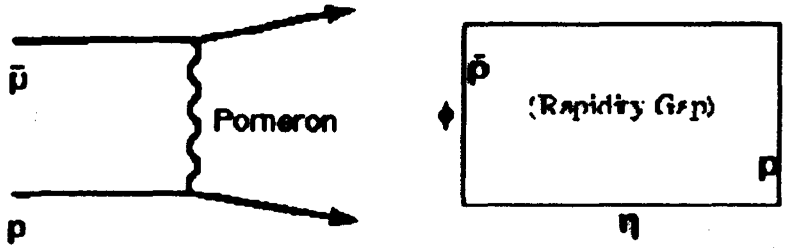
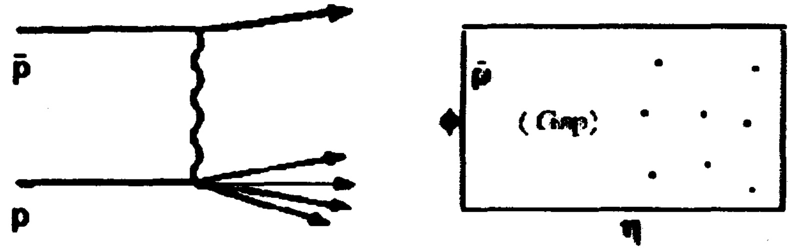
Diffraction at Tevatron

Soft Processes:



Elastic Scattering

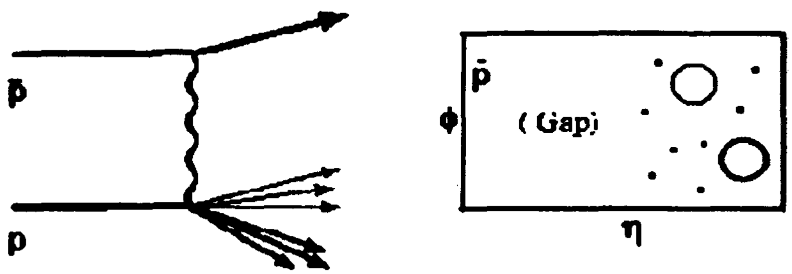
$p\,\bar{p} \rightarrow p\,\bar{p}$



Single Diffraction

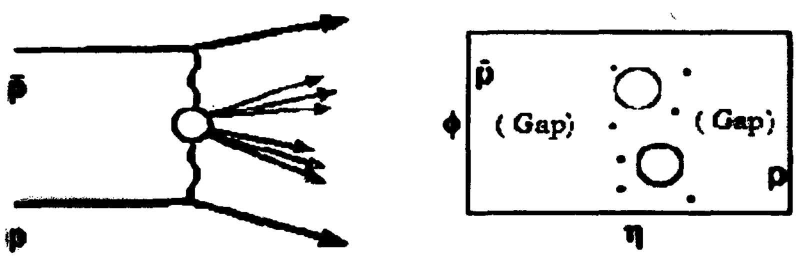
$p\,\bar{p} \rightarrow p\,(\bar{p}) + X$

Hard Processes (jet production):



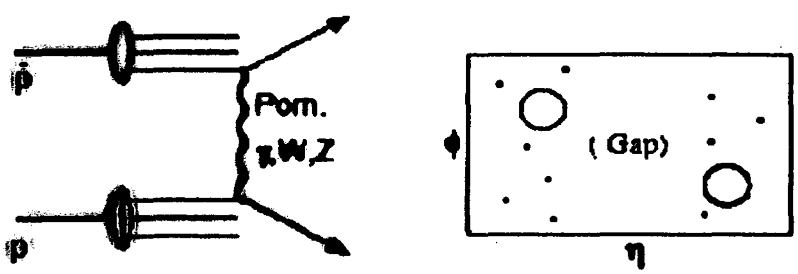
Hard Single Diffraction

$p\,\bar{p} \rightarrow p\,(\bar{p}) + j\,j$



Hard Double Pomeron

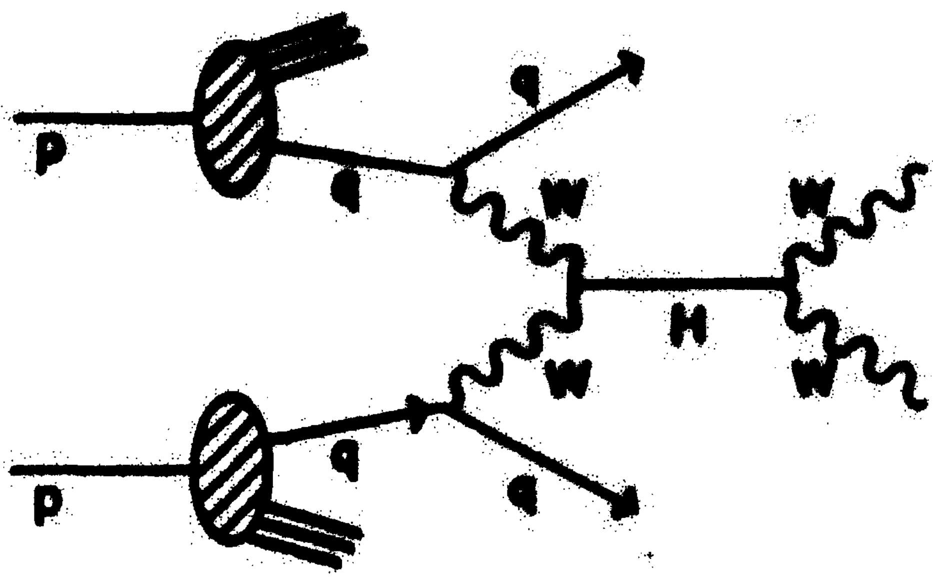
$p\,\bar{p} \rightarrow p\;\;\bar{p} + j\,j$

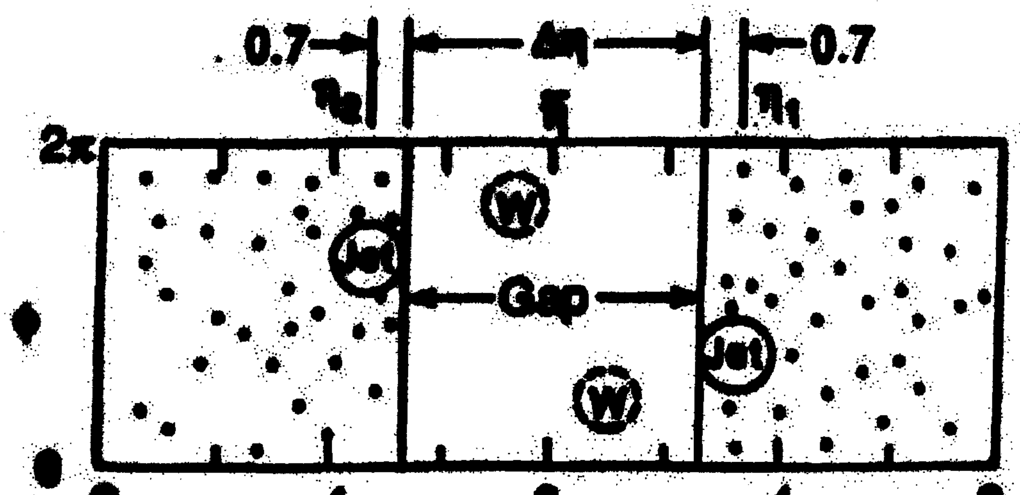


Hard Color Singlet

RAPIDITY GAPS + JETS AS SIGNATURE FOR NEW PHYSICS

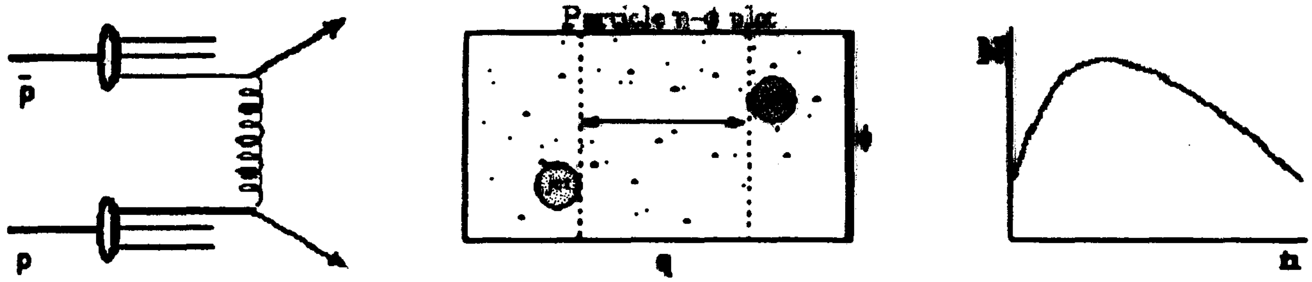
Bjorken SLAC Pub 561



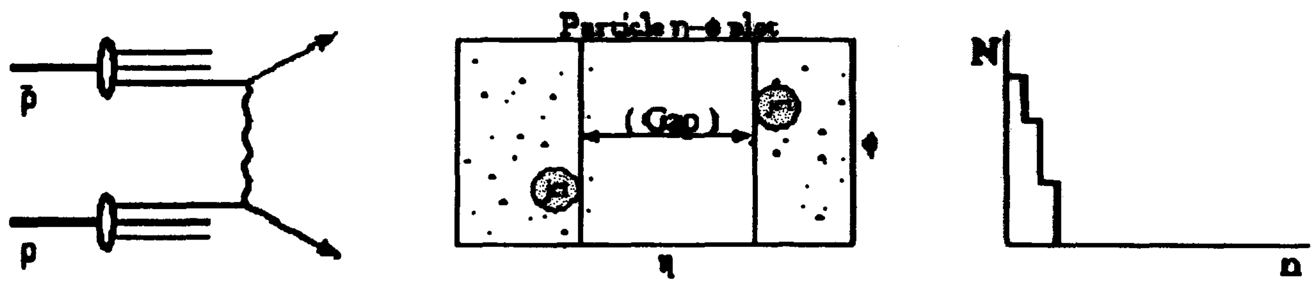


Color Singlet Exchange

Color exchange ⇒ **particles between jets**



Color-singlet exchange ⇒ **rapidity gaps**



Fraction of observable signal

$$f_{gap} = S \bullet \frac{\sigma_{gap}}{\sigma}$$

S ~ 10% - 30%

Gap Survival, ***(Bjorken, Gotsman et al.)***

Theoretical Estimates

(For large gaps, $\Delta\eta_c > 2$)

QCD color octet fluctuations:

$$\frac{\sigma_{gap}^{(octet)}}{\sigma} < 10^{-4}$$ (Chehime et al.)

Electroweak color singlet (γ, W, Z)

$$\frac{\sigma_{gap}^{(EW)}}{\sigma} \sim 10^{-3}$$ (Chehime et al.)

QCD color singlet (2-gluon hard Pomeron)

$$\frac{\sigma_{gap}^{(2g)}}{\sigma} \sim 10^{-1}$$ (Chehime et al., Bjorken)

Survival of the gap: S ~ 10% - 30% (Bjorken, Gotsman et al.)

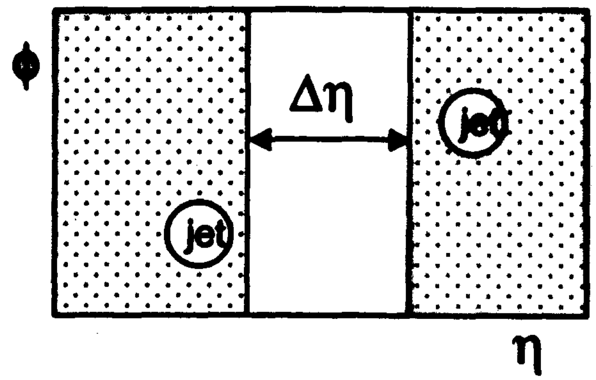
Predictions for the gap fraction (crude):

QCD color singlet ⇒ $10^{-2} < f^{(QCD\ singlet)} < 3 \times 10^{-2}$

All other procceses ⇒ $f \lesssim 10^{-4}$

Hard Color Singlet Studies

QCD color-singlet signal observed in ~ 1 % opposite-side events ($p\bar{p}$)



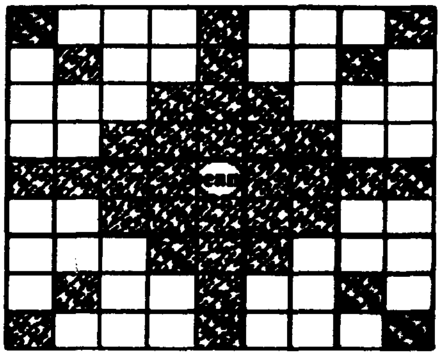
Publications

DØ: PRL 72, 2332(1994)
CDF: PRL 74, 885 (1995)
DØ: PRL 76, 734 (1996)
Zeus: Phys Lett B369, 55 (1996) (7%)
CDF: PRL 80, 1156 (1998)
DØ: PLB 440, 189 (1998)
CDF: PRL 81, 5278 (1998)
H1: hep-ex/0203011 (sub. to Eur Phys J C)

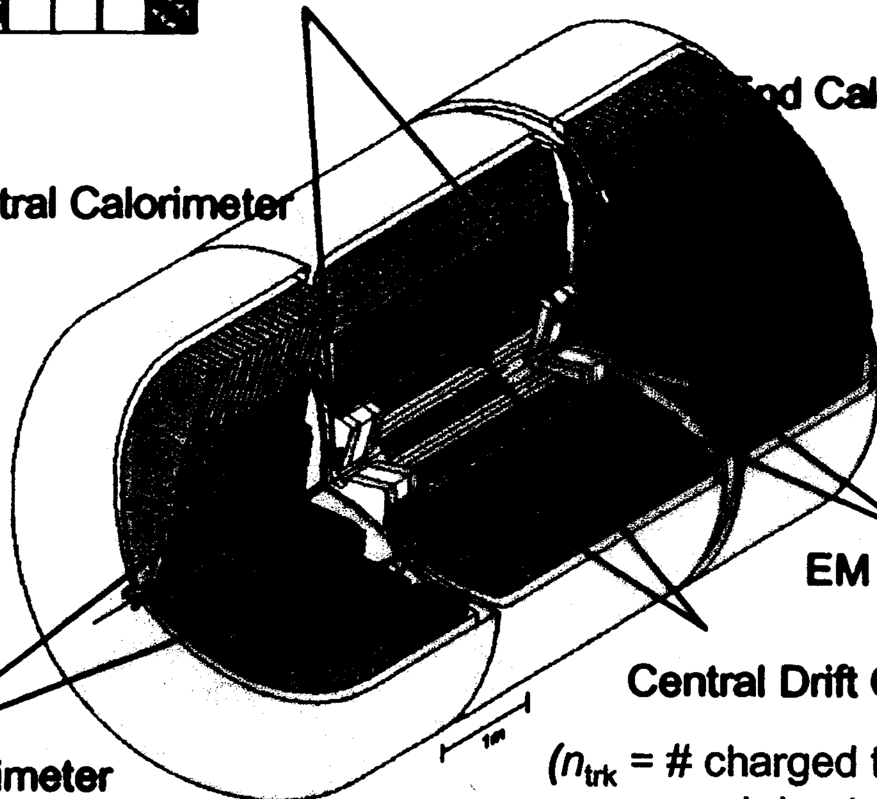
Newest Results

- Color-Singlet fractions at $\sqrt{s}$ = 630 & 1800 GeV
- Color-Singlet Dependence on: $\Delta\eta$, E_T, $\sqrt{s}$ (parton-x)

DØ Detector



(n_{l0} = # tiles in L0 detector with signal
$2.3 < |\eta| < 4.3$)



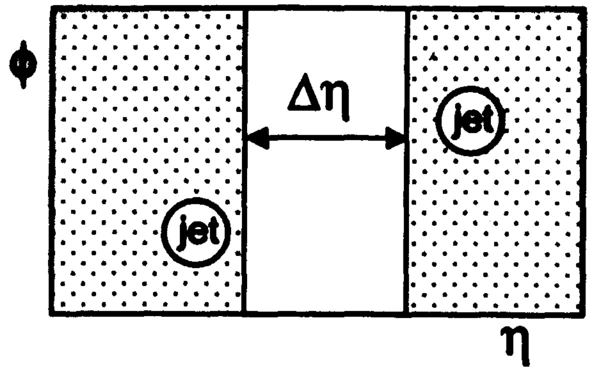
(n_{trk} = # charged tracks with
$|\eta| < 1.0$)

(n_{cal} = # cal towers with energy above threshold)

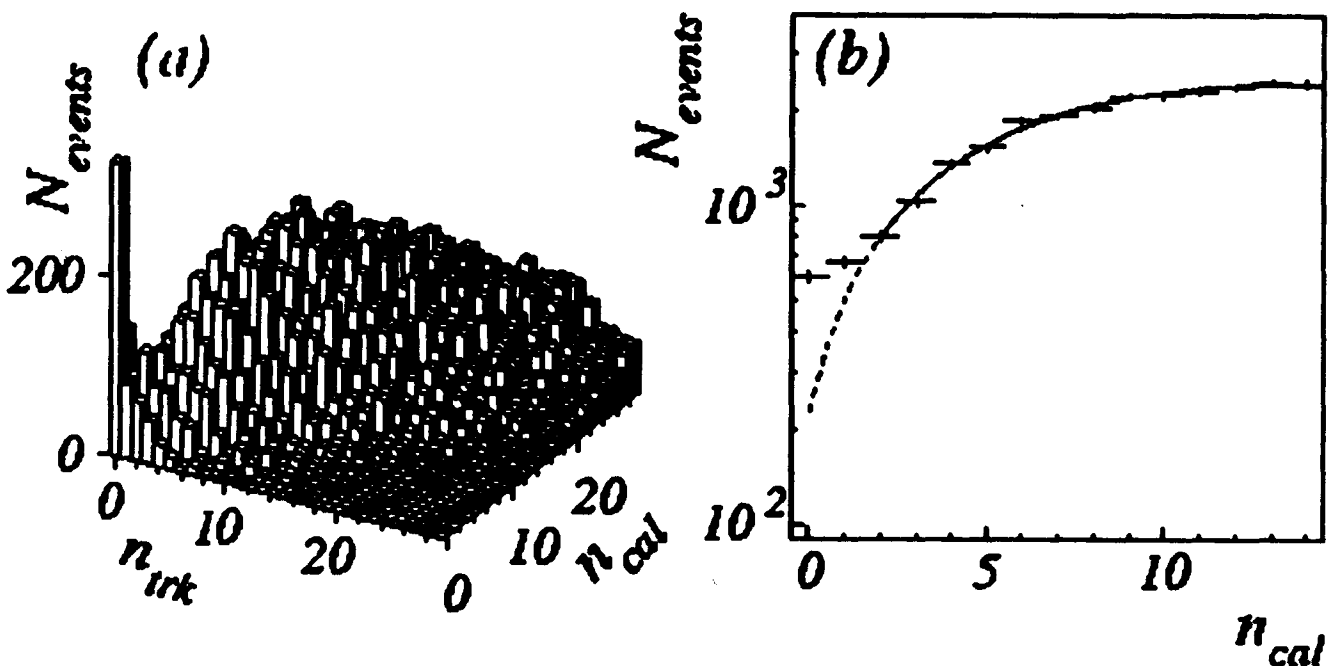
Central Gaps		
EM Calorimeter	$E_T > 200$ MeV	$|\eta| < 1.0$
Forward Gaps		
EM Calorimeter	$E > 150$ MeV	$2.0 < |\eta| < 4.1$
Had. Calorimeter	$E > 500$ MeV	$3.2 < |\eta| < 5.2$)

Measurement of f_s

Count tracks and EM Calorimeter Towers in $|\eta| < 1.0$



High-E_T sample (E_T > 30 GeV, $\sqrt{s}$ = 1800 GeV)



f_S = **color-singlet fraction** $=(N_{data} - N_{fit})/N_{total}$

$f_S^{1800} = 0.94 \pm 0.04_{stat} \pm 0.12_{sys}$ % E_T >30 GeV

(Includes correction for multiple interaction contamination. Sys error dominated by background fitting.)

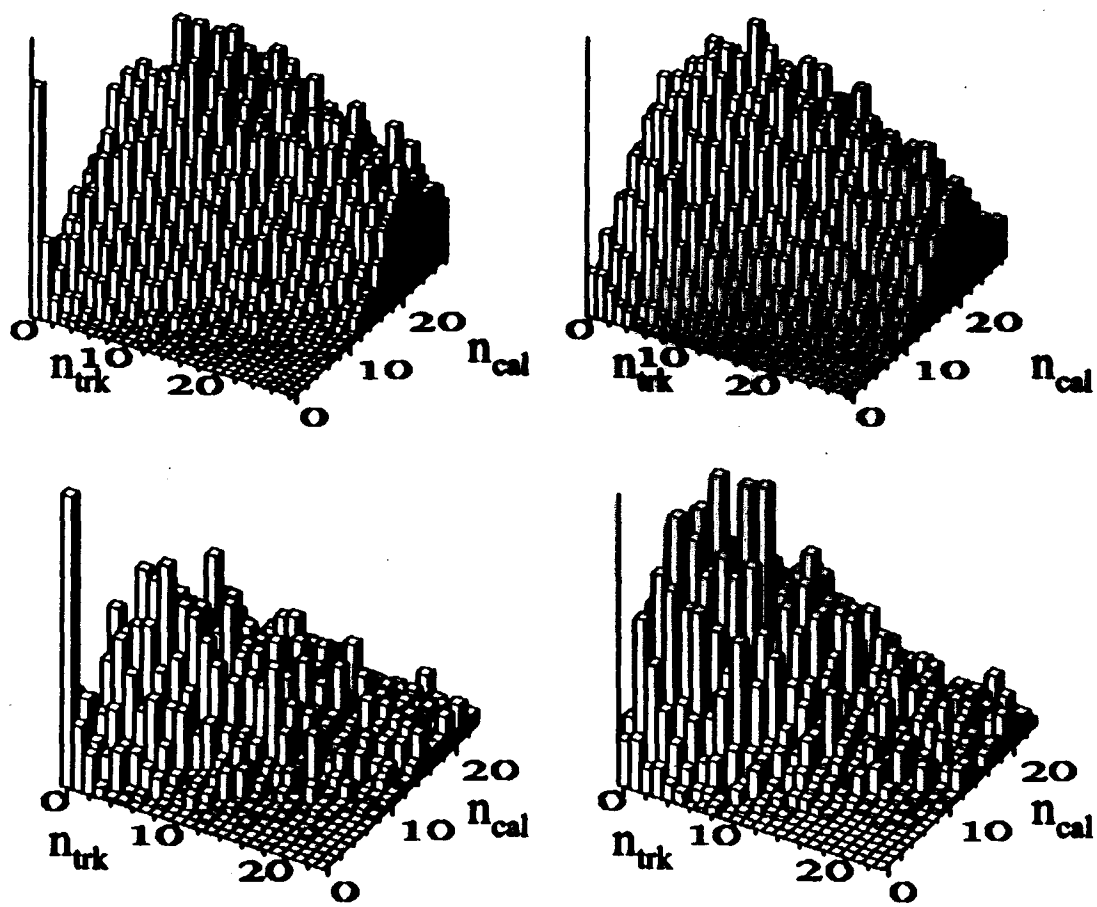
630 vs. 1800 Multiplicities

Jet $E_T > 12$ GeV, Jet $|\eta| > 1.9$, $\Delta\eta > 4.0$

Opposite-Side Data | Same-Side Data

1800 GeV:

630 Gev:



$$f_S^{1800}\ (E_T = 19.2\ GeV) = 0.54 \pm 0.06_{stat} \pm 0.16_{sys}\ \%$$

$$f_S^{630}\ (E_T = 16.4\ GeV) = 1.85 \pm 0.09_{stat} \pm 0.37_{sys}\ \%$$

$$R^{630}_{1800} = 3.4 \pm 1.2$$

Color Singlet Models

If color-singlet couples preferentially to quarks or gluons, fraction depends on initial quark/gluon densities (parton *x*)
larger x ⇒ more quarks

Gluon preference: perturbative two-gluon models have 9/4 color factor for gluons

- ***Naive Two-Gluon model*** (Bj)
- ***BFKL model***: LLA BFKL dynamics

Predictions:

$f_S(E_T)$ falls, $f_S(\Delta\eta)$ falls (2 gluon) / rises (BFKL)

Quark preference:

- ***Soft Color model***: non-perturbative "rearrangement" prefers quark initiated processes (easier to neutralize color)
- ***Photon*** and ***U(1)***: couple only to quarks

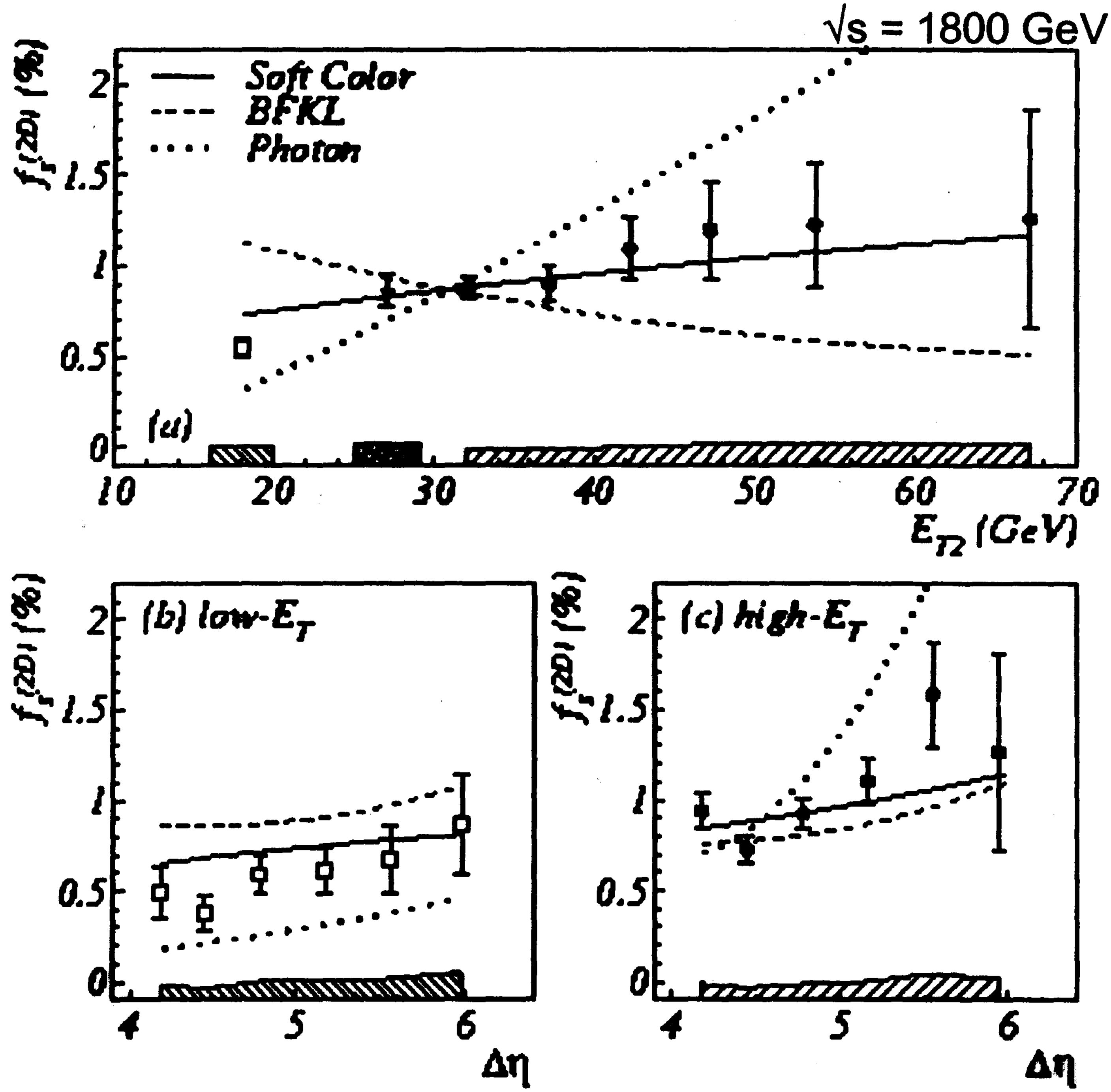
Predictions:

$f_S(E_T)$ & $f_S(\Delta\eta)$ rise

Model Fits to Data

DØ

Using *Herwig 5.9*



Soft Color model describes data

Survival Probability

- Assumed to be independent of parton x (E_T, $\Delta\eta$)

- Originally weak $\sqrt{s}$ dependence
  Gotsman, Levin, Maor Phys. Lett B 309 (1993)

- Subsequently recalculated $\frac{S(630)}{S(1800)} = 2.2 \pm 0.2$
  GLM hep-ph/9804404

- Using soft-color model
  $R^{630}_{1800} = 1.5 \pm 0.1$ (uncertainty from MC stats and model difference)

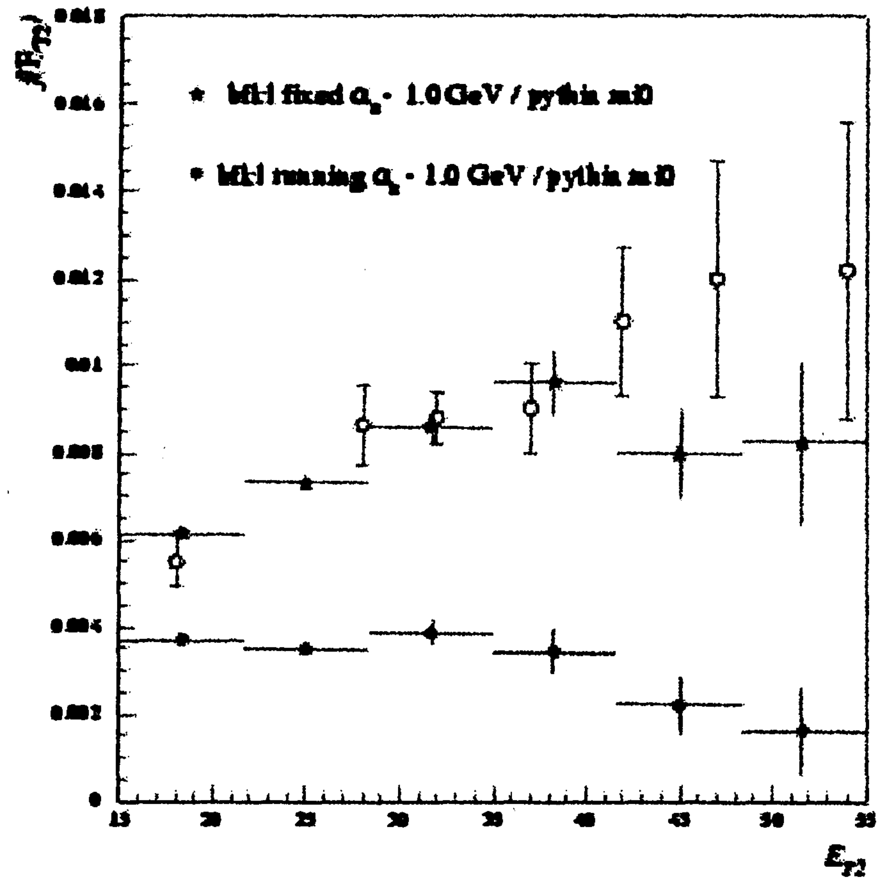
- $R^{630}_{1800}(\text{Data}) = R^{630}_{1800}(\text{Model}) \times \frac{S(630)}{S(1800)}$

  with $R^{630}_{1800}(\text{Data}) = 3.4 \pm 1.2$

$$\Rightarrow \frac{S(630)}{S(1800)} = 2.2 \pm 0.8$$

Modifications to Theory

- BFKL: Cox, Forshaw (manhep99-7) use a non-running α_s to flatten the falling E_T prediction of BFKL (due to higher order corrections at non-zero t)



- Soft Color: Gregores subsequently performed a more careful counting of states that produce color singlets to improve prediction.

LISHEP 2002, Workshop on Diffractive Physics
Rio de Janeiro
February 4 - 8, 2002

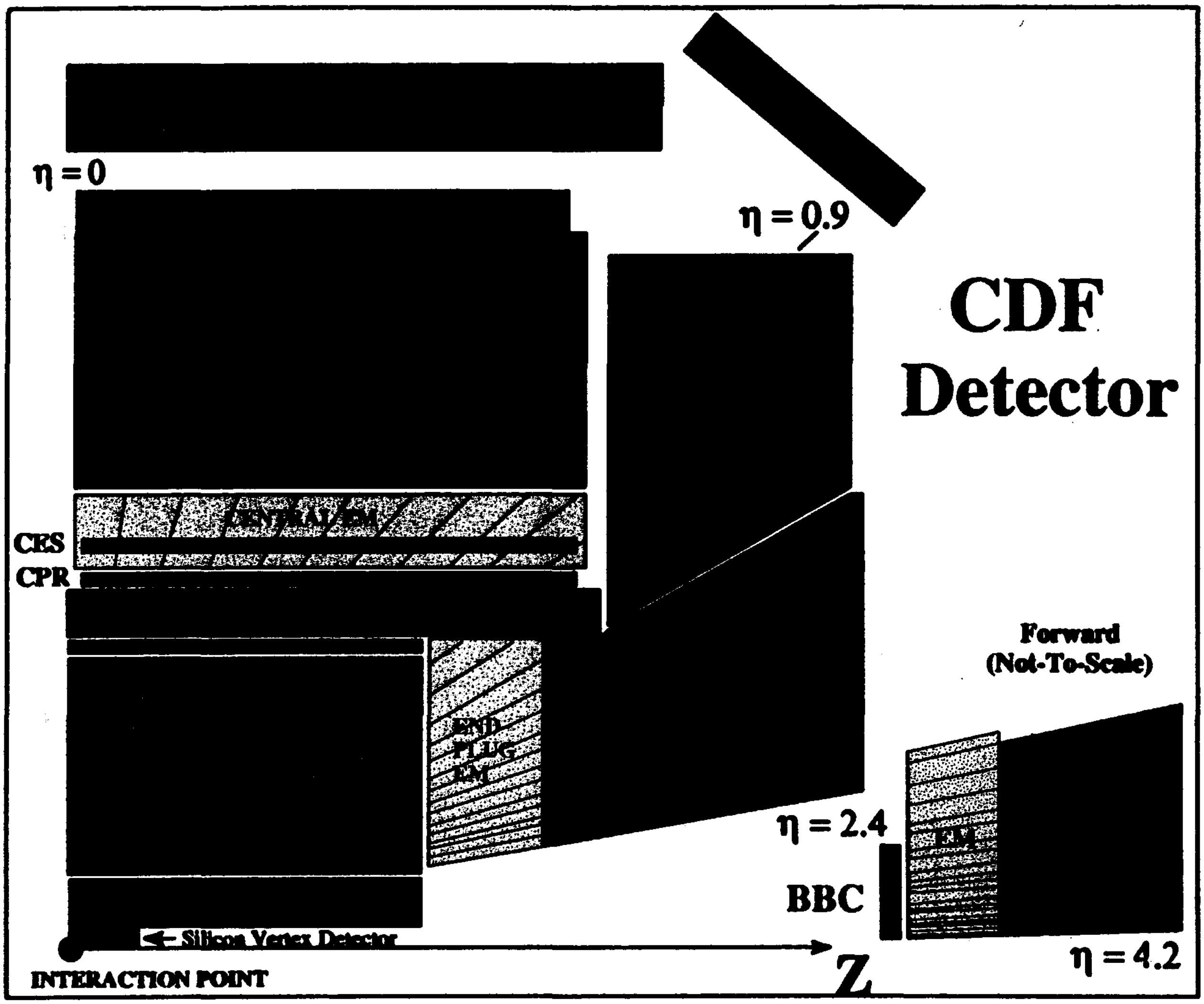
CDF Run 1 Diffractive Results

borrowed from K. **Hatakeyama**
The Rockefeller University
for the CDF Collaboration

Contents:

- Introduction
- Hard Single Diffraction with Rapidity Gaps: W, dijet, $b\bar{b}$ and J/ψ Production
- Diffractive Dijets with Leading Antiproton at $\sqrt{s} = 1800$ and 630 GeV
- Dijet Production in Double Pomeron Exchange

The CDF Detector



Rapidity Gap Detectors

BBC	$3.2 < \|\eta\| < 5.9$	Charged particles
FCAL	$2.4 < \|\eta\| < 4.2$	Charged and neutral

Require no hits in BBC and no tower with energy above 1.5 GeV in the forward region

CDF Run 1 Results on Diffraction

SOFT DIFFRACTION

1)Soft single diffraction	PRD 50 (1994) 5550
2)Soft double diffraction	PRL 87 (2001) 141802

RAPIDITY GAP RESULTS

3) Diffractive W	PRL 78 (1997) 2698
4) Diffractive Dijets	PRL 79 (1997) 2636
5) Diffractive Beauty	PRL 84 (2000) 232
6) Diffractive J/ψ	PRL 87 (2001) 241802
7) Jet-Gap-Jet 1800	PRL 74 (1995) 855
8) Jet-Gap-Jet 1800	PRL 80 (1998) 1156
9) Jet-Gap-Jet 630	PRL 81 (1998) 5278

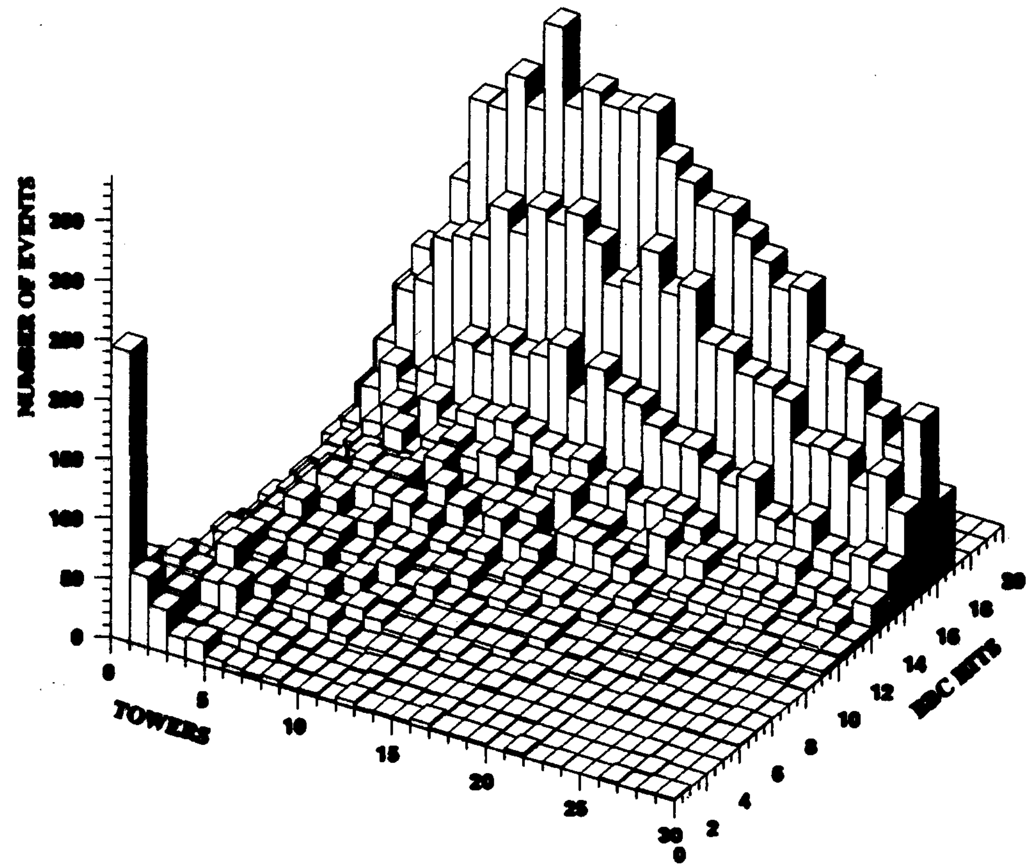
ROMAN POT RESULTS

10) Diffractive Dijets 1800	PRL 84 (2000) 5043
11) Diffractive Dijets 630	PRL 88 (2002) 151802
12) Double Pomeron Dijets	PRL 85 (2000) 4215

Darkblue : Today's Contents

Single Diffractive Dijet Production at $\sqrt{s} = 1800$ GeV

- Two jets, $E_T > 20$ GeV, $|\eta| > 1.8$, single interaction
- **Estimate the number of events in (0,0) bin above background by a smooth 2D extrapolation**
- **Calculate rapidity gap acceptance using POMPYT Monte Carlo based on Ingelmann-Schlein Model**



$$R_{JJ}\left[\frac{SD}{ND}\right] = [0.75 \pm 0.05(stat) \pm 0.09(syst)]\%$$

Diffractive W, dijet and b at $\sqrt{s} = 1800$ GeV

- ✔ Diffractive W production $q\bar{q} \to W,\ gq \to Wq$

  $R_W[\frac{SD}{ND}] = [1.15 \pm 0.51(stat) \pm 0.20(syst)]\%$

  ($p_T^e > 20$ GeV/c, $|\eta^e| < 1.1$, $\not{E}_T > 20$ GeV, $\xi < 0.1$)

- ✔ Diffractive dijet production $gg \to gg,\ qg \to qg$

  $R_{JJ}[\frac{SD}{ND}] = [0.75 \pm 0.05(stat) \pm 0.09(syst)]\%$

  ($E_T^{jet} > 20$ GeV, $1.8 < |\eta^{jet}| < 3.5, \eta_1\eta_2 > 0, \xi < 0.1$)

- ✔ Diffractive $b\bar{b}$ production $gg \to b\bar{b},\ q\bar{q} \to b\bar{b}$

  $R_{b\bar{b}}[\frac{SD}{ND}] = [0.62 \pm 0.19(stat) \pm 0.16(syst)]\%$

  ($p_T^e > 9.5$ GeV/c, $|\eta^e| < 1.1, \xi < 0.1$)

- ✔ Diffractive J/ψ production $gg \to J/\psi(g)$

  $R_{J/\psi}[\frac{SD}{ND}] = [1.45 \pm 0.25(stat \oplus syst)]\%$

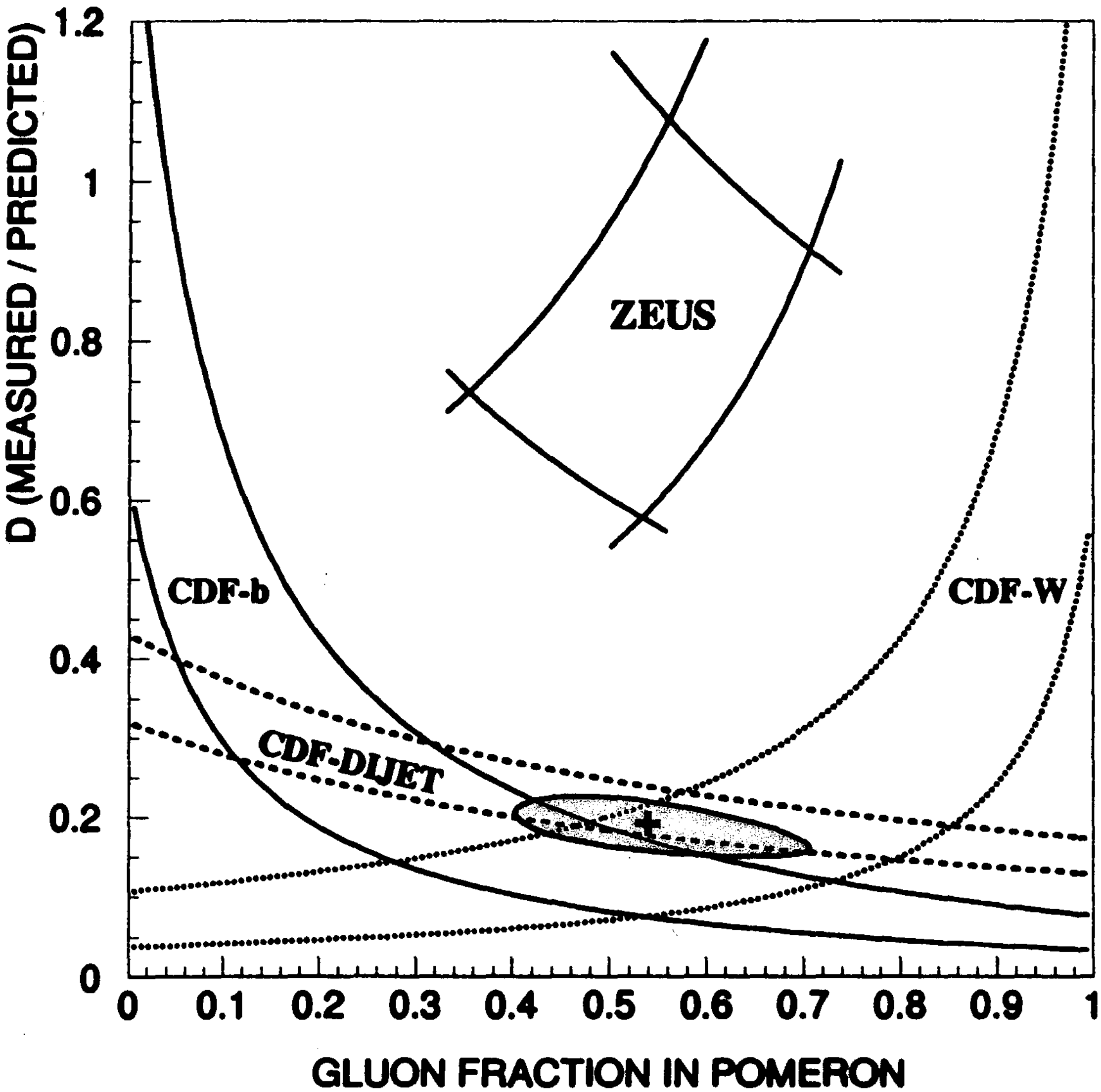
  ($p_T^\mu > 2$ GeV/c, $|\eta^\mu| < 1.0, \xi < 0.1$)

⬇

$R[\frac{SD}{ND}]$ is of order 1 % for W, dijet, $b\bar{b}$ & J/ψ

Diffractive W, dijet and b at $\sqrt{s} = 1800$ GeV

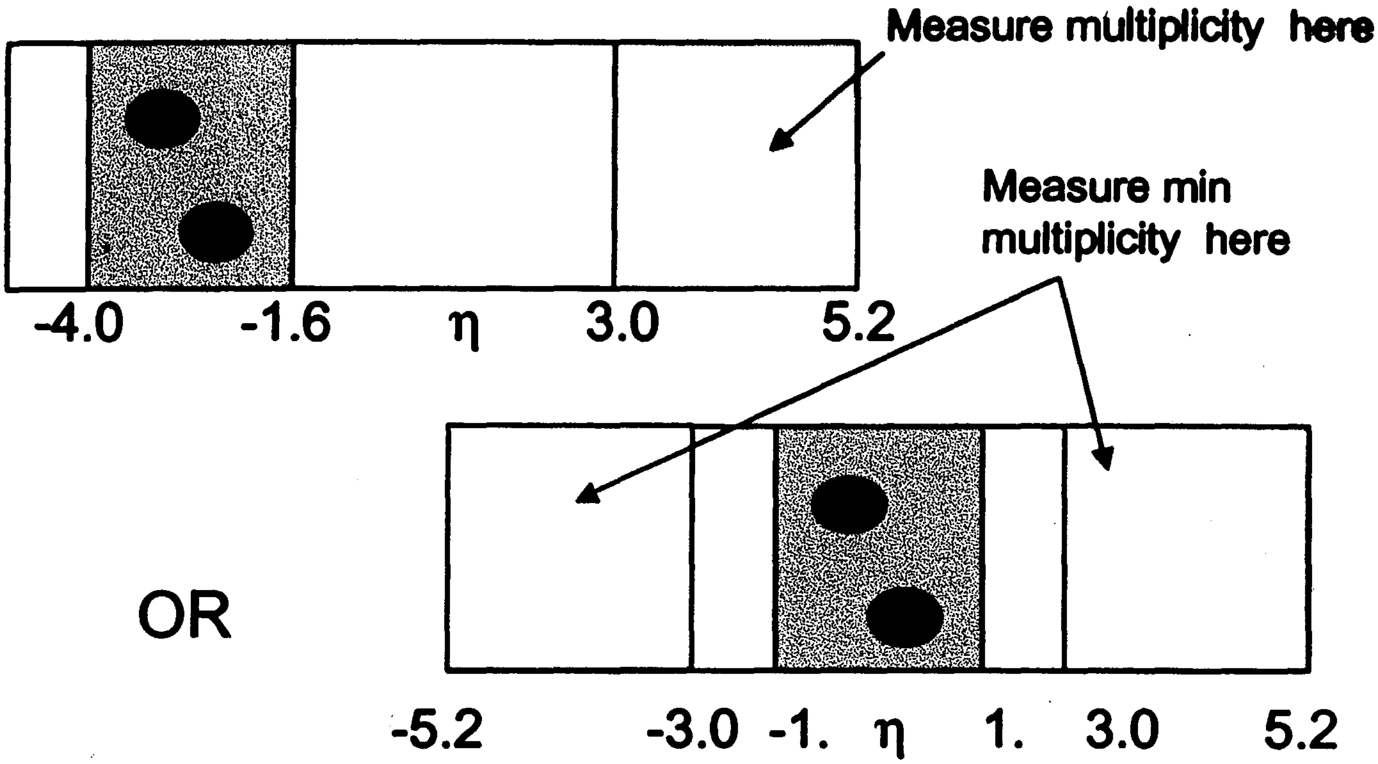
Gluon Fraction in Pomeron and Factorization



Gluon Fraction in Pomeron $f_g = 0.54^{+0.16}_{-0.14}$

D(Measured/Predicted) $= 0.19 \pm 0.04$

Hard Single Diffraction

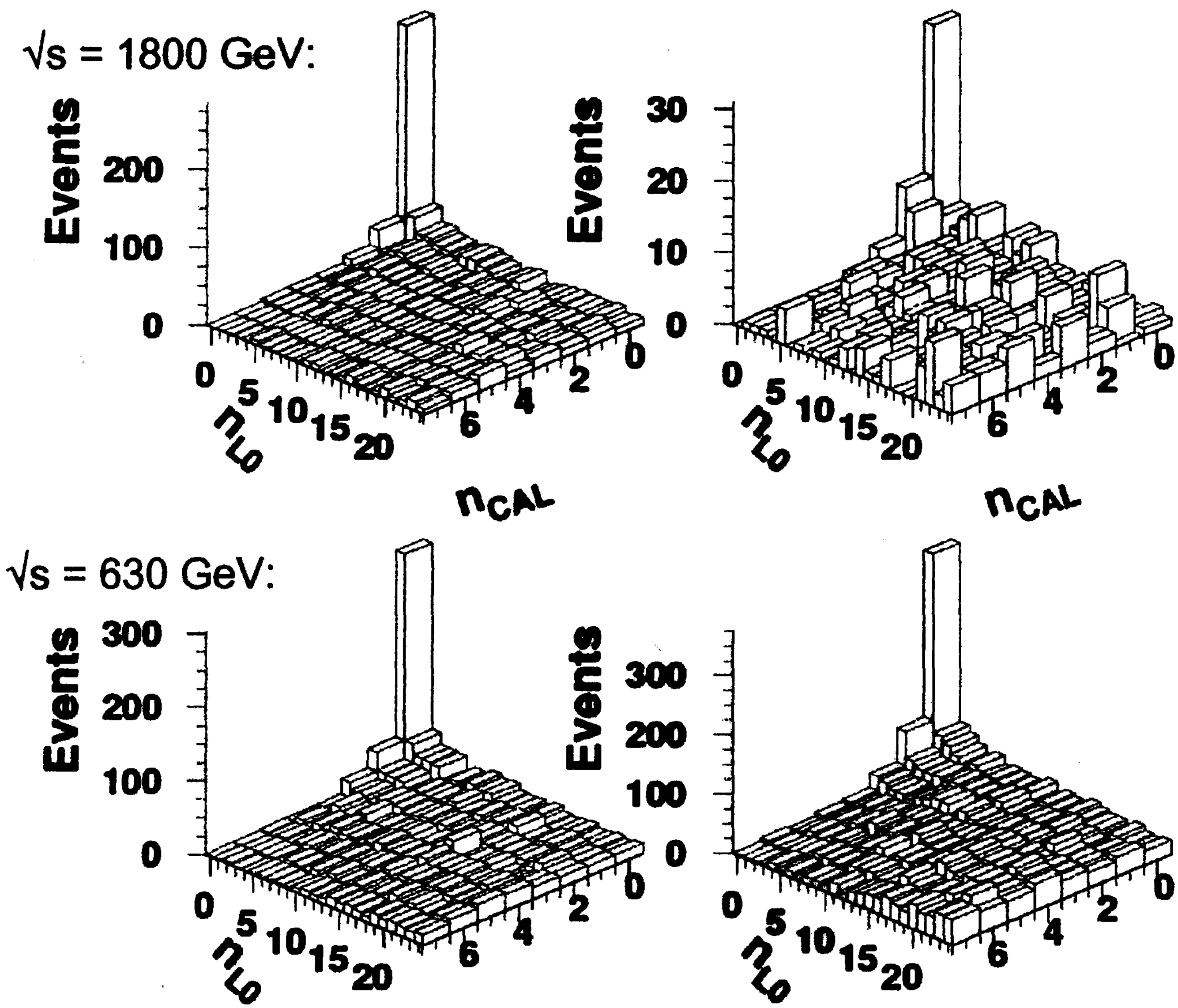


Phys Lett B 531 52 (2002)

- Gap fractions (central and forward) at $\sqrt{s}$ = 630 & 1800 GeV
- Single diffractive ξ distribution

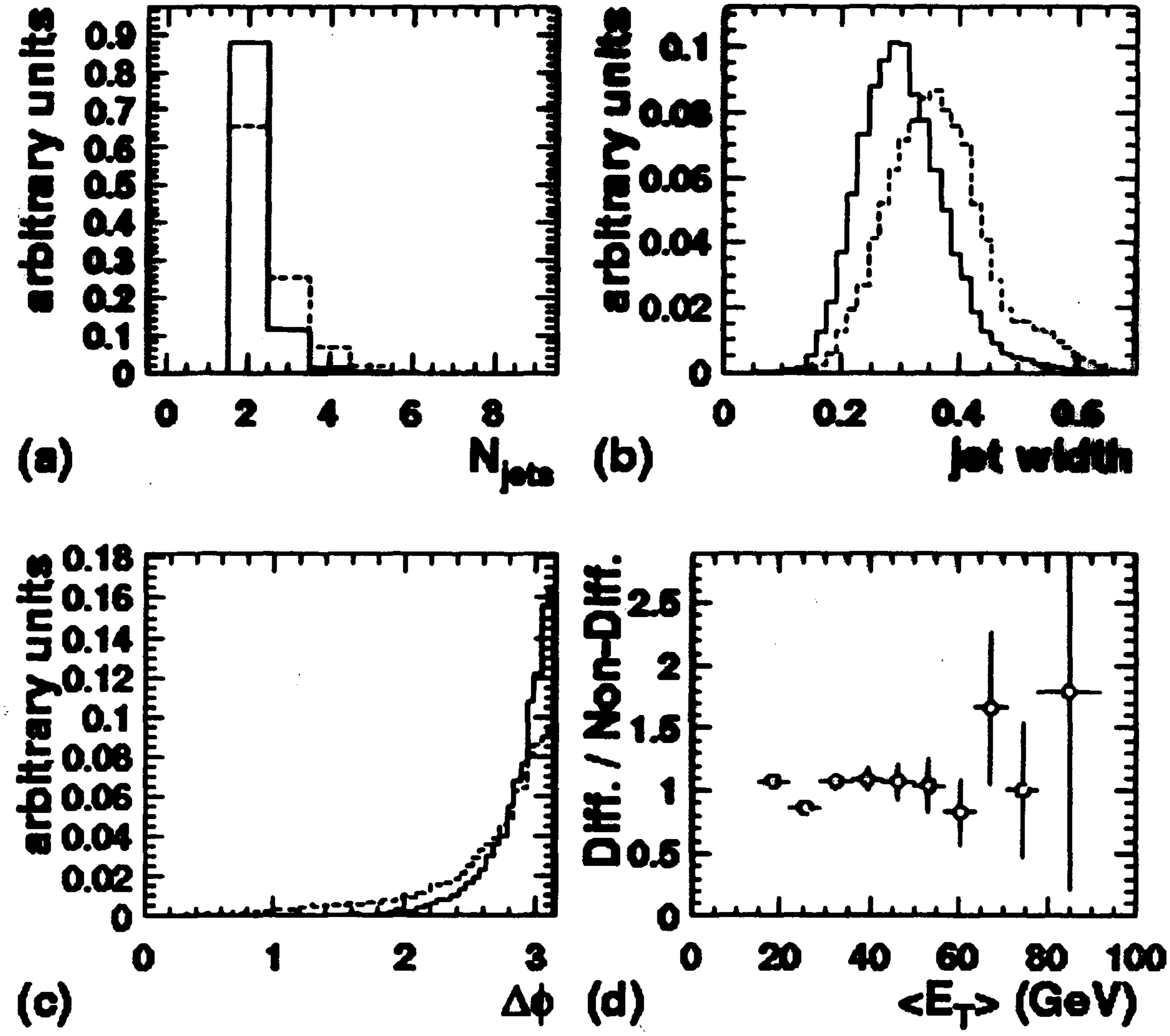
DØ

630 vs. 1800 Multiplicities



Event Characteristics

1800 Forward Jets



Solid lines show show HSD candidate events
Dashed lines show non-diffractive events

- Less jets in diffractive events
- Jets are narrower and more back-to-back
- Diffractive events have less overall radiation
- Gap fraction has little dependence on average jet E_T

Comparison to MC

DØ

$$f_{visible} = \varepsilon_{gap} \cdot f_{predicted}$$

⇒ ε_{gap}

*Add diffractive multiplicity from MC to background data distribution

*Fit to find percent of signal events extracted

⇒ Find predicted rate POMPYT x 2 / PYTHIA

*Apply same jet η cuts as data, jet E_T>12GeV

*Full detector simulation

* Model pomeron exchange in POMPYT26 (Bruni & Ingelman)

  * based on PYTHIA
  * define pomeron as beam particle
  * Use different structure functions

DØ Single Diffractive Results

	Gap Fraction (%)				
Sample	Data	Hard Gluon	Flat Gluon	Soft Gluon	Quark
($s(\beta) \propto$)		$\beta(1-\beta)$	const.	$(1-\beta)^5$	$\beta(1-\beta)$
1800 Fwd	0.65 ± 0.04	2.2 ± 0.3	2.2 ± 0.3	1.4 ± 0.2	0.79 ± 0.12
1800 Cent	0.22 ± 0.05	2.5 ± 0.4	3.5 ± 0.5	0.05 ± 0.01	0.49 ± 0.06
630 Fwd	1.19 ± 0.08	3.9 ± 0.9	3.1 ± 0.8	1.9 ± 0.4	2.2 ± 0.5
630 Cent	0.90 ± 0.06	5.2 ± 0.7	6.3 ± 0.9	0.14 ± 0.04	1.6 ± 0.2
	Ratio of Gap Fraction				
630/1800 Fwd	1.8 ± 0.2	1.7 ± 0.4	1.4 ± 0.3	1.4 ± 0.3	2.7 ± 0.6
630/1800 Cent	4.1 ± 0.9	2.1 ± 0.4	1.8 ± 0.3	3.1 ± 1.1	3.2 ± 0.5
1800 Fwd/Cent	3.0 ± 0.7	0.88 ± 0.18	0.64 ± 0.12	$30. \pm 8.$	1.6 ± 0.3
630 Fwd/Cent	1.3 ± 0.1	0.75 ± 0.16	0.48 ± 0.12	$13. \pm 4.$	1.4 ± 0.3

Within the *Ingelman-Schlein* model, DØ data can be reasonably described by a pomeron composed dominantly of quarks.

For the model to describe DØ data as well as other measurements, a *reduced flux* factor convoluted with a gluonic pomeron containing significant soft and hard components is required.

Pomeron Structure Fits

DØ

- Demand data fractions composed of linear combination of hard and soft gluons, let overall √ s normalization and fraction of hard and soft at each energy be free parameters

- If we have a √ s independent normalization then the data prefer :
  - 1800: hard gluon 0.18±0.05(stat)+0.04-0.03(syst)
  - 630: hard gluon 0.39±0.04(stat)+0.02-0.01(syst)
  - Normalization: 0.43±0.03(stat)+0.08-0.06(syst)

  with a confidence level of 56%.

- If the hard to soft ratio is constrained the data prefer:
  - Hard gluon: 0.30±0.04(stat)+0.01-0.01(syst)
  - Norm. 1800: 0.38±0.03(stat)+0.03-0.02(syst)
  - Norm. 630: 0.50±0.04(stat)+0.02-0.02(syst)

  with a confidence level of 1.9%.

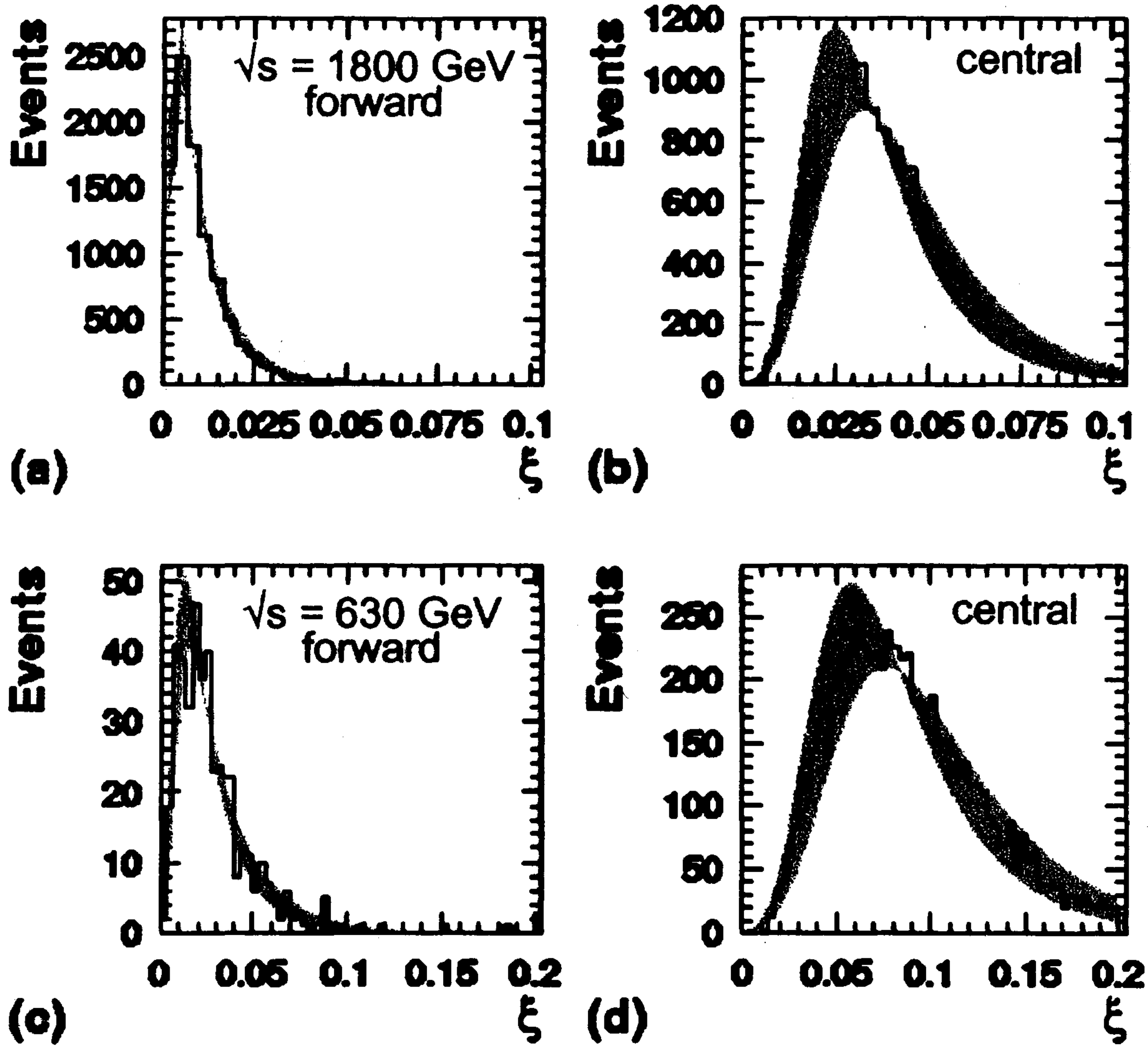
- To significantly constrain quark fraction requires additional experimental measurements.

- CDF determined 56% hard gluon, 44% quark but this does not describe our data without significant soft gluon or 100% quark at 630

Single Diffractive ξ Distributions

ξ distribution for forward and central jets using (0,0) bin

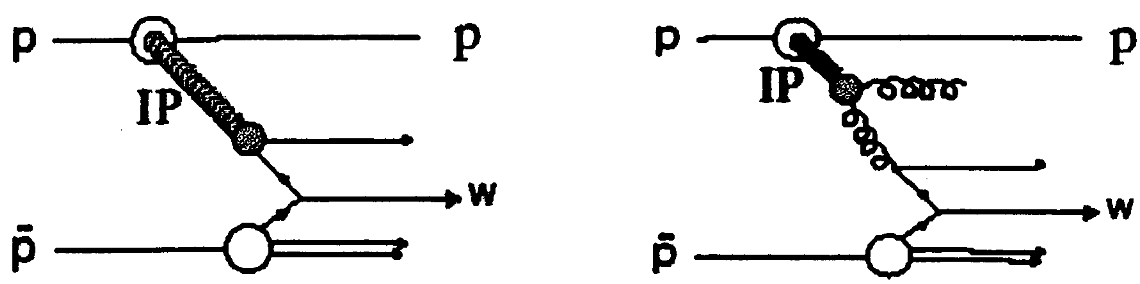
$$\xi = \sum_i \frac{E_{T_i} e^{y_i}}{\sqrt{s}} = \frac{\Delta p}{p}$$



$\xi \rightarrow 0.2$ for $\sqrt{s} = 630$ GeV

Why study the Diffractive W?

***The pomeron (IP) structure is not yet understood which motivates a study that will better clarify the quark/gluon composition involved. This is found in the diffractive W, which to leading order can only happen based on a quark component in the pomeron.*[1]**



a) LO: $q\bar{q} \rightarrow W$ *b) NLO:* $qg \rightarrow q + W$

Diffractive process (a) probes the quark content of the pomeron.

[1]*(Bruni & Ingelman, Phys. Lett. B311(1993)318)*

CDF Diffractive W

CDF used asymmetry to extract diffractive component of the W signal

1)TOPOLOGY

-lepton favors the hemisphere opposite the rapidity gap

-compare multiplicity for region on same side of lepton vs opposite side

2)CHARGE

-proton(uud) pomeron($q\bar{q}$) gives twice as many W^+ as W^-

-W^+ production is associated with gaps in $\bar{p}$ direction (and W^- with p)

Drawback: Asymmetry approach reduces statistical power of data

CDF Diffractive W

CDF {PRL 78 2698 (1997)} measured $R_W = 1.15 \pm 0.55\%$
where R_W = Ratio of diffractive/non-diffractive W
a significance of 3.8σ

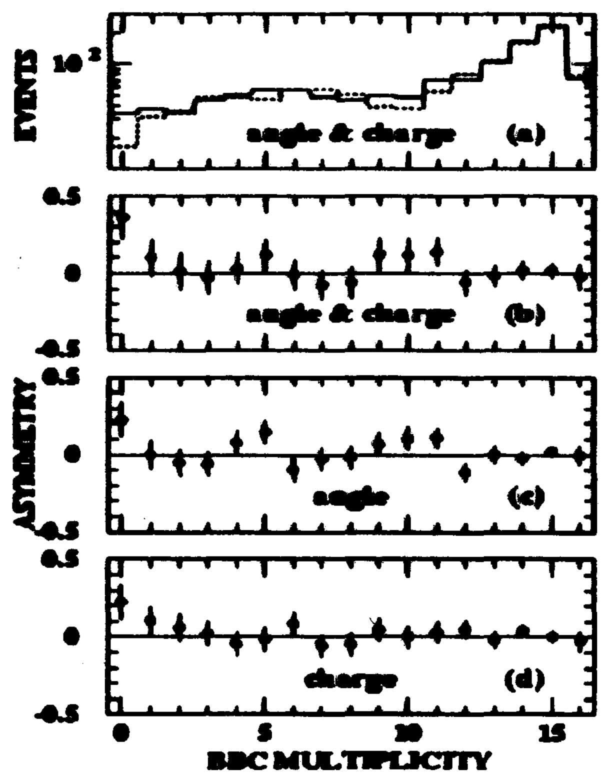
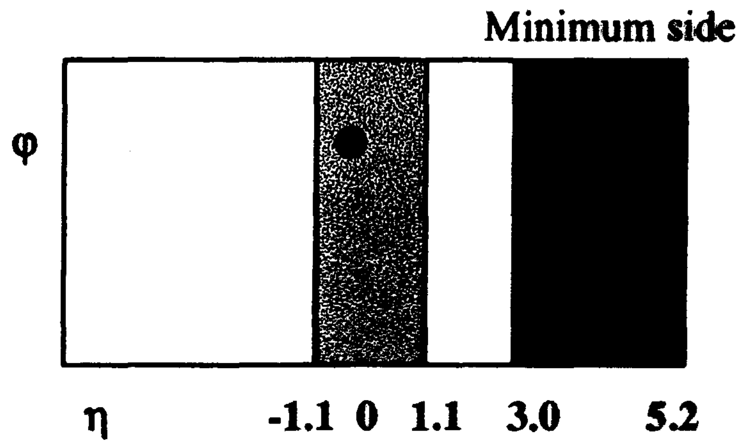
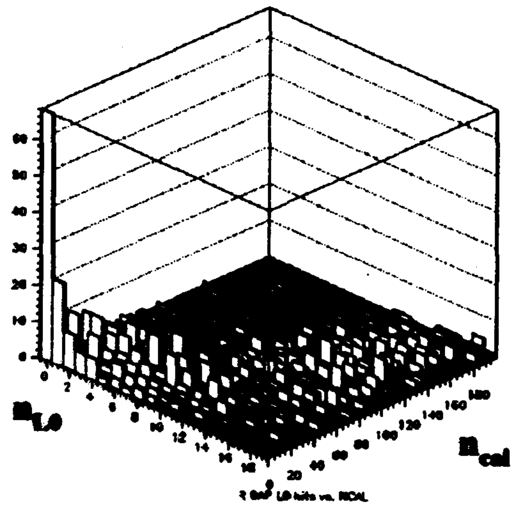
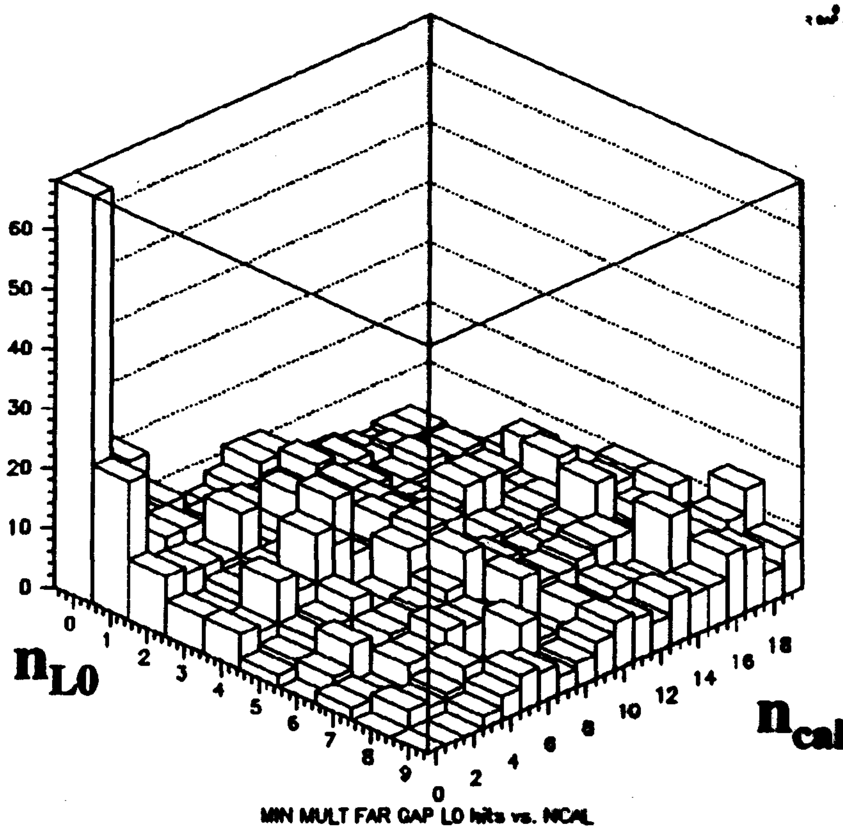


Figure 2: (a) Electron angle and charge doubly-correlated (solid) and anticorrelated (dashed) distributions (see text) versus BBC multiplicity, and (b) the corresponding asymmetry, defined as the bin-by-bin difference over sum of the two distributions in (a). The diffractive signal is seen in the first bin as an excess of events in the correlated distribution in (a), and as a positive asymmetry in (b). An asymmetry is also seen in the first bin of the individual angle (c) and charge (d) distributions.

DØ Central W Multiplicity





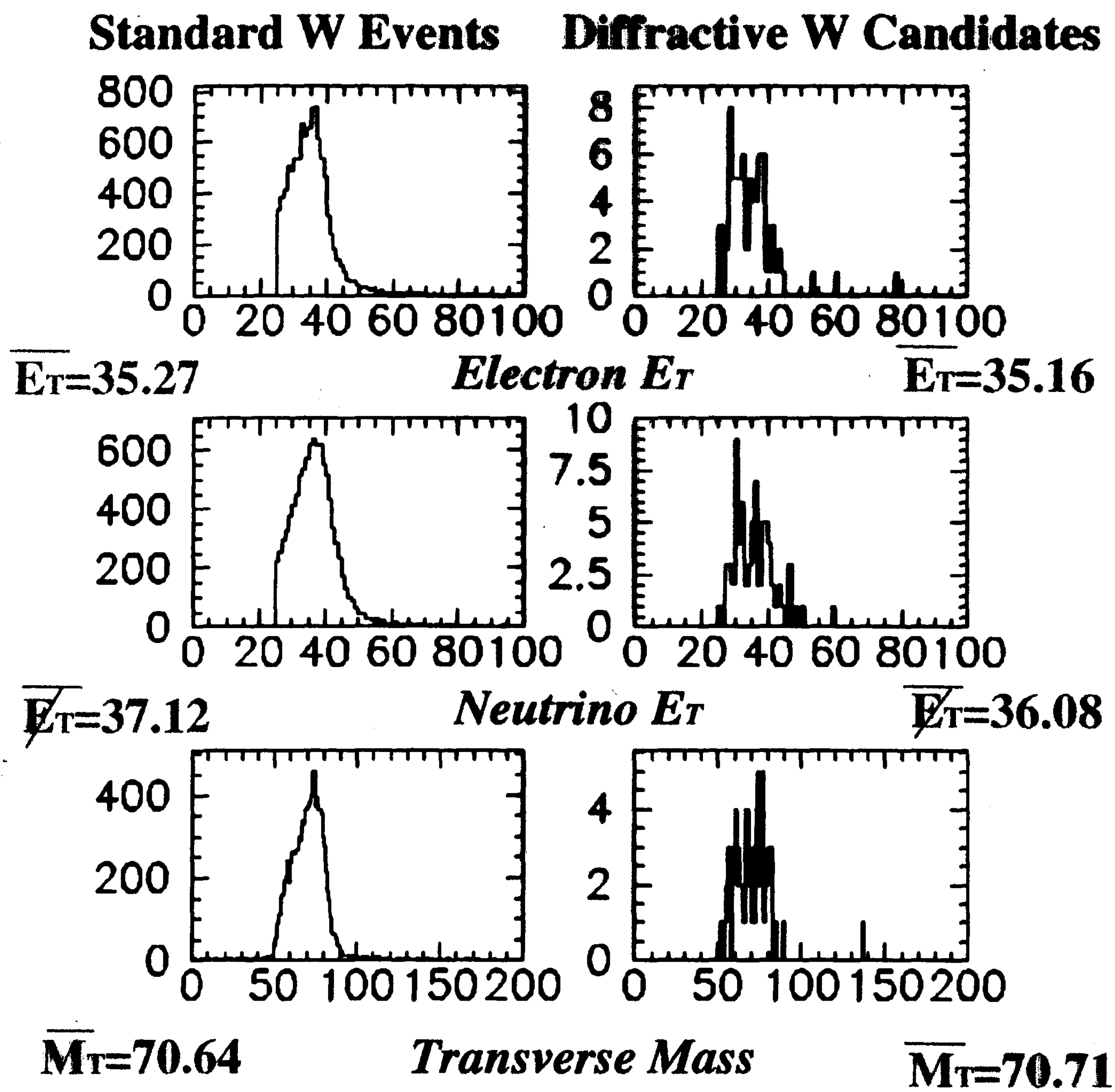


Peak at (0,0) indicates diffractive W-boson
Signal: 68 of 8724 events in (0,0) bin

DØ Preliminary

DØ

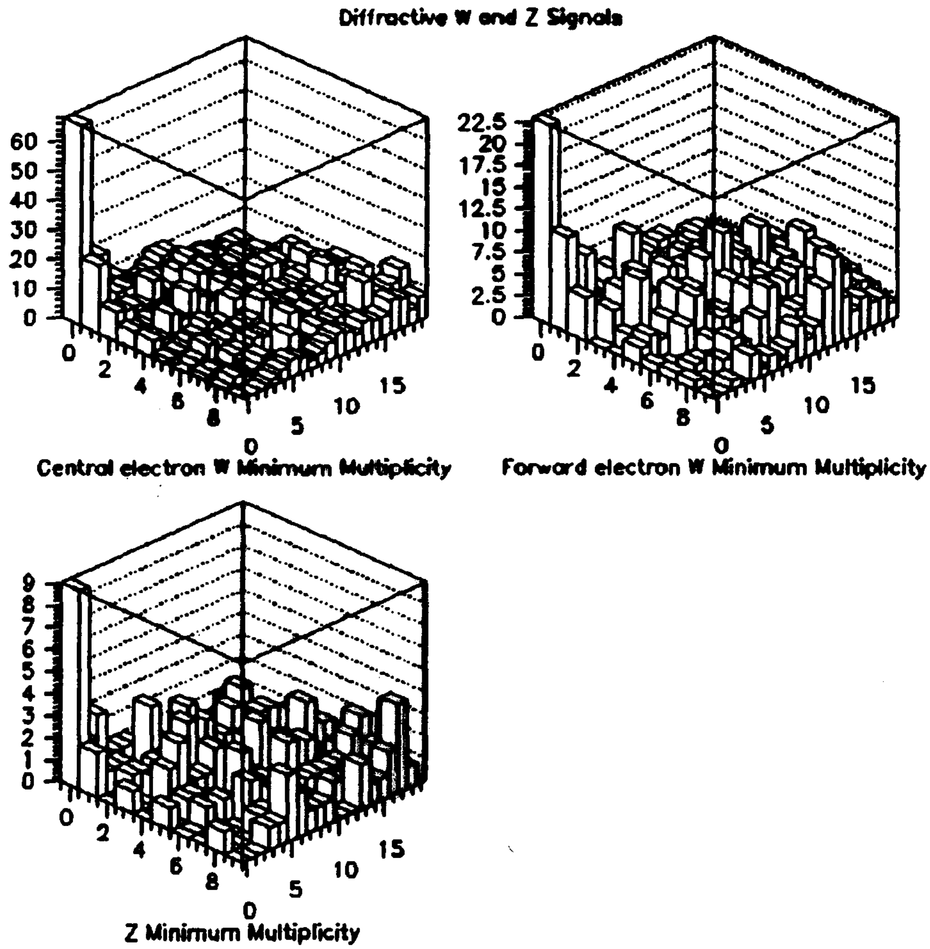
W Event Characteristics



DØ Preliminary

W/Z Data Results

***Observed clear Diffractive W and Diffractive Z signals**
***Measured Diffractive W/All W and Diffractive Z/All Z**



Sample	Diffractive/All	Probability Background Fluctuates to Data	
Central W	(1.08 + 0.19 - 0.17)%	1×10^{-14}	**7.7σ**
Forward W	(0.64 + 0.18 - 0.16)%	6×10^{-8}	**5.3σ**
All W	**(0.89 + 0.19 – 0.17)%**	3×10^{-14}	**7.7σ**
Z	(1.44 + 0.61 - 0.53)%	5×10^{-6}	**4.4σ**

DØ Preliminary

Rate Comparison

Correct MC for gap efficiency 20-30% for quark and hard gluon (soft gluon fractions <0.02%)

FINAL GAP FRACTION

Sample	Data	Quark	Hard Gluon
Cen W	(1.08 + 0.21 - 0.19)%	(4.1 ± 0.8)%	(0.15 ± 0.02)%
For W	(0.64 + 0.19 - 0.16)%	(7.2 ± 1.3)%	(0.25 ± 0.04)%
Z	(1.44 + 0.62 - 0.54)%	(3.8 ± 0.7)%	(0.16 ± 0.02)%

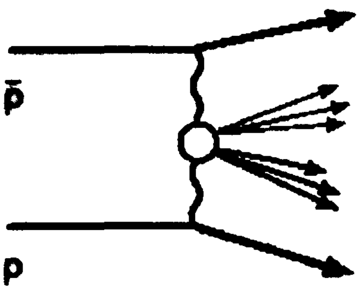
NOTE: Observe well-known normalization problem for all structure functions, also different dependence on η for data and MC, as in dijet case

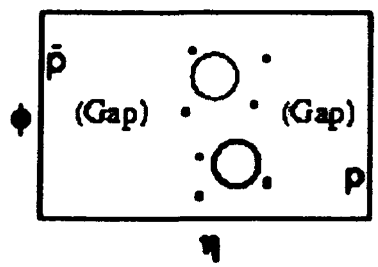
DØ Preliminary

DØ

Double Gaps at 1800 GeV

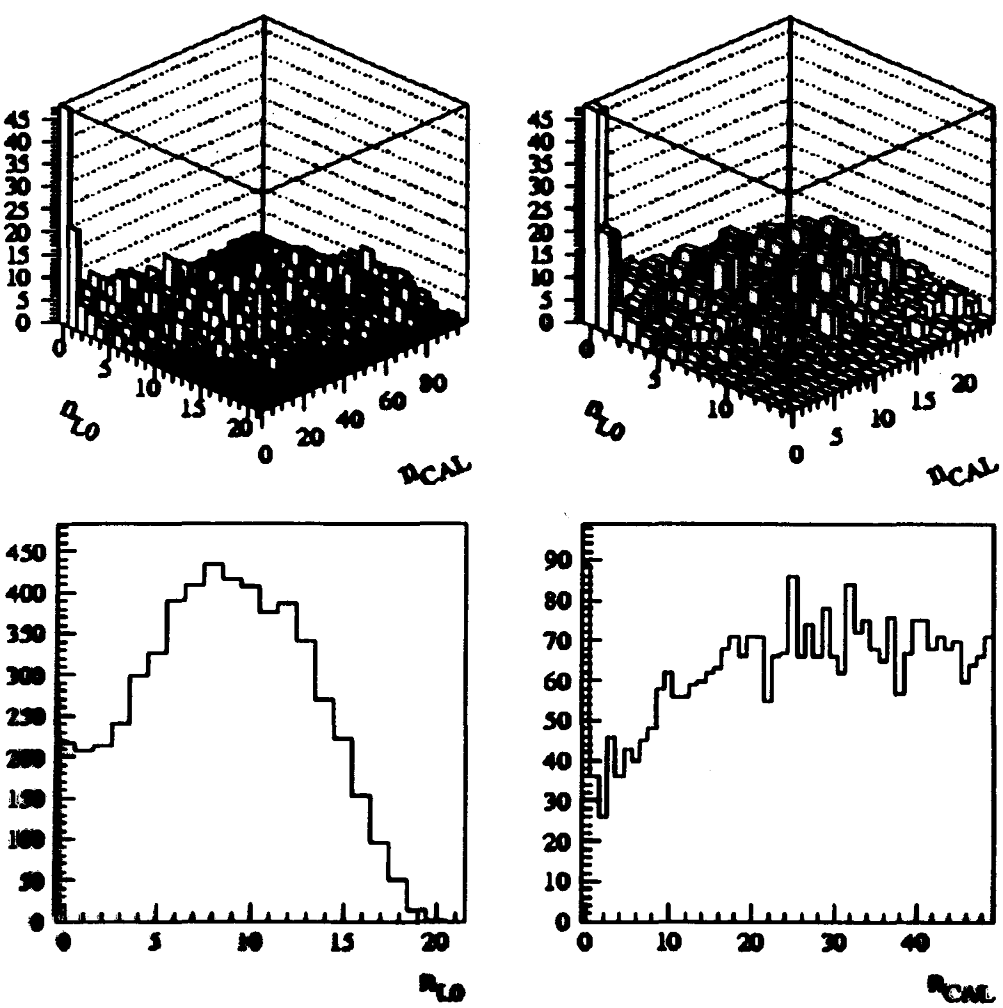
|Jet η| < 1.0, E_T>15 GeV





Gap Region
2.5<|η|<5.2

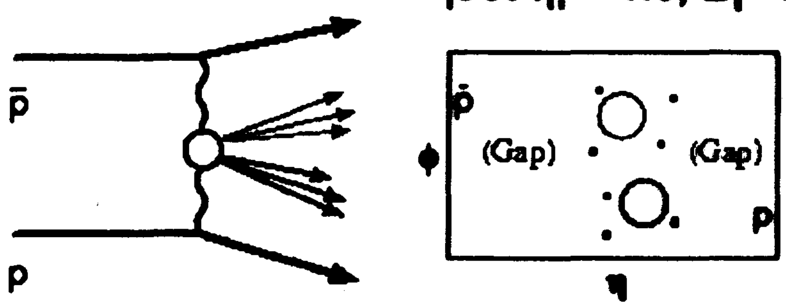
Demand gap on one side, measure multiplicity on opposite side



DØ Preliminary

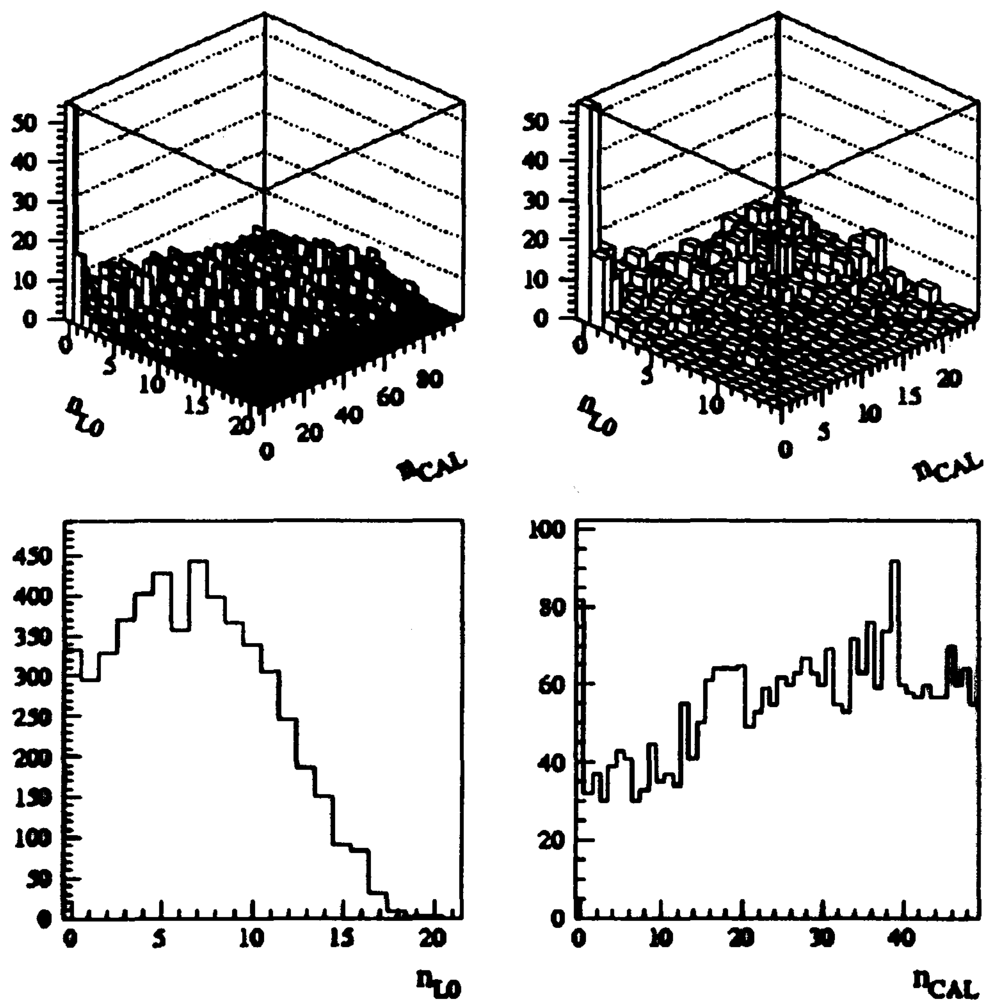
Double Gaps at 630 GeV

|Jet η| < 1.0, E_T>12 GeV



Gap Region
2.5<|η|<5.2

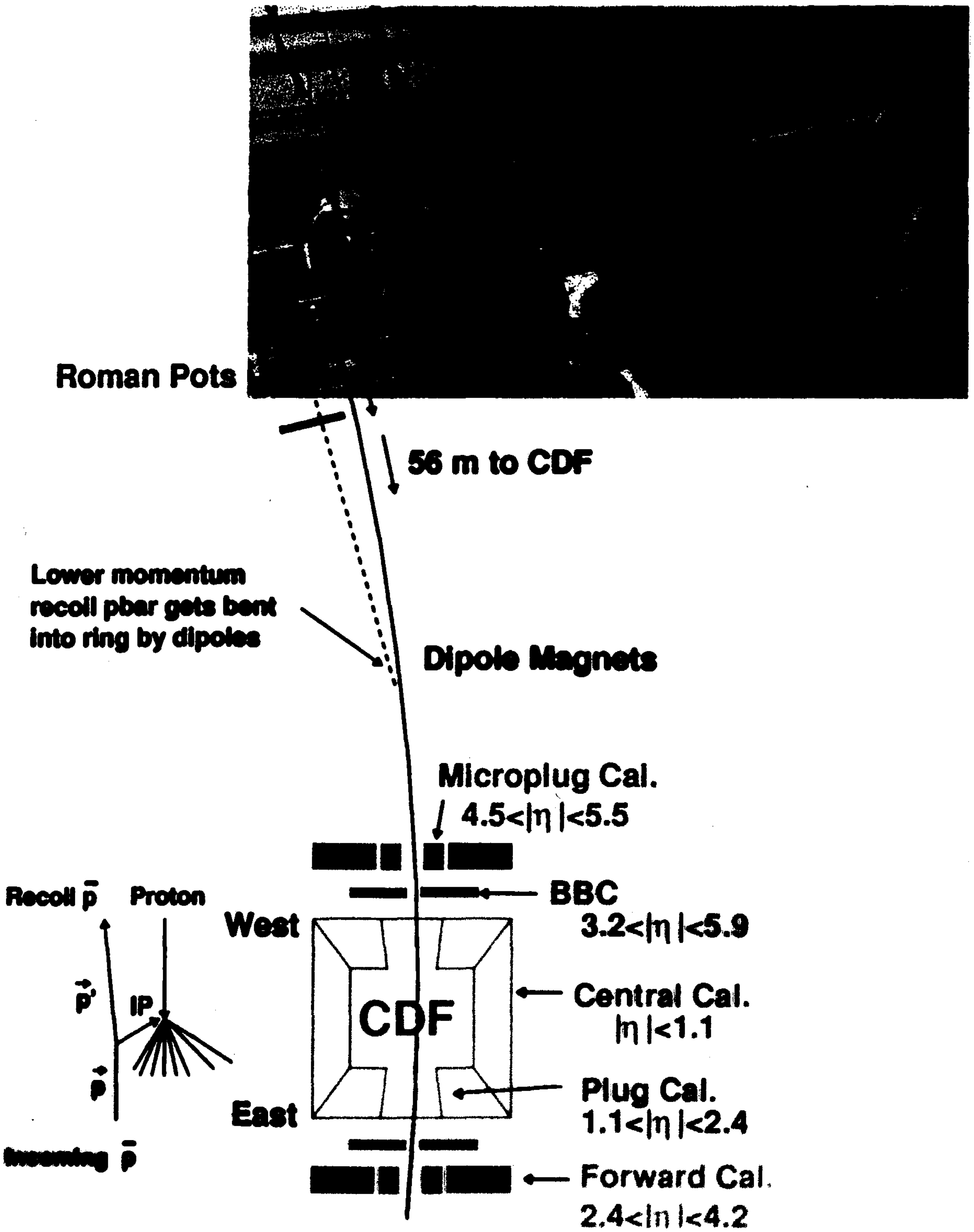
Demand gap on one side, measure multiplicity on opposite side



DØ Preliminary

Diffractive Dijets with Leading Antiproton

Roman Pot was employed in 1995-96 run



Diffractive Dijets with Leading Antiproton

Physics Motivation:

1. **Measure the diffractive structure function**
   $F^D_{jj}(\beta,\xi,Q^2,t)$

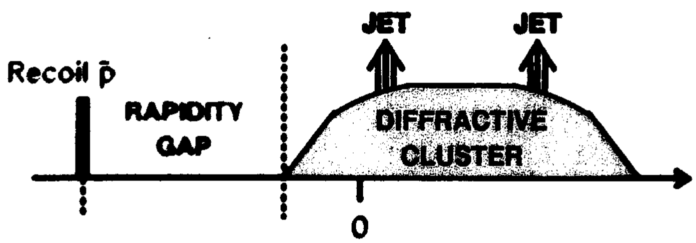
$$\left(\begin{array}{c} F^D_{jj}(x,\xi,Q^2,t) = x\left[g^D(x,\xi,Q^2,t) + \frac{4}{9}q^D(x,\xi,Q^2,t)\right] \\ F^D_{jj}(x,\xi,Q^2,t) \longrightarrow F^D_{jj}(\beta,\xi,Q^2,t) \end{array} \right)$$

$$\frac{d^5(p\bar{p}\to pjjX)}{dx_p\, d\beta\, d\xi\, dt\, dp_T^2} = \frac{F_{jj}(x_p,Q^2)}{x_p}\,\frac{F^D_{jj}(\beta,\xi,Q^2,t)}{\beta}\,\frac{d\hat{\sigma}_{gg\to gg}}{dp_T^2}$$

2. Test QCD factorization by comparing
   (a) $F^D_{jj}(\beta,\xi,Q^2,t)$ between $\sqrt{s}=630$ and 1800GeV
   (b) $F^D_{jj}(\beta,\xi,Q^2,t)$ with expectation from the measurements of diffractive DIS at HERA

3. Test Regge factorization

$$F^D_{jj}(\beta,\xi,Q^2,t) \stackrel{?}{=} f_{I\!P/p}(\xi,t)\; F^{I\!P}_{jj}(\beta,Q^2)$$



$$x_{\bar{p}} = p_{g,q}/p_{\bar{p}}, \qquad x_p = p_{g,q}/p_p$$

$$\xi = 1 - x_F = p_{I\!P}/p_{\bar{p}}, \qquad \beta = p_{g,q}/p_{I\!P}$$

Structure Function Measurement

❅ $$x_{\bar{p}} = p_{g,q}/p_{\bar{p}} = \frac{\sum_{i=1,2(3)} E_T^{(i)} \cdot e^{-\eta(i)}}{\sqrt{s}}$$

(if $E_T^{(3)} > 5$ GeV, include the 3rd jet)

❅ $$R_{\frac{SD}{ND}}(x_{\bar{p}}, \xi) = F_{jj}^{D}(x_{\bar{p}}, \xi)/F_{jj}(x_{\bar{p}})$$

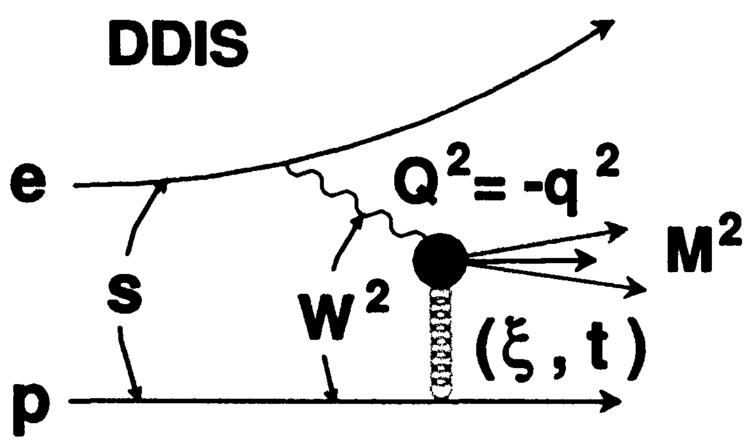
$$\left(F_{jj}^{(D)}(x_{\bar{p}}) = x_{\bar{p}} \left[g^{(D)}(x_{\bar{p}}) + \frac{4}{9} \sum (q_i^{(D)}(x_{\bar{p}}) + \bar{q}_i^{(D)}(x_{\bar{p}})) \right] \right)$$

❅ $$F_{jj}^{D}(x_{\bar{p}}, \xi) = R_{\frac{SD}{ND}}(x_{\bar{p}}, \xi) \times F_{jj}(x_{\bar{p}})$$

❅ $$F_{jj}^{D}(x_{\bar{p}}, \xi) \longrightarrow F_{jj}^{D}(\beta, \xi)$$

$$\beta = x_{\bar{p}}/\xi$$

Comparison with Expectations from H1 Results

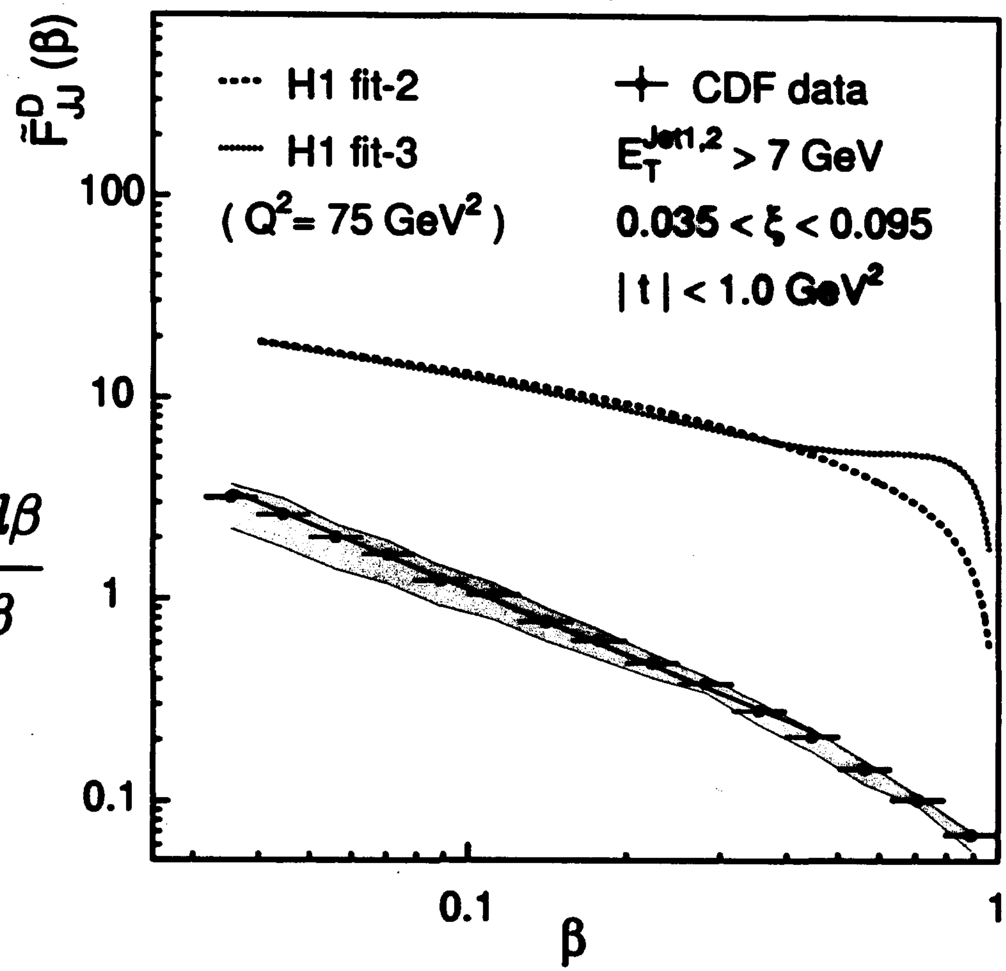


$$D = \frac{\int_{\log\beta=-1.4}^{\log\beta=0} F_{jj}^{D}(\beta;CDF)d\beta}{\int_{\log\beta=-1.4}^{\log\beta=0} F_{jj}^{D}(\beta;H1)d\beta}$$

$$= \begin{cases} 0.06 \pm 0.02 & \text{for fit-2} \\ 0.05 \pm 0.02 & \text{for fit-3} \end{cases}$$

Breakdown of Factorization

$\sqrt{s} = 1800$ GeV



CDF normalization uncertainty = ±26 %

Diffractive Structure $F_{jj}^{D}(\beta,\xi)$: 1800 GeV

$$F_{jj}^{D}(\beta,\xi) \overset{?}{=} f_{I\!P/p}(\xi)\ F_{jj}^{I\!P}(\beta)$$

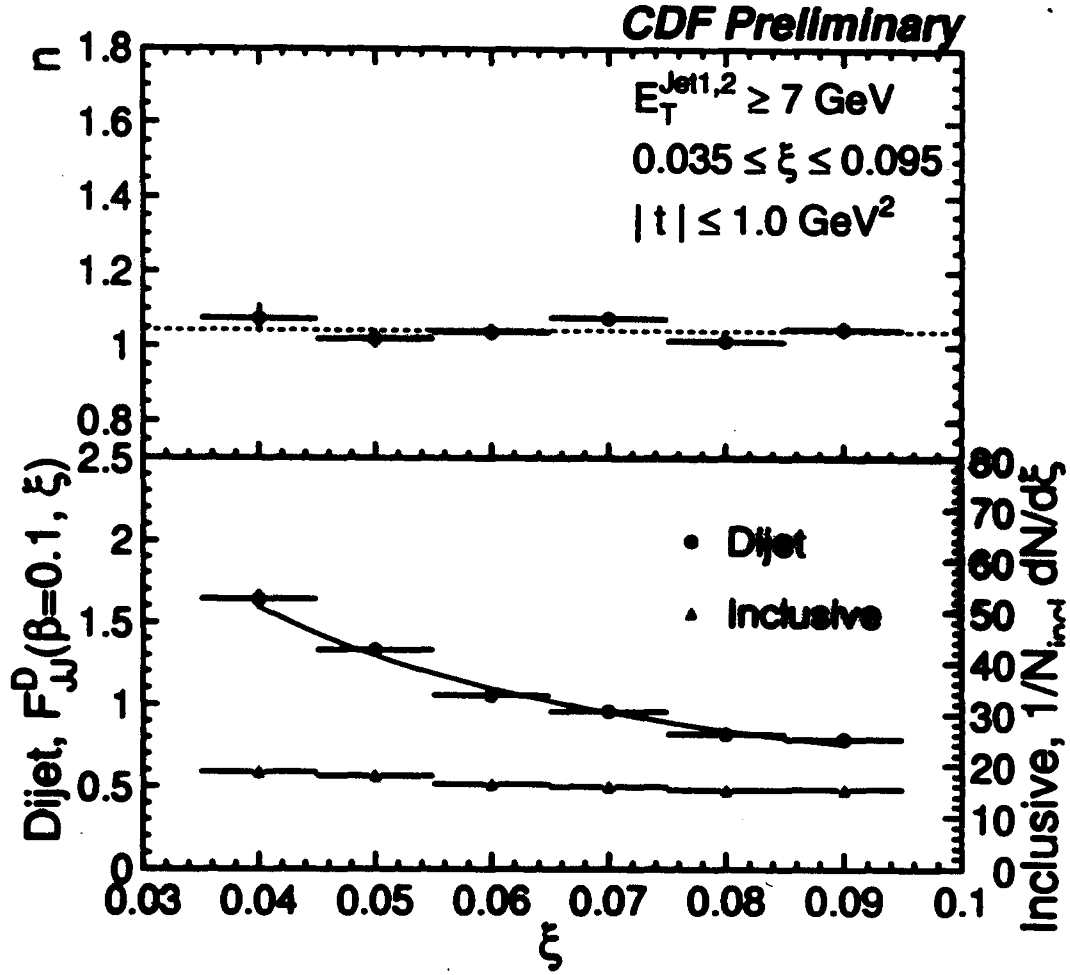
$$F_{jj}^{D}(\beta,\xi)|_{\xi} = C \times \beta^{-n}$$

$$(\beta < 0.5)$$

$$n = 1.0 \pm 0.1$$

$$F_{jj}^{D}(\beta,\xi)|_{\beta=0.1} = C \times \xi^{-m}$$

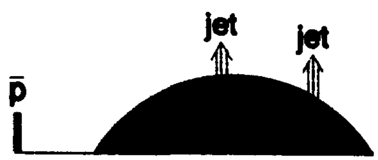
$$m = 0.9 \pm 0.1$$

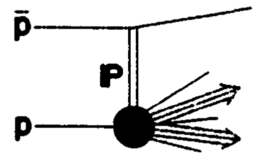


ξ, β-factorization :

$$F_{jj}^{D}(\beta,\xi) = C\,\frac{1}{\beta^{1.0\pm0.1}}\,\frac{1}{\xi^{0.9\pm0.1}} \qquad (10^{-3}/\xi < \beta < 0.5, 0.035 < \xi < 0.095)$$

Single Diffractive Dijet Production at $\sqrt{s} = 630$ GeV

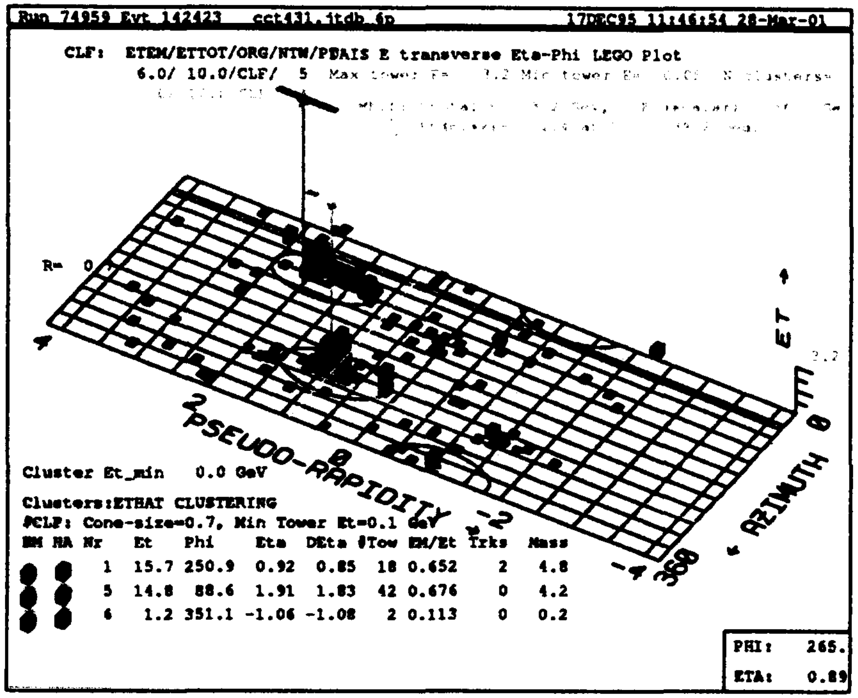


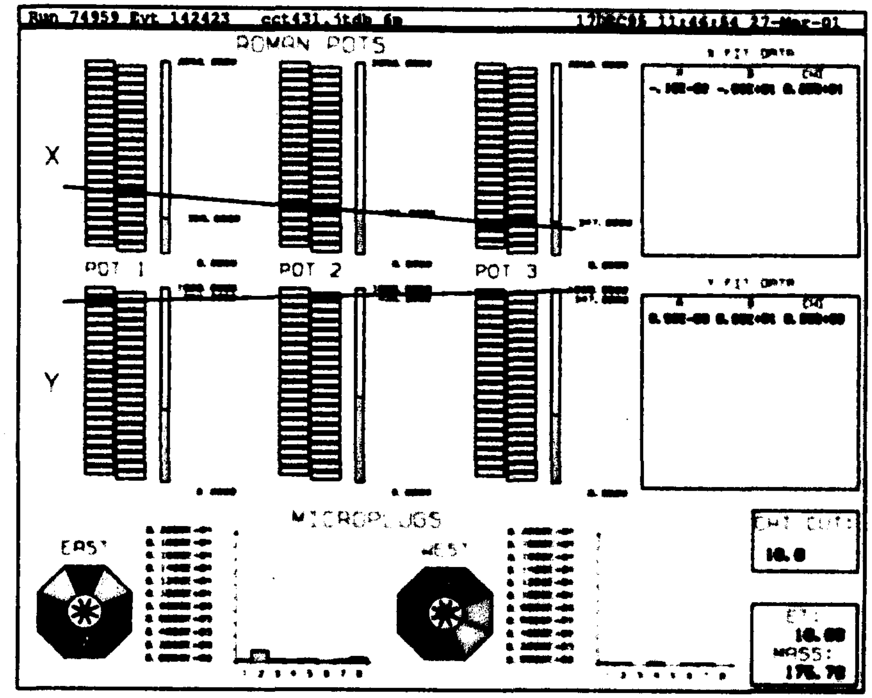


$\xi = 0.085, \quad t = -0.092$ GeV^2

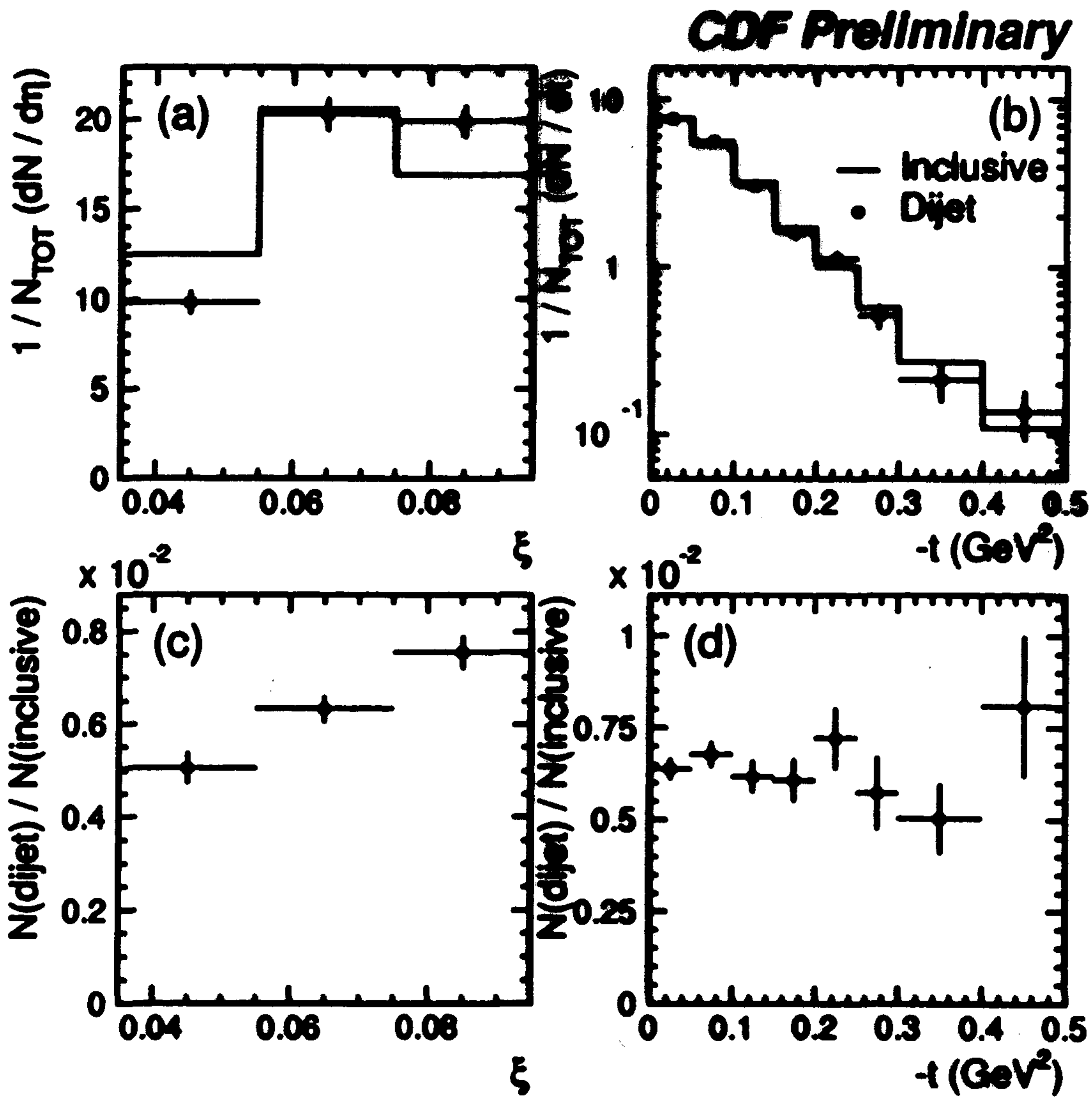
	West(negative-η) Outgoing $\bar{p}$ Side	East(positive-η) Outgoing p Side
N_{BBC}	0	8
N_{FCAL}	0	5

CDF Preliminary





Diffractive Dijet and Inclusive Events : 630 GeV



- Diffractive dijet events favor larger ξ values
- The ratio of dijet to inclusive events has a flat t-dependence

Consistent with 1800 GeV results

Diffractive Structure $F_{jj}^{D}(\beta)$: 630 vs. 1800 GeV

$$F_{jj}^{D}(x_{\bar{p}},\xi) = R_{\frac{SD}{ND}}(x_{\bar{p}},\xi) \times F_{jj}(x_{\bar{p}})$$

$$F_{jj}^{D}(x_{\bar{p}},\xi) \quad \longrightarrow \quad F_{jj}^{D}(\beta,\xi)$$

$$(\beta = x_{\bar{p}}/\xi)$$

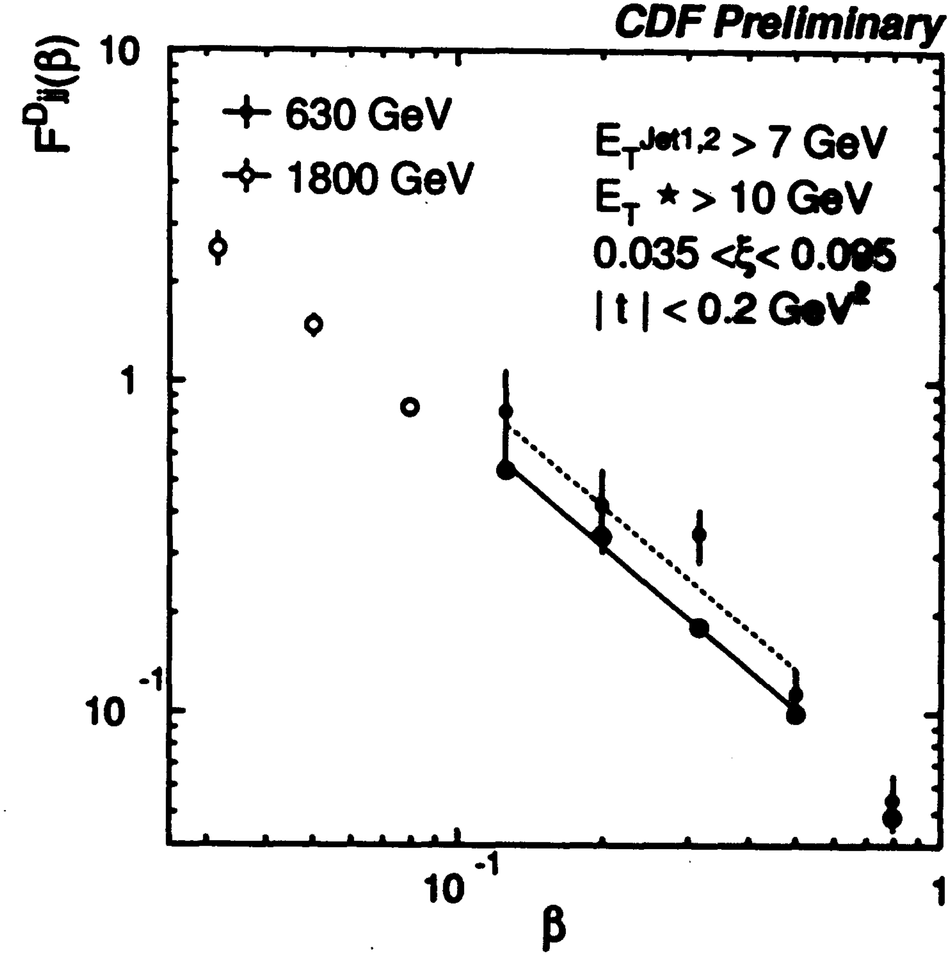
Does $F_{jj}^{D}(\beta,\xi)$ depend on s ?

Distributions are fitted to

$$F_{jj}^{D}(\beta) = B \times (\beta/0.3)^{-n}$$

$$(0.1 < \beta < 0.5)$$

with a common "n" value

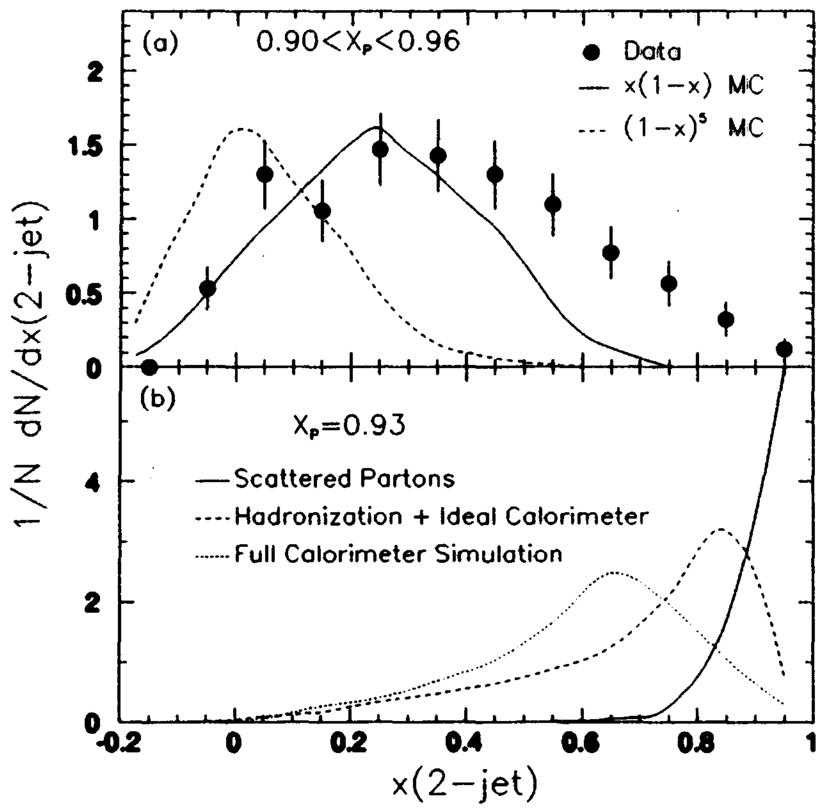


$$R\left[\frac{630}{1800}\right] = 1.3 \pm 0.2(stat)^{+0.4}_{-0.3}(syst)$$

UA8 Measurement

Physics Letters B 297 (1992) 417

UA8 study of diffractive dijet production in $\bar{p}p$ collisions at $\sqrt{s} = 630$ GeV at the CERN $Sp\bar{p}S$-Collider



x(2-jet) = β - x(proton)

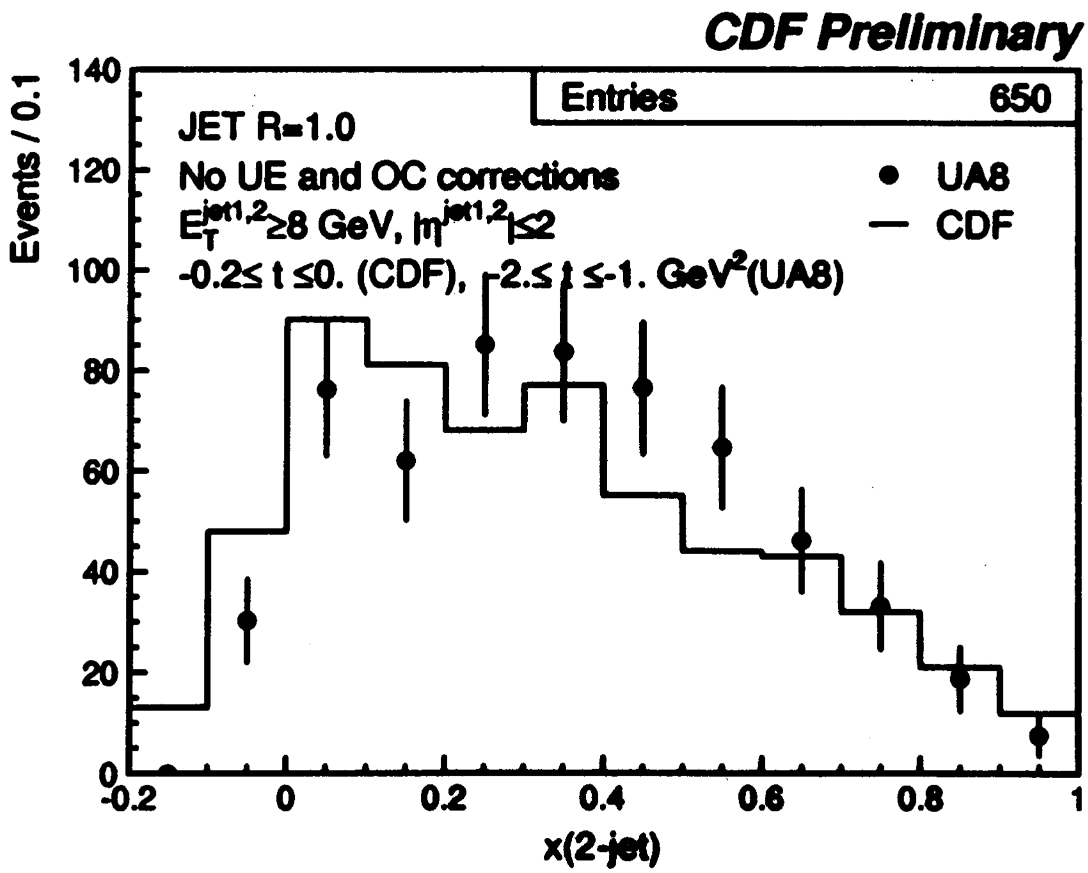
Pomeron structure derived from UA8 data :

$$\beta f(\beta) = \begin{cases} \delta(\beta - 1) & \text{(super-hard)} \quad 30\% \\ 6\beta(1-\beta) & \text{(hard)} \quad 57\% \\ 6(1-\beta)^5 & \text{(soft)} \quad 13\% \end{cases}$$

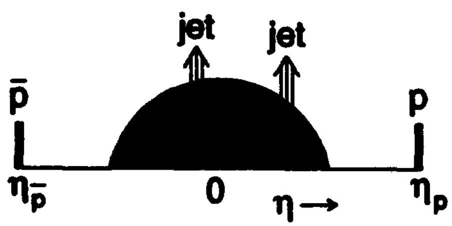
Comparison with UA8 : 630 GeV

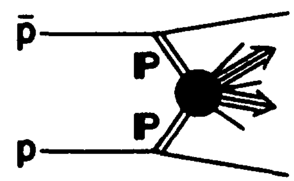
Reanalyze CDF 630 GeV data *à la* UA8

- $0.04 < \xi < 0.10$
- Jet cone radius $R = 1.0$
- No underlying event or out-of-cone corrections
- $E_T^{jet1,2} > 8$ GeV
- $|\eta^{jet1,2}| < 2$
- $\Delta\phi(jet1, 2) > 135°$
- $|t| < 0.2$ GeV^2 (UA8 : $0.9 < |t| < 2.3$ GeV^2)



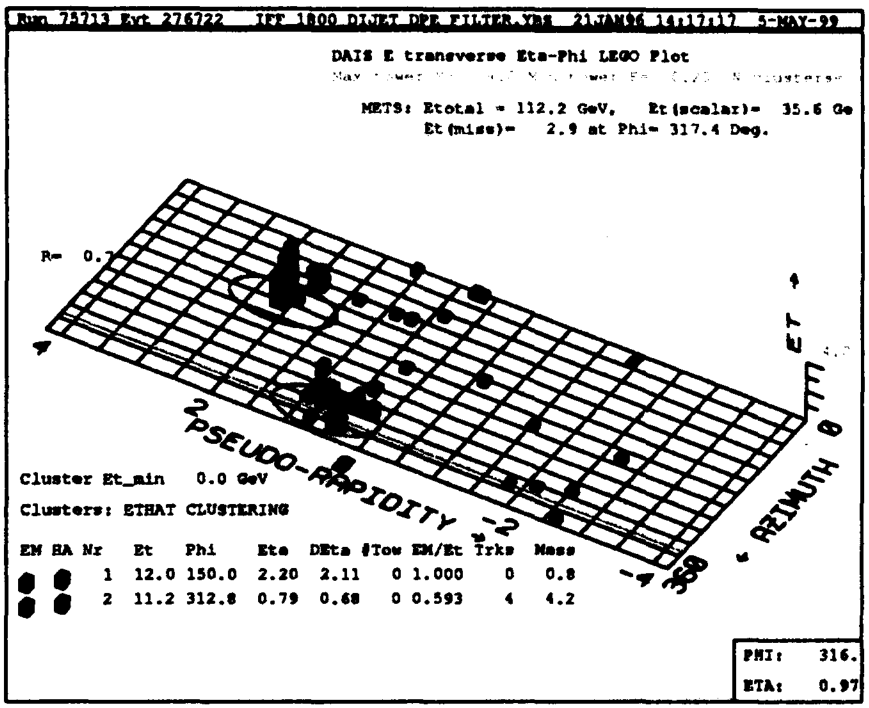
Dijet Production in Double Pomeron Exchange

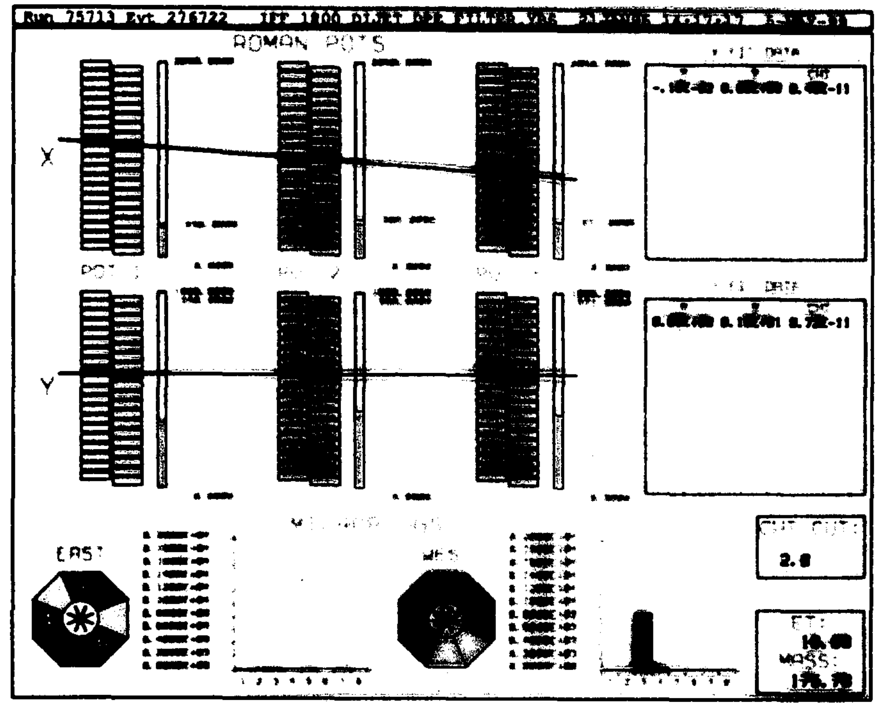




Test of Factorization

Compare the structure function in DPE with that in SD





Double Pomeron Exchange

$E_T^{(1)},\ E_T^{(2)} > 7$ GeV

$0.035 < \xi_{\bar{p}} < 0.095,\ |t_{\bar{p}}| < 1\ \mathrm{GeV}^2$

(a) Excess of events in (0,0) bin

→ Dijet Production in DPE

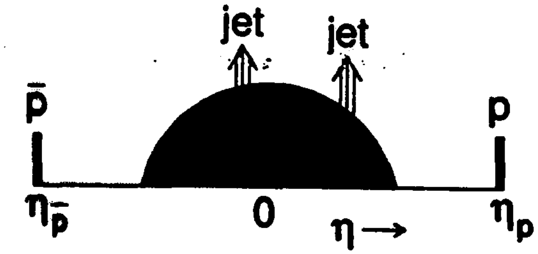
(b) $N_{DPE} =$

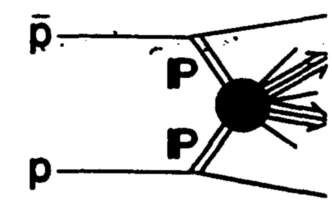
$117.7 \pm 12.1(stat) \pm 11.0(syst)_{fit}$

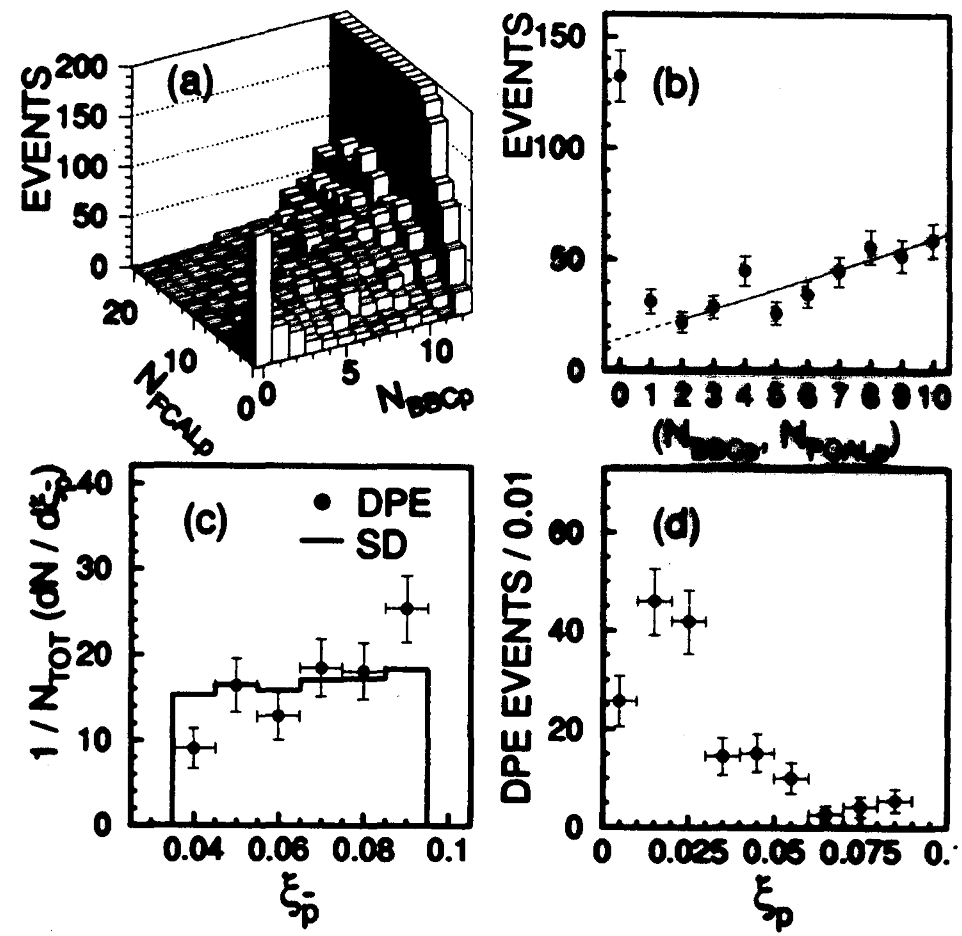
(c) $\xi_{\bar{p}}$ measured by Roman Pots

(d)

$$\xi_p = \frac{p_{I\!P}}{p_p} = \frac{\sum E_T e^{\eta}}{\sqrt{s}} = \left(\frac{M_{DPE}^2}{\xi_{\bar{p}} \cdot s}\right)$$







Double Pomeron Exchange : Test of Factorization

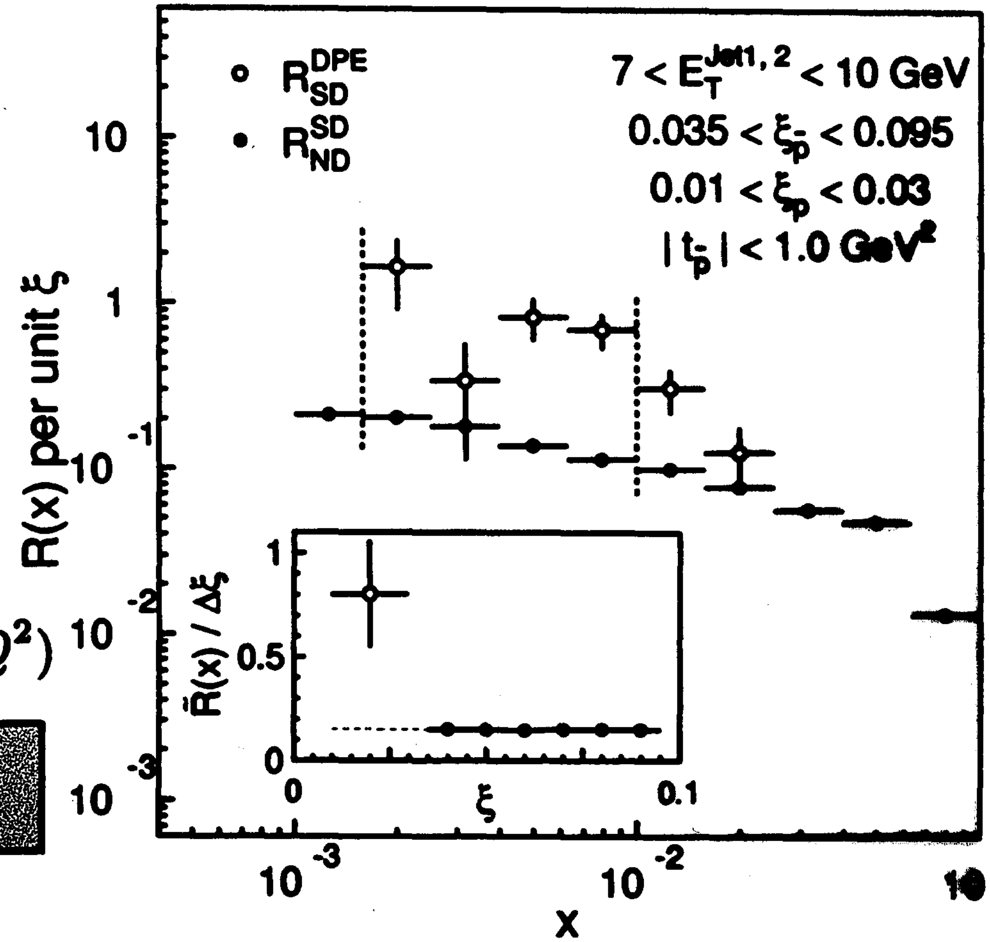
$$\sigma_{ND} = \sigma_0 F(x_p, Q^2)\, F(x_{\bar{p}}, Q^2)$$

$$\sigma_{SD} = \sigma_0 F(x_p, Q^2)\, F^D(x_{\bar{p}}, \xi, Q^2)$$

$$\sigma_{DPE} = \sigma_0 F^D(x_p, \xi, Q^2)\, F^D(x_{\bar{p}}, \xi, Q^2)$$

$$\langle R^{SD}_{ND} \rangle / \langle R^{DPE}_{SD} \rangle = 0.19 \pm 0.07$$

$(10^{-2.8} < x < 10^{-2})$



Deviation of D from unity ⟹ Breakdown of Factorization

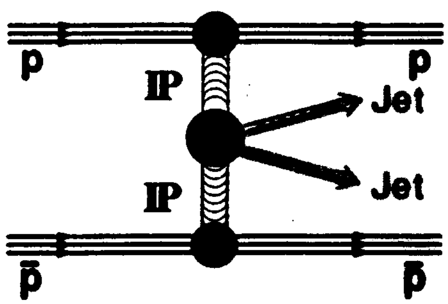
Double Pomeron Exchange

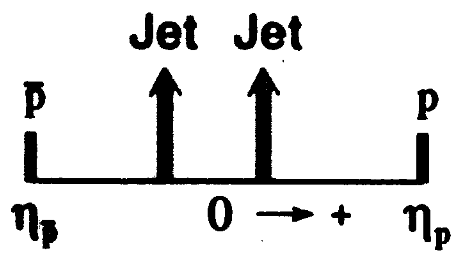
Dijet Cross Section

$$0.035 < \xi_{\bar{p}} < 0.095,\ 0.01 < \xi_p < 0.03$$

$$\sigma(E_T^{jet1,2} > 7\text{ GeV}) = 43.6 \pm 4.4(stat) \pm 21.6(syst)\text{ nb}$$
$$\sigma(E_T^{jet1,2} > 10\text{ GeV}) = 3.4 \pm 1.0(stat) \pm 2.0(syst)\text{ nb}$$

Exclusive dijet production





$$p + \bar{p} \to p' + (jet1 + jet2) + \bar{p}'$$
$$E_T^{jet1,2} > 7\text{ GeV}$$

$$\sigma(95\%\text{ C.L.}) < 3.7\text{ nb}$$

Predictions:

- ✔ A. Berera, hep-ph/991045
  $\sigma \sim \mathcal{O}(1\ \mu\text{b})$
- ✔ V.A.Khoze, A.D.Martin, M.G.Ryskin, hep-ph/0007083
  $\sigma \sim 2$ nb

Tevatron Summary

DØ

- Measurements at two CM energies with same detector adds critical new information for examining pomeron puzzle
  - The higher rates at 630 were not widely predicted before the measurements
- Pioneering work in Central Rapidity Gaps
  - Modifications to theory based on data have occured
- Hard Single Diffraction
  - Many processes observed and studied including Diffractive W (diffraction is not low p_T process)
  - Discrepancy in shape and normalization of β distribution confirms factorization breakdown
  - Results imply a non-pomeron based model should be considered
- Hard Double Pomeron
  - Observation of interesting new process
  - Confirms factorization breakdown

Proliferation of Pots

In late 80's there were UA8 Roman pots and temporary CDF pots (total cross section)

Since then ZEUS LPS has been very successful
H1 FPS less succesful due to acceptance, but VFPS planned.

E811 (total cross section)

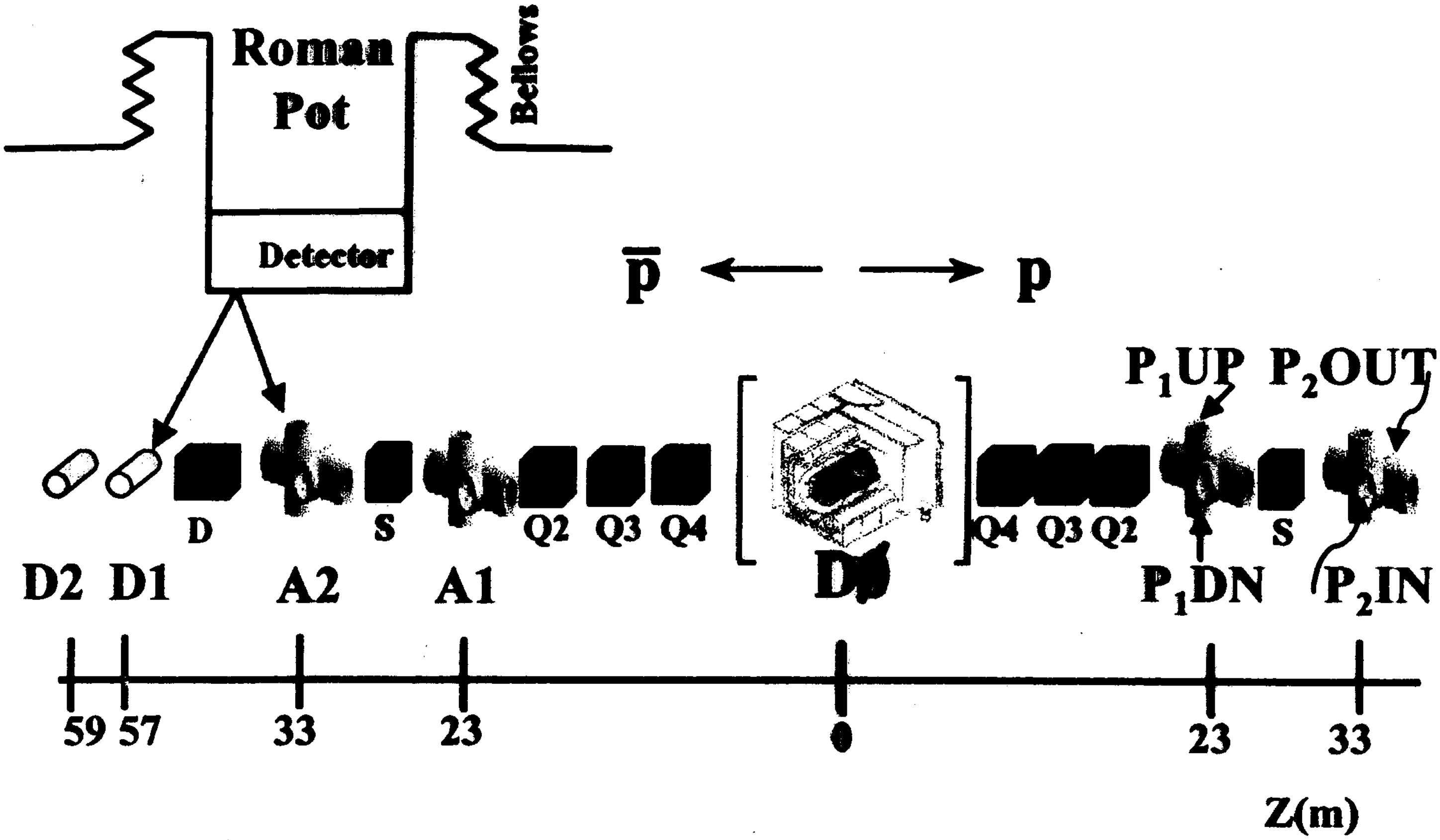
CDF (1 spectrometer) end of Run I and Run II

DØ FPD Run II

PP2PP (RHIC elastic scattering)

LHC: CMS, TOTEM, ATLAS

DØ Forward Proton Detector



Series of 18 Roman Pots forms 9 independent momentum spectrometers allowing measurement of proton momentum and angle.

1 Dipole Spectrometer ($\bar{p}$) $\xi > \xi_{min}$

8 Quadrupole Spectrometers (p or $\bar{p}$, up or down, in or out) $t > t_{min}$

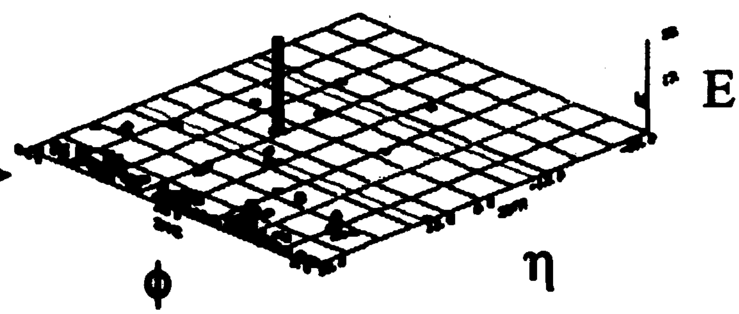
Diffraction Thesis Topics

Soft Diffraction and Elastic Scattering:

Inclusive Single Diffraction
Elastic scattering (t dependence)
Total Cross Section
Centauro Search
Inclusive double pomeron
Search for glueballs/exotics

Hard Diffraction:

Diffractive jet
Diffractive b,c
Diffractive W/Z →
Diffractive photon
Diffractive top
Diffractive Higgs
Other hard diffractive topics
Double Pomeron + jets
Other Hard Double Pomeron topics



<100 events in Run I, >1000 tagged events in Run II

Rapidity Gaps:

Central gaps+jets
Gap tags vs. proton tags
Double pomeron with gaps

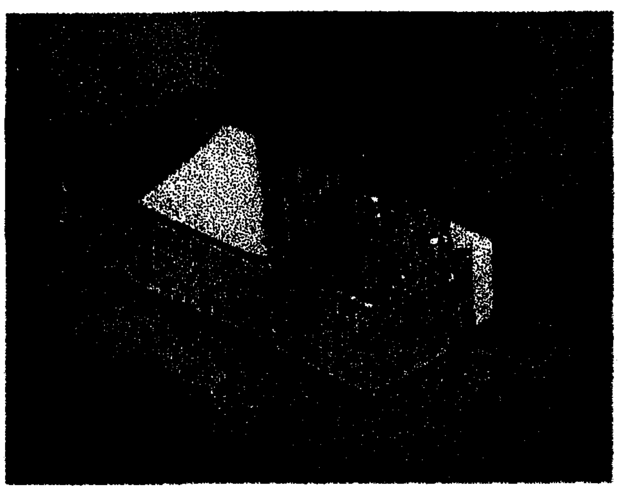
Castle Status

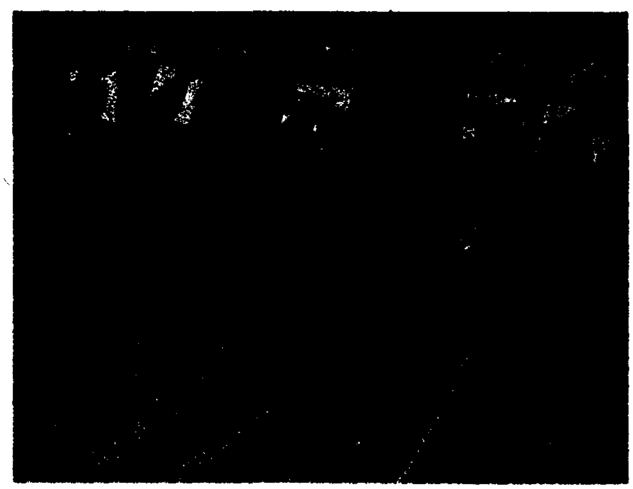
All 6 castles with 18 Roman pots comprising the FPD were constructed in Brazil, installed in the Tevatron in fall of 2000, and have been functioning as designed.

Quadrupole castle A2 installed in the beam line.

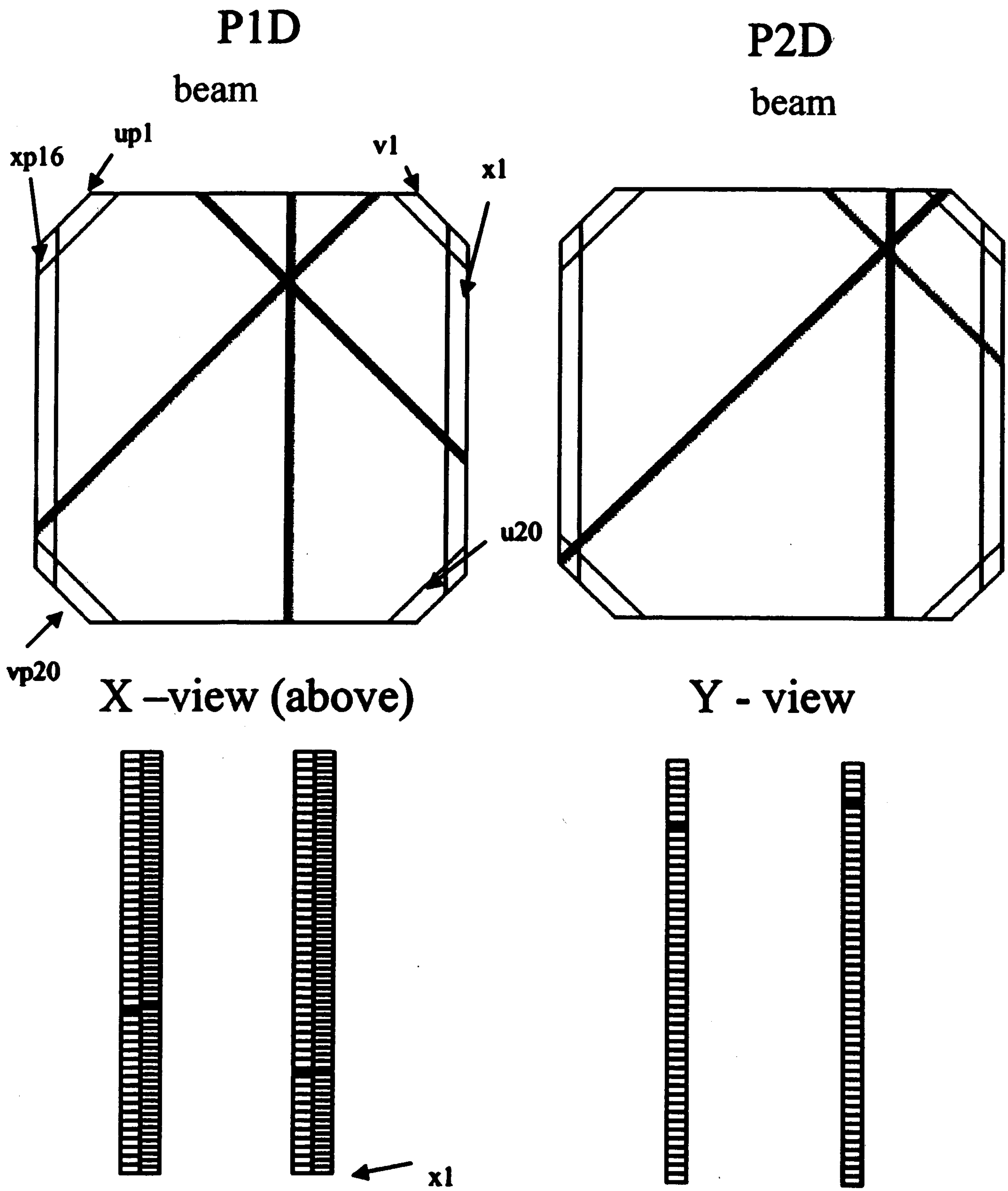
Detector Assembly

At the University of Texas, Arlington (UTA), scintillating and optical fibers were spliced and inserted into the detector frames.



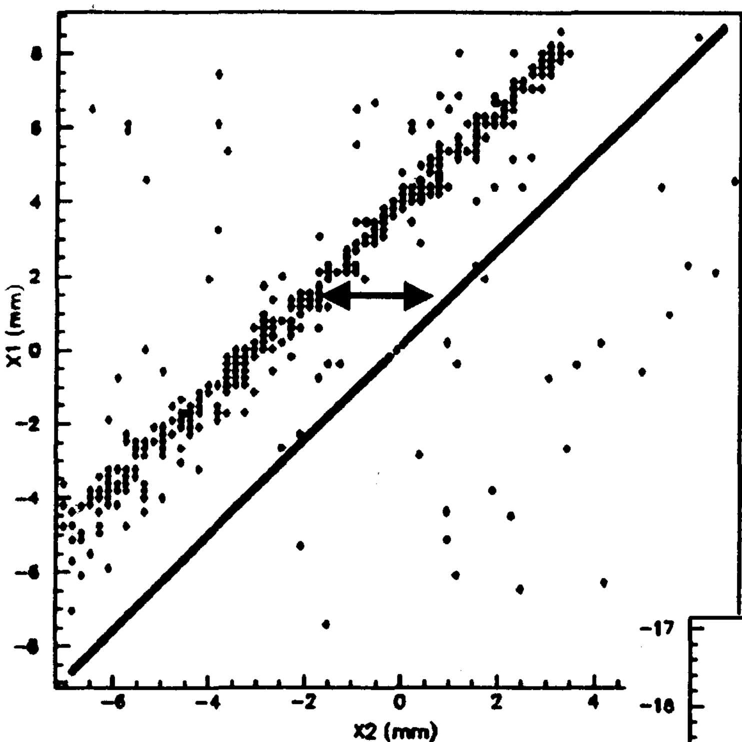


Event Display



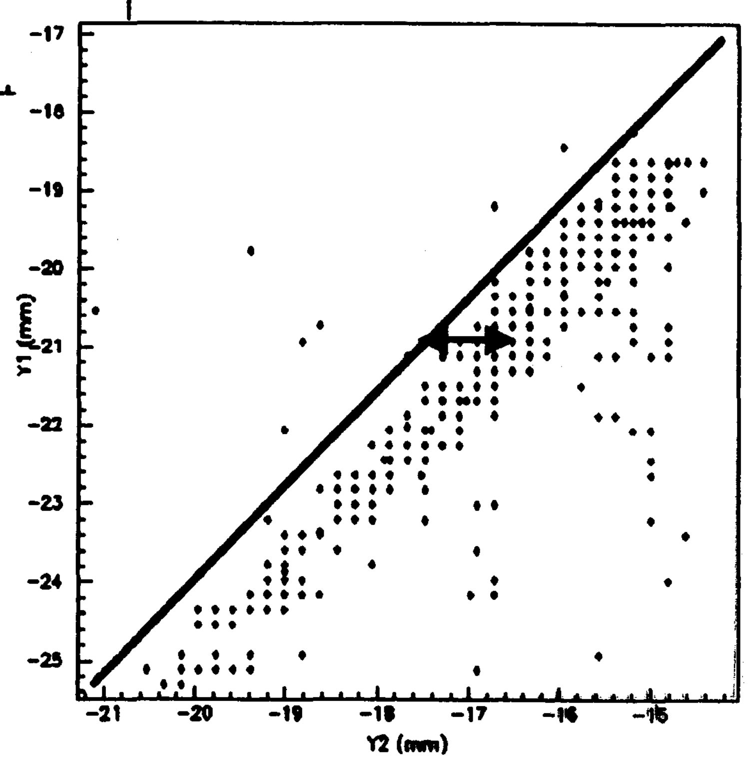
Data Elastic x,y Correlations

PD1x vs. PD2x (mm)

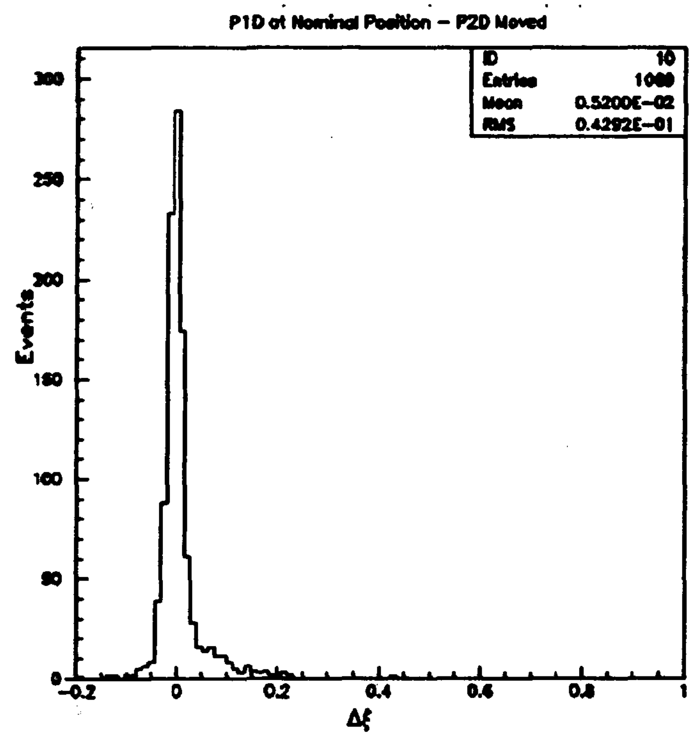


Good correlation between x1,x2 and y1,y2 in data but shifted from MC expectation (3 mm in x and 1 mm in y)

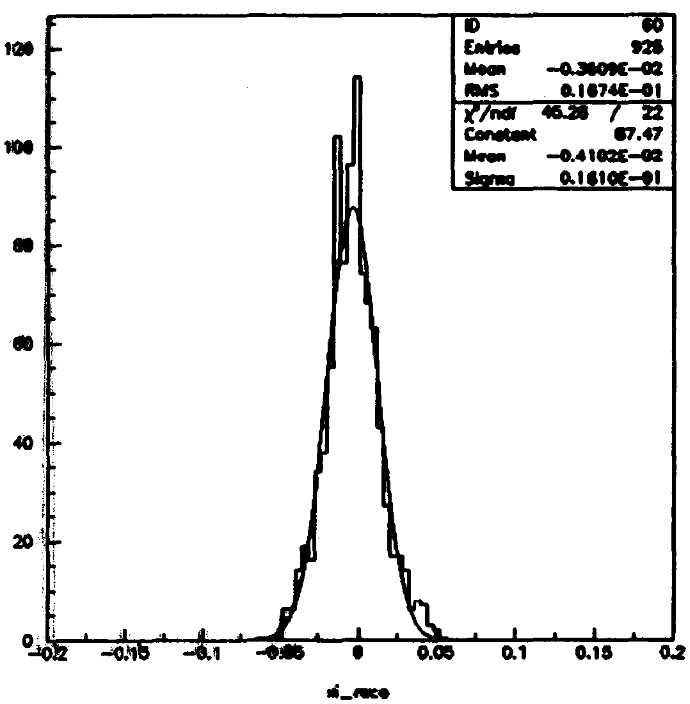
PD1y vs. PD2y (mm)

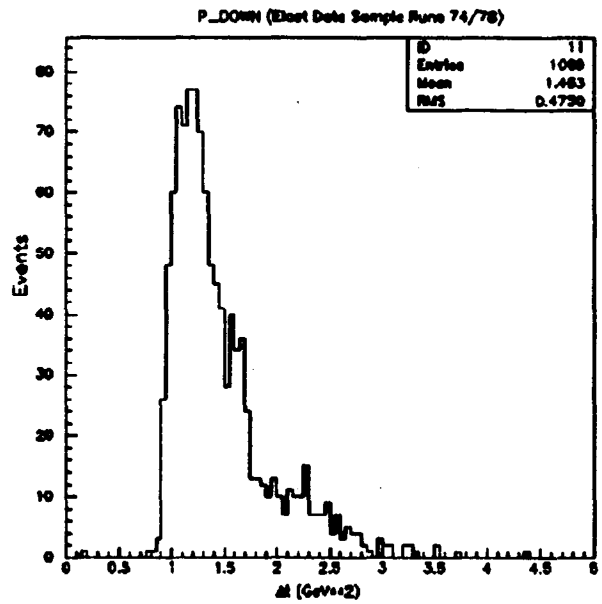


Elastic ξ,t (calibrated)



Calibrated ξ now peaks at 0





Minimum t about 1.0 Gev^2

ξ peak reasonably Gaussian, still 2x ideal MC resolution

FPD Goals for 2002

- Finish commissioning Phase I of FPD (10 pots/5 spectrometers)
- Become fully integrated with DØ
- Start with diffractive jets and double pomeron studies

pp2pp Physics Goals

pp2pp: A comprehensive spin-dependent *proton-proton* elastic scattering experiment at RHIC

- Study of total and differential cross-sections in *pp* scattering over a large kinematic range inaccessible to past experiments

$$50 \leq \sqrt{s} \leq 500\ \text{GeV}/c$$

$$4 \cdot 10^{-4} \leq |t| \leq 1.5\ (\text{GeV}/c)^2$$

- Measurements with transverse and longitudinally polarized protons to determine the *s*-channel helicity amplitudes Φ_i

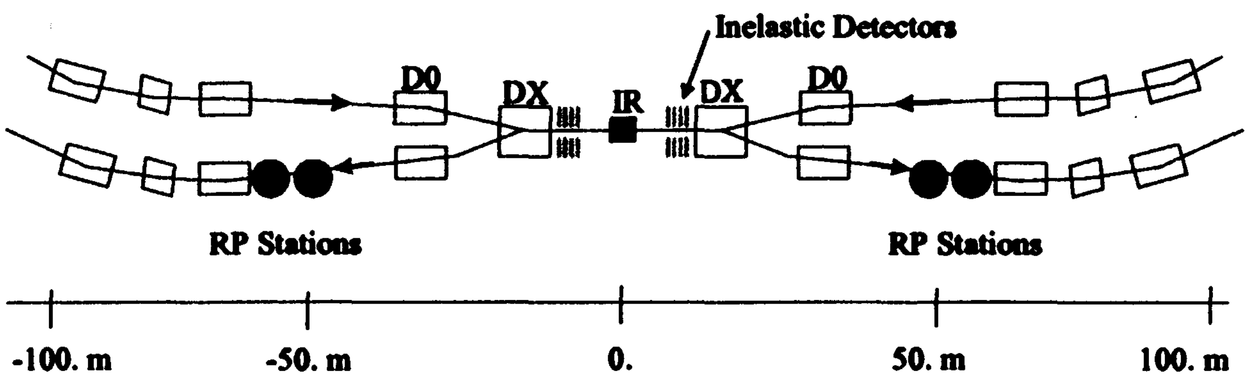
$$\Phi_1 \sim \langle ++|\, M\, |++\rangle$$
$$\Phi_2 \sim \langle --|\, M\, |++\rangle$$
$$\Phi_3 \sim \langle +-|\, M\, |+-\rangle$$
$$\Phi_4 \sim \langle +-|\, M\, |-+\rangle$$
$$\Phi_5 \sim \langle ++|\, M\, |+-\rangle$$

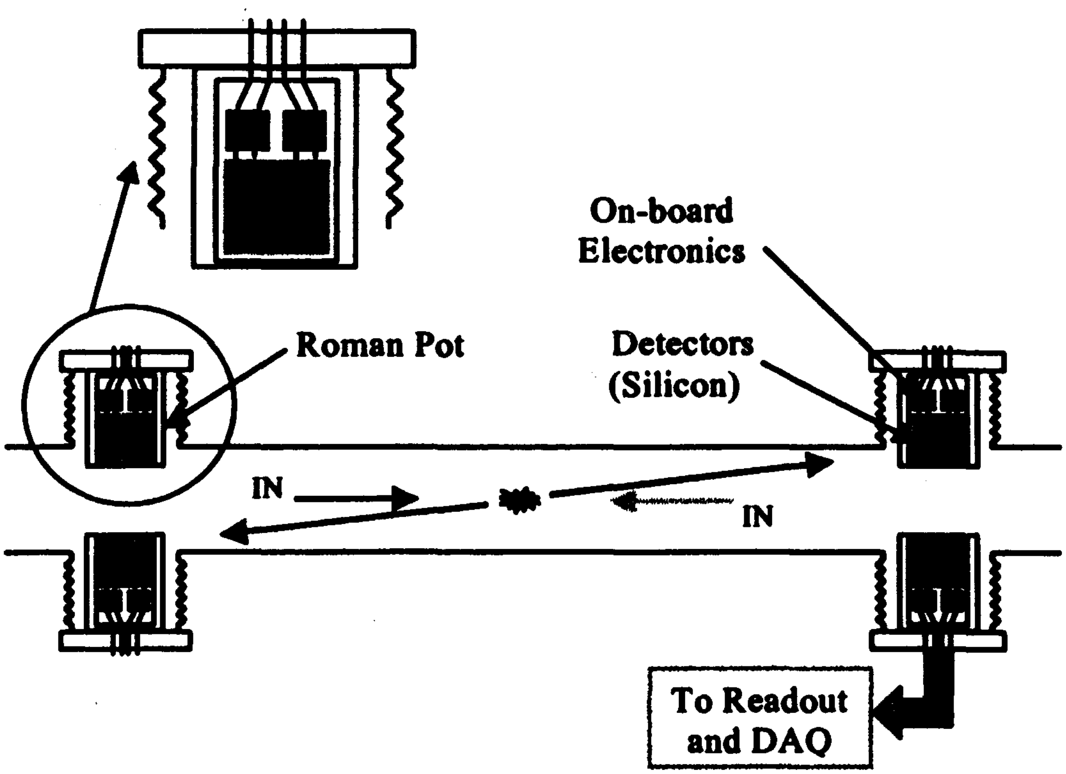
- Determine the nature of the mediator of the elastic interaction
- Diffractive physics at high $|t|$

From Kaush

pp2pp Setup

RHIC Intersection Region with PP2PP Basic CB Setup

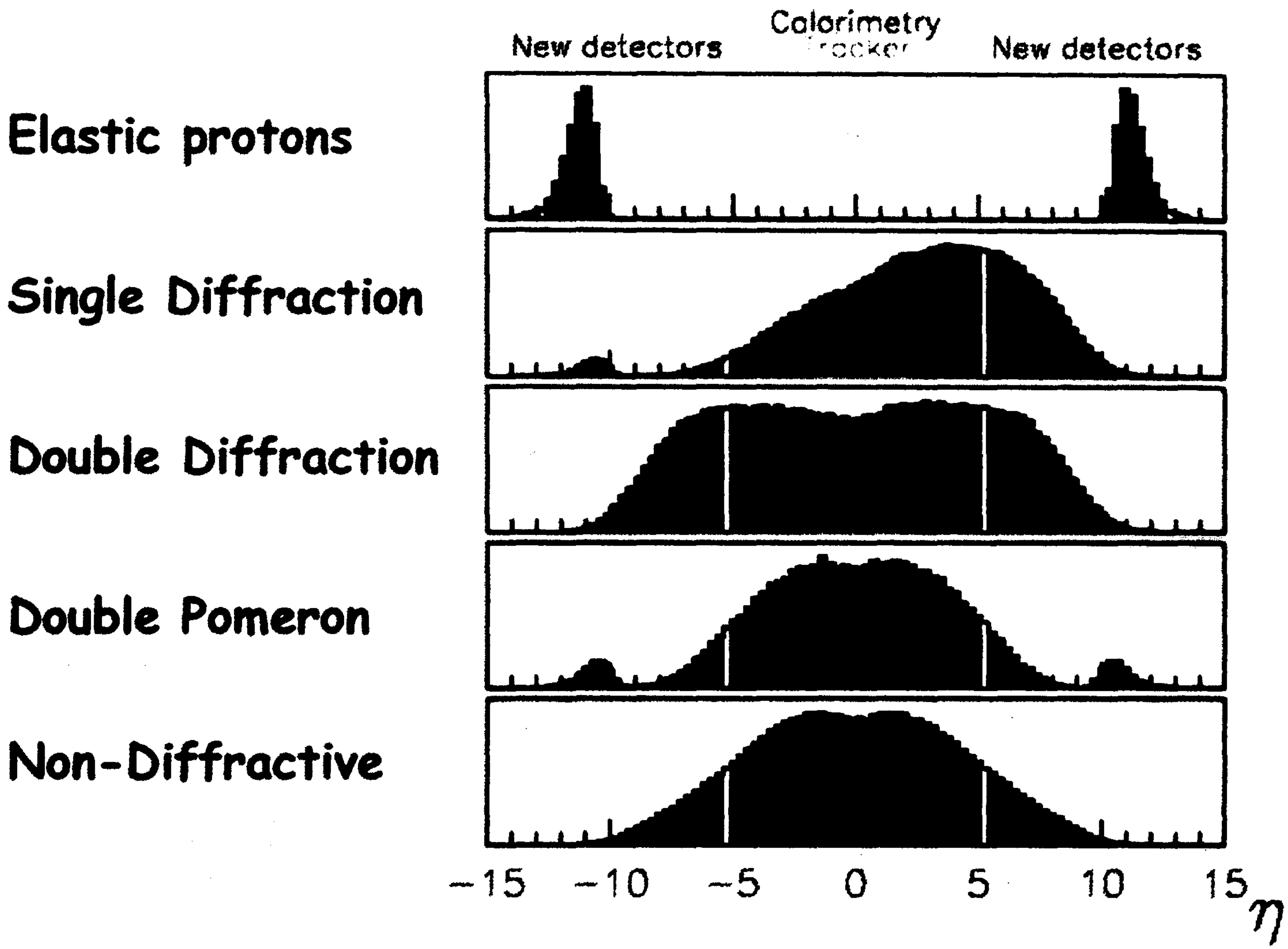




pp2pp Run in 2002

- Engineering run, p =100 GeV/c
- One Roman pot station on each side of interaction point (IP)
- Inelastic veto around IP
- Expected kinematics range: $0.005<|t|<0.02$ GeV^2
- 4 hours commissioning on 1/19
- 14 hours of data on 1/24: excellent beam quality
- Collected 974k events - elastic & inelastic triggers
- Data will primarily be used to study detector performance and to prepare for data run in 2003
- Bonus: high quality of data may provide new physics measurements

For forward physics processes at LHC need to extend the base line experiments.



Courtesy of [redacted]

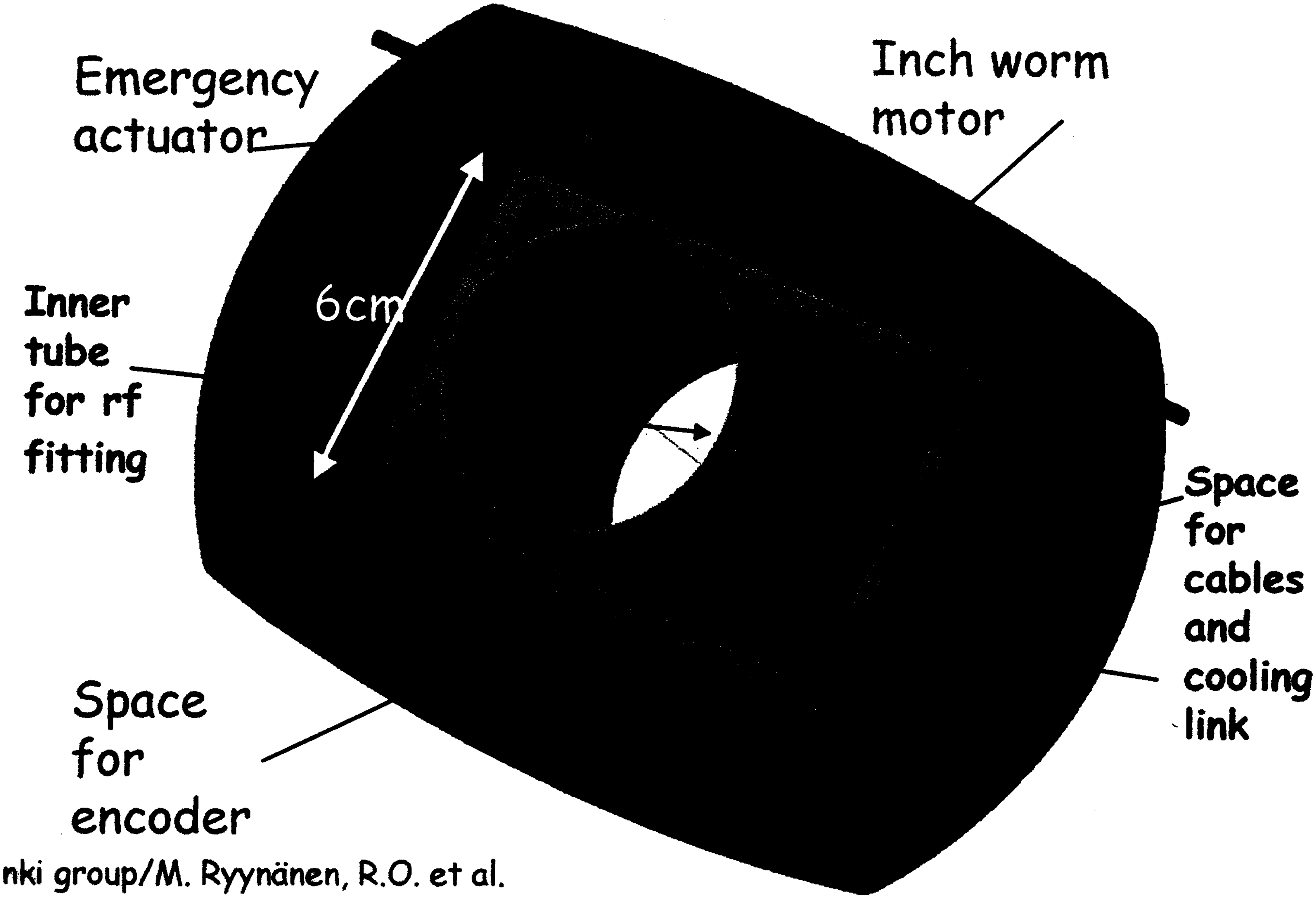
Diffraction is mostly beyond the reach of large baseline experiments at LHC (ATLAS & CMS). What should be done to increase their coverage in the forward region?

(1) **Leading proton measurement**

(2) **Upgrade forward detectors:**

- **ATLAS + A Foward Spectrometer**
- **CMS + TOTEM**
- **Roman Pots and MicroStations**

Microstation



Helsinki group/M. Ryynänen, R.O. et al.

As a *Gluon* Factory LHC could deliver...

- 100,000 high purity ($q/g = 1/3000$) gluon jets with $E_T > 50$ GeV in 1 year; gg-events as "Pomeron-Pomeron" luminosity monitor

- Possible new resonant states, e.g. Higgs (250 $H \to b\underline{b}$ events per year with $m_H = 120$ GeV, $L=10^{34}$)*, glueballs, quarkonia 0^{++} (χ_b), gluinoballs - background free environment ($b\underline{b}$, WW & $\tau^+\tau^-$ decays)

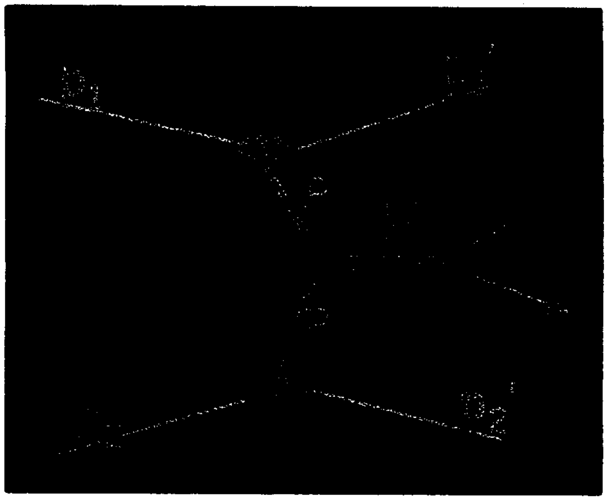
- Squark & gluino
  - practically background free signature: multijets & missing transverse energy
  - model independence (missing mass!)
  - expect 10-15 events for gluino/squark masses of 250 GeV

- Several events with isolated high mass $\gamma\gamma$ pairs, extra dimensions

*V.Khoze, Martin & Ryskin, Boonekamp, Peschanski, Royon,...

Higgs via Double Pomeron Exchange

[redacted]



$M_H^2 \leq \xi_1 \xi_2 s$

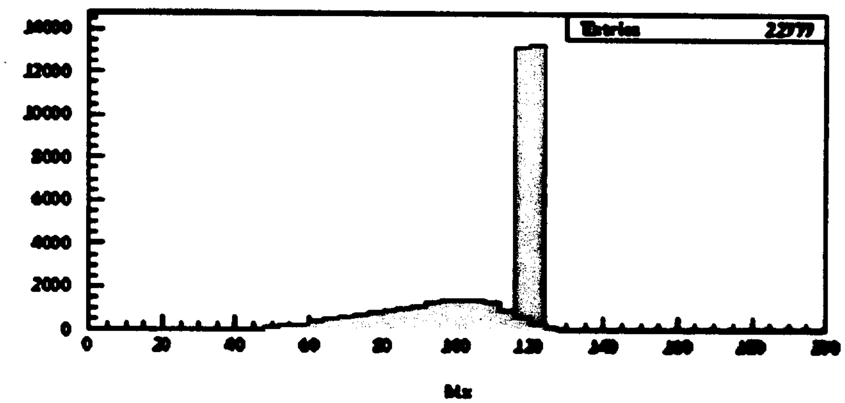
Two questions: Is the diffractive Higgs production cross section high enough? What do we gain compared to the standard Higgs production?

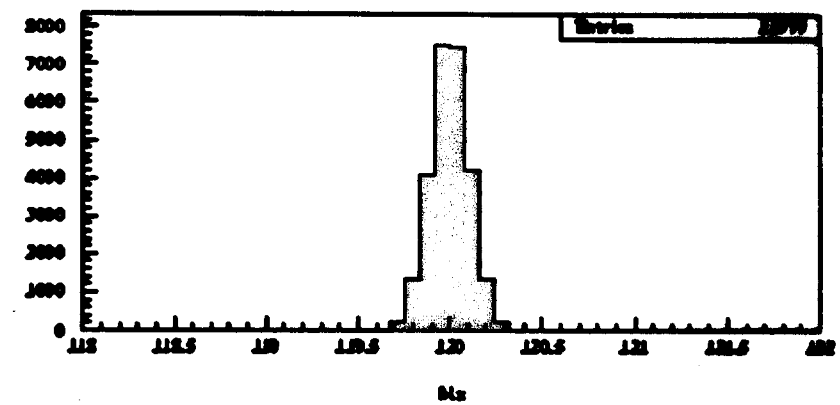
In the following, only diffractive Higgs produced via double pomeron exchange will be considered

Diffractive Higgs Motivation

Suppose the Higgs has a low mass, but the Tevatron luminosity is insufficient to find it, then it will be necessary to use the difficult $\gamma\gamma$ channel at LHC.

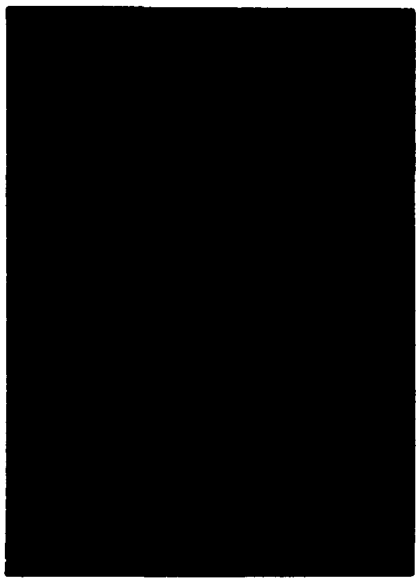
Higgs mass reconstruction: missing mass method (M.Albrow, A.Rostovtsev, hep-ph/0009336). For exclusive Higgs production (only Higgs and tagged protons), vastly superior Higgs mass resolution allows events to be extracted from high background, since
$$M_H^2 = \xi_1 \xi_2 s$$



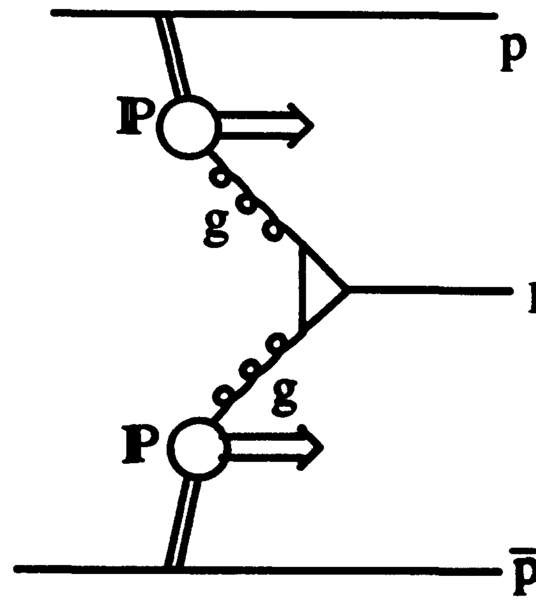


Resolutions of about 3 GeV may be possible at LHC, even in non-exclusive production, if a pomeron remnant tagger is used $(5 < \eta < 10)$

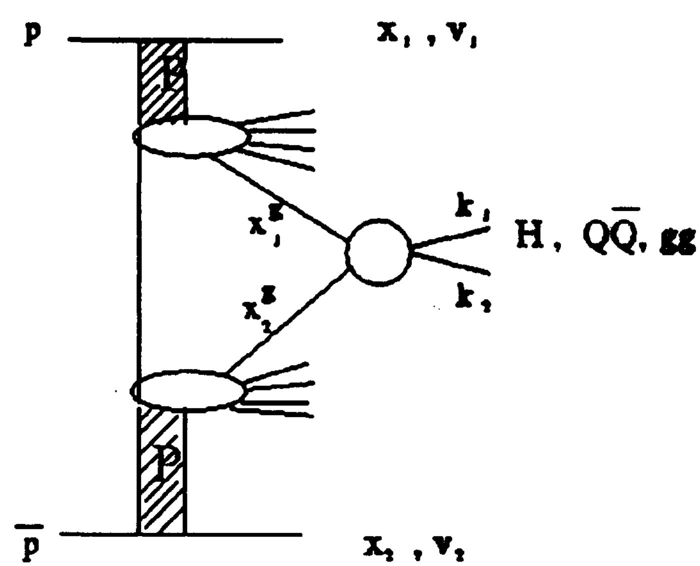
Pomeron-Based Diffractive Higgs Models



Factorizable:
Cox, Forshaw; Apply parameters from HERA measurements using POMWIG



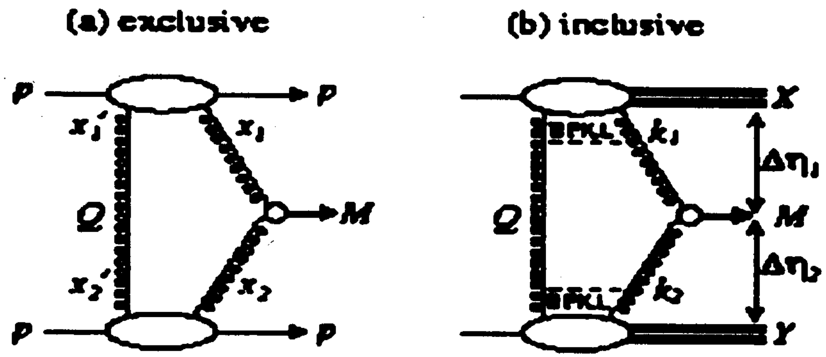
Non-factorizable:
Boonekamp, Peschanski, Royon; Convolute standard hadron-hadron cross section with parton distributions in pomeron (also has MC generator). Predictions scaled to CDF dijet measurement



Non-Pomeron Diffractive Higgs Models

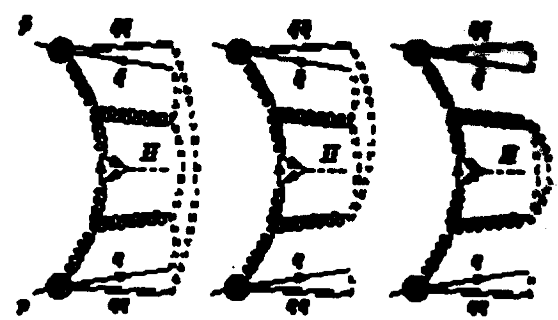
Proton-Based:

Khoze, Martin, Ryskin; Perturbative calculation using the gluon density in the proton (no pomeron). Exclusive events clean but rare.
Require rapidity gaps in final state. Currently no generator.



Soft Color Interactions:

Enberg, Ingelman, Timneanu
Variation of color string topologies gives
a unified description of final states
for diffracive and non-diffractive events



Diffractive Higgs Cross Sections

Cross Sections in fb^{-1} for 120 GeV Higgs mass

	SCI	Proton	Factorizable Pomeron	Non-Fact Pomeron
[illegible]	[illegible]	.03	0.3	2.2
[illegible]	.02	14	412	[illegible]

Predictions range over 4-5 orders of magnitude!

Detailed measurements of diffractive jet and photon production at Tevatron can distinguish between models

Conclusion

DØ

- Diffraction is a complex subject!
- **Much new experimental and theoretical work with promise of new more precise data to aid understanding**

Many open questions:

- Are the hard and soft Pomeron distinct objects?
- How to combine perturbative and non-perturbative concepts?
- How to extract unique parton distribution densities from HERA and Tevatron data?
- How to understand gap survival probability?
- Is there a particle-like pomeron?