Diffractive and Exclusive Production at CDF II

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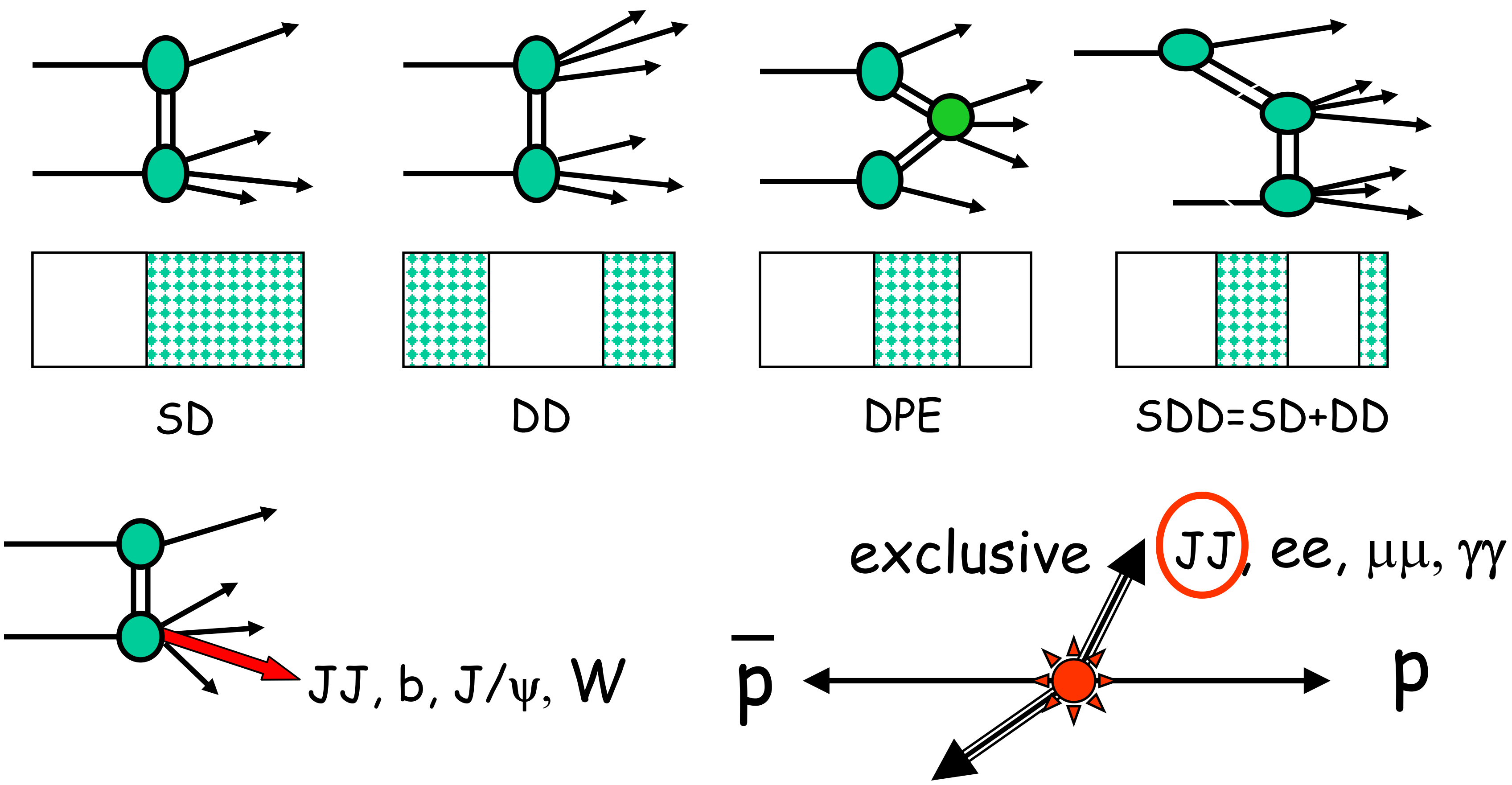
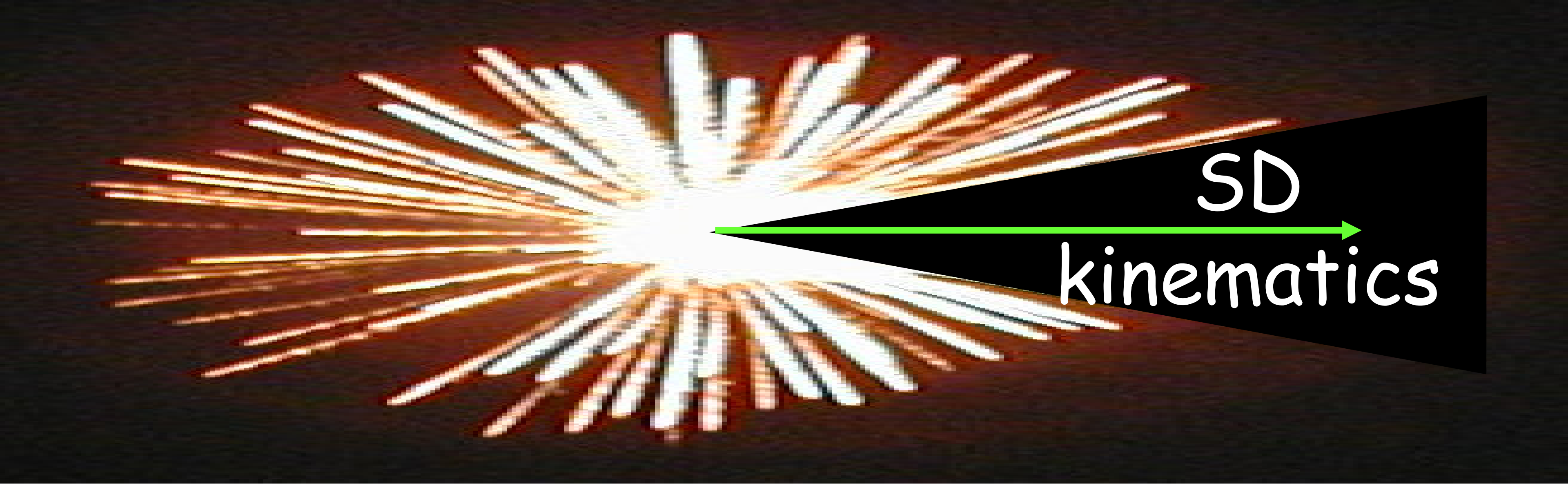
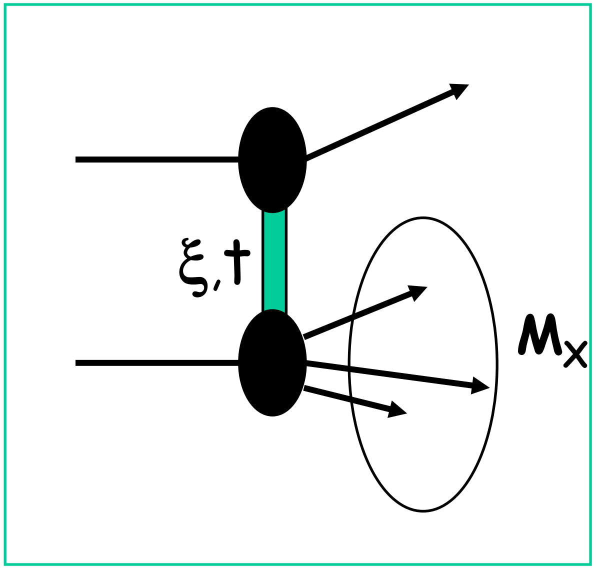
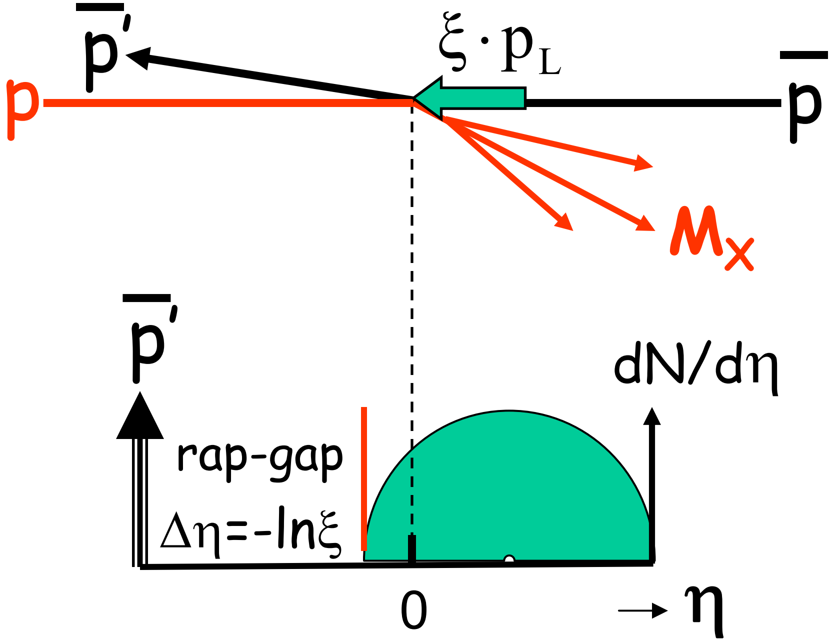
Soft and hard diffractive and exclusive studies at CDF



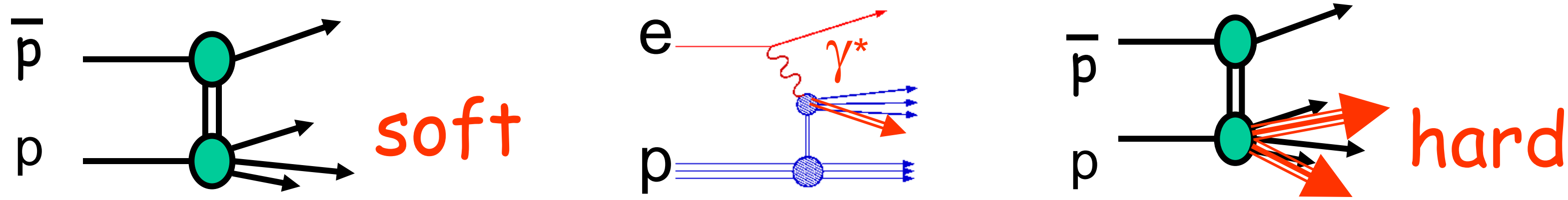

SD
kinematics

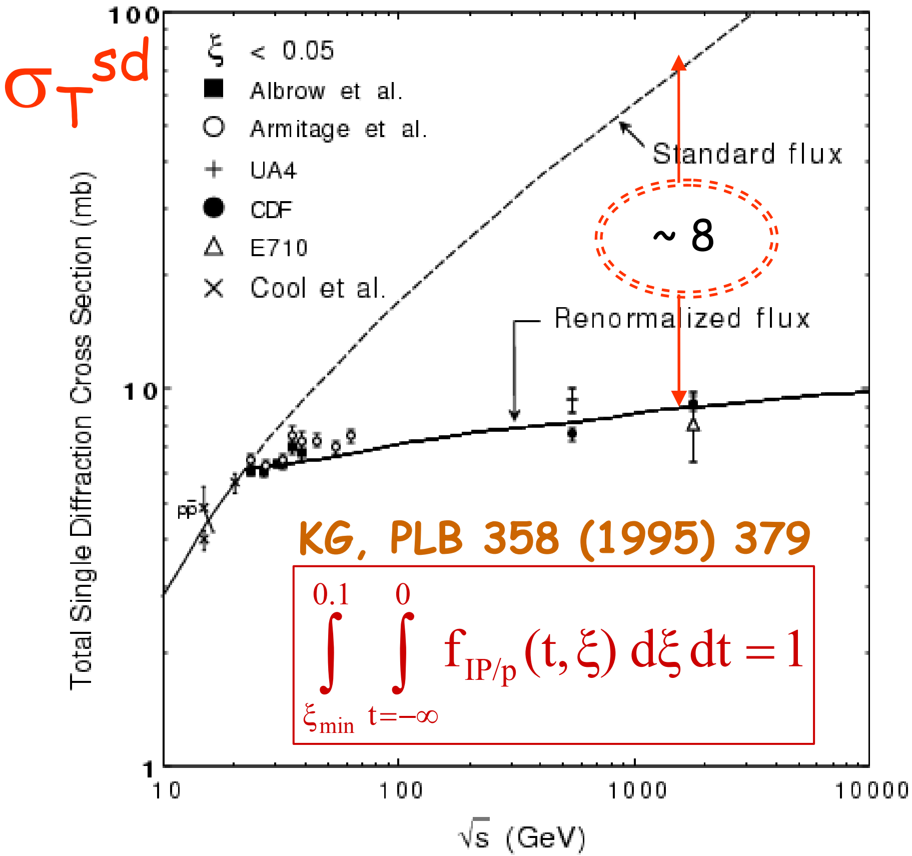

ξ,t
Mx

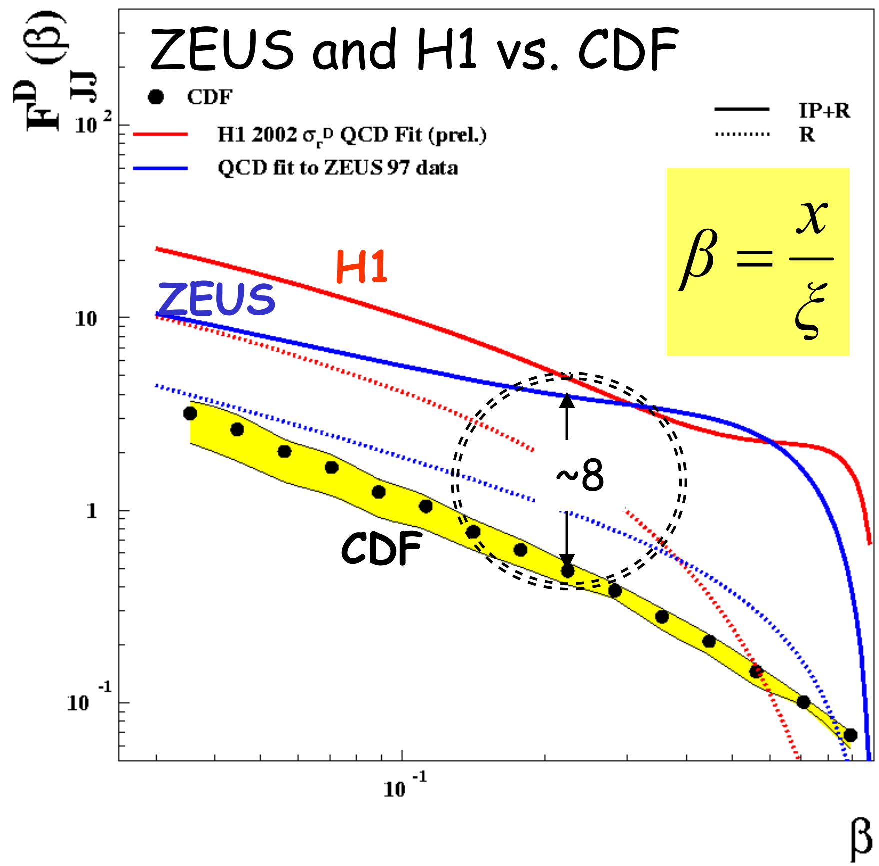

p̄'
ξ·pL
p
p̄
Mx
p̄'
dN/dη
rap-gap
Δη=-lnξ
0
η

Run I

Breakdown of factorization







Magnitude: same suppression factor in soft and hard diffraction!
Shape of β distribution: ZEUS, H1, and Tevatron – why different slapes?

Run I

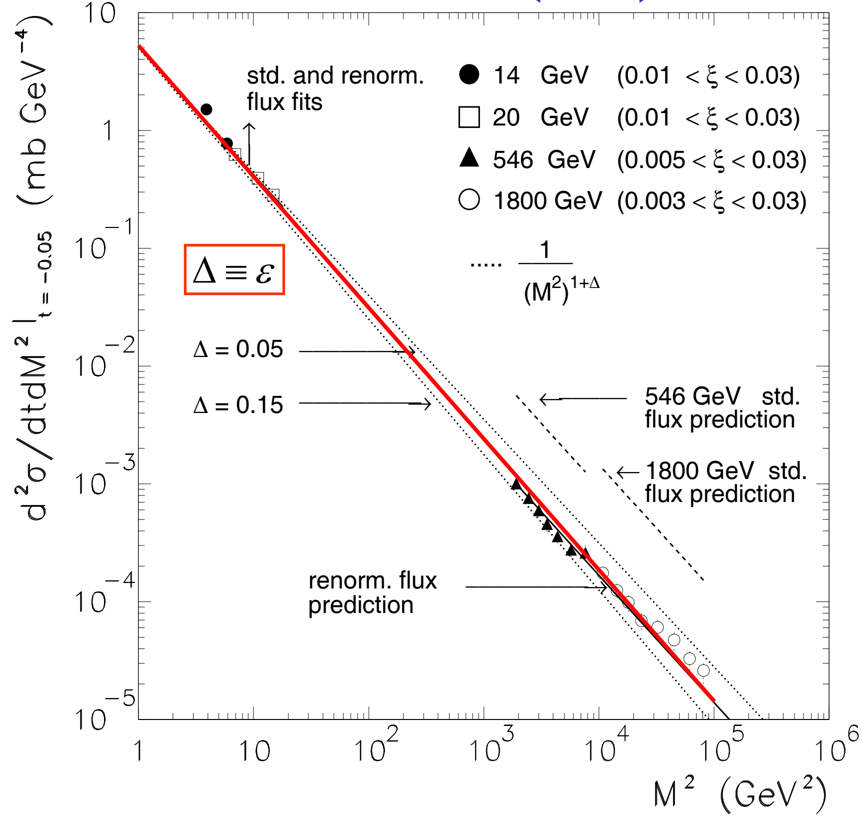
M^2 scaling
➔ ds/dM^2 independent of s !

renormalization

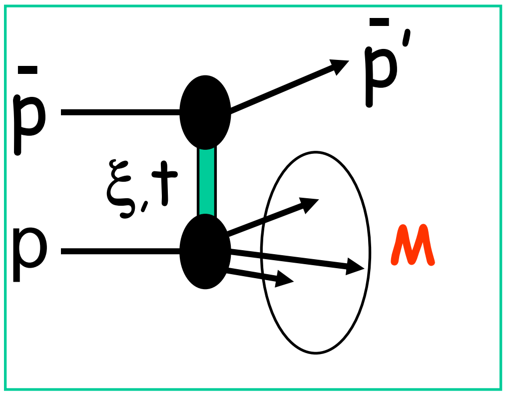
$$\frac{d\sigma}{dM^2} \propto \frac{s^{2\varepsilon} \rightarrow 1}{(M^2)^{1+\varepsilon}}$$

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

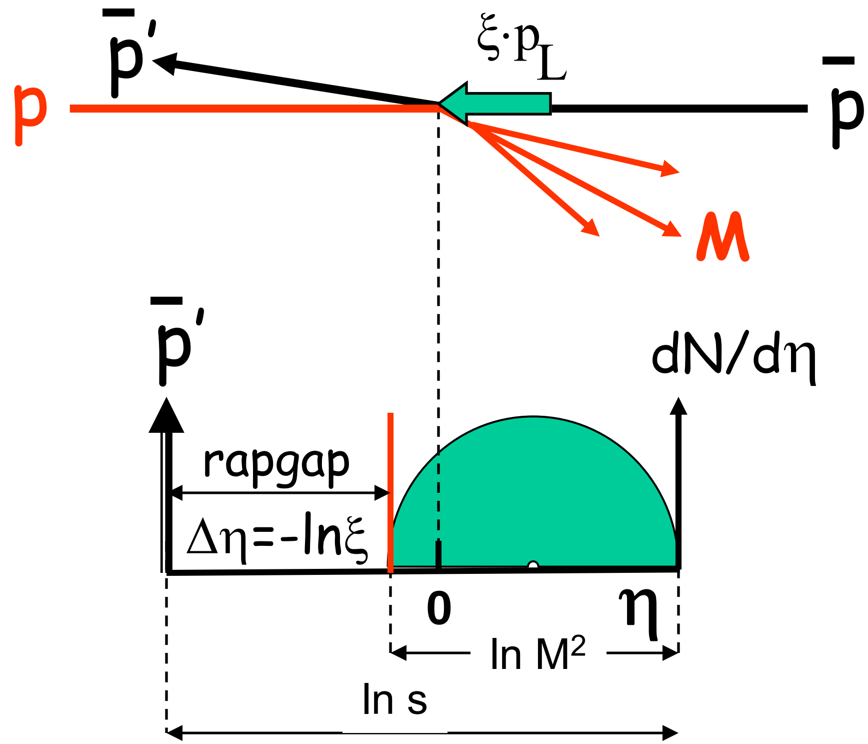
KG&JM, PRD 59 (1999) 114017



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



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



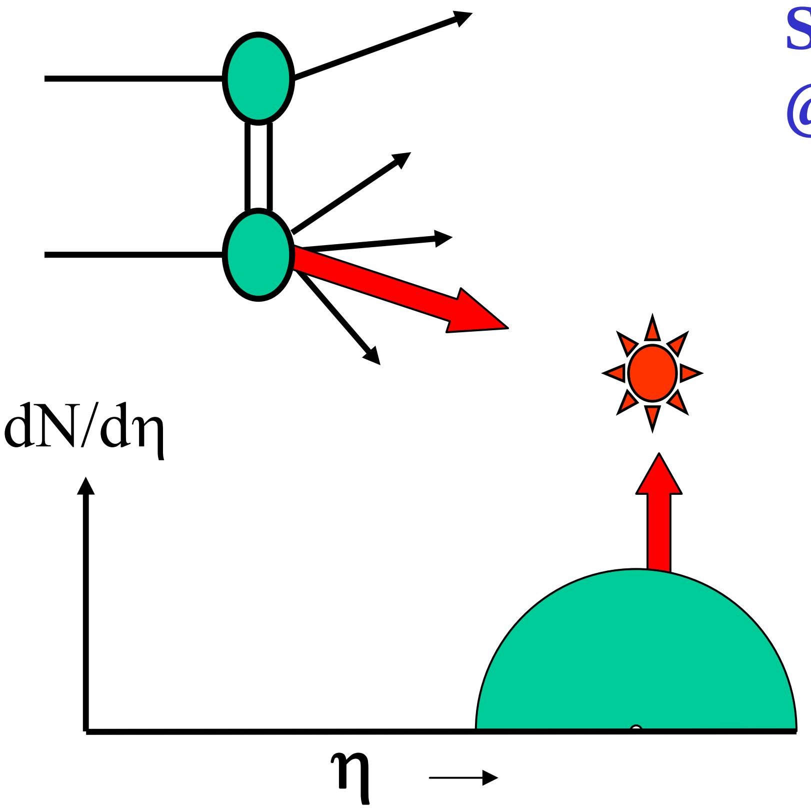
vacuum exchange ⇒

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

Run I

Hard diffractive fractions

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

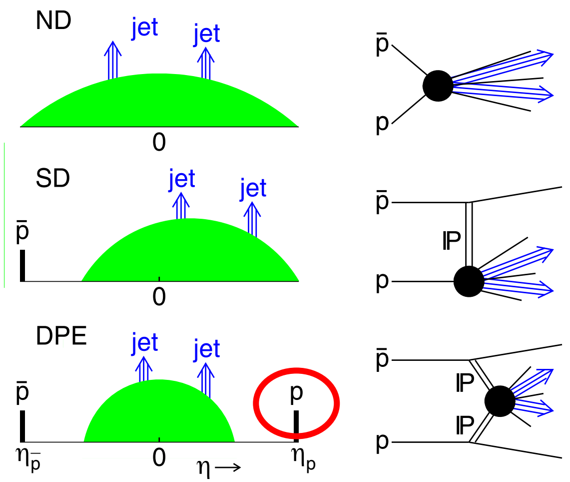


Fraction:
SD/ND ratio @ 1800 GeV

$\star$	Fraction %
JJ	0.75 +/- 0.10
W	0.115 +/- 0.55
b	0.62 +/- 0.25
J/ψ	1.45 +/- 0.25

All fractions ~ 1%
(differences due to kinematics)
- ~ uniform suppression
- ~ FACTORIZATION ! !

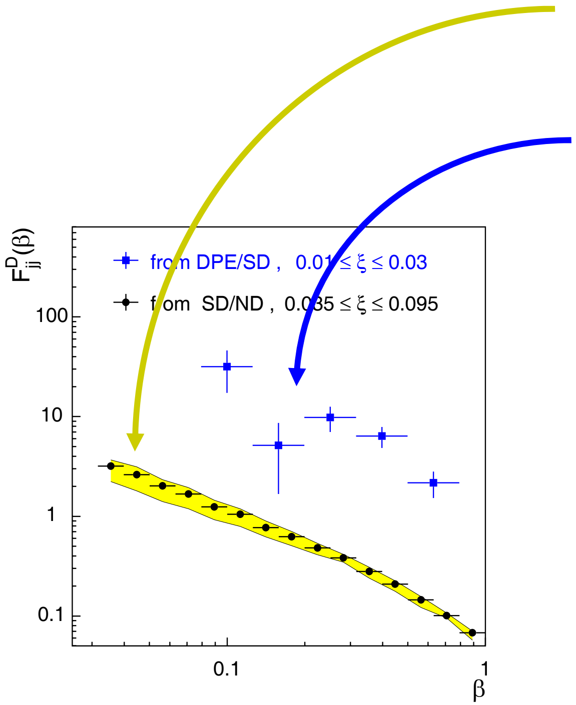
Multi-gap diffraction
- restoring factorization -

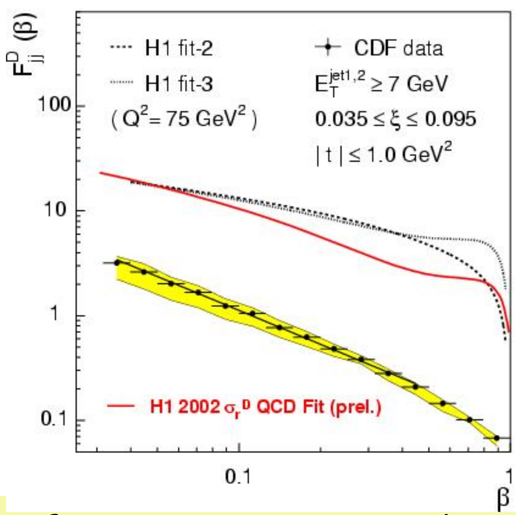


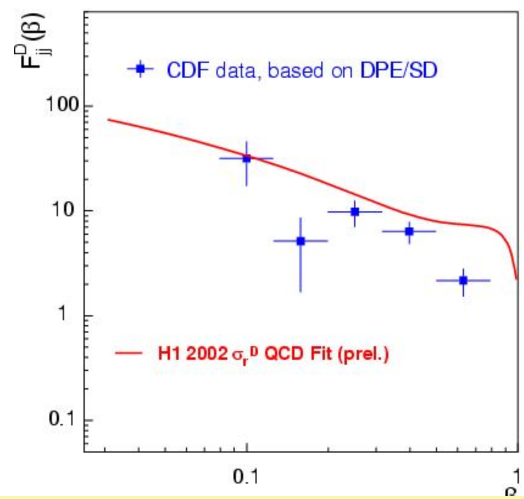
R(SD/ND)

R(DPE/SD)

DSF from ratio of two/one gap: factorization restored!

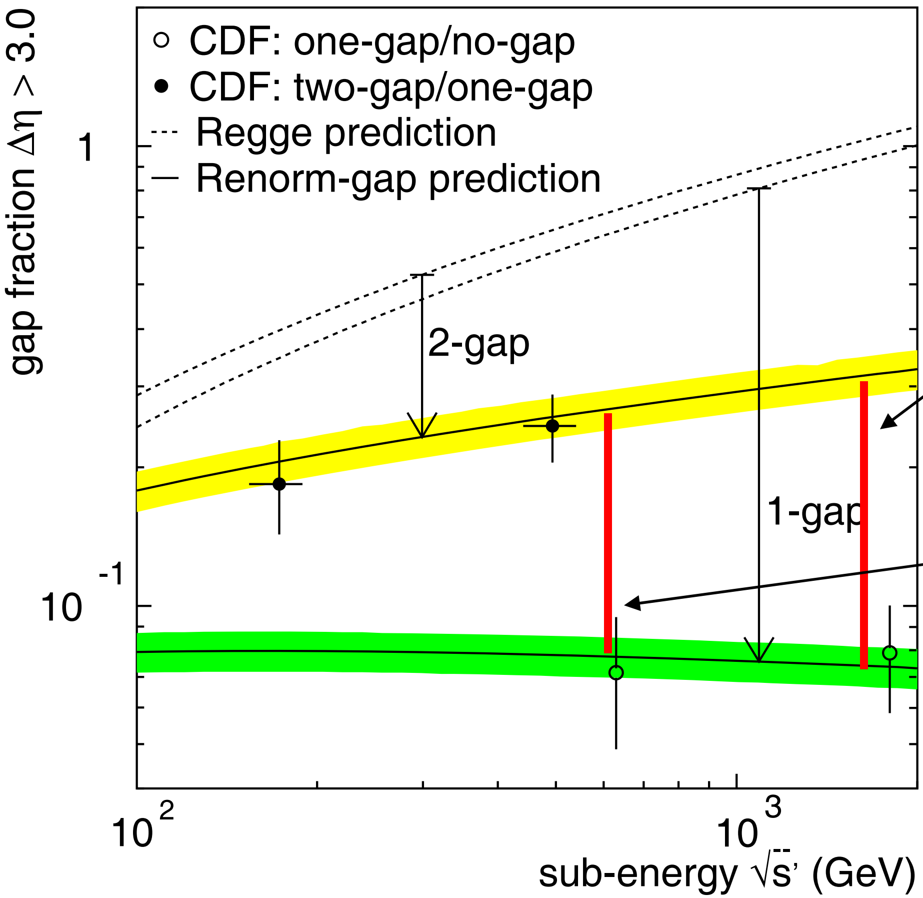


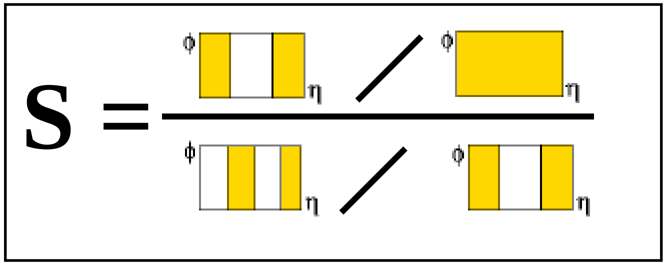




The diffractive structure function measured on the proton side in events with a leading antiproton is NOT suppressed relative to predictions based on DDIS

Gap Survival Probability

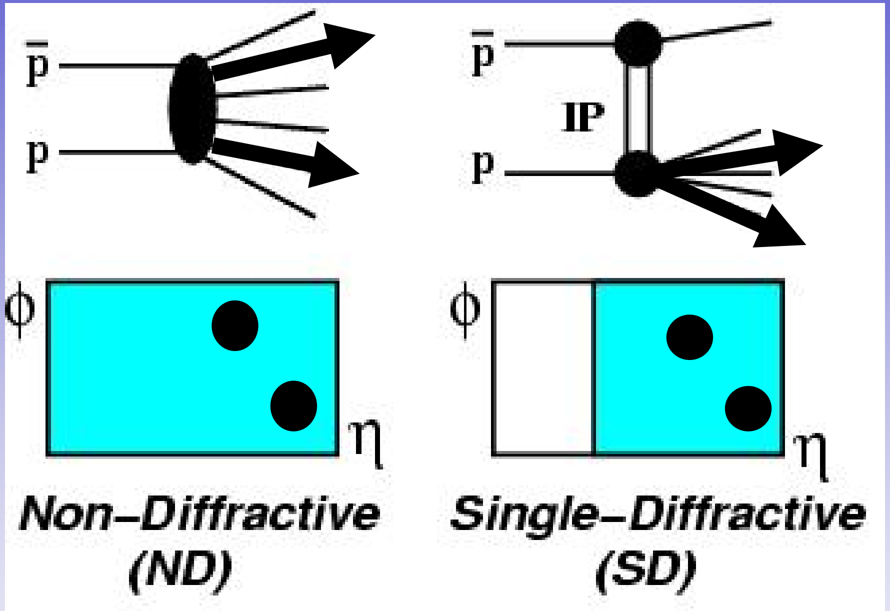




$$S^{1-gap/0-gap}_{2-gap/1-gap}(1800\ \text{GeV}) \approx 0.23$$

$$S^{1-gap/0-gap}_{2-gap/1-gap}(630\ \text{GeV}) \approx 0.29$$

DIFFRACTIVE DIJETS

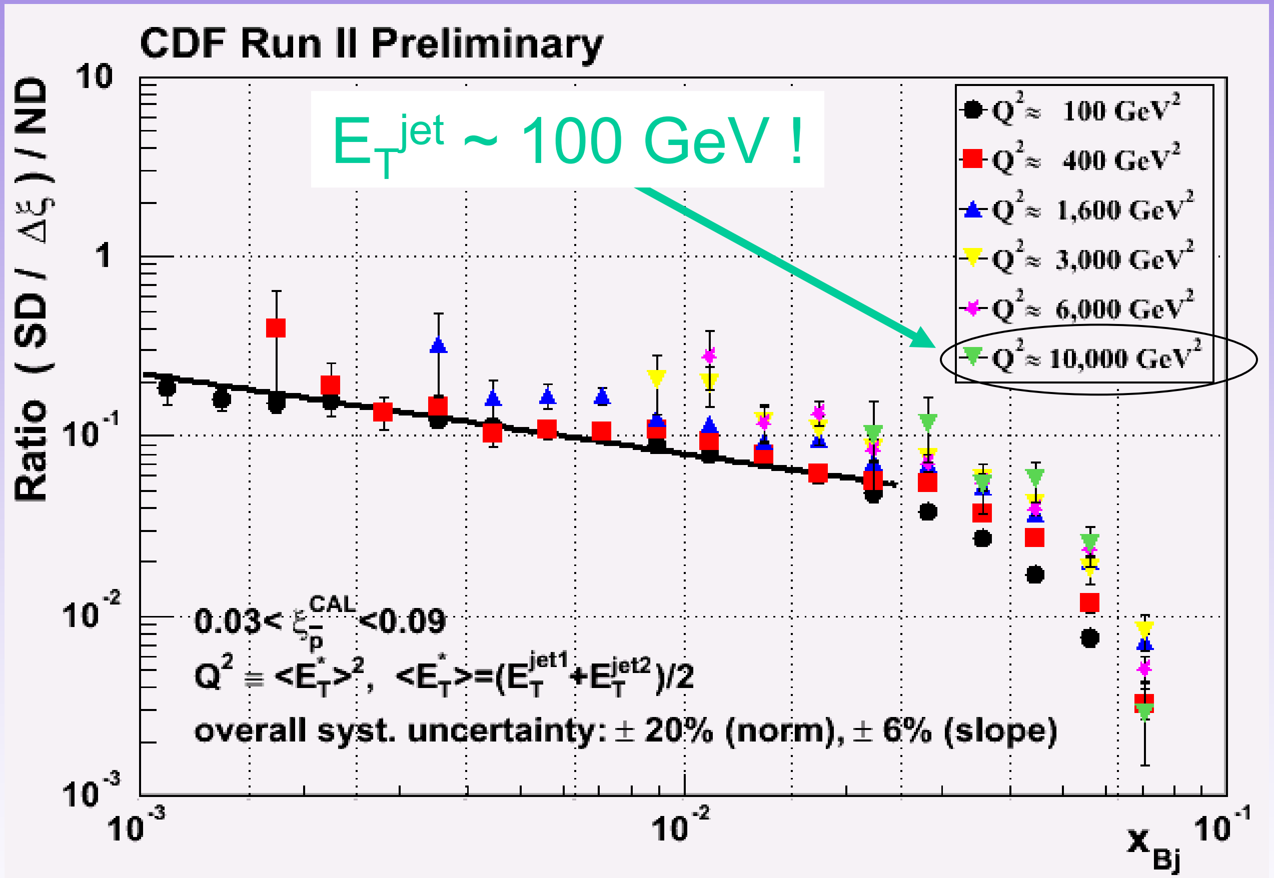


$$R(x_{Bj}) \equiv \frac{\mathrm{Rate}_{jj}^{SD}(x_{Bj})}{\mathrm{Rate}_{jj}^{ND}(x_{Bj})}$$

$$\Rightarrow \frac{F_{jj}^{SD}(x_{Bj})}{F_{jj}^{ND}(x_{Bj})}$$

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

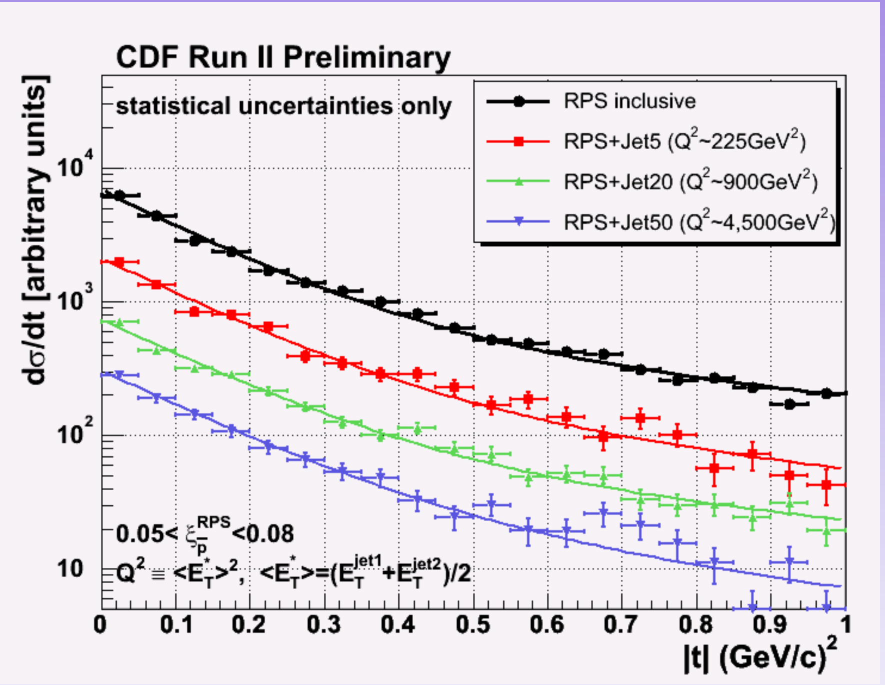
Diffractive Structure Function: X_{Bj} and Q^2 dependence

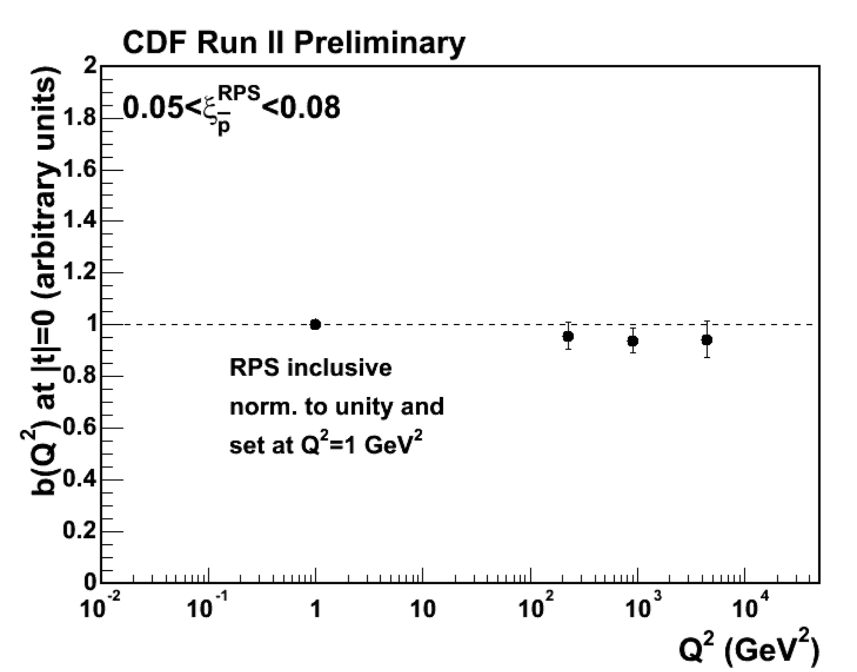


Small Q^2 dependence in region $100 < Q^2 < 10\,000$ GeV^2

⇨ Pomeron evolves as the proton!

Diffractive Structure Function:
t- dependence





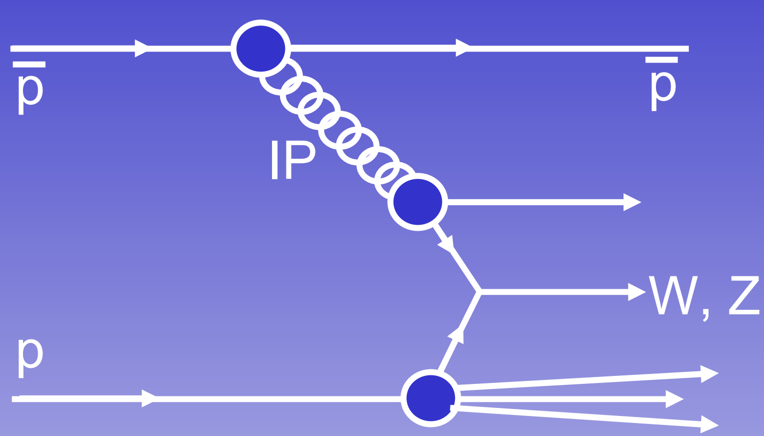
Fit $d\sigma/dt$ to a double exponential:

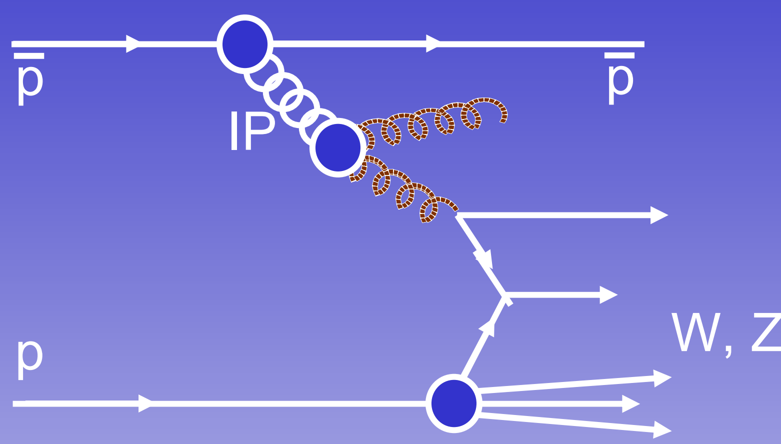
$$F = 0.9 \cdot e^{b_1 \cdot t} + 0.1 \cdot e^{b_2 \cdot t}$$

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

Remaining work:
- Obtain slope normalization
- Extend range to |t| ~ 4 GeV^2

Diffractive W/Z production





- Diffractive W production probes the quark content of the Pomeron
  - To leading order, the W is produced by a quark in the Pomeron

- Production by gluons is suppressed by a factor of α_S, and can be distinguished from quark production by an associated jet

Diffractive W/Z - motivation

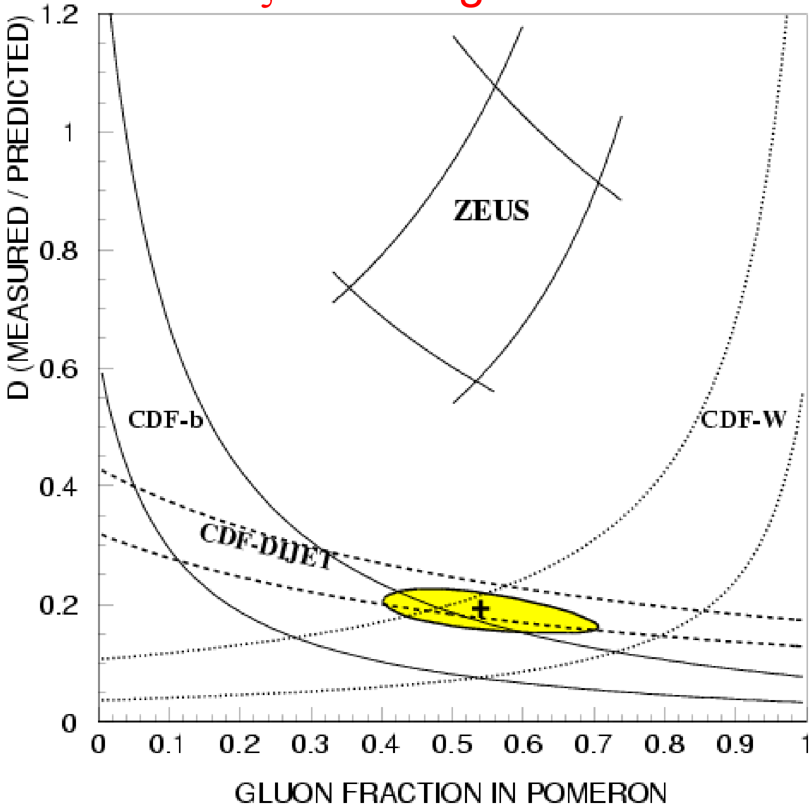
- In Run I, combining diffractive dijet production with diffractive W production was used to determine the quark/gluon content of the Pomeron ===➔
- In Run II, we aim at determining the diffractive structure function for a more direct comparison with HERA.
- To accomplish this we use:
  - ➢ New forward detectors
  - ➢ New methodology
  - ➢ More data

Phys Rev Lett **78**, 2698 (1997)

Fraction of W events due to SD

R_W=[1.15±0.51(stat)±0.20(syst)]%

for ξ<0.1 integrated over t



Diffractive W/Z analysis

Using RPS information:

- No background from gaps due to multiplicity fluctuations
- No gap survival probability problem
- The RPS provides accurate event-by-event ξ measurement
- Determine the full kinematics of diffractive W production by obtaining η_ν using the equation:

$$\xi^{RPS} - \xi^{cal} = \frac{\not{E}_T}{\sqrt{s}} e^{-\eta_\nu} \quad \text{where} \quad \xi^{cal} = \sum_{\text{towers}} \frac{E_T}{\sqrt{s}} e^{-\eta}$$

This allows determination of:

- W mass
- x_{Bj}
- Diffractive structure function

W/Z selection requirements

Standard W/Z selection

$E_T^e (p_T^\mu) > 25\ \text{GeV}$

$\not{E}_T > 25\ \text{GeV}$

$40 < M_T^W < 120\ \text{GeV}$

$|Z_{vtx}| < 60\ \text{cm}$

$E_T^{e1} (p_T^{\mu 1}) > 25\ \text{GeV}$

$E_T^{e2} (p_T^{\mu 2}) > 25\ \text{GeV}$

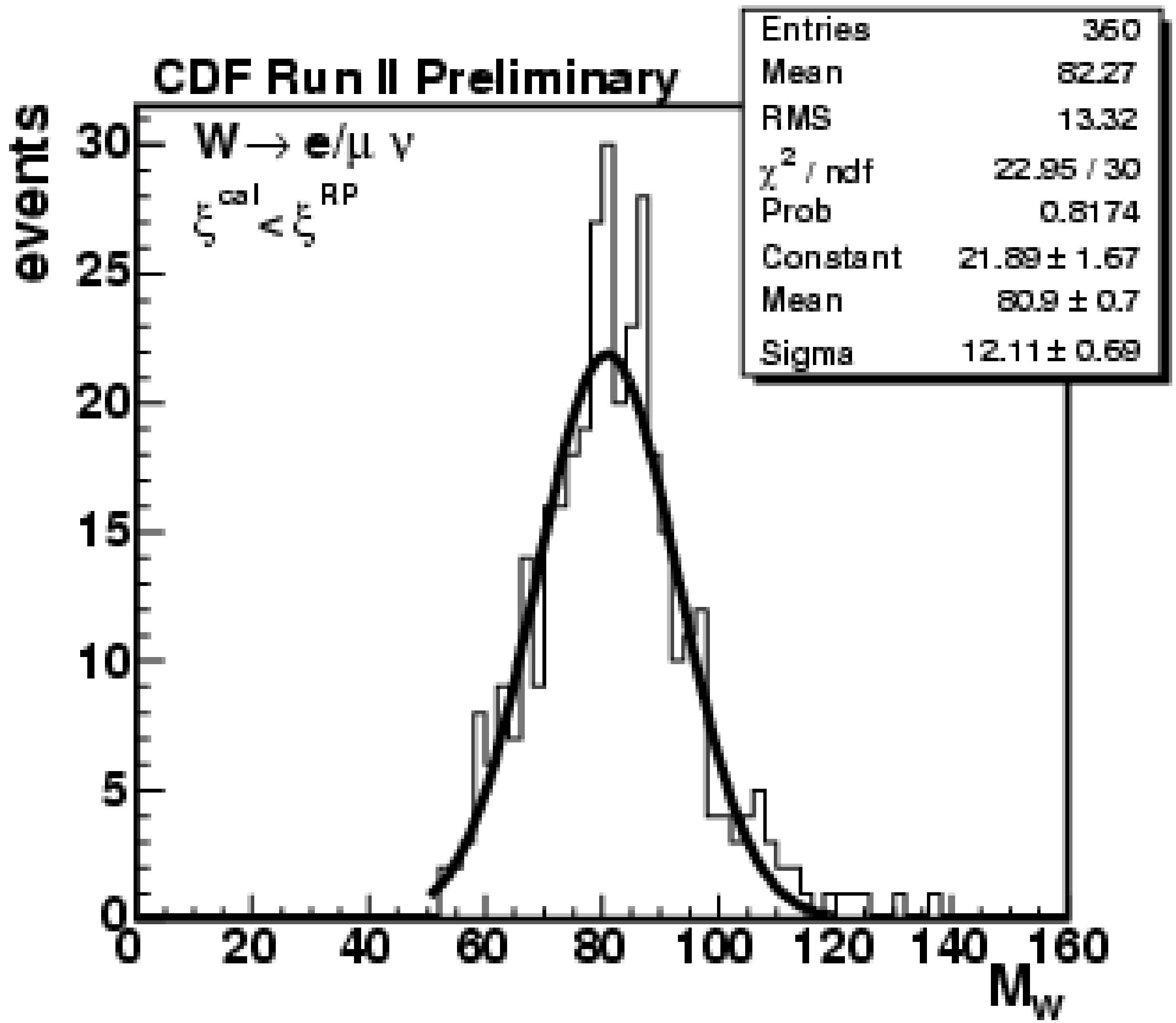
$66 < M^Z < 116\ \text{GeV}$

$|Z_{vtx}| < 60\ \text{cm}$

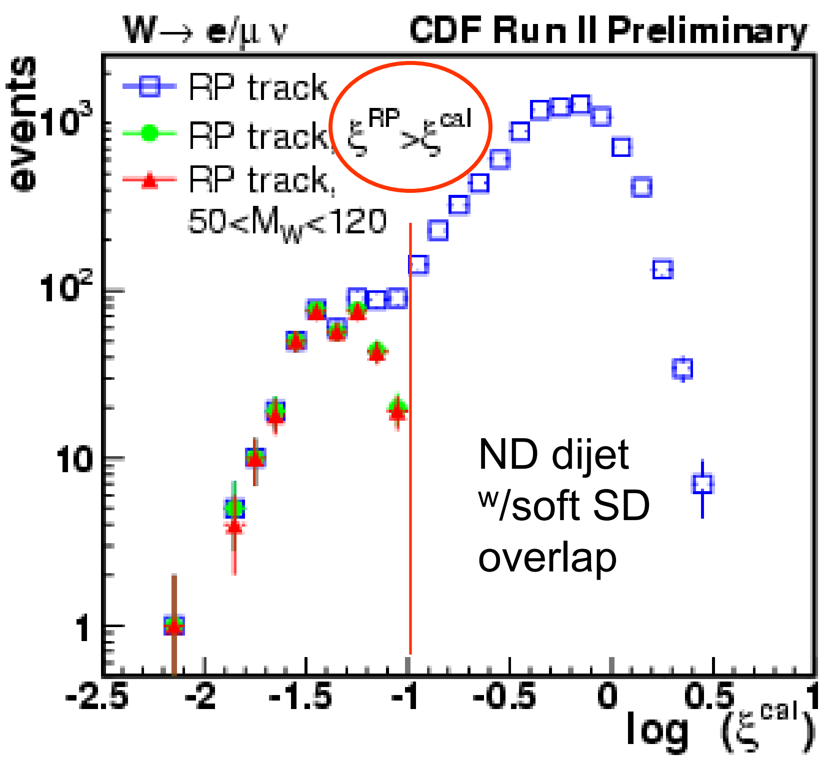
Diffractive W/Z selection

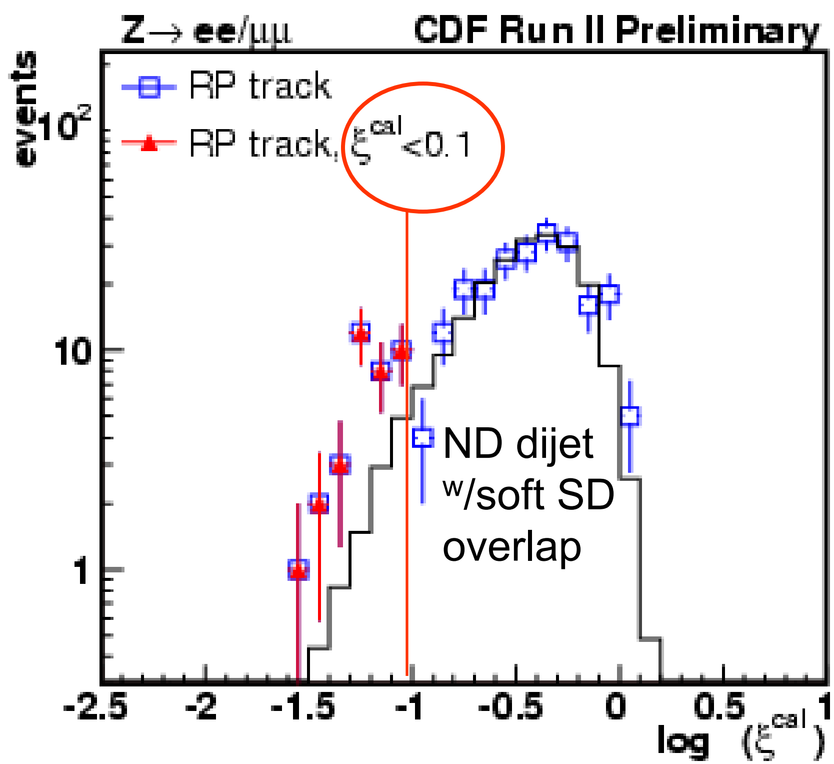
- RPS trigger counters - MIP
- RPS track - $0.03 < \xi < 0.10$, $|t| < 1$
- W ➔ $50 < M_W(\xi^{RPS}, \xi^{cal}) < 120$
- Z ➔ $\xi^{cal} < 0.1$

Reconstructed Diffractive W-Mass



Rejection of Multiple Interactions





Diffractive W/Z results

R^W (0.03 < ξ < 0.10, |t|<1)= [0.97 ± 0.05(stat) ± 0.11(syst)]%

Run I: R^W =1.15±0.55 % for ξ<0.1➔ estimate **0.97±0.47 %** in **0.03 < ξ < 0.10 & |t|<1)**

R^Z (0.03 < x < 0.10, |t|<1)= [0.85 ± 0.20(stat) ± 0.11(syst)]%

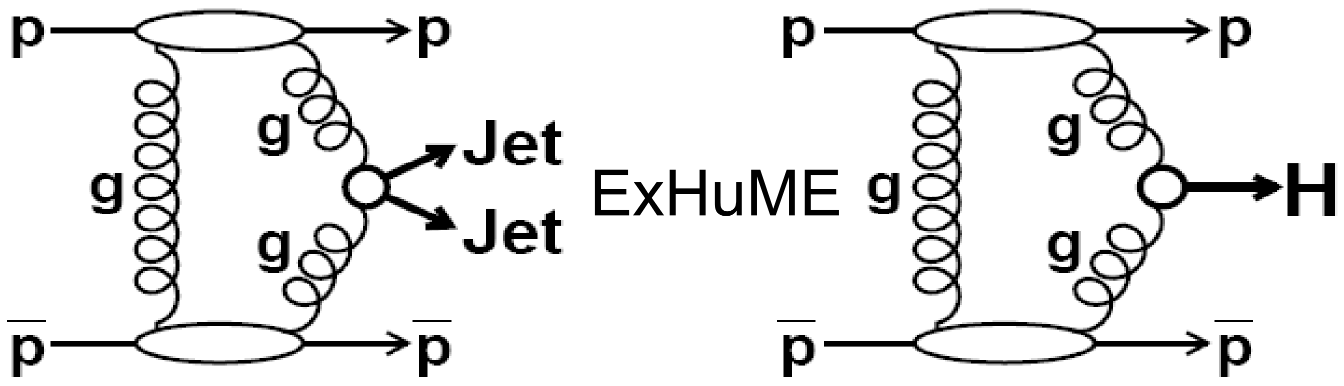
CDF/DØ Comparison – Run I (ξ < 0.1)

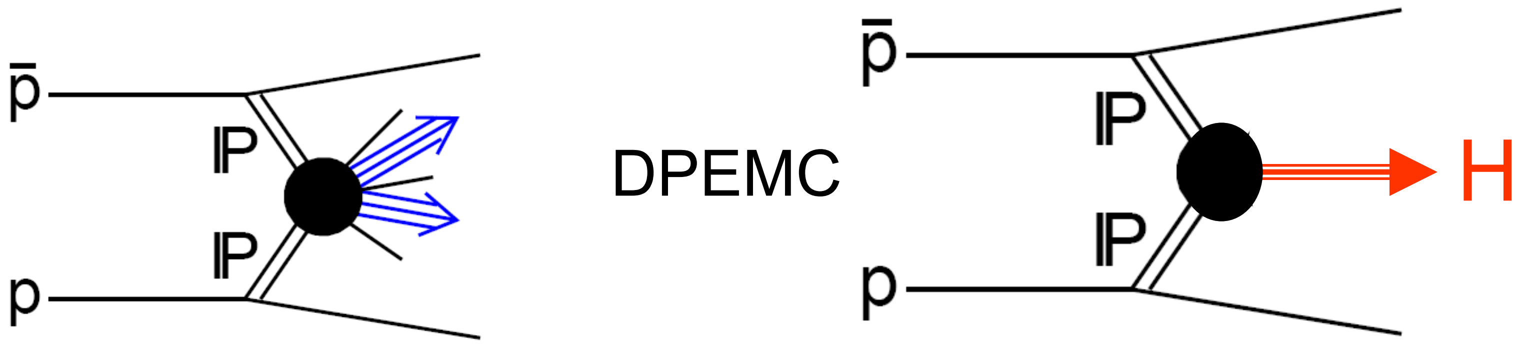
CDF	DØ
CDF PRL 78, 2698 (1997)	DØ Phys Lett B **574**, 169 (2003)
R^w=[1.15±0.51(stat)±0.20(syst)]%	R^w=[5.1±0.51(stat)±0.20(syst)]%
gap acceptance A^{gap}=0.81	gap acceptance A^{gap}=(0.21±4)%
uncorrected for A^{gap} ➔	uncorrected for A^{gap}➔
R^W=(0.93±0.44)%	R^W=[0.89+0.19-0.17]%
(A^{gap} calculated from MC)	R^Z=[1.44+0.61-0.52]%

Stay connected for $F^D_{W/Z}$

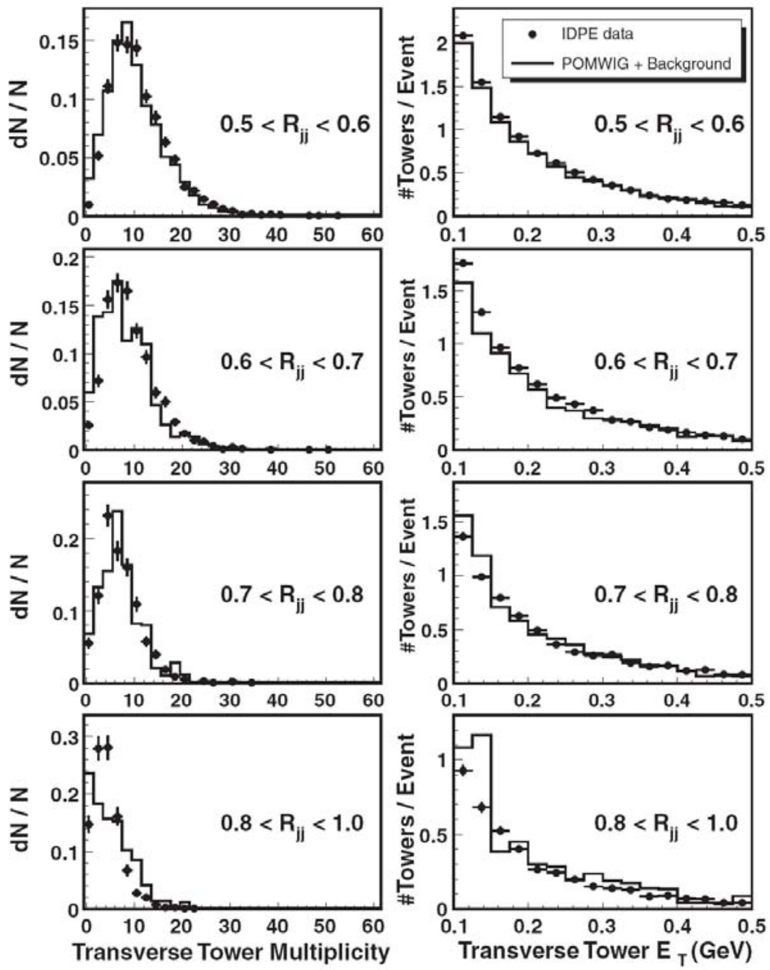
Exclusive Dijet and Higgs Production

Phys. Rev. D 77, 052004

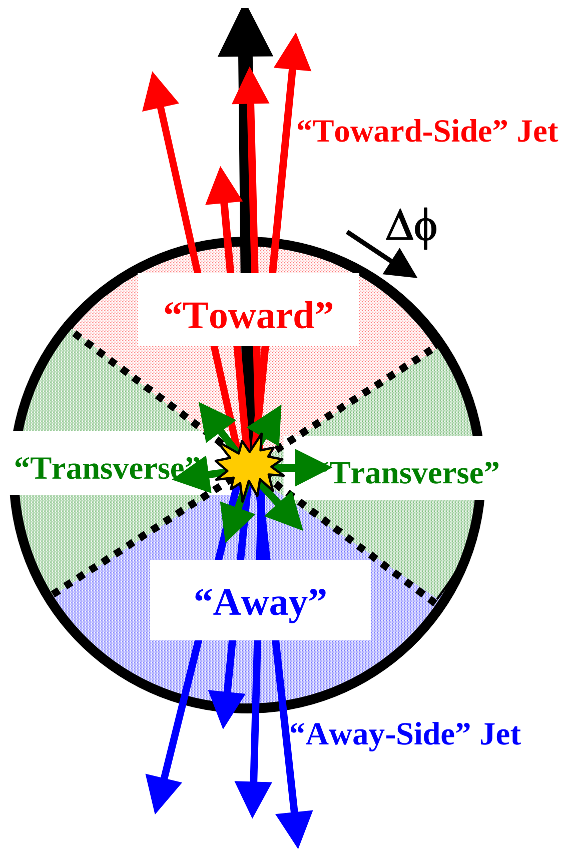




Underlying Event (UE)



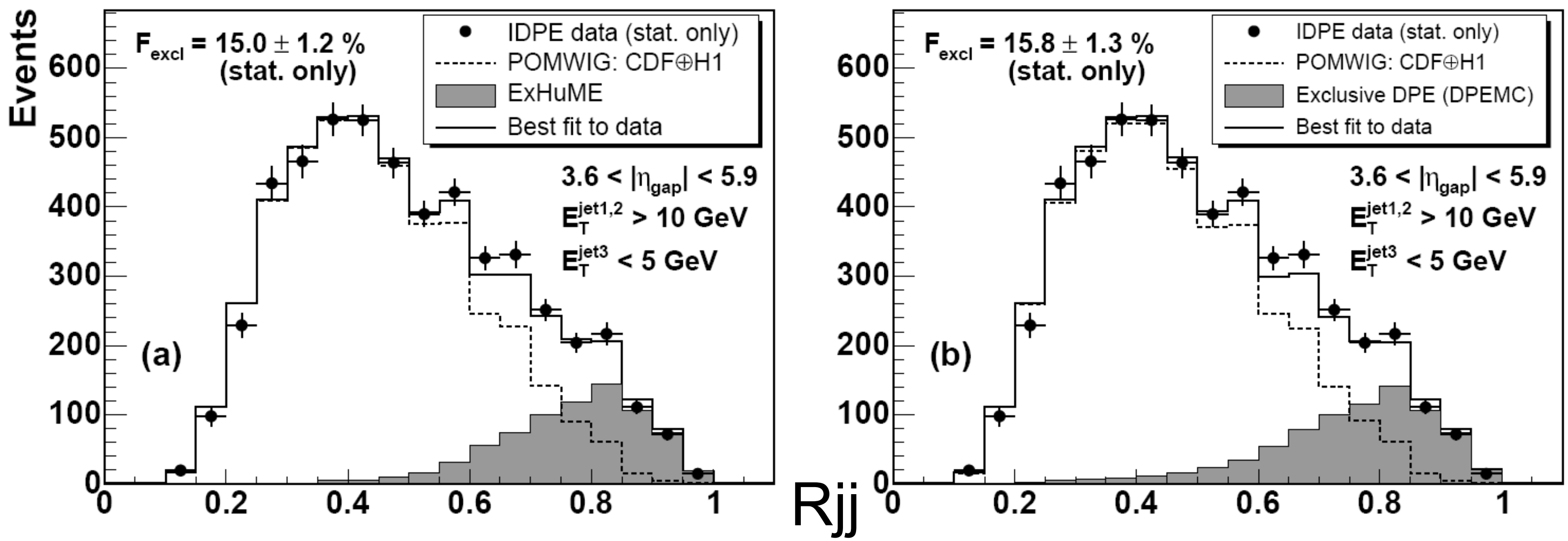
Is it modeled correctly?



The data and POMWIG+Background distributions in the transverse $\Delta\phi$-region relative to the di-jet axis agree, indicating that the UE is correctly modeled.

Inclusive DPE ^{W}/LRG$_{p}$: Data vs. MC

ExHuME ←exclusive MC models→ DPEMC

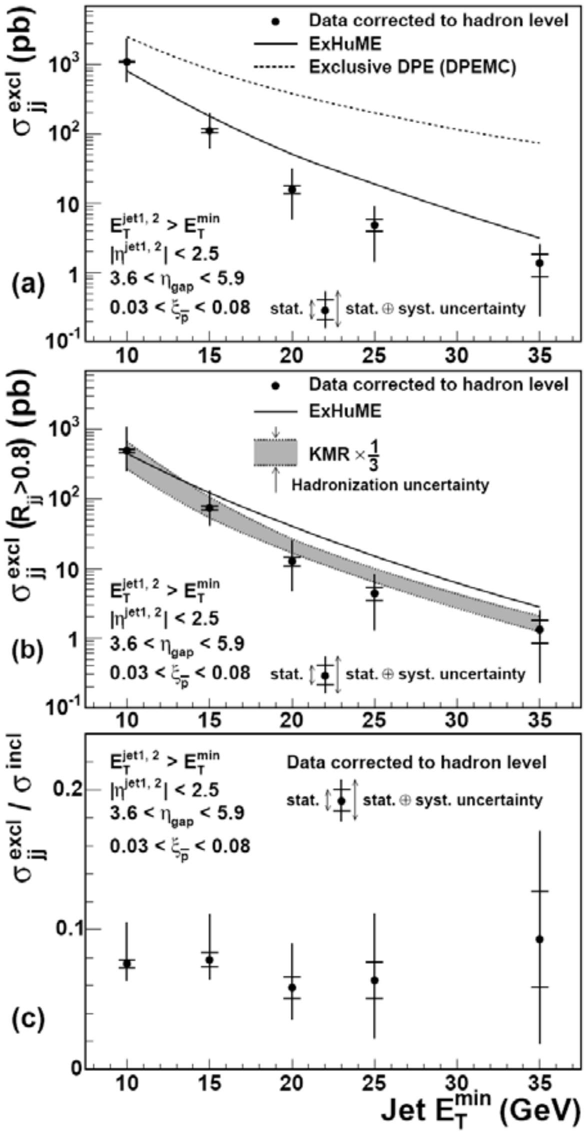


ExHuME (KMR): gg→gg process
(based on LO pQCD)

DPEMC: exclusive DPE MC
based on Regge theory

Shape of excess of events at high R_{jj}
is well described by both ExHuME & DPEMC – but…

ExHuME vs. DPEMC and vs. data



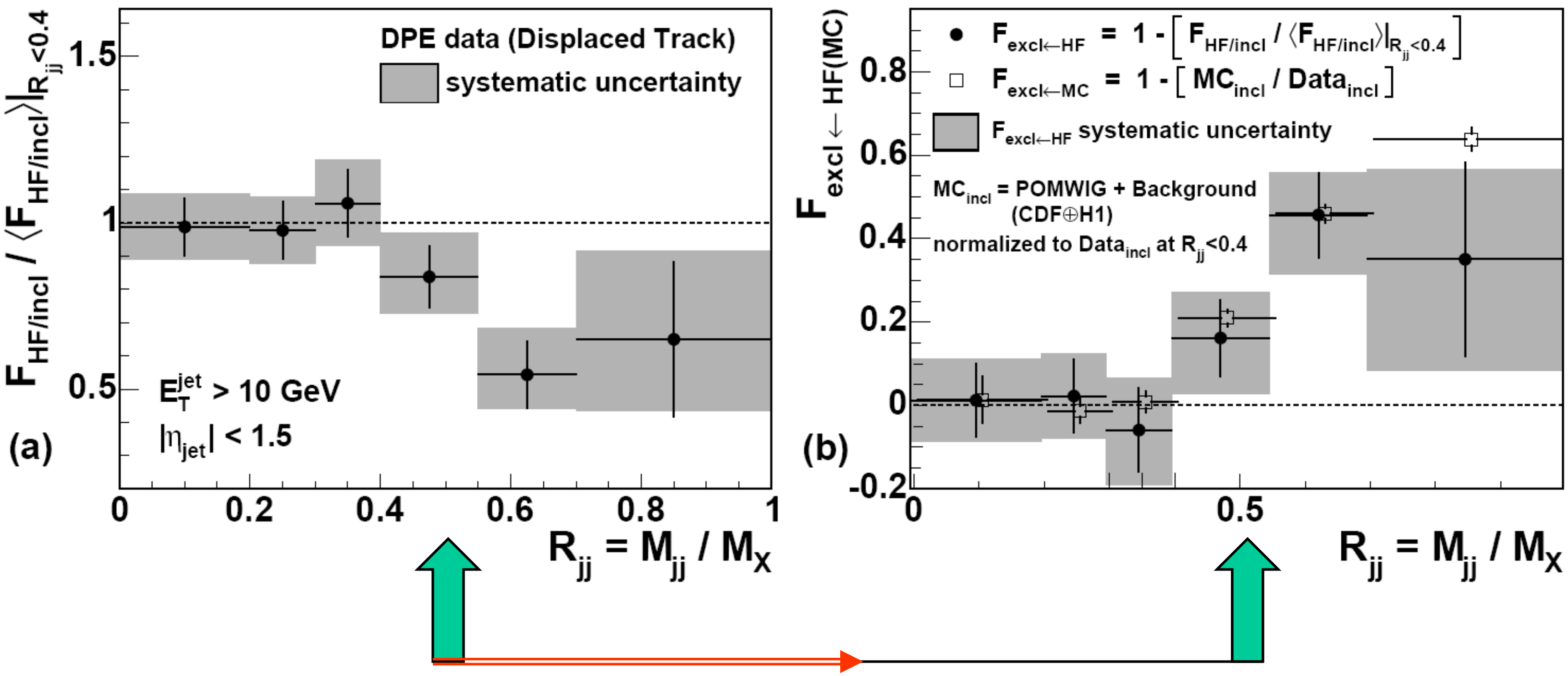
- Measured x-sections favor ExHuME

- KMR x 1/3 agrees with data
  - ➔ Within theoretical uncertainty of +/- factor of 3

- $\sigma_{jj}^{excl}/\sigma^{incl}$ approx. independent of E_T^{min}

Heavy Flavor suppression vs. Inclusive Signal

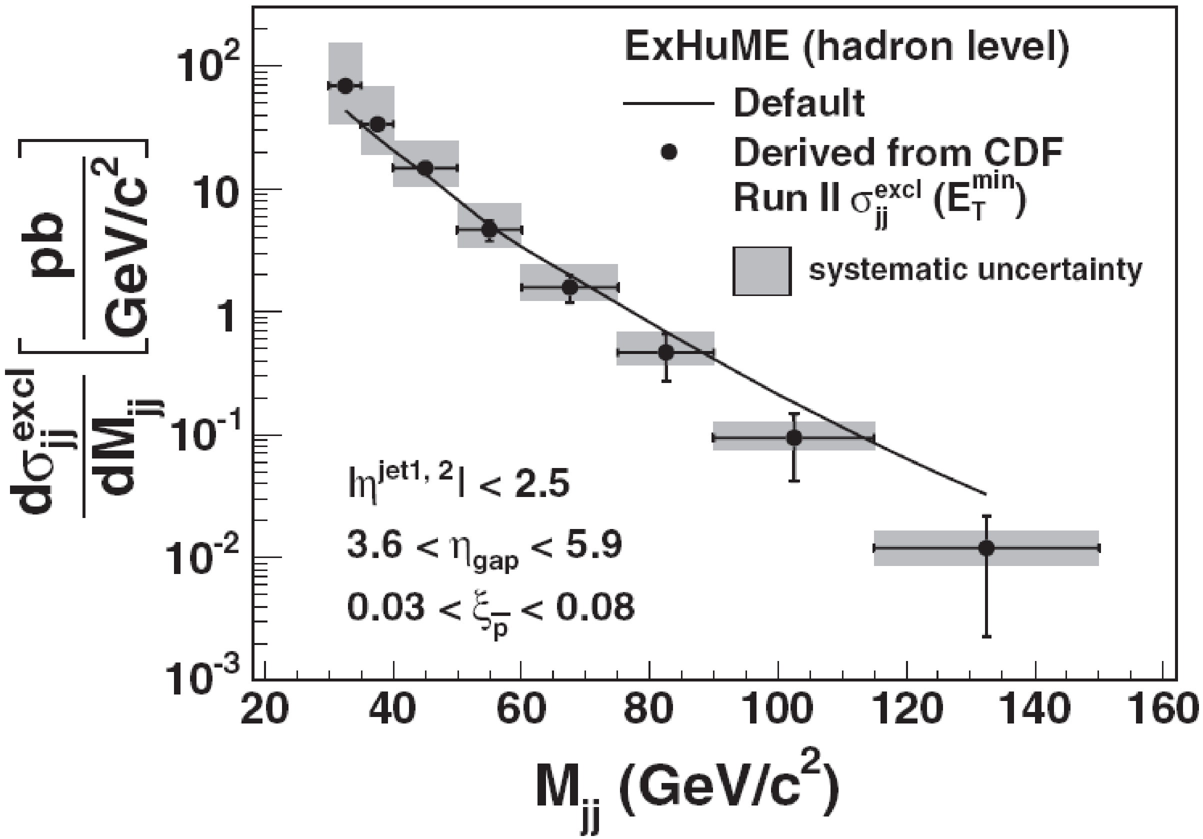
HF suppression   HF suppression vs. Incl



Invert HF vertically and compare with 1-MC/DATA

➔ good agreement observed

Exclusive Dijet x-section vs. M_{jj}



line: ExHuME hadron-level exclusive di-jet cross section vs. di-jet mass

points: derived from CDF excl. di-jet x-sections using ExHuME

Stat. and syst. errors are propagated from measured cross section uncertainties using M_{jj} distribution shapes of ExHuME generated data.

Exclusive $\ell\ell$ and $\gamma\gamma$

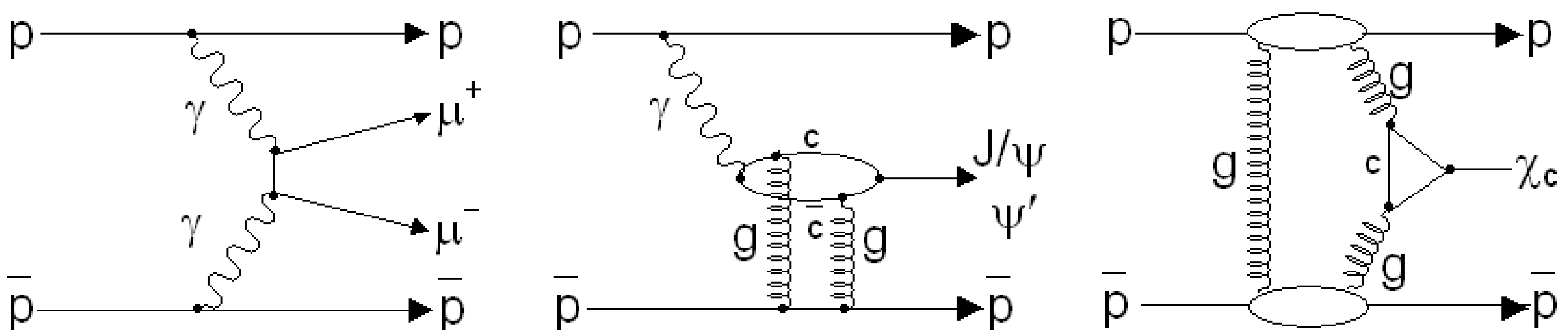
$$e^+e^-(>10),\ \gamma\gamma(>10),\ \mu^+\mu^-(3-4),\ J/\psi,\ \psi(2S),\ \chi_c^0,\ l^+l^-(>40),\ Z$$

PRL98, 112001 2007 — $e^+e^-(>10)$

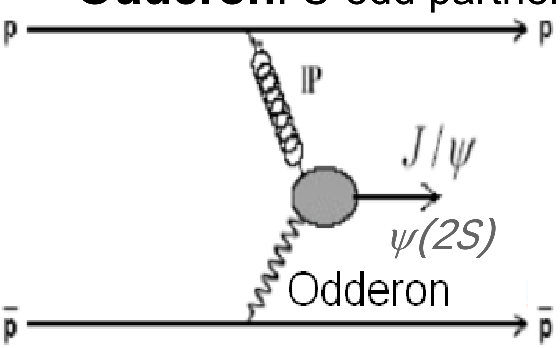
PRL99, 242002 2007 — $\gamma\gamma(>10)$

PRL under coll. review — $\mu^+\mu^-(3-4),\ J/\psi,\ \psi(2S),\ \chi_c^0$

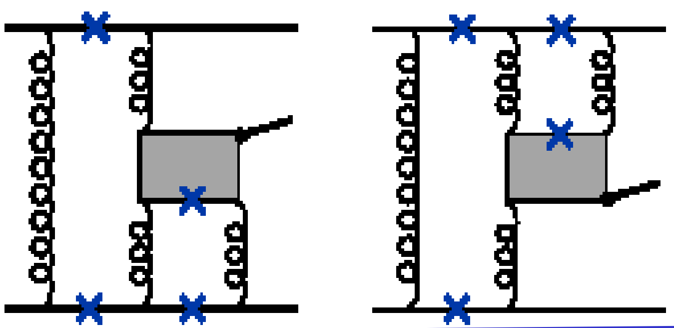
PRL under coll. review — $l^+l^-(>40),\ Z$



Odderon: C-odd partner of Pomeron →3 gluons in a color-neutral state



LO diagrams



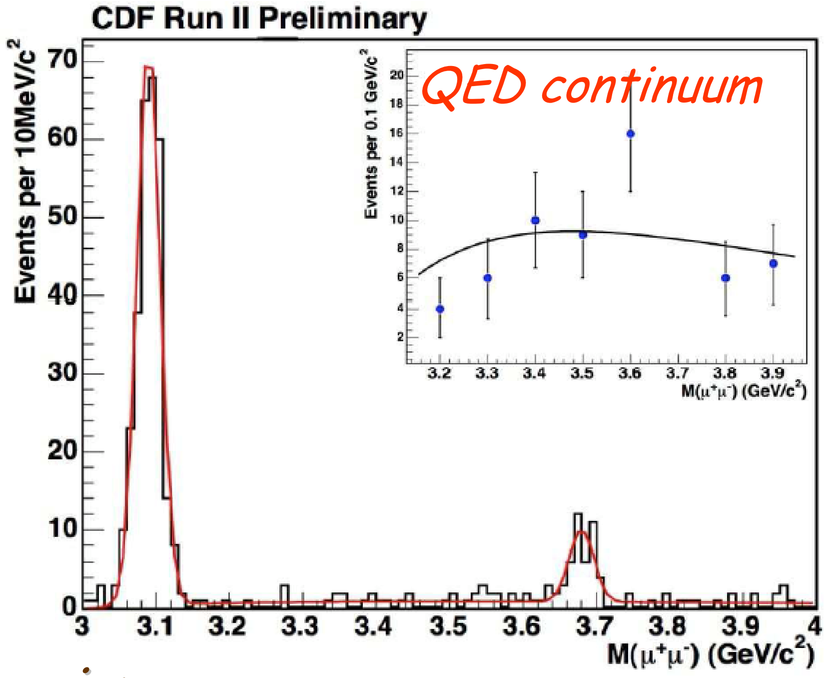
Exclusive J/ψ and ψ(2s) production*

J/ψ production

$d\sigma/dy|_{y=0}$ = 3.92 ± 0.62 nb

In agreement with av. Prediction of 3.0 ± 0.3 nb

2.8 nb [Szczurek07,], 2.7 nb [Klein&Nystrand04],
3.0 nb [Conclaves&Machado05], and
3.4 nb [Motkya&Watt08].



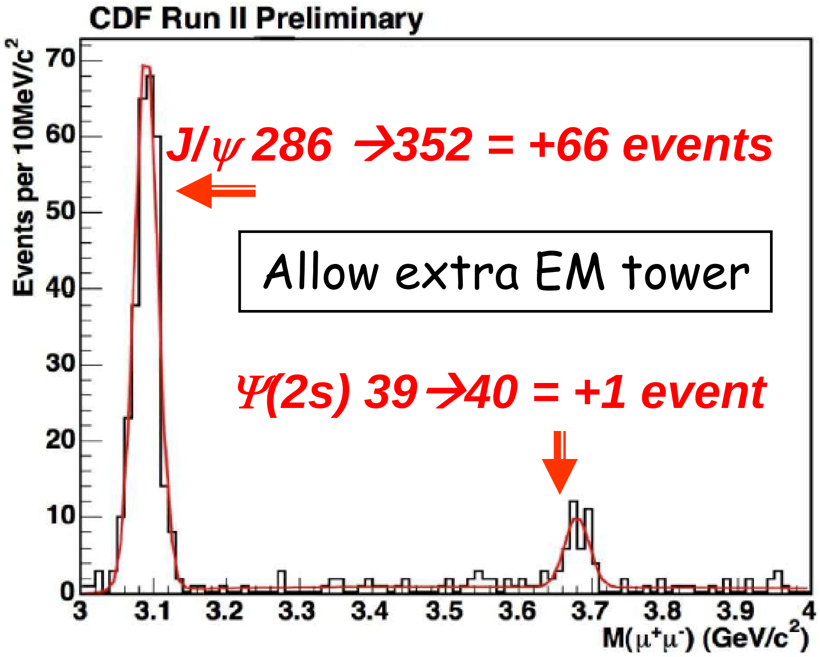
Ψ(2s) production

$d\sigma/dy|y=0$ = 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

* James Pinfold http://www.fp420.com/conference/dec2008/index.html

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



- *Allowing EM towers (with EmE_T > 80 MeV gives a large increase in the J/ψ peak but a minor change in the $\psi(2s)$ peak*

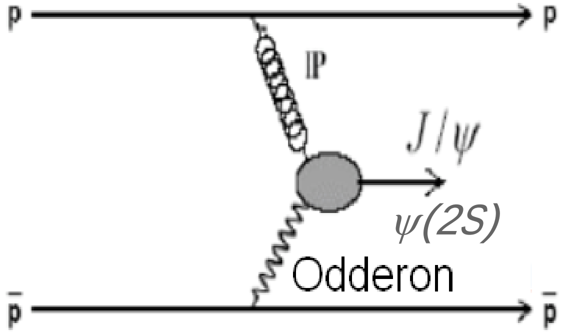
⇒ Evidence for $\chi_c \to J/\psi + \gamma$ production

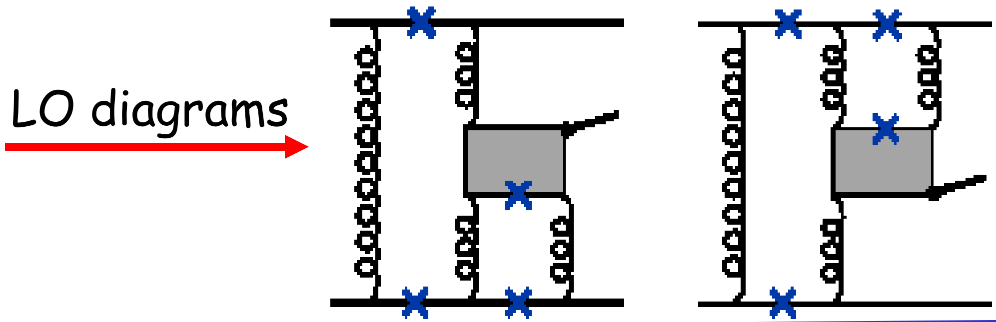
$d\sigma/dy|_{y=0}$ = 75 ± 14 nb, compatible with theoretical predictions of 150 nb (Yuan 01) & 130 nb (KRS01) – error of $\mathcal{O}$(50 nb)

* James Pinfold http://www.fp420.com/conference/dec2008/index.html

Exclusive $\mu^+\mu^-$ and the Odderon*

Odderon: C-odd partner of Pomeron →3 gluons in a color-neutral state

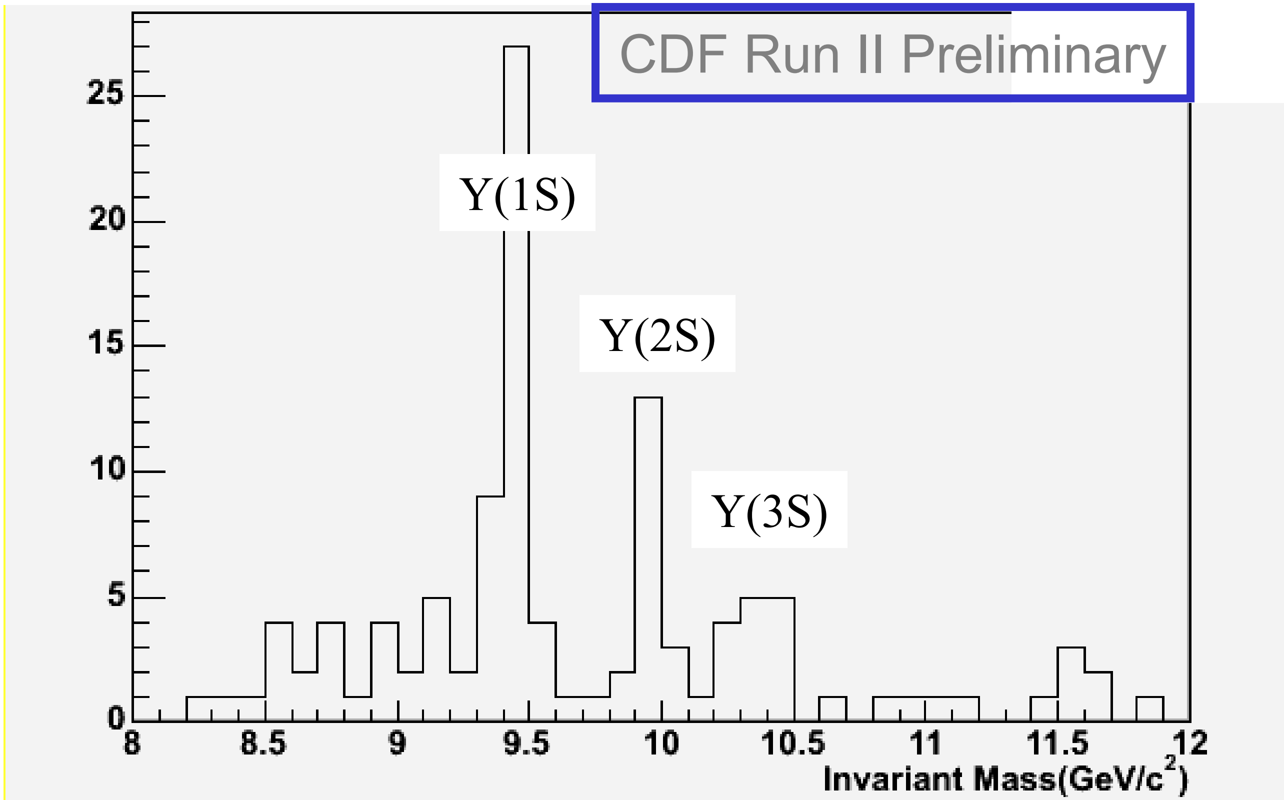




- ***The odderon would contribute to J/ψ, $\psi(2s)$ (& Υ) peaks*** *-not the χ_c*
- ***The J/ψ & $\psi(2s)$ cross-sections agree with predictions*** *(that fit the HERA data) → no significant odderon signa*
  - ***R (exp./theory)*** *$_{J/\psi}$ = 1.32 ± 0.41 ,* ***R (exp./theory)*** *$_{\psi(2s)}$ = 1.15 ± 0.21*
    ➔ ***R(data/theory)*** *[combined J/ψ & $\psi(2s)$]= 1.19 ± 0.19*
- ***Limit on odderon prod.*** *- R[(O-IP)→V/(γ-IP)→V] < 0.34 (95% CL)*
- ***Another limit****: R[(O+γ)IP→J/ψ / IP-IP→ χ_c(3415)] < 0.060 ± 0.015*

* James Pinfold http://www.fp420.com/conference/dec2008/index.html

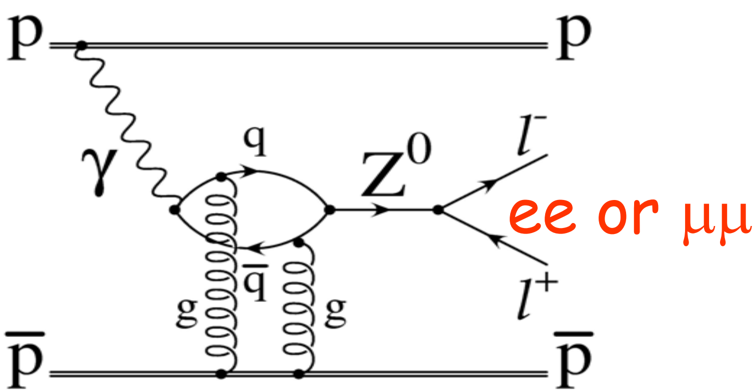
Exclusive Upsilon photoproduction*



$M(\mu^+\mu^-)$ with $p_T(\mu^+\mu^-) < 1.5$ GeV/c and $\pi - \Delta\phi < 0.34$ rad

* Michael Albrow http://www.fp420.com/conference/dec2008/index.html

Exclusive Z / $\gamma\gamma \rightarrow \ell\ell$ studies*



Exclusive Z SM cross section:

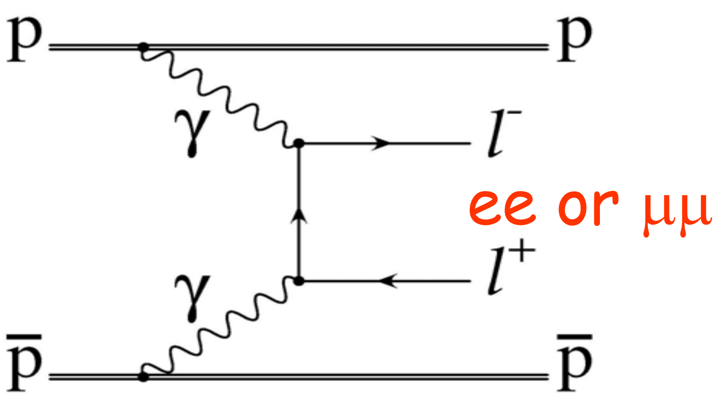
0.3 fb [Motyka & Watt][1]

1.3 fb [Goncalves & Machado][2]

Expect ~0.6 - 2.6 events in 2 fb-1 (not including 3.37% leptonic BF).

➔Search for BSM physics, e.g. color sextet quark model[3]: much enhanced cross section expected.

[1] Phys. Rev. D78, 014023 (2008)
[2] Eur. Phys. J., C56 33 (2008)
[3] Phys. Rev. D72,036007



Exclusive di-lepton cross section:

- Background to exclusive Z
- Can be used to calibrate forward proton detectors:

$$\xi = s^{-1/2} \sum p_T e^{-\eta}$$

* Emily Nurse http://www.fp420.com/conference/dec2008/index.html

Exclusive z / $\gamma\gamma \rightarrow \ell\ell$ results

$\mathcal{L}$ = 2.20 (2.03) fb^{-1} in the electron (muon) channels

e+e- or μ+μ- with p^T > 25 GeV

$|\eta_{\mu}^{1}| < 1.0$, $|\eta_{\mu 2}| < 1.5$

$|\eta_{e}^{1}| < 1.3$, $|\eta_{e}^{2}| < 3.6$

require $82 < M_{\ell\ell} < 98$ GeV

$W \rightarrow \ell\nu$ events used as a control to study exclusivity cuts

CDF Run II Preliminary

Exclusive di-leptons

$\sigma(pp \rightarrow p\,\ell\,\ell\,p) = 0.24^{+0.13}_{-0.10}$ pb

$M_{\ell\ell} > 40$ GeV, $|\eta_{\ell}| < 4.0$

LPAIR prediction: σ = 0.256 pb]

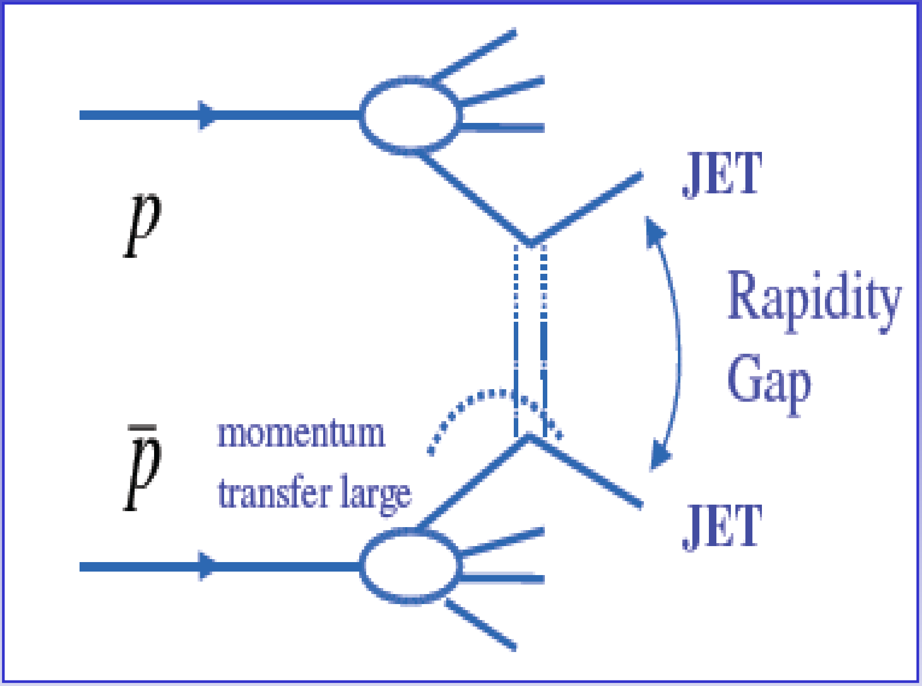
Exclusive Z

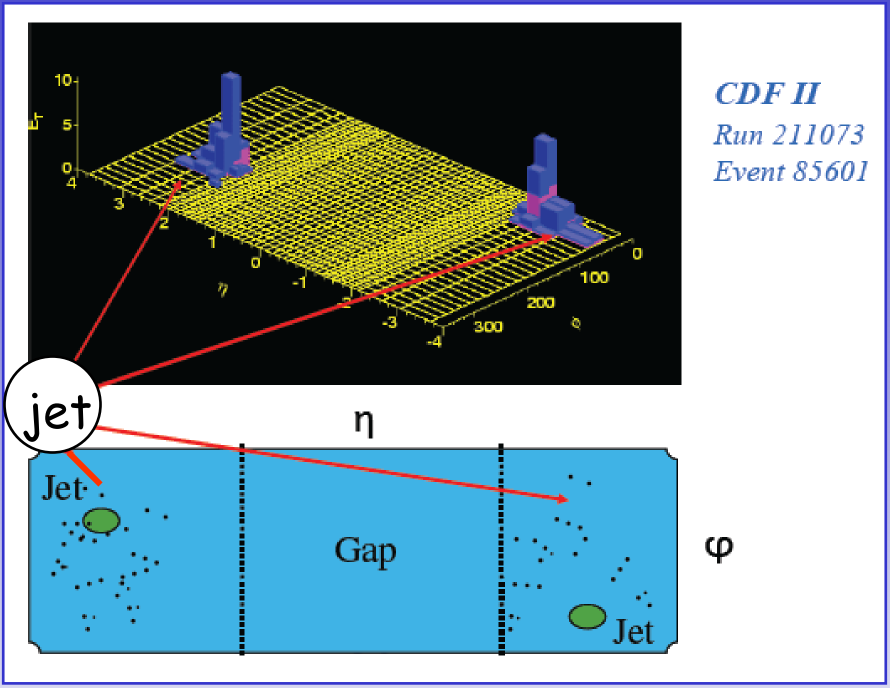
$\sigma(Z_{excl}) < 0.96$ pb @ 95% C.L.

SM: 0.3 fb [Motyka & Watt]

1.3 fb [Goncalves & Machado]

CENTRAL RAPIDITY GAPS *

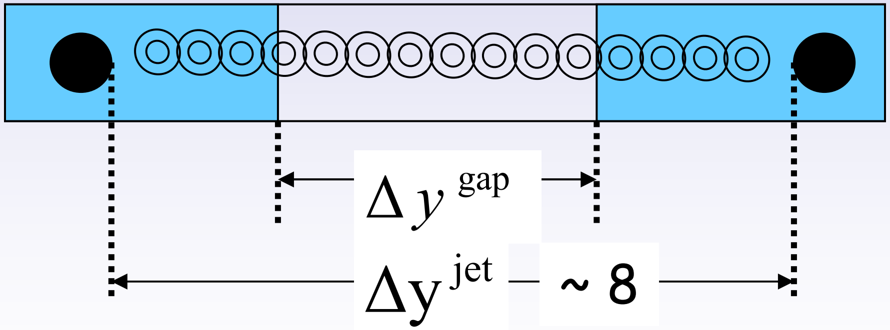




- Measure Δy^{gap} width and position to differentiate among models.

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

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

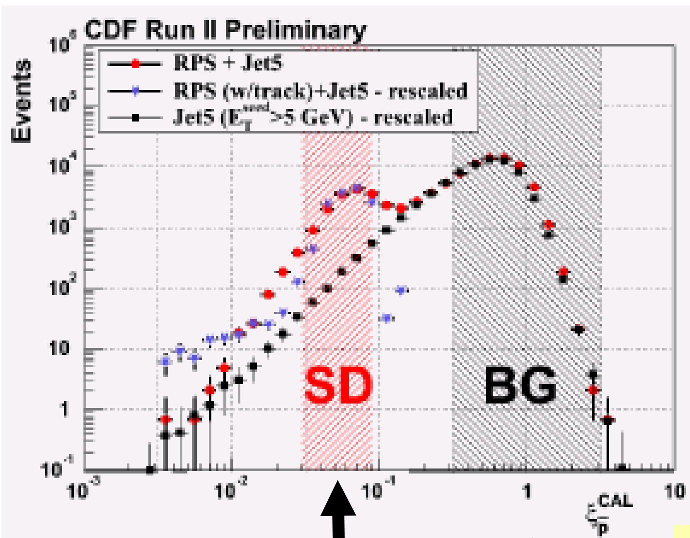


* Christina Mesropian http://www.cs.infn.it/diff2008/program.html

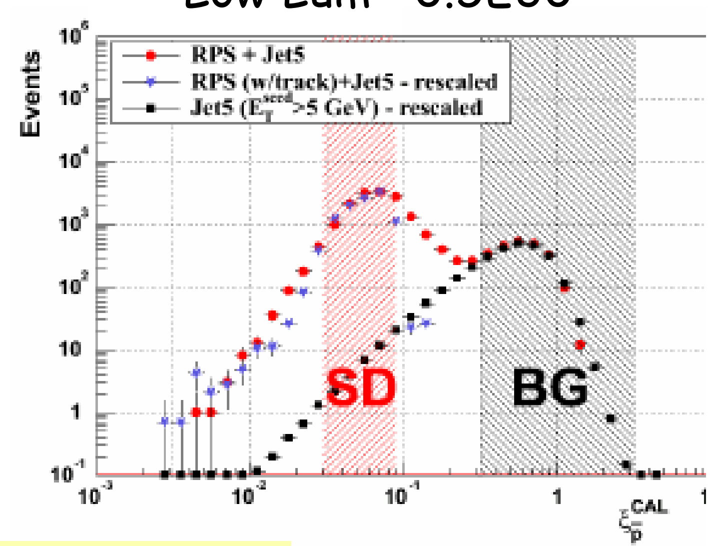
Low Luminosity Run

➔ January 2006: data with dedicated diffractive triggers ←

2002-303 data ~1.5E31



Low Lum ~0.5E30



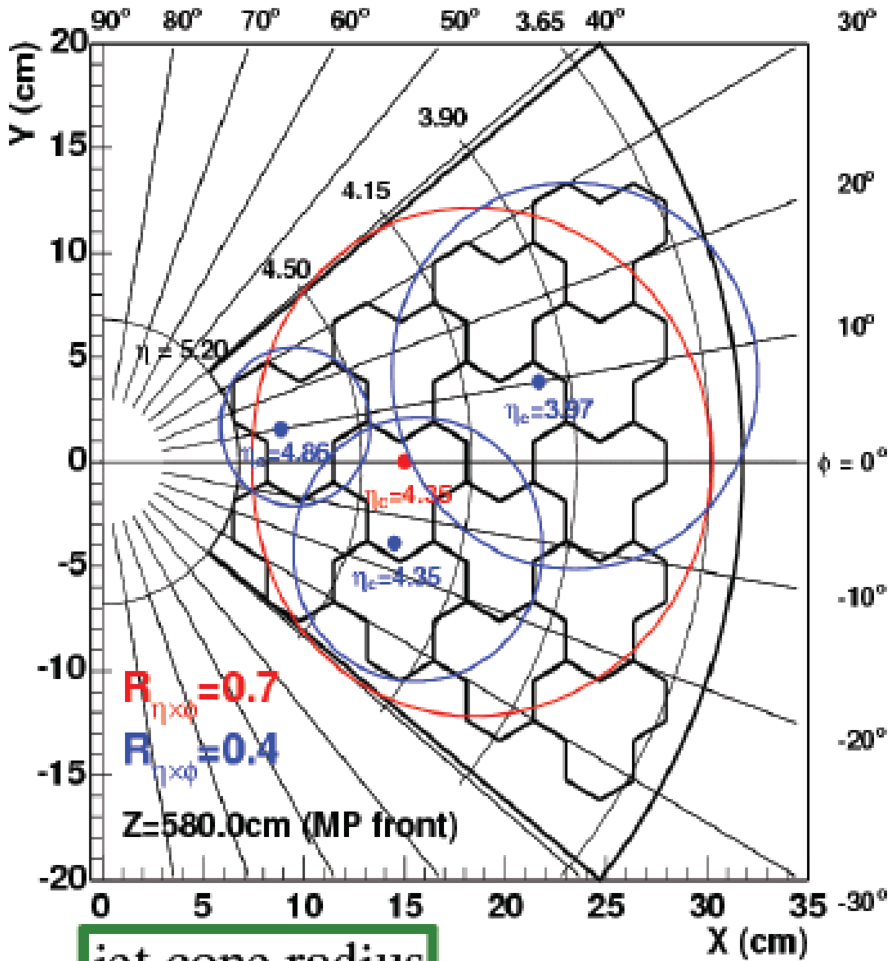
$$\xi^{cal} = \sum_{towers} \frac{E_T}{\sqrt{s}} e^{-\eta}$$

single diffraction
0.03 < ξ < 0.1

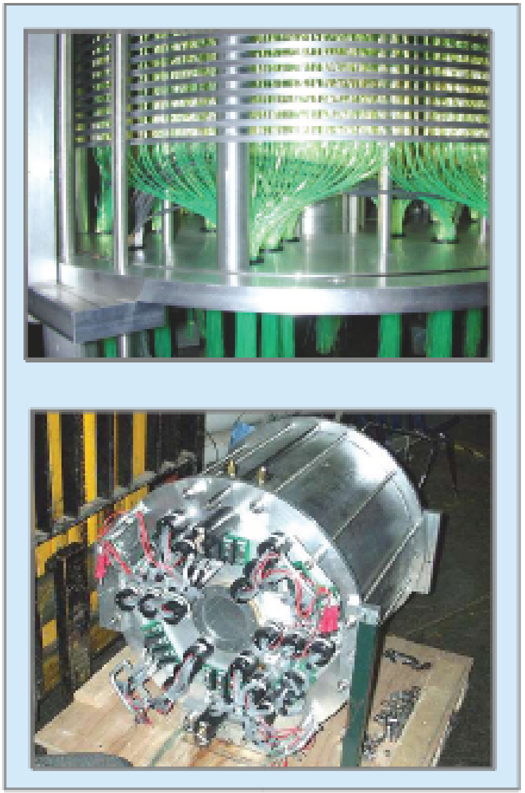
diffractive dijet overlapped with MB soft diffraction

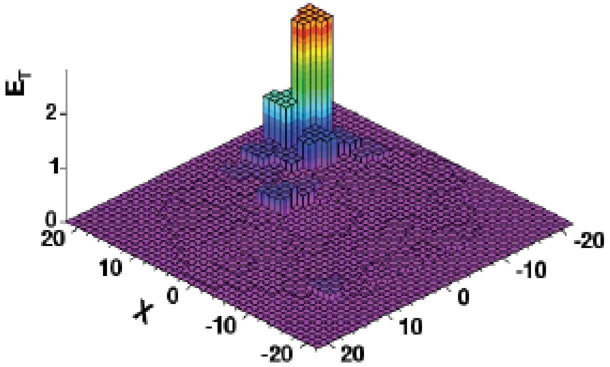
MiniPlug Jets

Nucl. Instrum. Meth. A518 (2004) 42.
Nucl. Instrum. Meth. A496 (2003) 333.



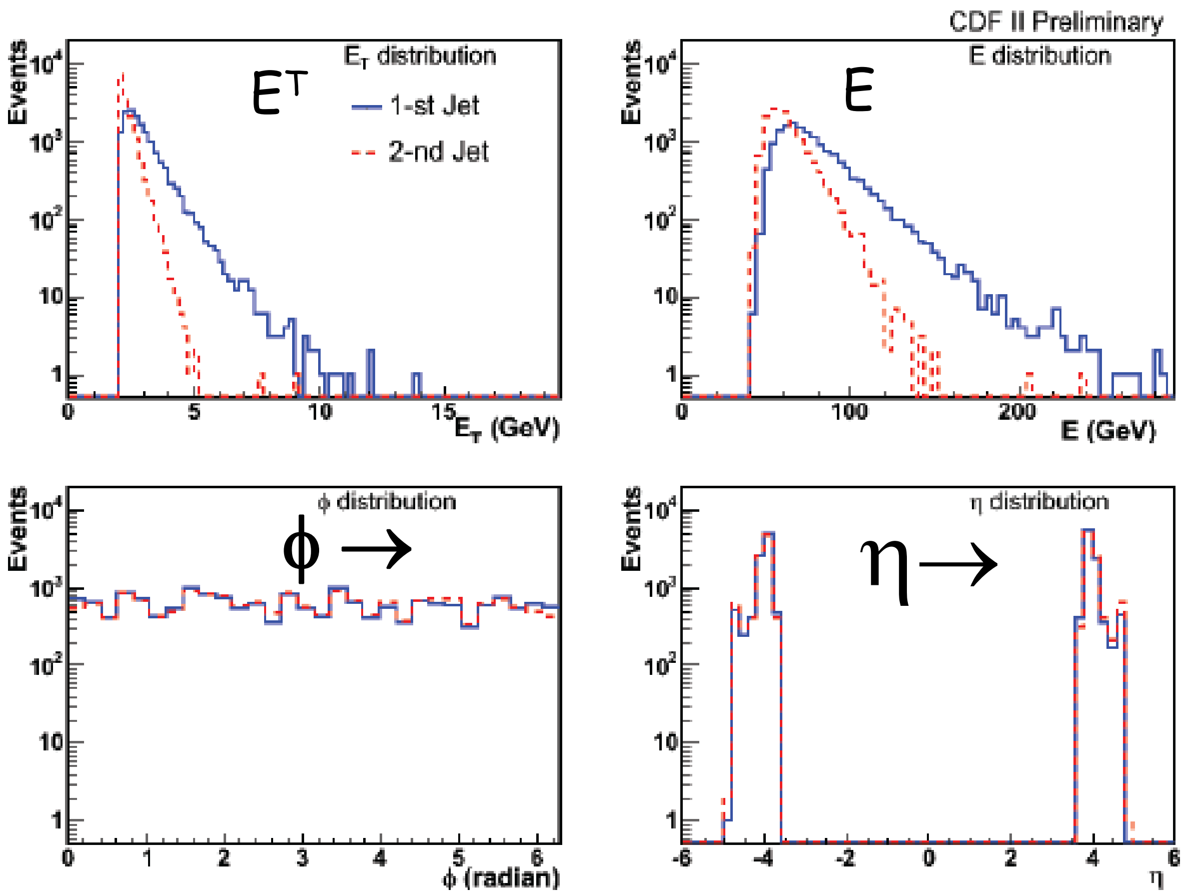
jet cone radius
R = 0.4 (0.7)



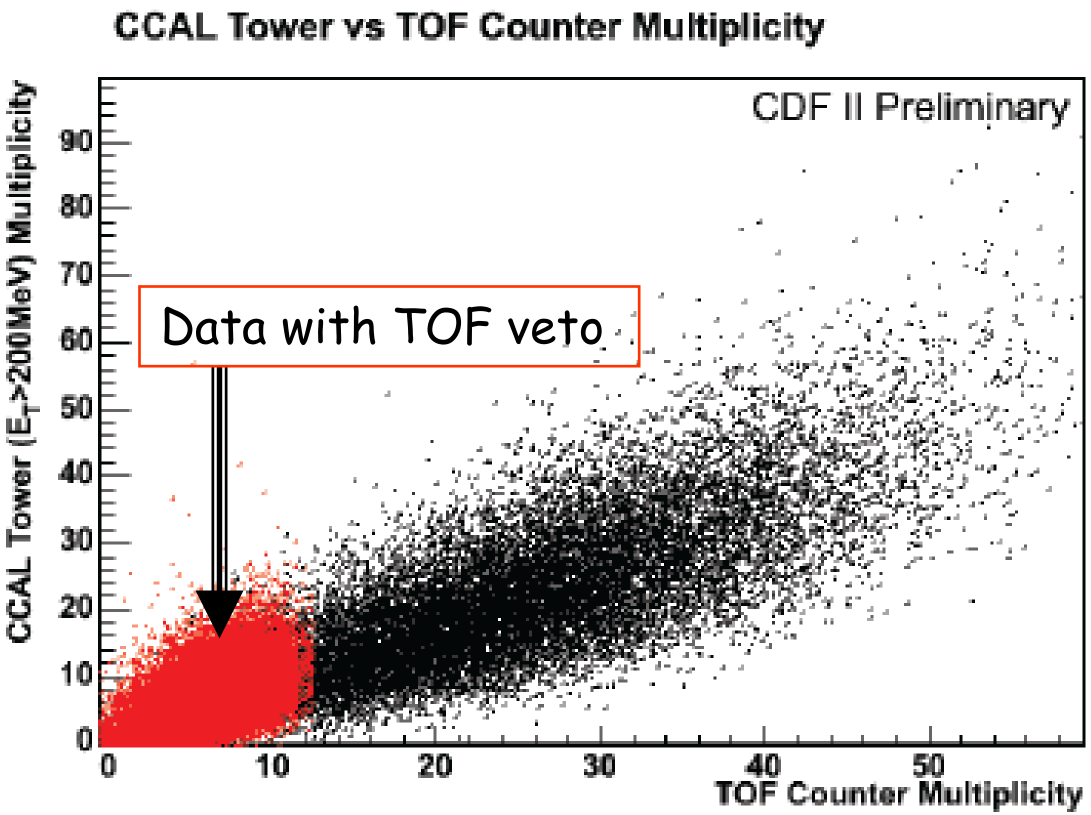


MiniPlug Jet Properties

$E_T^{jet1,2} > 2$ GeV, $3.5 < |\eta|^{jet1,2} < 5.1$, $\eta^{jet1}.\eta^{jet2} < 0$

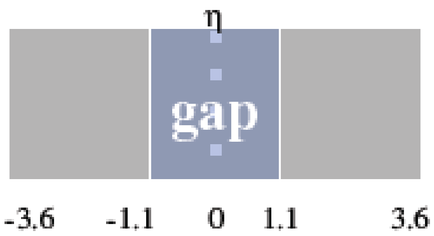


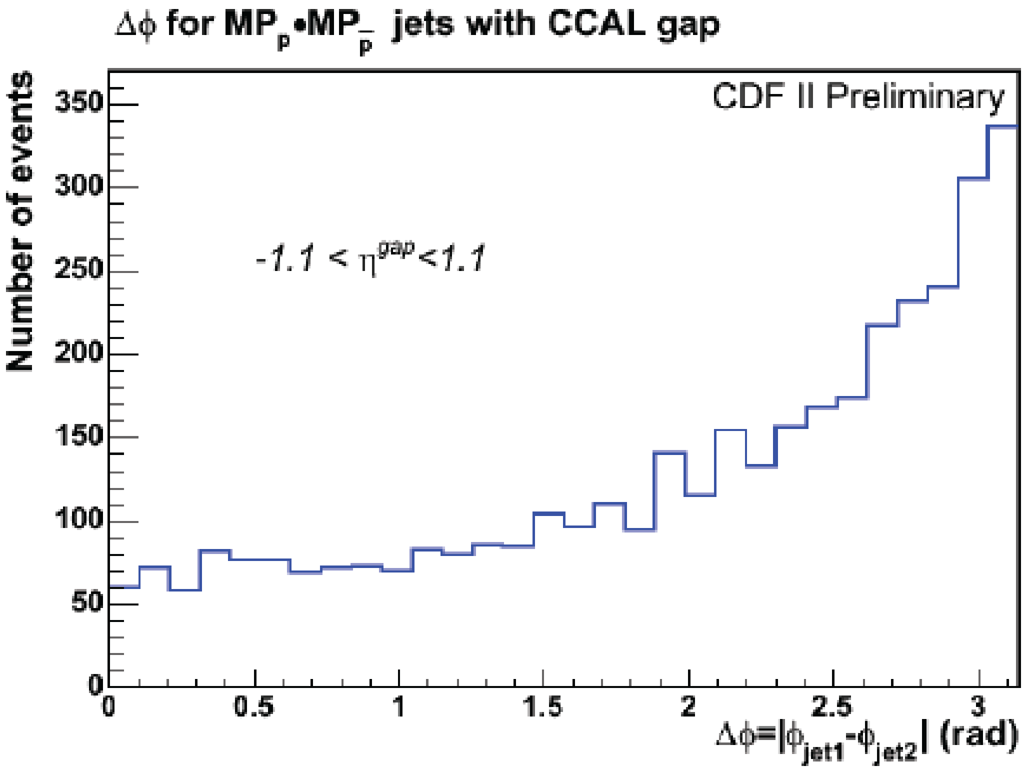
MP Jet Data with TOF Veto



The number of CCAL towers with E^T>200 MeV is suppressed by the TOF veto

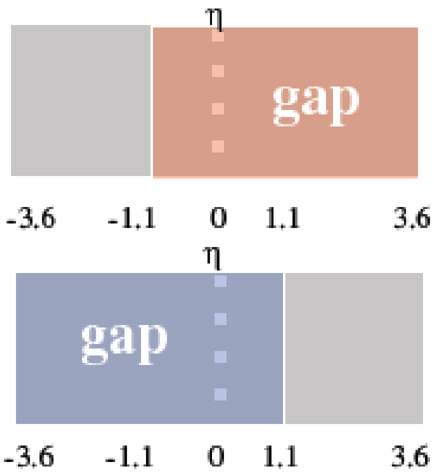
CCAL gap

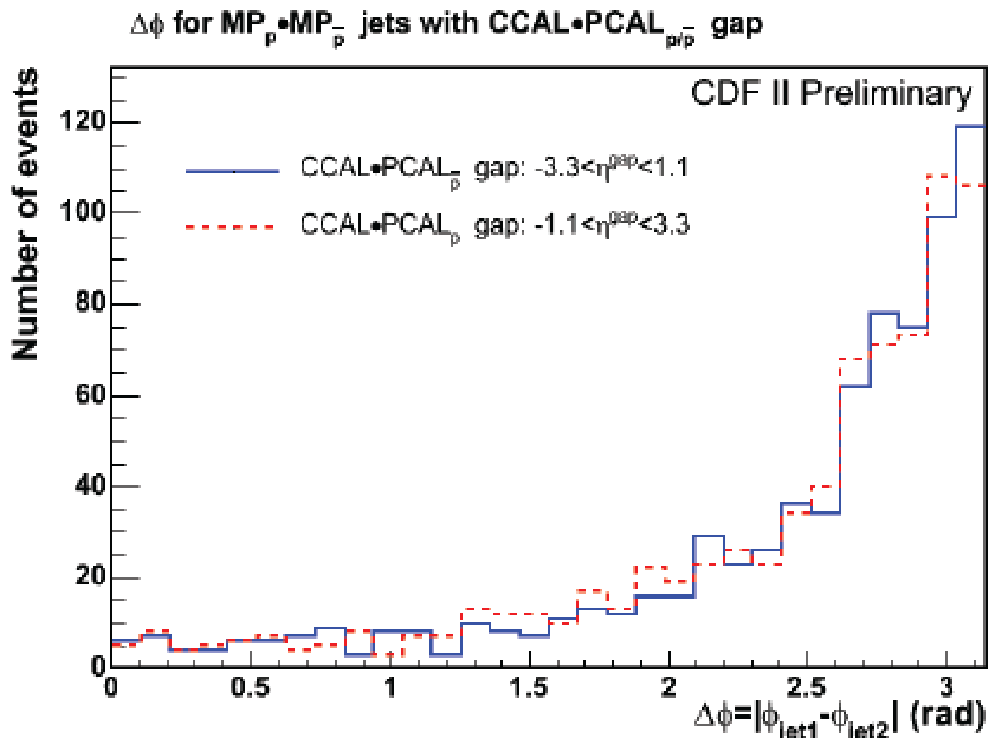




The distribution of $\Delta\varphi$ *for* $MP_p{\bullet}MP_{pbar}$ *jets of* $E_T{>}2$ *GeV with a gap in the central calorimeter (CCAL). The events at low values of* $\Delta\varphi$ *are presumed to be due to an imbalance caused by the* E_T *of* $PCAL_p$ *and* $PCAL_{\bar{p}}$ *towers from the underlying event.*

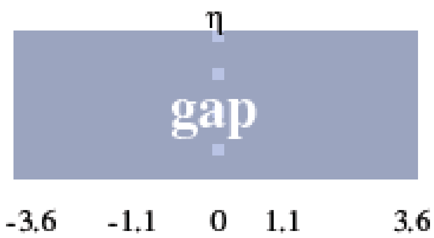
CCAL • PCAL $^{p}/_{pbar}$ Gap

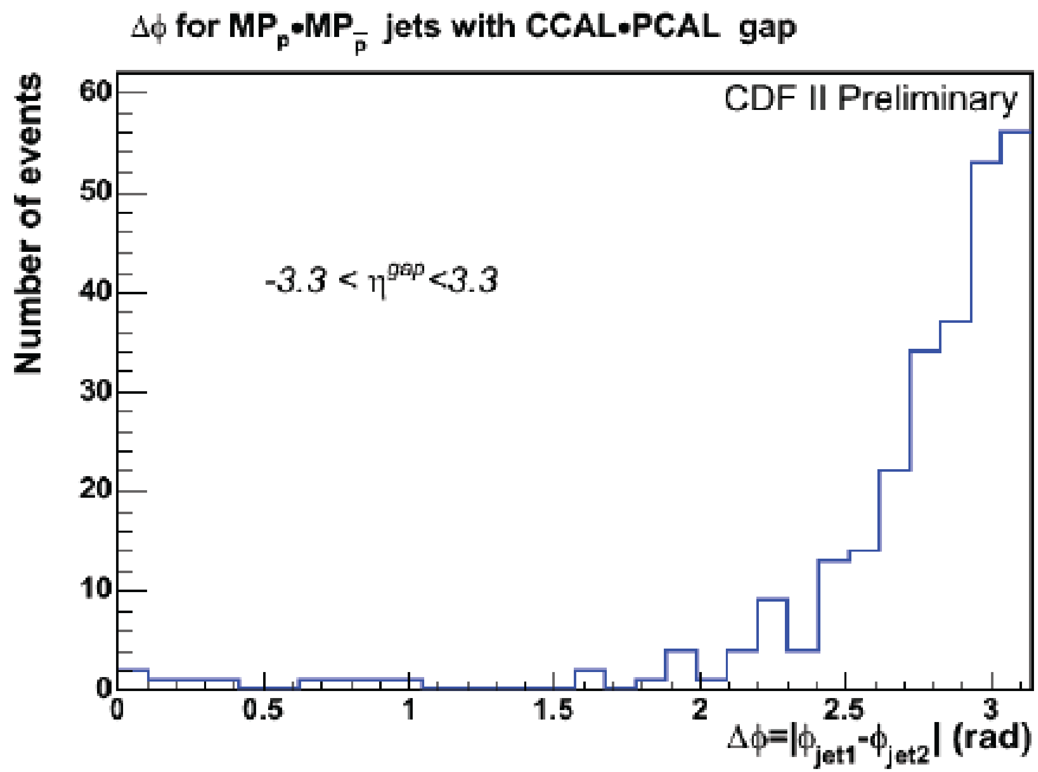




The distribution of $\Delta\varphi$ for $MP_p \bullet MP_{pbar}$ jets of E_T>2 GeV with a gap in the central calorimeter (CCAL) plus a gap in one of the Plug calorimeters PCAL(p) or PCAL(pbar). The events at low values of $\Delta\varphi$ are presumed to be due to the imbalance caused by the E_T of PCAL(p) or PCAL(pbar) towers from the underlying event. The agreement between the two distributions indicates that detector and beam conditins effects are similar between positive and negative eta-values.

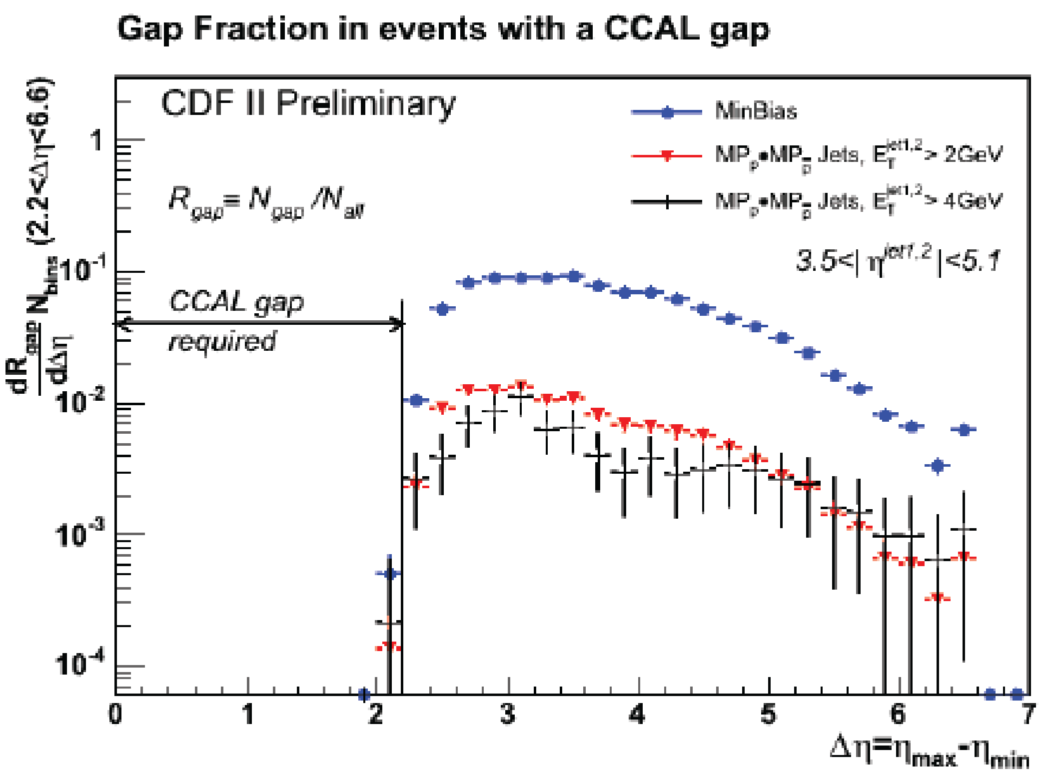
CCAL• $PCAL_p$ • $PCAL_{pbar}$ Gap





The distribution of Δφ for MP_p•MP_{pbar} jets of E_T>2 GeV with a gap in the central calorimeter (CCAL) plus a gap in both Plug calorimeters - PCAL(p) and PCAL(pbar).

Gap fraction in CCAL gap Events



The distribution of the gap fraction $R_{gap}=N_{gap}/N_{all}$ vs $\Delta\eta$ for MinBias (*CLC_p•CLC_{pbar}*) and MiniPlug jet events (*MP_p•MP_{pbar}*) of $E_{T(jet1,2)}$>2 GeV and $E_{T(jet1,2)}$> 4 GeV.

The distributions are similar in shape within the uncertainties.

SUMMARY

- Introduction
  - Renormalization, M^2-scaling, survival probability
  - Diffractive and non-diff. proton PDFs similar
- Diffractive dijets – x_{Bj}, Q^2 and t-dependece
- Diffractive W/Z with RPS data
  - W diffractive fraction in agreement with Run I
  - W and Z diffractive fractions are equal within error
- Exclusive dijets and exclusive Higgs @ LHC
- Exclusive di-lepton and di-photon measurements
- Exclusive Z production limit
- Central rapidity gaps
  - Gap fraction dependence on width and η-position of gap for hard / soft triggers at $|\eta|>4$
  - ➔ distributions shapes similar for hard / soft triggers
  - ➔ hard-scale fractions suppressed by factor of or ~10.


thank you

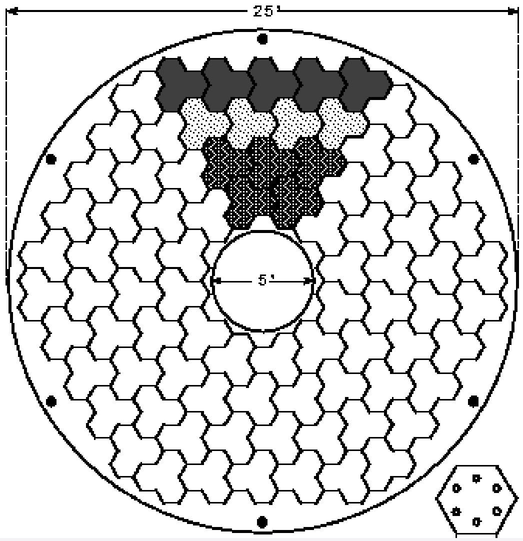
BACKUP

Measurements ^{w}/ the MiniPlugs

Dynamic Alignment of RPS Detectors

E^{T}_{jet} Calibration

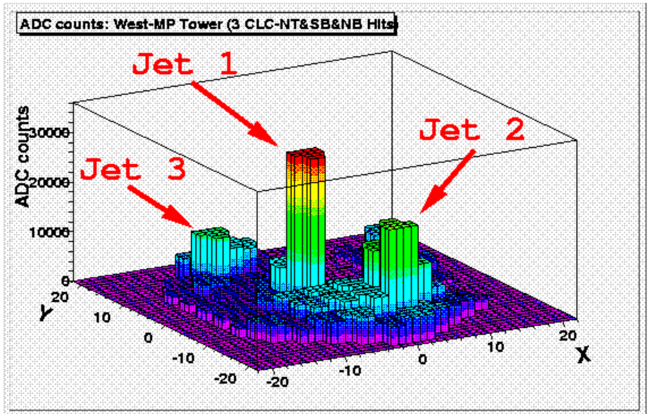
Measurements w/the MiniPlugs

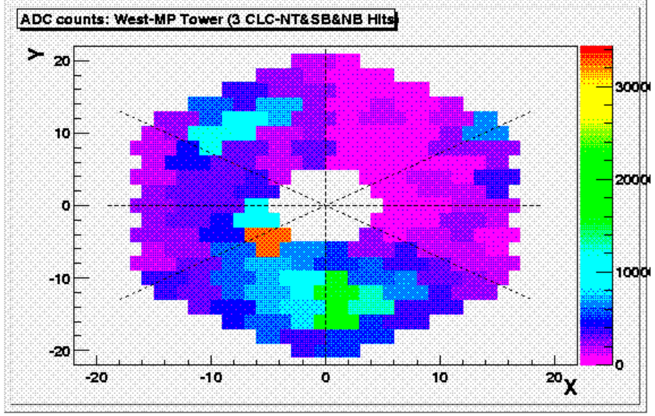


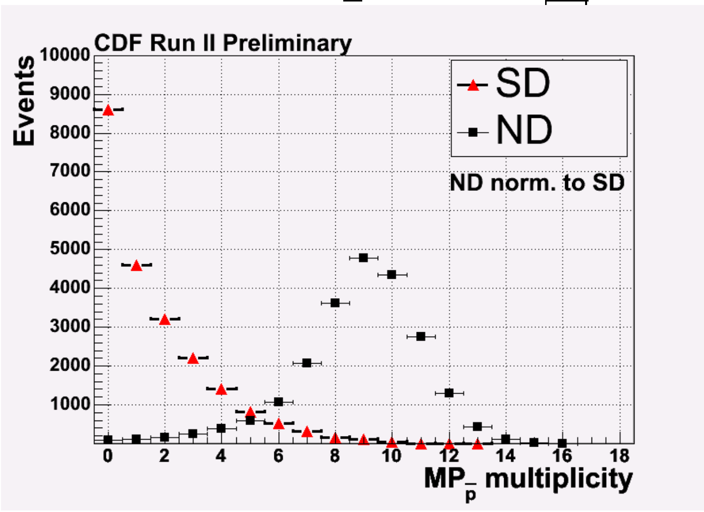
MP TOWER STRUCTURE

MULTIPLICITY @ POSITION

ENERGY







Multiplicity of SD and ND events

$$\xi^{CAL} = \frac{\Sigma_i E_T^i e^{-\eta_i}}{\sqrt{s}}$$

NIM A 430 (1999)

NIM A 496 (2003)

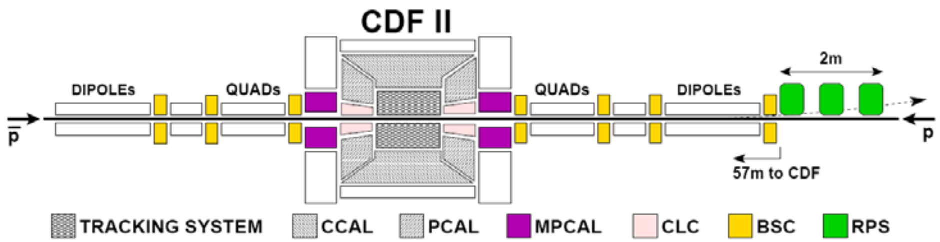
NIM A 518 (2004)

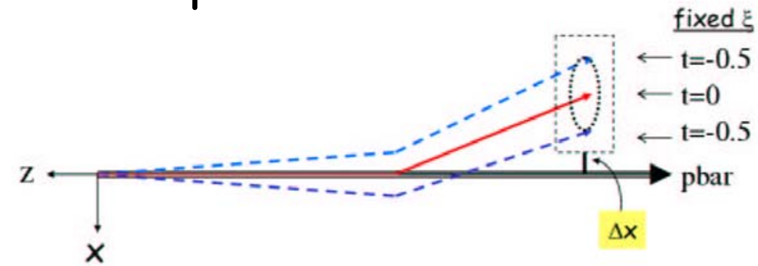
ADC counts in MiniPlug towers in a pbar-p event at 1960 GeV.

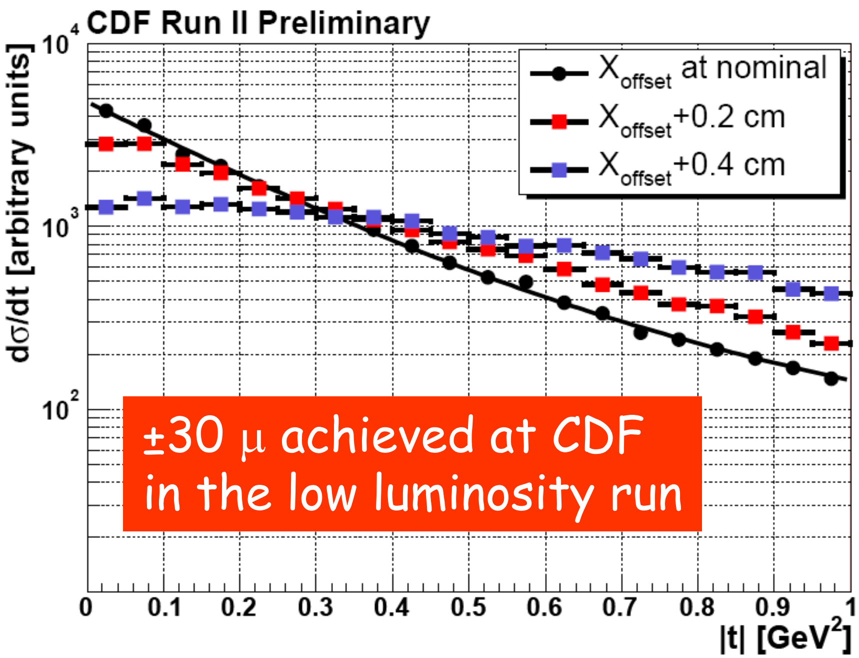
- "jet" indicates an energy cluster and may be just a hadron.
- 1000 counts ~ 1 GeV

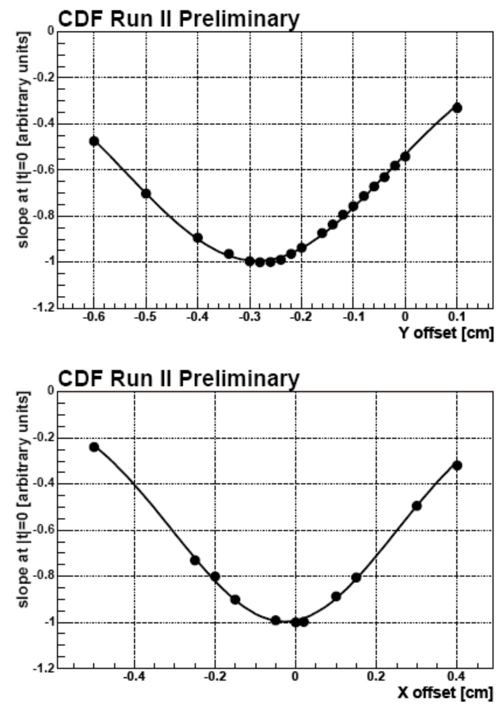
Dynamic Alignment of RPS Detectors

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.









Limiting factors

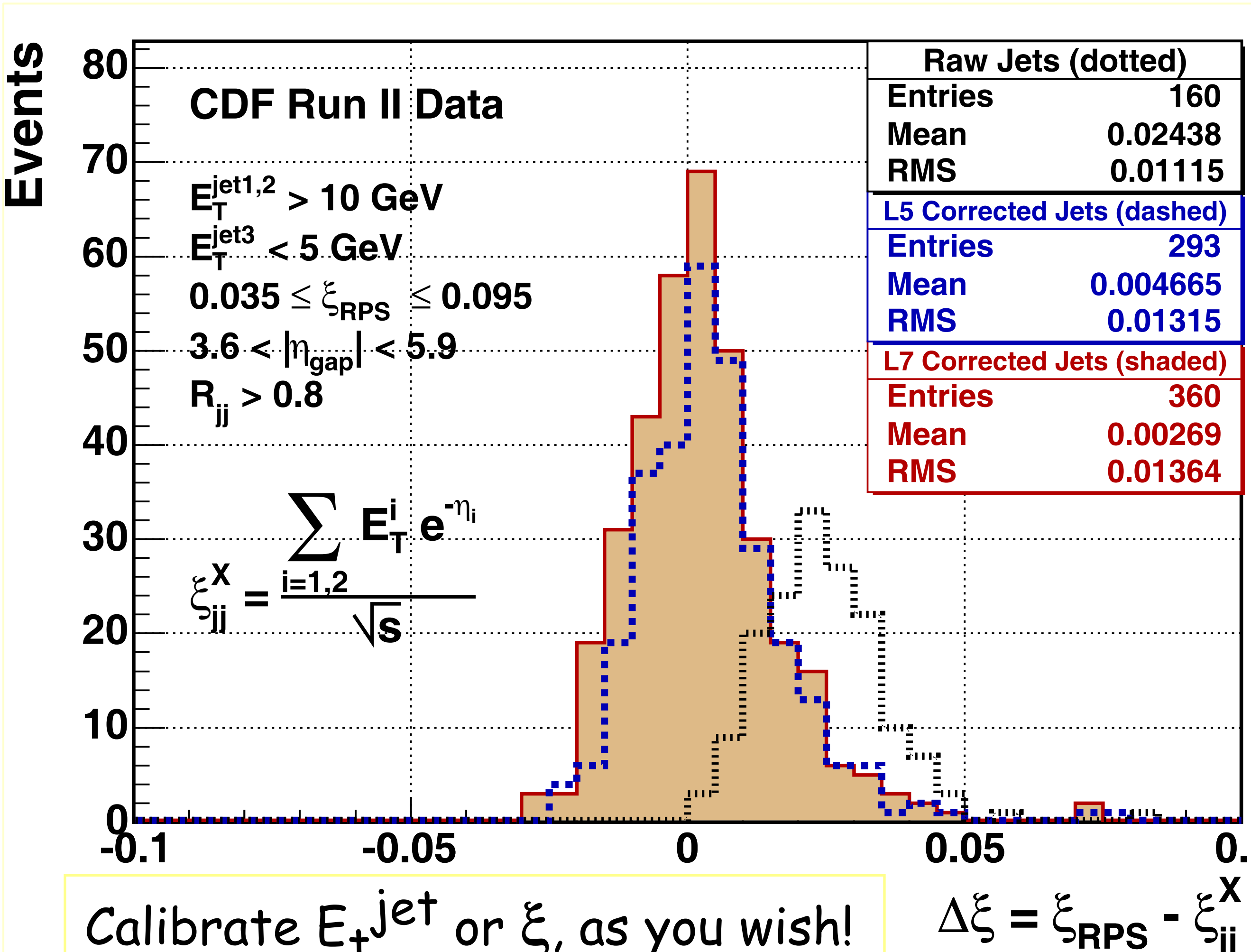
1-statistics
2-beam size
3-beam jitter

@ CDF
w/lowlum data

$\pm 30\ \mu m$

E_T^{jet} Calibration

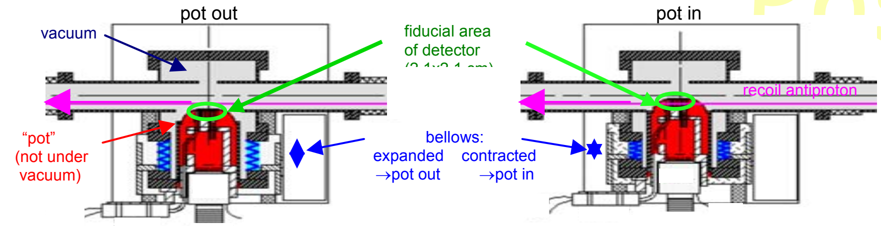
➔use RPS information to check jet energy corrections🡐



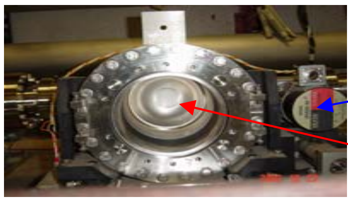
Calibrate E_T^{jet} or ξ, as you wish!

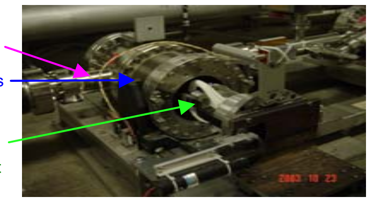
The Roman-Pot Detectors at CDF

Concept of a Roman Pot



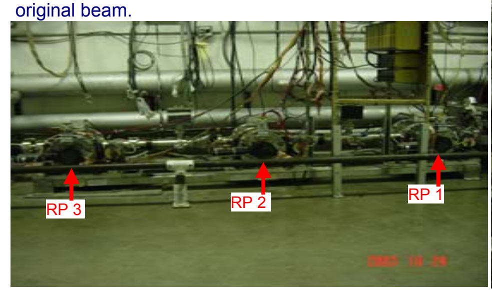
Bellows allow detectors to move close to the beam while maintaining vacuum

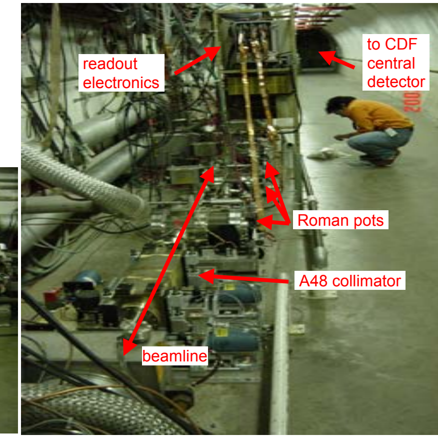




In the Tevatron Tunnel

CDF had three Roman pots (RP1, RP2, RP3) located 57m downstream of the interaction point along the antiproton beam direction.
They were used to detect antiprotons which underwent a "diffractive" interaction and were scattered in a direction very close to that of the original beam.

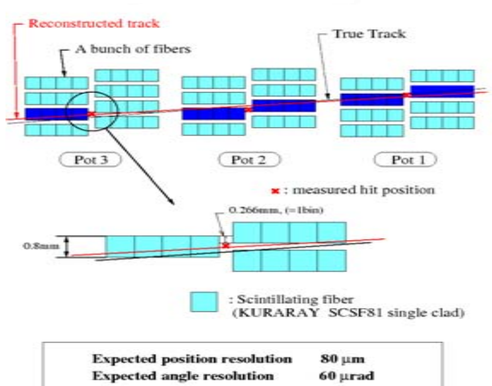




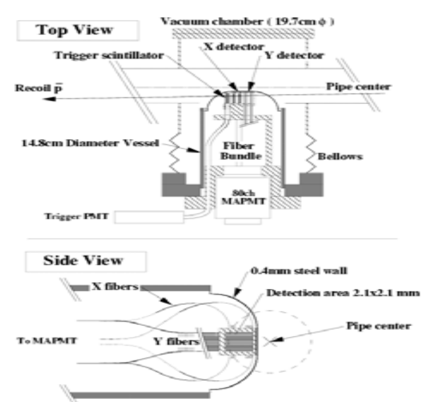
Roman-Pot Detector Design – by The Rockefeller University

The three Roman pots each contain detectors consisting of:

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

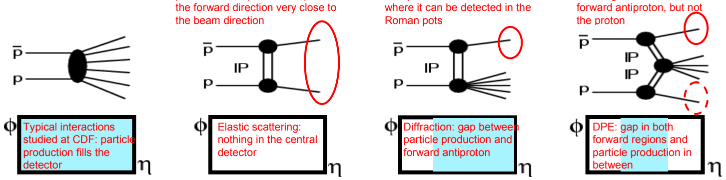


CDF "Tokyo"-Pot Detectors – Built by the University of Tsukuba, Japan



Physics Using the Roman-Pot Detectors

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



Path of the Antiproton through the Tevatron Magnets

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