HARD DIFFRACTION AT CDF

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(for the CDF II Collaboration)

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http://www.hip.fi/EDS2013//

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STUDIES OF DIFFRACTION AT CDF
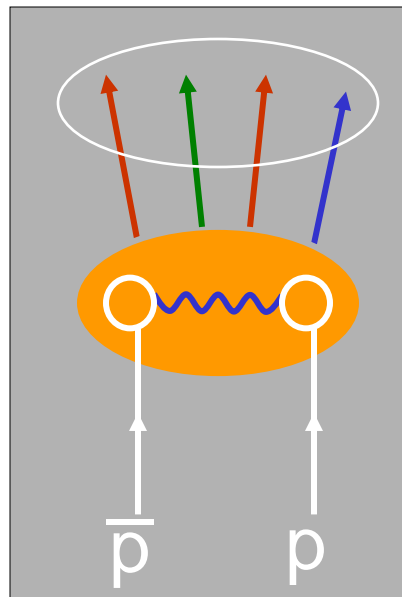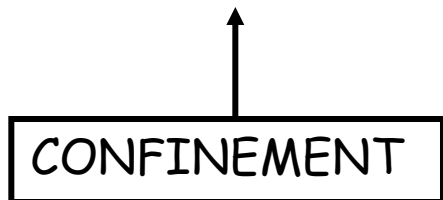
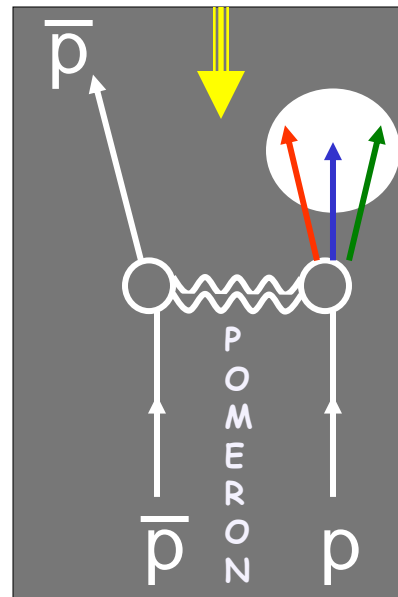## Non-diffractive
❖ color-exchange
➔ gaps exp'lly suppressed

Diffractive
❖ Colorless vacuum exchange
➔ large-gap signature

Incident hadrons acquire color and break upart

CONFINEMENT

rapidity gap

$\overline{p}$
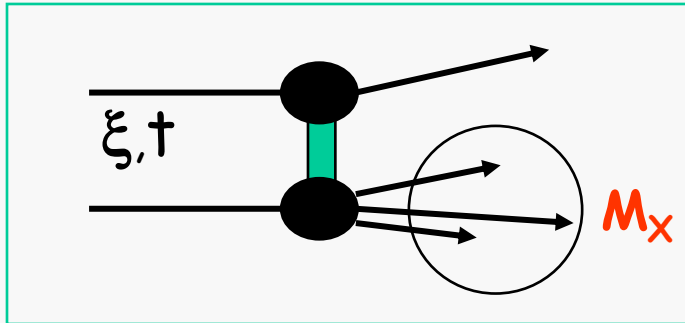
POMERON

$\overline{p}$ p

$\overline{p}$ p

Incident hadrons retain their quantum numbers remaining colorless

Goal: probe the QCD nature of the diffractive exchange

DEFINITIONS

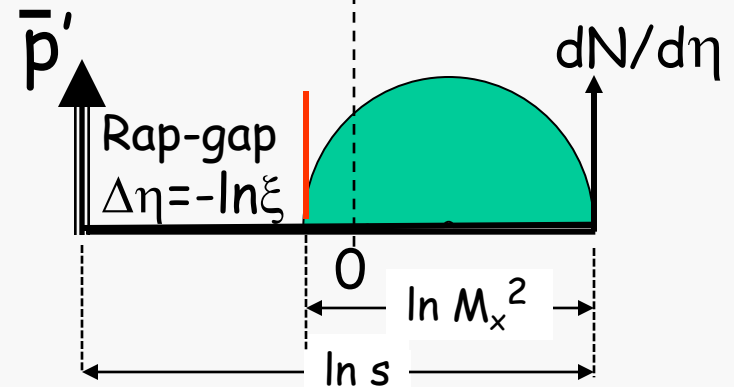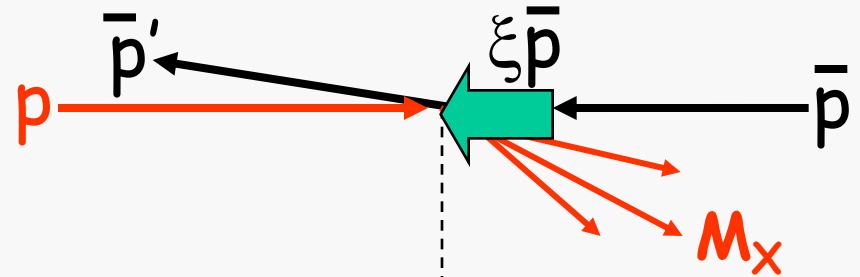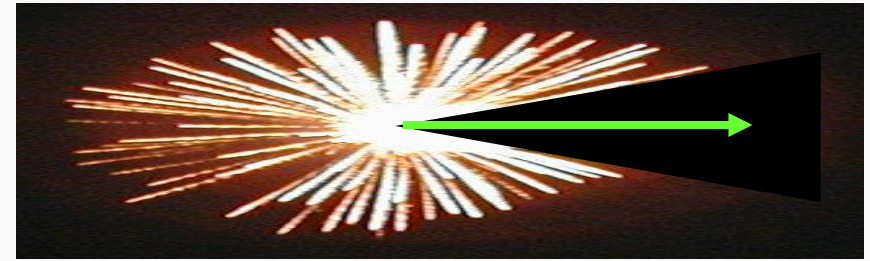**SINGLE DIFFRACTION**

$$1- x_{\mathrm{L}} \equiv \xi = \frac{M_X^2}{s}$$

$$\xi^{CAL} = \frac{\sum_{i=1}^{all} E_T^{i\text{-tower}} e^{-\eta_i}}{\sqrt{s}}$$

$\bar{p}'$ $\xi\bar{p}$ $\bar{p}$

p M_X

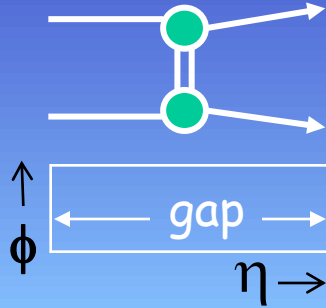$\bar{p}'$ dN/dη

Rap-gap
$\Delta\eta = -\ln\xi$

0

$\ln M_x^2$

$\ln s$

since no radiation →
no price paid for increasing diffractive gap size

$$\left(\frac{d\sigma}{d\Delta\eta} \right)_{t=0} \approx \text{ constant} \Rightarrow \frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \Rightarrow \frac{d\sigma}{dM_x^2} \propto \frac{1}{M_x^2}$$
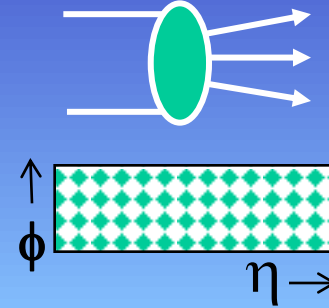
DIFFRACTION AT CDF

Elastic scattering

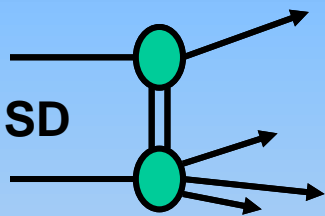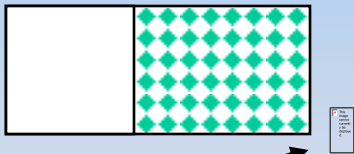$\sigma_T = \mathrm{Im}\, f_{el}\,(t=0)$

Total cross section

gap

OPTICAL THEOREM

SD

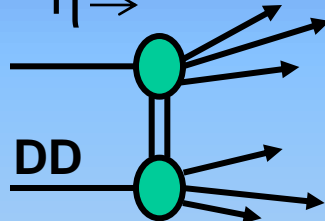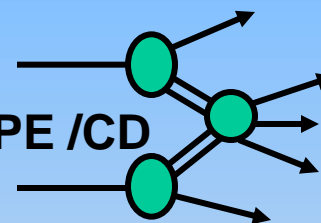**Single Diffraction or Single Dissociation**

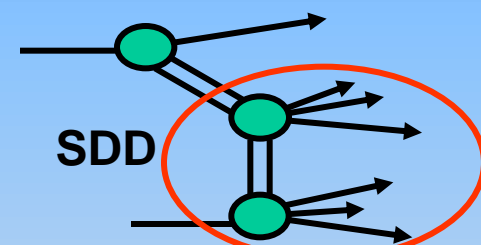**DD**

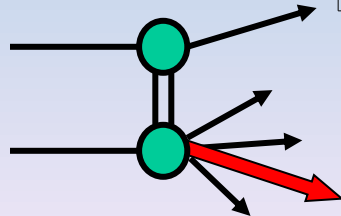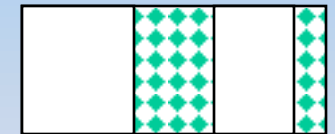**Double Diffraction or Double Dissociation**

DPE /CD

Double Pom. Exchange or Central Diffraction

SDD

Single + Double Diffraction (SDD)

$JJ, b, J/\psi, W, Z$

exclusive $JJ...ee...\mu\mu...\gamma\gamma\square\pi\pi$

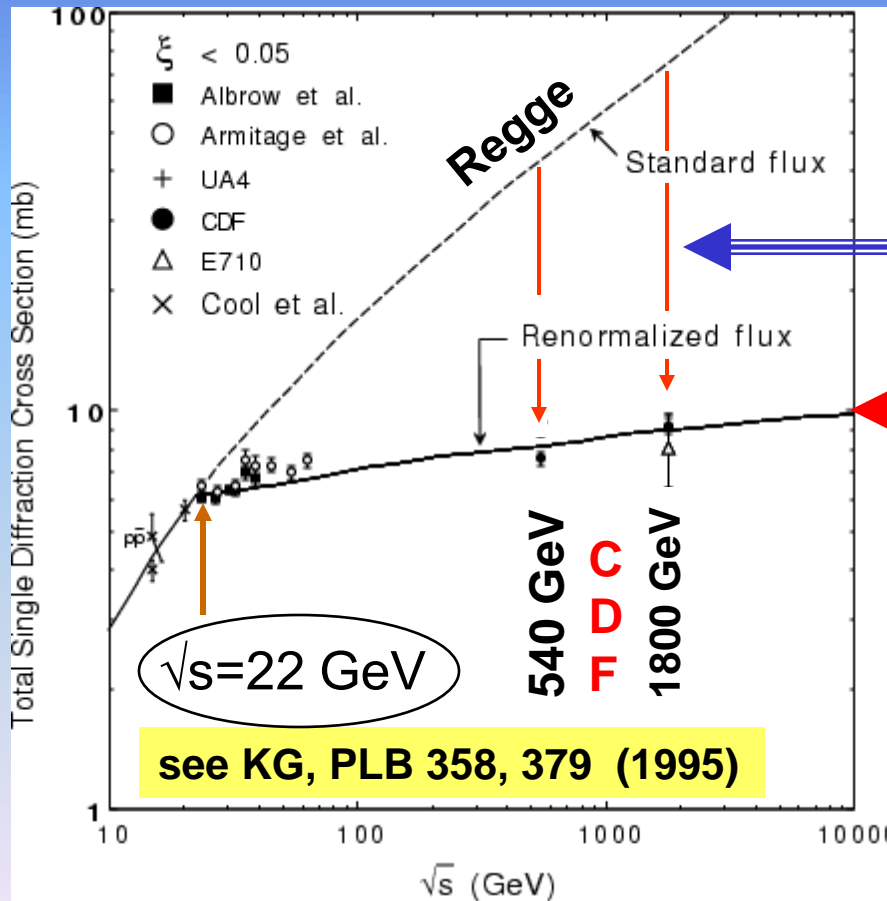$\overline{p}$

p

FACTORIZATION BREAKING IN SOFT DIFFRACTION

➔ diffractive x-section suppressed relative to Regge prediction as $\sqrt{s}$ increases
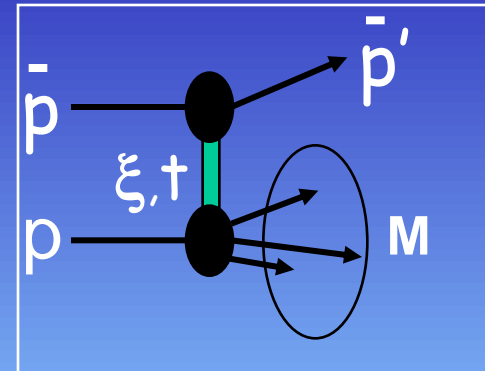
Factor of ~8 (~5) suppression at $\sqrt{s}$ = 1800 (540) GeV

RENORMALIZATION

❑ **Question:**
does factorization breaking affect *t*-distributions?

ξ < 0.05
- ■ Albrow et al.
- ○ Armitage et al.
- + UA4
- ● CDF
- △ E710
- ✕ Cool et al.

Regge

Standard flux

Renormalized flux

$\sqrt{s}$=22 GeV

540 GeV   **C**
          D
          F
1800 GeV

see KG, PLB 358, 379 (1995)

Total Single Diffraction Cross Section (mb)

$\sqrt{s}$ (GeV)

Hard diffraction

$$\bar{p}p \rightarrow (\text{☀} + X) + \text{gap}_p \text{ or gap}_{pbar}$$

Fraction:
SD/ND ratio
@ 1800 GeV

☀	Fraction %
JJ	0.75 +/- 0.10
W	1.15 +/- 0.55
b	0.62 +/- 0.25
J/ψ	1.45 +/- 0.25

dN/dη

☀ hard

η →
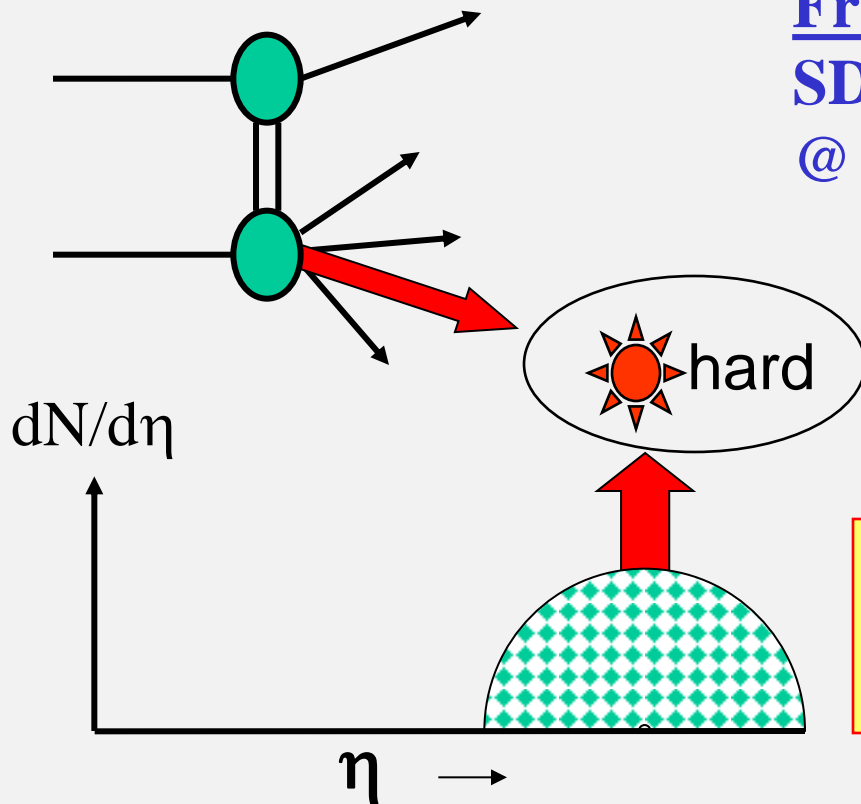
All fractions ~ 1%
(differences due to kinematics)
➢   ~ **FACTORIZATION !**

Diffractive dijets in Run I
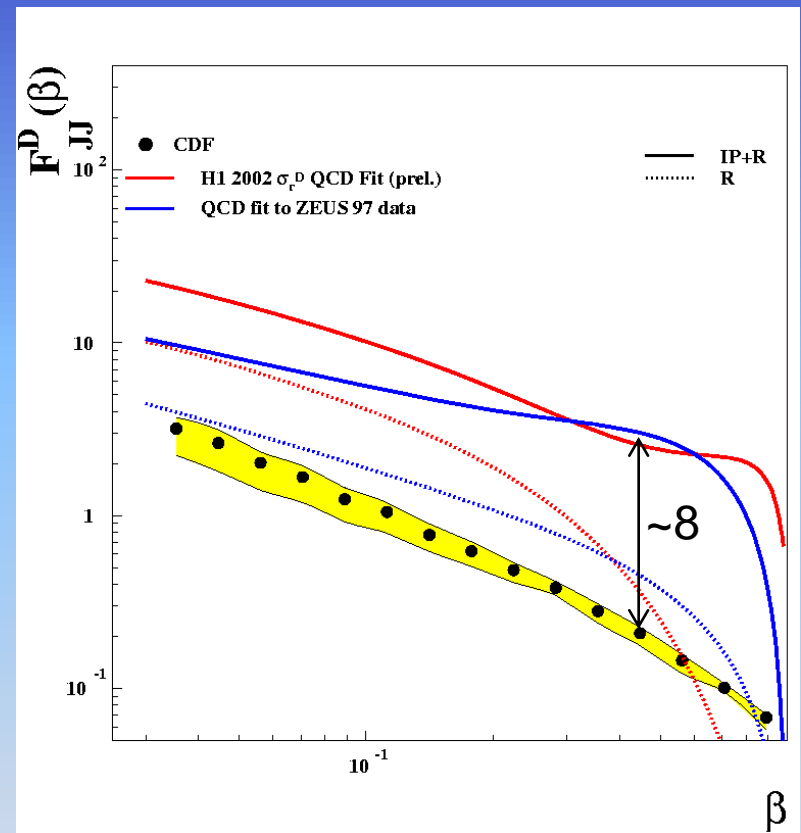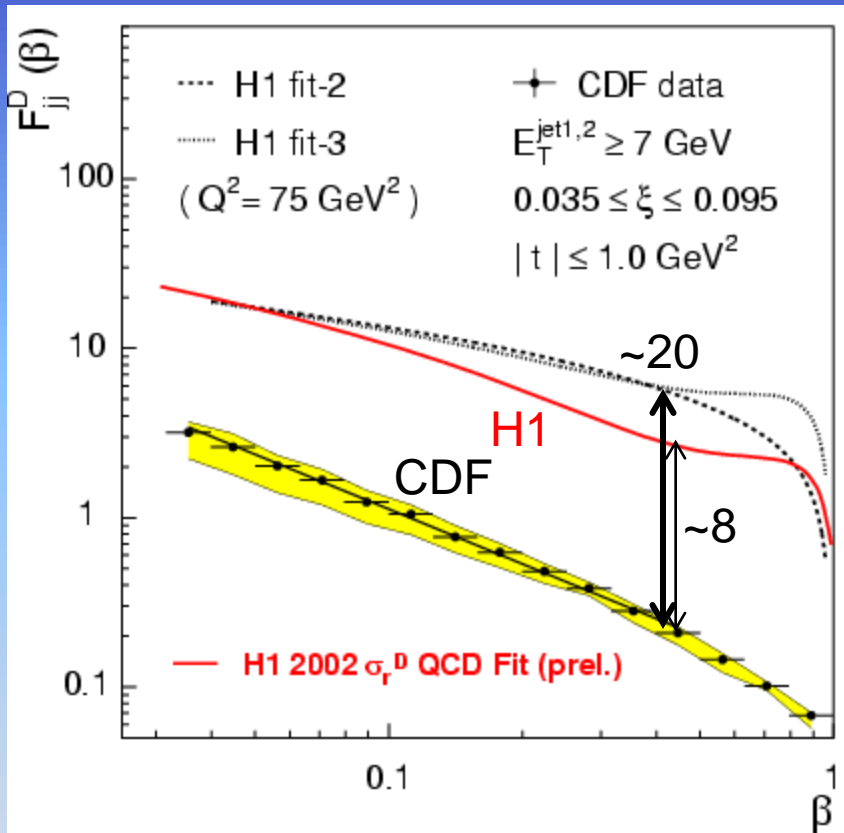
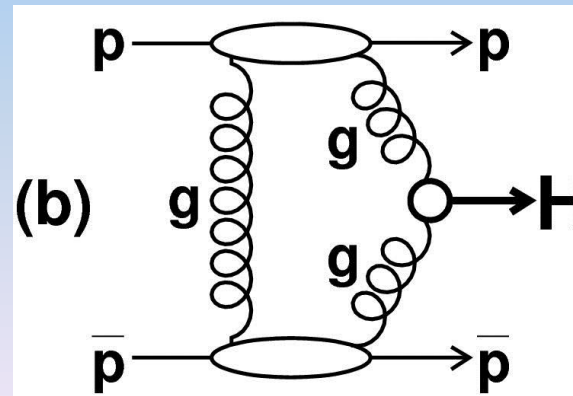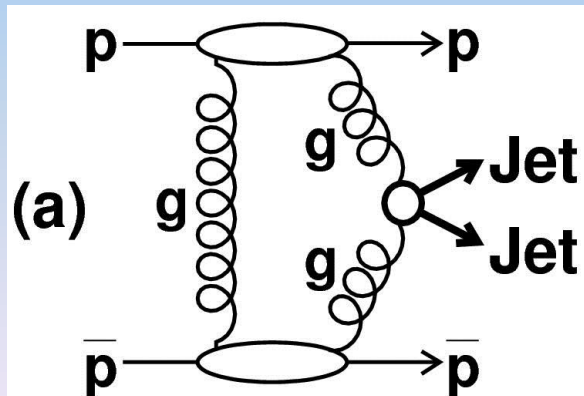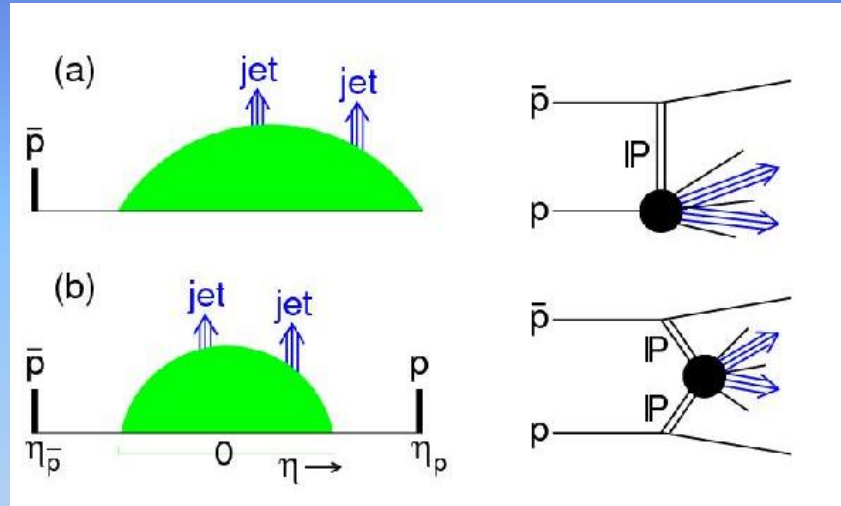☐ All hard-diffraction processes in Run I at √s=1.8 TeV are suppressed by factor ~8 relative to predictions based on HERA-measured PDFs.

Excusive dijets
Calibrate diffractive Higgs-production models

Phys. Rev. D 77, 052004 (2008)

THE CDF II DETECTOR

CDF-II

PLAN VIEW

DIPOLEs   EBS   QUADs   QUADs   EBS   DIPOLEs

2m

$\bar{p}$ p

57m to CDF-II-center (z=0)

TRACKING SYSTEM   CCAL   PCAL   MP   CLC   BSC   RPS
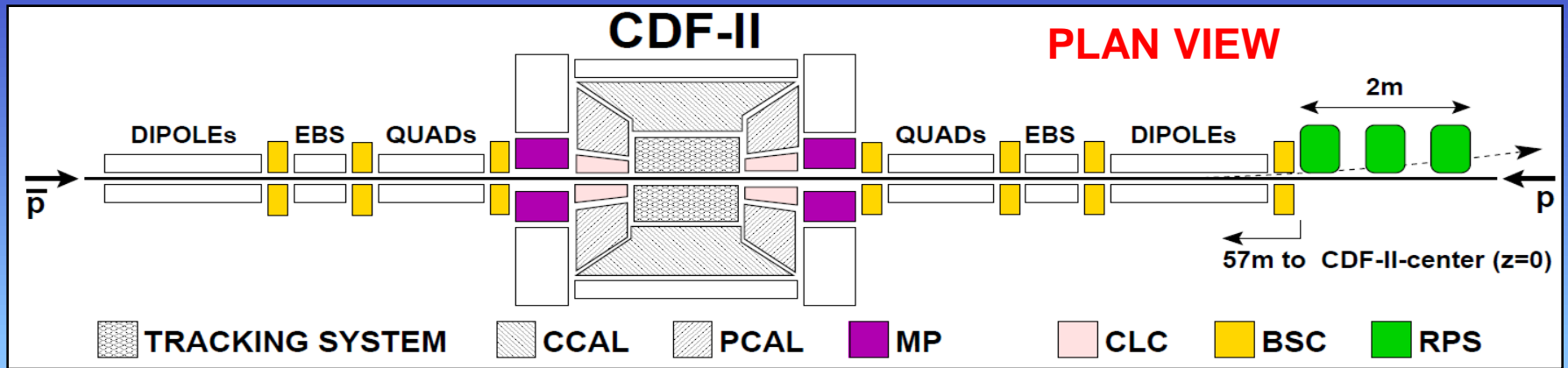
$|\eta|<2$ ←$|\eta|<3.6$→ $3.5<|\eta|<5.1$ $5.4<|\eta|<7.4$

~$0.03<\xi<0.09$ $0<|t|<4$ GeV^2
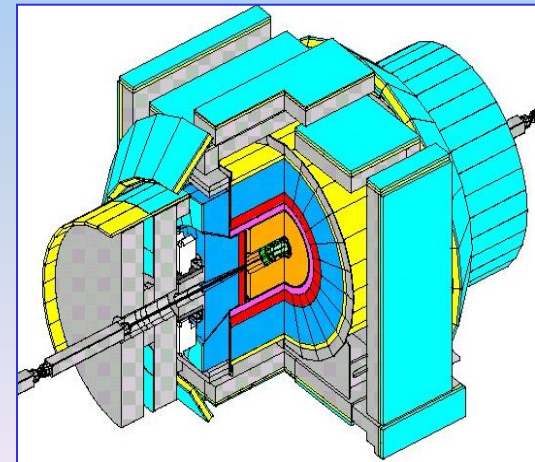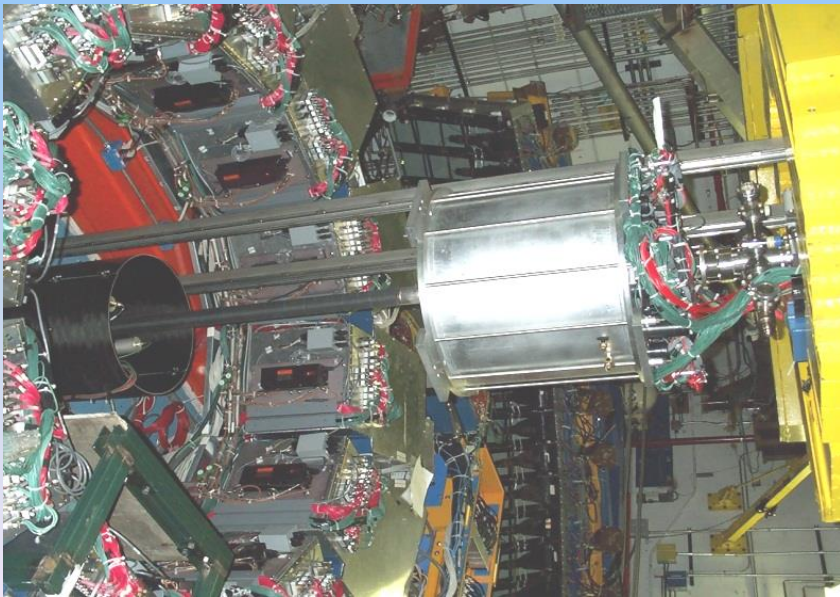
The RPS
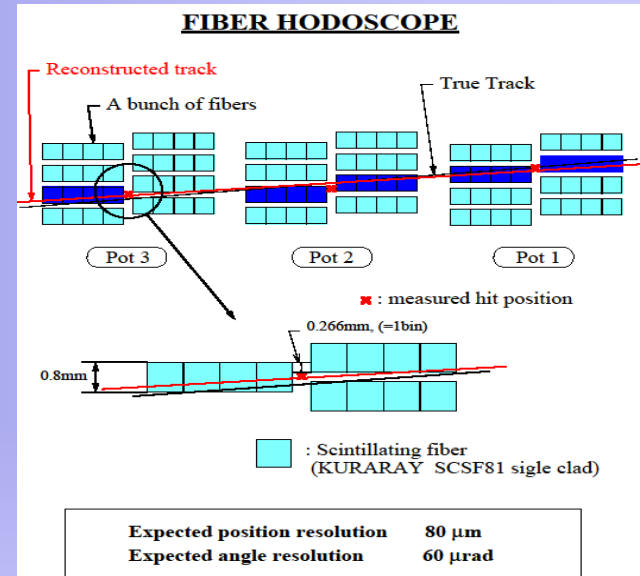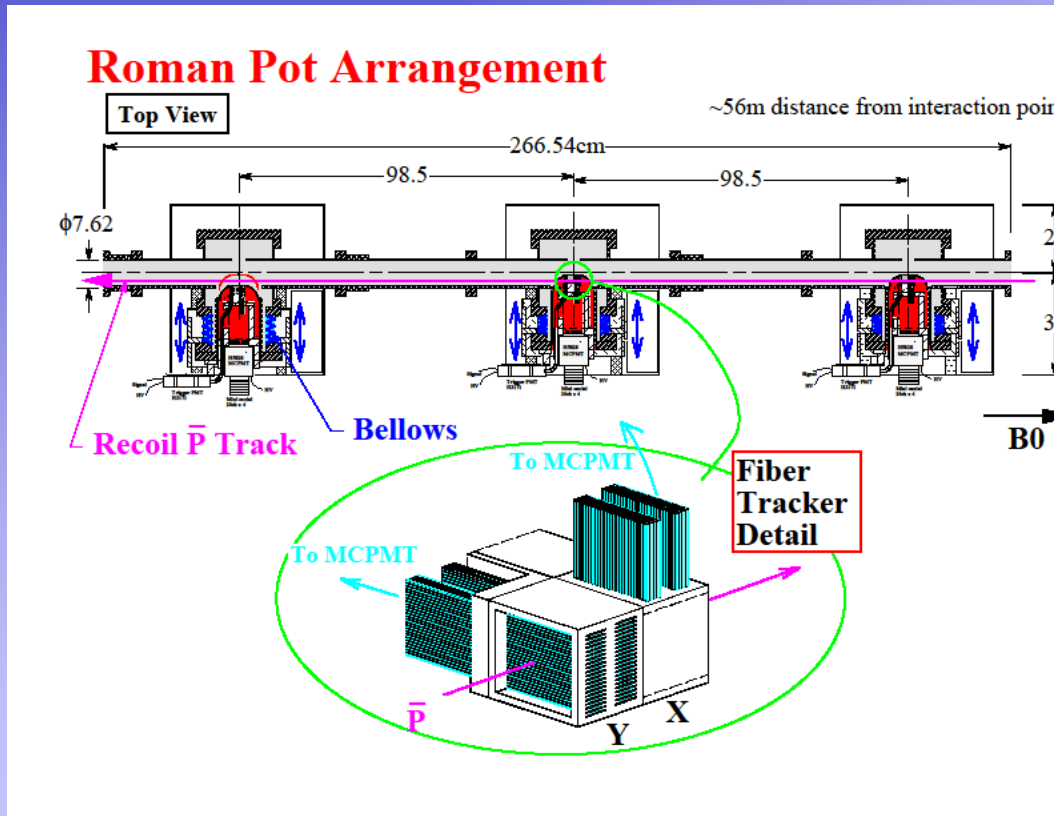
The MiniPlugs
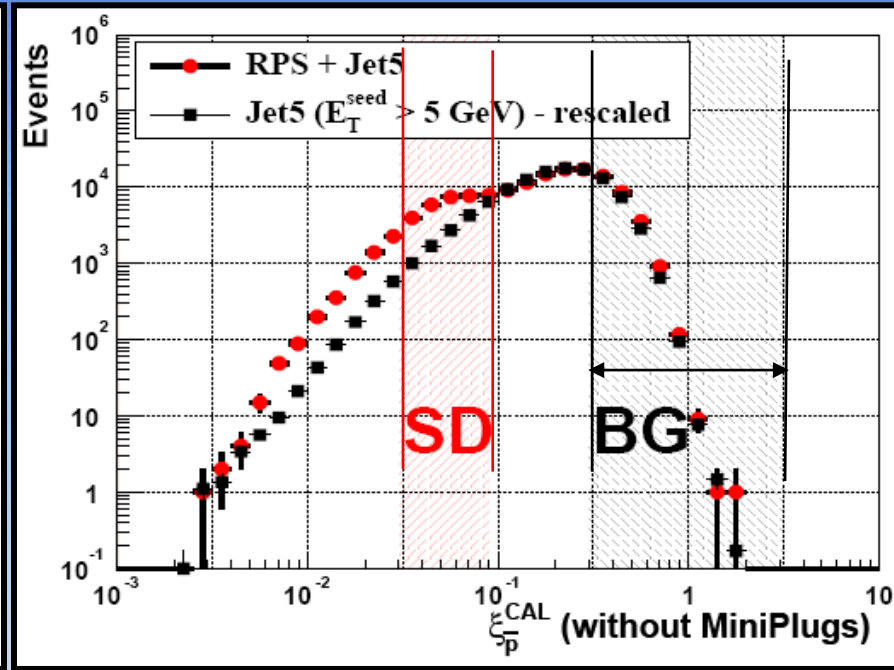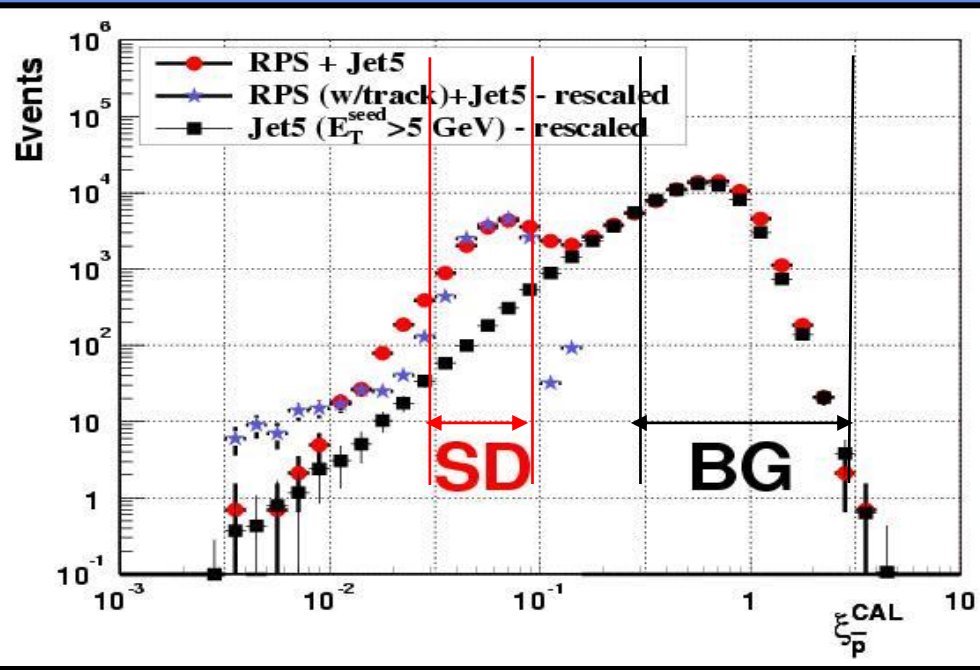
➜ overlap bgnd (BG) is reduced by including the MPs in the ξ^{CAL} evaluation

Dynamic Alignment of RPS

Method: iteratively adjust the RPS X and Y offsets from the nominal beam axis until a maximum in the b-slope is obtained @ t=0.
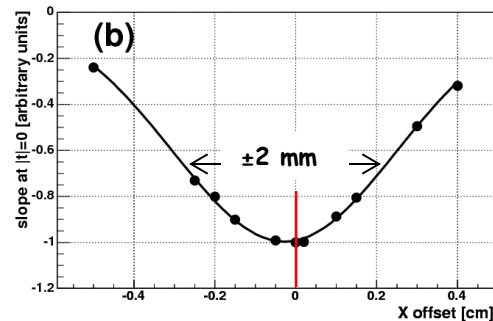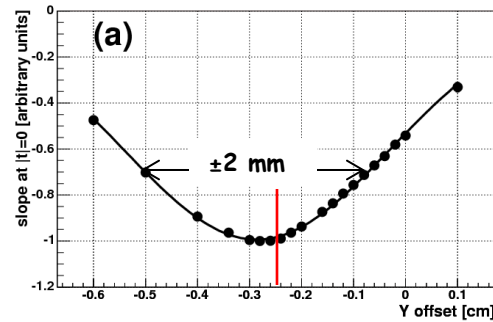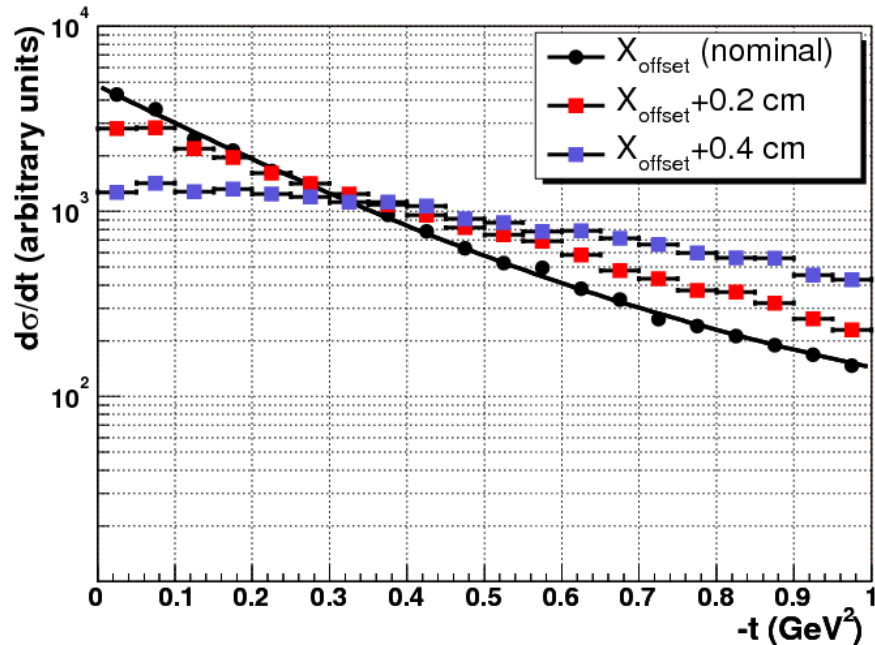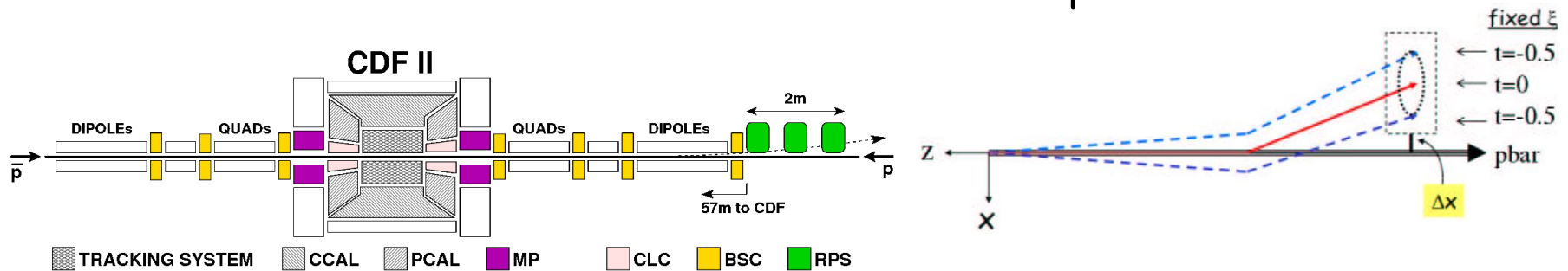
Limiting factors

1-statistics
2-beam size
3-beam jitter

use RPStrk data
width~ 2 mm/√N
N~1 K events
$\Delta X, \Delta Y = \pm 60 \ \mu$

ξ^{CAL} vs ξ^{RPS}

slice
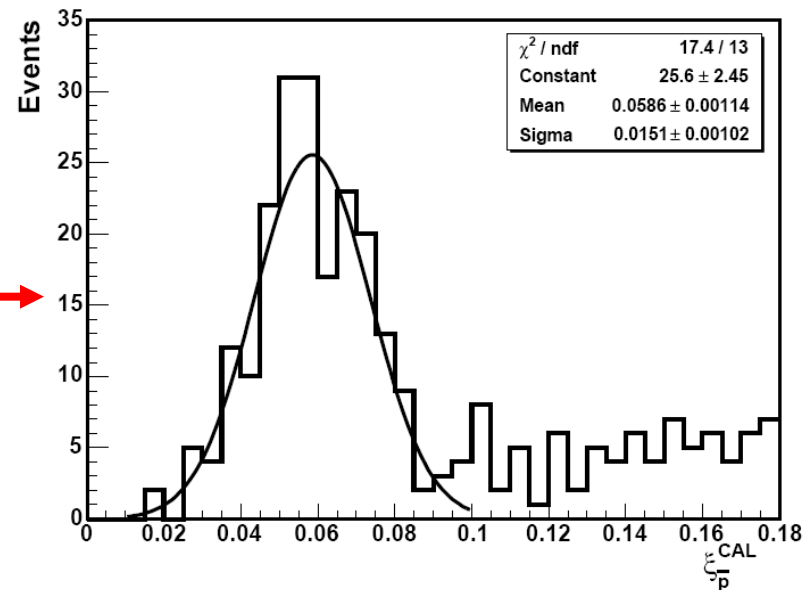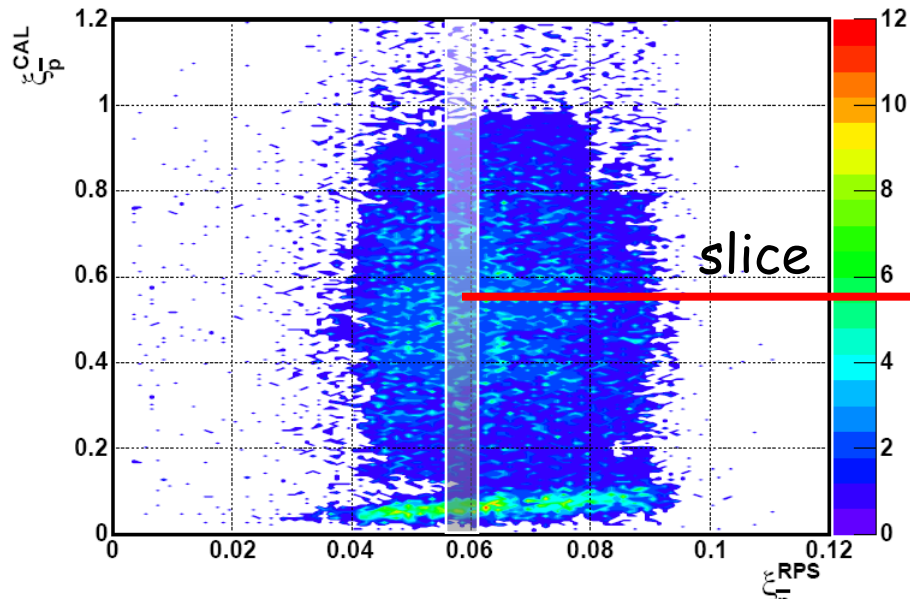
$$0.04 < \xi_{\overline{p}}^{\text{RPS}} < 0.09$$

$$\xi_{\overline{p}}^{\text{CAL}} = p^0 + p1 \cdot \xi_{\overline{p}}^{\text{RPS}}$$

$$p^0 = 0.007 \pm 0.002 \text{ and } p1 = 0.97 \pm 0.04$$
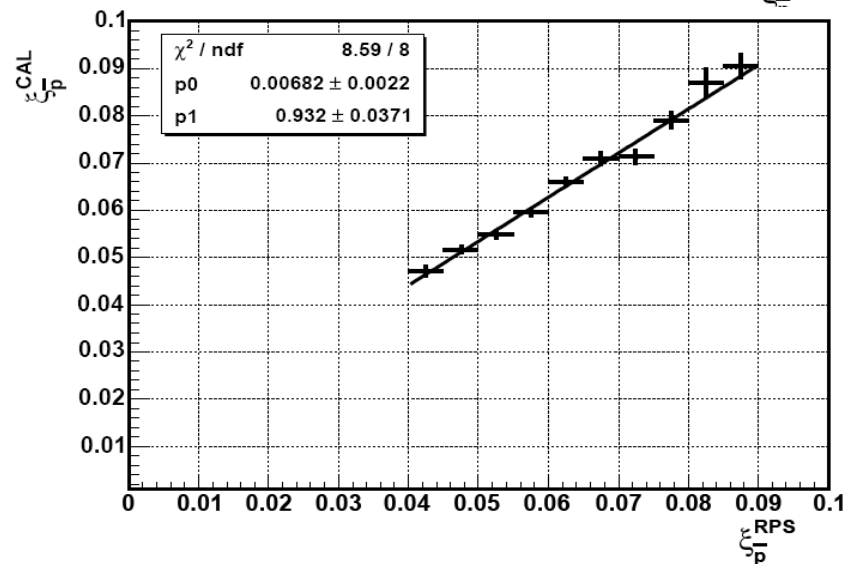
Why select $0.05 < \xi_{pbar} < 0.08$?
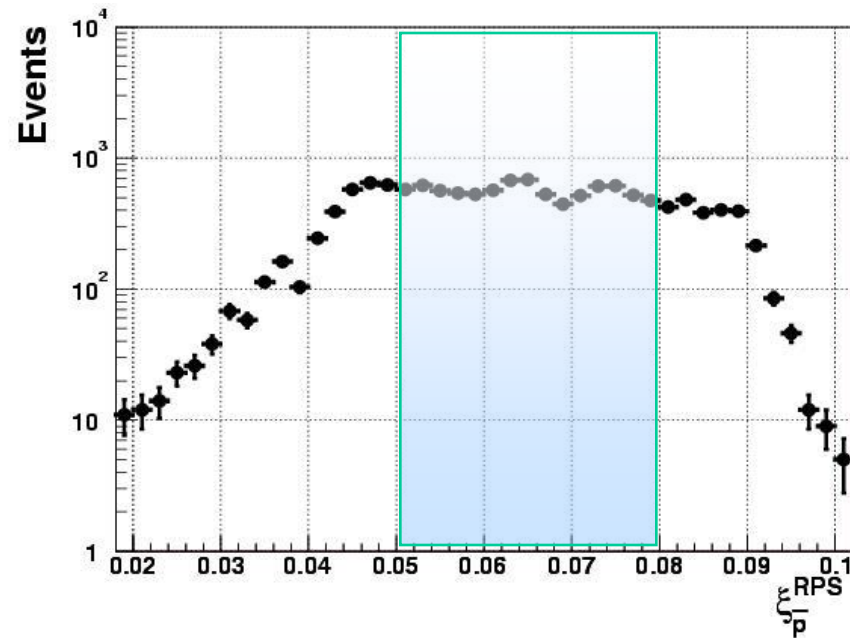
- ❑ be on the plateau of the $ds/d\ln\xi$ distribution
- ❑ allow enough room to avoid edge-effects
- ❑ accept enough events for good statistics

❑ **estimated width resulting from the $\Delta\xi$: $\Delta\tau \approx 0.47$**

RPS ACCEPTANCE

0.05 < ξ <0.08

slowly varying at high t
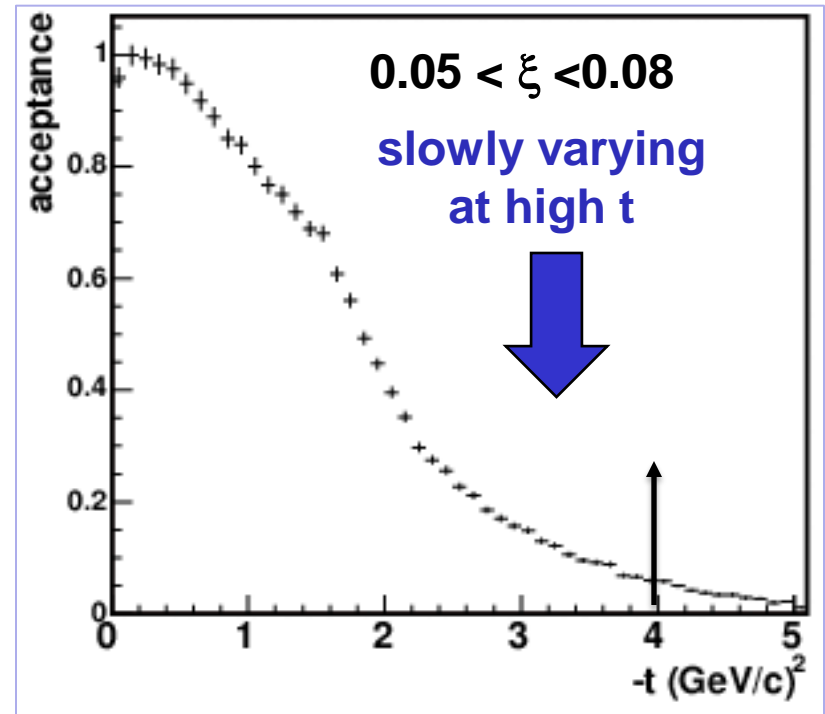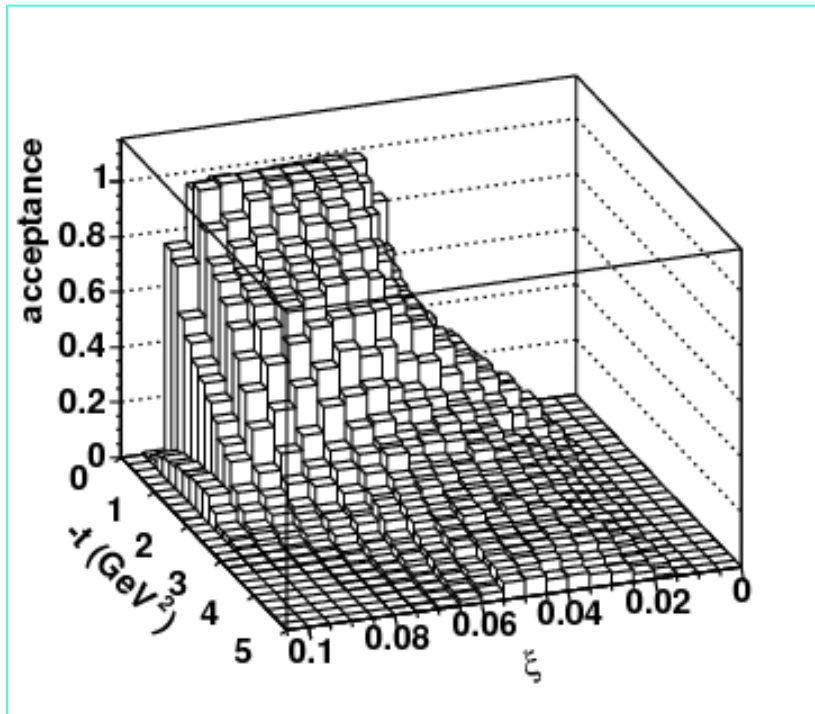
❑ **Measure up to –*t* = 4 GeV2**
❑ **Having acceptance beyond 4 GeV² minimizes edge effects**

$t > 1$ GeV^2: asymmetric t-distributions as a tool for evaluating bgd at high t

schematic view of fiber tracker

t-distributions
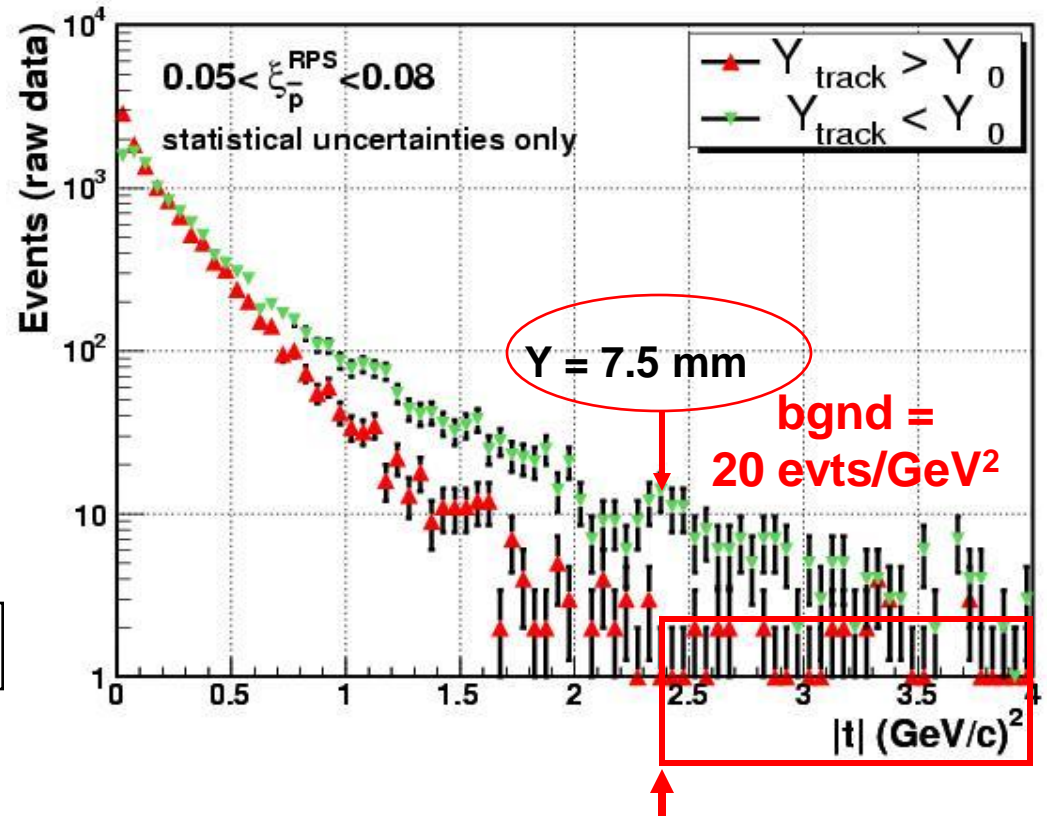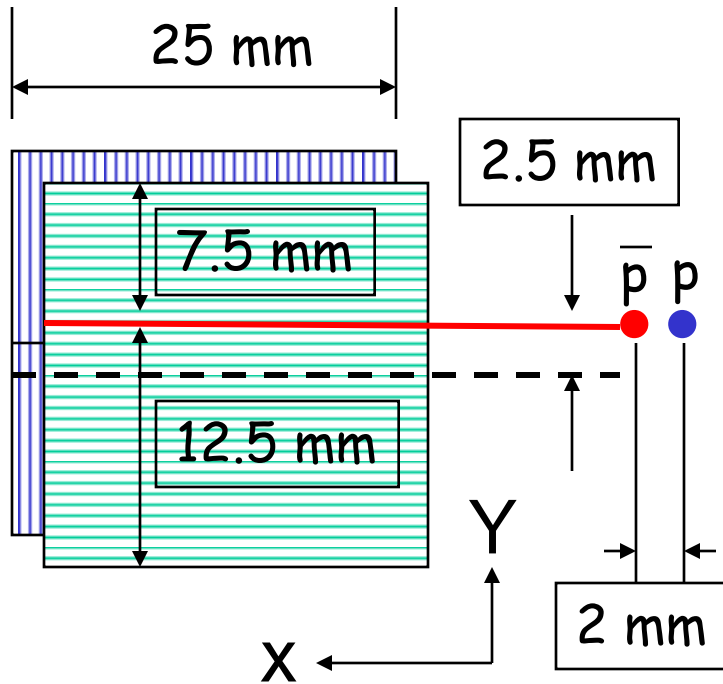
- tracker's upper edge: $|t|=2.3$ GeV^2, estimated from $t\sim\theta^2$
- the lower edge is at $|t|= 6.5$ GeV^2 (not shown)
- background level: region of $Y_{track}>Y_o$ data for $|t|>2.3$ GeV^2

Diffractive dijet results

http://arxiv.org/abs/1206.3955

PHYSICAL REVIEW D **86,** 032009 (2012)

Measurement of $F_{jj}^{\rm SD}$

$$\frac{d^5\sigma_{jj}^{\rm SD}}{dx_{\bar{p}}dx_p d\hat{t}d\xi dt} = \frac{F_{jj}^{\rm SD}(x_{\bar{p}}, Q^2, \xi, t)}{x_{\bar{p}}} \cdot \frac{F_{jj}^{\rm incl}(x_p, Q^2)}{x_p} \cdot \frac{d\hat{\sigma}_{jj}}{d\hat{t}}$$

$$F_{jj}^{\rm incl}(x, Q^2) = x\left[g(x, Q^2) + \frac{4}{9}\sum_i q_i(x, Q^2)\right]$$

$$\mathrm{R}_{\rm SD/ND}(x, Q^2, \xi, t) = \frac{n_{jj}^{\rm SD}(x, Q^2, \xi, t)}{n_{jj}^{ND}(x, Q^2)} \approx \frac{F_{jj}^{\rm SD}(x, Q^2, \xi, t)}{F_{jj}^{\rm ND}(x, Q^2)}$$

$$F_{jj}^{\rm SD}(x, Q^2, \xi, t) = \mathrm{R}_{\rm SD/ND}(x, \xi, t) \times F_{jj}^{\rm ND}(x, Q^2)$$

ξ^{CAL} vs ξ^{RPS}

❑ As RPS tracking was not available for all analyzed data, we used ξ^{CAL} and calibrated it vs ξ^{RPS} from data in which RPS tracking **was** available.
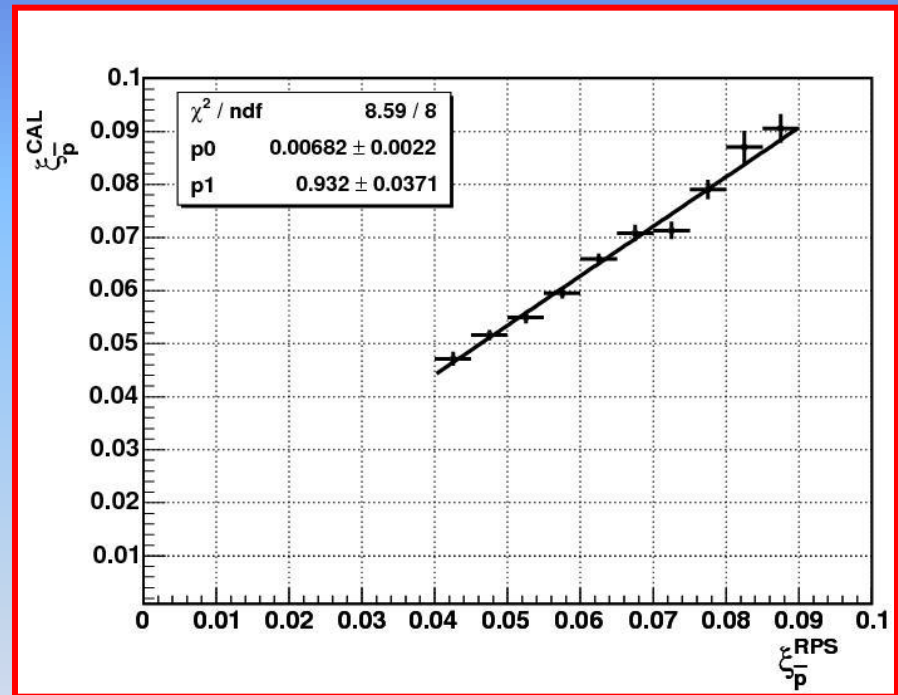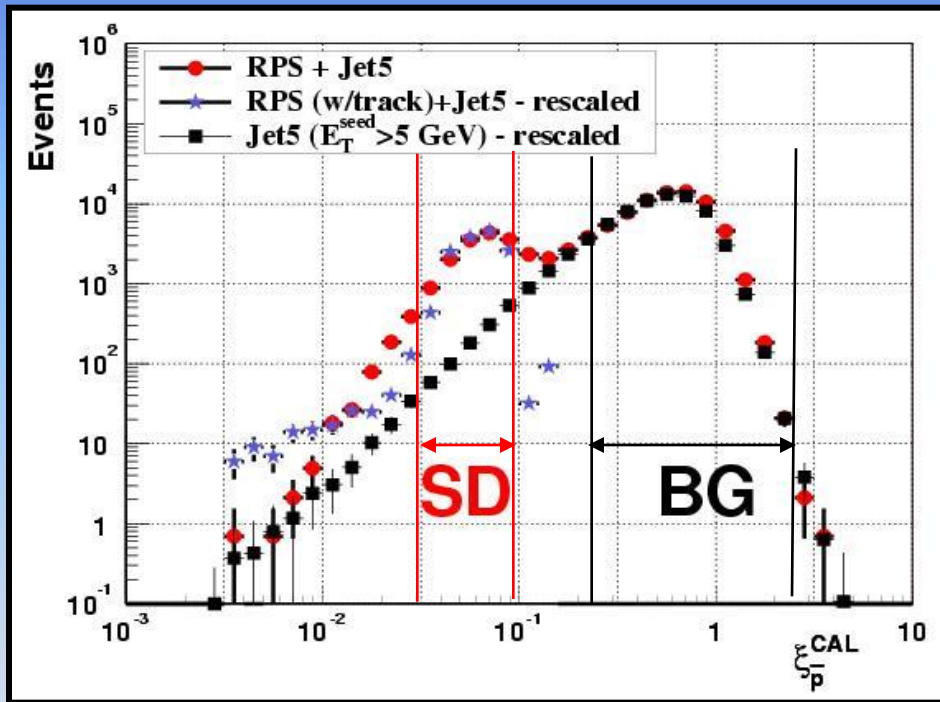
❑ A linear relationship is observed between ξ^{cal} vs ξ^{RPS} in the region of ξ^{cal} of the measurement

Average E_T^{jet} and η^{Jet}
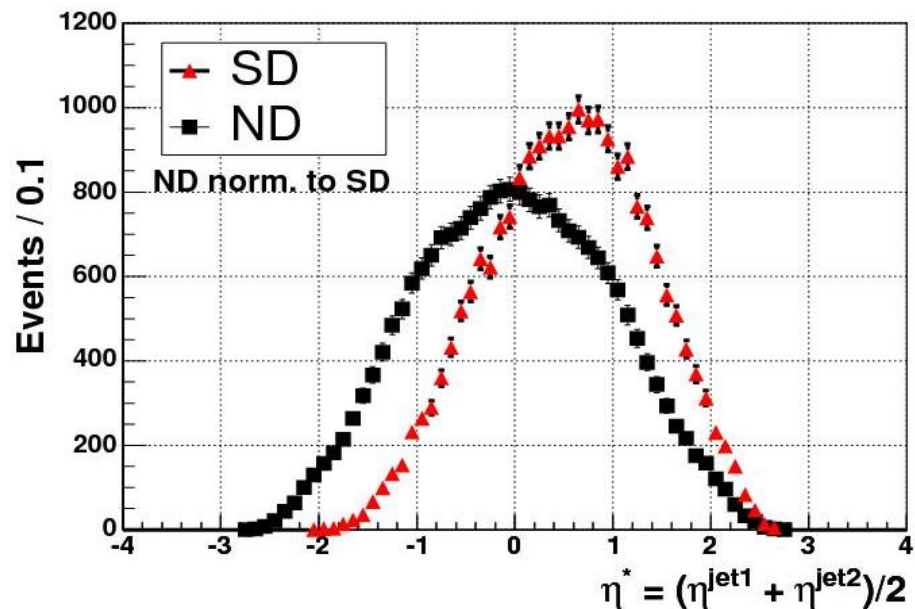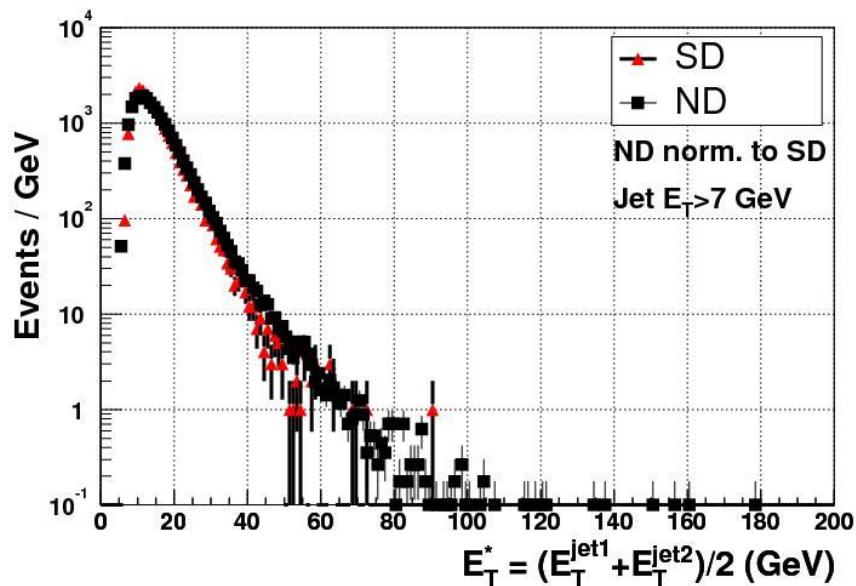
☐ The SD and ND E_T^{Jet} distributions are nearly identical
☐ The SD η^* distribution is shifted towards the c.m.s of the Pomeron-proton collision

Azimuthal angle difference of jets
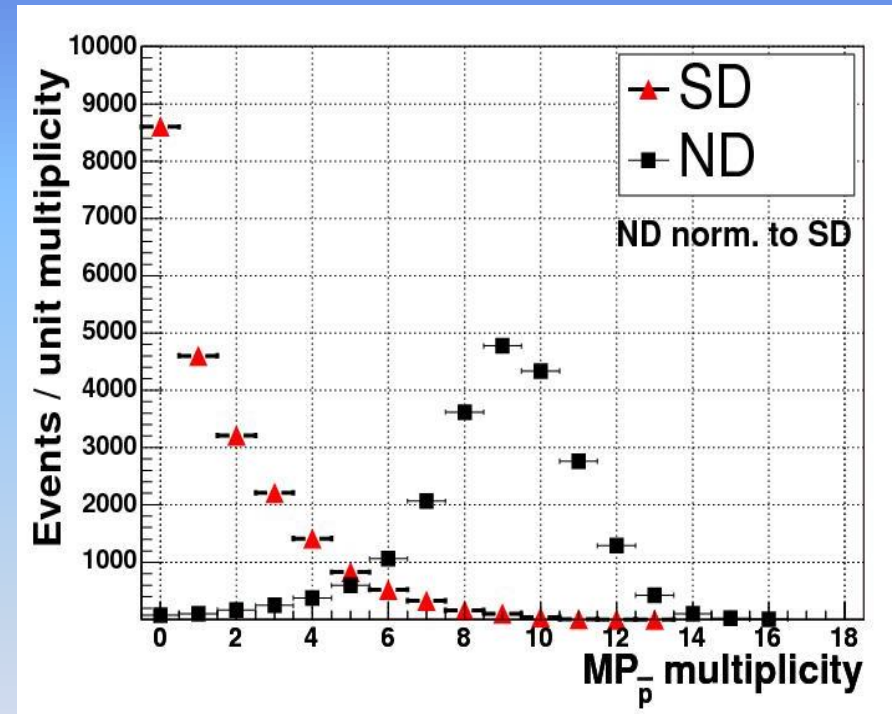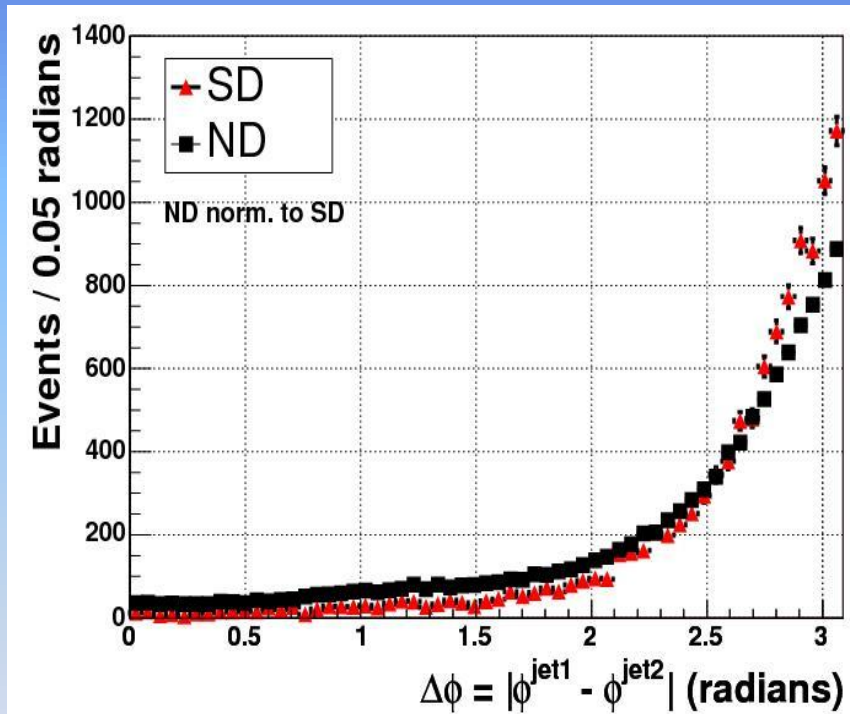
❑ *Left:* the SD distributions are more back-to-back
❑ *Right:* the SD multiplicity is peaked at zero, while the ND is peaked at 9.

x_{Bj} Distributions vs $<Q^2>$

$<Q^2>=100$ GeV^2
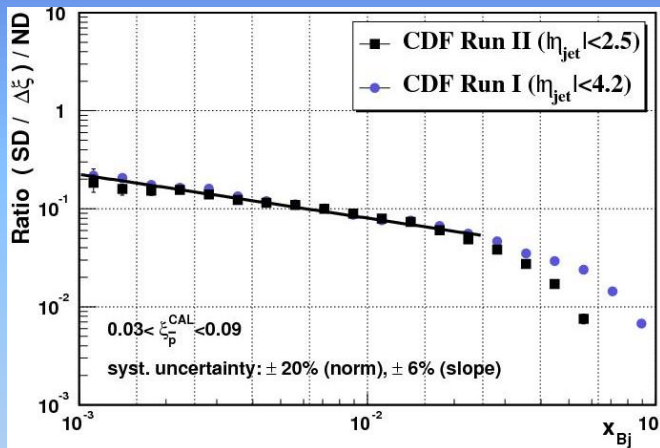
- ❑ The Run I result is confirmed.
- ➤ The drop-off on the rhs is due to the different range of the calorimeters in Run I and Run II.
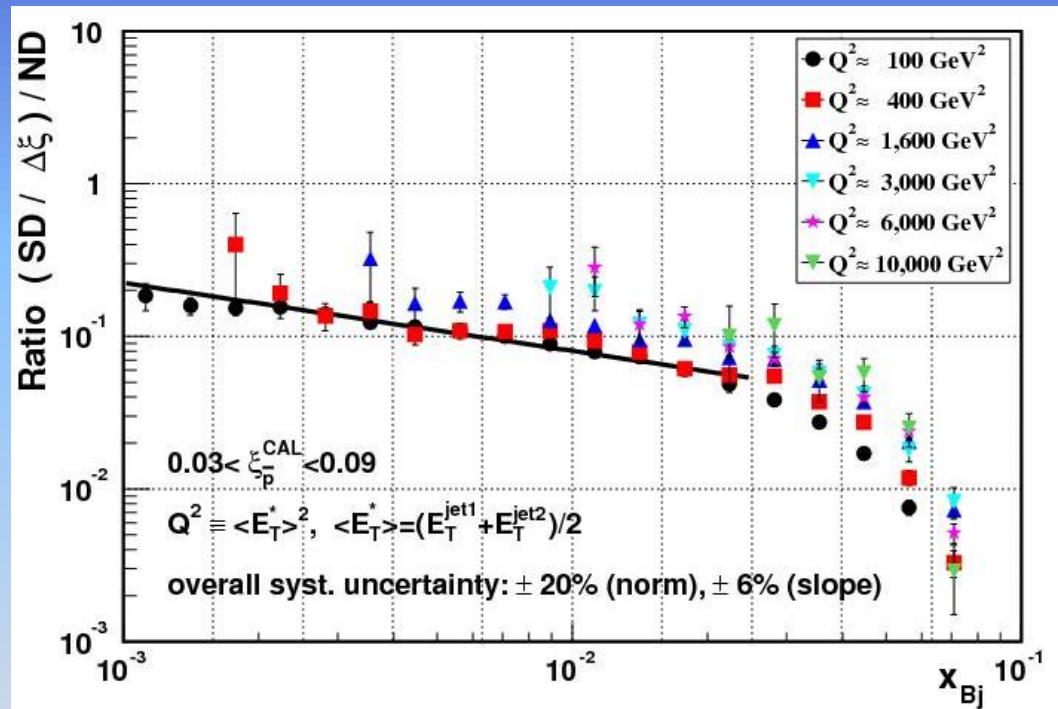
❑ The Bjorken-x distributions vary by only a factor of ~2 over a range of $<Q^2>$ of 2 orders of magnitude!

t-Distributions and Slopes vs $<Q^2>$ for $-t<1$ GeV^2

$$\frac{d\sigma}{dt} = N_{norm}\left(A_1 e^{b_1 t} + A_2 e^{b_2 t}\right)$$
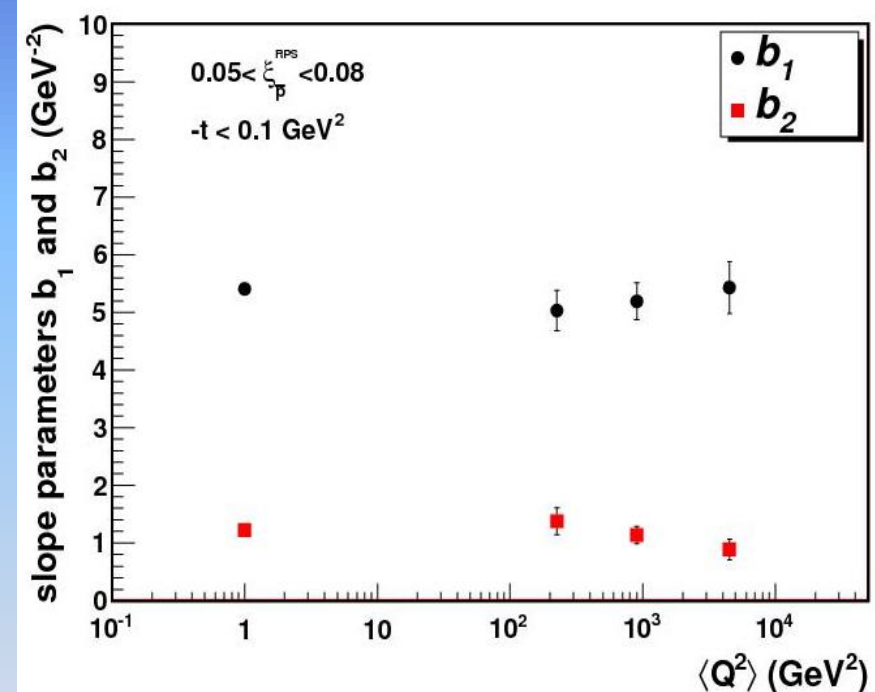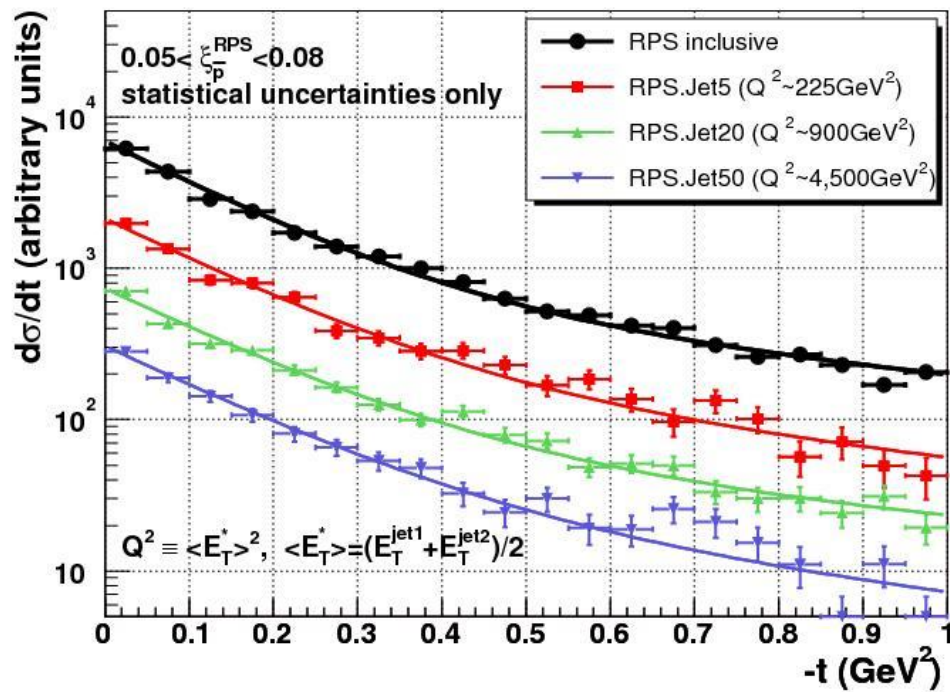
□ The slopes are nearly constant over a range of 4 orders of magnitude in $<Q^2>$!

t-Distributions for -*t*<4 GeV²

The plot shows: $0.05 < \xi_{\bar{p}}^{RPS} < 0.08$

Legend:
- **RPS inclusive**
- **systematics (±30%)**
- **RPS · Jet20 (Q²~900 GeV²)**
- **DL model**

$$\Delta t_{|t|=2.5} = \Delta |t|_{\xi-\text{bin}} + \delta t_{\text{res}} \approx 1 \text{ GeV}^2$$

Y-axis: **Corrected events per 0.05 GeV²**

X-axis: **-t GeV²**
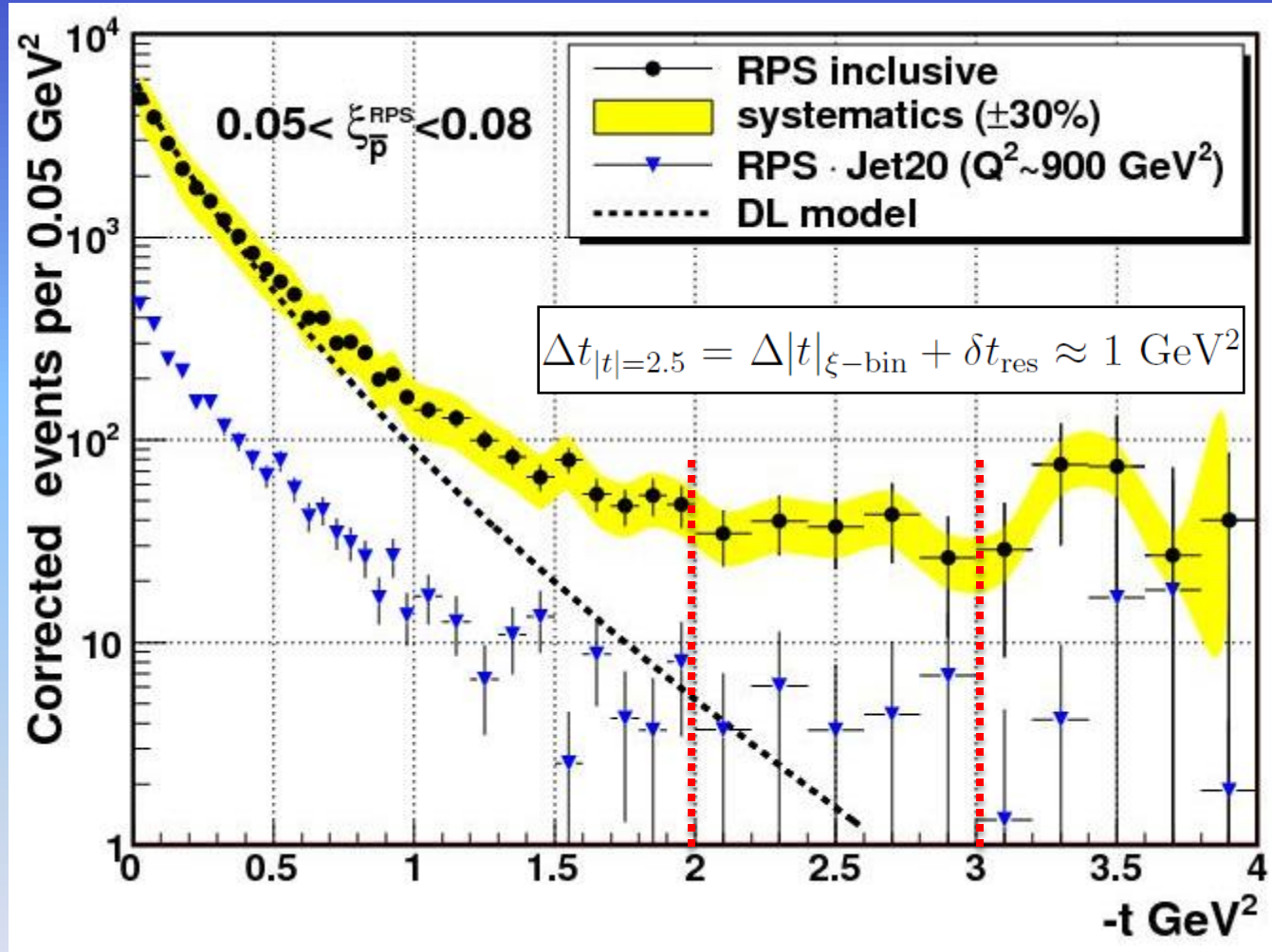
❑ The rather flat –t distributions at large –t are copatible with the existence of an underlying diffraction minimum around –t ~ 2.5 GeV².

Result of the Week

Pomeron creates jets at the Tevatron

rapidity gap
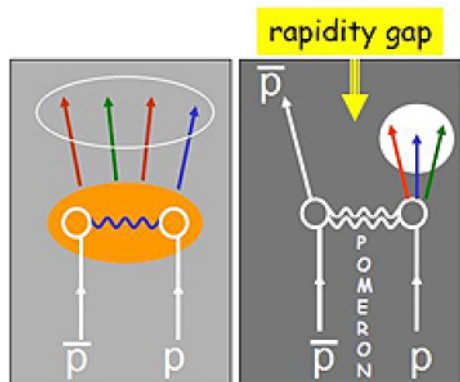
Antiproton-proton scattering by the strong interactions can be non-diffractive (left) or diffractive (right). Both original particles, the proton and antiproton, are colorless.

At the Fermilab Tevatron, protons and antiprotons were brought into collision at very high energies, equivalent to about 2,000 proton masses according to Einstein's equation, $E=mc^2$. In each collision, about 100 particles of different types are produced.

A small group at CDF has been studying what scientists call the diffractive production of jets, in which "ghost" particles help create these sprays of highly collimated particles. Exactly how are they produced?

The proton and antiproton each consists of three quarks bound by the strong force. Though the proton and antiproton are free to move inside a "bag" full of gluons and quarks, the gluons and quarks themselves are confined to each other in order to maintain something called color-neutrality.

Diffractive collisions, in the simplest case, are characterized by an outgoing antiproton, a region in which there are no particles (called a rapidity gap) and a particle cluster corresponding to the initial proton. The particle cluster is shown as the white circle in the top figure.

This kind of collision can be explained by the color-neutral exchange of a particle called a pomeron. With its vacuum-like properties, a pomeron can escape invisibly out of the quark-gluon bag like a ghost, strike the passing proton and give it an energy injection by allowing itself to be absorbed by the proton. The energy is used to create jets that faithfully obey the equation $E=mc^2$.

The results of this experiment can be explained by a model (called DL in the figure below) at low-momentum transfers (t) between the incoming and outgoing antiproton by way of the escaping pomeron. However, the model does not explain the result for high-momentum transfers, where the data is constant. It will be interesting to see how the theory can be adapted to the high-momentum data.

These measurements are being repeated at the higher energies of the LHC to provide more discrimination among theoretical models.

Learn more

—*edited by Dino Goulianos and Andy Beretvas*
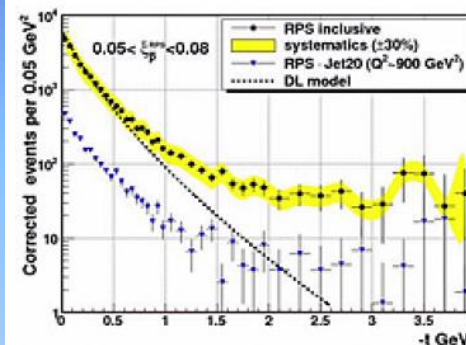
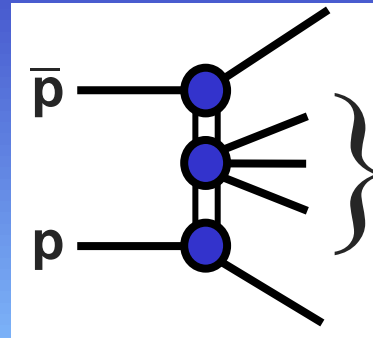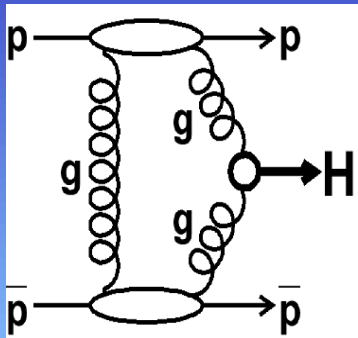A scintillator fiber tracker (RPS) is used to observe diffractive events as a function of the momentum transfer between the incoming and outgoing antiproton.
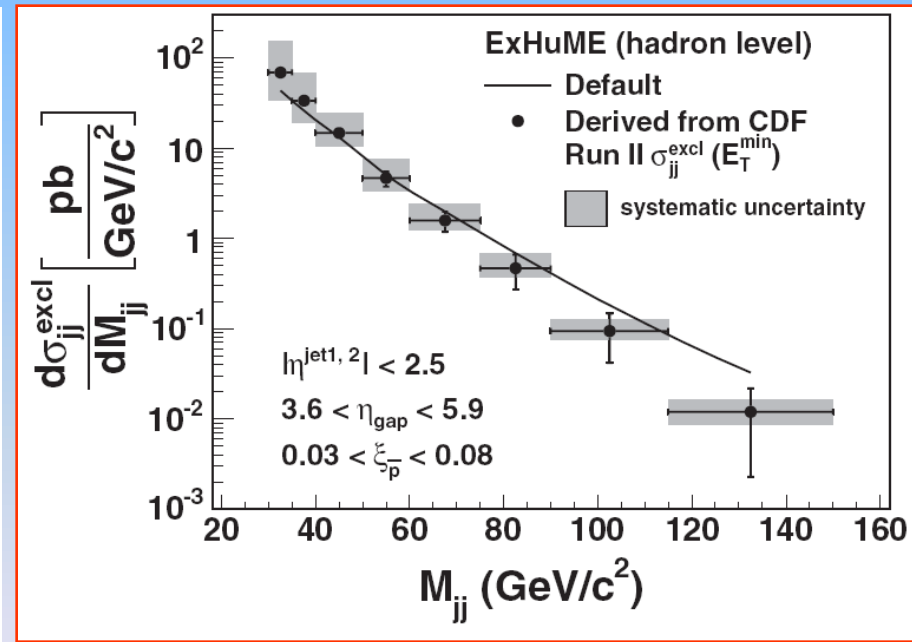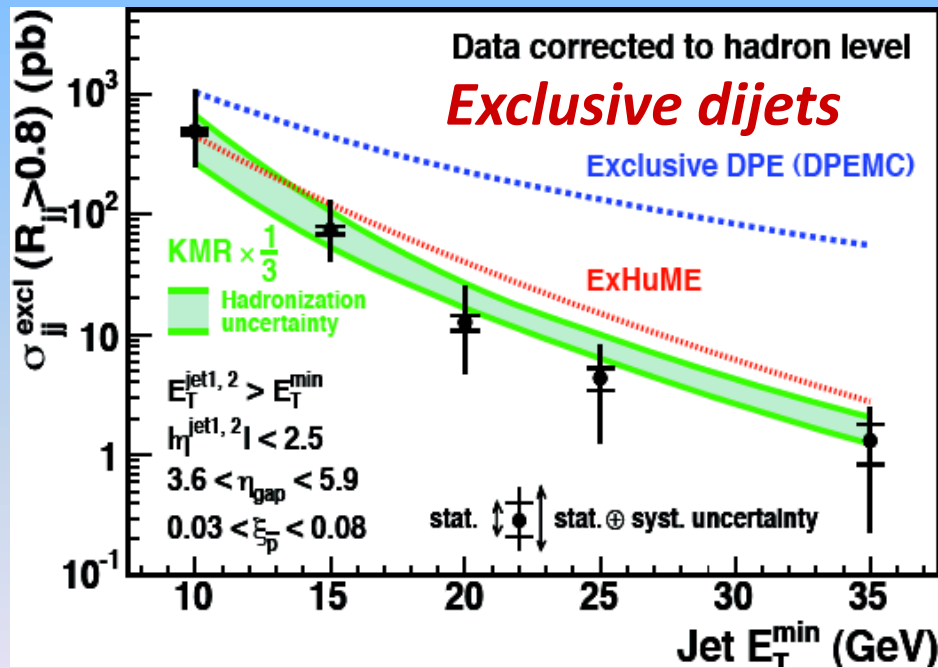

These physicists were responsible for this analysis. From left: Michele Gallinaro, Dino Goulianos and Koji Terashi, all from Rockefeller University.

EXCLUSIVE Dijet→ Excl. Higgs _THEORY CALIBRATION_

JJ   *PRD 77, 052004 (2008)*

CDF 4 LHC

❑   Larger Energy ➜ Larger ET
➢   **Multigap** diffraction
➢   **Diffractive Higgs** production

❑ **The CDF measurements are having an impact on all LHC physics**
    ➜ **the MBR (Minimum Bias Rockefeller) simulation is now in PYTHIA8**

arXiv.org > hep-ph > arXiv:1205.1446

High Energy Physics - Phenomenology

MBR Monte Carlo Simulation in PYTHIA8

R. Ciesielski, K. Goulianos

(Submitted on 7 May 2012)

Summary

❑ **We measured SD to ND ratios in dijet production vs Bjorken-x for $\langle Q^2 \rangle$ up to 10^4 GeV^2 and $-t > 4$ GeV^2**

❑ **We find:**
  - ✓ **nearly identical E_T^{jet} distributions for SD and ND events**
  - ✓ **small $\langle Q^2 \rangle$ dependence as a function of Bjorken-x**
  - ✓ **no $\langle Q^2 \rangle$ dependence of the b-slopes at low t**
  - ✓ **t distributions compatible with DL at low t**
  - ✓ **at high t the distributions lie increasingly higher than DL, becoming approximately flat for $-t > 2$ GeV^2**
  - ➔ **compatible with a diffraction minimum at $-t > 2.5$ GeV^2**

❑ **Our findings are compatible with models of diffraction in which the hard scattering is controlled by the PDF of the recoil antiproton, while the rapidity gap formation is governed by the color-neutral soft exchange.**

Thank you for your attention

BACKUP