Hard Diffraction Results and Prospects at the Tevatron

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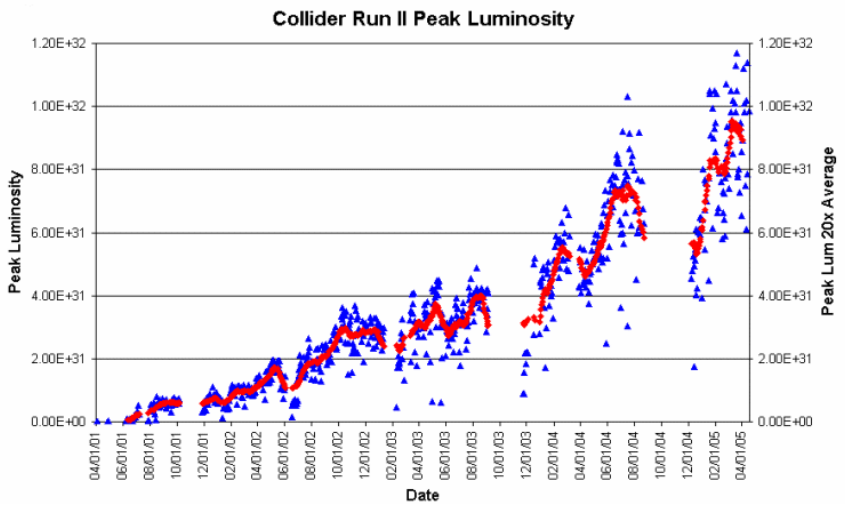
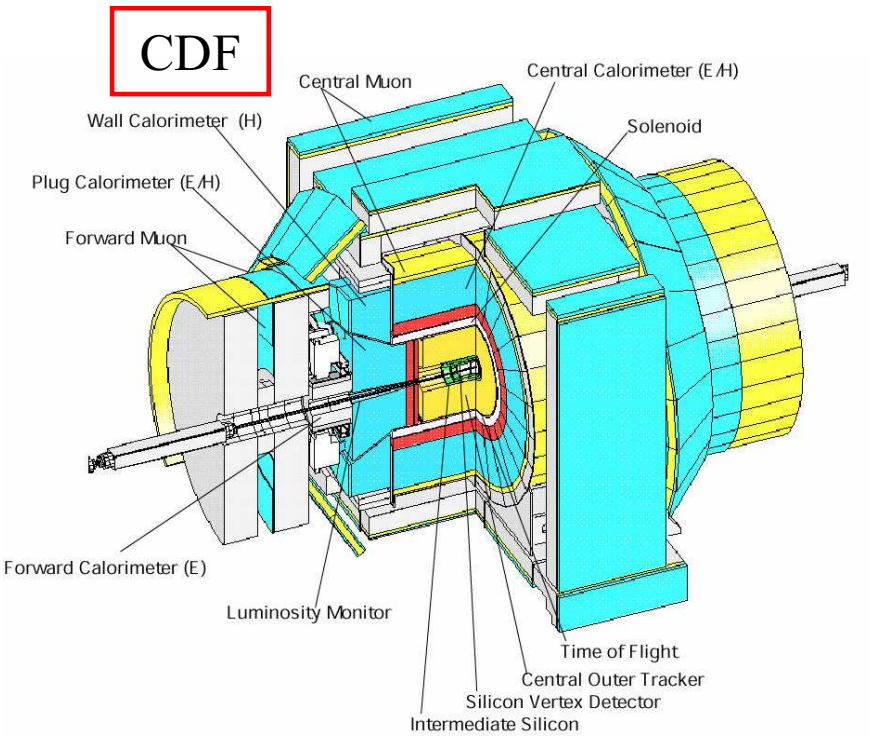
Tevatron

- Tevatron at Fermilab
- $p\bar{p}$-collisions
- Run II: $\sqrt{s} = 1.96$ TeV
- 36 bunches: 396 ns crossing time
- 2.3 interactions per bunch crossing



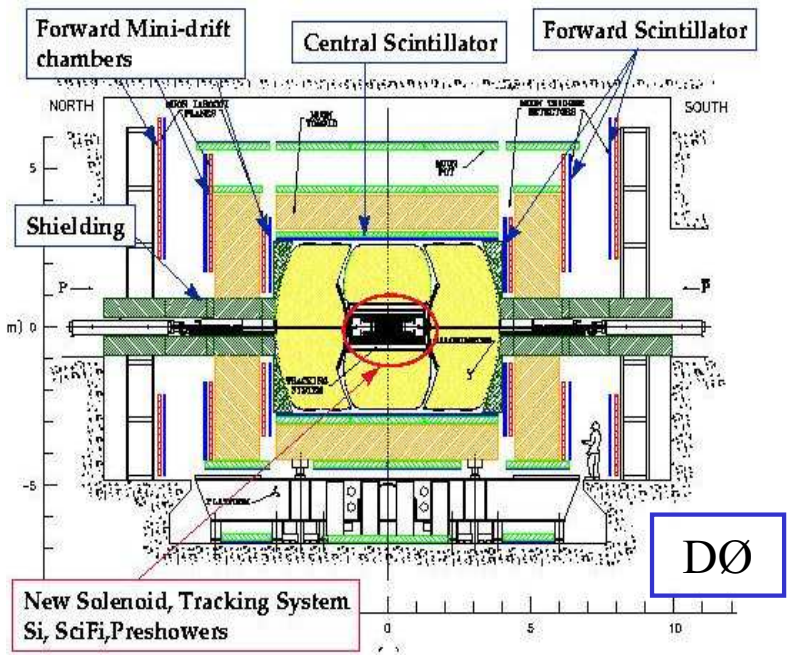
- Peak luminosity is now $\sim 10^{32} cm^{-2} s^{-1}$
- $\geq 1 fb^{-1}$ delivered!
- Design goal 8.5 fb^{-1} by '09

CDF and DØ at Run II



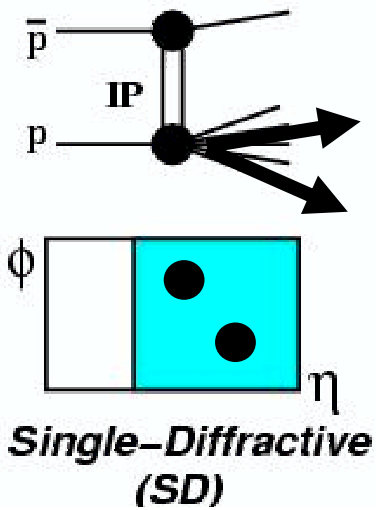
- Both experiments taking data with good efficiency $\sim 90\%$
- Each experiment has already collected on tape $\sim 0.8 fb^{-1}$

- High η coverage of calorimeters
- New Tracking System
- Upgraded Muon Chambers
- Forward detectors

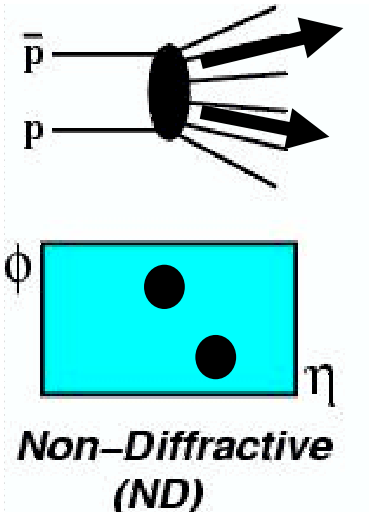


Diffraction

- Diffractive events: Exchange of colour singlets with vacuum quantum numbers
- Experimental signatures:
  $\Rightarrow$ Rapidity Gaps $\Delta\eta$. Absence of particles in some regions of rapidity.
  $\Rightarrow$ Tagged Proton: p or $\bar{p}$ scattered at small angle. Measured in Roman Pots far away from the interaction point.

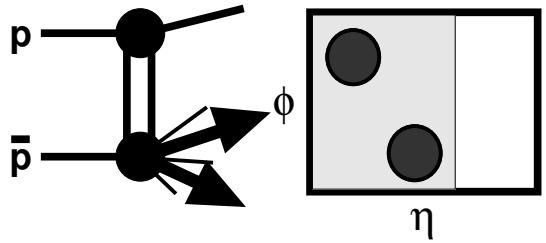


- Non-diffractive events: Colour exchange
- Gaps filled by soft additional parton interactions
  $\Rightarrow$ Exponential suppression of rapidity gaps

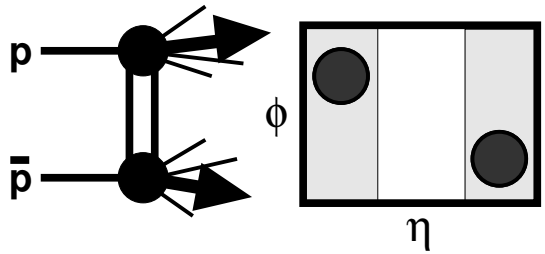


Hard diffractive event topologies at the Tevatron

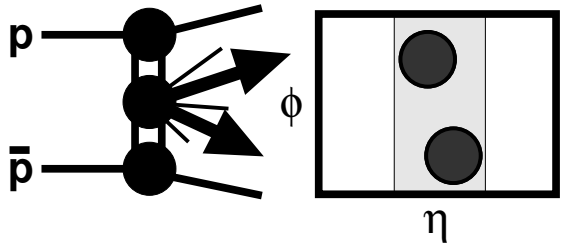
- Single diffraction (SD)
  W, Z, dijet, b-quark, J/ψ



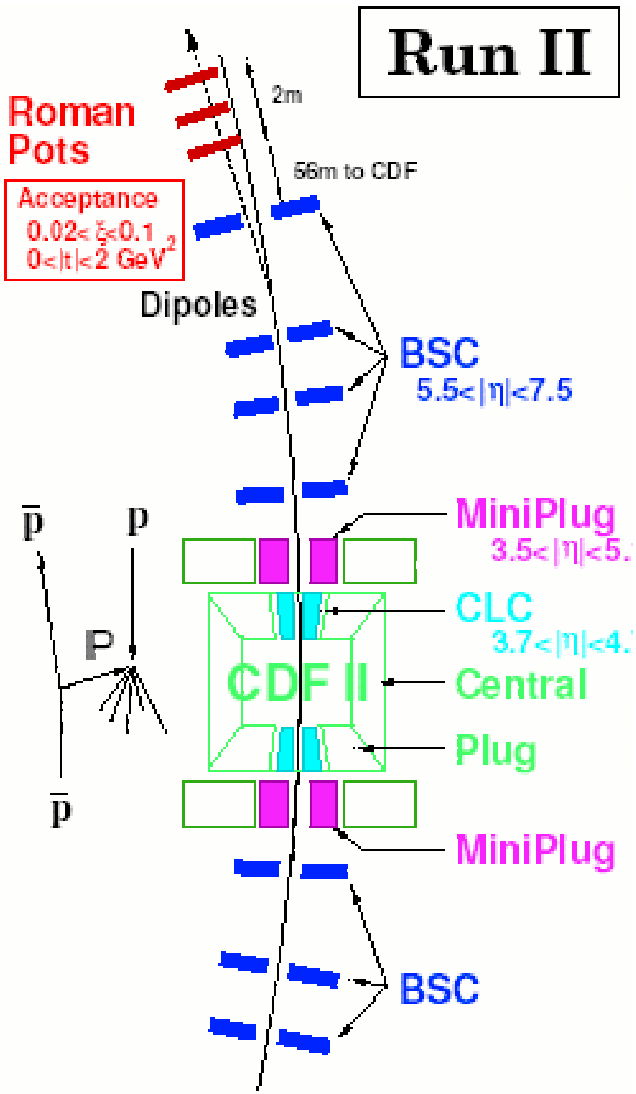
- Double diffraction (DD)
  jet-gap-jet



- Double pomeron exchange (DPE)
  dijet, χ_c etc.



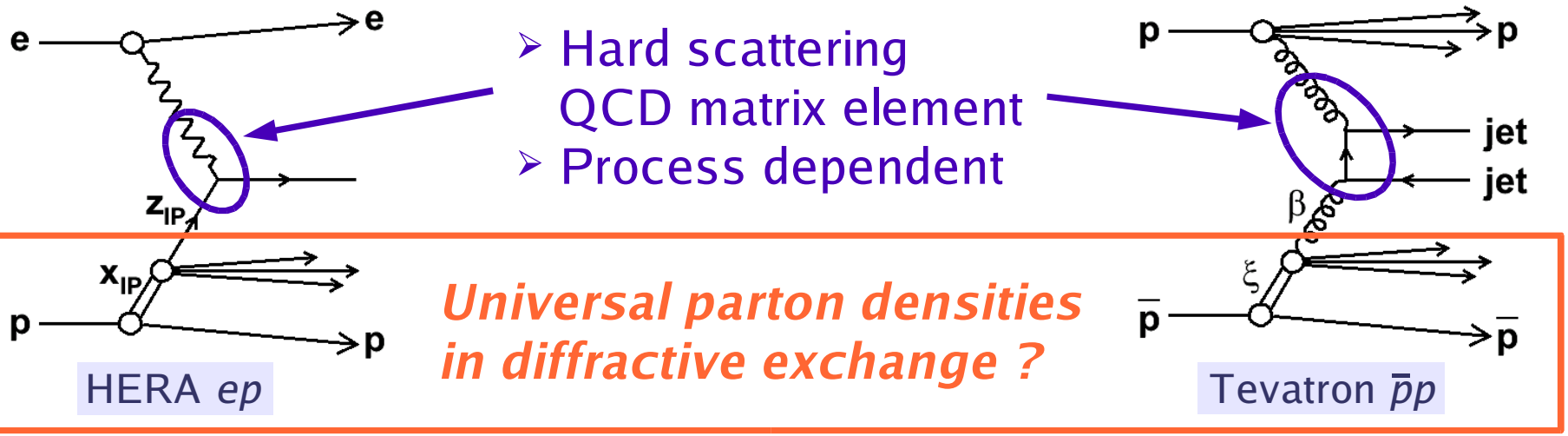
CDF Run II Forward Detectors



- Roman Pot Detectors
  - 57 m from IP
  - 3 stations
  - Fibre tracker + trigger counter
- Beam Shower Counters
  - Scintillation counters
  - Used to reject ND events
- Miniplug Calorimeter
  - Liquid scintillator + lead
  - Towerless geometry: no dead regions
- Large η coverage for rapidity gaps and jets

Factorisation in diffraction

- Factorisation theorem for the general class of DDIS processes:
  $\sigma(x, Q, x_p, t) \approx \sum_i f_i^D \otimes \hat{\sigma}_i$ [Collins, PRD 57 (1998) 3051]



- Fundamental for the understanding of diffraction
- Important for extrapolating Tevatron results to the LHC
- General strategy: extract PDFs and compare predictions to measurements of other processes and experiments

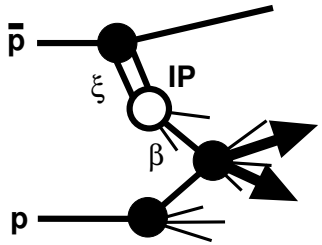
Hard diffraction at Tevatron

- Diffractive fractions: $\frac{\text{events with 1 gap}}{\text{all events}}$ (@ 1.8 TeV)

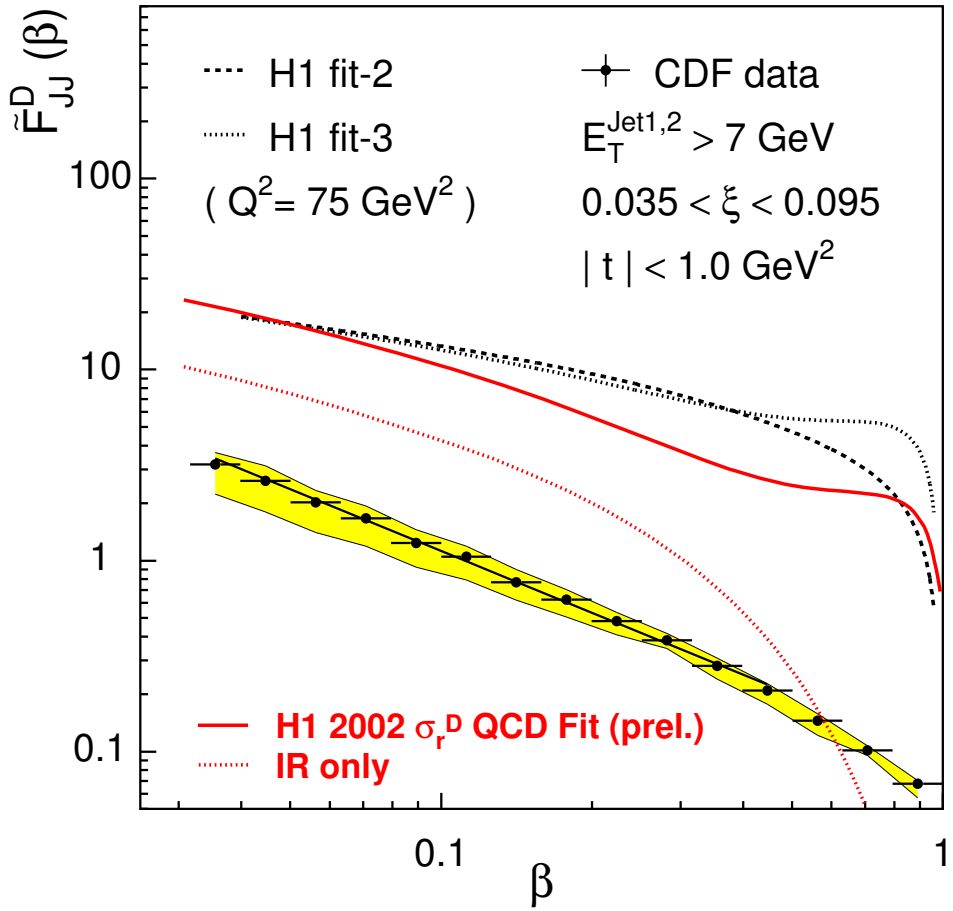
Process	Fraction	Experiment
SD: jet + jet +gap	$(0.75 \pm 0.10)\%$	CDF
SD: W + gap	$(1.15 \pm 0.55)\%$	CDF
	$(0.89 \pm 0.20)\%$	DØ
SD: Z + gap	$(1.44 \pm 0.62)\%$	DØ
SD: b + gap	$(0.62 \pm 0.25)\%$	CDF
SD: J/Ψ + gap	$(1.45 \pm 0.25)\%$	CDF
DD: jet + gap + jet	$(1.13 \pm 0.16)\%$	CDF
	$(0.94 \pm 0.13)\%$	DØ

- All ratios $\mathcal{O}(1\%) \Rightarrow$ Factorisation holds within Tevatron
  ... but, uniform gap suppression w.r.t HERA $\mathcal{O}(10\%)$
- Indicates break of QCD factorisation

CDF Run I: Diffractive structure functions



$F_{jj}^D(\beta)$ measured from SD dijets vs. DDIS expectation

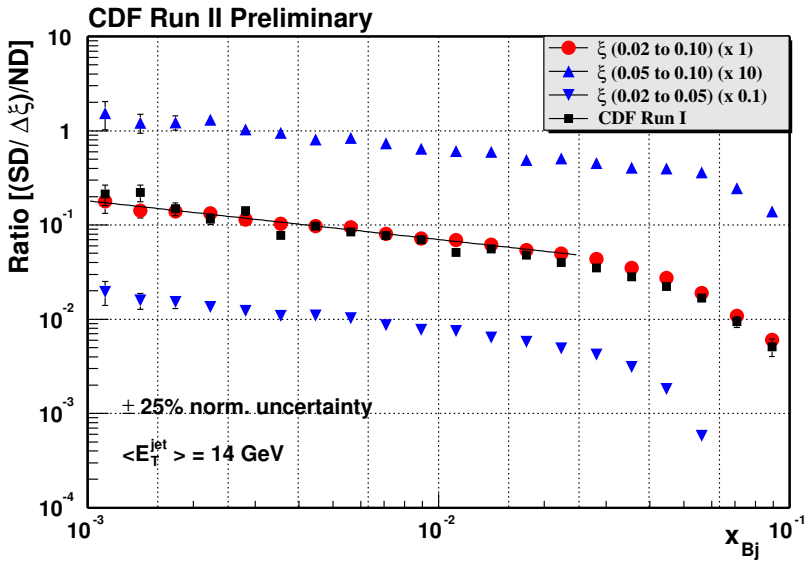


- $R(x)$ of $\frac{\sigma(SD_{jj})}{\sigma(ND_{jj})} \approx \frac{F_{jj}^D(x)}{F_{jj}(x)}$
- Shapes look similar, normalisation discrepancy of factor 10

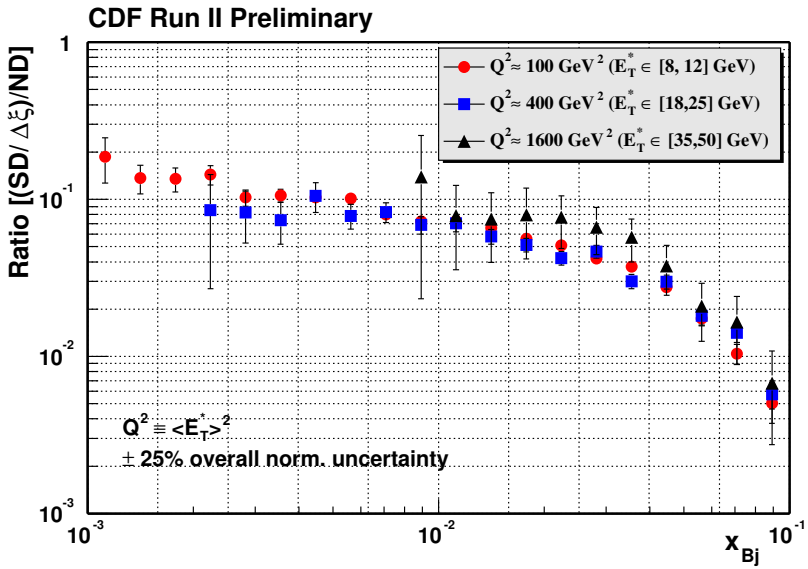
$\Rightarrow$ Diffractive factorisation breakdown

- More spectator partons in $p\bar{p}$ collisions w.r.t $\gamma^* p$
- Gap survival probability: $\sigma \approx F_{jj}^D \otimes \hat{\sigma} \otimes |S|^2$ (energy dependent)

CDF Run II: Ratio of SD/ND events



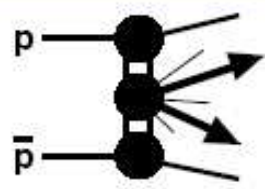
- Dedicated trigger
- Ratio of SD to ND dijet event rates
- No ξ dependence in $0.03 < \xi < 0.1$
- Slope and normalisation agree with Run I result

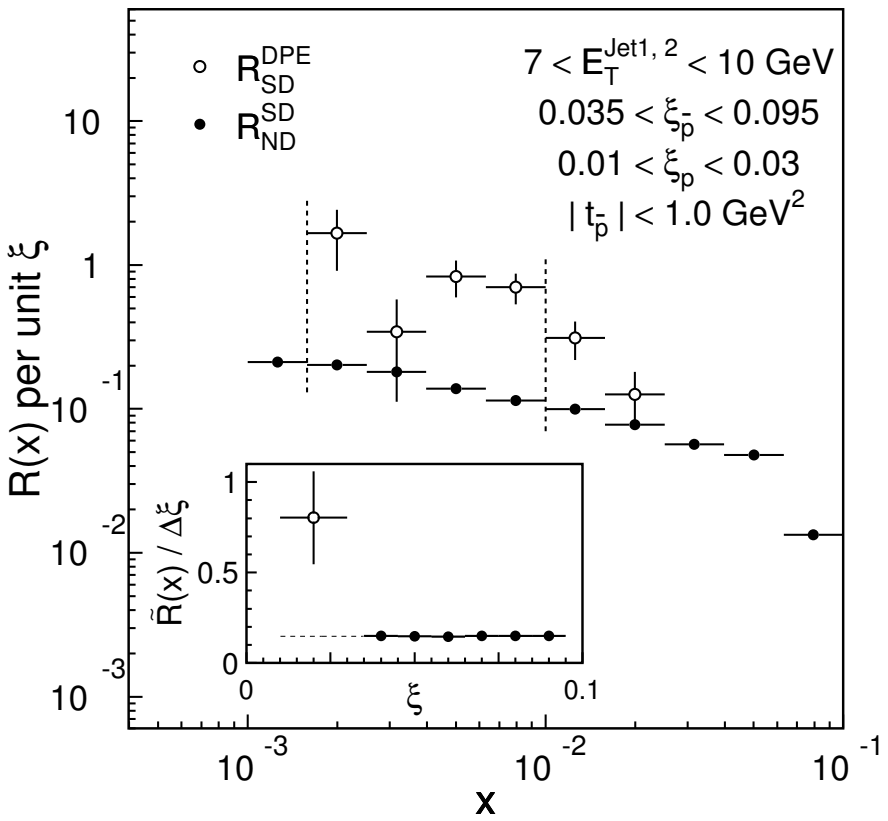


- No appreciable Q^2 dependence in region $100 < Q^2 < 1600$ GeV^2
- What is the mechanism of hard diffraction?
  - Hard Pomeron (colourless object)?
  - Soft colour rearrangement in final state?

CDF Run I: DPE dijet production

Comparison of $R_{SD}^{DPE}(x_p)$ and $R_{ND}^{SD}(x_{\bar{p}})$

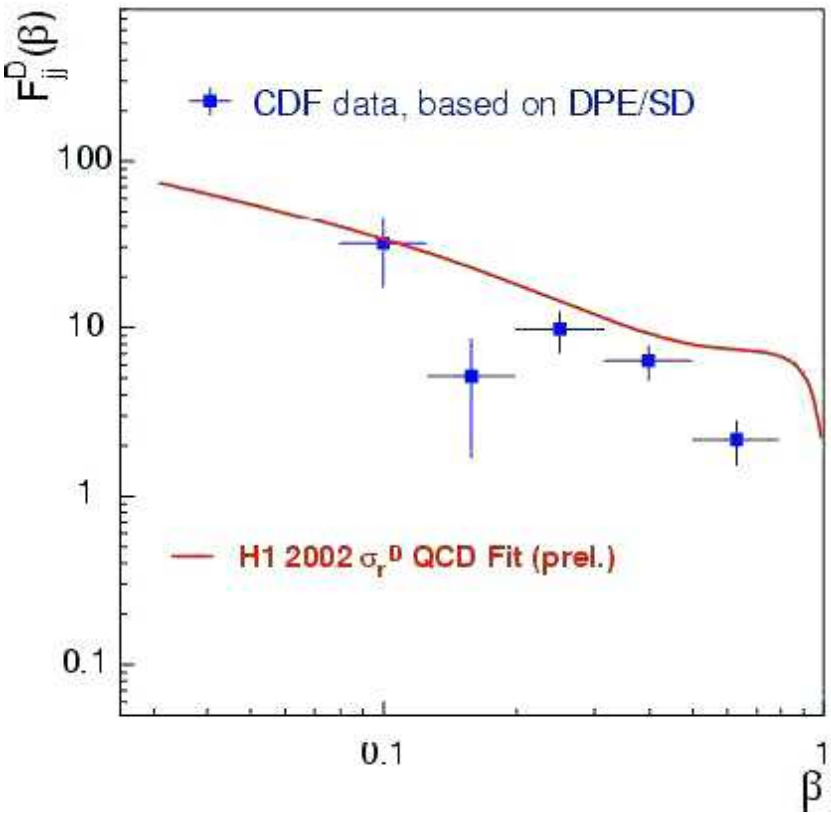




- Events with leading $\bar{p}$ and rapidity gap on outgoing p side
- Inset: ratio $\tilde{R}_{ND}^{SD}$ is flat in ξ
- $\tilde{R}_{ND}^{SD}$ extrapolated to $\xi = 0.02$ yields:
- $\tilde{R}_{ND}^{SD}/\tilde{R}_{SD}^{DPE} = 0.19 \pm 0.07$ Deviation from unity $\Rightarrow$ Breakdown of factorisation
- Formation of a second gap is less suppressed
- Result coherent with the concept of the "gap survival probability": do not pay the price for the gap two times

CDF Run I: DPE dijet production

$F_{jj}^{D}(\beta)$ measured using DPE dijets

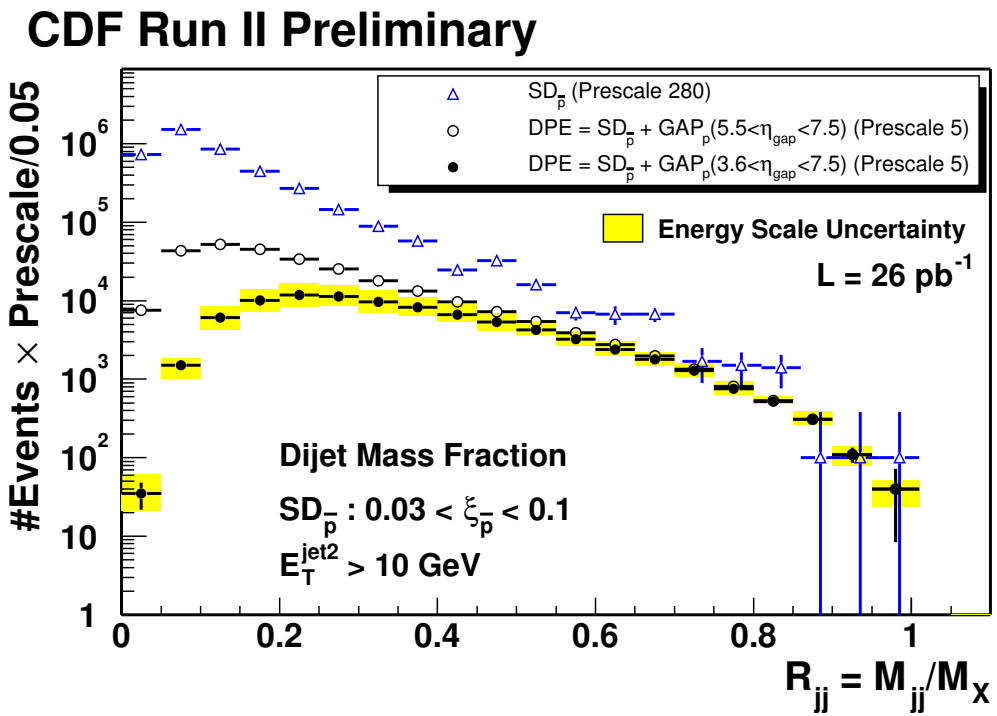


- Diffractive structure function extracted from R_{SD}^{DPE}
- Approximately equals expectations from H1
- Again: formation of second gap is less suppressed
- Is $|S|^2$ independent of the number of gaps?

- CDF & DØ: Analyses in progress to measure the t, ξ and flavour dependence of the DSF using dijet, W and J/ψ production

CDF Run II: dijet mass fraction

- In Run II: two orders of magnitude more DPE dijet data
  $\Rightarrow$ Study of exclusive dijet production in DPE
- Strategy:
  - Obtain inclusive DPE dijet $\bar{p} + p \rightarrow \bar{p} + \text{dijet} + X + \text{gap} + p$
  - Look for exclusive signature using dijet mass fraction $R_{jj} = \frac{M_{jj}}{M_X}$

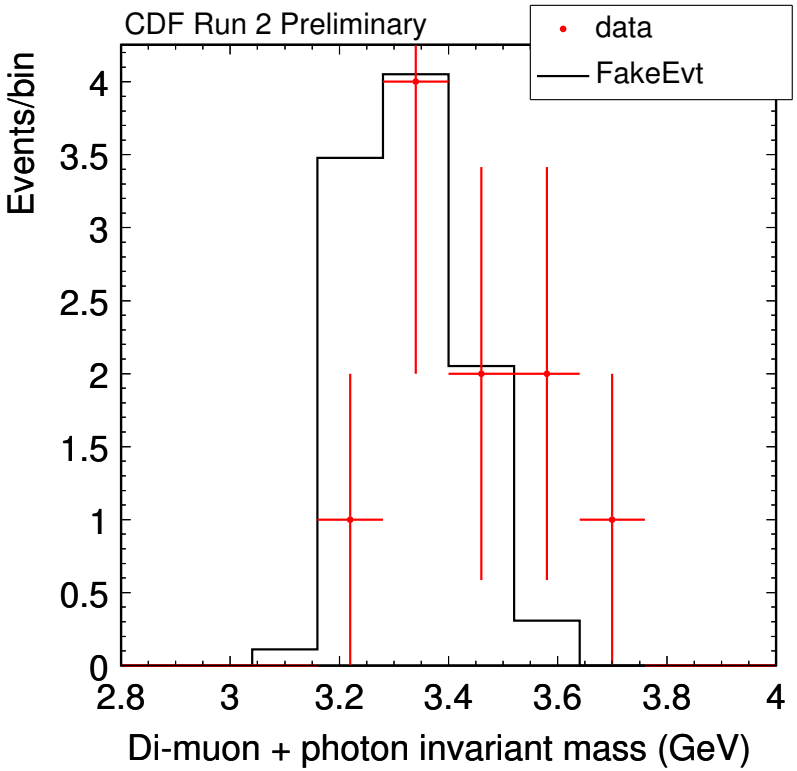


- No significant excess due to exclusive dijets seen at high R_{jj}
- $E_T^{\text{min}} = 10$ GeV : $\sigma(R_{jj} > 0.8) < 1.1 \pm 0.1(stat) \pm 0.5(sys)$ nb
- Difficult experimentally: sensitive to the dijet mass resolution

CDF Run II: Exclusive χ_c^0 production

$$p + \bar{p} \to p + \chi_c^0(\to J/\psi + \gamma) + \bar{p}$$

- χ_c^0: quantum numbers similar to Higgs boson
- Di-muon trigger data (muons with $p_T > 1.5$ GeV, $|\eta| < 0.6$)
- Select events in J/ψ mass window
- Require large gaps on both p and $\bar{p}$ sides

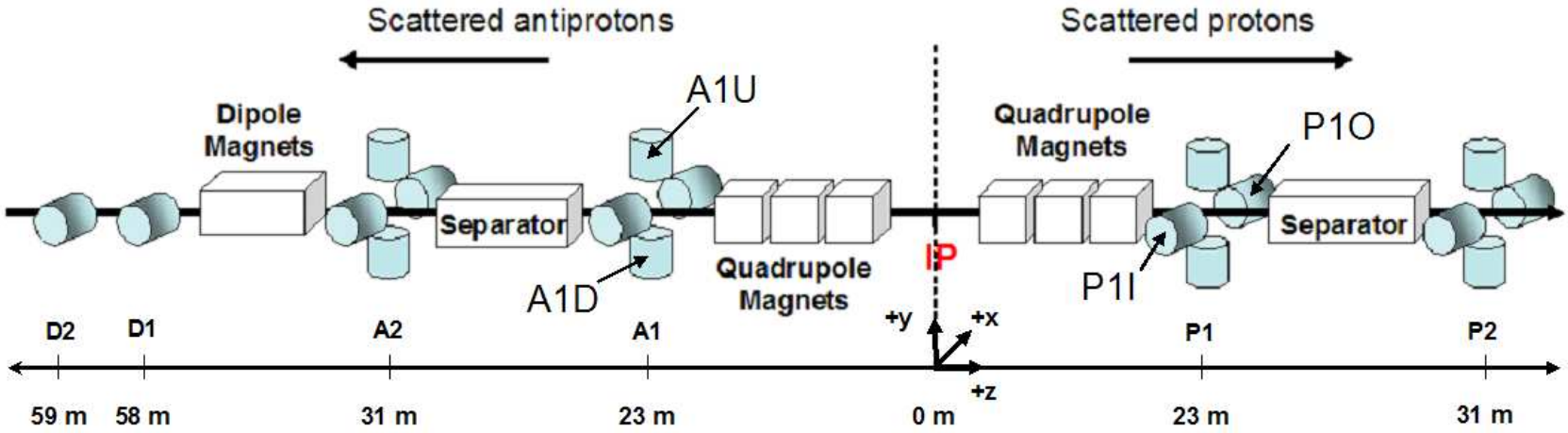


- 10 events: exclusive $\chi_c^0(\to J/\psi + \gamma)$ candidates
- Background difficult to be fully understood
- Assume 10 events are all $J/\psi+\gamma$

$\Rightarrow$ "Upper limit" on exclusive χ_c^0 production cross section:
$\sigma = 49 \pm 18(stat) \pm 39(sys)$ pb

DØ forward proton detectors

9 momentum spectrometers with 2 scintillating fibre detectors each

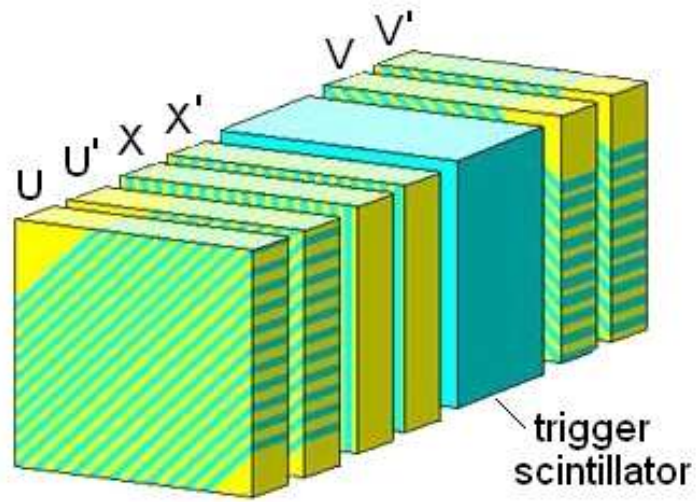


- 1 dipole spectrometer:
  $|t| \approx 0 - 1$ GeV^2
  $\xi \approx 0.03 - 0.07$
- 8 quadrupole spectrometers:
  $|t| \approx 0.8 - 3.0$ GeV^2
  $\xi \approx 10^{-3} - 0.05$
- Position detectors housed inside Roman Pots
- Reconstruct high-energy scattered p and $\bar{p}$ directly

$\Rightarrow$ First time possibility of tagging both p and $\bar{p}$ and measuring their ξ and t dependence at the Tevatron

DØ scintillating fibre detectors

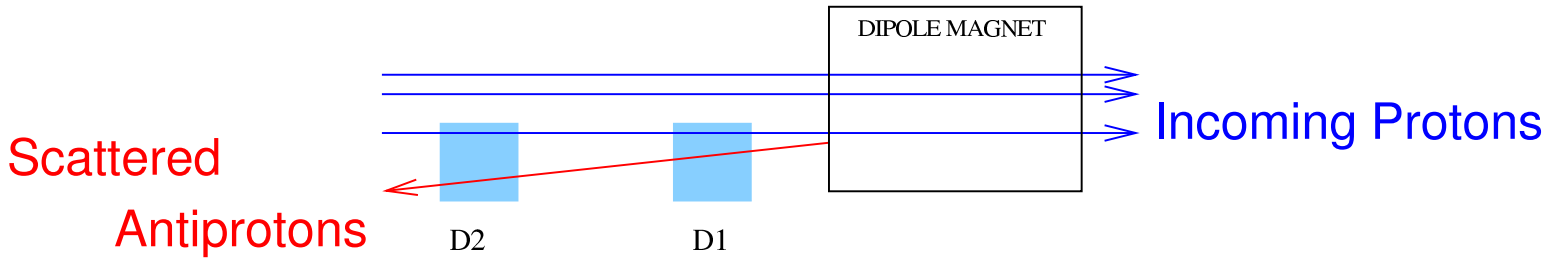
- 6 layers of scintillating fibre channels
- 1 trigger scintillator layer
- Fibres are oriented within $\pm 45^\circ$ to reconstruct hits and obtain redundancy

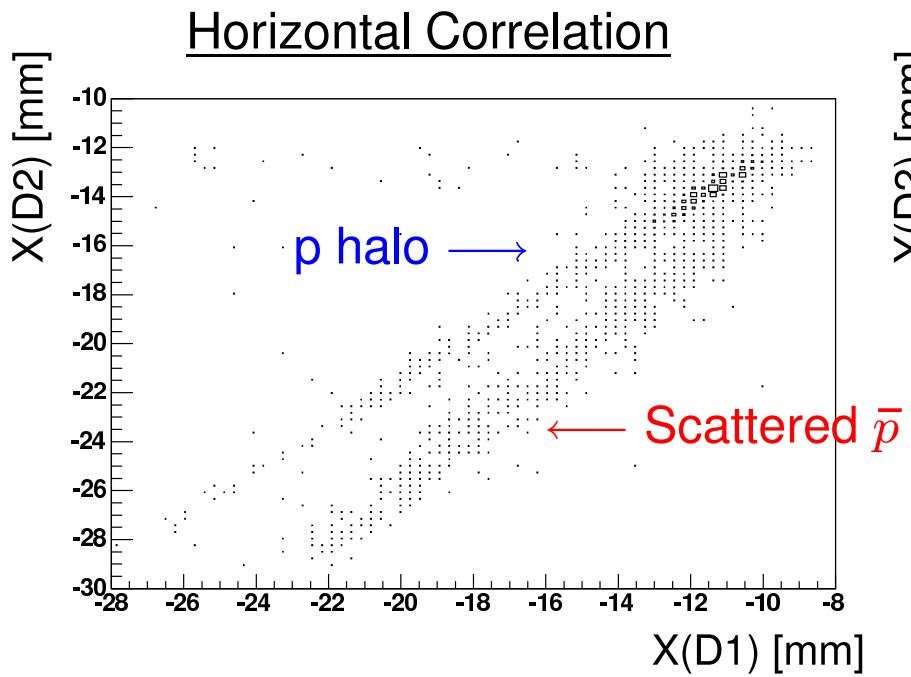


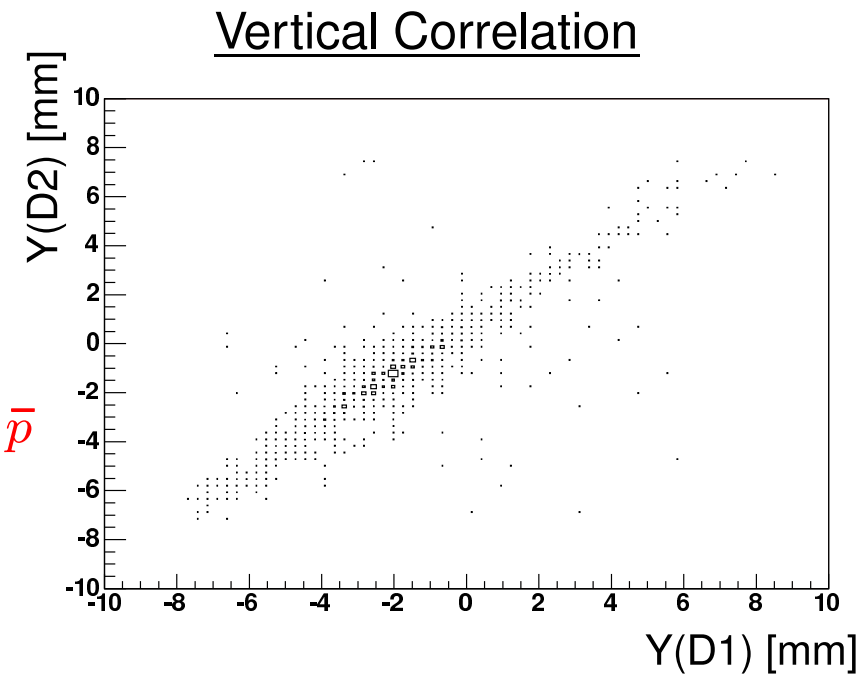
- Every second channels is offset by 2/3 fibre for a finer hit resolution
- Hits are grouped together into track fragments and tracks are reconstructed using vertex information and different position detectors
- All 18 detectors regularly brought close to the beamline and diffractive samples being collected

DØ FPD spectrometer signals

Overhead view of the dipole spectrometer system:

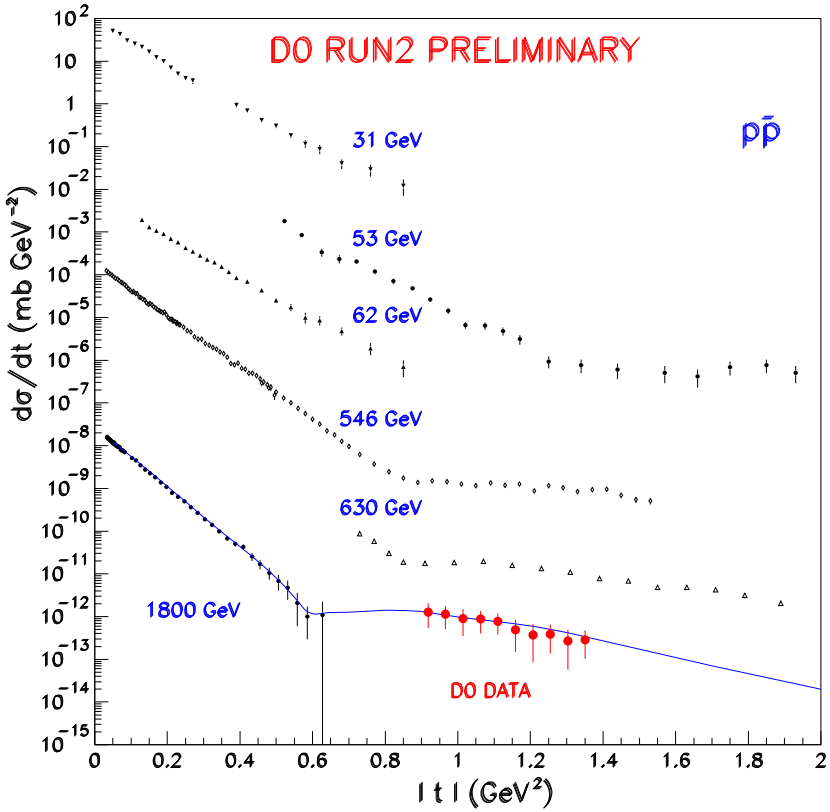






$\Rightarrow$ Good separation of signal and background

DØ: $p\bar{p}$ elastic scattering



- Small dedicated run, test of the FPD in stand alone mode
  $\Rightarrow$ Measurement of the slope of the elastic cross section in t (normalisation arbitrary) compared to predictions of [Block *et al.*, PRD 41,978]
- Good agreement and access to a new kinematic domain
- Measurement being redone using fully integrated FPD

- Alignment and detector understanding of roman pot detectors in progress
- Physics results expected soon

Summary

- CDF: diffractive structure function
  - Re-established Run I result
  - No Q^2 dependence of F_{jj}^D. Is diffraction $\mathbb{P}$ exchange or a pure soft process?
  - Studies of t, ξ and flavour dependence in progress
- Factorisation: broken at the Tevatron, but gluon shape similar as at HERA
- CDF: Double pomeron exchange
  - Upper limits on exclusive dijet and χ_c^0 production
- DØ forward proton detectors working, alignment in progress: many new physics results expected soon
  (Pomeron structure, high mass diffraction (W,Z), exclusive events, inclusive DPE, . . .)