Single-Inclusive Jets in DIS at low Q^2 at HERA

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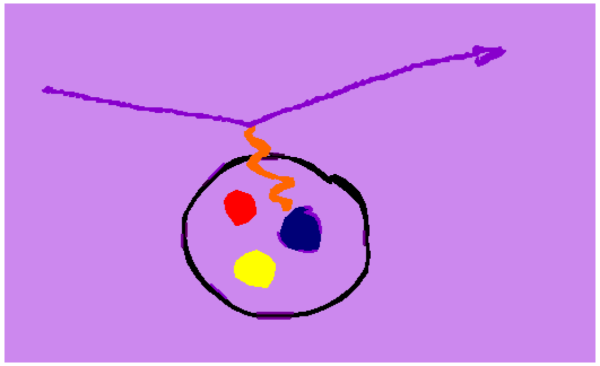
- Differential measurement of single-inclusive jets with high statistics
- Scanning phase space in $d\sigma/dE_T$ at low Q^2 and x_{Bj}
- Comparison of data to NLO calculations of direct (and resolved) processes
- Study of scale dependencies in NLO



Why measure single-inclusively?

- **Simple + natural:**
  - Count jets, not events!
- **Tradition in $p\bar{p}$:**
  - But go to lower E_T at HERA.
- **H1+ZEUS: 'Forward jets'**
  - Discrepancies observed
  - Does NLO work in larger phase space?
- **High statistics available:**
  - Typical stat. error less than 10 %
  - Typical syst. error 5-15 %
  - Often theoretical uncertainties larger than experimental ones.
- **Many effects to observe**

$d\sigma/dE_T$ in bins of η_{lab} (Q^2)

- most natural variable in jet physics
- first time at low Q^2

$d\sigma/d(E_T^2/Q^2)$ in bins of η_{lab} (Q^2)

- interplay of DIS scales
- study resolved processes in DIS

$d\sigma/dx_{Bj}$ in bins of η_{lab}

- DGLAP $\Leftrightarrow$ BFKL?
- 'forward jets'
  - $\eta_{lab} > 1.5$ (close to proton)
  - $x_{jet} = E_{jet}/E_p > 0.035$
  - $(E_T^2/Q^2 \sim 1)$

Forward Jets and Beyond

Is it the parton evolution?

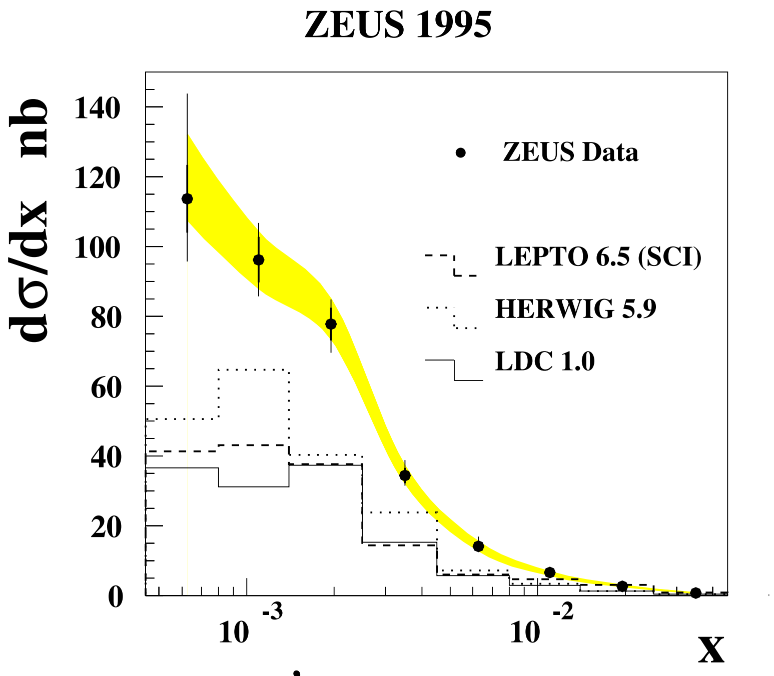
DGLAP

$$\alpha_S \cdot ln\frac{Q^2}{Q_0^2}$$

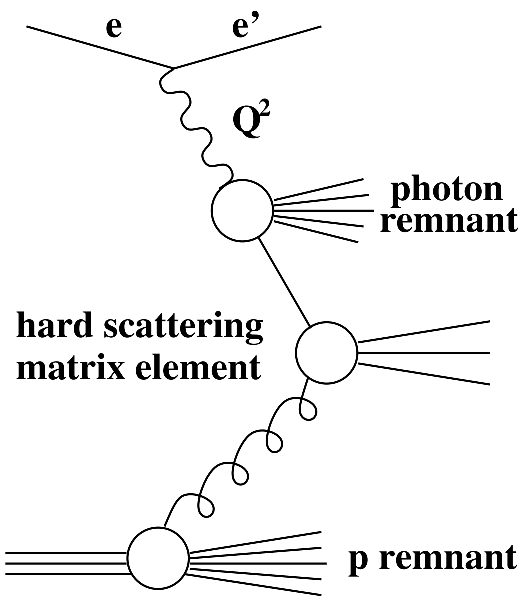
$$\Updownarrow$$

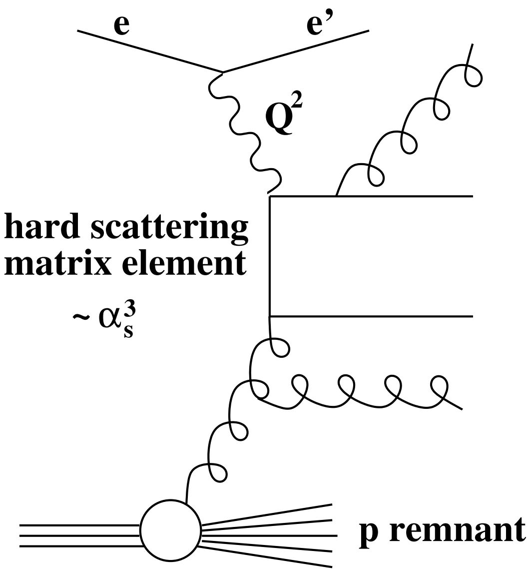
BFKL

$$\alpha_S \cdot ln\frac{1}{x}$$



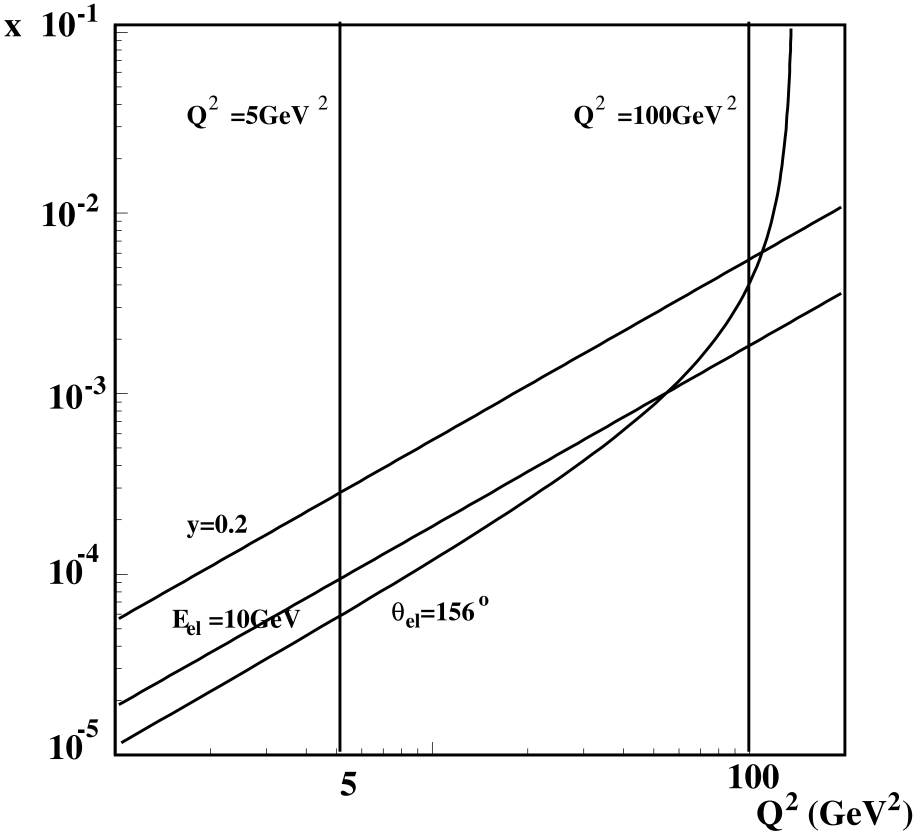
Or a resolved photon structure?





Do we need higher pQCD orders?

Analysis



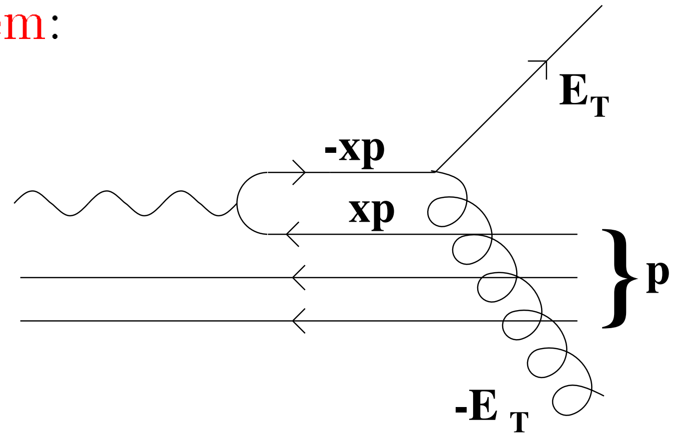
$5 < Q^2 < 100$ GeV^2

$E_T < 70$ GeV, $0.25 < E_T^2/Q^2 < 100$

140000 jets from 1996/97 data

=> high statistics for differential analysis

Jet finding with the inclusive k_T cluster algo in the Breit reference system:



Cuts on jets:

$E_T > 5$ GeV, -0.5 $< \eta_{lab} <$ 2.8

NLO calculations:

- DISENT: direct processes,

  $\mu_F^2 = Q^2$, $\mu_R^2 = E_T^2$ or Q^2

- JetViP: resolved processes,

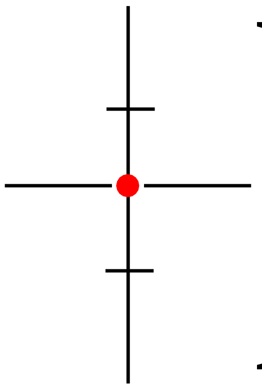
  $\mu_F^2 = \mu_R^2 = Q^2 + E_T^2$

A Guideline to the Plots

(NLO - Data) / Data including hadronisation

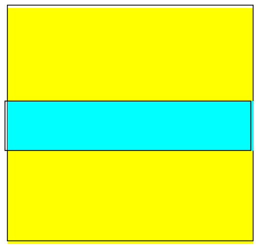
H1 preliminary

statistical error



statistical and systematic error

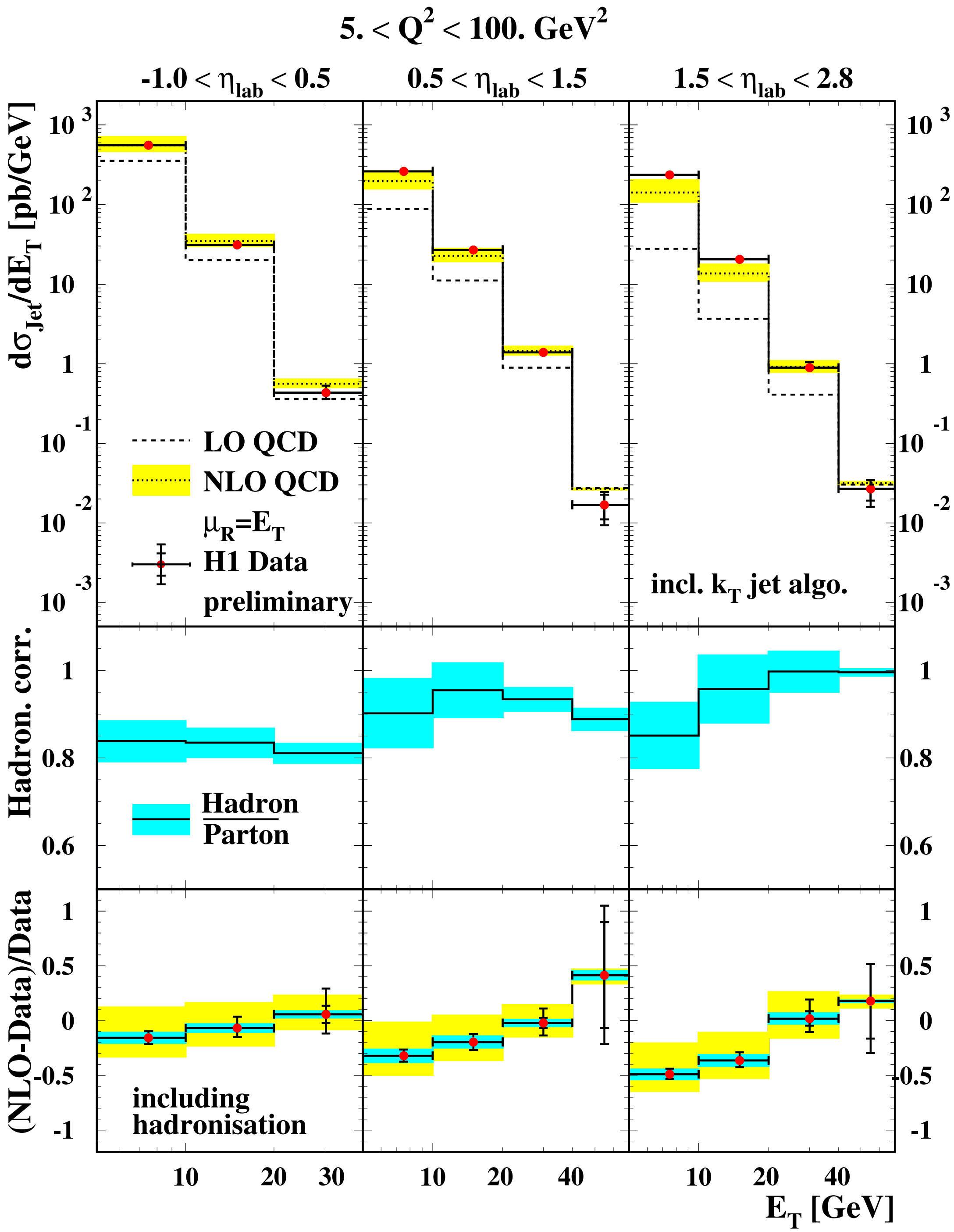
hadronisation uncertainty: difference between LEPTO and ARIADNE



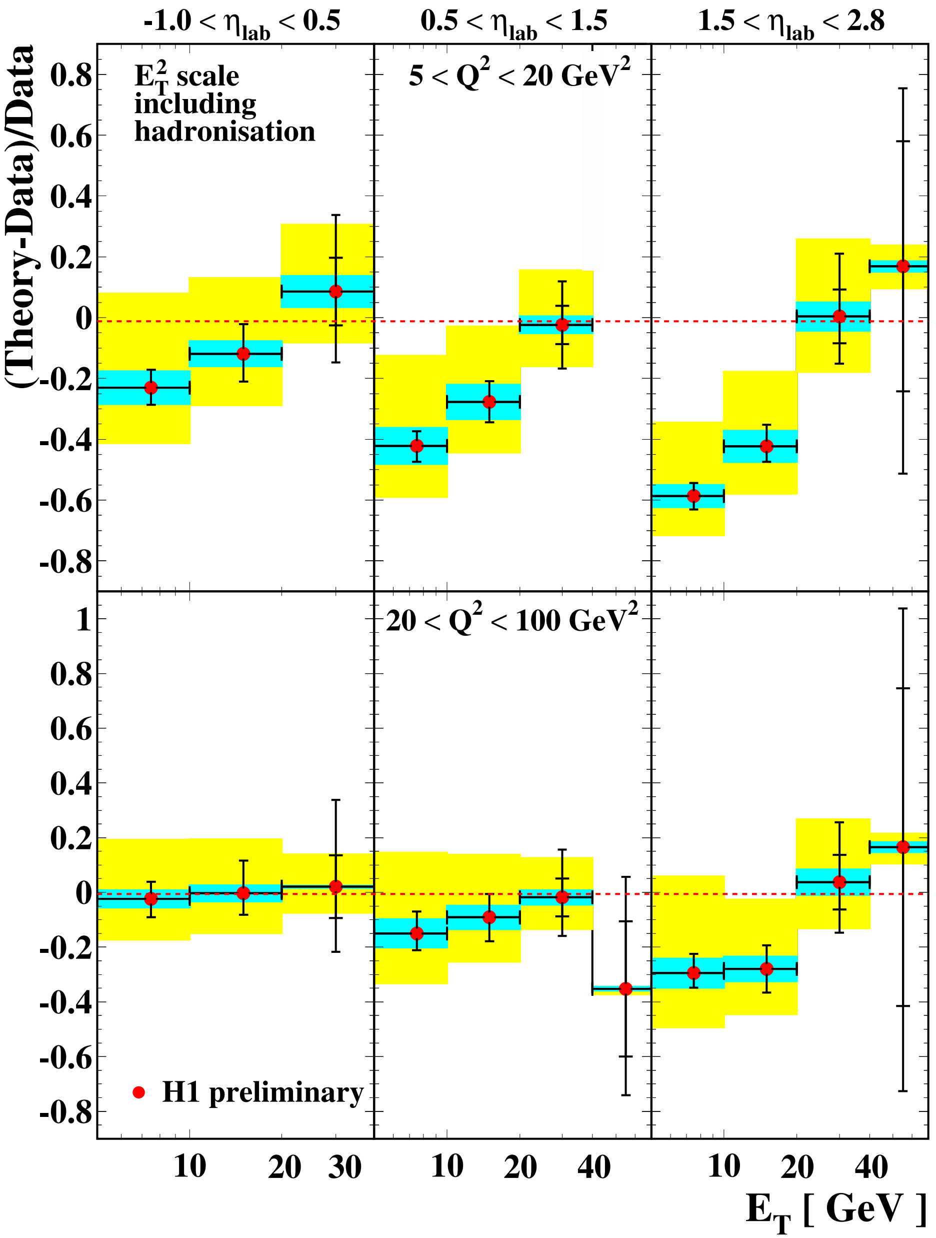
uncertainty from variation of μ_R^2 by factor 4 up and down.

$d\sigma/dE_T$ in η_{lab} bins

- $\mu_R^2 = E_T^2$
- **top: cross section $d\sigma/dE_T$**
  - yellow band: direct NLO
  - statistical error: 5 %
- **center: hadronisation**
  - correction $\sim$ 15 %
  - uncertainty $\sim$ 10 %
- **bottom: (NLO-Data)/Data**
  - theoretical error larger than exp. uncertainty
- **NLO works quite well**, but lets take a closer look...



$d\sigma/dE_T$ Measurements: Description by NLO

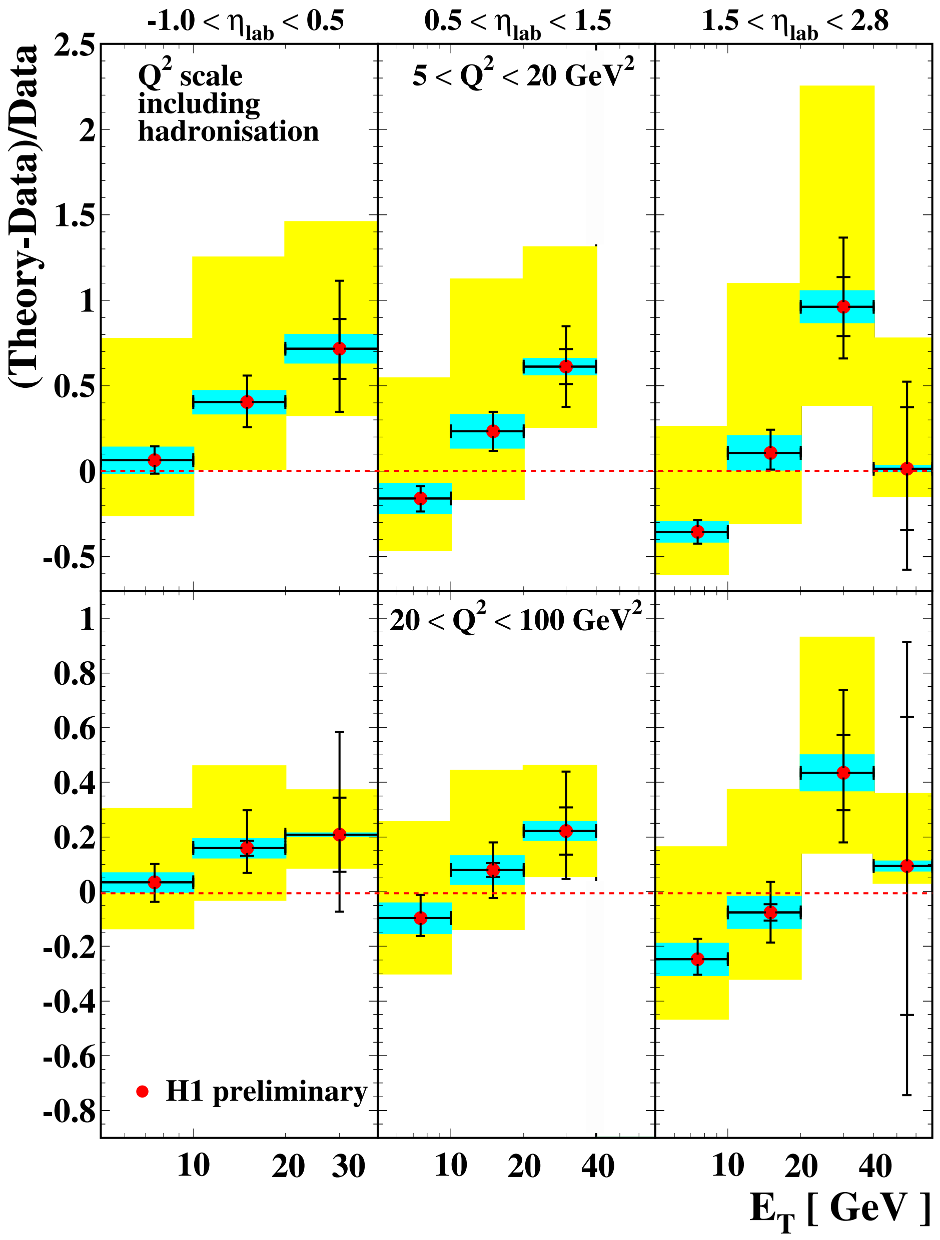


- (NLO-Data)/Data including hadronisation
- $\mu_r^2 = E_T^2$
- top: $5 < Q^2 < 20$ GeV^2
- bottom: $20 < Q^2 < 100$ GeV^2

Description fails for low $E_T < 20$ GeV at low Q^2 in the forward direction, also k factors large

=> Scales? NNLO?

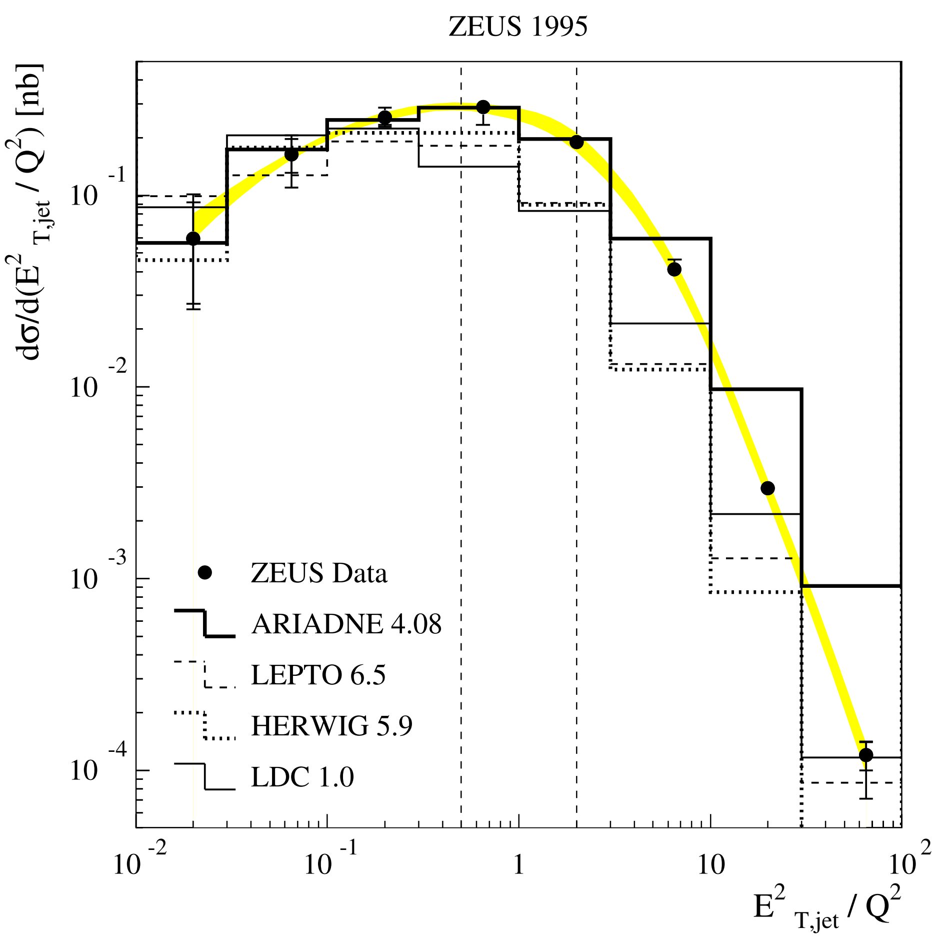
dσ/dE_T Measurements: Description by NLO



- (NLO-Data)/Data including hadronisation
- $\mu_r^2 = Q^2$
- top: $5 < Q^2 < 20$ GeV^2
- bottom: $20 < Q^2 < 100$ GeV^2
- Scale uncertainties larger than for $\mu_R^2 = E_T^2$

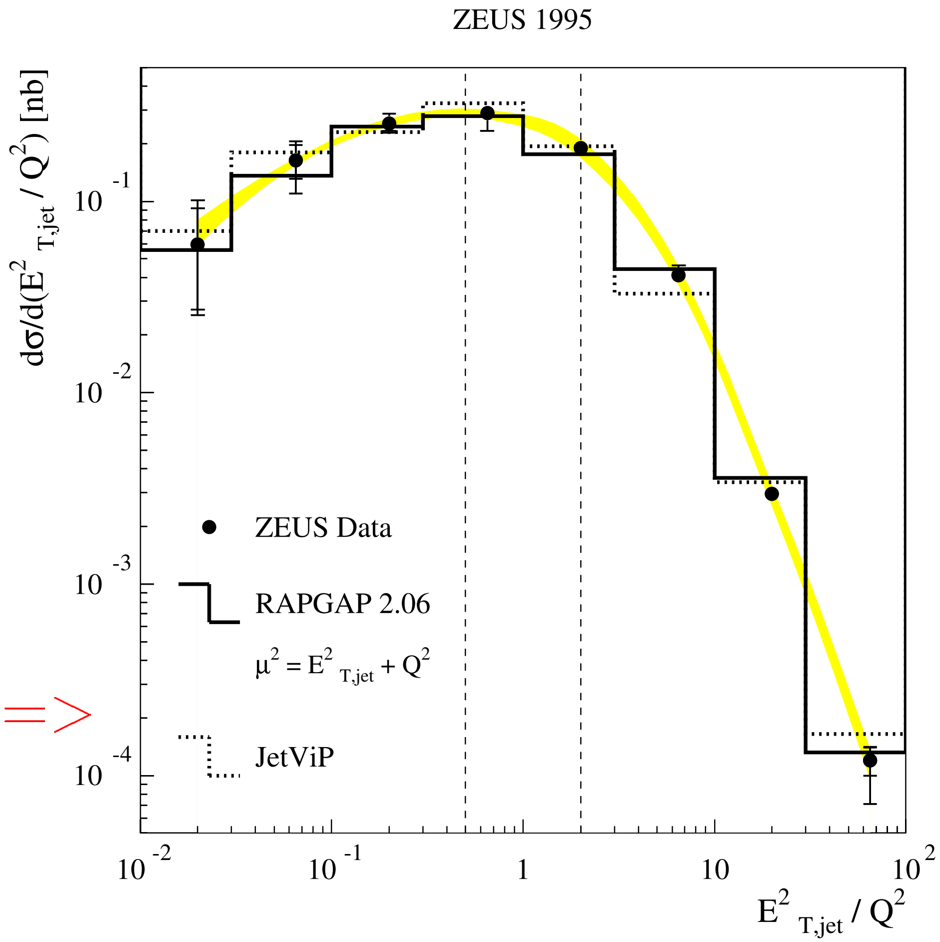
Description fails for high E_T
=> Q^2 bad scale if $E_T^2 \geq Q^2$?

Interplay of DIS Scales: $d\sigma/d(E_T^2/Q^2)$ at ZEUS



$(10 < Q^2 < 10000\ \mathrm{GeV}^2,\ x_{jet} > 0.036)$

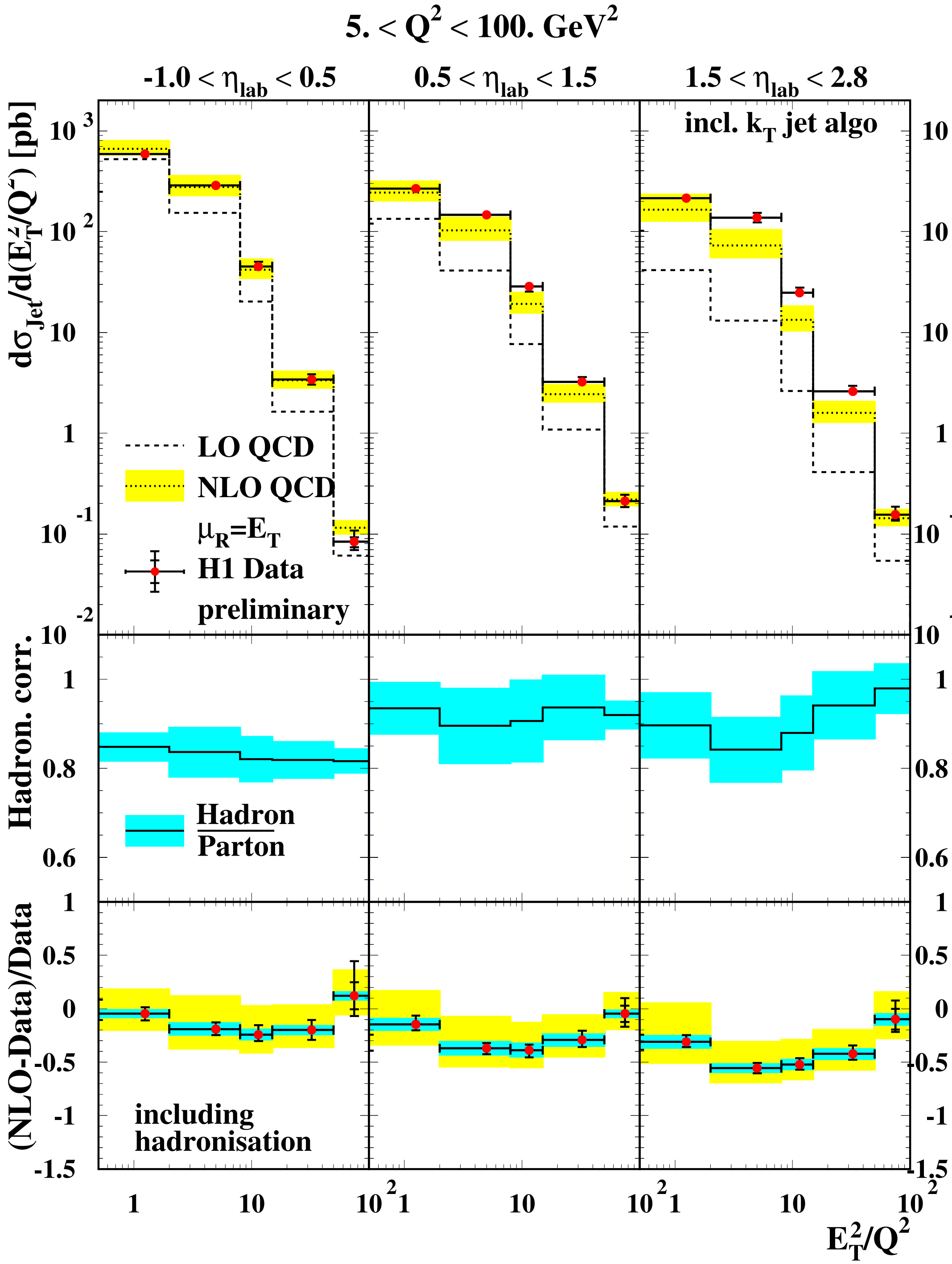
$\Leftarrow$ LO Monte Carlos for direct γ processes fail to describe data for medium values of E_T^2/Q^2 (2-50).



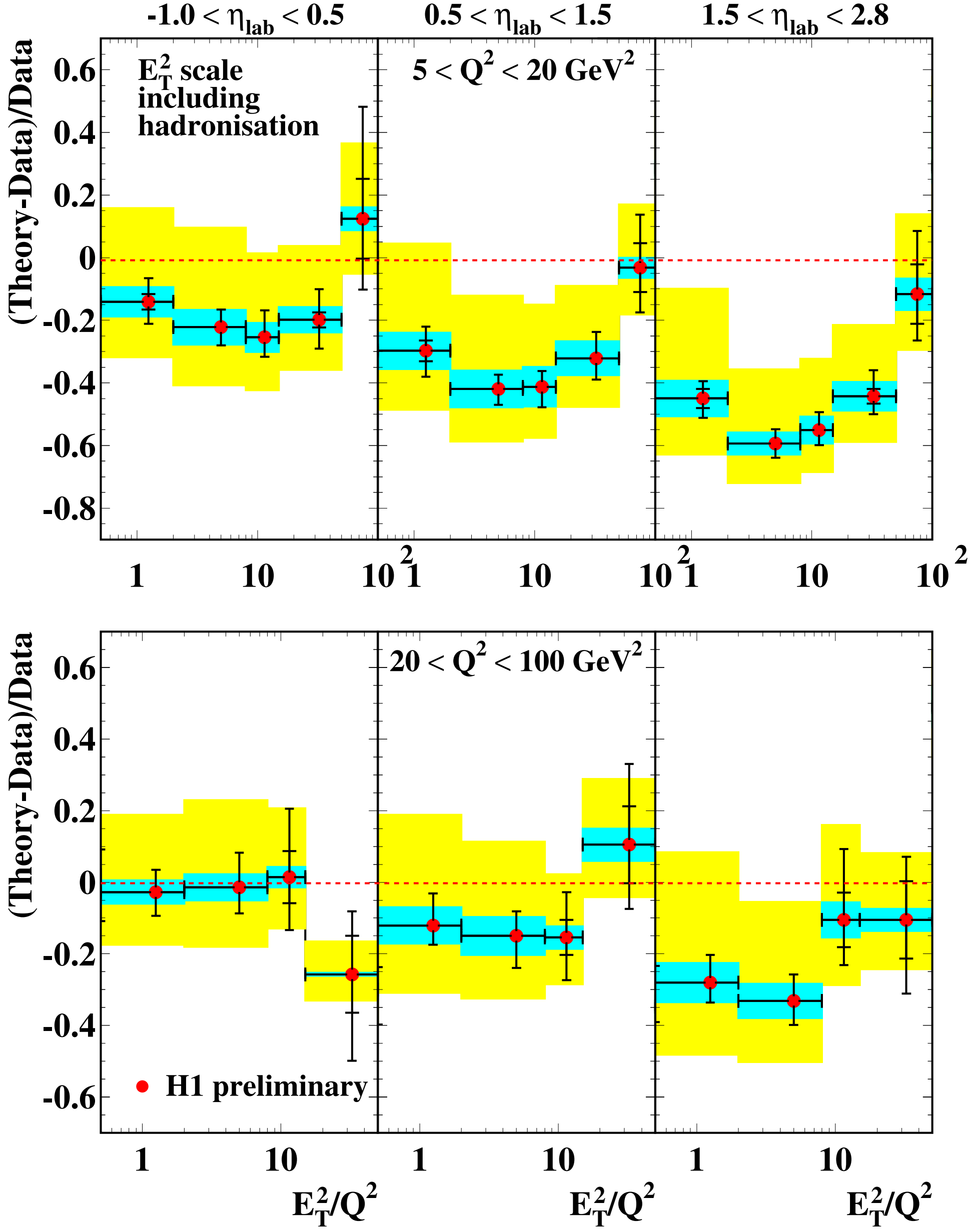
Calculations including resolved photons seem to work also for $2 < E_T^2/Q^2 < 50$. $\Rightarrow$

$\mathrm{d}\sigma/\mathrm{d}(\mathrm{E}_\mathrm{T}^2/\mathrm{Q}^2)$ **in** η_{lab} **bins**

- $\mu_R^2 = E_T^2$
- cross section $\mathrm{d}\sigma/\mathrm{d}(\mathrm{E}_\mathrm{T}^2/\mathrm{Q}^2)$
  - yellow band: direct NLO
  - statistical error: 5 %
  - systematic errors: 5-15 %
- hadronisation
  - correction $\sim$ 15 %$\pm$ 10 %
- (NLO-Data)/Data
  - theoretical error larger than exp. uncertainty
- LO/NLO calculations below data for $2 < E_T^2/Q^2 < 50$.

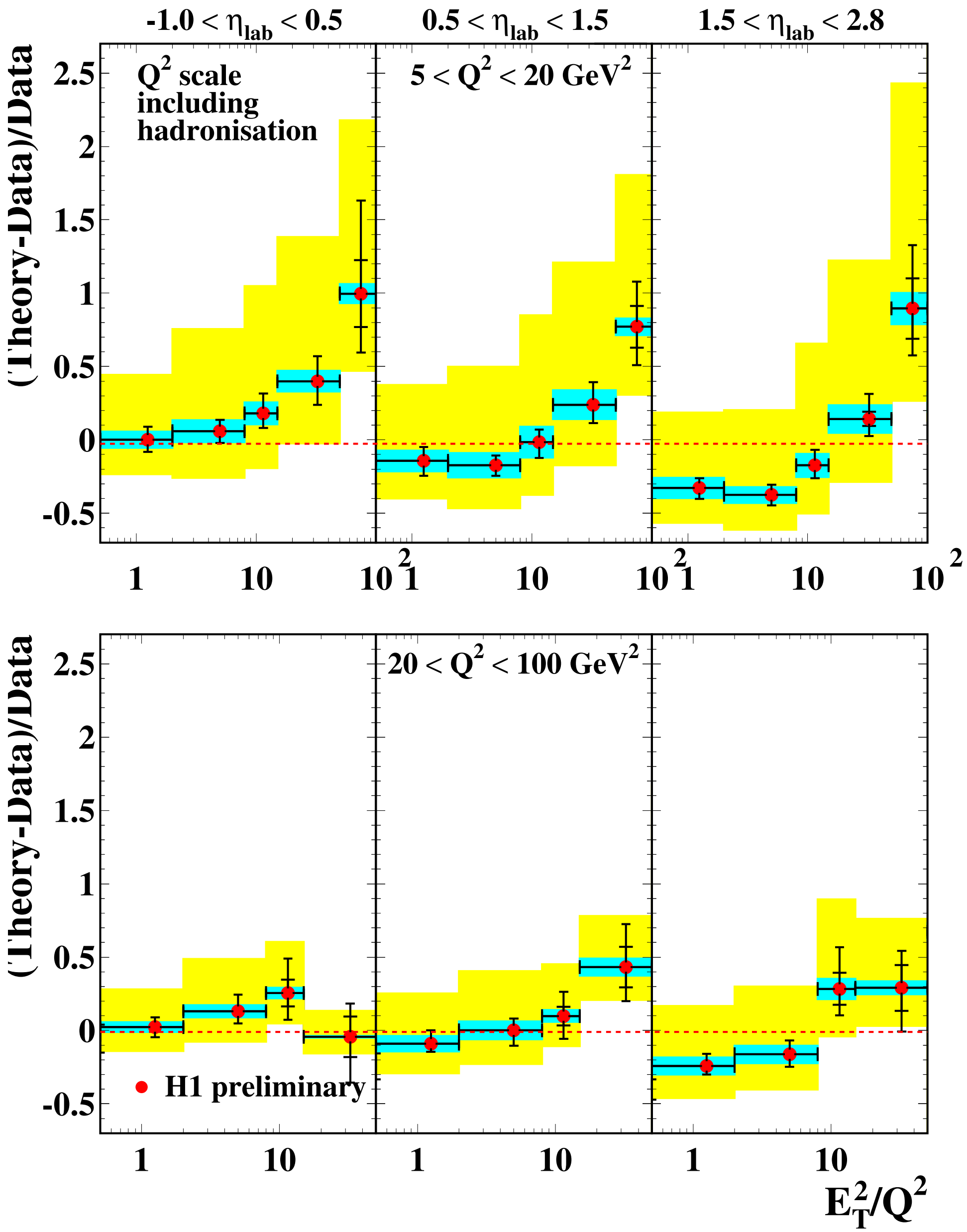


$d\sigma/dE_T^2/Q^2$ Measurements: Description by NLO



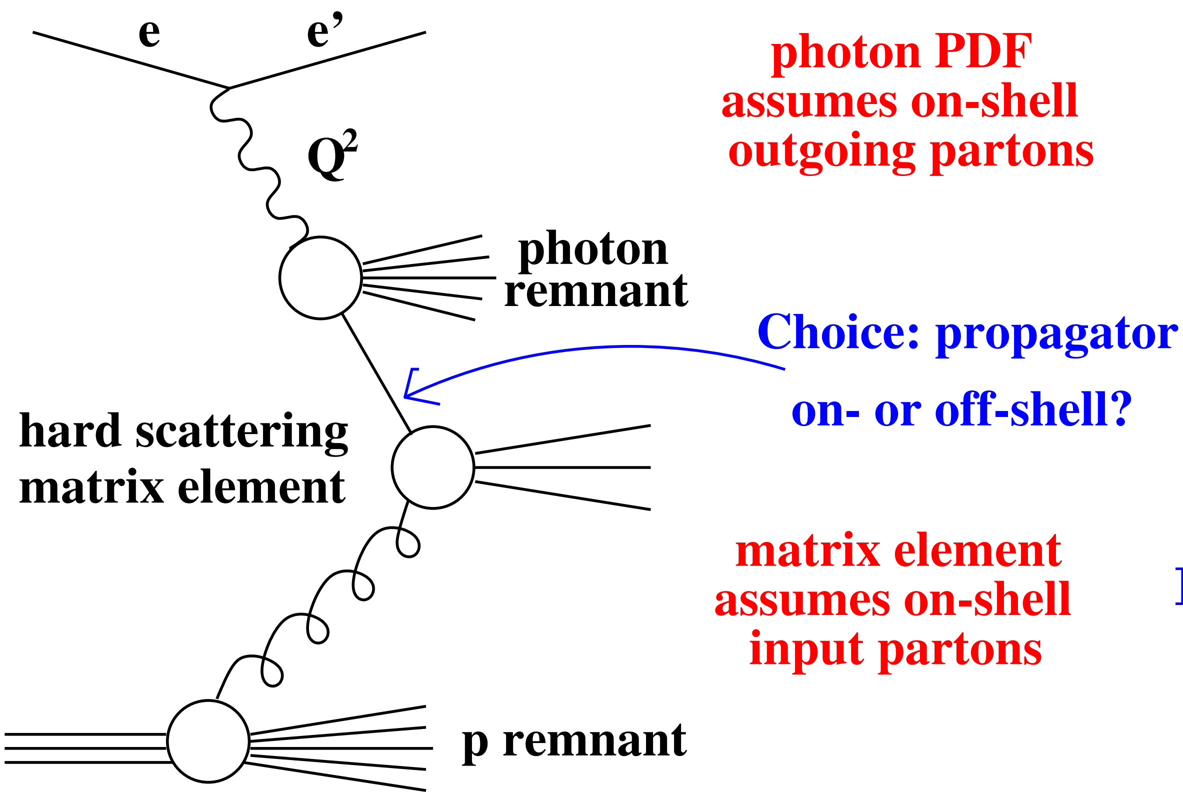
- $\mu_R^2 = E_T^2$
- top: $5 < Q^2 < 20$ GeV^2
- bottom: $20 < Q^2 < 100$ GeV^2
- forward, low Q^2: theory undershoots data for medium E_T^2/Q^2 (2-50).
- Need additional resolved photon contributions?

$d\sigma/dE_T^2/Q^2$ Measurements: Description by NLO



- $\mu_R^2 = Q^2$
- top: $5 < Q^2 < 20$ GeV^2
- bottom: $20 < Q^2 < 100$ GeV^2
- high $E_T^2/Q^2 > 50$:
  direct NLO too high.
- Q^2 scale not appropriate
  for high E_T?

JetViP: Resolved Photons at $Q^2 \geq 0$?



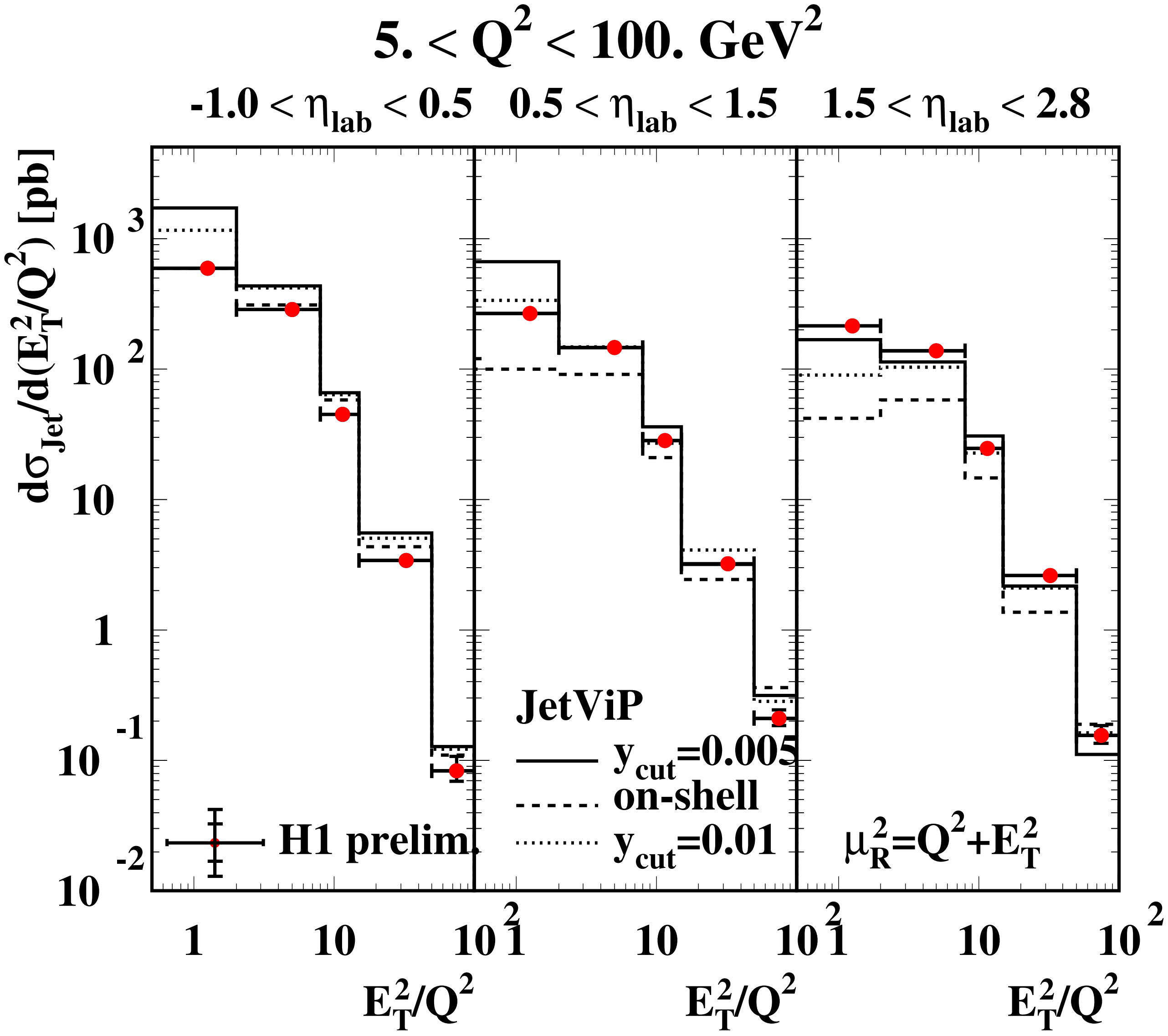
Parton propagator on-shell:

- theoretically consistent
- on-shell partons bad assumption for $Q^2 > 0$?

Parton propagator off-shell:

- two inconsistencies
- dependence of results on phase space slicing parameter y_{cut} introduced.

Data versus JetViP $\sigma_{dir+resolved}$



Best description:

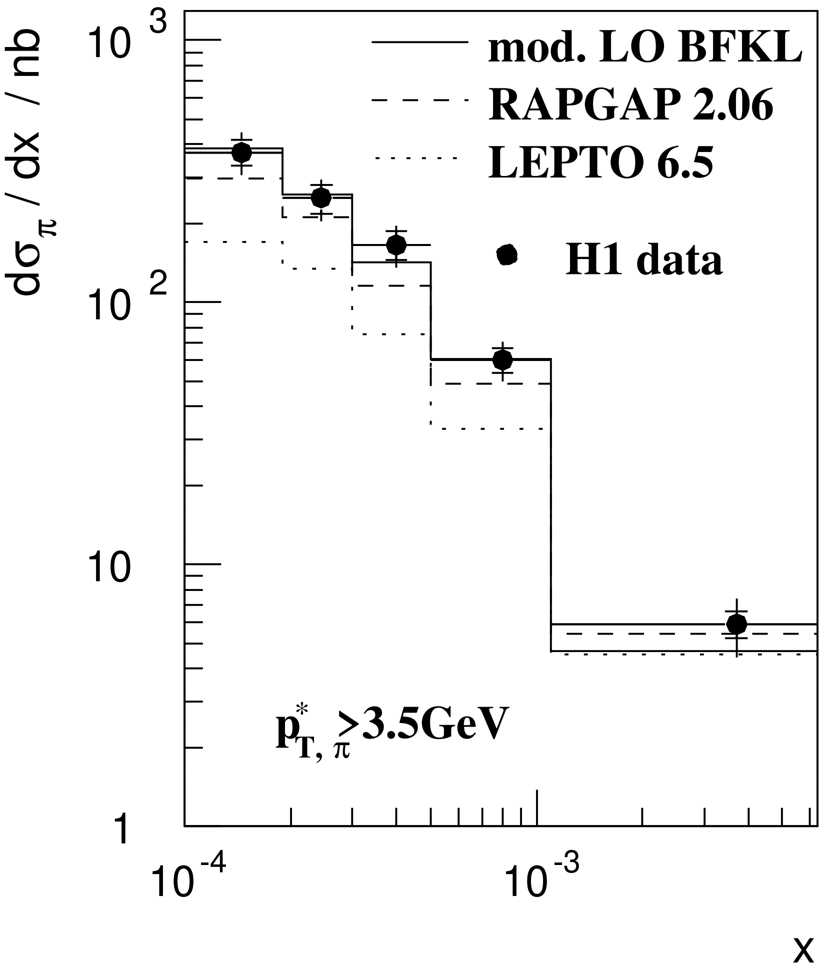
Backward:
on-shell scenario!

Central:
off-shell $y_{cut} = 0.01$

Forward:
off-shell $y_{cut} = 0.005$

No scenario describes
data everywhere!
Off-shell tunable!

$d\sigma/dx_{Bj}$ for Forward π_0

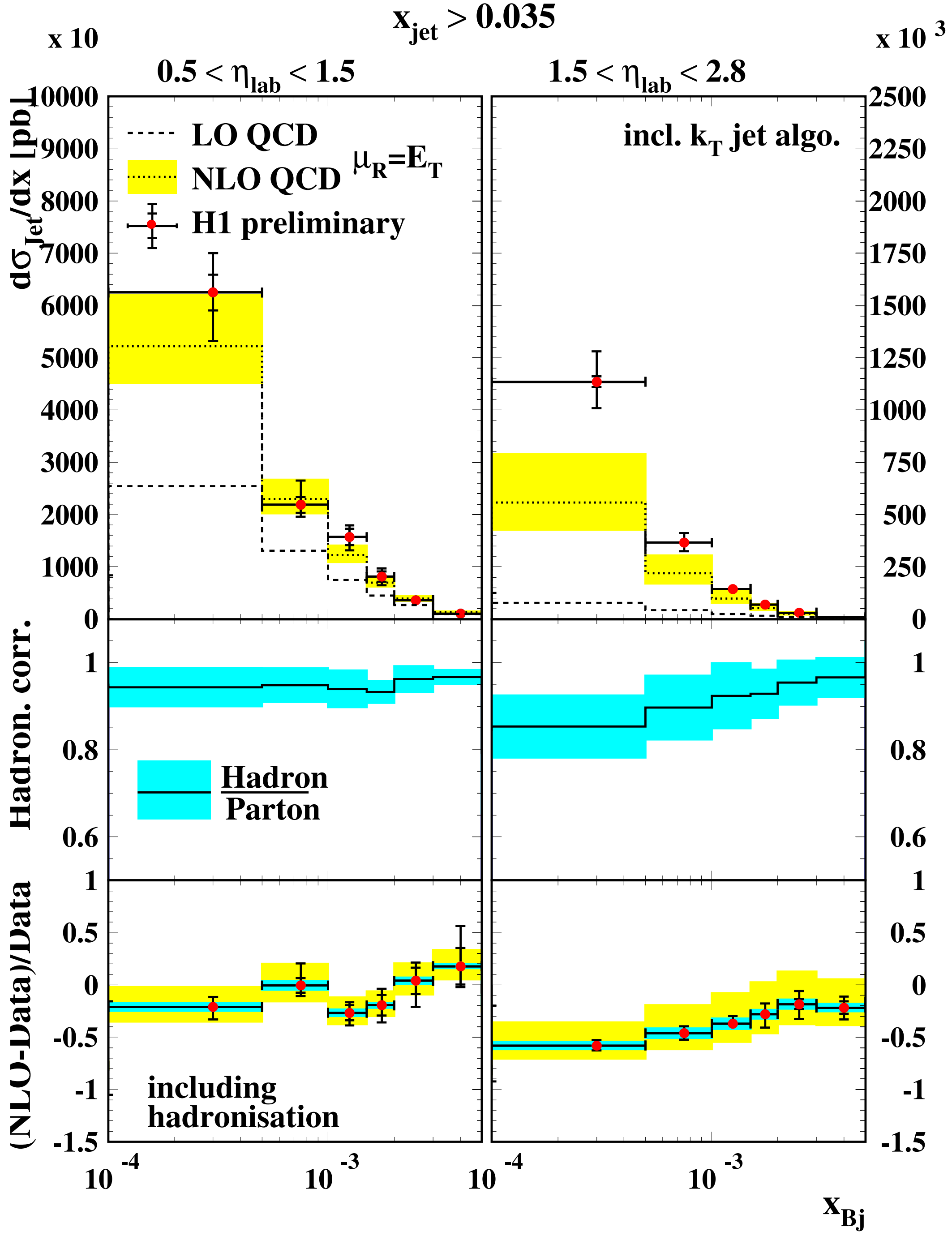


Selection:

- $2 < Q^2 < 70$ GeV^2
- $x_\pi > 0.01$
  => strong BFKL x ordering possible
- $5^o < \theta_\pi < 25^o$
  => in DGLAP little activity.
- $p^*_{T,\pi} > 3.5$ GeV in hadronic CMS

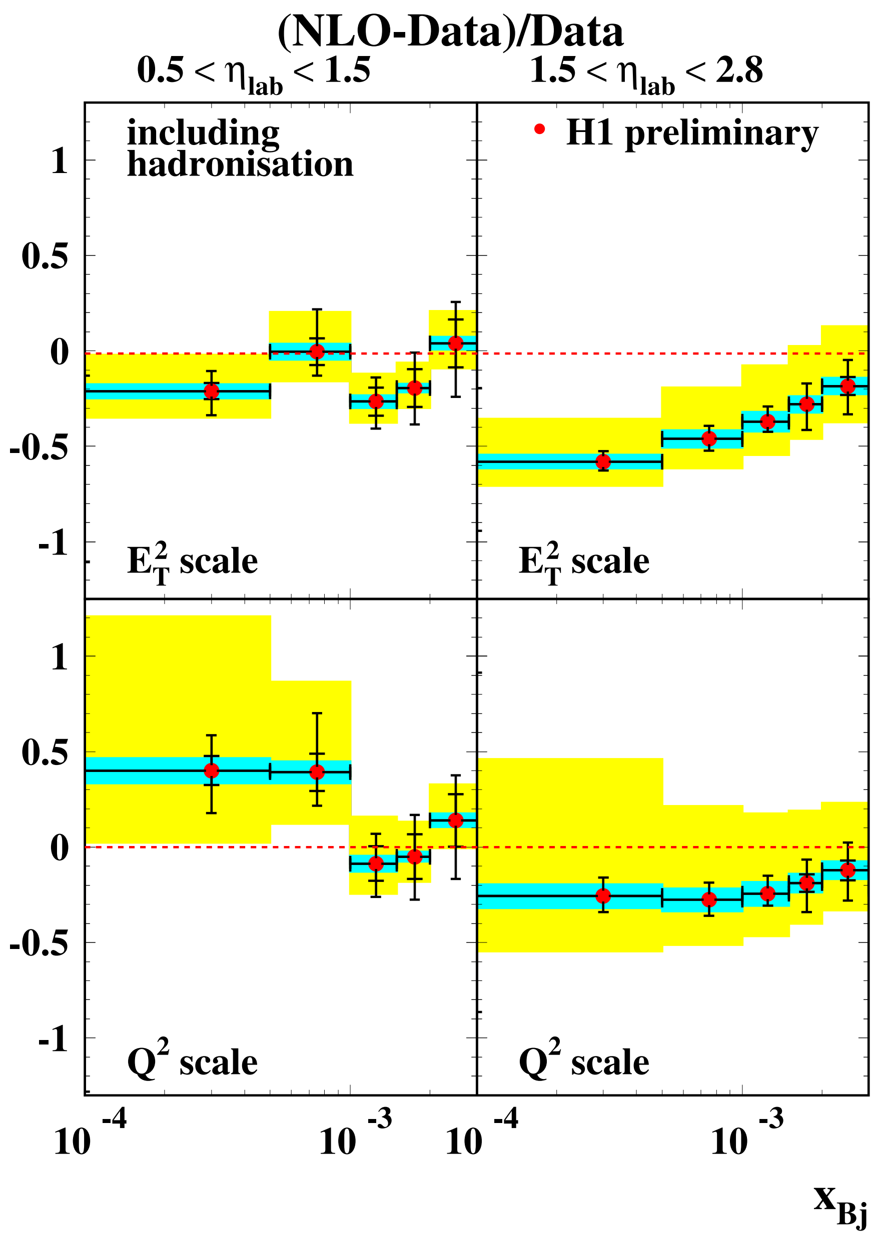
- **LO MCs (direct and direct+resolved): too low!**
- **BFKL does a good job.**

Forward Jets: $d\sigma/dx_{Bj}$



- $\mu_R^2 = E_T^2$
- cut $E_T^2/Q^2 \sim 1$ omitted:
  experimentally difficult.
  => cuts close to H1 forward π_0 analysis.
- data described in central rapdity region
- large discrepancy at low x in forward direction
- large scale uncertainties at low x.

$\mathrm{d}\sigma/\mathrm{d}x_{Bj}$ Measurements: Description by NLO



- E_T^2 scale too low in many bins; effect gets worse for low x_{Bj} forward.
- Q^2 scale describes data almost everywhere but for central low x_{Bj}.
- large uncertainties for $\mu_R^2 = Q^2$.

Summary

- **Measurement of cross sections in E_T, E_T^2/Q^2 and x_{Bj}.**
- **Scanning total phase space, not only forward jet regime.**
- **Various discrepancies between data and NLO QCD observed:**
  - Differences are scale-dependant.
  - Scale $\mu_R^2 = E_T^2$ okay for E_T or $Q^2 > 20$ GeV, backward.
  - Scale $\mu_R^2 = Q^2$ okay for low E_T.
- **Resolved calculations currently do not solve all problems.**
  - Calculation ambiguities due to only massless NLO matrix elements.
  - No global E_T^2/Q^2 description by JetViP.
- **Theorists encouraged:**
  - BFKL?
  - NNLO?
  - Resolved photon?