Measurement of forward jet production at low x in DIS

on behalf of the

H1 collaboration

DIS 2005, Madison USA

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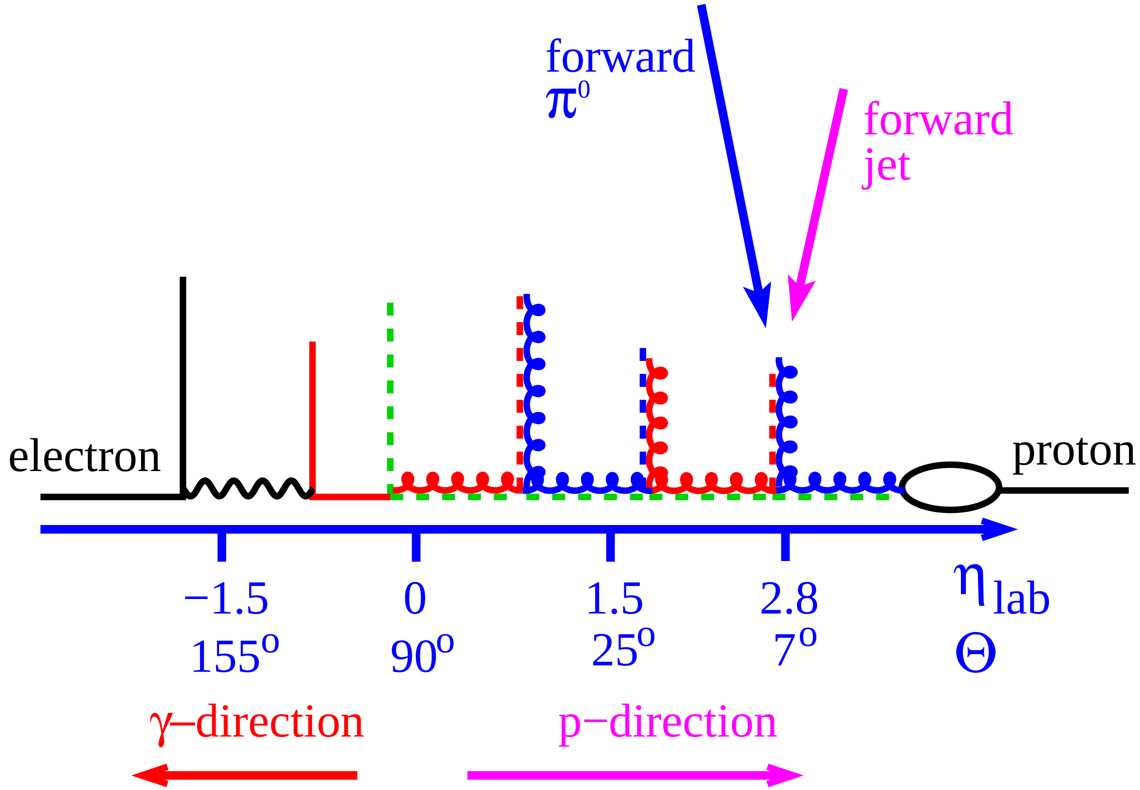
Outline

- Why is the forward region important?
- Forward jet selection
- Theoretical Calculations / MC Models
- Results
- 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.

Physics motivation, continued...

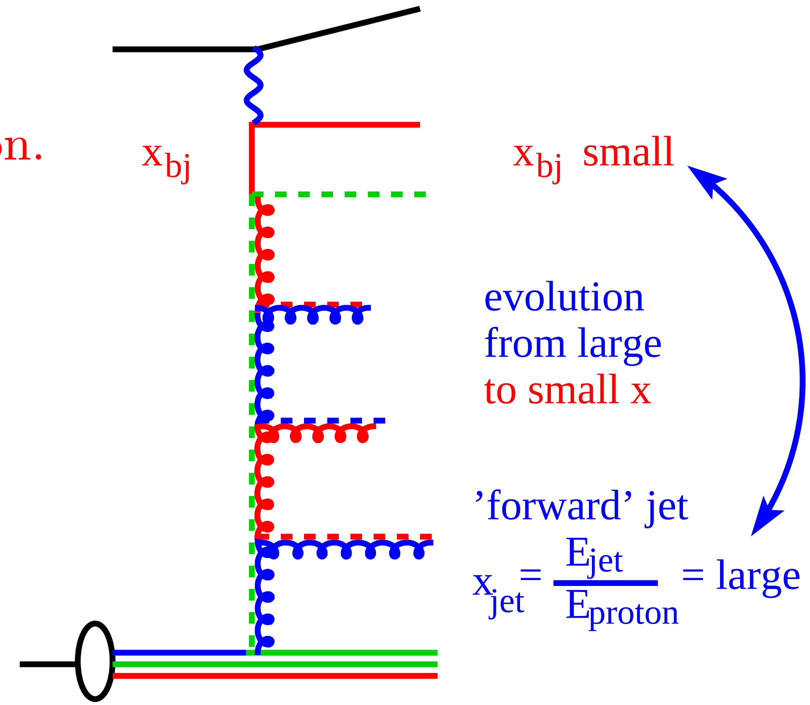
Test QCD at small x.

Signals of parton dynamics beyond DGLAP?

Events with energetic jet in the forward region.

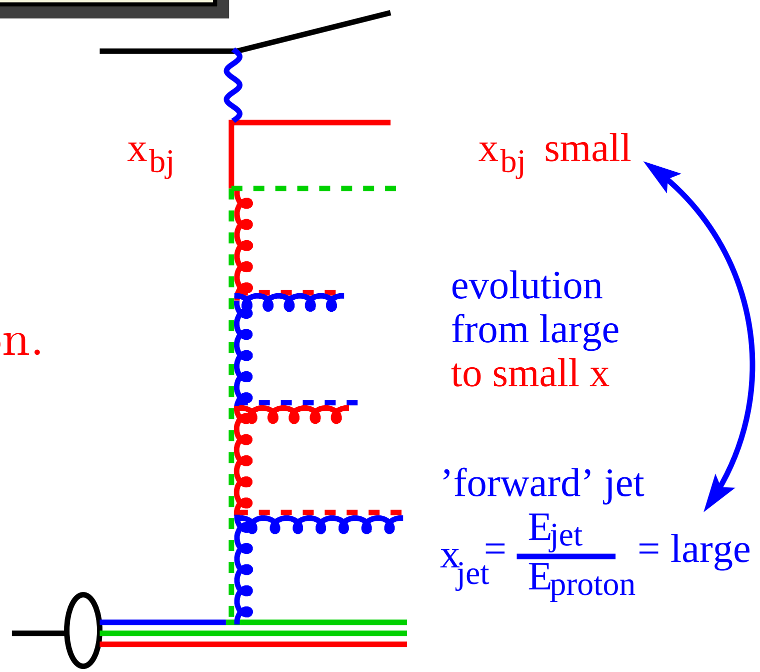
Target phase space for evolution in x
(BFKL)
$x_{jet} >> x_{Bj}$.

Suppress phase space for evolution in Q^2.
(Suppress DGLAP)
$p^2_{\mathrm{t,\ forward\ jet}} \sim Q^2$.



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.

Forward jet	$1.74 < \eta_{jet} < 2.79$
	$p_t > 3.5$ GeV
Suppress QPM	$x_{JET} = \frac{E_{JET}}{E_p} > 0.035$
Suppress DGLAP	$0.5 < \frac{p_t^2}{Q^2} < 5$

If $N_{\text{forward jet}} > 1 \rightarrow$ Most forward jet is selected

Kinematic range and Measurements

Kinematic range

$$
\begin{aligned}
5 <\ & Q^2 < 85\ \mathrm{GeV}^2 \\
0.1 <\ & y < 0.7 \\
0.0001 <\ & x_{Bj} < 0.004 \\
10\ \mathrm{GeV} <\ & E'_e
\end{aligned}
$$

Measurements

Forward jet cross-sections

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

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

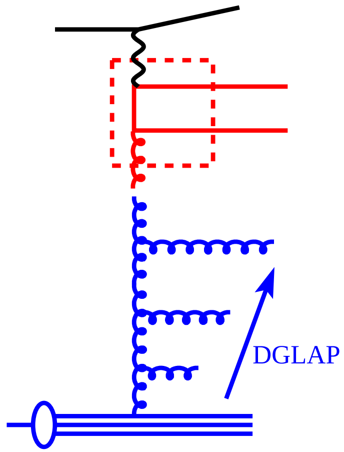
2+Forward jet cross-sections, $\frac{d\sigma}{d\Delta\eta_2}$

As a function of the rapidity

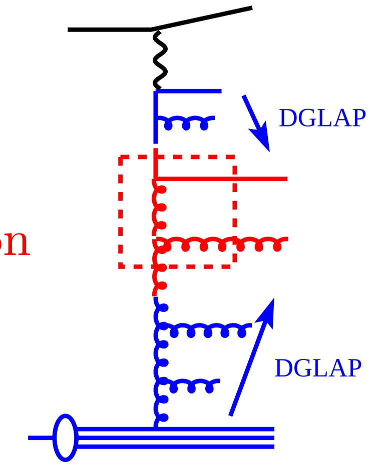
between the forward jet and

the most forward di-jet.

QCD Models



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

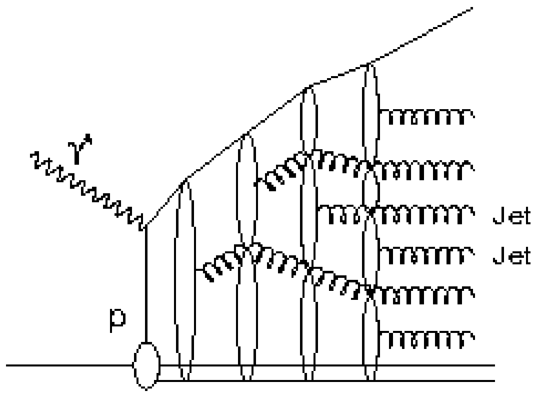


RAPGAP RES γ: RAPGAP with an additional DGLAP evolution parton ladder from the hard subsystem to the photon.

PDF: CTEQ6L , γPDF: SaS1D Scales: $\mu_r^2 = \mu_f^2 = Q^2 + p_t^2$

QCD Models continue...

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



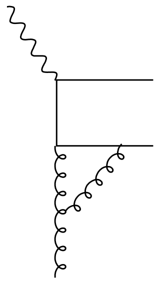
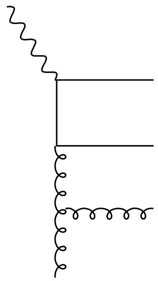
PDF: CTEQ6L

CASCADE: LO ME. Initial state CCFM partons showers with emissions ordered in angle.

Fixed Order Calculations

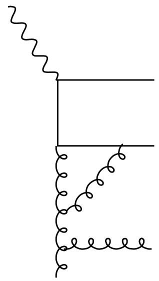
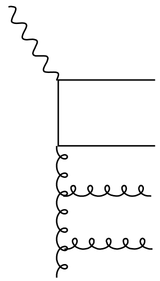
DISENT: NLO di-jet (α_s^2).

(Forward jet cross-sections.)

 ,  , ...

NLOJET++: NLO 3-jet (α_s^2).

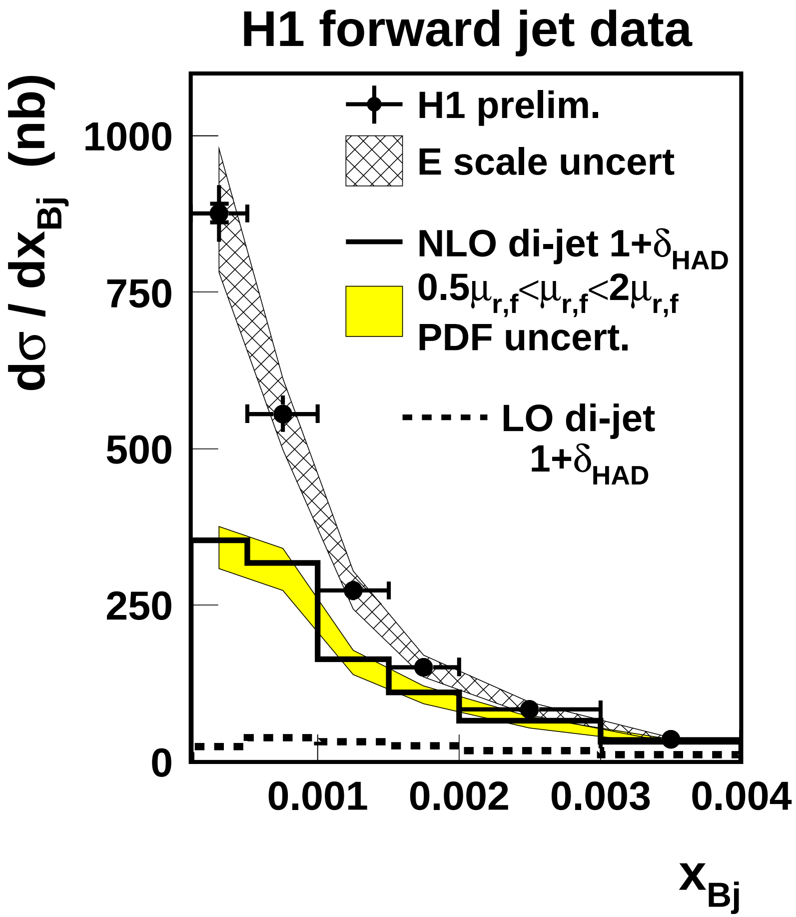
(2+forward jet cross-sections.)

 ,  , ...

(Need to correct for hadronization effects.)

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

Comparison to Exact Calculations (DISENT)



$\boldsymbol{\mu_r^2 = p_t^2}$

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

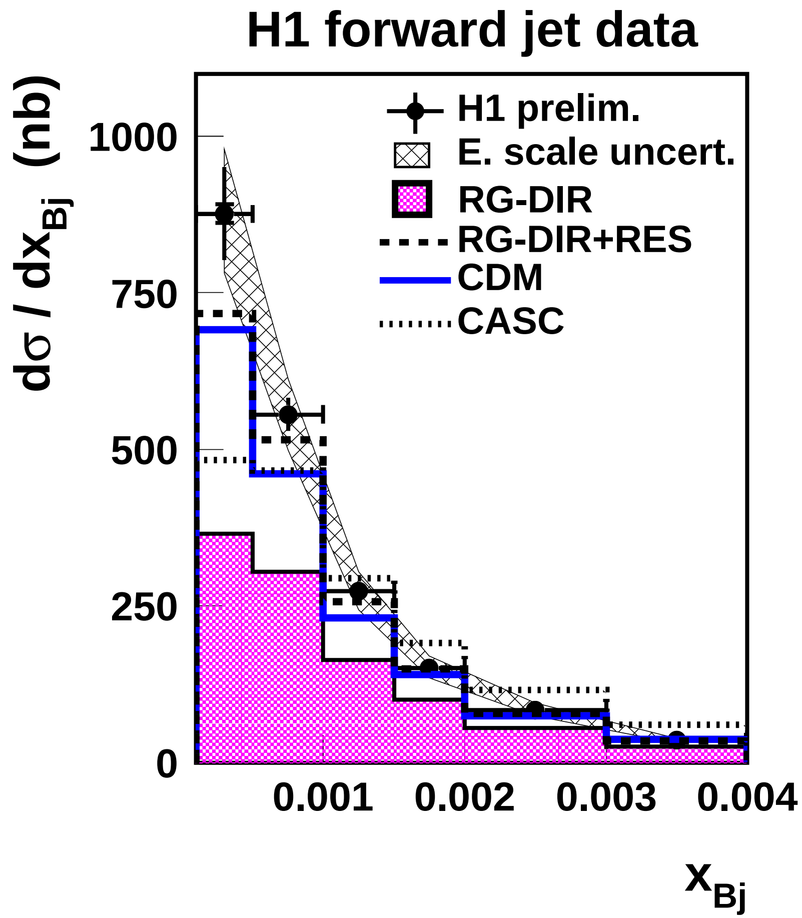
$\boldsymbol{0.25\mu_{r,f}^2 < \mu_{r,f}^2 < 4\mu_{r,f}^2}$

PDF: CTEQ6M

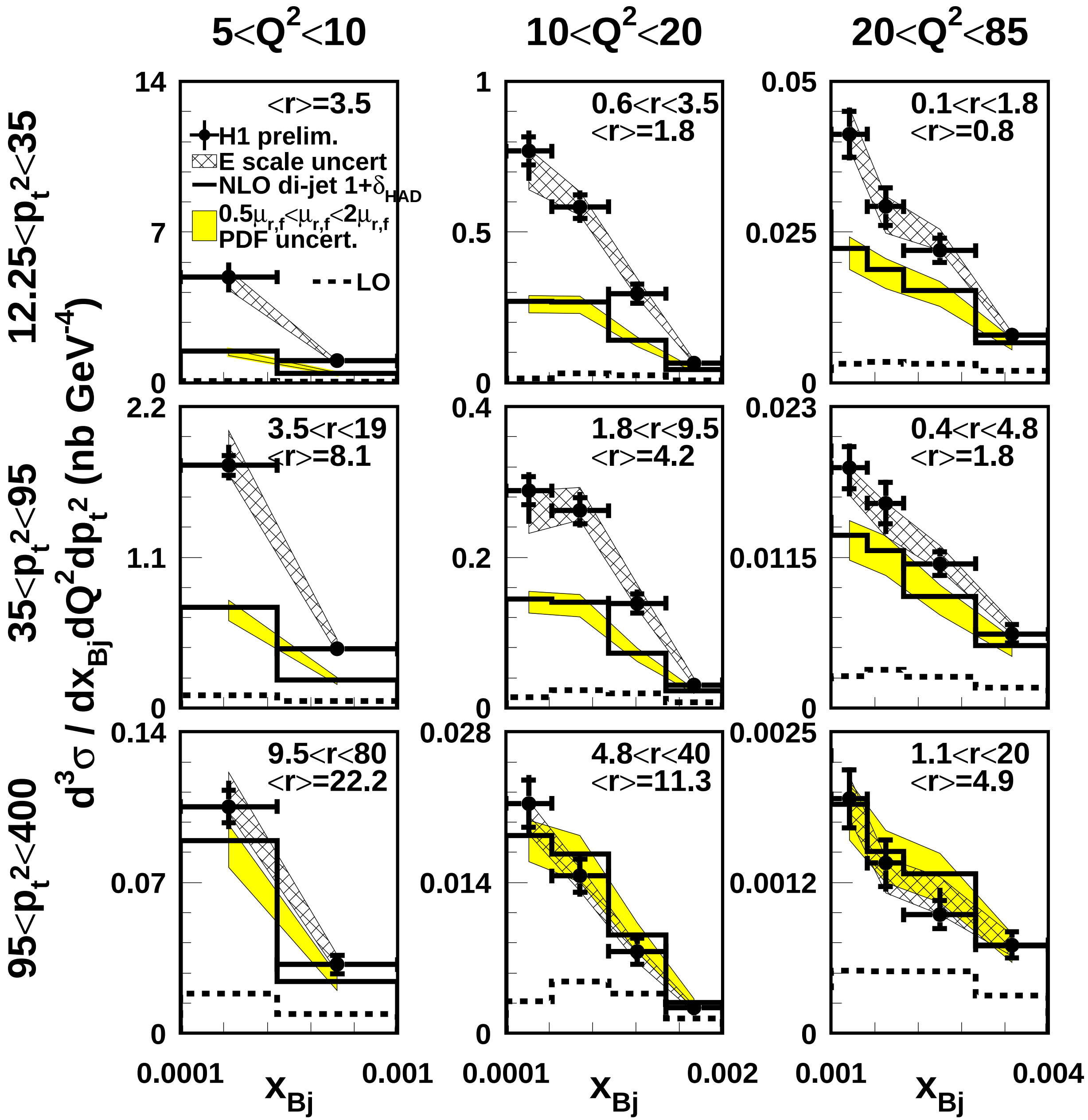
- NLO di-jet ok for larger x_{Bj}.
- LO contribution $(\alpha_s) \ll$ NLO contribution (α_s^2)

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

Comparison to QCD Models



- 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.



$\mu_r^2 = p_t^2$, $\mu_f^2 = \langle p^2_{t,\mathrm{fwdjet}} \rangle = 24,\ 55$ resp. $183\ \mathrm{GeV}^2$

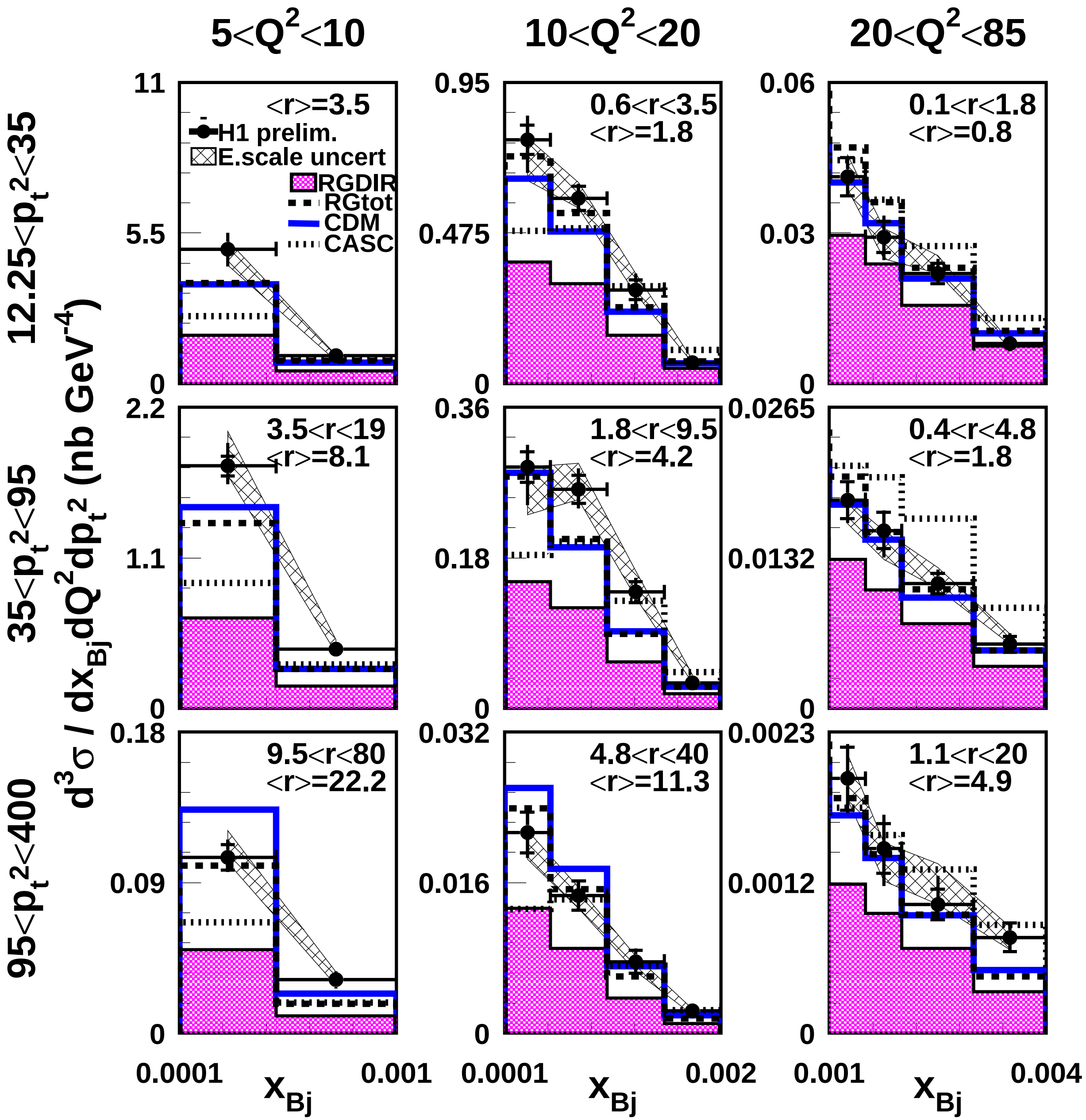
$$\frac{d^3\sigma}{dx_{Bj}\,dp_t^2\,dQ^2}$$

Cross-section as a function of x_{Bj} in 3x3 p_t^2-Q^2 bins. No $\frac{p_t^2}{Q^2}$-cut. (Different regions in $\frac{p_t^2}{Q^2} = \mathrm{r}$.)

Large x_{Bj}, Q^2 and p_t^2 $\Rightarrow$ NLO describes data

Smaller x_{Bj}, Q^2 and p_t^2 $\Rightarrow$ NLO insufficient

Note different ranges in x_{Bj}!



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

Comparison to QCD models.

$p_T^2 < Q^2$ $(r < 1)$-
DGLAP-like dynamics

$p_T^2 \sim Q^2$ $(r \sim 1)$-
BFKL-like dynamics

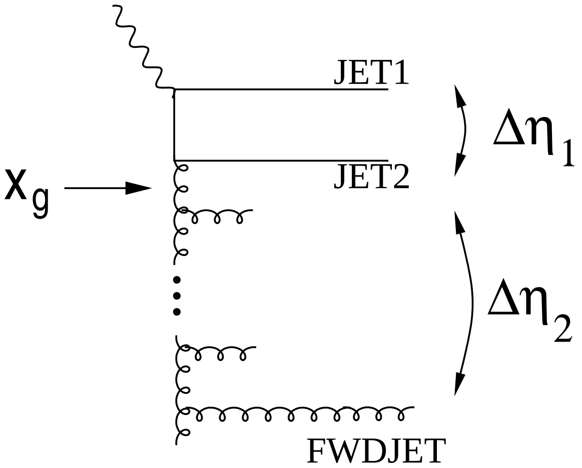
$p_T^2 > Q^2$ $(r > 1)$-
resolved γ-like dynamics

- 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, $\frac{d\sigma}{d\Delta\eta_2}$

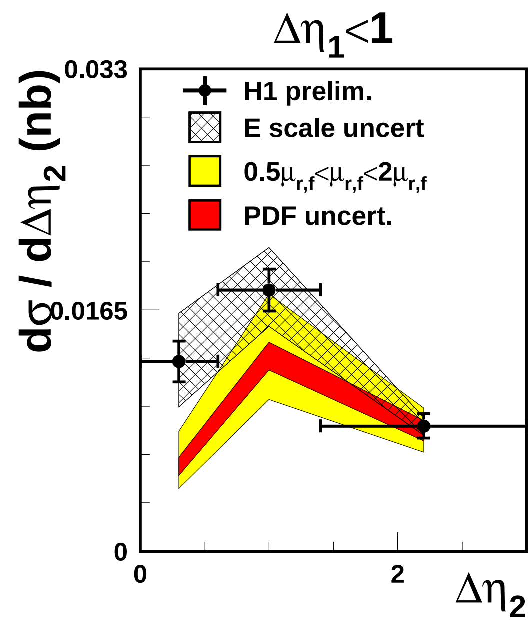
Select two hardest jets ($p_t > 6$ GeV) JET1 and JET2 - in addition to the forward jet ($p_t > 6$ GeV) - 2+Forward Jet Event. (No $\frac{p_t^2}{Q^2}$-cut.)

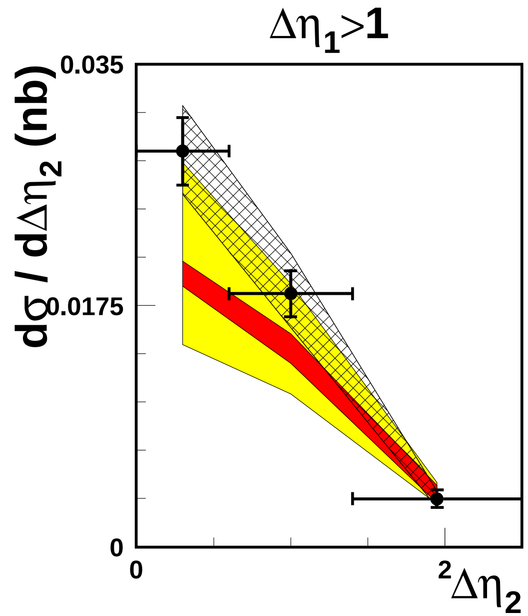
$$\eta_e < \eta_{JET1} < \eta_{JET2} < \eta_{FWDJET}$$



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

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





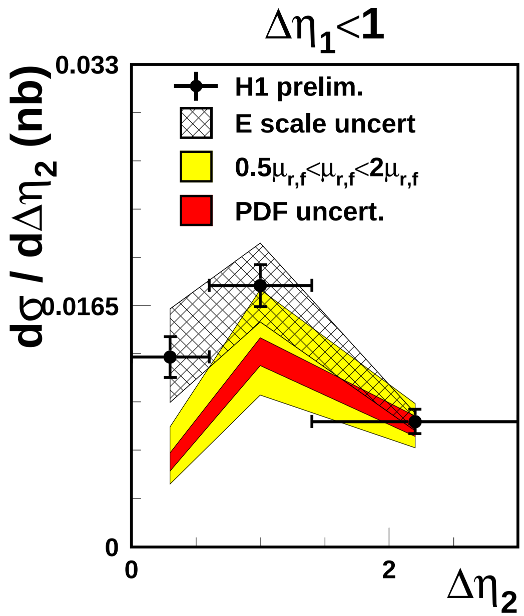
$\Delta\eta_1 < 1$: small η separation between the two hard jets - small x_g - room for many emissions - long ladder favoured

$\Delta\eta_1 > 1$: large η separation between the two hard jets - Shorter parton ladder

2+forward jet cross-section

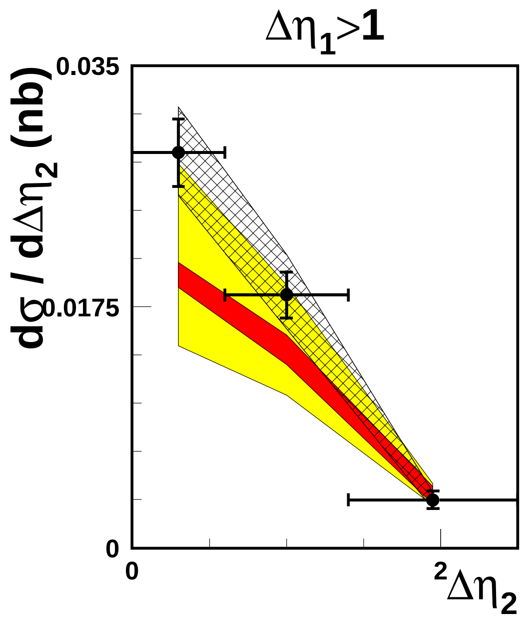
NLO 3-jet $1 + \delta_{had}$ calculations

(NLOJET++)



$$\mu_r^2 = \mu_f^2 = \frac{p_{t,JET1}^2 + p_{t,JET2}^2 + p_{t,FWDJET}^2}{3}$$

$$0.25\mu_{r,f}^2 < \mu_{r,f}^2 < 4\mu_{r,f}^2$$



Data within scale uncertainity

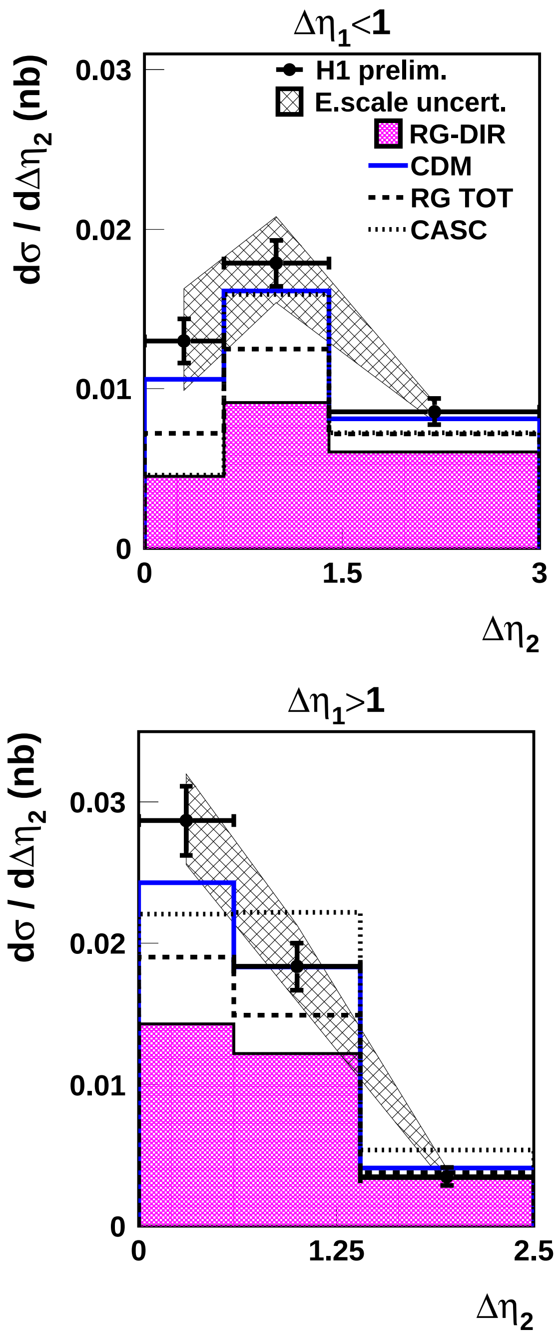
for $\Delta\eta_1 > 1$ ("short ladder"-region)

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

- CDM close to describe the data.

- CASCADE closer to data than RG-DIR

- ME+PS fails, except for at high $\Delta\eta_2$ where $\Delta\eta_1 > 1$ (the "non-BFKLish"-region), as is the case for the resolved photon model.



Conclusions - Forward Jet Measurement

- Large x_{Bj}, Q^2 and p_t^2 $\rightarrow$ NLO dijet describes forward jet cross section.
  Small x_{Bj}, Q^2 and p_t^2 $\rightarrow$ NLO dijet fails.

- \- DGLAP LO ME+PS (RAPGAP) and NLO di-jet fail for fwd 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.
  CDM good.

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

- Models that break the ordering of transverse momenta give better agreement with data (CDM, RES-γ, CASCADE), while simple DGLAP evolution restricts the phase space too much.