Experimental results on diffraction at CDF

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(on behalf of the CDF collaboration)

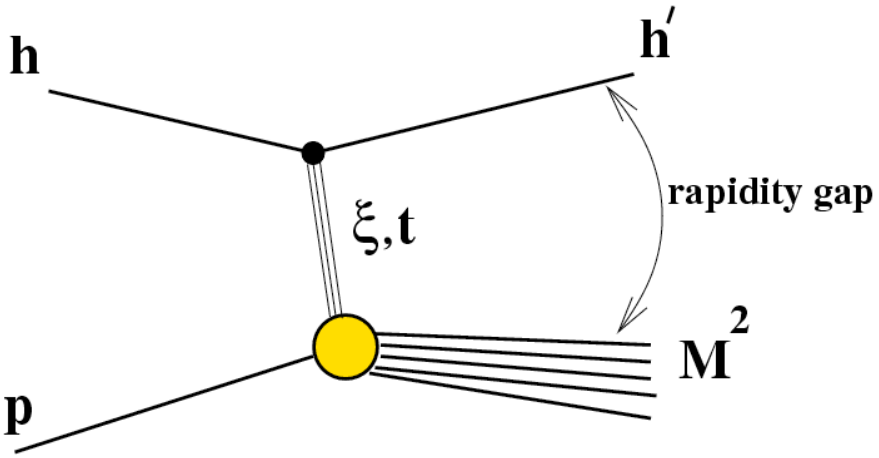
January 5, 2010

- Introduction
- Diffractive production (dijets, W/Z, Forward jets)
- Exclusive dijets
- Conclusions

Hadronic diffraction

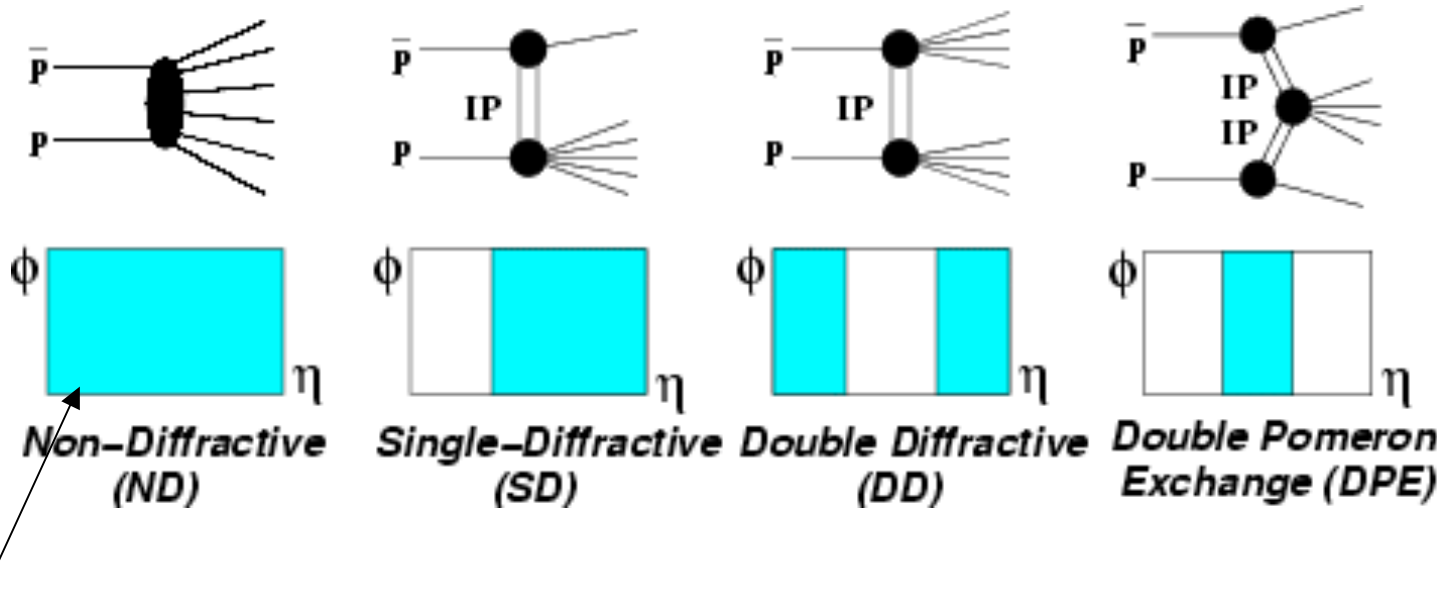
Elastic and diffractive processes
⇨ leading hadron emitted at small angle

The exchange (“pomeron”) is colorless
⇨ large rapidity gap



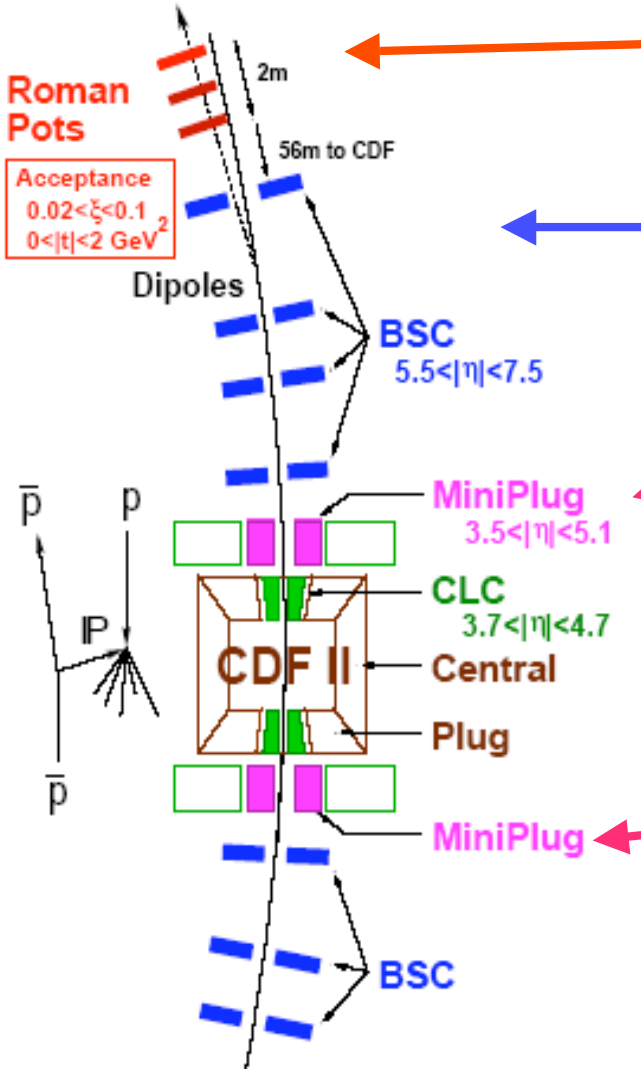
Introduction

- In diffraction no quantum numbers are exchanged



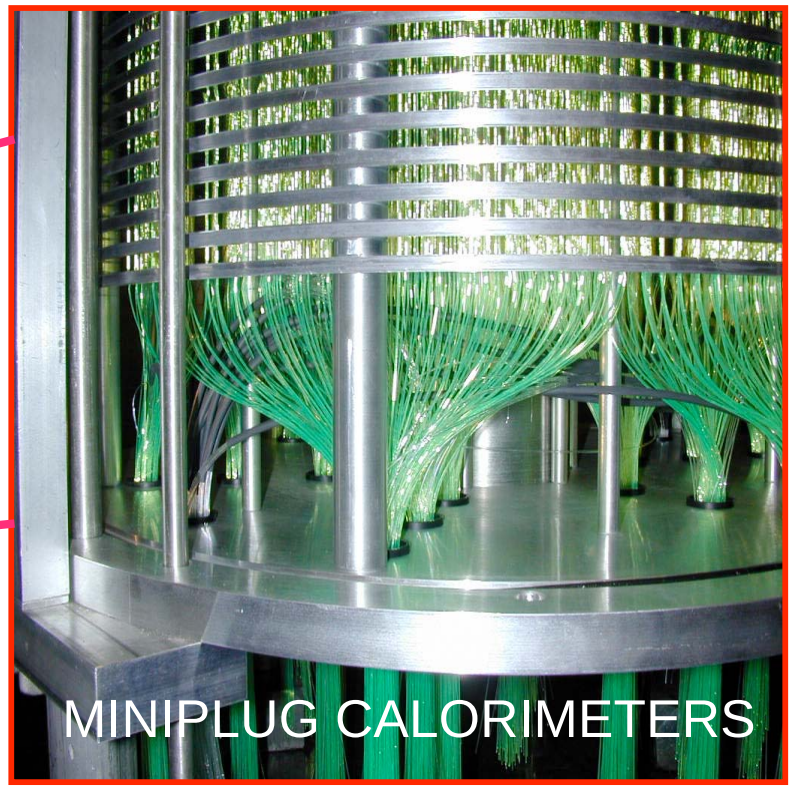
Shaded area corresponds to particle production

CDF central and forward detectors



ROMAN POT DETECTORS

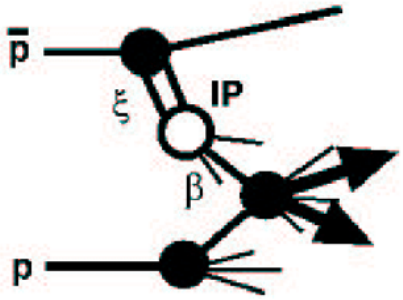
BEAM SHOWER COUNTERS: used to reject ND events



Single diffraction

- Examine partonic structure of diffractive exchange using high-p_T probes (hard diffraction)
- Confirm and extend the kinematical reach of Run I results
  - Diffractive dijet production in ranges of Q^2
  - Diffractive structure functions

Diffractive dijets



ξ: fraction of anti-proton momentum loss

β: fraction of Pomeron momentum carried by parton

parton $x_{Bj} \equiv \beta \cdot \xi$

$$x_{Bj} = \frac{\sum_{jet} E_T \cdot e^{-\eta}}{\sqrt{s}}$$

Measure SD/ND ratio of dijet rates

$$\frac{\sigma(SD_{jj})}{\sigma(ND_{jj})} = \frac{F_{jj}^{D}(x)}{F_{jj}(x)}$$

extract (LO QCD)

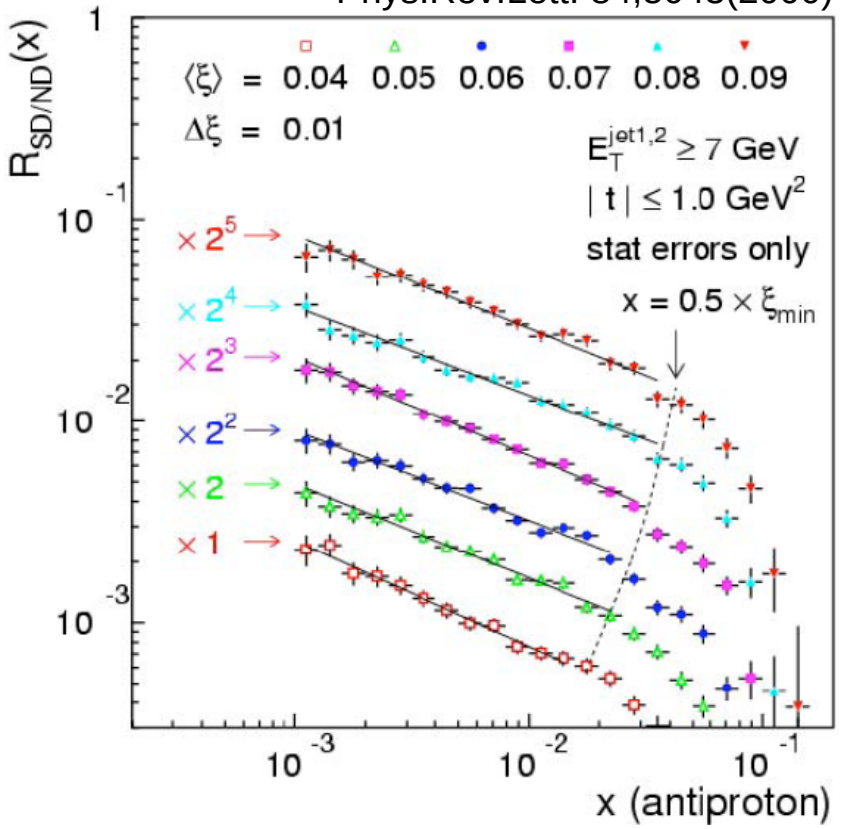
measure

known

$$R_{SD/ND} = R_0 \cdot x^{-0.45}$$

⇨**no significant ξ dependence**

Phys.Rev.Lett. 84,5043(2000)



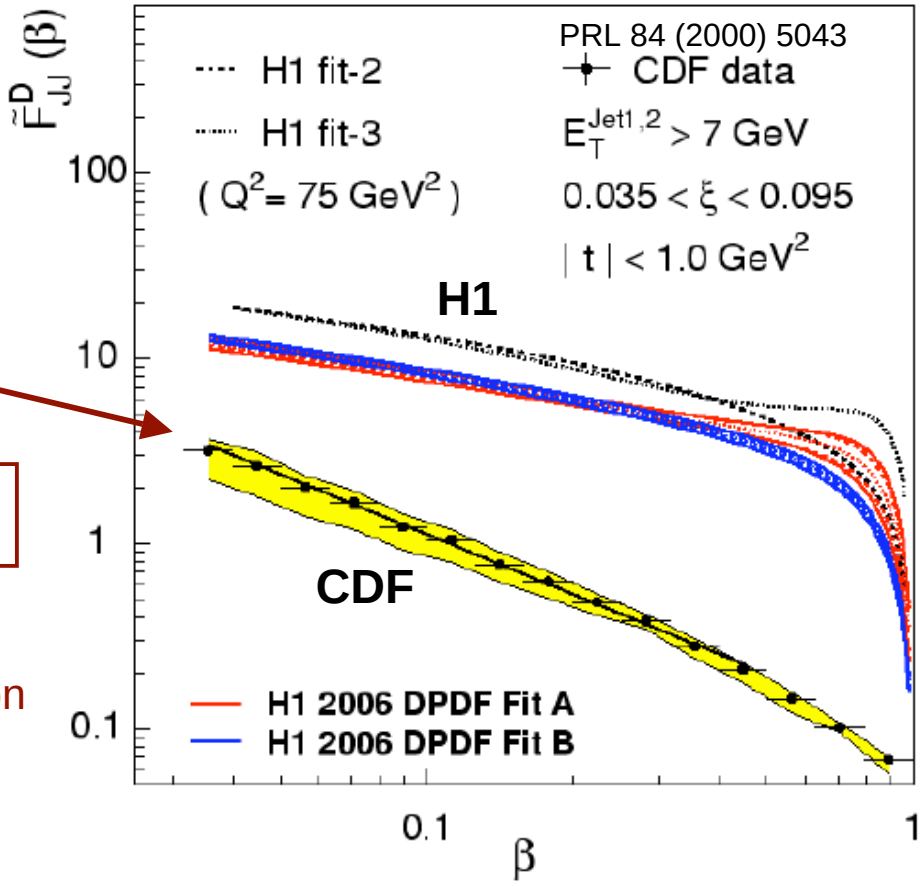
in the ratio SD/ND many systematic uncertainties cancel out

Diffractive structure function

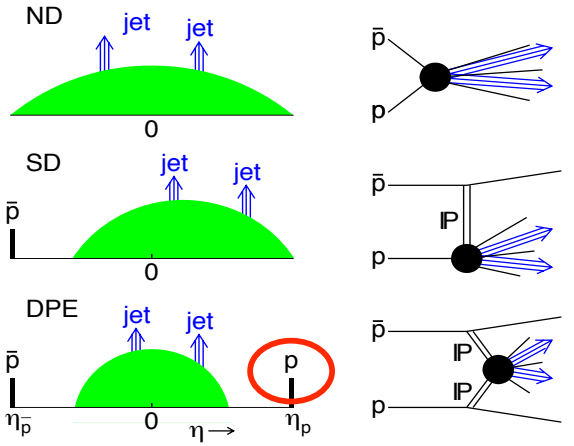
CDF Run I result suppressed
by factor of ~10 relative to HERA

⇨breakdown of QCD factorization

Discrepancy can be attributed to additional color exchange which spoil the gap formation

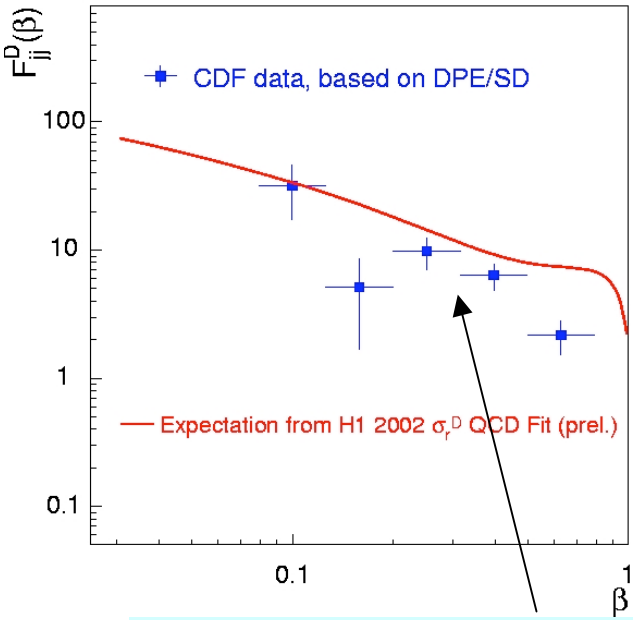


Restoring factorization



R(SD/ND)

R(DPE/SD)



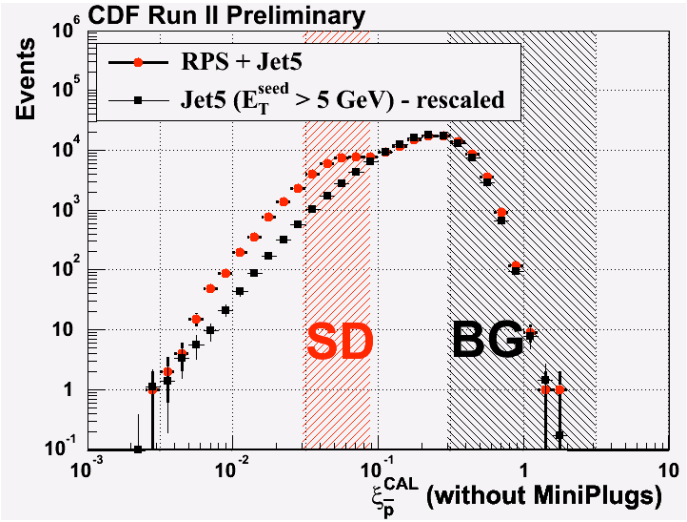
factorization is restored !

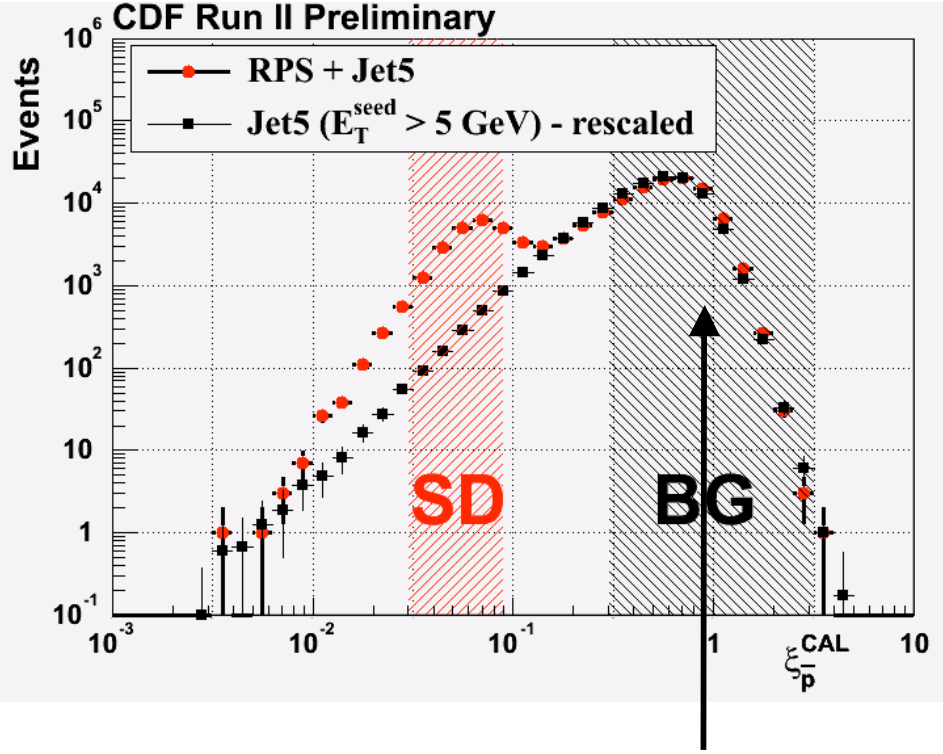
The diffractive structure function measured using DPE events is approximately the same as the one expected from HERA

Event selection in Run II

ξ: momentum loss fraction of pbar

$$\xi = \frac{\Sigma_{(\text{all towers})}\, E_T\, e^{-\eta}}{\sqrt{s}}$$

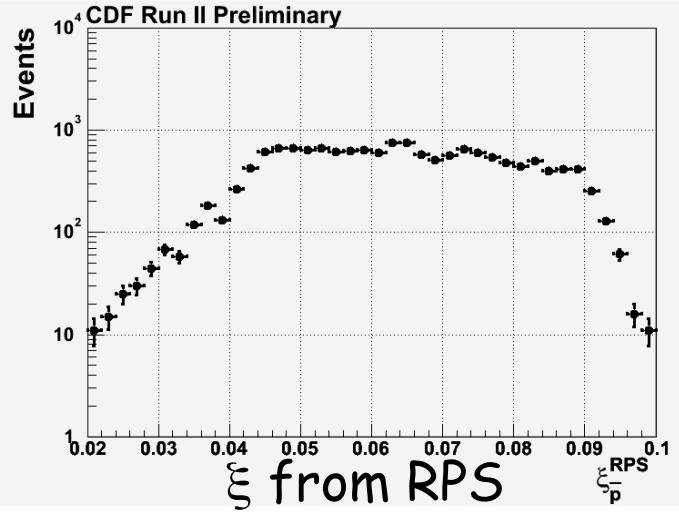


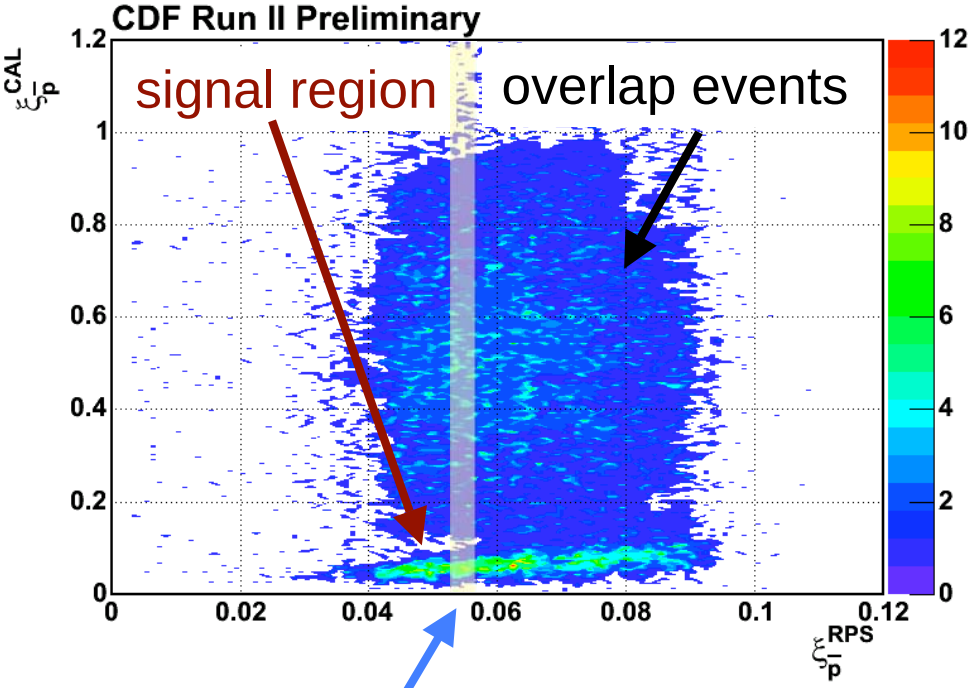


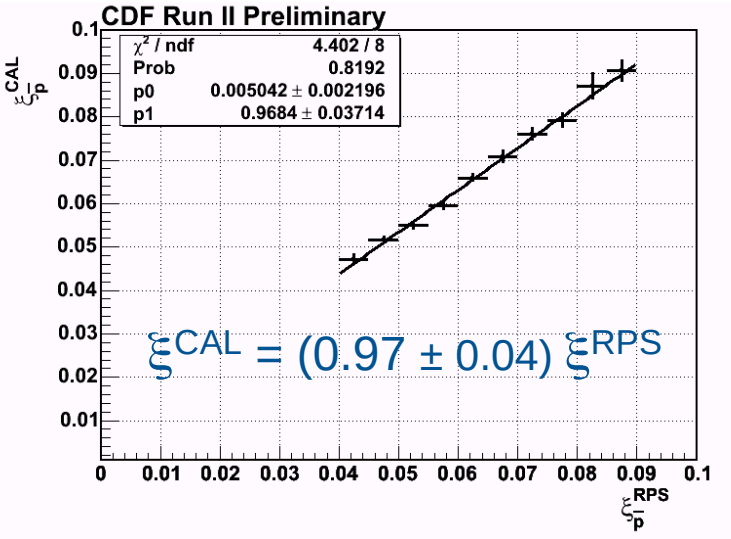
overlap events
(multiple $p\bar{p}$ interactions)

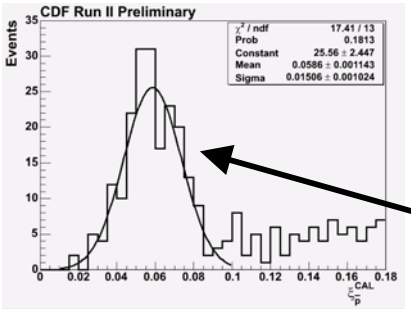
MP energy scale: ±30% →Δlogξ = ±0.1
RP acceptance (0.03<ξ< 0.09) ~ 80%

Multiple interactions in Run II





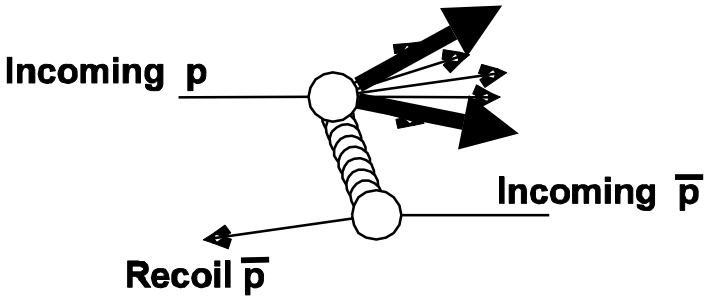




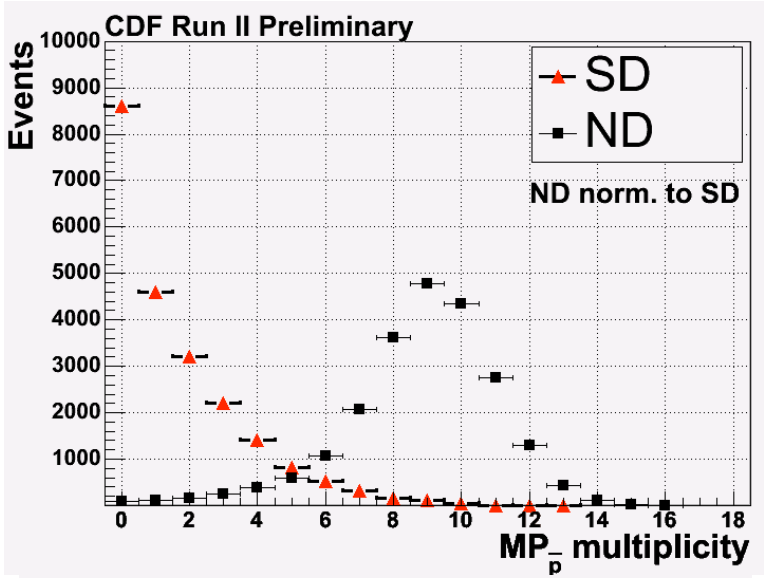
ξ^{cal} distribution for slice of ξ^{RPS}

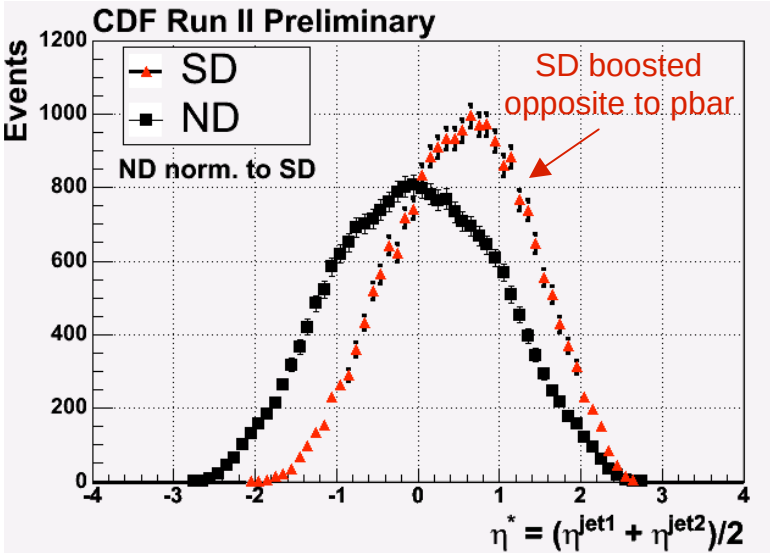
σ / mean ~ 30%

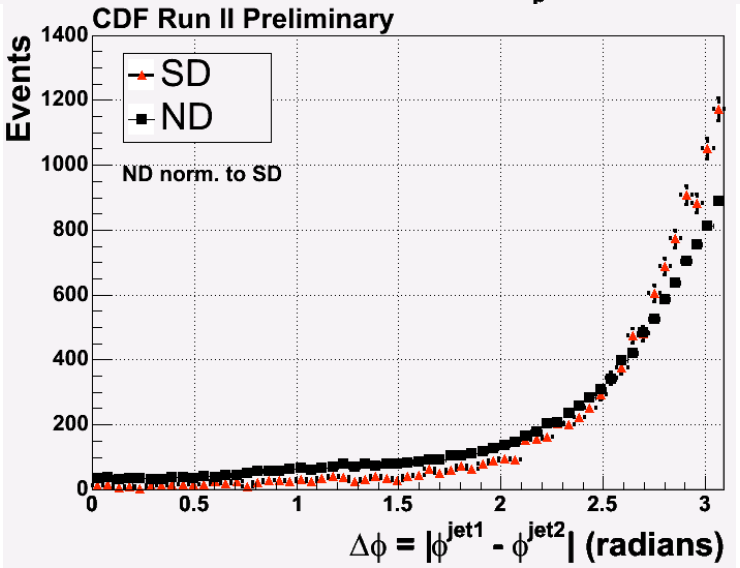
Kinematical properties



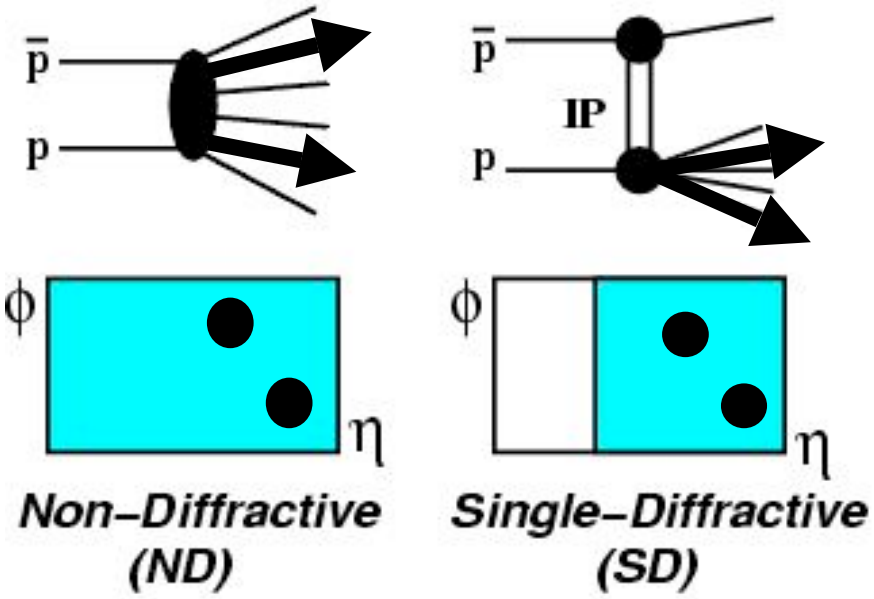
compare ND and SD







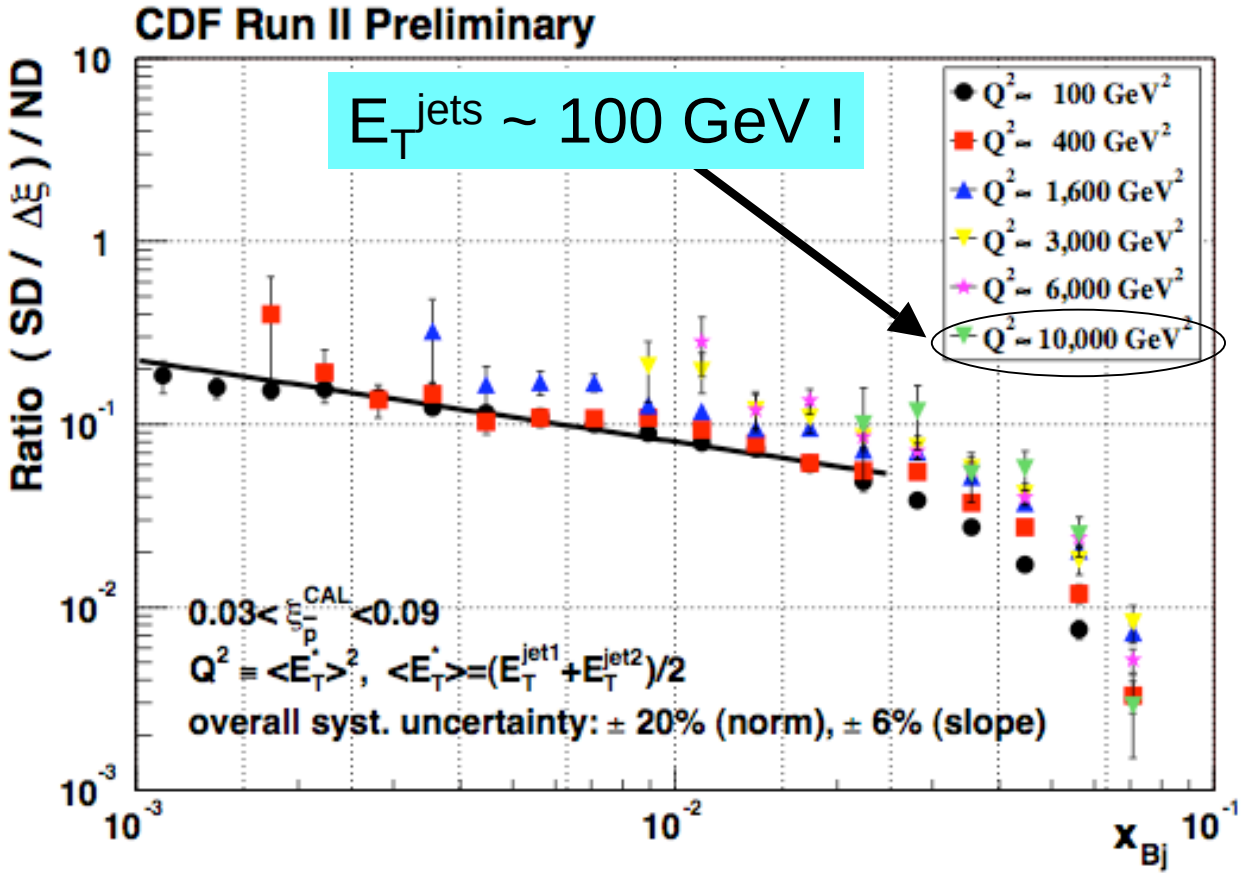
Diffractive structure function



$$R(x_{Bj}) \equiv \frac{Rate_{jj}^{SD}(x_{Bj})}{Rate_{jj}^{ND}(x_{Bj})}$$

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

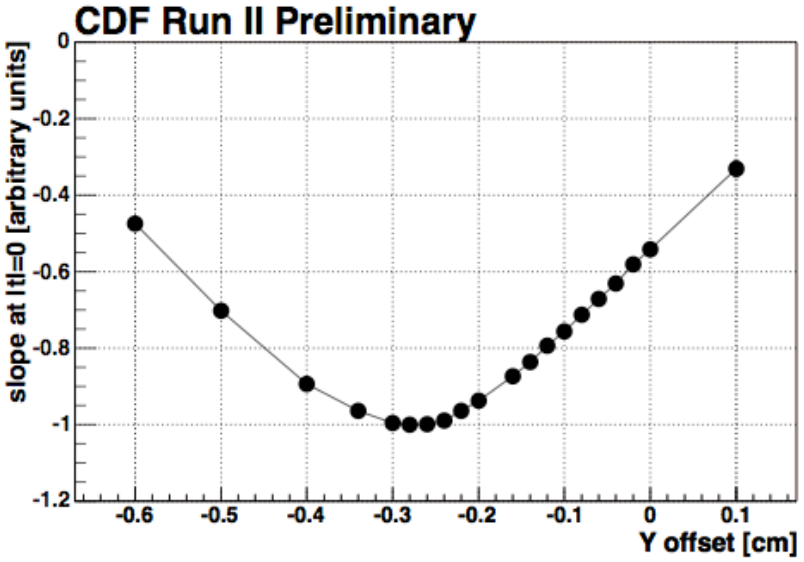
Q^2 dependence



small Q^2 dependence for $100 < Q^2 < 10{,}000$ GeV^2

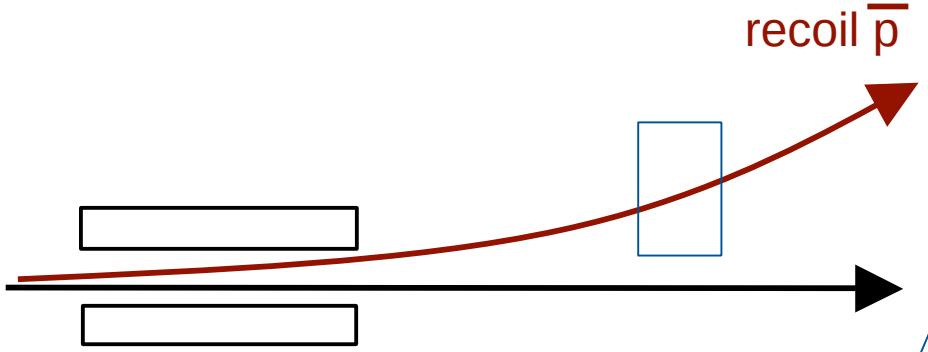
⇨ Pomeron evolves as proton

RPS dynamic alignment

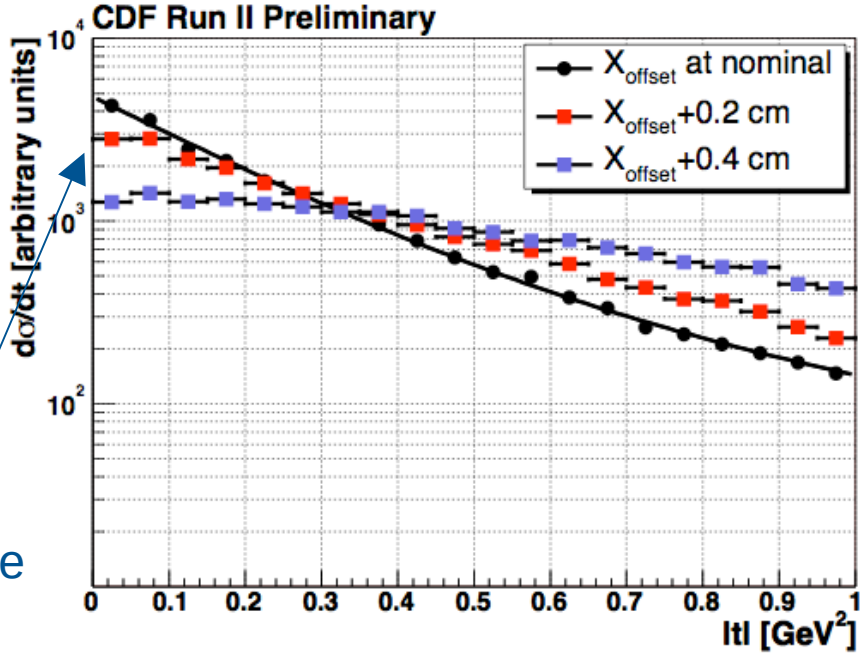


maximize the |t|-slope
(normalized to max slope)

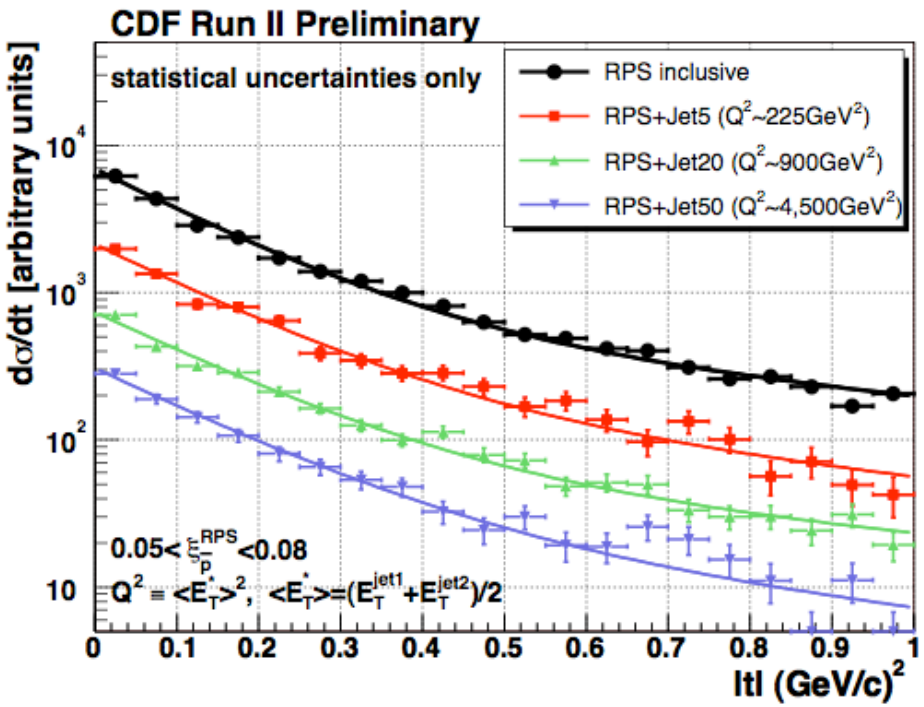
⇨determine X and Y offsets

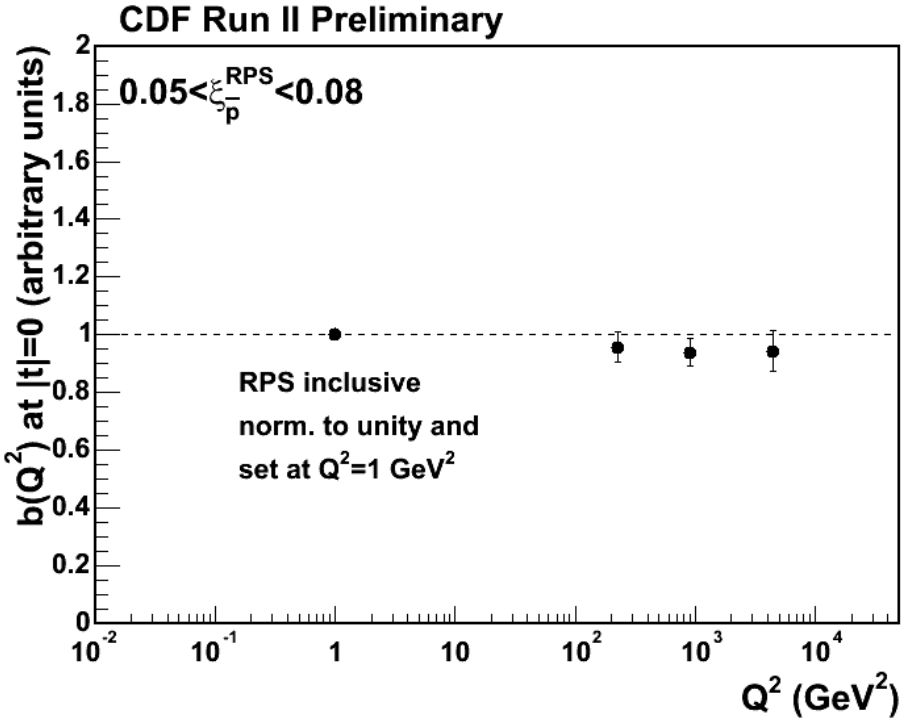


maximize the slope



|t| distribution

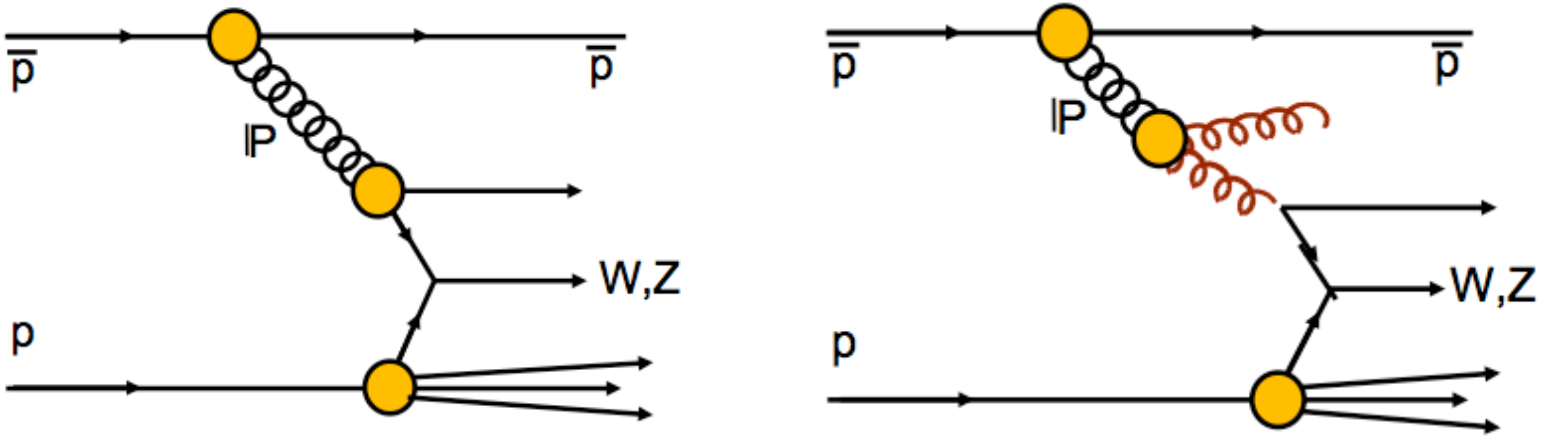




- No diffraction `dips' observed at |t|<1
- Soft and hard diffractive events have the same slope

Diffractive W/Z production

Study W/Z boson production helps to determine the **quark** content of the Pomeron



At LO, the W/Z is produced by a quark in the Pomeron

or

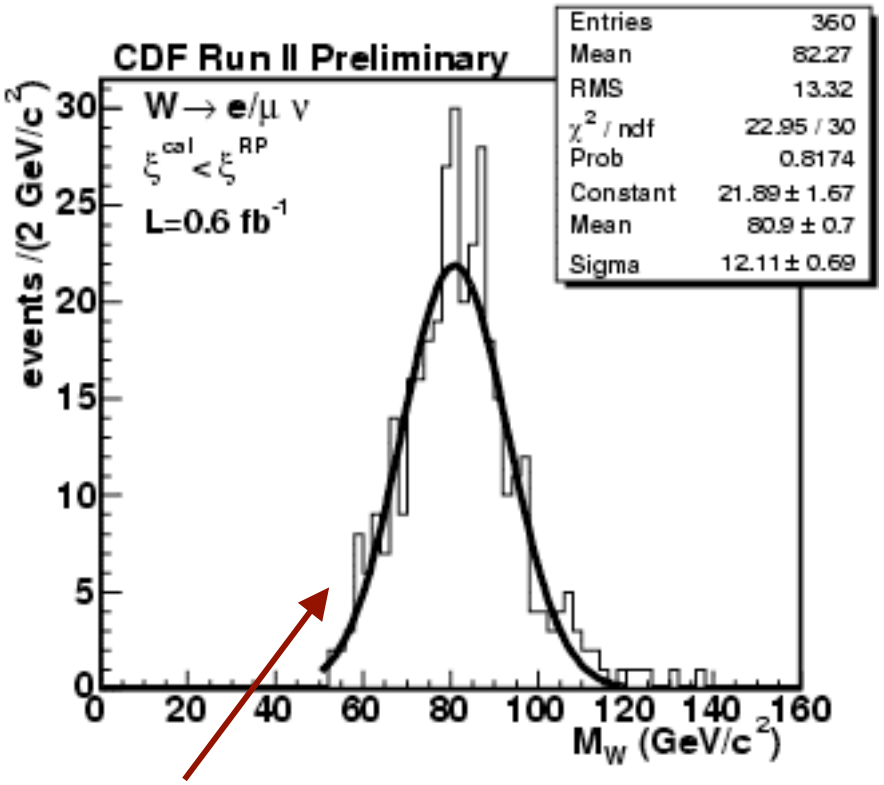
Production by a gluon is suppressed by α_s. Can look at additional jet.

Diffractive W/Z production (cont)

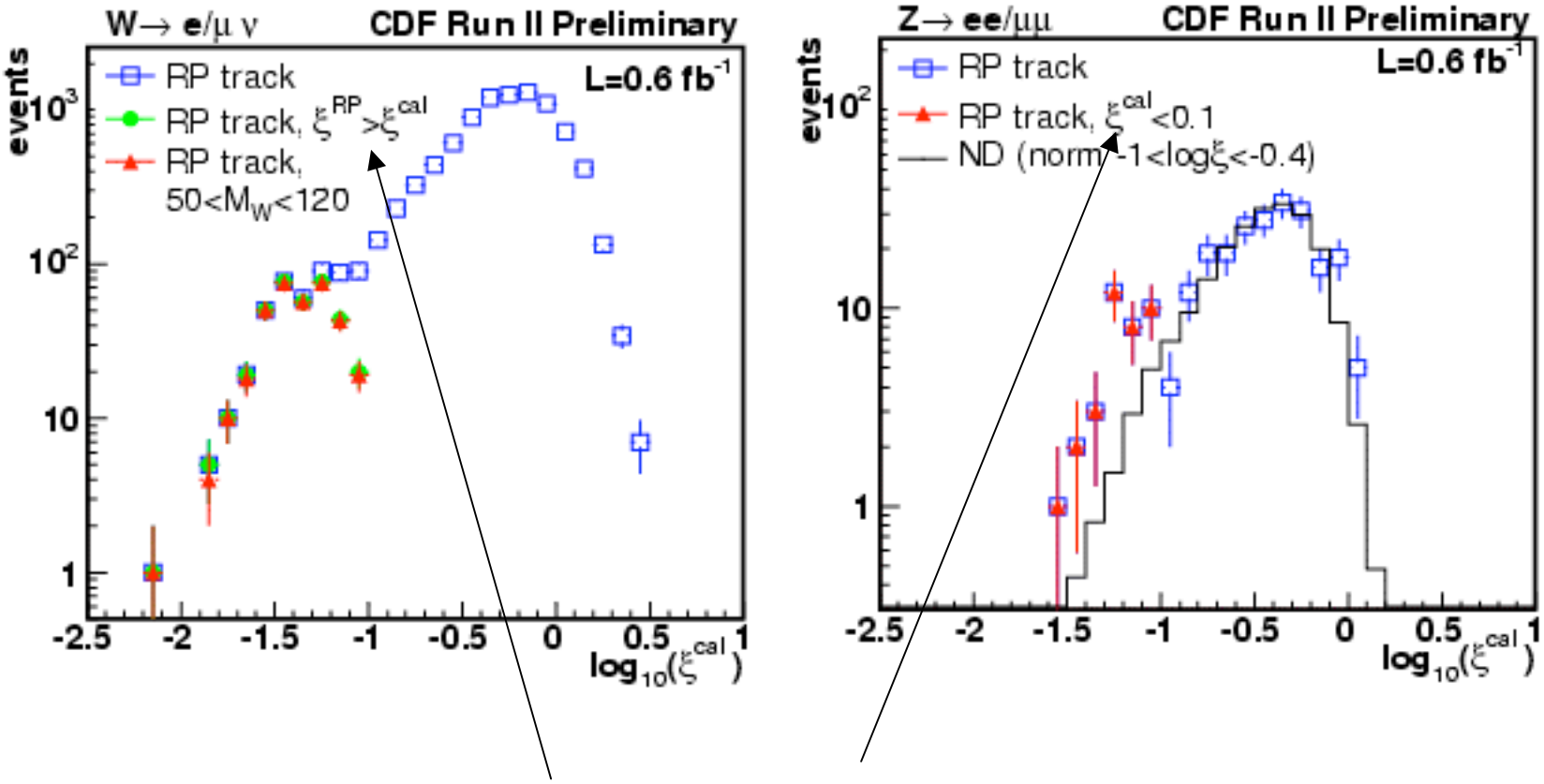
- Identify diffractive events using RPS
- Calculate ξ from calorimeter
- In W production, difference ξ^{cal}-ξ^{RPS} is due to missing E_T, and η_ν.

$$\xi^{RP} - \xi^{cal} = \frac{\not{E}_T}{\sqrt{s}} e^{-\eta_\nu}$$

- Can estimate:
  - neutrino kinematics
  - W kinematics
  - x_{Bj}
- Then, determine structure function in diffractive W production



Diffractive W/Z production (cont)



Remove events with non diffractive W/Z production+soft SD interaction

Diffractive W/Z measurement

- Measured fractions:

$$R_W = 0.97 \pm 0.05(\text{stat}) \pm 0.11(\text{syst}) \%$$
$$R_Z = 0.85 \pm 0.20(\text{stat}) \pm 0.11(\text{syst}) \%$$

- Run I diffractive W studies performed with rapidity gap instead of RPS
- CDF: Phys.Rev.Lett. 78,2698(1997)
  - Fraction of events due to SD for x<0.1: **[1.15±0.51(stat)±0.20(syst)]%**
  - Combined with other SD measurements (b-quark,jet), quark-gluon content of the Pomeron is determined: $f=0.54^{+0.16}_{-0.14}$
- D0: Phys.Rev.Lett.B 574,169(2003)
  - Fraction of events with rapidity gap:
  - W: **$[0.89^{+0.19}_{-0.17}]\%$**
  - Z: **$[1.44^{+0.61}_{-0.52}]\%$**
  - [If correction for rapidity gap acceptance is applied…R(W): 5.1%]

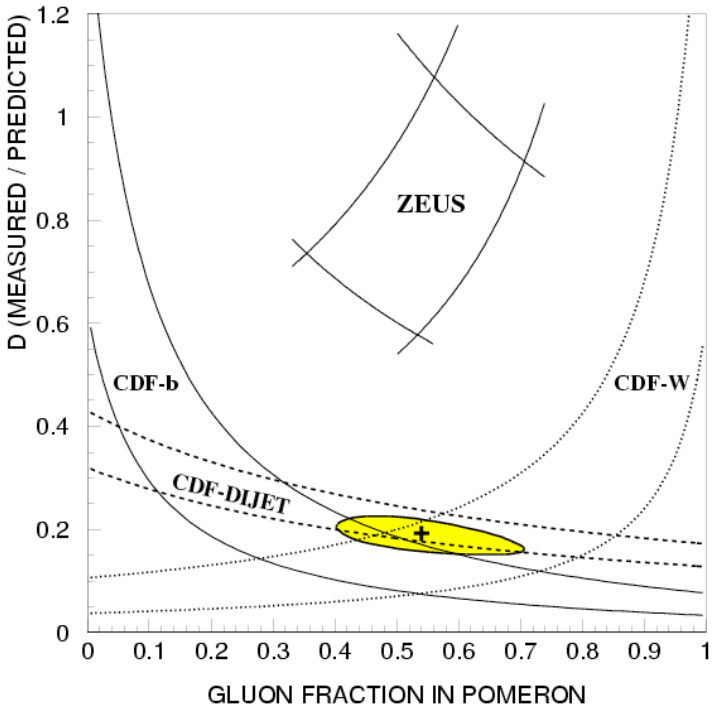
Diffractive rates

$$p\bar{p} \rightarrow X + \text{gap}$$

Measured SD/ND fractions at 1.8 TeV

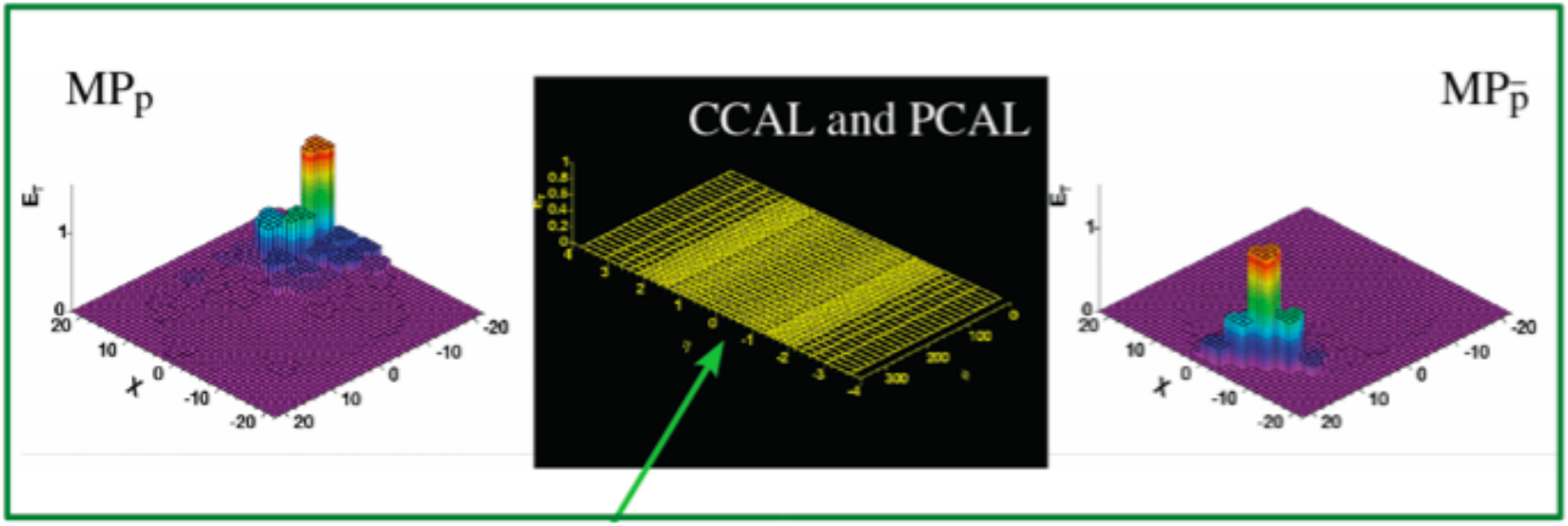
PRL	process	fraction [%]
84 (1997) 2698	W(eν)	1.15 (0.55)
PLB 574 (2003) 169	Z	1.44 (0.60)
84 (1997) 2636	jet-jet	0.75 (0.10)
84 (2000) 232	b	0.62 (0.25)
87 (2001) 241802-1	J/ψ	1.45 (0.25)

W probes quark component ($q\bar{q} \rightarrow W$)



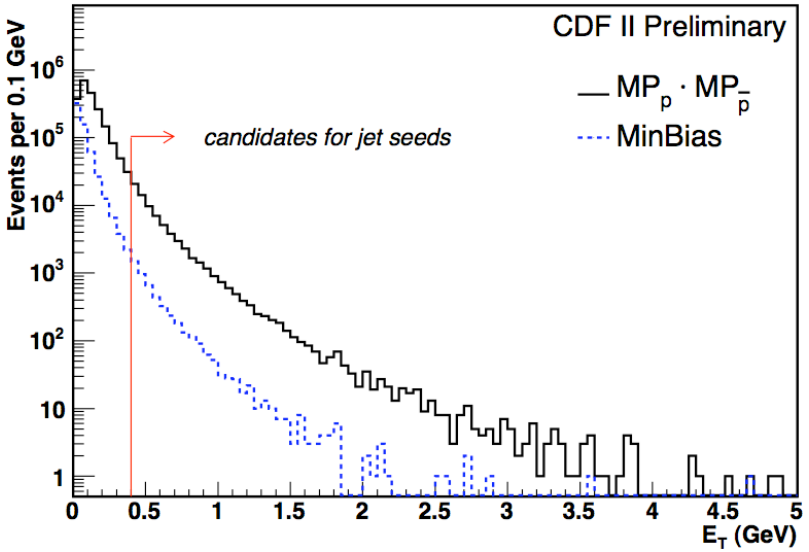
- All SD/ND fractions ~ 1% ⇨ uniform suppression
- Different sensitivities to quark/gluon ⇨ gluon fraction f_g=0.54 (0.15)

Central gap between forward jets

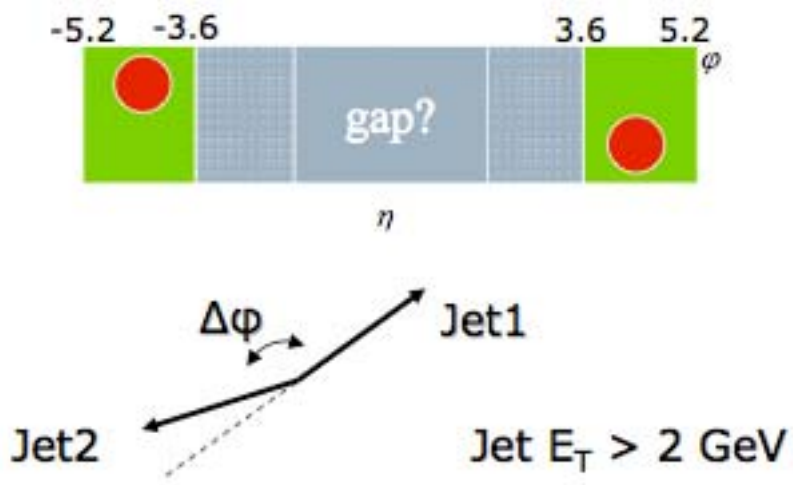


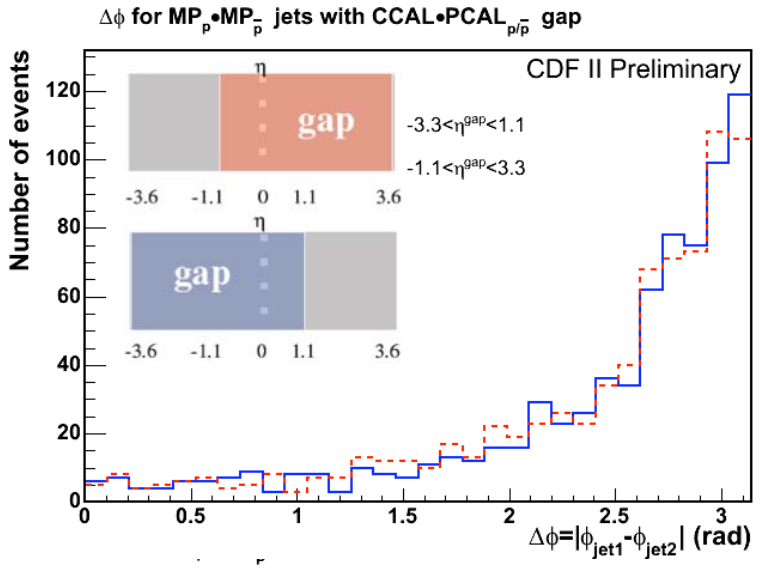
Rapidity gap in Central and Plug calorimeter

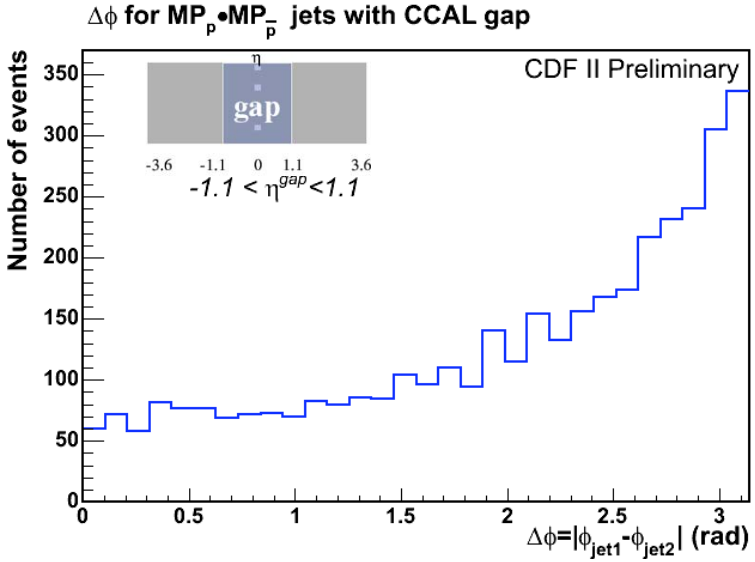
- Characterize gap formation
  - fraction of gap events (soft and hard interactions)
  - dependence on gap size
- Mueller-Navelet jets

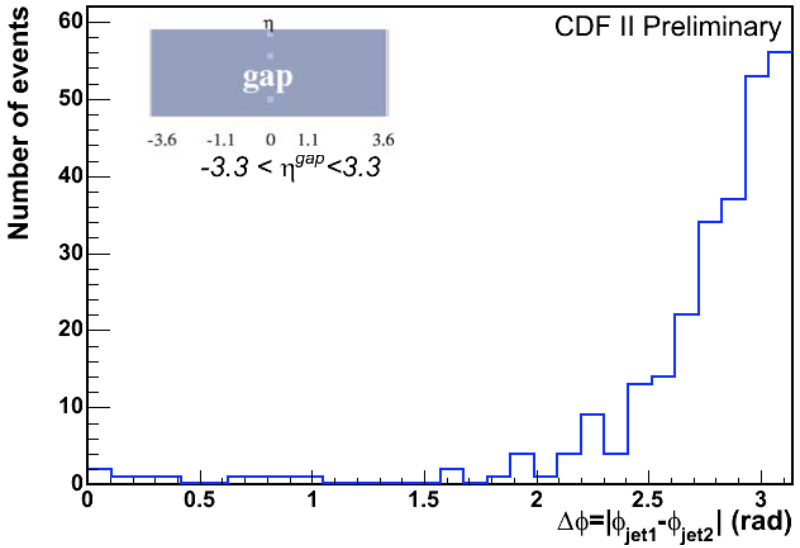


Jet Δϕ correlation

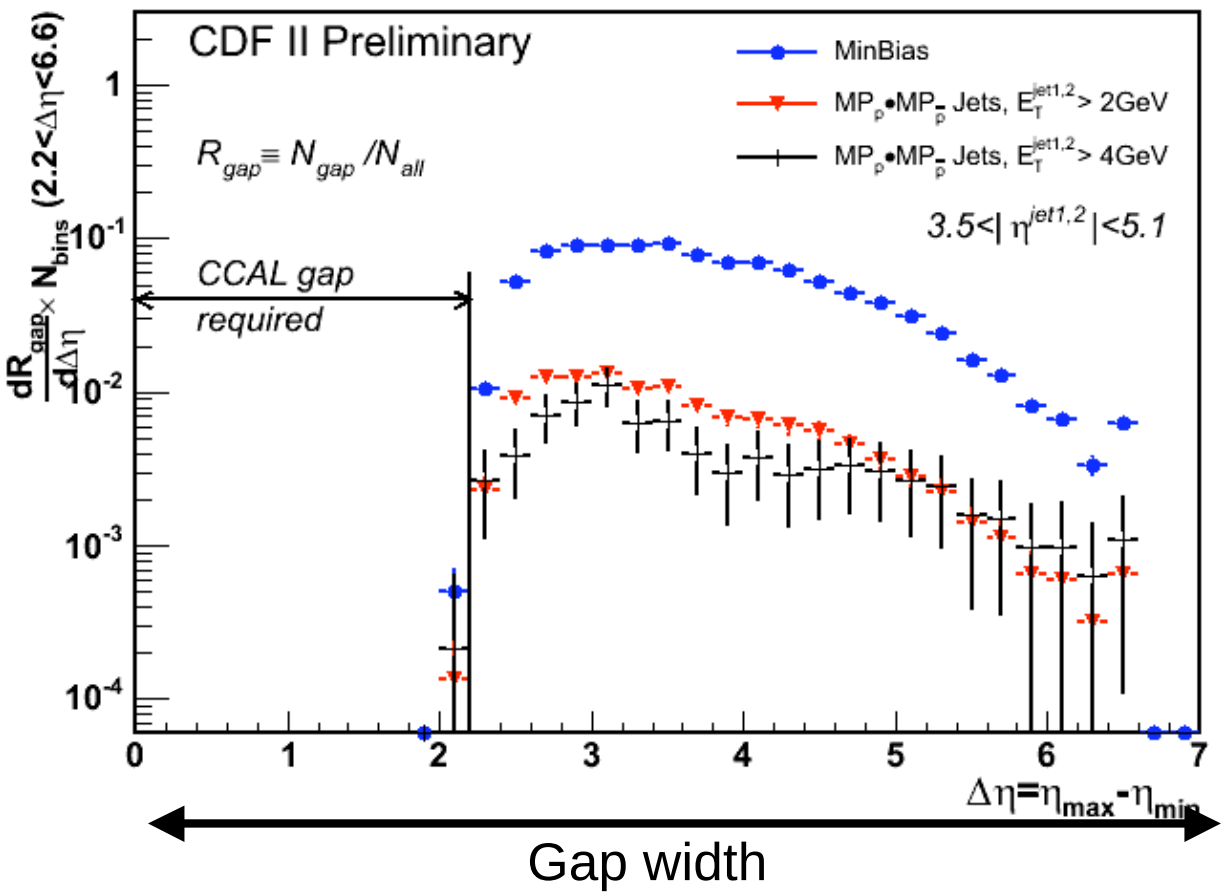


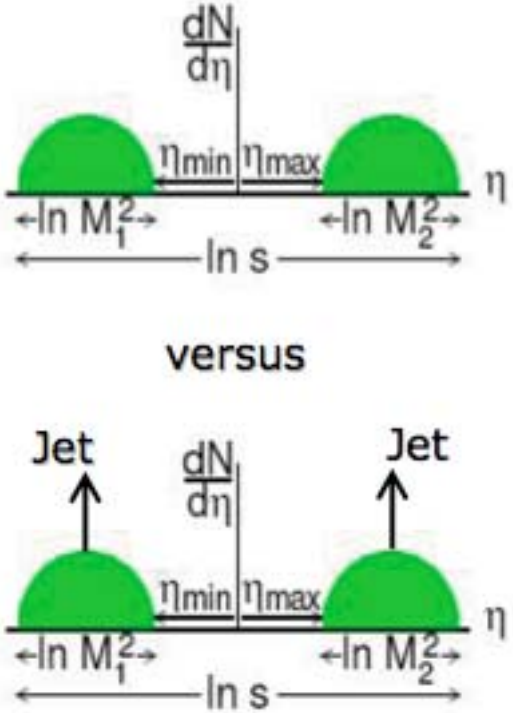






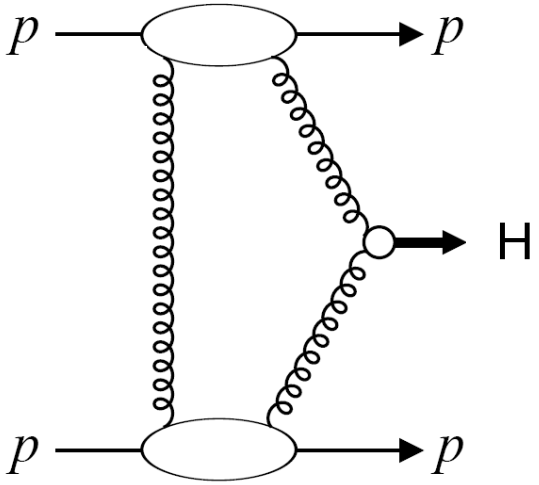
Rapidity gap event fraction





- Event fraction is ~10% in soft events, and ~1% in jet events
- Shapes are similar

Exclusive production

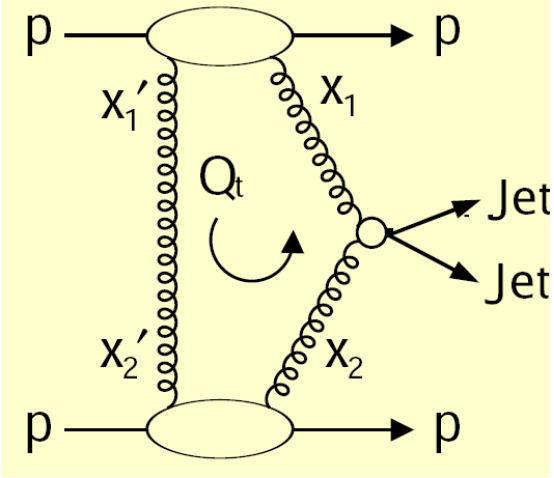


✓clean process

✓exclusive $b\bar{b}$ suppressed

Khoze Martin Ryskin: σ_H(LHC)~3 fb, signal/bkg~3 (if ΔM_{miss}=1 GeV)

Attractive Higgs discovery channel at the LHC

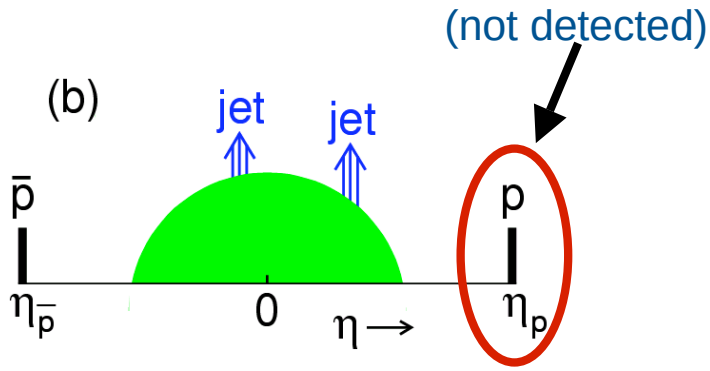


⇨much larger cross section

Goal:

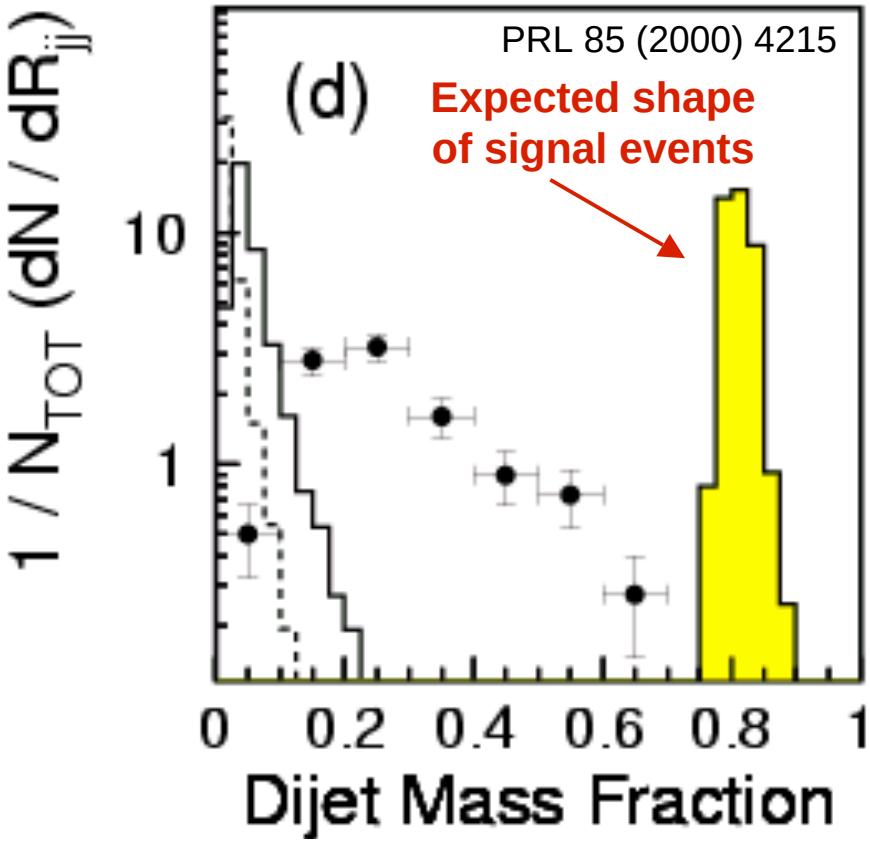
- measure exclusive dijet production (if it exists)
- test/calibrate Higgs predictions at LHC

Exclusive dijets in Run I



Mass fraction: $R_{jj} = \frac{M_{jj}}{M_x}$

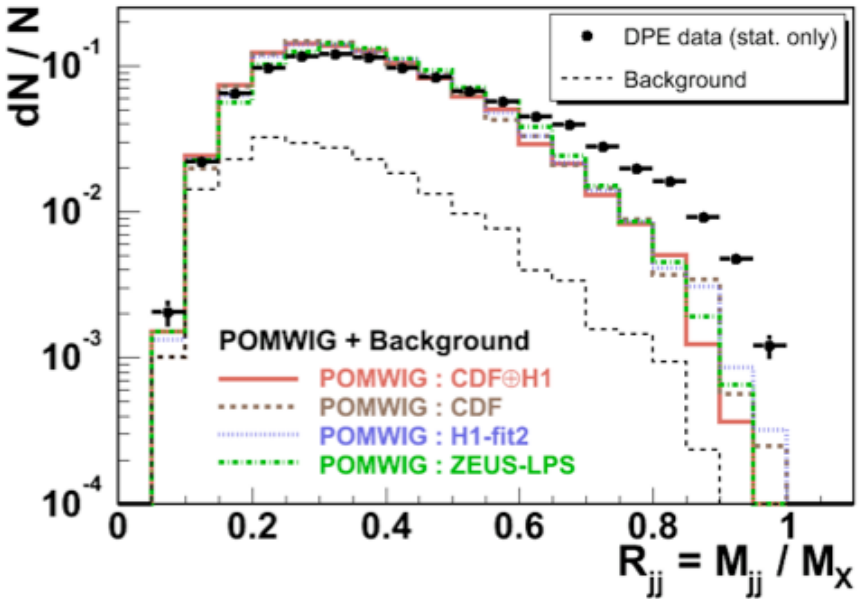
Exclusive dijet limit:
Run I: PRL 85 (2000) 4215
⇨ σ_{jj} (excl.) < 3.7 nb (95% CL)



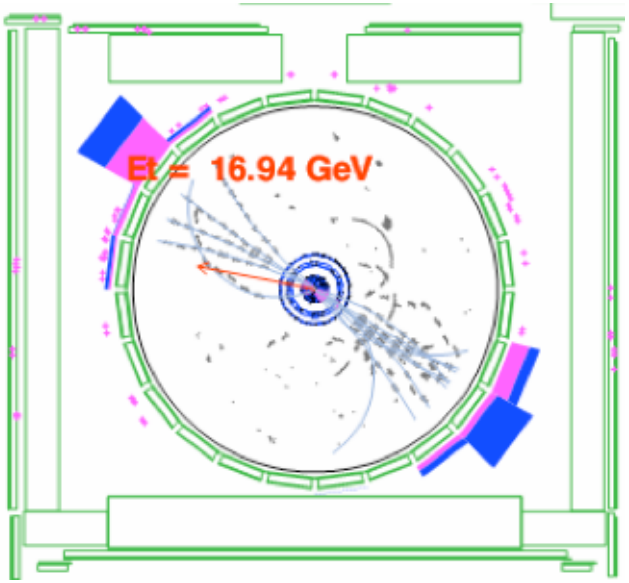
Observation of exclusive dijets

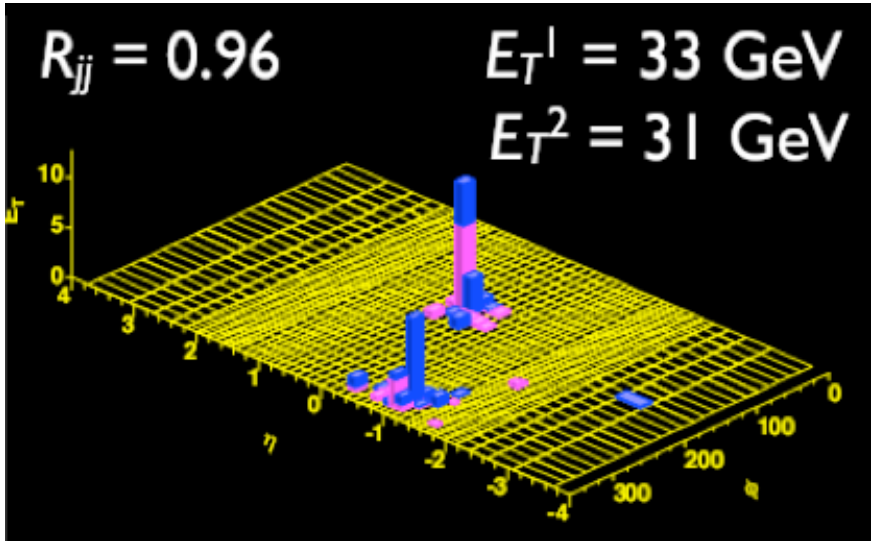
Phys.Rev.D77:052004,2008

Observe excess over inclusive DPE at large Mjj



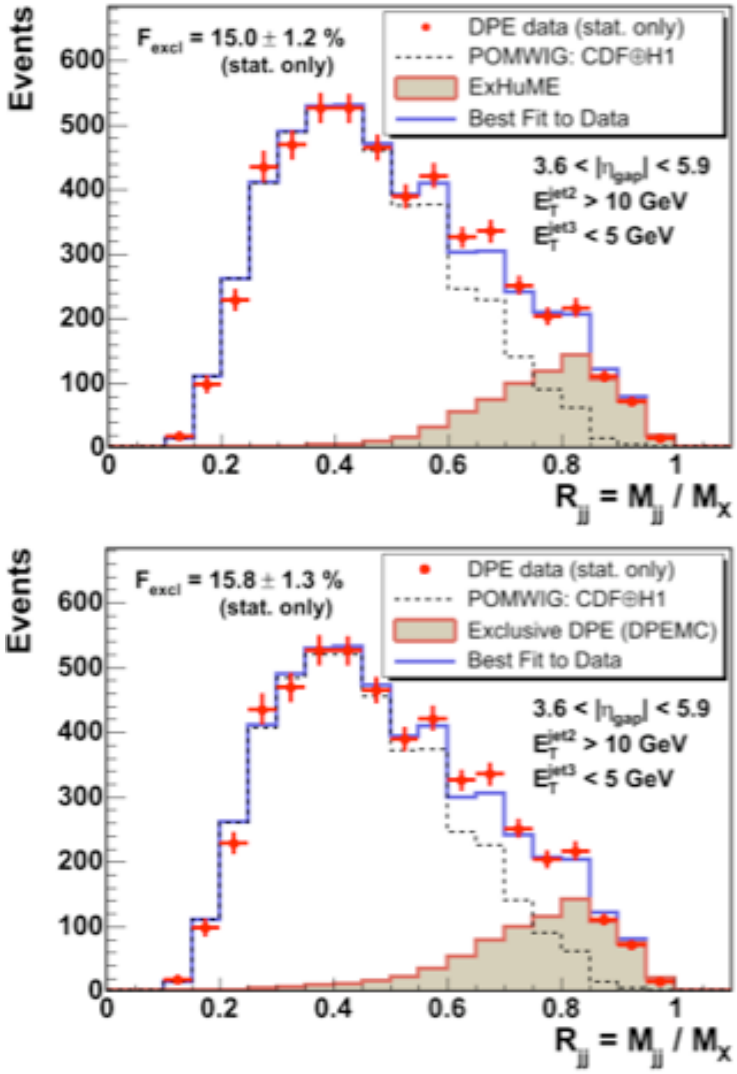
⇨ exclusive signal?



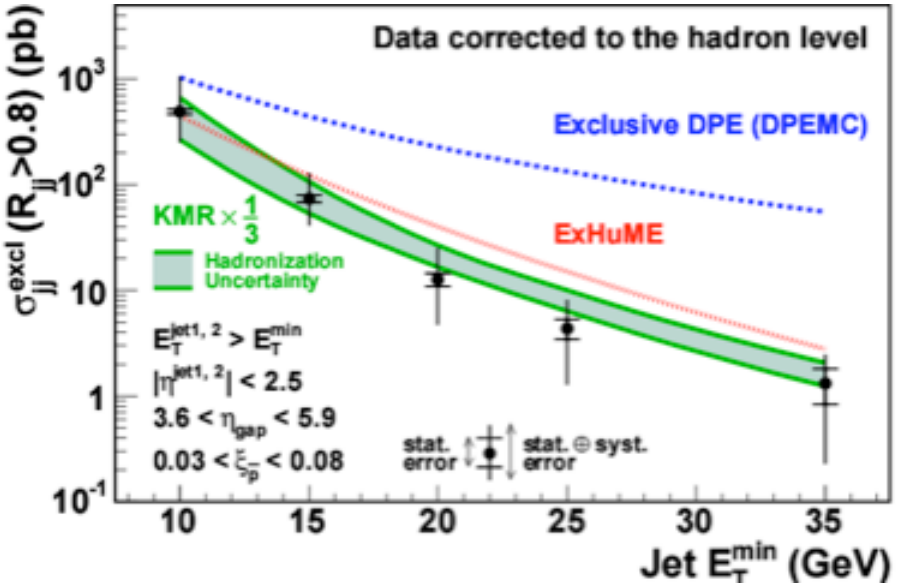


Exclusive dijet cross section

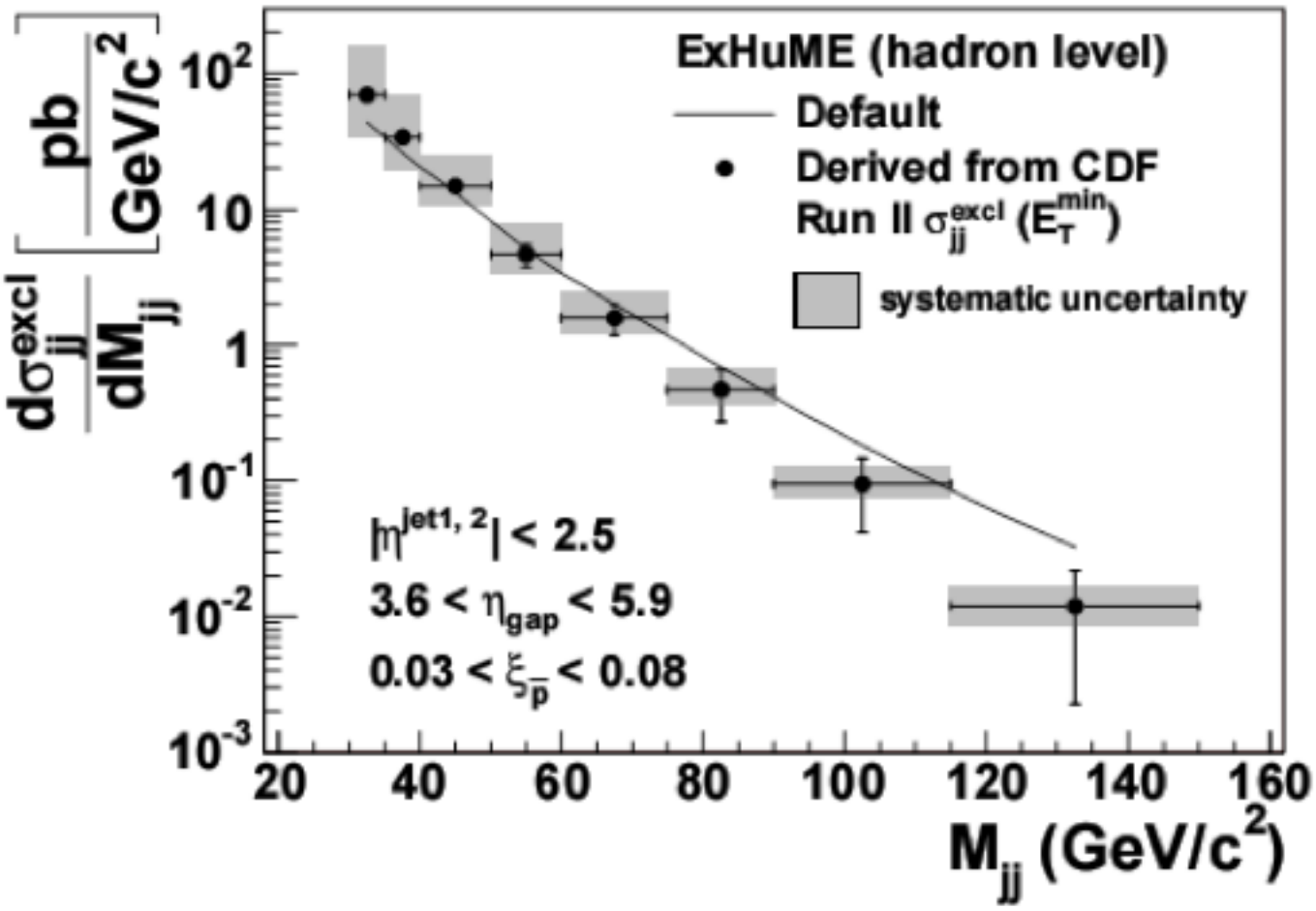
Phys.Rev.D77:052004,2008



- R_{jj} shape described by MC based on two models (ExHuME, DPEMC)
- Cross section agrees with ExHuME
- Data favor KMR model (uncertainty ~factor of 3)



Exclusive cross section



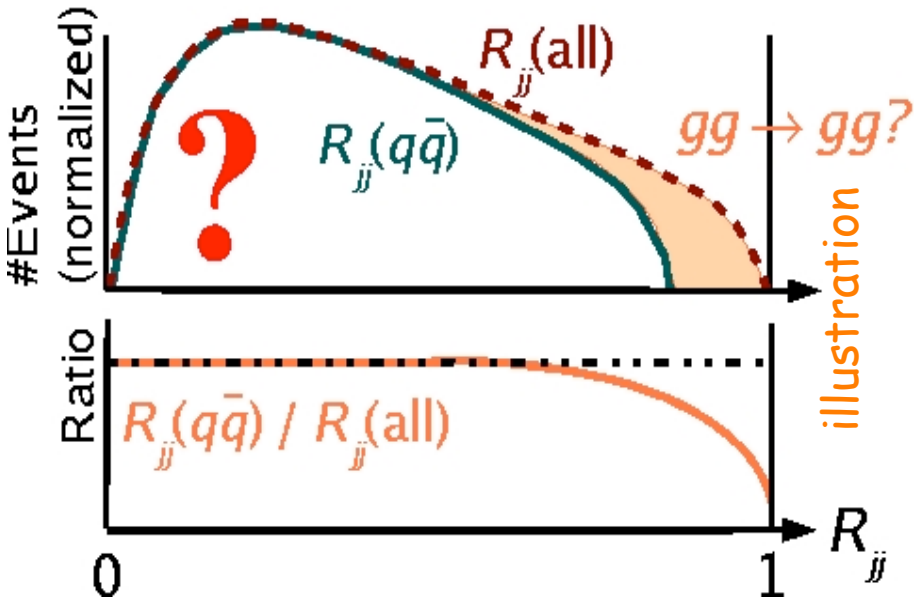
Exclusive dijets w/heavy flavor

Theory:
J_Z=0 spin selection rule
gg→gg dominant contribution at LO
gg→$q\bar{q}$ suppressed when $M_{jj} >> m_q$

Experimental method:
normalize R_{jj} for $q\bar{q}$ to R_{jj} for all jets
⇨look for event suppression at large R_{jj}

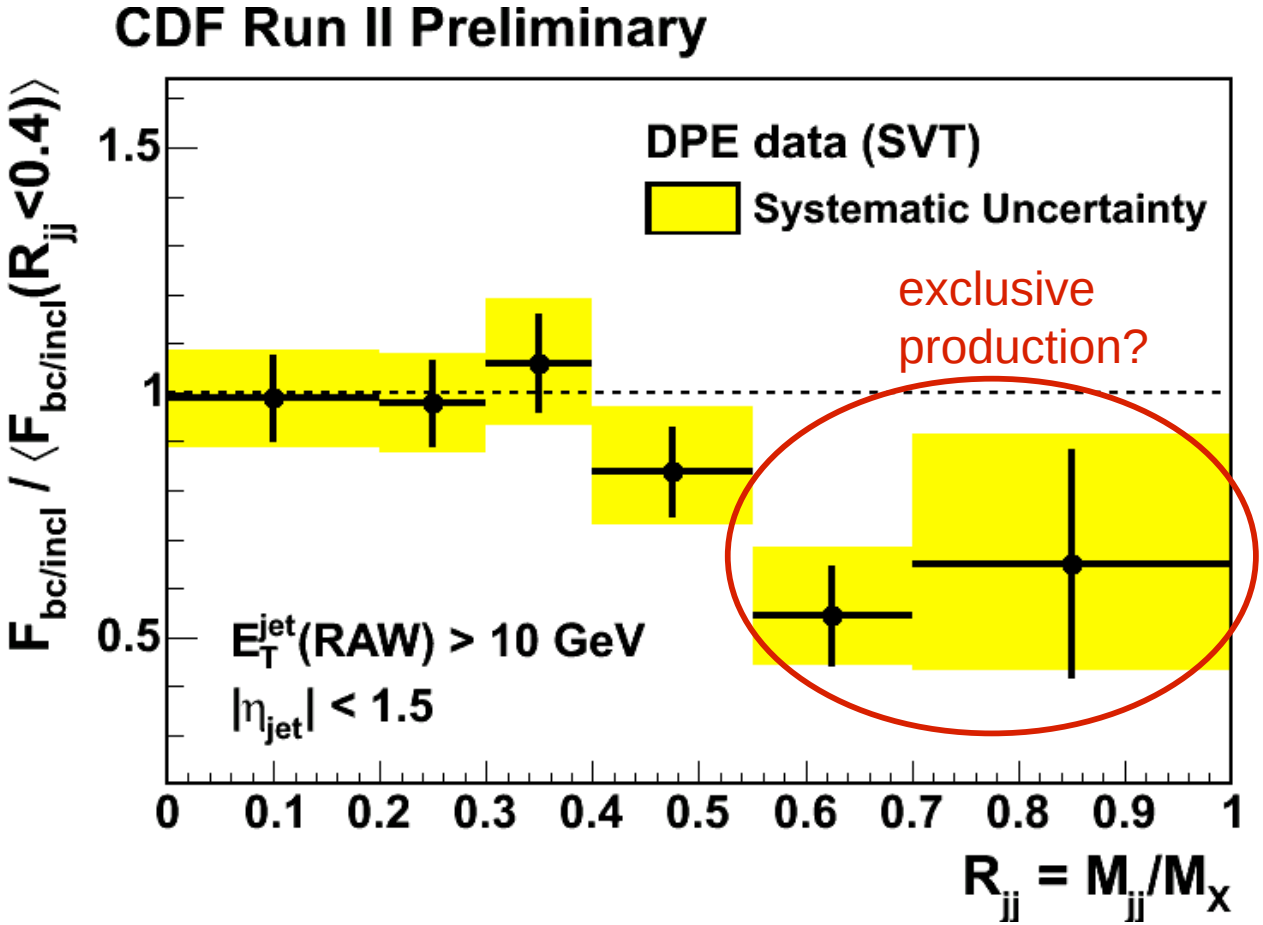
Pros: -many systematics cancel out
-good HF quarks id
-small g mistag O(1%)

Cons: -heavy quark mass:
contribution from exclusive b/c



⇨ use b-quark jets

b-tagged jet fraction



ratio of b/c jets to all jets (norm. to $R_{jj}<0.4$)

⇨ ratio decreases at high R_{jj}

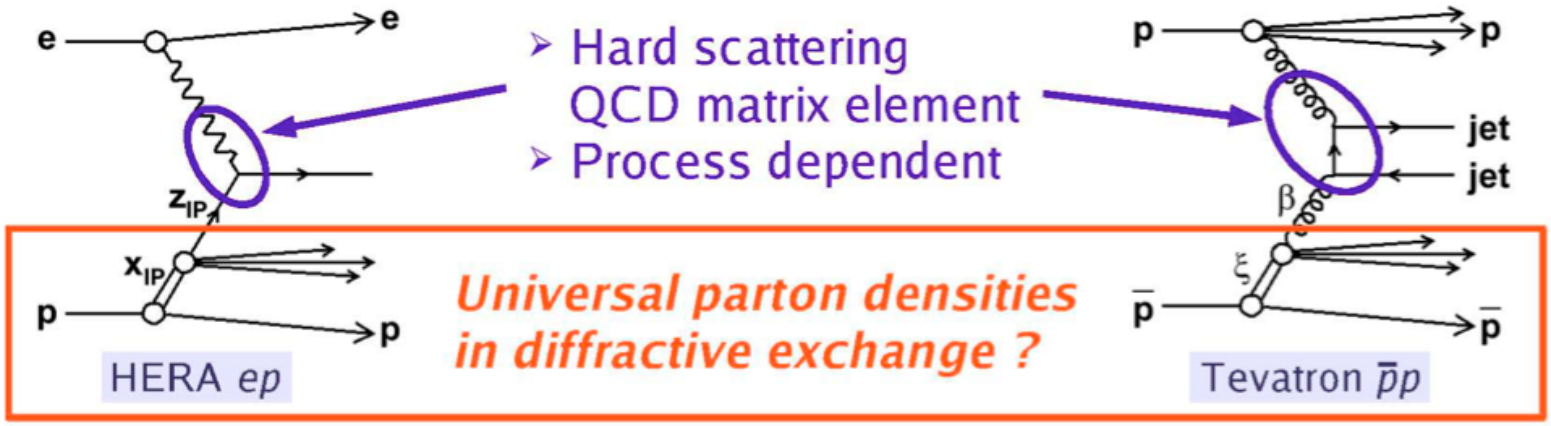
Summary

- CDF diffractive program continuing the improvement of understanding of diffractive processes
  - measured DSF at different Q^2 values
  - measured t-distribution in diffractive events
  - dijets, W/Z, forward jets, exclusive jets, etc.
- Comparison of diffractive and non-diffractive processes
- Measurements of exclusive production important to calibrate predictions for exclusive Higgs production at LHC
- General tools which can be used at LHC:
  - Roman Pot dynamic alignment
  - use calorimeter information to measure ξ

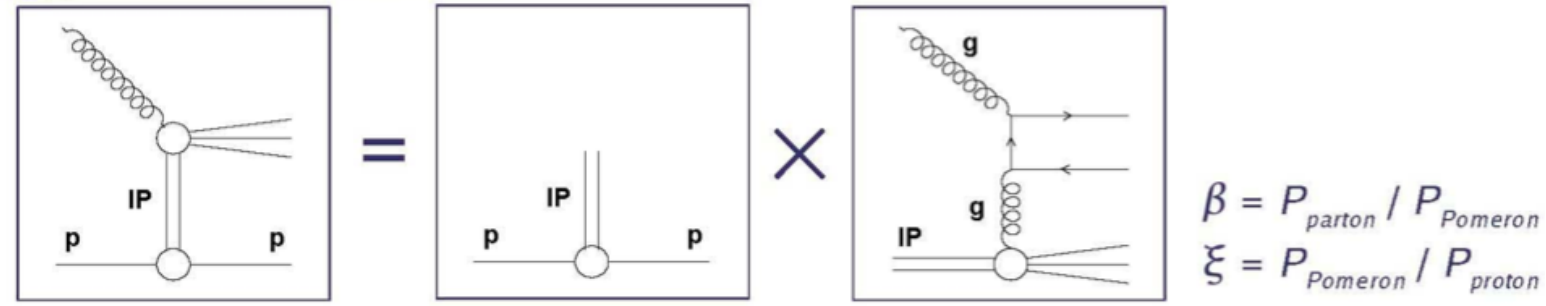
backup

Factorization

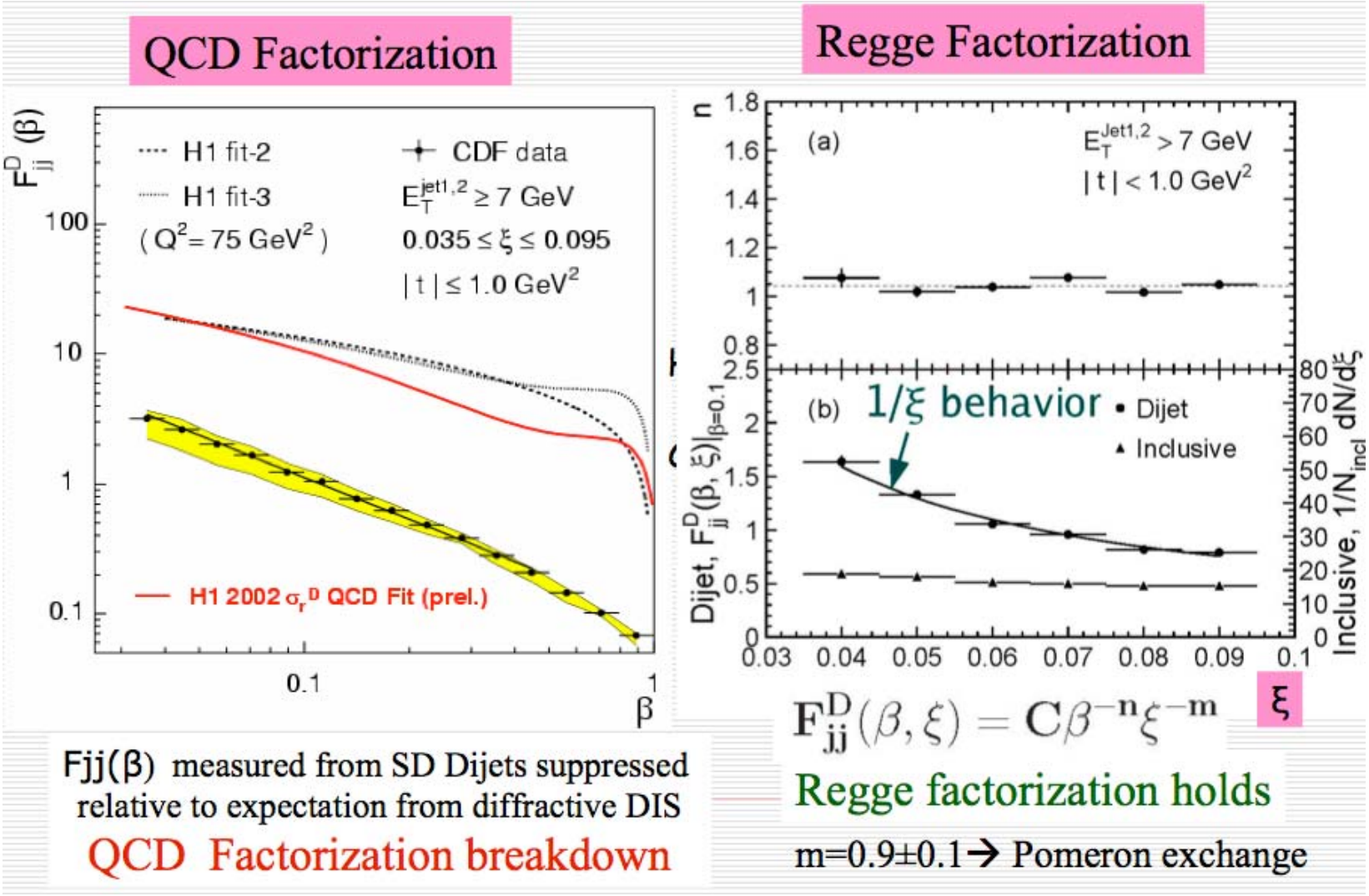
QCD factorization : $\sigma(\bar{p}p \to \bar{p}X) \approx F^{D}_{a/\bar{p}}(\xi, t; \beta, Q^2) \otimes \hat{\sigma}(ab \to jj)$



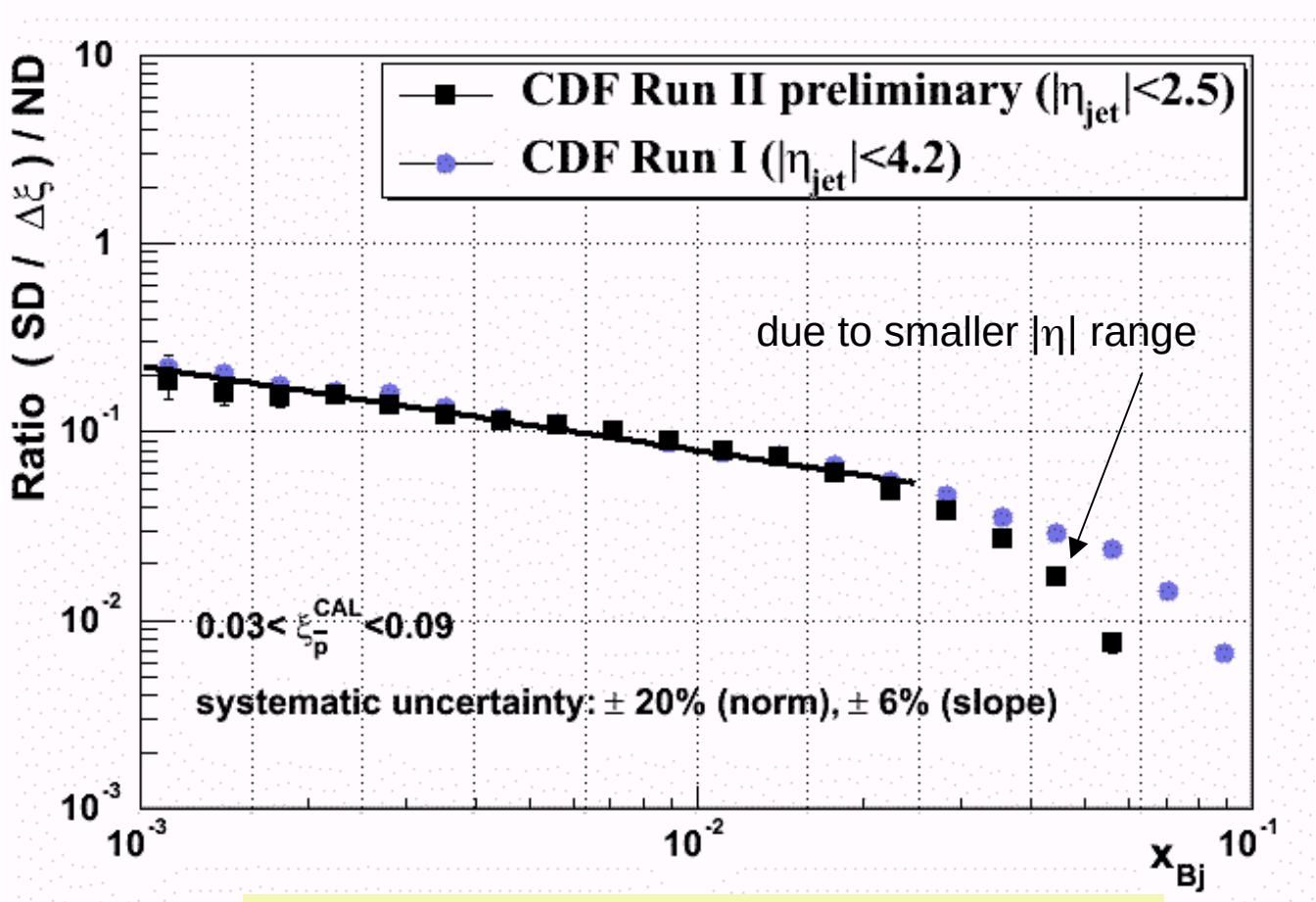
Regge factorization :



Factorization (cont.)



SD/ND ratio

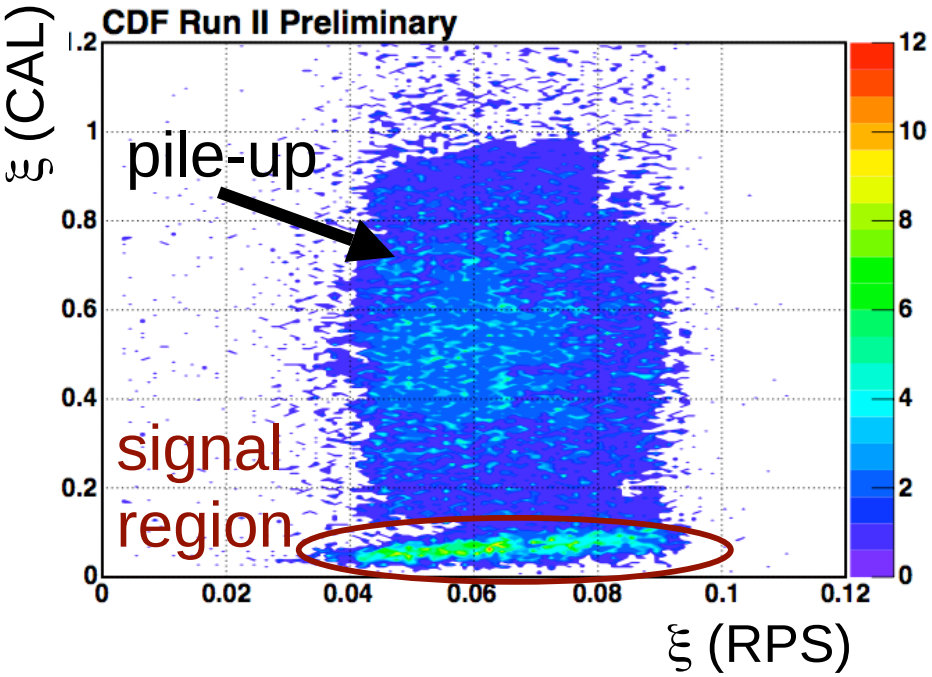


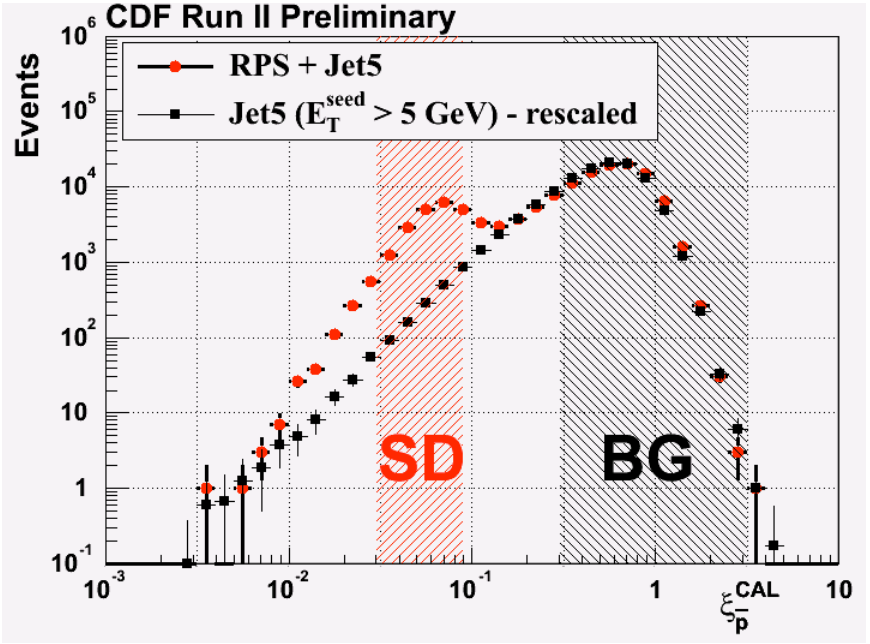
ratio of SD/ND dijet event rates

⇨ confirms Run I results

Multiple interactions in Run II

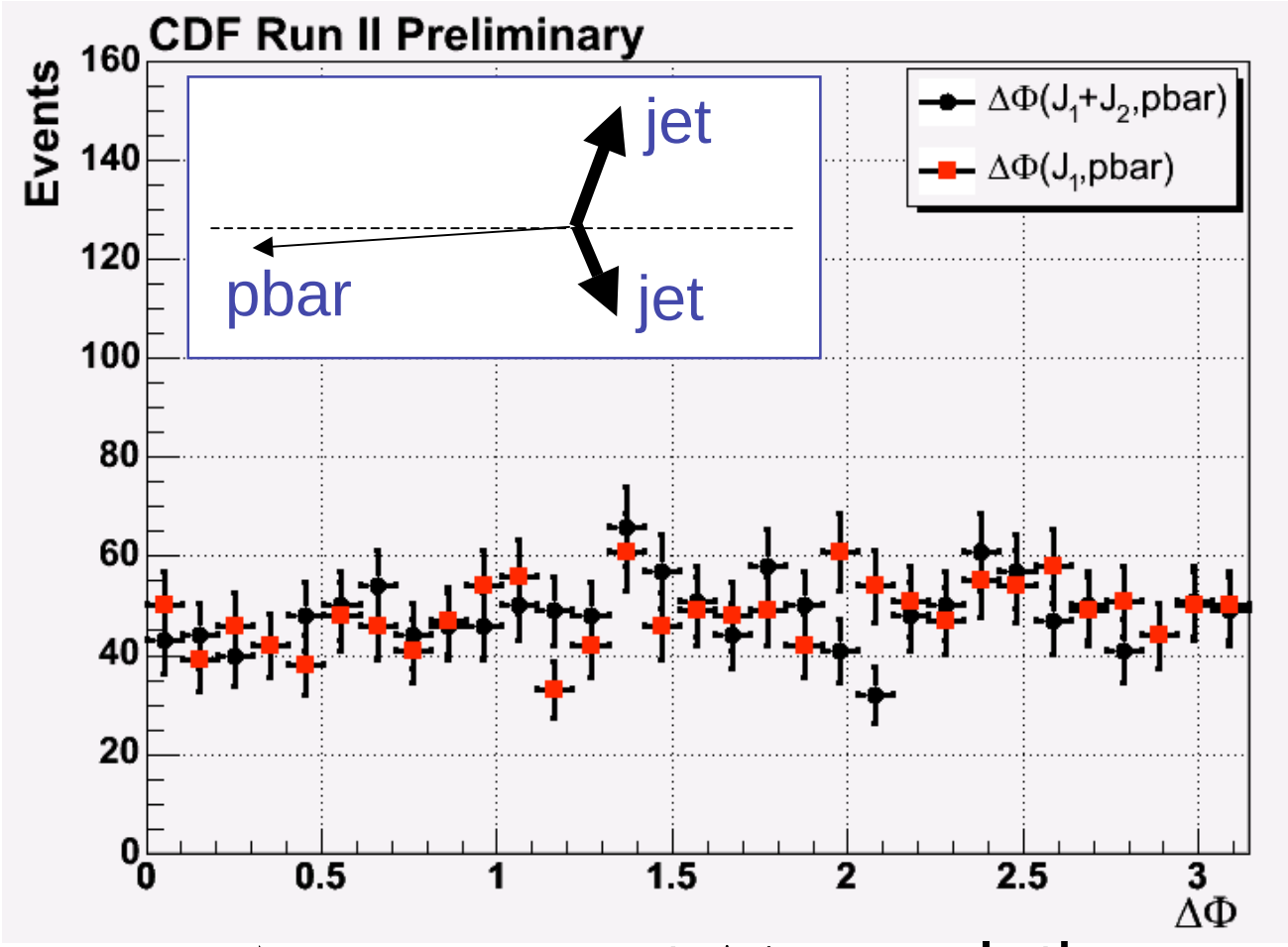
- Multiple proton-antiproton interactions spoil diffractive signature





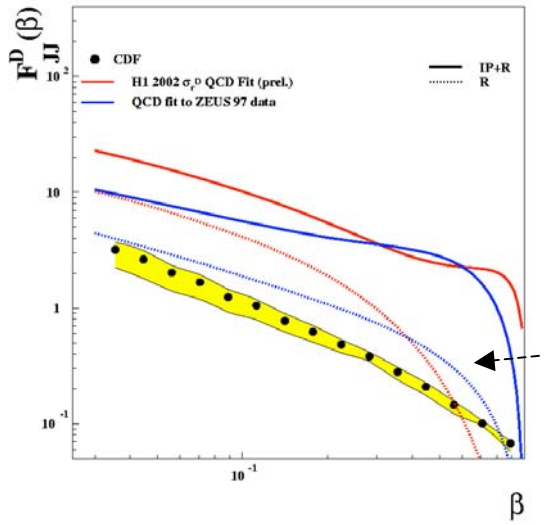
- Measure ξ from calorimeter and from RP tracking
- Reject multiple interactions
  - exclude ξ>0.1 (ND+SD interactions)

(un)correlation



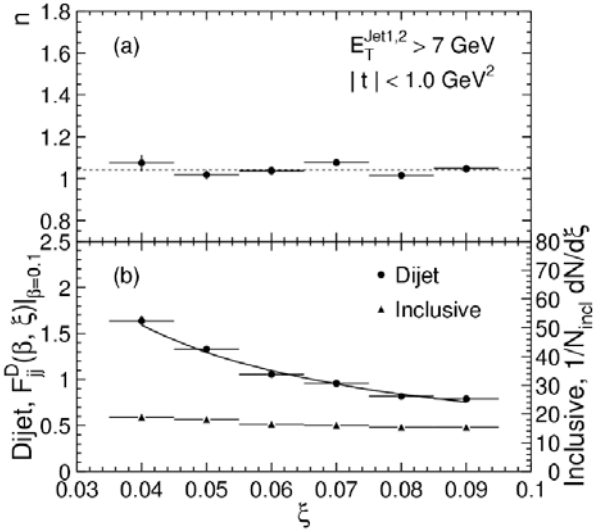
⇨no apparent Δϕ correlation

a few comments



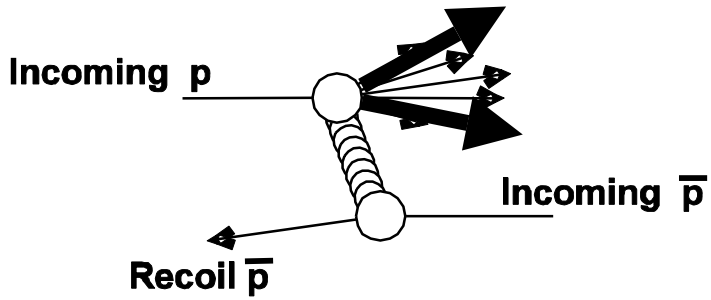
- large uncertainty at high β (no coverage!) but result stable at low β
- small reggeon contribution

- $F_{jj}^{D}(\beta, \xi) \sim 1/\beta^{n}$ [indep. of ξ]
  - ⇨ no change from IP to IR region
- $F_{jj}^{D}(\beta=0.1, \xi) \sim 1/\xi^{m}$ m=1.0±0.1 for dijets
  - ⇨ dijets are IP dominated, `inclusive' more IR like

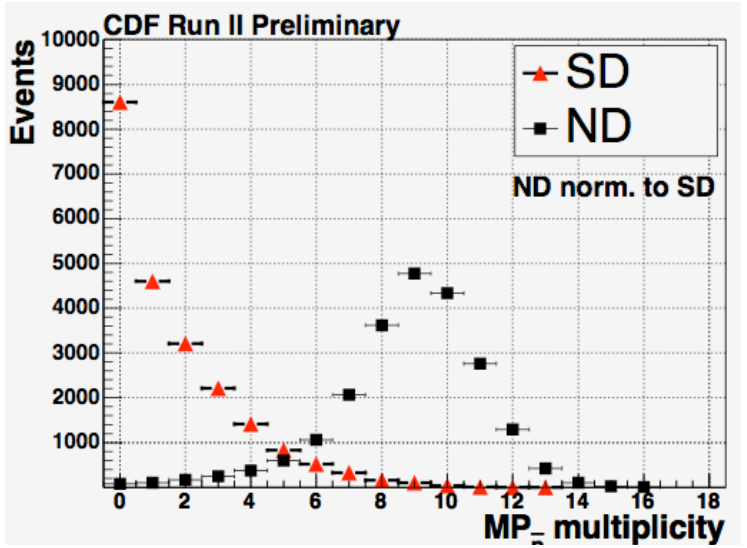


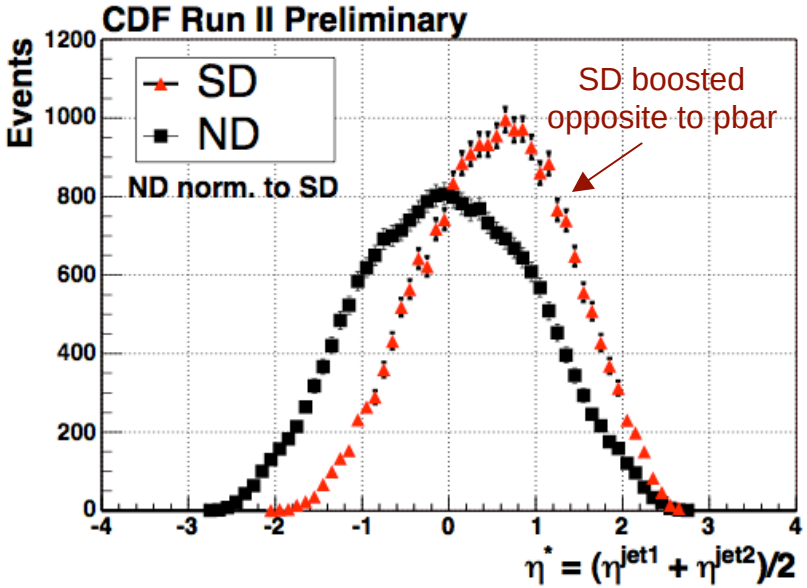
ξ-dependence is IP like (m for IP is ~1.1, for IR ~0 at Tevatron)

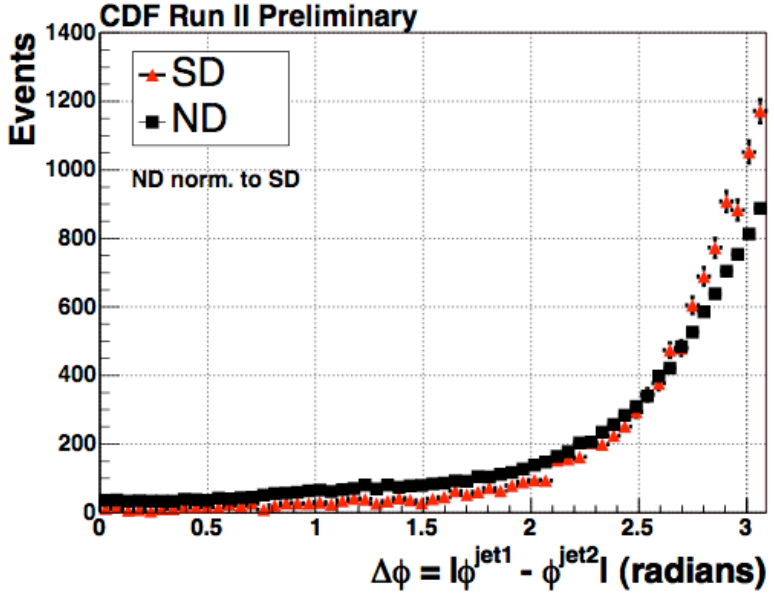
Kinematical properties



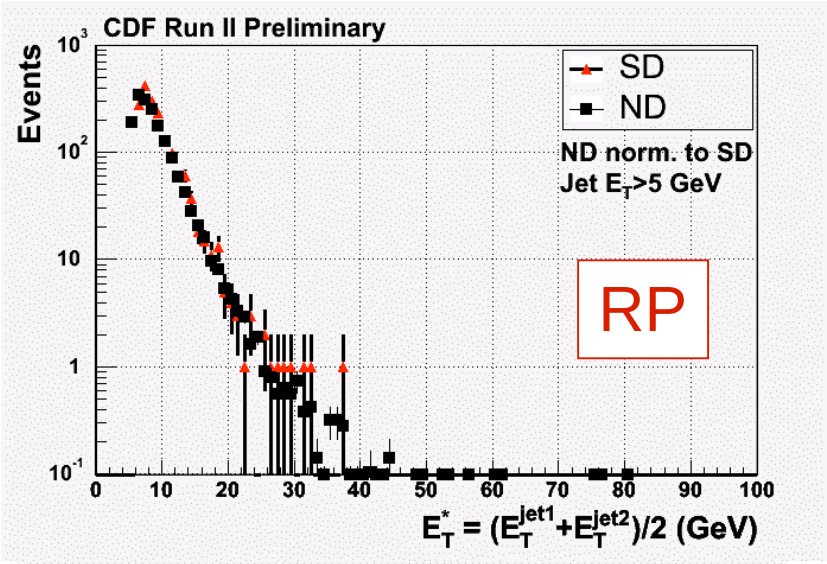
⇨compare ND and SD

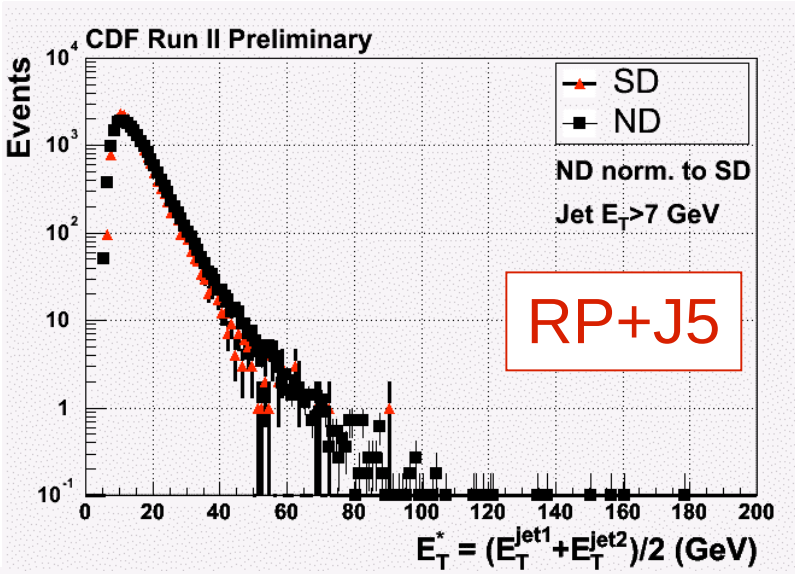


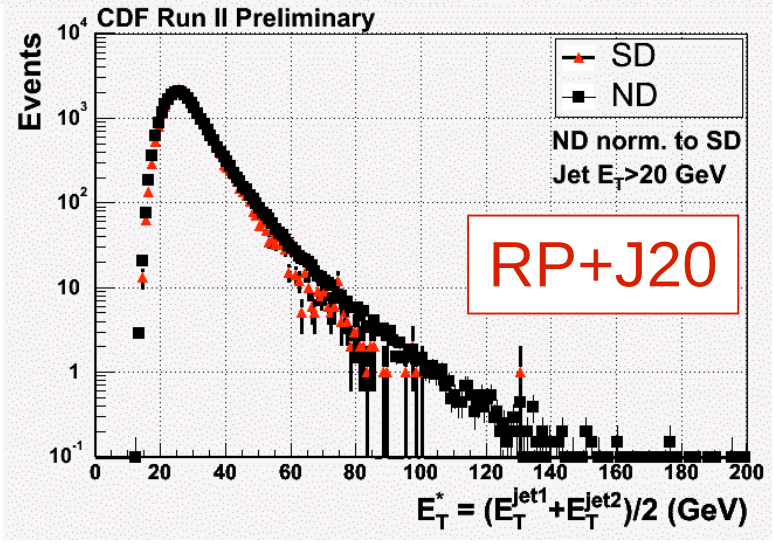


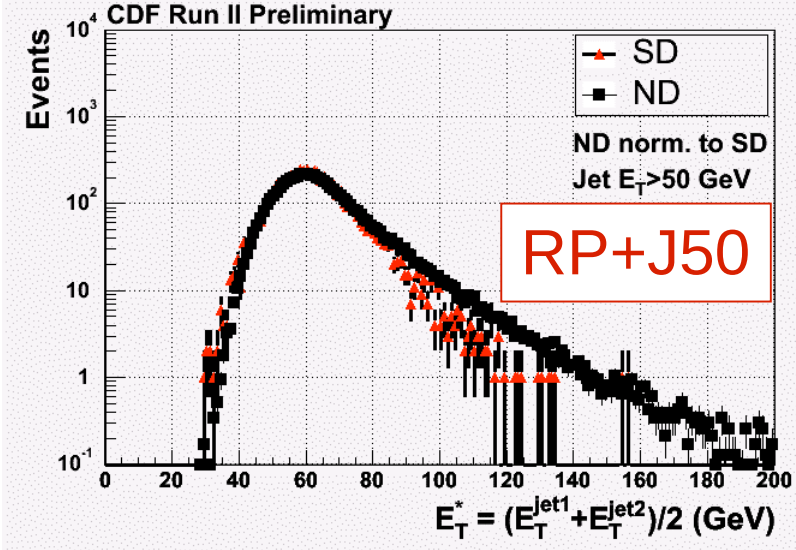


Transverse energy



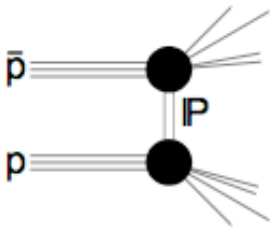


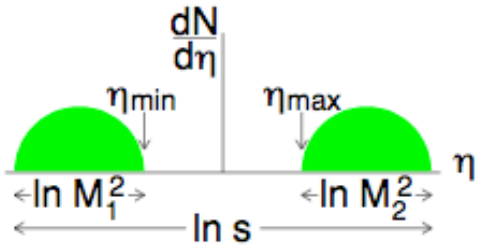




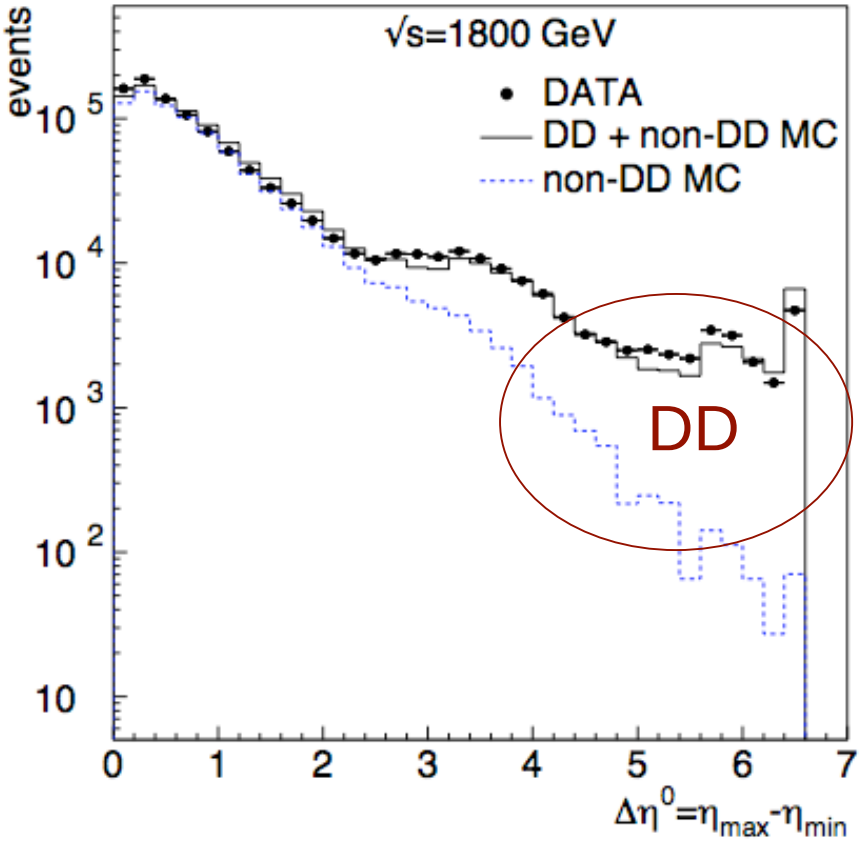
Rapidity gap fraction vs gap width

- Soft double diffraction
- No hard scattering required
- Look for rapidity gaps

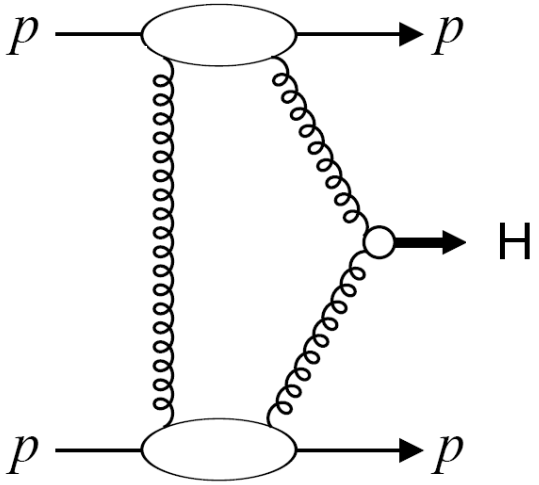




Phys.Rev.Lett.87,141803(2003)



Exclusive production

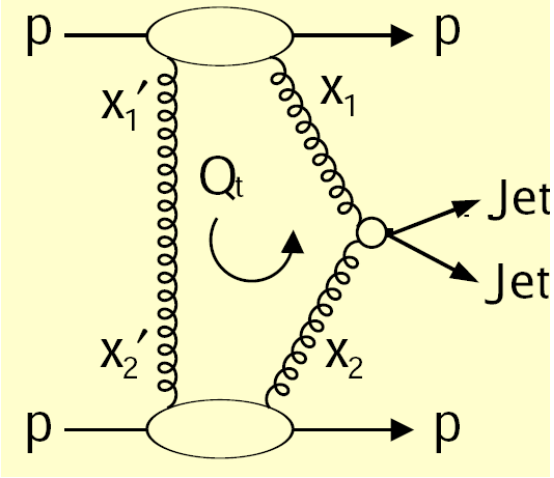


✓clean process

✓exclusive $b\bar{b}$ suppressed

Khoze Martin Ryskin: σ_H(LHC)~3 fb, signal/bkg~3 (if ΔM_{miss}=1 GeV)

Attractive Higgs discovery channel at the LHC



⇨much larger cross section

Goal:

- measure exclusive dijet production (if it exists)
- test/calibrate Higgs predictions at LHC