Small-x effects in forward-jet production at HERA

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Introduction

BFKL evolution and saturation

- example: γ^*-γ^* total cross-section $\gamma^*\gamma^* \to X$ suitable to test fixed-scale evolution BFKL prediction:

  $$\sigma_{BFKL}(Q_1, Q_2, \Delta\eta) \propto \exp(\lambda\Delta\eta)$$

  Saturation: restores unitarity

- High-energy behavior:
  determined by dipole-dipole scattering

  $$\sigma_{dd}(\Delta\eta, r_1, r_2)$$

- Tîmneanu, Kwiecinski and Motyka (2002)
  Kozlov and Levin (2003)

Forward-jet production

- $p+\gamma^* \rightarrow jet+X$
  $Q, k_T \gg \Lambda_{QCD}$ $\exp(\Delta\eta) \gg 1$

  $\sigma_{BFKL}(k_T, Q, \Delta\eta) \propto \exp(\lambda\Delta\eta)$
- Same kind of process than γ^*-γ^* but more statistics
  data from H1 and ZEUS
- Is the BFKL resummation seen at HERA?
- Are saturation effects sizable at HERA?

The high-energy behavior is also determined by dipole-dipole scattering

Gluon emission by a hadron

C. M., Nucl. Phys. B 705 (2005) 319

It can be formulated in terms of the gluon dipole cross-section $\sigma_{(gg)t}$:

$$\frac{d\sigma^{h+t\to J+X}}{d^2k\,dx_J} = \frac{1}{2k^2} g_h(x_J,\mu^2) \int dr\, J_0(kr) \frac{\partial}{\partial r} r \frac{\partial}{\partial r} \sigma_{(gg)t}(r)$$

- x_J is the longidudinal momentum fraction of the gluon-jet
- k is the transverse momentum of the gluon-jet
- g_h is the gluon density inside the incident hadron
- μ is the factorization scale

- This formula is valid in the leading-logarithmic approximation
- One recovers the kT-factorization formula by restricting $\sigma_{(gg)t}$ to a two-gluon exchange (BFKL)

The forward-jet cross-section

- x, y, Q_2 : usual kinematic variables of DIS
- x_J, k : longitudinal and transverse momentum of the jet
- $\Delta\eta = \log(x_J/x)$: rapidity interval

$$\frac{d\sigma}{dx\,dQ^2dx_J\,dk^2} = \frac{\alpha\, g_p(x_J, k^2)}{2xk^2Q^2}\left\{\frac{y^2}{2}\frac{d\sigma_T}{dk^2} + (1-y)\left(\frac{d\sigma_T}{dk^2} + \frac{d\sigma_L}{dk^2}\right)\right\}$$

with the hard cross-section given by

$$\frac{d\sigma_{T,L}}{dk^2} = \int d^2r_1\, d^2r_2 \left|\psi_{T,L}(r_1\,, Q^2)\right|^2 \frac{J_0(kr_2)}{2\pi\, r_2}\, \frac{\partial}{\partial r_2} r_2 \frac{\partial}{\partial r_2}\, \sigma_{(gg)d}(\Delta\eta, r_1\,, r_2)$$

Parametrizations of $\sigma_{(gg)d}$

BFKL parametrization

- The BFKL dipole-dipole cross-section:

$$\sigma_{(gg)d}(\Delta\eta, r_1, r_2) = 2\pi\alpha_S^2 r_1^2 \int \frac{d\gamma}{2i\pi} \left| r_1/r_2 \right|^{2\gamma} \frac{\exp(\bar{\alpha}\chi(\gamma)\,\Delta\eta)}{\gamma^2(1-\gamma)^2}$$

with the BFKL kernel

$$\chi(\gamma) = 2\psi(1) - \psi(\gamma) - \psi(1-\gamma)$$

- We fit the parameter $\lambda = 4\bar{\alpha}\ln(2)$ and a normalization

Saturation parametrization

- An extension of the GBW model
  Tîmneanu, Kwiecinski and Motyka (2002)

$$\sigma_{(gg)d}(\Delta\eta, r_1, r_2)/\sigma_0 = 1 - \exp\left(-r_{eff}^2 / 4R_0^2(\Delta\eta) \right)$$

with $r_{eff}^2 = r_<^2 \left(1 + \ln(r_> / r_<) \right)$

$$r_< = \min(r_1, r_2) \quad r_> = \max(r_1, r_2)$$

- The saturation radius is

$$R_0(\Delta\eta) = \frac{1}{Q_0} \exp\left(-\frac{\lambda}{2}(\Delta\eta - \Delta\eta_0) \right) \qquad Q_0 \equiv 1 \text{ GeV}$$

we fit the parameters λ , $\Delta\eta_0$ and a normalization

Fitting the HERA data

J. Contreras, R. Peschanski and C. Royon, Phys. Rev. D 62 (2000) 034006

C.M., R. Peschanski and C. Royon, Phys. Lett. B 599 (2004) 236

Results of the fits

fit	λ	$\Delta\eta_0$	χ^2 (/dof)
BFKL	0.430	******	12 (/13)
sat.	0.402	-0.82	6.8 (/11)
weak sat.	0.370	8.23	8.3 (/11)

- The BFKL fit is a measure of the hard Pomeron intercept
- We obtain two χ^2 minima for the saturation fit:

The « sat. » solution corresponds to significant saturation effects

The « weak sat. » solution corresponds to weak saturation effects

The intercept λ is in both cases higher than what was found for F_2 ($\lambda_{GBW} = 0.288$)

The BFKL fit

The saturation fit

The saturation scales

- The saturation scale is
  $Q_S \equiv 1/R_0(\Delta\eta)$
- The plot represents

$$\log(Q_S^2/Q_0^2) = \lambda\,(\Delta\eta - \Delta\eta_0)$$

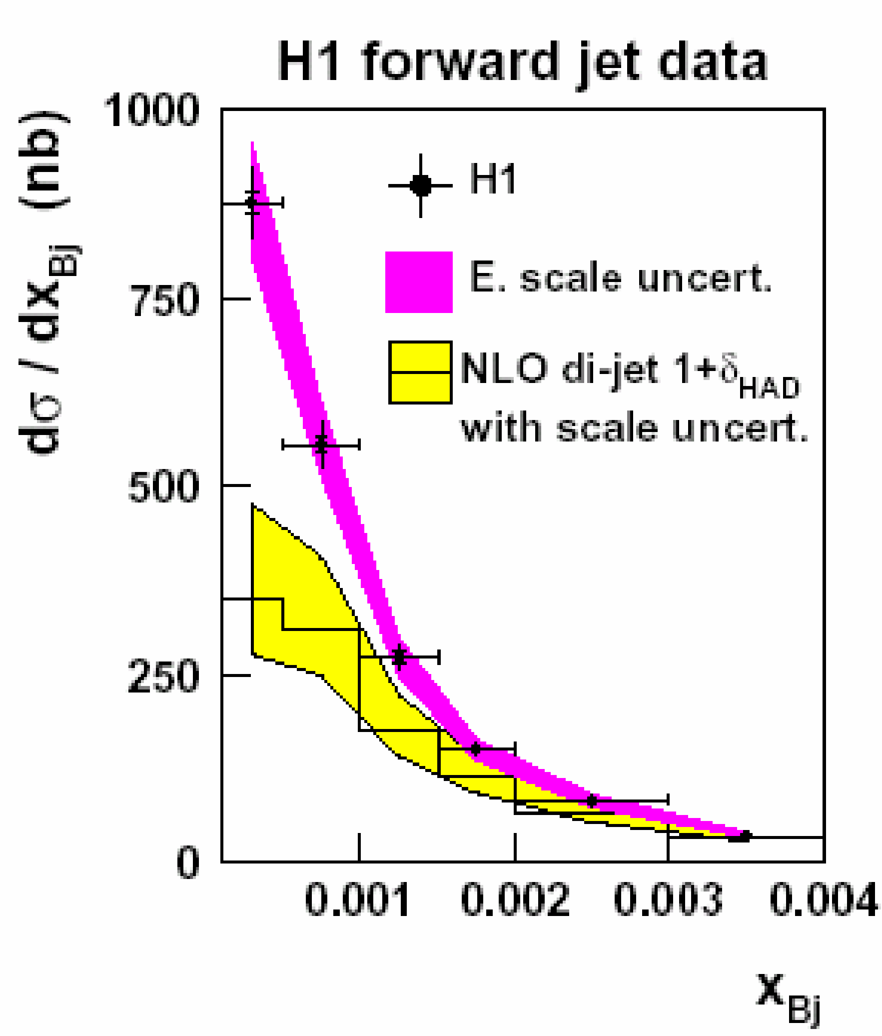
- The weak saturation solution is compatible with the F_2 parametrization
- The other solution shows a harder saturation scale

Comparisons with new data and predictions

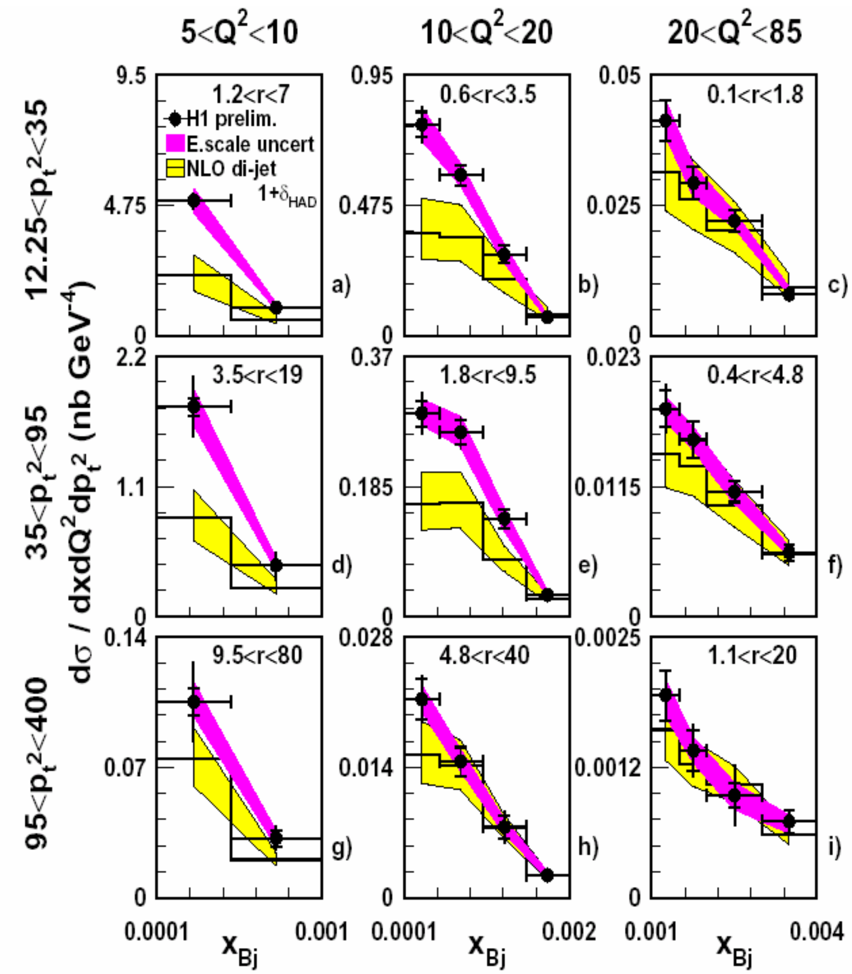
C. M. and C. Royon, in preparation

Comparisons with ZEUS data

Predictions for H1 preliminary data



Predictions for $d\sigma/dxdQ^2dk^2$



Conclusion and outlook

- Studies of small-x effects in forward jets at HERA using BFKL and GBW parametrizations

  using the parameters fit to the old data for $d\sigma/dx$:

  we describe well the new data for $d\sigma/dx$

  we make predictions for $d\sigma/dxdQ^2dk^2$ (H1)

- Study to be completed with $d\sigma/dQ^2$, $d\sigma/d\eta_J$, $d\sigma/dk^2$ (ZEUS)
- At small-x

  NLO QCD is below the data

  BFKL LL agrees well

  The saturation model is compatible with the data, (as it is for F_2)

- But two different saturation scales work

  we need other observables to distinguish them

  Other forward-jet cross-sections? Mueller-Navelet at LHC?