Results on Diffraction at CDF

Mary Convery
The Rockefeller University
for the CDF Collaboration

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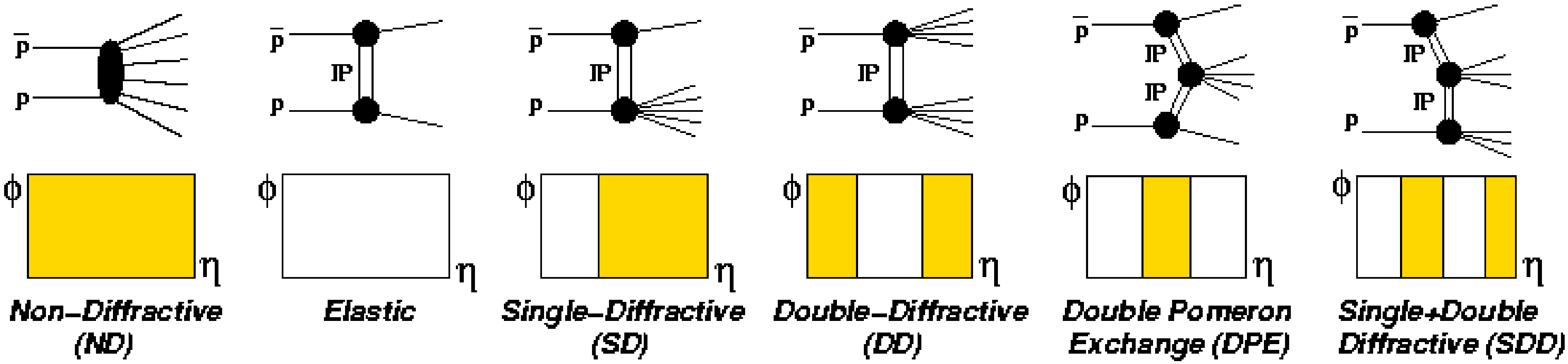
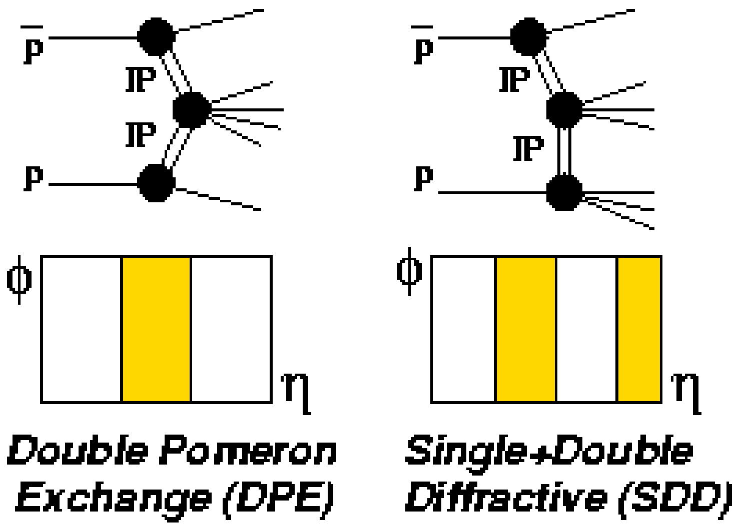
Diffraction at CDF



Total cross section	Elastic	Single diffraction	Double diffraction	DPE	SDD
		Soft Diffraction			
**PRD 50, 5550 (94)	**PRD 50, 5518 (94)	**PRD 50, 5535 (94)	PRL 87, 141802 (01)	*Accepted by PRL	*PRL 91, 011802 (03)
		Hard Diffraction			
		W PRL 78, 2698 (97)	**JJ** PRL 74, 855 (95)	**JJ** PRL 85, 4217 (00)	
		JJ PRL 79, 2636 (97)	**JJ** PRL 80, 1156 (98)		
		B PRL 84, 232 (00)	**JJ** PRL 81, 5278 (98)		
		J/ψ PRL 87, 241802 (01)			
		***JJ** PRL 84, 5043 (00)			
		***JJ** PRL 88, 151802 (02)			
		Run II (in progress)			
		***JJ**	**JJ**	***JJ**	
		***W,Z**		**Xc**	
				***Bb**	

* Using Roman pots on antiproton side ** In Run 0 there were Roman pots on both the proton and antiproton sides

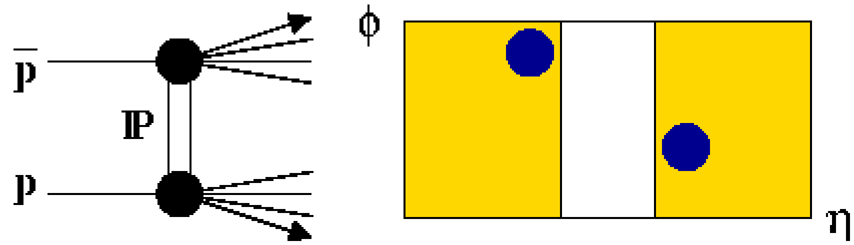
Events with multiple rapidity gaps



- What can we learn about rapidity gap production/survival in events with multiple gaps?
- Can think about it as producing a gap in the presence of an existing gap
  - Is the second gap easier to produce? More likely to survive?

Rapidity gap survival probability

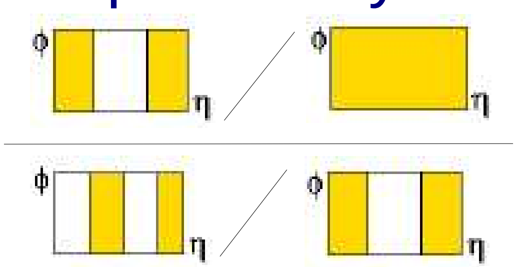
- Motivation: test QCD calculations of the production of a rapidity gap between jets
- 2 factors enter in the calculation
  - QCD (Bj 2-gluon, BFKL, ...)
  - Gap survival probability (products of spectator interactions spoil gap)
    Bjorken PRD 47, 101 (1993)
- Eliminate gap survival $\rightarrow$ address QCD

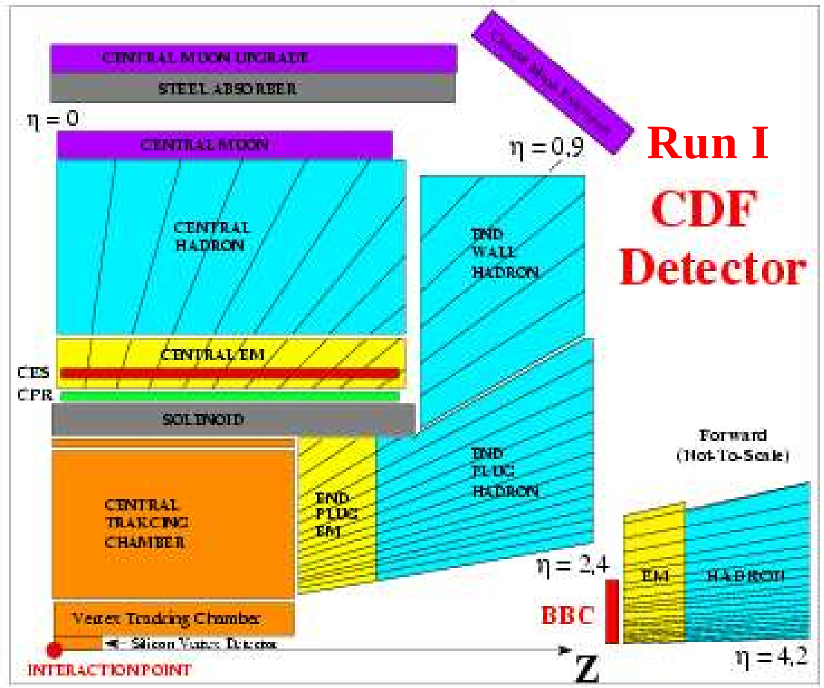


- Jet-gap-jet rate suppressed by
  - Jet radiation: perturbative, calculable in QCD
  - Nonperturbative effects, phenomenological models
- Determine nonperturbative experimentally

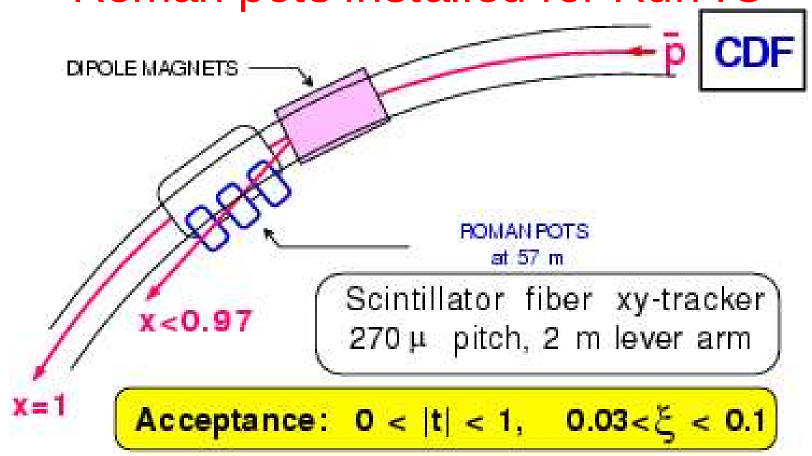
Central gaps in Roman-Pot-triggered events in Run I

- Determine gap survival probability experimentally in soft diffraction
- Multiple gaps: first gap survived ⇒ additional gaps also expected to survive
- Measure rate of additional (central) gaps in sample of events with a forward $\bar{p}$ PRL **91**, 011802 (2003)
- survival probability

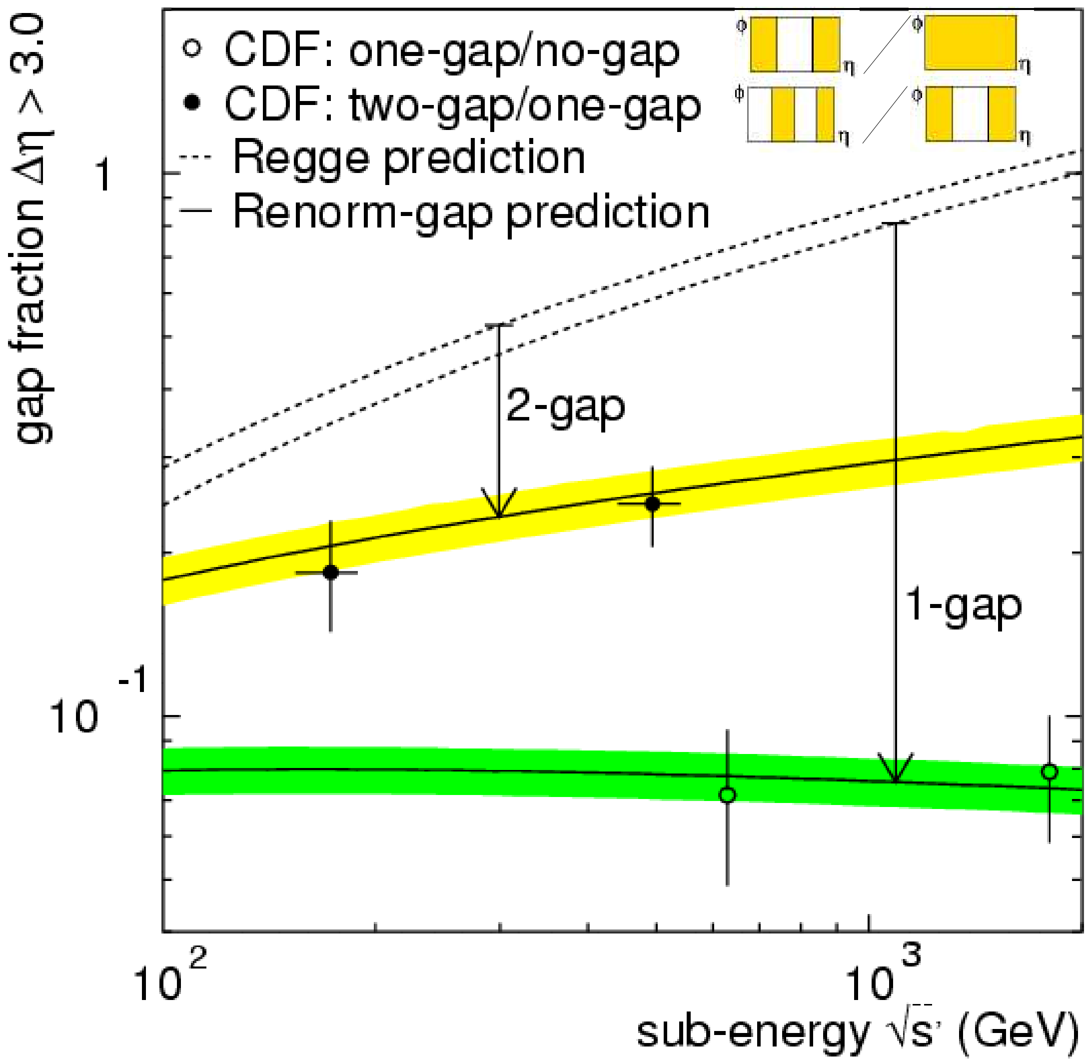
$S =$




Roman pots installed for Run IC



Fraction of events with a gap

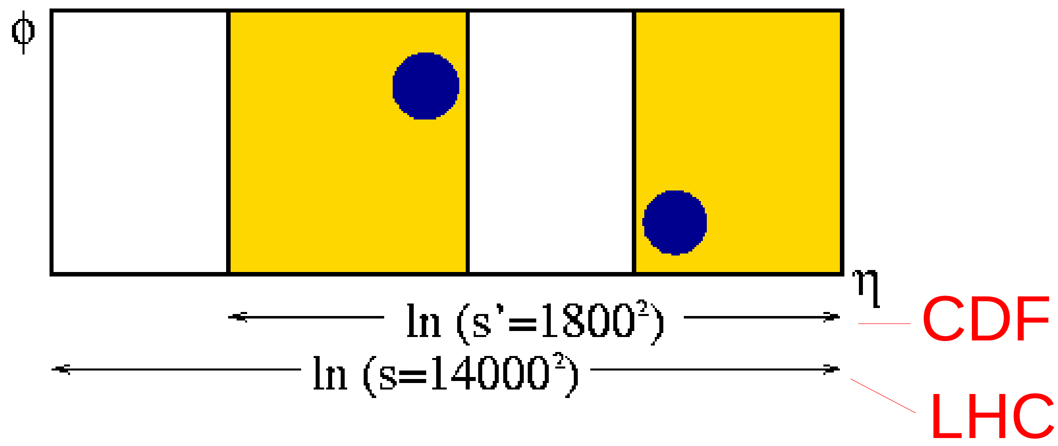


Soft gap

<u>Survival probability</u>

- $S = R^{1\text{-gap}/0\text{-gap}}_{2\text{-gap}/1\text{-gap}}$
- $\sqrt{s}$=1800 GeV
  $S \approx 0.23 \pm 0.07$
- $\sqrt{s}$=630 GeV
  $S \approx 0.29 \pm 0.09$
- $S(630)/S(1800) \approx 1.29$

Prediction for LHC $\sqrt{s}$ = 14 TeV



R^{LHC}(JGJ/JJ) = (1.13±0.16)% / (0.23±0.07) = (4.9±1.6)%

Renormalized gap probability: Multiple gaps

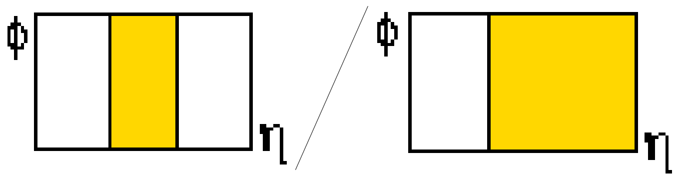
K. Goulianos, hep-ph/0203141

Gap probability - norm to 1

- SD: $d^2\sigma/d\Delta y'dt = C\cdot F_p^2(t)\cdot e^{2(\varepsilon+\alpha' t)\Delta y} \times \kappa\, \sigma_0 e^{\varepsilon\Delta y'}$
- SDD: $d^5\sigma/d\Delta y'dt... = C\cdot F_p^2(t)\cdot\prod_{i=1,2} e^{2(\varepsilon+\alpha' t_i)\Delta y_i} \times \kappa^2 \sigma_0 e^{\varepsilon(\Delta y'_1+\Delta y'_2)}$
- $\Rightarrow$ SDD/SD ~ $\kappa = g(t)/\beta(0) \approx g(0)/\beta(0) = 0.17\pm0.02$
- We find for $\sqrt{s'} \approx$ 170-500 GeV, SDD/SD $\approx$ 0.2

- DPE: $d^4\sigma/dt_1dt_2d\Delta y_1 d\Delta y_2 = \prod_{i=1,2} C\cdot F_p^2(t_i)\cdot e^{2(\varepsilon+\alpha' t_i)\Delta y_i} \times \kappa^2 \sigma_0 e^{\varepsilon\Delta y'}$

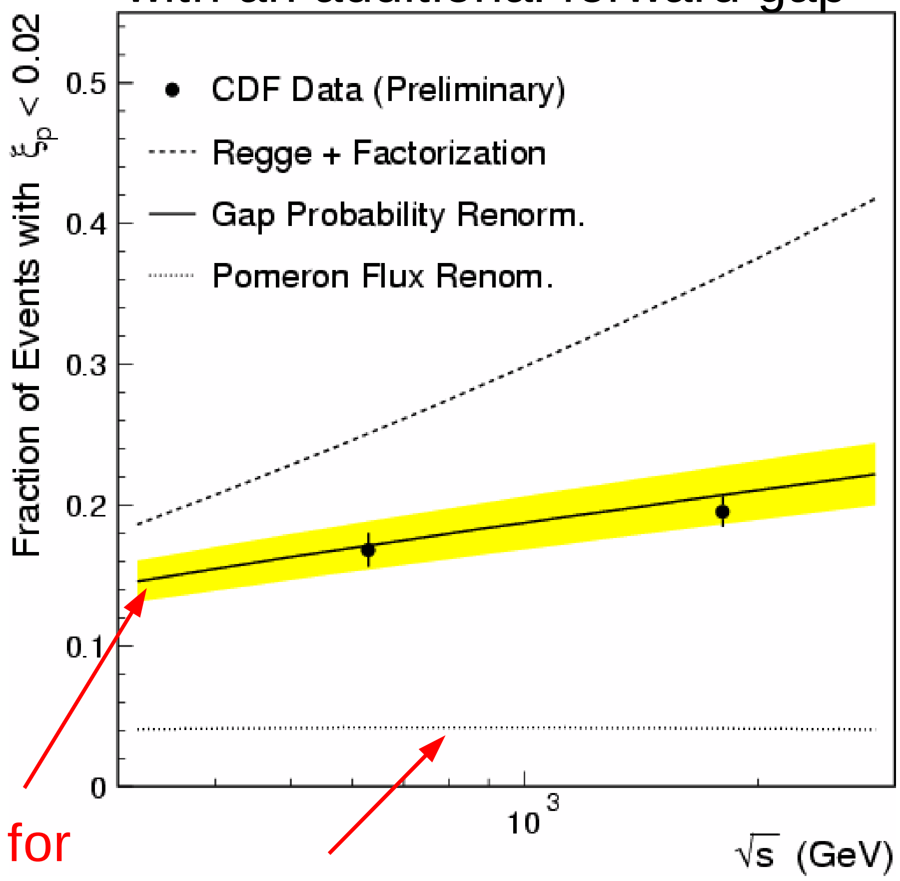
Run I Inclusive Double Pomeron Exchange



- Fraction of Roman-Pot triggered events with an additional forward gap due to DPE
  accepted for publication in PRL

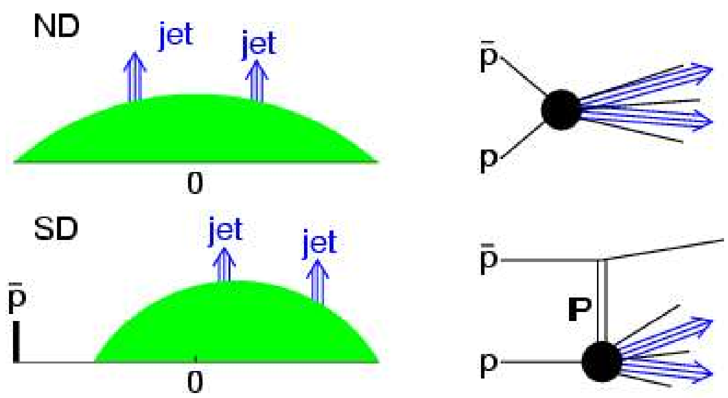
- Again we see that the second gap is less suppressed

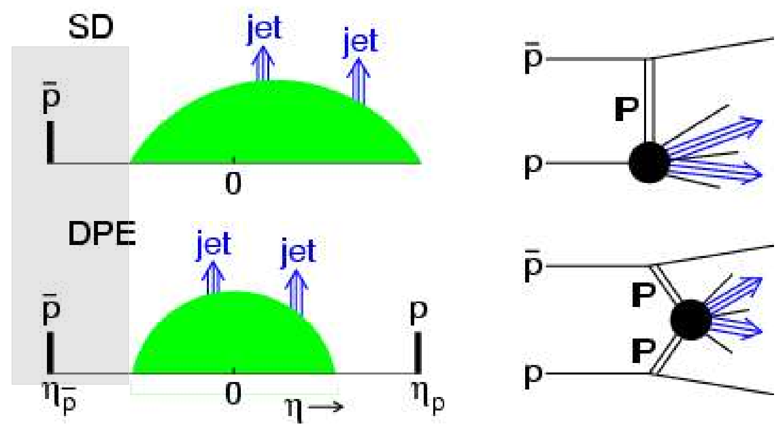
Fraction of RP-triggered events with an additional forward gap

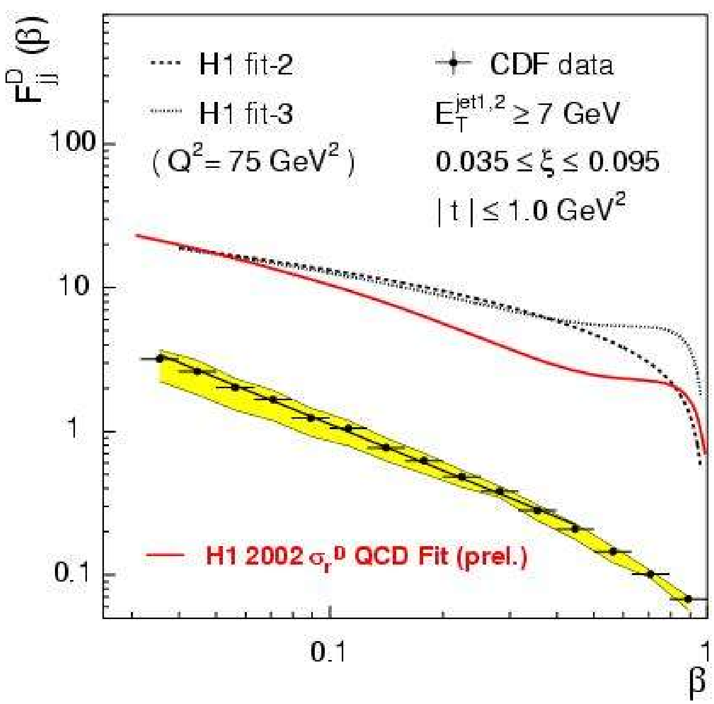


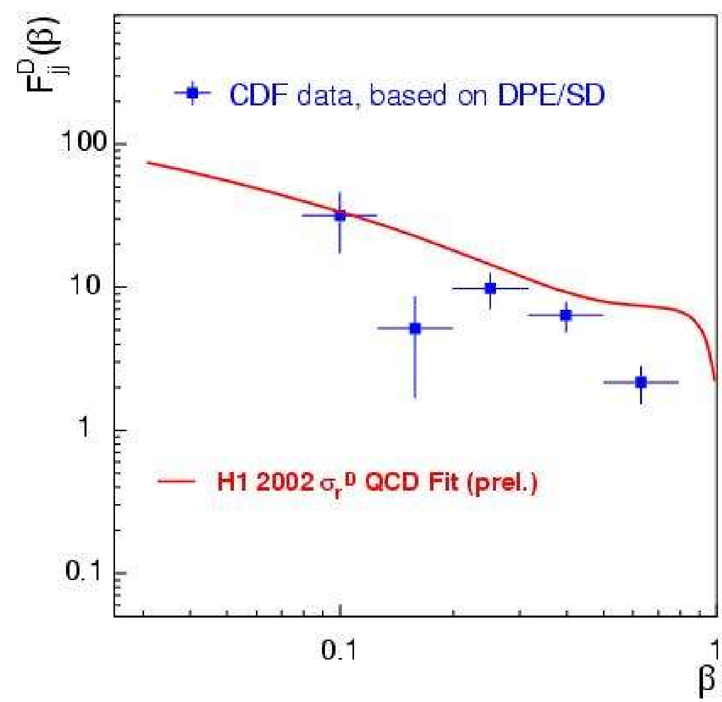
DPE Dijet Production in Run I

- Single gaps – breakdown of QCD factorization
- Double gaps – factorization holds for second gap!

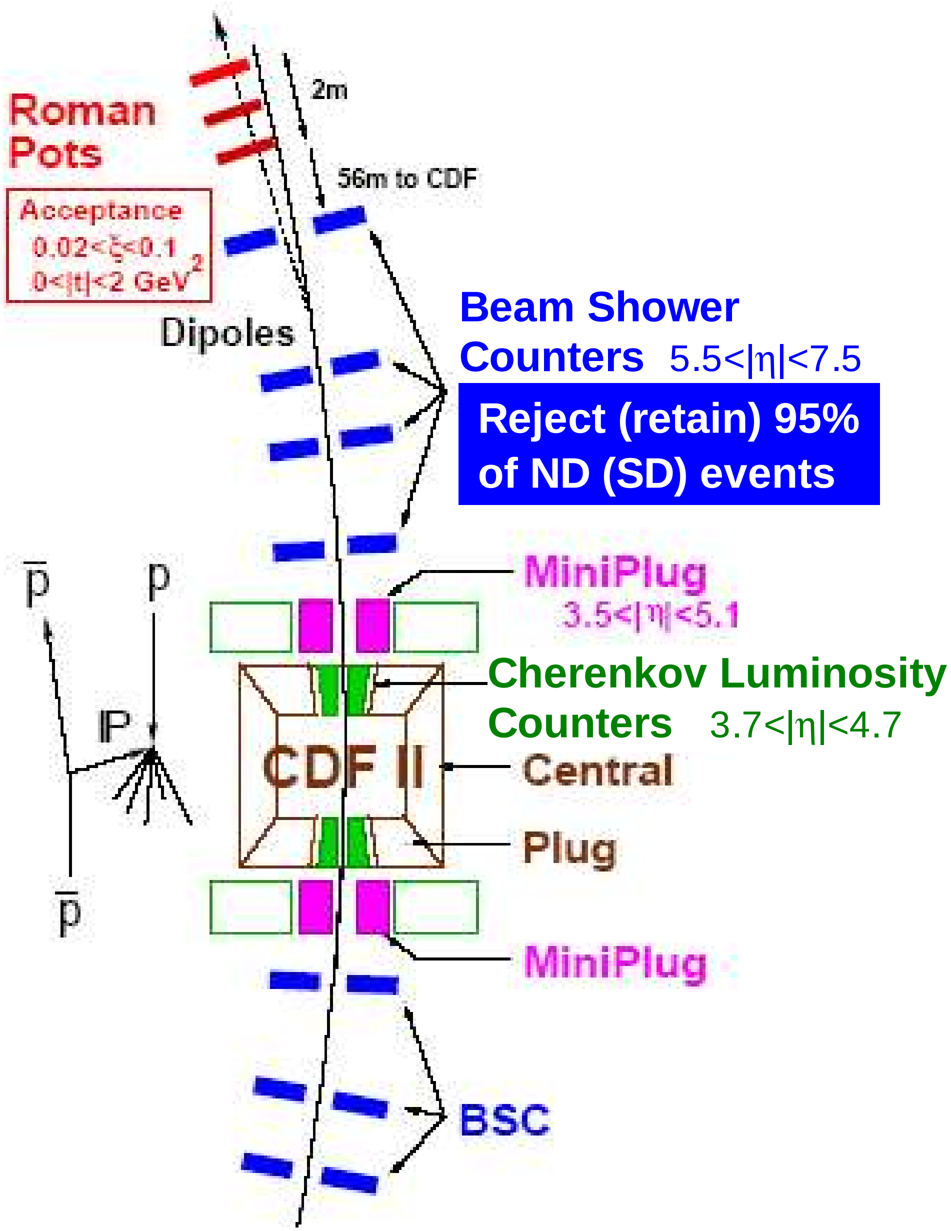


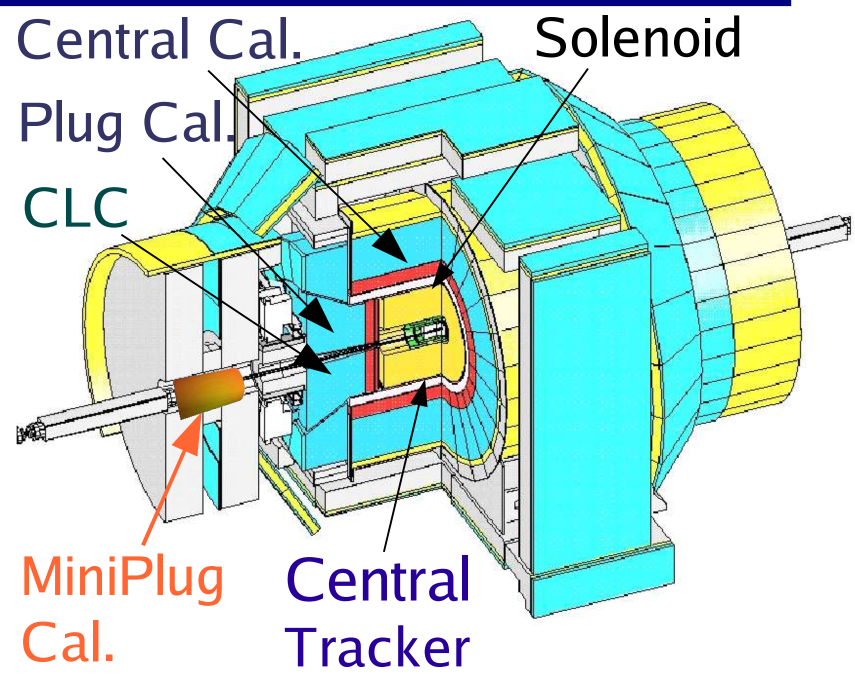


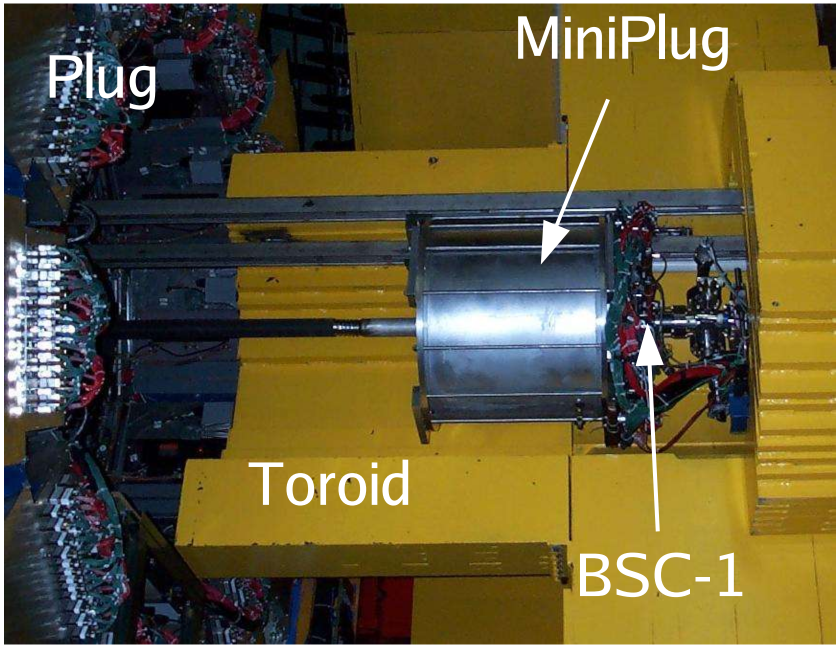




CDF Run II Detector







Run II physics in progress

- Diffractive structure function F^D
  - Single Diffractive dijet production
    - Measure Q^2 dependence
    - Measure ξ dependence (extend range from Run I)
  - Measure F^D in other processes such as SD *W* (probes quark) and J/ψ (gluon) production
  - Measure F^D from DPE dijets: F^D vs gap width on other side

- Exclusive production in Double Pomeron Exchange
  - Exclusive dijet, χ_c , $\gamma\gamma$ production as benchmark for exclusive Higgs production at LHC

Run II SD dijets

- Trigger on RP coincidence plus calorimeter tower E_T>5 GeV
- Momentum fraction ξ determined by summing over all particles except leading $\bar{p}$

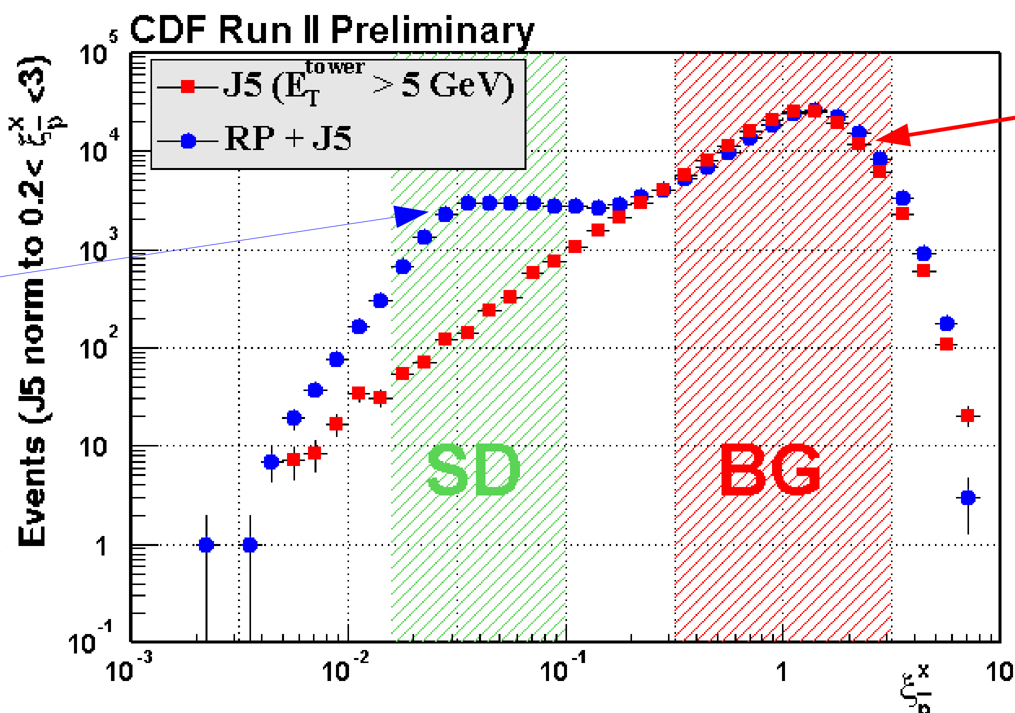
$$\xi_{\bar{p}}^{X} = \frac{M_X^2}{s} \approx \frac{\Sigma_i E_T^i e^{-\eta_i}}{\sqrt{s}}$$

  - Use calorimeter towers with E_T>100 MeV
  - MiniPlug energy scale: ±25% → Δlog ξ = ±0.1

RP acceptance 0.03 < ξ < 0.10

$$\frac{d\sigma}{d\xi} \propto \frac{1}{\xi}$$

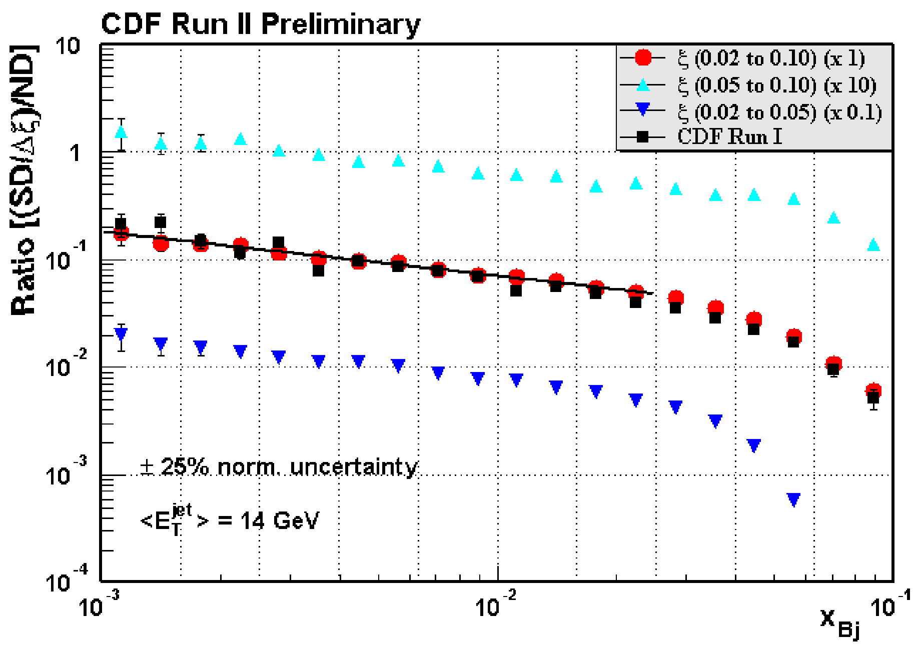
$$\frac{d\sigma}{d(\log \xi)} = constant$$

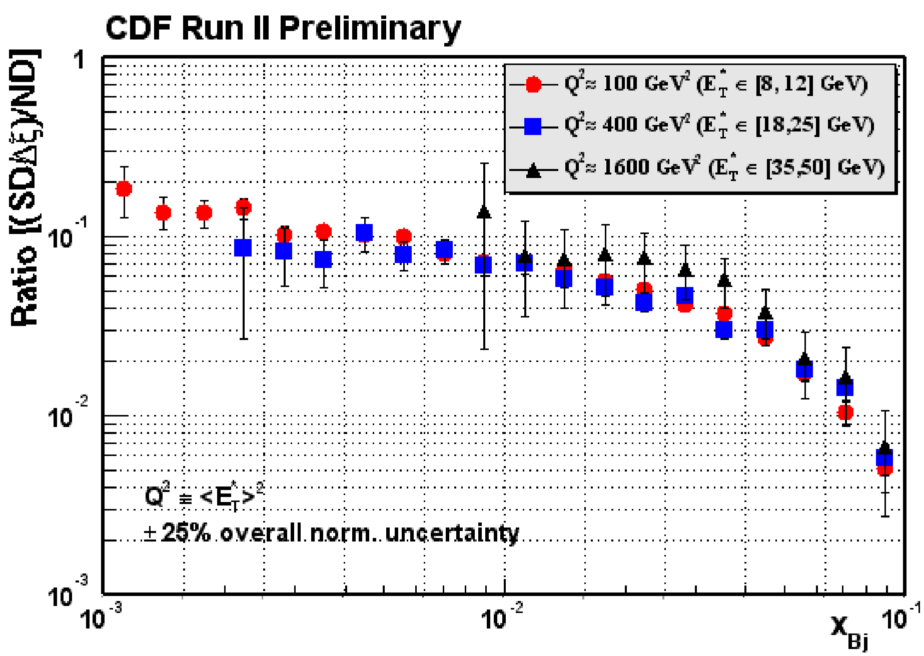


Jet5 data normalized to RP+jet5 in the region 0.2<ξ<3

This allows us to estimate the contribution from ND events with a coincident RP trigger

SD dijet ξ, Q^2 dependence



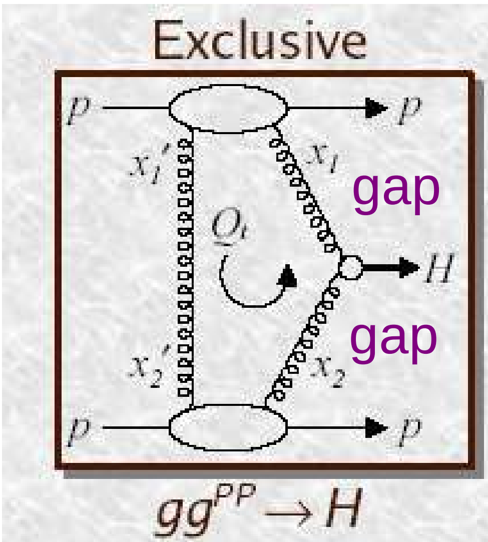


Ratio of SD to ND dijet event rates as a function of x_{Bj}

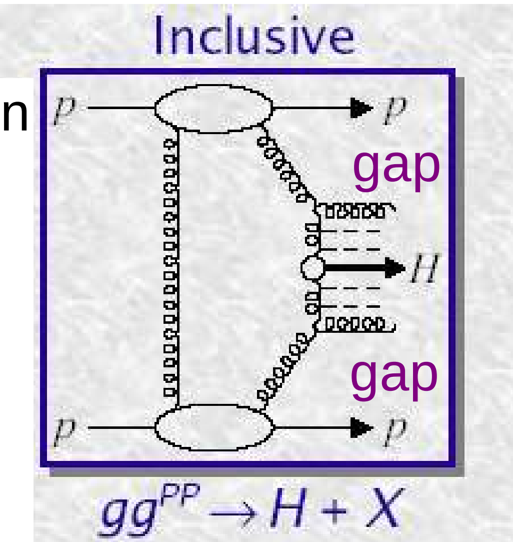
- No ξ dependence observed within 0.03<ξ<0.1 (confirms Run I result)
- Will use gap+jet data to go beyond reach of RP (ξ<0.03) by summing over particles in calorimeter to determine ξ – possible to reach ξ~0.001 for Q^2>100 GeV^2
- No appreciable Q^2 (=E_T^2) dependence observed within 100<Q^2<1600 GeV
- Can reach higher Q^2 range using higher-E_T jets once enough statistics are accumulated

Exclusive production in Double Pomeron Exchange

- Exclusive Higgs production in DPE is an attractive channel for observing relatively light Higgs bosons at the LHC
  - Clean environment
  - $b\bar{b}$ background suppressed
  - Determination of Higgs mass with good accuracy



Khoze, Martin, Ryskin
Eur. Phys. J.
C23, 311 (2002),
C25, 391 (2002),
C26, 229 (2002)



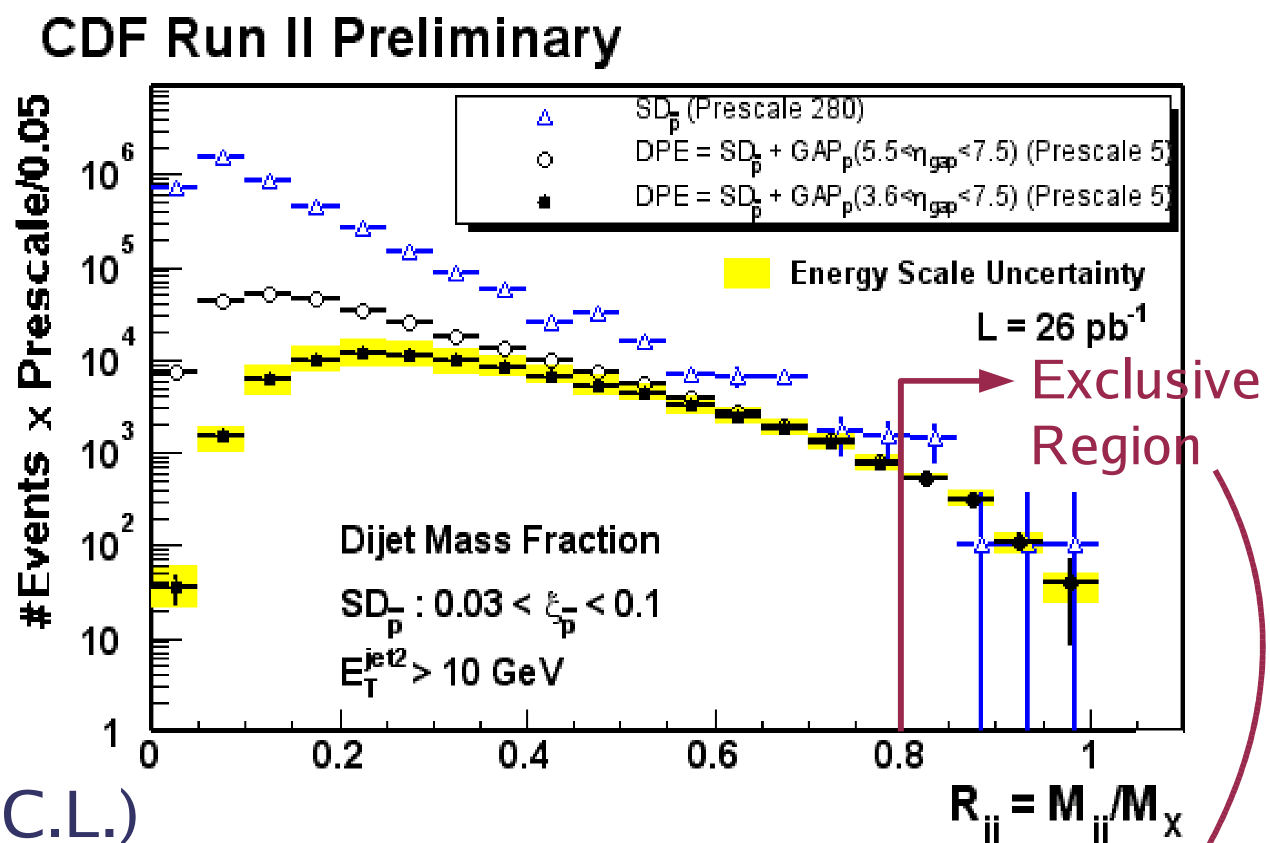
- Exclusive production of dijets, χ_c, $\gamma\gamma$ in DPE can be studied at the Tevatron and used to constrain predictions for exclusive Higgs

Exclusive Dijet Cross Section Limit

- Trigger: RP+Jet5+GAP
- Dijet mass fraction:

$$R_{jj} = \frac{M_{jj}^{cone}}{M_X}$$

- Falls smoothly as $R_{jj} \rightarrow 1$
- No significant excess at high R_{jj}



Run I : σ_{excl} < 3.7 nb (95% C.L.)

$|\eta^{jet1,2}|<2.5$, $0.03<\xi_p\leq 0.1$, $3.6<\eta_{gap}<7.5$, $R_{cone}=0.7$

$\sigma_{DPE}(R_{jj}>0.8)$ = 970 ± 65(stat) ± 272(syst) pb (E_T^{jet1} > 10 GeV)

34 ± 5(stat) ± 10(syst) pb (E_T^{jet1} > 25 GeV)

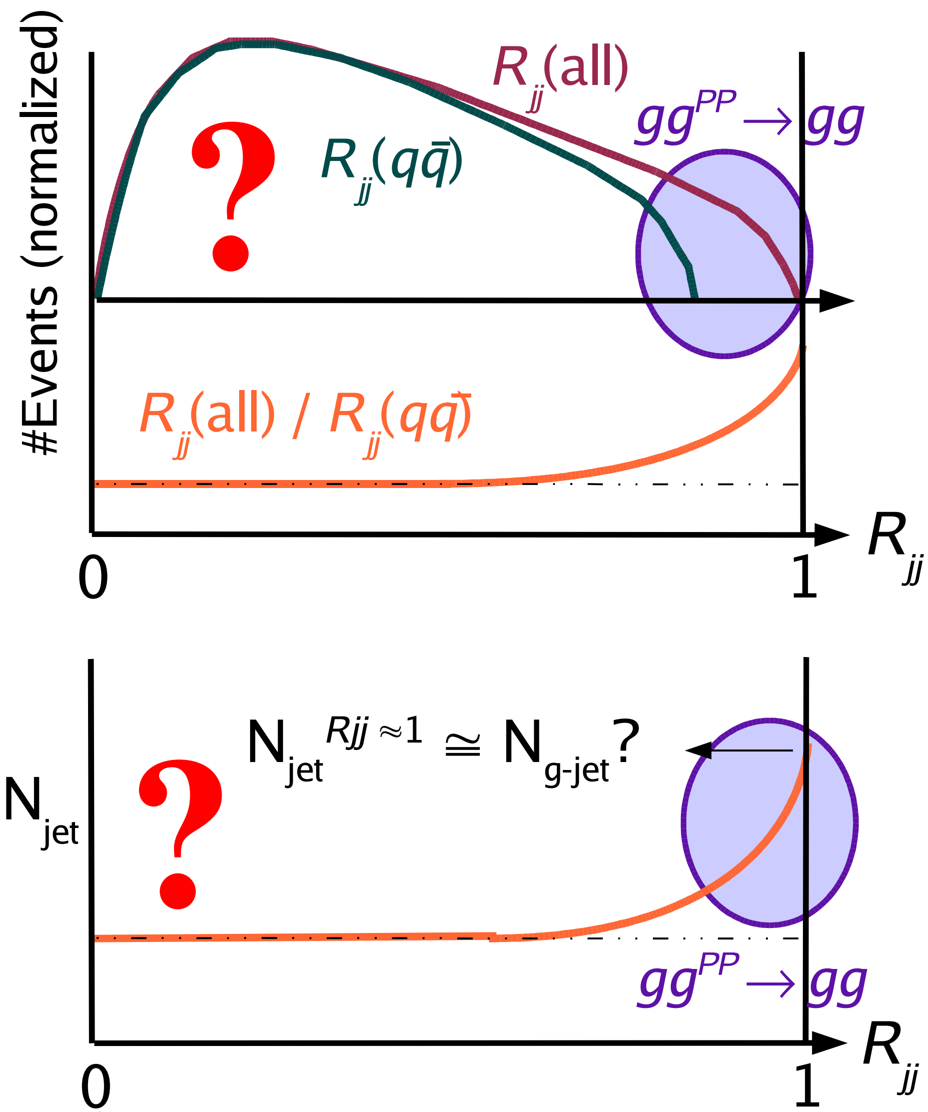
Khoze, Martin, Ryskin → 60 pb (factor 2 uncertainty)

Eur. Phys. J. C23, 311 (2002)

@ $25<E_T^{jet}<35$ GeV, $|\eta^{jet1}-\eta^{jet2}|<2$

Exclusive dijet production in Double Pomeron Exchange

- LO exclusive dijet production:
  - *gg*→*gg* dominant, *gg*→$q\bar{q}$ strongly suppressed for $m_q^2/M_{jj}^2 \to 0$ (J_Z=0 selection rule)
    Bialas, Landshoff
    Berera, Collins
    Khoze, Martin, Ryskin
- Exclusive $q\bar{q}$ suppressed for light quarks (*u*,*d*,*s*) or dijet mass large compared to *b* mass
- Exclusive *gg*→*gg* contribution might be seen as an excess over inclusive $q\bar{q}$ at high R_{jj} ~1



if exclusive *gg* is sizable relative to "inclusive tail" background at high R_{jj}

Exclusive dijet production in DPE – Heavy flavor quark jets

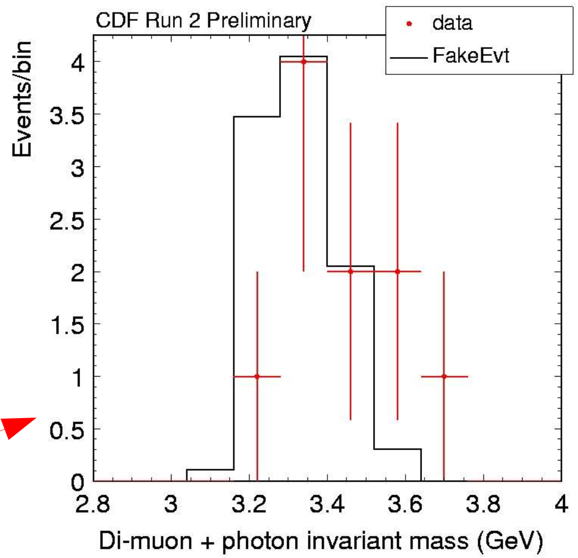
- Easy to identify HF (*c*,*b*) jets
- Need dijet mass large compared to *b* mass
- $q\bar{q}$ suppressed only for direct production of HF quarks – need to separate out HF from gluon splitting (significant contribution especially in events with only one tagged *b* jet)
  - Plan to use double-tagged events with $\Delta\phi$ cut

Exclusive dijet production in DPE – Separating q and g jets

- May see enhancement of gluon jets in exclusive region over inclusive background (mixture of *q* and *g* jets)
- Sensitive to light quarks which should be suppressed more than heavy quarks by J_Z=0 rule
- Difficult to separate *q* and *g* jets (only statistically)
  - *g* jets found to have higher charged particle multiplicity than *q* jets, *g* (*q*) jets have more soft (energetic) particles

Exclusive χ_c

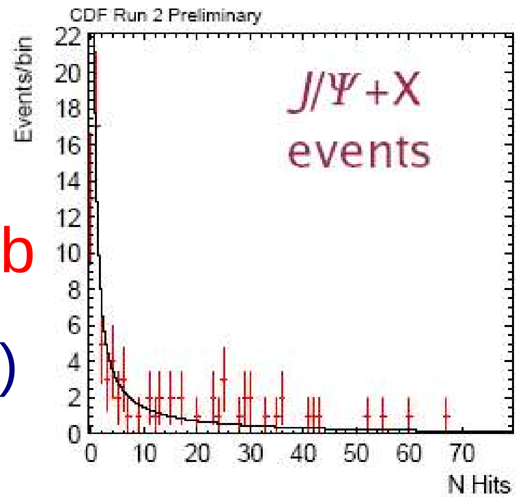
- Di-muon trigger (p_T>1.5 GeV, |η|<0.6)
- Reject cosmic rays with TOF info
- Select *J/ψ* mass window
- Require large gaps on *p* and $\bar{p}$ sides
- 10 candidate events found for exclusive χ_c^0 (→ *J/ψ*+γ)



⇒ Upper limit of

$\sigma(p\bar{p} \to p + J/\psi + \gamma + \bar{p}) = 49 \pm 18(\text{stat}) \pm 39(\text{syst})$ pb

– KMR prediction $\sigma \approx 70$ pb (factor 2-5 uncertainty)
  Eur. Phys. J. C19, 477 (2001)



- Now collecting data with a new trigger for $\chi_c^0 \to J/\psi(\to\mu\mu) + \gamma$ requiring gaps on both sides, 1 muon + 1 track with *J/ψ* mass cut

Summary

- Multiple gaps can be used to eliminate gap survival from QCD calculations
  - Production of additional gaps unsuppressed
  - Factorization in diffractive dijet production restored with the requirement of a second gap (DPE vs SD dijets)
- Diffractive structure function:
  - ξ and Q^2 dependence measured in SD dijets
  - Work in progress to extend range to lower ξ, higher Q^2, and to other processes such as SD *W* production
- Exclusive production in DPE:
  - Improved upper limit on exclusive dijet production
  - Upper limit on exclusive χ_c production
  - New triggers for DPE χ_c, *bb*, $\gamma\gamma$ in the works

Diffractive structure function in SD dijets

ND : $$\frac{d\sigma^3(ND_{jj})}{dx_p\, dx_{\bar{p}}\, d\hat{t}} = F_{jj}(x_p, Q^2) F_{jj}(x_{\bar{p}}, Q^2) \frac{d\hat{\sigma}(ab \to jj)}{d\hat{t}}$$

SD : $$\frac{d\sigma^4(SD_{jj})}{dx_p\, dx_{\bar{p}}\, d\xi\, d\hat{t}} = F_{jj}(x_p, Q^2) F_{jj}^D(x_{\bar{p}}, \xi, Q^2) \frac{d\hat{\sigma}(ab \to jj)}{d\hat{t}}$$

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

Experimental Measurement of F_{jj}^D

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

Measure (the $\sigma(SD_{jj})/\sigma(ND_{jj})$ ratio) — Known LO PDF ($F_{jj}(x)$)

parton $x = \beta\xi$

β = mom. fraction of parton in Pomeron

ξ = mom. fraction of Pomeron in proton

$$F_{jj}^D(x, \xi, Q^2) \Rightarrow\Rightarrow\Rightarrow F_{jj}^D(\beta, \xi, Q^2)$$