DO Measurement of Triple Differential Photon + Jet Cross Section in p-pbar Collisions at 1.96 TeV

Nikolay Skachkov

JINR, Dubna

On behalf of D0 Collaboration

This work is a natural development of the previous Run II publication:

"Measurements of the isolated photon cross section in pbarp Collisions at √s = 1.96 TeV" ,

Phys. Lett. B {639}, 151 (2006),

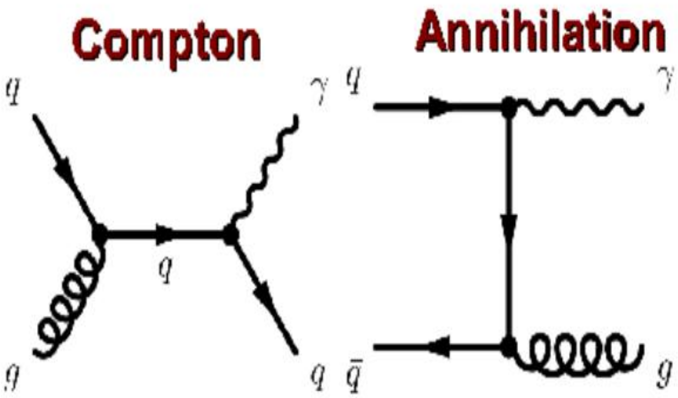
where the problem of photon identification was carefully studied (more material appeared in the detector after Run I).

The main background is caused by the EM-jets from QCD events in which parton jets contain high energetic π^0-, η -, ω - mesons accompanying by soft particles.

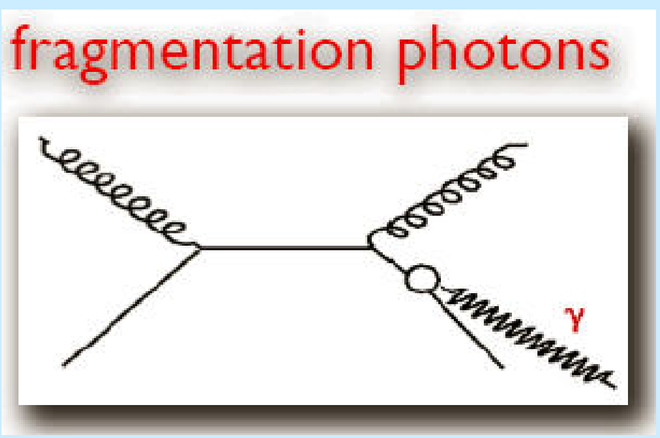
Fraction of *W* → *e*ν events is suppressed to a level of <*1%.*

The same methods of photon identification are used in this analysis.

Jet + Isolated Photon Triple Differential Cross Section



- 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?



There is also another diagram that describes fragmentation into a photon.

Its contribution is supressed by photon isolation criteria and drops with p_t^{γ} -growth

Jet + Isolated Photon Triple Differential Cross Section

The measurement of the triple differential cross-section for "ppbar → γ + jet + X" was done in 4 pseudorapidity regions,

(*the kinematic domain in the x – Q^2 plain covered by this 4 regions and the chosen* p_T^{γ} *range significantly extends previous "γ + jet(s)" measurements of ISR-AFS- , UA2- and CDF-Collaborations*.)

defined by the following boundaries:

a) central photons with $|\eta^{\gamma}| < 1.0$

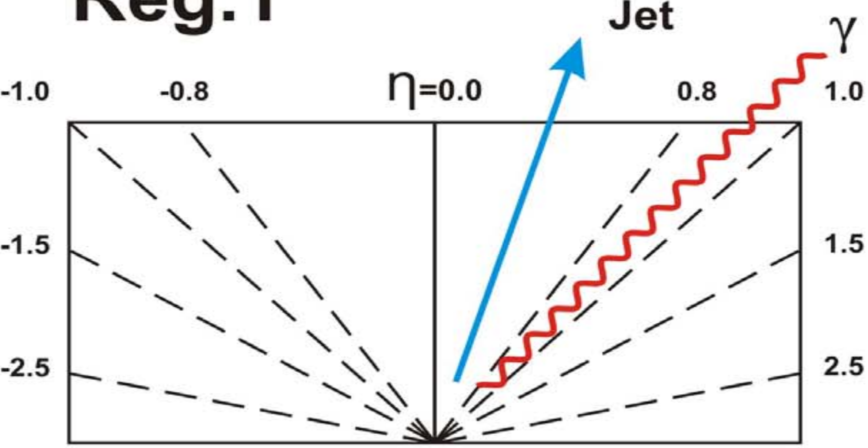
b) central jets with $|\eta^{Jet}| < 0.8$ or forward jets with $1.5 < |\eta^{Jet}| < 2.5$

(The rates of collected events in these Regions are: ~34.4% in Region 1, ~30.2% in Region 2, ~20.1% in Region 3, ~13.3% in Region 4.)

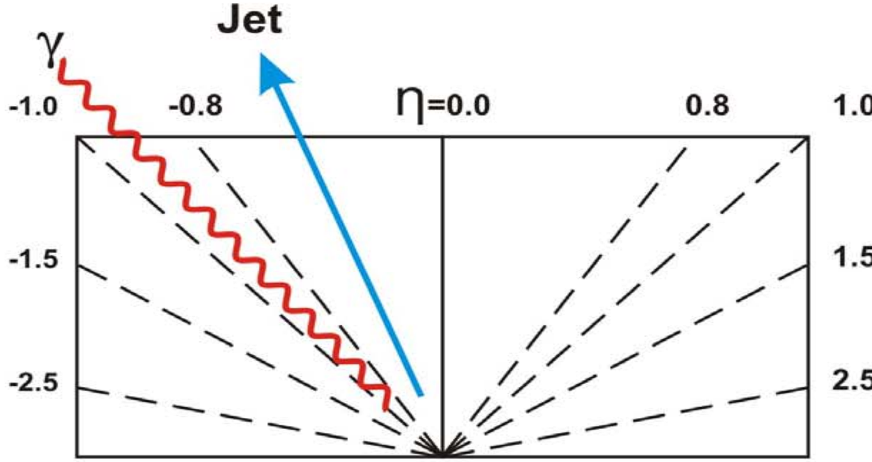
The corresponding "photon + jet" relative angular orientations look as follows:

Jet + Isolated Photon Triple Differential Cross Section

Reg.1

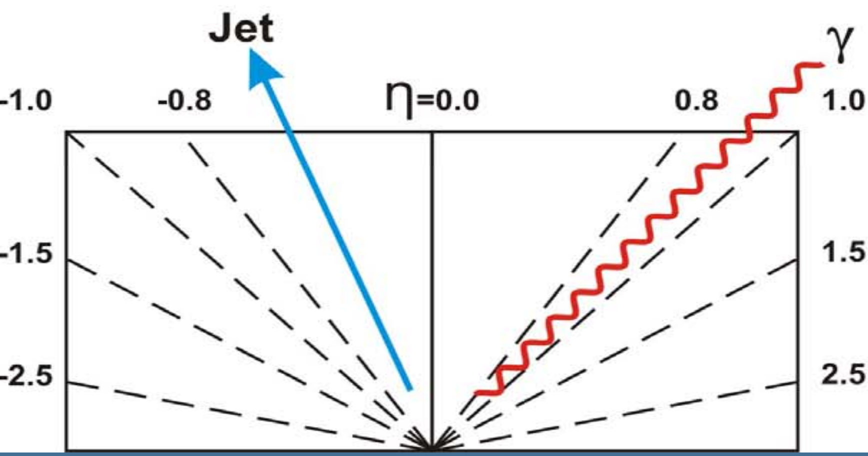


or



$$\eta = -\ln(tg\theta/2)$$

Reg.2



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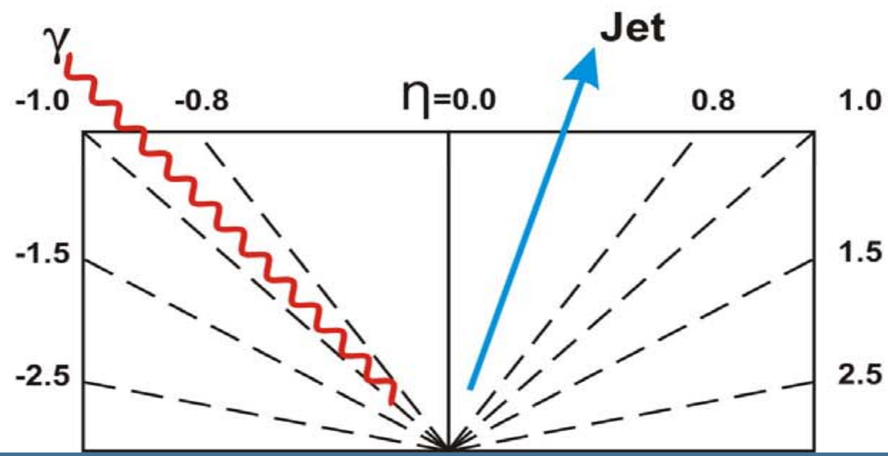
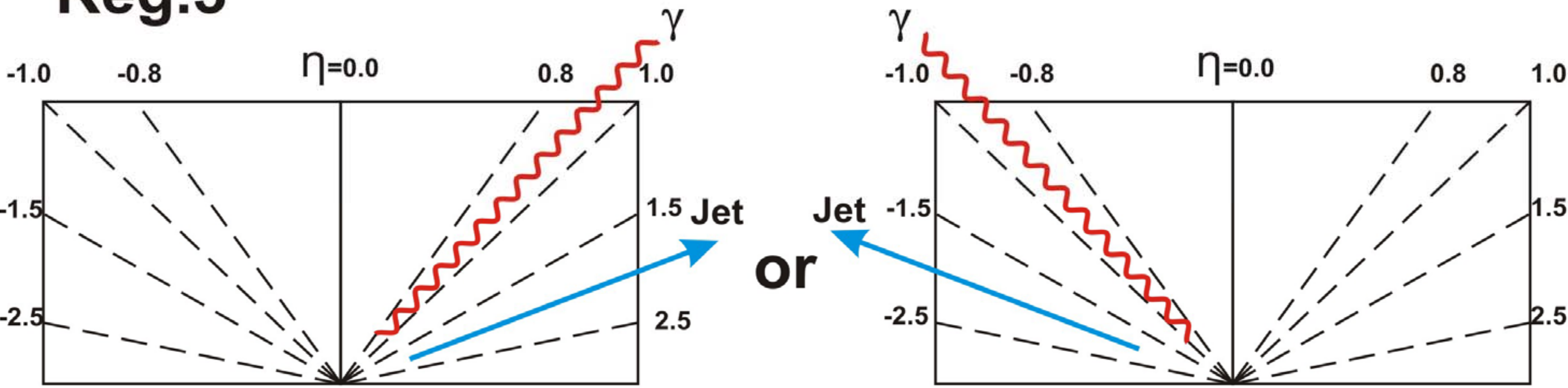


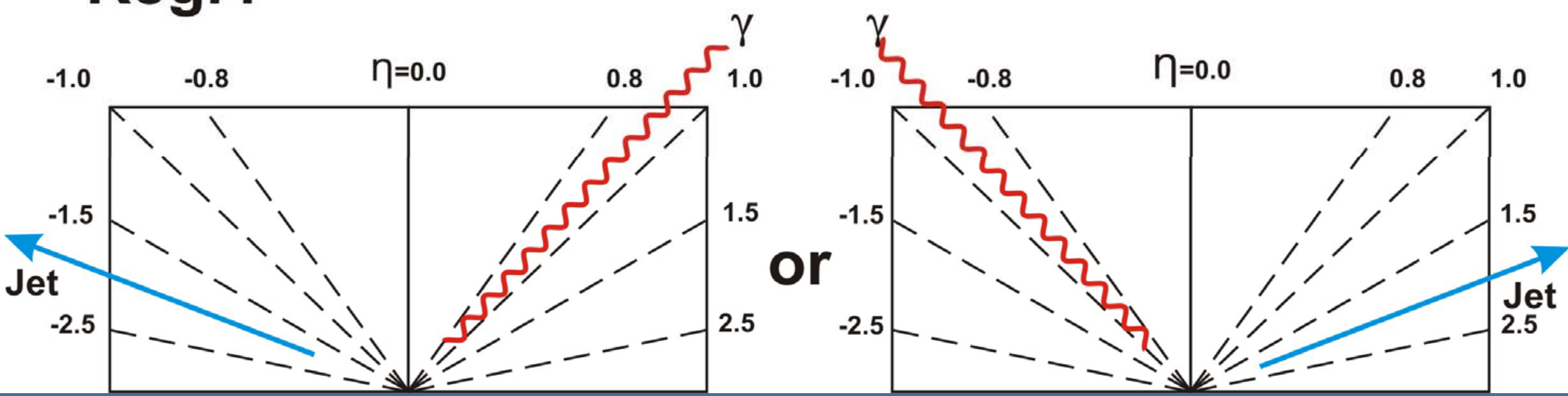
Jet + Isolated Photon Triple Differential Cross Section

Reg.3



$$\eta = -\ln(tg\,\theta/2)$$

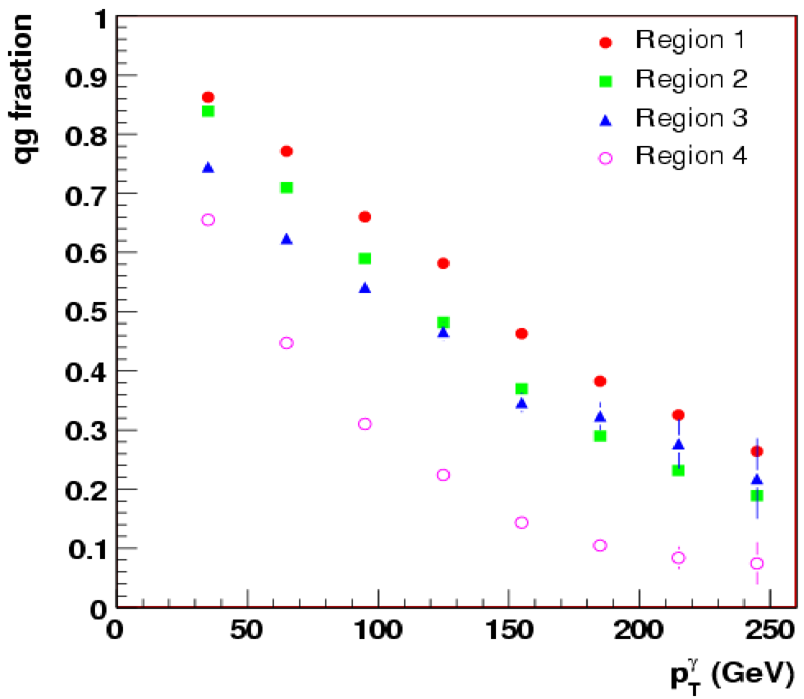
Reg.4



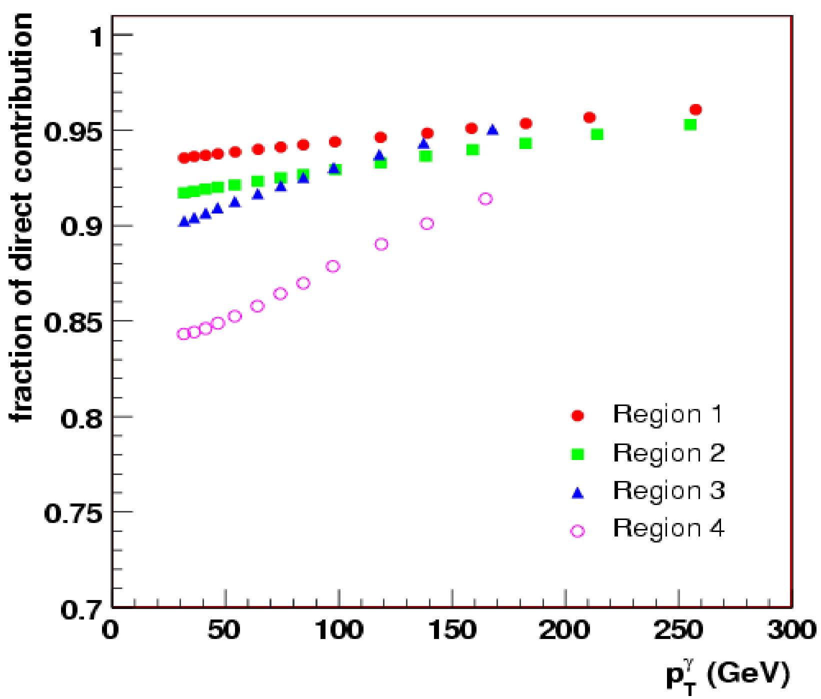
Jet + Isolated Photon Triple Differential Cross Section

PYTHIA6 gives an estimate of gluonic Compton process fraction.

JETPHOX (P.Aurenche et.al) allows to estimate fragmentaion photon effect.



Fraction of qg →qg process estimated with PYTHIA



Fraction of direct(γ+jet) / (direct(γ+jet)+fragmentation) where (direct(γ+jet) + fragmentation) is estimated with JETPHOX

Jet + Isolated Photon Triple Differential Cross Section

General selection cuts:

1. Leading Jet: $\left|\eta^{Jet}\right| < 0.8$ or $1.5 < \left|\eta^{Jet}\right| < 2.5$; $p_T^{Jet} > 15\, GeV$
2. Photon: $\left|\eta^{\gamma}\right| < 1.0$; $30 < p_T^{\gamma} < 300\, GeV$
3. *γ - Jet* separation in *η-φ*:

$$\Delta R(\gamma, Jet) = \sqrt{\left(\eta^{\gamma} - \eta^{Jet}\right)^2 + \left(\varphi^{\gamma} - \varphi^{Jet}\right)^2} > 0.7$$

4. $\left|z_{vtx}\right| < 50\ \mathrm{cm}$; vertex includes at least 3 charged tracks
5. $E_T^{miss} < 12.5\,\mathrm{GeV} + 0.36\, p_T^{\gamma}$ (cracks, $\eta_{\det}^{\max} = 5$, cosmics and W's)
6. Events are required to pass one of the unprescaled EM-trigger

Jet + Isolated Photon Triple Differential Cross Section

Photon candidate selection cuts:

1. **γ - candidate** is an isolated cluster of energy in calorimeter layers EM1 – EM4 (cells 0.1 x 0.1 of 2, 2, 7 and 10 rad. length)

$$R^{\gamma}_{clust} = \sqrt{\Delta\eta^2 + \Delta\varphi^2} = 0.2$$

2. $$Iso\,(\Delta R = 02) = \frac{E(R \le 0.4) - E(R \le 0.2)}{E(R \le 0.2)} \le 0.07$$

3. **γ - candidate** originates from the best primary vertex**:** fit of:
   1. center of gravity of EM cluster energy in EM1 – EM4 layers &
   2. Central Preshower cluster position
4. EM fiducial cuts (internal calorimeter structure + cracks)

⇒ total geometrical acceptance A=0.80 – 0.83

Photon candidate selection cuts:

5. EM fraction in calorimeter: *EMFr > 0.96* (deposited E)
6. Probability of charged track matching ≤ *0.001*
7. Limit on the width of energy cluster in the finely-segmented EM3 layer (cells with 0.05 x 0.05 size)

Three additional variables (used for the inclusive photon analysis)

1) number of cells in EM1 (with $E_T^{cell} > 0.4$)
2) fraction of E deposited in EM1 (with $E_T^{cell} > 0.4$)
3) $\sum P_T^{track}$ in the ring (*0.05 ≤ R ≤ 0.4*) (with $p_T^{track} > 0.4$)

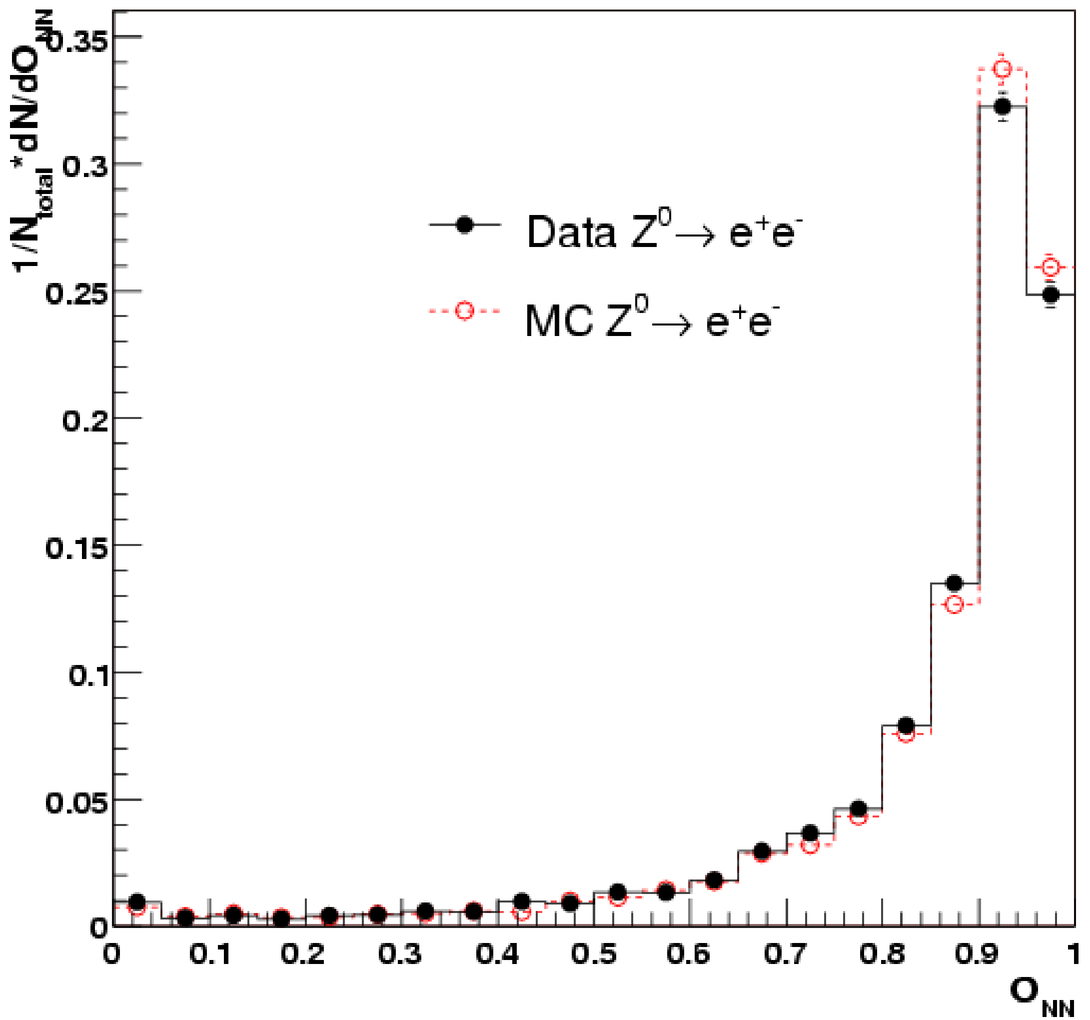
used as input for ANN (JETNET)

8. Additional cut on the ANN output: $O_{NN} > 0.7$, is applied.

Jet + Isolated Photon Triple Differential Cross Section

ANN methods allowed to achieve a good agreement between $Z^0 \rightarrow e^+e^-$ D0 data and MC.

Plot shows the normalized distribution of ANN output O_{NN} for $e^{\pm}$ from Z^0 decay in data and MC events.



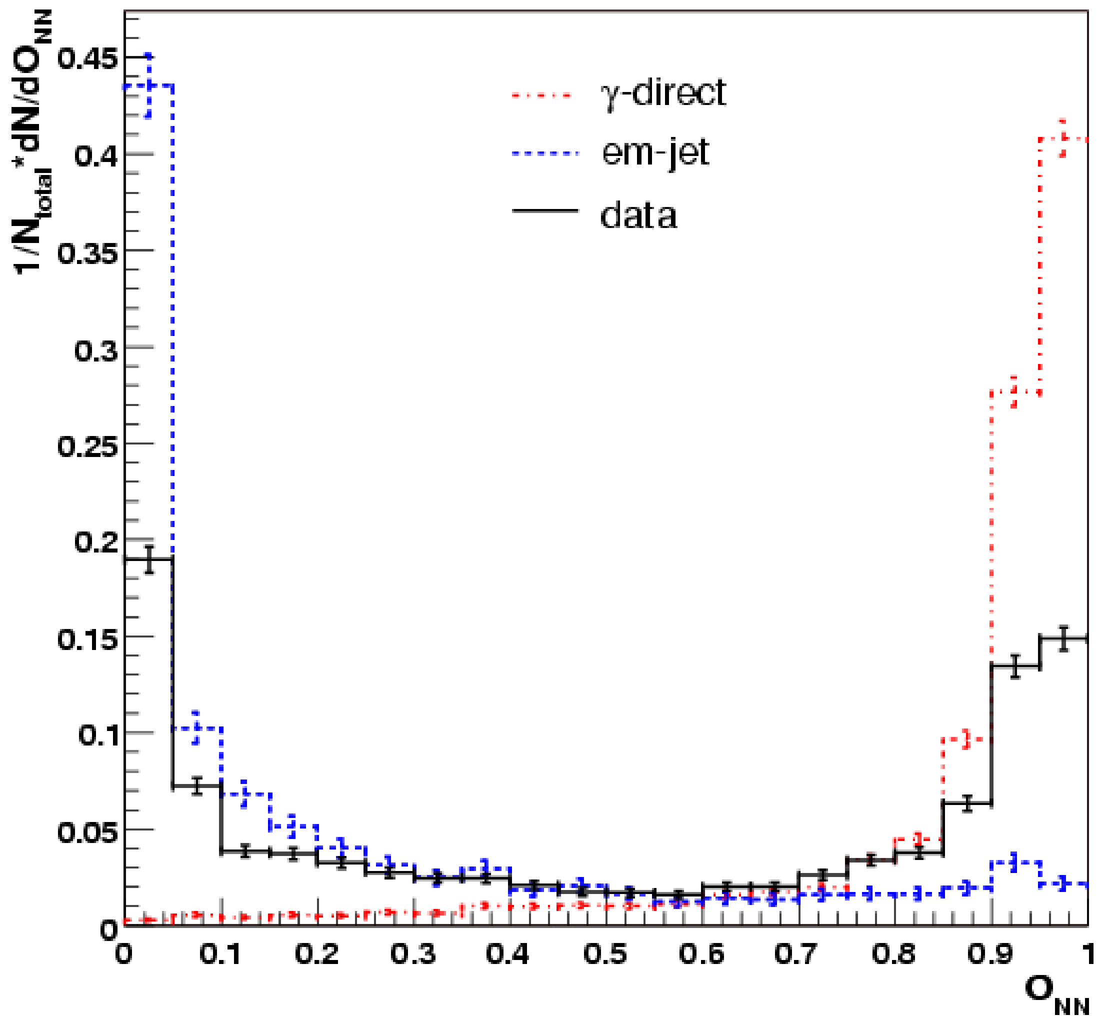
Jet + Isolated Photon Triple Differential Cross Section

ANN methods developed for analysis $Z^0 \to e^+e^-$ D0 data were applied to separate signal "$\gamma + jet$" from background.

The plot shows the normalized distribution for data, MC "$\gamma + jet$" signal and QCD dijet "*jet + jet*" background events (one jet appears as EM-jet) for

$$44 < p_T^{\gamma} < 50\,GeV$$

after application of the main selection criteria.



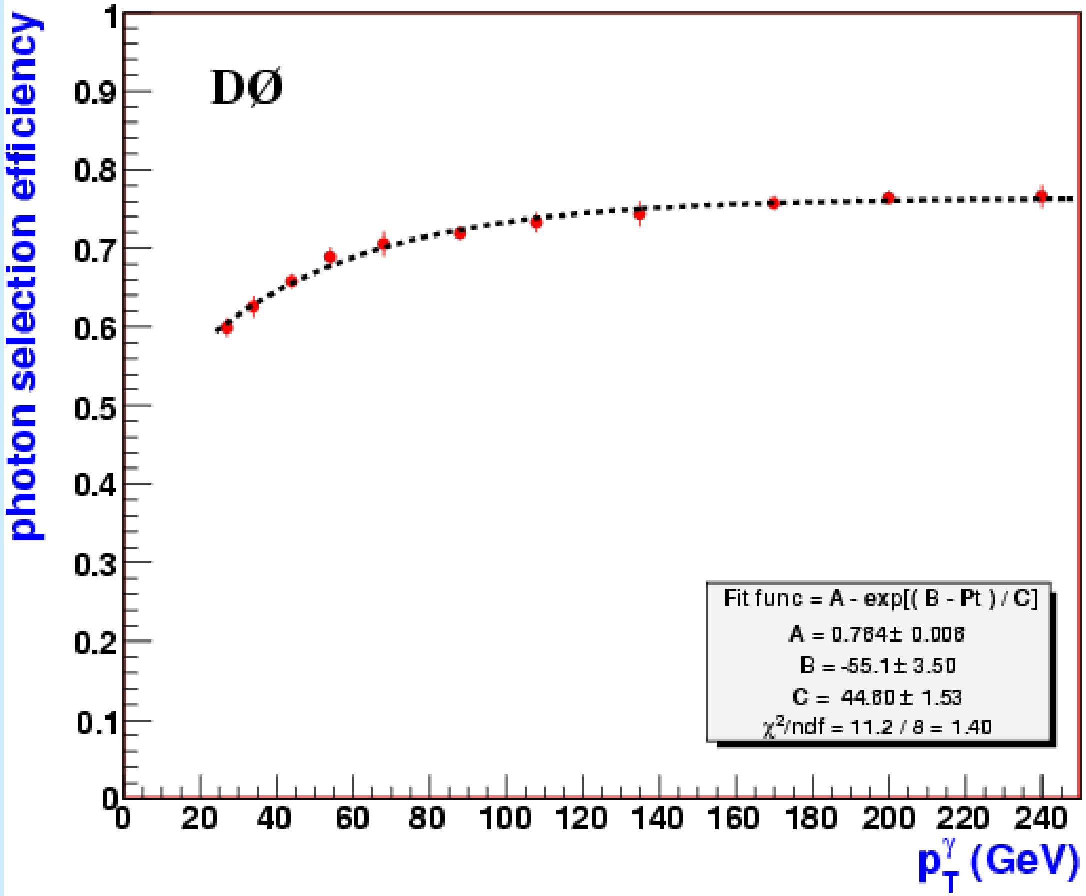
Jet + Isolated Photon Triple Differential Cross Section

The photon selection eff. ε_s^γ as function of p_T^γ (statistical uncertainties are shown)

ε_s^γ overall systematical uncertainty varies within 4.5-5.2% depending on p_T^γ interval.

It is caused by:

1. anti-track match cut: 3%
2. photon pointing cut uncertainty: 2%
3. ANN cut uncertainty: 2%
4. correction due to difference from Z→ee events: 1.5-2%
5. fitting uncertainty: <1%.



Jet + Isolated Photon Triple Differential Cross Section

Dependence of the "γ + *jet*" events PURITY on p_T^γ In Region 1.

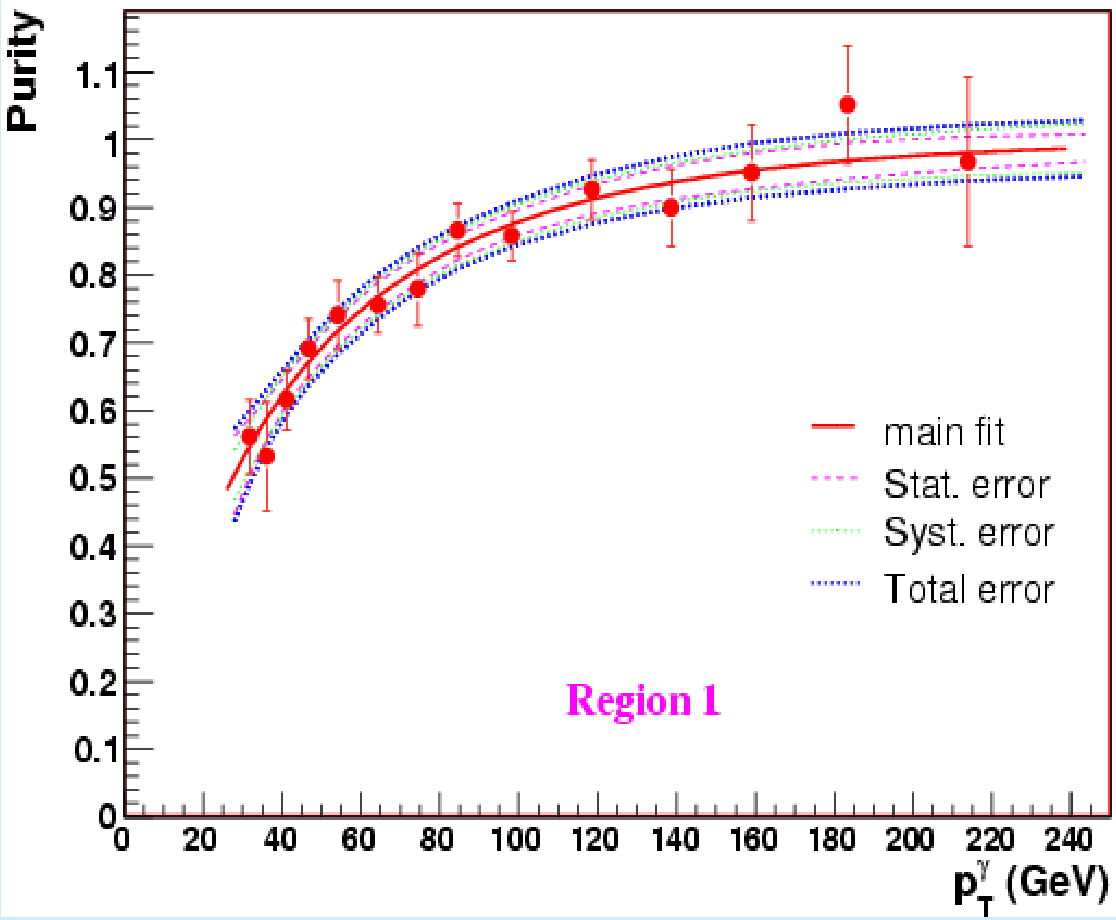
$$P = \frac{N^\gamma}{N^\gamma + N^{EM-jet}}$$

N^γ - N of signal events

N^{EM-jet} - N of bkgd events.

Purity is determined from the fit of ANN output in the two MC sources (signal and background) to the data.

Plot shows default fit (red full lines), statistical error band from the default fit (purple dashed lines), a band in systematic uncertainty (green dotted lines) and the total uncertainty (blue dash-dotted lines).



Main purity fitting function $P_f = 1 \Big/ \left[1 + a\left(p_T^\gamma\right)^b \left(1 - 2p_T^\gamma / \sqrt{s}\right)^c \right]$

PURITY uncertainty (4-10%)

appears mainly due to:

1. uncertainties of fitting functions parameters;
2. choice of different forms of fitting functions;
3. choice of the binning (3.5%);
4. statistics in p_T bin of distribution plots for data and MC events;
5. uncertainty in the choice of parameters of fragmentation functions of photon parents mesons $D_q^{\pi}(z)$, $D_q^{\eta}(z)$, $D_q^{\varpi}(z)$,... used in Pythia generator for MC production. This uncertainty was found to be 5% at $p_T^{\gamma} \cong 30\,GeV$, 2% at $p_T^{\gamma} \cong 50\,GeV$, and 1% at $p_T^{\gamma} \cong 70\,GeV$.

Jet + Isolated Photon Triple Differential Cross Section

$$\frac{d^3\sigma}{dp_T^\gamma \, d\eta^\gamma \, d\eta^{jet}} = \frac{N \; P \; f_{unsm}}{L_{\text{int}} \, \Delta p_T^\gamma \, \Delta\eta^\gamma \, \Delta\eta^{jet} \, A \, \varepsilon_t \, \varepsilon_s^\gamma \, \varepsilon_s^{jet}}$$

N – number of selected "γ + jet" events after cuts →

N_selected **= 2.4*10E+6 events**, what corresponds to L_{int} =**1.1±0.07fb-1**

P – photon purity: ~0.5 – 1.0 (depends on the rapidity Region 1 - 4);

f_{unsm} unsmearing correction factor: 0.95 – 0.98;

L_{int} – total integrated luminosity; $\Delta p_T^\gamma, \Delta\eta^\gamma, \Delta\eta^{jet}$ - bin sizes;

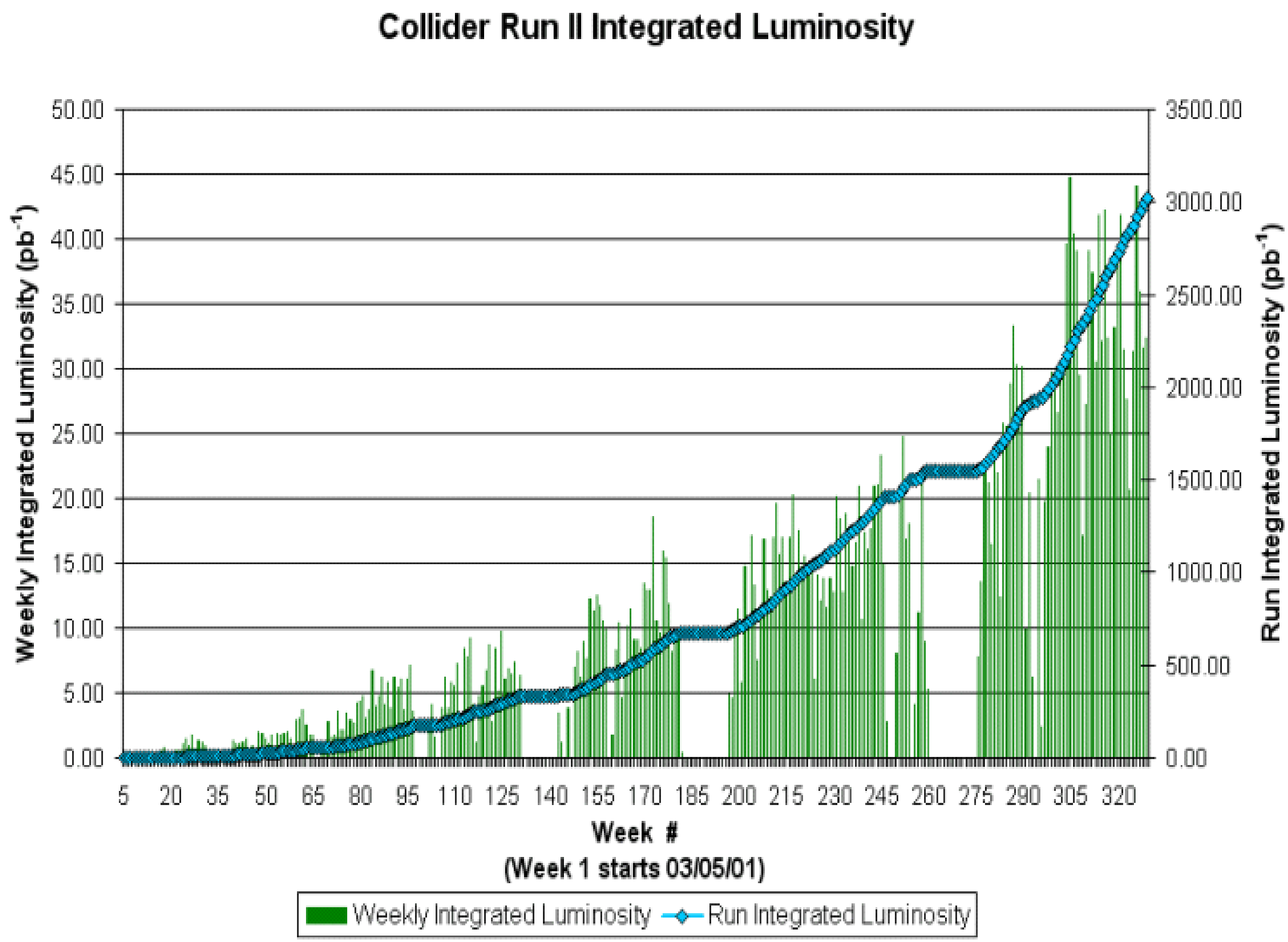
A – geometric acceptance: A = 0.80 – 0.83;

ε_t – trigger efficiency: 0.95 – 1.0;

ε_s^γ – photon selection criteria efficiency: 0.60 – 0.75;

ε_s^{jet} – leading jet selection criteria efficiency: from 94% to 99-100%, with syst. uncertainties of 5.7% at $p_T^\gamma \cong 30\,GeV$ and 2% at $p_T^\gamma > 200\,GeV$.

Jet + Isolated Photon Triple Differential Cross Section



Now DZero has collected almost 3 fb-1 of data (i. e. doubling every year).

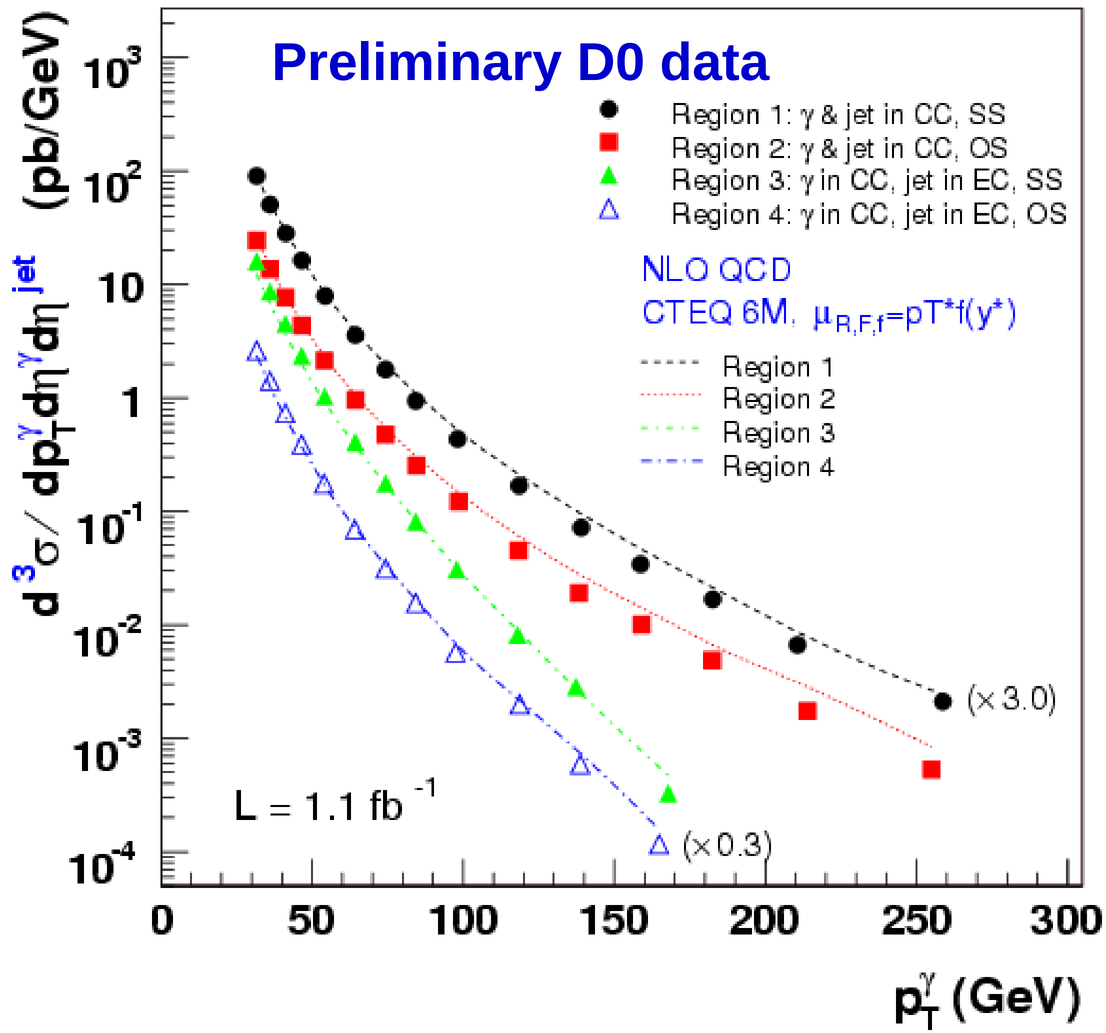
Jet + Isolated Photon Triple Differential Cross Section

"$\gamma + jet$" cross section versus p_T^{γ} for the 4 Regions (scaled by factors 3.0 and 0.3 for Regions 1 and 4).

The full (systematic ⊕ statistical) errors are shown.

The curves are theoretical NLO QCD predictions from the JETPHOX program with the choice of CTEQ6.1M PDF.

The data are plotted at the p_T^{γ} -weighted average of the fit function for each bin.



Jet + Isolated Photon Triple Differential Cross Section

Total statistical errors are:

- about 0.2% - 14.5% in Regions 1 and 2;
- about 0.3% - 21% in Regions 3 and 4.

Total systematical errors are:

- about 11.1% - 15.4% in Regions 1 and 2;
- about 11.2% - 15.2% in Regions 3 and 4;
- overall normalization uncertainty is 7.8%.

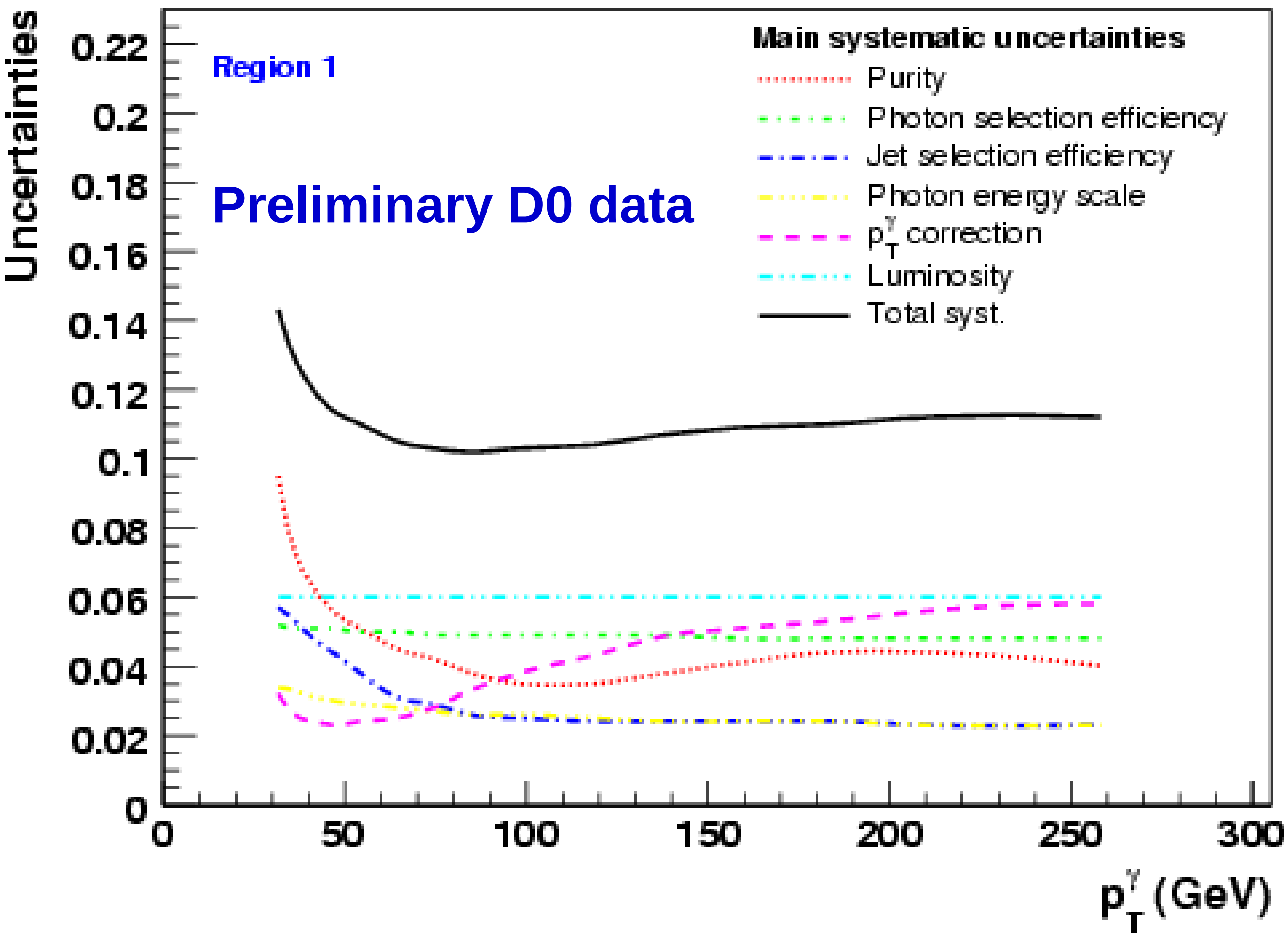
Total errors are:

- about 13.8% - 18.5% in Regions 1 and 2;
- about 14.3% - 24.2% in Regions 3 and 4.

For more details see Tables of differential cross sections for different Regions.

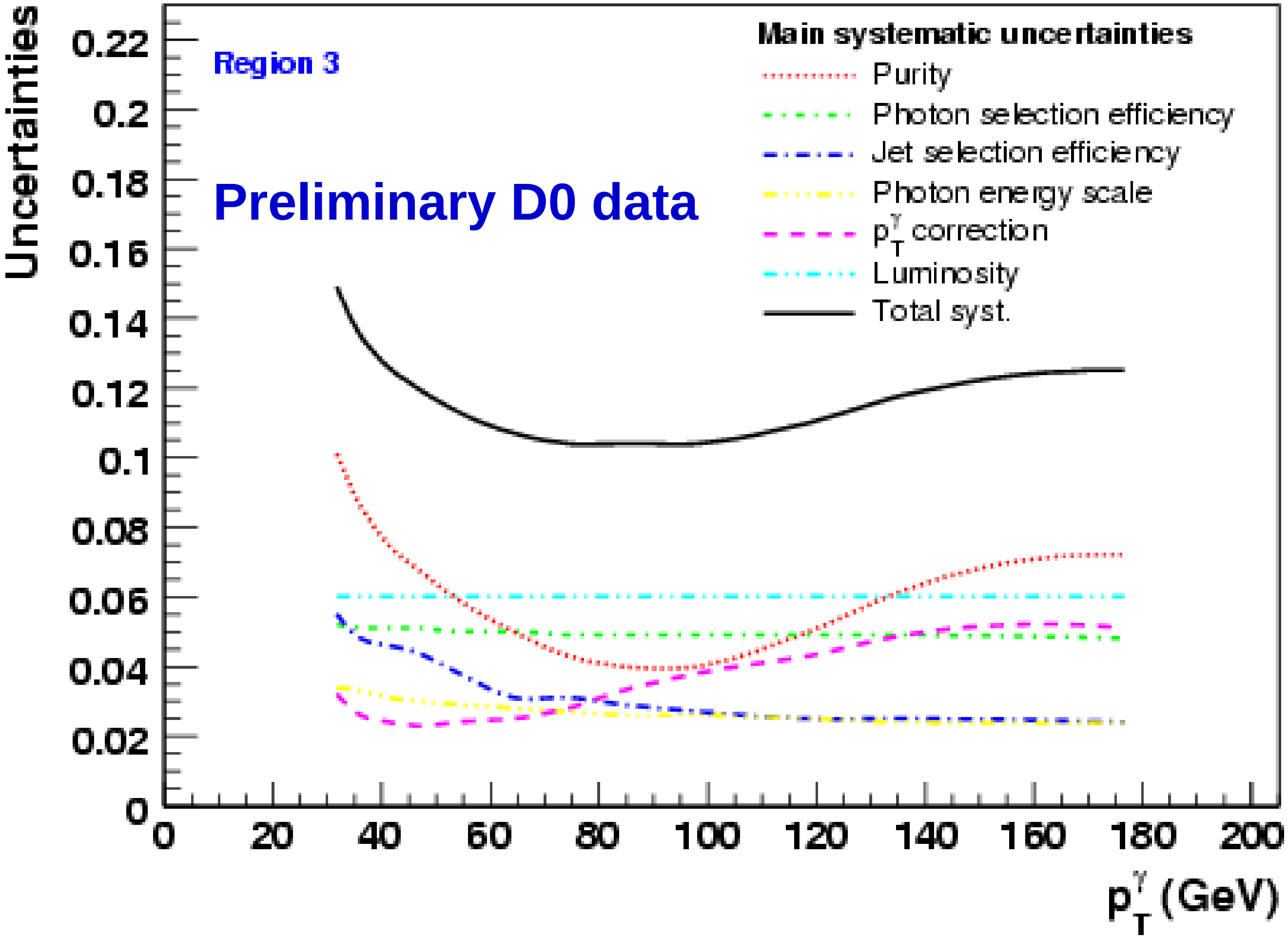
Region 1

The main systematic uncertainties for the triple differential cross section measured in Region 1.



Jet + Isolated Photon Triple Differential Cross Section

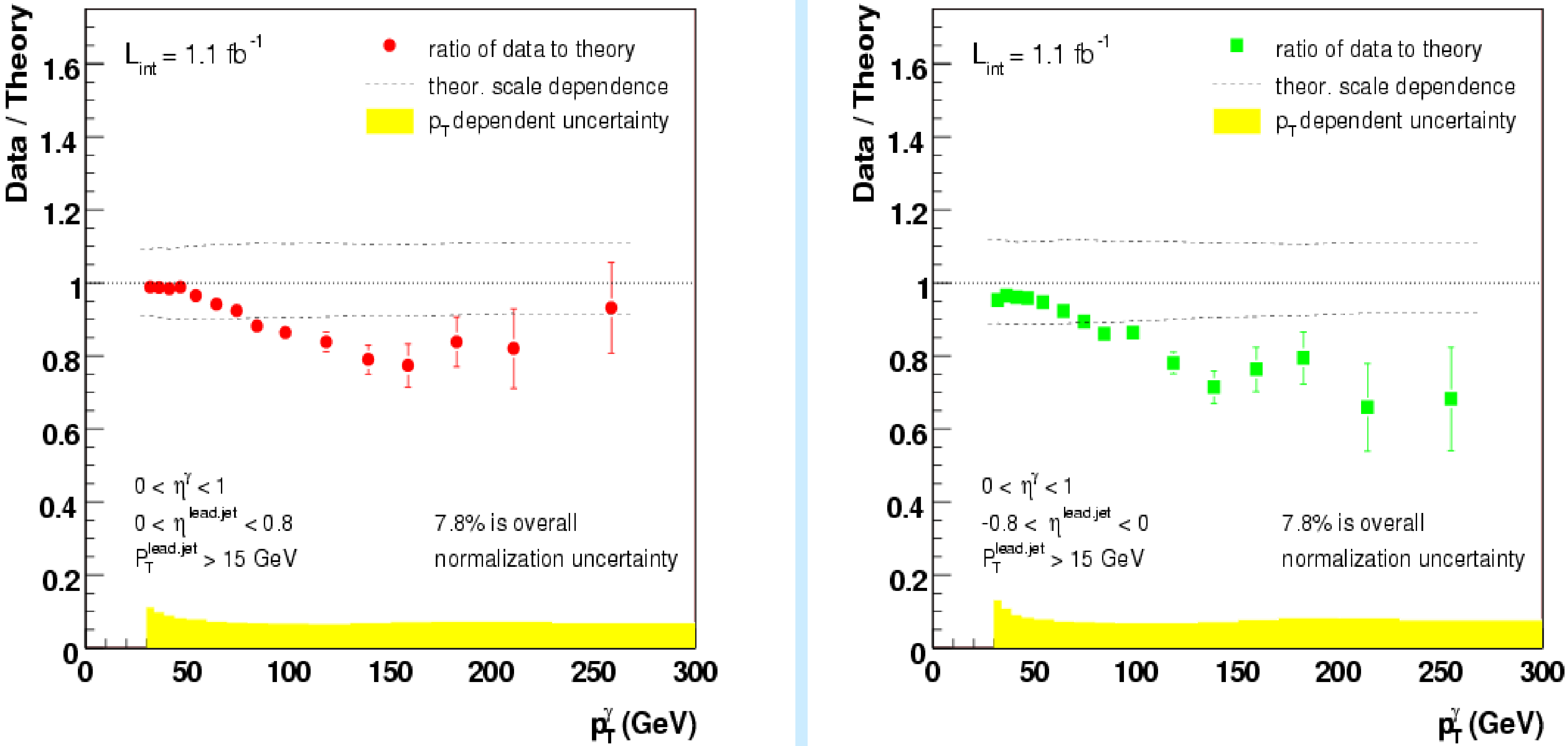
Region 3



The main systematic uncertainties for the triple differential cross section measured in Region 3.

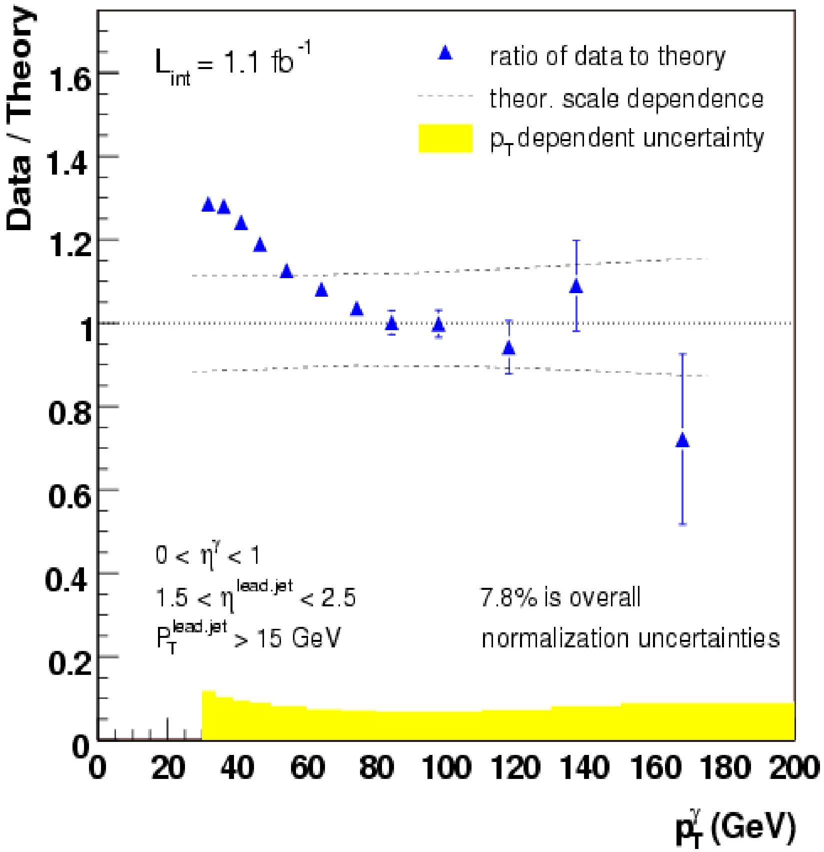
Jet + Isolated Photon Triple Differential Cross Section

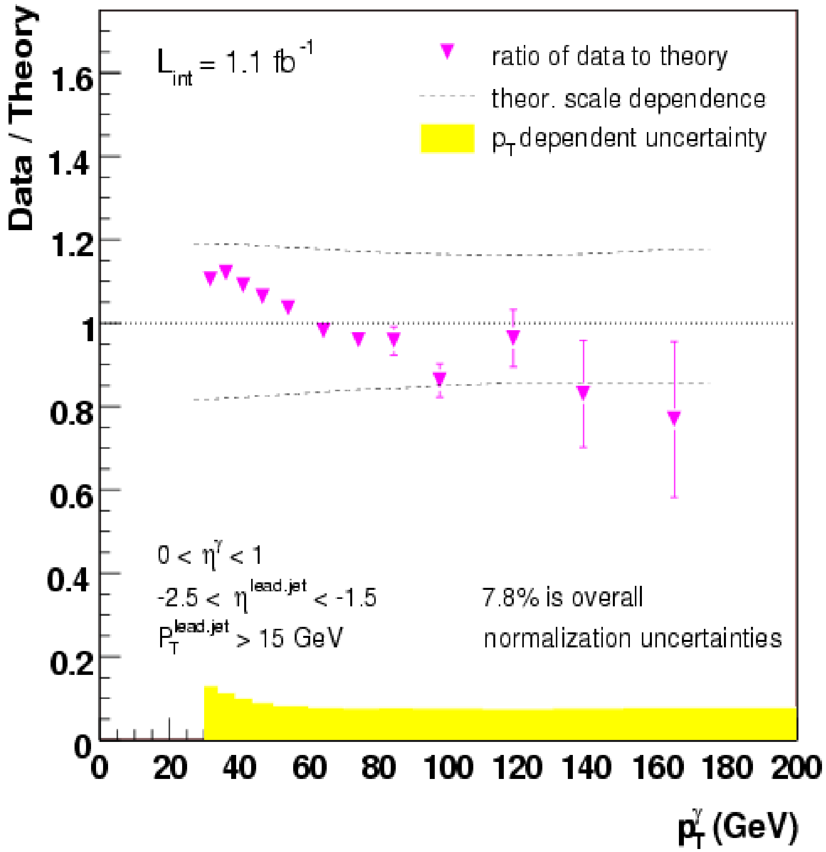
Theory to Data (preliminary) ratio for Reg.1 and Reg. 2



Jet + Isolated Photon Triple Differential Cross Section

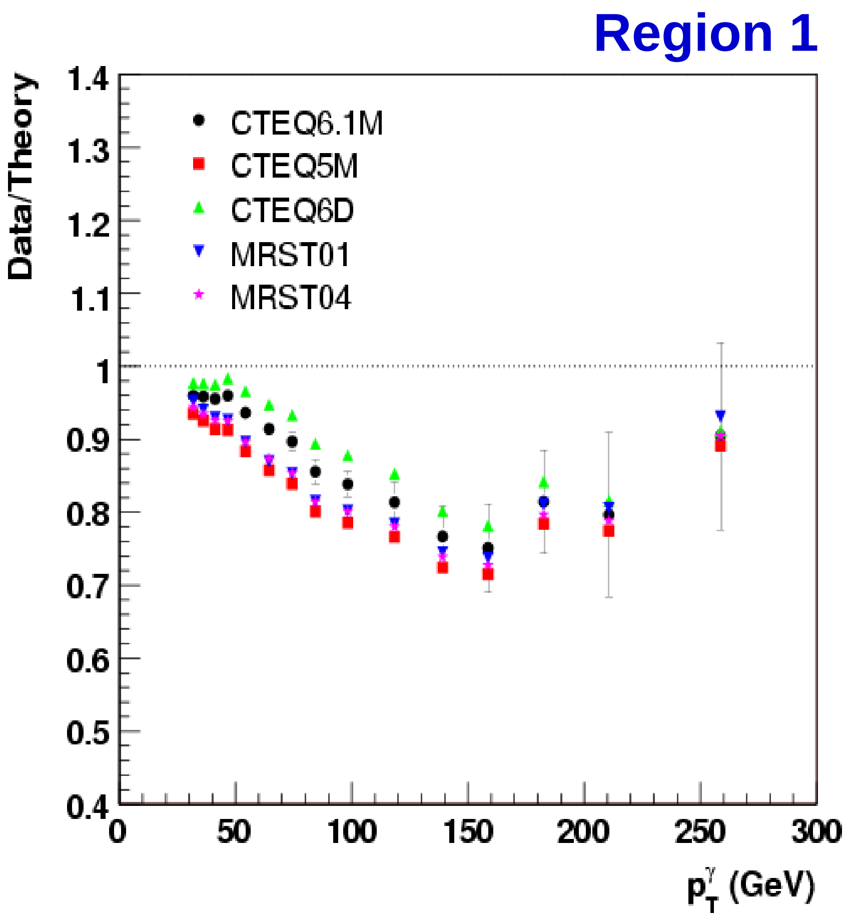
Theory to Data (preliminary) ratio for Reg.3 and Reg. 4

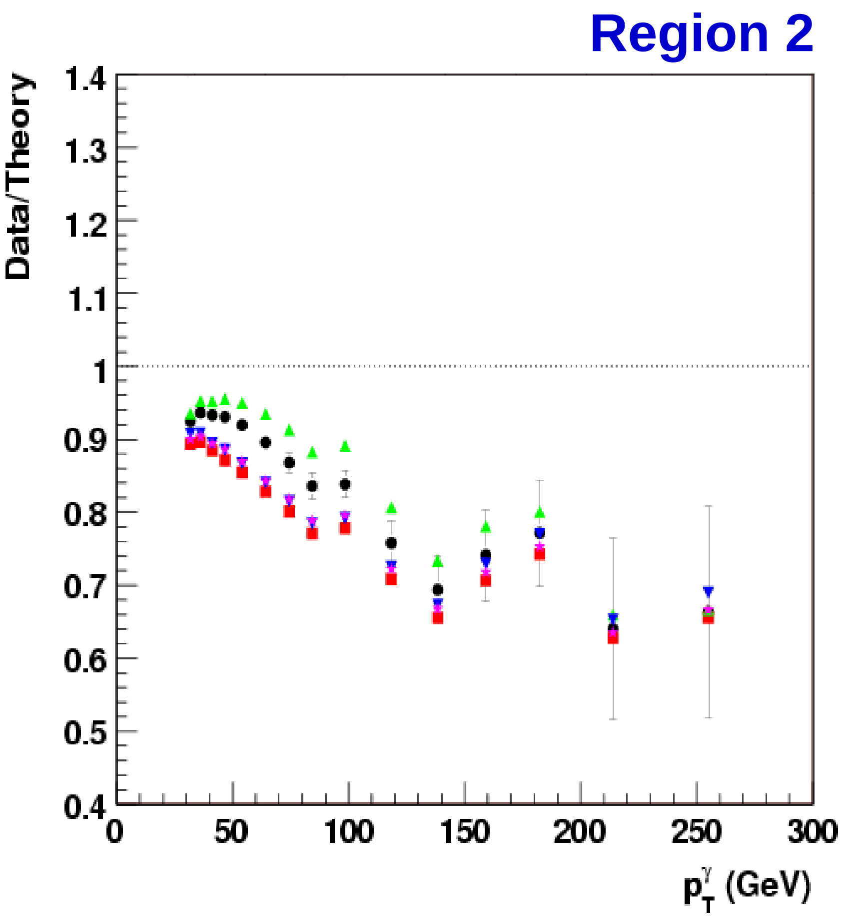




Jet + Isolated Photon Triple Differential Cross Section

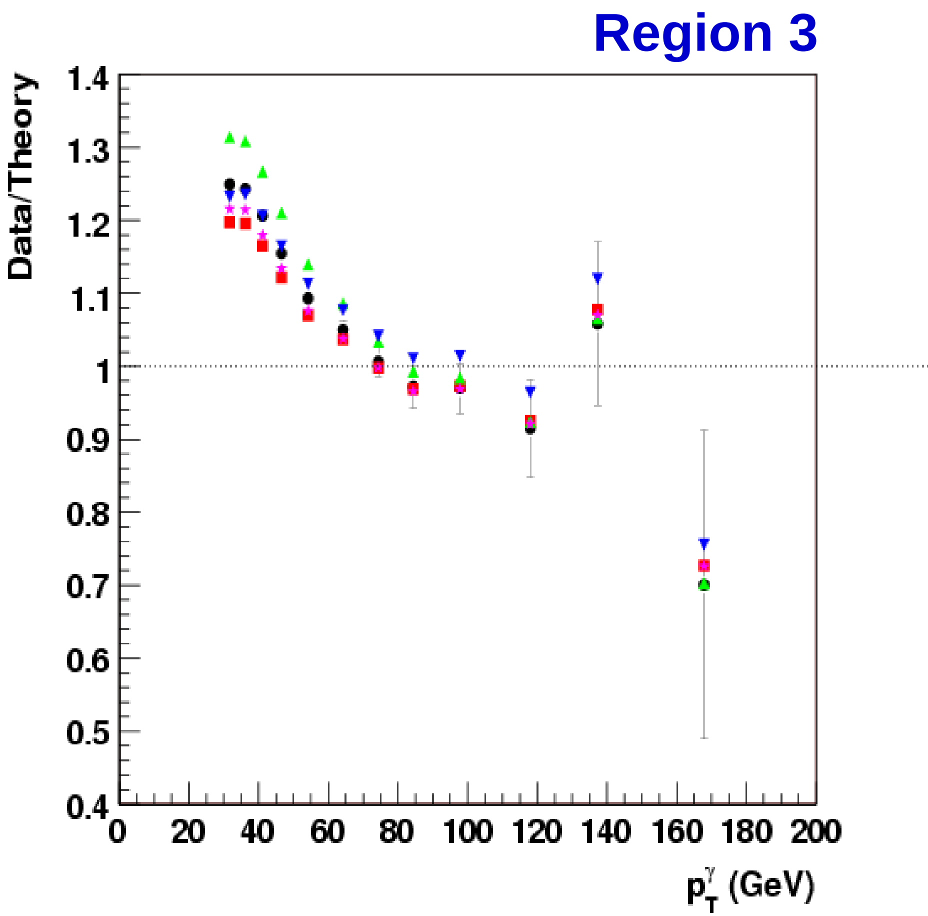
The ratio of the measured cross section in Regions 1 and 2 to the NLO QCD predictions done with various PDF. Statistical uncertainties are shown.

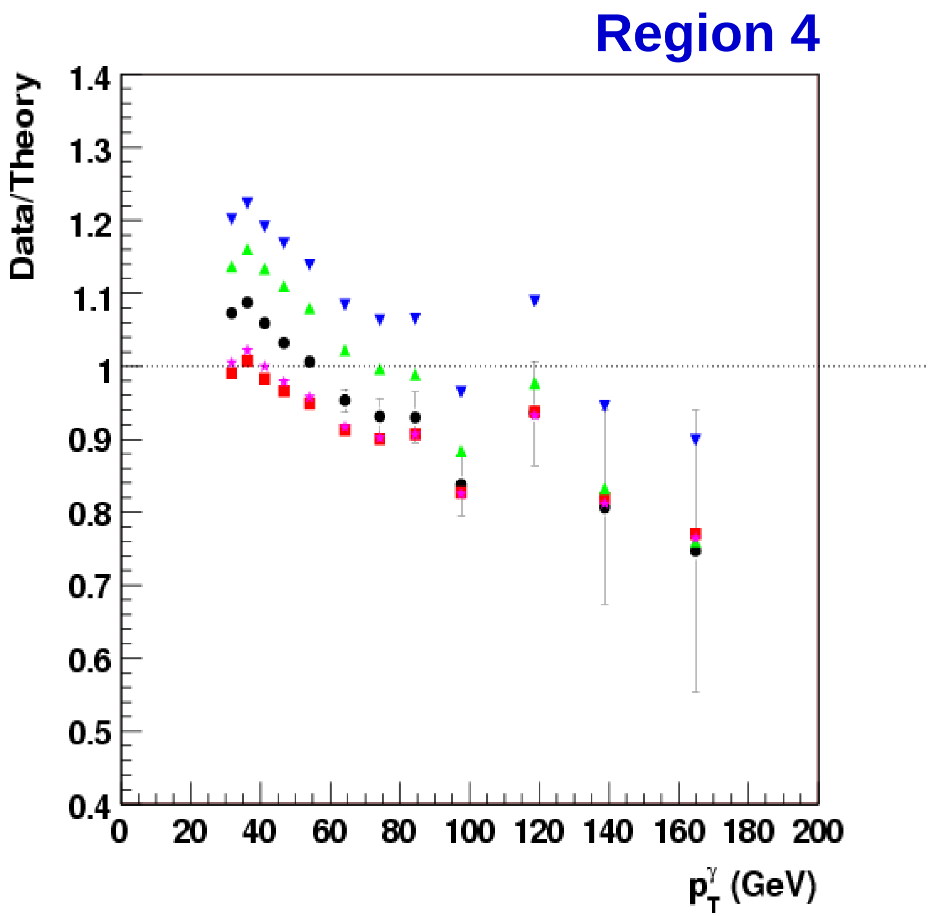




Jet + Isolated Photon Triple Differential Cross Section

The ratio of the measured cross section in Regions 3 and 4 to the NLO QCD predictions done with various PDF. Statistical uncertainties are shown.

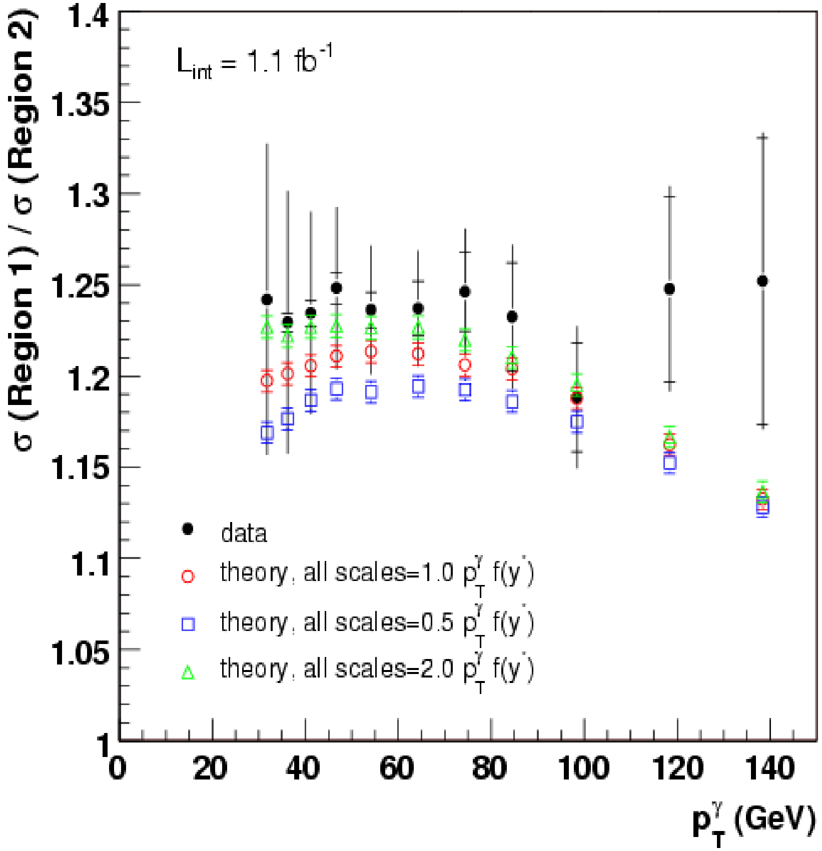




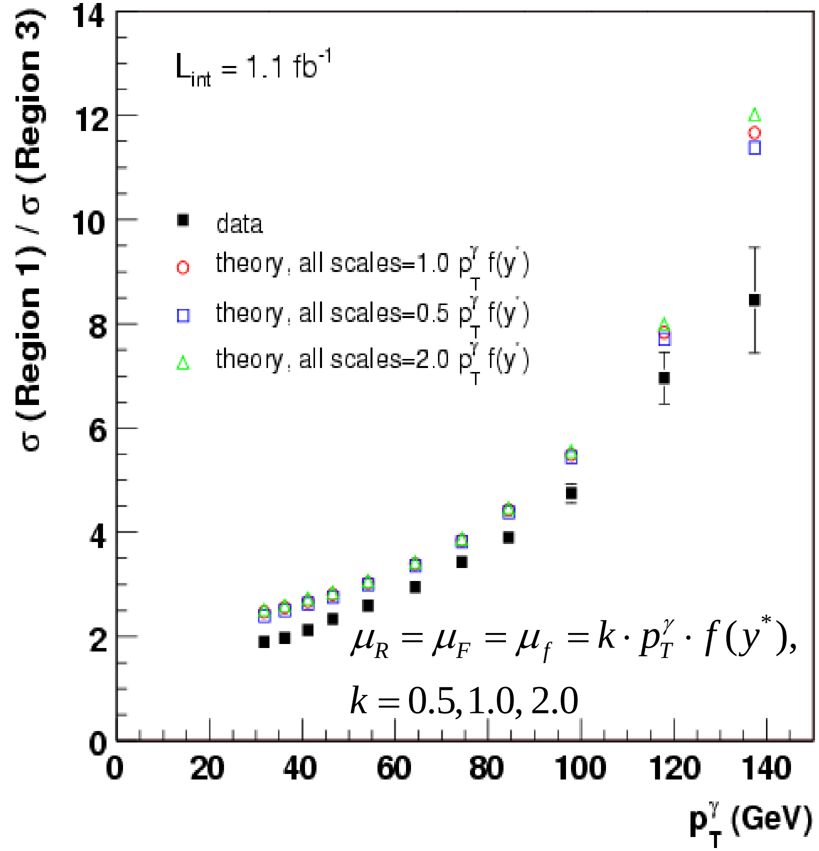
Jet + Isolated Photon Triple Differential Cross Section

The ratio of the differential cross sections in Region 1 to Region 2 (left).
Right plot is the ratio of cross sections in Region 1 to Region 3.

Region 1/Region 2



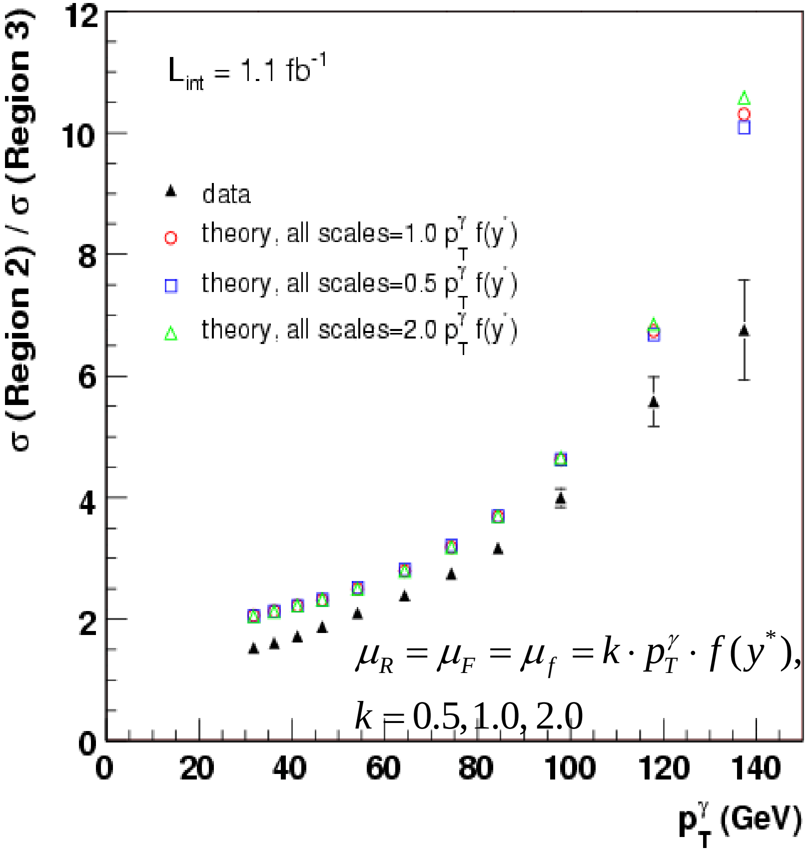
Region 1/Region 3



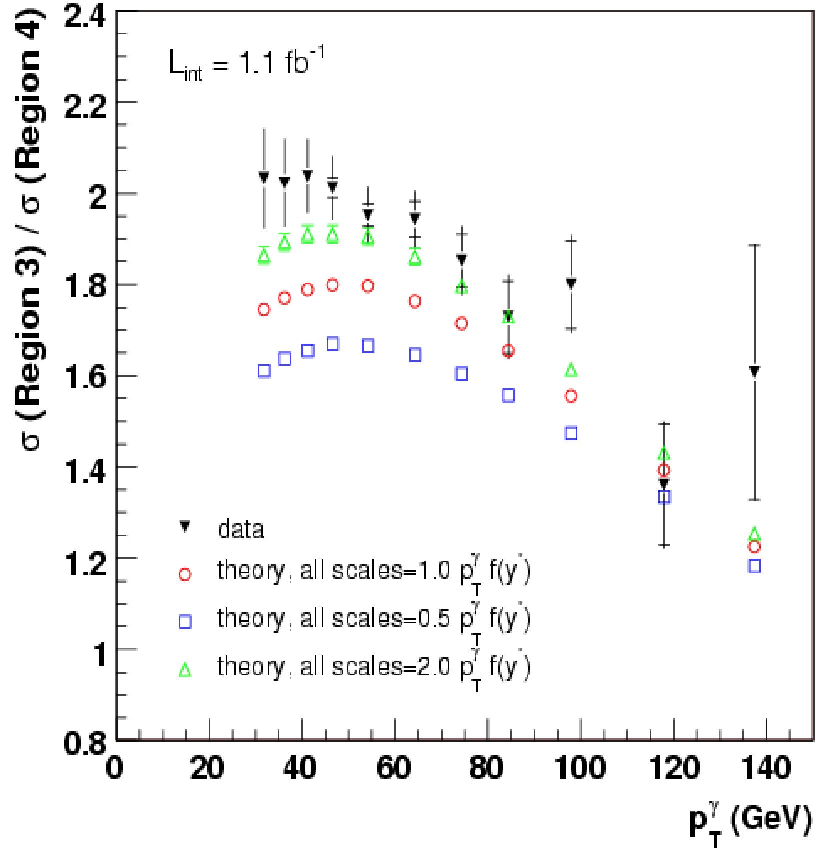
Jet + Isolated Photon Triple Differential Cross Section

The ratio of the differential cross sections in Region 2 to Region 3 (left).
Right plot is the ratio of cross sections in Region 3 to Region 4.

Region 2/Region 3



Region 3/Region 4



Summary

1. D0 performed a measurement of triple differential cross section of "γ+jet" events production with high statistics: $N_{event}^{selected}$ = **2.4*10E+6, i.e.** L_{int} **=1.1fb-1 → (~34.4% in Region 1, ~30.2% in Region 2, ~20.1% in Region 3, ~13.3% in Region 4).**
2. Preliminary data (that show 5 orders of magnitude variation in the cross section) qualitatively fit to QCD NLO predictions in four kinematical regions defined by photon and jet pseudorapidities. The dependence of Data/Theory ratio on PDFs and QCD scale parameters $\mu_{R,F,f}$ choice is studied.
3. Nevertheless, the ratios of cross sections from different pseudorapidity Regions (especially between Regions 1 and 3 as well as between Regions 2 and 3) show a noticeable deviation from theory predictions.