Preliminary Results on Multiple Parton Interactions

from HERA and TEVATRON

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EPS-HEP, Krakow, 2009, 16-July-2009

Study of Multiple Interactions in photoproduction at HERA

H1prelim-08-036

The sample of quasi-real photoproduction (Q^2 ~0) events, having two dijets with PT_ jet > 5GeV, is analysed .

The two jets define in azumuth angle phi a ***Toward region*** *(Leading jet) and an* ***Away region*** *(2-nd jet) and two* ***Transverse regions*** *between them.*

The charged particle multiplicity is measured in these regions as the function of the ***x_gamma*** *and* ***PT_leading jet*** *.*

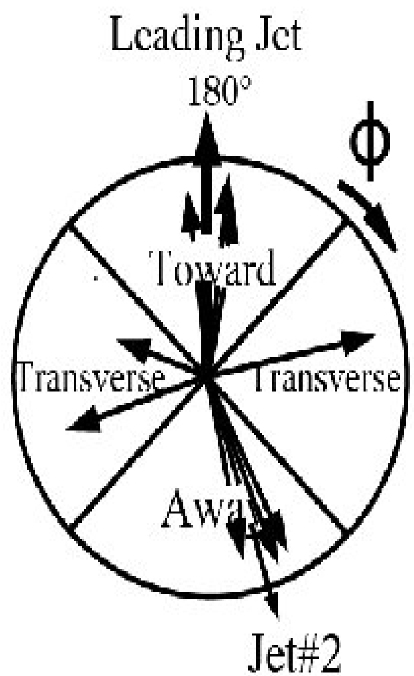


Figure 1: *Toward, away and transverse regions defined. In the toward region the leading jet is always at* $\phi = 180^o$ *and is the reference to define the other regions.*

Luminosity =48 pb^(-1) ; E_e = 26.7 GeV ; E_p = 920 GeV ; E_c.m. = 318 GeV .

Selection criteria:

1. *Signal in the electron tagger (it has acceptance in the inelasticity range 0.3 < y < 0.65, which results in Q^2 < 0.01GeV);*
2. *Reconstructed primary vertex position (z-vert) within 35cm of the nominal one.*

Jets are selected with the inclusive k_t-jet algorithm using as input combined objects, i.e. four-vectors objects, where information from track and/or cluster is combined. At least two jets are required with $P_T^{jet} > 5$ GeV within a pseudorapidity range in the laboratory frame of $-1.5 < \eta_{lab} < 1.5$. The jet with the highest P_T^{jet} defines the leading jet, Jet_1. From the jets the value x_γ is calculated:

$$x_\gamma = \frac{\sum_{h \in Jet_1}(E - P_z) + \sum_{h \in Jet_2}(E - P_z)}{\sum_h (E - P_z)} \quad (1)$$

Tracks are selected having a $P_T^{track} > 150$ MeV within $|\eta| < 1.5$. The difference in azimuthal angle $\Delta\phi = \phi_{Jet_1} - \phi_i$ with i running over all charged particles satisfying the above cuts, is calculated, with the leading jet set to $\phi = 180^o$.

Four different regions in azimuth with respect to the leading jet are defined, see Fig.1:

- the toward region (including the leading jet) with $120^o < \Delta\phi < 240^o$
- the away region with $300^o < \Delta\phi < 60^o$
- the transverse region with $60^o < \Delta\phi < 120^o$ and $240^o < \Delta\phi < 300^o$

In quasi-real photoproduction ($Q^2 \sim 0$) the photon has a point-like as well as a <u>hadronic</u> (i.e., <u>resolved</u> component).

Multi-parton interactions are expected within the PYTHIA model (6.2 and 6.4 versions) for $x_{gamma} < 1$!!!

But not for the point-like photons which have $x_{gamma} \sim 1$.

Multi-parton interactions take place when the density of partons in a collision

(resolved component of photon contribution !!!) is large enough that more

than one interaction happens within one collision.

The data are compared with PYTHIA predictions with multi-parton interactions switched on and off.

For the photoproduction case only a simple version of this model is available.
(The proton pdf was CTEQ6L and the photon pdf was SaS1D.)

All generated events are passed through the full simulation of the H1 apparatus and are <u>reconstructed using the same program chain as for the data.</u>

The average track multiplicity as a function of azimuth angle difference Dphi in two x_*gamma* regions

MI: Multiple Interactions
*are **switched on!***
in PYTHIA simulation

NMI--> No Multiple Inter.

Leading jet at phi ~180
Away jet --> at ~ 0, 360
3-rd jet: 240< phi <340

Clearly seen that in left, resolved photon case, switching on MI

*!! **improves** !!*

the description of data

resolved photon enriched region (x_gamma < 0.7)

point-like photon enriched region (x_gamma>0.7)

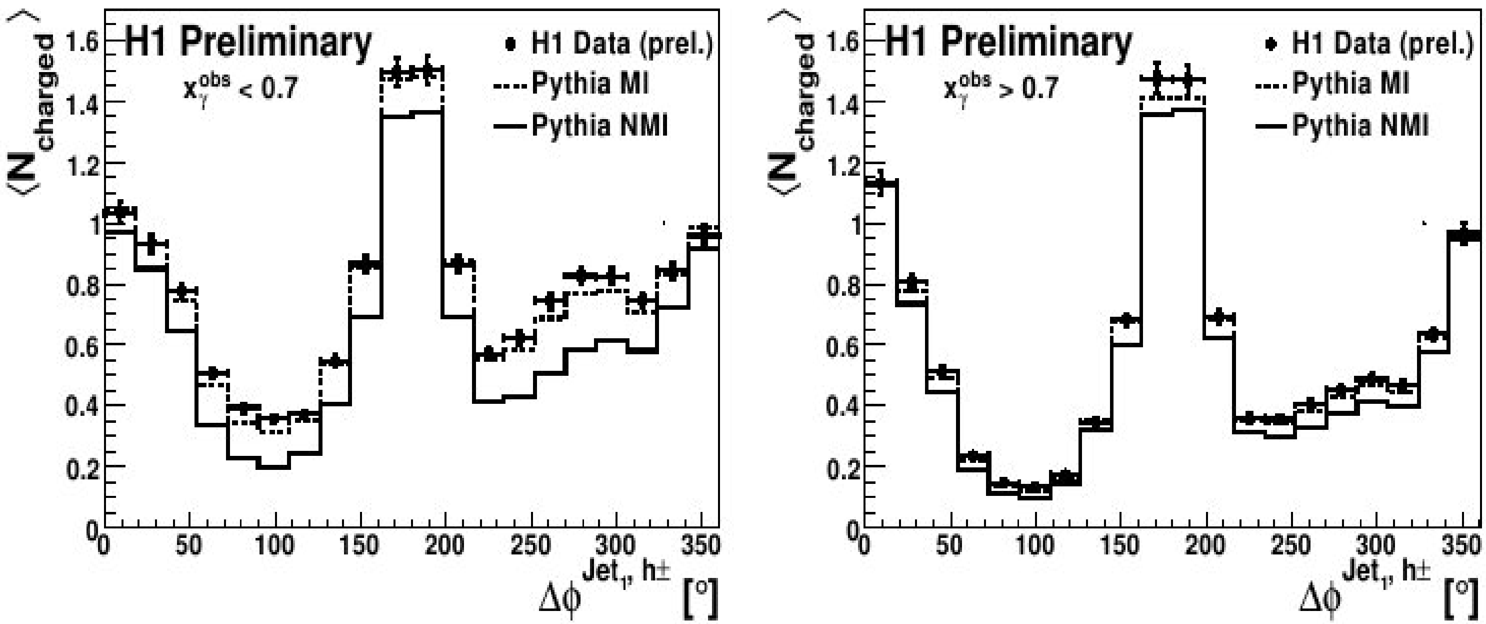


Figure 2: Charged particle multiplicity for $x_\gamma < 0.7$ (left) and for $x_\gamma > 0.7$ (right). The leading jet axis is by definition at 180^o. Data is compared to PYTHIA with and without MPI.

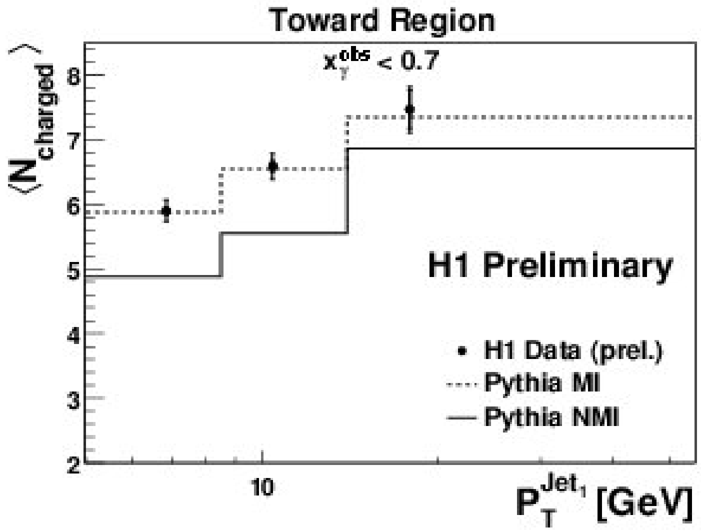
The dependence of average track multiplicity on PT^{Jet{1}} in Toward and Away regions

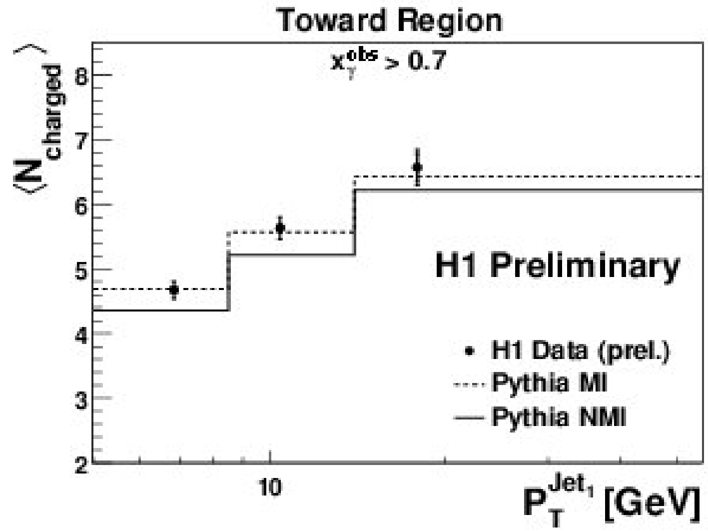
resolved photon enriched region (x_gamma < 0.7)

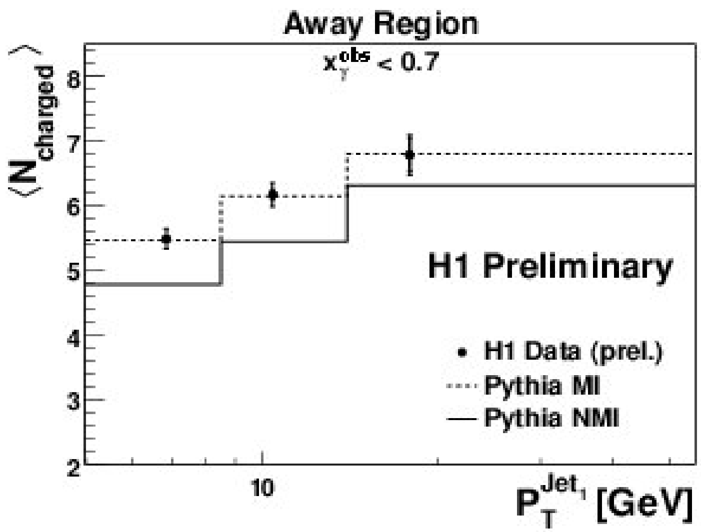
point-like photon enriched region (x_gamma > 0.7)

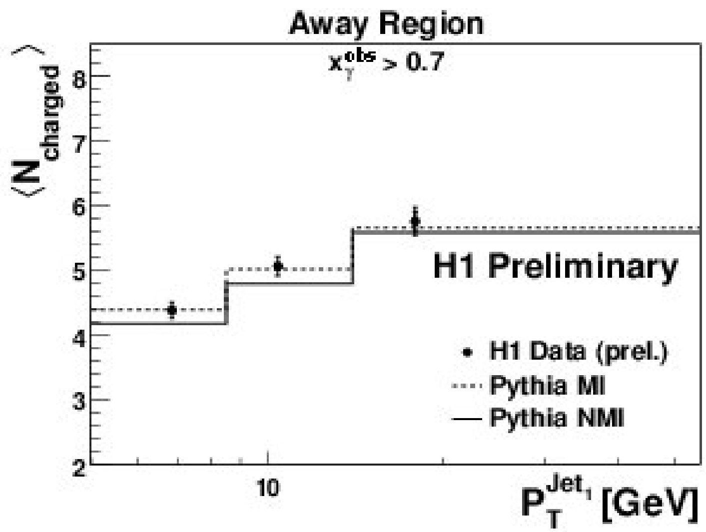
The average track multiplicity rises with increasing PT^ (Jet_1) of the leading jet from ~ 4-5 particles at PT^ (Jet_1) ~5GeV to~ 6-7 particles at PT^ (Jet_1) > 15GeV also depending on x_gamma.

It is clearly seen that in the resolved photon case (left, x_gamma < 0.7)) in both Toward and Award regions inclusion of MI leads to a better agreement of data and theory predictions.









The dependence of average track multiplicity on PT^{Jet_{1 }} in the Transverse regions

resolved photon enriched region (x_gamma < 0.7) | point-like photon enriched region (x_gamma>0.7)

Scalar sums of transverse momenta are calculated in both transverse regiones mentioned at slide #2:

ET sum *=*

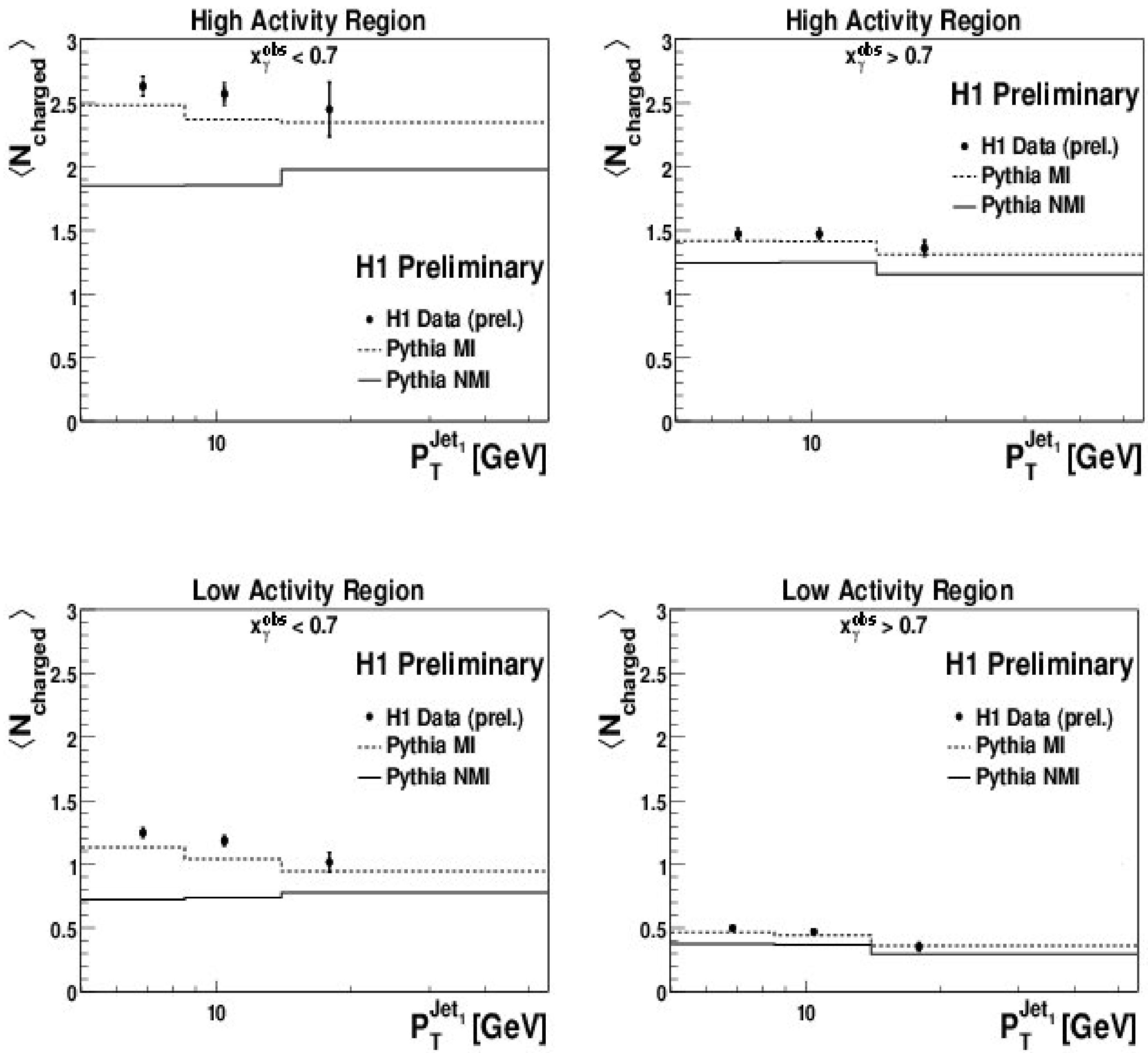
*= **Sum{i}** PT^_{track_**i**)*

*The region with the **higher ET sum** is defined as the*

high activity region.

<u><N_charged> is small and it</u> drops with PT^{Jet_{1}} growth.

Point-like photon enriched region (right) x-gamma >0.7 is resonably ***well described*** *by* ***NMI*** *case.*

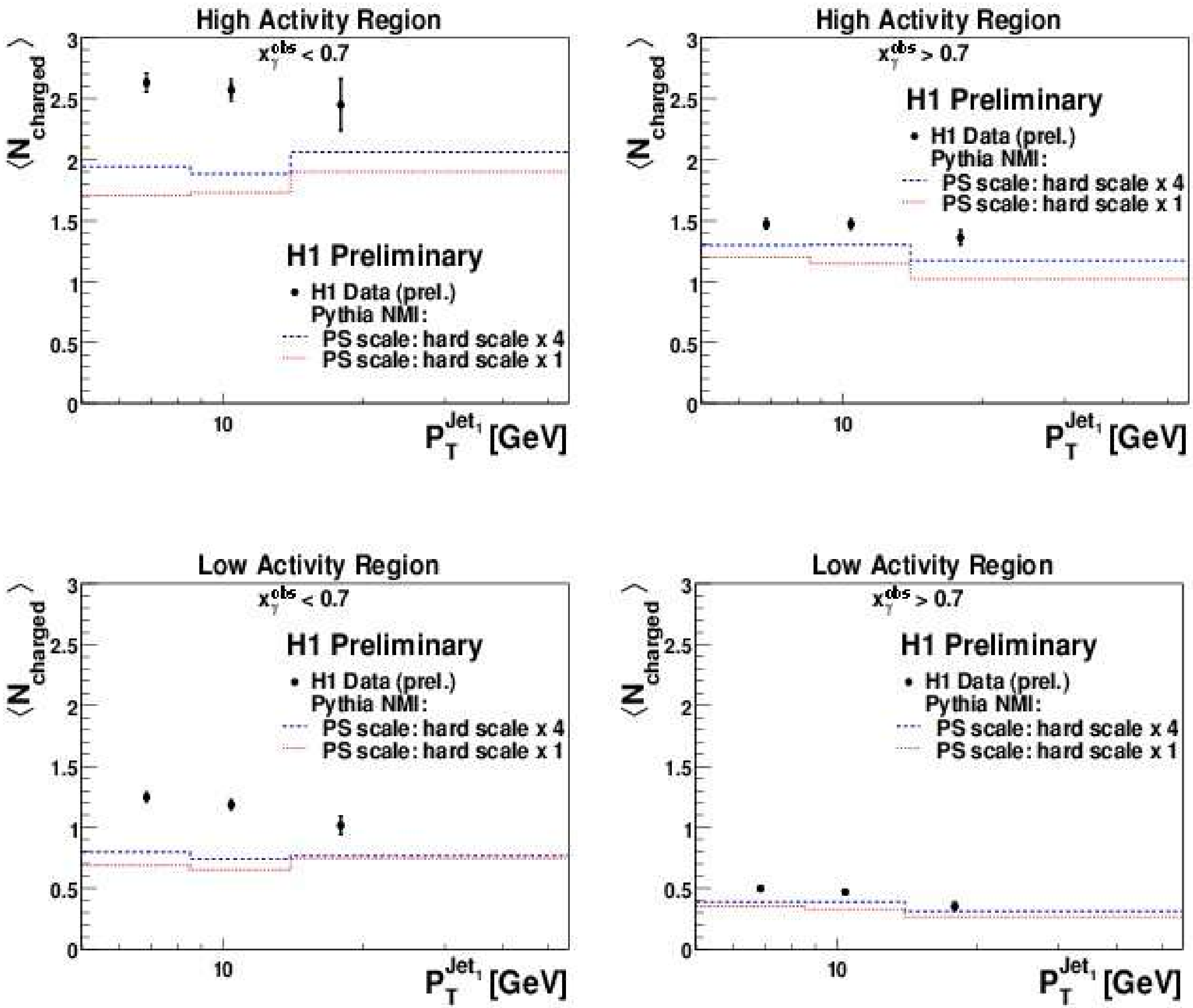


Study of higher order QCD radiation influence on $PT^{Jet_{1}}$ spectrum in Transverse regions

resolved photon enriched region (x_{gamma} < 0.7) | point-like photon enriched region (x_{gamma}>0.7)

Different choice of the upper scale for the initial and final state parton shower simulation with PYTHIA was done to get as a very approximate ***estimation of the impact of higher order QCD radiation*** *on $PT^{Jet_{1}}$ spectrum in the Transverse region for the* ***NMI*** *case (i.e. Multiple Interactions of partons were not switched while a simulation).*

No sizable changes were found *in both High and Low activity Transverse regions for resolved and poiint-like photon enriched regions.*



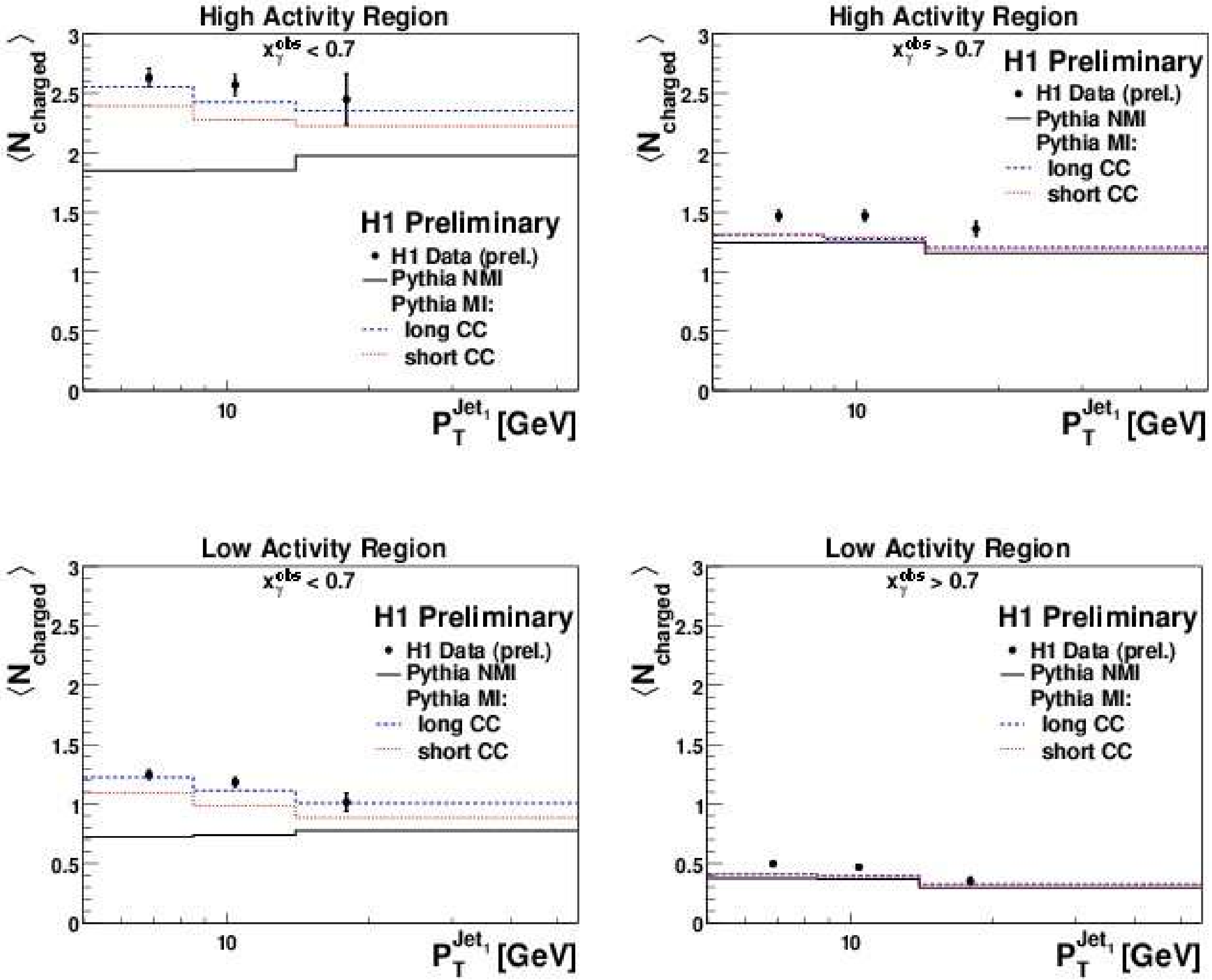
Study of color structure of the final effect on PT^{Jet_{1}} spectrum in Transverse regions

resolved photon enriched region (x_gamma < 0.7)

point-like photon enriched region (x_gamma>0.7)

Since the particle multiplicity is sensitive to the color structure of the final state, the effect of choosing short or long string configuration was also studied in the Transverse region.

The results of PYTHIA simulation with inclusion of Multiple Interaction show that the use of long string configuration can lead to a better agreement with data.



Summary

1. *The averaged charged particle multiplicity in quasi-real photoproduction of dijet events has been measured. Its spectra were used to find out the effects which may be caused by Multiple Interaction of partons which appear as a part of hadronic component in "resolved photons".*

2. *The analysis has shown that inclusion of effects predicted by PYTHIA models of Multiple Parton Interaction allows one to reach a better agreement between data and theory.*

3. *To my mind the started work is very promising as it is differs from the traditional search for MPI in hadron-hadron collisions.*

Double Parton Scattering in γ+3 jet events

D0 note 5910 - CONF (2009)

Basing on previouse measurements of direct photons production at D0 in RunII:

1. Inclusive isolated photon production

D0 Collab., Phys. Lett. B 639, 151 (2006)

2. Inclusive photon+jet production

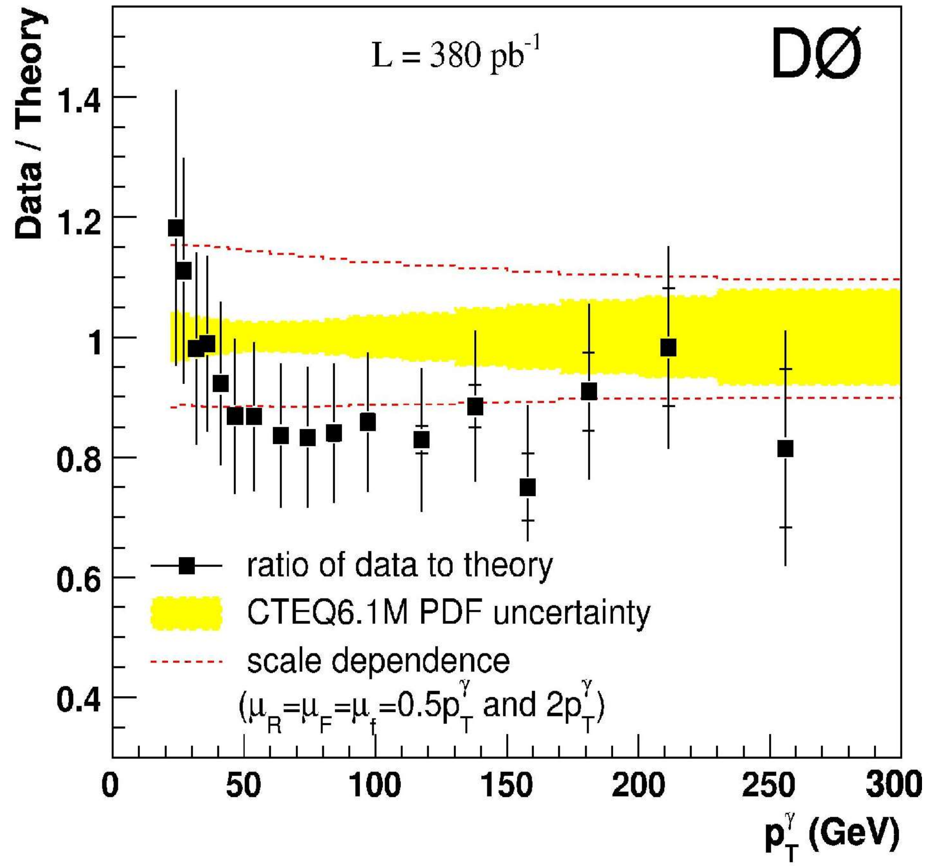
D0 Collab., Phys. Lett. B 666, 2435 (2008)

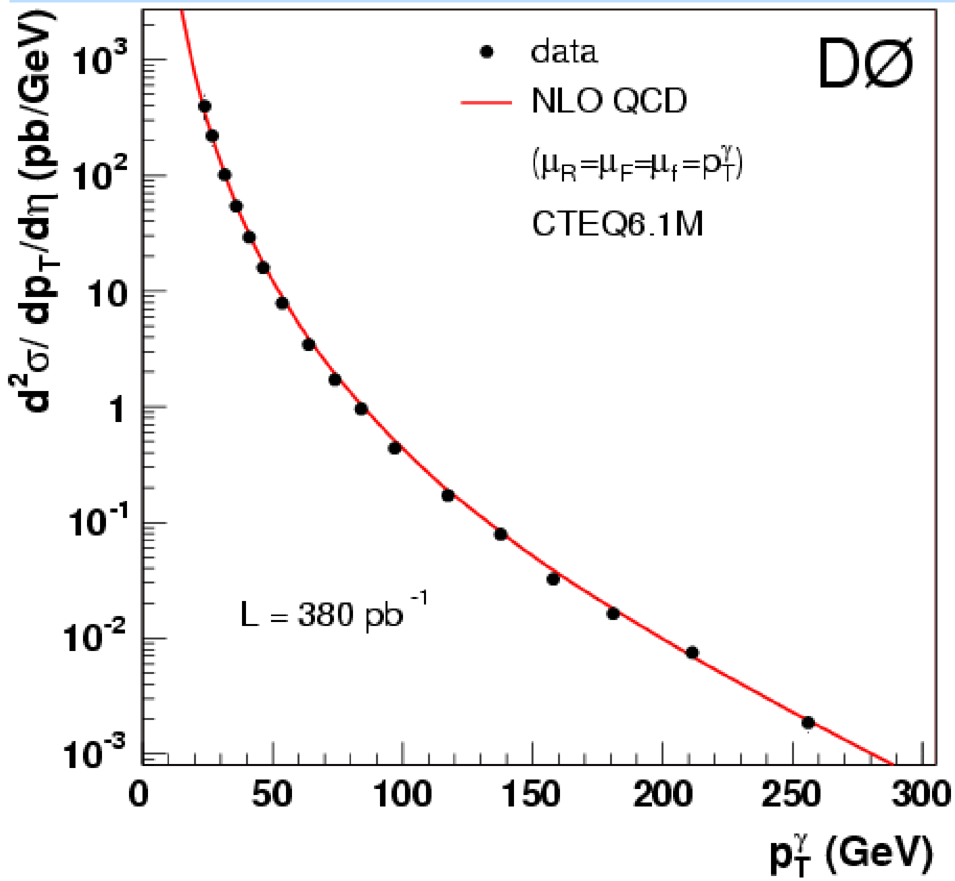
16-July-2009

Inclusive isolated photon production

D0 Collab., Phys. Lett. B 639, 151 (2006)

- Plotted: p_T^γ weighted bin centers
- Large range: 23 – 300 GeV
- QCD test at >5 orders of magnitude of cross section variation
- Compared to JetPhoX (NLO QCD)
- BFG photon fragmentation functions





Data-to-theory comparison

- Results are consistent with theory
- Variation/Shape similar to former observations (UA2, CDF)

⇒ suggests more detailed check

=>Recent CDF result (2009) agrees with D0 Data/Theory plot.

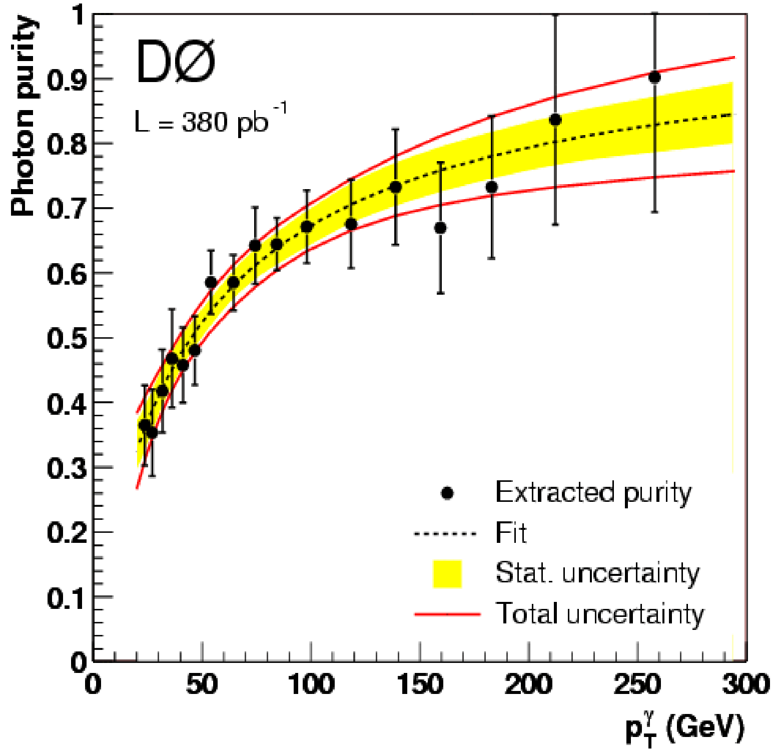
Inclusive isolated photon production

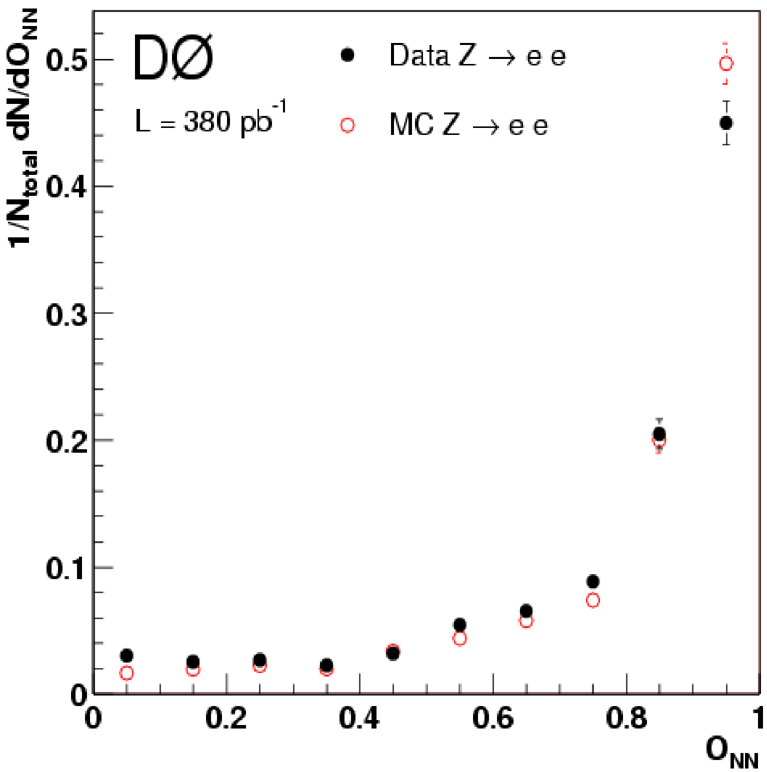
D0 Collab., Phys. Lett. B 639, 151 (2006)

L = 380 pb^{-1}

Main selection criteria:

- $p_T^\gamma > 23$ GeV and $|\eta| < 0.9$
- Isol < 0.10, EM frac > 0.95, $O_{NN} > 0.5$
- Missing Et < 0.7 p_T^γ (cosmics, $W \rightarrow e\nu$)





- Neural Net (NN) is trained to discriminate photons from EM jets
- EM shower shape + track pT sum is input to NN
- Tested on $Z \rightarrow ee$ in data/MC
- Photon purity obtained from fit of NN output for MC signal and EM jets to data

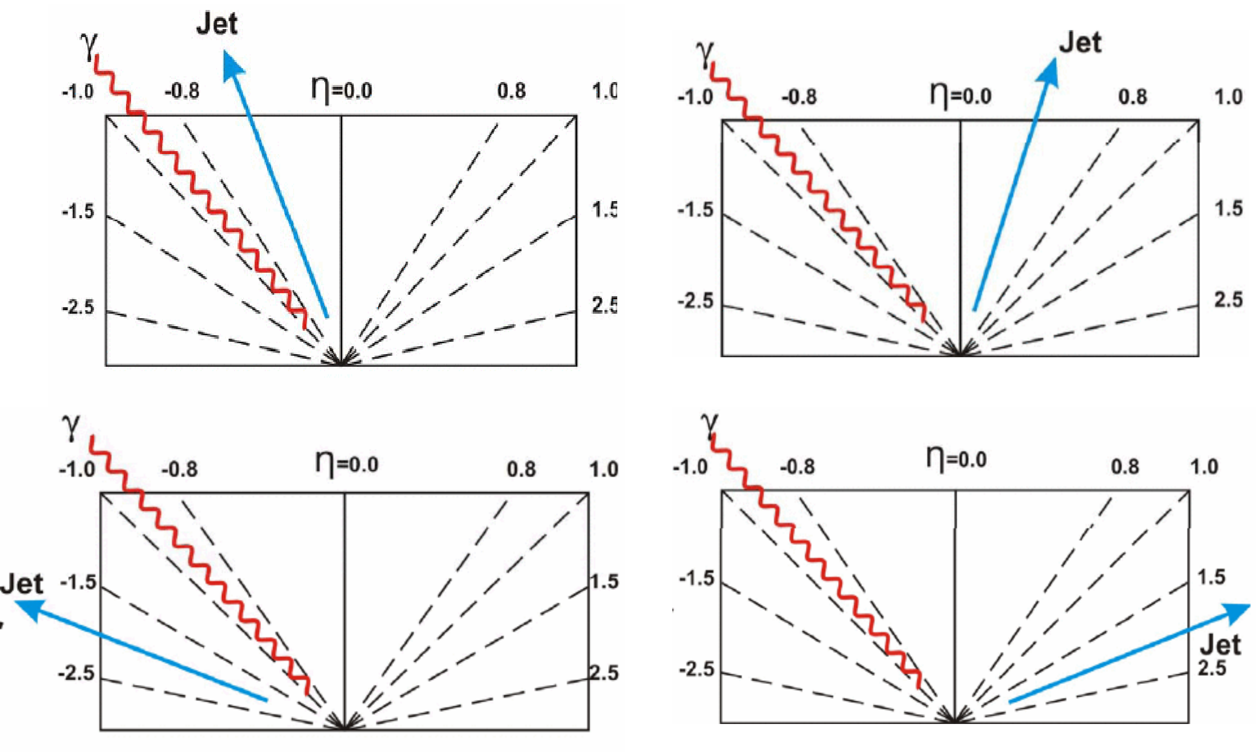
Inclusive photon+jet production

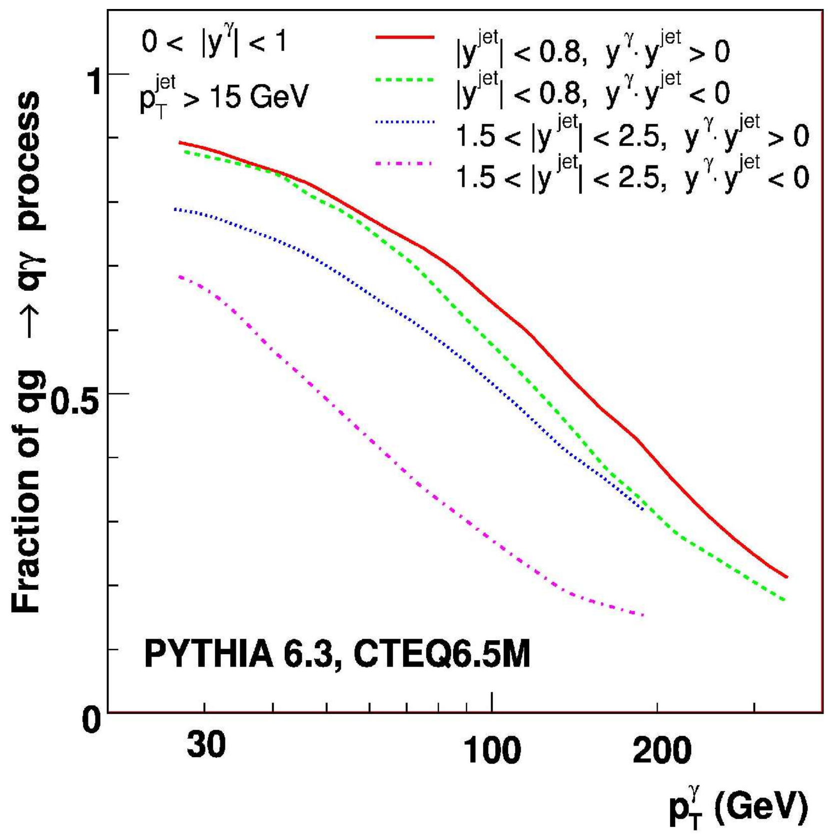
$$\frac{d^3\sigma}{dp_T^\gamma\, d\eta^\gamma\, d\eta^{jet}}$$

D0 Collab., Phys. Lett. B 666, 2435 (2008)

L = 1 fb^{-1}

- Tag photon and jet, ⇒ full control of the 2-body kinematics in the final state
- Measurement done in the four photon-jet rapidity regions
- Photons: 30 < p_T^γ < 400 GeV with $|\eta|$ < 1.0
- Jets (cone with R=0.7): pT > 15 GeV and $|\eta|$<0.8 or 1.5<$|\eta|$<2.5
- Dominant production at p_T^γ < 120 GeV is through Compton scattering: $qg \to \gamma q$
- Various rapidity regions ⇒ various parton x and qg fractions.





Inclusive photon+jet production

- Cross section is directly proportional to PDFs in a given (x,Q^2)
- Probe PDFs in the range

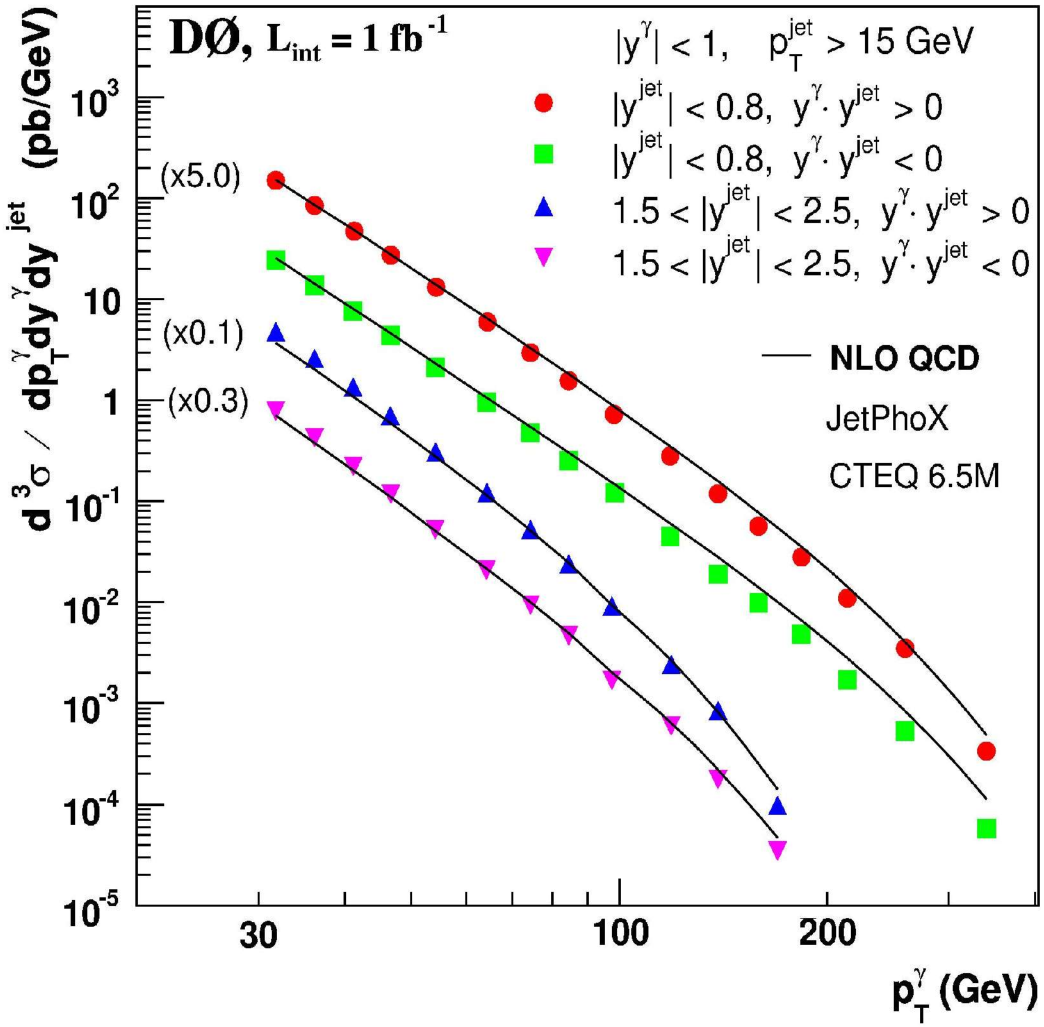
$$0.007 \leq x \leq 0.7 \text{ and } 900 \leq Q^2 \leq (0.4 - 1.0)\text{x}10^5 \text{ GeV}^2$$

Triple differential cross section

- Cross section results are shown with stat.+syst. uncertainties
- Analytical unfolding is applied to remove detector resolution effects

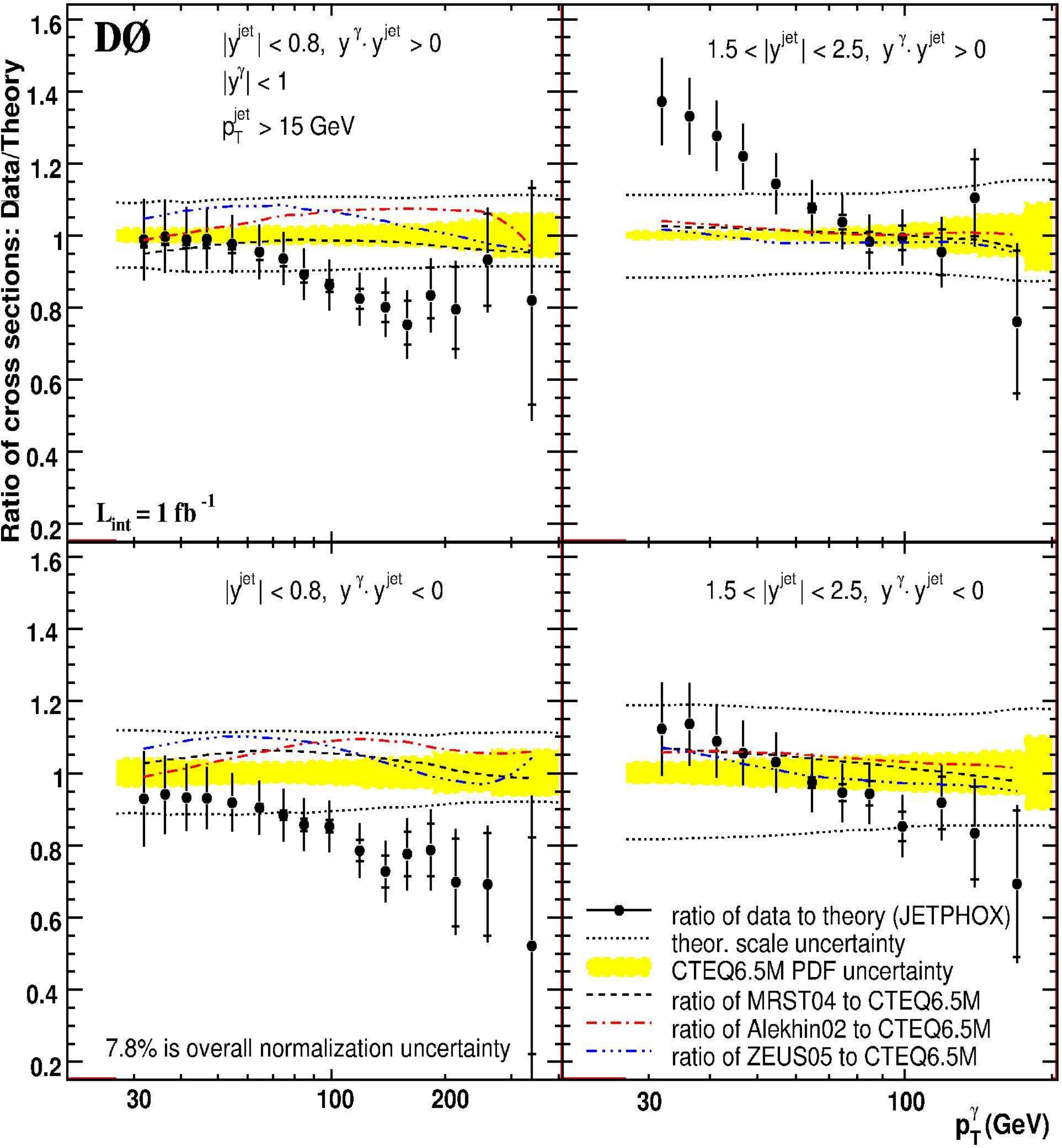
- Theory: JetPhoX (NLO QCD) with CTEQ6.5M and $\mu = \mu_f = \mu_F = p_T^\gamma f(y^*)$

$$f(y^*) = \sqrt{\tfrac{1}{2}(1 + \exp(-2y^*))}, \quad y^* = \tfrac{1}{2}(y^\gamma - y^{jet})$$



Inclusive photon+jet production

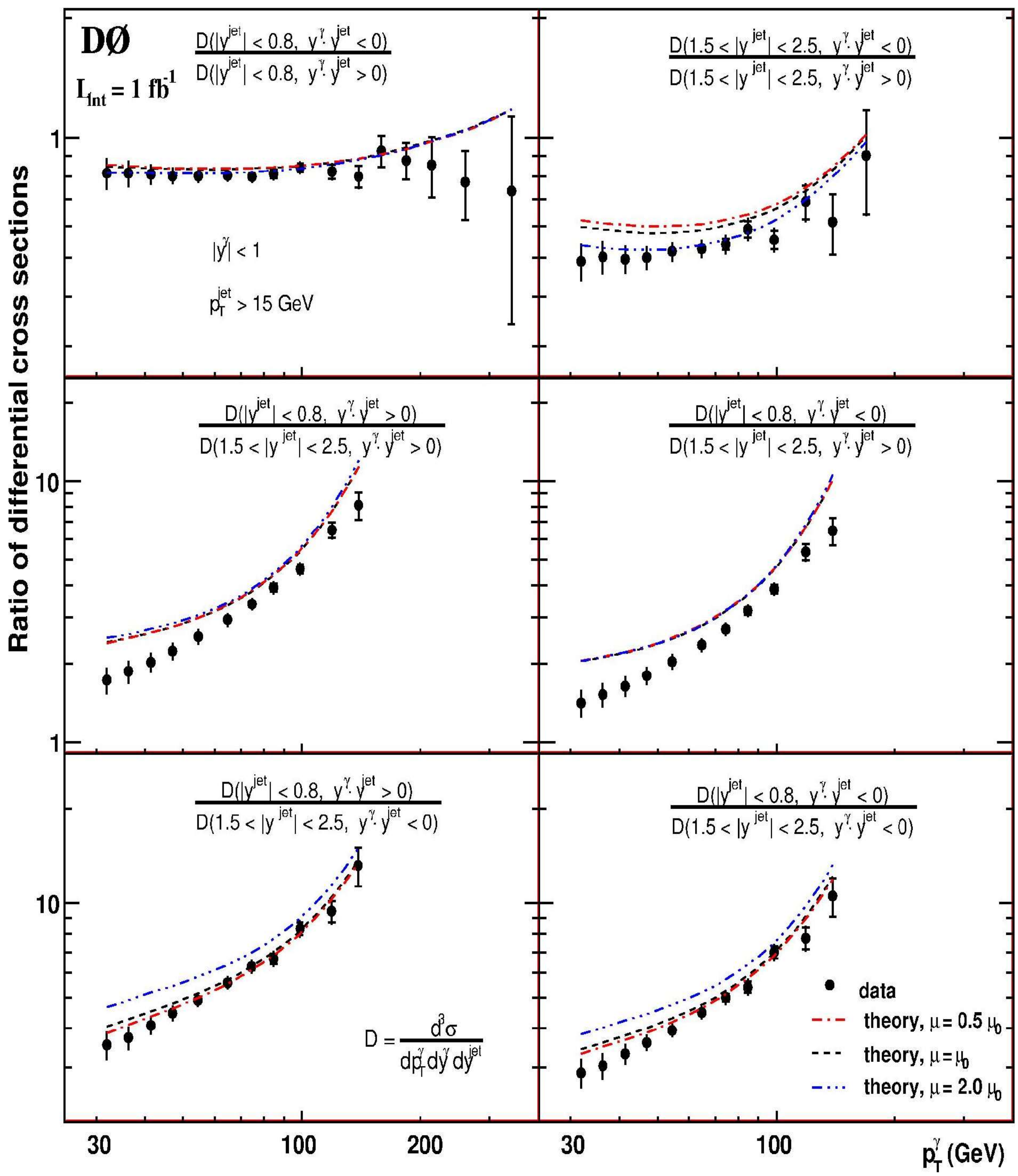
Data/Theory comparison



- ✓Theory does not describe shape of data in the whole measured region.
- ✓Deviation for central jets at $p_T^\gamma > 100$ GeV
- ✓Deviation for forward jets $(y^\gamma y^{jet} > 0)$ at $p_T^\gamma < 50$ GeV.
- ✓Structure similar to observed at UA2, CDF and D0 inclusive photons.

Inclusive photon+jet production

Cross section ratios between different regions

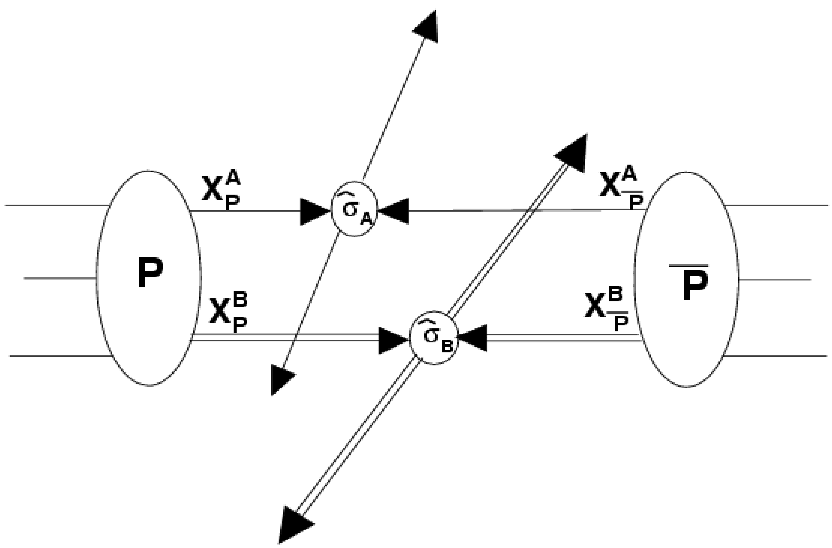


- ✓ Cross section ratio vs p_T^{γ}: *reduced systematics* (both data & theory)
- ✓ Shapes of measured cross section ratios in data *qualitatively reproduced* by theory in general
- ✓ But *quantitative disagreement* for some kinematic regions, in particular central jets over same rapidity side forward jets

Double Parton Scattering in γ+3 jet events

D0 note 5910 - CONF (2009)

- Complementary information about proton structure: Spatial distribution of partons
  ⇒ Possible parton-parton correlations. Impact on PDFs?
- Needed for understanding many signal events and correct estimating backgrounds to many rare processes.
- Especially important at high luminosities due to additional pp(bar) interactions.



Selections: 60 < photon pT < 80 GeV, lead. jet pT > 25, other 2 jets with pT > 15 GeV

Main Background: Single Parton scattering

$$\sigma_{DP} = m \cdot \sigma_A \cdot \frac{\sigma_B}{2\sigma_{eff}}$$

σ_A, σ_B: cross sections of processes A, B

σ_{eff}: characterising size of effective interaction region

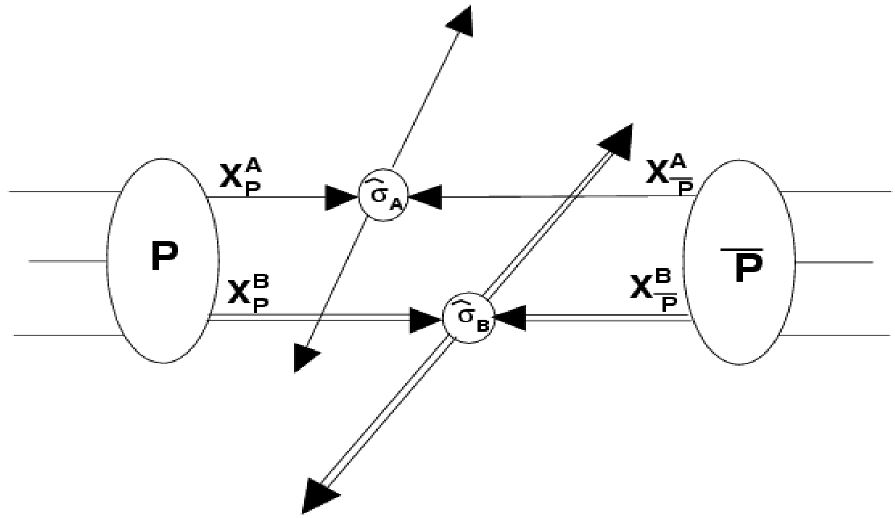
$\sigma_B / 2\sigma_{eff}$: prob. of 2^{nd} interaction, given 1^{st} one

($m = 2(1)$ when A and B are (not) distinguishable)

Effective cross section

$$\sigma_{DP} = m\, \sigma_A \frac{\sigma_B}{2\sigma_{eff}}$$

Factor 2 is due to Poisson statistcs
m is combinatorial factor
m=2 (1) when A and B are (not) distinguishable



σ_A, σ_B – cross sections of any processes A,B.

σ_{eff} – a factor characterizing a size of effective interaction region, i.e. contains information on the spatial distribution of partons.

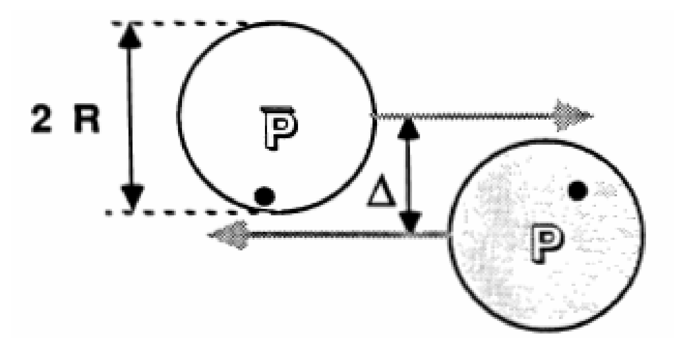
$\sigma_B/2\sigma_{eff}$ – probability of 2[nd] interaction B with A already happened.

Uniform parton distribution

→ σ_{eff} is large and σ_{DP} is small

Clumpy parton distribution

→ σ_{eff} is small and σ_{DP} is large



Parton-parton luminosity as a function of impact parameter △ and proton spatial density D(r)

△

History of measurements

- ♦ Theoretical discussion on DPS continues for many years (~ beginning of 1980's)
- ♦ Experimental problem is extracting DP signal from more probable double bremstr. background.

Typical experiments choose 4-jet sample motivated by a large di-jet cross section. Measuring σ_{eff} in 4-jet sample:

$$\sigma_{DP} = \frac{\sigma_{JJ}^2}{2\sigma_{eff}}$$

☞ Measure σ_{DP} but need then QCD calculations of σ_{jj} to get σ_{eff} And MC signal & background modeling.

CDF 1997: photon+3jet events. A new, data-driven, method developed:

☞ Use of Double interaction (two separate ppbar collisions) and DPS rates from a single ppbar collision rates to extract σ_{eff}, → reduce dependence on MC

	$\sqrt{s}$ (GeV)	final state	p_T^{min} (GeV/c)	η range	Result
AFS, 1986	63	$4jets$	$p_T^{jet} > 4$	$\lvert\eta^{jet}\rvert < 1$	$\sigma_{eff} \sim 5$ mb
UA2, 1991	630	$4jets$	$p_T^{jet} > 15$	$\lvert\eta^{jet}\rvert < 2$	$\sigma_{eff} > 8.3$ mb (95% C.L.)
CDF, 1993	1800	$4jets$	$p_T^{jet} > 25$	$\lvert\eta^{jet}\rvert < 3.5$	$\sigma_{eff} = 12.1^{+10.7}_{-5.4}$ mb
CDF, 1997	1800	$\gamma + 3jets$	$p_T^{jet} > 6$	$\lvert\eta^{jet}\rvert < 3.5$	
			$p_T^{\gamma} > 16$	$\lvert\eta^{\gamma}\rvert < 0.9$	$\sigma_{eff} = 14.5 \pm 1.7^{+1.7}_{-2.3}$ mb

Selections

Vertex: $|Z|<60$cm, Ntrk>=3.

Jets:
- Midpoint Cone algo with R=0.7
- $|\eta|<3.0$
- #jets $\geq$ 3
- pT of any jet > 15 GeV
- pT of leading jet > 25 GeV
- pT of 2nd jet$\in$(15,20), (20,25), (25,30) GeV.

Photons:
- photons with $|\eta|<1.0$ and $1.5<|\eta|<2.5$
- 60< pT< 80 GeV (good separation of lead. jet from 2 other jets)
- Shower shape cuts
- Calo isolation (0.2< dR< 0.4) < 0.07
- Track isolation (0.05< dR <0.4)< 1.5 GeV
- Track matching probability < 0.001

- $\triangle$dR(any objects pair)>0.7

Different to CDF(1997) this analysis was done:

1. *basing on higher RunII statistics :*

$L_{CDF\_1997} = 16\ pb^{-1}$ ==> $L_{D0\_2009} = 1.0\ fb^{-1}$

2. *D0(2009) used "gamma + 3jets" events (Purity_gamma~60%)*

CDF(1997) used "gamma/pi0 + 3jets" events .

3. *D0(2009) measured at 3 high $PT^{2nd\text{-}jet} > 15$ GeV regions*

CDF(1997) meas. at 1 low PT region $5 < PT^{2nd\text{-}jet} < 7$ GeV

Measurement of σ_{eff}

At two hard scattering events: $$P_{DI}=2\left(\frac{\sigma^{\gamma j}}{\sigma_{hard}}\right)\left(\frac{\sigma^{jj}}{\sigma_{hard}}\right)$$

The number of DI events: $$N_{DI}=2\frac{\sigma^{\gamma j}}{\sigma_{hard}}\frac{\sigma^{jj}}{\sigma_{hard}}N_C(2)A_{DI}\epsilon_{DI}\epsilon_{2vtx}$$

At one hard interaction: $$P_{DP}=\left(\frac{\sigma^{\gamma j}}{\sigma_{hard}}\right)\left(\frac{\sigma^{jj}}{\sigma_{eff}}\right)$$

Then the number of DP events: $$N_{DP}=\frac{\sigma^{\gamma j}}{\sigma_{hard}}\frac{\sigma^{jj}}{\sigma_{eff}}N_C(1)A_{DP}\epsilon_{DP}\epsilon_{1vtx}$$

Therefore one can extract:

$$\sigma_{eff}=\frac{N_{DI}}{N_{DP}}\frac{N_C(1)}{2N_C(2)}\frac{A_{DP}}{A_{DI}}\frac{\epsilon_{DP}}{\epsilon_{DI}}\frac{\epsilon_{1vtx}}{\epsilon_{2vtx}}\sigma_{hard}$$

Discriminating variables

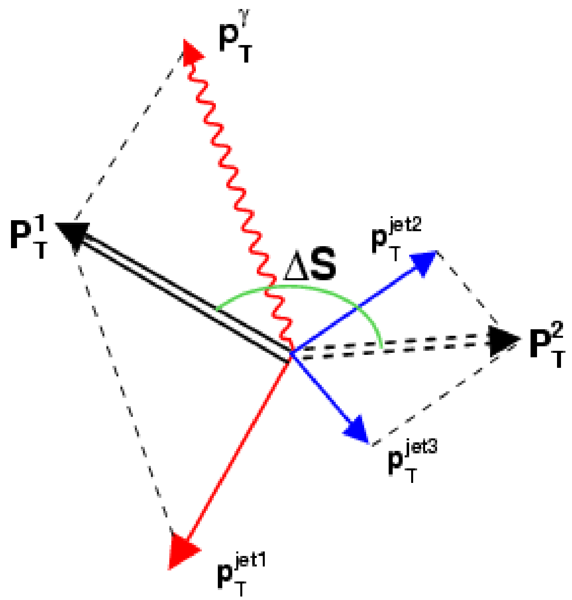
$$S_\phi = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{\Delta\phi(\gamma,i)}{\delta\phi(\gamma,i)}\right)^2 + \left(\frac{\Delta\phi(j,k)}{\delta\phi(j,k)}\right)^2}$$

$$S_{p_T} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|\vec{P_T}(\gamma,i)|}{\delta P_T(\gamma,i)}\right)^2 + \left(\frac{|\vec{P_T}(j,k)|}{\delta P_T(j,k)}\right)^2}$$

$$\Delta S = \Delta\phi(p_T^{\gamma,\,\mathrm{jet}}, p_T^{\mathrm{jet}_i,\,\mathrm{jet}_k})$$

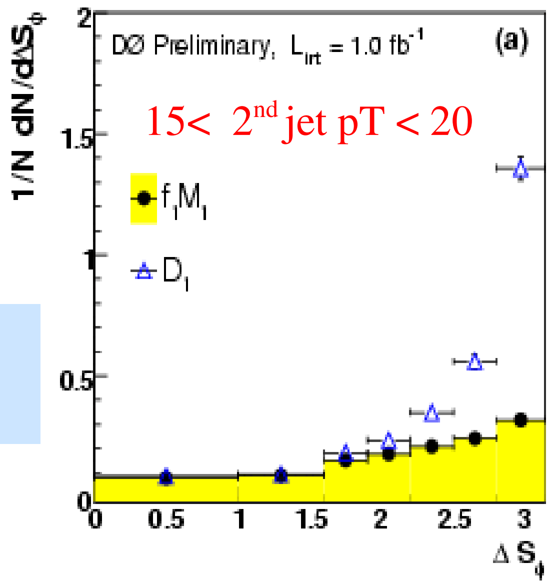
Computed for pair with minimum S

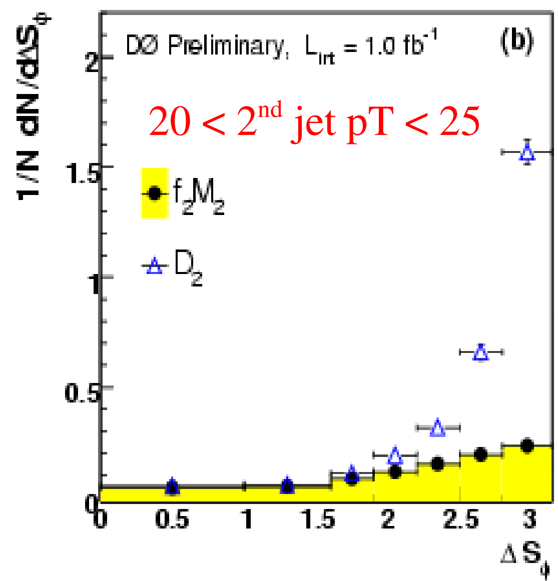
>95% of signal DP events are minimized by pairs (γ, jet1) and (jet1, jet3)



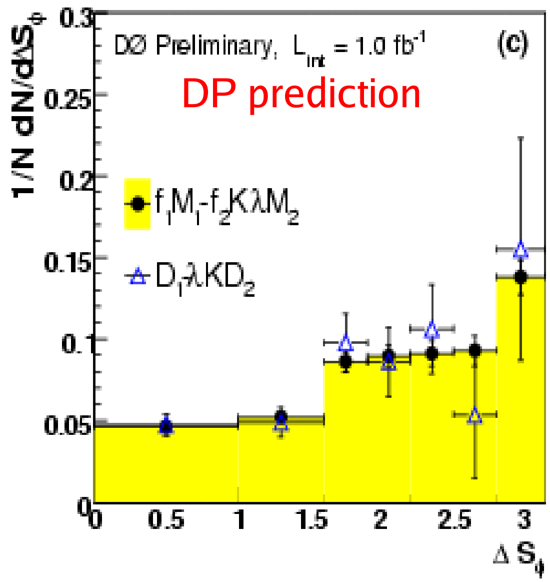
– Measurement is done in three bins of 2nd jet pT: 15-20, 20-25 and 25-30 GeV

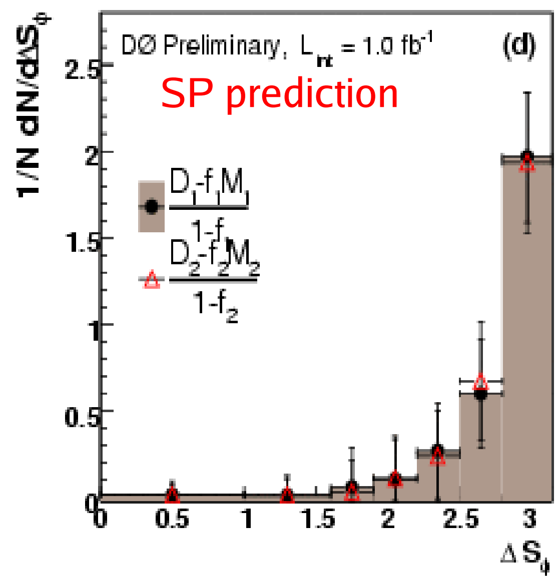
– Data-driven technique: since dijet pT spectrum is steeper than that for radiation jets the DP fractions should drop for larger jet pT.



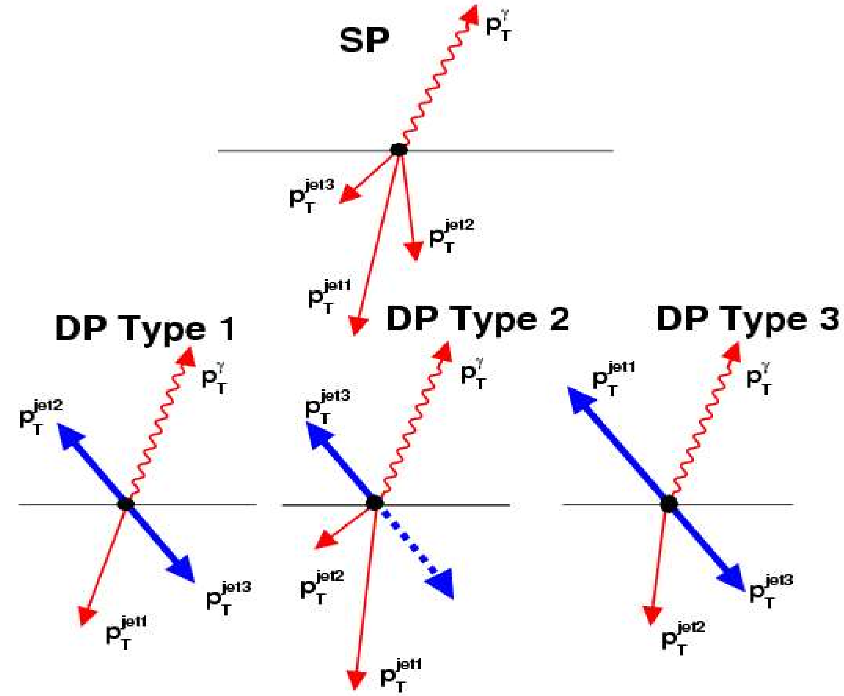


D0 data and DP model



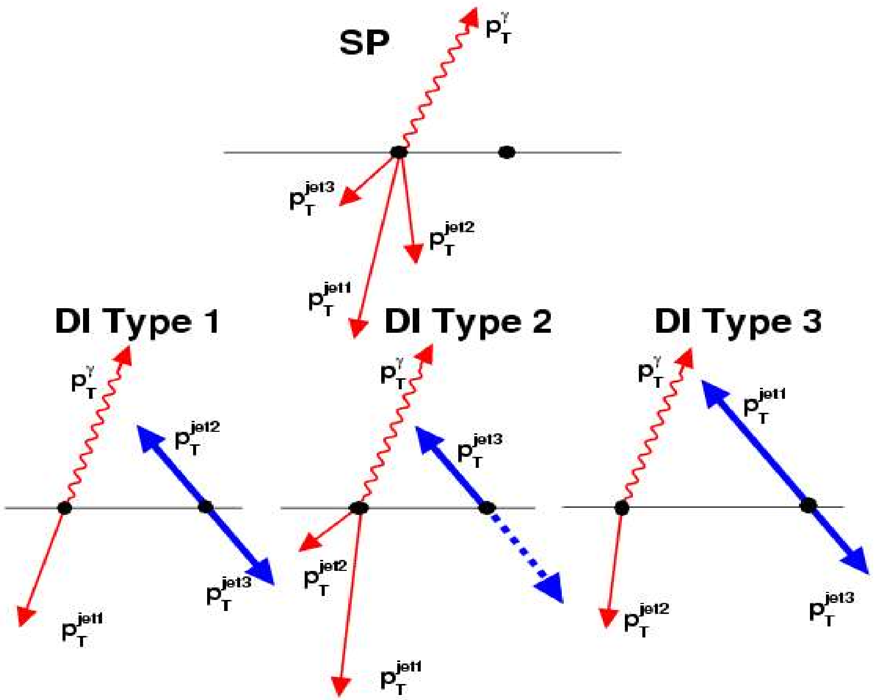


γ+3 jets events topology: DP and DI events



B: Single Parton (SP) 1PV production:
single hard scattering with bremsstrahlung radiation in 1vtx events.

S: Double Parton (DP) production:
1st process produces photon-jet pair, while 2nd produces dijet pair or photon plus 2 jets from 1st interaction plus 1 observed jet from dijet pair.



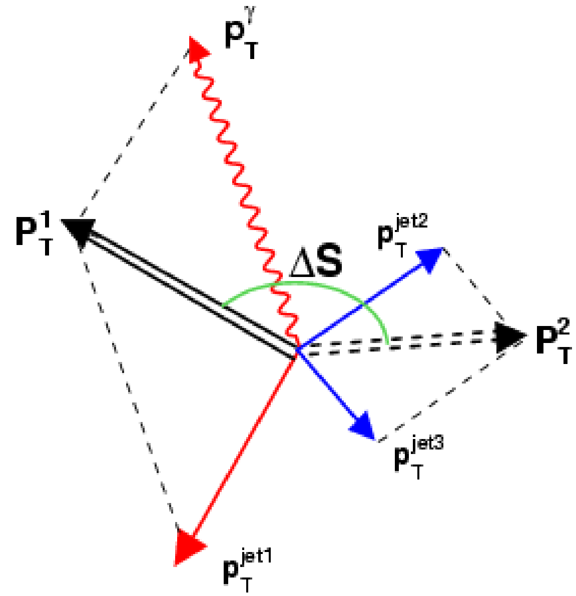
B: Single Parton (SP) 2PV production:
Single hard scattering in 1vtx with bremsstrahlung radiation.

S: Double Interaction (DI) production:
two separate collisions within the same beam crossing.

"ΔS-family" variables

- azimuthal angles between pT-vectors of the pairs that give minimum S value.

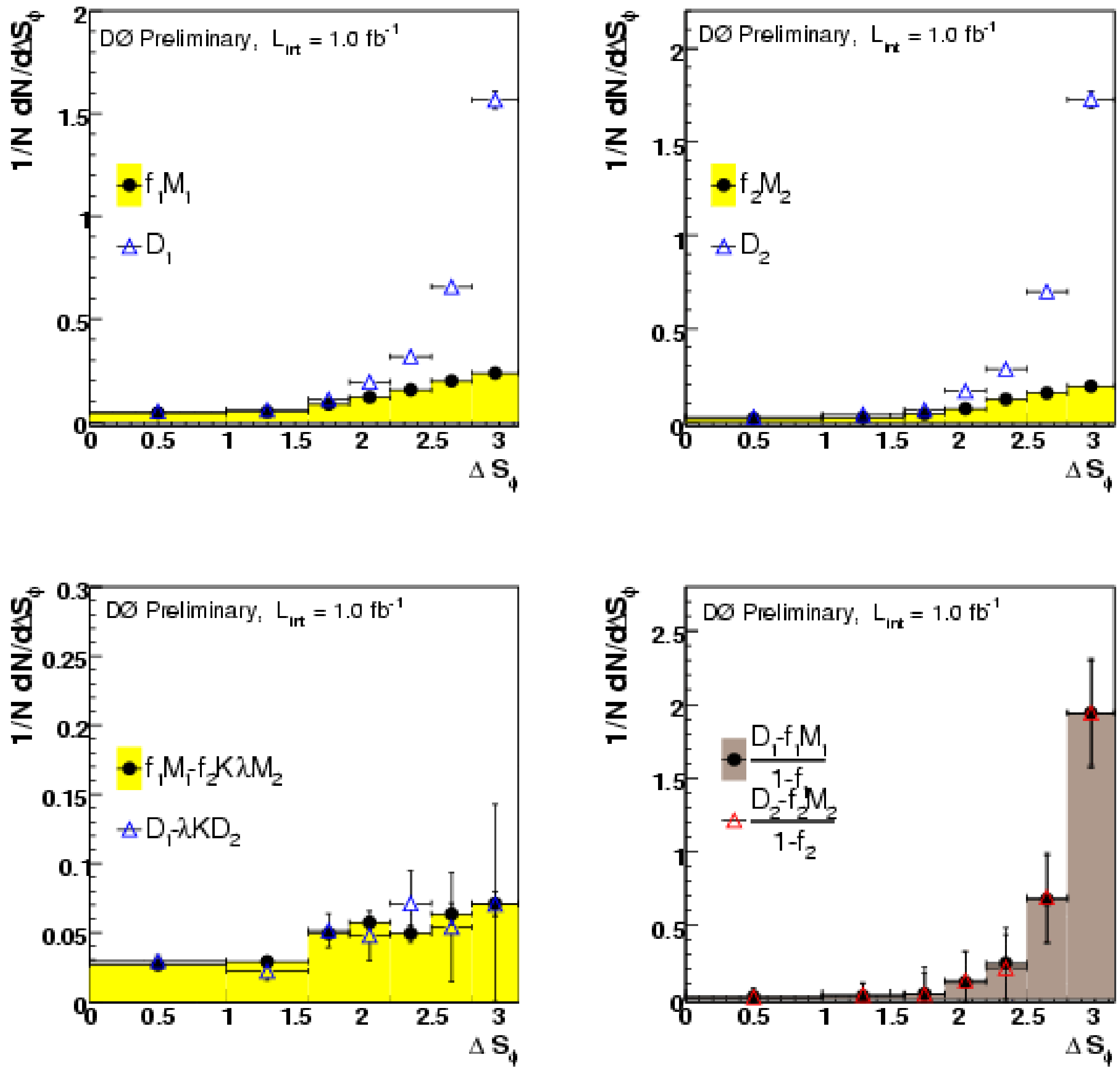
$$\Delta S = \Delta\phi\left(\mathbf{p}_{\mathrm{T}}^{\gamma, jet_i},\ \mathbf{p}_{\mathrm{T}}^{jet_j, jet_k}\right)$$



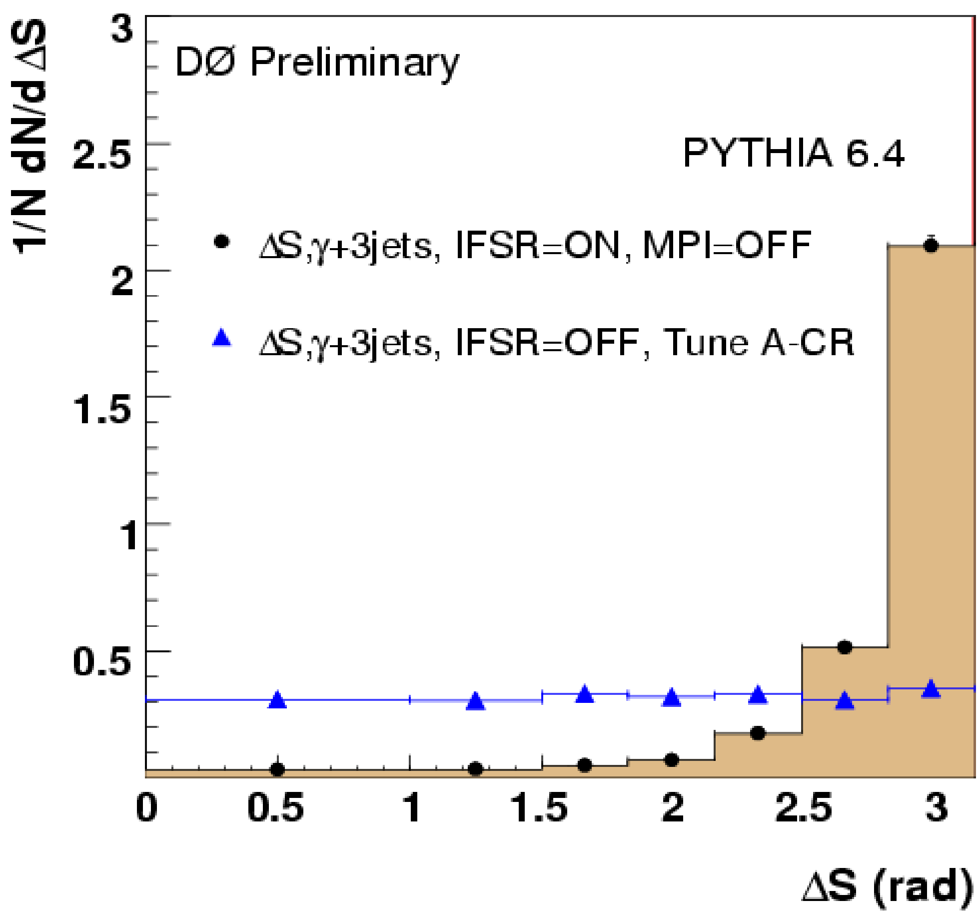
- For "γ+3jets" events from the single parton interactions we expect ΔS to peak at Pi, while it should be flat for "ideal" double parton interaction when both, 2nd and 3rd jets in the "γ+3jets" system are from 2nd (dijet) interaction.

- In reality, one of the dijet jets can be replaced by a radiation jet with a larger pT what makes ΔS distribution less flat with a bump closer to Pi.

Dataset 1: Photon pT: 60-80 GeV, 2nd jet pT: 20-25 GeV
Dataset 2: Photon pT: 60-80 GeV, 2nd jet pT: 25-30 GeV

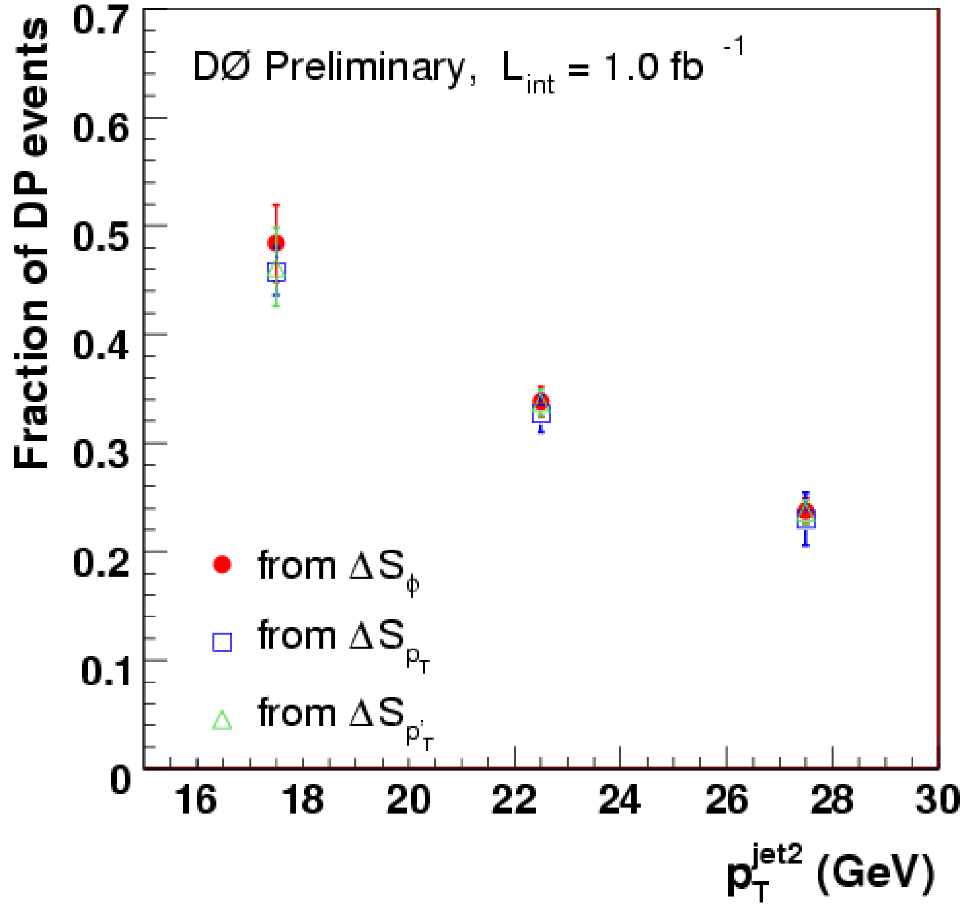


$\triangle$S distribution for γ+3jets events for pure SP events
(Pythia, particle distribution smeared with detector resolution)

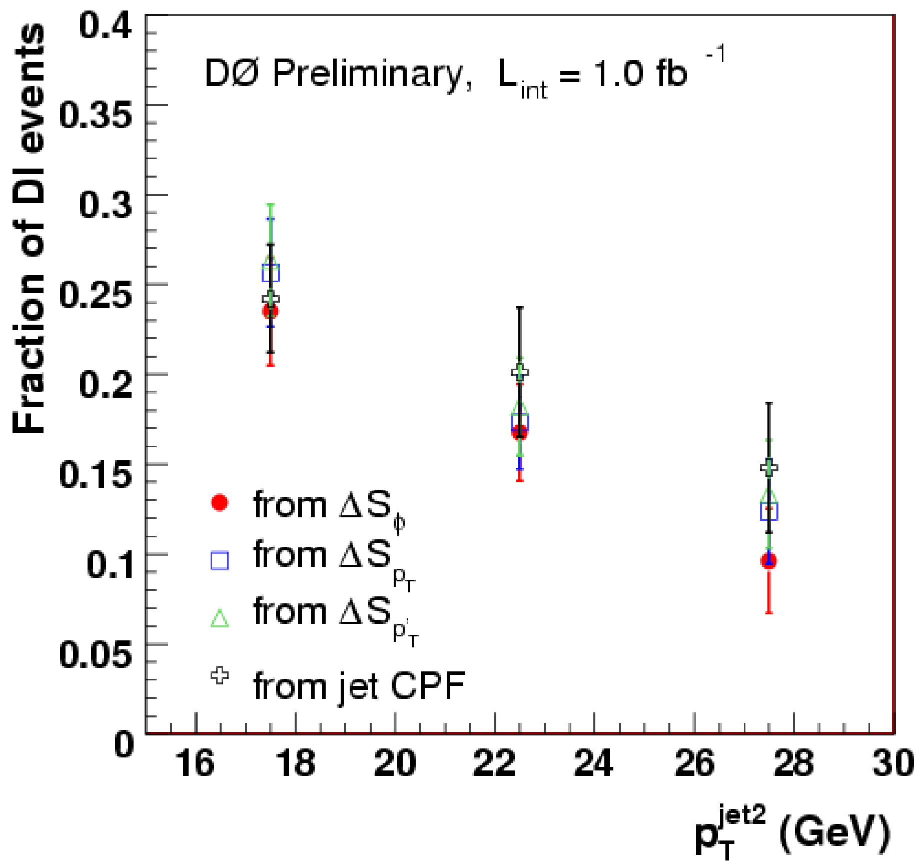


To be compared with bottom right plots from the previous 2 slides.

Fractions of DP events

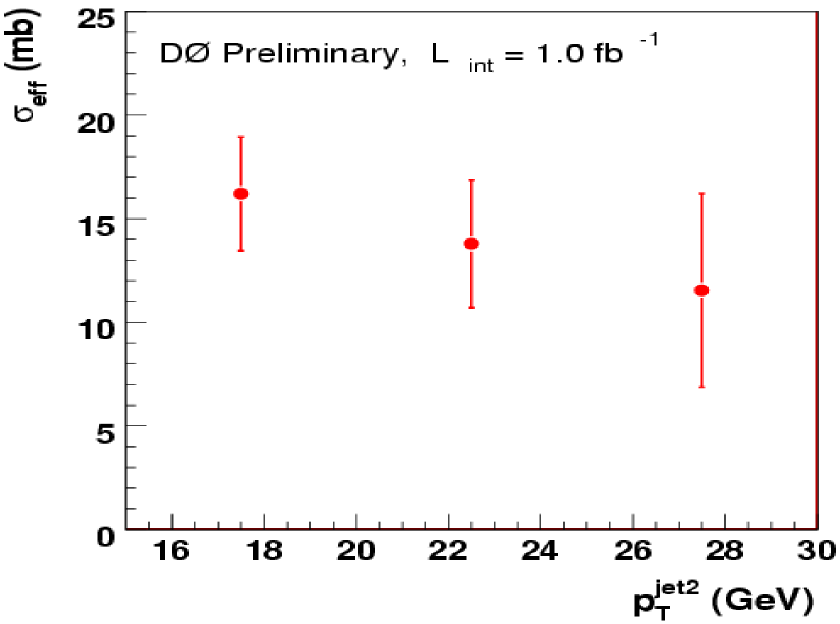


Fractions of DI events



Calculation of σ_{eff}

We sum up all together and calculate σ_{eff} in the three bins of 2nd jet pT:



$$\sigma_{\mathrm{eff}}^{aver.} = 15.1 \pm 1.9 \;\; \mathrm{mb}.$$

TABLE IV: Effective cross section σ_{eff} (mb) found in the three p_T^{jet2} intervals (GeV).

σ_{eff}	$15 - 20$	$20 - 25$	$25 - 30$
p_T^{jet2}	16.2 ± 2.8	13.8 ± 3.1	11.5 ± 4.7

TABLE V: Systematic and statistical uncertainties (in %) for σ_{eff}.

p_T^{jet2} (GeV)	f_{DP}	f_{DI}	$\varepsilon_{\mathrm{DI}}/\varepsilon_{\mathrm{DP}}$	JES	$R_c \cdot \sigma_{\mathrm{hard}}$	Syst. Total	Stat. Total	Exp. Total
$15 - 20$	8.8	11.5	6.5	5.5	2.0	16.9	2.8	17.1
$20 - 25$	6.9	20.0	6.5	2.0	2.0	22.3	2.3	22.5
$25 - 30$	11.4	38.2	6.5	3.0	2.0	40.6	2.5	40.6

Summary

In the current analysis we have measured:

- ***DP*** *fractions in three jet* pT *intervals*: *15-20; 20-25; 25-30 GeV*..

  It drops from 0.46 at *15< pT < 20 GeV* to 0.22 at *25< pT <30 GeV*.

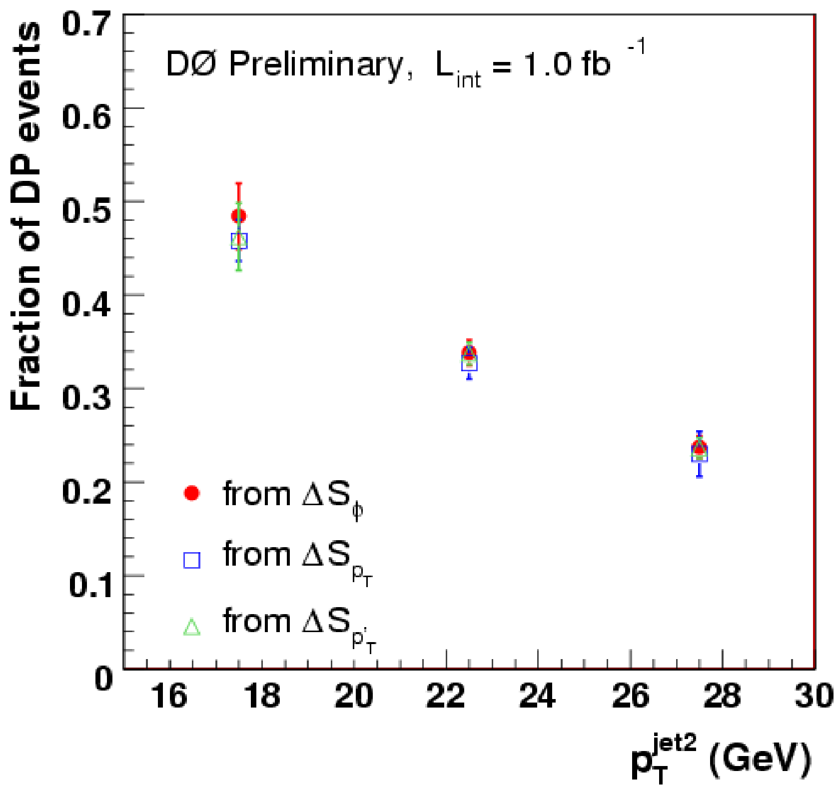
- *Effective cross section* σ_*eff* *has been measured in the same jet pT bins and found to be stable within uncertainties*.

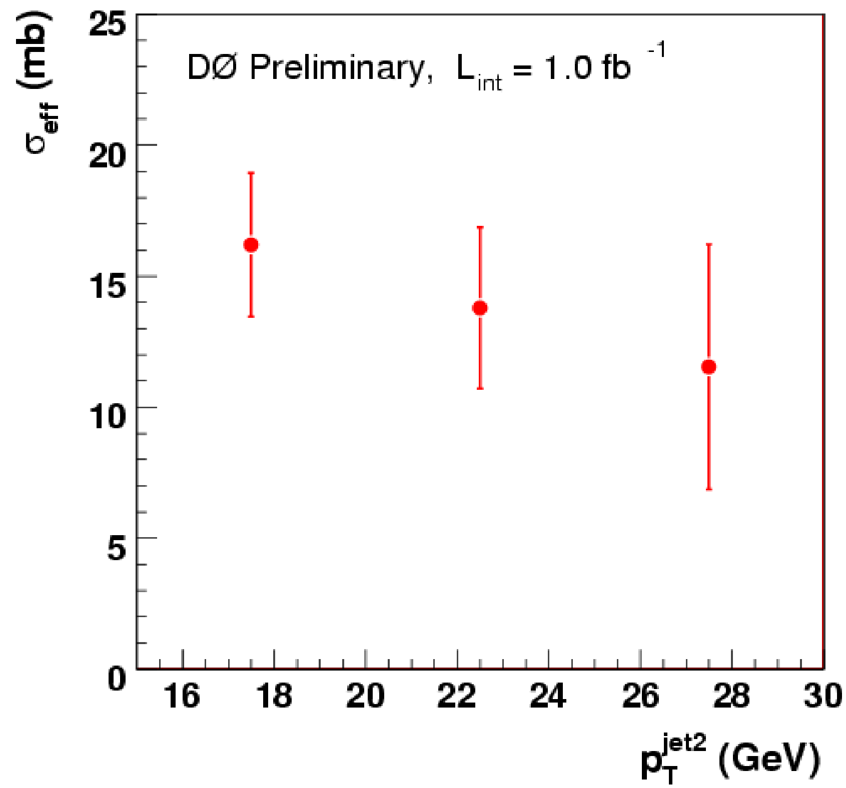
- *Results are consistent with previous UA2 and two CDF measurements.*

Summary

- Tevatron and D0 are performing well
- Inclusive photon production cross section $d^2\sigma/dp_T^\gamma d\eta^\gamma$ Published – In agreement with theory
  - Data/Theory shape is similar to UA2 and CDF (Run I); still needs to be understood
- Photon+jet production cross section $d^3\sigma/dp_T^\gamma d\eta^\gamma d\eta^{jet}$ Published
  - Four γ-jet rapidity regions
  - Ratios of cross section between regions
  - Some deviations from theory predictions observed
- Photon+HF jet production cross section Published
  - γ+b cross section is in agreement with theory
  - γ+c cross section does not agree with theory at p_T^γ 70 GeV
- Double parton interactions in γ+3 jet events Preliminary
  - Measured DP fractions in three bins of $p_T^{2nd\ jet}$
  - Measured effective cross section in the same bins
  - Good agreement with CDF (Run I) measurements.

DP fractions and effective cross section





- The measured DP fractions drop from 0.47 ± 0.04 at 15 < 2nd jet pT < 20 GeV to 0.23 ± 0.03 at 25 < 2nd jet pT < 30 GeV.

- Effective cross section is varied for the same bins as 16.2 ± 2.8 mb to 11.5 ± 4.7 mb and agree for all jet pT bins within uncertainties. Systematic uncertainties have negligible bin-to-bin correlations. Averaging over pT bins gives

$$= 15.1 \pm 1.9 \text{ mb}$$

- Good agreement with two previous Run I measurements by CDF ("4 jets", $\sigma_{eff} = 12.1^{+1.7}_{-2.3}$ mb and "γ+3jets", $\sigma_{eff} = 14.5 \pm 1.7^{+1.7}_{-2.3}$ mb)