Measurement of Photon + Jet

Differential Cross Section

in p-pbar Collisions at DO

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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" ,

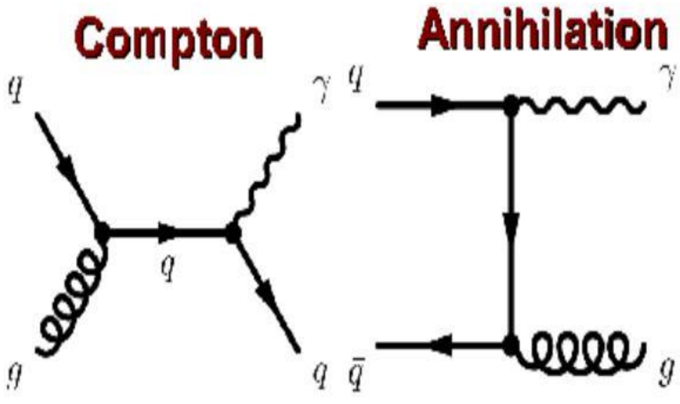
Phys. Lett. B {639}, 151 (2006),

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

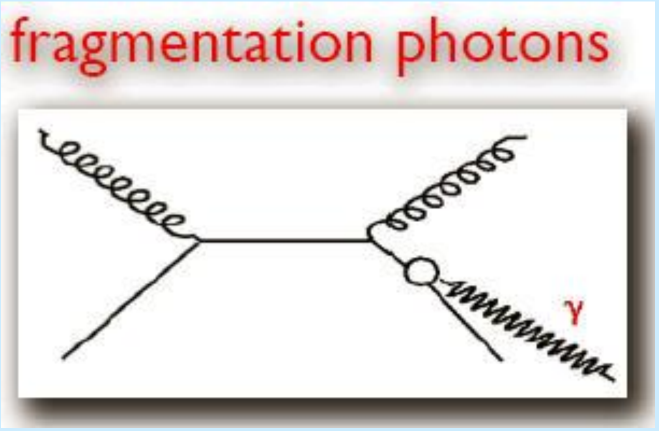
The main background comes from QCD events gq → gq, gg → gg , qq → qq, … , i.e. from $\pi^0 \to \gamma^0\gamma^0$, ω -- , η -- , K_S^0 -- , … *decays as well as from EM-jets (most hard background).*

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 – Q² 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 $|\eta^\gamma| < 1.0$

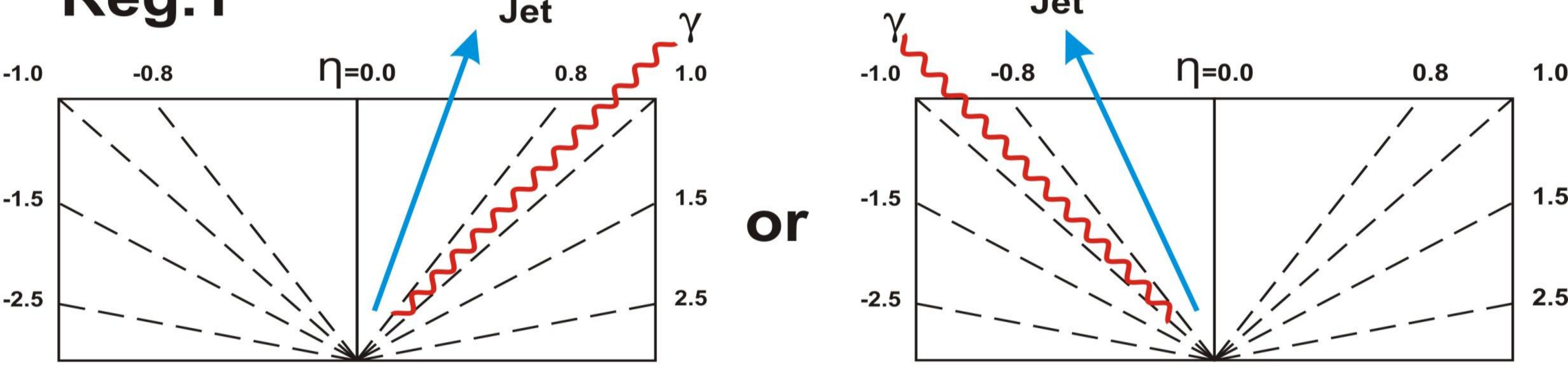
b) central $|\eta^{Jet}| < 0.8$, or forward $1.5 < |\eta^{Jet}| < 2.5$

(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:

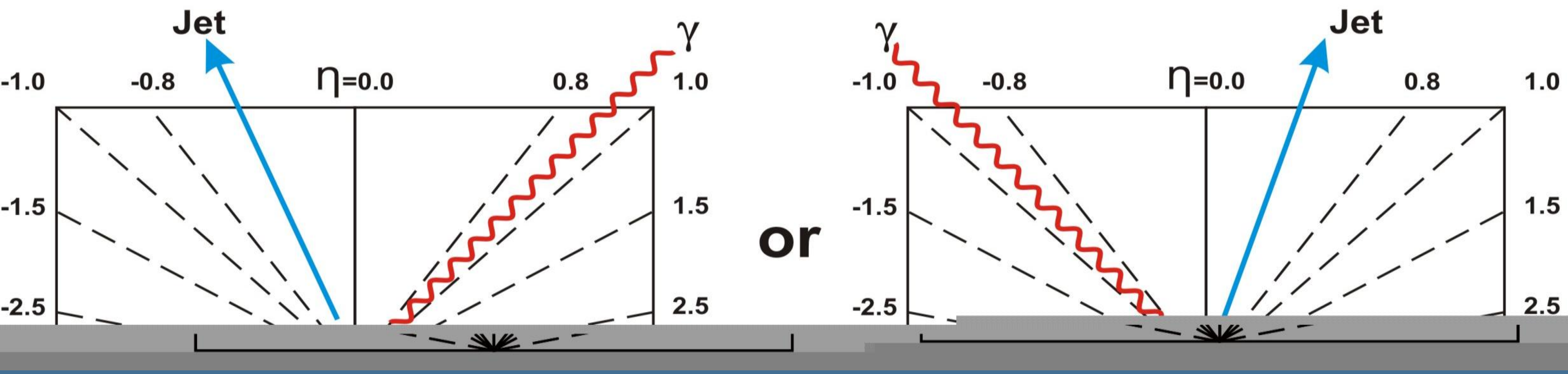
Jet + Isolated Photon Triple Differential Cross Section

Reg.1



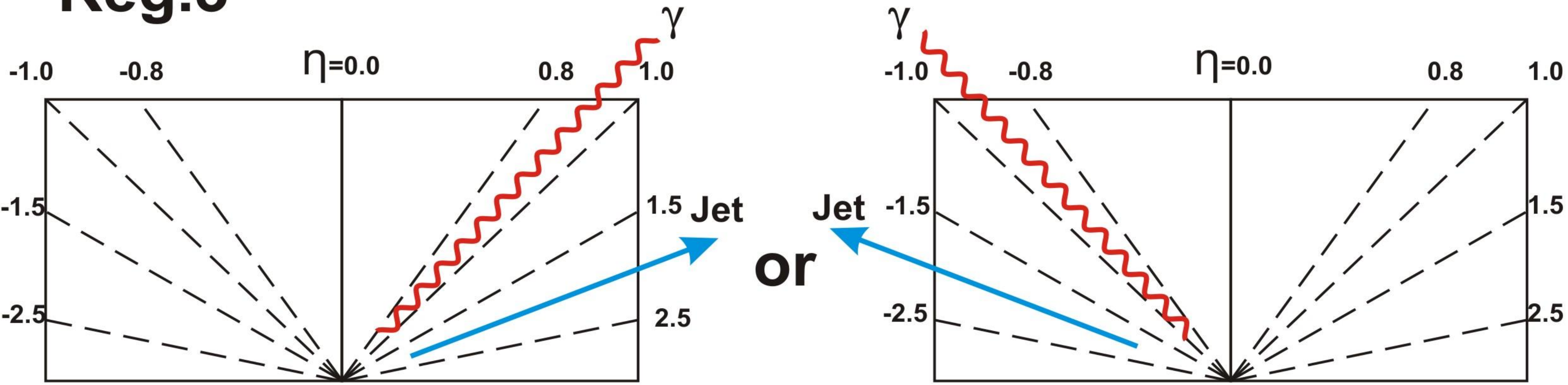
$$\eta = -\ln(tg\theta/2)$$

Reg.2



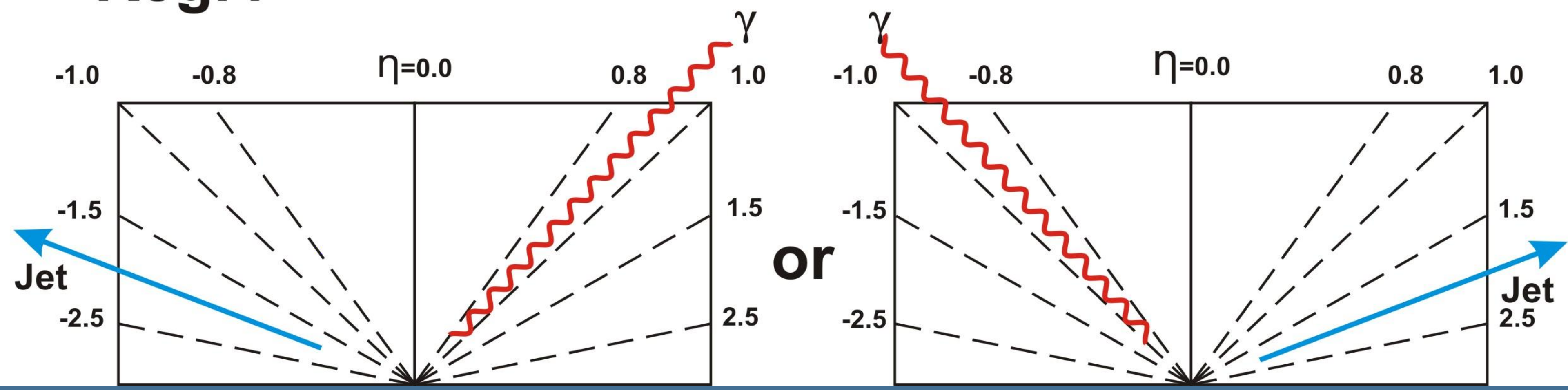
Jet + Isolated Photon Triple Differential Cross Section

Reg.3



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

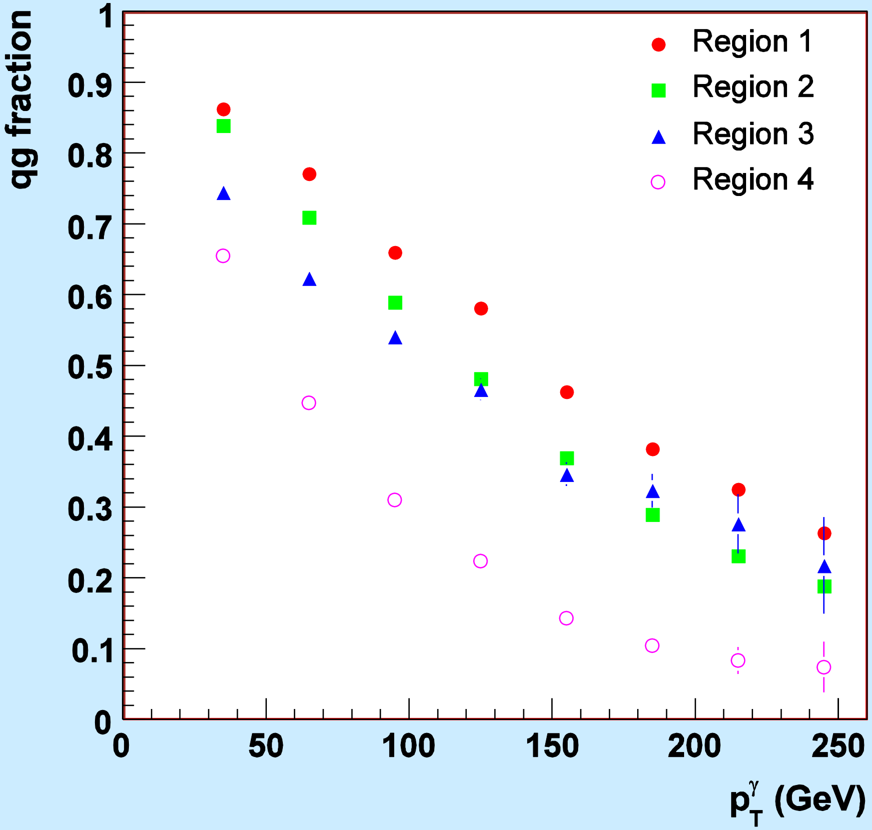
Reg.4



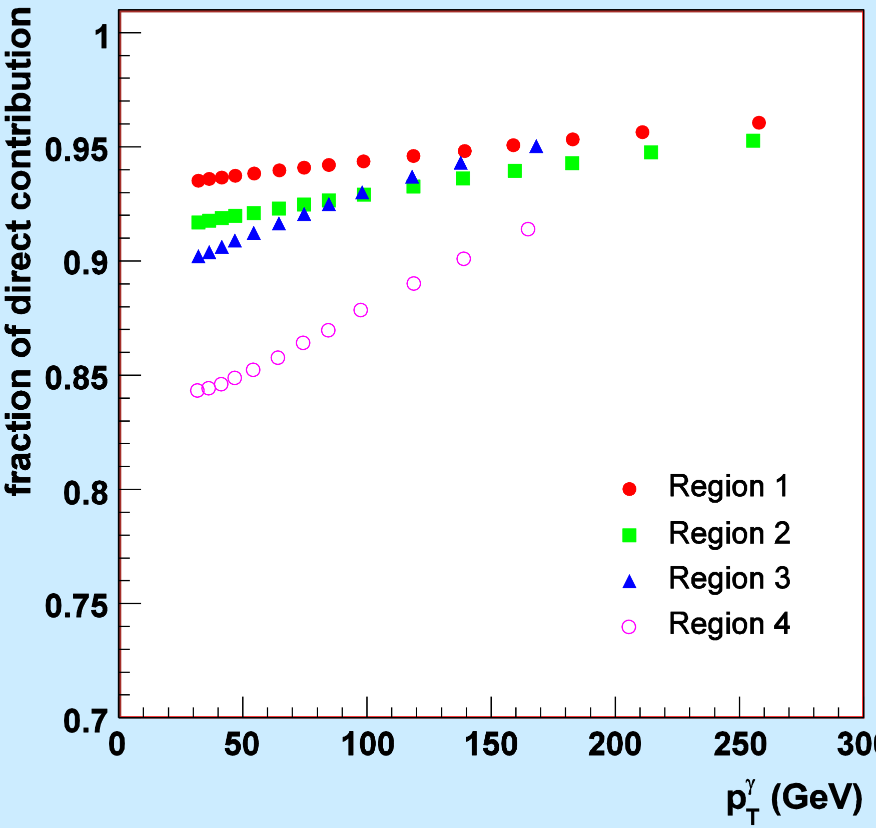
Jet + Isolated Photon Triple Differential Cross Section

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 (γ+jet_direct) / (γ+jet_dir+fragment) where γ+jet_dir+fragment is estimated with JETPHOX

Jet + Isolated Photon Triple Differential Cross Section

General selection cuts:

1. Leading Jet: $|\eta^{Jet}| < 1.0$ or $1.5 < |\eta^{Jet}| < 2.5$; $p_T^{Jet} > 15\, GeV$

2. Photon: $|\eta^{\gamma}| < 1.0$; $30 < p_T^{\gamma} < 300\, GeV$

3. *γ - Jet* separation in ***η-φ*:**

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

4. $|z_{vtx}| < 50\,\mathrm{cm}$; vertex includes at least 3 charged tracks

5. $E_T^{miss} < 12.5\,\mathrm{GeV} + 0.36\, p_T^{\gamma}$ (cracks, $\eta_{\mathrm{det}}^{\max} = 5$, cosmics and W's)

6. Events are required to pass one of the unprescaled EM-trigger

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. **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

3. EM fiducial cuts (internal calorimeter structure + cracks) ⇒

total geometrical acceptance A=0.80 – 0.83

4. EM fraction in calorimeter: *EMFr > 0.96* (deposited E)
5. Probability of charged track matching ≤ *0.001*

Photon candidate selection cuts:

6. $Iso(\Delta R = 02) = \dfrac{E(R \le 0.4) - E(R \le 0.2)}{E(R \le 0.2)} \le 0.07$

7. Limit on the width of energy cluster in the finely-segmented EM3 layer (cells with 0.05 x 0.05 size)

⇨ 3 additional variables (used in D0 MC/data Z→ee analysis)

1) number of cells in EM1 (with $E_T^{cell} > 0.4$)

2) fraction of E deposited in EM1 (with $E_T^{cell} > 0.4$)

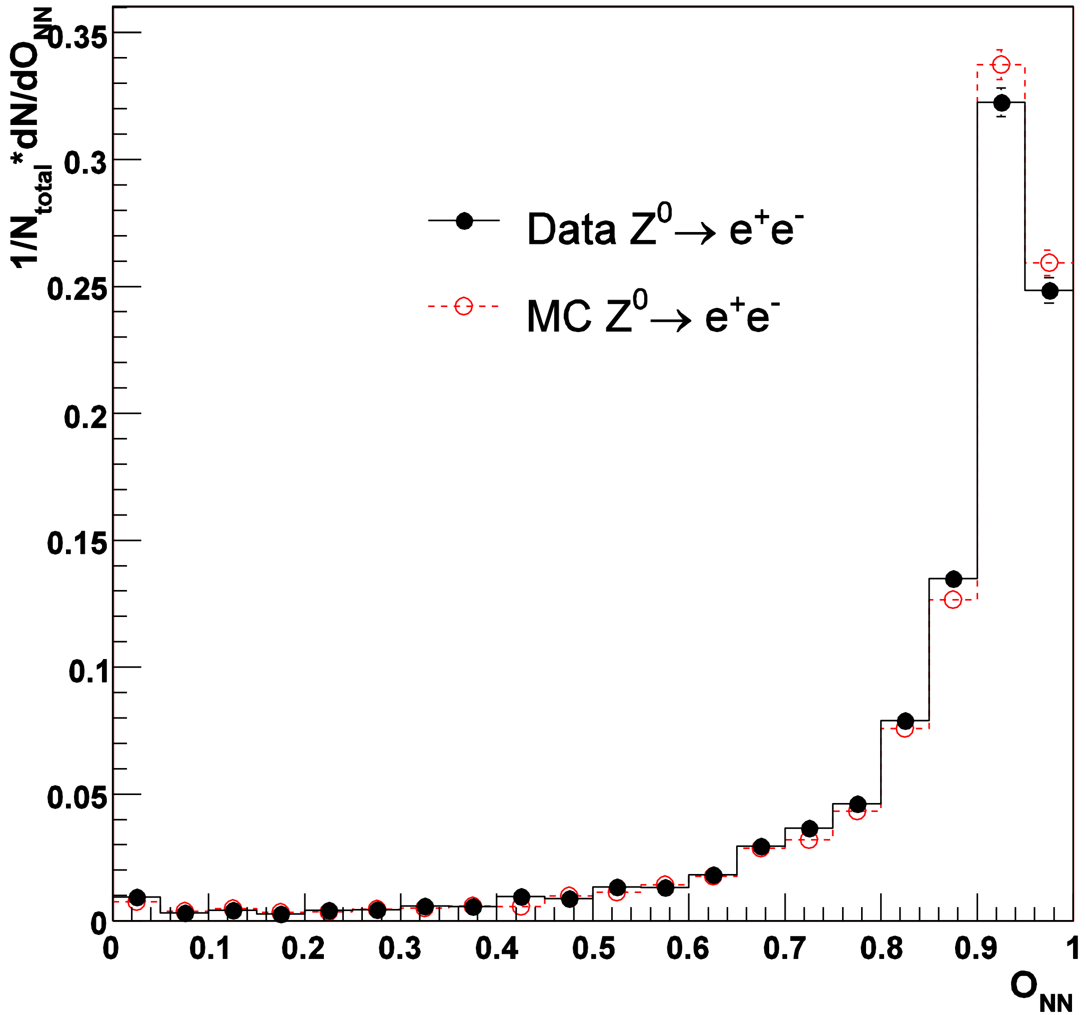
3) $\sum P_T^{track}$ in the ring ($0.05 \le R \le 0.4$) (with $p_T^{track} > 0.4$)

used as input for ANN (JETNET) ⇨

8. Additional cut (7) on the ANN output: $O_{NN} > 0.7$, is applied.

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.



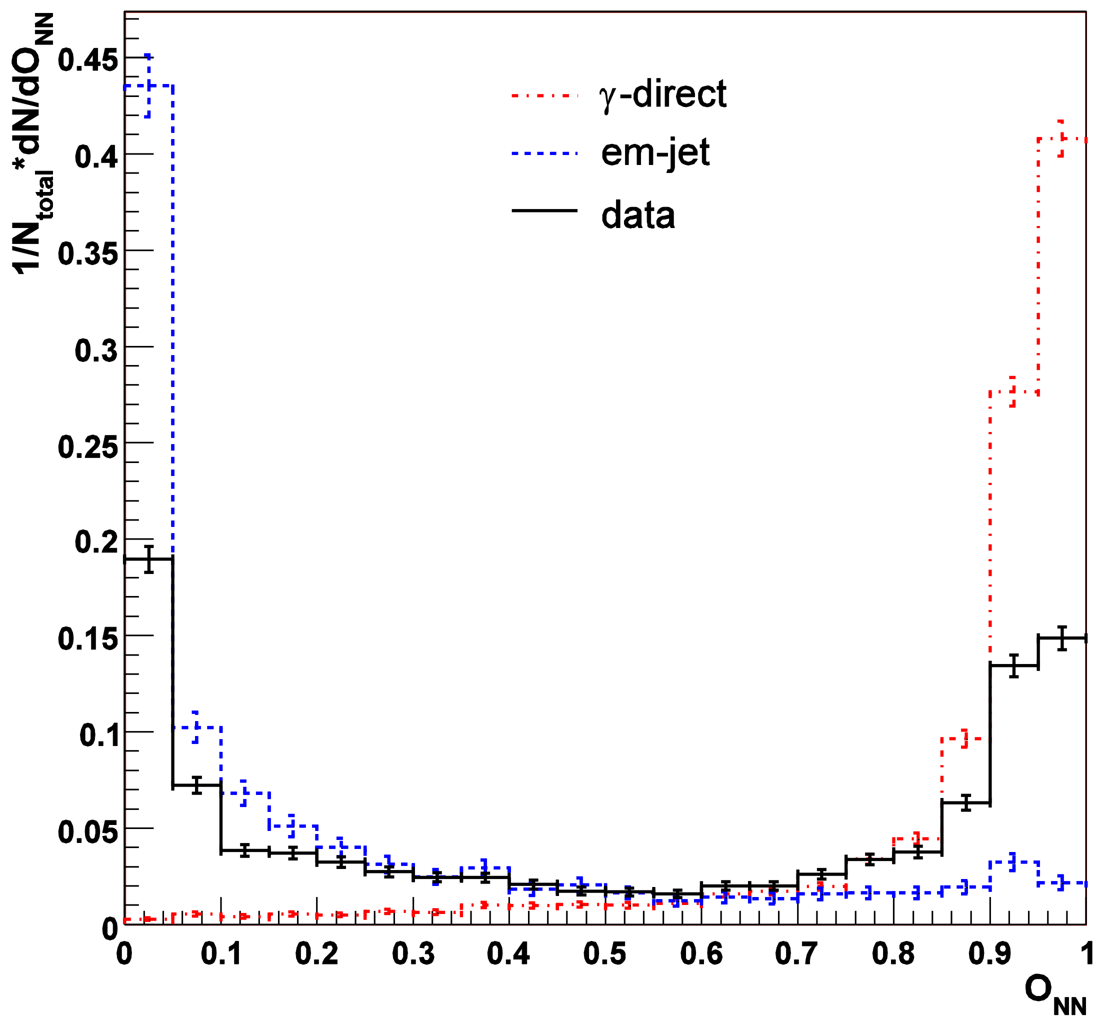
Jet + Isolated Photon Triple Differential Cross Section

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

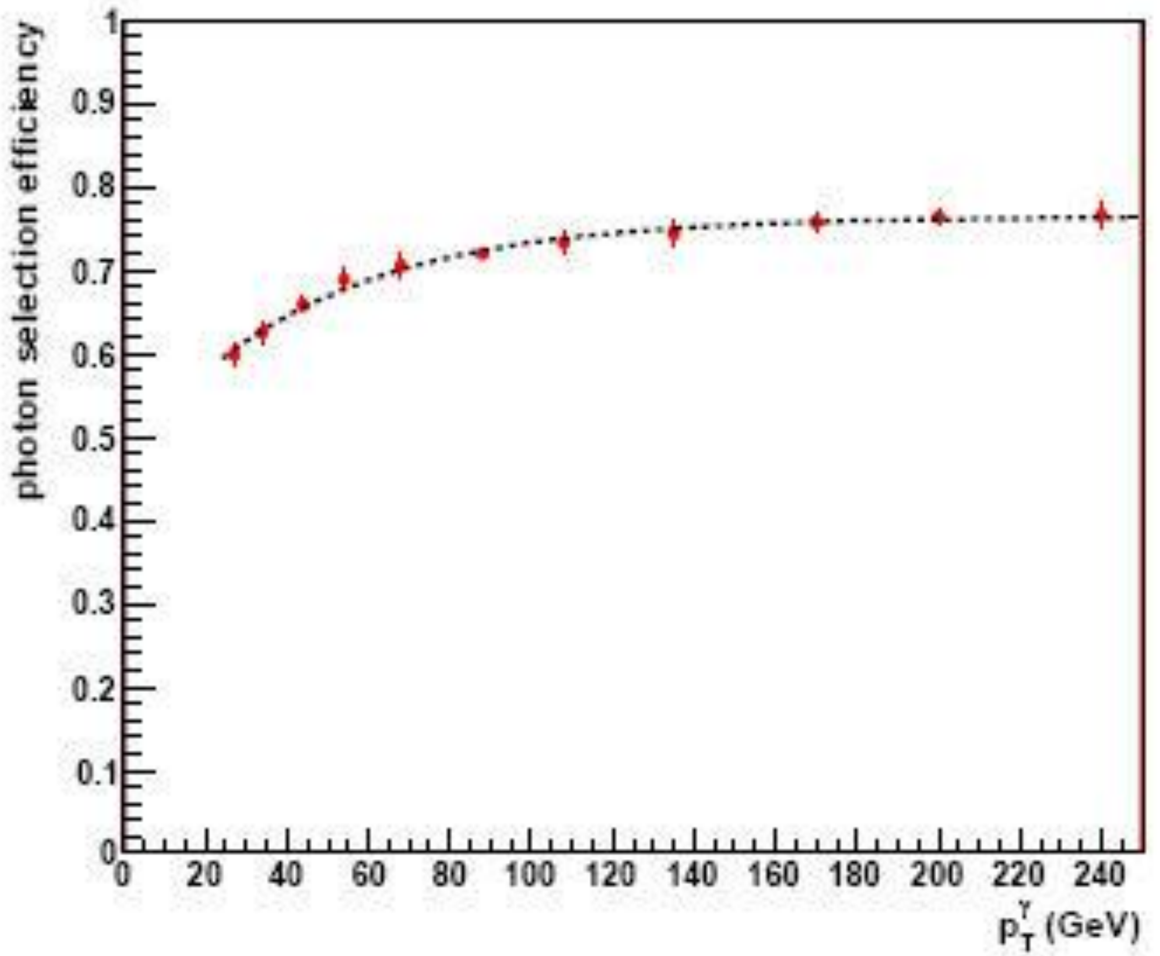
The plot shows the normalized distribution for data, MC "$\gamma + jet$" signal and QCD dijet "$jet + jet$" background events (one jet appears as EM-jet) for

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

after application of the main selection criteria.



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

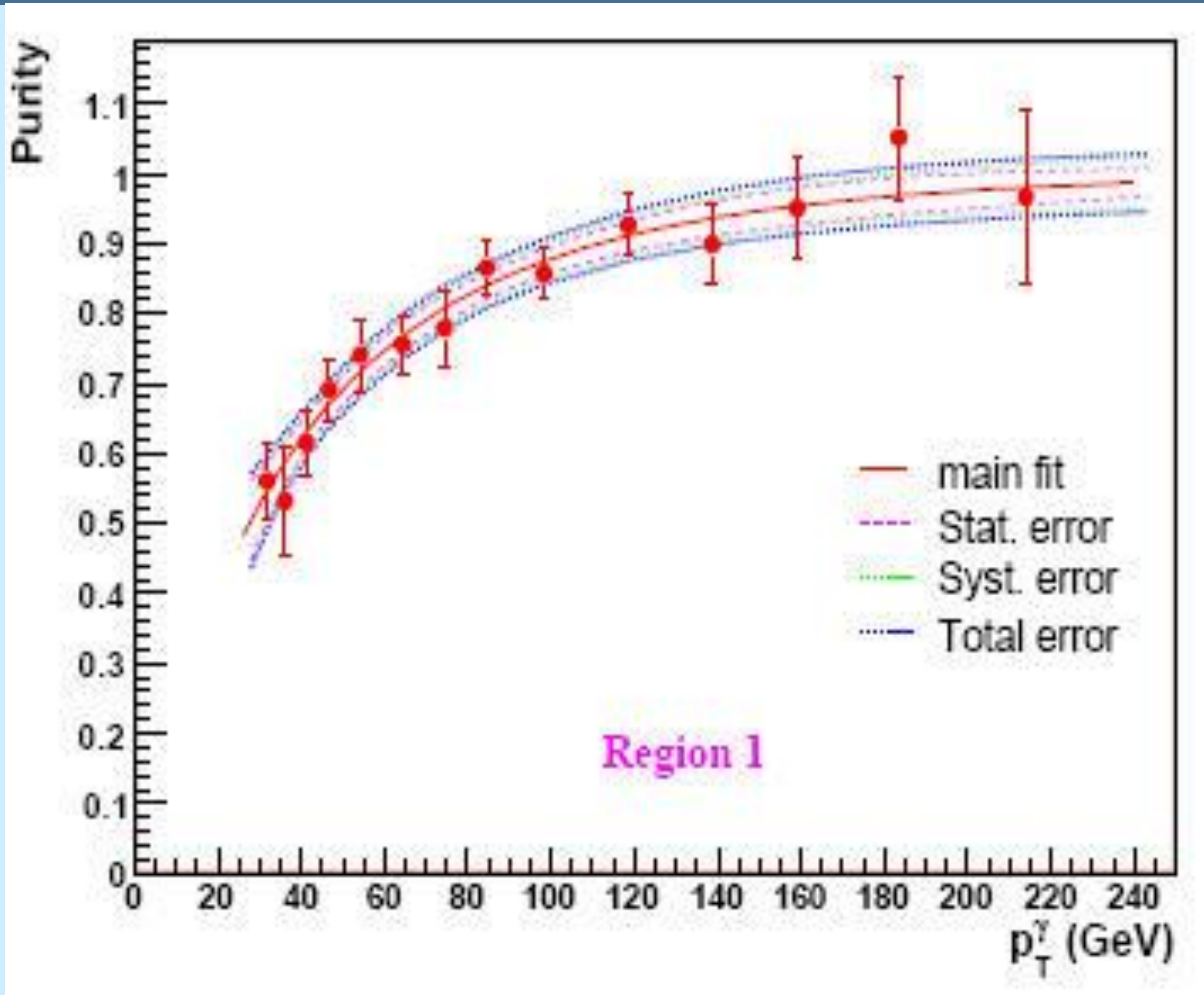
Dependence of the "γ + *jet*" events PURITY on p_T^γ In Region 1.

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).

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

N^γ - N of signal events

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



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 bin;
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

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

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

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

P – photon purity;

f_{unsm} – unsmearing correction factor;

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

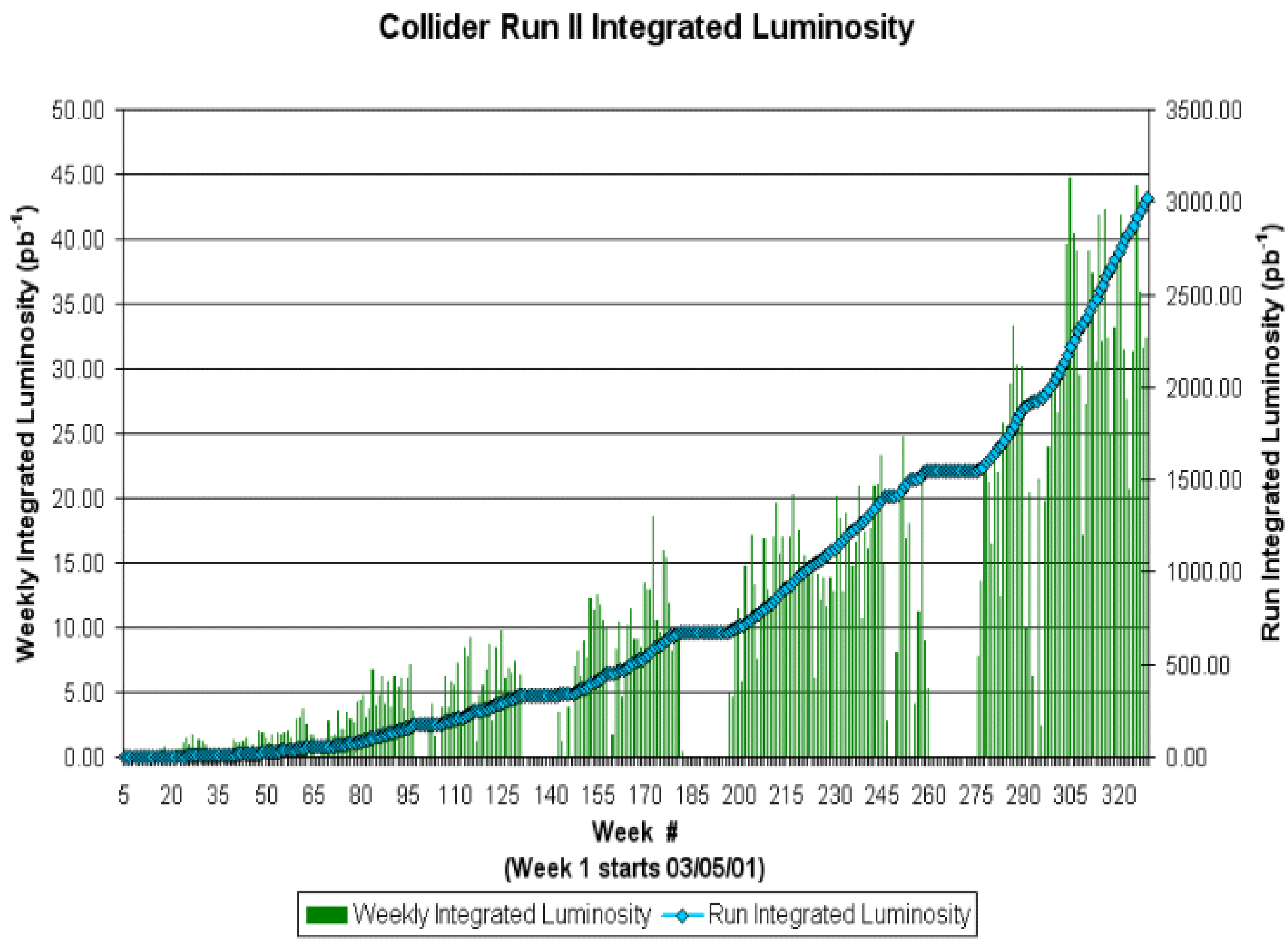
A – geometric acceptance: A = 0.80 – 0.83;

ε_t – trigger efficiency;

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).

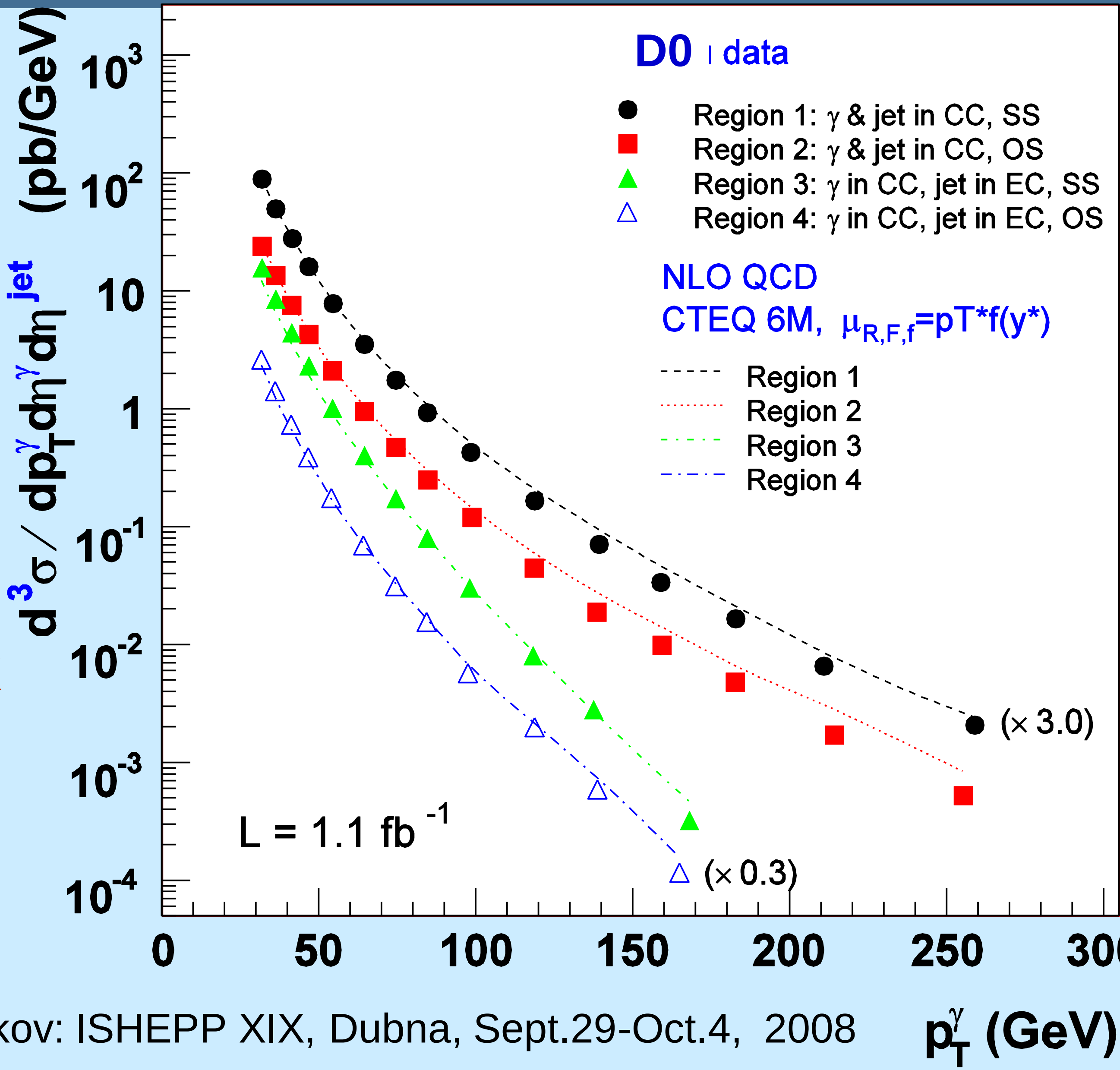
Jet + Isolated Photon Triple Differential Cross Section

"$\gamma + jet$" 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.

Total errors are:

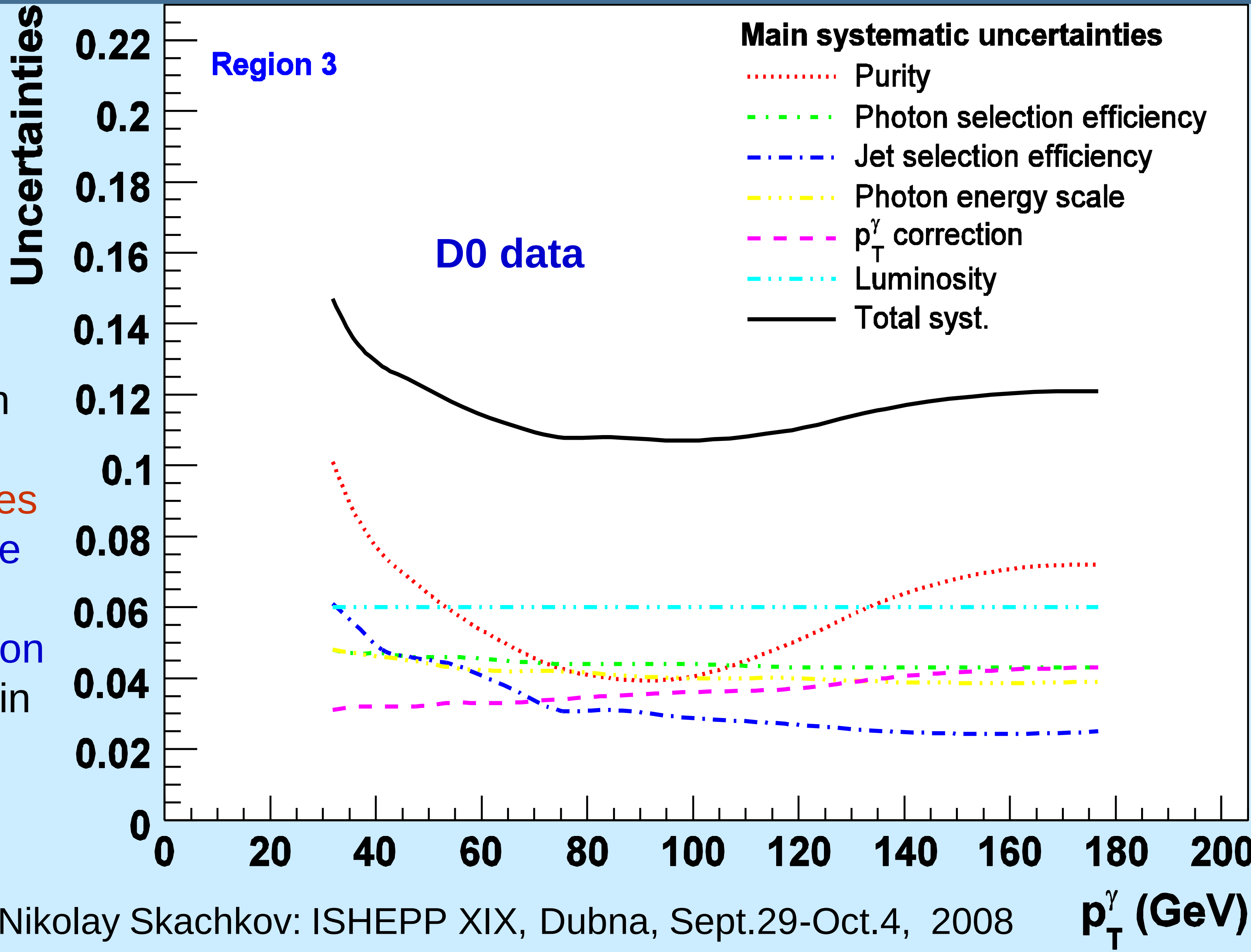
- about 13.8% - 18.5% in Regions 1 and 2;
- about 14.3% - 24.2% in Regions 3 and 4.

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

Jet + Isolated Photon Triple Differential Cross Section

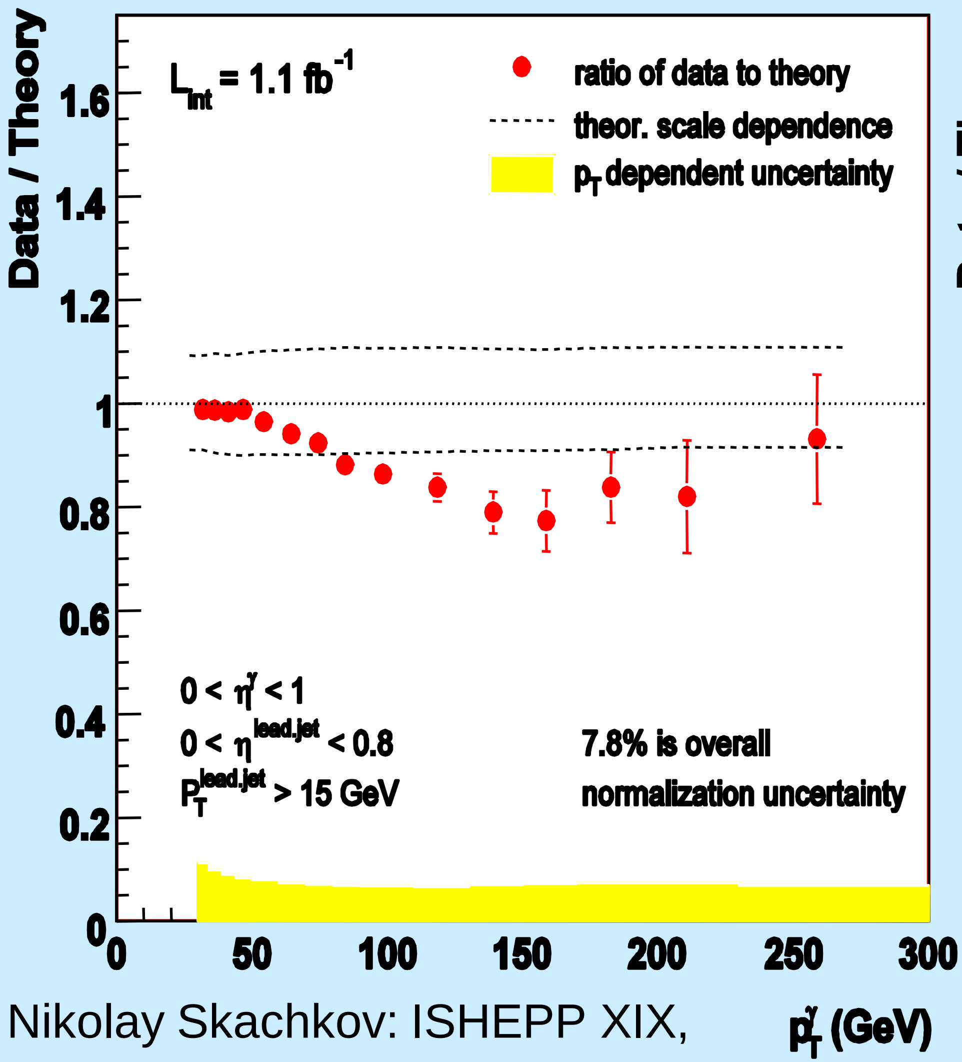
Region 3

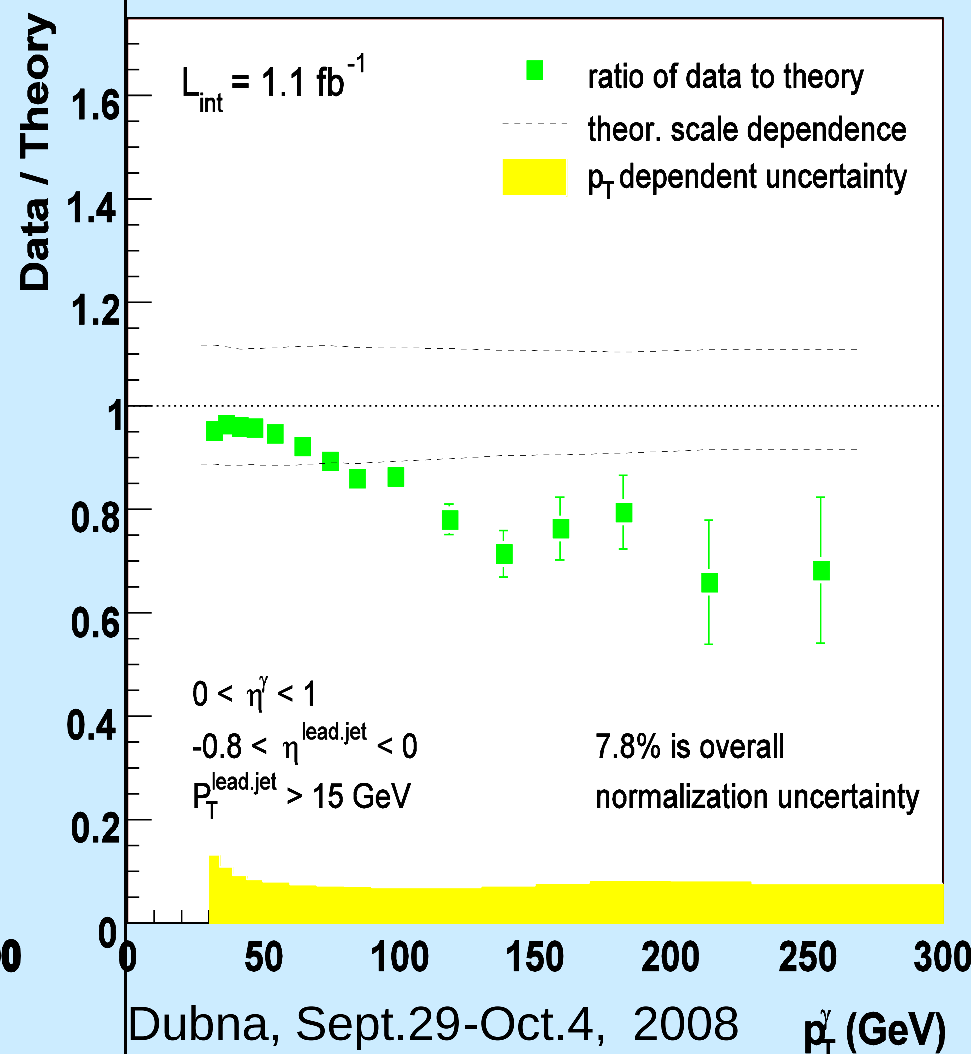
The main systematic uncertainties for the triple differential cross section measured in Region 3.



Jet + Isolated Photon Triple Differential Cross Section

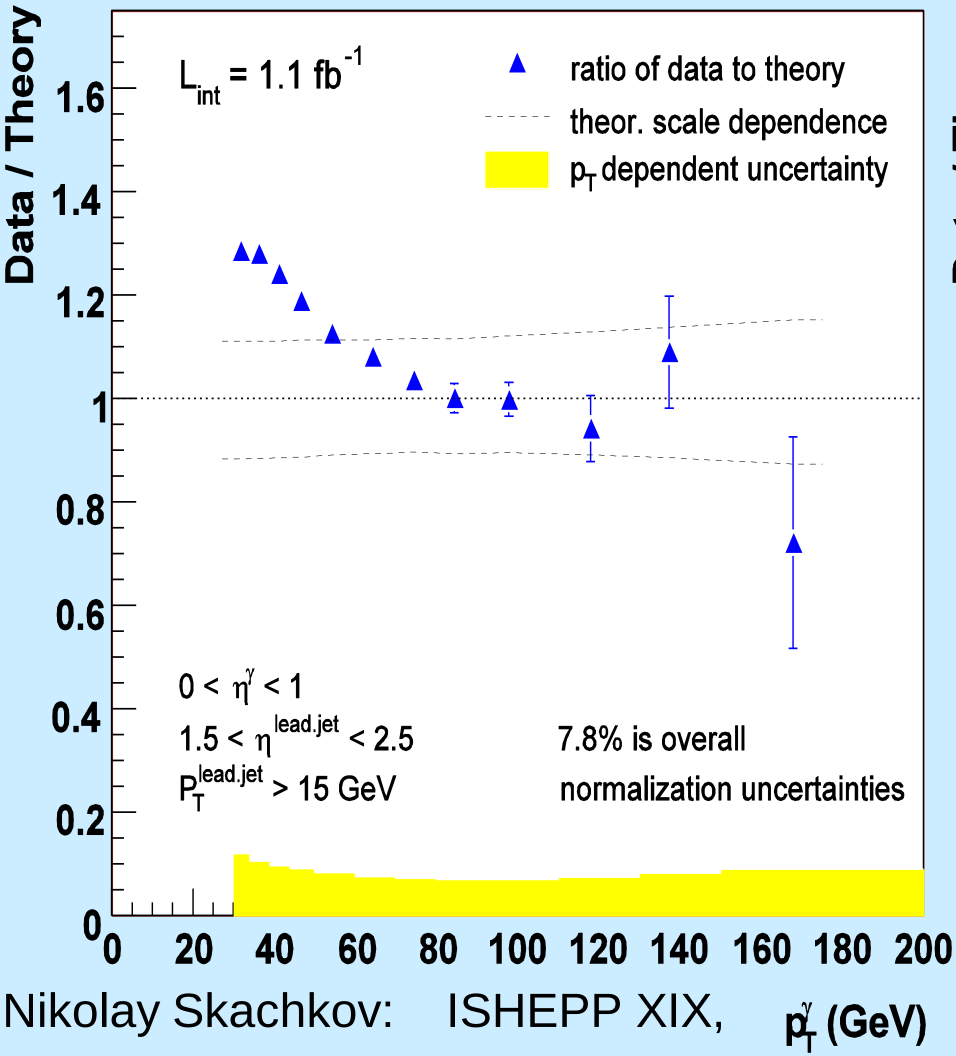
Theory to Data ratio for Reg.1 and Reg. 2

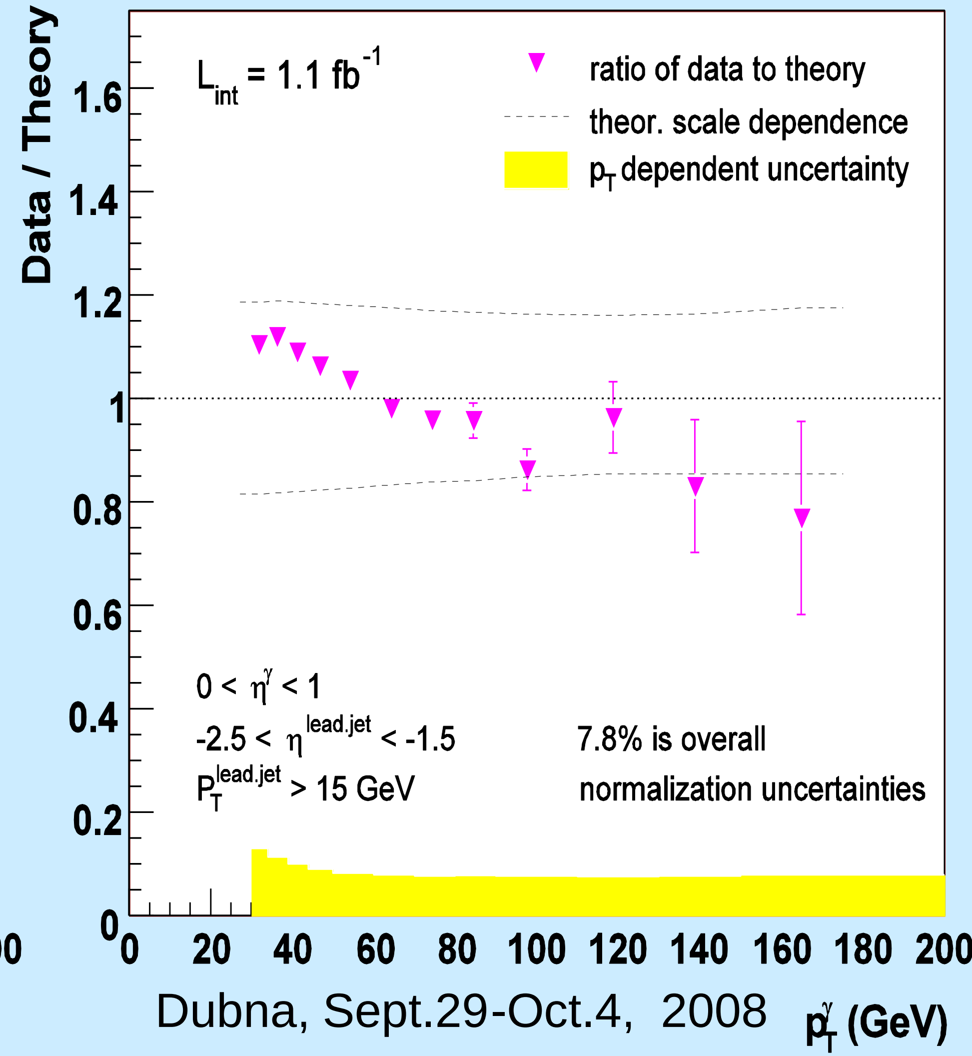




Jet + Isolated Photon Triple Differential Cross Section

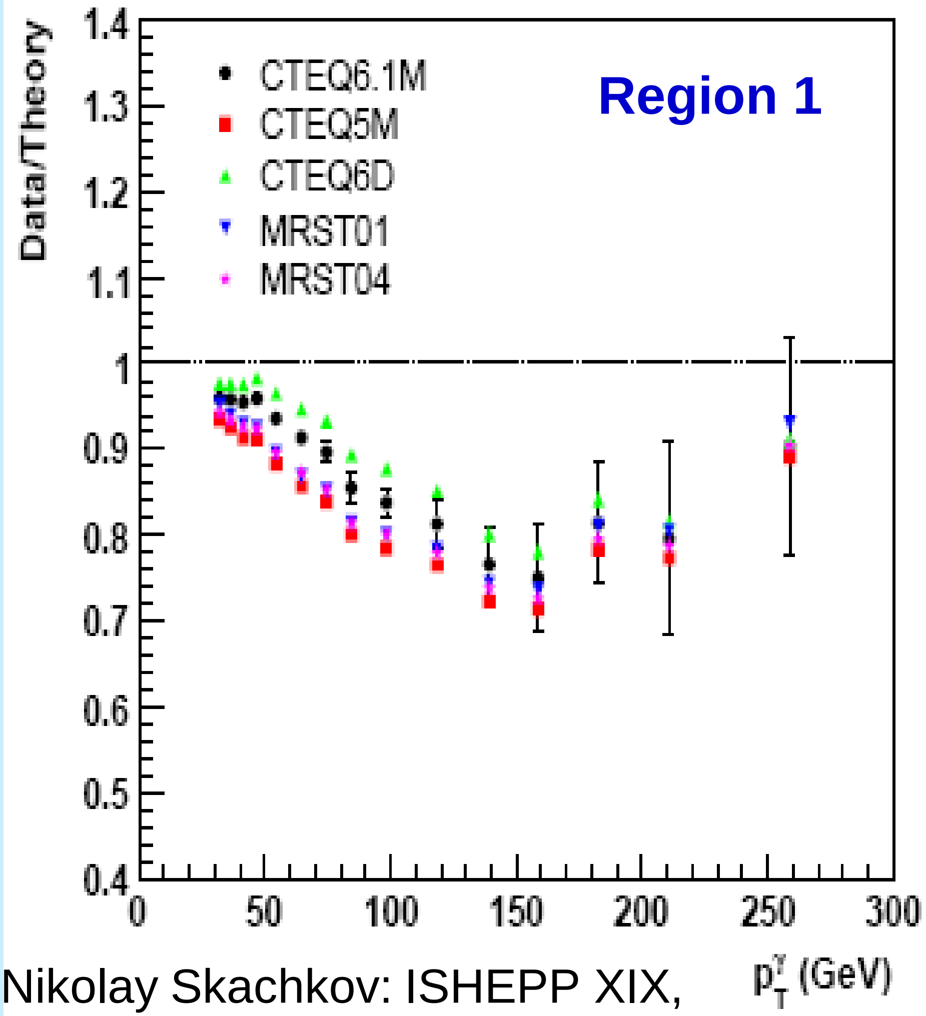
Theory to Data ratio for Reg.3 and Reg. 4

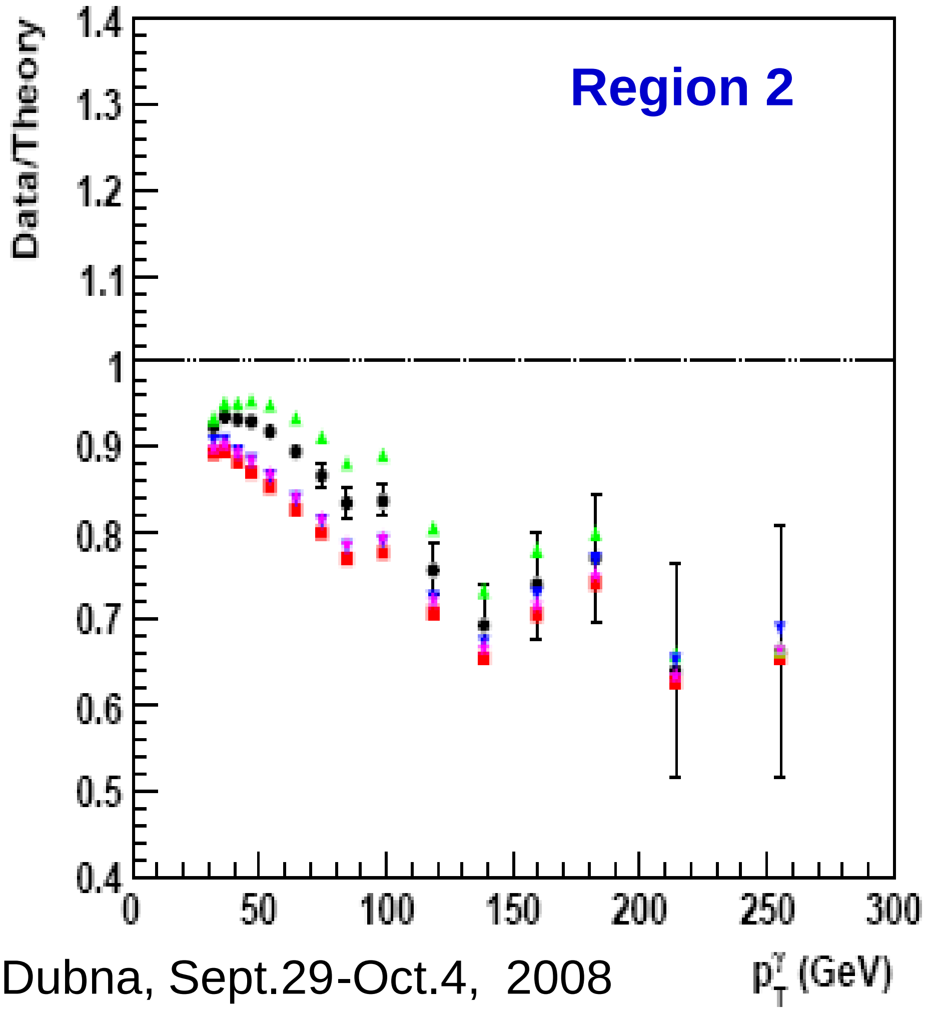




Jet + Isolated Photon Triple Differential Cross Section

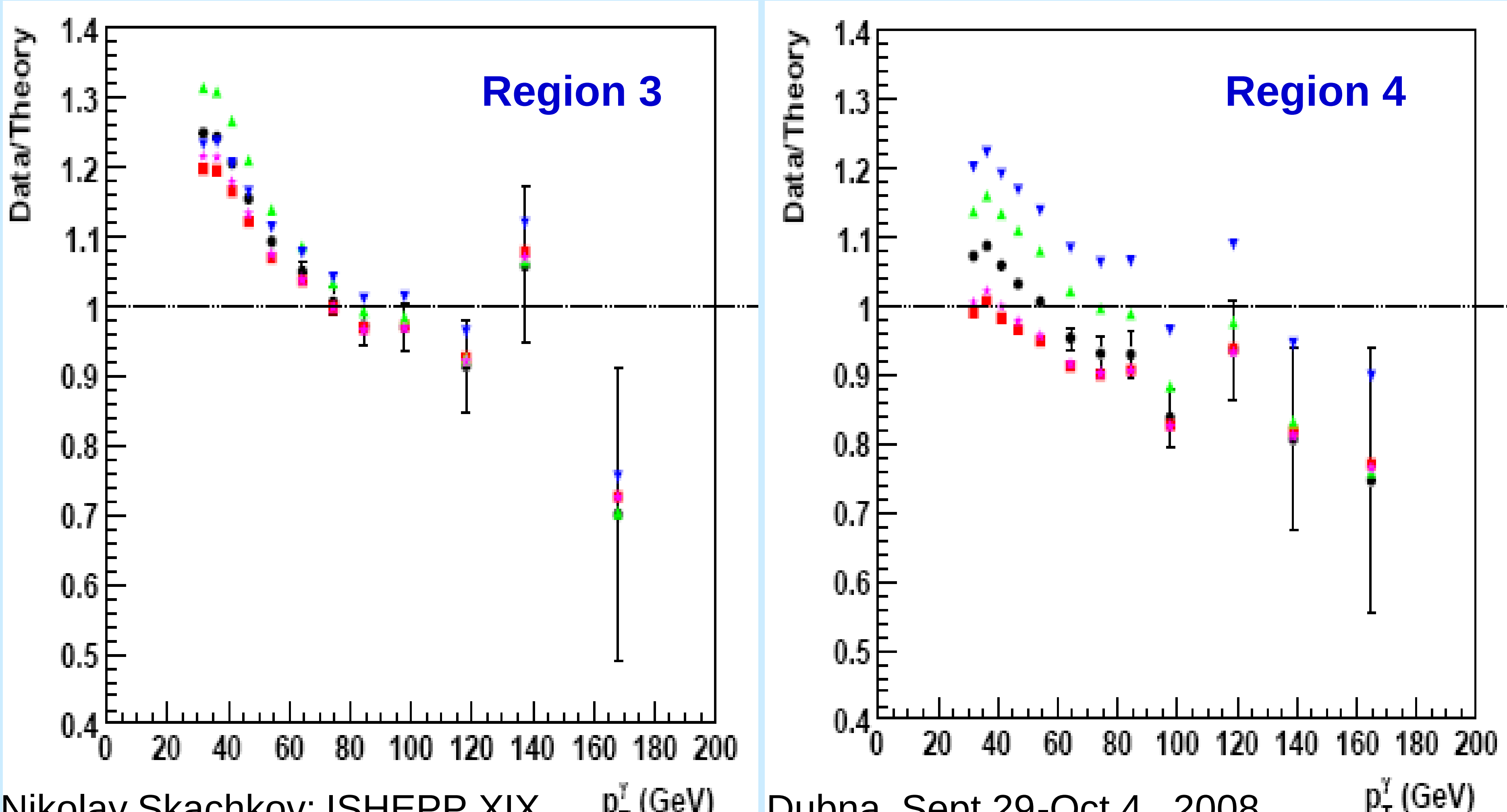
The ratio of the measured cross section in Regions 1 and 2 to the NLO QCD predictions done with various PDF. Statistical uncertainties are shown.





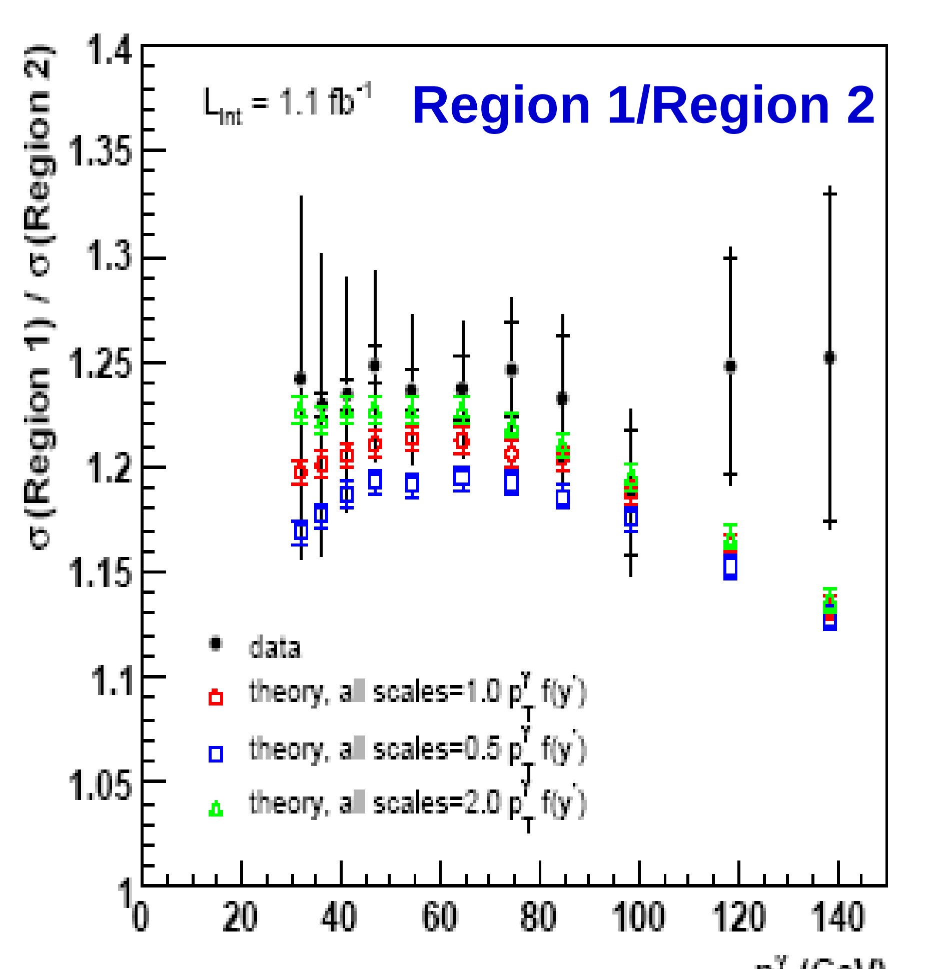
Jet + Isolated Photon Triple Differential Cross Section

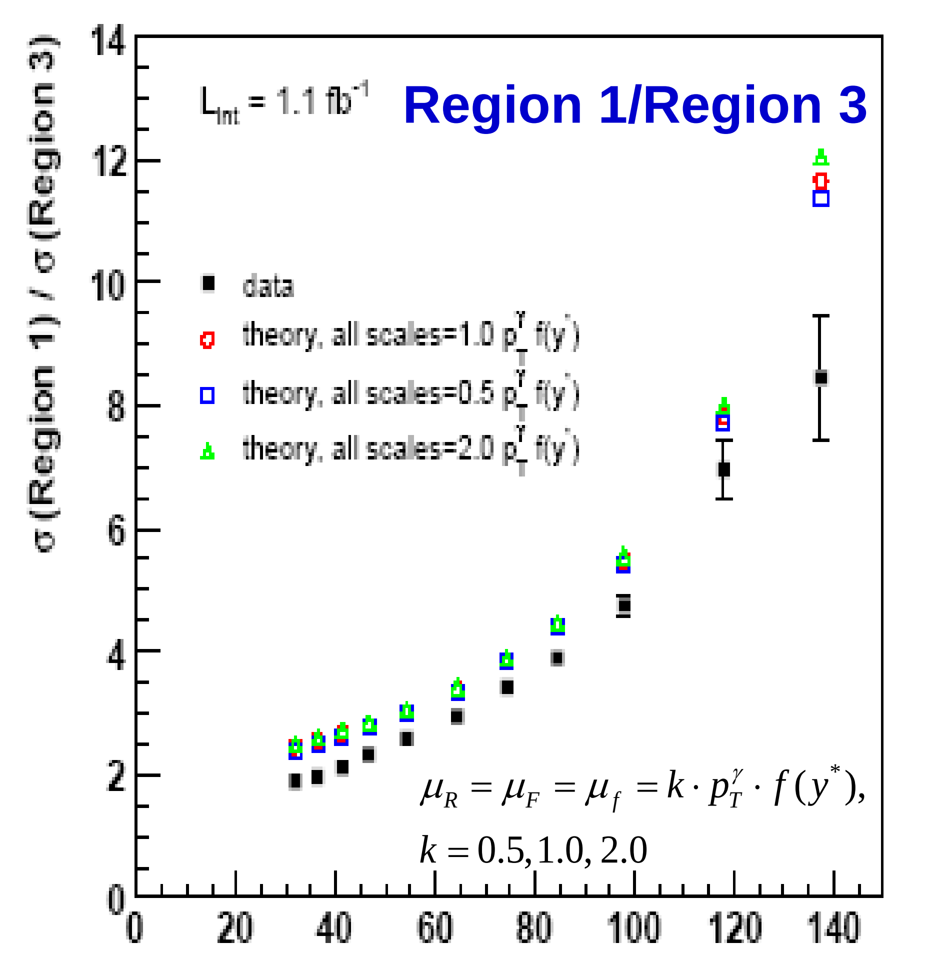
The ratio of the measured cross section in Regions 3 and 4 to the NLO QCD predictions done with various PDF. Statistical uncertainties are shown.



Jet + Isolated Photon Triple Differential Cross Section

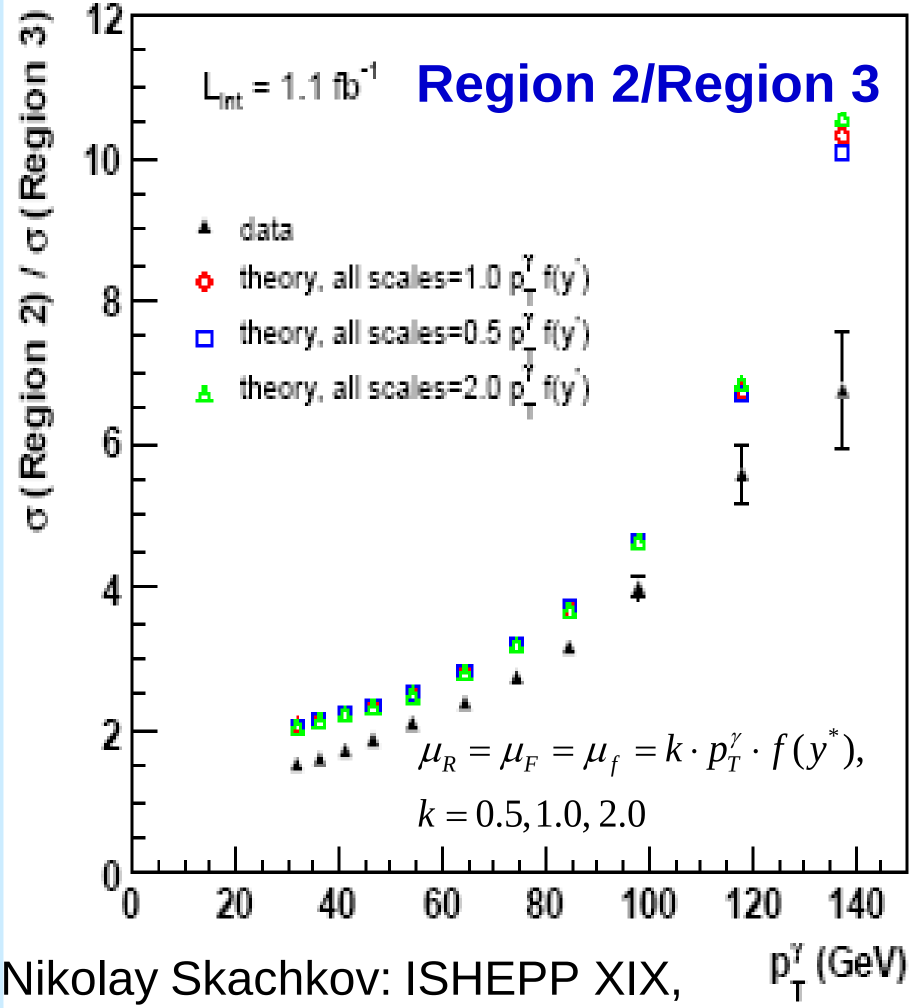
The ratio of the differential cross sections in Region 1 to Region 2 (left). Right plot is the ratio of cross sections in Region 1 to Region 3.

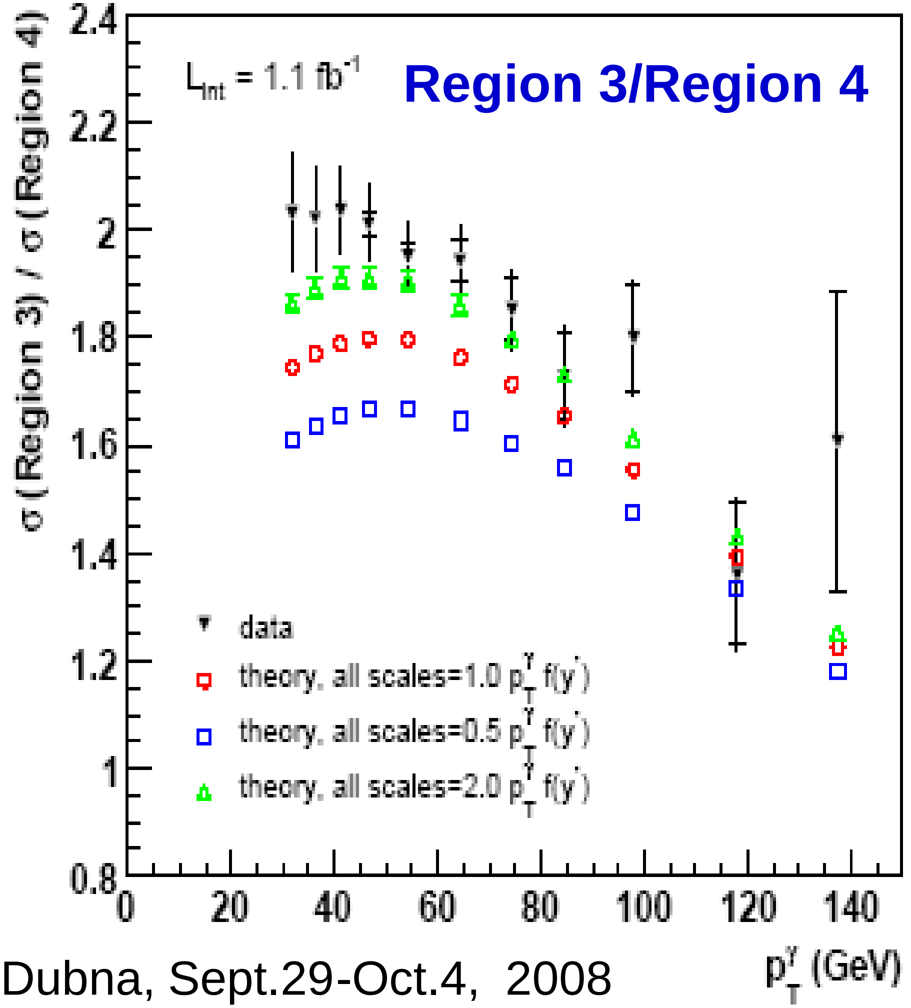




Jet + Isolated Photon Triple Differential Cross Section

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.





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. The 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.