Exploring the potential role of diquarks in hadronization using SIDIS on nuclear targets

2022 International Conference on the Structure of Baryons

9 November 2022

Will Brooks

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UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

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CENTRO CIENTÍFICO TECNOLÓGICO DE VALPARAÍSO

Comprehensive review from last year

Progress in Particle and Nuclear Physics 116 (2021) 103835

Contents lists available at ScienceDirect

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp

Review

Diquark correlations in hadron physics: Origin, impact and evidence

M.Yu. Barabanov [1], M.A. Bedolla [2], W.K. Brooks [3], G.D. Cates [4], C. Chen [5], Y. Chen [6,7], E. Cisbani [8], M. Ding [9], G. Eichmann [10,11], R. Ent [12], J. Ferretti [13], R.W. Gothe [14], T. Horn [15,12], S. Liuti [4], C. Mezrag [16], A. Pilloni [9], A.J.R. Puckett [17], C.D. Roberts [18,19,*], P. Rossi [12,20], G. Salmé [21], E. Santopinto [22], J. Segovia [23,19], S.N. Syritsyn [24,25], M. Takizawa [26,27,28], E. Tomasi-Gustafsson [16], P. Wein [29], B.B. Wojtsekhowski [12]

https://doi.org/10.1016/j.ppnp.2020.103835

https://arxiv.org/abs/2008.07630

Diquarks in theory
2.1. Phenomenological quark models
2.1.1. Diquark wave functions
2.1.2. Diquark masses
2.1.3. Light and heavy-light baryons in the diquark model
2.1.4. Compact tetraquarks in the diquark model
2.1.5. Compact pentaquarks in the diquark model
2.2. Continuum schwinger function methods
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2.2.4. *Ab initio* approach
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2.3. Lattice-regularised QCD
2.3.1. Effective masses of diquarks in Landau gauge
2.3.2. Diquark correlations within baryons
2.3.3. Bethe–Salpeter wave function approach
2.3.4. Light-cone distribution amplitudes

Diquarks in theory ....
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2.3.2. Diquark correlations within baryons ....
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2.3.4. Light-cone distribution amplitudes ....

Diquark correlations as an ingredient of nucleon structure have been studied within many frameworks for decades.

They seem to exist in QCD.

But how to prove it experimentally?

Diquarks in experiment and phenomenology ....

3.1. Space-like nucleon form factors ....

3.2. Time-like nucleon form factors..

3.3. Nucleon to resonance transition form factors..

3.4. Multidimensional structure of baryons..

3.4.1. Transverse momentum dependent parton distributions......

3.4.2. Generalised parton distributions..

3.5. Meson structure as a window onto diquark structure ....

3.6. Exotic hadrons and their connection to diquarks ....

3.6.1. Experimental status at a glance ....

3.6.2. Theoretical tools for analyses of exotics ....

3.6.3. Production of exotic states in *pp* and heavy-ion collisions ..

There are experimental indications of diquarks too, but more limited than the theoretical evidence.

How can we improve the experimental evidence?

SIDIS on Nuclear Targets!

A full-QCD lattice study of diquarks was carried out with lattice chiral fermions:

"Diquark mass differences from unquenched lattice QCD"

Yujiang Bi, Hao Cai, Ying Chen, Ming Gong, Zhaofeng Liu, Hao-Xue Qiao, Yi-Bo Yang

https://iopscience.iop.org/article/10.1088/1674-1137/40/7/073106/pdf

Table 2.3.3
Effective masses M_q of u, d quarks, M_s of the strange quark, and those of diquarks (m_{0^+} and m_{1^+}), computed in Landau gauge and extrapolated to the chiral limit.

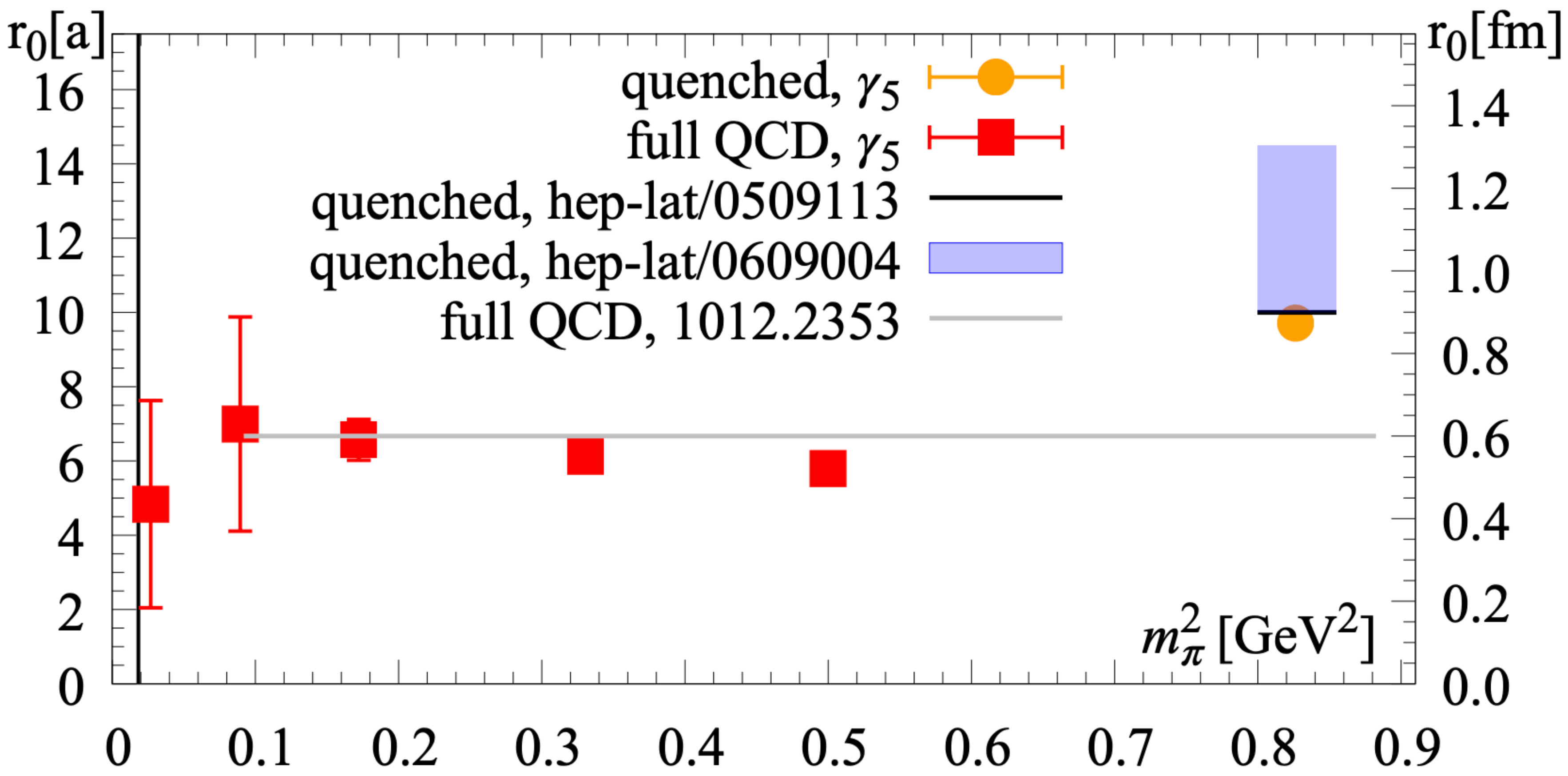
	M_q (MeV)	M_s (MeV)	m_{0^+} (MeV)	m_{1^+} (MeV)	$m_{1^+} - m_{0^+}$ (MeV)
c02	492(19)	575(23)	797(24)	1127(28)	330(35)
c005	427(25)	586(16)	725(20)	1022(44)	297(48)
f004	413(12)	603(15)	690(47)	990(60)	300(76)

The diquark mass can exceed the proton mass (0.7-1.1 GeV). Such large masses are found in models of diverse types.

"Diquark properties from full QCD lattice simulations"

Anthony Francis, Philippe de Forcrand, Randy Lewis, Kim Maltmane

https://link.springer.com/article/10.1007/JHEP05(2022)062



Obtained in a ***gauge-invariant*** way in this work.

The **diquark shape** is estimated to be ***spherical***.

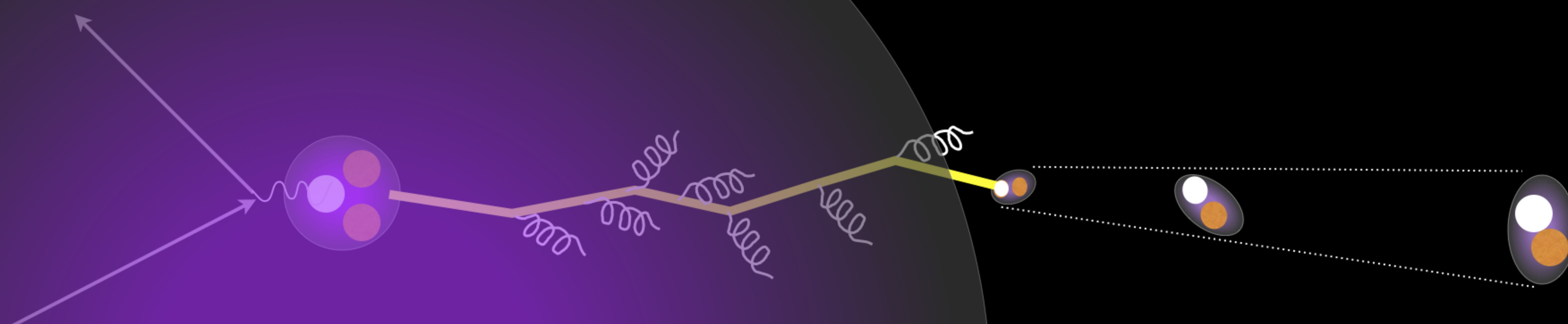
Some diquarks have 'good' flavor, color and Dirac quantum numbers ($\bar{3}_F$, $\bar{3}_c$, $J^P = 0^+$).

"Both one-gluon-exchange and instanton interactions are attractive in this channel."

"Good" diquark size is estimated to be 0.6 fm

By implanting the hadronization process within a nucleus, we gain new dynamical information at ***femtometer distance scales*.**

From the modifications of kinematic distributions for A(e,e'*h*)X scattering, we can infer hadronization mechanisms for hadron *h*.



Important kinematic variables used here

Four-momentum transfer squared Q^2

Energy transfer ν (=E-E' in the laboratory frame)

"Relative energy" $z = z_h = \frac{E_{hadron}}{\nu}$

Note: if the virtual photon is absorbed by a light object like a single quark, $z_h \leq 1.0$, but if it is absorbed by a heavy object, it can be **greater than 1.0**

Momentum transverse to the virtual photon direction p_T

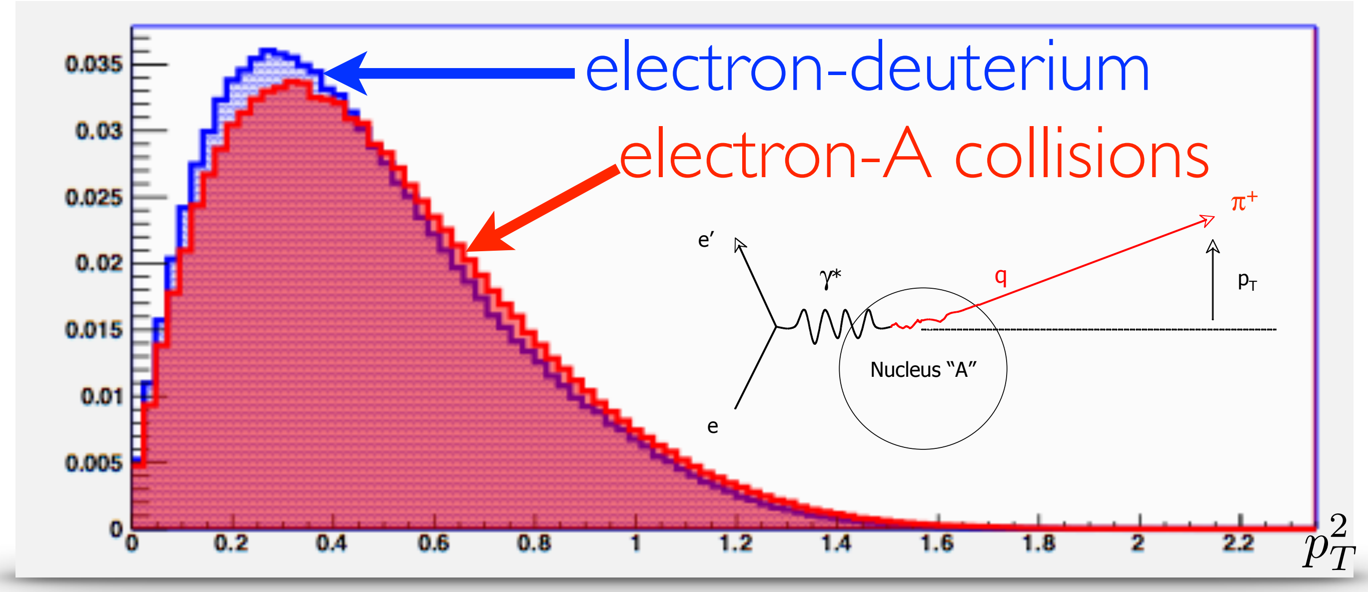
NB, what once was "hadronization" and then "hadron formation" is evidently now more popularly included as "Emergent Hadron Mass" ("EHM")

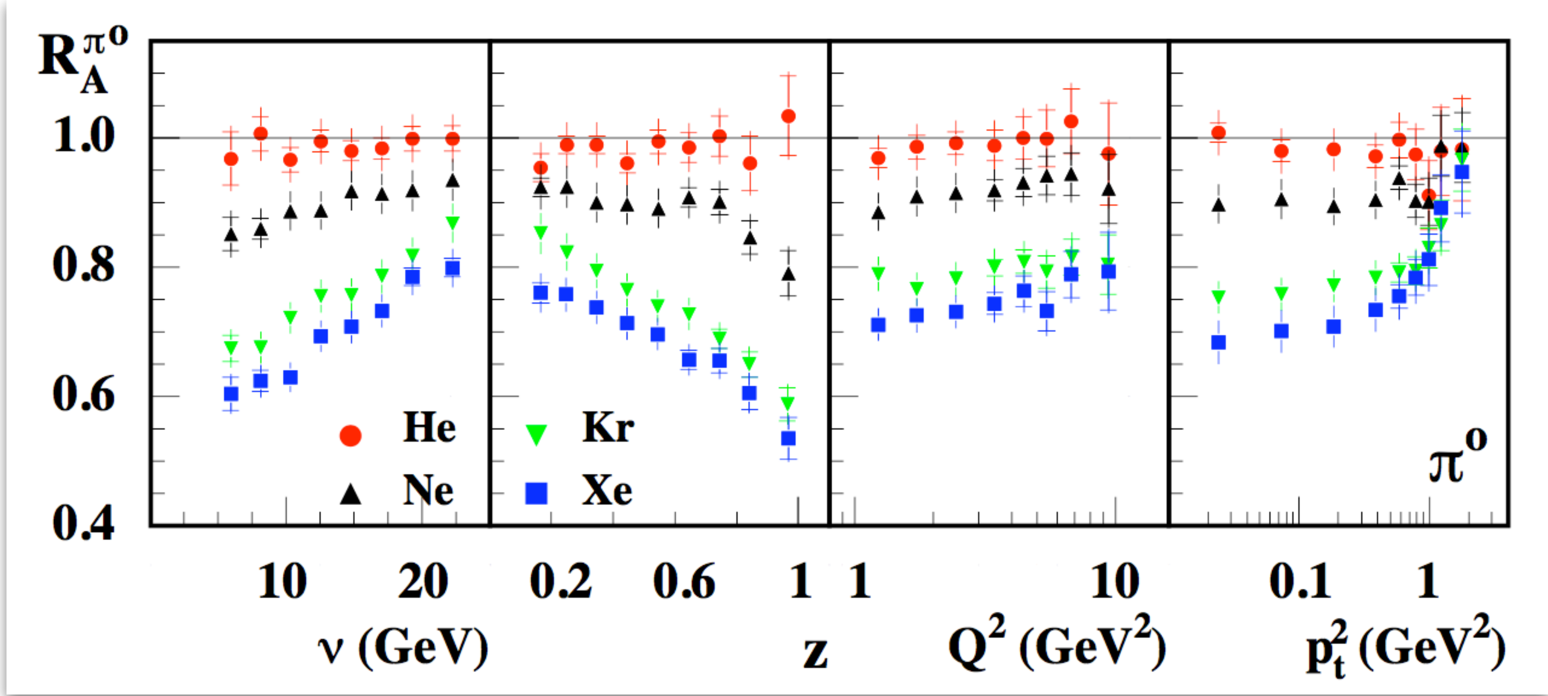
EHM = EHM(time) in these studies, on the fm/c timescale

$$\Delta p_T^2(Q^2, \nu, z_h) \equiv \langle p_T^2(Q^2, \nu, z_h) \rangle |_A - \langle p_T^2(Q^2, \nu, z_h) \rangle |_D$$

Experimental observables

Transverse momentum broadening





Hadronic multiplicity ratio

$$R_M^h(Q^2, \nu, z_h, p_T) \equiv \frac{\frac{1}{N_e(Q^2,\nu)} \cdot N_h(Q^2, \nu, z_h, p_T)|_A}{\frac{1}{N_e(Q^2,\nu)} \cdot N_h(Q^2, \nu, z_h, p_T)|_D}$$

https://arxiv.org/abs/2004.07236

Physics Letters B 816 (2021) 136171

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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]

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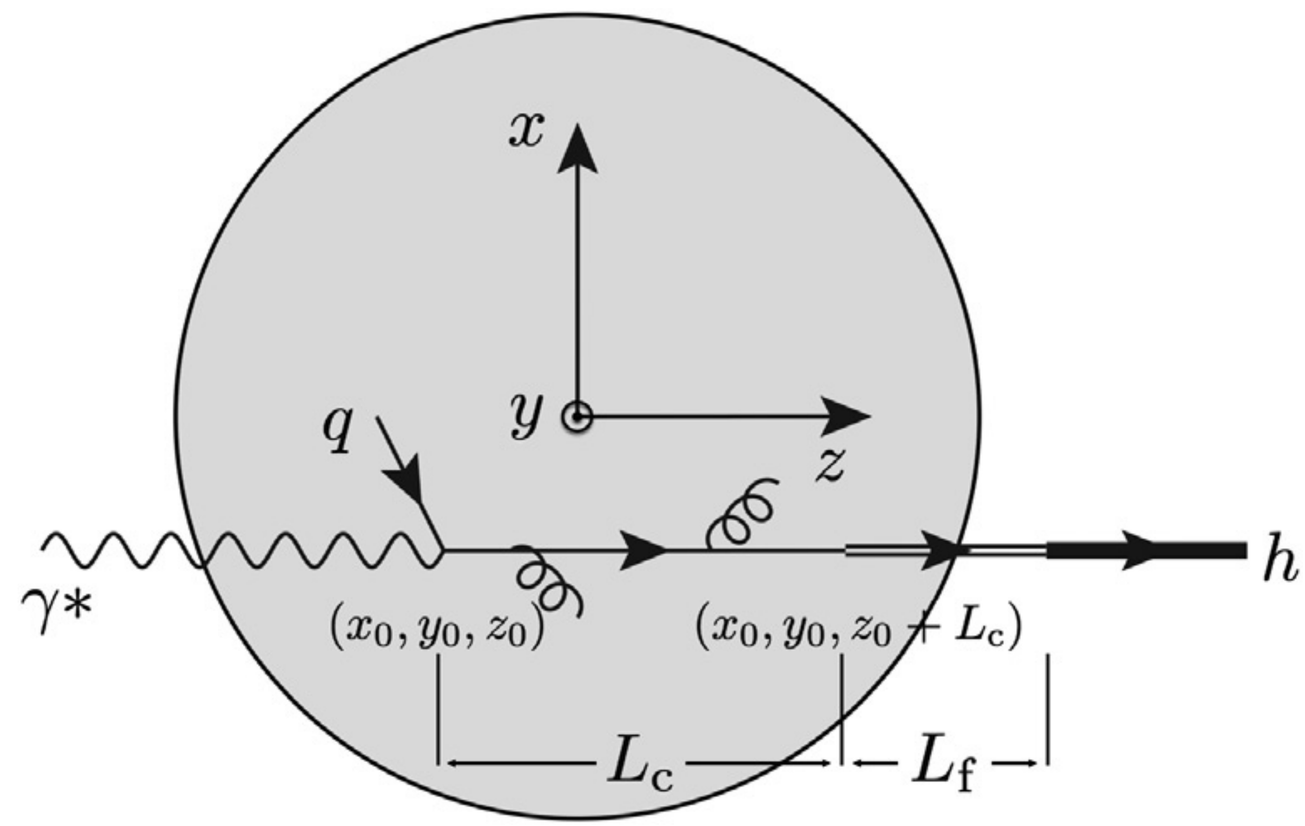
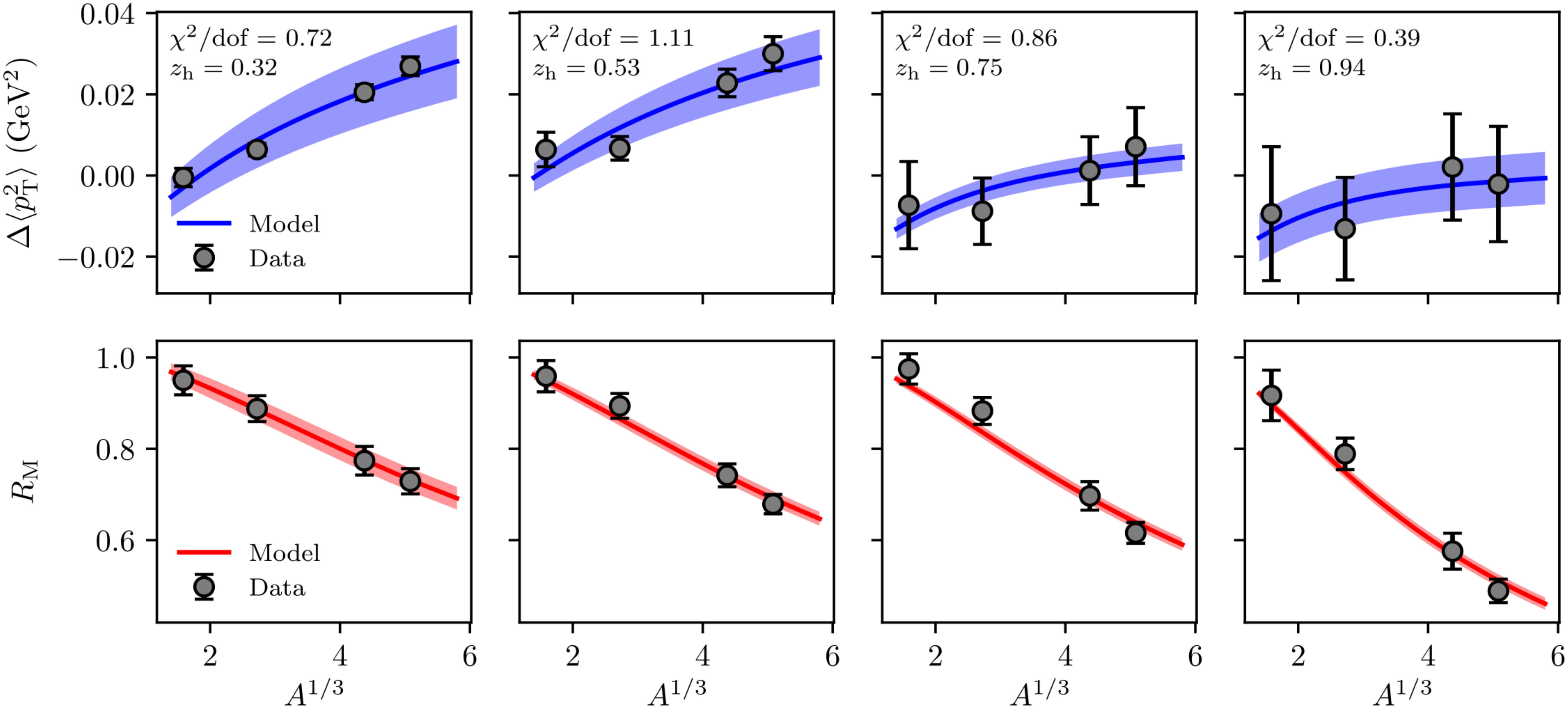
[b] Centro Científico Tecnológico de Valparaíso, Valparaíso, Chile
[c] Department of Physics and Astronomy, University of New Hampshire, Durham NH, USA
[d] Physikalisches Institut, Universität Heidelberg, Heidelberg, Germany

Struck quark moves a distance L_c as a colored object, then becomes a hadron. If the hadron forms inside the medium, it can interact with hadronic cross section.

The color lifetime of the struck quark is distributed stochastically as a decaying exponential.



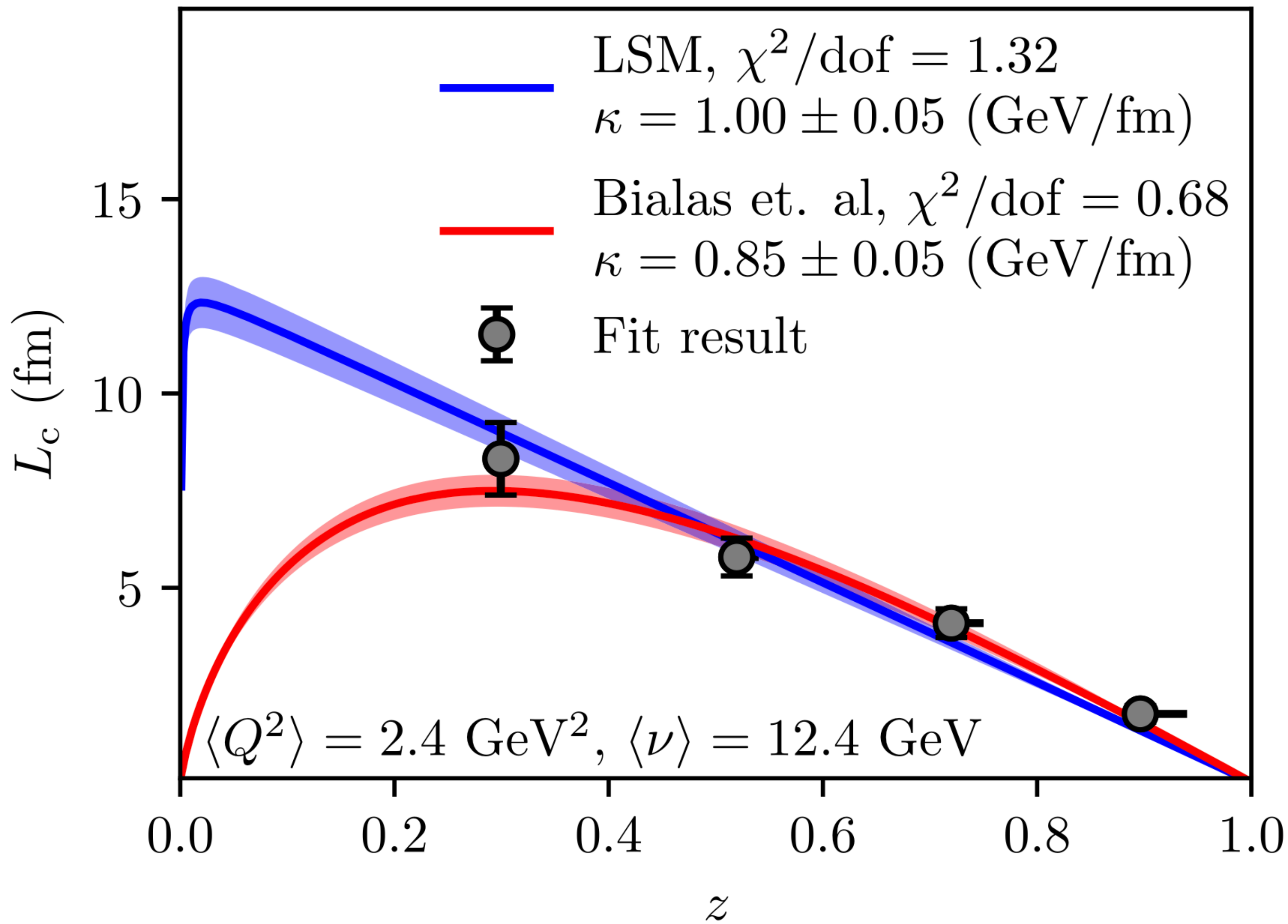
These are the results of the simultaneous fit to two observables



This 3-parameter space-time model that fits two observables simultaneously gives the semi-classical limit of the true quantum-mechanical system

https://arxiv.org/abs/2004.07236

This is a fit of the color lifetime parameter L_c we find to the color lifetime calculated in the Lund String Model



The blue line only describes the **struck quark**

The red line describes the **struck quark <u>and</u> the residual quarks**

<u>Independent determination of the string constant of the LSM!</u>

Message: our space-time model is **consistent** with known **string fragmentation**, and for HERMES the **time range is 2-8 fm/c**.

We believe we have a correct physical picture for **pion formation**.

<u>https://arxiv.org/abs/2004.07236</u>

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

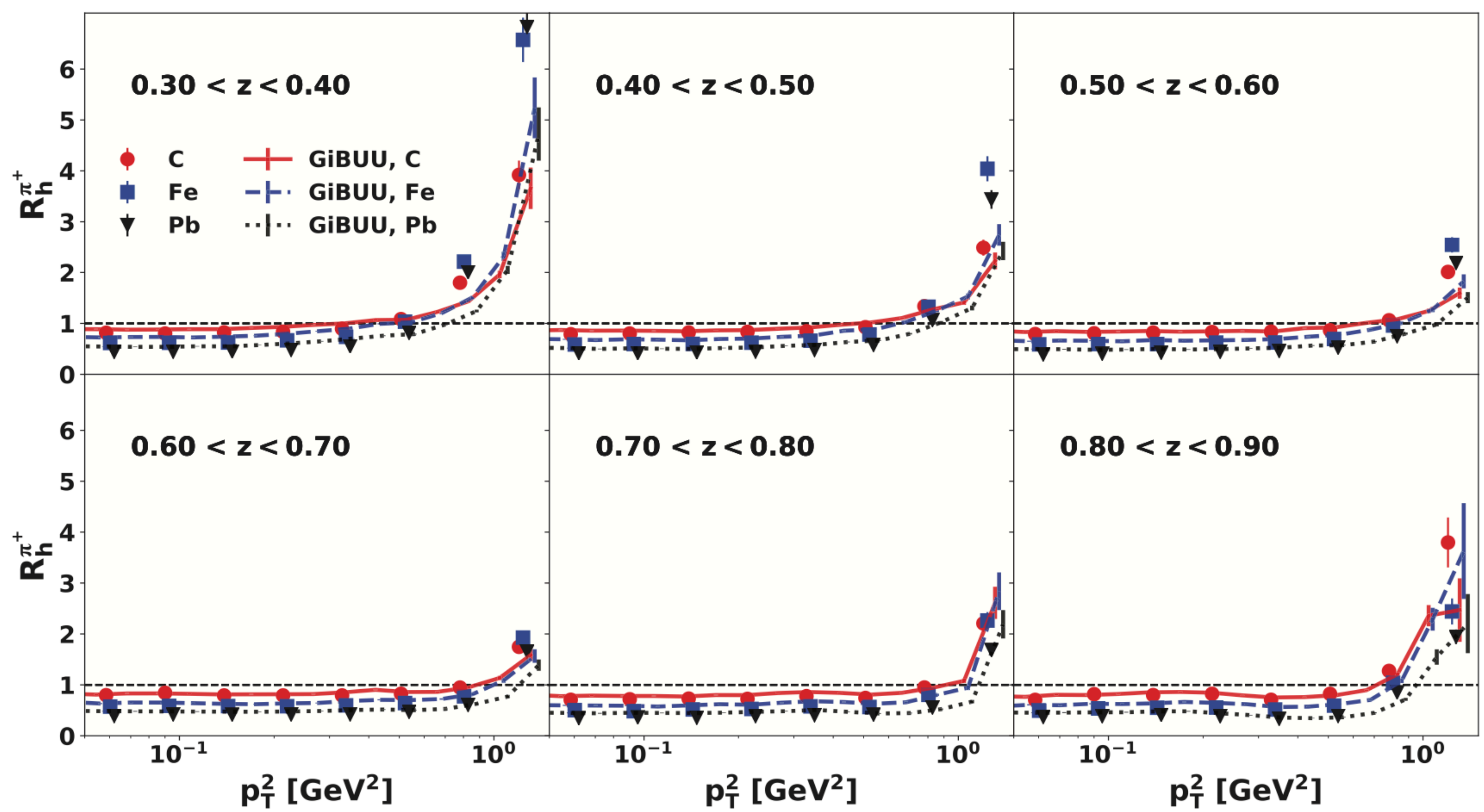
Measurement of charged-pion production in deep-inelastic scattering off nuclei with the CLAS detector

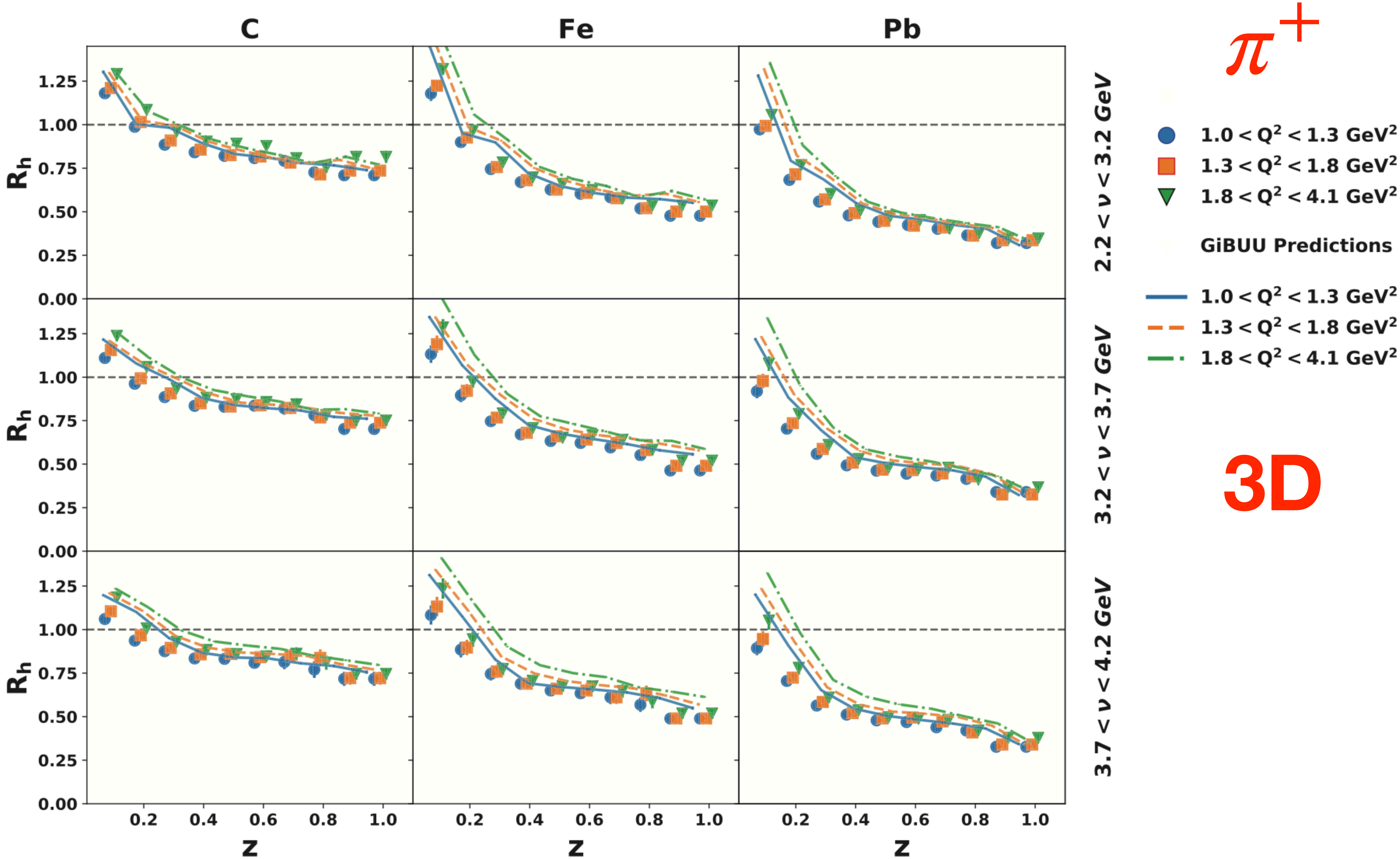
S. Morán,[1,3] R. Dupre,[2] H. Hakobyan,[1,52] M. Arratia,[3] W. K. Brooks,[1] A. Bórquez,[1] A. El Alaoui,[1] L. El Fassi,[4,5] K. Hafidi, R. Mendez,[1] T. Mineeva,[1] S. J. Paul,[3] M. J. Amaryan,[36] Giovanni Angelini,[19] Whitney R. Armstrong,[5] H. Atac,[43]

In this paper we compare high-precision CLAS data with the predictions of the **GiBUU** and **GK** models for charged pions in a *three dimensional analysis*, finding semi-quantitative **agreement**.

2D

Lines are *predictions* from the GiBUU event generator with standard parameters





π^+

3D

Lines are *predictions* from the GiBUU event generator with standard parameters

Phys. Rev. C 105, 015201 (2022)

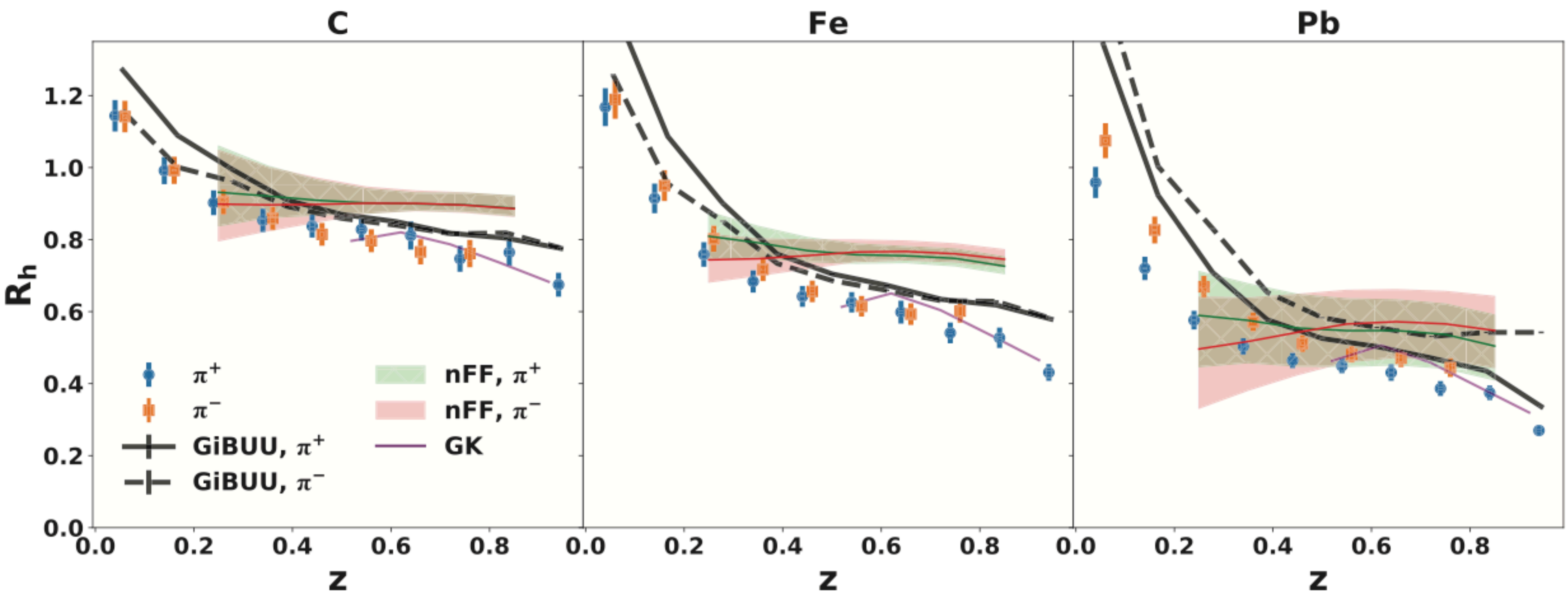
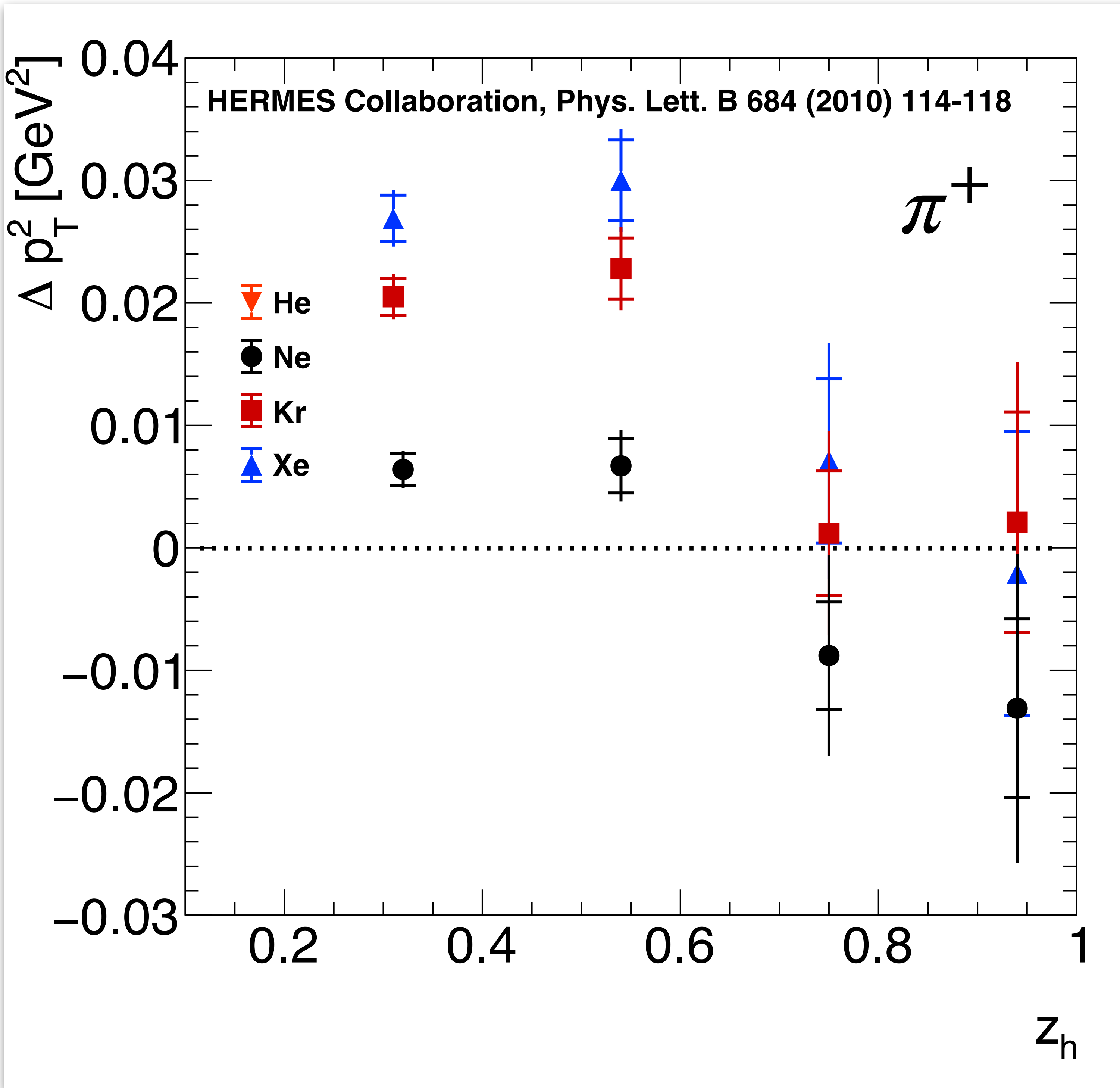


FIG. 1. Multiplicity ratio of π^+ and π^- as a function of z; the three different panels show results for C, Fe, and Pb targets, respectively. The error bars represent the quadrature sum of systematic and statistical uncertainties, which is dominated by the systematic uncertainties that are partially correlated point to point. The points have a small horizontal shift for better visualization. The lines correspond to model calculations from GiBUU, GK, and the LIKEn21 nFFs. The bands represent the uncertainty of the LIKEn21 nFF set. The numerical values of the data points and associated errors of this figure are shown in Table II in the Appendix section of the article.

Message: GiBUU can describe up to 3D **pion** production
We *believe* we have a correct physical picture.

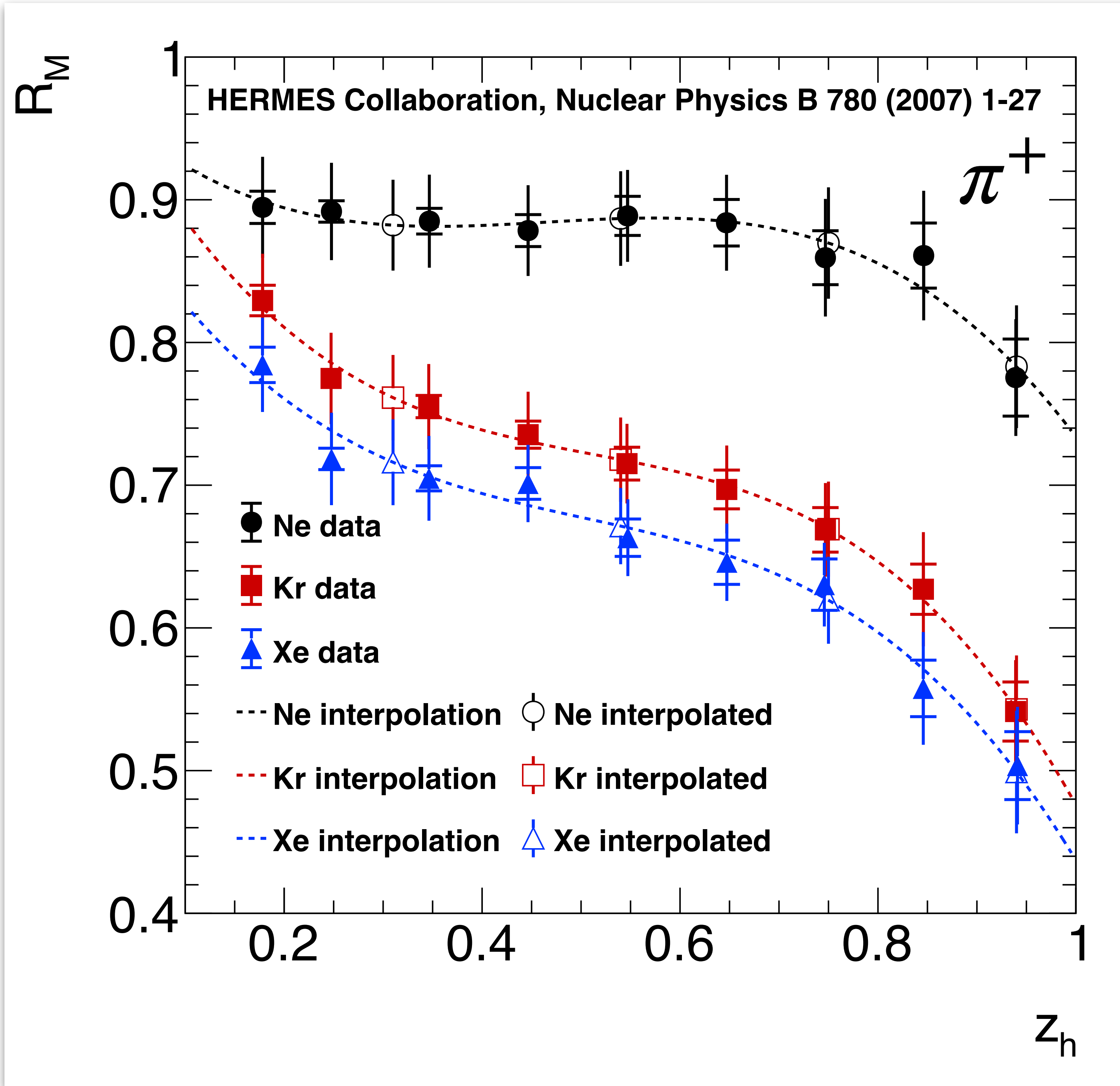
GiBUU uses hadronic degrees of freedom, it incorporates formation times, "prehadron" interactions,[3] color transparency, and nuclear shadowing. These ingredients have been postulated to be necessary to describe nuclear modification of hadrons produced in DIS by the HERMES and EMC experiments. The default parameters of GiBUU 2019 are used.

Hermes data for p_T broadening vs. $z_h = E/\nu$



Note for later discussion: maximum is 0.03 GeV²

Hermes data, hadronic multiplicity ratio vs. z_h=E/ν



Note for later discussion: for this range in z_h,

$$R_M^\pi < 1$$

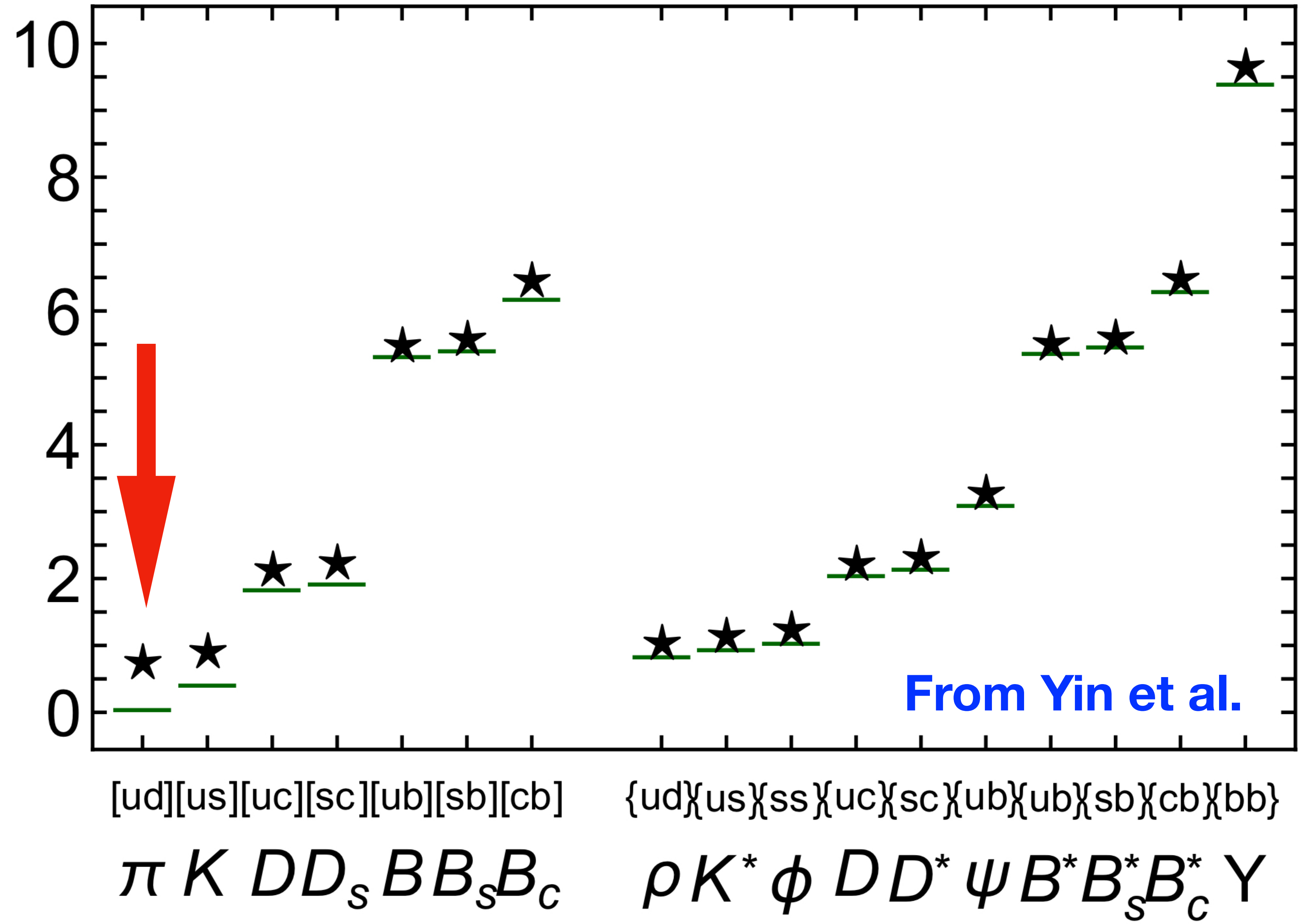
Always attenuation, never enhancement

Masses of ground-state mesons and baryons, including those with heavy quarks

Pei-Lin Yin,[1,*] Chen Chen,[2,†] Gastão Krein,[2] Craig D. Roberts,[3,‡] Jorge Segovia,[4] and Shu-Sheng Xu[1]

arXiv 1903.00160

Phys. Rev. D 100, 034008 (2019)



The ud diquarks are heavy, as seen previously in the lattice calculation.

FIG. 2. Comparison between computed masses of diquark correlations and their symmetry-related meson counterparts: diquarks – (black) stars and mesons – (green) bars.

Experimental evidence of diquark scattering from the HERMES data for SIDIS on nuclear targets

"***Multidimensional*** study of hadronization in nuclei"
arXiv:1107.3496v3 [hep-ex] 13 Sep 2011
Eur. Phys. J. A47:113, 2011

Interpreting HERMES Nuclear DIS DATA: <u>MESONS</u>

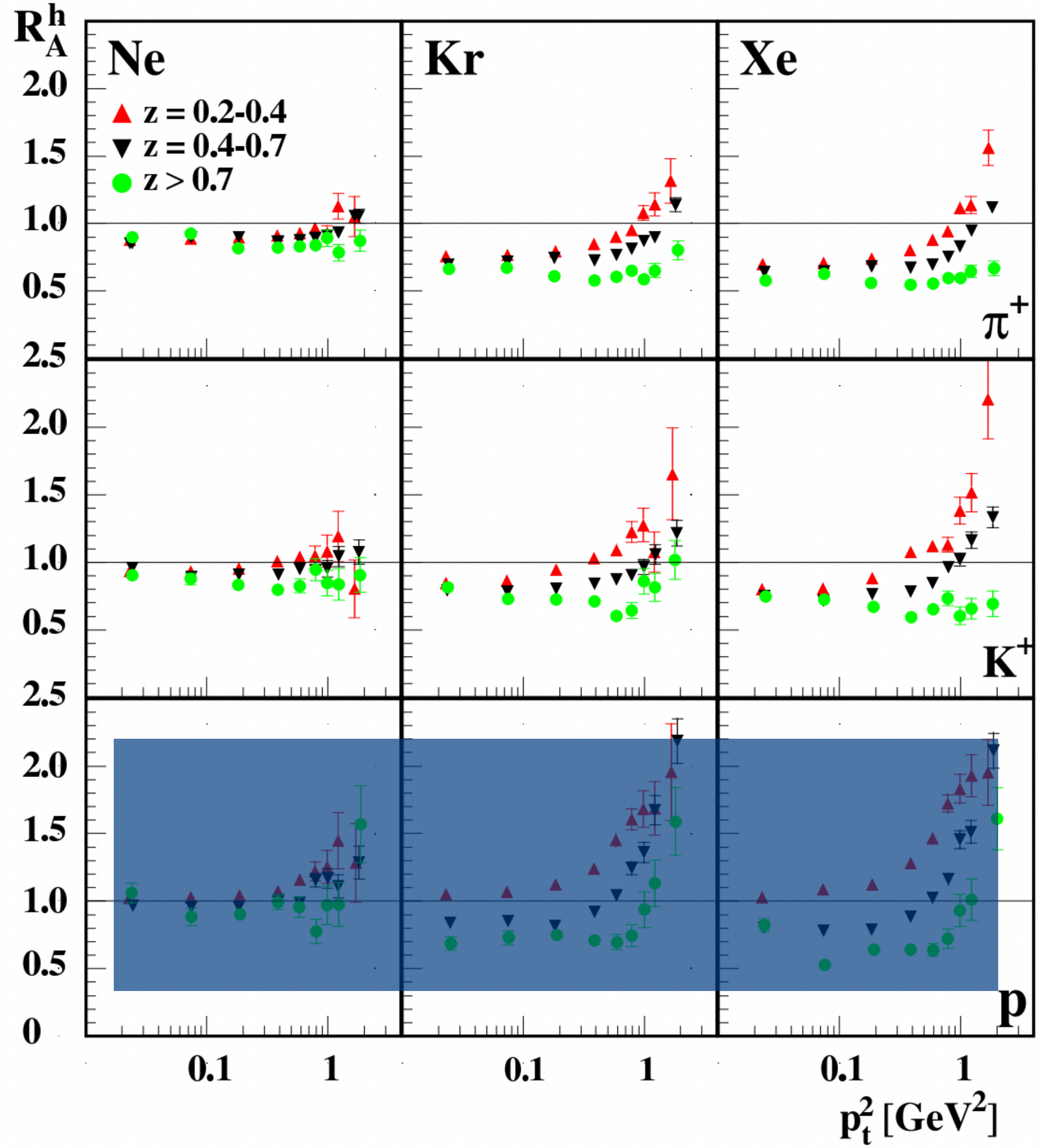
The multiplicity ratio measures effects of the nuclear medium.

"No nuclear effects" means R=1.0

$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_A}{\left(\frac{N^h(\nu,Q^2,z,p_t^2)}{N^e(\nu,Q^2)}\right)_D}$$

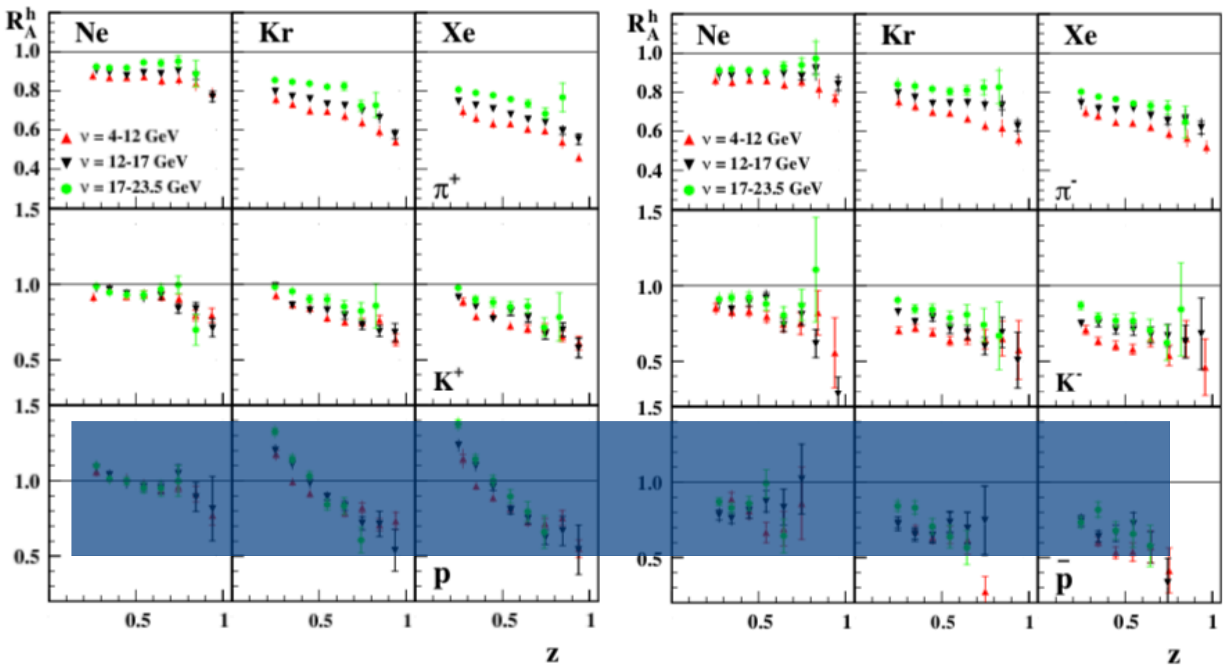
Most basic indicator is p_T dependence of multiplicity ratio.

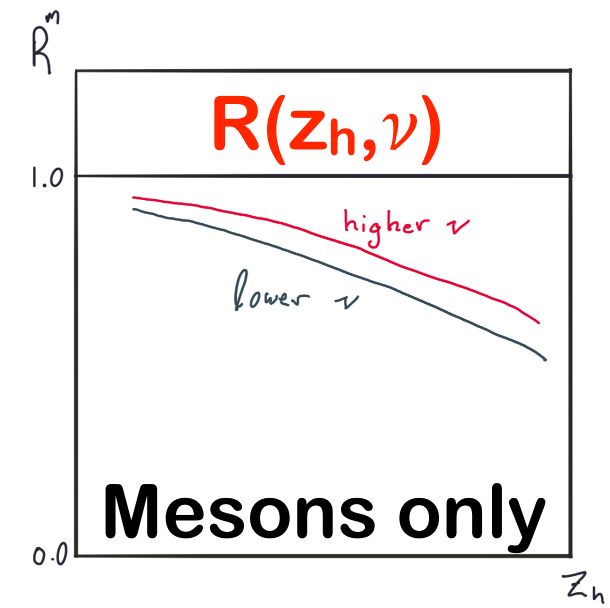
R>1 at high p_T because particles that interact with the medium acquire more p_T than those that don't interact as much.



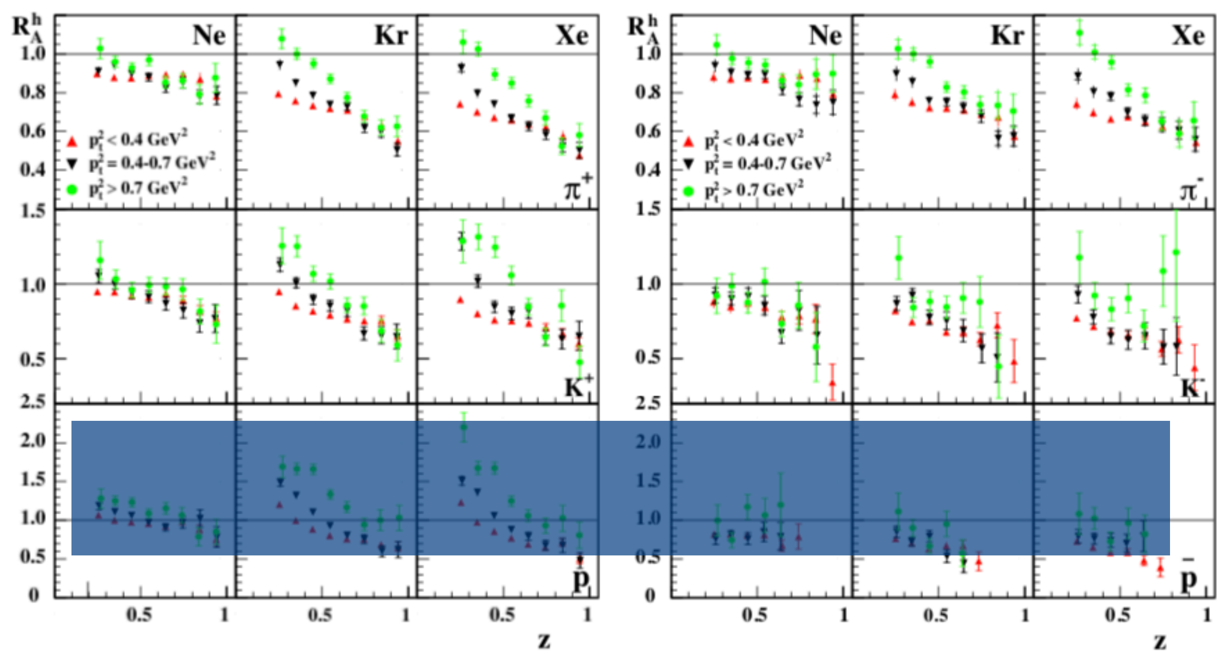
"Interact" = hadronic interaction + partonic multiple scattering

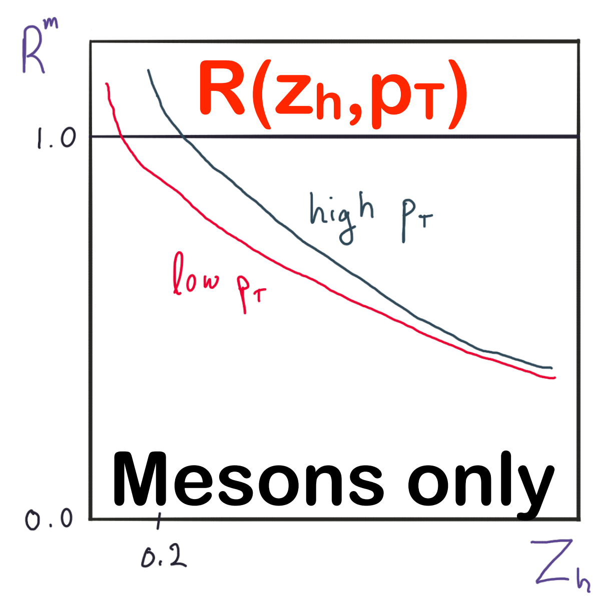
Empirically, from these plots, low-z <u>mesons</u> acquire more p_T than high-z.



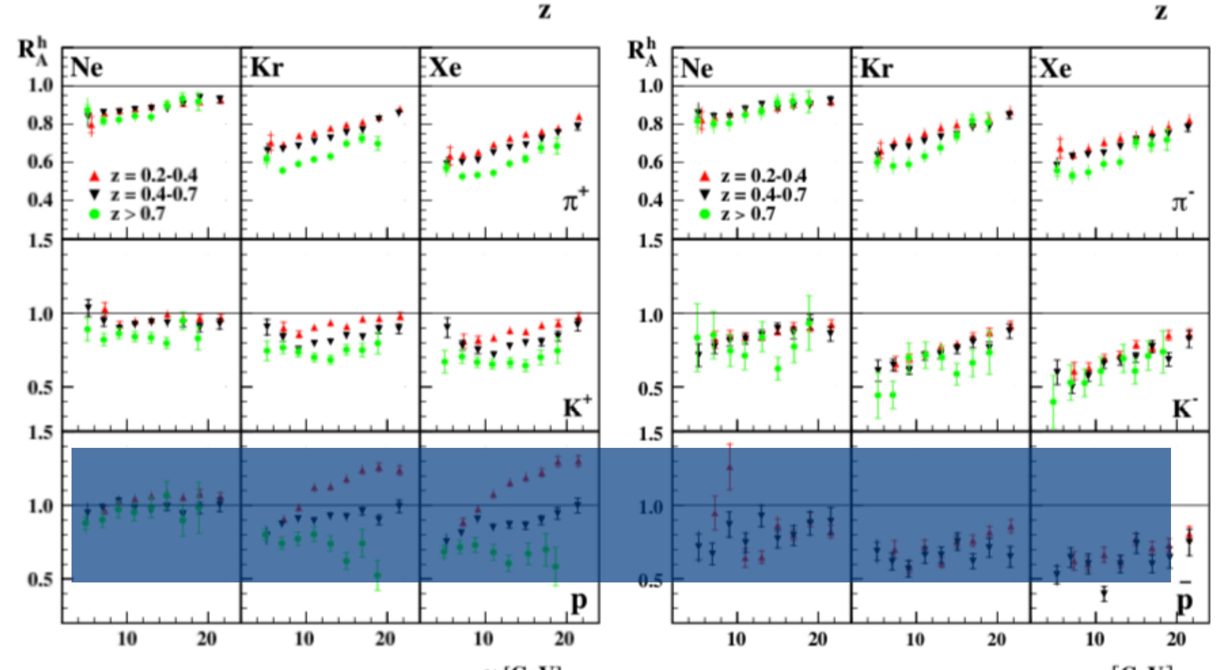


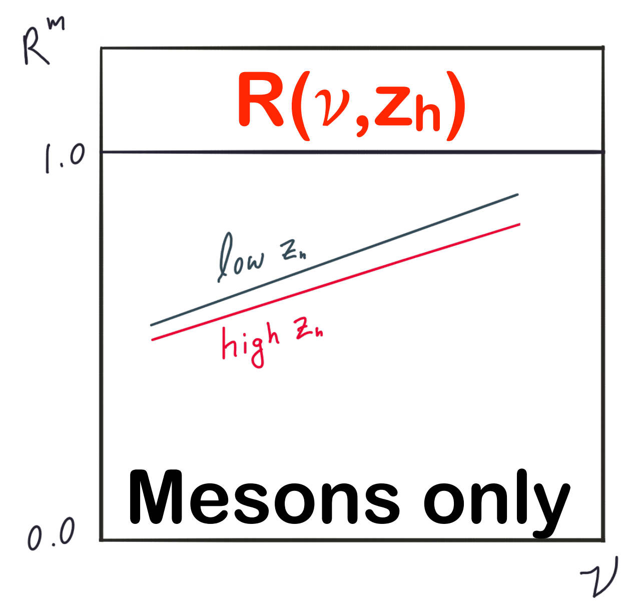
Integrated over pT, so always < 1. At higher ν, less attenuation because of time dilation of color lifetime.





Not integrated over pT, so can exceed 1. Exceeds 1 faster for higher pT, so crossing point is pT dependent.





Time dilation is proportional to ν. Slow approach to 1.0 at infinite ν. Color lifetime goes to zero at high z, so high z is attenuated more.

So far, we have a reasonable qualitative interpretation for mesons that explains multi-dimensional behavior.

Let's see if we can understand HERMES baryon data!

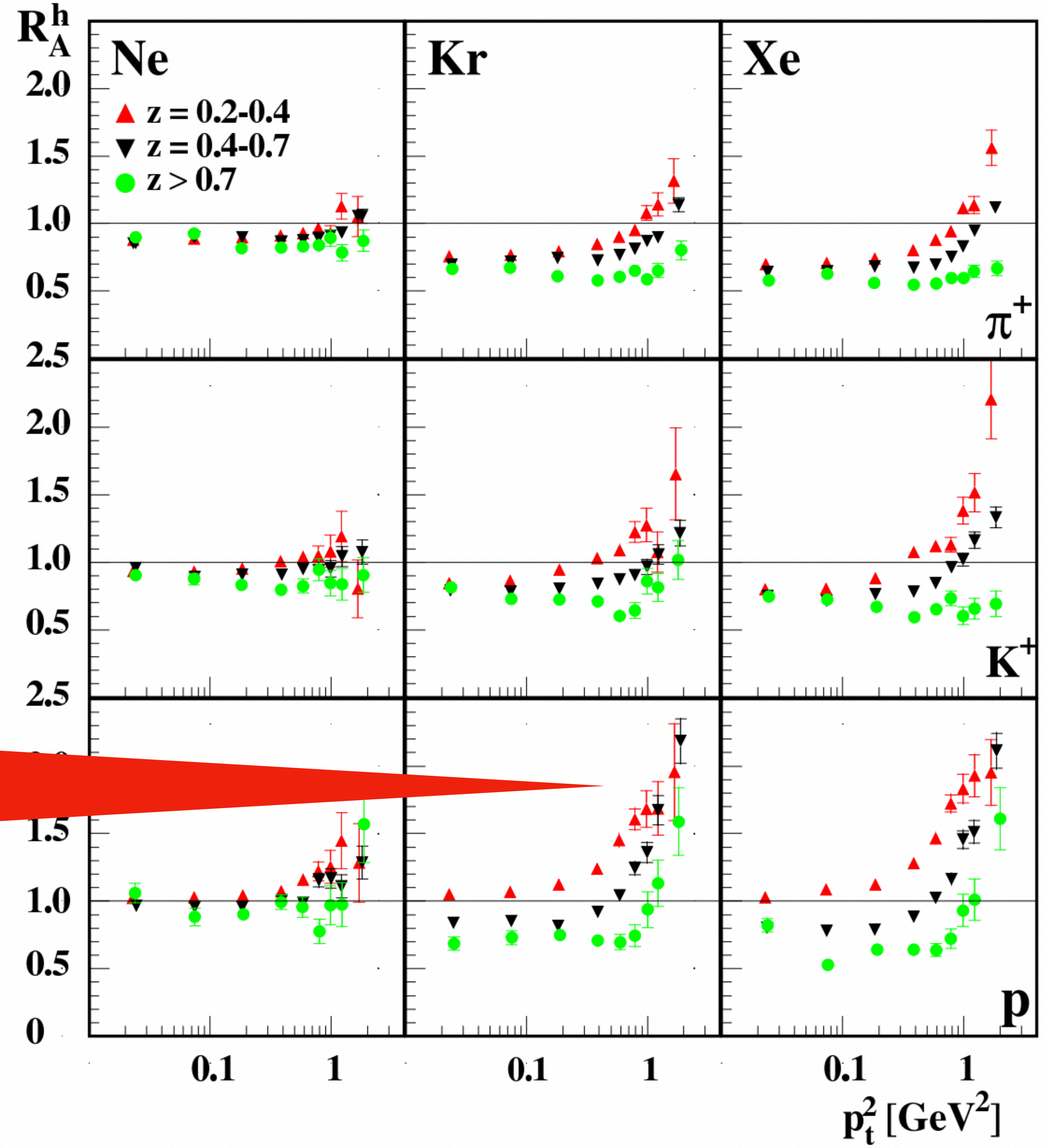
Interpreting HERMES Nuclear DIS DATA: MESONS

The multiplicity ratio measures effects of the nuclear medium. "No effects" means R=1.0

$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\frac{N^h(\nu, Q^2, z, p_t^2)}{N^e(\nu, Q^2)}\right)_A}{\left(N^h(\nu, Q^2, z, p_t^2)\right. \cdots}$$

The ordering in z seen for mesons *disappears* at high p_T for protons.

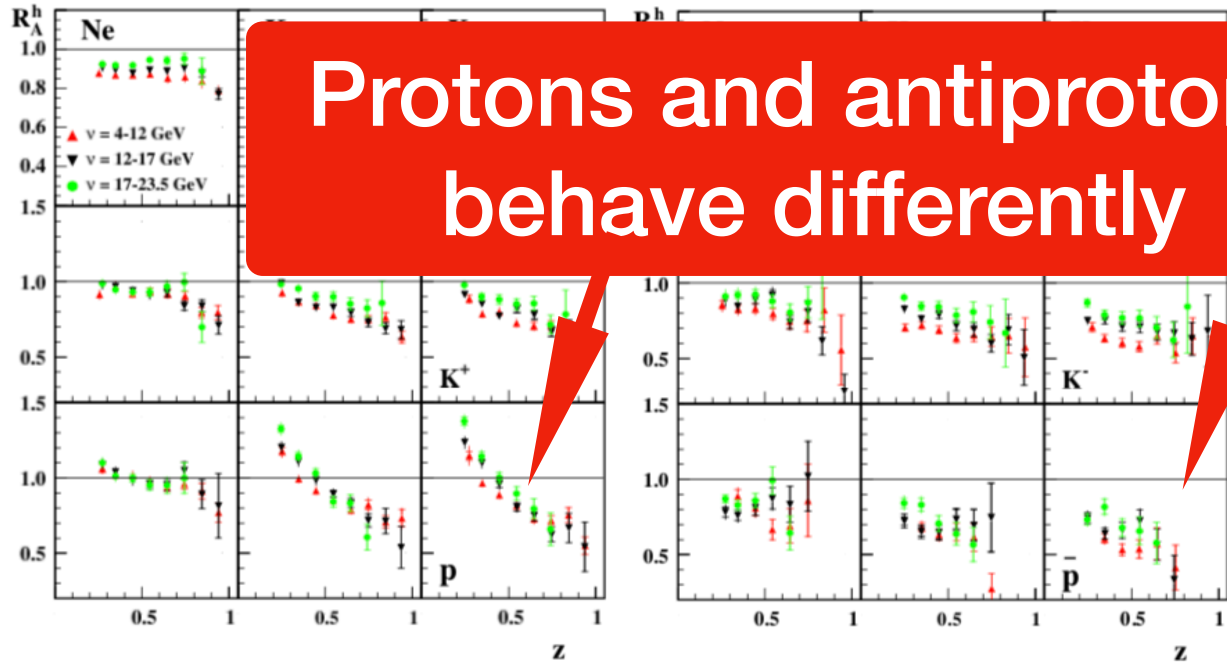
<u>A strong interaction</u> occurs at all values of z at high p_T.



of forming hadrons, + quark energy loss.

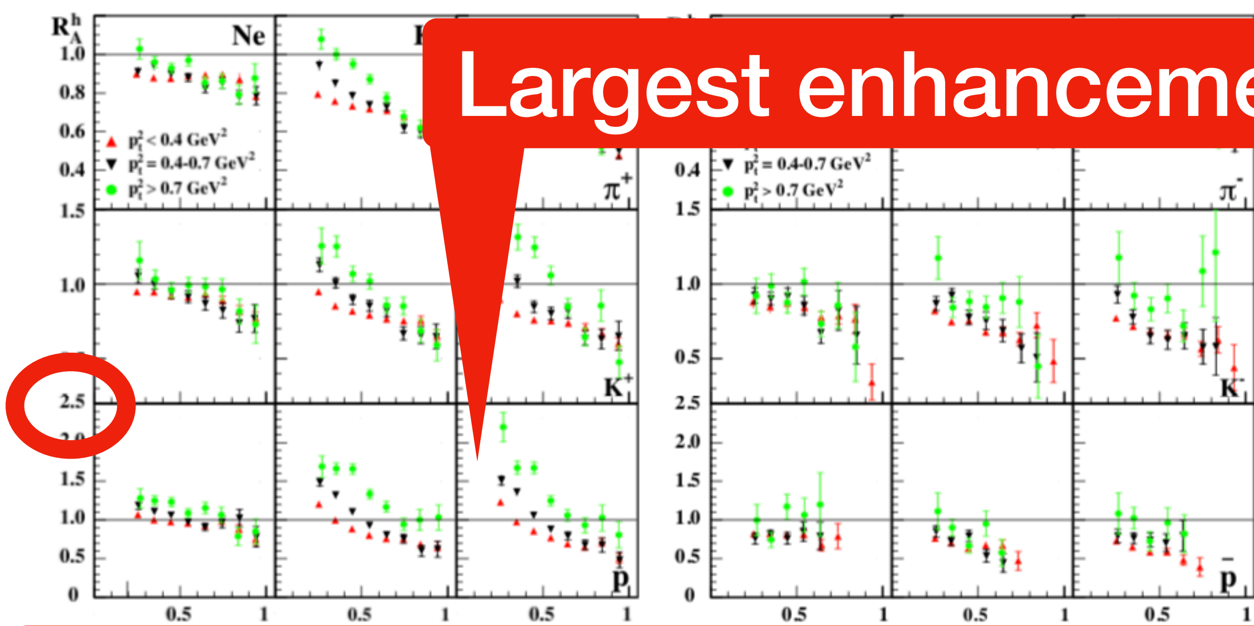
Empirically, from these plots, low-z mesons acquire more pT than high-z.

Enhancement at high pT mostly caused by hadronic interactions at low z.

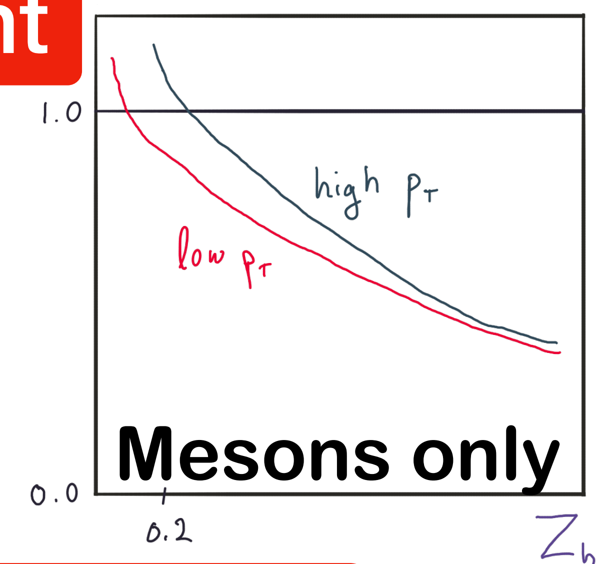


Protons and antiprotons behave differently

Integrated over pT, so always < 1. At higher ν, less attenuation because of time dilation of color lifetime

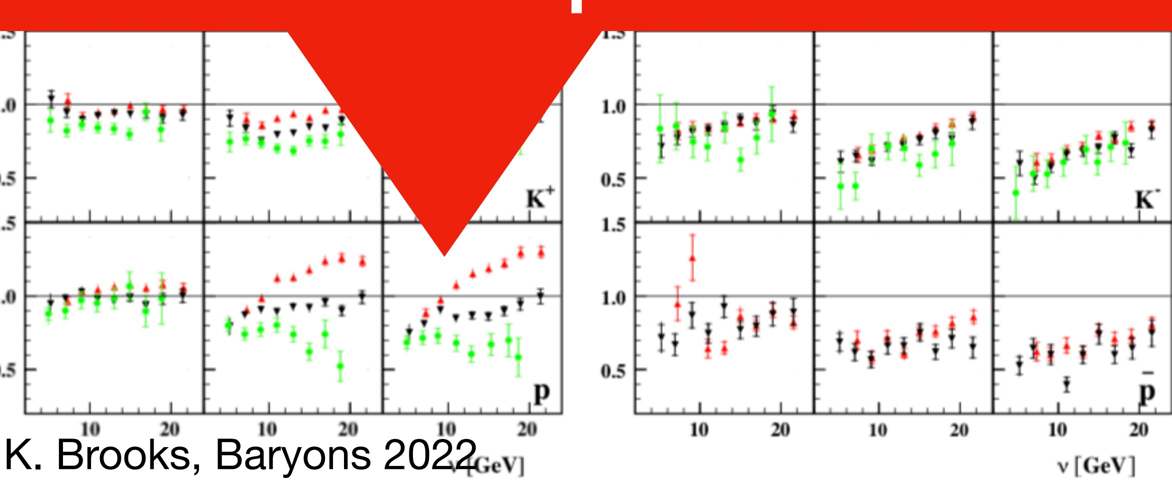


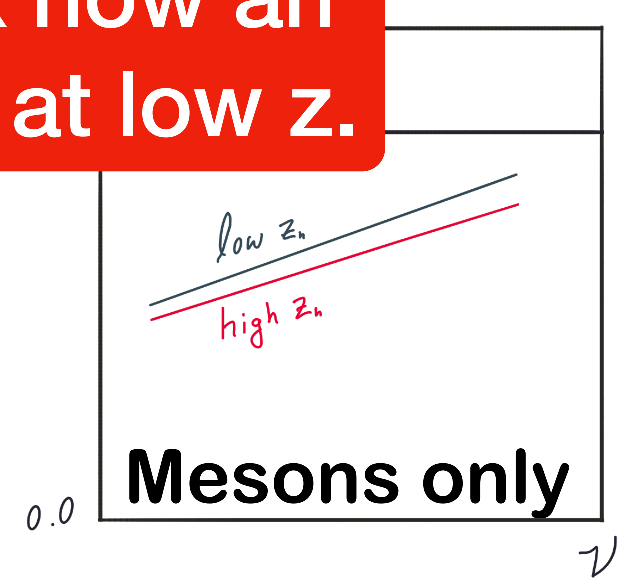
Largest enhancement



Not integrated over pT, so can exceed 1. Exceeds 1 faster for higher pT, so crossing point is pT dependent.

Time dilation of a single quark now an infeasible interpretation: R>>1 at low z.

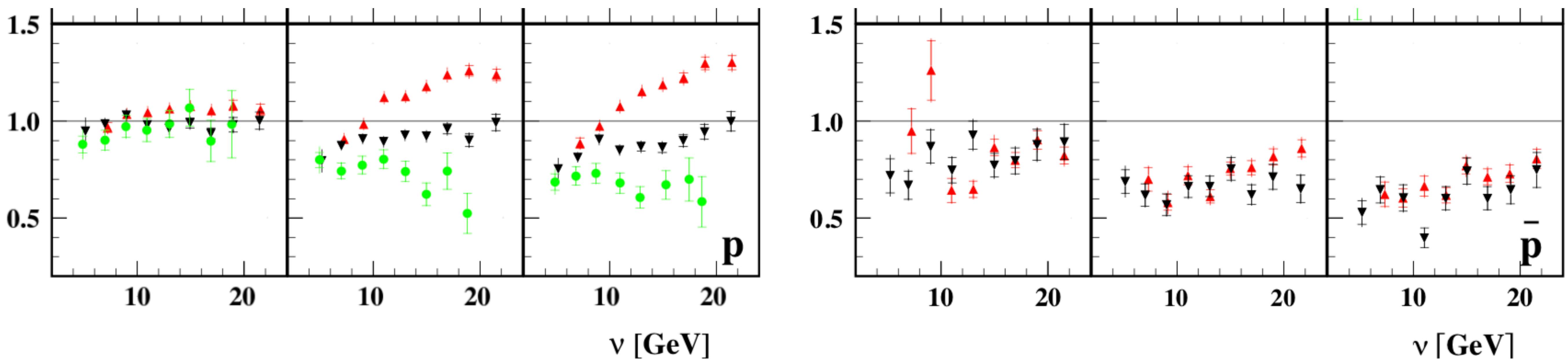




Time dilation is proportional to ν. Slow approach to 1.0 at infinite ν. Color lifetime goes to zero at high z, so high z is attenuated more.

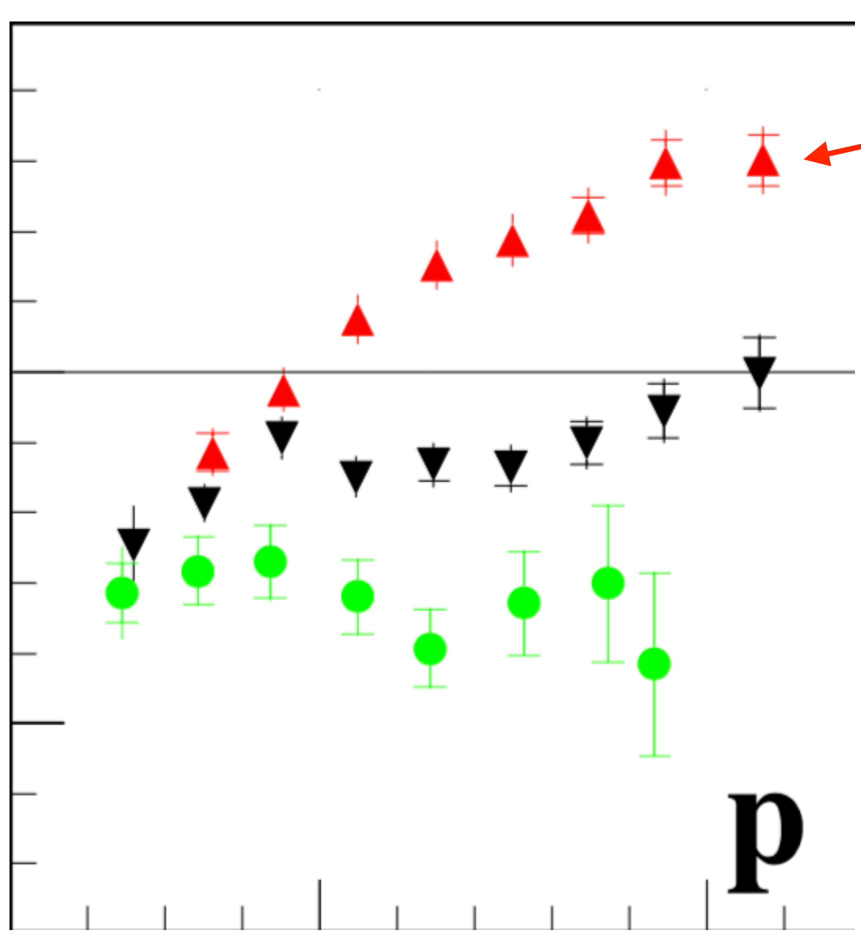
W. K. Brooks, Baryons 2022

HERMES Proton Multiplicity Ratios

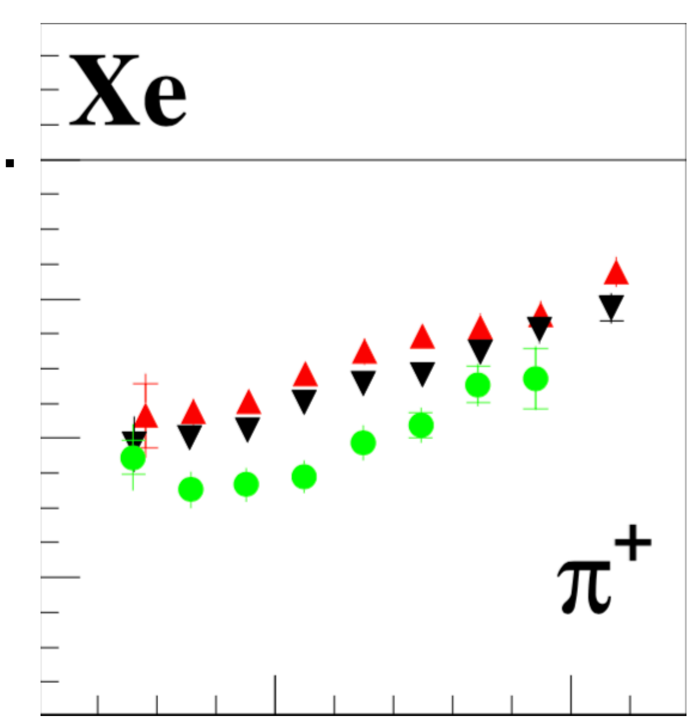


proton (left) and antiproton (right) are totally different

Proton multiplicity ratios qualitatively different from mesons.



This
vs.
this



I will argue that this behavior may be due to diquarks in the target protons/neutrons

CLAS6 nuclear DIS data for Lambda Baryons

$A(e, e'\Lambda)X$ in DIS Kinematics, with A = D, C, Fe, Pb

"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

Analysis Team from Mississippi State University:

Prof. Lamiaa El Fassi

Dr. Taya Chetry

Dr. Latif-ul Kabir

Analysis Contributions from U. Técnica Fed. Santa María:

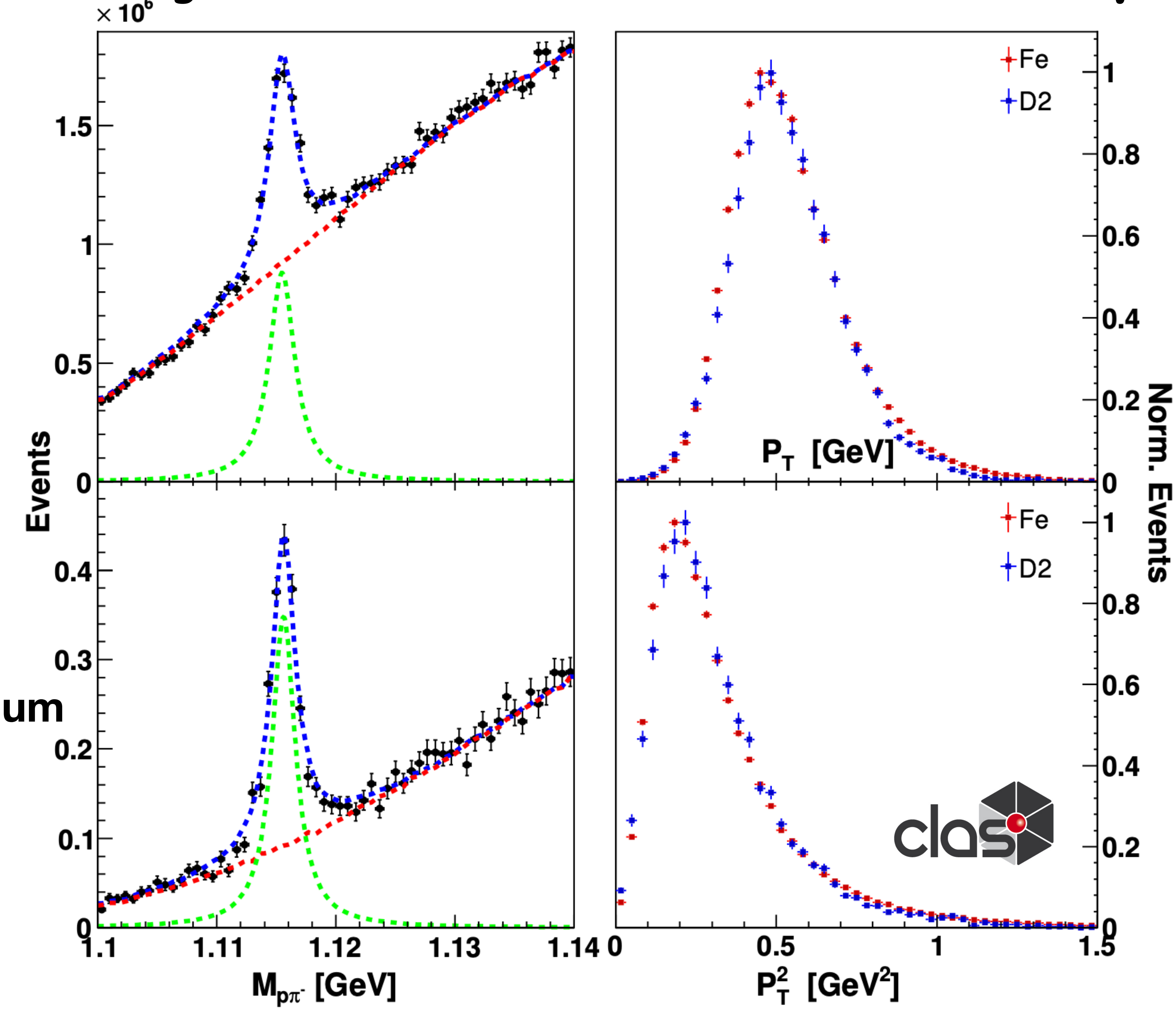
Dr. Ahmed El Alaoui

Initial work performed at ANL.

Lambda Baryons are well-identified in $\pi^- p$ channel

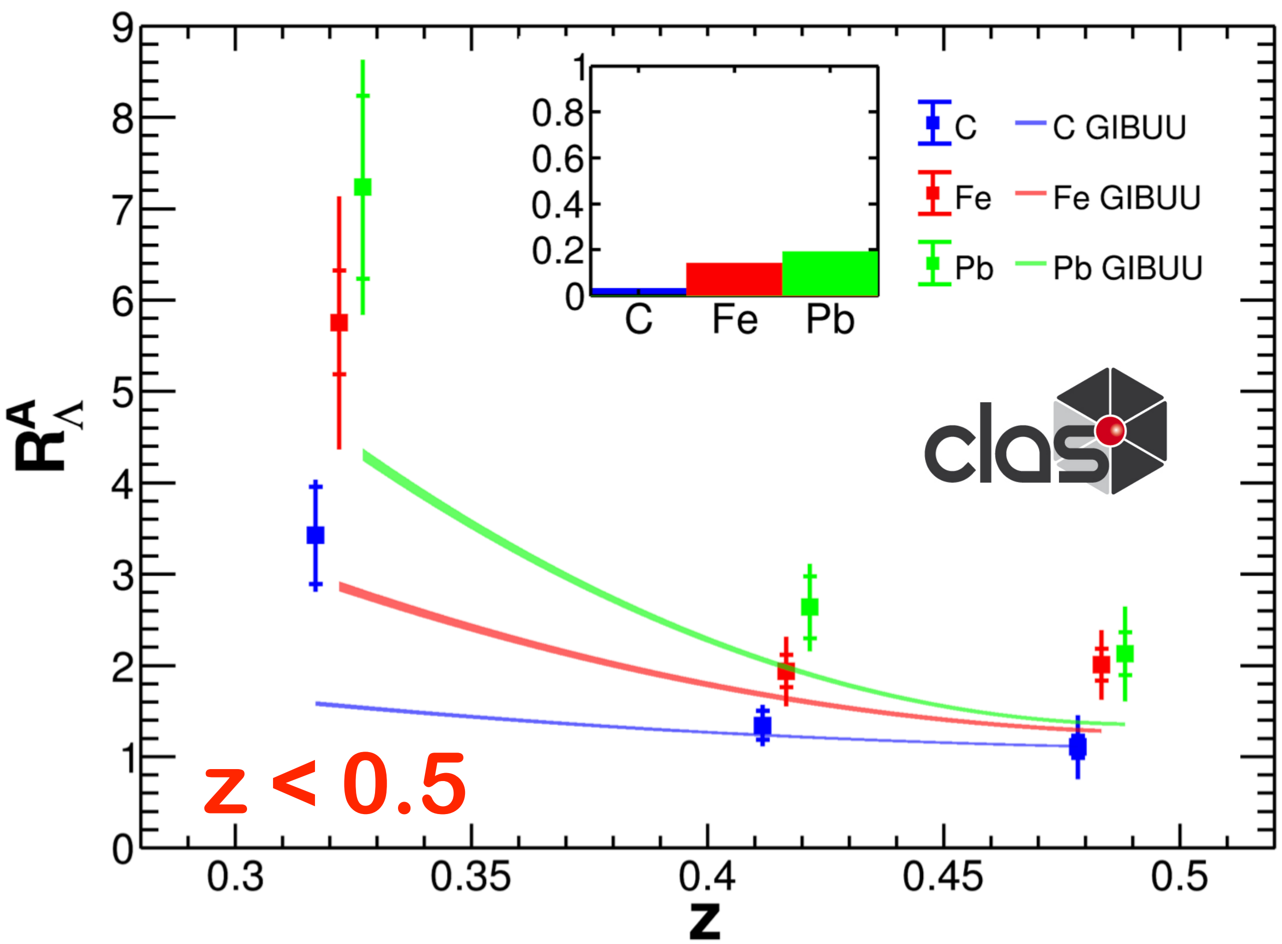
CLAS
Iron Target

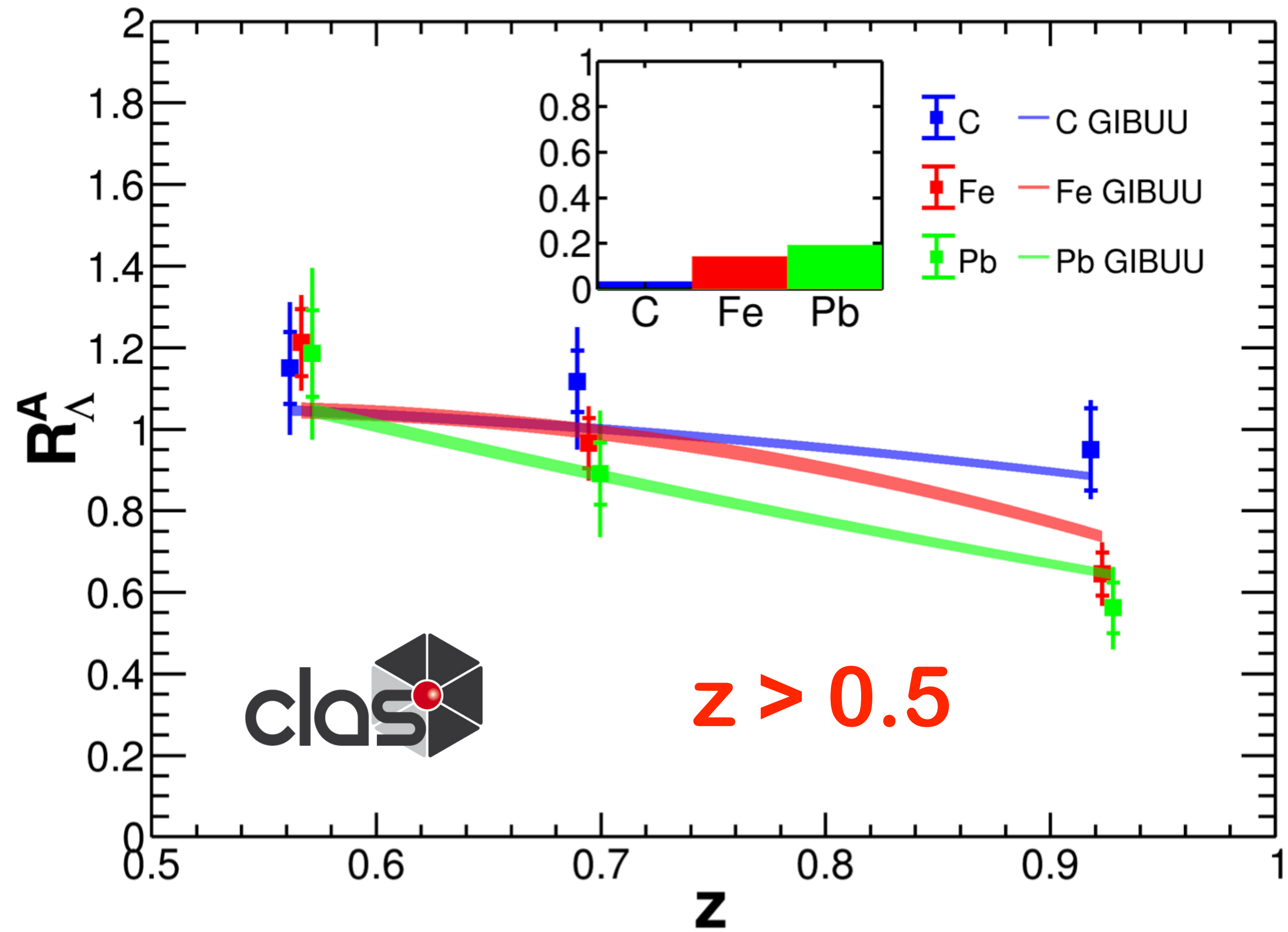
CLAS
Liquid Deuterium Target



Backgrounds are under control - three different extraction methods agree.
p_T broadening is easily visible by eye.

https://doi.org/10.48550/arXiv.2210.13691





“Pile-up” of events at low z - <u>huge</u> compared to pion production: 7.5 vs. ~1.0

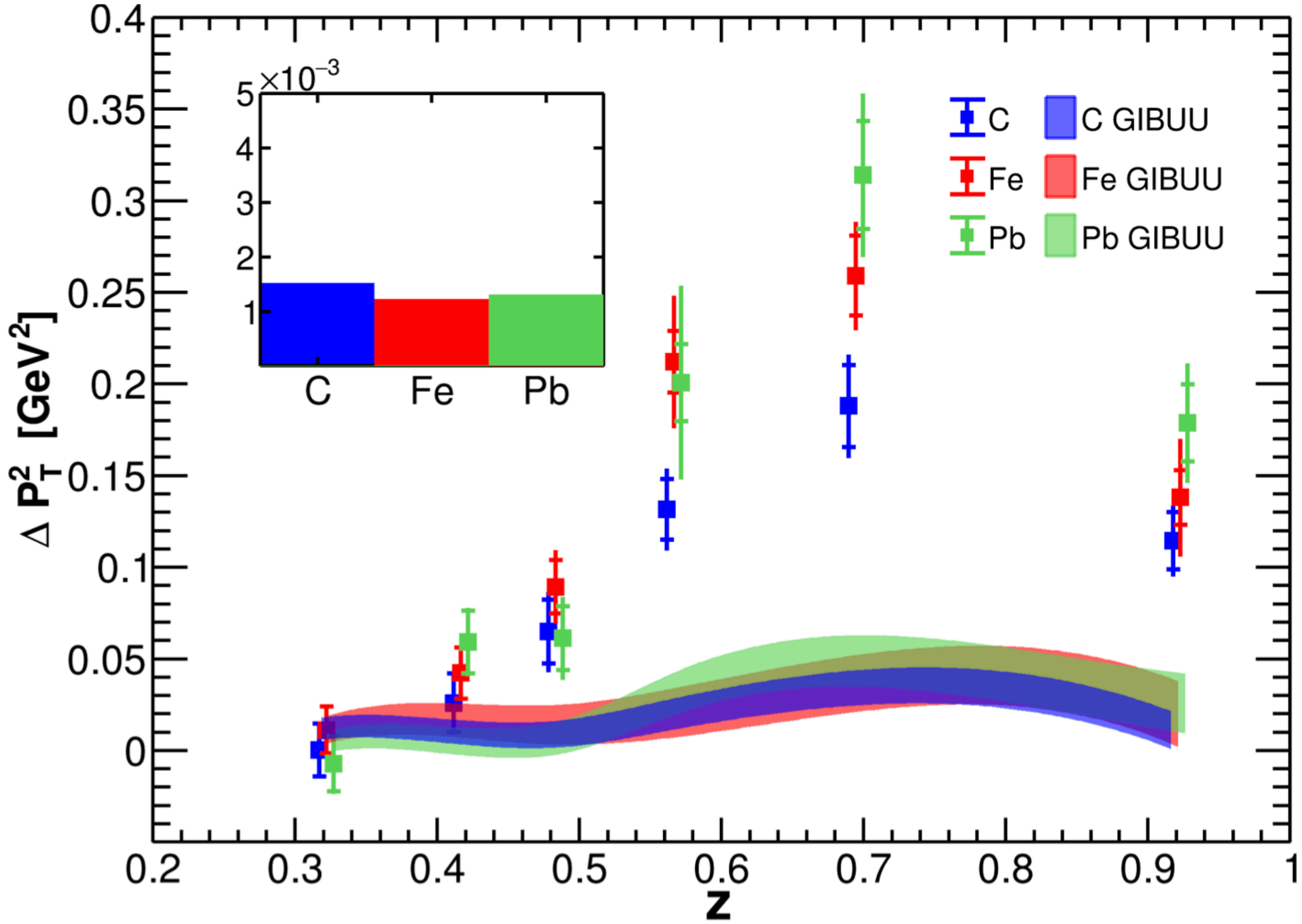
Underpredicted by GiBUU.

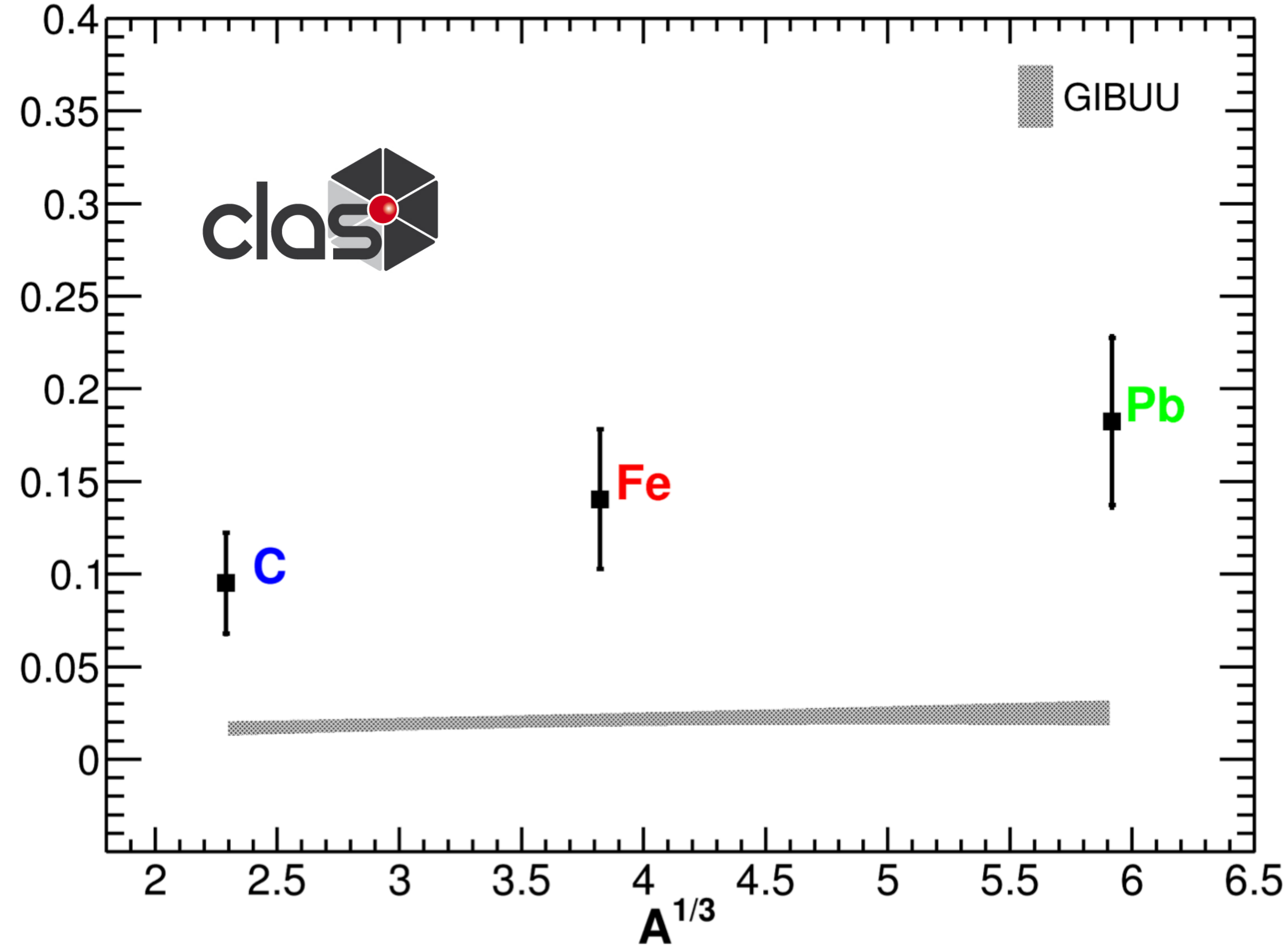
At higher z, there is relatively little attenuation.

Agrees with GiBUU prediction for high z.

https://doi.org/10.48550/arXiv.2210.13691

Lambda Transverse Momentum Broadening





Maximum is 0.3 GeV^2

Compare to maximum for pions of 0.03 GeV^2!

The object passing through the medium is disruptive!

E.g., it is "large" (has an extended color field).

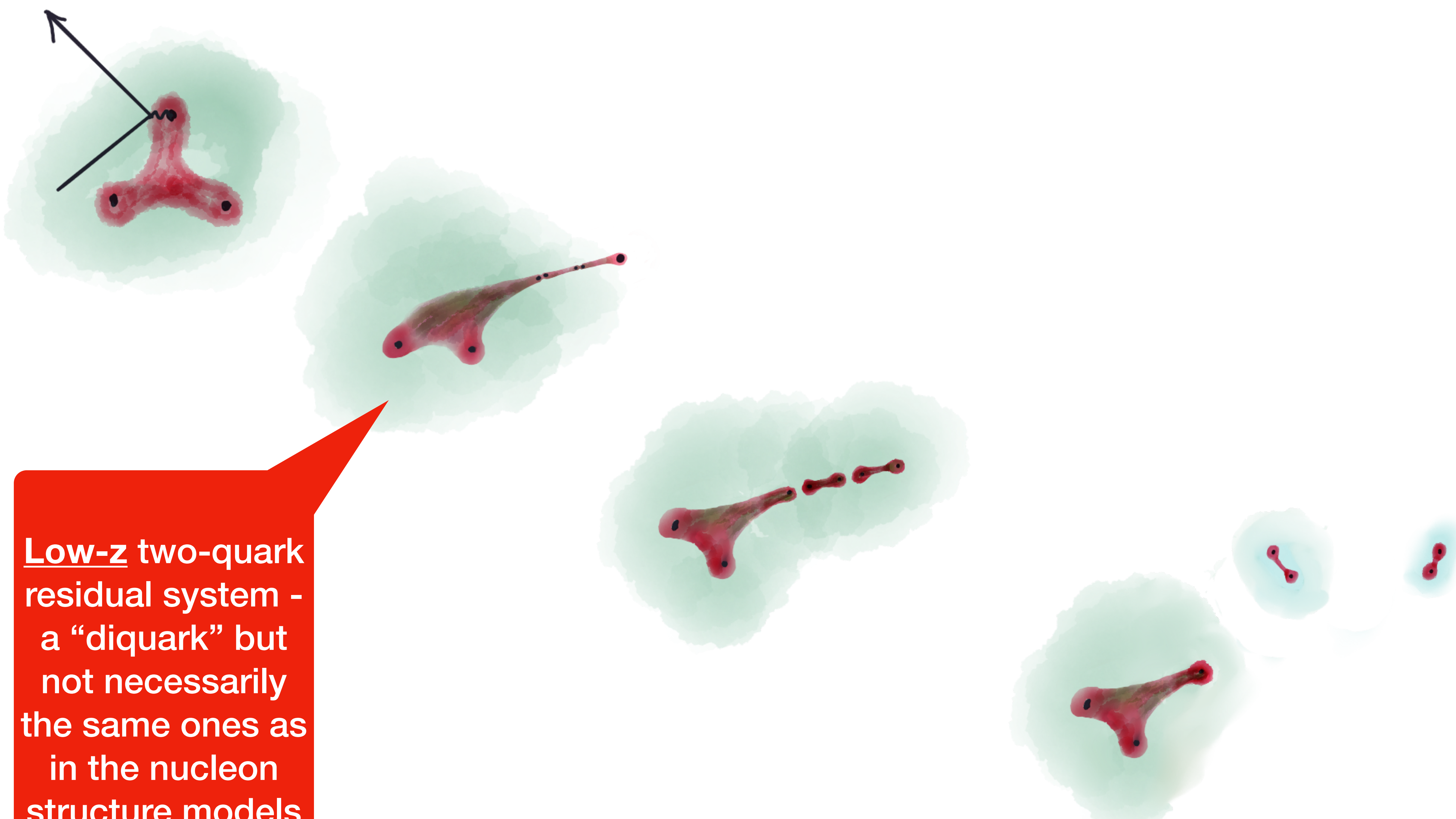
Unlike for pions, GiBUU cannot predict this observable.

We apparently do not have the correct physical picture in the case of baryon hadronization.

Could it be possible that the virtual photon is sometimes absorbed by a diquark?

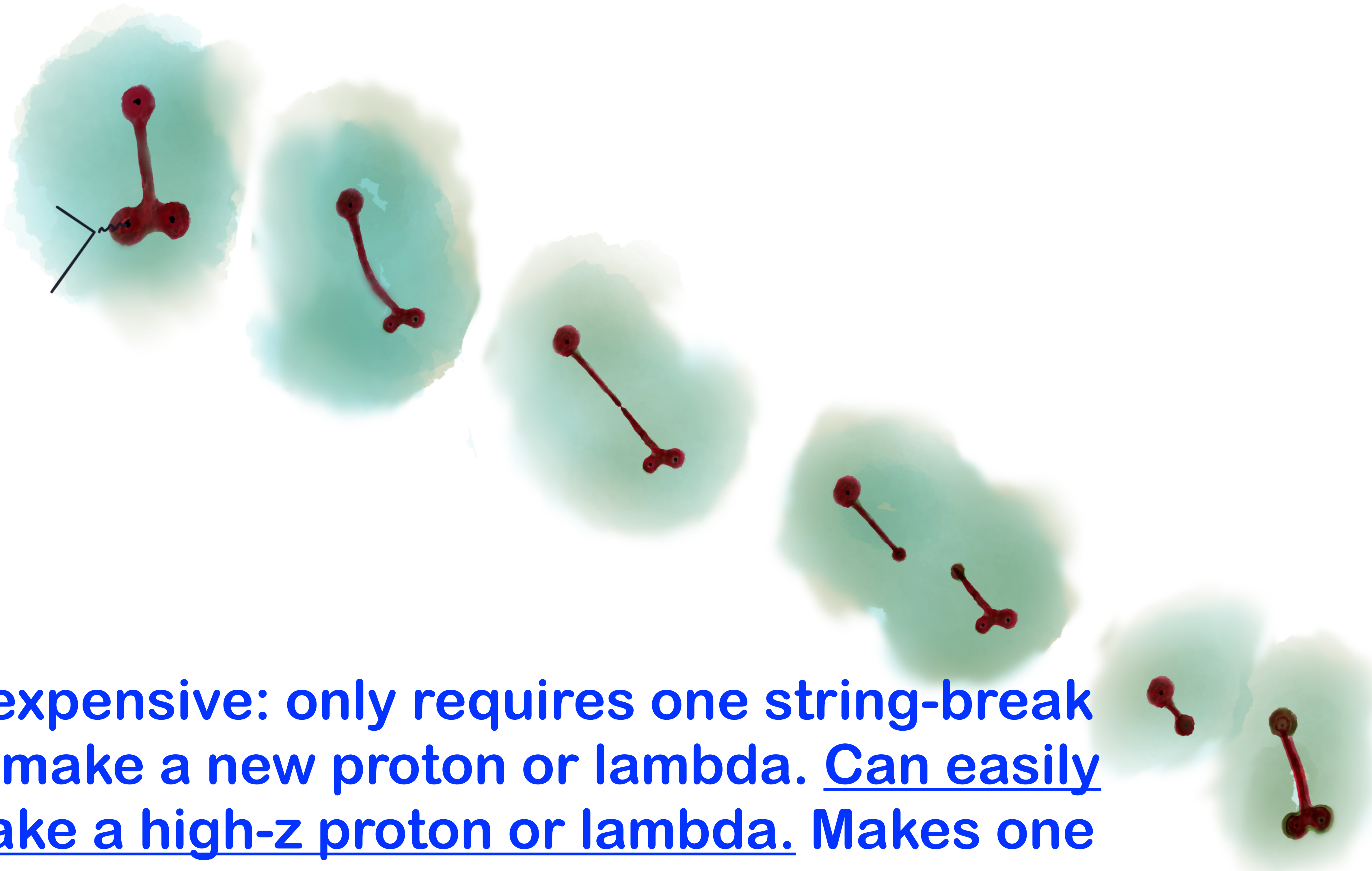
Let's call this Direct Diquark Scattering (DDS)

<u>Traditional</u> picture of particle production from proton with string fragmentation: Single Quark Scattering



<u>Low-z</u> two-quark residual system - a "diquark" but not necessarily the same ones as in the nucleon structure models

Alternative picture of particle production from proton: Direct Diquark Scattering



Inexpensive: only requires one string-break to make a new proton or lambda. Can easily make a high-z proton or lambda. Makes one or more backward-going pions or kaons.

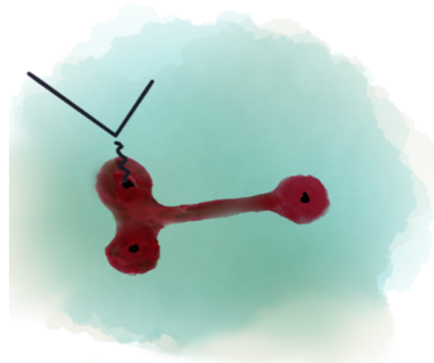
DDS mechanism makes it much easier to form a proton or a lambda baryon.

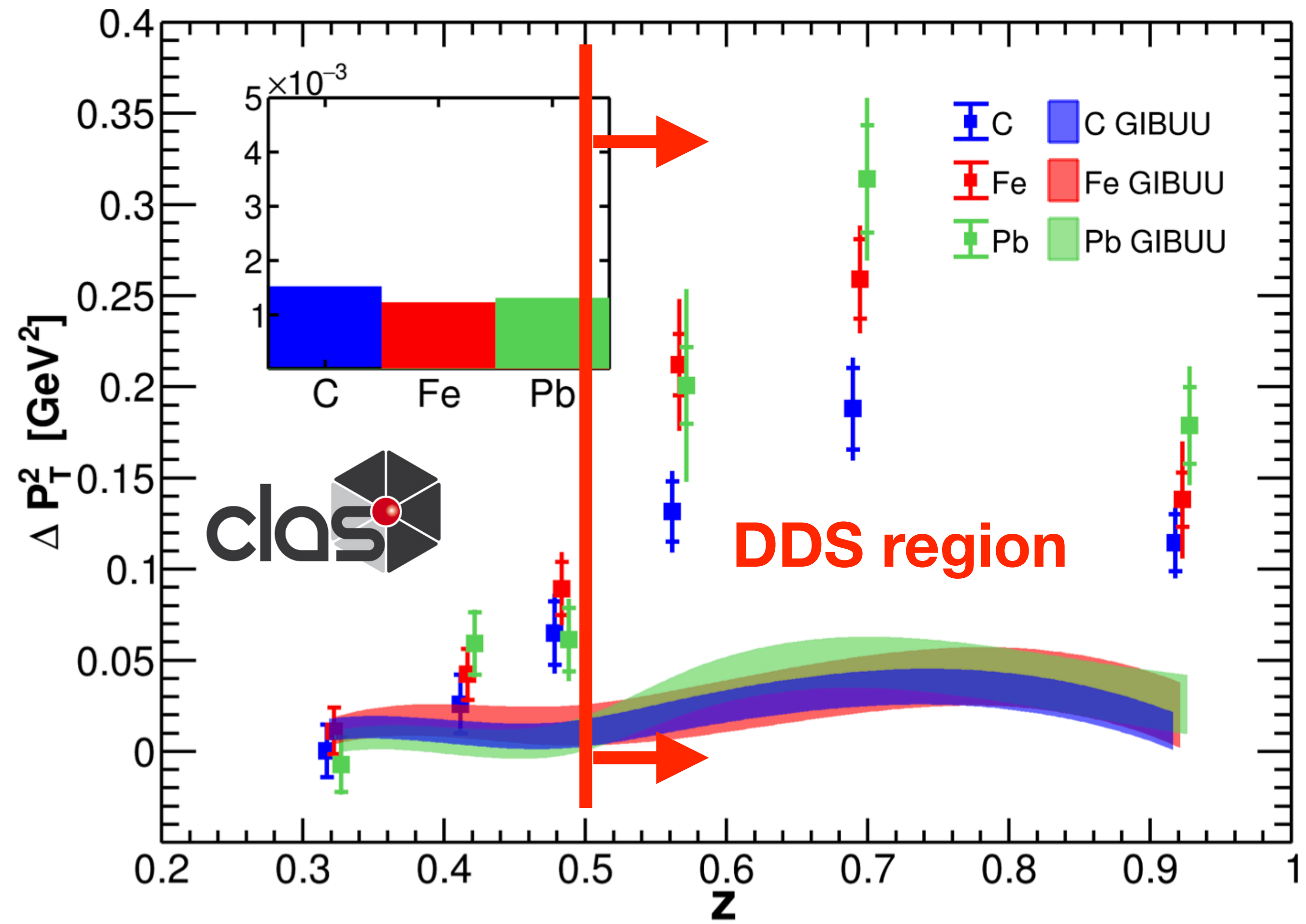
Especially true for these low energies.

With nuclear DIS baryon production, we will be able to gather substantial evidence to test this idea.

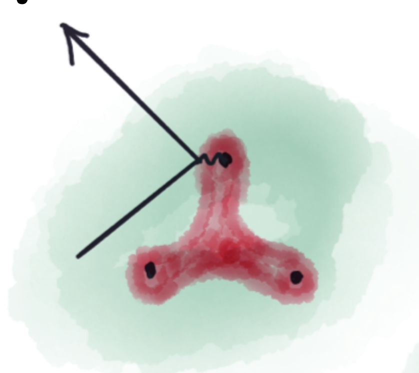
Multiplicity ratio, p_T broadening, and correlations between hadrons will provide the evidence.

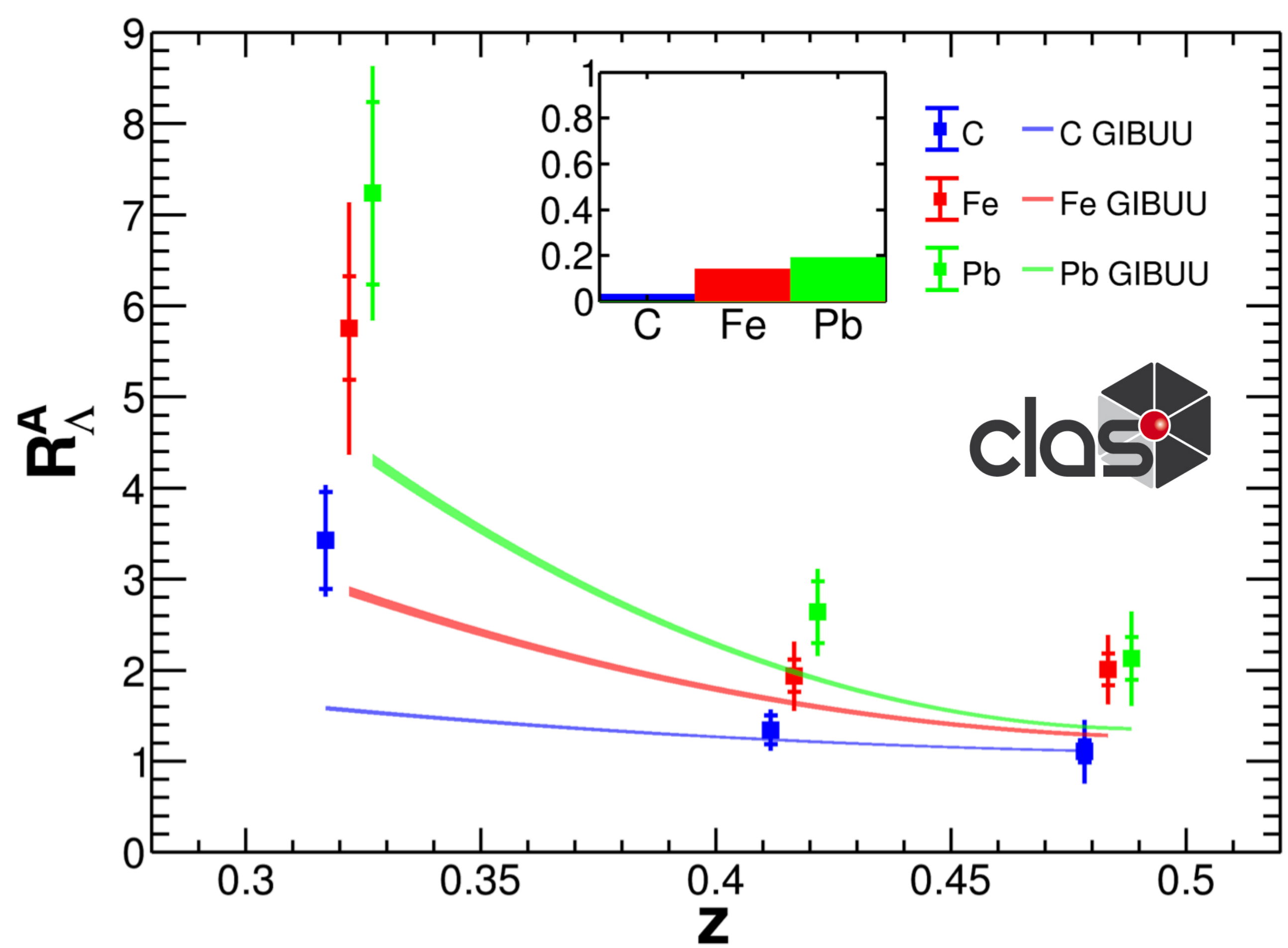
If DDS occurs, it will appear for z>0.5, where the observed hadron is very likely to contain the struck object (quark or diquark).





Low-z production of lambdas will naturally occur via the traditional mechanism of single-quark scattering.





Future tests of the Direct Diquark Scattering hypothesis with CLAS12 nuclear DIS on nine baryons

Actively underway with existing 5 GeV data

meson	cτ	mass	flavor content
π^0	25 nm	0.13	$u\bar{u}d\bar{d}$
π^+, π^-	7.8 m	0.14	$u\bar{d}$, $d\bar{u}$
η	170 pm	0.55	$u\bar{u}d\bar{d}s\bar{s}$
ω	23 fm	0.78	$u\bar{u}d\bar{d}s\bar{s}$
η'	0.98 pm	0.96	$u\bar{u}d\bar{d}s\bar{s}$
ϕ	44 fm	1.0	$u\bar{u}d\bar{d}s\bar{s}$
$f1$	8 fm	1.3	$u\bar{u}d\bar{d}s\bar{s}$
K^0	27 mm	0.50	$d\bar{s}$
K^+, K^-	3.7 m	0.49	$u\bar{s}$, $\bar{u}s$

baryon	cτ	mass	flavor content
p	stable	0.94	ud
$\bar{p}$	stable	0.94	$\overline{ud}$
Λ	79 mm	1.1	uds
$\Lambda(1520)$	13 fm	1.5	uds
Σ^+	24 mm	1.2	us
Σ^-	44 mm	1.2	ds
Σ^0	22 pm	1.2	uds
Ξ^0	87 mm	1.3	us
Ξ^-	49 mm	1.3	ds

Masses of ground-state mesons and baryons, including those with heavy quarks

Pei-Lin Yin,[1,*] Chen Chen,[2,†] Gastão Krein,[2] Craig D. Roberts,[3,‡] Jorge Segovia,[4] and Shu-Sheng Xu[1]

arXiv 1903.00160

Phys. Rev. D 100, 034008 (2019)

Baryon	$M^{e/l}$	M^{CI}	dom. corr.
p (B.5a)	0.94	0.94	$[ud]u$
Λ (B.5b)	1.12	1.06	$[ud]s$
Σ (B.5c)	1.19	1.20	$[us]u$
Ξ (B.5d)	1.32	1.24	$[us]s$
Λ_c (B.5e)	2.29	2.50	$[uc]d - [dc]u$
Σ_c (B.5f)	2.45	2.53	$\{uu\}c$? almost
Ξ_c (B.5g)	2.47	2.66	$[uc]s - [sc]u$
Ξ'_c (B.5h)	2.58	2.68	$\{us\}c$
Ω_c (B.5i)	2.70	2.83	$\{ss\}c$

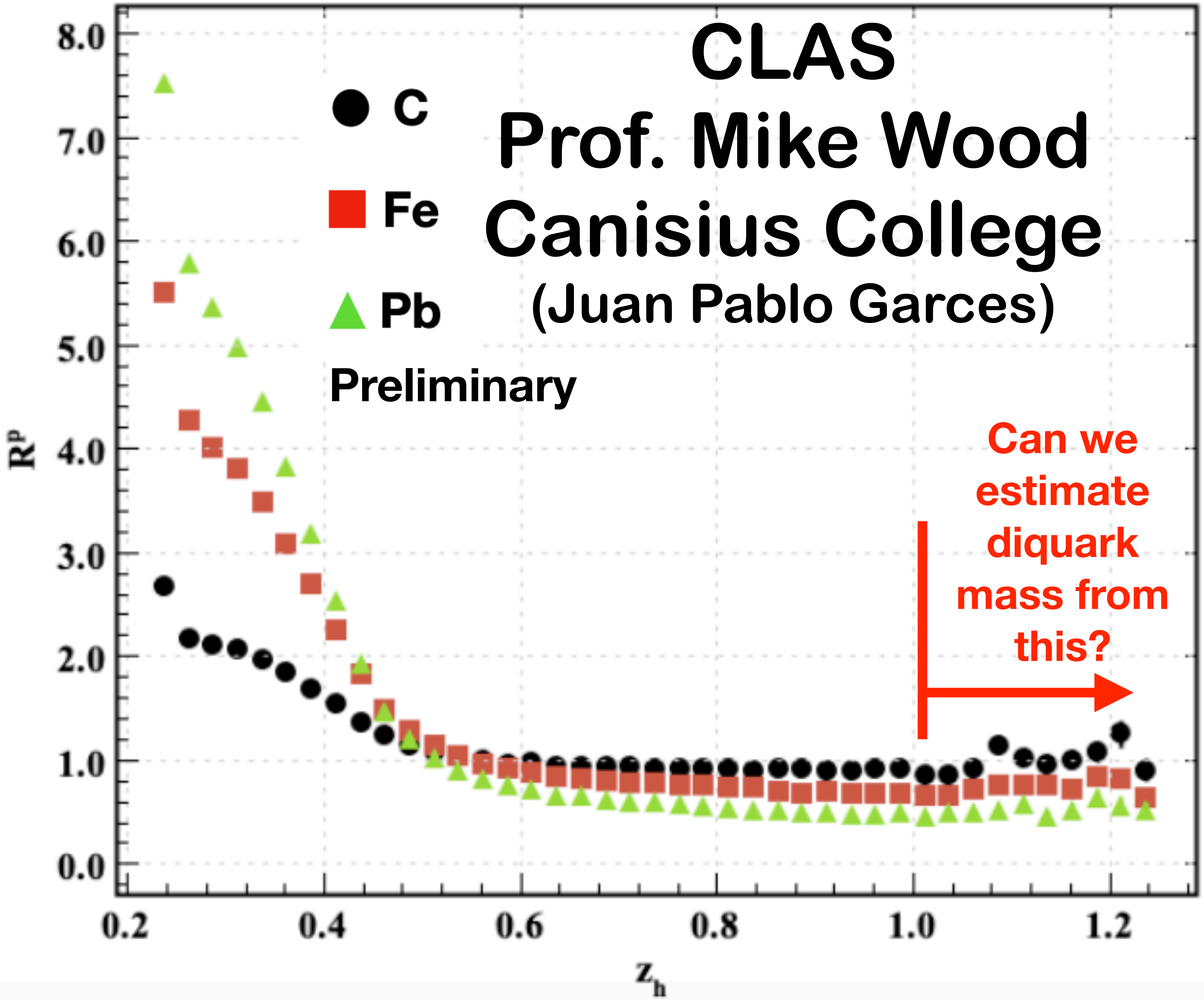
This suggests a specific behavior for DDS.

Only p, n, lambda can easily be formed by DDS.

Prediction: proton (neutron) and lambda will behave similarly; the others will be different.

We can test this prediction already, with our new preliminary data on the proton!

Proton multiplicity ratio

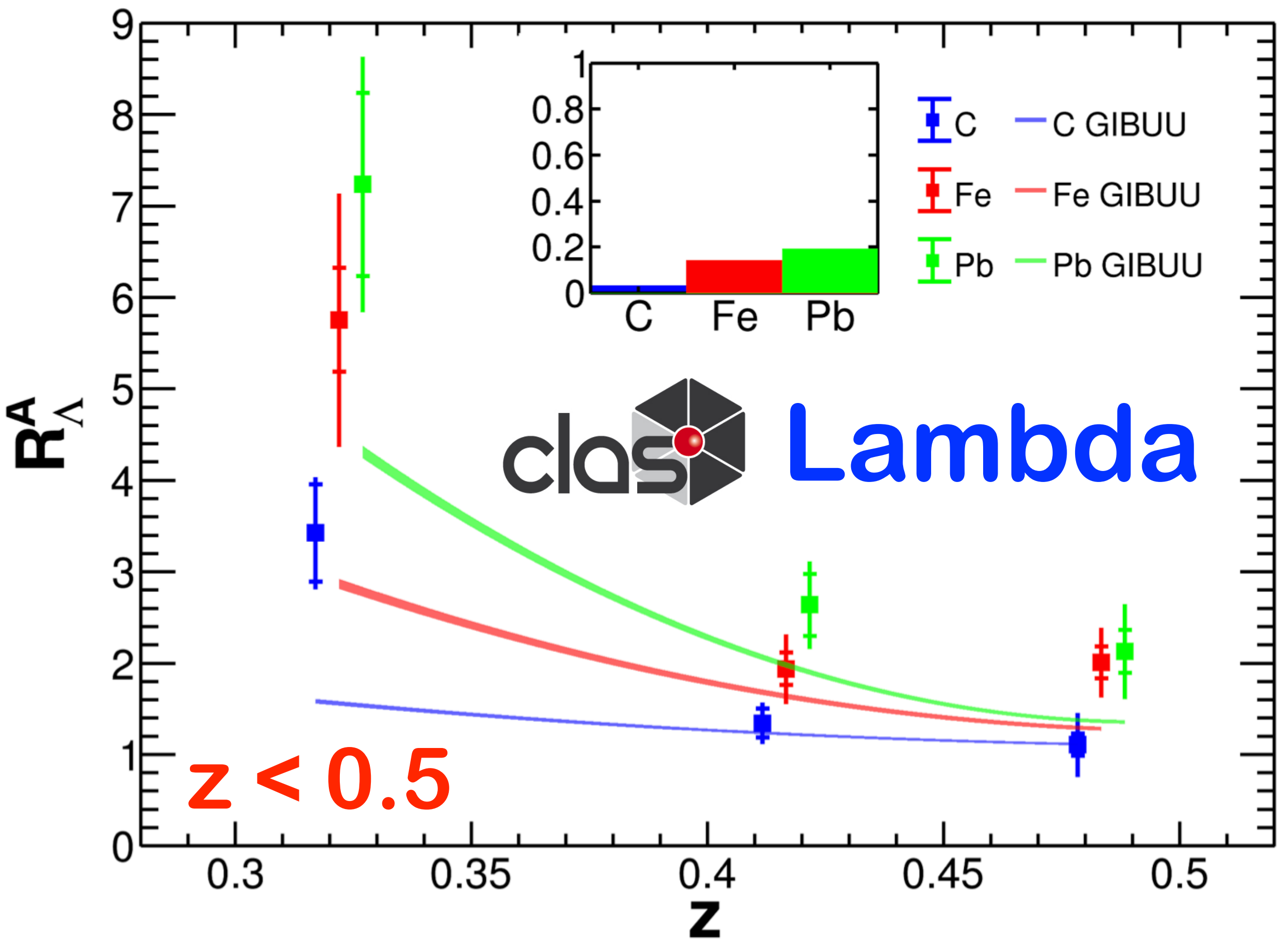


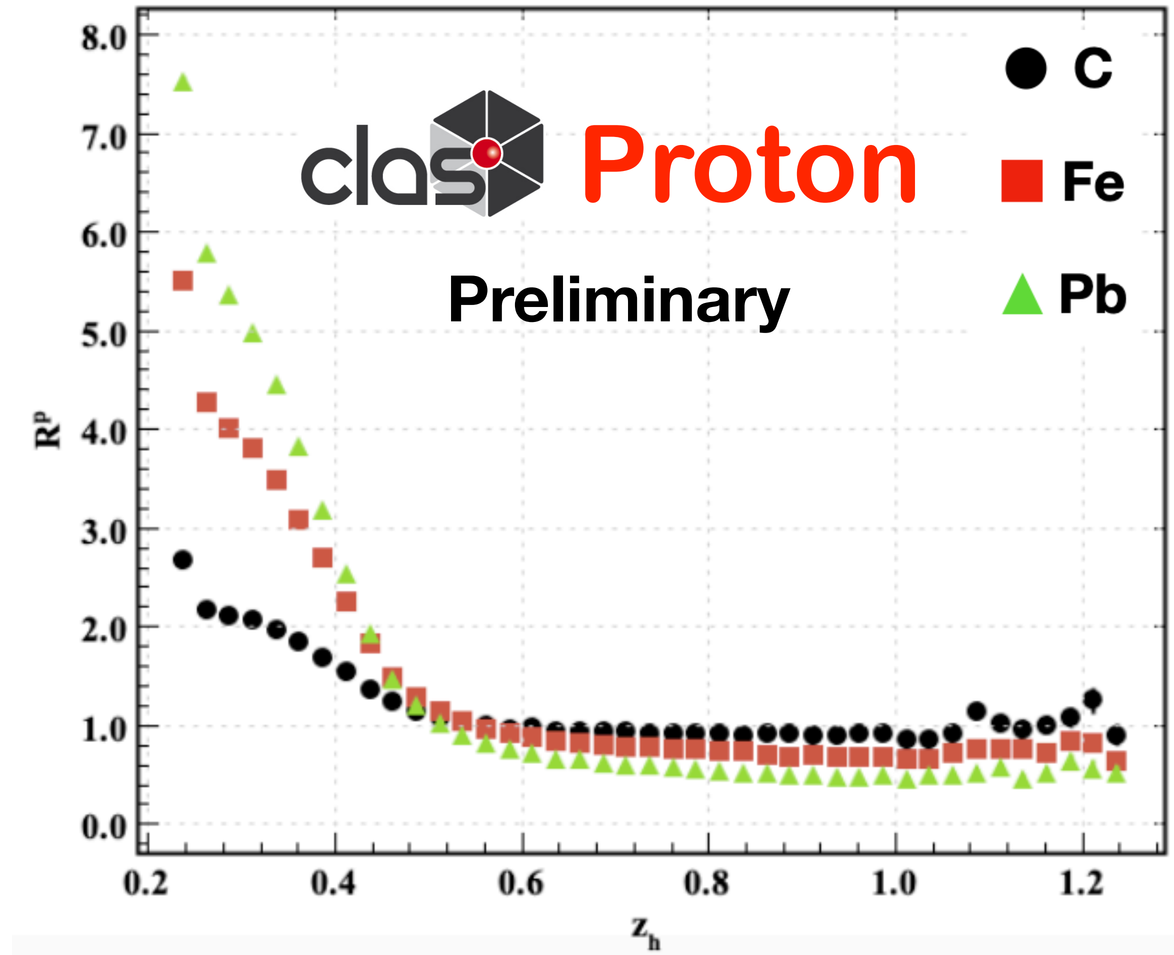
Maximum value 7.5

The same number as for the lambda!

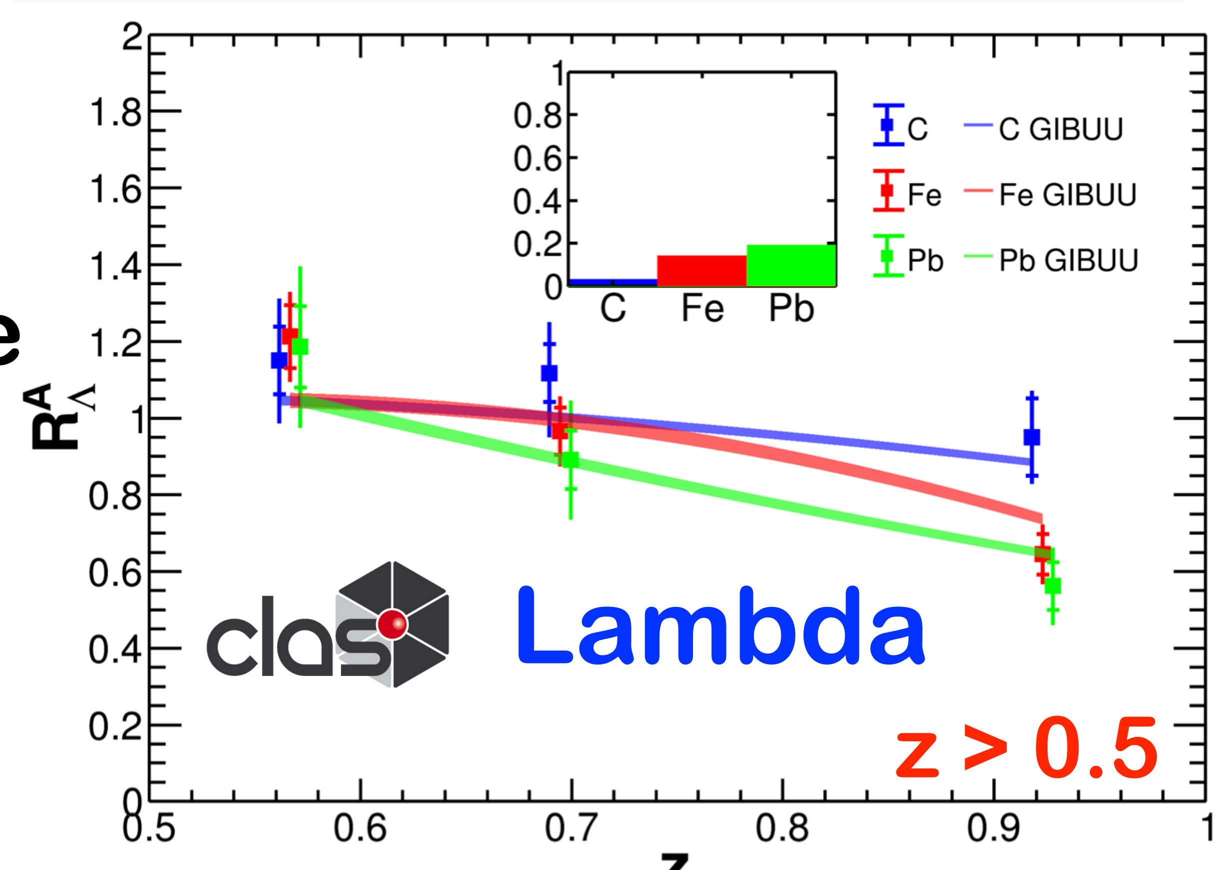
Unlike the lambda, we have tiny statistical uncertainties

So we can probe the multidimensional behavior





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



Next Steps

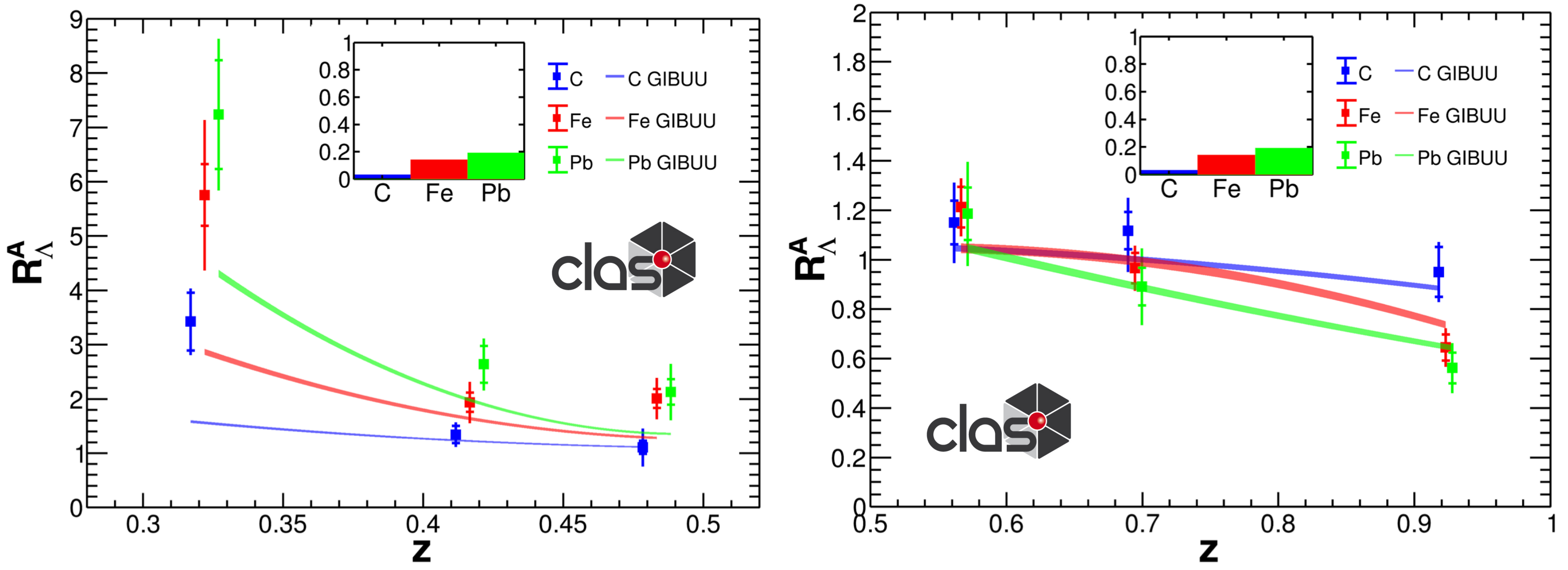
- Build a semi-classical space-time model for <u>baryon</u> hadronization like our meson model
- Make a two-observable fit, as with the mesons

- New ingredients:

  1. <u>Two independent mechanisms</u> are needed because the enhancement at low z is far too big to explain by the attenuation at high z

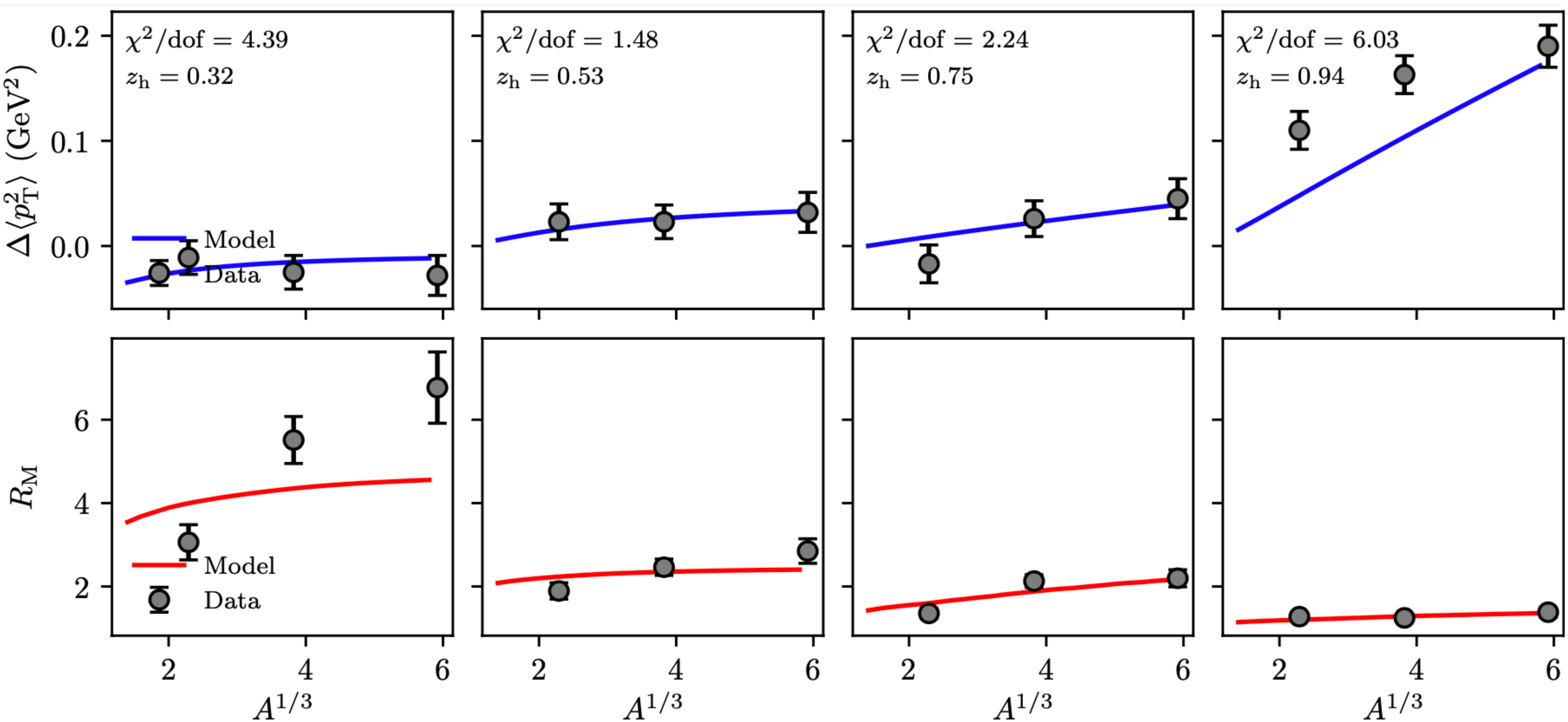
  2. A diquark-medium effective cross section σ_{qqA} and transport coefficient $\hat{q}_{qqA}$ will be needed

- Test the model on all baryons with two observables



One-mechanism model does not give good results

Discrepancy is biggest for the multiplicity ratio at low z and for p_T broadening at high z



Conclusions

- Baryon nDIS data from HERMES and CLAS behave qualitatively differently from mesons, in multiplicity ratios and in transverse momentum broadening.
- The hypothesis is that Direct Diquark Scattering may be one mechanism for formation of protons and lambdas, for z>0.5. Protons, neutrons and lambdas should behave the same if this is actually a valid mechanism, based on advanced models of diquarks. Two mechanisms are needed.
- More theoretical work is needed to determine the feasibility and plausibility of this interpretation, and distinguish it from, e.g., color recombination hadronization
- The planned and approved CLAS12 Color Propagation program is ideal for testing these ideas: access to production of nine long-lived baryons.

Acknowledgments

This work was funded in part by:

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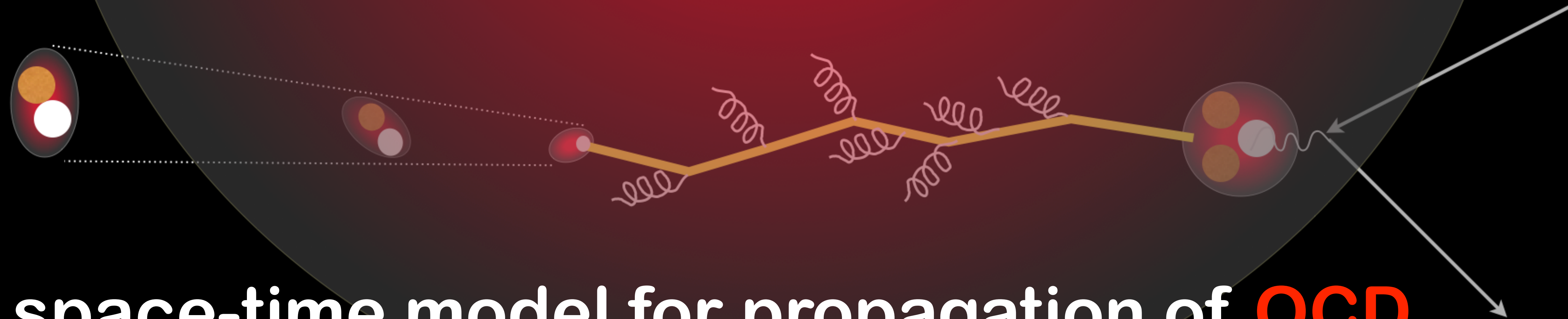
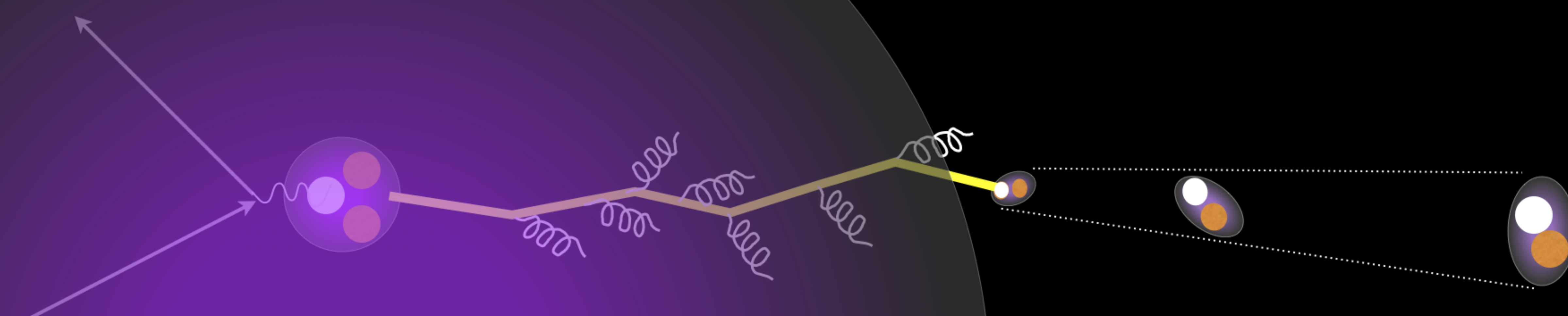
Universidad Técnica Federico Santa María (Technical University of Federico Santa Maria), Valparaíso, Chile.

Backup slides



A space-time model for propagation of QCD color through strongly interacting systems

Will Brooks and Jorge López
(UTFSM) (Heidelberg)



https://arxiv.org/abs/2004.07236

Physics Letters B 816 (2021) 136171

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Physics Letters B

www.elsevier.com/locate/physletb

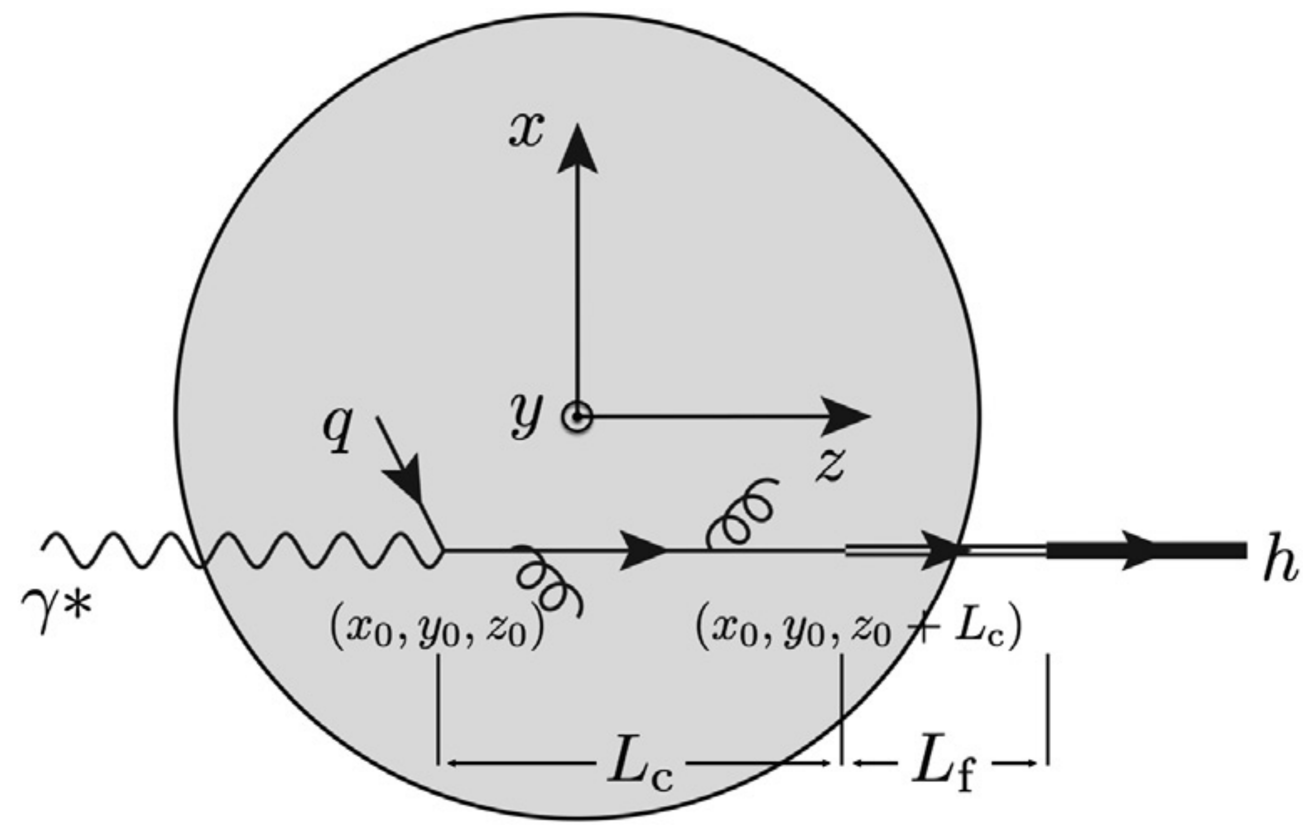
Estimating the color lifetime of energetic quarks

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

[a] Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
[b] Centro Científico Tecnológico de Valparaíso, Valparaíso, Chile
[c] Department of Physics and Astronomy, University of New Hampshire, Durham NH, USA
[d] Physikalisches Institut, Universität Heidelberg, Heidelberg, Germany

Struck quark moves a distance L_c as a colored object, then becomes a hadron. If the hadron forms inside the medium, it can interact with hadronic cross section.

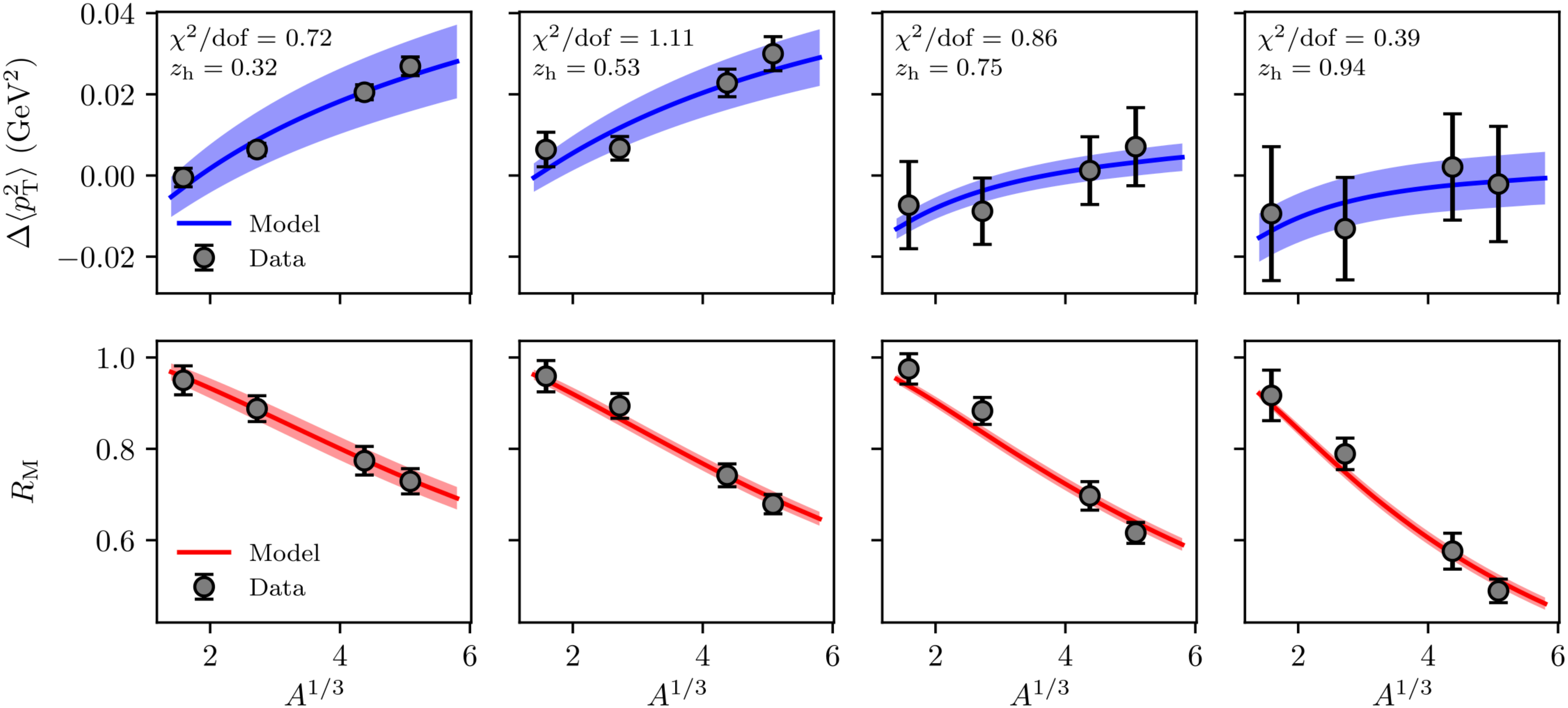
The color lifetime of the struck quark is distributed stochastically as a decaying exponential.



About this model

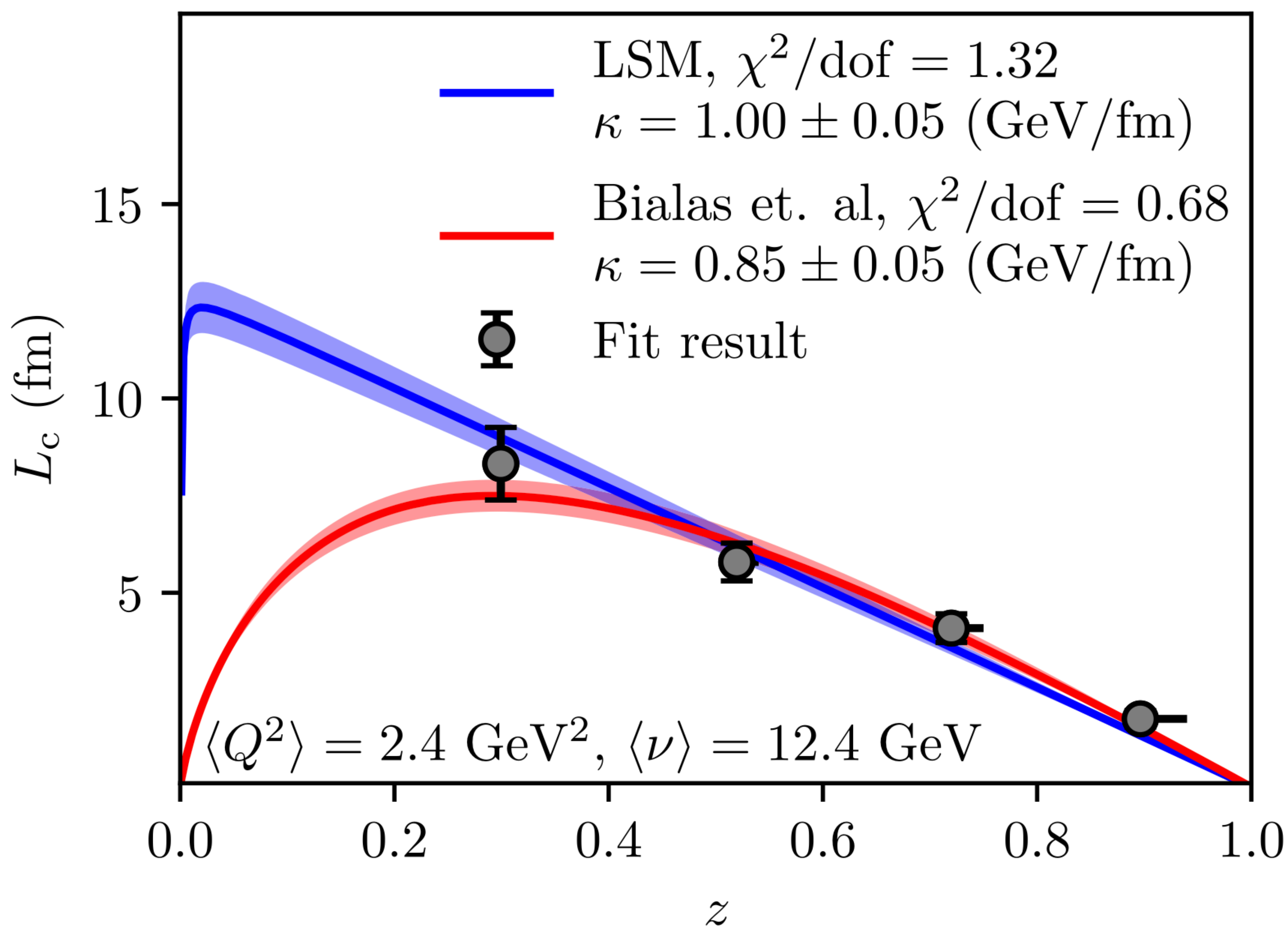
- A new analysis of two published HERMES measurements. We isolate the roles of quark energy loss and pre-hadron formation in describing the data.
- Two observables are fitted simultaneously.
- The primary ingredient is the well-known density distribution in nuclei.
- A second ingredient is the measured pi-N cross section
- Only 3 parameters

These are the results of the simultaneous fit to two observables



Message: we *believe* we understand pion hadronization well, in a simple space-time picture

This is a fit of the color lifetime parameter L_c we find to the color lifetime calculated in the Lund String Model



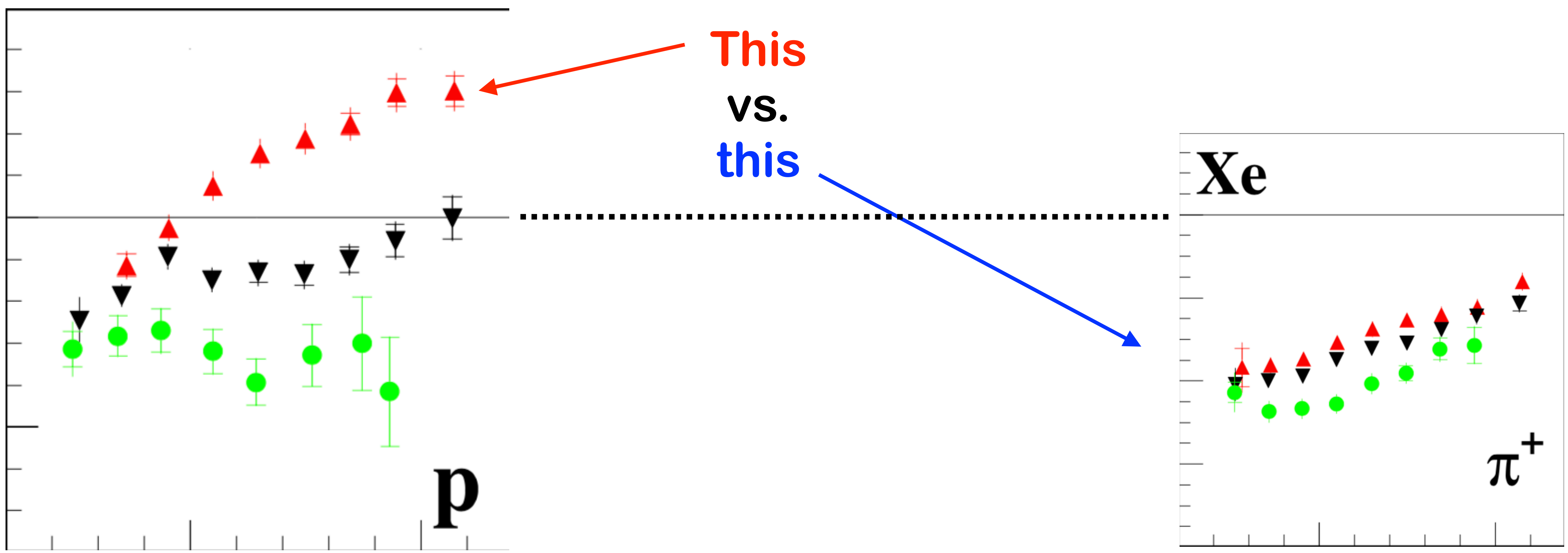
The blue line only describes the **struck quark**

The red line models the **struck quark and the residual quarks**

Independent determination of the string constant of the LSM!

Message: our space-time model is consistent with known string fragmentation.

We believe we have a correct [simplified] physical picture.



HERMES paper explanation: FSI are "knocking out protons." Maybe.
But, at high W and Q^2, if virtual photon strikes one quark: need to make an energetic pion <u>in-medium</u> to knock out a proton.

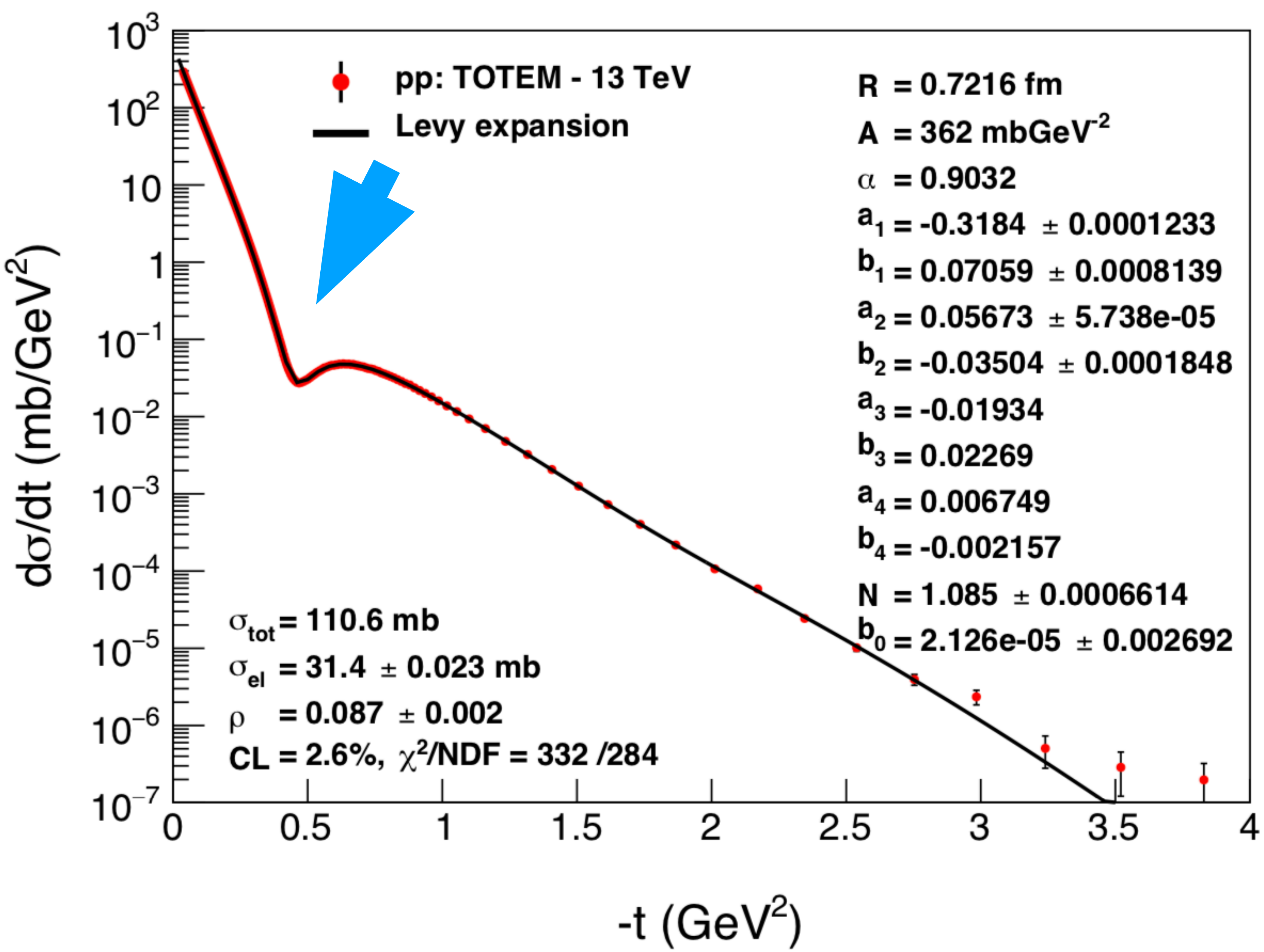
But maybe it could be <u>diquarks</u> knocking them out. Diquark "size" must be similar to proton (0.6 fm in LQCD)

= diquark color field much more extended in space

Test this hypothesis: CLAS new nDIS data for <u>Lambda Baryons</u>

Diquarks have been invoked for hadron beam scattering

"**Convergence properties of Lévy expansions: implications for Odderon and proton structure**,"
T. Csörgő, R. Pasechnik, A. Ster,
https://arxiv.org/pdf/1903.08235



Having only one minimum implies there are only two internal substructures, such as quark-diquark.

https://arxiv.org/abs/1903.08235
https://arxiv.org/abs/1902.00109
https://arxiv.org/abs/1811.08913
https://arxiv.org/abs/1807.02897

Diquarks have been invoked for hadron beam scattering

To explain anomalies in proton production!

Breakstone et al. (following 2 slides) 1985 ISR data

http://cds.cern.ch/record/158001/files/198503162.pdf

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 85-30
5 March 1985

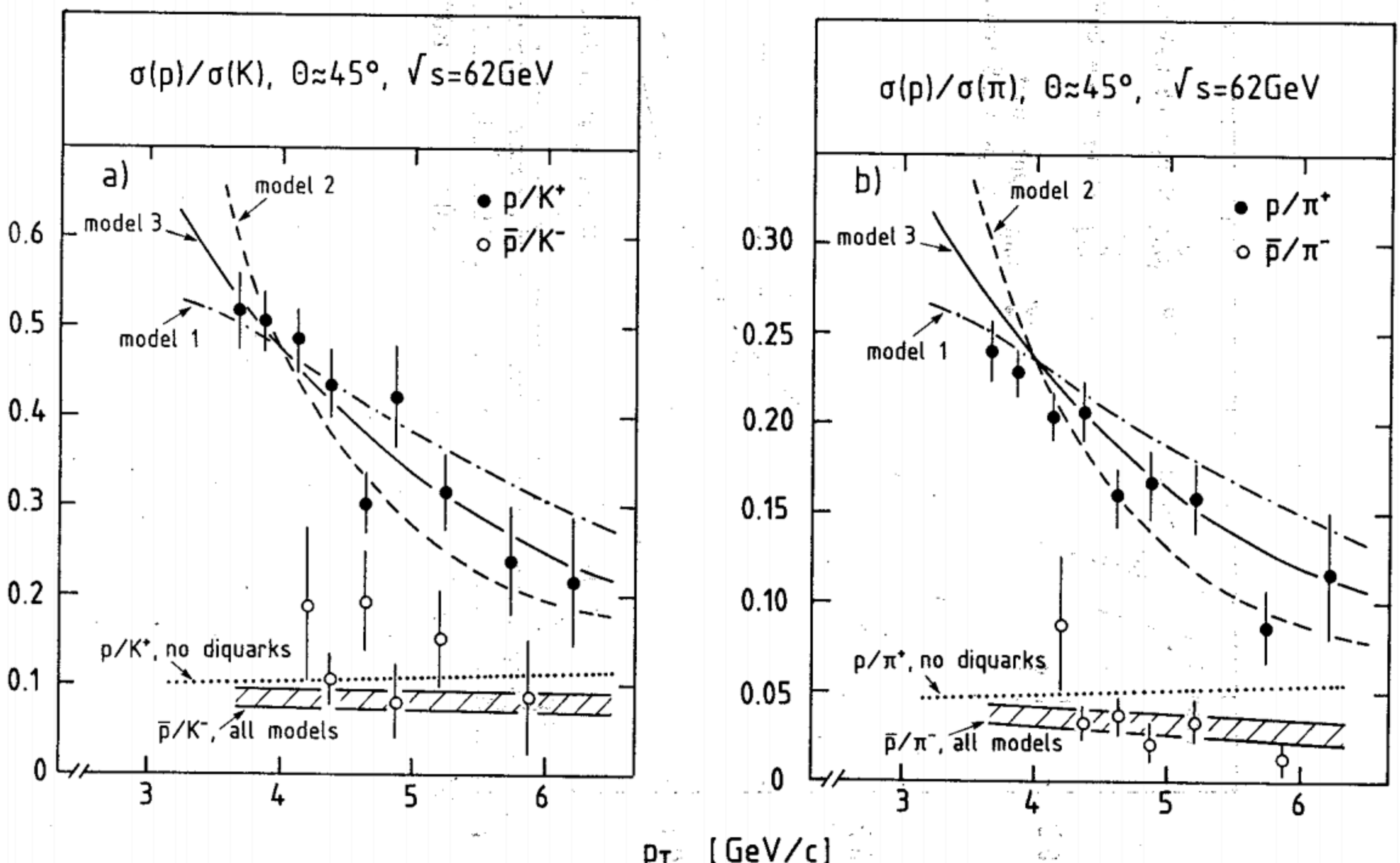
A DIQUARK SCATTERING MODEL FOR HIGH p_T PROTON PRODUCTION IN pp COLLISIONS AT THE ISR

Ames-Bologna-CERN-Dortmund-Heidelberg-Warsaw Collaboration

A. Breakstone[1(+)], H.B. Crawley[1], G.M. Dallavalle[5], K. Doroba[6], D. Drijard[3], F. Fabbri[3], A. Firestone[1], H.G. Fischer[3], H. Frehse[3(*)], W. Geist[3(**)], G. Giacomelli[2], R. Gokieli[6], M. Gorbics[1], P. Hanke[5], M. Heiden[3(**)], W. Herr[5], E.E. Kluge[5], J.W. Lamsa[1], T. Lohse[4], R. Mankel[4], W.T. Meyer[1], T. Nakada[5(***)], M. Panter[3], A. Putzer[5], K. Rauschnabel[4], B. Rensch[5], F. Rimondi[2], M. Schmelling[4], G. Siroli[2], R. Sosnowski[6], M. Szczekowski[3], O. Ullaland[3] and D. Wegener[4]

Breakstone et al.

http://cds.cern.ch/record/158001/files/198503162.pdf



Breakstone et al.

http://cds.cern.ch/record/158001/files/198503162.pdf

Fig. 1

P_T broadening for positive pions in CLAS

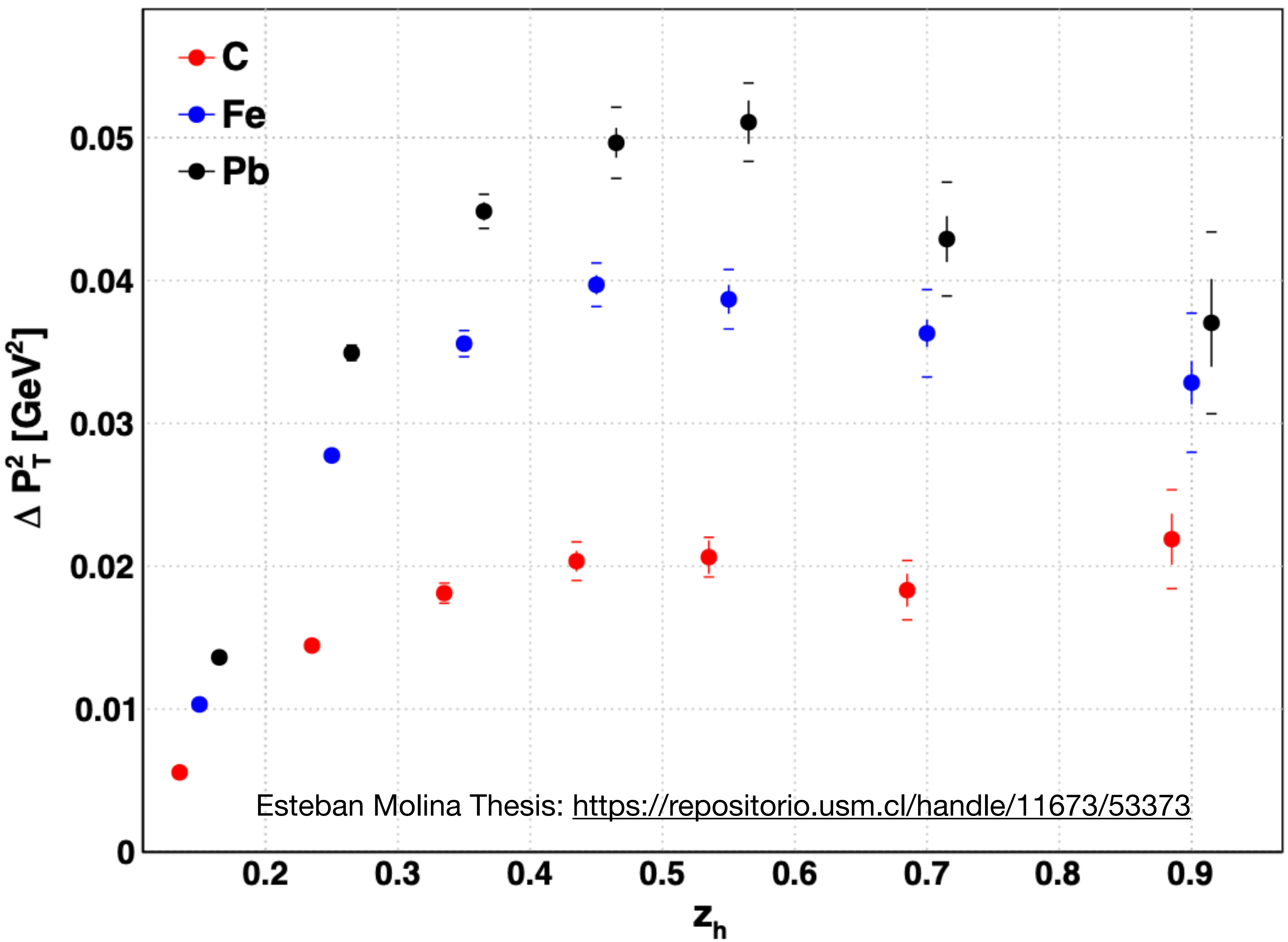


Figure B.63: ΔP_T^2 with all variables integrated except z_h.

P_T broadening for positive pions in CLAS

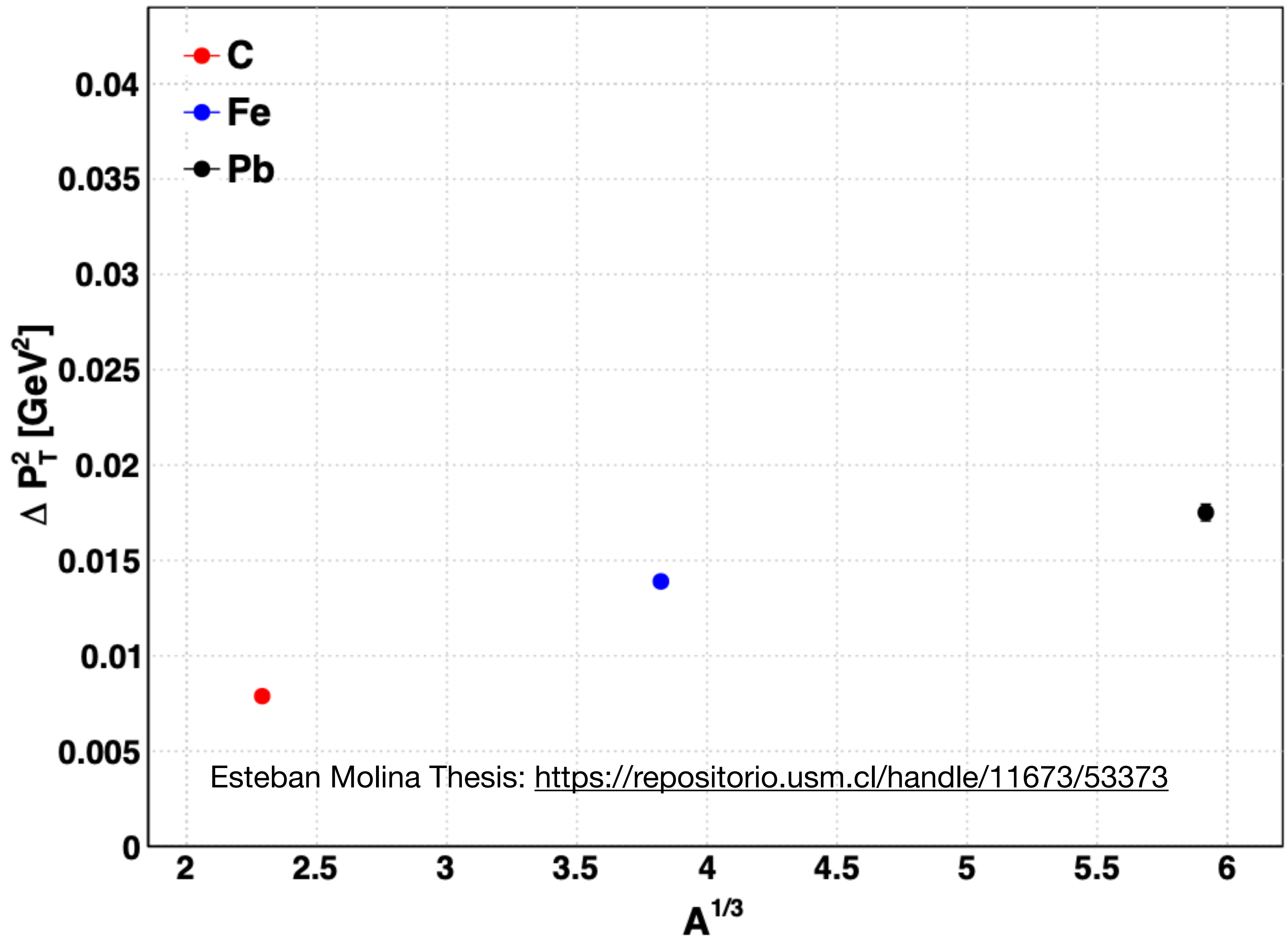


Figure B.59: ΔP_T^2 with all variables integrated and no x_f cut.