Nuclear modifications of fragmentation functions and rescaling models

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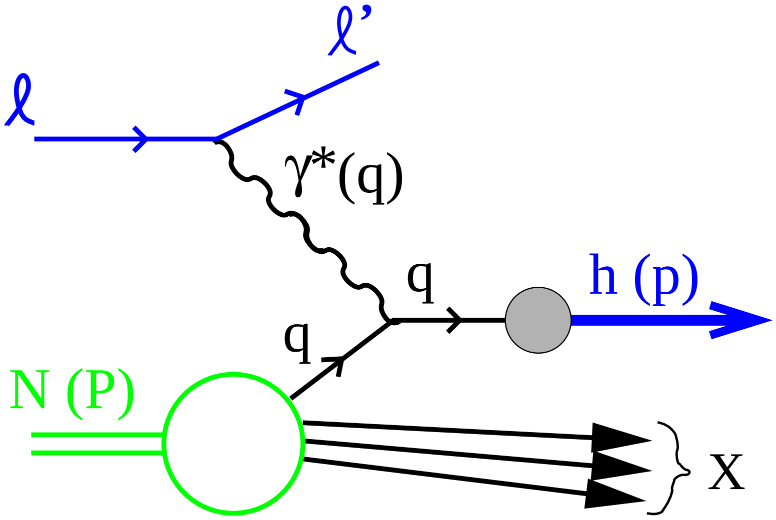
SUMMARY

- Rescaling models
  - Partial deconfinement in nuclei
- Results at EMC energy
  - Nuclear absorption
  - Charged hadron production
- Results at HERMES energy
  - Charged hadron production
- Conclusions

DIS and hadron production



KINEMATIC VARIABLES

$$x = \frac{-q^2}{2q \cdot P} = \frac{Q^2}{2M\nu}$$

$$\nu = \frac{q \cdot P}{P^2} = E_\ell - E'_\ell$$

$$z = \frac{q \cdot p}{q \cdot P} = \frac{E_h}{\nu}$$

$$Q^2 = -q^2 = 2Mx\nu$$

Experimentally

Hadron production presented in terms of the *multiplicity ratio*

$$R_M^h(z) = \frac{\frac{1}{N_A^\ell}\frac{dN_A^h}{dz}}{\frac{1}{N_D^\ell}\frac{dN_D^h}{dz}}$$

or w.r.t. ν. $R_M^h(z) < 1 \Longrightarrow$ NUCLEAR EFFECTS

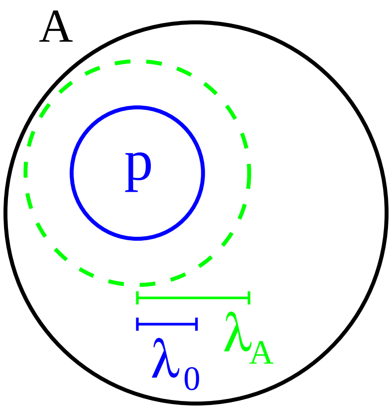
Theoretical models

- nuclear absorption Bialas & Chmaj '83, Bialas & Gyulassy '87
- gluon-bremsstrahlung model Kopeliovich et al. '95
- higher-twist effects Guo & Wang '00, Qiu & Sterman '01, Wang^2 '02
- rescaling models

Rescaling models

Let's assume a change of confinement scale in nuclei:

$$\lambda_A > \lambda_0$$



Parton Distributions

Nachtmann & Pirner '84,Close et al. '84

For valence quarks $\lambda_0 Q_0 = \lambda_A Q_A$:

$$G_f(x, Q_0) = G_f^A(x, Q_A = \frac{\lambda_0}{\lambda_A} Q_0)$$

where Q_0 = starting scale for DGLAP evolution.

Fragmentation functions Dias de Deus '87

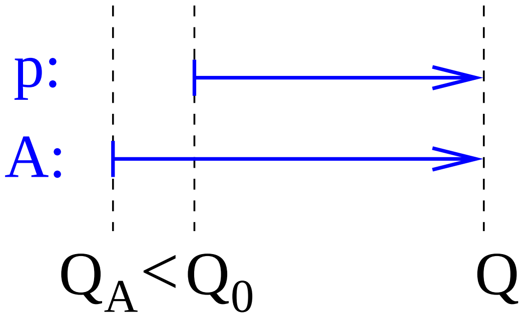
Quark and hadron effective masses sensitive to λ_A:

$$D_f^h(x, Q_0) = D_f^{h|A}(x, Q_A = \frac{\lambda_0}{\lambda_A} Q_0)$$

where Q_0 = physical threshold for hadron formation.

pQCD evolution:

longer in nuclei than in isolated nucleons



$$\boxed{G_f^A(x, Q) = G_f(x, \xi_A(Q) Q)} \quad \boxed{D_f^{h|A}(z, Q) = D_f^h(x, \xi_A(Q) Q)}$$

Two models for deconfinement:

- Partial (CJRR): $\lambda_A \propto$ nucl. overlap
$$\xi_A = \xi_A(Q) = \left(\lambda_A/\lambda_0\right)^{\frac{1}{2}\frac{\alpha_s(Q_0)}{\alpha_s(Q)}}$$
- Maximal (NP): $\lambda_A = R_A$ (nuclear radius)
$$\xi_A = R_A/R_p$$

	D	^{14}N	^{63}Cu	^{84}Kr
$\xi_{\mathrm{CJJR}}(Q = 4.5\text{ GeV})$	1.07	~1.62	2.02	~2.17
ξ_{NP}	1.93	2.09	3.79	4.20

Multiplicity ratio:

$$R_M^h(z) = \frac{1}{N_A^\ell}\frac{dN_A^h}{dz} \Bigg/ \frac{1}{N_D^\ell}\frac{dN_D^h}{dz}$$

where:

$$N_A^\ell = \int_{\text{exp. cuts}} dx\, d\nu \sum_f e_f^2\, G_f(x, \xi_A Q)\, \underbrace{\frac{d\sigma^{\gamma^* q}}{dx\, d\nu}}_{\text{pQCD at LO}}$$

$$\frac{dN_A^h}{dz} = \int_{\text{exp. cuts}} dx\, d\nu \sum_f e_f^2\, G_f(x, \xi_A Q)\overbrace{\frac{d\sigma^{\gamma^* q}}{dx\, d\nu}} D_f^h(z, \xi_A Q)$$

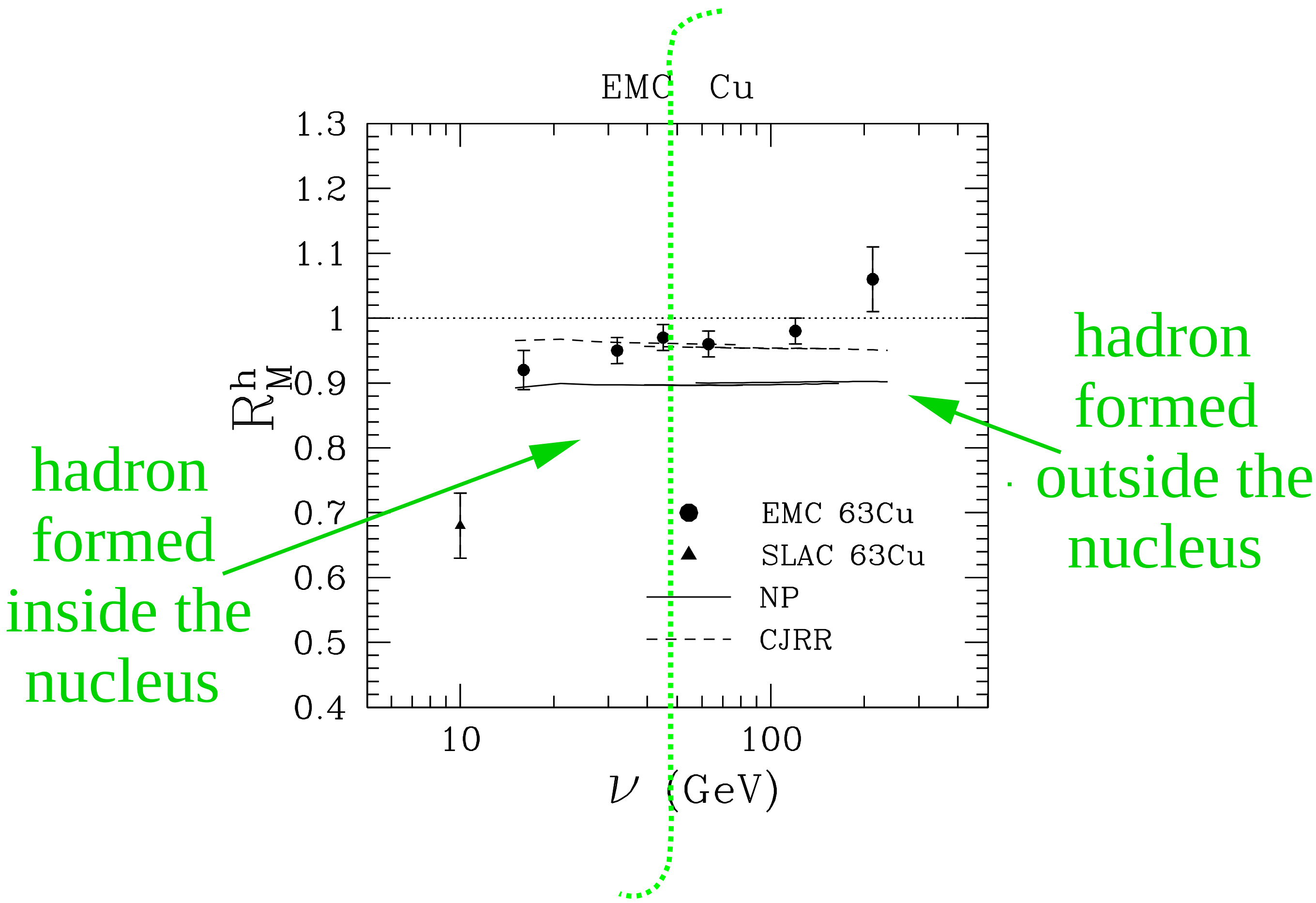
and $Q^2 = 2Mx\nu$

Results at EMC

$$E_{lab} = 100\text{-}280 \text{ GeV} \Longrightarrow \begin{cases} \text{high } \nu\text{'s} \\ \text{large formation time } \tau_F \end{cases}$$

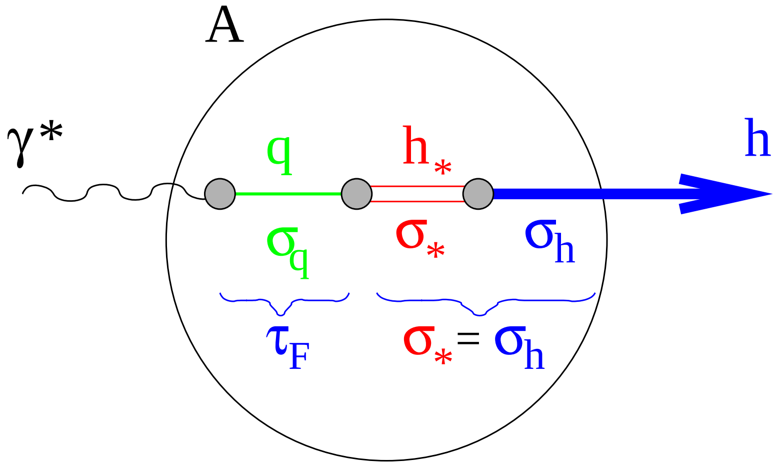
$\tau_F \propto \nu$ due to Lorentz dilatation

ν-distribution $(0.2 \leq z \leq 1)$



- rescaling models good at high ν (hadron formed outside the nucleus)
- nuclear absorption needed at low ν

Nuclear absorption



$\sigma_q = 0$ mbarn $\sigma_* = \sigma_h = 20$ mbarn $\kappa = 0.5$ GeV/fm
${}^2D_1 \to$ Gaussian ρ $R_D = 2.17$ fm ${}^AN_Z \to$ Wood-Saxon ρ $R_A = 1.12A^{1/3} - 0.86A^{-1/3}$

Nuclear absorption factor

Bialas & Chmaj, PLB133(83)241

Average over production points with prob. dens. ρ...

$$\mathcal{N}_A = \int d^2b \int_{-\infty}^{\infty} dy\, \rho_A(b,y)\, [S_A(b,y)]^{A-1}$$

...of the hadron survival probability

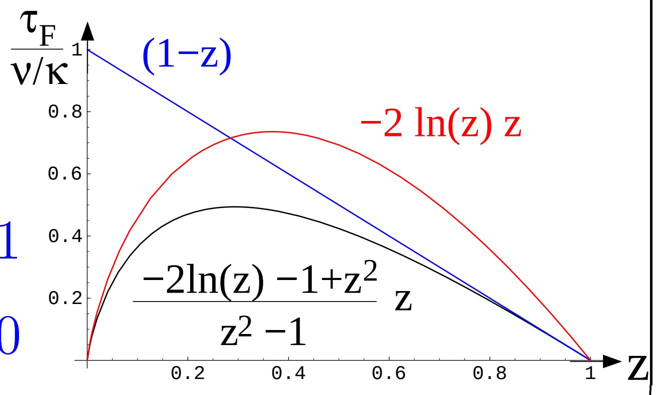
$$S_A(b,y) = 1 - \sigma_h \int_y^{\infty} dy' \rho_A(b,y') \left(1 - e^{-(y'-y)/\tau_F}\right)$$

Formation time

Bialas & Gyulassy, NPB291(87)813

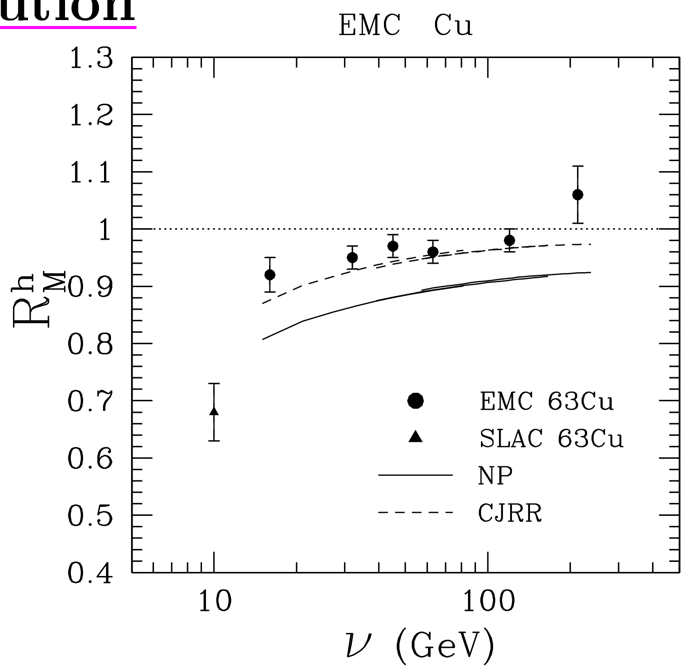
$$\tau_F = \left(\frac{-\ln(z^2) - 1 + z^2}{1 - z^2}\right) \frac{z\nu}{\kappa}$$

$$\tau_F \longrightarrow \begin{cases} (1-z)\nu/\kappa & z \to 1 \\ -2\ln(z) z\nu/\kappa & z \to 0 \end{cases}$$

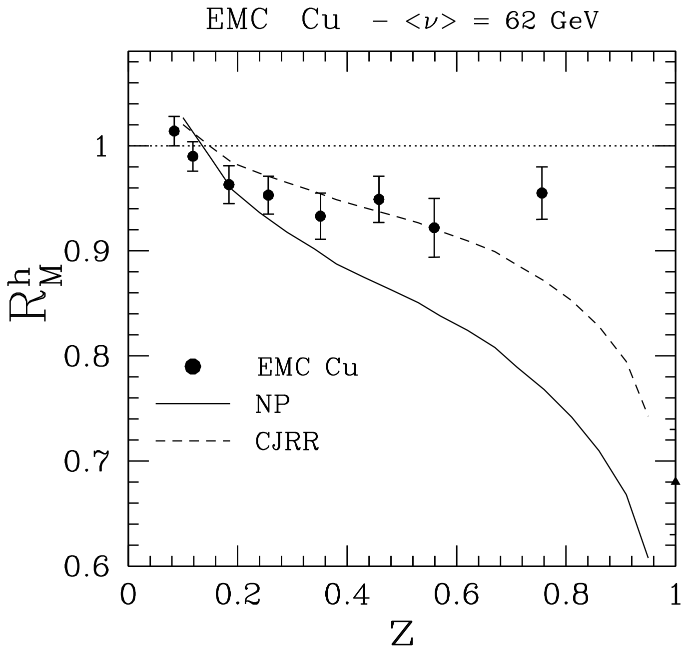


Results at EMC with absorption

ν-distribution



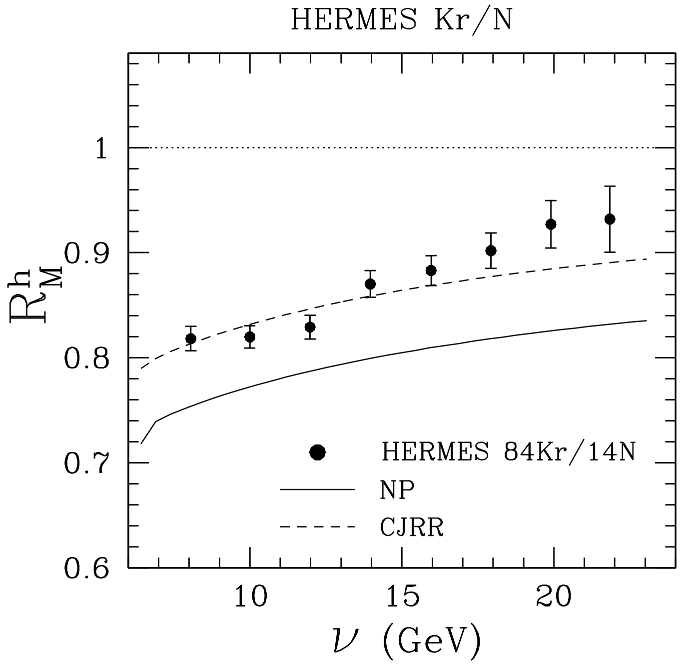
z-distribution



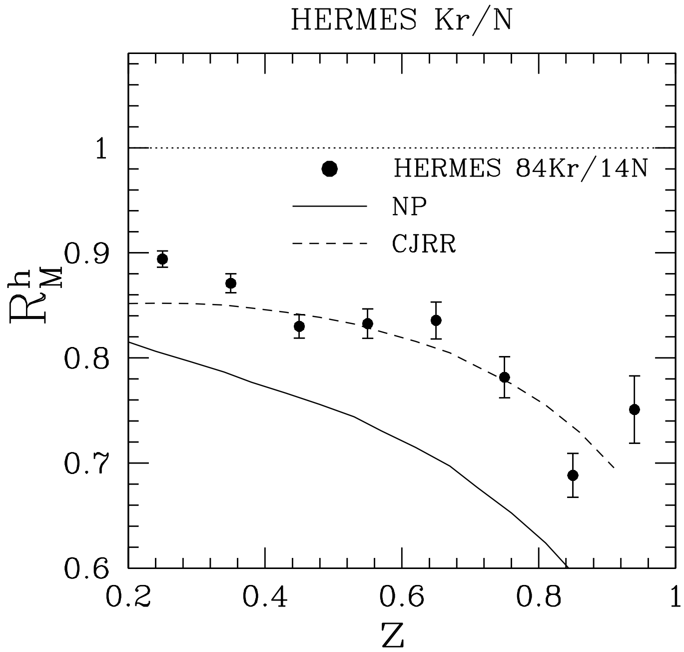
- Maximal deconfinement (NP) RULED OUT
- Partial deconfinement (CJRR) OK

Results at HERMES with absorption

ν-distribution

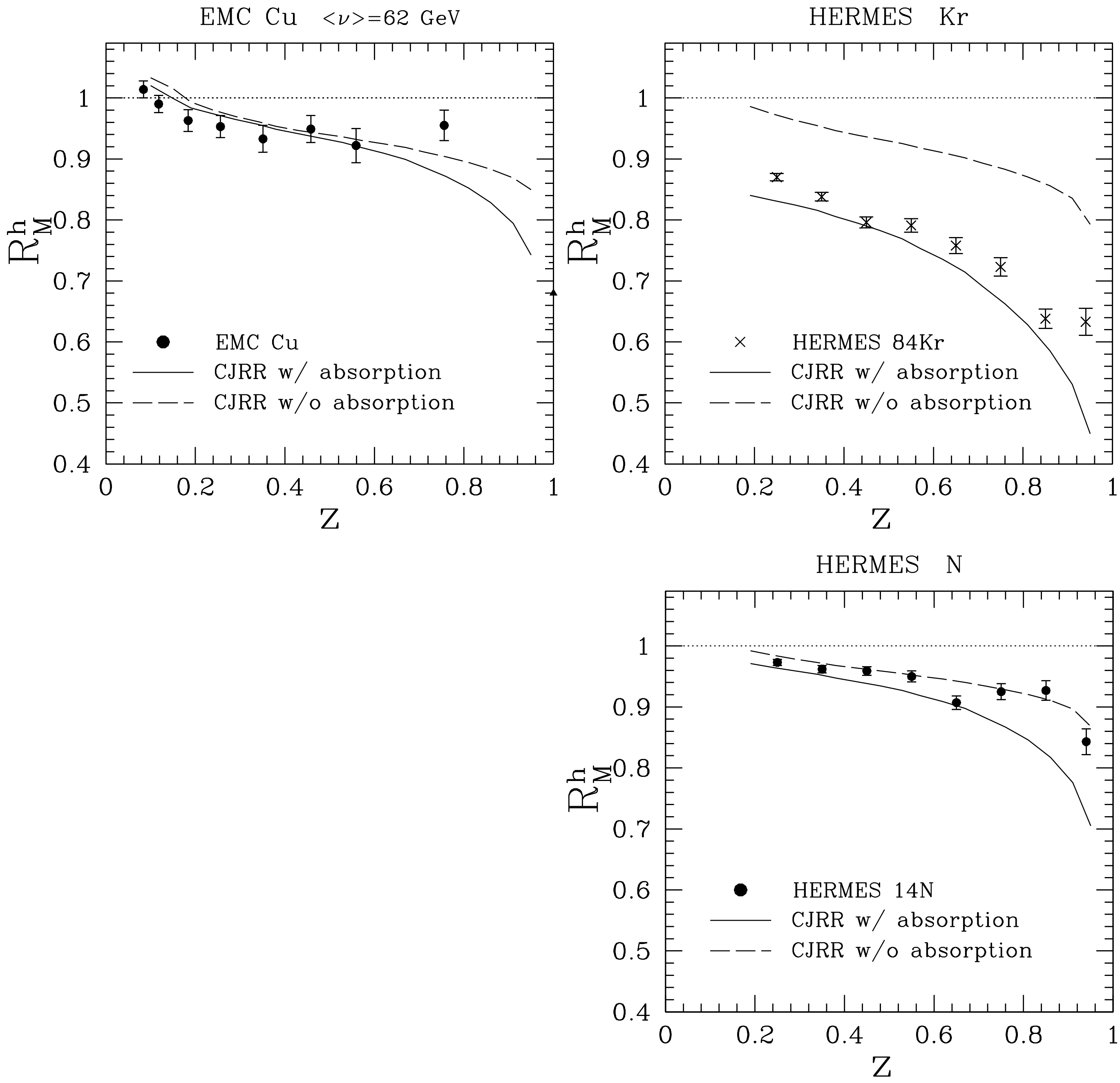


z-distribution



- E_{lab} =27.5 Gev $\Rightarrow$ low ν's $\Rightarrow$ big absorption
- Partial deconfinement (CJRR) OK

Rescaling vs. absorption



- At large $\langle \nu \rangle$ (EMC) rescaling is the dominant effect
- At small $\langle \nu \rangle$ (HERMES) absorption is dominant
- Rescaling larger at HERMES than at EMC

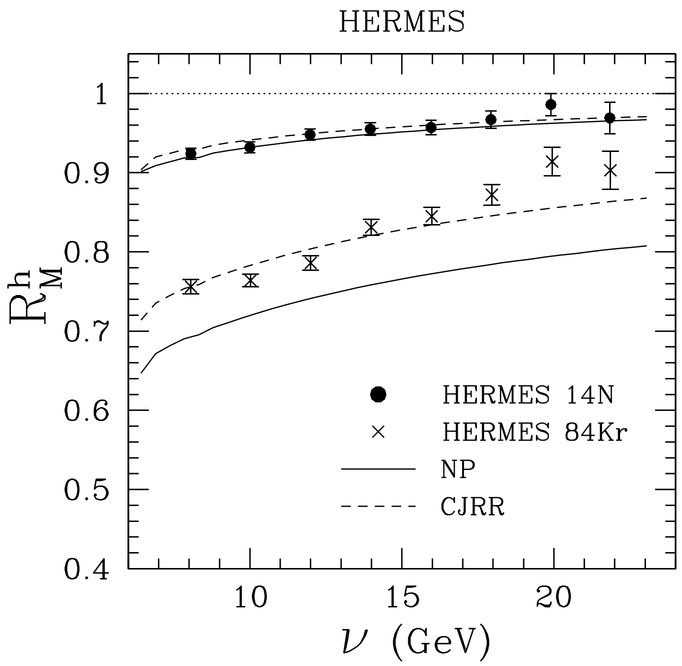
Conclusions

- "Rescaling" models for nuclear modifications of FF's, supplemented by nuclear absorption:
  - reproduce quite well experimental data at $0.2 \lesssim z \lesssim 0.8$
  - "maximal" deconfinement (NP) ruled out
  - "partial" deconfinement (CJRR) is OK
- Need of further precise measurements at
  - high ν's
  - different nuclear targets ($12 \lesssim A \lesssim 208$)

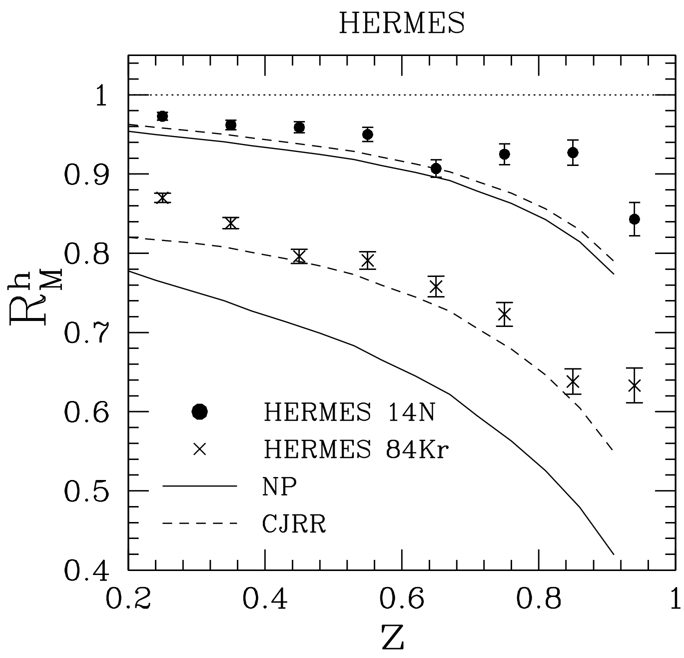
  to disentangle rescaling and formation time effects.

HERMES N vs. Kr

ν-distribution



z-distribution



NOTE: nuclear absorption is included