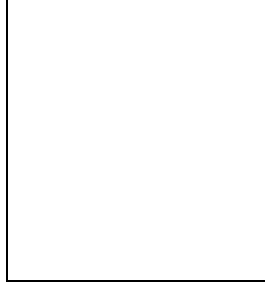# SELECTED RESULTS IN HADRONIC FINAL STATE PHYSICS AT HERA

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This presentation reports recent results from the hadronic final state in DIS at HERA. Forward jet and π^0 production have been measured by the H1 experiment. The forward jet production cross section shows significant deviation from the predictions based on DGLAP evolution. The forward π^0 data discriminate between different QCD models and are best described by models which take into account the partonic substructure of virtual photons. Inclusive $K_s^0 K_s^0$ production in ep has been studied with the ZEUS detector using an integrated luminosity of 120 pb^{-1}. Two states are observed at masses of 1537 MeV and 1726 MeV as well as an enhancement around 1300 MeV. The state at 1537 MeV is consistent with the well established $f_2'(1525)$. The state at 1726 MeV may be the glueball candidate $f_0(1710)$.

1 Forward Jet and π^0 Production at HERA

The HERA collider has extended the available kinematic range for Deep-Inelastic Scattering (DIS) to regions of large values of the four momentum trasfer Q^2 ($\leq 10^5\ GeV^2$) and small Bjorken-x_{Bj} ($x_{Bj} \simeq 10^{-5}$). Studies at low x_{Bj} could reveal novel features of parton dynamics. At small x_{Bj} it is very probable that the quark struck by the virtual photon originates from a QCD cascade initiated by a parton in the proton. In different regions of Q^2 and x_{Bj} different approximations to QCD are expected to describe the parton evolution: the most discussed being DGLAP[1], BFKL[2] and CCFM[3]. At high Q^2 and high x_{Bj} the initial state radiation is described by the DGLAP evolution equations which resum the leading $\alpha_s ln(Q^2/Q_0^2)$ terms. In this scheme a space-like chain of subsequent gluon emissions is characterized by a strong ordering of transverse momenta k_T. However at small x_{Bj} the contribution of large $ln(1/x)$ terms may become important. Resummation of these terms leads to the BFKL evolution equation. No ordering on transverse momenta k_T of emitted gluons is imposed here. The CCFM evolution
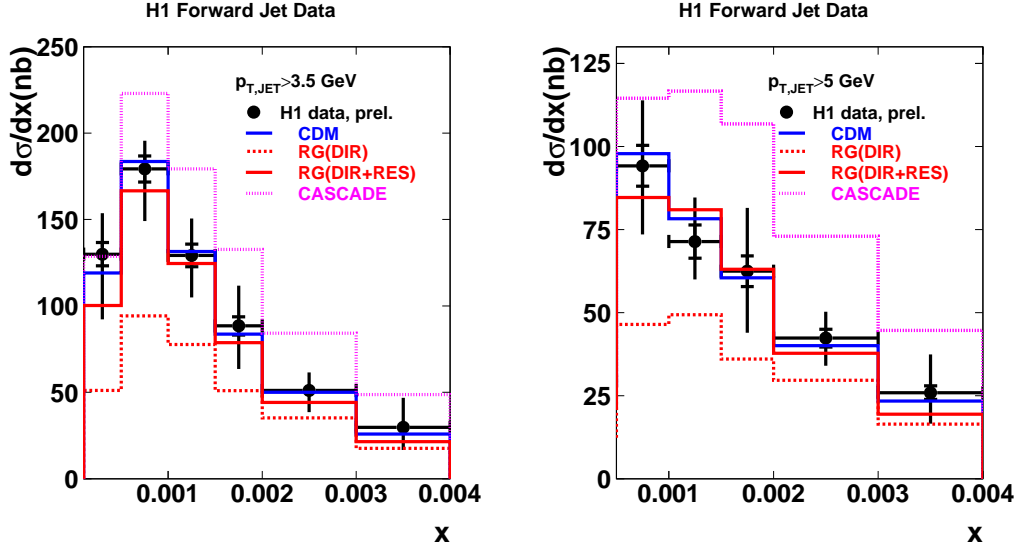
Figure 1: The cross section for forward jet production at the hadron level, as a function of x_{Bj} for $p_{t\ jet} >$ 3.5 GeV (left) and $p_{t\ jet} >$ 5 GeV (right). Also shown are the predictions from the CDM (ARIADNE), RAPGAP (RG) and CASCADE Monte Carlos.

equation based on angular ordering and colour coherence interpolates between the BFKL and DGLAP approaches.

Differences between the different dynamical approaches to the parton cascade are expected to be most prominent in the "forward" phase-space region towards the proton remnant direction, i.e. away from the scattered quark. In this talk studies of the parton evolution at small x_{Bj} using jet and π^0 production in the forward angular region in the laboratory frame, are presented. The study of DIS events with a single forward particle is complementary to forward jet production: a forward parton is tagged by a single energetic fragmentation product.

In figures 1 and 2 the cross section for forward jet and π^0 production as a function of x_{Bj} is shown. The data are compared to MC model predictions. RAPGAP (RG) [4] uses LO matrix elements supplemented with initial and final state DGLAP parton showers (DIR-model) and resolved virtual photon processes (RES-model). DJANGO [5] is used together with the Color-Dipole-Model as implemented in ARIADNE [6] for higher order QCD radiation, labeled as CDM. In ARIADNE the parton emissions perform a random walk in p_T leading to a situation similar to the one expected in BFKL. CCFM evolution is implemented in the CASCADE Monte Carlo.

In summary, for the forward jet production case the data are up to a factor of two larger than the predicted cross section based on $O(\alpha_s)$ matrix elements and parton showers in the collinear factorization ansatz (DGLAP). Using a MC model incorporating resolved virtual photon processes in addition to the usual direct photon processes, the data are reasonably well described. Also the Color Dipole Model, which simulates higher order QCD radiation without strong ordering in the p_T of the emitted partons, describes the measurements well. The CCFM approach, which is based on angular ordering coming from color coherence, predicts too high a rate of forward jet events.

Measurements of the forward π^0 cross-sections can discriminate between different QCD models and are best described by an approach in which the partonic substructure of virtual photons
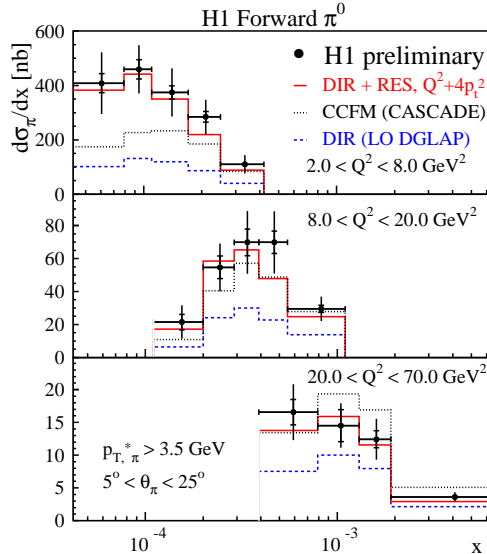
Figure 2: Inclusive π^0 production cross section as a function of x_{Bj} for $p_{T,\pi}^* > 3.5$ GeV in three regions of Q^2. The QCD models RAPGAP based on LO DGLAP parton showers with (DIR+RES) and without (DIR) resolved photon processes and CASCADE as an implementation of the CCFM equation, are compared to the data.

is taken into account, though with a scale of $Q^2 + 4p_T^2$ which is unusually large.

2 Observation of $K_s^0 K_s^0$ resonances in deep inelastic scattering at HERA

The $K_s^0 K_s^0$ system is expected to couple to the scalar ($J^{PC} = 0^{++}$) and tensor ($J^{PC} = 2^{++}$) glueballs. This has motivated intense experimental and theoretical study during the past few years [7]. Lattice QCD calculations [8] predict the existence of a scalar glueball with a mass of 1730 ± 100 MeV and a tensor glueball at 2400 ± 120 MeV. The scalar glueball can mix with $q\bar{q}$ states with $I = 0$ from the scalar meson nonet, leading to three $J^{PC} = 0^{++}$ states whereas only two fit in the nonet. Experimentally four states with $I = 0$ and $J^{PC} = 0^{++}$ have been established: $f_0(980)$, $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$ [9].

The state most frequently considered to be a glueball candidate is $f_0(1710)$ [9], but its gluon content has not yet been established. This state was first observed in radiative J/ψ decays [10] and its $J = 0$ angular momentum was established by the WA102 experiment using a partial-wave analysis in the $K^+ K^-$ and $K_s^0 K_s^0$ final states [11]. Observation of $f_0(1710)$ in $\gamma\gamma$ collisions may indicate a large quark content. A recent publication from L3 [12] reports the observation of two states above 1500 MeV in $\gamma\gamma \to K_s^0 K_s^0$, the well established $f_2'(1525)$ and a broad resonance at 1760 MeV. It is not clear if this state is the $f_0(1710)$.

The ep collisions at HERA provide an opportunity to study resonance production in a new environment. In this talk, the first observation of resonances in the $K_s^0 K_s^0$ final state in inclusive ep DIS is reported.

Oppositely charged track pairs reconstructed by the ZEUS central tracker (CTD) and assigned to a secondary vertex were selected and combined to form K_s^0 candidates. Both tracks were assigned the mass of a charged pion and the invariant-mass $M(\pi^+\pi^-)$ was calculated. Events with at least two K_s^0 candidates were selected and the $K_s^0 K_s^0$ invariant-mass was calculated. Figure 3 shows the $K_s^0 K_s^0$ invariant-mass spectrum in the range $0.995 < M(K_s^0 K_s^0) <$
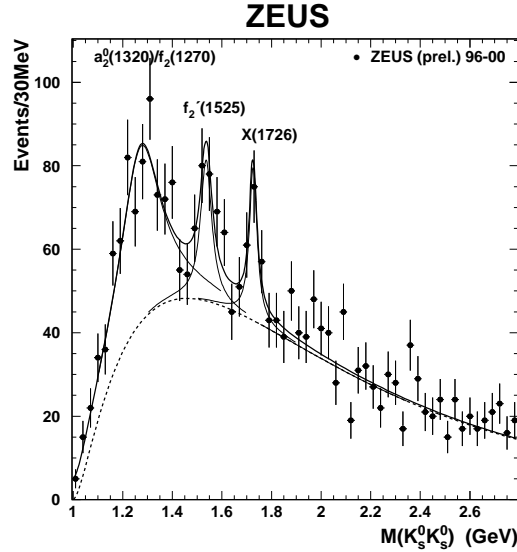
Figure 3: $K_s^0 K_s^0$ invariant-mass spectrum fitted with three Breit-Wigners and a background function. The $cos\theta_{K_s^0 K_s^0}$ cut is used to separate the KK attraction at threshold $f_0(980)/a_0(980)$ from the rest of the spectrum.

2.795 GeV for data (filled circles with error bar) after applying a $cos\theta_{K_s^0 K_s^0} < 0.92$ cut. This cut removes the effect of $f_0(980)/a_0(980)$ at the threshold which decays to collinear K_s^0 pairs affecting the measurement in the 1300 MeV mass region. Two clear peaks are seen, one around 1500 MeV and the other around 1700 MeV. This is the first observation in ep DIS of a state near 1537 MeV consistent with $f_2'(1525)$ and another near 1726 MeV close to $f_0(1710)$. There is also an enhancement near 1300 MeV which may arise from the production of $f_2(1270)/a_2^0(1320)$.

References

1. V.N. Gribov, L.N. Lipatov, *Sov.J.Nucl.Phys.* **15**, 438 and 675 (1972); Yu.L. Dokshitzer, *Sov. Phys. JETP* **46**, 641 (1977); G. Altarelli, G. Parisi, *Nucl. Phys.* **126**, 297 (1978).

2. E.A. Kuraev, L.N. Lipatov, V.S. Fadin, *Sov. Phys. JETP* **45**, 199 (1972); Y.Y. Balitsky, L.N. Lipatov, *Sov.J.Nucl.Phys.* **28**, 822 (1978).

3. M. Ciafaloni, *Nucl. Phys.* B **296**, 49 (1988); S. Catani, F. Fiorani, G. Marchesini, *Phys. Lett.* B **234**, 339 (1990), *Nucl. Phys.* B **336**, 18 (1990); G. Marchesini, *Nucl. Phys.* B **445**, 49 (1995).

4. H. Jung, http://www.quark.lu.se/~hannes/rapgap/.

5. G.A. Schuler, H. Spielberger, *Proc. Physics at HERA*, vol.3, 1419-1432, Hamburg 1991.

6. L. Lonnblad, *Comp. Phys. Comm.* **71**, 15 (1992).

7. S. Godfrey, J. Napolitano, *Review of Mod. Phys.* **71**, 1411 (1999).

8. C.J. Morningstar, M. Peardon, *Phys. Rev.* D **60**, 034509 (1999); C. Michael, M. Teper, *Nucl. Phys.* B **314**, 347 (1989).

9. K. Hagiwara et al, *Phys. Rev.* D **66**, 1 (2002).

10. J.Z. Bai et al, *Phys. Rev. Lett.* **77**, 3959 (1996).

11. D. Barberis et al, *Phys. Lett.* B **453**, 305 (1999).

12. M. Acciari et al, *Phys. Lett.* B **501**, 173 (2001);