# Diffractive and exclusive dijets at CDF

FP@LHC, Manchester, UK, 8-12 Dec 2007

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# Hadronic Interactions

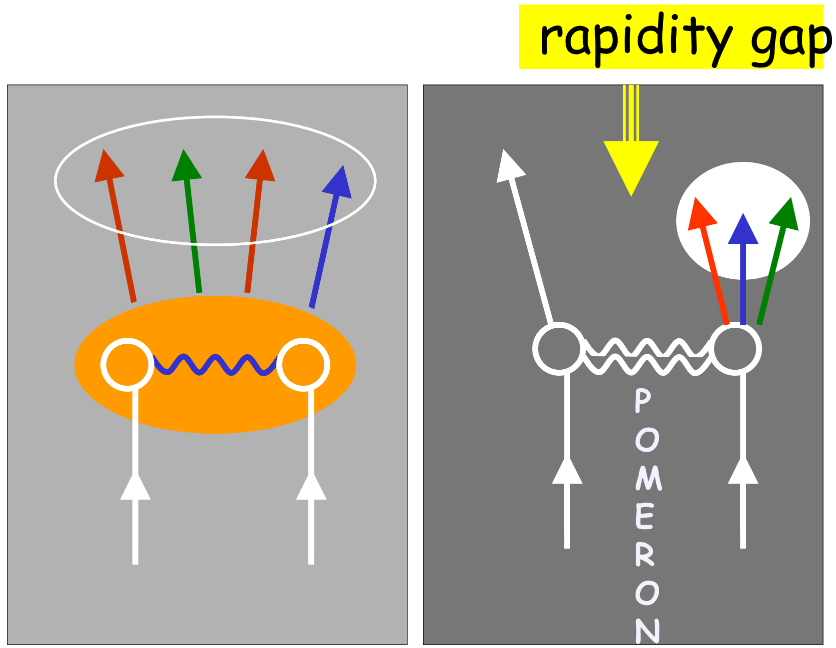
## Non-diffractive:

Color-exchange

## Diffractive:

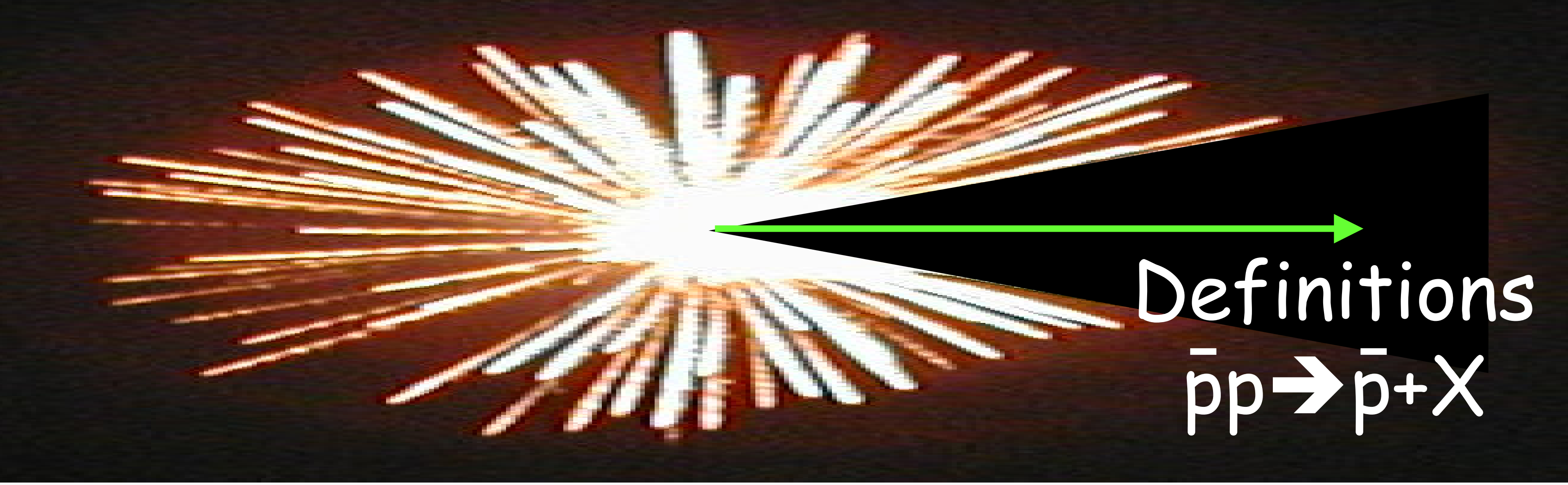
Colorless exchange with vacuum quantum numbers

Incident hadrons acquire color and break apart



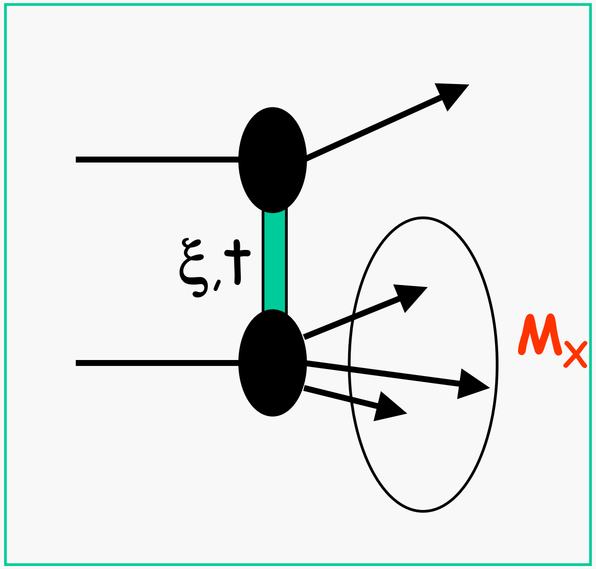
Incident hadrons retain their quantum numbers remaining colorless

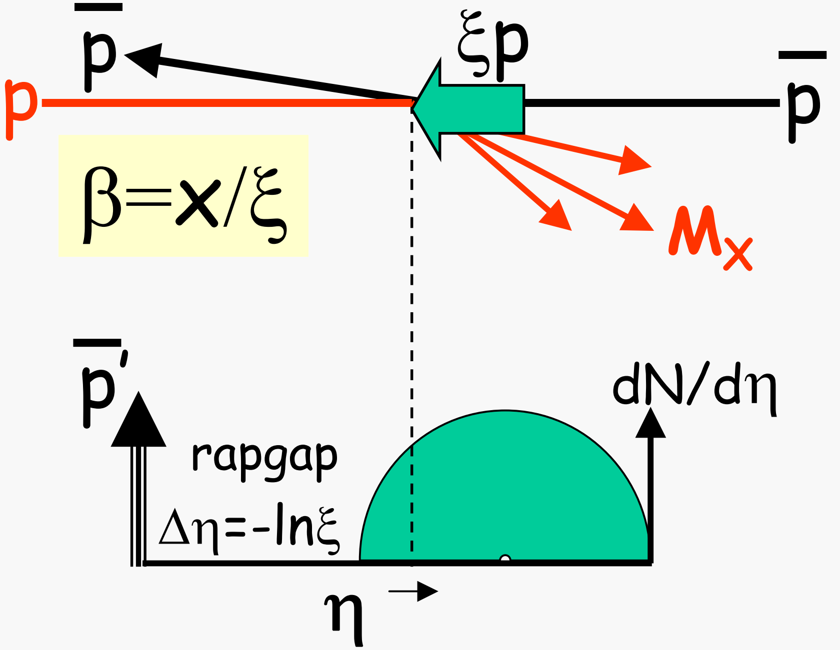
**Goal**: understand the QCD nature of the diffractive exchange



# Definitions

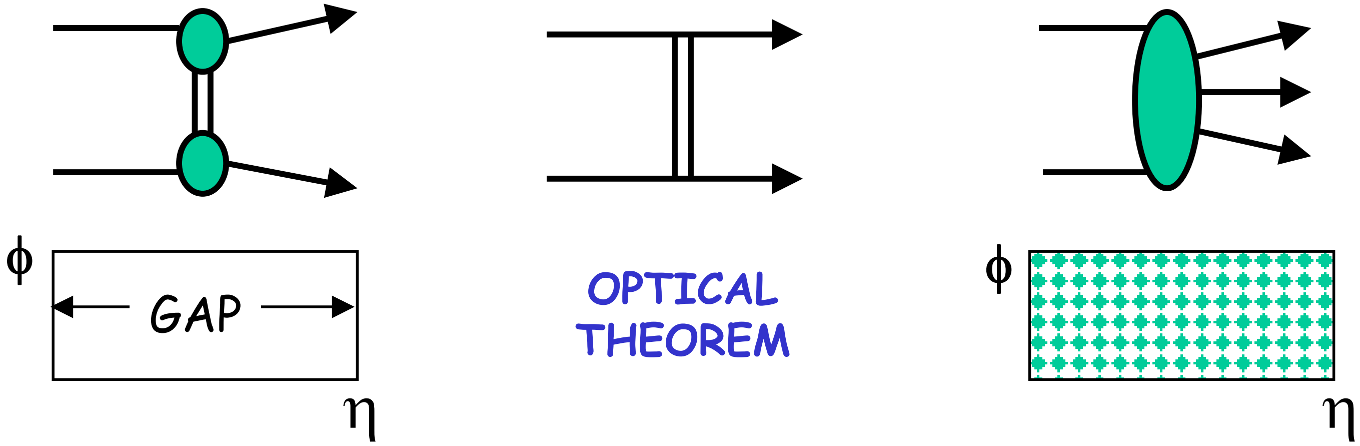
$\bar{p}p \rightarrow \bar{p}+X$



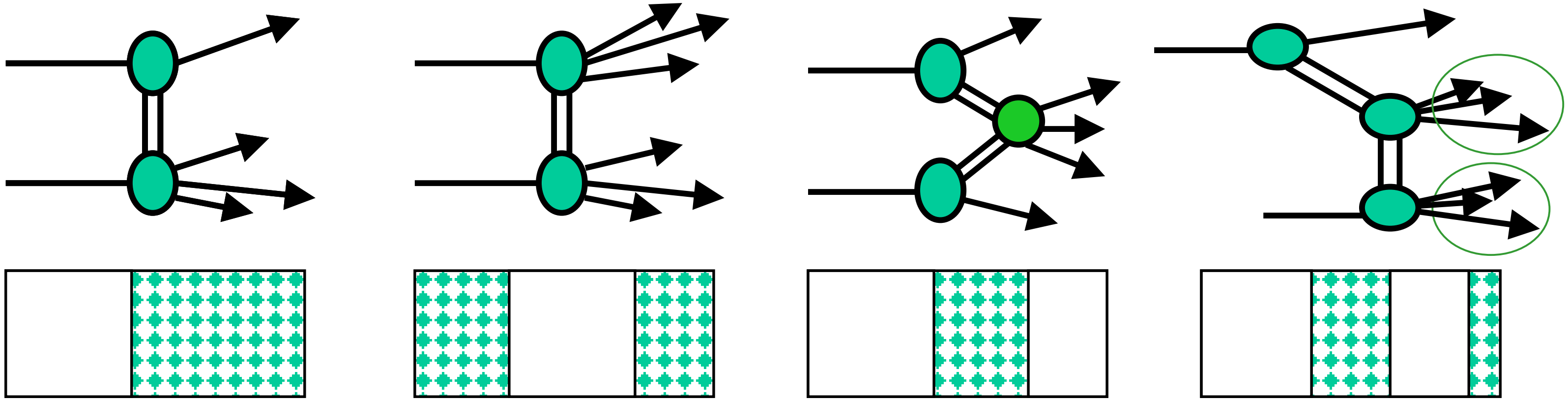


# Diffraction at CDF

Elastic scattering $\sigma_T = \mathrm{Im}\, f_{el}\,(t=0)$ Total cross section

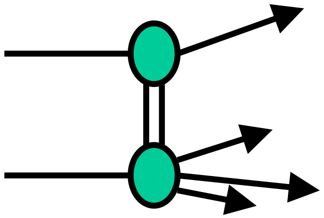


**OPTICAL THEOREM**



SD DD DPE SDD=SD+DD

# Soft Diffraction



Factorization →

$$\frac{d^2\sigma_{SD}}{dt\,d\xi} = f_{IP/p}(t,\xi)\bullet\sigma_{IP-\bar{p}}(M_X^2)$$

Pomeron flux

$$\boxed{\sigma_{SD} \sim s^{2\varepsilon}}$$

- **Regge theory**

  $\sigma_{SD}$ exceeds $\sigma_T$ at

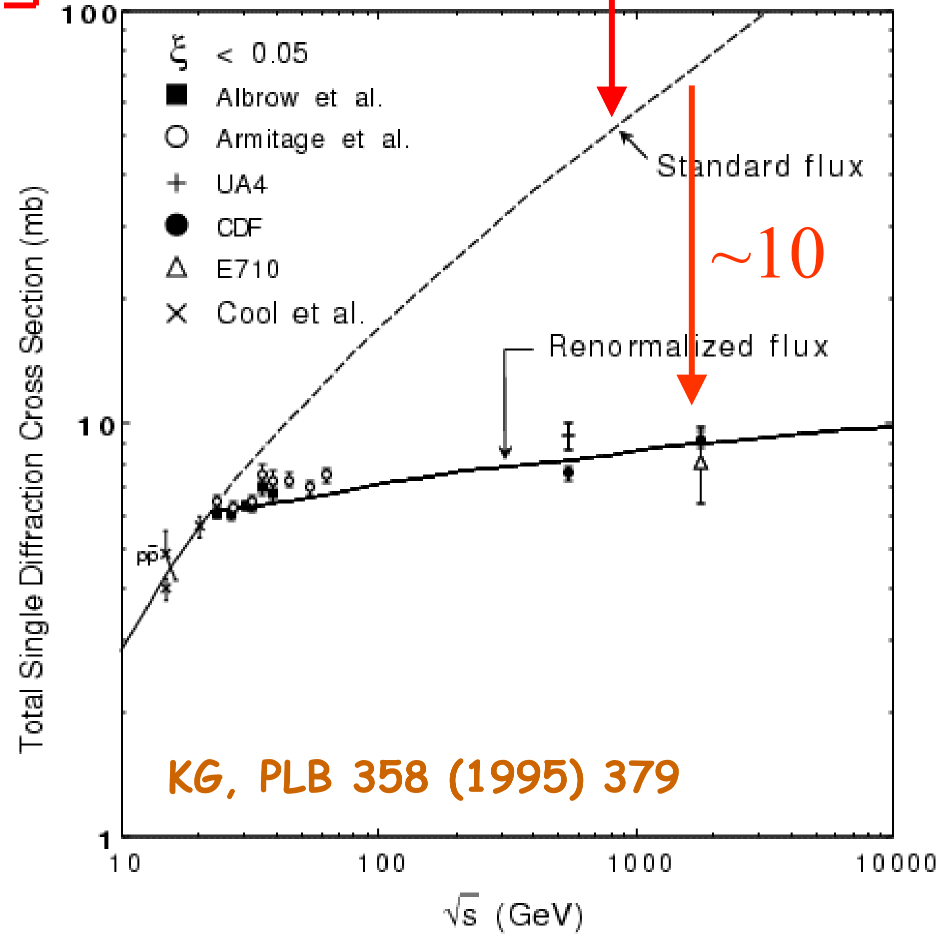
  $$\sqrt{s} \approx 2\ \text{TeV}.$$

- **Renormalization**

  Pomeron flux integral (re)normalized to unity

  **KG, PLB 358 (1995) 379**

$$\boxed{\int_{\xi_{min}}^{0.1}\int_{t=-\infty}^{0} f_{IP/p}(t,\xi)\,d\xi\,dt = 1}$$



**KG, PLB 358 (1995) 379**

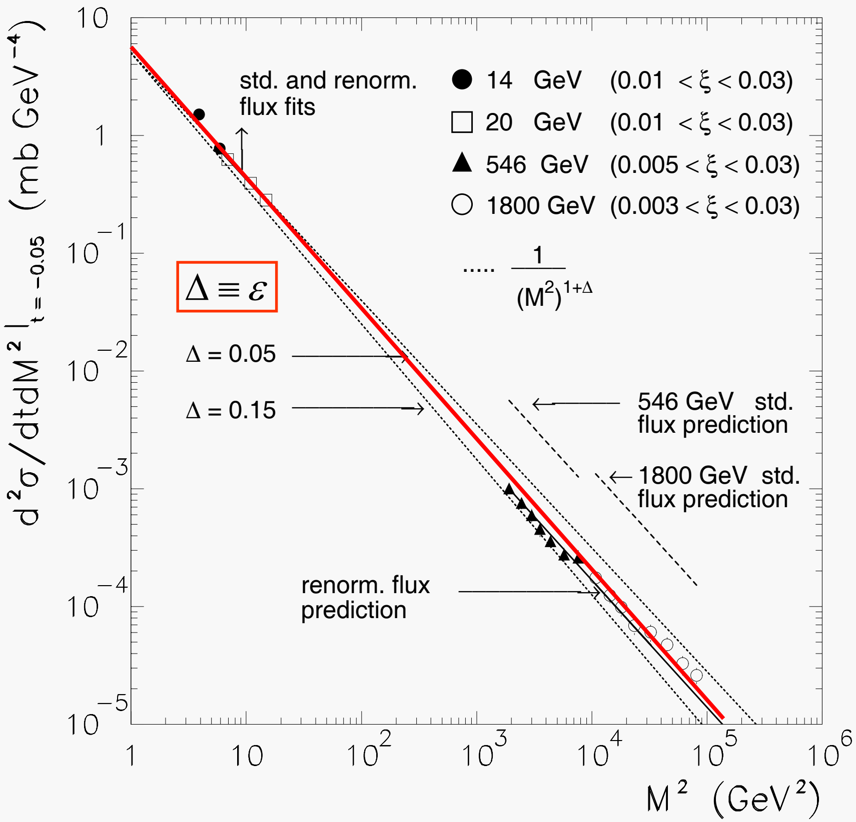
# $M^2$-scaling

**KG&JM, PRD 59 (1999) 114017**

renormalization

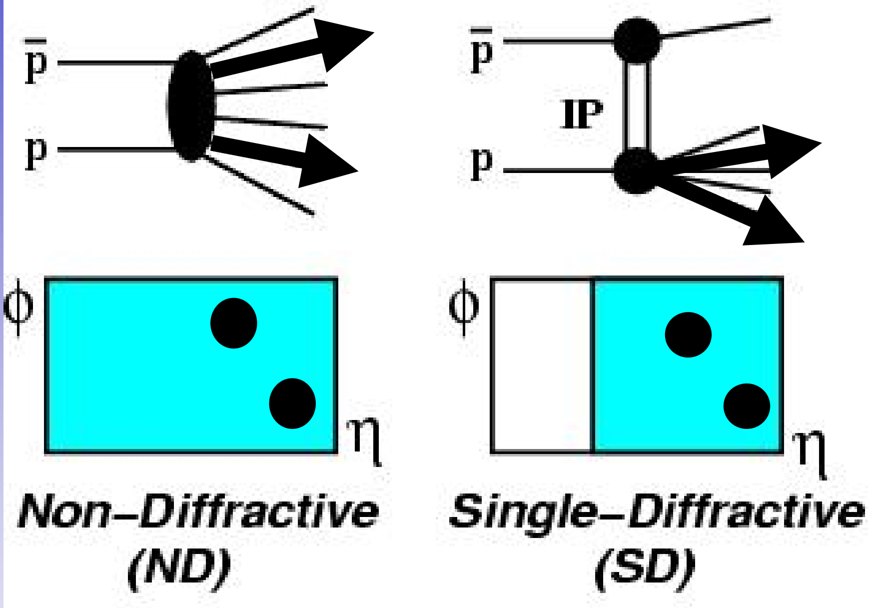
$$\frac{d\sigma}{dM^2} \propto \frac{s^{2\varepsilon} \rightarrow 1}{(M^2)^{1+\varepsilon}}$$

➔ Independent of S over 6 orders of magnitude in $M^2$ !



**Factorization breaks down so as to ensure $M^2$-scaling!**

# DIFFRACTIVE STRUCTURE FUNCTION



$$R(x_{Bj}) \equiv \frac{\mathrm{Rate}^{SD}_{jj}(x_{Bj})}{\mathrm{Rate}^{ND}_{jj}(x_{Bj})}$$

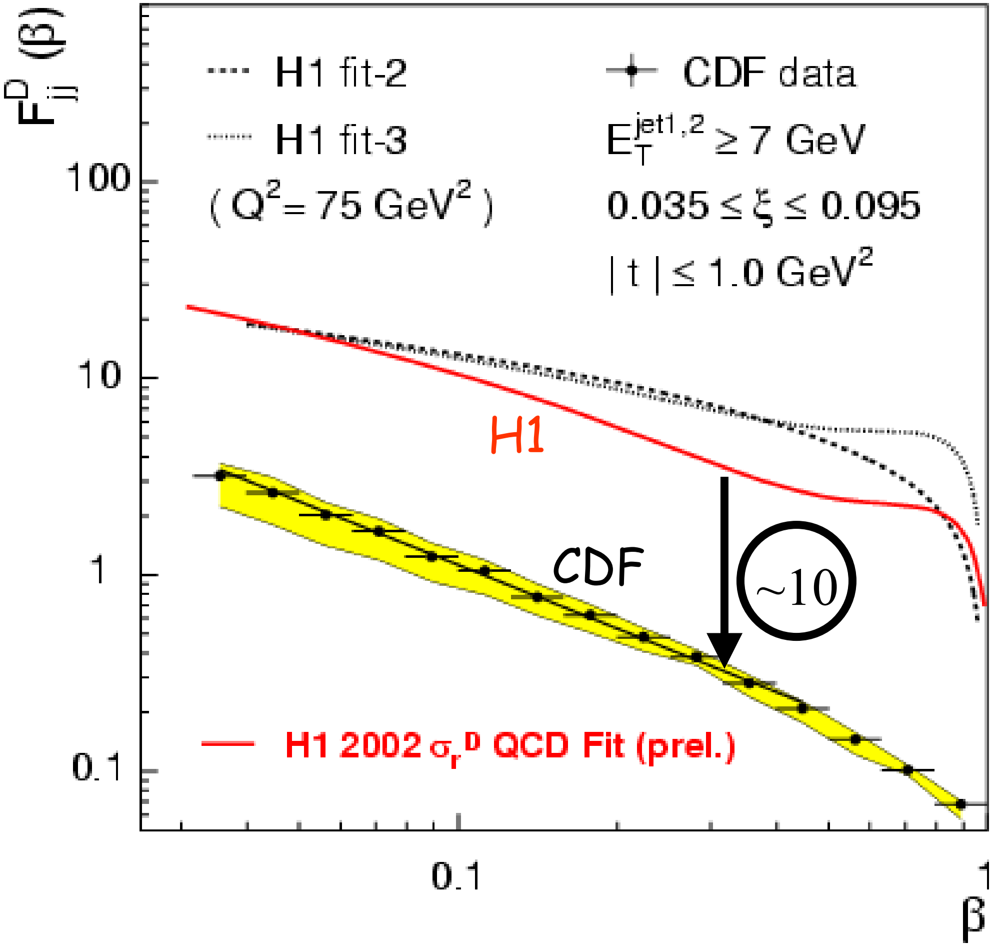
$$\Rightarrow \quad \frac{F^{SD}_{jj}(x_{Bj})}{F^{ND}_{jj}(x_{Bj})}$$

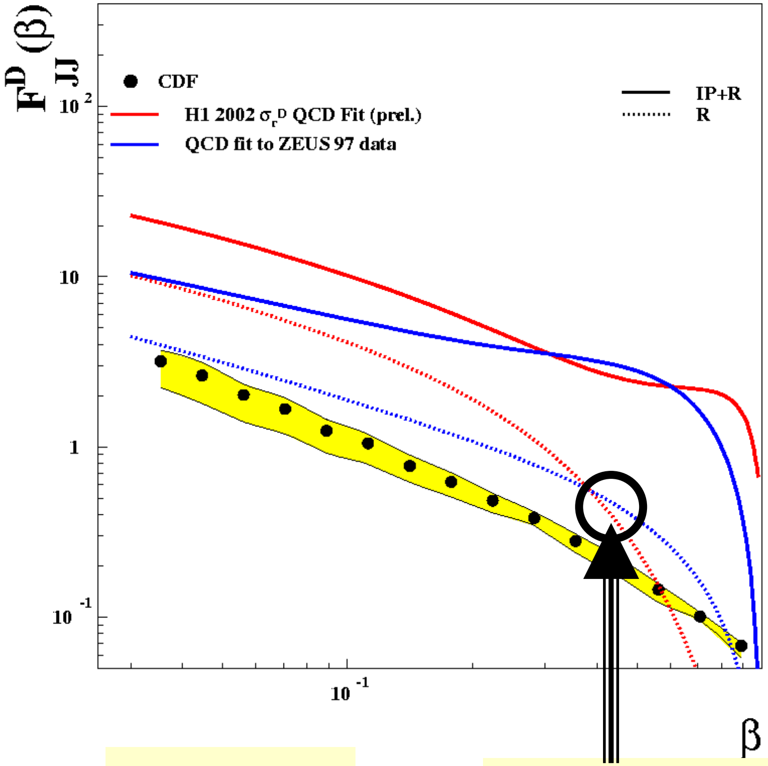
Systematic uncertainties due to energy scale and resolution cancel out in the ratio

# Diffractive Structure Function

## Breakdown of QCD Factorization

$$\bar{p}p \rightarrow \bar{p} + \mathrm{dijet} + X$$



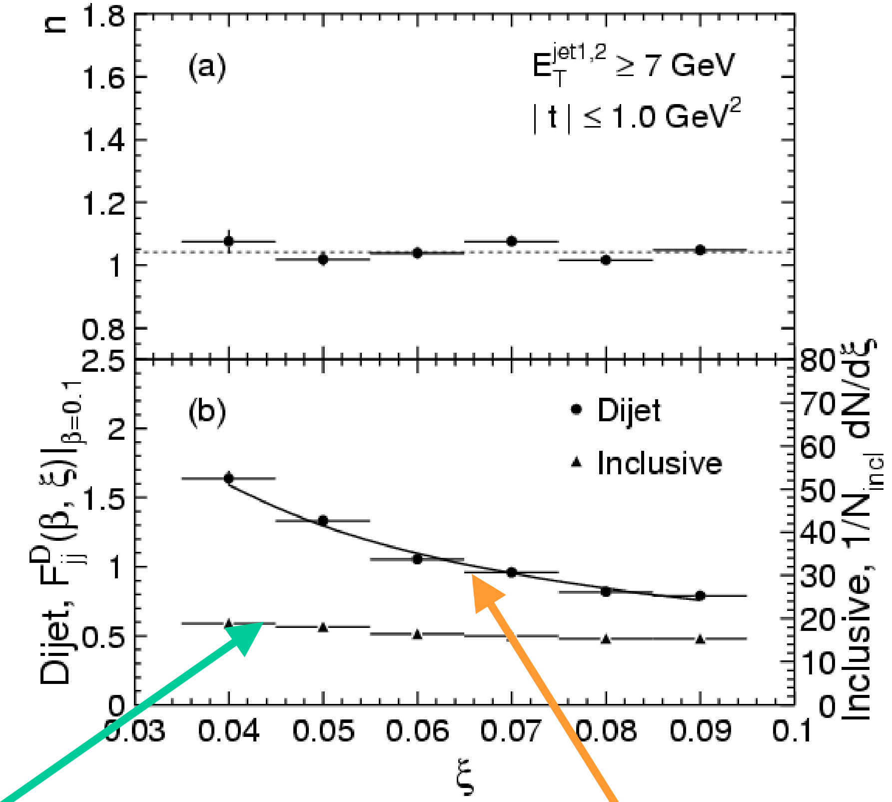


$\beta = x/\xi$

Reggeon

~10-20%

# ξ-dependence: Inclusive vs Dijet

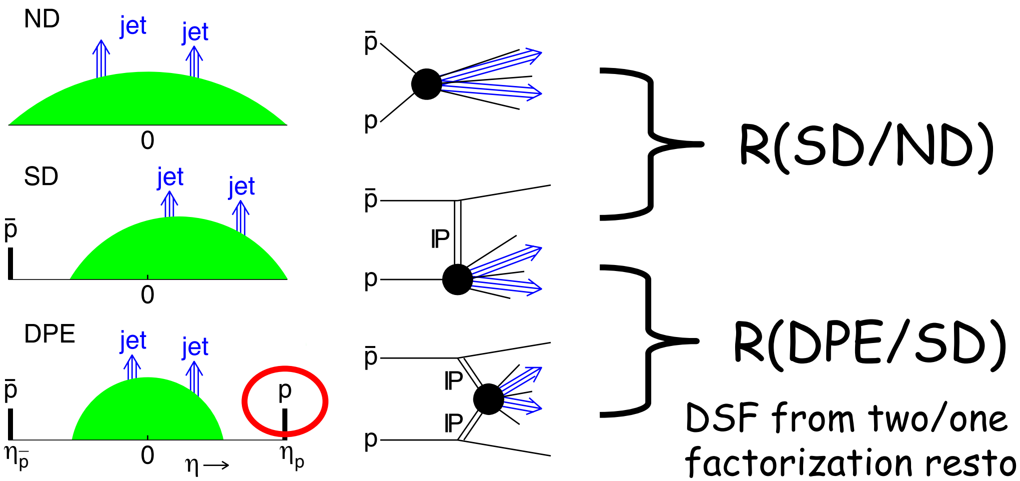


$$\frac{d\sigma_{incl}}{d\xi} \propto \text{constant}$$

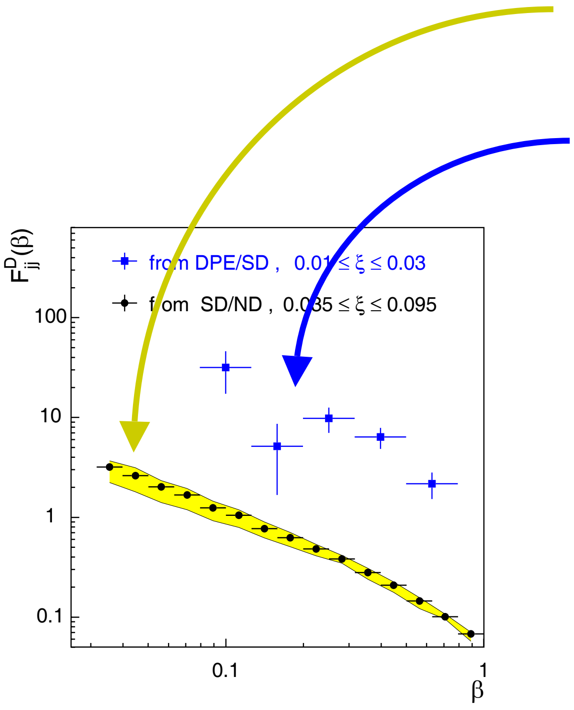
$$F_{jj}^{D}(\beta,\xi) \propto \frac{1}{\beta^{n}} \cdot \frac{1}{\xi^{m}} \quad (n = 1.0 \pm 0.1, \quad m = 0.9 \pm 0.1)$$

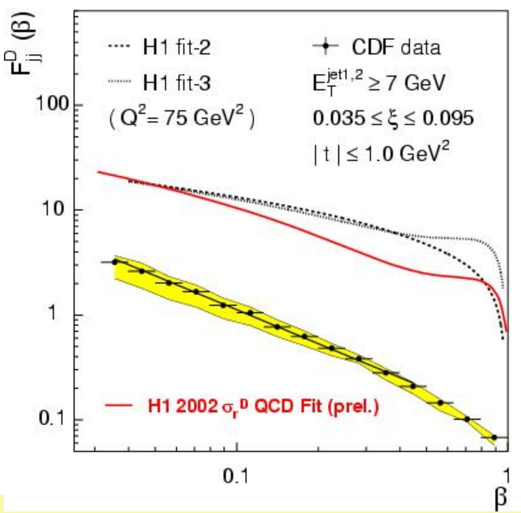
Pomeron dominated

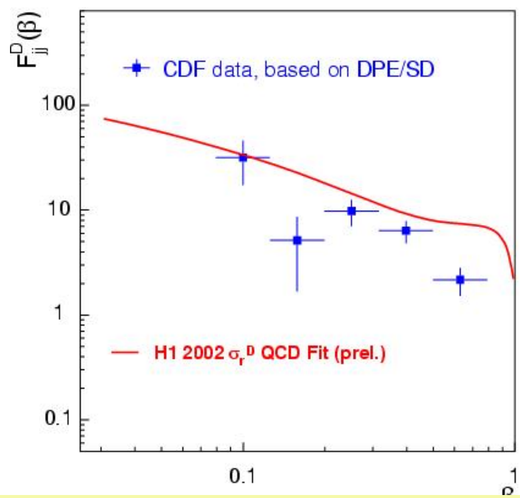
# Multigap Diffraction
# Restoring Factorization



DSF from two/one gap: factorization restored!

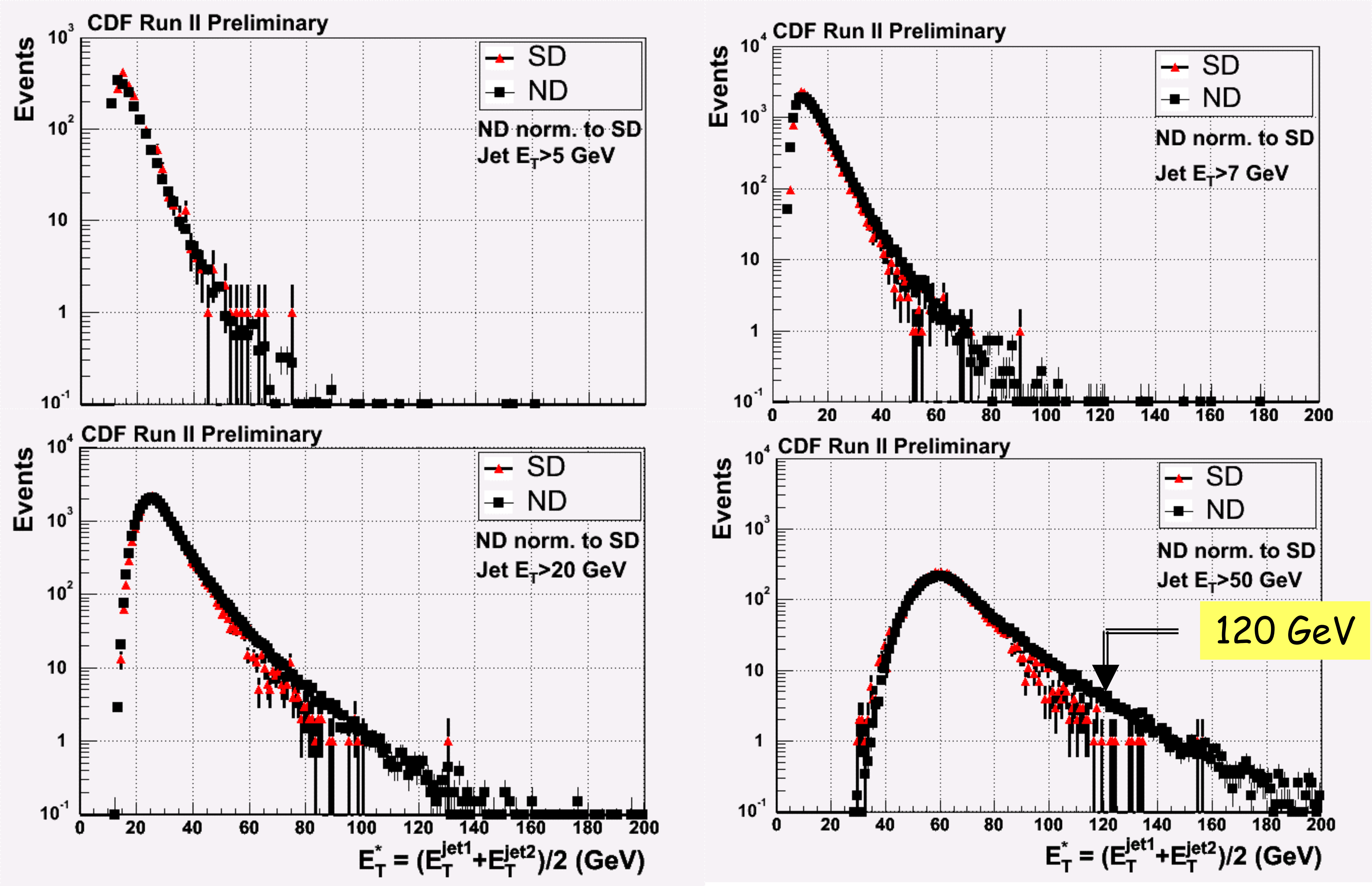






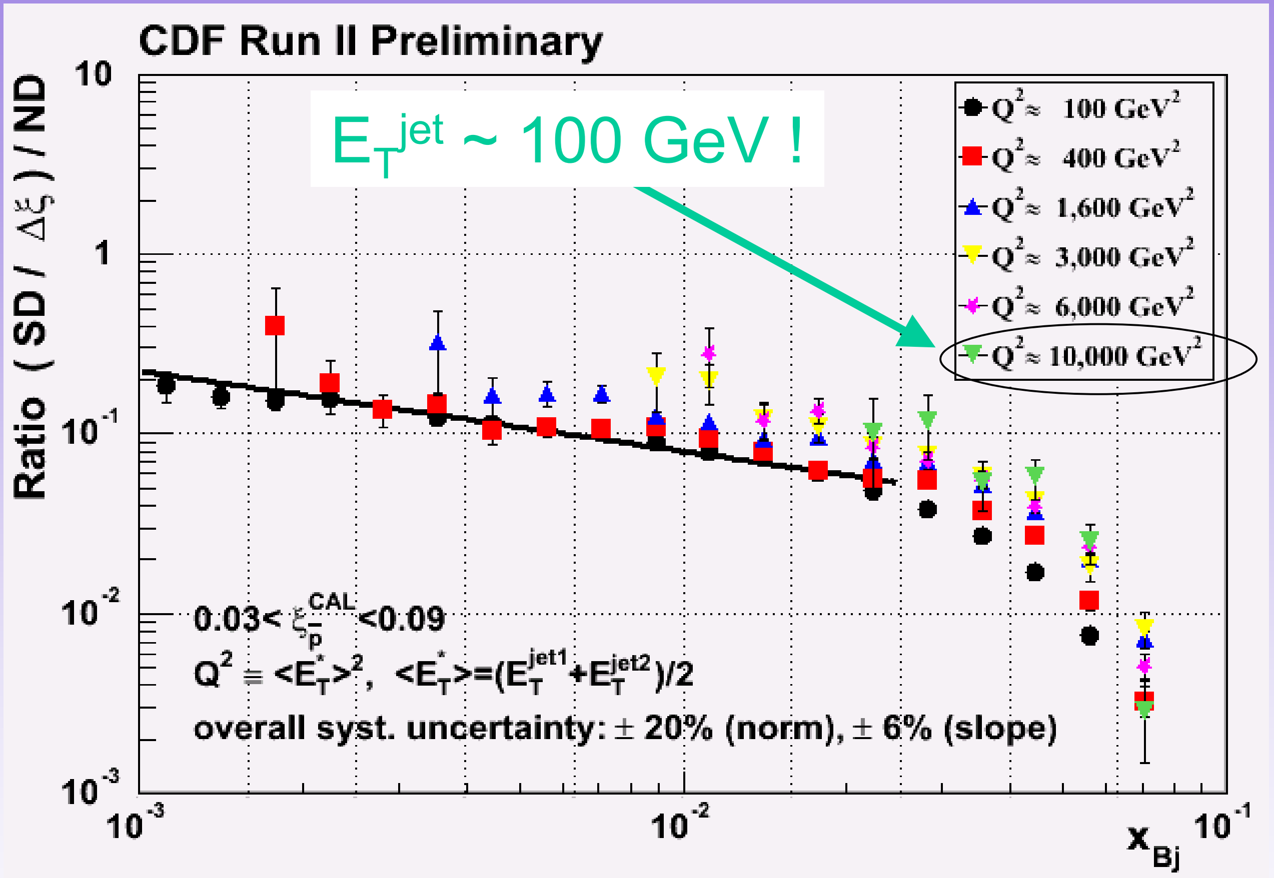
The diffractive structure function measured on the proton side in events with a leading antiproton is NOT suppressed relative to predictions based on DDIS

# $E_T$ distributions



# Diffractive Structure Function:

## $Q^2$ dependence

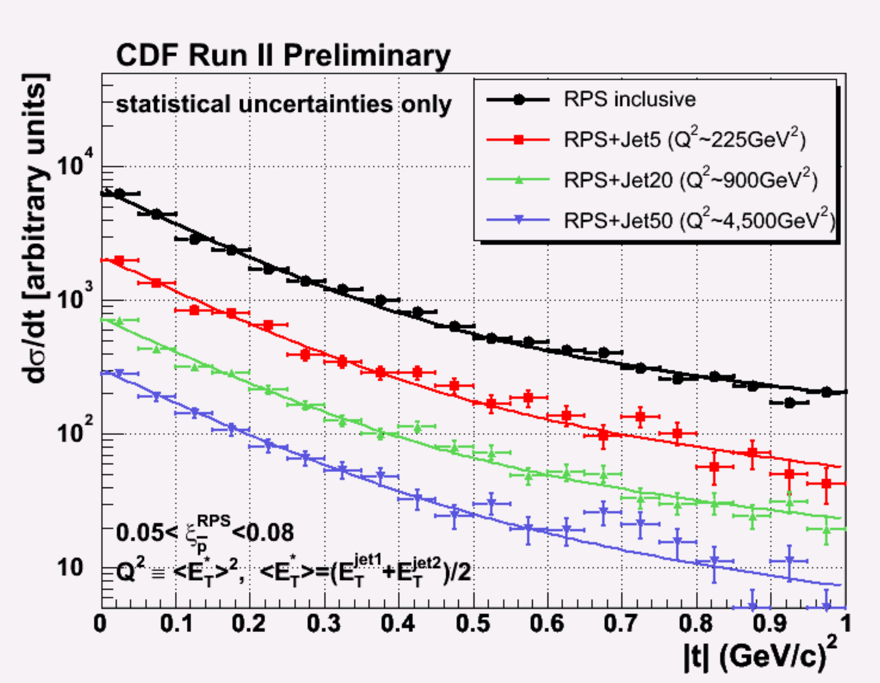


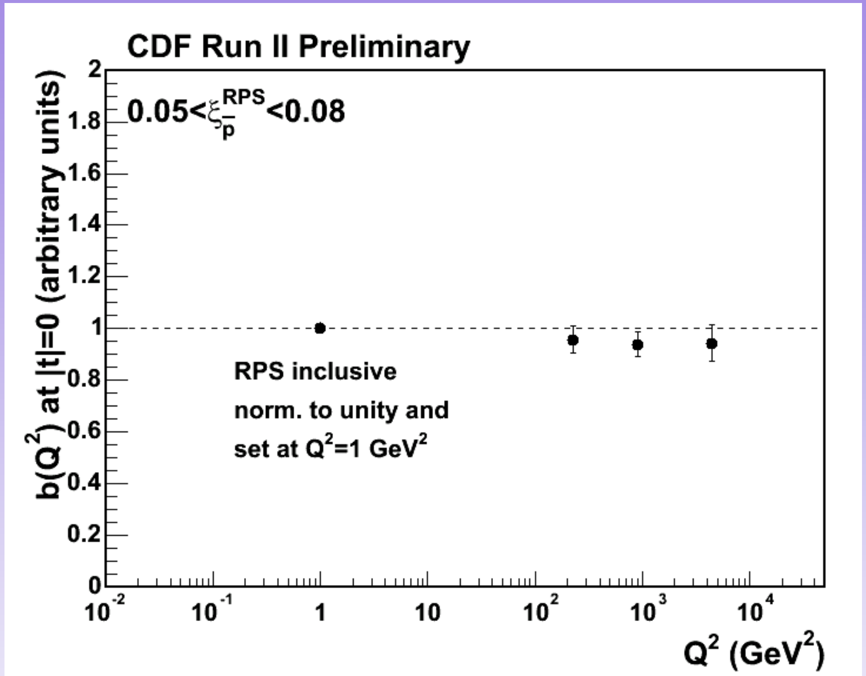
$E_T^{jet} \sim 100$ GeV !

Small $Q^2$ dependence in region $100 < Q^2 < 10{,}000$ GeV$^2$

⇨ Pomeron evolves as the proton!

# Diffractive Structure Function:
## t- dependence





Fit $d\sigma/dt$ to a double exponential:

$$F = 0.9 \cdot e^{b_1 \cdot t} + 0.1 \cdot e^{b_2 \cdot t}$$

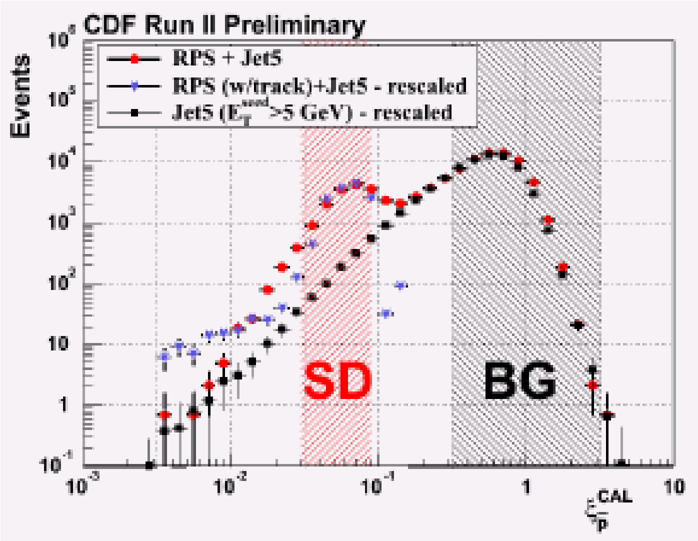
- ➢ No diffraction dips
- ➢ No Q2 dependence in slope from inclusive to $Q^2$~$10^4$ $GeV^2$

- ➢ Same slope over entire region of $0 < Q^2 < 4{,}500$ $GeV^2$ across soft and hard diffraction!

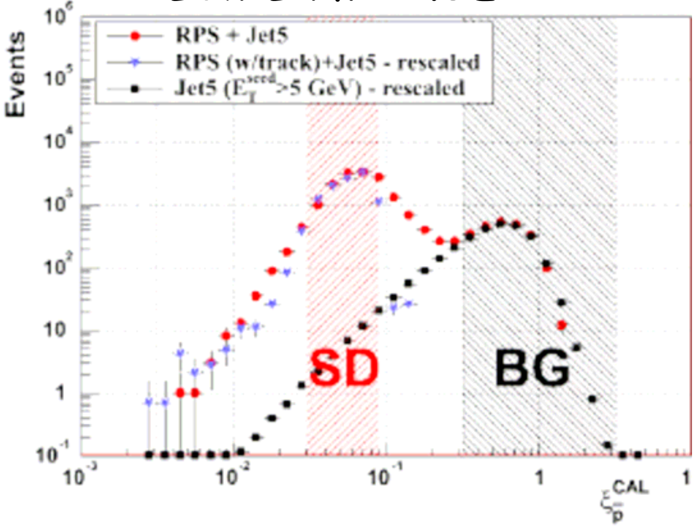
# Luminosity Run – Jan 2006

→ with dedicated diffractive triggers ←

2002-303 data ~1.5E31

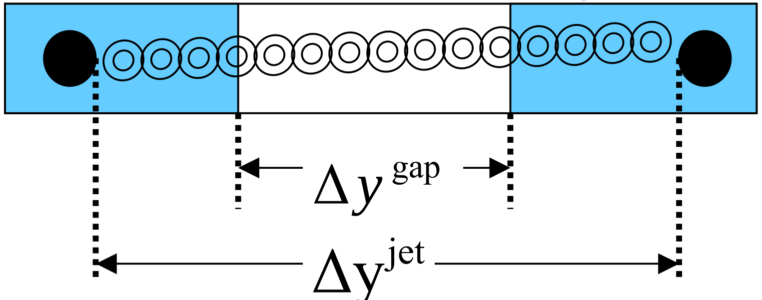


Low Lum ~0.5E30



<u>Physics goals:</u>

- t-distributions up to t ~ 4 GeV$^2$
- Jet-Gap-Jet fraction vs. $\Delta y^{gap}$



$$\Delta y^{gap} = \Delta y^{jet} \Rightarrow \text{BFKL}$$

$$\Delta y^{gap} \neq \Delta y^{jet} \Rightarrow \text{composite}$$

# Diffraction for All

Run I

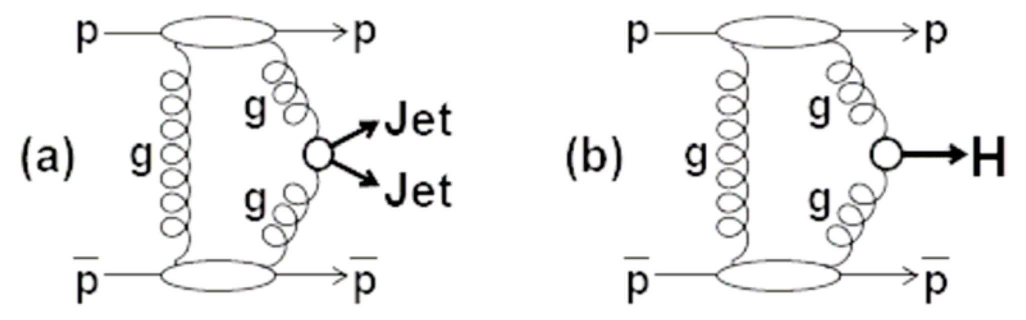
- Suppression of single gap diffraction
- $M^2$ – scaling: $d\sigma/dM^2$ independent of s
- Non-suppressed double-gap to single-gap ratios

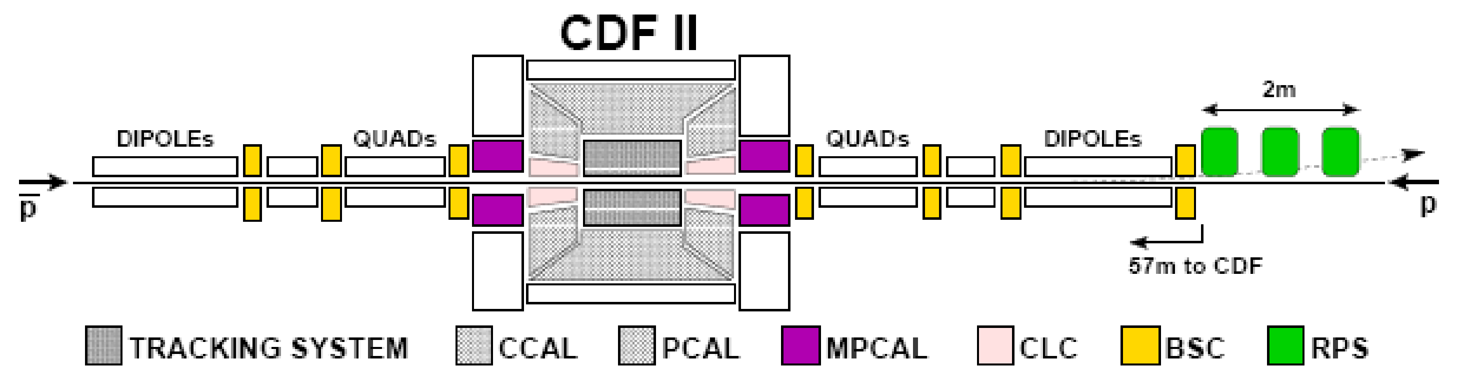
Run II

- Diffractive structure function vs $x_{Bj}$, $Q^2$, and t: similar to proton structure function
- Diffractive t distributions: slope independent of $Q^2$

→Composite Pomeron made up from proton pdf's
http://physics.rockefeller.edu/dino/myhtml/talks/lathuile07.pdf

# EXCLUSIVE DIJET PRODUCTION





$$R_{jj} = \frac{M_{jj}}{M_X(\text{all calorimeters})}$$

Look for signal as $R_{jj} \to 1$

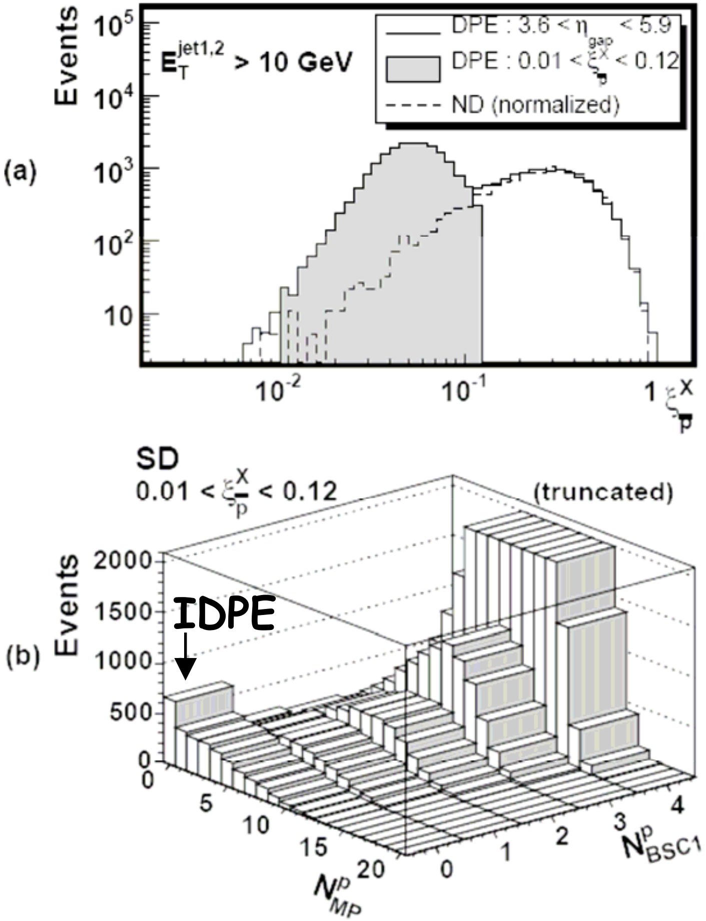
$$\xi_{\bar{p}}^{X} = \frac{1}{\sqrt{s}} \sum_{i=1}^{N_{tower}} \left(E_T^i \, e^{-\eta^i}\right)$$

Use it to kill overlaps

# DATA SAMPLES

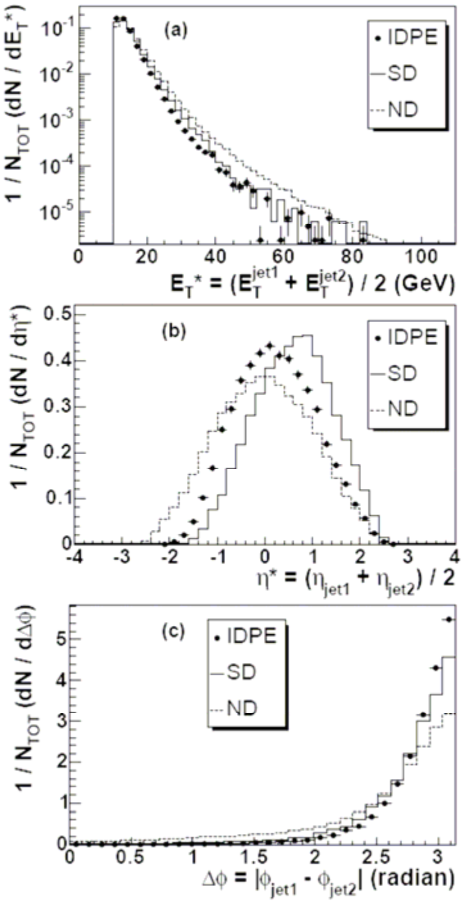
DPE sample:

$J5 \cdot RPS \cdot \overline{BSC1_p} \cdot VTX \cdot RPST \cdot JET$



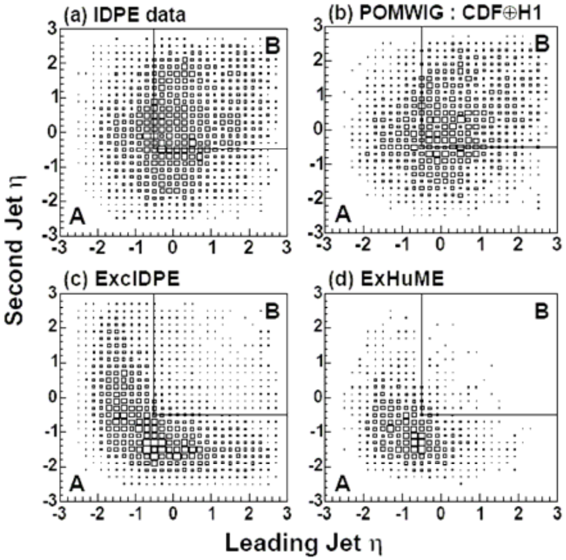
IDPE sample:

$DPE \cdot LRG_p \cdot \xi_{\bar{p}}^X$



Jet η-correlations

➔ enhance signal

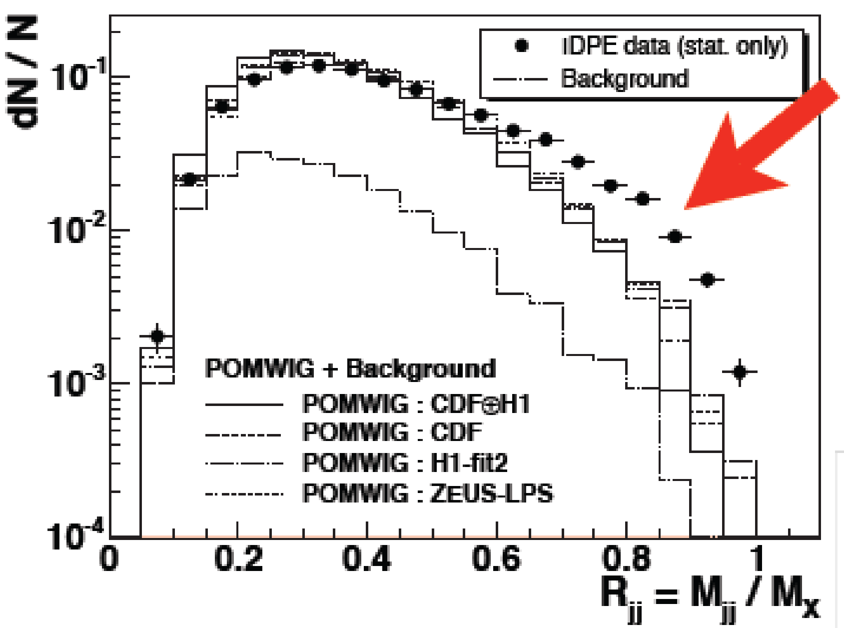


Examine two regions

A – signal enhanced

B – bgd dominated

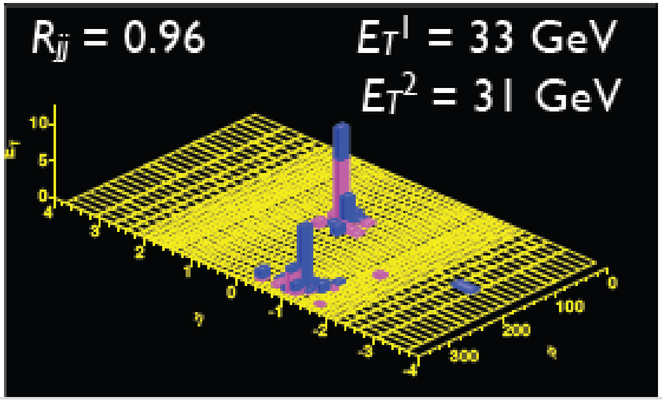
# SEARCH FOR THE SIGNAL

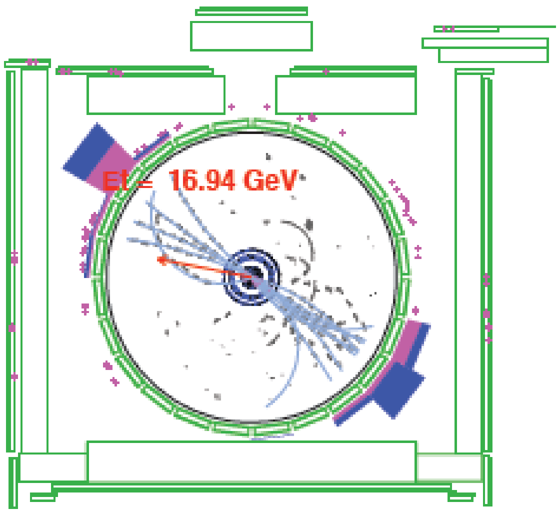


Excess over inclusive DPE dijet MCs observed at high $R_{jj}$

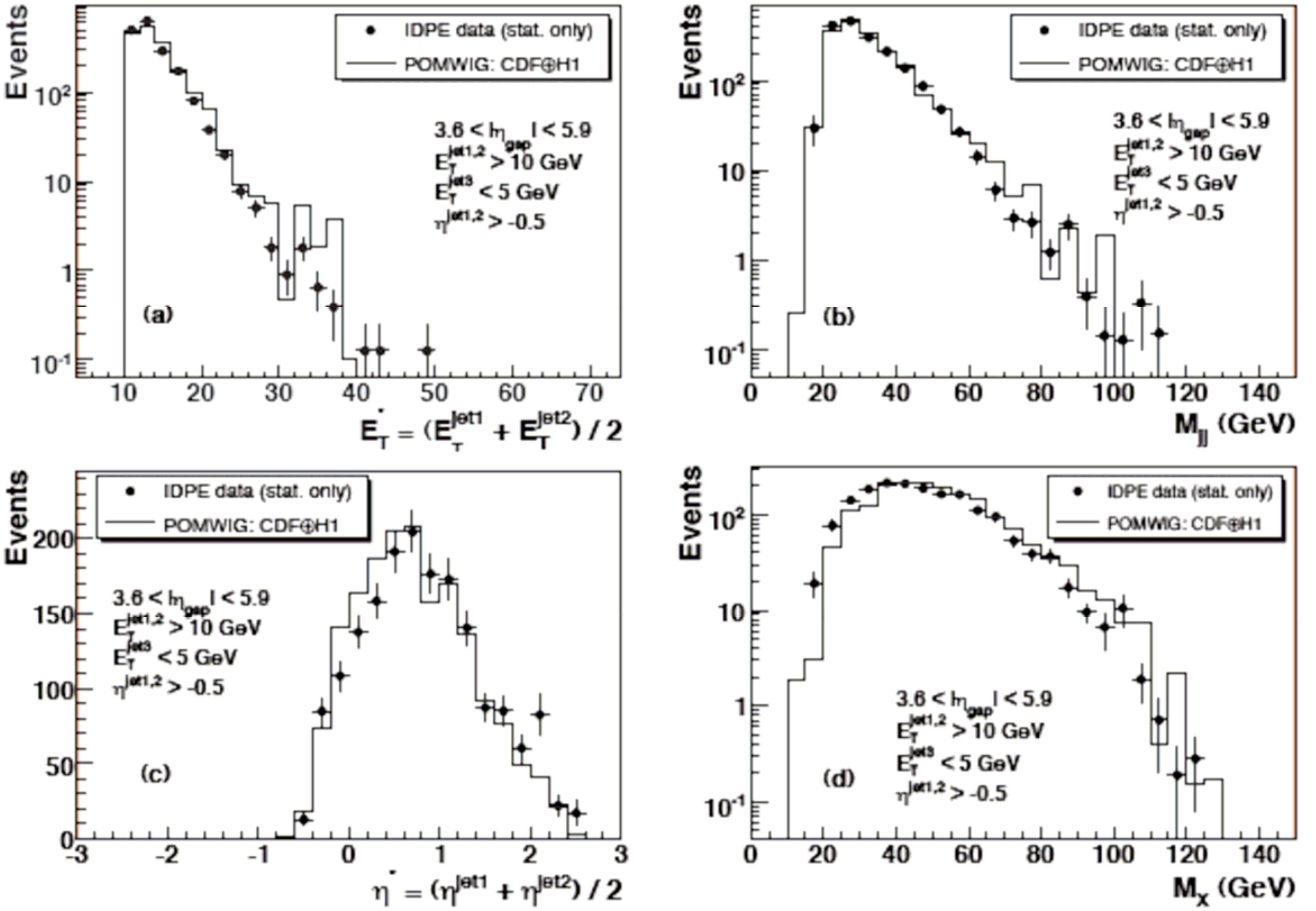
→ Examined for consistency with exclusive dijet signal

An exclusive di-jet candidate

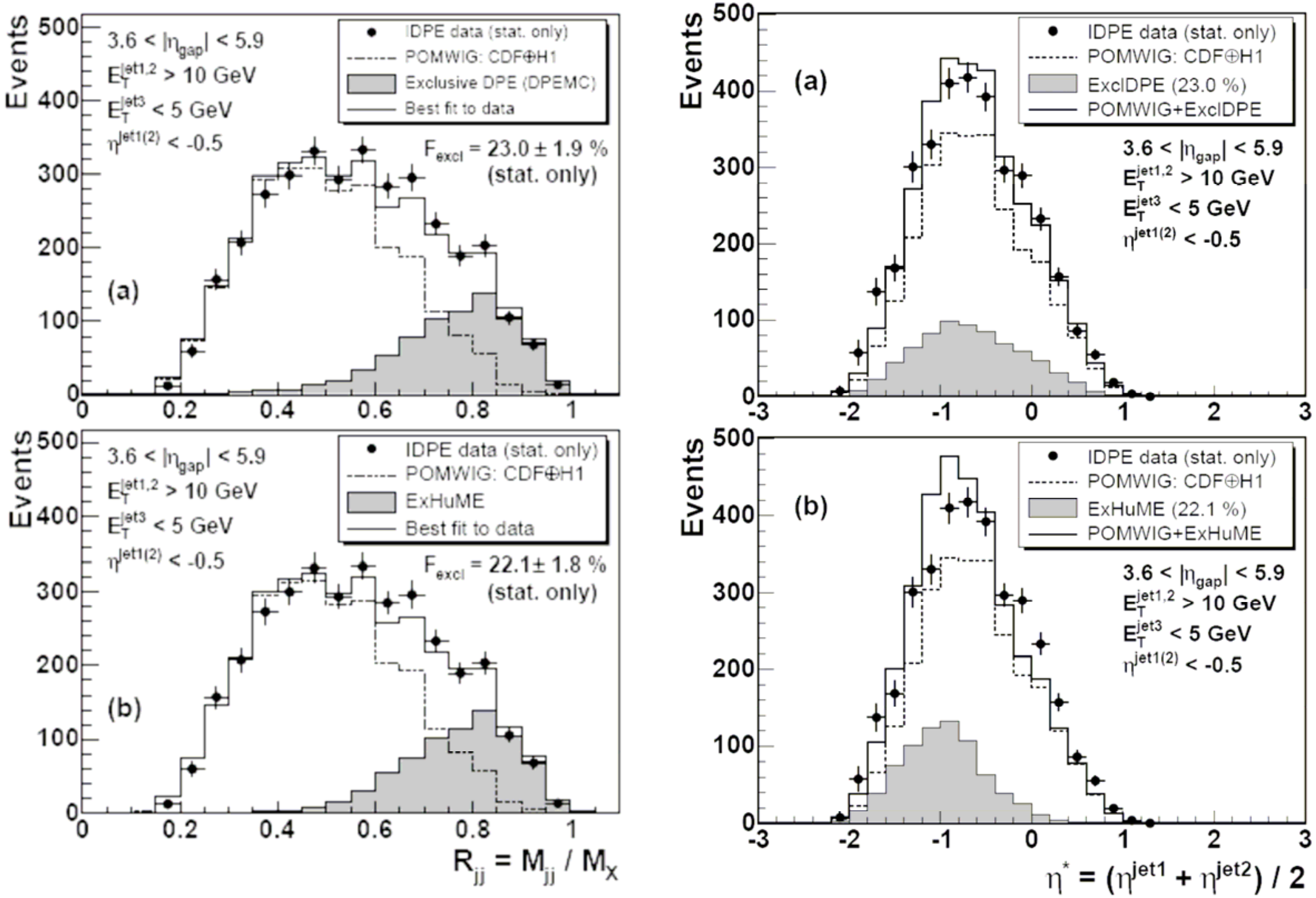




# Data vs MC in bgd Region B



# Rjj and η* in Signal Region A

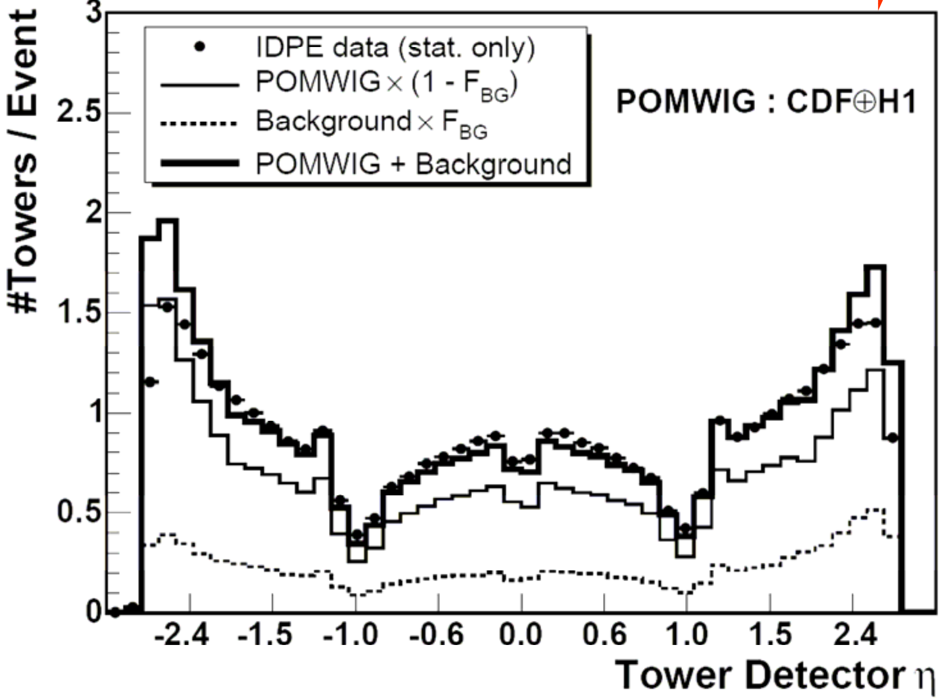


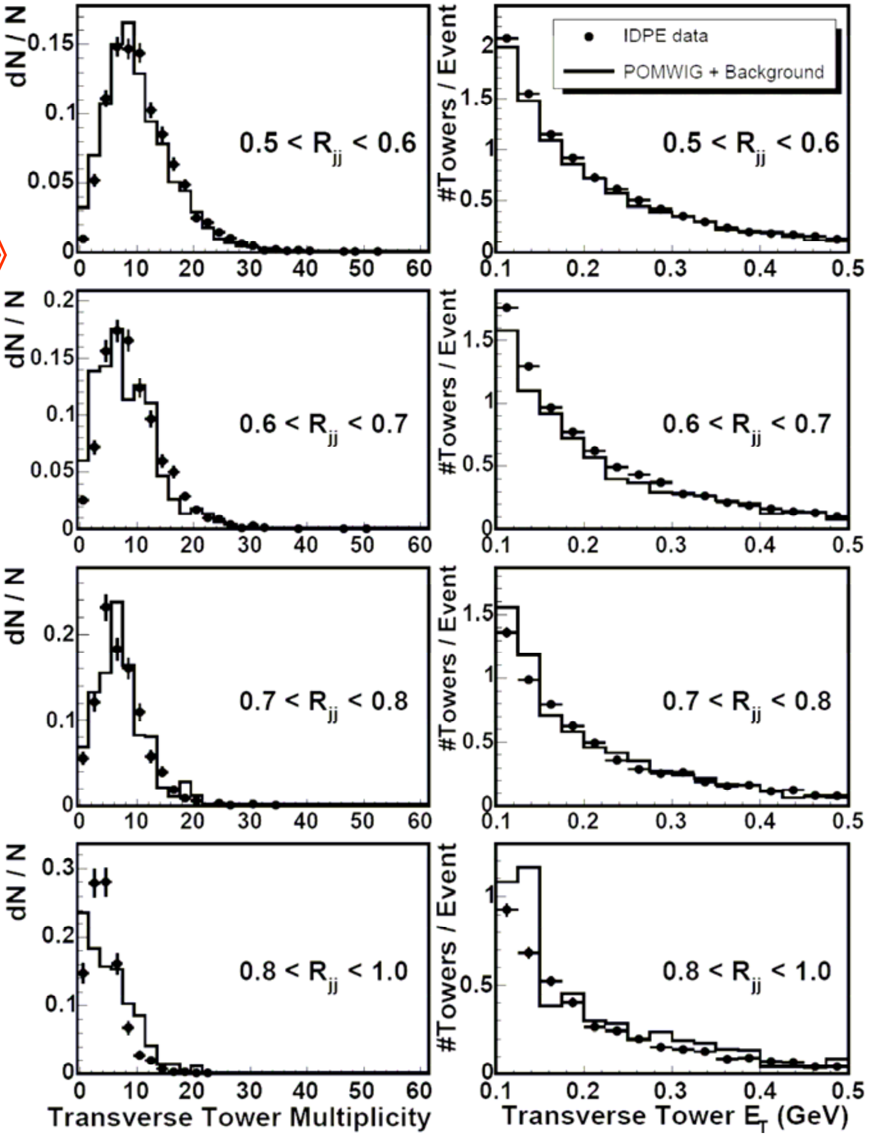
# Underlying Event: Data vs MC

**MC vs data UE distributions**

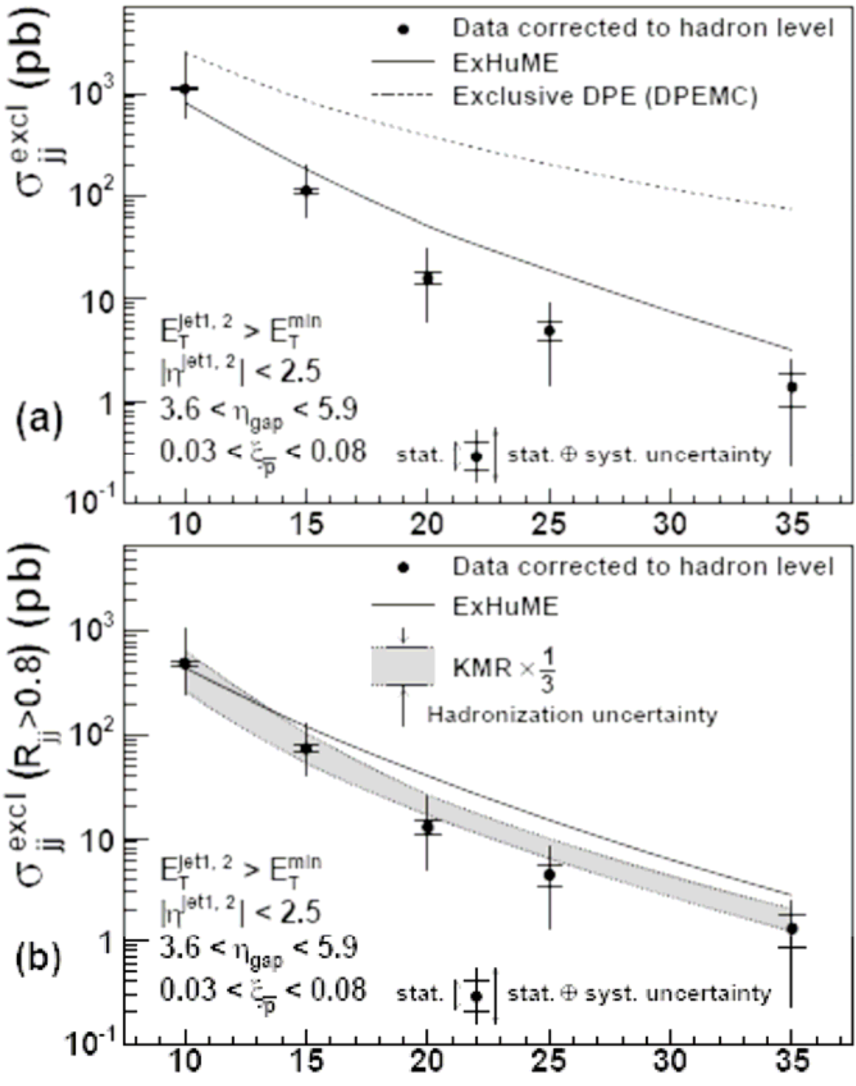
central
detector
tower
thresholds

region
transverse
to dijet $\phi$





# Data Compared to MC Predictions



🡐 DPEMC

- normalization high
- slope low

Sudakov suppression?

🡐 ExHuME

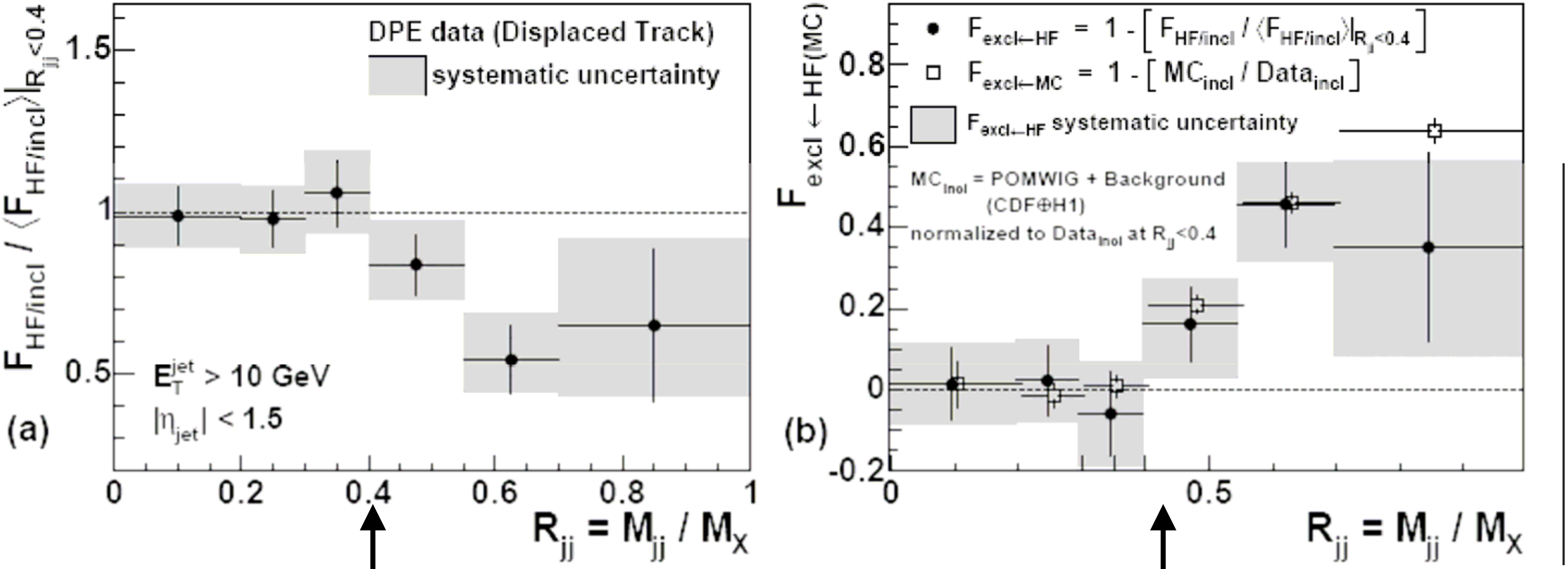
🡐 KMR x 1/3

🡐 $\mathrm{Jet}_{ET}^{min}$(GeV)

# Heavy Flavor Dijets

HF suppressed at high Rjj

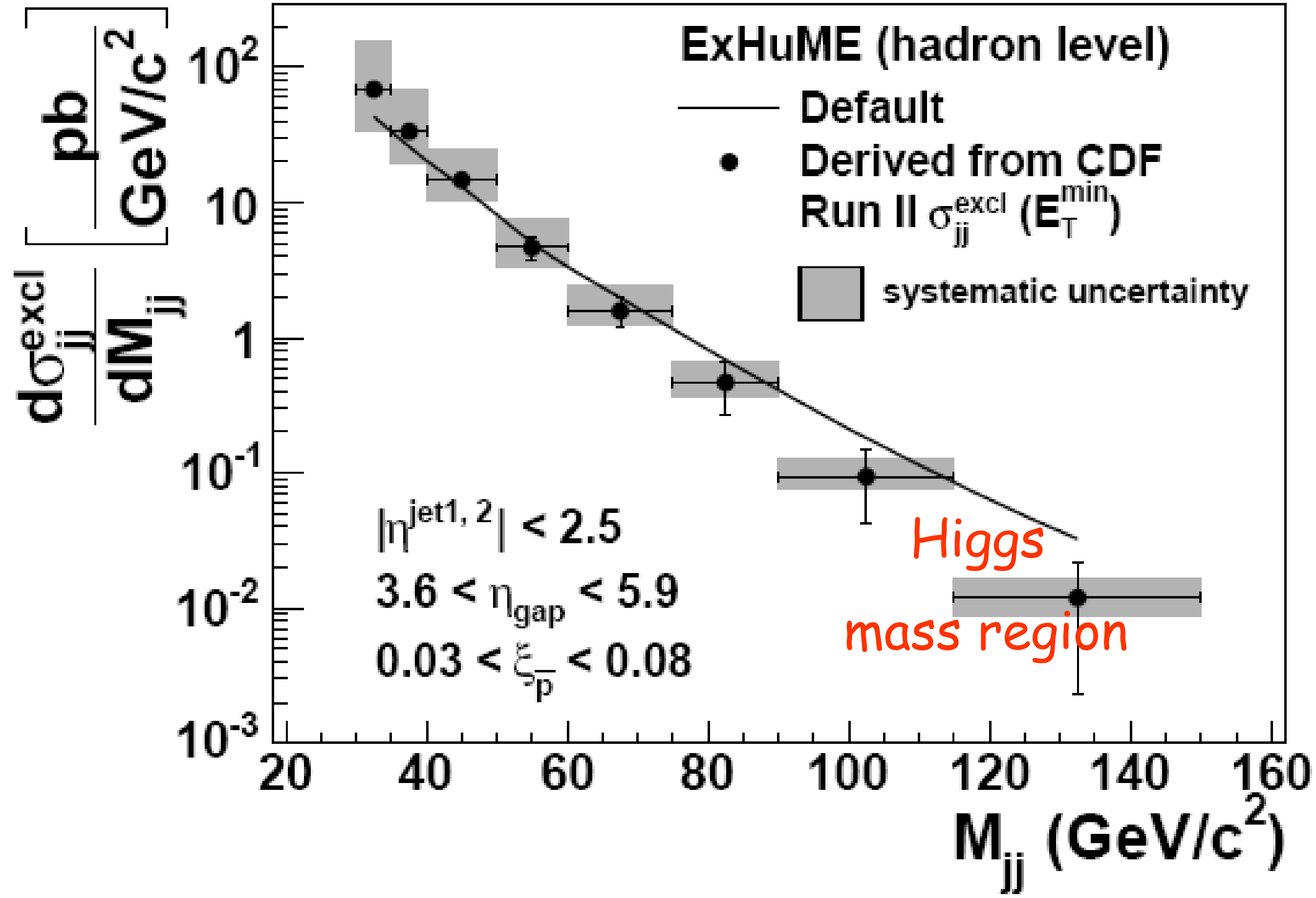
Incl/MC & Incl/HF agree



HF and inclusive data normalized at Rjj<0.4

# Extracted Mjj Distribution

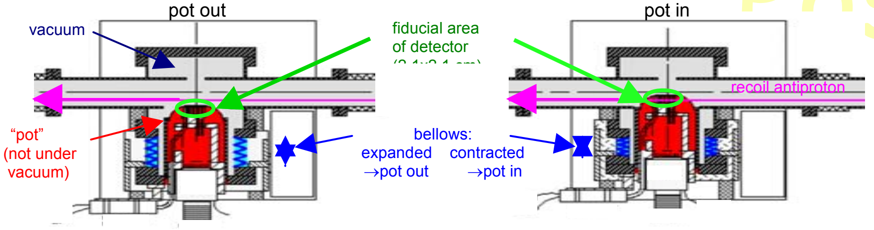
Extract Mjj distribution using ExHuME normalized to data $\sigma_{jj}^{excl}(E_T)$



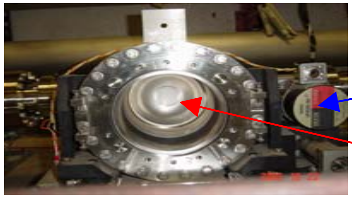
Higgs mass region

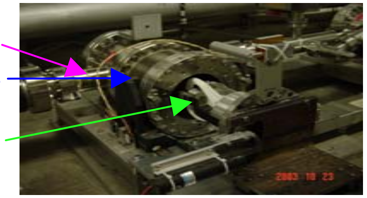
# The Roman-Pot Detectors at CDF

## Concept of a Roman Pot



Bellows allow detectors to move close to the beam while maintaining vacuum

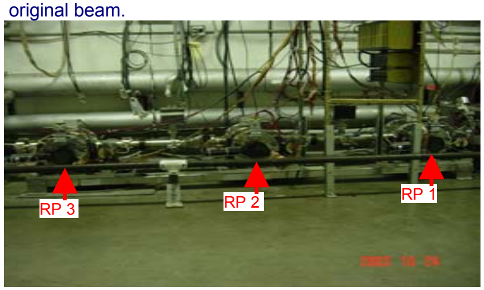


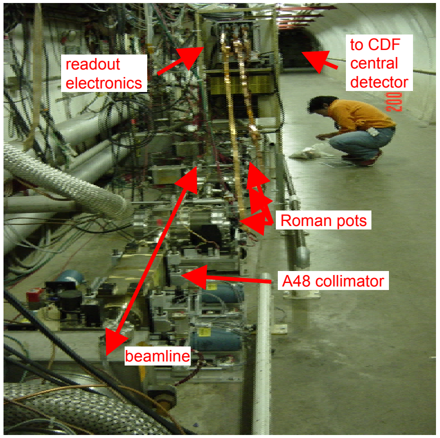


## In the Tevatron Tunnel

CDF had three Roman pots (RP1, RP2, RP3) located 57m downstream of the interaction point along the antiproton beam direction.

They were used to detect antiprotons which underwent a "diffractive" interaction and were scattered in a direction very close to that of the original beam.

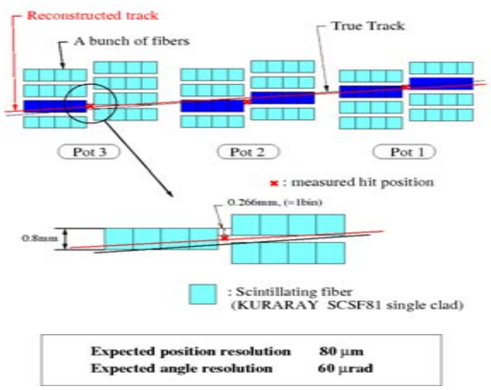




## Roman-Pot Detector Design – by The Rockefeller University

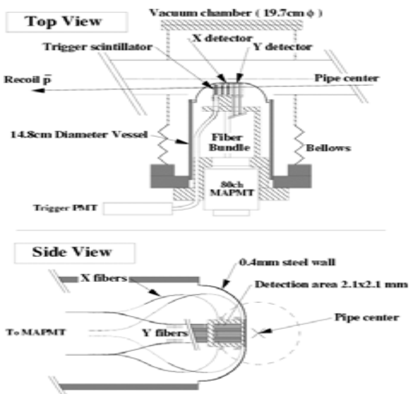
The three Roman pots each contain detectors consisting of:

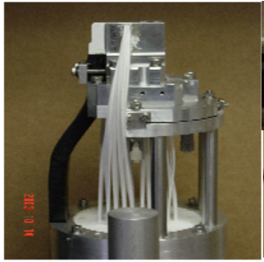
- Trigger scintillation counter 2.1x2.1x0.8 cm$^3$
- 40 X + 40 Y fiber readout channels
  - Each consists of 4 (→ bigger signal) clad scintillating fibers 0.8x0.8 mm$^2$ (new technology at the time)
  - X,Y each have 2 rows of 20 fibers spaced 1/3 fiber width apart for improved position resolution (three times better than with a single row)

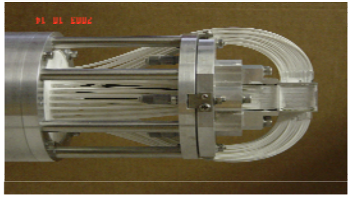


Expected position resolution 80 μm
Expected angle resolution 60 μrad

## CDF "Tokyo"-Pot Detectors – Built by the University of Tsukuba, Japan

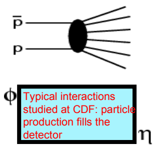






## Physics Using the Roman-Pot Detectors

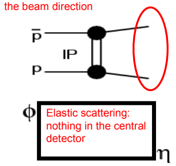
- The Roman-pot detectors are used to study diffractive interactions
- Elastic scattering was measured by CDF in 1988-1989 using Roman pots (not those described here) in both the proton and antiproton direction



Typical interactions studied at CDF: particle production fills the detector

Non-Diffractive

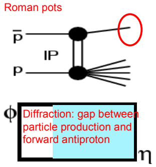
In elastic scattering, both the proton and antiproton escape in the forward direction very close to the beam direction



Elastic scattering: nothing in the central detector

Elastic Scattering

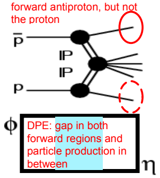
In single diffraction, the (anti)proton escapes in the forward direction where it can be detected in the Roman pots



Diffraction: gap between particle production and forward antiproton

Single Diffractive

In double pomeron exchange, CDF detects the forward antiproton, but not the proton



DPE: gap in both forward regions and particle production in between

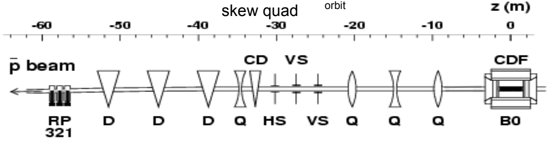
Double Pomeron Exchange

## Path of the Antiproton through the Tevatron Magnets

- Dipole magnets bend recoil antiprotons which have lost momentum towards the inside of the Tevatron ring, into the Roman pots
- Knowledge of the beam optics, the collision vertex position, and the antiproton track position and angle in the Roman-pot detectors are used to reconstruct the kinematics of the diffractive antiproton

Corrector dipoles and skew quad

used for fine tuning the beam orbit



dipoles

bend the beams around the ring and the diffractive antiprotons into the Roman pots

electrostatic separators

separate the proton and antiproton beams

low-beta quadrupoles

focus the beams at the CDF interaction point