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Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

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Hadron Production in Particle Nucleus Scattering

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Hadron production in particle nucleus scattering

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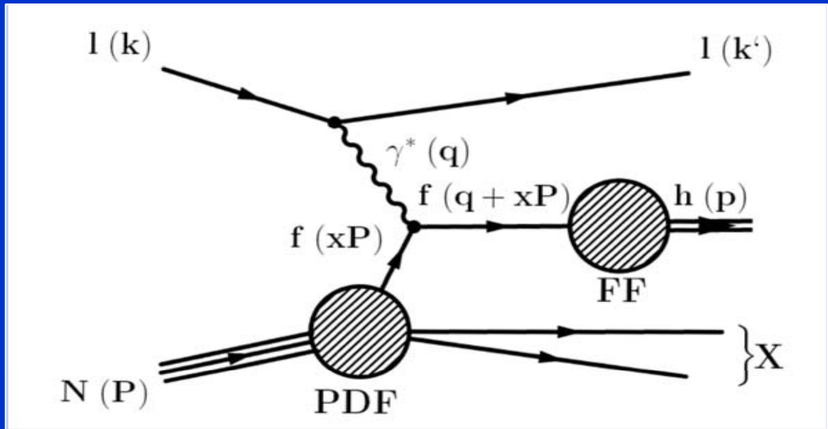
A. Accardi, V. Muccifora, D. Grünewald and H.J. Pirner, Nucl.Phys. A761 67-91,2005 and hep-ph/0508036, S. J. Brodsky, J. Raufeisen and H.J. Pirner, hep-ph/0502072, Phys.Lett.B July 2006

Outline

- Hadron Production in deep inelastic e-A scattering
- Space time development of hadron production
- Scaling in high pt hadron production
- Conclusions

I. Semi-inclusive deep inelastic scattering



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

- 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:

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

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

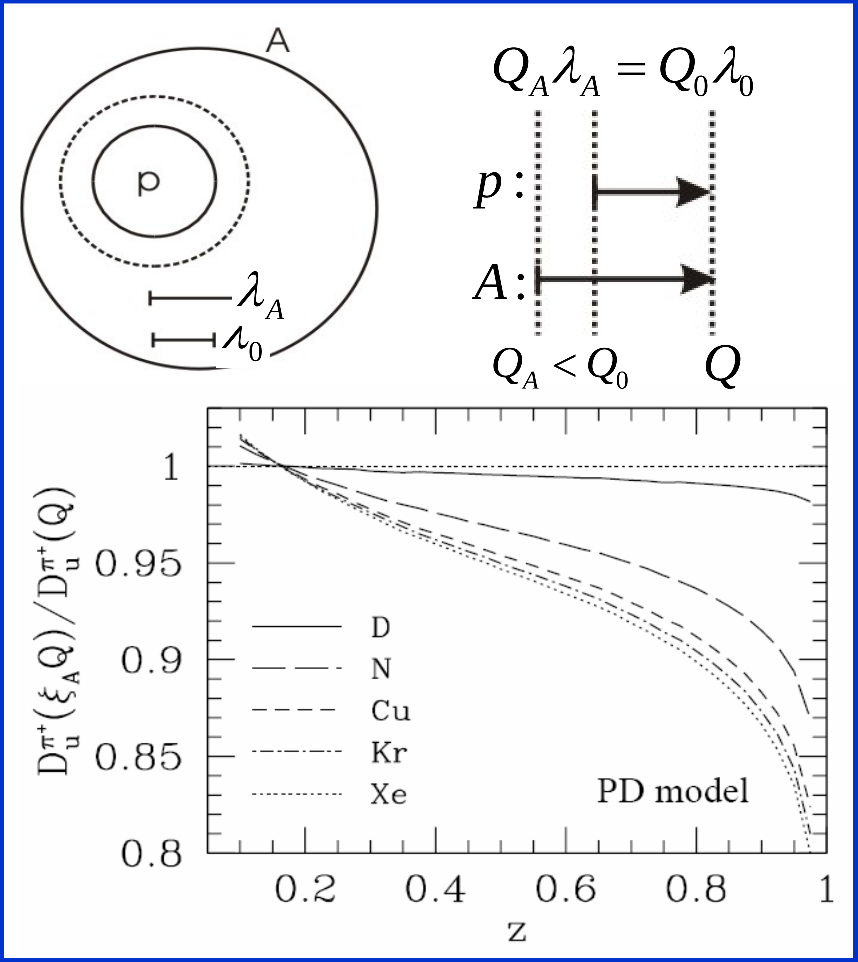
$$\sigma^{lp} = \int_{\text{exp. cuts}} dx\,d\nu \sum_f e_f^2 q_f(x,\xi_A(Q^2)Q^2)\frac{d\sigma^{lq}}{dx\,d\nu}$$

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.)

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

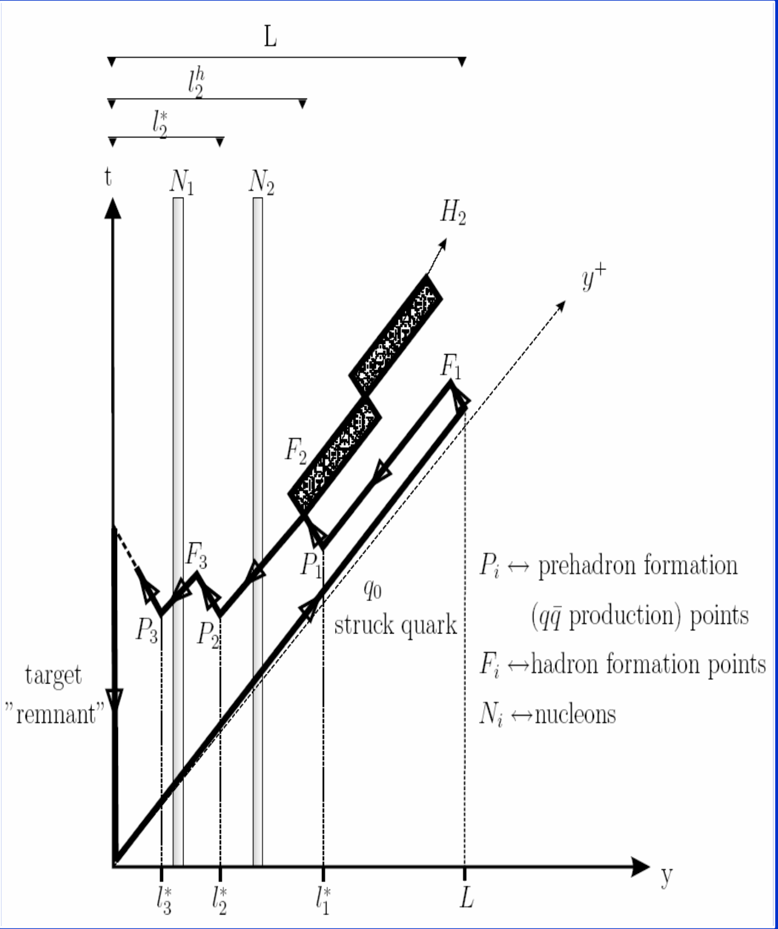
$$D_f^{h|A}(z, Q^2) = D_f^h(z, \xi_A(Q^2)Q^2)$$

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

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

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

String Fragmentation



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

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

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

-> dominantly quark production

-> diquark production is suppressed

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

Turning point of struck quark: $L_h = \frac{\nu\,\tau_h^2}{\kappa\,\tau_\pi^2}$

Prehadron Formation Lengths

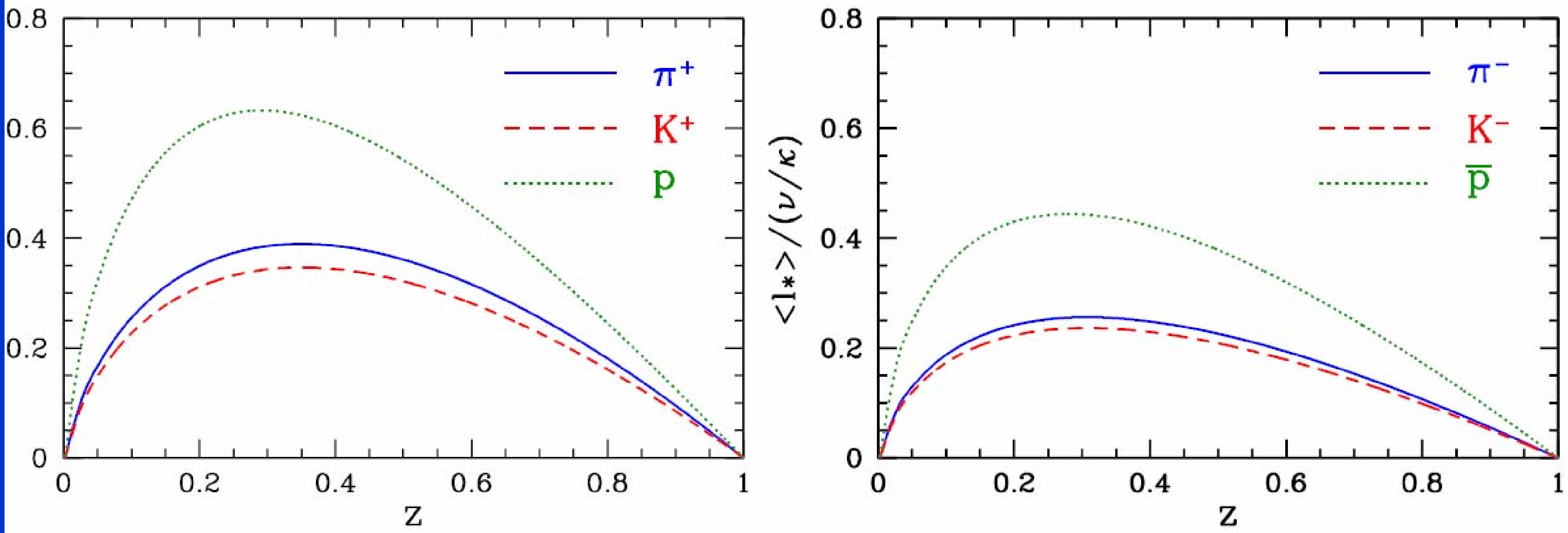


Fig. 3. Computed prehadron formation lengths when an up quark is struck by the virtual photon. *Left:* When a π^+, K^+ or p is observed, the corresponding prehadron can be created at rank $n \geq 1$. *Right:* When a π^-, K^- or $\bar{p}$ is observed, the corresponding prehadron can be created only at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

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

Absorption model

- Inelastic scattering of (pre)hadrons on nucleons removes them from the considered (z,nu) bin, absorption rate is determined by the prehadron mean free path-Fitted prehadron-nucleon absorption cross section is about 1/3 of hadron nucleon cross section

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

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

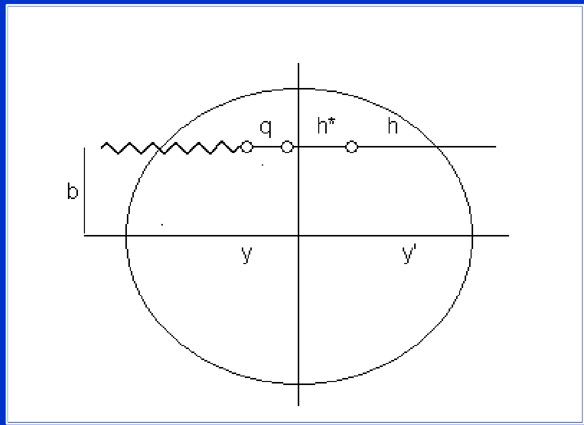
$$\frac{\partial P_h(y,y')}{\partial y'} = \frac{P_*(y,y')}{\langle \Delta l \rangle} - \frac{P_h(y,y')}{\lambda_h(y')} \qquad , P_h(y, y' = y) = 0$$

- Absorption factor:

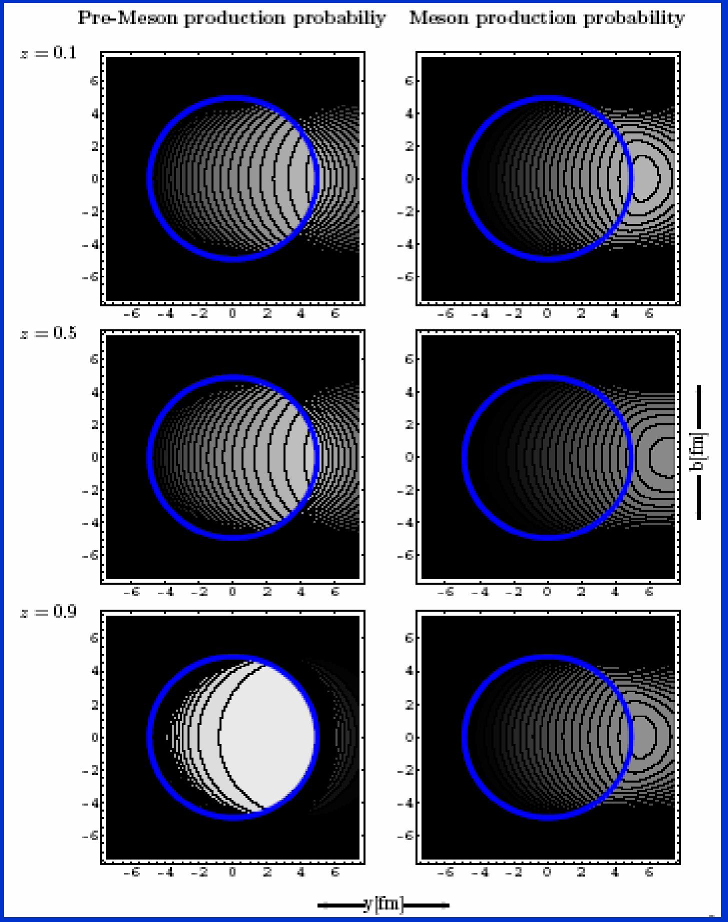
$$N_A = \lim_{y' \to \infty} \int d^2b \int_{-\infty}^{\infty} dy \rho_A(b,y) P_h(y', y)$$

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

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

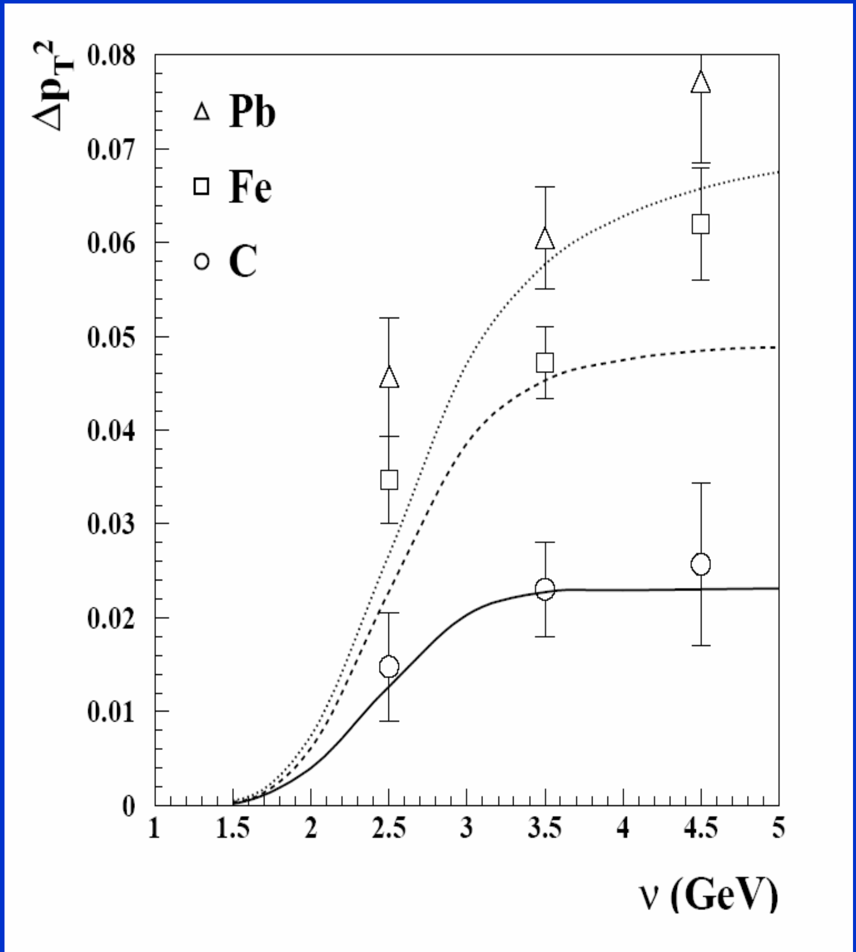


Prehadron und Hadron-Production probabilities at HERMES energies for Kr target without absorption



Additional indication for prehadron formation from JLAB-data (W. Brooks)

GeV^2

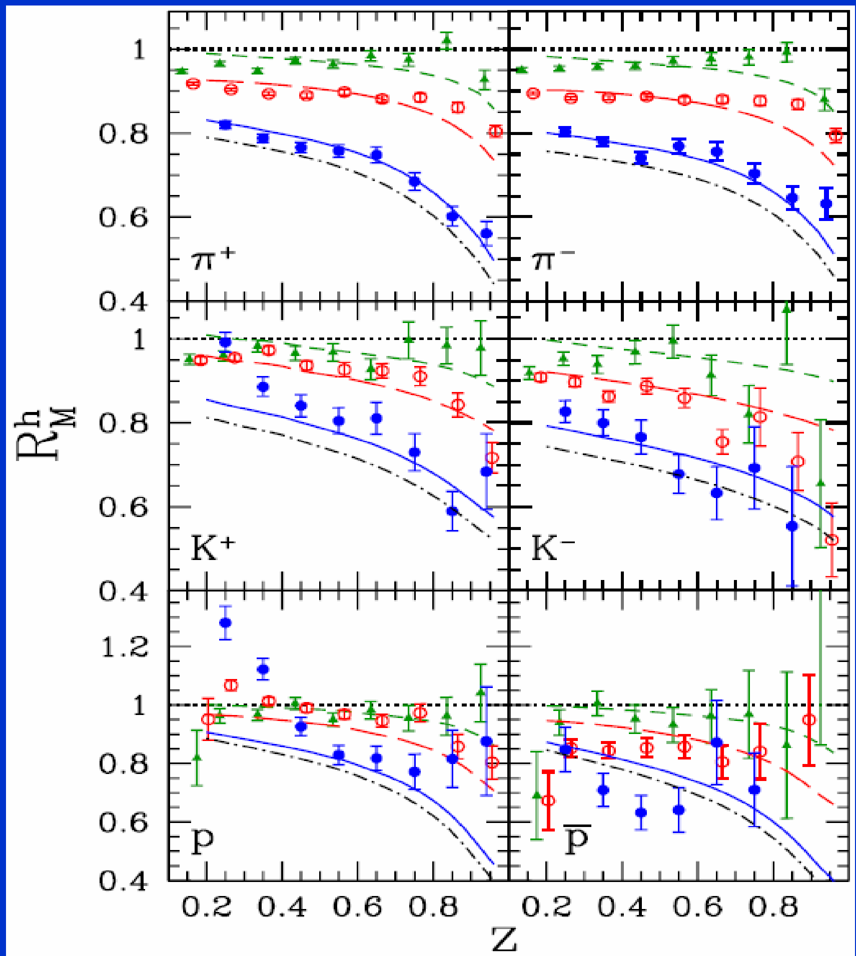


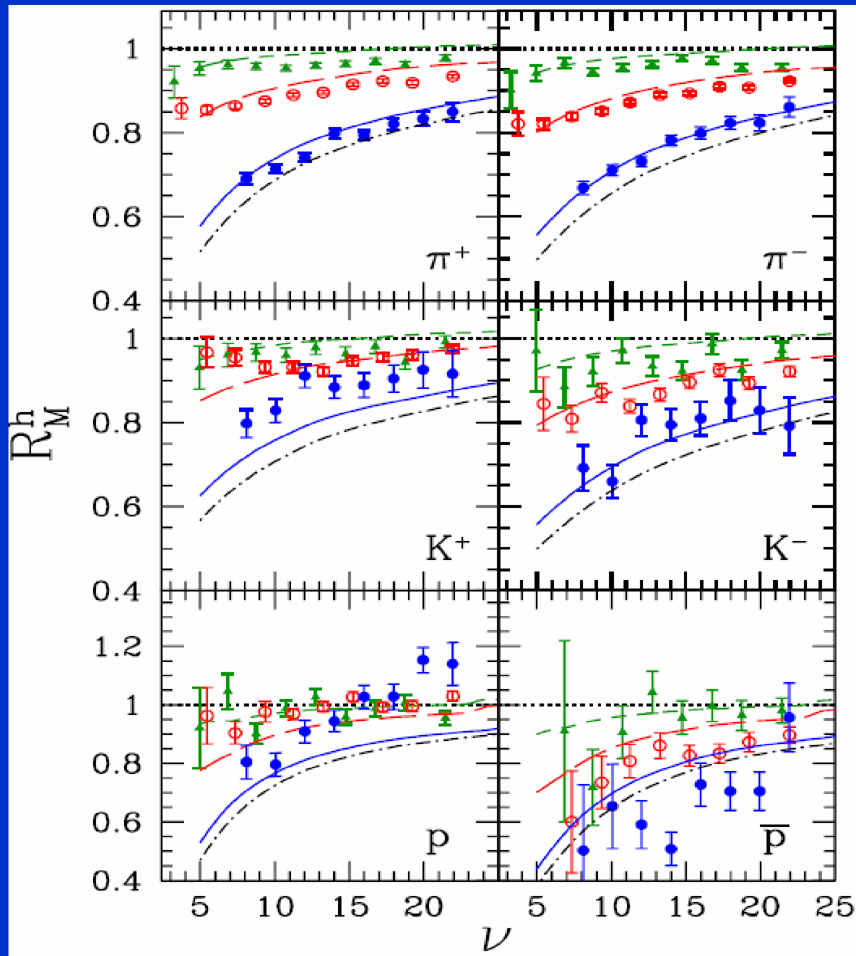
- Variation of mean produced hadron pt^2 shows that only the pt acquired by the propagating quark does contribute (Kopeliovich and Nemcik, work in preparation)
- In large Pb-nucleus, when the nu dependent formation of the prehadron occurs outside of the nucleus, no more pt can be acquired. The process terminates.
- In smaller Fe and C nuclei the size of the nucleus terminates the process earlier

<-Energy transfer to the quark

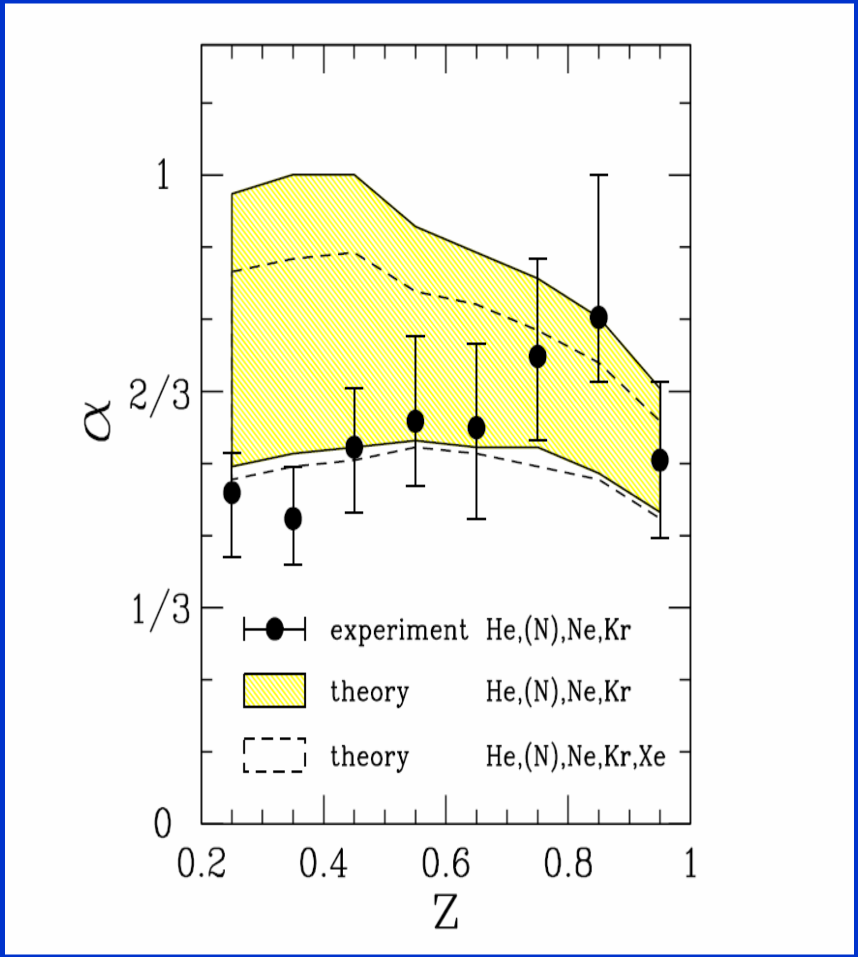
Comparison with HERMES data

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





A-dependence of model



- The absorption model gives an A-dependence A^(2/3) in agreement with the data
- The figure represents a fit of the exponent at each z to the theoretical calculation for different sets of nuclei
- The A dependence cannot be used to differentiate between energy loss picture and absorption

II. Space time Structure of hadron production

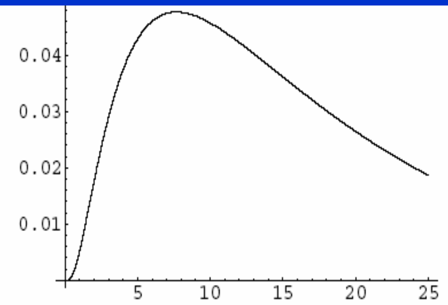
- In pp or AA collisions, the produced parton has time like virtuality t_0 >0 and loses energy even in vacuum (vacuum energy loss). (Thesis :C. Zapp)
- No difference in decay time between charm quarks and light quarks because t_0>>mc
- Each new virtualty t´=kt^2/z has to be lower than the original virtuality
- Most descriptions treat first the energy loss of an on shell quark in the medium and then hadronization
- (Induced) radiation and fragmentation, however, can not be separated

$$z_c D'_{h/c}(z_c, Q_c^2) = z'_c D_{h/c}(z'_c, Q_{c'}^2) + N_g z_g D_{h/g}(z_g, Q_g^2) \ ;$$

$$z'_c = \frac{p_h}{p_c - \Delta E_c(p_c, \phi)} \ , \quad z_g = \frac{p_h}{\Delta E_c(p_c, \phi)/N_g} \ ,$$

Modification of fragmentation function separated from energy loss is not justified

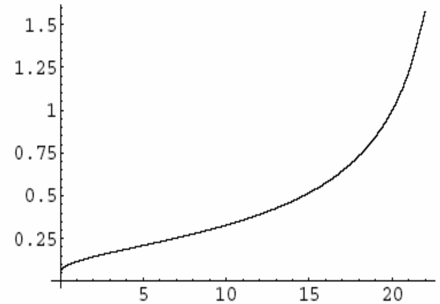
Space time development (Initial virtuality t0=100 Gev^2-→t1)



Out [45]= - Graphics -

- **Probability Distribution of radiated virtualities t1 when original virtuality is t0=100 GeV^2**

In [46] := Plot[{.2*T[t]}, {t, 0.1, 22}]



Out [46]= - Graphics -

- **Mean Time in fm for radiation as a function of radiated virtuality t1 [GeV^2]**

Take RHIC case:
Mean final virtuality [GeV^2] of radiated gluons is t1=10 GeV^2

Mean time for radiation
<t>=0.7 fm/c

This changes the picture of high p_T Suppression

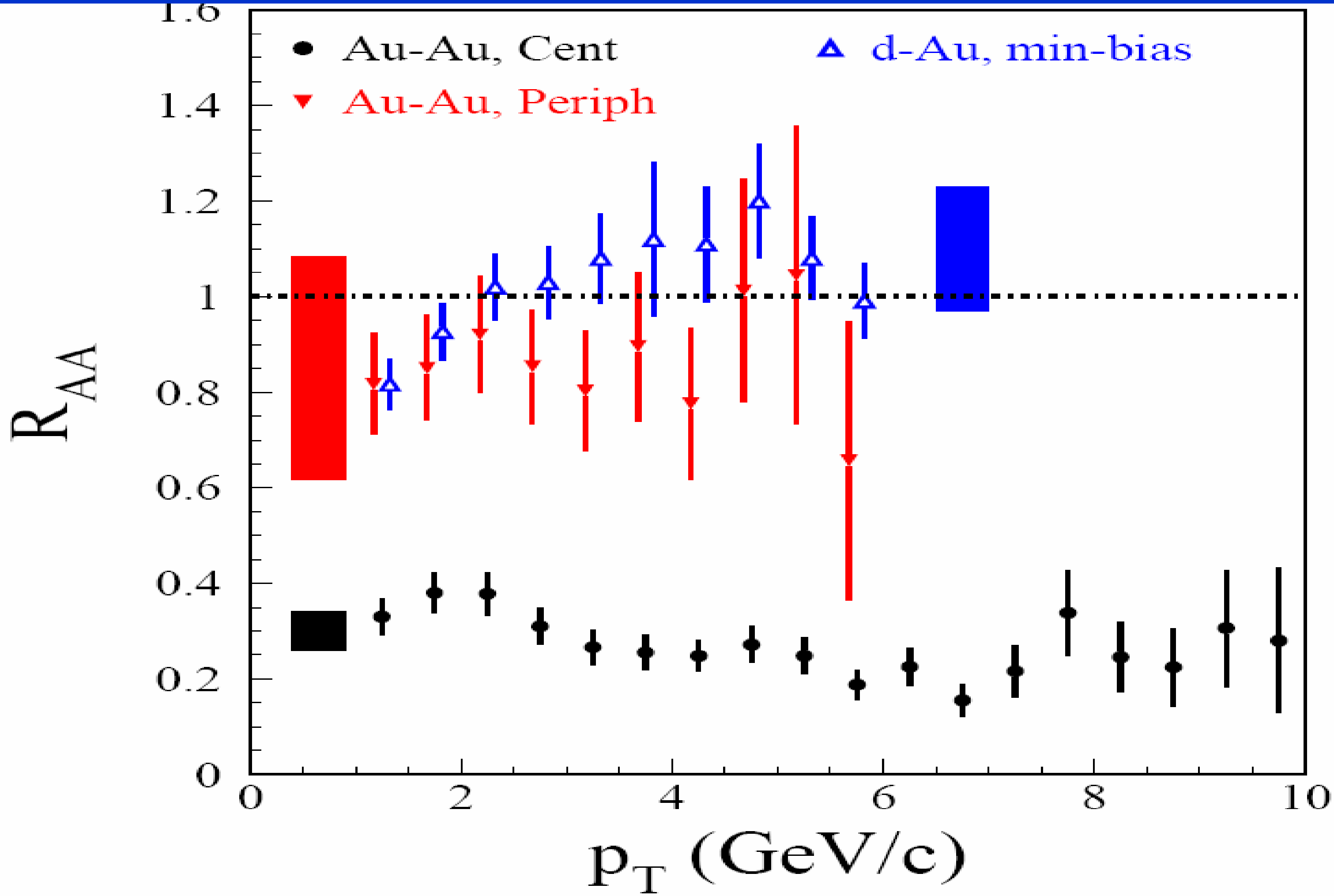


Fig. 36. π^0 $R_{AA}(p_T)$ for central (0–10 %) and peripheral (80–92 %) Au+Au collisions

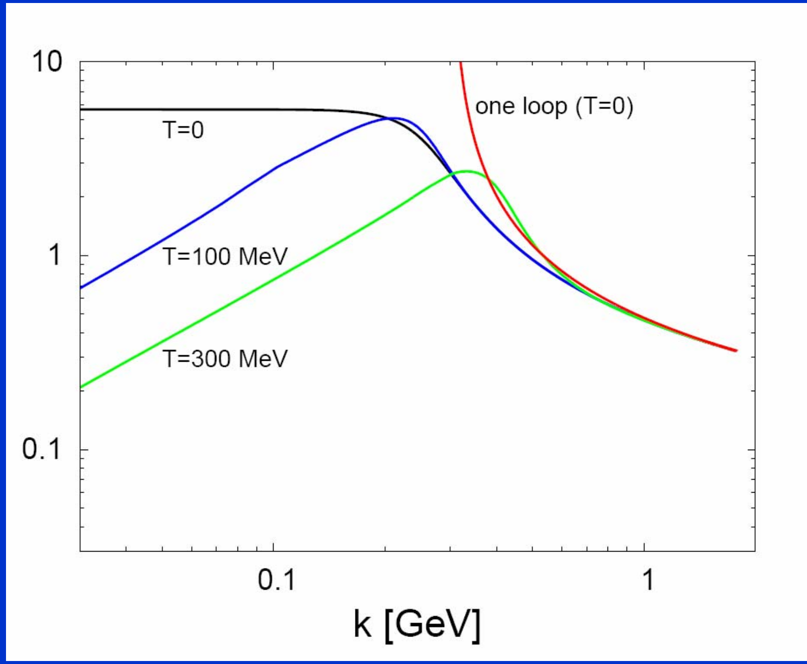
High p_t Suppression

- Quantum coherence (like in angle ordered MLLA of gluon radiation in the vacuum) may be destroyed in propagation through QGP
- Medium enhances emission of gluon radiation, effective QCD coupling in hot quark gluon plasma is larger than fixed alpha=0.5
- If gluon radiation is hard, then the gluon can neutralize the original radiating source
- Consequently prehadron formation may be also important at RHIC

Medium induced scattering

- Mean free path is shorter due to larger coupling alpha(k,T)
- Debye Mass can be determined selfconsistently from strong coupling alpha(k,T)
- Running alpha(k,T) at finite temperature is calculated from RG equation (J.Braun,H. Gies,**hep-ph/0512085** and J. Braun and H.J. Pirner work in progress)

$$d\sigma_i/dq_{\perp i}^2 \approx C_i \frac{4\pi\alpha^2}{(q_{\perp i}^2+\mu^2)^2}$$



III. Binary Scaling and Hard Scattering

- Fixed Angle, e.g. y=0 90° in cm-system
- Compare various energies, same xt
- Expect n=4 from lowest order pQCD

$$x_T = 2p_T/\sqrt{s}.$$

$$E\frac{d^3\sigma}{d^3p} = \frac{1}{p_T^n}F(x_T) = \frac{1}{\sqrt{s}^n}G(x_T)\ ,$$

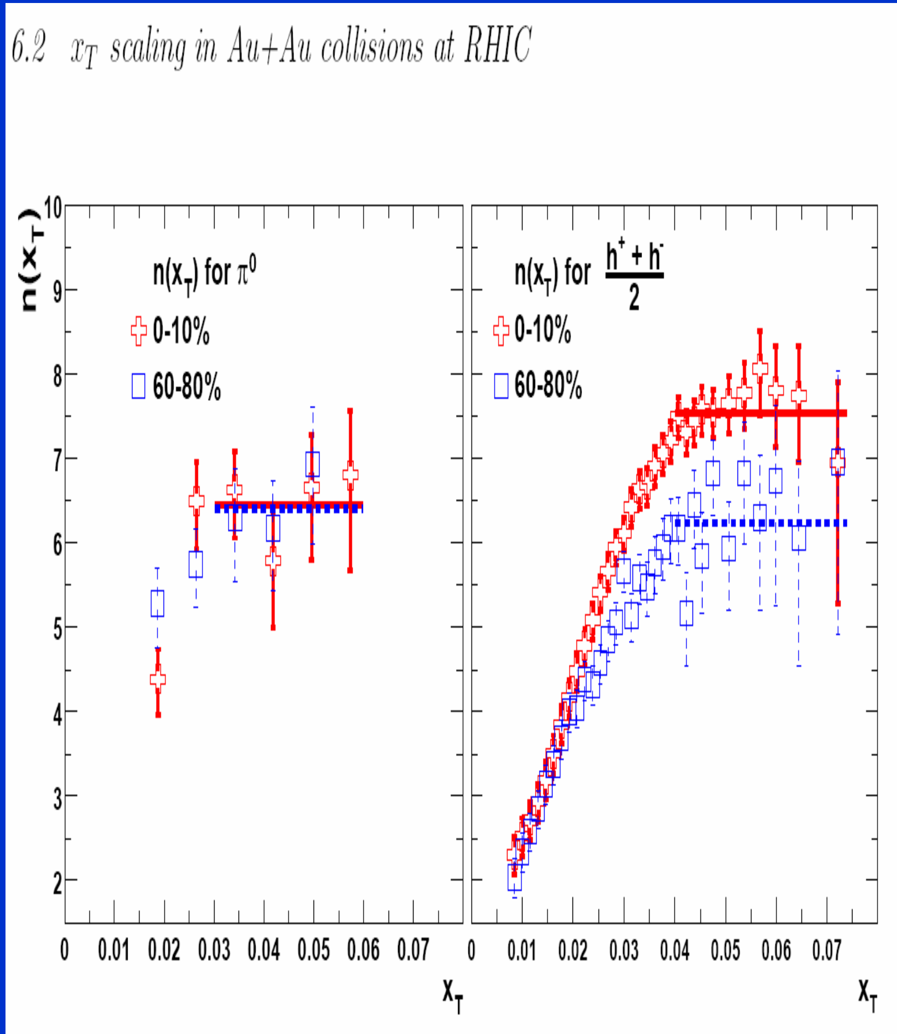
Pure dimensional counting of the number of active participants determines the exponent

$$E\frac{d^3\sigma(h_a h_b \to hX)}{d^3p} = \frac{F(y, x_R)}{p_T^{n(y,x_R)}}.$$

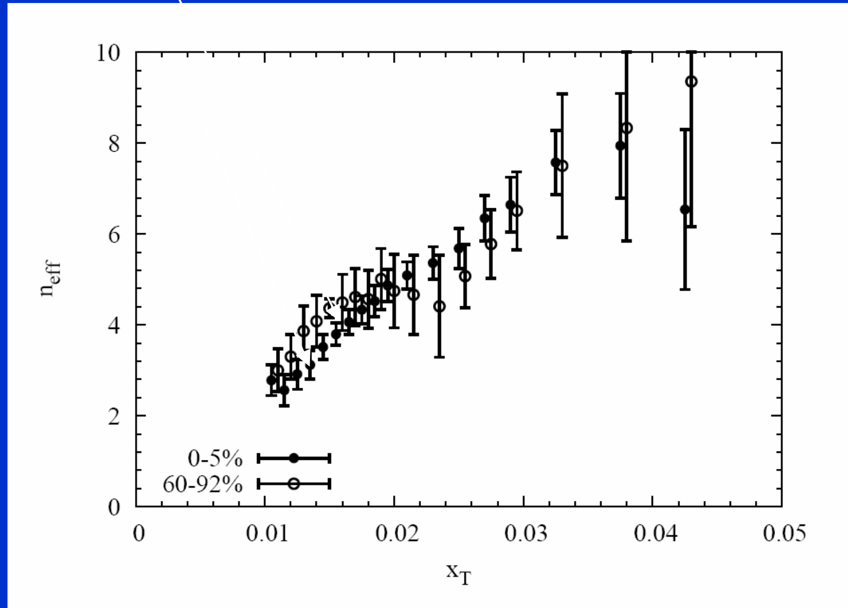
- n(y,x_R)=2*n(active with hard pt)-4 ; (x_R=xt at y=0)
- 4 active participants give n(y,x_R)=4
- RHIC measures n=6.3 or n=7.8,depending on particle species
- The smaller number n=6 is compatible with hard gluon radiation NLO calculations
- The larger number n=8 points to more complicated processes e.g. for proton production (q+q->qqq+qbar)

Data show nonscaling behaviour for protons

Phenix analysis



Protons

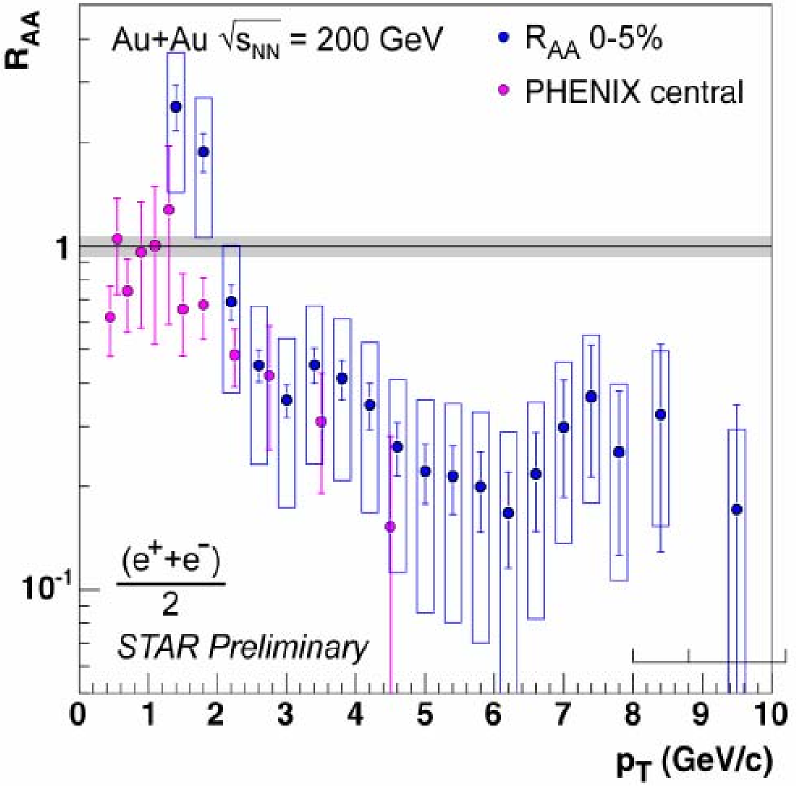


Final state interaction
may change the scaling behaviour
¢ n would decrease with x_t
if energy loss
like in BDMPS occurs

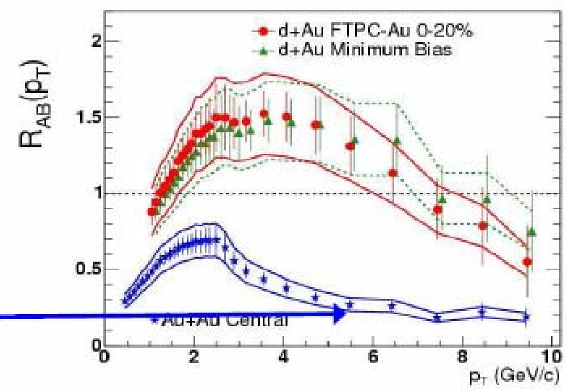
Conclusions

- Meson production at low <Q^2 >=2.5 GeV^2 in Hermes is well described by the string model with prehadron formation and absorption
- Data with high <pt^2>=100GeV^2 at RHIC or LHC need a correct treatment of vacuum energy loss
- The gluon radiation time of the time like parton is of the same size as its mean free path
- The initial gluon cascade for fragmentation is entwined with induced medium scattering
- Violation of xt-scaling relations behave differently then expected from BDMPS-energy loss picture

Heavy Flavor R_{AA}



Charged Hadron R_{AA}



- R_{AA} to 10 GeV/c in non-photonic electrons
- Suppression is approximately the same as for hadrons
- B contribution? Challenge for radiative picture?

See talk,Bielcik(5c)

Calculation of Prehadron Formation Lengths

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

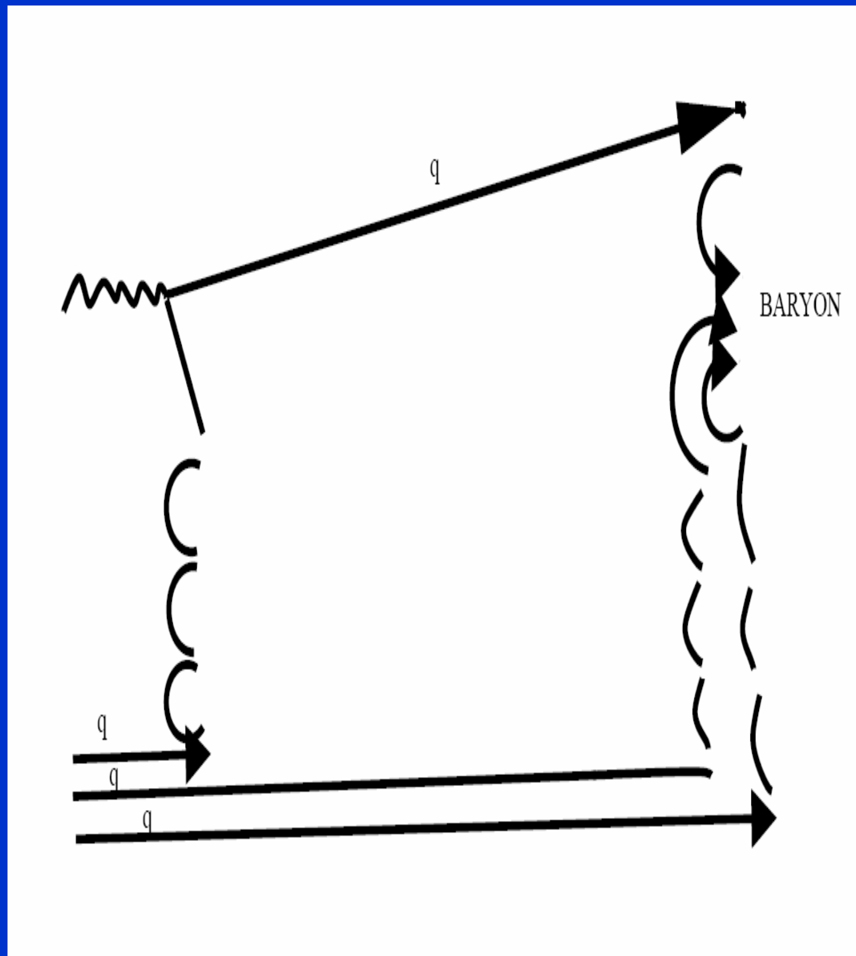
F- Hypergeometric Function, C=0.3, D arise from the string fragmentation f(u)=(1-u)^D
Dq=0.3 for producing a quark and Dqq=1.3 for producing a diquark

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

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)



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