Studies of Forward Jets in DIS

on behalf of the

H1 and Zeus collaborations

DIS 2004, Strbske Pleso

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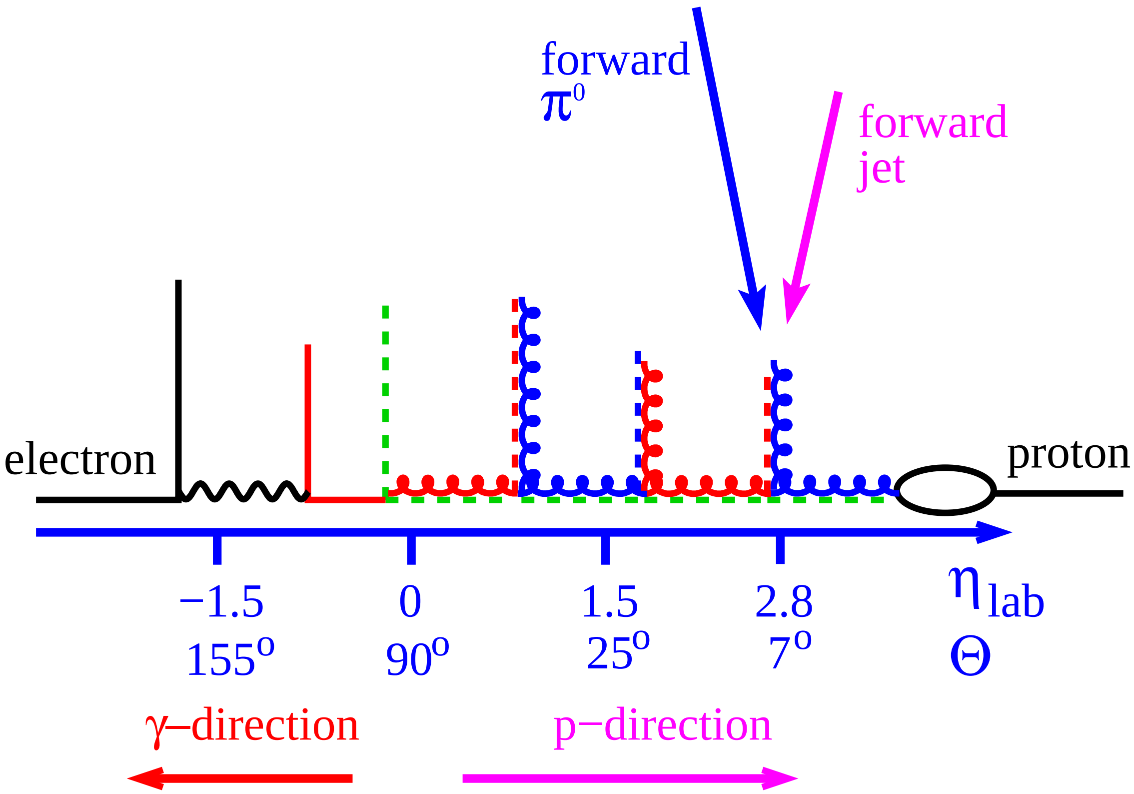
Outline

- Why forward?
- Monte Carlo Models
- Forward jet selection
- Results from H1
- Results from ZEUS
- Conclusions

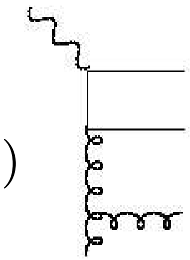
Why Forward?



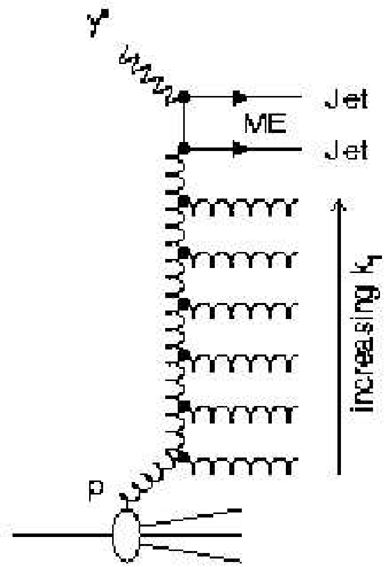
F_2 - very inclusive - very well described by DGLAP.	Dijet cross-section, Jet Rates - measure hard subsystem.	Energetic jet/particle in forward region - information on full evolution ladder.

Monte Carlo Models

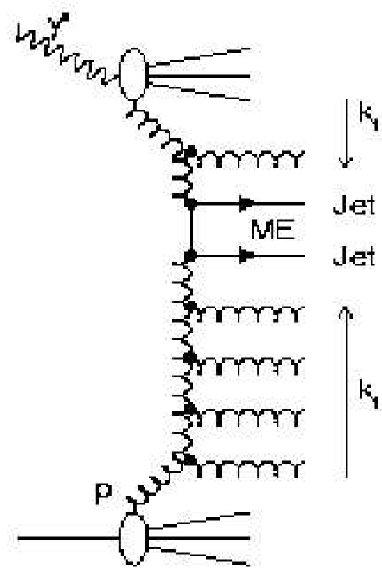
DISENT: NLO di-jet. (Need to correct for hadronization effects.)



RAPGAP/LEPTO: LO ME+PS:DGLAP evolution where the parton ladder is strongly ordered in Q^2 and k_t^2.

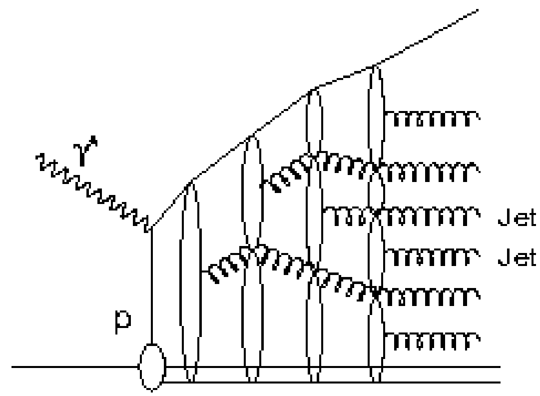


RAPGAP RES γ: RAPGAP with an additional DGLAP evolution parton ladder from the hard subsystem to the photon.



Monte Carlo Models continue...

CDM (ARIADNE): LO ME (QPM, BGF). Color Dipole Model (QCDC and higher orders). Random walk in k_t.

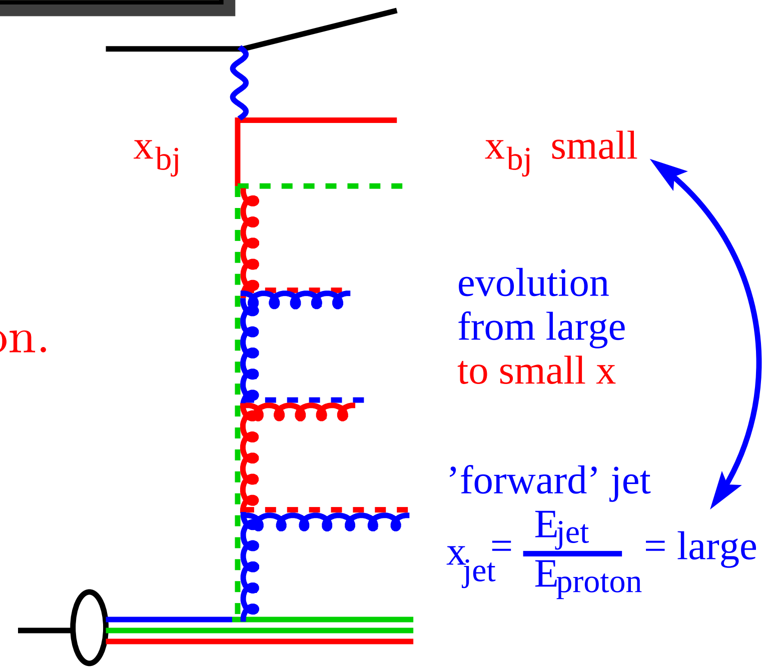


CASCADE: LO ME (off-mass shell). Initial state CCFM partons showers with emissions ordered in angle. ($\sim$ 1 tuning parameter)

Forward Jets

Jet algorithm: Inclusive k_t-algorithm

Events with energetic jet in the forward region.
Target phase space for evolution in x.
Suppress phase space for evolution in Q^2.



	H1	ZEUS
Forward jet	$1.74 < \eta_{jet} < 2.79$	$0\ (2) < \eta_{jet} < 3$
Hard forward jet	$p_t > 3.5$ GeV	$p_t > 6$ GeV
Target BFKL	$x_{JET} = \frac{E_{JET}}{E_p} > 0.035$	$\cos\gamma_{had} < 0$ (suppress QPM)
Suppress DGLAP	$0.5 < \frac{p_t^2}{Q^2} < 5$	$0.5 < \frac{p_t^2}{Q^2} < 2$ (always)
	If $N_{\rm jet} > 1 \rightarrow$ The forward jet $= \eta_{\rm max}$	Event and jet cross-sections

Kinematic range and Measurements

Kinematic range

H1	ZEUS
$5 < Q^2 < 85$ GeV	$Q^2 > 25$ GeV
$0.1 < y < 0.7$	$y > 0.04$
$0.0001 < x_{Bj} < 0.004$	no restriction
$E'_e > 10$ GeV	$E'_e > 10$ GeV

Measurements

Forward jet cross-sections

$\frac{d\sigma}{dx_{Bj}}$ (H1, ZEUS)

$\frac{d\sigma}{dQ^2}$, $\frac{d\sigma}{dE_T}$, $\frac{d\sigma}{d\eta}$ (ZEUS)

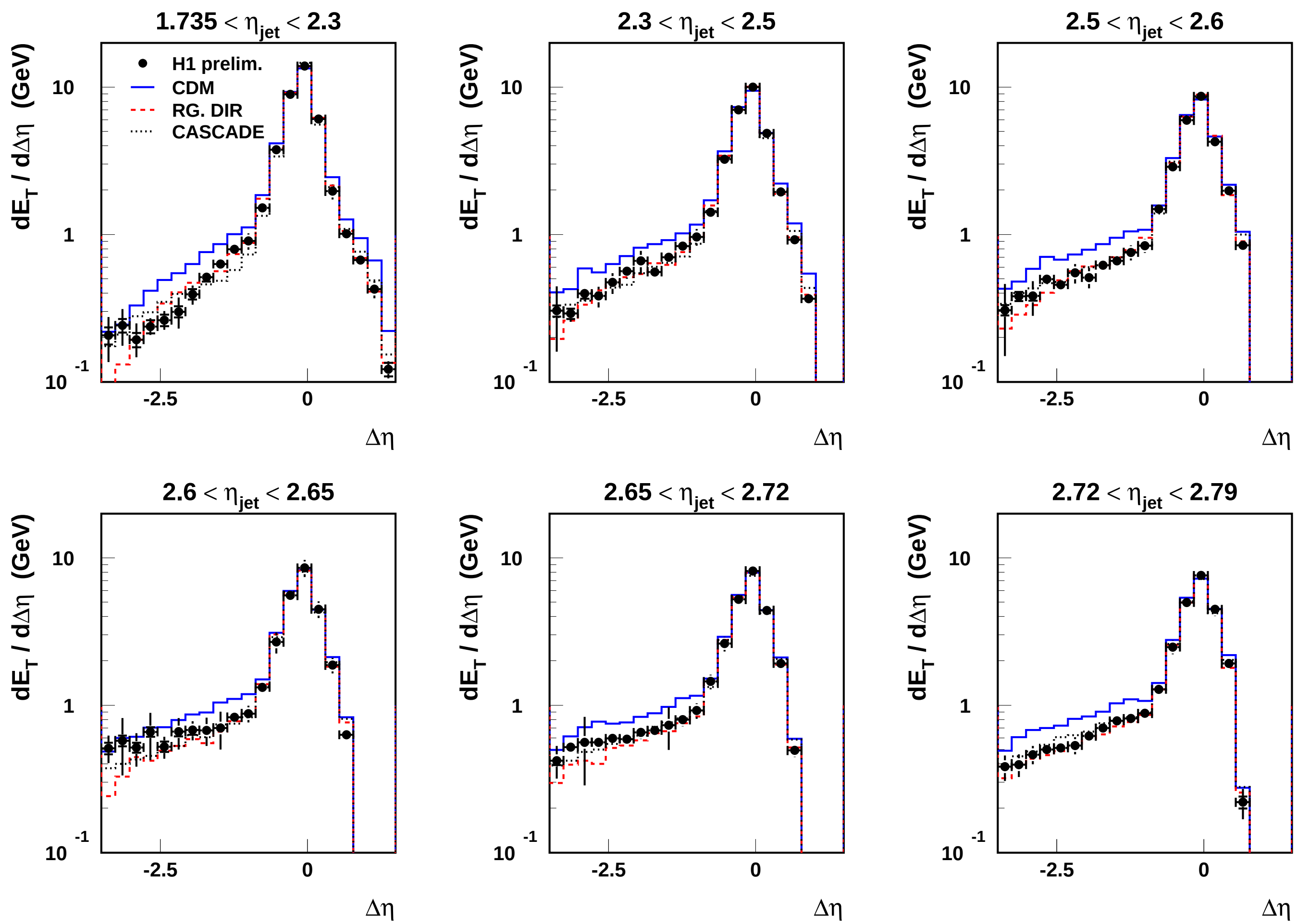
$\frac{d\sigma}{dx_{Bj}dp_t^2dQ^2}$ (H1)

2+Forward jet cross-sections (H1), $\frac{d\sigma}{d\Delta\eta_2}$

As a function of the rapidity between the forward jet and the most forward di-jet.

H1 results

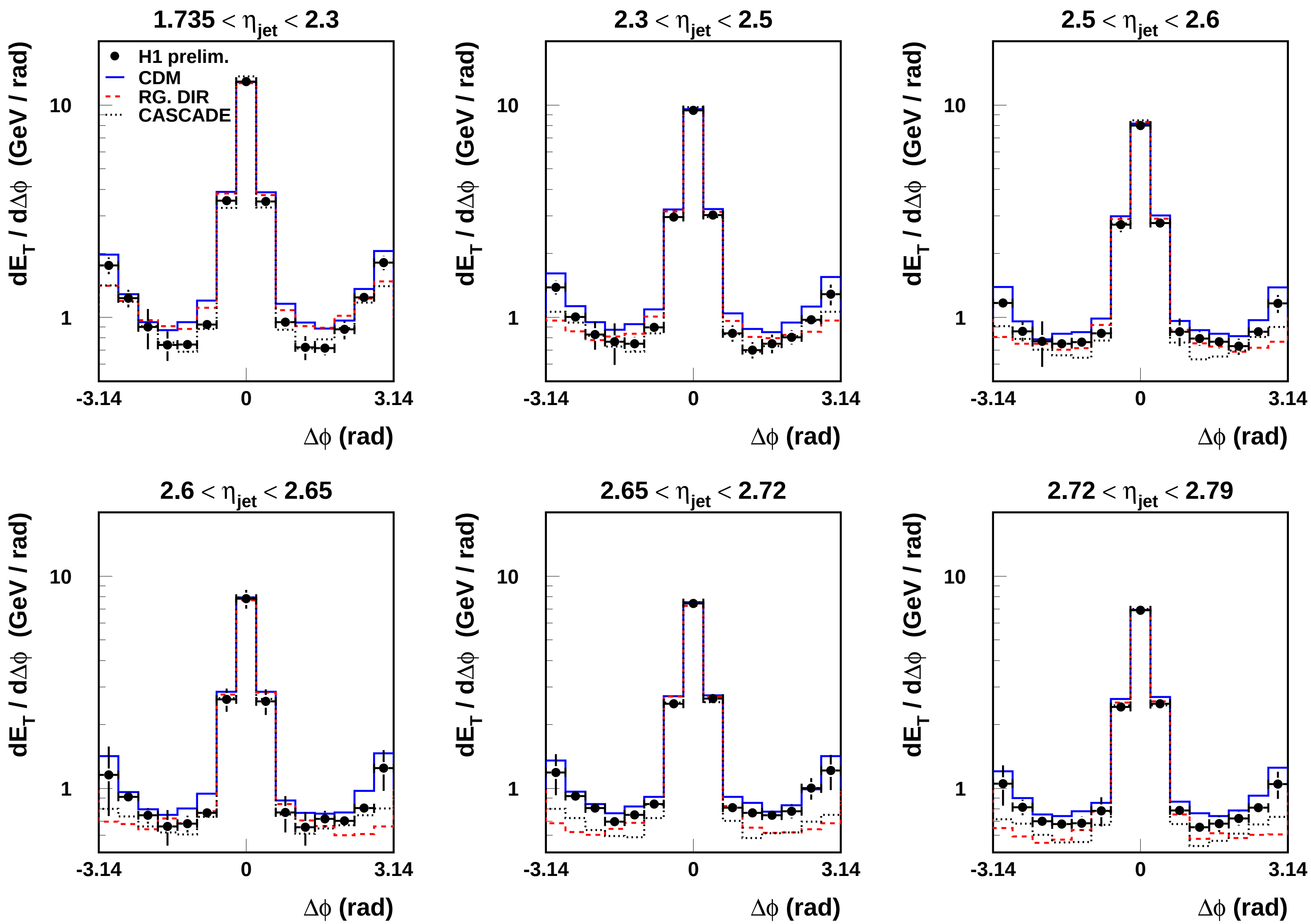
Jet-profiles ($\Delta\eta$) in bins of the forward jet rapidity (hadron level)



Profiles are OK described by generators.

No obvious broadening for higher η_{fwdjet} → forward jets not affected by proton remnant.

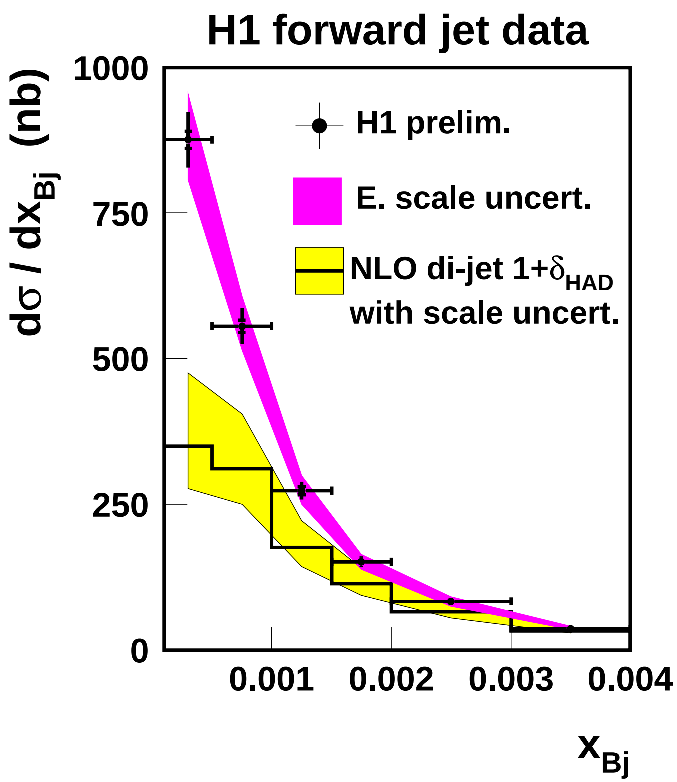
Jet-profiles ($\Delta\phi$) in bins of the forward jet rapidity (hadron level)

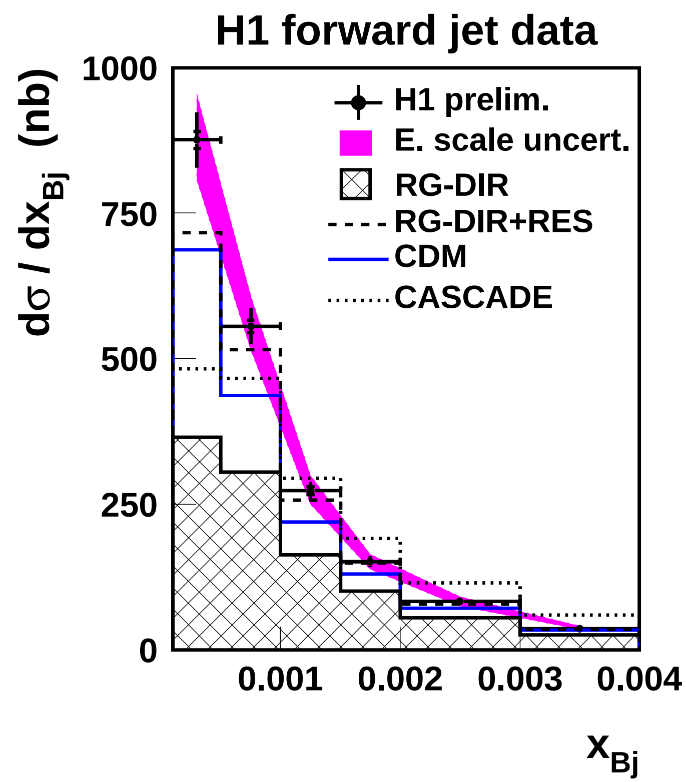


Profiles are OK described by generators.

No obvious broadening for higher η_{fwdjet} $\rightarrow$ forward jets not affected by proton remnant.

$$\frac{d\sigma}{dx_{Bj}}$$





$\boldsymbol{\mu_r^2 = \langle p_{t,fwd}^2 \rangle = 45\ \mathrm{GeV}^2}$

$\boldsymbol{0.25\langle p_{t,fwd}^2 \rangle < \mu_r^2 < 4\langle p_{t,fwd}^2 \rangle}$

(**CTEQ6M**)

NLO di-jet ok for larger x_{Bj}.

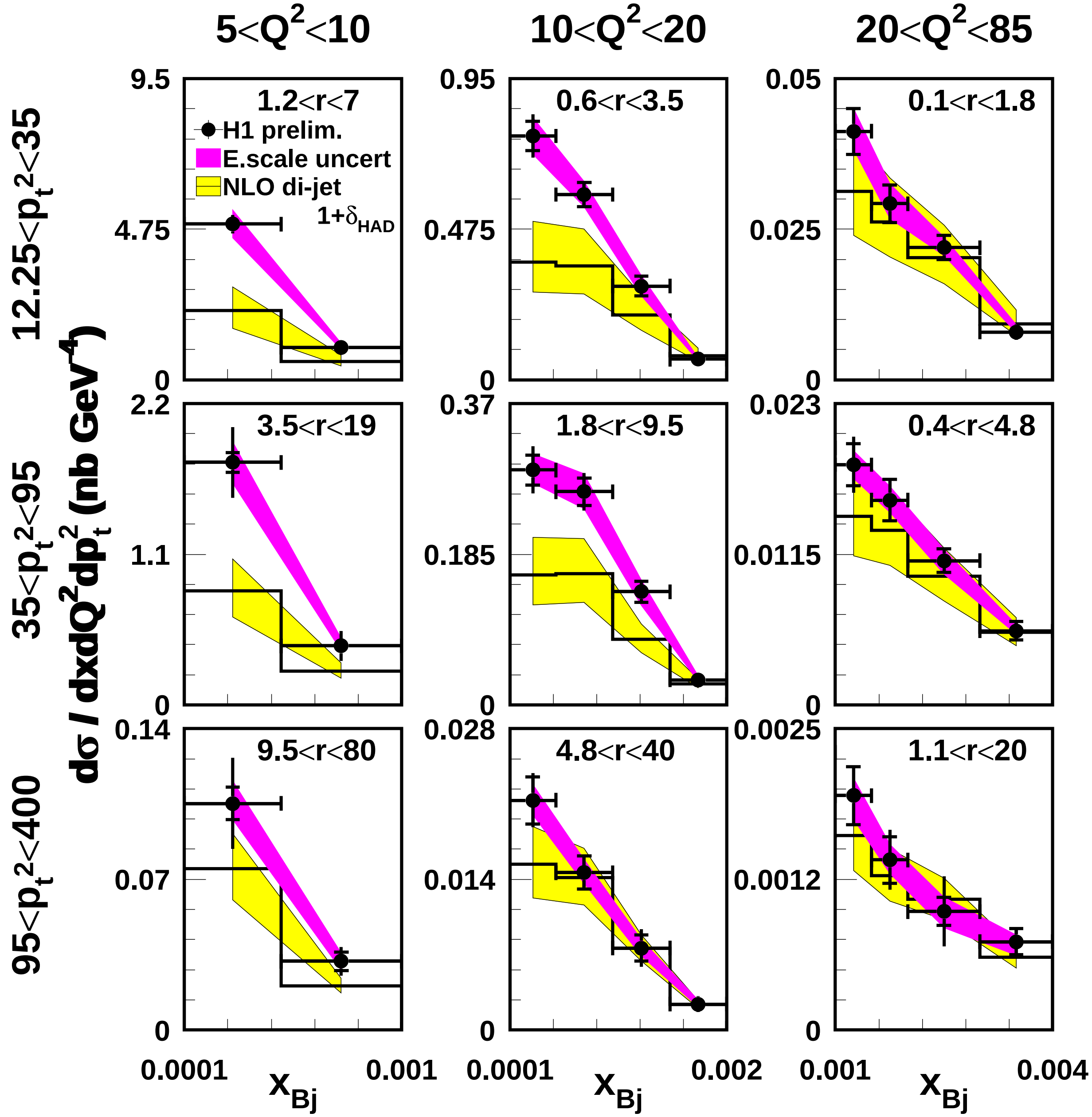
PS with DGLAP evolution similar to NLO.

RG DIR+RES best.

CDM and RG DIR+RES too low for lower x_{Bj}.

CASCADE to low at lower x_{Bj}, to high at higher x_{Bj}.

All models to low in lowest x_{Bj}-bin.



$$\mu_r^2 = < p_{t,fwd}^2 > = 67\ \mathrm{GeV}^2$$

$$\frac{d^3\sigma}{dx_{Bj}\,dp_t^2\,dQ^2}$$

Cross-section as a function of x_{Bj} in 3x3 p_t^2-Q^2 bins. No $\frac{p_t^2}{Q^2}$-cut.

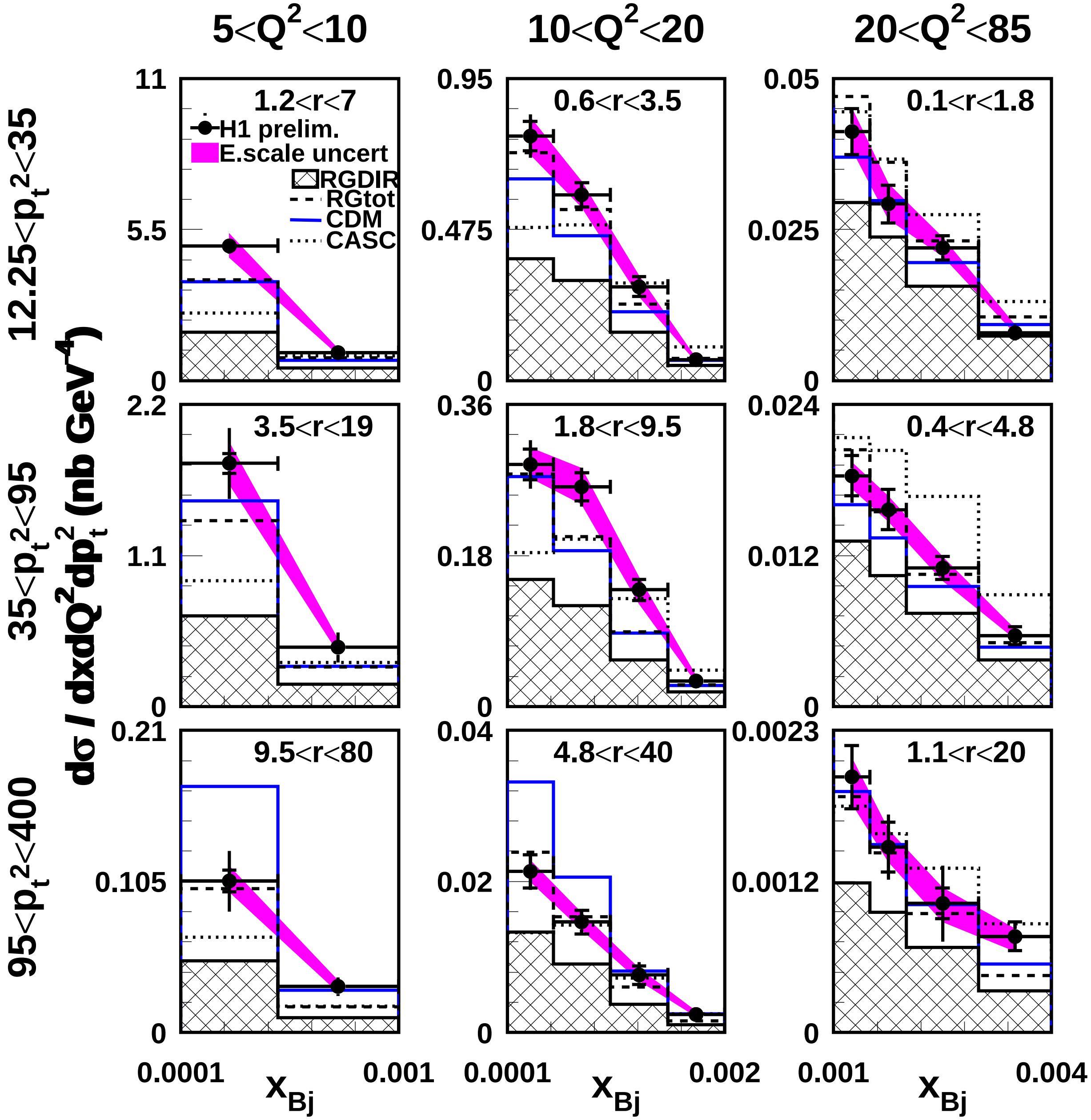
Kinematical regions in $\frac{p_t^2}{Q^2} = \mathrm{r}$:

$p_T^2 < Q^2$ -
DGLAP-like dynamics

$p_T^2 \sim Q^2$ -
BFKL-like dynamics

$p_T^2 > Q^2$ -
resolved γ-like dynamics

Note different ranges in x_{Bj}!



$$\frac{d^3\sigma}{dx_{Bj}\,dp_t^2\,dQ^2}$$

Comparison to QCD models.

$p_T^2 < Q^2$ - DGLAP-like dynamics

$p_T^2 \sim Q^2$ - BFKL-like dynamics

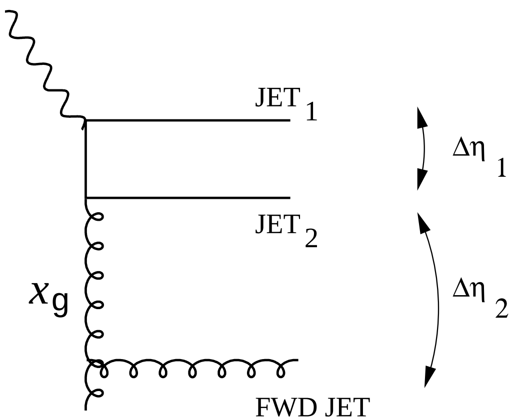
$p_T^2 > Q^2$ - resolved γ-like dynamics

- RAPGAP DIR - fails, but is closest to the data in the most DGLAP like region
- RAPGAP DIR+ RES γ - Good
- CDM - Alright, but problems in res. γ region.
- CASCADE - Goes in the right direction.

2+forward jet cross-section, $\frac{d\sigma}{d\Delta\eta_2}$

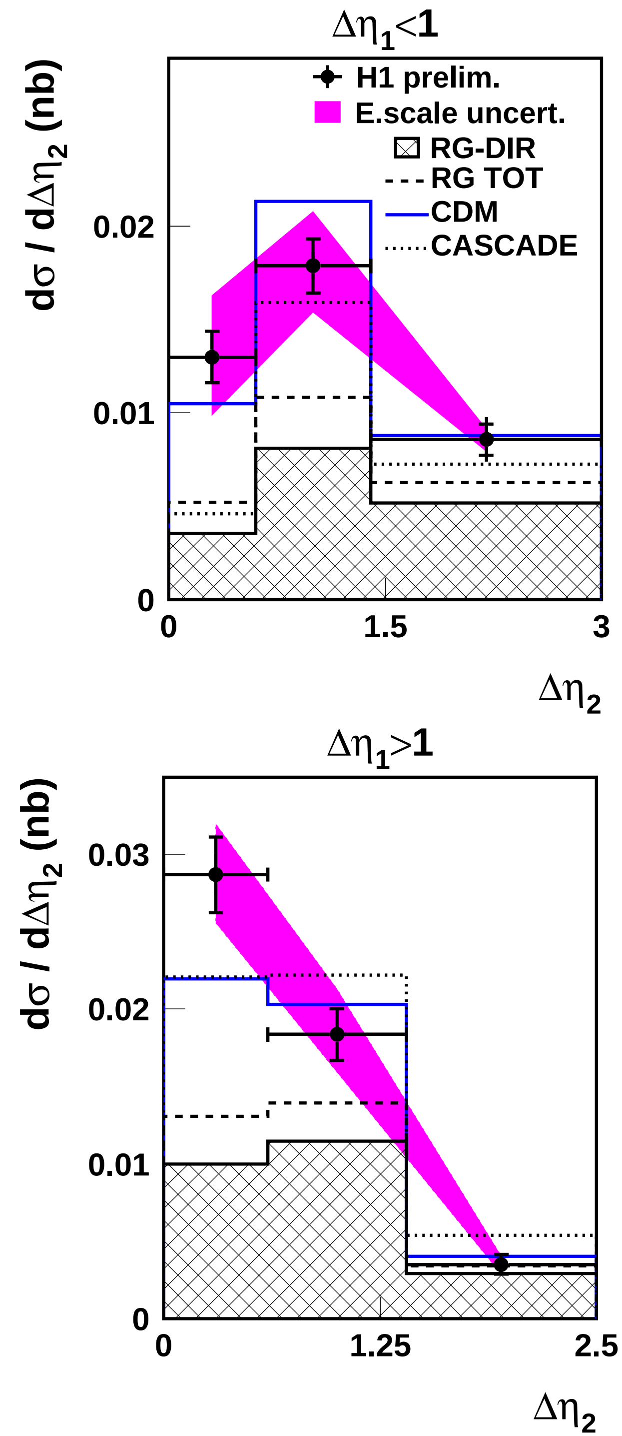
Select two hardest jets ($p_t > 6GeV$) JET1 and JET2 - in addition to the forward jet ($p_t > 6GeV$) - 2+Forward Jet Event. (No $\frac{p_t^2}{Q^2}$-cut.)

$$\eta_e < \eta_{JET1} < \eta_{JET2} < \eta_{FWDJET}$$



$$\Delta\eta_1 = \eta_{JET2} - \eta_{JET1}$$

$$\Delta\eta_2 = \eta_{FWDJET} - \eta_{JET2}$$

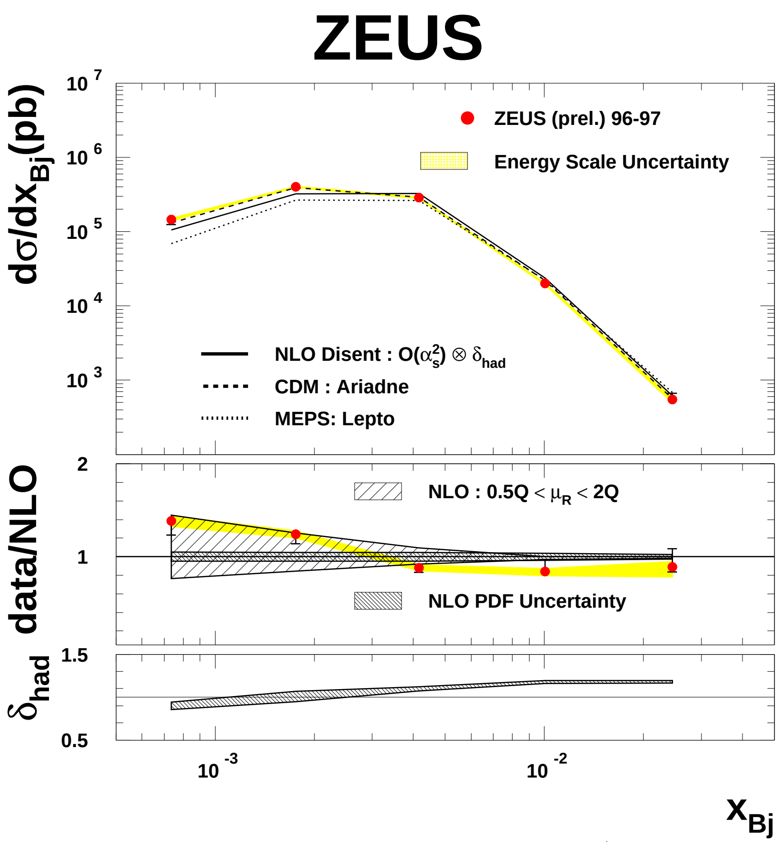


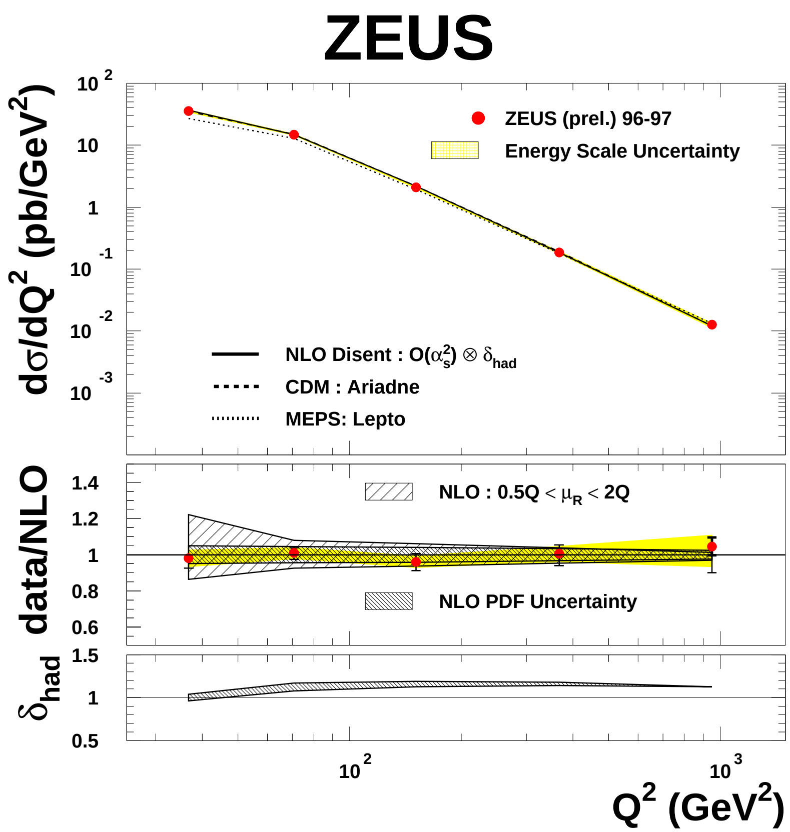
$\Delta\eta_1 < 1$: small η separation between the two hard jets - small x_g - room for many emissions and evolution in x - BFKL-like ladder.

$\Delta\eta_1 > 1$: large η separation between the two hard jets - Shorter parton ladder - not that BFKLish

Results from ZEUS

$0 < \eta_{jet} < 3$





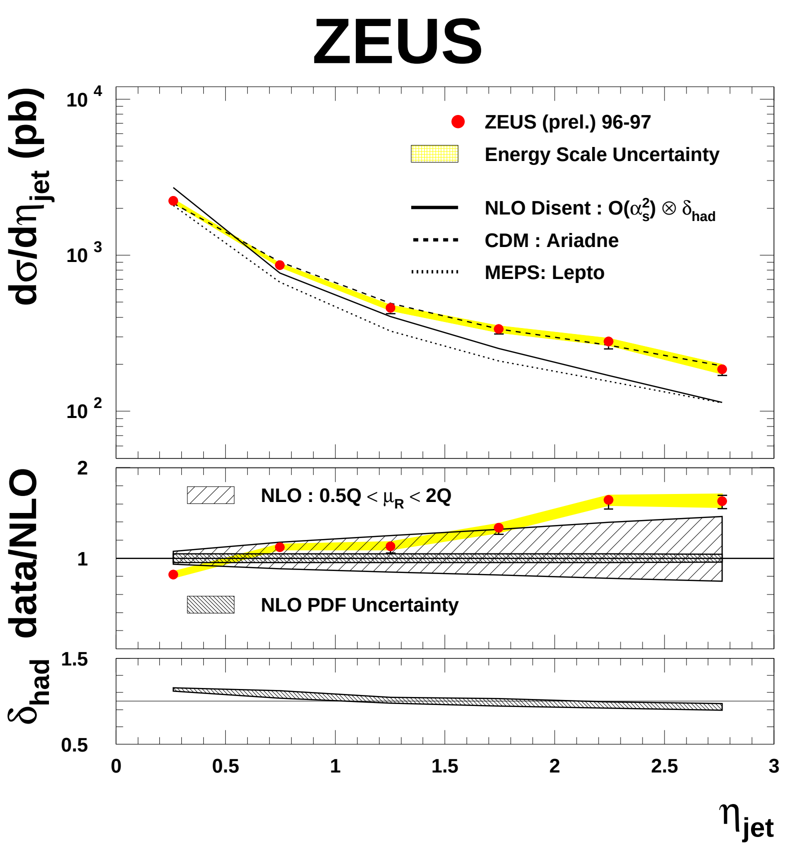
NLO too low for lower x_{Bj} (as for H1), but data within the μ_r^2 scale uncertainty.

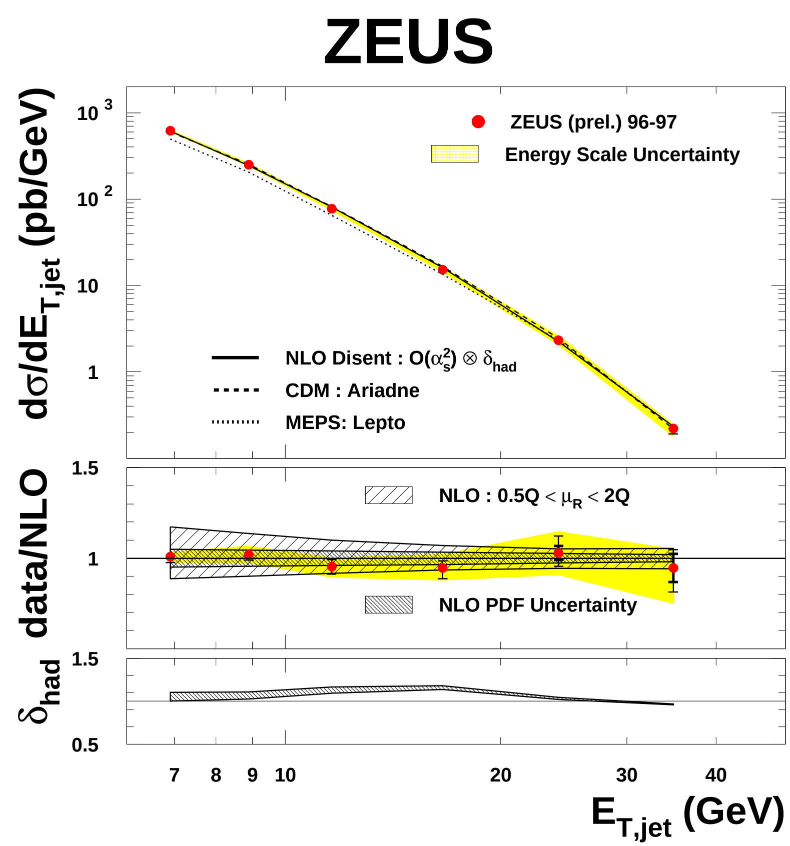
Note $\mu_r^2 = Q^2$.

Cross-sections described by CDM.

LEPTO (which should correspond to RAPGAP) fails for lower x_{Bj} and Q^2.

$$0 < \eta_{jet} < 3$$





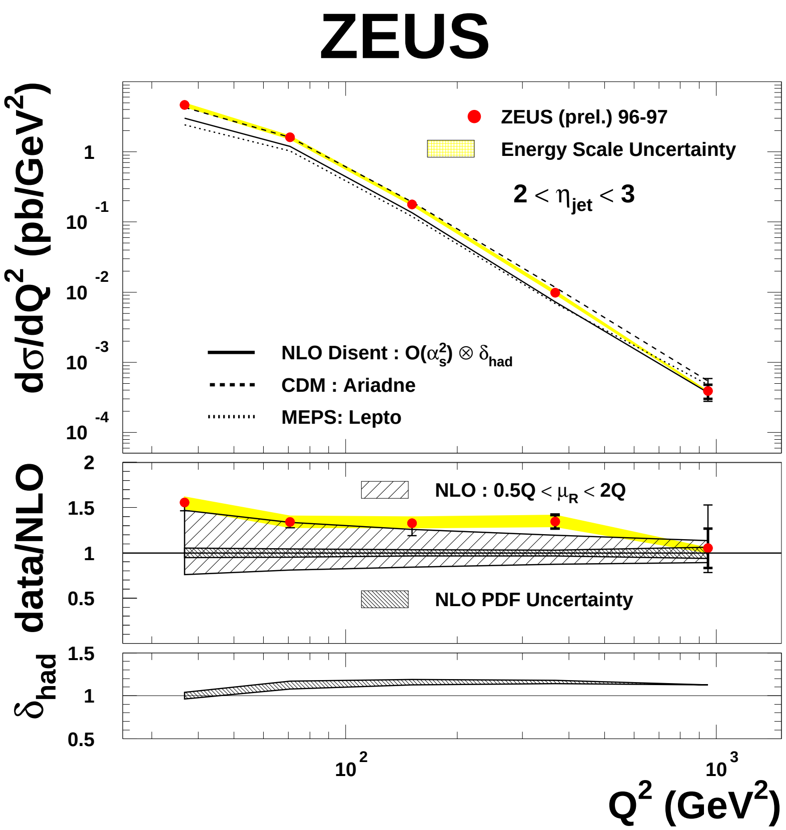
More forward jets → Higher sensitivity to higher order emissions.

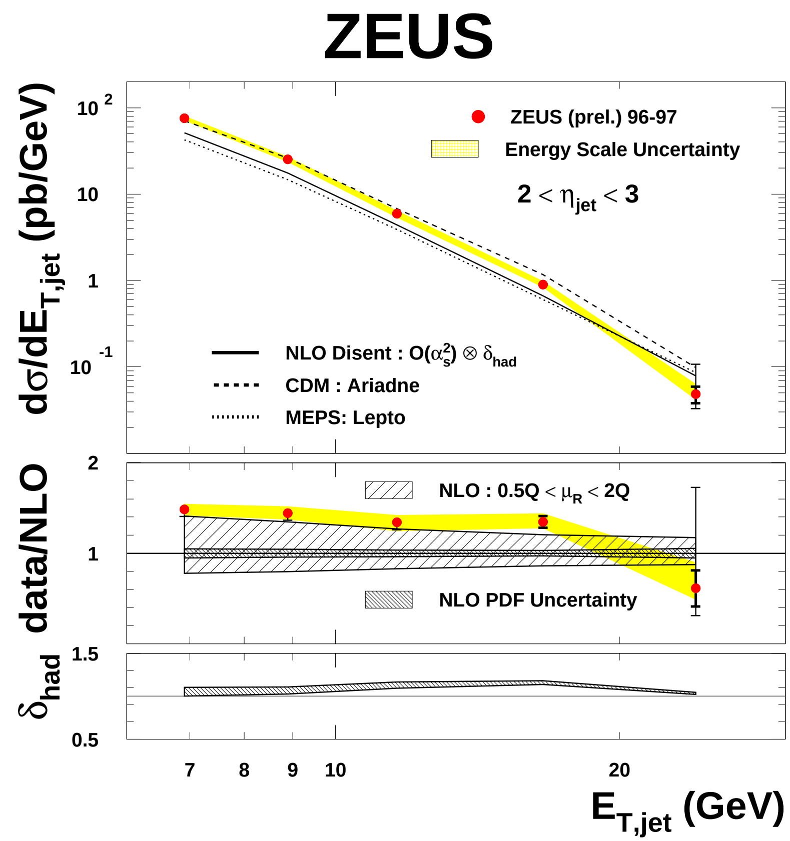
CDM again a good job.

NLO di-jet fails in description of η but is OK for E_T.

ME+PS fails in description of η and for lowest E_T.

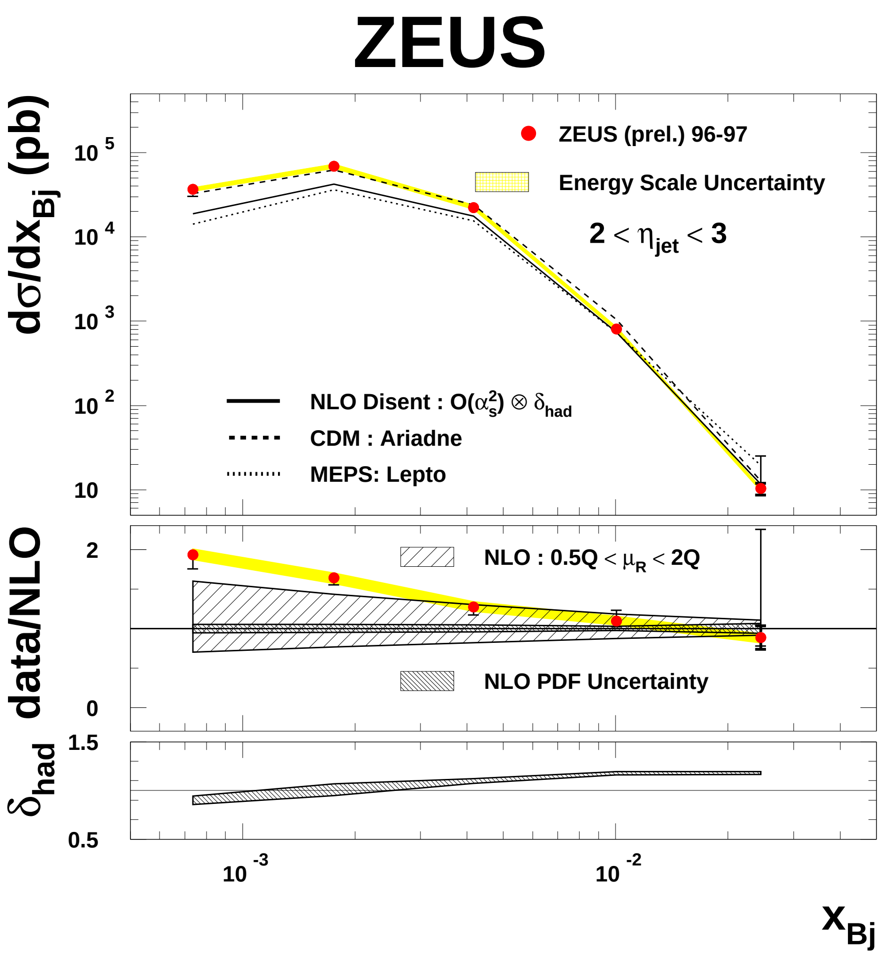
$2 < \eta_{jet} < 3$





CDM is OK for Q^2, but slightly to high for higher $E_{\mathrm{T,jet}}$.
ME+PS and NLO fail for smaller Q^2 and $E_{\mathrm{T,jet}}$.
Data within the NLO scale uncertainty.

$2 < \eta_{jet} < 3$



Data very well discribed by NLO at high x_{Bj}.

NLO scale uncertainty and the difference to data diverge for smaller x_{Bj}.

ME+PS different dependence on x_{Bj} compared to data.

CDM good.

$\Longrightarrow$ Data suggests more hard radiation needed at high η and low x_{Bj}.

$\Longrightarrow$ Large renormalization scale uncertainty indicates that terms missing in the calculation are important in this region.

Conclusions - Forward Jet Measurement

- H1 and ZEUS forward jet measurements give similar conclusions.

- DGLAP LO ME+PS (RAPGAP, LEPTO) and NLO di-jet fail for forward jet cross-sections - CDM and LO ME+PS DIR+RESolved γ OK (except 2+fwdjet) -
  - CASCADE is in improvement compared to simple DGLAP evolution.

- 2+fwd cross-section -
  Models not ordering the transverse momenta still predict a higher cross-section.

- Data suggests that more hard radiation (CDM, RES-γ, CASCADE) - compared to NLO and simple DGLAP evolution - is needed.

- Models that break the ordering of transverse momenta go in the right direction (CDM, RES-γ, CASCADE), while simple DGLAP evolution restricts the phase space too much.