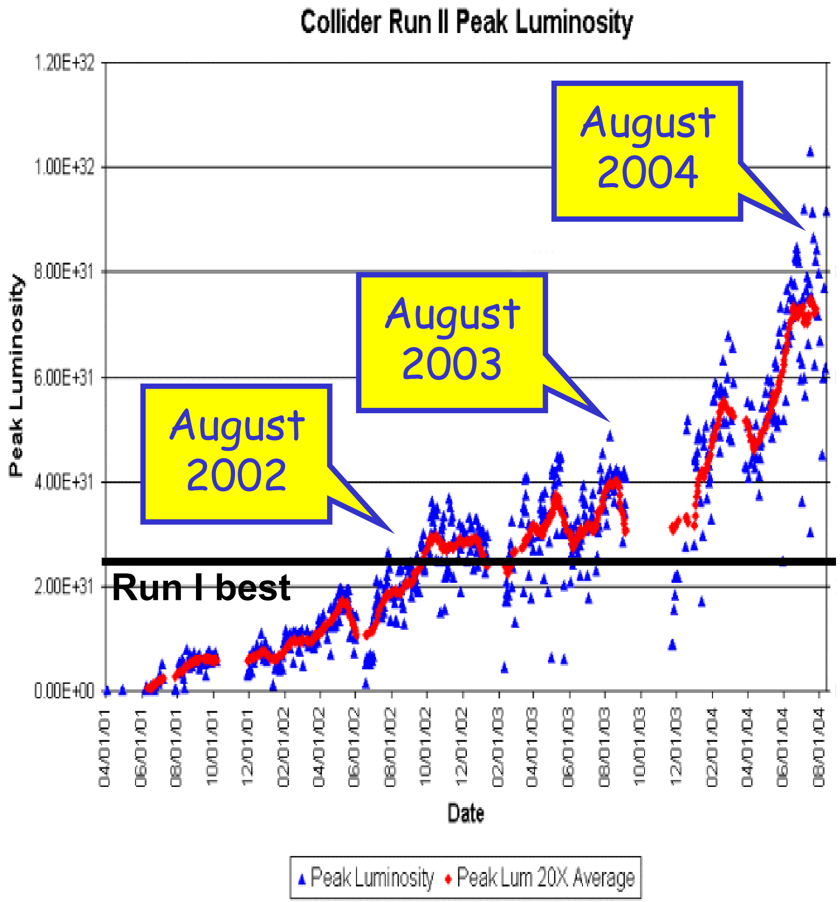
Diffractive results at the Tevatron

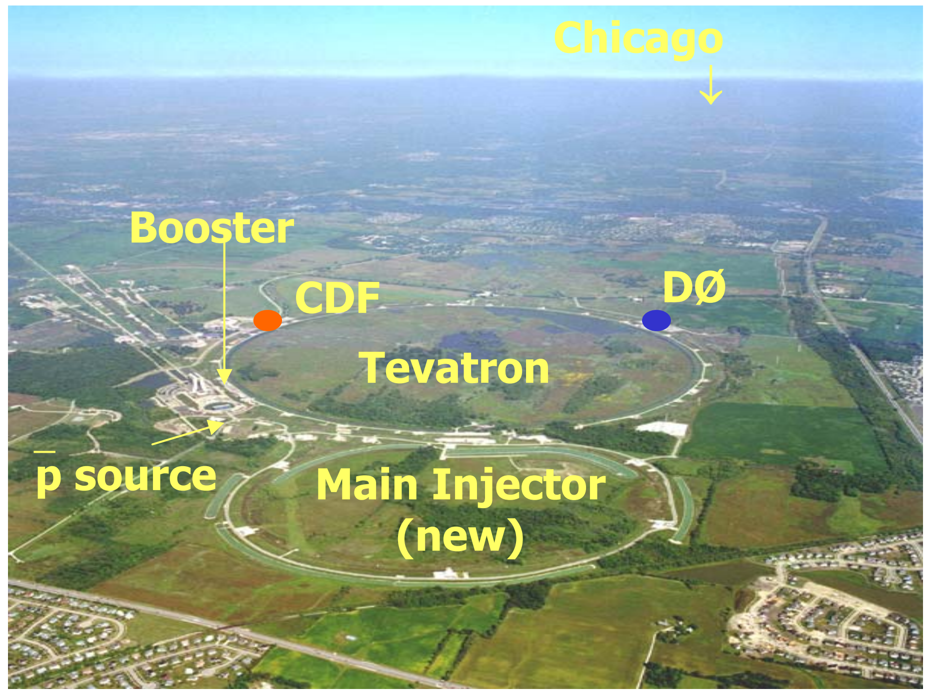
Michele Gallinaro
The Rockefeller University

- ✓ Introduction
- ✓ Soft and hard diffraction
- ✓ Run II diffractive program
- ✓ Exclusive production (Higgs etc.)

Tevatron Collider

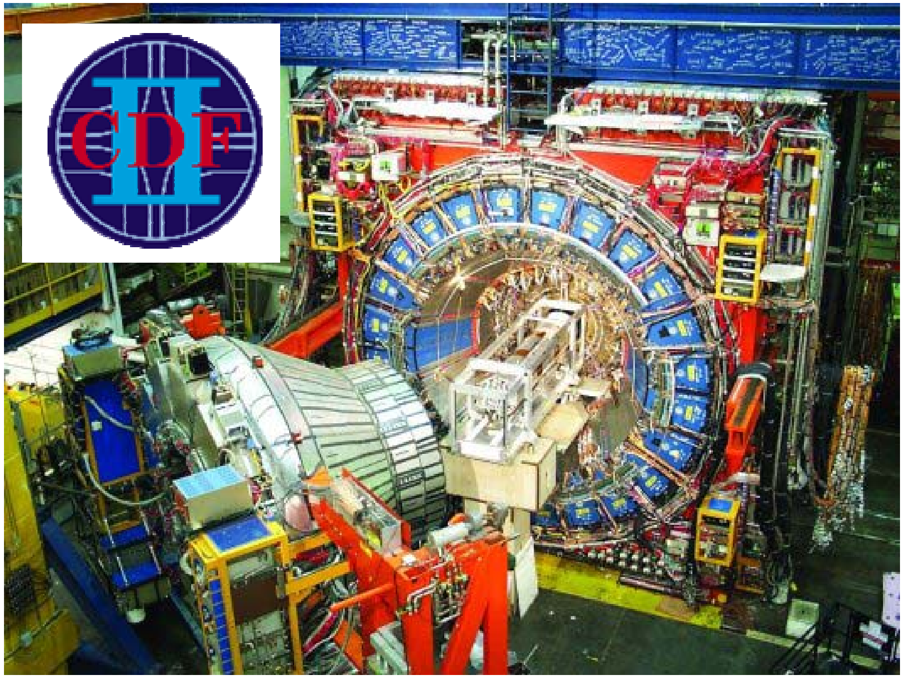


- Tevatron and detector upgrades
  - ✓C.M. energy 1.96 TeV
  - ✓396 nsec bunch spacing
  - ✓600 pb^{-1} delivered (as of Aug. 2004)

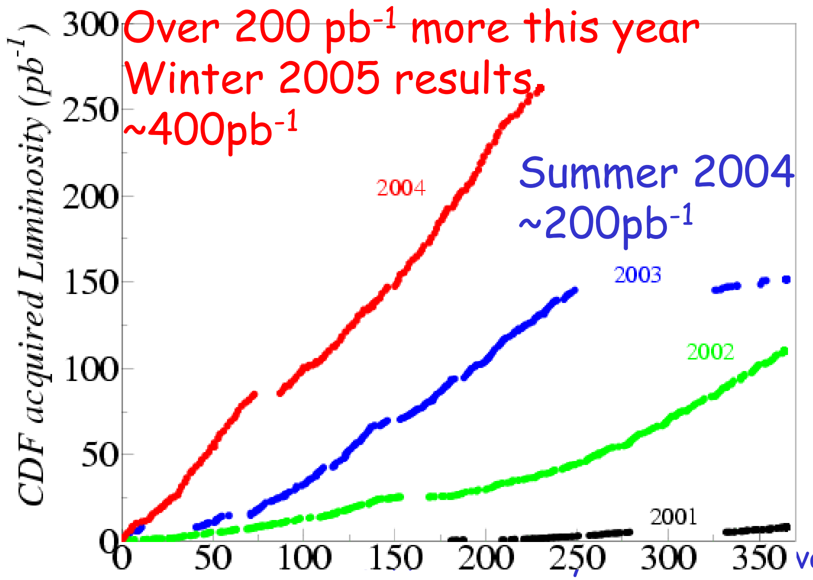


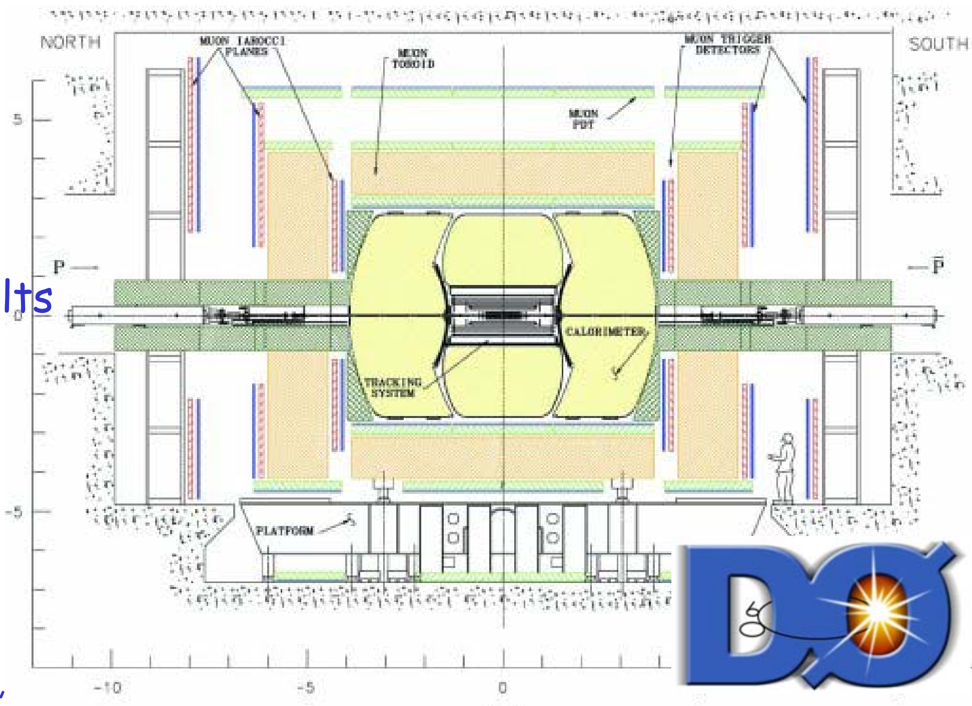
- high (low ?) inst. luminosity
  (L ~ 2-3 x 10^{31} $cm^{-2}sec^{-1}$)
- multiple interactions

Tevatron Experiments



- Peak luminosity
  - ✓ x2 increase since 2003
  - ✓ reached $L=10^{32}cm^{-2}s^{-1}$
- Future
  - ✓ run until 2009
  - ✓ deliver 4-9 fb^{-1}



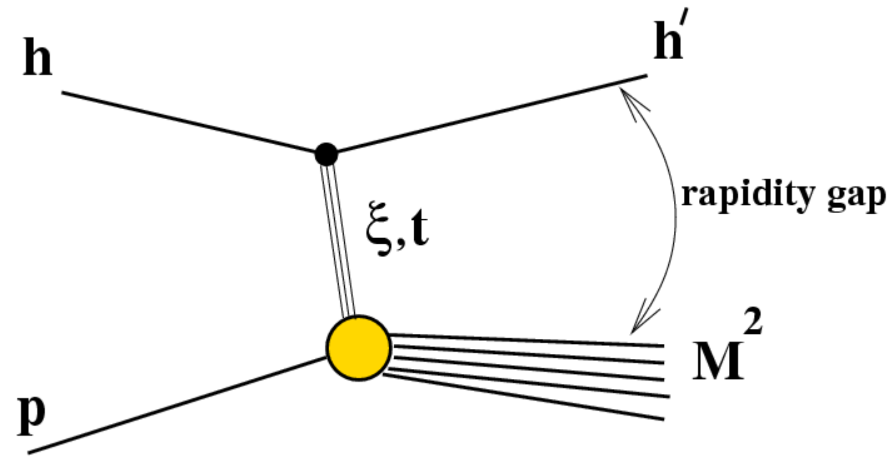


Hadronic Diffraction

Small transferred momentum

Elastic and diffractive processes:
leading hadron emitted at small angle

Rapidity gap:
the exchange ("pomeron") is colorless



Diffraction and Rapidity Gaps

✓rapidity gaps are regions of rapidity devoid of particles

- **Non-diffractive interactions:**
  rapidity gaps are formed by multiplicity fluctuations

From Poisson statistics:

↓

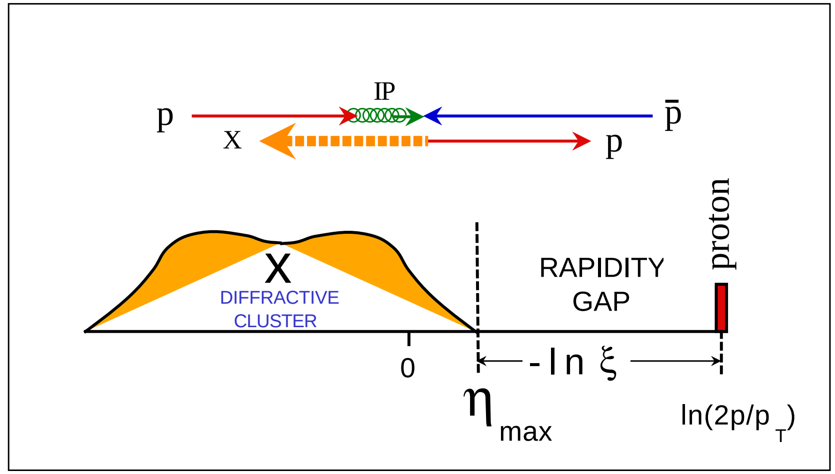
$$P(\Delta\eta) = e^{-\rho\,\Delta y} \quad \left(\rho = \frac{dn}{dy}\right)$$

(ρ=particle density in rapidity space)

Gaps are exponentially suppressed

- **Diffractive interactions:**
  rapidity gaps survive unaltered

$$\Delta y \approx \ln(1/\xi) = \ln s - \ln M^2$$



$$\frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \quad \rightarrow \quad \frac{d\sigma}{d\Delta y} \sim \text{constant}$$

✓ large rapidity gaps are signatures for diffraction

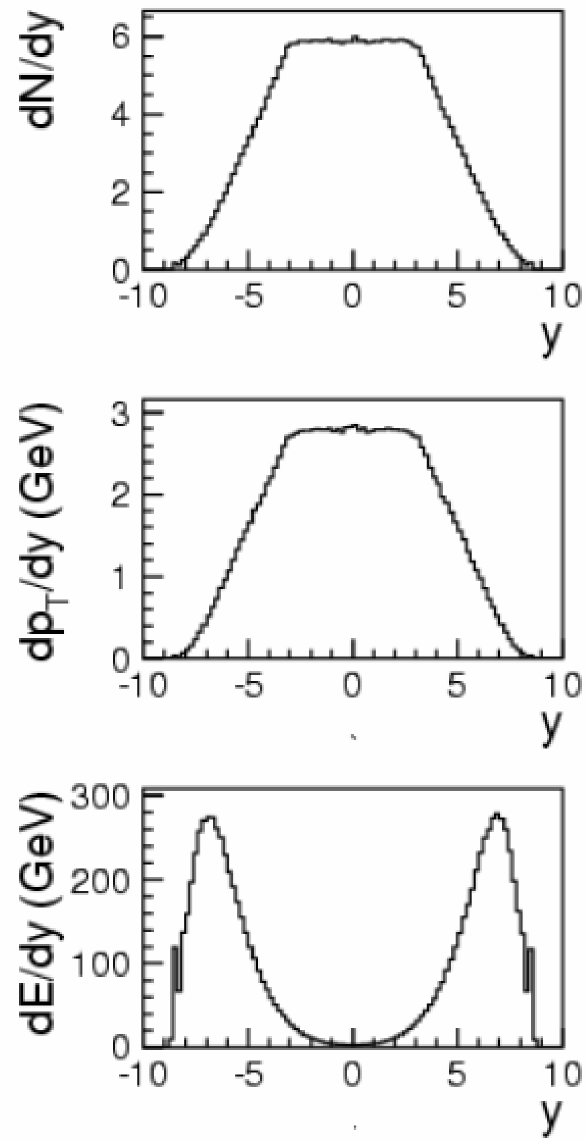
Energy flow in MB events

•most particles are in the central region ($|y|<3$)

•all particles on average have the same p_T

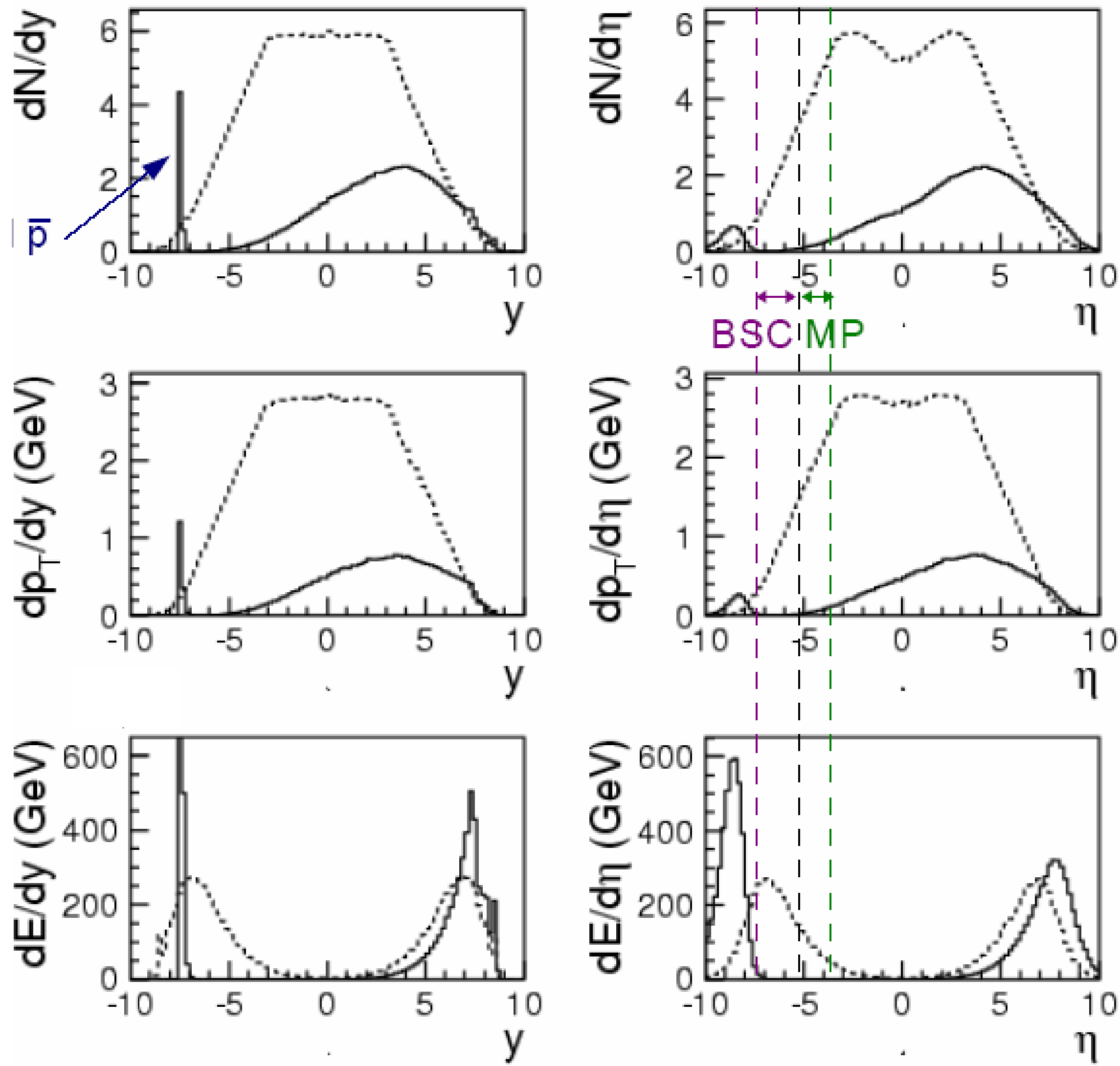
<u>however,</u>

•most of the energy is carried by a few forward particles



Energy flow in SD events

Diffractive events are
"asymmetric"



Soft diffraction

unitarity problem

$\sigma_{SD} \sim s^{2\varepsilon} \qquad \sigma_T \sim s^{\varepsilon}$

⇨ σ_{SD} exceeds σ_T at ~2 TeV

Renormalization

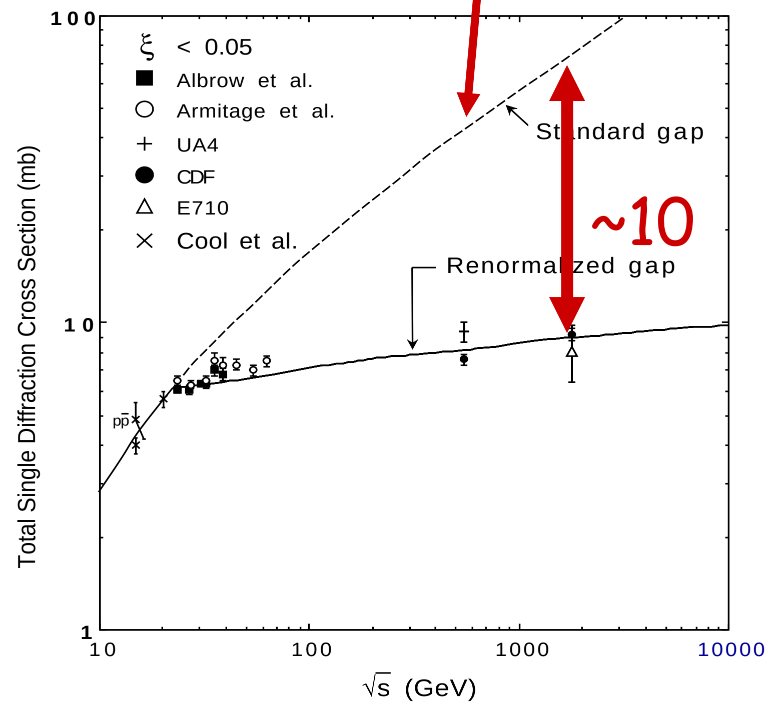
(normalize flux to 1)

$$\frac{d^2\sigma_{SD}}{dt\,d\xi} = f(t,\xi)\cdot\sigma(M_X^2)$$

≡ 1

K. Goulianos, PLB 358 (1995) 379

$\sigma \sim s^{2\varepsilon}$



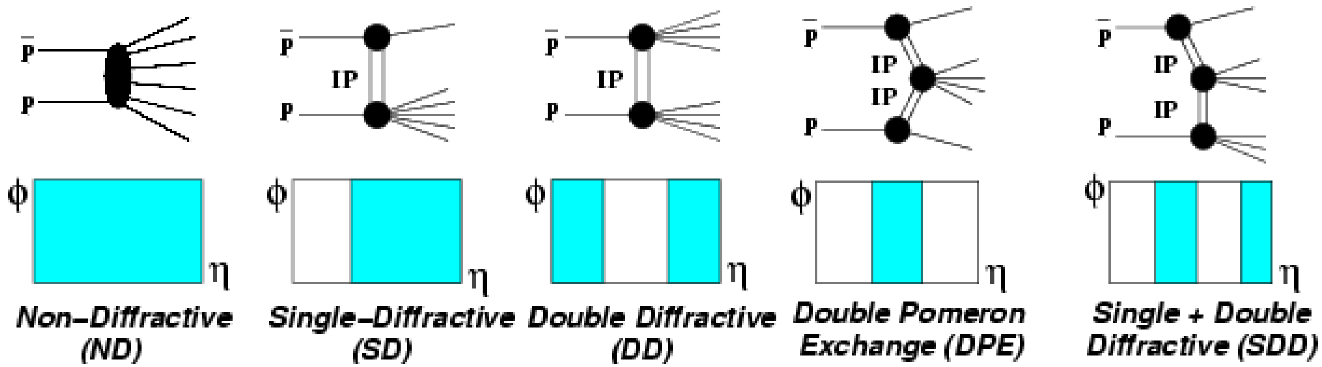
⇨ measurement is suppressed by a factor of ~10 to Regge theory and agrees with renormalization model

PRD 50 (1994) 5518, 5535, 5550

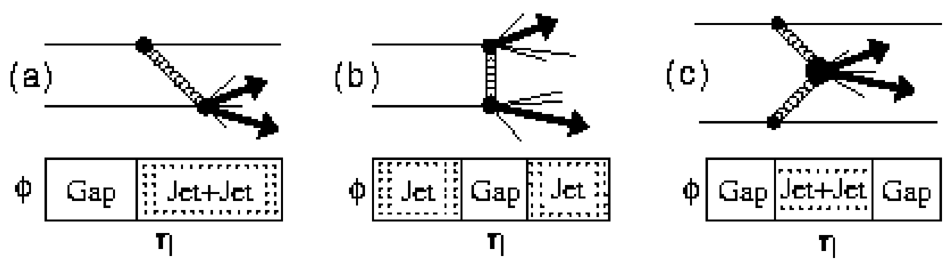
Diffraction in Run I

➤Large rapidity gaps are signatures for diffraction

Soft diffraction



Hard diffraction

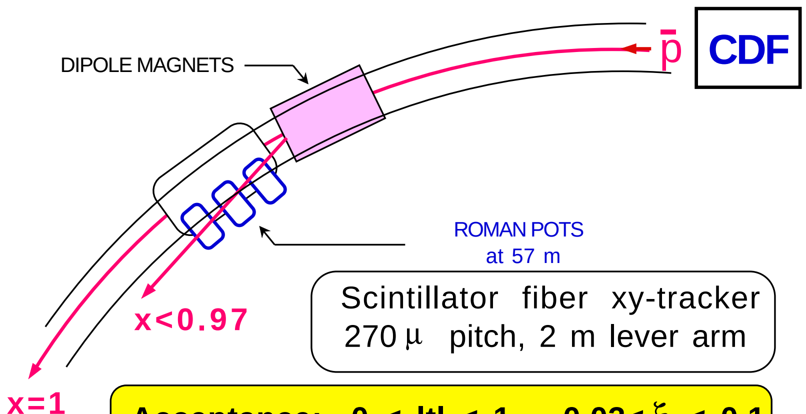


Methods: large rapidity gaps or leading anti-proton tag

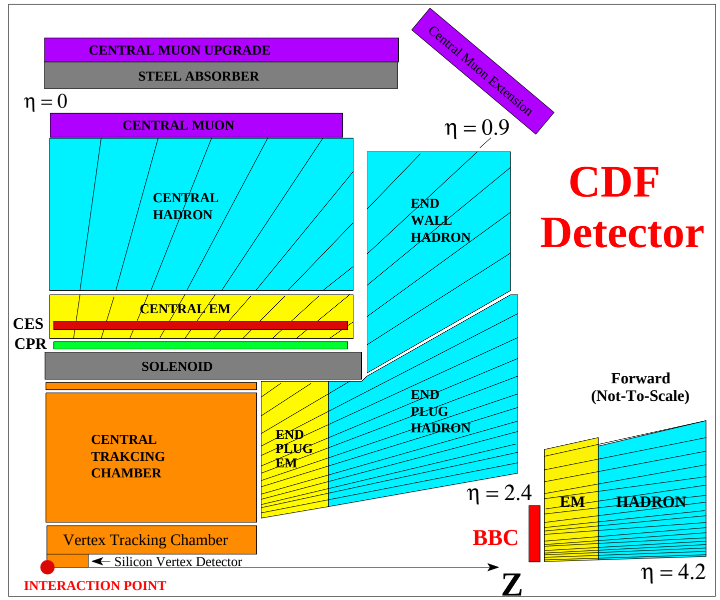
Detectors in Run I

tag rapidity gaps

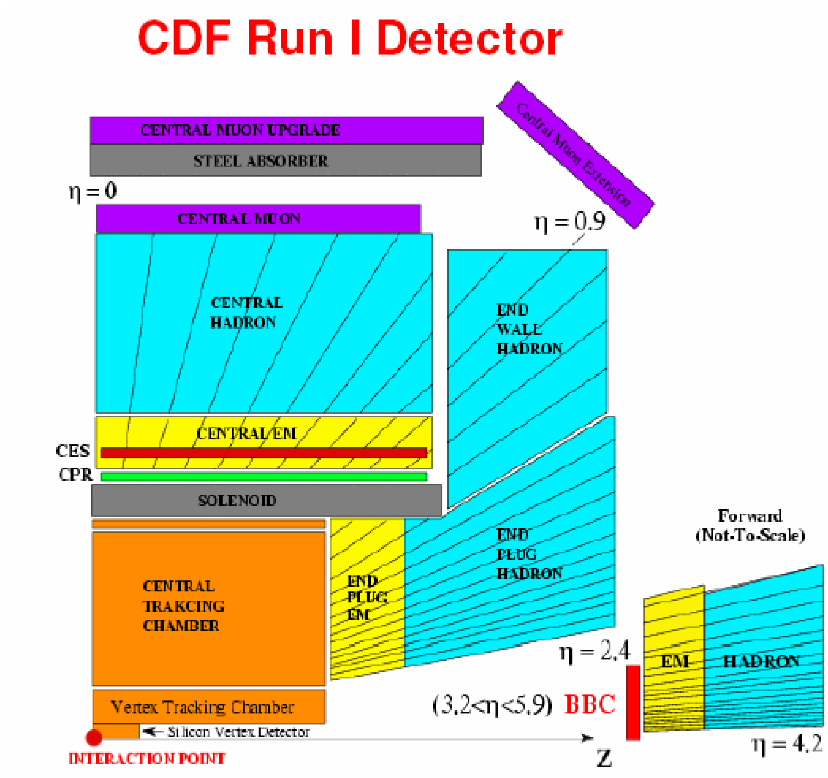
tag antiproton

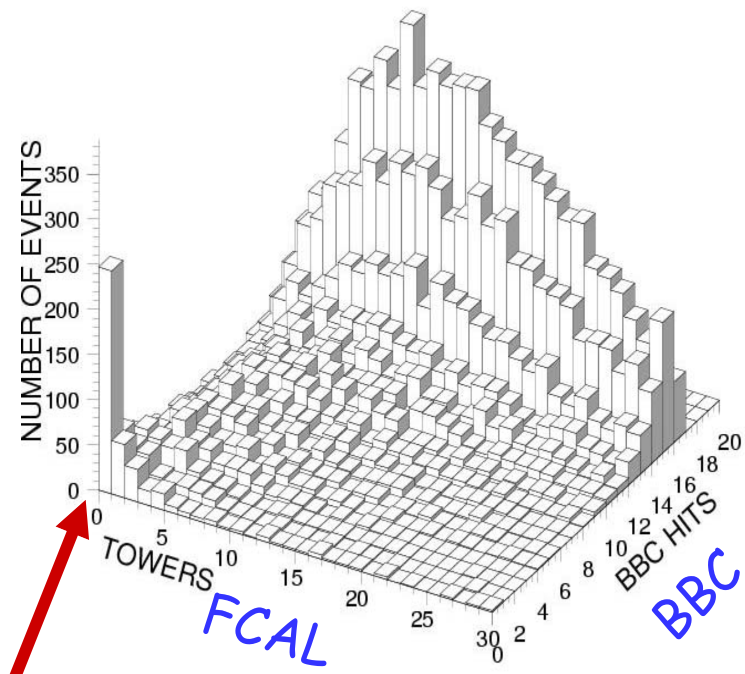


Acceptance: $0 < |t| < 1$, $0.03 < \xi < 0.1$



Rapidity gaps





BBC 3.2<η<5.9

FCAL 2.4<η<4.2

Rapidity gaps seen as zero multiplicity in both forward calorimeter and beam-beam counters

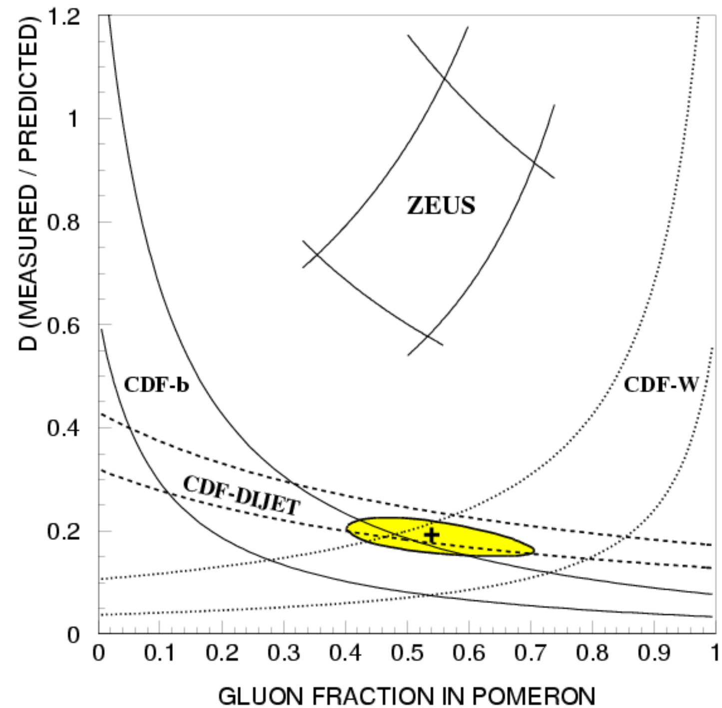
Diffractive rates

$$p\,\overline{p} \to X + \text{gap}$$

Measure SD/ND fractions
at 1800 GeV

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 ($q\bar{q} \to W$)



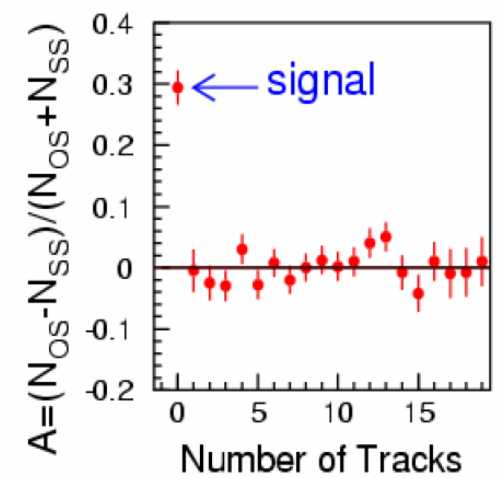
All SD/ND fractions ~ 1%
Different sensitivities to quark/gluon
⇨gluon fraction f_g=0.54 (0.15)

Gap between jets

$$p\bar{p} \to \text{jet} + \text{gap} + \text{jet}$$

extend range in Run II

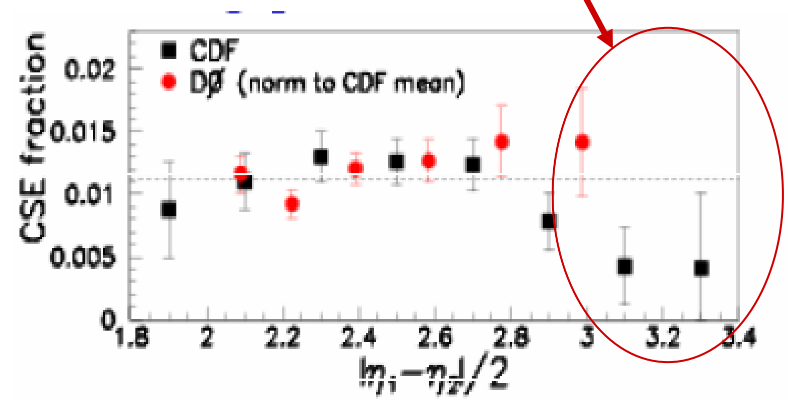
DD/ND fractions

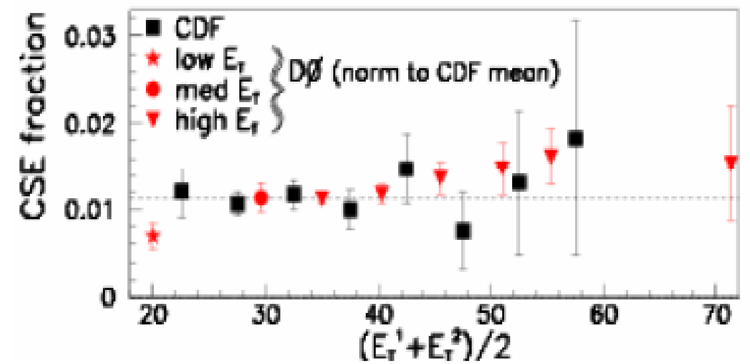


PRL

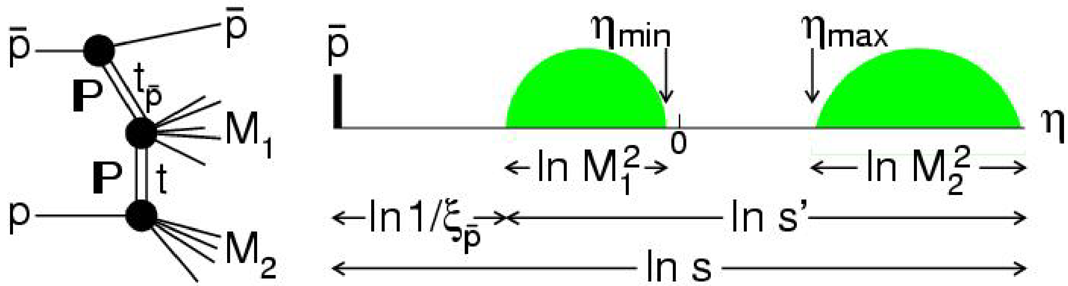
74 (1995) 855
80 (1998) 1156
81 (1998) 5278

72 (1994) 2332
76 (1996) 734
PLB 440 (1998) 189





Multiple gaps



Determine gap survival probability experimentally in soft diffraction

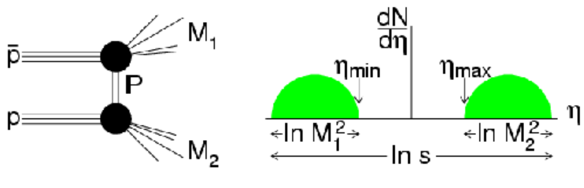
Gap rates suppressed by:
jet radiation and non-pQCD

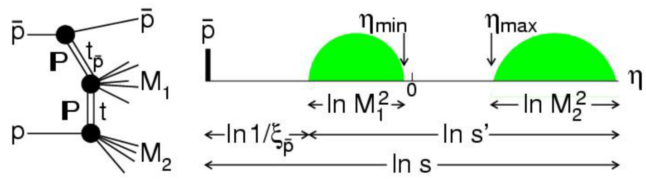
Measure the rate of additional gaps in soft diffractive events

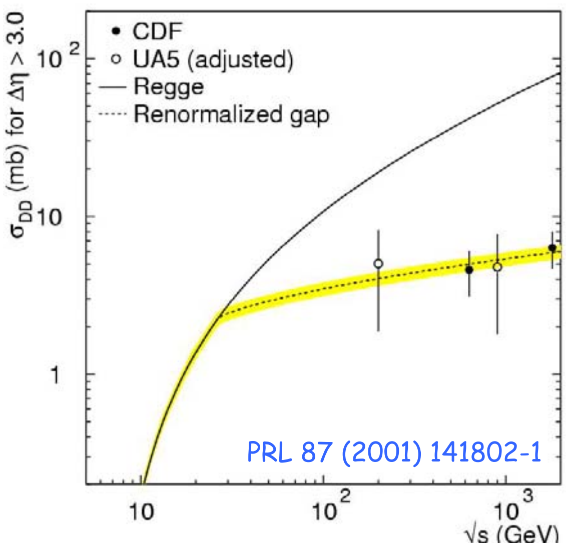
$$R^{2\text{-}gap}_{1\text{-}gap} \stackrel{?}{=} R^{1\text{-}gap}_{0\text{-}gap}$$

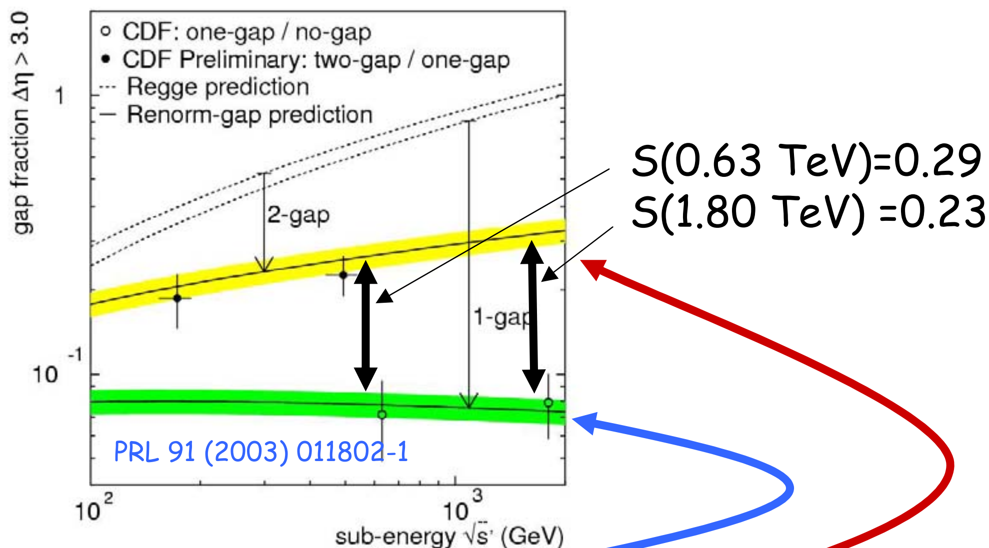
Gap survival

$$S = R^{1-gap/0-gap}_{2-gap/1-gap}$$ ⇨survival probability





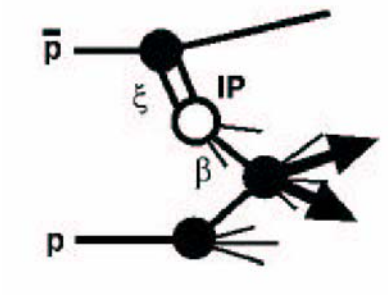




one-gap cross sections suppressed

two-gap to one-gap ratios not suppressed

Diffractive dijets



ξ: fraction of anti-proton momentum loss
β: fraction of pomeron momentum carried by parton

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

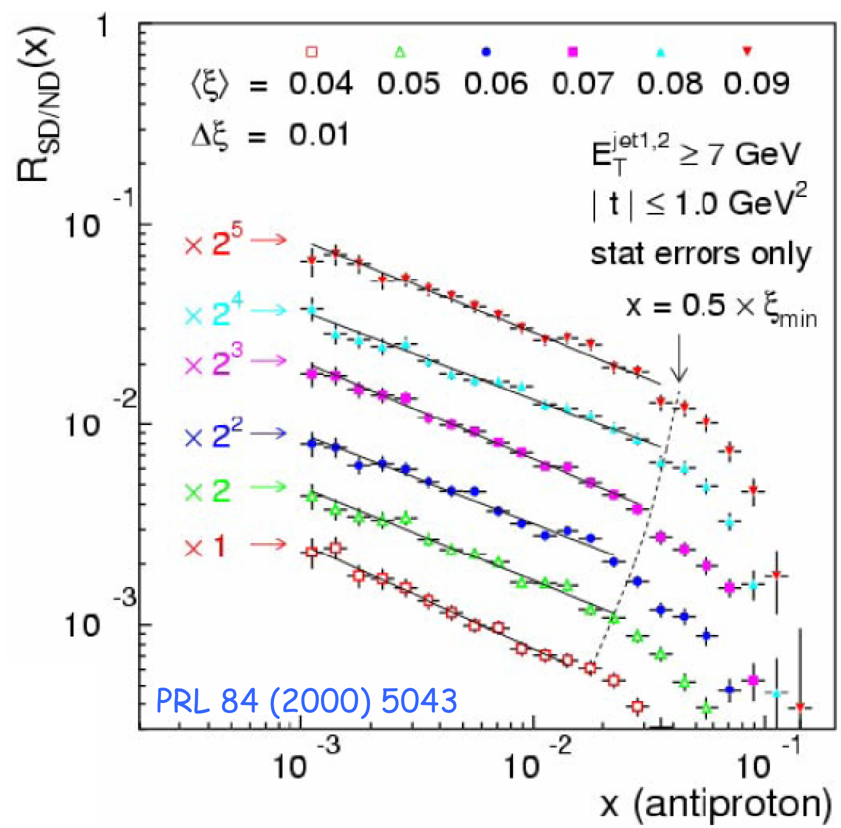
$$x_{Bj} = \frac{\sum_{jet} E_T \cdot e^{-\eta}}{\sqrt{s}}$$

Measure SD/ND ratio of dijet rates

$$\frac{\sigma(SD_{jj})}{\sigma(ND_{jj})} = \frac{F^D_{jj}(x)}{F_{jj}(x)} \quad \text{(LO QCD)}$$

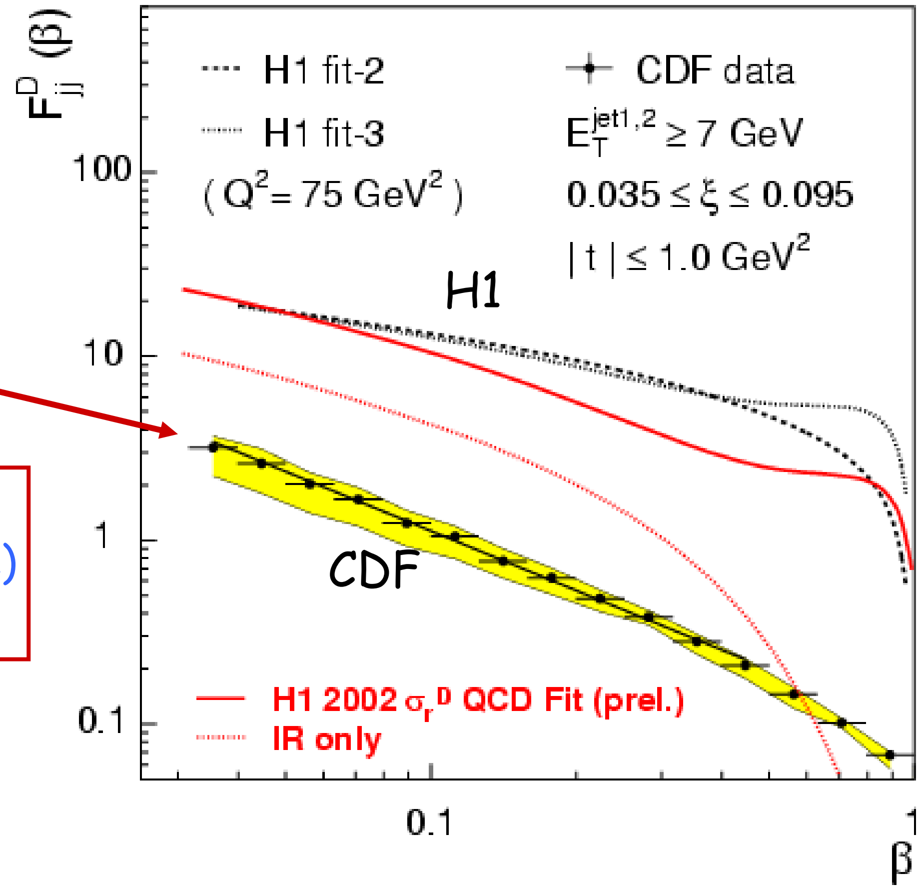
$$R_{SD/ND} = R_0 \cdot x^{-0.45}$$

⇨no significant ξ dependence



Diffractive structure function

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



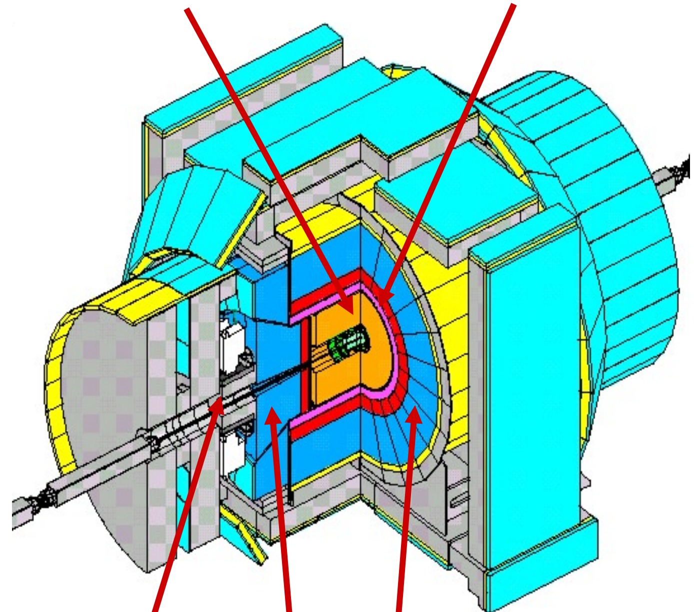
⇨breakdown of QCD factorization
(renormalization removes s-dependence)
K. Goulianos, PLB 358 (1995) 379

Goals for Run II

- ✓ Diffractive structure function
  - ⇨ Q^2 and ξ dependence
  - ⇨ process dependence
- ✓ Exclusive production in DPE
  - ⇨ dijet, heavy flavor, low-mass
- ✓ Jet-Gap-Jet w/large gaps

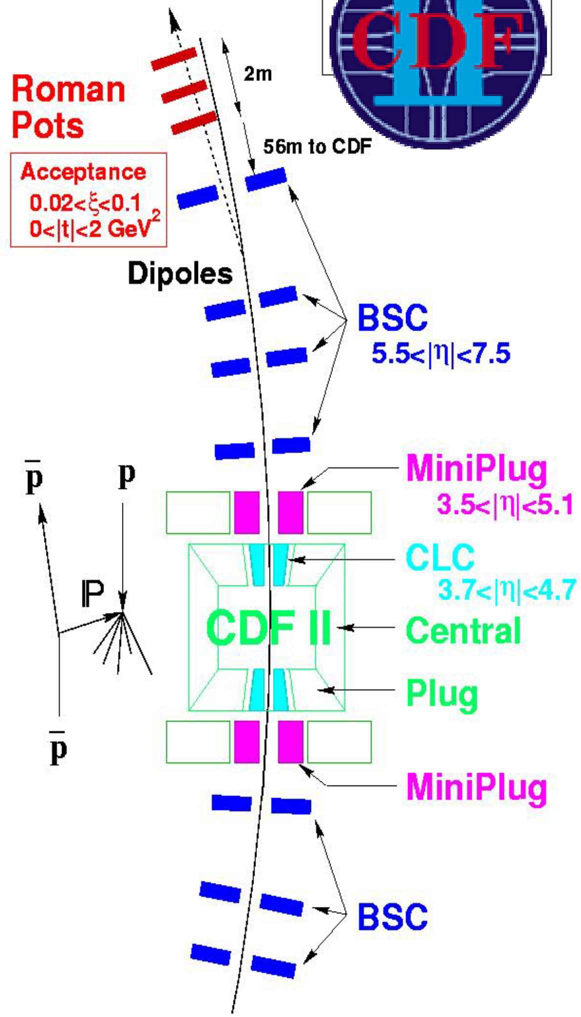
New Detectors for Run II

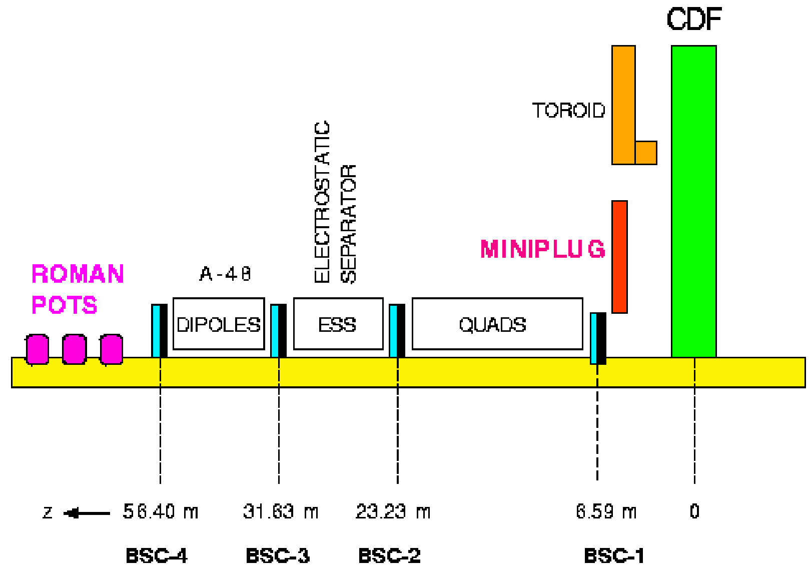
- Tracking
  - -Silicon
  - -Central Outer Tracker
- Time of Flight
- Expanded Muon Coverage
- Endplug Calorimeter
- **Forward Detectors**
  - -Beam Shower Counters
  - -Miniplugs
  - -Roman Pots (same as Run I)



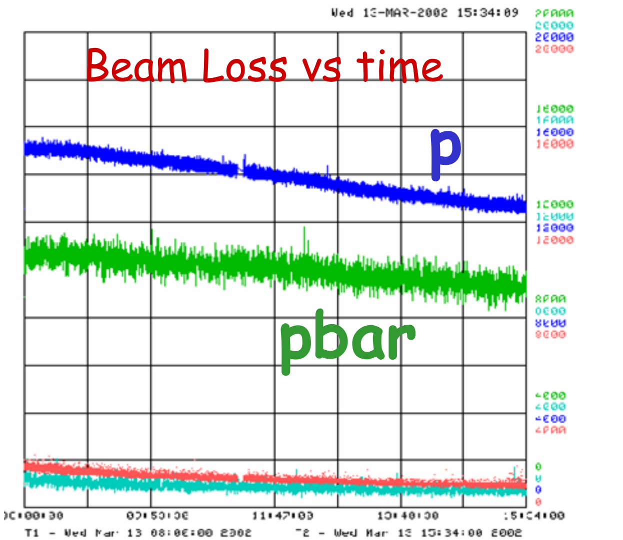
All detectors are used in the diffractive program !

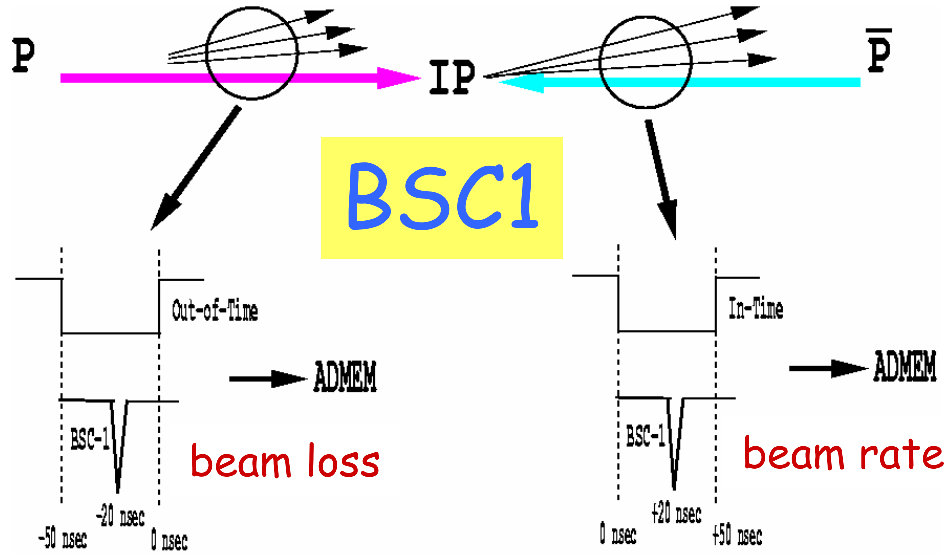
Run II diffractive program

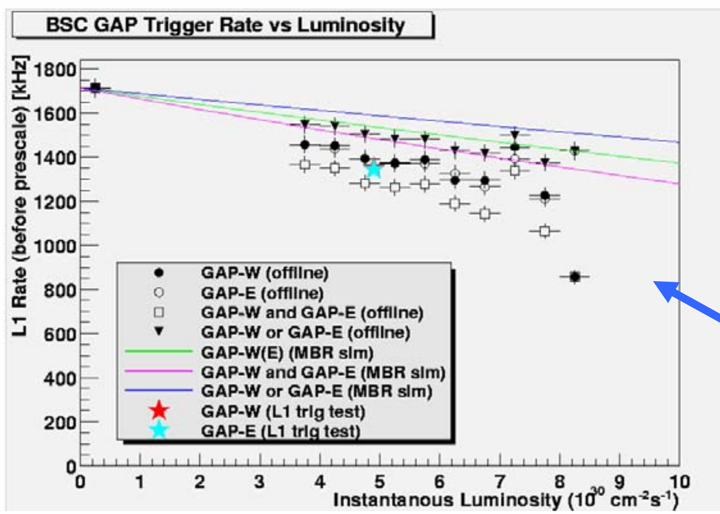




Beam Shower Counters







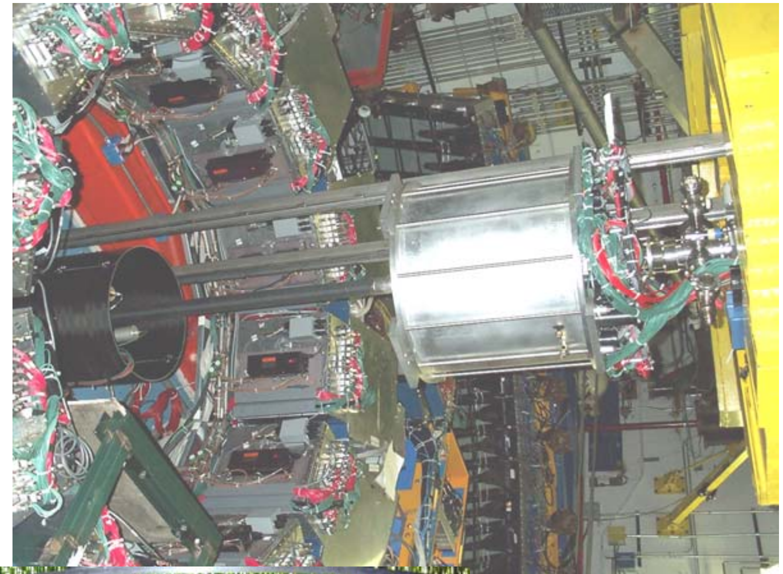
rate vs inst. luminosity

<u>Rapidity gap trigger</u>

BSC1+BSC2+BSC3(+BSC4)

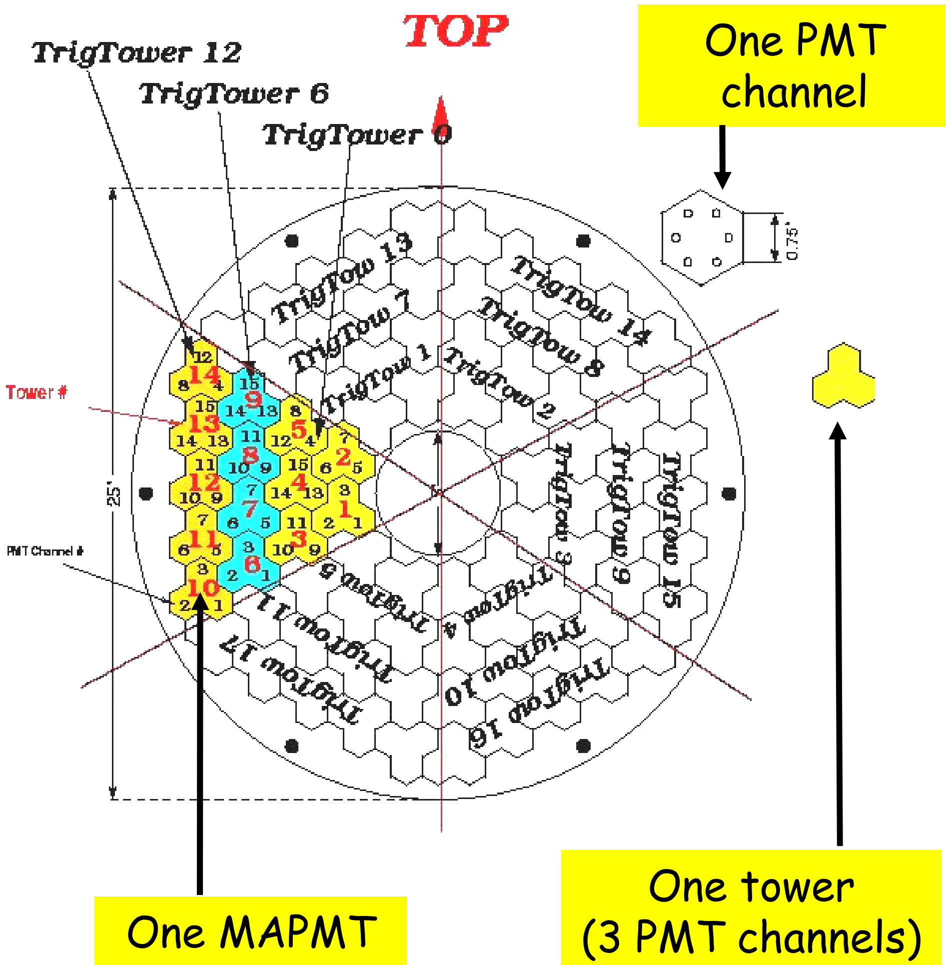
MiniPlug Calorimeters

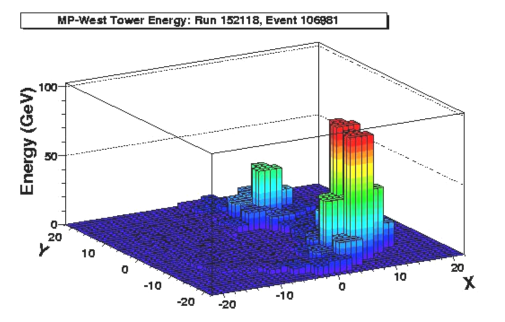
- liquid scintillator + lead
- flexible tower geometry
- full coverage (no dead regions)
- detect charged/neutral

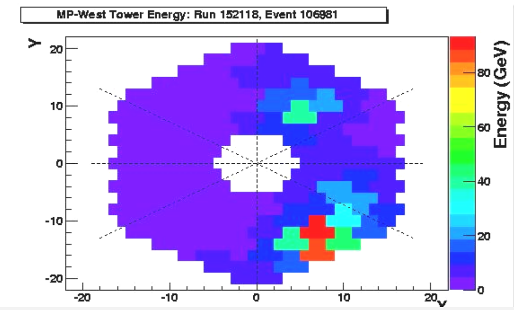


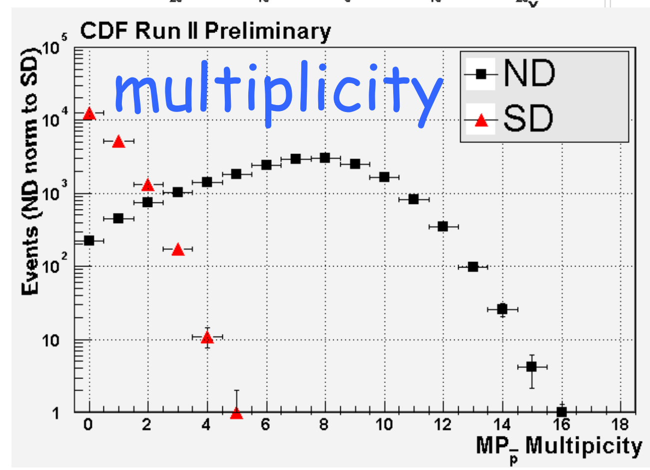
Group fibers to form "towers"

Particles/jets in MP

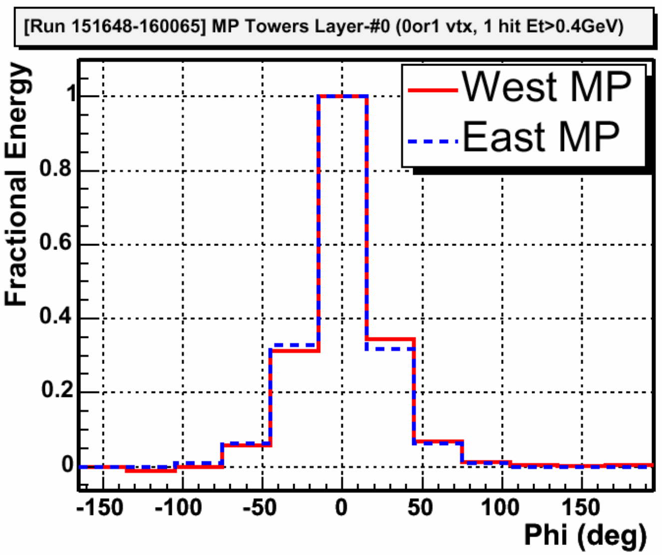




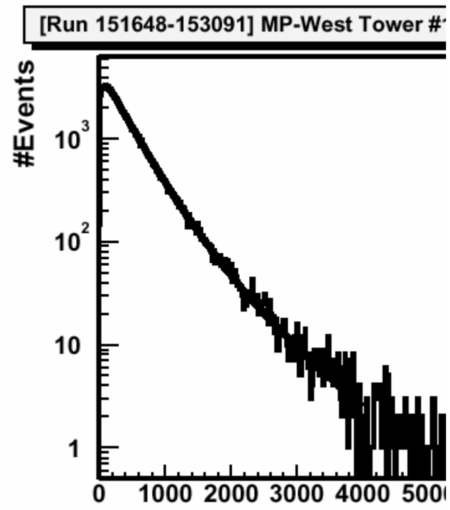




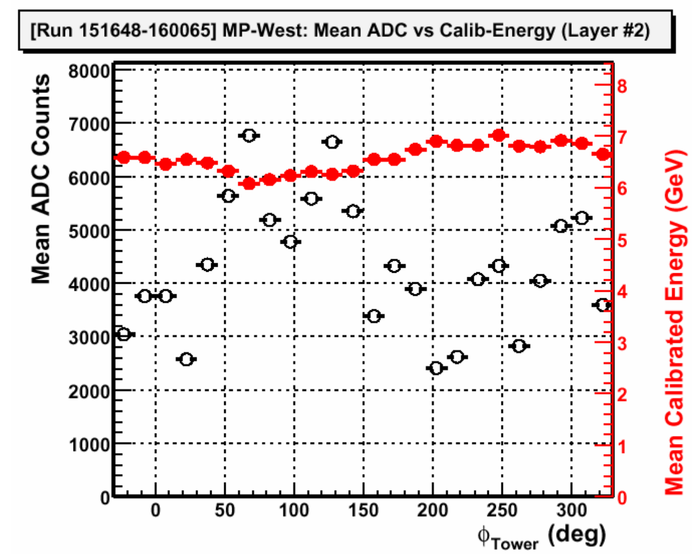
MP calibration



“Seed” and neighbor towers in ϕ



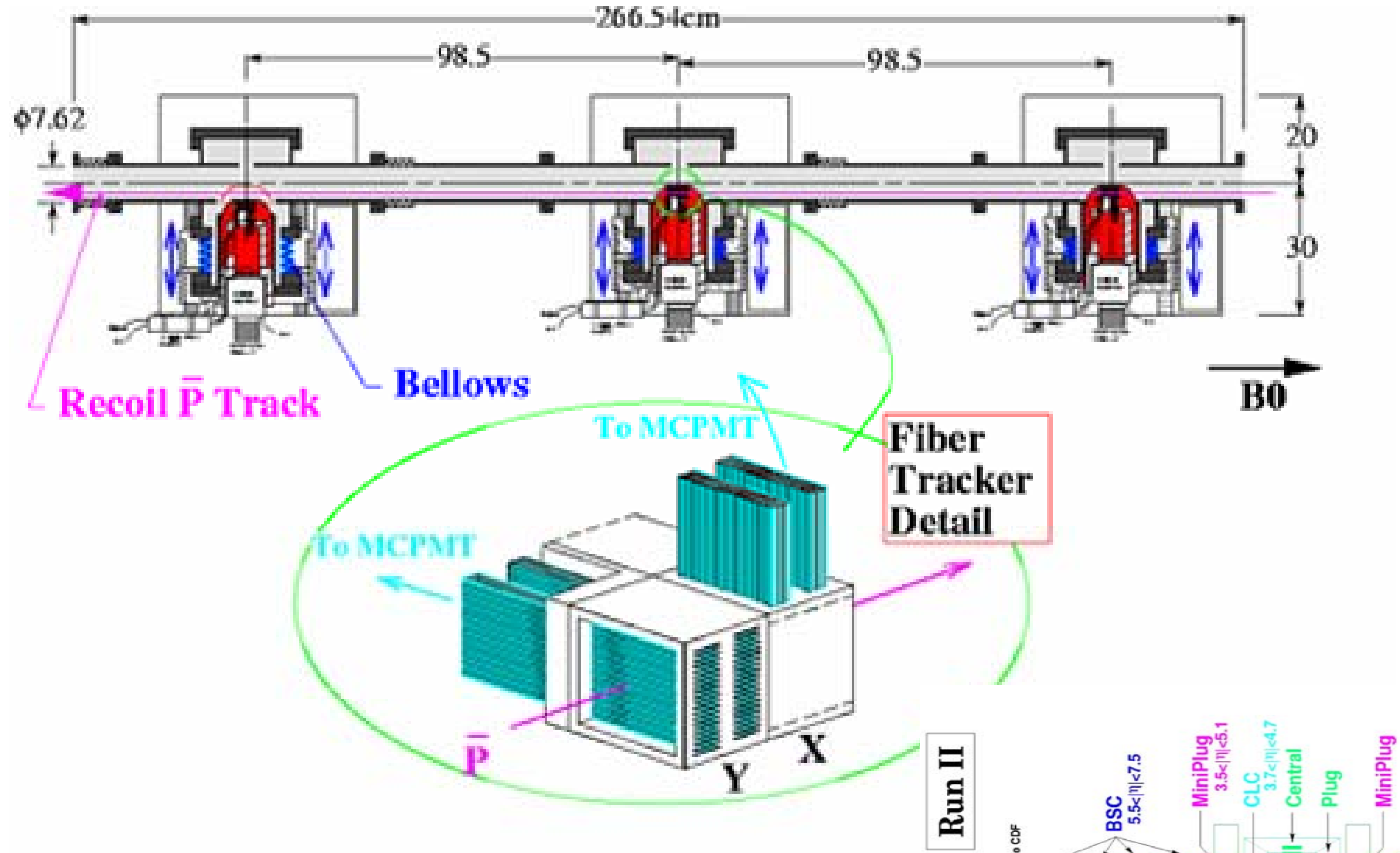
“Seed” tower ADC counts

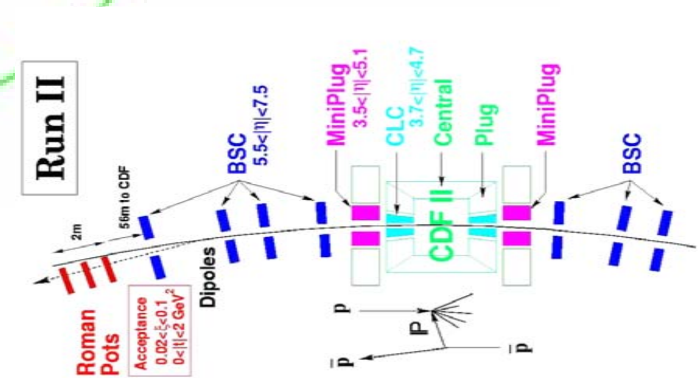


ADC counts vs ϕ before/after calib.

- ✓ use data for relative calib. of towers at same η
- ✓ use MC for relative calib. vs η and overall energy scale

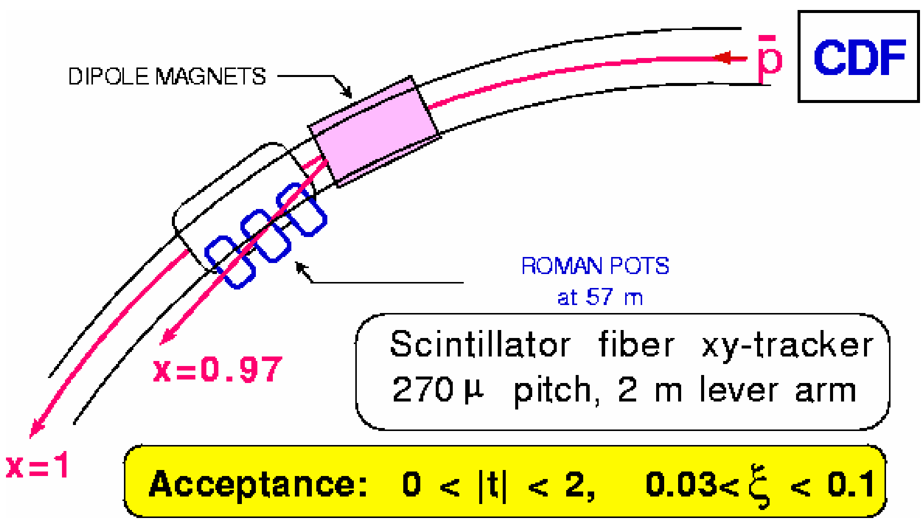
Roman Pot Spectrometer

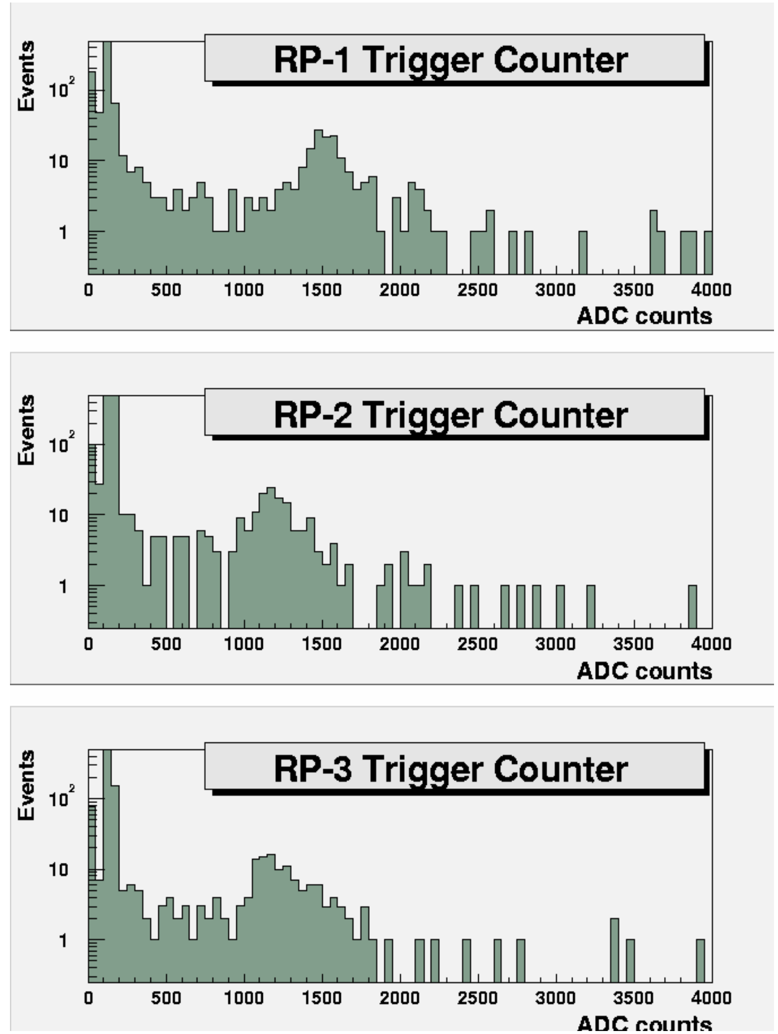




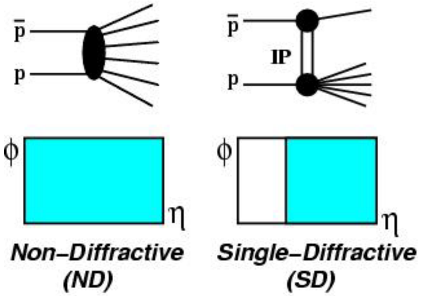
Roman Pot Trigger

Use 3-fold coincidence
of RP trigger counters



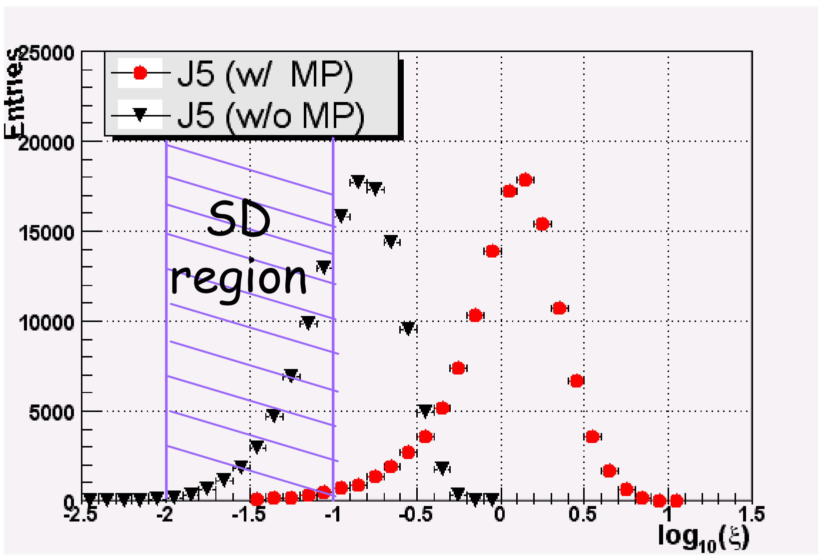


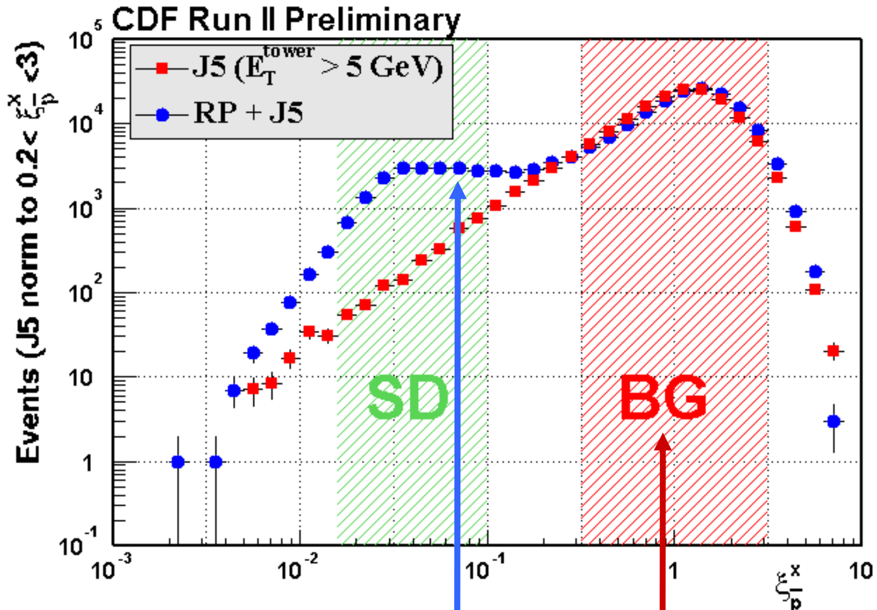
Diffractive dijets



ξ : momentum loss fraction of pbar

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





Approx. flat at ξ<0.1

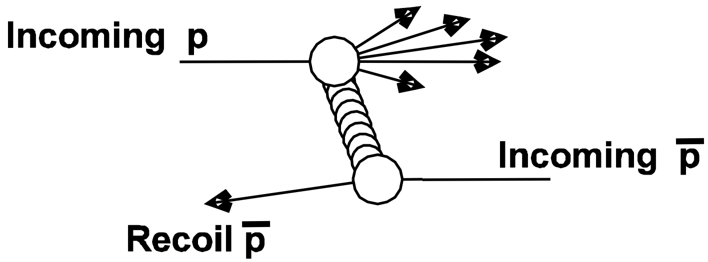
$$\frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \rightarrow \frac{d\sigma}{d(\log \xi)} = \text{const}$$

overlap events

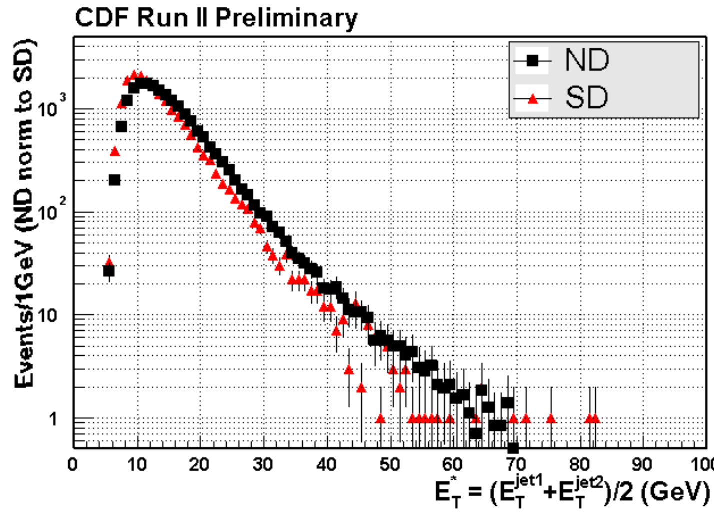
MP energy scale: ±25% →Δlogξ = ±0.1

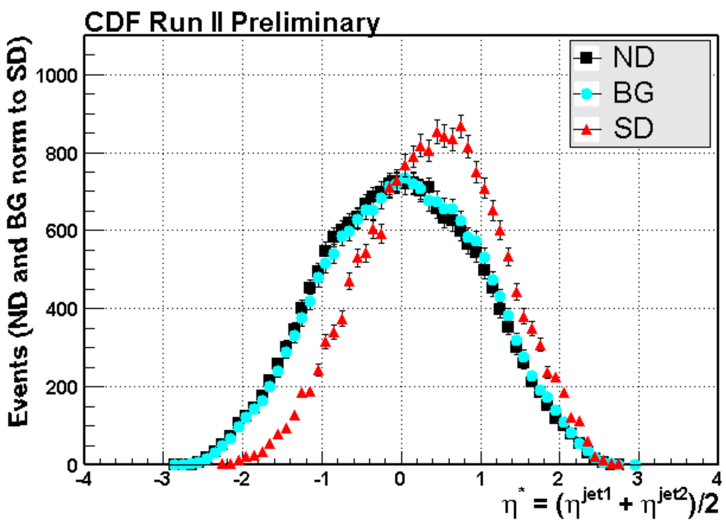
RP acceptance (0.03<ξ< 0.1) ~ 80% (Run I)

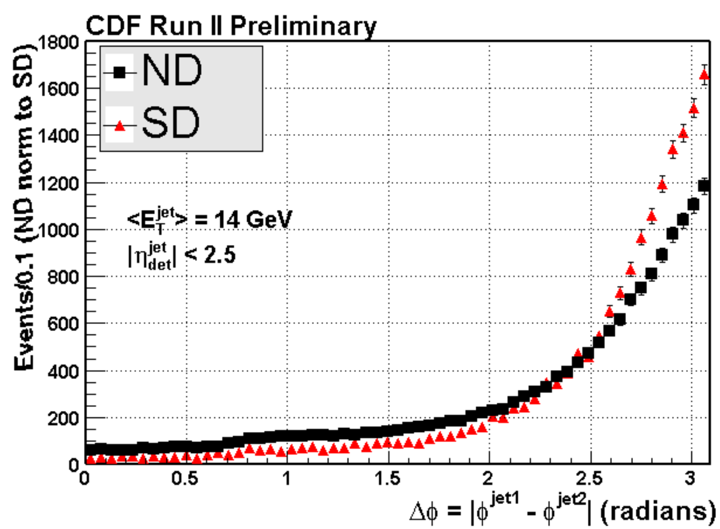
Kinematic Properties



compare ND and SD





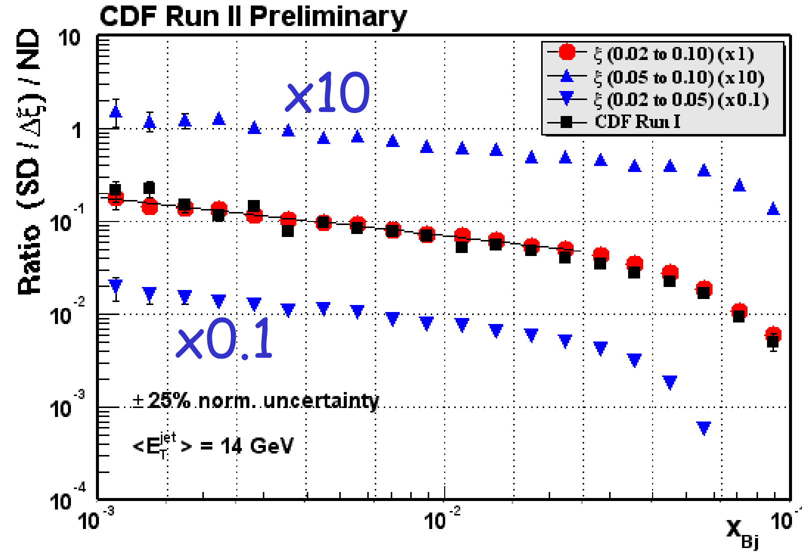


SD/ND ratio in Run II

ratio of SD/ND dijet event rates compared to Run I data

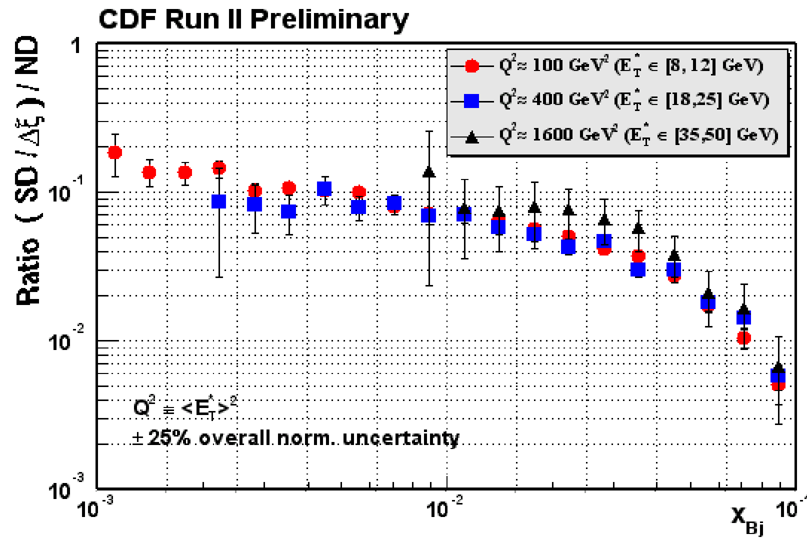
- slope and normalization agree with Run I result
- no ξ dependence observed $0.03<\xi<0.1$

⇨confirms Run I results

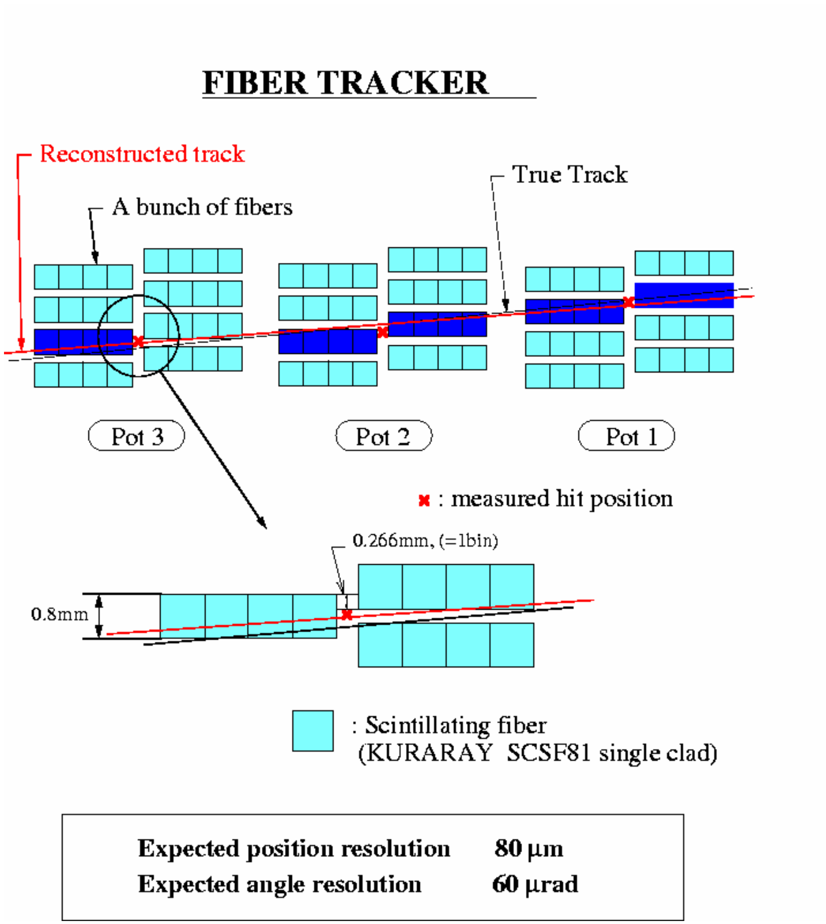


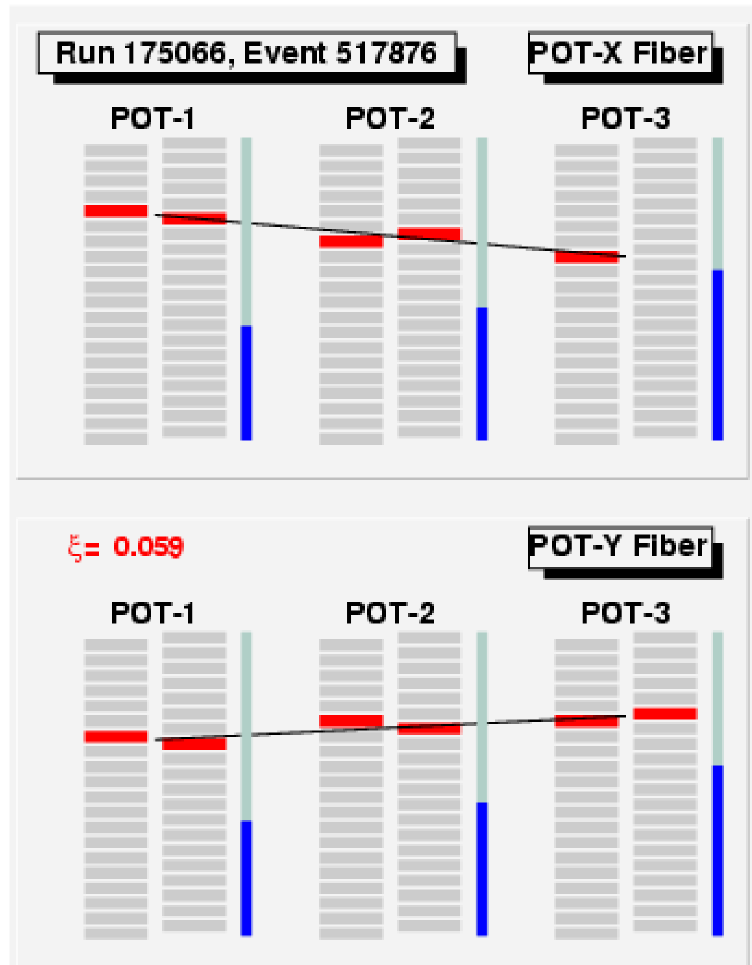
no appreciable Q^2 dependence observed within $100 < Q^2 < 1{,}600\ GeV^2$

⇨pomeron evolves similarly to proton

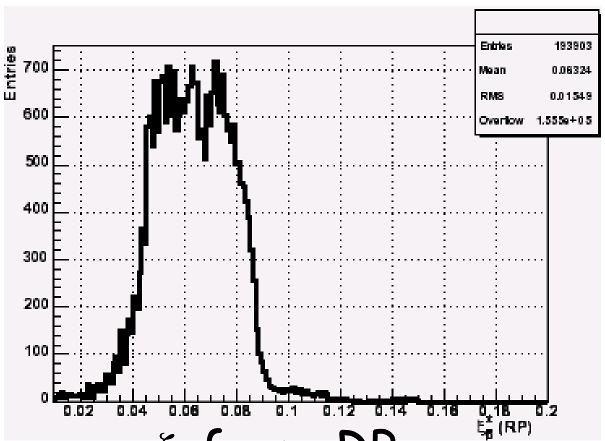


Roman Pot tracking

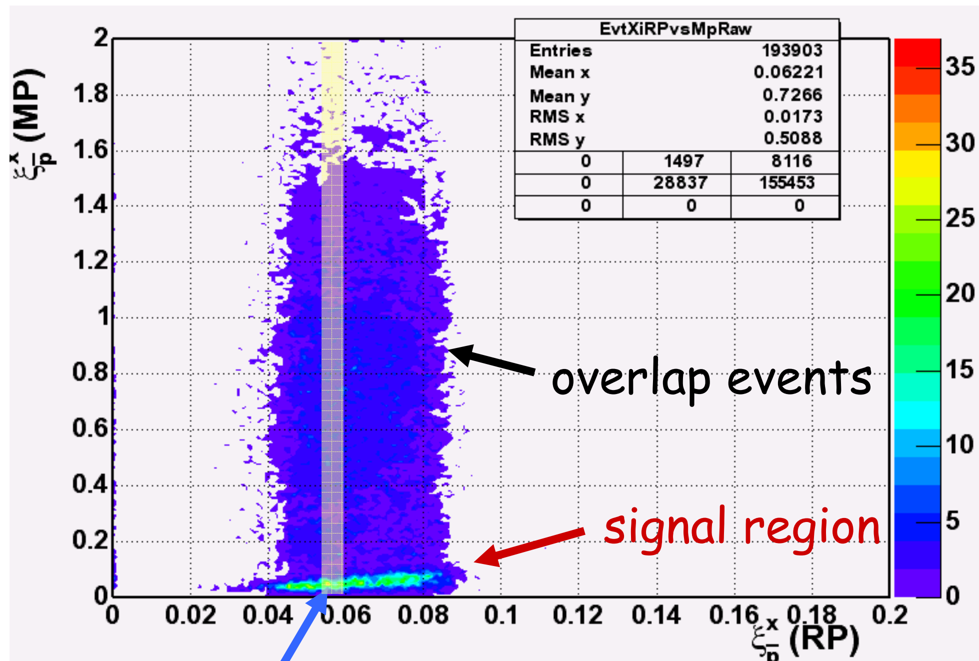


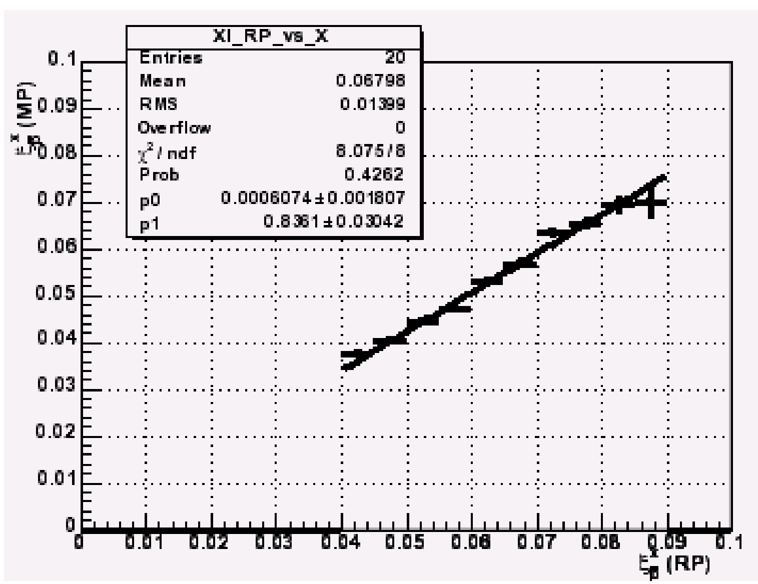


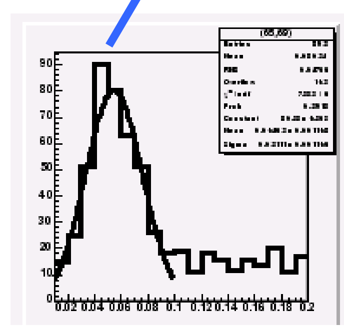
ξ: RP vs calorimeter



ξ from RP



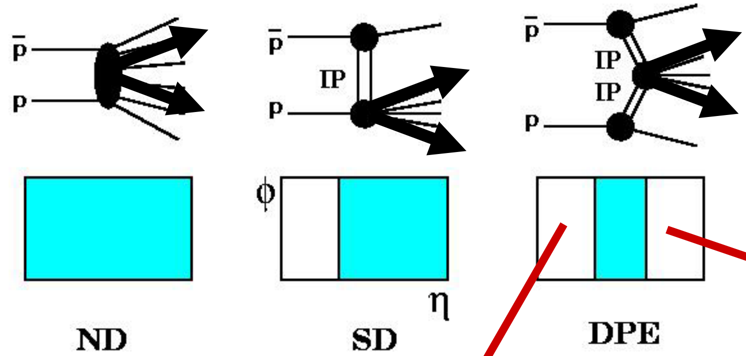


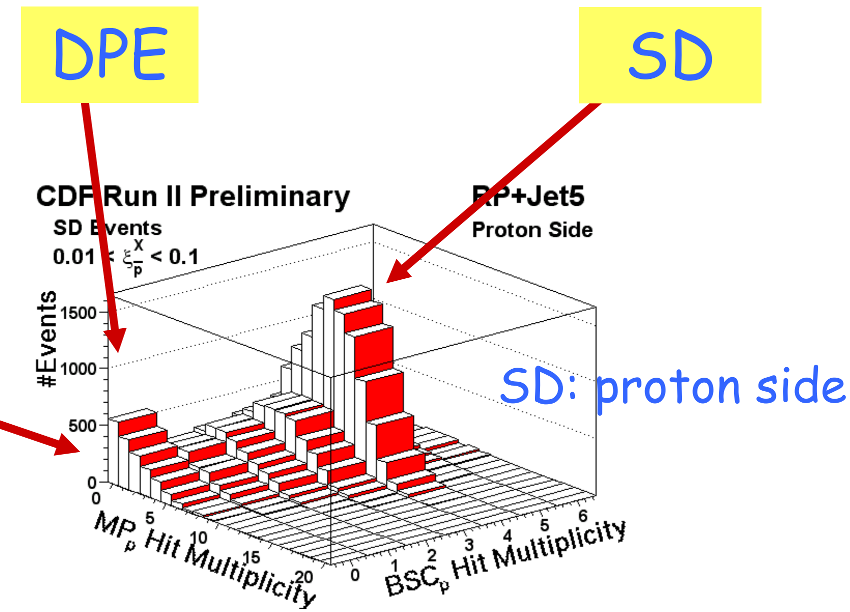


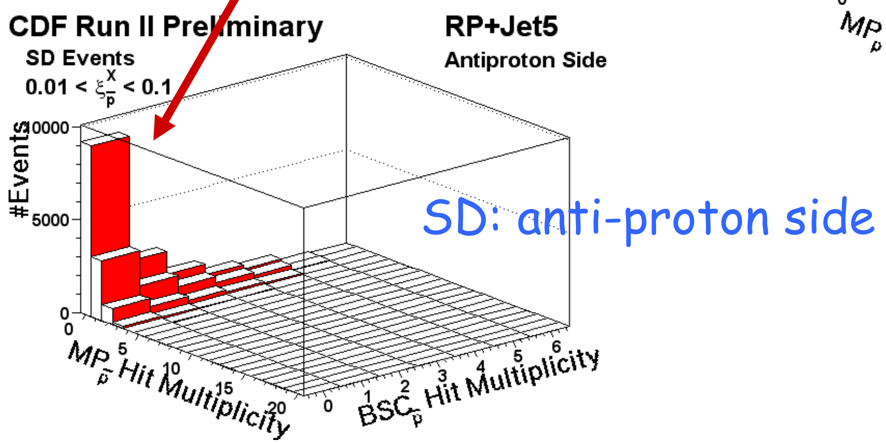
ξ^{cal} distribution for slice of ξ^{RP}

DPE Dijet Production

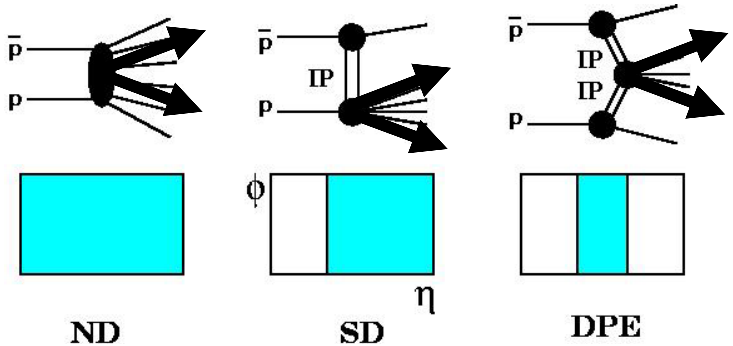
from SD data:







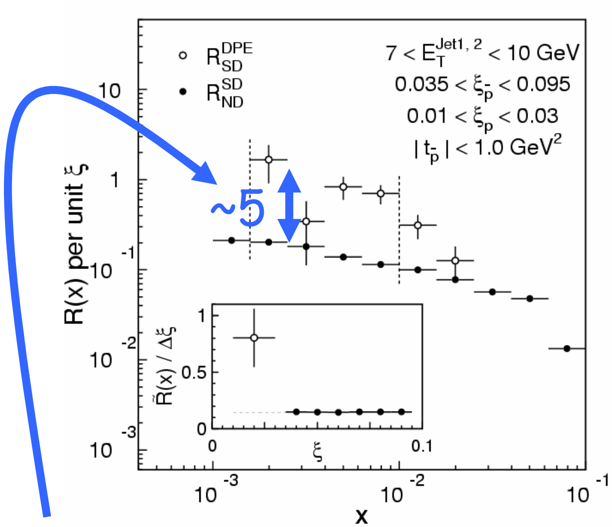
DPE dijets

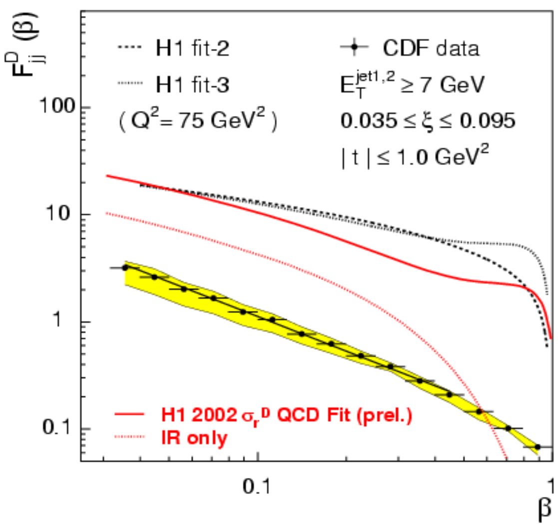


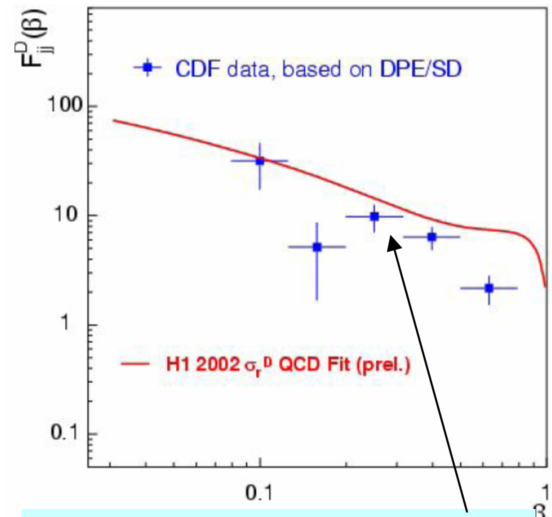
R(DPE/SD) vs R(SD/ND) ?

2-gap/1-gap

1-gap/0-gap







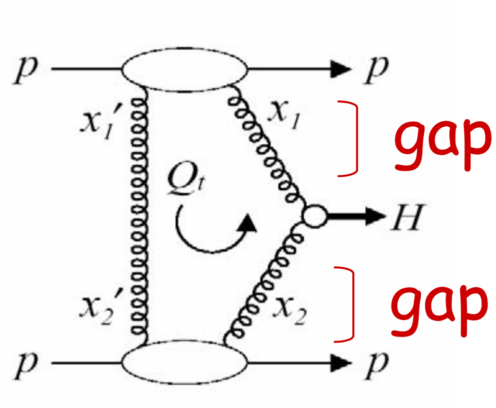
R(DPE/SD) ≈ 5 × R(SD/ND)

factorization is restored !

⇨additional gap is not suppressed

Exclusive production in DPE

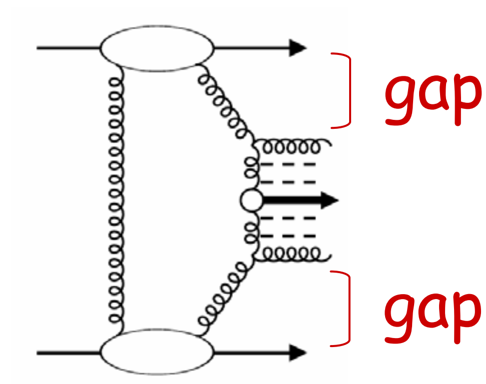
exclusive



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

C. Royon, hep-ph/0308283

inclusive



Attractive Higgs discovery channel at the LHC

$$p\bar{p} \rightarrow p\, H\, \bar{p}, \quad H \rightarrow b\bar{b}$$

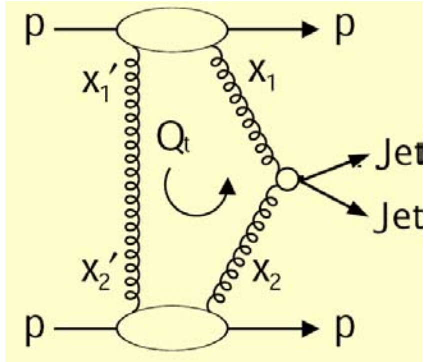
Standard Model light Higgs:

- "exclusive" channel ⇨ clean signal
- $M_H = M_{miss} = (s\, \xi_1\, \xi_2)^{1/2}$
- σ_H(LHC)~3 fb, signal/background~3 (if ΔM_{miss}=1 GeV)

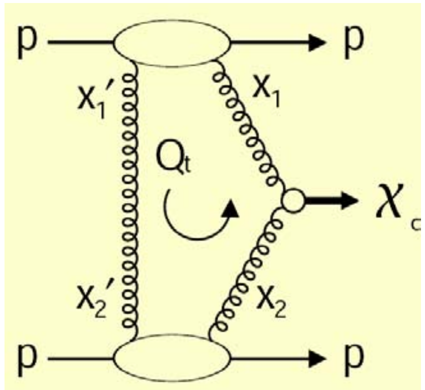
Exclusive production

Measurement of exclusive processes can be used to calibrate Higgs predictions

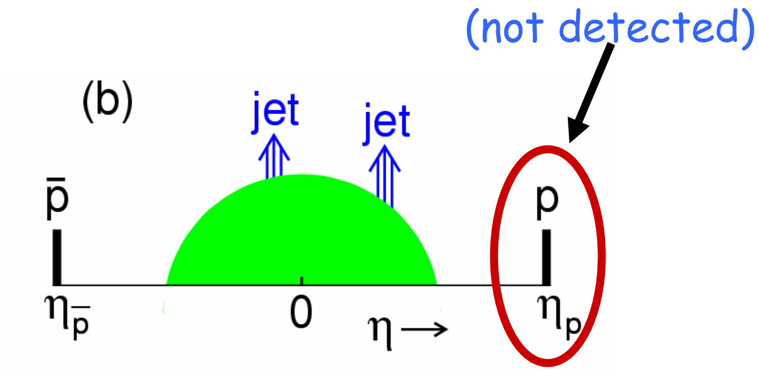
Exclusive dijets: $gg \rightarrow gg$
- exclusive $gg \rightarrow q\bar{q}$ is suppressed



Exclusive χ_c:
- small cross section, clean signal

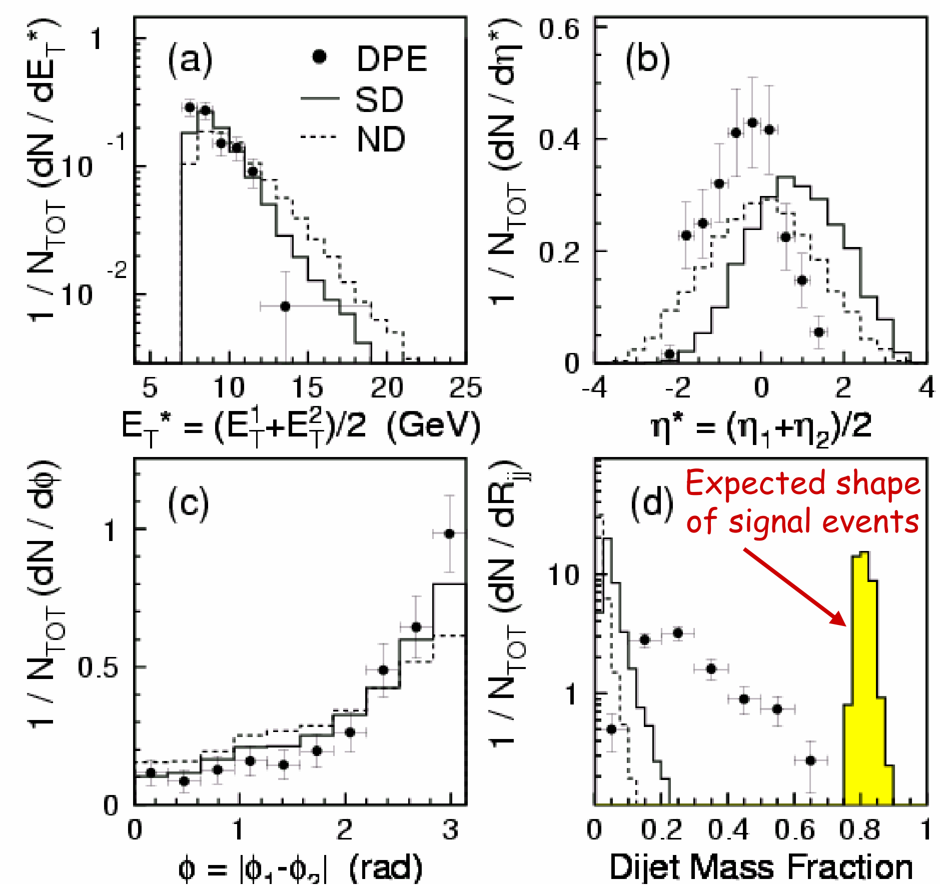


Exclusive Dijets in Run I



PRL 85 (2000) 4215

✓antiproton tag: $0.035<\xi<0.095$
✓2 jets, $E_T>7$ GeV
✓proton-side gap ($2.4<\eta<5.9$)
⇨ **observed 132 events**



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

⇨ σ_{jj} (excl.) < 3.7 nb (95% CL)
theory expectns ~1 nb (Run I kinematics)

DPE Enhanced Sample

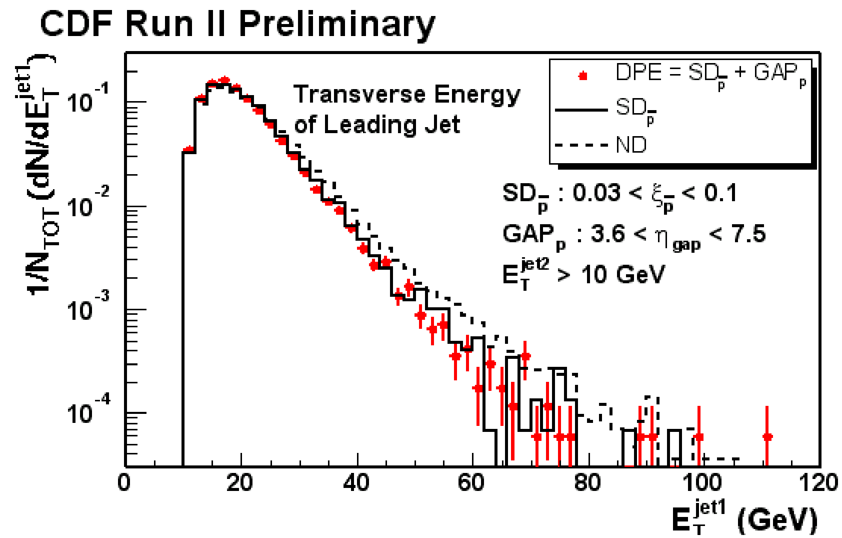
- Use Run II dedicated DPE trigger (RP+J5+BSC_Gap_P)

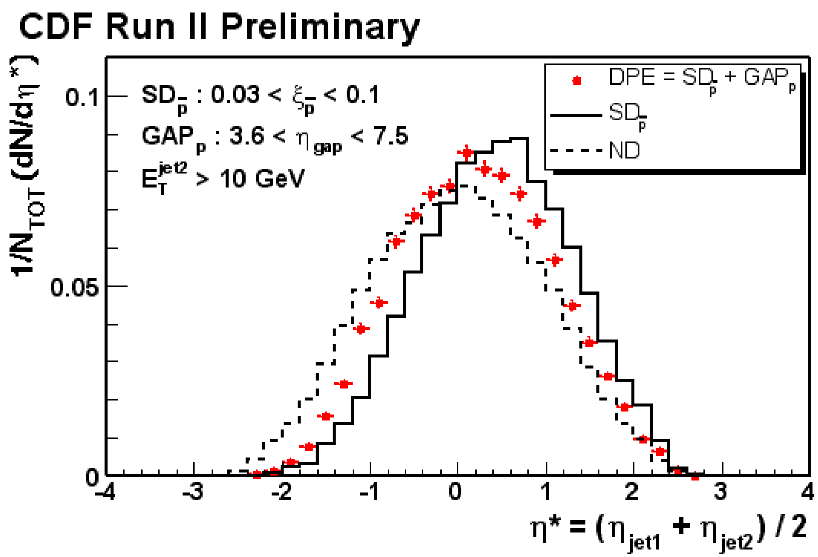
Data presented from 26 pb^{-1}:

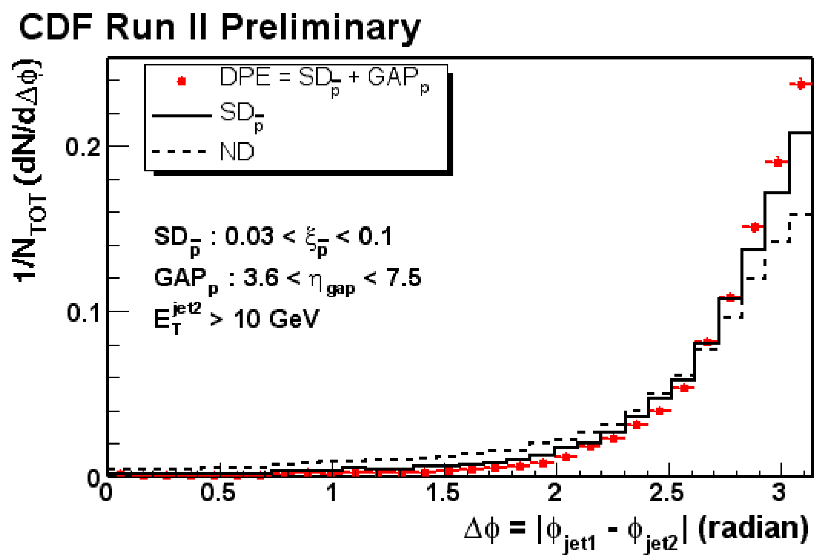
Triggers	397 k
$N_{vertex} \leq 1$, $\lvert z_{vertex} \rvert < 60$ cm	365 k
RP offline cut	309 k
$N_{jets} \geq 2$ ($E_T > 5$ GeV, $\lvert\eta\rvert < 2.5$)	163 k
E_T(jet2)>10 GeV	116,473
SD ($0.01 < \xi < 0.1$)	54,552
DPE (MP-East $N_{hit}=0$)	17,101

DPE: kinematics

Compare ND and SD and DPE





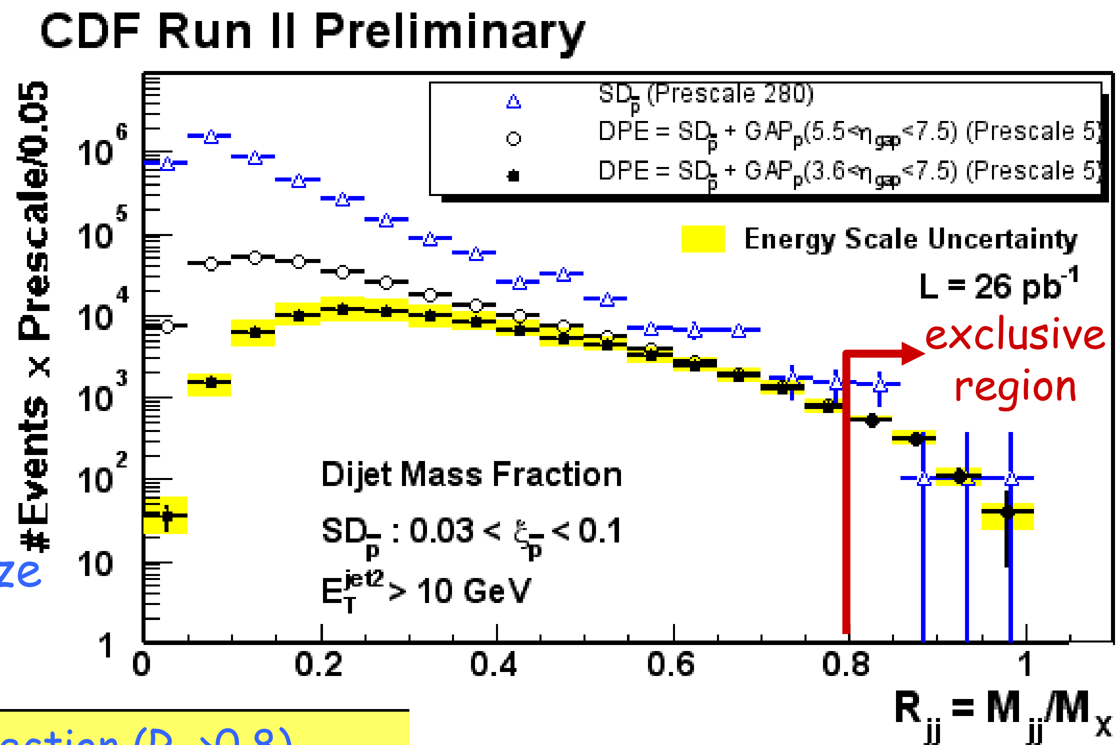


Dijet Mass Fraction

use dedicated DPE trigger (RP+J5+BSC_Gap_P)

rate falls smoothly as $R_{jj} \to 1$
no excess at large R_{jj}

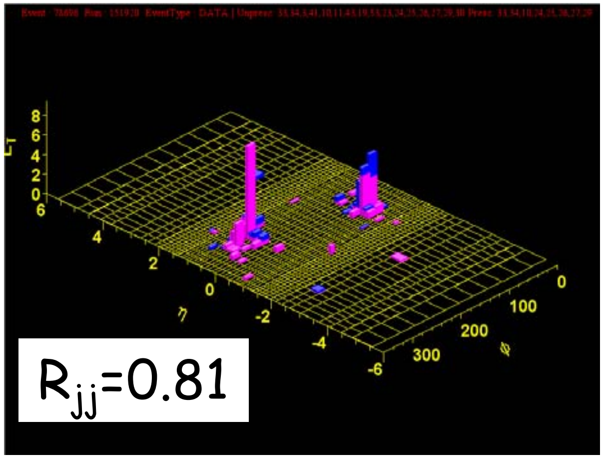
independent of rapidity gap size

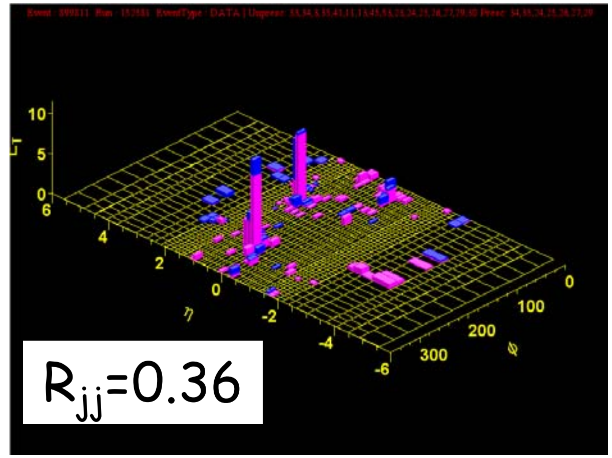


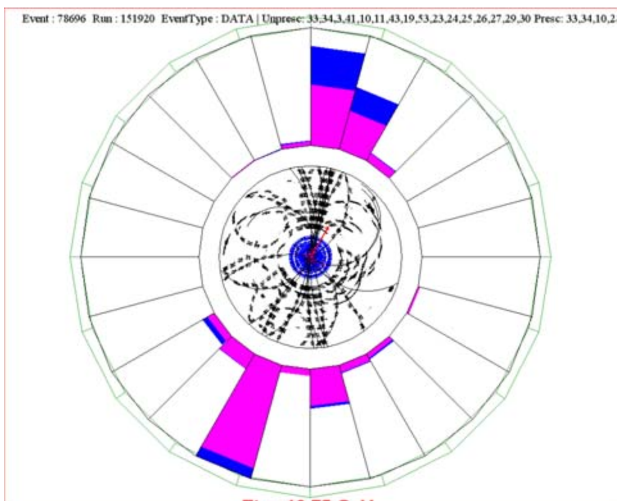
Minimum E_T(Jet1)	Cross section (R_{jj}>0.8)
10 GeV	970 ± 65(stat) ± 272(syst) pb
25 GeV	34 ± 5(stat) ± 10(syst) pb

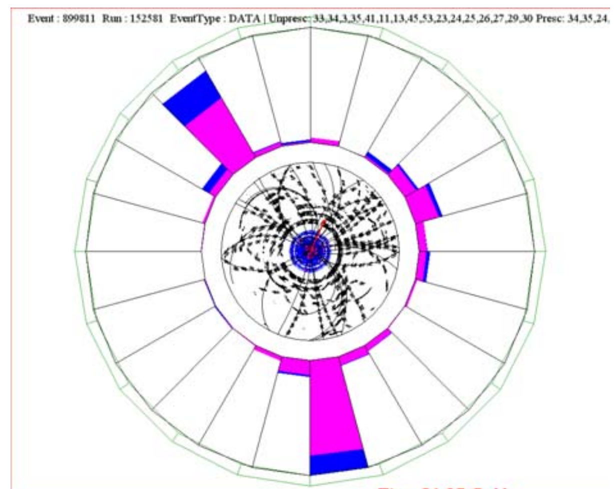
Khoze, Martin, Ryskin - Eur. Phys. J. C23, 311, 2002
~ 60 pb (factor of 2 uncertainty)

Exclusive Dijet Events ?









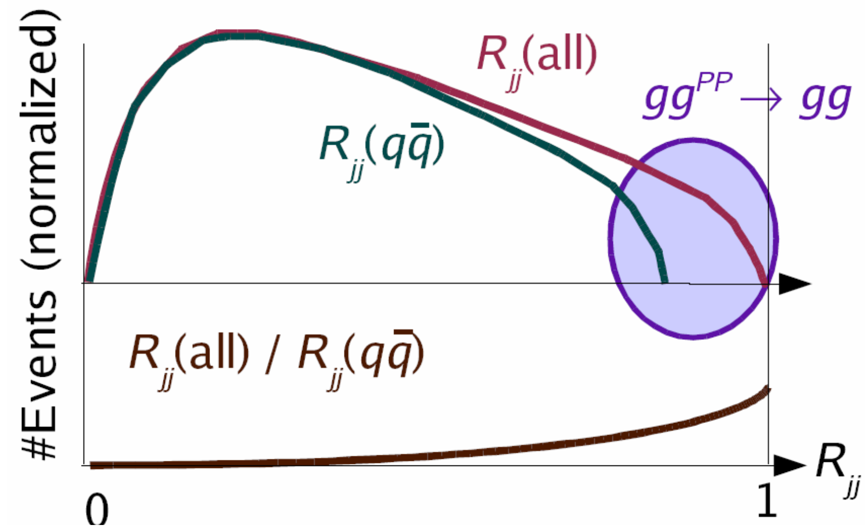
Prospects w/exclusive dijets

Experimental method:
normalize R_{jj} for all jets to R_{jj} for $\bar{q}q$
⇨look for excess of events at large Rjj

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

Cons: heavy quark mass
contribution from exclusive b/c

Theory:
$gg \rightarrow gg$ dominant contribution at LO
$gg \rightarrow qq$ suppressed when $M_{jj} \gg m_q$

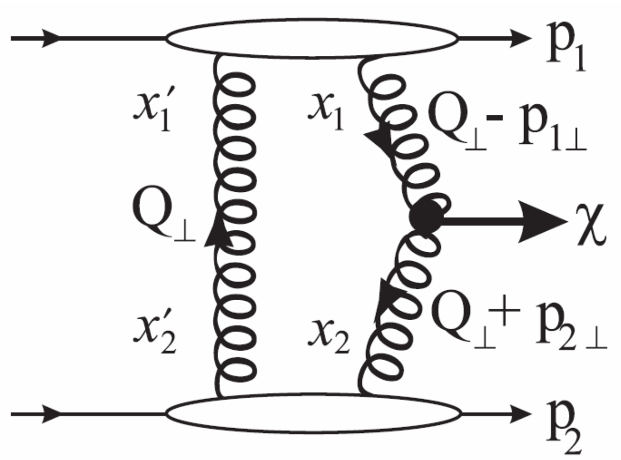


Difference between gluon and quark jet

•charged particle multiplicity in jet
$N_{g\text{-}jet}$=1.6 $N_{q\text{-}jet}$ (from Run I)
⇨study how N_{jet} behaves as Rjj→1

•sensitive to light quark jets
•q/g jets are not well separated

Exclusive low-mass states



$p\bar{p} \rightarrow p\chi\bar{p}$

$\quad\quad \chi \rightarrow J/\psi\,\gamma \rightarrow \mu\mu\gamma$

(γ is soft)

(same quantum numbers as Higgs boson)

Event selection:

✓start from J/ψ sample
✓exclusive events
✓invariant mass ($\mu\mu$+EM tower)

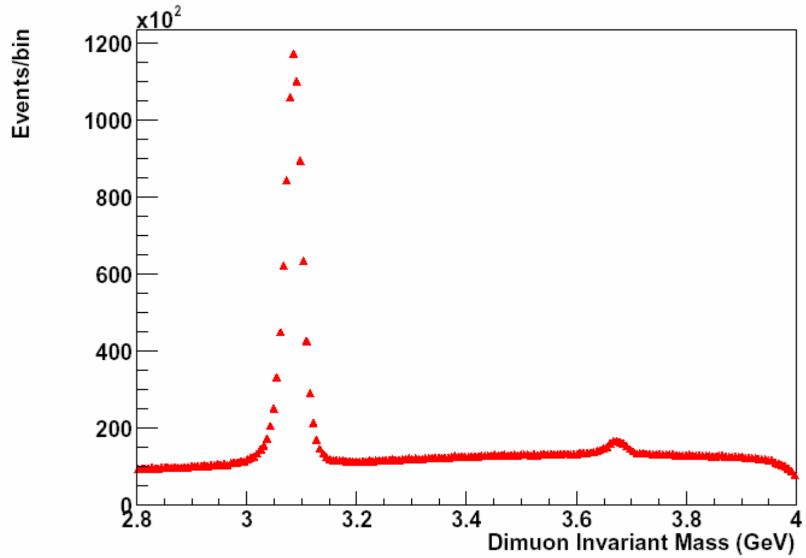
Background:

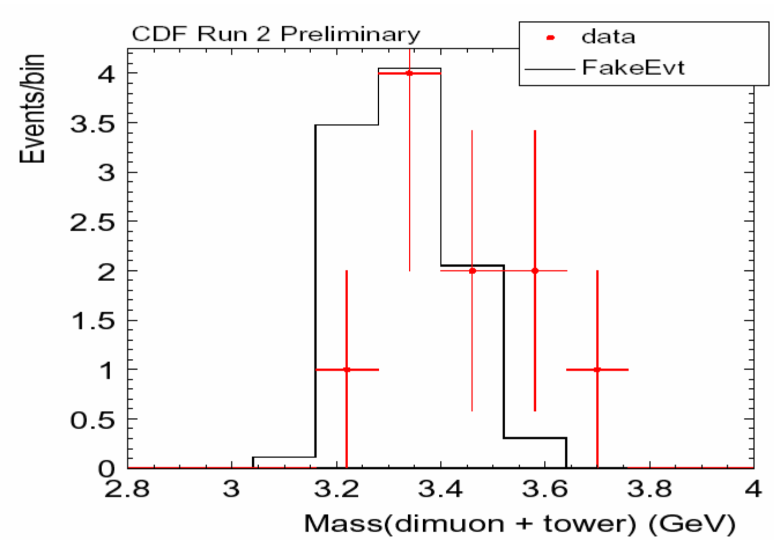
✓cosmics
✓calorimeter noise

Event Selection

Data sample of 93 pb^{-1}:

BSC+MP veto	107
(calorimeter+CLC+trk+muon) veto	23
EM tower	10





✓mass resolution is poor
✓bkg from multiplicity fluctuations (under threshold)
✓difficult to estimate noise contribution

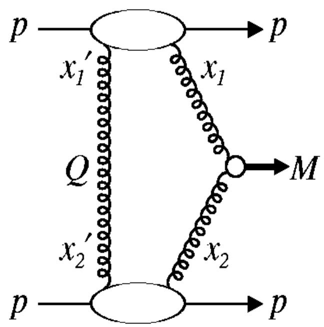
cross section upper limit for exclusive production

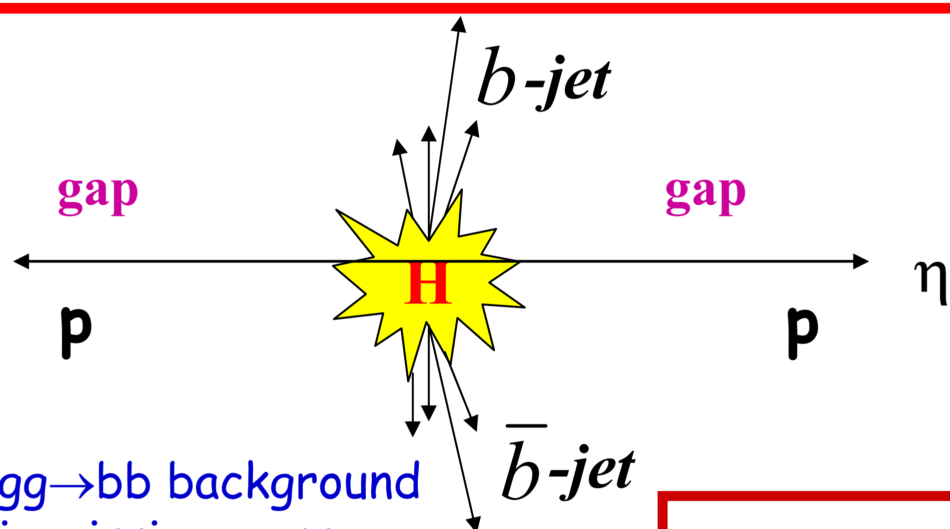
⇨ $\sigma_{excl}(J/\psi+\gamma) = 49 \pm 18(stat) \pm 39(syst)$ pb

~70 pb
Khoze, Martin, Ryskin, Stirling
Eur. Phys. J. C 35, 211 (2004)

Diffractive Higgs Production

Exclusive diffractive Higgs production pp→ p H p : 3-10 fb
Inclusive diffractive Higgs production pp → p+X+H+Y+p : 50-200 fb





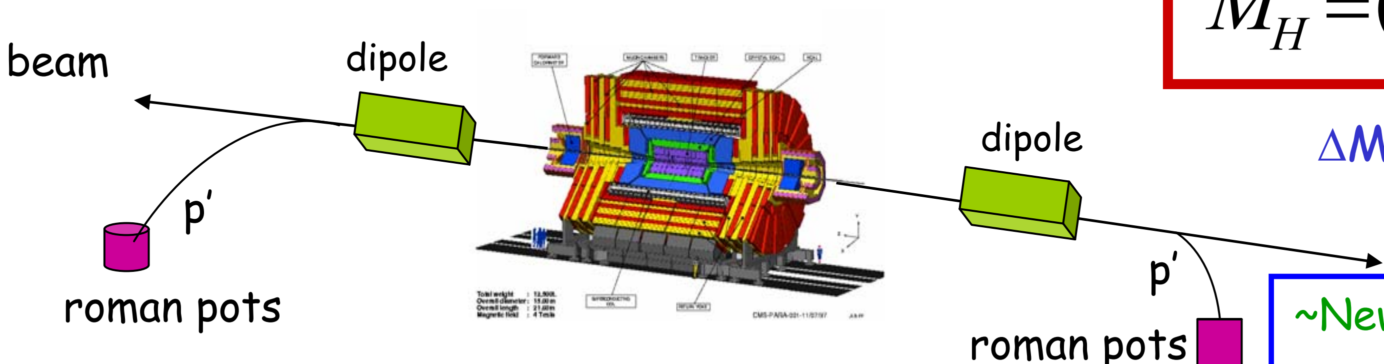
E.g. V. Khoze et al
M. Boonekamp et al.
B. Cox et al. …

Advantages Exclusive:

- Jz=0 suppression of gg→bb background
- Mass measurement via missing mass

$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

ΔM = O(1.0 - 2.0) GeV



Thanks to A. de Roeck: Tev4LHC, Sept 16-18, 2004

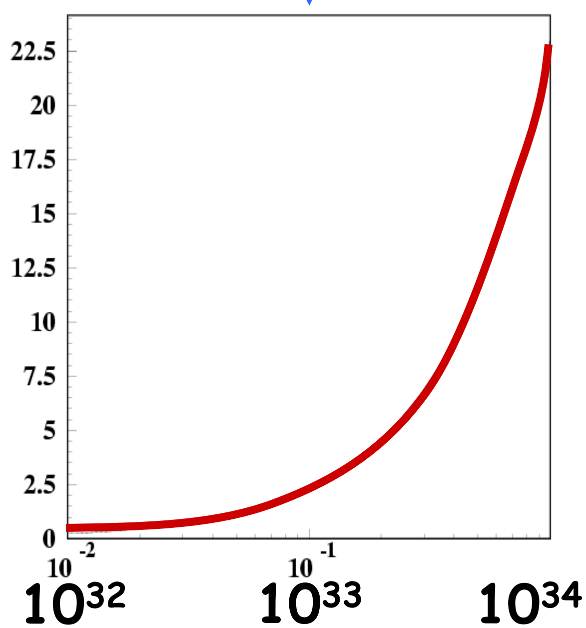
~New: Under study by many groups

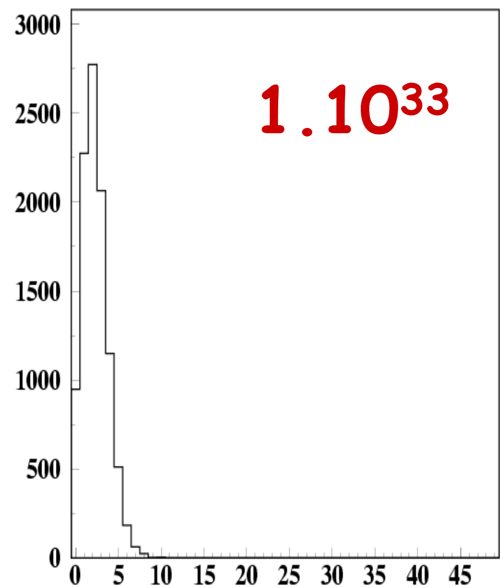
Rapidity Gaps at LHC

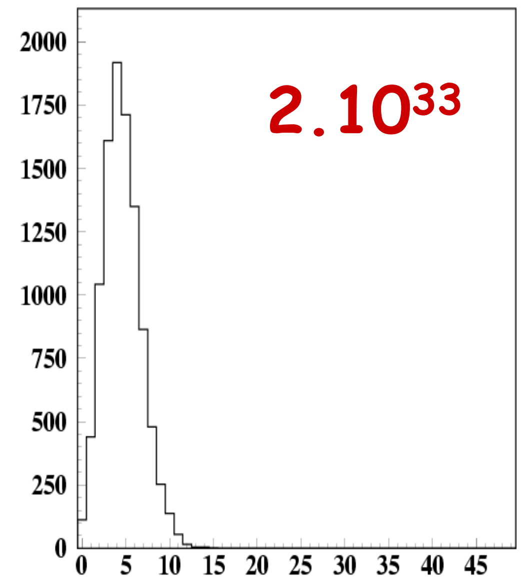
Number of overlap events versus LHC luminosity

distribution of number of interactions

Doable at startup luminosity!







1 int. 22% 4%

Benefit from experience of HERA/Tevatron experiments !!

Summary

Soft and hard diffraction
non suppressed two-gap to one-gap ratios

forward detectors working well
dedicated diffractive triggers

re-established Run I measurements
no significant Q^2 dependence in SD/ND ratio
no exclusive dijet/low-mass production