Signals for Double Parton Scattering

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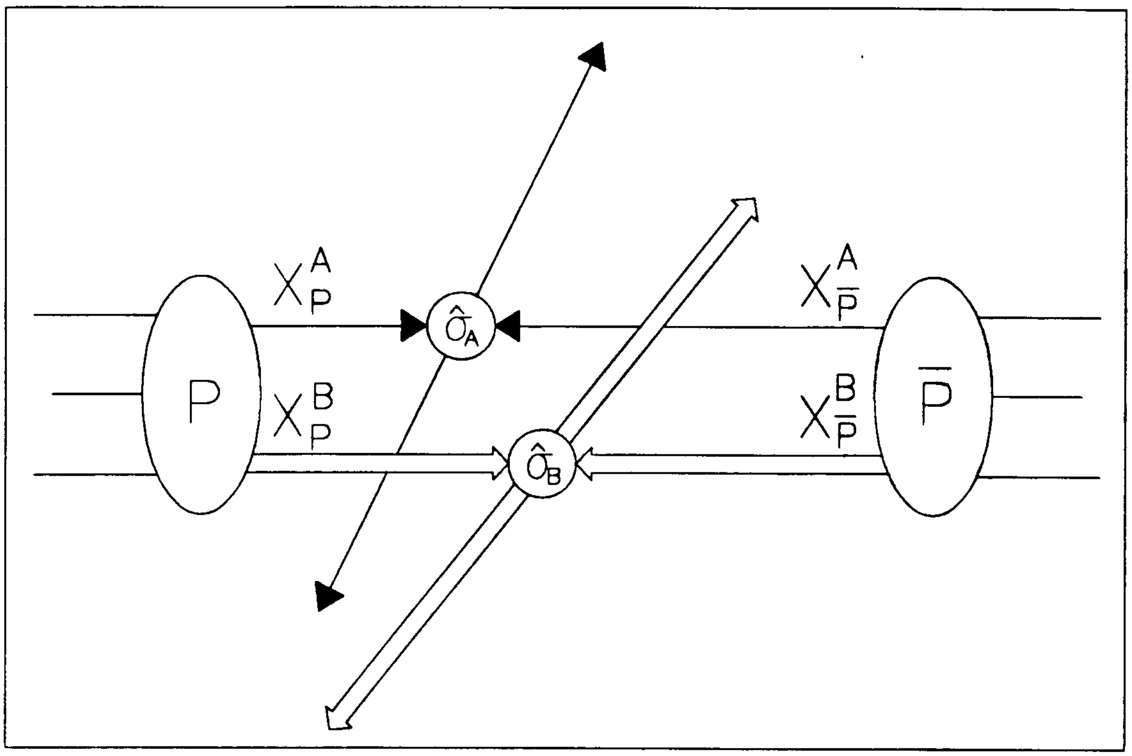
Double Parton Scattering (DPS)

Two parton-parton hard scatters in one $p\bar{p}$ collision.

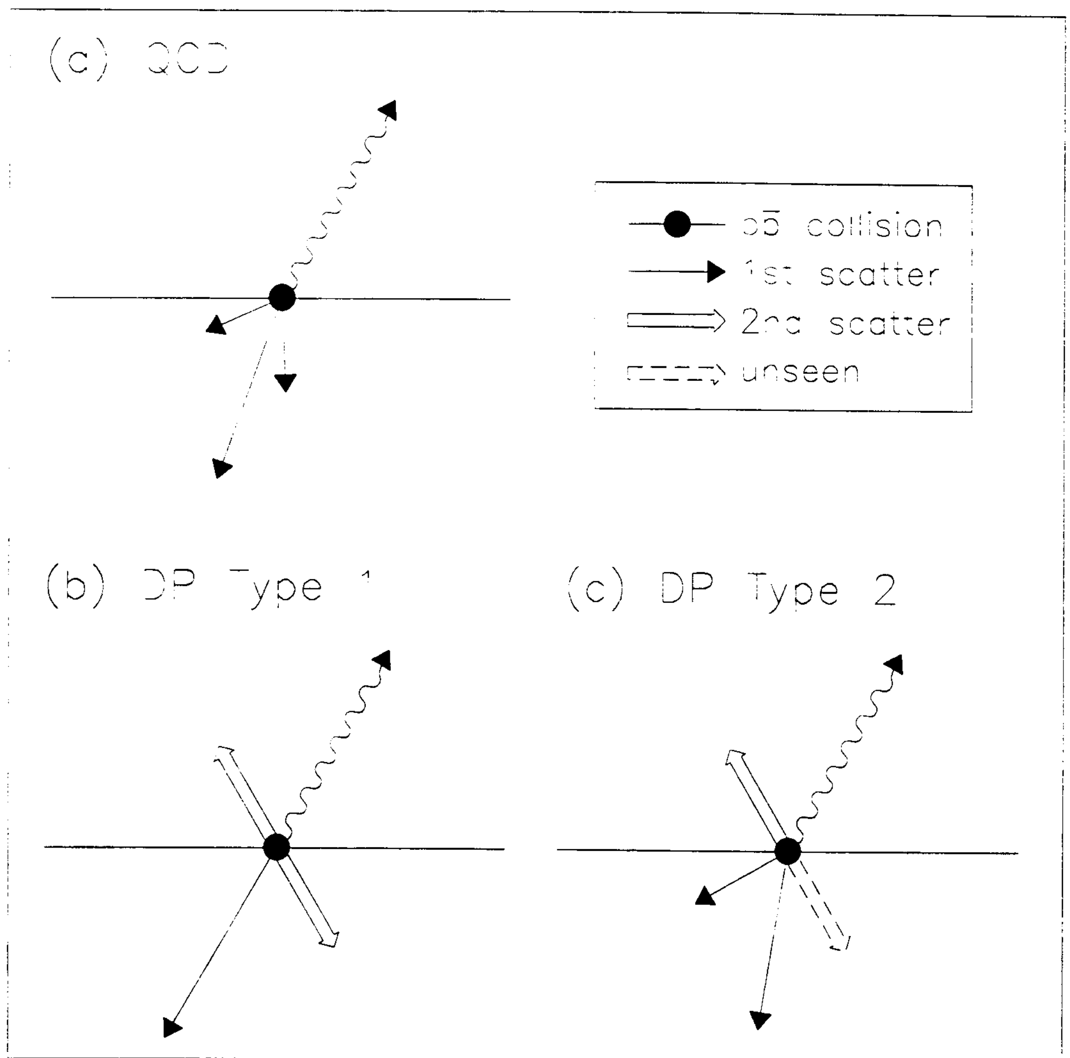


Extend knowledge of proton structure

- **spatial distribution of partons inside proton**
- **parton-parton correlations**

→ impact on PDFs?

QCD and Double Parton Scattering (DPS) in γ + 3 jet events



Double Parton Scattering Cross Section

DPS cross section: the product of two hard scatters modulated by a scale factor (σ_{eff}):

→ A , B

$$\sigma_{\mathrm{DP}} = \mathrm{m}\, \sigma_{\mathrm{A}} \frac{\sigma_{\mathrm{B}}}{2\sigma_{\mathrm{eff}}}$$

factor of 2 is convention (Poisson statistics)
m is a combinatorial factor:
m=2 when A and B are distinguishable
m=1 when A and B are NOT distinguishable

Uniform parton distribution
→ σ_{eff} is large and σ_{DP} is small

Clumpy parton distribution
→ σ_{eff} is small and σ_{DP} is large

If assume protons are spheres with constant parton density:

$$2\sigma_{eff} \approx \frac{\sigma_{NSD}}{2.3} \Rightarrow \sigma_{eff} \approx 11mb$$

No reason to assume DPS does not take place. In fact it must occur at some level.

Theoretical discussion of DPS has been going on many years, at least since the early 1980's.

Problem is experimentally extracting a signal from double brem background

Typically experiments choose 4-jet samples $\rightarrow$ high cross section.

Measuring σ_{eff} in 4-jet samples:

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

m = 1: two 2-jet events are indistinguishable

Measure σ_{DP} but need QCD calculations of σ_{JJ} to get σ_{eff}.

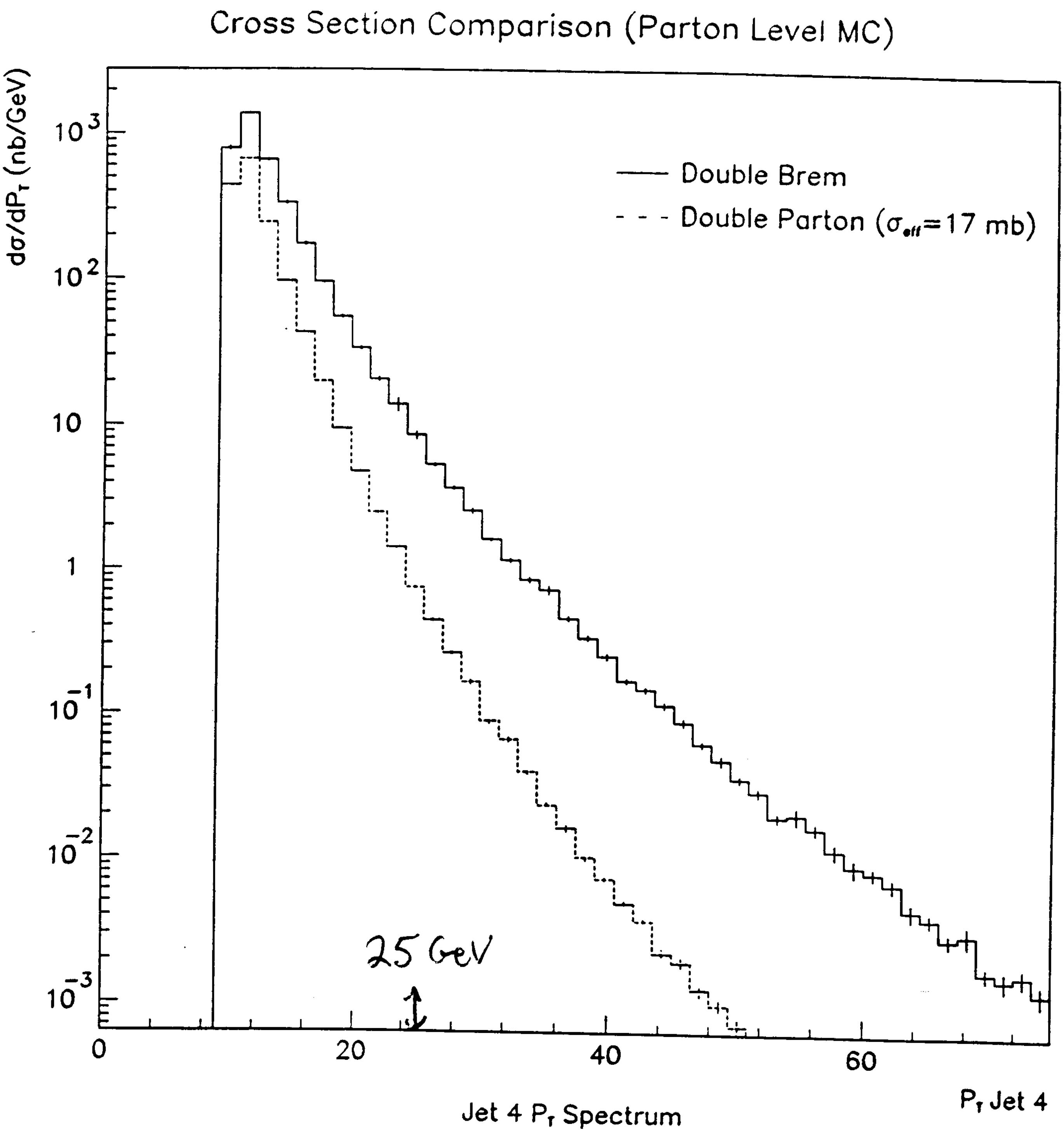
Another problem:

$$\frac{\sigma(DP)}{\sigma(QCD)}$$

decreases as P_T increases.

Effect of P_T cut on

Double Parton content



Measuring σ_{DP}

use topological variables sensitive to pairwise P_T balance:

$$S(A,B) = \frac{1}{\sqrt{2}}\sqrt{\frac{|\mathbf{P_t(A)}|^2}{\delta_{\mathbf{A}}^2} + \frac{|\mathbf{P_t(B)}|^2}{\delta_{\mathbf{B}}^2}}$$

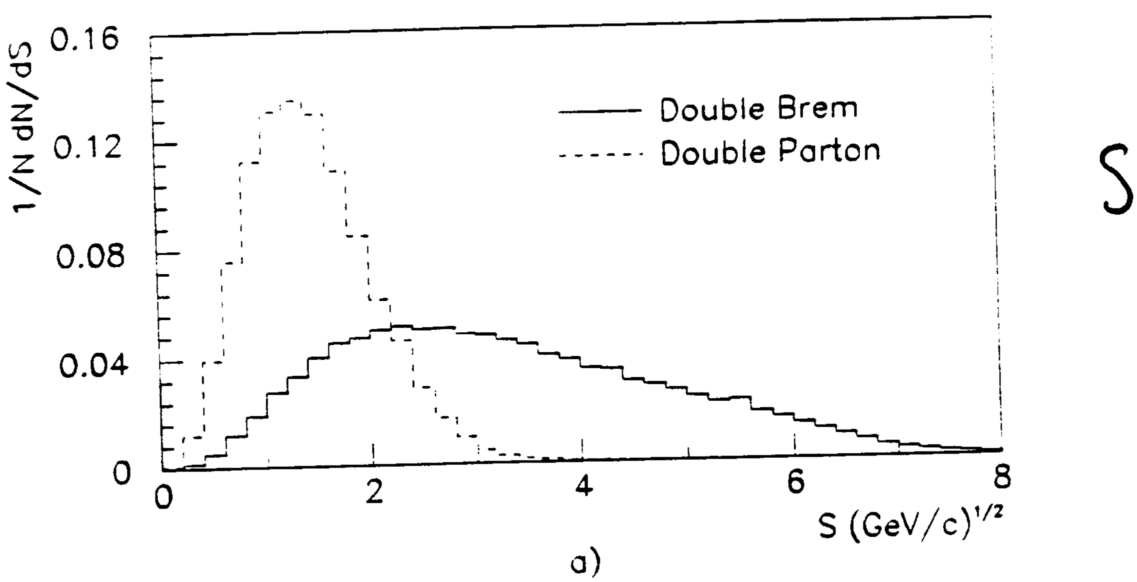
A and B are the best two-body pairs
$P_t(A)$, $P_t(B)$ **= pair transverse momentum**
δ_A, δ_B **= momentum resolution for** $P_t(A)$, $P_t(B)$.
QCD: S is broad distribution
DPS: S is peaked toward low values

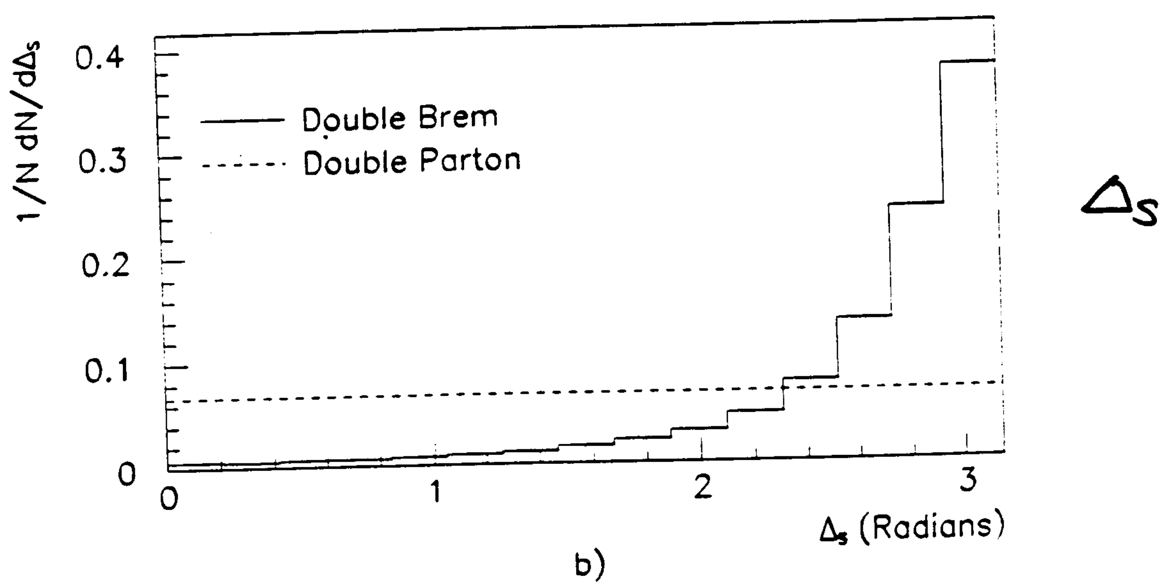
ΔS $\equiv$ angle between $P_t(A)$ **and** $P_t(B)$
QCD: ΔS $\approx \pi$
DPS: ΔS $\approx$ flat , random

QCD Monte Carlo → Double Brem shapes
DPS: combine two 2-jet events from data.

Double parton fraction: fit data distributions to a linear combination of Double Brem and Double Parton shapes.

Shape of topological Variables S and Δ_S for QCD Double Brem and for Double Parton Model.





Previous 4-jet measurements:

- **AFS:** $\sqrt{s}$ **= 63 GeV,** E_T **>4 GeV** Z. Phys. C 34, 163 (1987)
  $\Rightarrow \sigma_{eff} \approx$ **5 mb**
- **UA2:** $\sqrt{s}$ **= 630 GeV** E_T **>15 GeV** Phys. Lett. B 268, 145 (1991)
  $\Rightarrow \sigma_{eff} >$ **8.3 mb**
- **CDF-1989:** $\sqrt{s}$ **= 1800 GeV,** E_T **>25 GeV** PRD 47, 4857 (1993)
  $\Rightarrow \sigma_{eff} = 12.1^{+10.7}_{-5.4}$ **mb,**
  $\Rightarrow$ **DP fraction** $= 5.4^{+1.6}_{-2.0}\%$

New analyses by CDF and D0:

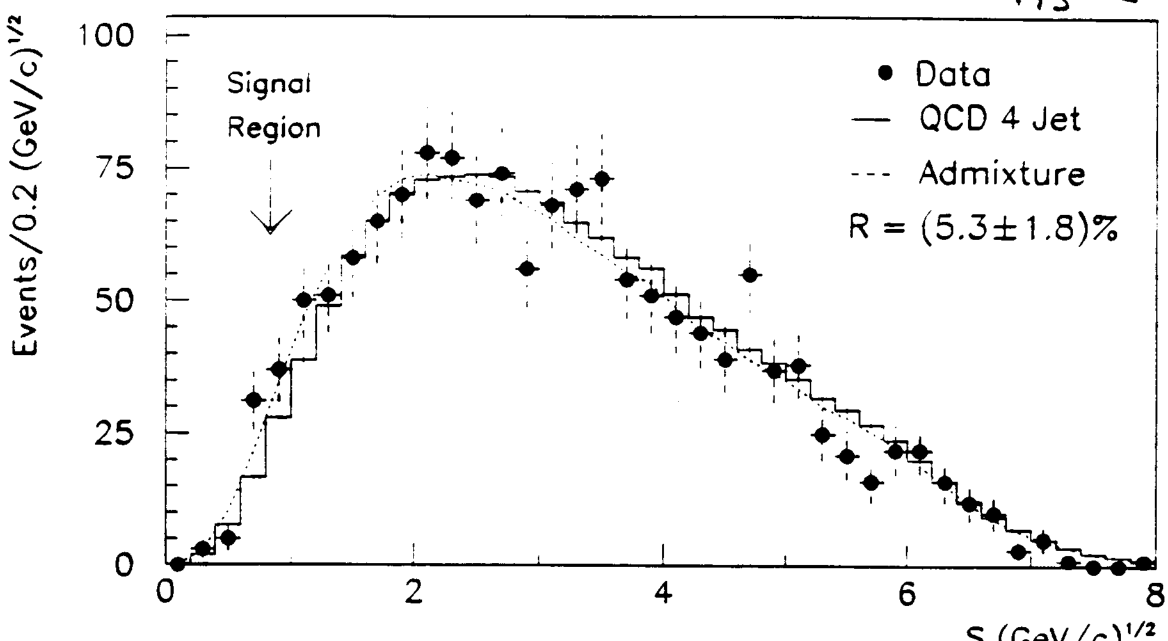
D0: 4-jets $E_T >$ **25 GeV, Neural Net**
compare data and QCD (Pythia 4-jets).

CDF: γ **+ 3 jet** $\rightarrow$ **low** E_T**:**
$E_T^{photon} >$ **16 GeV,** E_T^{jet} **>5 GeV**
Use ratio of Double Interaction (two separate $p\bar{p}$ **collisions) and DPS rates to extract** σ_{eff} New trick
$\rightarrow$ **reduce dependence on Monte Carlo.**

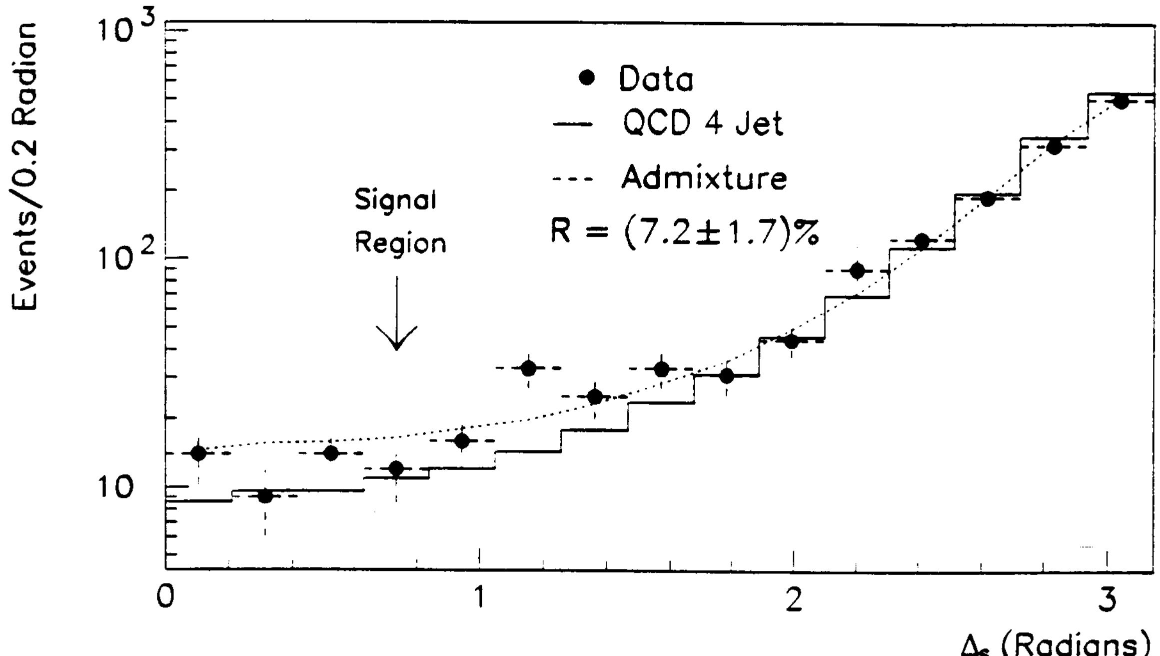
CDF 1989 Result

CDF 4-Jet Data compared to 4 Jet M.C. and to best fit admixture of QCD double brem. + Double Parton Scattering

$P_{T5} < 15$ GeV



a)

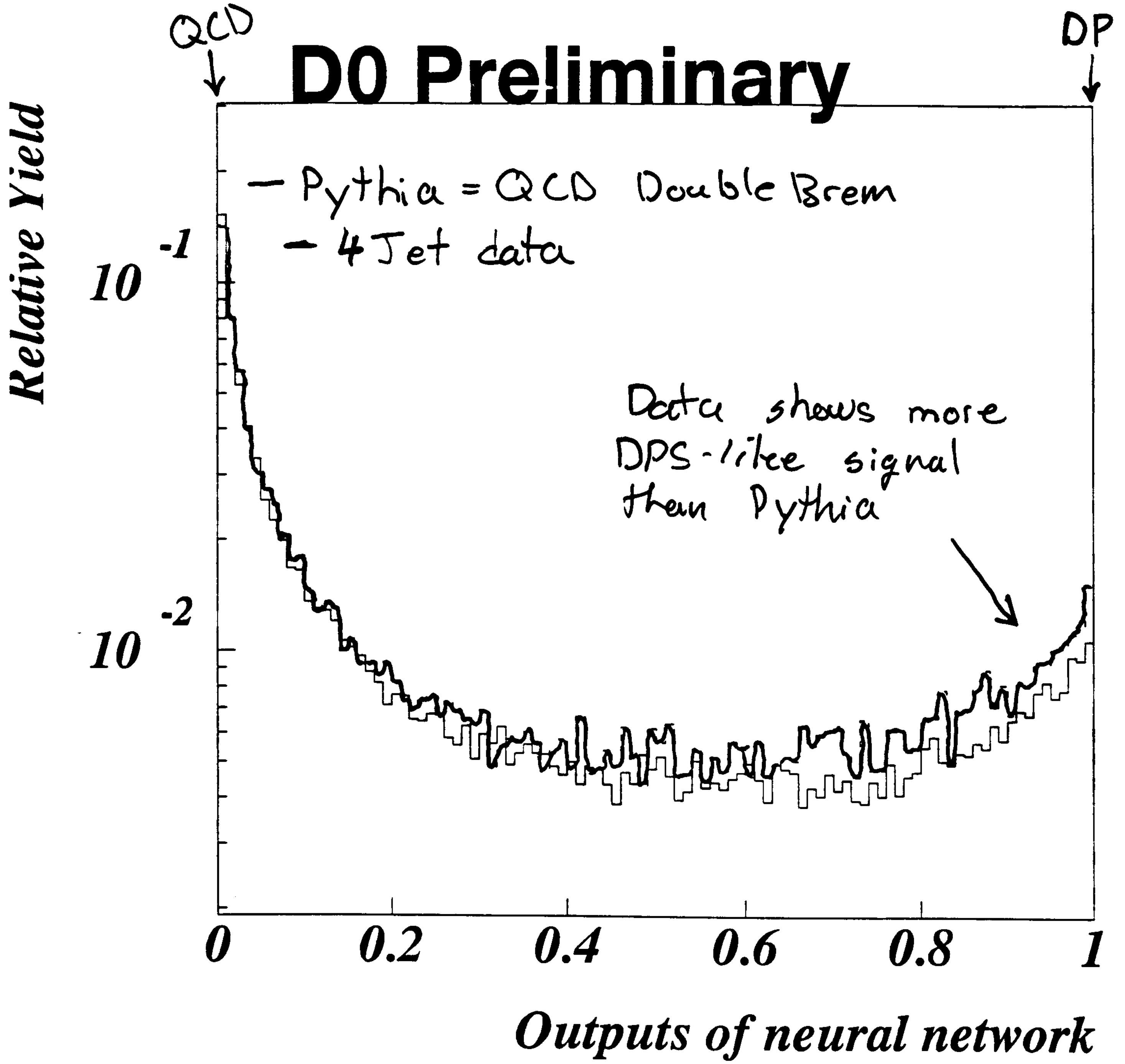


b)

DØ DPS analysis

4 Jet $E_T > 25$ GeV

Train Neural Net to separate
DP model from 2-Jet + 2 Jet data = 1
Independent 4 Jet data sample ~ Double Brem QCD = 0

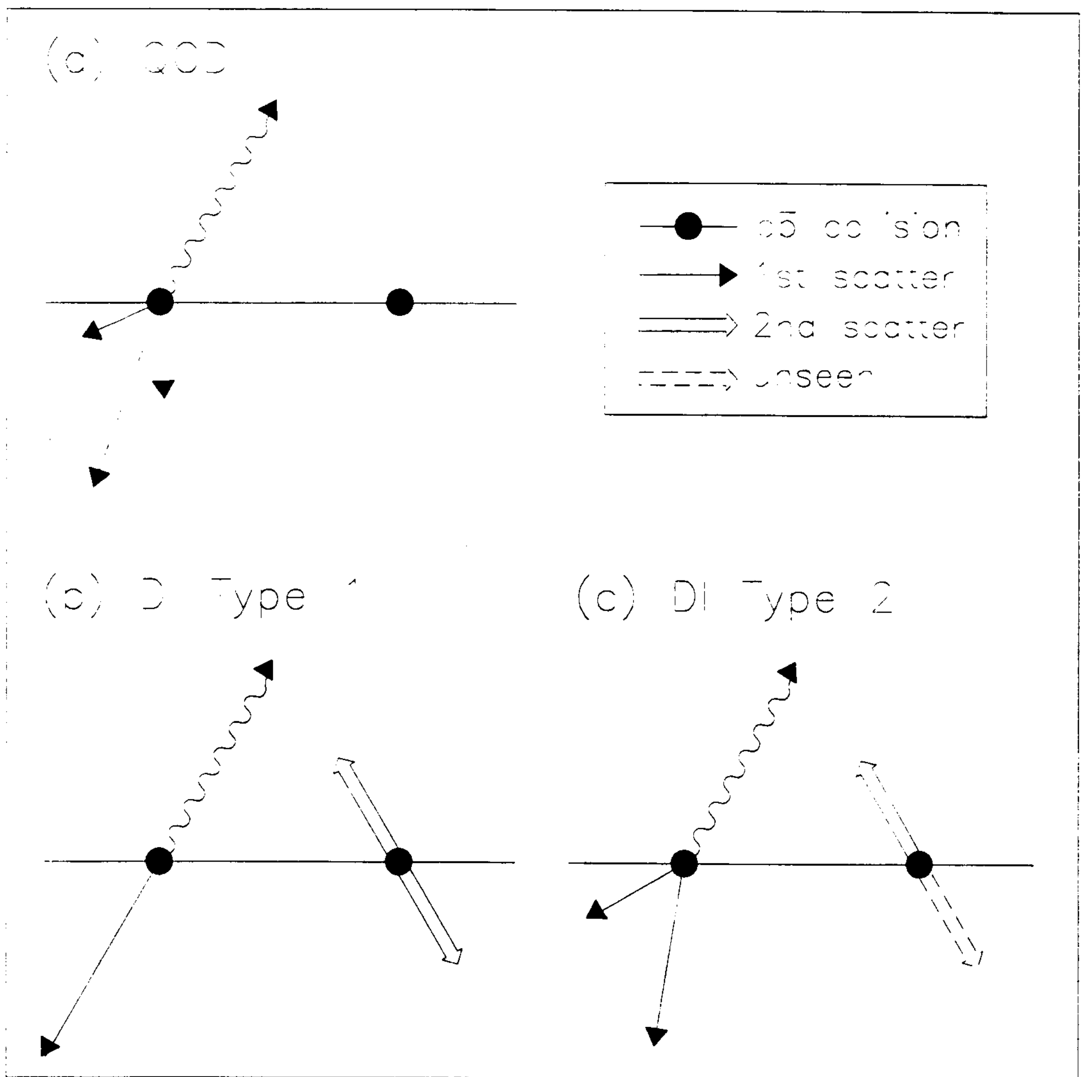


Data Sample: CDF γ + 3 jet analysis

- **Trigger:** E_T^γ **>16 GeV**
- **Run 1A: 16** pb^{-1}
- $|\eta^\gamma|$ **<0.9**
- **Isolation <4 GeV in cone R=0.7 around** γ
- $|\eta^{jet}|$ **<4**
- **# jets = 3**
- E_T^{jet1} **>5 GeV**
- **5 GeV<** E_T^{jet2}, E_T^{jet3} **<7 GeV**

$\Rightarrow \approx$ **16,000** $N_{VTX} = 1$ **DP candidates**
$\Rightarrow \approx$ **5,500** $N_{VTX} = 2$ **DI candidates**

QCD and Double Interactions (DI)



To separate types a, b, and c, associate tracks in jets to a vertex.
DI $\equiv\ \geq 1$ jet from second vertex

Goals of $\gamma + 3$ jet analysis

Determine $f_{DP} = \frac{\#DPS}{Total}$ **events**

Determine σ_{eff}

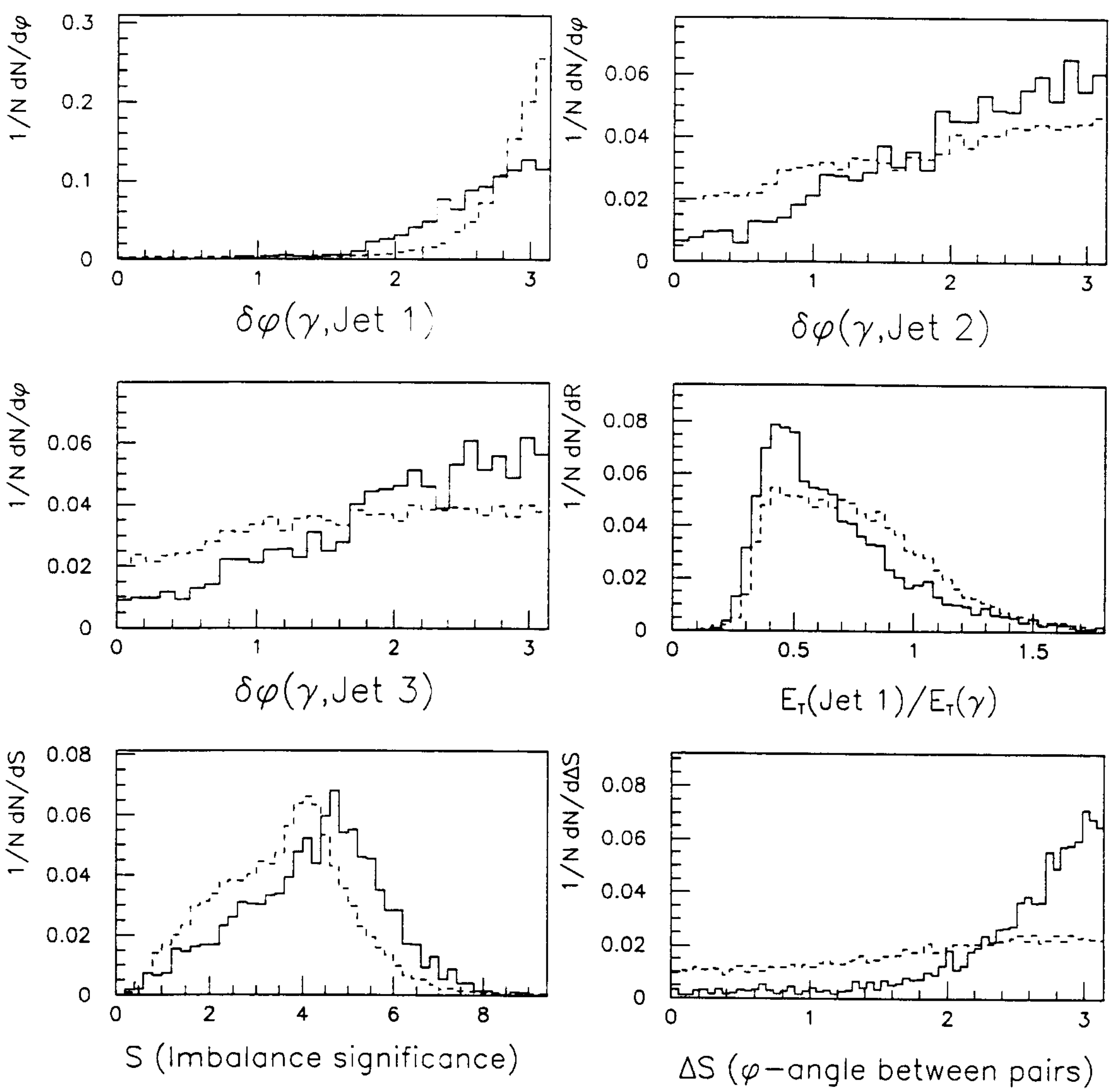
Look for parton correlations

Two approaches to measuring f_{DP}**:**

- **Like 4-jet analysis:**
  use Pythia to model QCD double brem,
  combine events to model DPS
  $\rightarrow$ **fit distributions for** f_{DP} f_{QCD}.
- **Use data: contrast two separate data samples which have different** f_{DP} **to determine** f_{DP} **and** f_{QCD}

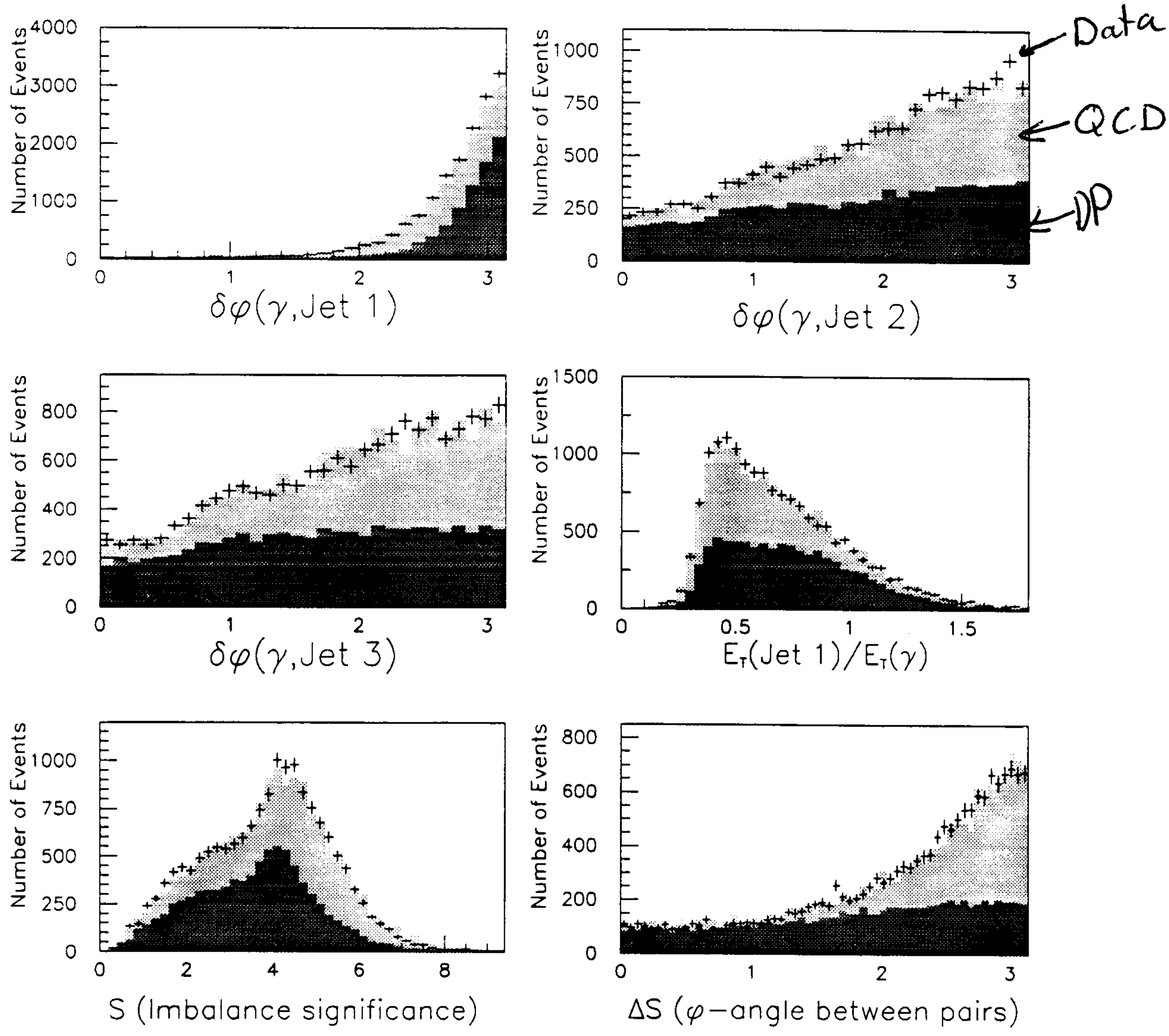
$\Rightarrow$ **both give similar results:**
$f_{DP} = 52 \pm 1$ **% stat.**

To measure f_{DP} and f_{QCD} use 6 variables:



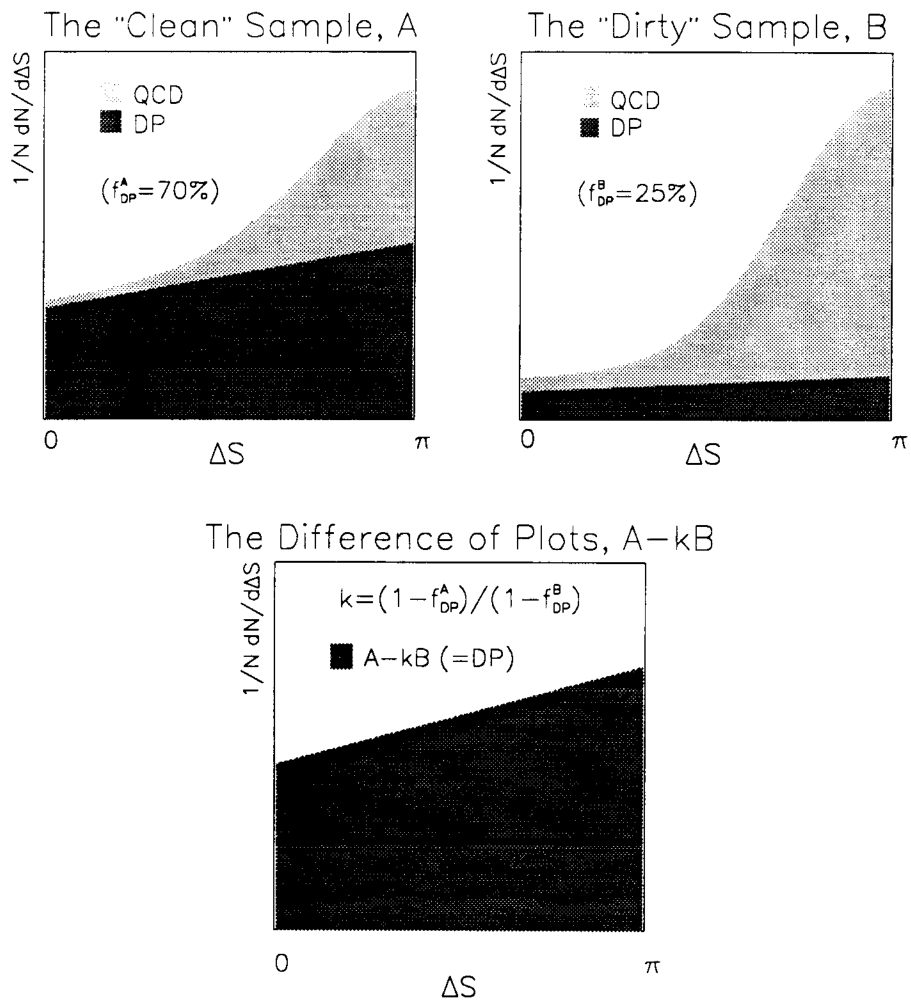
solid = Pythia, dashed = Double Parton Model

Admixture of 52% DP + 48% QCD provides best fit to the data.



Two Dataset Method

Know signal (DP) properties from Mixed event sample, but not BKG (QCD).
Separate data into 2 samples:



Assume QCD component has same shape in A and B.
Vary k until A-kB distribution = the DP distribution.
Extract f_{DP} from k: Result $\rightarrow f_{DP} = 52\%$

Determination of σ_{eff}

Previous 4-jet analysis:

$$\sigma_{\text{eff}} = \mathbf{m}\, \sigma_{\text{A}} \frac{\sigma_{\text{B}}}{2\sigma_{\text{DP}}}$$

Processes A and B were dijets, $\sigma_A = \sigma_B = \sigma_{JJ}$, calculated by Monte Carlo, and m=1

CDF has developed new way to extract σ_{eff}:
Number of DPS events in 1-VTX $\equiv N_{DP}$
Number of DI events in 2-VTX $\equiv N_{DI}$
(associate tracks in jets to a vertex,
DI $\equiv \geq 1$ jet came from 2nd vertex.)

$$\sigma_{eff} = \left(\frac{N_{DI}}{N_{DP}}\right)\left(\frac{\sigma_{NDS}}{2}\right)\left(\frac{m}{2}\right)\left(\frac{N_C(1)}{N_C(2)}\right)$$

$N_C(1)$ and $N_C(2)$ are the # beam crossings with 1 or 2 collisions

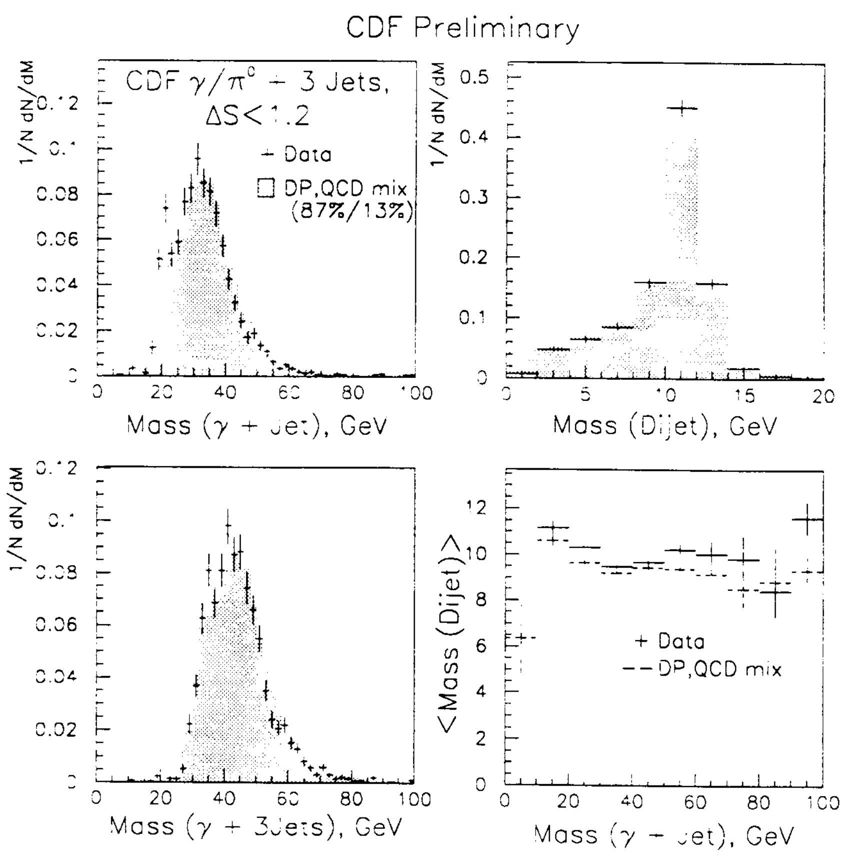
Preprint from Drees and Han: if A and B are distinguishable, then m=2 $\rightarrow$ under discussion

If m=2 $\Rightarrow$ σ_{eff} = 10 $\pm 1^{+4}_{-2}$ mb

Parton Correlations

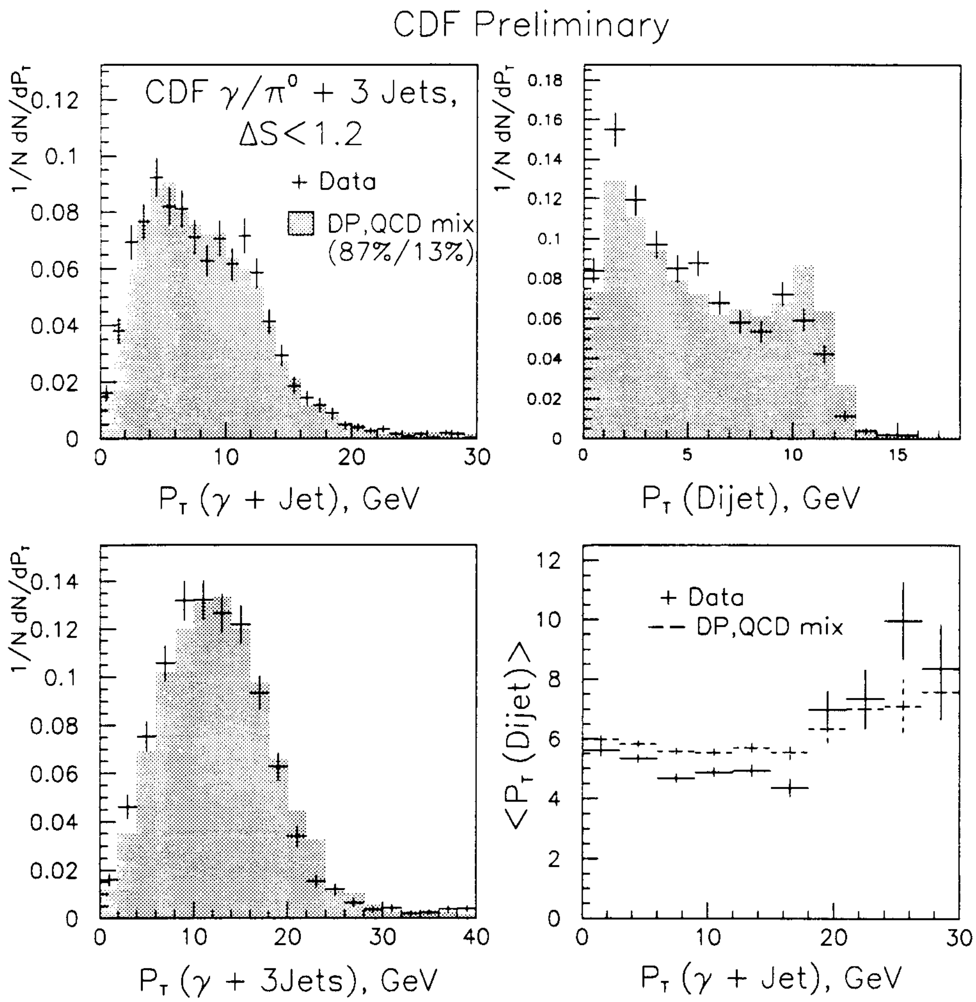
Clumpy parton distribution: If one collision is at high x other one will be too.

Look for x dependence to σ_{eff} in enriched DPS sample: Δ S < 1.2 $\Rightarrow f_{DP} = 87\%$
Compare data (Correlations?) to
DP model (NO Correlations)



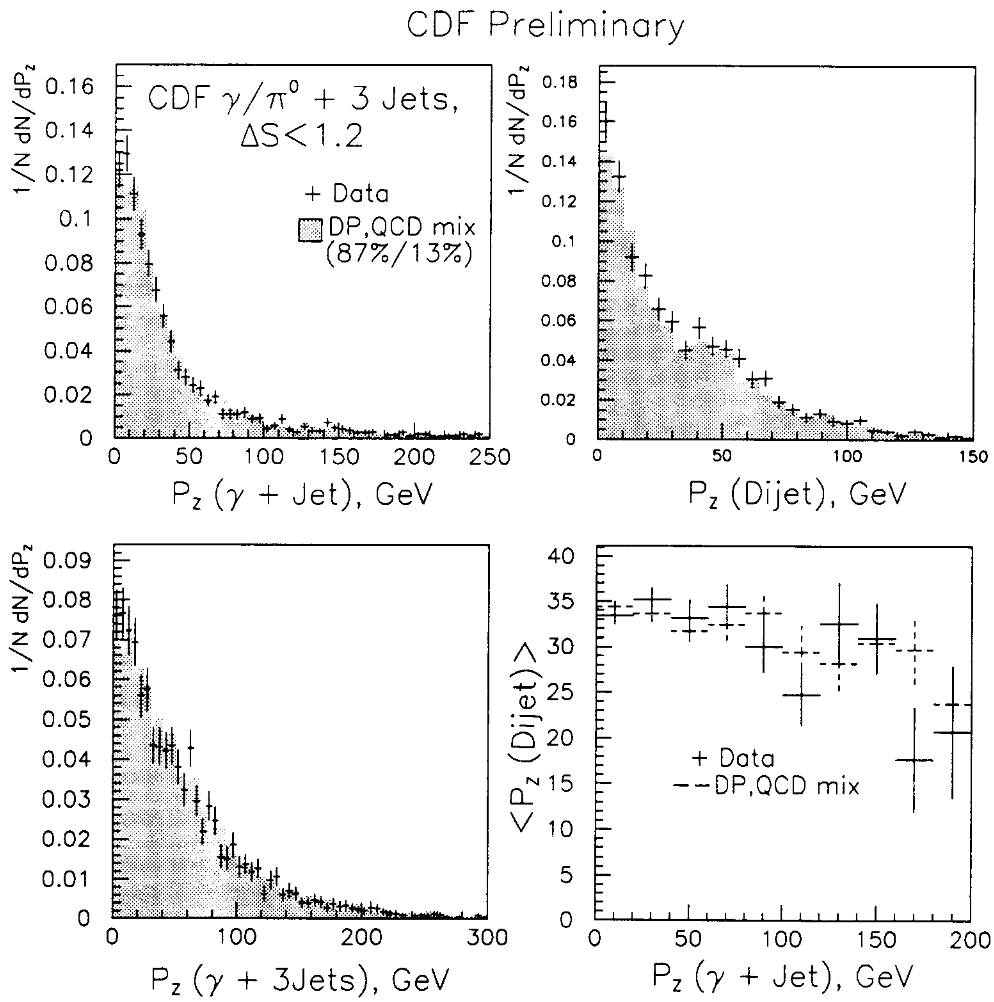
Parton Correlations

Also look at P_t:



Parton Correlations

Also look at P_z:



Data and uncorrelated DPS model show good agreement

⇒ No correlations in Mass, P_t or P_z

Conclusions

CDF has observed a strong signal for Double Parton Scattering:

- **factor of ≈10 increase in signal strength**
- **factor of ≈8 increase in statistics**
- **developed new technique which is ≈ independent of QCD Modeling**

CDF PRELIMINARY:

$f_{DP} = \mathbf{52 \pm 1\%}$ **stat.**

$\sigma_{eff} = \mathbf{10 \pm 1^{+4}_{-2}}$ **mb (if m=2)**

No kinematic correlations observed

Future:

- **determine m**
- **study possible correlations**
- **Quantify D0 Neural Net observation**
- **extend to other processes:**
  γ, γ **jet, jet**
  e, e, jet, jet ....