Proton production in deep inelastic lepton nucleus scattering

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A. Accardi, V. Muccifora and H.J. Pirner, Nucl.Phys. A720 (2003) 131, and the same authors with D. Grünewald, **hep-ph/0502072**

Outline

- What is special about proton production?
- The absorption model
- Rescaling of PDF and FF
- String fragmentation
- Comparison with HERMES data
- Higher twist diquark scattering for high z
- String branching for protons at low z
- Conclusions

Motivation

- Absorption of prehadron describes meson production at Hermes well
- Z-distribution of proton production at Hermes is anomalous
- Also at RHIC, proton production is high compared with meson production

Proton to Pion Ratio- unpredicted

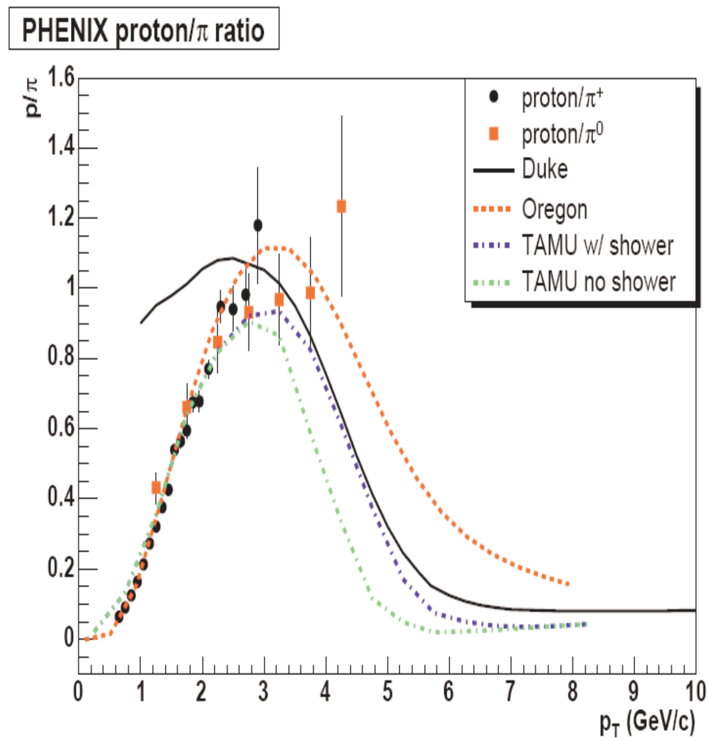
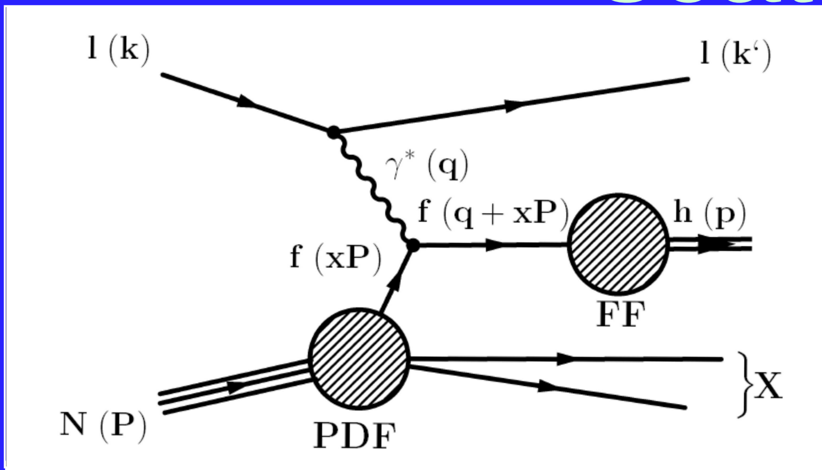


Fig. 53. The proton to pion ratio measured by PHENIX for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV[52]. Several comparisons to recombination models as mentioned in the text are shown.

- Figure shows several recombination models
- At higher pt other baryons?
- Protons are also exceptionally numerous at Hermes at low z- puzzle

Semi-inclusive deep inelastic scattering



Variable	Covariant	Lab. frame
Q^2	$-q^2$	$2Mx\nu$
ν	$\frac{qp}{\sqrt{P^2}}$	$E'-E$
x	$\frac{-q^2}{2Pq}$	$\frac{Q^2}{2M\nu}$
z	$\frac{pP}{qP}$	$\frac{E_h}{\nu}$
y	$\frac{qP}{kP}$	$\frac{\nu}{E}$
W^2	$(P+q)^2$	$M^2+2M\nu-q^2$

- Factorization theorem in QCD:

$$\left.\frac{d^2\sigma}{dx\,d\nu\,dz}\right|_{SIDIS} = \sum_f e_f^2 q_f(x,Q^2)\frac{d^2\sigma^{lq}}{dx\,d\nu}D_f^h(z,Q^2)$$

- Multiplicity:

$$M^h(z) = \frac{1}{N_A^{DIS}}\frac{dN_A^h(z)}{dz}$$

$$\frac{1}{N^{DIS}}\frac{dN^h(z)}{dz} = \frac{1}{\sigma^{lp}}\int_{\text{exp. cuts}} dx\,d\nu \sum_f e_f^2 q_f(x,Q^2)\frac{d\sigma^{lq}}{dx\,d\nu} \times D_f^h(z,Q^2)$$

$$\sigma^{lp} = \int_{\text{exp. cuts}} dx\,d\nu \sum_f e_f^2 q_f(x,\xi_A(Q^2)Q^2)\frac{d\sigma^{lq}}{dx\,d\nu}$$

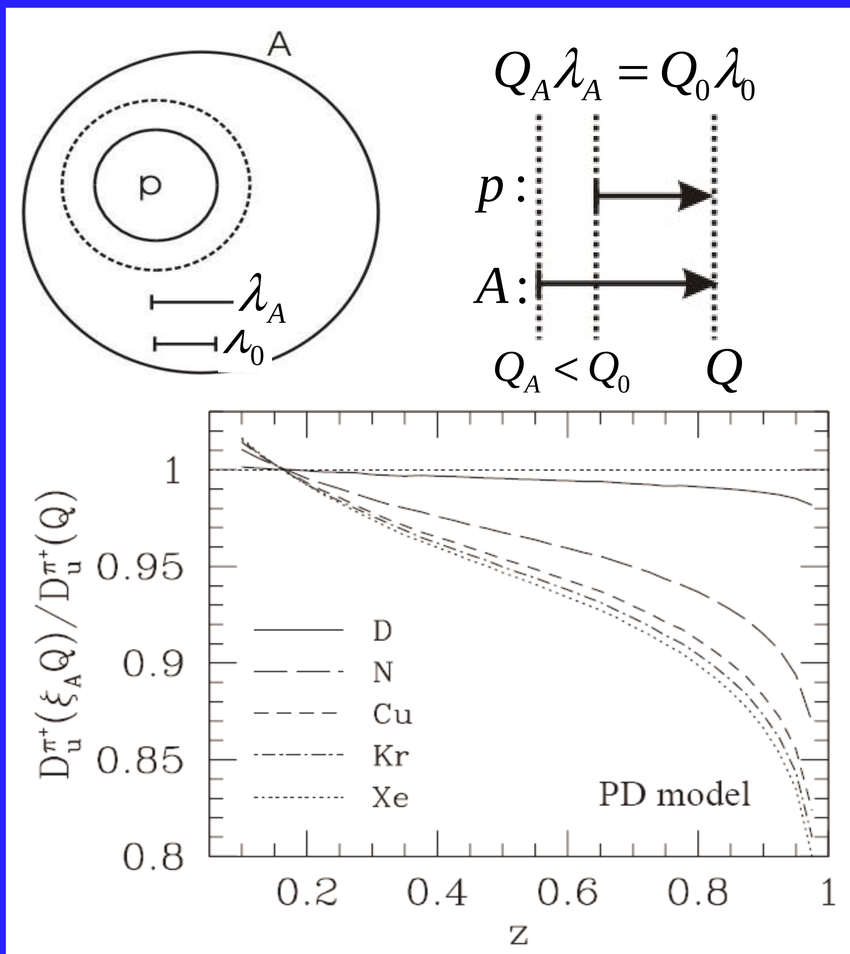
The Calculation of Absorption

$$\frac{1}{N_A^{DIS}}\frac{dN_A^h(z)}{dz} = \frac{1}{\sigma^{lA}}\int_{\text{exp. cuts}} dx d\nu \sum_f e_f^2 q_f^A(x, \xi_A Q^2)\frac{d\sigma^{lq}}{dx d\nu}$$

$$\times D_f^h(z, \xi_A Q^2) N_A(z, \nu),$$

Rescaling of Parton Distribution, Rescaling of Fragmentation Function
Calculation of the mean formation times of the prehadron and hadron
Calculation of the Nuclear Absorption Factor N_A,using formation times

Rescaling of PDF and FF



- Assume change of confinement scale in bound nucleons $\lambda_A > \lambda_0$
- Two consequences:

1.)

$$\frac{1}{A} q_f^{N|A}(x, Q^2) = q_f^N(x, \xi_A(Q^2) Q^2)$$

$$D_f^{h|A}(z, Q^2) = D_f^h(z, \xi_A(Q^2) Q^2)$$

$$\xi_A(Q^2) = \left(\frac{\lambda_A}{\lambda_0}\right)^{\frac{\bar{\alpha}_s}{\alpha_s(Q^2)}}$$

2.)

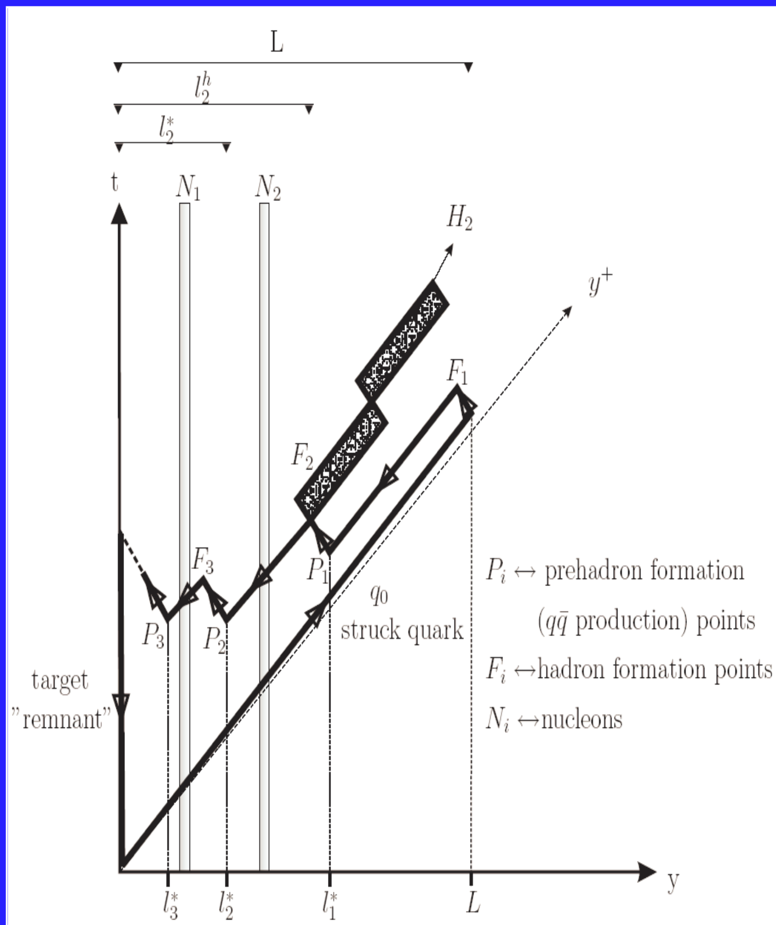
$$\kappa_A \lambda_A^2 = \kappa \lambda_0^2$$

- Rescaling implies a longer DGLAP evolution (increased gluon shower)

Why should the Fragmentation Function be rescaled?

- Fragmentation starts immediately after the quark has been struck, i.e. at Hermes in the cold nucleus - at RHIC in deconfined quark matter
- The emitted gluons can have lower frequencies than in the vacuum because of partial (Hermes) or full deconfinement (RHIC)
- There is also the possibility that induced scattering increases the factorization scale by the amount of enhanced transverse momentum squared (c.f. B. Kopeliovich)

String Fragmentation



- **First rank particle contains struck quark -> flavor dependent formation length**
- **String fragmentation function:**

$$f(u) \propto (1-u)^{D_q} \qquad D_q = 0.3 \text{ and } D_{qq} = 1.3$$

proportional to $\exp\left(-\frac{\pi\mu^2}{\kappa}\right)$

-> dominantly quark production

-> diquark production is suppressed

$$L = \frac{\nu}{\kappa} \qquad \kappa = 1GeV/fm$$

Turning point of struck quark:

$$L_h = \frac{\nu}{\kappa}\frac{\tau_h^2}{\tau_\pi^2}$$

Calculation of Prehadron Formation Lengths

$$\langle l^*_{\geq 1} \rangle = \frac{1+D_a}{1+C+(D_a-C)z}(1-z)\,z\,L$$
$$\times \left[1+\frac{1+C}{2+D_a}\frac{(1-z)}{z^{2+D_a}}\,{}_2F_1\left(2+D_a,2+D_a;3+D_a;\frac{z-1}{z}\right)\right]$$

F- Hypergeometric Function, C=0.3, D arise from the string fragmentation f(u)=(1-u)^D
Dq=0.3 for producing a quark and Dqq=1.3 for producing a diquark

Prehadron Formation Lengths

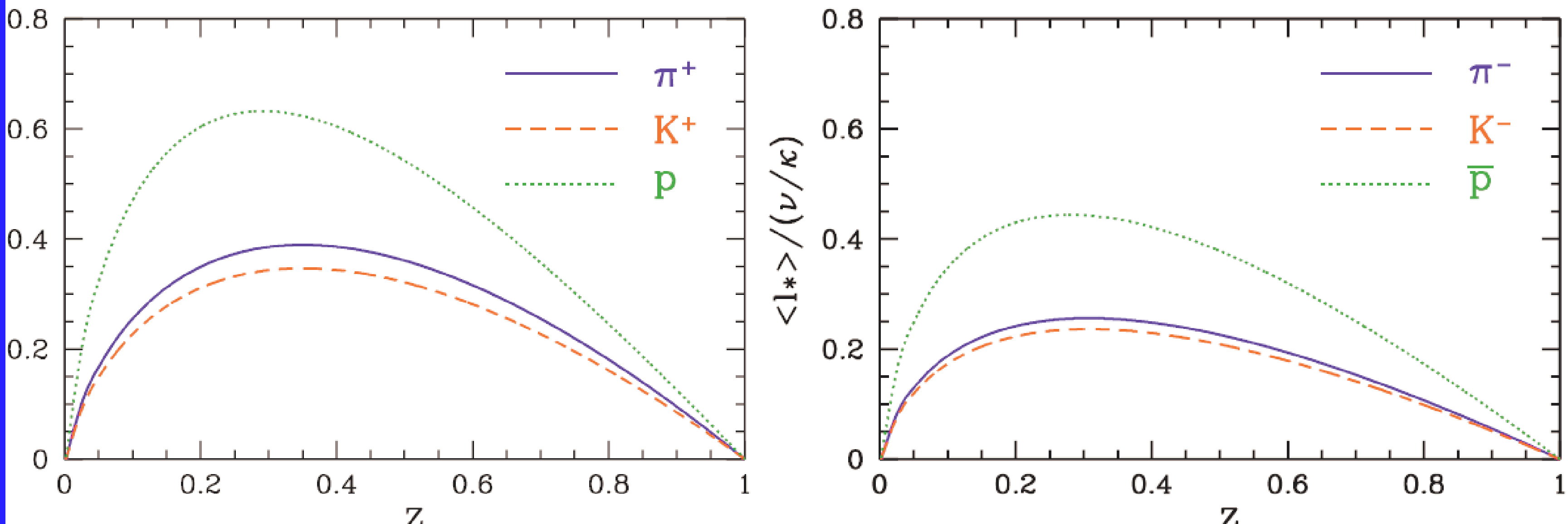
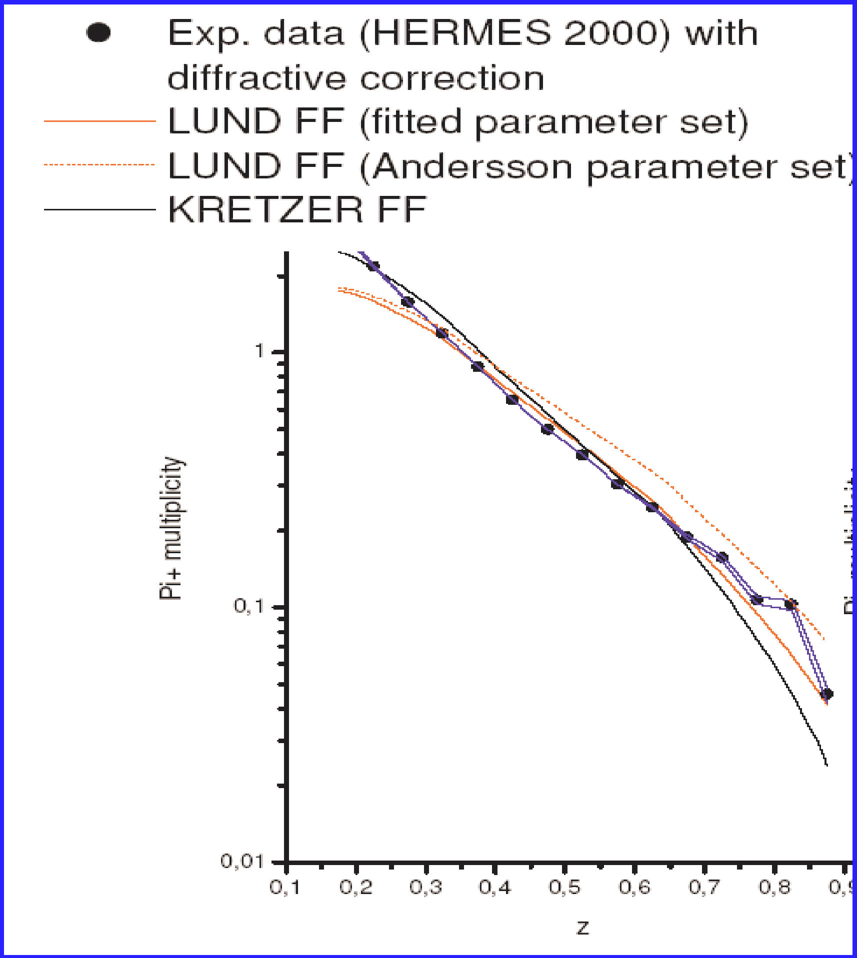


Fig. 3. Computed prehadron formation lengths when an up quark is struck by the virtual photon. *Left:* When a π^+, K^+ or p is observed, the corresponding prehadron can be created at rank $n \geq 1$. *Right:* When a π^-, K^- or $\bar{p}$ is observed, the corresponding prehadron can be created only at rank $n \geq 2$.

Scaled Hadron
f.l.=p.f.l.+z

Pion Multiplicity on the Proton

- D. Grünewald (Diploma Thesis) has calculated meson and baryon multiplicities in this Lund picture
- Unfortunately experimental baryon multiplicities are not available to compare with



Absorption model

- Inelastic scattering of (pre)hadrons on nucleons removes them from the considered (z,nu) bin, absorption rate is determined by the fitted prehadron mean free path

$$\frac{\partial P_q(y,y')}{\partial y'} = -\frac{P_q(y,y')}{\langle l^* \rangle} \qquad , P_q(y,y'=y)=1$$

$$\frac{\partial P_*(y,y')}{\partial y'} = \frac{P_q(y,y')}{\langle l^* \rangle} - \frac{P_*(y,y')}{\langle \Delta l \rangle} - \frac{P_*(y,y')}{\lambda_*(y')} \qquad , P_*(y,y'=y)=0$$

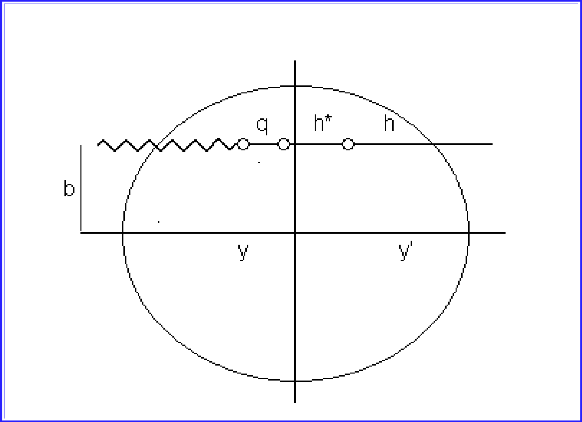
$$\frac{\partial P_h(y,y')}{\partial y'} = \frac{P_*(y,y')}{\langle \Delta l \rangle} - \frac{P_h(y,y')}{\lambda_h(y')} \qquad , P_h(y,y'=y)=0$$

- Absorption factor:

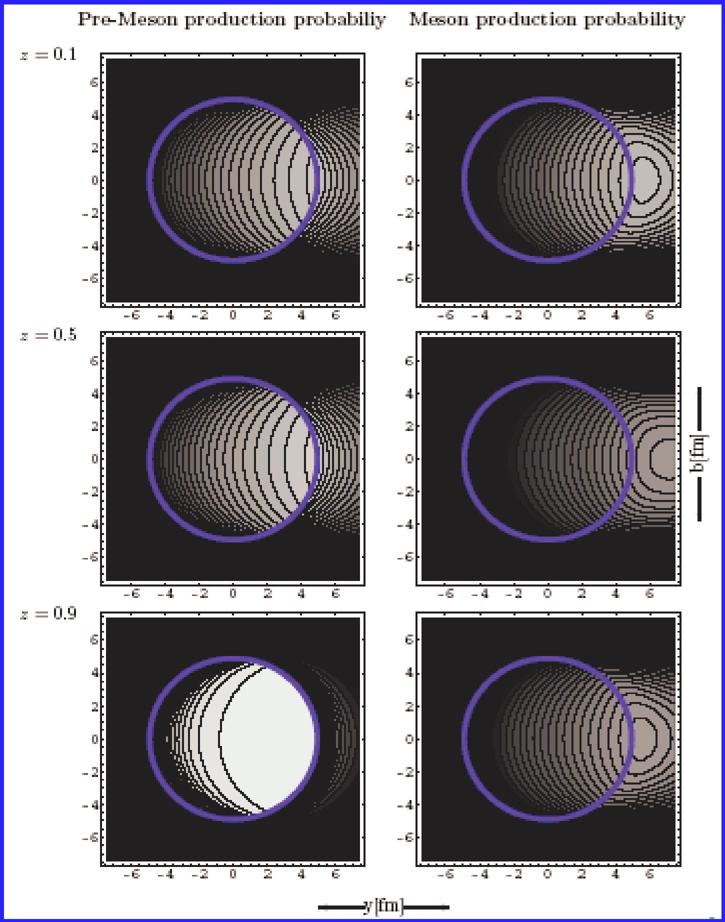
$$N_A = \lim_{y'\to\infty} \int d^2b \int_{-\infty}^{\infty} dy \rho_A(b,y) P_h(y',y)$$

$$= \int d^2b \int_{-\infty}^{\infty} dy \rho_A(b,y) \int_y^{\infty} dx' \int_y^{x'} dx \frac{e^{-\frac{x-y}{\langle l^* \rangle}}}{\langle l^* \rangle} e^{-\sigma_* \int_x^{x'} ds A \rho_A(s)}$$

$$\times \frac{e^{-\frac{x'-x}{\langle \Delta l \rangle}}}{\langle \Delta l \rangle} e^{-\sigma_h \int_{x'}^{\infty} ds A \rho_A(s)}$$

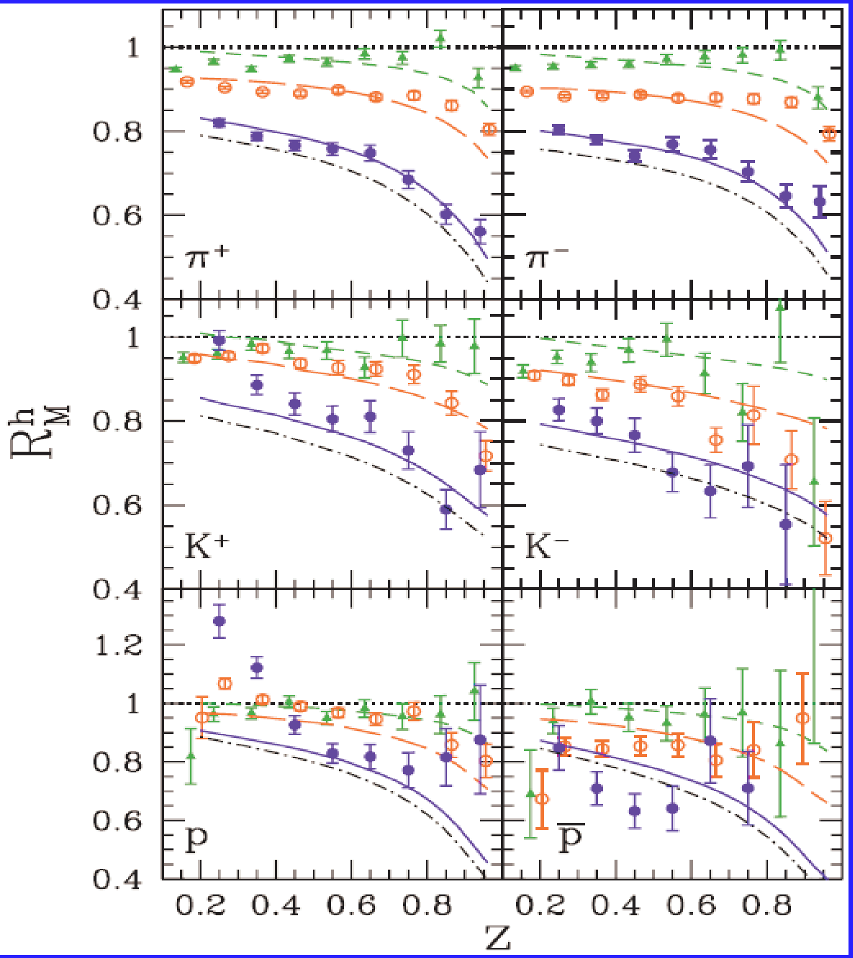


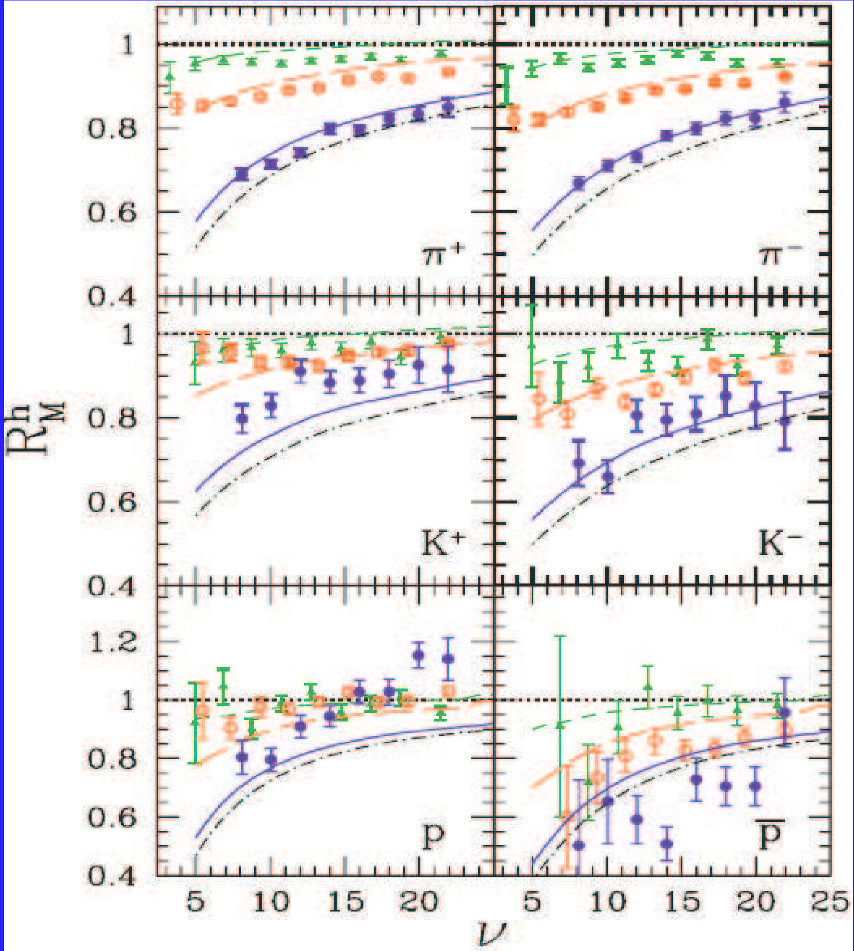
Prehadron und Hadron-Production probabilities at HERMES energies for Kr target without absorption



Comparison with HERMES data

Hermes Coll. A.Airapetian et al. Phys. Lett. B577 (2003) 37-Xe,Kr,Ne,He target





Result of Absorption Model

- Rescaling + absorption are able to describe the data
- Flavor dependence is reproduced in accordance with the first and second rank description
- Proton multiplicities are not reproduced well

1) Higher Twist Effect

- Virtual Photon can interact with a diquark

Let us consider here the unpolarized structure function $F_2(x, Q^2)$ only. It is straightforward to extract from the full contribution of the quark–diquark model to F_2 all terms which are proportional to the diquark form factors [8]. These terms vanish at large Q^2 values, but at moderate Q^2 values they give non negligible contributions. These are the terms which we assume to model higher-twist effects in DIS. Explicitely – following the notations of Refs. [7,8] – they are given by

$$
\begin{aligned}
F_2^{HT} &= \sum_S e_S^2\, S(x)\, x\, D_S^2 + \sum_V \frac{1}{3} e_V^2 V(x)\, x \Bigg\{ \Bigg[\left(1 + \frac{Q^2}{2m_N^2 x^2}\right) D_1 + \\
&- \frac{Q^2}{2m_N^2 x^2} D_2 + Q^2 \left(1 + \frac{Q^2}{4m_N^2 x^2}\right) D_3 \Bigg]^2 + 2\left[D_1^2 + \frac{Q^2}{4m_N^2 x^2} D_2^2 \right] \Bigg\} \\
&+ \frac{1}{4} \sum_S e_S^2\, S(x)\, x Q^2\, D_T^2 + \frac{1}{12} \sum_V e_S^2\, V(x)\, x Q^2\, D_T^2 \qquad (2) \\
&- \sum_{q_S} e_{q_S}^2\, x\, q_S(x, Q^2) D_S^2 - \sum_{q_V} e_{q_V}^2\, x\, q_V(x, Q^2) D_V^2
\end{aligned}
$$

Anselmino et al.

Z.Phys.C71:625-630,1996

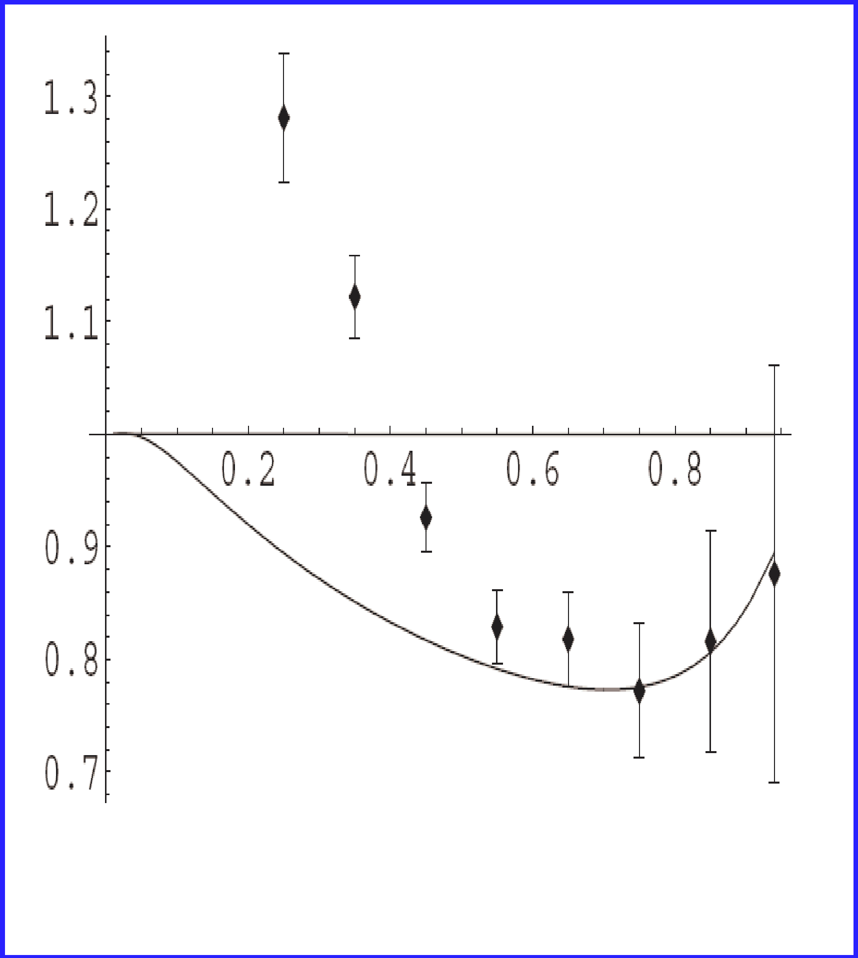
Q0^2=2 GeV^2

New Transport Equations

- Diquark can become prebaryon or lose one quark by stripping reaction on a nucleon
- Quark distribution is symmetric after stripping z(1-z)
- Stripping cross section is assumed to be pion-nucleon cross section
- Diquark fragmentation favours faster baryon

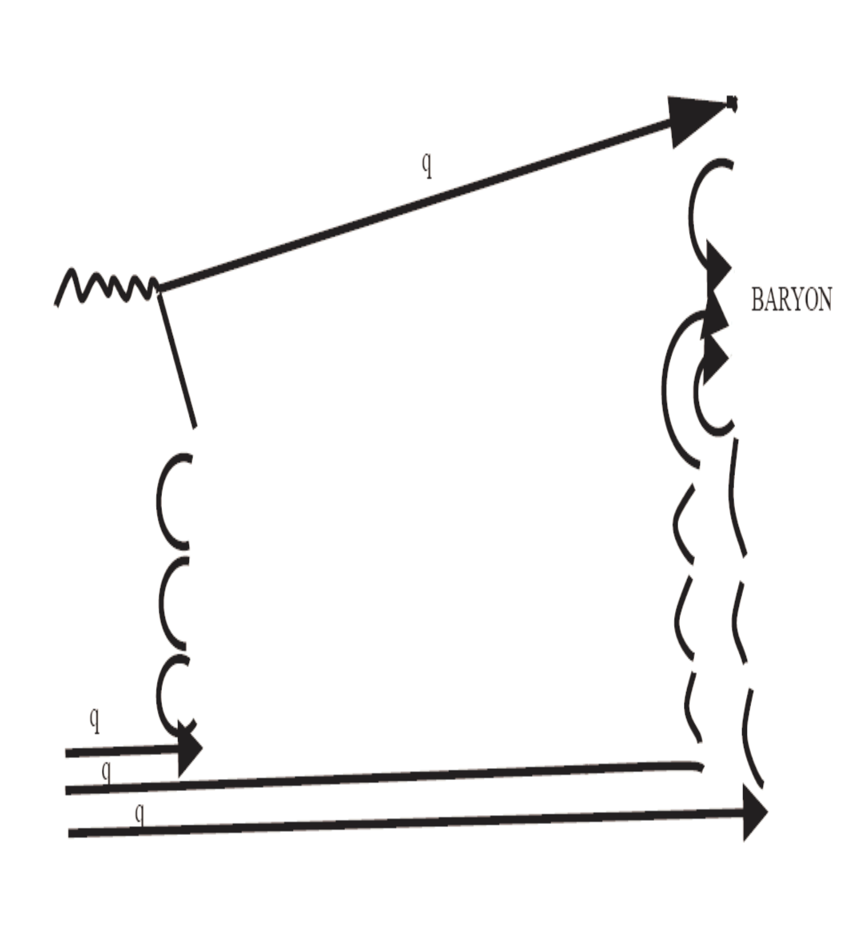
Multiplicity ratio in Krypton with Higher Twist Diquark Scattering

- Diquark scattering can increase the ratio at large z
- Only if we switch off nucleon absorption
- Needs further work
- At low z additional mechanism required



2) String branching

- Cut off (4 Gev) excludes target fragmentation at low z
- But string cannot only break, but also branch into two strings (cf.X.N. Wang et al., nucl-th/0407095)
- Main mechanism of baryon flow(Garvey, Kopeliovich,Povh, hep-ph/ 0006325)

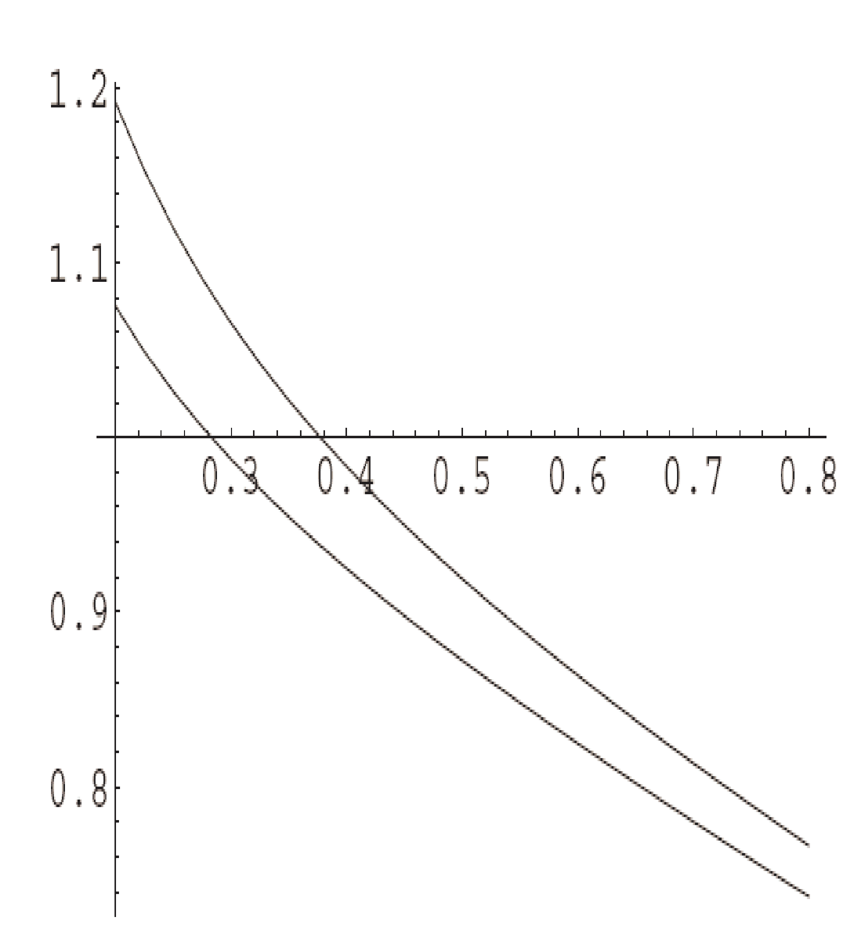


Multiplicity ratio with String Branching

- At low energies (Hermes) one of the quarks in the proton will shorten the string
- Multiplicity increases with number of rescattering centers
- Additional term proportional to

  C A^(1/3) exp[-1/2 yB]

  (Upper curve Kr,lower curve Ne)



Preliminary Conclusions:

- Absorption model describes data, besides p-production
- Reasonable prehadron (=2/3 of hadron) cross section
- Proton production at large z may get enhanced by higher twist effect
- String branching makes the baryon number flow away from the target fragmentation z values