Double Parton Interactions at D0 experiment

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Baldin ISHEPP XXII

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OUTLINE

DP Effective cross section measurement using γ+3jet events:

- Double parton event fraction
- Effective cross section measurement

DP Effective cross section measurement using γ+b/c+2jets events:

- Double parton event fraction
- Effective cross section measurement

Angular decorrelations in γ+2jet and γ+3jet events:

- Cross sections
- Double parton event fraction
- Tripple parton event fraction

Double Parton as a background WH production at Tevatron

Summary

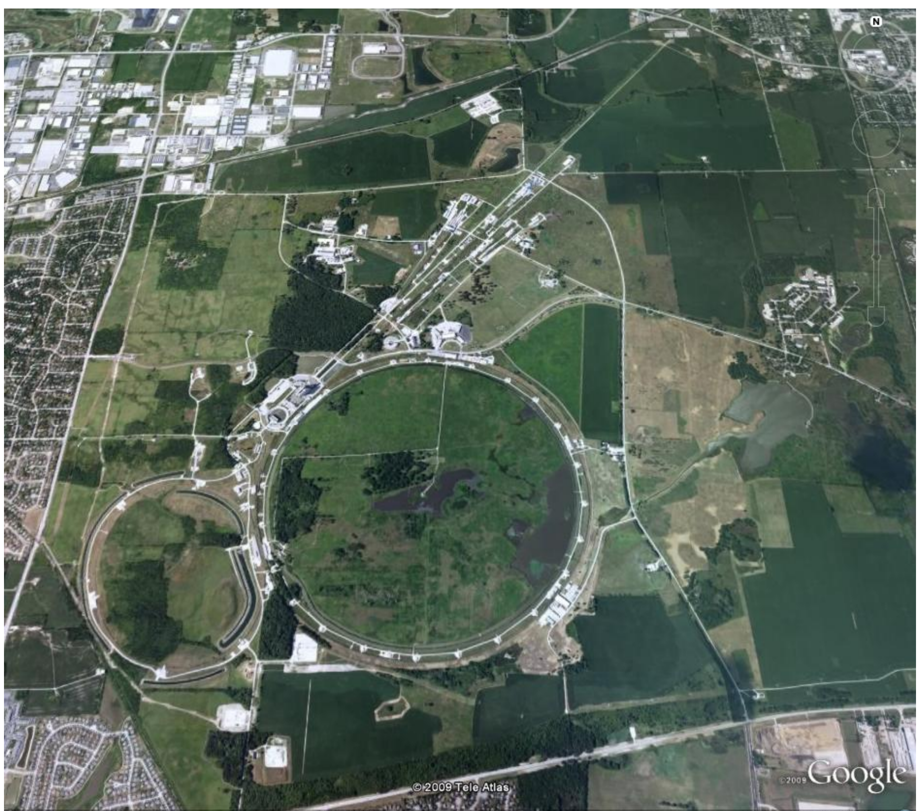
Run II ended on Sep 30, 2011

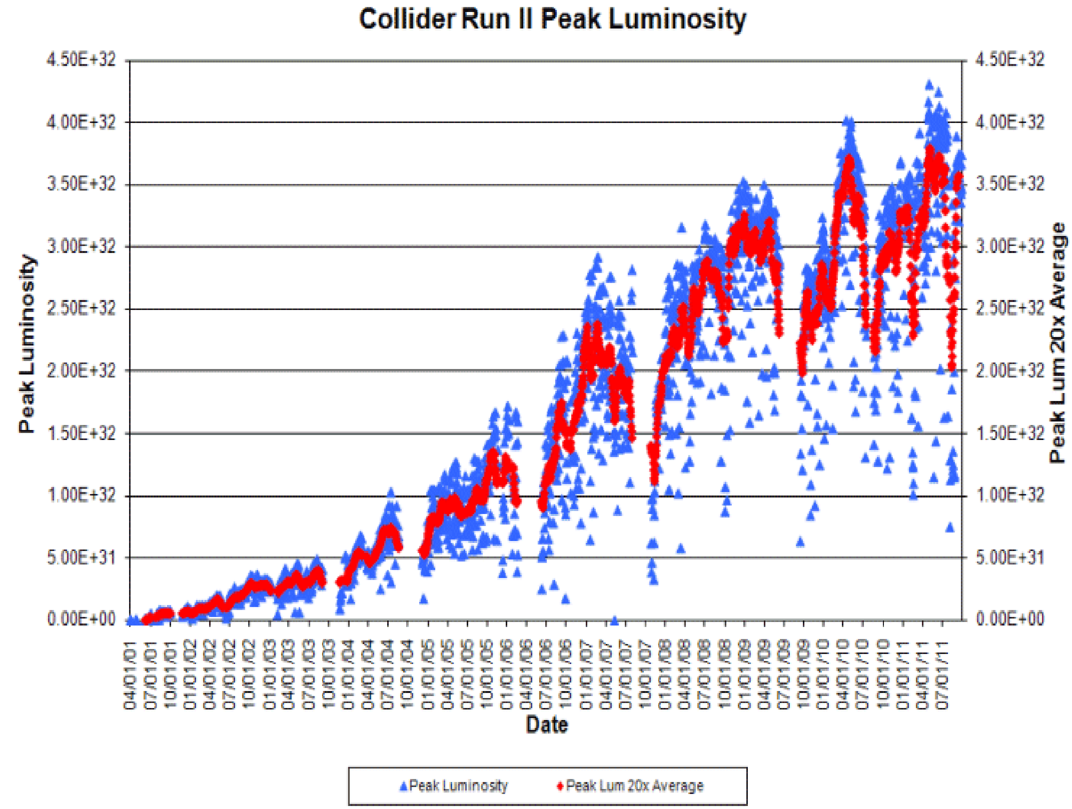
Typical data collection eff-cy is 90-92%

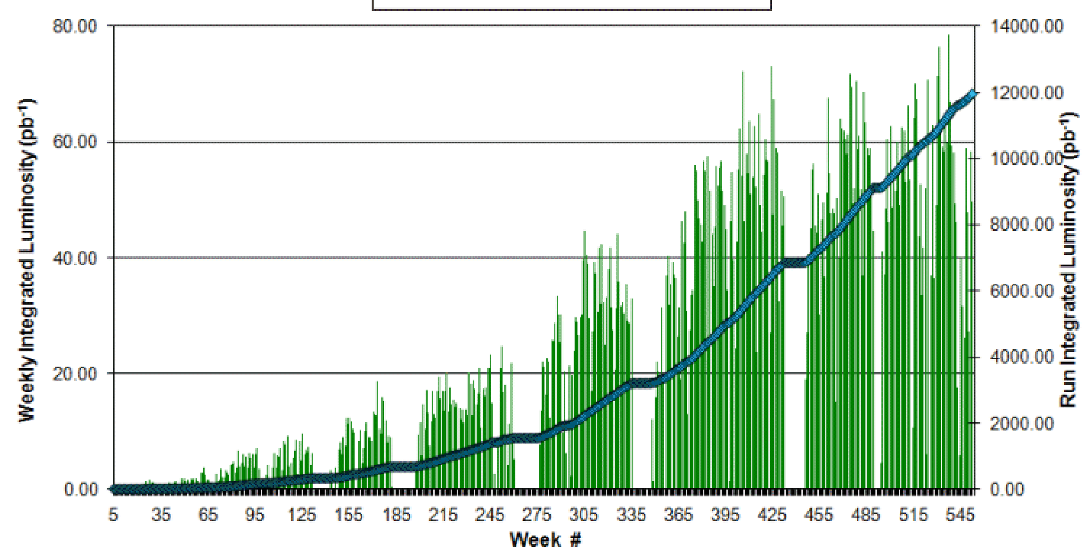
Peak Luminosity: 4.3×10^{32} $cm^{-2}s^{-1}$

Delivered about 12 fb^{-1}

To compare: Run I delivered 120 pb^{-1}



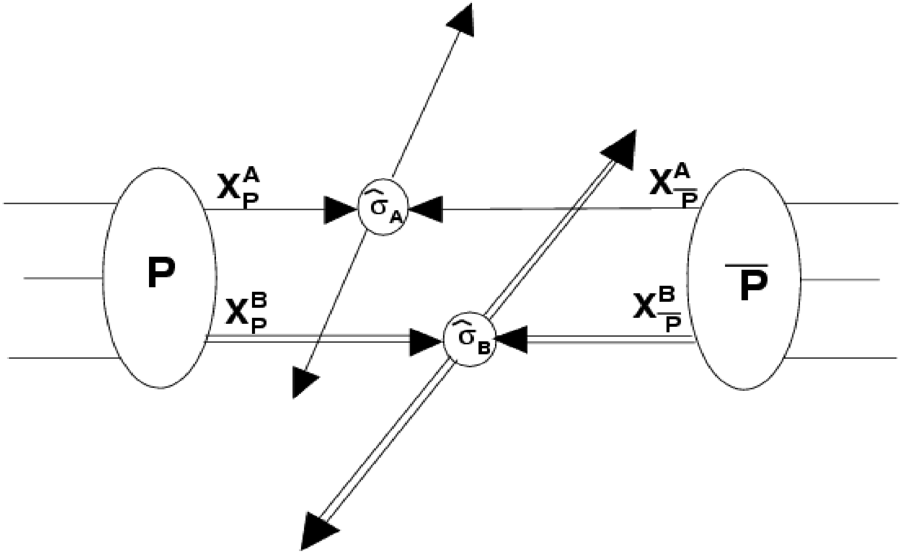




Double parton interactions in γ+3jet events in ppbar collisions at $\sqrt{s}$=1.96 TeV in D0

Phys.Rev.D81,052012(2010)
arXiv:0912.5104

$$\sigma_{DP} = \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$



σ_{DP} - double parton cross section for processes A and B

σ_{eff} - factor characterizing size of effective interaction region

 contains information on the spatial distribution of partons.

Uniform: σ_{eff} is large and σ_{DP} is small

Clumpy: σ_{eff} is small and σ_{DP} is large

- σ_A and σ_B grow with $\sqrt{s}$ σ_{DP} should grow even faster!
- σ_{eff} (on top of pure QCD motivations) is needed for precise estimates of background to many rare processes (especially with multi-jet final state)

 Being phenomenological, it should be measured in experiment !!

Experiment	$\sqrt{s}$ (GeV)	Final state	p_T^{min} (GeV)	η range	σ_{eff}
AFS (pp), 1986	63	4 jets	$p_T^{\text{jet}} > 4$	$\|\eta^{\text{jet}}\| < 1$	~ 5 mb
UA2 ($p\bar{p}$), 1991	630	4 jets	$p_T^{\text{jet}} > 15$	$\|\eta^{\text{jet}}\| < 2$	> 8.3 mb (95% C.L.)
CDF ($p\bar{p}$), 1993	1800	4 jets	$p_T^{\text{jet}} > 25$	$\|\eta^{\text{jet}}\| < 3.5$	$12.1^{+10.7}_{-5.4}$ mb
CDF ($p\bar{p}$), 1997	1800	$\gamma + 3$ jets	$p_T^{\text{jet}} > 6$	$\|\eta^{\text{jet}}\| < 3.5$	
			$p_T^{\gamma} > 16$	$\|\eta^{\gamma}\| < 0.9$	$14.5 \pm 1.7^{+1.7}_{-2.3}$ mb
DØ ($p\bar{p}$), 2010	1960	$\gamma + 3$ jets	$60 < p_T^{\gamma} < 80$	$\|\eta^{\gamma}\| < 1.0$ ||	
			$15 < p_T^{\text{jet2}} < 30$	$1.5 < \|\eta^{\gamma}\| < 2.5$	
				$\|\eta^{jet}\| < 3.0$	$\sigma_{eff} = 16.4 \pm 0.3(\text{stat}) \pm 2.3(\text{syst})$ mb

D0, Phys.Rev.D81, 052012(2010)

AFS'86, UA2'91 and CDF'93

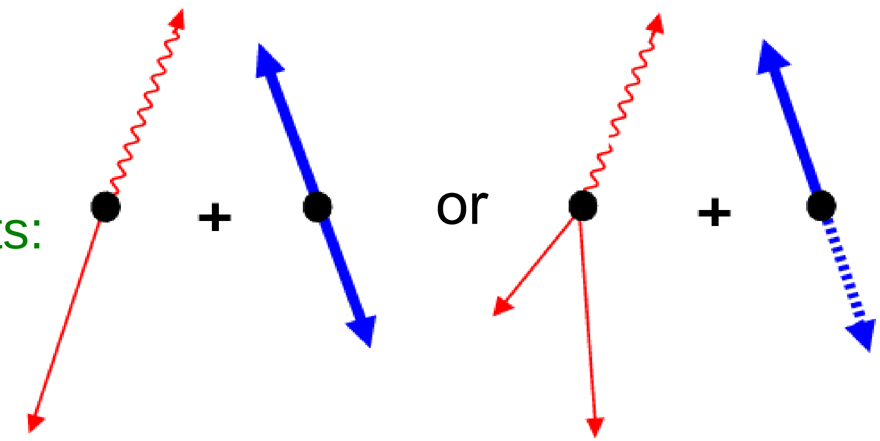
4-jet samples, motivated by a large dijet cross section (but low DP fractions)

CDF’97, D0’10

γ+3jets events, data-driven method: use rates of Double Interaction events (two separate ppbar collisions) and Double Parton (single ppbar collision) events to extract σ_{eff} from their ratio.

- reduces dependence on Monte-Carlo and NLO QCD theory predictions.

Model is built using DØ data
by mixing the samples:



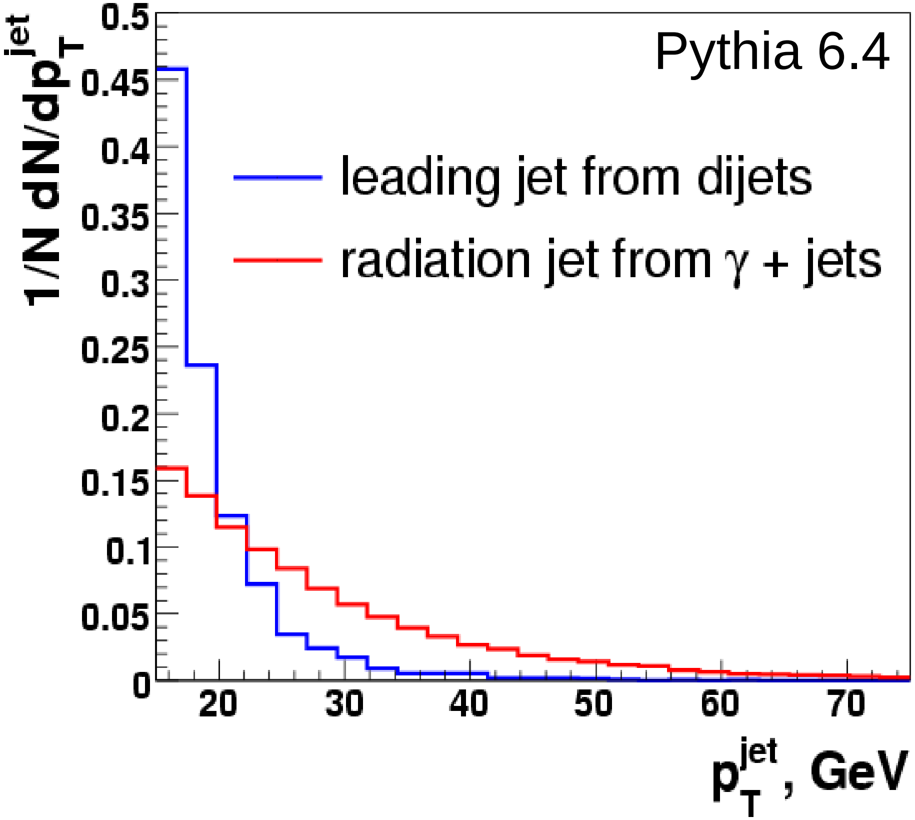
A: photon + 1 jet from γ+jets data events:
- 1-vertex events
- photon pT: 60-80 GeV
- leading jet pT>25 GeV, | |<3.0.

B: Events with 1 jets from MinBias:
- 1-vertex events
- jets with pT's recalculated to the primary vertex of sample A have pT>15 GeV and | |<3.0.

- **A** & **B** samples have been (randomly) mixed with following jet pT re-ordering
- Events should satisfy photon+ 3 jets requirement.
- △R(photon, jet1, jet2, jet3)>0.9

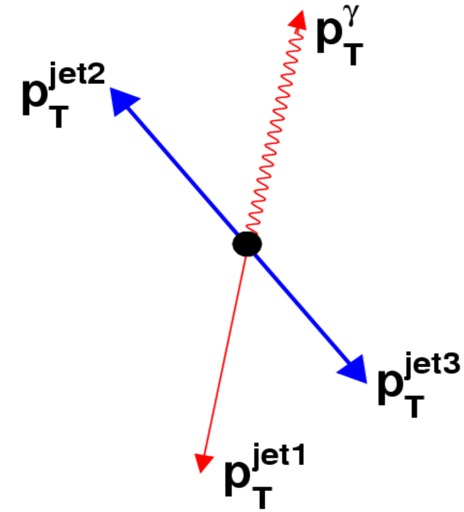
⇨ Two parton scatterings are independent by construction!

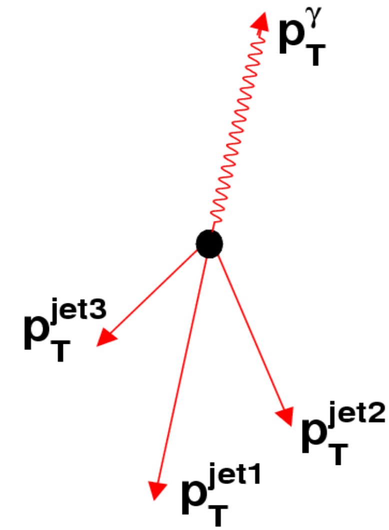
Jet pT: jet from dijets vs. radiation jet from γ+jet events



$\sim 1/p_T^4$

$\sim 1/p_T^2$



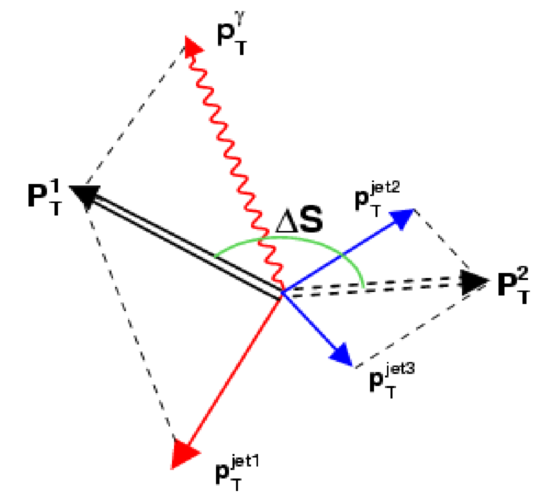


Jet pT from dijets falls much faster than that for radiation jets, i.e. Fraction of dijet (Double Parton) events should drop with increasing jet PT

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

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

$\Delta\phi$ angle between two best pT-balancing pairs



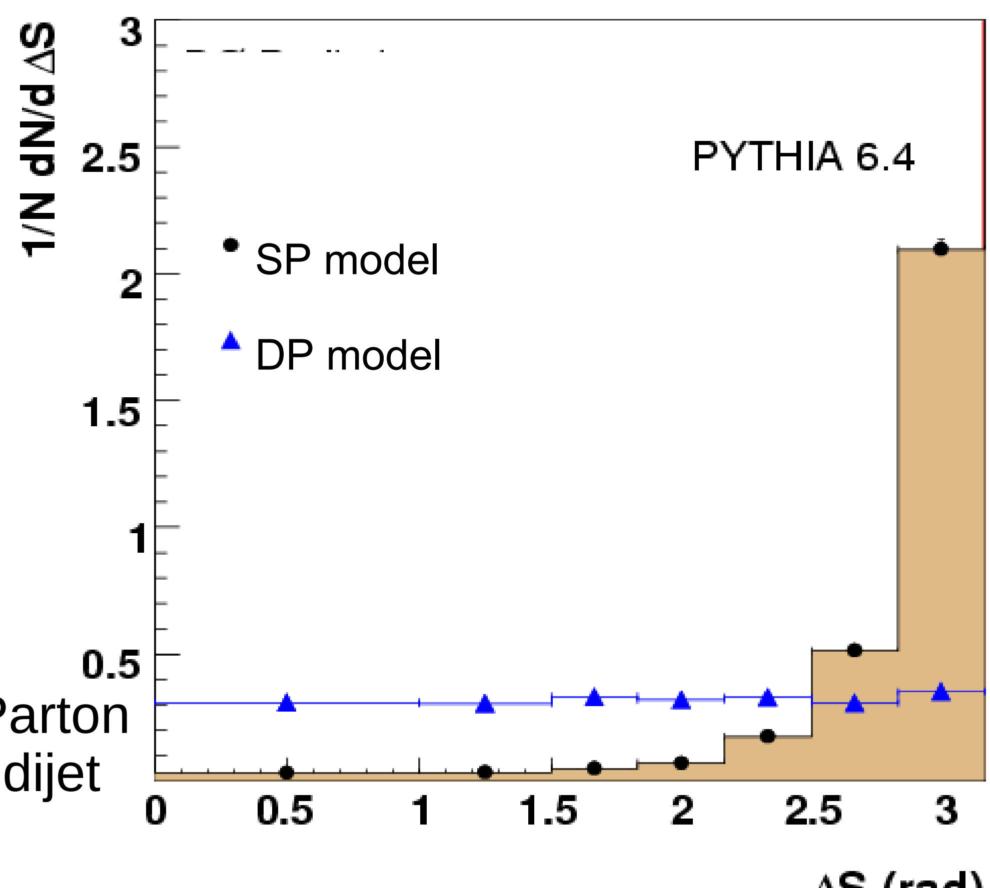
The pairs should correspond to a minimum S value:

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

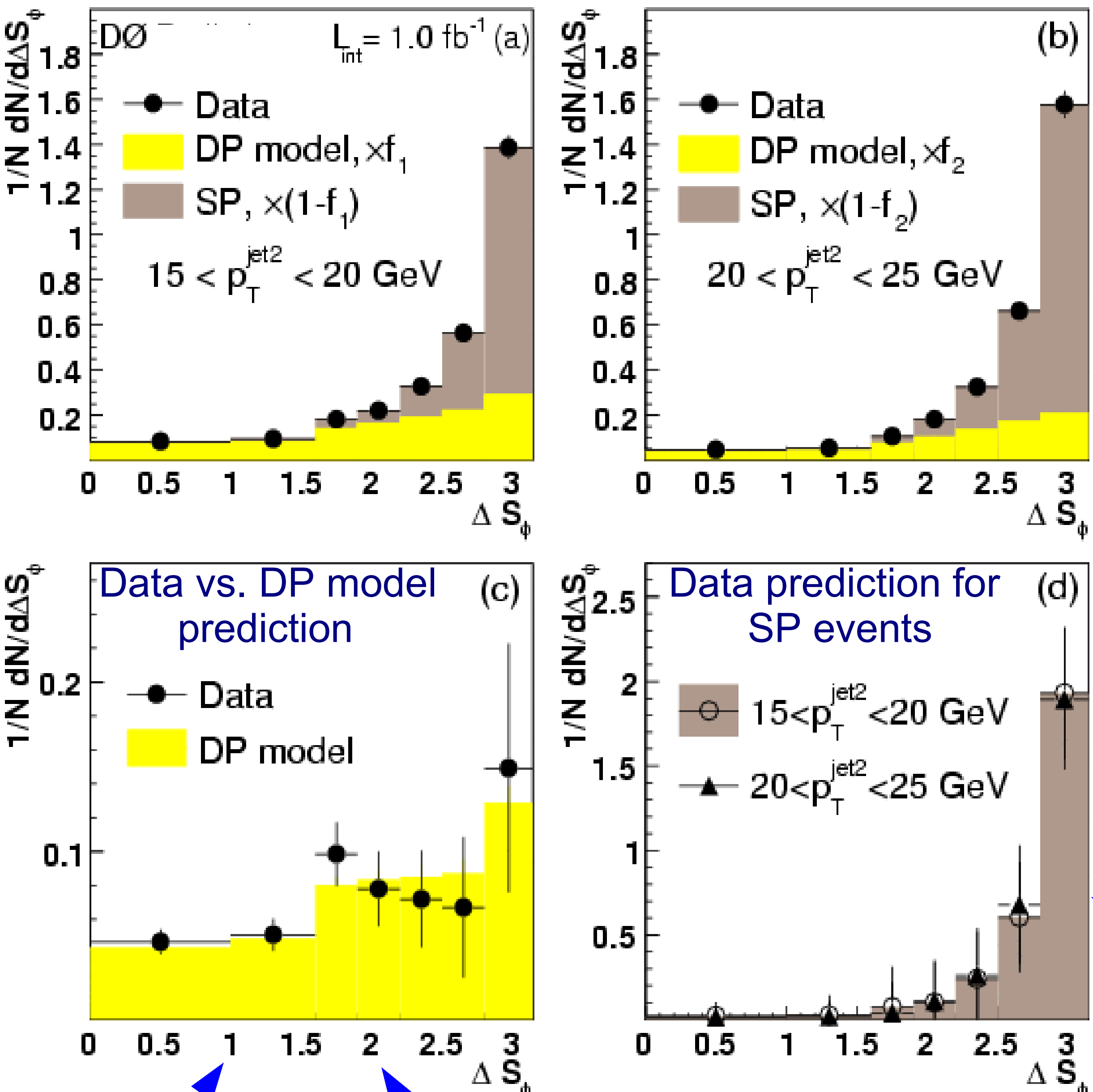
$$S_{p_T} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|\vec{P_T}(\gamma,i)|}{\delta P_T(\gamma,i)}\right)^2 + \left(\frac{|\vec{P_T}(j,k)|}{\delta P_T(j,k)}\right)^2}$$

In the signal DP sample most likely (>94%) S-variables are minimized by pairing photon with the leading jet.

For "γ+3-jet" events from Single Parton scattering we expect ΔS to peak at π, while it should be flat for "ideal" Double Parton interaction (2nd and 3rd jets are both from dijet production).



THE TWO DATASET METHOD



Dataset (a): 2[nd] jet pT: 15-20 GeV
Dataset (b): 2[nd] jet pT: 20-25 GeV

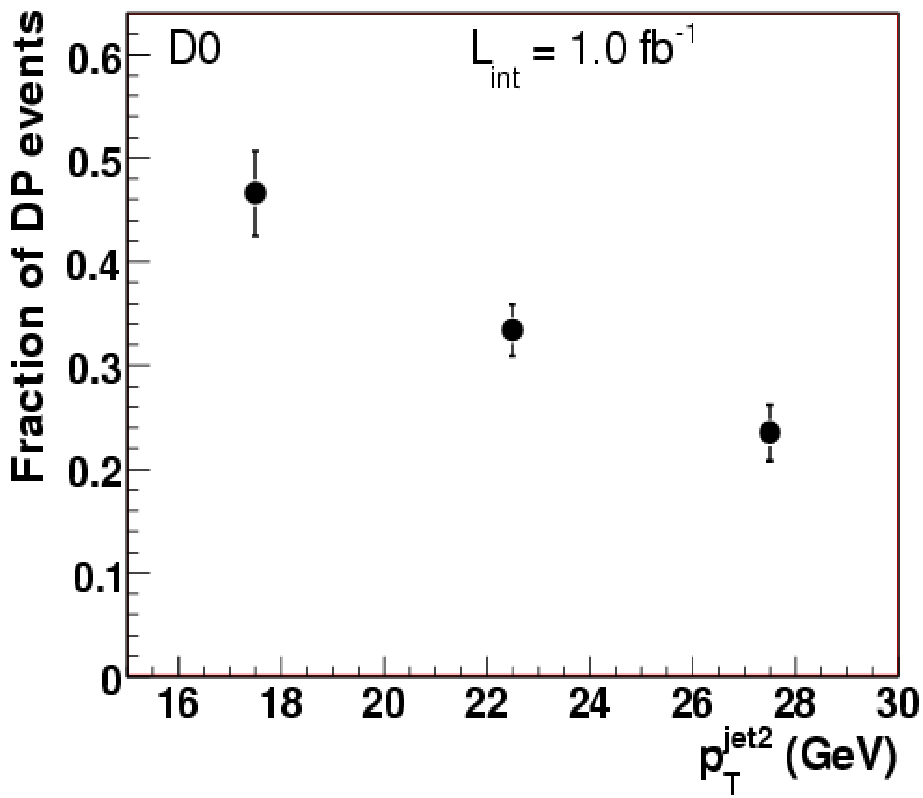
✓ Fraction of Double Parton in bin 15-20 GeV (f_1) is the only unknown
→ get from minimization.

✓ Good agreement of the ΔS Single Parton distribution extracted in data and in MC

→ another confirmation for the found DP fractions.

Data are corrected for the DP fractions

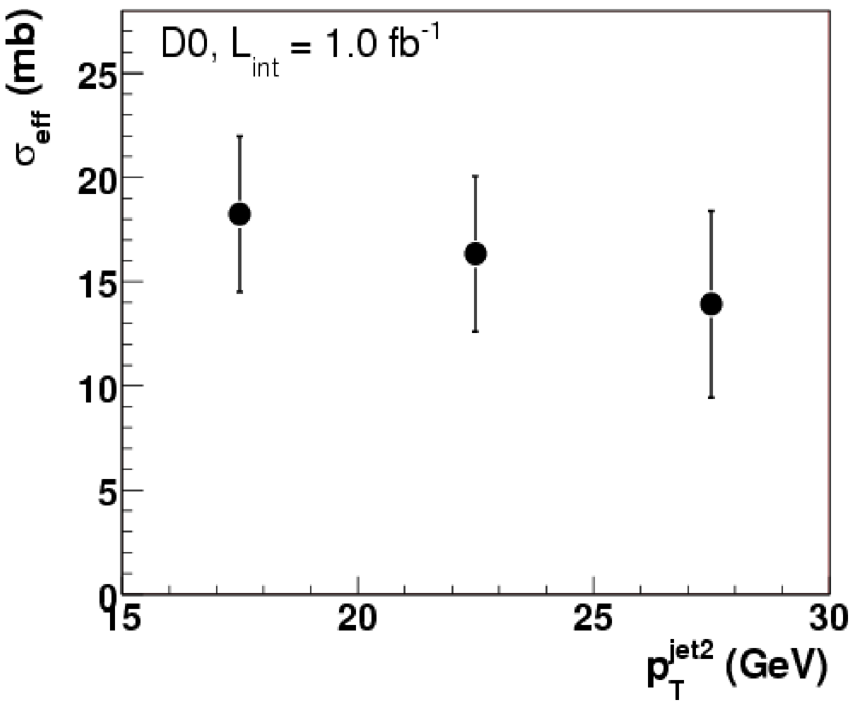
✓ Good agreement of Data and DP model



Found DP fractions are pretty sizable: they drop from ~46-48% at 2nd jet pT 15-20 GeV to ~22-23% at 2nd jet 25-30 GeV with relative uncertainties ~7-12%.

CDF Run I: 53±3% at 5-7 GeV of uncorrected jet pT.

Phys.Rev.D81,052012(2010), arXiv:0912.5104



- σ_{eff} values in different jet pT bins agree with each other within their uncertainties (also compatible with a slow decrease with pT).
- Uncertainties have very small correlations between 2nd jet pT bins.
- One can calculate the averaged (weighted by uncertainties) values over the pT bins:

$$\sigma_{eff}^{ave} = 16.4 \pm 0.3(stat) \pm 2.3(syst)\,mb$$

Main systematic and statistical uncertainties (in %) for σ_{eff}.

p_T^{jet2} (GeV)	Systematic uncertainty sources					δ_{syst} (%)	δ_{stat} (%)	δ_{total} (%)
	f_{DP}	f_{DI}	$\varepsilon_{DP}/\varepsilon_{DI}$	JES	$R_c\sigma_{hard}$			
15 – 20	7.9	17.1	5.6	5.5	2.0	20.5	3.1	20.7
20 – 25	6.0	20.9	6.2	2.0	2.0	22.8	2.5	22.9
25 – 30	10.9	29.4	6.5	3.0	2.0	32.2	2.7	32.3

- σ_{eff} is directly related with parameters of models of parton spatial density
- Three models have been considered: Solid sphere, Gaussian and Exponential.

TABLE VI: Parameters of parton spatial density models calculated from measured $\sigma_{\rm eff}$.

Model for density	$\rho(r)$	$\sigma_{\rm eff}$	$R_{\rm rms}$	Parameter (fm)	$R_{\rm rms}$ (fm)
Solid Sphere	Constant, $r < r_p$	$4\pi r_p^2/2.2$	$\sqrt{3/5}r_p$	0.53 ± 0.06	0.41 ± 0.05
Gaussian	$e^{-r^2/2a^2}$	$8\pi a^2$	$\sqrt{3}a$	0.26 ± 0.03	0.44 ± 0.05
Exponential	$e^{-r/b}$	$28\pi b^2$	$\sqrt{12}b$	0.14 ± 0.02	0.47 ± 0.06

– The rms-radia above are calculated w/o account of possible parton spatial correlations. For example, for the Gaussian model one can write [Trelelani, Galucci, 0901.3089,hep-ph]:

$$\frac{1}{\sigma_{eff}} = \frac{3}{8\pi R_{rms}^2}(1+Corr.)$$

- If we have rms-radia from some other source, one can estimate the size of the spatial correlations (the larger Corr. ↔ the larger rms-radius with a fixed σ_{eff})

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Double parton interactions in γ + b/c + dijet events in ppbar collisions at $\sqrt{s}$=1.96 TeV in D0

Phys.Rev.D89,072006(2014)
arXiv:1402.1550

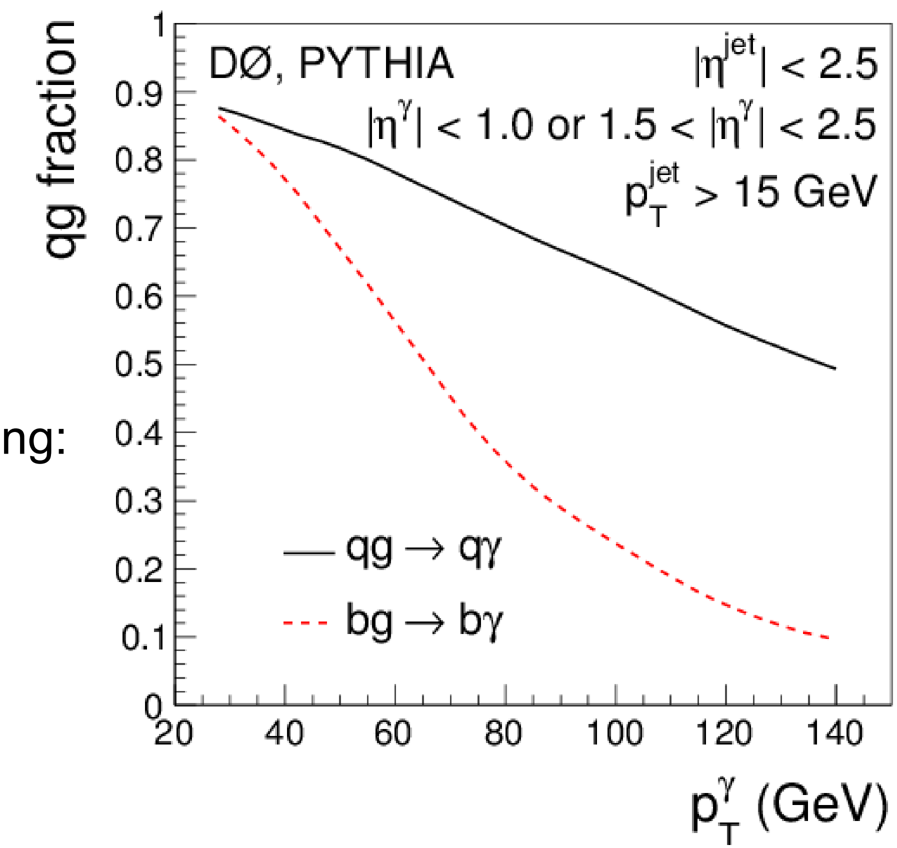
In general, transverse spatial distribution of light and heavy quarks in nucleon can be different.

Experimentally it means that one could expect different DP rates and σ_{eff} measured using γ+3 jet and γ + b/c + dijet final states.

The Compton-like process: $Qg \rightarrow Q\gamma$
Heavy flavor quark (Q) comes from the input parton.

The annihilation process: qqbar $\rightarrow g\gamma$
Heavy flavor quark is produced by gluon splitting: g $\rightarrow$ Qqbar.

Additional LO processes with fragmentation are mostly suppressed by photon isolation requirements.



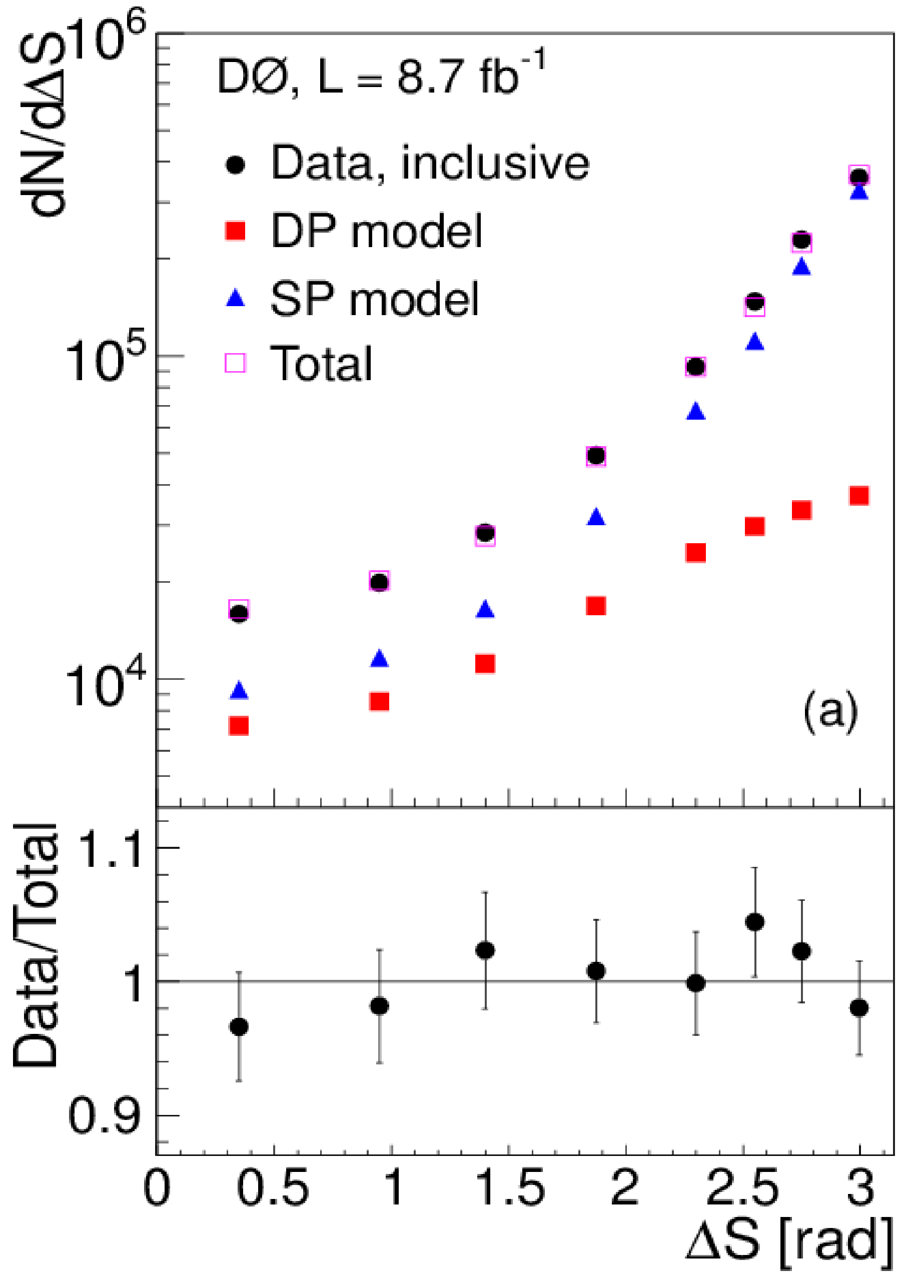
Case 1: No leading jet flavor requirement

Case 2: Leading jet Heavy flavor requirement (b/c jets)

At the chosen operation point the fraction of heavy flavor jets is 90%.

DP event fraction is found by fitting Single Parton event model (SHERPA) and Double Parton signal event model (MixDP) to data.

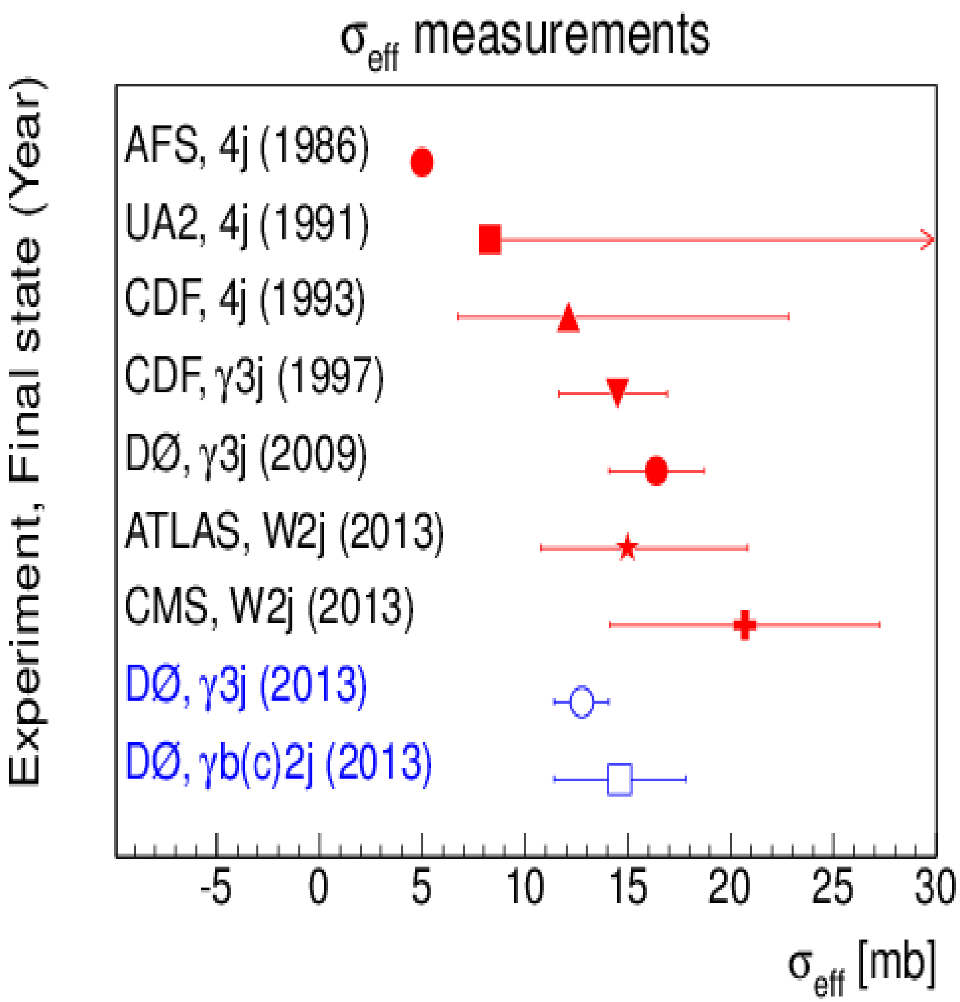
γ+HF+dijet	γ+3 jet
0.171 ± 0.020	0.202 ± 0.007



Having measured number of DP events and corresponding acceptances and efficiencies one can calculate σ_{eff} or both final states.

Measured σ_{eff} is in agreement with all Tevatron and LHC measurement.

No dependence of σ_{eff} on initial parton flavor has been observed.



Final state	γ+HF+dijet	γ+3 jet
$\sigma_{eff}(mb)$	14.6 ± 3.26	12.7 ± 1.32

Azimuthal angular decorrelation in γ+2jet and γ+3jet events produced in ppbar collisions at $\sqrt{s}$=1.96 TeV in D0

Phys.Rev.D83, 052008 (2011),
arXiv:1101.1509

Phys.Rev.D83, 052008 (2011), arXiv:1101.1509

Motivations:

- The provided experimental inputs have been based so far mainly on the minbias and DY Tevatron data (0.63, 1.8, 1.96 TeV) and minbias SPS (0.2, 0.54, 0.9 TeV) data.

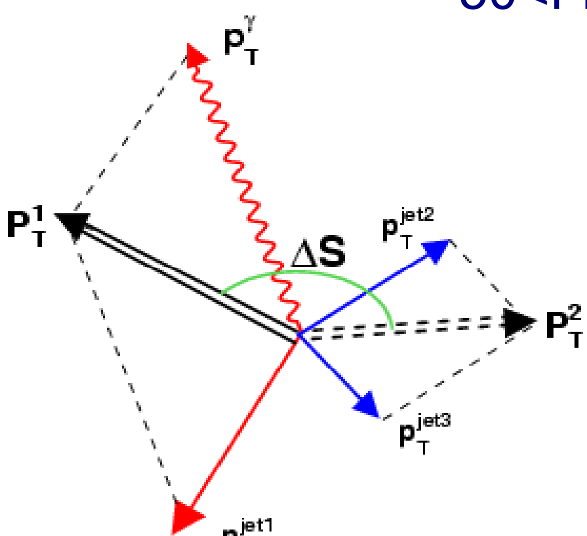
– The results of measuring the **differential** cross sections vs. the azimuthal angles in γ+3(2) jet events can be used for setting the parameters of MPI models in events with high pT jets.

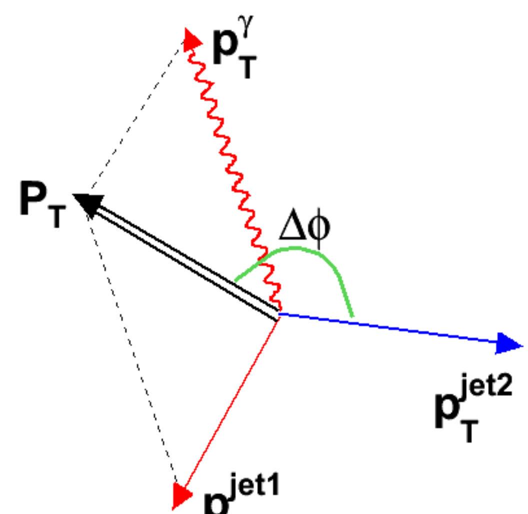
– Differentiation in jet pT increases sensitivity to the models even further.

Four normalized differential cross sections are measured (for the first time):

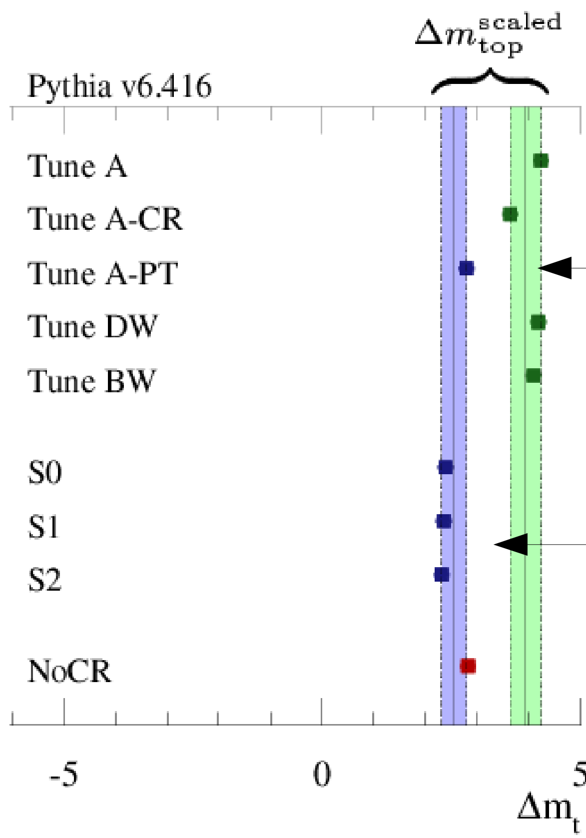
- $\Delta\phi(\gamma+\text{jet1, jet2})$ in 3 bins of 2nd jet pT: 15-20, 20-25 and 25-30 GeV
- $\Delta S(\gamma+\text{jet1, jet2+jet3})$ for 2nd jet pT 15-30 GeV

50<Photon pT < 90 GeV, Leading jet pT > 30 GeV





Comparison of the top-quark mass offset corrections with a few MPI models

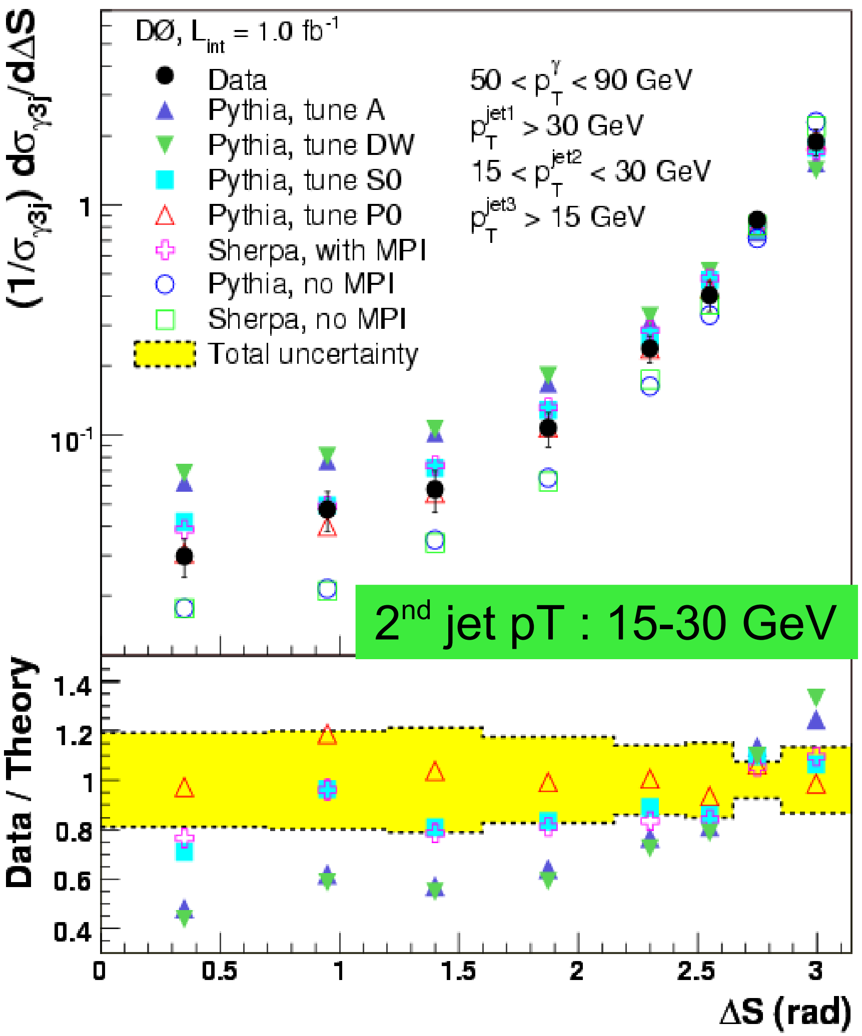


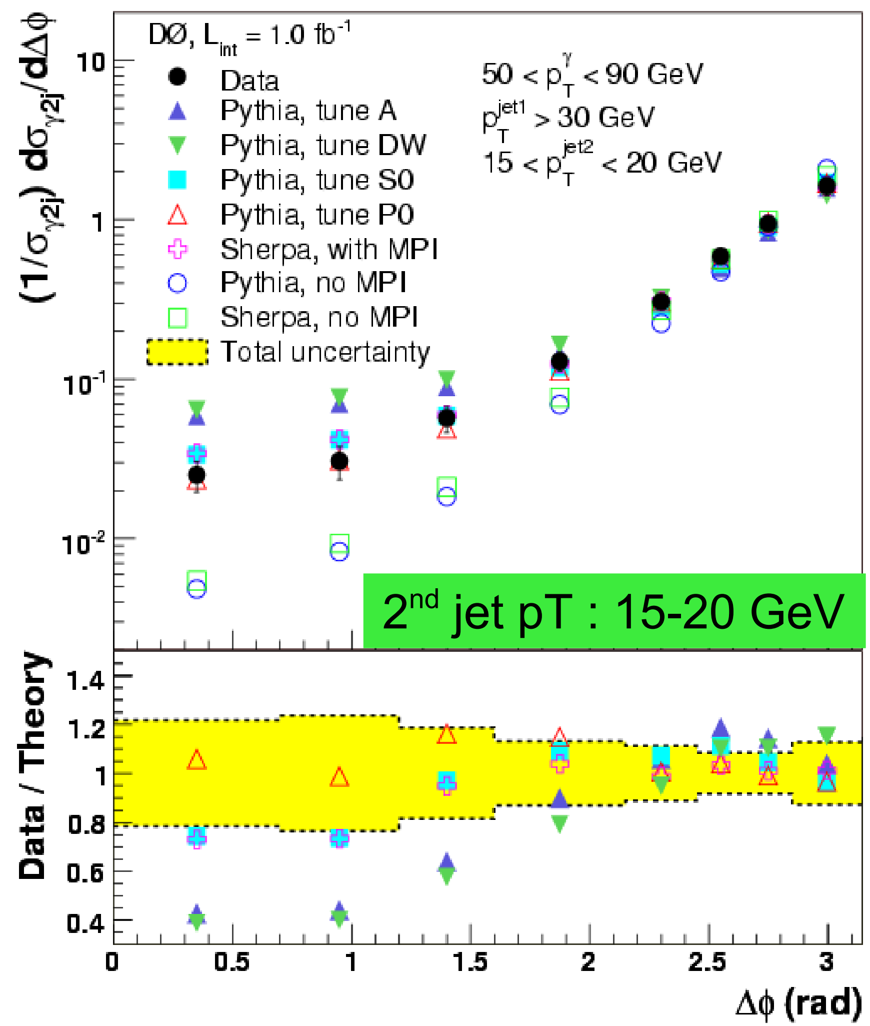
Plot from: D.Wicke, P.Z.Skands, Nuovo Cim. 123B, s1 (2008), arXiv:0807.3248v1 [hep-ph]

Models with virtuality-ordered parton shower

Models with pT-ordered parton shower

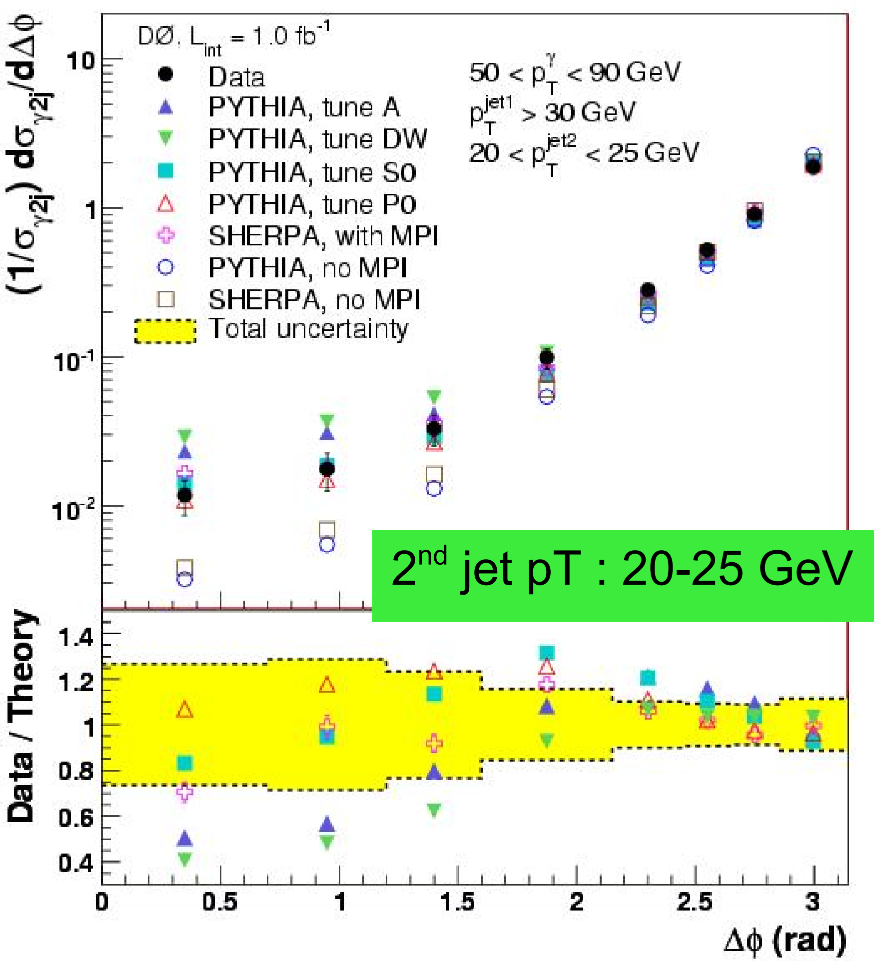
Difference between the two sets of the models leads to about 0.5-1.0 GeV uncertainty to the offset corrections for the top-quark mass.





- MPI models substantially differ from any SP (=single parton scattering) prediction.
- Large difference between SP models and data confirms presence of DP events in data.
- MPI models differ noticeably, especially at small angles
  ⇒ we can tune the models or just choose the best one(s)
- Data are close to Perugia (P0), S0 and Sherpa MPI tunes.

N.B.: the conclusion is valid for both the considered variables and 3 jet pT intervals!



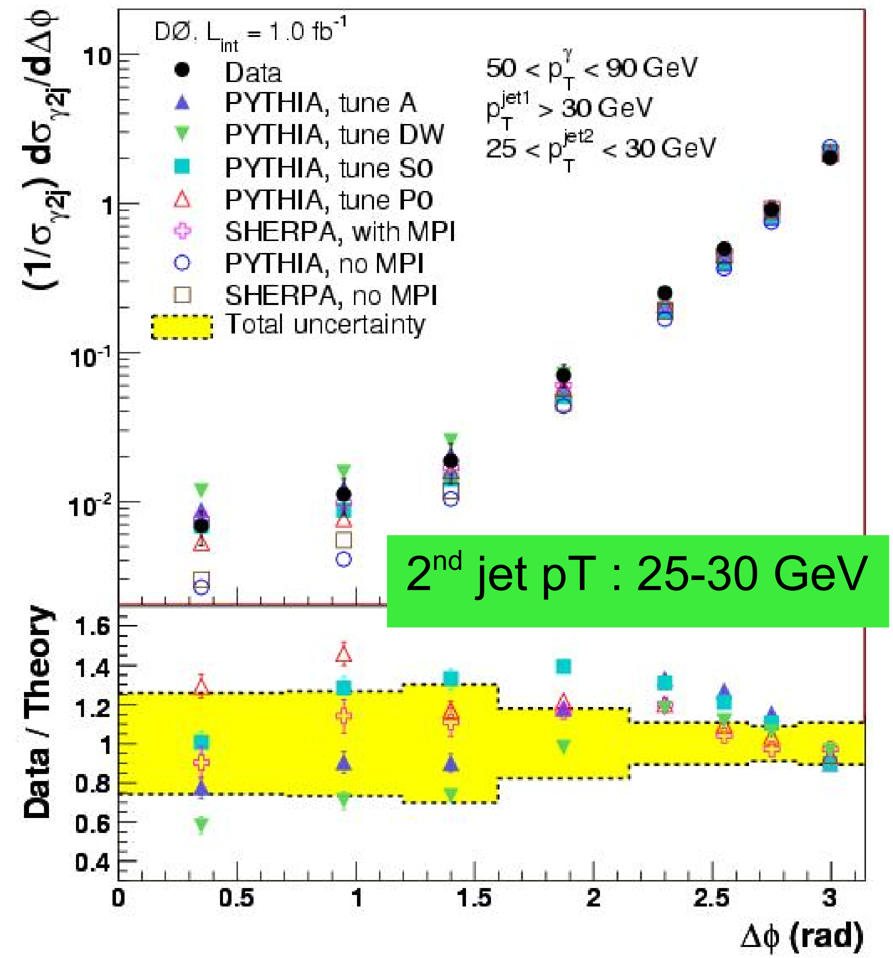
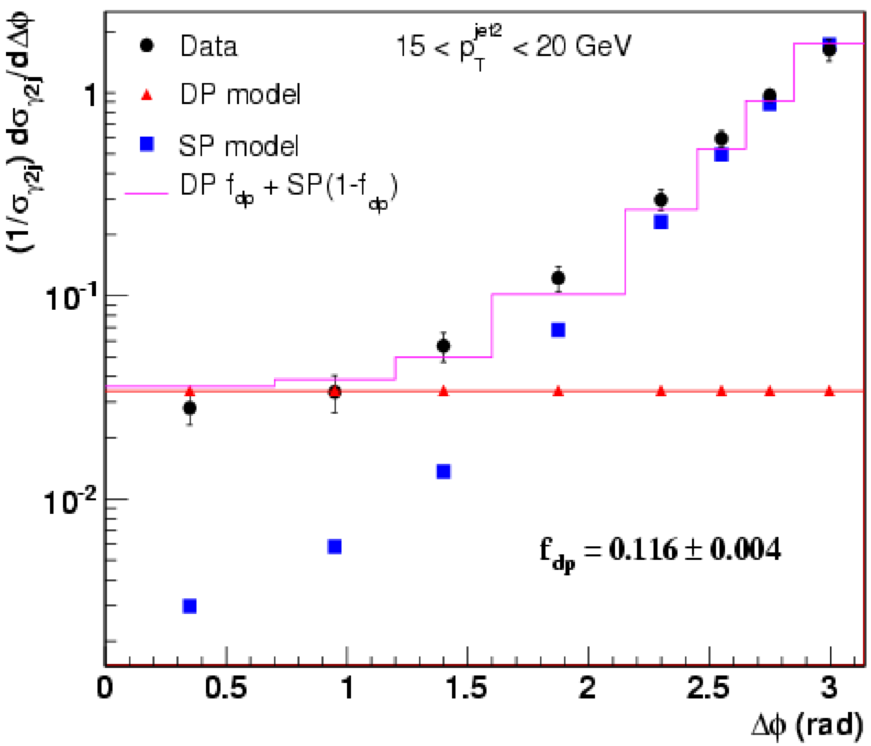


TABLE V: The results of a χ^2 test of the agreement between data points and theory predictions for the ΔS ($\gamma + 3$ jet) and $\Delta\phi$ ($\gamma + 2$ jet) distributions for $0.0 \leq \Delta S(\Delta\phi) \leq \pi$ rad. Values are χ^2/ndf.

Variable	p_T^{jet2}	SP model		MPI model									
	(GeV)	PYTHIA	SHERPA	A	DW	S0	P0	P-nocr	P-soft	P-hard	P-6	P-X	SHERPA
ΔS	15 − 30	7.7	6.0	15.6	21.4	2.2	0.4	0.5	2.9	0.5	0.4	0.5	1.9
$\Delta\phi$	15 − 20	16.6	11.7	19.6	27.7	1.6	0.5	0.9	1.6	0.9	0.6	0.8	1.2
$\Delta\phi$	20 − 25	10.2	5.9	4.0	7.9	1.1	0.9	1.4	2.1	1.1	1.3	1.5	0.4
$\Delta\phi$	25 − 30	7.2	3.5	2.8	3.0	2.4	1.1	1.1	3.7	0.2	1.3	1.9	0.7

- In γ+2 jet events in which 2nd jet is produced in the 2nd parton interaction, $\Delta\phi$≥ (γ+jet1, jet2) distribution should be flat.
- Using this fact and also SP prediction for $\Delta\phi$≥ (γ+jet1, jet2) one can get DP fraction from a maximal likelihood fit to data.

Example of the fit for 2nd jet pT bin 15 – 20 GeV



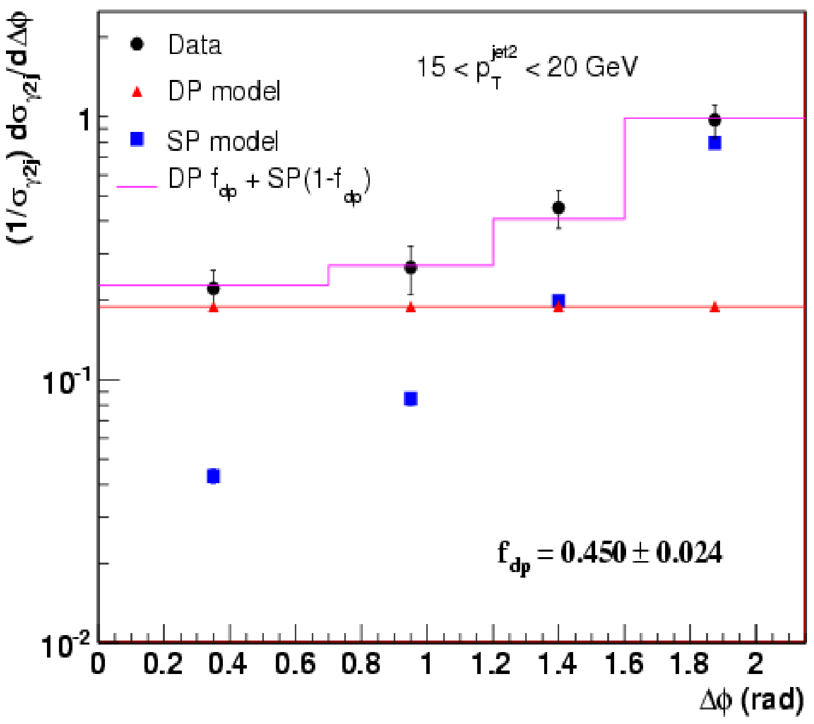
DP fractions f_{DP} in γ+2 jet events

p_T^{jet2} (GeV)	$\langle p_T^{jet2} \rangle$ (GeV)	$f_{dp}^{\gamma 2j}$ (%)	Uncertainties (in %) Fit	δ_{tot}	SP model
15 – 20	17.6	11.6 ± 1.0	5.2	8.3	6.7
20 – 25	22.3	5.0 ± 1.2	4.0	20.3	11.0
25 – 30	27.3	2.2 ± 0.8	27.8	21.0	17.9

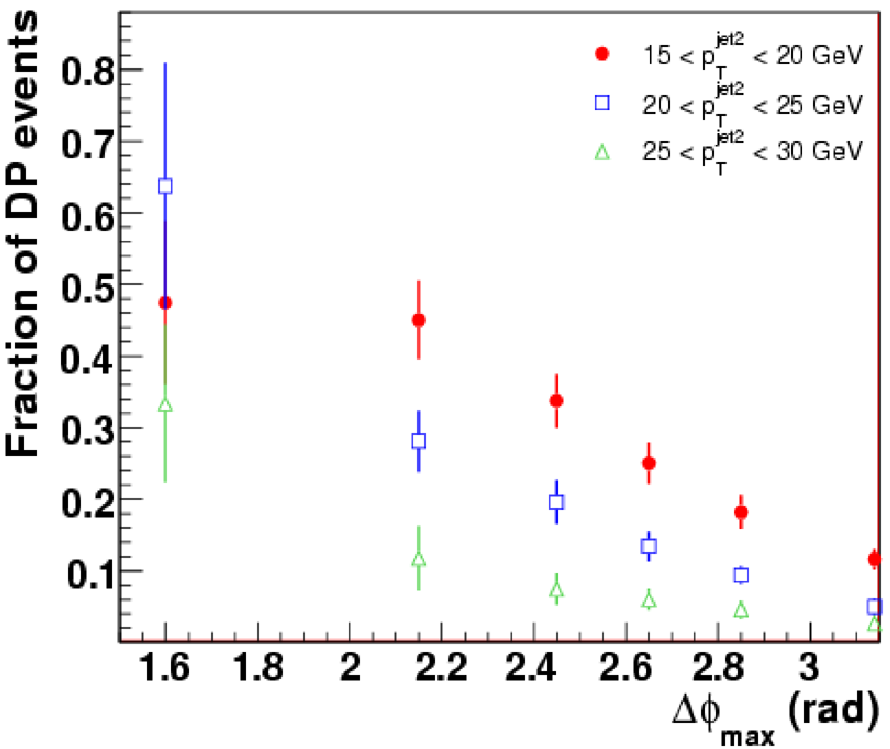
CDF Run I: 14% at jet pT > 8 GeV and photon pT > 16 GeV

- DP fractions should depend on $\Delta\phi$(γ+jet1, jet2): the smaller $\Delta\phi$ angle the larger DP fraction (for example, see plot on previous slide).
- We can find this dependence by repeating the same fits in smaller $\Delta\phi$ regions.

DP fit for 2nd jet pT bin 15 – 20 GeV
$0 < \Delta\phi < 2.15$



DP fractions vs $\Delta\phi$ bin for 3 bins of 2nd jet pT



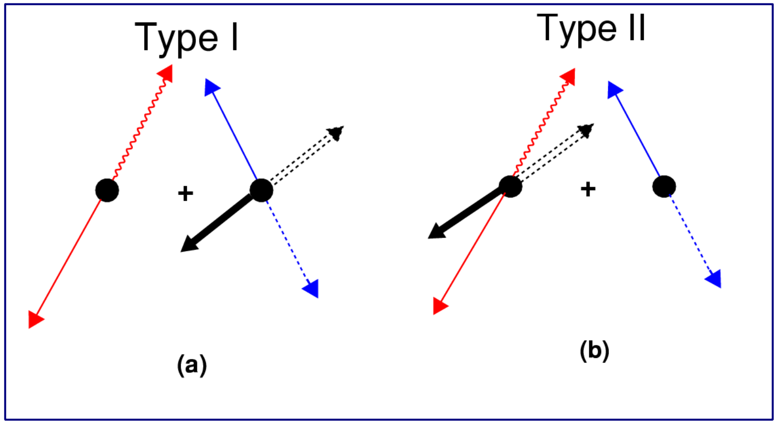
⇒ DP fractions are larger at smaller angles and smaller 2nd jet pT

γ+3jet final state can also be produced by Tripple Parton interaction (TP).
In γ+3jet events all 3 jets should stem from 3 different parton scatterings.
To estimate the TP fraction we used results on DP+TP fractions and fractions of Type I (II) events found in our previous measurement (slide 12).
TP in γ+3jet data is calculated as:

$$f_{tp}^{\gamma\,3j} = f_{dp+tp}^{tp} \cdot f_{dp+tp}^{\gamma\,3j}$$

The fraction of TP in MixDP can be found as:

$$f_{tp}^{dp+tp} = F_{typeII} \cdot f_{dp}^{\gamma 2j} + F_{typeI} \cdot f_{dp}^{jj}$$



$f_{dp+tp}^{\gamma 3j}$ - measured in previous DP analysis;

f_{dp}^{jj} - estimated using dijet cross section;

$f_{dp}^{\gamma 2j}$ - measured;

$F_{typeI(II)}$ - found from the model (MixDP).

p_T^{jet2} (GeV) (GeV)	$f_{\mathrm{tp}}^{\gamma 3j}$ (%)	$f_{\mathrm{tp}}^{\gamma 3j} / f_{\mathrm{dp}}^{\gamma 3j}$ (%)
$15 - 20$	5.5 ± 1.1	13.5 ± 3.0
$20 - 25$	2.1 ± 0.6	6.6 ± 2.0
$25 - 30$	0.9 ± 0.3	3.8 ± 1.4

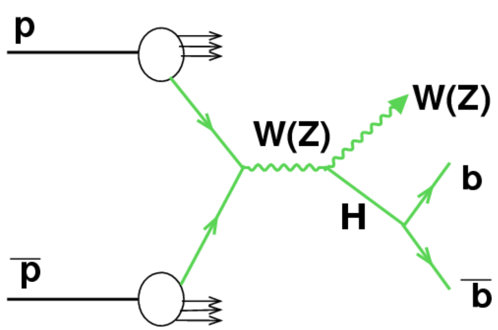
Probability to produce another parton scattering is proportional to $R = \sigma_{ij} / \sigma_{eff}$, the $f_{tp}^{\gamma 3j} / f_{dp}^{\gamma 3j}$ ratio should be proportional to *R*.

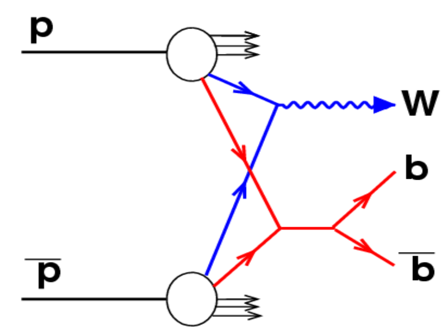
Double parton interactions as a background to rare processes

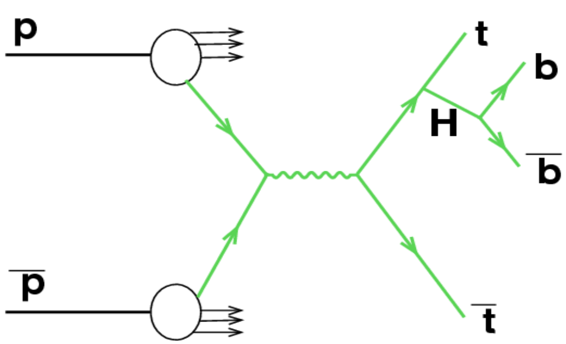
D.Bandurin,G.Golovanov,N.Skachkov
JHEP 1104 (2011) 054

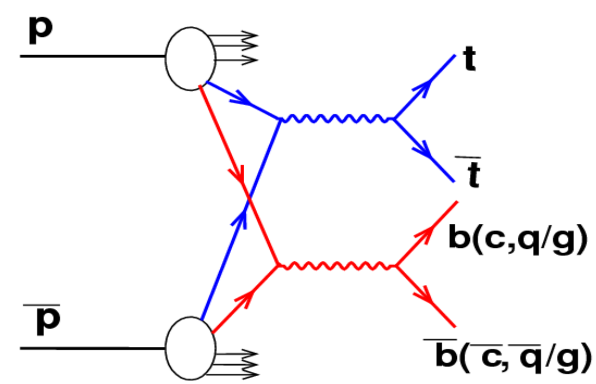
Signal

Double Parton background



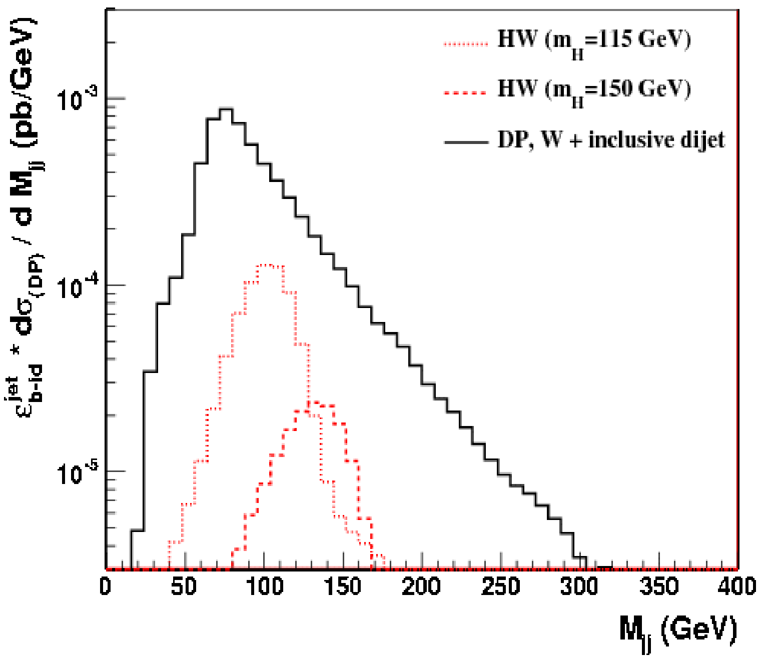


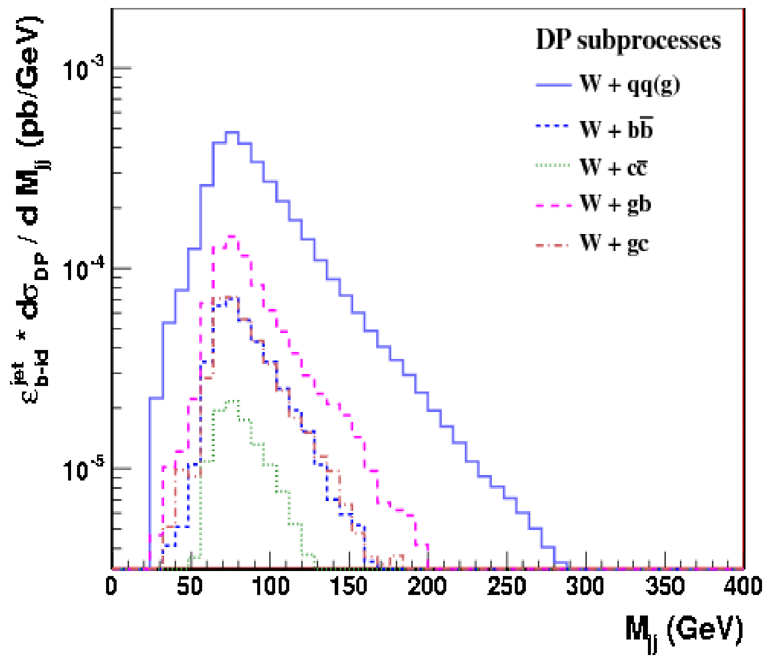




- Many Higgs production channels can be mimicked by Double Parton events!
- Some of them can be significant even after signal selections.
- Dedicated cuts are required to increase sensitivity to the Higgs signal (same is true for many other rare processes)!

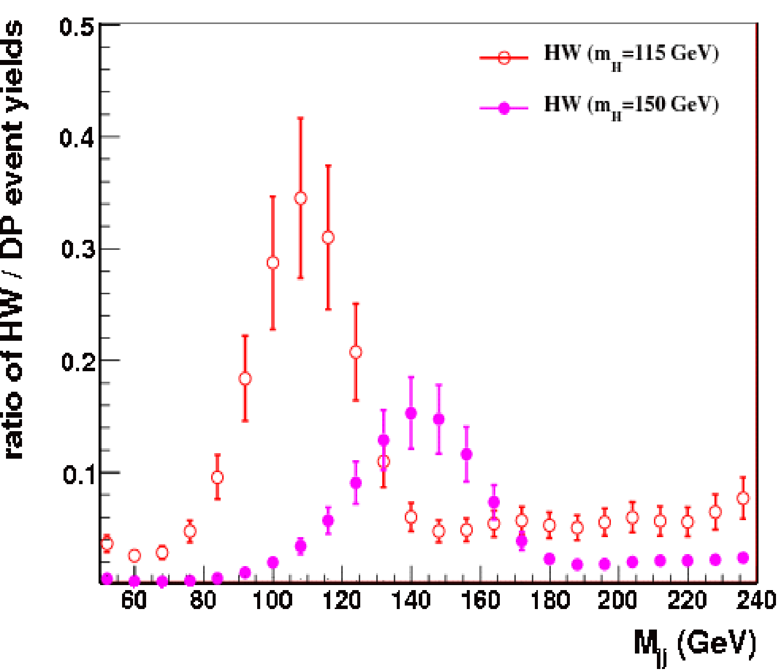
⇒ see example of possible variables in 0911.5348[hep-ph]





Fast MC based on Pythia-8

jet E smearing + b-tagging efficiencies for light/b/c jets

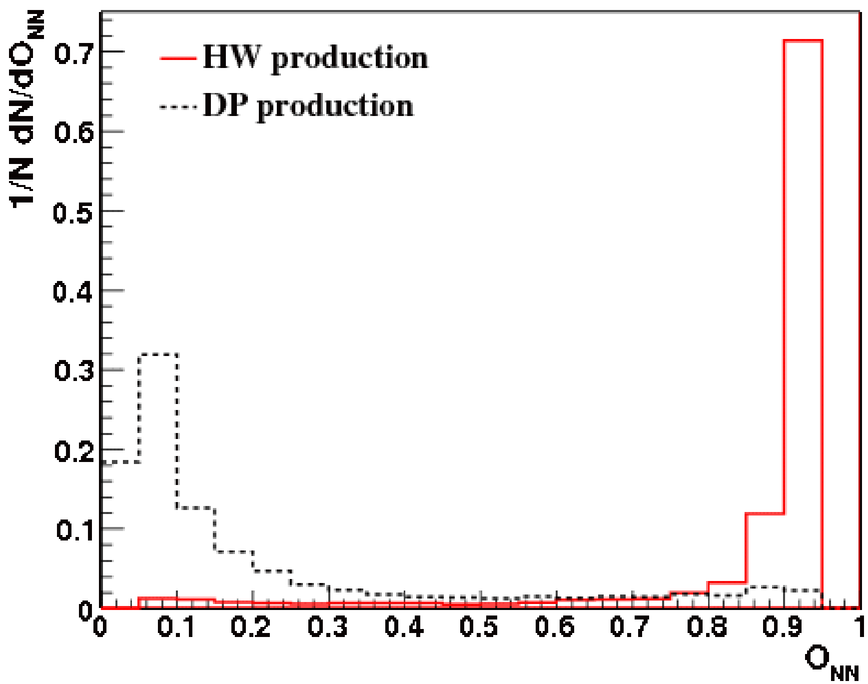


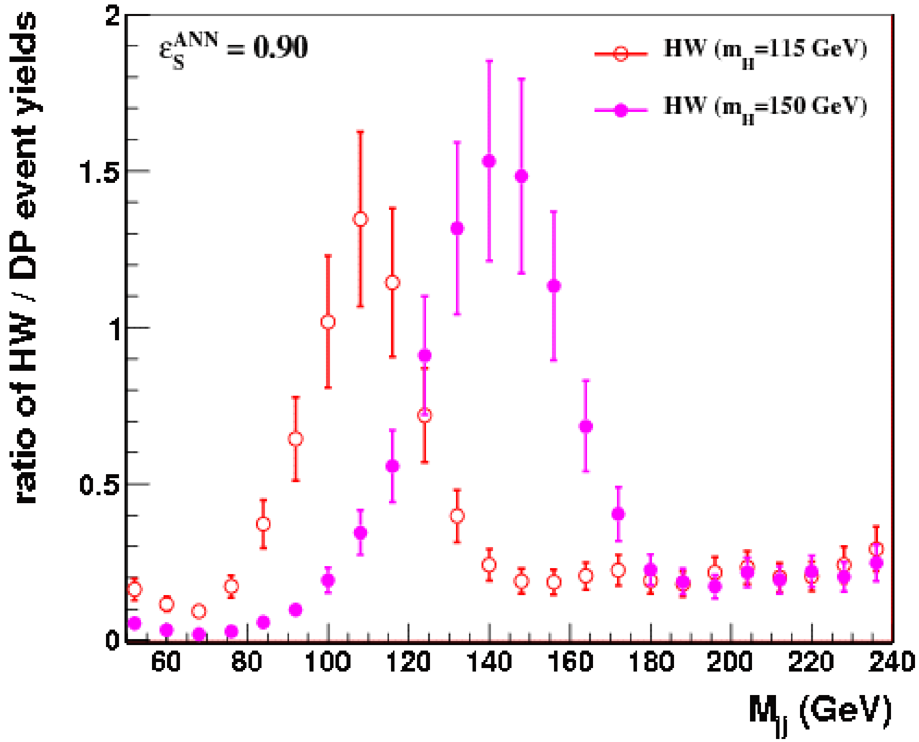
– Kinematic + bID selections are same as in actual D0 analyses.
– Dijet dσ/dM and W cross sections are normalized to D0 measurements.
– Higgs signal is suppressed even in the peak by a factor 2.5-5

To improve that:

A discriminator (ANN based) is built using all the variables sensitive to kinematics of HW /DP productions

… and with account of a cut on the output value of the dedicated ANN
The cut is chosen to have 90% of signal HW events
The 85% cut gives another factor 1.5-1.8 of the S/B increase





- In D0 we have measured:
- Fraction of DP events in γ+3-jet events in three pT bins of 2nd jet : 15-20, 20-25, 25-30 GeV. It varies from 47% at 15-20 GeV to 23% at 25-30 GeV;

- Effective cross section (process-independent, defines rate of DP events) σ_{eff} in the same jet pT bins with average value (agrees with CDF'97):

$$\sigma_{eff}^{ave} = 16.4 \pm 0.3 (stat) \pm 2.3 (syst) mb$$

$$\sigma_{eff}^{ave} = 14.6 \pm 3.3 (stat) \pm 2.3 (syst) mb$$

- No dependence of σ_{eff} on initial state has been found;

- The DP fraction in γ+2jets: 11.6% at 15-20 GeV to 2.2% at 25-30 GeV.

- The TP fractions in γ+3-jet events are determined for the first time. As a function of 2nd jet pT, they drop from 5.5% at 15-20 GeV, to 0.9% at 25-30 GeV.

- The $\triangle$S and $\Delta\phi$ cross sections. They allow to tune MPI models: Data prefer the Sherpa and Pythia MPI models (P0, P0-X, P0-hard).

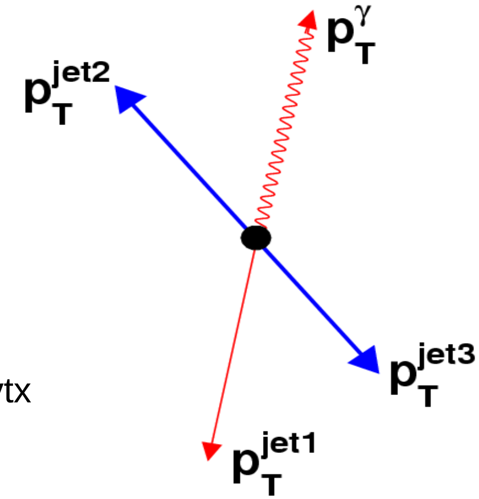
- DP production can be a significant background to many rare processes, especially with multi-jet final state. A set of variables allowing to reduce the DP background is suggested.

- Measurement of effective x-section in photon+HF+dijet events is in a good progress now

Backup slides

For two hard scattering events (two separate $p\bar{p}$ collisions):

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



The number of Double Interaction events:

$$N_{DI} = 2\frac{\sigma^{\gamma j}}{\sigma_{hard}}\frac{\sigma^{jj}}{\sigma_{hard}} N_C(2) A_{DI}\,\epsilon_{DI}\,\epsilon_{2vtx}$$

For one hard interaction:

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

Then the number of Double Parton events:

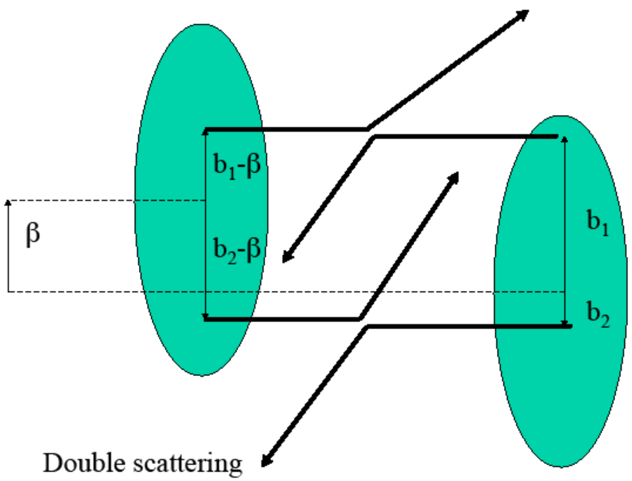
$$N_{DP} = \frac{\sigma^{\gamma j}}{\sigma_{hard}}\frac{\sigma^{jj}}{\sigma_{eff}} N_C(1) A_{DP}\,\epsilon_{DP}\,\epsilon_{1vtx}$$

Therefore one can extract:

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

Double parton cross section

$$\sigma_{\rm dp} = \sum_{q/g} \int \frac{\sigma_{12}\sigma_{34}}{2\sigma_{\rm eff}} D_p(x_1,x_3) D_{\bar{p}}(x_2,x_4) dx_1 dx_2 dx_3 dx_4$$



Effective cross section

$$\sigma_{eff}^{-1} = \int d^2\beta [F(\beta)]^2,$$

β is impact parameter

$$F(\beta) = \int f(b) f(b-\beta) d^2 b,$$

where f(b) is the density of partons in transverse space.

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

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

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

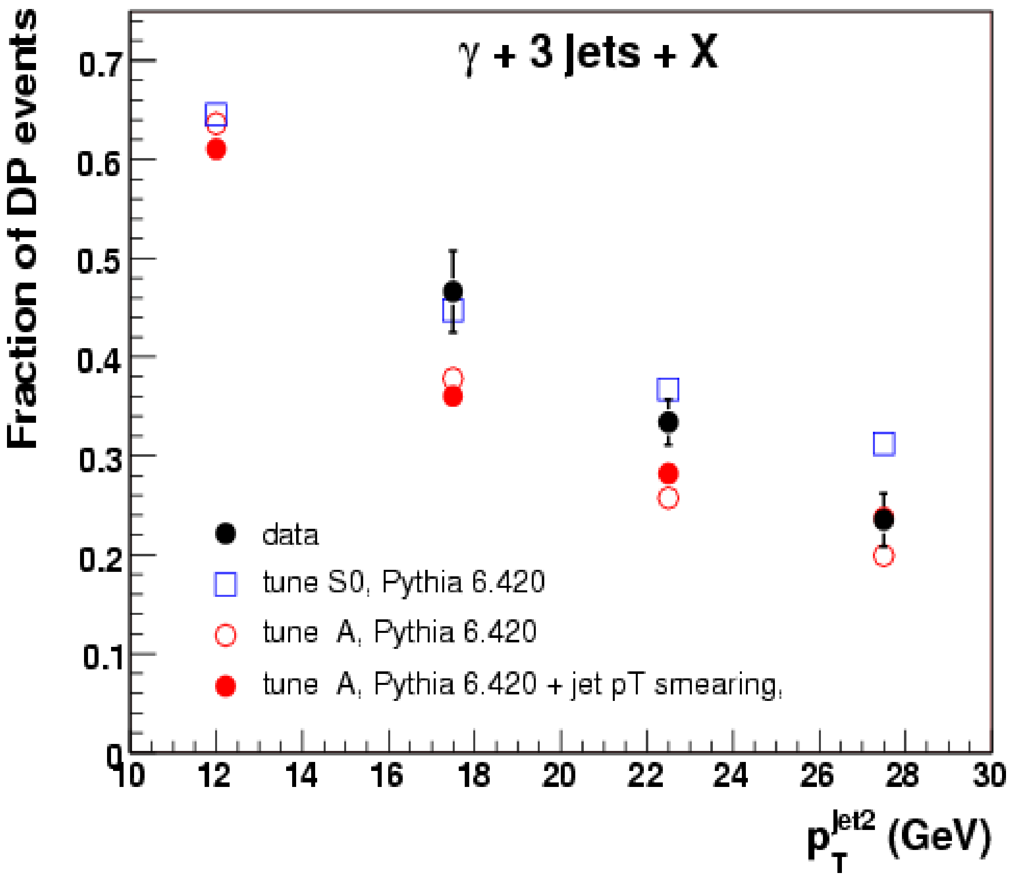
$$D_2 - f_2 M_2 = (1 - f_2) B_2$$

From SP MC

From MixDP

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

f_1 is the only unknown obtained from minimization



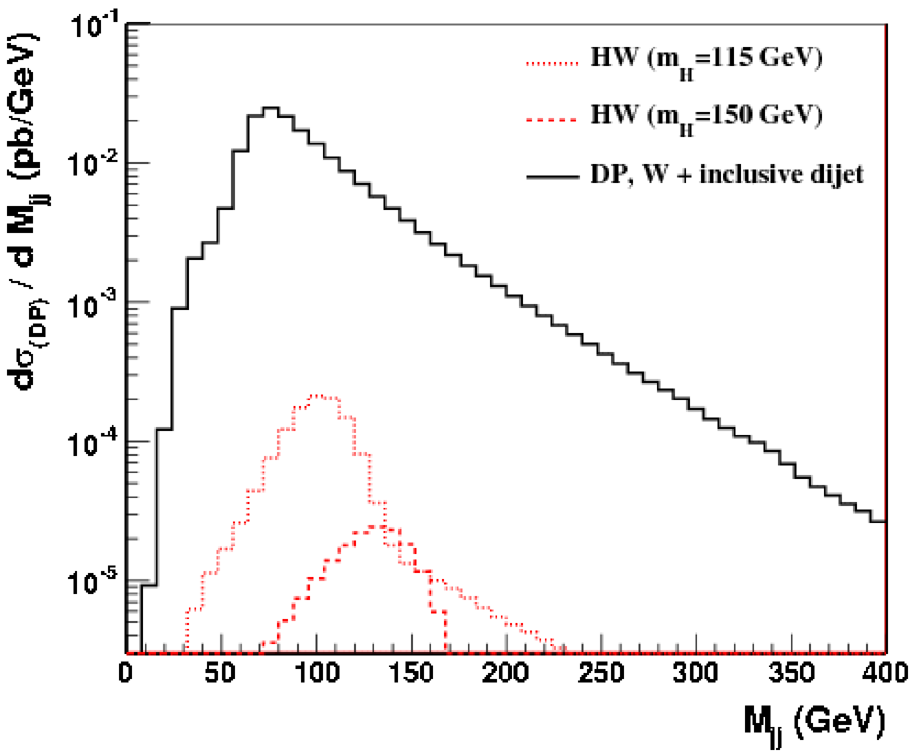
- Pythia MPI Tune A and S0 are considered.
- Data are in between the model predictions.
- Data should be corrected to the particle level.
- Will be done later to find the best MPI Tune

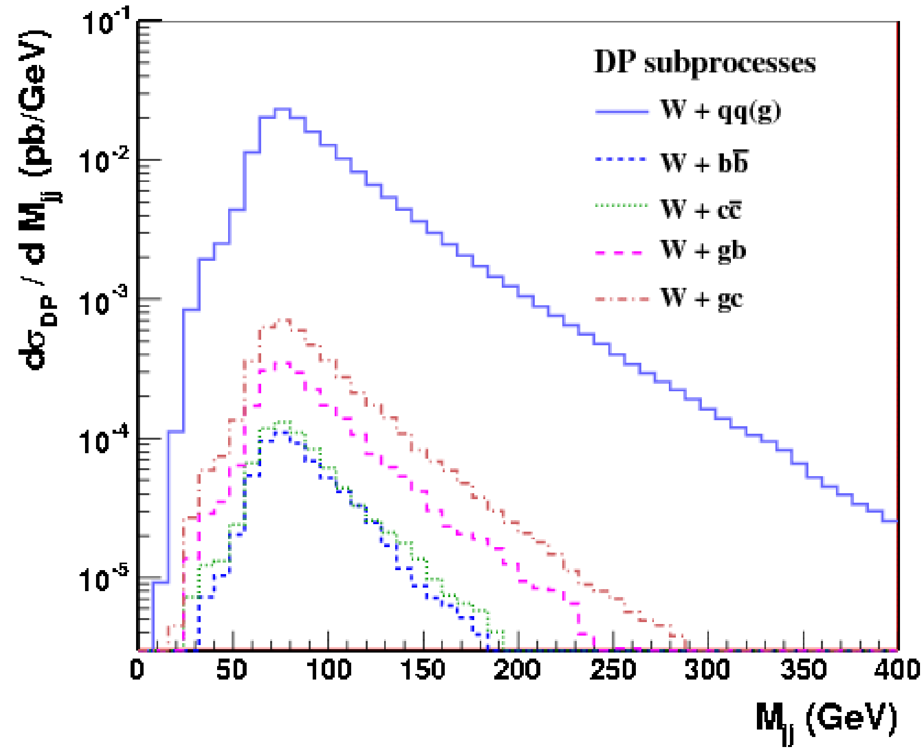
Fast MC based on Pythia-8 (detector smearing)

D.Bandurin,G.Golovanov, N.Skachkov
JHEP 1104 (2011) 054

HW, H→bb: DP and SP cross sections

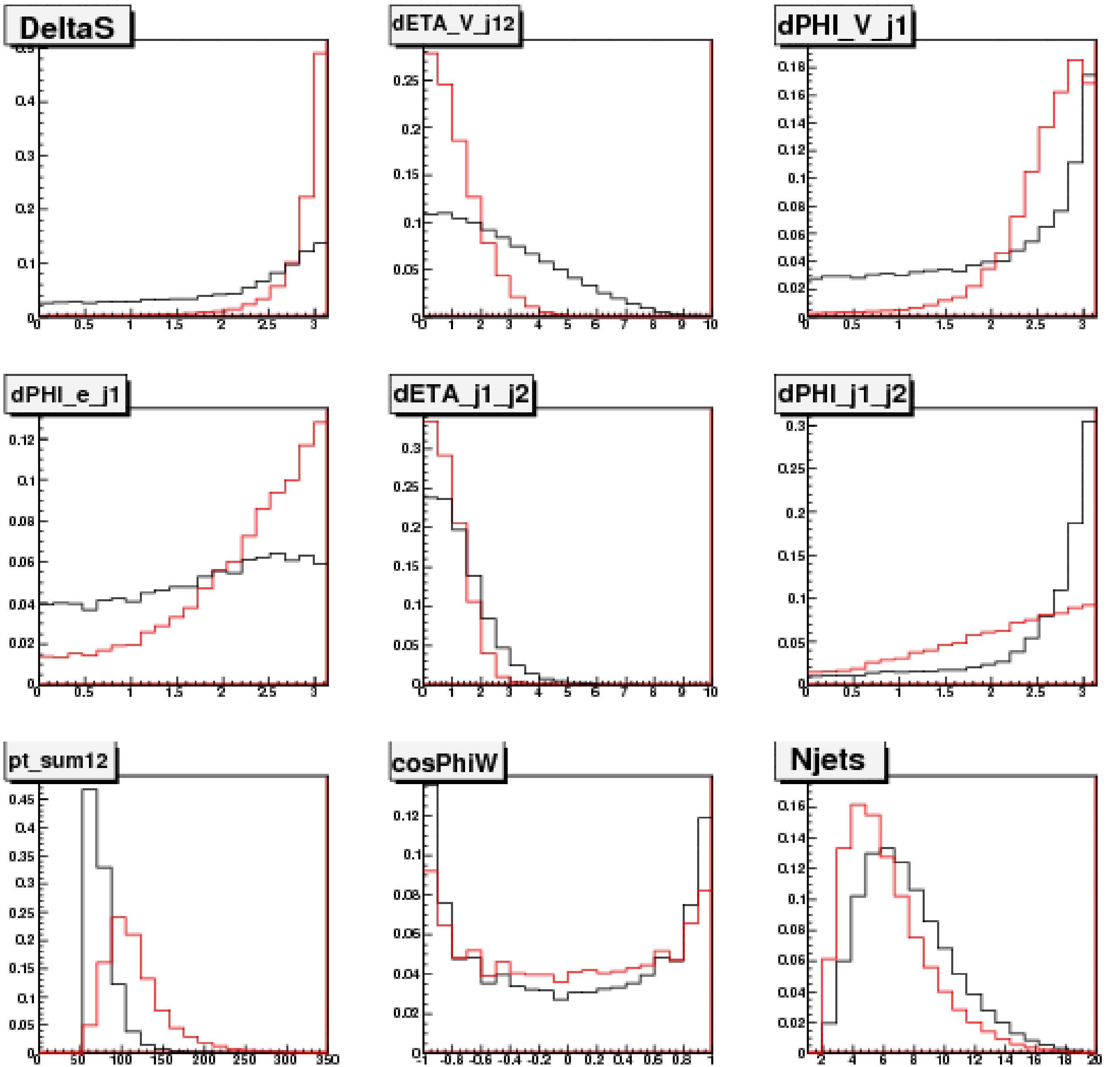
No bID selections





– Kinematic selections are same as in actual D0 analyses.
– Dijet dσ/dM and W(Z) cross sections are normalized to D0 measurements.
– DP background can be significant for both the Higgs productions channels!

Input ANN variables



Red is WH
Black is DP