Hadron Attenuation and Results from HERMES

Dave Gaskell
Jefferson Lab
(for the HERMES Collaboration)

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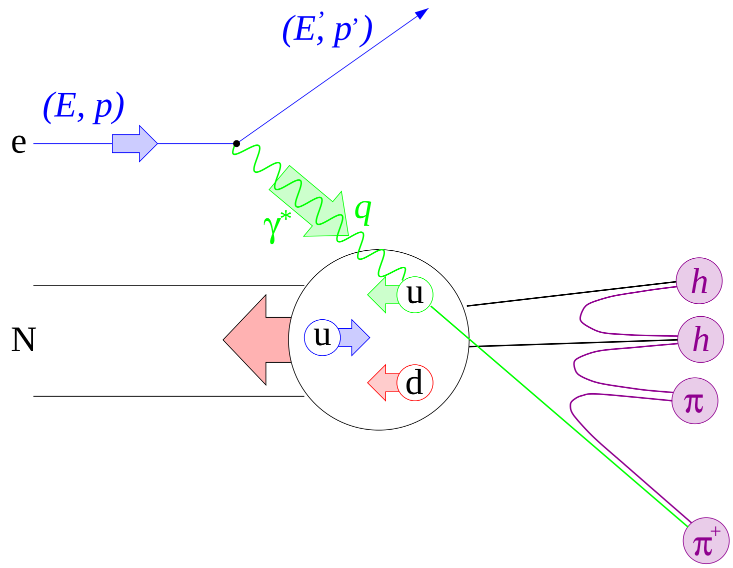
- Nuclear Attenuation in Semi–inclusive Hadron Production
- Models of Hadron Attenuation
- ν and z Dependence
- Results for ^{14}N and ^{84}Kr
- P_t dependence
- Summary

Semi–inclusive Hadron Production



- Semi–inclusive cross section:

$$\sigma \sim \sum_f e_f^2 q_f(x) D_f^h(z)$$

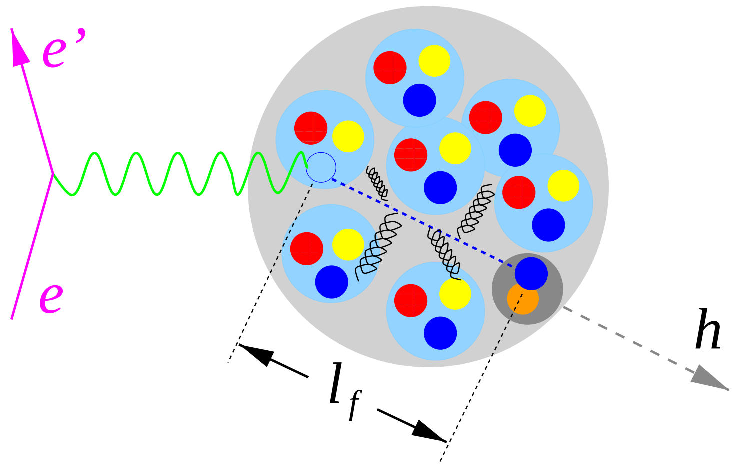
- $q_f(x)$ = parton distribution function

- $D_f^h(z)$ = fragmentation function

- $x = Q^2/2m\nu$ – momentum fraction of struck quark

- $z = E_h/\nu$ – fraction of virtual photon energy transfered to hadron

Hadron Production in Nuclei



- Hadron production from nuclei can be influenced by,
  - → Pre–hadronized quark interactions with extra nucleons in nucleus
  - → Produced hadron interactions with spectator nucleons

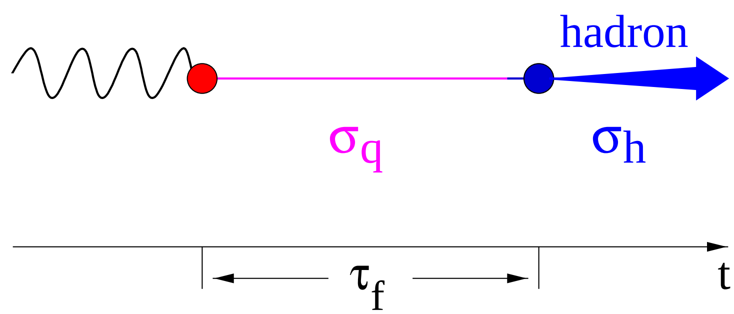
- $\tau_f = l_f/c$, hadron formation time will affect which dominates

- Attenuation ratio

$$R_A(z,\nu) = \frac{\left(\frac{1}{\sigma}\frac{d\sigma}{dzd\nu}\right)_A}{\left(\frac{1}{\sigma}\frac{d\sigma}{dzd\nu}\right)_D} = \frac{\left(\frac{1}{N_e}\frac{dN_h}{dzd\nu}\right)_A}{\left(\frac{1}{N_e}\frac{dN_h}{dzd\nu}\right)_D}$$

where $$\frac{1}{N_e}\frac{dN_h}{dzd\nu} \approx \frac{\sum_f e_f^2 q_f(x) D_f^h(z)}{\sum_f e_f^2 q_f(x)}$$

Models of Hadron Attenuation (I)
One Time–Scale Model



- One time–scale model - hadron produced "directly"

$$\tau_f \propto \frac{E_h}{m_h} \qquad\qquad \tau_f \propto \frac{E_q}{m_q}$$

- Hadron attenuation

$$R_A = 2\pi \int_0^\infty bdb \int_{-\infty}^\infty dl\ \rho_A(b,l)\ \ [P_A(b,l)]^{A-1}$$

- No–interaction probability

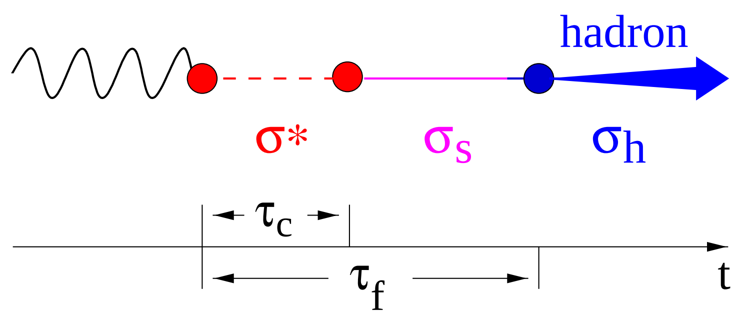
$$P_A = 1 - \sigma_q \int_l^\infty dl'\ \rho_A(b,l')\ P_q(l'-l) - \sigma_h \int_l^\infty dl'\ \rho_A(b,l')\ P_h(l'-l)$$

- ρ_A = nuclear density $\qquad \tau = l/c$

- $\sigma_q << \sigma_h \approx 20$ mb

  Bialas and Chmaj, Phys. Lett. B 133, 241 (1983)

Models of Hadron Attenuation (II)
Two Time–Scale Model



- Two time–scale (string) model – some hadronic constituents formed earlier than others and may interact with the nucleus

$$\tau_f - \tau_c = c\frac{E_h}{\kappa}$$

where κ is the string constant, $\kappa \approx 1$ GeV/fm

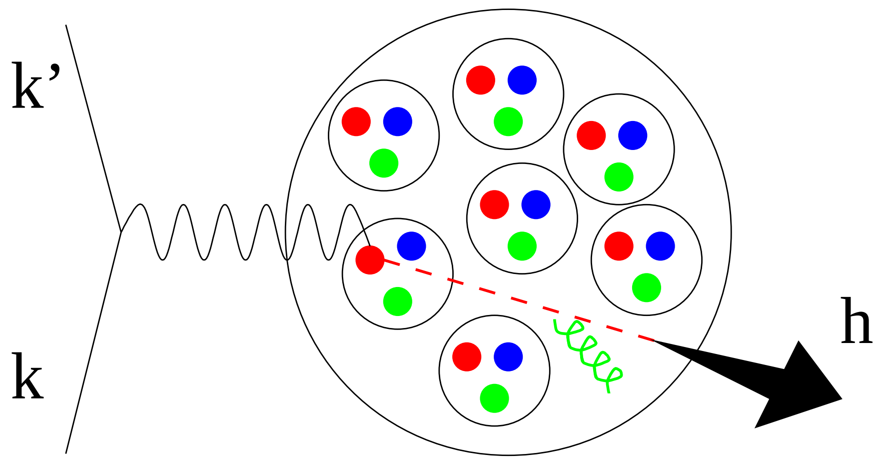
- Hadron attenuation

$$R_A = 2\pi \int_0^\infty bdb \int_{-\infty}^\infty dl\ \rho_A(b,l)\ \left[P_A(b,l)\right]^{A-1}$$

$$P_A = 1 - \sigma^* \int_l^{l_c} dl'\ \rho_A(b,l') - \sigma_s \int_{l_c}^{l_f} dl'\ \rho_A(b,l') - \sigma_h \int_{l_f}^\infty dl' \rho_A(b,l')$$

Bialas and Gyulassy, Nuc. Phys. B 291, 793 (1987)

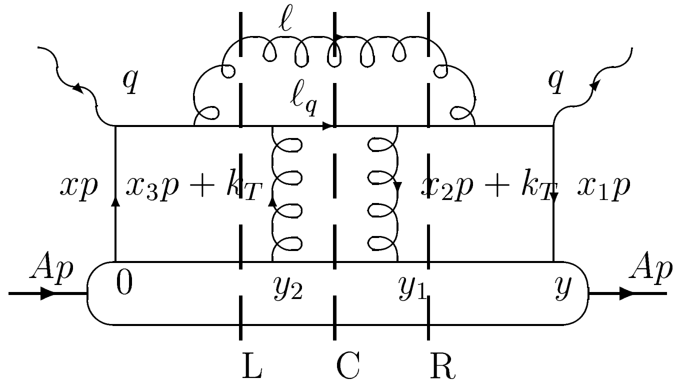
Models of Hadron Attenuation (III) Gluon Bremsstrahlung



- Hadrons form when struck parton combines with a q or $\overline{q}$ from emitted gluon
- At large z, the hadron retains the energy of the struck quark
- In nucleus, presence of extra nucleons increases probability of gluon radiation
- High z hadrons suppressed in nuclei

B. Kopeliovich *et al.*, hep-ph/9511214

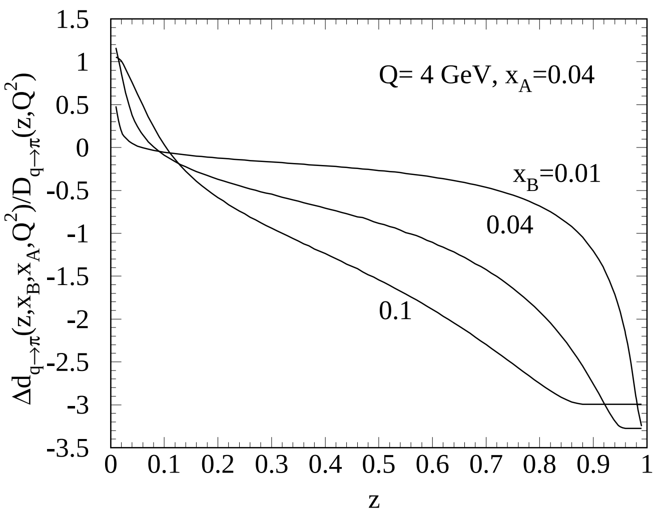
Models of Hadron Attenuation (IV)
Multiple Parton Scattering



- Fragmentation functions are modified via quark rescattering with partons in other nucleons (higher–twist effects)

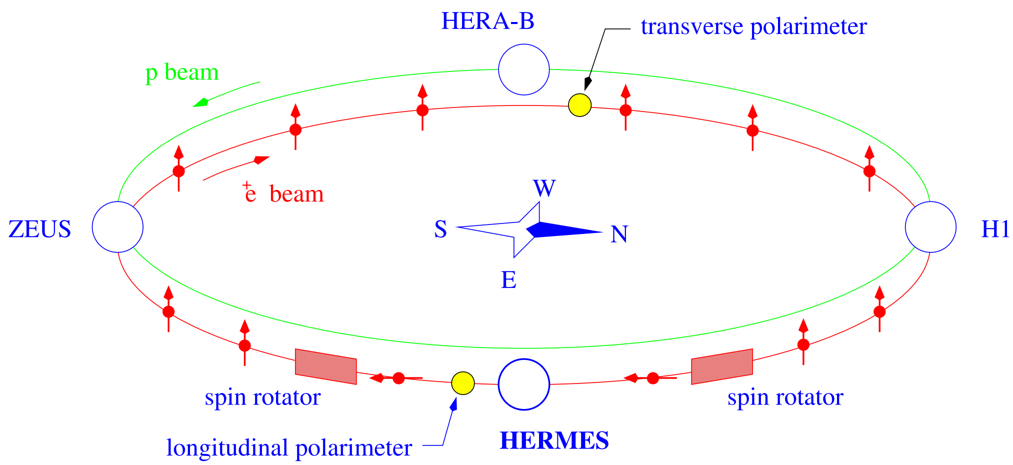
- Dominant contribution from term involving gluon radiation and rescattering with gluon from other parton

- Modification of fragmentation functions $\propto A^{2/3}$



Guo and Wang, Phys. Rev. Lett. 85, 3591 (2000)

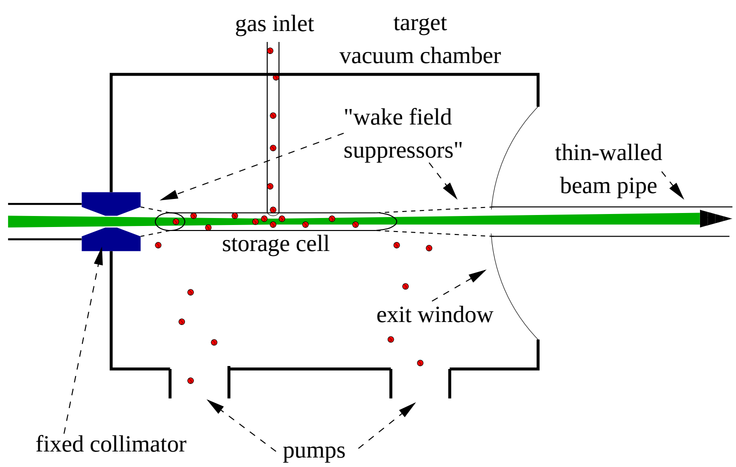
The HERMES Experiment



The HERMES experiment at HERA/DESY

Current $\approx$ 30 mA

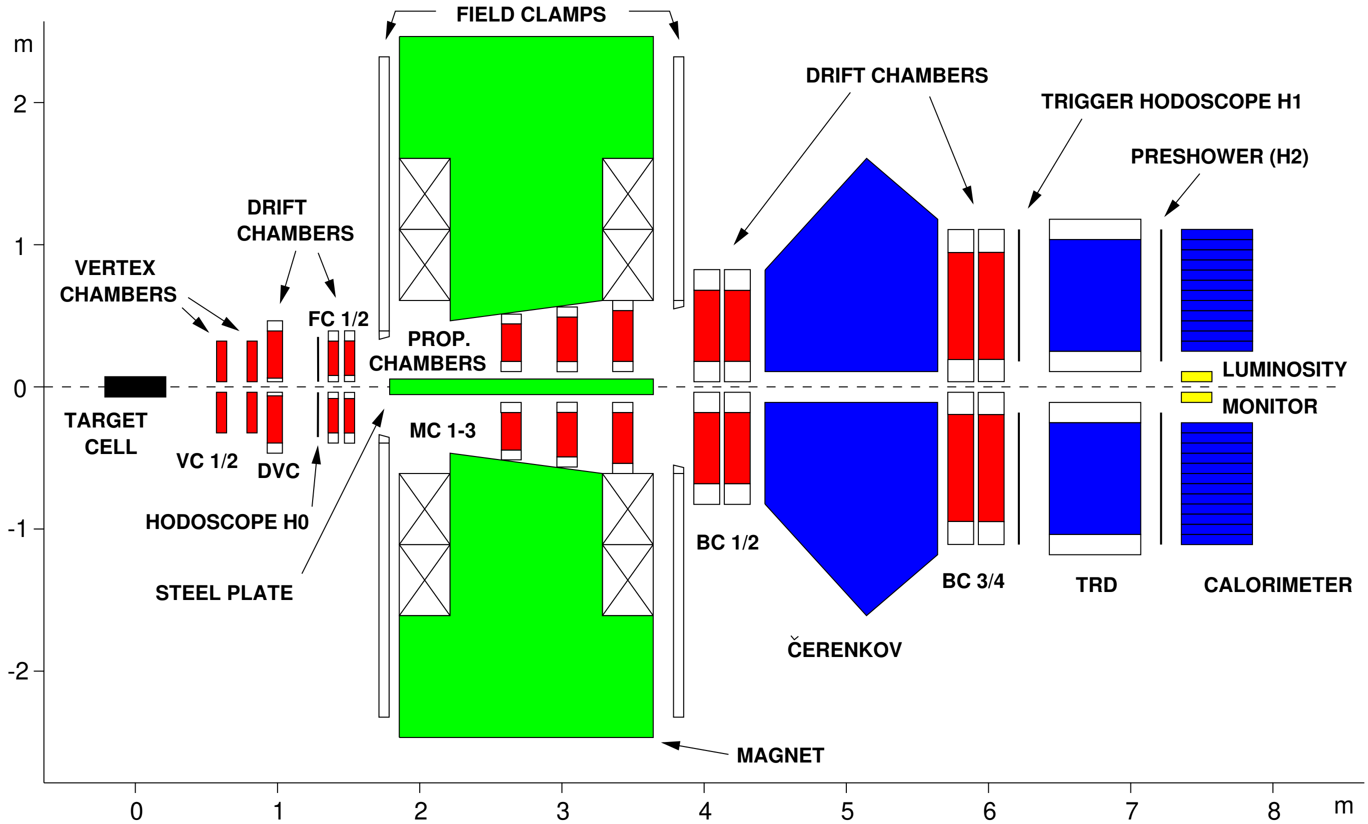
$\langle$Beam Polarization$\rangle \approx 50\%$



The HERMES target (H_2, D_2, ^3He, N_2, Kr)

$\langle$Target Thickness $\rangle \approx 10^{13} - 10^{15}\mathrm{atoms/cm}^2$

The HERMES Spectrometer



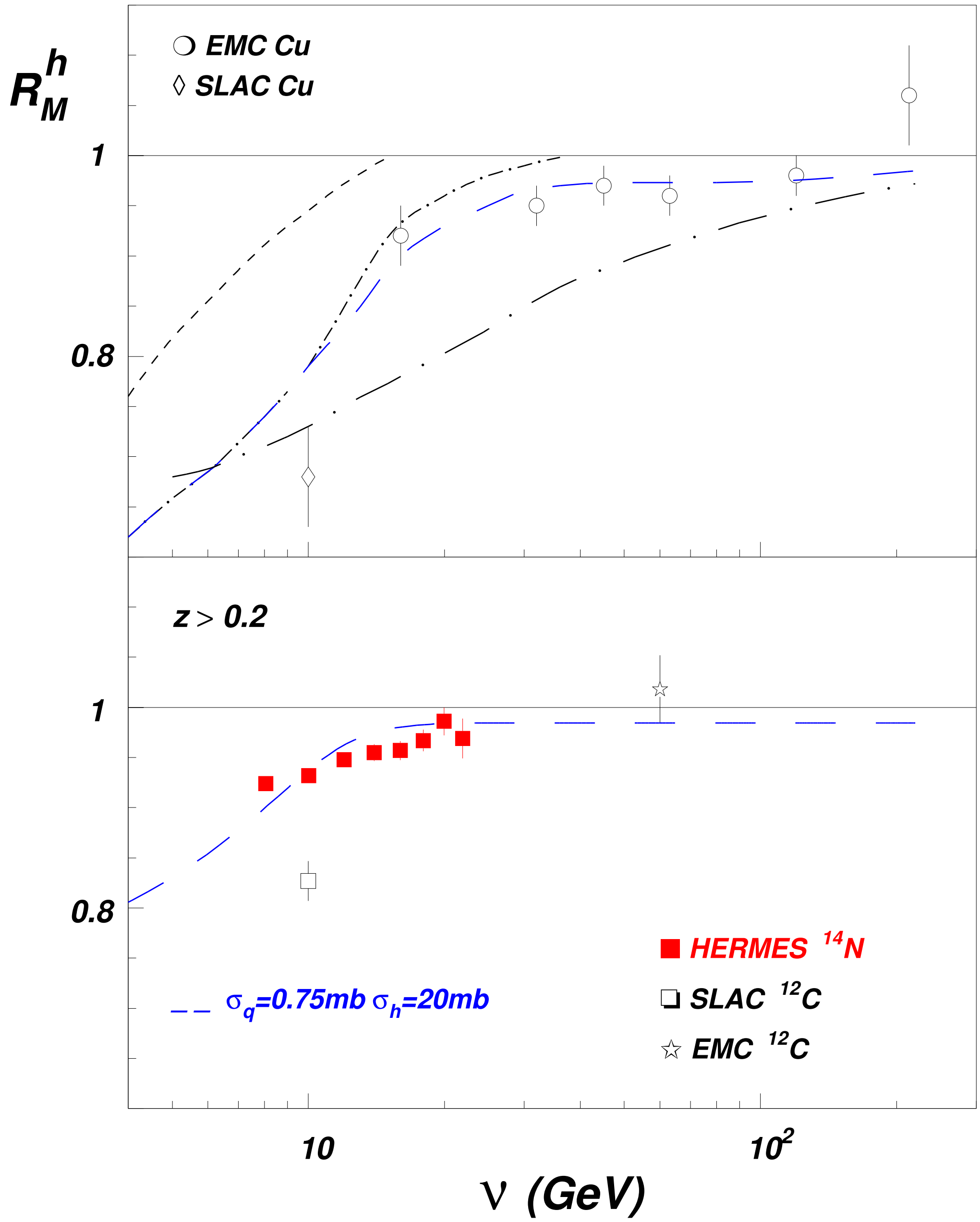
- Large solid angle: $|\theta_x| < 170\ \mathrm{mrad}$
  $40 < \theta_y < 140\ \mathrm{mrad}$

- Momentum resolution $\sim$ 1% from 1 to 27 GeV
- Hadron/lepton contamination $<$ 1% (with high efficiency)

- Pre–1998: π identification from 4 to 13.5 GeV with threshold Cerenkov

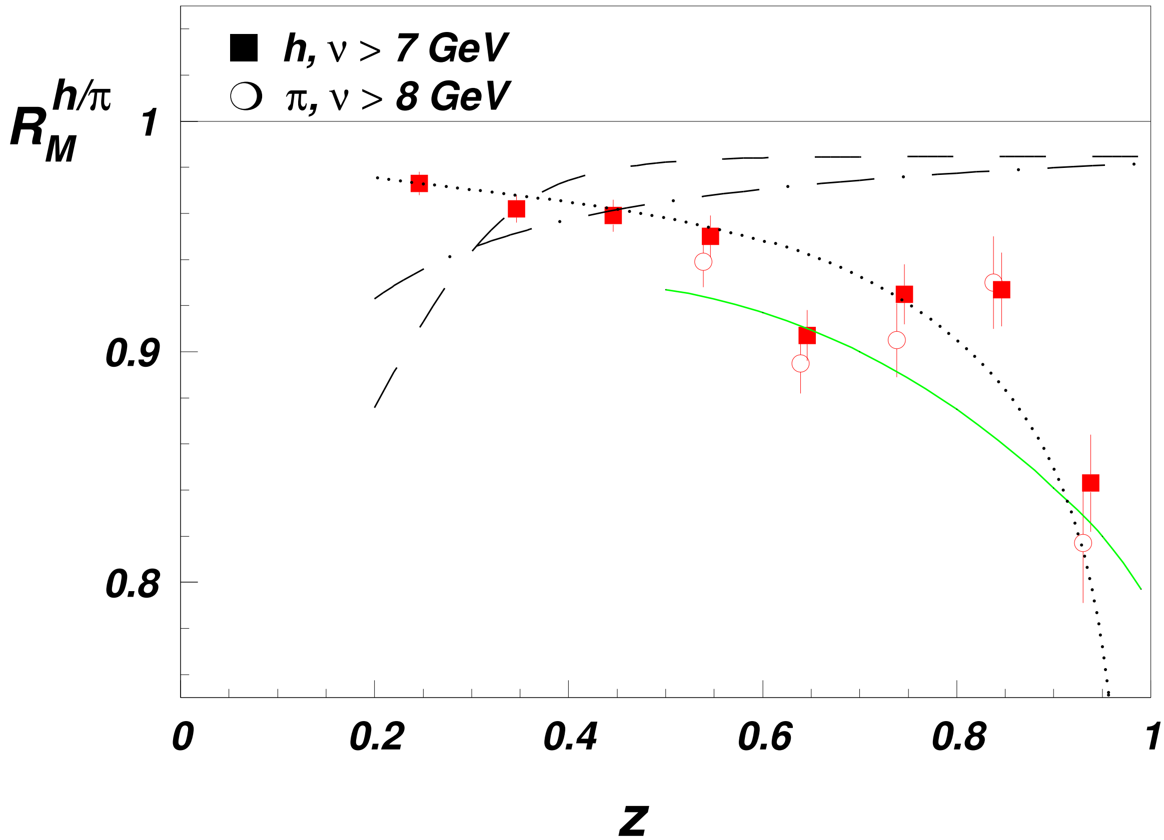
- After 1998: hadron identification with RICH (allows $\pi/K/p$ separation)

Hadron Attenuation vs. ν



- Blue curve is one time–scale model
- At large ν, $R \to 1$ – hadron formation outside nucleus

Hadron Attenuation vs. z

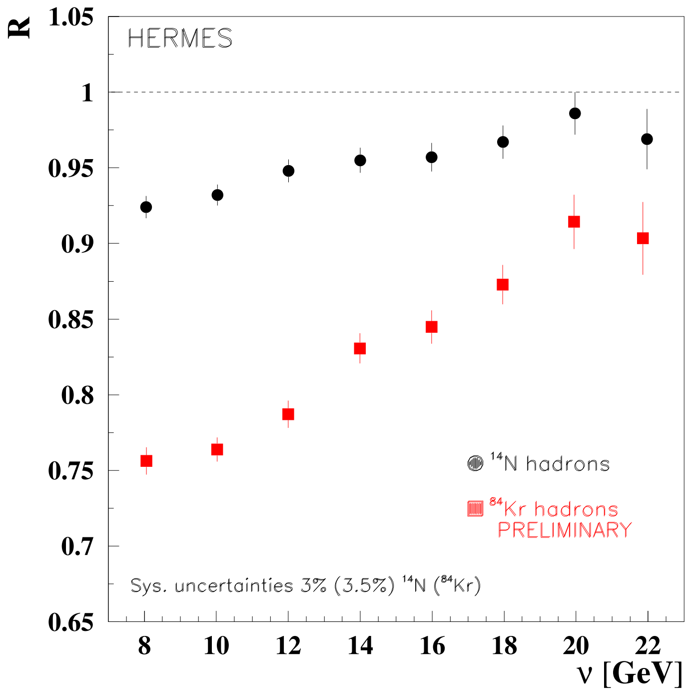


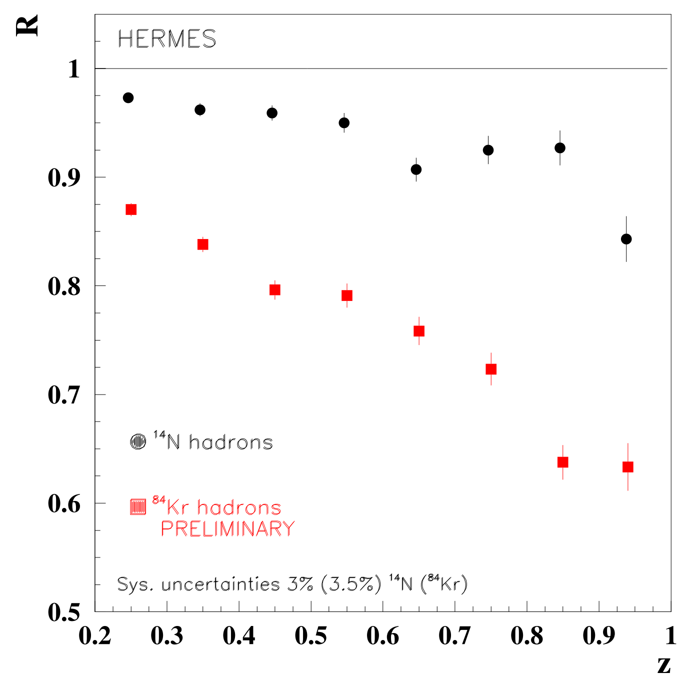
- Two time–scale models

— · — · —	$\tau_f \propto E_h$
— — ——	$\tau_f \propto (1 - ln(z)) \cdot E_h$
· · · · · · · ··	$\tau_f \propto (1 - z) \cdot \nu$

- Gluon–bremsstrahlung model shows good agreement

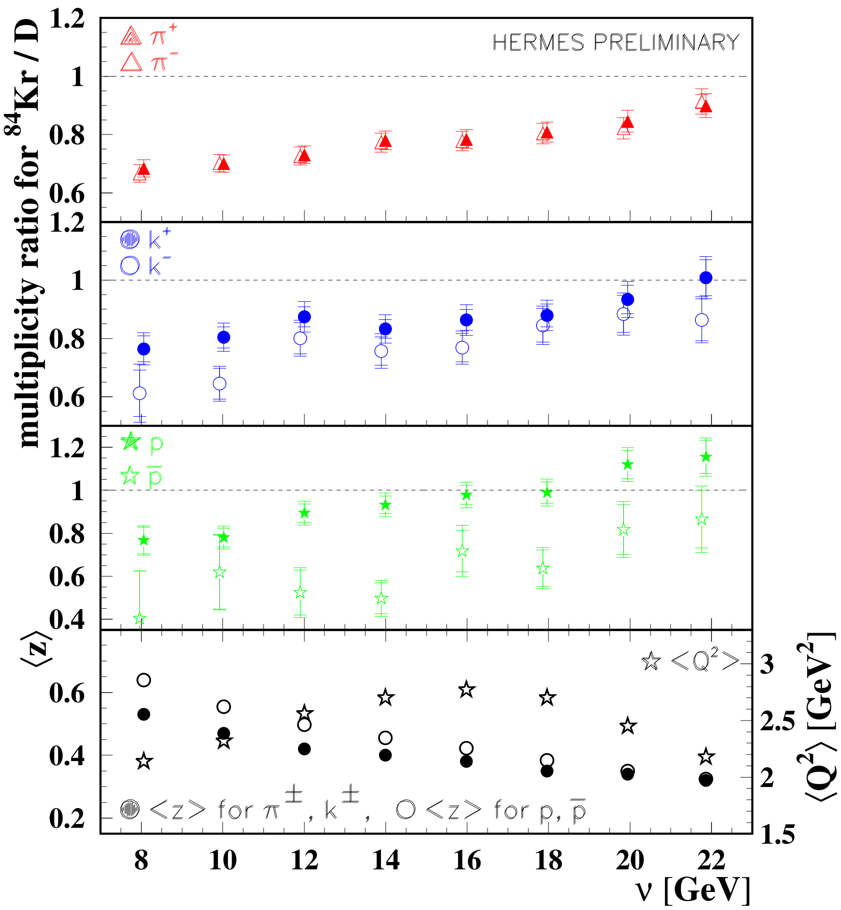
Mass Dependence





- Suppression also seen in ^{84}Kr
- Attenuation is $\approx$ 3 times larger
- Guo and Wang predict the fragmentation function modification $\propto A^{2/3} \rightarrow$ (Kr/N)$^{2/3}$ = 3.3

Hadron Type Dependence
(ν Dependence)



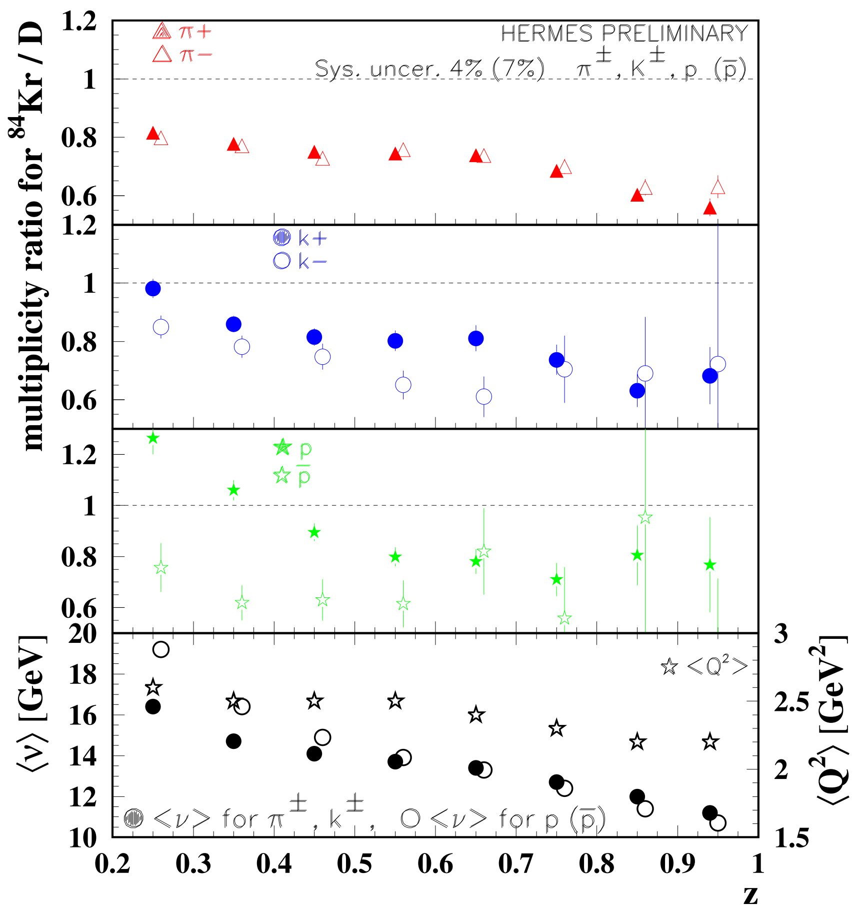
- RICH allows separation of hadron species (^{84}Kr only)
- Protons are less attenuated than pions and kaons $\rightarrow$ longer formation time?

$\sigma_{\pi^\pm} \approx 25$ mb

$\sigma_{K^+} \approx 17$ mb $\quad \sigma_{K^-} \approx 23$ mb

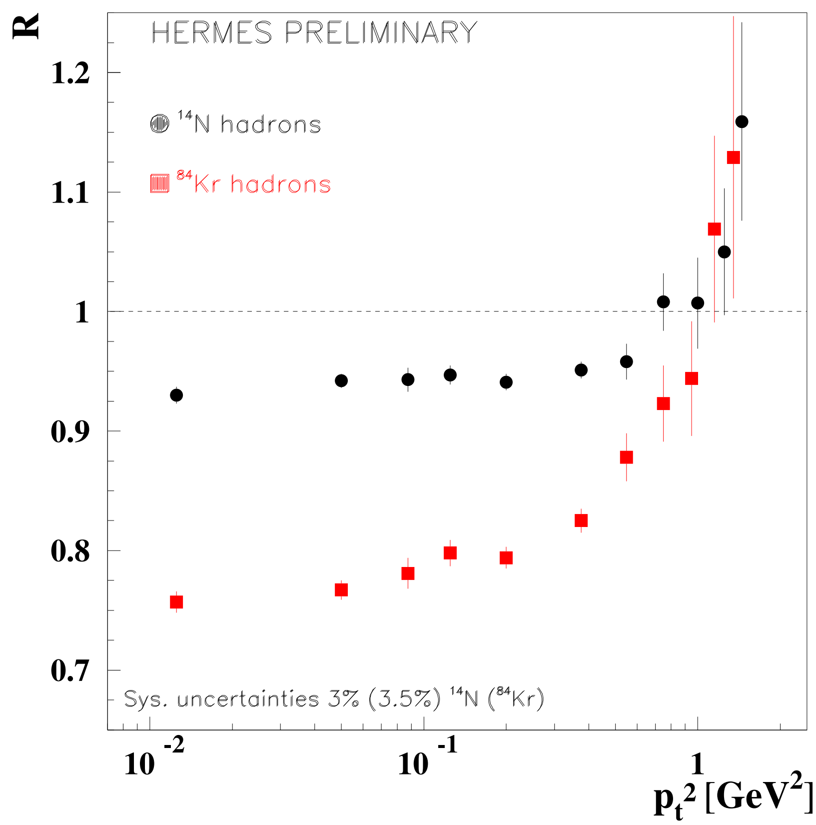
$\sigma_{p} \approx 40$ mb $\quad \sigma_{\bar{p}} \approx 60$ mb

Hadron Type Dependence
(z Dependence)



- At large momentum $\sigma_{\bar{p}} \approx 1.5\ \sigma_p$
- Momentum range = 4–15 GeV
- At lower momenta anti–proton annihilation becomes more significant $\rightarrow$ may explain difference between proton and anti–proton attenuation

P_t Dependence



- pA experiments see enhancement of high p_t particle production
- Parton multiple scattering calculations describe this enhancement

  (E. Wang and X.N. Wang, nucl-th/0104031)
- Qualitatively, HERMES hadron attenuation data is similar
- Further studies of $\langle p_t^2 \rangle$ necessary to investigate parton multiple scattering

Summary

- Several models describing attenuation of semi–inclusive hadron production in nuclei

- Models that rely only on hadron rescattering (one and two time–scale models) seem inadequate

- Gluon bremsstrahlung and parton multiple scattering models do a good job describing the z dependence of the hadron attenuation ratio

- Recent calculations that incorporate *both* gluon bremsstrahlung and hadron absorption give quantitative agreement with HERMES data (A. Accardi, V. Muccifora, and H.J. Pirner nucl-th/0211011)

- P_t dependence consistent with parton multiple scattering predictions – further studies will hopefully shed more light