Selected results in hadronic final state in DIS at HERA

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Outline

• Forward jet and $\pi^0$ production in DIS
• First observation of $K_sK_s$ resonances in DIS
Multi-parton dynamics at low $x$

- Multi-parton emissions are described only by approximations.
- Everything beyond $O(a_s^2)$ is put into Evolution Equations.
- DGLAP, BFKL, CCFM evolution schemes.

DGLAP: ordered in $k_t$

DGLAP+resolved photon: 2 ladders ordered in $k_t$

CCFM BFKL: not ordered in $k_t$
Parton dynamics at small $x$: forward jets and forward $\pi^0$

- An extended parton ladder at low $x$ leads to high $k_T$ partonic emission in the forward region.
- A forward parton can be tagged by a jet OR by a single forward particle (like a $\pi^0$).

DGLAP (strictly increasing gluon virtuality from proton to $\gamma^*$) works very well in the central rapidity region.

How about the forward region (small $x$)? Can we see any evidence for BFKL? (in BFKL the parton propagator virtualities perform a “random walk”.)
Forward Jet production: $E_T$ flow

- Transverse energy flow around the selected forward jet as a function of $\Delta \eta$ and $\Delta \phi$

- DGLAP + resolved photon describes the $E_T$ flow better than CDM which simulates higher order QCD radiation without strong ordering in $k_t$ of emitted partons (similar to BFKL)
**Forward jet production**

- $x_{Bj}$ small
- $\gamma_{jet} = \frac{E_{jet}}{E_{proton}}$ = large

- DGLAP (dashed) too small
- DGLAP + resolved photon describes well the data
- CCFM (CASCADE) too large
- Color Dipole Model (CDM) simulates higher order QCD radiation without strong ordering in $k_t$ of emitted partons (similar to BFKL); describes well the data
Fwd jet production: $p_T$ dependence

$\chi_B$ small

$\chi_{jet} = \frac{E_{jet}}{E_{proton}} = \text{large}$

- CCFM (CASCADE) gets larger with increasing $p_T$
- Color Dipole Model (CDM) describes better the data
- DGLAP + resolved photon describes well the data
- DGLAP (dashed) too small

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Forward $\pi^0$ production

$\pi^0$ production in the forward direction with small $x_B$.

$x_{\pi} = \frac{E_\pi}{E_{proton}}$ is large.

- DGLAP (dashed) too small
- DGLAP + resolved photon describes well the data
- CCFM too small at small $x$

Graph showing $d\sigma/dx$ in different $Q^2$ ranges.
Forward \( \pi^0 \): \( E_T \)-flow around \( \pi \) in \( \gamma^* p \) CMS

- \( \pi^0 \) close to proton
- \( \eta^* \): p-rapidity in the \( \gamma^* p \) CMS frame

- Energy flow is highly collimated around the direction of the \( \pi \)
- Large amounts of transverse energy are also produced away from the \( \pi \)
- Transverse Energy flow around the \( \pi \) reflects how the transverse momentum of the jet is compensated along the ladder
- DGLAP+resolved photon describes better the \( E_T \) flow when \( \pi \) is close to the proton

\( \pi^0 \) towards photon
$K_sK_s$ final state in DIS

- $K_sK_s$ couples to meson states with $J^{CP}=$ (even)$^{++}$
- Scalar meson sector is not fully understood: there are too many candidates for the two $I=0$ available positions in the nonet
- Lattice QCD predicts the existence of hadrons made up by gluons (glueballs): the lightest glueball has $J^{CP}=0^{++}$ with a mass $1730\pm100$ MeV
- $ep$ is gluon rich
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**Tensor $J^{CP}=2^{++}$ Nonet**

- $K_2^0(1430)$
- $K_2^+(1430)$
- $f_2(8)$
- $f_2(1)$
- $f_2(1270) \sim u\bar{u}+d\bar{d}$
- $f_2(1525) \sim s\bar{s}$
- $a_2^0(1320) \sim u\bar{u} - d\bar{d}$

**Scalar $J^{CP}=0^{++}$ Nonet**

- $K_0^0(1430)$
- $K_0^+(1430)$
- $f_0(8)$
- $f_0(1)$
- $f_0(1370) \sim u\bar{u}+d\bar{d}$
- $f_0(1500) \sim ?$
- $f_0(1710) \sim s\bar{s}$

$J=0$ glueball can mix with the $I=0$ scalar mesons!
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x vs $Q^2$ and $K_s$ mass

DIS events with at least 2 $K_s$ were selected

Very clean $K_s$ sample
First observation of $J^{CP}=$(even)$^{++}$ in DIS: two states are observed: a state consistent with $f_2'(1525)$ and $X(1726)$ (is this the $f_0(1710)$?)

Several states have been observed in the 2GeV region (see PDG02)

$f_0(980)/a_0(980)$ gives $K_s$ pair with very small opening angle in the lab. We would like to remove collinear $K_s$ pairs and then fit the spectrum.
Observation of $K_sK_s$ resonances in DIS

Applied cut: $\cos K_s K_s < 0.92$ to remove threshold enhancement

Attempt to fit with 4 Breit-Wigner
K_{s}K_{s} in the Breit Frame

Current region in DIS is equivalent to an e^{+}e^{-} hemisphere

2x\vec{p} + \vec{q} = 0

Increasing \ x_p
78\% of the K_{s}K_{s} pairs have \ x_p > 1

\begin{align*}
P_q &= \frac{Q}{2}, \quad x_p^{MAX} = \frac{P_{K_{s}K_{s}}^{MAX}}{P_q} = \frac{1-x}{x}
\end{align*}
Summary

• New high statistics measurement of forward jets and pions performed
  - Data discriminate between different models
  - Cross sections much larger than standard DGLAP but DGLAP including the partonic substructure of the virtual photon describes the data

• First observation of $J^{PC}=\text{even}^{++}$ resonances in $K_sK_s$ final state in inclusive DIS
  - $a_2(1320)/f_2(1270)$ and $f_2'(1525)$ observed
  - $X(1726)$ is observed, this is probably the $f_0(1710)$ (glueball candidate)