Measurement of Triple Differential photon+jet Cross Section

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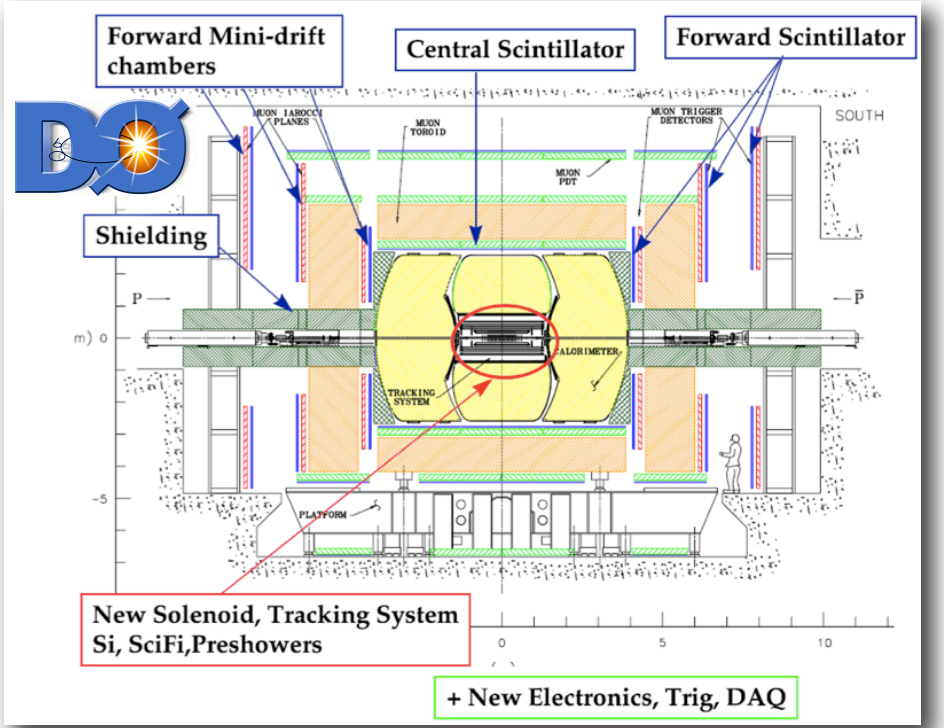
On behalf of the DZero Collaboration

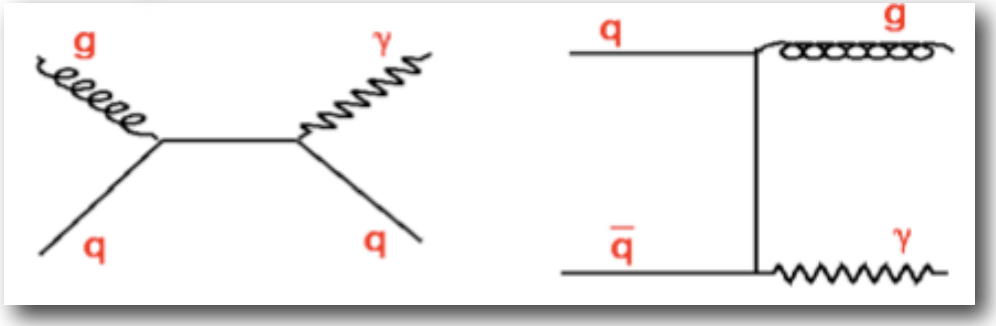
DZero, Fermilab Tevatron - Run II

- higher energy: $\sqrt{s}$=1.96 TeV (vs 1.8 TeV)
- more bunches: 36 (vs 6)
- higher collision rate: 396ns (vs 3500ns)
- electron cooling brought about record high luminosity: 2.8E32 $cm^{-2}s^{-1}$
- reported results use full Run IIa 1.1 fb^{-1} dataset

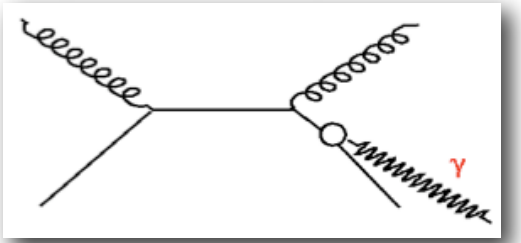


γ+jet: Motivation

direct photons



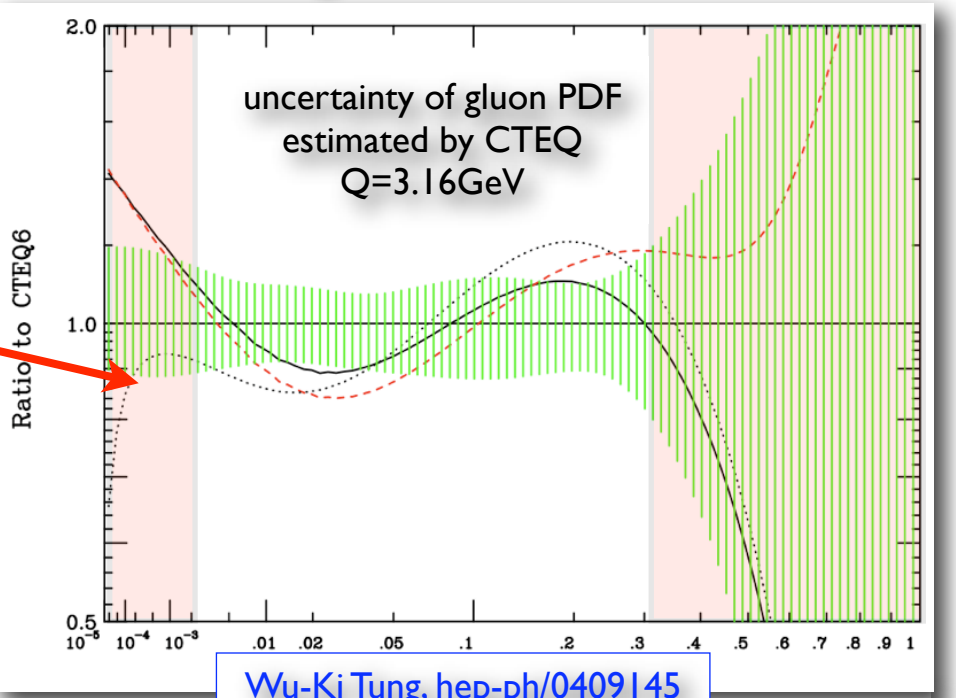
fragmentation photons

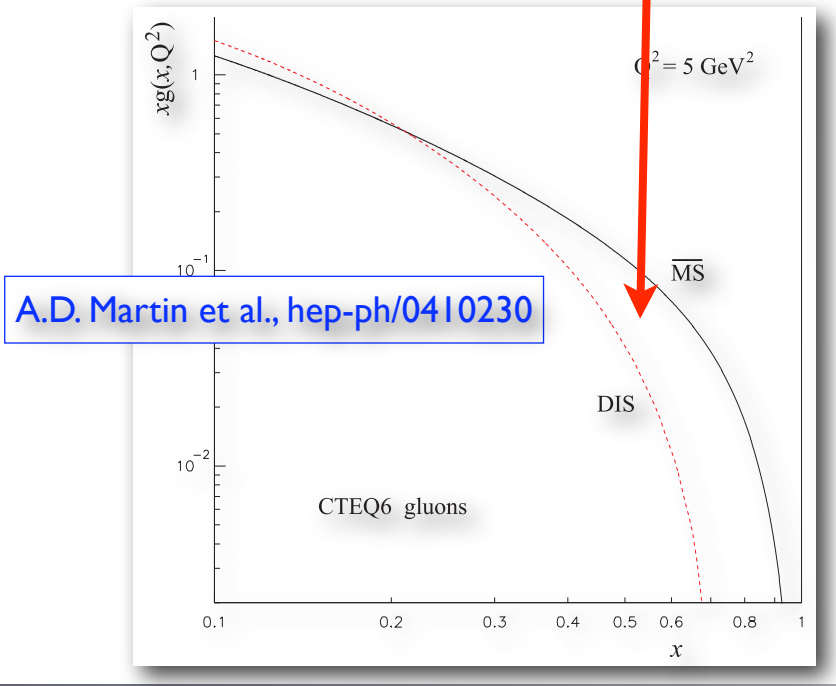


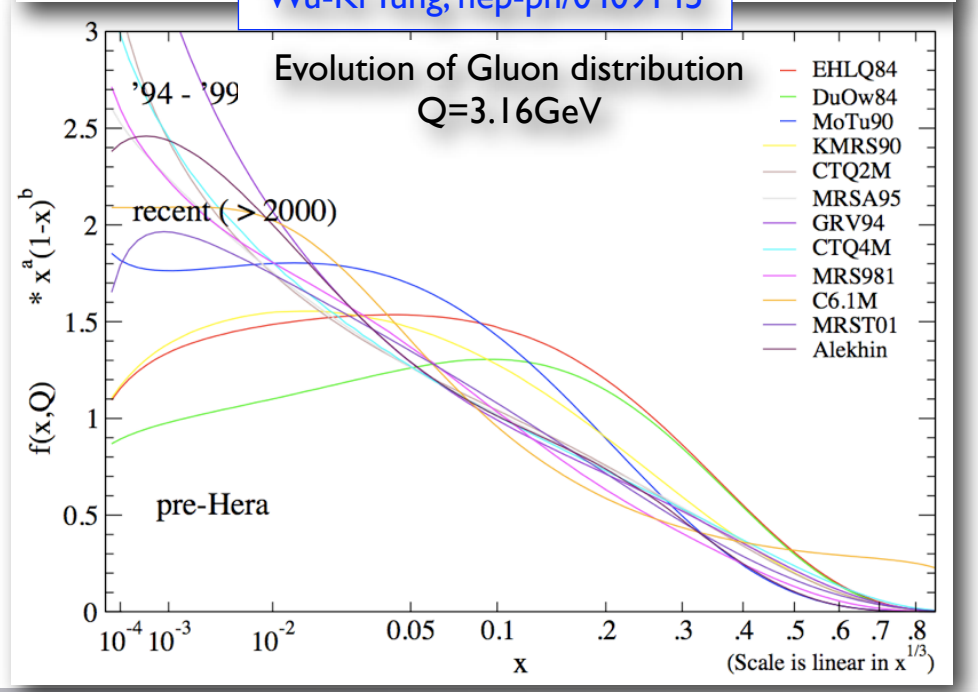
- direct photons emerge unaltered from the hard interaction
  - an important test of hard scattering dynamics
  - no significant systematics or complications with fragmentation associated with jets
  - more abundant than Z/W+jets (a few millions at $1 fb^{-1}$)
- precision tests of pQCD
- γ+jet+X this channel is sensitive to the gluon density
- more detailed test of underlying processes than inclusive photon measurement
- understanding the QCD production mechanisms is a prerequisite to searches for new physics (especially LHC)

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)

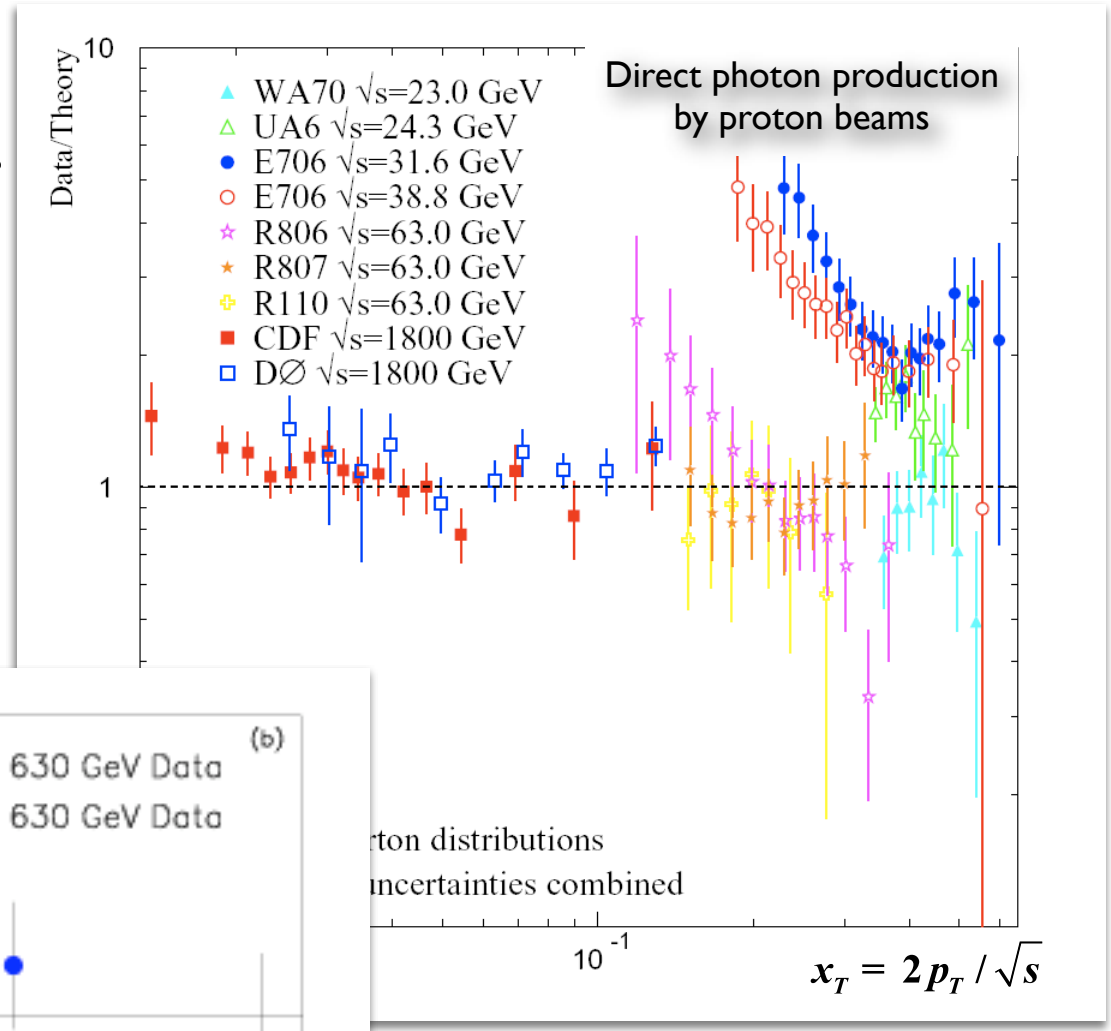


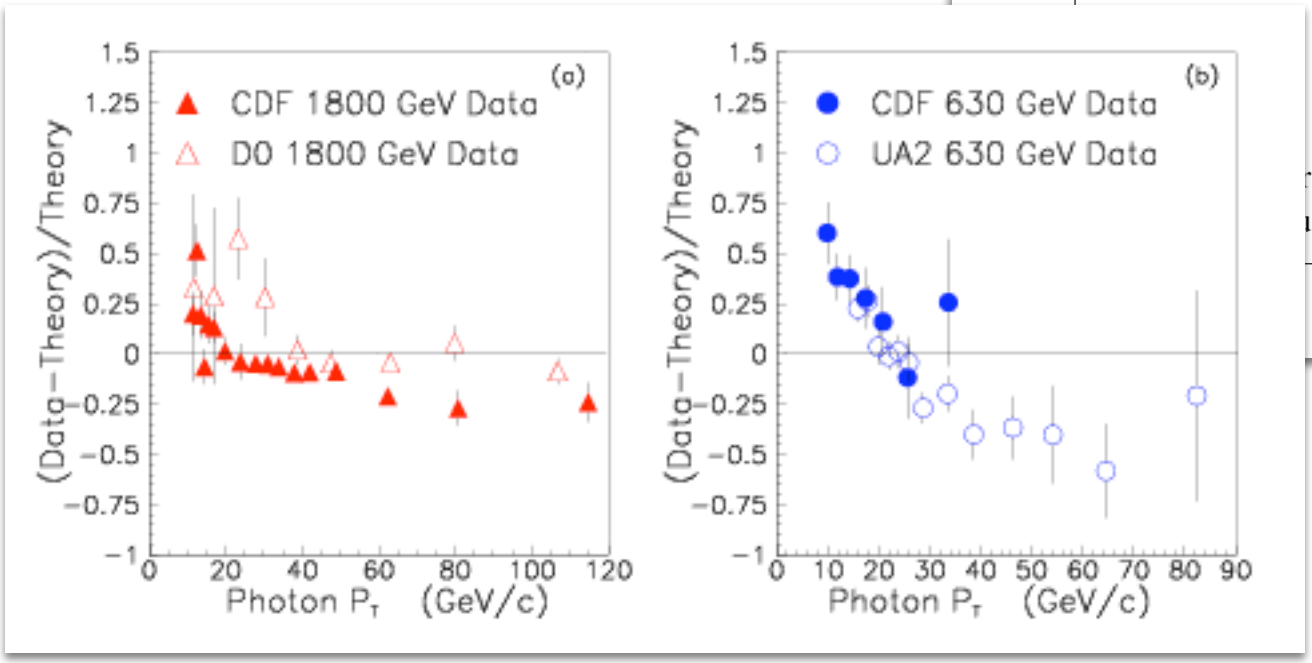




Previous data

- there is some discrepancy in previous measurements of the inclusive single photon cross section
- recent DZero Rull result is further in the talk



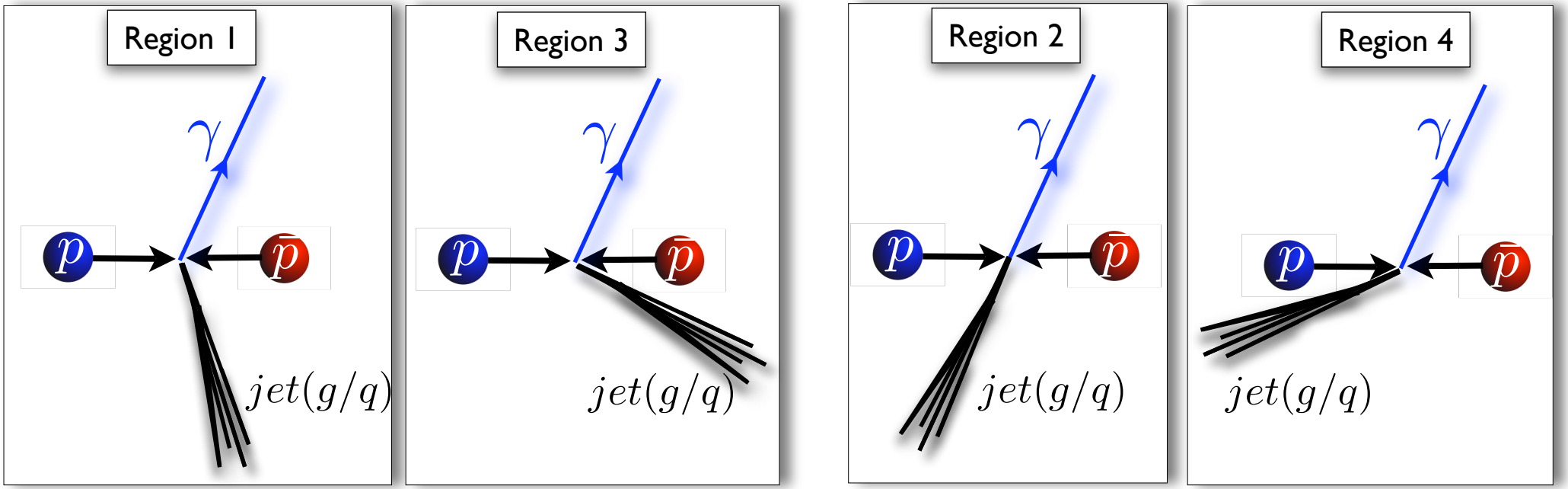


Four Regions

- in the first approximation (up to ISR/FSR) *x*'s of the partons can be written as:

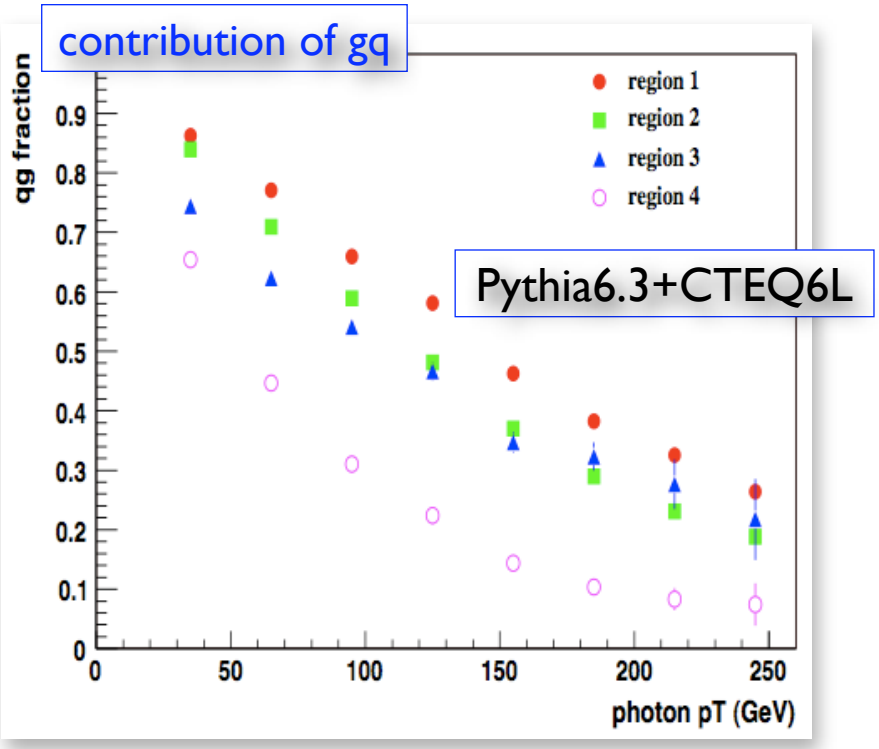
$$x_{1,2}^{LO} \approx p_T^{\gamma}/\sqrt{s} \cdot (e^{\pm\eta^{\gamma}} + e^{\mp\eta^{jet}})$$

- which suggests binning of jet's rapidity into four regions:



- Region 1 - $x_{1,2}$ cover adjacent intervals
- Region 2 - $x_{1,2}$ are almost identical
- Regions 3&4 - $x_{1,2}$ cover very different intervals (very small and very large x values)
- see Backup slides for characteristic numerical values

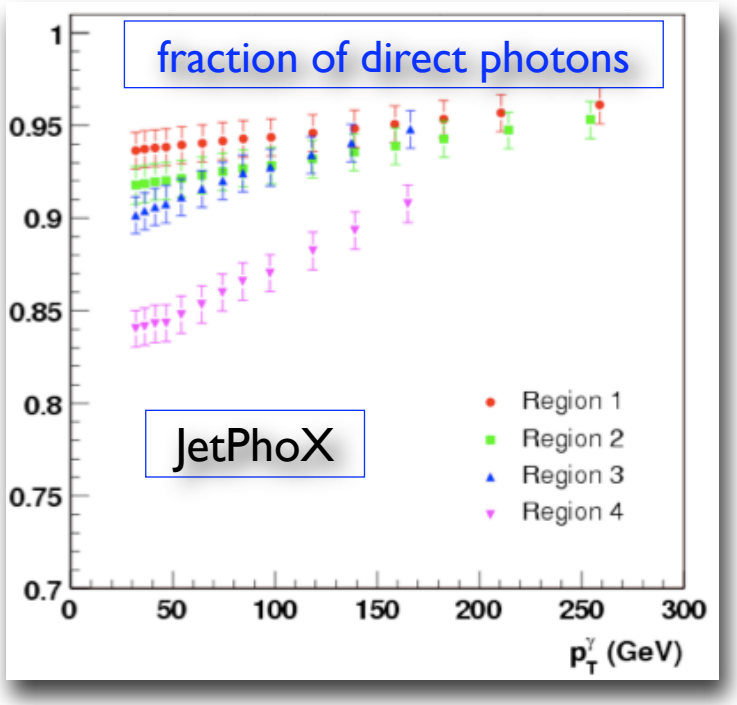
γ+jet Production



- primarily produced by gq for pT<150GeV
- precision test of QCD over **wider pT range** than Run I
- probe G(x,Q^2) with large Q^2 and in wide range of **x: 0.007-0.8**

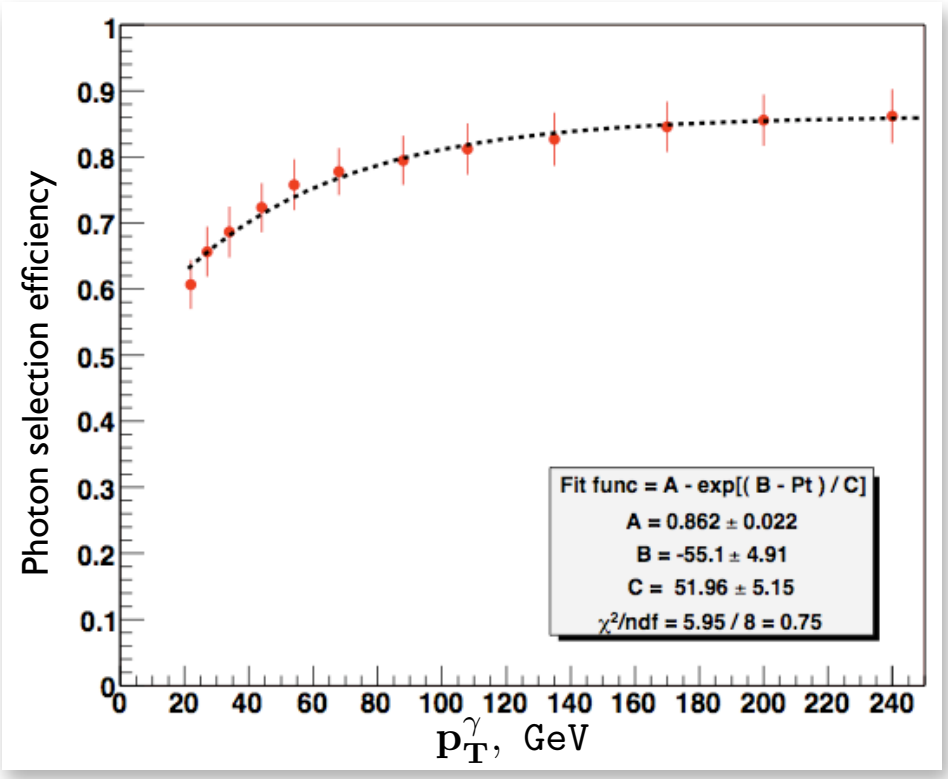
Extremely challenging!

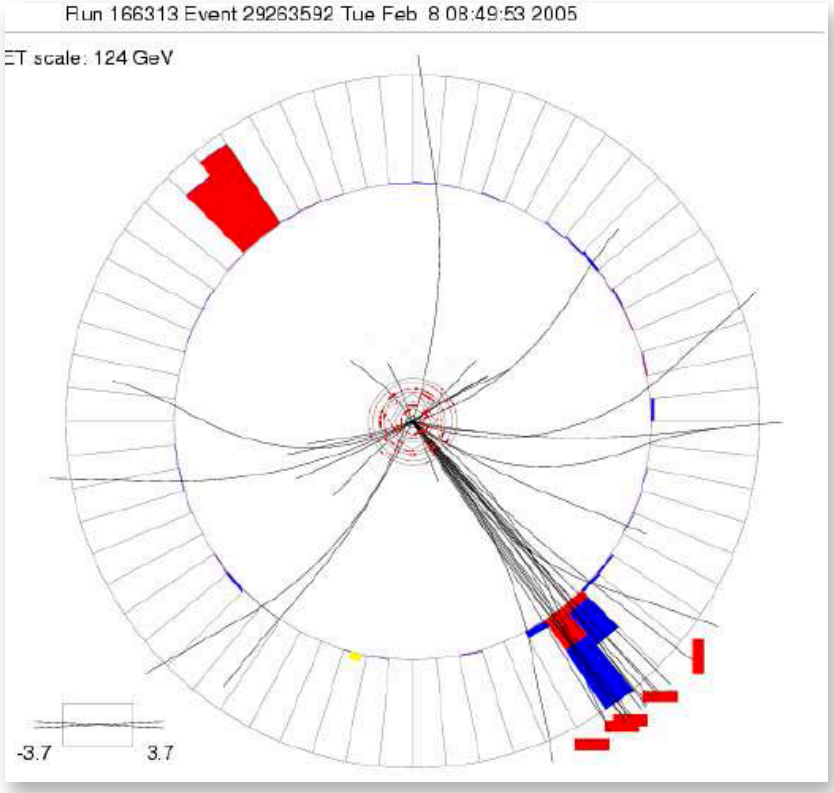
- $\sigma(jet)/\sigma(\gamma)\sim 10^3$ - severe background from jets misidentified as photons (due to leading π^0's or η's)
- almost 5 orders of magnitude variation in the cross section requires a very good understanding on the detector
- also, photon-id, by itself is a challenge since there are no pure sources



Event Selection

- events selected with single EM Calorimeter triggers
- one isolated photon, pT >30 GeV, central ($|\eta|<1.0$)
- leading jet with pT>15GeV, central ($|\eta|\in<0.8$) or forward ($1.5<|\eta|<2,5$])
- dR(γ,jet)>0.7
- transverse momentum imbalance < 12.5+0.36·pT (GeV), (cosmics and W's)

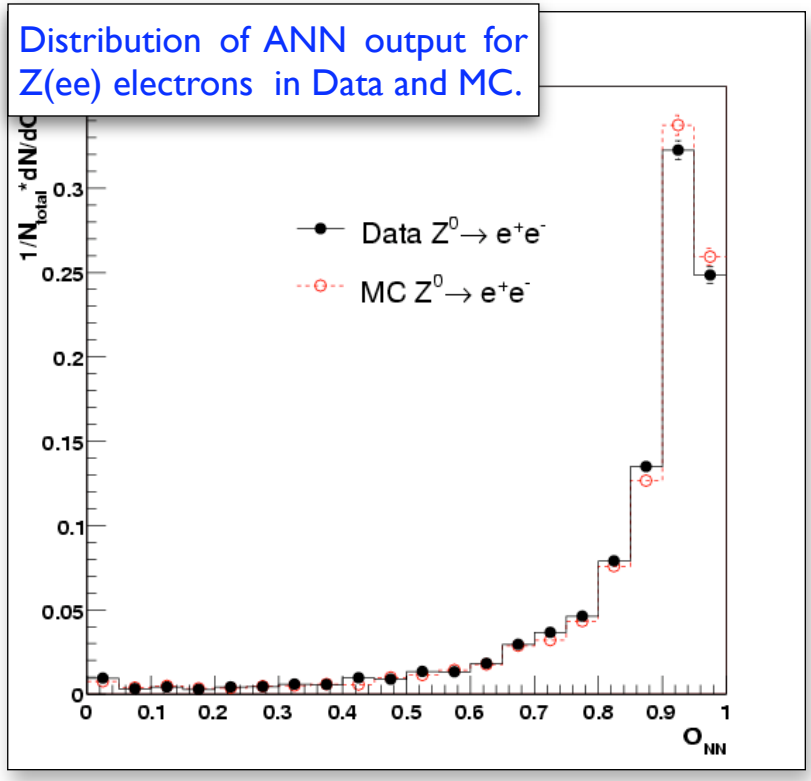


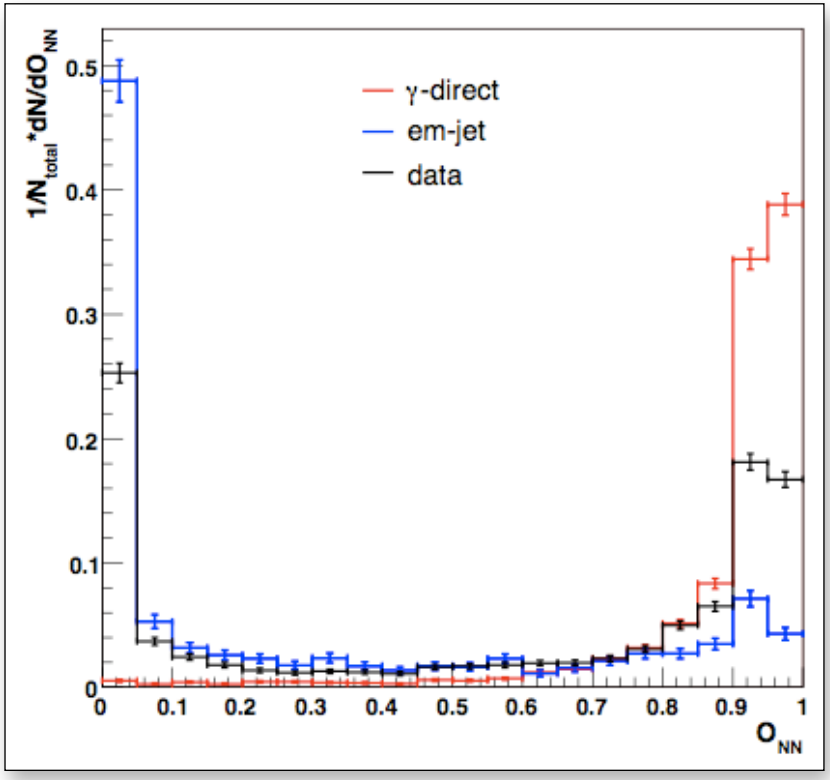


NN

- in addition to stringent rectangular calorimeter and tracker cuts on a photon we trained Neural Net to discriminate between em-jets and photons
- NN was trained on γ+jet and di-jet events from Pythia 6.3 with an overlay of "zero bias" events to mimic ambient hadronic activity in the detector
- good performance on electrons in data and MC

Distribution of ANN output for Z(ee) electrons in Data and MC.

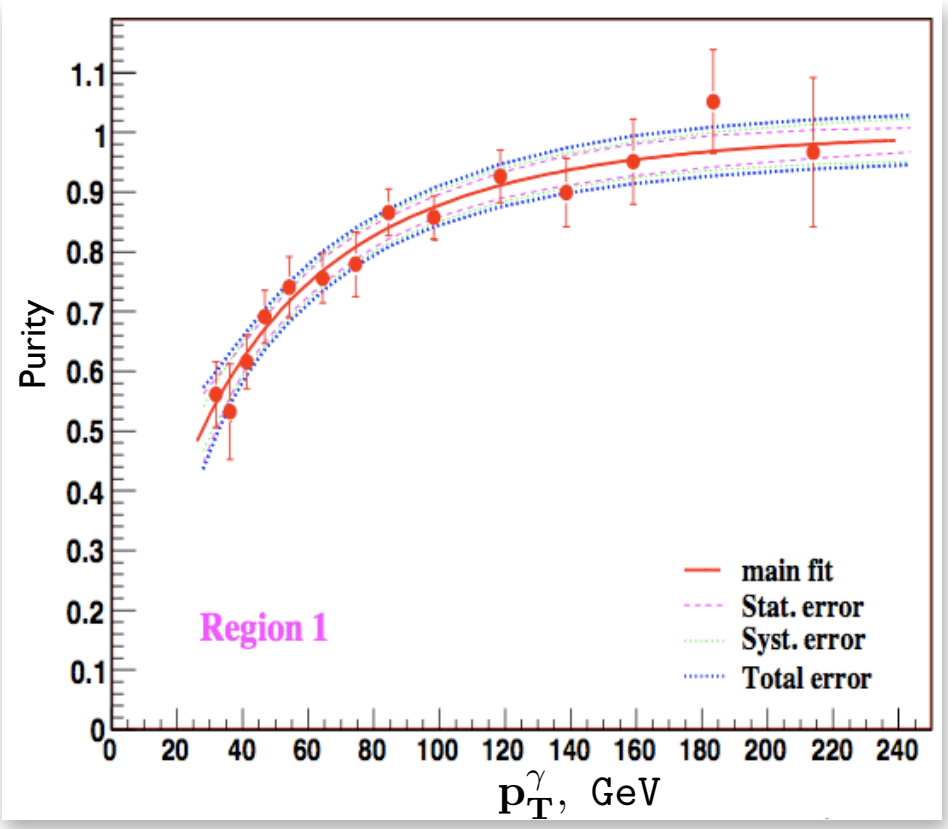




Purity of the γ+jet data

- even after tight event requirements there remains a sizable amount of em-like jets
- to determine the content of real photons, i.e. purity, we fit NN distribution in data with the mixture of profiles from MC ($\alpha \cdot \gamma j + \beta \cdot jj$)
- purity has qualitatively similar shape in Region1-4, lower in Region 4

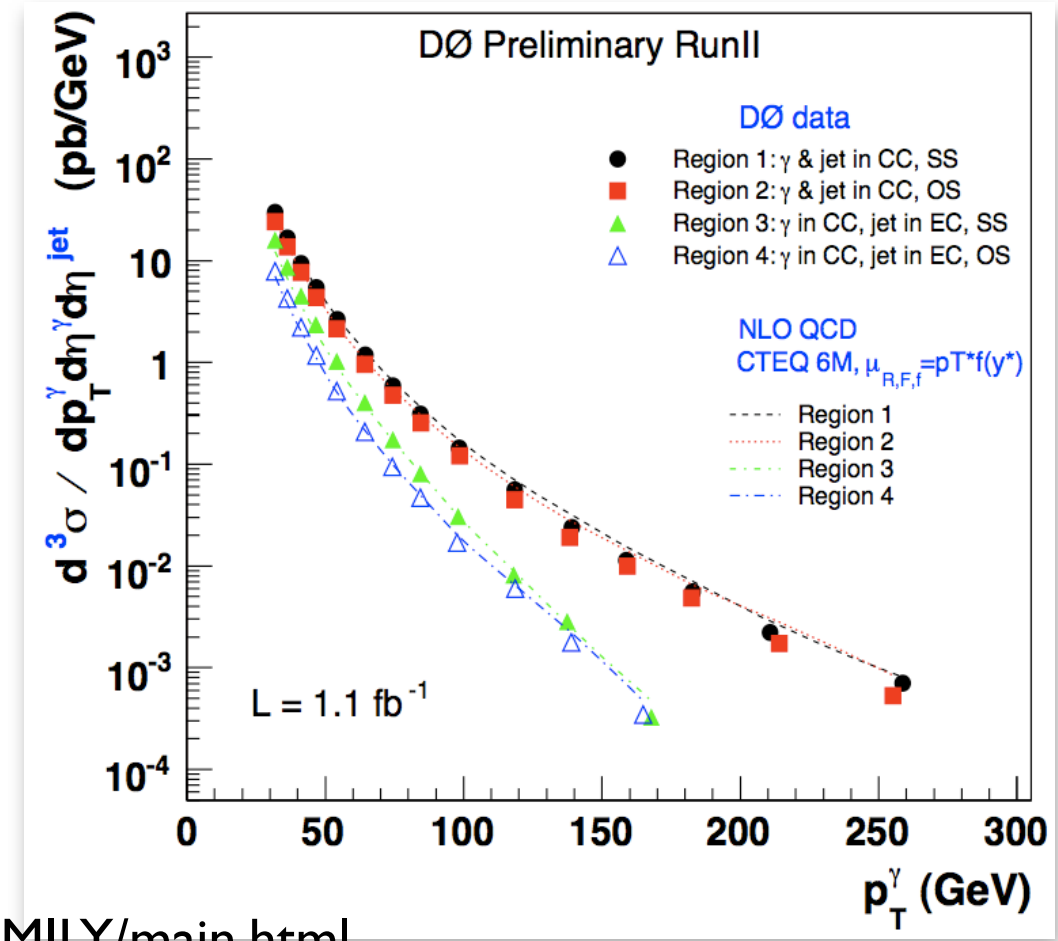
- uncertainty (4-10%):
  - fitting
  - statistics in a bin
  - binning (3.5%)
  - uncertainty in $D\pi,\eta(z)$ fragmentation functions used in Pythia(5-1%)



Cross Sections

$$\frac{\partial^3\sigma}{\partial p_T^\gamma \partial\eta^\gamma \partial\eta^{jet}} = \frac{N \cdot P \cdot f_{unsm}}{\mathcal{L}_{int} \cdot \Delta p_T^\gamma \cdot \Delta\eta^\gamma \cdot \Delta\eta^{jet} \cdot A \cdot \epsilon}$$

- Total number of γ+jet events: 2.41M
  - 34.4% Region 1
  - 30.2% Region 2
  - 20.1% Region 3
  - 13.3% Region 4
- data is plotted at the pT-weighted average of the fit function at each bin
- statistical errors: 0.2%-8% R1&2, up to 20% in Regions 3, 4
- syst errors are within 10-15%

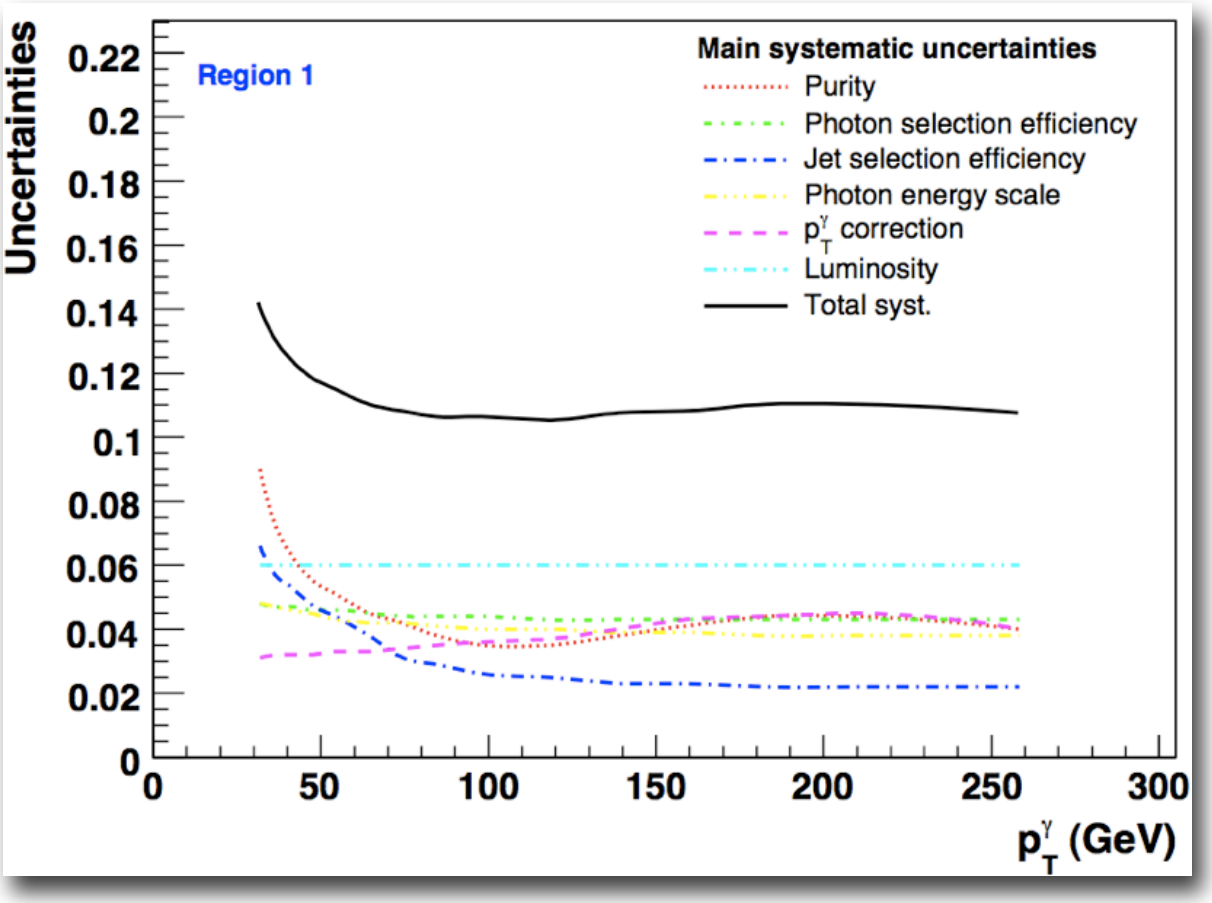


- Theory: NLO pQCD from JETPHOX (P.Aurenche et. al.) with CTEQ6.1M PDF

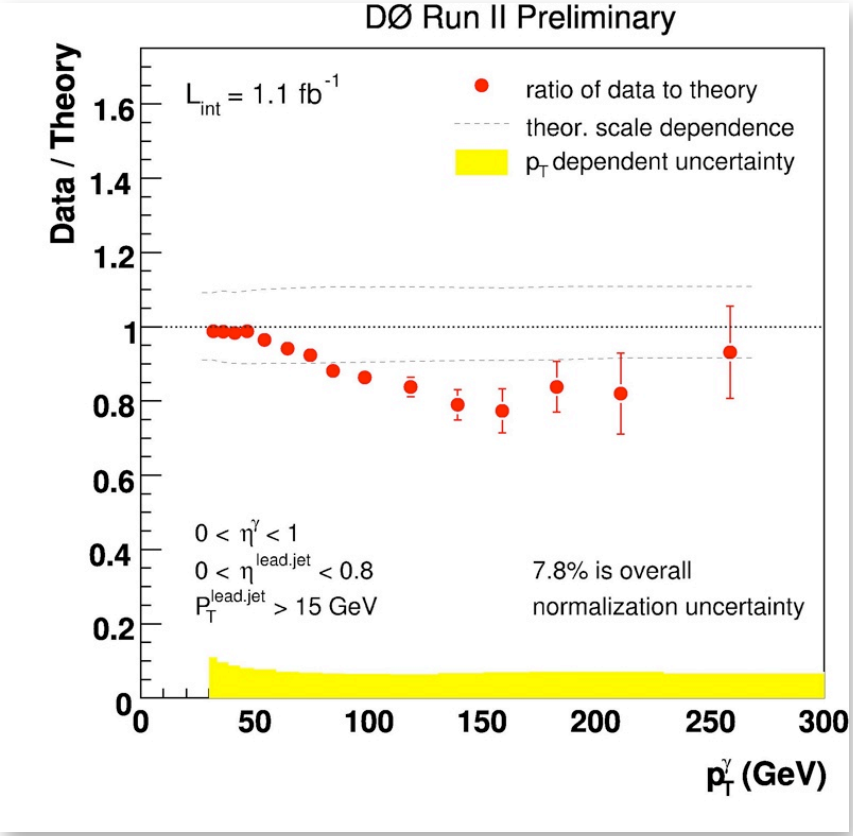
http://wwwlapp.in2p3.fr/lapth/PHOX_FAMILY/main.html

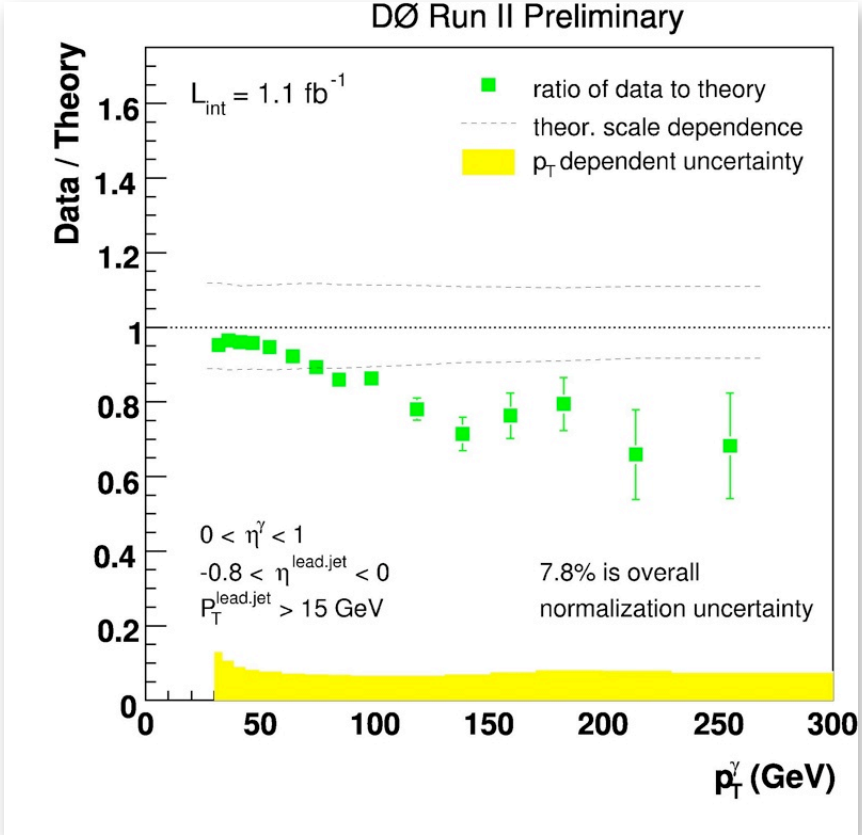
$$\mu_R = \mu_F = \mu_f = p_T^\gamma f(y^*),\ f(y^*) = \sqrt{1 + exp(-y^2)/2},\ y^* = 0.5(\eta^\gamma - \eta^{jet})$$

Main systematic uncertainties



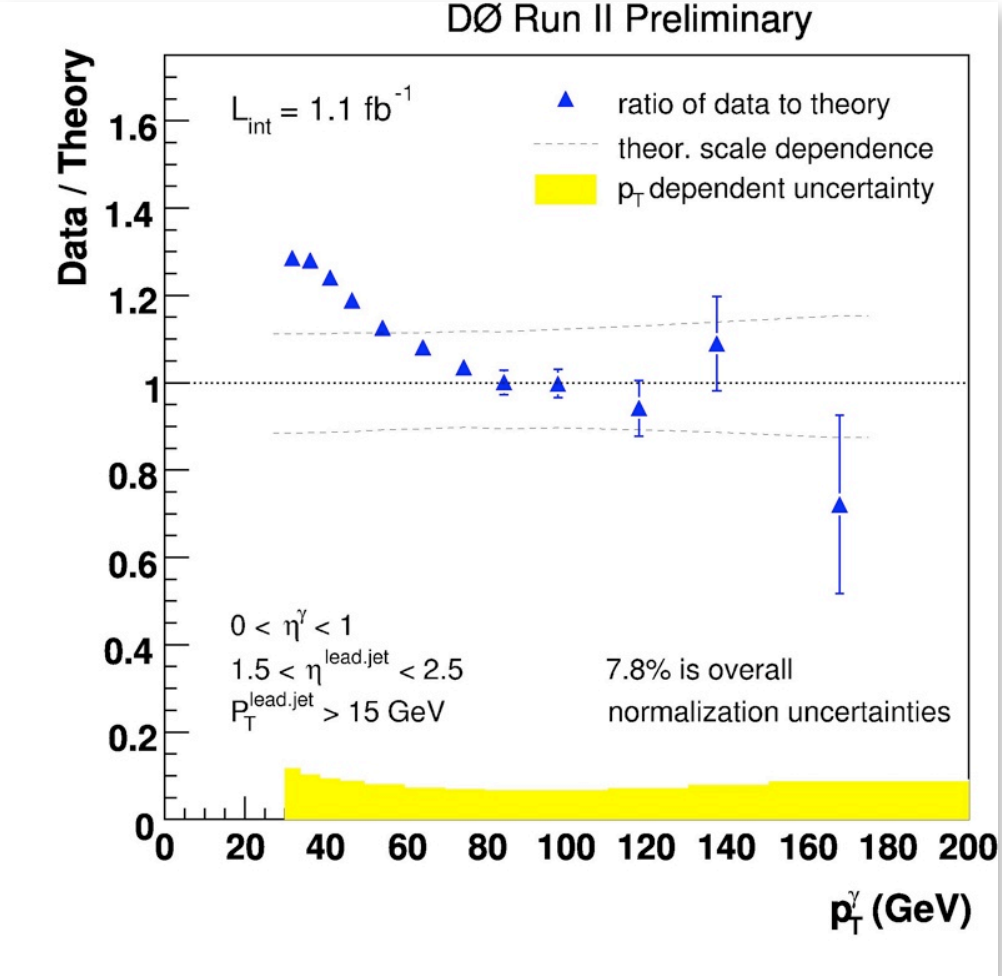
Comparison with theory

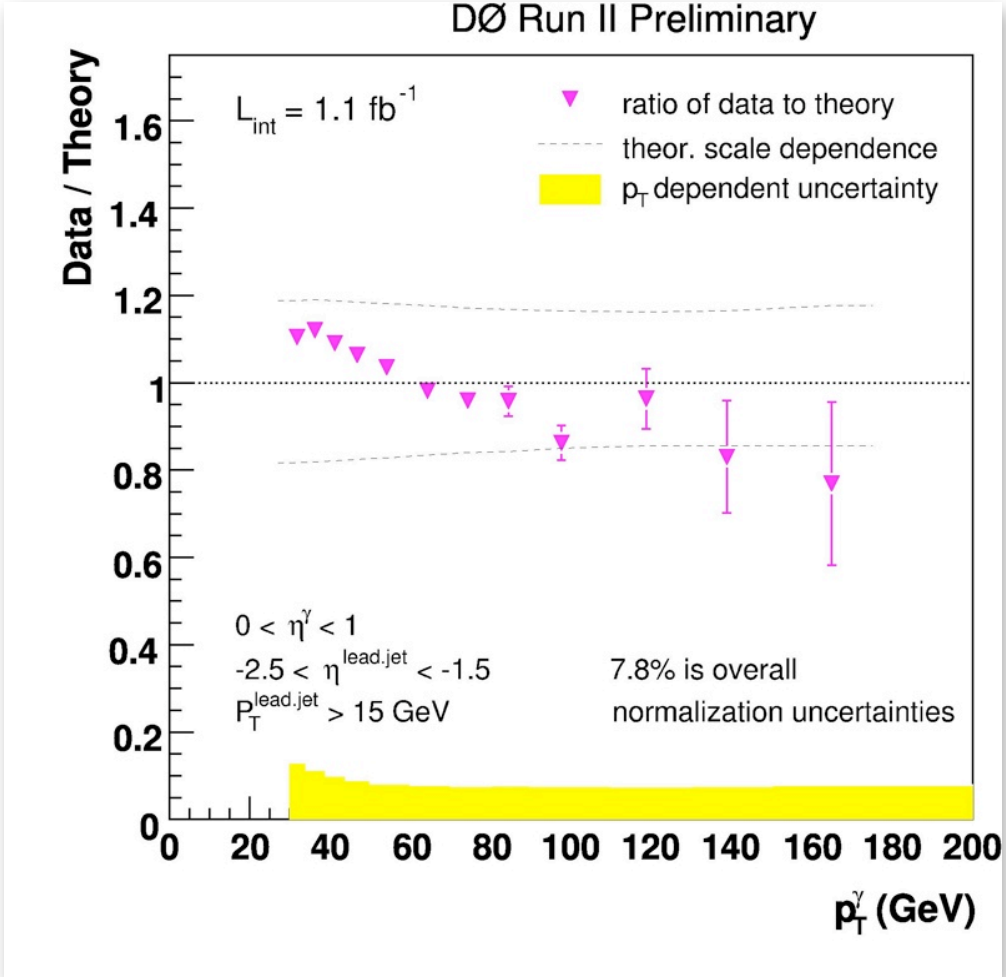




- shown here only statistical and correlated uncertainties
- the cross sections show deviation from the theory predictions for pT>100 GeV for these two regions where jets are located in the central rapidity region
- shape of the data-to-theory above has the same structures as observed earlier in UA2, CDF, and D0 RunII (erratum is to be released soon) in inclusive photon measurements

Comparison with theory



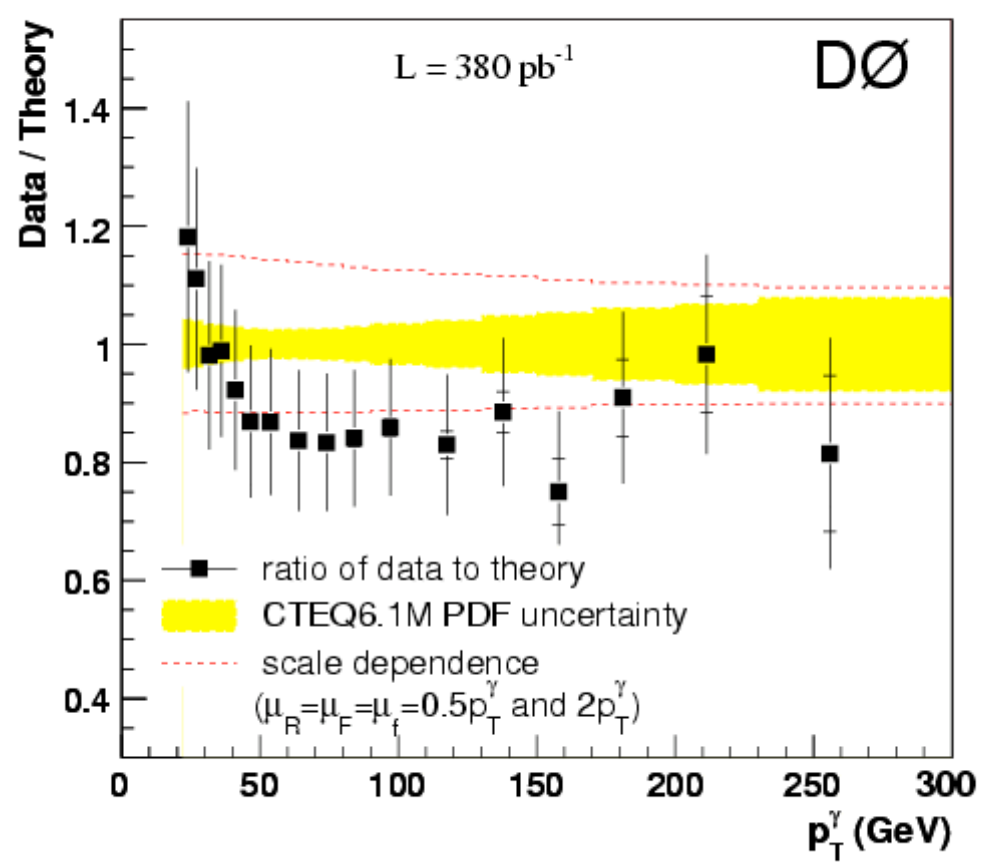


- deviation is also seen for pT<50GeV for Region 3
- same shape, although within error bands in Region 4

Inclusive Direct Single photon: erratum

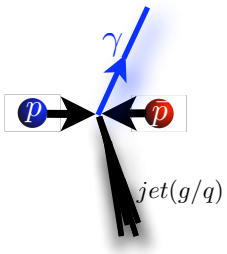
Erratum to PLB 639,151 (2006)

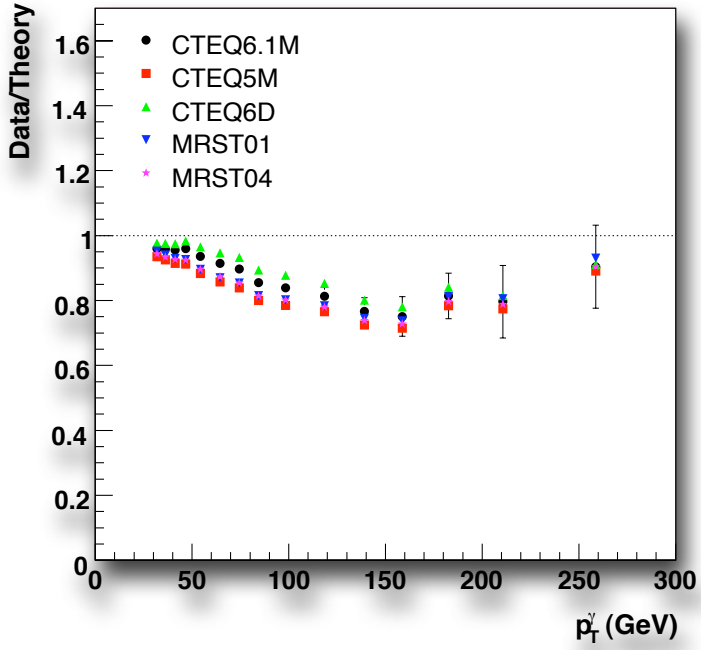
- increase in the integrated luminosity by 16.7%; decreased its uncertainty from 6.5% to 6.1%
- adjustment to the estimation of energy response
  - instead of estimated PhES (e.g. 2%@20GeV) accounting for ES of the em-jets requires new correction, e.g. 3.5%(24GeV,) ~1% (pT>60GeV)

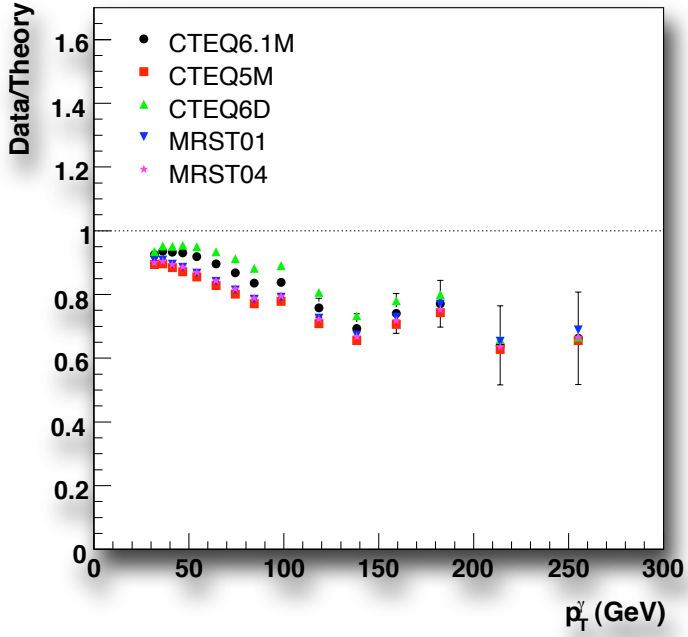


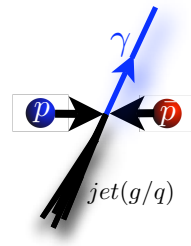
- these two effects incidentally approximately cancel each other, however at high pT cross section drops by 15%
- similar size of disagreement as the one seens by UA2 and CDF for the photons in the central rapidities

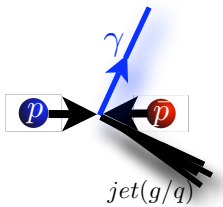
Data/Theory: CTEQxx, MRSTxx

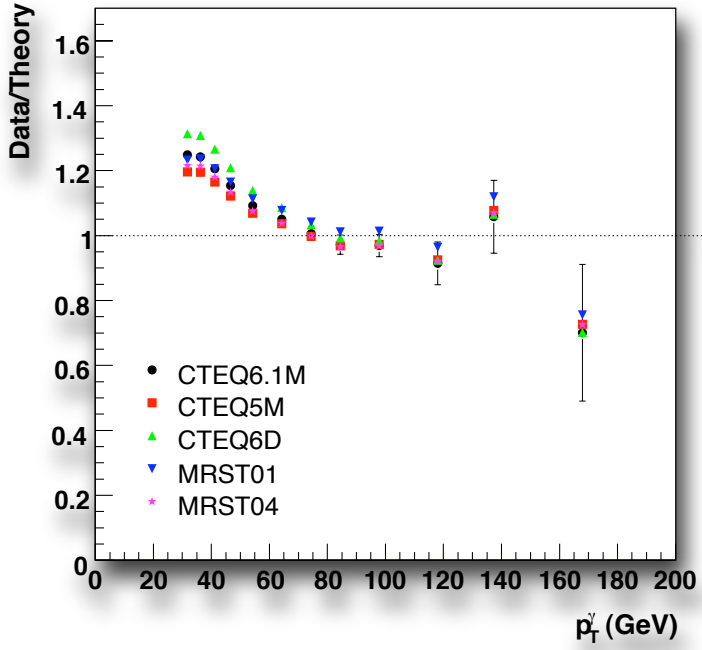


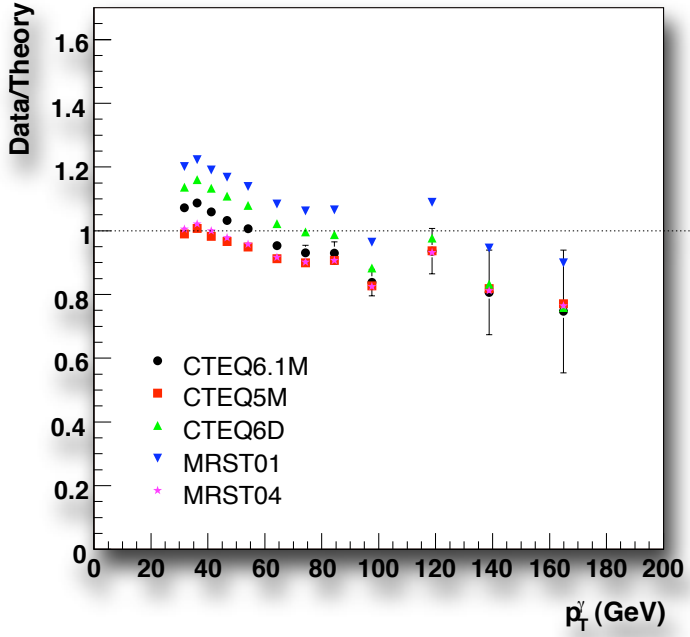


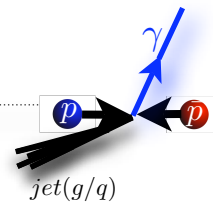




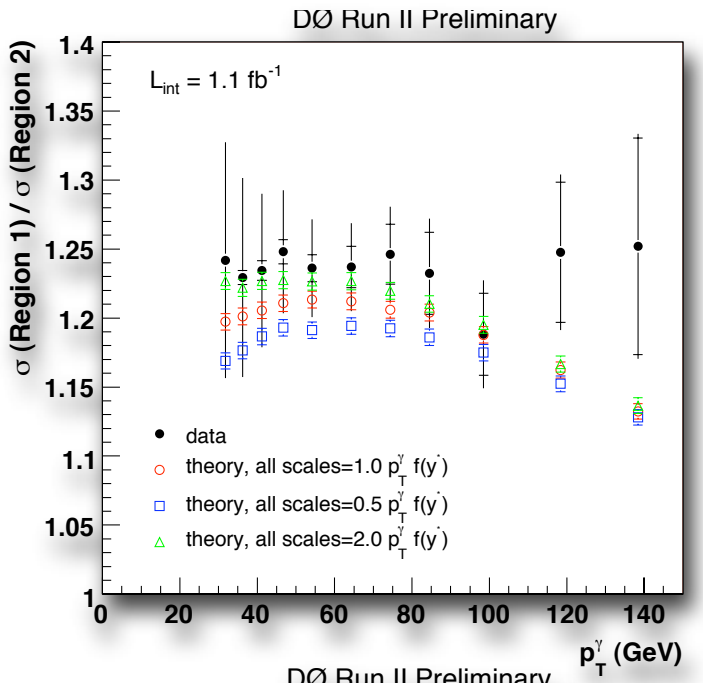


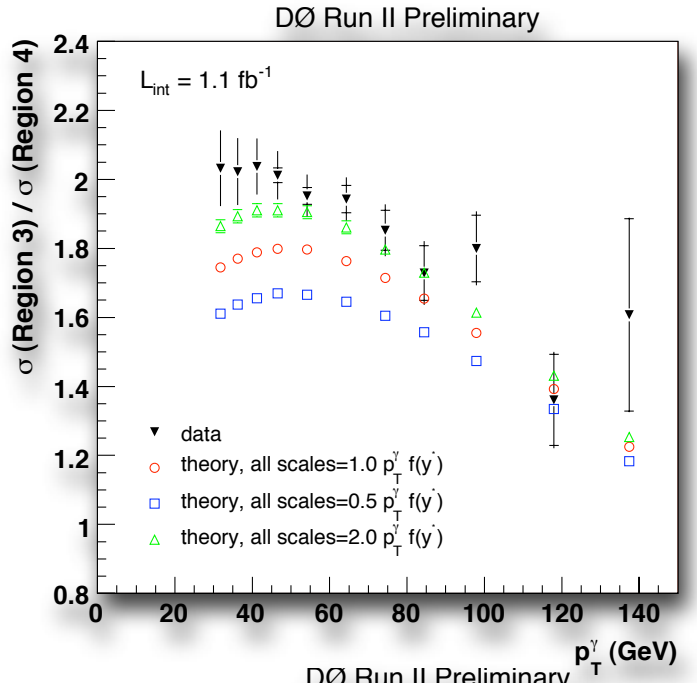


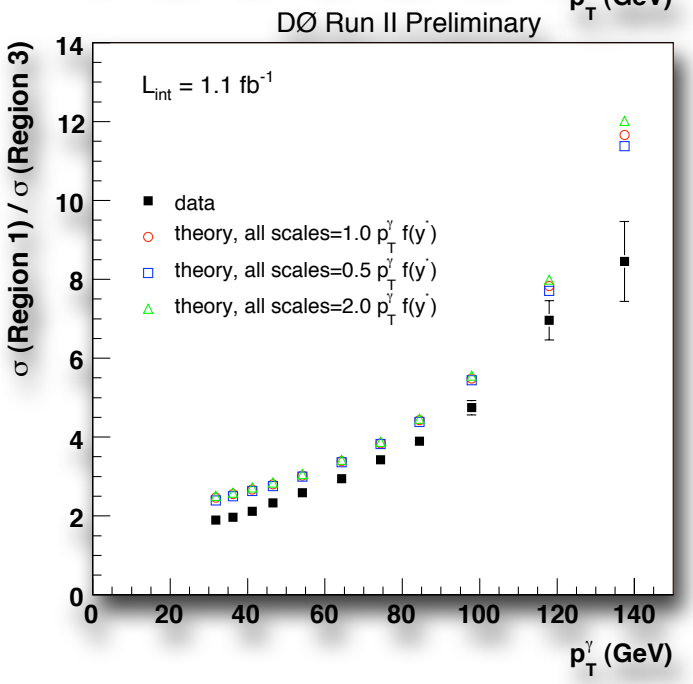


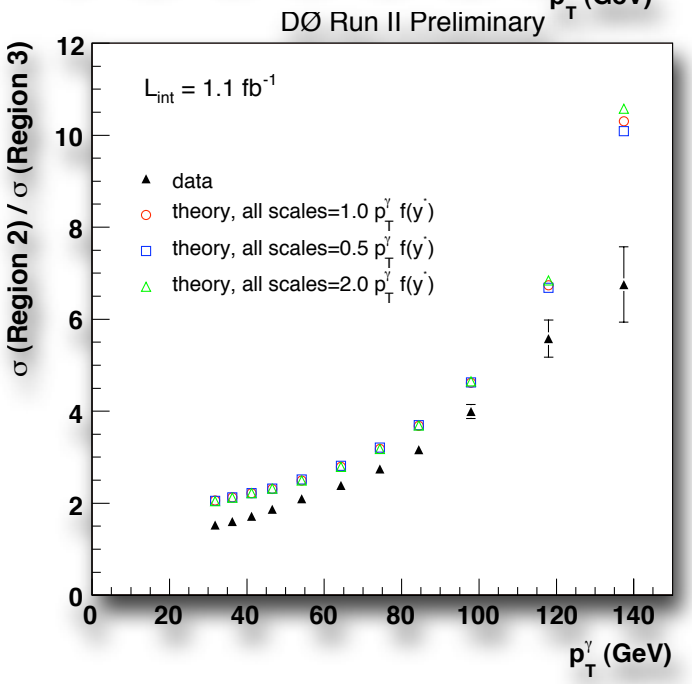


Region a/Region b







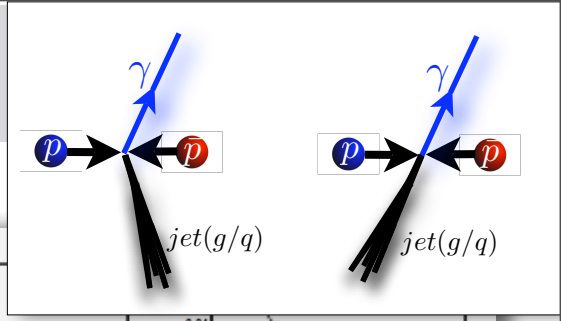


Summary

- We have performed a measurement of triple differential cross section of γ+jet production.
- Considered γ+jet topologies open a new window to study gluon distribution functions and that were previously unaccessible:
  $7 \cdot 10^{-3} < x < 0.8$ and $0.9 \cdot 10^{3} < Q^2 < 0.8 \cdot 10^{5}$ GeV^2 (with $Q=p^{\gamma}_{T}$)
- By taking ratios of cross sections significantly reduced effect of correlated uncertainties (both exp and th.).
- We compare our results with various theoretical predictions and checked their stability against 50% variation in choice of renorm., fact., and fragmentation scales, energy isolation (around 10%).
- We observe a quantitative deviation from the QCD predictions for some kinematic regions. The shape of Data/Theory ratios with photon and jet in the central rapidity regions is similar to a structure previously observed in UA2, CDF and D0 Run II inclusive photon measurements.
- As of now DZero has collected almost 3fb-1 of data and doubling every year.
- Study of photon production with colored jets is underway.

Auxiliary Slides

Pythia: Bjorken x Regions 1&2



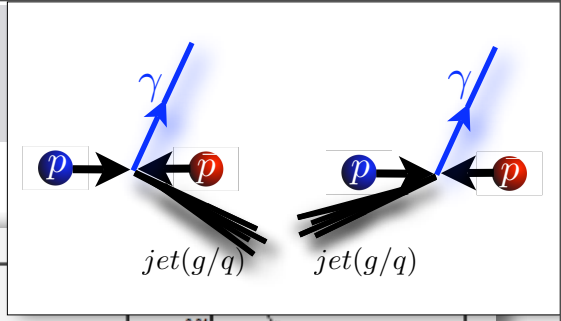
pT∈[34,39] GeV

pT∈[60,70] GeV

pT∈[110,130] GeV

pT∈[180,220] GeV

Pythia: Bjorken x Regions 3&4



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