

DIFFRACTIVE AND EXCLUSIVE PRODUCTION AT CDF



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(for the CDF II Collaboration)



LOW X MEETING
PAPHOS, CYPRUS
27 JUNE - 1 JULY

2012

HEP@Rockefeller



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- **CDF4LHC**



❑ Mike Albrow was scheduled to present this part, but unfortunately he couldn't attend the workshop.

STUDIES OF DIFFRACTION IN QCD

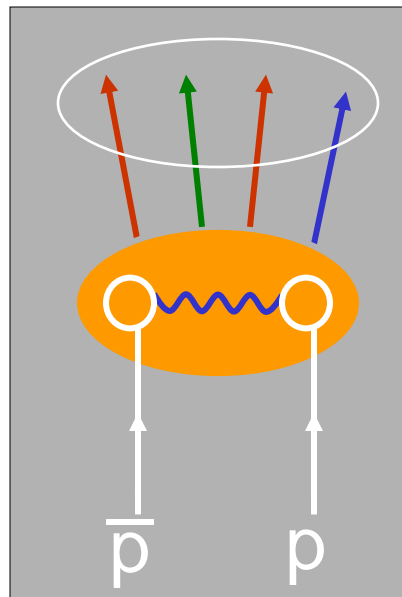
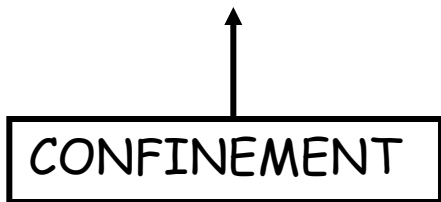
Non-diffractive

- ❖ color-exchange \rightarrow gaps exponentially suppressed

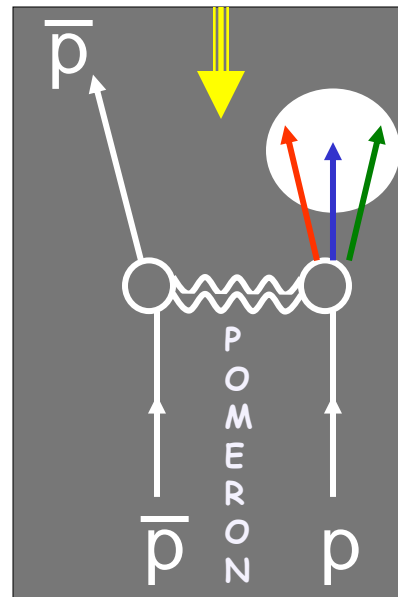
Diffractive

- ❖ Colorless vacuum exchange \rightarrow large-gap signature

Incident hadrons acquire color and break apart



rapidity gap



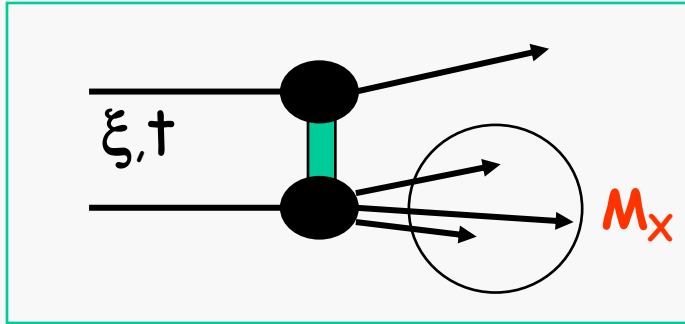
Incident hadrons retain their quantum numbers remaining colorless



Goal: probe the QCD nature of the diffractive exchange

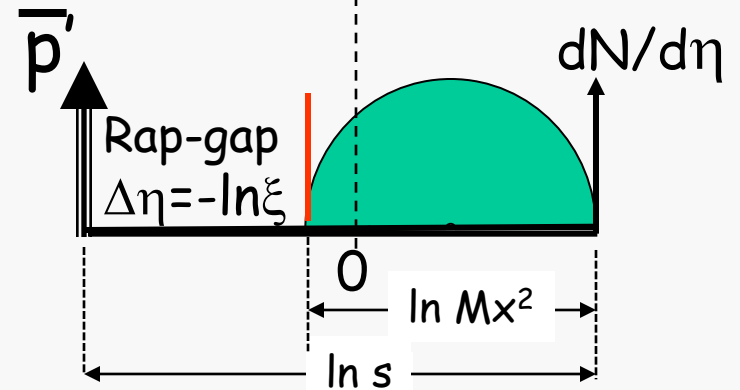
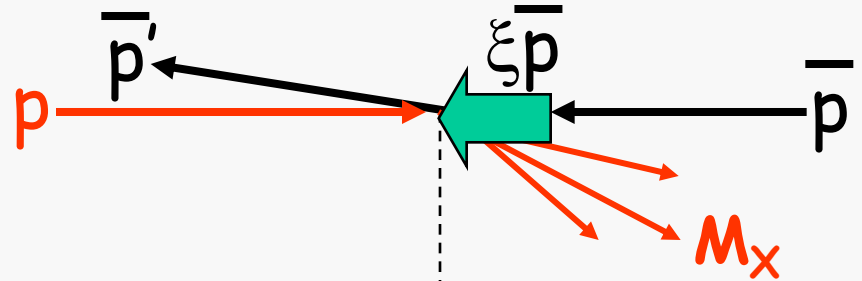
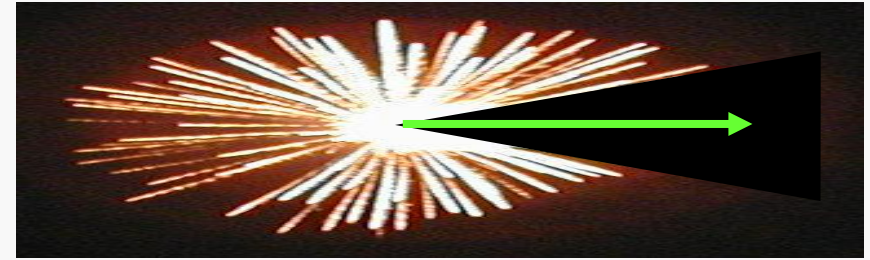
DEFINITIONS

SINGLE DIFFRACTION



$$1 - x_L \equiv \xi = \frac{M_X^2}{s}$$

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

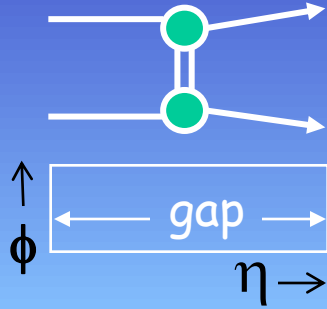


since no radiation \rightarrow
no price paid for increasing
diffractive gap size

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

DIFFRACTION AT CDF

Elastic scattering

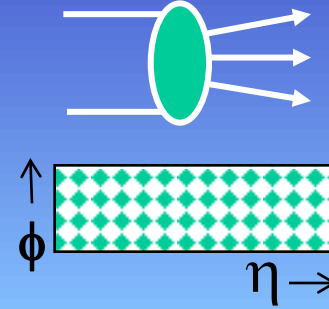


$\sigma_T = \text{Im } f_{el}(t=0)$

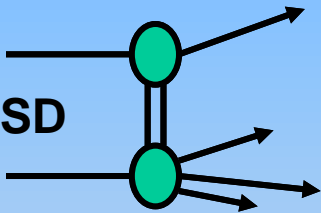


OPTICAL THEOREM

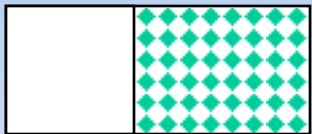
Total cross section



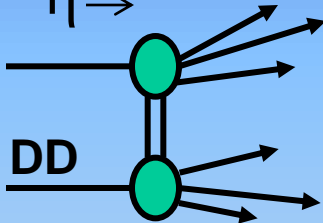
SD



Single Diffraction or Single Dissociation



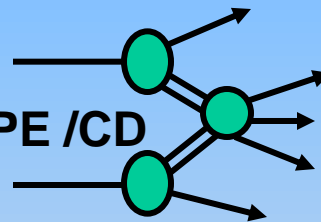
DD



Double Diffraction or Double Dissociation



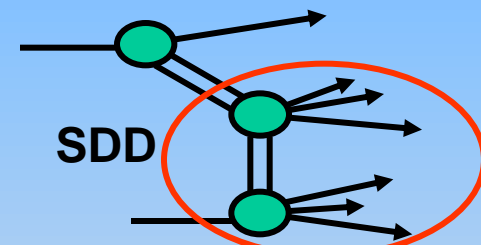
DPE / CD



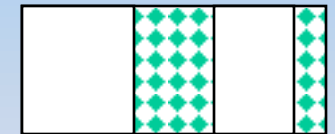
Double Pom. Exchange or Central Dissociation



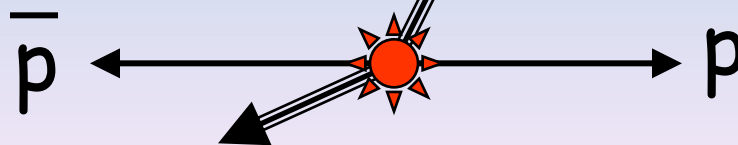
SDD



Single + Double Diffraction (SDD)

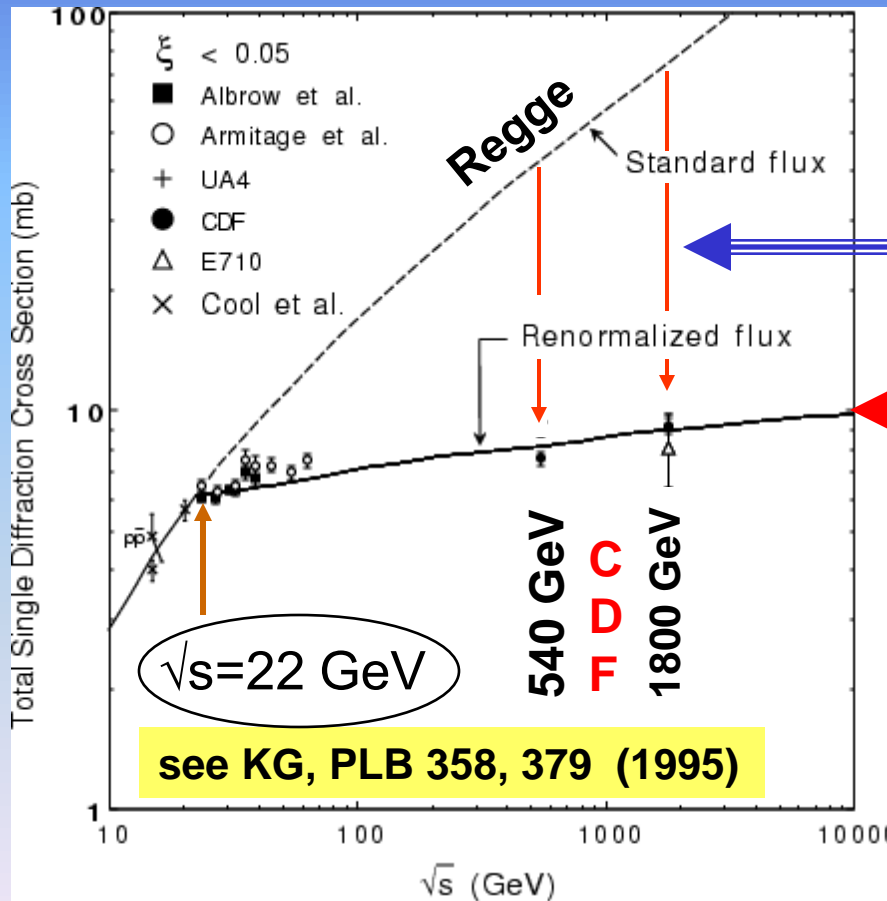
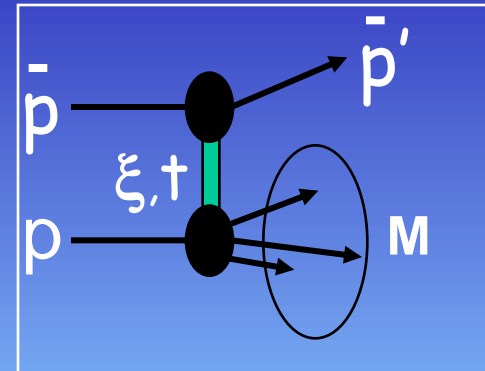


JJ, b, J/ψ, W



FACTORIZATION BREAKING IN SOFT DIFFRACTION

→ diffractive x-section suppressed relative to Regge prediction as \sqrt{s} increases

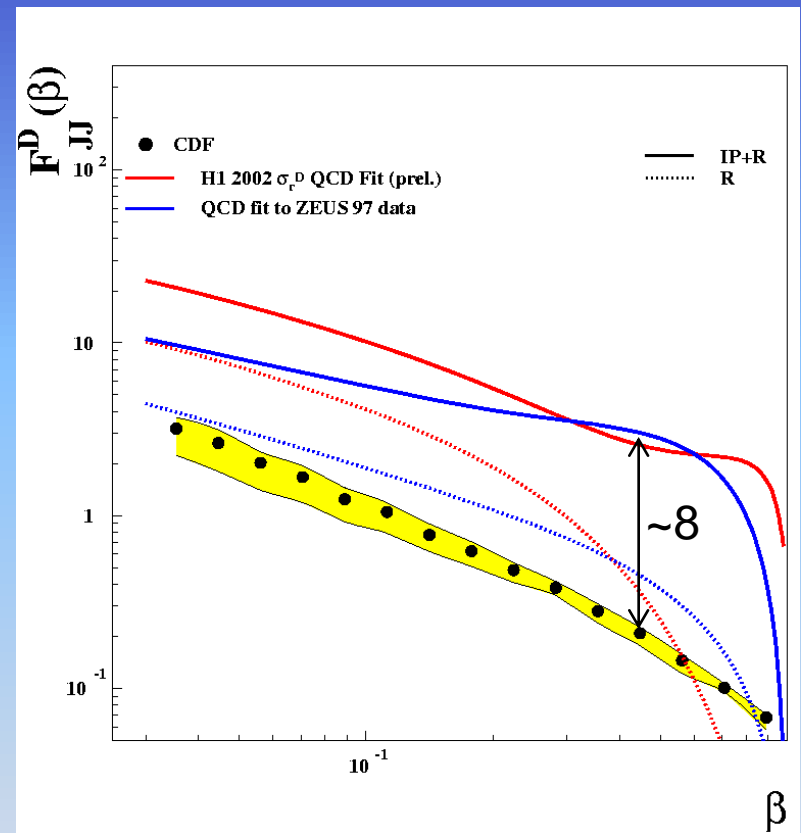
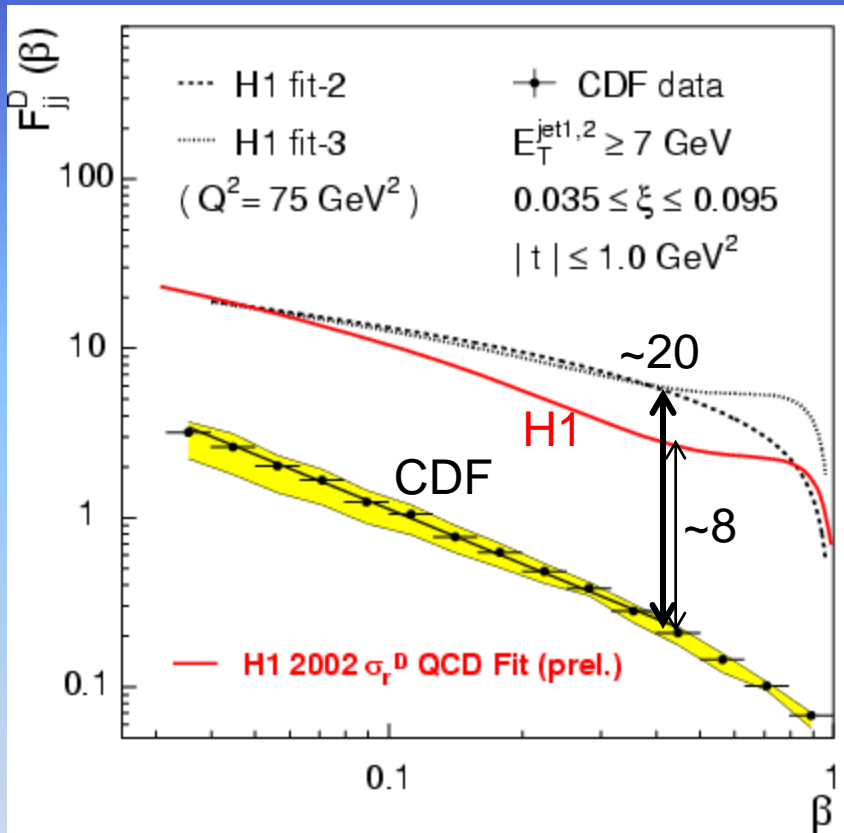


Factor of ~ 8 (~ 5)
suppression at
 $\sqrt{s} = 1800$ (540) GeV

RENORMALIZATION

Question:
does factorization breaking
affect t -distributions?

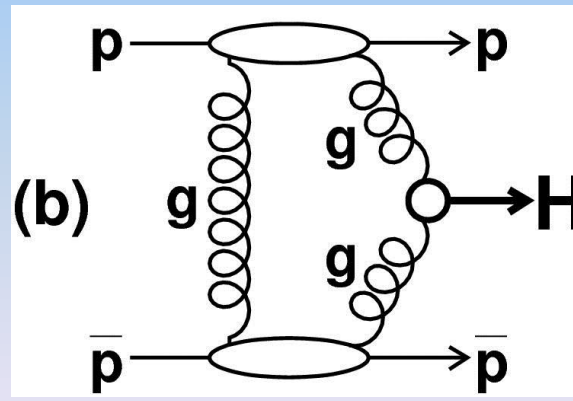
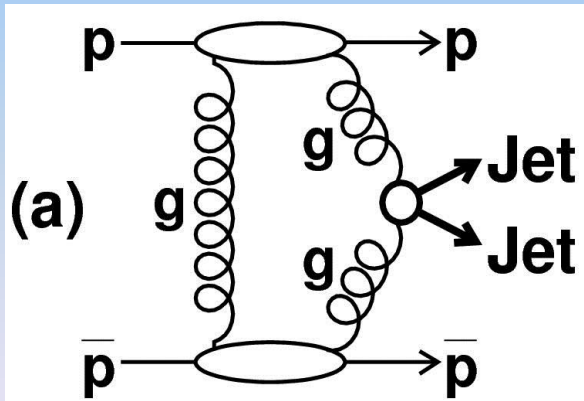
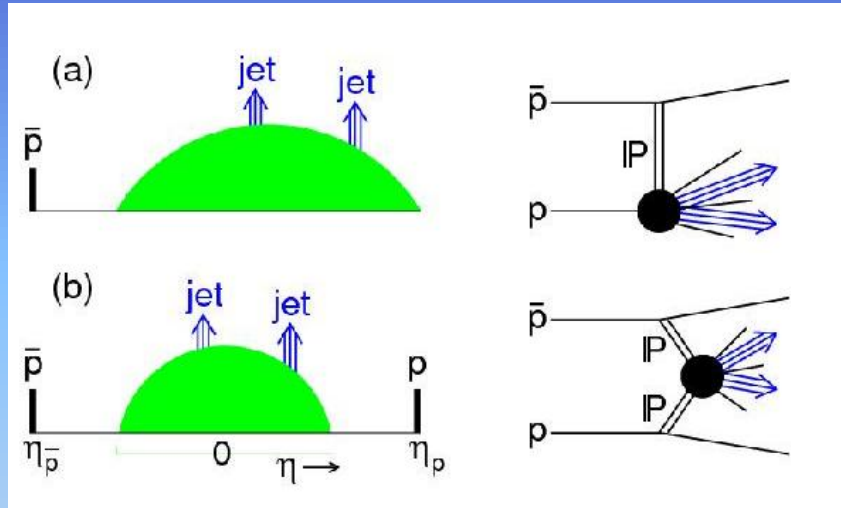
Diffractive Dijets in Run I



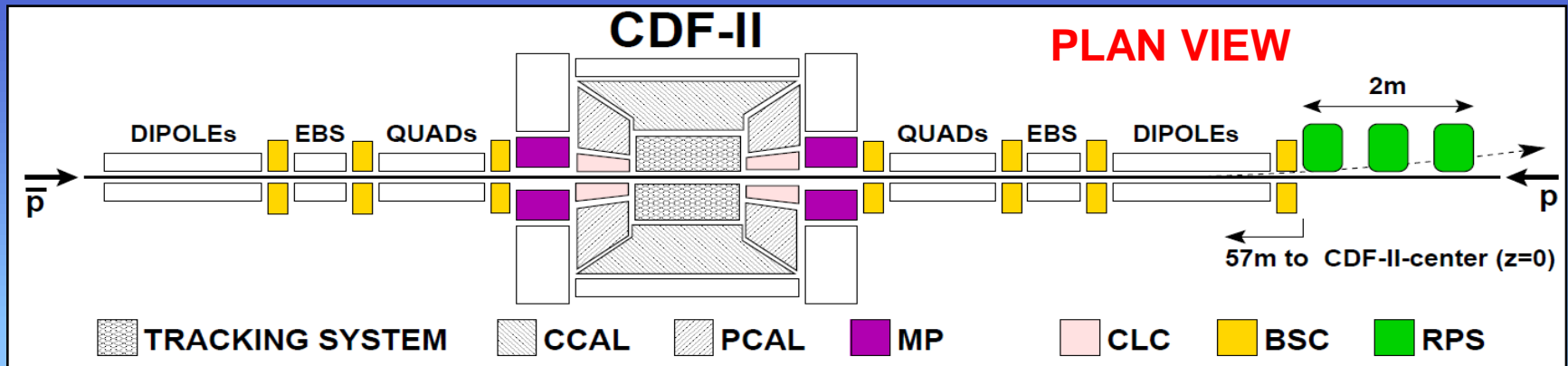
All hard-diffraction processes studied at CDF are suppressed by a factor of ~ 8 relative to predictions based on HERA-measured PDFs.

EXTRA MOTIVATION:

calibrate diffractive Higgs production models



The CDF II Detector



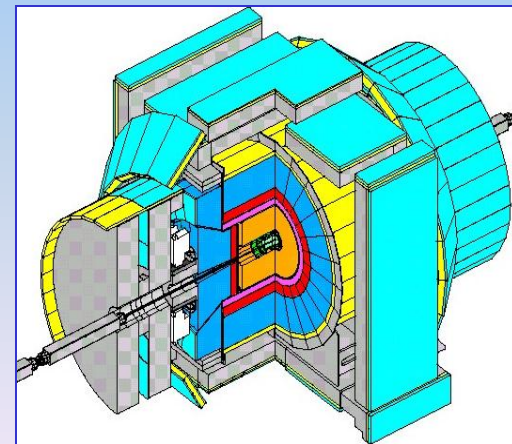
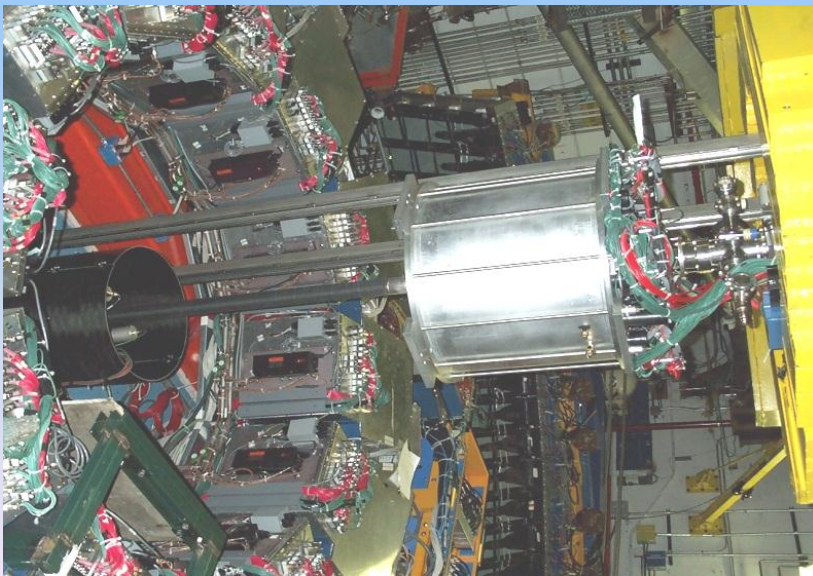
$$|\eta| < 2$$

$$\leftarrow |\eta| < 3.6 \rightarrow$$

$$3.5 < |\eta| < 5.1$$

$$5.4 < |\eta| < 7.4$$

$$\sim 0.03 < \xi < 0.09 \quad 0 < |t| < 4 \text{ GeV}^2$$



Diffractive Dijets

<http://arxiv.org/abs/1206.3955>

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Measurement of F_{jj}^{SD}

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

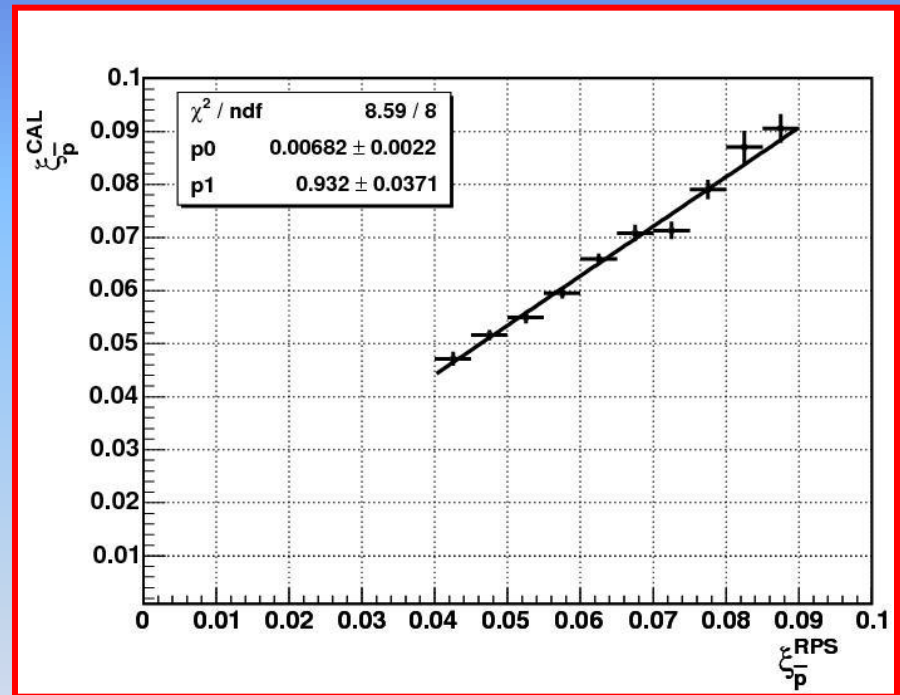
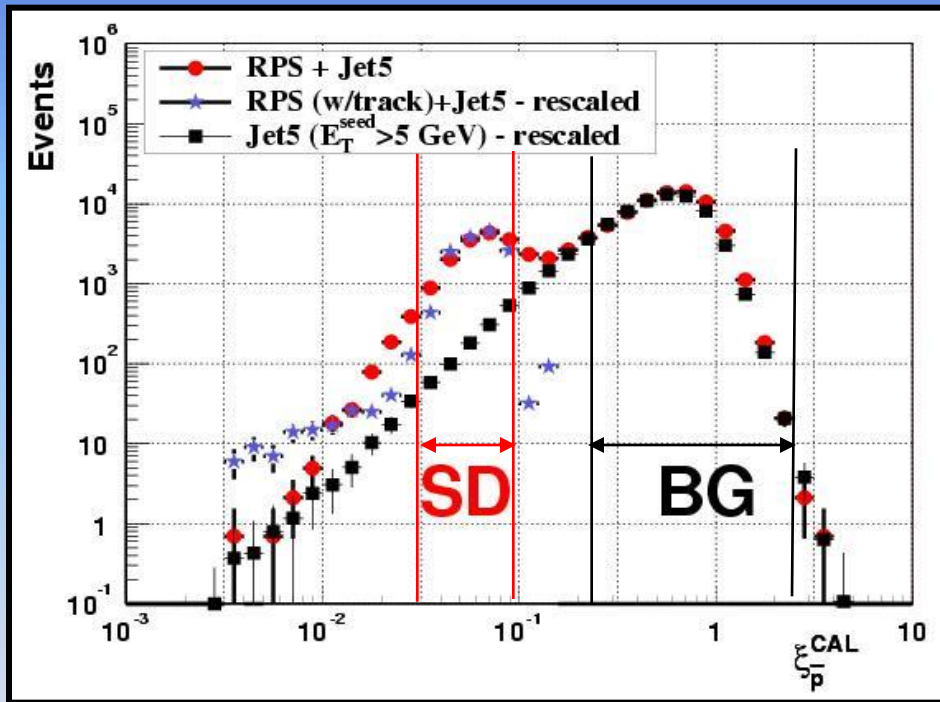
$$F_{jj}^{\text{incl}}(x, Q^2) = x \left[g(x, Q^2) + \frac{4}{9} \sum_i q_i(x, Q^2) \right]$$

$$R_{\text{SD/ND}}(x, Q^2, \xi, t) = \frac{n_{jj}^{\text{SD}}(x, Q^2, \xi, t)}{n_{jj}^{\text{ND}}(x, Q^2)} \approx \frac{F_{jj}^{\text{SD}}(x, Q^2, \xi, t)}{F_{jj}^{\text{ND}}(x, Q^2)}$$

$$F_{jj}^{\text{SD}}(x, Q^2, \xi, t) = R_{\text{SD/ND}}(x, \xi, t) \times F_{jj}^{\text{ND}}(x, Q^2)$$

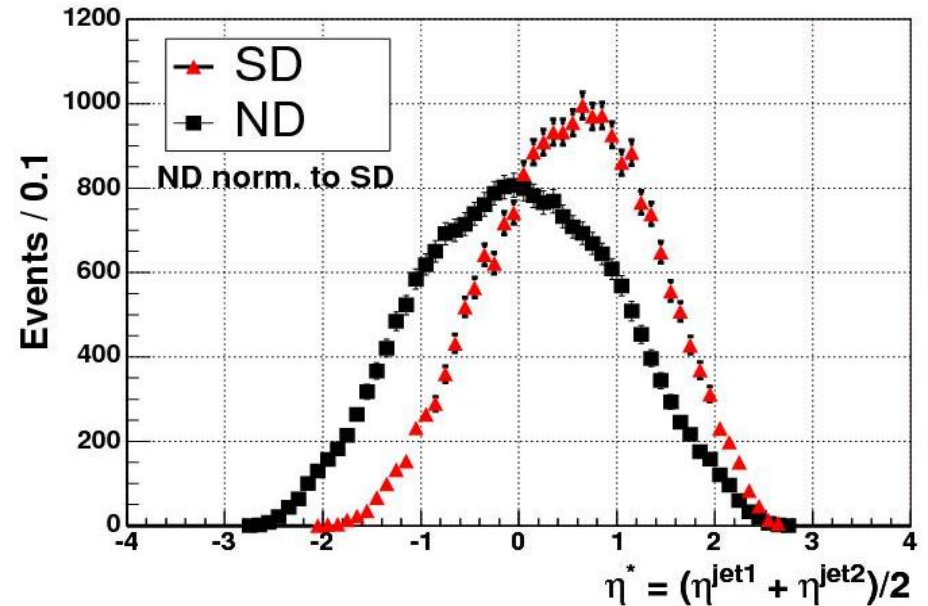
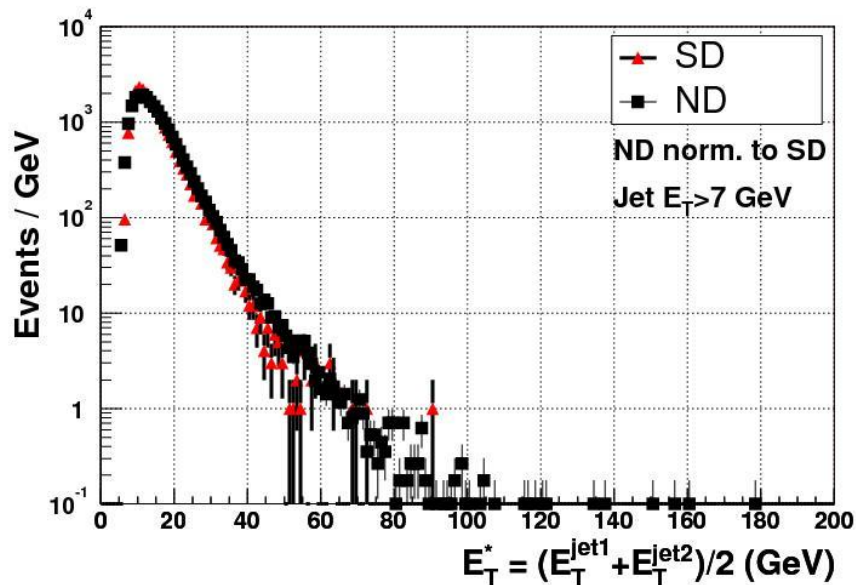
ξ^{CAL} VS ξ^{RPS}

- 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.



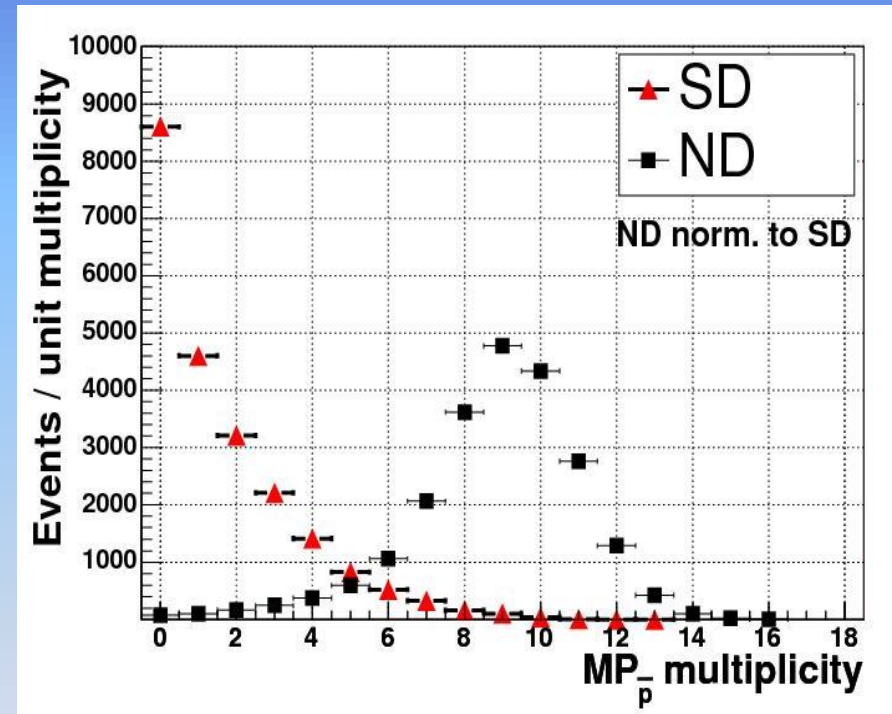
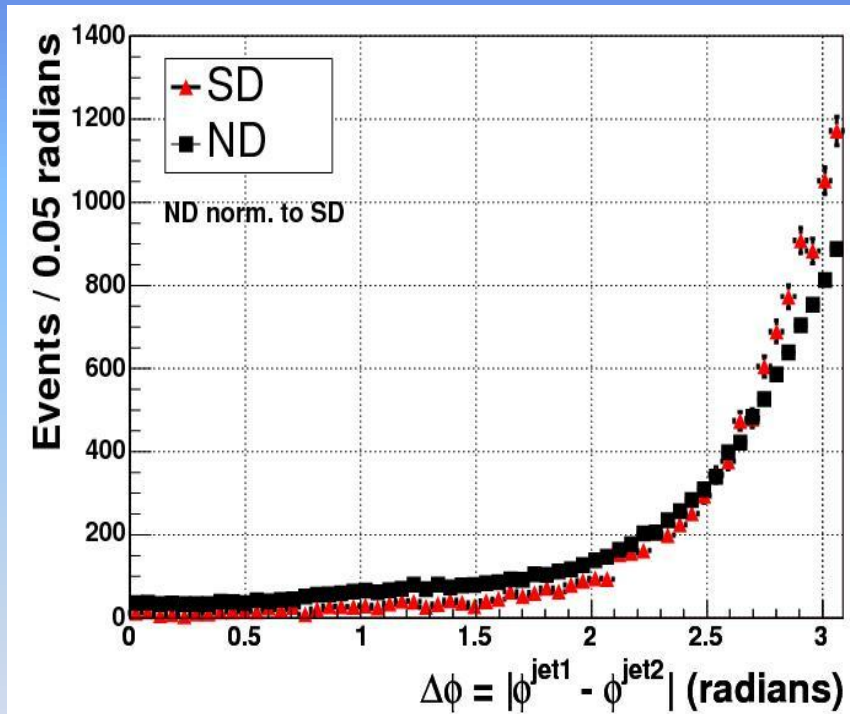
- A linear relationship is observed between ξ^{CAL} vs ξ^{RPS} in the region of ξ^{CAL} of the measurement

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

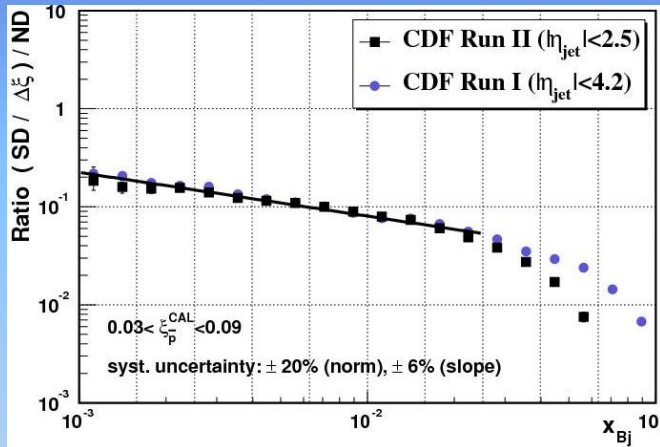


Left: the SD distributions are more back-to-back

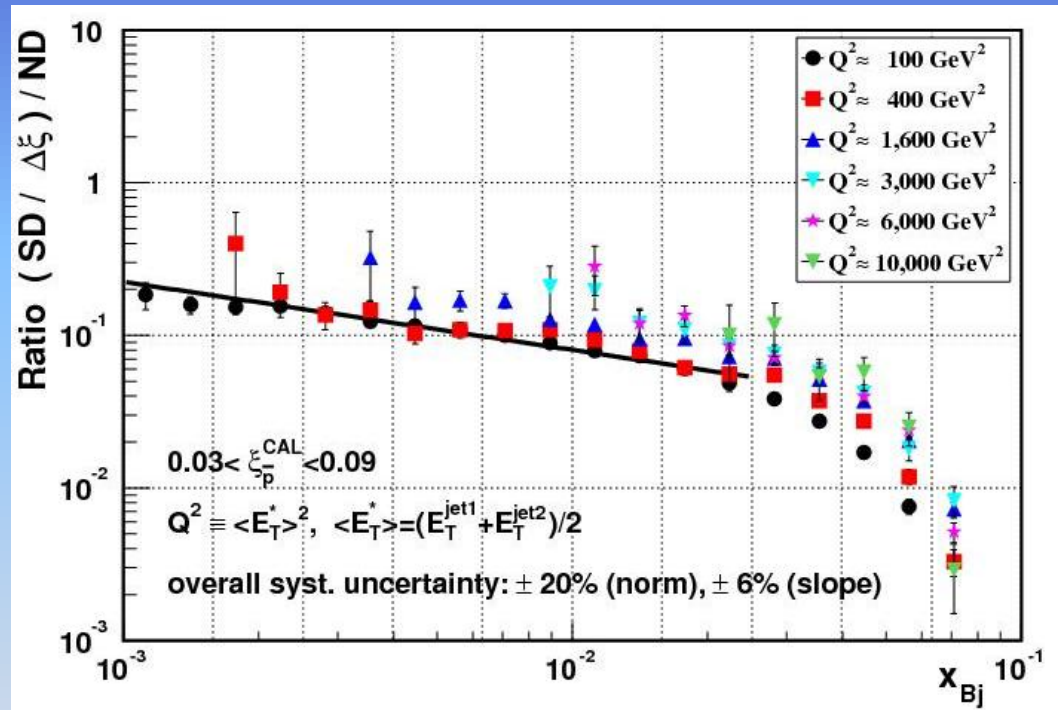
Right: the SD multiplicity is peaked at zero, while the ND is peaked at 9.

x_{Bj} Distributions vs $\langle Q^2 \rangle$

$\langle Q^2 \rangle = 100 \text{ GeV}^2$



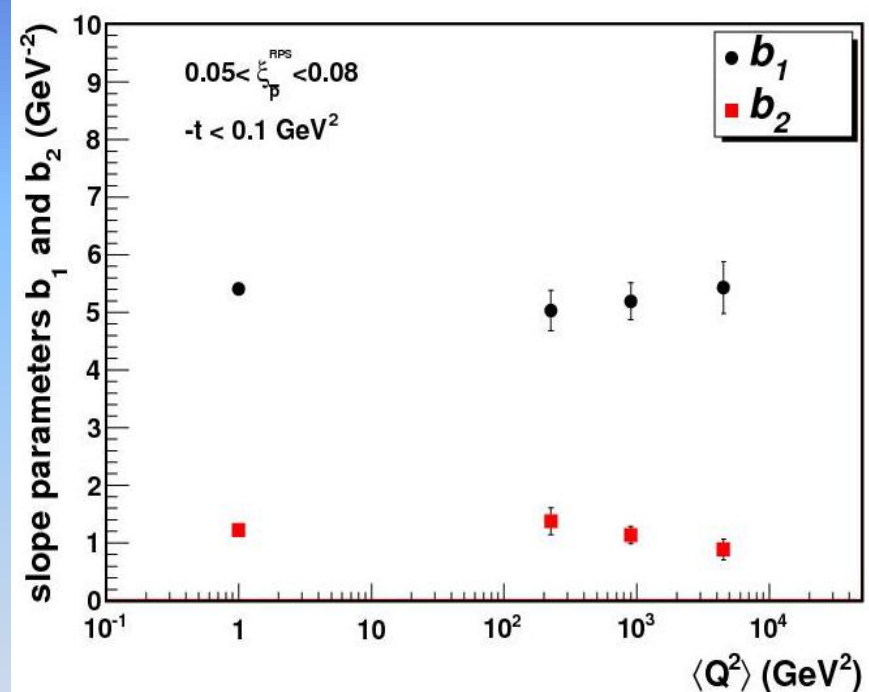
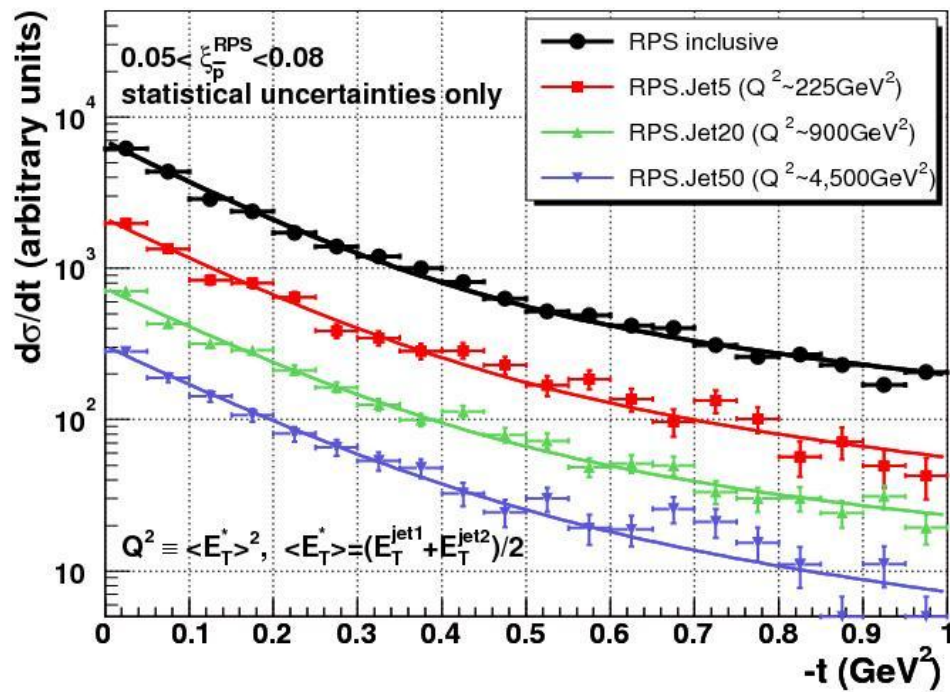
- The Run I result is confirmed.
- The drop-off on the rhs is due to the different range of the calorimeters in Run I and Run II.



□ The Bjorken- x distributions vary by only a factor of ~ 2 over a range of $\langle Q^2 \rangle$ of 2 orders of magnitude!

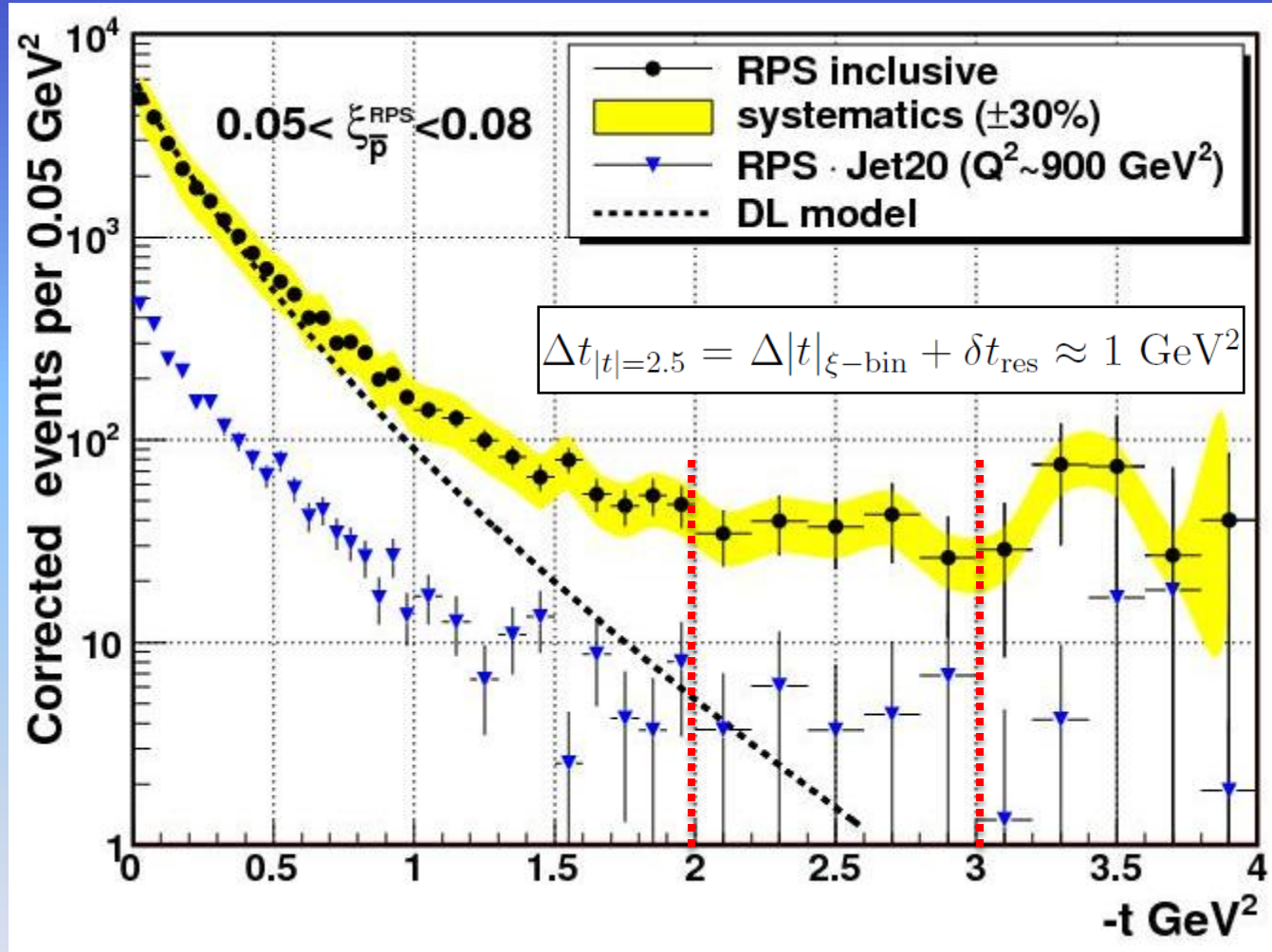
t -Distributions and Slopes vs $\langle Q^2 \rangle$ for $-t < 1 \text{ GeV}^2$

$$\frac{d\sigma}{dt} = N_{norm} (A_1 e^{b_1 t} + A_2 e^{b_2 t})$$



□ The slopes are nearly constant over a range of 4 orders of magnitude in $\langle Q^2 \rangle$!

t -Distributions for $-t < 4 \text{ GeV}^2$



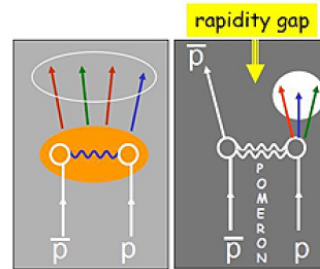
- The rather flat $-t$ distributions at large $-t$ are compatible with the existence of an underlying diffraction minimum around $-t \sim 2.5 \text{ GeV}^2$.

Dijet Results Summary

- ❑ We measured SD to ND ratios in dijet production vs Bjorken- x for 10^4 in $\langle Q^2 \rangle$ (or jet E_T) $-t > 4 \text{ GeV}^2$
- ❑ 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 $-t > 2 \text{ GeV}^2$
 - ➔ compatible with a diffraction minimum at $-t > 2.5 \text{ GeV}^2$
- ❑ 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.

Result of the Week

Ghost particle creates jets at Fermilab



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

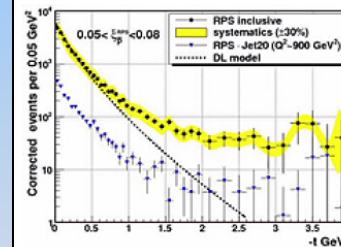
the color-neutral exchange of a particle called a [pomeron](#). With its vacuum-like properties, a pomeron can escape invisibly out of the quark-gluon bag like a ghost, strike the passing proton and give it an energy injection by allowing itself to be absorbed by the proton. The energy is used to create 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 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.

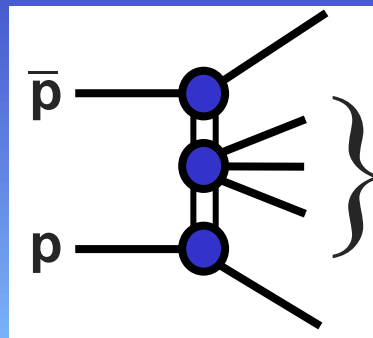
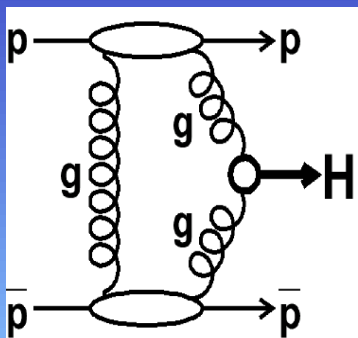


These physicists were responsible for this analysis. From left: Michele Gallinaro, Dino Goulianos and Koji Terashi, all from Rockefeller University.

Exclusive Production

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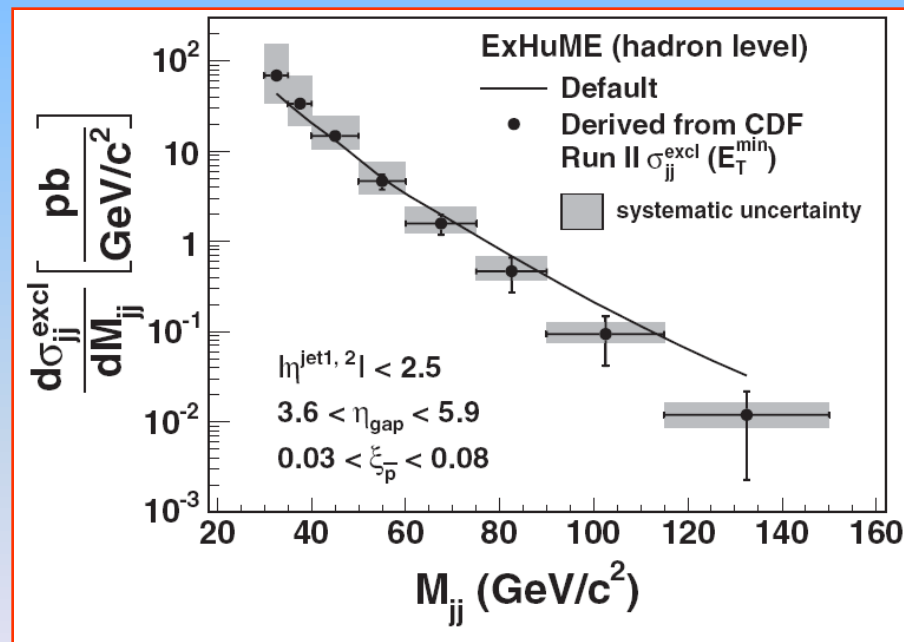
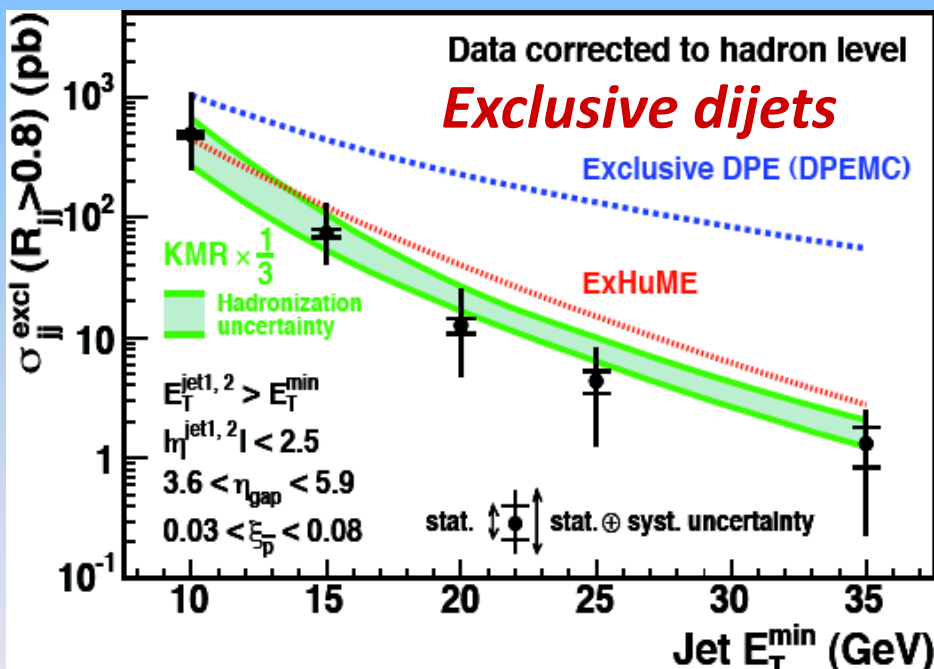
EXCLUSIVE Dijet \rightarrow Excl. Higgs THEORY CALIBRATION



JJ *PRD 77, 052004 (2008)*

$\gamma\gamma$ *PRL 99, 242002 (2007)*

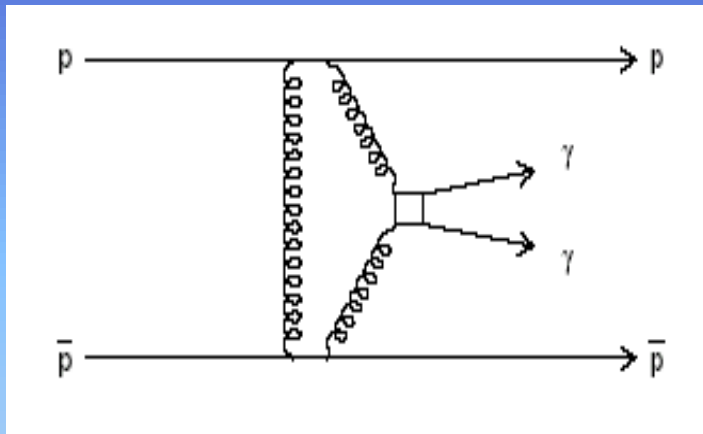
χ_c *PRL 242001 (2007)*



Exclusive $\gamma\gamma$ production



Phys.Rev.Lett. 99,242002 (2007)



$$E_T^\gamma > 5 \text{ GeV}$$
$$|\eta^\gamma| < 1.0$$

- 3 $\gamma\gamma / \pi^0\pi^0$ evts observed
 - 2 $\gamma\gamma$ candidates
 - 1 $\pi^0\pi^0$ candidate

V.A.Khoze et al. Eur. Phys. J C38, 475 (2005):

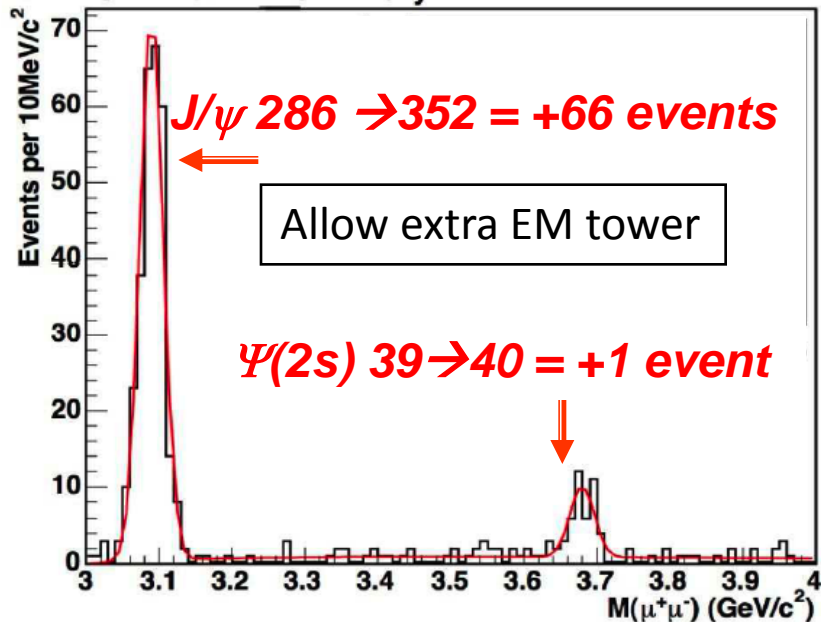
$$\sigma(\text{with CDF cuts}) = 56_{-24}^{+72} \text{ fb} \Rightarrow 0.8_{-0.5}^{+1.6} \text{ events}$$

- 2 events $\rightarrow \sigma \sim 90$ fb, in agreement with theory
- cannot claim discovery as bgd study was made *a posteriori*

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



PRL 242001 (2009)



- Allowing EM towers ($E_T > 80\text{MeV}$)
→ large increase in the J/ψ peak & minor change in the $\psi(2s)$ peak
- Evidence for:

$\chi_c \rightarrow J/\psi + \gamma$ production

$d\sigma/dy|_{y=0} = 75 \pm 14 \text{ nb}$,

compatible with theoretical predictions

- 160 nb (Yuan 01)
- 90 nb (KMR01)

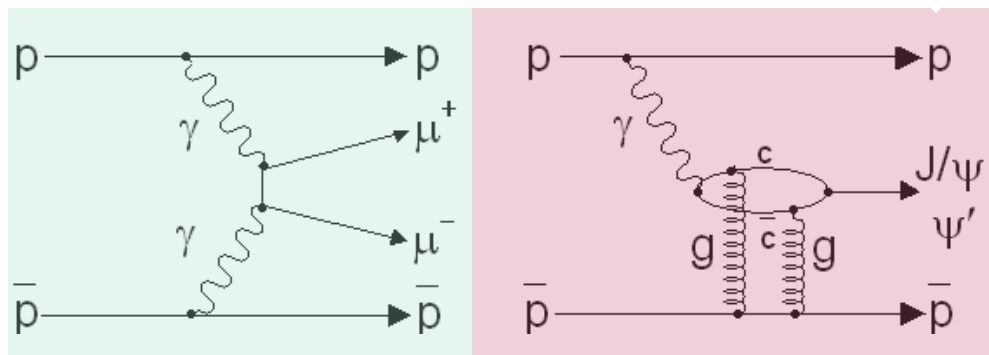
Exclusive Dimuon Production



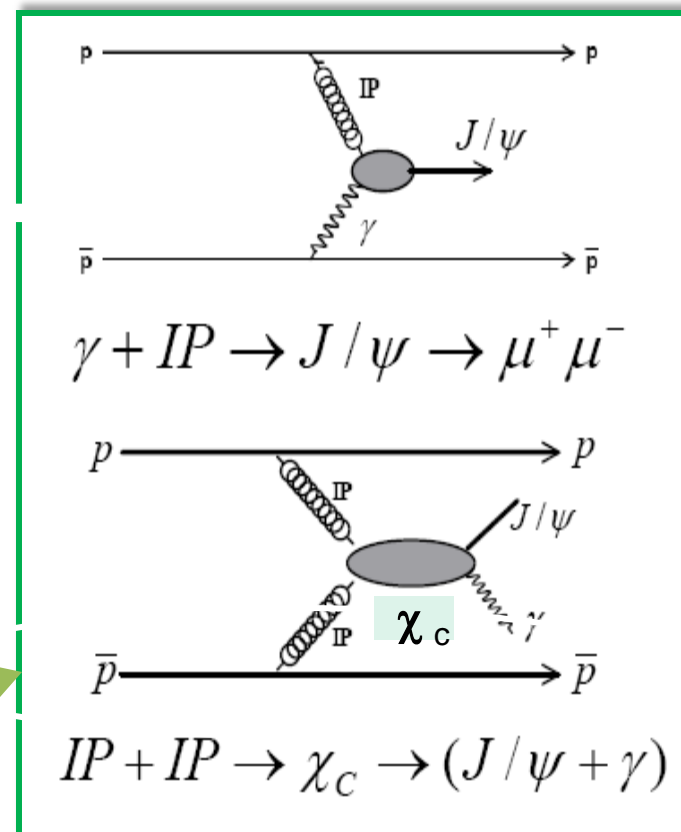
$$p + p \rightarrow p + \mu^+ \mu^- + p$$

$$3 \text{ GeV}/c^2 < M_{\mu\mu} < 4 \text{ GeV}/c^2$$

many physics processes in this data set:



exclusive χ_c in DPE



Exclusive J/ψ and $\psi(2s)$



J/ψ production

243 ± 21 events

$$d\sigma/dy|_{y=0} = 3.92 \pm 0.62 \text{ nb}$$

Theoretical Predictions

- 2.8 nb [Szczyrek07,],
- 2.7 nb [Klein&Nystrand04],
- 3.0 nb [Conclaves&Machado05], and
- 3.4 nb [Motkya&Watt08].

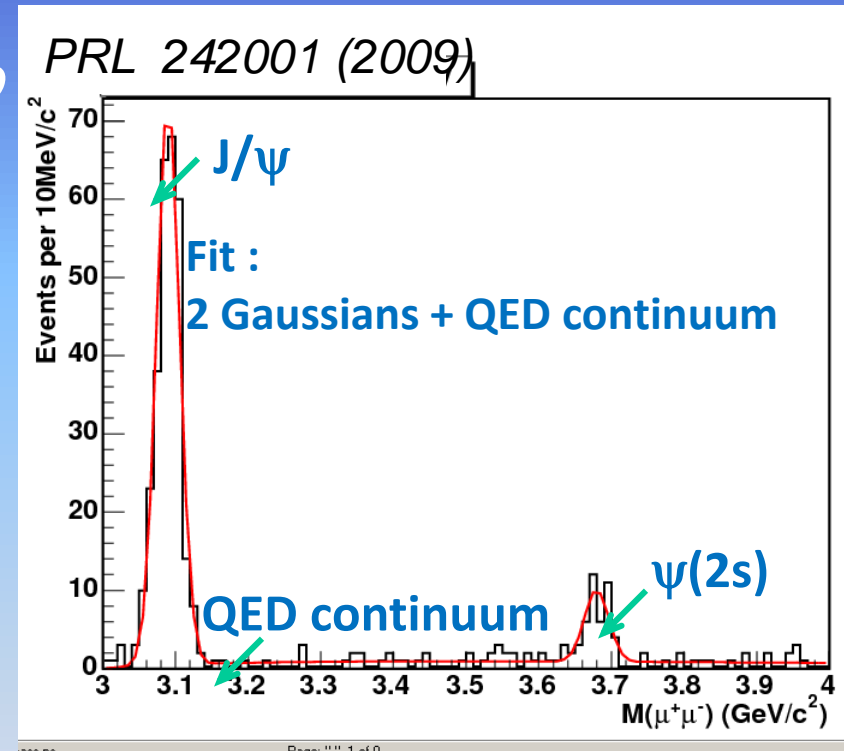
$\Psi(2s)$ production

34 ± 7 events

$$d\sigma/dy|_{y=0} = 0.54 \pm 0.15 \text{ nb}$$

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

In agreement with HERA: $R = 0.166 \pm 0.012$ in a similar kinematic region



Exclusive $\gamma\gamma$ production – *new!*

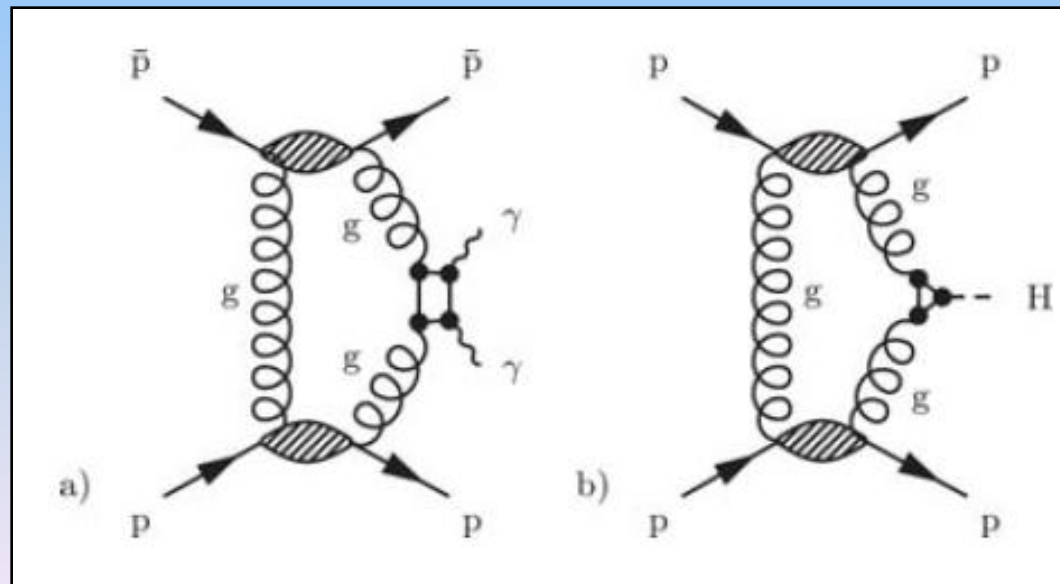


(Published in PRL: [arXiv:1112.0858](https://arxiv.org/abs/1112.0858))

Observation of exclusive $\gamma\gamma$ production in $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV

T. Aaltonen et al.

Accepted Friday Jan 06, 2012

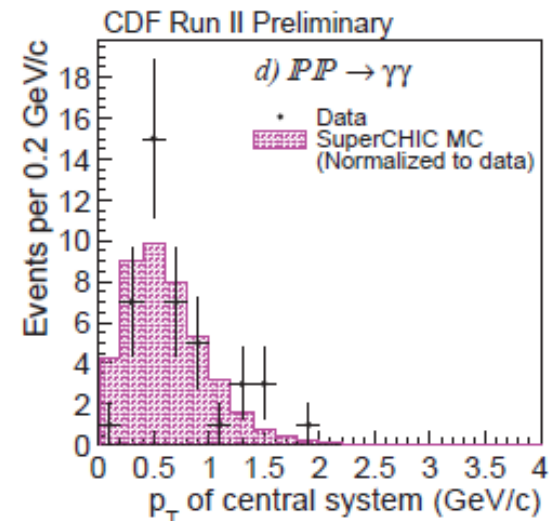
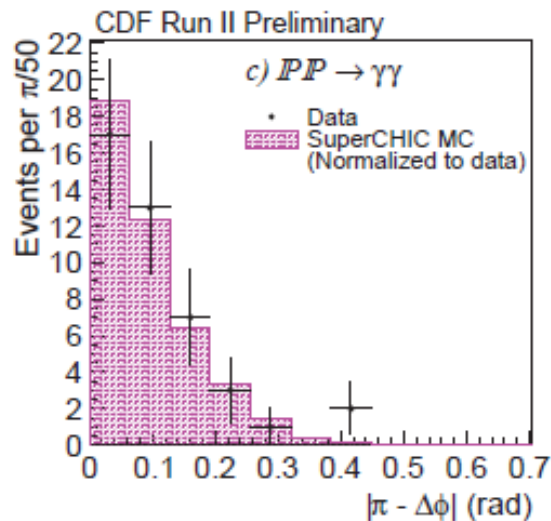
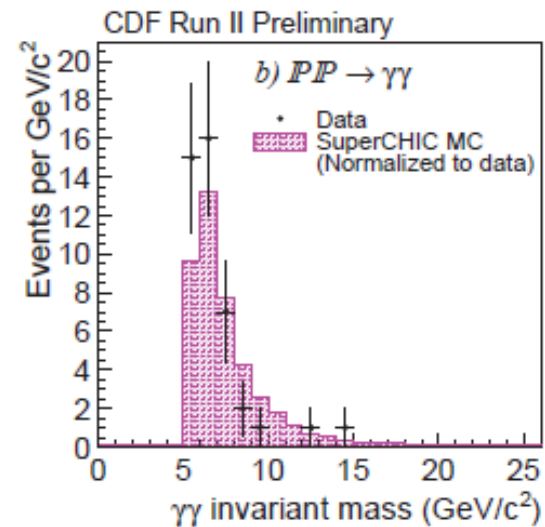
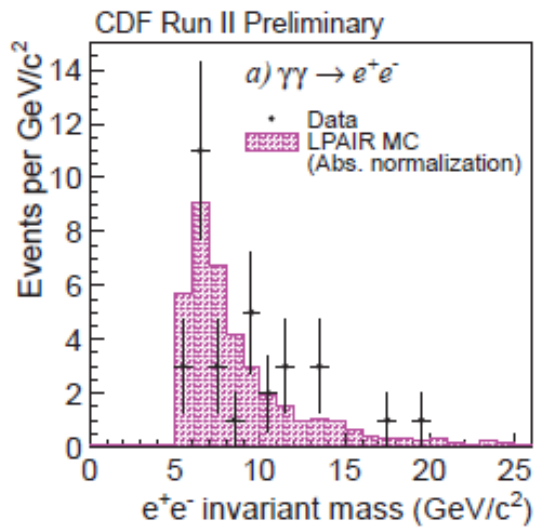


Exclusive $\gamma\gamma$ and e^+e^- events

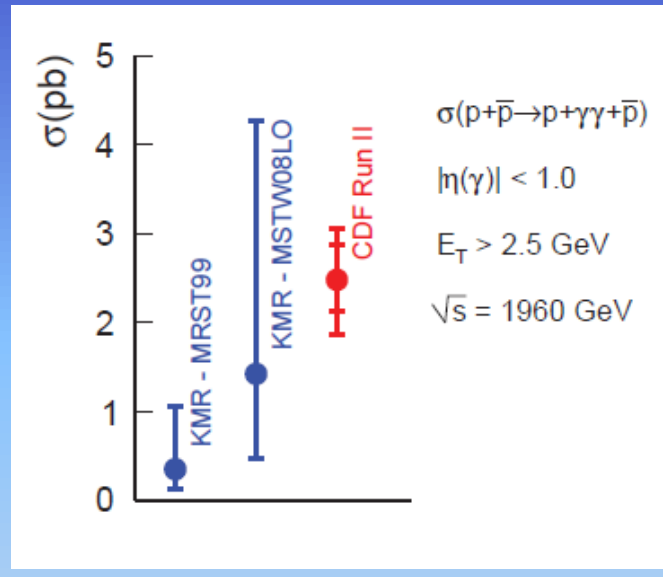
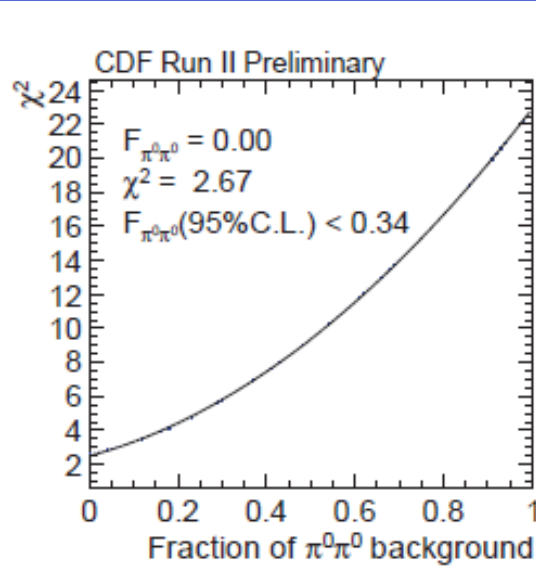
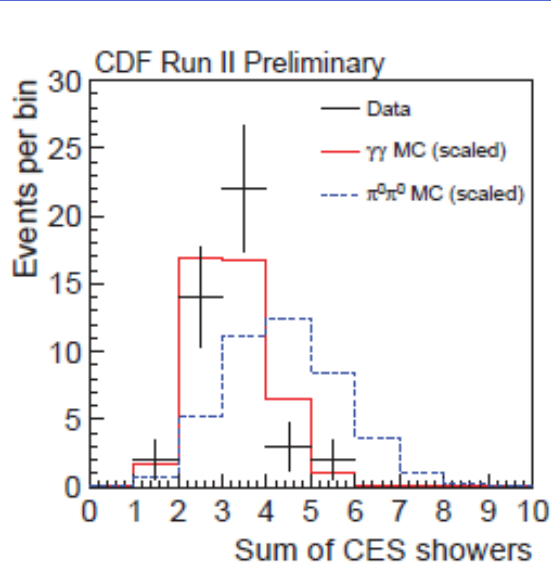


Integrated luminosity \mathcal{L}_{int}	$1.11 \pm 0.07 \text{ fb}^{-1}$
Exclusive efficiency	$0.068 \pm 0.004 \text{ (syst)}$
Exclusive $\gamma\gamma$	
Events	43
Photon pair efficiency	$0.40 \pm 0.02 \text{ (stat)} \pm 0.03 \text{ (syst)}$
Probability of no conversions	$0.57 \pm 0.06 \text{ (syst)}$
$\pi^0\pi^0$ b/g (events)	0.0, < 15 (95% C.L.)
Dissociation b/g (events)	$0.14 \pm 0.14 \text{ (syst)}$
Exclusive e^+e^-	
Events	34
Electron pair efficiency	$0.33 \pm 0.01 \text{ (stat)} \pm 0.02 \text{ (syst)}$
Probability of no radiation	$0.42 \pm 0.08 \text{ (syst)}$
Dissociation b/g (events)	$3.8 \pm 0.4 \text{ (stat)} \pm 0.9 \text{ (syst)}$

Exclusive $\gamma\gamma$ data vs. MC



Exclusive $\gamma\gamma$ cross section

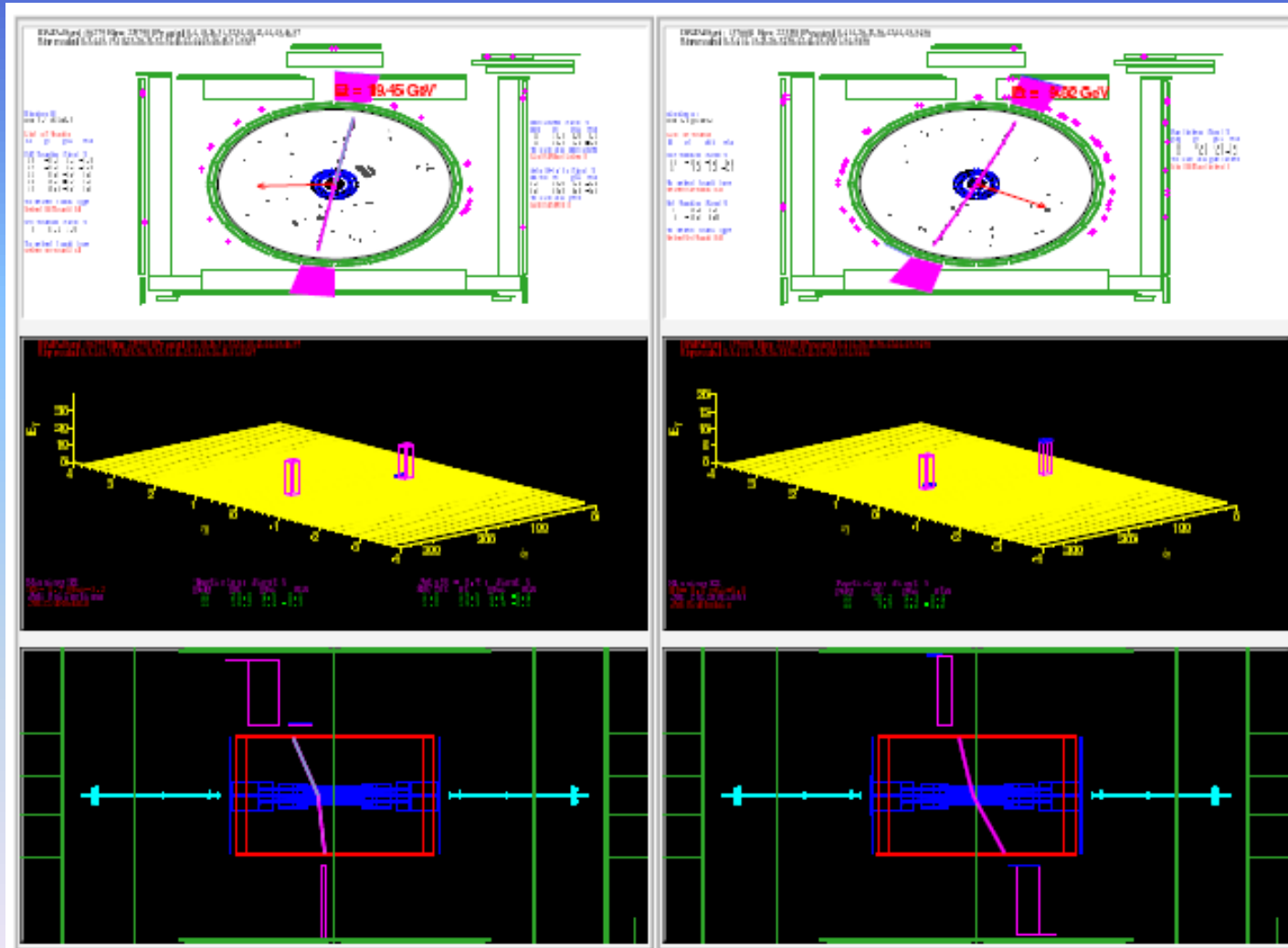


$$S_{\text{SuperCHIC}}^{|\eta| < 1, E_T > 5 \text{ GeV}} = 0.35_{\div 3}^{\times 3} \text{ pb (MRST99)}$$

$$S_{\text{SuperCHIC}}^{|\eta| < 1, E_T > 5 \text{ GeV}} = 1.42_{\div 3}^{\times 3} \text{ pb (MSTW08LO)}$$

$$S_{\gamma\gamma \text{ excl}}^{|\eta| < 1, E_T > 5 \text{ GeV}} = 2.48_{\div 3}^{\times 3} \pm 0.42(\text{stat}) \pm 0.41(\text{syst}) \text{ pb}$$

Exclusive $\gamma\gamma$ event candidate



Summary

- Introduction
 - Diffractive Dijets
 - Exclusive Production
 - **Summary**
 - CDF4LHC
- 

- ❑ **Dijets.** The hard scattering is controlled by the PDF of the antiproton, while the rapidity gap is governed by a color-neutral soft exchange, traditionally referred to as **pomeron exchange**
 - The diffractive t-distribution shapes are independent of $\langle Q^2 \rangle$ over 4 orders of magnitude!
- ❑ **Exclusive production.** Exclusive $\gamma\gamma$ production “seals the deal” on exclusive Higgs predictions – if there is a Higgs!

CDF4LHC

- Introduction
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- **CDF4LHC**

CDF @ 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)

*Thank you for your
attention*