

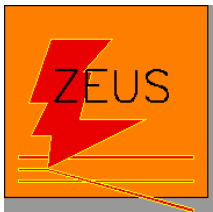


# Interjet Energy Flow Measured in ep Collisions at ZEUS

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University of Wisconsin

Aug. 27, 2004

**DPF 2004**  
**Riverside, CA**

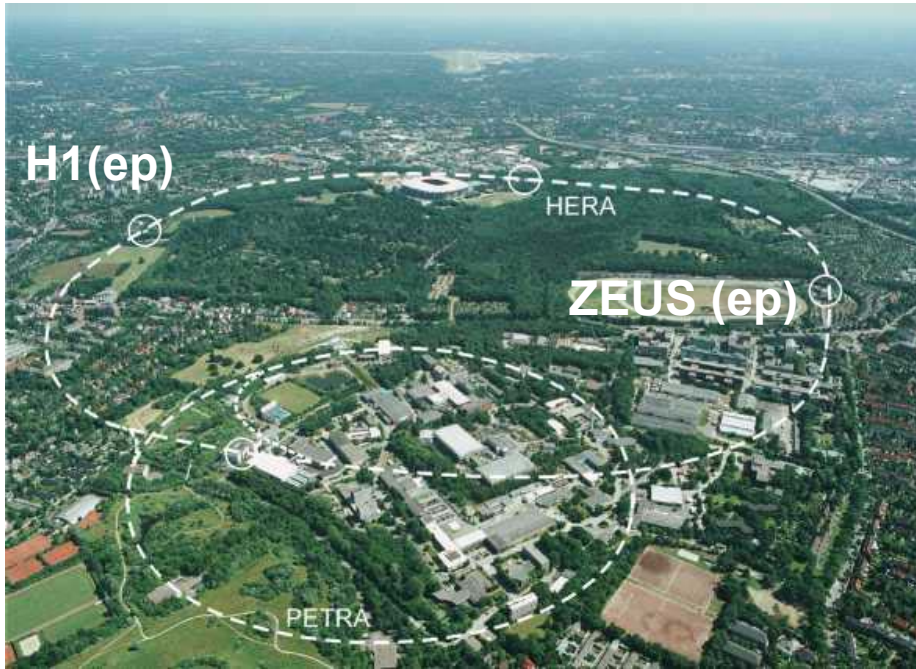


# HERA Description

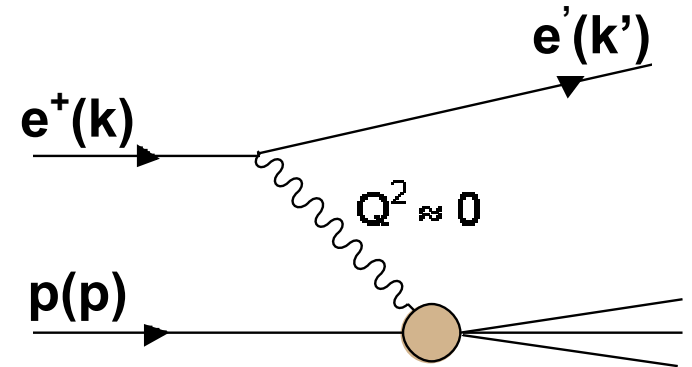


DESY

Hamburg, Germany



## Photoproduction Event in ep Collisions



## Virtuality of Photon

$$Q^2 = -q^2 = -(k - k')^2 \approx 0$$

## Inelasticity

$$y = \frac{p \cdot q}{p \cdot k}$$

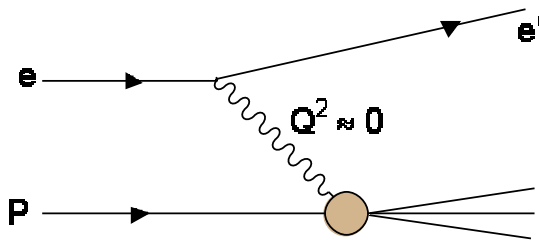
- 820/920 GeV Protons
- 27.5 GeV e<sup>-</sup> or e<sup>+</sup>
- CMS Energy 300/318 GeV
  - Equivalent to 50 TeV fixed target



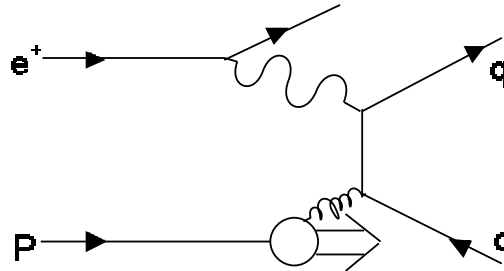
# Photoproduction



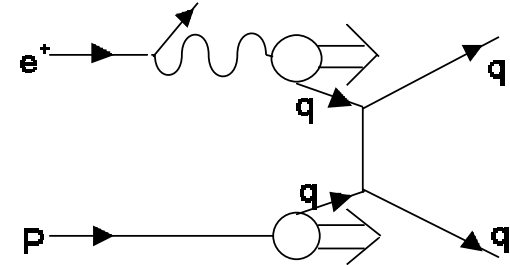
## General Photoproduction



## Direct



## Resolved



- **Photon carries very little 4-momentum ( $Q^2 \sim 0$ )**
- **Photon is almost real**
- **Most ep events are photoproduction**
  - **Cross section has  $1/Q^4$  dependence**
- **Direct:  $\gamma$  couples directly to a parton in proton**
- **Resolved:**
  - **Fluctuation of  $\gamma$  into partonic state**
  - **Parton from  $\gamma$  couples to parton in proton**

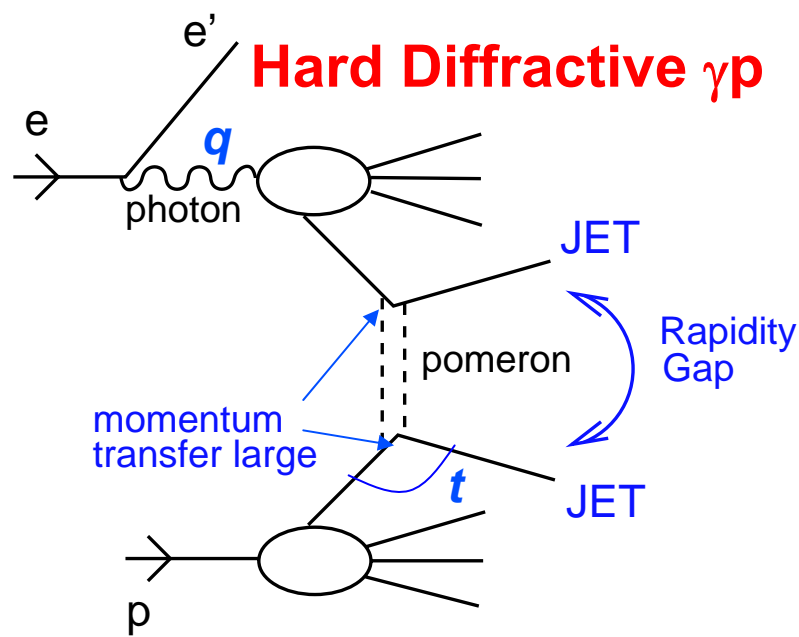
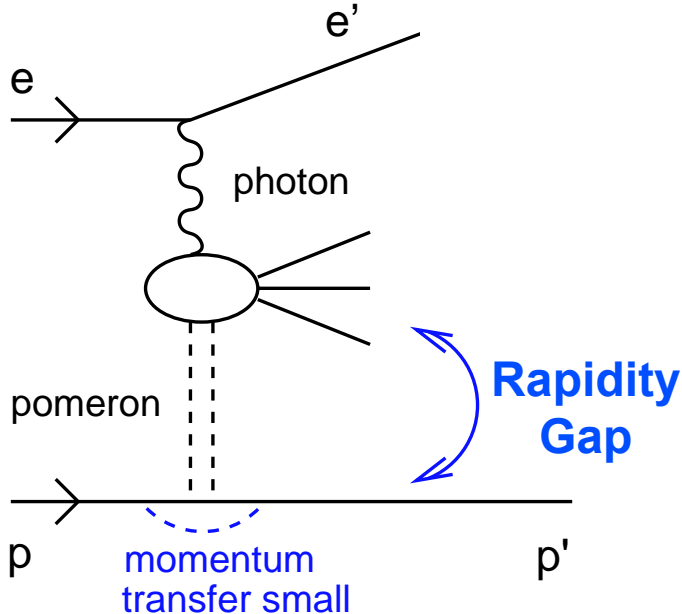


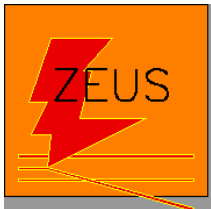
# Diffractive $\gamma p$ in ep Collisions



- Use pQCD to study diffraction in ep collisions
- Hard Diffractive Photoproduction
  - Hard: High  $E_T$  Jets ( $E_T > 5$  GeV)
  - Diffractive: Gap Between jets, small momentum transfer at P vertex
  - Photoproduction:  $Q^2 \sim 0$

## Standard Diffraction

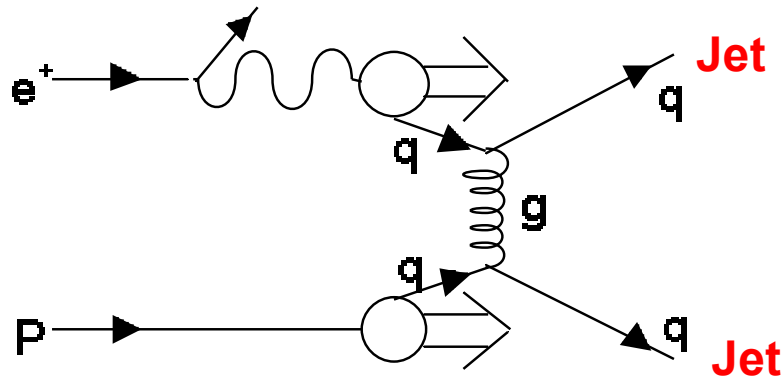




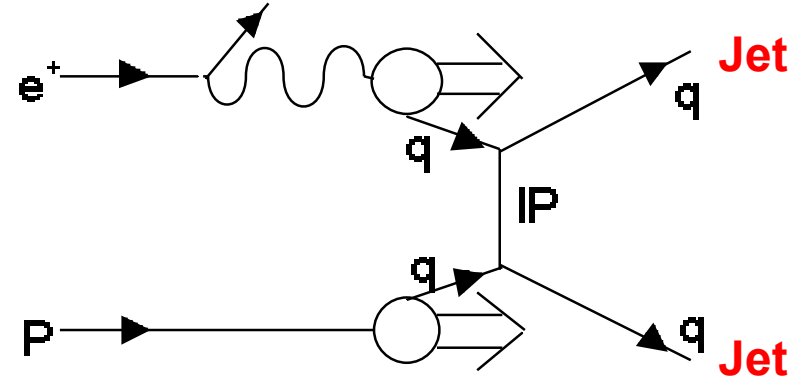
# Color Non-Singlet and Singlet Exchange in Resolved $\gamma P$



## Color Non-Singlet Exchange



## Color Singlet Exchange



## •Color Non-Singlet Exchange:

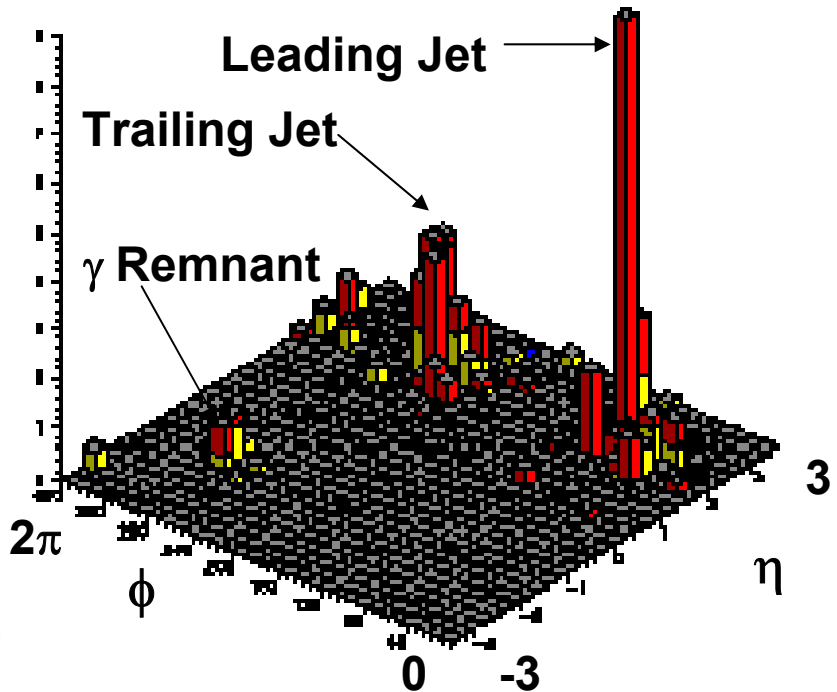
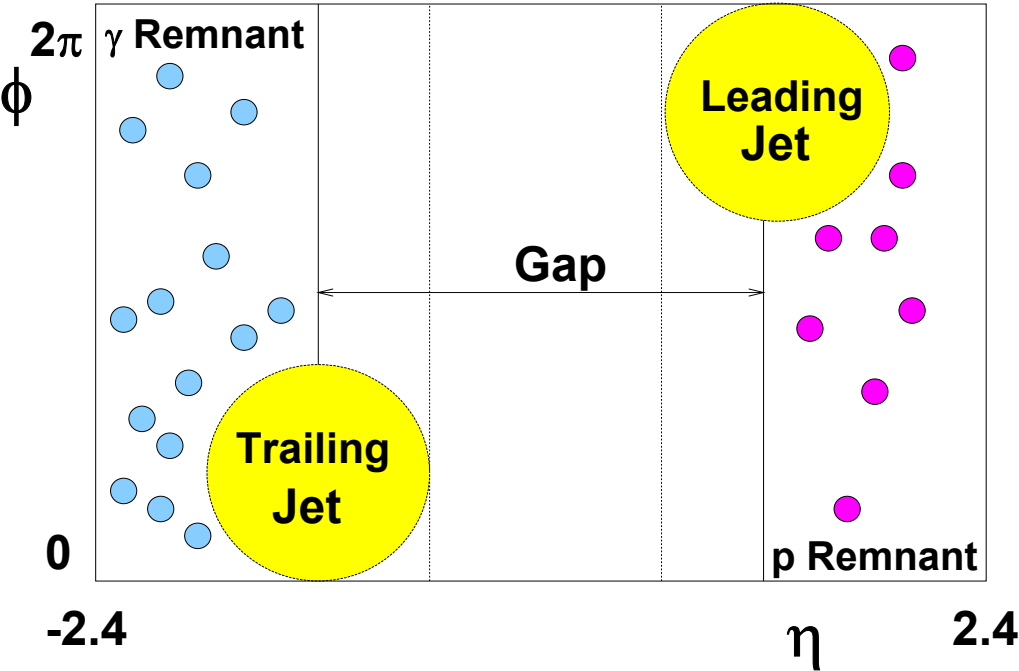
- Final state partons are color connected
- Space between final state partons filled with final state particles
  - No Gap between jets

## •Color Singlet Exchange:

- Final state partons are not color connected
- Space between final state partons empty
  - Rapidity Gap between jets



# Topology of Rapidity Gaps



**Distance between jet centers:  $\Delta\eta$**

**•  $E_T^{\text{Gap}}$  = Total  $E_T$  between leading and trailing jets**

**• Gap Event:  $E_T^{\text{Gap}} < E_T^{\text{Cut}}$**

**• Gap indicates color singlet exchange**



# The Gap Fraction



**Dijet Events with Rapidity Gap and  $E_T^{Gap} < E_T^{Cut}$**

$$f(\Delta\eta) = \frac{d\sigma_{Gap} / d\Delta\eta}{d\sigma / d\Delta\eta}$$

**All Dijet Events with Rapidity Gap**

**Expectation for Behavior of Gap Fraction (J.D. Bjorken, V.Del Durca, W.-K. Tung)\***

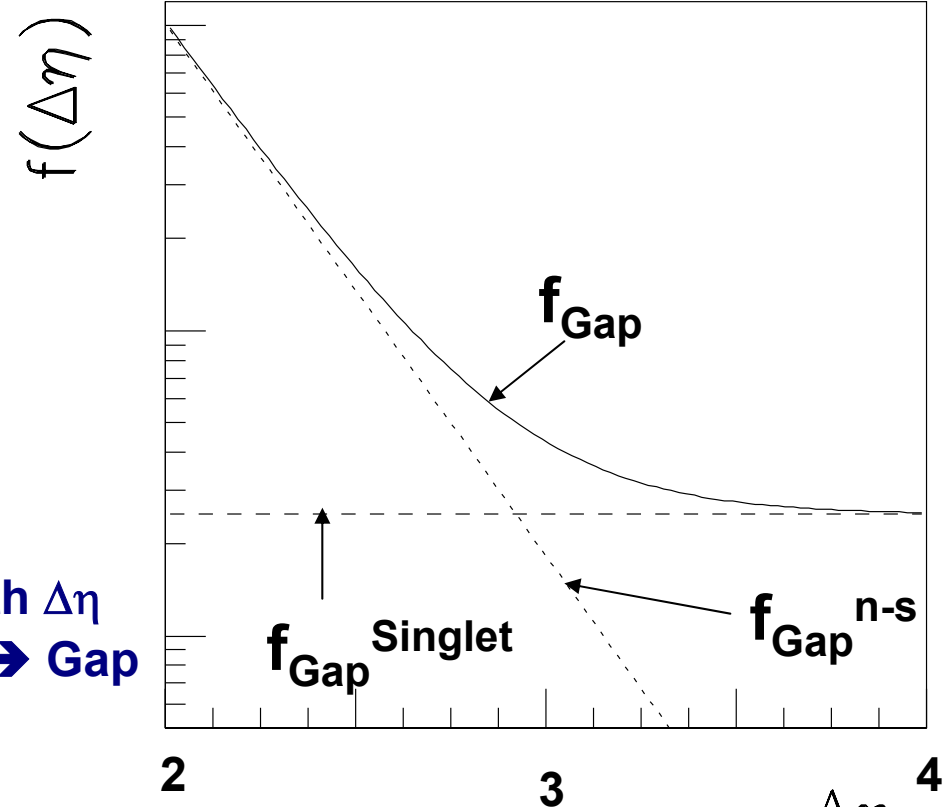
$$\sigma_{Gap} = \sigma_{gap}^{Non-Singlet} + \sigma_{gap}^{Singlet}$$

**• Non-Singlet**

- $f(\Delta\eta)$  decreases exponentially with  $\Delta\eta$
- Particle production fluctuations  $\rightarrow$  Gap
- Non diffractive exchange

**• Singlet**

- $f(\Delta\eta)$  constant in  $\Delta\eta$



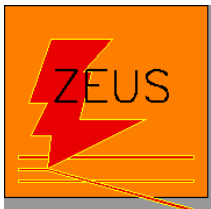
\*Phys. Rev. D47 (1992) 101  $\Delta\eta$   
 Phys Lett. B312 (1993) 225



# Simulation of $\gamma p$ Events



- **PYTHIA 6.1 and HERWIG 6.1**
  - Shown to match  $\gamma p$
  - Use different Fragmentation and Hadronization models
- **Direct and Resolved MC generated separately**
  - Resolved MC includes Multi Parton Interactions
  - Dir and Res combined by fitting  $x_\gamma$  distributions to Data (coming)
- **PDFs**
  - PDF(p): GRV-LO
  - PDF( $\gamma$ ): WHIT 2
- **Color Singlet Exchange MC**
  - **PYTHIA: High- $t$   $\gamma$** 
    - Purpose is simply to match the data
    - Note: Rapidity Gap not due to photon exchange
  - **HERWIG: BFKL**
    - Uses BFKL Pomeron as exchange object in Rapidity Gap events



# Event Selection and $x_\gamma$ Fitting



## •ZEUS 96-97 Data

- Luminosity: 38 pb<sup>-1</sup>

## •Offline Cleaning Cuts

- $|z_{vtx}| < 40$  cm
- No e<sup>+</sup> with E<sub>e</sub> > 5 GeV, y<sub>e</sub> < 0.85
- $0.2 < y_{jb} < 0.85$

## •Jet Selection

- E<sub>T</sub><sup>1,2</sup> > 5.1, 4.25 GeV
- $|\eta^{1,2}| < 2.4$
- $\frac{1}{2}|\eta^1 + \eta^2| < 0.75$
- $[(\sum p_x)^2 + (\sum p_y)^2] / \sum E_T < 2 \text{ GeV}^{1/2}$
- $2.5 < |\eta^1 - \eta^2| < 4.0$

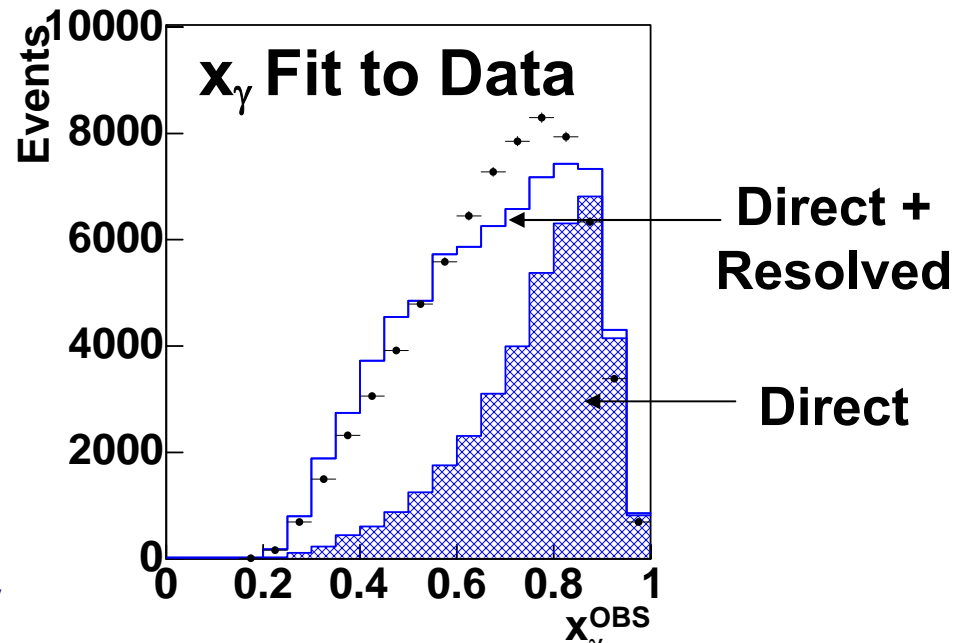
## •4 Gap Samples

- E<sub>T</sub><sup>GAP</sup> < E<sub>T</sub><sup>CUT</sup> = 0.5, 1, 1.5, 2 GeV

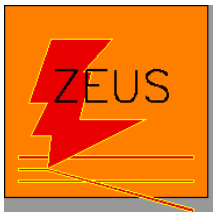
## •~70,000 Inclusive Events

• $x_\gamma$ : Fraction of  $\gamma$  momentum involved in collision

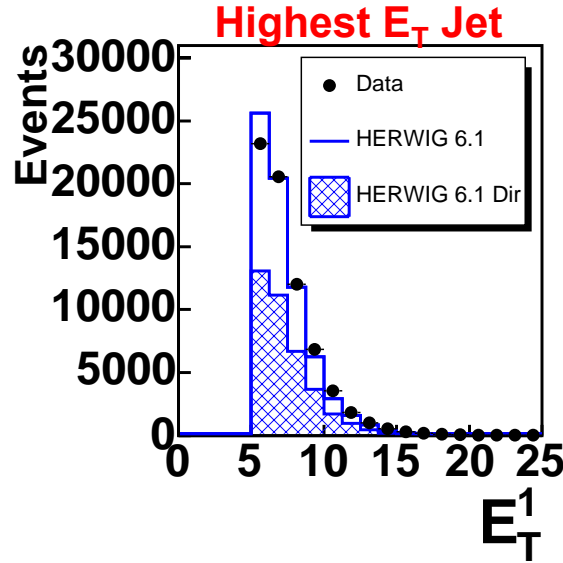
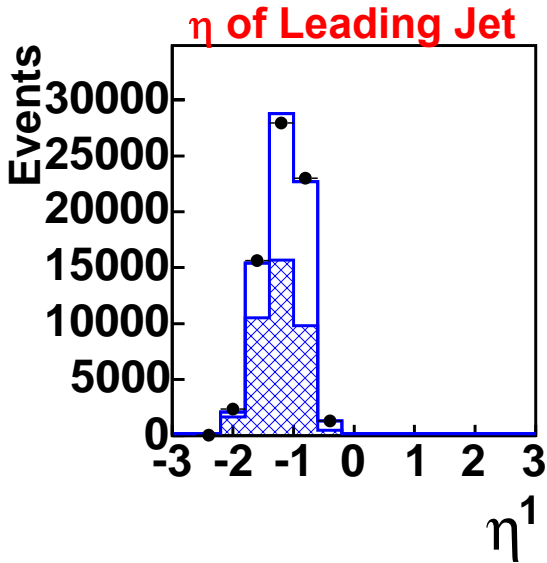
$$x_\gamma^{OBS} = \frac{\sum_{jets} E_T e^{-\eta}}{2yE_e}$$



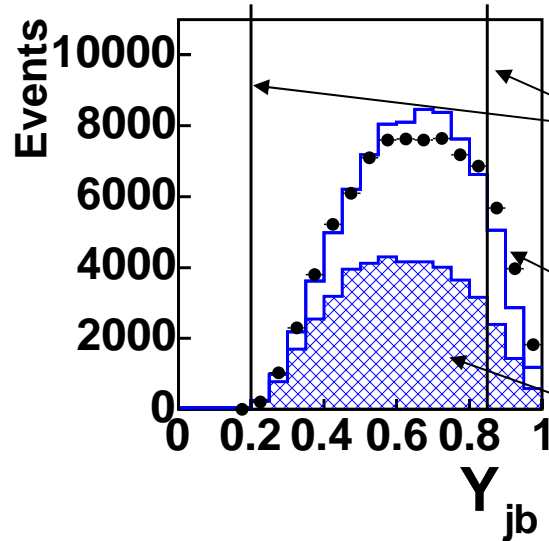
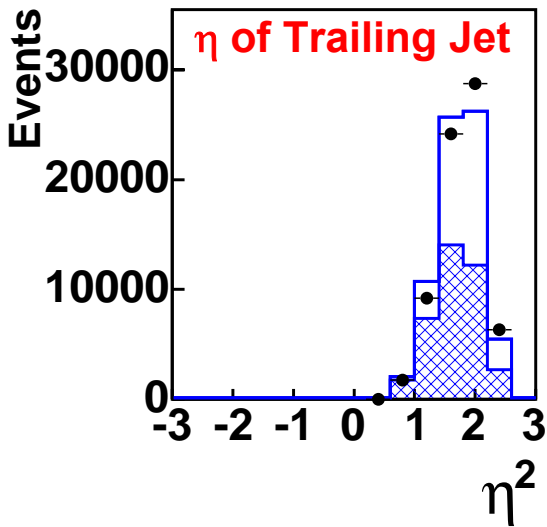
46% Direct + 54% Resolved  
Mixing used in all calculations



# Valid Simulation of $\gamma p$ by HERWIG

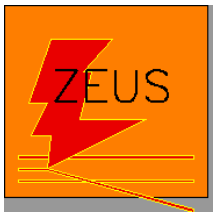


**Data well described by HERWIG**



**Cut  $0.2 < Y_{JB} < 0.85$   
Applied to other plots**

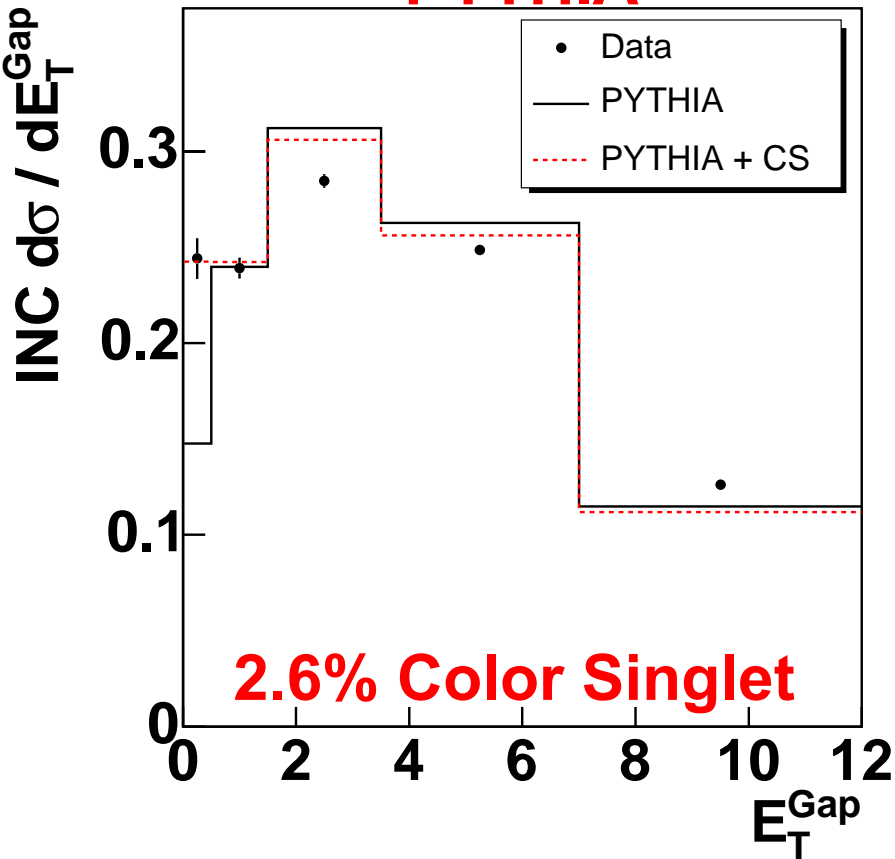
**Direct + Resolved  
Direct**



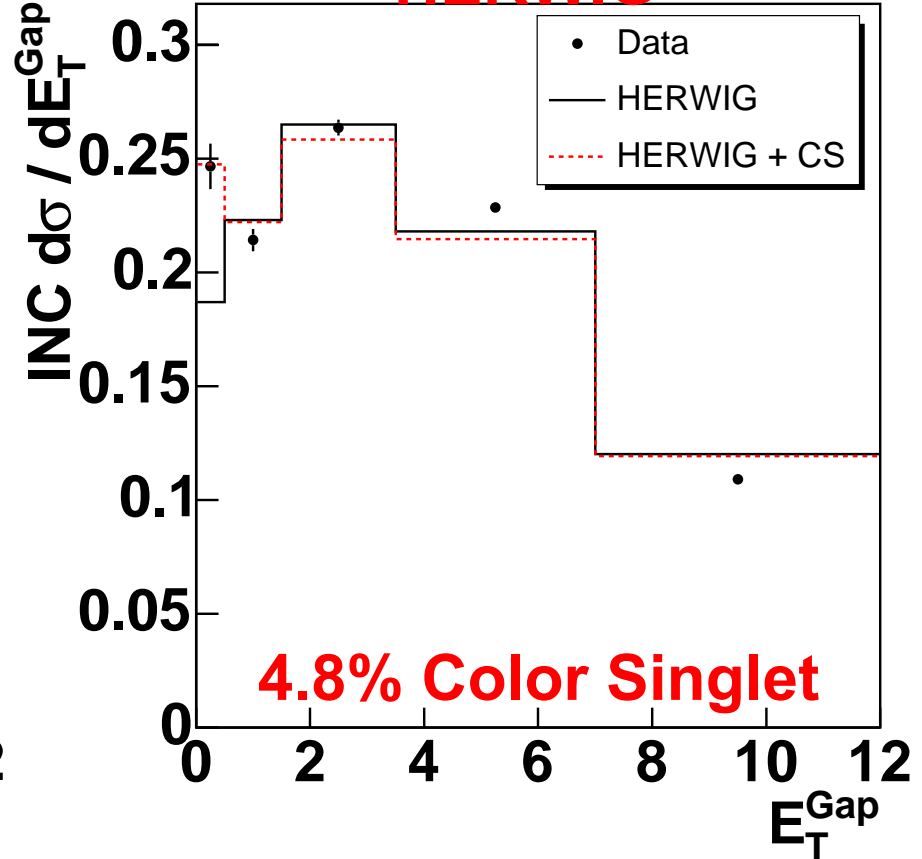
# Energy in the Gap



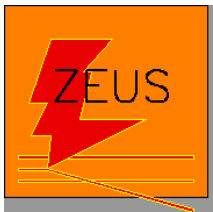
**PYTHIA**



**HERWIG**



- Addition of CS MC gives better agreement at low  $E_T^{\text{Gap}}$ 
  - Enough CS added to match Data in lowest bin
- HERWIG agrees better than PYTHIA with Data (used in next plots)
- Agreement can be improved by tuning input parameters

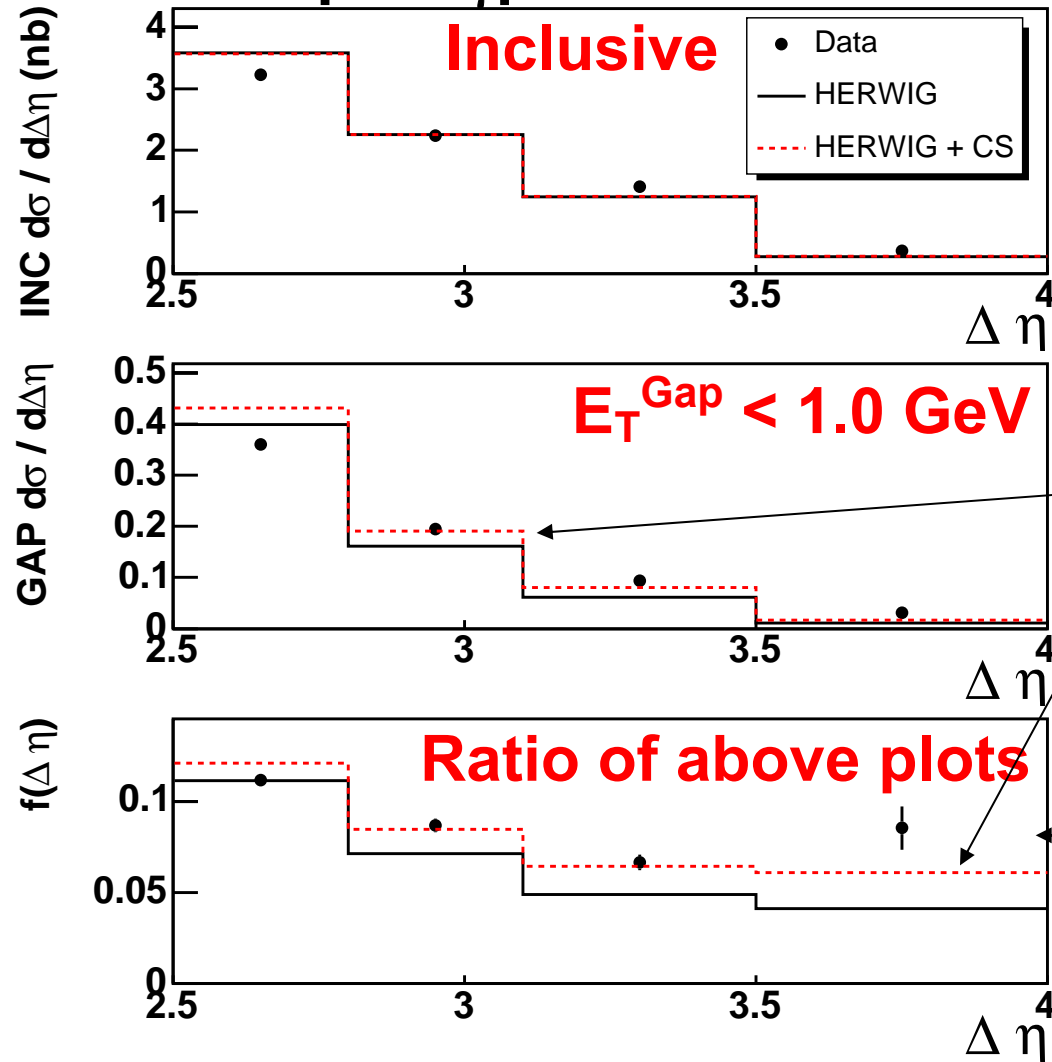


# Inclusive and Gap Cross Sections



## Compare $\gamma p$ Data to HERWIG

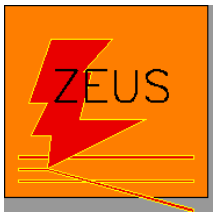
Error bars show statistical errors only



Addition of 4.8% color singlet MC improves agreement with data

**Gap Fraction:**

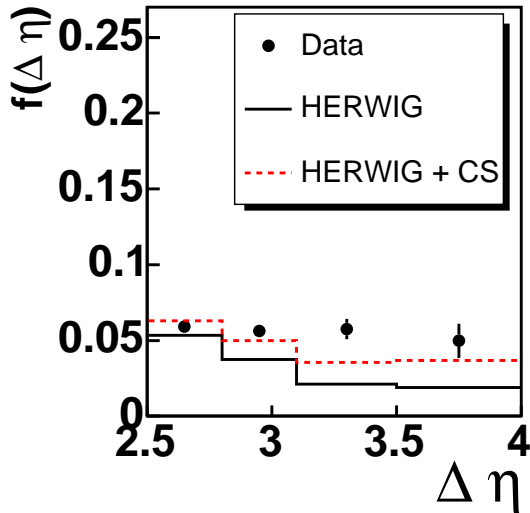
$$f(\Delta\eta) = \frac{d\sigma_{\text{Gap}} / d\Delta\eta}{d\sigma / d\Delta\eta}$$



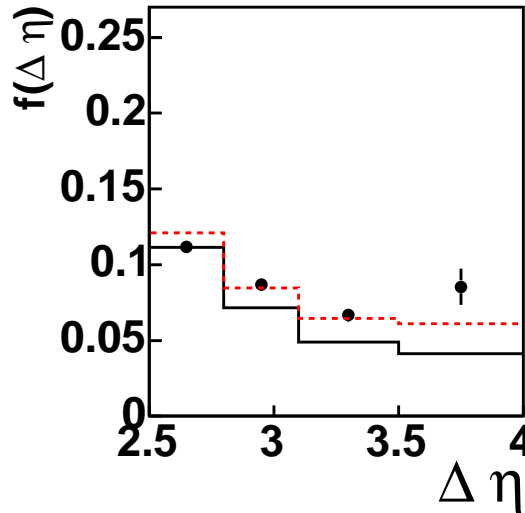
# Gap Fractions for Different Gap $E_T$



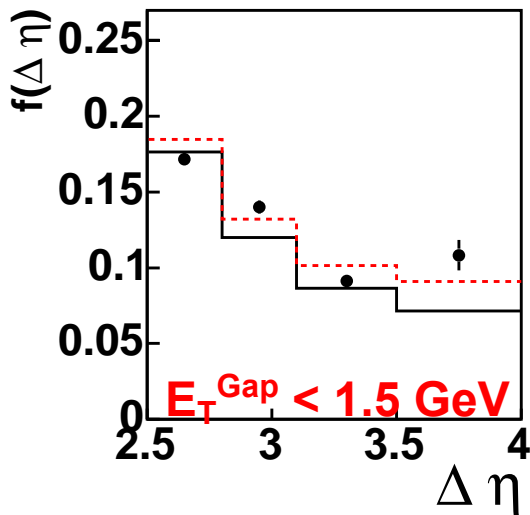
$E_T^{Gap} < 0.5 \text{ GeV}$



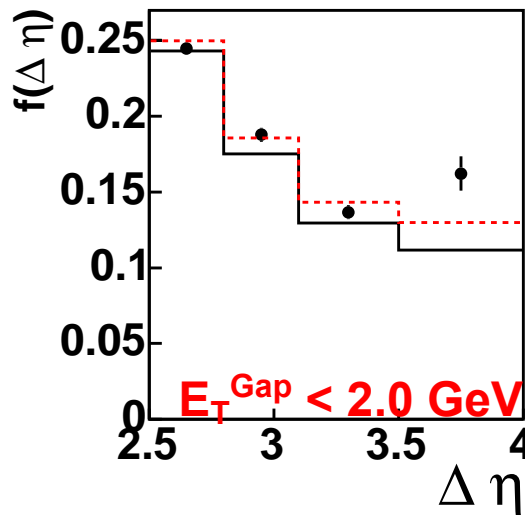
$E_T^{Gap} < 1.0 \text{ GeV}$



$E_T^{Gap} < 1.5 \text{ GeV}$



$E_T^{Gap} < 2.0 \text{ GeV}$



$$f(\Delta\eta) = \frac{d\sigma_{Gap} / d\Delta\eta}{d\sigma / d\Delta\eta}$$

- Observed excess of Data over MC without CS exchange
- Data has better agreement with MC (95.2%) + CS (4.8%)
- Evidence that CS exchange is occurring



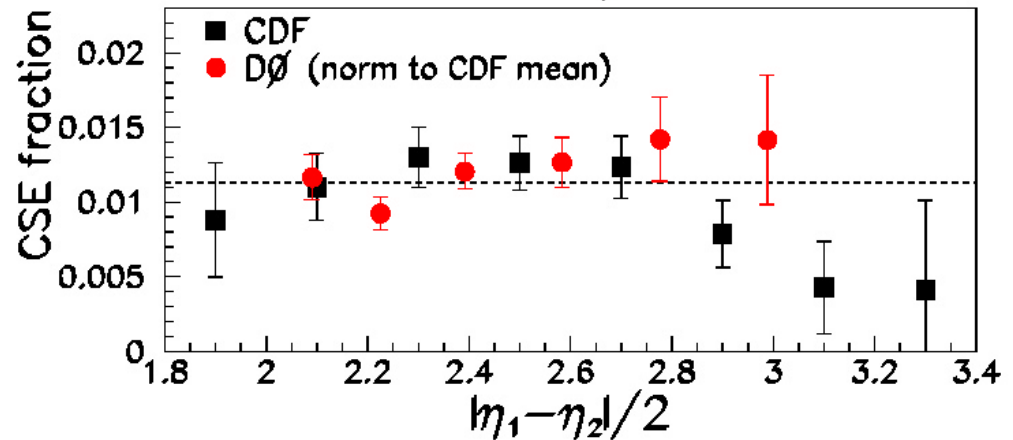
# Tevatron and H1 Results



## Fraction of CSE at Tevatron

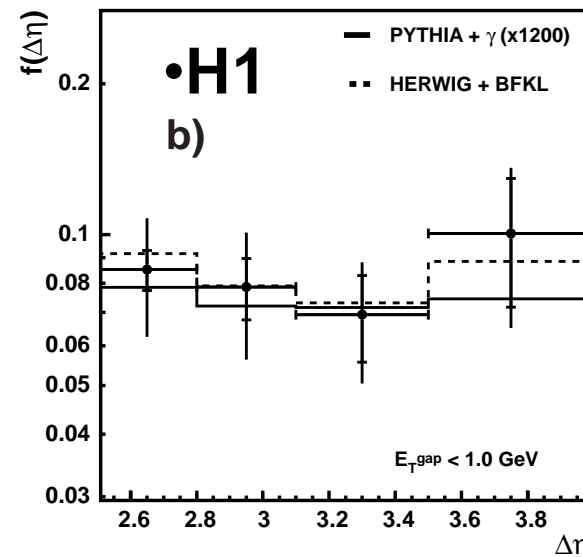
- $\sqrt{s} = 1800$  GeV
  - CDF:  $1.13\% \pm 0.12(\text{stat}) \pm 0.11(\text{sys})$
  - D0: Rising Slightly
  - Consistent within errors
- $\sqrt{s} = 630$  GeV
  - CDF:  $2.4\% \pm 0.7 \pm 0.6$
- ZEUS: 4.8% at  $\sqrt{s} = 300$  GeV

CDF & D0 CSE Fractions  $\sqrt{s} = 1800$  GeV



## Gap Fraction at H1

- Consistent with ZEUS within errors
- $6.6 \text{ pb}^{-1}$  of Lumi





# Summary



- **Conclusions on  $\gamma p$  with Rapidity Gap**
  - HERWIG + BFKL and PYTHIA + High- $t$   $\gamma$  describe data
  - Evidence for Color Singlet Exchange
    - 3-5% of CSE added to data improves match at high  $\Delta\eta$
  - ZEUS results consistent with H1 within errors
  - ZEUS observes larger CSE than CDF/D0 at lower  $\sqrt{s}$ 
    - CDF/D0: 1%/2.4% CSE at 1800/630 GeV
- **Next steps**
  - Include 98-2000 Data
    - 3x higher statistics
    - Can go to higher jet  $E_T \rightarrow$  Less sensitivity to underlying event models
  - Study properties of color singlet exchange