# Diffractive results at the Tevatron

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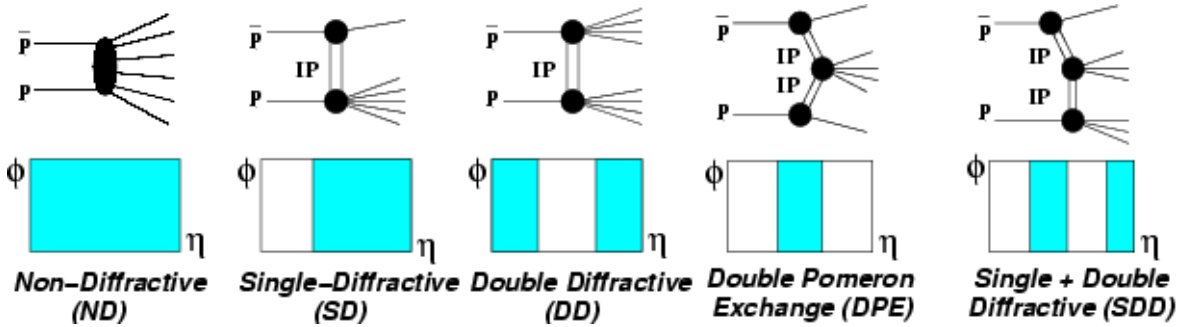
ICHEP, Beijing Aug. 16, 2004

- ✓ Soft and hard diffraction
- ✓ Run II diffractive program
- ✓ Exclusive production

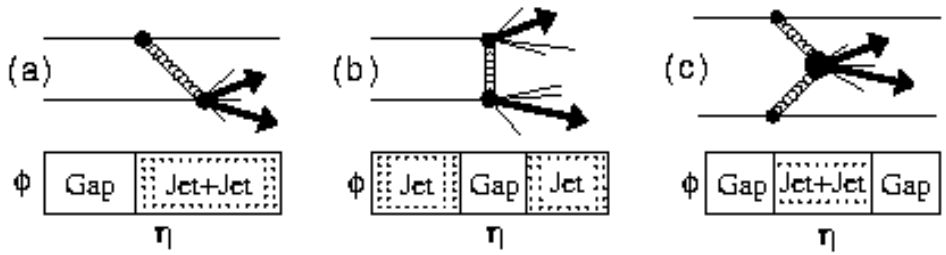
# Diffraction in Run I

- Large rapidity gaps are signatures for diffraction

Soft diffraction




Hard diffraction




Methods: large rapidity gaps or leading anti-proton tag

# Soft diffraction

unitarity problem

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

⇨ $\sigma_{ND}$ exceeds $\sigma_T$ at ~2 TeV

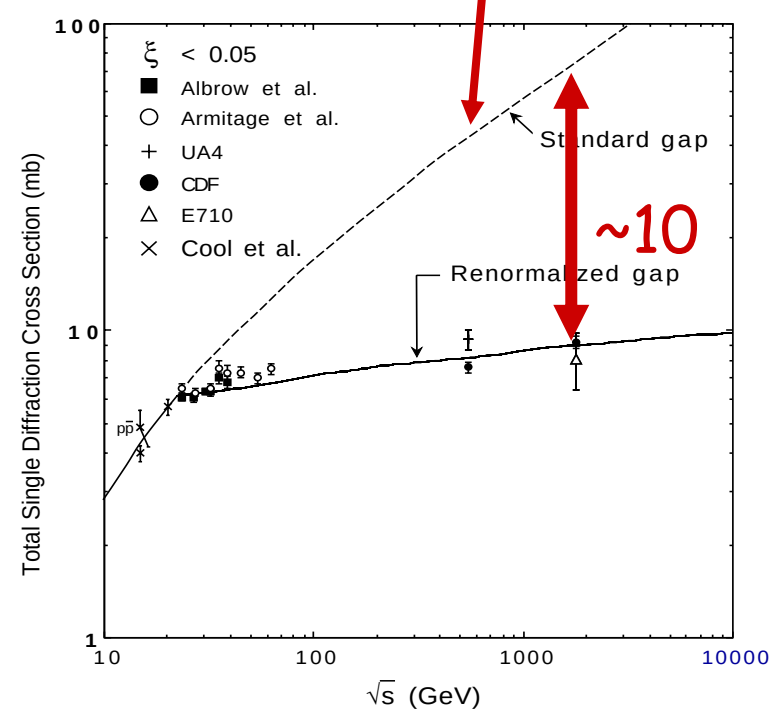
Renormalization
(normalize flux to 1)

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

$\equiv 1$

K. Goulianos, PLB 358 (1995) 379

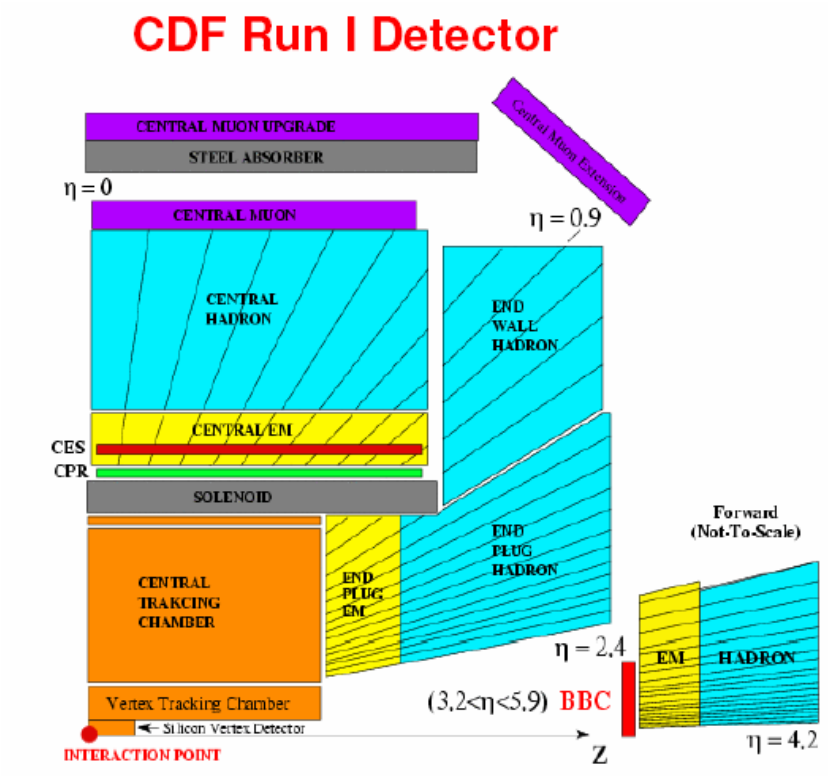
$$\sigma \sim s^{2\varepsilon}$$

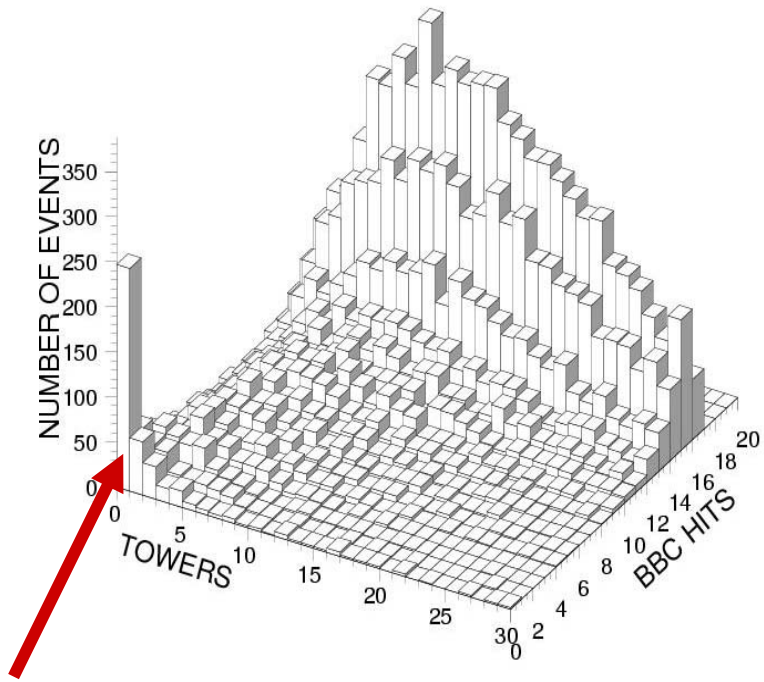



⇨measurement is suppressed by a factor of ~10 to Regge theory and agrees with renormalization model

PRD 50 (1994) 5518, 5535, 5550

# Rapidity gaps




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

# Diffractive rates

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

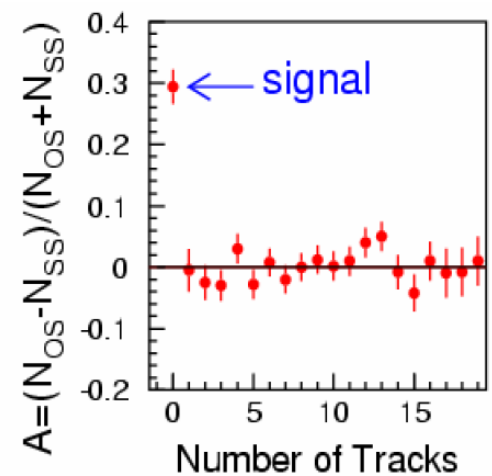
Measure SD/ND fractions at 1800 GeV

| 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) |

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

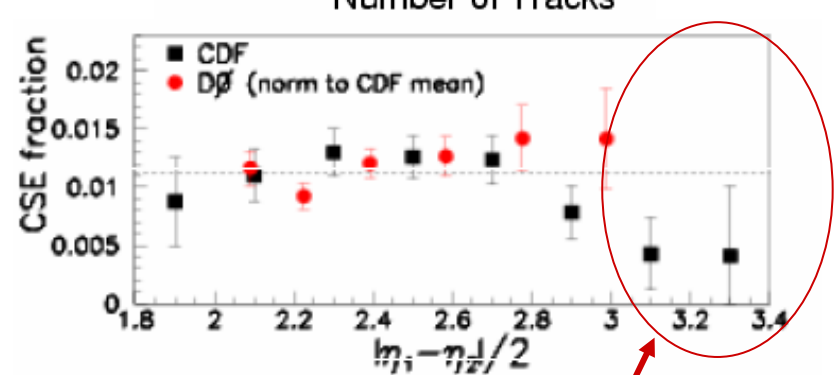
$$p\bar{p} \rightarrow \text{jet} + \text{gap} + \text{jet}$$

DD/ND fractions



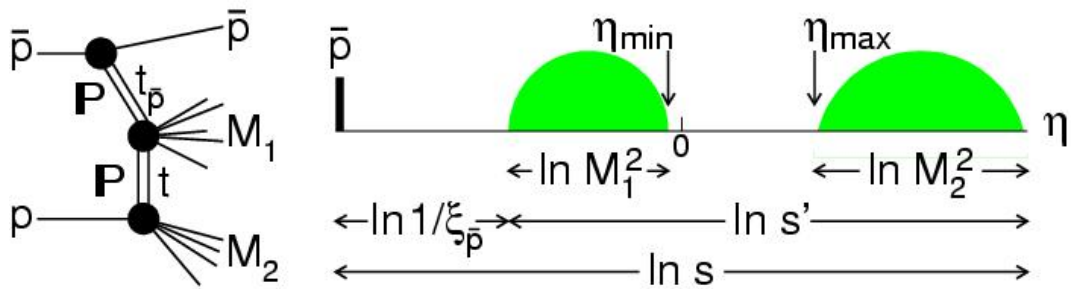

PRL
74 (1995) 855
80 (1998) 1156
81 (1998) 5278

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




extend range in Run II

# Multiple gaps




Determine gap survival probability experimentally in soft diffraction

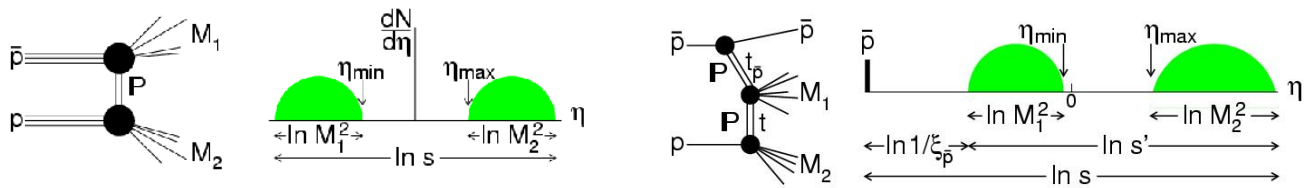
Gap rates suppressed by:
jet radiation and non-pQCD

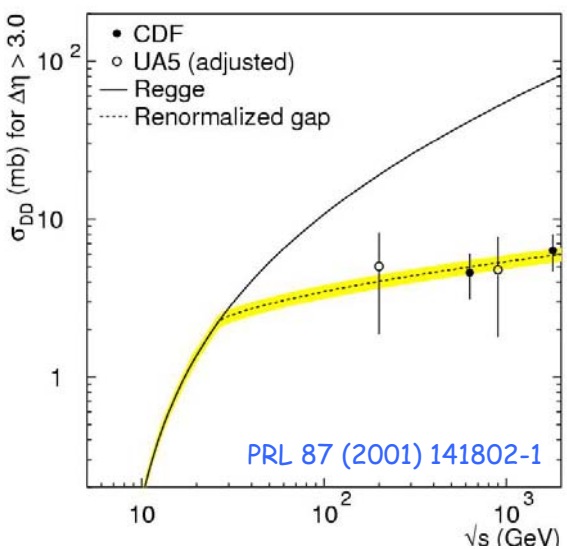
Measure the rate of <u>additional</u> gaps in soft diffractive events

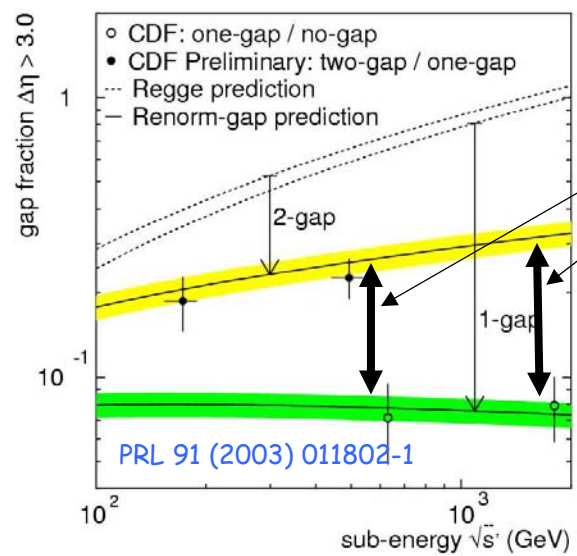
# Gap survival

$$S = R^{1\text{-gap}/0\text{-gap}}_{2\text{-gap}/1\text{-gap}}$$

⇨survival probability



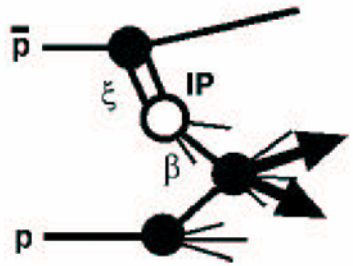




S(0.63 TeV)=0.29
S(1.80 TeV) =0.23

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

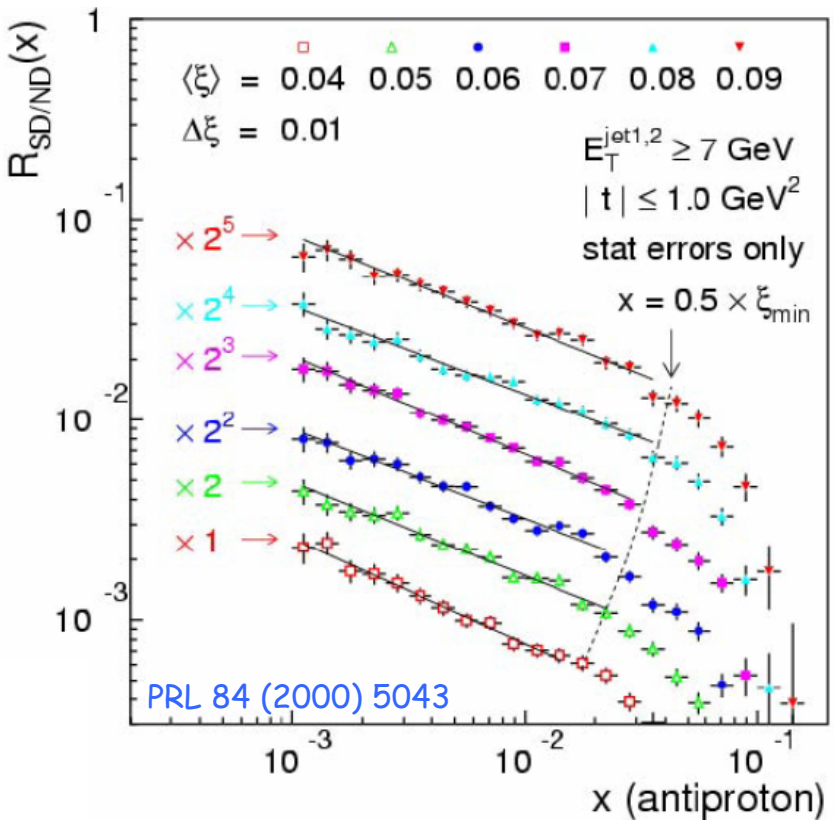
$$x_{Bj} = \frac{\sum_{jet} E_T \cdot e^{-\eta}}{\sqrt{s}}$$

Measure SD/ND ratio of dijet rates

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

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

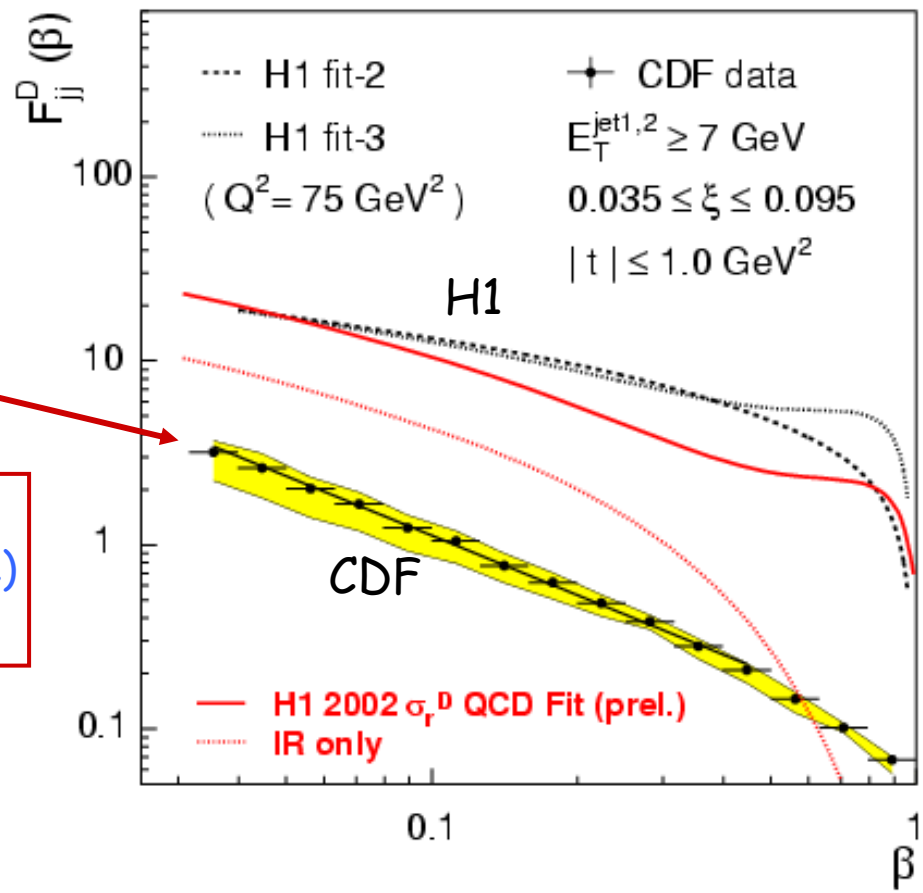
⇨no significant ξ dependence



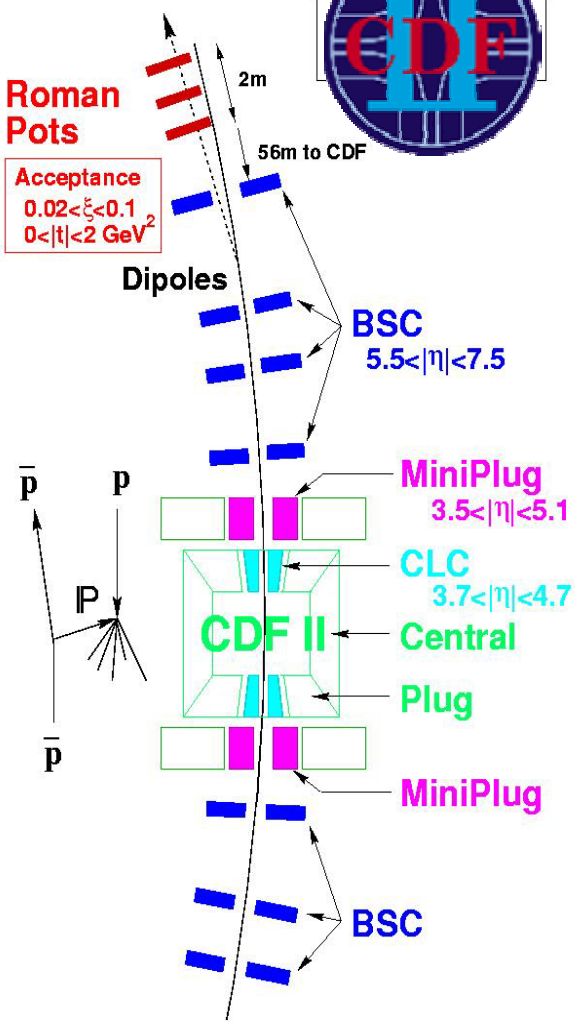
# Diffractive structure function

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



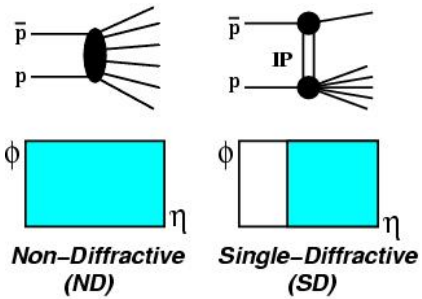
# Run II diffractive program




Diffractive structure function
- ⇨ $Q^2$ and $\xi$ dependence
- ⇨ process dependence

Exclusive production in DPE
- ⇨ dijet, heavy flavor, low-mass

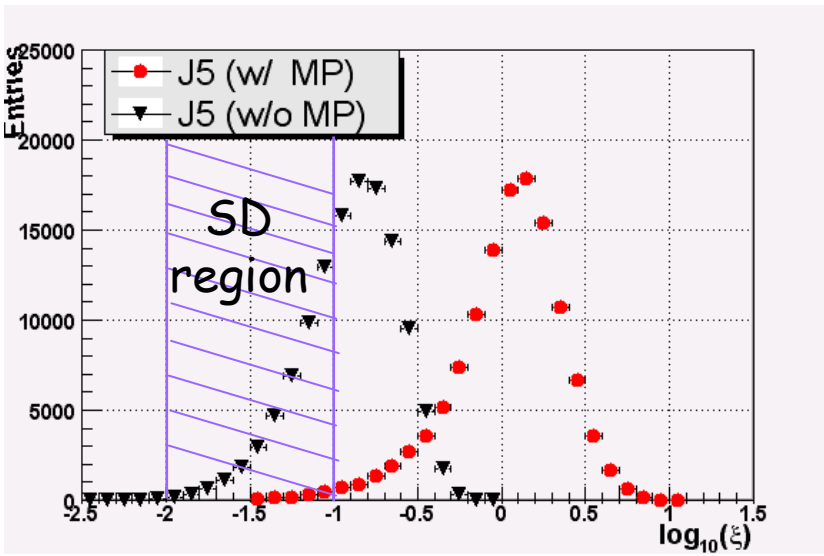
Jet-Gap-Jet w/large gaps

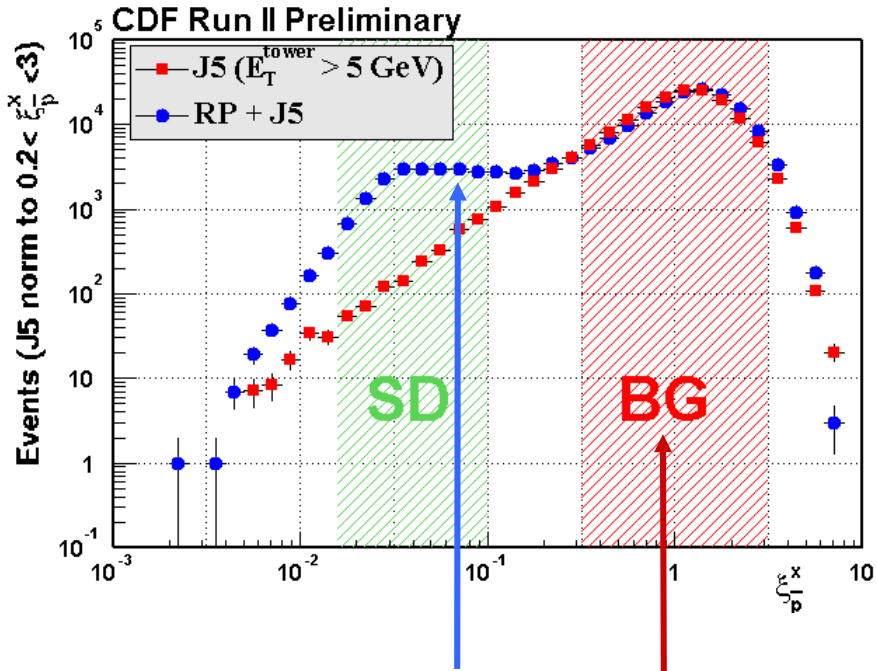



# Diffractive dijets

$\xi$ : momentum loss fraction of pbar

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



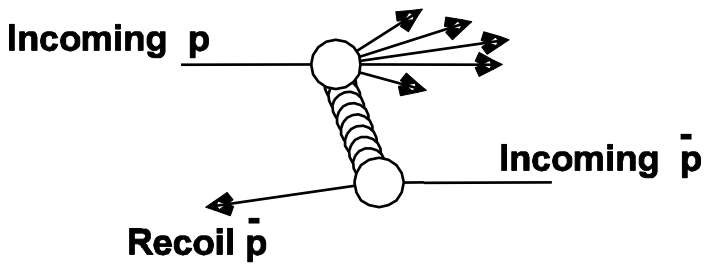




Approx. flat at $\xi<0.1$

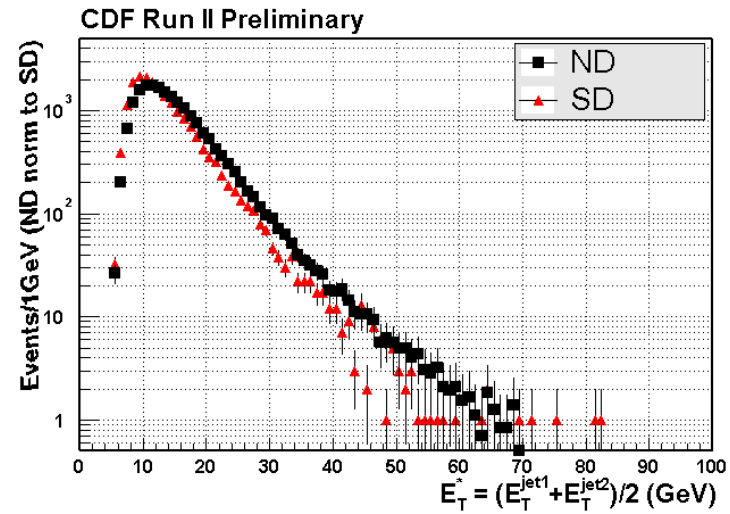
$$\frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \rightarrow \frac{d\sigma}{d(\log \xi)} = \text{const}$$

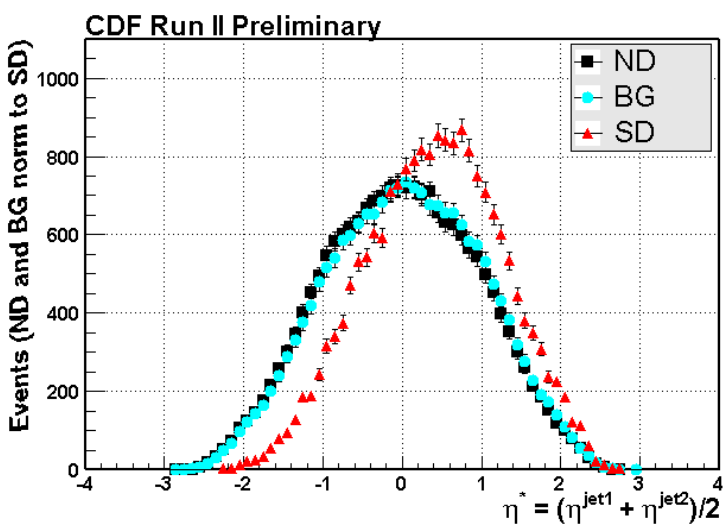
overlap events

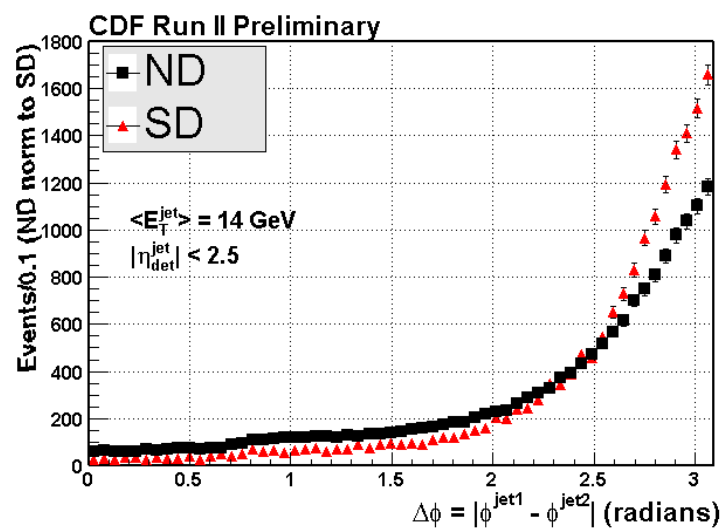
# Kinematic Properties




compare ND and SD



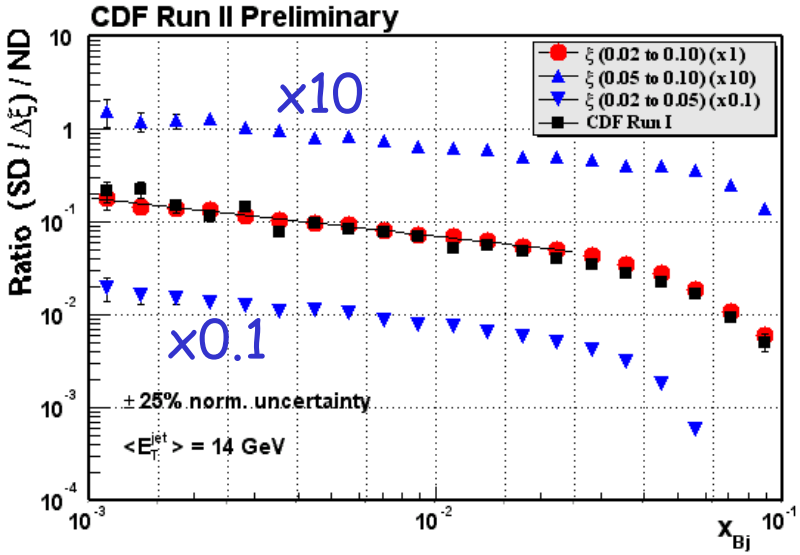



# SD/ND ratio in Run II

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

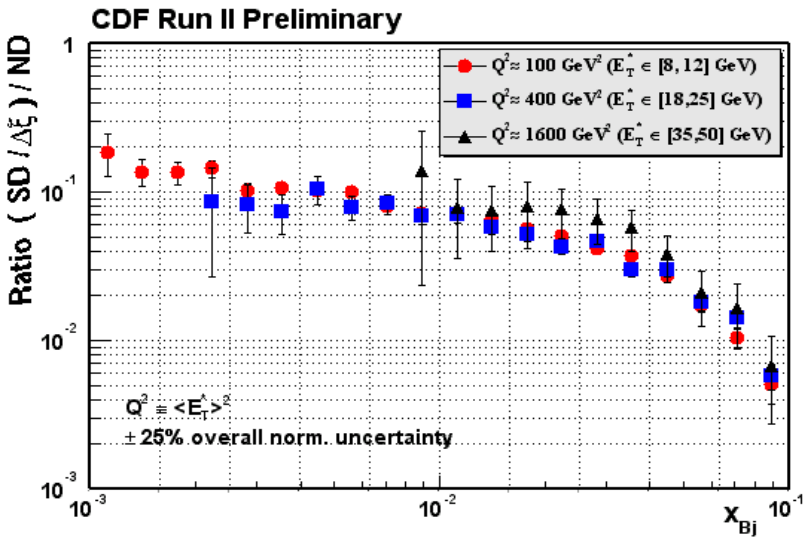
- slope and normalization agree with Run I result
- no $\xi$ dependence observed $0.03<\xi<0.1$

⇨confirms Run I results



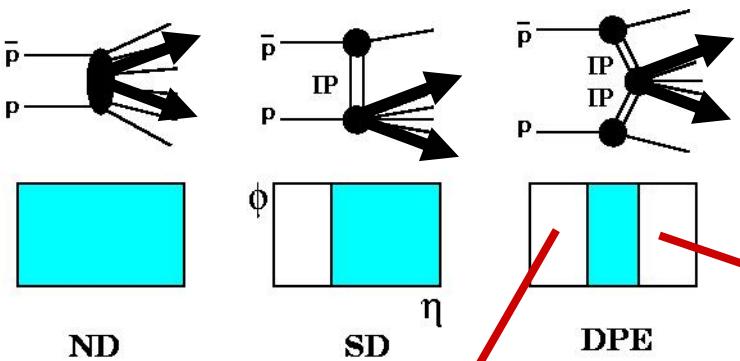

no appreciable $Q^2$ dependence observed within $100 < Q^2 < 1{,}600$ GeV$^2$

⇨pomeron evolves similarly to proton



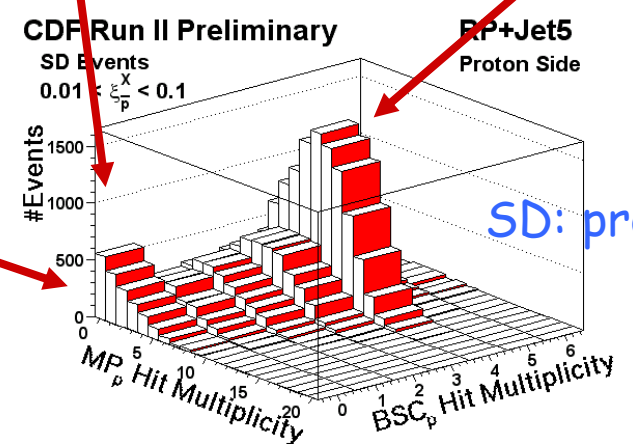
# DPE Dijet Production

from SD data:

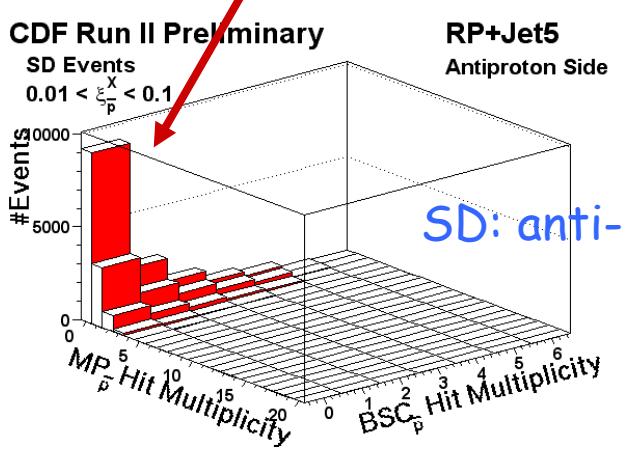



DPE

SD

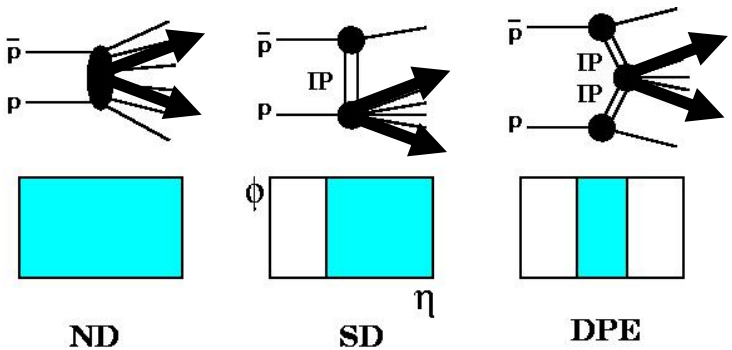



SD: proton side



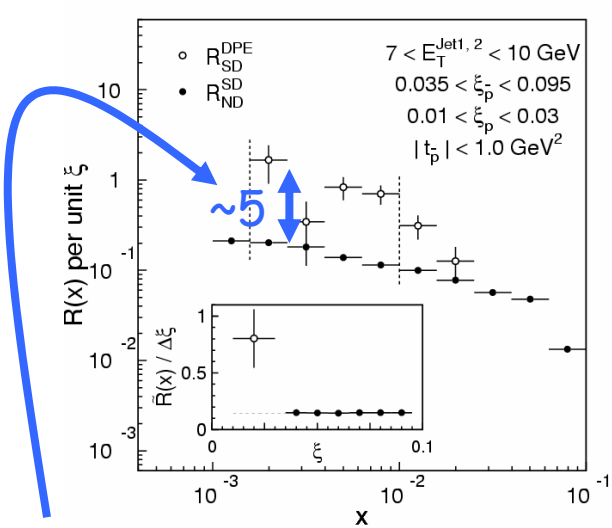

SD: anti-proton side

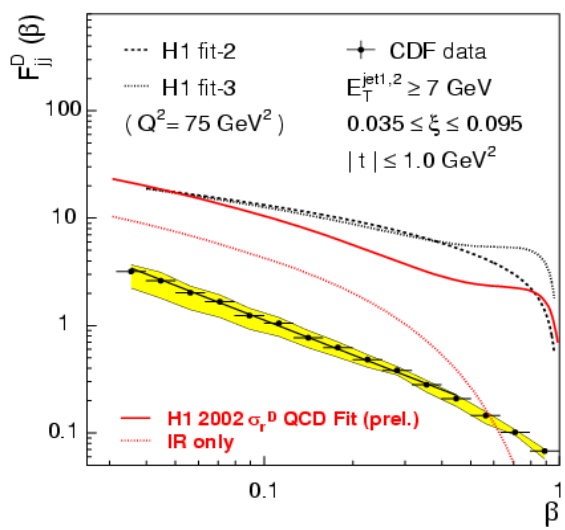
# DPE dijets

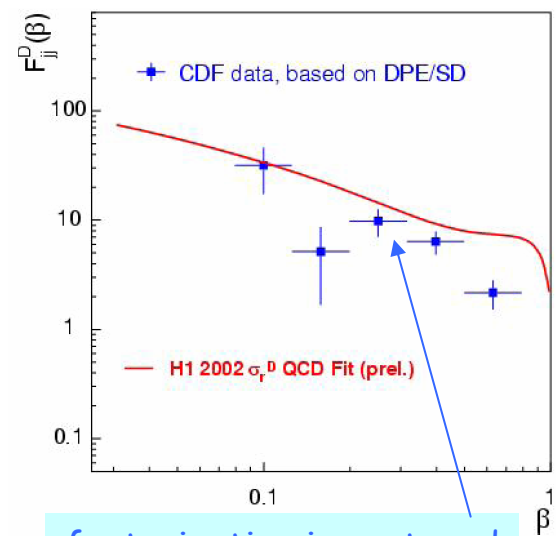



R(DPE/SD) vs R(SD/ND) ?

2-gap/1-gap 1-gap/0-gap



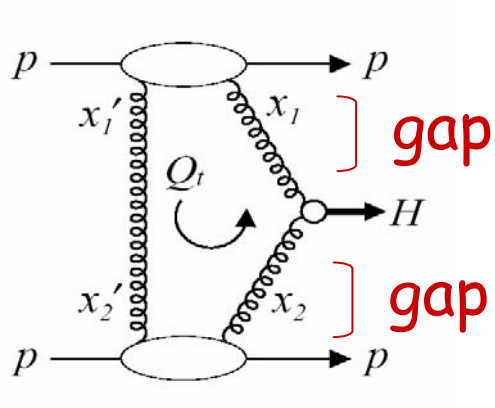

R(DPE/SD) ≈ 5 × R(SD/ND)

factorization is restored

⇨additional gap is not suppressed

# Exclusive production in DPE

exclusive

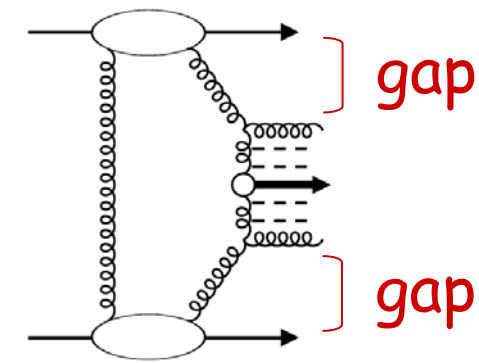



Khoze, Martin, Ryskin
Eur. Phys. J.
C23, 311 (2002)
C25, 391 (2002)
C26, 229 (2002)

C. Royon, hep-ph/0308283

see next talk!

inclusive




Attractive Higgs discovery channel at the LHC

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

$$H \rightarrow b\bar{b}$$

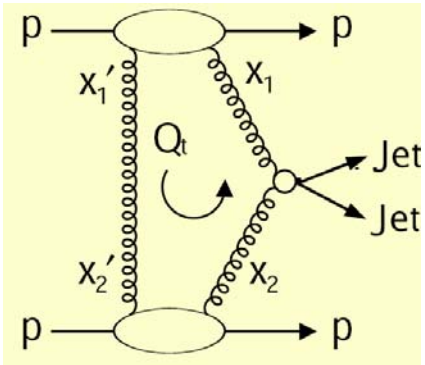
Standard Model light Higgs:

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

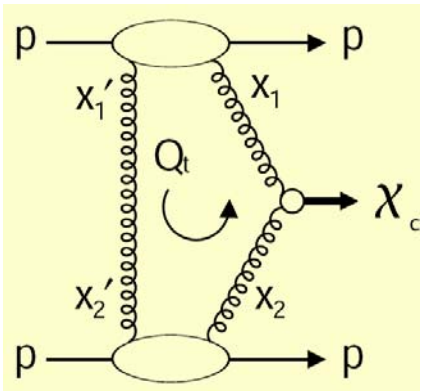
# Exclusive production

Measurement of exclusive processes can be used to calibrate Higgs predictions

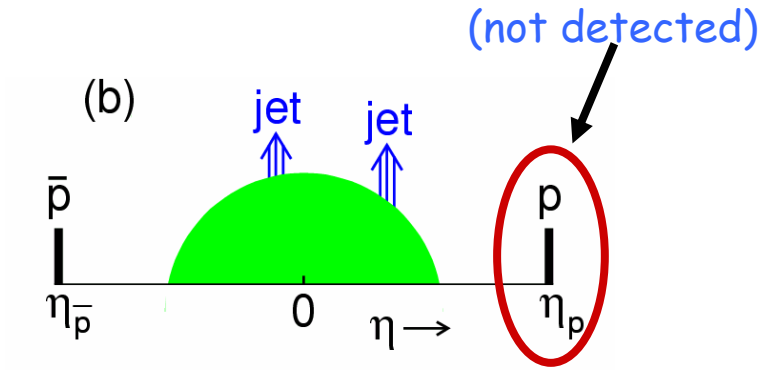
Exclusive dijets: $gg \rightarrow gg$
- exclusive $gg \rightarrow q\bar{q}$ is suppressed




Exclusive $\chi_c$:
- small cross section, clean signal

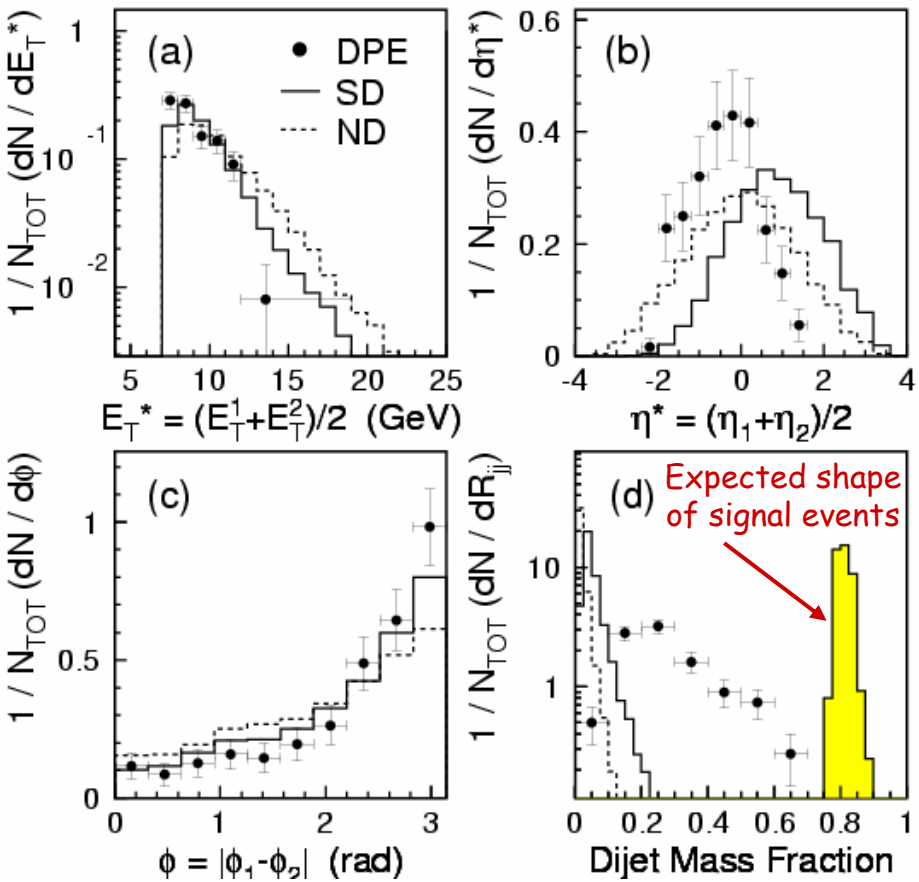


# Exclusive Dijets in Run I




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

⇨ $\sigma_{jj}$ (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 $pb^{-1}$:

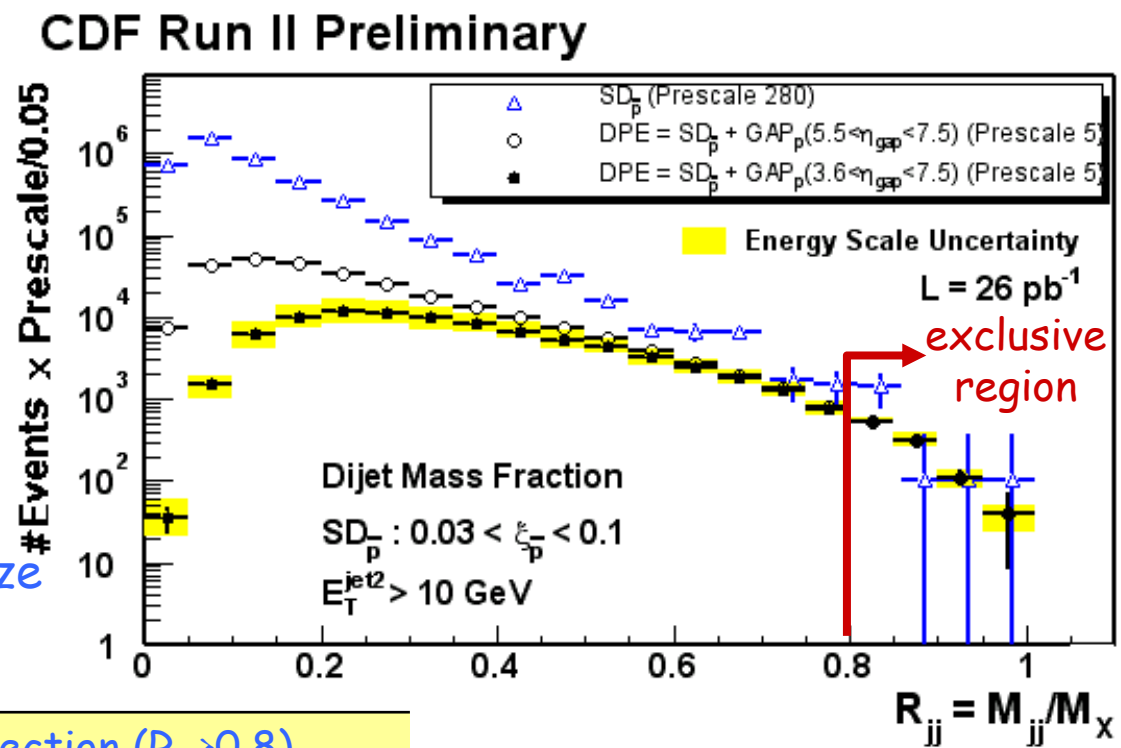
| | |
|---|---|
| Triggers | 397 k |
| $N_{vertex} \leq 1$, $\lvert z_{vertex} \rvert < 60$ cm | 365 k |
| RP offline cut | 309 k |
| $N_{jets} \geq 2$ ($E_T > 5$ GeV, $\lvert \eta \rvert < 2.5$) | 163 k |
| $E_T$(jet2)>10 GeV | 116,473 |
| SD ($0.01 < \xi < 0.1$) | 54,552 |
| DPE (MP-East $N_{hit}=0$)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

# Dijet Mass Fraction

use dedicated DPE trigger (RP+J5+BSC_Gap_P)

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

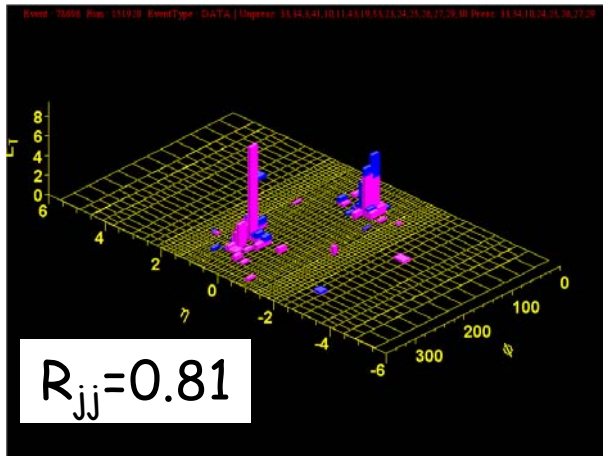
independent of rapidity gap size

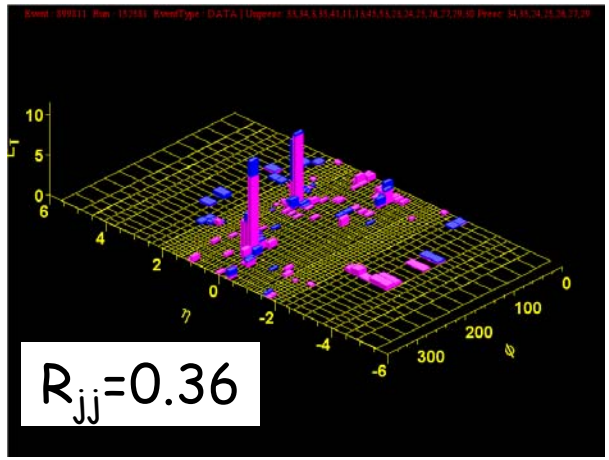


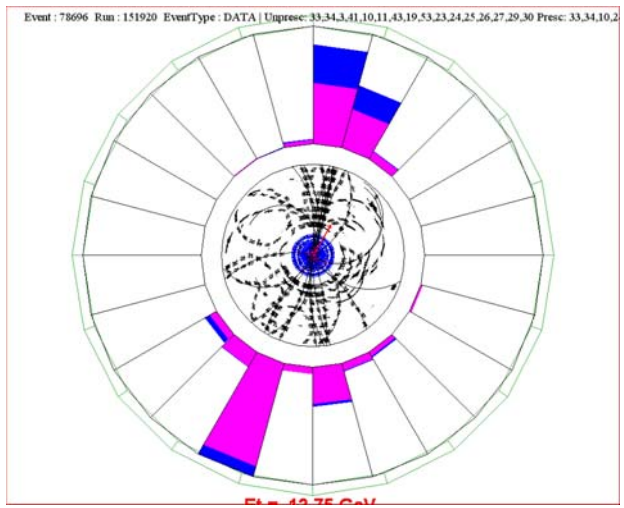

| Minimum $E_T$(Jet1) | Cross section ($R_{jj}$>0.8) |
|---|---|
| 10 GeV | 970 ± 65(stat) ± 272(syst) pb |
| 25 GeV | 34 ± 5(stat) ± 10(syst) pb |

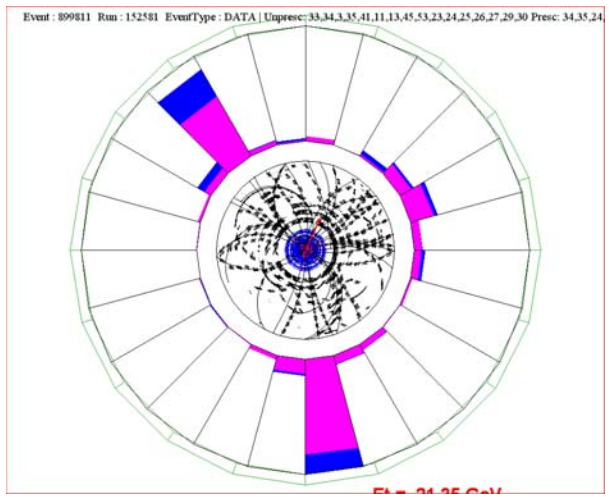
Khoze, Martin, Ryskin - Eur. Phys. J. C23, 311, 2002
~ 60 pb (factor of 2 uncertainty)

# Exclusive Dijet Events ?

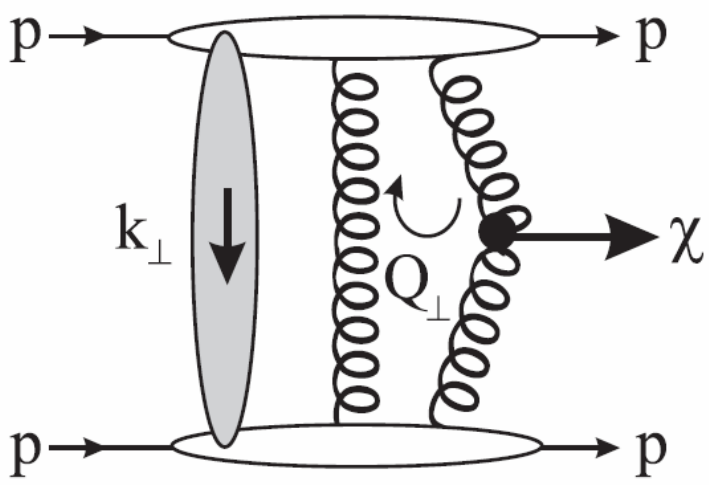




# Exclusive low-mass states




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

$\rightarrow J/\psi\ \gamma \rightarrow \mu\mu\gamma$

($\gamma$ is soft)

(same quantum numbers as Higgs boson)

**Event selection:**

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

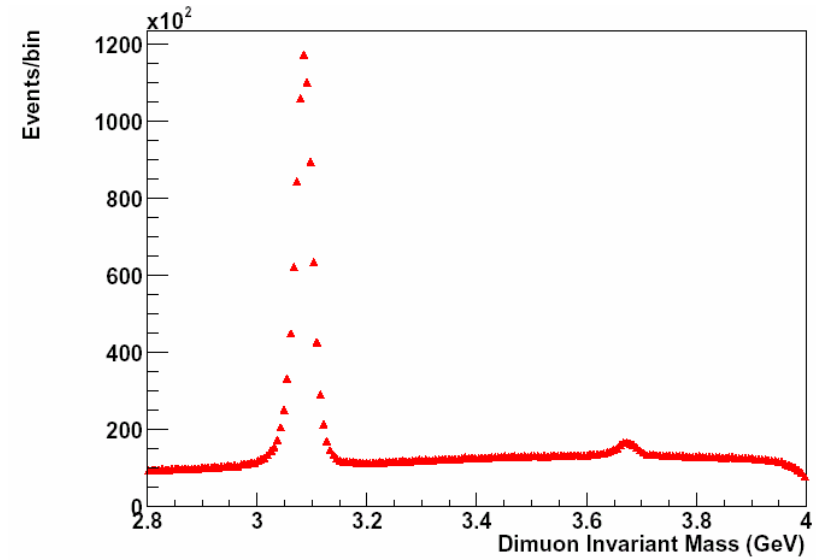
**Background:**

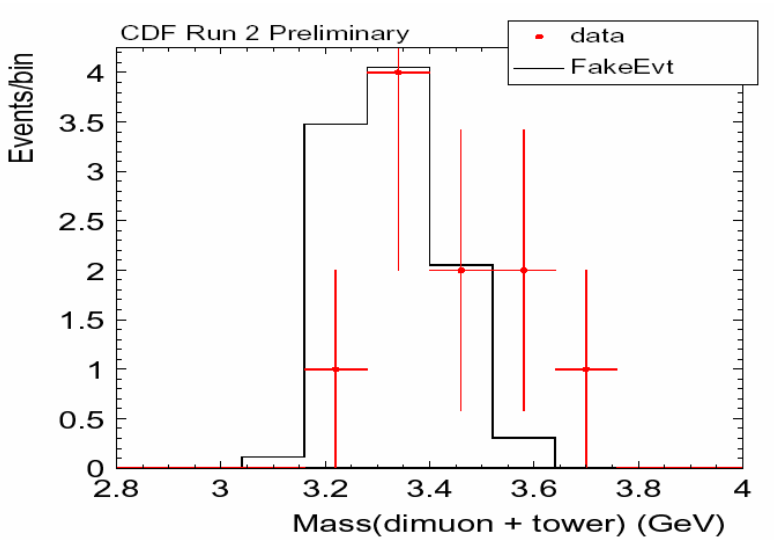
- ✓cosmics
- ✓calorimeter noise

# 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)

# Summary

- 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

# If you want to know more…

| | | |
|---|---|---|
| **Soft diffraction** | SD | PRD 50 (1994) 5535 |
| | DD | PRL 87 (2001) 141802 |
| | DPE | to be published in PRL |
| | multi-gap | PRL 91, 011802 (2003) |
| **Hard diffraction** | W | PRL 78 (1997) 2698 |
| | b-quark | PRL 84 (2000) 232 |
| | $J/\psi$ | PRL 87 (2001) 241802 |
| | jet-jet | PRL 79 (1997) 2636 |
| | jj w/RP | PRL 84 (2000) 5043, PRL 88 (2002) 151802 |
| | forward jets | PRLs 74 (1995) 855; 80 (1998) 1156; 81 (1998) 5278 |
| | DPE dijets | PRL 85 (2000) 4217 |

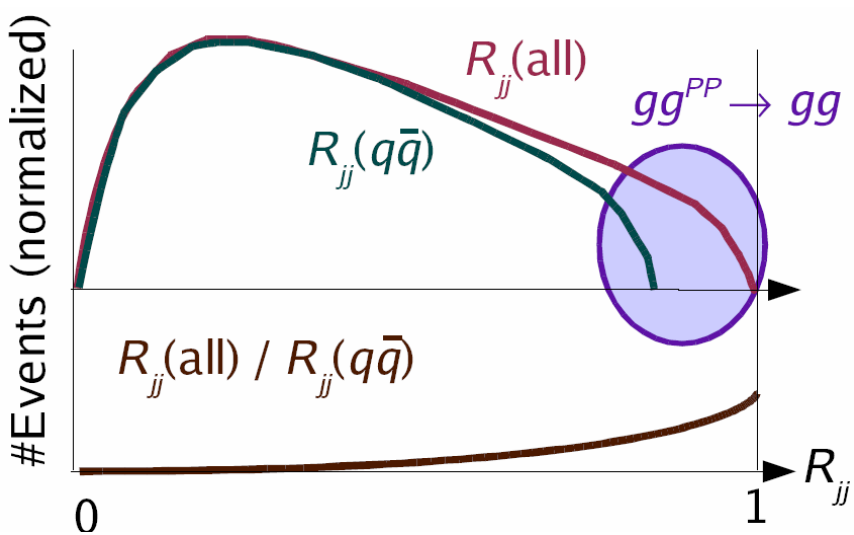
# Heavy flavor quark jets

Khoze, Martin, Ryskin
Eur. Phys. J. C23, 311 (2002)

$$\sigma^{excl}(gg \to q\bar{q}) \to 0$$

$$(at\ large\ M_{jj} >> m_q)$$

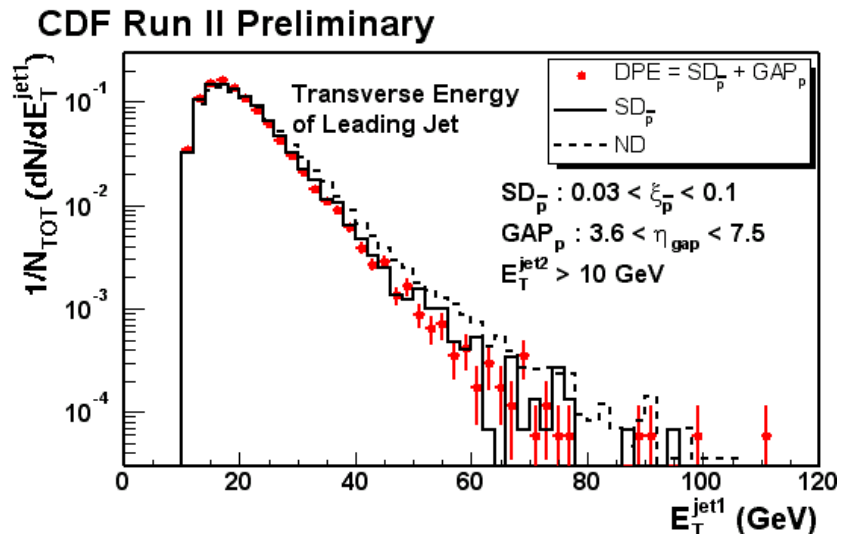
exclusive dijets: $gg \to gg$ only

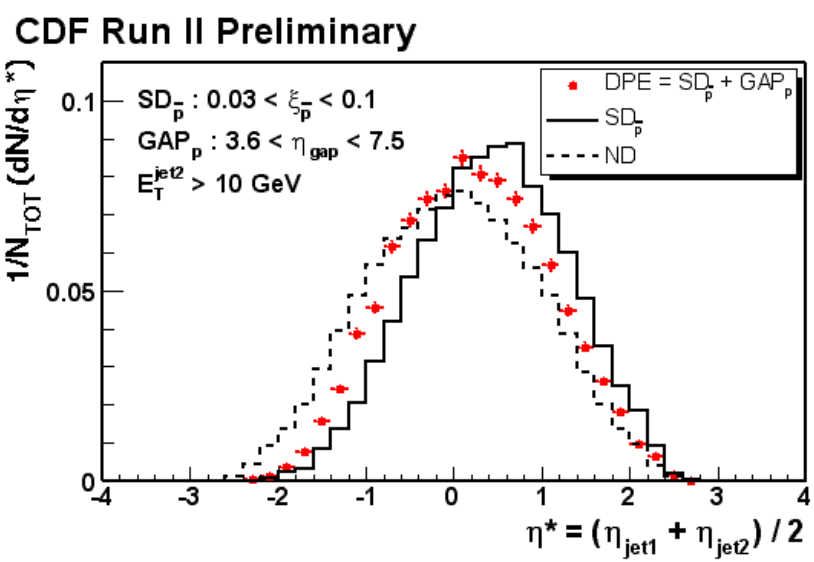


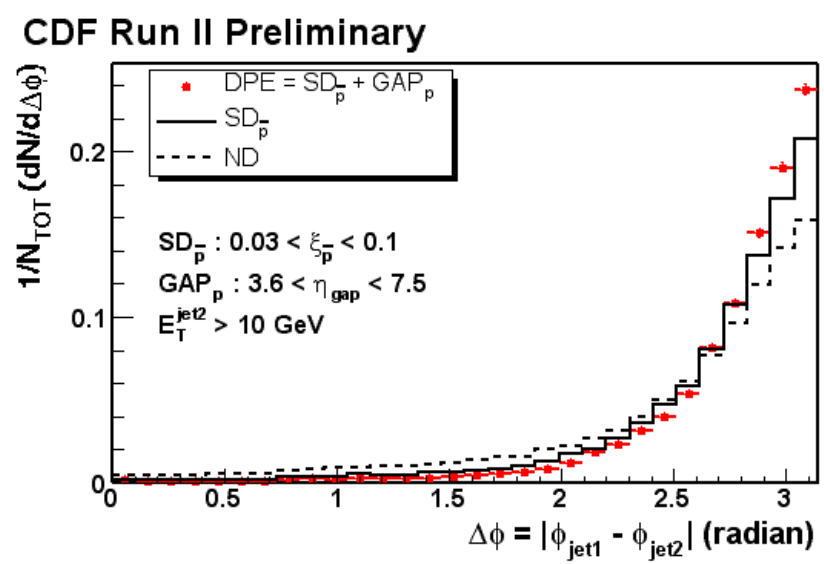

⇨look for excess of events at large $R_{jj}$

# DPE: kinematics

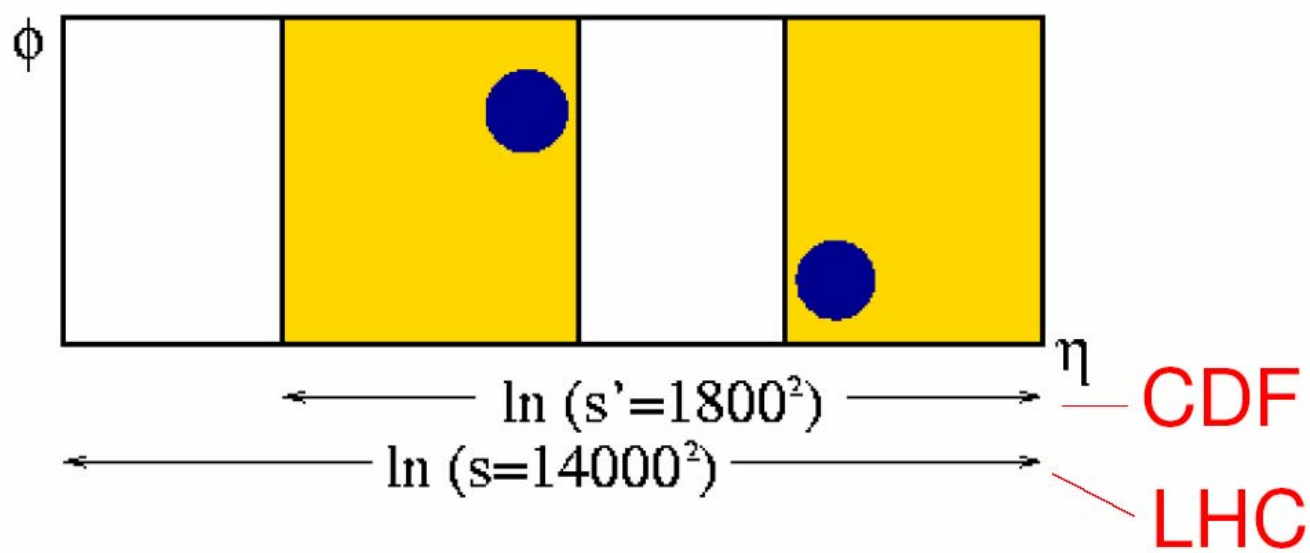
Compare ND and SD and DPE



# Predictions for LHC




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