DIFFRACTIVE AND EXCLUSIVE PRODUCTION AT CDF

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(for the CDF II Collaboration)


HEP@Rockefeller

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- **Diffractive Dijets**
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- **Summary**
- **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 ➔ gaps exponentially suppressed

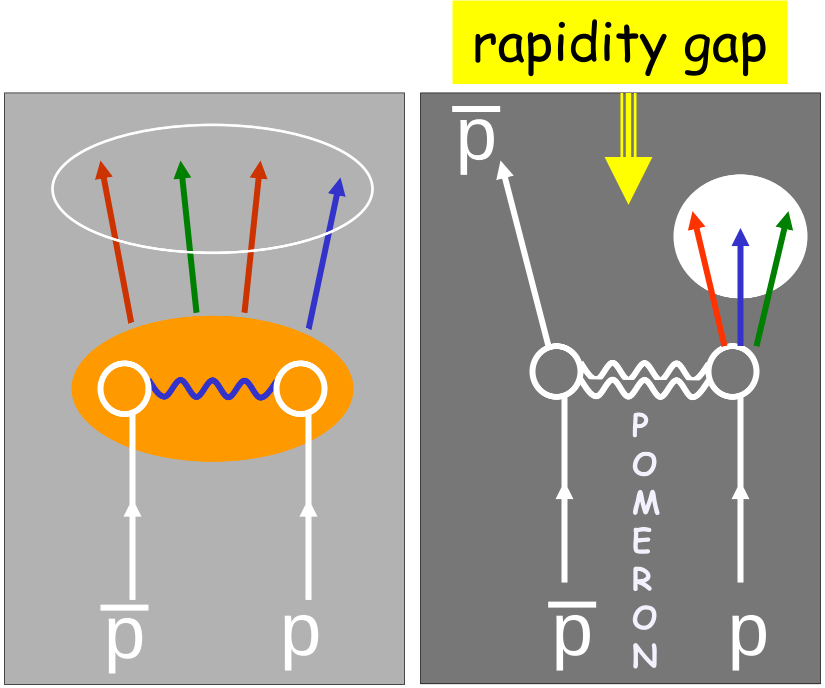
Diffractive

❖ Colorless vacuum exchange

➔ large-gap signature

Incident hadrons acquire color and break upart

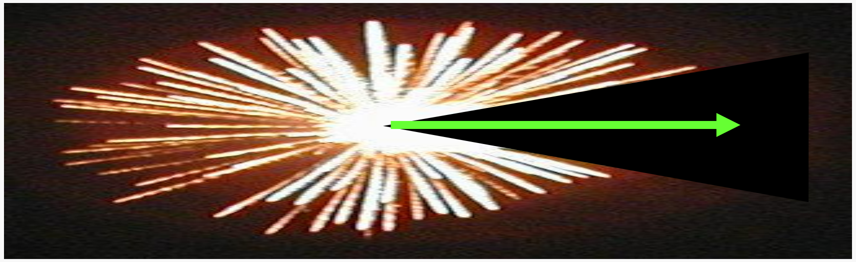
CONFINEMENT



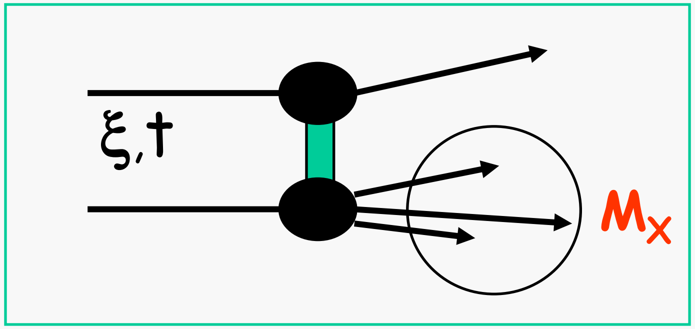
Incident hadrons retain their quantum numbers remaining colorless

Goal: probe the QCD nature of the diffractive exchange

DEFINITIONS

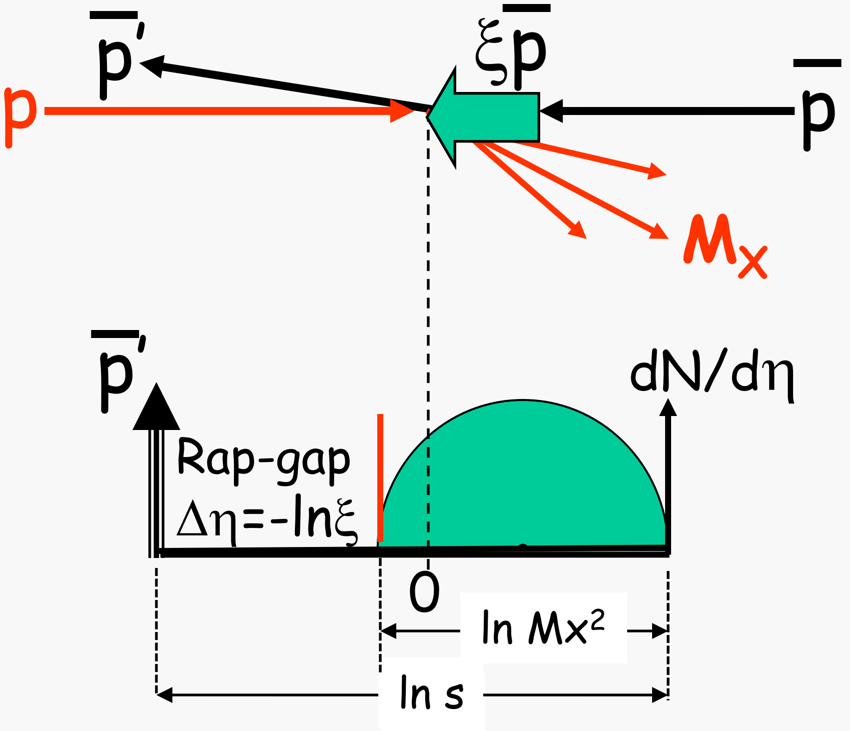


SINGLE DIFFRACTION



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

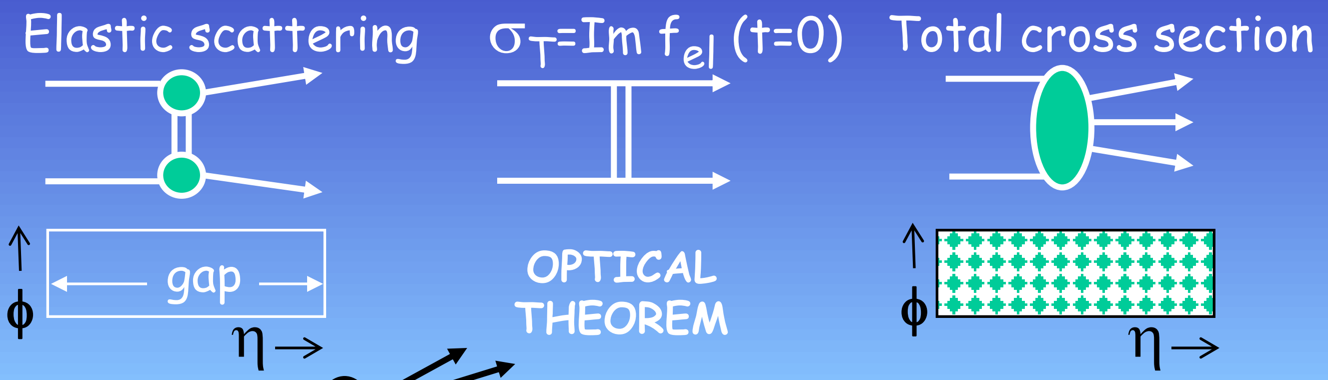
$$\xi^{CAL} = \frac{\sum_{i=1}^{all} E_T^{i\text{-tower}} e^{-\eta_i}}{\sqrt{s}}$$



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

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

DIFFRACTION AT CDF

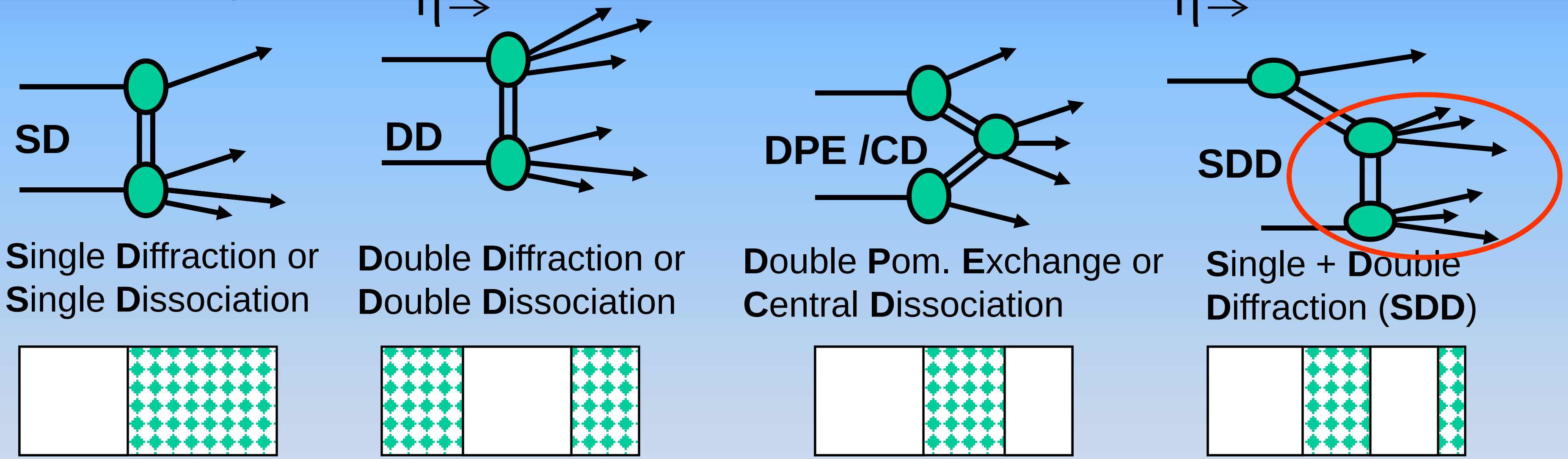


Elastic scattering

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

Total cross section

OPTICAL THEOREM



SD

Single **D**iffraction or
Single **D**issociation

DD

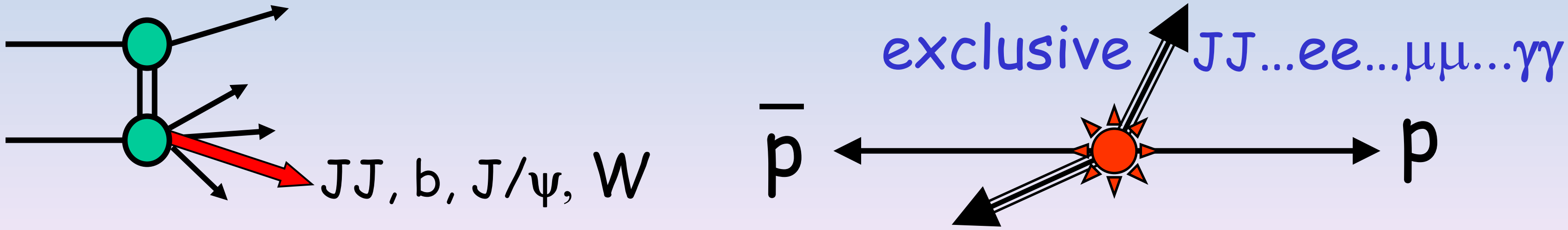
Double **D**iffraction or
Double **D**issociation

DPE /CD

Double **P**om. **E**xchange or
Central **D**issociation

SDD

Single + **D**ouble
Diffraction (**SDD**)



JJ, b, J/ψ, W

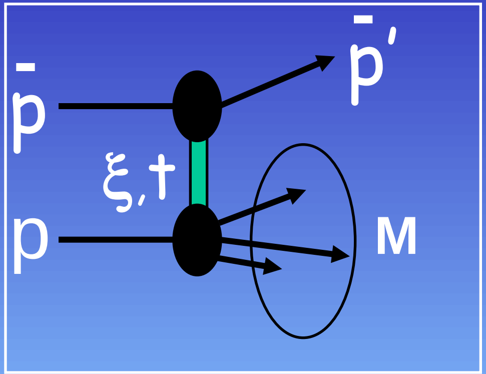
exclusive JJ…ee…μμ…γγ

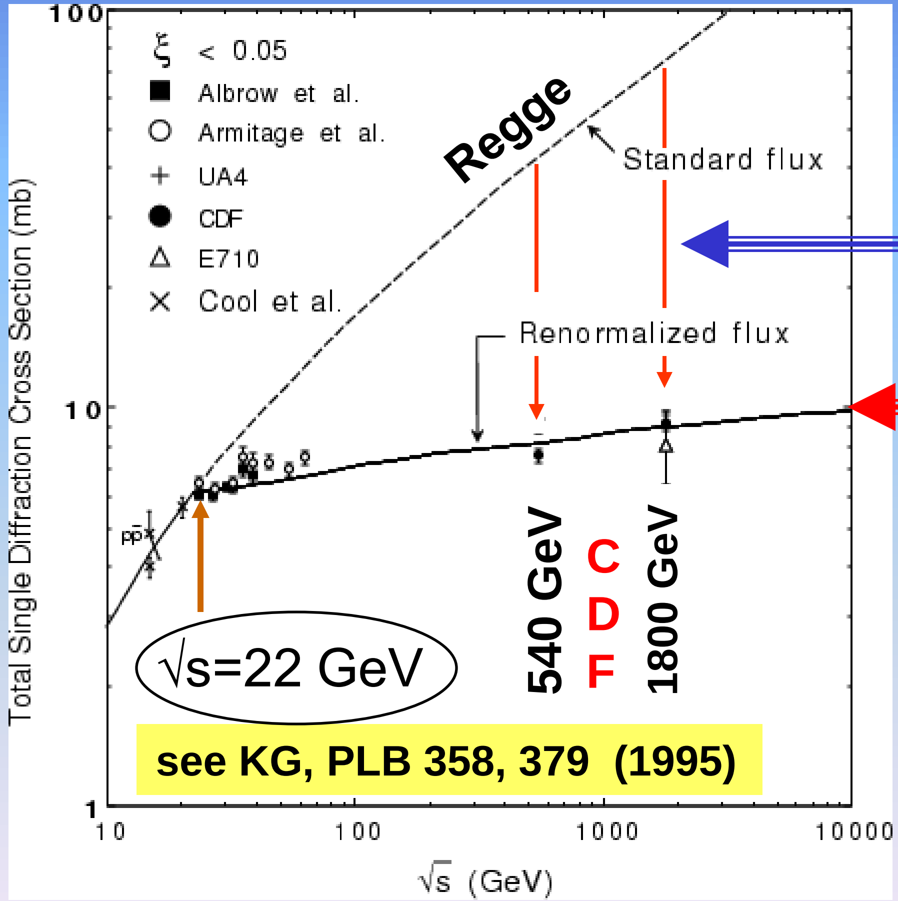
$\bar{p}$

p

FACTORIZATION BREAKING IN SOFT DIFFRACTION

➔diffractive x-section suppressed relative to Regge prediction as √s increases





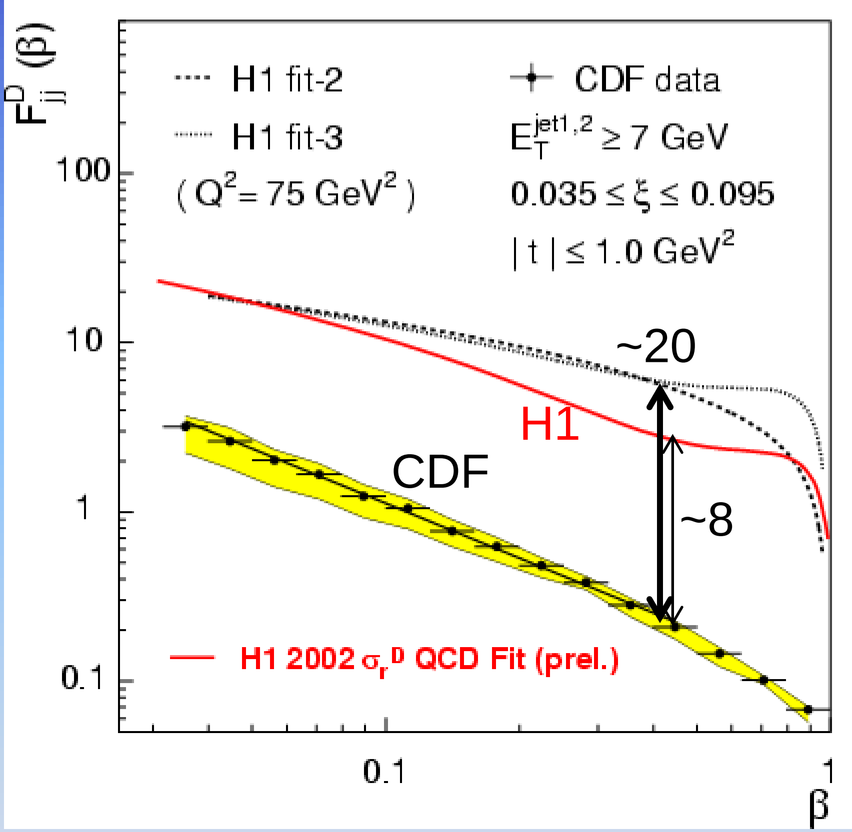
see KG, PLB 358, 379 (1995)

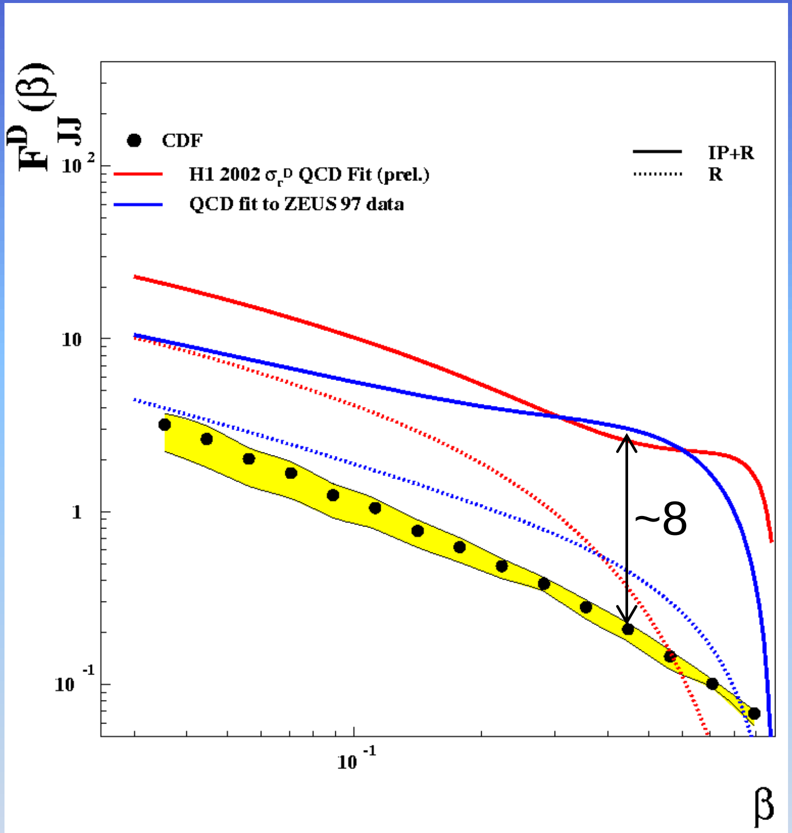
Factor of ~8 (~5) suppression at √s = 1800 (540) GeV

RENORMALIZATION

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

Diffractive Dijets in Run I

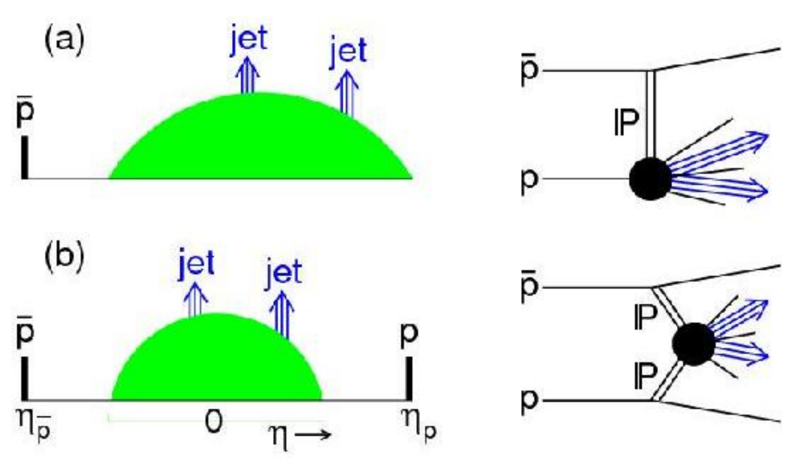


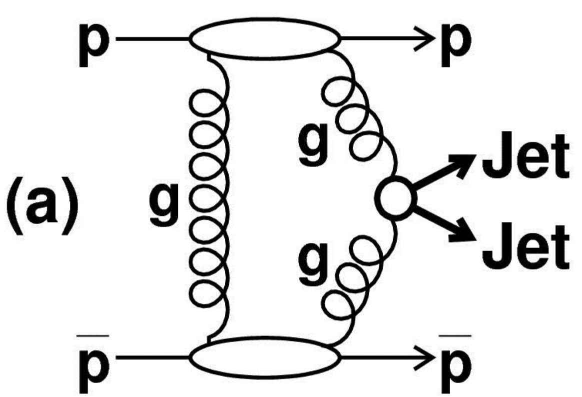


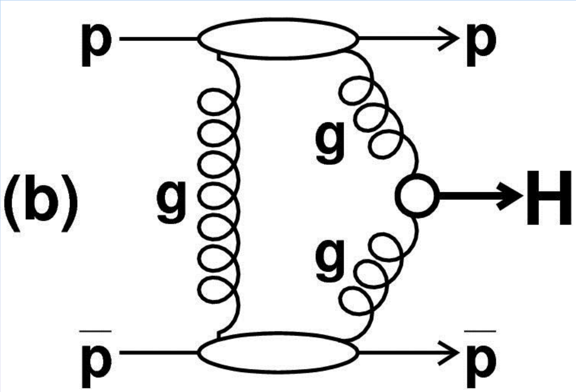
- ❑ All hard-diffraction processes studied at CDF are suppressed by a factor of ~8 relative to predictions based on HERA-measured PDFs.

EXTRA MOTIVATION:

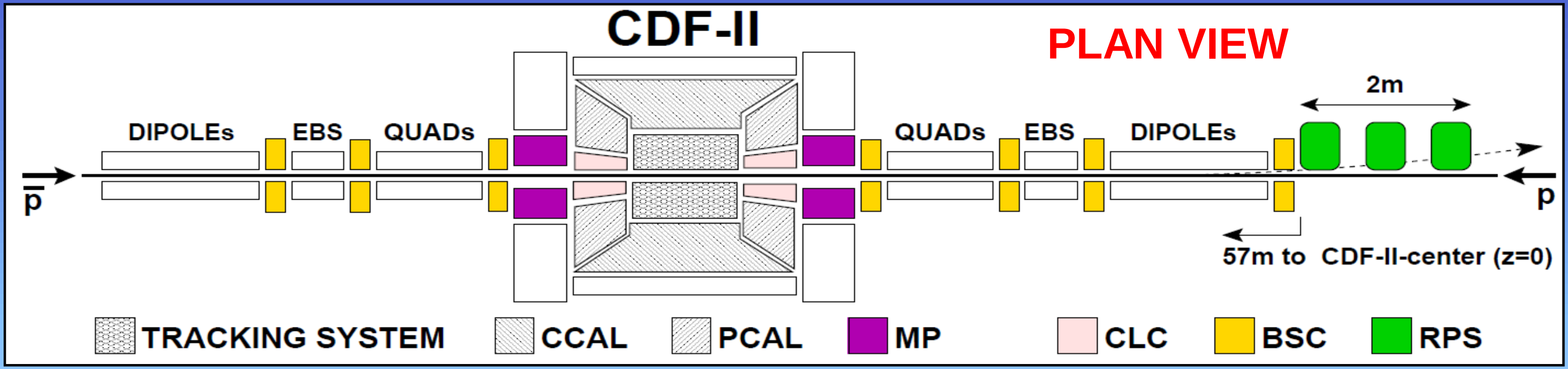
calibrate diffractive Higgs production models





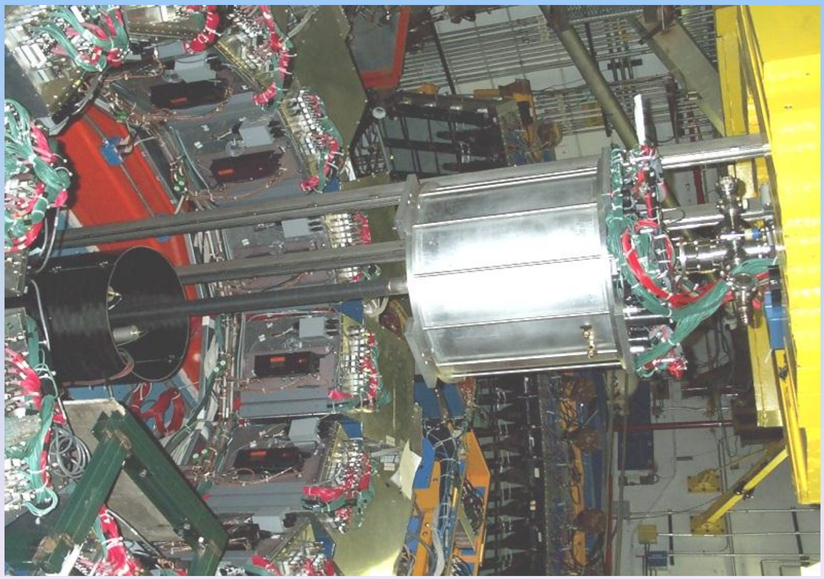


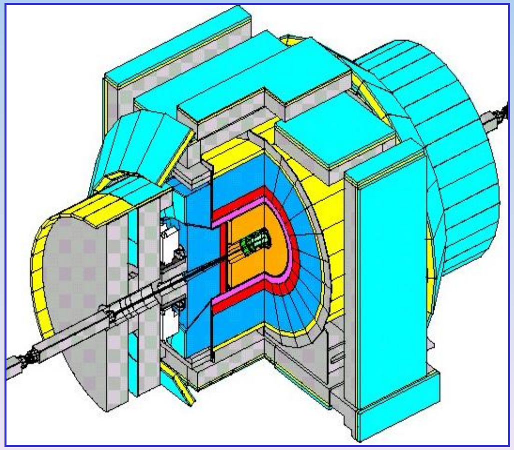
The CDF II Detector



$|\eta|<2$ ← $|\eta|<3.6$ → $3.5<|\eta|<5.1$ $5.4<|\eta|<7.4$

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





Diffractive Dijets

http://arxiv.org/abs/1206.3955

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Measurement of F_{jj}^{SD}

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

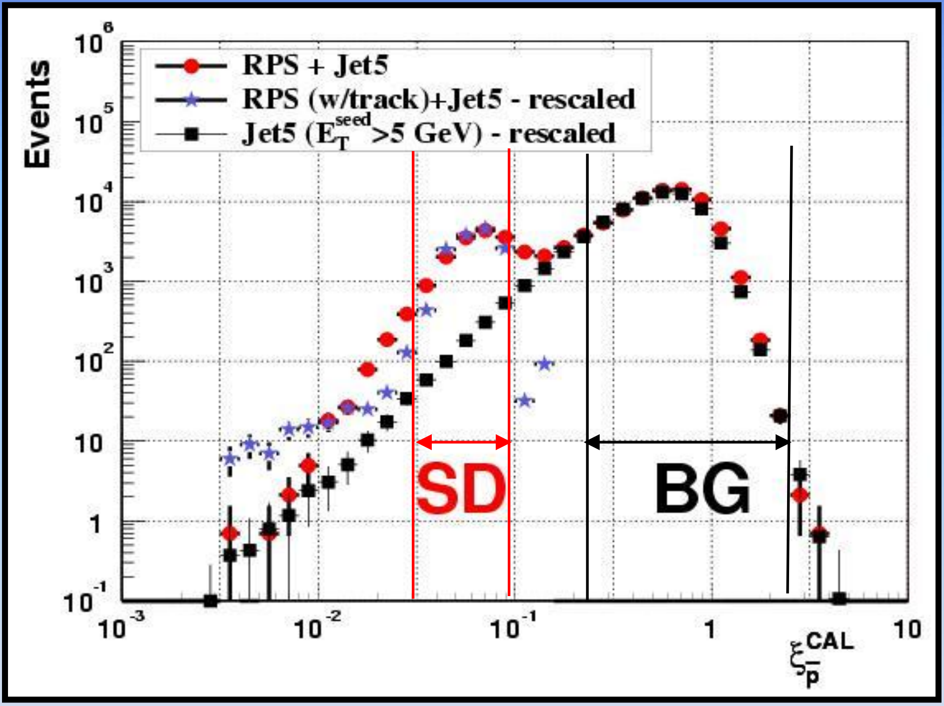
$$F_{jj}^{\mathrm{incl}}(x, Q^2) = x\left[g(x, Q^2) + \frac{4}{9}\sum_i q_i(x, Q^2)\right]$$

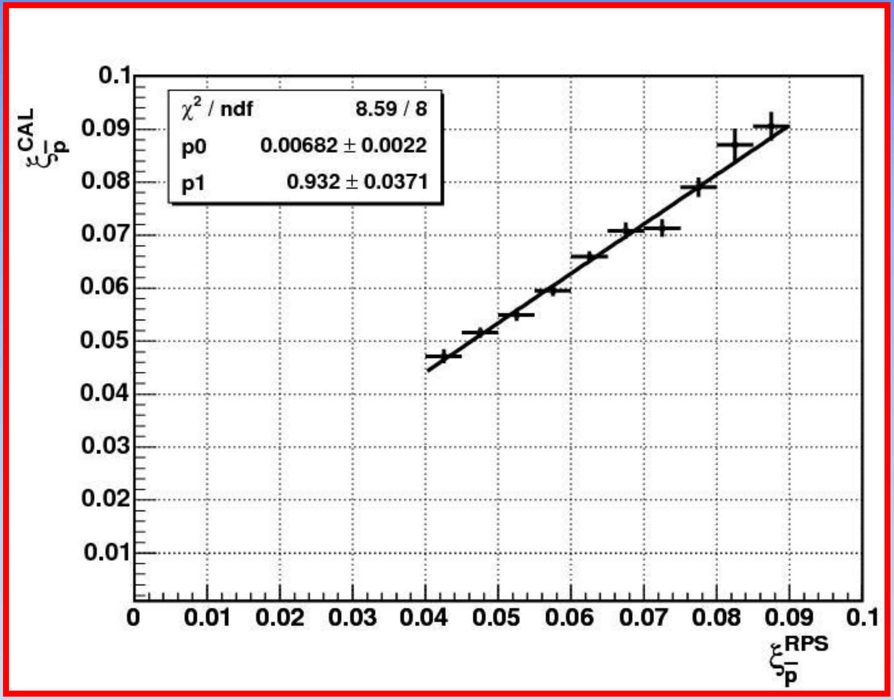
$$\mathrm{R}_{\mathrm{SD/ND}}(x, Q^2, \xi, t) = \frac{n_{jj}^{\mathrm{SD}}(x, Q^2, \xi, t)}{n_{jj}^{ND}(x, Q^2)} \approx \frac{F_{jj}^{\mathrm{SD}}(x, Q^2, \xi, t)}{F_{jj}^{\mathrm{ND}}(x, Q^2)}$$

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

ξ^{CAL} vs ξ^{RPS}

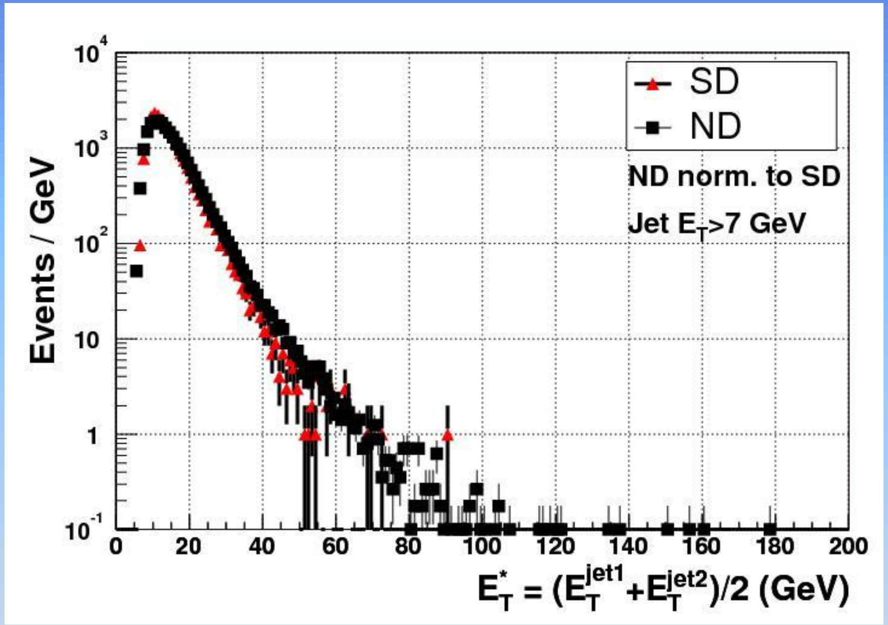
- ☐ As RPS tracking was not available for all analyzed data, we used ξ^{CAL} and calibrated it vs ξ^{RPS} from data in which RPS tracking **was** available.

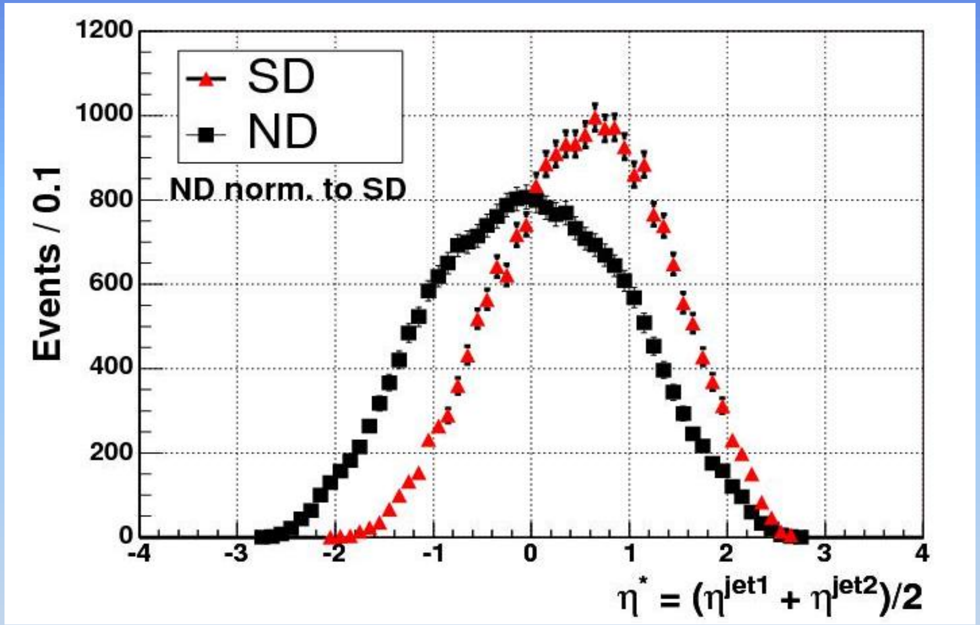




- ☐ A linear relationship is observed between ξ^{CAL} vs ξ^{RPS} in the region of ξ^{CAL} of the measurement

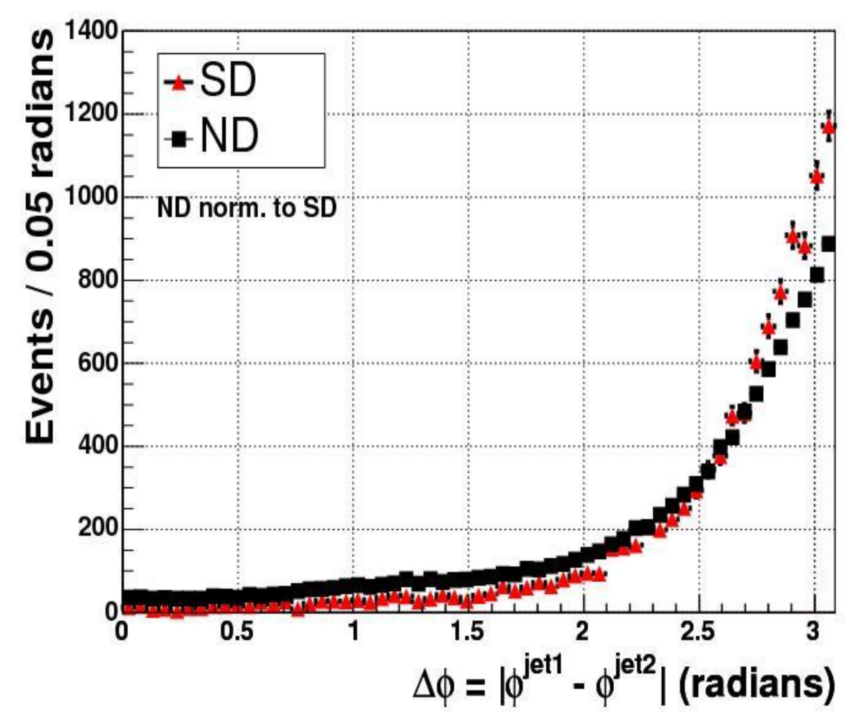
Average E_T^{jet} and η^{Jet}

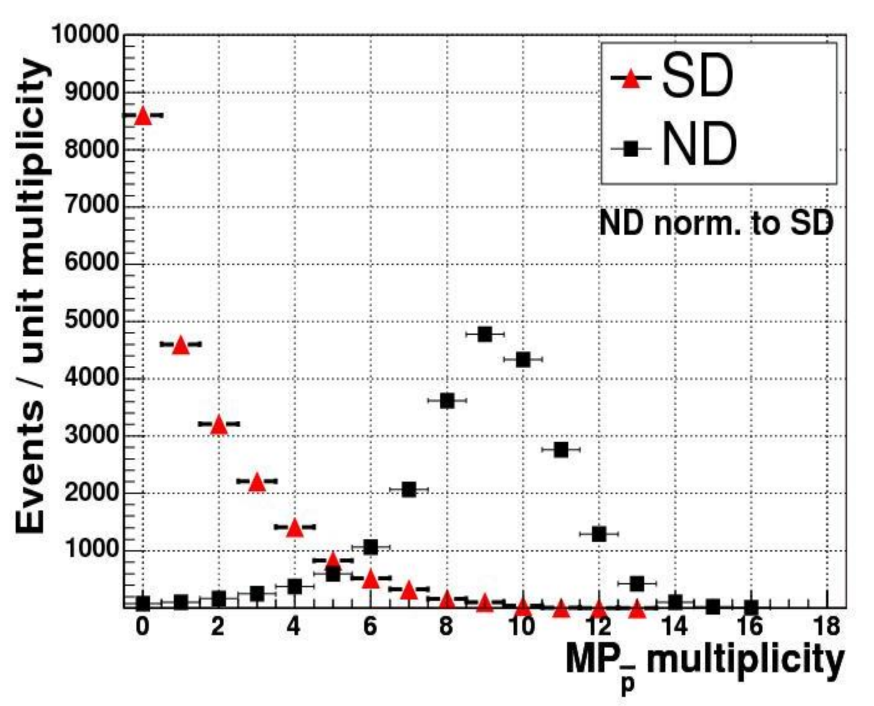




- The SD and ND E_T^{Jet} distributions are nearly identical
- The SD η^* distribution is shifted towards the c.m.s of the Pomeron-proton collision

Azimuthal angle difference of jets

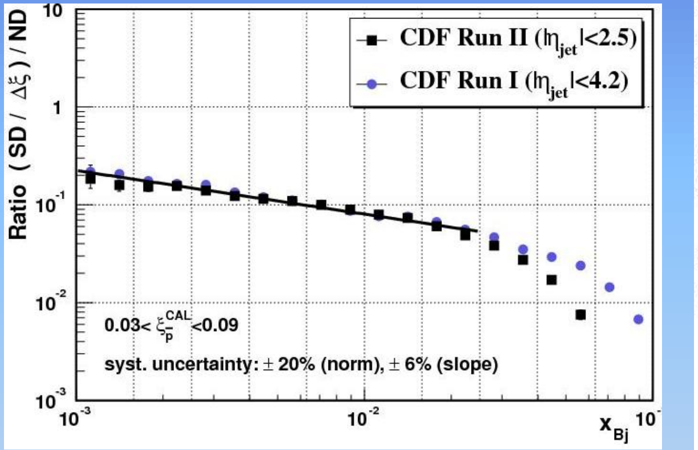




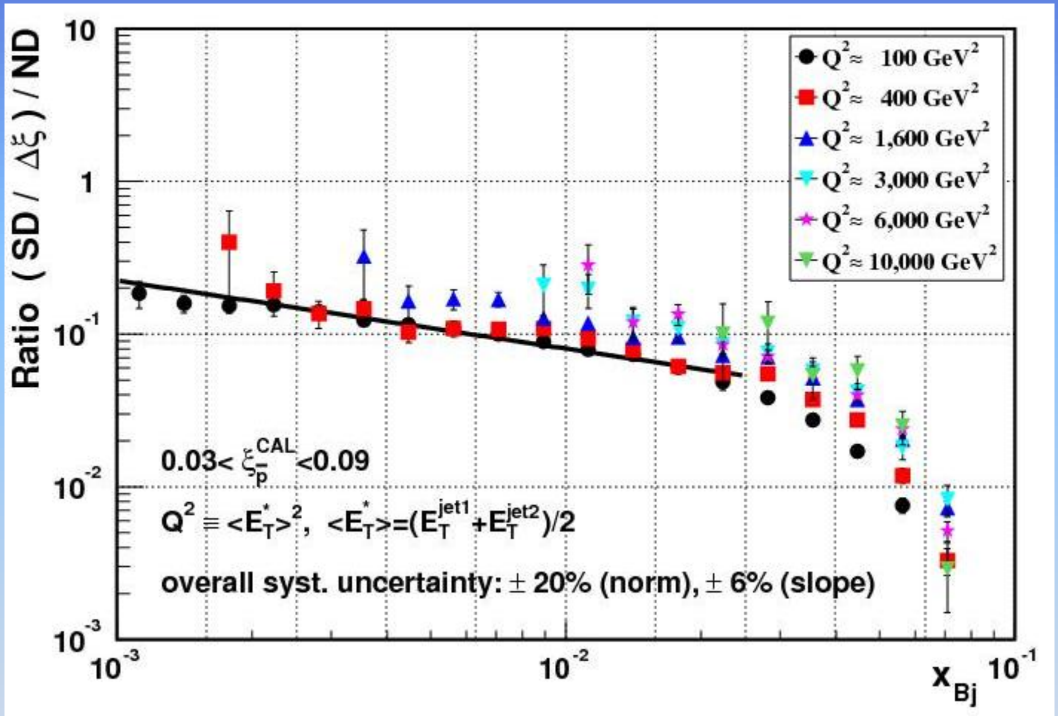
- ❑ *Left:* the SD distributions are more back-to-back
- ❑ *Right:* the SD multiplicity is peaked at zero, while the ND is peaked at 9.

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

$<Q^2>=100\ \text{GeV}^2$



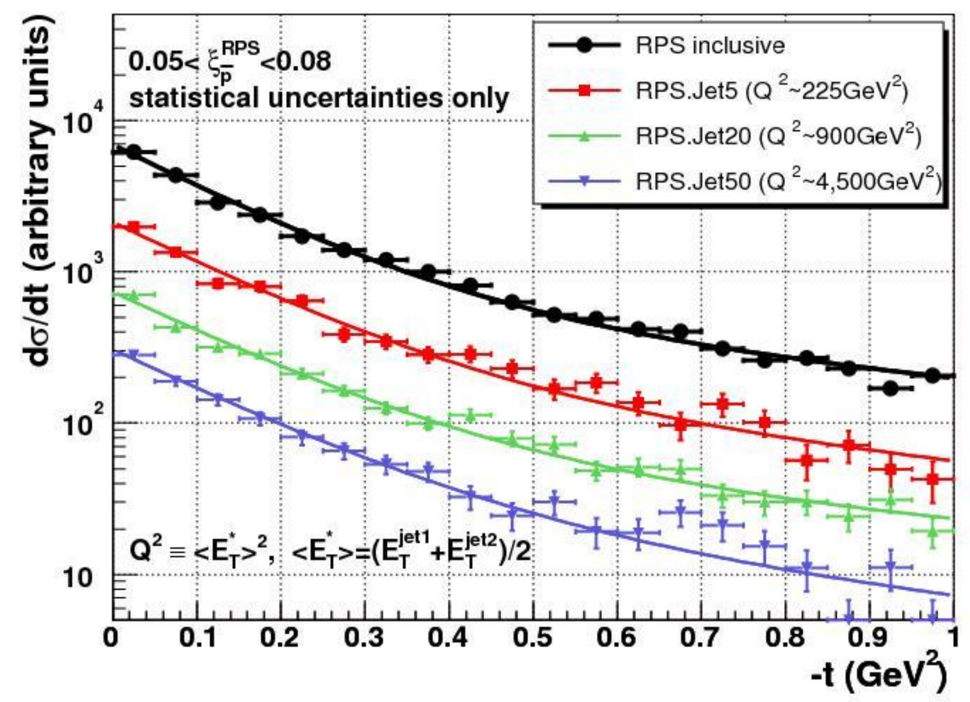
- ❑ The Run I result is confirmed.
- ➢ The drop-off on the rhs is due to the different range of the calorimeters in Run I and Run II.

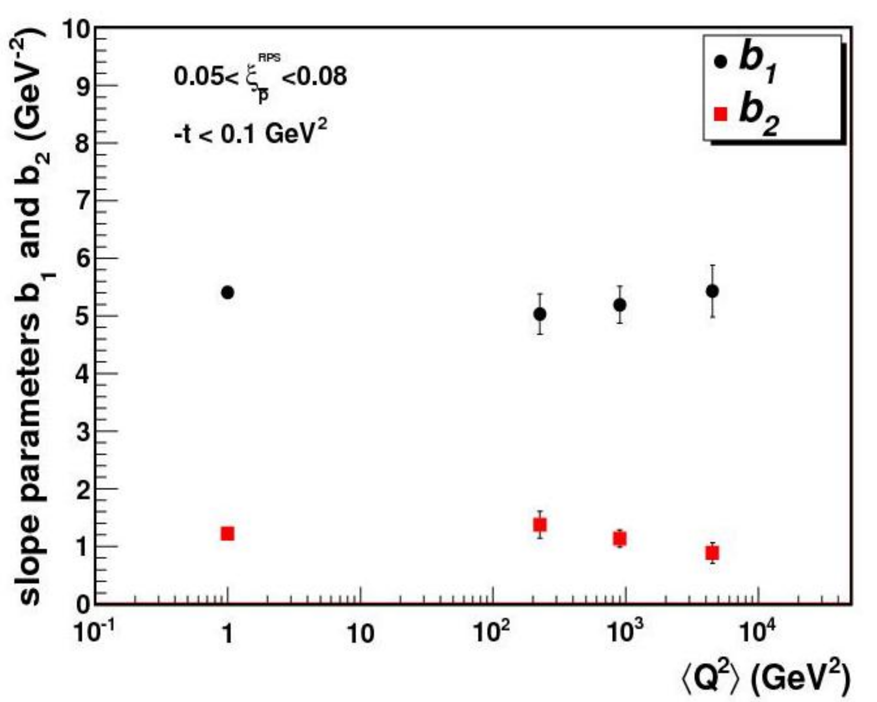


- ❑ The Bjorken-x distributions vary by only a factor of ~2 over a range of $<Q^2>$ of 2 orders of magnitude!

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

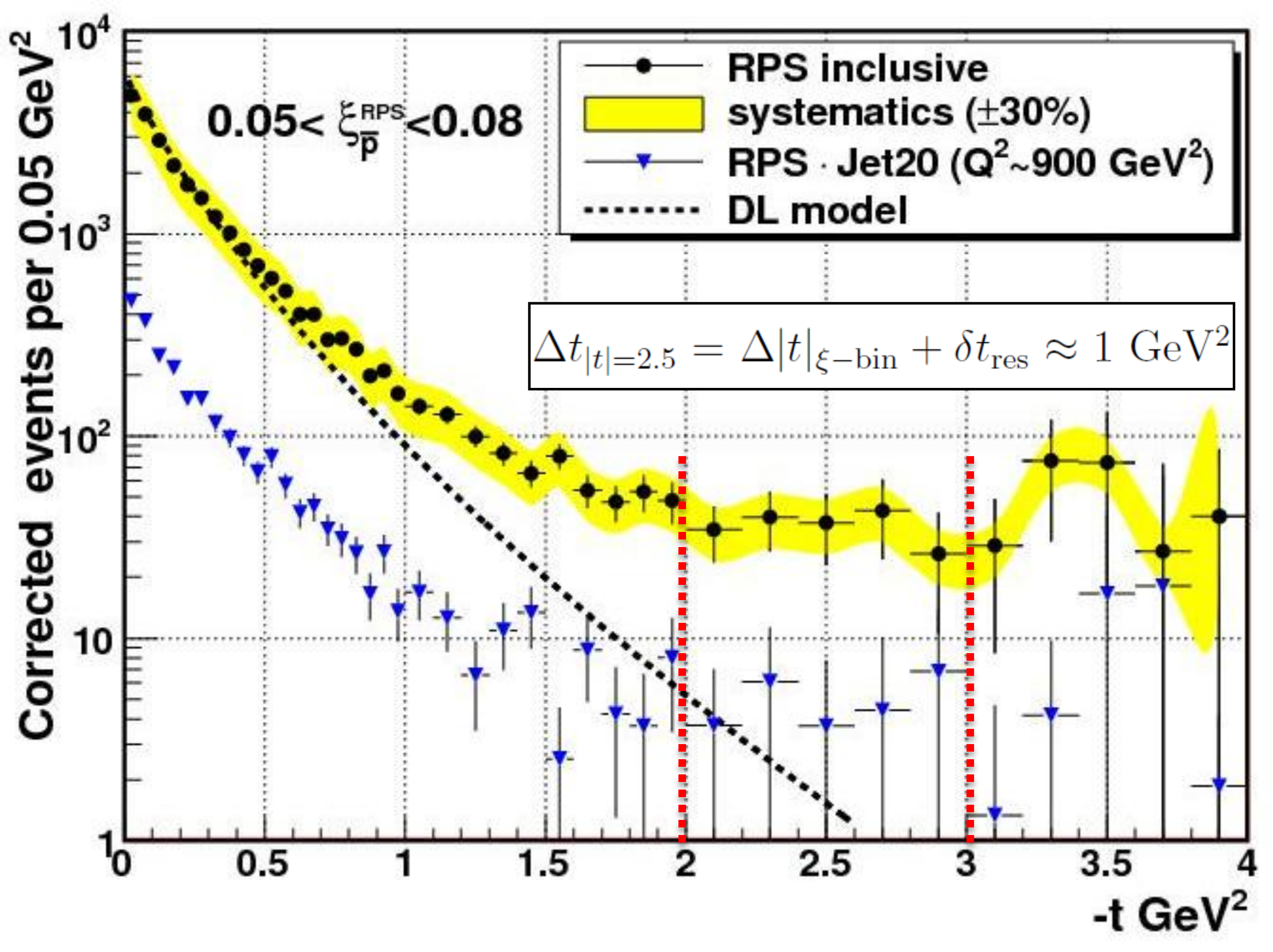
$$\frac{d\sigma}{dt} = N_{norm}\left(A_1 e^{b_1 t} + A_2 e^{b_2 t}\right)$$





- ☐ The slopes are nearly constant over a range of 4 orders of magnitude in <Q^2> !

t-Distributions for -*t*<4 GeV^2

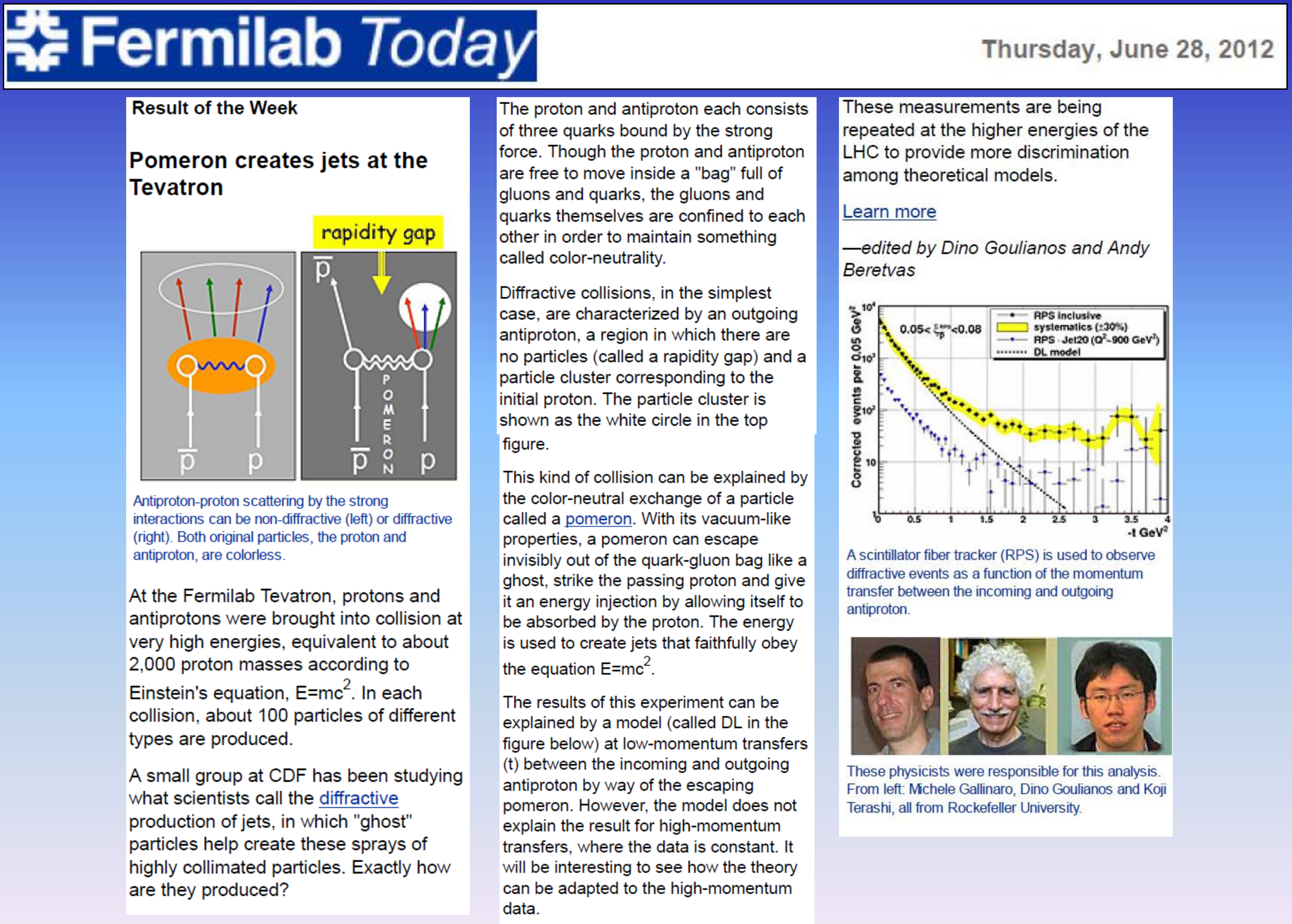


- The rather flat –t distributions at large –t are copatible with the existence of an underlying diffraction minimum around –t ~ 2.5 GeV^2.

Dijet Rsults Summary

- **We measured SD to ND ratios in dijet production vs Bjorken-x for 10^{4} in $<Q^2>$ (or jet E_T) $–t>4$ GeV^2**
- **We find:**
  - ✓ **nearly identical E_T^{jet} distributions for SD and ND events**
  - ✓ **small $<Q^2>$ dependence as a function of Bjorken-x**
  - ✓ **no $<Q^2>$ dependence of the b-slopes at low t**
  - ✓ **t distributions compatible with DL at low t**
  - ✓ **at high t the distributions lie increasingly higher than DL, becoming approximately flat for $–t >2$ GeV^2**

  ➔compatible with a diffraction minimum at $–t >2.5$ GeV^2
- **Our findings are compatible with models of diffraction in which the hard scattering is controlled by the PDF of the recoil antiproton, while the rapidity gap formation is governed by the color-neutral soft exchange.**



Fermilab Today

Thursday, June 28, 2012

Result of the Week

Pomeron creates jets at the Tevatron

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

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

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

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

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

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

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

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

Learn more

—edited by Dino Goulianos and Andy Beretvas

A scintillator fiber tracker (RPS) is used to observe diffractive events as a function of the momentum transfer between the incoming and outgoing antiproton.

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

Exclusive Production

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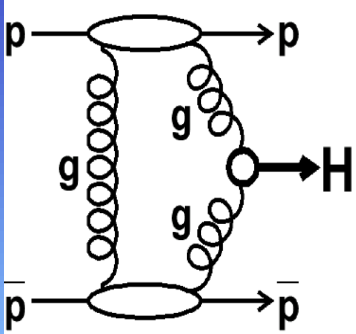
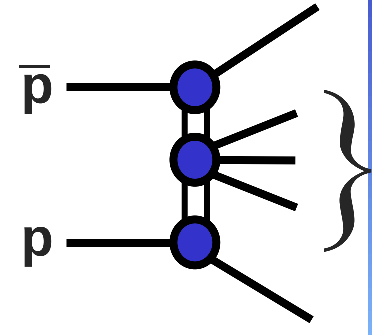
EXCLUSIVE Dijet→ Excl. Higgs *THEORY CALIBRATION*

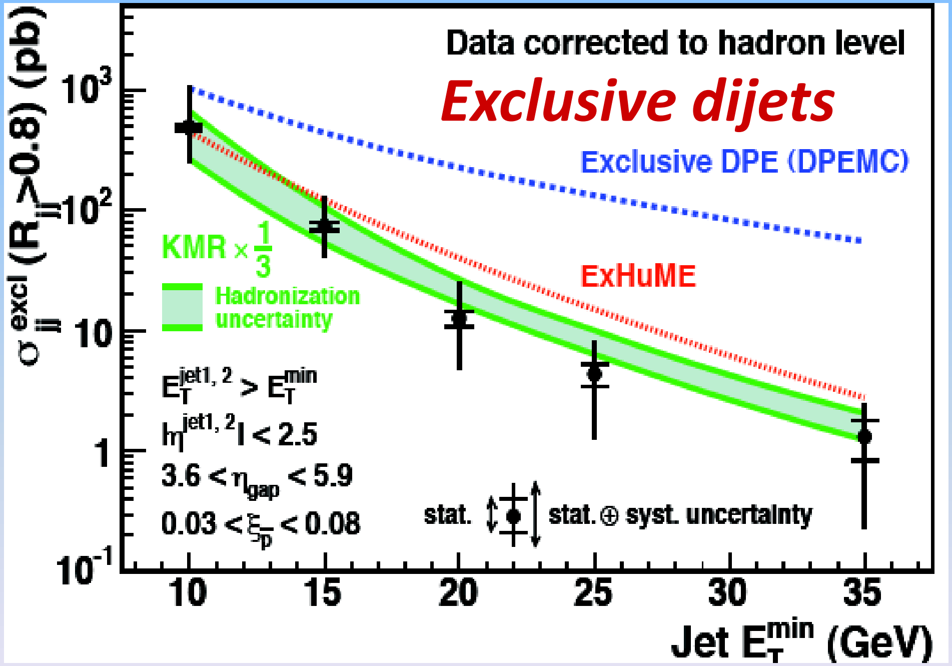


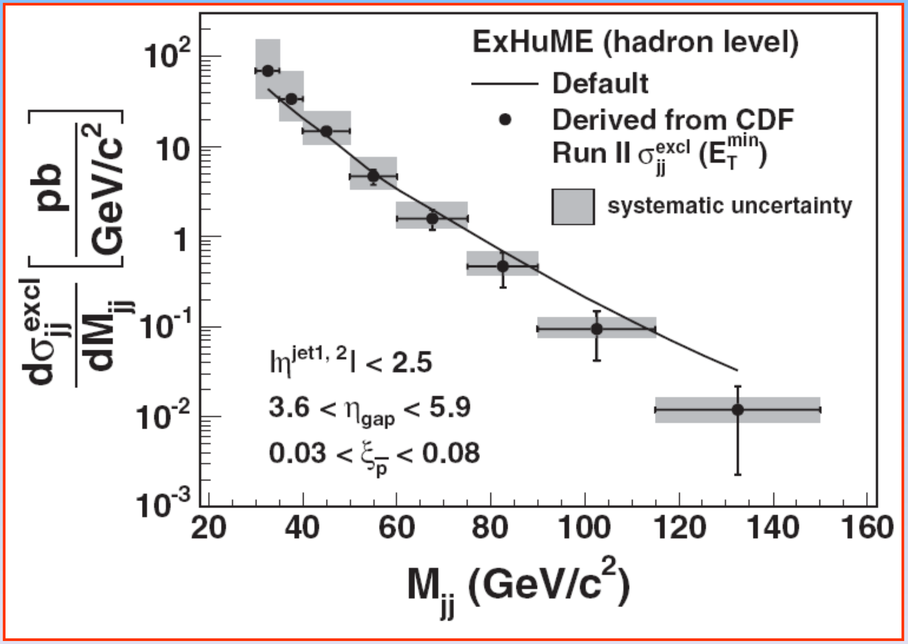


JJ *PRD 77, 052004 (2008)*

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

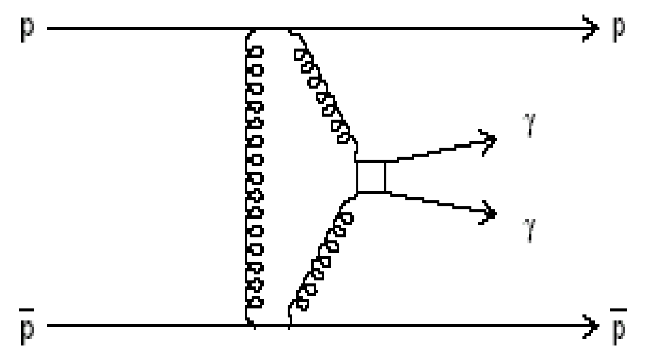
χ_c *PRL 242001 (2007)*





Exclusive $\gamma\gamma$ production

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



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

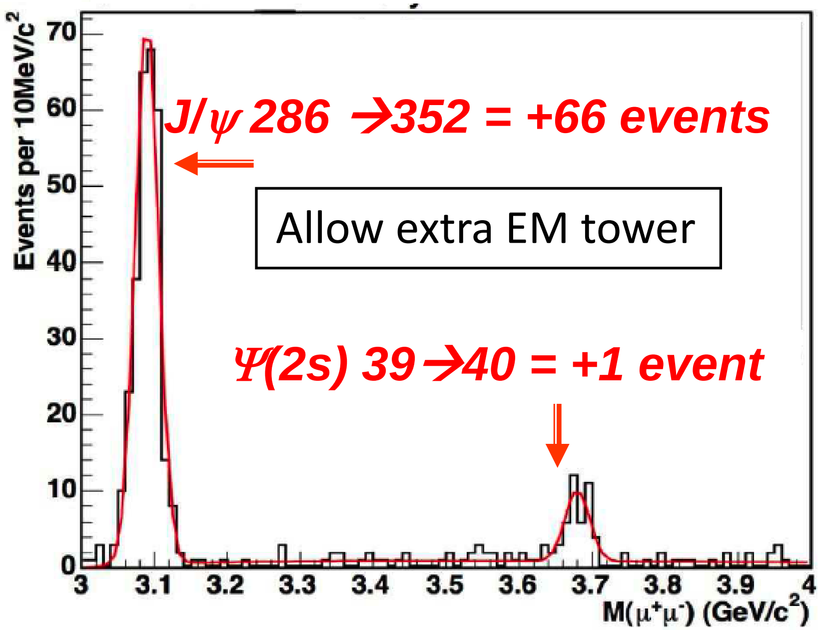
- 3 $\gamma\gamma$ / $\pi^o\pi^o$ evts observed
  - 2 $\gamma\gamma$ candidates
  - 1 $\pi^0\pi^0$ candidate

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

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

- 2 events ➔ $\sigma \sim 90$ 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)

J/ψ 286 →352 = +66 events

Allow extra EM tower

Ψ(2s) 39→40 = +1 event

- ☐ Allowing EM towers (E_T >80MeV)

  →large increase in the J/ψ peak & minor change in the ψ(2s) peak

➔ Evidence for:

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

$d\sigma/dy|_{y=0}$ = 75 ± 14 nb,

compatible with theoretical predictions

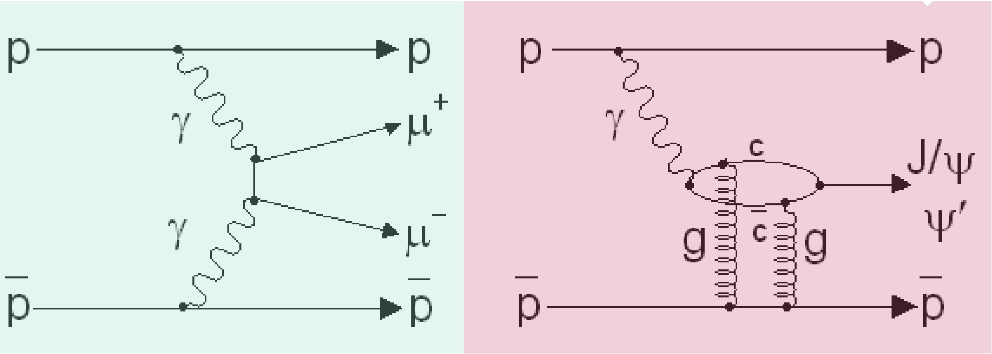
- 160 nb (Yuan 01)
- 90 nb (KMR01)

Exclusive Dimuon Production

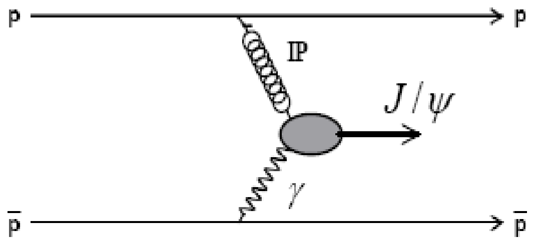
$$\mathbf{p + p \rightarrow p + \mu^{+}\mu^{-} + p}$$

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

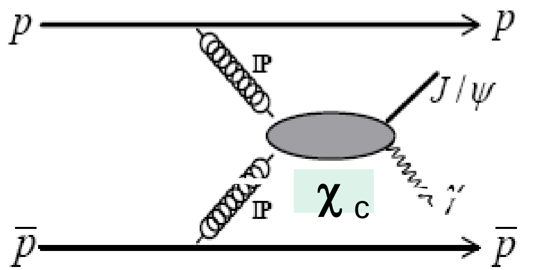
☐ many physics processes in this data set:



exclusive χ_c in DPE



$$\gamma + IP \rightarrow J/\psi \rightarrow \mu^{+}\mu^{-}$$



$$IP + IP \rightarrow \chi_C \rightarrow (J/\psi + \gamma)$$

Exclusive J/ψ and ψ(2s)

J/ψ production

243 ±21 events

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

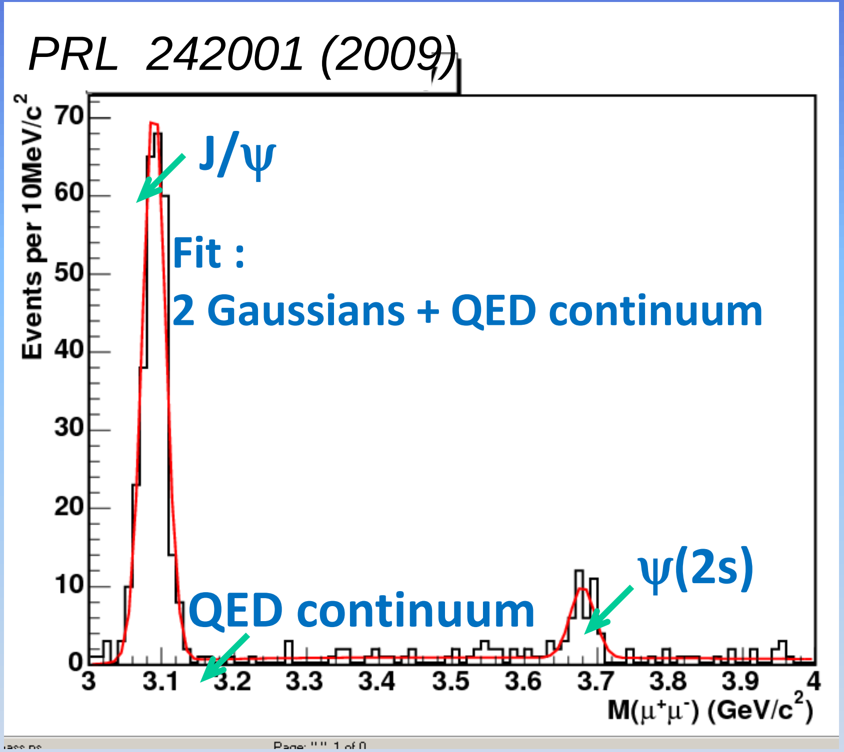
Theoretical Predictions

2.8 nb [Szczurek07,],

2.7 nb [Klein&Nystrand04],

3.0 nb [Conclaves&Machado05], and

3.4 nb [Motkya&Watt08].


PRL 242001 (2009)

J/ψ

Fit :

2 Gaussians + QED continuum

QED continuum

ψ(2s)

Ψ(2s) production

34±7 events

$d\sigma/dy|_{y=0}$ = 0.54 ± 0.15 nb

R = ψ(2s)/J/ψ = 0.14 ± 0.05

In agreement with HERA: R = 0.166 ± 0.012 in a similar kinematic region

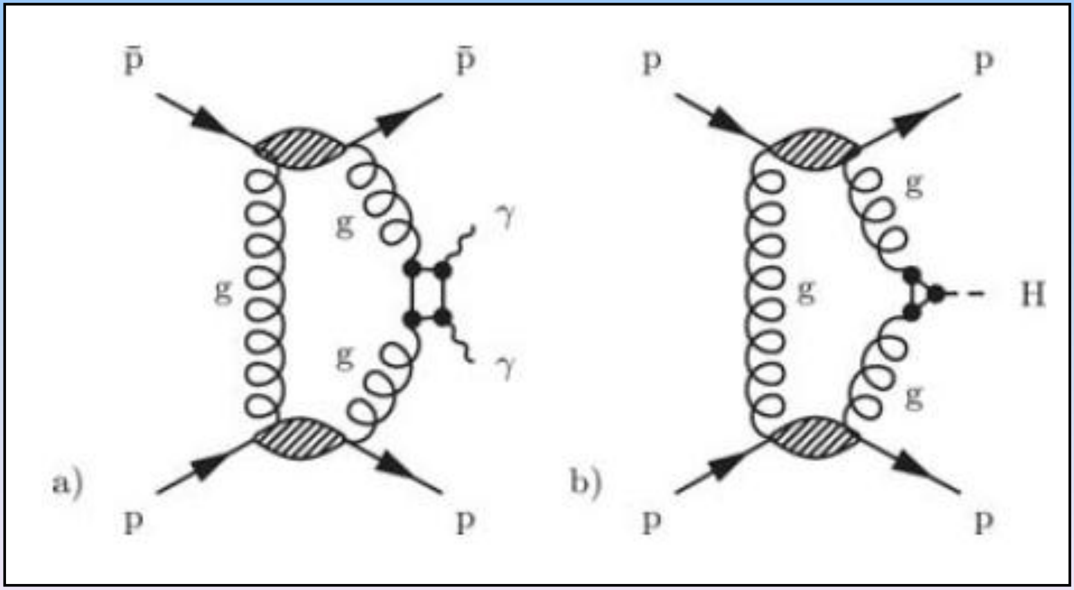
Exclusive $\gamma\gamma$ production – *new!*

(Published in PRL: **arXiv:1112.0858**)

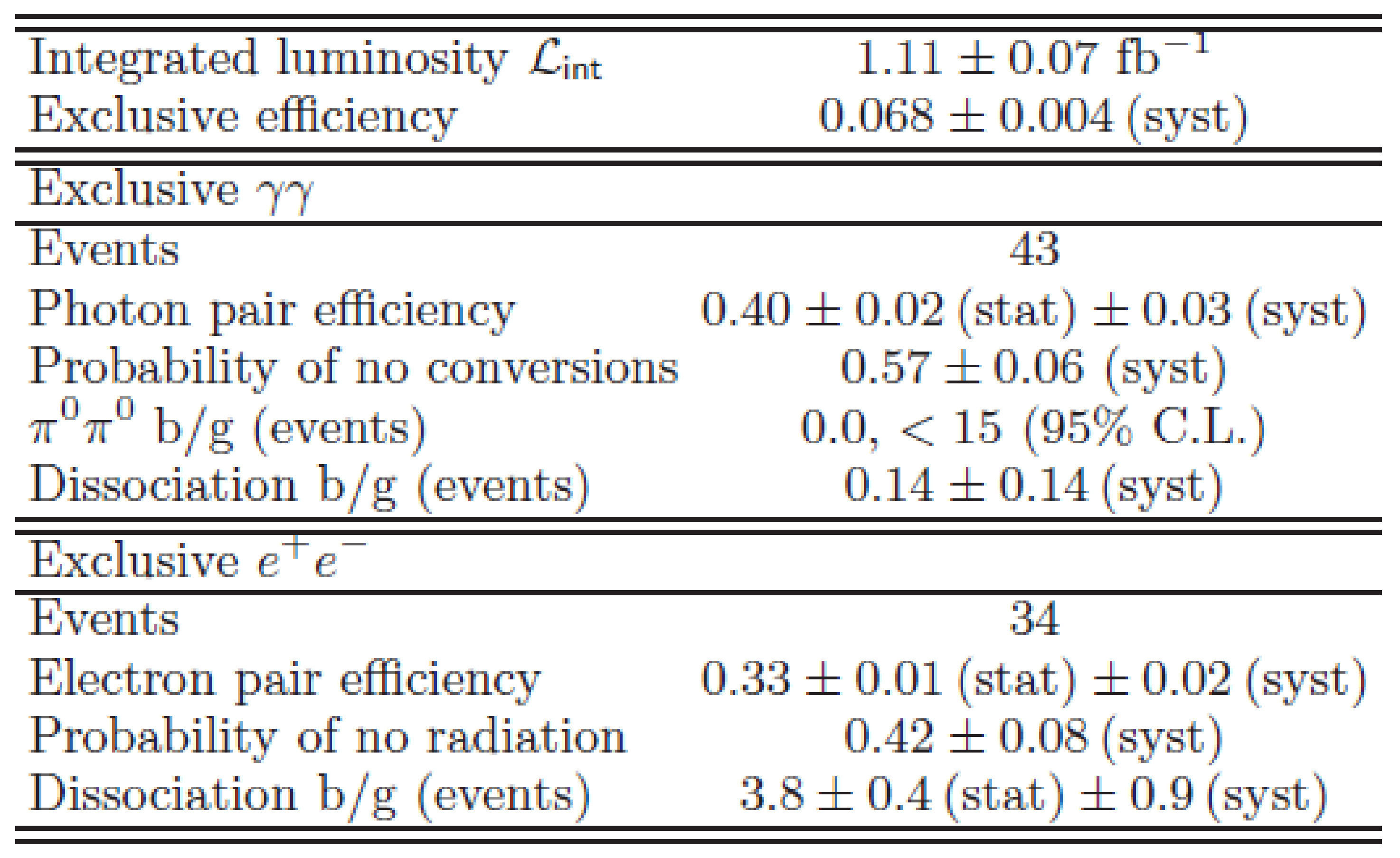
Observation of exclusive \gamma\gamma production in p\bar{p} collisions at \sqrt{s}=1.96 TeV

T. Aaltonen et al.

Accepted Friday Jan 06, 2012

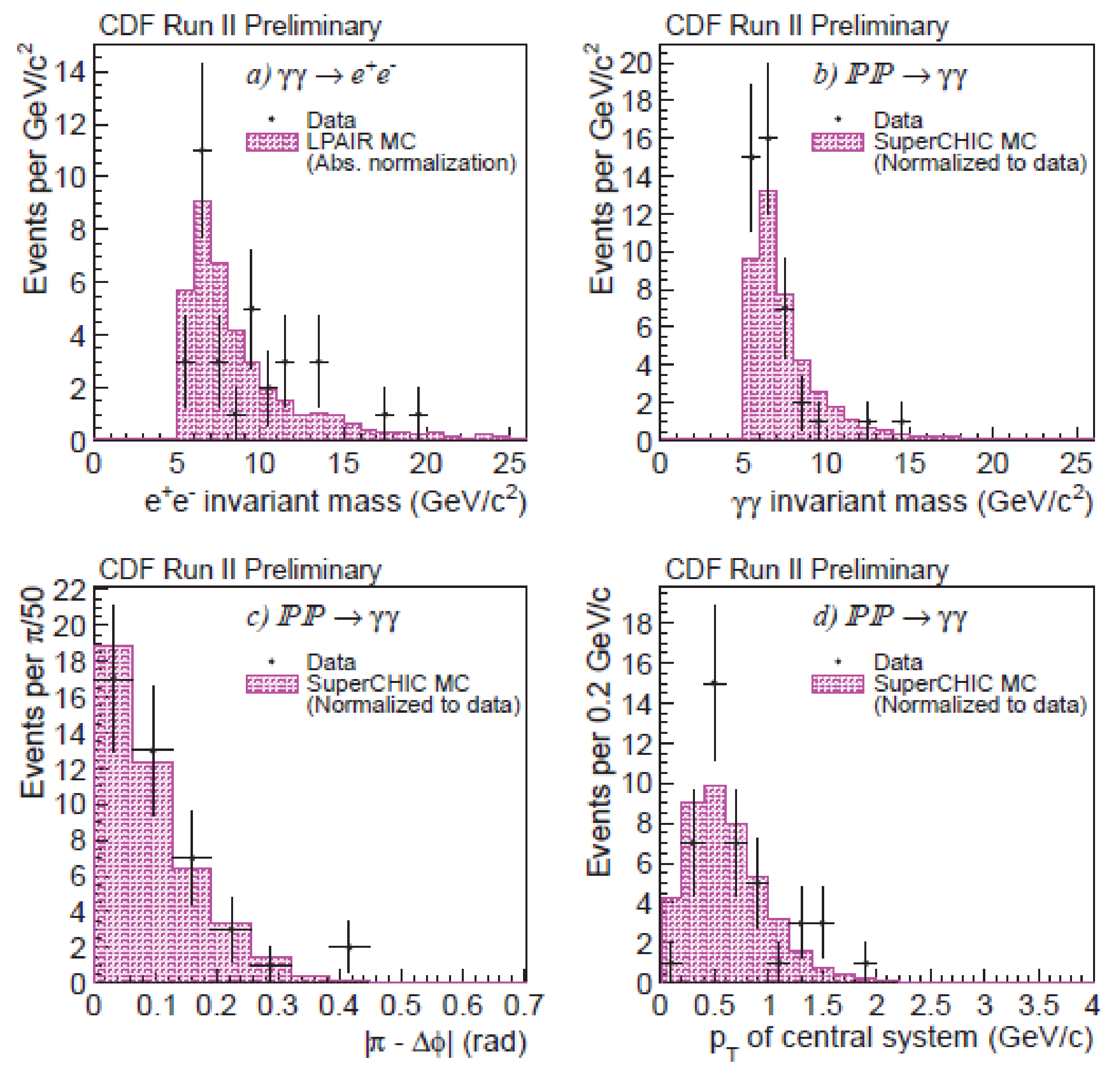


Exclusive $\gamma\gamma$ and e^+e^- events

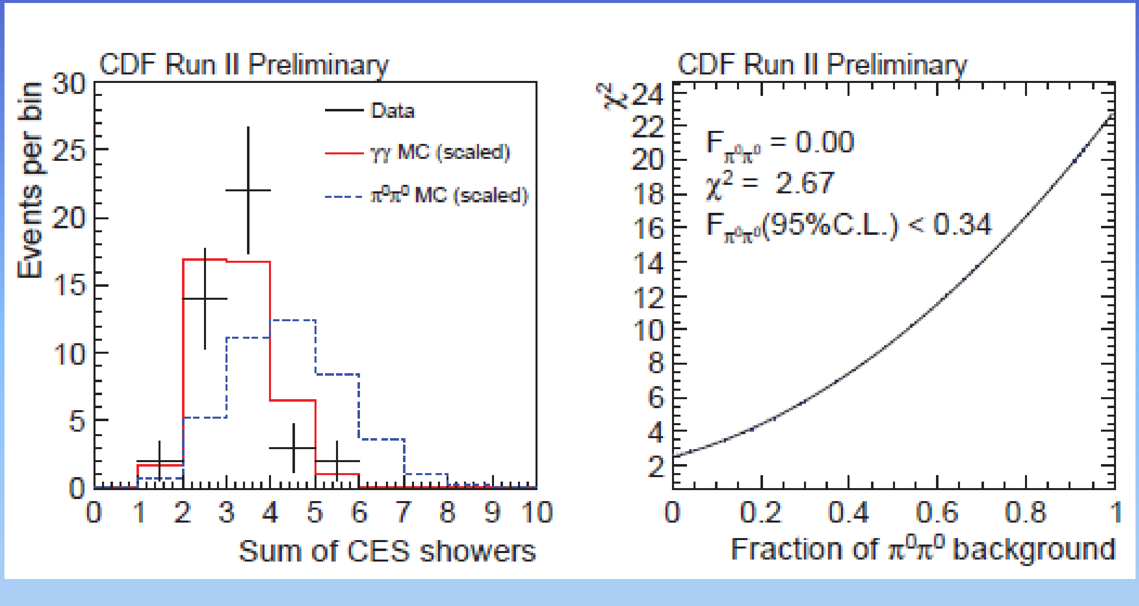


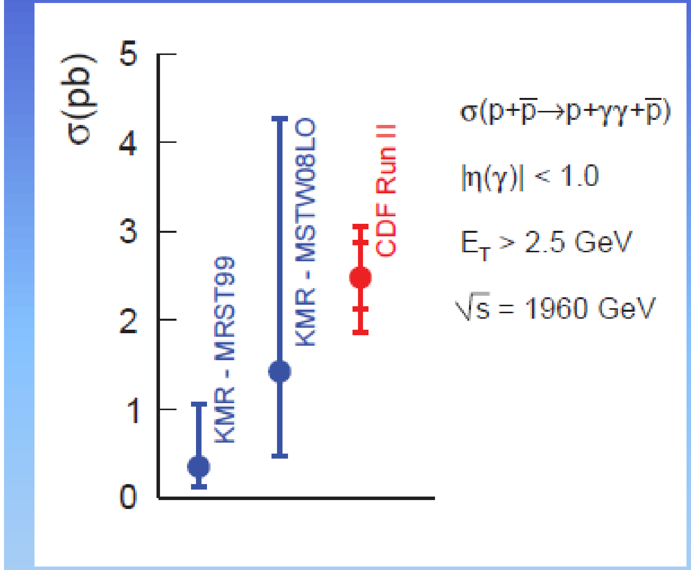
Integrated luminosity $\mathcal{L}_{\text{int}}$	1.11 ± 0.07 fb^{-1}
Exclusive efficiency	0.068 ± 0.004 (syst)
Exclusive $\gamma\gamma$	
Events	43
Photon pair efficiency	0.40 ± 0.02 (stat) ± 0.03 (syst)
Probability of no conversions	0.57 ± 0.06 (syst)
$\pi^0\pi^0$ b/g (events)	0.0, < 15 (95% C.L.)
Dissociation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

Exclusive $\gamma\gamma$ data vs. MC



Exclusive γγ cross section



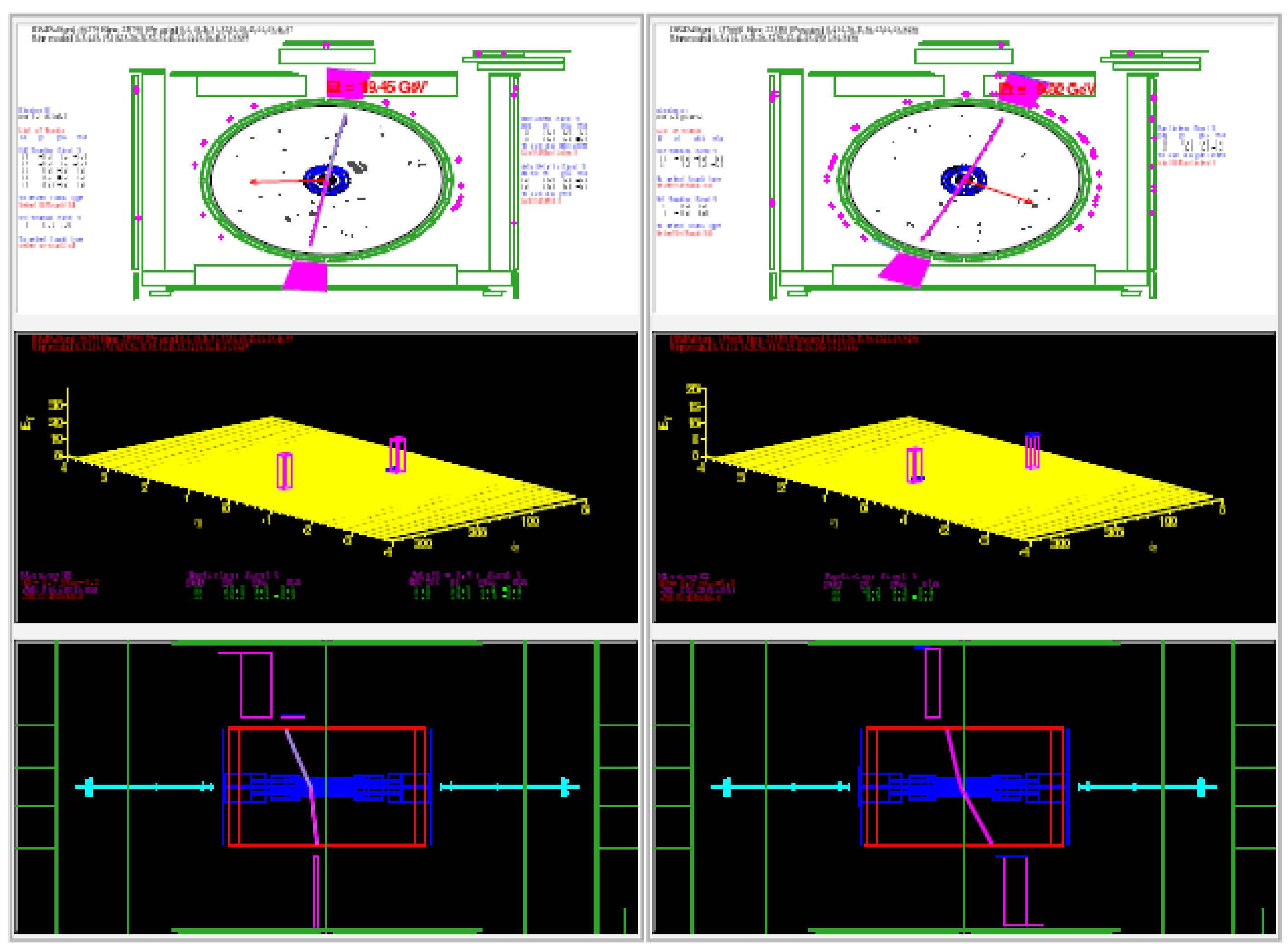


$$s_{\mathrm{SuperCHIC}}^{|\eta|<1,\,E_T>5\mathrm{GeV}} = 0.35^{\times 3}_{\div 3}\,\mathrm{pb}\,(\mathrm{MRST99})$$

$$s_{\mathrm{SuperCHIC}}^{|\eta|<1,\,E_T>5\mathrm{GeV}} = 1.42^{\times 3}_{\div 3}\,\mathrm{pb}\,(\mathrm{MSTW0SLO})$$

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

Exclusive γγ 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 exchenge**
  - The diffractive t-distribution shapes are independent of $<Q^2>$ over 4 orders of magnitude!
- **Exclusive production.** Exclusive $\gamma\gamma$ production "seals the deal" on exclusive Higgs predictions – if there is a Higgs!

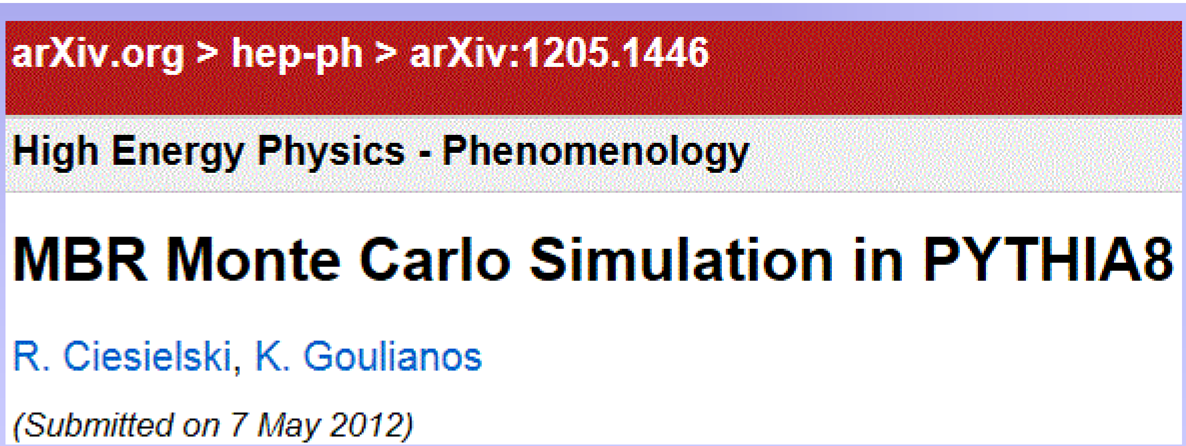
CDF4LHC

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

CDF 4 LHC

❑ Larger Energy → Larger ET
➢ Multigap diffraction
➢ Diffractive Higgs production

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



arXiv.org > hep-ph > arXiv:1205.1446

High Energy Physics - Phenomenology

MBR Monte Carlo Simulation in PYTHIA8

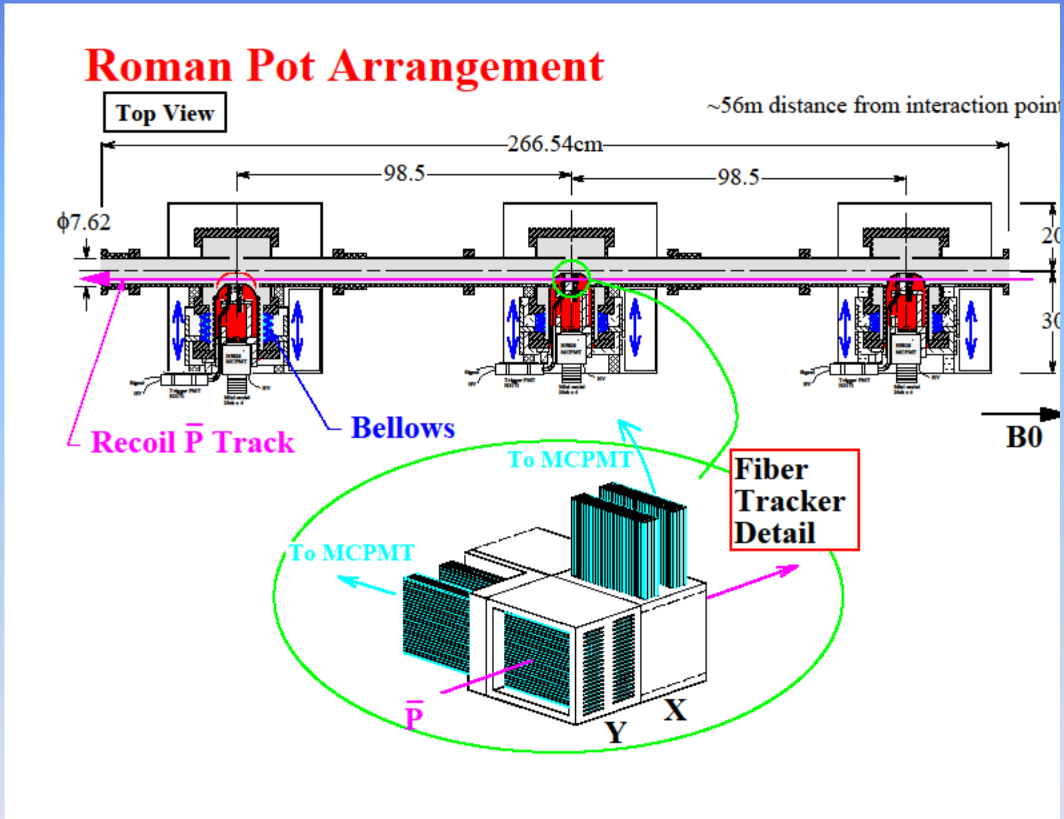
R. Ciesielski, K. Goulianos

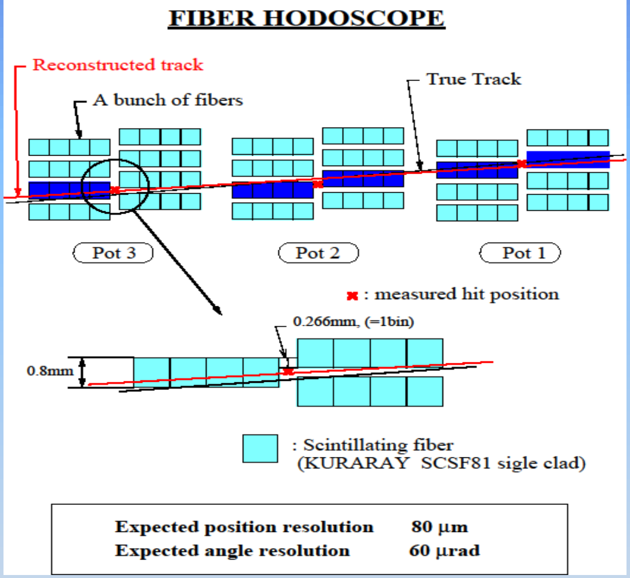
(Submitted on 7 May 2012)

Thank you for your attention

BACKUP FOR DIJETS

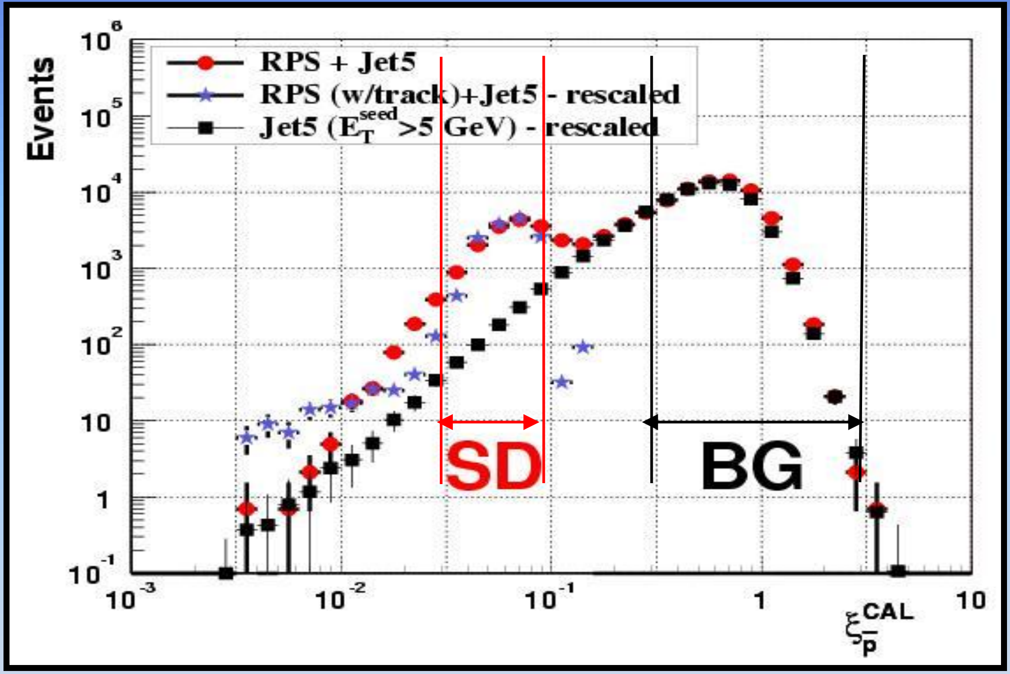
The RPS in CDF II

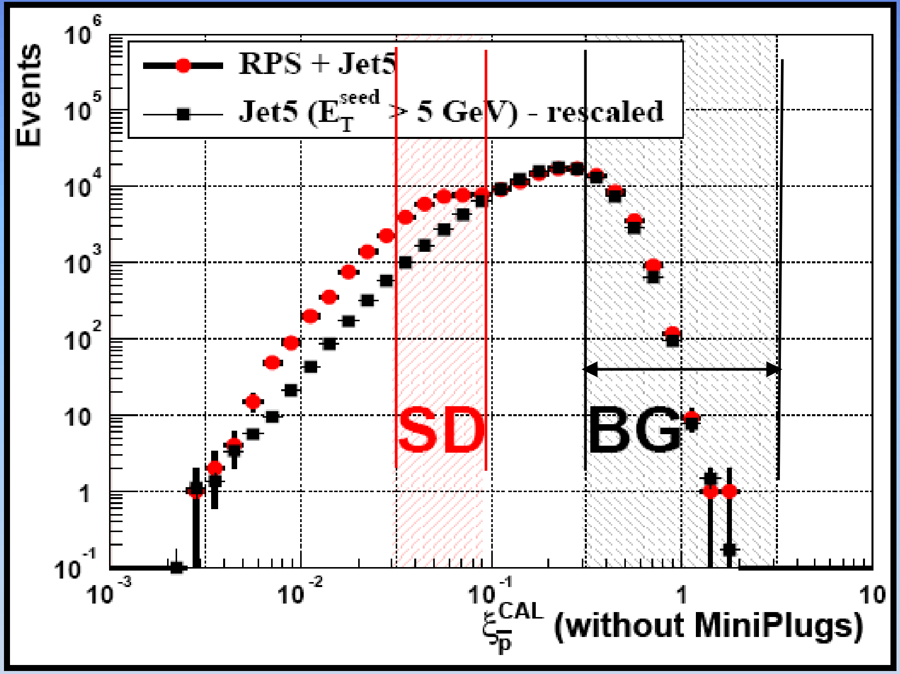




Expected position resolution	80 µm
Expected angle resolution	60 µrad

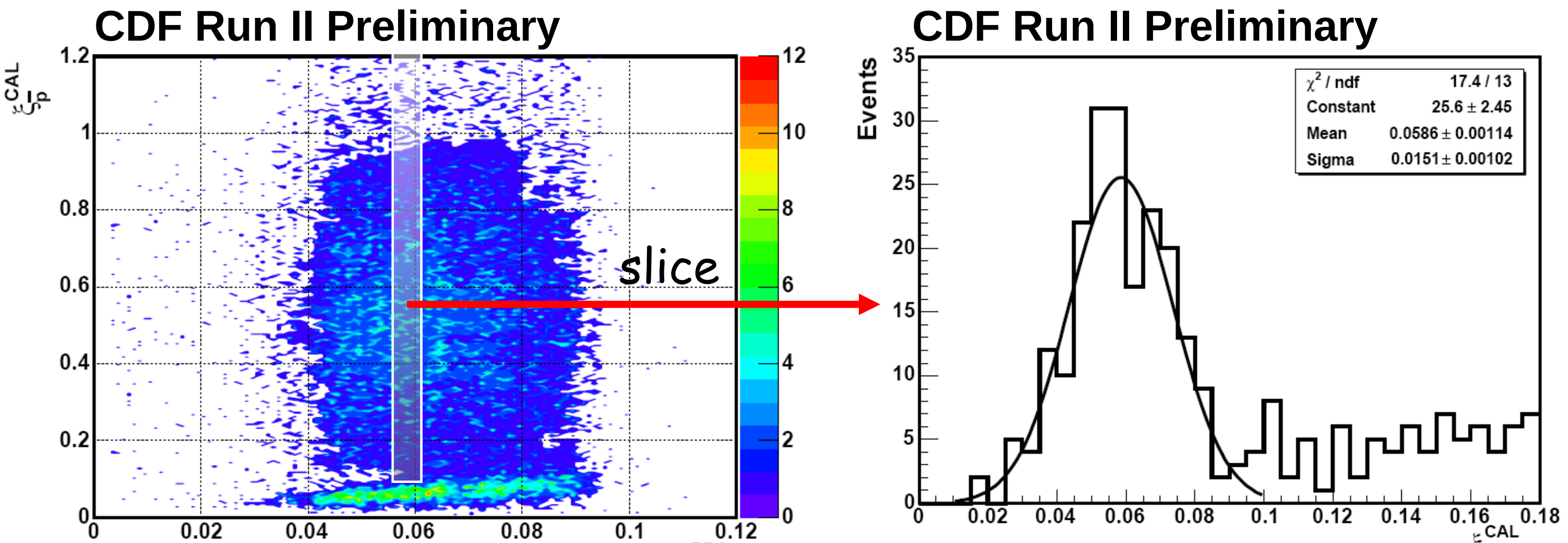
The MiniPlugs

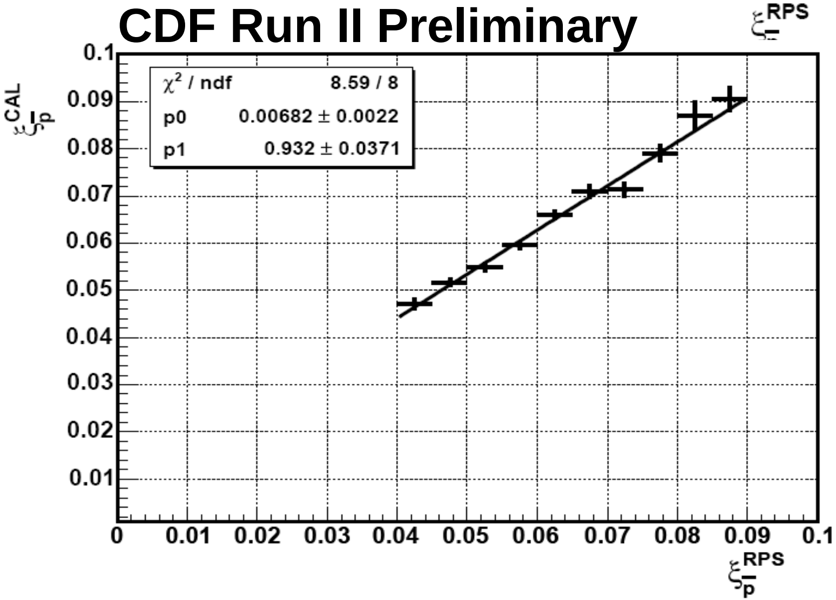




➔ overlap bgnd (BG) is reduced by including the MPs in the ξ^{CAL} calculation

ξ^{CAL} vs. ξ^{RPS}





$$\boxed{0.04 < \xi_{\bar{p}}^{RPS} < 0.09}$$

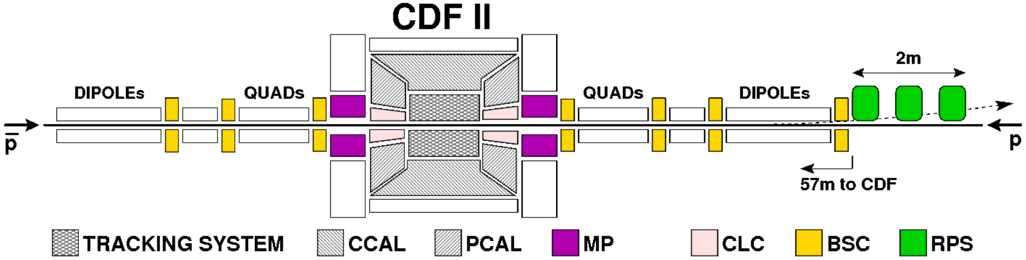
$$\xi_{\bar{p}}^{CAL} = p^0 + p1 \cdot \xi_{\bar{p}}^{RPS}$$

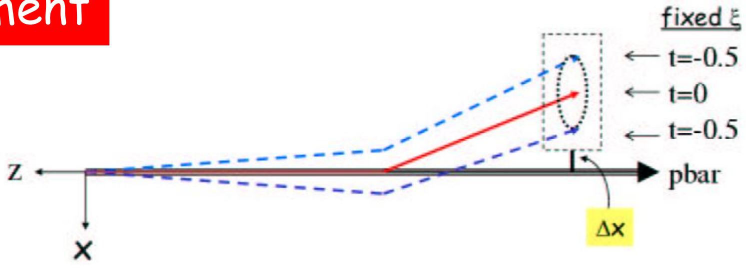
$$p^0 = 0.007 \pm 0.002 \text{ and } p1 = 0.97 \pm 0.04$$

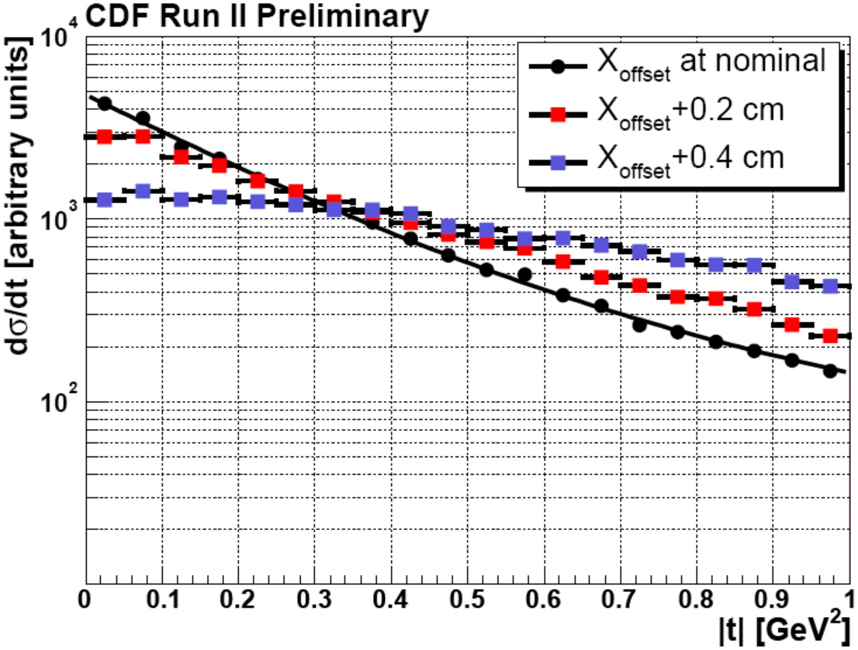
Dynamic Alignment of RPS

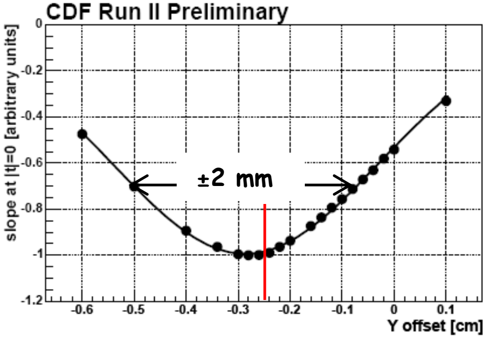
Method: iteratively adjust the RPS X and Y offsets from the nominal beam axis until a maximum in the b-slope is obtained @ t=0.

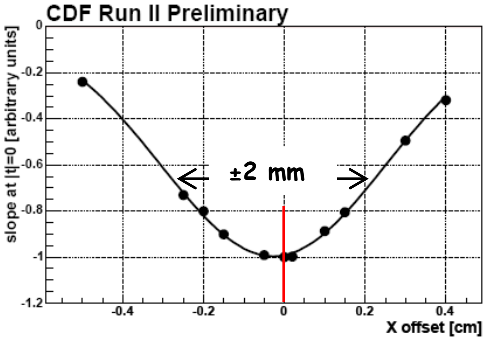
New: uncertainty in the slope due to alignment









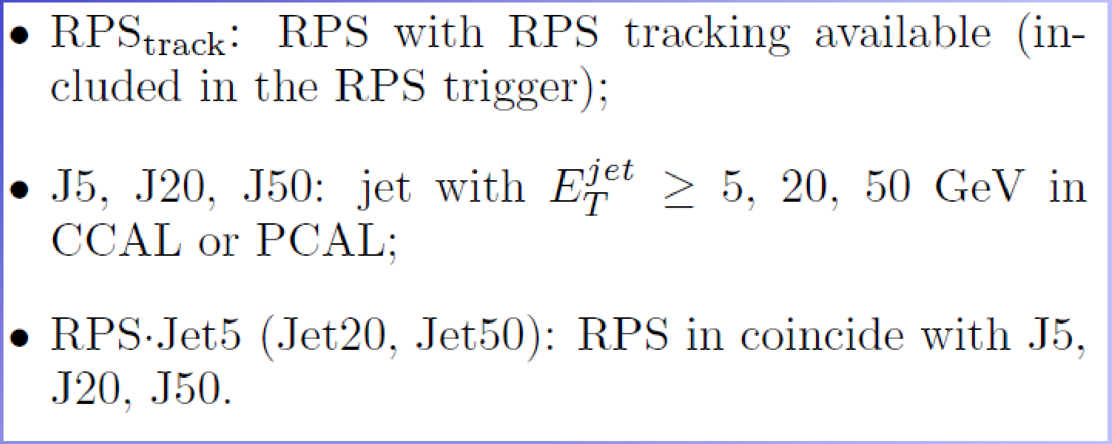


Limiting factors

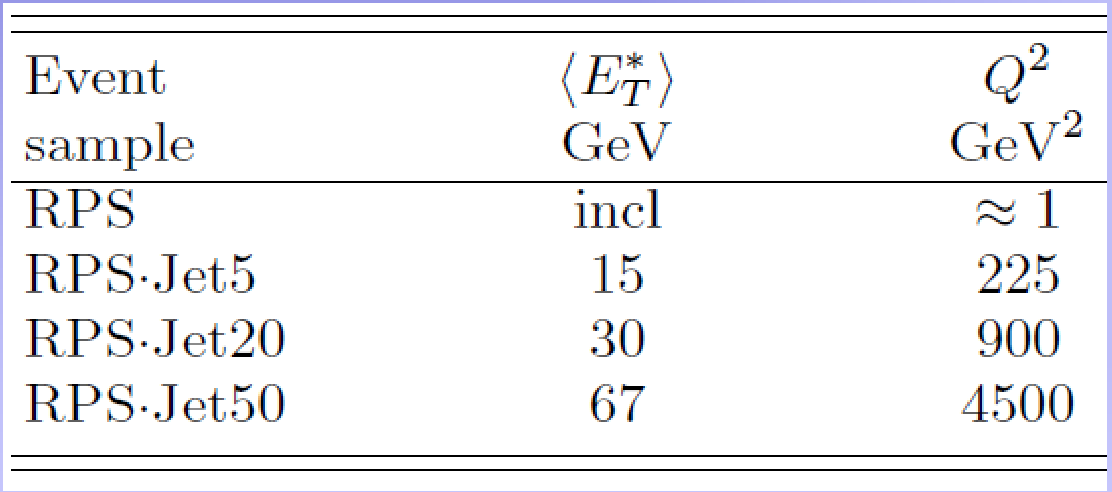
1-statistics
2-beam size
3-beam jitter

use RPStrk data
width~ 2 mm/√N
N~1 K events
ΔX,ΔY = ± 60 μ

TRIGGERS AND EVENT SAMPLES

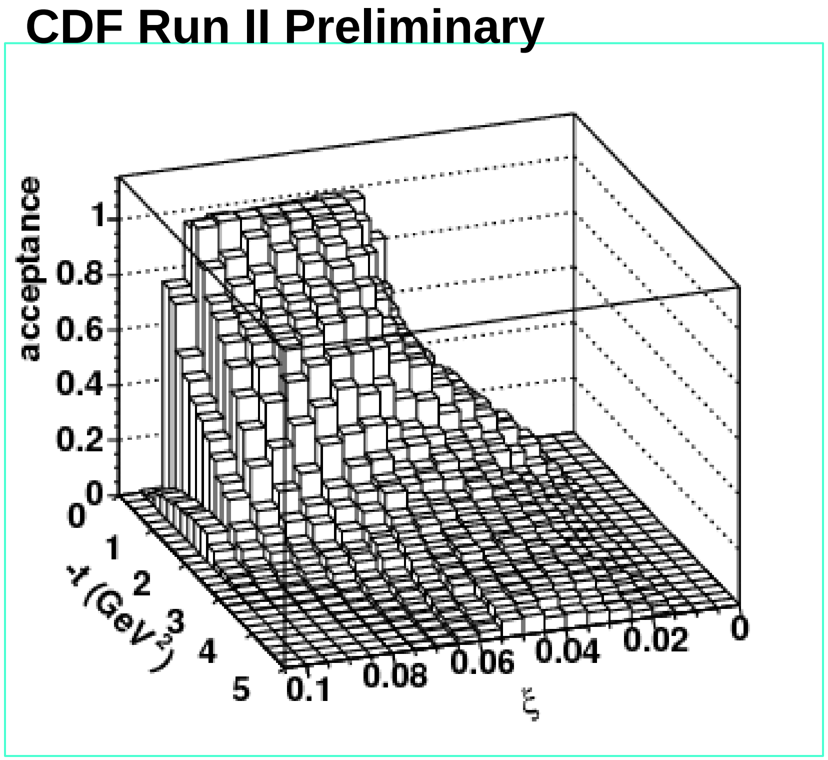


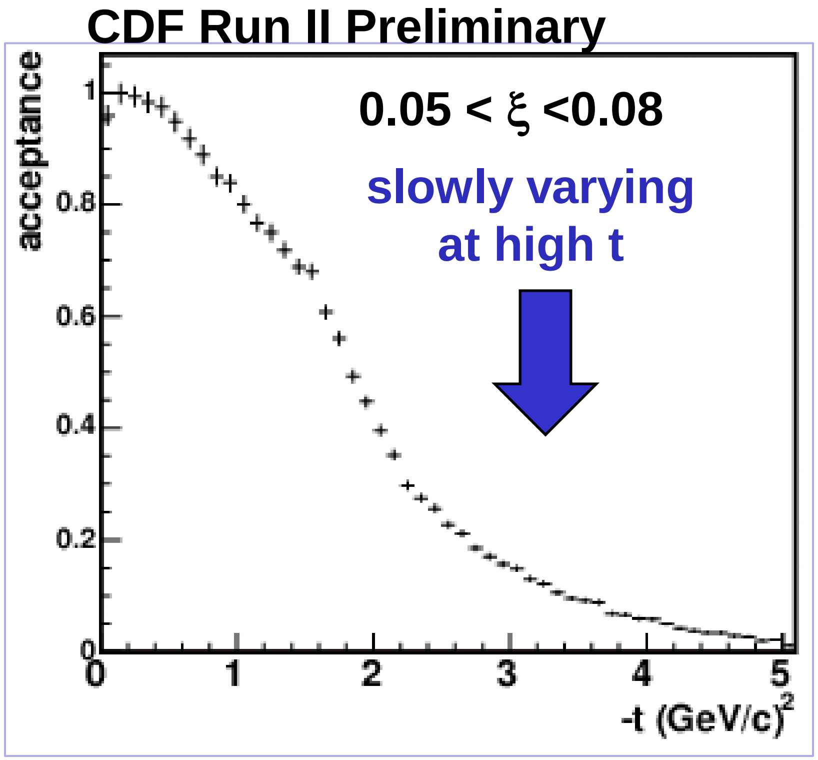
- $\mathrm{RPS}_{\mathrm{track}}$: RPS with RPS tracking available (included in the RPS trigger);
- J5, J20, J50: jet with $E_T^{jet} \geq 5$, 20, 50 GeV in CCAL or PCAL;
- RPS·Jet5 (Jet20, Jet50): RPS in coincide with J5, J20, J50.



Event sample	$\langle E_T^* \rangle$ GeV	Q^2 GeV^2
RPS	incl	≈ 1
RPS·Jet5	15	225
RPS·Jet20	30	900
RPS·Jet50	67	4500

RPS ACCEPTANCE

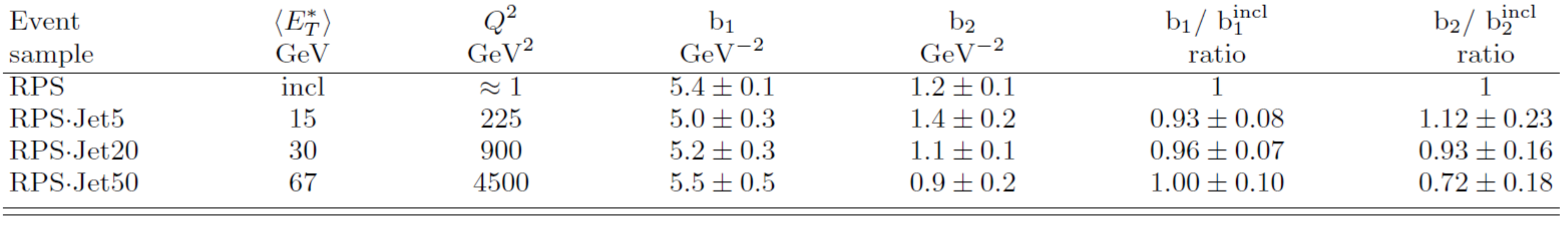




- ❑ **acceptance beyond 4 GeV^2 minimizes edge effects**

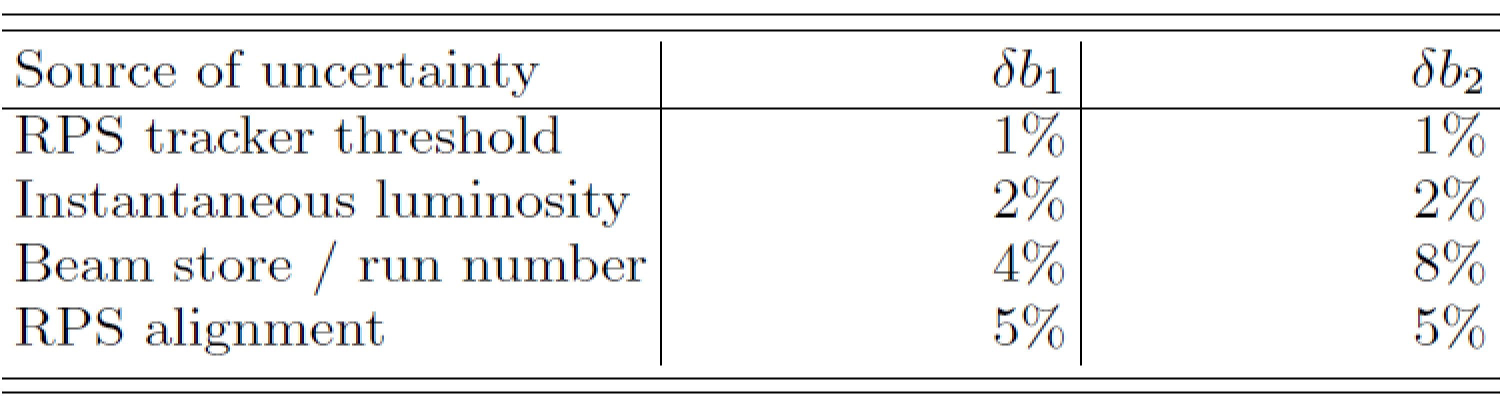
b-slopes for $-t \leq 1$ GeV^2 (1)

CDF Run II Preliminary



Event sample	$\langle E_T^* \rangle$ GeV	Q^2 GeV^2	b$_1$ GeV^{-2}	b$_2$ GeV^{-2}	b$_1$/ b$_1^{\text{incl}}$ ratio	b$_2$/ b$_2^{\text{incl}}$ ratio
RPS	incl	≈ 1	5.4 ± 0.1	1.2 ± 0.1	1	1
RPS·Jet5	15	225	5.0 ± 0.3	1.4 ± 0.2	0.93 ± 0.08	1.12 ± 0.23
RPS·Jet20	30	900	5.2 ± 0.3	1.1 ± 0.1	0.96 ± 0.07	0.93 ± 0.16
RPS·Jet50	67	4500	5.5 ± 0.5	0.9 ± 0.2	1.00 ± 0.10	0.72 ± 0.18

CDF Run II Preliminary

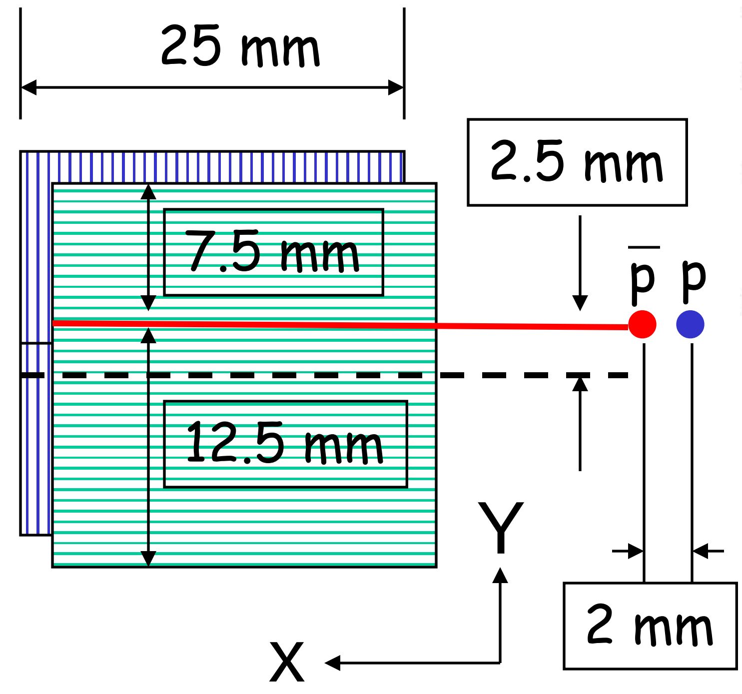


Source of uncertainty	δb_1	δb_2
RPS tracker threshold	1%	1%
Instantaneous luminosity	2%	2%
Beam store / run number	4%	8%
RPS alignment	5%	5%

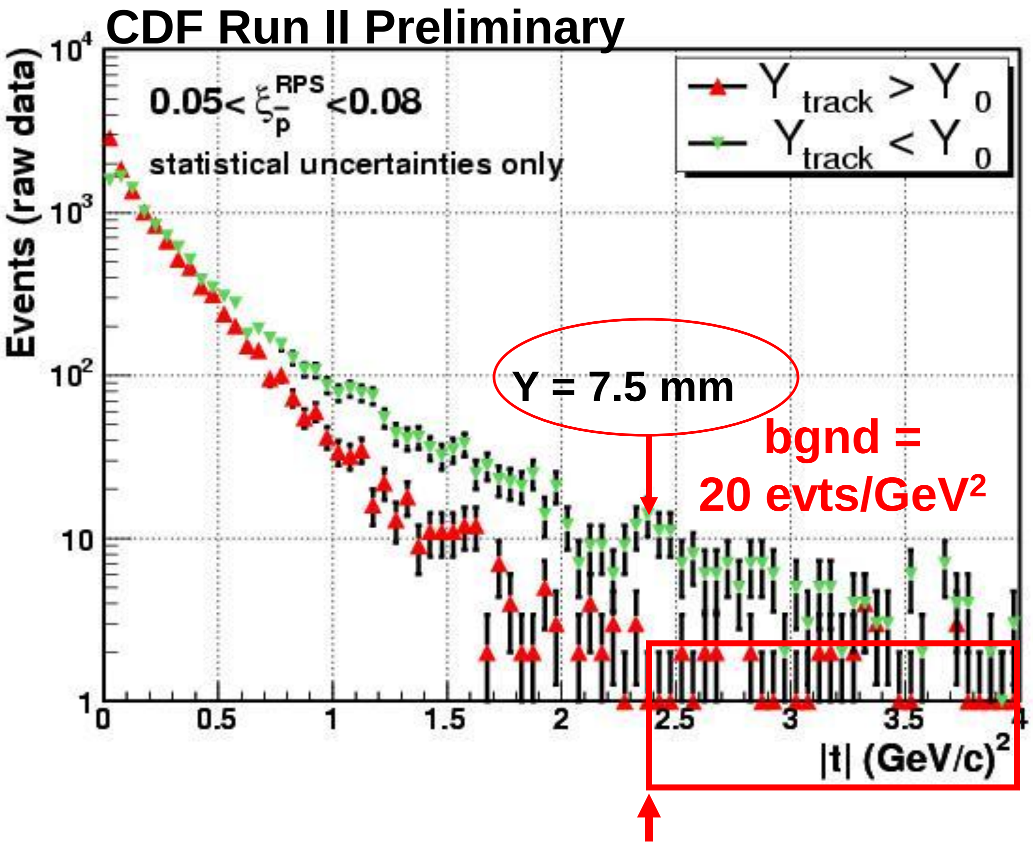
- **≤ 20% dependence on Q^2 over ~ 4 orders of magnitude**

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

schematic view of fiber tracker

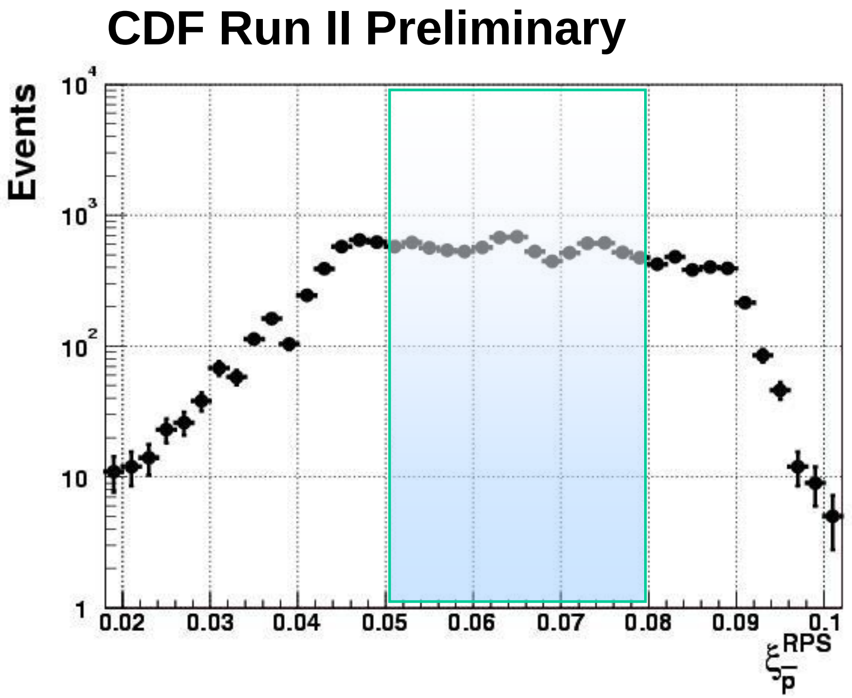


t-distributions



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

Why select $0.05<\xi_{pbar}<0.08$?



- ☐ be on the plateau of the ds/dlnξ distribution
- ☐ allow enough room to avoid edge-effects
- ☐ accept enough events for good statistics

☐ estimated width resulting from the Δξ : Δτ ≈ 0.47

The end!