Prompt Photons at HERA

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HERA/LHC Workshop 13/03/07 - Multi-jet final states and energy flows

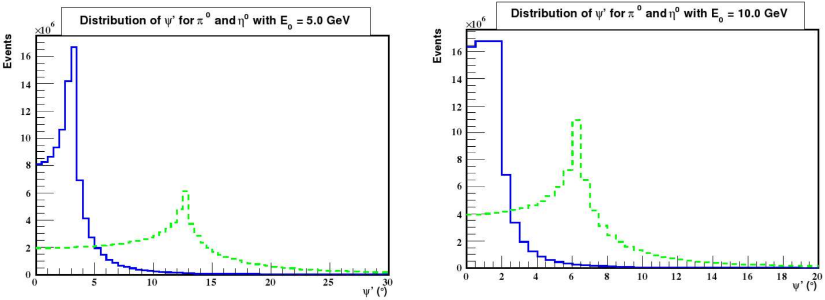
Outline

Prompt Photon Introduction

- A prompt photon is defined experimentally as a an isolated, high p_T photon.
- Studies of prompt photons can allow precision testing of QCD.
- Photons can be measured more precisely than hadronic jets - Nice for Experimentalists.
- Photons are not QCD objects themselves so are not subject to higher order effects and can be calculated within QED - Nice for Theorists.
- Prompt photon studies can be used to constrain the gluons pdfs, particularly if forward region can be accessed.
- There has been a new prediction by Gehrmann-De Ridder *et al* for the quark-to-photon fragmentation function (hep-ph/0604030). This has not been measured since LEP.

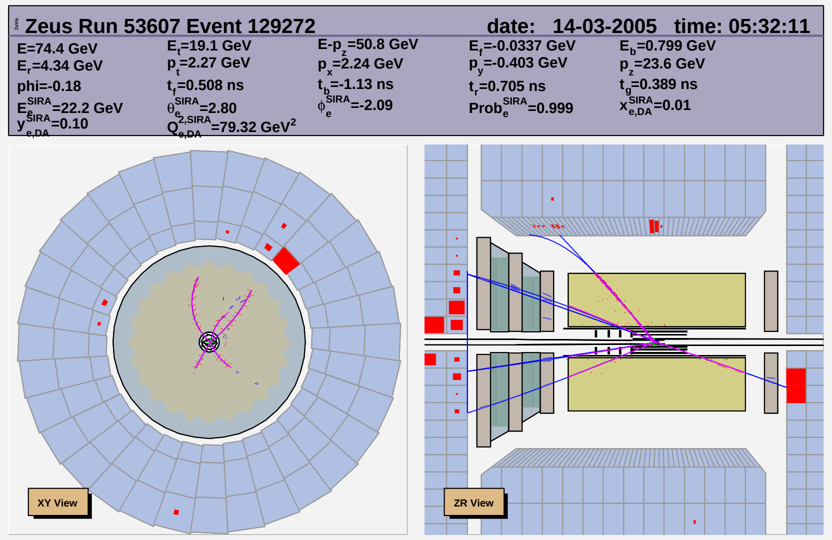
Background Considerations

- The main background to prompt photon studies is neutral mesons which decay to photons, namely π^0 and η mesons.
- The higher the energy of the meson, the smaller the opening angle between the decay photons.



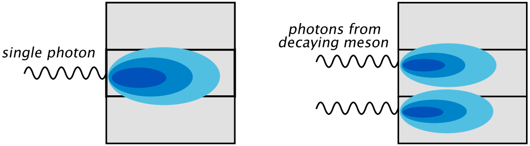
Most of these mesons originate from jets so imposing isolation criteria reduces this background significantly but not completely.

Candidate Event



Photon/Meson Discrimination

- We require good discrimination between prompt photons and isolated neutral mesons decaying to photons with small opening angles.
- The mesons will decay into at least two photons which will produce a wider shower in the calorimeter.



- Commonly used method is to define shower shape variables which exploits knowledge of the energy deposits in the electromagnetic calorimetry to quantify the width of the shower.
- At ZEUS we use f_{max} and $\langle \delta z \rangle$.

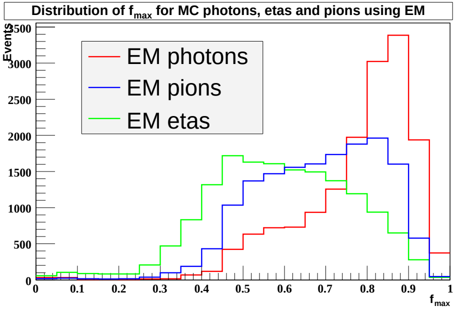
Shower Shape Variables at ZEUS

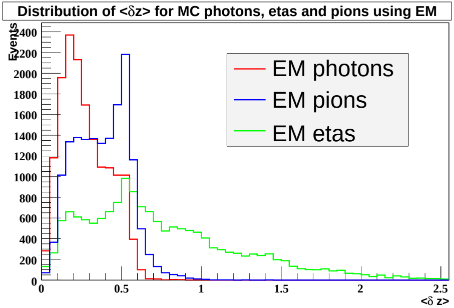
f_{max}

$$\frac{\text{Energy in most energetic BEMC cell}}{\text{Total energy of cluster}}$$

$\langle \delta z \rangle$

$\langle \delta z \rangle$ is defined as the energy-weighted width in the z-direction





The Barrel Presampler

The Barrel Presampler is a scintillation detector which sits immediately in front of the BCAL.
Its readout signals are dependant on the number of particles passing through it (MIPs), not the energy of the particles.

- Isolated photons will give predominently low MIPs signal.
- Neutral meson background will give higher MIPs signal due to their many photon decay states.

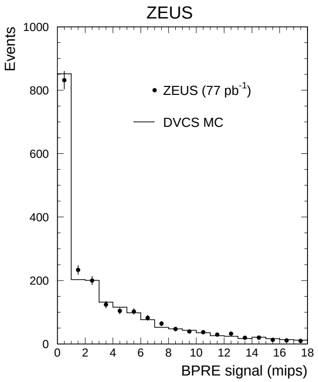
Prompt photon candidates are selected as

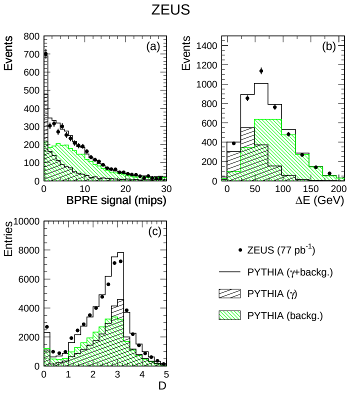
- k_T jets in the BCAL
- Low multiplicity
- $E_{EMC}/E_{Total} \geq 0.9$
- No associated track

BPRES signal extraction

Inclusive Monte Carlo (without prompt photon emission) is used to model hadronic background.

BPRES signal is extracted by fitting prompt photon Monte Carlo and inclusive background on a bin-by-bin basis for E_T and η.

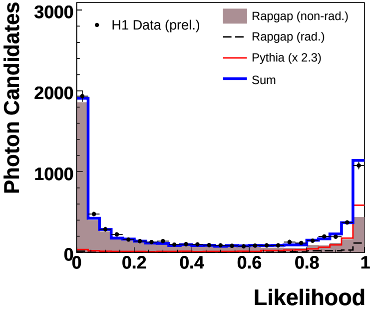




Shower Shape Variables at H1

H1 have different granularity in their calorimetry and use 6 shower shape variables.

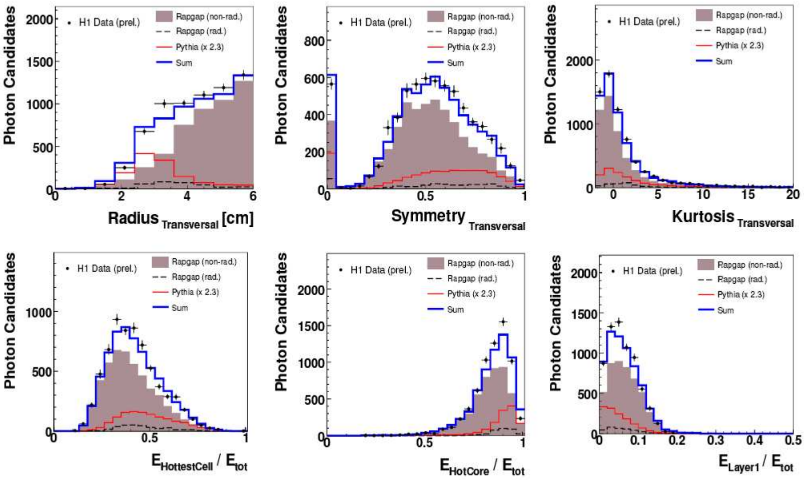
- Transverse Radius
- Transverse Symmetry
- Transverse Kurtosis
- Fraction of energy in most energetic cell
- Fraction of energy in 'Hot Core'
- Fraction of energy in first layer



Nice separation in Likelihood Method.

Shower Shape Variables at H1

Discriminating Cluster Variables



Photon/Neutral Pion separation at the LHC

Decaying meson will have very much smaller opening angles due to higher energies.

Calorimeter granularity will become finer (from about 5cm to about 2 cm).

But this will not be enough to rely on transverse shower shape variables alone.

Added discrimination will come from the trackers identifying charged particles from early photon conversions and longitudinal measures.

At ATLAS this gives background rejection factors of order 10^3 at about 80% efficiency.

How would you then extract a signal?

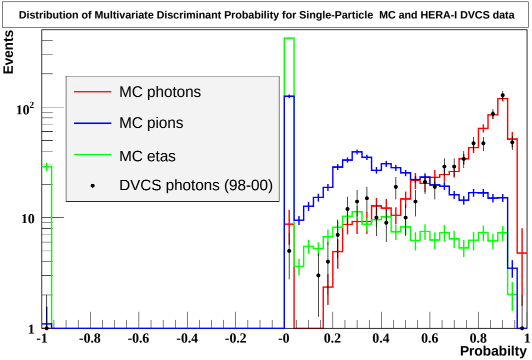
Multivariate Discriminant Method

It is intended to apply a new statistical method to extract a prompt photon signal from the neutral meson background by using a quantity known as a *Multivariate Discriminant*. In general this uses information from N variables to produce the individual probabilty that a particle is signal or background. All variables are treated equally but correlations between variables are taken into acount. The current plan is to use 5 variables,

- $f^{\gamma}_{\mathrm{max}}$ -shower shape variable
- $\langle \delta z \rangle^{\gamma}$ -shower shape variable
- BPRE mips
- Transverse energy E^{γ}_{T}
- Pseudo-rapidity η^{γ}

Discriminant Method

- Distribute large single particle MC of γ and background in N-dimensional space (one dimension per variable).
- Evaluate probability of a particle being γ or background by considering a box in N-dimensional space, counting the number of γ and background MC particles in the box.



No BPRE info yet.

Prompt Photon Cross Sections

Prompt photon cross sections are considered a sensitive test of QCD.

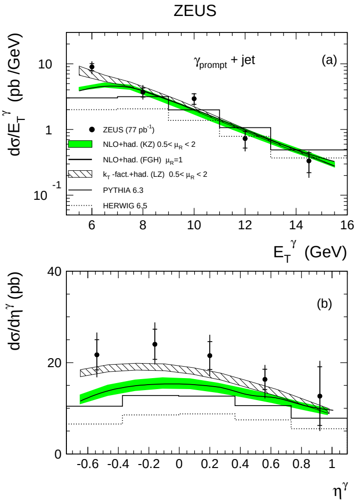
Compared to jet measurements:

- Cross sections are smaller $\Rightarrow$ Larger Statistical Uncertainty.
- Measured more precisely $\Rightarrow$ Smaller Systematic Uncertainty.

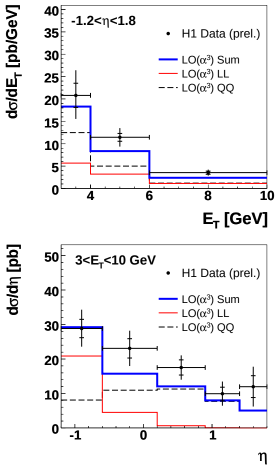
Understanding Prompt Photon cross sections is important for the low mass Higgs at LHC. Prompt photons are an irreducible background for $H \rightarrow \gamma\gamma$.

Cross Sections at HERA

ZEUS Photoproduction 2004
(hep-ex/0608028)

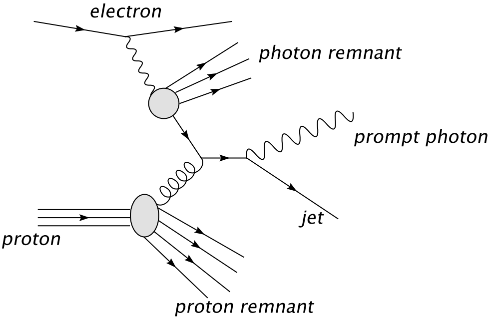


H1 DIS 2006
(preliminary hep-ex/0607093)



Constraining the Gluon

Resolved photoproduction is sensitive to the gluon content of the proton by this diagram ($g^P + q^\gamma \rightarrow \gamma + jet$).



By studying optimised cross sections it is possible to enhance this diagram.
M. Fontannaz and G. Heinrich detail two cuts do this (hep-ph/0312009).

Observables - x_{LL}

Previously the longitudinal momentum fraction from the parton in the proton and photon had been described by x^P_{obs} and x^γ_{obs}.

x^P_{obs}

$$\frac{p^\gamma_T e^{\eta^\gamma} + E^{jet}_T e^{\eta^{jet}}}{2E^P}$$

x^γ_{obs}

$$\frac{p^\gamma_T e^{-\eta^\gamma} + E^{jet}_T e^{-\eta^{jet}}}{2E^\gamma}$$

But uncertainty in jet energies is high. At leading order photon momentum and jet energy should be the same

$\rightarrow$ Replace E^{jet}_T with p^γ_T

x^P_{LL}

$$\frac{p^\gamma_T (e^{\eta^\gamma} + e^{\eta^{jet}})}{2E^P}$$

x^γ_{LL}

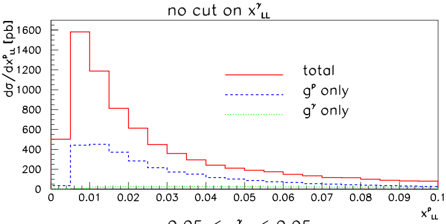
$$\frac{p^\gamma_T (e^{-\eta^\gamma} + e^{-\eta^{jet}})}{2E^\gamma}$$

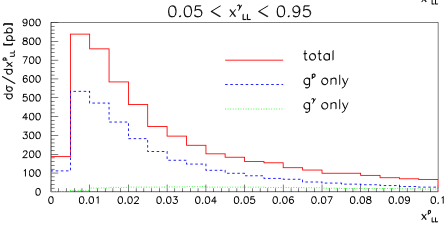
Optimising Cuts - x_{LL}^{γ}

Cutting $0.05 < x_{LL}^{\gamma} < 0.95$ significantly increases contribution from $g^P + q^{\gamma}$

$0.05 < x_{LL}^{\gamma}$ reduces contribution from the gluon in the *photon* and the larger uncertainty that this brings.

$x_{LL}^{\gamma} < 0.95$ removes direct initial state photons which correspond to low x_{LL}^{P}



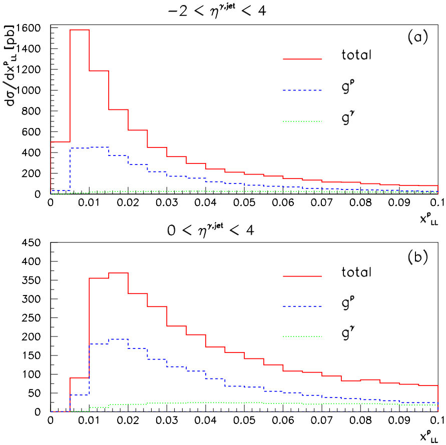


Optimising Cuts - Rapidity

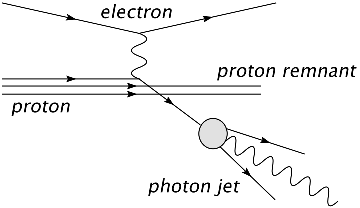
It is also possible to improve the contribution from $g^P + q^\gamma$ by imposing the rapidity restriction $0 < \eta^{\gamma,jet} < 4$.

These cuts increase the $g^P + q^\gamma$ contribution from 35% to 48% but with about a 70% reduction in the cross-section

The x_{LL}^γ cuts increase the contribution from 35% to 56% for only a 31% decrease in cross section



Quark-to-Photon Fragmentation



Usually quark-to-photon contribution is supressed by imposing $z > z_{cut}$ where,

z (photon energy fraction)

$$z = \frac{E_\gamma}{E_\gamma + E_{had}}$$

Note $z_{cut} < 1$ to ensure infrared finiteness.

Quark-to-Photon Fragmentation Function

AT HERA we require $z > 0.9$.

By loosening this cut a measurement of the Quark-to-Photon fragmentation function can be made. This has not been measured since LEP.

The is a recent prediction from A. Gehrmann-De Ridder, T. Gehrmann and E. Poulsen for $0.7 < z < 1$ and HERA kinematics.

Measuring this would require an exprimental re-think.

- Selection would be for *photon jets*.
- Shower shape variables would be less useful due to hadronic activity.
- Barrel Presampler, jet multiplicities and energy fractions would be useful.

Conclusions

- At high energies prompt photons measurements are challenging but possible.
- Prompt photon cross sections should be well understood and implemented in Monte Carlo for effective $H \rightarrow \gamma\gamma$ searches. HERA measurements will facilitate this.
- HERA prompt photon measurements can constrain the gluon pdf, reducing the error on Large 'Gluon' Collider cross sections.
- The quark-to-photon fragmentation can and should be measured at HERA.