Preliminary Examination

Shedding Light on the Structure of the Photon

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ZEUS

Zeus in Numbers

Calorimeter: DU / Scintillator $(EMC = 25x_0 \;\; HAC = 75 \rightarrow 150x_0$

99.7% Coverage $2.5 \leq \theta \leq 176$

Resolution: $\frac{18\%}{\sqrt{E}} = \frac{\sigma(E)}{E}$ electrons

$\frac{35\%}{\sqrt{E}}$ hadrons

$< 1ns$ time

Tracking: $Ar/CO_2/C_2H_6$(72 layers, 9 super with 4 stereo)

Coverage: $15^\circ \rightarrow 164^\circ$

Resolution: 4 cm in z -- 1mm in xy

Vertex Resolution: 0.4 cm in z -- 0.1 cm in xy

Momentum Resolution: $\frac{\sigma(P_t)}{P_t} = 0.003P_t$

$B = 1.43T$

Luminosity: Pb (electon), Pb (photon)

$\sigma(\mathcal{L}) < 1\%$

Luminosity Monitor

ZEUS Trigger

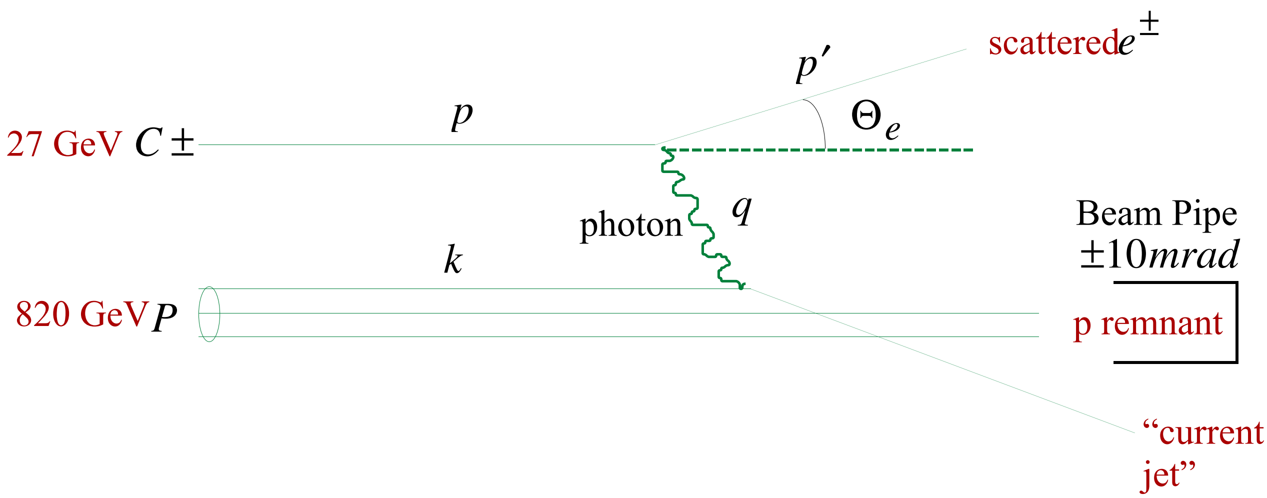
- **First Level Trigger:**
  - 10^7 Hz input
  - 600 Hz output
    - Calorimeter First Level Trigger (no Deadtime)
      - Global and regional energy sums
      - Isolated electron/muon finding
    - Track/Muon hits
- **Second Level Trigger:**
  - 600 HZ input
  - 70 HZ output
    - Timing cuts
    - $E\text{-}p_z$ cuts
    - Spark rejection
- **Third Level Trigger:**
  - 70 Hz input
  - 14 Hz output (100 KBytes/Event)
    - Physics filters
    - Some timing

Timing of Background vs. Physics

(Forward Cal. Time - Rear Cal. Time) vs. (Rear Cal. Time)

96 ns First Level Trigger Pipeline

Deep Inelastic Scattering



$$Q^2 = -q^2 = 2EE'(1-\cos\Theta_e)$$

$$x = \frac{Q^2}{2(q \cdot k)}$$

$$y = \frac{q \cdot k}{p \cdot k} \qquad y_e = 1 - \frac{E'}{E}\cos^2\frac{\Theta}{2}$$

$$y_{JB} = y_{cal} = \frac{\sum_i (E - p_z)_i}{2E_e}$$ (valid if $e^{\pm}$ down BP)

$$Q^2 = xys$$

$$s = (p+k)^2$$

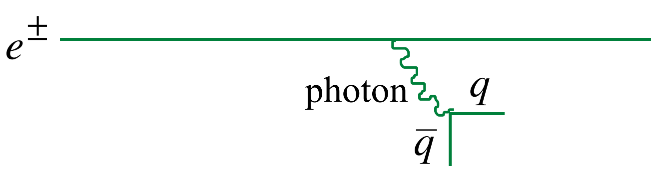
ZEUS Kinematic Coverage

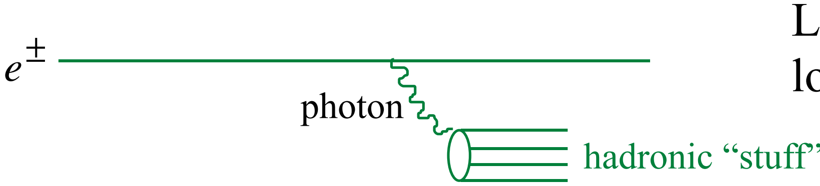
GeV^2

ZEUS covers previously unmeasured range.

If the photon lives long enough...

Short-lived γ (high Q^2 <=> short life) -- virtual

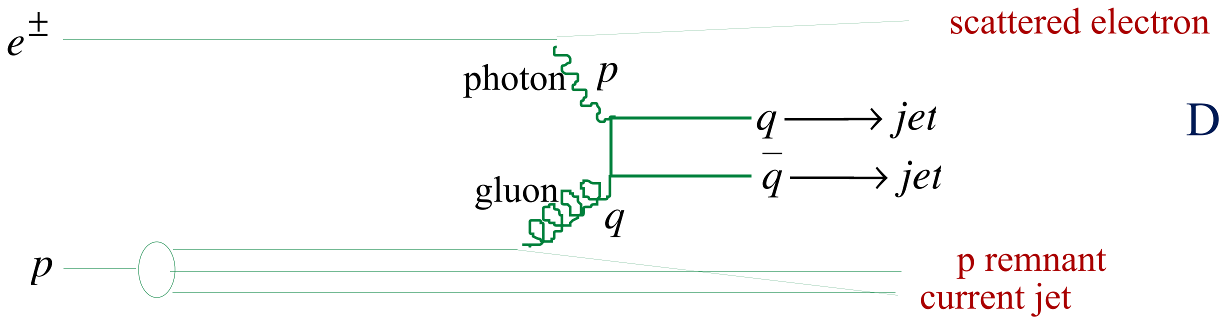




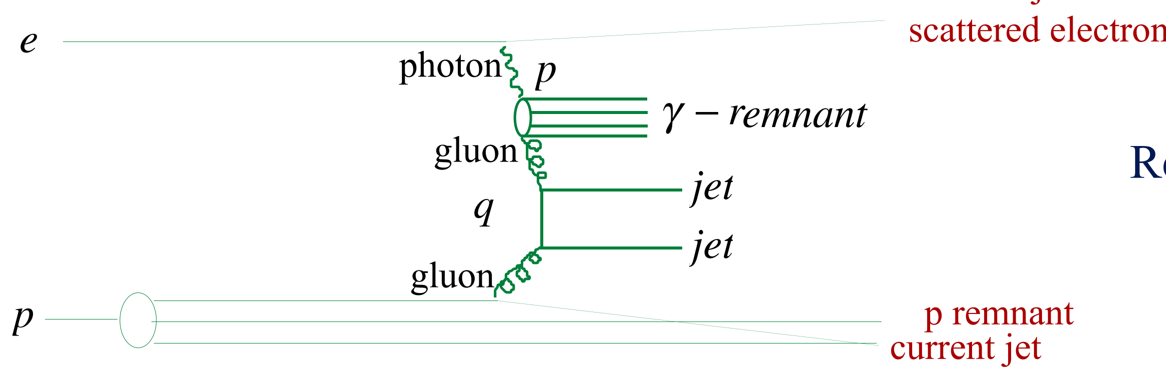
Longer lived γ (low Q^2<=> longer life) -- Quasi-real

Photoproduction at Electron Proton Collider

Leading Order

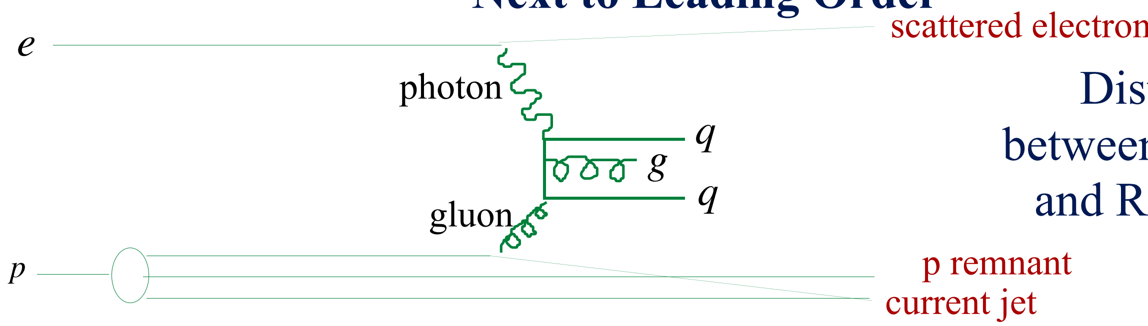


Direct



Resolved

Next to Leading Order



Distinction between Direct and Resolved blurs

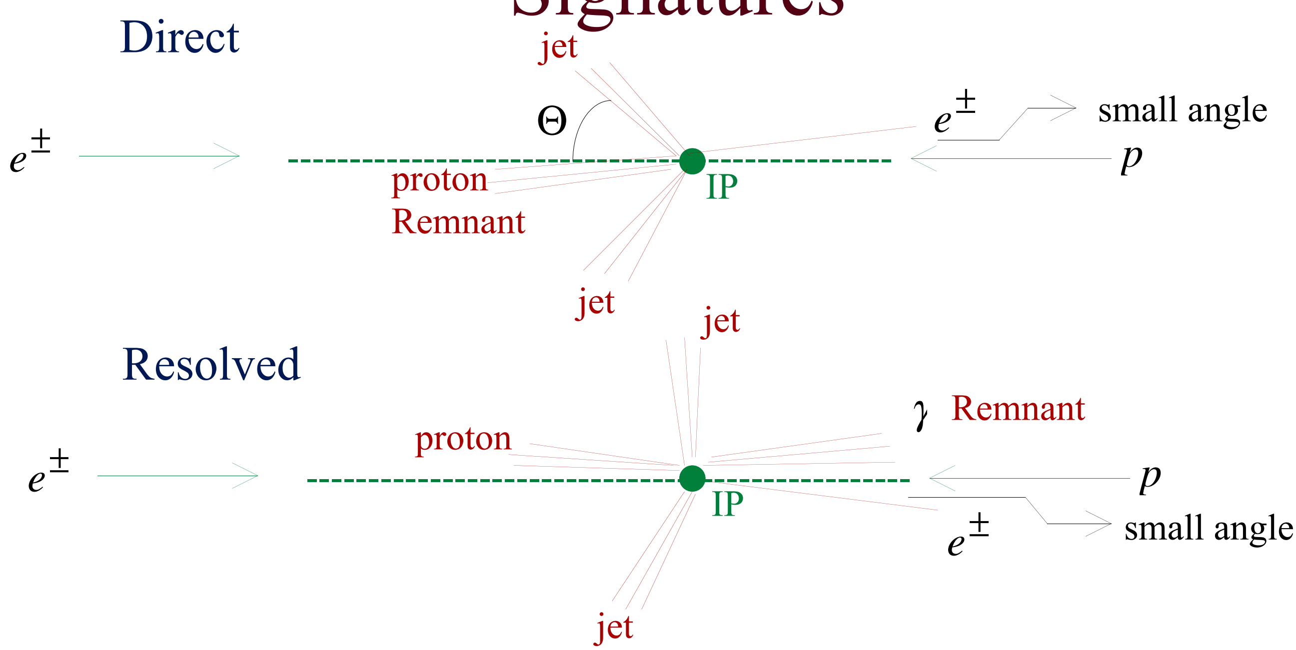
$$W^2 = (p+q)^2 = 4y_{JB}E_eE_p$$

$$x_\gamma = \frac{\sum_{jets}(E-p_z)_{jets}}{2yE_e}$$

hard vs. soft

Photoproduction at ZEUS

Signatures



$$\eta = -\ln(\tan\frac{\Theta}{2})$$

ZEUS Run 13299 Event 7428 (LAZE)

ZEUS Run 6790 Event 24894 (LAZE)

Photon has Hadronic Structure

In proton (DIS) case:

$$\frac{d\sigma(ep \to eX)}{dxdy} = \frac{4\pi\alpha^2 s}{Q^4}[(1-y+\frac{y^2}{2})F_2^p(x,Q^2) - \frac{y^2}{2}F_L^p(x,Q^2)]$$

F(x,Q²) is a structure function and includes the momentum distribution of the partons.

$$F_2^p(x,Q^2) \approx x\{4/9[u(x)+\bar{u}(x)] + 1/9[d(x)+\bar{d}(x)+s(x)+\bar{s}(x)]\}$$

In photon (2γ exchange) case:

$$\frac{d\sigma(e\gamma \to eX)}{dxdy} = \frac{4\pi\alpha^2 s}{Q^4}[(1-y+\frac{y^2}{2})F_2^\gamma(x,Q^2) - \frac{y^2}{2}F_L^\gamma(x,Q^2)]$$

$y \to 0$

$$\frac{d\sigma(e\gamma \to eX)}{dxdy} \sim F_2^\gamma(x,Q^2)$$

Why is $F_2^\gamma(x,Q^2)$ Interesting?

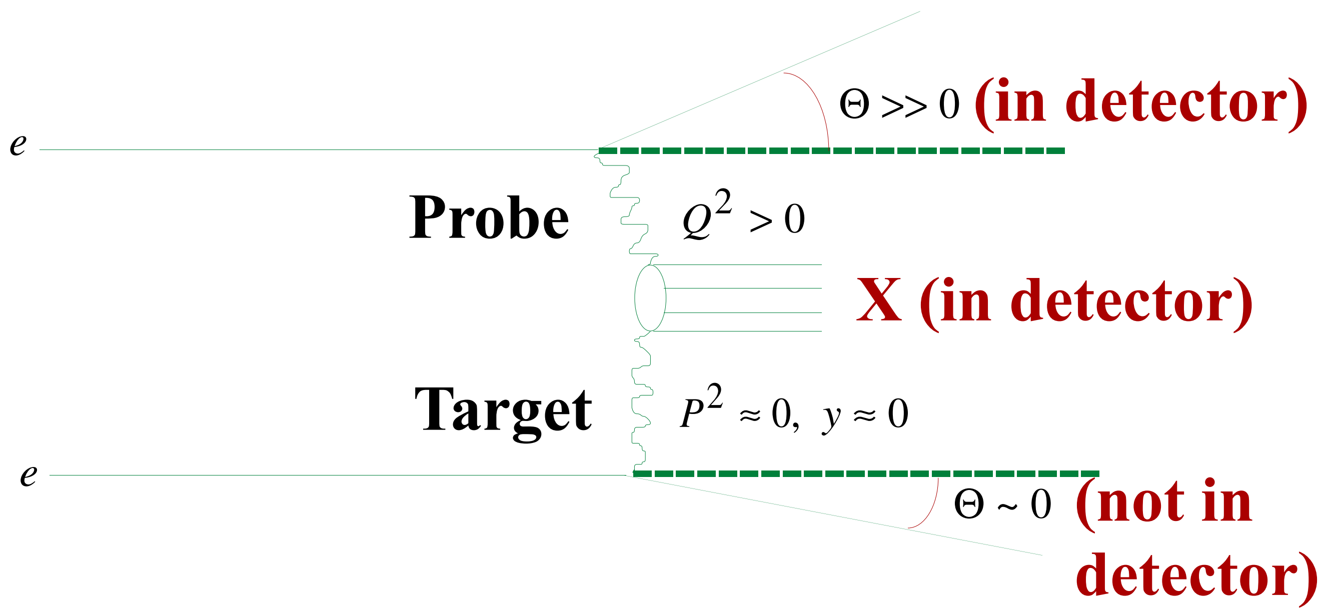
- **Test of Quark Parton Model (QPM)**
  - F_2^γ should peak toward high x
  - Pair Production of Quarks (Direct Photoproduction)
- **Test of Quantum Chromo-Dynamics (QCD)**
  - F_2^γ should peak toward low x
  - Gluon Bremsstrahlung, Quarks Radiating Gluons (Resolved Photoproduction)

Why is $F_2^{\gamma}(x,Q^2)$ Interesting?

- **F_2^{γ} scaling violation different than F_2^{p} violation**
  - The Quark Parton Model of the proton is expected to fulfill Bjorken scaling.
    - Gluon Bremsstrahlung causes scaling violation in the proton. (QCD)
  - The Quark Parton Model of the photon violates Bjorken scaling.
- **No sum rule for photon**
  - The momentum of the partons in the proton must sum to the total momentum of the proton.
  - The photon may remain a photon, in which case the partons in the photon carry none of the photon’s momentum.
    - F_2^{γ} is large in the high x region

$\sigma(\gamma * p)[\mu b]$ vs. $W_{\gamma p}^2[GeV^2]$ Plot

Electron Positron Collider as Gamma Gamma Collider



Previous Measurements of $F_2^\gamma(x,Q^2)$

Scaling violation seen as well as low and high x peaks.

ZEUS Data Set and Monte Carlo

- **Accumulated Data**
  - 1993: 550 nb^{-1} (~4.5 Million Events on Tape)
  - 1994: 3300 nb^{-1} (~10 Million Events on Tape)
  - 1995: 6400 nb^{-1} (~15 Million Events on Tape)
- **Monte Carlo**
  - HERWIG
    - Uses Lowest Order Diagrams
    - Fragmentation done by cluster algorithm
    - Exact matrix elements used for photon-lepton vertex
  - PYTHIA
    - UsesLowest Order Diagrams
    - Fragmentation done by LUND string model
    - Weizsaecker-Williams approximation for photon-lepton vertex

ZEUS Photoproduction Cuts

- **2 Jets as found by cone algorithm**
  - $E_T^{jet} > 5$ GeV (compensate for energy loss in dead material)
  - $-1.125 < h^{jet} < 1.875$ (keep edge of jet in detector)
- **Remove beam gas events**
  - At least 2 tracks pointing to vertex
  - Vertex position along beam axis -48 cm < z < 36 cm
  - Fewer than 5 tracks not pointing to vertex
  - $y_{JB} > 0.2$ (if lots of stuff in Forward Cal, $E\text{-}p_z$ will be small)
- **Reject charged current events**
  - Missing $p_T / E_T^{0.5} < 2\ \text{GeV}^{0.5}$
- **Reject DIS**
  - Identify Electrons (Energy Distribution in Cal)
    - Reject event if $y_e < 0.7$ (Electrons that are not scattered beam electrons tend to have high y_e)
      - Very effective against DIS events with $Q^2 > 4\ \text{GeV}^2$
  - $y_{JB} < 0.7$ (If electron in Rear Cal, $E\text{-}p_z$ will be high)

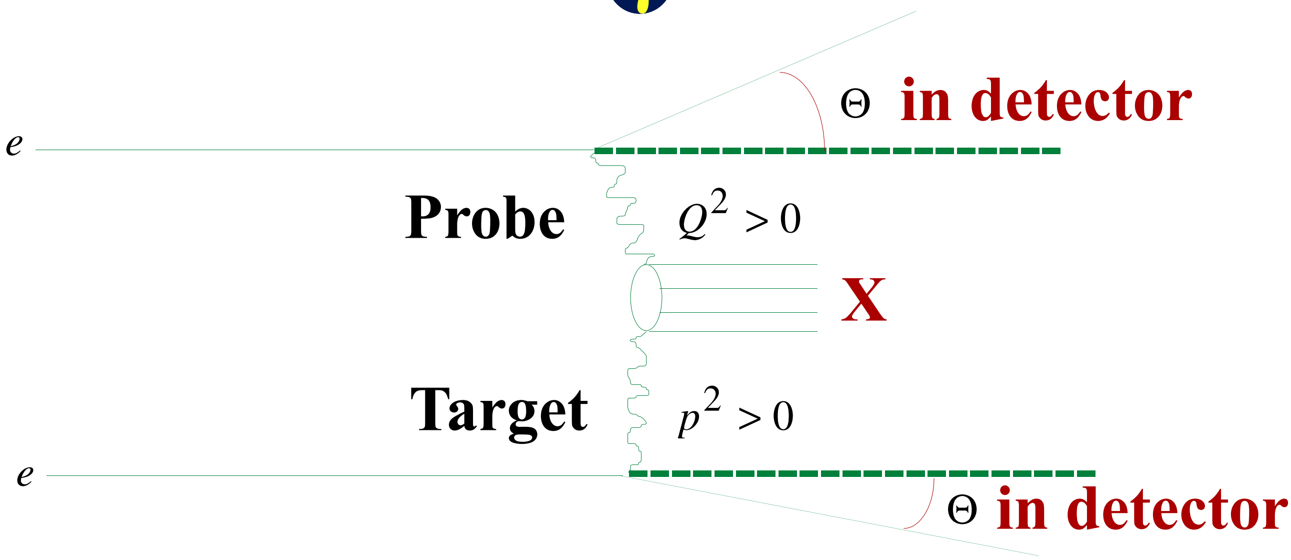
ZEUS Results

Hard processes observed in both Direct and Resolved photoproduction.

ZEUS Results

Poor reproduction of Resolved, while Direct is described more accurately.

Previous Result for Virtual Photons



PLUTO

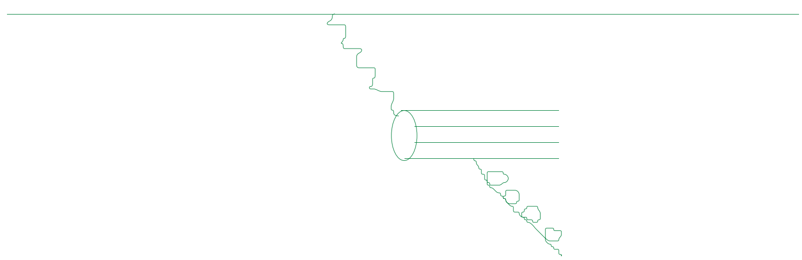
74 Events

Decrease of F_{eff} with increasing P^2 seen

Virtual γ sturcture at ZEUS

How does F_2^γ change with P^2?

- **Expect partonic content (i.e. resolved) of photon to decrease with increasing P^2.**



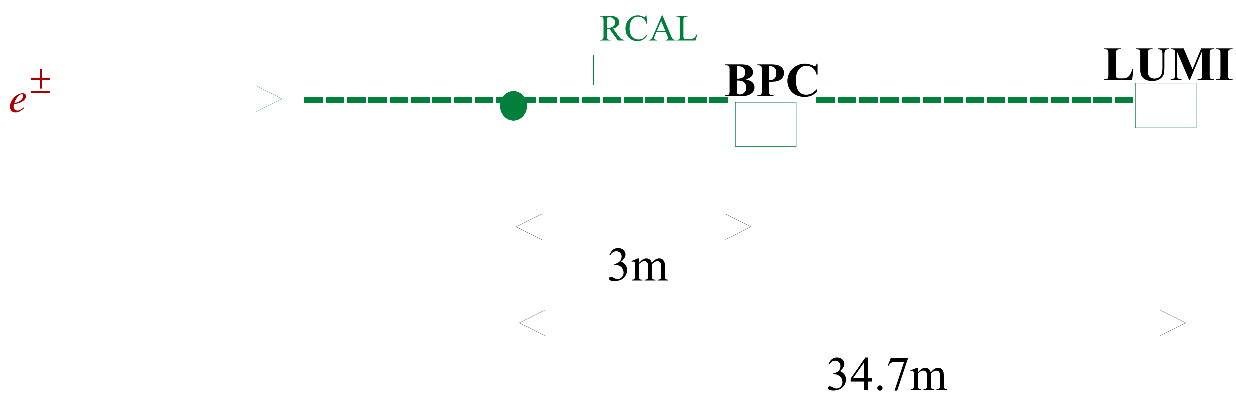
- **Each "fluctuation step" takes time and life time of γ decreases as P^2 increases.**
  - expect gluons to be suppressed faster than quarks
- **Prediction by Drees and Godbole:**
  - Expect Direct/Resolved fraction to increase as P^2 increases.

Theoretical Prediction

- **Quarks and gluons suppressed in virtual photon**

Tag Real and Virtual Photons at ZEUS

Use Beam Pipe Calorimeter and Luminosity monitor. (BPC and LUMI)



Measure $\frac{D}{R}$ in BPC ($0.1<P^2<0.55$ GeV^2)
and in LUMI ($P^2<0.02$ GeV^2,
median $P^2=10^{-5}$ GeV^2)

The Beam Pipe Calorimeter (BPC)

Beam Pipe Calorimeter Measures Position

BPC Resolution

Tungsten with Scintilator layers

- **Total $24X_0 \rightarrow$ 24 layers**
- **1994**

$$\frac{\Delta E}{E} = \frac{30\%}{\sqrt{E}} \quad \text{(in GeV)}$$

$$\Delta x = 2mm$$

$$17mrad \le \Theta \le 35mrad$$

$$0.1GeV^2 \le Q^2 \le 0.55GeV^2$$

$$\Delta Q^2 = 3 - 6\%$$

Zeus 95 Data Plot

$\sigma(\gamma * p)[\mu b]$ vs. $W_{\gamma p}^2[GeV^2]$ Plot

BPC fills in important unexplored territory.

Luminosity Monitor

- **Lead/Scintilator sandwich**
  - 24 X_0 total

$$\frac{\Delta E}{E} = \frac{16-18\%}{\sqrt{E}}$$ **(in GeV)**

$$0.2E_e \le E_e' \le 0.9E_e$$

$$\Delta x = 3mm$$

$$0 \le Q^2 \le 0.02GeV^2 \quad (median = 10^{-5}GeV^2)$$

$$\Delta Q^2 = \sim 10^{-4} \to \sim 10^{-2}GeV^2$$

Preliminary Results from ZEUS

- **Distributions of x_γ for virtual and real photons in photoproducion.**

BPC
(0.1<P^2<0.55 GeV^2)

LUMI
(P^2~0 GeV^2)

Enhancement of Resolved in LUMI (lower virtuality) observed.

P^2 Evolution of Direct to Resolved Ratio

Ratio decreases with P^2 but errors to large to constrain theory.

Outlook

- **Increase in Statistics**
  - 1994: ~2pb^{-1}
    - 375 “BPC events” (Virtual)
    - 14 181 “LUMI events” (Quasi-real)
  - 1995: ~6pb^{-1} project:
    - 1125 BPC
    - 42 500 LUMI
- **New BPC**
  - 1994: $\frac{\Delta E}{E} = \frac{30\%}{\sqrt{E}}$ $\Delta x = 2mm$
  - 1995: $\frac{\Delta E}{E} = \frac{16\%}{\sqrt{E}}$ $\Delta x = 1mm$

- **Expect to be able to make firm statement about P^2 evolution of photon structure.**