The Underlying Event at HERA

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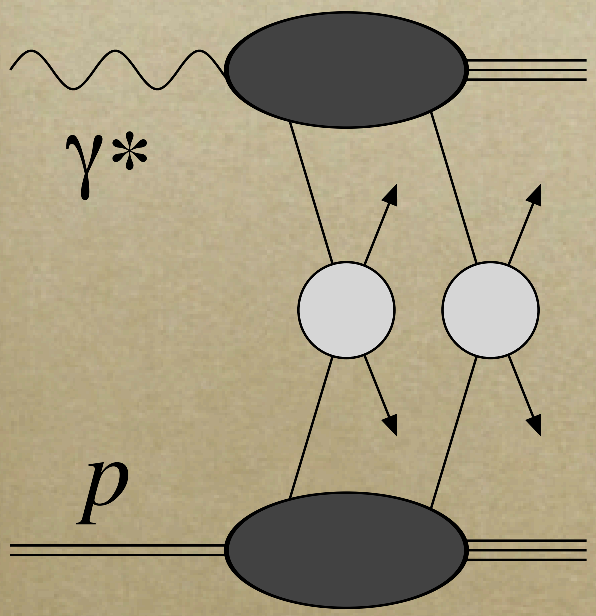
Underlying Event

- *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)*

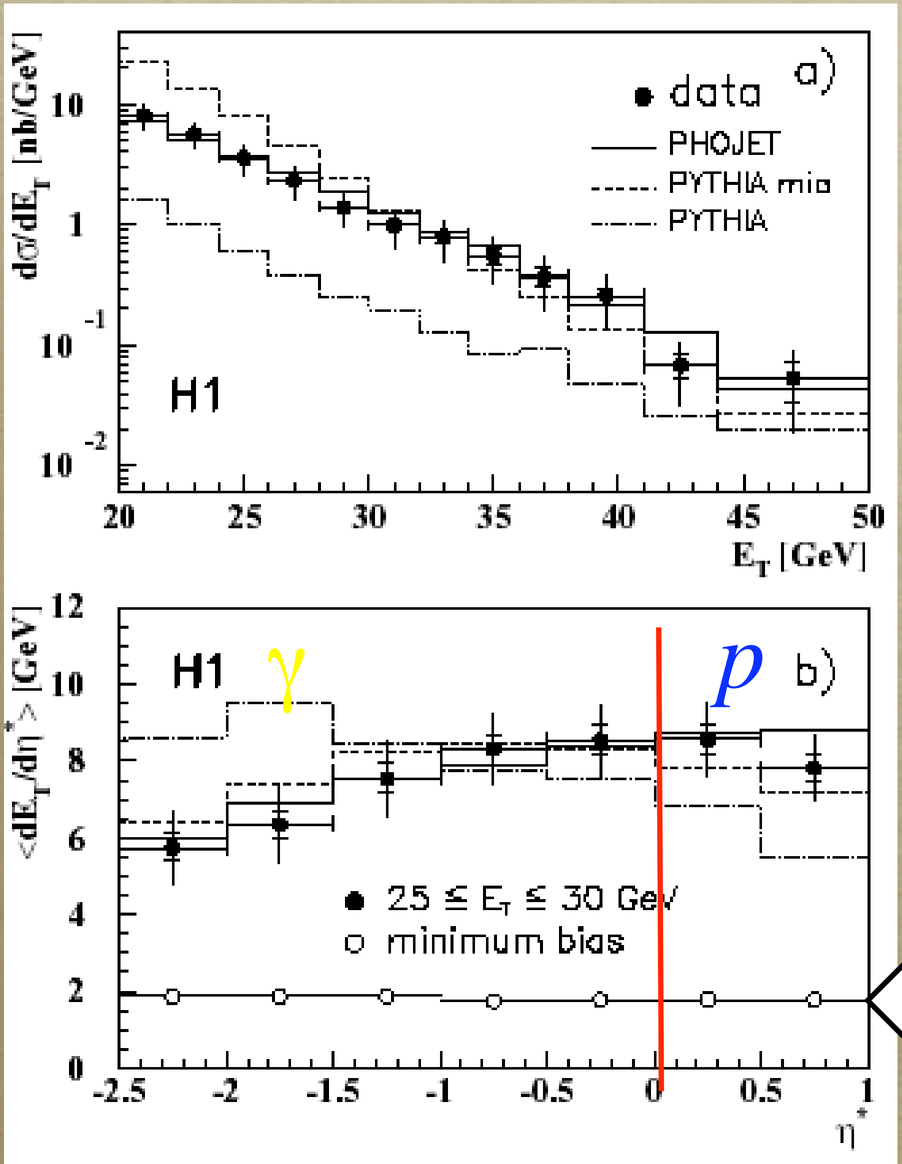
Models

- *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*

dσ/dE_T & <dE_T/dη*>



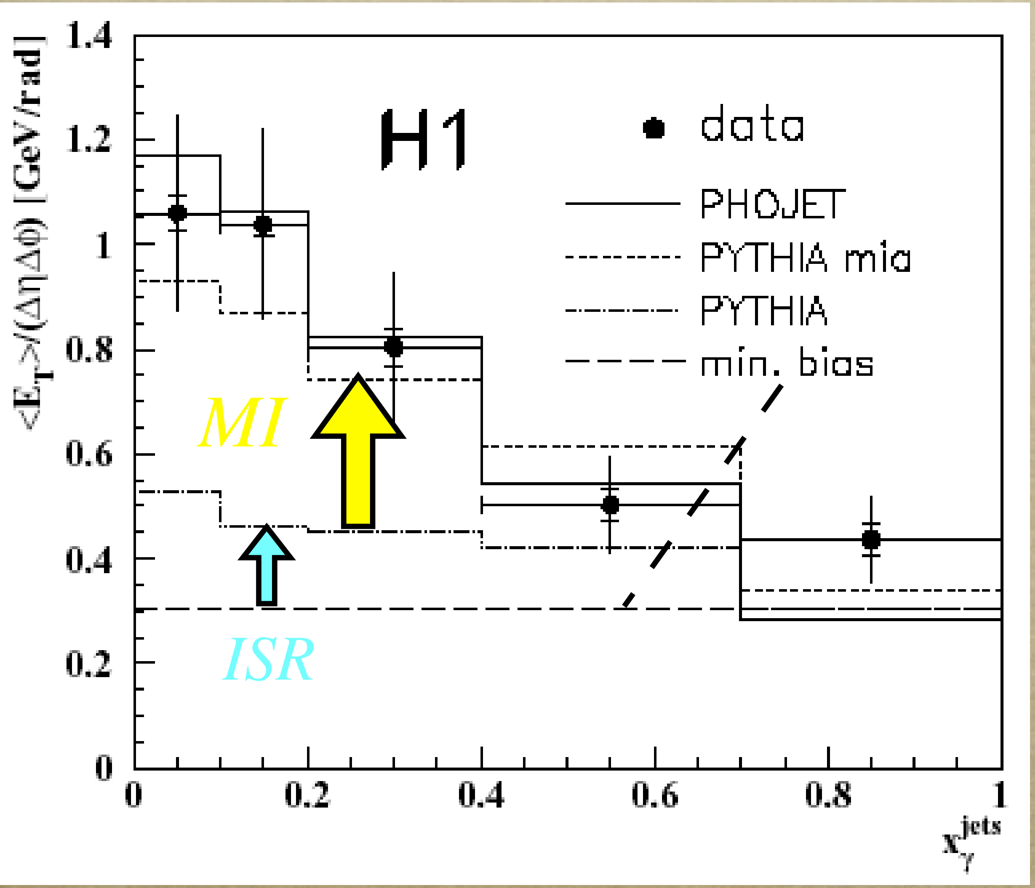
High E_T sample

- *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?

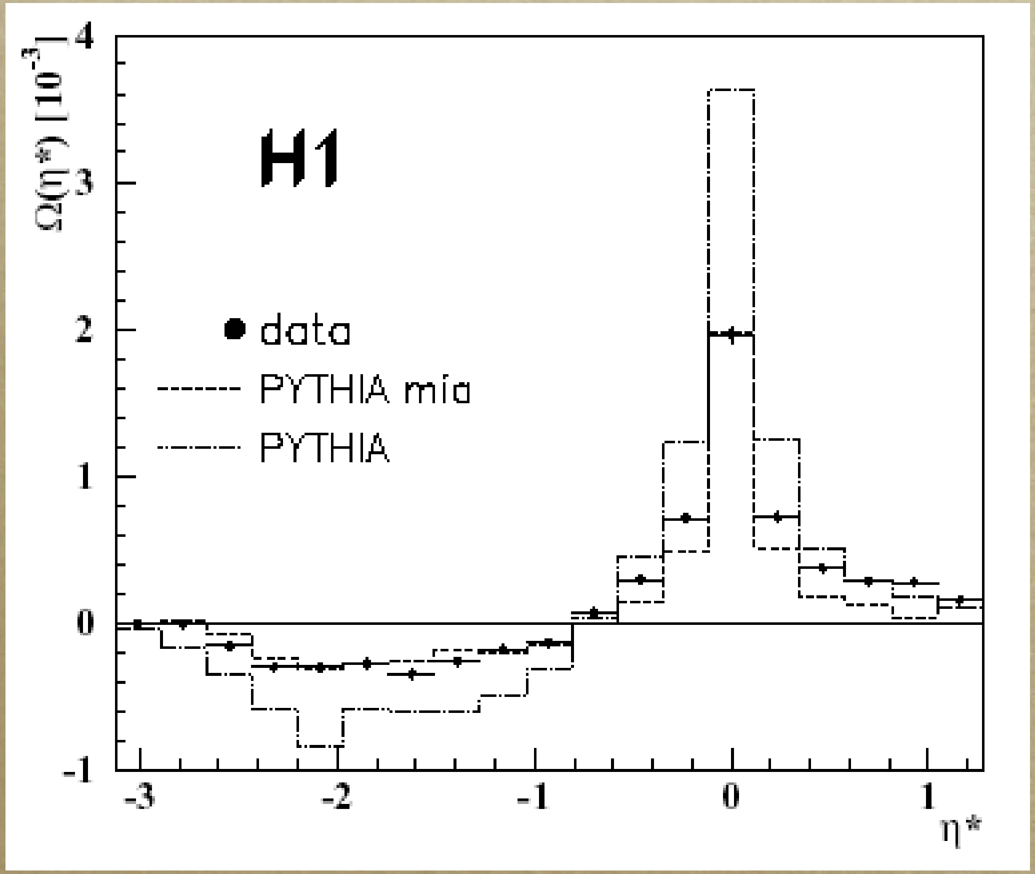
- *in MI the scatterings are mainly independent of each other*
- *study E_T correlations w.r.t. the central rapidity region in* γp

$\Omega(\eta*) = 1/N \sum(\langle E\_T,\eta*=0\rangle - E\_T,\eta*=0)\_i \; (\langle E\_T,\eta*\rangle - E\_T,\eta*)\_i \, /(E^2\_T)\_i$

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



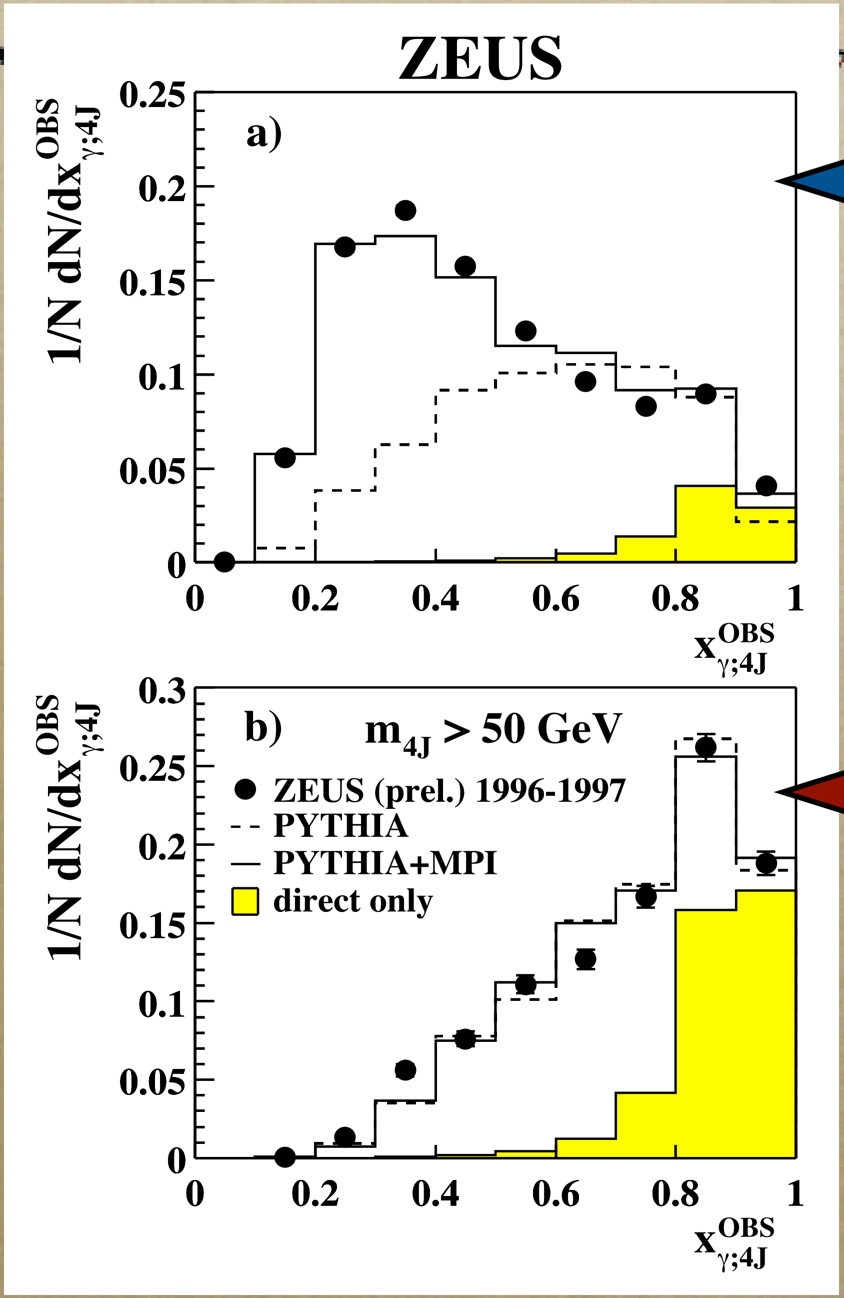
- *short range correlations near mid-rapidity*
- *anti-correlations are observed at* $\eta* \sim 1.8$
- *PYTHIA+MI is ok, with MI the correlation strength is reduced (as expected) by a factor of 2*

Multijets in Photoproduction

- *Events with 4 jets (1+2 → 3+4+5+6)*
- *in resolved events they may arise from MI*
- $E\_T_{3,4} > 6$, $E\_T_{5,6} > 5$ *GeV*
- x_γ,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

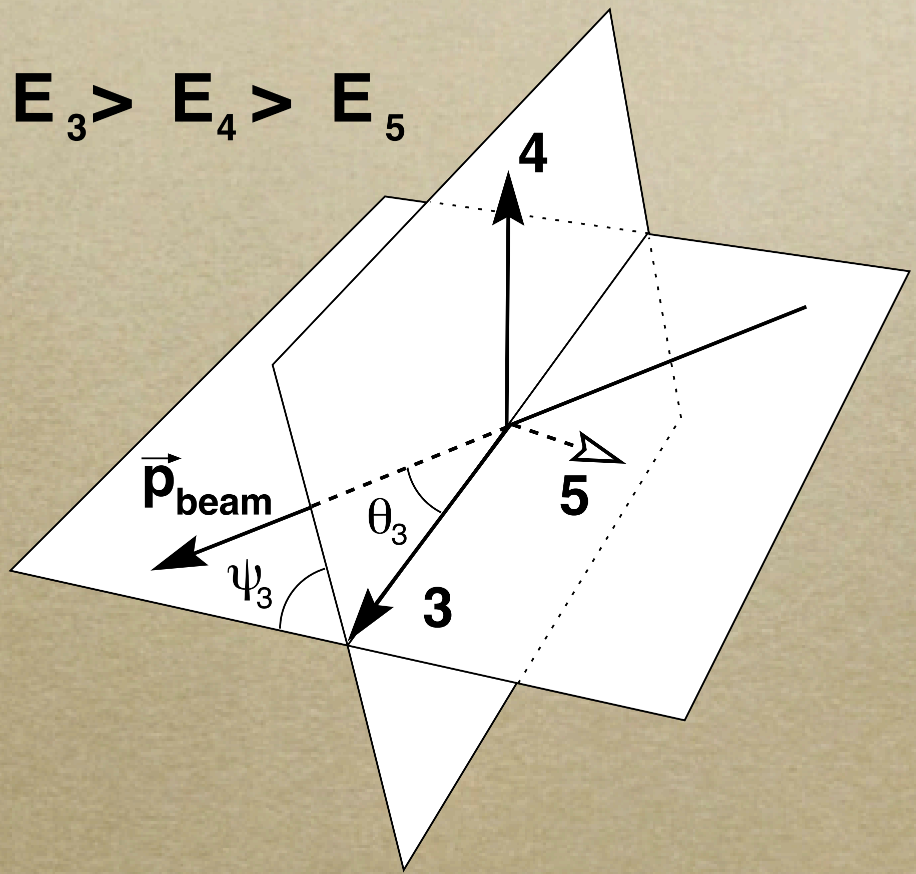


- *the inclusive data show a clear enhancement at low x_γ* and can be better described by including MI with PYTHIA
- *the high mass data (M_4J > 50 GeV) show little difference between PYTHIA with or without MI*

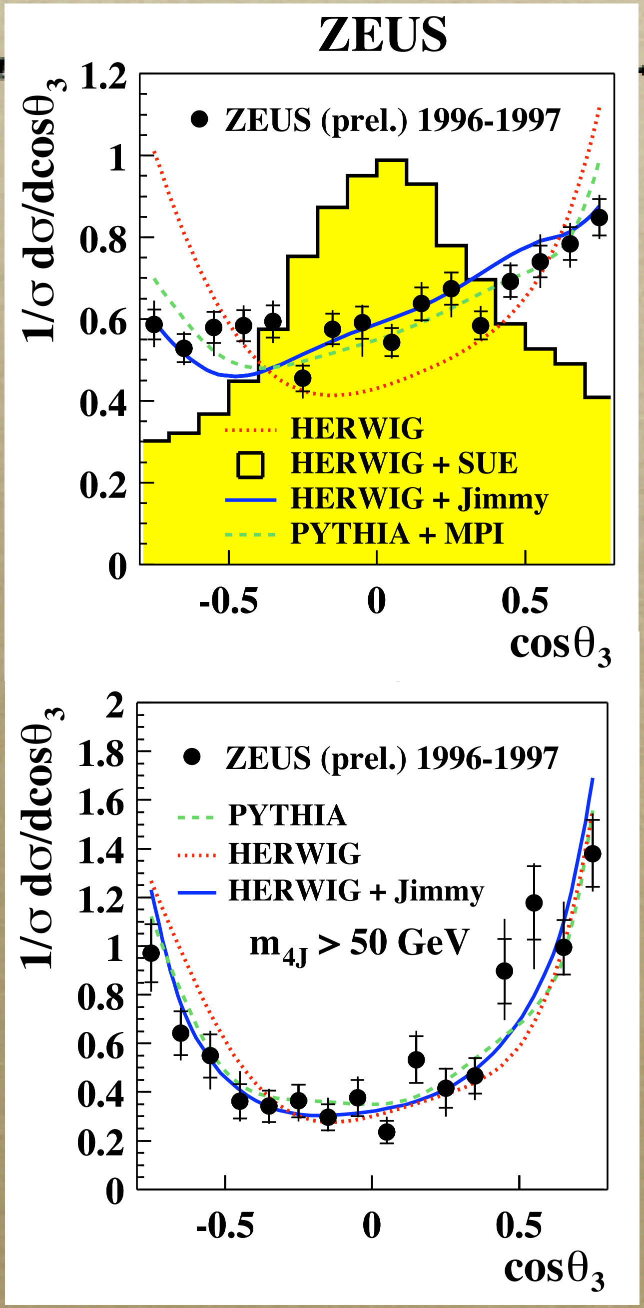
Orientation of the pseudo-jets

- $cos\ \theta_3$ 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: $\cos\theta_3$ Distribution



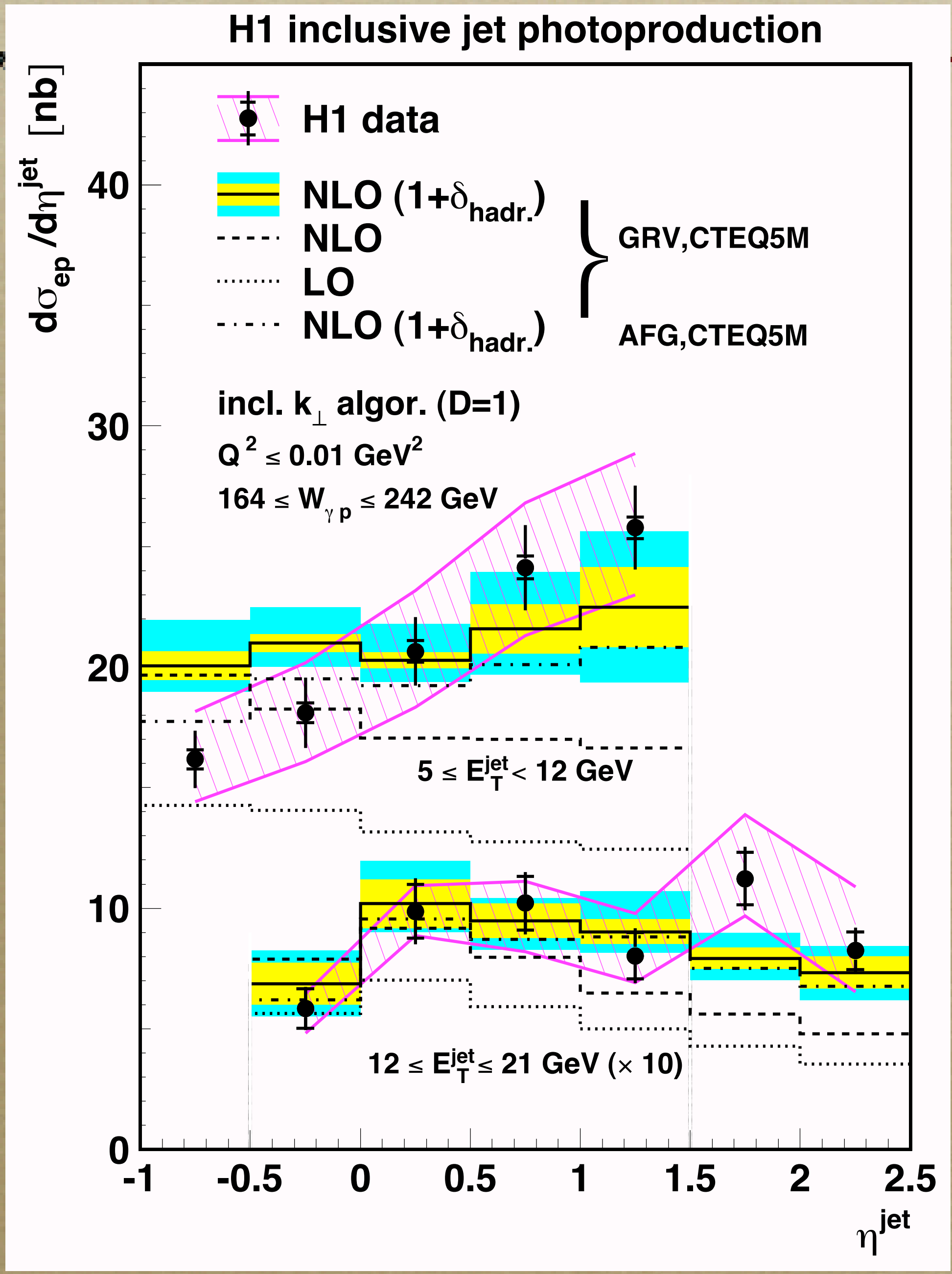
Inclusive data sample

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

High mass data sample

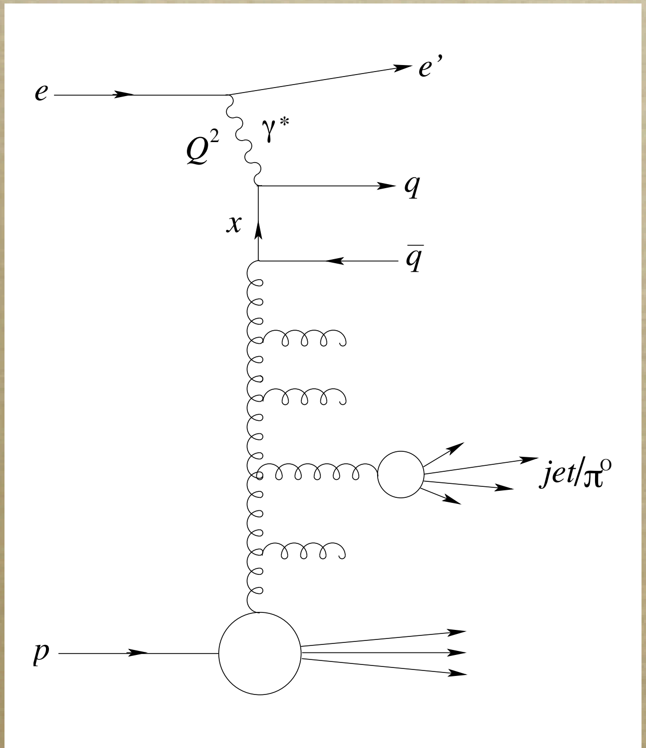
- *inclusion of MI makes little difference*

Inclusive Jets: Data vs. NLO



- *$5 \le E\_T < 12$ GeV*
- *falling LO/NLO prediction for increasing η*
- *with hadronisation, incl. MI, the predictions rise*
- (1+δhadr) = (1+δMI) (1+δfrag)
- δMI~0.3 at η~-0.75 and δMI~1.0 at η~1.25 (p-dir.) and δfrag ~ - 0.3
- H1, Eur. Phys. J C29 (2003) 497

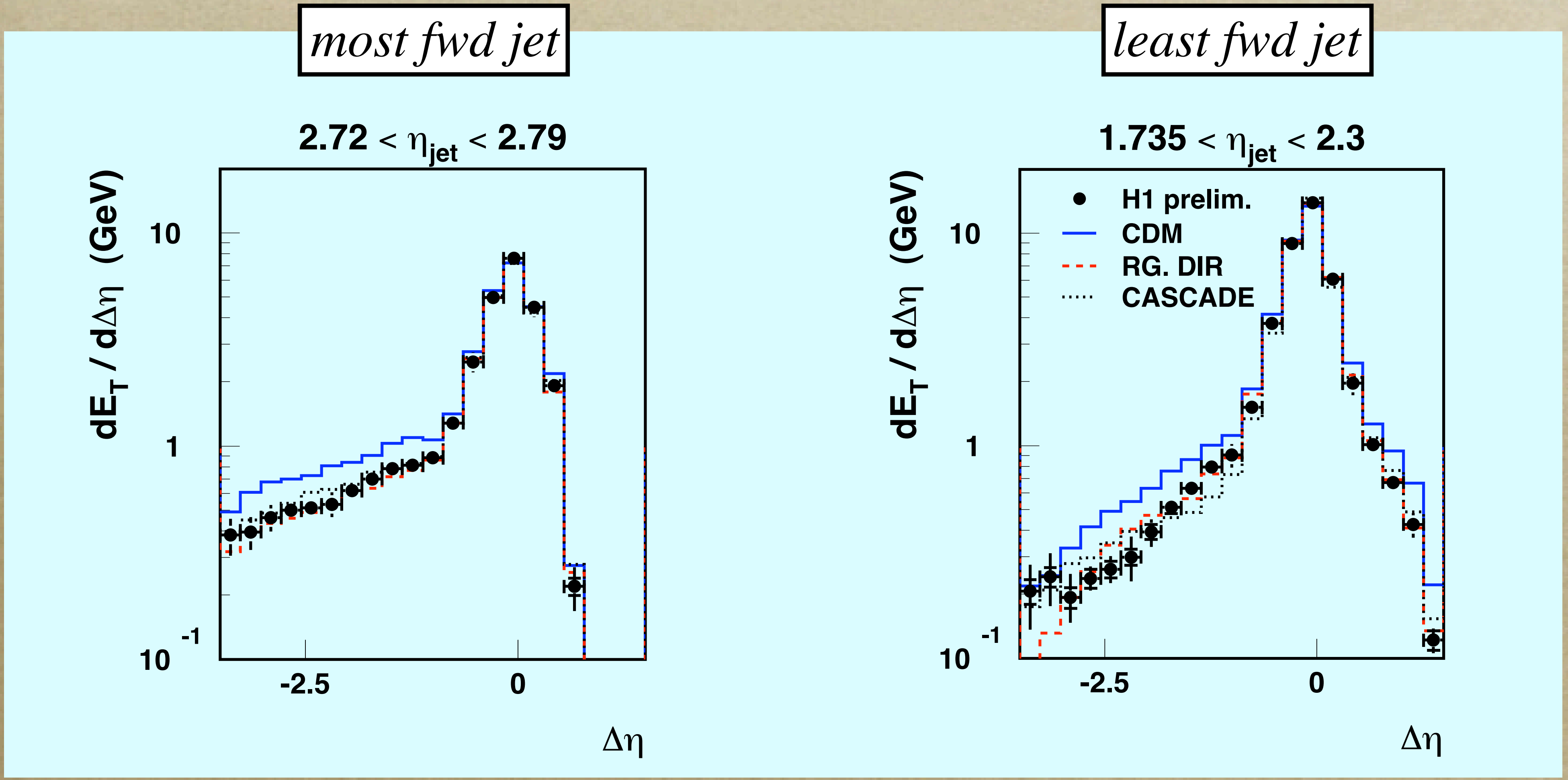
Forward jets



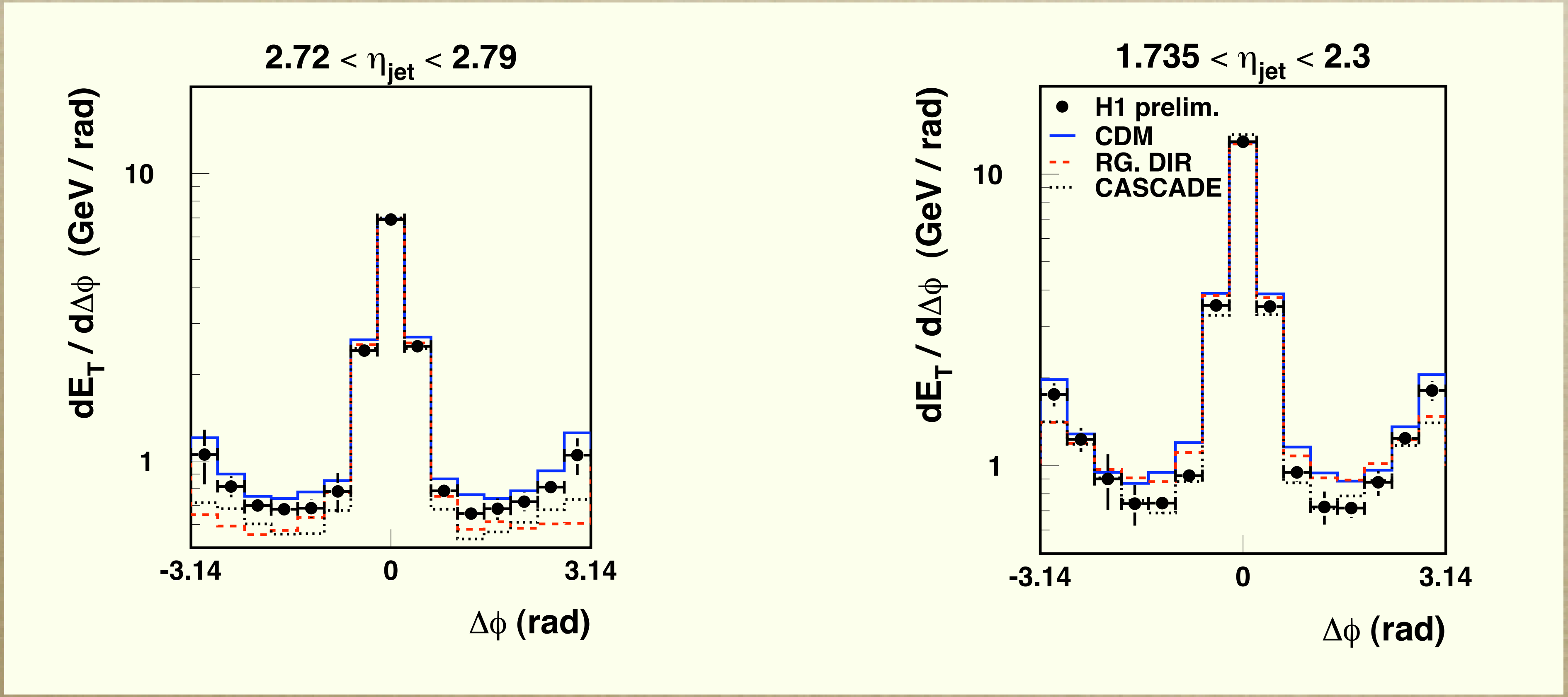
(see talk by A.Knutsson)

- *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

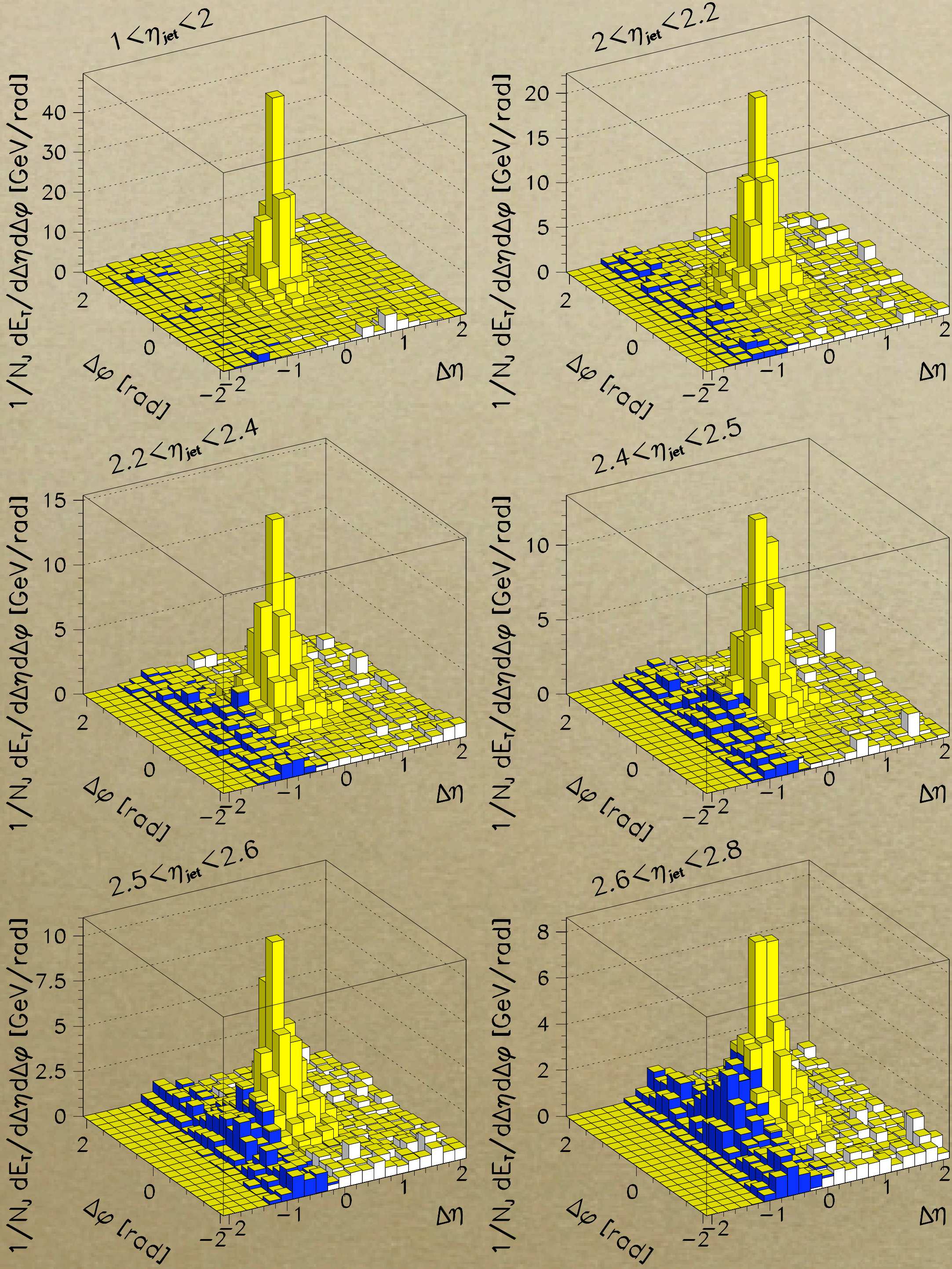
Forward Jet Profiles in Δη



Forward Jet Profiles in ΔΦ



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

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*
- *Which measurements should still be done at HERA?*