CDF: Recent Results on Diffractive and Exclusive Production

Christina Mesropian

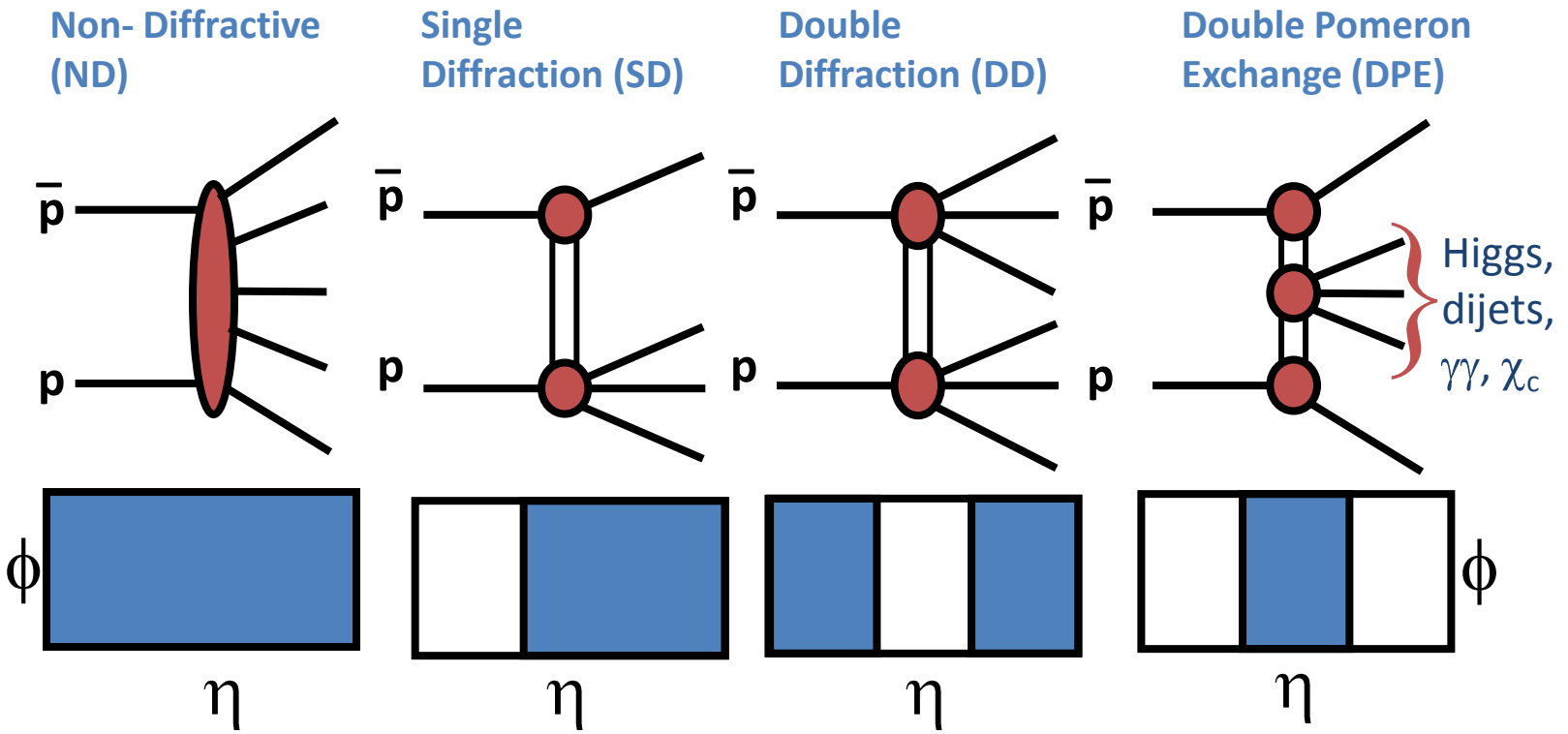
The Rockefeller University

Diffraction: Definition and Signatures

Diffractive reactions at hadron colliders are defined as reactions in *which no quantum numbers* are exchanged between colliding particles

Diffractive events could be Identified by presence of:

- ❑ **intact leading particle**
- ❑ **large non exponentially suppressed rapidity gap**



Diffraction: definitions

y - rapidity

η - pseudorapidity

$y=1/2 \ln((E+p_z)/E-p_z))$

$\eta \equiv y\big|_{m=0} = -\ln \tan(\vartheta/2)$

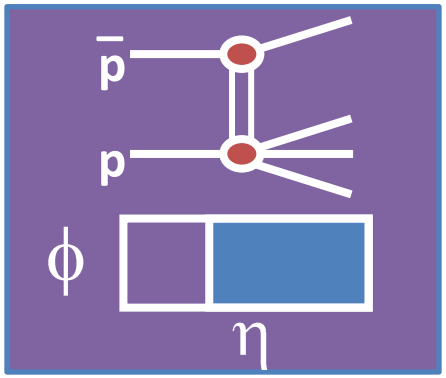
t - four-momentum transfer squared

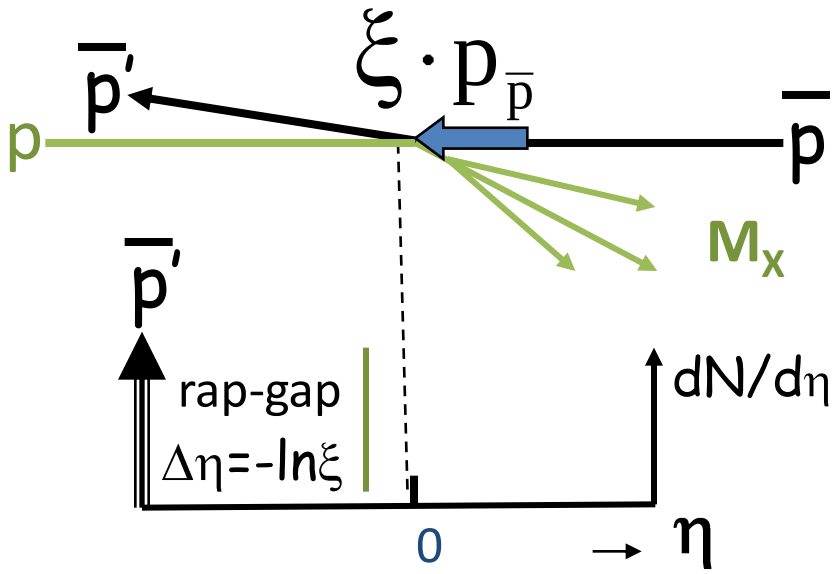
ξ - fractional momentum loss of pbar

$\mathbf{M_X}$ - mass of diffractive system X

$\xi = M_X^2/s$

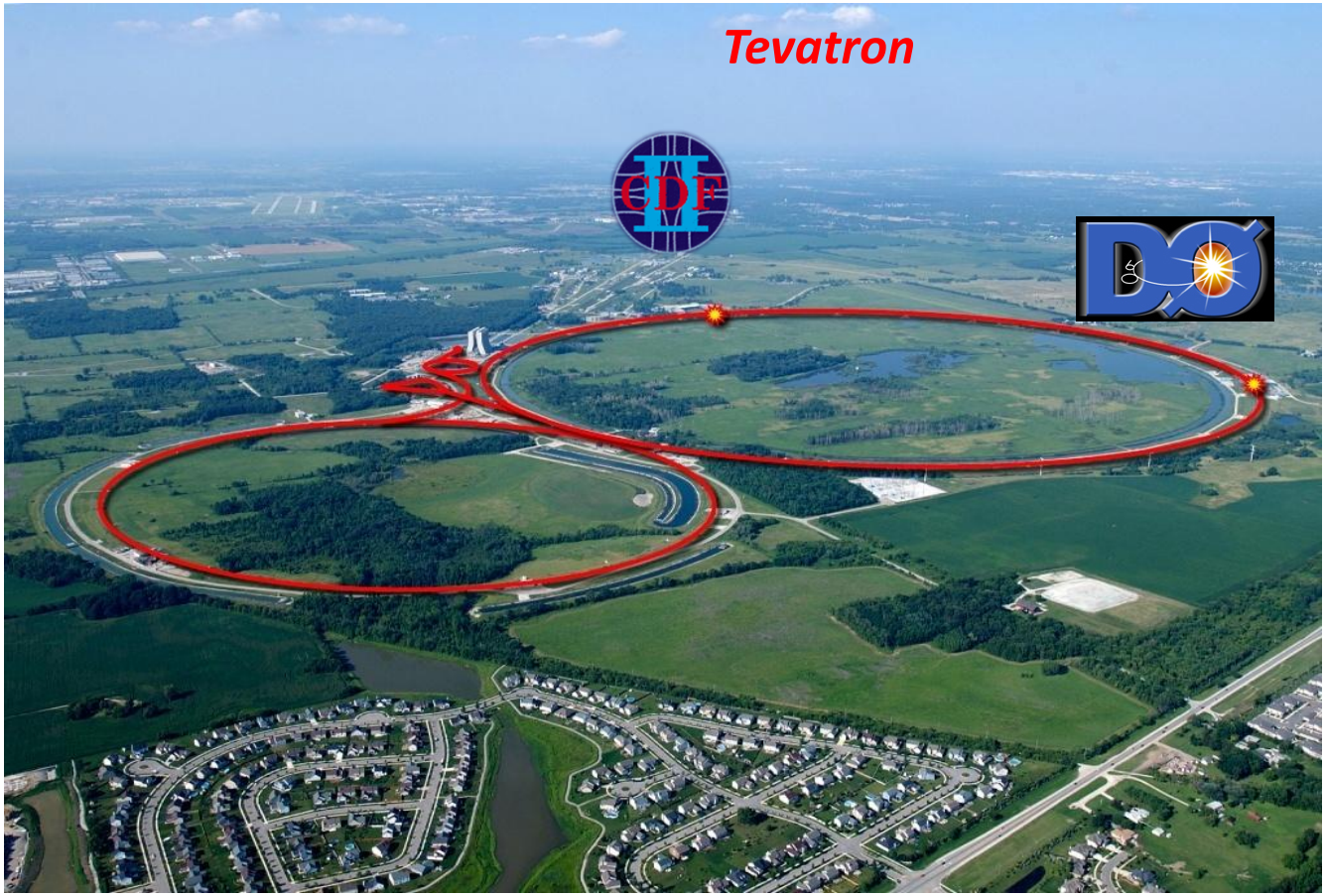
$\Delta\eta \approx \ln(s/M_X^2)$



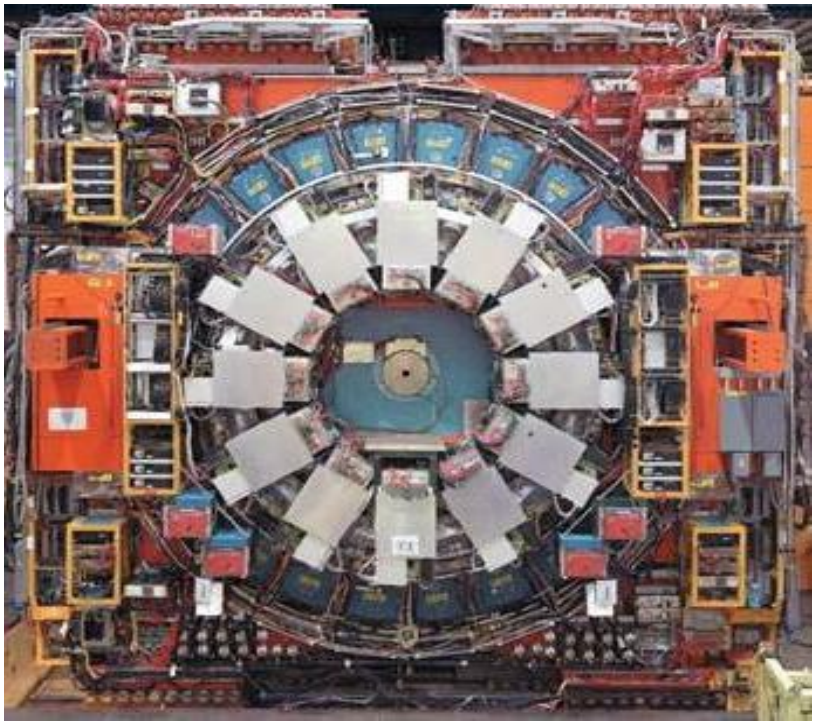


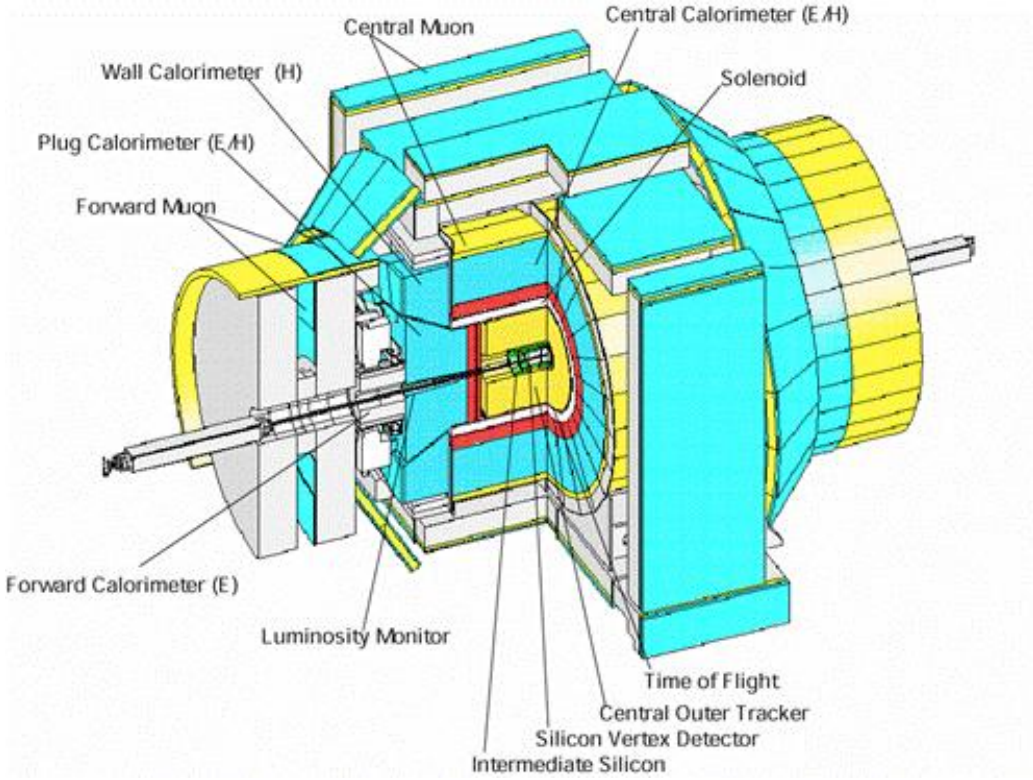
Tevatron $p\bar{p}$ Collider

was shut down on September 30, 2011



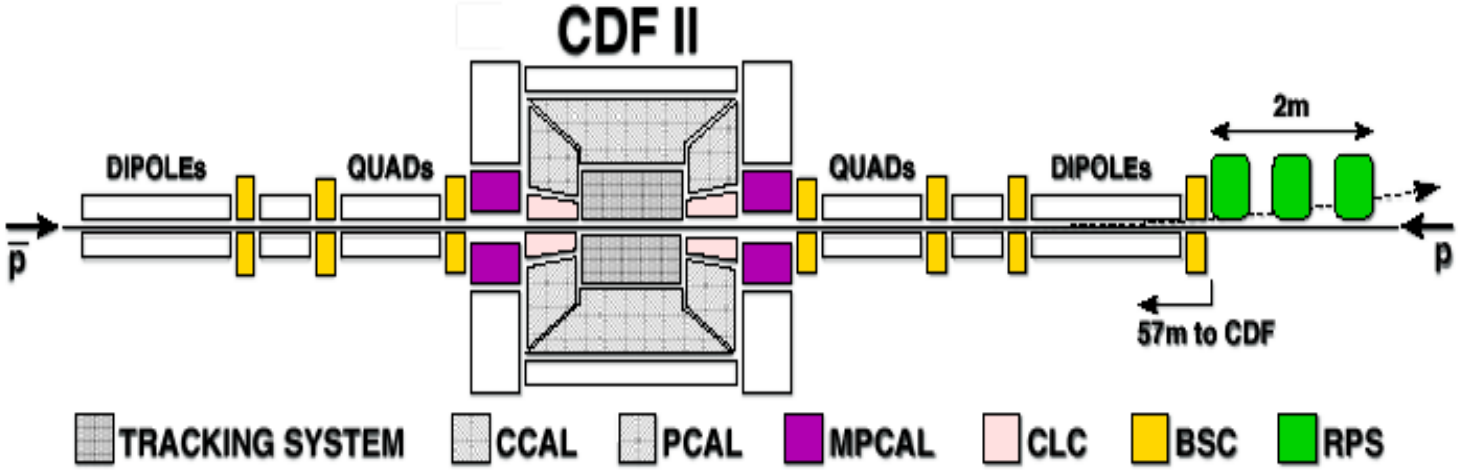
The Collider Detector at Fermilab (CDF)





- Top performance (>85% data taking efficiency)
- ~10 fb^{-1} good for analysis data

CDF II Detectors

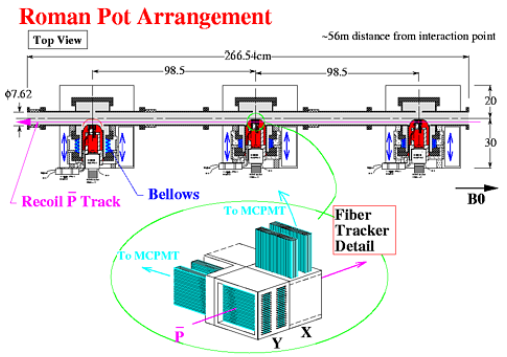


- Tracking – Tracking Detectors $|\eta| < 2.0$
- CCAL, PCAL – Calorimeters $(15°(\text{in } \varphi) \times 0.1(\text{in } \eta))$ $|\eta| < 3.6$
- RPS – Roman Pot Spectrometers $0.02 < \xi < 0.1$, $0 < |t| < 2\ \text{GeV}^2$
- BSC – Beam Shower Counters $5.4 < |\eta| < 7.4$
- MPCAL – MiniPlug Calorimeters $3.5 < |\eta| < 5.1$

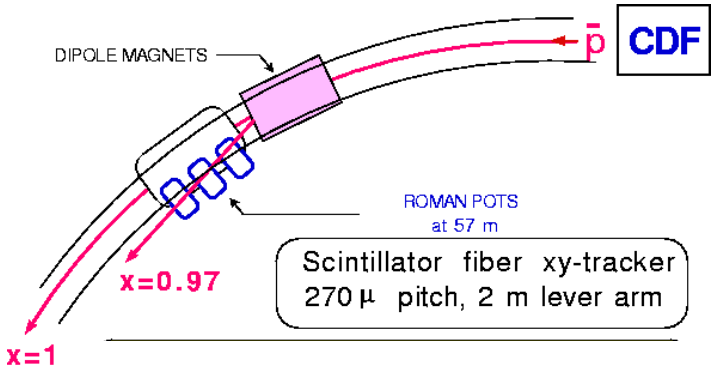
Forward Detectors at CDFII:
Roman Pot Spectrometers (RPS)

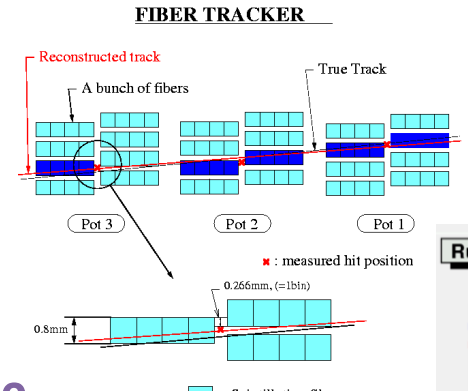
Fiber Tracker

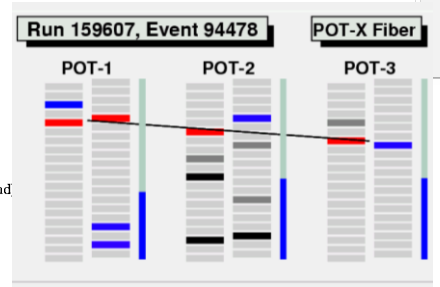
- 3 stations
- 57 meters from IP

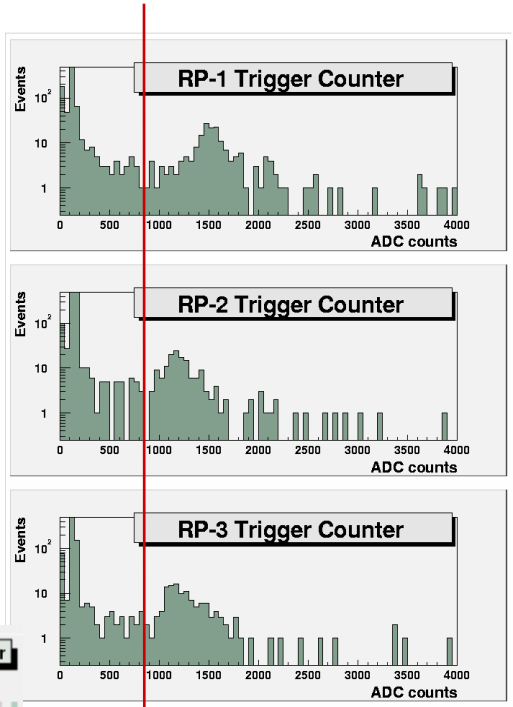


- 3 trigger counters
- 240 channels







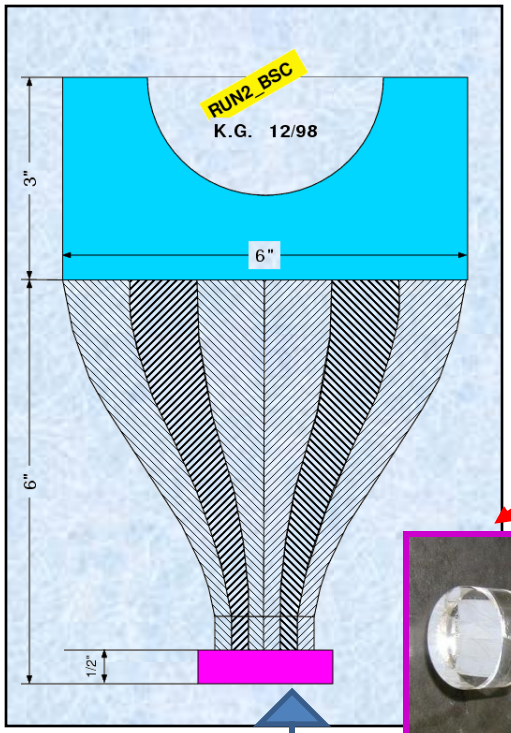


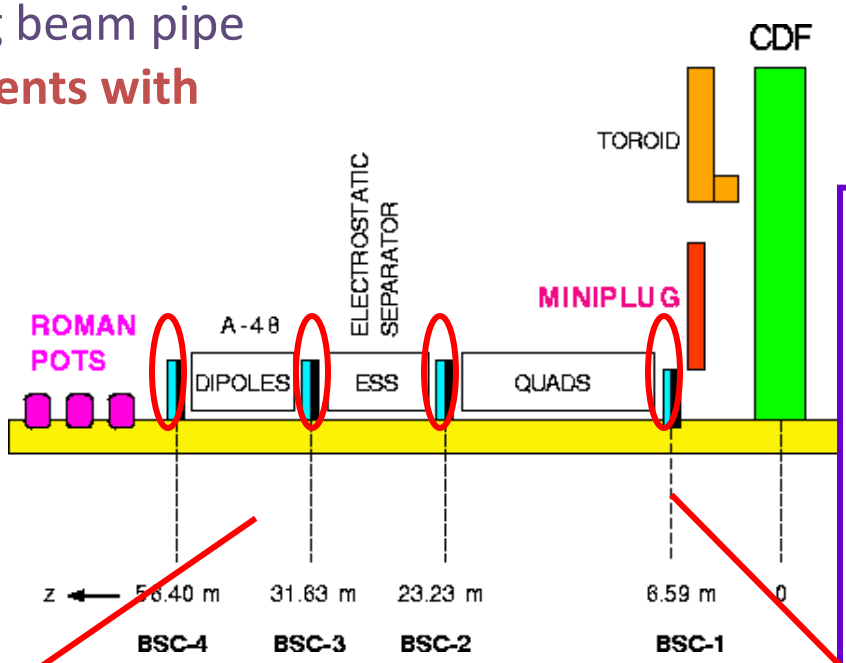
MIPs (>1000 counts)

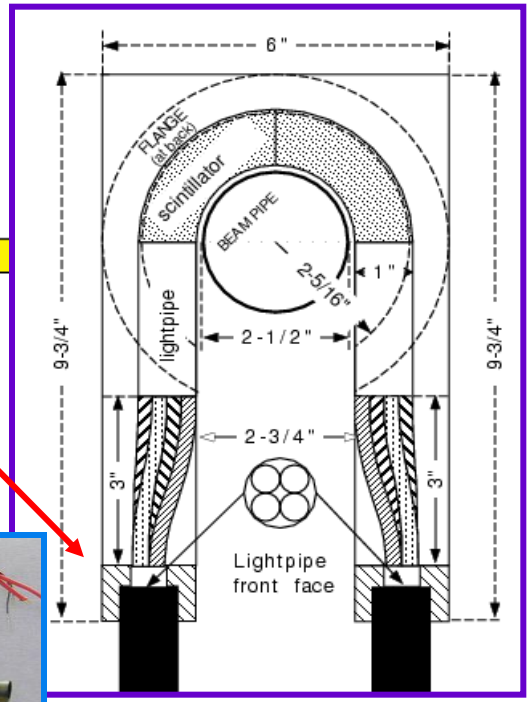
position resolution ±80μm
typical resolutions
in ξ δξ=±0.001; in t δt=±0.07GeV²

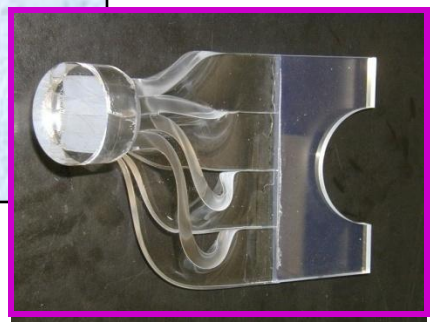
Forward Detectors at CDFII:
Beam Shower Counters (BSCs)

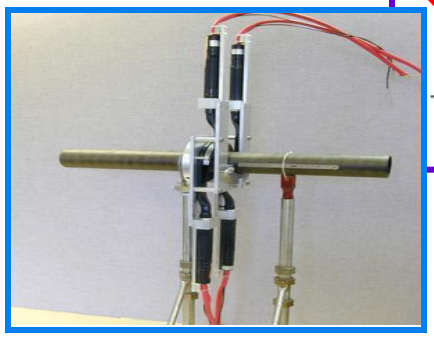
BSCs are located along beam pipe used for **triggering events with forward rapidity gaps**











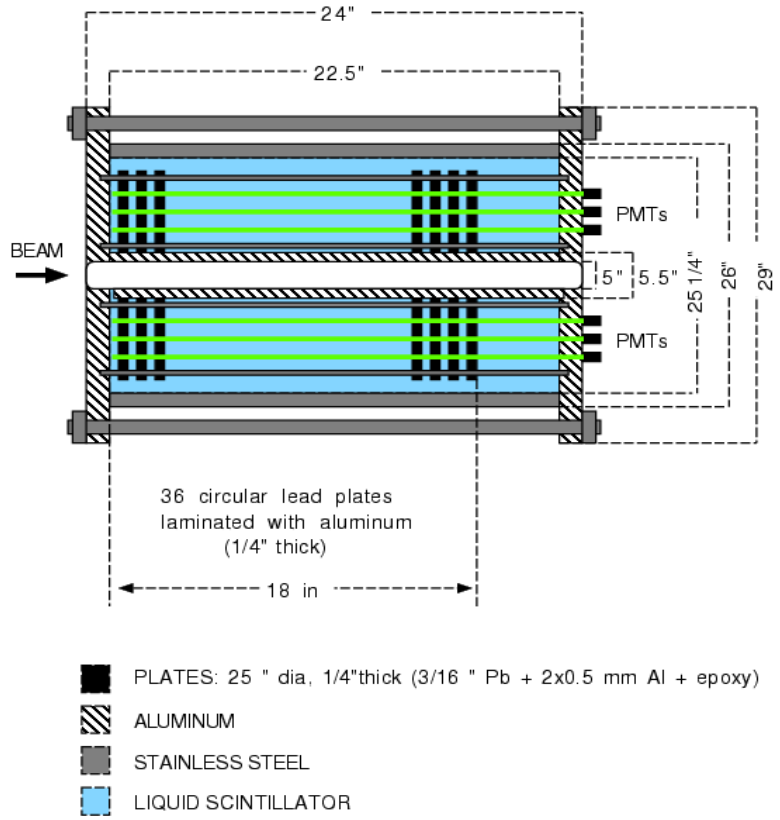
BSC-2,3,4

BSC-1

Forward Detectors at CDFII: MiniPlug Calorimeters (MPs)

*Nucl. Instrum. Meth. **A**518 (2004) 42.*

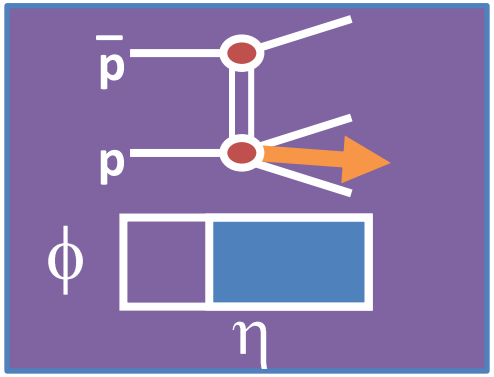
*Nucl. Instrum. Meth. **A**496 (2003) 333.*



designed to **measure the energy and lateral position** of both electromagnetic and hadronic showers

"towerless" geometry – no dead regions

Single Diffraction



Diffractive signature:

- ❑ large rapidity gap
- ❑ intact pbar detected in RPS

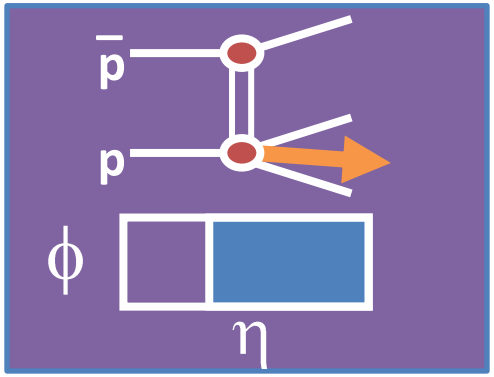
Can study diffractive production of high p_T objects:

jets, W, J/Ψ, b

different insight into the nature of Pomeron

Method: measure ratio of single diffractive (SD) to non-diffractive (ND) production

Single Diffraction



Diffractive signature:

- ☑ large rapidity gap
- ☐ intact pbar detected in RPS

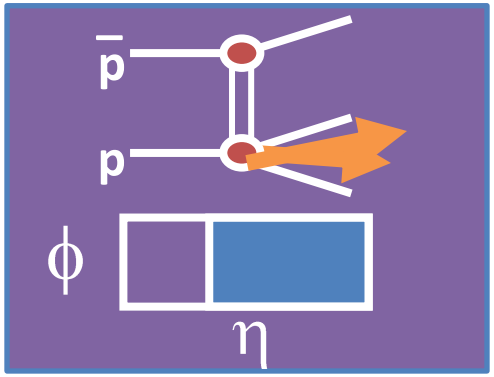
Fraction:
R≡SD/ND ratio
@ 1800 GeV

Hard component	Fraction (R) %
Dijet	0.75 ± 0.10
W	1.15 ± 0.55
b	0.62 ± 0.25
J/ψ	1.45 ± 0.25

All fractions ~ 1% (differences due to kinematics)

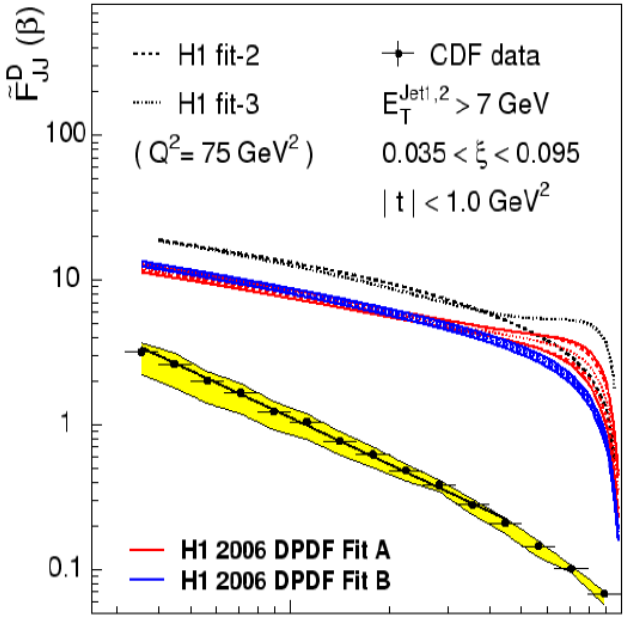
⇒ ~ uniform suppression

Single Diffraction: Diffractive Dijet Production



Diffractive signature:

- ☐ large rapidity gap
- ☑ intact pbar detected in RPS



β - momentum fract.of parton in IP

$$\sigma(\bar{p}p \to \bar{p}X) \approx F_{jj} \otimes F_{jj}^D \otimes \hat{\sigma}(ab \to jj)$$

diffractive structure function

$$F_{jj}^D = F_{jj}^D(x, Q^2, t, \xi)$$

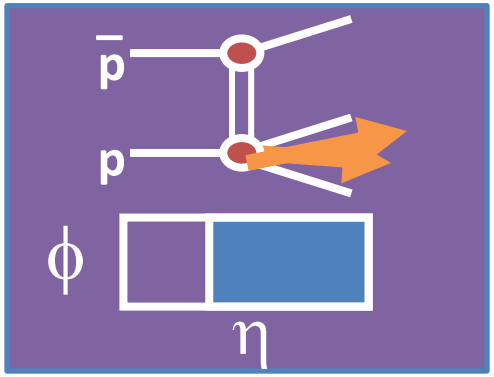
Extract

at LO →

$$R_{\frac{SD}{ND}}(x,\xi) = \frac{\sigma(SD_{jj})}{\sigma(ND_{jj})} = \frac{F_{jj}^D(x,Q^2,\xi)}{F_{jj}(x,Q^2)}$$

data *ND PDF*

Single Diffraction: Diffractive Dijet Production



Phys. Rev. D 86, 032009, 2012

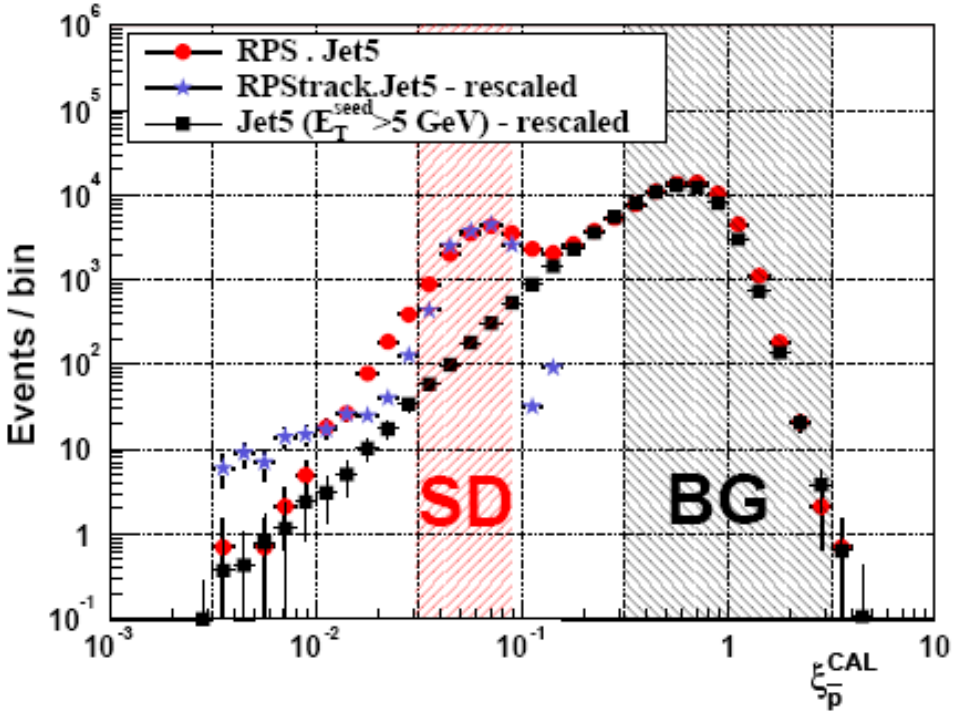
Diffractive signature:

- ☑ large rapidity gap
- ☑ intact pbar detected in RPS

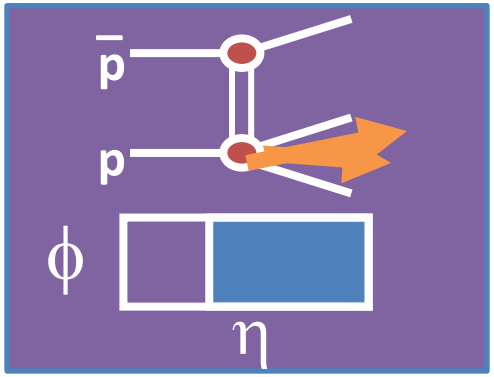
METHODOLOGY:

ξ variable can be reconstructed from

- **RPS tracking information: ξ^{RPS}**
- **from the fully reconstructed final state:**
  $\xi^{cal}=(1/\sqrt{s})\times\sum E_T^i e^{-\eta^i}$



Single Diffraction: Diffractive Dijet Production



Phys. Rev. D 86, 032009, 2012

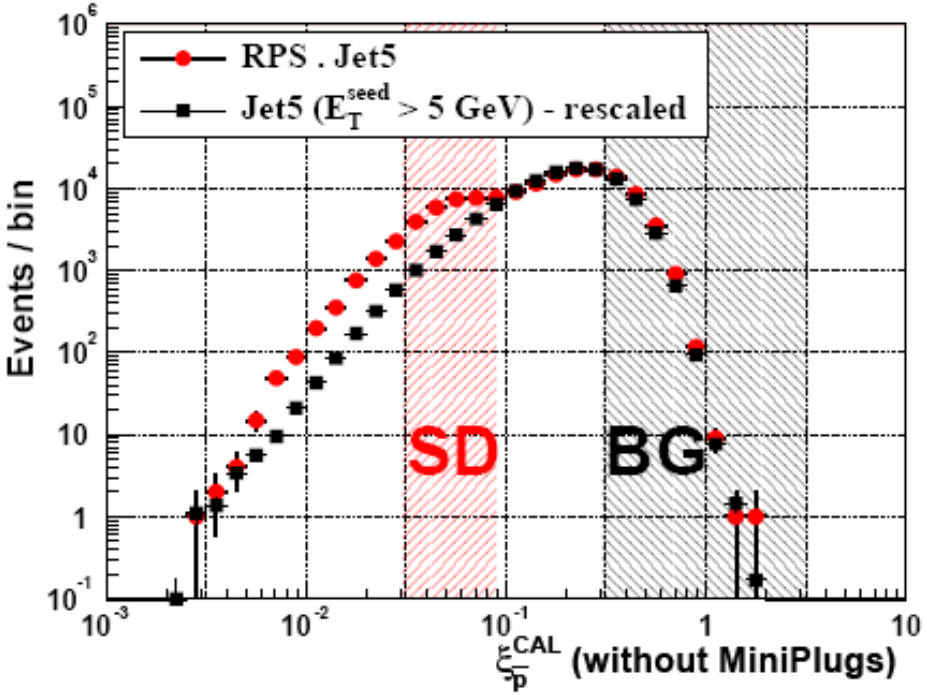
Diffractive signature:

- ☐ large rapidity gap
- ☑ intact pbar detected in RPS

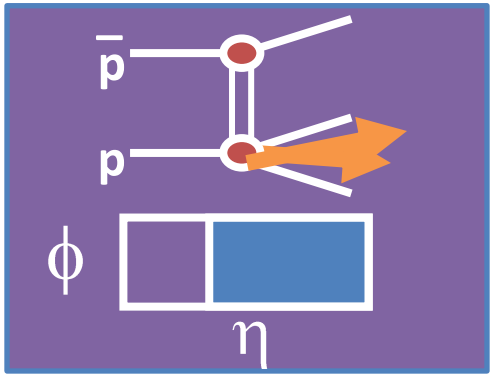
METHODOLOGY:

ξ variable can be reconstructed from

- **RPS tracking information - ξ^{RPS}**
- **from the fully reconstructed final state - $\xi^{cal}=(1/\sqrt{s})\times\sum E_T^i e^{-\eta^i}$**



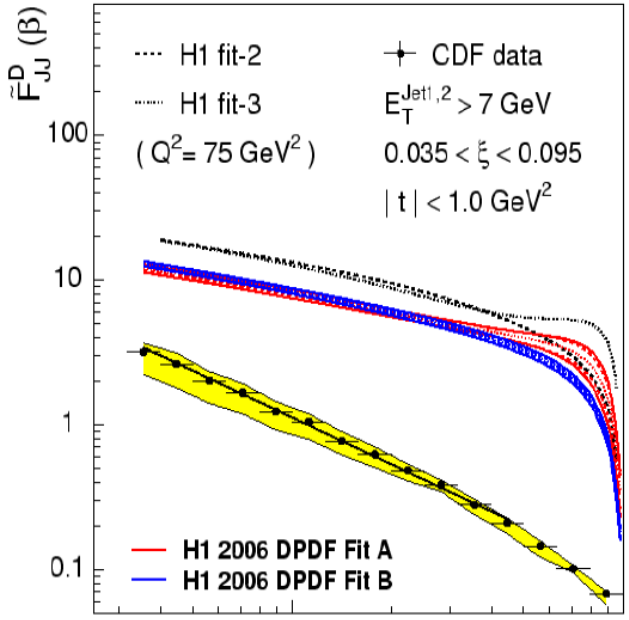
Single Diffraction: Diffractive Dijet Production



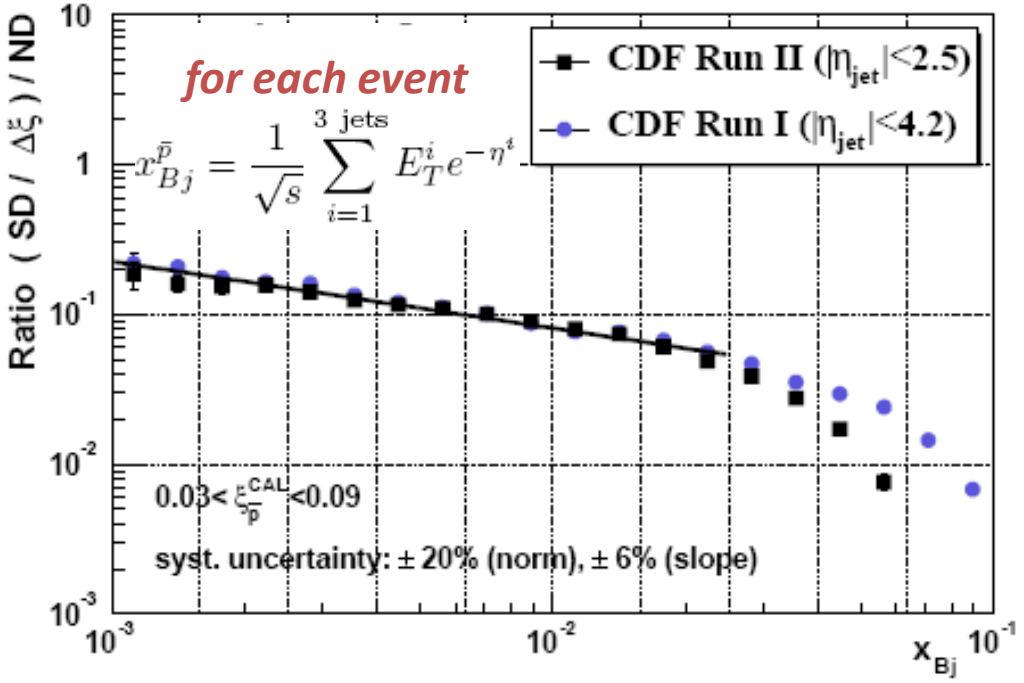
Phys. Rev. D 86, 032009, 2012

Diffractive signature:

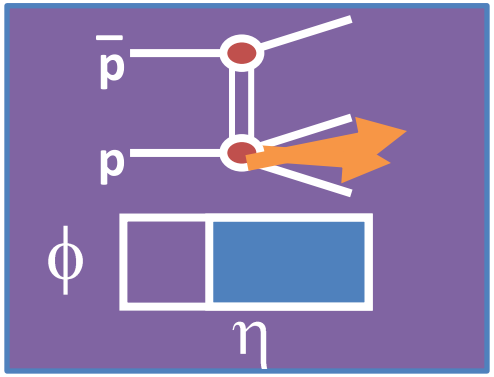
- ☑ large rapidity gap
- ☑ intact pbar detected in RPS



β - momentum fract.of parton in IP



Single Diffraction: Diffractive Dijet Production



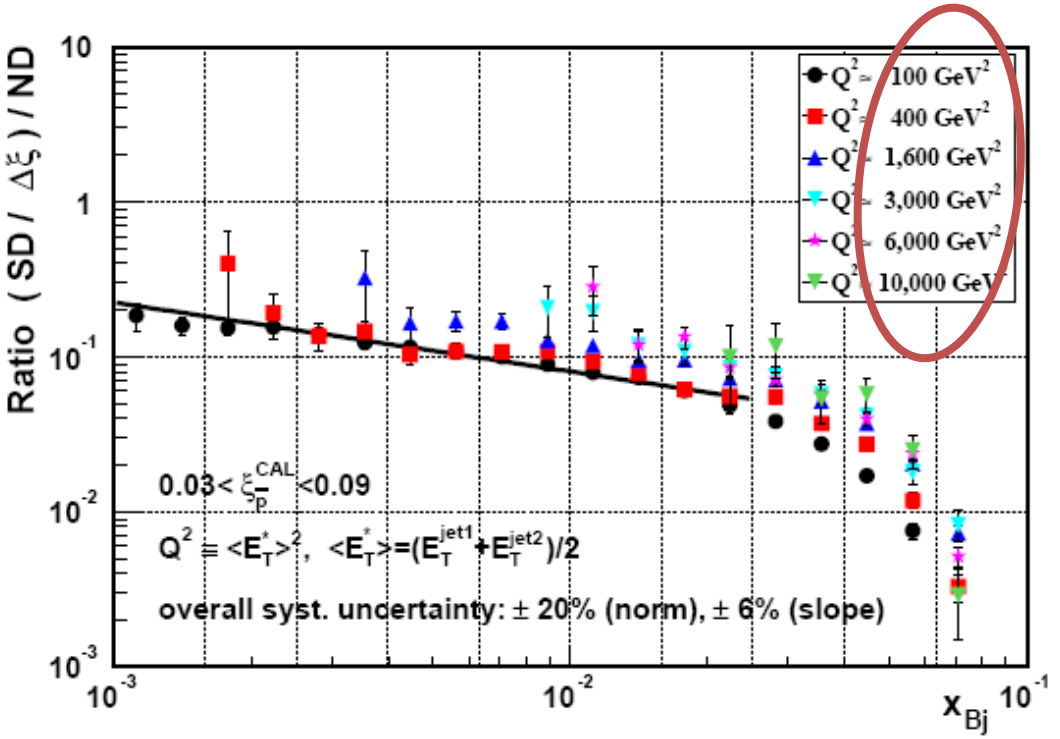
Phys. Rev. D 86, 032009, 2012

Diffractive signature:

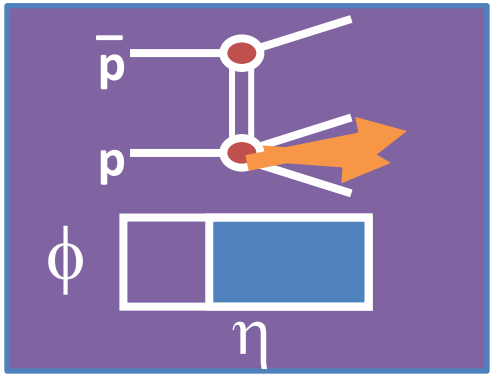
- ☐ large rapidity gap
- ☑ intact pbar detected in RPS

Ratio of SD/ND events as a function of x_{BJ}

Similar behavior for different Q^2



Single Diffraction: t distribution (|t|<1 GeV^2)



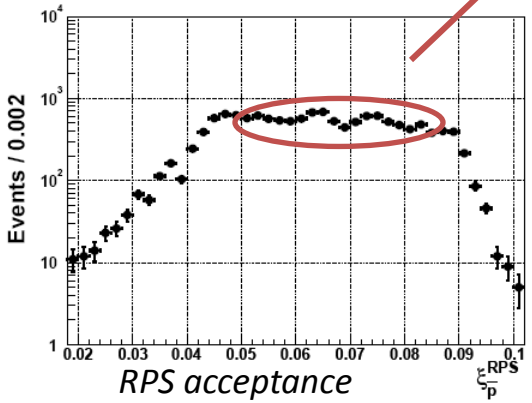
Phys. Rev. D 86, 032009, 2012

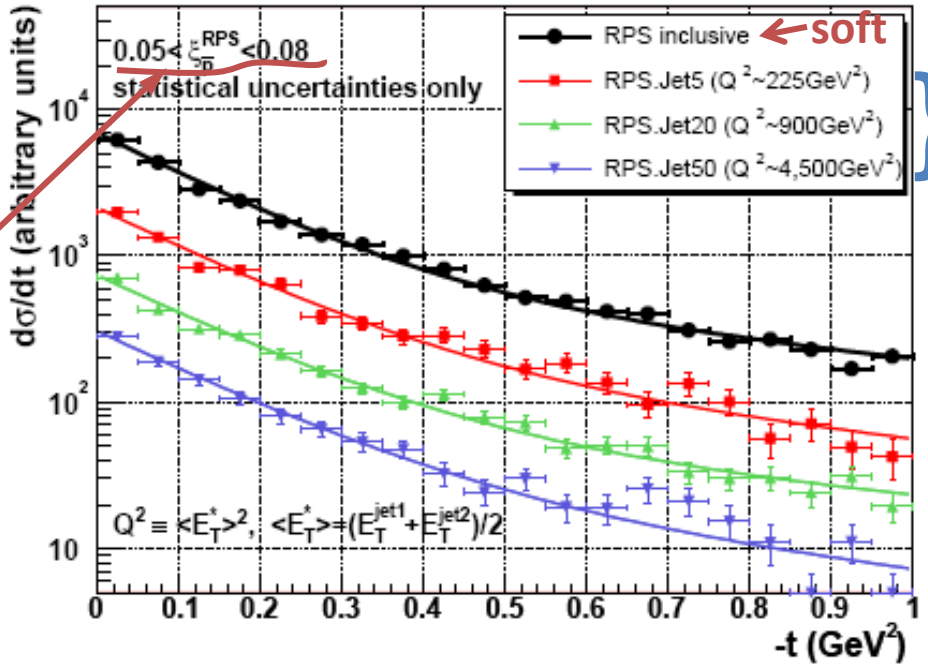
Diffractive signature:

- ☐ large rapidity gap
- ☑ intact pbar detected in RPS

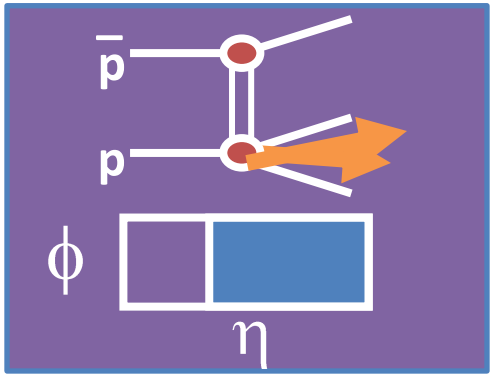
***t* distribution measured for both soft and hard SD samples**

Fit to double exponential function:
$d\sigma/dt \propto 0.9\, e^{b1\ t} + 0.1\, e^{b2\ t}$





Single Diffraction: t distribution (|t|<1 GeV^2)



Phys. Rev. D 86, 032009, 2012

Diffractive signature:

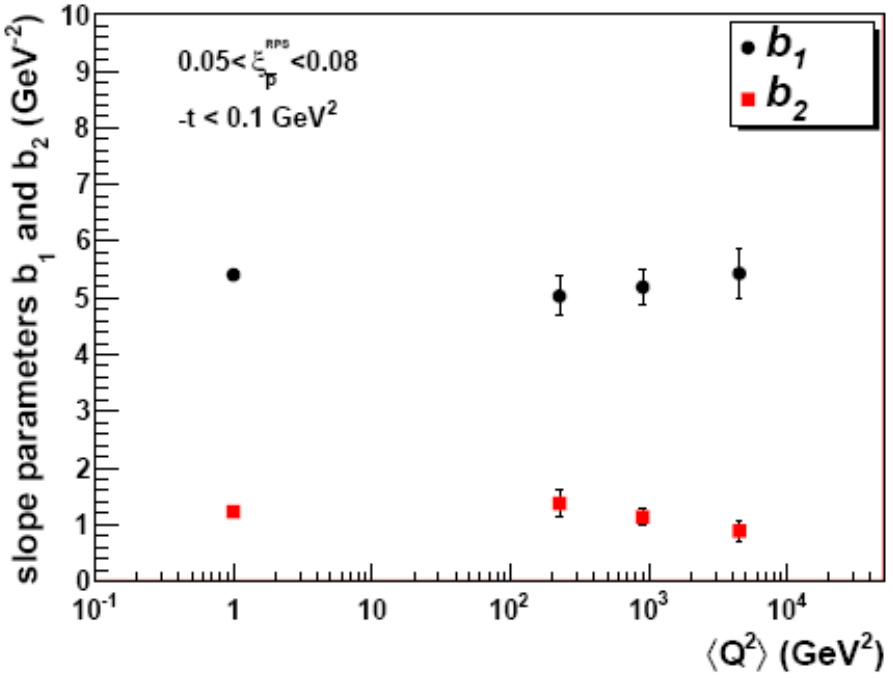
- ☐ large rapidity gap
- ☑ intact pbar detected in RPS

***t* distribution measured for both soft and hard SD samples**

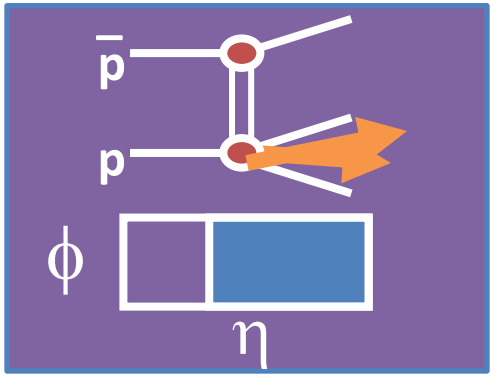
Fit to double exponential function:

$d\sigma/dt \propto 0.9\ e^{b1\ t} + 0.1\ e^{b2\ t}$

- **no Q^2 dependence in slope from inclusive to $Q^2 \sim 10^4$ GeV^2**



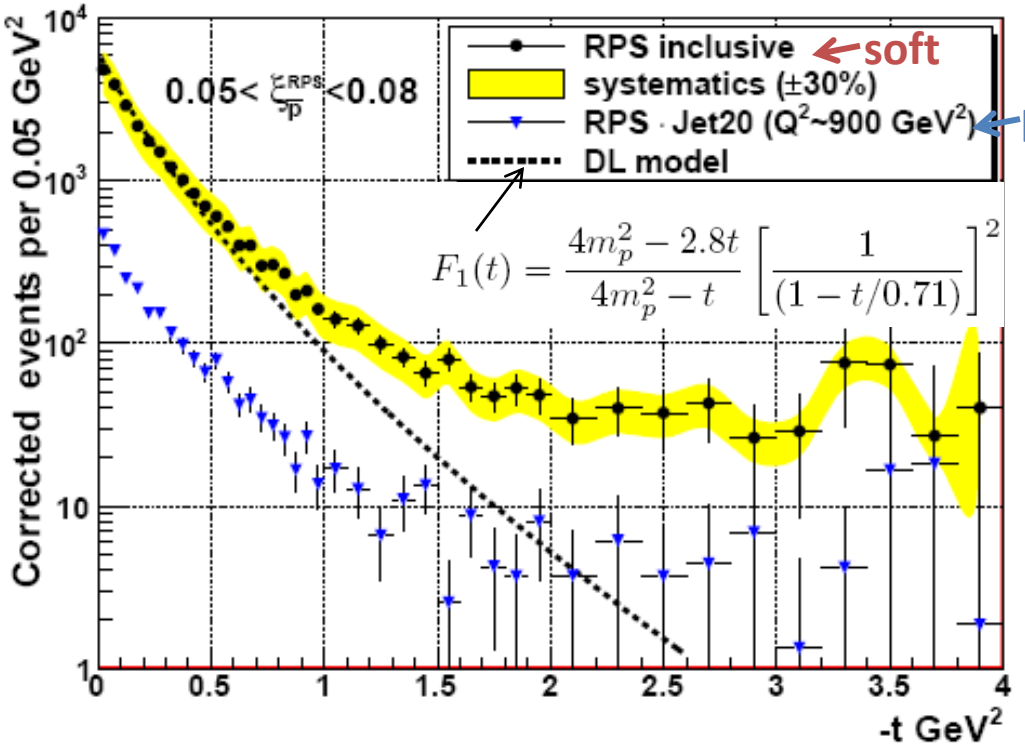
Single Diffraction: t distribution (|t|≤4 GeV^2)



Phys. Rev. D 86, 032009, 2012

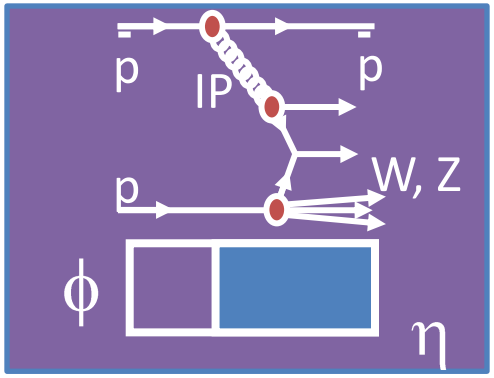
Diffractive signature:

- ☐ large rapidity gap
- ☑ intact pbar detected in RPS



- low |t| - good agreement with the Donnachie-Landshoff (DL) model
- scale independence
- high |t| - search for *diffraction minimum*?

Single Diffraction: W Production



Previous Tevatron measurements at ✓s=1.8 TeV

Diffractive signature:

- ☑ large rapidity gap
- ☐ intact pbar detected in RPS

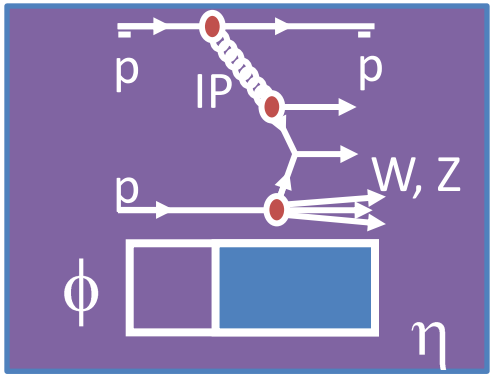
Diffractive W/Z production probes the quark content of the Pomeron

- to Leading Order
  the W/Z are produced
  by a **quark** in the Pomeron
  - production by gluons is suppressed by a factor of α_S and can be distinguished by an associated jet

CDF PRL 78, 2698 (1997)
R^W=[1.15±0.51(stat)±0.20(syst)]%
gap acceptance A^{gap}=0.81
Uncorrected for A^{gap}
R^W=(0.93±0.44)%

DØ Phys Lett B **574**, 169 (2003)
R^W=[5.1±0.51(stat)±0.20(syst)]%
gap acceptance A^{gap}=(0.21±4)%
Uncorrected for A^{gap}
R^W=[0.89+0.19-0.17]% R^Z=[1.44+0.61-0.52]%

Single Diffraction: W Production



Phys. Rev. D 82, 112004, 2010

Diffractive signature:

- ☑ large rapidity gap
- ☑ intact pbar detected in RPS

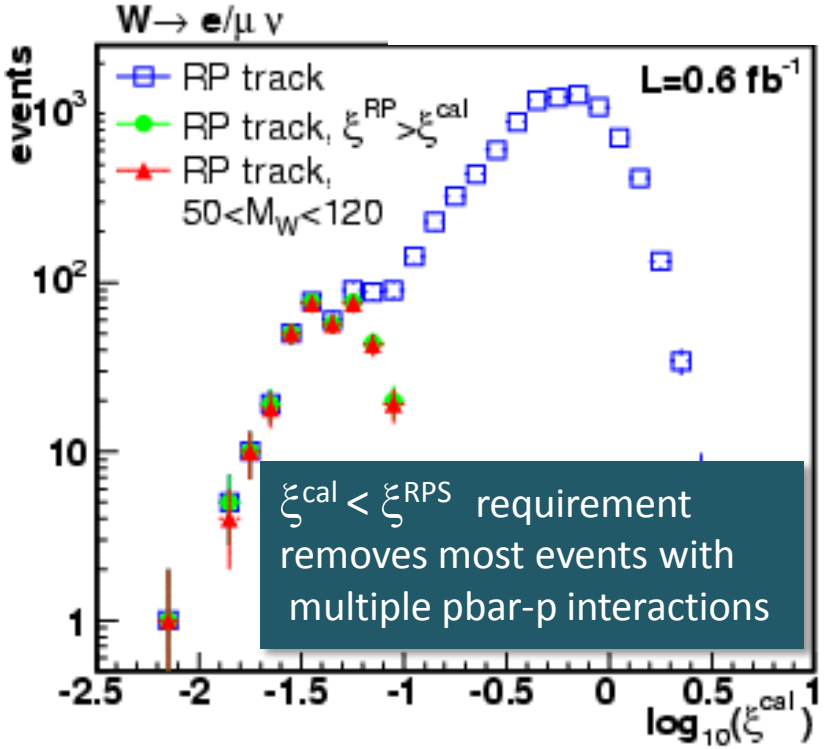
METHODOLOGY:

ξ variable can be reconstructed from

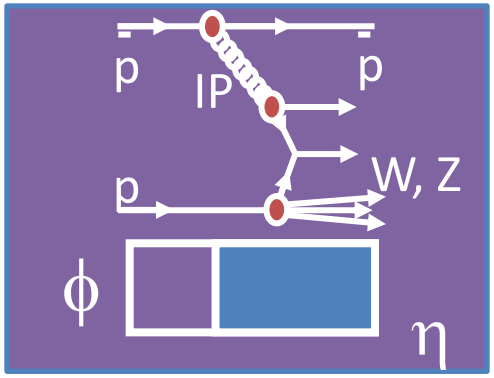
- **RPS tracking information: ξ^{RPS}**
- **from the fully reconstructed final state: $\xi^{cal}=(1/\sqrt{s})\times \sum E_T^i e^{-\eta^i}$**

In W production, the difference between ξ^{cal} and ξ^{RPS} is related to missing E_T and η_ν allows to determine ν and W kinematics

$$\xi^{RPS} - \xi^{cal}=(1/\sqrt{s})\times E_T^{\nu} e^{-\eta^{\nu}}$$



Single Diffraction: W Production



Phys. Rev. D 82, 112004, 2010

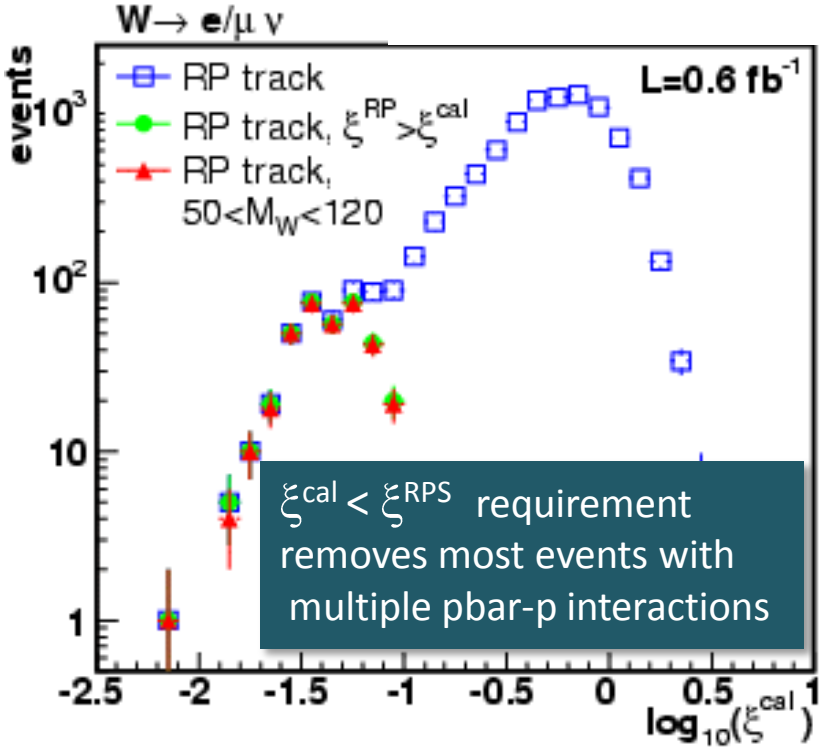
Diffractive signature:

- ☐ large rapidity gap
- ☑ intact pbar detected in RPS

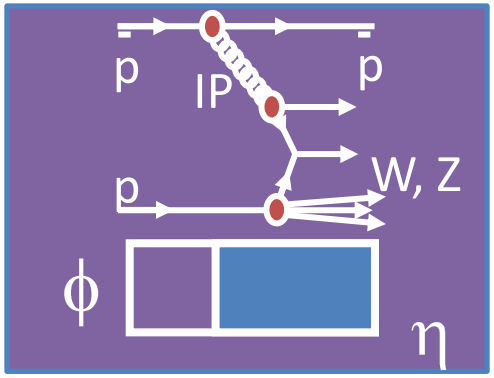
Fraction of diffractive W

$R_W(0.03<\xi<0.10, |t|<1)$= [0.97 ±0.05(stat) ±0.10(syst)]%

Consistent with Run I result, extrapolated to all ξ



Single Diffraction: Z Production

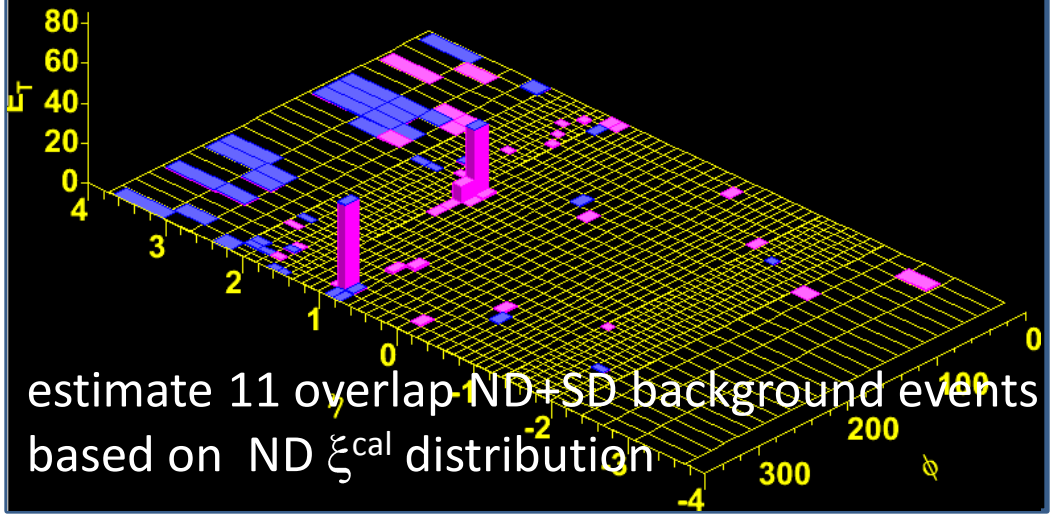


Phys. Rev. D 82, 112004, 2010

Diffractive signature:

- ☐ large rapidity gap
- ☑ intact pbar detected in RPS

37 diffractive Z→ ee/μμ candidates
(RPS track, ξ^{cal}<0.1)

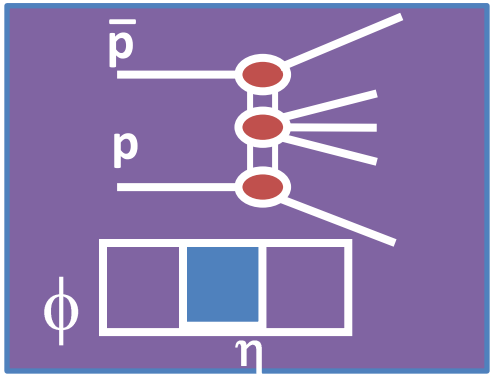


estimate 11 overlap ND+SD background events
based on ND ξ^{cal} distribution

Fraction of diffractive Z

R_Z (0.03<ξ<0.10, |t|<1)=
[0.85±0.20(stat) ±0.08(syst)]%

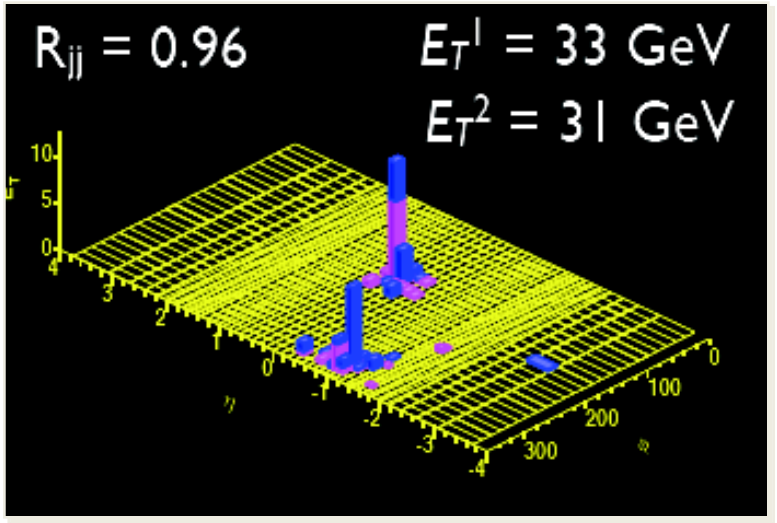
Central Exclusive Production



Diffractive signature:

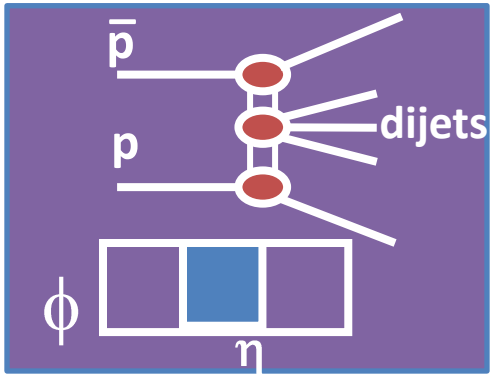
- ☑ large rapidity gap
- ☑ intact pbar detected in RPS

- suppression at LO of the background sub-processes (J_z=0 selection rule)
- "exclusive channel" → clean signal (no underlying event activity)



Many measurements at CDF to test and calibrate theoretical predictions

Central Exclusive Production: Observation of exclusive dijets



Phys. Rev. D 77, 052004, 2008

Diffractive signature:

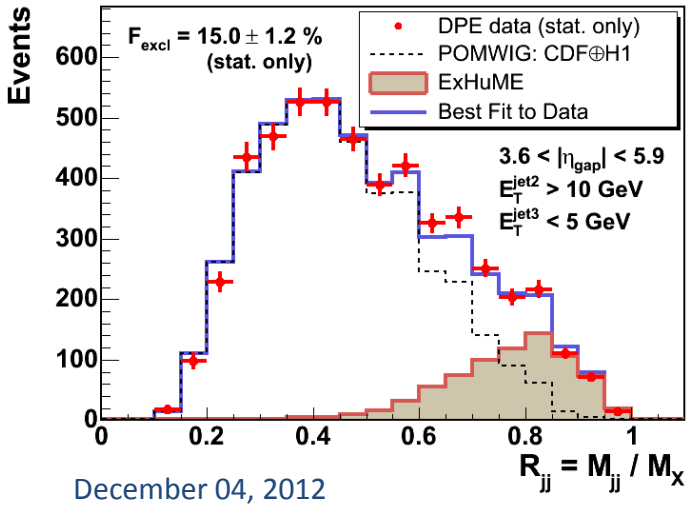
- ☑ large rapidity gap
- ☑ intact pbar detected in RPS

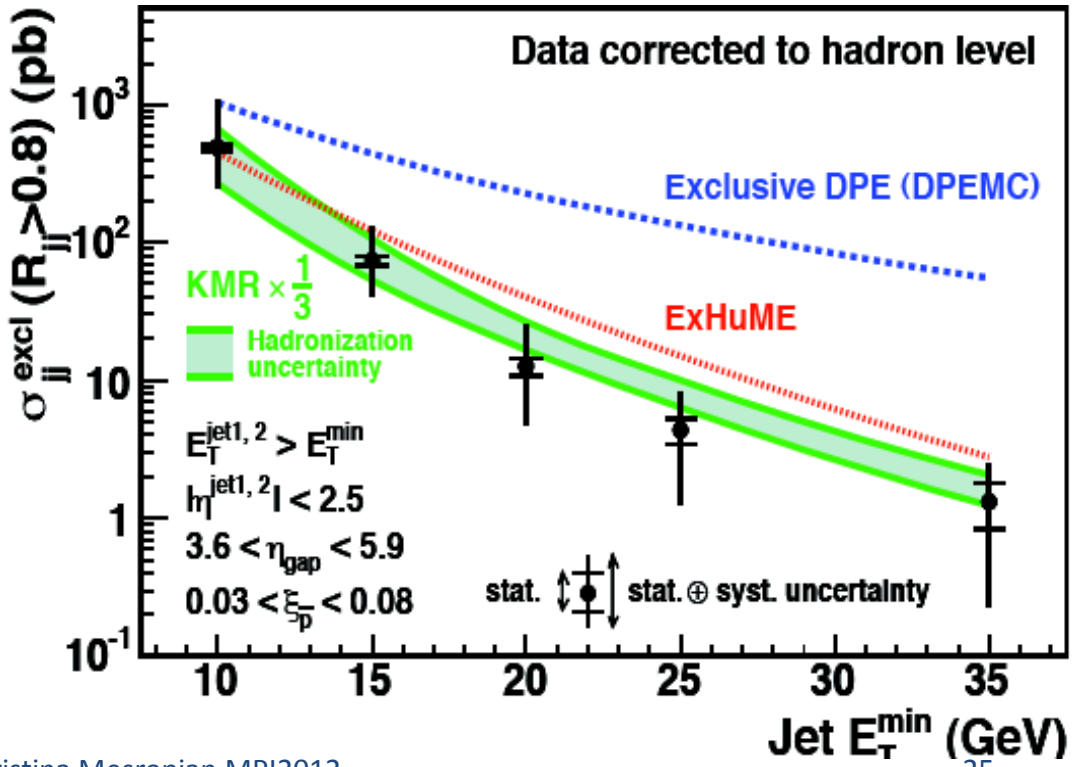
Methodology:

Reconstruct $\mathbf{R_{jj}=M_{jj}/M_X}$, where

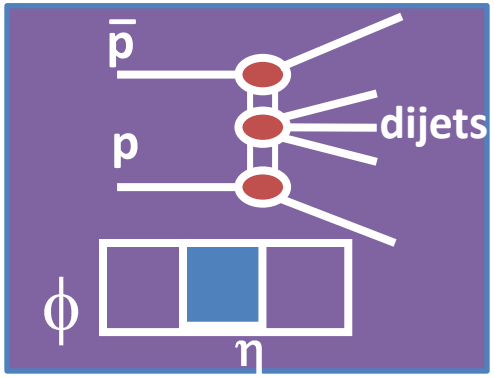
M_{jj} mass of dijet system, M_x mass of X

Exclusive signal : $R_{jj}>0.8$





Central Exclusive Production: Observation of exclusive dijets

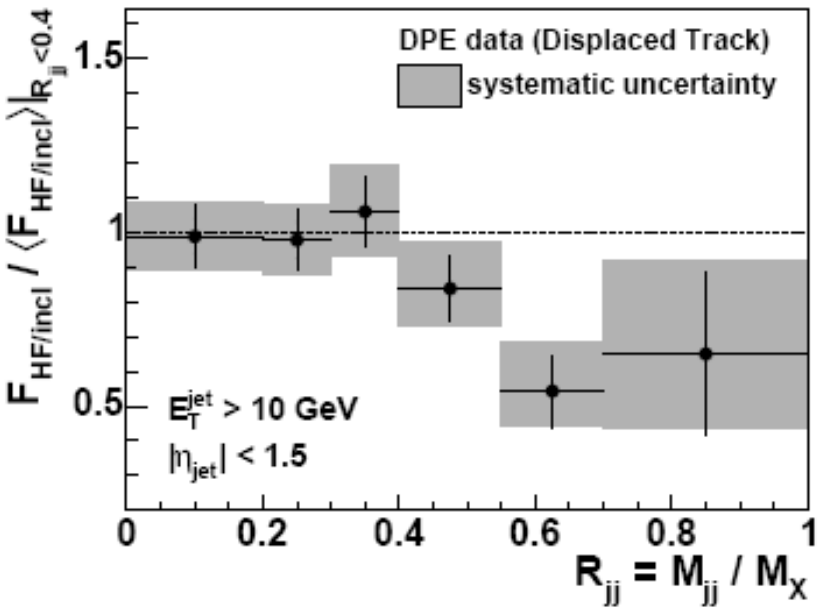


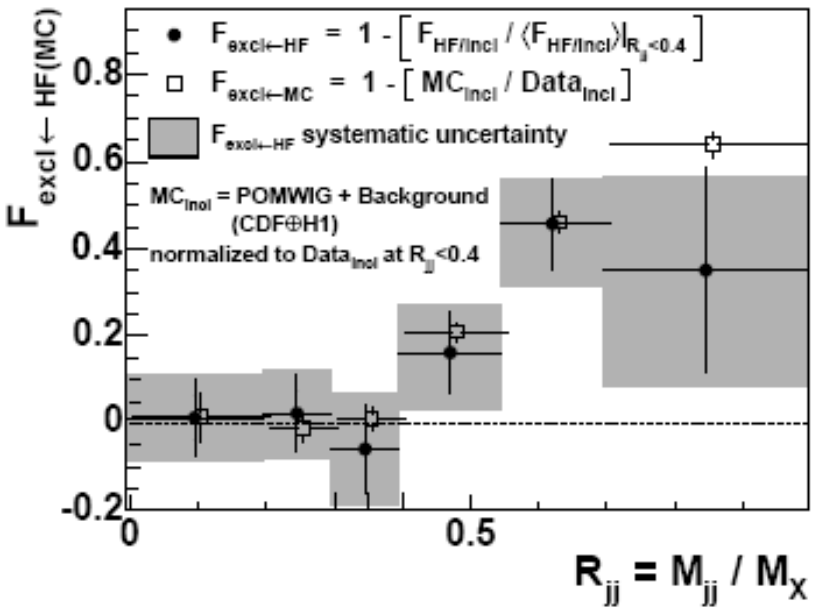
Phys. Rev. D 77, 052004, 2008

Diffractive signature:

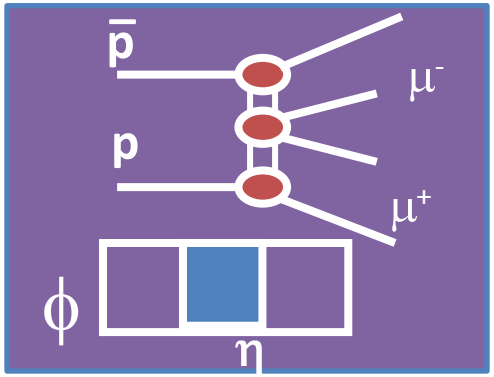
- ☑ large rapidity gap
- ☑ intact pbar detected in RPS

Look for **heavy flavor jet suppressio**n relative to inclusive dijets at high Rjj





Central Exclusive Production: Observation of exclusive dimuons and χ_c



Phys. Rev. Lett. 102, 242001, 2009

Diffractive signature:

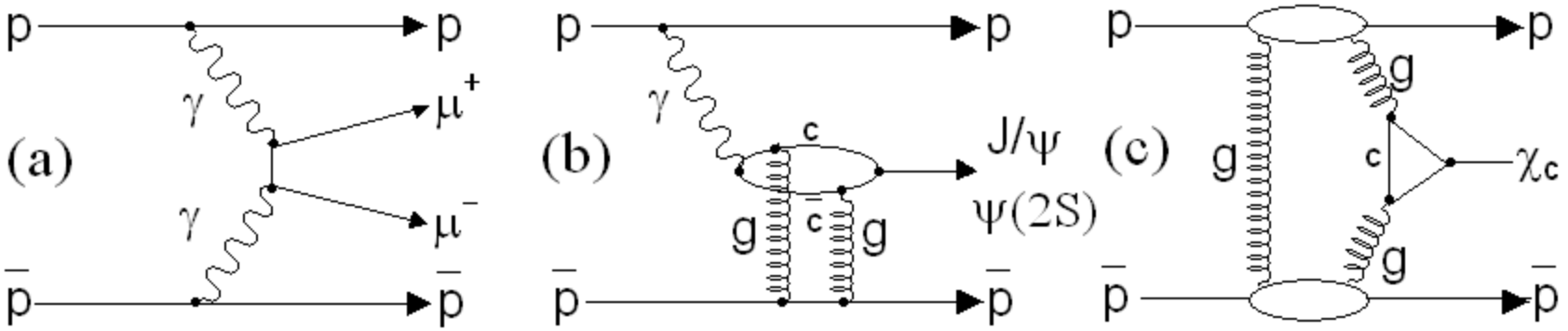
- ☑ large rapidity gap
- ☐ intact pbar detected in RPS

Trigger:

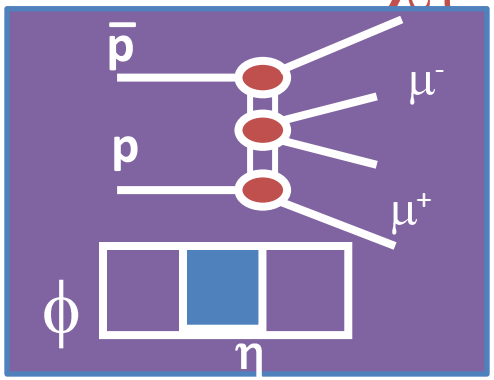
muon + track + forward rapidity gaps in BSCs

2 oppositely charged muon tracks with
p_T>1.4 GeV/c, $|\eta|$<0.6

3 GeV/c² <$M_{\mu\mu}$<4 GeV/c²



Central Exclusive Production: Exclusive $\chi_c \to J/\psi(\to \mu^+\mu^-)+\gamma$



Phys. Rev. Lett. 102, 242001, 2009

Diffractive signature:

- ☑ large rapidity gap
- ☐ intact pbar detected in RPS

J/ψ production: 243 ±21 events

$d\sigma/dy|_{y=0}$ = 3.92 ± 0.62 nb

$\Psi(2s)$ production: 34±7 events

$d\sigma/dy|_{y=0}$ = 0.54 ± 0.15 nb

$R = \psi(2s)/J/\psi = 0.14 \pm 0.05$

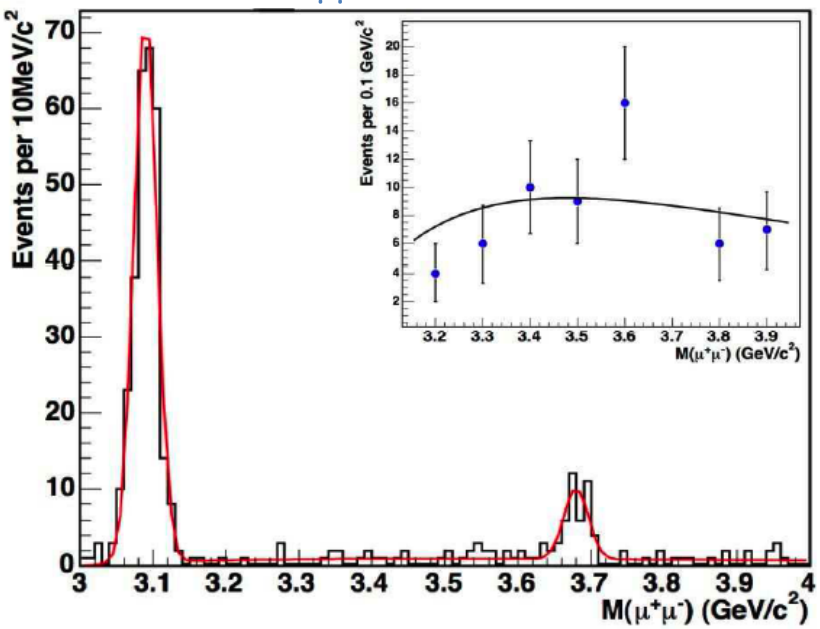
In agreement with HERA:

R = 0.166 ± 0.012 in a similar kinematic region

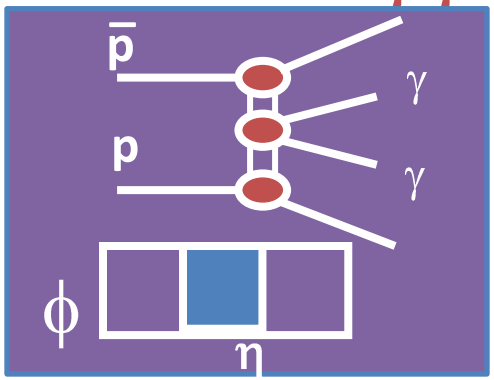
$\chi_c \to J/\psi(\to \mu^+\mu^-)+\gamma$

$d\sigma/dy|_{y=0}$ = 0.54 ± 0.15 nb

3 GeV/c² <$M_{\mu\mu}$<4 GeV/c²



Central Exclusive Production: Exclusive $\gamma\gamma$ production

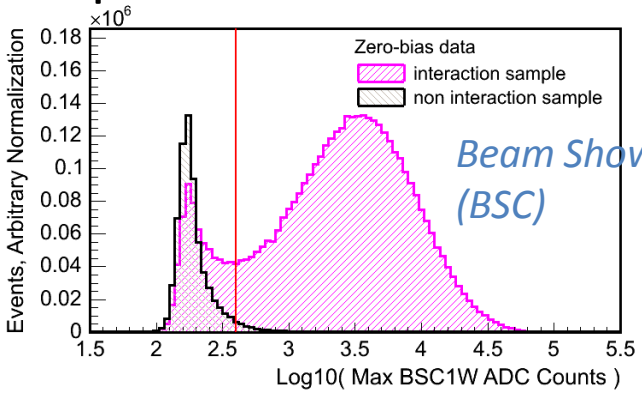


Phys. Rev. Lett. 99, 242002, 2007

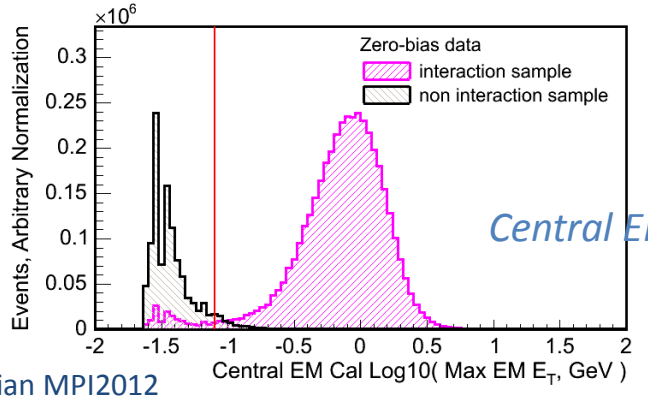
3 candidates observed, limit set

Diffractive signature:

- ☑ large rapidity gap
- ☐ intact pbar detected in RPS



Beam Shower Counters (BSC)



Central EM calorimeter

Methodology:

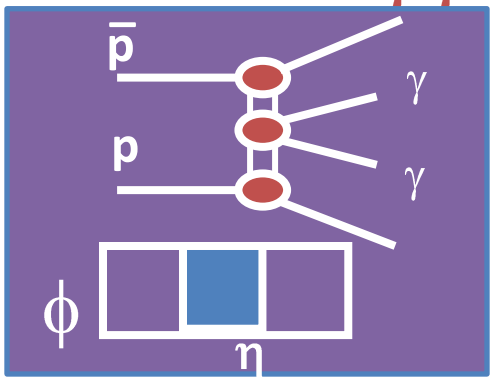
Require : no other particles in the detectors **up to $|\eta| < 7.4$**

Study noise level by looking at "zero-bias" events:

"no interaction" class of events

"interaction" class of events

Central Exclusive Production: Exclusive $\gamma\gamma$ production



Phys. Rev. Lett. 109, 081801, 2012

Diffractive signature:

- ☑ large rapidity gap
- ☐ intact pbar detected in RPS

Methodology:

Require : no other particles in the detectors **up to $|\eta| < 7.4$**

Study noise level by looking at "zero-bias" events:

"no interaction" class of events

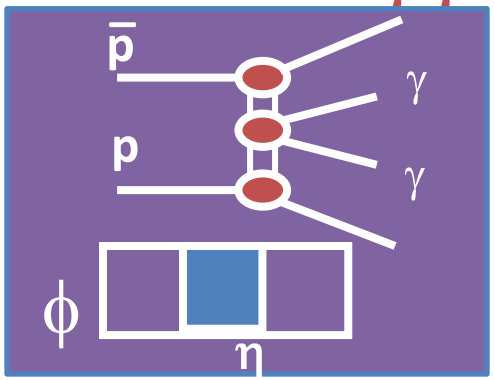
"interaction" class of events

Validate using control sample :

$p + \overline{p} \rightarrow p + e^+e^- + \overline{p}$ *via* $\gamma + \gamma$ *(QED)*

$\sigma^{\lvert\eta\rvert<1, E_T>2.5\text{GeV}}_{e^+e^-\text{excl.}}$	=	$2.88 \pm 0.59(\text{stat}) \pm 0.62(\text{sys})$ pb
$\sigma^{\lvert\eta\rvert<1, E_T>2.5\text{GeV}}_{\text{LPair}}$	=	3.25 ± 0.07 pb
$\sigma^{\lvert\eta\rvert<1, E_T>5.0\text{GeV}}_{e^+e^-\text{excl.}}$	=	$0.60 \pm 0.28(\text{stat}) \pm 0.14(\text{sys})$ pb
$\sigma^{\lvert\eta\rvert<1, E_T>5.0\text{GeV}}_{\text{LPair}}$	=	0.58 ± 0.003 pb

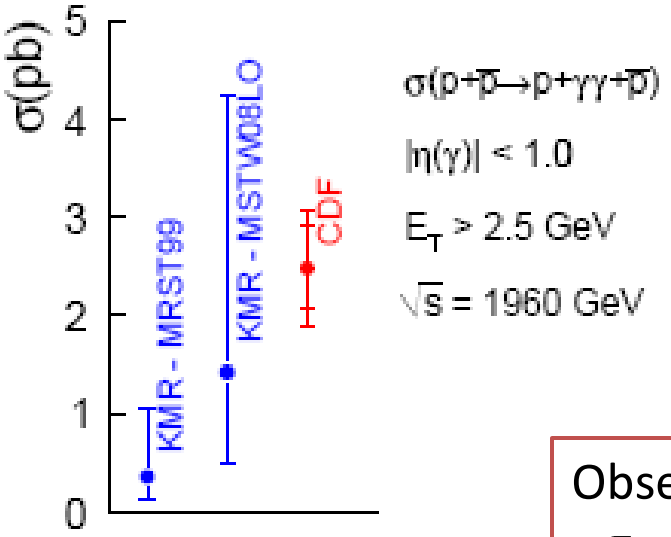
Central Exclusive Production: Exclusive $\gamma\gamma$ production

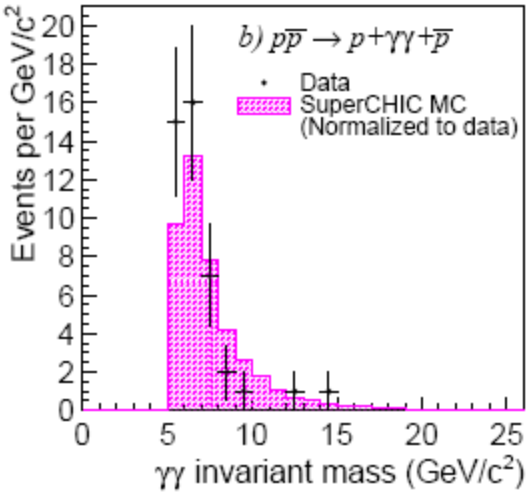


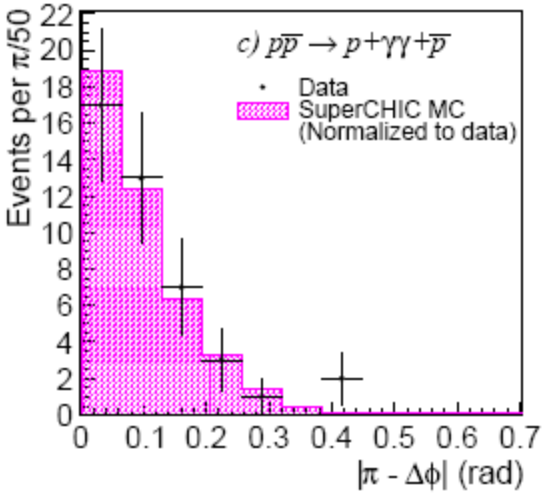
Phys. Rev. Lett. 109, 081801, 2012

Diffractive signature:

- ☑ large rapidity gap
- ☐ intact pbar detected in RPS





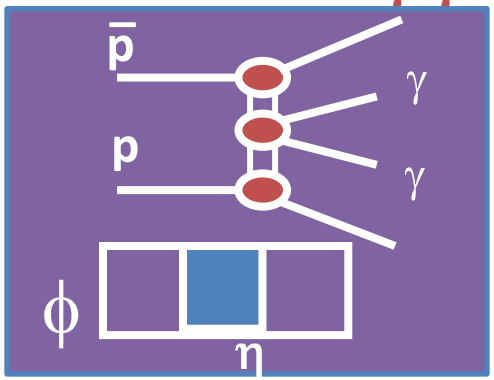


Observed 43 events >> 5 σ

$\sigma_{\gamma\gamma_{excl}}$ = 2.48±0.42(stat)±0.41(sys) pb

Good agreement with the theoretical predictions

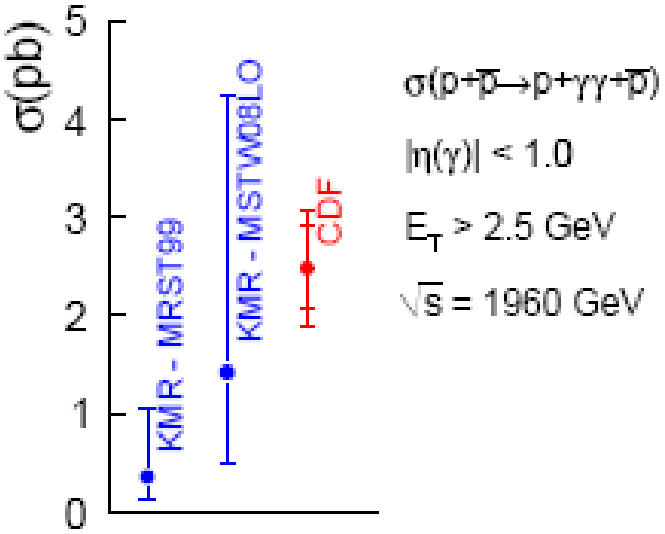
Central Exclusive Production: Exclusive $\gamma\gamma$ production

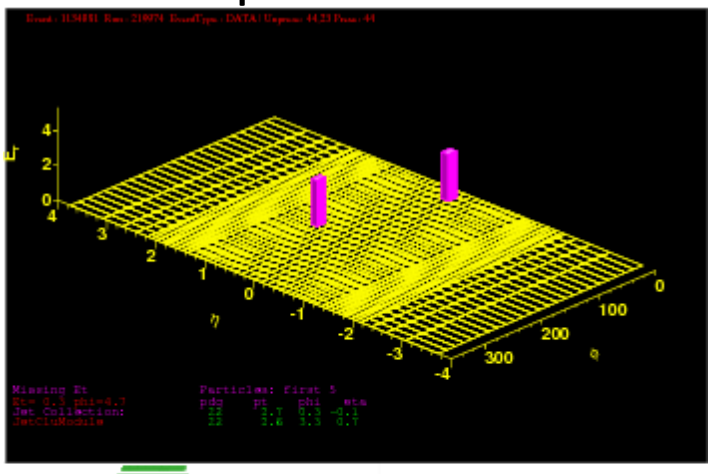


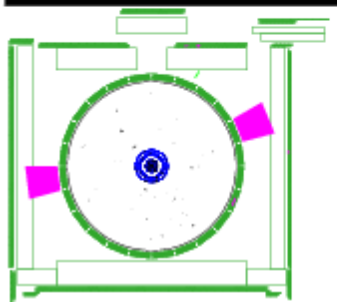
Phys. Rev. Lett. 109, 081801, 2012

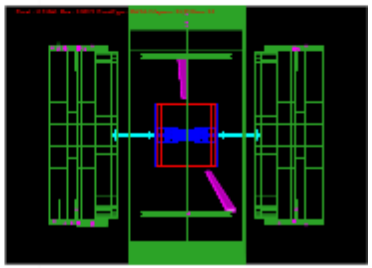
Diffractive signature:

- ☑ large rapidity gap
- ☐ intact pbar detected in RPS





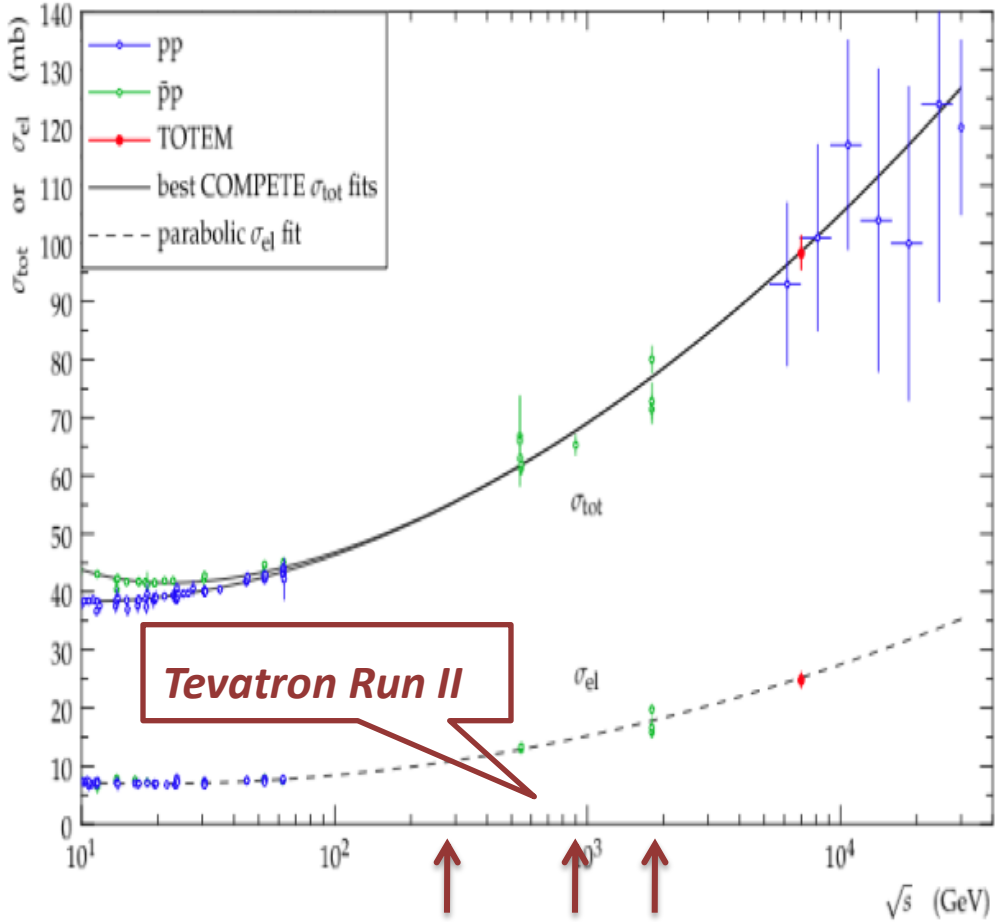




Tevatron energy scan

Study s-dependence of high cross-sections physics

…mostly non-pQCD



1.Study of MB events:

2.Study of UE events

3.Gap-X Gap events

Tevatron energy scan - data

September 8 – 16, 2011

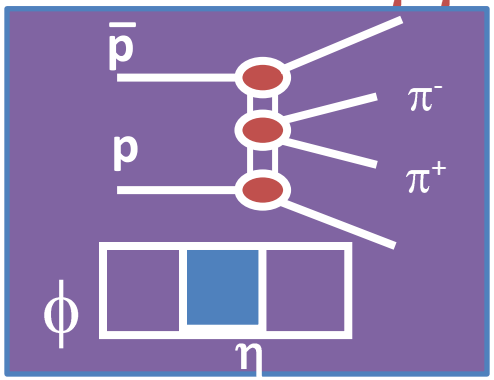
- 3x3 bunches
- Special trigger
- 1 interaction per crossing (no pile-up)

Total data taking time :

10 h at 300 GeV and 39 h at 900 GeV

$\sqrt{s}$	0-bias	Minbias	Gap-X-Gap	Jets	e,μ,ν	Total # events
300	1.89 M	12.1 M	9.2 M	8.3 K	352	23.2 M
900	8.0 M	54.3 M	21.8 M	550 K	16 K	84.7 M

Central Exclusive Production: Exclusive $\gamma\gamma$ production



Diffractive signature:

- ☑ large rapidity gap
- ☐ intact pbar detected in RPS

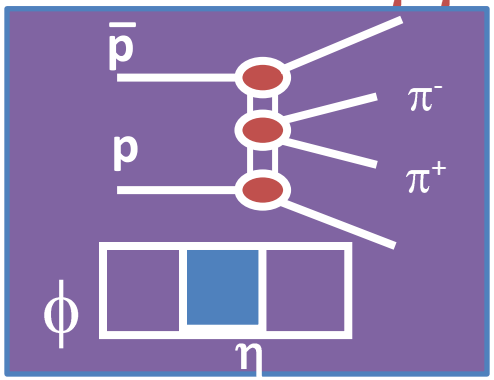
2-track mass spectra between rapidity gaps from $1.32<|\eta|<5.9$ at $\sqrt{s}$ = 1960 & 900 GeV

L_{eff}(no-PU) = 1.18(0.059)/pb at 1960(900) GeV

All CDF detectors below noise level except two tracks

- **Meson spectroscopy:**
  - **glue-rich**
- **Understanding nature of pomeron P (~ gg)**
- **Only comparable data at $\sqrt{s}$ = 63 GeV, η-gaps 3.2**

Central Exclusive Production: Exclusive $\gamma\gamma$ production

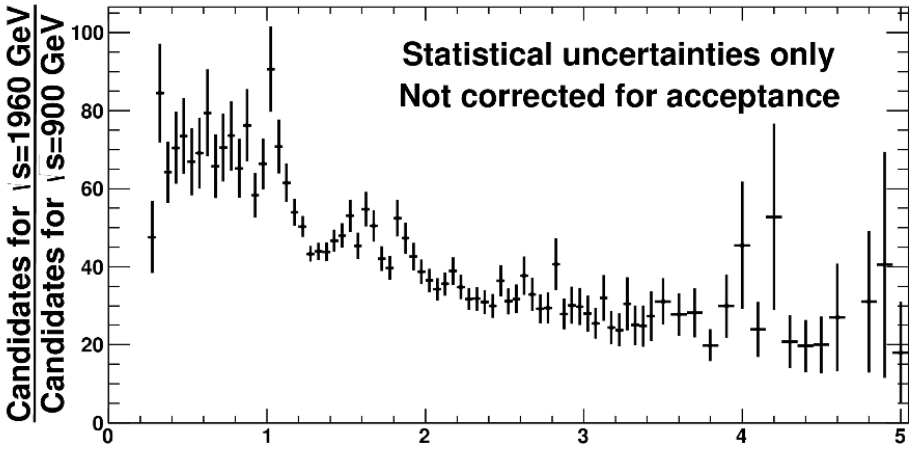


Work in Progress…

Diffractive signature:

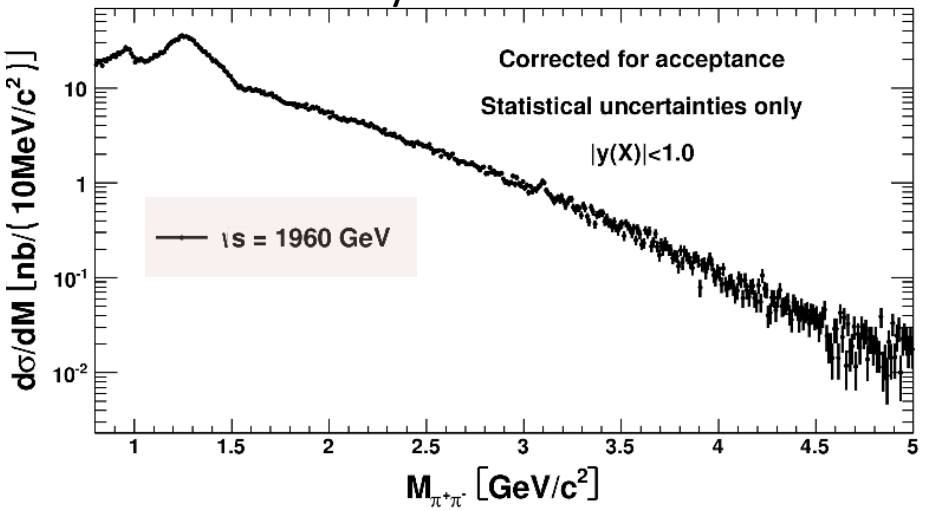
- ☑ large rapidity gap
- ☐ intact pbar detected in RPS

CDF II Preliminary



Ratio of mass distributions for ✓s = 1960 GeV and ✓s = 900 GeV

CDF II Preliminary



Invariant mass distribution of 2 particles assuming pion masses

Conclusions

We have very extensive program of diffractive studies at the Tevatron – new forward detectors R&D, new methodologies developed, many pioneering measurements performed.

- **new SD measurements**
  - t distributions for $|t|<4$ GeV^2
  - diffractive W and Z production
- **new measurements on central exclusive production**
  - observation of exclusive diphoton production
- **work in progress on datasets collected at $\sqrt{s}$=300 and 900 GeV**
  - plan to have more results soon

more information available on CDF QCD public webpage

http://www-cdf.fnal.gov/physics/new/qcd/QCD.html

Ref: Papers on diffraction at CDF

Soft Diffraction

Double Pomeron Exc.
PRL 93,141603 (2004)
Multi-Gap Diffraction
PRL 91, 011802 (2003)

Single Diffraction
PRD 50, 5355 (1994)

Double Diffraction
PRL 87, 141802 (2001)

Hard Diffraction

Dijets:
1.8 TeV PRL 85, 4217 (2000)
1.96 TeV PRD 77, 052004 (2008)
Di-photons
1.96 TeV PRL 99, 242002 (2007)
1.96 TeV PRL 108,081801 (2012)
Charmonium
1.96 TeV PRL 102, 242001 (2009)

Rapidity Gap Tag
W PRL 78, 2698 (1997)
Dijets PRL 79, 2636 (1997)
b-quark PRL 84, 232 (2000)
J/Ψ PRL 87, 241802 (2001)
Roman Pot Tag
Dijets:
1.8 TeV PRL 84, 5043 (2000)
630 GeV PRL 88, 151802 (2002)
W/Z:
1.96 TeV PRD 82,112004 (2010)

Jet-Gap-Jet
1.8 TeV PRL 74, 855 (1995)
1.8 TeV PRL 80, 1156 (1998)
630 GeV PRL 81, 5278 (1998)