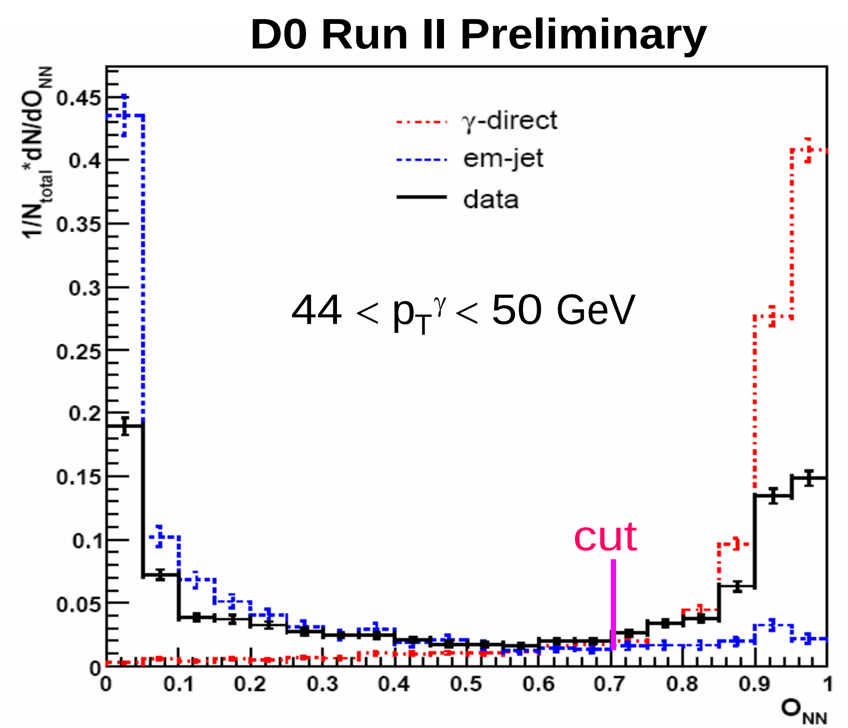
$E_{EM1}/E_{Tot(EM)}\ (E_T^{cell} > 0.4\ GeV)$

$\sum_{0.05<R<0.4} p_T(\text{tracks})\ \text{with}\ p_T^{track} > 0.4\ GeV$

NN trained on fully simulated γ+jet & di-jet samples from Pythia.

Good performance on electrons in data and MC.





Purity of γ+jet data

Purity has qualitatively similar shape in regions 1-4, lower in region 4.

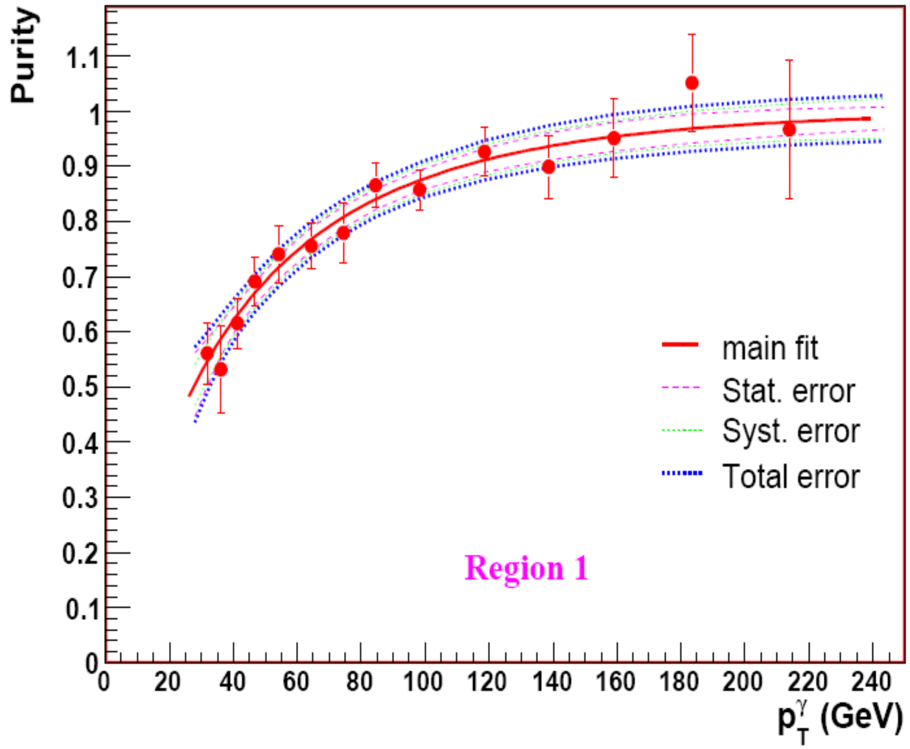
Uncertainty :

--statistics in a bin

--fitting

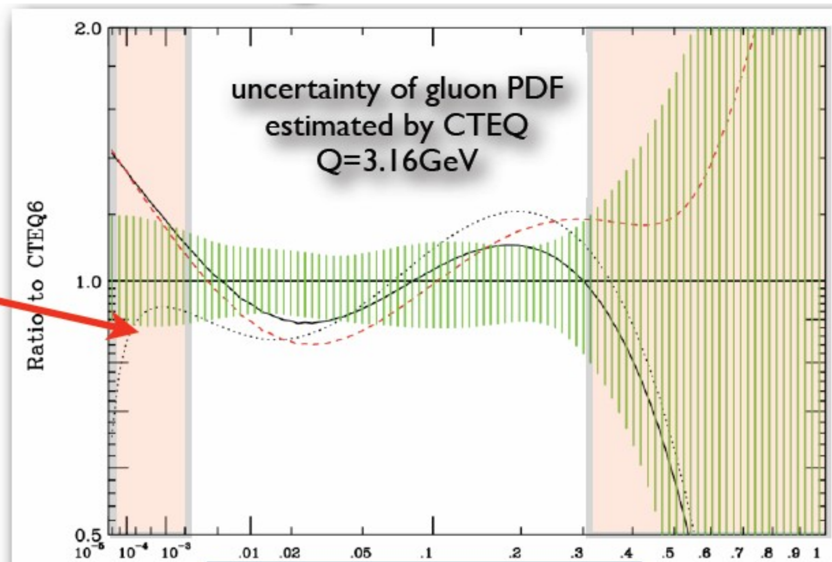
--binning

--fragmentation model used in pythia

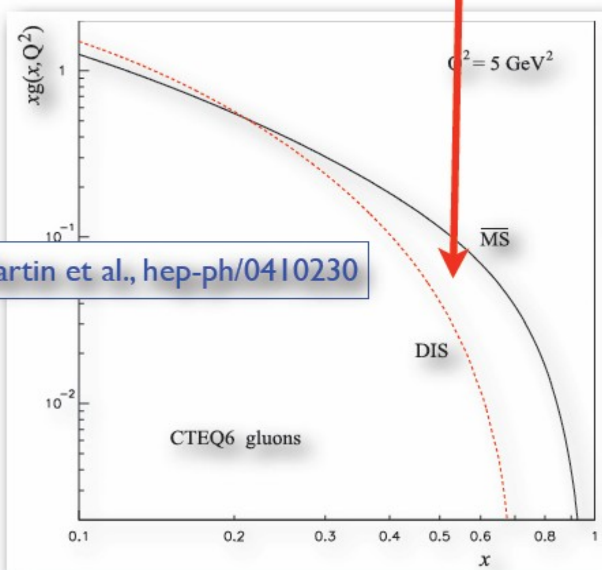


Theoretical Uncertainties of Gluon PDF

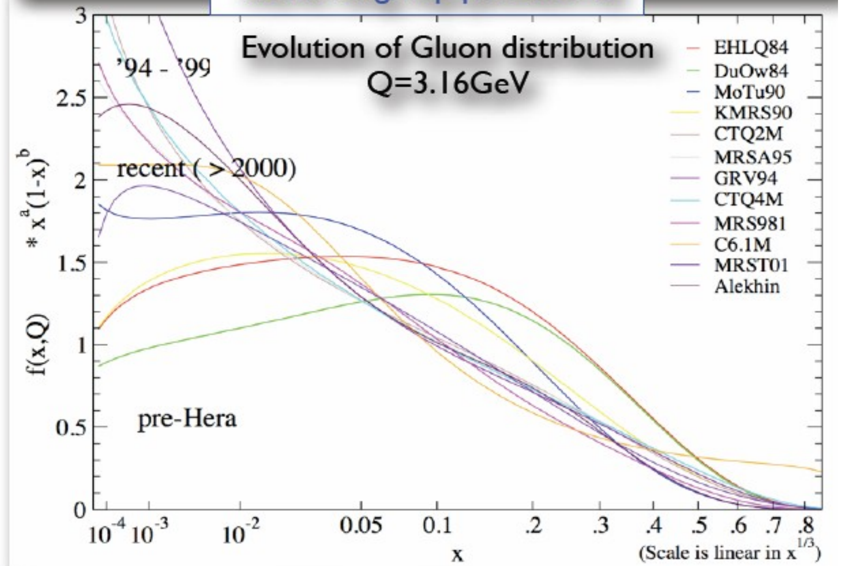
- uncertainty on the gluon structure function is large at both low-x and large-x regions,
- only experimental uncertainties on this plot, theoretical are divergent at low-x
- at Tevatron's momentum transfers these uncertainties get even larger
- sensitivity to a choice of factorization scheme (e.g. DIS vs MS-bar)

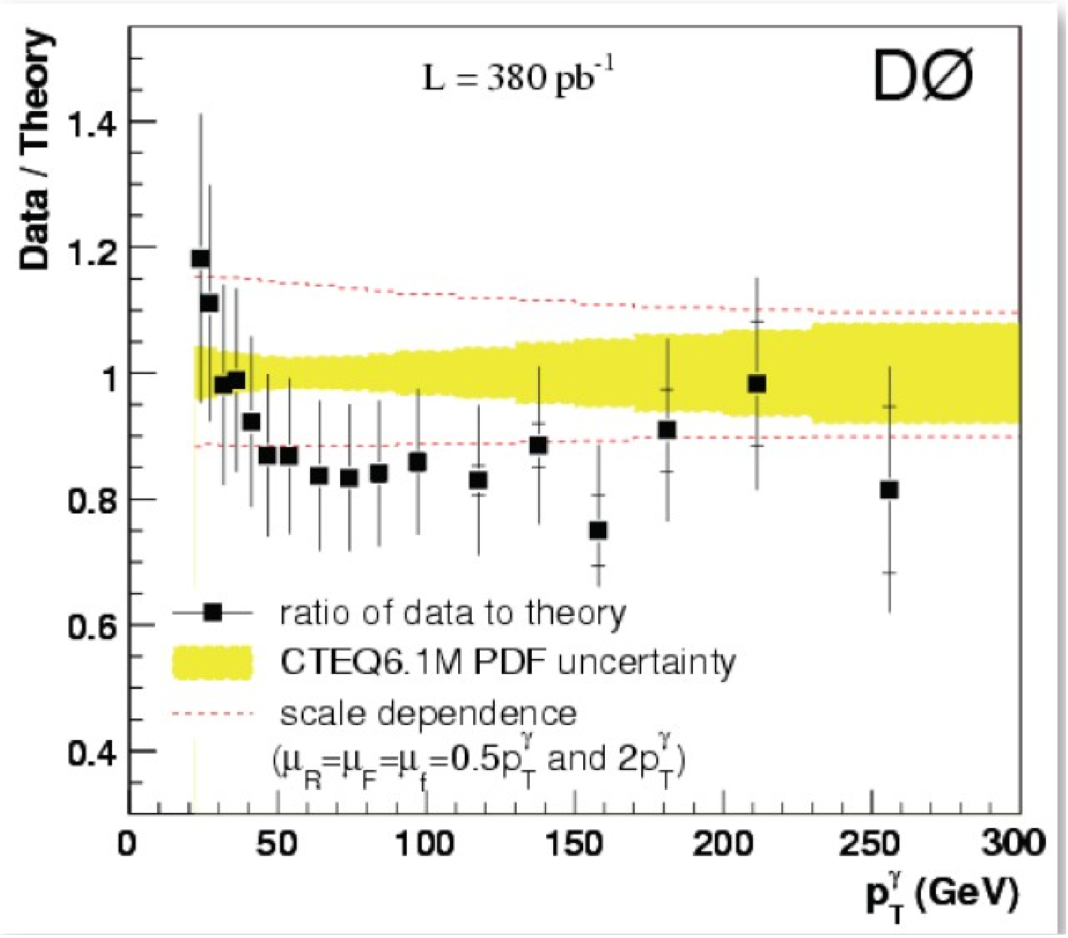


Wu-Ki Tung, hep-ph/0409145



A.D. Martin et al., hep-ph/0410230





L = 380 pb-1
DØ
Data / Theory
1.4
1.2
1
0.8
0.6
0.4
0
50
100
150
200
250
300
ratio of data to theory
CTEQ6.1M PDF uncertainty
scale dependence
(μR=μF=μf=0.5pTγ and 2pTγ)
pTγ (GeV)