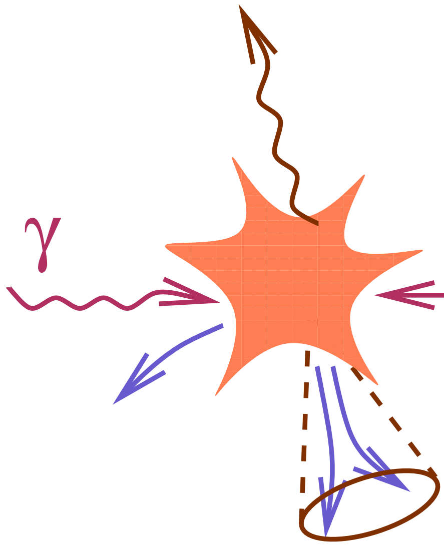
Prompt Photons in Photoproduction at HERA



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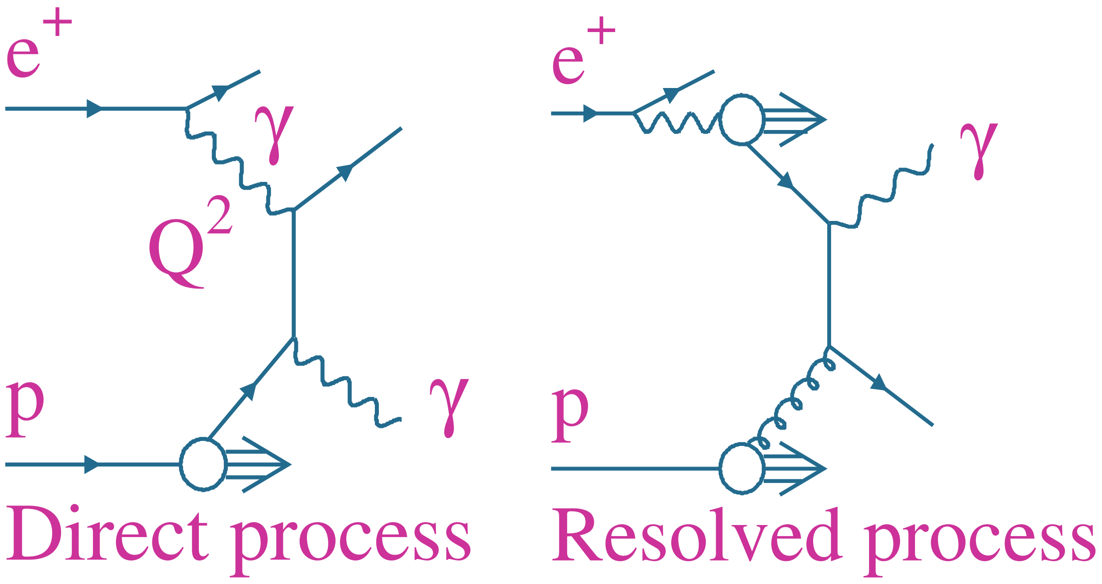
Outline

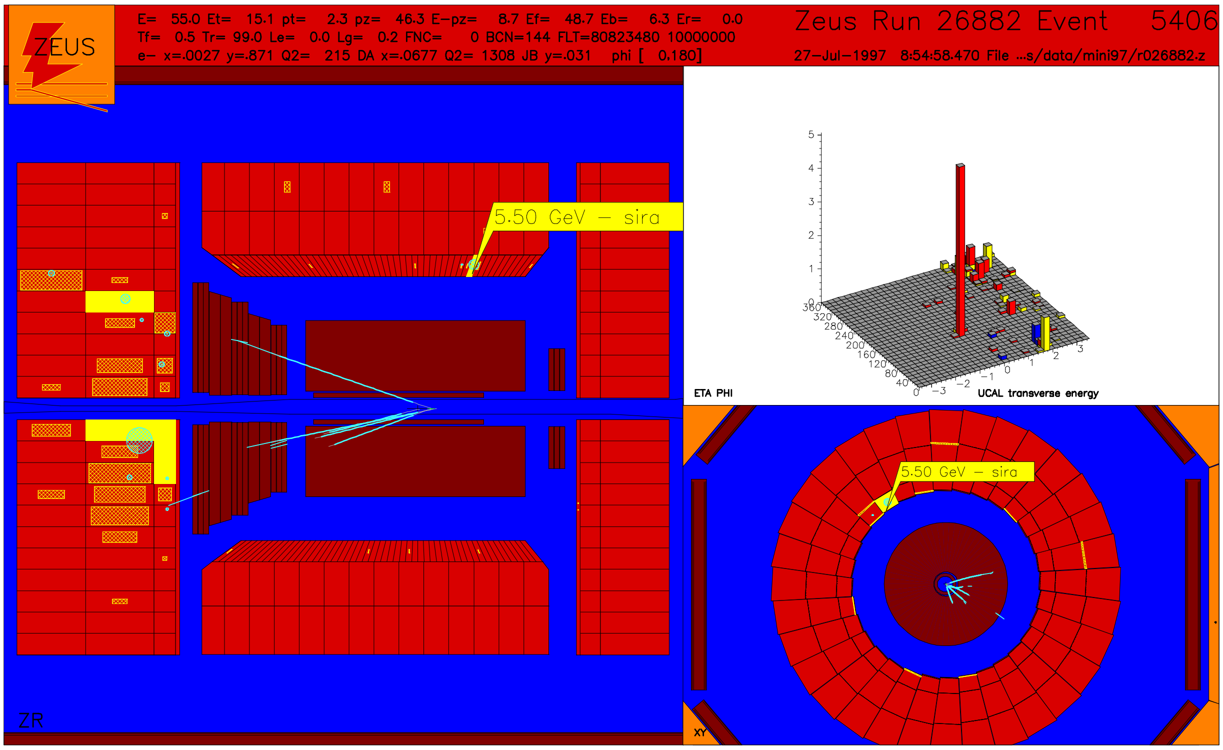
- Prompt γ Production at HERA
- Event Selection
- Background Separation
- Cross section Measurements
  - Inclusive prompt photons
  - Prompt γ + jet production
- Comparisons with LO/NLO
- Conclusions & Outlook

Prompt γ Production at HERA



- Only one LO direct process
  $\Rightarrow$ Direct Compton process ($\gamma q \to \gamma q$)
- In the resolved process, HERA kinematics favour g from Proton and q from incoming γ
- Direct link to the parton level interaction
- Less sensitive to Hadronization
- But small Cross Section ; $\sigma(\gamma)/\sigma(\text{jets}) \sim 10^{-3}$
- The clean signature of the prompt γ can provide a good means to test QCD
  $\Rightarrow$ eg) γ Structure, Intrinsic k_T, NLO etc...

Prompt γ Measurement at HERA



- Example of direct process prompt γ
  $\Rightarrow$ Clearly identified in CAL / well isolated.
- ZEUS BCAL has good granularity to separate high–E_T^γ from π^0/η backgrounds
- Potentially significant backgrounds from jet fragments (unresolved γ pairs) in dijet
  eg) mostly π^0 ($\to \gamma\gamma$), η ($\to \gamma\gamma$, $\pi^0\pi^0\pi^0$)
  - Isolation cut & Shower shape cuts are required to remove these events

Event Selection

Inclusive photon Measurement

- ZEUS 96–97 Data : 38.4 pb^{-1}
- $5 < E_T^\gamma < 10$ (15) GeV for $d\sigma/d\eta_\gamma$ $(d\sigma/dE_T^\gamma)$
- $-0.7 < \eta^\gamma < 0.9$ (Barrel region)
- Track Isolation
  $\Delta R \equiv \sqrt{(\Delta\phi)^2 + (\Delta\theta)^2} < 0.3$
- Energy Isolation
  within cone in (η,ϕ) of R = 1 around γ
  demand $\sum E_T^{calo+tracks} < 0.1 \cdot E_T^\gamma$
  $\Rightarrow$ Removes most π^0,η and γs radiated from final state quarks
- $120 < W^{meas} < 270$ GeV, $Q^2 < 1$ GeV^2

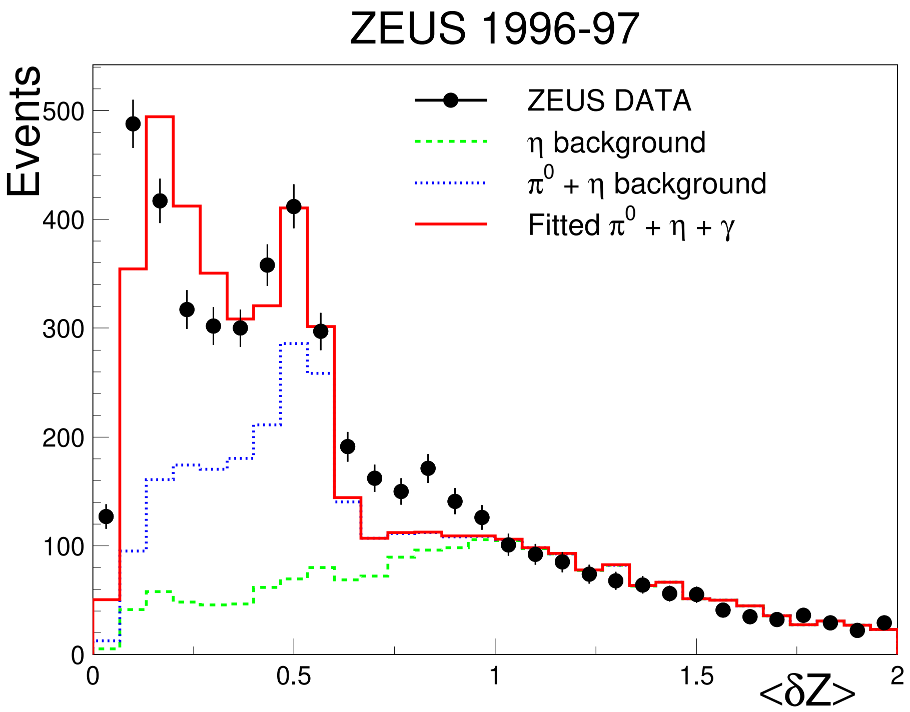
Photon + jet Measurement

- All above requirements &
- $E_T^{jet} > 4.5$ GeV, $-1.5 < \eta^{jet} < 1.8$
  (Cone, R=1.0)

IDENTIFICATION OF γ SIGNAL (1)

- Still have some π^0, η backgrounds
  $\Rightarrow$ use two shower shape quantities
  on BCAL cell cluster $\equiv$ γ candidates

- (1) Width of γ candidate in Z
  $\Rightarrow$ $<\delta Z> = \sum \left(E_{cell} \cdot |Z_{cell} - \overline{Z}| \right) / \sum E_{cell}$

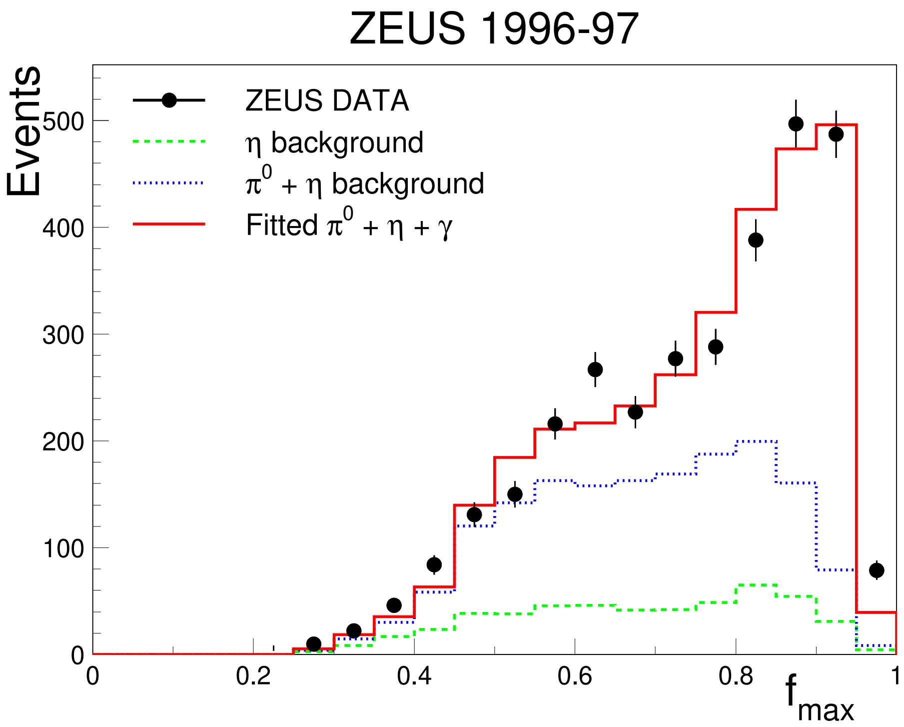


- Structure indicating γ, π^0 and a multi–π tail modelled as η mesons
  $\Rightarrow$ Peaks are attributable to γ's and π^0's

- Cut at 0.65 in $<\delta Z>$ to remove most η's, quantify remaining η's

IDENTIFICATION OF γ SIGNAL (2)

- Now broad clusters removed, look at f_{max}
- (2) f_{max} = fraction of total energy of γ which is in the most energetic calorimeter cell
- Similar shape for π^0 & remaining η mesons



- fitted MC f_{max} curves describes data well
- Large γ component with $f_{max} > 0.75$
- γ signal extracted by comparing events with $f_{max} > 0.75$ and $f_{max} < 0.75$ (3362 events)

Signal/Background Separation

- Divide the data into two subsamples, consisting of events whose γ candidate has $f_{max} \geq 0.75$ and $f_{max} < 0.75$ respectively
- Both Signals and Backgrounds are calculated in each bin from following Eq.

$$\boxed{N_{f_{max} \geq 0.75} = \alpha N_{sig} + \beta N_{bgd}}$$

$$\boxed{N_{f_{max} < 0.75} = (1 - \alpha) N_{sig} + (1 - \beta) N_{bgd}}$$

- Where
  - N_{sig} : Number of signal (ie. γ)
  - N_{bgd} : Number of background (ie. π^0 or η)
  - α: Probability of γ have $f_{max} \geq 0.75$
  - β: Probability of bgd have $f_{max} \geq 0.75$
  - α, β are known from the MC f_{max} shapes of γ and of $(\pi^0 + \eta)$ background

Hadron Level Cross Section

- Cross sections ($d\sigma/d\eta^{\gamma}$, $d\sigma/dE_T^{\gamma}$) are corrected back to the final state hadron level using PYTHIA 5.7
- Correction factors are estimated from prompt photon MCs
  $\Rightarrow$ Direct / Resolved Fragmentation
  $+$ Non–Fragmentation Processes
- Hadron Level Cross Section

$$\frac{\text{Number of Signal} \cdot \text{Correction factor}}{\text{Integrated luminosity} \cdot \text{Bin–width}}$$

- Hadron Level Event Selection
  - Isolated photon with $5 < E_T^{\gamma} < 10$ GeV and $-0.7 < \eta^{\gamma} < 0.9$ ($Q^2 < 1$ GeV)
  - $134 <$ W < 285 GeV
  - When a jet was demanded, $E_T^{jet} > 5$ GeV , $-1.5 < \eta^{jet} < 1.8$

Systematic Uncertainties

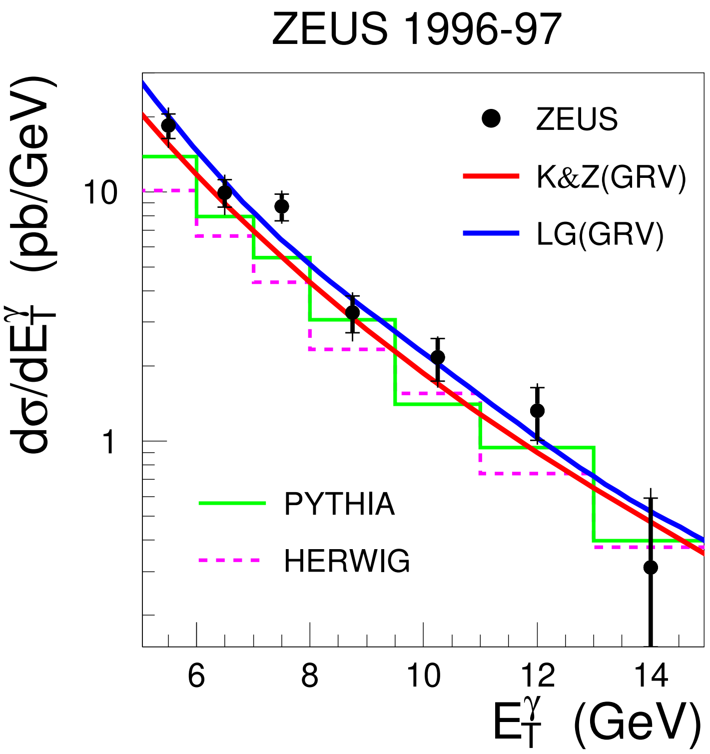
- The following sources of systematic error were taken into account
  - Calorimeter energy scale ($\pm 3\%$) $\Rightarrow \pm 7\%$
  - Modelling of the shower shape $\Rightarrow \pm 8\%$
  - Kinematic cuts $\Rightarrow \pm 5\%$
  - $\eta/(\eta + \pi^0)$ ratio $\Rightarrow \pm 2\%$
  - Vertex cuts $\Rightarrow \pm 4\%$
  - Others $\Rightarrow \pm 1\%$ level
    HERWIG 5.9 for correction factors
    Varying the E_T of Single Particle MC
    Varying the radiative process fraction
- The individual contributions were combined in quadrature to give the total systematic uncertainties

$$\boxed{\text{Total Systematic Uncertainty} \sim \pm 15\%}$$

Cross Section Measurement

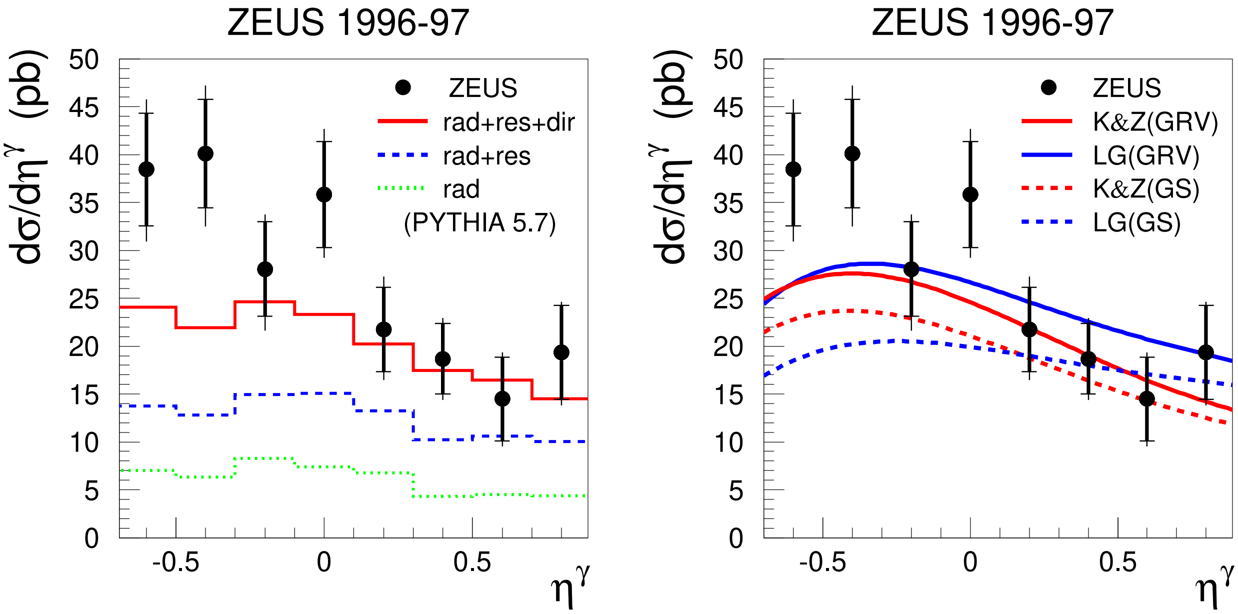
- Inclusive Prompt Photons
  - $d\sigma/dE_T^{\gamma}$, $d\sigma/d\eta^{\gamma}$
- Prompt γ + Jet Production
  - $d\sigma/dE_T^{\gamma}$, $d\sigma/d\eta^{\gamma}$
  - x_{γ}^{meas}

Inclusive $d\sigma/dE_T^\gamma$ for Prompt γ Production



- NLO parton–level calculations
  - L.Gordon ⇒ $\Lambda_{\overline{MS}} = 200$ MeV (5 flavours)
  - Krawczyk & Zembrzuski ⇒ Box diagram, $\Lambda_{\overline{MS}} = 320$ MeV (4 flavours)
- All theoretical models describe the shape of the data well. PYTHIA does fairly well, HERWIG is a little low in magnitude
- NLO calculations give better agreement

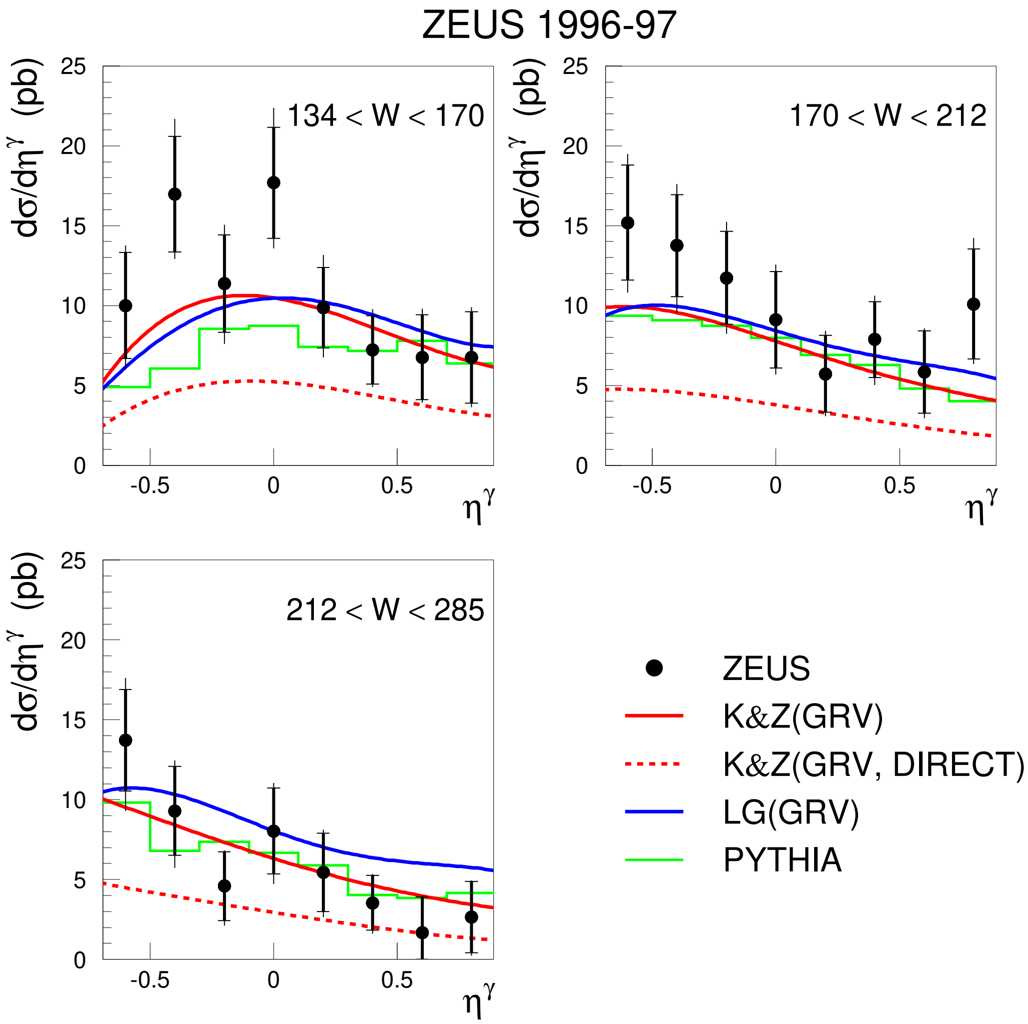
INCLUSIVE $d\sigma/d\eta^\gamma$ FOR PROMPT γ PRODUCTION



- Using GRV in photon, PYTHIA gives a good description of data for forward η^γ
- All NLO describe the data well for $\eta^\gamma > 0.1$ but are low at more negative η^γ
  (GRV photon structure apparently favoured)
- For forward η^γ (proton direction) good agreement is found, but in the rear direction all predictions lie below the data

SIGNS OF A DISCREPANCY ?

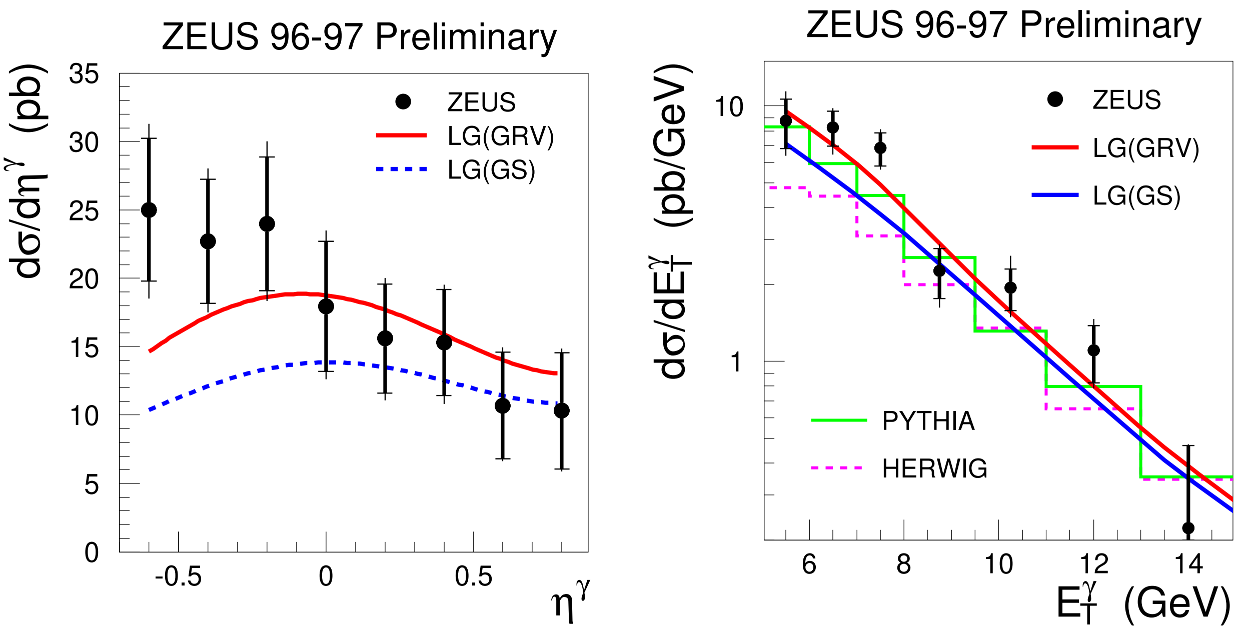
Inclusive $d\sigma/d\eta^\gamma$ for Prompt γ Production



- Divide the γ energy range into 3 bands
- Discrepancy between data and theory at negative η^γ is found to be strongest at low W
- By varying the theoretical parameters in K&Z, discrepancy could correspond to insufficient x_γ partons in resolved γ

Cross Sections for γ + Jet Production

- Look at events in more detail

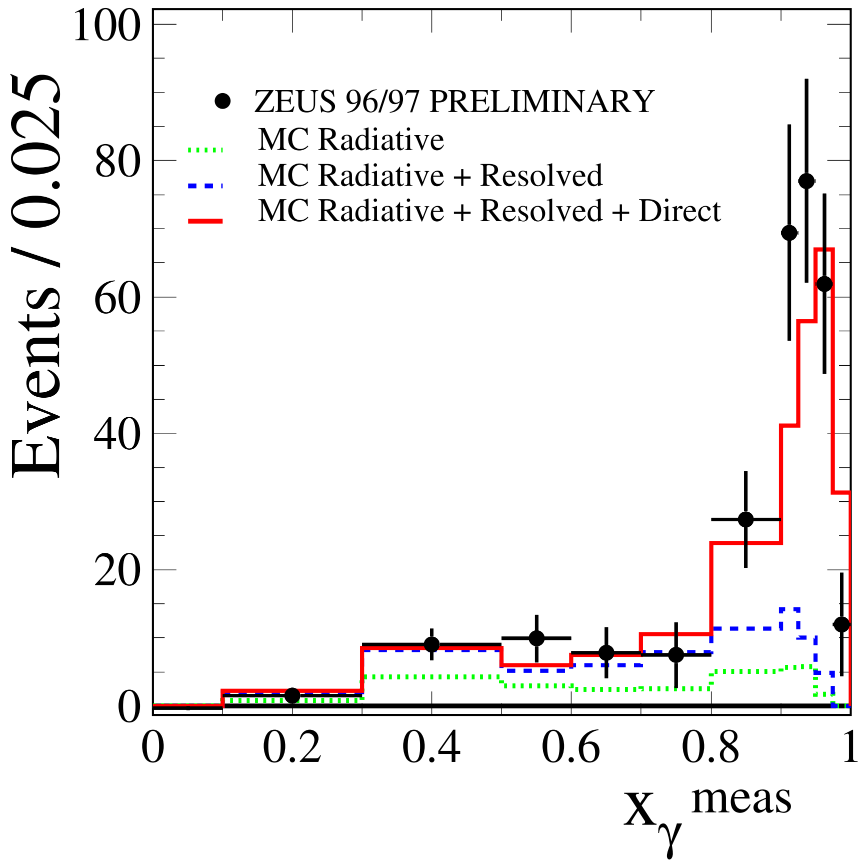


- Additional requirement for jet ($E_T^{jet} > 5$ GeV)
- Both the measured and theoretical distributions were found to be of a similar shape to those of inclusive γ production
  $\Rightarrow$ but less strong discrepancy

PROMPT γ + JET

CAN USE γ+JET EVENTS TO EVALUATE

x_γ^{meas} $(= \sum_{\gamma+jet}(E - p_z) \;/\; \sum_{all}(E - p_z))$



- x_γ = fraction of incoming γ energy taking part in the hard interaction
- Clear peak near $x_\gamma = 1$ corresponding to Direct Compton process ($\gamma q \rightarrow \gamma q$)
- PYTHIA gives a reasonable description
- There is resolved contribution in x_γ, observations are consistent with MC

Conclusions

- The $d\sigma/d\eta^{\gamma}$, $d\sigma/dE_T^{\gamma}$ for the (1) inclusive photon and (2) photon + a jet have been measured using 96–97 ZEUS data (36.7 pb^{-1})
  $\Rightarrow$ ZEUS Inclusive prompt γ ; PLB 472 (2000)

- Comparisons are made with predictions from PYTHIA, HERWIG and two NLO parton level calculations

- Measured cross sections are generally described by LO and NLO QCD calculations over forward rapidities, but there is a possible discrepancy in the rear region

- Prompt γs in Photoproduction at HERA shows strong Direct Compton signals in γ + jet events

Outlook

- Better statistics soon available to give better guidence to theory
- Recent experiments have questioned current pQCD description of high p_T prompt γ production. eg) E706, CDF, D0 etc ...
- Suspected origin of the disagreements is from effects of initial–state soft–gluon radiation, parton–k_T effects
- Have started to study intrinsic k_T effects in prompt γ + jet production at HERA
- Prompt γ is a powerful tool to study partonic nature of matter at HERA