Isolated photons at HERA

on behalve of ZEUS and H1

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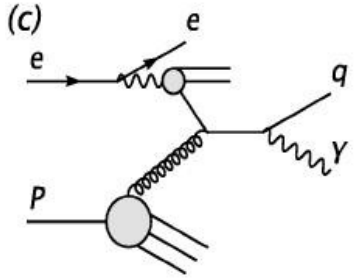
Two recent results:

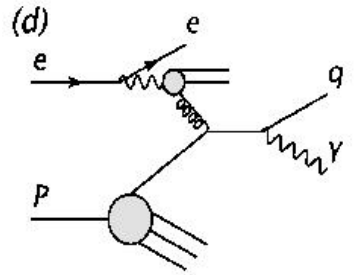
- Measurement of prompt photons with associated jets in photoproduction (ZEUS)
  [Eur. Phys. J. C 49, 511, 2007]

- Measurement of isolated photons produced in deep inelastic scattering (H1)
  [paper to be published soon]

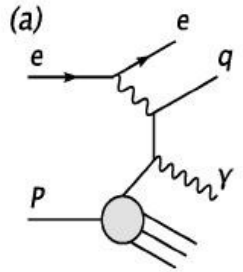
Photons in photoproduction

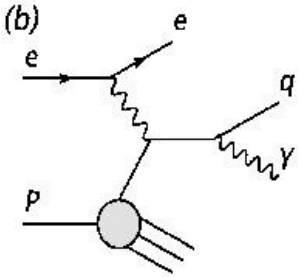
1.) Contributions from „resolved“ photon
(also sensitive to photon p.d.f.).





2.) Contributions from partons of the proton
(„direct“ photons).

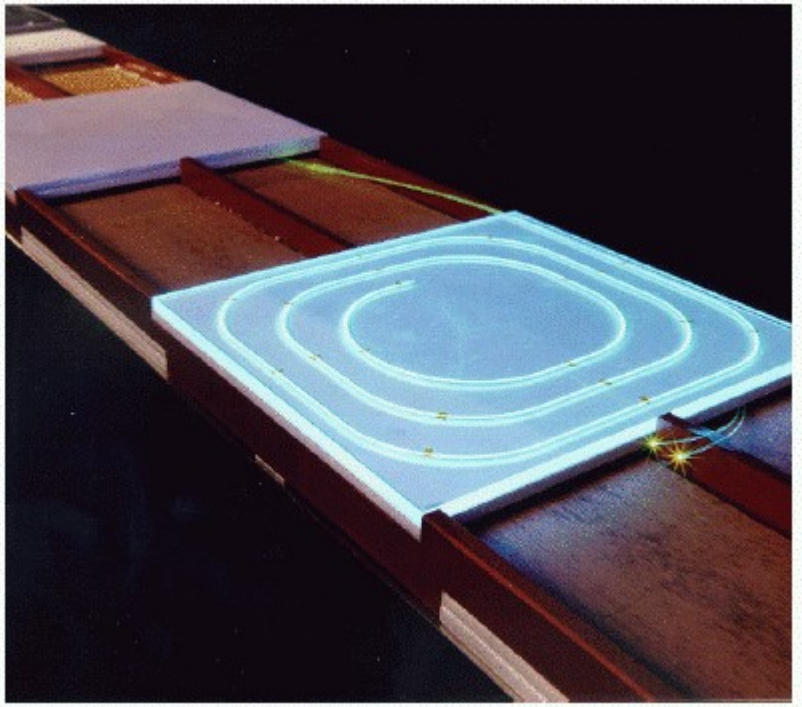




3.) Originating from hadron decays: π^0, η etc.
(treated as background).

Identification of isolated photons

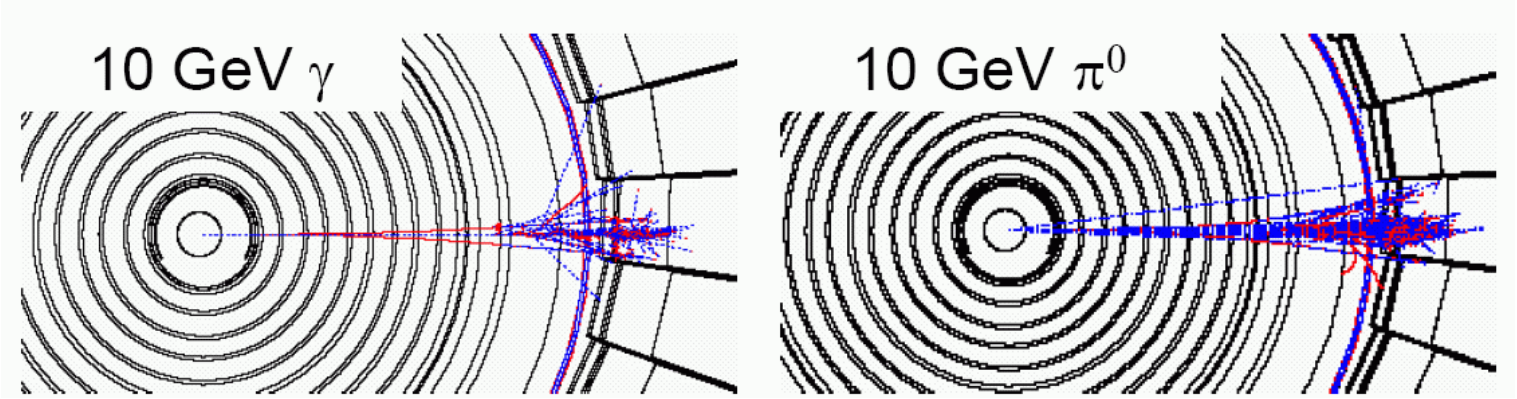
ZEUS BPRE:
Barrel PREshower detector



Scintillator tiles in front of calorimeter

- Energy in presampler is
  proportional to number of photons.
- Converted in material in front of it (about 1 X0)
- Well described by detector Monte Carlo,
  checked with QED Compton events.

→ Background separation, even at high energies.



Data selection

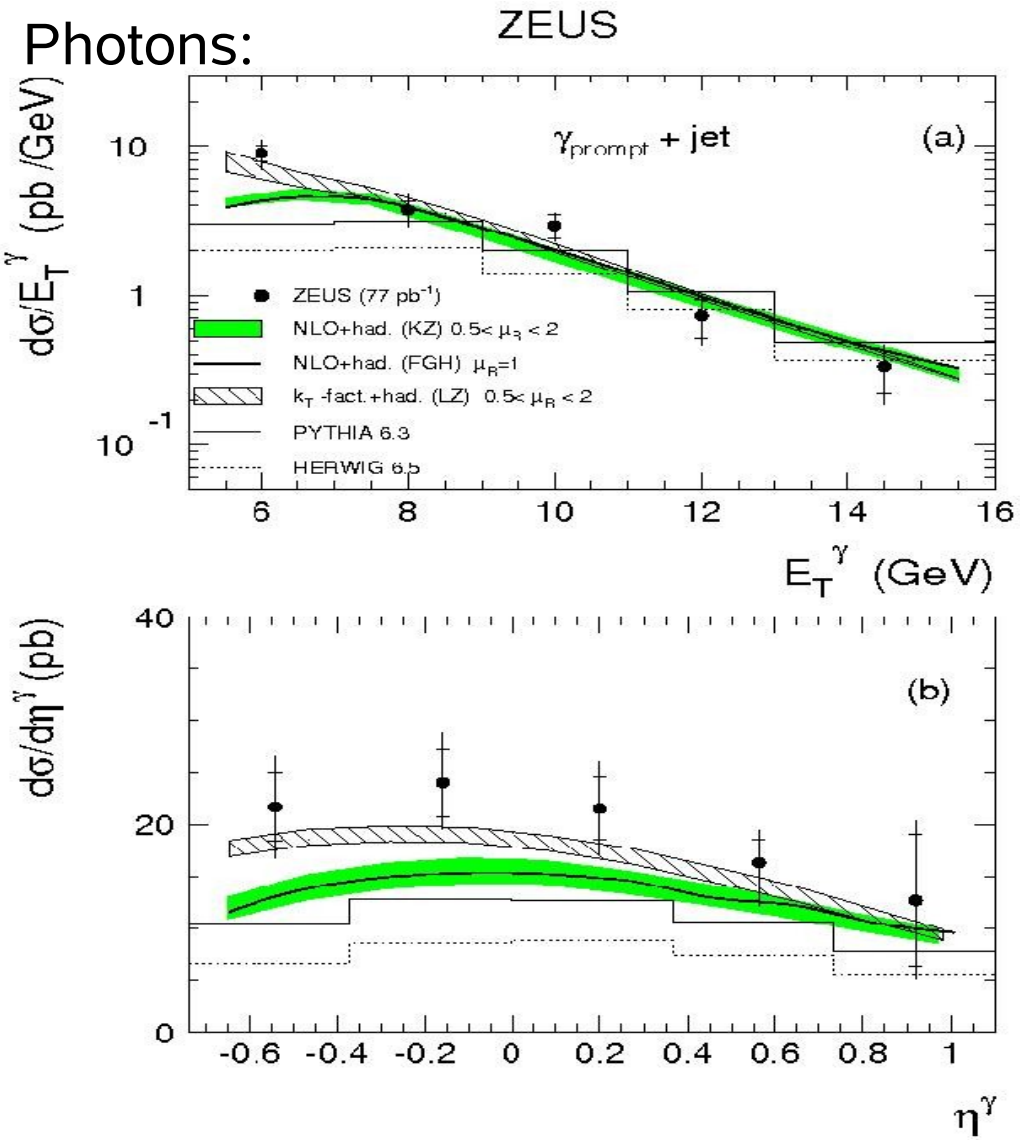
- 77 pb^{-1} from 1999-2000 run.
- Event kinematics: $Q^2 < 1\ GeV^2$, $0.2 < y < 0.8$
- Photon candidates: $E_T^{\gamma} > 5$ GeV, $-0.74 < \eta^{\gamma} < 1.1$
- Photon isolation: $E_{elm.} / E_{photon\text{-}jet} > 0.9$
- Jet reconstruction: longitudinally-invariant k_T algorithm
  $E_T^{jet} > 6$ GeV, $-1.6 < \eta^{jet} < 2.4$

Data are compared to:

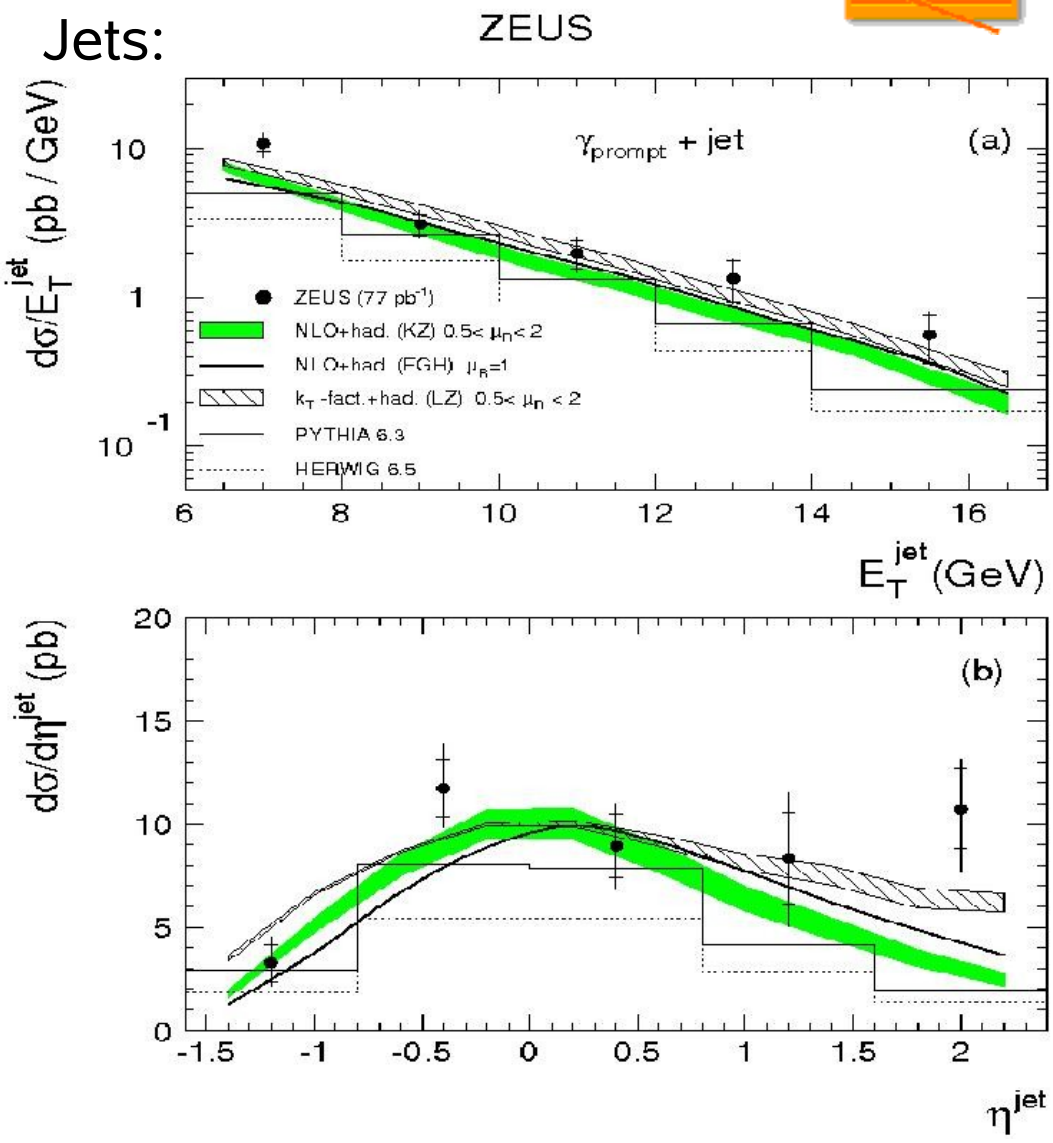
- Pythia and Herwig.
- QCD predictions:
  Two different NLO QCD predictions,
  and one predictions based on k_T factorization (Lipatov and Zotov),
  Parton-to-hadron correction based on PYTHIA.

Photon + jet cross sections

Photons:

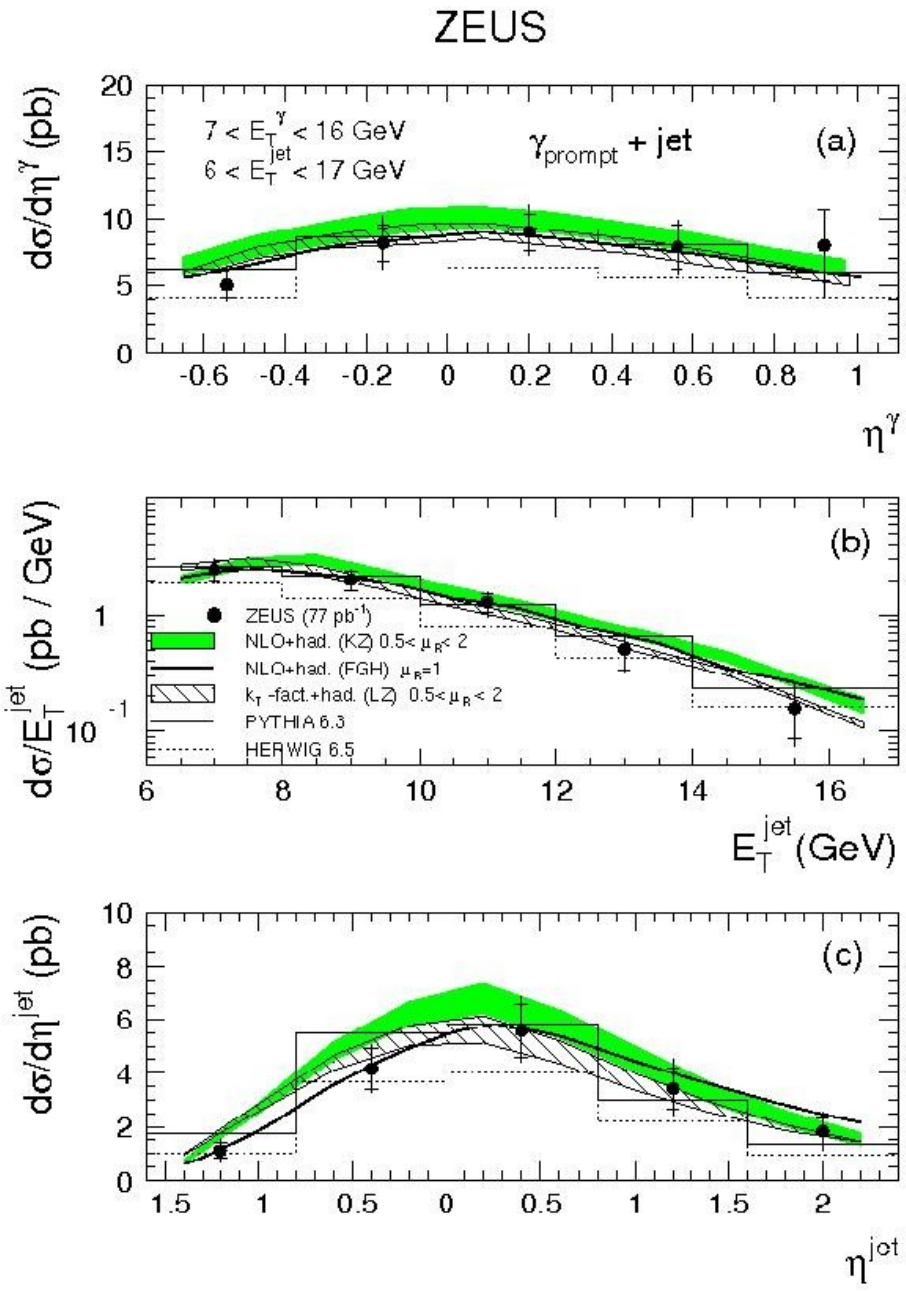


Jets:



- Reasonable agreement with newest LZ (k_T factorisation based) prediction.
- Largest discrepancies at low E_T^γ and forward jets, also between theoretical predictions.

Select photons with $E_T^\gamma > 7$ GeV



Increased cut on E_T^γ from 5 to 7 GeV (now $E_{T\ min}^\gamma > E_{T\ min}^{jet}$).

- Improves agreement between data and theory.
- Seems to become less sensitive to details of theory.

Photons in photoproduction

Summary:

At $E_{t\ min}^{\gamma} = 5$ GeV **<** $E_{t\ min}^{jet} = 6$ GeV:

- PYTHIA and HERWIG have wrong shapes and normalization.
- Theory predictions differ at low E_T^{γ} and forward jet .
- LZ (k_T factorisation) fits data better than NLO calculations.

At $E_{t\ min}^{\gamma} = 7$ GeV **>** $E_{t\ min}^{jet} = 6$ GeV:

- good agreement between data and calculations.

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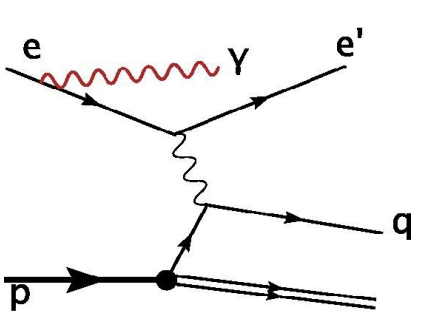
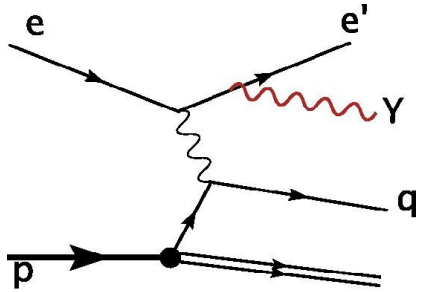
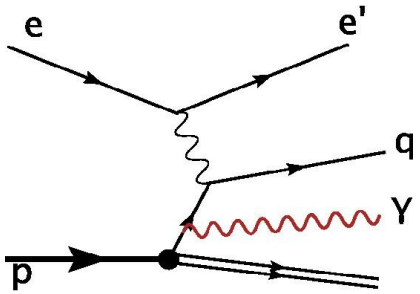
Photons in DIS

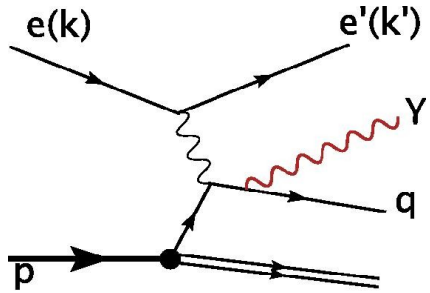
1.) Originating from electron radiation
„LL“





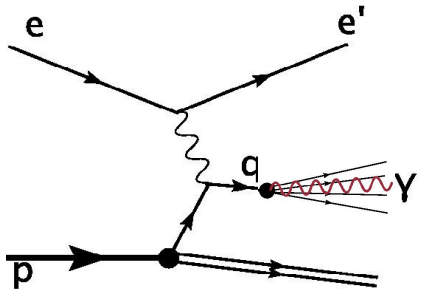
2.) Originating from partons of the proton
„QQ“, sensitive to p.d.f.
(usually called „prompt“ photons).





3.) Originating from hadron decays: π^0, η etc.
(treated as background).

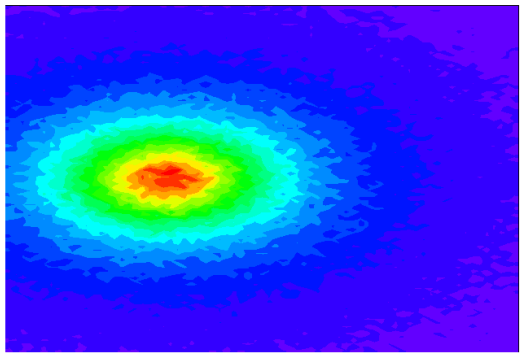
4.) From within jets: „photon fragmentation function“ $D_{q\to\gamma}(z)$
z = fraction of jet E_T carried by photon
$z \to 1$ in this analysis (isolation required)
$D_{q\to\gamma}$ is not calculable, needs to be measured



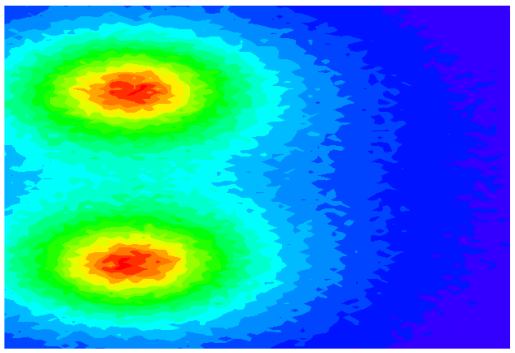
The understanding of photon rates is also relevant for searches, e.g. at LHC.

Photon showers

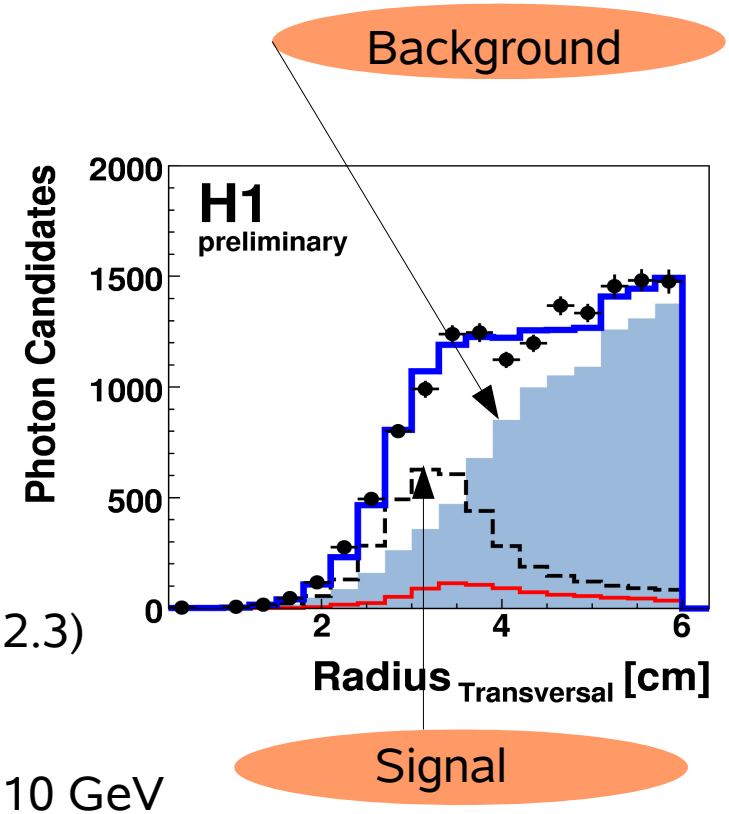
Signal: single photons



Background: multi-photon clusters
from neutral hadron decays: π^0, η etc.



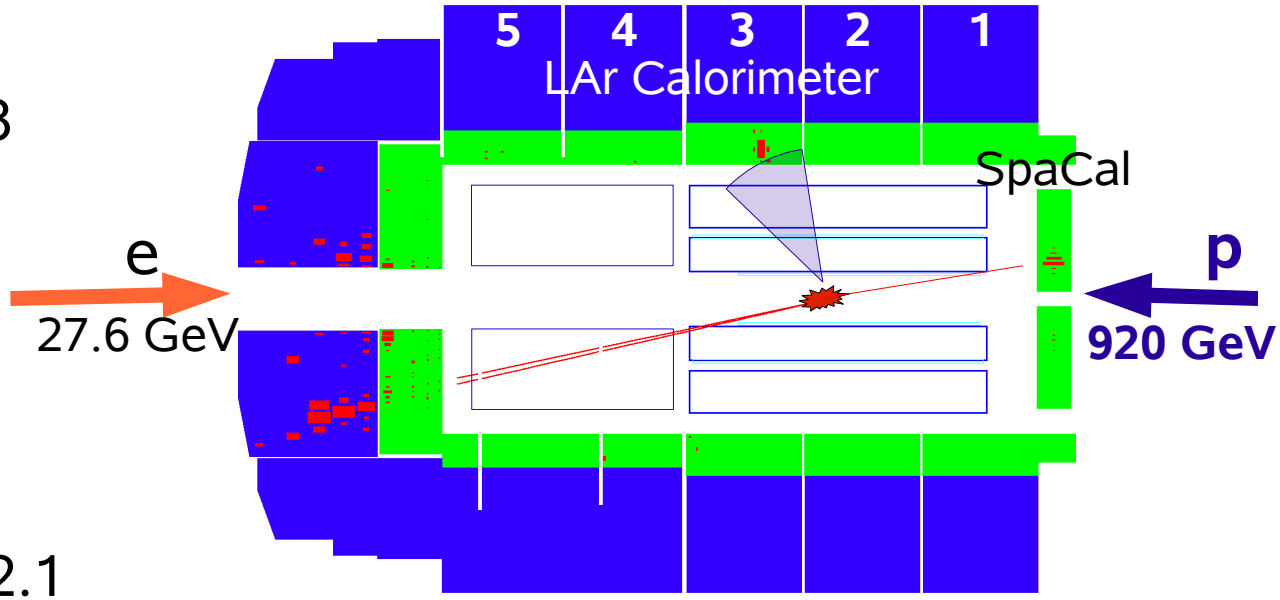
- less compact
- transversly wider
- more asymmetric
- shower starts earlier



- Background: use detector simulation for single particles with high statistics mix of neutral hadrons π^0,η,η',ρ,ω,K^*,K_S,K_L,n.
  Relative contributions are taken from RAPGAP MC.
- Signal: photons simulated by PYTHIA (with normalization factor 2.3)
- Multidimensional shower analysis, using 6 shape and energy distribution variables (likelyhood approach). Works fine for E_T^{γ} <10 GeV

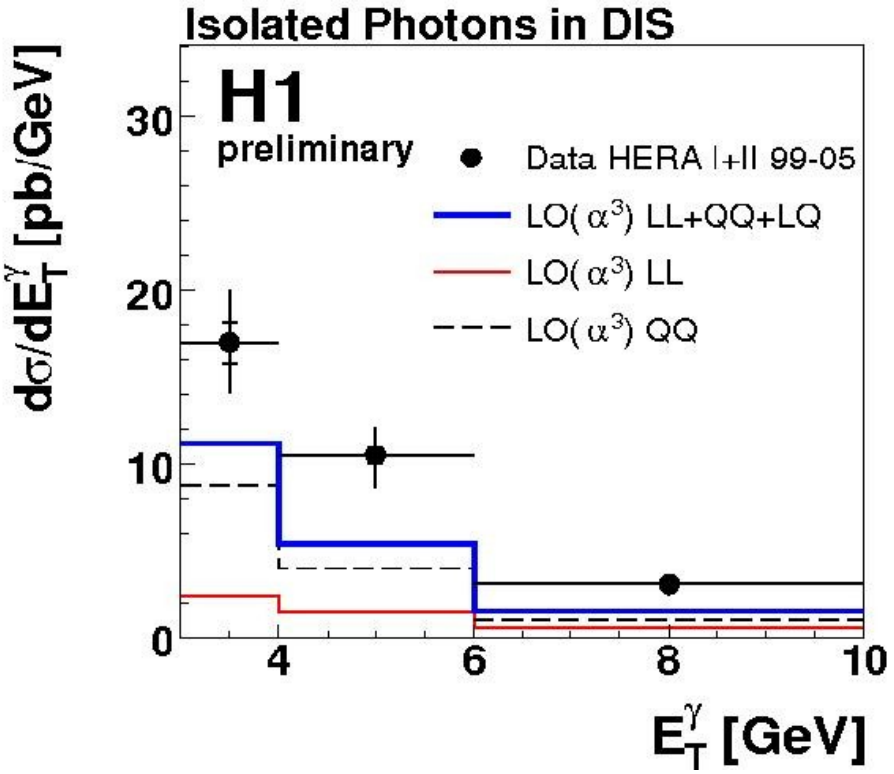
Data selection

- 226.2 pb $^{-1}$ from 1999-2005 (HERA I+II)
- Event kinematics
  $4 < Q^2 < 150\ \text{GeV}^2$, $y > 0.05$
  $W_X^2 = (p_e + p_p - p_e' - p_\gamma)^2 > 2500\ \text{GeV}^2$
- Photon candidates
  $3 < E_T^\gamma < 10$ GeV $-1.2 < \eta^\gamma < 1.8$
- Photon isolation
  $z = E_t^\gamma / E_T^{jet} > 0.9$
- Jet reconstruction
  k_T algorithm $R_0 = 1$
  $P_t^{jet} > 2.5$ GeV, $-1.0 < \eta^{Jet} < 2.1$



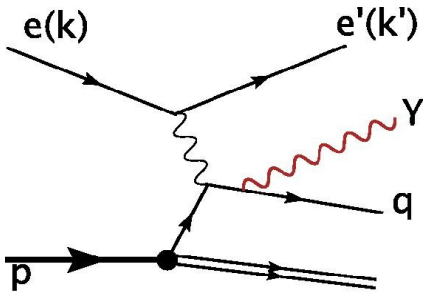
- 14 670 events, 6 495 with an additional jet.

Differential cross section: E_T^γ

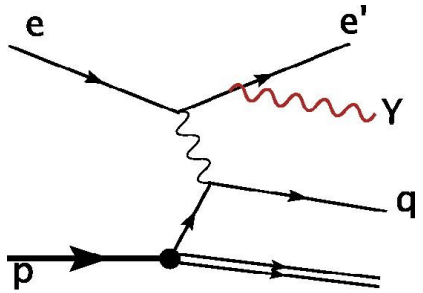


- LO calculation ($\alpha^3\alpha_s^0$).
  [Gehrmann et al. Eur. Phys. J. **C47**, 395, 2006.]
- QQ from quarks, LL from leptons.
  LQ interference (<3%) between QQ and LL.

QQ: — — —

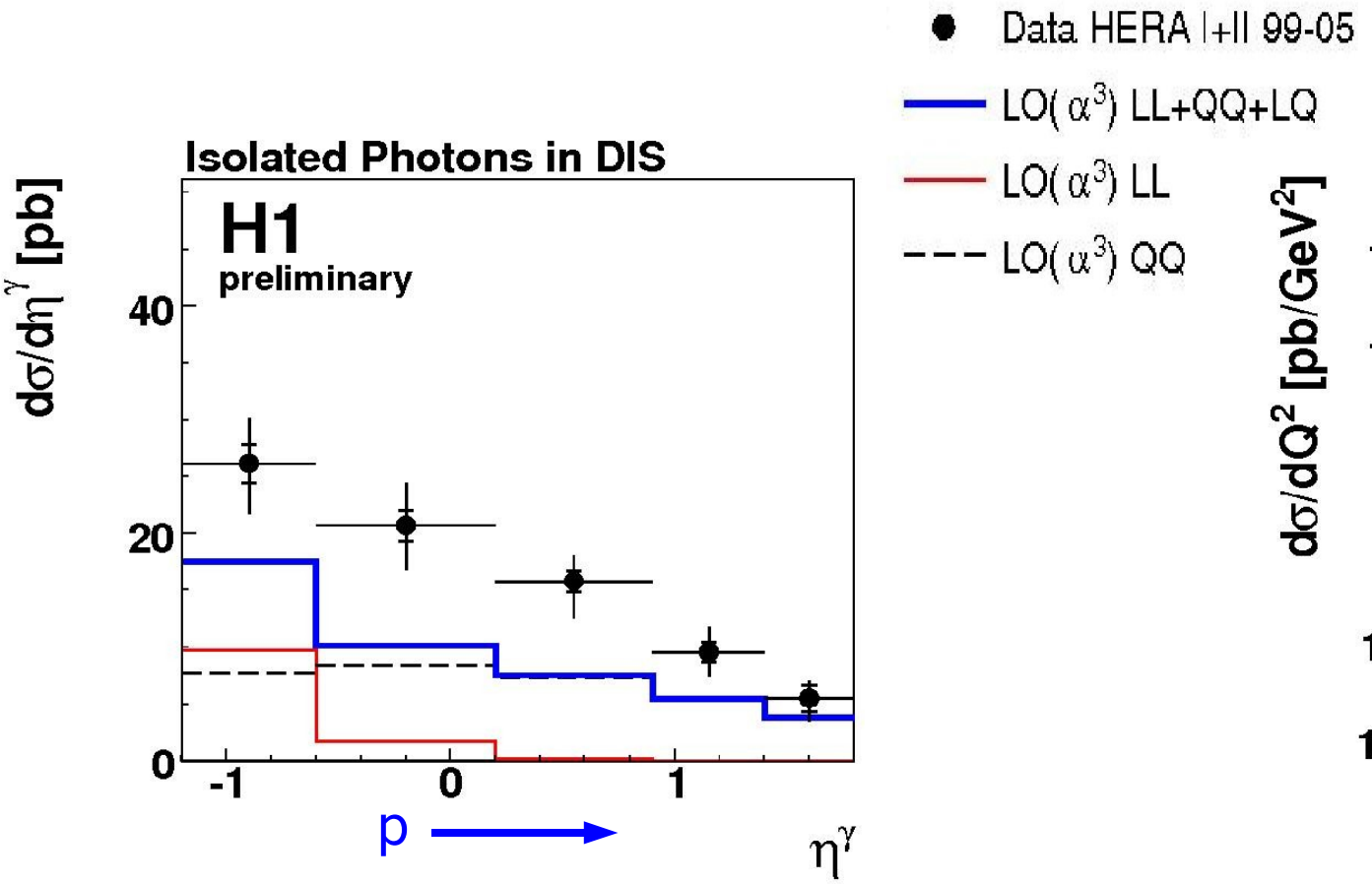


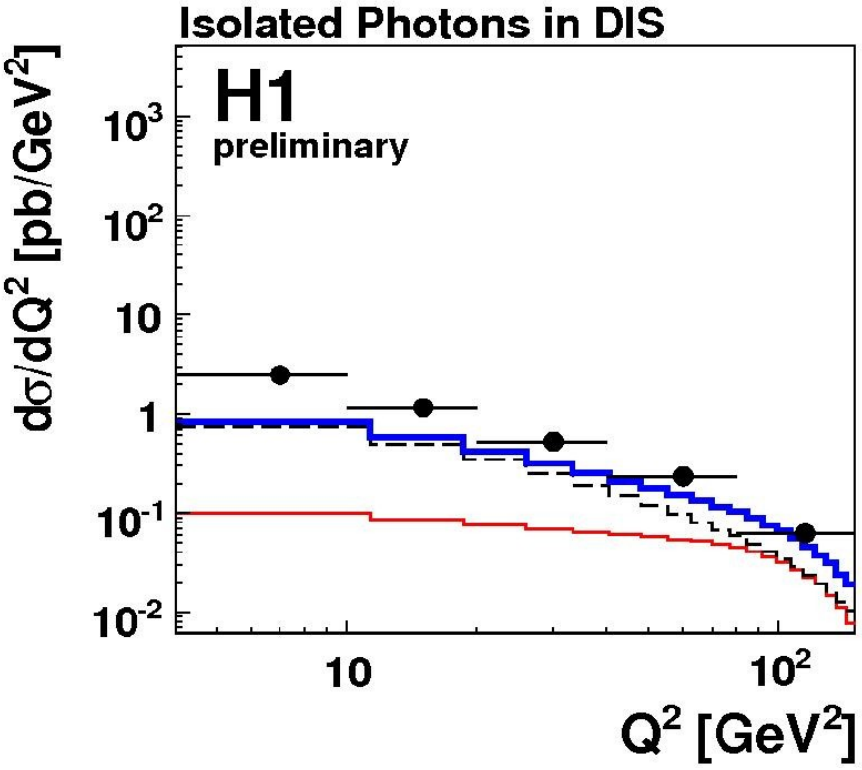
LL: ———



- LO prediction does not describe the data very well (in average at 56% of data.)
- Using PYTHIA for the QQ part and RAPGAP (rad.) for the LL radiation gives a very similar picture
- LO prediction was corrected to hadron level (average -14%, at most -22%, uncertainty < 5%).

Pseudorapidity and Q^2

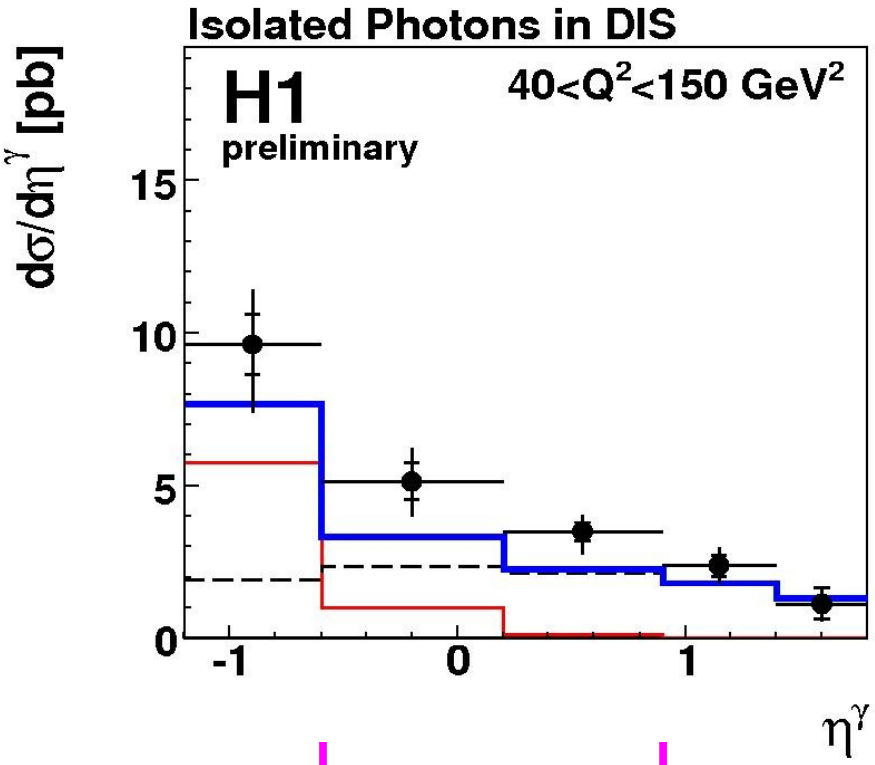




- LL contributes only at $\eta^\gamma < -0.6$.
  QQ dominates at larger η^γ (in p direction).
- Discrepancy probably related to QQ

- Theory underestimates
  - strongly at low Q^2,
  - slightly at higher Q^2.

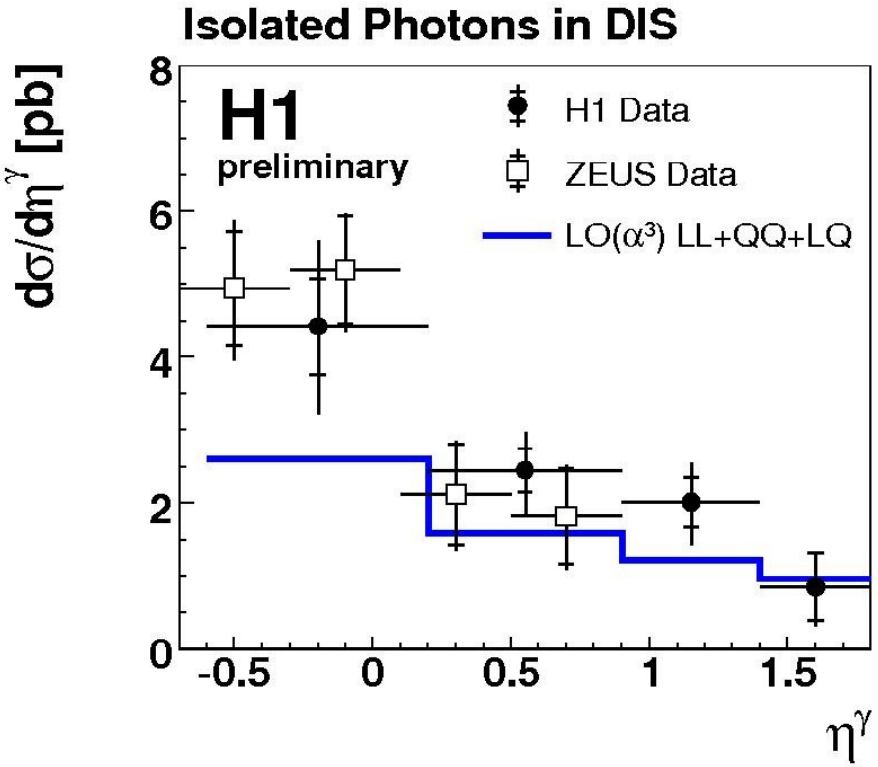
High Q^2 > 40 GeV^2



in this region
ZEUS data available

Comparison to ZEUS measurement [Phys, Lett. B595, 86, 2004]:
E_t^γ >5 GeV, Q^2 >35 GeV^2, smaller θ_e

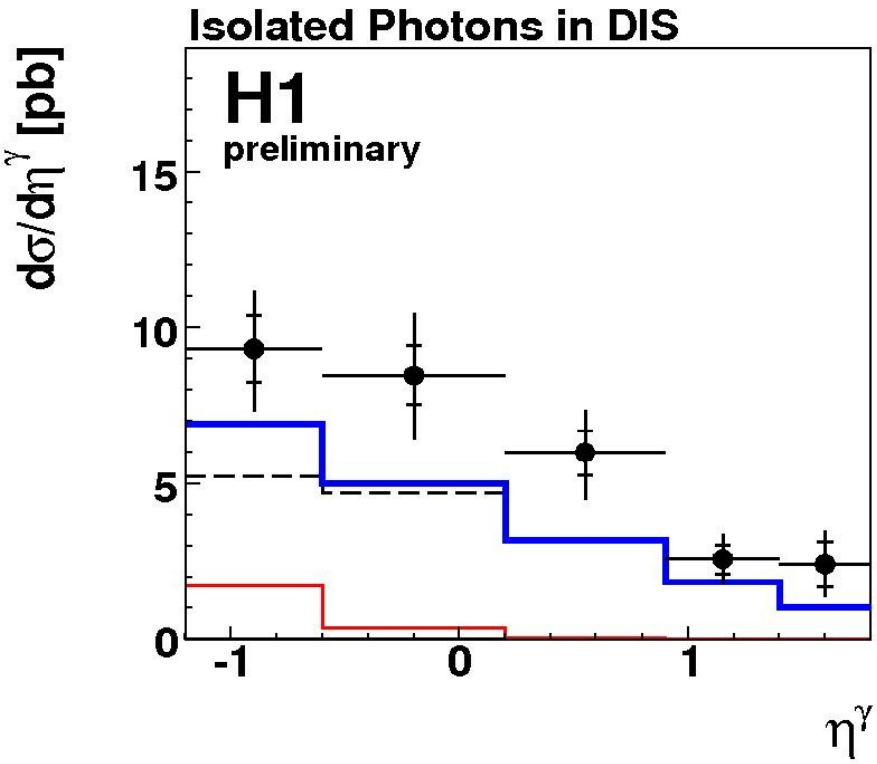
- Extrapolate / cut of the H1 measurements to the ZEUS phase space:

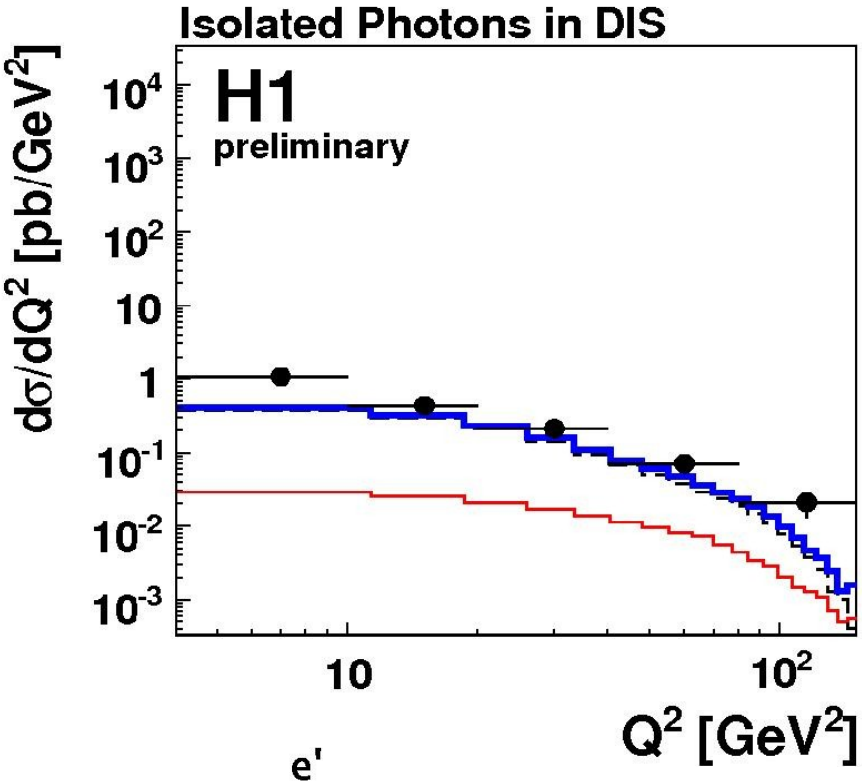


- LO theory still lower, at 74% of data.
- Shape reasonably well described.
- Data consistent between ZEUS and H1.

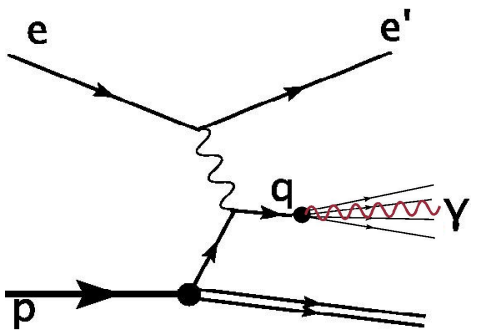
Exclusive: photon + no jet:

No hadronic jet with (E_T^{jet}>2.5 GeV and -1< η^{jet}<2.1)



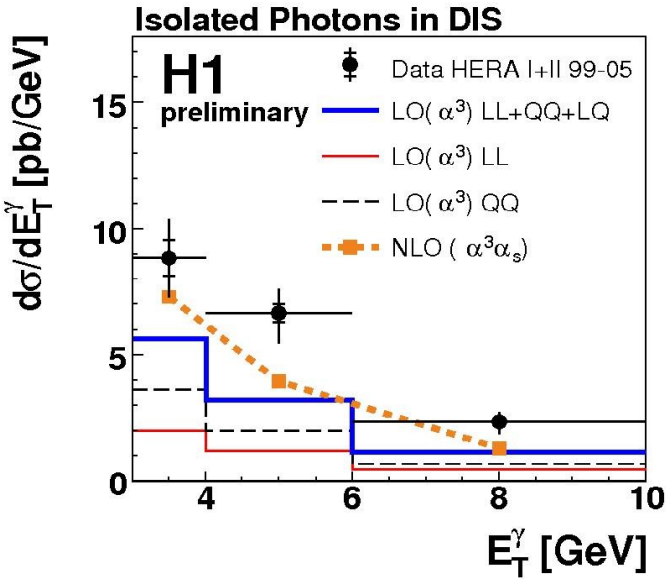


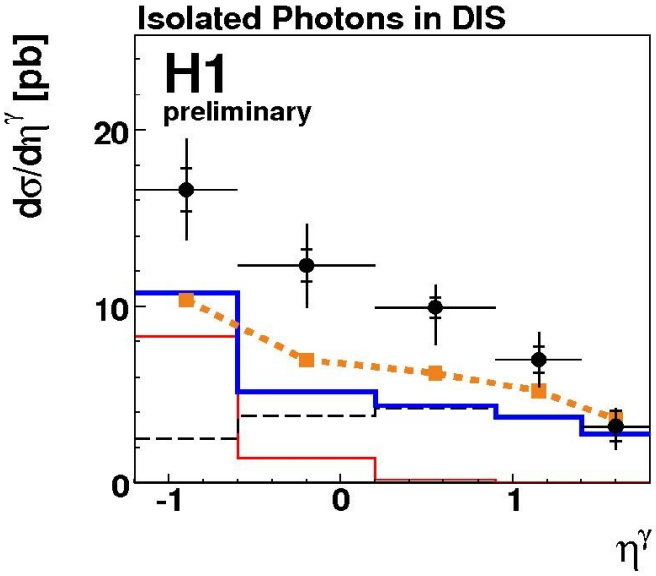
- Expect this data to be most sensitive to quark-to-photon fragmentation.
- LO theory is at 63% of the data.
- Largest discrepancies in central bins.

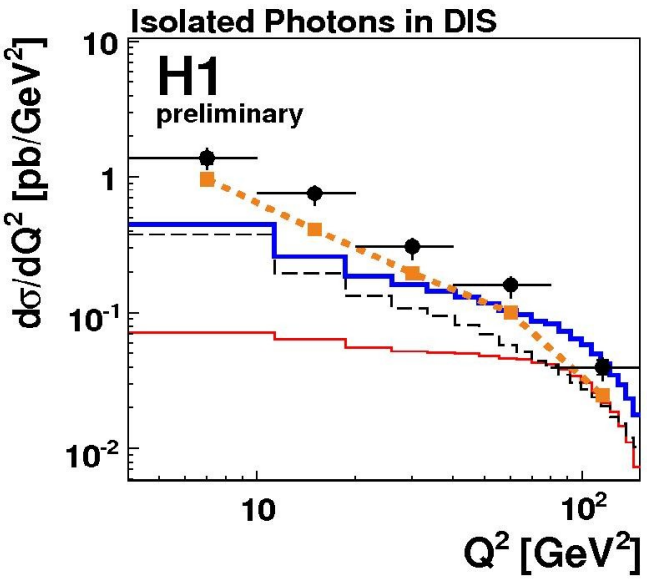


Exclusive: photon plus ≥1 jet:

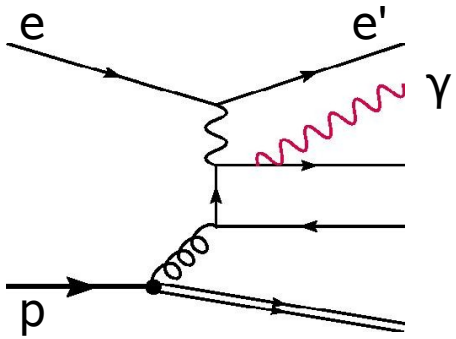
NLO $\alpha^3\alpha_s^1$ calculation available [G. Kramer and H. Spiesberger].







- Higher than LO,
  most significantly at low Q^2,
  but still only 64% of data.
- Shapes are reasonably well described.



- Do not expect contribution from quark-to-photon fragmentation here (in LO).
  → Fragmentation alone can not explain the discrepancy.

Photons in DIS

Summary of first measurement of isolated photons in DIS by H1:

- Multiparameter shower analysis allows to separate single photons from neutral hadron decays.
- LO and NLO (for photon + jets only) calculation available
- Theory describes shape of data reasonably well, but falls short by 30-40% in normalization.
- Comparison with ZEUS in limited phase space shows good absolute agreement.

Backup slides

Photons in photoproduction

Theoretical predictions:

KZ: M. Krawczyk and A. Zembrzuski
NLO using GRV (proton+photon p.d.f.).
[hep-ph/0309308]

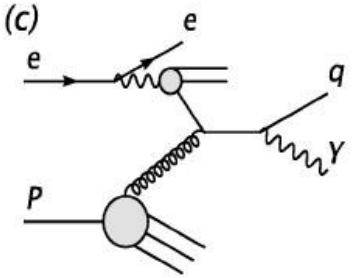
FGH: M. Fontanaz, J.P. Guillet and G. Heinrich
Additional higher order corrections to resolved photon process
using MRST01 (proton p.d.f.), AFG02 (photon p.d.f.).
[Eur. Phys. J. **C34**, 191, 2004]

LZ: A. Lipatov and N. Zotov (k_t factorization approach)
Unintegrated quark gluon densities using Kimber-Martin Ryskin prescription.
[Phys. Rev. **D72**, 054 002, 2005]

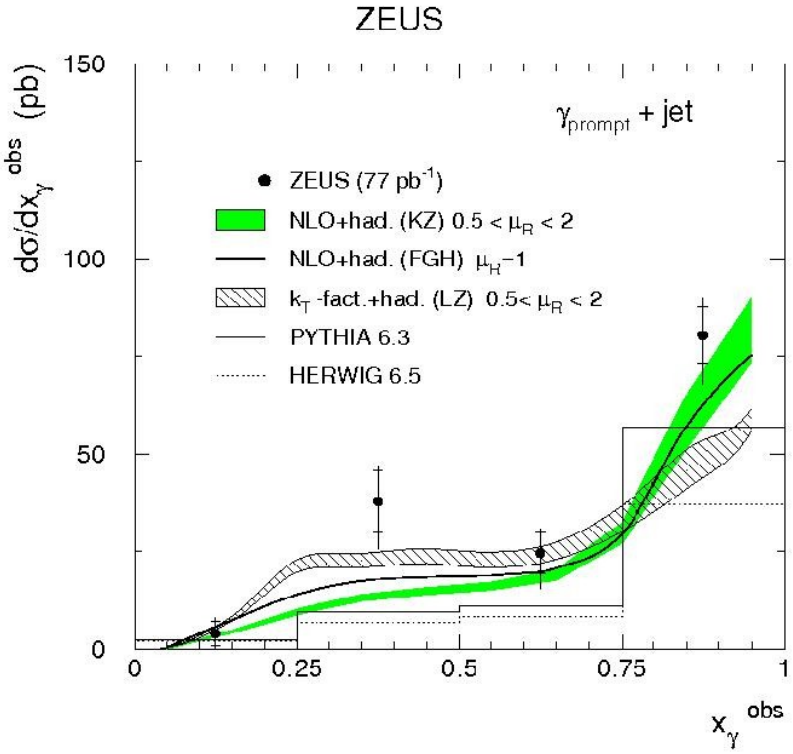
Resolved and direct part

Fraction of the incoming photon momentum, interacting with the (jet+photon) system.
$x_\gamma < 1$ resolved $x_\gamma = 1$ direct.

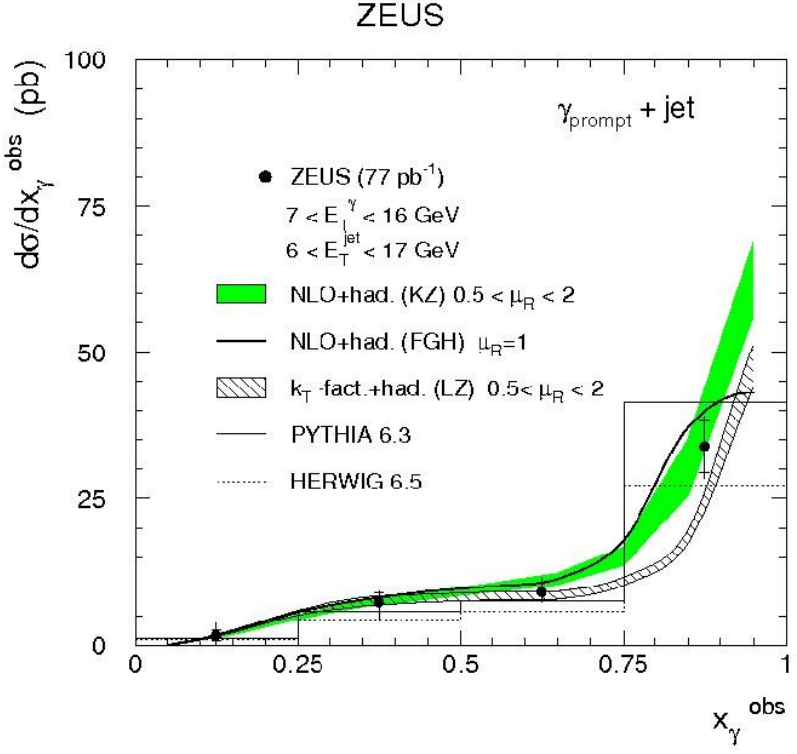
$$X_\gamma^{obs} = \sum_{\gamma,jet} \frac{(E - P_z)}{2E_e y}$$



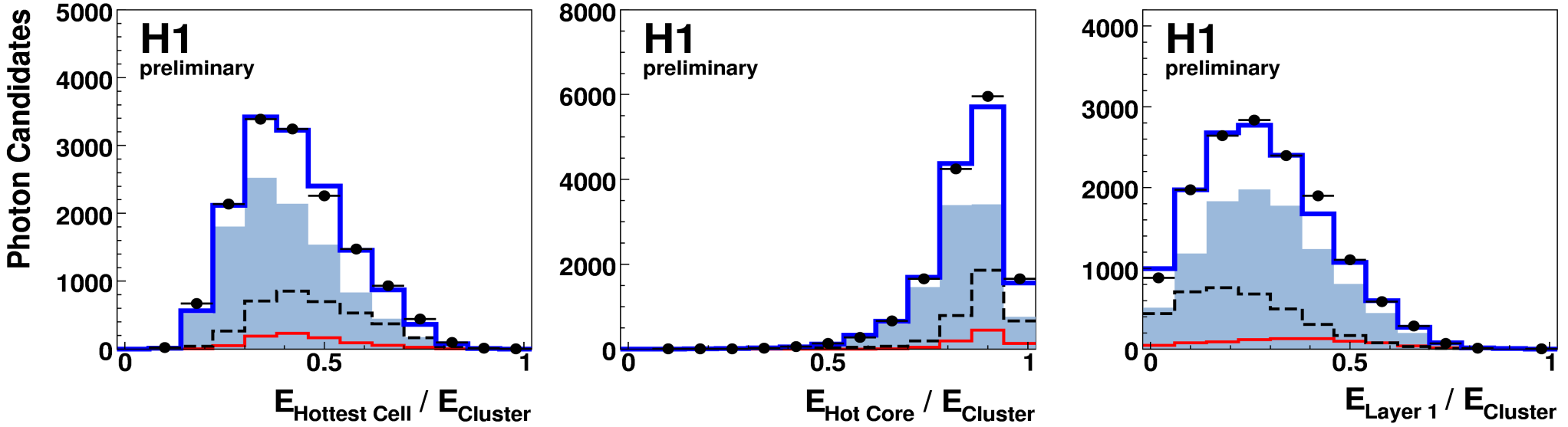
$E_T^\gamma > 5$ GeV



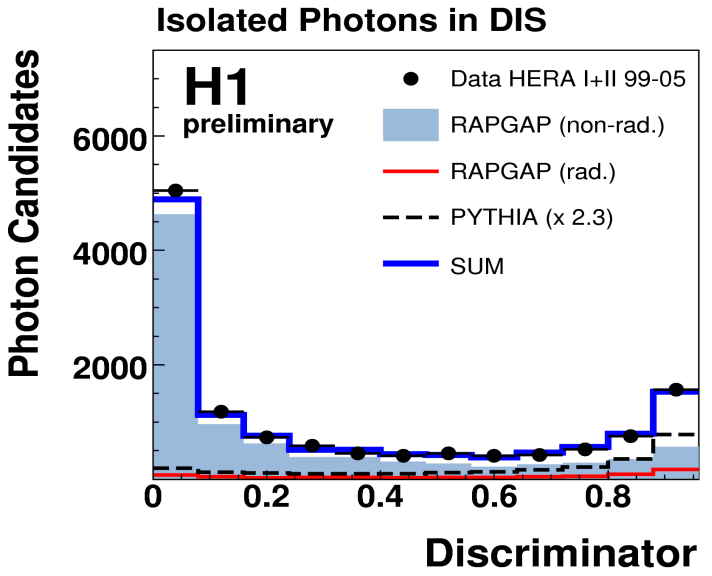
$E_T^\gamma > 7$ GeV



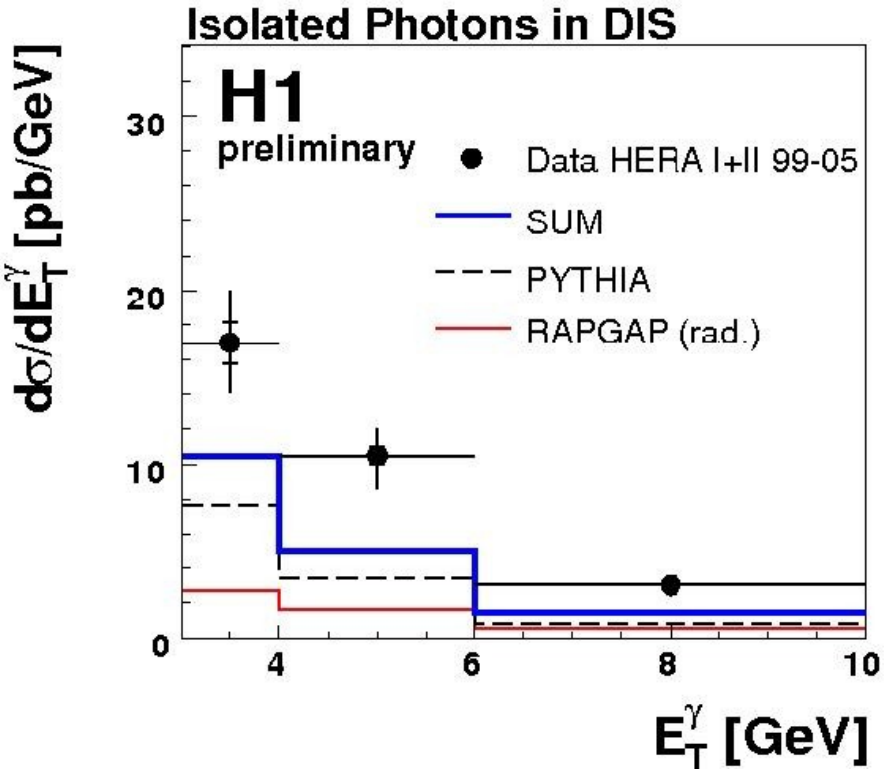
Multi dimensional shower analysis



- In addition three transverse shape variables.
- Analysed in bins of E_T^γ and η^γ.
- From 6 variables a discriminator is formed (likelihood approach).
- Extract photon content in each bin by independent χ^2 fit of the data to the simulated signal and background discriminator distributions.
- Works fine for E_T^γ<10 GeV.



Comparison to Monte Carlo



- PYTHIA: radiation from quark: normalization off by factor 2.3.
- RAPGAP: radiation from electron.
- Similar to LO calculation.