Suppression of π^0 electroproduction in eA from CLAS

International workshop on CLAS12 physics and future perspectives at JLab

23 March, 2023

Taisiya Mineeva

UNIVERSIDAD TECNICA
FEDERICO SANTA MARIA

CLAS committee approved paper draft

(F. Bossu, Z. Meziani, L. Weinstein)

Suppression of neutral pion production in deep-inelastic scattering off nuclei with the CLAS detector

Taisiya Mineeva,[1,*] William K. Brooks,[1,2,3,4] K. Joo,[5] H. Hakobyan,[1,2] Jorge A. López,[6] and O. Soto[7]

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[2] *Centro Cientifico y Tecnológico de Valparaíso, Valparaíso, Chile*
[3] *Instituto Milenio de Física Subatómica en la Frontera de Altas Energías, Santiago, Chile*
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[7] *Universidad de La Serena, La Serena, Chile*

(Dated: January 16, 2023)

We present the first threefold differential neutral pion multiplicity ratios produced in semi-inclusive deep inelastic electron scattering on carbon, iron and lead nuclei normalized to deuterium from CLAS measurements at Jefferson Lab. We found that the neutral pion multiplicity ratio is maximally suppressed for the leading hadrons (energy transfer $z \to 1$), varying from 25% on carbon up to 75% in lead. An enhancement of the multiplicity ratio at low z and high p_T^2 is observed suggesting an interconnection between these two variables. This behavior is qualitatively similar to the previous two-fold differential measurement of charged pions by the HERMES Collaboration. However, in contrast to the published CLAS and HERMES results on charged pions, we observe the largest enhancement at high p_T^2 for lightest nuclei - carbon, and the lowest enhancement for the heaviest nuclei - lead. This behavior suggests a competition between partonic multiple scattering, which causes enhancement, and hadronic inelastic scattering, which causes suppression.

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Important contribution to Hadronization programm @ CLAS and CLAS12

We present the first threefold differential neutral pion multiplicity ratios produced in semi-inclusive deep inelastic electron scattering on carbon, iron and lead nuclei normalized to deuterium from CLAS measurements at Jefferson Lab. We found that the neutral pion multiplicity ratio is maximally suppressed for the leading hadrons (energy transfer $z \to 1$), varying from 25% on carbon up to 75% in lead. An enhancement of the multiplicity ratio at low z and high p_T^2 is observed suggesting an interconnection between these two variables. This behavior is qualitatively similar to the previous two-fold differential measurement of charged pions by the HERMES Collaboration. However, in contrast to the published CLAS and HERMES results on charged pions, we observe the largest enhancement at high p_T^2 for lightest nuclei - carbon, and the lowest enhancement for the heaviest nuclei - lead. This behavior suggests a competition between partonic multiple scattering, which causes enhancement, and hadronic inelastic scattering, which causes suppression.

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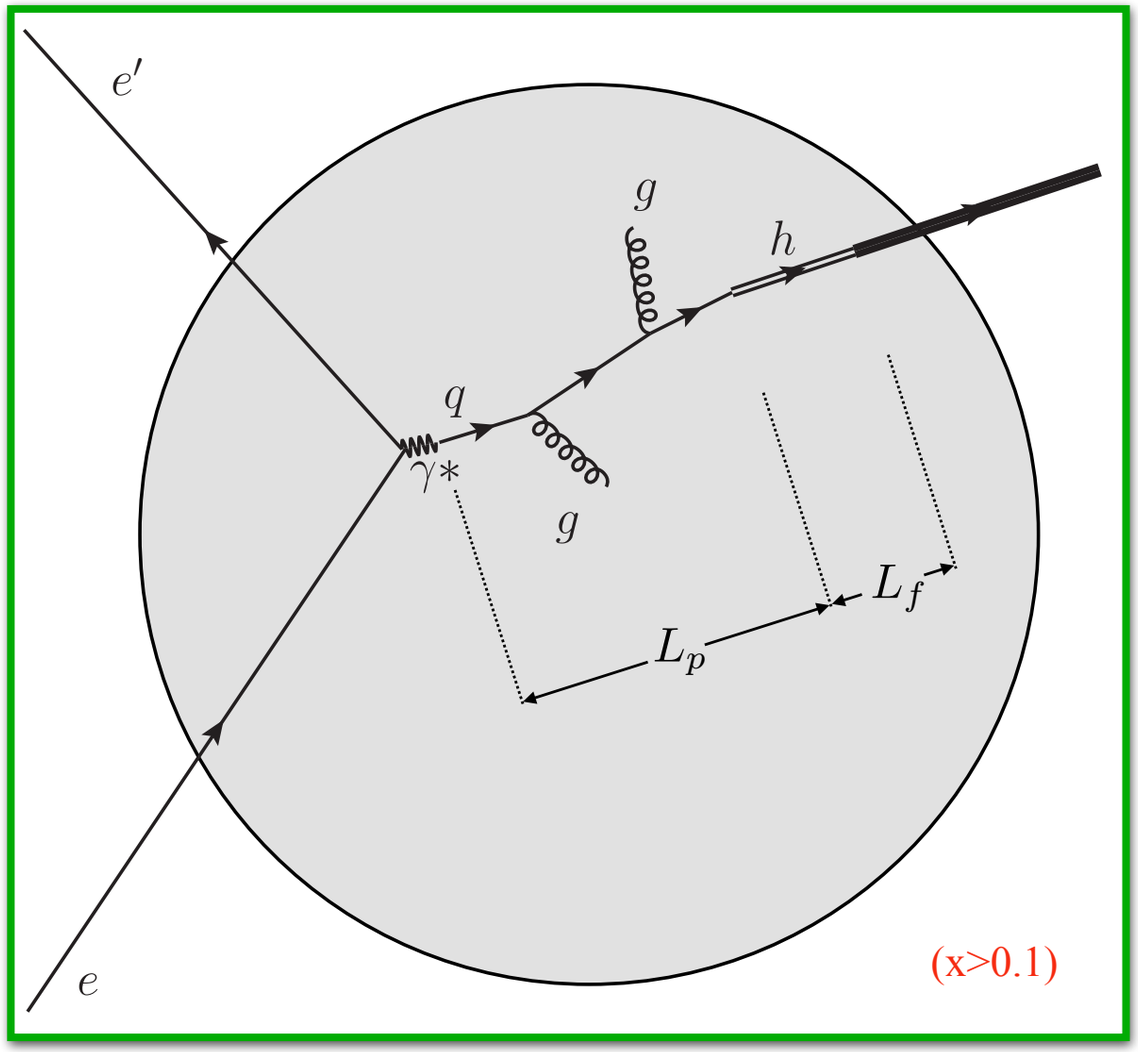
Why suppression in *eA*?

Color propagation and hadronization



EG2 collaboration

Will Brooks (UTFSM)

Raphael Dupré (Orsay)

Ahmed El Alaoui (UTFSM)

Lamiaa El Fassi (MSU)

Kawtar Hafidi (ANL)

Hayk Hakobyan (UTFSM)

Ken Hicks (Ohio)

Maurik Holtrop (UNH)

Kyungseon Joo (UCONN)

Taisiya Mineeva (UTFSM)

Brahim Mustapha (ANL)

Larry Weinstein (ODU)

Michael Wood (CC)

Master Students @ UTFSM

M.Barria

C.San Martin

B.Benkel

PhD Students @ UTFSM

A.Radic

M.Ungerer

Young researchers

E.Molina

Engineers @UTFSM

J.Gonzalez

A.Lepe Pino

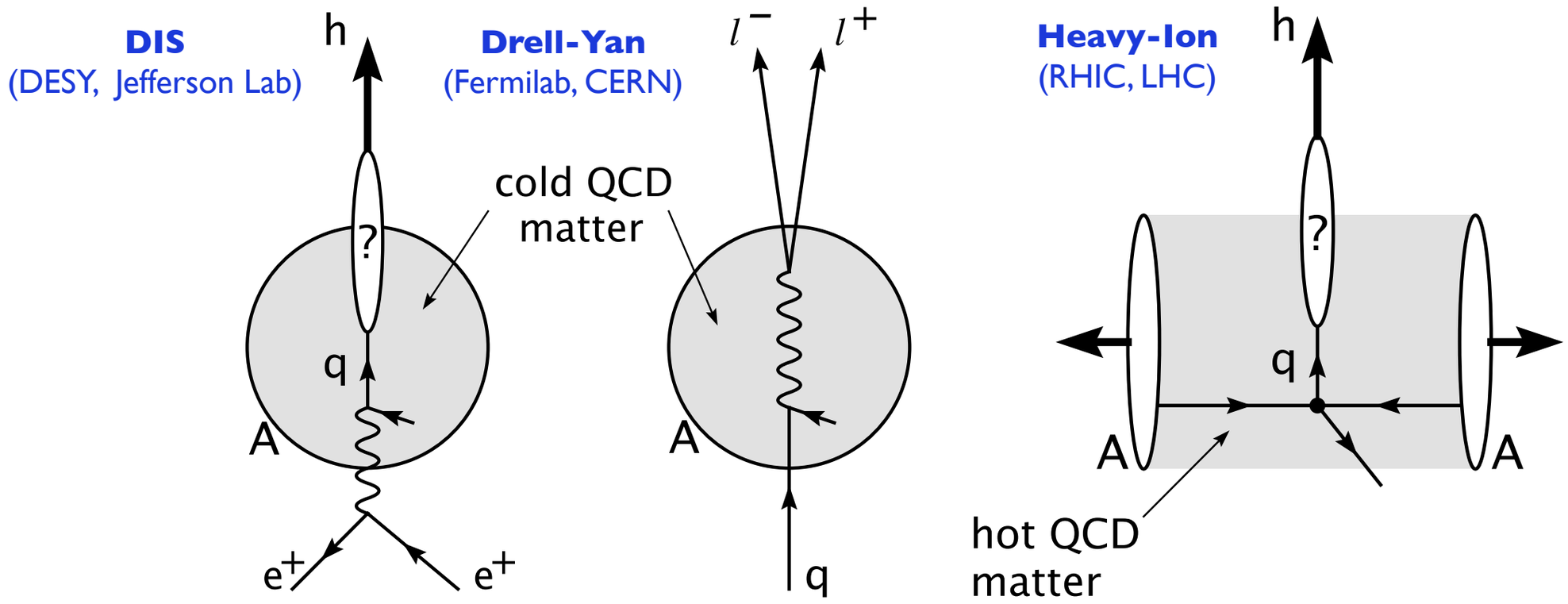
R.Rios

V.Saona Urmeneta

E.Valdivia

Color propagation and hadron formation

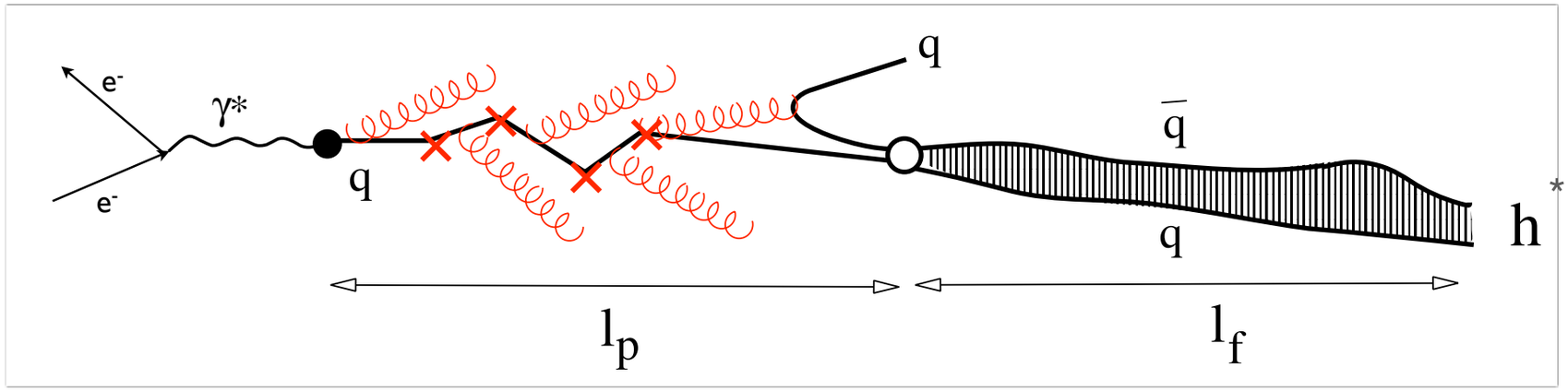
Access to microscopic information at the fm scale



Accardi, Arleo, Brooks, d'Enterria, Muccifora Riv.Nuovo Cim.032:439553,2010 [arXiv:0907.3534]

Space-time view of hadronization in DIS

In vacuum

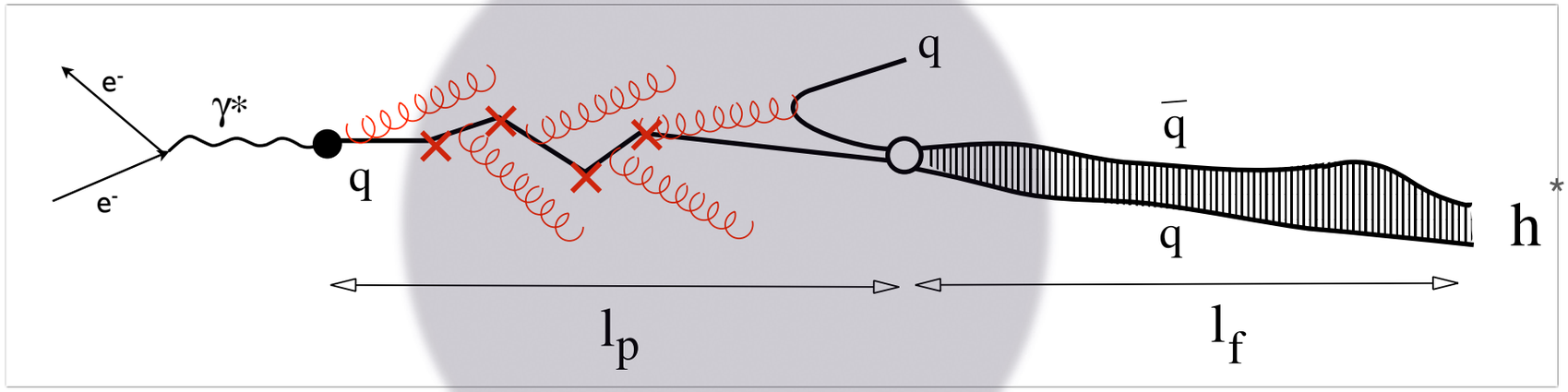


Path of (struck) quark is divided into
"partonic phase" and "hadronic phase"

* B.Z. Kopeliovich, J.Nemchik, I.Schmidt, Nucl. Phys A 782 (2007)

Space-time view of hadronization in DIS

In medium *A*



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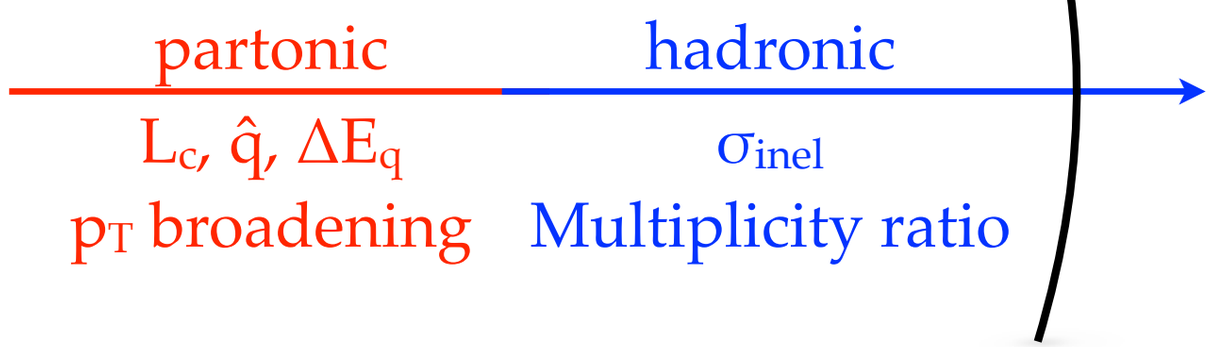

Partonic energy losses
Increase of transverse momentum

Hadron inelastic scattering
Decrease of the number of observed hadrons

• *We infer hadronization mechanisms from modification of kinematic distributions in A(e, e'h)X in nuclear medium of variable size*

visualization from W. Brooks

Observables

Transverse momentum broadening

Connects to color lifetime τ_p , quark k_T,
transport coefficient qhat and quark E_{loss}

$$\Delta\langle p_{\mathrm{T}}^2\rangle = \langle p_{\mathrm{T}}^2\rangle_A - \langle p_{\mathrm{T}}^2\rangle_p$$

Hadronic Multiplicity ratio

Connects to hadron formation phase
In-medium interaction of forming hadron

$$R_{\mathrm{A}}^h\left(\nu, Q^2, z, p_T\right) = \frac{\left.\frac{N_h(\nu,Q^2,z,p_T)}{N_e(\nu,Q^2)|_{\mathrm{DIS}}}\right|_{\mathrm{A}}}{\left.\frac{N_h(\nu,Q^2,z,p_T)}{N_e(\nu,Q^2)|_{\mathrm{DIS}}}\right|_{\mathrm{D}}}$$

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Extraction of color lifetime Brooks-Lopez model

Physics Letters B 816 (2021) 136171

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

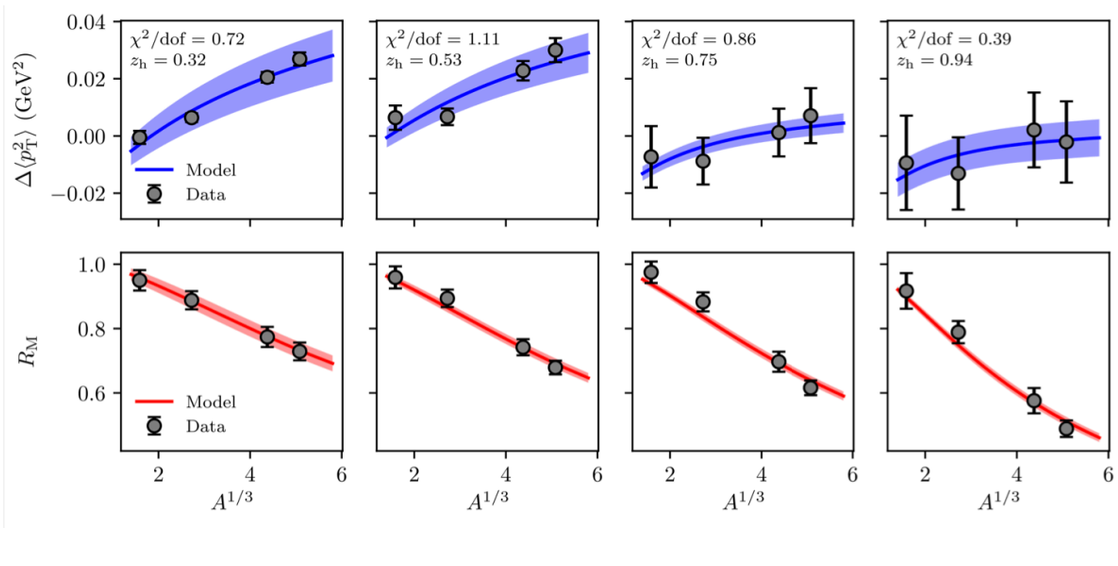
Estimating the color lifetime of energetic quarks

William K. Brooks [a,b,c,*], Jorge A. López [b,d]

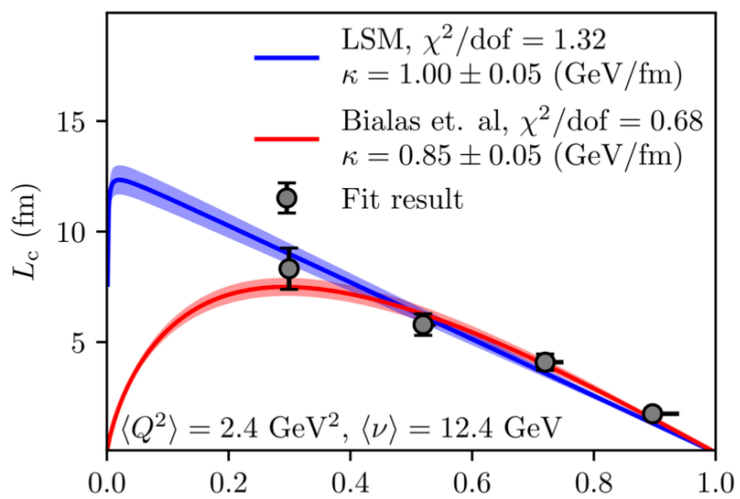
•The **color lifetime** was estimated using two observables in the HERMES data with a space-time model that is consistent with, but independent of, Lund string fragmentation.

•The answer depends on the kinematics and ranges from **2 to 8 fm/c**.

Simultaneous fit to two observables, *ΔpT2* and *R* for charged pions



The values of the color length **Lc** resulting from simultaneous fit to *pT2* and *R*



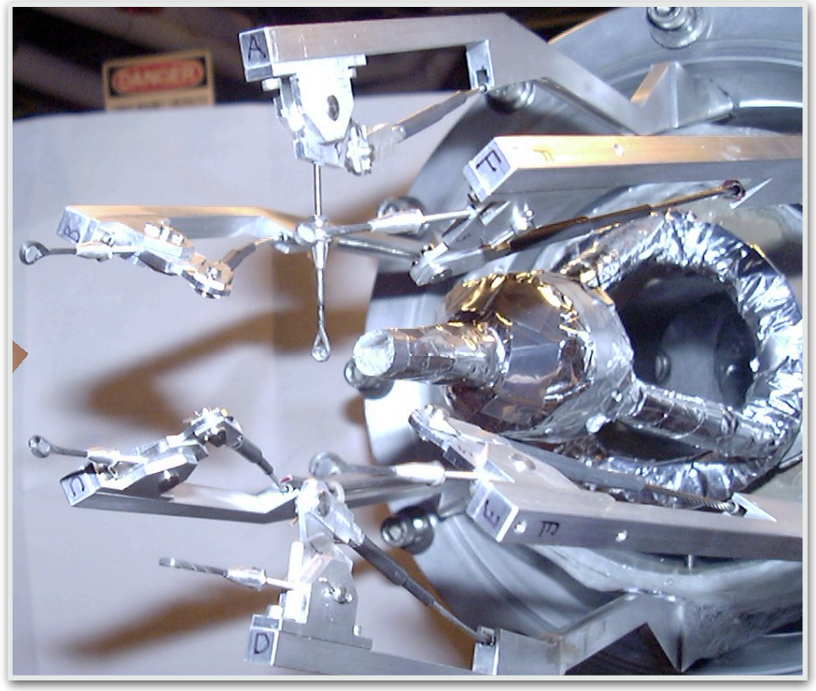
https://arxiv.org/abs/2004.07236

EG2 experiment @ 5 GEV

By using dual target approach, EG2 experiment makes a *precise* comparison of observables in a large nucleus A with respect to a small D

EG2 experiment running conditions

- Electron beam 5.014 GeV
- Targets ^{2}H, ^{12}C, ^{56}Fe, ^{207}Pb (Al, Sn)
- Luminosity $2 \cdot 10^{34}$ $1/(s \cdot cm^2)$

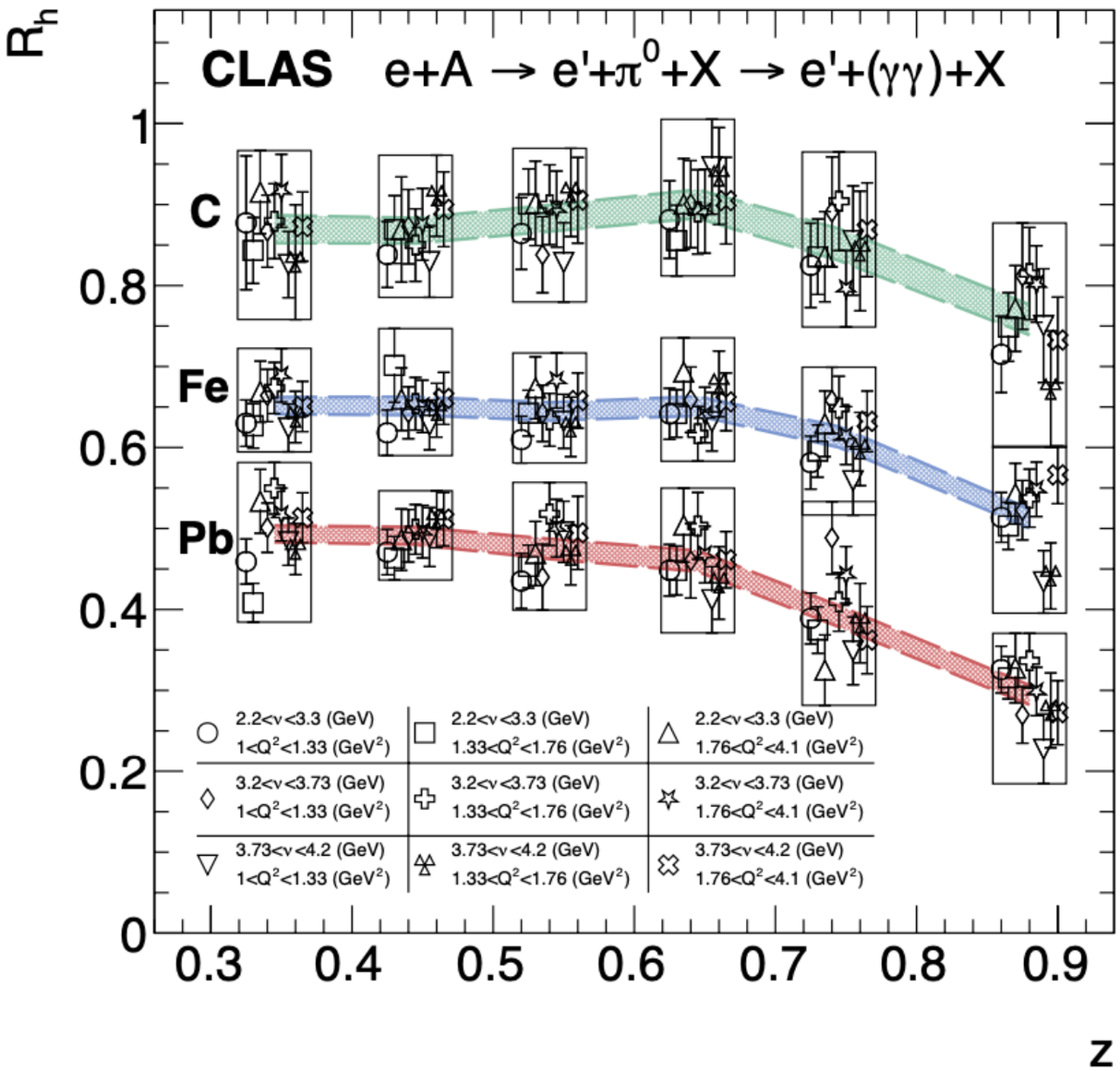


"A double-target system for precision measurements of nuclear medium effects," H. Hakobyan et al. NIM A 592 (2008) 218– 223

Interpreting Nuclear DIS Data: π^0 multiplicity ratios

3D Multiplicities $R_{\pi 0}\,(Q^2\,, \nu,\, z\,)$ on ^{12}C, ^{56}Fe, ^{207}Pb to D

T.Mineeva et al.



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Interpreting Nuclear DIS Data: π^0 multiplicity ratios

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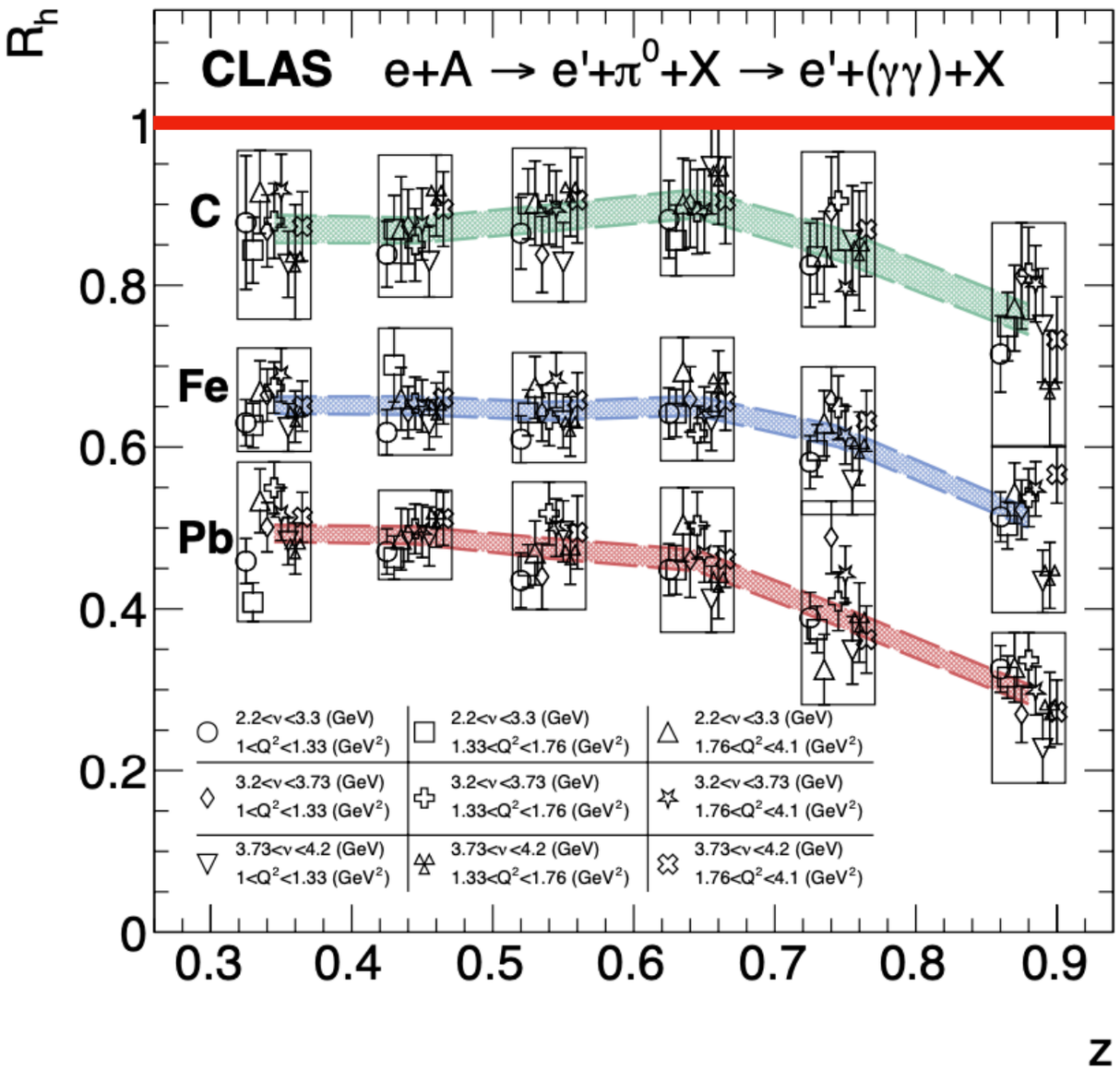

In the absence of any nuclear effects this observable is equal to unity

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Interpreting Nuclear DIS Data: π^0 multiplicity ratios

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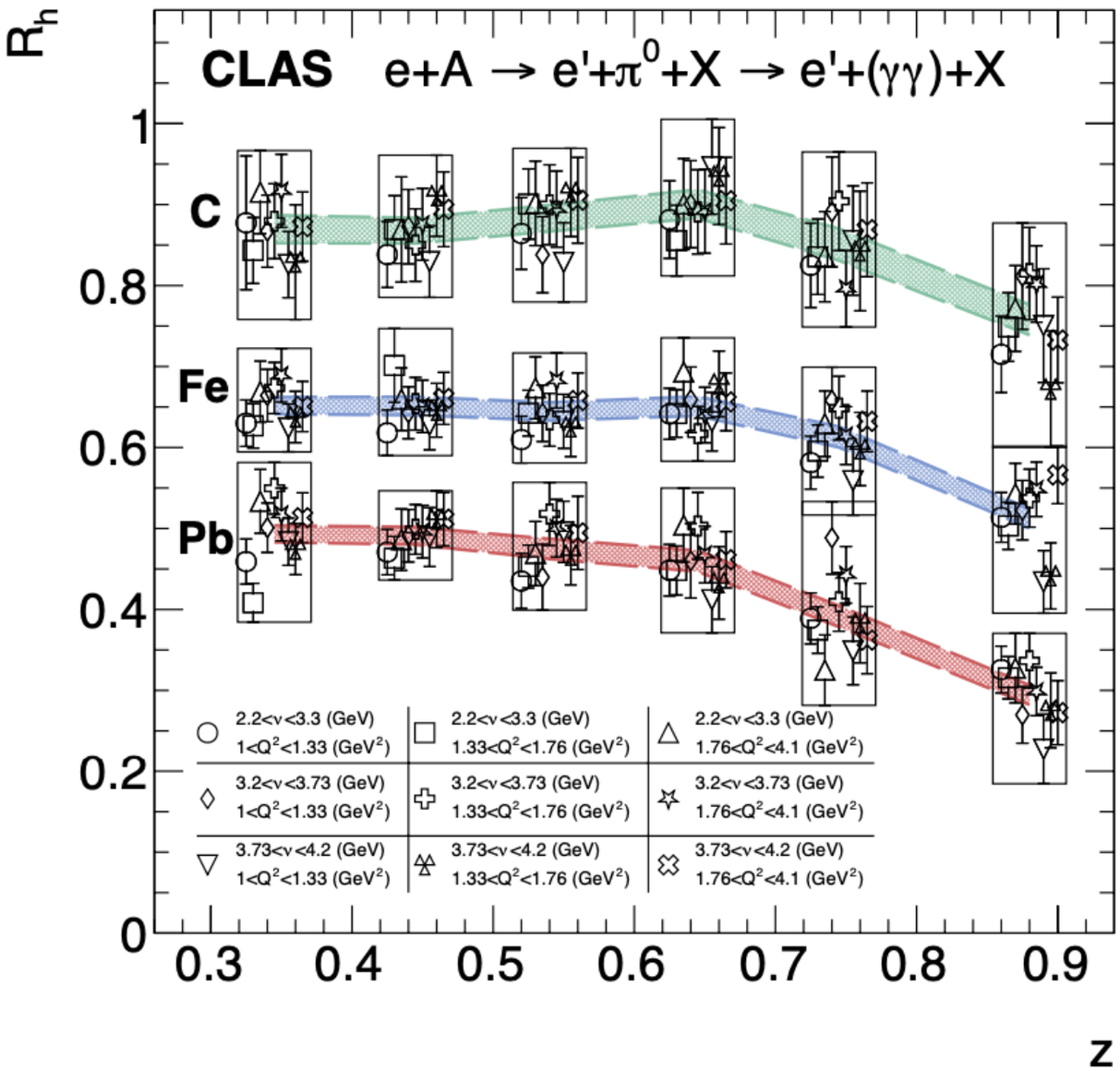
T.Mineeva et al.



- Attenuation depends on nuclear size *A*
- Maximally suppressed for leading hadrons: from 25% on C to 75% on Pb
- No dependence on Q^2 and ν observed
- Quantitative behavior compatible with Hermes

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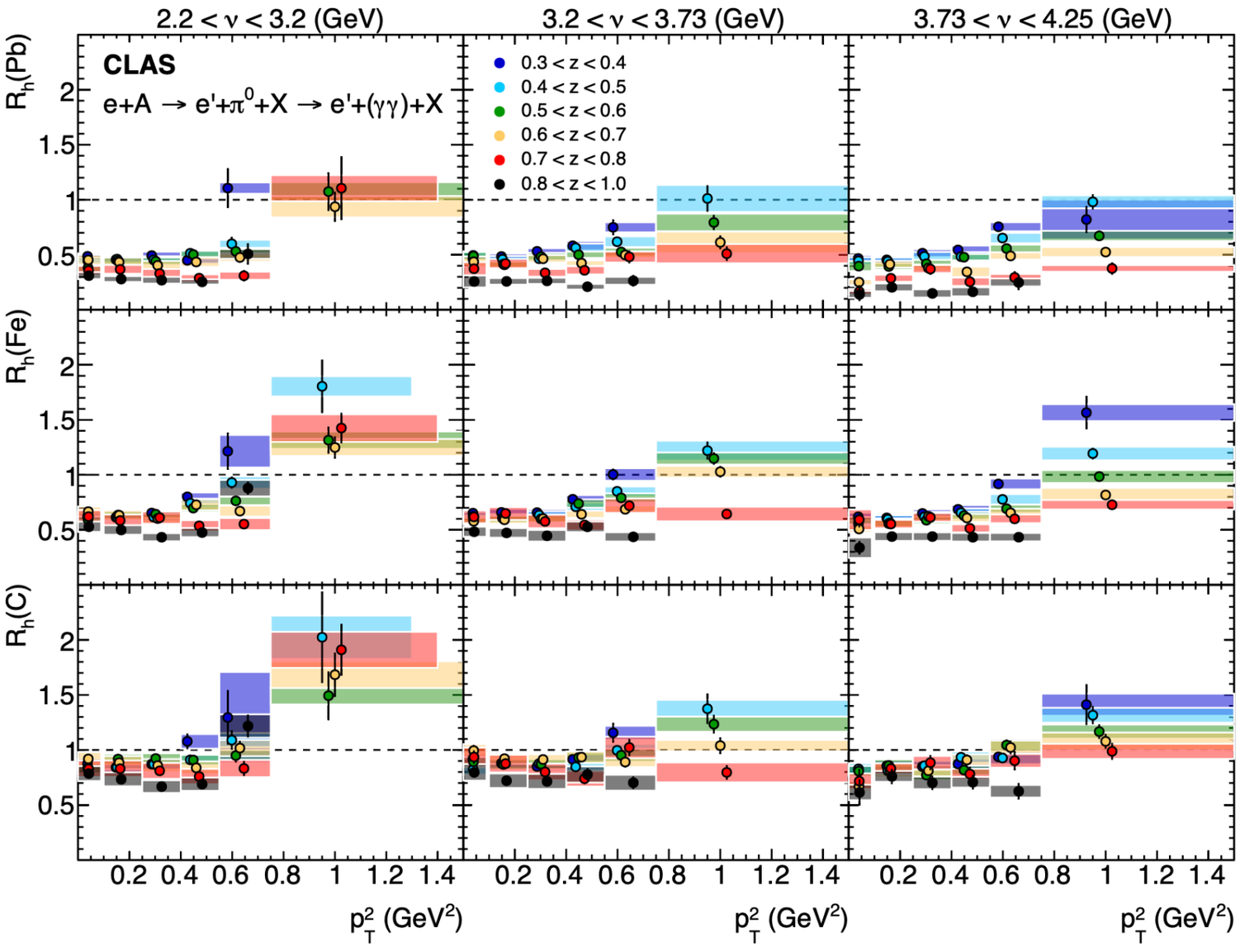
Interpreting Nuclear DIS Data: π^0 multiplicity ratios

3D Multiplicities $R_{\pi 0}(\nu, z, pT^2)$ on ^{12}C, ^{56}Fe, ^{207}Pb to D

T.Mineeva et al.



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Interpreting Nuclear DIS Data: π^0 multiplicity ratios

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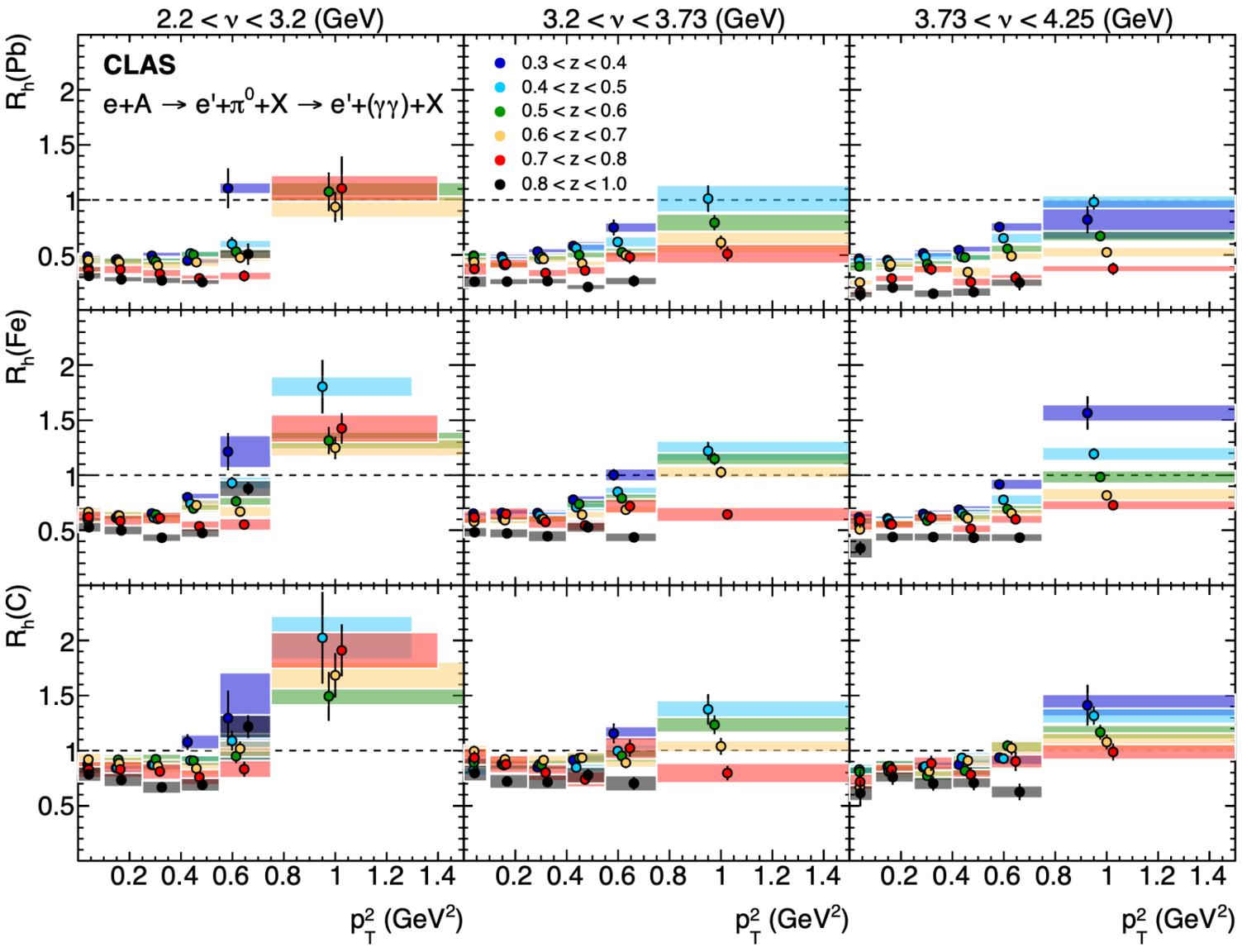
T.Mineeva et al.



- Enhancement of $R_{\pi 0}$ at low *z* and high on *pT2*
- Largest enhancement at hight pT2 for C, lowest - for Pb
- Opposite to CLAS and HERMES data on charged pions

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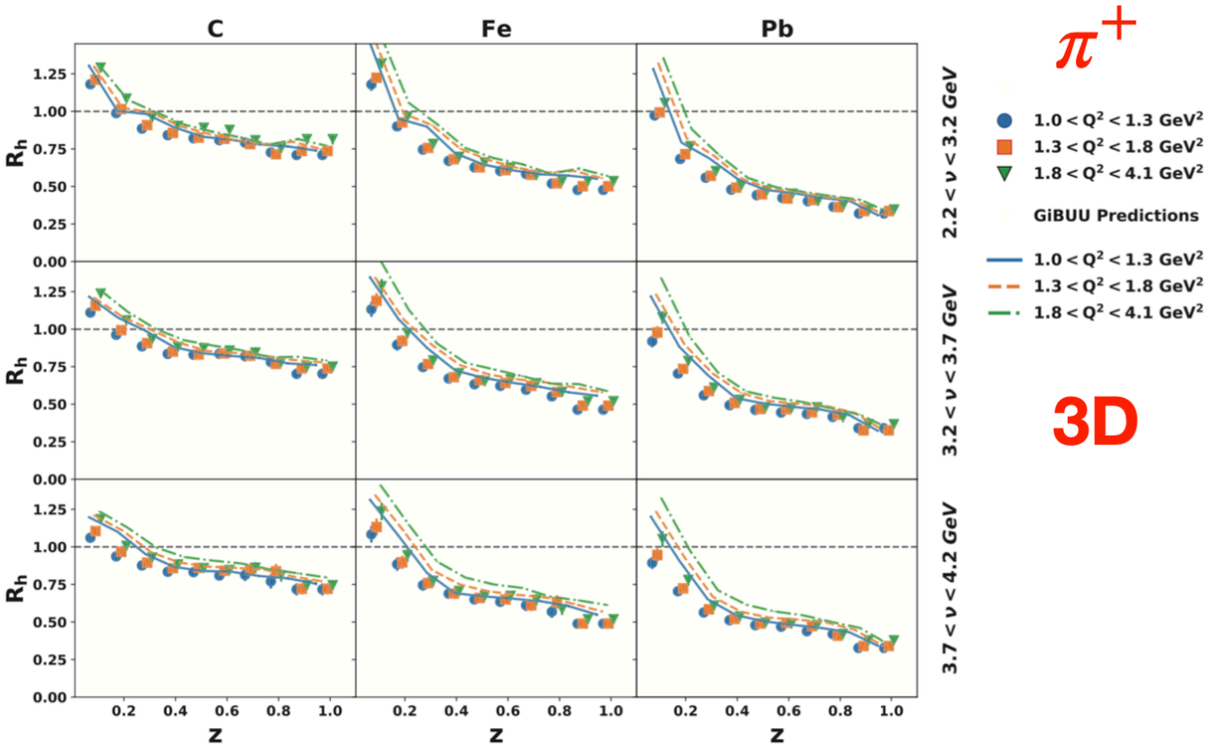
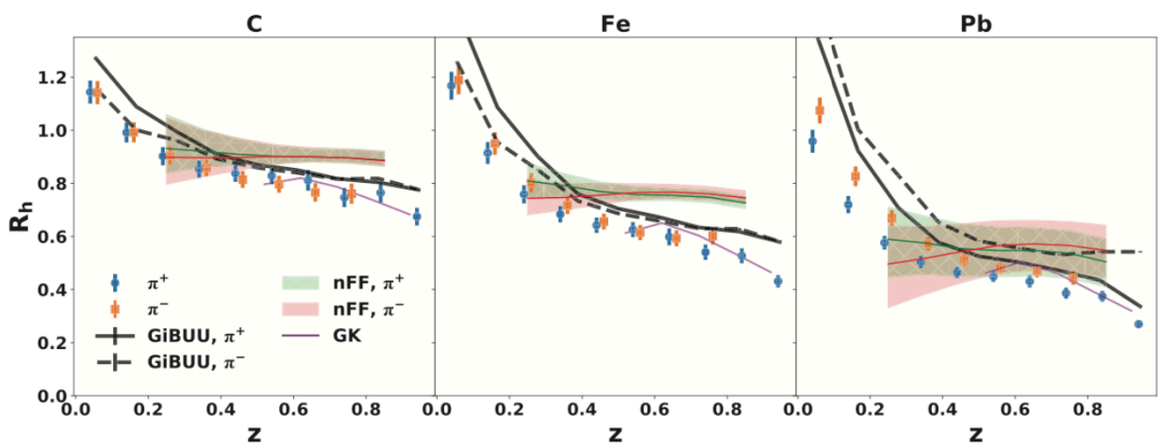
Interpreting Nuclear DIS Data: π^+ and π^- multiplicity ratios

PHYSICAL REVIEW C **105**, 015201 (2022)

Measurement of charged-pion production in deep-inelastic scattering off nuclei with the CLAS detector

S. Morán,[1,3] R. Dupre,[2] H. Hakobyan,[1,52] M. Arratia,[3] W. K. Brooks,[1] A. Bórquez,[1] A. El Alaoui,[1] L. El Fassi,[4,5] K. Hafidi, R. Mendez,[1] T. Mineeva,[1] S. J. Paul,[3] M. J. Amaryan,[36] Giovanni Angelini,[19] Whitney R. Armstrong,[5] H. Atac,[43]





High-precision three-dimensional data is compared to the model predictions; GiBUU and Guiot-Kopeliovich models find semi-qualitative agreement

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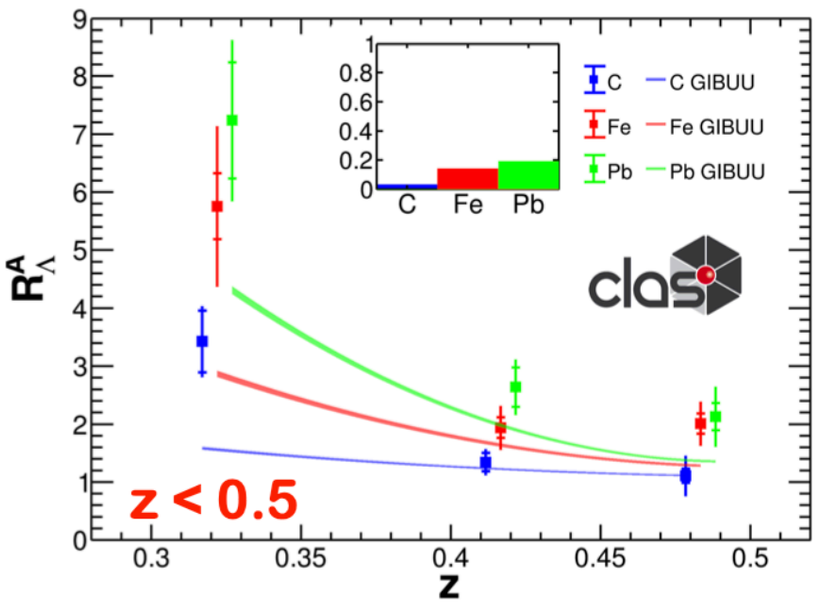
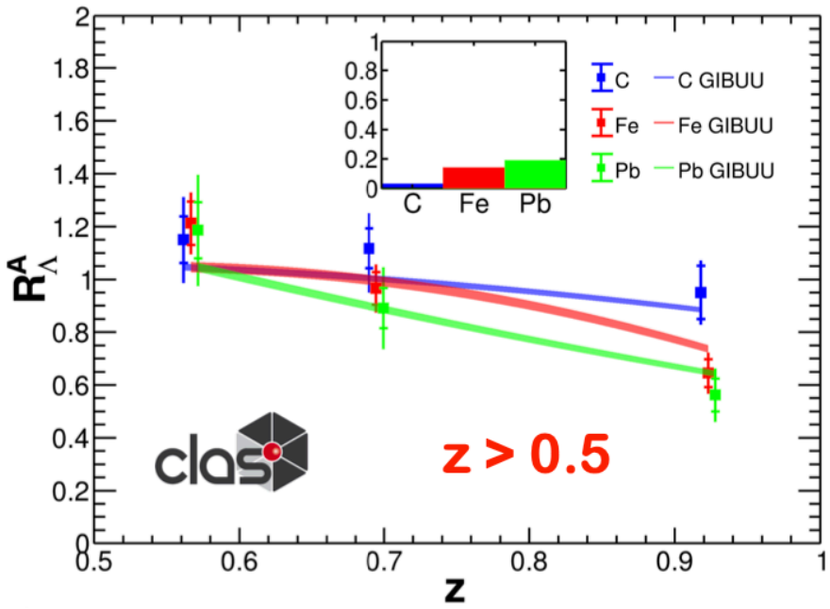
Results from EG2: Λ and p multiplicities

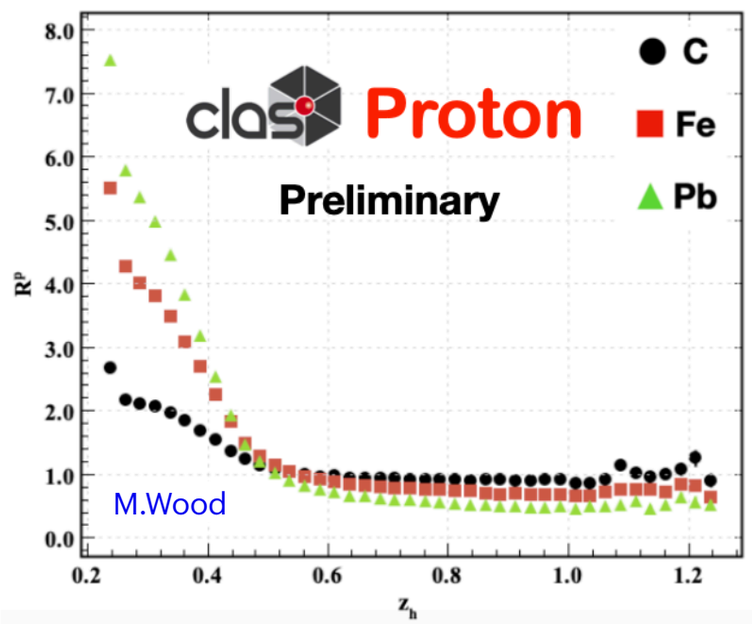
“First Measurement of Λ Electroproduction off Nuclei in the Current and Target Fragmentation Regions”

T. Chetry, L. El Fassi, W.K. Brooks, R. Dupré, A. El Alaoui, K. Hafidi et al (CLAS Collaboration) https://doi.org/10.48550/arXiv.2210.13691





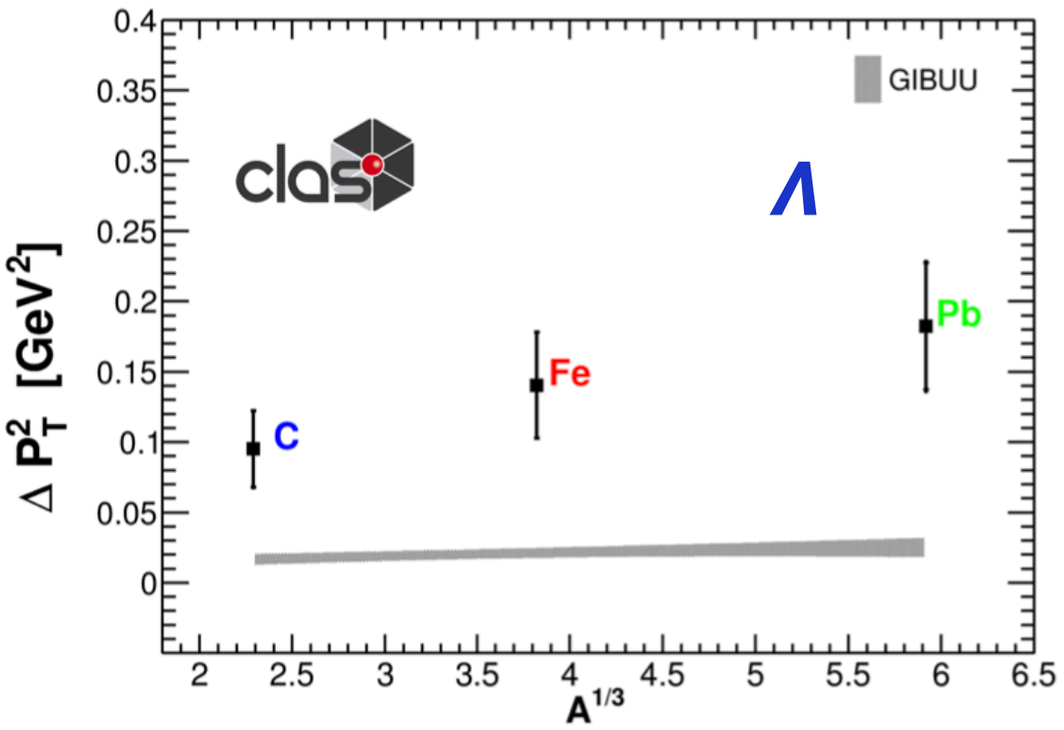
- At low-z there is a “pile up” of events 7 times more than for pion! Underpredicted by GiBUU.
- At high-z there is little attenuation compared to that on the pion. Agrees with GiBUU.



- The multiplicity ratio for the lambda and the proton have the same magnitude and the same pattern of ordering

Results from EG2 $\Delta\langle p_{\mathrm{T}}^2\rangle$

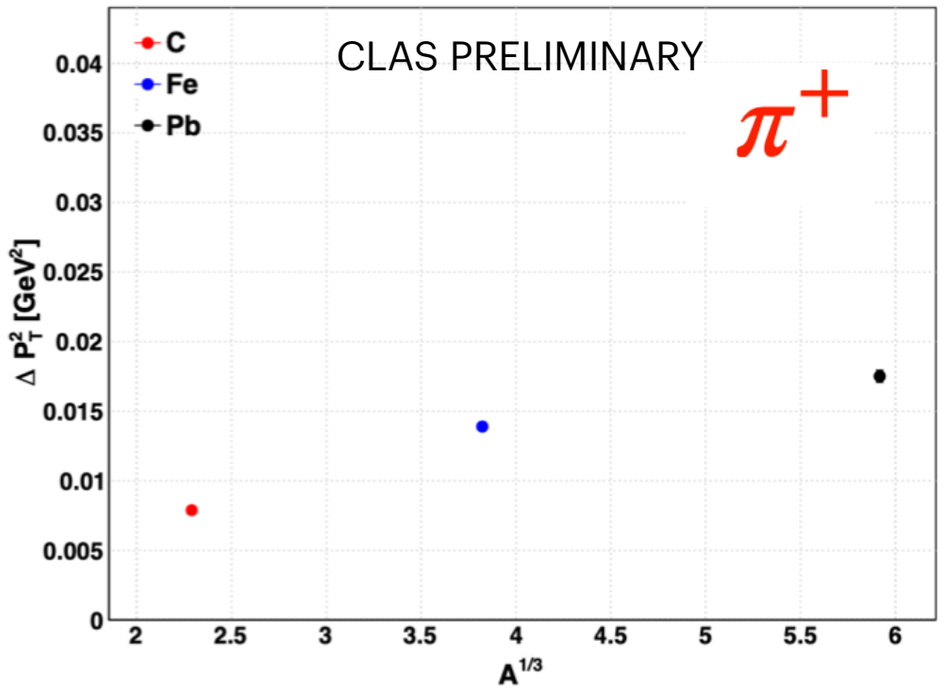
T. Chetry et al.



Maximum for Λ is 0.3 GeV^2

E.Molina Thesis

https://repositorio.usm.cl/handle/11673/53373



Maximum for pions of 0.03 GeV^2

- **GiBUU cannot predict this observable. We apparently do not have the correct physical picture in the case of baryon hadronization**

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Quark Propagation and Hadronization at CLAS12

Approved experiment Run Group E (E-12-06-117) to start in Jan, 2024

PAC rating of the experiment = **A**-, reaffirmed at Jeopardy Review in PAC 48

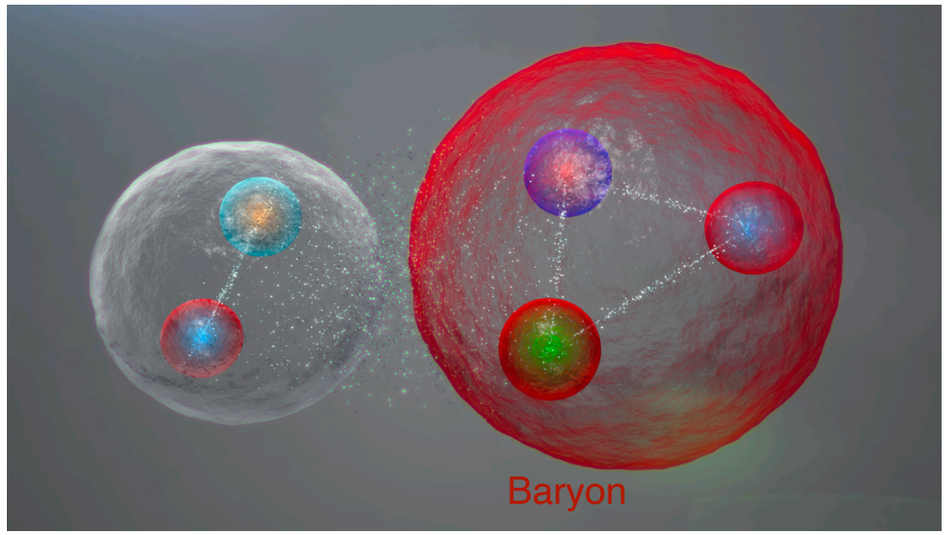
Number of PAC days granted = **60 PAC days**, reaffirmed at JR in PAC 48.

see H.Hakobyan talk on RG-E update

Quark Propagation and Hadronization at CLAS12

hadron	cτ	mass	flavor content	limiting error (60 PAC days)
π^0	25 nm	0.13	uūdd̄	5.7% (sys)
π^+, π^-	7.8 m	0.14	ud̄, dū	3.2% (sys)
η	170 pm	0.55	uūdd̄ss̄	6.2% (sys)
ω	23 fm	0.78	uūdd̄ss̄	6.7% (sys)
η'	0.98 pm	0.96	uūdd̄ss̄	8.5% (sys)
ϕ	44 fm	1	uūdd̄ss̄	5.0% (stat)*
f1	8 fm	1.3	uūdd̄ss̄	-
K^0	27 mm	0.5	ds̄	4.7% (sys)
K^+, K^-	3.7 m	0.49	us̄, ūs	4.4% (sys)
p	stable	0.94	uud	3.2% (sys)
$\bar{p}$	stable	0.94	ūūd̄	5.9% (stat)**
Λ	79 mm	1.1	uds	4.1% (sys)
$\Lambda(1520)$	13 fm	1.5	uds	8.8% (sys)
Σ^+	24 mm	1.2	uus	6.6% (sys)
Σ^-	44 mm	1.2	dds	7.9% (sys)
Σ^0	22 pm	1.2	uds	6.9% (sys)
Ξ^0	87 mm	1.3	uss	16% (stat)*
Ξ^-	49 mm	1.3	dss	7.8% (stat)*

More Luminosity More Acceptance Better Particle ID



First look at GeV-scale meson formation!

Measurements of baryon formation!

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eA kinematics: past & future

CLAS @ 5 GeV: $\sqrt{s}$ = 3.2 GeV

CLAS @11 GeV: $\sqrt{s}$ = 4.6 GeV

CLAS @ 22 GeV: $\sqrt{s}$ = 6.4 GeV

EIC eRHIC: $\sqrt{s}$ = 20 - 140 GeV

HERMES @27 GeV: $\sqrt{s}$ = 7.2 GeV

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Summary

- The microscopic information on space-time dynamics of hadronization can be accessed in DIS using nuclear medium *A* of increasing size

- Transverse momentum broadening and hadronic multiplicity ratio observables provide insight on the lifetime of ‘free’ quark and formation of hadrons

- Extraction of ‘free’ quark lifetime in Brooks-Lopez geometrical model based on simultaneous fit to multiplicity ratios and ΔpT2 to HERMES data

- CLAS at 6 GeV high luminosity data on ^{2}H, ^{12}C, ^{56}Fe, ^{207}Pb:
  - CLAS committee approved paper on three-dimensional π^0 multiplicity ratios
  - Published results on multi-dimensional π^+ and π^- multiplicities (S.Morán et al.)
  - Published results on Λ multiplicity ratios and ΔpT2 (T.Chetry et al.)
  - In process: proton multiplicities (M.Wood), ΔpT2 for π^+ (E.Molina), ΔpT2 for double pion production (M.Barria), π^+ azimuthal dependencies (C. San Martin), ω and η multiplicities (A.Borguez, O.Soto), Bose-Einstein correlations (A.Radic)

- CLAS at 11 GeV: approved CLAS12 experiment (E12-06-117) will provide higher statistics and enable extraction of 4D multiplicities for a large spectrum of hadrons.

Merci !

Backup slides

Interpreting Nuclear DIS Data

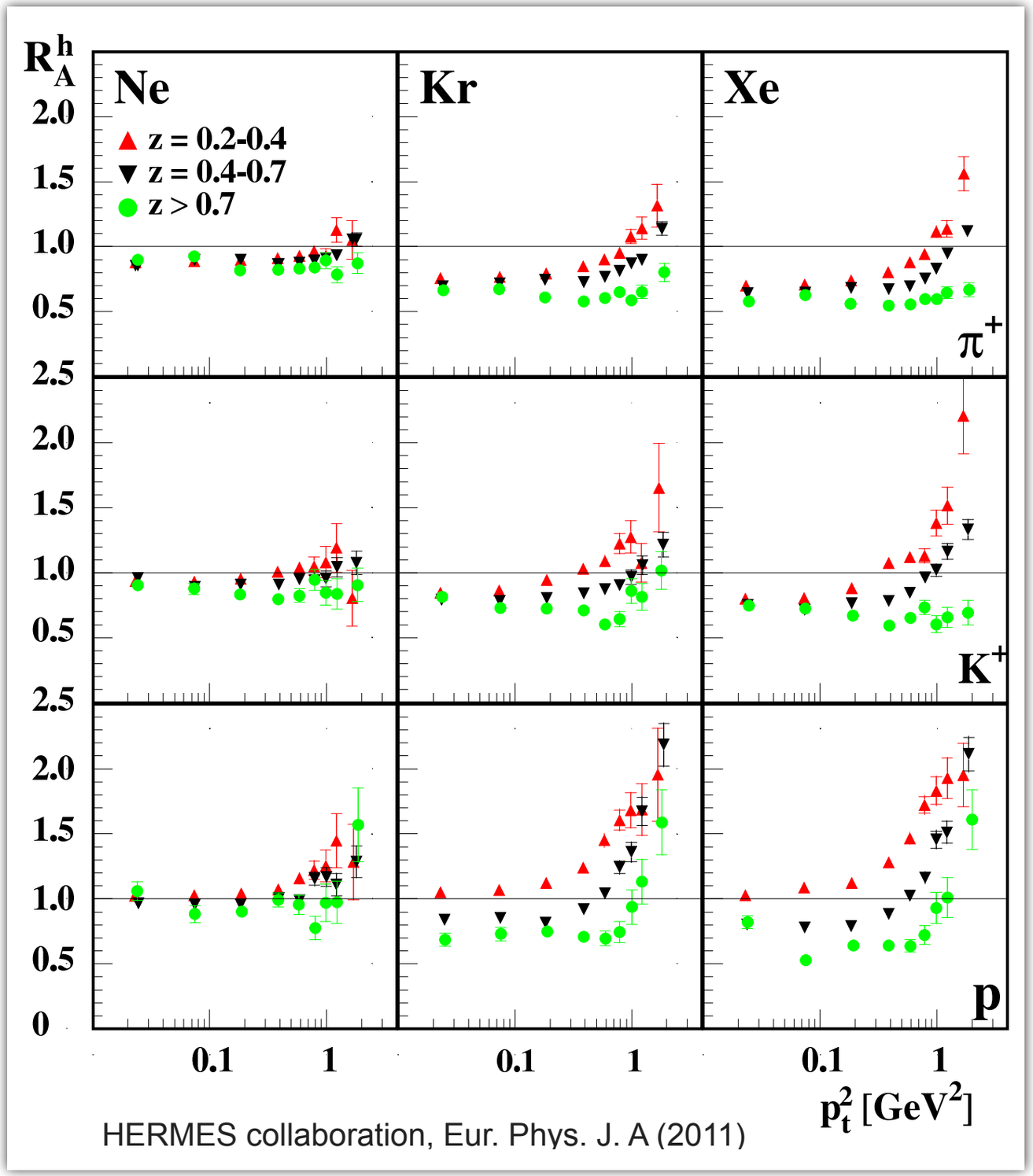
HERMES published results

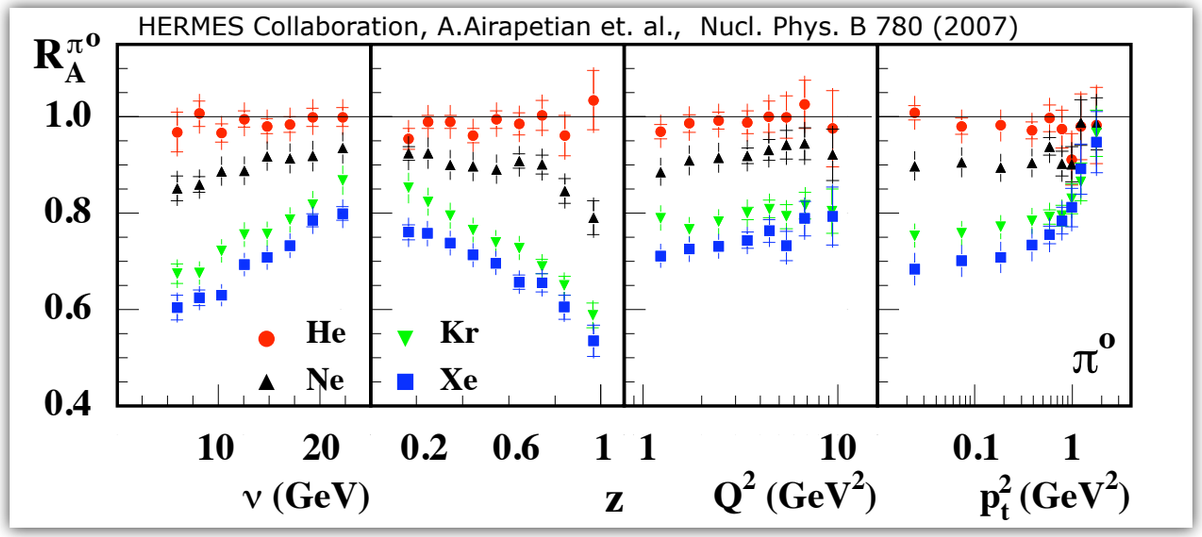
multiplicities R(*z*, pT^2)
integrated over ν, Q^2

Flavor separation: $\pi^{+/-}$, $K^{+/-}$ and p/p̄

2D distributions for charged hadrons

1D extraction of multiplicities for π^0





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Interpreting Nuclear DIS Data

HERMES published results

$$\Delta\langle p_{\mathrm{T}}^2\rangle$$

Maximum for pions of 0.03 GeV^2