Double Parton Scattering

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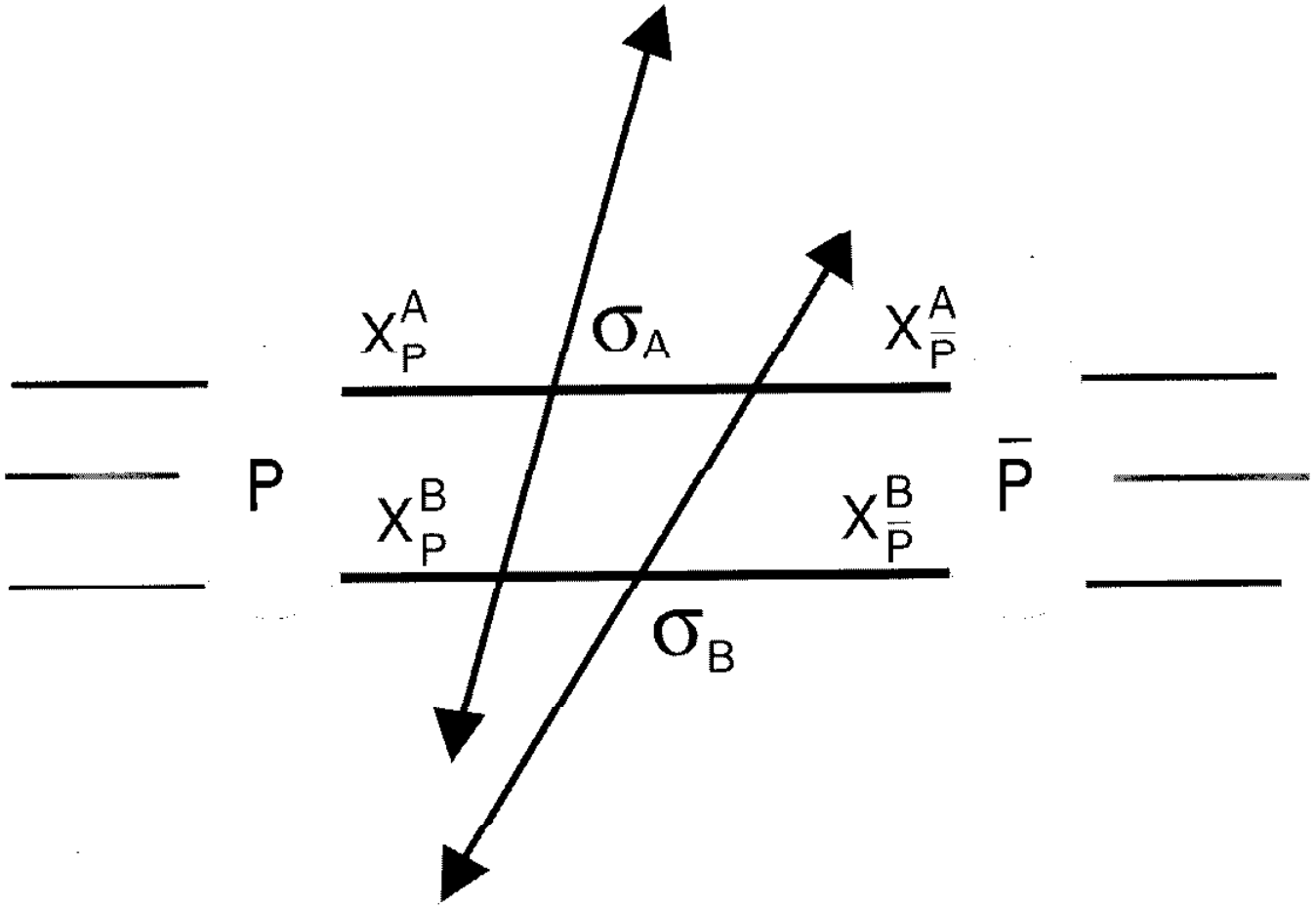


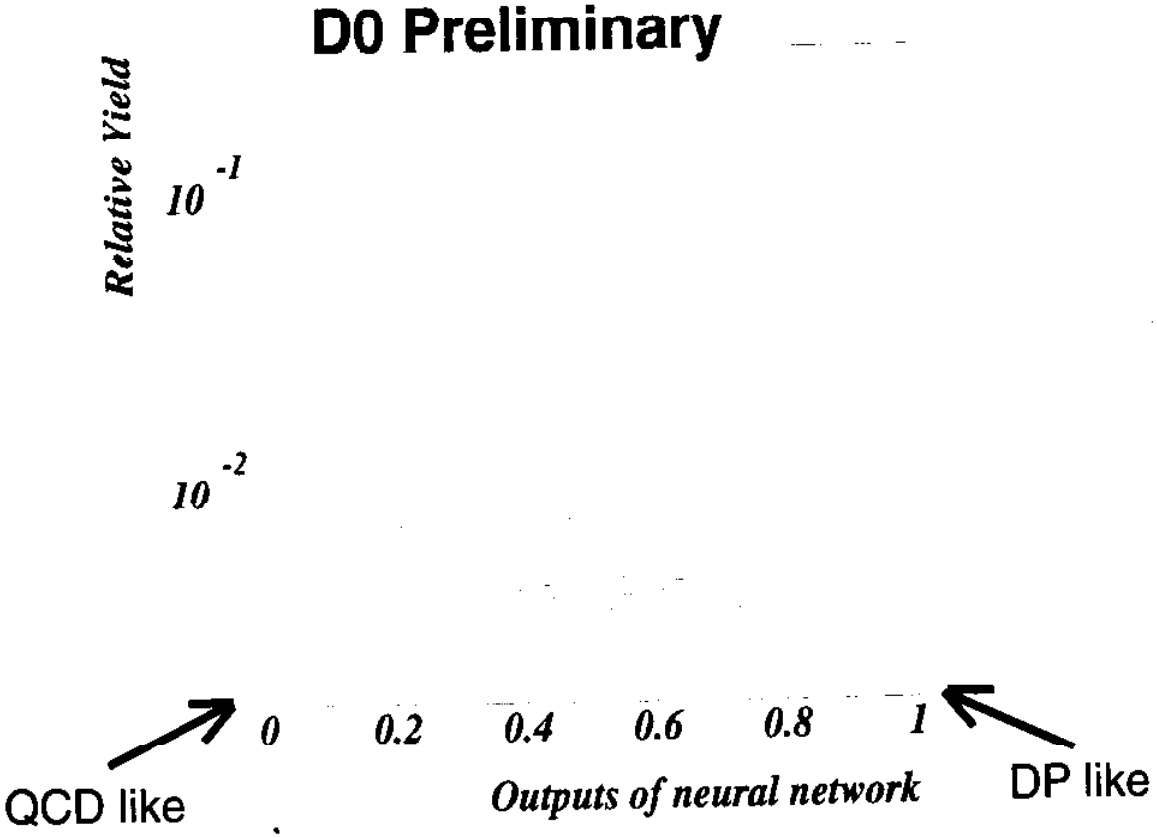
$$\sigma_{DP} = m \frac{\sigma_A \sigma_B}{2 \sigma_{eff}}$$

m = 2 if A and B are distinguishable
1 if A and B are indistinguishable

Previous measurements of σ_{eff}

Each used a 4 jet data sample and searched for the presence of uncorrelated dijets.

- AFS σ_{eff} ~ 5 mb [Z. Phys. C34, 163 (1987)]
- UA2 $\sigma_{eff} > 8.3$ mb [Phys. Lett. B268, 145 (1991).]
- CDF $\sigma_{eff} = 12.1 \,^{+10.7}_{-5.4}$ mb [Phys Rev D68, 4857 (1993)]
- Prediction - hard sphere proton 11 mb
- D0 preliminary - Et > 25 GeV, 1 vertex
  Use 10 input variables to tune neural net
  $\Delta\phi$ between jets, energy balance of jet pairs, S, ΔS
  Tune on PYTHIA's QCD prediction of 4 jets
  and a model derived from combining 2 dijet events. [FERMILAB-CONF-96/304-E]



CDF "Photon" + 3 Jet DP search

PRL preprint FERMILAB-PUB-97-083-E
PRD preprint posted April 15.

16 pb $^{-1}$ of data collected in 1992-93.

Photons candidates (isolated Em clusters)
Et > 16 Gev, $|\eta|$ < 0.9

3 Jets
Et > 5 GeV
ΔR between photon and jet pairs > 0.8
Lowest two jets Et < 7 GeV

No 4th Jet with Et > 5 GeV

Two data sub-samples were constructed

1 vertex events: double parton rate
2 vertex events: double interaction rate

New Method for extracting σ_{eff} at CDF

Use Double Parton (DP) events

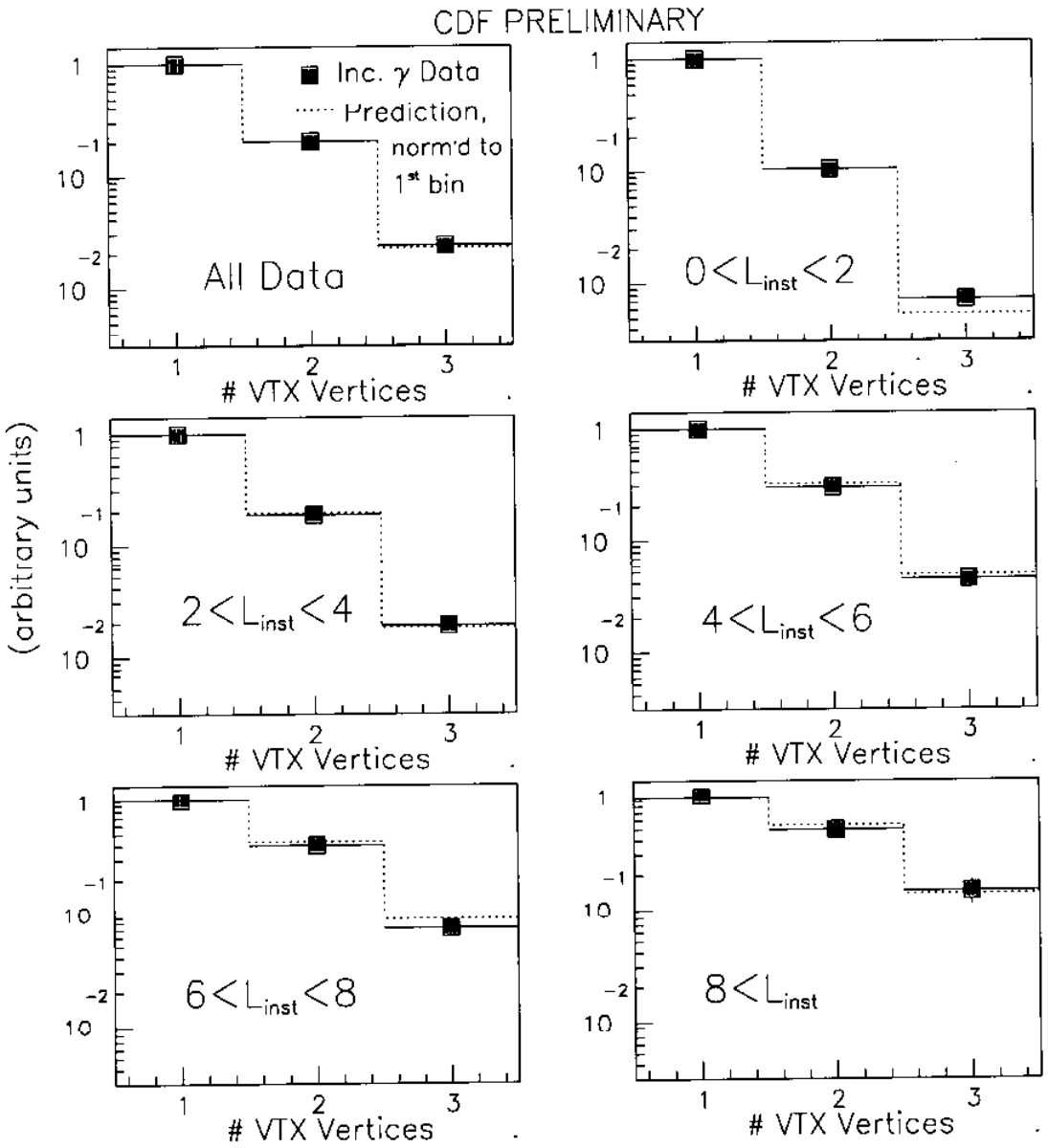
$$N_{DP} = \frac{\sigma_A \sigma_B}{\sigma_{NDS} \sigma_{eff}} N_{cross}(1)$$

and Double Interaction (DI) events

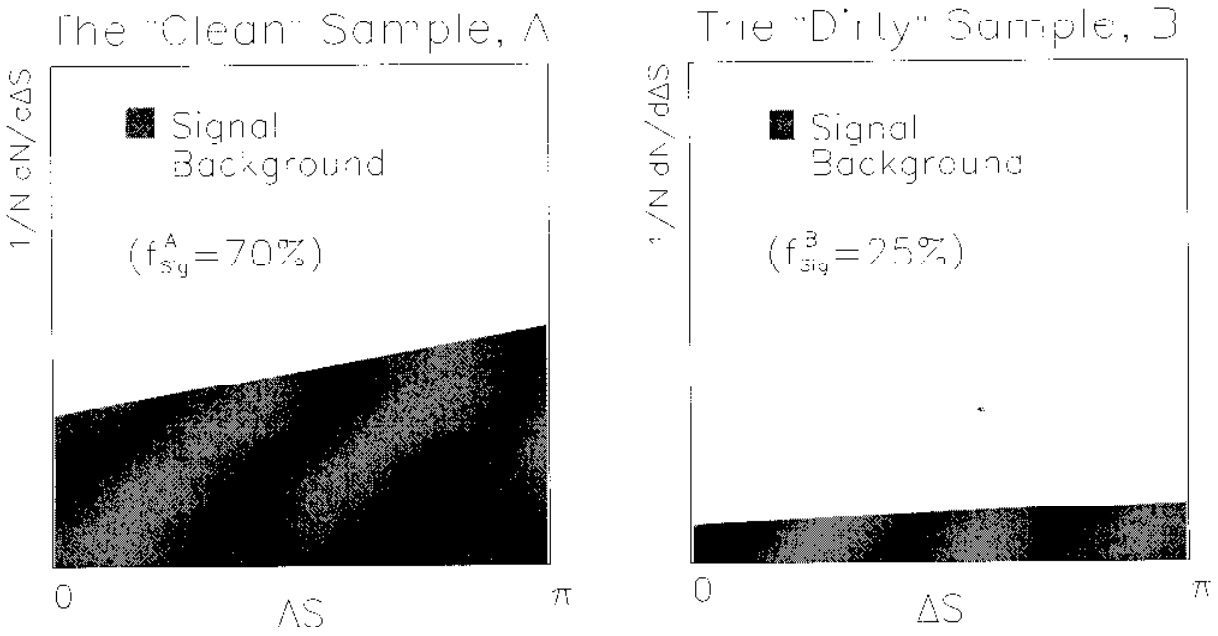
$$N_{DI} = 2 \frac{\sigma_A \sigma_B}{\sigma_{NDS} \sigma_{NDS}} N_{cross}(2)$$

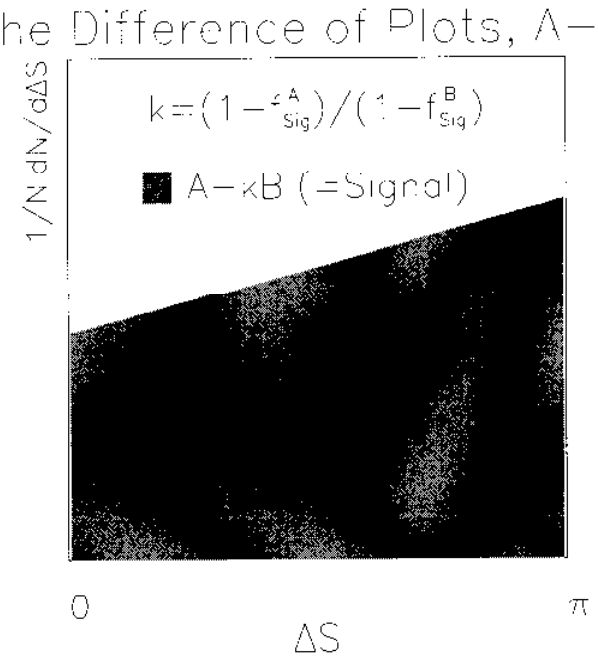
Ratio solved for σ_{eff}

$$\sigma_{eff} = \frac{N_{DI} \; N_{cross}(1)}{N_{DP} \; 2 N_{cross}(2)} \sigma_{NDS}$$


CDF PRELIMINARY
Inc. γ Data
Prediction, norm'd to 1st bin
All Data
0<L_inst<2
2<L_inst<4
4<L_inst<6
6<L_inst<8
8<L_inst
(arbitrary units)
VTX Vertices

Two data set method:

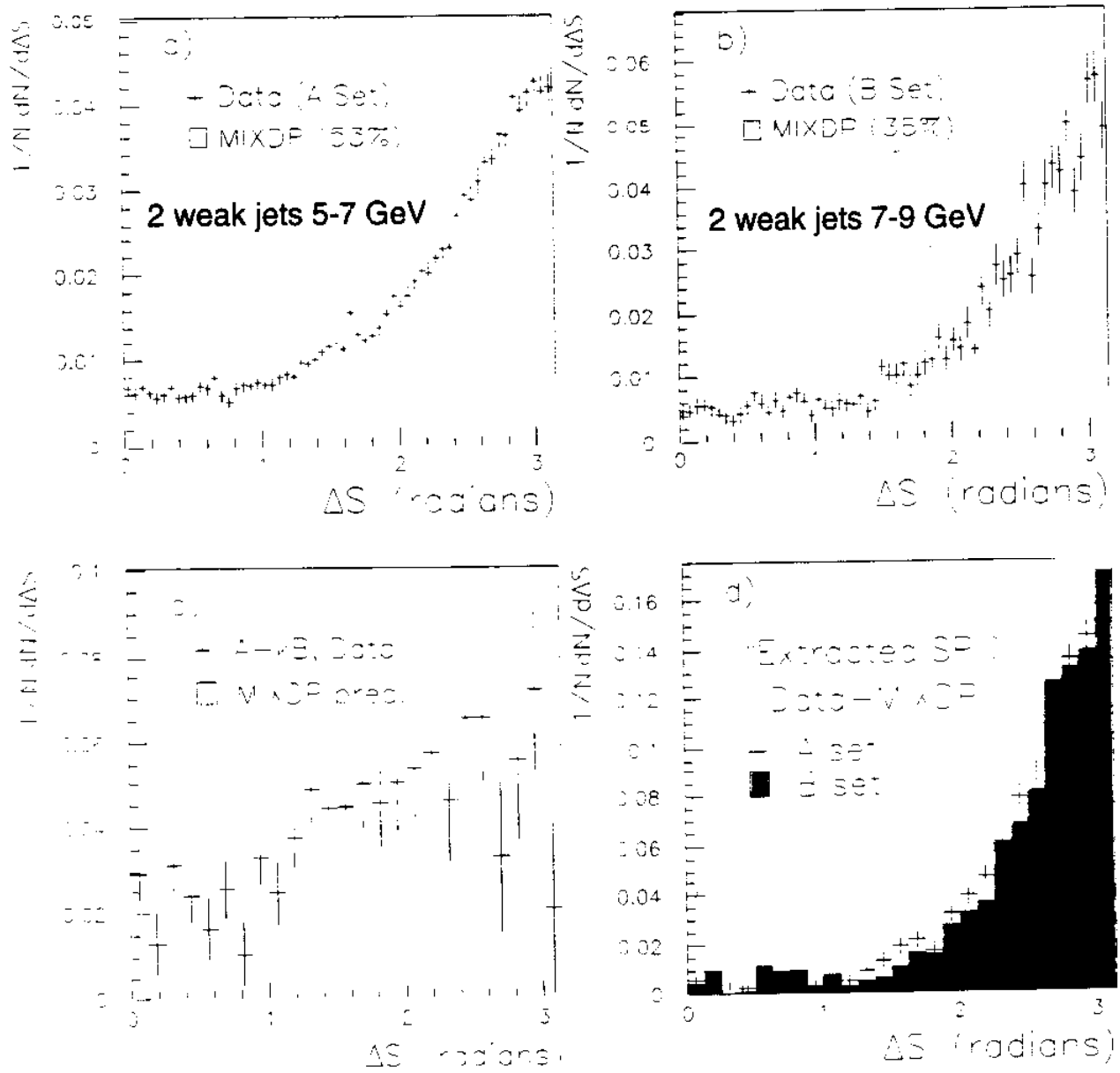




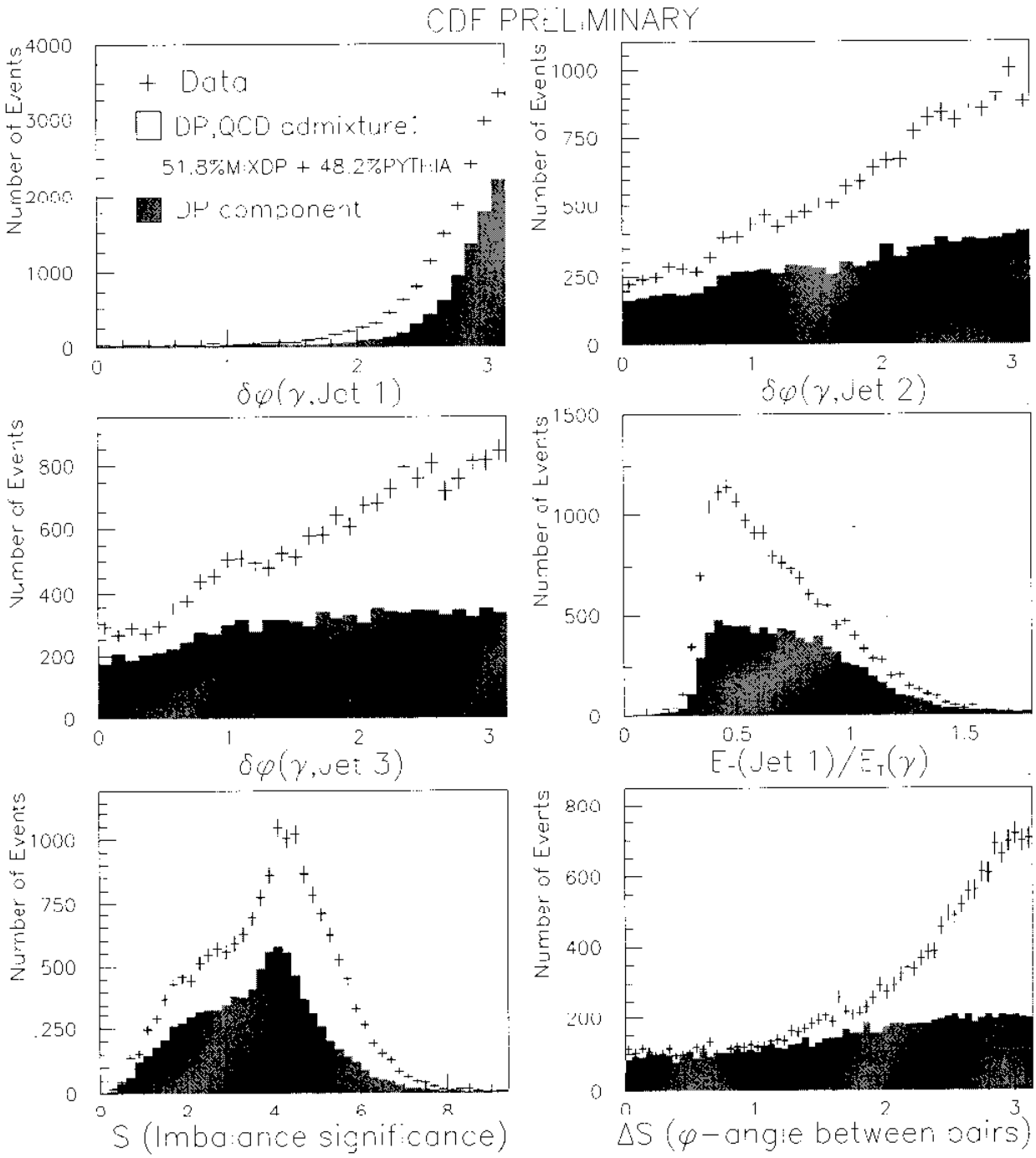
S is the significance away from pairwise momentum balance

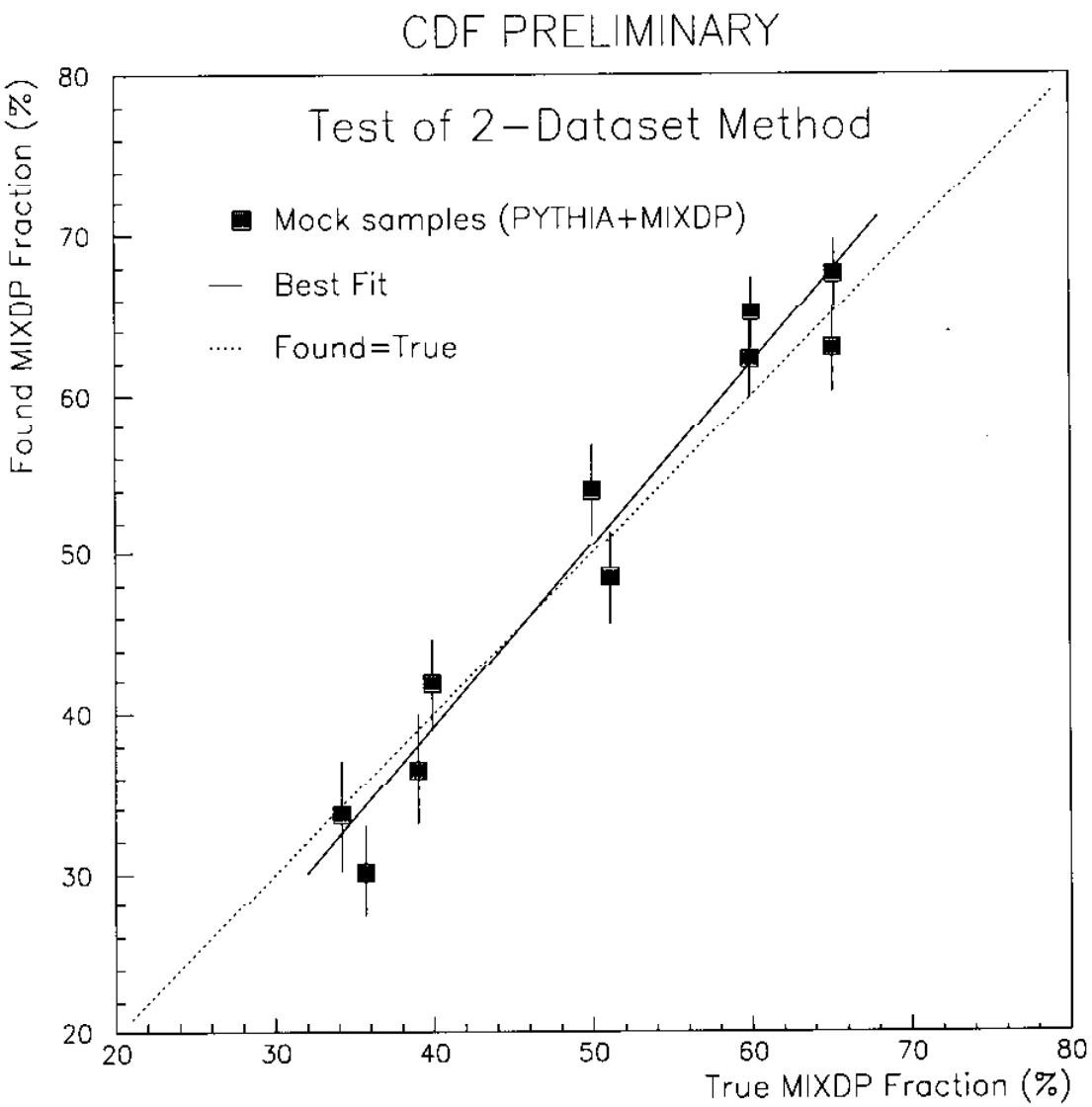
$$S = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|\vec{p}_T(\gamma J)|}{\delta p_T(\gamma J)}\right)^2 + \left(\frac{|\vec{p}_T(JJ)|}{\delta p_T(JJ)}\right)^2}$$

ΔS is the Δφ angle between the pt vectors of the pairs which have the best momentum balance.

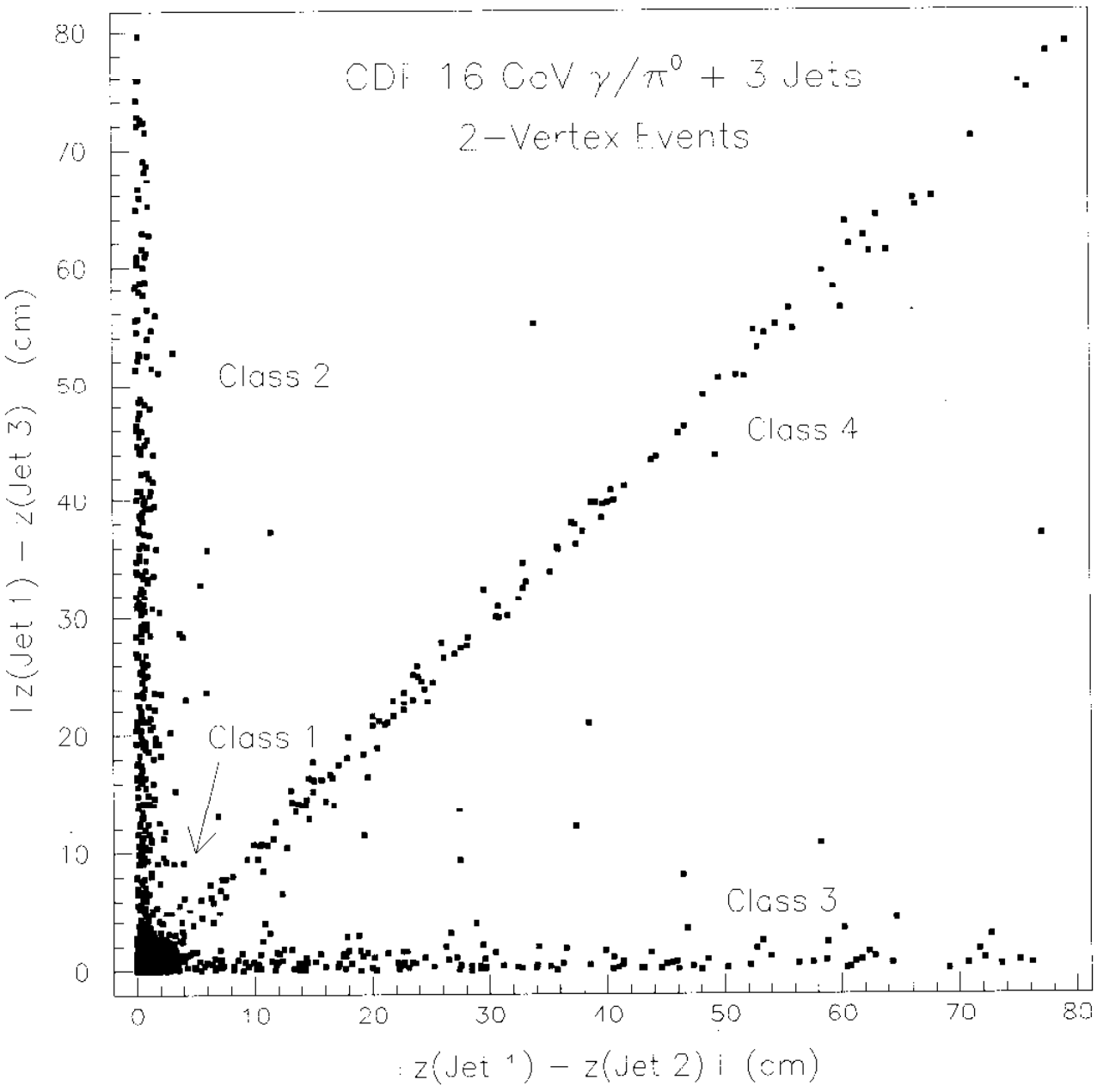


Six Sensitive Variables:

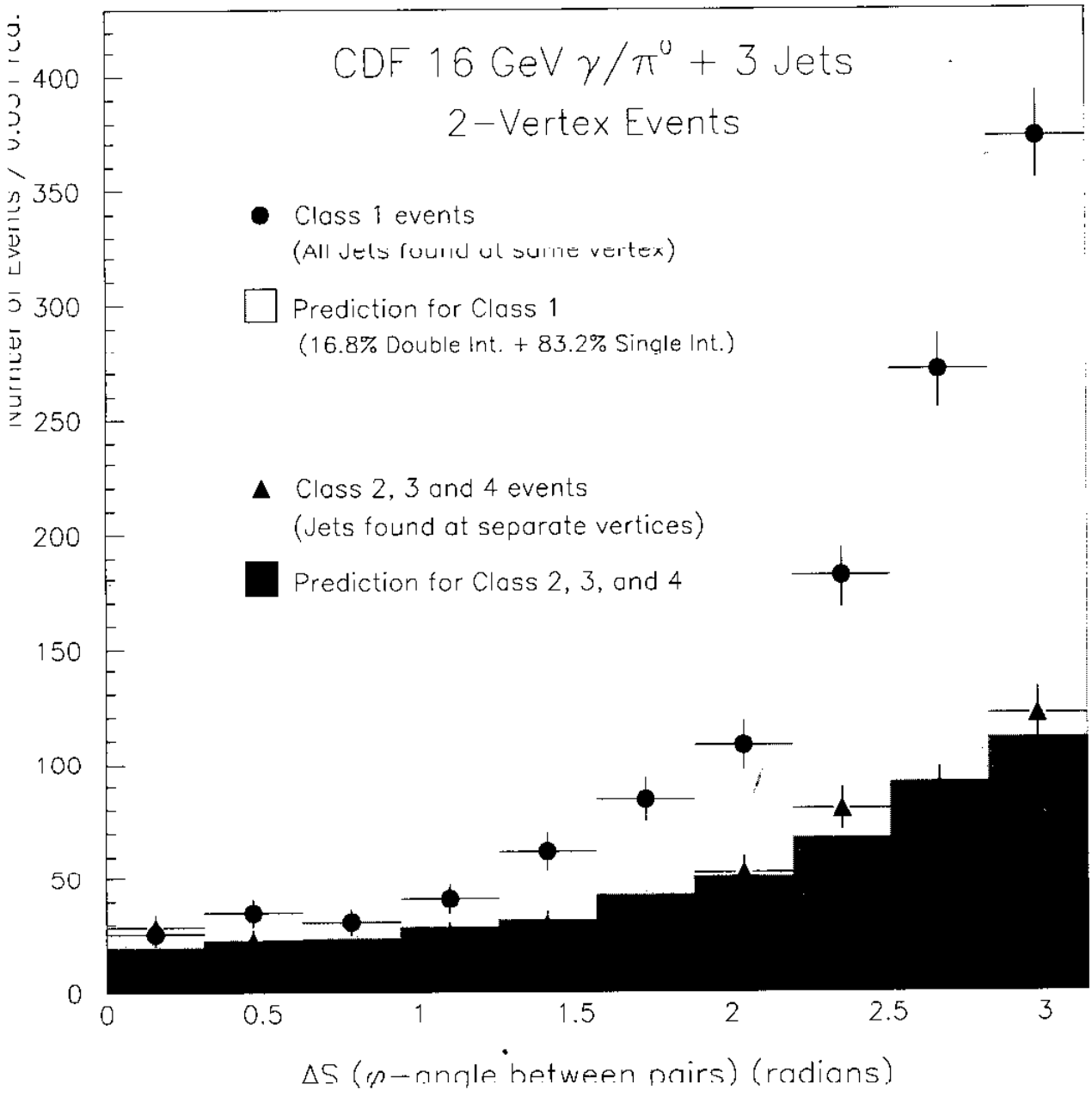



CDF PRELIMINARY
Test of 2−Dataset Method
Mock samples (PYTHIA+MIXDP)
Best Fit
Found=True
Found MIXDP Fraction (%)
True MIXDP Fraction (%)
20
30
40
50
60
70
80

Use tracks in jets to find double interaction contribution, N_{DI} to 2 vertex sample.



17% of 2 vertex data contain at least one jet from the second interaction.


CDF 16 GeV γ/π^0 + 3 Jets
2−Vertex Events
Class 1 events
(All Jets found at same vertex)
Prediction for Class 1
(16.8% Double Int. + 83.2% Single Int.)
Class 2, 3 and 4 events
(Jets found at separate vertices)
Prediction for Class 2, 3, and 4
Number of Events / 0.05 rad.
0
50
100
150
200
250
300
350
400
0
0.5
1
1.5
2
2.5
3
ΔS (φ−angle between pairs) (radians)

Double Parton Result:

$$\sigma_{eff} = \frac{N_{DI}\ N_{cross}(1)}{N_{DP}\ 2\,N_{cross}(2)} \frac{A_{DP}}{A_{DI}}\ \sigma_{NDS}$$

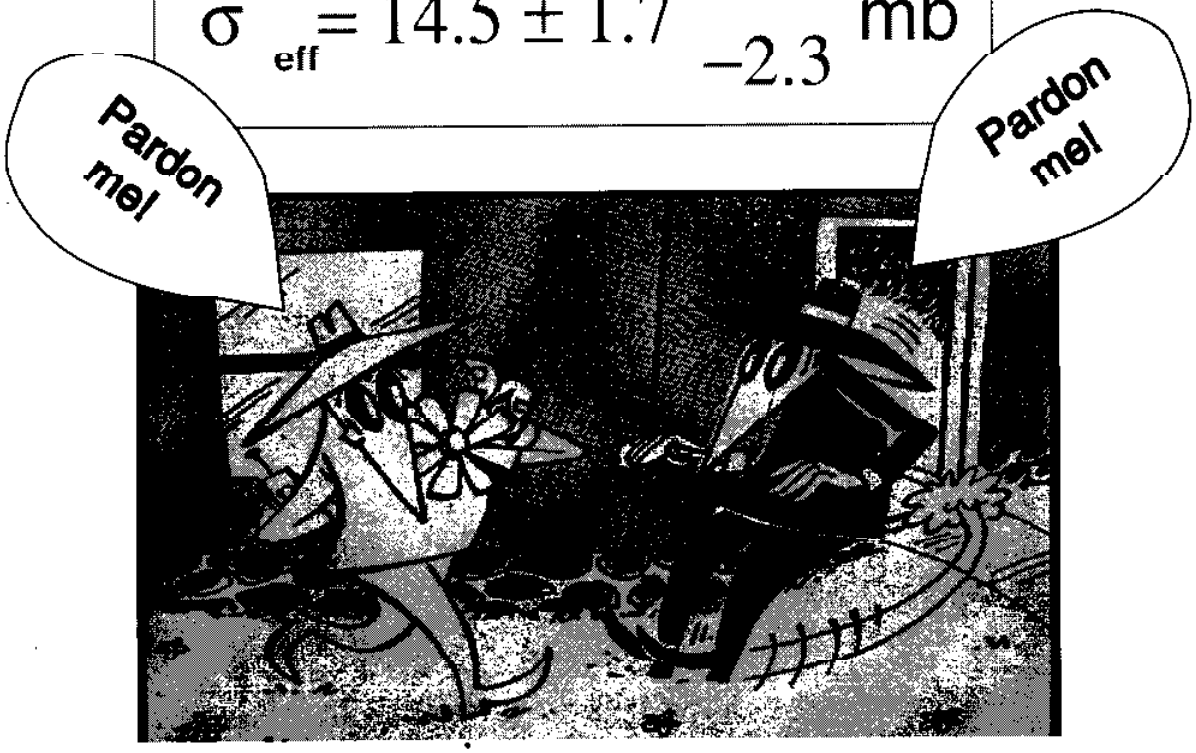
$$N_{DP} = 7{,}360 \pm 360\ ^{+720}_{-380} \qquad (52.6\%\ 1\ \text{vertex})$$

$$N_{DI} = 1060 \pm 110 \pm 110 \qquad (17.7\%\ 2\ \text{vertex})$$

$$\frac{N_{cross}(1)}{N_{cross}(2)} = 2.06 \pm 0.02\ ^{+0.01}_{-0.13} \qquad \frac{A_{DP}}{A_{DI}} = 0.958$$

$$\sigma_{NDS} = 50.9 \pm 1.5\ \text{mb}$$

$$\sigma_{eff} = 14.5 \pm 1.7\ ^{+1.7}_{-2.3}\ \text{mb}$$



Radius of the Proton:

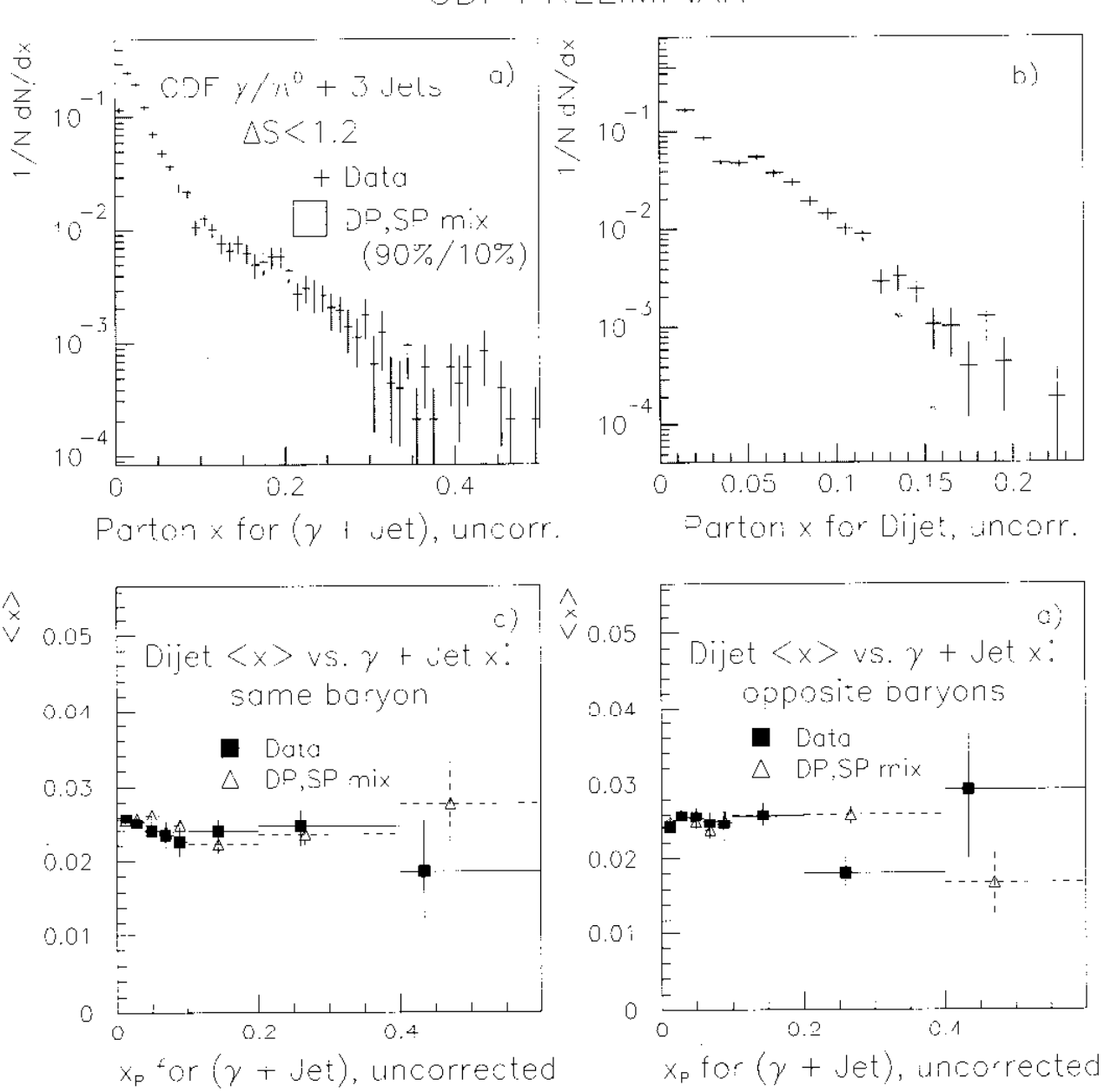
Model for density	Form of density, dN/d^3r	Predictions RMS r	σ_{eff}	Measurements scale (fm)	RMS r (fm)	n
Uniform Sphere	Constant, $r < r_p$	$\sqrt{3/5}r_p$	$4\pi r_p^2/4.6$	r_p=0.73	0.56	0.87
Gaussian	$e^{-r^2/2\Sigma^2}$	$\sqrt{3}\Sigma$	$4\pi\Sigma^2$	Σ=0.34	0.59	1.9
Exponential	$e^{-r/\lambda}$	$\sqrt{12}\lambda$	$35.5\lambda^2$	λ=0.20	0.70	3.2
Fermi, $\lambda/r_0 = 0.2$	$(e^{(r-r_0)/\lambda}+1)^{-1}$	$1.07r_0$	$4.6r_0^2$	r_0=0.56	0.60	1.1
Fermi, $\lambda/r_0 = 0.5$	" "	$2.01r_0$	$14.5r_0^2$	r_0=0.32	0.63	2.0
Fermi, $\lambda/r_0 = 0.8$	" "	$3.05r_0$	$32.8r_0^2$	r_0=0.21	0.64	3.0

RMS radius varies by 20%.

Compares well with RMS radius = 0.77 ± 0.10 fm measured in ep scattering at Q^2 of order 0.1 GeV^2.
R. Hofstadter Rev. Mod. Phys. 28, 214 (1956).

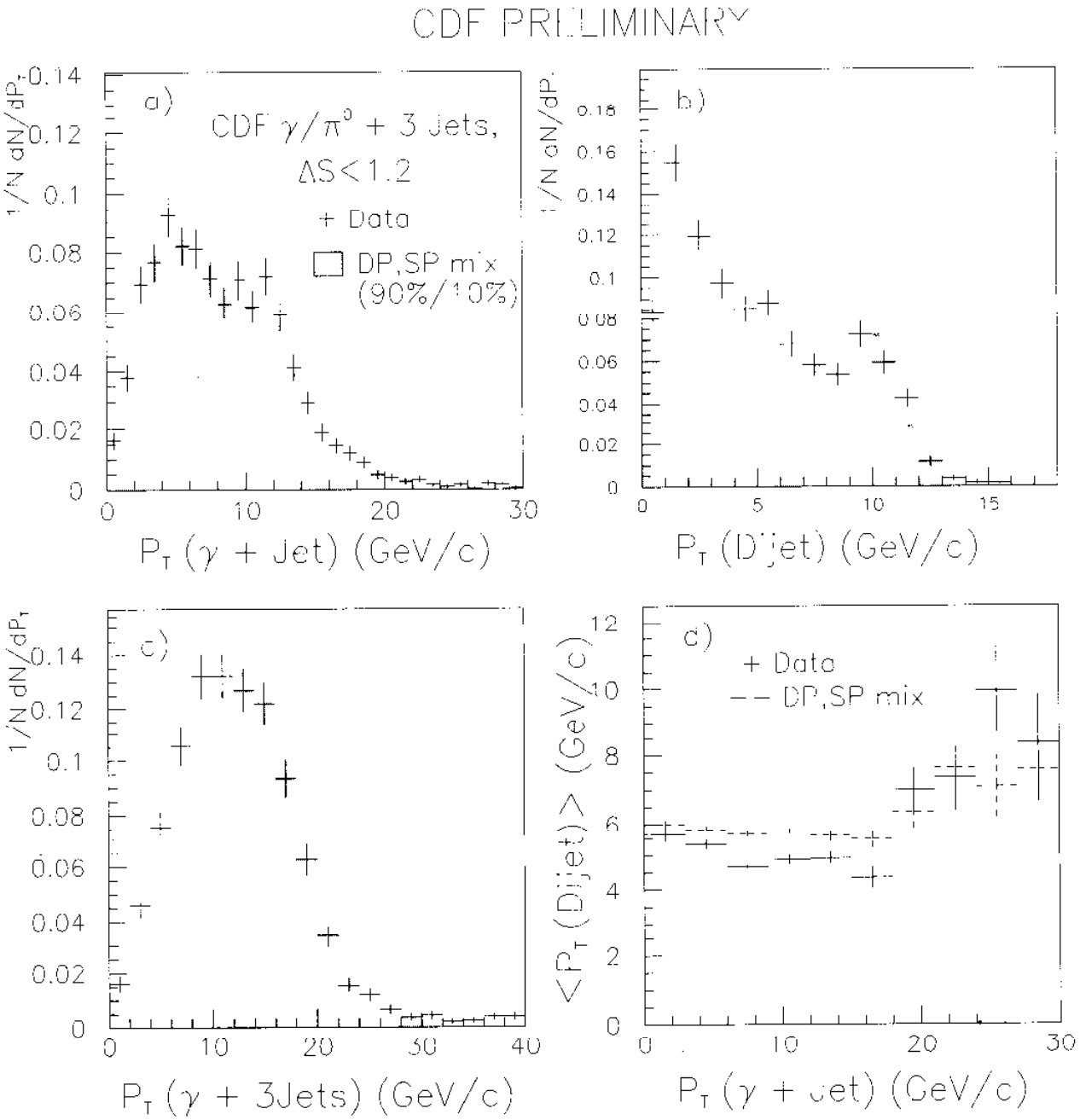
Correlations in x

Take double parton enriched sample, $\Delta S < 1.2$ 90% DP
Does σ_{eff} have an x dependence?

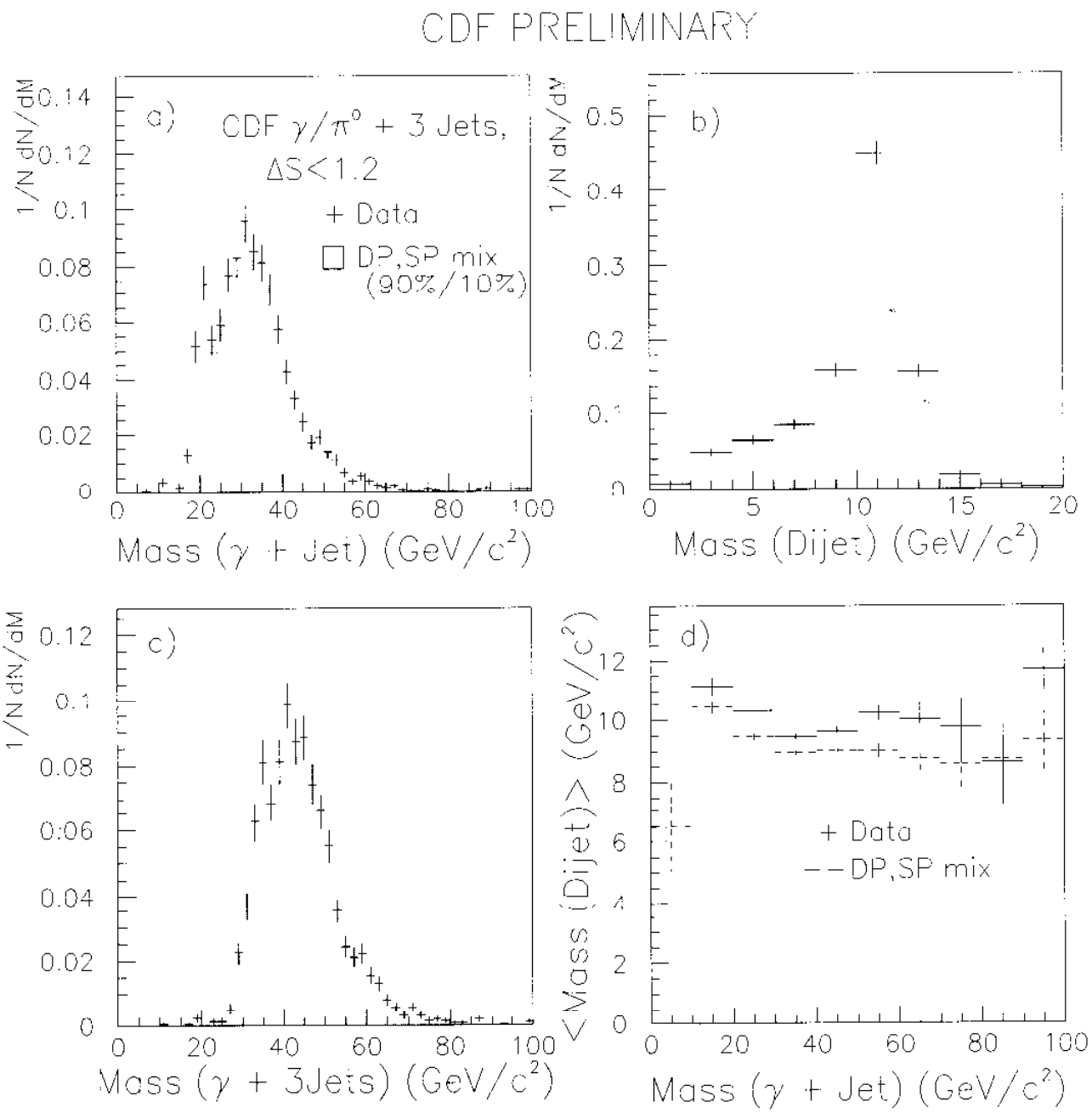


No observable x dependence to σ_{eff} is apparent.

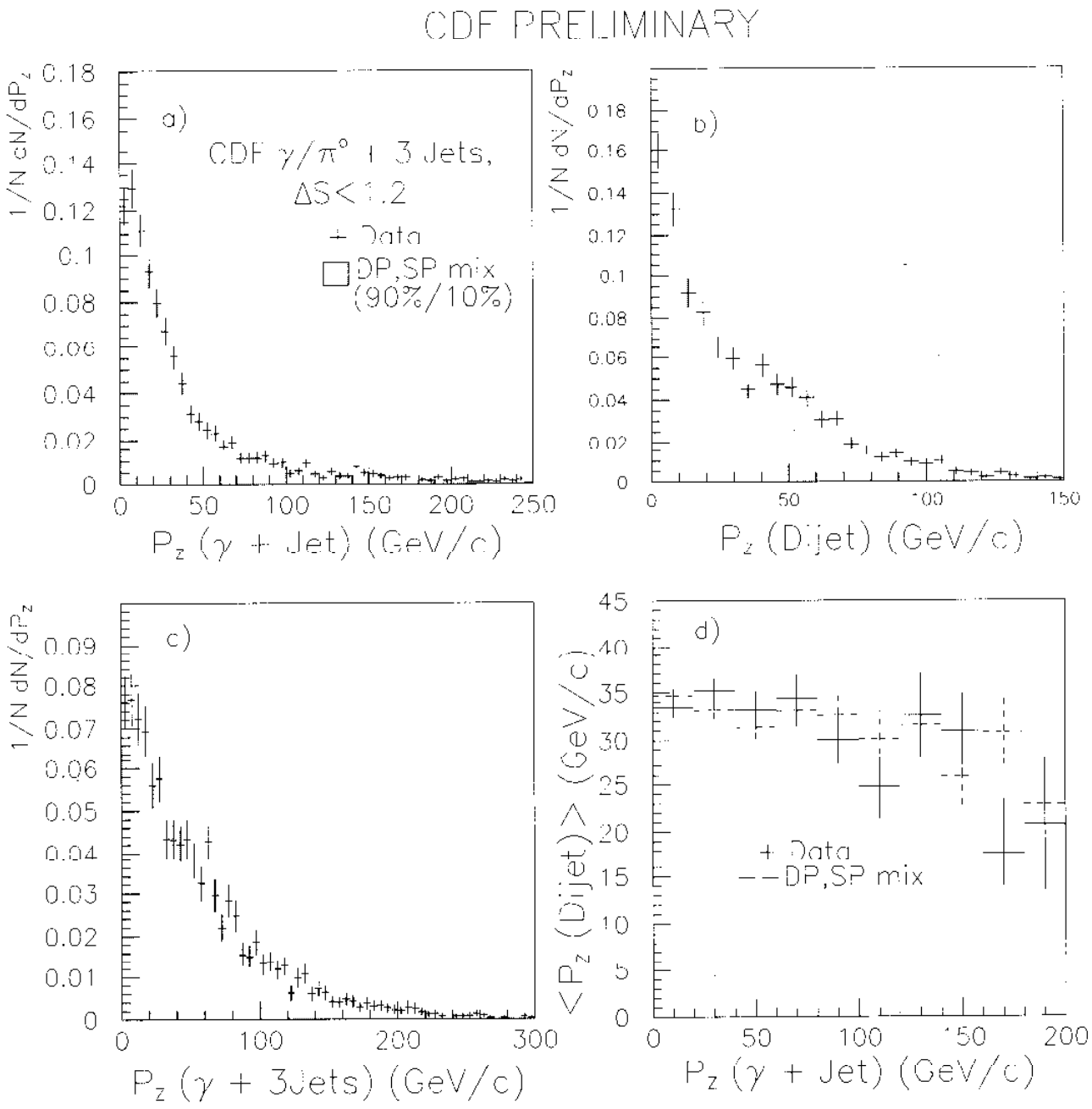
Are there correlations in the pt of the two scatters?



Correlation study:



Correlation Study:



Conclusions:

First observation of a statistically significan double parton signal.

$$\sigma_{eff} = 14.5 \pm 1.7 \,^{+1.7}_{-2.3} \text{ mb}$$

In agreement with the hard sphere prediction of 11 mb.

The radius of the proton is 0.73 ± 0.07 fm assuming a constant density spherical proton.

No x dependence to σ_{eff} is apparent.

No correlations in pt, pz or mass have been observed.

This represents a milestone in the study of double parton production.