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Multiparticle Dynamics
Brown University
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CDF Results on Hard Diffraction and Rapidity Gap Physics

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II. Rapidity gaps in hard single diffraction:
W, dijet, b, and J/ψ production

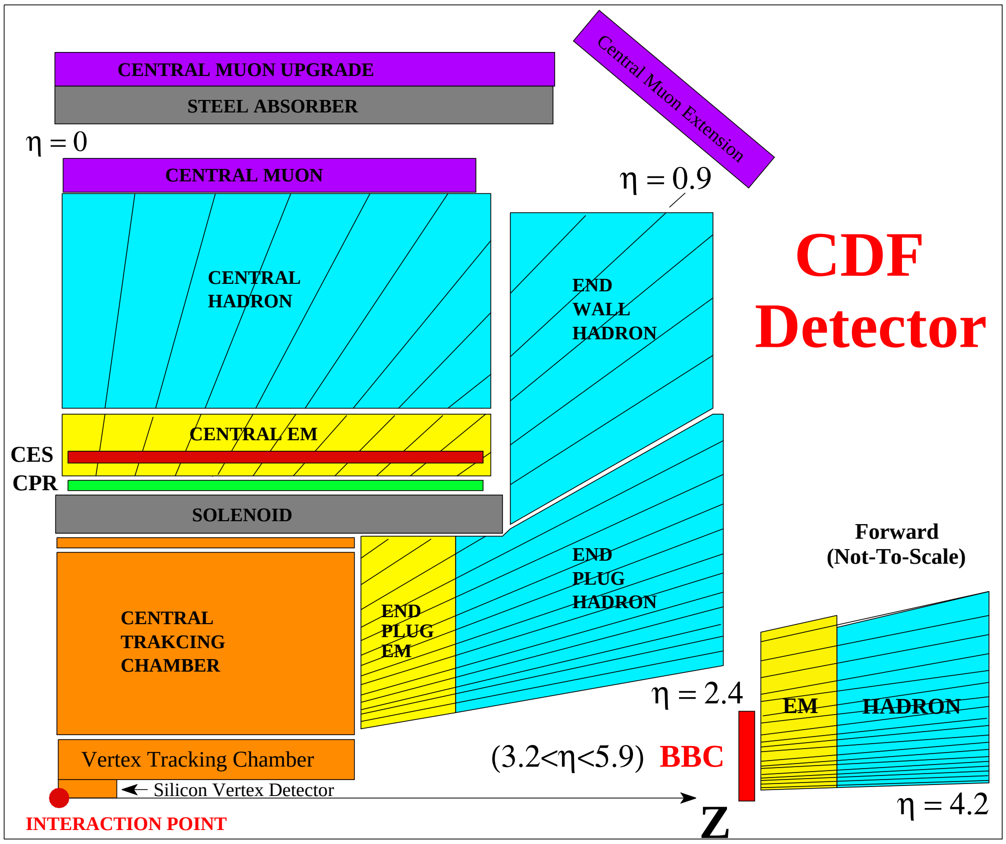
III. Diffractive dijets with Roman pots

IV. Double Pomeron exchange

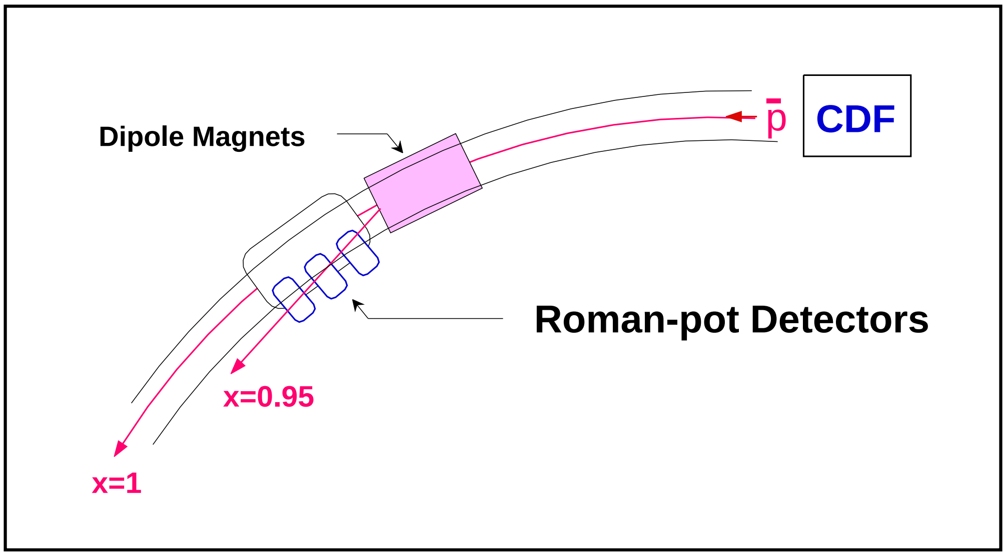
V. Hard and soft double diffraction

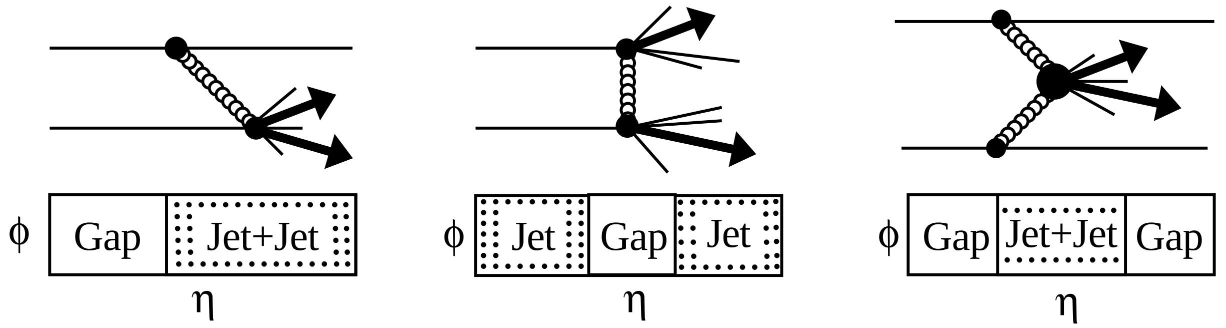
VI. Future plans

Apparatus



In Run 1C ('95-'96)





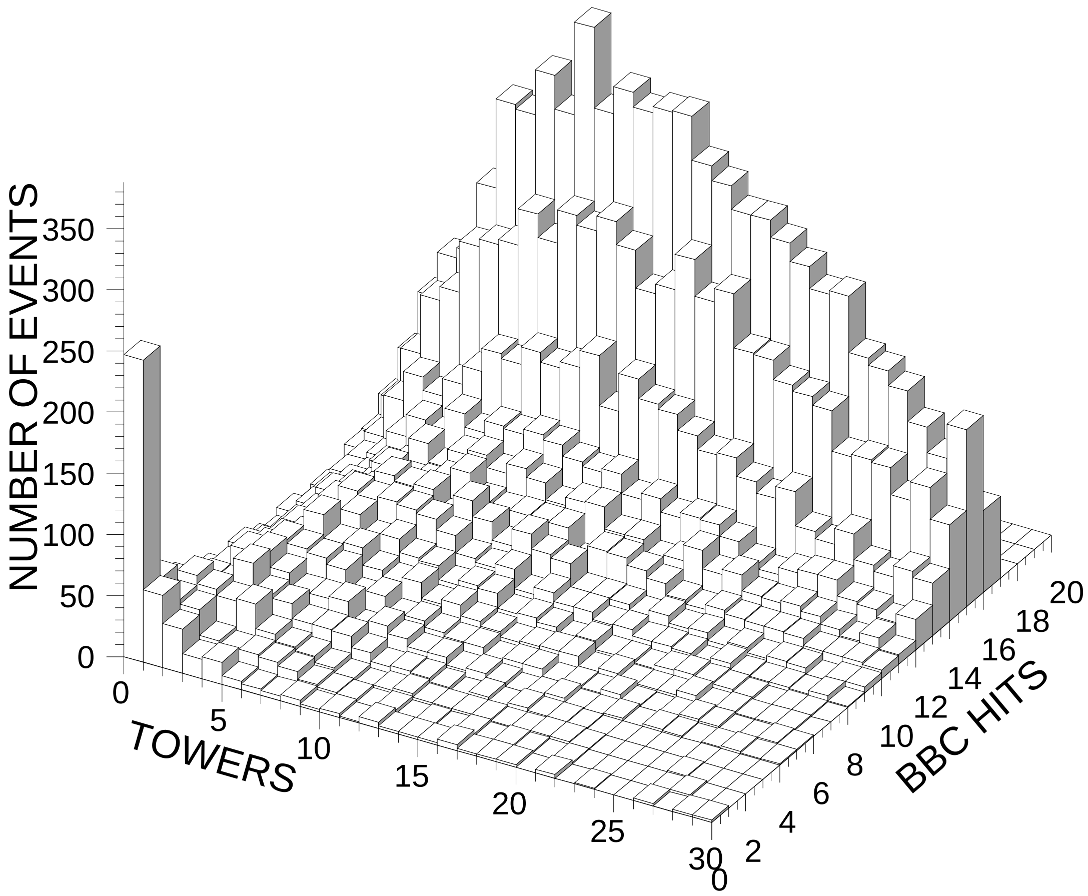
Single Diffraction Double Diffraction Double Pomeron Exchange

Diffractive W and Dijets at $\sqrt{s} = 1800$ GeV

Published CDF results:

- Diffractive W production PRL 78(1997)2698
  $R_W = [1.15 \pm 0.51(stat) \pm 0.20(syst)]\%$ $(\xi < 0.1)$
- Diffractive dijet production PRL 79(1997)2636
  $R_{GJJ} = [0.75 \pm 0.05(stat) \pm 0.09(syst)]\%$
  $(E_T^{jet} > 20\mathrm{GeV}, 1.8 < |\eta^{jet}| < 3.5, \eta_1 \cdot \eta_2 > 0, \xi < 0.1)$
- Gluon fraction in the pomeron: $f_g = 0.7 \pm 0.2$
- Momentum/flux discrepancy: $D = 0.18 \pm 0.04$

Diffractive Dijets at $\sqrt{s} = 1800$ GeV

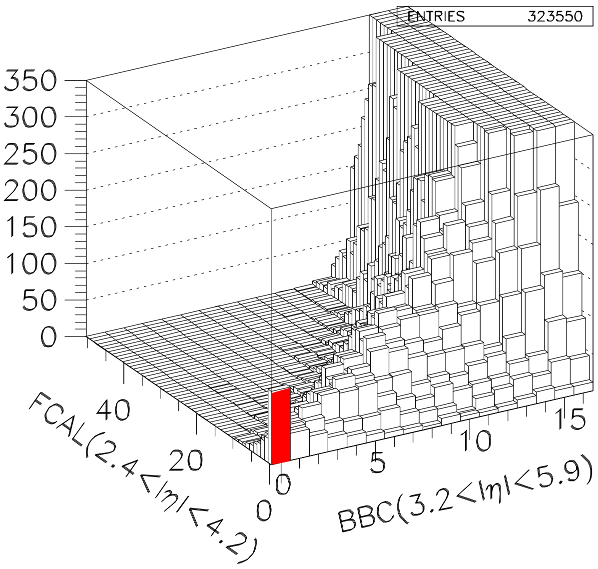


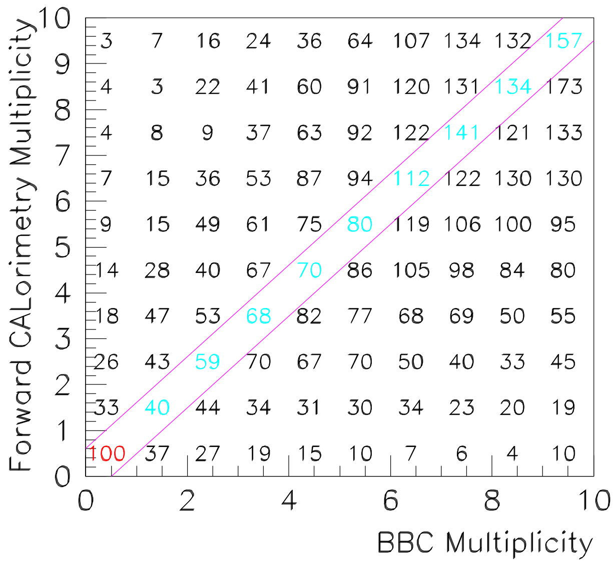
Beam-Beam Counter multiplicity (BBC hits) versus forward tower multiplicity in the pseudorapidity regions $3.2 < |\eta_{(BBC)}| < 5.9$ and $2.4 < |\eta_{(TOWER)}| < 4.2$ opposite the dijet system.

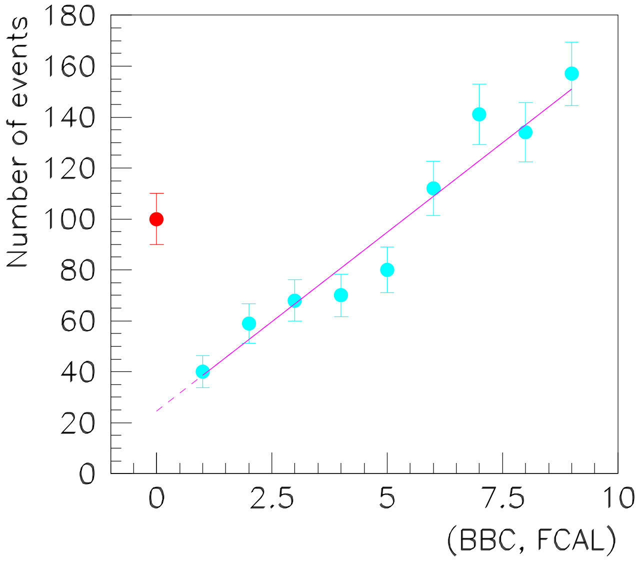
$$R_{JJ}\left[\frac{diff}{non-diff}\right] = (0.75 \pm 0.10)\%$$

Diffractive b-quark production at $\sqrt{s} = 1800$ GeV

CDF Preliminary







Diffractive/Non−Diffractive Ratio

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

where A is the GAP Acceptance

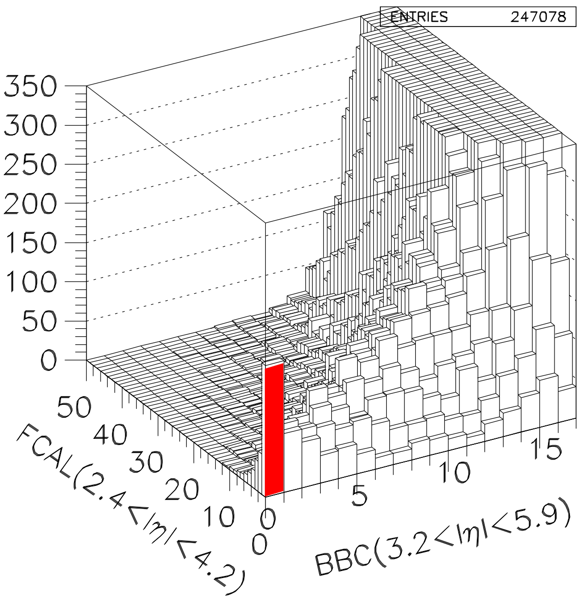
GAP definition:

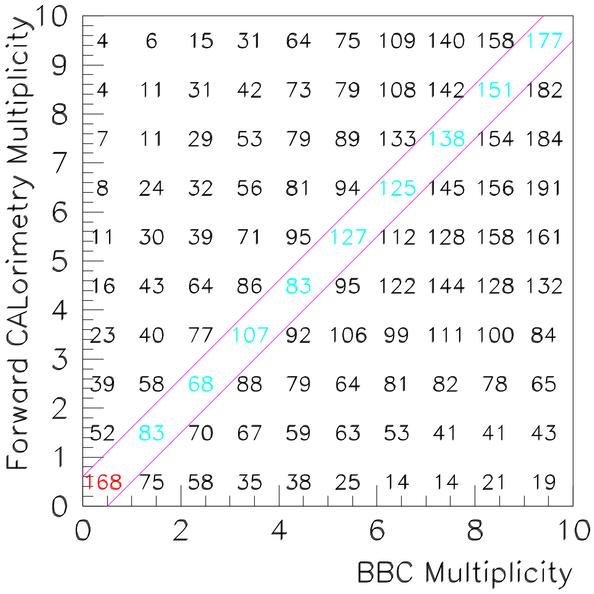
- $-5.9 \leqq \eta \leqq -3.2$ or $3.2 \leqq \eta \leqq 5.9$
  No charged particles
- $-4.2 \leqq \eta \leqq -2.4$ or $2.4 \leqq \eta \leqq 4.2$
  No charged or neutral particles
  of $E \geqq 1.5$GeV

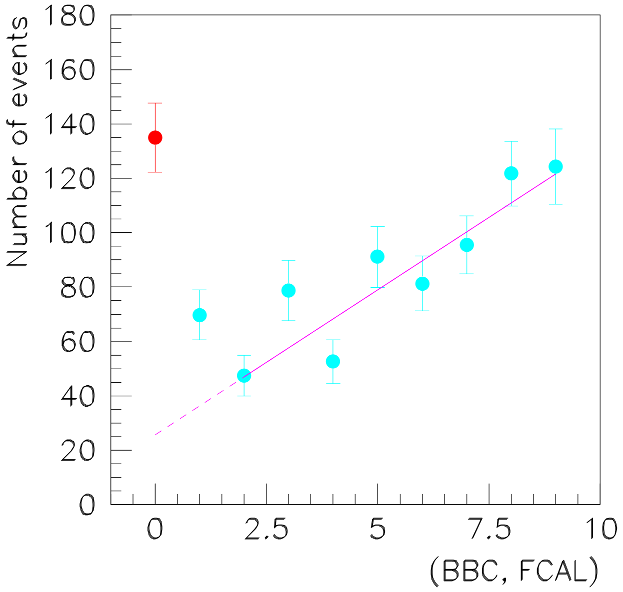
$$R_{\bar{b}b} = [0.62 \pm 0.19(stat) \pm 0.14(syst)]\%$$

Diffractive J/ψ production at $\sqrt{s} = 1800$ GeV

CDF Preliminary







Diffractive/Non−Diffractive Ratio

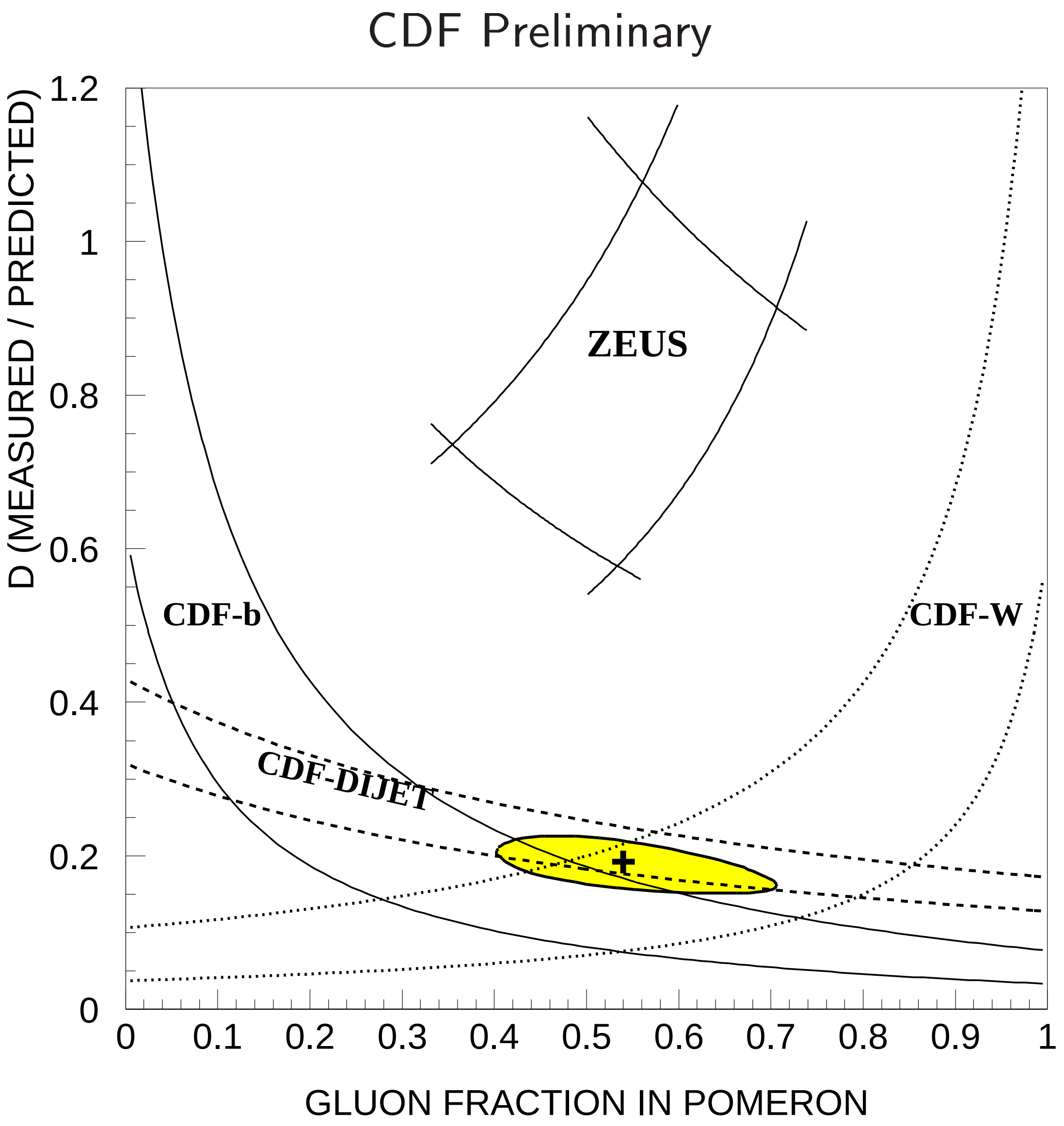
$R_{J/\psi} \times A = [0.64 \pm 0.10(\text{stat.})]\%$

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

Gluon Content



$$f_g = 0.54^{+0.16}_{-0.14}$$

CDF Hard Diffractive Rapidity Gap Results

Diffractive W

$R_W\left(\frac{SD}{ND}\right) = (1.15 \pm 0.55)\%$

PRL 78, 2698 (1997)

Diffractive dijets

$R_{JJG}\left(\frac{SD}{ND}\right) = (0.75 \pm 0.10)\%$

$E_T^{jet} > 20$ GeV, $\eta^{jet} > 1.8$, $\eta_1 \cdot \eta_2 > 0$

PRL 79, 2636 (1997)

b-quark production

$R_b\left(\frac{SD}{ND}\right) \times A = (0.26 \pm 0.08)\%$

$E_T^e > 9.5$ GeV, $\eta^e < 1.1$

$A \approx 0.4\ (2.4 \leq |\eta^{gap}| \leq 5.9)$

Preliminary

J/ψ production

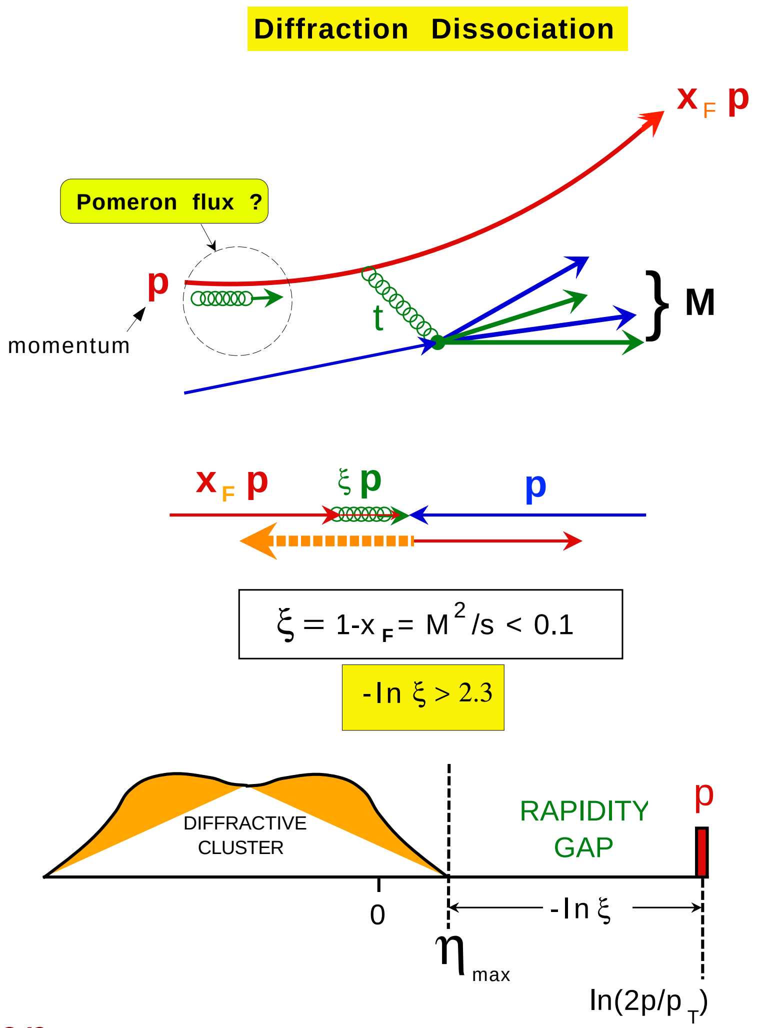
$R_{J/\psi}\left(\frac{SD}{ND}\right) \times A = (0.64 \pm 0.10)\%$

$p_T(\mu_1, \mu_2) > 2$ GeV, $\eta^\mu < 1.1$

Preliminary

all ratios $\sim 1\%$

Hard Diffraction in $\bar{p}p$ Collisions



Factorization

$$\frac{d\sigma(\bar{p}\,p \;\to\; \bar{p} \,+\, X)}{d\xi\;dt\;dx_{\bar{p}}\;dx_p} = f_{I\!P/\bar{p}}(\xi,t)\;\frac{d\sigma(p\;I\!P \;\to\; X)}{d\beta\;dx_p}, \quad (x_{\bar{p}} = \beta\cdot\xi)$$

$t\;:\;$ *Four Momentum Transfer Squared*

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

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

Diffractive Dijets in Roman-pot Data

Diffractive Inclusive Trigger (Roman-pot Trigger)

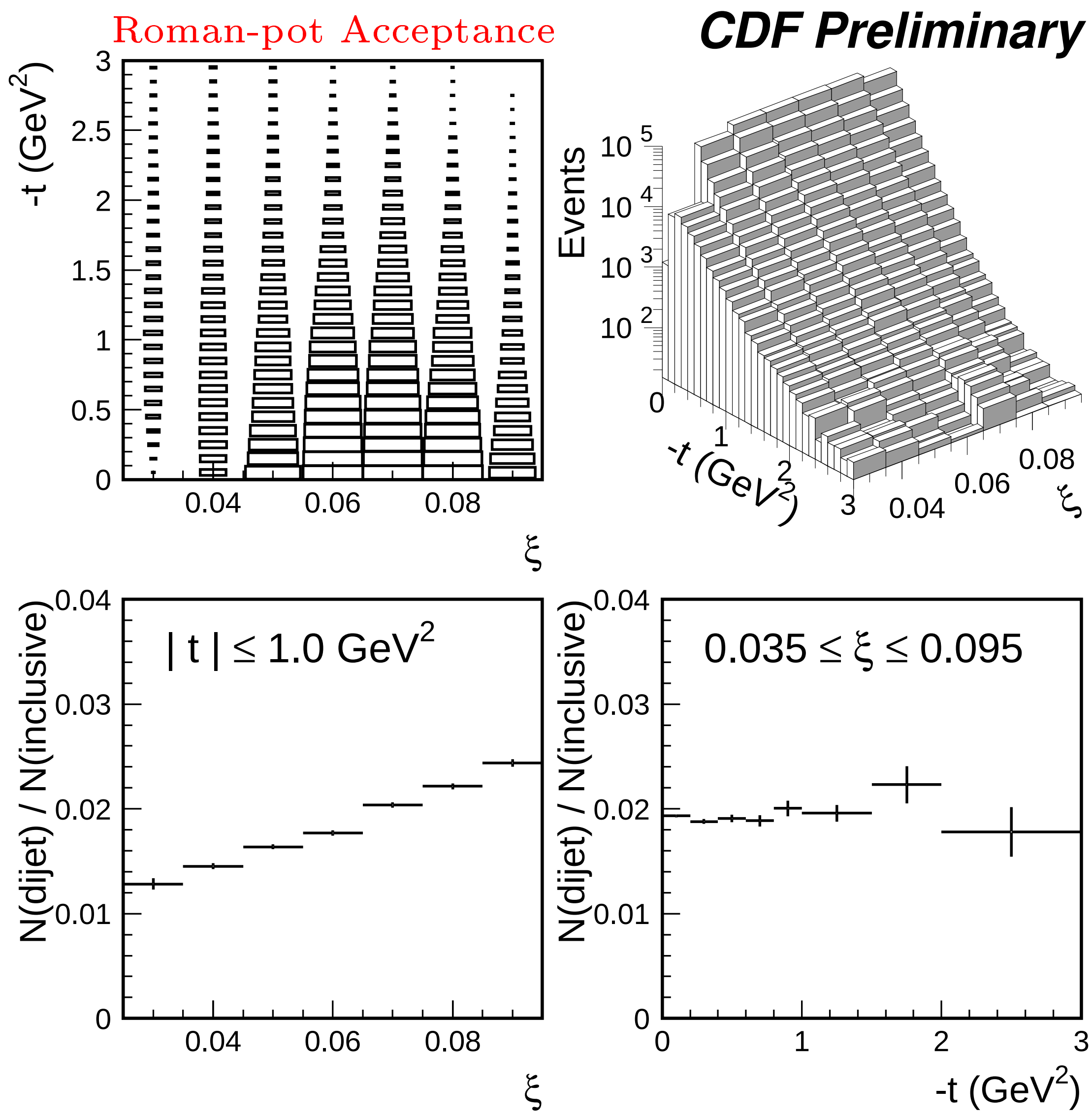
$\sim$ 3 M events

Offline Cuts

- Reject
  - Cosmic ray background
  - Main ring background
  - Events with more than one vertex
- Select Events with
  - a roman-pot track
  - two jets with $E_T > 7$ GeV

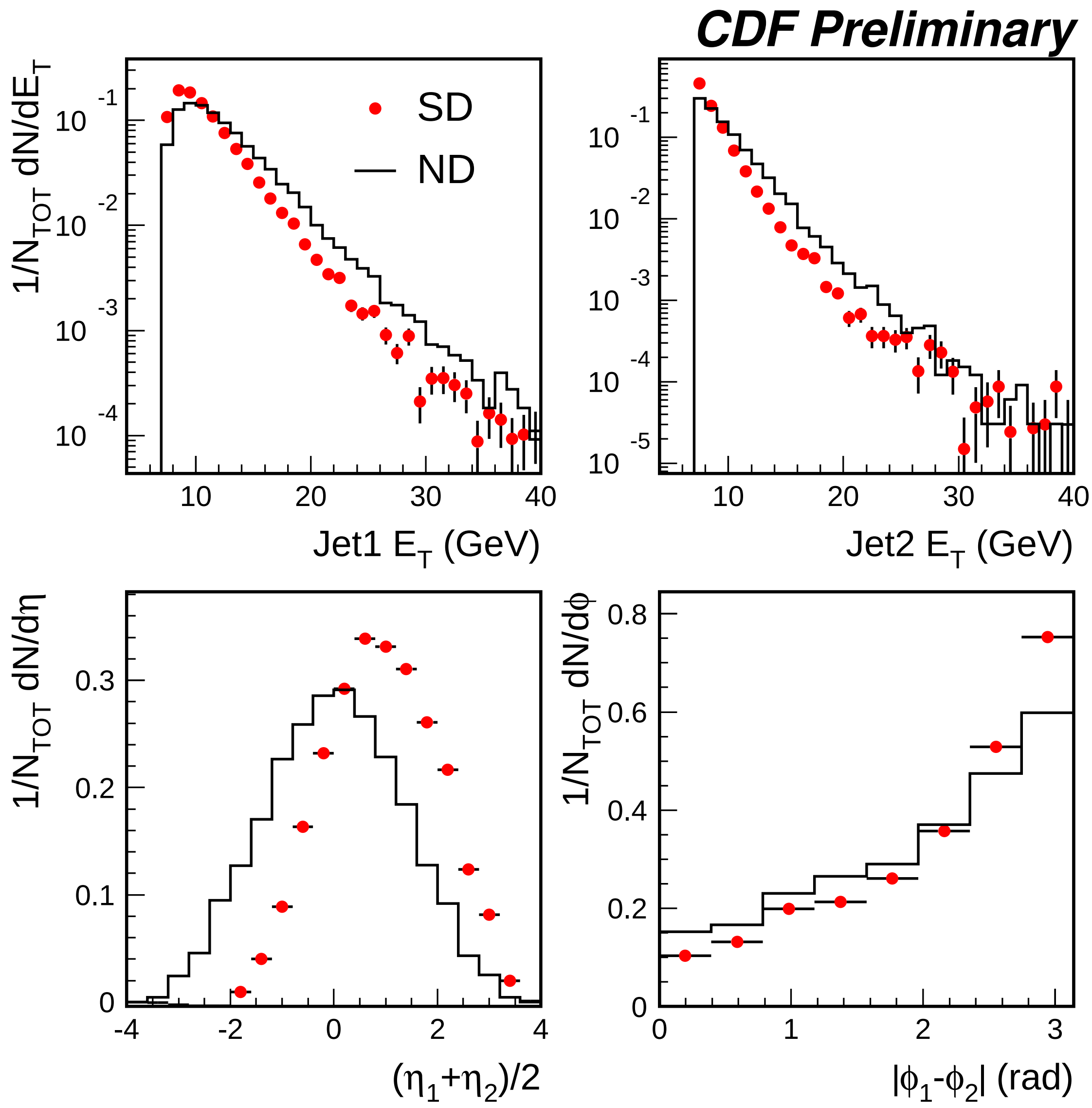
$\Longrightarrow$ Final sample contains $\sim$ 30 K diffractive events

Roman-pot Acceptance, $R_{\frac{dijet}{incl}}$ vs ξ, t



- R(Dijet/Inclusive) increases with increasing ξ.
- R(Dijet/Inclusive) is approximately flat in the measured t region.

E_T, η and $\Delta\phi$ of Diffractive Dijets



- Diffractive dijet boosted to the $p-$beam direction
- Diffractive dijets are more back-to-back $\Rightarrow$ less radiation

Strategy for the Diffractive Structure Study

From the detected jets, we measure :

$$x_{\bar{p}} = p_{g,q}/p_{\bar{p}} = \frac{\Sigma_{i=1,2(or\ 3)} E_T^i \cdot e^{-\eta_i}}{2 \cdot p_0^{\bar{p}}}$$

(if $E_T^{jet3} > 5$ GeV, include the 3rd jet in the $x_{\bar{p}}$ calculation)

Study of the ratio of diffractive to non-diffractive dijet cross sections as a function of $x_{\bar{p}}$,
$\Longrightarrow$ Ratio of diffractive to non-diffractive (anti)proton structure functions, $R_{\frac{SD}{ND}}(x_{\bar{p}}) = F_{JJ}^D(x_{\bar{p}})/F_{JJ}(x_{\bar{p}})$,

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

From the leading antiproton detected by the Roman-pot detectors, we measure :

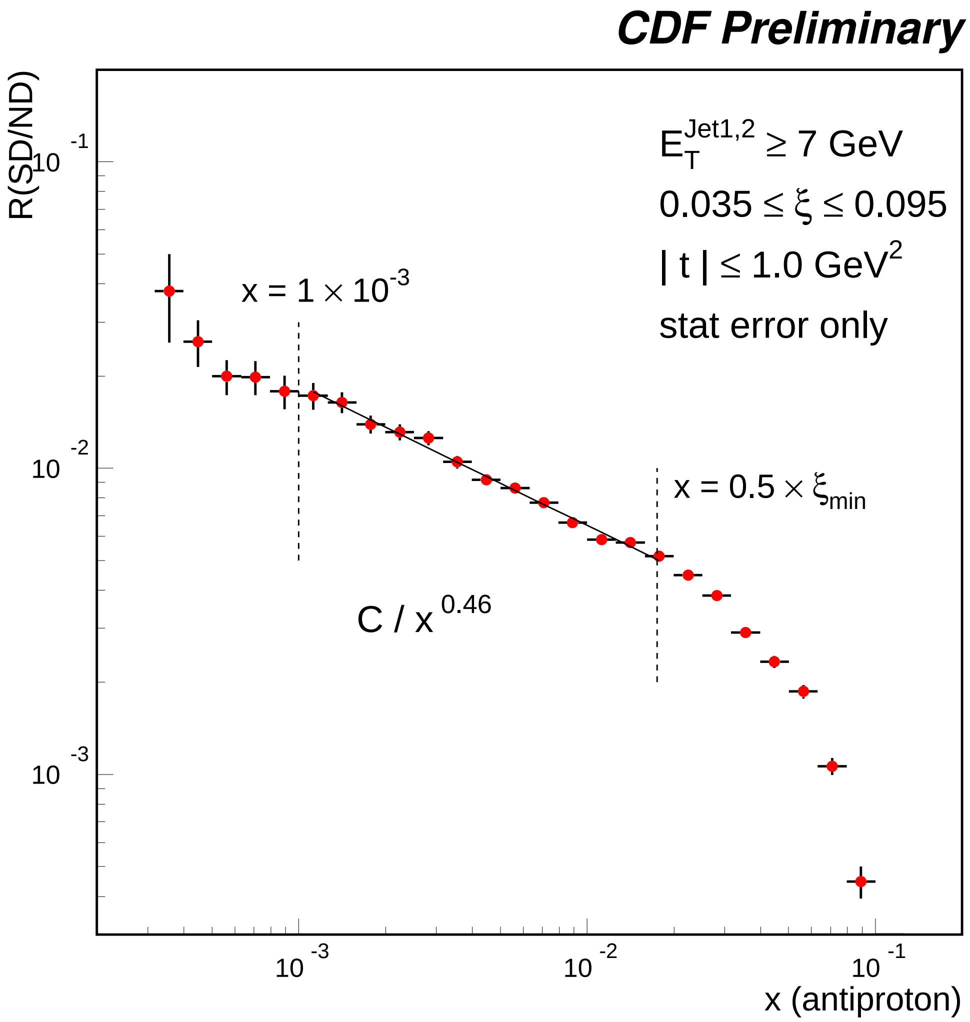
$$\begin{array}{lccccc} & \xi = p_{I\!P}/p_{\bar{p}} & \rightarrow & \beta = p_{g,q}/p_{I\!P} = x_{\bar{p}}/\xi & & \\ \Longrightarrow & F_{JJ}^D(x_{\bar{p}},\xi) & \rightarrow & F_{JJ}^D(\beta,\xi) & & \\ & & & & \longrightarrow & F(\xi)\cdot\mathcal{F}(\beta) \\ & & & & (?) & \end{array}$$

- The shape of the β distribution
- ξ-dependence of F_{JJ}^D
- Comparison with HERA results

Diffr. to Non-diffr. Ratio as a Function of $x_{\bar{p}}$

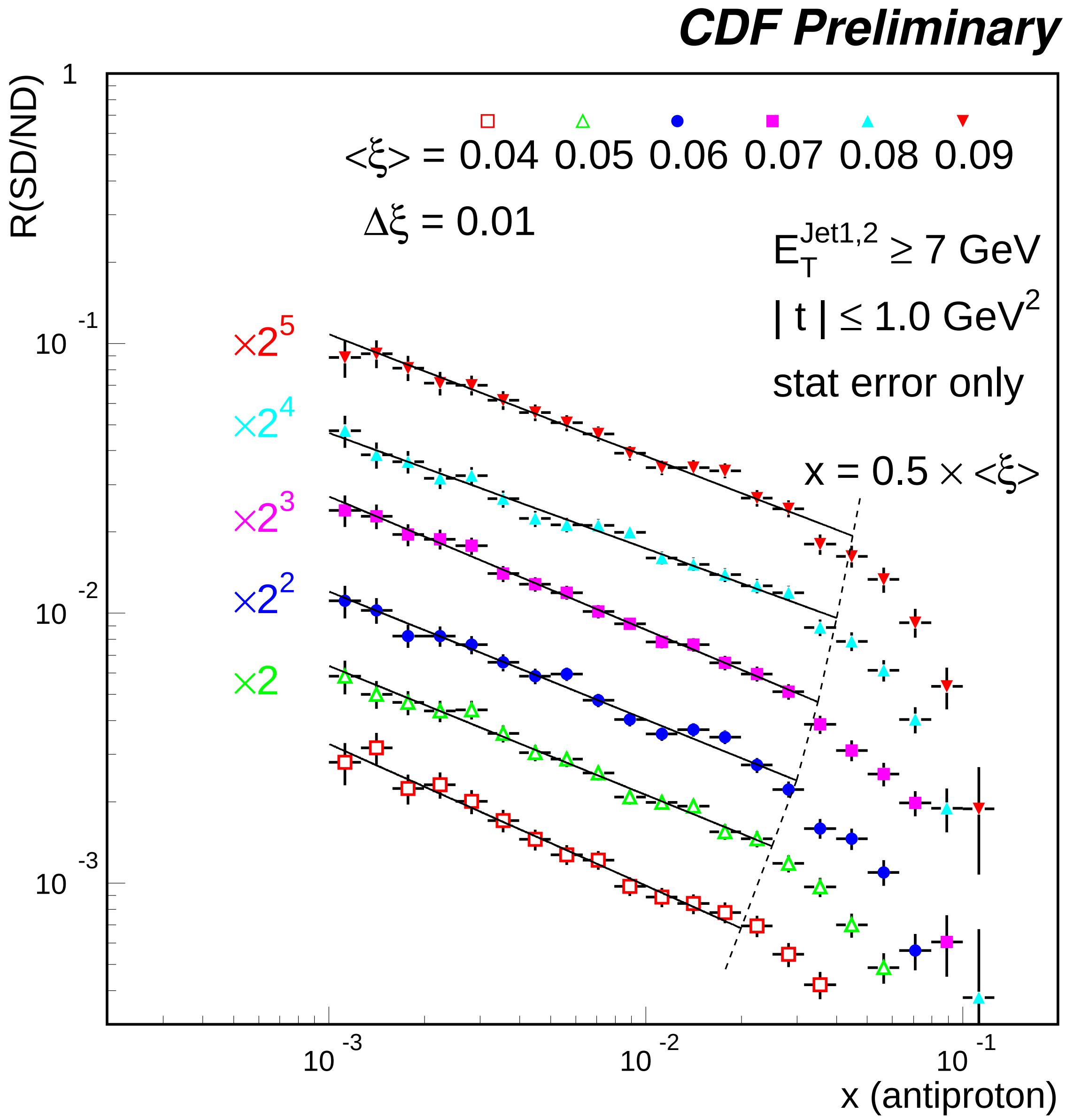
$$R_{\frac{SD}{ND}}(x_{\bar{p}}) = \frac{F_{JJ}^{D}(x_{\bar{p}})}{F_{JJ}(x_{\bar{p}})}$$

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



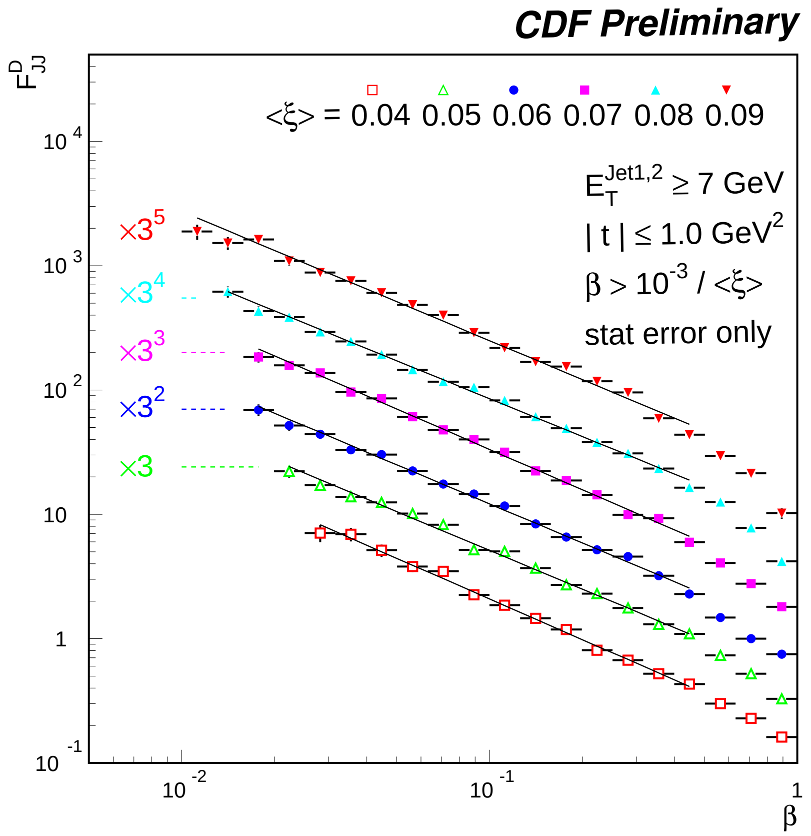
The distribution fits to $C/{x_{\bar{p}}}^n$ in the range of $10^{-3} < x_{\bar{p}} < 0.5 \times \xi_{min}$.

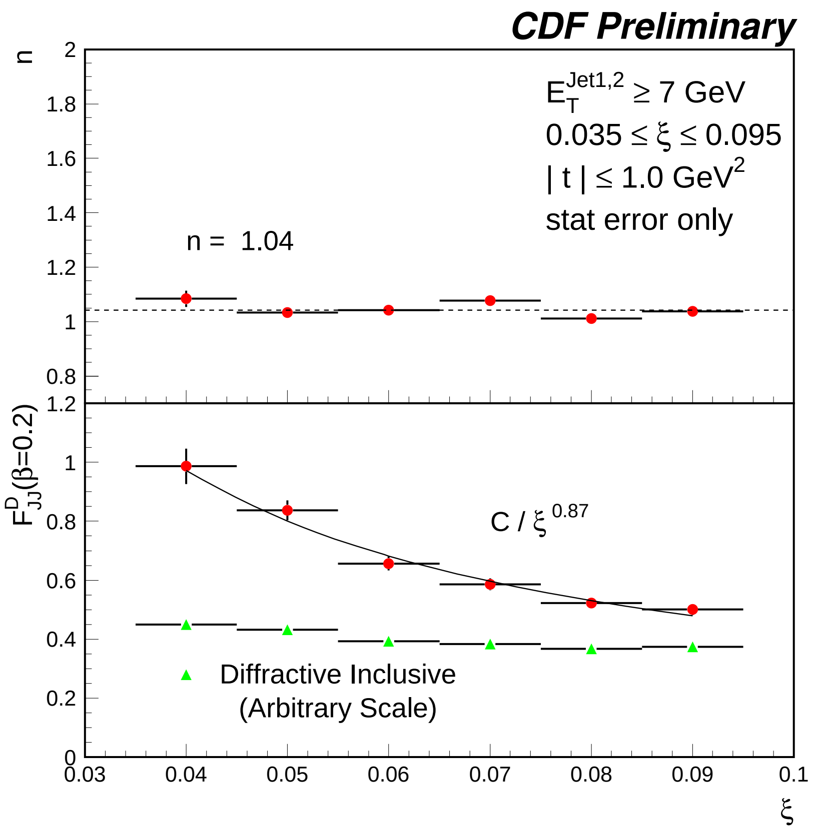
ξ-dependence of $R_{\frac{SD}{ND}}(x_{\bar{p}})$



The slope is approximately the same over the measured ξ range.

Diffractive Structure as a function of ξ & β





These distribution can be fitted to C/β^n in the region of $10^{-3}/\langle\xi\rangle < \beta < 0.5$.

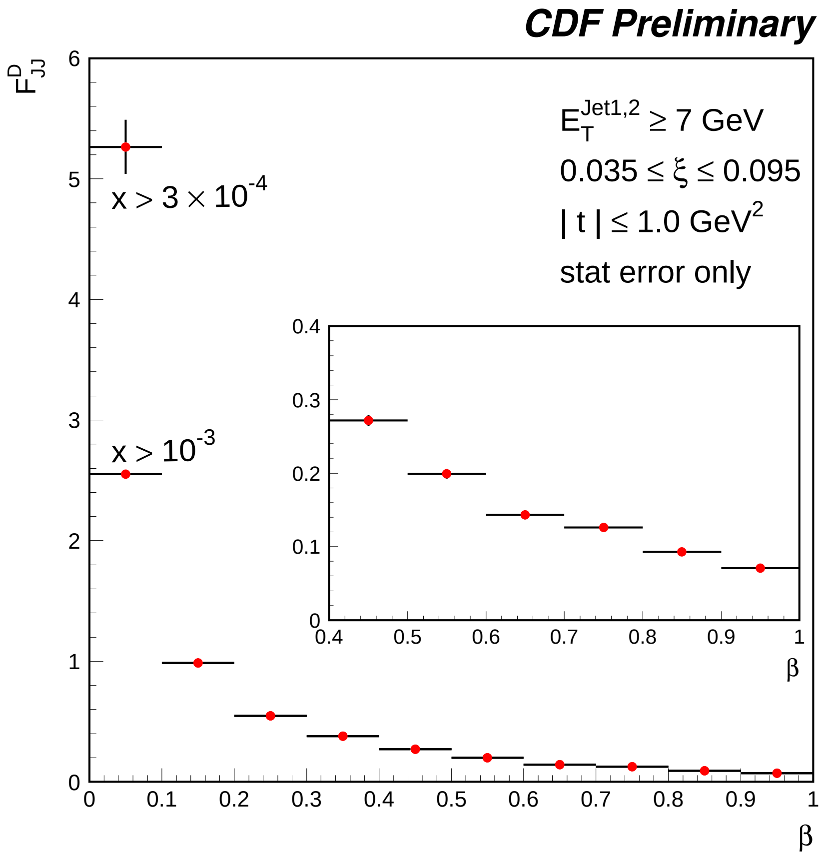
- The slope is almost constant over the measured ξ range.
- F^D_{JJ} is falling with ξ, $\propto 1/\xi^{0.87}$.

Diffractive Structure in terms of β

$$F^D_{JJ}(x_{\bar p},\xi) = R_{\frac{SD}{ND}}(x_{\bar p},\xi) \times F_{JJ}(x_{\bar p})$$

$$F^D_{JJ}(x_{\bar p},\xi) \quad \longrightarrow \quad F^D_{JJ}(\beta,\xi)$$
$$(\beta = x_{\bar p}/\xi)$$

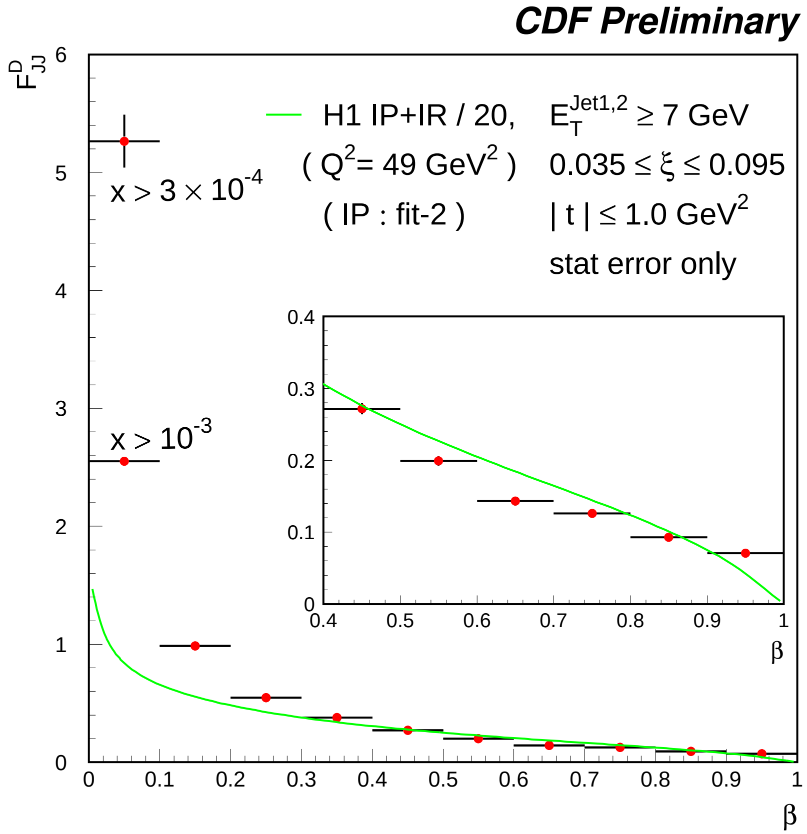
$F_{JJ}(x_{\bar p})$ extracted from PDFLIB ($Q^2 = {E_{T,\mathrm{threshold}}}^2$).



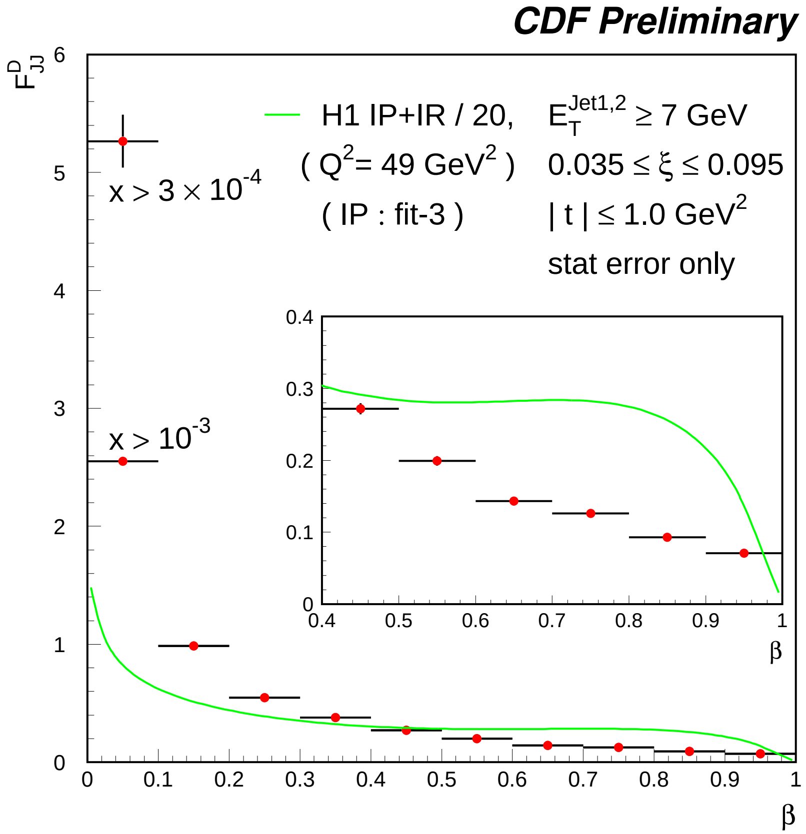
The height of the first point depends on the minimum $x_{\bar p}$ (or β) value we choose.

Comparison with H1 results

Fit-2



Fit-3



Shape :

Favor fit-2 rather than fit-3
Larger enhancement in low β
(CDF is more sensitive to low β.)

Rate :

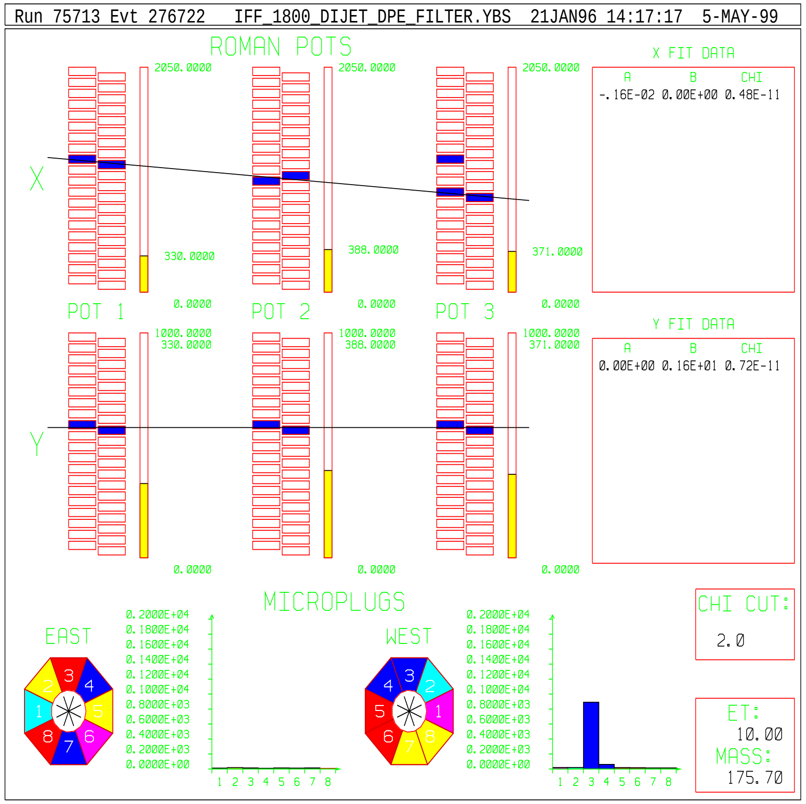
H1 results : $\approx$ 20 larger in higher β
: $\approx$ 10 larger in total

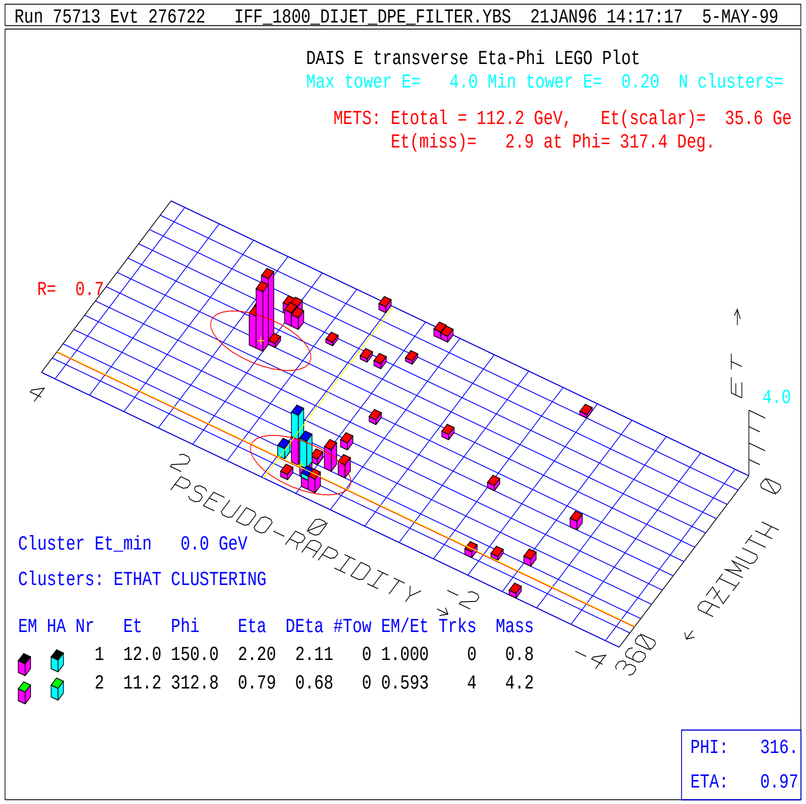
Summary

We have studied diffractive dijet production and diffractive structure using the roman-pot trigger data collected at $\sqrt{s} = 1800$ GeV.

- The ratio of diffractive to non-diffractive dijet cross sections as a function of $x_{\bar{p}}$ $(= p_{g,q}/p_{\bar{p}})$,
  - Diffr. to non-diffr. ratio increases as $x_{\bar{p}}$ decreases.
  - Slope approximately the same over the measured ξ range, i.e., $0.035 < \xi < 0.095$.
- F^D_{JJ} in terms of β $(= p_{g,q}/p_{I\!P})$,
  - Shape :
    Obey power-law ($\approx 1/\beta$) in the region of
    $10^{-3}/\langle\xi\rangle < \beta < 0.5 \Rightarrow$ Enhancement at low β
    Power is almost constant over the measured ξ
    region, i.e., $0.035 < \xi < 0.095$.
  - Rate :
    H1 results : $\approx$ 20 larger in higher β
    : $\approx$ 10 larger in total
  - ξ-dependence :
    F^D_{JJ} is falling with ξ, $\propto 1/\xi^{0.87}$.

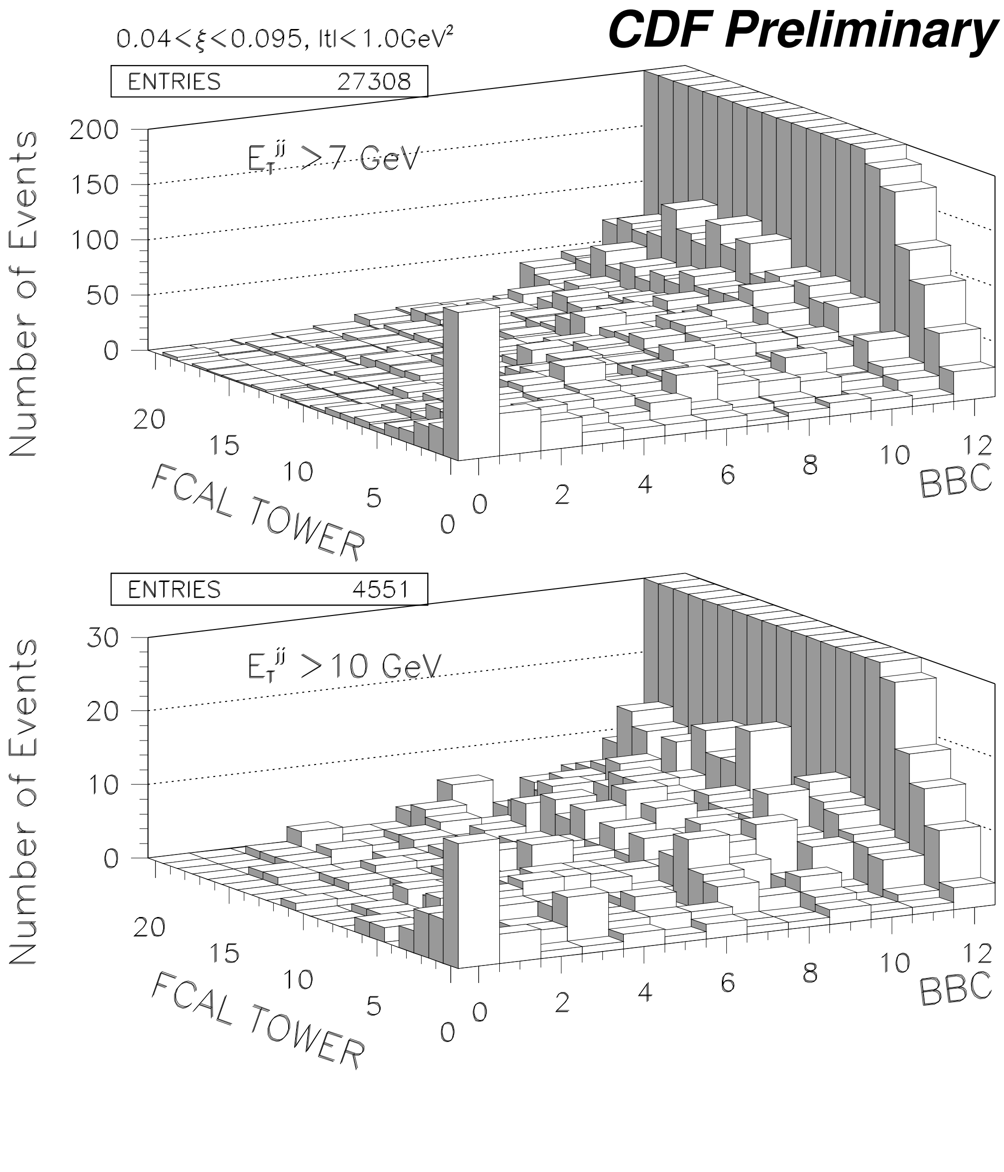
Candidate of Double Pomeron Exchange Dijet





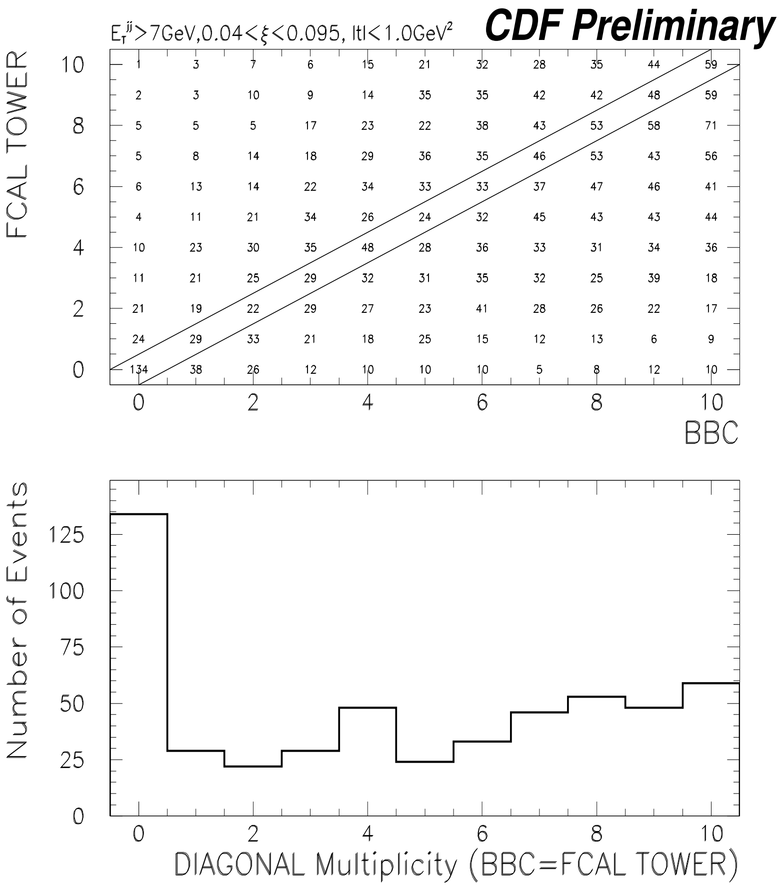
Jet 1	$E_T = 19.0$ GeV, $\eta = 2.2$	Proton Side	$N_{BBC}(2.4 < \eta < 4.2) = 0$
Jet 2	$E_T = 18.1$ GeV, $\eta = 0.79$		$N_{FCAL}(2.4 < \eta < 4.2) = 0$
Pot	$\xi = 0.070$, $\lvert t\rvert = 0.0097$ GeV^2		

Search for Double Pomeron Dijets



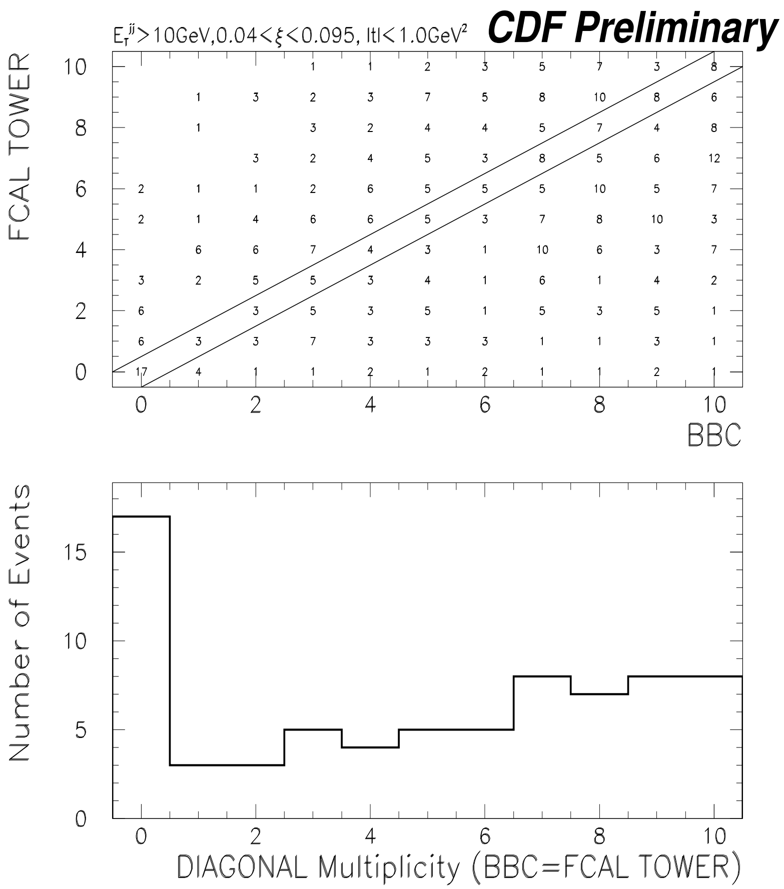
Diagonal BBC$(3.2 < \eta < 5.9)$ vs FCAL$(2.4 < \eta < 4.2)$

$E_T > 7$ GeV



$$R\left(\frac{DPE}{SD}\right) = (0.39 \pm 0.07)\%$$

$E_T > 10$ GeV

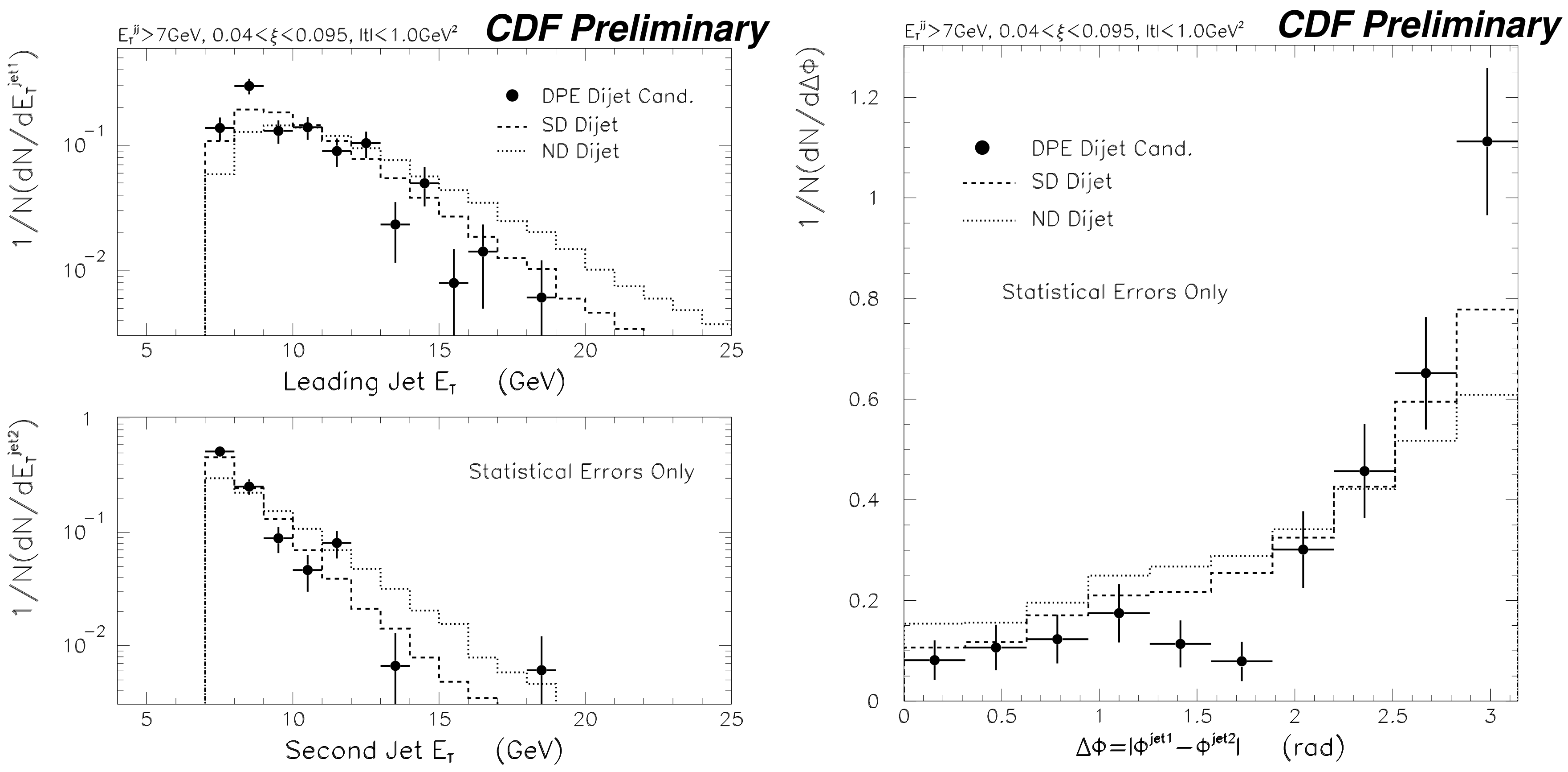


$$R\left(\frac{DPE}{SD}\right) = (0.28 \pm 0.09)\%$$

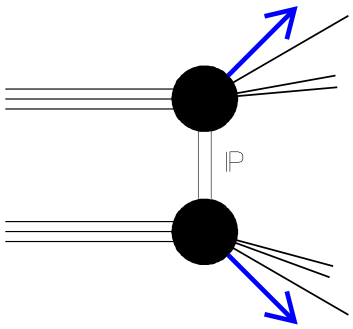
DPE Dijet Kinematics

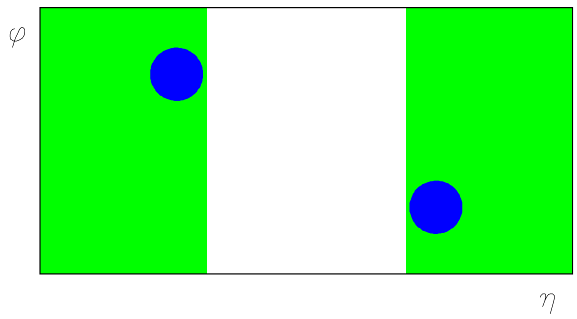
Comparison with Single Diffractive (SD) and Non-Diffractive (ND) Dijets

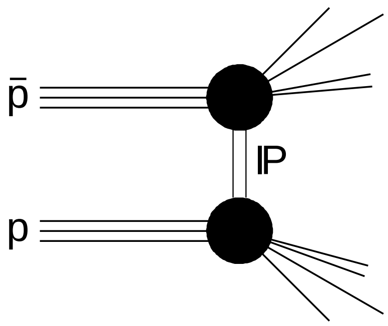
Dijet $E_T > 7$ GeV, $\quad 0.04 < \xi < 0.095, \quad |t| < 1.0$ GeV^2

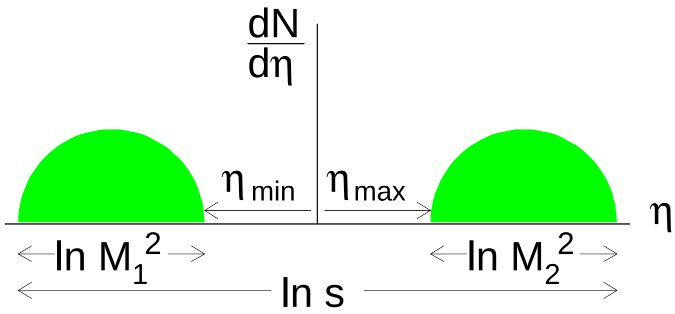


Hard and soft double diffraction

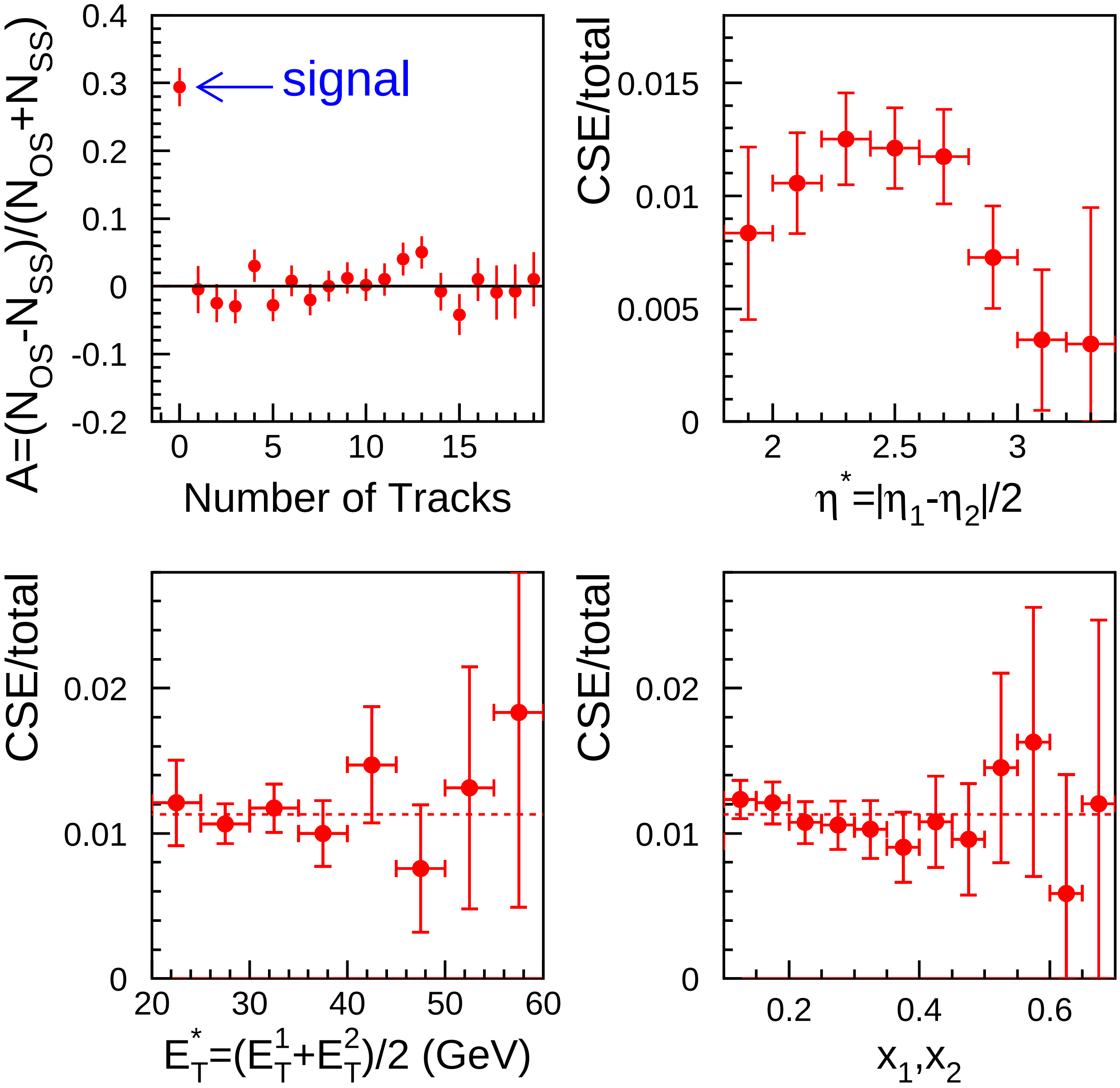








CDF Color-Singlet-Exchange fractions



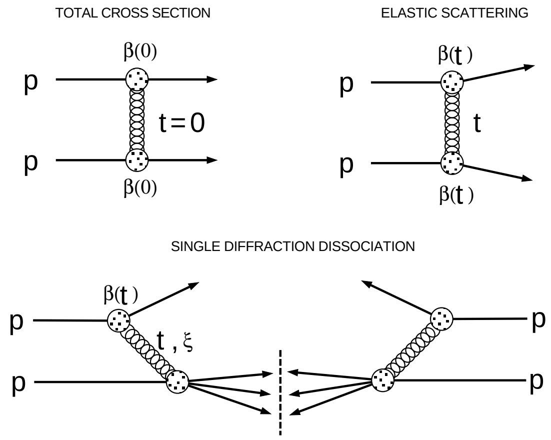
$$R_{JGJ}(1800) = [1.13 \pm 0.12(\mathrm{stat}) \pm 0.11(\mathrm{syst})]\%$$

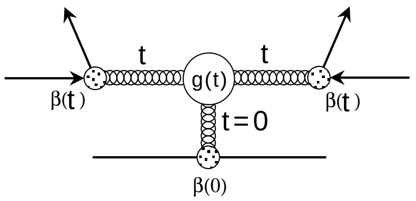
$$R_{JGJ}(630) = [2.7 \pm 0.7(\mathrm{stat}) \pm 0.6(\mathrm{syst})]\%$$

$$R(630)/R(1800) = 2.4 \pm 0.7(\mathrm{stat}) \pm 0.6(\mathrm{syst})$$

PRL 80, 1156 (1998), PRL 81, 5278 (1998)

Single Diffraction
(Regge theory)





$$\alpha(t) = 1 + \epsilon + \alpha' t$$

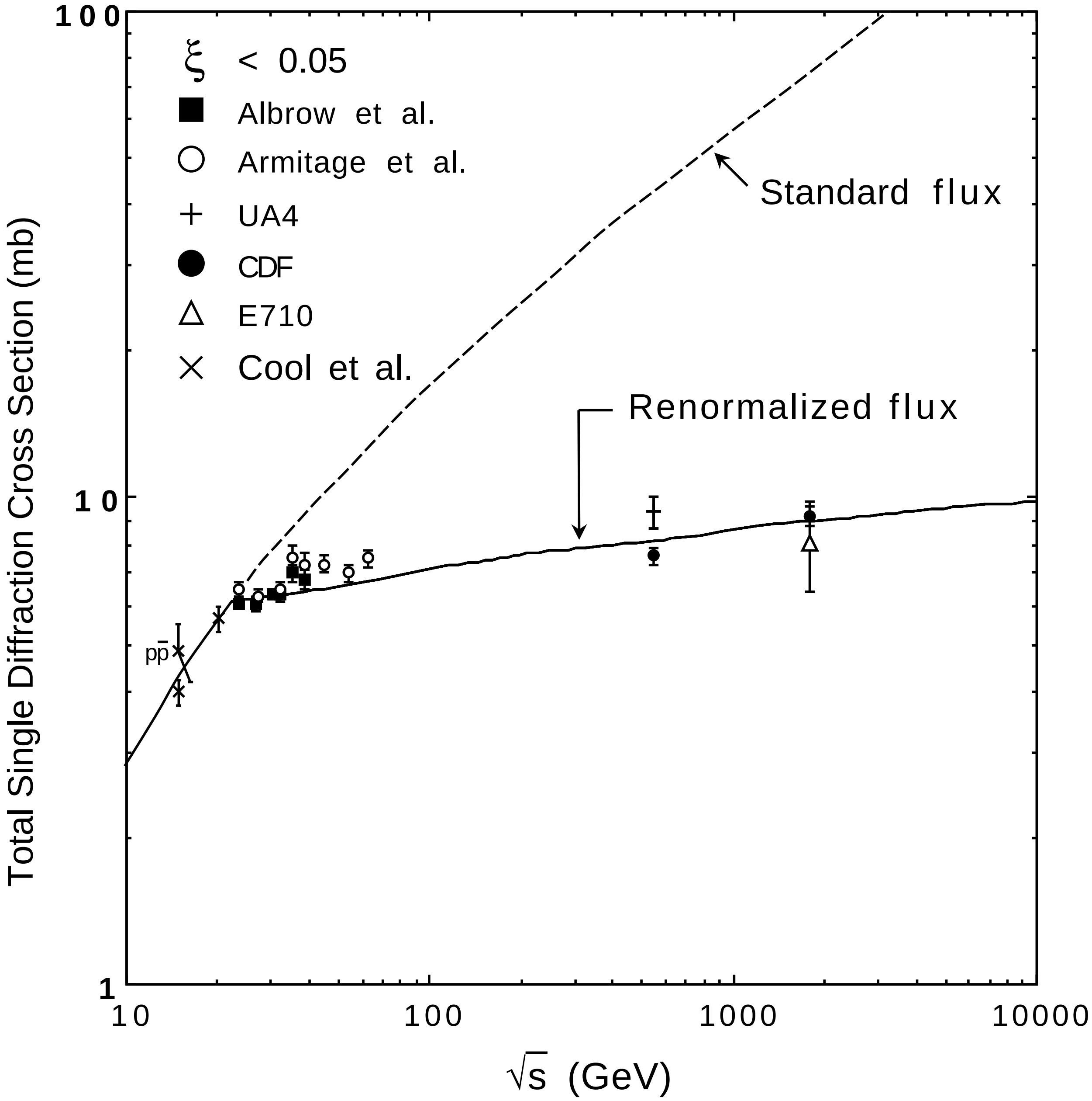
$$\sigma_T = \beta_1(0)\beta_2(0)\left(\frac{s}{s_0}\right)^{\alpha(0)-1}$$

$$\frac{d\sigma_{el}}{dt} = \frac{\beta_1^2(t)\beta_2^2(t)}{16\pi}\left(\frac{s}{s_0}\right)^{2[\alpha(t)-1]}$$

$$\frac{d^2\sigma_{SD}}{dt\,d\xi} = \underbrace{\frac{\beta_1^2(t)}{16\pi}\xi^{1-2\alpha(t)}}_{f_{I\!P/p}(\xi,t)}\ \underbrace{\kappa\beta_2^2(0)\left(\frac{s'}{s_0}\right)^{\alpha(0)-1}}_{\sigma^{I\!Pp}(s',t)}$$

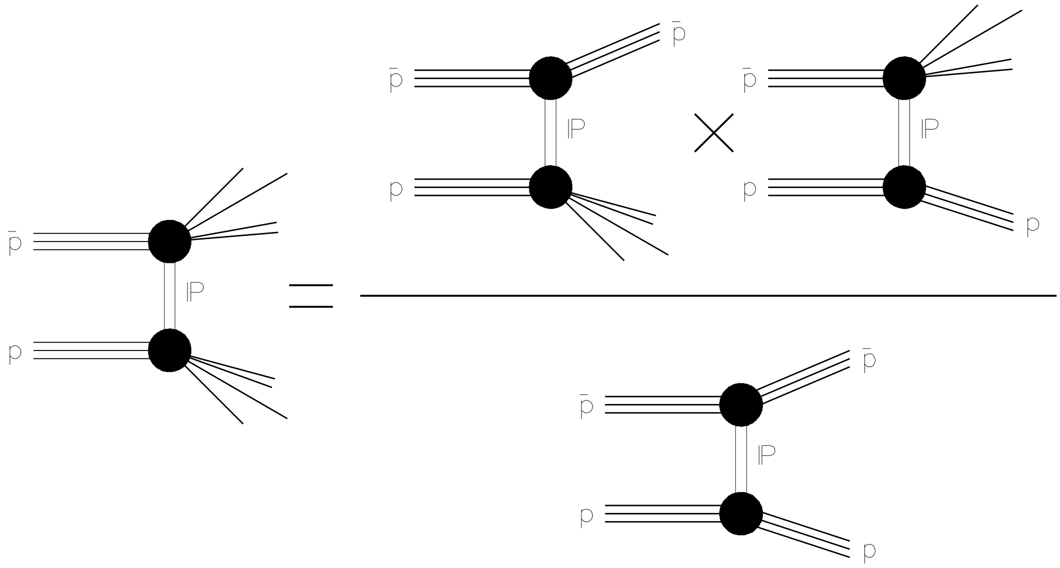
$$\xi = \frac{s'}{s} = \frac{M^2}{s} = e^{-\Delta y},\ s_0 = 1\ \mathrm{GeV}^2,\ g(t) \to g(0) = \kappa\beta_2(0)$$

Total Single Diffractive Cross Section



SD differential cross section from Regge theory ok, integral ($\sim s^{2\epsilon}$) too high

Double Diffraction
(Regge theory and factorization)



$$\frac{d^3\sigma_{DD}}{dt\,dM_1^2\,dM_2^2} = \frac{d^2\sigma_{SD}}{dt\,dM_1^2}\,\frac{d^2\sigma_{SD}}{dt\,dM_2^2} \Big/ \frac{d\sigma_{el}}{dt}$$

$$= \frac{[\kappa\beta_1(0)\beta_2(0)]^2}{16\pi}\,\frac{s^{2\epsilon}}{(M_1^2M_2^2)^{1+\epsilon}}\,e^{b_{DD}t}$$

$$b_{DD} = 2\alpha' \ln\frac{ss_0}{M_1^2M_2^2}$$

$$\kappa\beta^2(0) = 2.82 \text{ mb}, \quad \epsilon = 0.104, \quad \alpha' = 0.25 \text{ GeV}^{-2}$$

$$\text{gap width:} \qquad \Delta y \sim \ln\left(\frac{s s_0}{M_1^2 M_2^2}\right)$$

$$\text{center of gap:} \quad y_0 \sim \frac{1}{2}\ln\left(\frac{M_2^2}{M_1^2}\right)$$

$$0 \leq \Delta y \leq \ln\frac{s s_0}{M_0^4}, \qquad |y_0| \leq \frac{1}{2}\left(\ln\frac{s s_0}{M_0^4} - \Delta y\right)$$

$$(M_{1,2}^2)_{min} = M_0^2 = 1.5\ \mathrm{GeV}^2$$

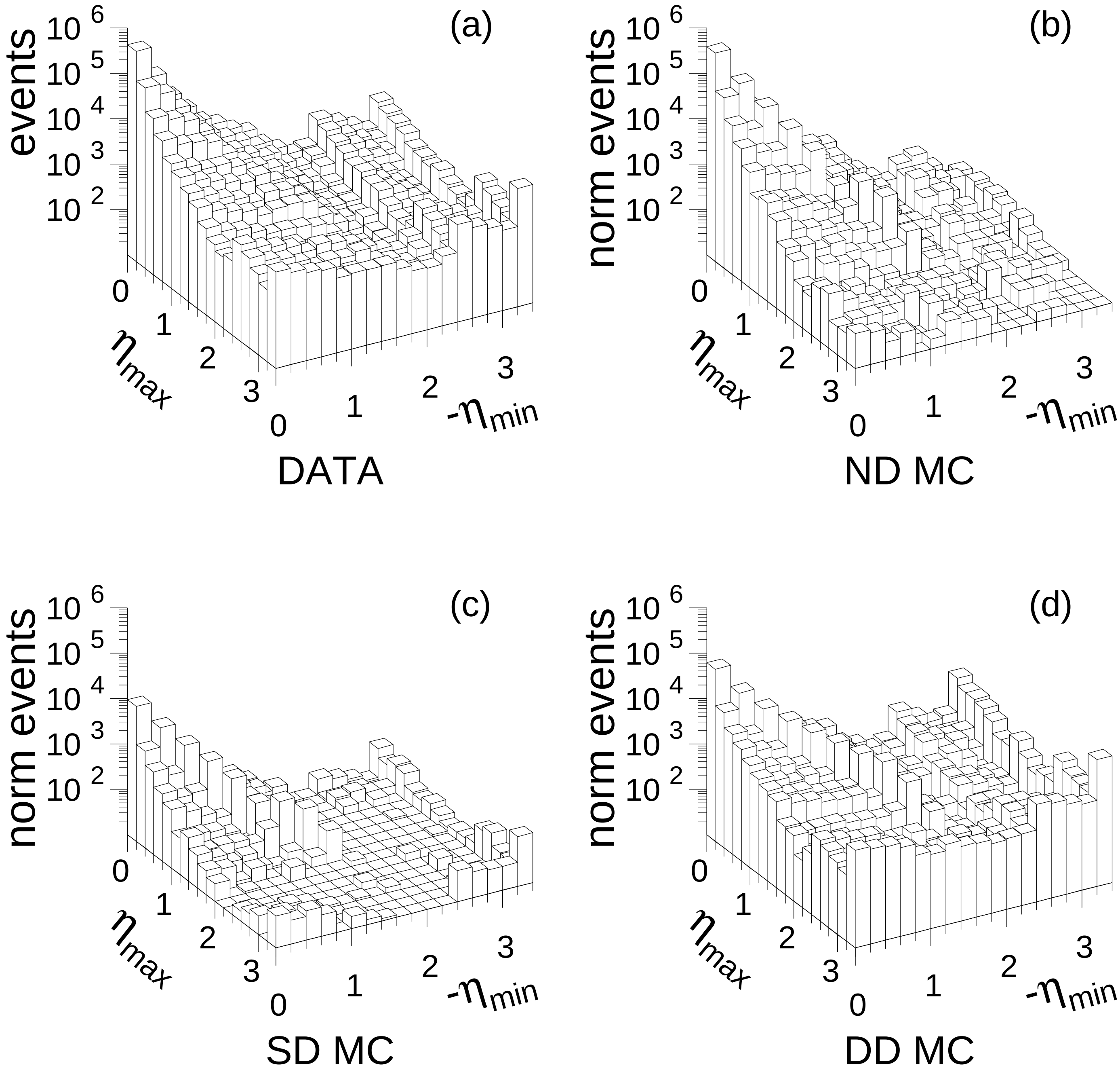
$$\frac{d^3\sigma_{DD}}{dt\, d\Delta y\, dy_0} = \underbrace{\frac{\kappa\beta^2(0)}{16\pi}\, e^{2\epsilon\Delta y} e^{2\alpha'\Delta y\, t}}\ \underbrace{\kappa\beta^2(0)\left(\frac{s'}{s_0}\right)^{\epsilon}}$$

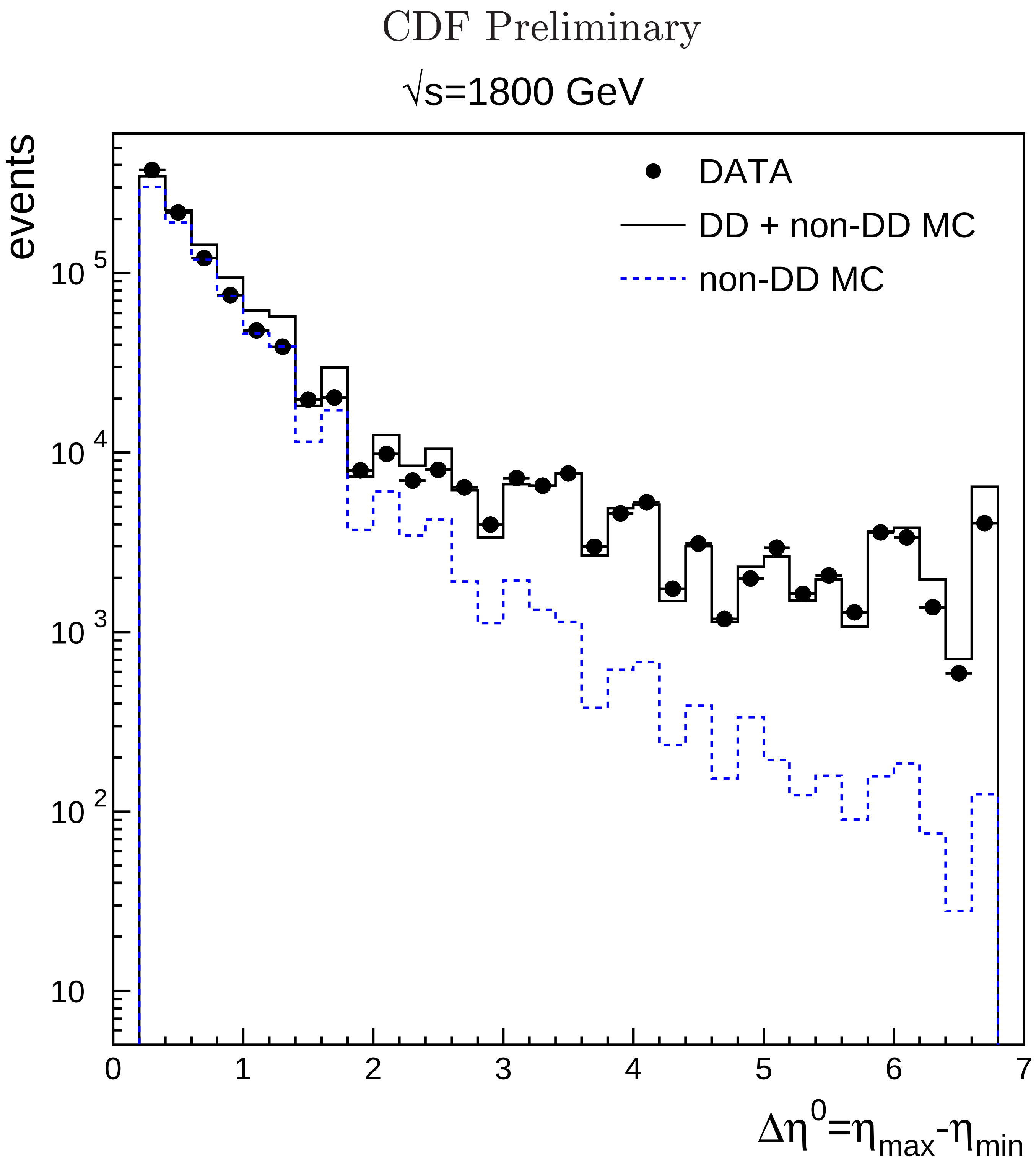
$$\text{reduced energy} \quad s' = M_1^2 M_2^2/s_0 = s\, e^{-\Delta y} = s\xi$$

$$\frac{d^3\sigma_{DD}}{dt\, d\xi\, dy_0} = \underbrace{\frac{\kappa\beta^2(0)}{16\pi}\, \xi^{1-2\alpha(t)}}_{\sim \frac{1}{\xi^{1+2\epsilon}}}\ \underbrace{\kappa\beta^2(0)\left(\frac{s'}{s_0}\right)^{\alpha(0)-1}}$$

CDF Preliminary

$\sqrt{s}$=1800 GeV




CDF Preliminary
√s=1800 GeV
events
DATA
DD + non-DD MC
non-DD MC
10
10 2
10 3
10 4
10 5
0
1
2
3
4
5
6
7
Δη0=ηmax-ηmin

CDF Preliminary

DD cross section for central gaps $\Delta\eta^0 > 3$
$\sqrt{s} = 1800$ GeV

$$\sigma_{DD}(\Delta\eta^0 > 3) = (51.2\pm1.7 \text{ mb}) \frac{59880 - 7234^{+3917}_{-3911}}{1021400(1.151)A}$$

$$= [2.29\pm0.01(\text{stat})\pm0.08(\sigma_{BBC})^{+0.18}_{-0.17}(\text{bkgrd}) \text{ mb}]/A$$

Regge theory

$$\sigma_{DD}(\Delta\eta^0 > 3) = [24.3\pm0.3(\text{stat})^{+2.7}_{-2.1}(\text{calib}) \text{ mb }]/A$$

$\rightarrow$ discrepancy factor $D = 0.09 \pm 0.1$

trigger efficiency $A \sim 50\%$

CDF Preliminary

DD cross section for central gaps $\Delta\eta^0 > 3$

$\sqrt{s} = 630$ GeV

$$\sigma_{DD}(\Delta\eta^0 > 3) = (39.9 \pm 1.2 \text{ mb}) \, \frac{136671 - 13802}{1670764(1.107)A}$$

$$= [2.65 \pm 0.01(\text{stat}) \pm 0.08(\sigma_{BBC})^{+0.13}_{-0.35}(\text{bkgrd}) \text{ mb}]/A$$

Regge theory

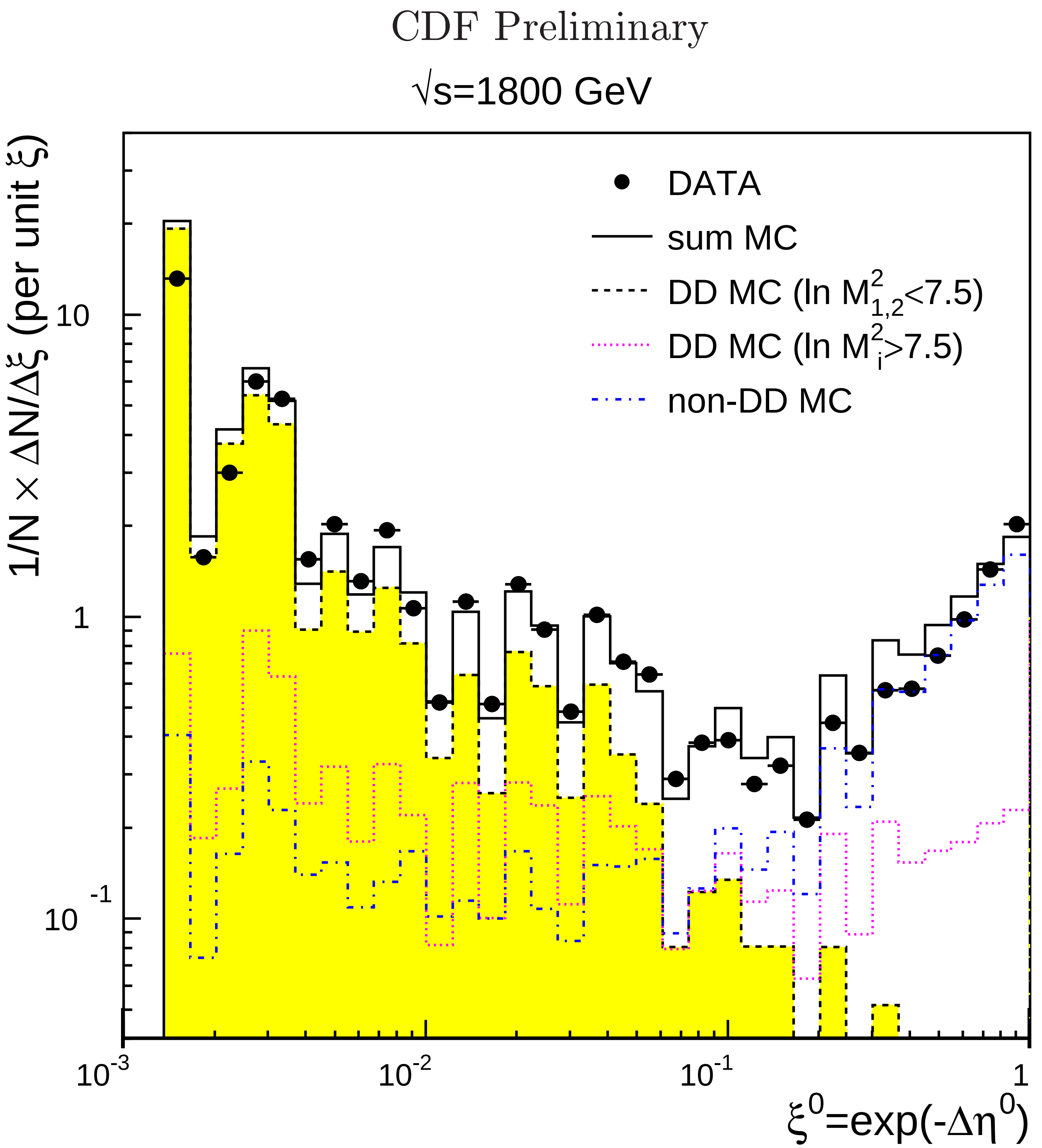
$$\sigma_{DD}(\Delta\eta^0 > 3)) = [18.4 \pm 0.2(\text{stat})^{+1.7}_{-1.5}(\text{calib}) \text{ mb}]/A$$

$$\rightarrow \text{discrepancy factor } D = 0.14 \pm 0.02$$

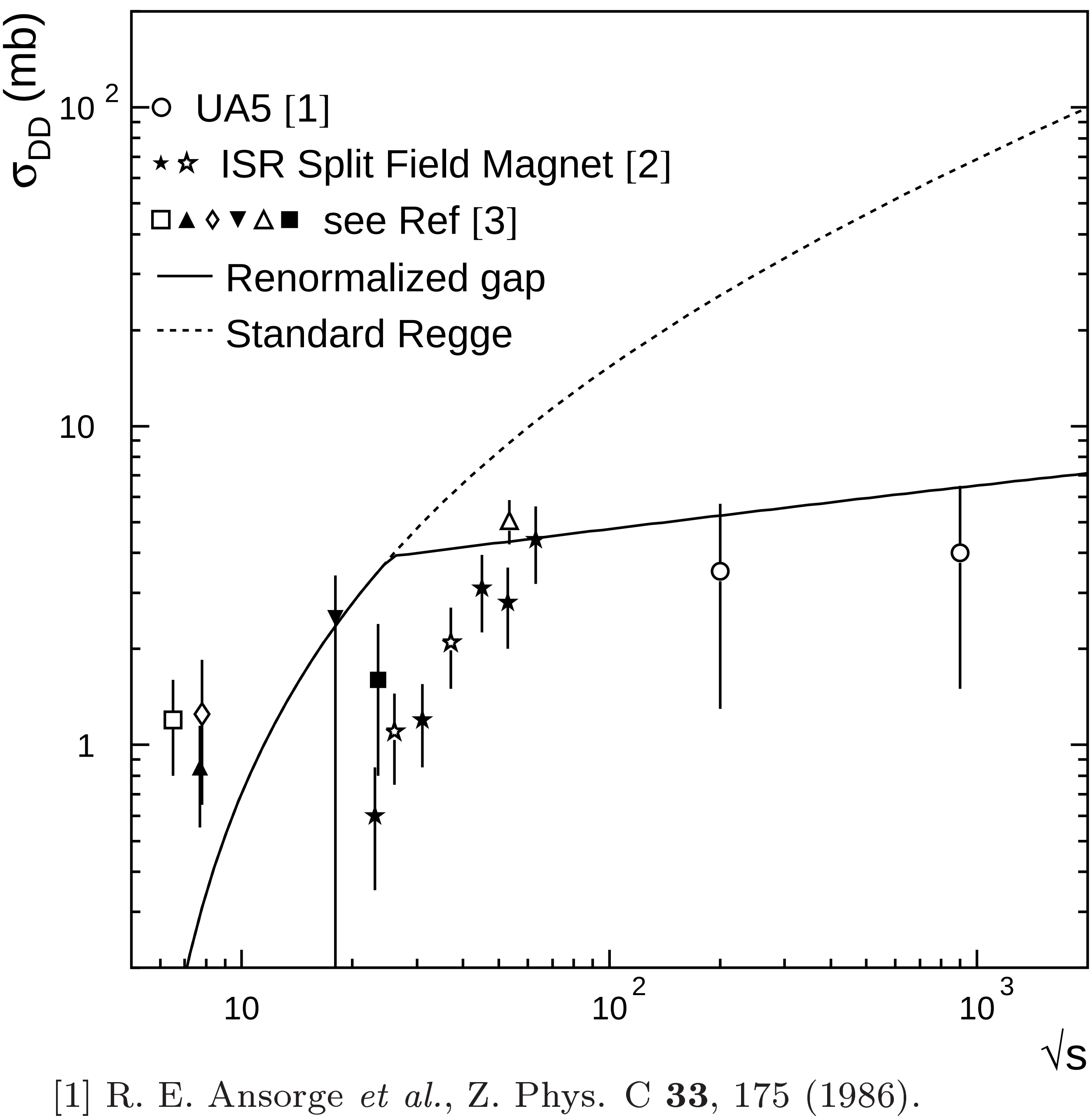
$$A \sim 60\%$$

$$D(630)/D(1800) \sim 1.5 \rightarrow D \sim 1/s^{2\epsilon}$$

Goulianos, Phys. Lett. B**358**, 379 (1995)



CDF Preliminary
√s=1800 GeV
DATA
sum MC
DD MC (ln $M^2_{1,2}$<7.5)
DD MC (ln M^2_i>7.5)
non-DD MC
$1/N \times \Delta N/\Delta\xi$ (per unit ξ)
10
1
10^{-1}
10^{-3}
10^{-2}
10^{-1}
1
$\xi^0=\exp(-\Delta\eta^0)$



[1] R. E. Ansorge *et al.*, Z. Phys. C **33**, 175 (1986).

[2] C. Conta *et al.*, Nucl. Phys. B **175**, 97 (1980).

[3] A. Givernaud *et al.*, Nucl. Phys. B **152**, 189 (1979) and references therein.

Preliminary Results for Central Rapidity Gaps in Minimum-Bias Events

The shape of the mass distribution is in agreement with the standard theory.

The measured double-diffractive cross sections at $\sqrt{s} = 1800$ and 630 GeV are an order of magnitude smaller than what is predicted using Regge theory based on the triple Pomeron amplitude and factorization.

Both cross sections are in general agreement with the renormalized gap model [Goulianos, Phys. Lett. B**358**, 379 (1995)].

Plans for Run II

MiniPlugs

$3.5 < \eta < 5.5$

lead plates, liquid scintillator, WLS fibers

Beam Shower Counters

scintillator covering $5 < \eta < 7$ used as veto for gap trigger

reinstall Roman Pot detectors on $\bar{p}$ side