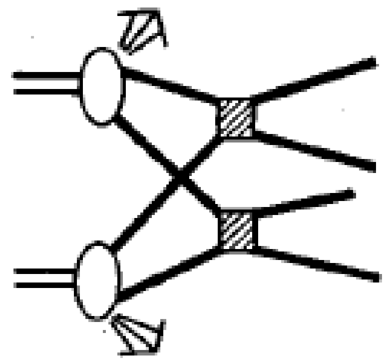
Double Parton Interactions in γ+3jets events in D0



Dmitry Bandurin
(Kansas State University)

on behalf of D0 Collaboration

1st Joint Workshop on Energy Scaling of Hadron Collisions

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Motivations

or Why we study DP events?

- **New and complementary information about proton structure:**

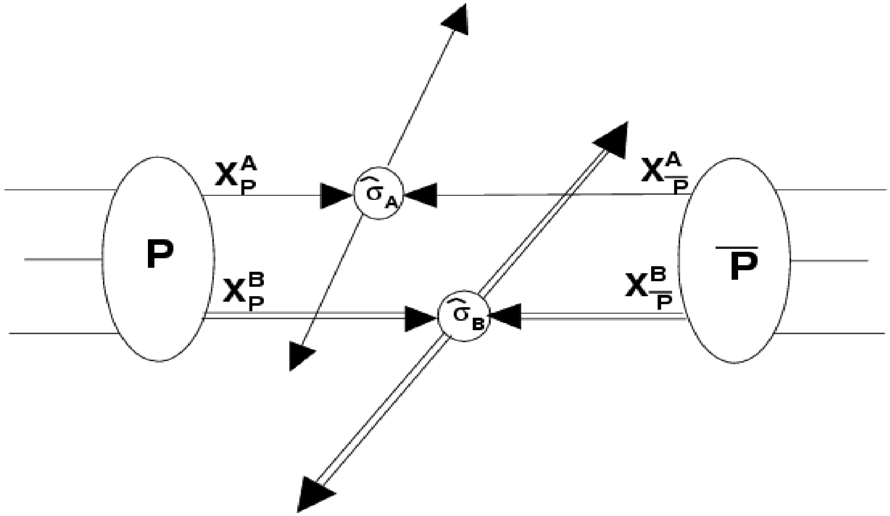
- spatial distribution of partons within proton;
- possible parton-parton correlations.
- impact on PDFs?

- Needed for correct u**nderstanding of signal events and correct estimating background to many rare processes** especially with multi-jet final state (many Higgs, SUSY productions).

- Especially important at high luminosities due to additional pp(bar) interactions.

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 the processes A,B.

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

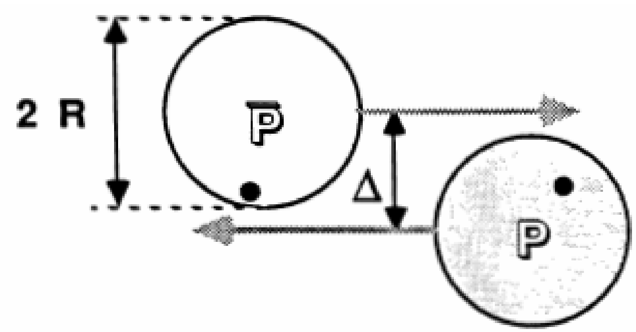
$\sigma_B / 2\sigma_{eff}$ – probability of 2nd interaction B with A already happened.

Uniform parton distribution

$\rightarrow$ σ_{eff} is large and σ_{DP} is small

Clumpy parton distribution

$\rightarrow$ σ_{eff} is small and σ_{DP} is large

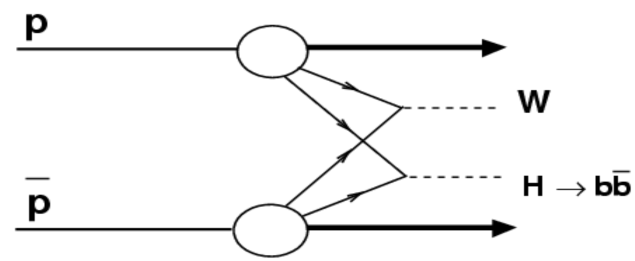


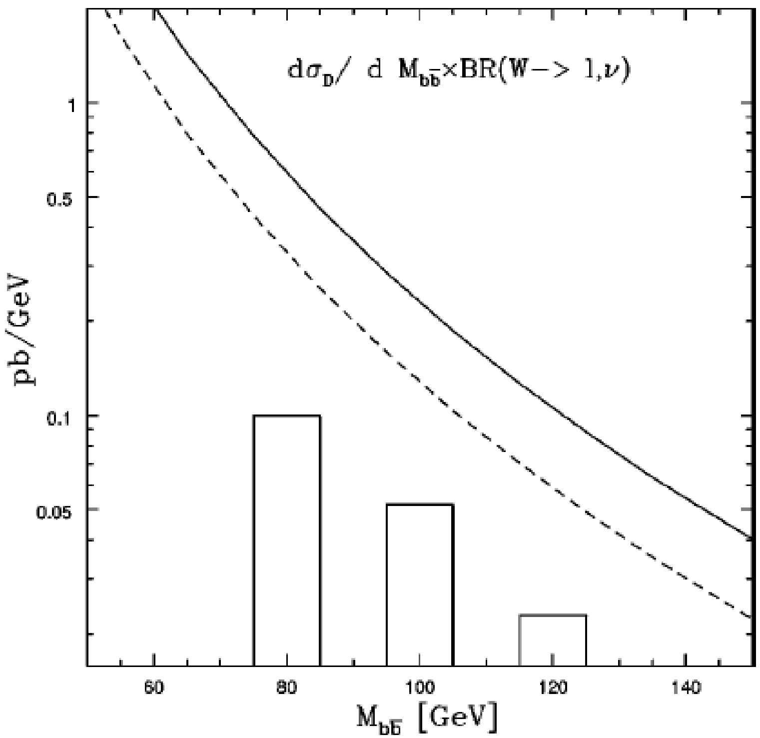
Parton-parton luminosity L_{eff} ($\sim\sigma_{eff}^{-1}$) as a function of impact parameter $\triangle$ and proton spatial density D(r)

$$L_{eff}(\triangle) = \int D(r) D(r') dV_{overlap}$$

Example: DPS as a background to p + p → WH (LHC)

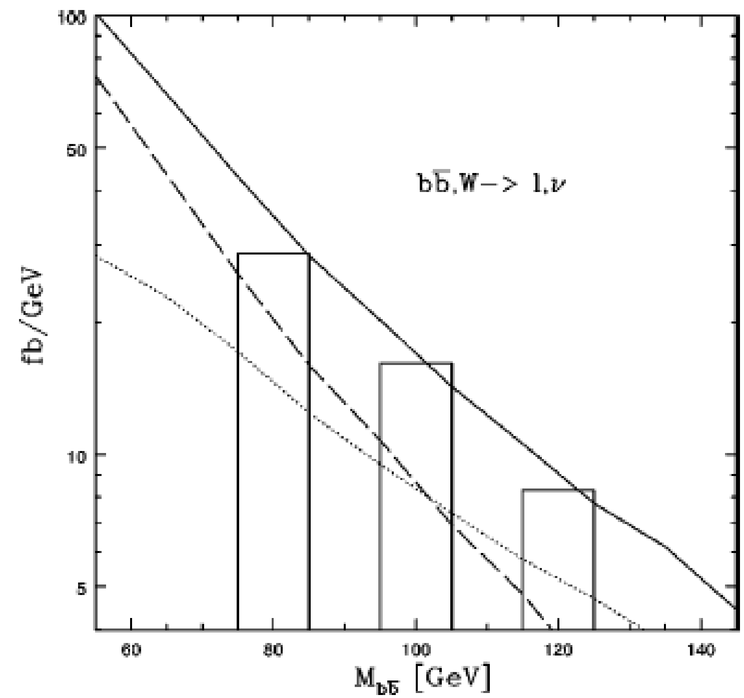
From PRD61, Fabro, Treleani (2000)





DP background as a function oh H mass:
LO and NLO bb production
(σ_{eff} = 14.5 mb used here)

DP background is 3 orders of magnitude higher than the HW cross section



SM/SP (dotted) and DP (dashed) cross sections after selection cuts

DP background is still very important even after selections

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:

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

☞ 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}, $\rightarrow$ reduce dependence on MC

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

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:

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

1st and 2nd interactions: Estimates of possible correlations

... in the momentum space:

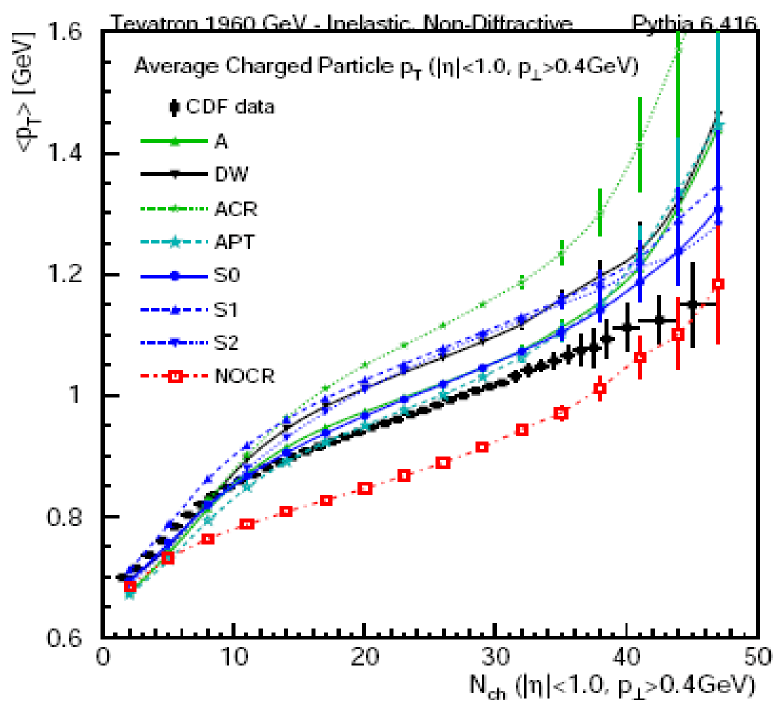
1st interaction: photon pT $\simeq$ 70 GeV, $\Rightarrow$ parton *xT* $\simeq$ *0.035*
2nd interaction: jet pT $\simeq$ 20 GeV, $\Rightarrow$ parton *xT* $\simeq$ *0.01*

➲ large (almost unlimitted) kinematic space for the 2nd interaction

... at the fragmentation stage :

=> Simulate γ+3 jets and di-jets with switched off ISR/FSR; then additional 2 jets in γ+3 jets should be from 2nd parton interaction
=> compare 2nd (3rd) jets pT/Eta in γ+3 jets with 1st (2nd)jet pT/Eta in dijets

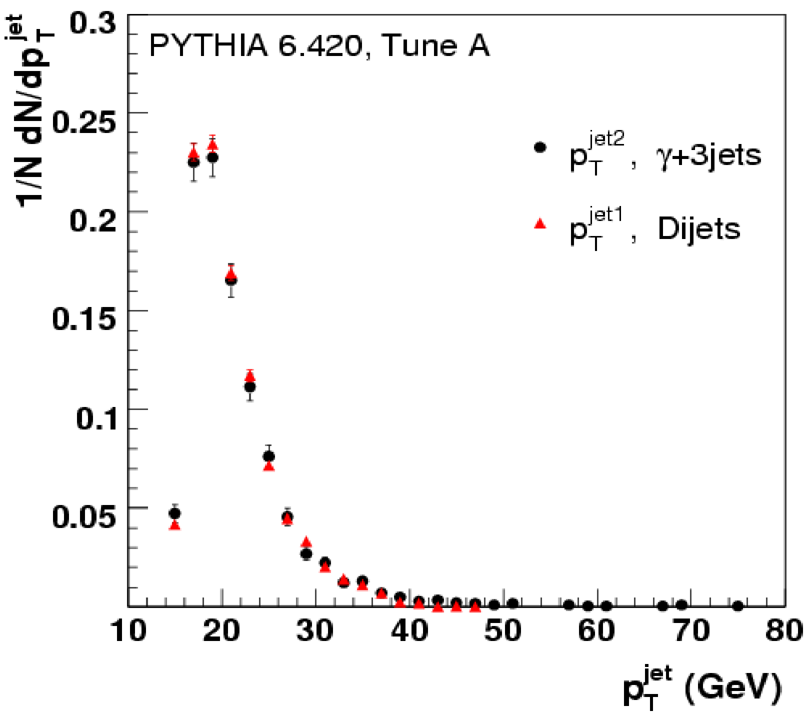
=>Tunes tested: A, A-CR, S0

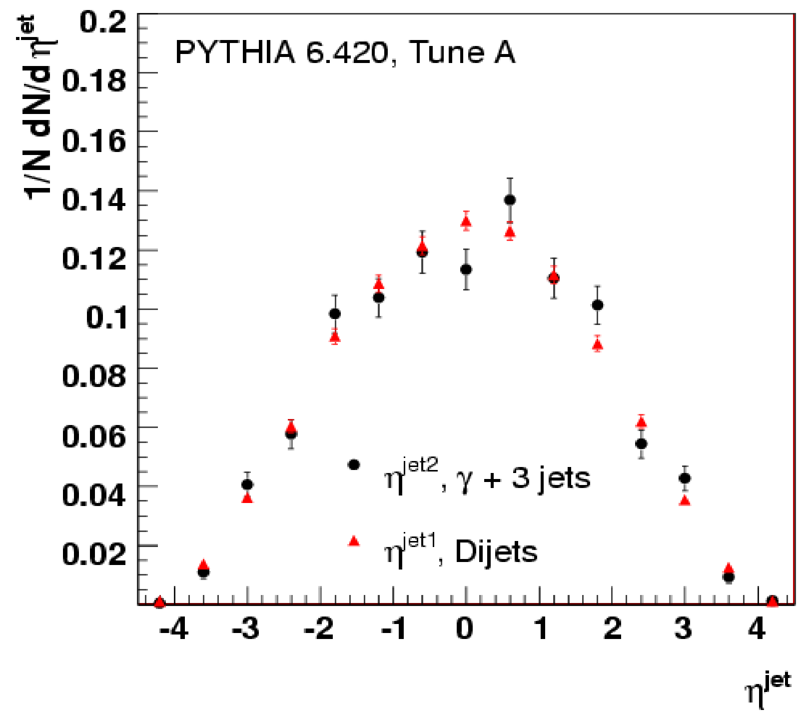


From D.Wicke & P.Skands hep-ph:0807.3248

γ+3 jets and di-jets, IFSR=OFF: jets pT comparison.

Tune A

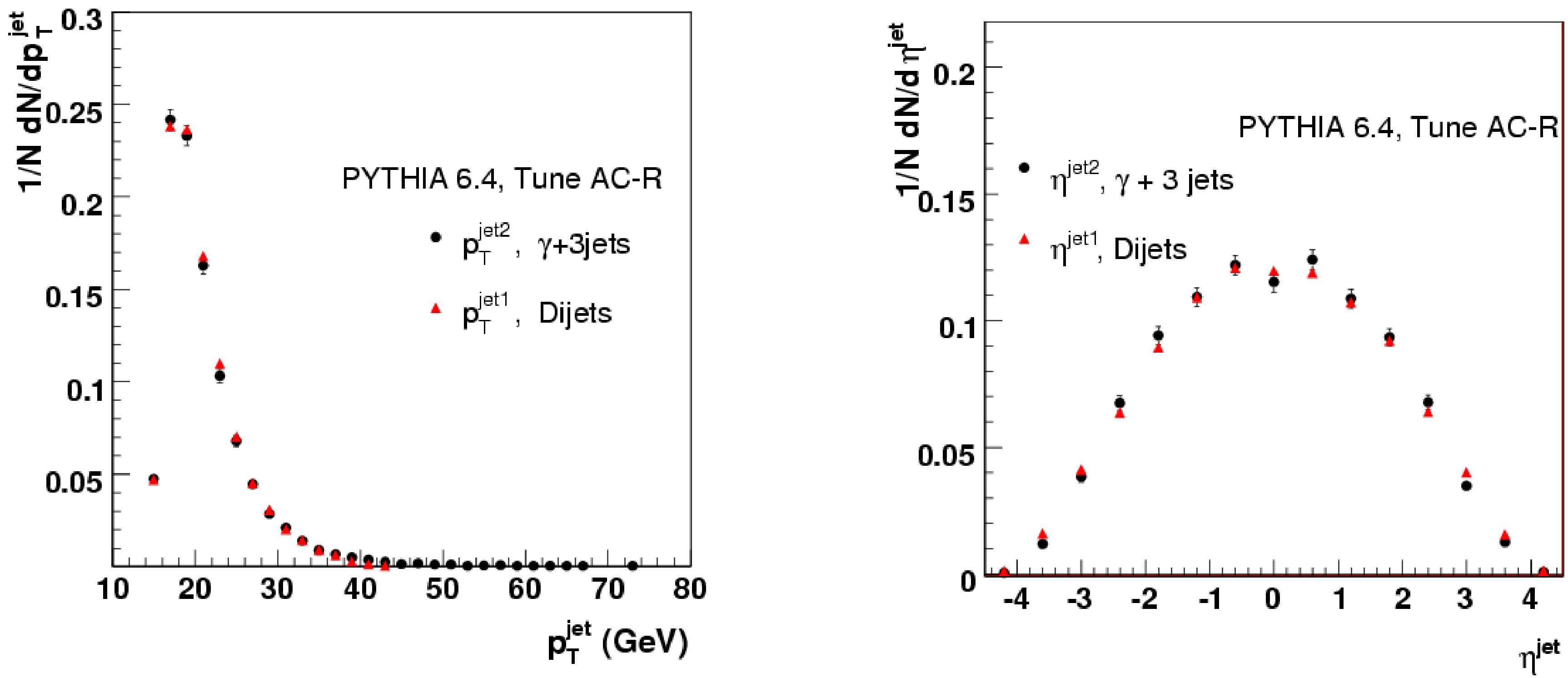




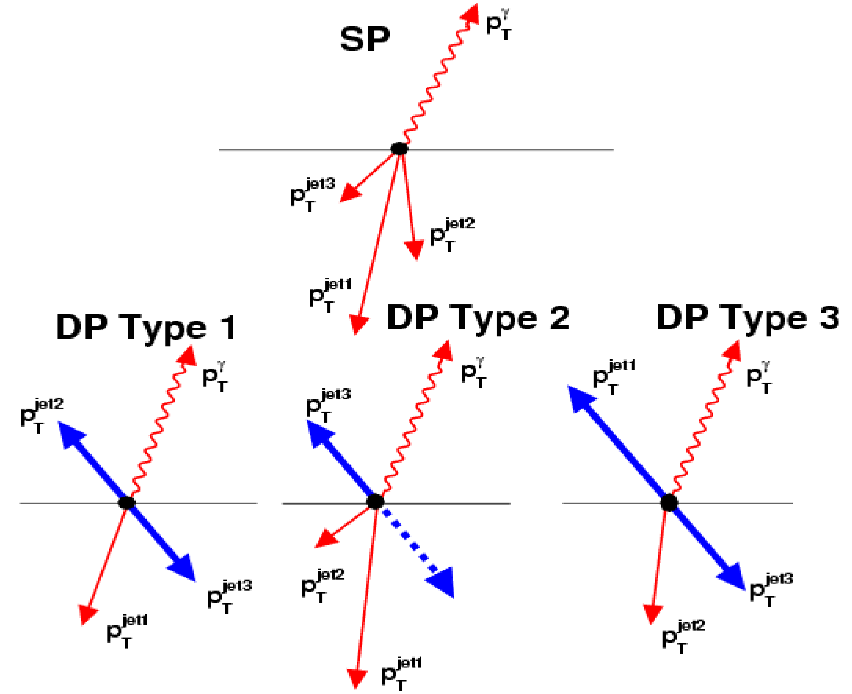
- pT and Eta distributions are analogous for jets from 2nd interaction in γ+3jets and di-jet events
- Analogous results (incl. 3rd jet from γ+3jets and 2nd from di-jets) are obtained for Tunes A-CR, S0.

γ+3 jets and di-jets, IFSR=OFF: jets pT comparison.

Tune A-CR

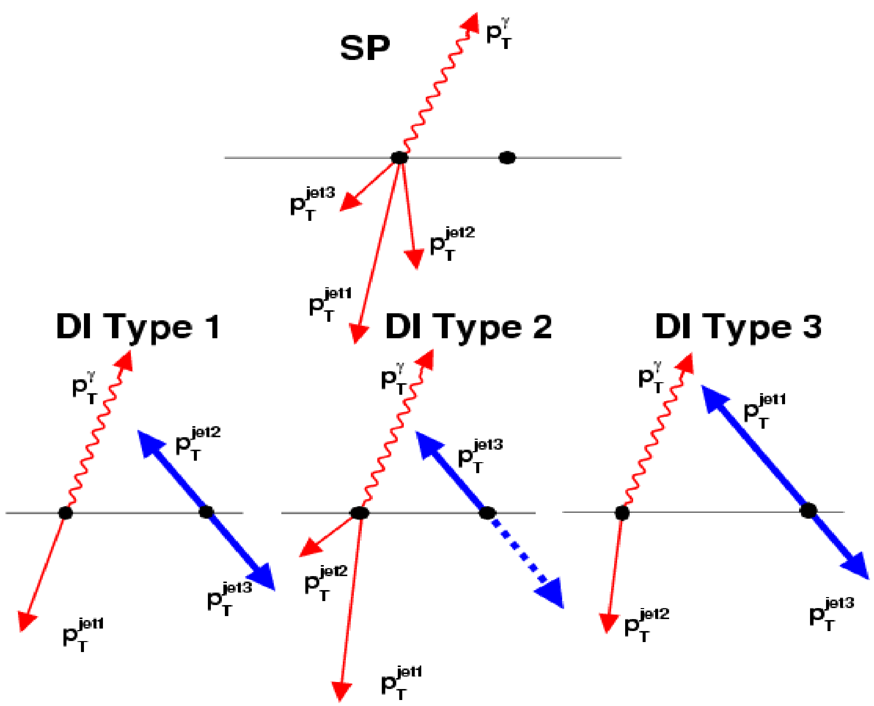


γ+3 jets events topology: DP and DI events



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.

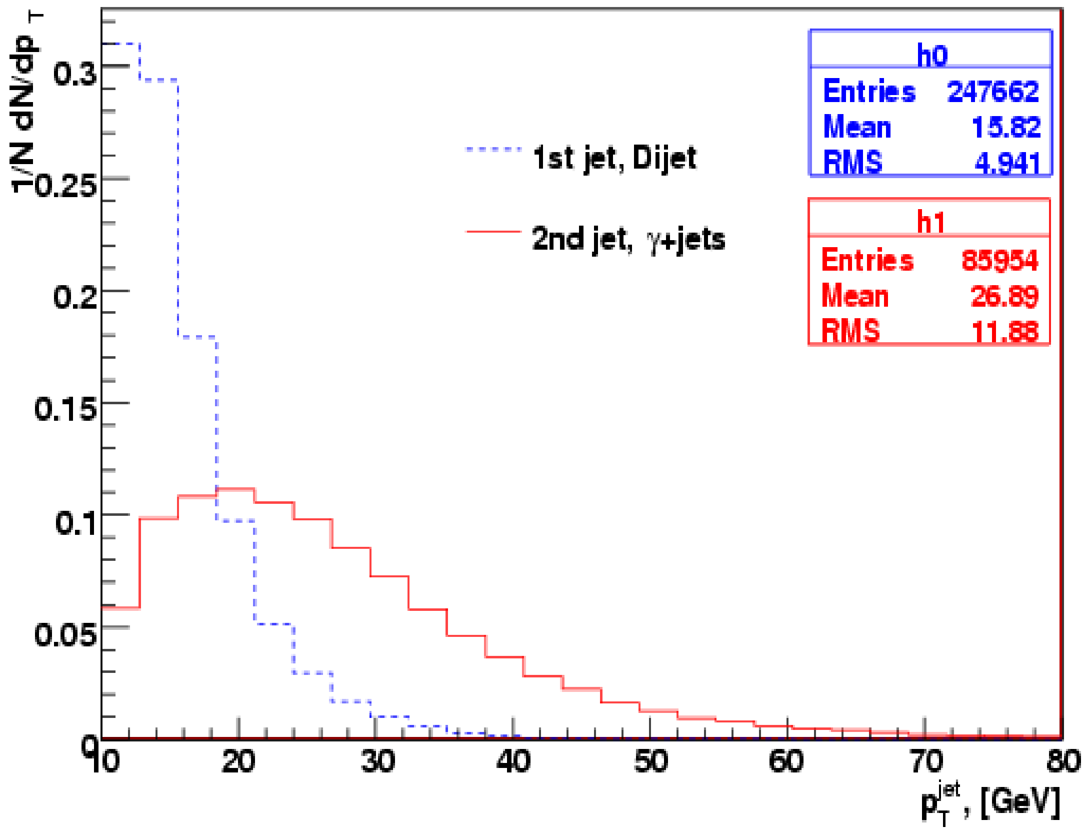


B: Single Parton (SP) 2PV production:
single hard scattering in 1vtx with bremsstrahlung radiation.

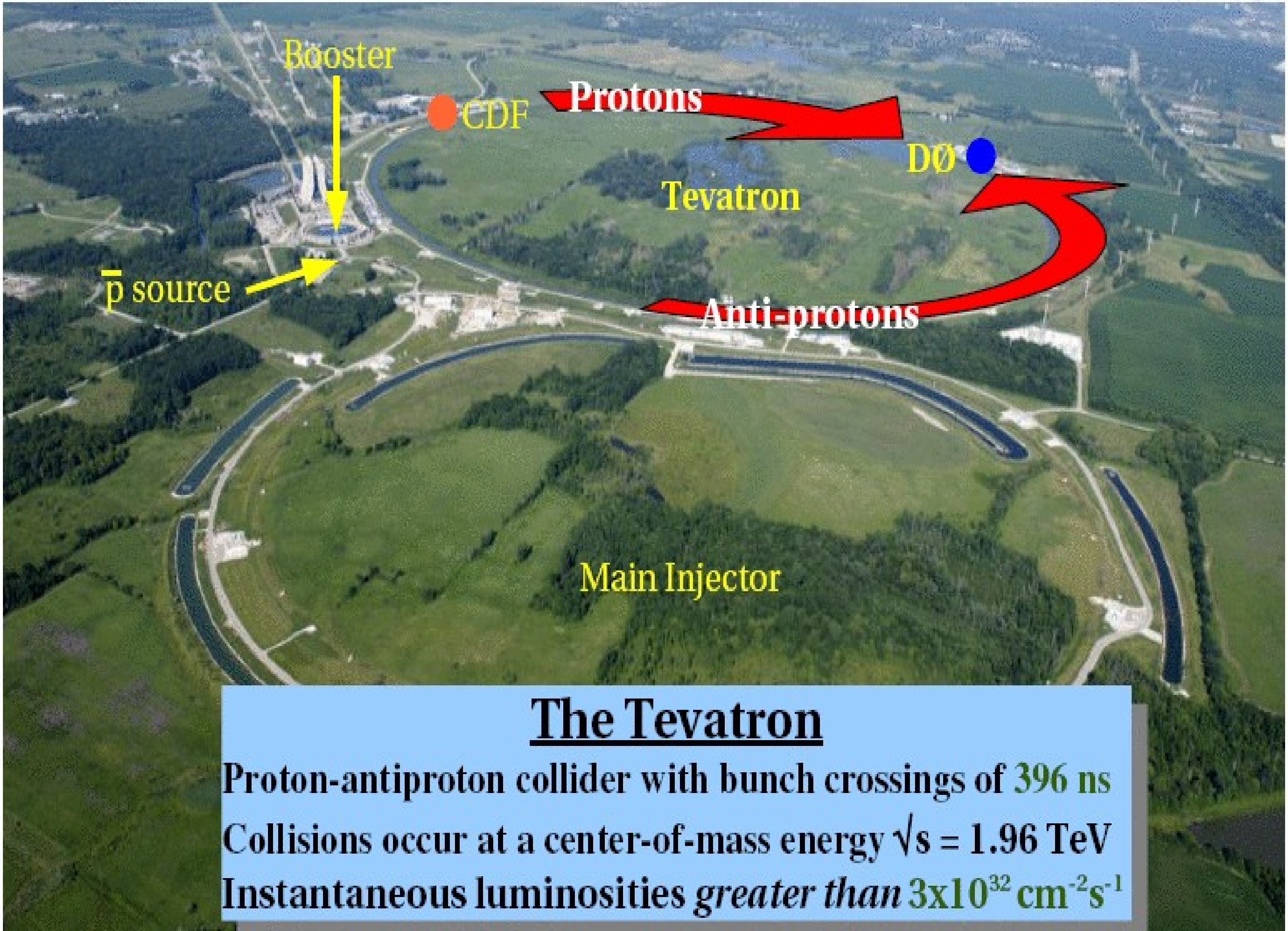
S: Double Interaction (DI) production:
two separate collisions within the same beam crossing.

Motivation of jet pT binning

Jet PT: jet from dijets vs. bremstrahlung jet from γ+jet events (Pythia 6.4)

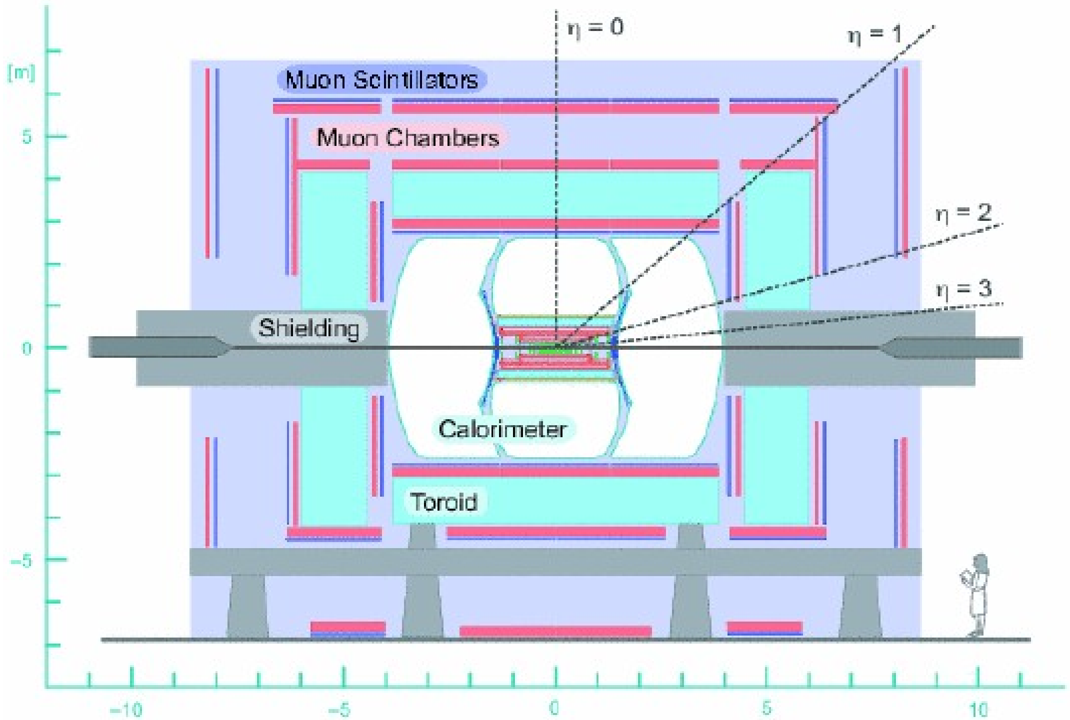


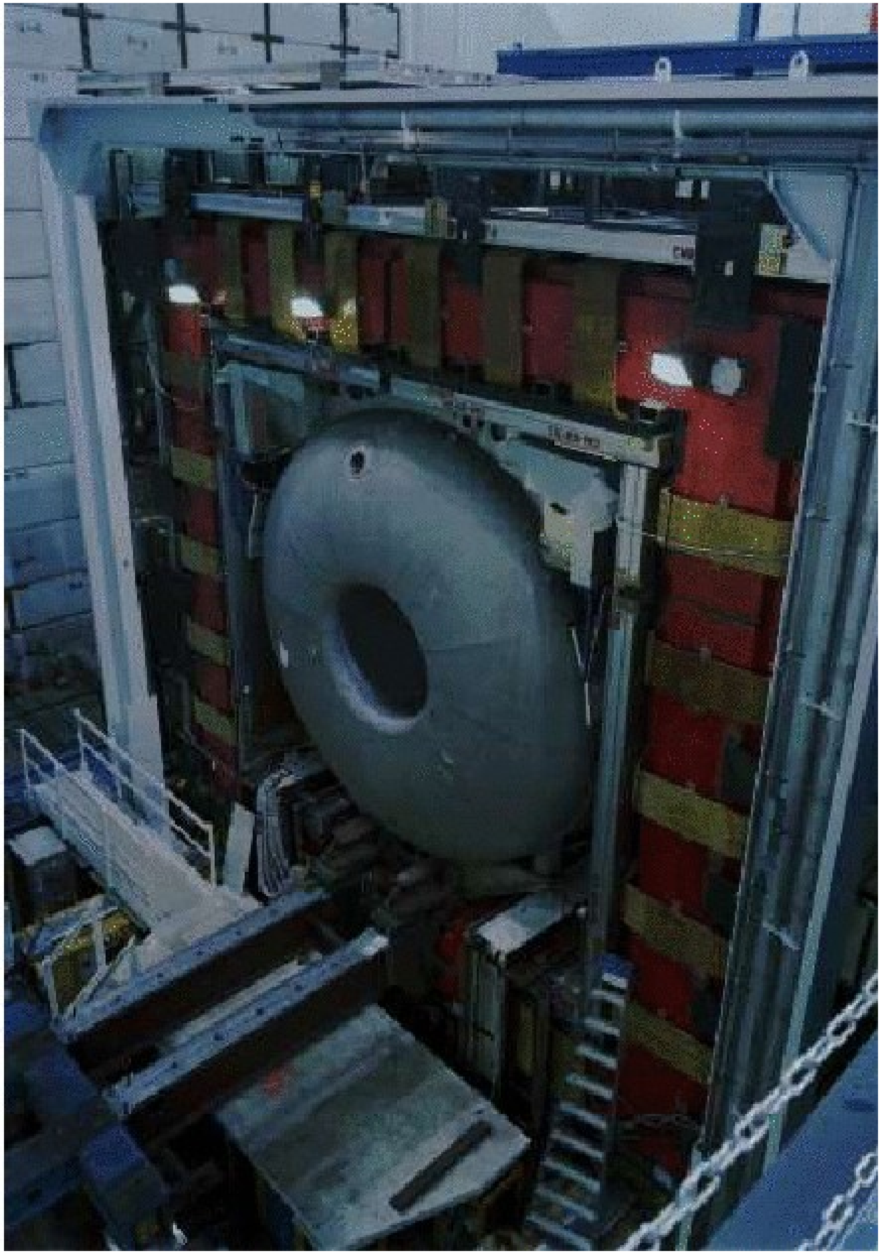
- Fraction of dijet (DP) events drops with increasing jet PT
- Measurement is done in the three bins of 2nd jet pT: 15-20, 20-25, 25-30 GeV


Booster
CDF
Protons
DØ
Tevatron
$\bar{p}$ source
Anti-protons
Main Injector
The Tevatron
Proton-antiproton collider with bunch crossings of 396 ns
Collisions occur at a center-of-mass energy $\sqrt{s}$ = 1.96 TeV
Instantaneous luminosities *greater than* 3×10^{32} $cm^{-2}s^{-1}$

D0 detector

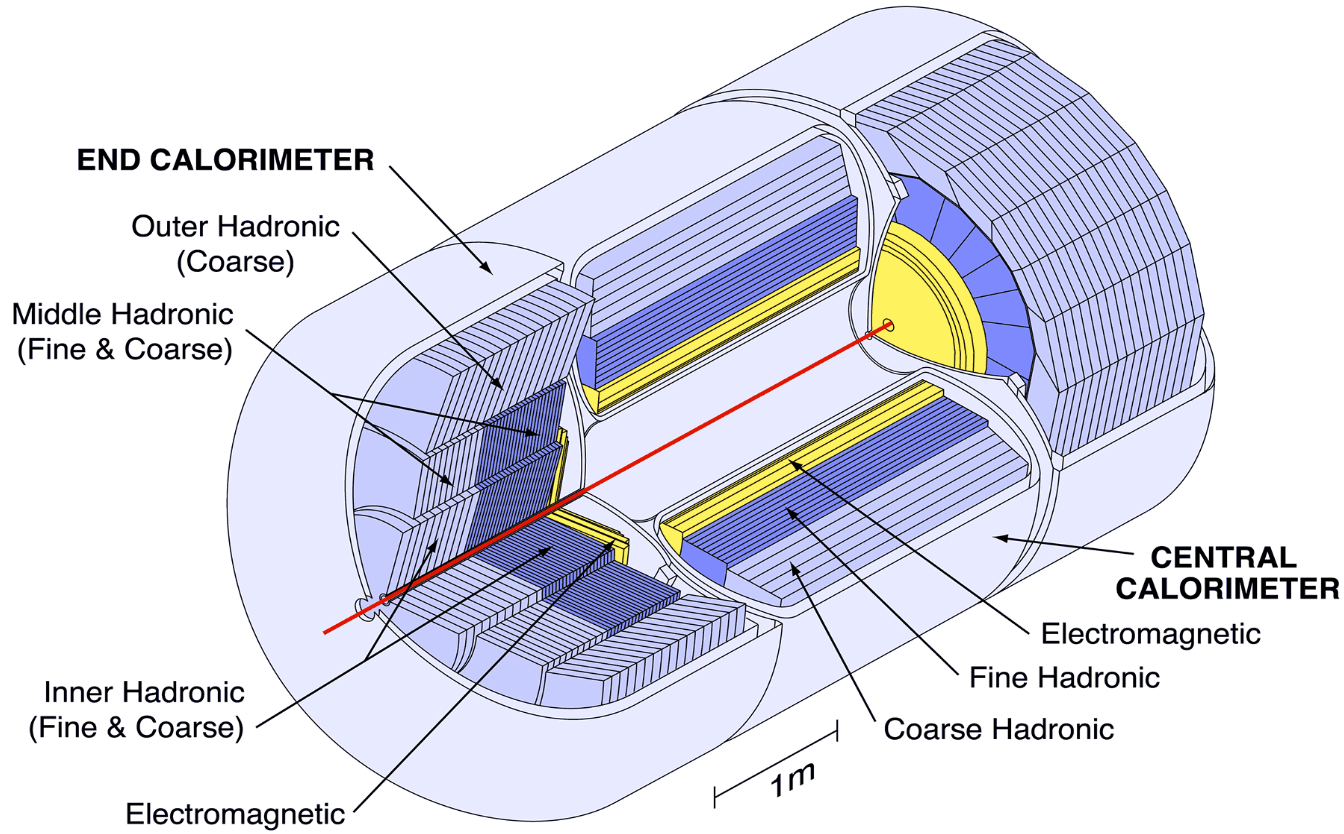
- Three main systems:
  - Tracker (silicon and scintillating fibre)
  - Calorimeter (lAr/U, some scintillator)
  - Muon chambers and scintillators
- First two used in this measurement





D0 calorimeter

✓ The most important detector for photon and jet measurements



✓ Calorimeter has three main subregions: Central (||<1.1), Intercryostat ($1.1 < |\eta| < 1.5$) and End calorimeters ($1.5 < |\eta| < 4.2$)

✓ Liquid argon/Uranium Calorimeter:

- Stable response, good resolution
- Partially compensating (e/h ~1)

Photon and jet identification

JETS:

- Midpoint Cone algo with R=0.7
- $|\eta|<3.5$
- #jets ≥ 3
- pT of any jet > 15 GeV
- pT of leading jet > 25 GeV
- pT of 2nd jet (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

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

DOUBLE PARTON INTERACTION MODEL (MIXDP)

Built from D0 data samples:

A: photon + ≥1 jet from γ+jets data sample:
- 1 VTX events
- leading jet pT>25 GeV, |η|<3.5.

B: ≥1 jets from MinBias sample:
- 1 VTX events
- jets with pT's recalculated to the primary vertex of sample A have pT>15 GeV and |η|<3.5.

- **A** & **B** samples have been mixed with jets pT re-ordering
- Events should satisfy photon+≥3 jets requirement.
- △R(photon, jet1, jet2, jet3)>0.7

⇨ Two scatterings are assumed to be independent by construction

DOUBLE PPbar INTERACTION MODEL (MIXDI)

Built from D0 data samples:

A: photon + ≥1 jet from γ+jets data sample:
- 2 VTX events
- jets with leading jet pT>25 GeV, |η|<3.5.

B: ≥1 jets from MinBias sample:
- 2 VTX events (to take in account underlying energy)
- jets with pT's recalculated to the vertex of sample A.

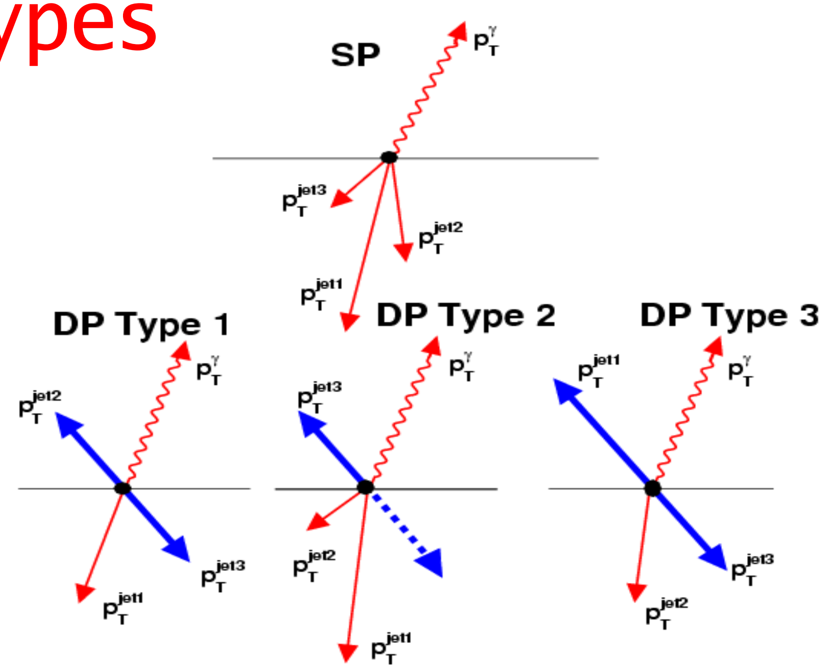
- in case of 2 jets, both jets are required to originate from the same events vertex using jet track info.
- **A** & **B** samples have been mixed with jets pT re-ordering
- Events should satisfy photon+≥3 jets requirement.
- $\triangle$R(photon, jet1, jet2, jet3)>0.7

BGD2VTX (background sample)

Obtained by a direct requirement for all three jets to originate from one vertex using jet track information.

Fractions of MixDP event types

Event Types	$p_T^{\mathrm{jet}\,2}$ (GeV)		
	$15-20$	$20-25$	$25-30$
Type 1	0.261 ± 0.005	0.217 ± 0.016	0.135 ± 0.006
Type 2	0.729 ± 0.007	0.778 ± 0.008	0.861 ± 0.009
Type 3	0.010 ± 0.001	0.005 ± 0.001	0.004 ± 0.001



- Type 2 events (1 jet from dijet and 1 brems. jet) dominate ($\geq$73%): It is caused by the jet reco eff-cy and threshold (6 GeV for jet pT_raw) and difference in the jet pT (it is smaller for dijets)
- CDF ('97) found at least 75% Type 2 events: a good agreement.
- Small fraction of Type 3 events.
- Important: dominance of Type 2 naturally reduces a dependence of results (see variable ΔS below) on possible issues with correlations between 1st & 2nd parton interactions.

Distinguishing variables

"S-family" variables:

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

$\vec{P}_T(\gamma,i)$ $\vec{P}_T(j,k)$ – transverse momenta of the two-body system.

$$S'_{pT} = \frac{1}{\sqrt{2}} \sqrt{\left(\frac{|\vec{P}_T(\gamma,i)|}{|\vec{P}_T^{\gamma}|+|\vec{P}_T^{i}|}\right)^2 + \left(\frac{|\vec{P}_T(j,k)|}{|\vec{P}_T^{j}|+|\vec{P}_T^{k}|}\right)^2}$$

$\Delta\phi(\gamma,i)$ $\Delta\phi(j,k)$ – azimuthal angles between them

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

$\delta P_T(\gamma,i)$ $\delta P_T(j,k)$ $\delta\phi(\gamma,i)$ $\delta\phi(j,k)$ – the corresponding uncertainties from MIXDP events

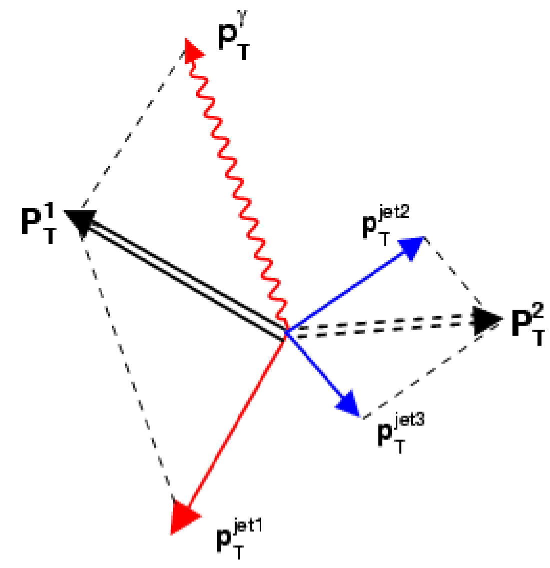
The pairs are constructed by grouping photon with 3 jets in three possible configurations: $(\gamma + jet_i) \times (jet_j + jet_k)$ where i, j, k = (1,2,3).

In the signal sample most likely (>90%) S are minimized by pairing photon with the leading jet.

"ΔS-family" variables

ΔS_{pT} $\Delta S'_{pT}$ ΔS_{ϕ} – 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* (Type 1) double parton interaction when both, 2nd and 3rd jets in the "γ+3jets"s ystem are from 2nd (dijet) interaction.

➔ In reality, one of the dijet jets can be replaced by a radiation jet (Type 2) with a larger pT what makes ΔS distribution less flat with a bump closer to Pi.

The number (fraction) of DP events

Since dijet pT cross section drops faster than that of radiation jets the different DP fractions in various (2nd) jet pT intervals are expected. The larger 2nd jet pT the smaller DP fraction.

Dataset 1 - “DP-rich”, smaller 2nd jet pT bin, e.g. 15-20 GeV
Dataset 2 - “DP-poor”, larger 2nd jet pT bin, e.g. 20-25 GeV

Each distribution can be expressed as a sum of DP and SP :

$$D_1 = f_1 M_1 + (1 - f_1) B_1$$

$$D_2 = f_2 M_2 + (1 - f_2) B_2$$

D_i - data distribution
M_i - MIXDP distribution
B_i - background distribution
f_i - fraction of DP events
$(1 - f_i)$ - fraction of SP events

$$D_1 - \lambda K D_2 = f_1 M_1 - \lambda K f_2 M_2 \quad \text{where} \quad \lambda = \frac{B_1}{B_2} \qquad K = \frac{(1 - f_1)}{(1 - f_2)}$$

$$D_1 - \lambda K D_2 = f_1 M_1 - \lambda K C f_1 M_2$$

Here $C = \frac{f_2}{f_1}$ is a ratio of signal fractions.

Behaviour of the dijet events in the single interaction is found to be identical to the behaviour of dijets from the 2nd hard (DP) interaction. Therefore MIXDP sample should model correctly properties of DP events and one can write :

$$\frac{N_2^{DP}}{N_1^{DP}} = \frac{N_2^{MIXDP}}{N_1^{MIXDP}}$$

The C parameter is determined from the MIXDP and DATA samples, i.e. without knowledge of a real amount of the DP fraction in data:

$$C = \frac{f_2}{f_1} = \left(\frac{N_2^{DP}}{N_2^{DATA}}\right)\left(\frac{N_1^{DATA}}{N_1^{DP}}\right) = \left(\frac{N_2^{MIXDP}}{N_2^{DATA}}\right)\left(\frac{N_1^{DATA}}{N_1^{MIXDP}}\right)$$

To get DP fraction in a given bin of 2nd jet pT, we fit MIXDP to data by minimizing χ^2:

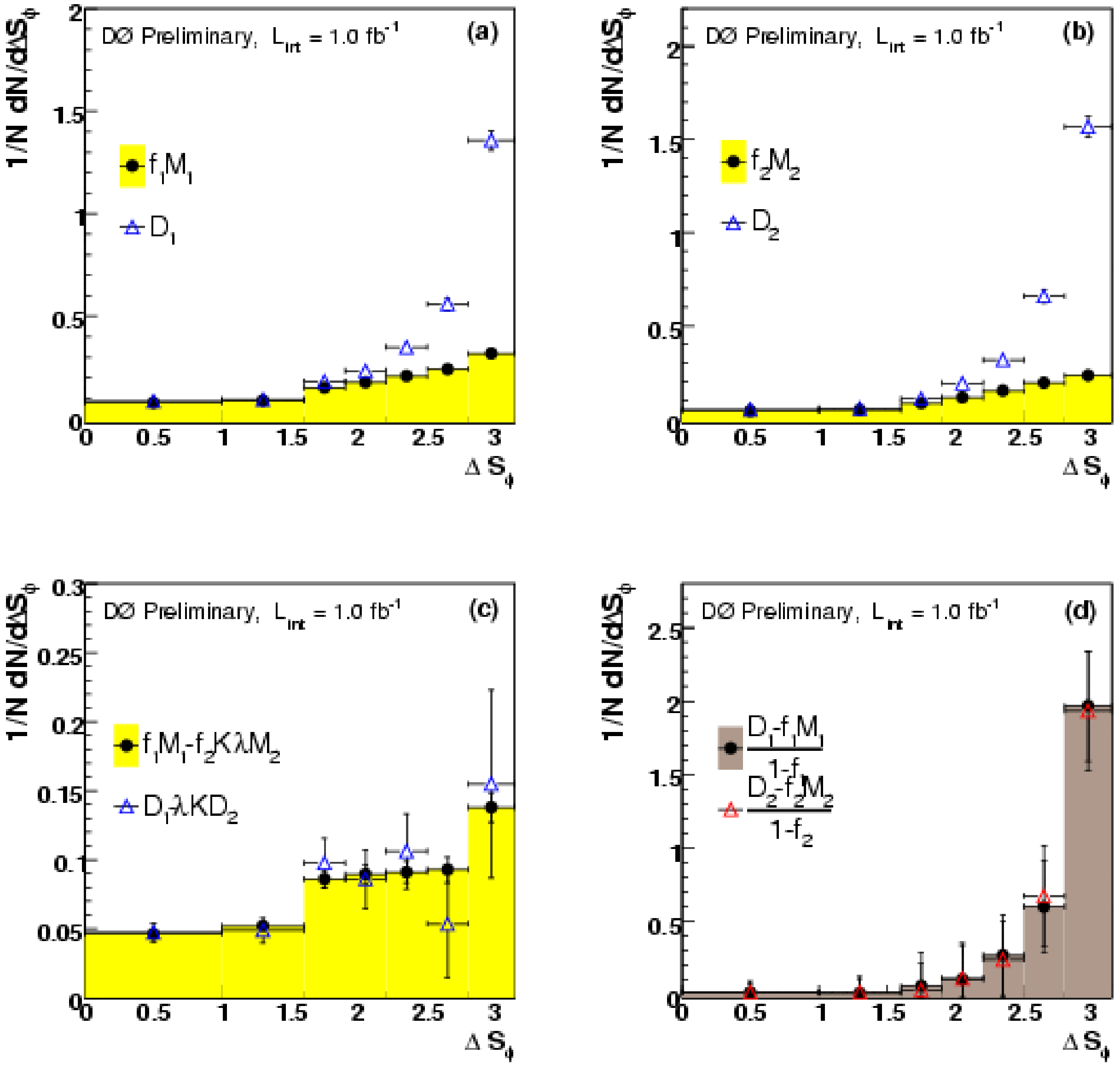
$$\chi^2 = \sum_{i=1}^{Nbins} (F_i)^2$$

where $$F = |D_1 - f_1 M_1 - \lambda K D_2 + \lambda K C f_1 M_2| / \sigma$$

and valid in each i-th bin of ΔS.

Parameter σ contains uncertainties from C, D_1, D_2, M_1, M_2 and λ.
The only free parameter f_1 is obtained from minimization.

Dataset 1: Photon pT: 60-80 GeV, 2^{nd} jet pT: 15-20 GeV
Dataset 2: Photon pT: 60-80 GeV, 2^{nd} jet pT: 20-25 GeV



$$D_1 - \lambda K D_2 = f_1 M_1 - \lambda K f_2 M_2$$

a) Distributions for the 1^{st} dataset: data points and MIXDP weighted with f1 found from the minimization.

b) Distributions for the 2^{nd} dataset: data points and MIXDP weighted with f2=C·f1.

c) Difference of the data distributions in 1 and 2 datasets i.e. the left side of the equation (1):

$$D_1 - K D_2$$

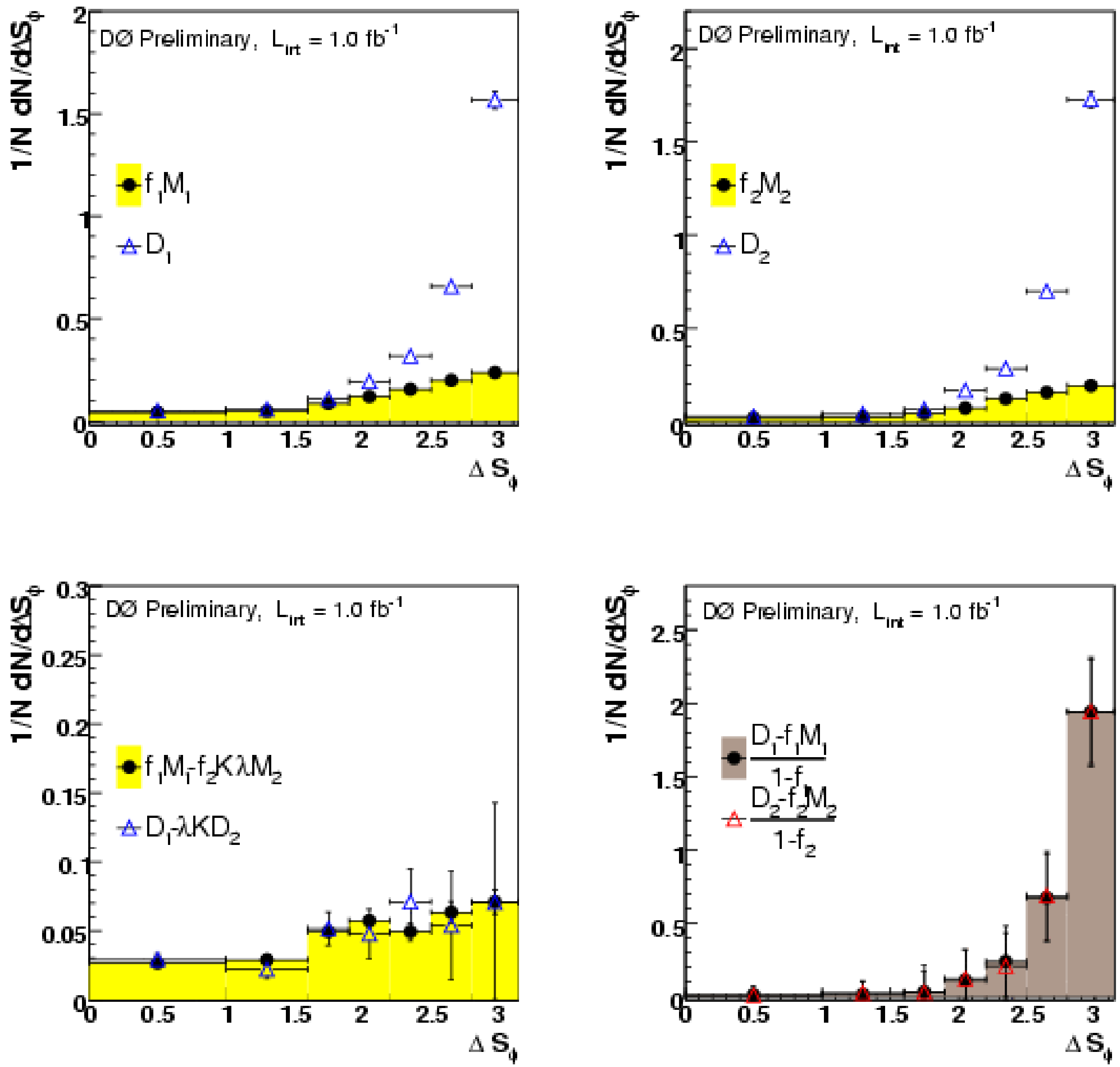
and MIXDP prediction i.e. right side of the equation (1):

$$f_1 M_1 - C f_1 K M_2$$

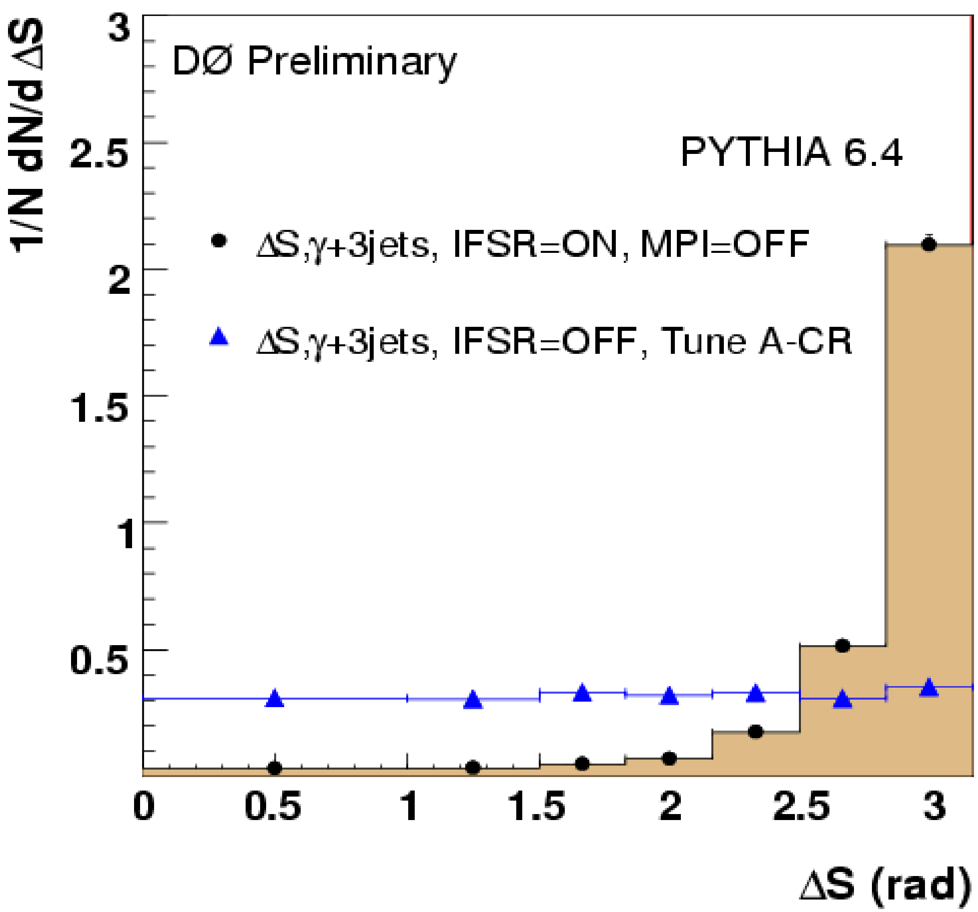
d) Extracted SP distributions in the 1^{st} and 2^{nd} datasets, obtained by subtracting MIXDP from the Data:

$$\frac{D_1 - f_1 M_1}{1 - f_1} \qquad \frac{D_2 - f_2 M_2}{1 - C f_1}$$

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

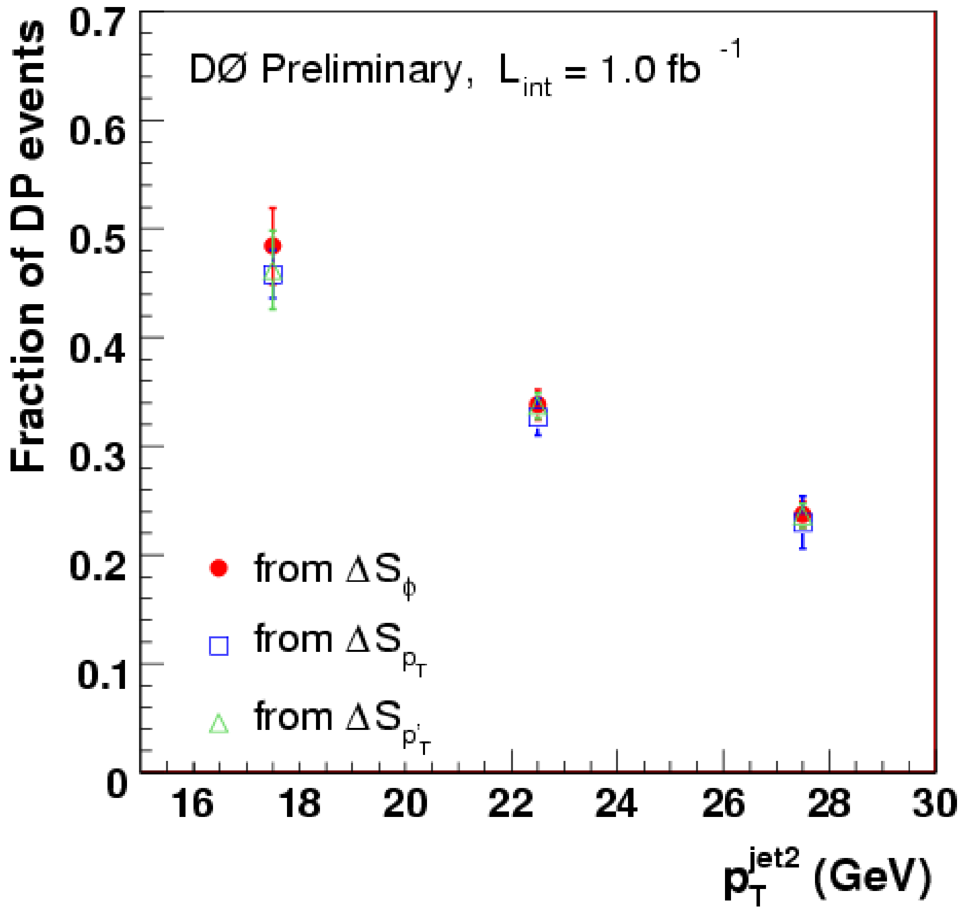


$\triangle$S distribution for γ+3jets events for pure SP events
(Pythia, particle distribution smeared with detector resolution)

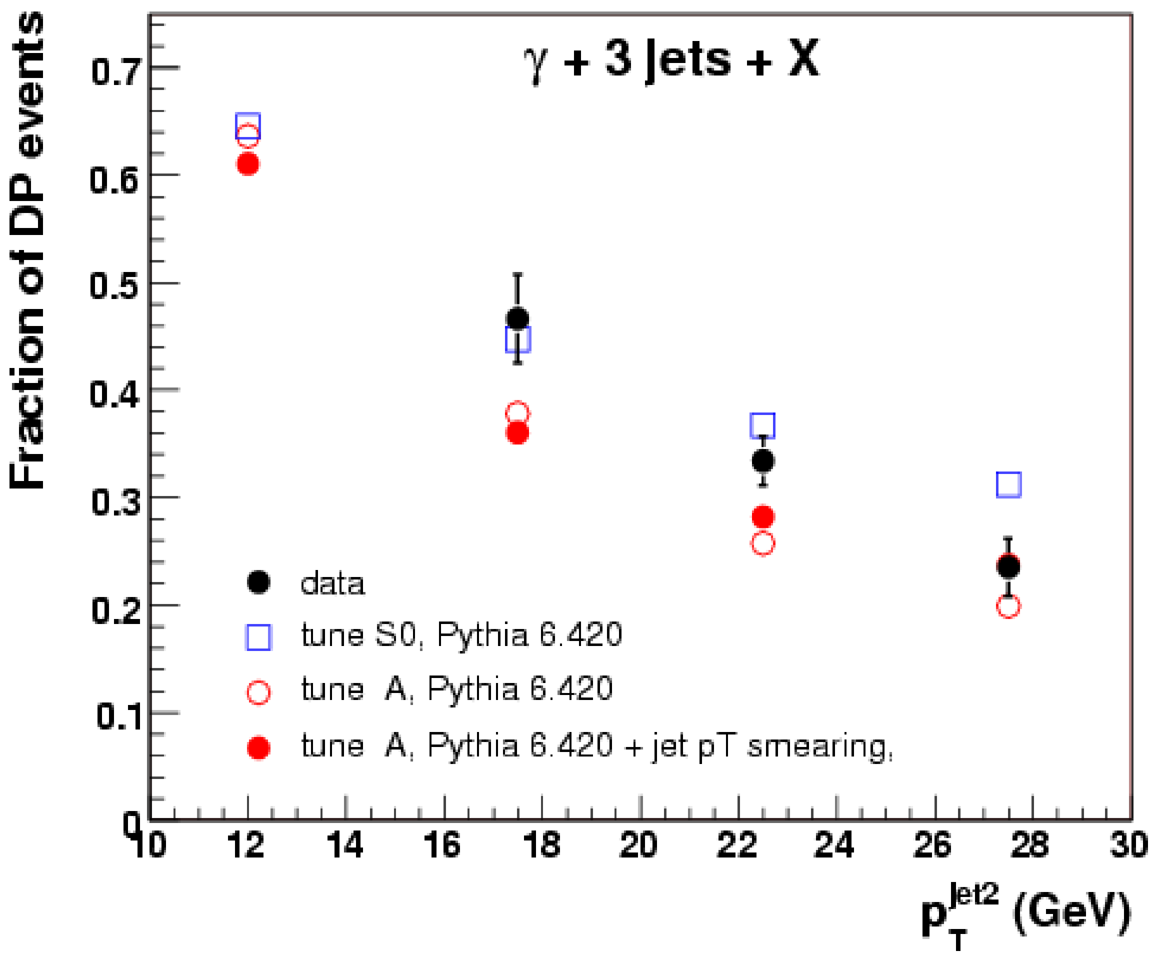


To be compared with bottom right plots from the previous 2 slides.

Fractions of DP events



Fractions of DP events extracted from the γ+3jets events with different MPI models (Pythia) and in D0 data.



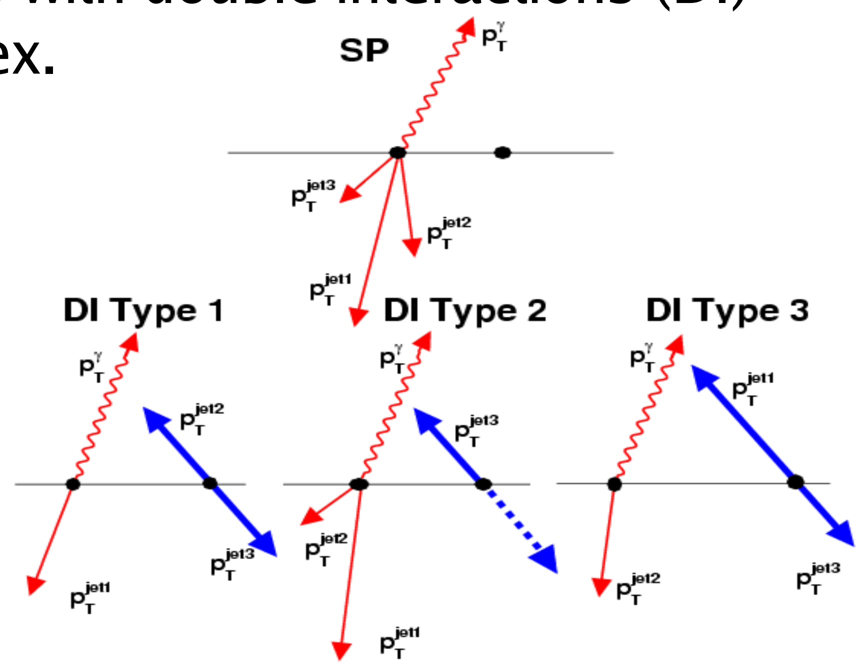
The number (fraction) of DI events

Possible event classes can be defined according the jet origin vertex: 1st vertex (V1) or 2nd vertex (V2)

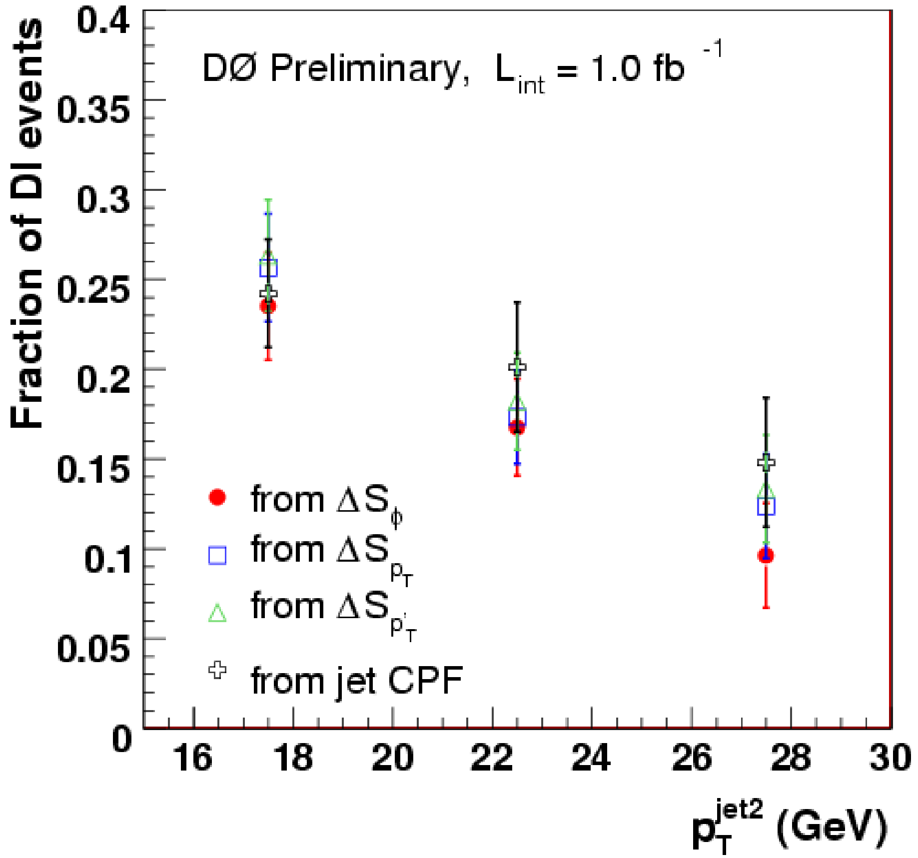
1. All three jets have originated from V1 or V2
2. Jet-1 and Jet-2 are from V1(V2) while Jet-3 is from V2(V1).
3. Jet-1 and Jet-3 are from V1(V2) while Jet-2 from V2(V1).
4. Jet-1 is from V1(V2) while Jet-2 and Jet-3 are from V2(V3).

Class (1) corresponds to “ γ+3jets”co ming from a single ppbar collision, ie. same vertex. All other classes are events with double interactions (DI) in which 1 or 2 jets come from different vertex.

Fractions of DI events are found using the main distinguishing variables and cross checked using jet track information (looking at the vertex with largest track pT fractions).



Fractions of DI events



Photon and jet efficiencies

The difference in DI and DP efficiencies can be caused by different amount of underlying energy in the single and double ppbar collision events. As a result, one can expect different photon selection, jet reco and jet finding efficiencies as well as jet energy scale.

The jet efficiencies are calculated using MIXDP and MIXDI "γ+3jets" signal samples built in data. The ratios of DI/DP efficiencies are found to be varied as 0.58 – 0.55 for different 2nd jet pT. Systematics is relative 5.5%.

Photon efficiencies have been calculated in '$\gamma+\geq 3$ jets' MC events with 1 and 2 vertices. Found ratio for 1VTX/2VTX events is 0.96 ± 0.03.

Agreement of photon purities has been checked separately using di-jet QCD 1&2 VTX samples. The found ratio is 0.99 ± 0.06.

Vertex efficiencies

- Distance to the detector center in Z : |Z|<60cm;
- The number of tracks associated with the vertex Ntrk=3.

The vertex efficiency corrects for single (double) collision events that are lost in the DP (DI) candidate sample.

We found that both, 1- and 2-vertex, efficiencies do not depend on 2nd jet pT and have similar luminosity dependencies.

We found the the ratio of 2vtx/1vtx efficiencies = 1.08±0.01.

$N_c(n)$ and σ_{hard}

It is calculated from the expected average number of hard interactions at a given instantaneous luminosity L_{inst}:

$$\bar{n} = (L_{inst}/f_0)\,\sigma_{hard}$$

using Poisson statistics.

Here:
f_0 is frequency of beam crossings at the Tevatron in RunII.
σ_{hard} is hard (non-elastic, ND) ppbar cross section.

σ_{hard} can be obtained from the total inelastic cross section (FERMILAB-TM-2365) σ_{inel}=60.7±2.4 mb and single, double diffractive cross sections measured by CDF at sqrt(s)=1.8 TeV (σ_{sd} = 9.46±0.44 mb, σ_{dd} = 6.42±1.70 mb) and extrapolated to sqrt(s)=1.96 TeV.

Then σ_{hard} (1.96 TeV) = 44.76 ± 2.89 mb.

Nc(n) can be calculated using RunIIa luminosity profile using either averaged L_{inst} or integrating over the L_{inst} profile and summing Nc(1) and Nc(2) in all L_{inst} bins.
The both methods give about the same result.
The 2nd method is taken as default and it gives

$$R_C = \frac{N_C(1)}{2N_C(2)} \sigma_{hard} = 52.3 \pm 3.1\, mb$$

Variation of σ_{hard} within uncertainty (3.1 mb) gives the uncertainty for Rc just ~1.0 mb.

Calculation of σ_{eff}

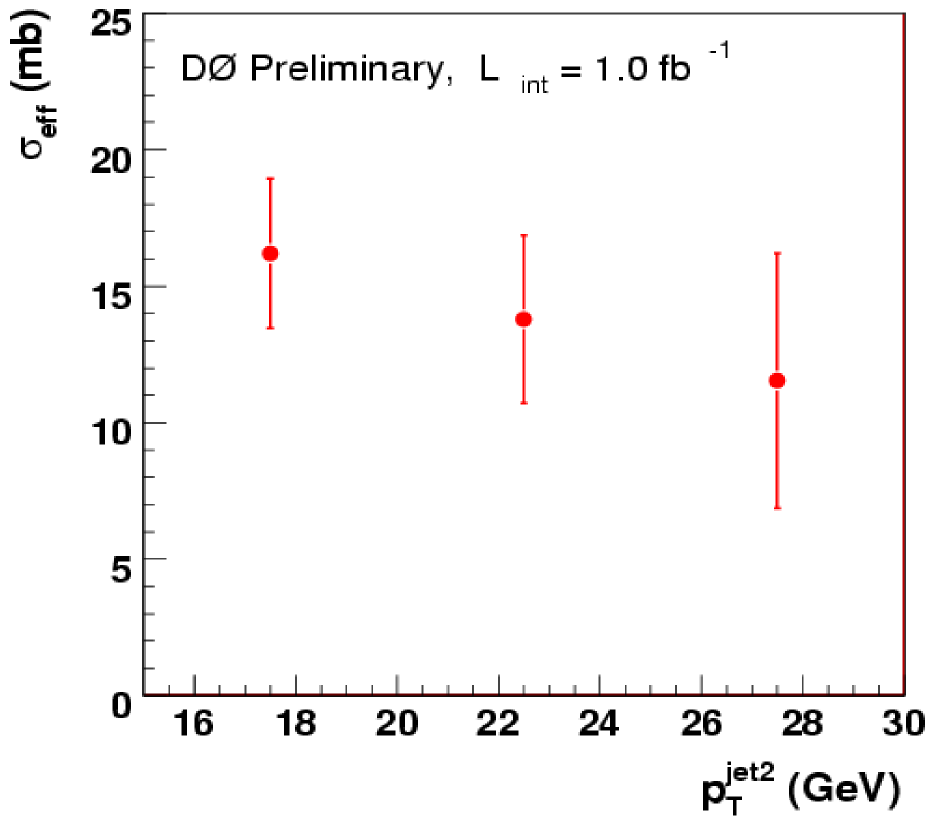
We sum up all together and calculate σ_{eff} in the three bins of 2nd jet pT:

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}	$\varepsilon_{\text{DI}}/\varepsilon_{\text{DP}}$	JES	$R_c \cdot \sigma_{\text{hard}}$	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



We can state that σ_{eff} values in different jet pT bins agree with each other within their uncertainties. Using this fact and also that syst. uncertainties between pT bins have very small correlation one can calculate averaged value:

$$\boxed{\sigma_{eff} = 15.1 \pm 1.9 \ mb}$$

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 about 0.46 at 15<pT<20 GeV to 0.22 at 25<pT<30 GeV.

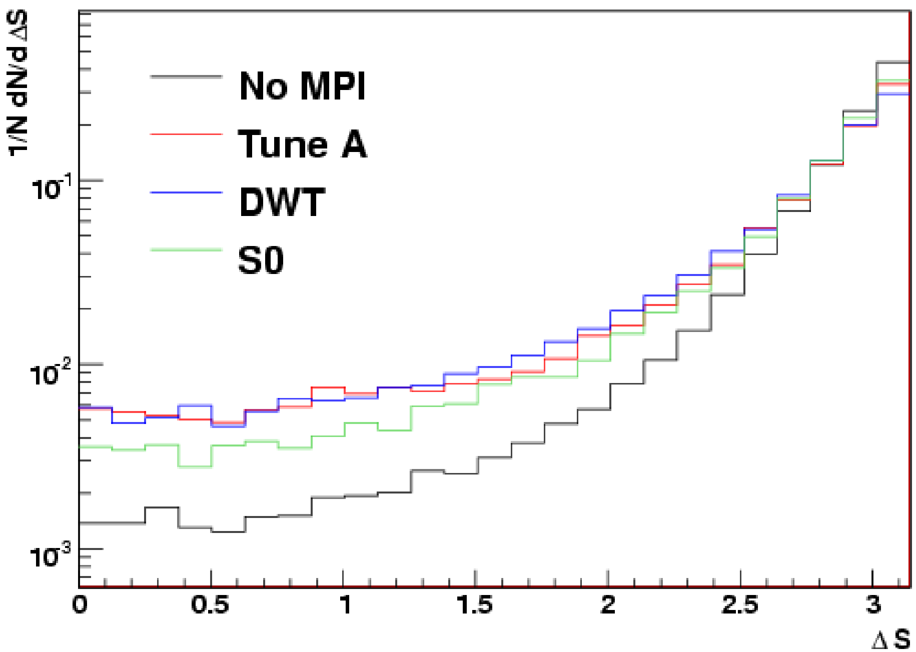
- Effective cross section σ_{eff} has been measured in the same jet pT bins and found to be stable within uncertainties.

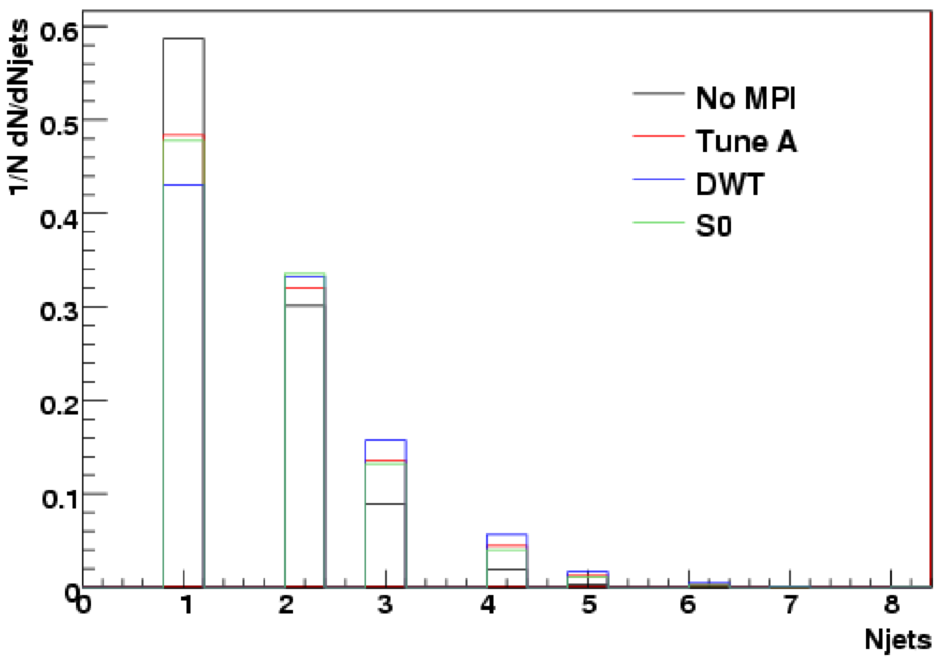
- Results are consistent with previous two CDF, UA2 (AFS?) measurements.

These facts indicate a stable behavior of σ_{eff} w.r.t. the transverse momentum of the jet produced in the second parton-parton interaction.

BACK-UP SLIDES

Pythia MPI Tunes: ΔS and Njets

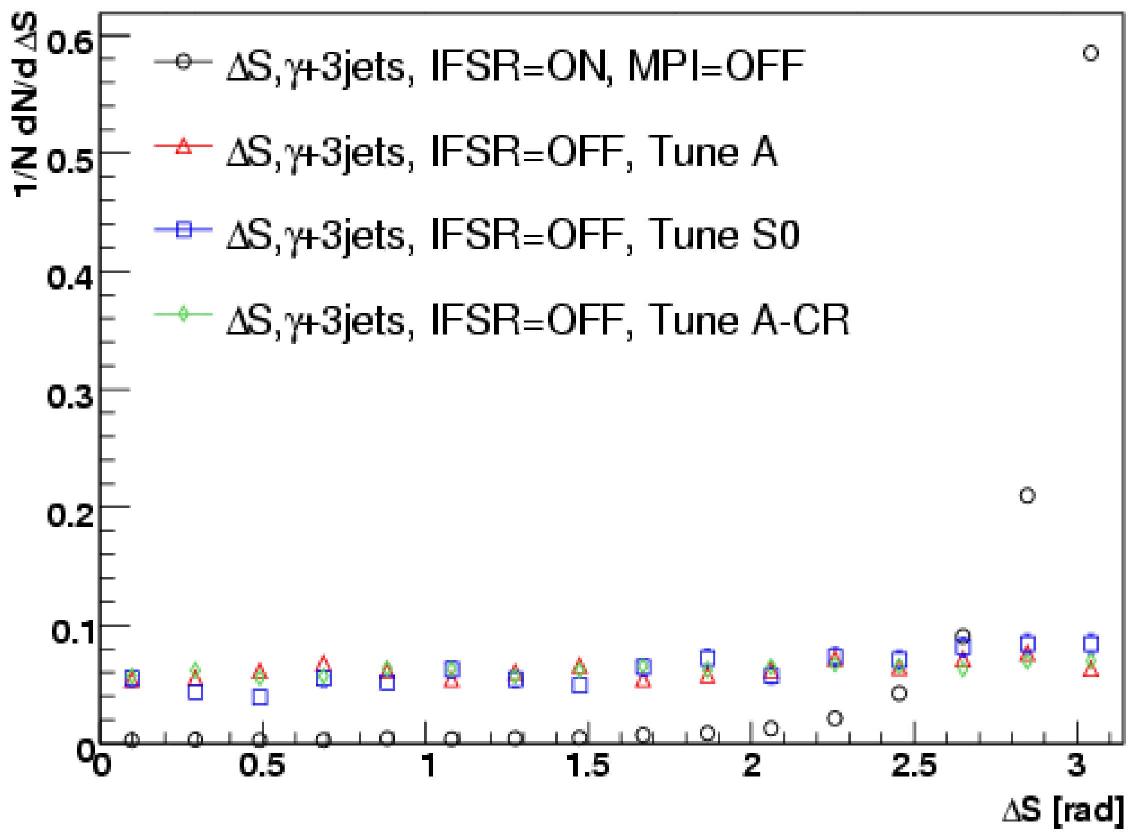




Pythia predictions with MPI tunes:

- ΔS is much broader for events with MPI events and almost flat at $\Delta S < 1.5$
- #events(Njest$\geq$1) / #events(Njets$\geq$3) is larger by a factor 2(!) for MPI events

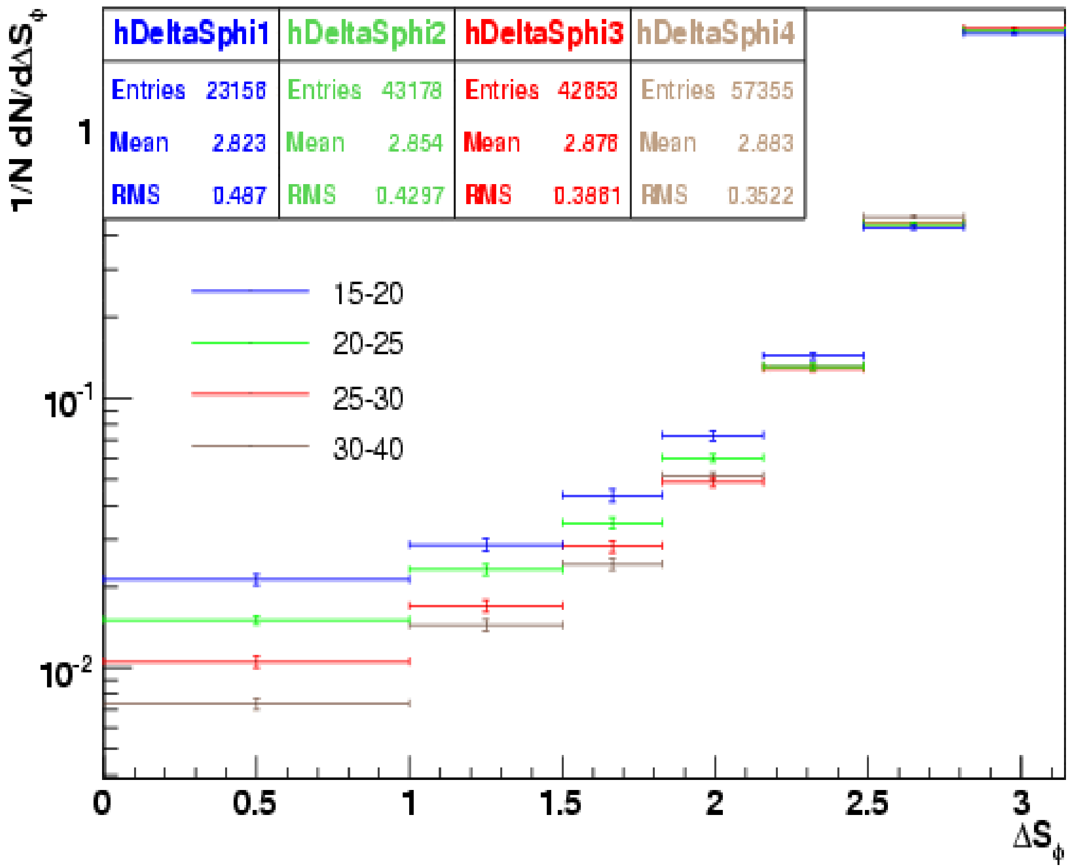
γ+3 jets : Delta S for 3 MPI tunes vs. "no MPI"



- DeltaS for all the MPI tunes (A,S0, A-CR) is expected to be flat while for the single parton interactions (MPI is off) it peaks at Pi .

Extraction of λ-factor

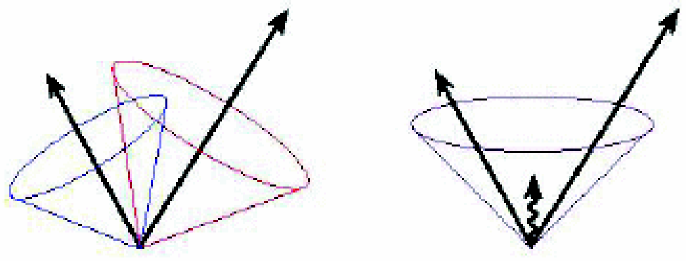
Factor is extracted as a ratio of the fits for ΔS-family variables obtained from the SP (Pythia) background samples in each ΔS bin of the adjacent 2nd jet pT intervals.



ΔS shifts more to Pi with growing 2nd jet pT since they become less sensitive to the soft gluon radiation.

Jet finding algorithm

- Detailed comparison to theory needs a precise definition of jet algorithm
- This measurement uses Run II Midpoint Cone with $R_{cone} = 0.7$



Run I Legacy Cone:

Draw a cone of fixed size in $\eta-\phi$ space around a seed

Compute jet axis from E_T-weighted mean and jet E_T from $\sum E_T$'s

Draw a new cone around the new jet axis and recalculate axis and new E_T

Iterate until stable

Algorithm is **sensitive to soft radiation**

Run II Midpoint Cone:

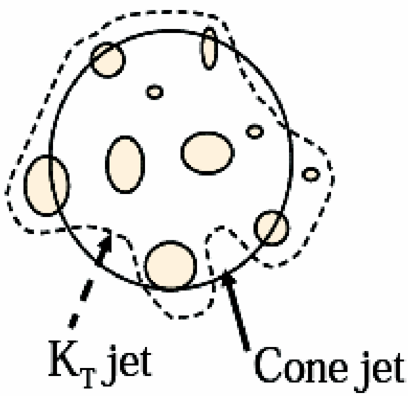
Use 4-vectors instead of E_T

Add additional midpoint seeds between pairs of close jets

Split/merge after stable protojets found

Improved infrared safety at NLO

(D0 Run II/CDF MIDPOINT)



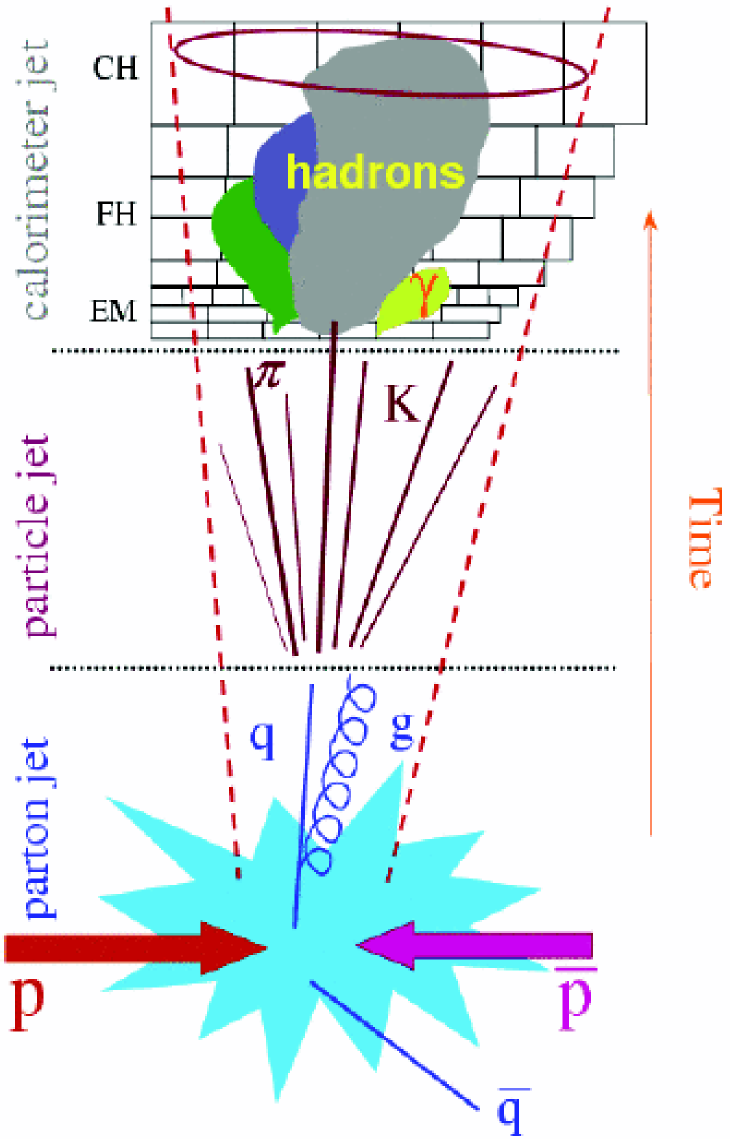
We characterize jets in terms of p_T and y

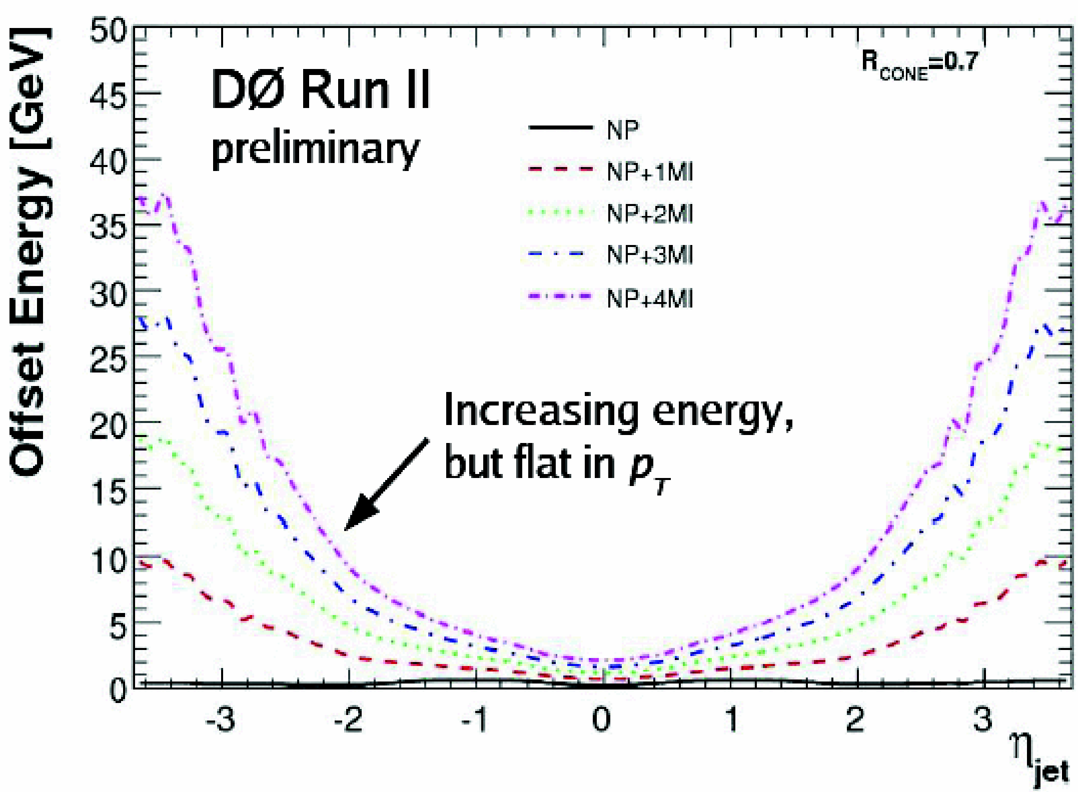
Jet energy scale

- Jet Energy Scale returns the measured calorimeter jet **energy** to the **particle level**

$$E_{ptcl} = \frac{E_{cal} - Offset}{(F_\eta \cdot R) \cdot S} \cdot k_{bias}$$

- Offset is energy not associated to the hard scatter: noise, pile-up, **multiple interactions**
- Response is the fraction of particle jet energy deposited in the calorimeter by the particles
- Detector showering accounts for **energy flow** in and out of the calorimeter jet due to detector effects (finite calorimeter tower and hadron shower size, magnetic field)
- Method biases corrected using tuned MC




Offset Energy [GeV]
DØ Run II
preliminary
R_CONE=0.7
NP
NP+1MI
NP+2MI
NP+3MI
NP+4MI
Increasing energy,
but flat in p_T
η_{jet}

Photon Isolation