Workshop on
Deep Inelastic Scattering and QCD
April 19-23, 1999
DESY Zeuthen

Hard Diffraction at CDF

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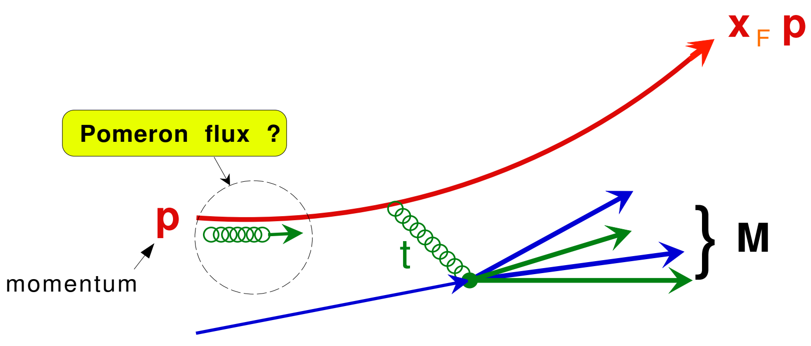
The Rockefeller University

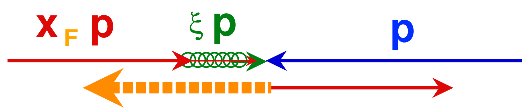
The CDF Collaboration

Contents:

Hard Diffractive Dissociation in $p\,\bar{p}$

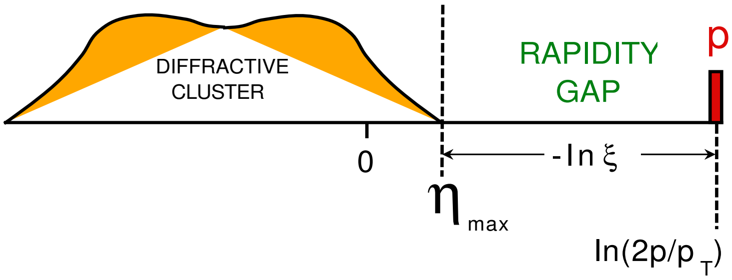
Diffraction Dissociation





$$\xi = 1 - x_F = M^2/s < 0.1$$

$$-\ln \xi > 2.3$$



Hard diffraction without a Pomeron:

study $x_{\bar{p}}$ distributions in single and non diffractive events.

Hard diffraction with a Pomeron:

assume factorization

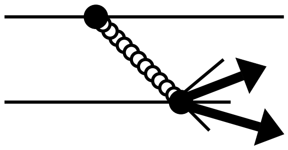
$$\frac{d\sigma(h\ p \to p + X)}{d\xi\ dt\ dx_1\ d\beta} = f_{I\!P/p}(\xi, t)\ \frac{d\sigma(h\ I\!P \to X)}{dx_1\ d\beta}$$

Pomeron flux: $f_{I\!P/p}(\xi, t) = \frac{9\ \beta_0^2}{4\ \pi^2}\ [F_1(t)]^2 (\frac{1}{\xi})^{2\ \alpha(t) - 1}$

(DL flux with CDF parameters β_0, ϵ, α')

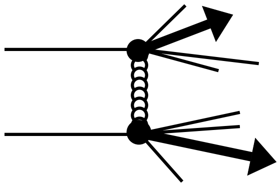
$$\frac{d\sigma(h\ I\!P \to X)}{dx_1\ d\beta} = f_{p1/h}(x_1, Q^2)\ f_{p2/I\!P}(\beta, Q^2)\ \ \frac{d\hat{\sigma}}{d\hat{t}}$$

CDF Studies on Diffraction with Rapidity Gaps



Forward Rapidity Gaps:

Diffractive W production PRL 78 (1997) 2698	$R_W\left(\frac{\mathrm{SD}}{\mathrm{ND}}\right) = (1.15 \pm 0.55)\%$
Diffractive dijets PRL 79 (1997) 2636	$R_{JJG}\left(\frac{\mathrm{SD}}{\mathrm{ND}}\right) = (0.75 \pm 0.10)\%$ $E_T^{jet} > 20$ GeV, $\eta^{jet} > 1.8$, $\eta_1 \cdot \eta_2 > 0$
Gluon fraction in $I\!\!P$	$\boxed{f_g = 0.7 \quad \pm 0.2}$
$I\!\!P$-flux discrepancy	$\boxed{D = 0.18 \pm 0.04}$
b-quark production Preliminary	$R_b\left(\frac{\mathrm{SD}}{\mathrm{ND}}\right) \times \mathcal{A} = [0.26 \pm 0.08(stat)]\%$ $\lvert\eta^e\rvert < 1.1$, $E_T^e > 9.5$ GeV $\mathcal{A} \approx 0.4 \ \ (2.4 \leq \lvert\eta^{\mathrm{gap}}\rvert \leq 5.9)$
J/ψ production Preliminary	$R_{J/psi}\left(\frac{\mathrm{SD}}{\mathrm{ND}}\right) \times \mathcal{A} = [0.64 \pm 0.12]\%$ $\lvert\eta^\mu\rvert < 0.6$, $p_T(\mu_1, \mu_2) > 2$ GeV



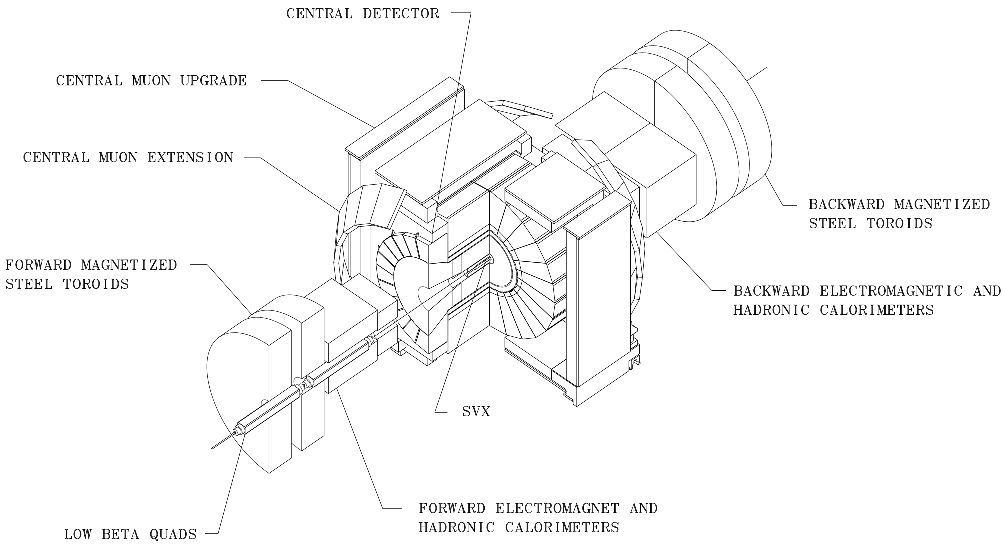
Central Rapidity Gaps:

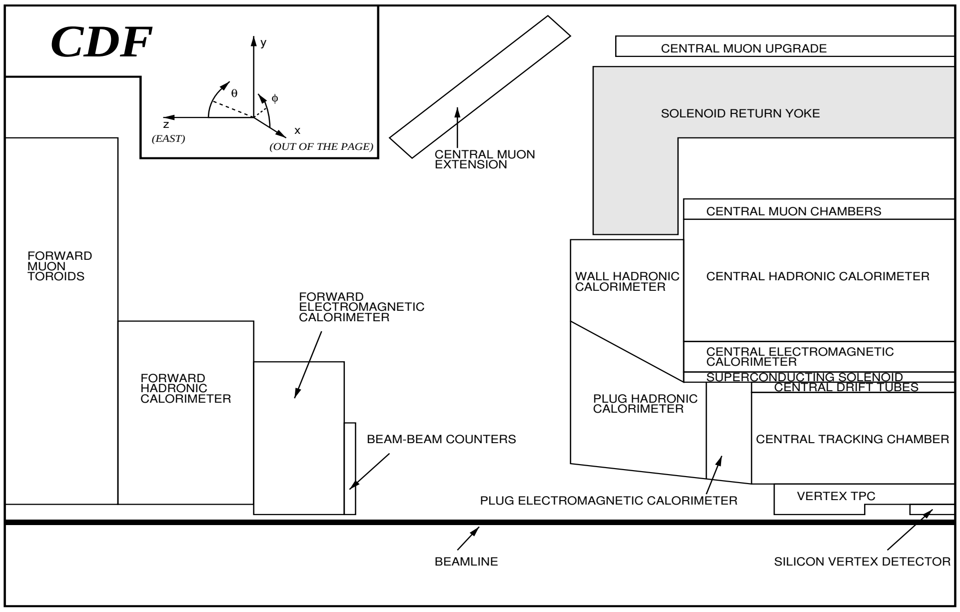
Jet-Gap-Jet events

$\sqrt{s} = 1800$ GeV PRL74(1995)855 PRL80(1998)1156	$R_{JGJ}\left(\frac{\mathrm{GAP}}{\mathrm{NO\!-\!GAP}}\right) = (1.13 \pm 0.16)\%$ $E_T^{jet} > 20$ GeV, $\eta^{jet} > 1.8$, $\eta_1 \cdot \eta_2 < 0$
$\sqrt{s} = 630$ GeV PRL 81 (1998) 5278	$R_{JGJ}(E_T^{jet} > 8$ GeV$) = (2.7 \pm 0.9)\%$ $R_{JGJ}(630/1800) = 2.4 \pm 0.9$

Soft Double Diffraction In progress

The CDF Detector

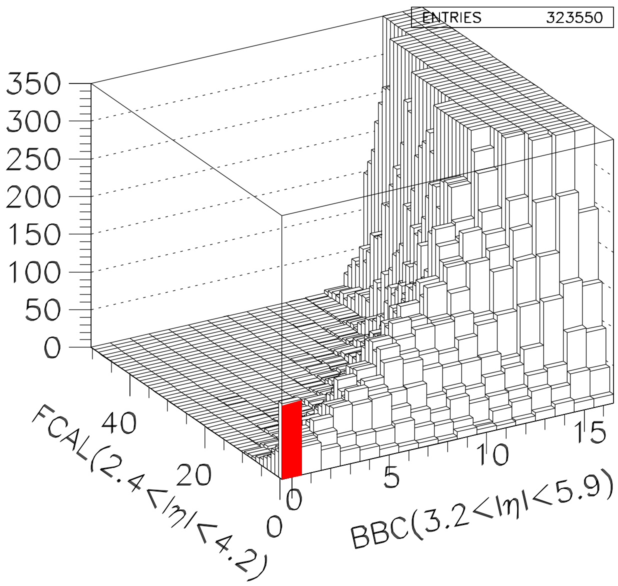


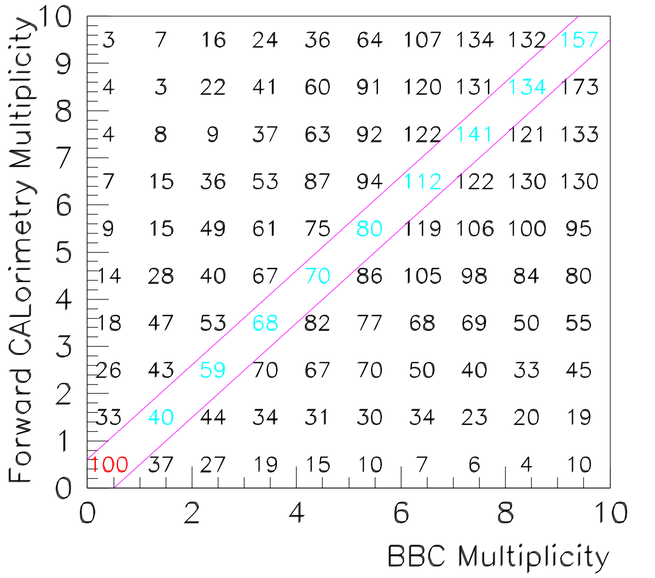


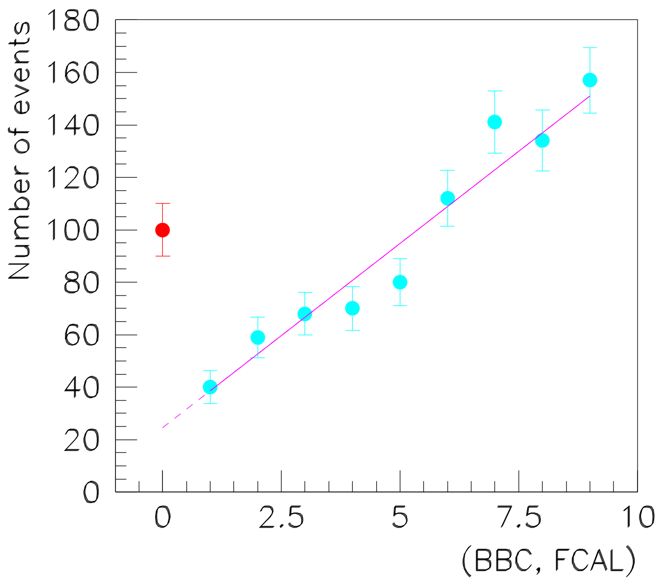
	FWD CALO	B B C
Coverage: Segmentation:	$2.4 < \|\eta\| < 4.2$ $\Delta\eta \times \Delta\phi$ $= 0.1 \times 5^\circ$	$3.2 < \|\eta\| < 5.9$ $X \times Y$: 8×8 scintillators

Diffractive Heavy Quark Production

CDF Preliminary







Diffractive/Non−Diffractive Ratio

$R_{bb} \times A = [0.26 \pm 0.08(\text{stat.})]\%$

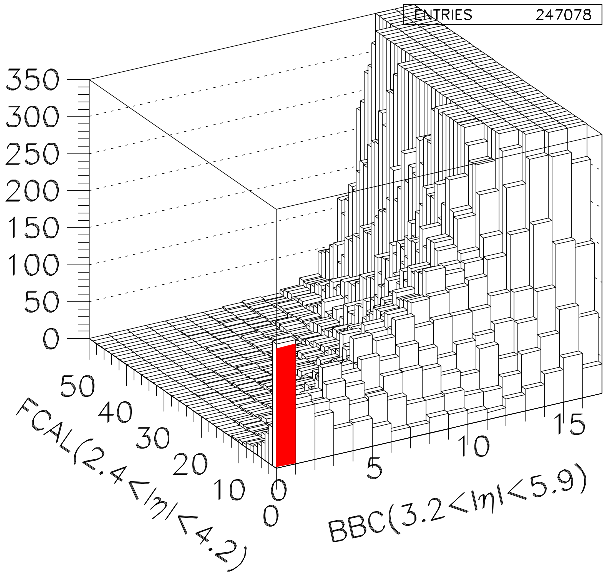
where A is the GAP Acceptance

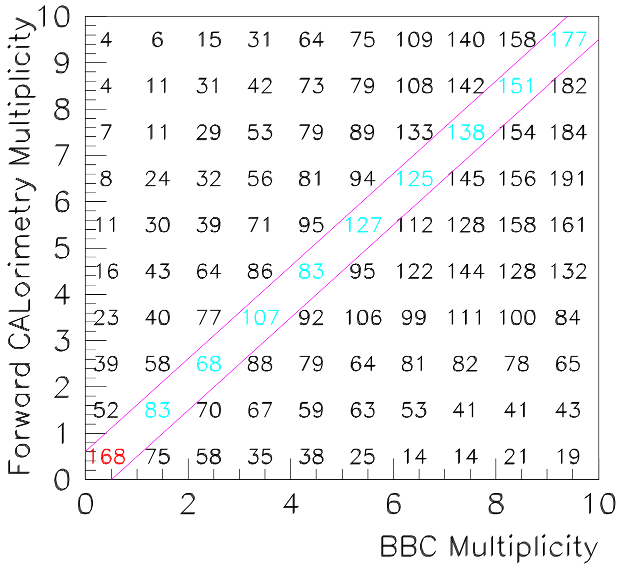
GAP definition:

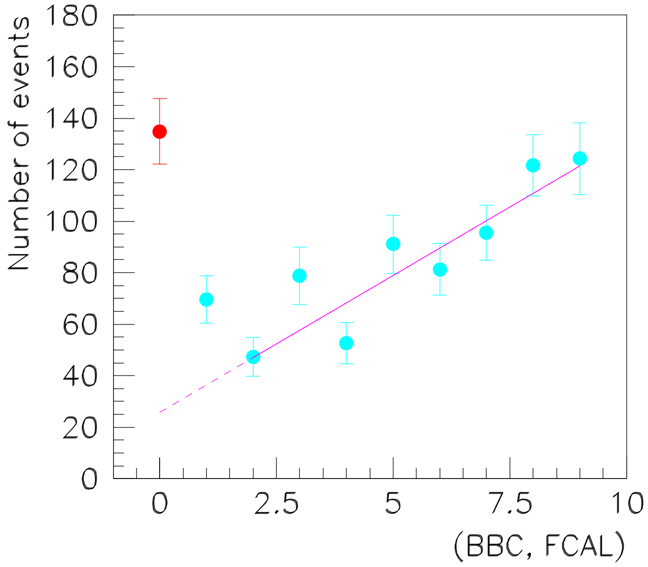
- $-5.9 \leqq \eta \leqq -3.2$ or $3.2 \leqq \eta \leqq 5.9$
  No charged particles
- $-4.2 \leqq \eta \leqq -2.4$ or $2.4 \leqq \eta \leqq 4.2$
  No charged or neutral particles of $E \geqq 1.5$GeV

Diffractive J/ψ Production

CDF Preliminary







Diffractive/Non–Diffractive Ratio

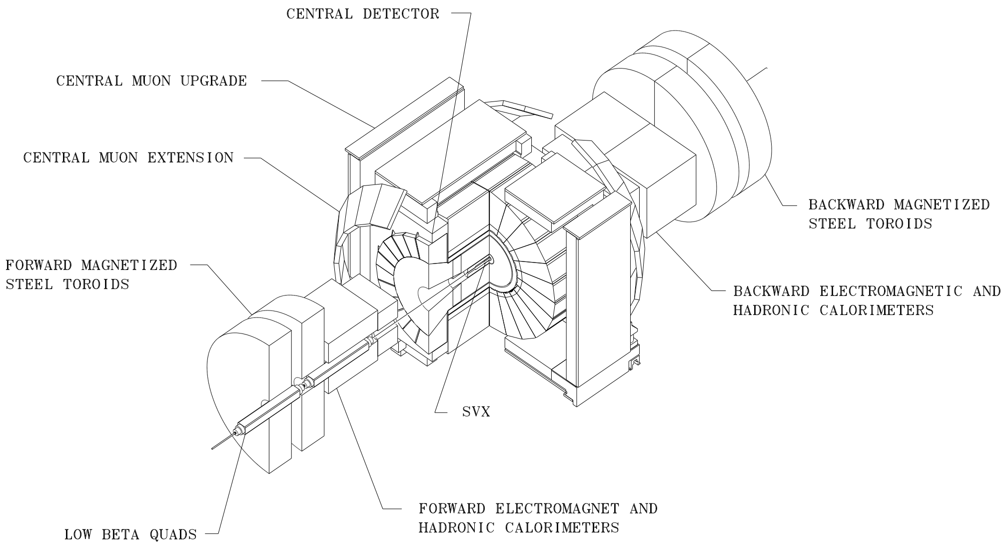
$R_{J/\psi} \times A = [0.64 \pm 0.10(\text{stat.})]\%$

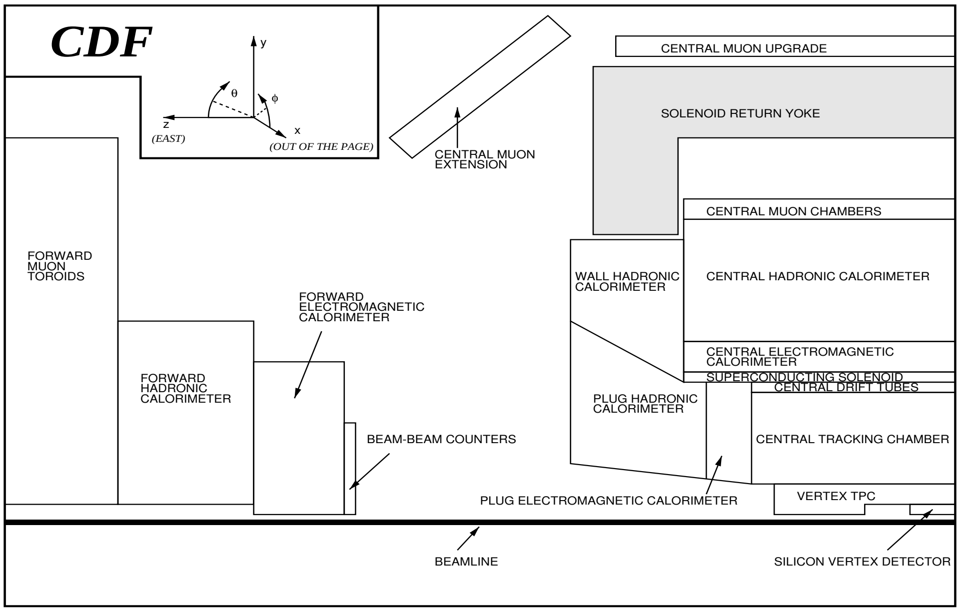
where A is the GAP Acceptance

GAP definition:

- $-5.9 \leqq \eta \leqq -3.2$ or $3.2 \leqq \eta \leqq 5.9$
  No charged particles
- $-4.2 \leqq \eta \leqq -2.4$ or $2.4 \leqq \eta \leqq 4.2$
  No charged or neutral particles of $E \geqq 1.5$GeV

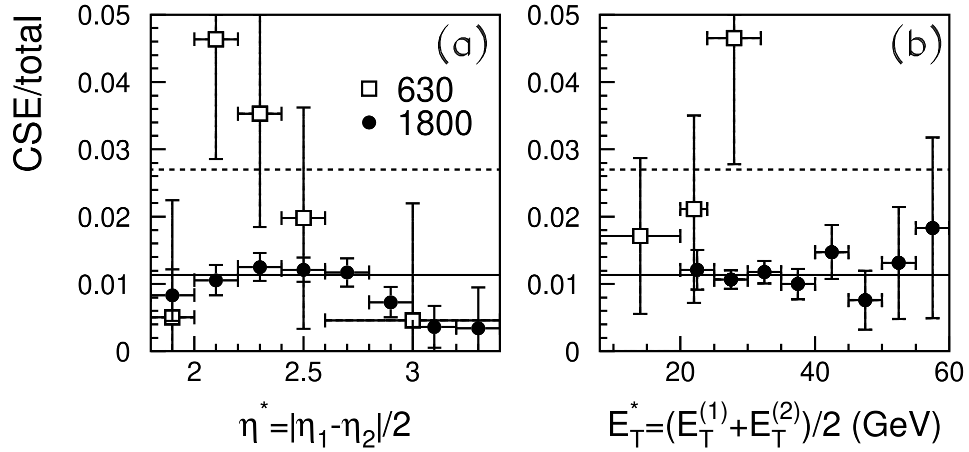
The CDF Detector



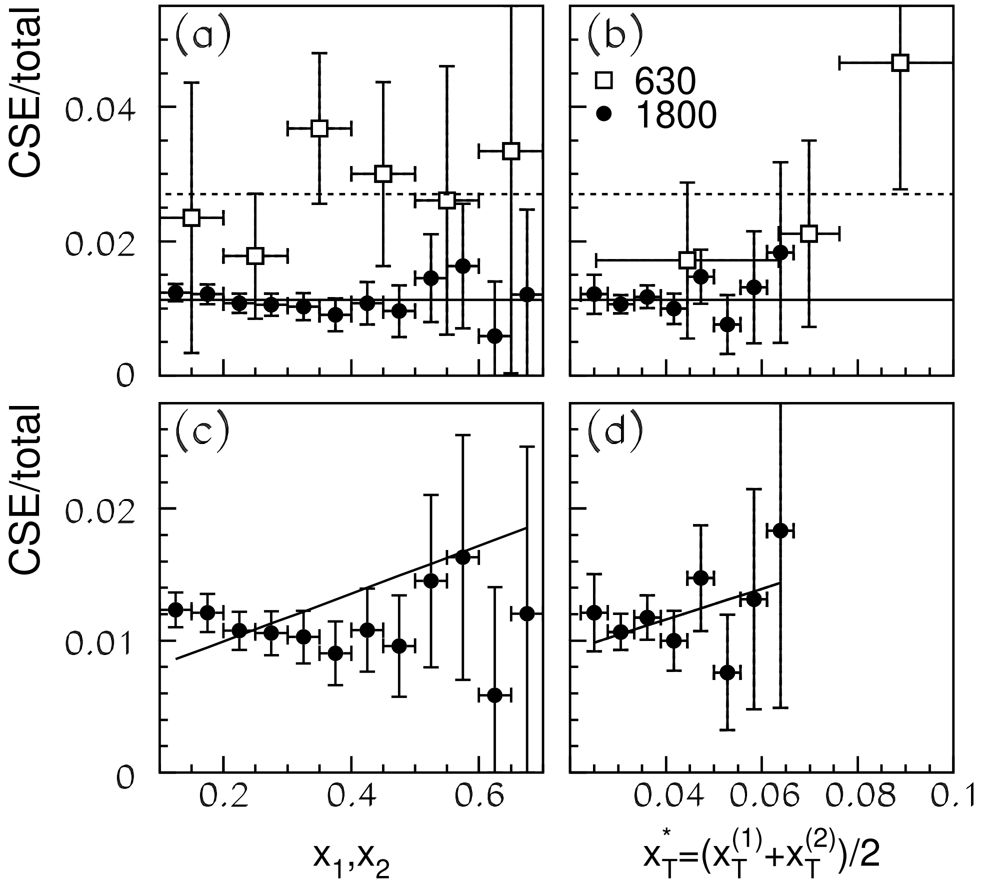


	Central Tracking	Central Calo
Coverage:	$\|\eta\| < 1.8$	$\|\eta\| < 1.1$
Cut:	$p_T > 300$ MeV	$E_T > 200$ MeV (corr. 300 MeV)

$\sqrt{s} = 630$ GeV and $\sqrt{s} = 1800$ GeV Central Gaps



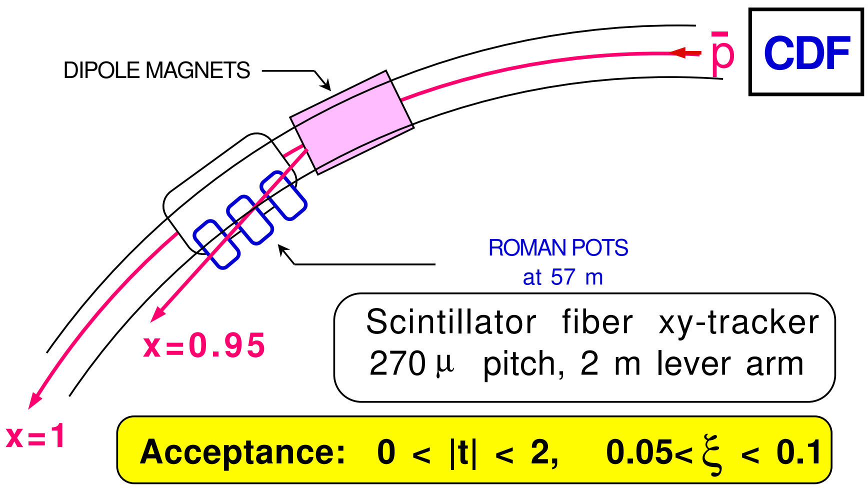
Ratio of color-singlet exchange to total number of events at 630 and 1800 GeV as a function of (a) half the pseudorapidity separation between the jets and (b) the average transverse energy of the jets. The solid (dashed) lines represent the average ratio R_{1800} (R_{630}).



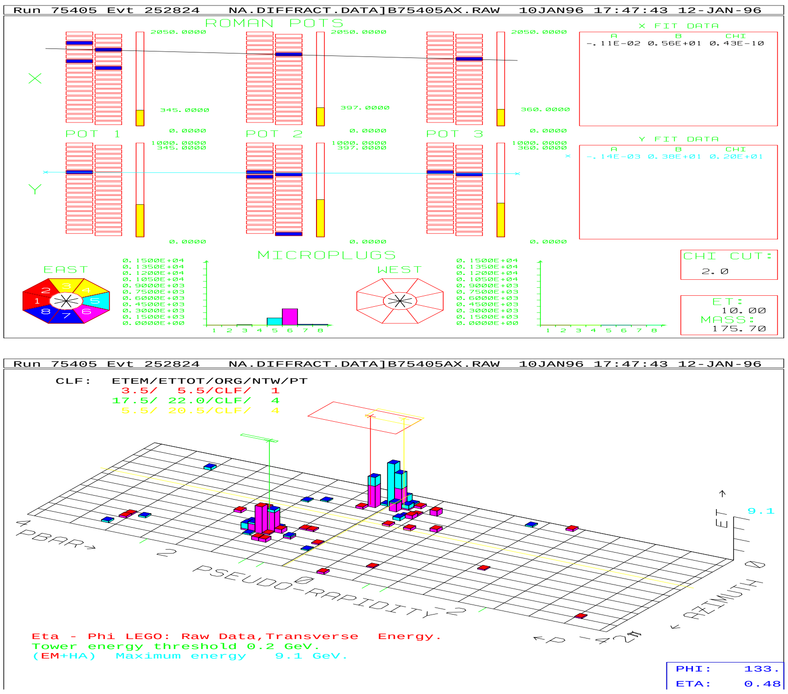
Ratio as function of (a,c) x, the ratio of the jet momentum along the beam to the momentum of the beam (two entries per event) and (b,d) x_T^*, the average scaled transverse energy of the two jets. The solid (dashed) lines in (a,b) are the average ratio R_{1800} (R_{630}). The solid lines in (c,d) are the distributions of the fraction of CE dijet events due to quark-(anti)quark scattering to all CE dijet events produced by a HERWIG Monte Carlo simulation, including the CDF detector. The normalization of the Monte Carlo result was adjusted to yield the best fit to the data.

Dijets in Roman Pot Data

Roman Pots at CDF:

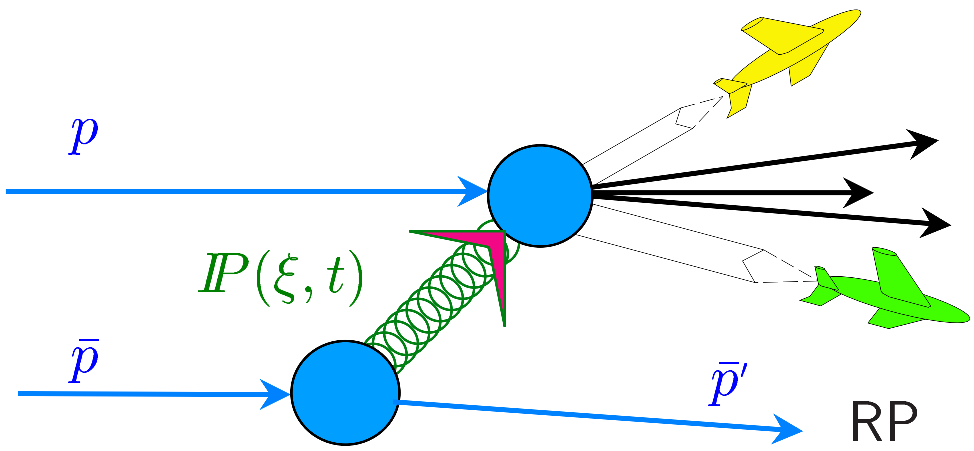


Dijet Event with Roman Pot Track:



Study single and double pomeron exchange.

What are we looking for ?



Dijets $\Longrightarrow$ hard interaction on the parton level

We measure:

with the dijets: $x_{\bar{p}} = \frac{E_T^{jet_1} \cdot e^{-\eta_1} + E_T^{jet_2} \cdot e^{-\eta_2}}{2 \cdot p_{beam}}$

with the Roman Pots: $\xi = p_{I\!P}/p_{\bar{p}}$
and the dijets: $\beta = p_{g,q}/p_{I\!P} = x_{\bar{p}}/\xi$

$\Rightarrow$

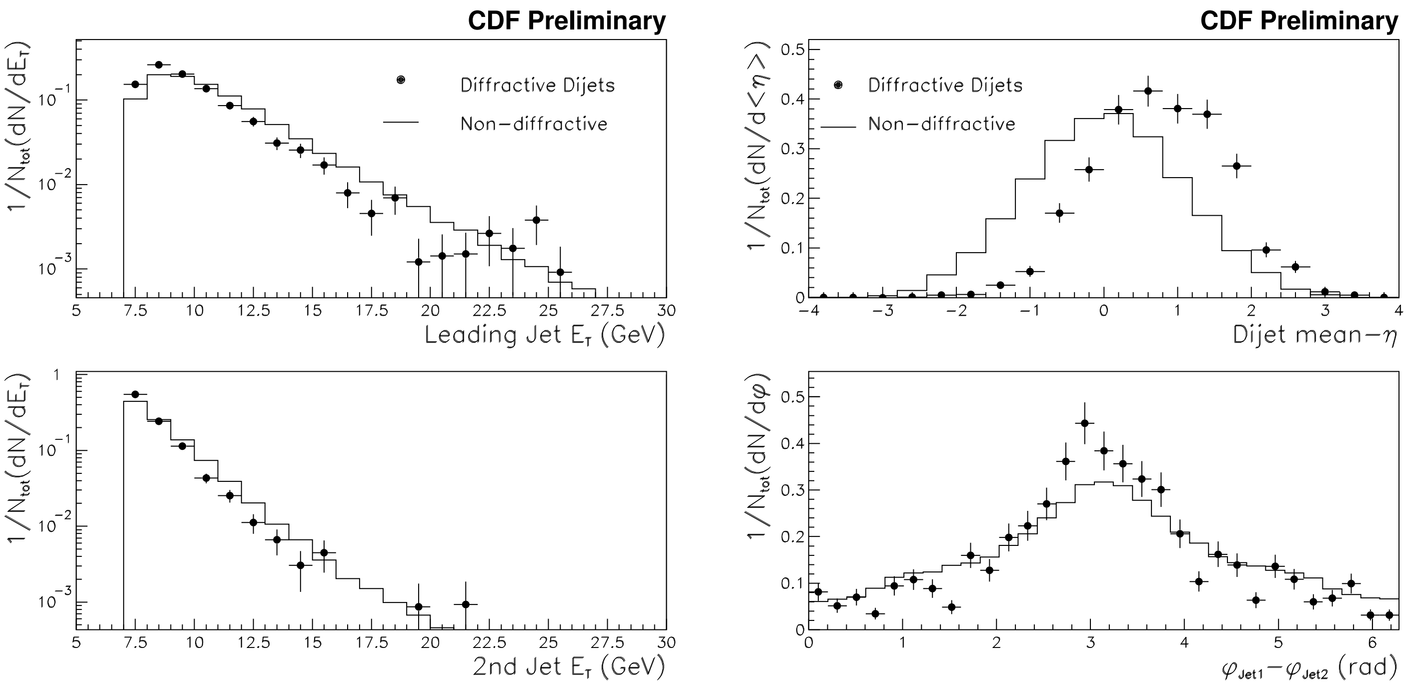
- **Shape of $x_{\bar{p}}$ distribution:** diffractive structure function
- **Shape of β distribution:** structure of the pomeron
- **Rate:** depends on pomeron flux factor
  (a) Standard flux: Regge picture with factorization
  (b) Renormalized flux: one pomeron per proton

$\Rightarrow$ Various comparisons possible:
$\sqrt{s} = 630$ GeV, $\sqrt{s} = 1800$ GeV, HERA and UA8 results.

Comparison between Diffractive and Non-diffractive Dijets

$0.04 \leq \xi \leq 0.10$ $|t| \leq 0.2$ GeV^2 $\sqrt{s} = 630$ GeV

$E_T \geq 7$ GeV (stat. err. only)



Study of the Diffractive Structure Function

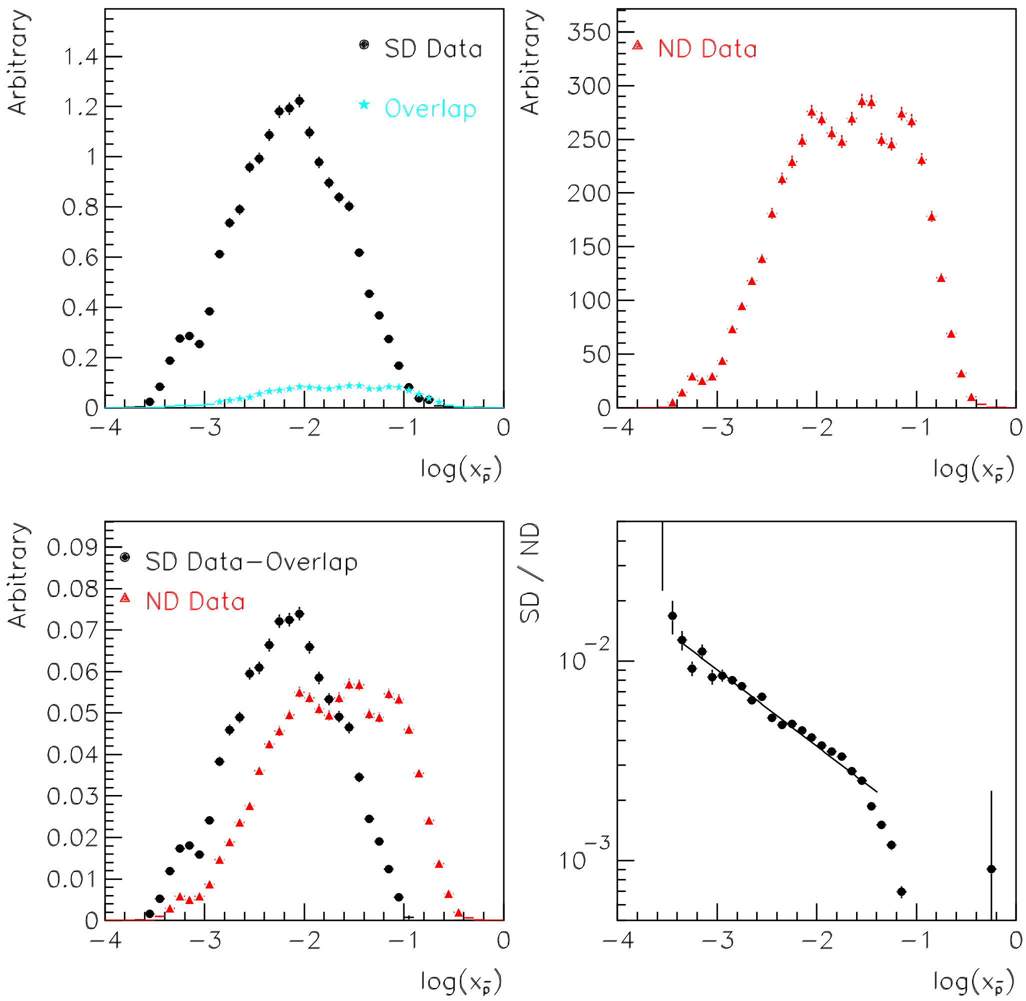
Diffr. and non–diffr. Ratio as function of $x_{\bar{p}}$

$0.04 < \xi < 0.1 \quad -1.0 < t < t_{min} \quad \sqrt{s} = 1800$ GeV

(stat. err. only)

$E_T^{jet} \geq 7$ GeV

CDF PRELIMINARY

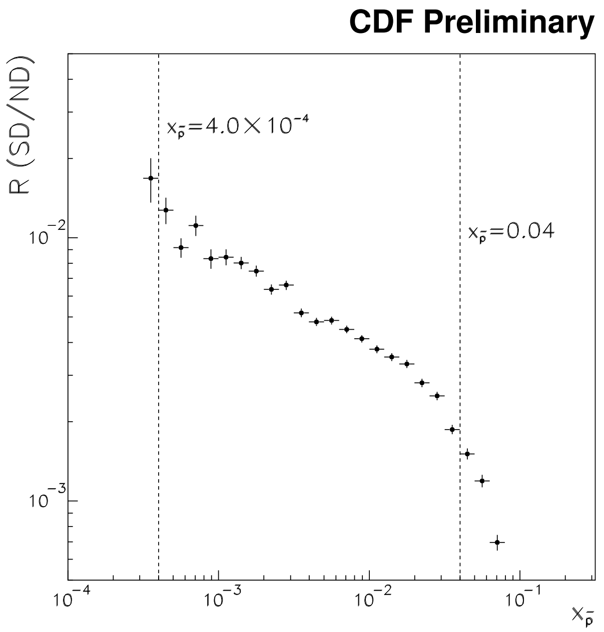


Ratio of diffractive to non-diffractive dijet cross section increases as $x_{\bar{p}}$ decreases.

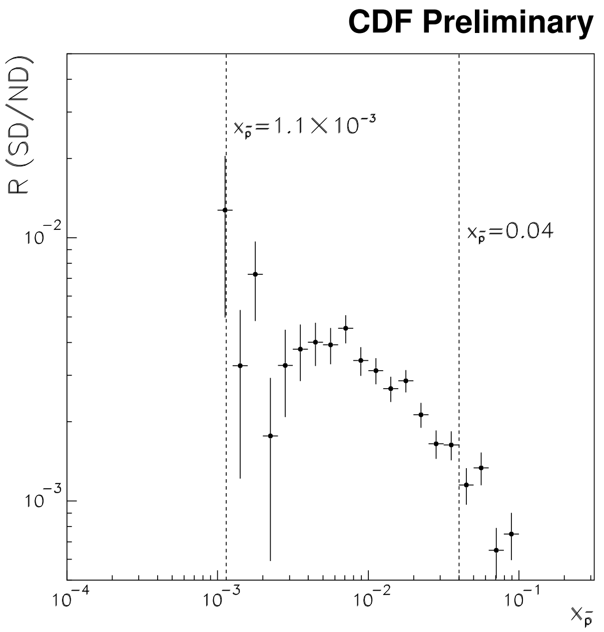
Diff to Non-diff Ratio as a function of $x_{\bar{p}}$

$$x_{\bar{p}} = \frac{E_T^{jet1} \cdot e^{-\eta_1} + E_T^{jet2} \cdot e^{-\eta_2}}{2 \cdot p_0^{\bar{p}}}$$

$0.04 < \xi < 0.1$ $|t| < 1.0$ GeV^2 $\sqrt{s} = 1800$ GeV
$E_T \geq 7$ GeV (stat. err. only)



$0.04 < \xi < 0.1$ $|t| < 0.2$ GeV^2 $\sqrt{s} = 630$ GeV
$E_T \geq 7$ GeV (stat. err. only)

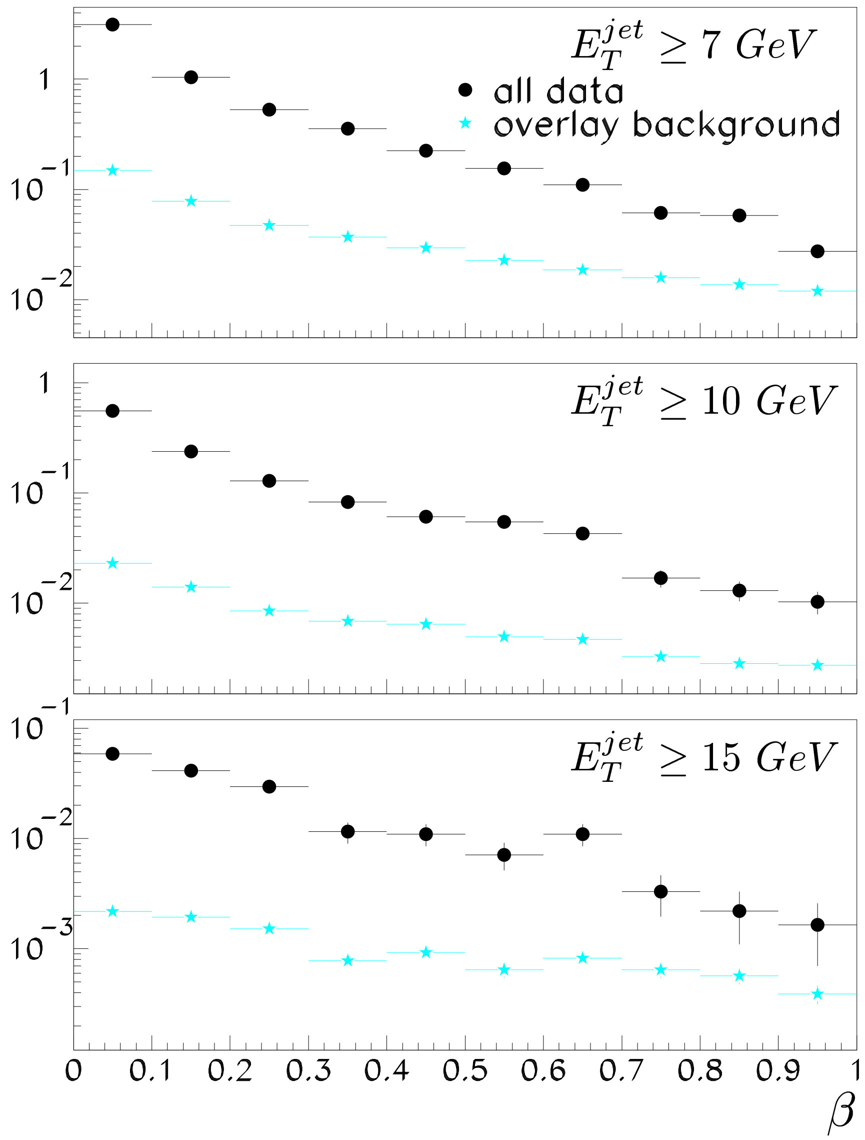


β from Data and Overlay Background

Roman Pot Dijet Data

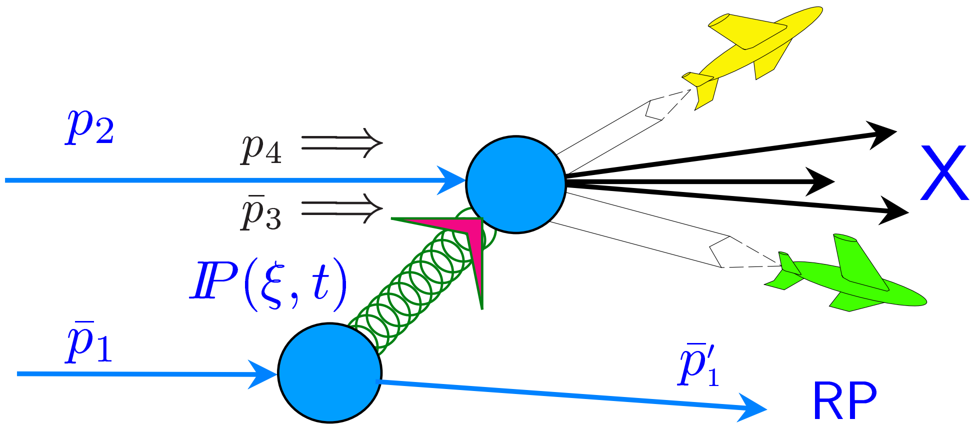
$0.05 < \xi < 0.1 \quad -1.0 < t < t_{min} \quad \sqrt{s} = 1800$ GeV
(stat. err. only)

arbitrary scale **CDF PRELIMINARY**



uncorrected β distributions

Overlay (pile–up) Background



Overlay of a soft diffractive event without jets, $\bar{p}_1 + p_2 \rightarrow \bar{p}'_1 + X$, with a non–diffractive dijet event, $\bar{p}_3 + p_4 \rightarrow$ jets.

$\Rightarrow$

- Select a dijet event from the minimum bias inclusive data sample.
- Choose a ξ value randomly within 0.05$\leq \xi \leq$0.1.
- Evaluate β assuming a single diffractive event.
- Subtract the obtained β distribution normalized to the amount of non–diffractive background.

What do we expect to measure ?

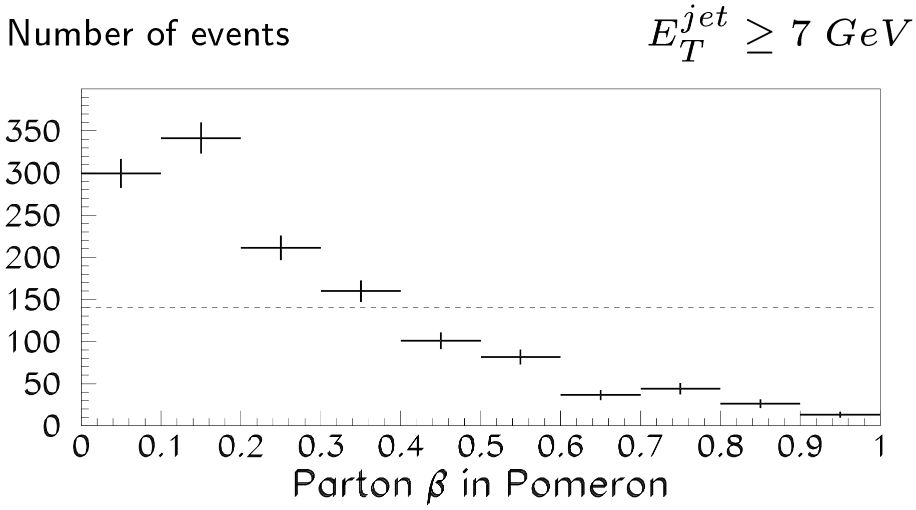
Detector acceptance depends on β, ξ and E_T^{jet}:

approximately: $\eta_{jet} \geq ln(\frac{E_T^{jet}}{2 \cdot \beta \cdot \xi \cdot p_{beam}})$

in addition cross section dependencies from E_T^{jet}...

$\Longrightarrow$ Use a pomeron structure which is flat in β.
Generate events with POMPYT2.6.
Simulate the detector for the generated events.
Divide data β distribution with reconstructed flat gluon MC distribution.

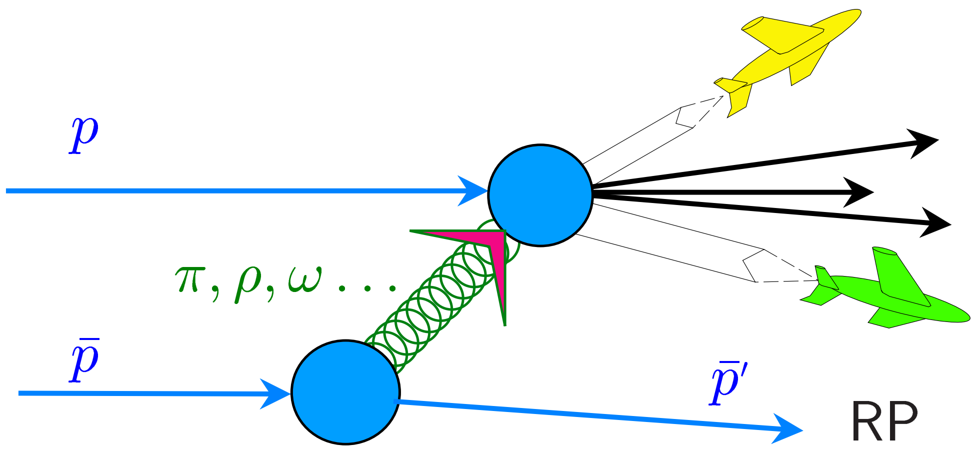
β reconstructed from a flat gluon $I\!P$:



$$\beta_{I\!P} = \frac{\text{data}}{\text{flat gluon} I\!P (reconstructed)}$$

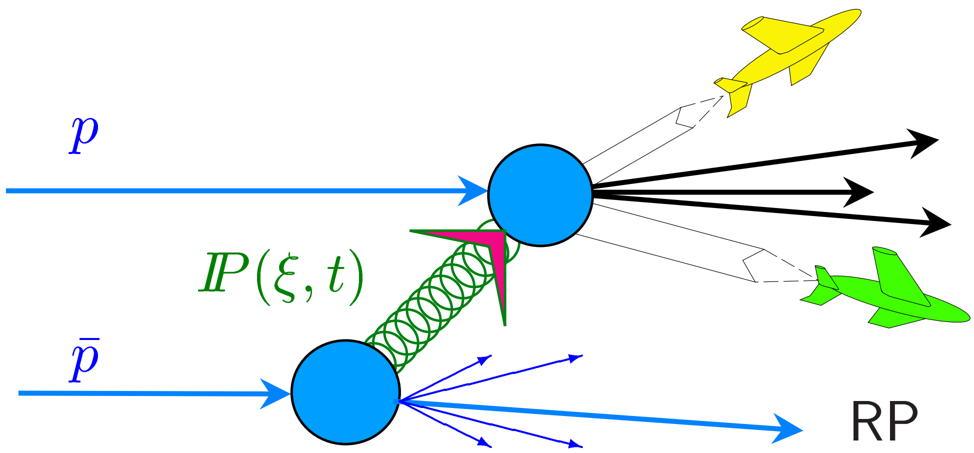
Background Contributions from Physics Processes

a) Meson Exchange



Instead of a pomeron a π, ρ, $\omega \cdots$ is exchanged
$\Rightarrow$ POMPYT with effective meson flux and π structure.

b) Double Diffractive Dissociation



The recoil $\bar{p}$ dissociates and one of the dissociation products gives a track in the Roman Pots
$\Rightarrow$ POMPYT simulations with the chosen pomeron structure and ξ from double diffractive dissociation.

Effective Meson Contribution

(K. Goulianos, J. Montanha in hep-ph/9805496)

Cross sections $d^2\sigma_{sd}/d\xi dt$ at $t = -0.05$ GeV^2

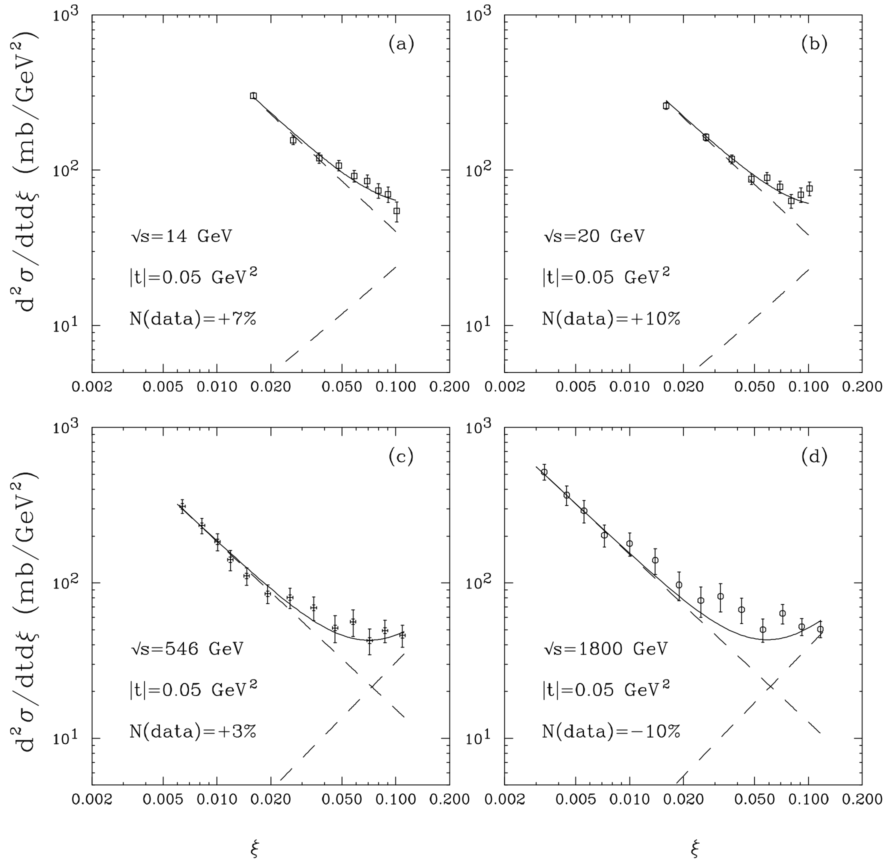


Figure 10 : Cross sections $d^2\sigma_{sd}/d\xi dt$ for $p + p(\bar{p}) \to p(\bar{p}) + X$ at $t = -0.05$ GeV^2 and $\sqrt{s} = 14$, 20, 546 and 1800 GeV are compared with the results (solid lines) of a simultaneous one parameter fit with a renormalized $I\!\!P I\!\!P I\!\!P$ amplitude and a pion exchange contribution. The dashed lines represent the individual pomeron and pion contributions. To account for systematic uncertainties, the normalization of each data set was allowed to vary within $\pm 10\%$ of its nominal value; the parameter "N(data)" represents the shift in the data normalization for which the best fit was obtained.

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Fits with a $I\!\!P$ and an effective π component.

Reconstructed β and Background Contributions

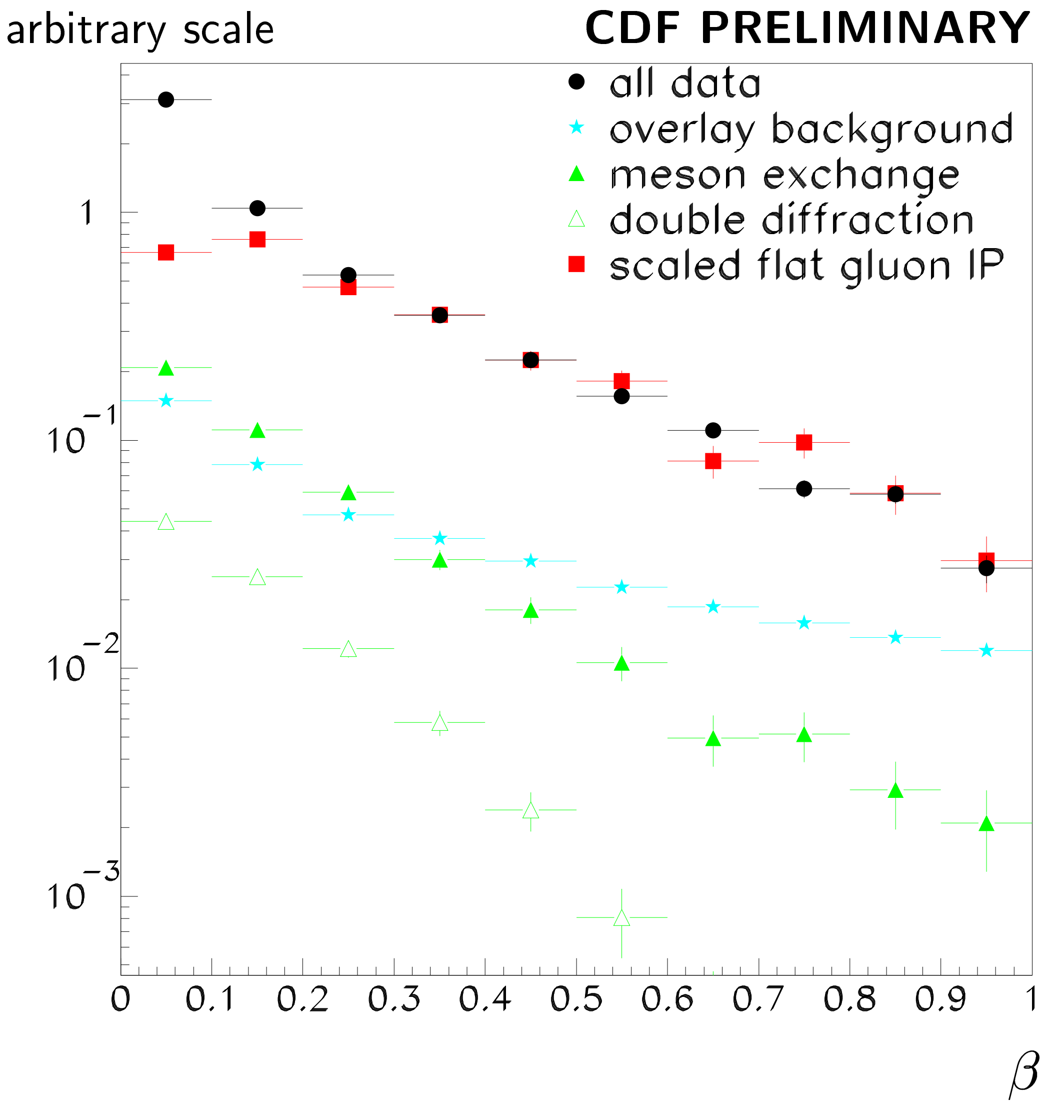
Roman Pot Dijet Data

Diffractive and non–diffractive contributions

$0.05 < \xi < 0.1 \quad -1.0 < t < t_{min} \qquad \sqrt{s} = 1800$ GeV

(stat. err. only)

$E_T^{jet} \geq 7$ GeV

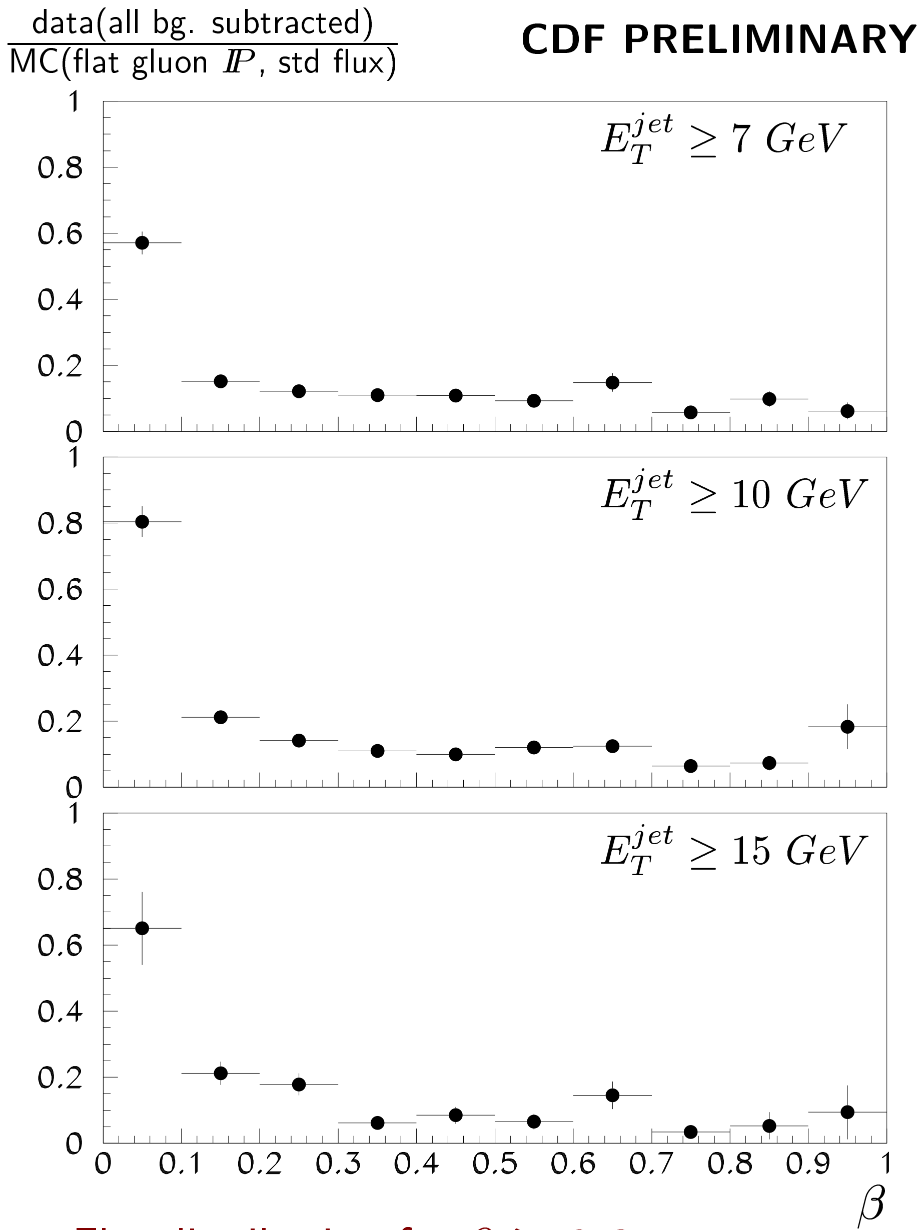


Demonstration of the detector acceptance:
flat gluon $I\!P$ simulations with standard flux scaled to the data value at $\beta = 0.45$.

Corrected $\beta_{I\!P}$ After Background Subtraction

Ratio Data(all bg. subtr.) to MC simulations using a flat gluon $I\!P$ and a standard flux

$0.05 < \xi < 0.1 \quad -1.0 < t < t_{min} \quad \sqrt{s} = 1800$ GeV (stat. err. only)



- Shape: Flat distribution for $\beta \geq 0.2$.
  Rising behavior for $\beta < 0.2$.
- Rate: Discrepancy from standard flux prediction for $\beta \geq 0.2$ agrees with previous CDF result $D = 0.18 \pm 0.04$.

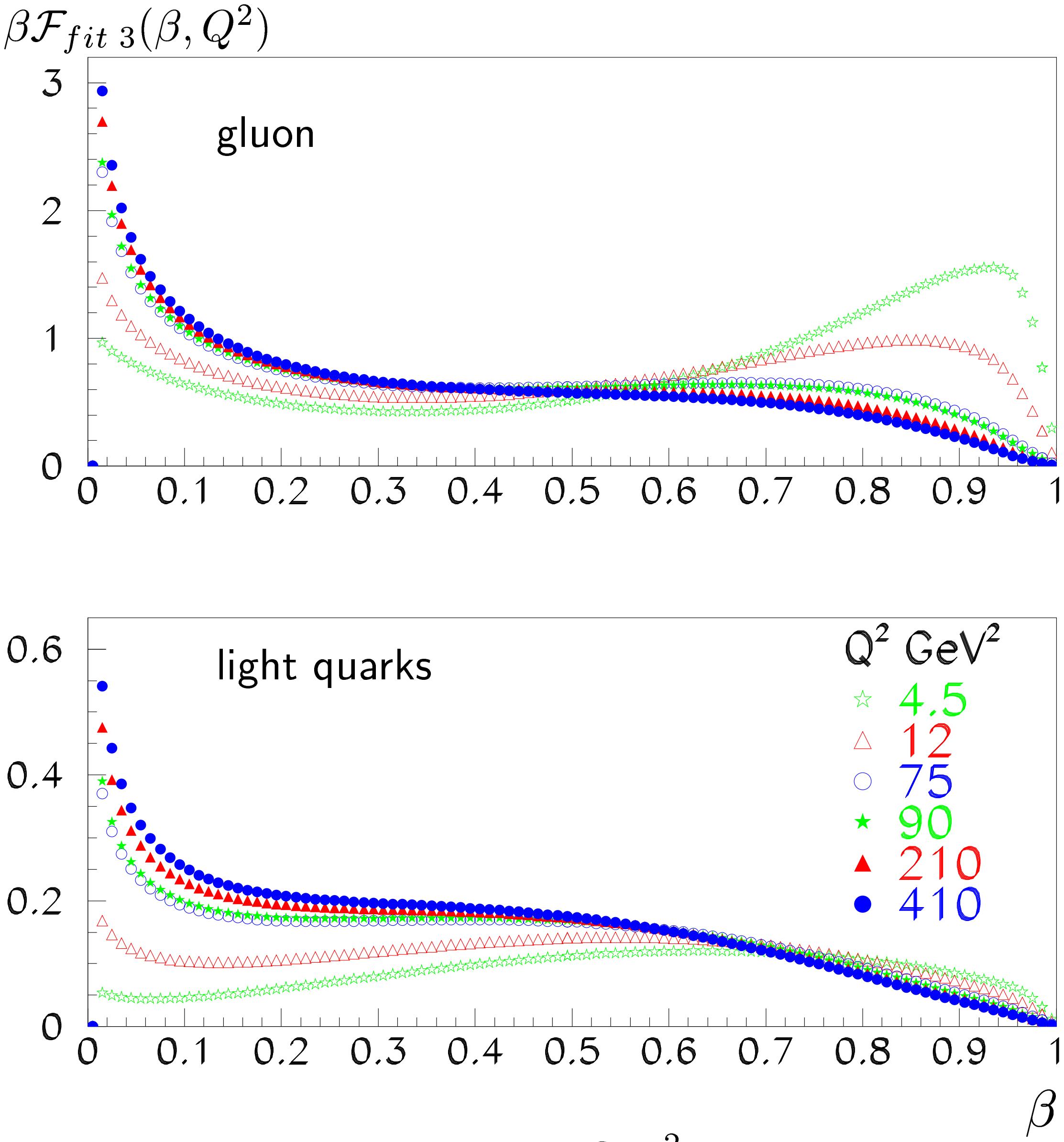
H1 Measurements

(Z.Phys.C363(1997)613)

Diffractive Structure Function from H1

$$\mathcal{F}^{D(3)}(\xi,\beta,Q^2) = f_{I\!P/p}(\xi)\ \ \mathcal{F}_{fit\ 3}(\beta,Q^2)$$

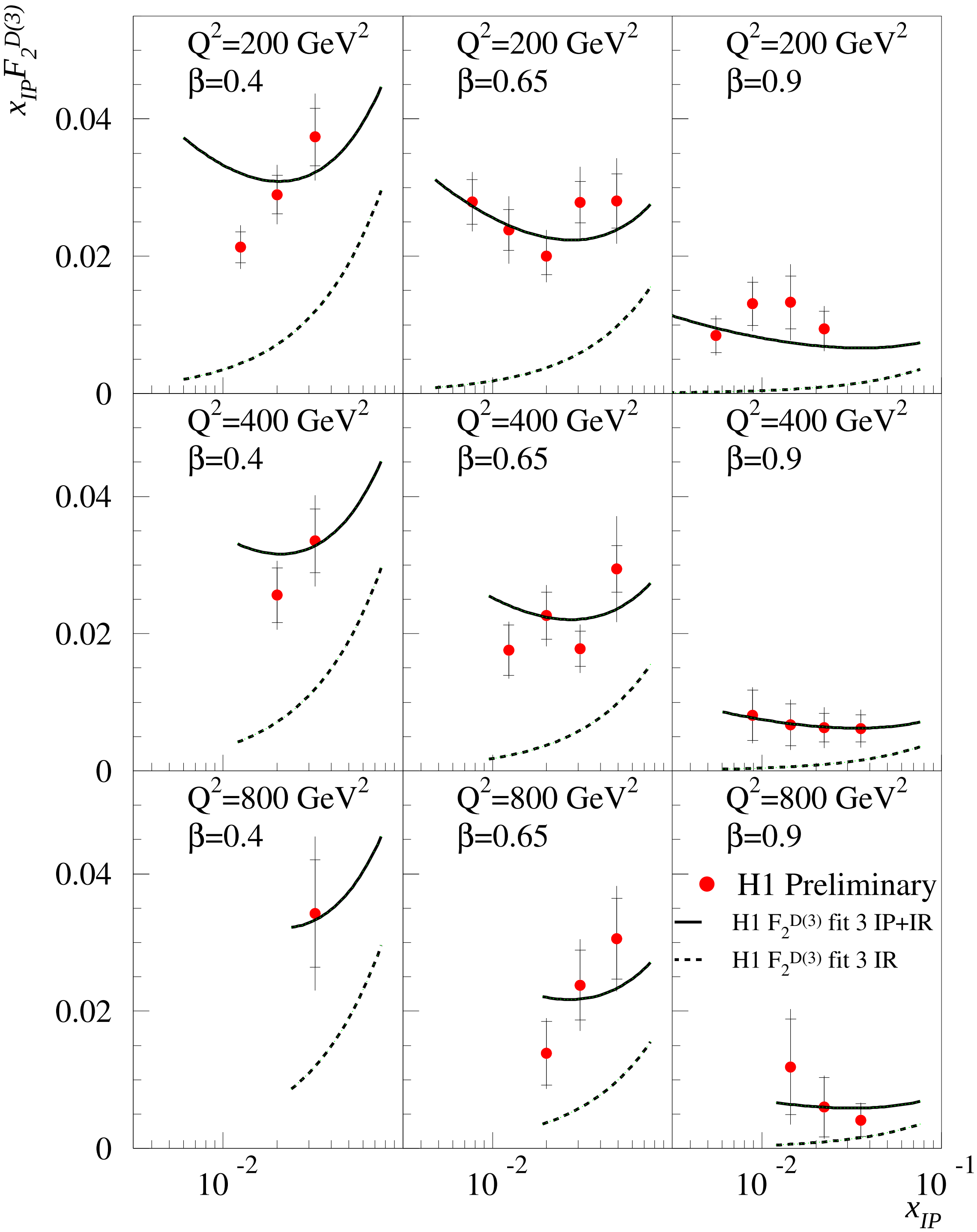
$$f_{I\!P/p} = \int_{t_{cut}}^{t_{min}} \frac{\exp(B_{I\!P}\ t)}{\xi^{2\alpha_{I\!P}(t)-1}}\, dt, \qquad \begin{array}{l} B_{I\!P} = 4.6\ \mathrm{GeV}^{-2} \\ \alpha_{I\!P}(0) = 1.20 \\ \alpha'_{I\!P} = 0.26\ \mathrm{GeV}^{-2} \end{array}$$



Q^2 range in the publication: up to $75\mathrm{GeV}^2$.
Higher Q^2 values: obtained with further evolution done by the H1 Collaboration.

H1 Measurements

(ICHEP '98, Abstract 571)



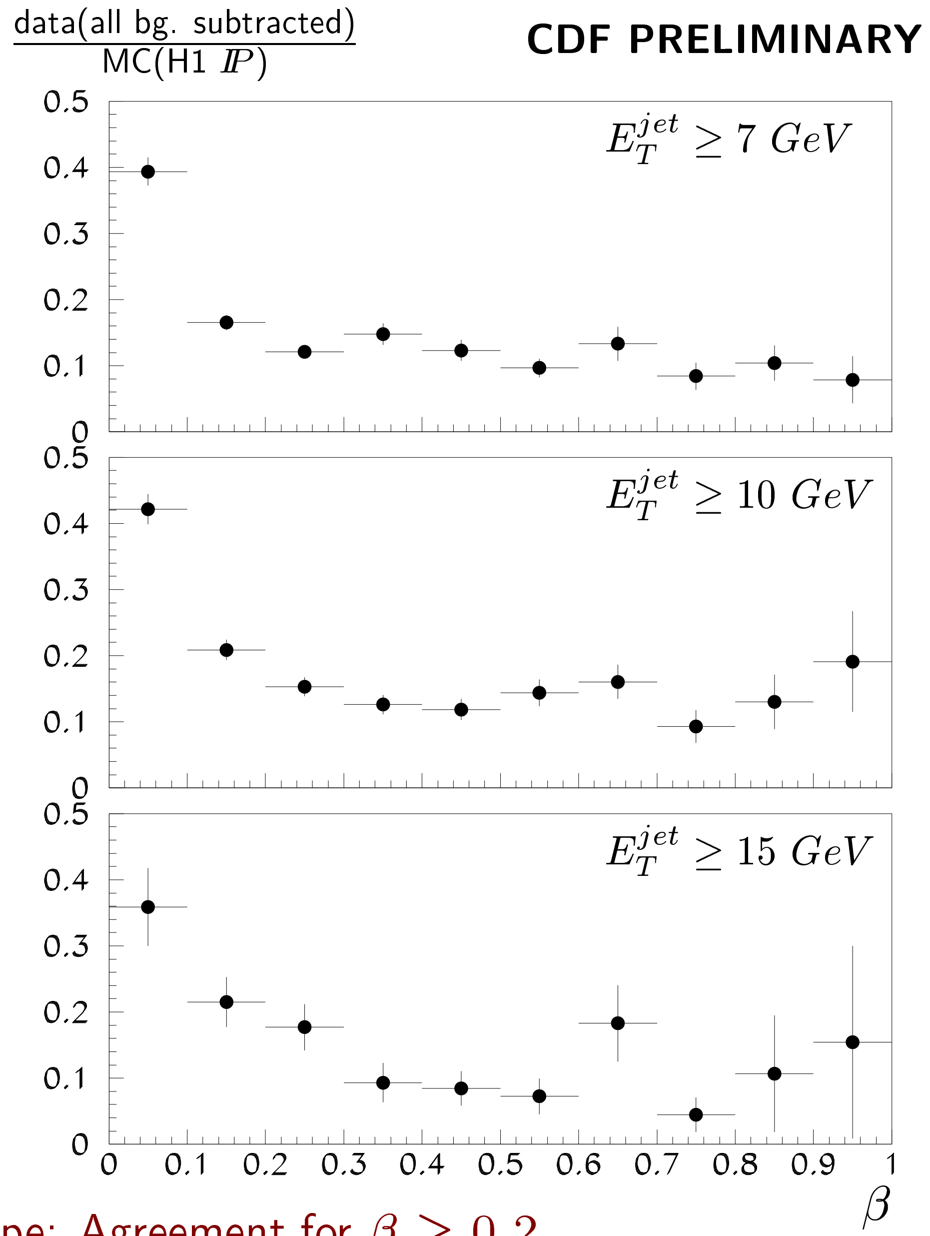
H1 measurements for high Q^2 values in agreement with the further evolved fit.

No measurement for low β at higher Q^2.

Comparison with H1 Measurements

Ratio Data(all bg. subtr.) to MC using
the H1 Fit 3 of the diffractive structure function

$0.05 < \xi < 0.1 \quad -1.0 < t < t_{min} \quad \sqrt{s} = 1800$ GeV
(stat. err. only)



- Shape: Agreement for $\beta \geq 0.2$.
  Enhancement for $\beta < 0.2$ decreased, but still there.
- Rate: Discrepancy from standard flux prediction
  for $\beta \geq 0.2$ agrees with previous CDF result
  $D = 0.18 \pm 0.04$.

The Renormalized $I\!\!P$ Flux

(K. Goulianos in Phys.Lett.B358(1995)379; Phys.Lett.B363(1995)268 and DIS'97, AIP Conference Proceedings,pp527, Chicago, 1997)

Main assumption:

The total probability for having a diffractive rapidity gap is normalized to 1.

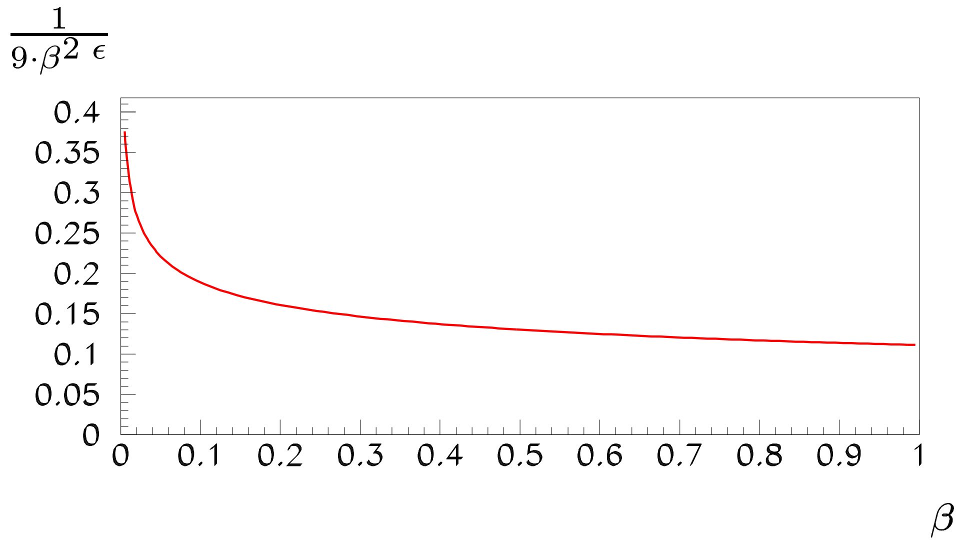
$\Rightarrow$ there is only one $I\!\!P$ per interaction emitted !

$\Rightarrow$ Standard $I\!\!P$ Flux has to be renormalized:

$$\int_{\xi_{min}}^{0.1} f_{I\!\!P/p} = 1 \qquad \xi_{min} \approx \frac{M_0^2}{s \cdot \beta}$$

for $\sqrt{s} = 1800$ GeV: $\frac{1}{9{\cdot}\beta^{2\ \epsilon}}$

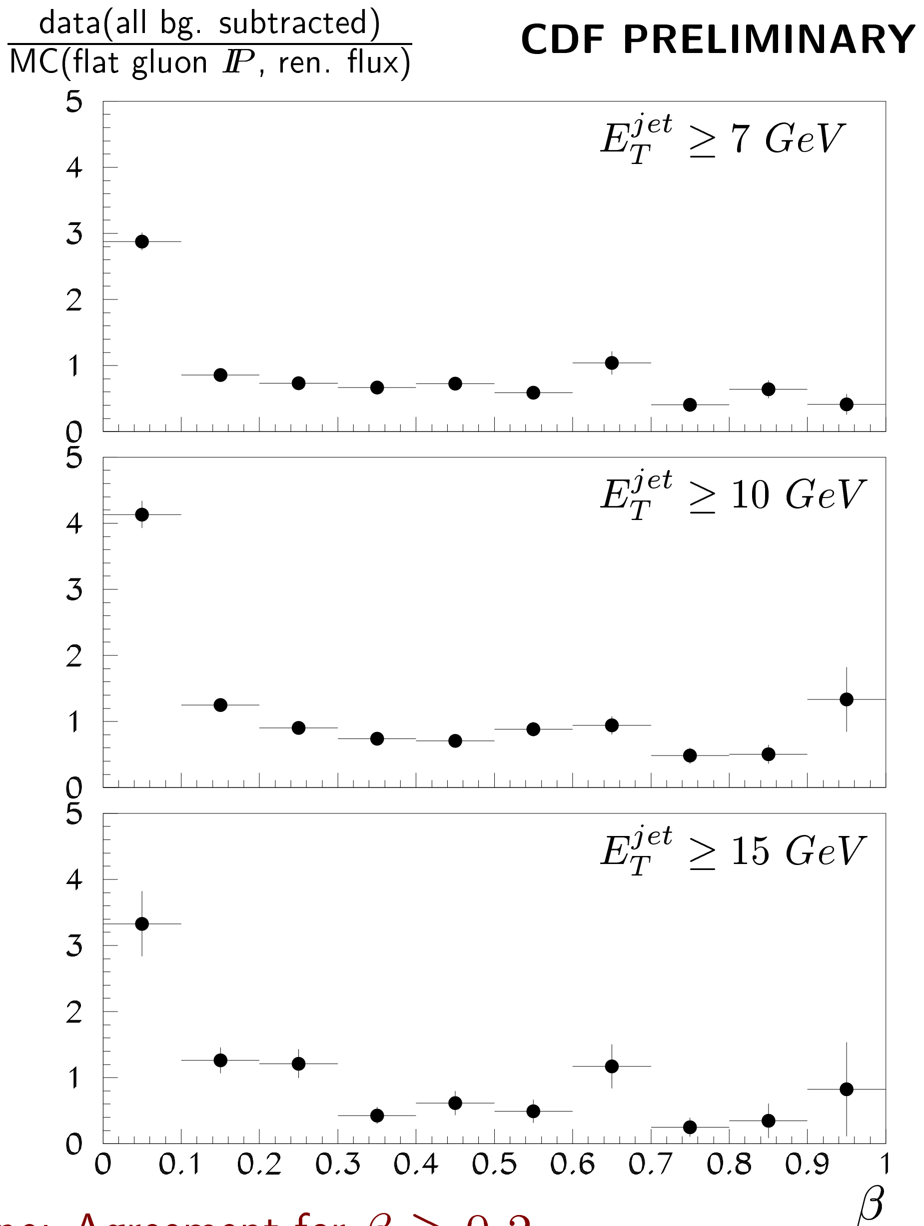
$\Rightarrow$ A flat parton distribution in the pomeron results in a measured β distribution with a soft component:



Comparison with the Renormalized $I\!P$ Flux

Ratio Data(all bg. subtr.) to MC simulations
using a flat gluon $I\!P$ and the renormalized flux

$0.05 < \xi < 0.1 \quad -1.0 < t < t_{min} \qquad \sqrt{s} = 1800$ GeV
(stat. err. only)



- Shape: Agreement for $\beta \geq 0.2$.
  Enhancement for $\beta < 0.2$ decreased, but still there.
- Rate: Agreement with renormalized flux prediction,
  for $\beta \geq 0.2$ ratio agrees with expectations (≈ 0.85)
  from the previous CDF result of $f_g = 0.7 \pm 0.2$.

Dijet Kinematics

Roman Pot Dijet Data

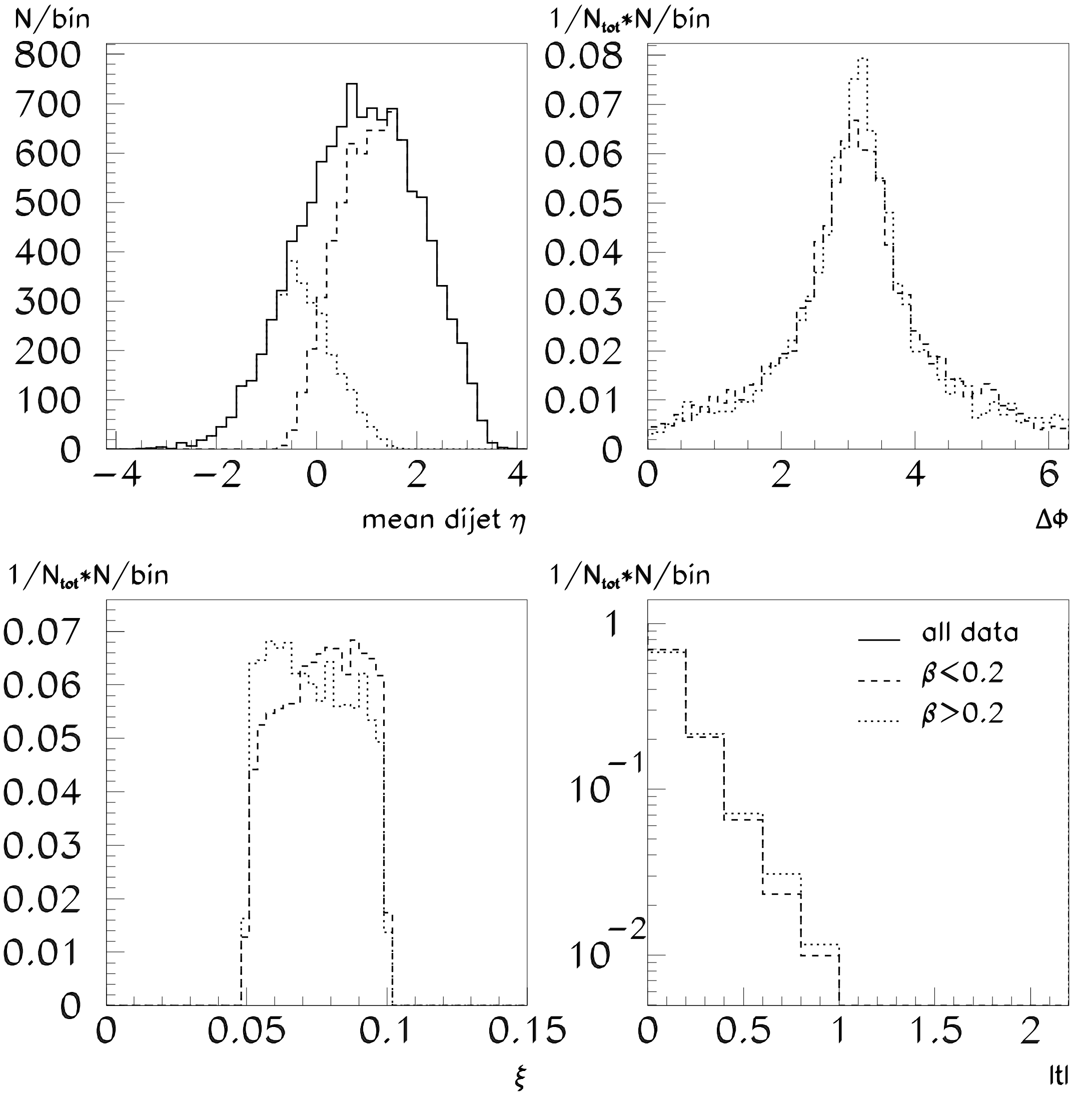
Comparison between low and high β events

$0.05 < \xi < 0.1 \quad -1.0 < t < t_{min} \qquad \sqrt{s} = 1800$ GeV

(stat. err. only)

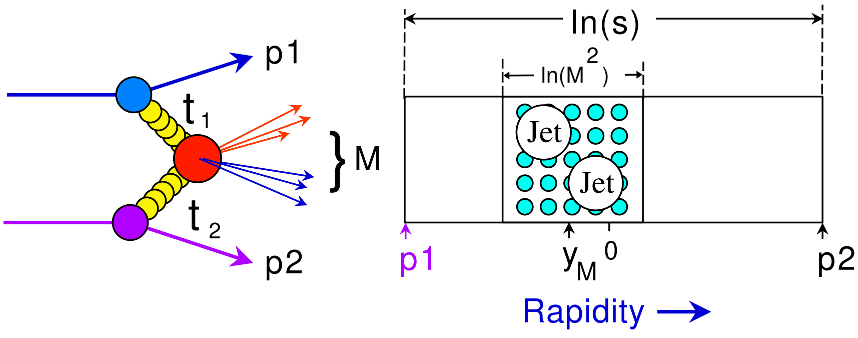
$E_T^{jet} \geq 7$ GeV

CDF PRELIMINARY



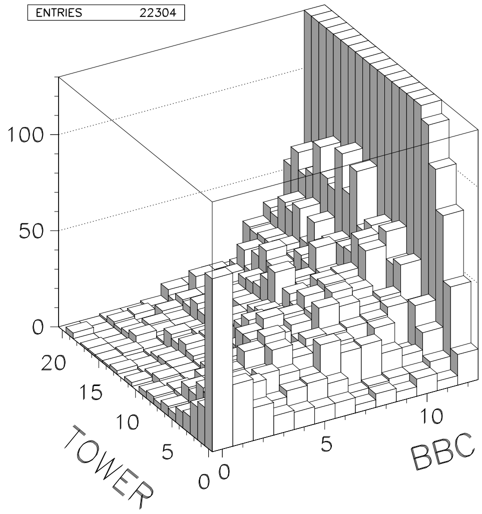
Observed differences can be reproduced by pure kinematics.

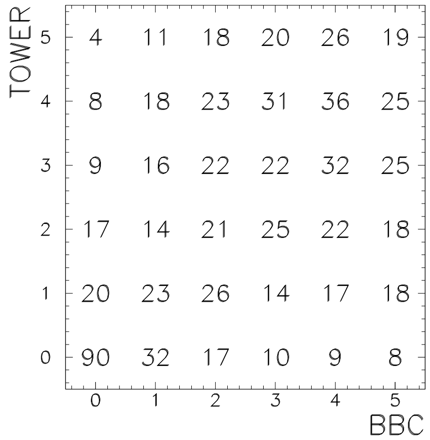
Double Pomeron Exchange

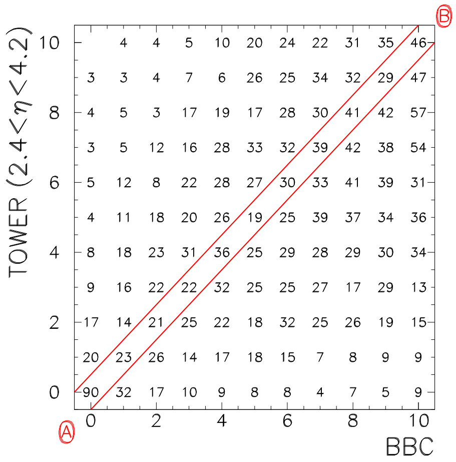


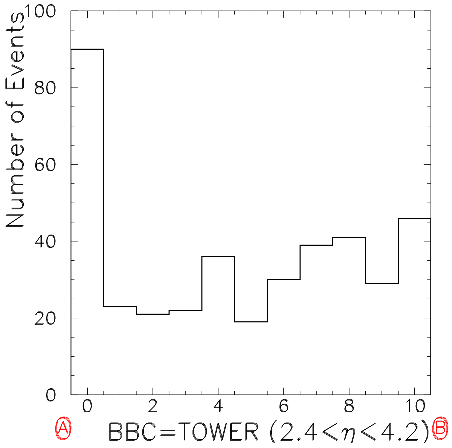
CDF PRELIMINARY :

BBC$(3.2 < \eta < 5.9)$ **vs TOWER**$(2.4 < \eta < 4.2)$









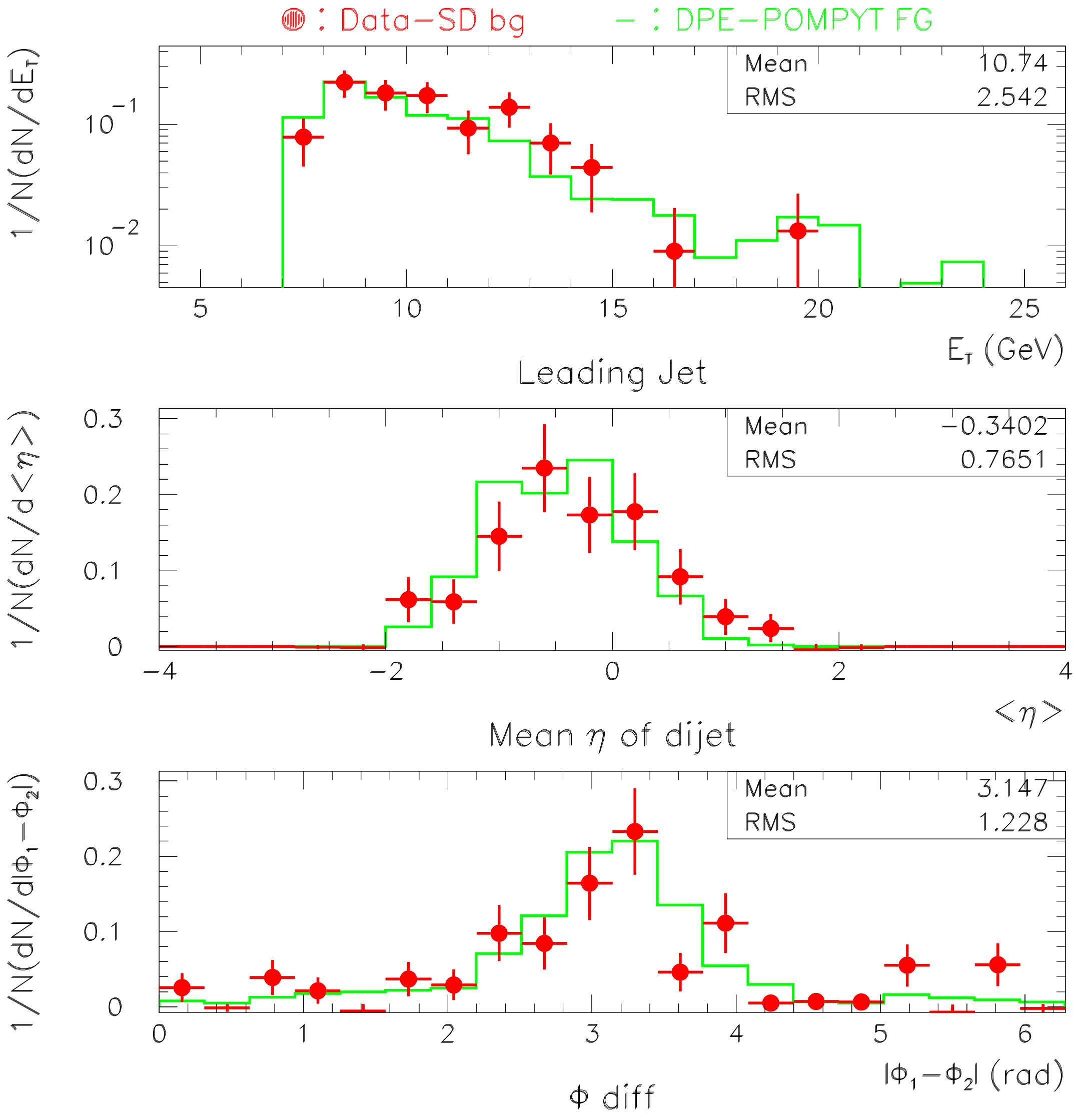
$$R_{\frac{GJJP}{JJP}} = 0.26 \pm 0.05(\text{stat.}) \pm 0.04(\text{syst.})\%$$

DPE Dijet Kinematics

Comparison with DPE-POMPYT MC Shape Predictions

(Flat Gluon Pomeron Structure)

CDF Preliminary



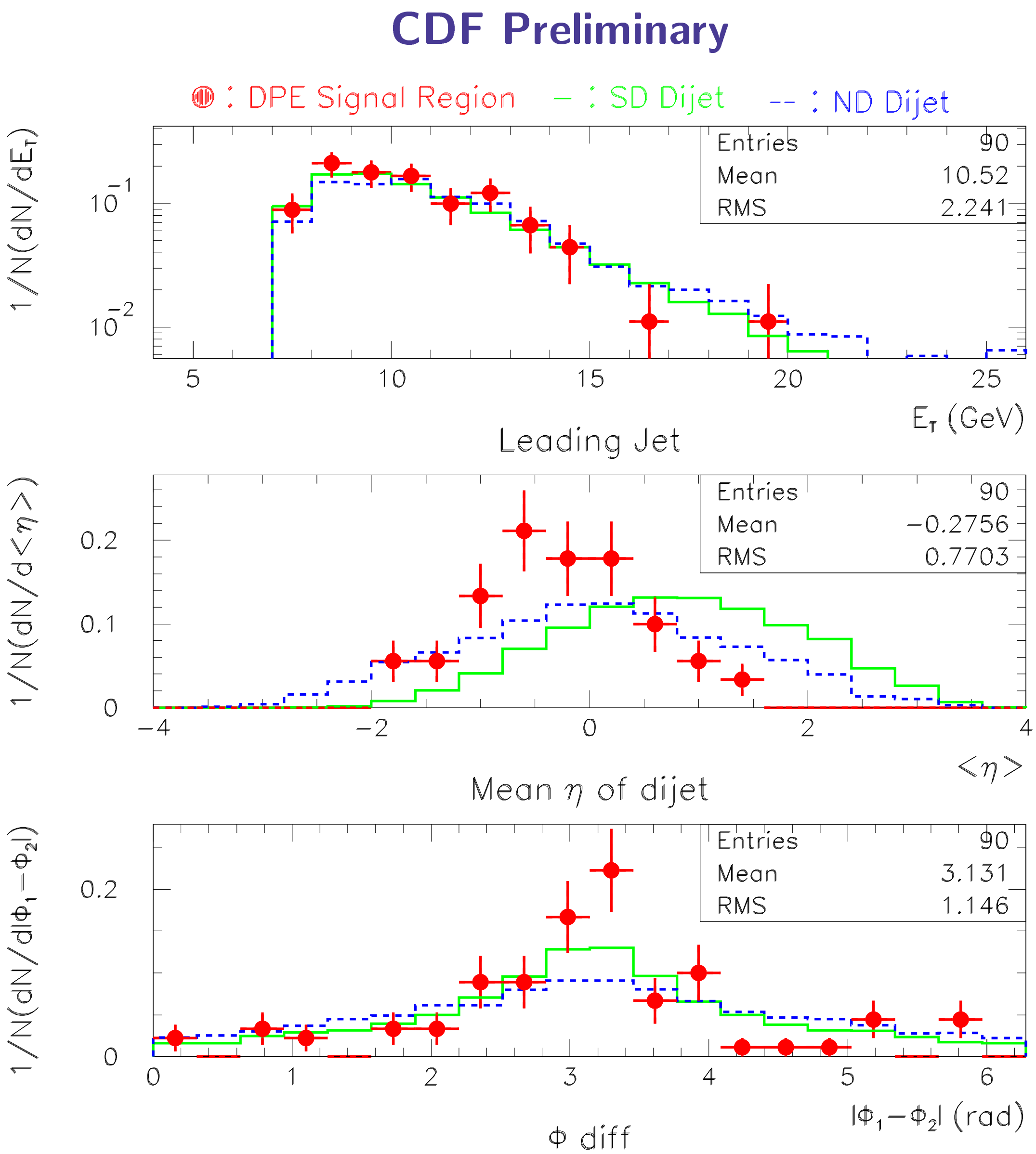
MC Rate Prediction:

	standard flux	renormalized flux
$R_{\frac{GJJP}{JJP}}$:	1.4%	0.25%

$\Rightarrow$ MC prediction with renormalized flux agrees with data.

DPE Dijet Kinematics

Comparison with Single Diffractive (SD) and Non-Diffractive (ND) Dijets



Summary of Hard Diffraction at CDF

1. RAPIDITY GAP RESULTS:

   - Jet-Gap-Jet: $R\left(\frac{\text{gap}}{\text{all}}\right)$ (%) 1.13 ± 0.16 (2.7 ± 0.9) at $\sqrt{s} = 1800$ (630) GeV

   - Diffractive production: $R\left(\frac{\text{diff}}{\text{non}-\text{diff}}\right)$ (%)

W	JJ	b-quark x $\mathcal{A}$	J/Ψ x $\mathcal{A}$
1.15 ± 0.55	0.75 ± 0.1	$[0.26 \pm 0.08$(stat)$]$	$[0.64 \pm 0.12$(stat)$]$

     Gluon fraction in $I\!P$: $f_g = 0.7 \pm 0.2$
     $I\!P$-flux discrepancy: $D = 0.18 \pm 0.04$

2. ROMAN POT RESULTS: $\bar{p} + p \to \bar{p} + Jet1 + Jet2 + X$

   - Dijets at $\sqrt{s} = 1800$ and 630 GeV:
     (a) $R\left(\frac{\text{diff}}{\text{non}-\text{diff}}\right)$ increases as $x^{\bar{p}}$ decreases
     (b) β-distribution($I\!P$-structure) increases as β decreases
     (c) Rates are $\sim 5 - 10$ times smaller than predictions based on HERA data or on the standard DL $I\!P$-flux $\Rightarrow$ factorization breakdown
     (d) Rates $\approx$ agree with the renormalized flux prediction of [PLB 358(1995)379]

   - Double Pomeron Exchange (DPE) Dijets:
     (a) event candidates successfully identified
     (b) E_T^{jet} spectrum is $\approx$ the same as for SD and ND dijets

$\boxed{\text{MORE TO COME SOON !}}$