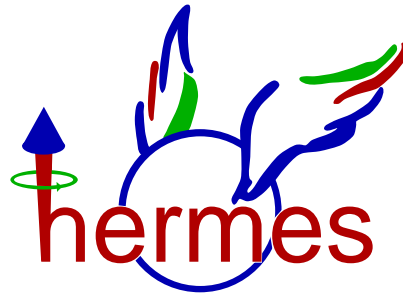


Hadron Attenuation and Results from HERMES

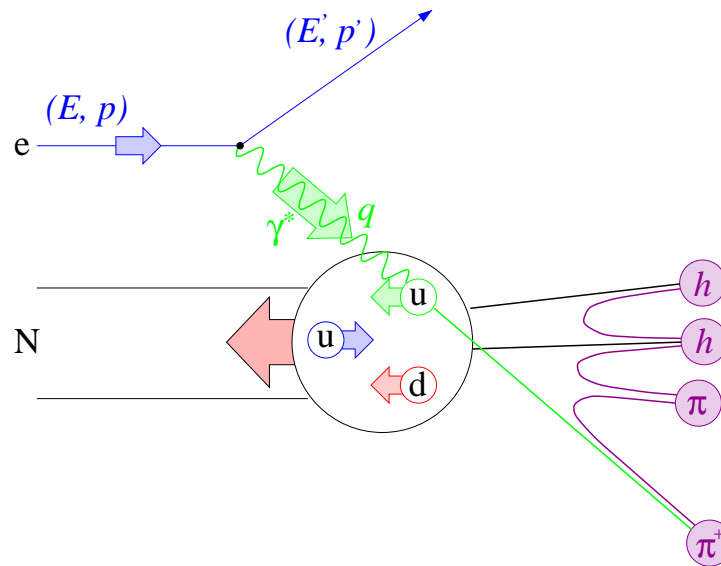
Dave Gaskell
Jefferson Lab
(for the HERMES Collaboration)

NUINT'02
December 14, 2002



- 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

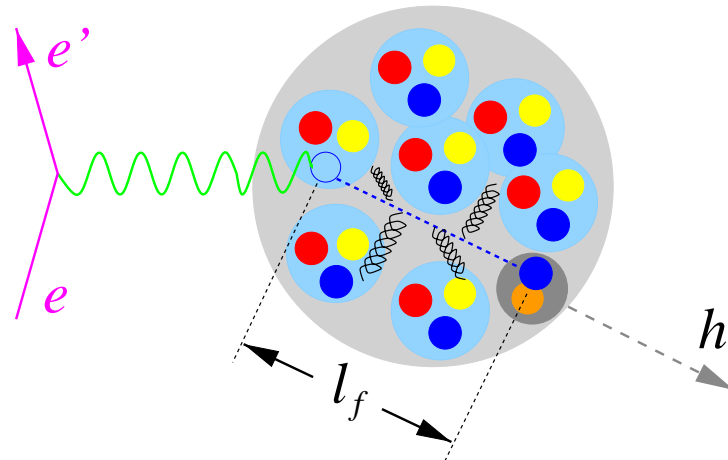


- Semi-inclusive cross section:

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

- $q_f(x)$ = 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 transferred 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

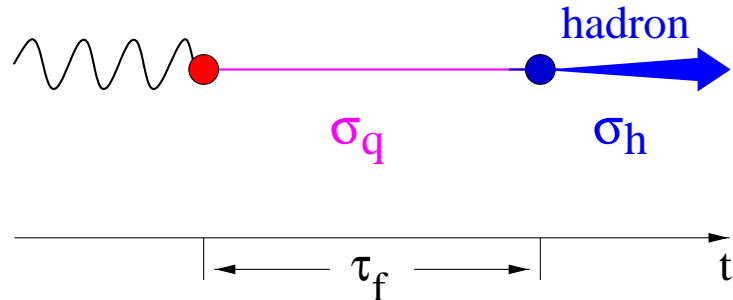
$$R_A(z, \nu) = \frac{\left(\frac{1}{\sigma} \frac{d\sigma}{dz d\nu}\right)_A}{\left(\frac{1}{\sigma} \frac{d\sigma}{dz d\nu}\right)_D} = \frac{\left(\frac{1}{N_e} \frac{dN_h}{dz d\nu}\right)_A}{\left(\frac{1}{N_e} \frac{dN_h}{dz d\nu}\right)_D}$$

where

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

Models of Hadron Attenuation (I)

One Time-Scale Model



- One time-scale model - hadron produced “directly”

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

- Hadron attenuation

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

- No-interaction probability

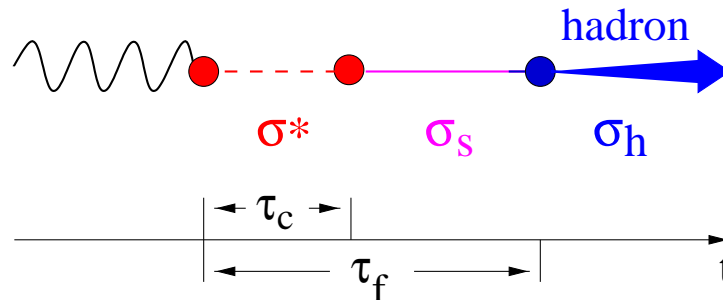
$$P_A = 1 - \sigma_q \int_l^\infty dl' \rho_A(b, l') P_q(l' - l) - \sigma_h \int_l^\infty dl' \rho_A(b, l') P_h(l' - l)$$

- ρ_A = nuclear density $\tau = l/c$

- $\sigma_q \ll \sigma_h \approx 20$ 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, $\kappa \approx 1 \text{ GeV/fm}$

- Hadron attenuation

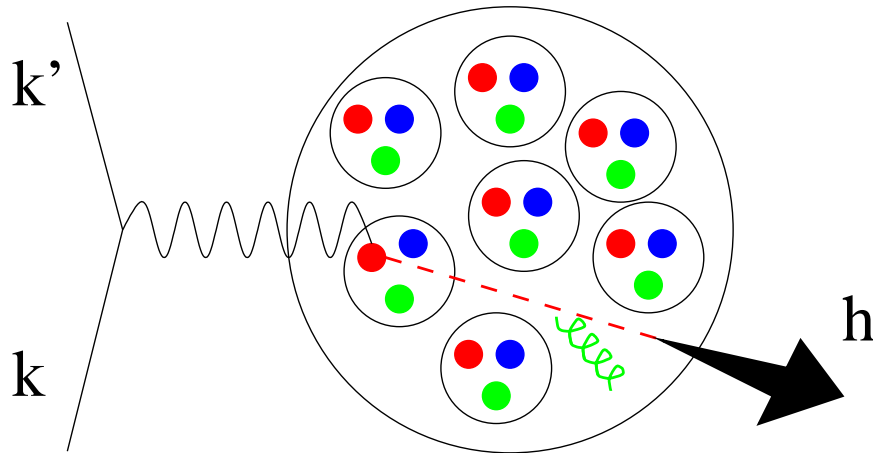
$$R_A = 2\pi \int_0^\infty b db \int_{-\infty}^\infty dl \rho_A(b, l) [P_A(b, l)]^{A-1}$$

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

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

Models of Hadron Attenuation (III)

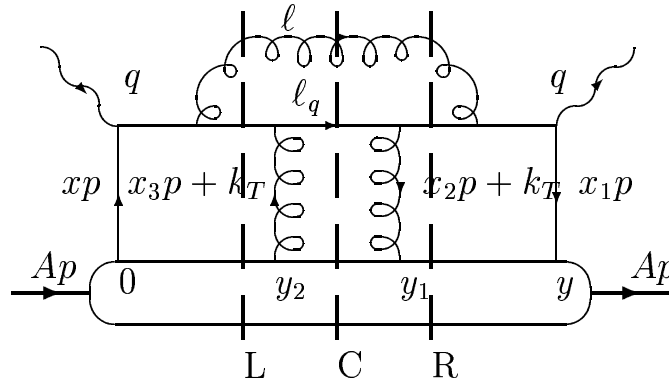
Gluon Bremsstrahlung



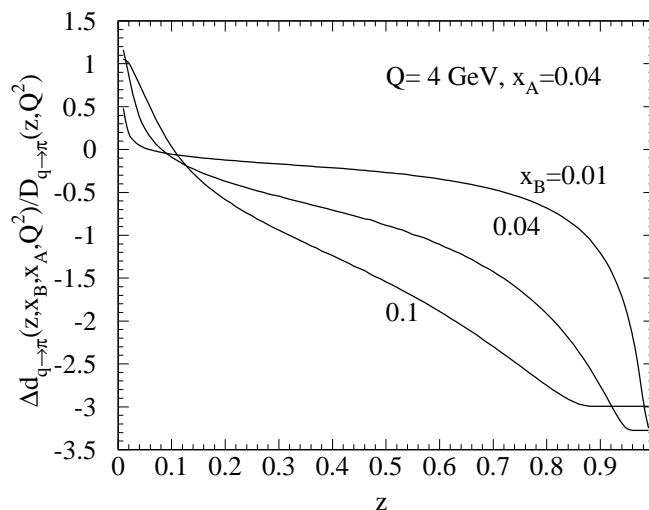
- Hadrons form when struck parton combines with a q or \bar{q} from emitted gluon
- At large z , the hadron retains the energy of the struck quark
- In nucleus, presence of extra nucleons increases probability of gluon radiation
- High z hadrons suppressed in nuclei

Models of Hadron Attenuation (IV)

Multiple Parton Scattering

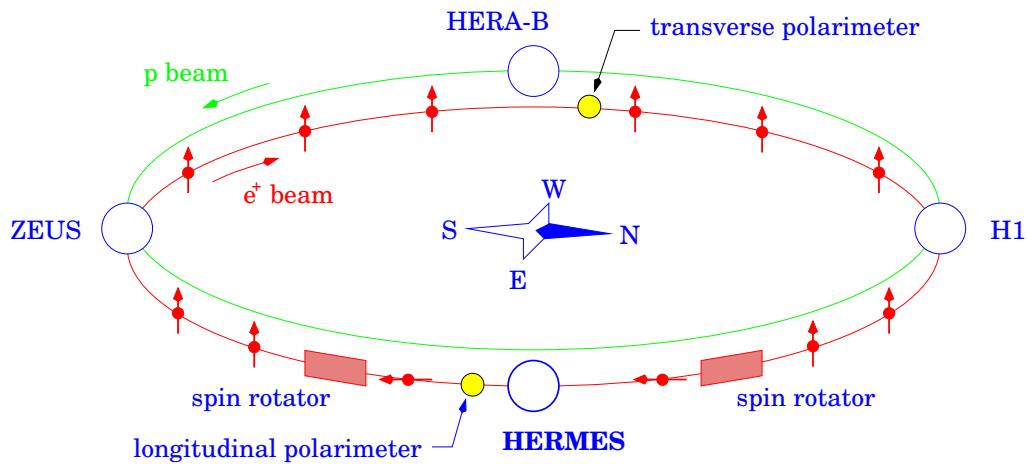


- Fragmentation functions are modified via quark rescattering with partons in other nucleons (higher-twist effects)
- Dominant contribution from term involving gluon radiation and rescattering with gluon from other parton
- Modification of fragmentation functions $\propto A^{2/3}$

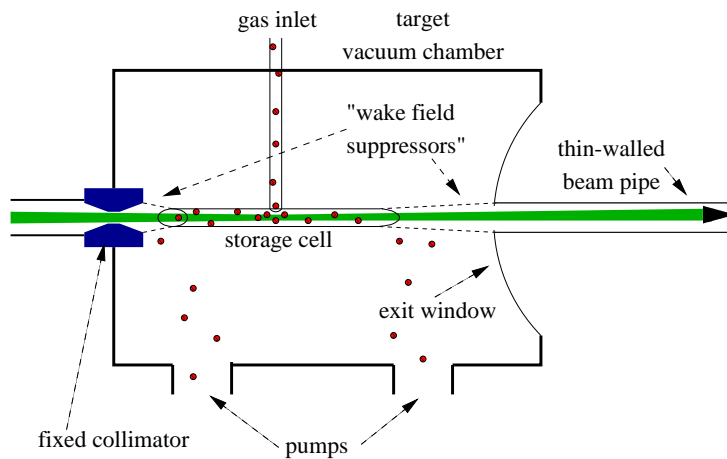


Guo and Wang, Phys. Rev. Lett. 85, 3591 (2000)

The HERMES Experiment

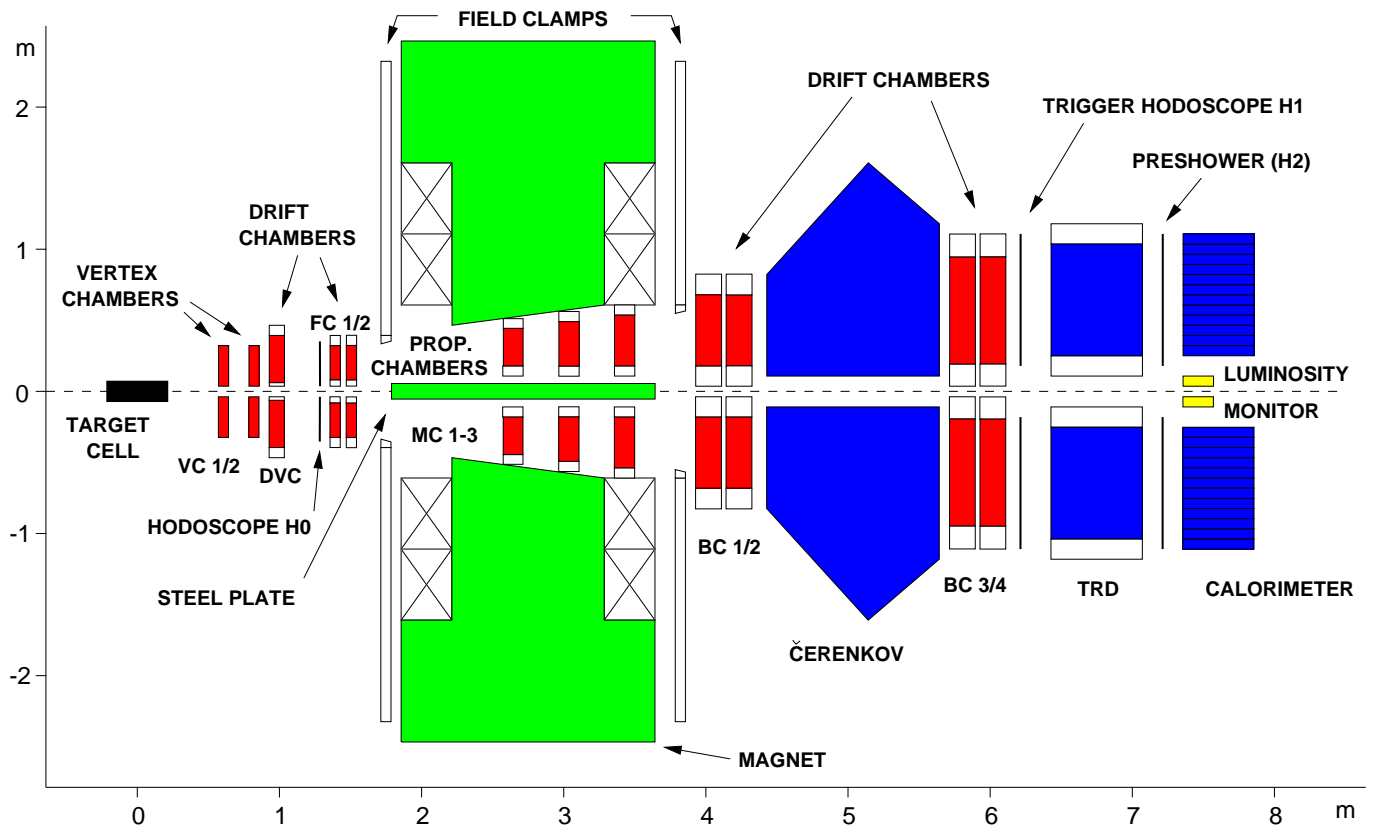


The HERMES experiment at HERA/DESY
 Current ≈ 30 mA
 \langle Beam Polarization $\rangle \approx 50\%$



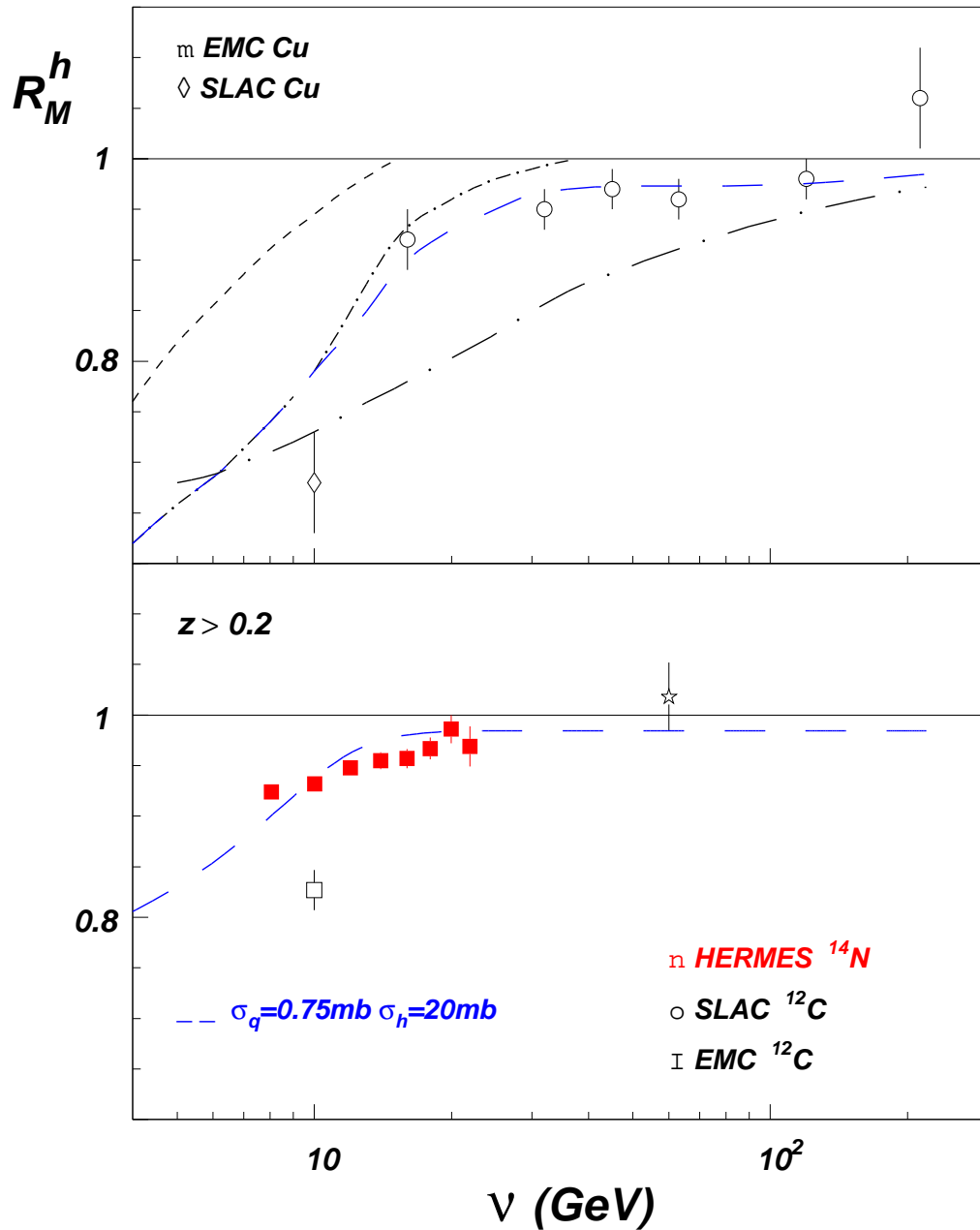
The HERMES target ($H_2, D_2, {}^3He, N_2, Kr$)
 \langle Target Thickness $\rangle \approx 10^{13} - 10^{15}$ atoms/cm²

The HERMES Spectrometer



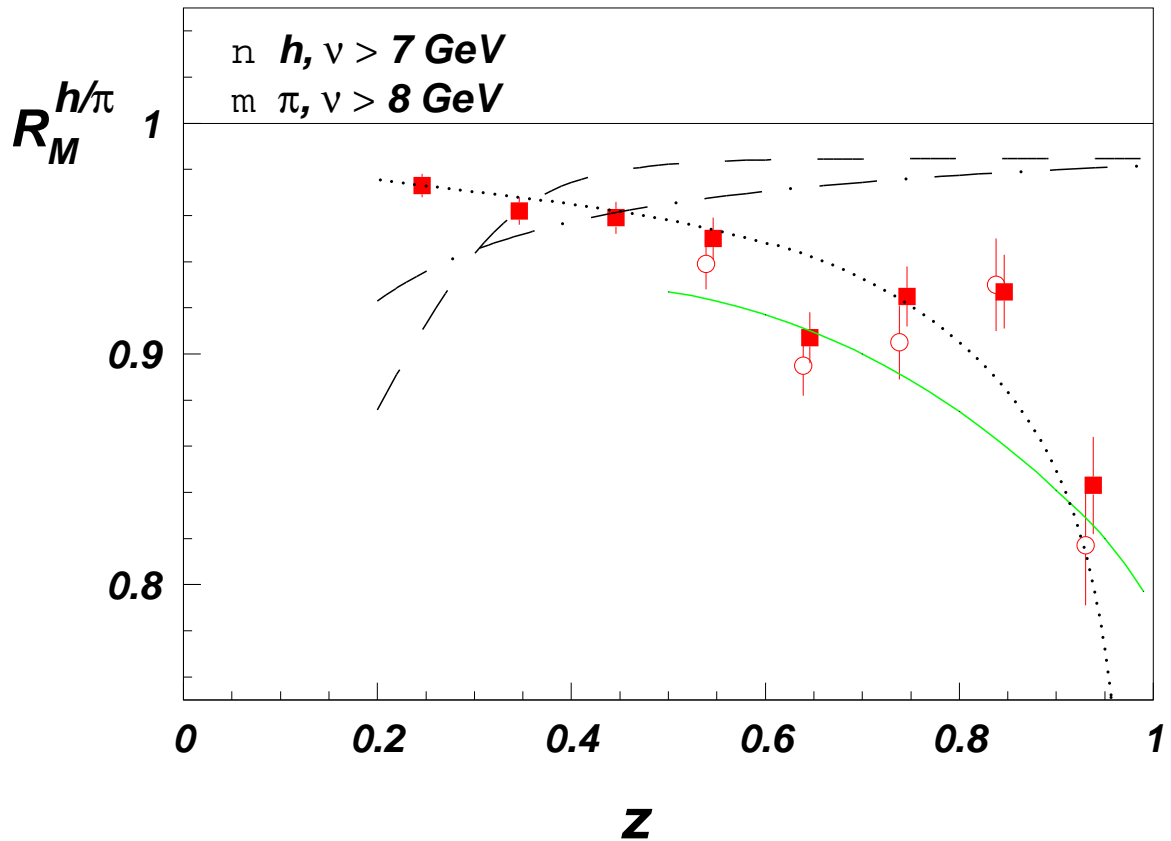
- Large solid angle: $|\theta_x| < 170$ mrad
 $40 < \theta_y < 140$ mrad
- Momentum resolution $\sim 1\%$ from 1 to 27 GeV
- Hadron/lepton contamination $< 1\%$ (with high efficiency)
- Pre-1998: π identification from 4 to 13.5 GeV with threshold Čerenkov
- After 1998: hadron identification with RICH (allows $\pi/K/p$ separation)

Hadron Attenuation vs. ν



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

Hadron Attenuation vs. z

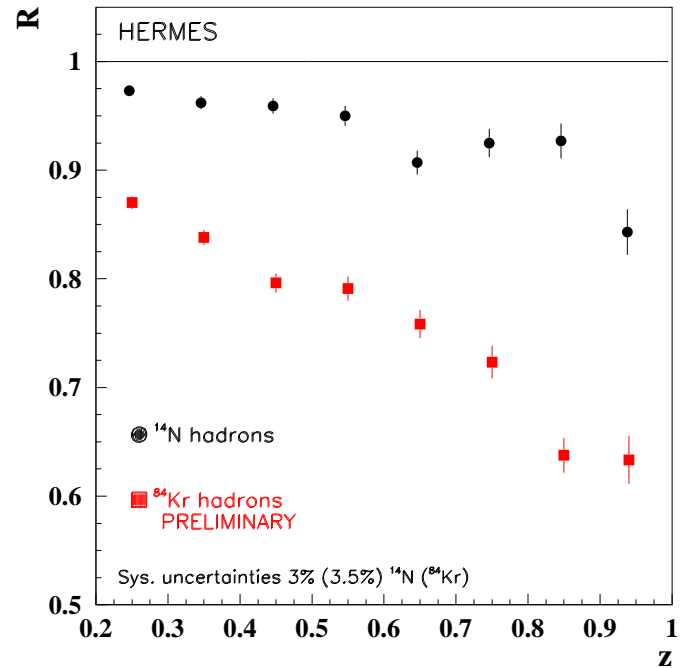
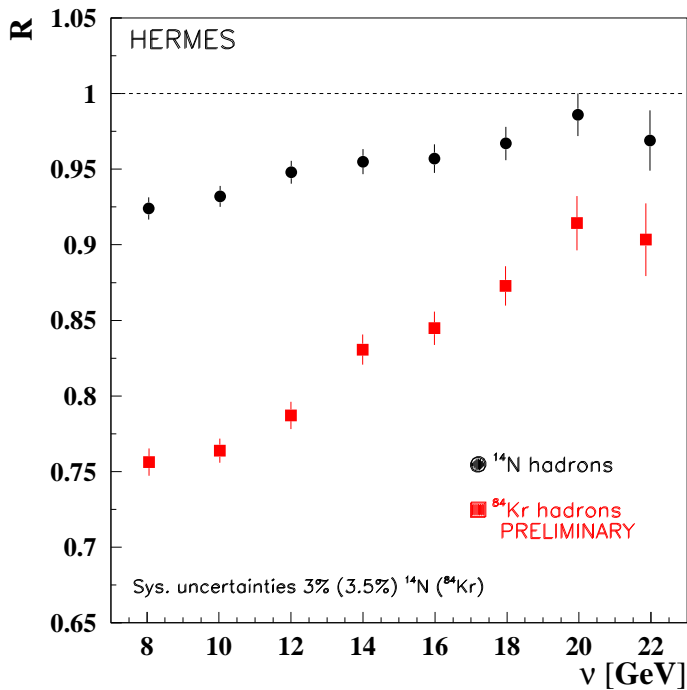


- Two time-scale models

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

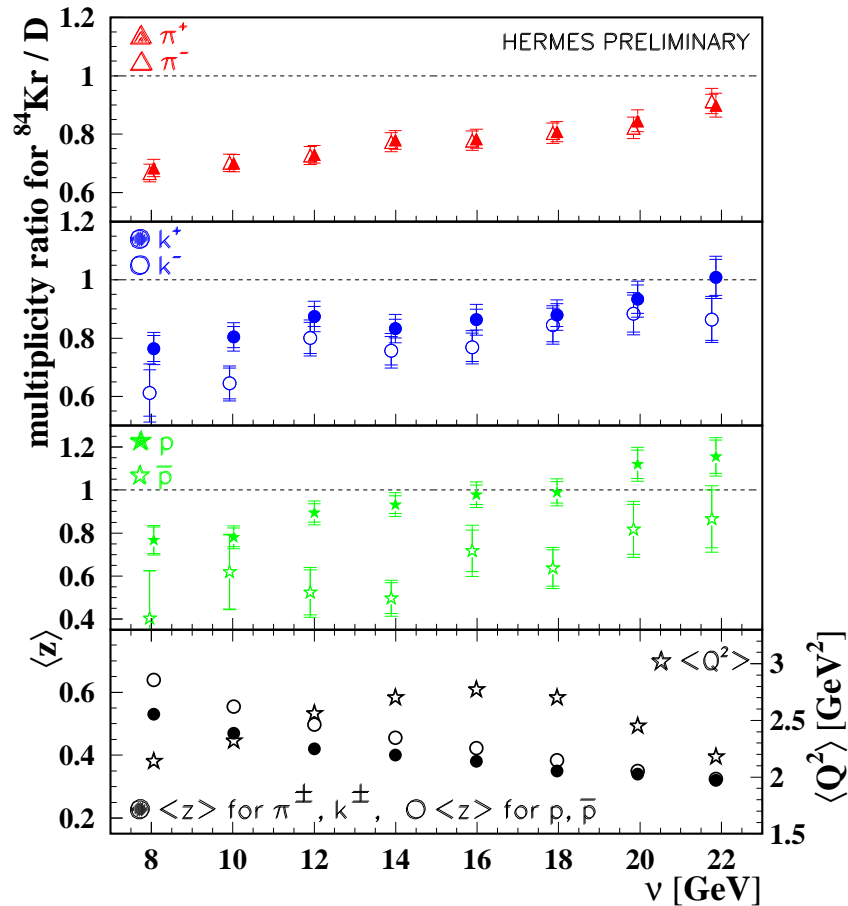
- **Gluon-bremstrahlung model** shows good agreement

Mass Dependence



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

Hadron Type Dependence (ν Dependence)



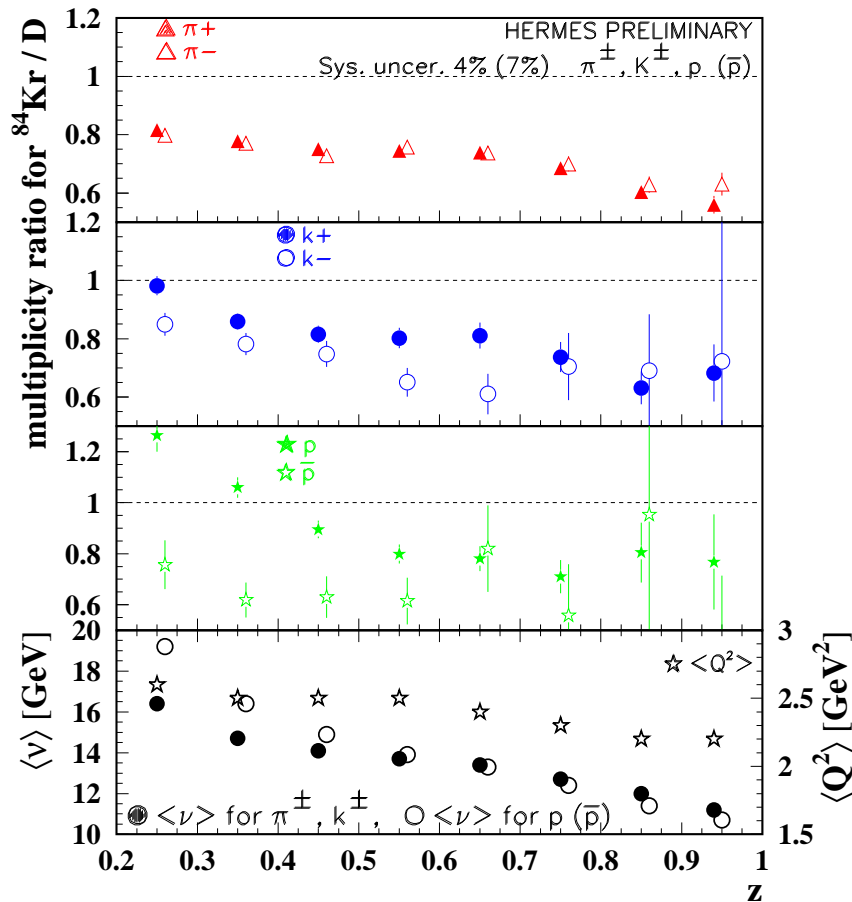
- RICH allows separation of hadron species (^{84}Kr only)
- Protons are less attenuated than pions and kaons \rightarrow longer formation time?

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

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

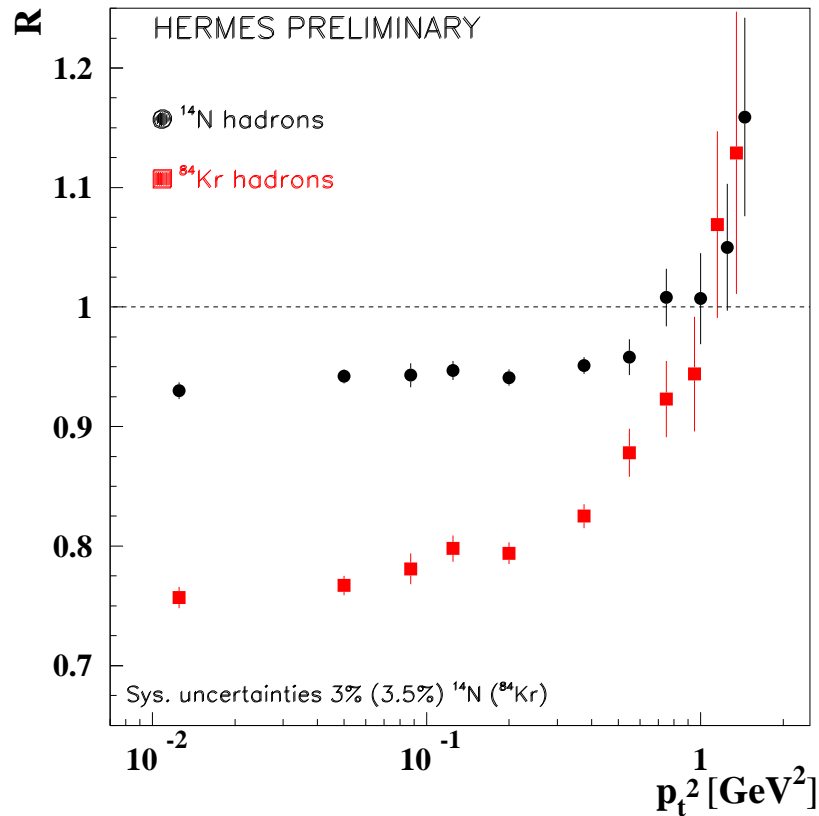
$$\sigma_p \approx 40 \text{ mb} \quad \sigma_{\bar{p}} \approx 60 \text{ mb}$$

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