Results from CDF on Diffraction

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→ presented on behalf of the CDF collaboration ←

Workshop on Low x Physics

Lisbon, Portugal, 28 June – 1 July, 2006

Contents

- Introduction & Run I results
- Run II results
  - ✓Exclusive Production
  - ✓Diffractive structure function

$\bar{p}$-p Interactions

Non-diffractive:

Color-exchange

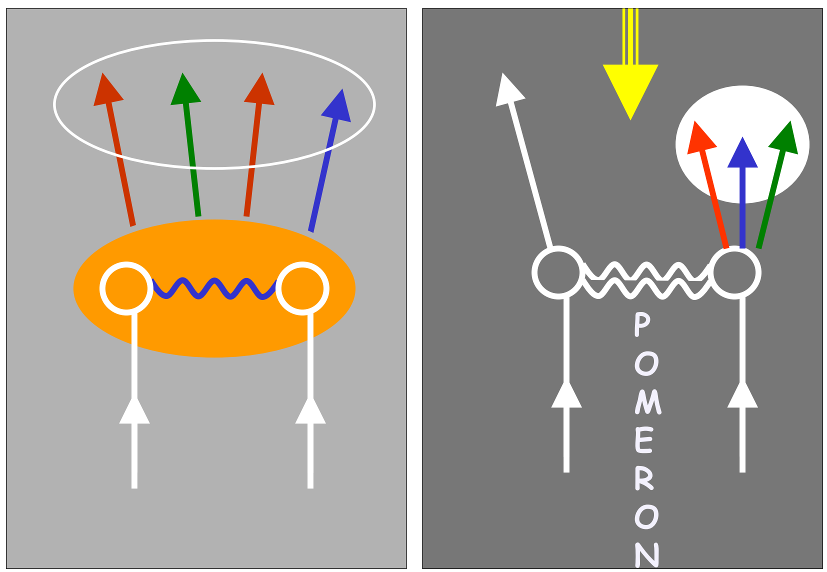
Diffractive:

Colorless exchange with vacuum quantum numbers

rapidity gap

Incident hadrons acquire color and break apart

CONFINEMENT

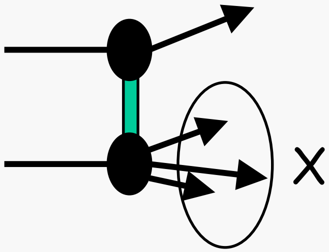


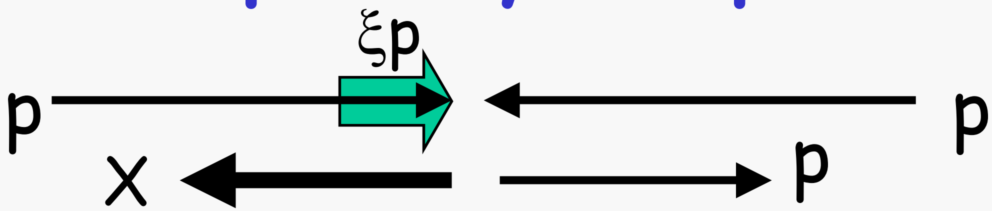
Incident hadrons retain their quantum numbers remaining colorless

pseudo-DECONFINEMENT

Goal: understand the QCD nature of the diffractive exchange

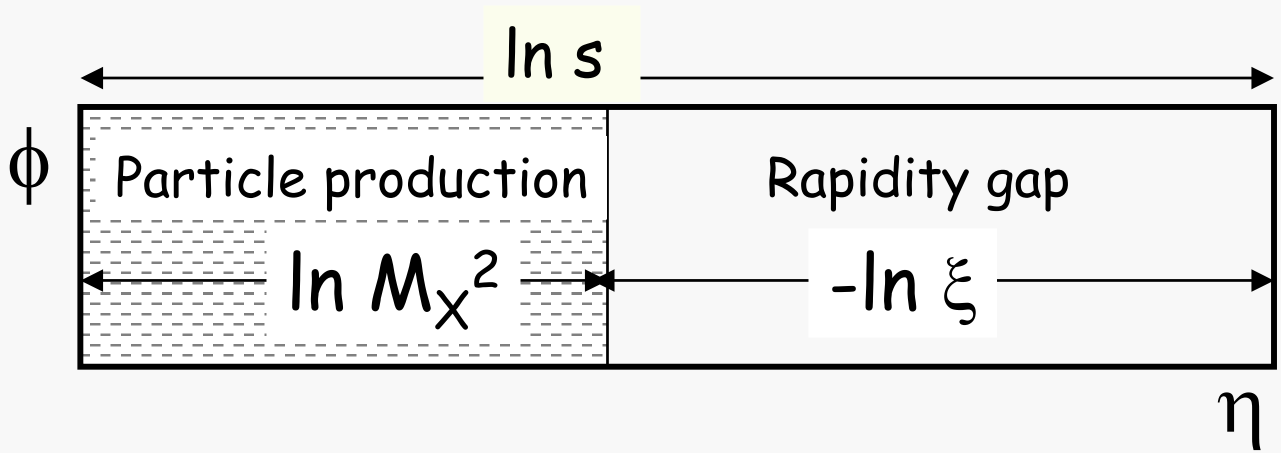
Rapidity Gaps





Momentum loss fraction

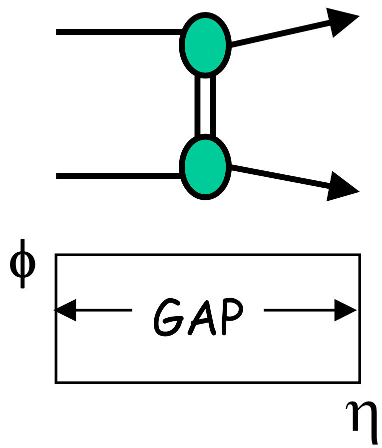
$$\xi = \frac{\Delta P_L}{P_L} = \frac{M_X^2}{S}$$



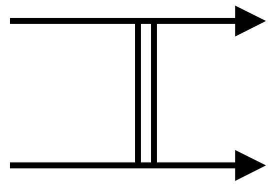
$$\left(\frac{d\sigma}{d\Delta\eta}\right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \Rightarrow \frac{d\sigma}{d\xi} \sim \frac{1}{\xi}$$

Diffraction @ CDF

Elastic scattering

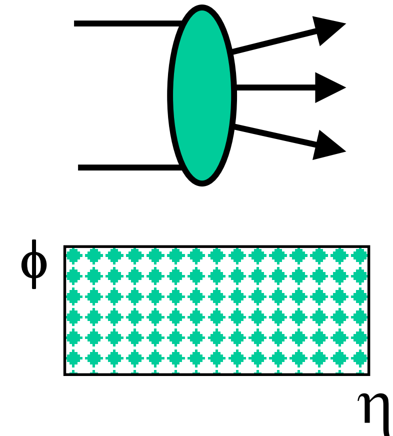


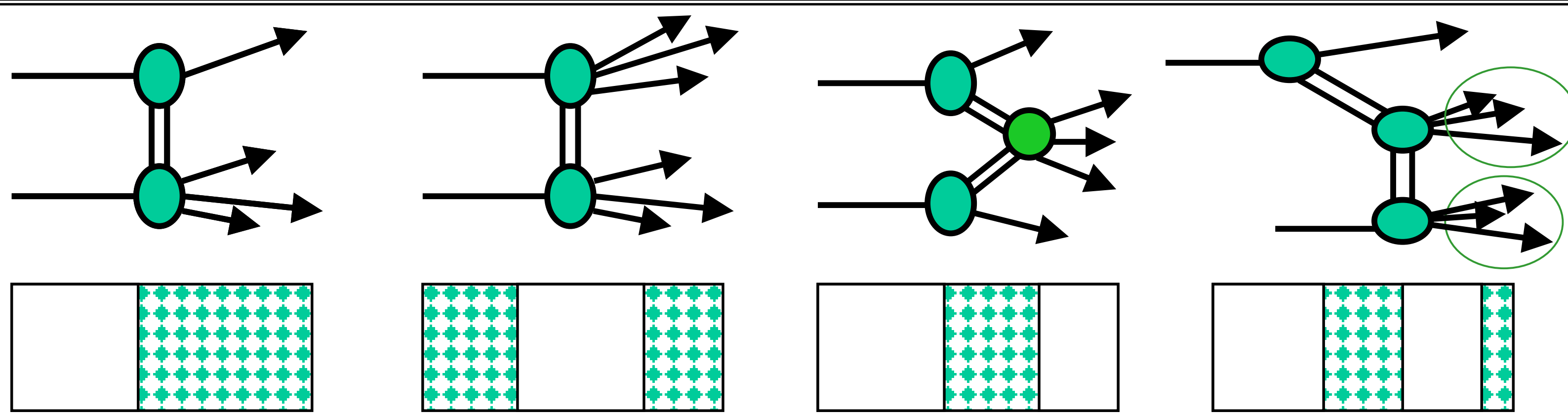
$\sigma_T = \text{Im}\, f_{el}\,(t=0)$



OPTICAL THEOREM

Total cross section



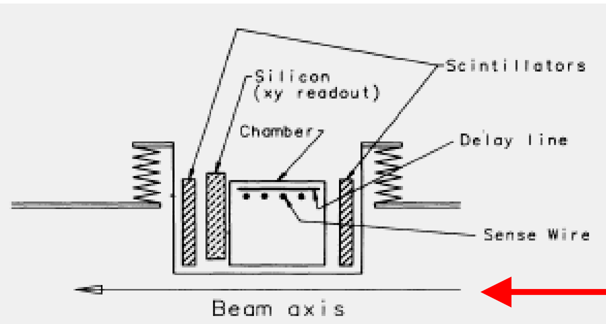


SD DD DPE SDD=SD+DD


Gaps in the sky!

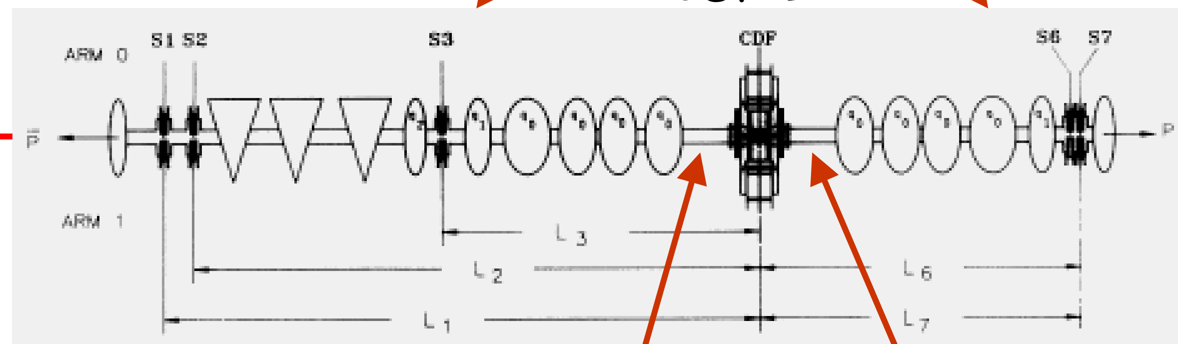
Run 1-0 (1988-89)

Elastic, single diffractive, and total cross sections @ 546 and 1800 GeV



Roman Pot Spectrometers

CDF-I



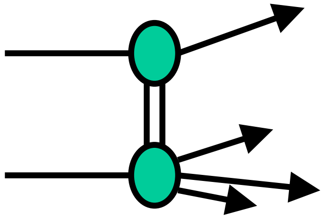
Roman Pot Detectors

- Scintillation trigger counters
- Wire chamber
- Double-sided silicon strip detector

Roman Pots with Trackers up to $|\eta| = 7$

- Total cross section $\sigma^{tot} \sim s^{\varepsilon}$
- Elastic cross section $d\sigma/dt \sim \exp[2\alpha' \ln s]$ → shrinking forward peak
- Single diffraction **Breakdown of Regge factorization**

Renormalization



Factorization ➔

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

Pomeron flux

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

❖ Regge theory

σ_{SD} exceeds σ_T at

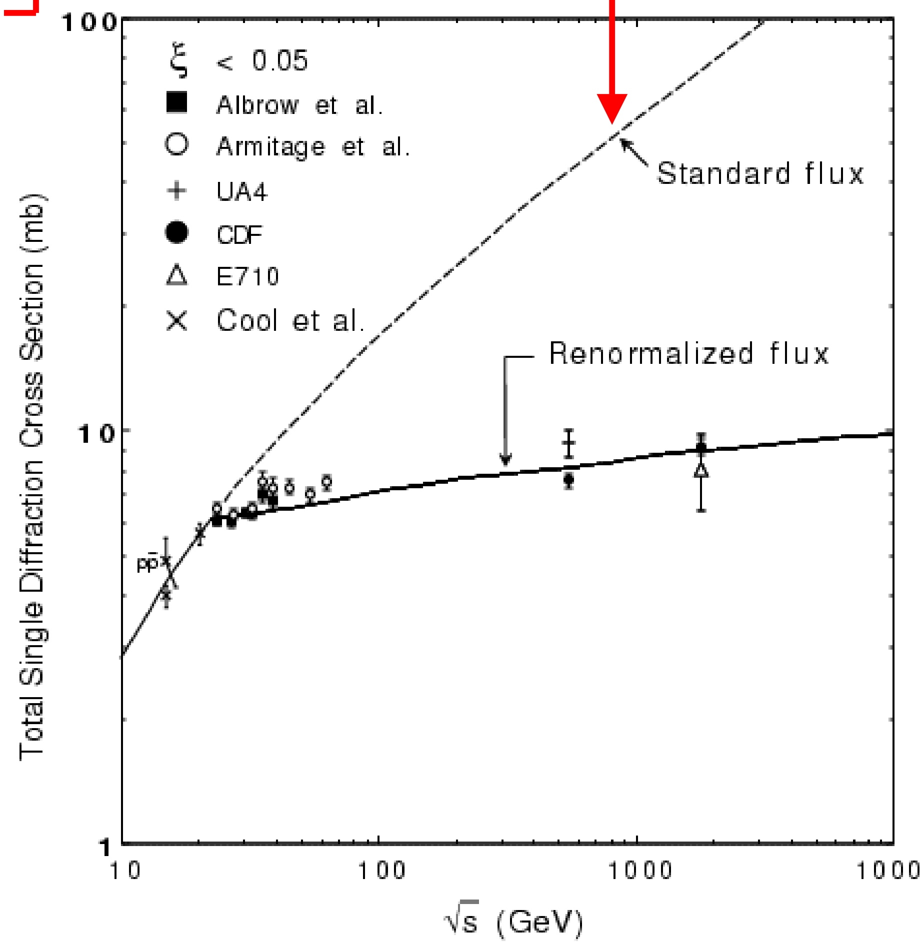
$$\sqrt{s} \approx 2\ \text{TeV}.$$

❖ Renormalization

Pomeron flux integral (re)normalized to unity

KG, PLB 358 (1995) 379

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



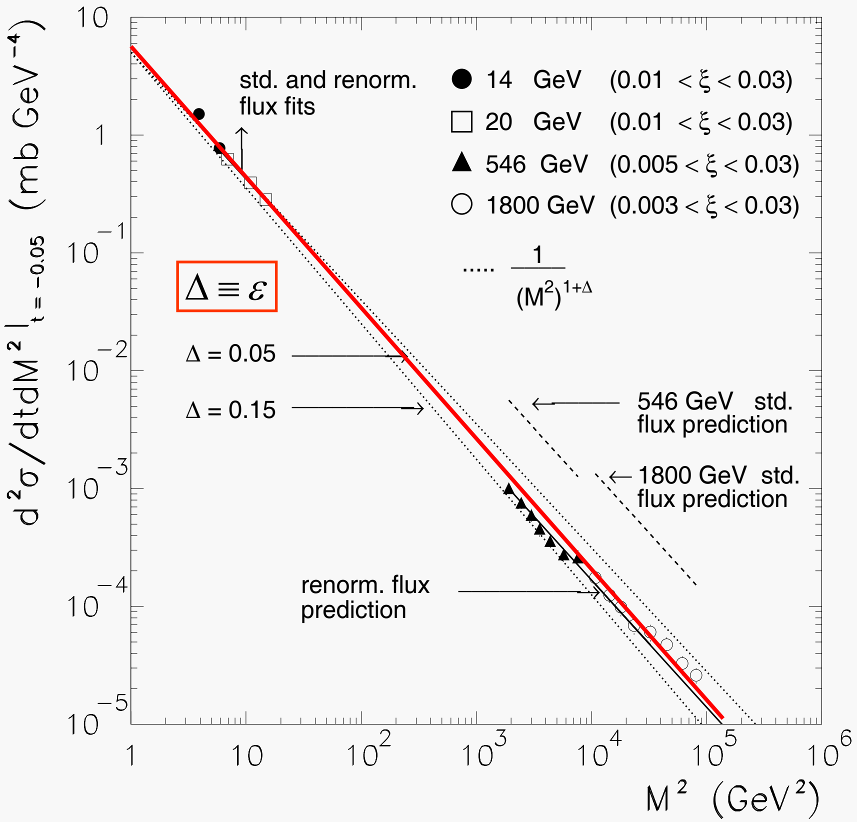
A Scaling Law in Diffraction

KG&JM, PRD 59 (1999) 114017

renormalization

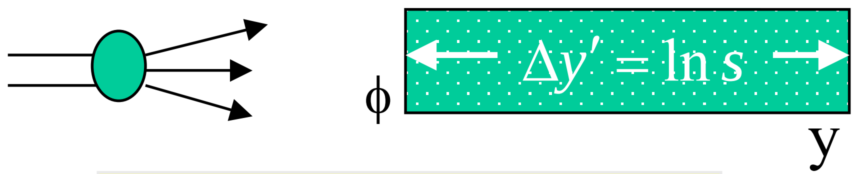
$$\frac{d\sigma}{dM^2} \propto \frac{s^{2\varepsilon}}{(M^2)^{1+\varepsilon}} \quad s^{2\varepsilon} \rightarrow 1$$

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



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

The QCD Connection

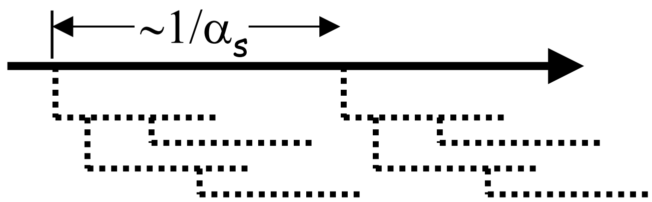


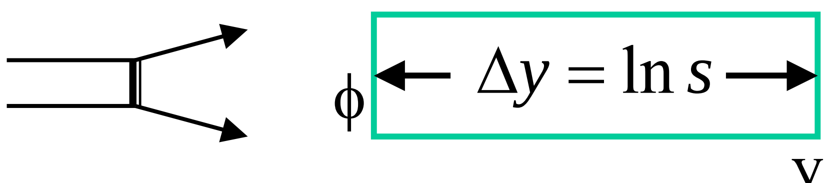
$$\sigma_T(s) = \sigma_o\, e^{\varepsilon \Delta y'} = \sigma_o\, s^{\varepsilon}$$

The exponential rise of $\sigma_T(\Delta y')$ is due to the increase of wee partons with $\Delta y'$

(E. Levin, An Introduction to Pomerons, Preprint DESY 98-120)

Total cross section:
power law increase versus s



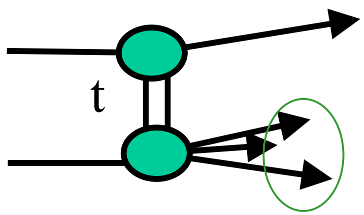


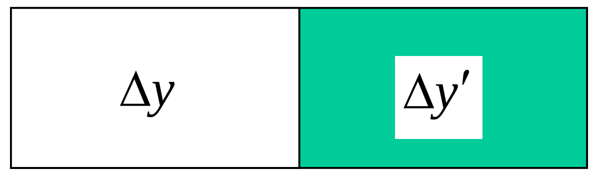
$$\mathrm{Im}\ f_{el}(s,t) \propto e^{(\varepsilon + \alpha' t)\Delta y}$$

Elastic cross section:
forward scattering amplitude

Single Diffraction in QCD

(KG, hep-ph/0205141)





$$\left.\frac{d\sigma}{dM^2}\right|_{\text{REGGE}} \propto \frac{s^{2\varepsilon}}{(M^2)^{1+\varepsilon}}$$

2 independent variables: $t, \Delta y$

color factor

$$\frac{d^2\sigma}{dt\, d\Delta y} = \underbrace{C \bullet F_p^2(t) \bullet \left\{ e^{(\varepsilon+\alpha' t)\Delta y} \right\}^2}_{\text{Gap probability}} \bullet \kappa \bullet \underbrace{\left\{ \sigma_o\, e^{\varepsilon\, \Delta y'} \right\}}$$

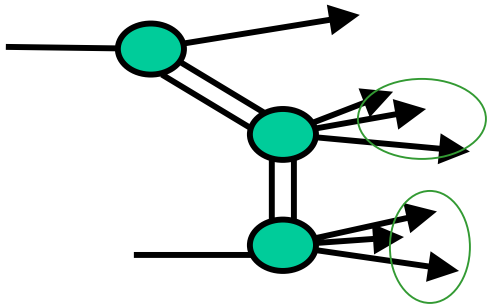
Gap probability

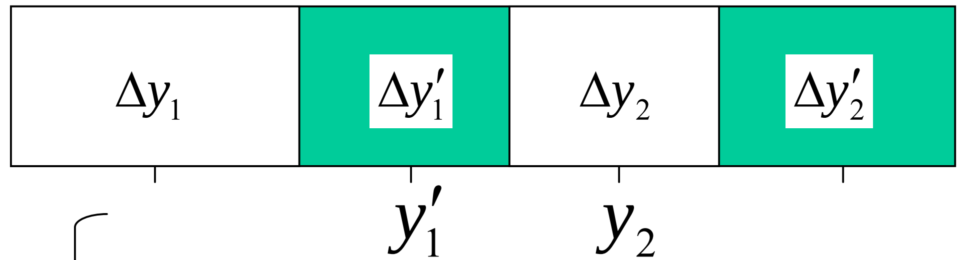
$$\sim e^{2\varepsilon \Delta y} \longrightarrow \int_{\Delta y_{\min}}^{\Delta y = \ln s} s^{2\varepsilon\,\Delta y} \approx s^{2\varepsilon}$$

Renormalization removes the s-dependence → SCALING

Multi-gap Renormalization

(KG, hep-ph/0205141)





5 independent variables $\left\{ t_1 \quad \Delta y = \Delta y_1 + \Delta y_2 \quad t_2 \right.$

color factors

$$\frac{d^5\sigma}{\prod_{i=1-5} dV_i} = C \times F_p^2(t_1) \prod_{\mathrm{i=1\text{-}2}} \left\{ e^{(\varepsilon + \alpha' t_i)\Delta y_i} \right\}^2 \times \kappa^2 \left\{ \sigma_o \, e^{\varepsilon(\Delta y'_1 + \Delta y'_2)} \right\}$$

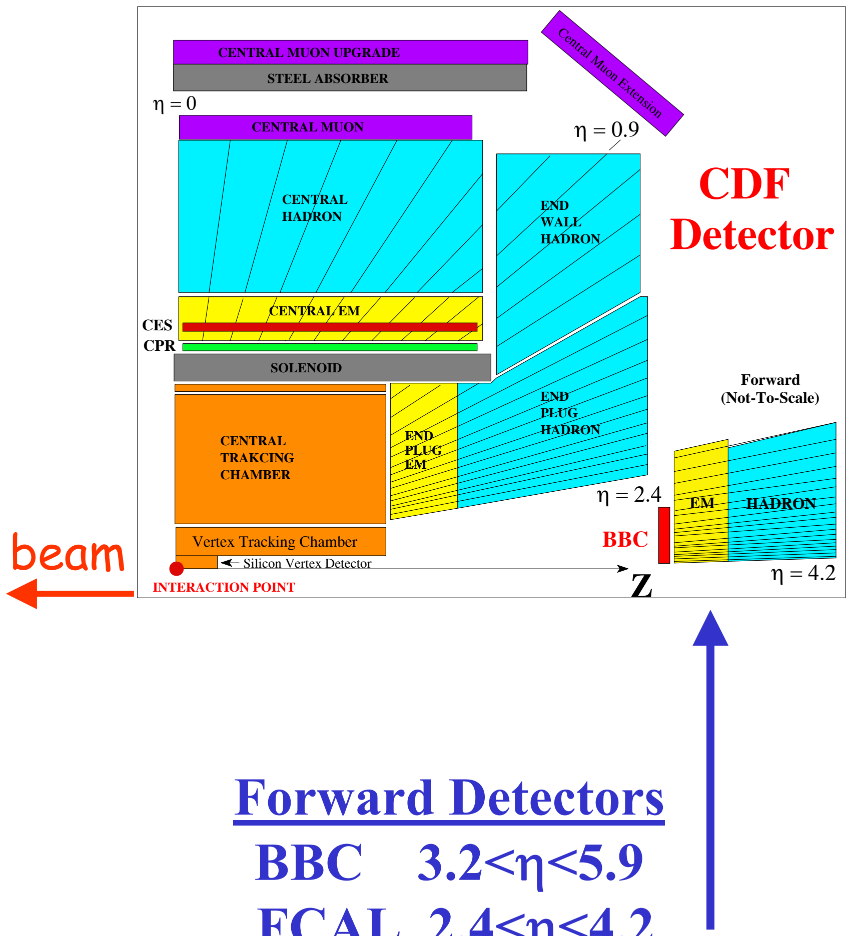
Gap probability $\sim e^{2\varepsilon \Delta y}$

Sub-energy cross section (for regions with particles)

$$\int_{\Delta y_{\min}}^{\Delta y = \ln s} s^{2\varepsilon \, \Delta y} \approx s^{2\varepsilon}$$

Same suppression as for single gap!

CDF-IA, IB

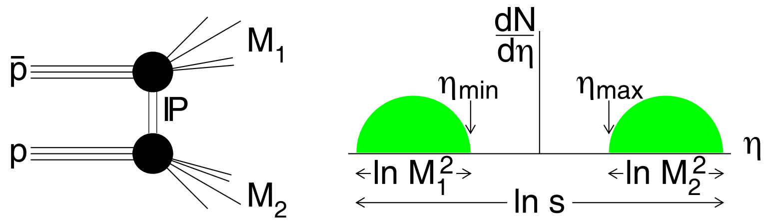


Forward Detectors

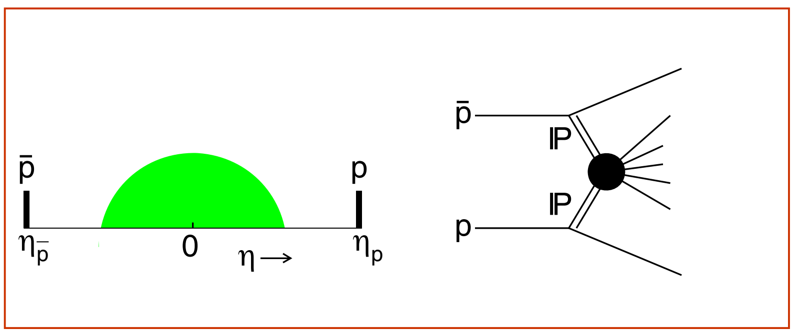
BBC $3.2<\eta<5.9$

FCAL $2.4<\eta<4.2$

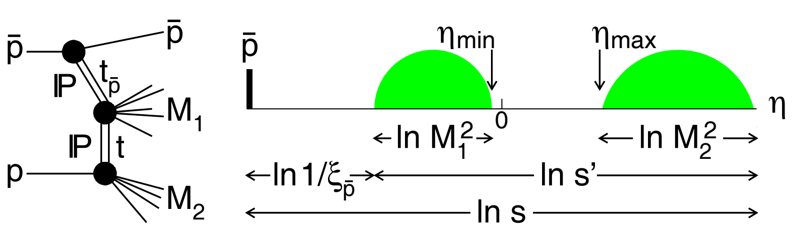
Central and Double Gaps



- **Double Diffraction Dissociation**
  - **One central gap**



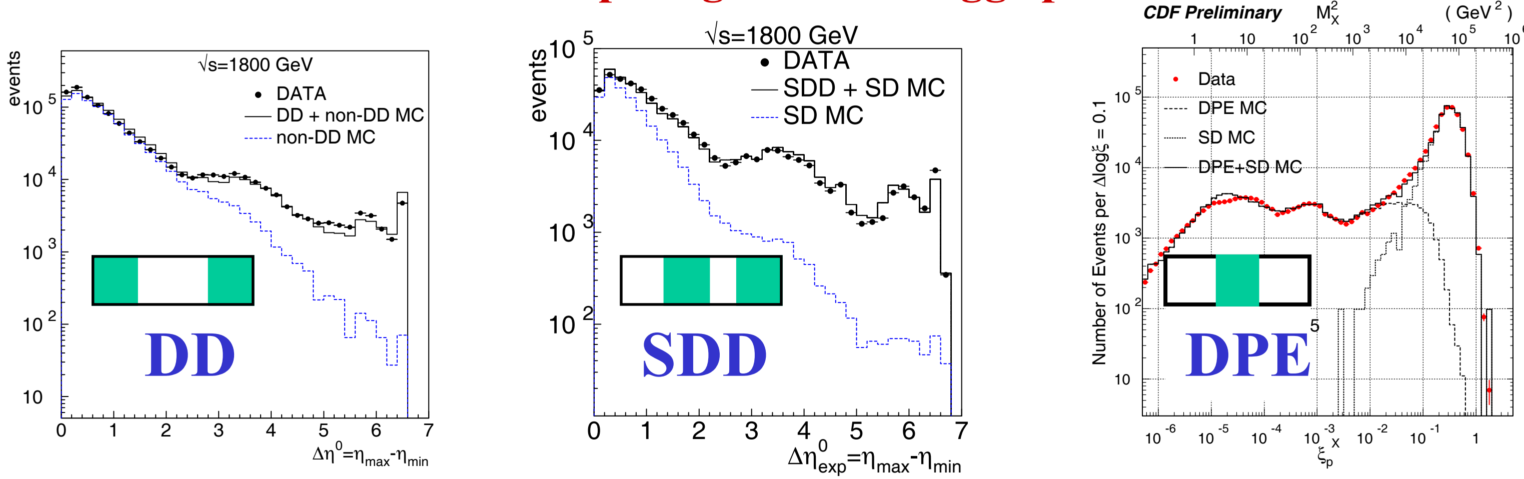
- **Double Pomeron Exchange**
  - **Two forward gaps**



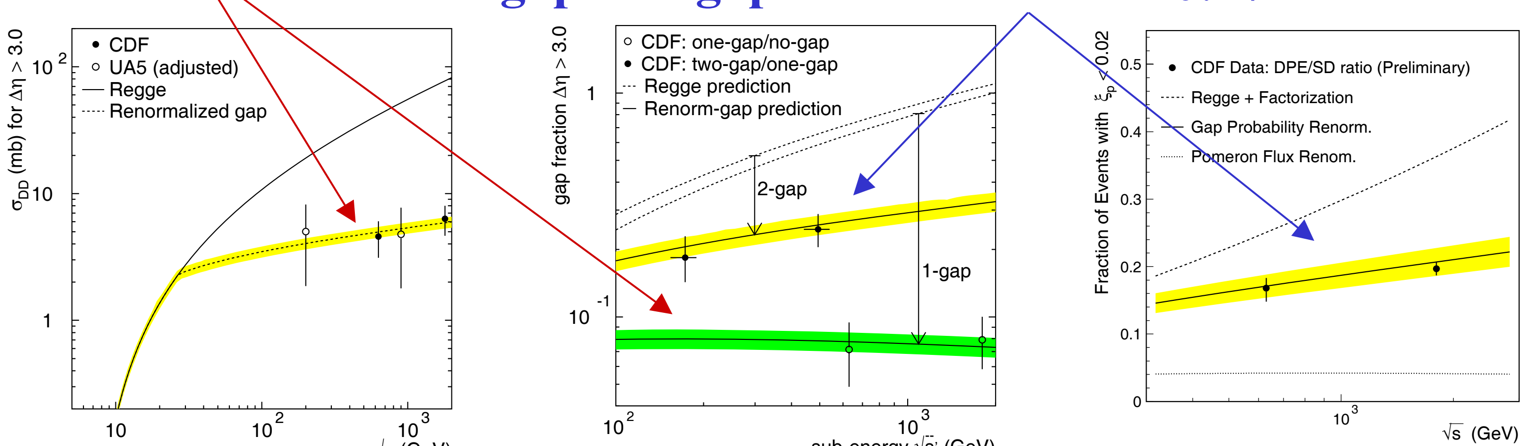
- **SDD: Single+Double Diffraction**
  - **One forward + one central gap**

Central & Double-Gap CDF Results

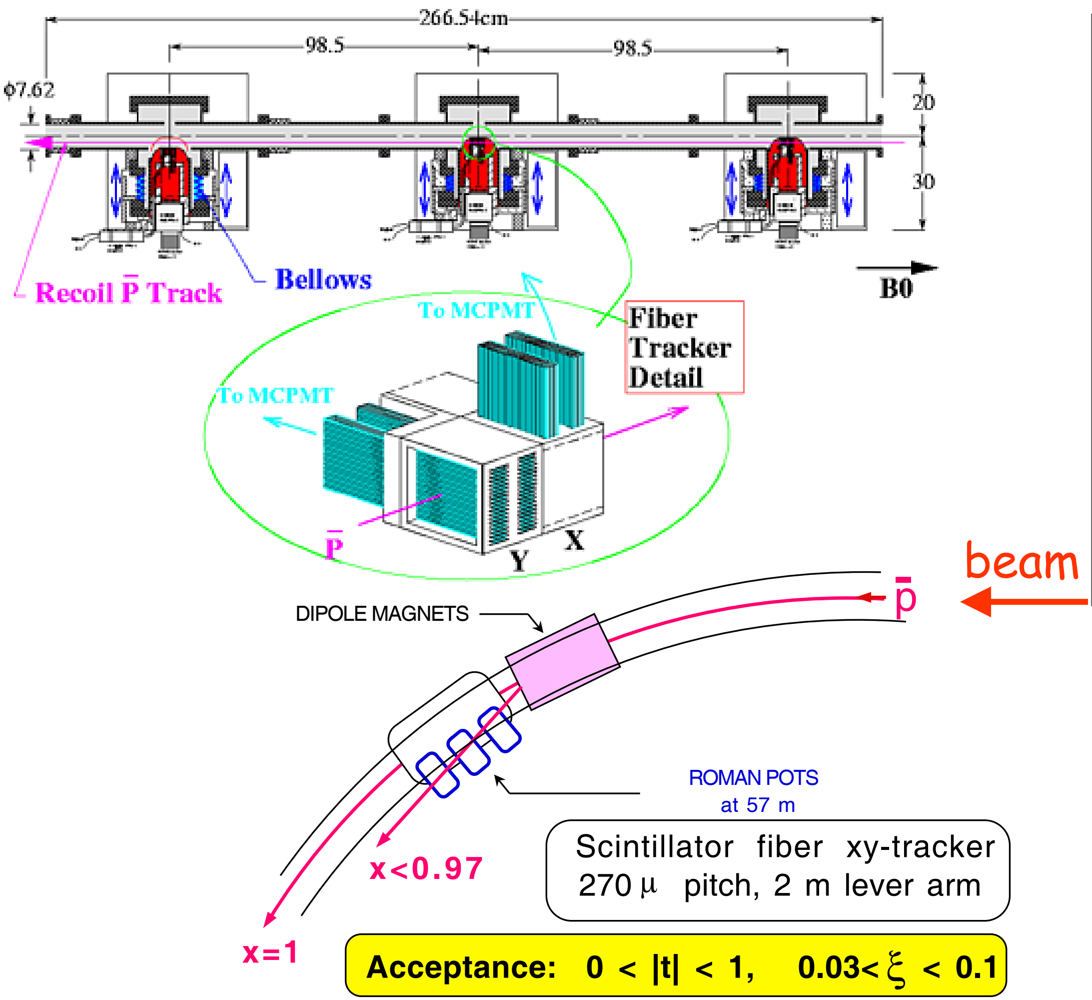
Differential shapes agree with Regge predictions

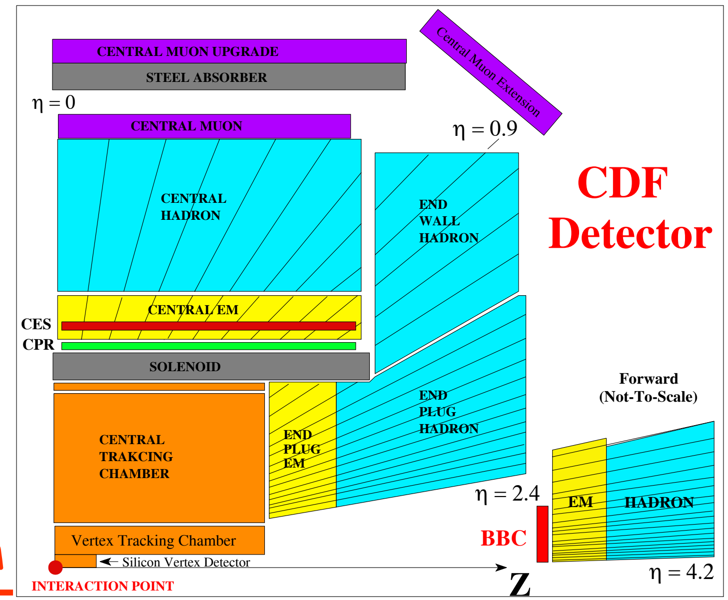


- **One-gap cross sections are suppressed**
  - **Two-gap/one-gap ratios are** $\approx \kappa = 0.17$



CDF-IC



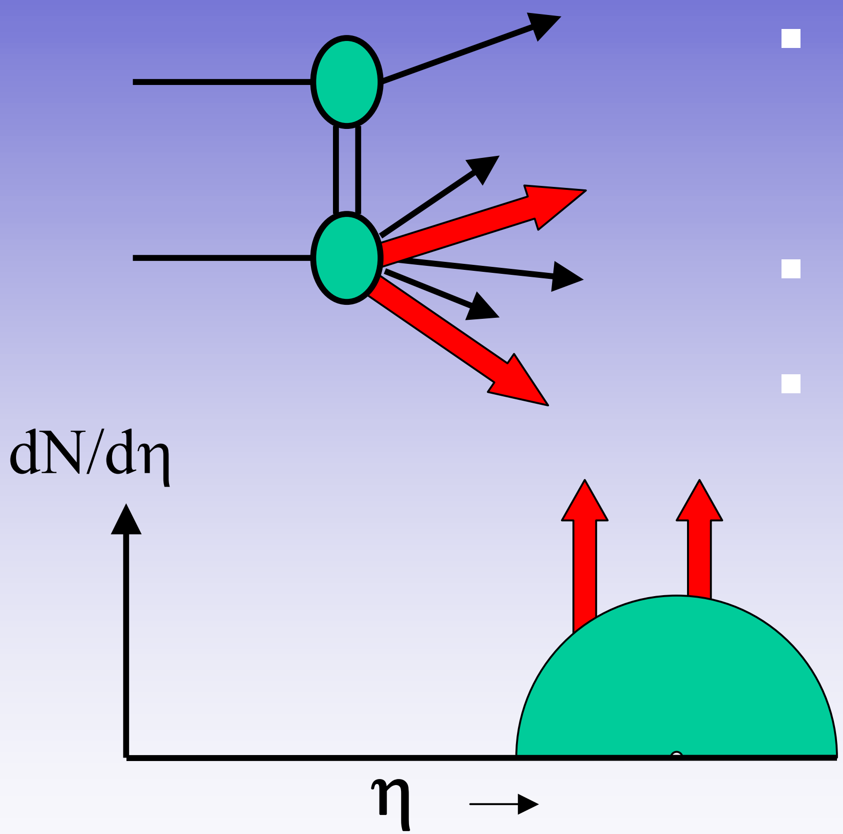


Forward Detectors

BBC $3.2<\eta<5.9$

FCAL $2.4<\eta<4.2$

HARD DIFFRACTION



- Diffractive fractions
- Diffractive structure function
  - ➔ factorization breakdown
- Restoring factorization
- Hard diffraction in QCD

JJ, W, b, J/ψ

Diffractive Fractions

$$\bar{p}p \rightarrow (\ ☼ + X\ ) + \text{gap}$$

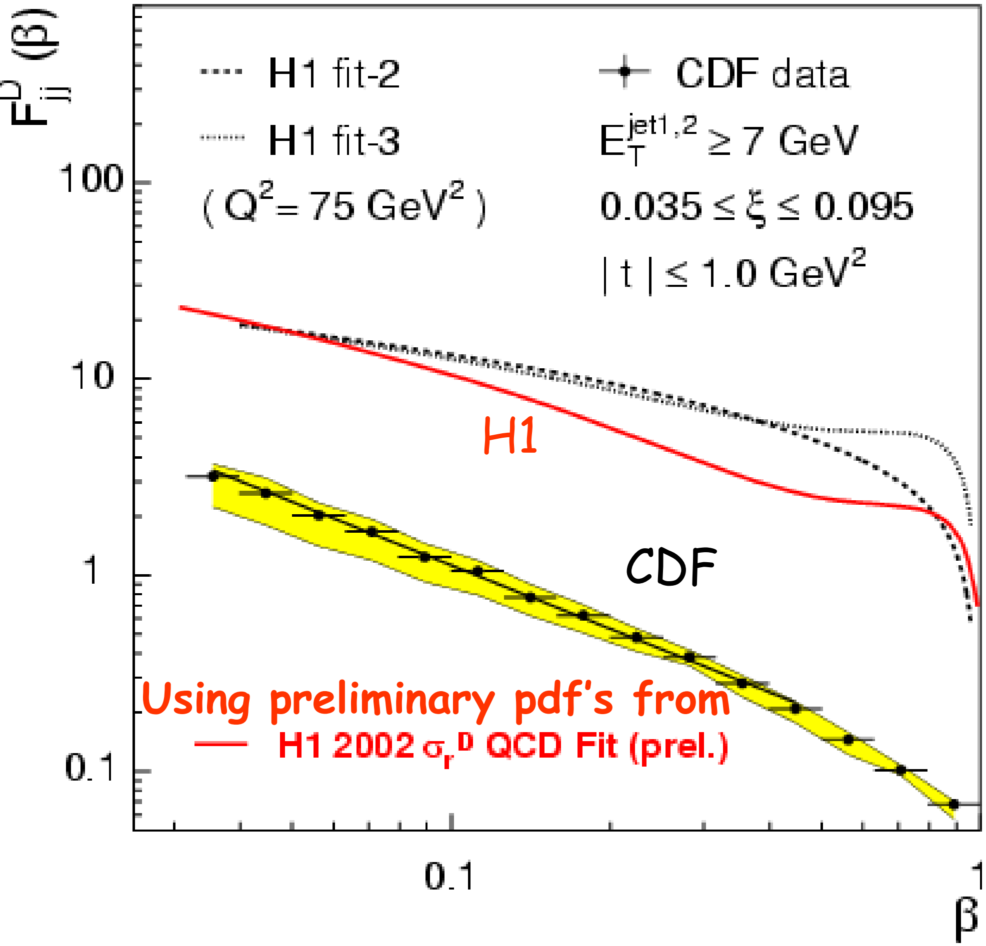
Fraction:
SD/ND ratio at 1800 GeV

☼	Fraction(%)
W	1.15 (0.55)
JJ	0.75 (0.10)
b	0.62 (0.25)
J/ψ	1.45 (0.25)

All ratios ~ 1%
➔ ~ uniform suppression
~ FACTORIZATION !

Diffractive Structure Function:

Breakdown of QCD Factorization

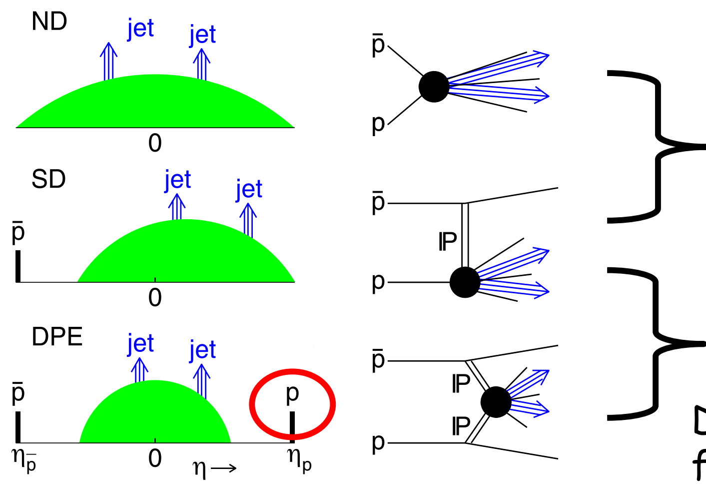


β = momentum fraction of parton in Pomeron

The diffractive structure function at the Tevatron is suppressed by a factor of ~10 relative to expectation from pdf's measured by H1 at HERA

Similar suppression factor as in soft diffraction relative to Regge expectations!

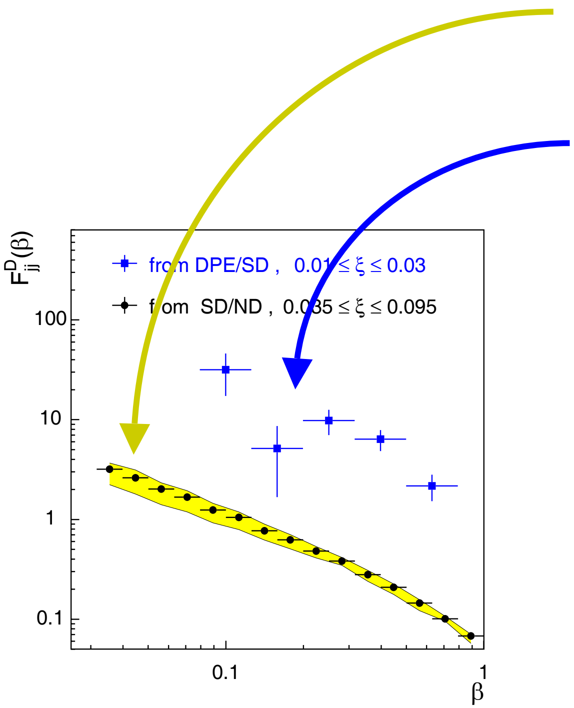
Restoring QCD Factorization

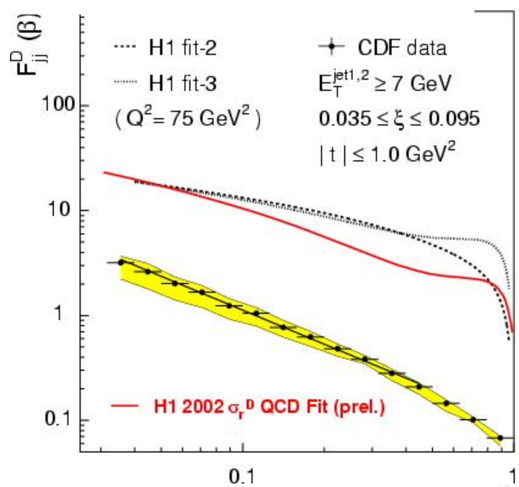


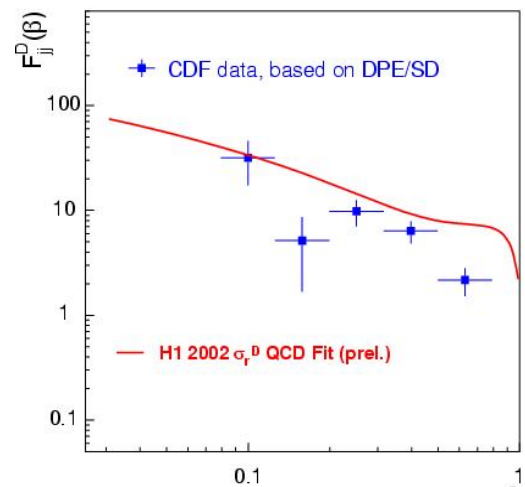
R(SD/ND)

R(DPE/SD)

DSF from two/one gap: factorization restored!

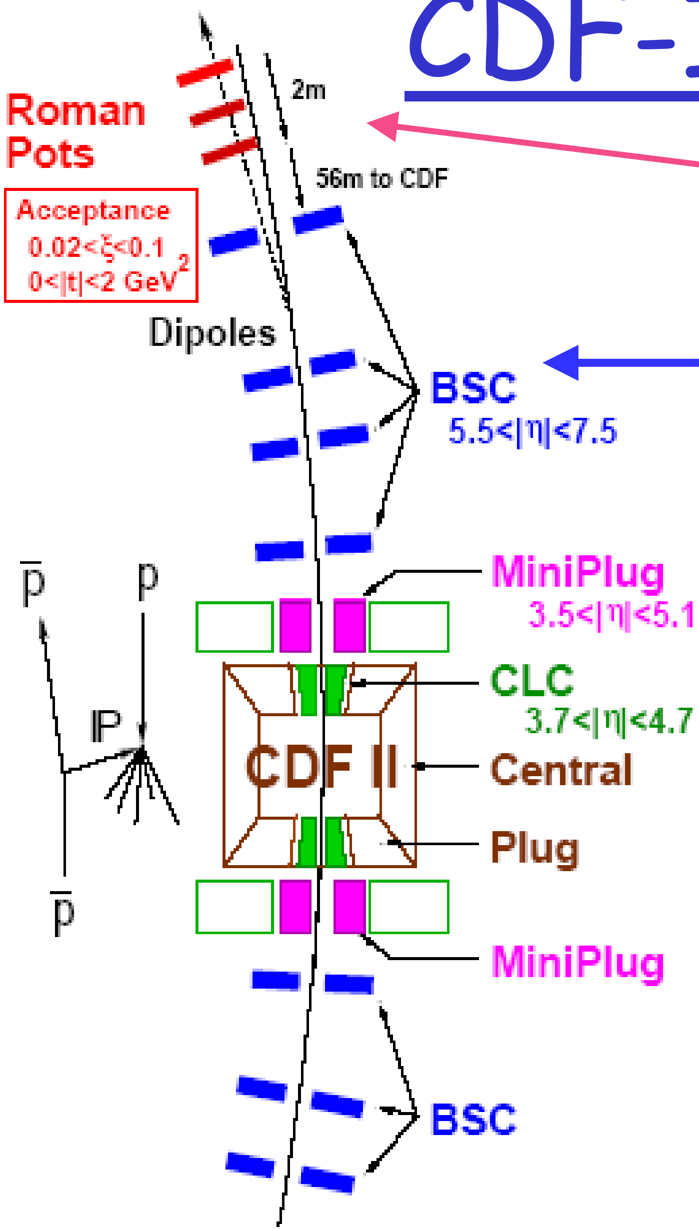






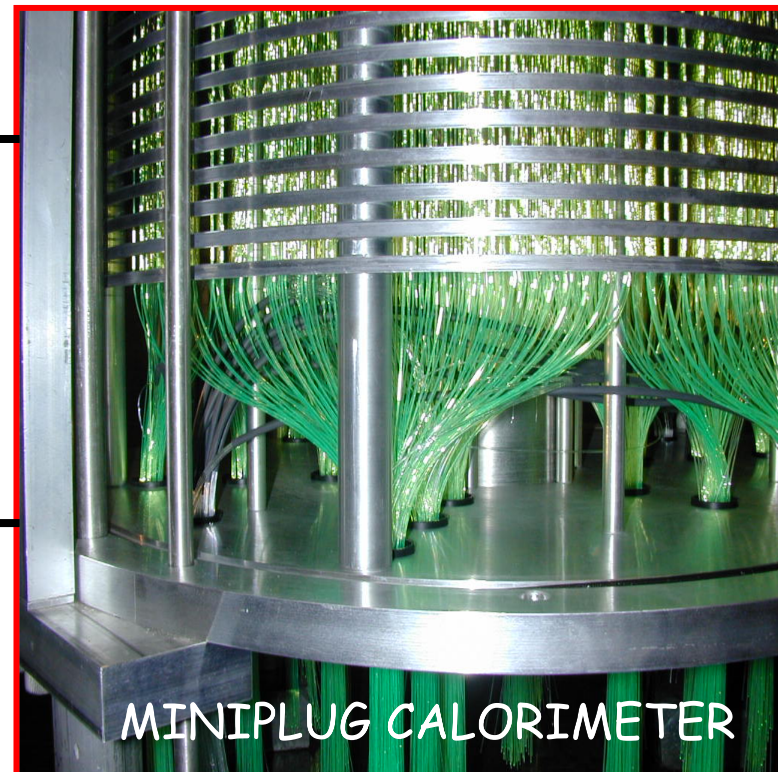
The diffractive structure function measured on the proton side in events with a leading antiproton is NOT suppressed relative to predictions based on DDIS

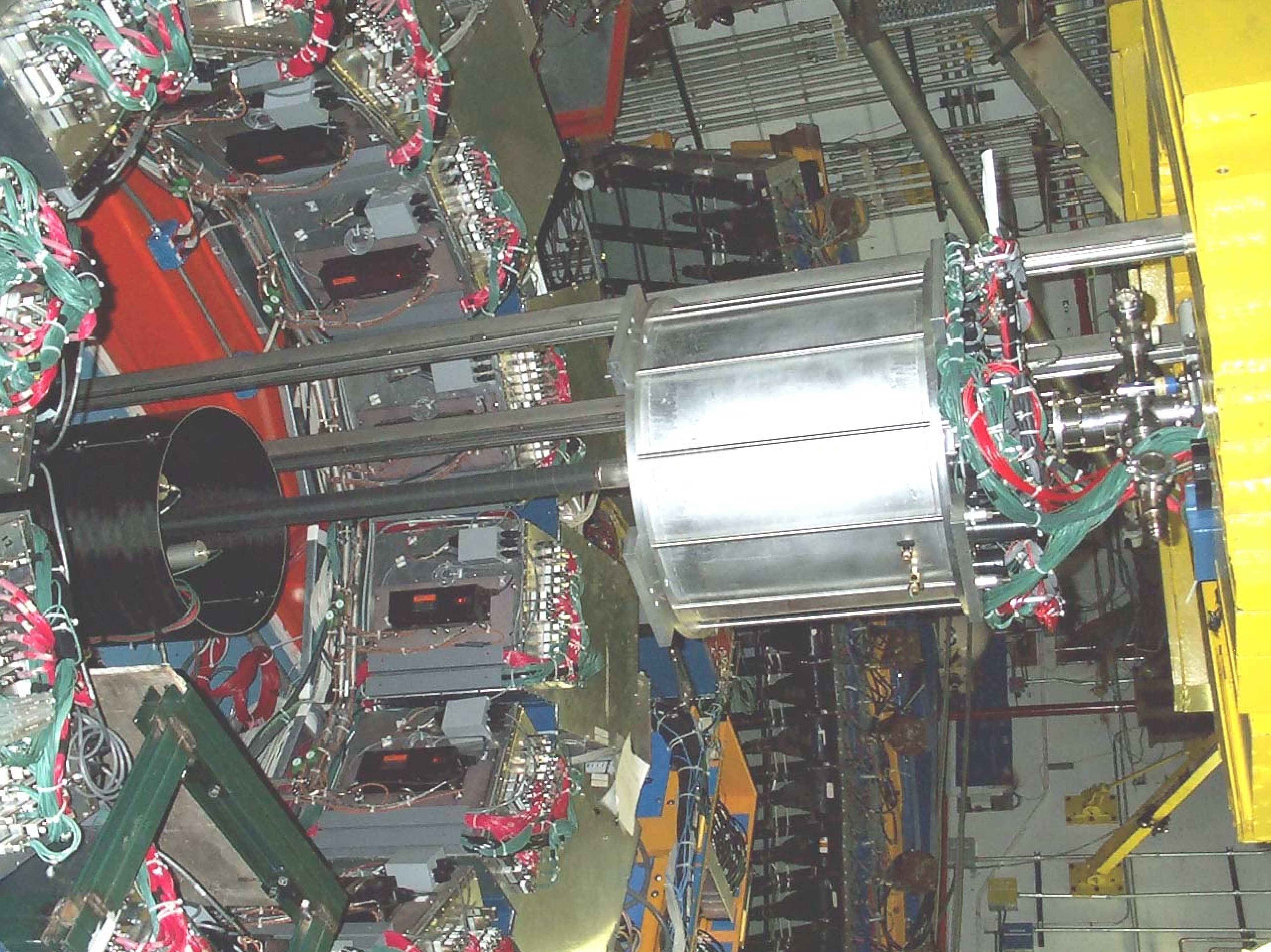
CDF-II



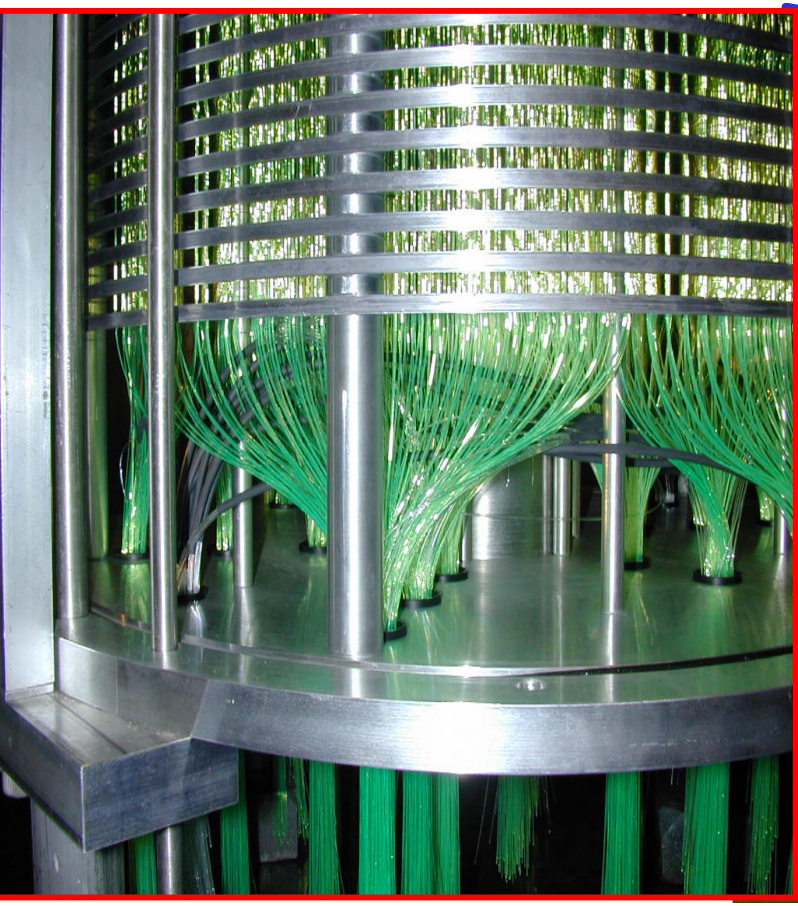
ROMAN POT DETECTORS

BEAM SHOWER COUNTERS:
Used to reject ND events





MiniPlug Calorimeter



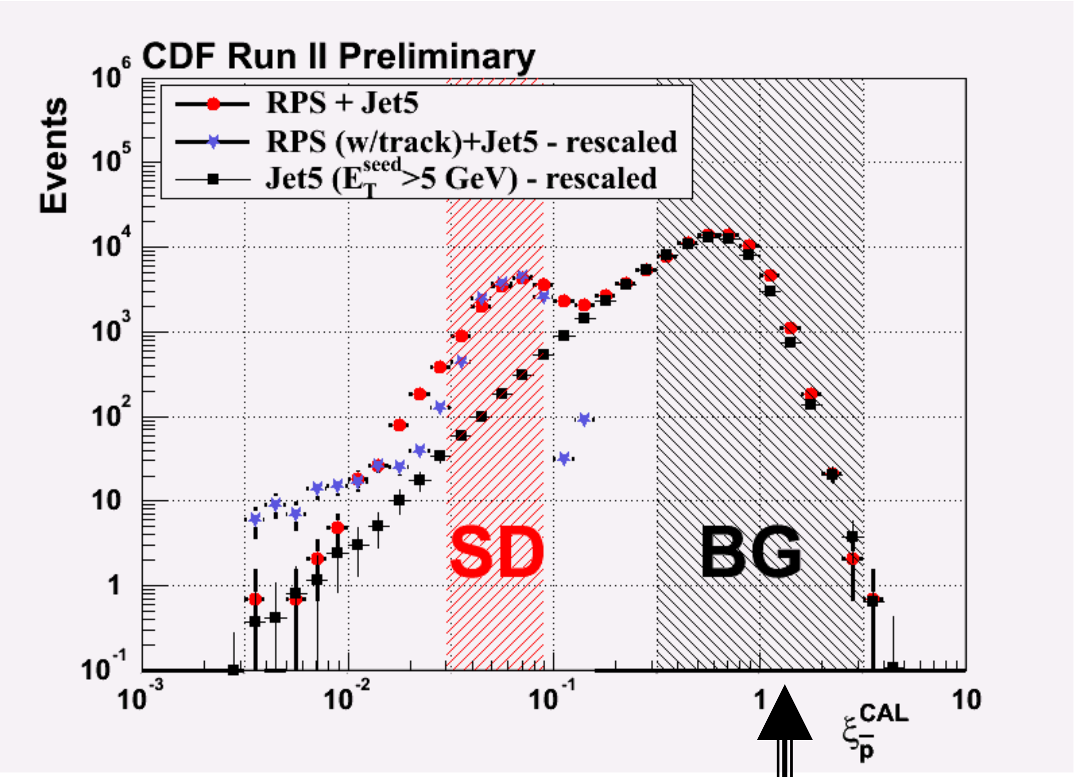
About 1500 wavelength shifting fibers of 1 mm dia. are 'strung' through holes drilled in $36\text{x}\frac{1}{4}$" lead plates sandwiched between reflective Al sheets and guided into bunches to be viewed individually by multi-channel photomultipliers.

Run II Results

- Diffractive structure function
  - Q^2 - dependence
  - t - dependence
- Exclusive production
  - dijet
  - diphoton

Diffractive Dijet Signal

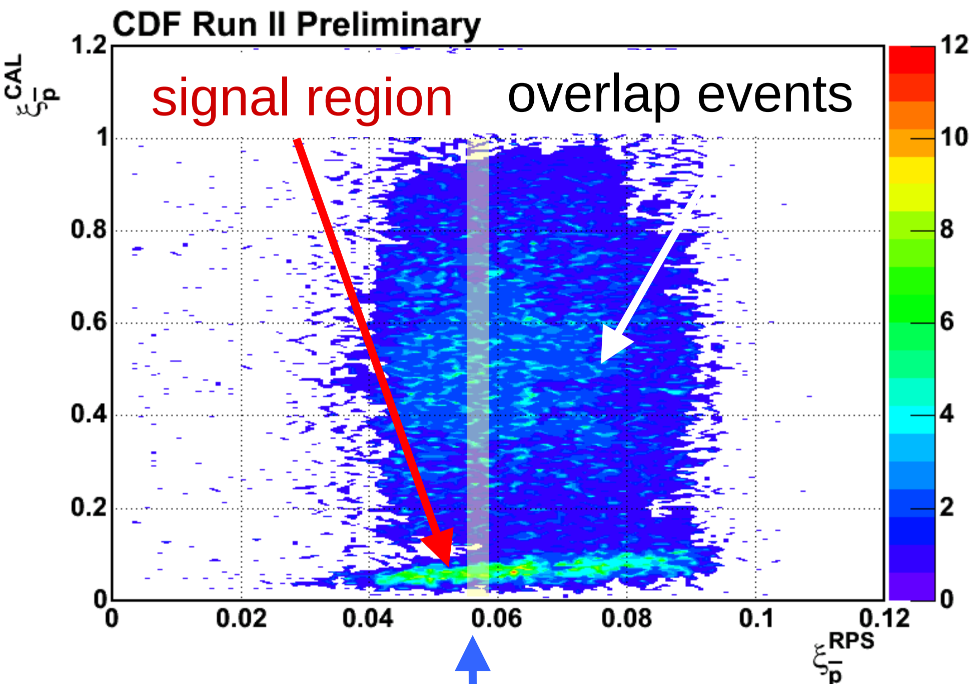
- Bulk of data taken with RPS trigger but no working RPS tracking
- Extract ξ from calorimetric information
- Calibrate calorimetric ξ using limited sample of RPS tracking data
- Subtract overlap background using a rescaled dijet event sample
- Verify diffractive ξ range by comparing ξ^{RPS} with ξ^{CAL}

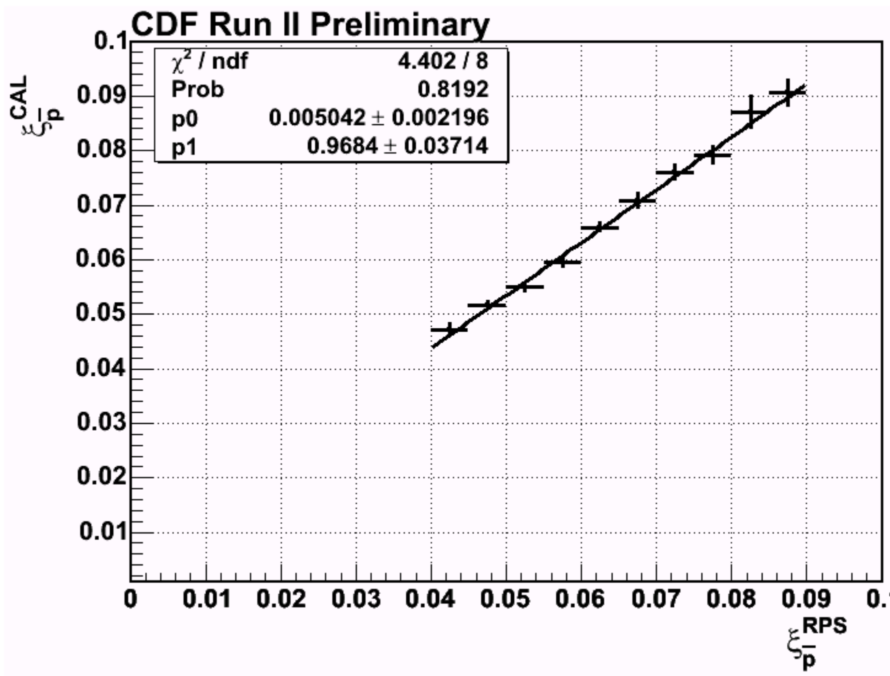


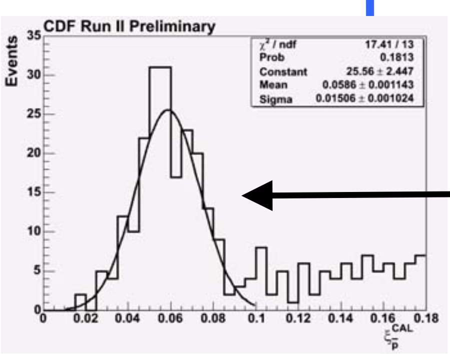
$$\xi^{CAL} = \frac{\sum_{\text{all towers}} E_T\, e^{-\eta}}{\sqrt{s}}$$

Overlap events: mainly ND dijets plus SD low ξ RPS trigger

ξ^{CAL} Calibration





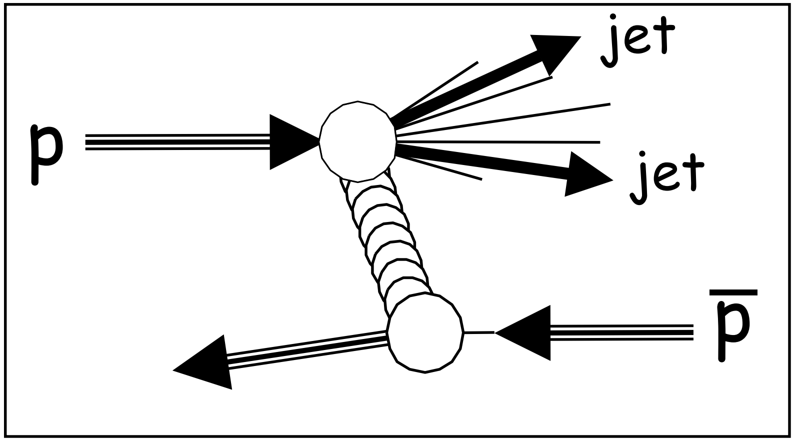


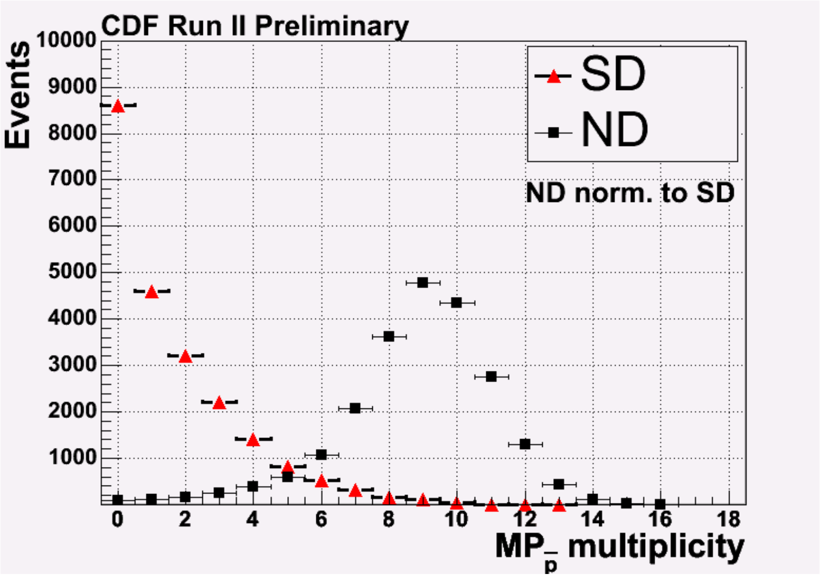
ξ^{cal} distribution for slice of ξ^{RPS}

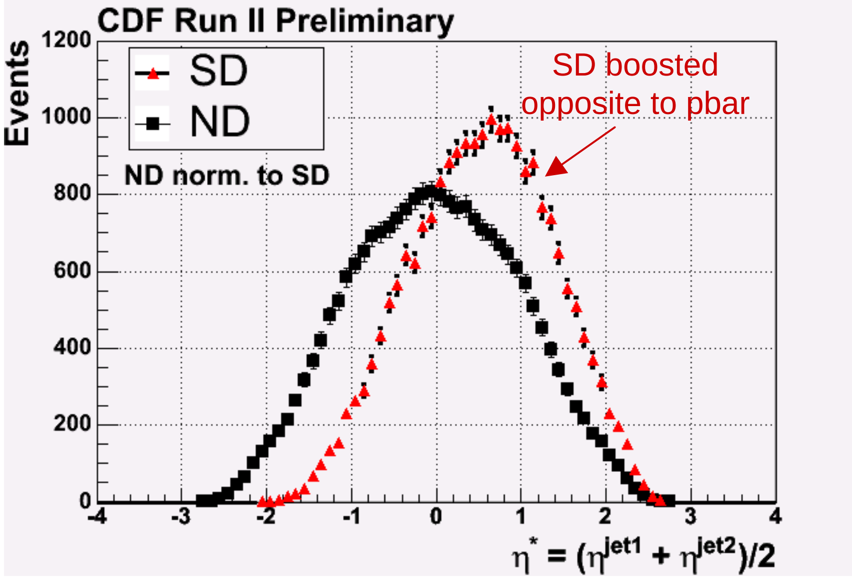
σ / mean ~ 30%

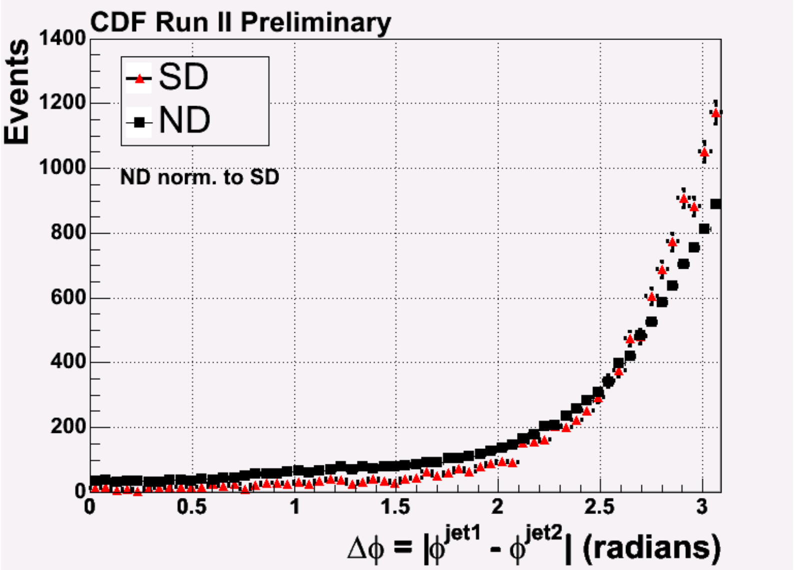
$$\xi^{CAL} = (0.97 \pm 0.04)\,\xi^{RPS}$$

Dijet Properties

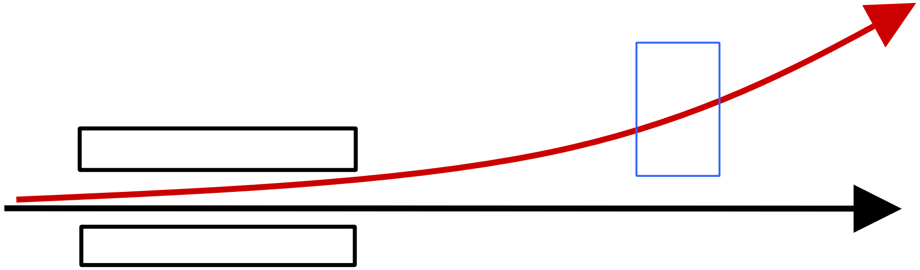






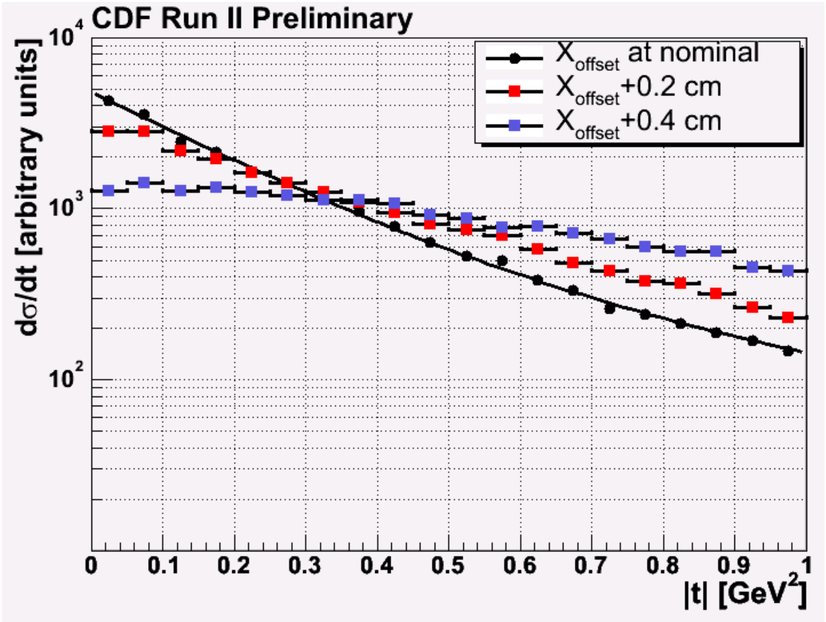


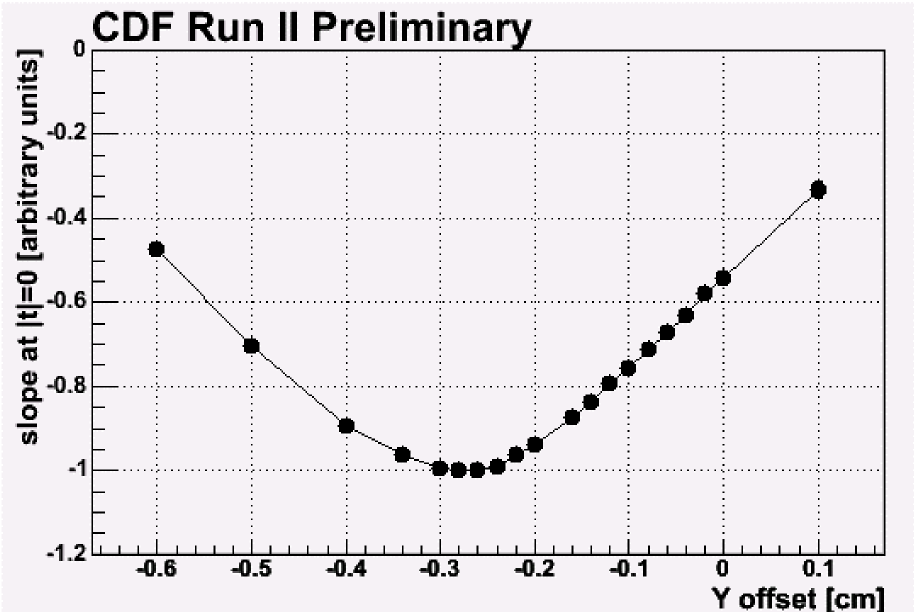
Alignment of RPS using Data



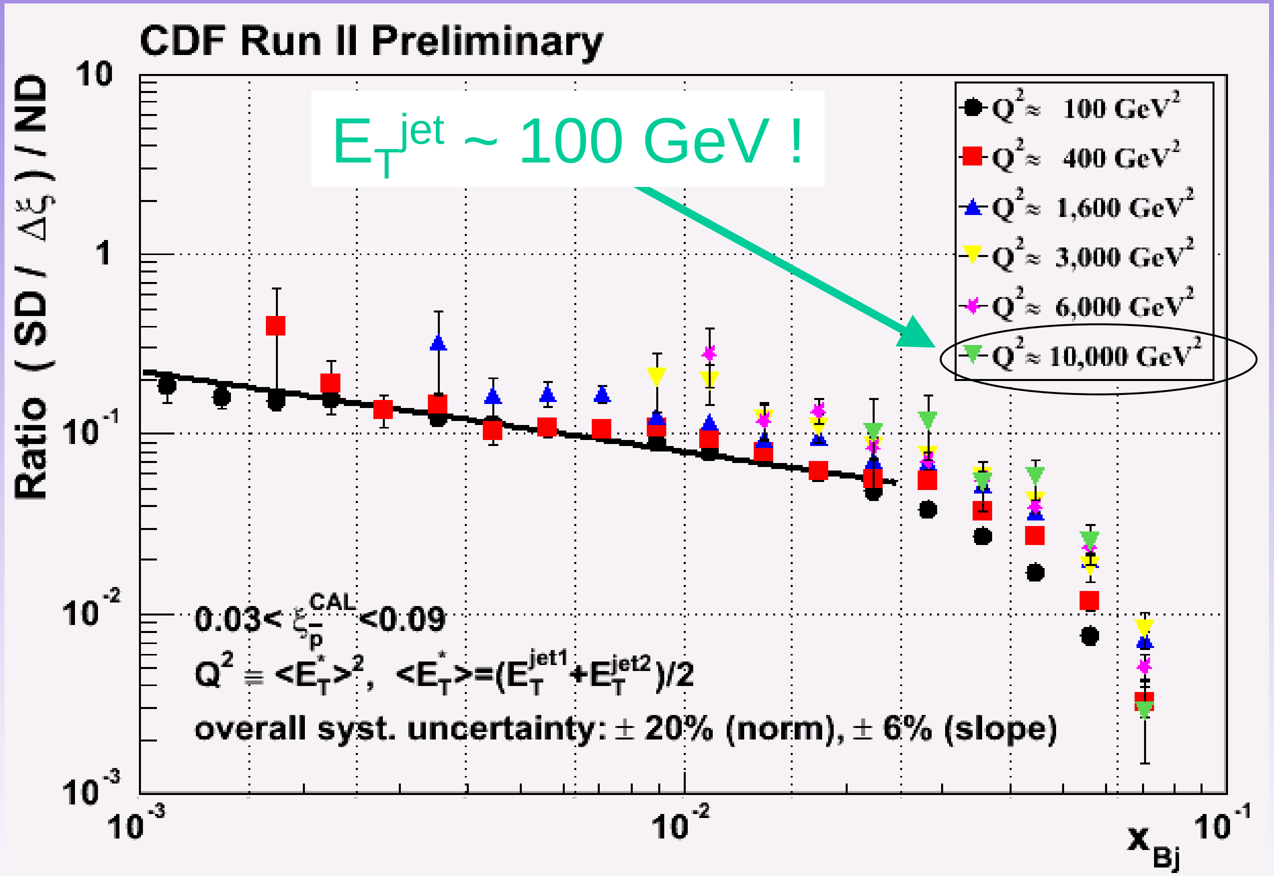
maximize the |t|-slope

⇨ determine X and Y offsets





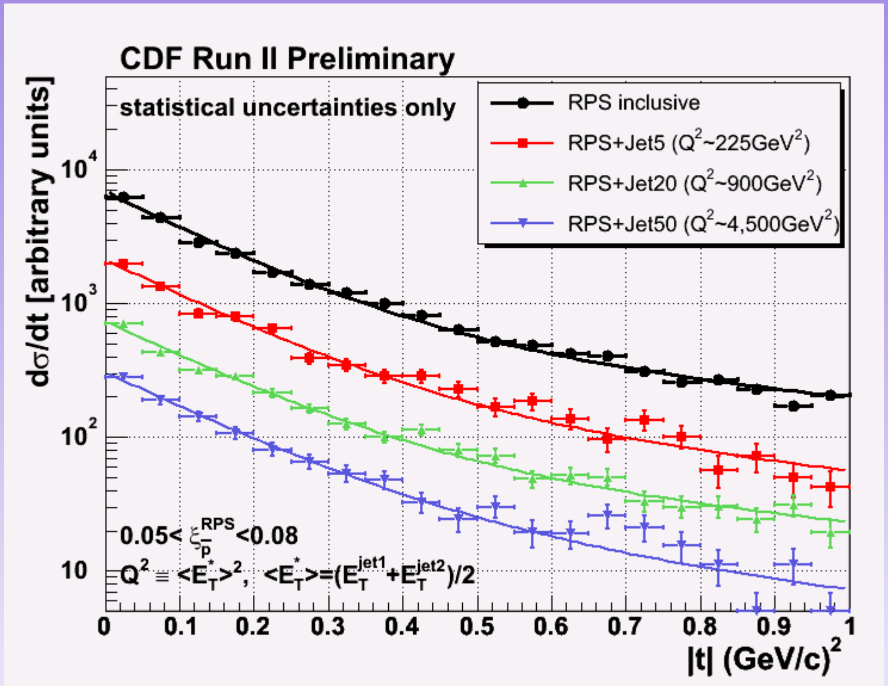
Diffractive Structure Function:
Q^2 dependence

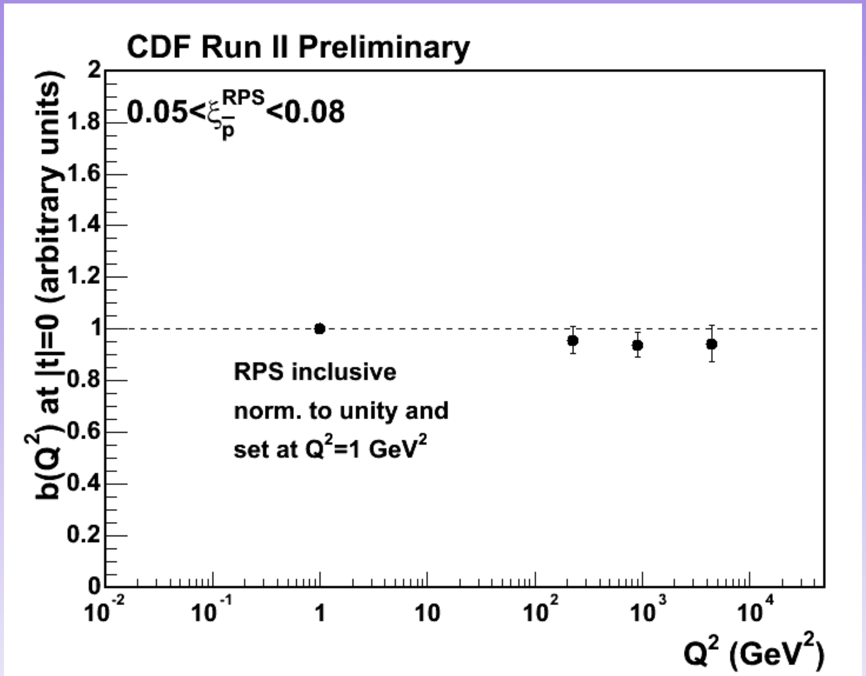


Small Q^2 dependence in region 100 < Q^2 < 10,000 GeV^2

⇨ **Pomeron evolves similarly to proton!**

Diffractive Structure Function: t- dependence





Fit dσ/dt to a double exponential:

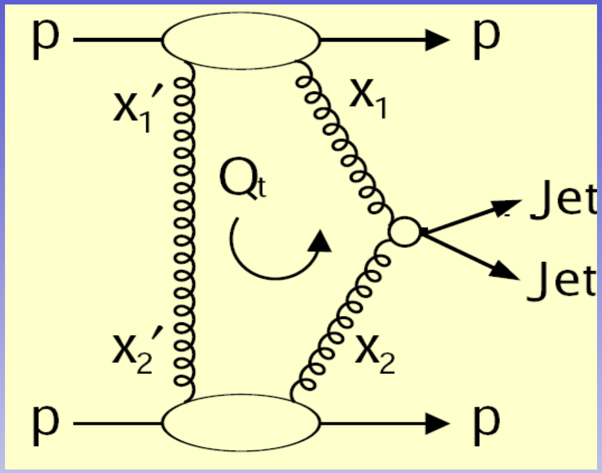
$$F = 0.9 \cdot e^{b_1 \cdot t} + 0.1 \cdot e^{b_2 \cdot t}$$

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

- Same slope over entire region of $0 < Q^2 < 10{,}000$ GeV^2 across soft and hard diffraction!

EXCLUSIVE PRODUCTION

Measure exclusive jj & $\gamma\gamma$ ➔ ➔ ➔ Calibrate predictions for H production rates @ LHC



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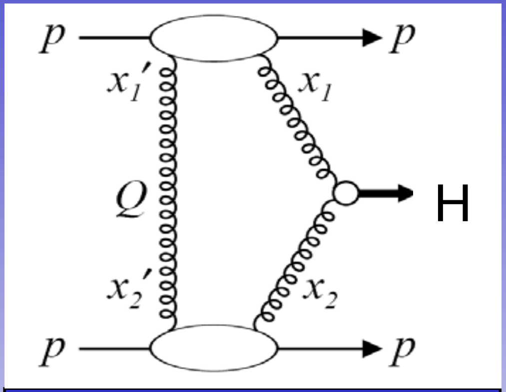
C25,391 (2002);C26,229 (2002)
C. Royon, hep-ph/0308283
B. Cox, A. Pilkington,
PRD 72, 094024 (2005)
OTHER……………………….

Clean discovery channel

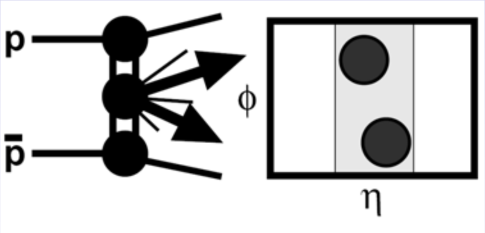


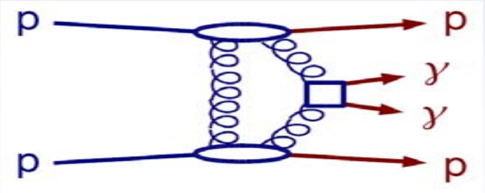
KMR: σ_H(LHC) ~ 3 fb
S/B ~ 1 if ΔM ~ 1 GeV

Search for exclusive dijets:
Measure dijet mass fraction

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

Look for signal as M_{jj} ➔ 1





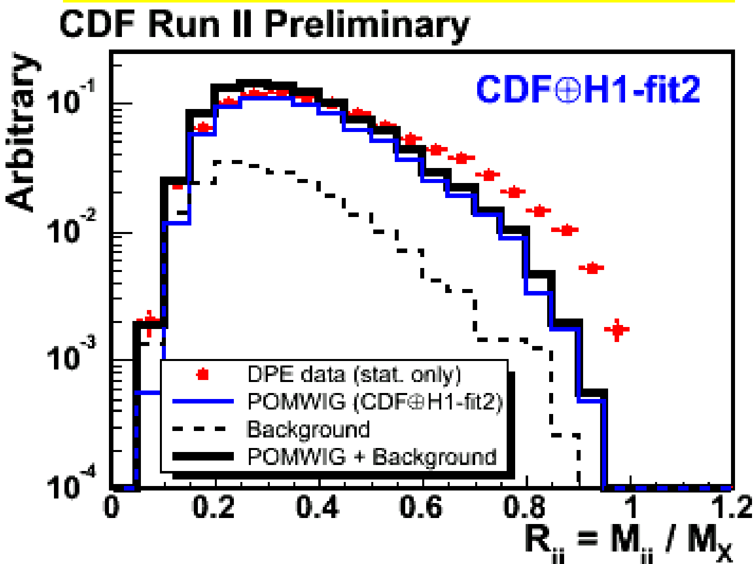
Search for exclusive $\gamma\gamma$

Search for events with two high E_T gammas and no other activity in the calorimeters or BSCs

Exclusive Dijet and γγ Search

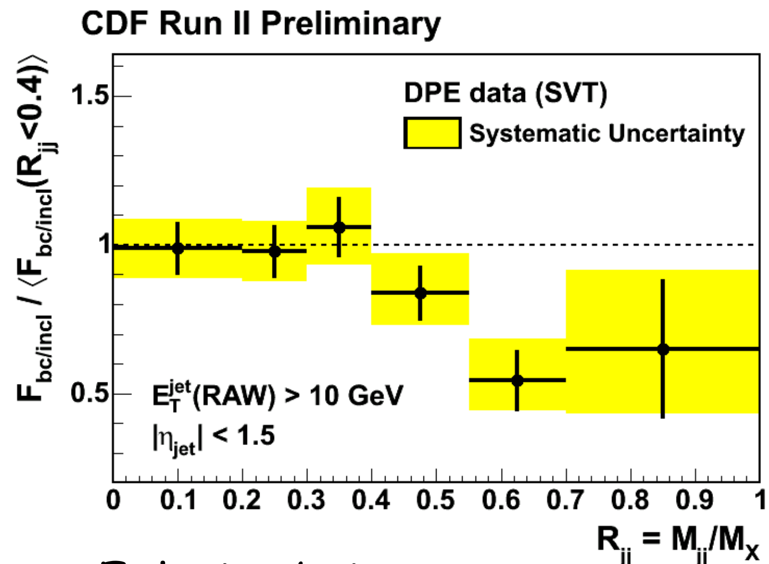
DIJETS

Dijet fraction – all jets



Excess over MC predictions at large dijet mass fraction

b-tagged dijet fraction



Exlusive b-jets are suppressed by J_Z= 0 selection rule

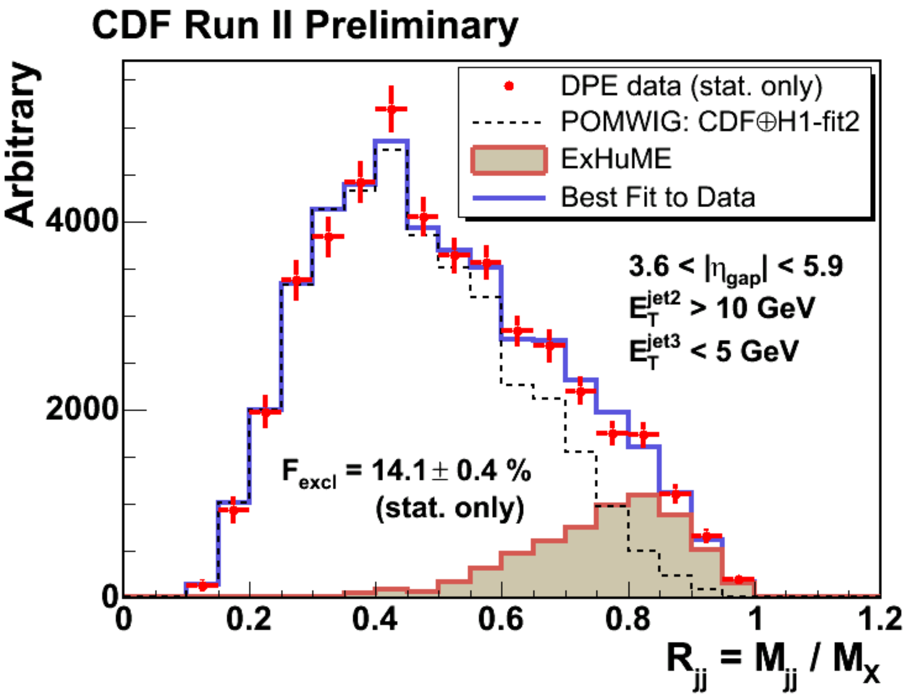
Systematic uncertainties under study: tune in soon for results!

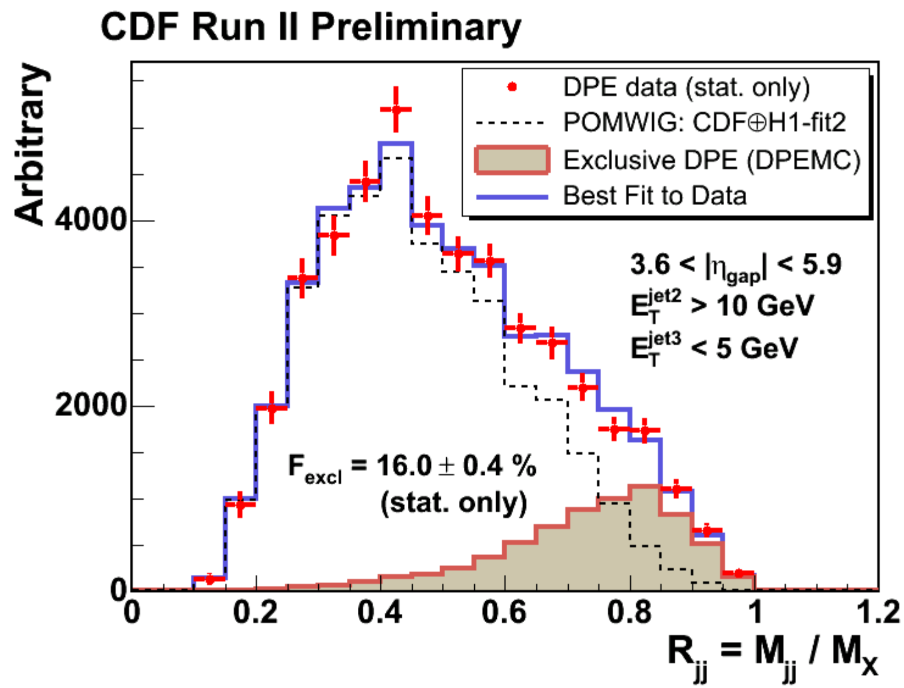
Exclusive γγ

Based on 3 events observed: $\sigma_{MEAS} = 0.14^{+0.14}_{-0.04}(\text{stat}) \pm 0.03(\text{syst})$ pb

Good agreement with KMR: $\sigma_{KMR} = 0.04 \pm 0.04(\times 2-3)$ pb

Dijets: Data vs MC





ExHuME (KMR): gg→gg process
➔ uses LO pQCD

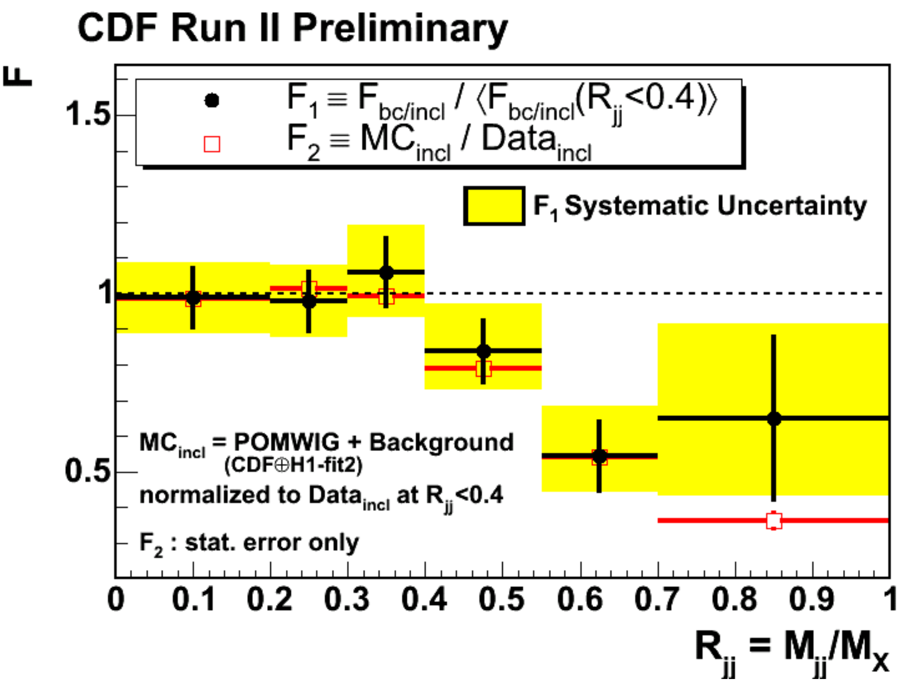
Exclusive DPE (DPEMC)
➔ non-pQCD based on Regge theory

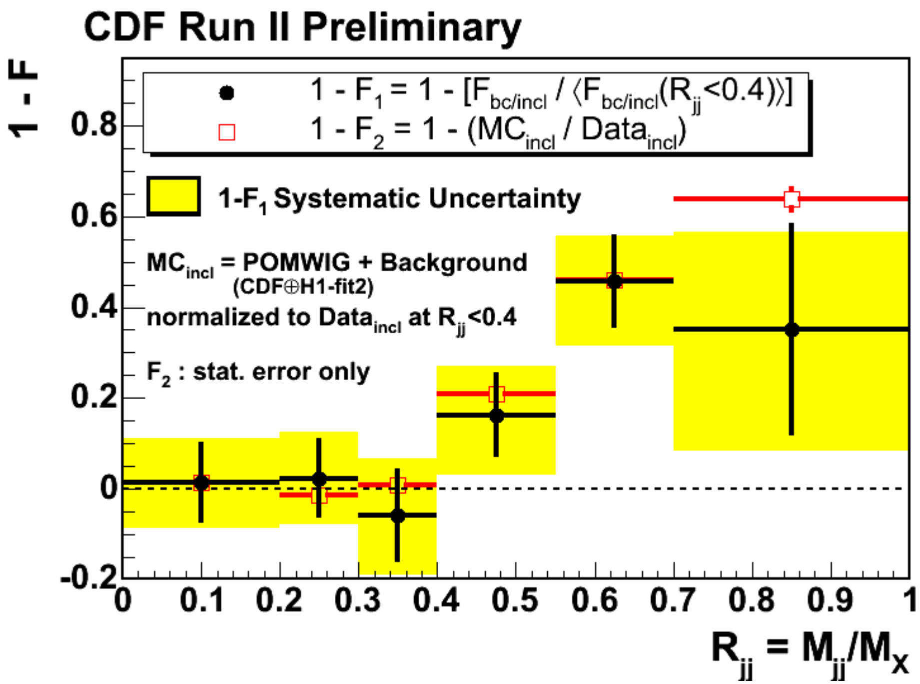
- ⇨ Excess of events at high R_{jj} is well described by both exclusive dijet production models
- ⇨ Currently investigating the dependence of the cross section on second jet E_T to differentiate between the two models

Exclusive Dijet Signal

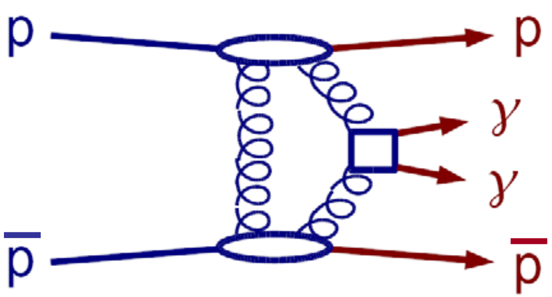
COMPARISON

inclusive data vs MC @ b/c-jet data vs inclusive

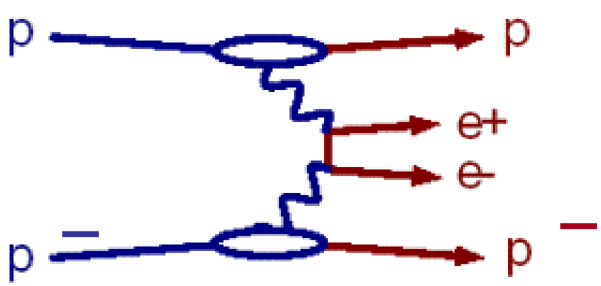




Exclusive γγ/ee Search



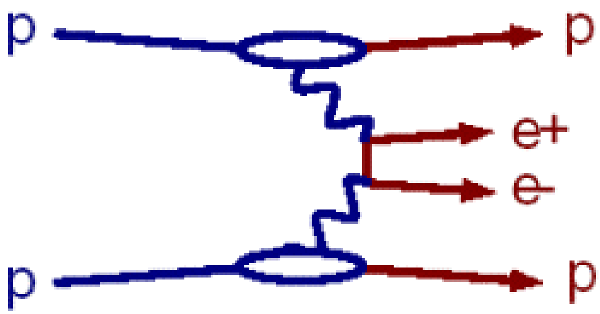
$$p\bar{p} \rightarrow p + \gamma\gamma + \bar{p}$$



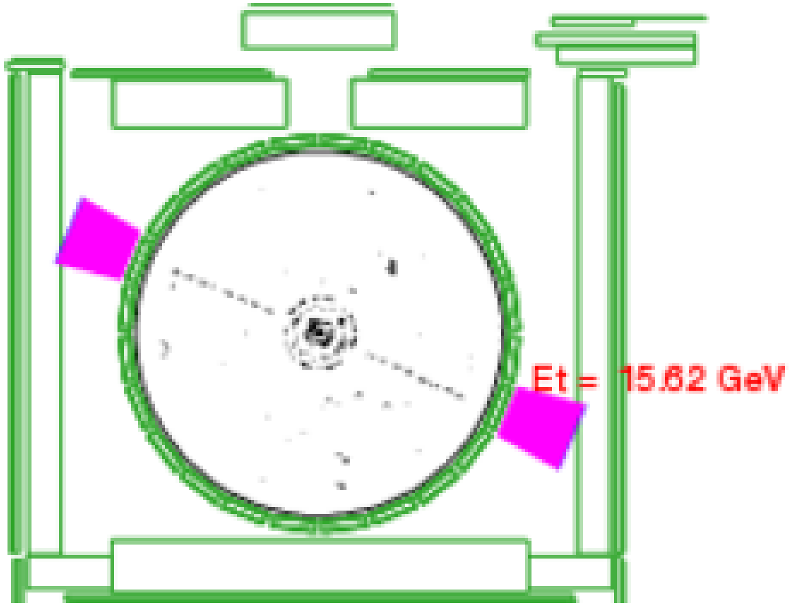
QED process: cross-check to exclusive γγ

- ✓ (anti)proton not detected
- ✓ require 2 EM showers (E_T>5 GeV, |h|<2)
- ✓ veto on all BSCs and all calorimetery except for the 2 EM showers
- ✓ L~530 pb^{-1} delivered ➔ $L_{effective}$=46 pb^{-1}
- ✓⇨ 19 events with 2 EM showers + "nothing" [above threshold]

Exclusive *ee* Search



control sample for $\gamma\gamma$ search



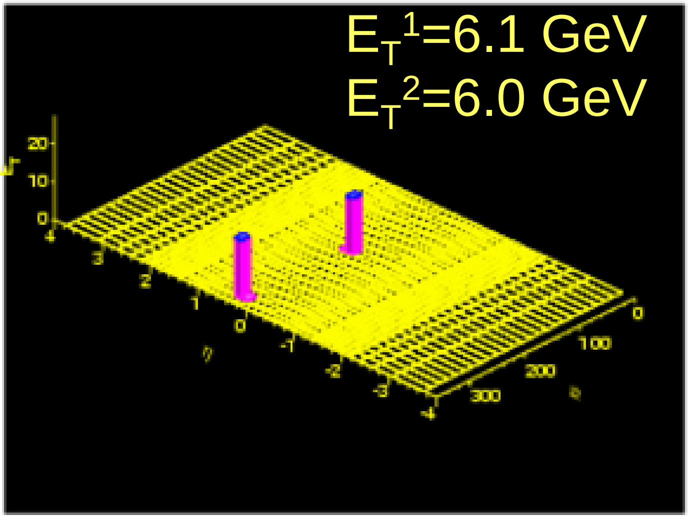
⇨16 candidate events found

background $2.1^{+0.7}_{-0.3}$ events

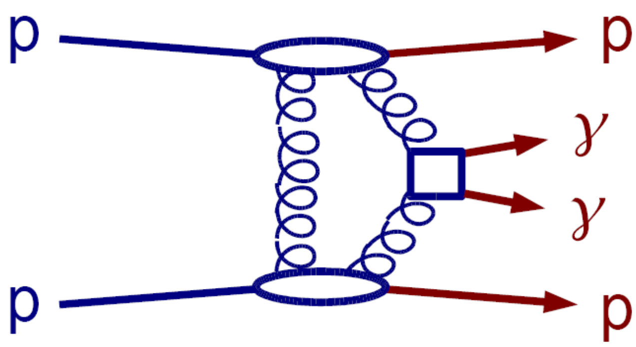
$\sigma_{MEASURED} = 1.6^{+0.5}_{-0.3}$ (stat) $\pm$ 0.3 (sys) pb

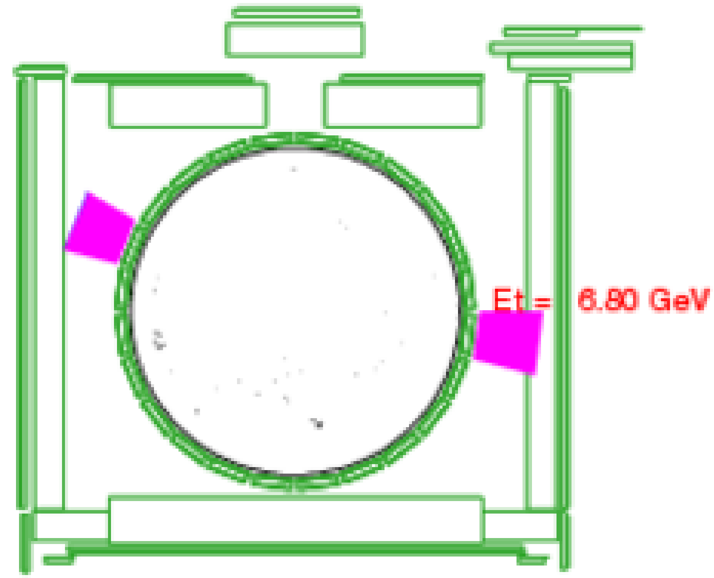
good agreement with LPAIR:

$\sigma_{LPAIR} = 1.711 \pm 0.008$ pb



Exclusive $\gamma\gamma$ Search

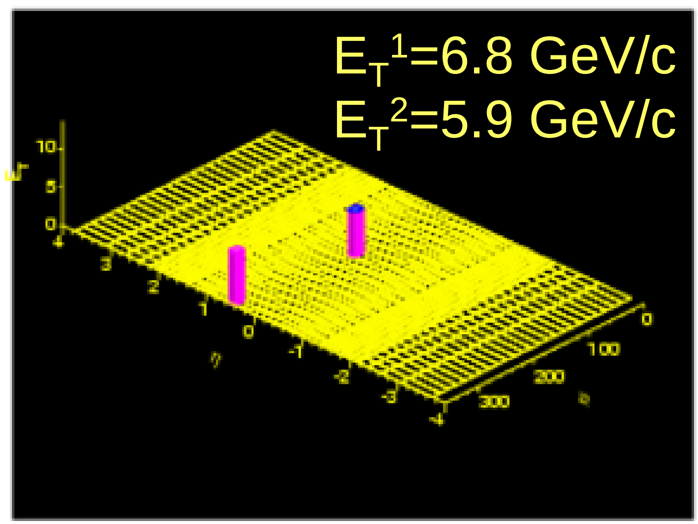




⇨ 3 candidate events found

background: $0.0^{+0.2}_{-0.0}$ events

$$\sigma_{MEASURED} = 0.14\ ^{+0.14}_{-0.04}\ (stat) \pm 0.03\ (sys)\ pb$$



good agreement with KMR:

$$\sigma_{KMR} = 0.04\ \pm(\times 2\ -3)\ pb$$

⇨ σ_H ~ 10 fb (if H exists)
within a factor ~ 2-3 , higher in MSSM

Dark Energy

Non-diffractive interactions

Rapidity gaps are formed by multiplicity fluctuations:

$$P(\Delta y) = e^{-\rho\,\Delta y}, \quad \rho = \frac{dN_{particles}}{dy}$$

P(Δy) is exponentially suppressed

Diffractive interactions

Rapidity gaps at t=0 grow with Δy:

$$\Delta y \approx -\ln\xi = \ln s - \ln M^2$$

$$P(\Delta y)\big|_{t=0} \sim e^{2\varepsilon\Delta y}$$

2ε: negative particle density!

⬇

Gravitational repulsion?

Summary

TEVATRON – what we have learnt

- M^2 - scaling
- Non-suppressed double-gap to single-gap ratios

➔ Pomeron: composite object made up from underlying pdf's subject to color constraints

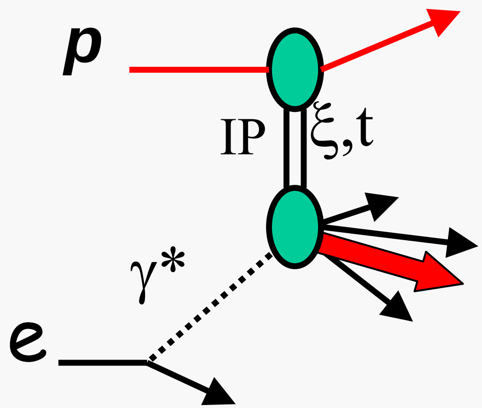
LHC - what to do

- High mass (➔ 4 TeV !) and multi-gap diffraction
- Exclusive production
  - ➔ Reduced bgnd for std Higgs to study properties
  - ➔ Discovery channel for certain Higgs scenarios

BACKUP

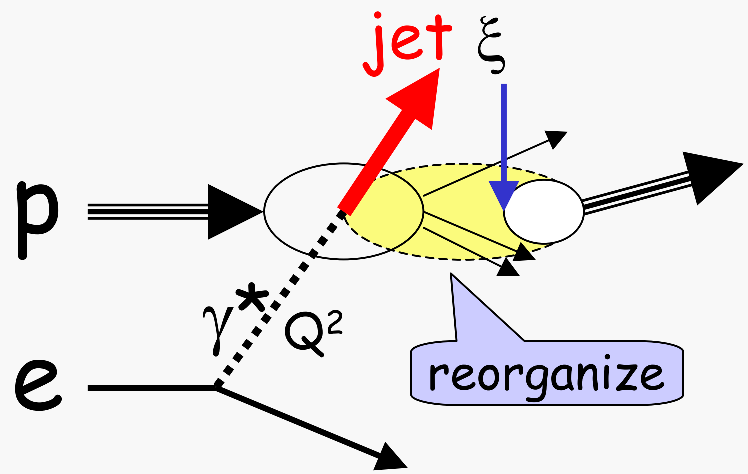
Diffractive DIS: two models

Particle-like Pomeron



what is the Pomeron structure?

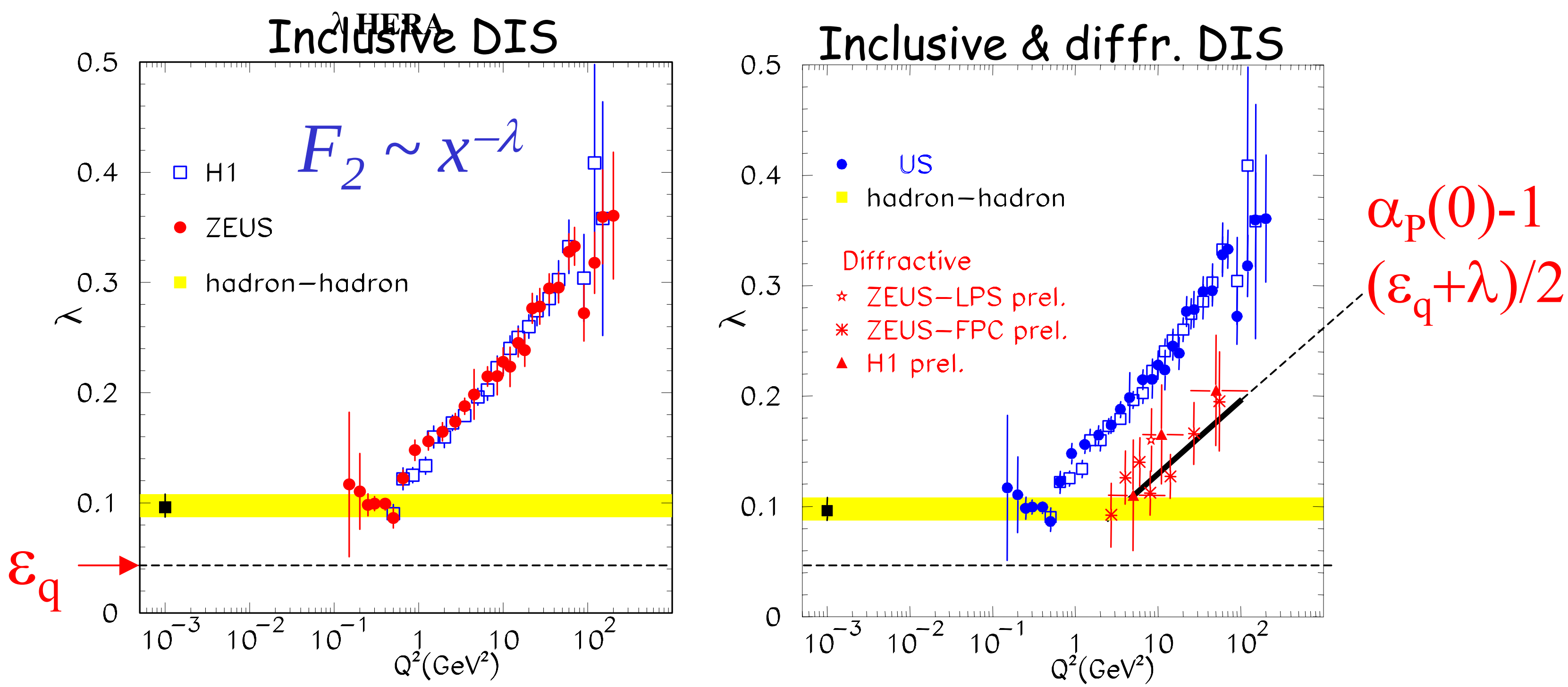
Color reorganization



probing the proton structure!

Inclusive vs Diffractive DIS

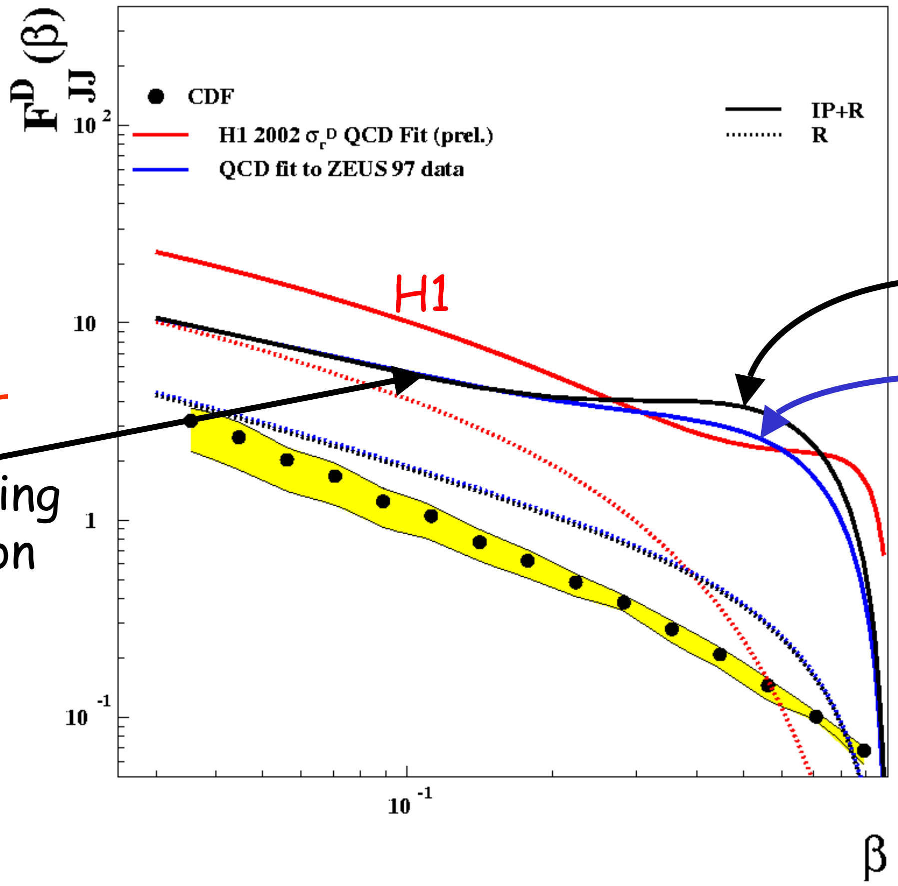
KG, "Diffraction: a New Approach," J.Phys.G26:716-720,2000 e-Print Archive: **hep-ph/0001092**



$$F_2^{D(3)}(\xi,\beta,Q^2) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot \frac{C(Q^2)}{(\beta\xi)^{\lambda(Q^2)}} \propto \frac{1}{\xi^{1+\varepsilon+\lambda}} \cdot \frac{C}{\beta^{\lambda}}$$

DSF: H1 vs ZEUS

M. Arneodo, HERA/LHC workshop, CERN, 11-13 Oct 2004



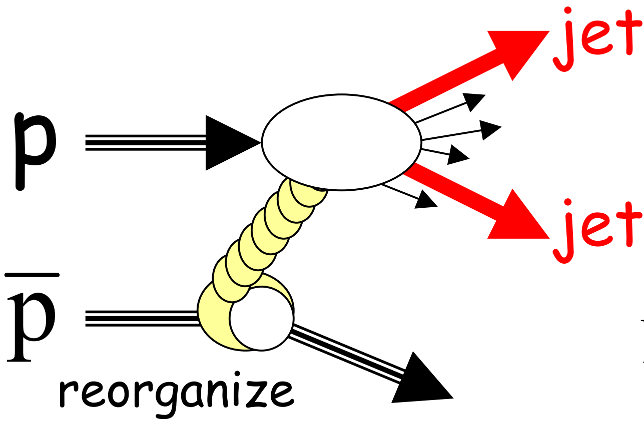
ZEUS
Fit including charm data

Fit without charm data

Flat after subtracting Reggeon contribution

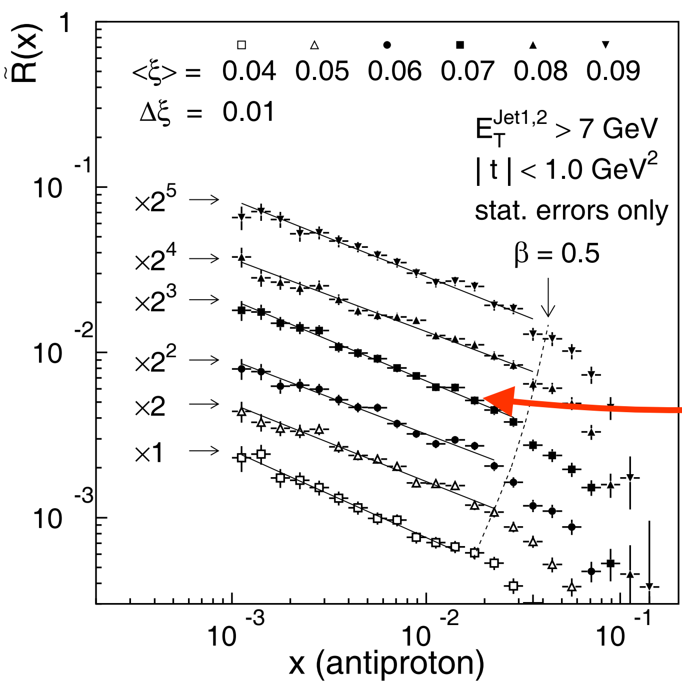
Using preliminary

Diffractive Dijets @ Tevatron



$$F^D(\xi, x, Q^2) = N_{renorm} \frac{1}{\xi^{1+2\varepsilon}} \cdot F(x/\xi, Q^2)$$

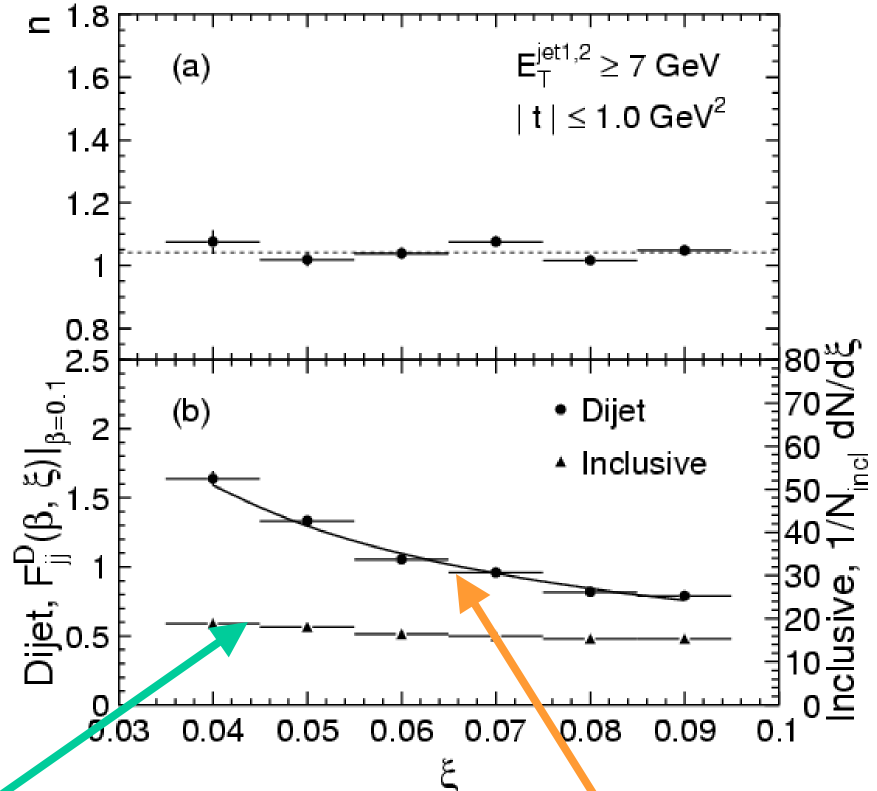
$$N_{renorm}^{-1} = \int_{\xi_{min}}^{1} \frac{d\xi}{\xi^{1+2\varepsilon}} \xrightarrow{\xi_{min} = \frac{x_{min}}{\beta} \approx \frac{1}{\beta s}} \frac{(\beta s)^{2\varepsilon}}{2\varepsilon}$$



$$R_{\frac{SD}{ND}}(x)\Big|_{renorm} \propto \frac{1}{\xi^{1-\lambda(Q^2)}} \cdot x^{-2\varepsilon_g}$$

ε_g~ 0.2 ➔ Agreement with data!

ξ-dependence: Inclusive vs Dijet



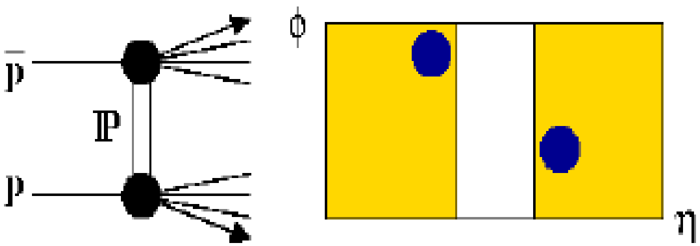
$$\frac{d\sigma_{incl}}{d\xi} \propto \text{constant}$$

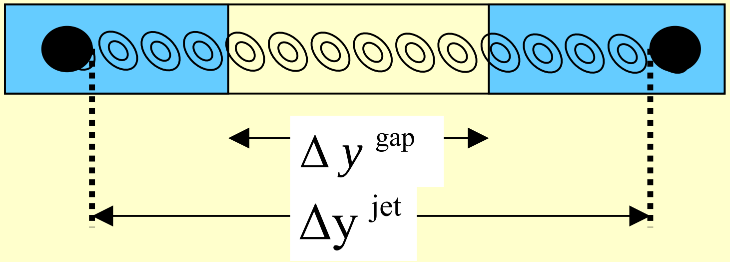
$$F_{jj}^D(\beta,\xi) \propto \frac{1}{\beta^n} \cdot \frac{1}{\xi^m} \quad (n = 1.0 \pm 0.1, \quad m = 0.9 \pm 0.1)$$

Pomeron dominated

Gap Between Jets

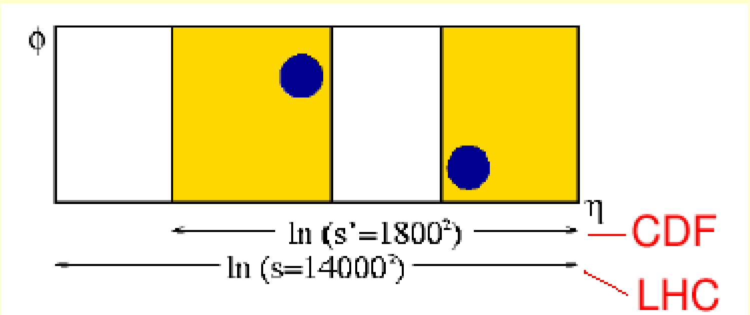
$$\bar{p} + p \rightarrow Jet + Gap + Jet$$





Question

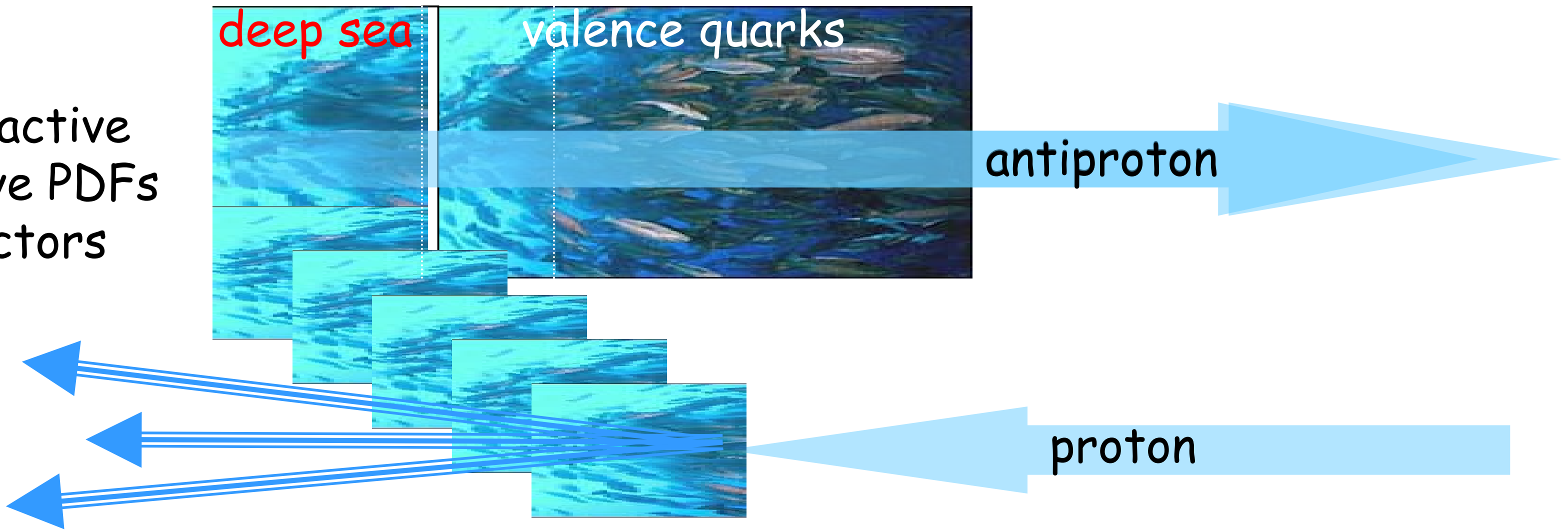
$$\Delta y^{gap} \overset{???}{\longleftrightarrow} \Delta y^{jet}$$

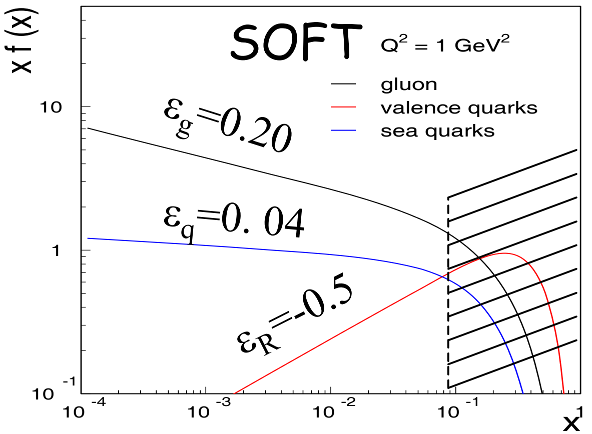


$$R_{LHC}^{J-G-J}(s') = R_{TEV}^{J-G-J}/S \approx 1\%/0.2 \approx 5\%$$

Diffraction from the Deep Sea

Derive diffractive from inclusive PDFs and color factors





$$x \cdot f(x) = \frac{1}{x^{\varepsilon\,(\mathrm{or}\ \lambda)}}$$