Prompt photons with associated jets in photoproduction at HERA

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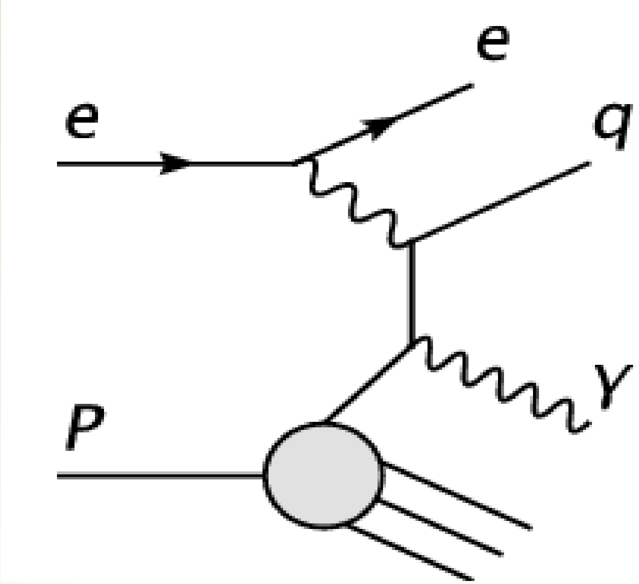
Prompt-photon production

- **Sensitive to quark and gluon densities**
- **Several QCD calculations can be confronted with the data**
  - NLO QCD, k_T-factorization, Monte Carlo models (LO+PS)
- **Avoid systematics associated with jet identification and measurement**
  - photons are simple, well measured EM objects
  - emerge directly from the hard scattering without fragmentation
    - no need for “hadronisation” corrections at low transverse momenta



Still experimentally challenging measurement:

- large background expected from fragmentation (decays of π^0, η,)
- must be subtracted on statistical basis for data
- conventional isolation requirement: $E_T^{\gamma(true)} > 0.9\ E_T$

γ+jet final state

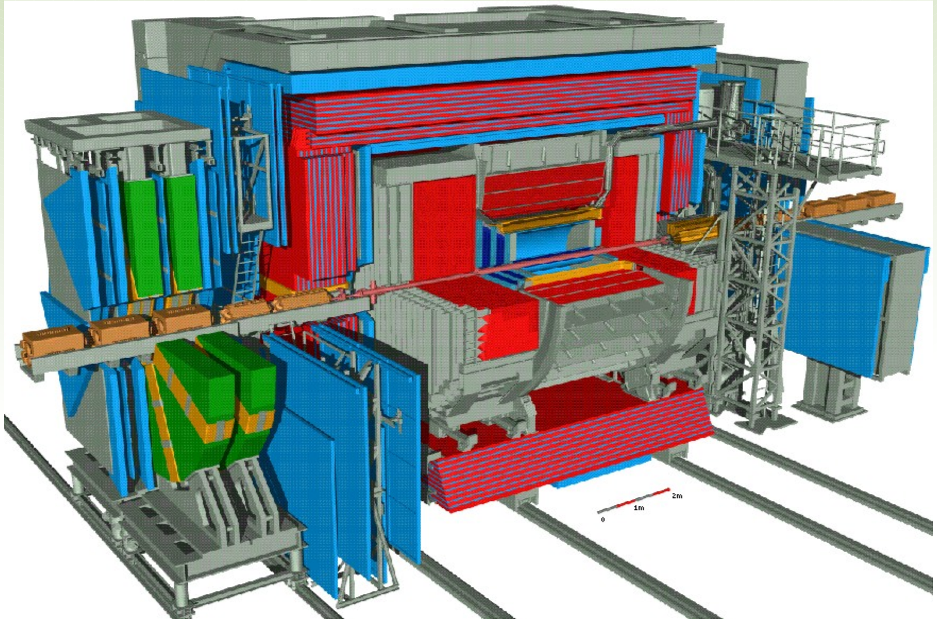
Look at γ+jet topologies: $e + p \rightarrow e + \gamma(prompt) + jet + X$

- **Expected to be more sensitive to the underlaying partonic process than the inclusive prompt photons**
- **Hadronisation corrections are smaller than for dijets at similar E_T**

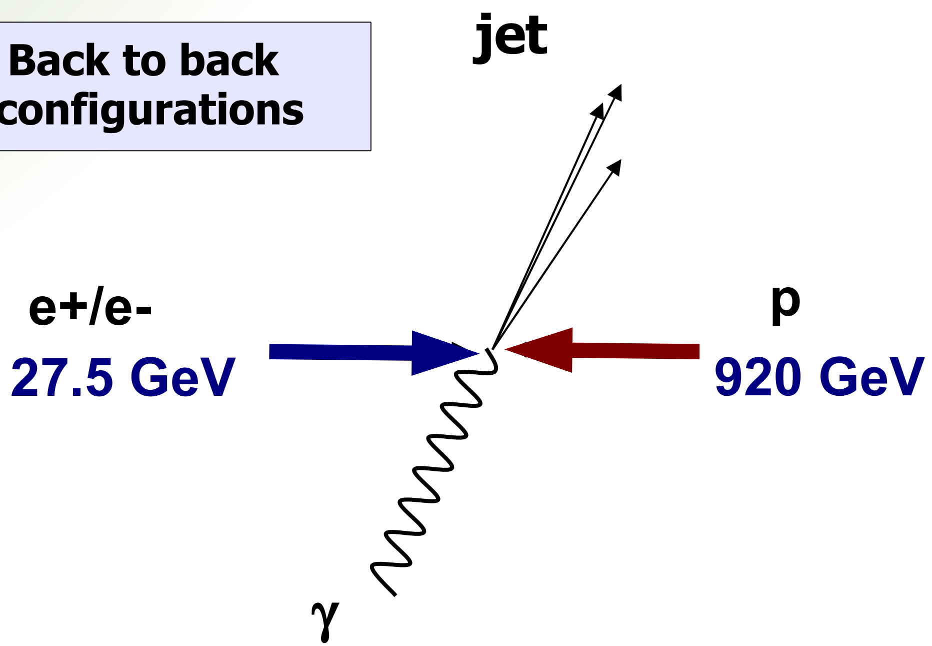
  - more reliable predictions

- **Experimentally, very clean signatures**

  - jet should balance EM object in P_T



Back to back configurations



QCD predictions

NLO QCD

Collinear factorisation

- dominant contribution from diagrams where partons are strongly ordered in virtualities.
- DGLAP evolution for PDF

- K.Krawczyk & A.Zembrzuski (KZ)
  - (not all) NLO corrections
  - resolved & direct contributions
  - GRV PDF
- Fontanaz, Guillet, Heinrich (FGH)
  - full NLO corrections for resolved component
  - MST01 proton PDF
  - AFG02 photon PDF
- $\mu_R = \mu_F = E_T^{\gamma}$ for all above

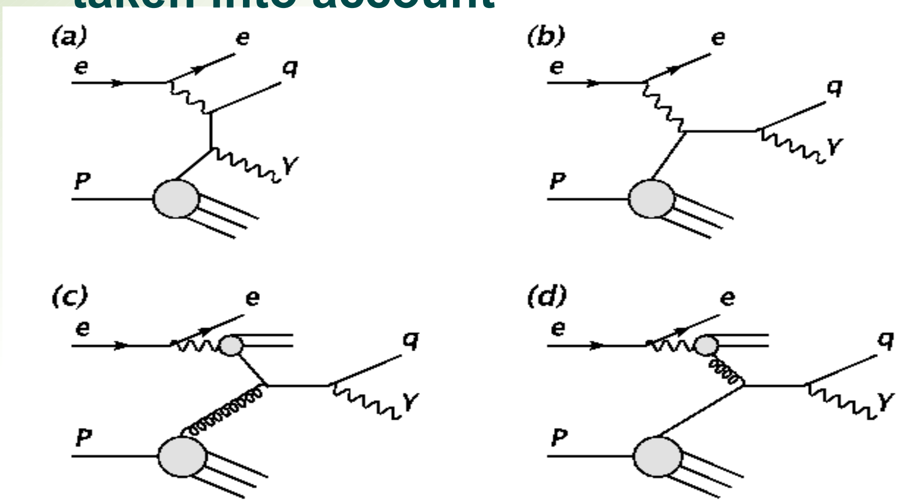
Monte Carlo models (LO+parton showers) also available: PYTHIA and HERWIG

k_T factorization QCD predictions

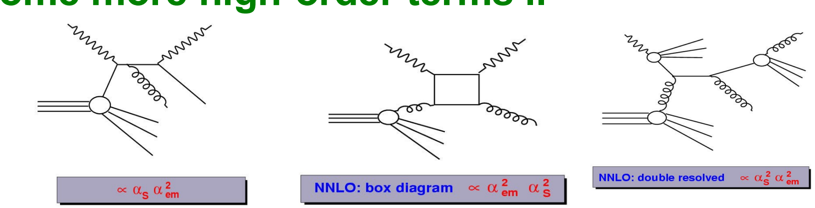
Virtualities/k_T are no longer ordered:

- Off-shell matrix elements
- Unintegrated PDF
- Kimber-Martin-Ryskin prescription for PDF

- A.Lipatov & A.Zotov (LZ)
  - Direct & resolved processes taken into account

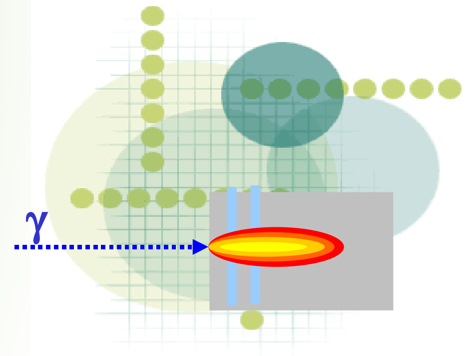


+ some more high-order terms ..

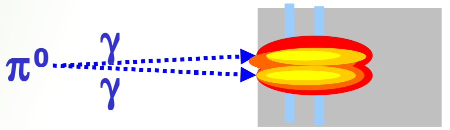


etc.

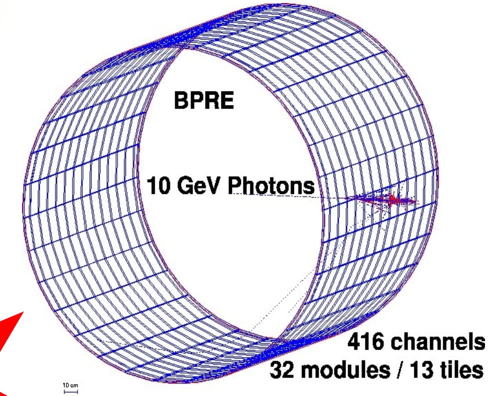
Photon reconstruction



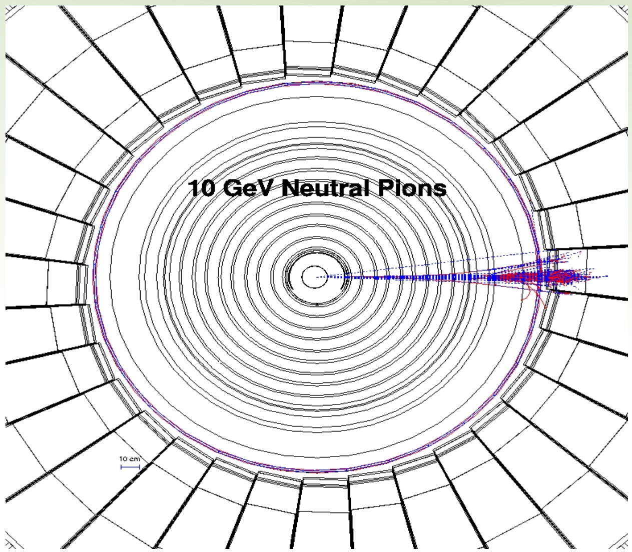
- Previous measurements based on information on shapes of calorimeter clusters associated with electromagnetic (EM) objects
  - Example: γ should have a narrower width of a EM cluster compared to contributions from π^0

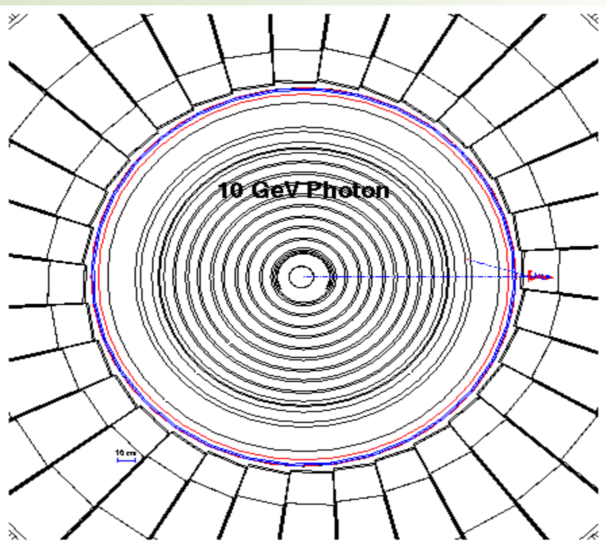


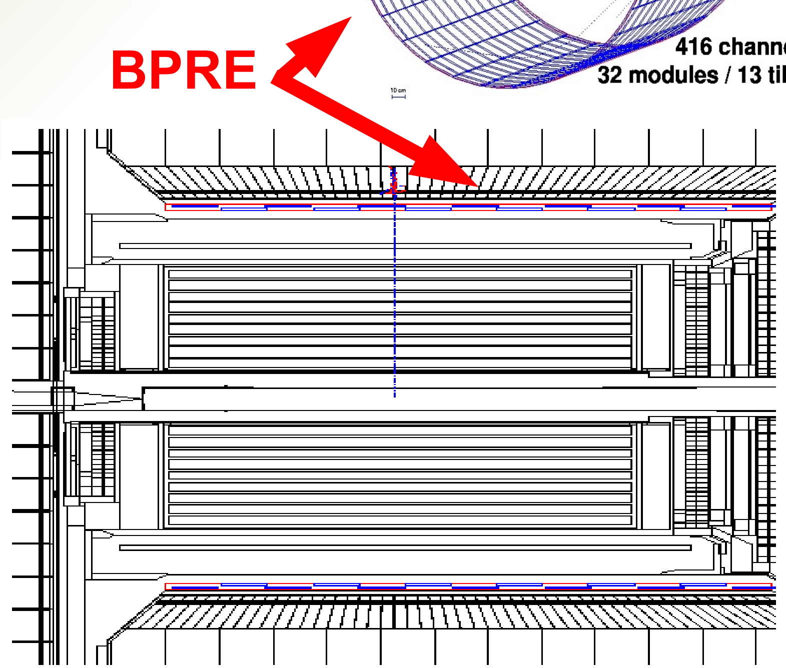
- Present measurement uses complementary information based on Barrel Preshower detector (BPRE):
  - Inactive material (solenoid) leads to conversions of γ to e+e- pairs. Conversions of π^0 and η are stronger
  - BPRE counts charged particles from γ conversions. Low mip signal is used to distinguish between γ and hadrons (on a statistical basis)



Geant simulation: isolated π^0 and γ

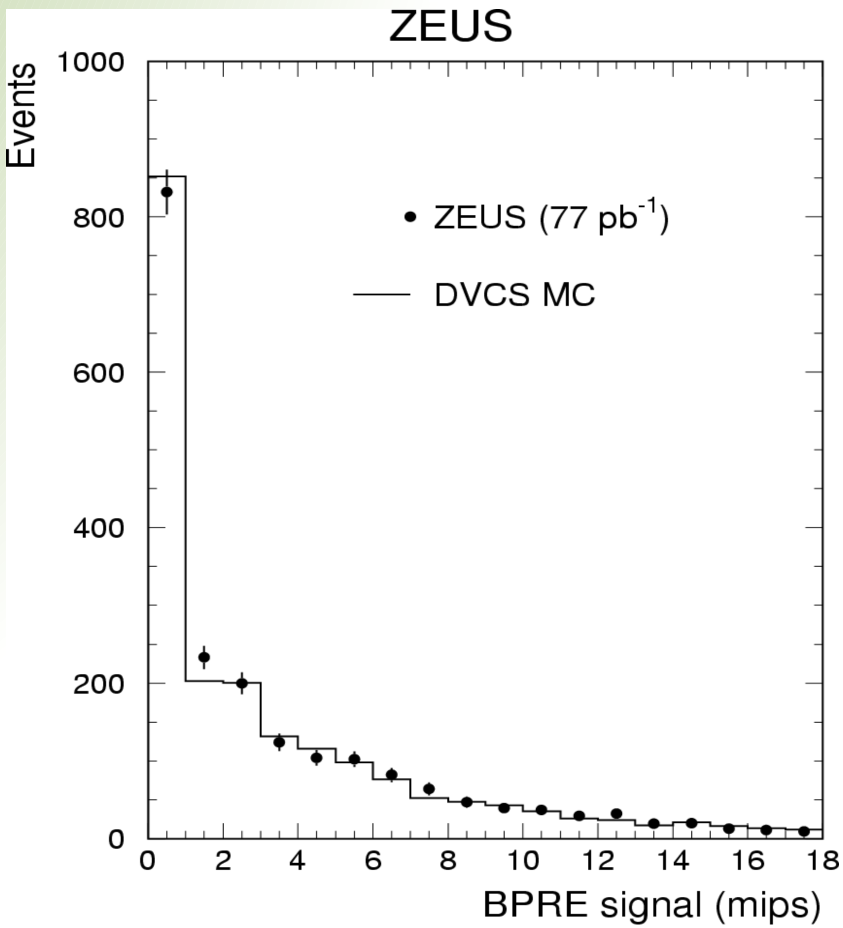






Identification of isolated photons

- Verify BPRE response by looking at single photons produced in the deeply virtual compton scattering (DVCS):
  - $ep \rightarrow \gamma e' p$
- Reconstruct isolated γ using the same reconstruction method as for γ+jet analysis
- Fraction of events without conversions is similar to the expectation for ~1X0 (~40%)
- Signal for isolated π^0 is by a factor 2 larger
- Dead-material map had to be tuned to obtain good agreement between data and MC



Data sample

Selected events:

- 77 pb^{-1}
- $Q^2 < 1\ GeV^2$
- $0.2 < y < 0.8$

~4000 candidate events

Reconstruction:

- Use Energy-Flow Objects (EFO)
- Reconstruct > 1 jets using longitudinally-invariant k_T algorithm
- γ candidates:
  - large electromagnetic fraction $E^{EMC}/E^{tot} > 0.9$
  - $E_T > 5$ GeV $-0.74 < \eta < 1.1$
- Associated jet:
- $E_T > 6$ GeV $-1.6 < \eta < 2.4$
- $E^{EMC}/E^{tot} < 0.9$

Detector correction:

- correct data using a MC
- assume isolation $E_t^{\gamma(true)} > 0.9 E_T$ requirement
- apply parton-to-hadron correction to QCD parton predictions based on PYTHIA (due to measurement of associated jet at rather low E_T)

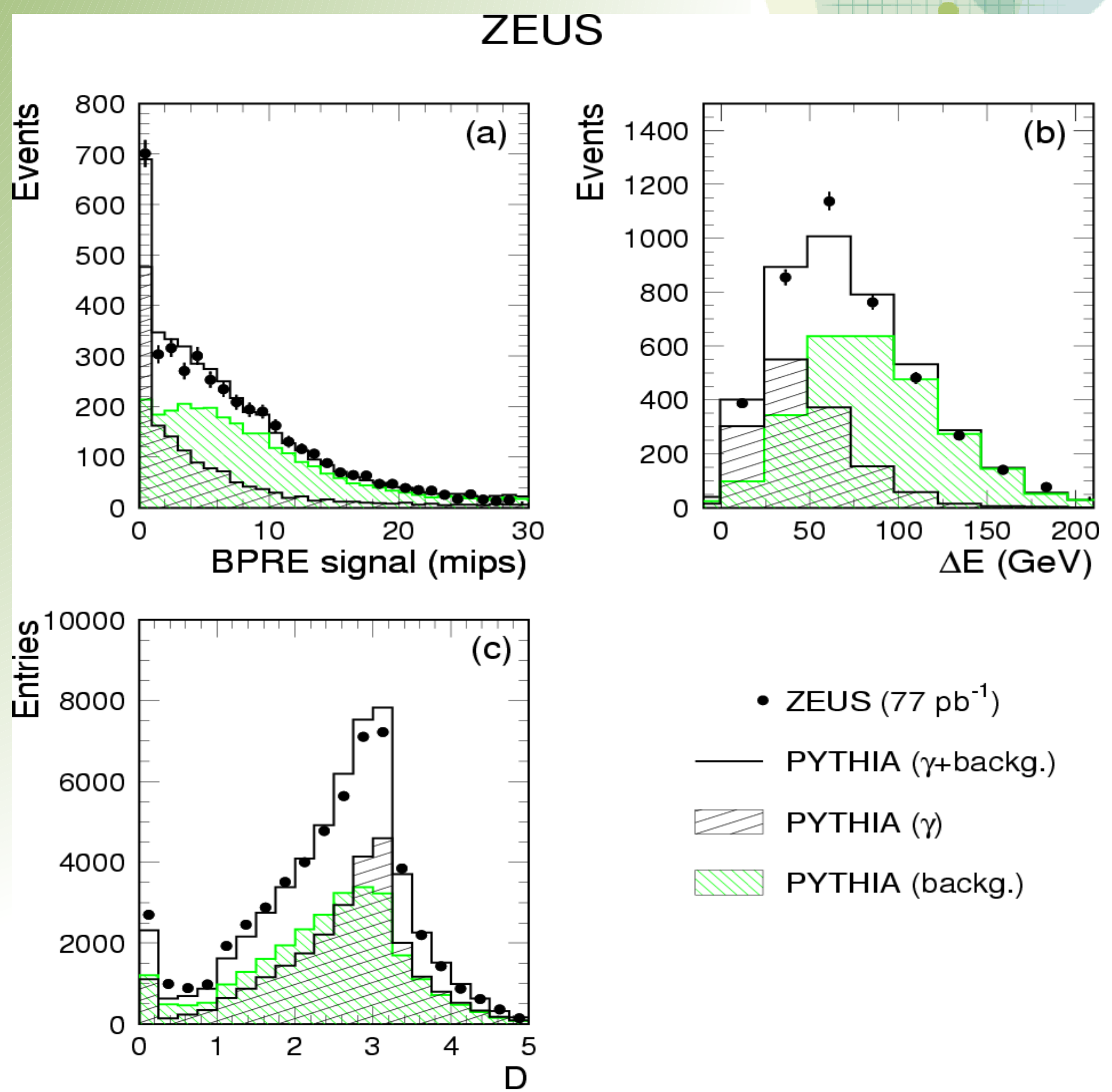
Extraction of prompt-photon signal

Based on statistical subtraction method

In each E_T & η bin, BPRE mips distribution is fitted with the signal + background from MC

- The method does not rely on transverse size of photon object in calorimeter

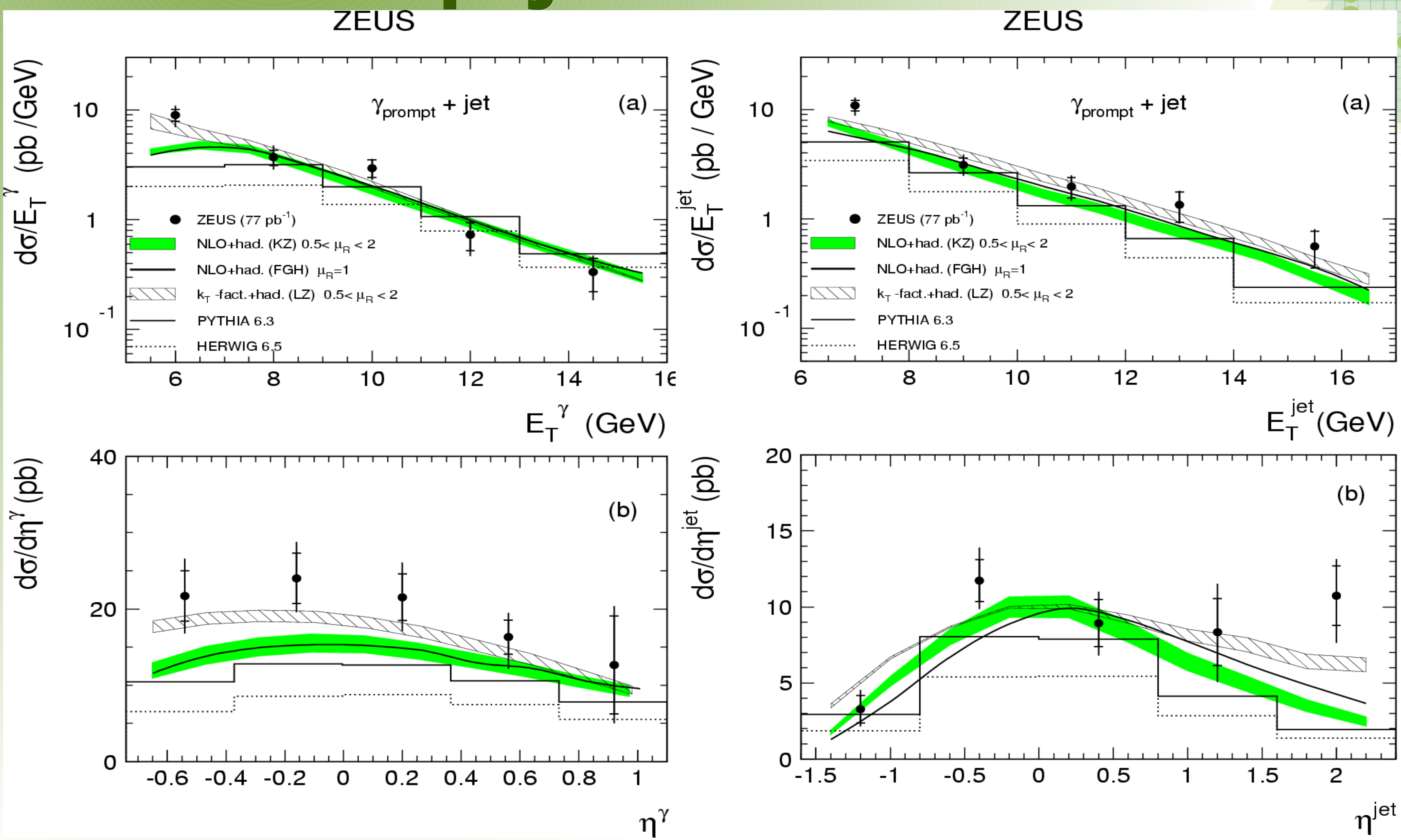
- Complimentary to H1 analysis & previous ZEUS results based on the calorimeter shape method.



Several other variables for checks:

- Distance (D) from γ-object to EFO
- Energy outside of γ+jet configuration

γ+jet cross sections



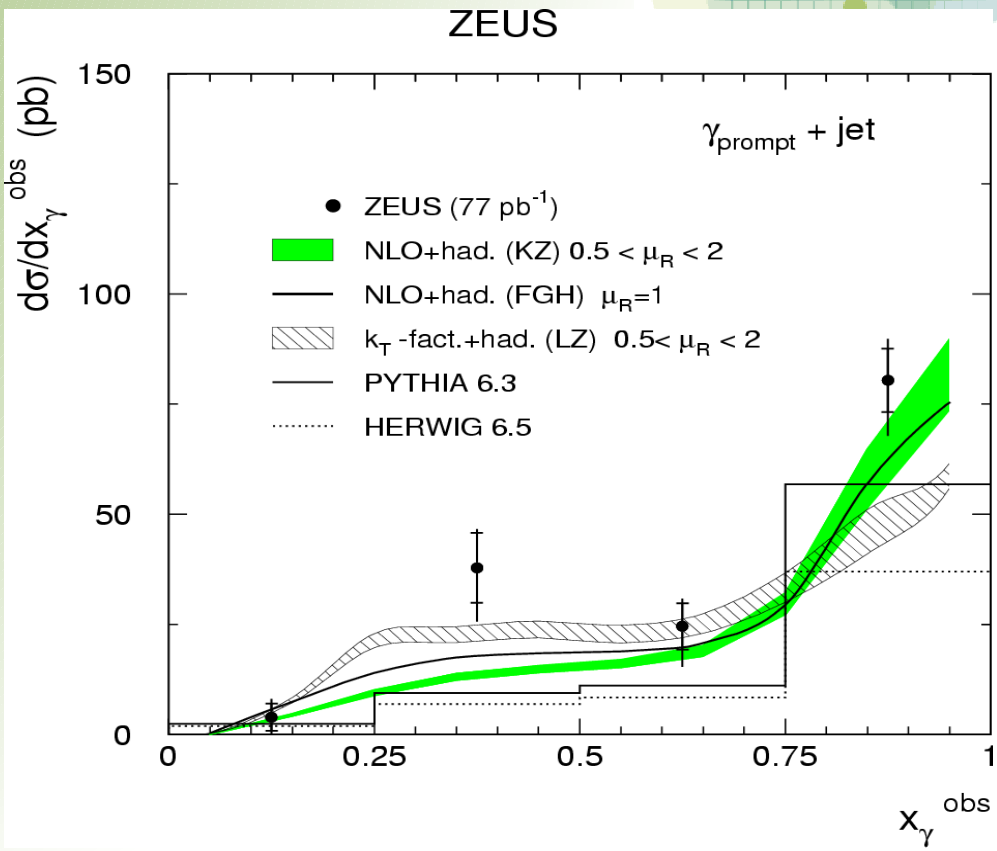
- **Both PYTHIA & HERWIG fail (both in normalization & shape)**
- **NLO QCD calculations are closer to the data, but also fail at low E_T**
- **k_T - factorization approach works the best (but somewhat larger scale uncertainty)**

γ+jet cross sections

$x_\gamma^{obs} = \sum_{jet,\gamma} (E_i - P_{Z,i}) / 2 E_e y$

fraction of the incoming γ-momentum taken by the γ-jet system

k_T- factorisation approach better describes the resolved part



Total cross-section in the kinematic region:

$0.2<y<0.8$	$E_T^{\gamma(true)} > 0.9 E_T$
$5 < E_T^\gamma < 16$ GeV	$-0.74 < \eta^\gamma < 1.1$
$6 < E_T^{jet} < 17$ GeV	$-1.6 < \eta^{jet} < 2.4$

$$\sigma(ep \to e + \gamma_{\rm prompt} + {\rm jet} + X) = 33.1 \pm 3.0\,({\rm stat.})\,^{+4.6}_{-4.2}({\rm syst.})\;{\rm pb}$$

Compare to: 23.3 pb (KZ) 23.5 pb (FGH) 30.5 pb (LZ)
(scale uncertainty ~ 2 pb for all)
Monte Carlo models: PYTHIA: 20 pb HERWIG: 13.5 pb

γ+jet cross sections

Previous phase space defined as $E^{\gamma}_{T} < E^{jet}_{T}$

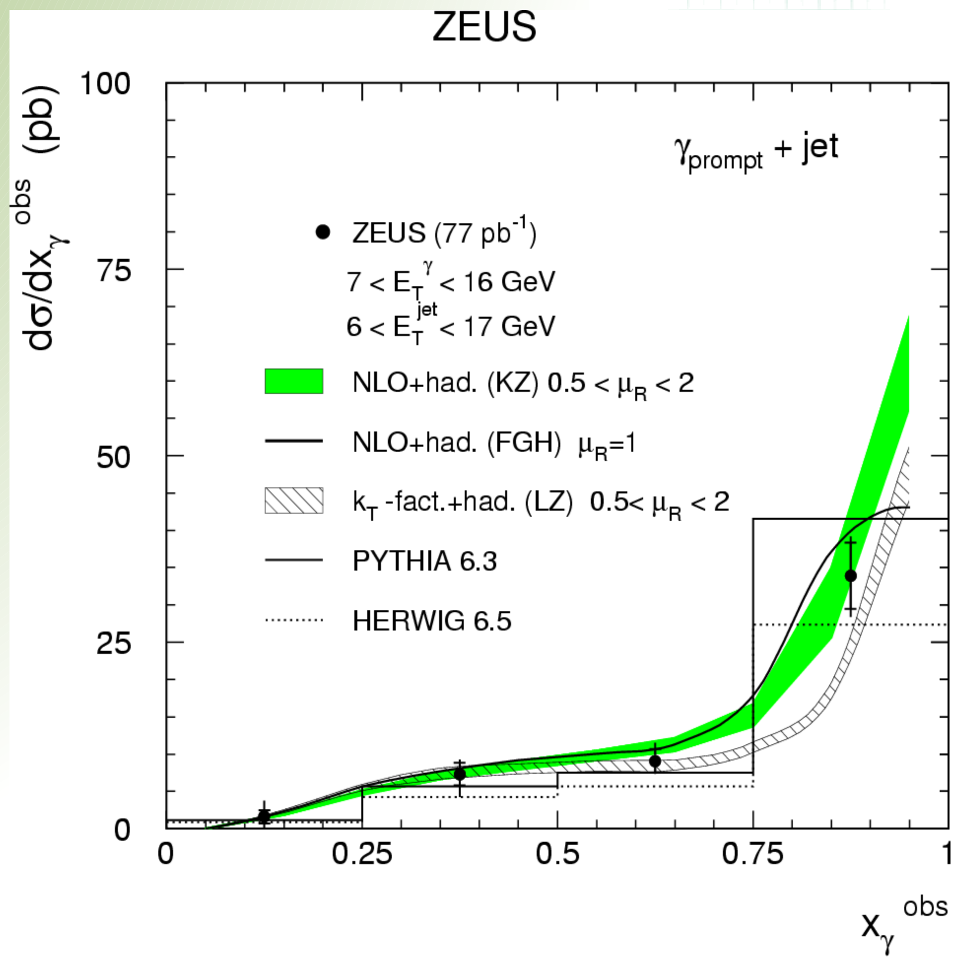
What about changing the phase space available for QCD radiation, i.e.

$E^{\gamma}_{T} > E^{jet}_{T}$?

Sensitive to different aspect of high-order QCD contributions?

Difference between the k_T factorization approach and NLO QCD is smaller for $E^{\gamma}_{T} > E^{jet}_{T}$

Both NLO QCD and k_T factorization calculations start to describe the data

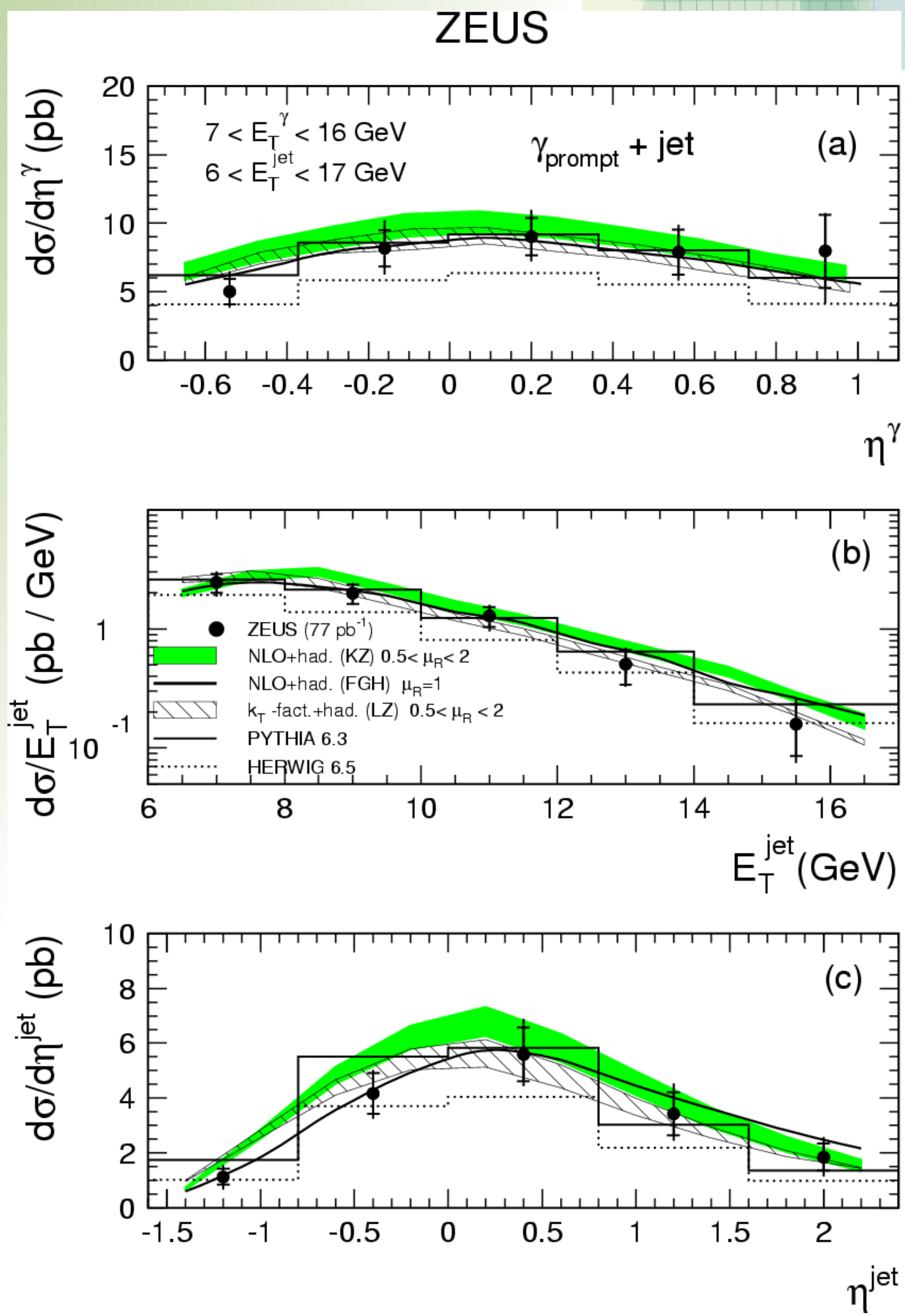


$E_T^{\gamma} > 7$ GeV
$E_t^{jet} > 6$ GeV

γ+jet cross sections

- **Same conclusion for other kinematic variables**
- **All QCD calculations describe the data well for**

$E_T^{\gamma} > 7$ GeV
$E_T^{jet} > 6$ GeV



Summary

- First measurement of prompt photons based on conversion probabilities measured using a dedicated detector (BPRE)
- PYTHIA and HERWIG have wrong shapes and normalizations
- Difference with KZ & FGH NLO QCD calculations
  - mainly in the forward-jet and low E_T region
- k_T-factorisation QCD prediction is closer to the data than NLO QCD
- If transverse-momentum cuts are changed from $E^{\gamma}_T < E^{jet}_T$ to $E^{\gamma}_T > E^{jet}_T$ all QCD calculations describe the data due to harder E^{γ}_T cut
  - different sensitivity to QCD dynamics?