The Underlying Event at HERA

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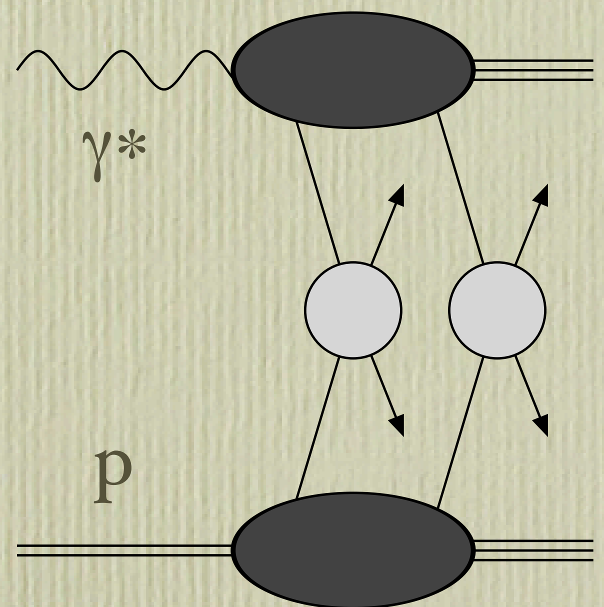
Underlying Event

- *An excess of underlying event energy above QCD calculations was observed in ppbar*
- *The data could be described by adding beam remnant interactions (Sjöstrand, van Zijl, ‘87)*
- *Since at HERA the (resolved) photon interacts like a hadron, underlying event effects have been observed there too*

Underlying Event & Resolved γp



HERA: vary Q^2

measure x_γ and compare

direct and resolved events

- *Primary hard parton parton interaction*
- *Underlying event*
  - *multiple soft to hard parton interactions (MI)*
  - *initial/final state radiation*
  - *fragmentation*
  - *beam remnants*

Underlying Event

- *A nuisance:*
  - *energy of jets of hard interaction measured too large*
  - *resulting in overestimate of jet x-section*
- *Of interest by itself:*
  - *study models of MI*
  - *understanding beam remnants (color connected to interacting partons)*

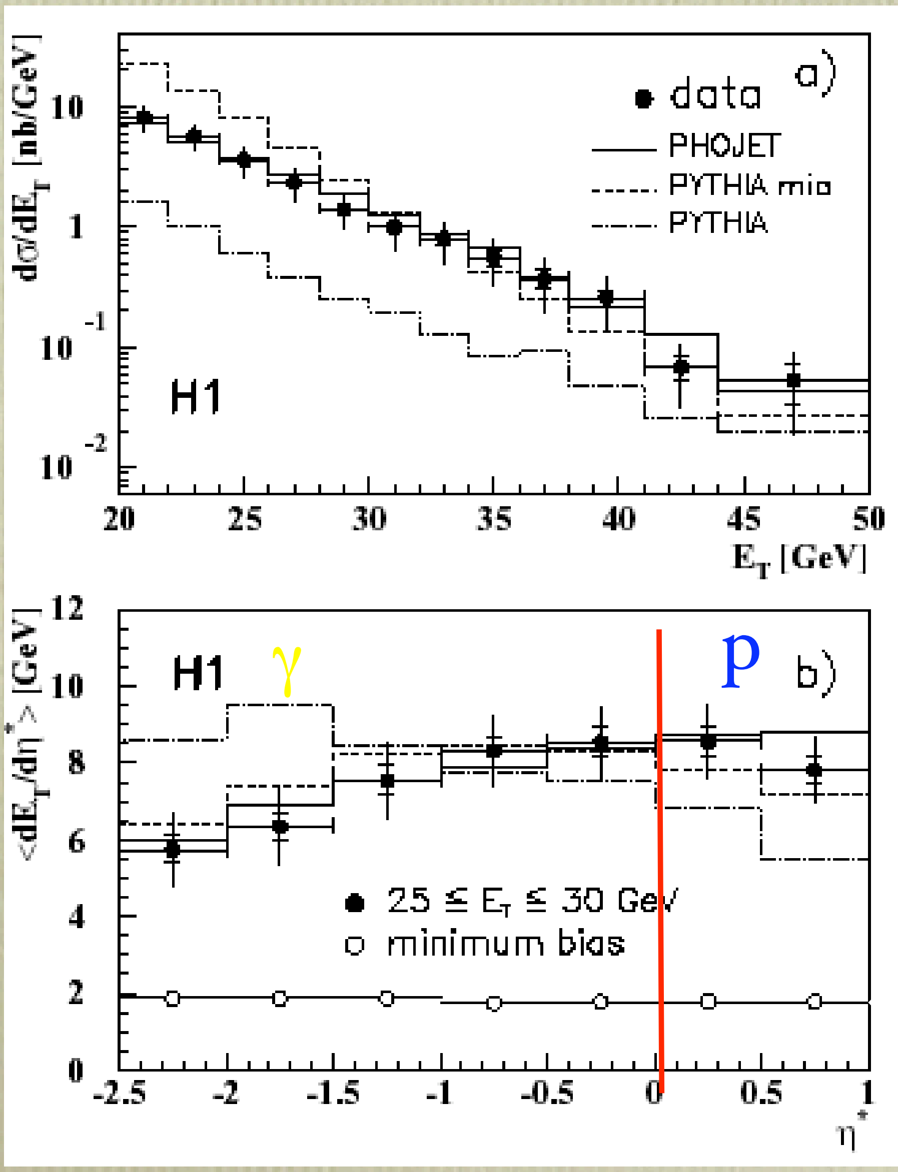
Models

- *HERWIG*
  - *soft underlying event: parametrized results of soft hadron hadron interactions are added in a fraction of the events*
  - *JIMMY: “add on” to generate MI*
- *PYTHIA with MI (LO + unitarization)*
- *PHOJET includes multiple soft and hard parton interactions + unitarization scheme*

Energy Flow and Jets in γp

- *Tagged γp events, $Q^2 < 0.01$ GeV^2, $0.25 < y < 0.7$*
- *Minimum bias sample*
  - *≥ 1 charged particle, $p_t > 0.3$ GeV*
- *High E_T sample:*
  - *$E_T \geq 20$ GeV in $-0.8 \leq \eta \leq 3.3$*
- *Jet sample:*
  - *≥ 1 cone jet, $E_T \geq 20$ GeV in $-1 \leq \eta \leq 2.5$*
- *H1, Z.Phys. C70 (1996) 17*

$d\sigma/dE_T$ & $\langle dE_T/d\eta^* \rangle$



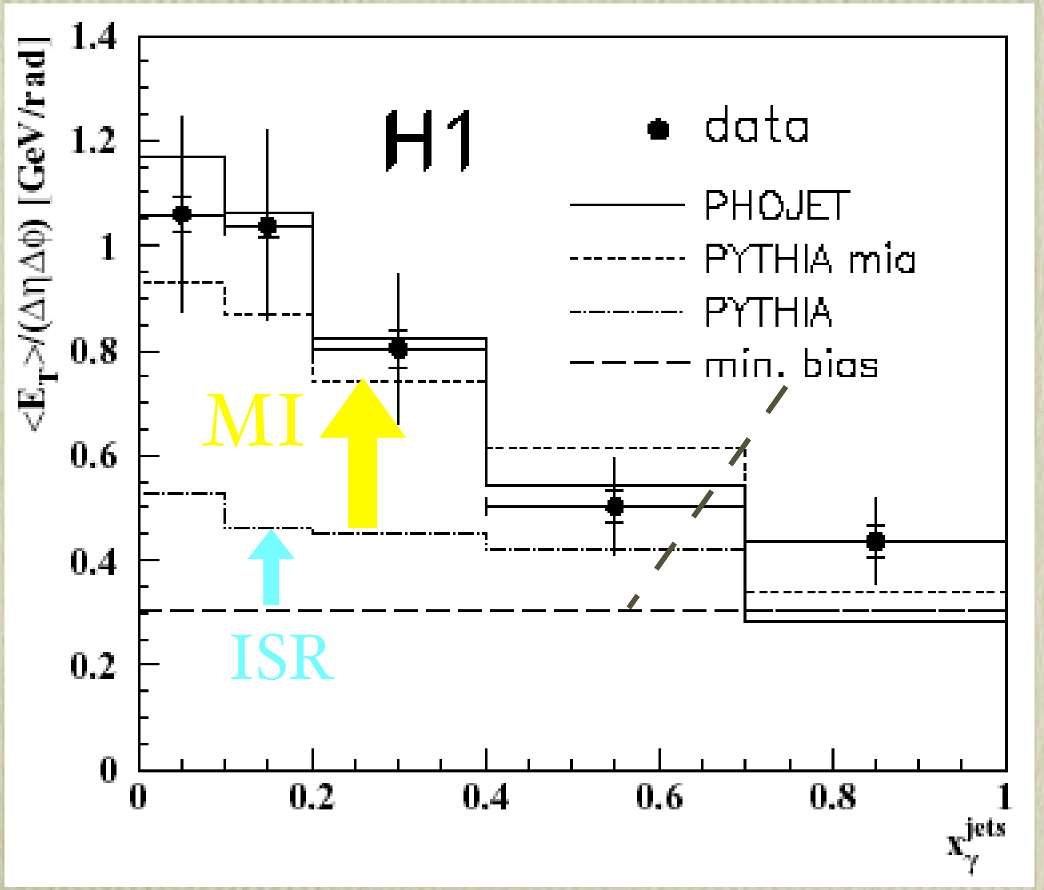
High E_T sample

- *PHOJET ok, PYTHIA+MI has wrong shape (normalization ?)*
- *PYTHIA without MI peaks in γ hemispere, MI move the peak towards the origin of the γp cms as in data.*
- *PYTHIA and PHOJET ok*

Minimum bias sample

(η measured in γp cms)*

E_T Density outside of Jets



Sum E_T in -1 ≤ η ≤ -1, exclude E_T from jets*

- *Direct γp*
- *no MI*
- *no ISR on photon side*
- *same FSR as resolved γp*

⇨ *MI by comp. to resolved*

- *Resolved γp*
- *reconstruct x_γ from the 2 highest E_T jets*

- *Models with MI, PHOJET and PYTHIA, describe data*

E_T Rapidity Correlation

How is energy distributed over the available phase space?

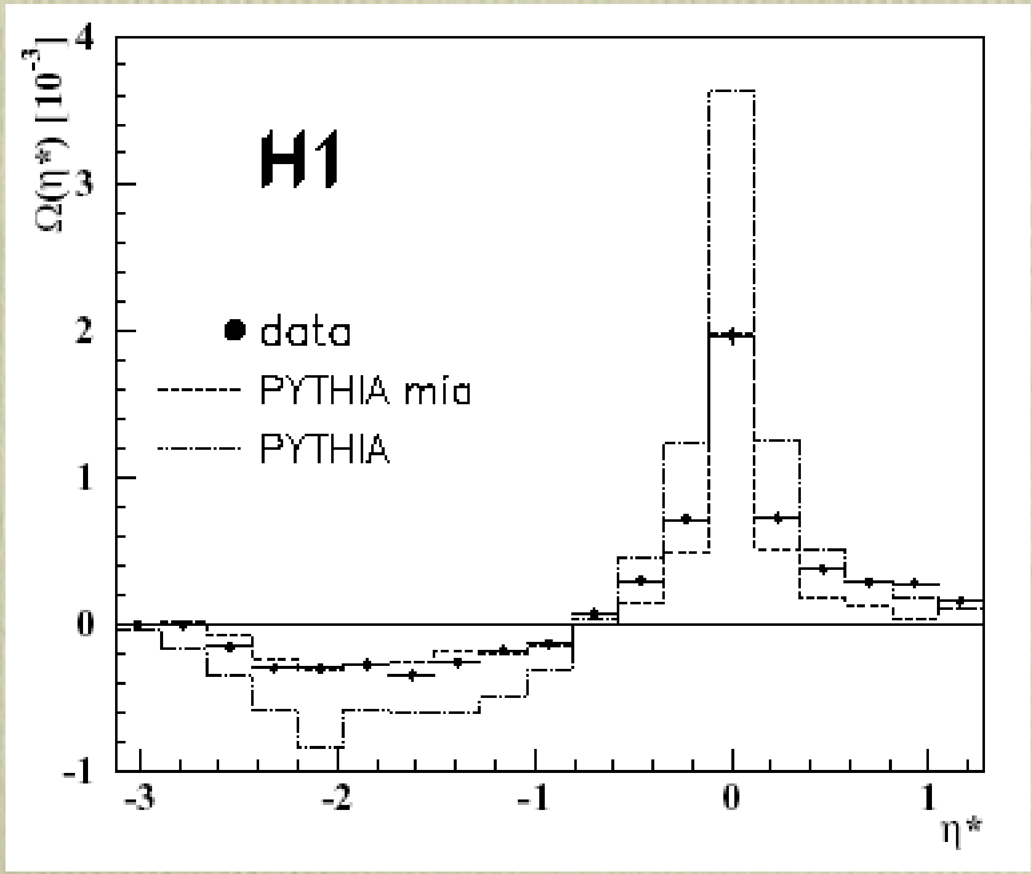
- *in MI the scatterings are mainly independent of each other*
- *study E_T correlations w.r.t. the central rapidity region in γp*

$$\Omega(\eta^*) = \frac{1}{N}\sum_{i=1}^{N}\frac{(< E_{T,\eta^*=0} > -(E_{T,\eta^*=0})_i)(< E_{T,\eta^*} > -(E_{T,\eta^*})_i)}{(E_T^2)_i}$$

N ... number of events, E_T measured calorimetrically in $-3.1 \leq \eta* \leq 1.3$

- *use high E_T sample*
- *data are not corrected for detector effects*

E_T Rapidity Correlation



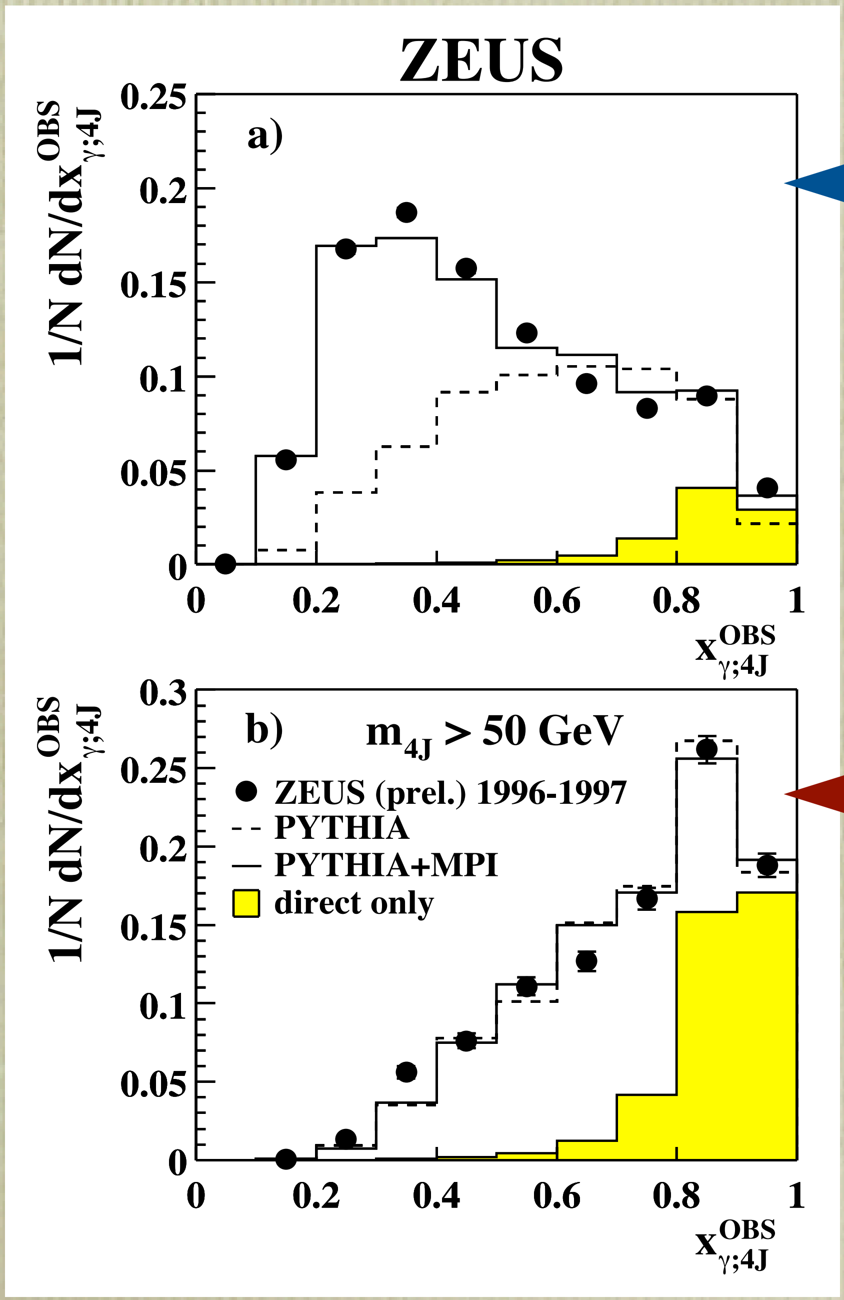
- *short range correlations near mid-rapidity*
- *anti-correlations are observed at* $\eta* \sim 1.8$
- *PYTHIA+MI is ok, with MI the correlation strength is reduced (as expected) by a factor of 2*

Multijets in Photoproduction

- *Events with 4 jets (1+2 → 3+4+5+6)*
- *in resolved events they may arise from MI*
- $E_{T_{3,4}} > 6,\ E_{T_{5,6}} > 5\ \mathrm{GeV}$
- $x_{\gamma,4J} = \sum_3^6 E_T \exp(-\eta)/(2yE_e)$
- *for simplicity, map 4 jets onto 3 by combining the 2 jets of lowest invariant mass into one jet; relabel jets in order of decreasing energy 3', 4', 5'*

- *ZEUS preliminary result, ICHEP 2002, Amsterdam*

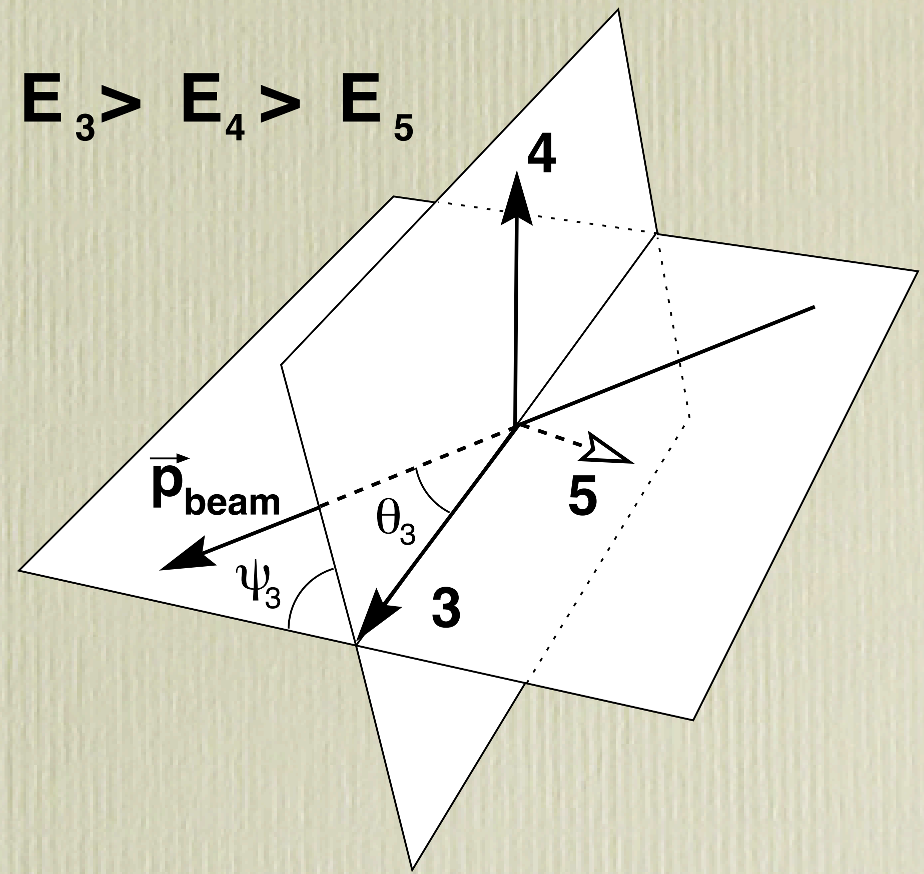
Multijets: x_γ Distribution



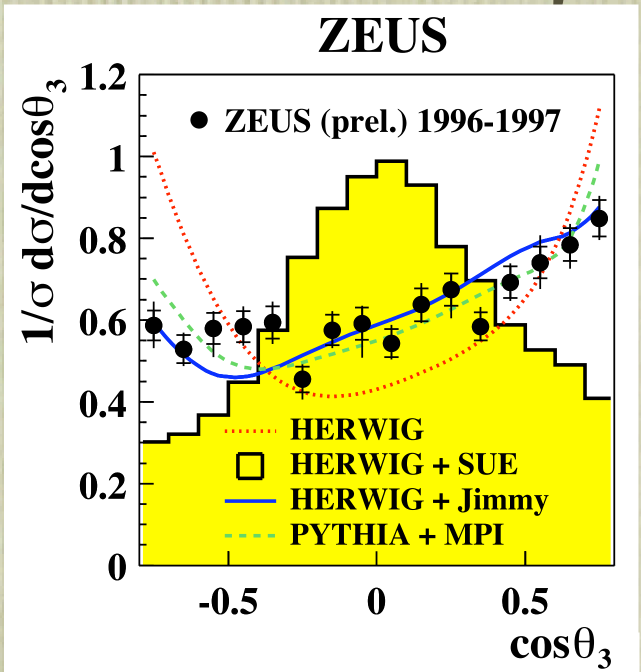
- *the inclusive data show a clear enhancement at low x_γ and can be better described by including MI with PYTHIA*
- *the high mass data ($M_{4J} > 50$ GeV) show little difference between PYTHIA with or without MI*

Orientation of the pseudo-jets

- *cos* θ_3 *gives the direction of the leading pseudo-jet w.r.t. the beam*
- ψ_3 *reflects the orientation of the lowest energy pseudo-jet*

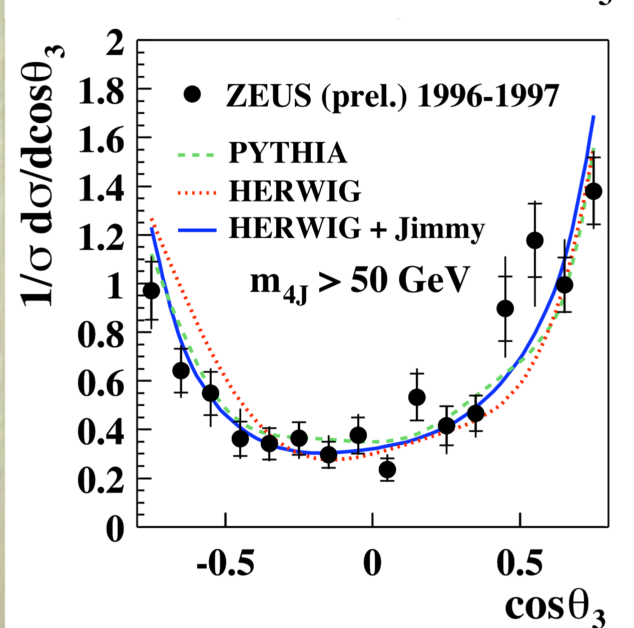


Multijets: cosθ₃ Distribution



Inclusive data sample

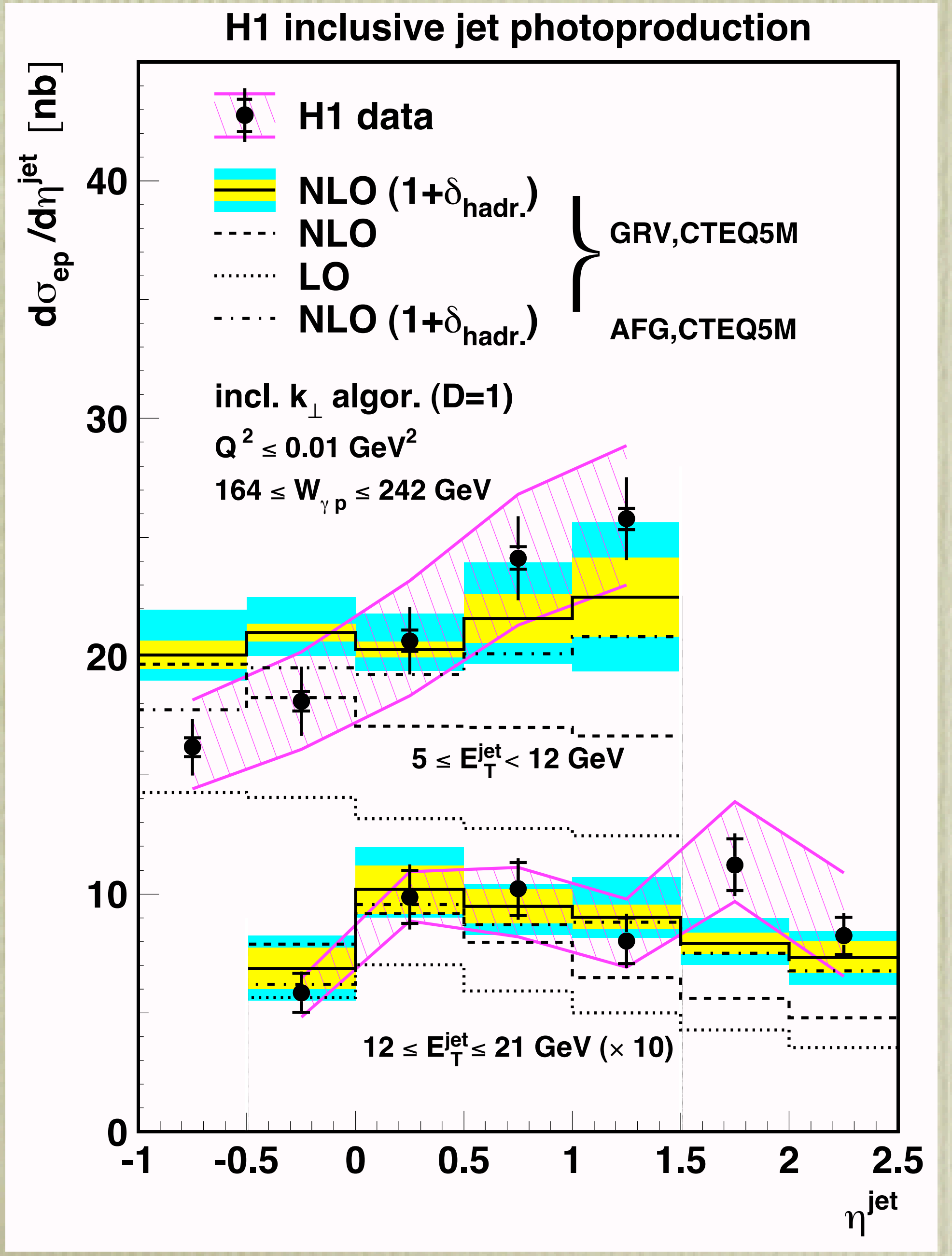
- *HERWIG with/without the soft underlying event fails to describe the data*
- *HERWIG + **JIMMY** is ok*
- *PYTHIA + **MI** is ok*



High mass data sample

- *inclusion of MI makes little difference*

Inclusive Jets: Data vs. NLO

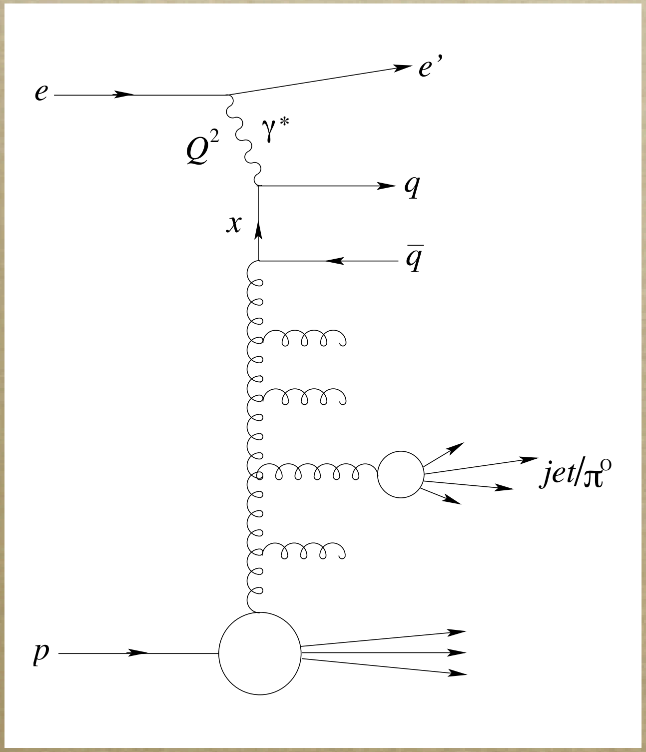


- *$5 \leq E_T < 12$ GeV*
- *falling LO/NLO prediction for increasing η*
- *with hadronisation, incl. MI, the predictions rise*
- $1 + \delta_{had} = (1 + \delta_{MI})(1 + \delta_{frag})$
- $\delta_{MI} \approx 0.3 \,\text{at}\, \eta \approx -0.75$

  $\delta_{MI} \approx 1.0 \,\text{at}\, \eta \approx 1.25 (\mathrm{p-dir.})$

  $\delta_{frag} \approx -0.3$
- *H1, Eur. Phys. J C29 (2003) 497*

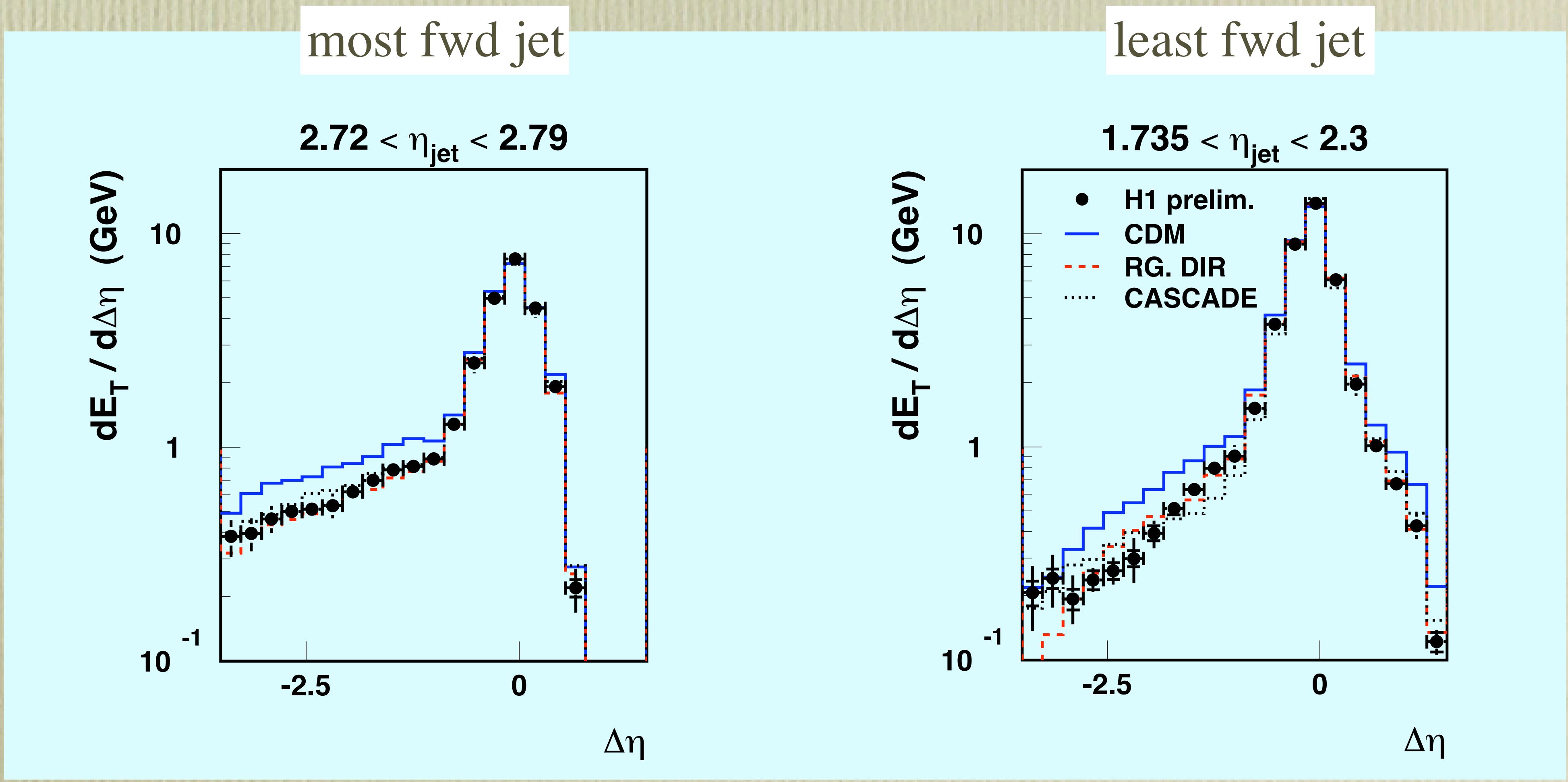
Forward jets



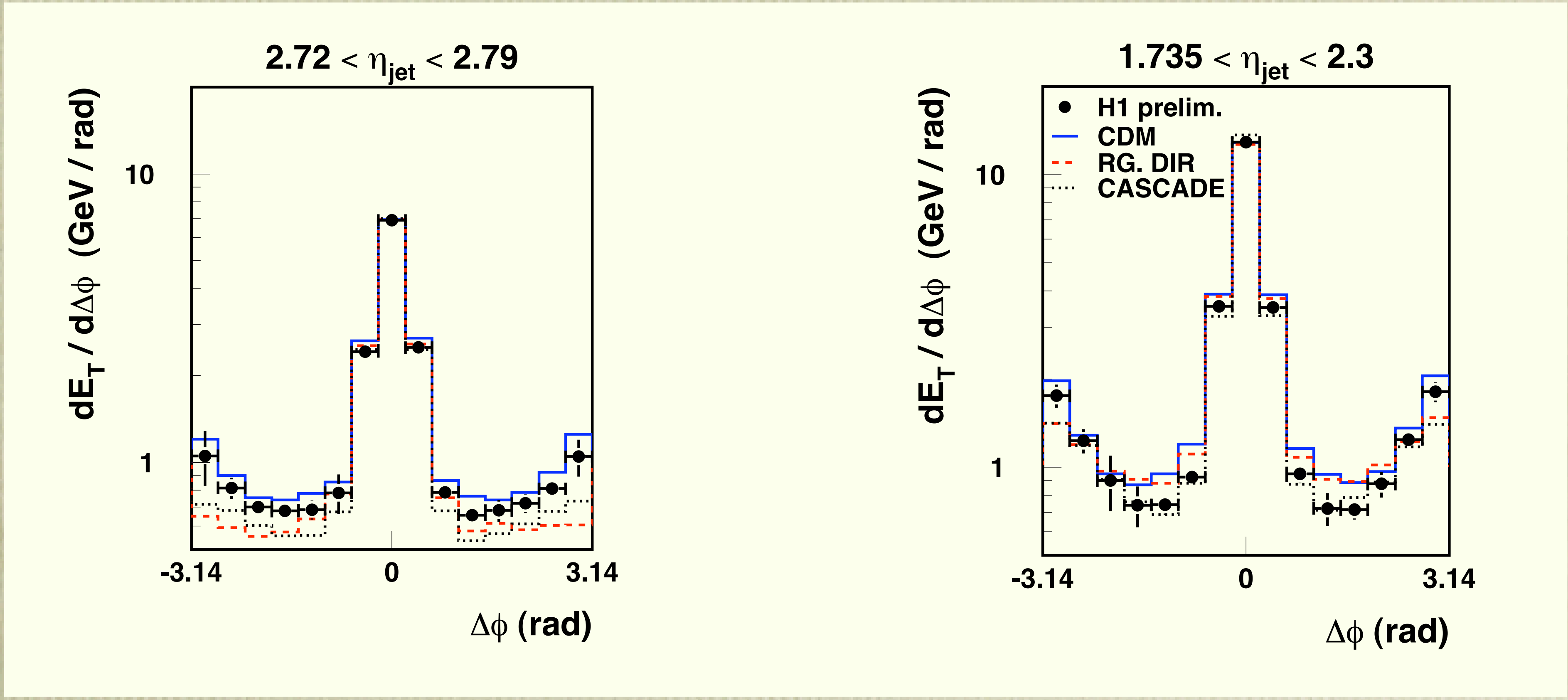
(see talk by A.Knutsson)

- *DIS phase space:*
- $5 < Q^2 < 85\ GeV^2$
- $0.1 < y < 0.7$
- $0.0001 < x < 0.004$
- *Fwd-jet phase space:*
- $p_t > 3.5\ GeV$
- $7° < \theta < 20°$
- $x > 0.035$

Forward Jet Profiles in Δη

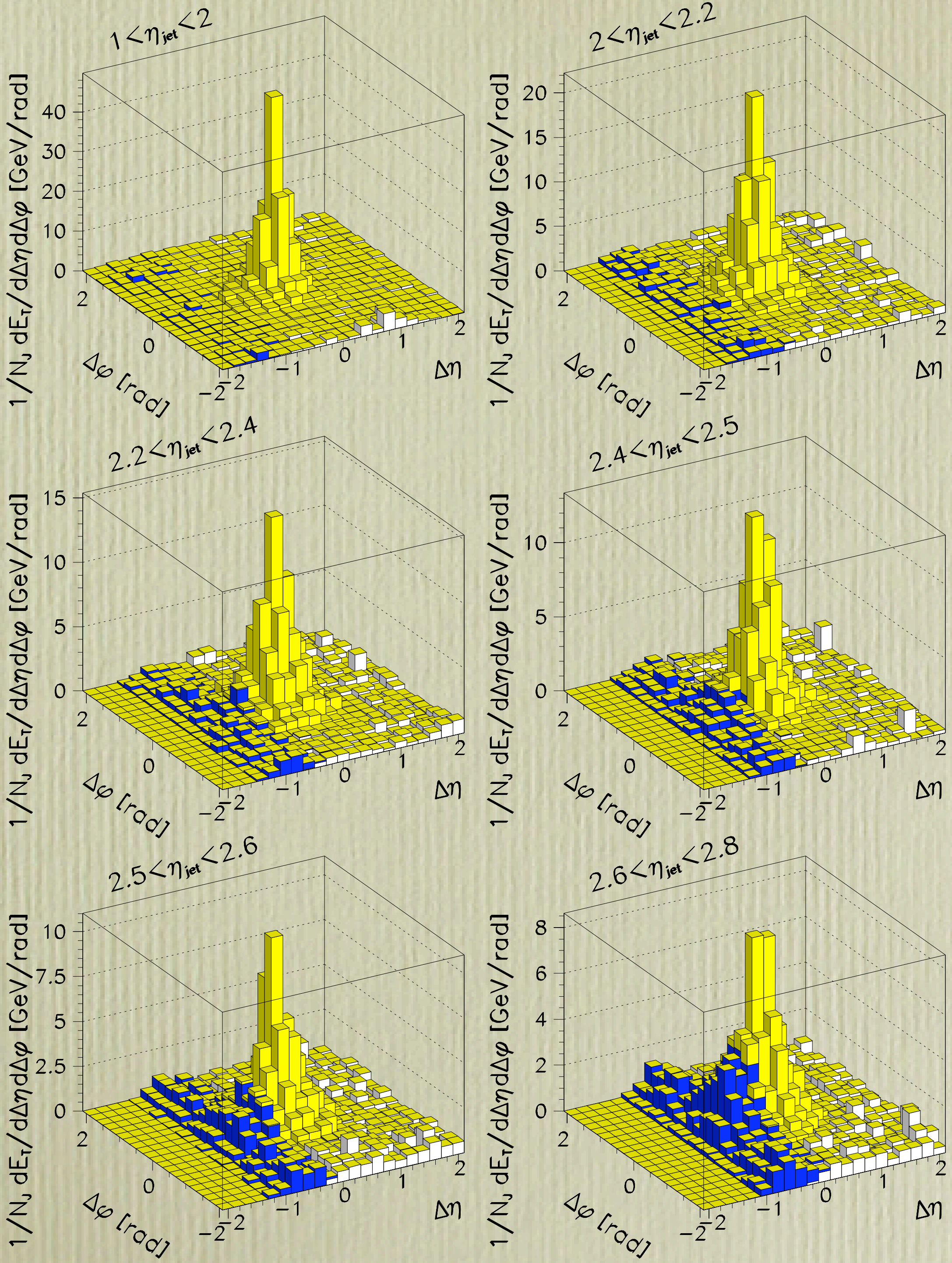


Forward Jet Profiles in $\Delta\Phi$



none of the models decribe the jet pedestals well

E_T flow around the fwd jet axis for different η-jet regions



- *for increasing η-jet activity around the fwd-jet grows, particularly around the beam-pipe (remnant?)*

- *ZEUS, Eur. Phys. J C6 (1999) 239*

What do we know about the γ-remnant ?

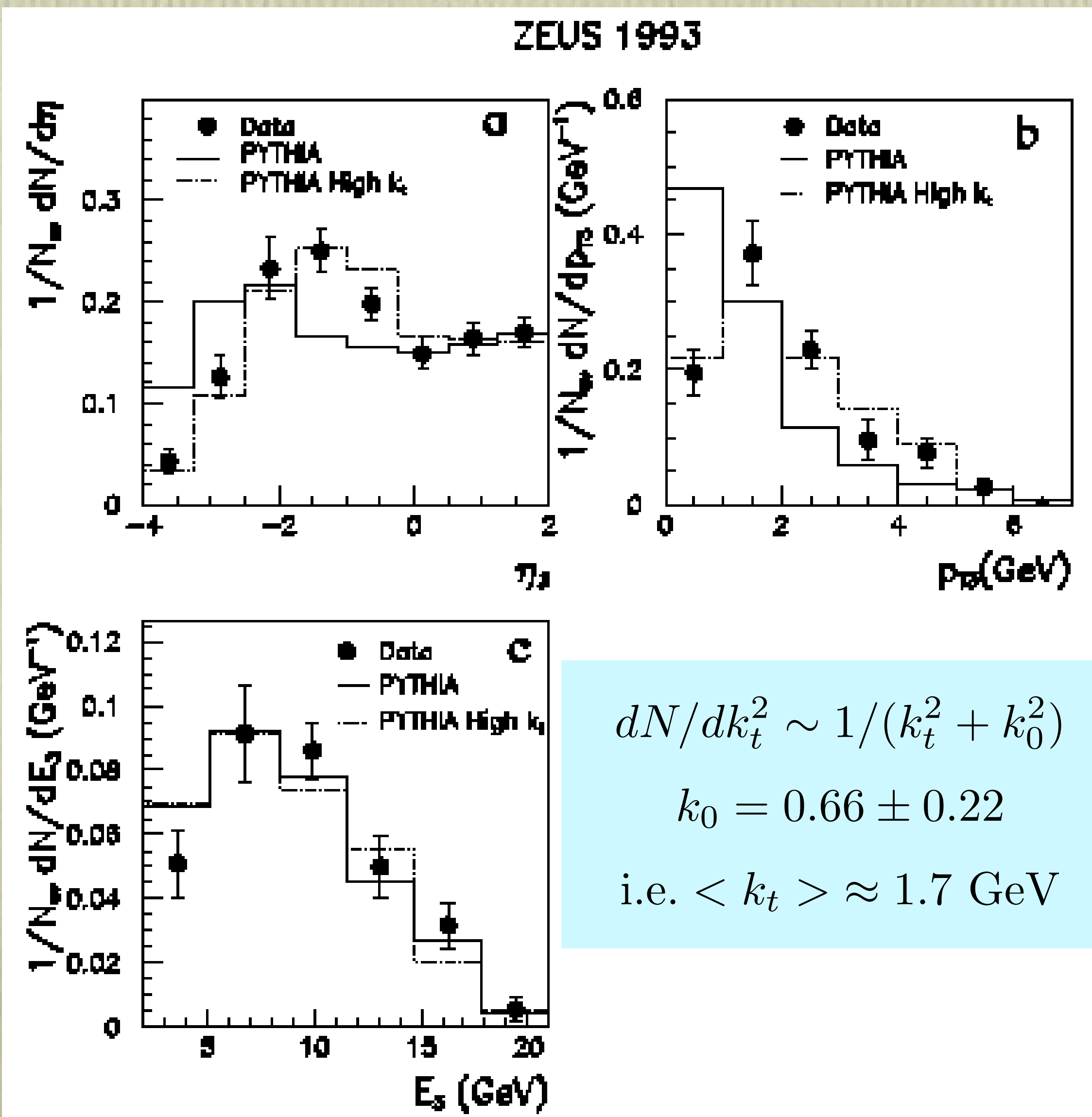
There is only one paper from HERA dealing specifically with the photon remnant:

- *ZEUS: Study of the Photon Remnant in Resolved Photoproduction at HERA, Phys. Lett. B354 (1995) 163*

- *untagged γp with $130 \le W \le 270$ GeV*

- *study events with 2 jets with $E_T \geq 6$ GeV and a third cluster in the approximate direction of the electron beam*

Intrinsic k_t of γ-remnant



$$dN/dk_t^2 \sim 1/(k_t^2 + k_0^2)$$

$$k_0 = 0.66 \pm 0.22$$

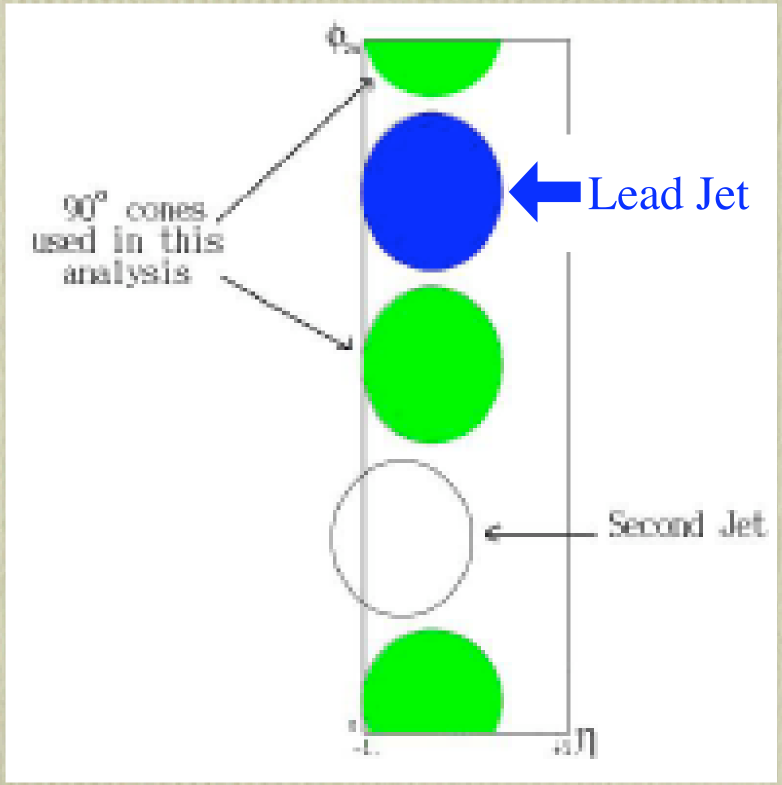
$$\text{i.e. } < k_t > \approx 1.7 \text{ GeV}$$

- *2 hard jets: $E_{T_{1,2}} \geq 6$ GeV, $\eta_{1,2} \leq 1.6$*
- *3rd jet ($E_{T_3} < E_{T_{1,2}}$, $E_3 \geq 2$ GeV) ⇒ proton remnant for $\eta_3 \leq -1$ (in figures b and c)*
- *harder intr. k_t than in the proton: fit k_0 to the data*

Summary

- *Many distributions in resolved γp scattering are better described by QCD models which include MI*
- *There is evidence that the effects seen are due to MI*
- *These effects were studied mainly in the early years of HERA with limited statistics - we should revisit*
- *Compare CDF-tunes of underlying event with HERA data during the workshop*
- *Which measurements should still be done at HERA?*

New Measurements at HERA

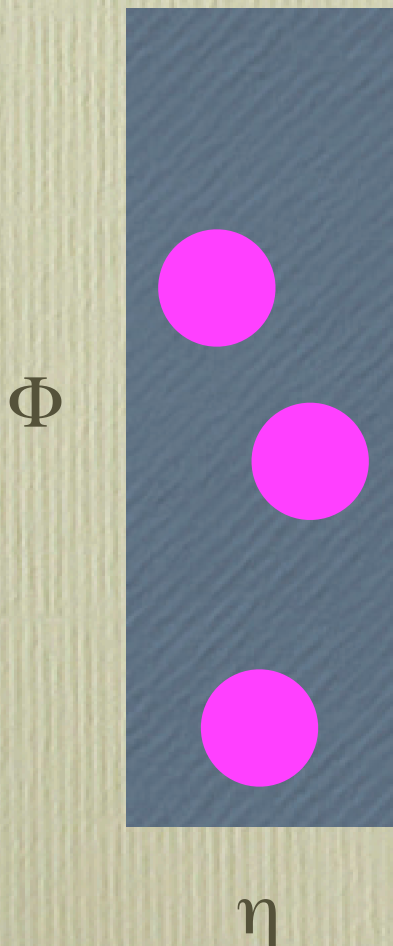


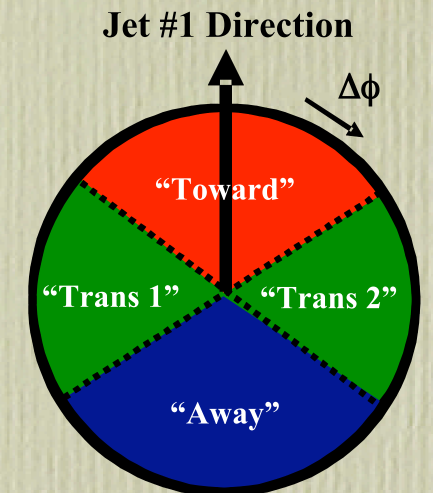
CDF: hep-ex/0404004

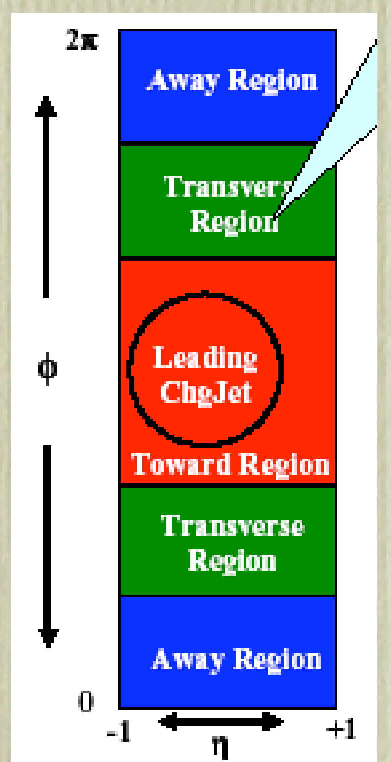
It might be advantageous to make measurements similar to the ones made at the TEVATRON

- *2 cones with R=0.7 at* $\eta=\eta_1$ *and* $\Phi=\Phi_1\pm 90°$ *are defined w.r.t. the highest energy jet (lead jet) in the event* (E_T *>20 GeV)*
- *in both cones the* p_t *of all tracks are summed* $\Rightarrow$ $p_{t,max}$ *and* $p_{t,min}$
- $p_{t,min}$ *is a measure of the underlying* p_t *in the event*

New measurement continued







- *"swiss cheese" measurement*
- *toward/away regions and transverse regions lead to similar studies of the underlying event*
- *CDF: Phys.Rev. D65 (2002) 092002*