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Rapidity Gaps in $\bar{p}p$, ep and e^+e^- Collisions

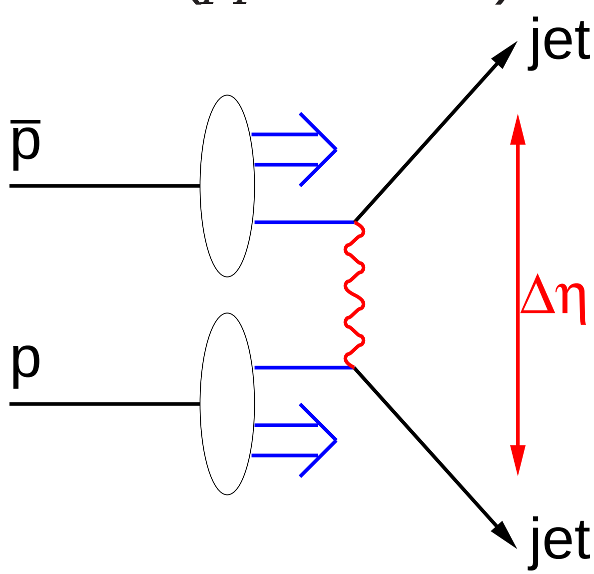
K. Hatakeyama
The Rockefeller University
For the CDF, ZEUS, H1 and L3 Collaborations

- ☞ Rapidity gaps between jets at Tevatron and HERA
- ☞ Rapidity gaps in hadronic Z decays at LEP
- ☞ Multigap diffraction at Tevatron

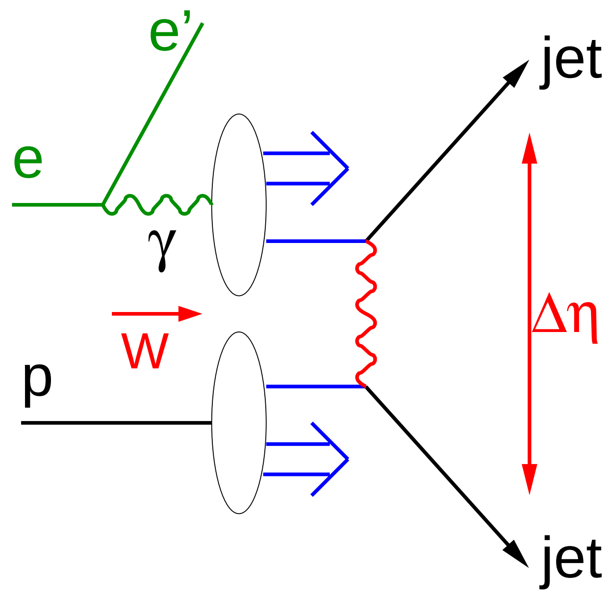
Rapidity Gaps between Jets

(Color Singlet Exchange – CSE)

At Tevatron ($\bar{p}p$ collider),



At HERA (ep collider),



- PRL 72, 2332 (1994) : DØ
- PRL 74, 885 (1995) : CDF
- PRL 76, 734 (1996) : DØ
- PRL 80, 1156 (1998) : CDF
- PLB 440, 189 (1998) : DØ
- PRL 81, 5278 (1998) : CDF

- PLB 369, 55 (1996) : ZEUS
- hep-ex/0203011 (2002) : H1
- Preliminary results (2002) : ZEUS

Rapidity Gaps between Jets at Tevatron

- CDF and DØ measured CSE fraction at $\sqrt{s} = 1800$ and 630 GeV

- Ratio of CSE fraction

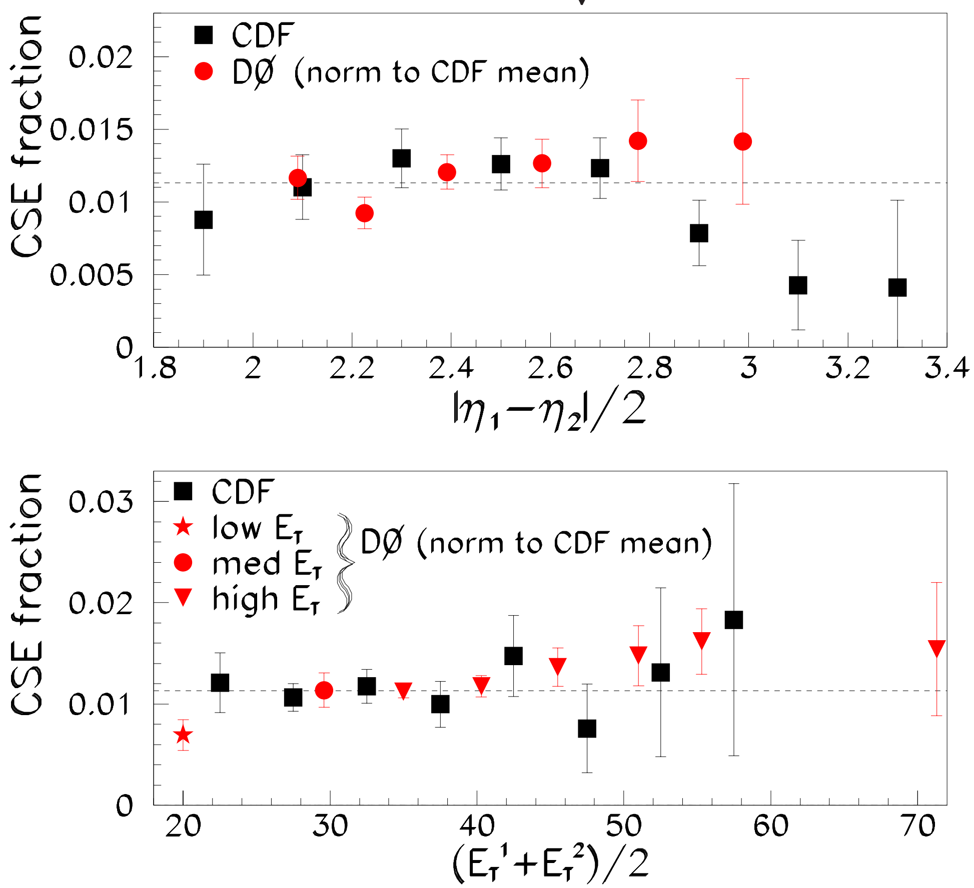
  $R[\frac{630}{1800}] = 2.4 \pm 0.7 \pm 0.7$: CDF

  $R[\frac{630}{1800}] = 3.4 \pm 1.2$: DØ

- CSE fraction vs E_T and $\Delta\eta$ at $\sqrt{s} = 1800$ GeV
  - rising trend : DØ
  - approx. flat : CDF

  → Not inconsistent within errors

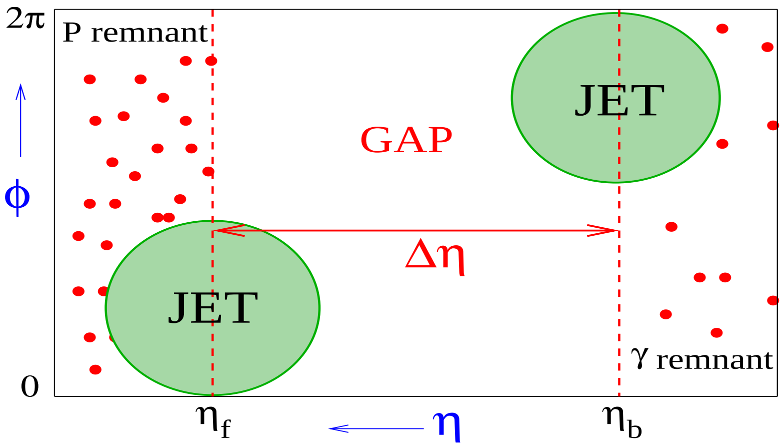
$\sqrt{s} = 1800$ GeV



PLB 440, 189 (1998) : DØ

PRL 81, 5278 (1998) : CDF

Rapidity Gaps between Jets at HERA : H1

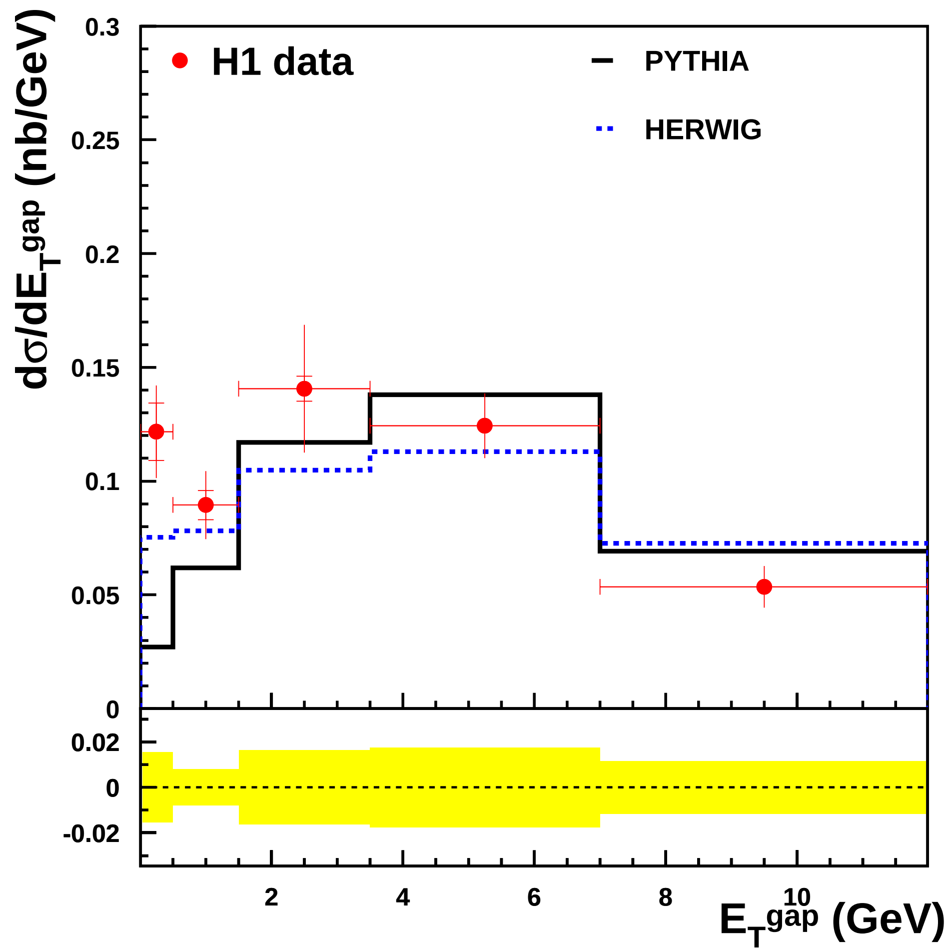


- E_T^{gap} : total E_T between the two highest E_T jets

- Excess at $E_T^{gap} < 0.5$ GeV over PYTHIA and HERWIG

- Significant difference between PYTHIA and HERWIG (due to different hadronization models)

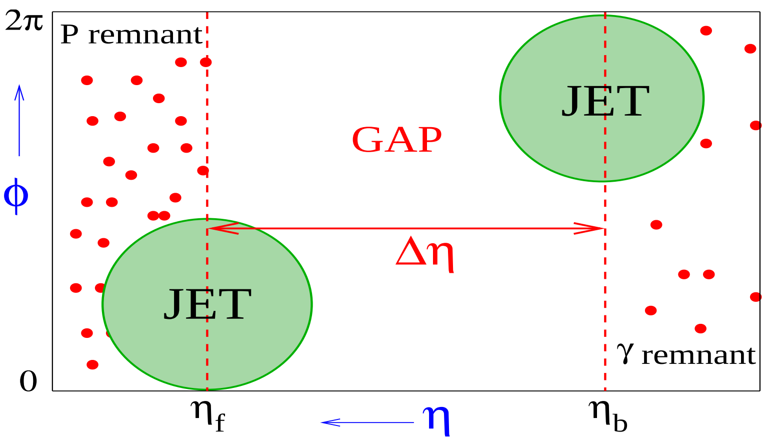
Differential Cross Section vs E_T^{gap}



$E_T^{jet1} > 6.0$ GeV , $E_T^{jet2} > 5.0$ GeV

$2.5 < \Delta\eta < 4.0$

Rapidity Gaps between Jets at HERA : H1



☞ Gap event: $E_T^{gap} < E_T^{cut}$

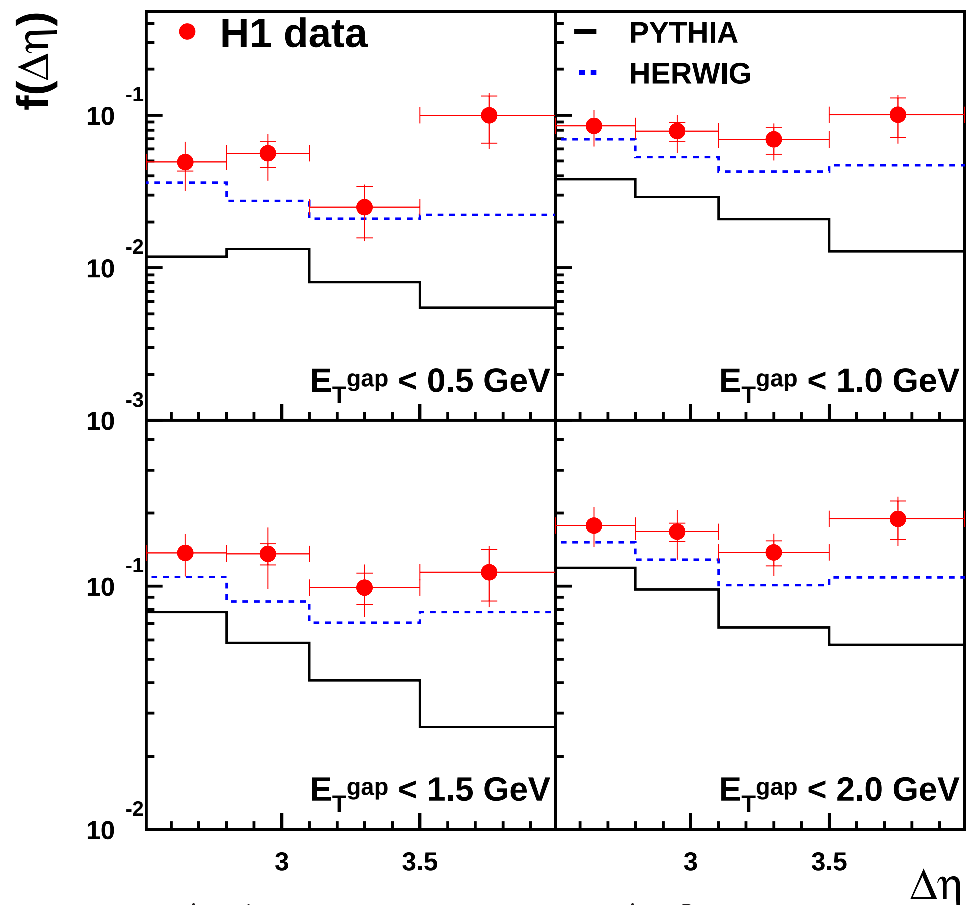
☞ Gap fraction: $f = N_{gap}/N_{incl}$

☛ PYTHIA predictions fall exponentially with $\Delta\eta$

☛ Data distributions are flat or rising : CSE

Gap Fraction vs $\Delta\eta$

for different gap definitions



$E_T^{jet1} > 6.0$ GeV , $E_T^{jet2} > 5.0$ GeV

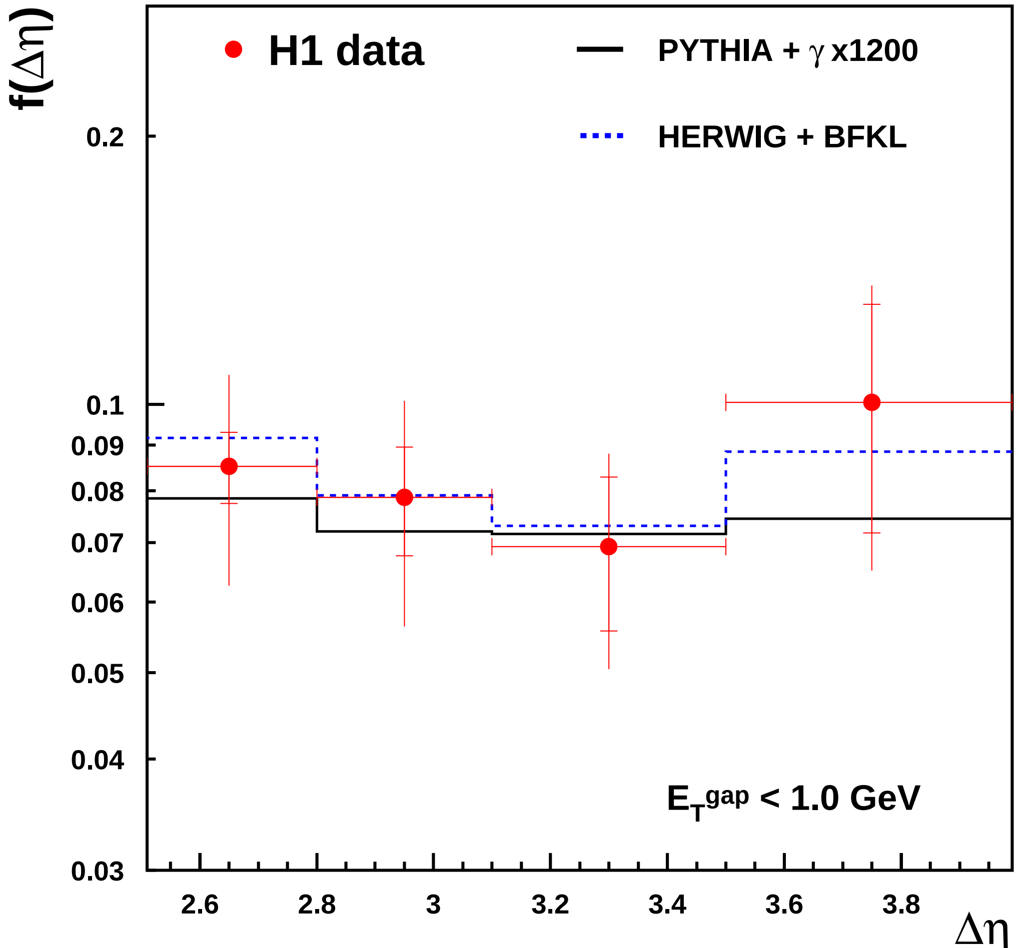
Rapidity Gaps between Jets at HERA : H1

Color Singlet Models :

- ☞ HERWIG 6.1 + BFKL
- ☞ PYTHIA 5.7 high-t γ exchange ($\times 1200$)

☛ BFKL describes data normalization and shape reasonably well

Gap Fraction vs $\Delta\eta$

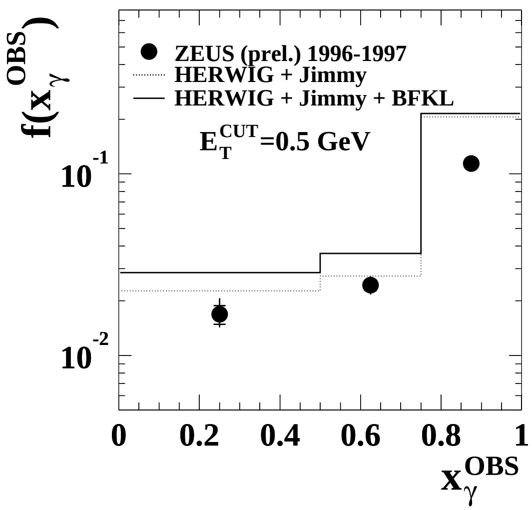


$E_T^{jet1} > 6.0$ GeV , $E_T^{jet2} > 5.0$ GeV

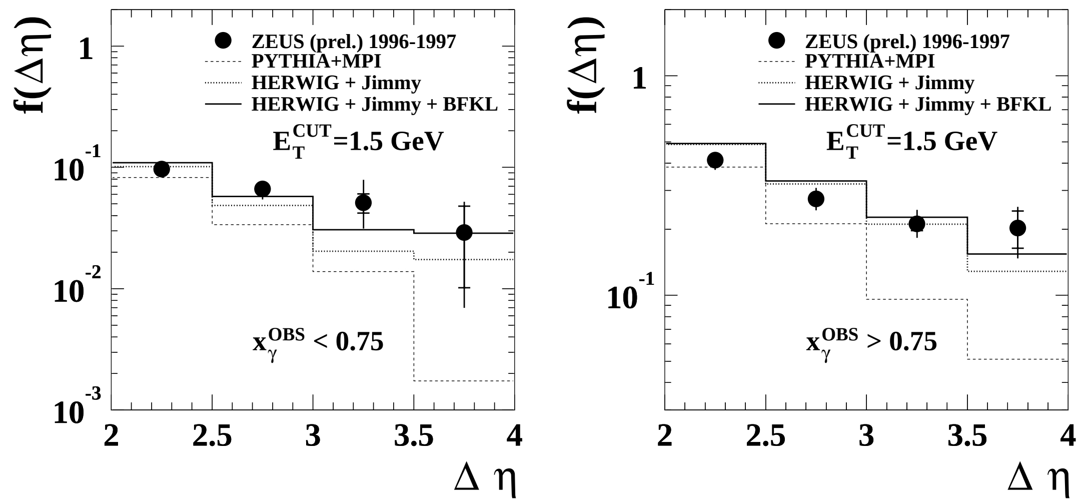
Rapidity Gaps between Jets at HERA : ZEUS

- ☞ x_γ^{OBS} : momentum fraction of γ participating in 2-jet production
- Gap fraction and cross section are larger at high x_γ^{OBS}
- At high x_γ^{OBS}, MC models do not describe data well especially at low $\Delta\eta$
- At low x_γ^{OBS} where BFKL contribution is larger, data are better described by the model with BFKL

ZEUS

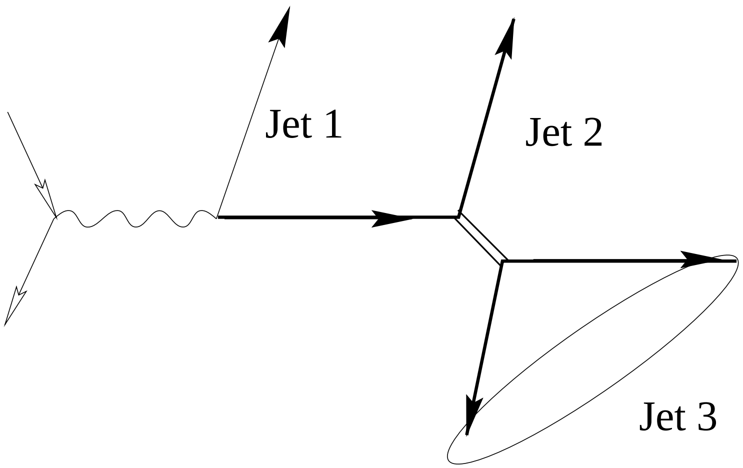


$E_T^{jet1} > 6.0$ GeV
$E_T^{jet2} > 5.0$ GeV
$2.0 < \Delta\eta < 4.0$



Rapidity Gaps in Hadronic Z Decays at LEP

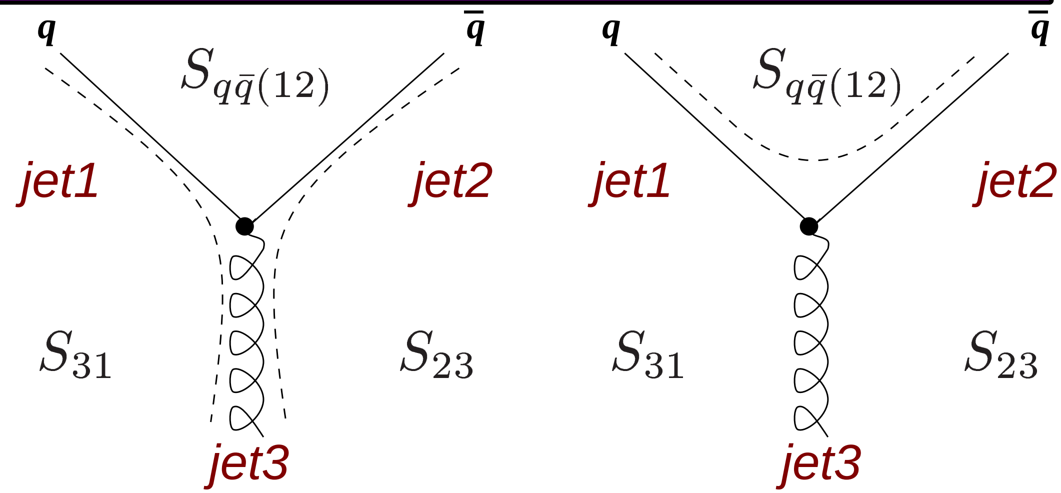
At LEP (e^+e^- collider),



Look for rapidity gaps in *symmetric* 3-jet events produced in e^+e^- annihilations

☞ hep-ex/0205004 : L3

☞[PRL 76, 4886 (1996) : SLD]



Color Octet (CO)	Color Singlet (CS)
$S_{23} \approx S_{31} < S_{q\bar{q}(12)}$	$S_{23} \approx S_{31} > S_{q\bar{q}(12)}$
$A^S_{23} \approx A^S_{31} > A^S_{q\bar{q}(12)}$	$A^S_{23} \approx A^S_{31} < A^S_{q\bar{q}(12)}$

S : Separation angle , A^S : Asymmetry of S

$$A^S_{12} = \frac{-S_{12} + S_{23} + S_{31}}{S_{12} + S_{23} + S_{31}}$$

- ❐ CO simulated by JETSET
- ❐ CS simulated using the color flow of $q\bar{q}\gamma$
  - CS0 : γ replaced by $q\bar{q}$, then parton shower
  - CS2 : γ replaced by g, then parton shower

Rapidity Gaps in Hadronic Z Decays at LEP : L3

Data are in good agreement with color octet exchange (JETSET) predictions

Fraction of CSE events, R :

$$R = 0.015 \pm 0.030 \text{ (from fit to } A^S_{12}\text{)}$$

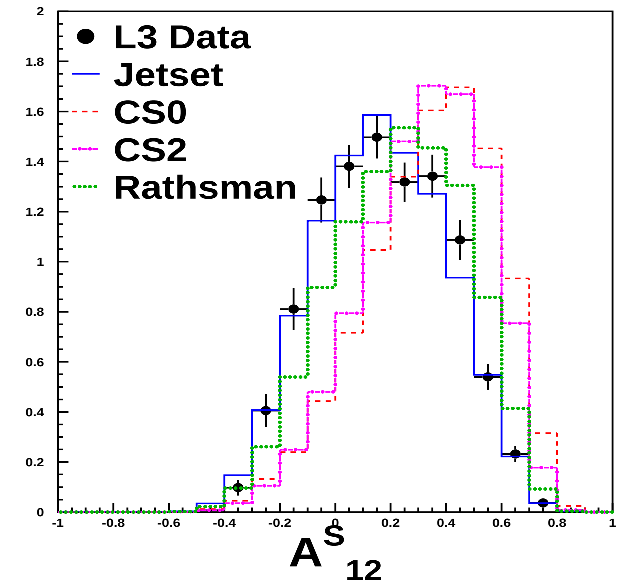
$$(\chi^2/d.o.f. = 4.5/11)$$

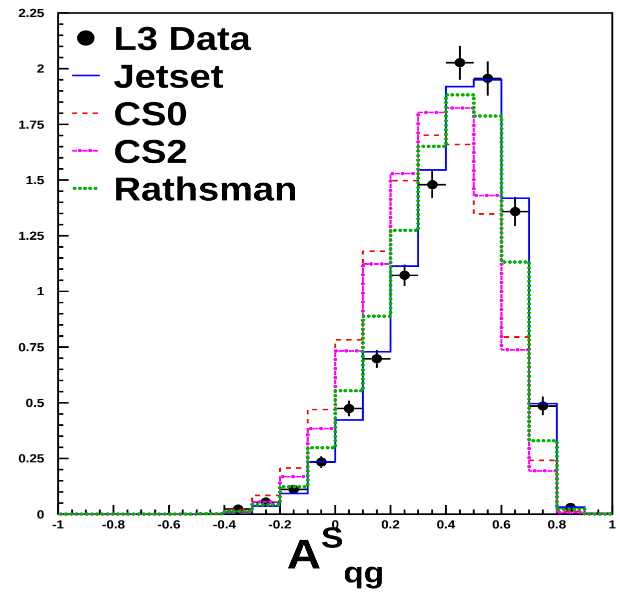
All estimates of R are compatible with 0

Obtain 95% C.L. upper bound

$$R(\text{95\% C.L.}) < 6.7(9.0)\%$$

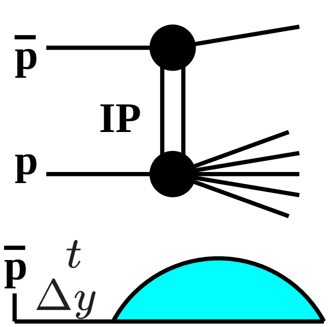
for CS0 (CS2)



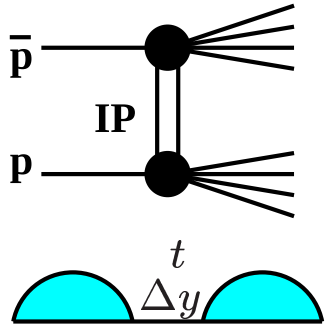


Multigap Diffraction : Introduction

Events with one rapidity gap

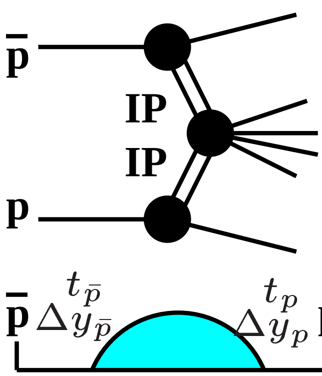


Single Diffraction (SD)

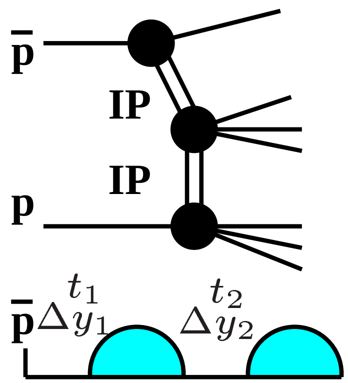


Double Diffraction (DD)

Events with two rapidity gaps



Double Pomeron Exchange (DPE)



Single + Double Diffraction (SDD)

CDF studied inclusive (soft) SD and DD events previously

SD : PRD 50, 5535 (1994)

DD : PRL 87, 141802 (2001)

Regge theory based on factorization

$\alpha_{I\!P}(t) = 1+\epsilon+\alpha' t$ ($\epsilon = 0.104$, PLB 389,176)

$$\frac{d^2\sigma_{SD}}{d\xi\, dt} = \underbrace{\frac{\beta^2(t)}{16\pi}\xi^{1-2\alpha_{I\!P}(t)}}_{f_{I\!P/p}(\xi,t)} \underbrace{\beta(0)g(t)(s')^{\epsilon}}_{\sigma_{I\!P\bar{p}}(s')}$$

$f_{I\!P/p}(\xi,t)$: Pomeron flux factor

$\alpha_{I\!P}(t)$: Pomeron trajectory

$\beta(t)$: $I\!P$-$p(\bar{p})$ coupling

$g(t)$: triple-$I\!P$ coupling

ξ : fractional momentum loss of $p(\bar{p})$

Multigap Diffraction : Introduction

Regge theory formula in terms of rapidity gap width

$$\kappa \equiv \frac{g(0)}{\beta(0)} = 0.17, \quad \xi = e^{-\Delta y}, \quad (s')^{\epsilon} = e^{\epsilon \Delta y'}. \quad \Delta y' = \ln s - \sum \Delta y_i$$

Process		Gap Probability(P_{gap})	$\sigma_{tot}(\Delta y')$
SD:	$\frac{d^2\sigma_{SD}}{dtd\Delta y} =$	$\left[\frac{\beta(t)}{4\sqrt{\pi}} e^{(\epsilon+\alpha' t)\Delta y}\right]^2$	$\kappa[\beta^2(0)e^{\epsilon\Delta y'}]$
DD:	$\frac{d^3\sigma_{DD}}{dtd\Delta y dy_c} =$	$\kappa\left[\frac{\beta(0)}{4\sqrt{\pi}} e^{(\epsilon+\alpha' t)\Delta y}\right]^2$	$\kappa[\beta^2(0)e^{\epsilon\Delta y'}]$
DPE:	$\frac{d^4\sigma_{DPE}}{dt_{\bar{p}}dt_p d\Delta y_{\bar{p}} d\Delta y_p} =$	$[\prod_{i=\bar{p},p} \frac{\beta(t_i)}{4\sqrt{\pi}} e^{(\epsilon+\alpha' t_i)\Delta y_i}]^2$	$\kappa^2[\beta^2(0)e^{\epsilon\Delta y'}]$

The Regge formulae have unitarity problem, e.g. $\sigma_{SD}/\sigma_{tot} \to 1$ at $\sqrt{s} \sim 2$ TeV

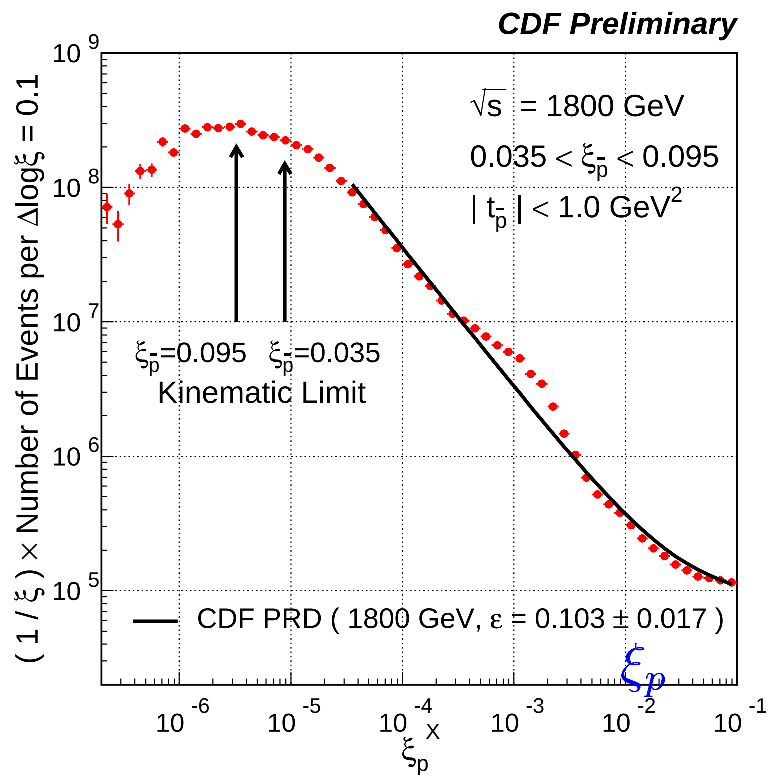
Renormalization : (K. Goulianos, PLB 358,379(1995), hep-ph/0110240)

Normalizing the integral of the gap probability P_{gap} to unity yields the correct $\sqrt{s}$ dependence of σ_{SD} and σ_{DD}. What about σ_{DPE} and σ_{SDD}?

Double Pomeron Exchange (DPE) Analysis : CDF

For events triggered on a leading antiproton, plot the distribution of ξ_p obtained by :

$$\xi_p = \frac{M^2}{s\,\xi_{\bar{p}}} \approx \frac{\sum_i E_{T,i}\exp(+\eta_i)}{\sqrt{s}}$$

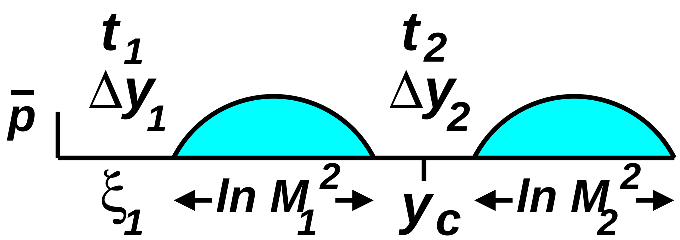


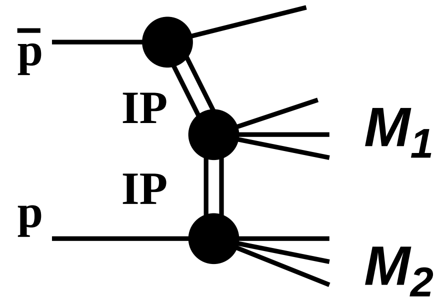
- ξ_p distribution $\not\propto 1/\xi^{1+\epsilon}$
  (The line is from single diffraction)
- The bump at $\xi_p \sim 10^{-3}$ is due to cab. noise

DPE fraction in leading-$\bar{p}$ triggered SD events $0.035 < \xi_{\bar{p}} < 0.095,\ \xi_p < 0.02$

Source	R(1800 GeV)	R(630 GeV)
Data	$0.197 \pm 0.001 \pm 0.010$	$0.168 \pm 0.001^{+0.015}_{-0.020}$
Regge $\oplus$ Factorization	0.36 ± 0.04	0.25 ± 0.03
Renormalized $I\!P$-flux (PLB 358,379(1995))	0.041 ± 0.004	0.041 ± 0.004
Renormalized P_{gap} (hep-ph/0110240)	0.21 ± 0.02	0.17 ± 0.02

Single + Double Diffraction (SDD) Analysis : CDF





$$\frac{d^5\sigma_{SDD}}{dt_1 dt_2 d\Delta y_1 d\Delta y_2 dy_c} = P_{gap}(t_1, t_2, \Delta y_1, \Delta y_2, y_c) \times \kappa^2 \beta^2(0)(s')^{\epsilon}$$

$$P_{gap} = \left[\frac{\beta(t_1)}{4\sqrt{\pi}} e^{(\epsilon+\alpha' t_1)\Delta y_1}\right]^2 \kappa \left[\frac{\beta(0)}{4\sqrt{\pi}} e^{(\epsilon+\alpha' t_2)\Delta y_2}\right]^2$$

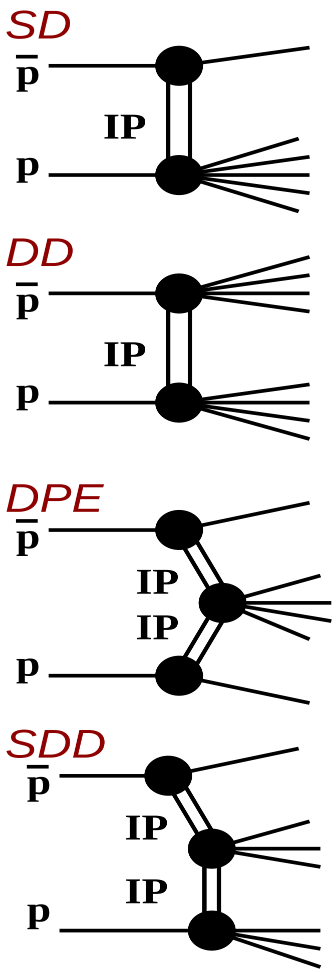
SDD fraction in leading-$\bar{p}$ triggered SD events

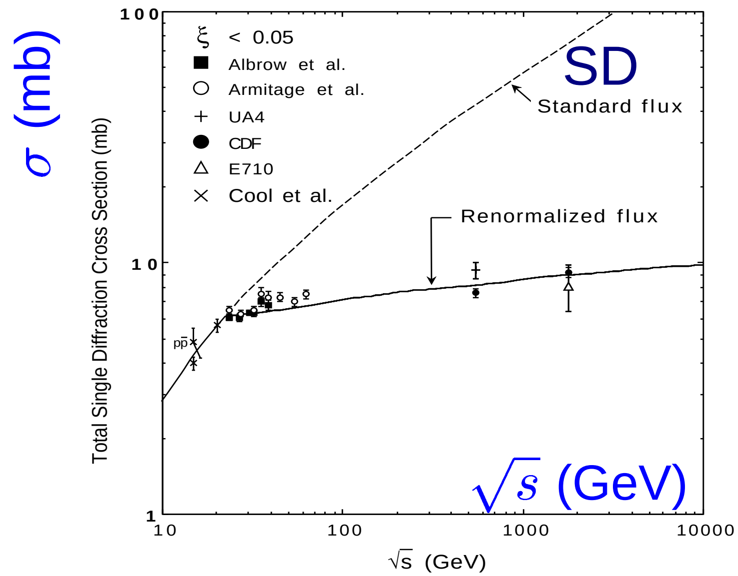
$0.06 < \xi_1 < 0.09,\ \Delta\eta_2 > 3$

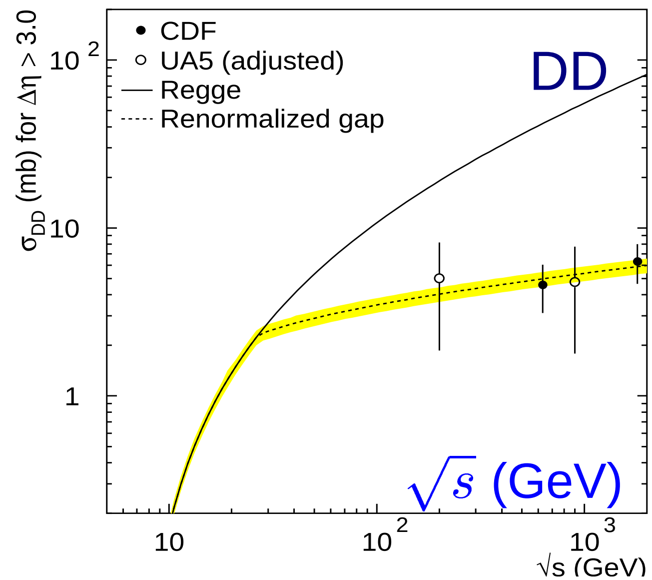
Source	R(1800 GeV)	R(630 GeV)
Data	$0.252 \pm 0.001 \pm 0.045$	$0.192 \pm 0.001 \pm 0.046$
Regge $\oplus$ Factorization	0.66 ± 0.07	0.40 ± 0.04
Renormalized P_{gap}	0.26 ± 0.03	0.21 ± 0.02

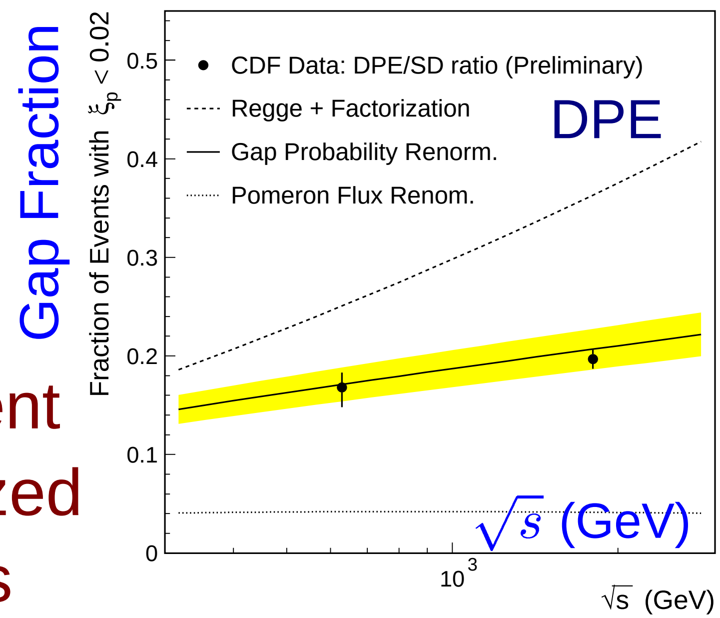
(predictions have $\pm 10\%$ uncertainty due to error in κ)

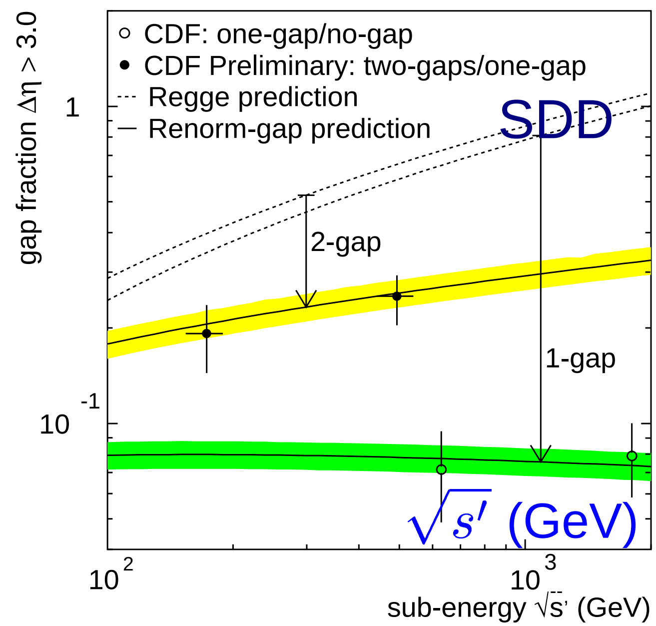
Summary of Soft Diffraction Results











Good agreement with renormalized gap predictions

Summary

Rapidity gaps between jets at Tevatron and HERA

☞ Evidence of an excess of events with a rapidity gap between jets at both Tevatron and HERA

☞ BFKL model gives reasonable description of data (H1) at low x_γ^{OBS} (ZEUS)

Rapidity gaps in hadronic Z decays at LEP

☞ Data are well explained by color octet exchange alone

Multigap diffraction at Tevatron

☞ Fractions of DPE and SDD events in SD events are measured at $\sqrt{s} = 1800$ and 630 GeV by CDF

☞ The measured DPE and SDD fractions are in agreement with renormalized gap predictions