BFKL NLL description of forward jets at HERA

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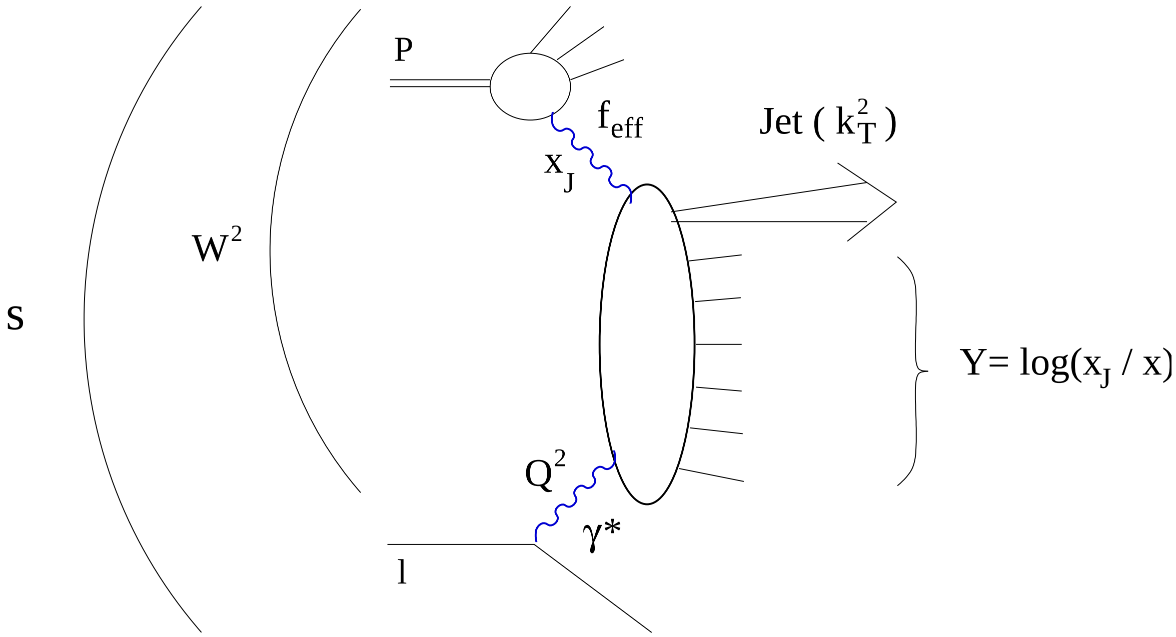
Contents:

- BFKL-NLL formalism
- Saddle point approximation for the forward jet cross section
- Fit to $d\sigma/dx$ data
- Comparison with other H1/ZEUS measurements

Work done in collaboration with O. Kepka, C. Marquet, R. Peschanski

BFKL LO formalism



- Typical kinematical domain where BFKL effects are supposed to appear with respect to DGLAP: $k_T^2 \sim Q^2$, and Q^2 not too large
- LO BFKL forward jet cross section
- Saddle point approximation and fits to the H1 $d\sigma/dx$ data: 2 parameters, α_S in exponential (constant and fitted at LO), and normalisation

BFKL LO formalism

- BFKL LO forward jet cross section, saddle point approximation:

$$
\begin{aligned}
\frac{d\sigma}{dx dk_T dQ^2 dx_{jet}} &= N \sqrt{\frac{Q^2}{k_T^2}} \alpha_S(k_T^2) \alpha_S(Q^2) \sqrt{aa} \\
&\exp\left(4\alpha (log2) \frac{N_C}{\pi} \log(\frac{x_J}{x})\right) \\
&\exp\left(-aa \log^2(\sqrt{\frac{Q}{k_T}})\right)
\end{aligned}
$$

where

$$
\frac{1}{aa} = \frac{7\zeta(3)}{\pi} \alpha \log \frac{x_J}{x}
$$

- 2 parameters in fits to $d\sigma/dx$: N, α

One parenthesis: cross section calculation

- Two difficulties: We need to integrate over the bin in Q^2, x_{jet}, k_T to compare with the experimental measurement and we need to take into account the experimental cuts (as an example: $E_e > 10$ GeV, $k_T > 3.5$ GeV, $7 \leq \theta_J \leq 20$ degrees....)
- We perform the integration numerically: we chose the variables for which the cross section is as flat as possible to avoid numerical difficulties in precision: k_T^2/Q^2, $1/Q^2$, $log 1/x_{jet}$
- We take into account some of the cuts at the integration level (k_T for instance) and the other ones using a toy Monte Carlo

How to go to BFKL-NLL formalism?

- Simple idea: Keep the saddle point approximation, and use the BFKL NLO kernel
- Formula at NLL:

$$
\begin{aligned}
\frac{d\sigma}{dx} &= N \left(\frac{Q^2}{k_T^2}\right)^{exp} \alpha_S(k_T^2)\alpha_S(Q^2)\ \sqrt{aa} \\
& \exp\left(\alpha_S(k_t^2)\frac{N_C}{\pi}\chi(\gamma_C)\log(\frac{x_J}{x})\right) \\
& \exp\left(-aa\alpha_S(k_T^2)\log^2(\sqrt{\frac{Q}{k_T}})\right)
\end{aligned}
$$

where

$$
\begin{aligned}
\frac{1}{aa} &= \frac{3\alpha_S(k_T^2)}{4\pi}\log\frac{x_J}{x}\chi''(\gamma_C) \\
exp &= \gamma_C + \frac{\alpha_S(k_T^2)\chi(\gamma_C)}{2}
\end{aligned}
$$

- Only free parameter in the BFKL NLL fit: absolute normalisation

BFKL NLL and resummation schemes

- NLO BFKL: Corrections were found to be large with respect to LO, and lead to unphysical results
- NLO BFKL kernels need resummation: to remove additional spurious singularities in γ and $(1-\gamma)$
- NLO BFKL kernel:

$$\chi_{NLO}(\gamma,\omega) = \chi^{(0)}(\gamma,\omega) + \alpha(\chi_1(\gamma) - \chi_1^{(0)}(\gamma))$$

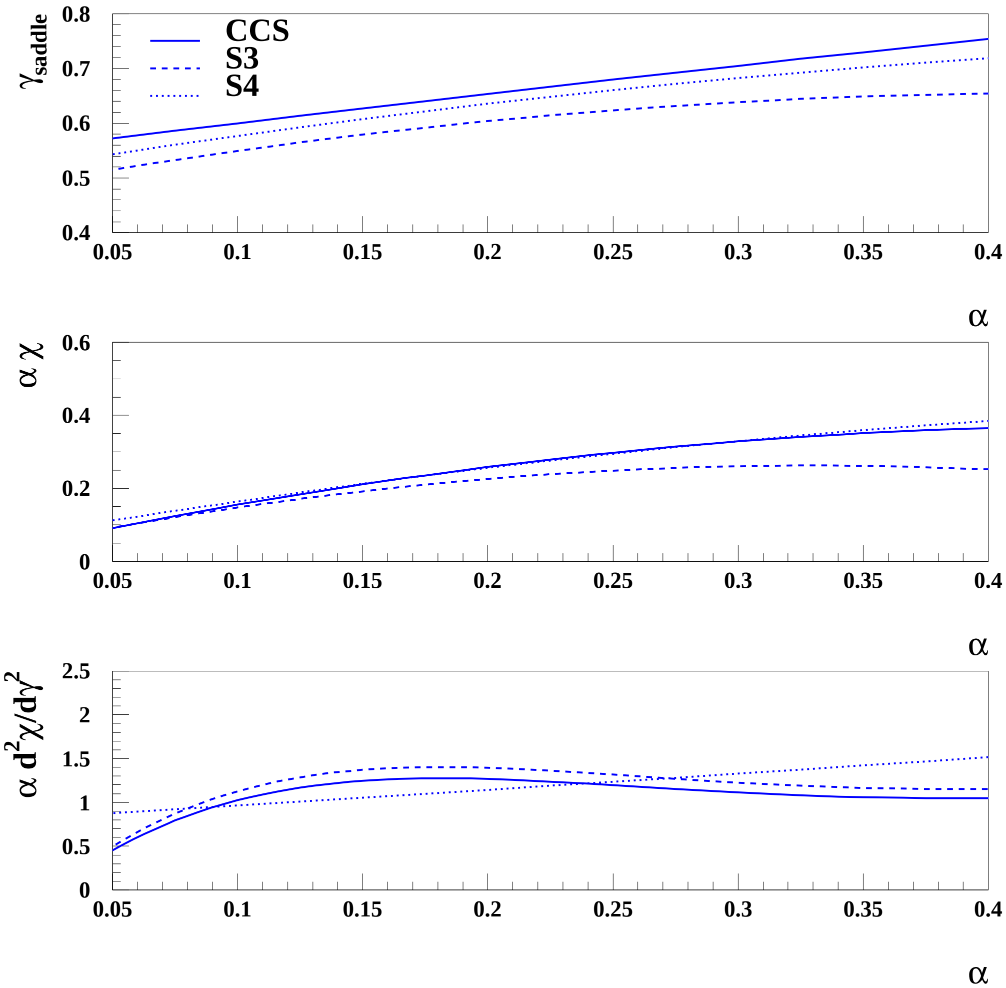
- $\chi_1(\gamma)$: calculated, NLO BFKL eigenvalues (Lipatov, Fadin, Camici, Ciafaloni)
- $\chi^{(0)}$ and $\chi_1(0)$: ambiguity of resummation at higher order than NLO, different ways to remove these singularities, not imposed by BFKL equation, Salam, Ciafaloni, Colferai
- Transformation of the energy scale: $\gamma \to \gamma - \omega/2$ (Salam) needed for F_2 but not for forward jet cross sections (the problem is symmetric contrary to F_2)

How to determine γ_C, $\chi(\gamma_C)$, and $\chi''(\gamma_C)$?

- First step: Knowledge of $\chi_{NLO}(\gamma, \omega, \alpha)$ from BFKL equation and resummation schemes (ω is the Mellin transform of Y)
- Second step: Use implicit equation $\chi(\gamma, \omega) = \omega/\alpha$ to compute numerically ω as a function of γ for different schemes and values of α
- Third step: Numerical determination of saddle point values γ_C as a function of α as well as the values of χ and χ''
- Study performed for three different resummation schemes: S3 and S4 from Gavin Salam, and CCS from Ciafaloni et al.
- For more information: see R. Peschanski, C. Royon, and L. Schoeffel, Nucl.Phys.B716 (2005) 401, hep-ph/0411338

γ_C, $\chi(\gamma_C)$, and $\chi''(\gamma_C)$ as a function of α

Determination of γ_C, $\chi(\gamma_C)$, and $\chi''(\gamma_C)$ as a function of α



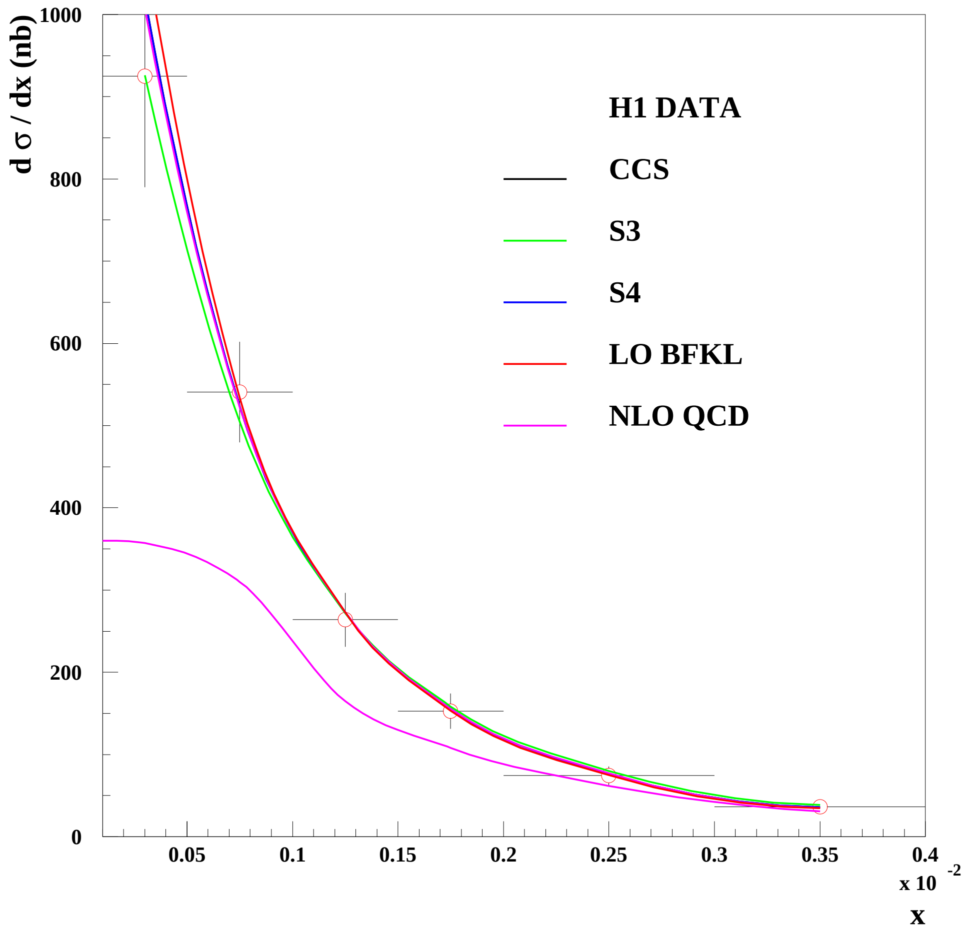
Fit procedure

- Fit to H1 $d\sigma/dx$ data only
- Fit using the 6 data points or 5 points only, removing the lowest x point
- α (constant) is found to be small at LO, of the order of 0.1, and $\alpha_S(k_T^2)$ is imposed using the renormalisation group equation at NLL

fit	data set	χ^2/dof	N	α
LO	6 pts	13/4 (0.47)	0.42	0.102
LO	5 pts	2.4/3 (0.15)	0.37	0.133
CCS	6 pts	22.0/5 (0.6)	0.91	-
CSS	5 pts	2.4/4 (0.21)	0.95	-

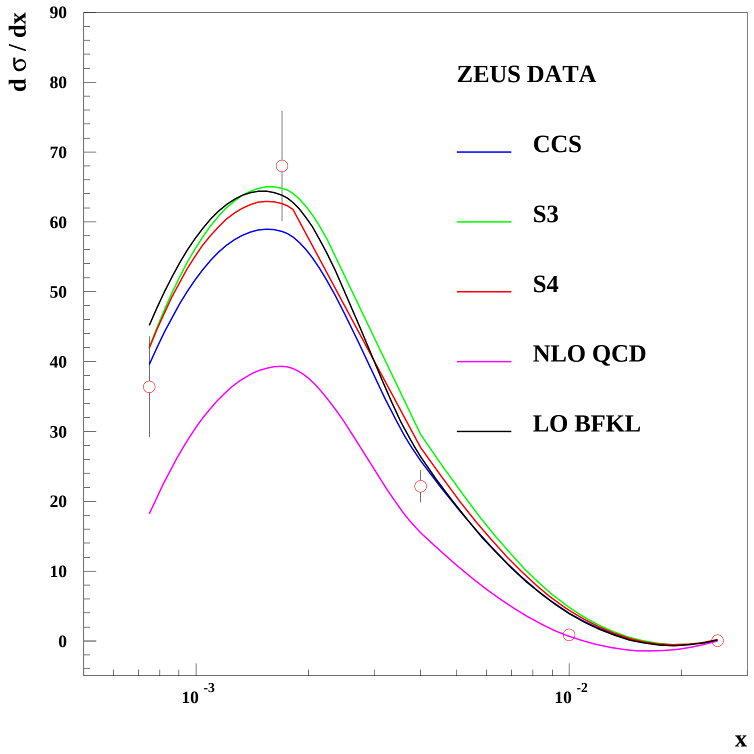
Fit results

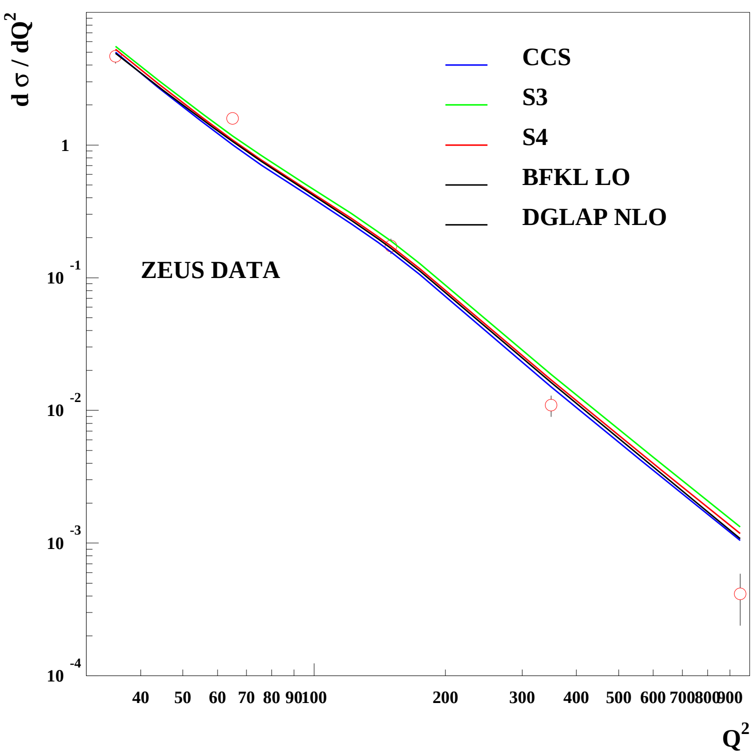
- χ^2 for CCS: 2.4 (0.2), S3: 15.5 (0.8), S4: 4.2 (0.2)
- Good description of H1 data using BFKL LO and BFKL NLL formalism, DGLAP-NLO fails to describe the data
- BFKL higher corrections found to be small (We are in the BFKL-LO region, cut on $0.5 < kT^2/Q^2 < 5$)



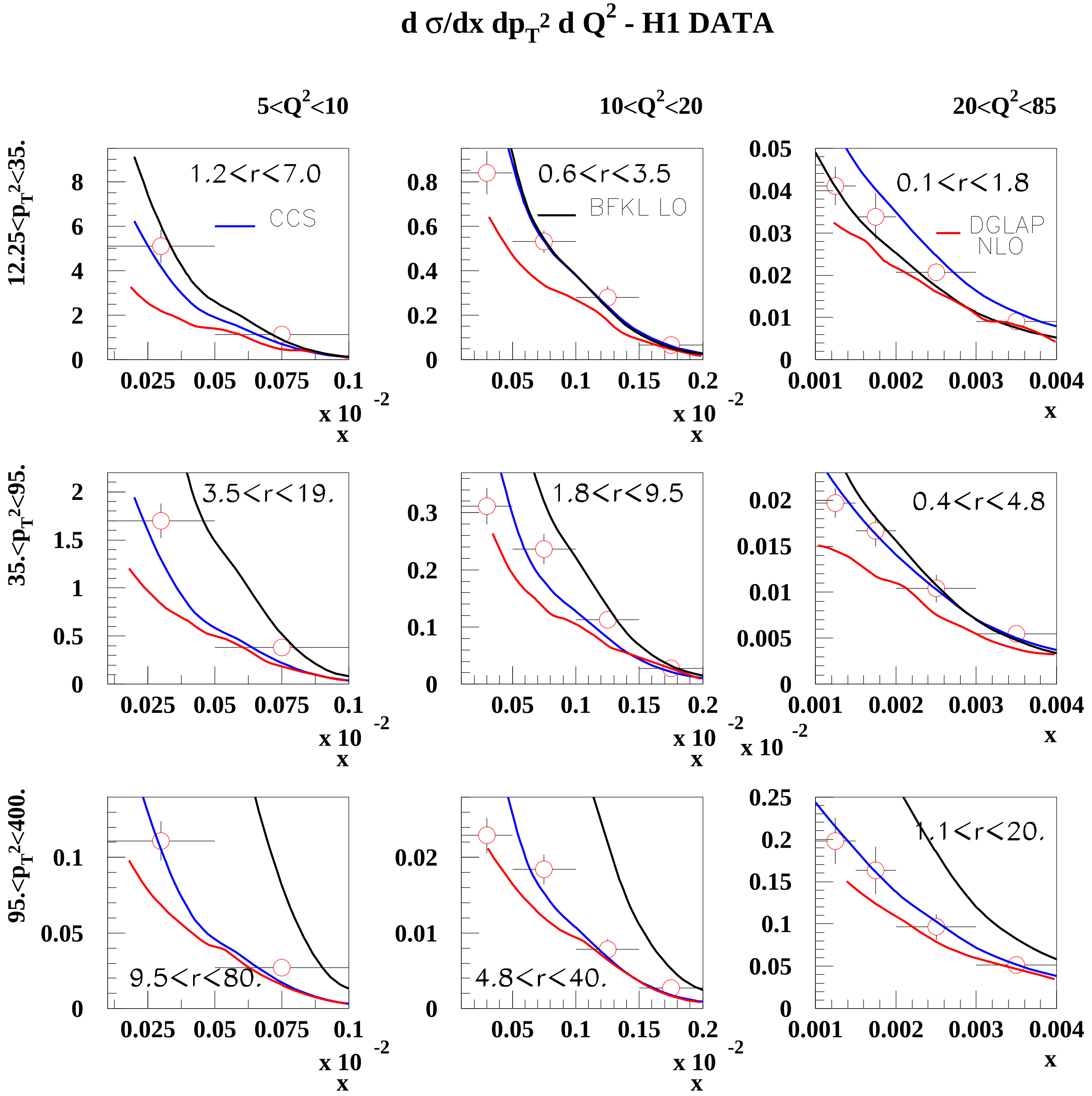
Comparison with ZEUS data

Comparison with ZEUS $d\sigma/dx$ and $d\sigma/dQ^2$ data (similar with $d\sigma/dk_T$ data)





Comparison with H1 triple differential data

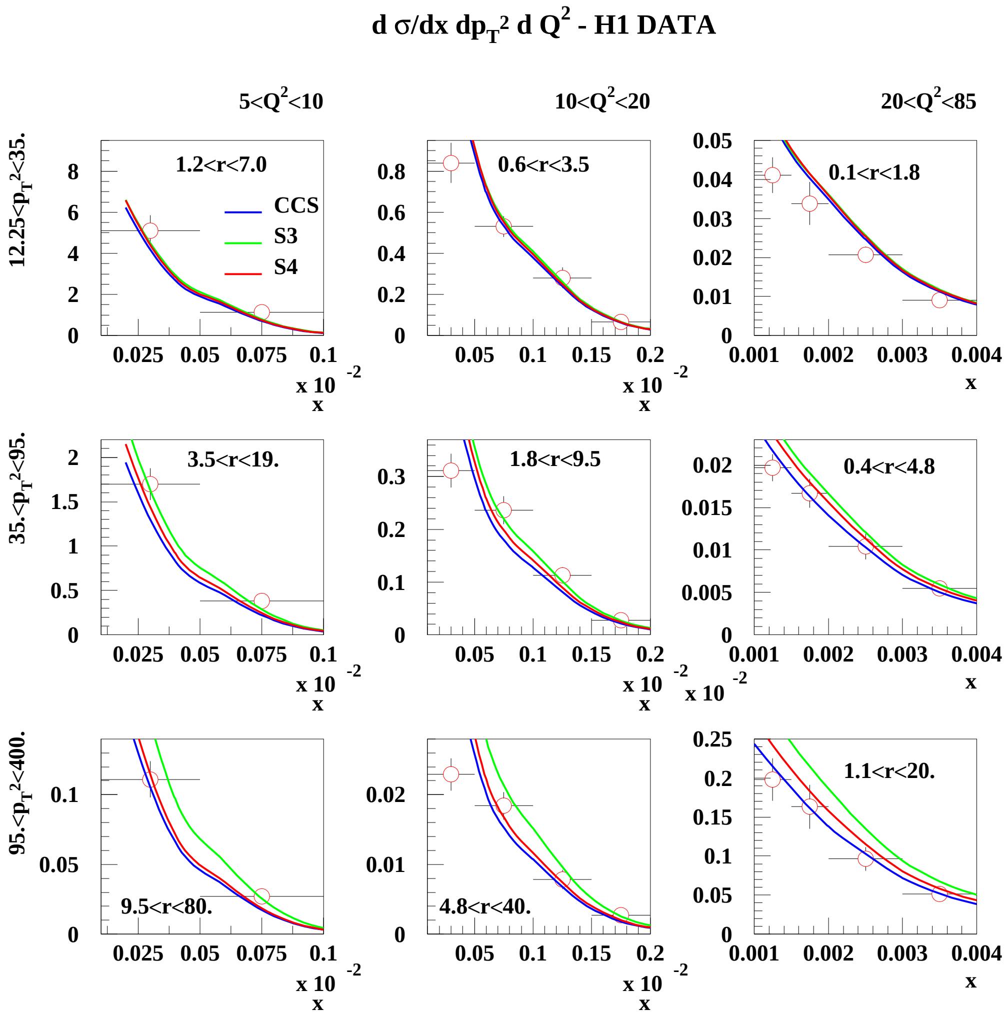


Comparison with H1 triple differential data

- DGLAP NLO predictions cannot describe H1 data in the full range, and large difference between DGLAP NLO and DGLAP LO results (DGLAP NLO includes part of the small x resummation effects)
- BFKL LO describes the H1 data when $r = k_T^2/Q^2$ is close to 1
- BFKL LO fails outside the region $r \sim 1$ specially at high Q^2
- BFKL higher order corrections found to be small (as expected) when $r \sim 1$
- Higher order BFKL corrections larger when r further away from 1, where the BFKL NLL prediction is closer to the DGLAP one (Q^2 resummation effects are starting to be large)
- BFKL NLL gives a good description of data over the full range: first success of BFKL higher order corrections, shows the need of these corrections

Comparison with H1 triple differential data

- Comparison between the three resummation schemes: CCS, S1 and S3
- CCS and S4 lead to similar description of data while S3 is slightly disfavoured



Conclusion

- DGLAP NLO fails to describe forward jet data
- First BFKL NLL description of H1 and ZEUS forward jet data: very good description
- The BFKL scale which is used in the exponential $\alpha_S(k_T^2)$ can describe the H1 cross section measurements
- Higher order corrections small when $r = kt^2/Q^2 \sim 1$ and larger when r is further away from 1 as expected
- BFKL NLL formalism leads to a better description than the BFKL LO one for the triple differential cross section: Resummed BFKL NLO kernels include part of the evolution in Q^2