Studies of Diquark Characteristics via DIS on Nuclear Targets

QNP2022 - The 9th International Conference on ***Quarks*** *and* ***Nuclear Physics***

5 September 2022

Will Brooks

SAPHIR

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

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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

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

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They exist.

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They exist.

But how to prove it experimentally?

Example: a recent full-QCD lattice study of diquarks was carried out with lattice chiral fermions.

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

Table 2.3.2
Parameters of configurations with 2+1 flavour dynamical domain wall fermions (RBC-UKQCD). am_l and am_s are the bare mass parameters of the degenerate u, d sea quarks and strange sea quark, respectively. The residual masses are from Ref. [325]. The lattice spacings are from Ref. [327].

a^{-1}(GeV)	Label	am_l/am_s	Volume	am_{res}
∼1.75(4)	c005	0.005/0.04	$24^3 \times 64$	0.003152(43)
	c02	0.02/0.04	$24^3 \times 64$	
∼2.33(5)	f004	0.004/0.03	$32^3 \times 64$	0.0006664(76)

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). Large masses are found in models of different types.

Quark Model Estimates

Godfrey, Isgur 1985

Capstick, Isgur 1986

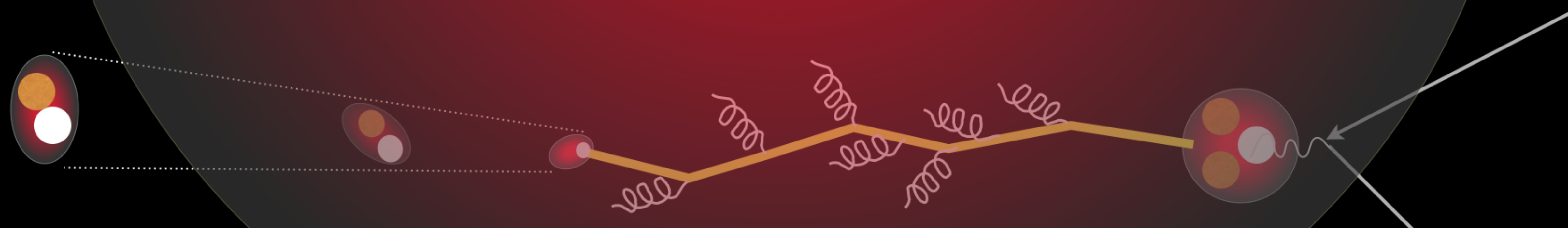
Scalar and axial–vector diquark masses, M^{sc} and M^{av}, respectively, computed by means of the relativised QM Hamiltonian of Refs. [114,179]. Notation: q indicates light, u or d, quarks. These results were previously reported in Ref. [178, Table 1].

Flavour content	M^{sc} (MeV)	M^{av} (MeV)
qq	691	840
qs	886	992
ss	–	1136
qc	2099	2138
sc	2229	2264
cc	–	3329
qb	5451	5465
sb	5572	5585
cb	6599	6611
bb	–	9845

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

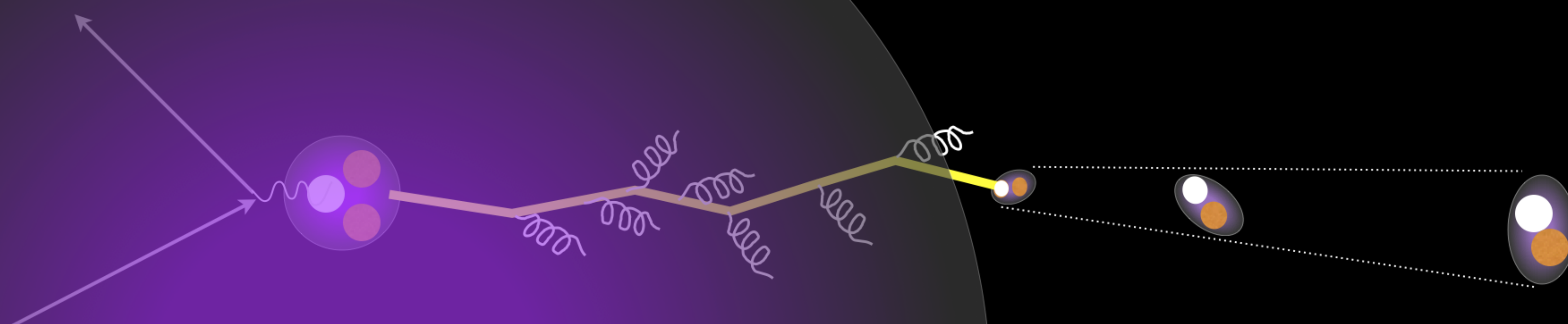
How can we improve the experimental evidence?

SIDIS on Nuclear Targets!



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)

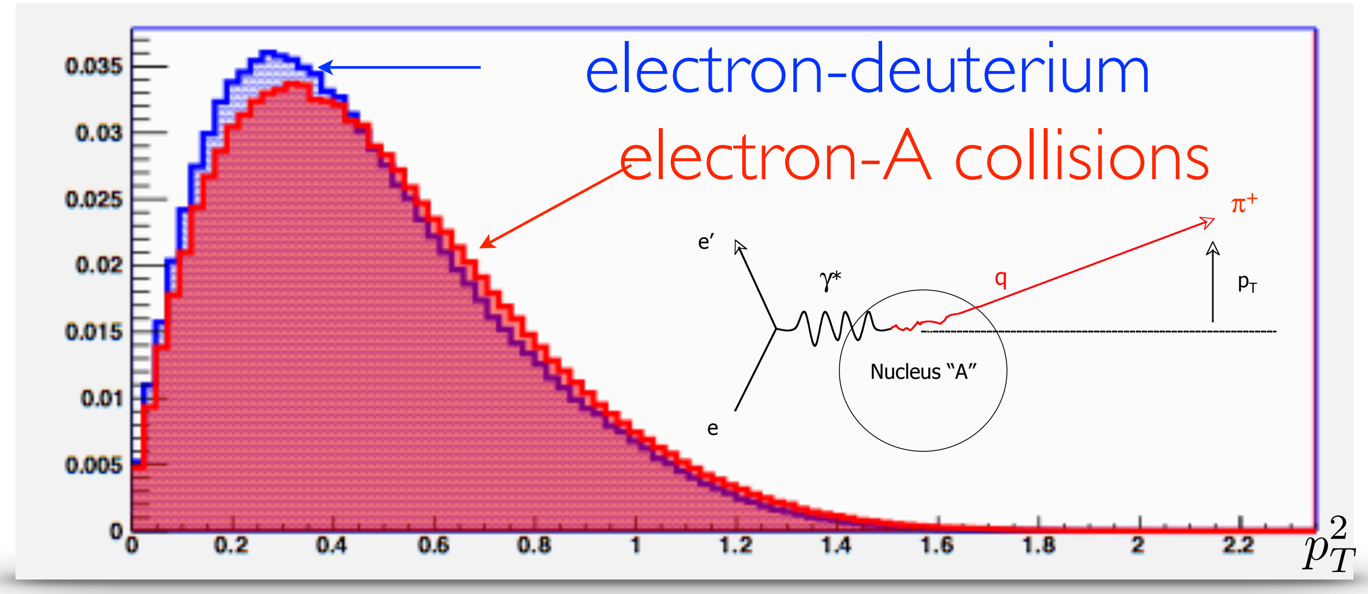
"Relative energy" $z = z_h = \dfrac{E_{hadron}}{\nu}$

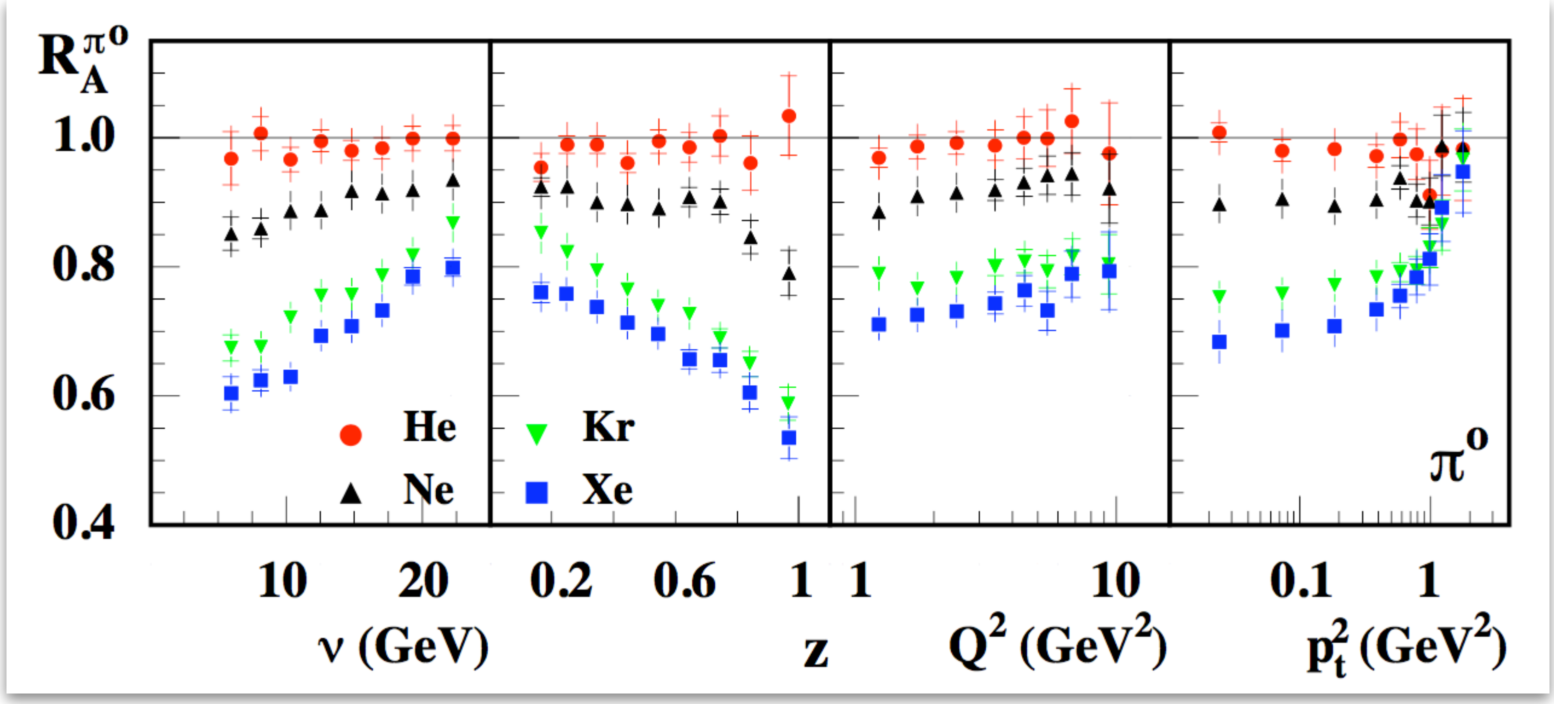
Momentum transverse to the virtual photon direction p_T

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

Experimental observables

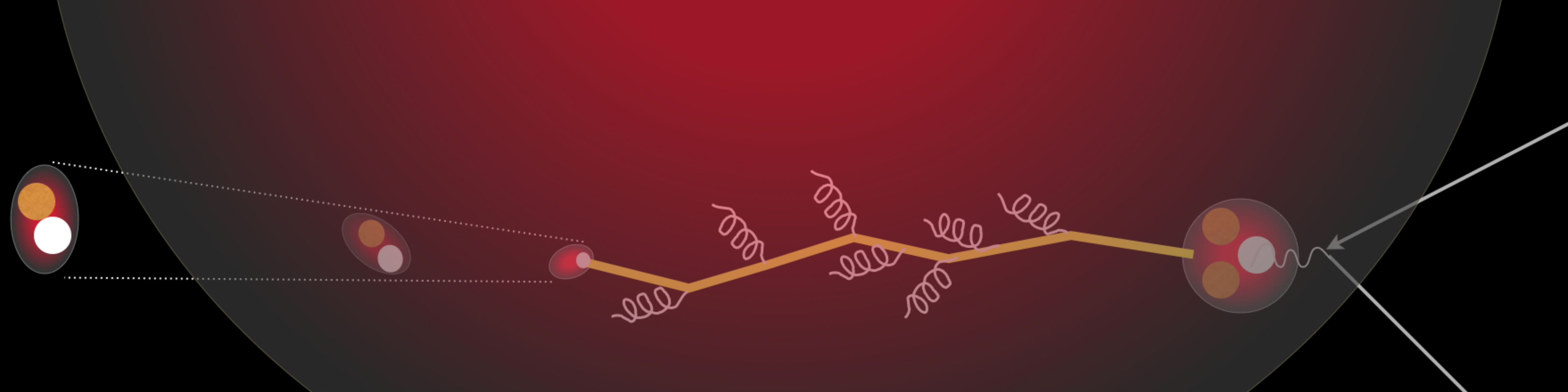
Transverse momentum broadening





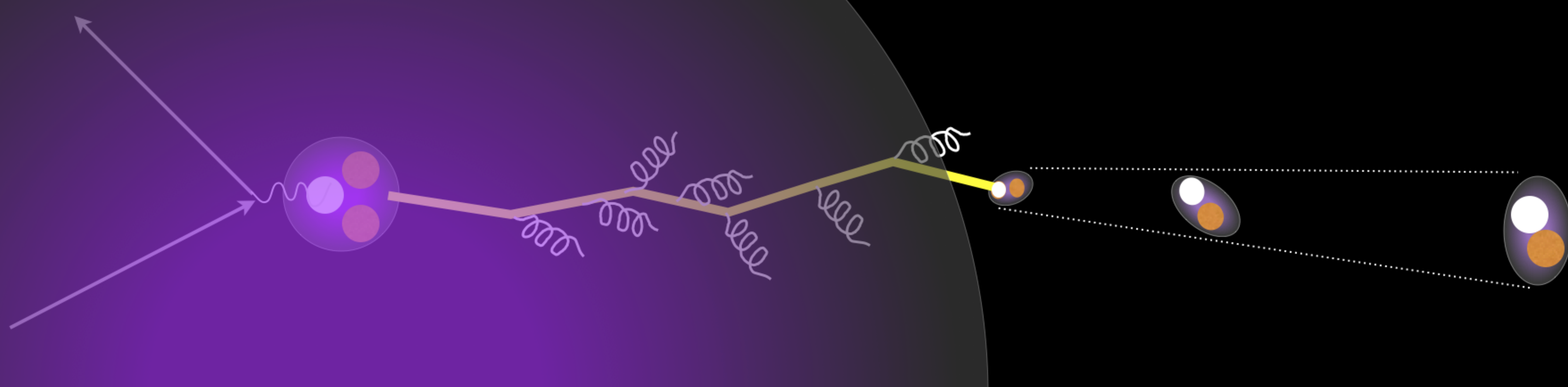
Hadronic multiplicity ratio

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



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

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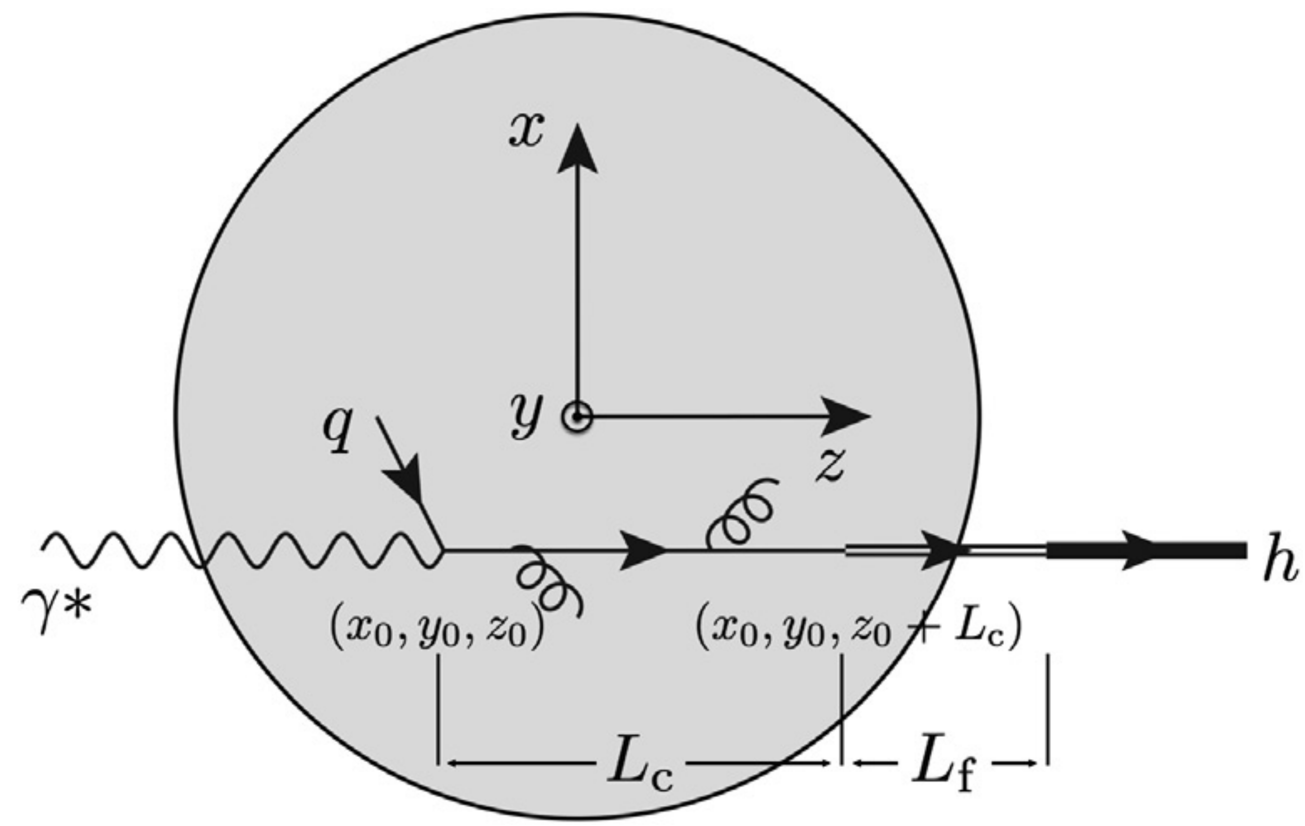
Struck quark moves a distance L_c as a colored object, then becomes a hadron. If the hadron forms inside the medium, it can interact with hadronic cross section.

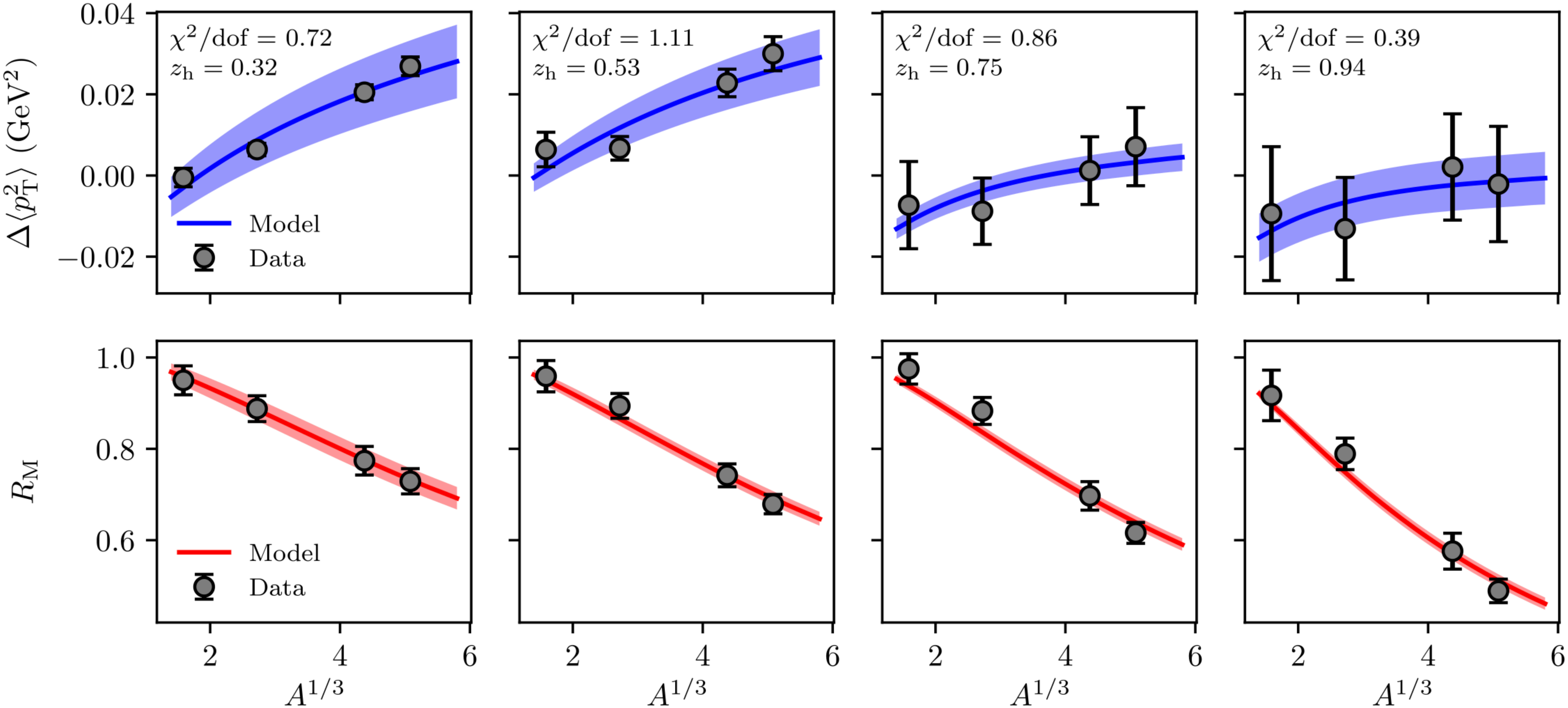
The color lifetime of the struck quark is distributed stochastically as a decaying exponential.



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

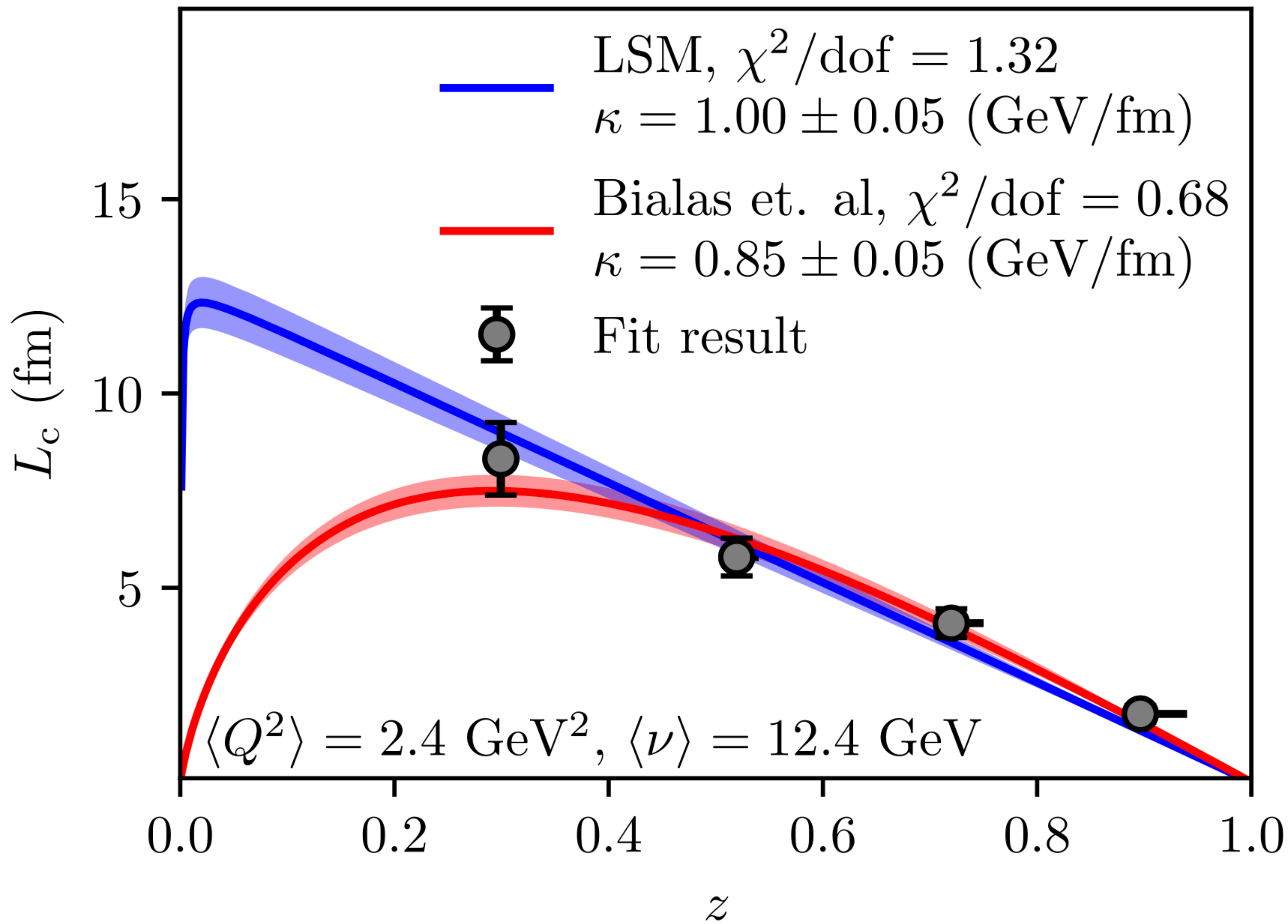
These are the results of the simultaneous fit to two observables



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

W. K. Brooks, QNP2022

This is a fit of the color lifetime parameter 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.

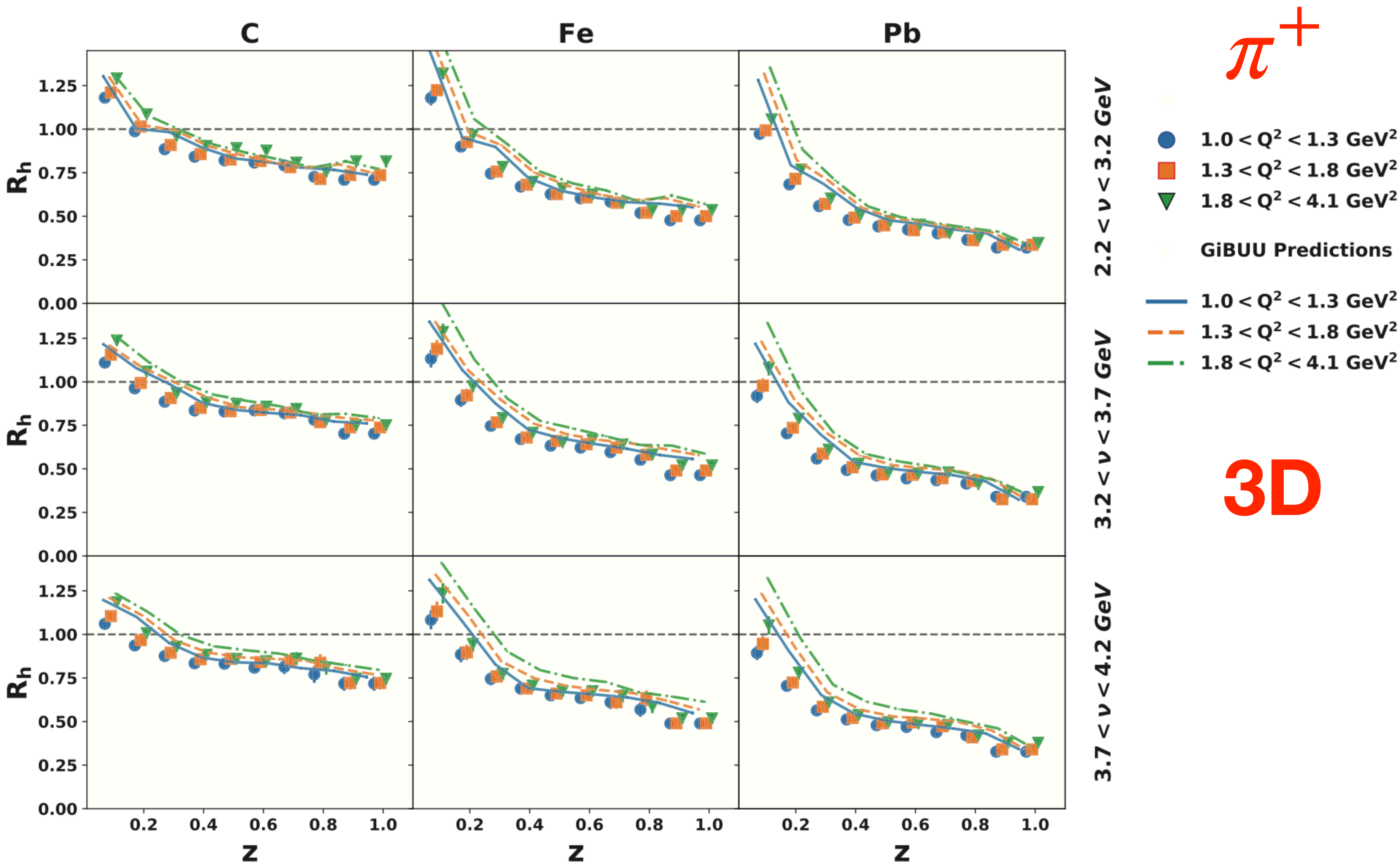
We believe we have a correct [simplified] physical picture.

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

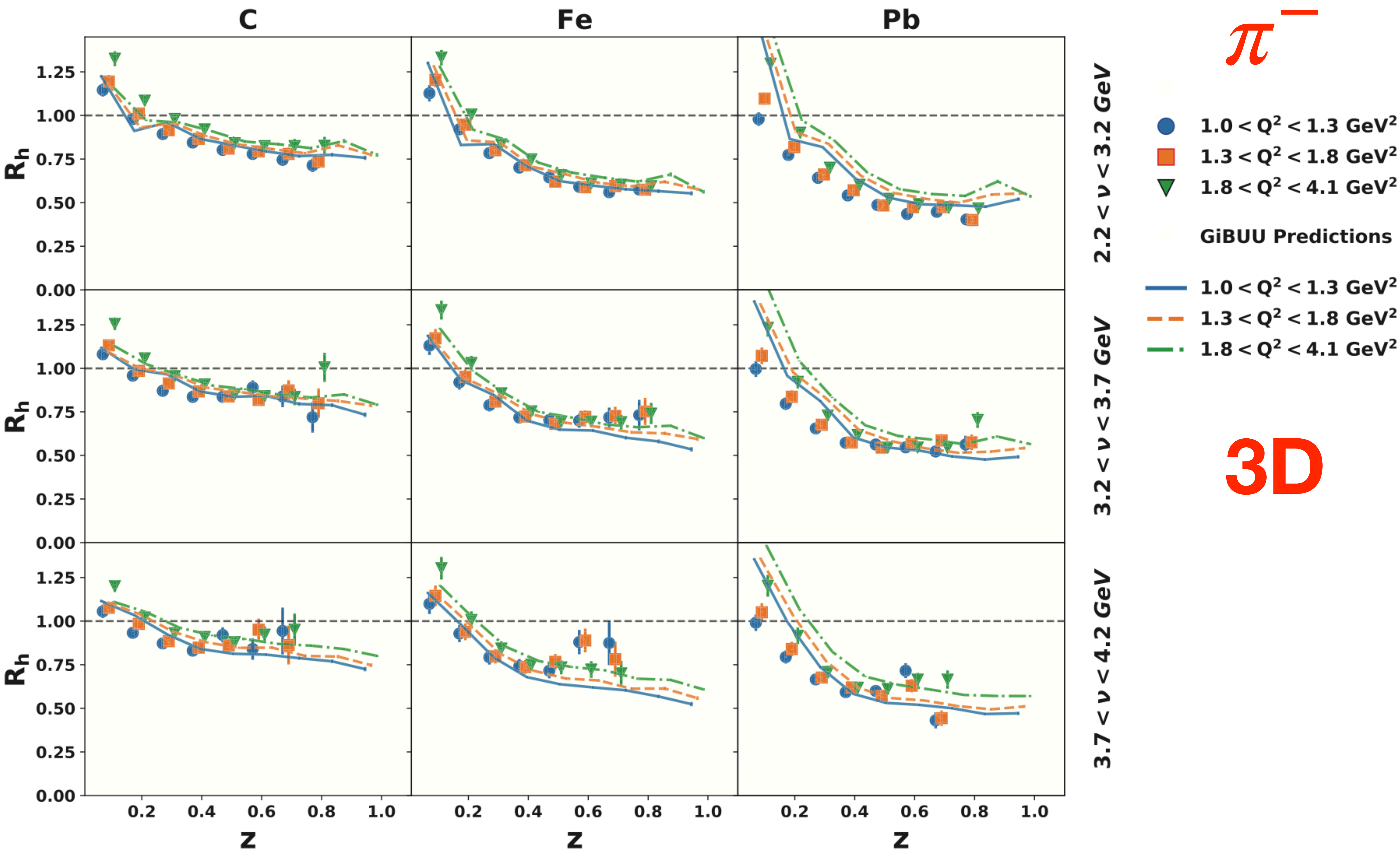
Measurement of charged-pion production in deep-inelastic scattering off nuclei with the CLAS detector

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]
N. A. Baltzell,[44] L. Barion,[20] M. Bashkanov,[49] M. Battaglieri,[44,22] I. Bedlinskiy,[31] Fatiha Benmokhtar,[14] A. Bianconi,[46,26]
L. Biondo,[22,25,47] A. S. Biselli,[15,8] F. Bossù,[10] S. Boiarinov,[44] W. J. Briscoe,[19] D. Bulumulla,[36] V. D. Burkert,[44] D. S. Carman,[4]
P. Chatagnon,[2] V. Chesnokov,[41] T. Chetry,[4] G. Ciullo,[20,16] P. L. Cole,[30,9,44] M. Contalbrigo,[20] G. Costantini,[46,26]
A. D'Angelo,[23,40] N. Dashyan,[52] R. De Vita,[22] M. Defurne,[10] A. Deur,[44] S. Diehl,[37,12] C. Djalali,[35,42] H. Egiyan,[44]
L. Elouadrhiri,[44] P. Eugenio,[18] R. Fersch,[11,51] A. Filippi,[24] G. Gavalian,[44,32] Y. Ghandilyan,[52] G. P. Gilfoyle,[39]
A. A. Golubenko,[41] R. W. Gothe,[42] K. A. Griffioen,[51] M. Guidal,[2] M. Hattawy,[36] F. Hauenstein,[36] T. B. Hayward,[12]
D. Heddle,[11,44] K. Hicks,[35] A. Hobart,[2] M. Holtrop,[32] Y. Ilieva,[42] D. G. Ireland,[48] E. L. Isupov,[41] H. S. Jo,[29] D. Keller,[50]
A. Khanal,[17] M. Khandaker,[34,*] W. Kim,[29] F. J. Klein,[9] A. Kripko,[37] V. Kubarovsky,[44,38] S. E. Kuhn,[36] L. Lanza,[23]
M. Leali,[46,26] P. Lenisa,[20,16] K. Livingston,[48] I. J. D. MacGregor,[48] D. Marchand,[2] L. Marsicano,[22] V. Mascagna,[45,26]
B. McKinnon,[48] C. McLauchlin,[42] Z. E. Meziani,[5] S. Migliorati,[46,26] M. Mirazita,[21] V. Mokeev,[44,41] C. Munoz Camacho,[2]
P. Nadel-Turonski,[44] K. Neupane,[42] S. Niccolai,[2] G. Niculescu,[28] T. R. O'Connell,[12] M. Osipenko,[22] A. I. Ostrovidov,[18]
M. Ouillon,[2] P. Pandey,[36] M. Paolone,[33] L. L. Pappalardo,[20,16] E. Pasyuk,[44] W. Phelps,[11,19] O. Pogorelko,[31] J. Poudel,[36]
J. W. Price,[6] Y. Prok,[36,50] B. A. Raue,[17] Trevor Reed,[17] M. Ripani,[22] J. Ritman,[27] A. Rizzo,[23,40] G. Rosner,[48] J. Rowley,[35]
F. Sabatié,[10] C. Salgado,[34] A. Schmidt,[19] R. A. Schumacher,[8] Y. G. Sharabian,[44] E. V. Shirokov,[41] U. Shrestha,[12]
D. Sokhan,[10,48] O. Soto,[21] N. Sparveris,[43] S. Stepanyan,[44] I. I. Strakovsky,[19] S. Strauch,[42,19] R. Tyson,[48] M. Ungaro,[44,38]
L. Venturelli,[46,26] H. Voskanyan,[52] A. Vossen,[13,44] E. Voutier,[2] D. P. Watts,[49] Kevin Wei,[12] X. Wei,[44] L. B. Weinstein,[36]
R. Wishart,[48] M. H. Wood,[7,42] B. Yale,[51] N. Zachariou,[49] J. Zhang,[50] and Z. W. Zhao[13]
(CLAS Collaboration)

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**.



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



π^-

3D

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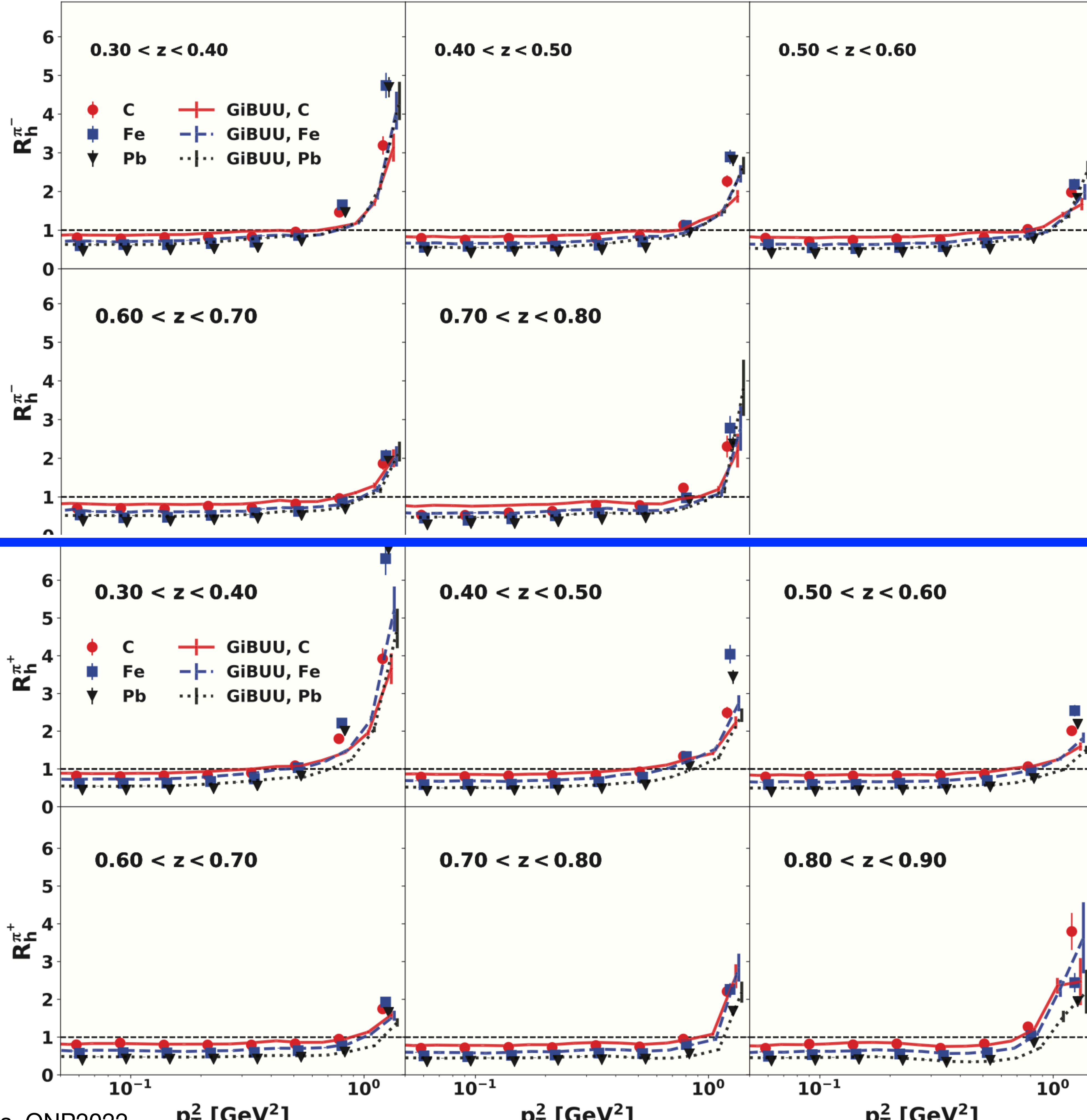
π^-



2D

π^+

Lines are from the GiBUU event generator with standard parameters

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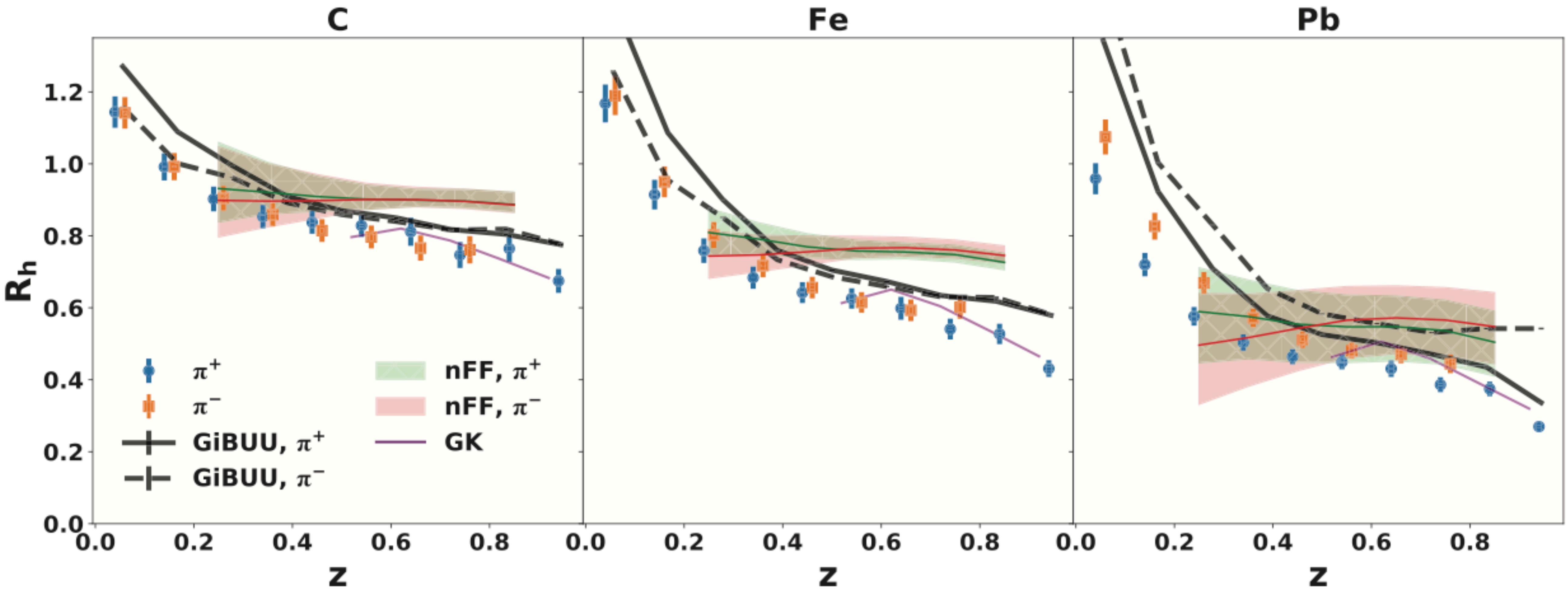
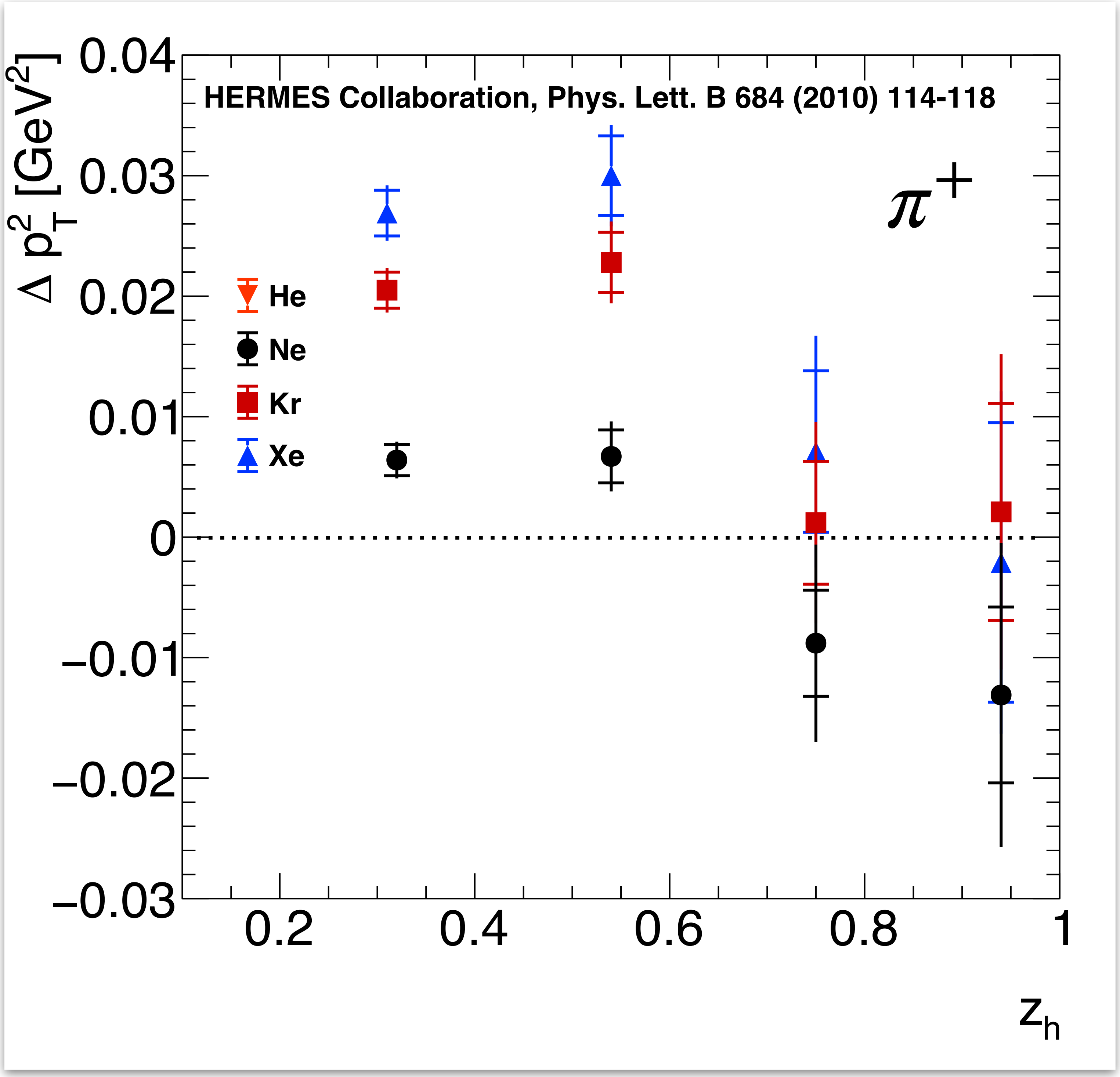


FIG. 1. Multiplicity ratio of π^+ and π^- as a function of z; the three different panels show results for C, Fe, and Pb targets, respectively. The error bars represent the quadrature sum of systematic and statistical uncertainties, which is dominated by the systematic uncertainties that are partially 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 [qualitative] physical picture
GiBUU has only string fragmentation, no quark energy loss.

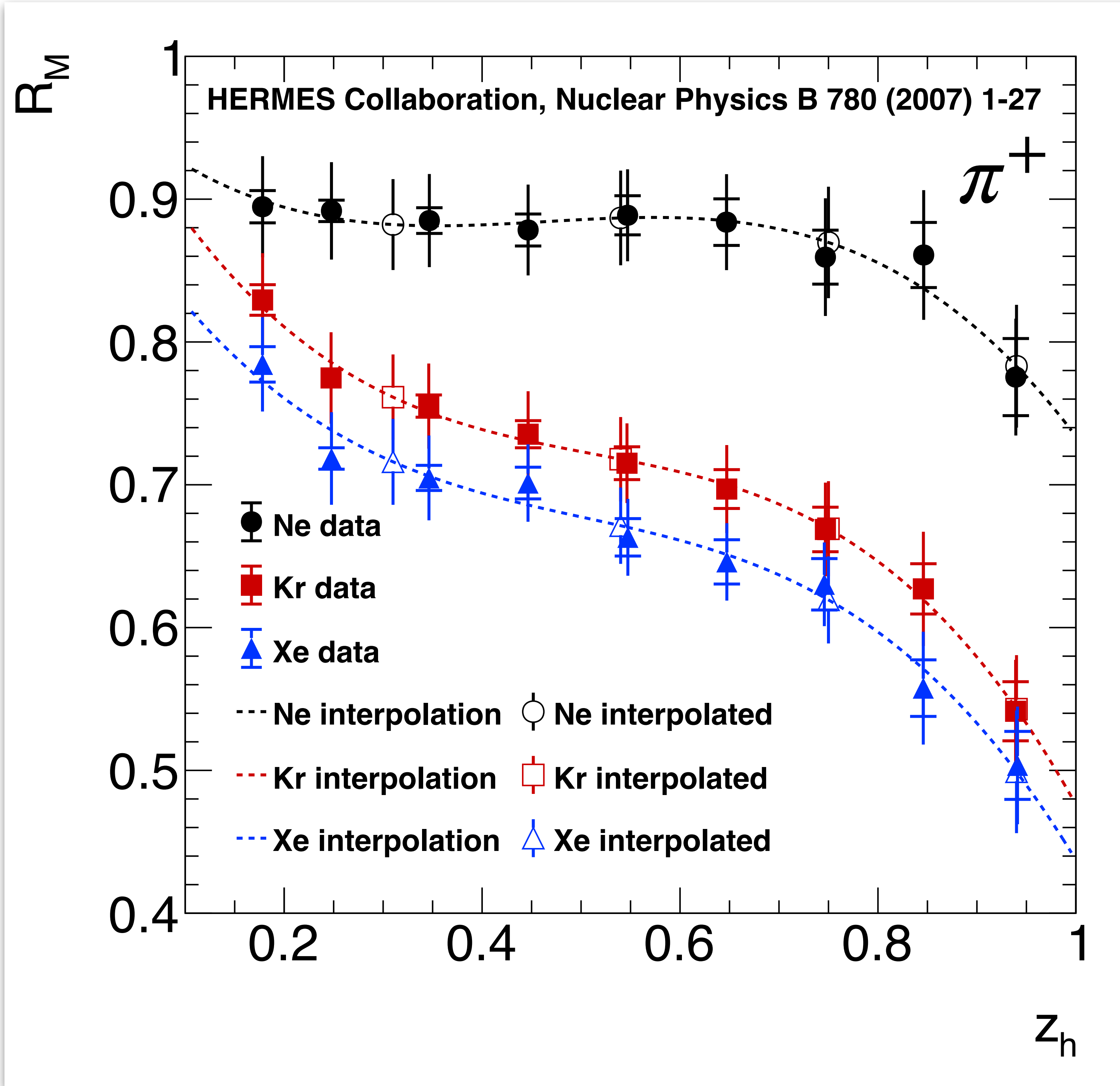
GiBUU uses hadronic degrees of freedom, it incorporates formation times, "prehadron" interactions,[3] color transparency, and nuclear shadowing. These ingredients have been postulated to be necessary to describe nuclear modification of hadrons produced in DIS by the HERMES and EMC experiments. The default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

Hermes data for p_T broadening vs. z_h=E/ν



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,

$$R_M^\pi < 1$$

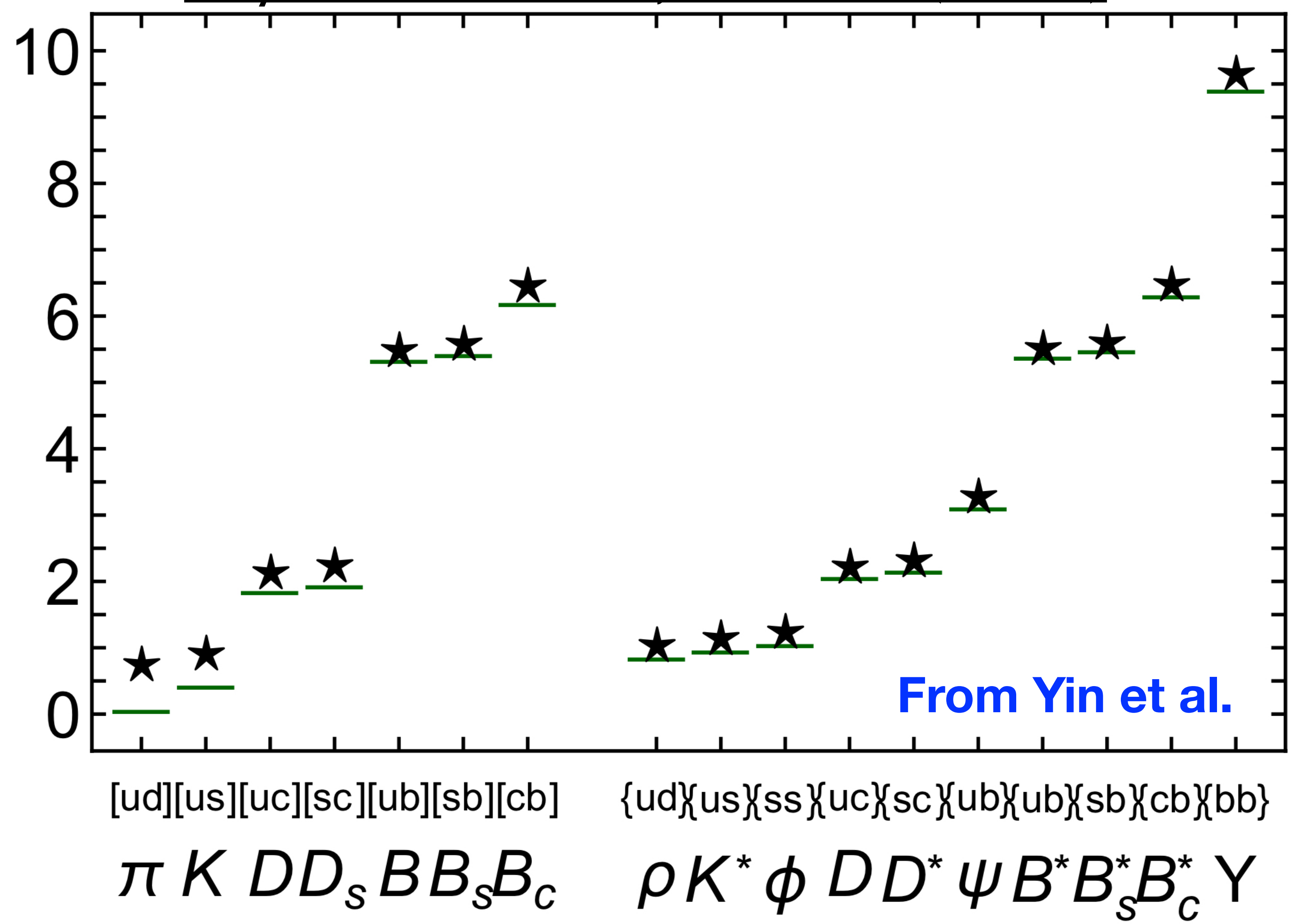
Always attenuation, never enhancement

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 and us diquarks are heavy. This is very relevant to what follows.

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: MESONS

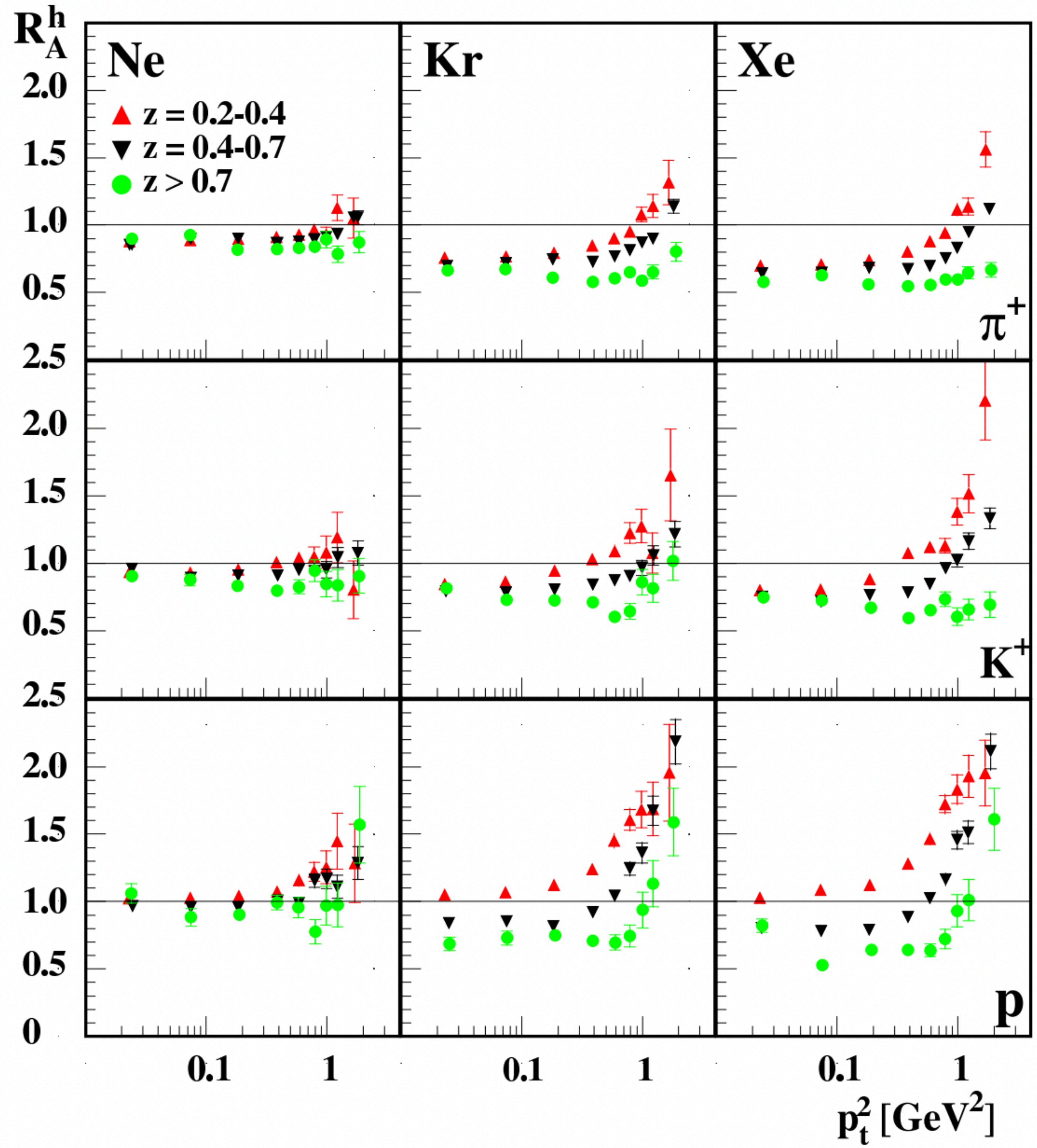
The multiplicity ratio measures effects of the nuclear medium.

"No nuclear effects" means R=1.0

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

Most basic indicator is p_T dependence of multiplicity ratio.

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



"Interact" = hadronic interaction of forming hadrons + gluon bremsstrahlung.

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

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

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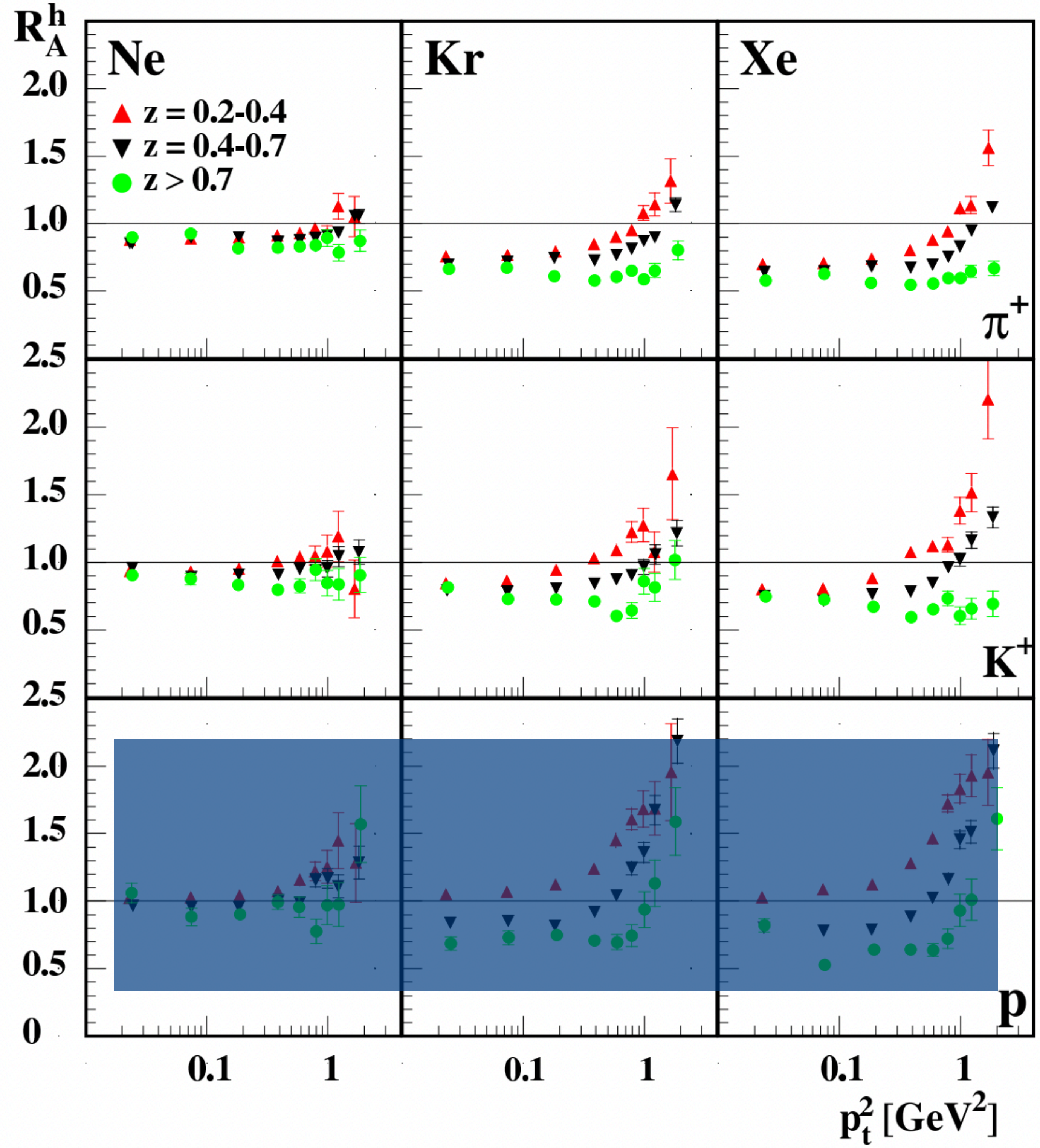

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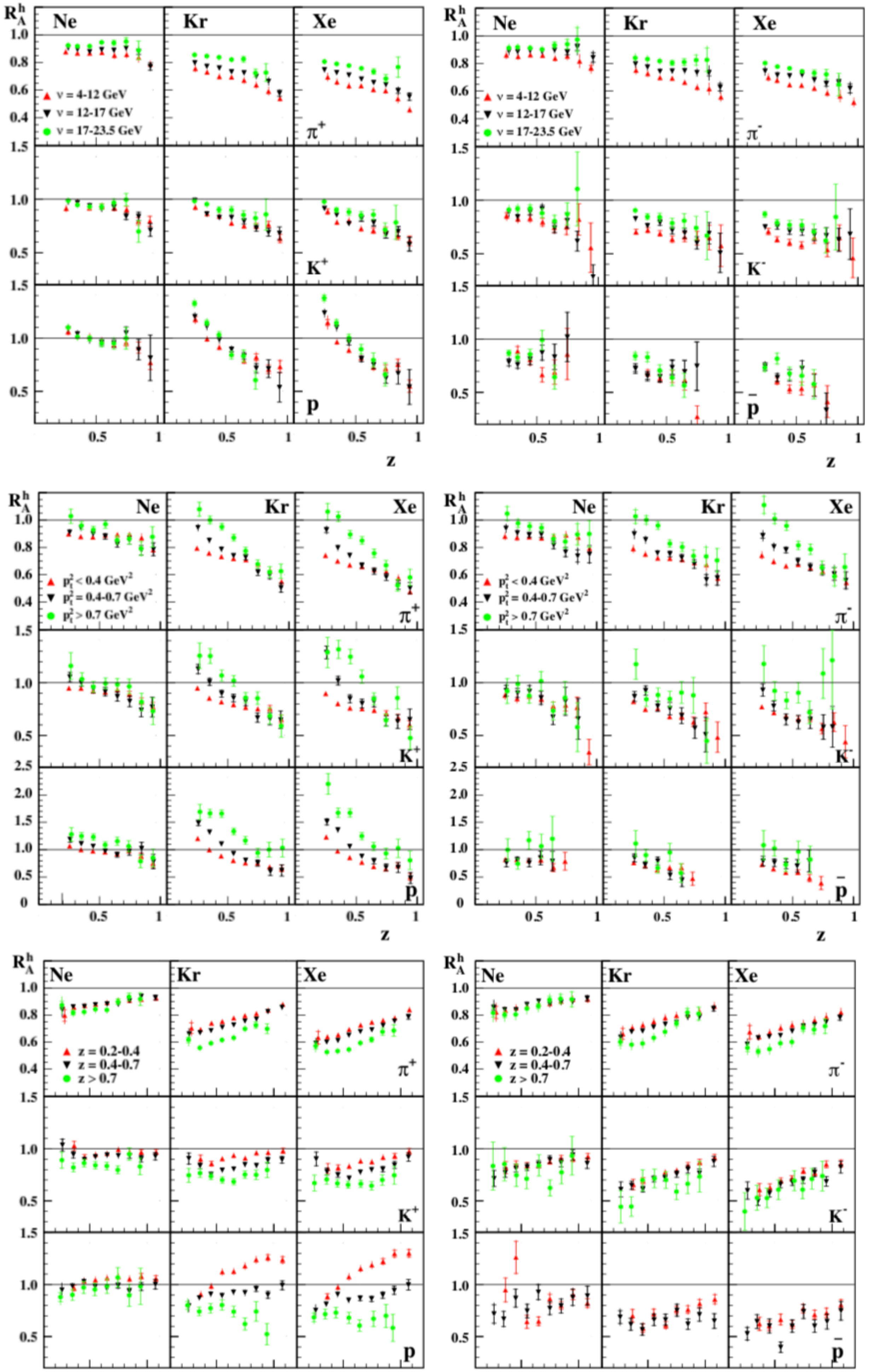
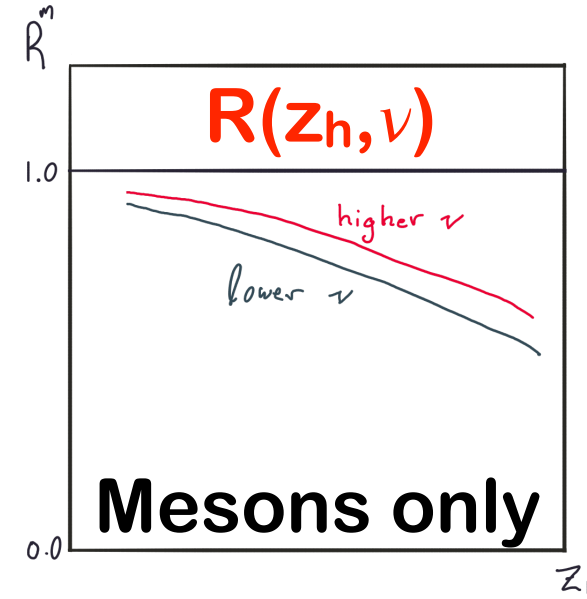
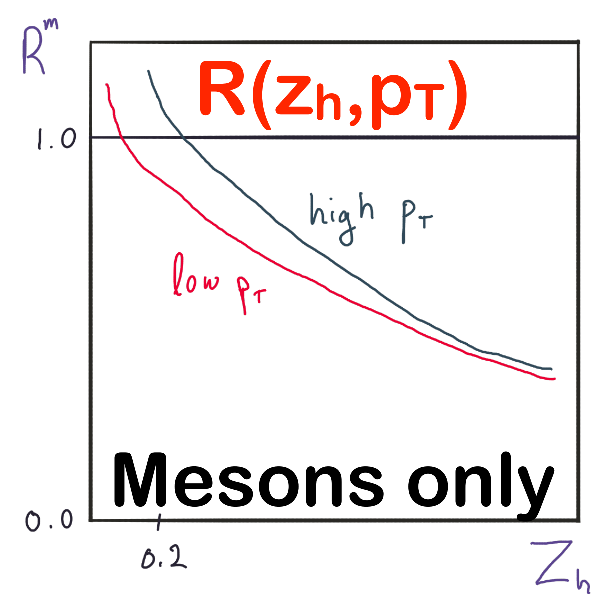
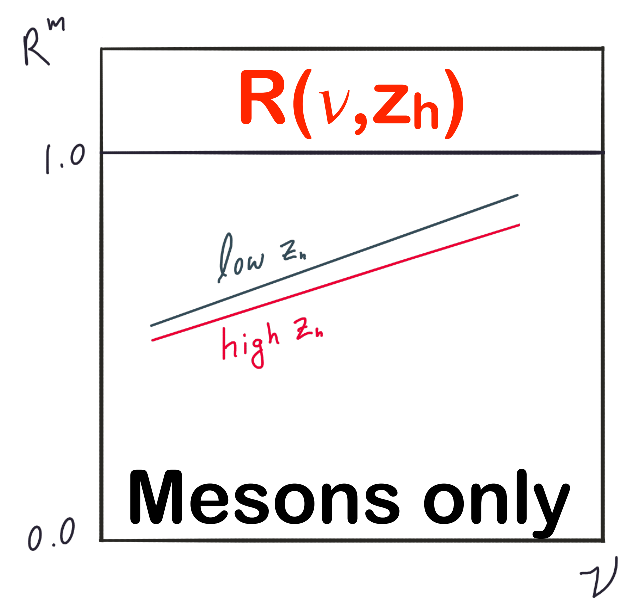




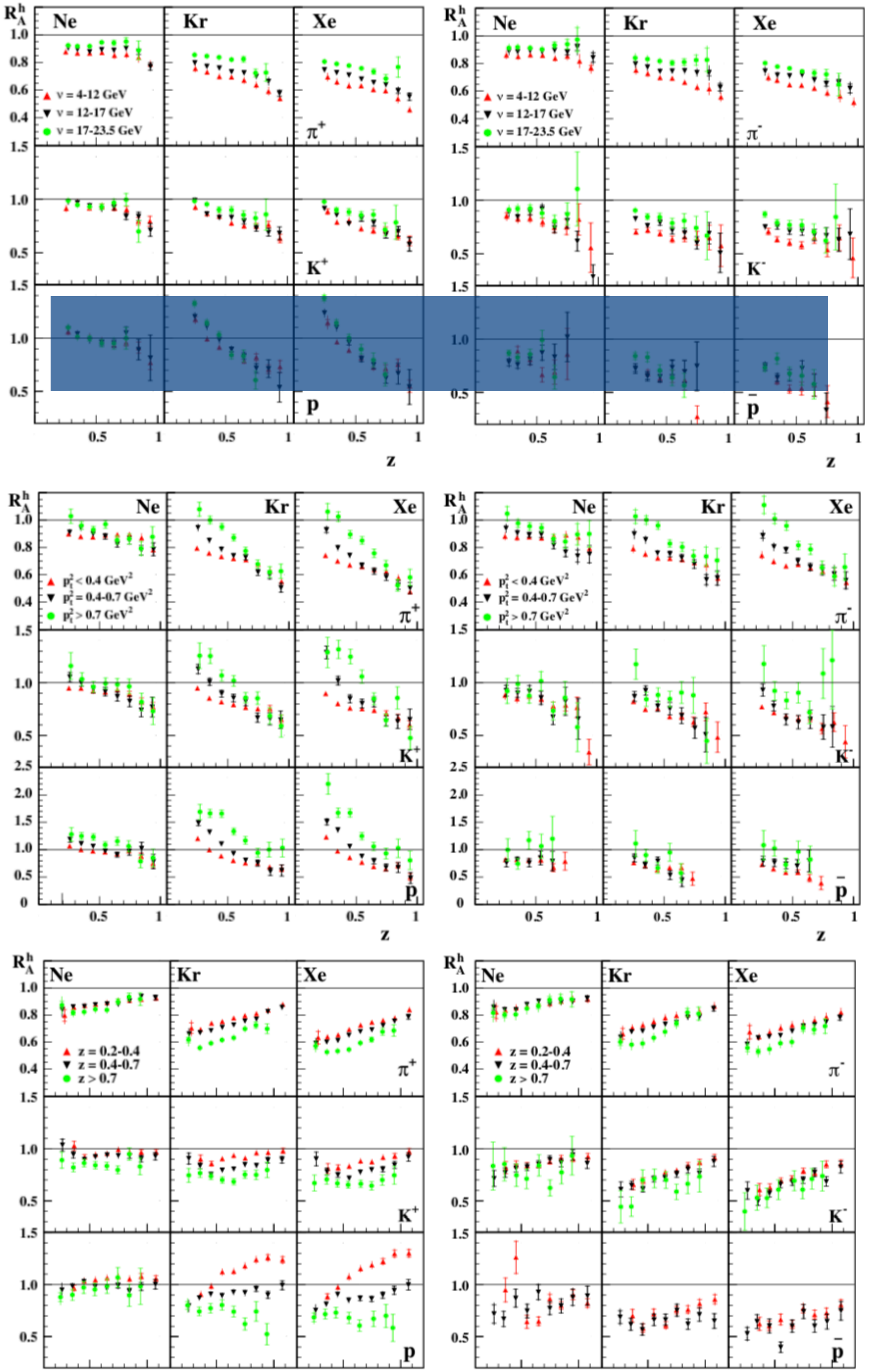
Integrated over p_T, so always < 1. At higher ν, less attenuation because of time dilation of color lifetime.



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



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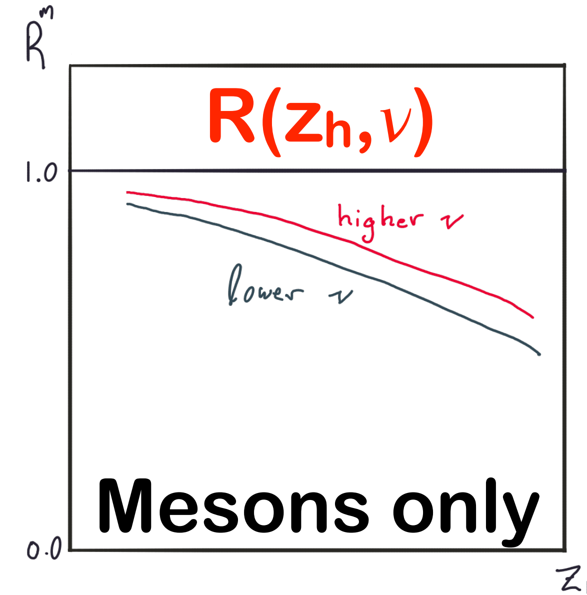

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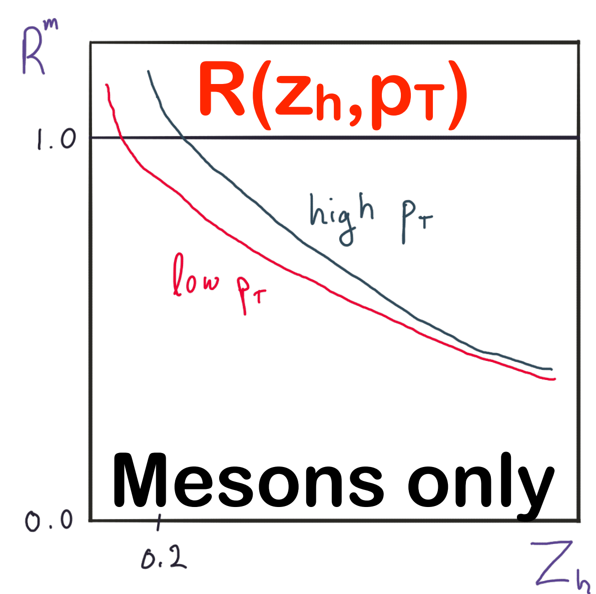

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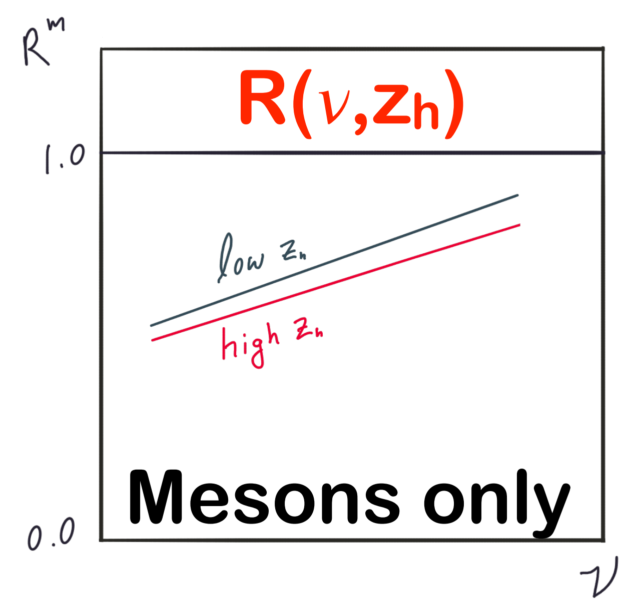

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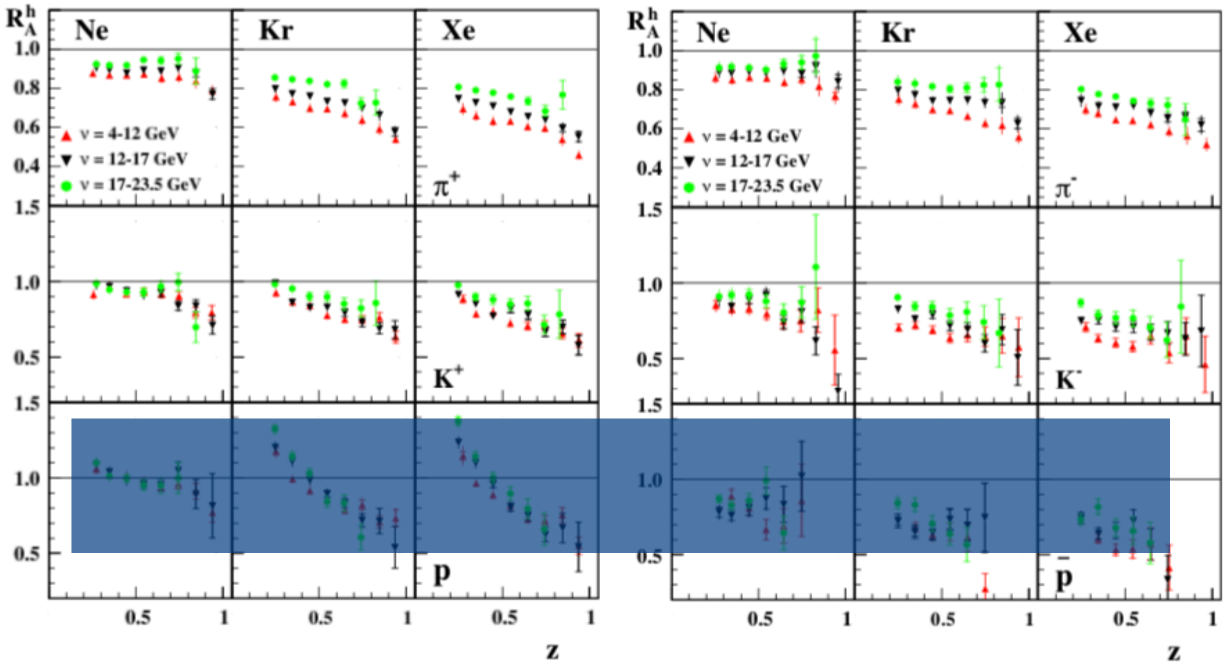

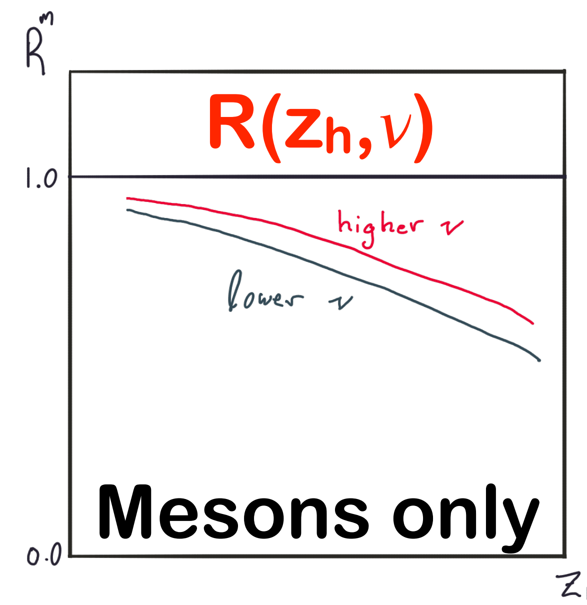

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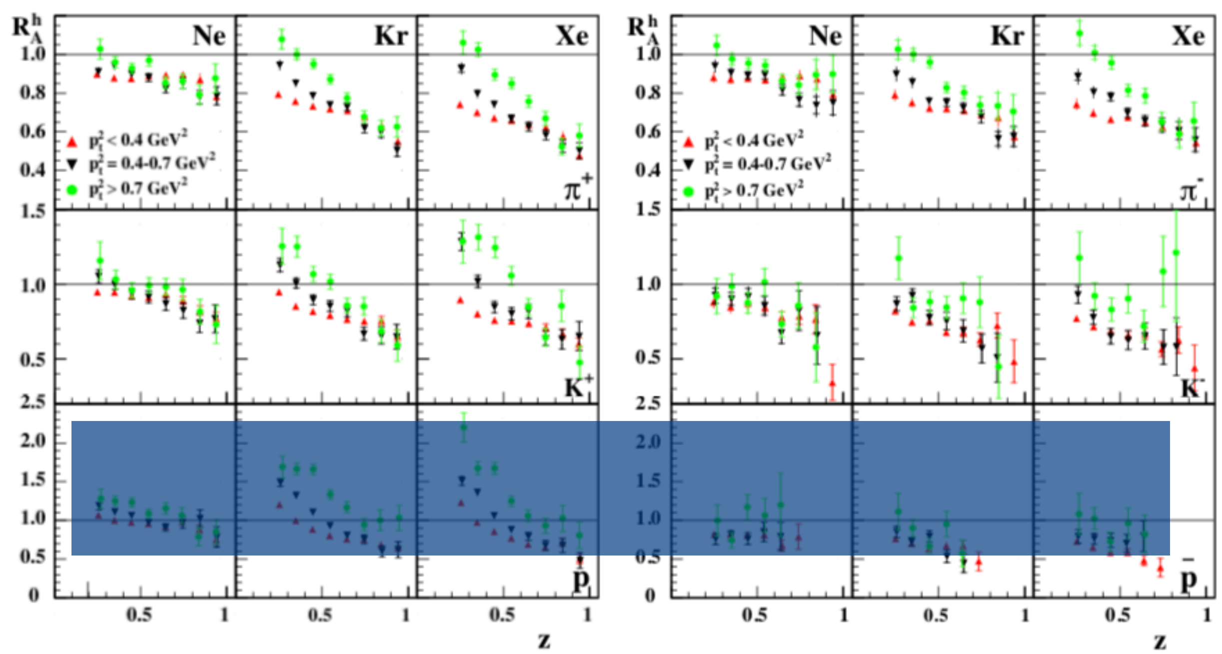

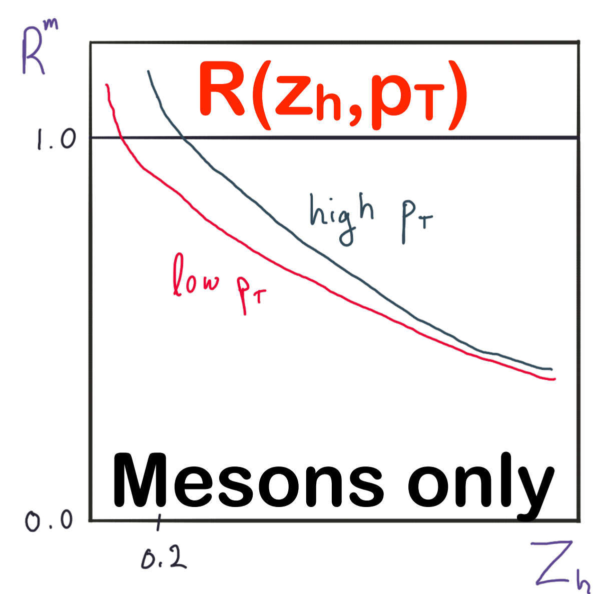

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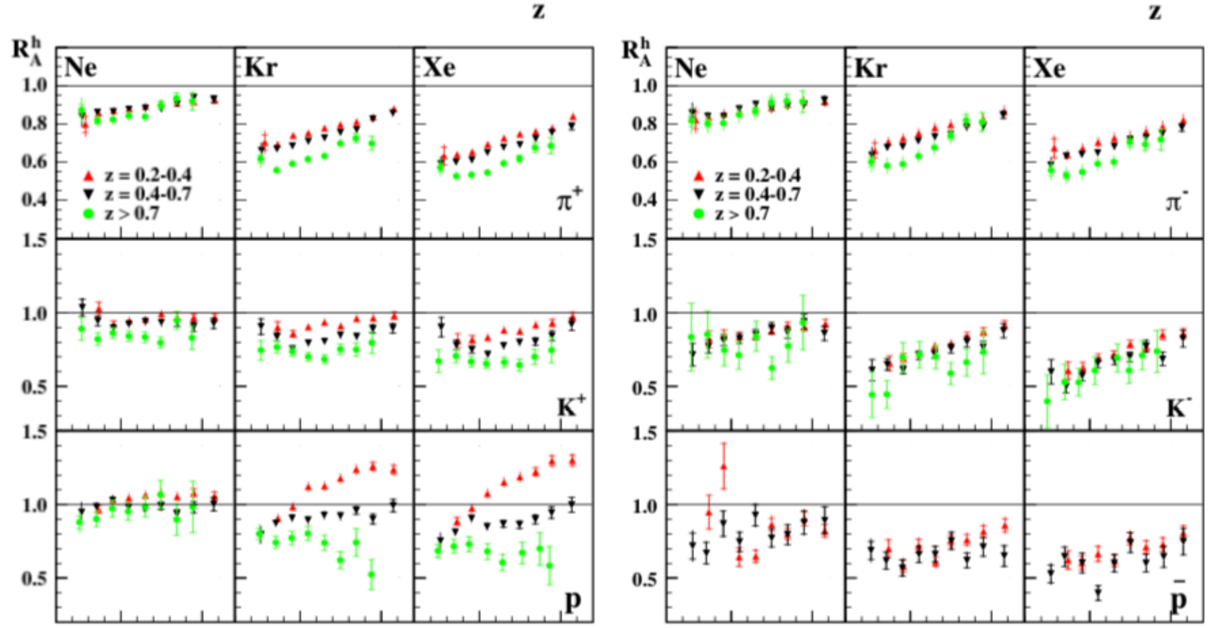

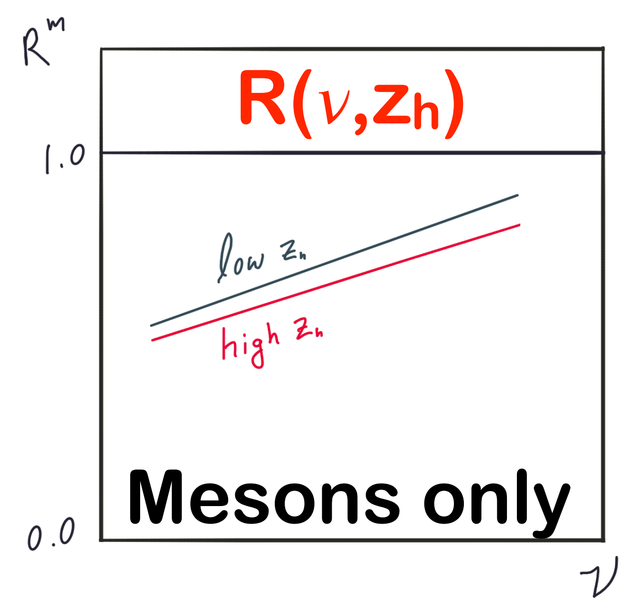

Time dilation is proportional to ν. Slow approach to 1.0 at infinite ν. Color lifetime goes to zero at high z, so high z is attenuated more.

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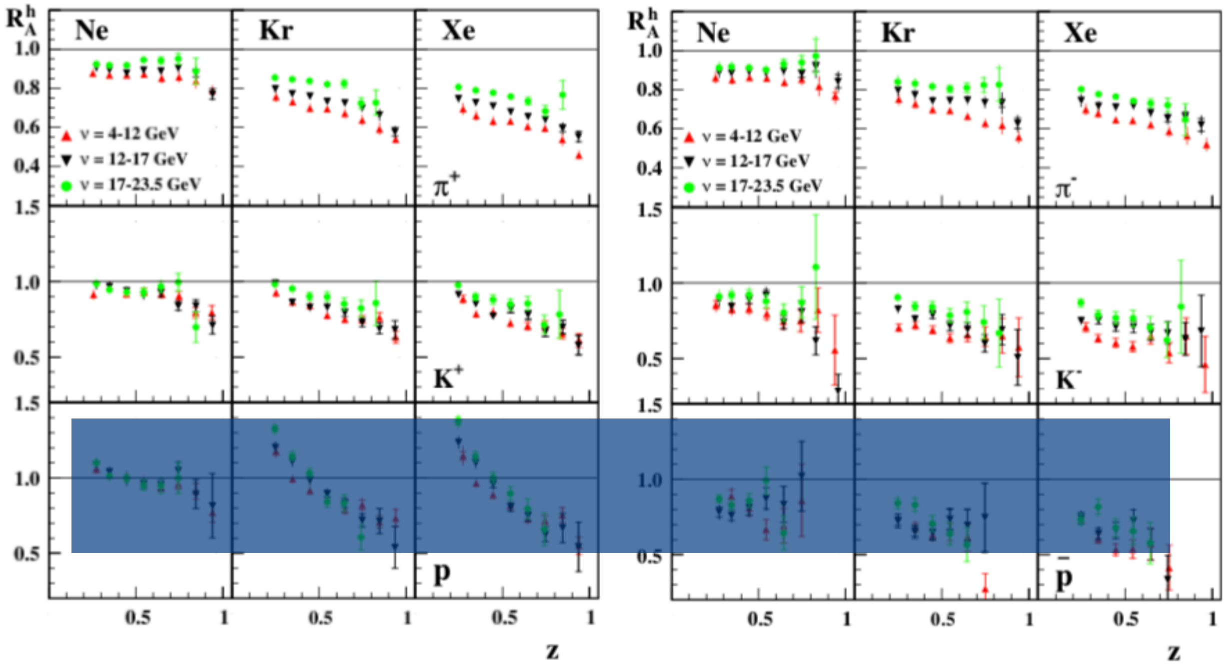
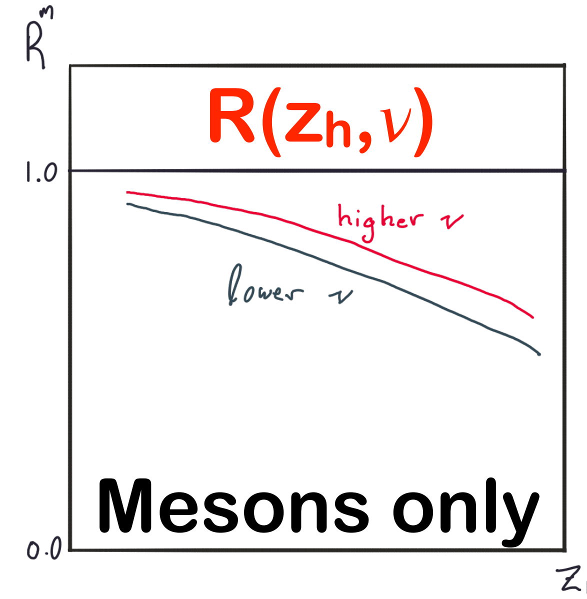
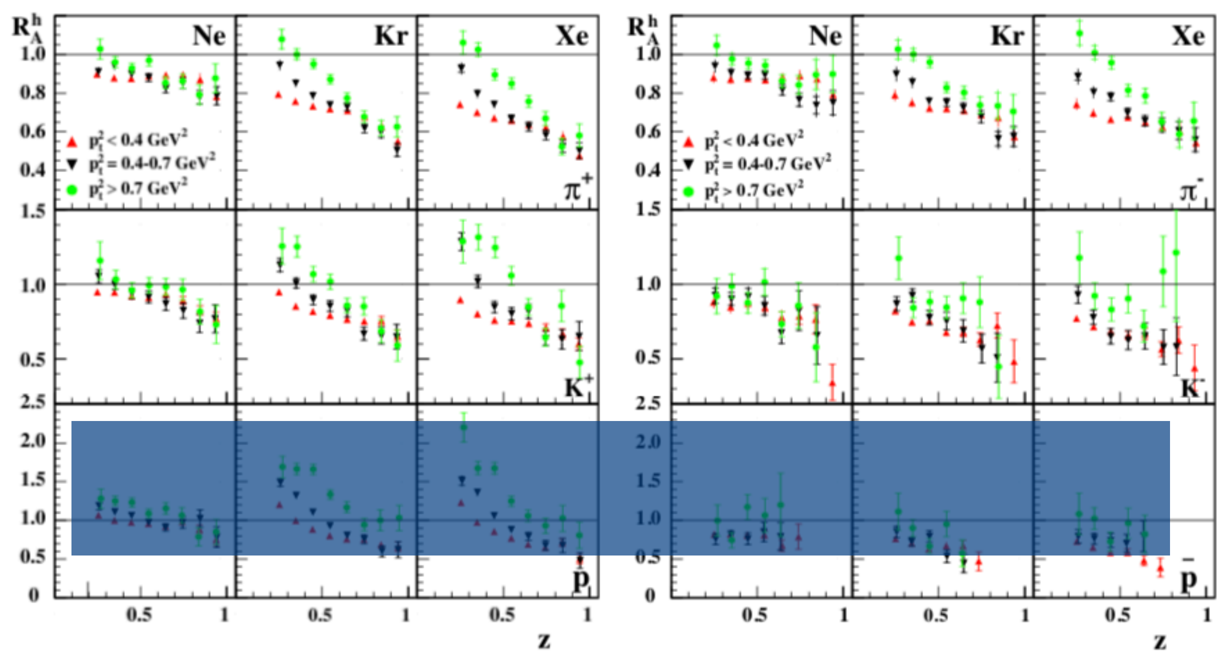
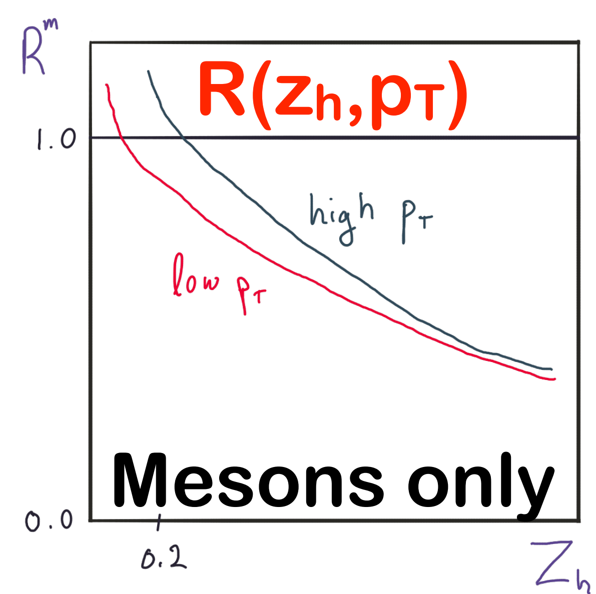


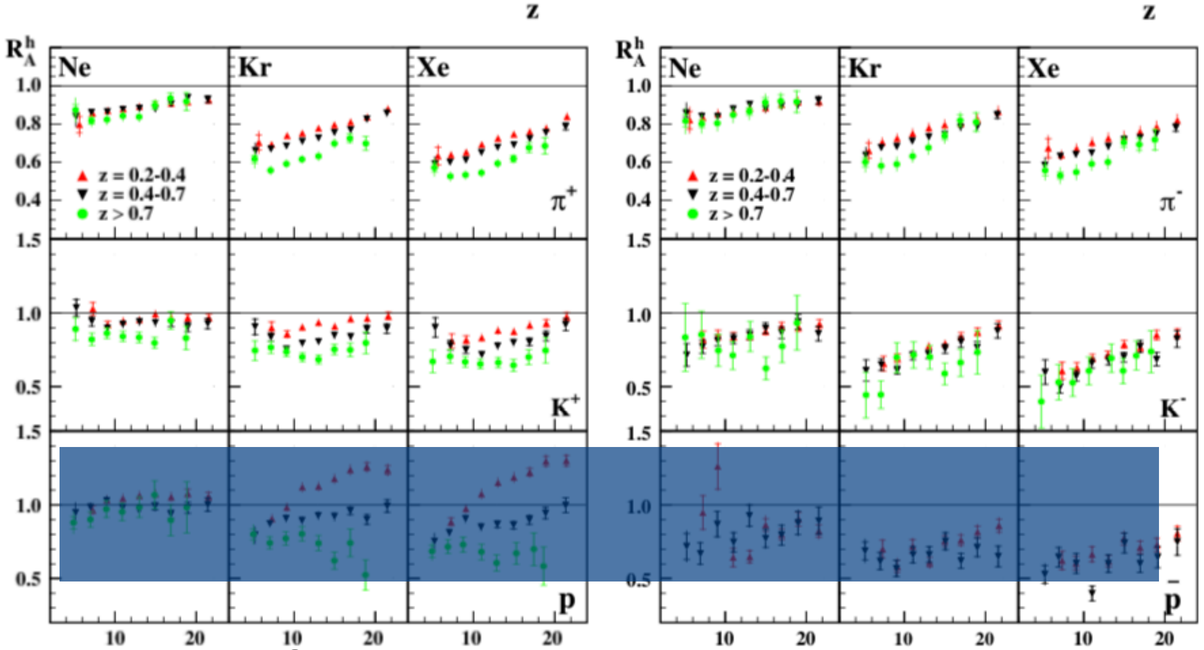


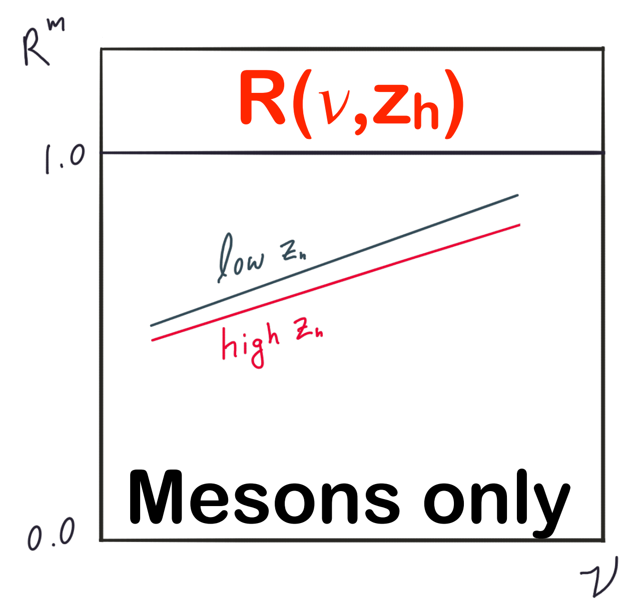
Integrated over pT, so always < 1. At higher ν, less attenuation because of time dilation of color lifetime.





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.

W. K. Brooks, QNP2022

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

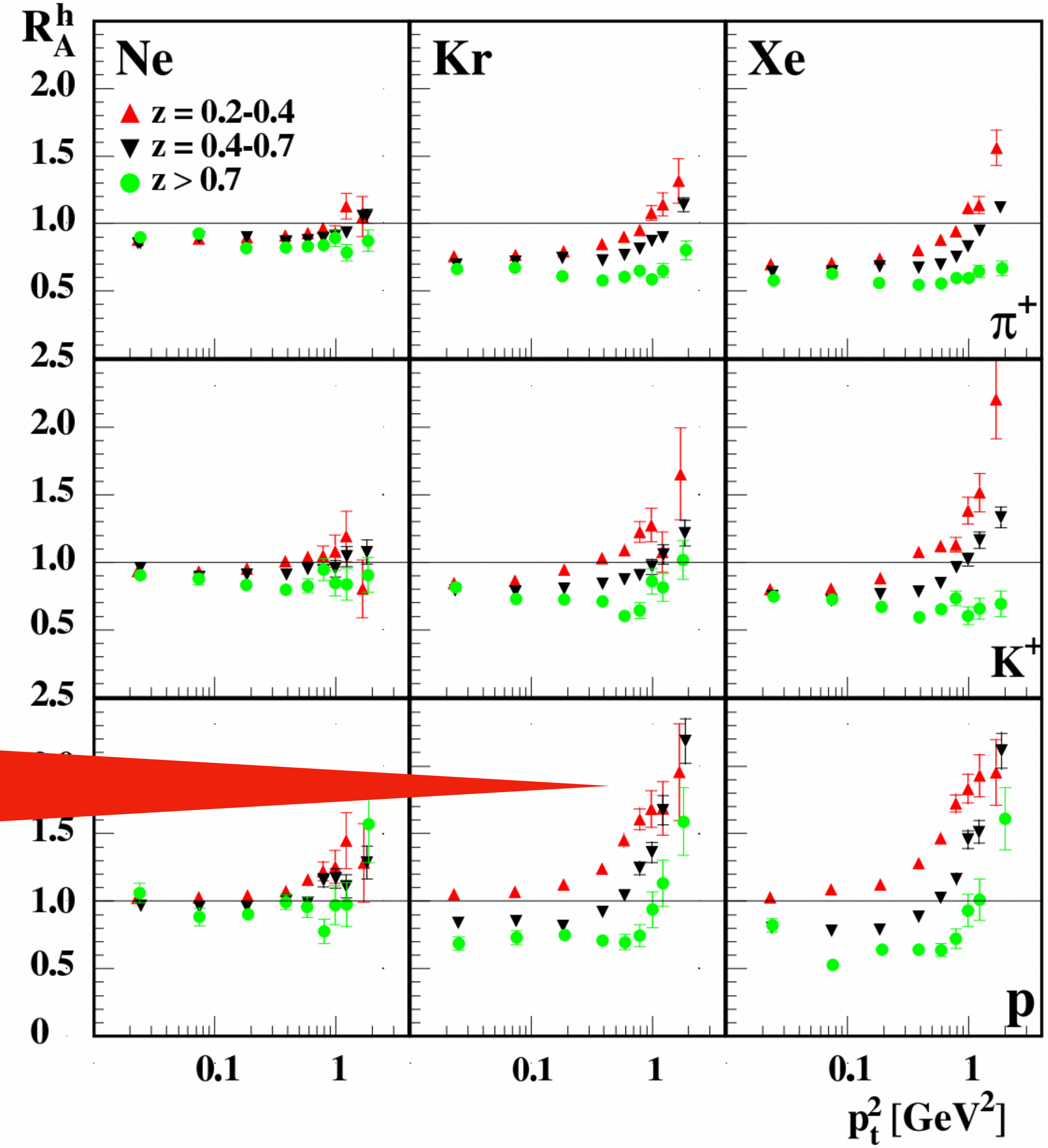
BUT: mesons don’t contain qq diquarks. Baryons do.

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

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



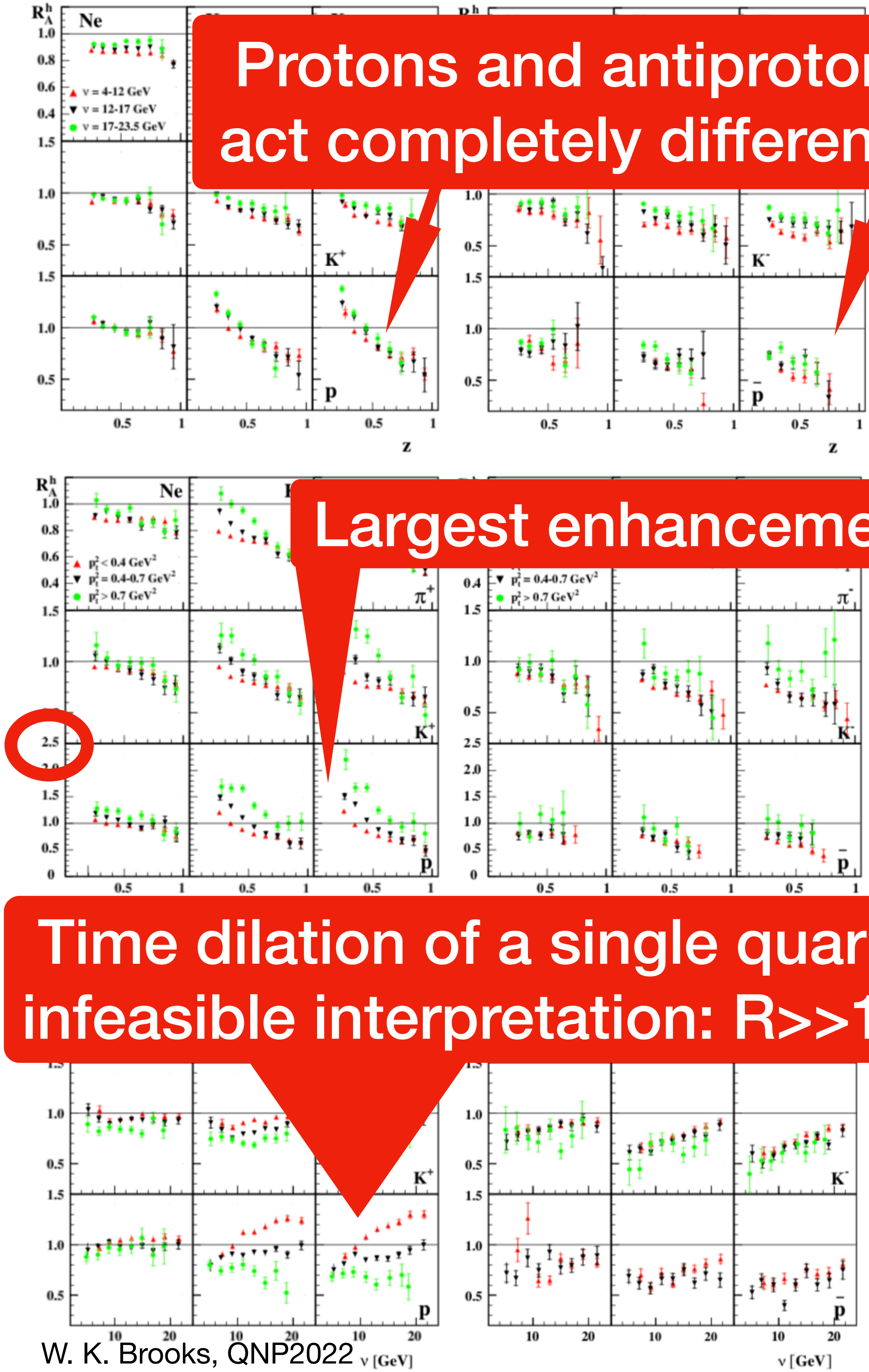
The ordering in z seen for mesons *disappears* at high p_T for protons.

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

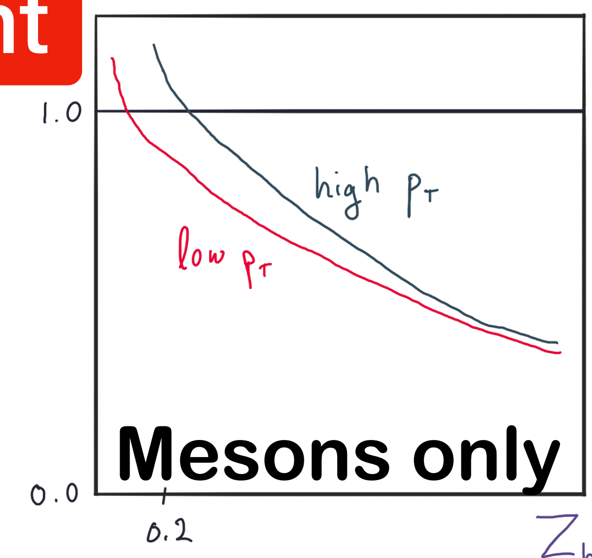
of forming hadrons, + quark energy loss.

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

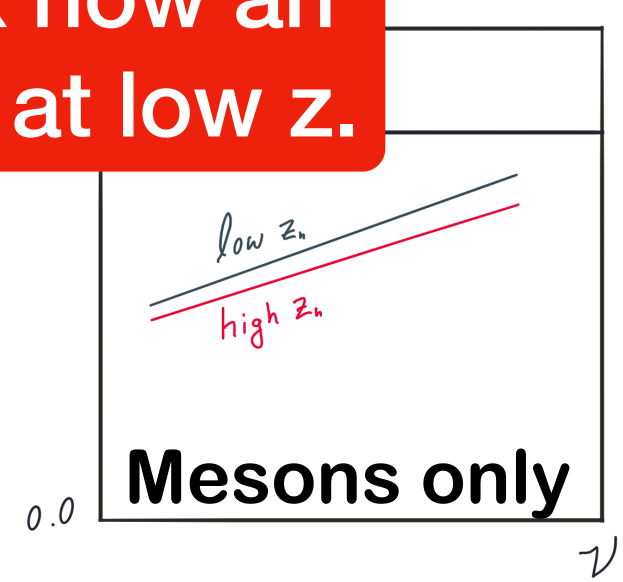
Enhancement at high pT mostly caused by hadronic interactions at low z.



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

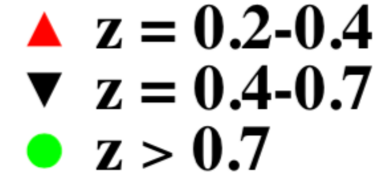


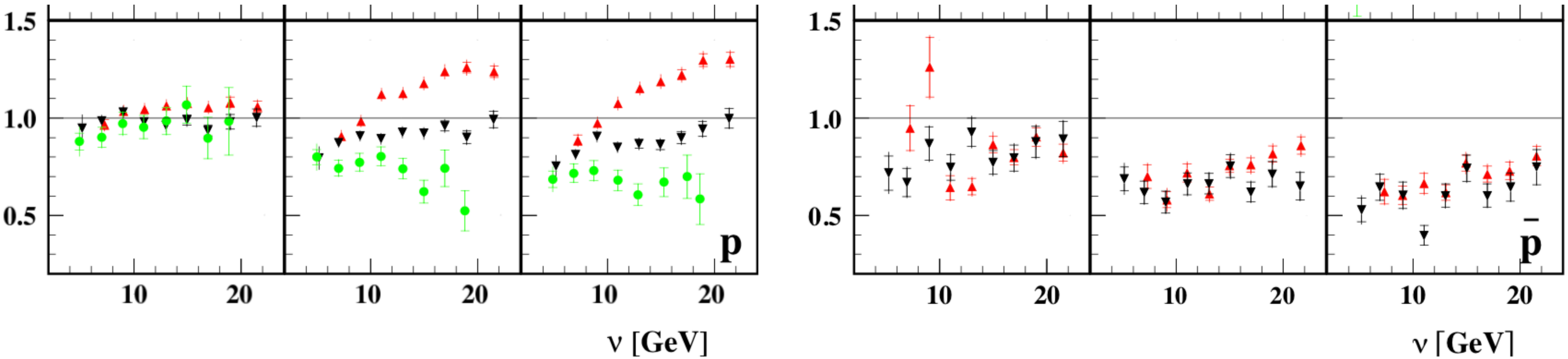
Not integrated over p_T, so can exceed 1. Exceeds 1 faster for higher p_T, so crossing point is p_T dependent.



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.

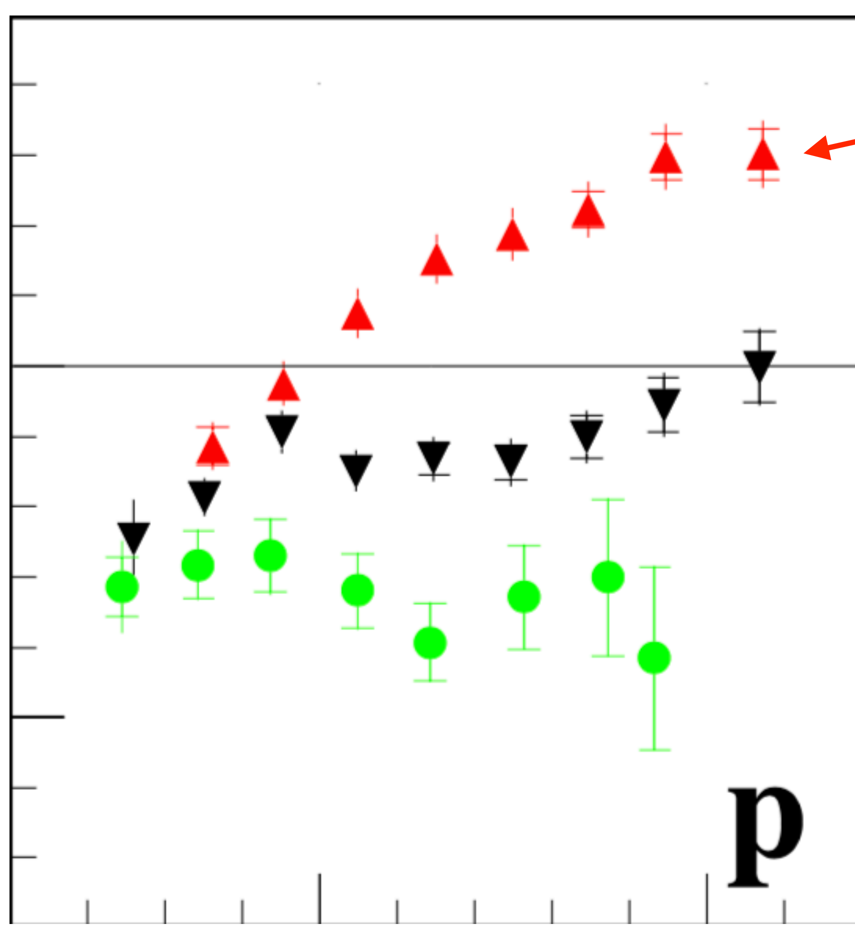
HERMES Proton Multiplicity Ratios





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

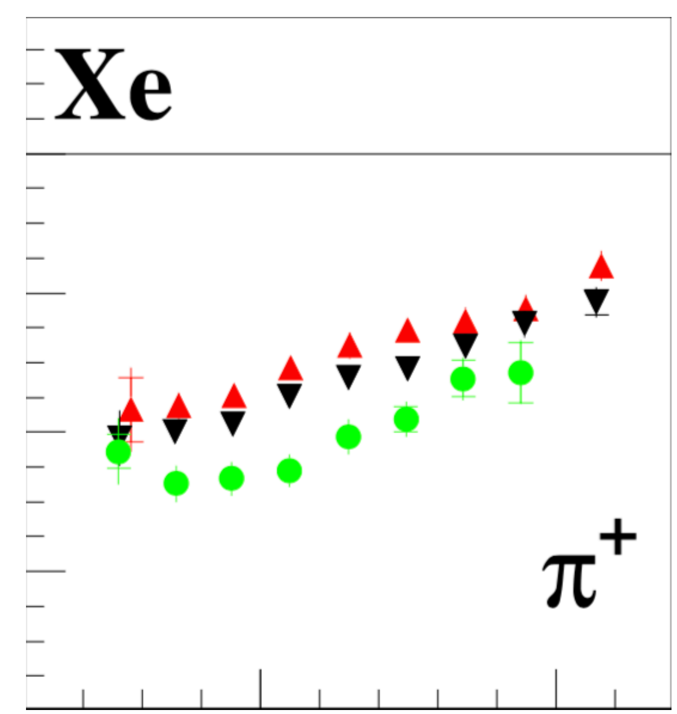
Proton multiplicity ratios qualitatively different from mesons.



This

vs.

this



I will argue that this behavior is due to diquarks

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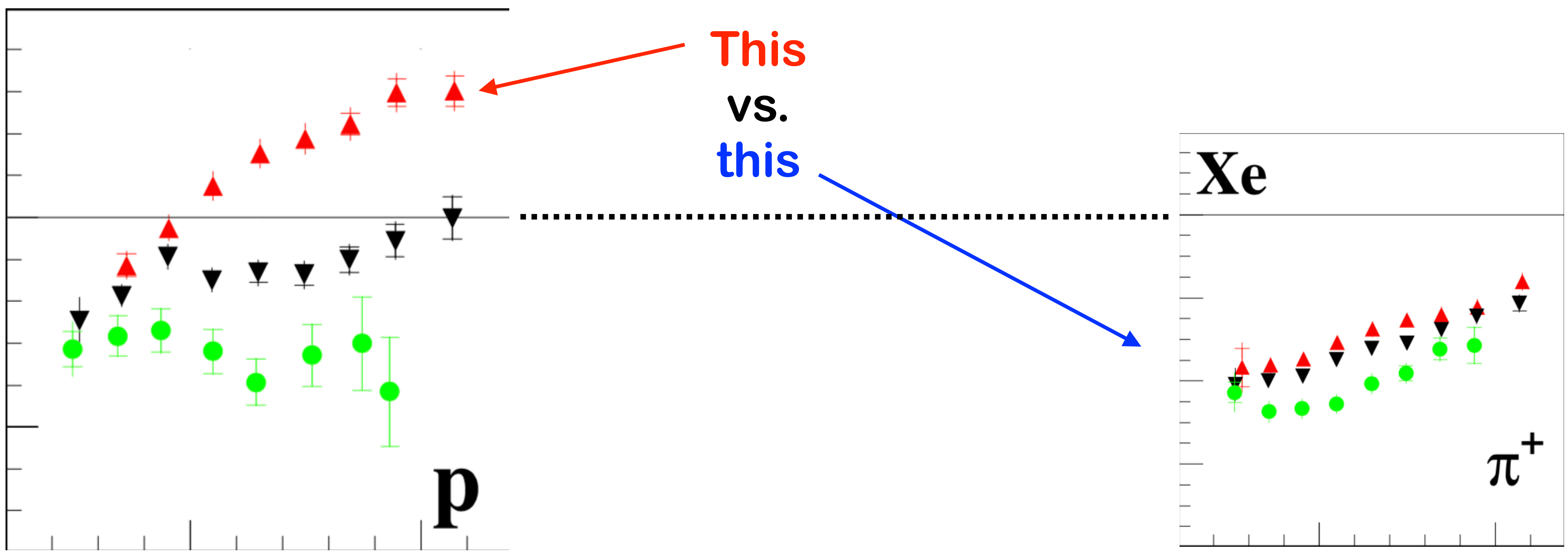


HERMES paper explanation: FSI are "knocking out protons." Maybe.
But, at high W and Q^2, if virtual photon strikes one quark: need to make an energetic pion in-medium to knock out a proton.

But maybe it could be diquarks knocking them out.
Diquark "size" must be similar to that of a proton (mass is similar to/larger than that of a proton).

= diquark color field much more extended in space

Test this hypothesis: CLAS new nDIS data for Lambda Baryons

CLAS6 final nDIS data for Lambda Baryons

$A(e, e'\Lambda)X$ **in DIS Kinematics**

Analysis Team from Mississippi State University:

Prof. Lamiaa El Fassi

Dr. Latif-ul Kabir

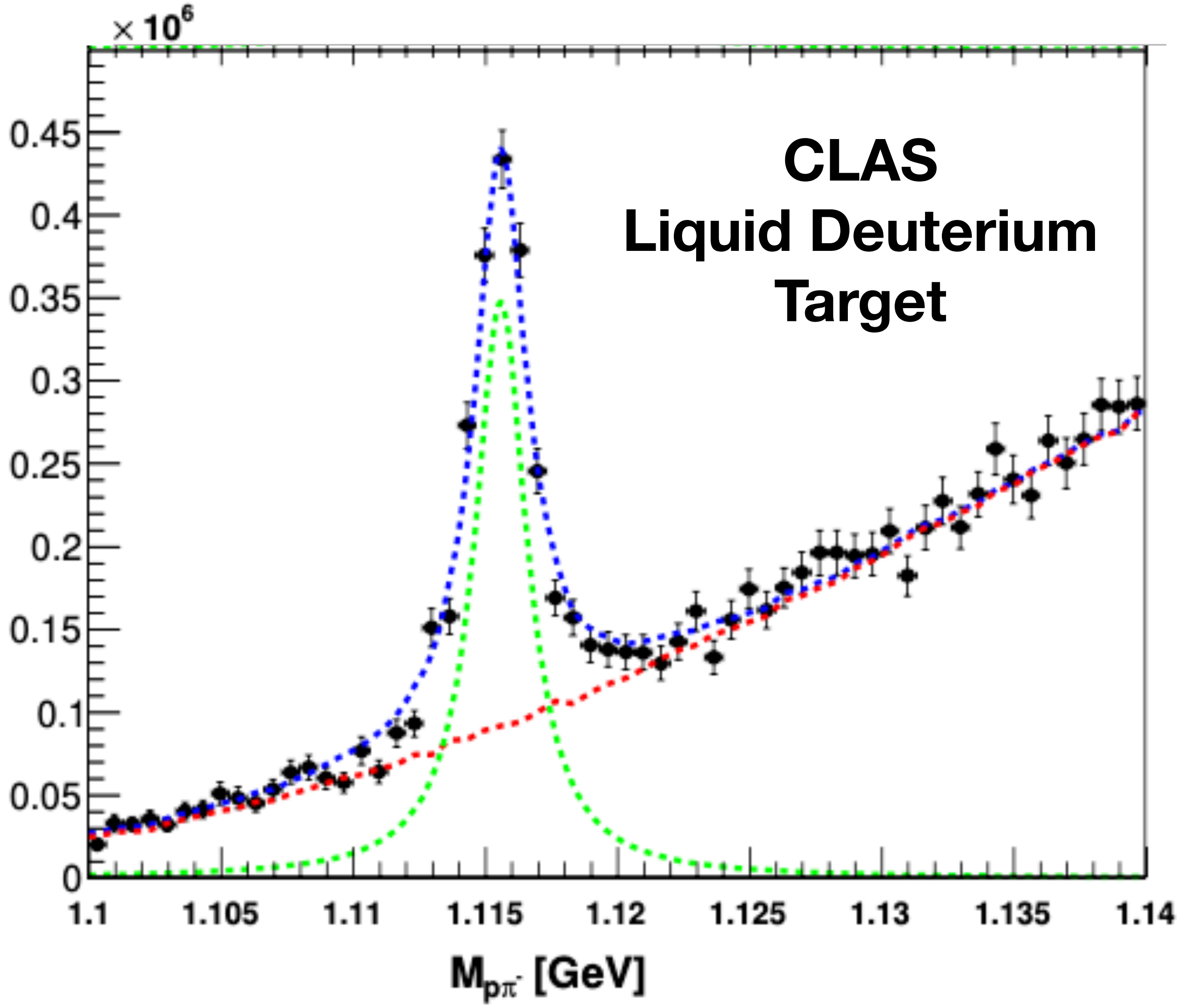
Dr. Taya Chetry

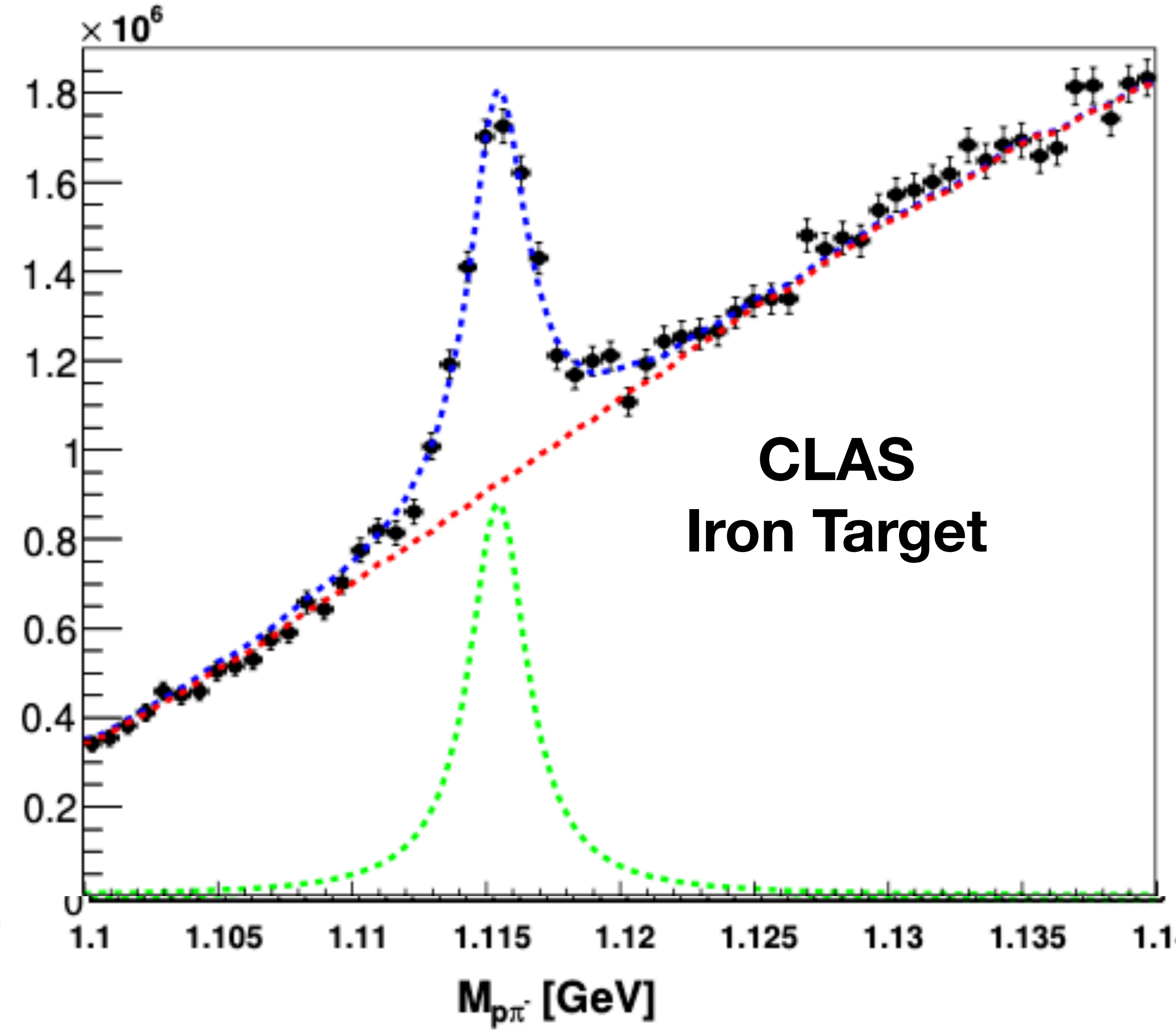
Analysis Contributions from U. Técnica Fed. Santa María:

Dr. Ahmed El Alaoui

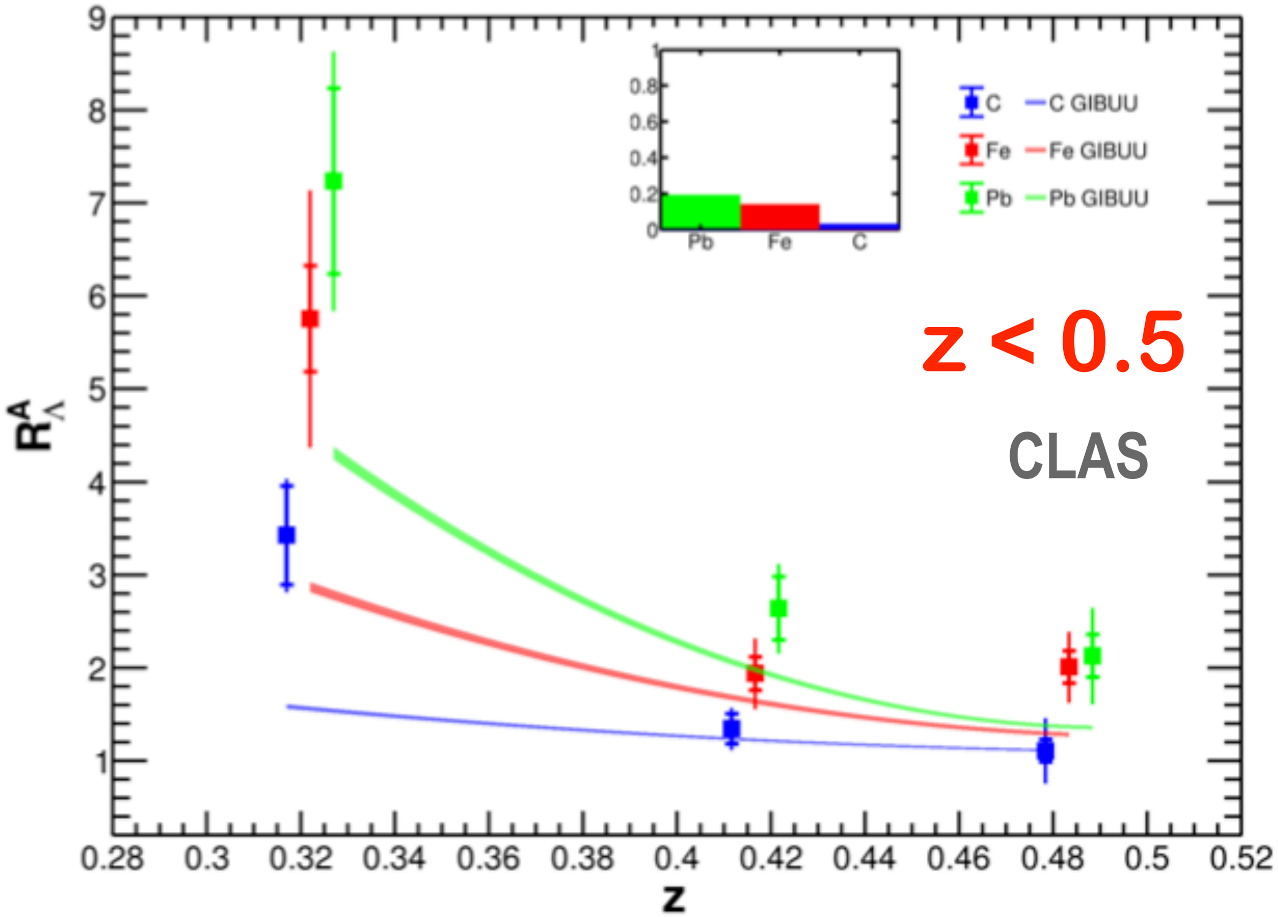
Initial work performed at ANL.

Lambda Baryons are well-identified in π^-p channel





Backgrounds are under control - three different extraction methods agree



"Pile-up" of events at low z - <u>huge</u> effect compared to pion production

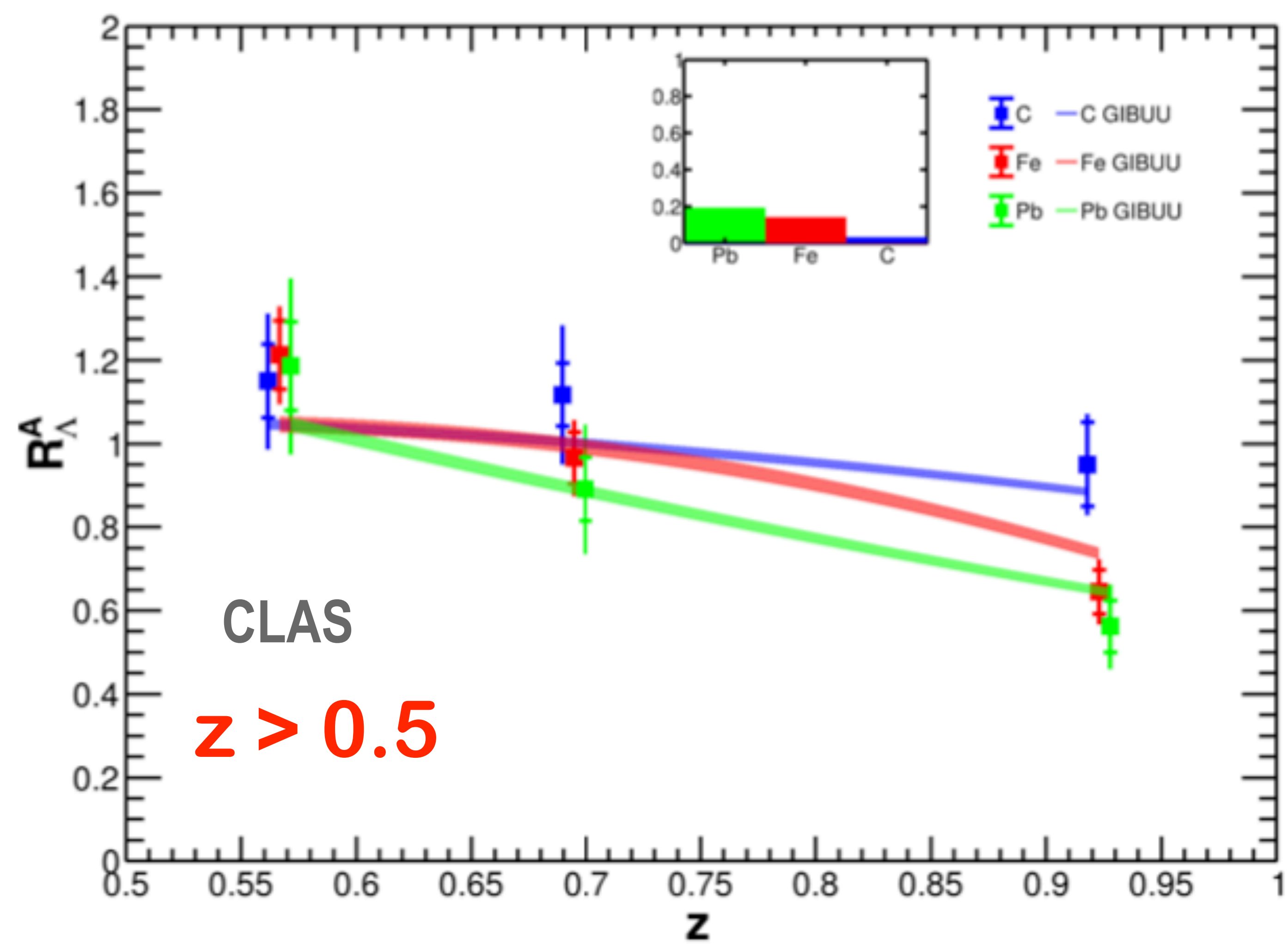
Underpredicted by GiBUU at low z.

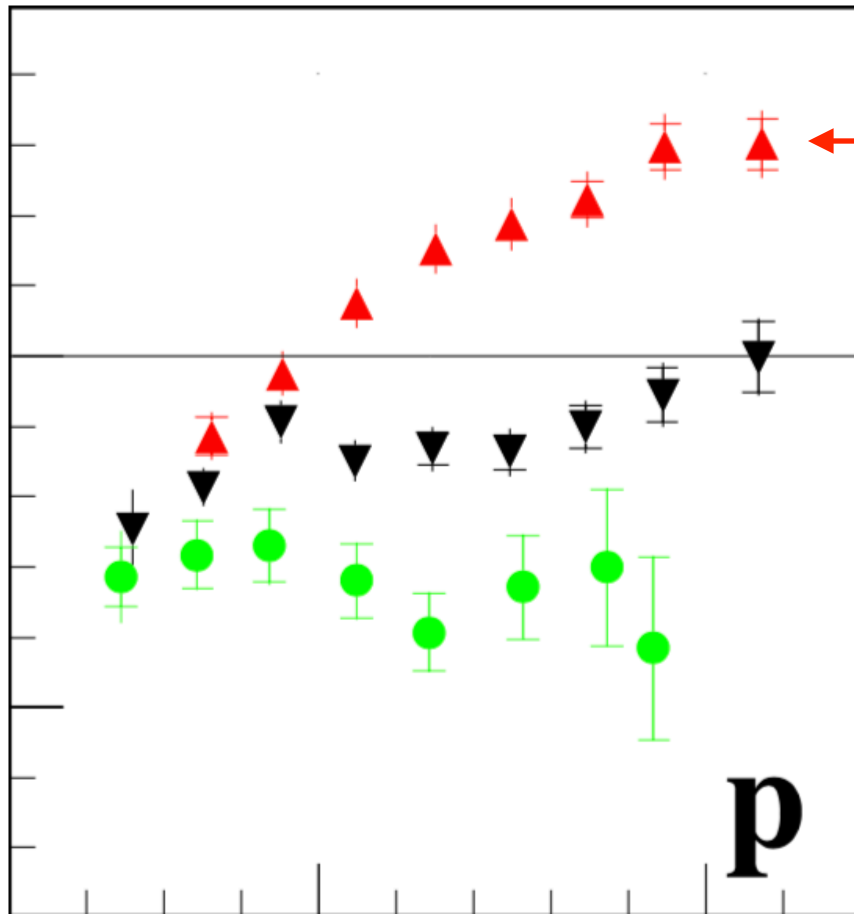
Order inverted as expected: heavy-to-light

At higher z, there is relatively little attenuation.

Order as expected: light-to-heavy

Agrees with GiBUU prediction for high z.

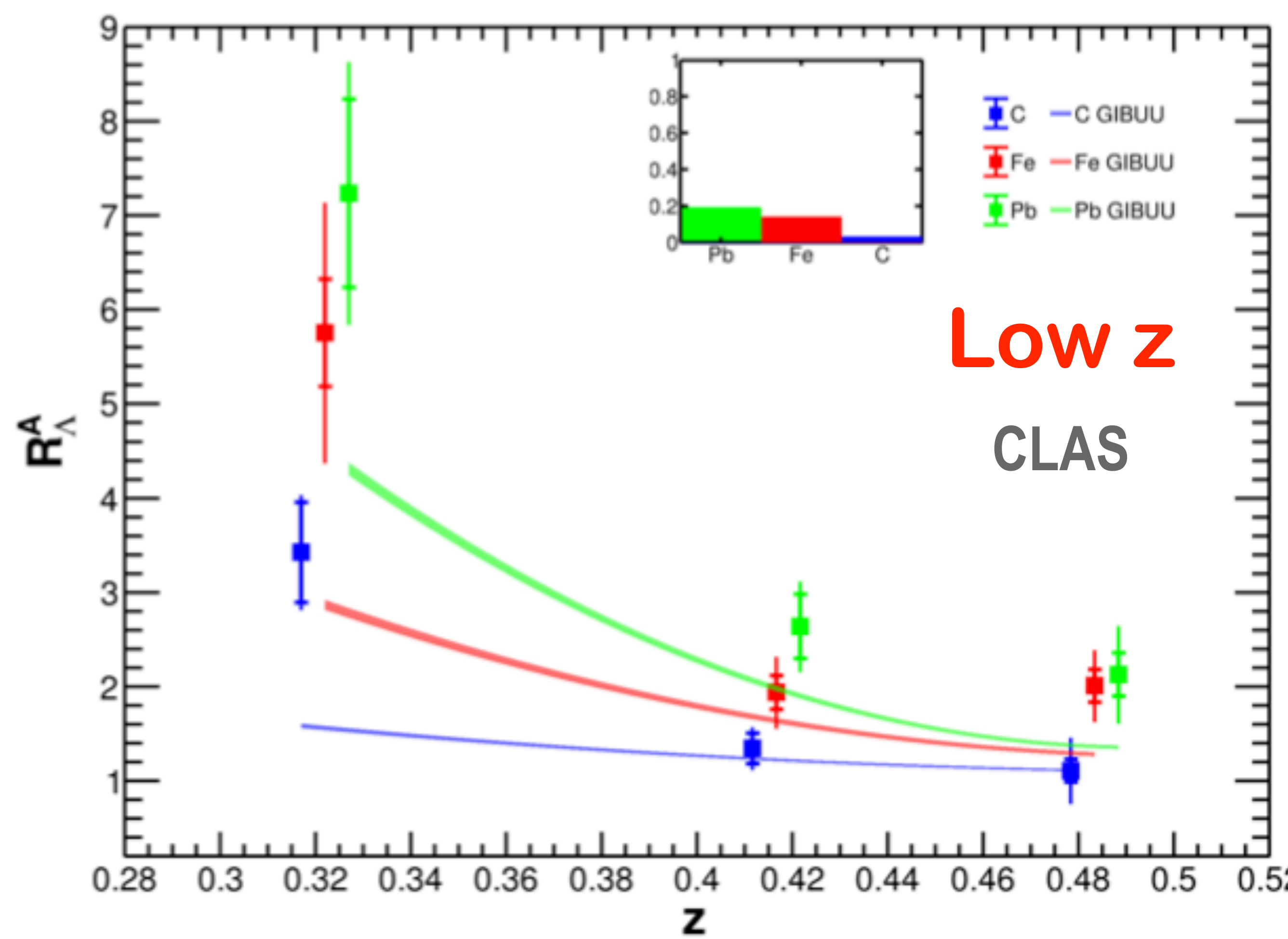




Excess of low-z protons in HERMES data

Explanation: FSI are "knocking out protons"?

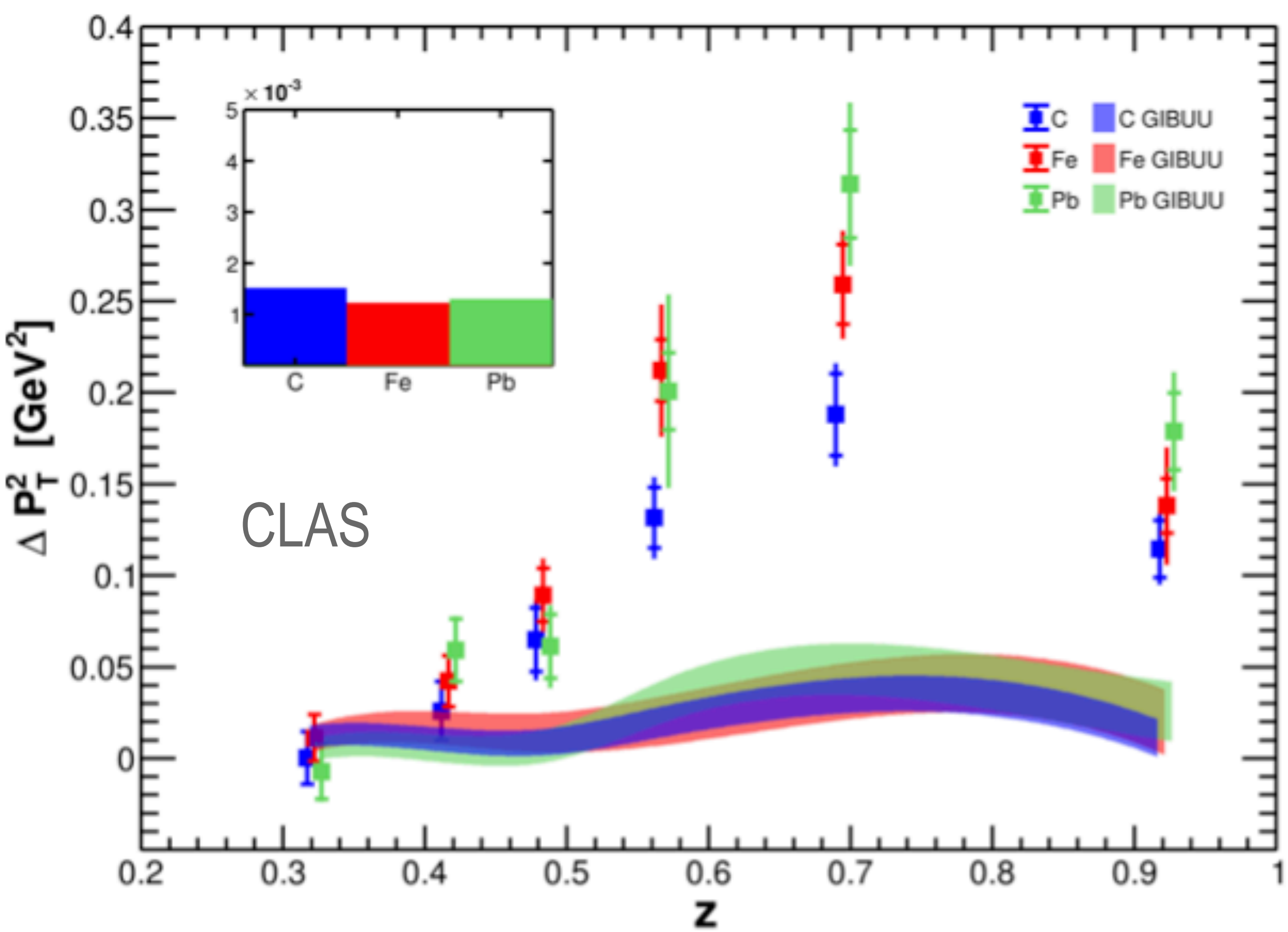
Excess of low-z Lambdas in CLAS data

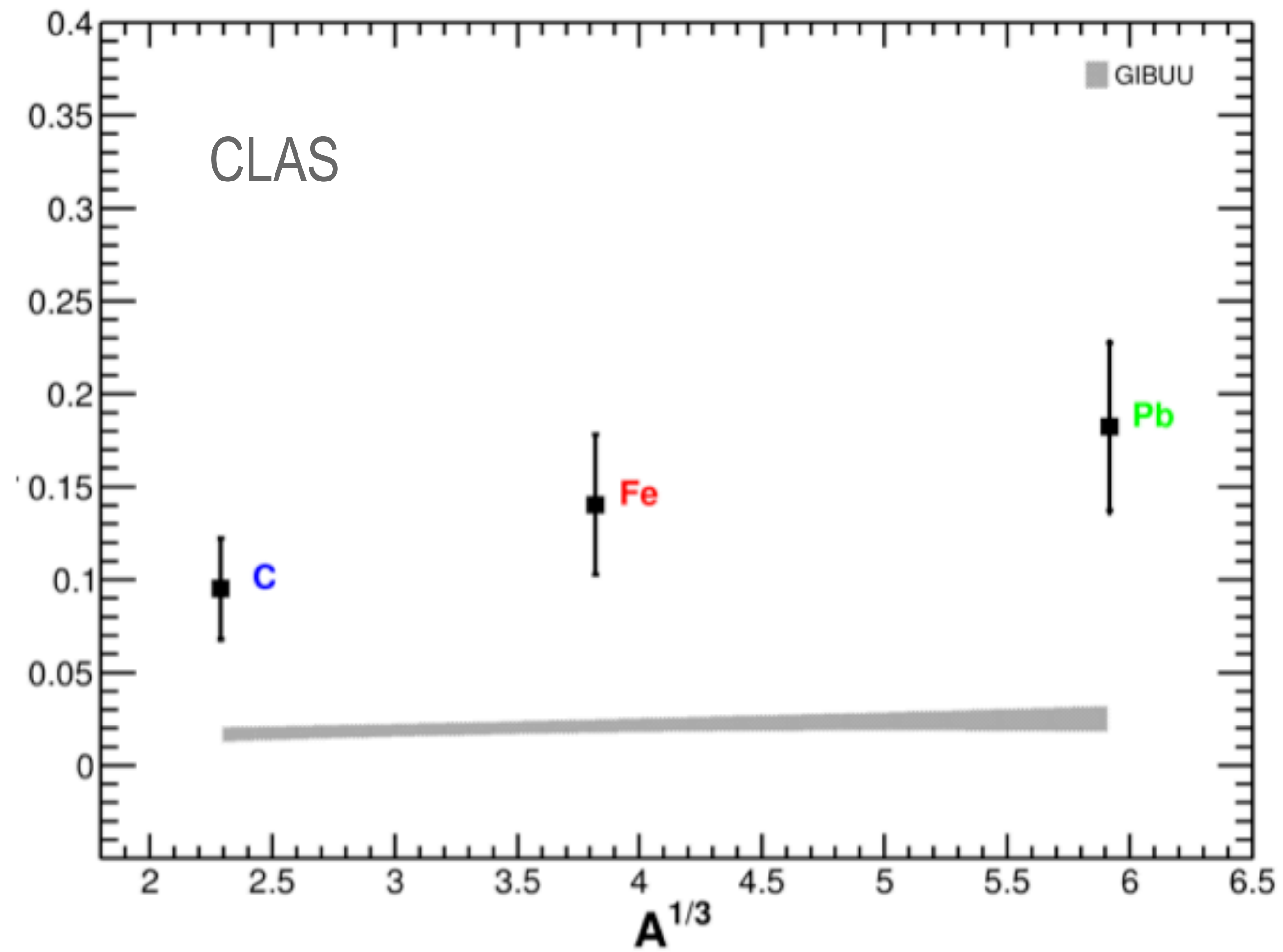


<u>Not</u> explained by FSI "knocking out Lambdas"!

I have an alternative explanation

Lambda Transverse Momentum Broadening





Maximum is 0.3 GeV²

Compare to maximum for pions of 0.03 GeV²!

The object passing through the medium is disruptive!

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

Unlike for pions, GiBUU cannot predict these data.

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

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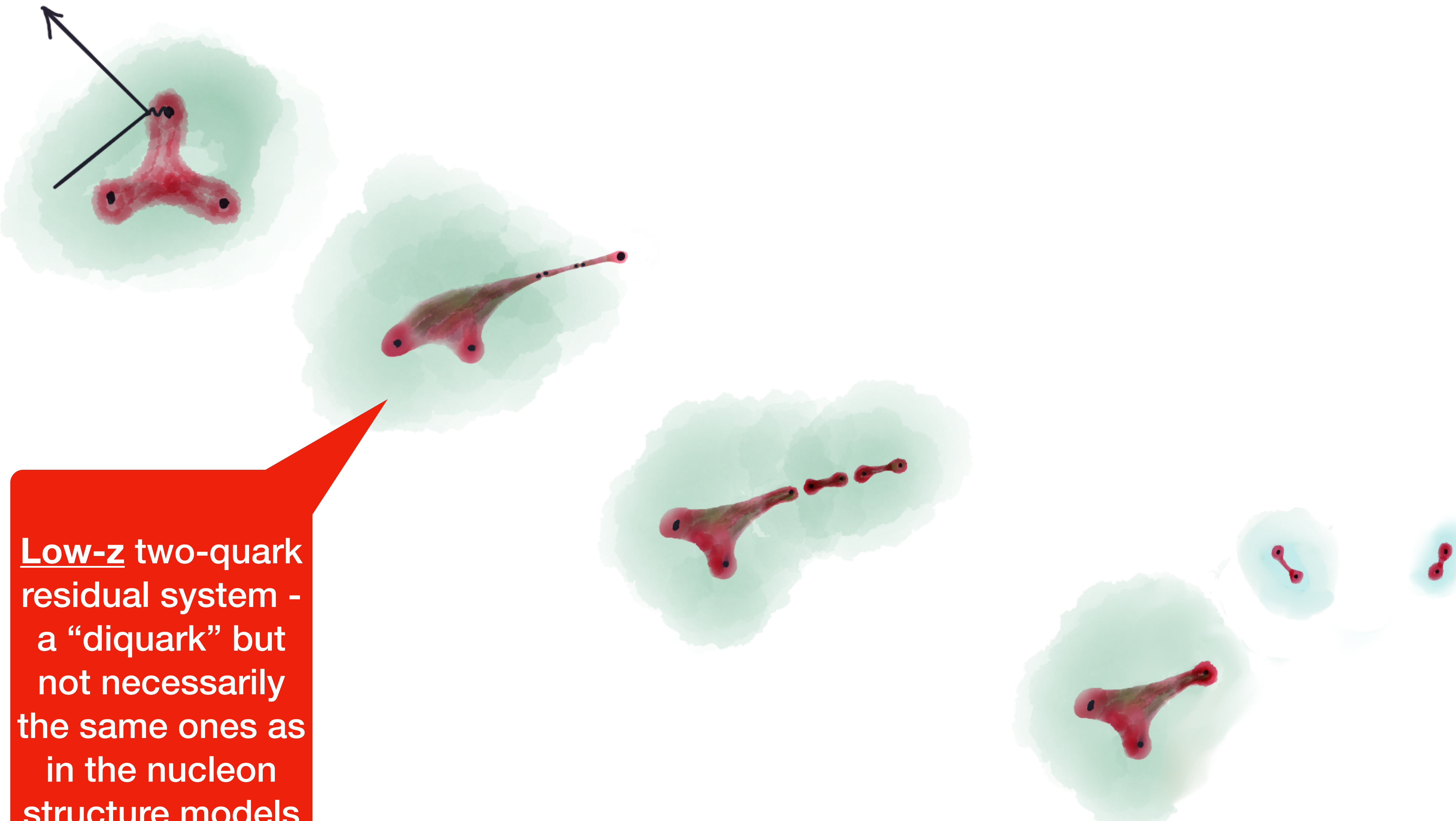
Could it be possible that the virtual photon is sometimes absorbed by a diquark?

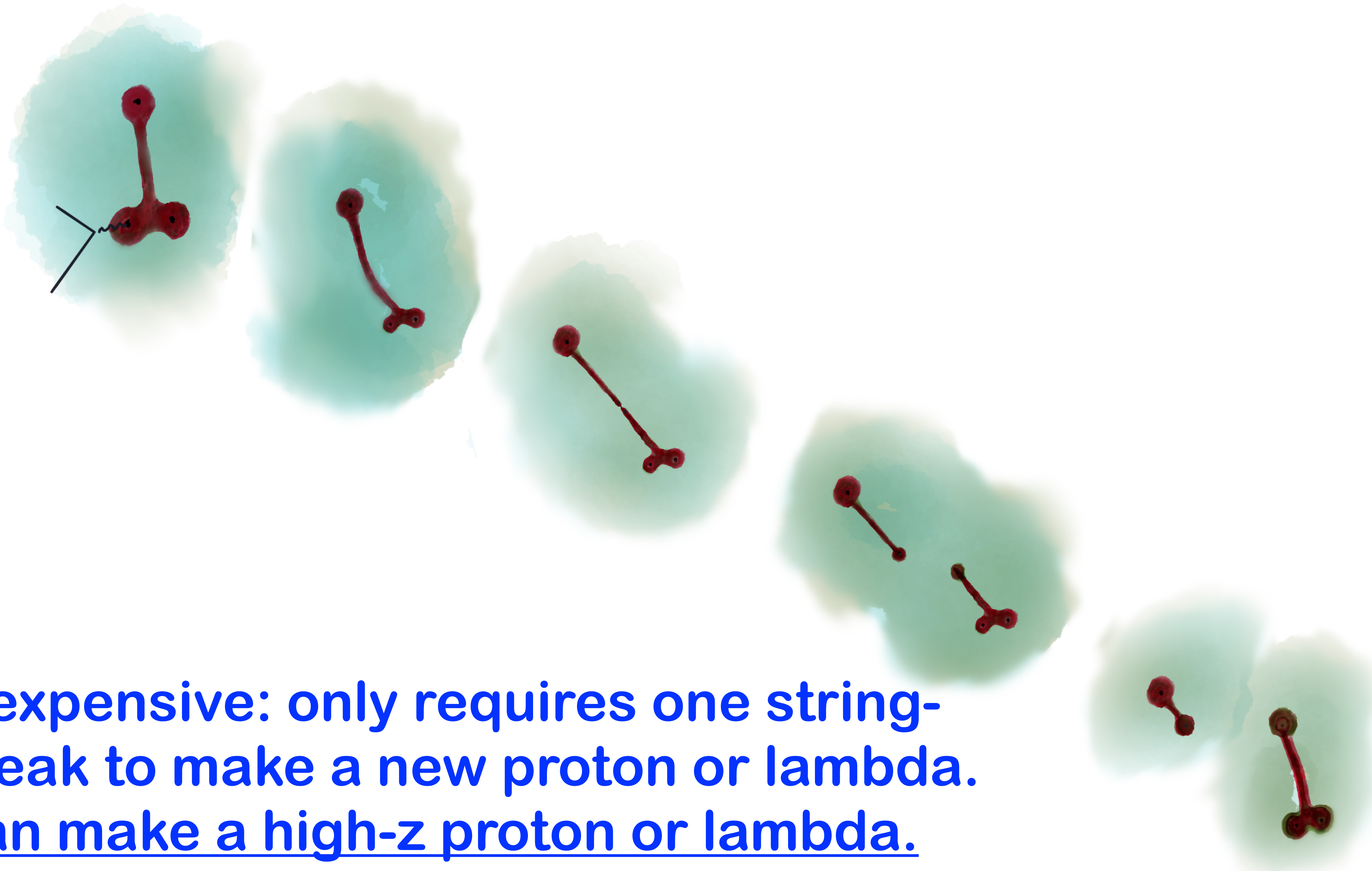
Let's call this Direct Diquark Scattering (DDS)

<u>Traditional</u> Lund String Model picture of particle production from proton: 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

<u>Alternative</u> Lund String Model picture of particle production from proton: Direct Diquark Scattering



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

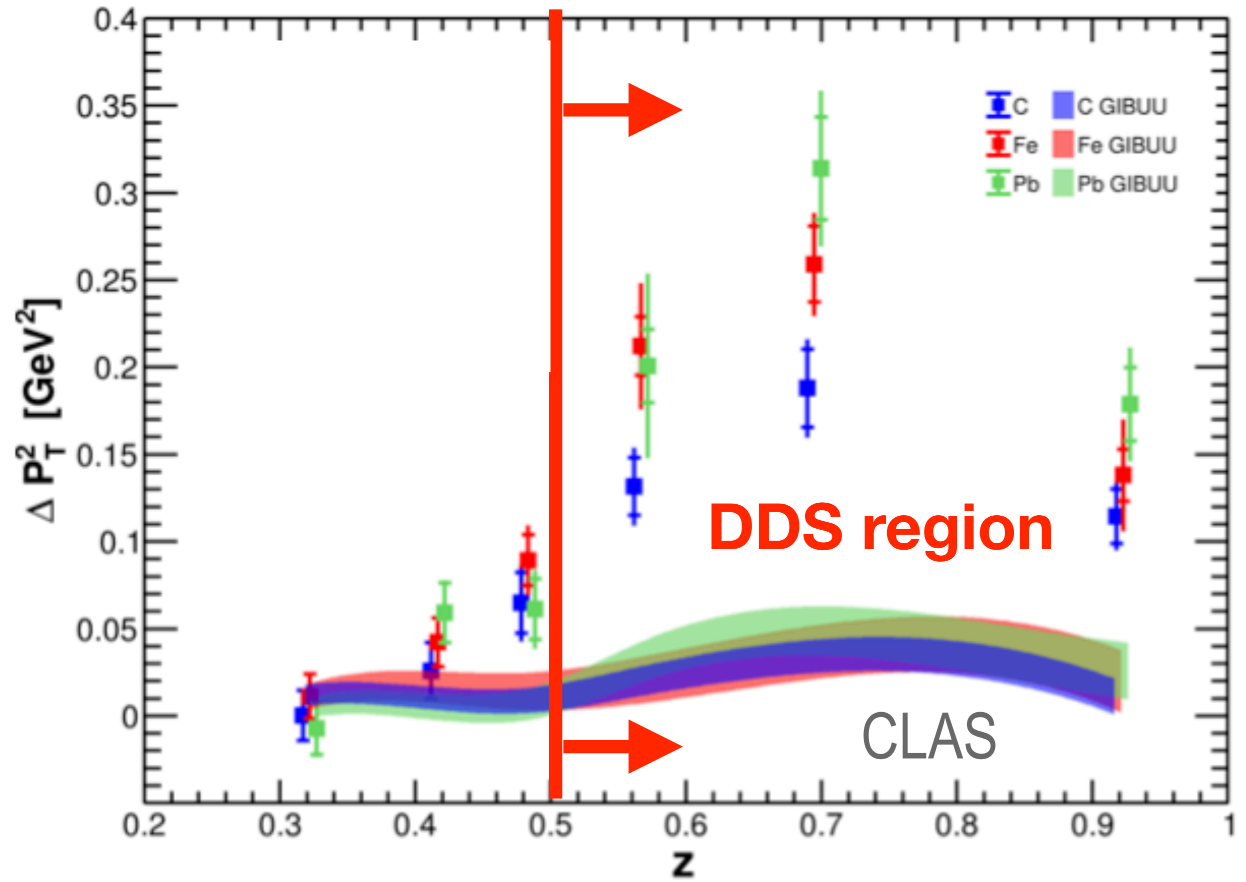
W. K. Brooks, QNP2022

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

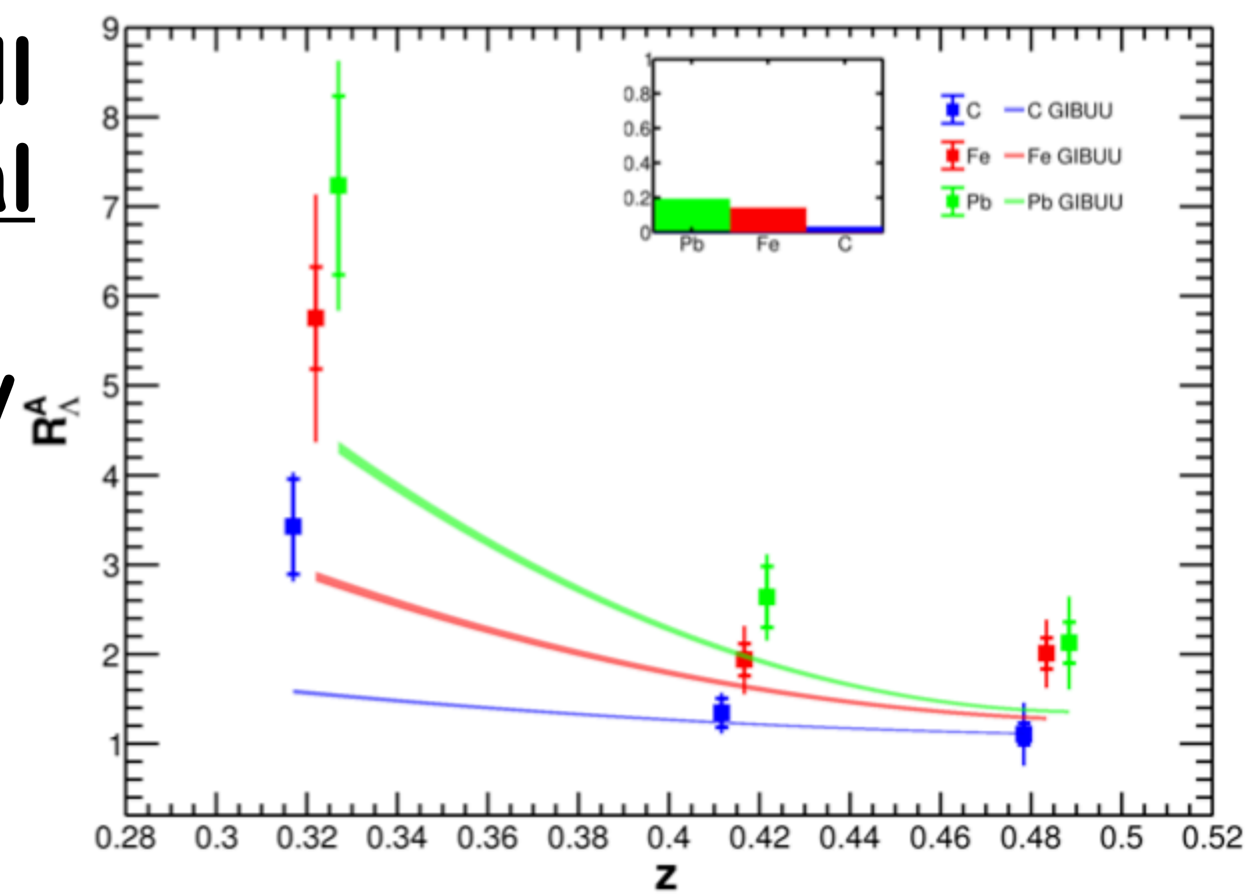
With nDIS baryon production, we will be able to gather a lot of evidence to test this idea.

Multiplicity ratio, pT 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. Very high multiplicity ratios might come from quark recombination/statistical hadronization*.



*See, e.g., references in https://doi.org/10.48550/arXiv.1901.09200 (Andronic et al.)

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Further tests of the Direct Diquark Scattering hypothesis with CLAS12 nDIS on <u>baryons</u>

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

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Baryon	$M^{e/l}$	M^{CI}	s^{r_1}	s^{r_2}	$a_1^{r_2}$	$a_2^{r_2}$	$a_1^{r_3}$	$a_2^{r_3}$	dom. corr.
p (B.5a)	0.94	0.94	0.89		−0.35	−0.14	0.25	0.098	$[ud]u$
Λ (B.5b)	1.12	1.06	0.67	0.59			−0.42	−0.16	$[ud]s$
Σ (B.5c)	1.19	1.20	0.87		−0.42	0.004	0.25	0.071	$[us]u$
Ξ (B.5d)	1.32	1.24	0.90		−0.29	−0.028	0.31	0.11	$[us]s$
Λ_c (B.5e)	2.29	2.50	0.21	0.86			−0.35	−0.32	$[uc]d - [dc]u$
Σ_c (B.5f)	2.45	2.53	0.48		−0.21	0.84	0.090	0.064	$\{uu\}c$
Ξ_c (B.5g)	2.47	2.66	0.22	0.84			−0.36	−0.34	$[uc]s - [sc]u$
Ξ_c' (B.5h)	2.58	2.68	0.50		−0.22	0.83	0.093	0.061	$\{us\}c$
Ω_c (B.5i)	2.70	2.83	0.51		−0.22	0.82	0.097	0.058	$\{ss\}c$

From Yin et al.

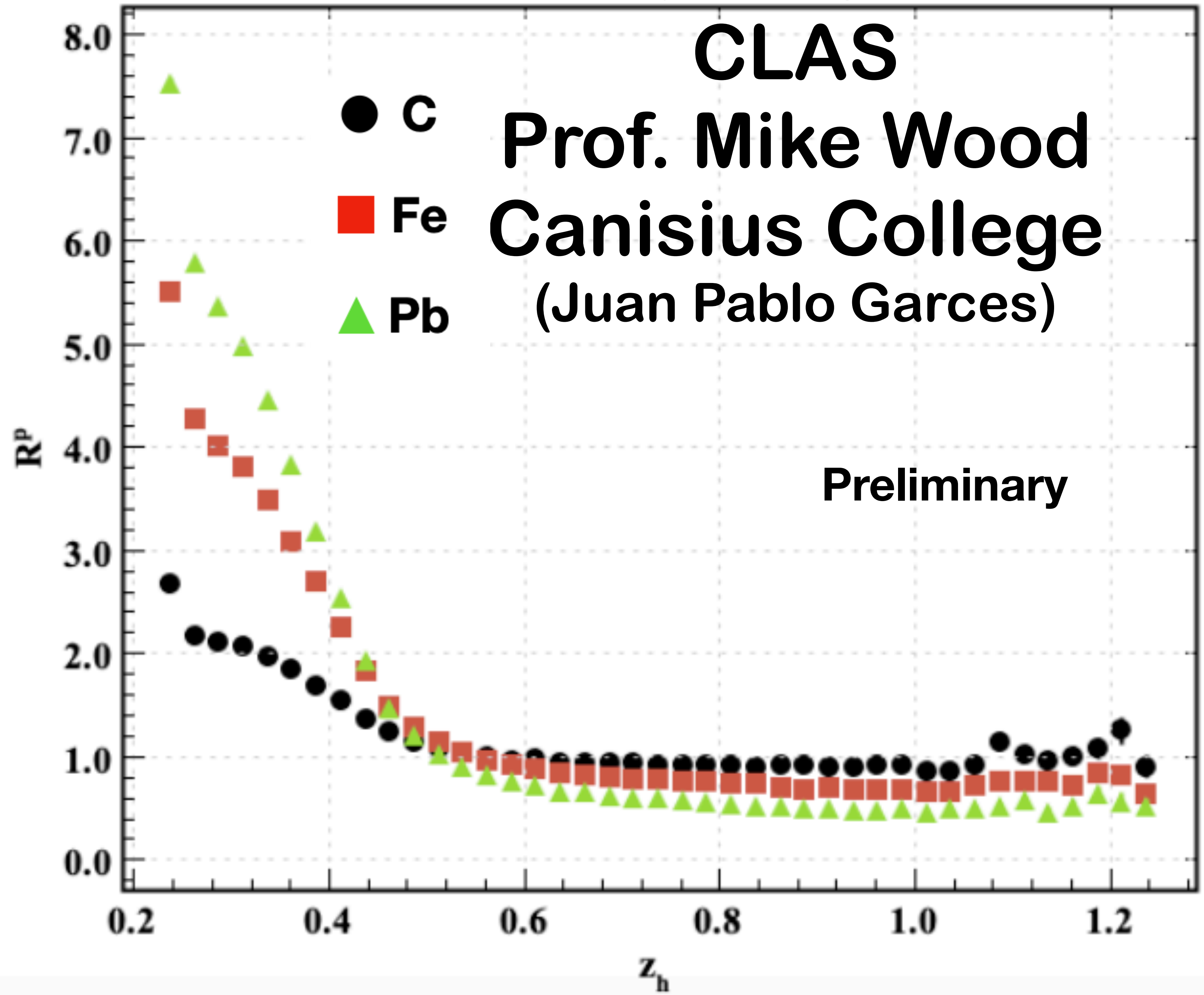
Baryon	$M^{e/l}$	M^{CI}	dom. corr.
p (B.5a)	0.94	0.94	$[ud]u$
Λ (B.5b)	1.12	1.06	$[ud]s$
Σ (B.5c)	1.19	1.20	$[us]u$
Ξ (B.5d)	1.32	1.24	$[us]s$
Λ_c (B.5e)	2.29	2.50	$[uc]d - [dc]u$
Σ_c (B.5f)	2.45	2.53	$\{uu\}c$? almost
Ξ_c (B.5g)	2.47	2.66	$[uc]s - [sc]u$
Ξ_c' (B.5h)	2.58	2.68	$\{us\}c$
Ω_c (B.5i)	2.70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

This suggests a specific behavior for DDS.

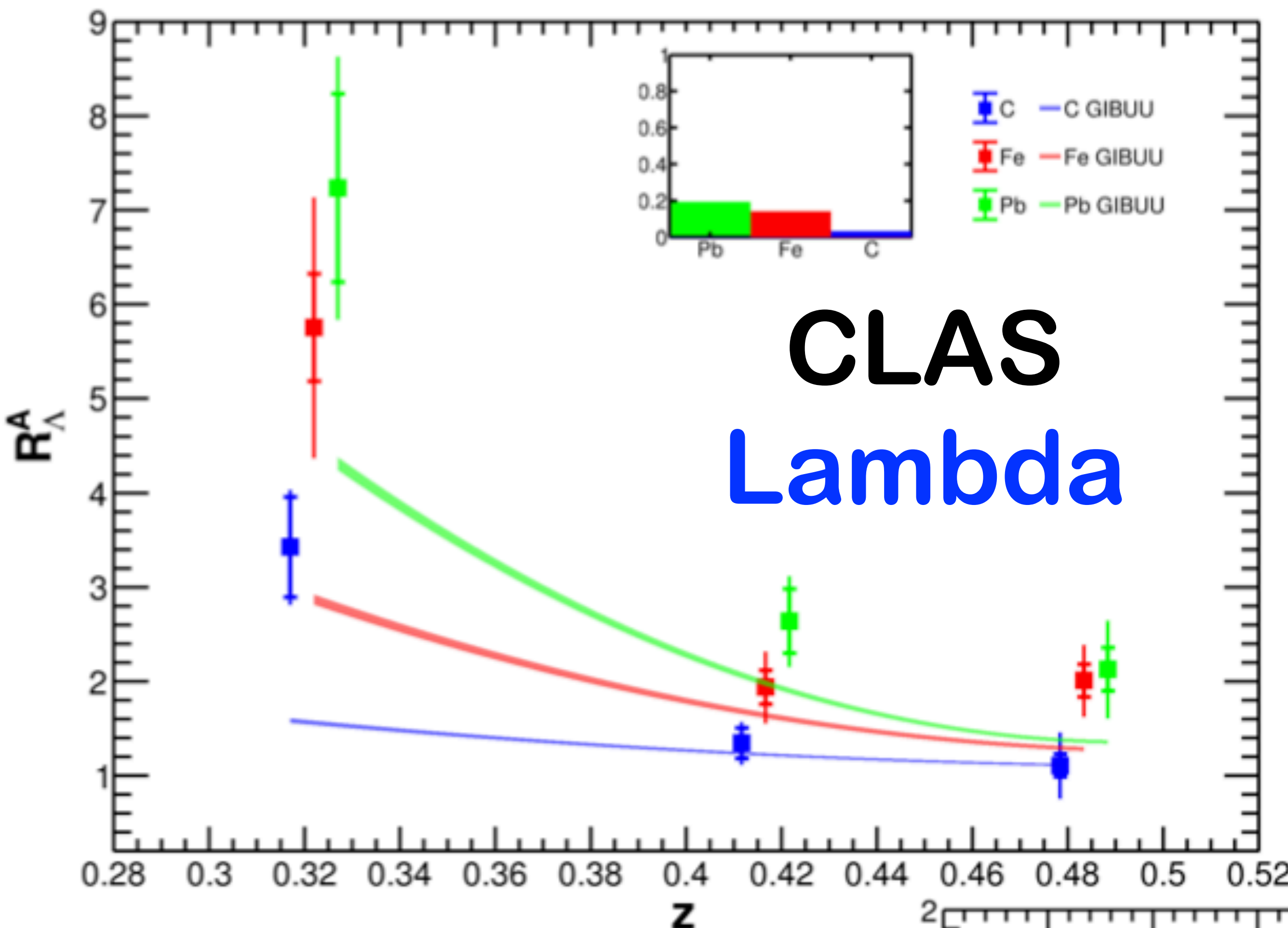
Only p, n, lambda can easily be formed by DDS.

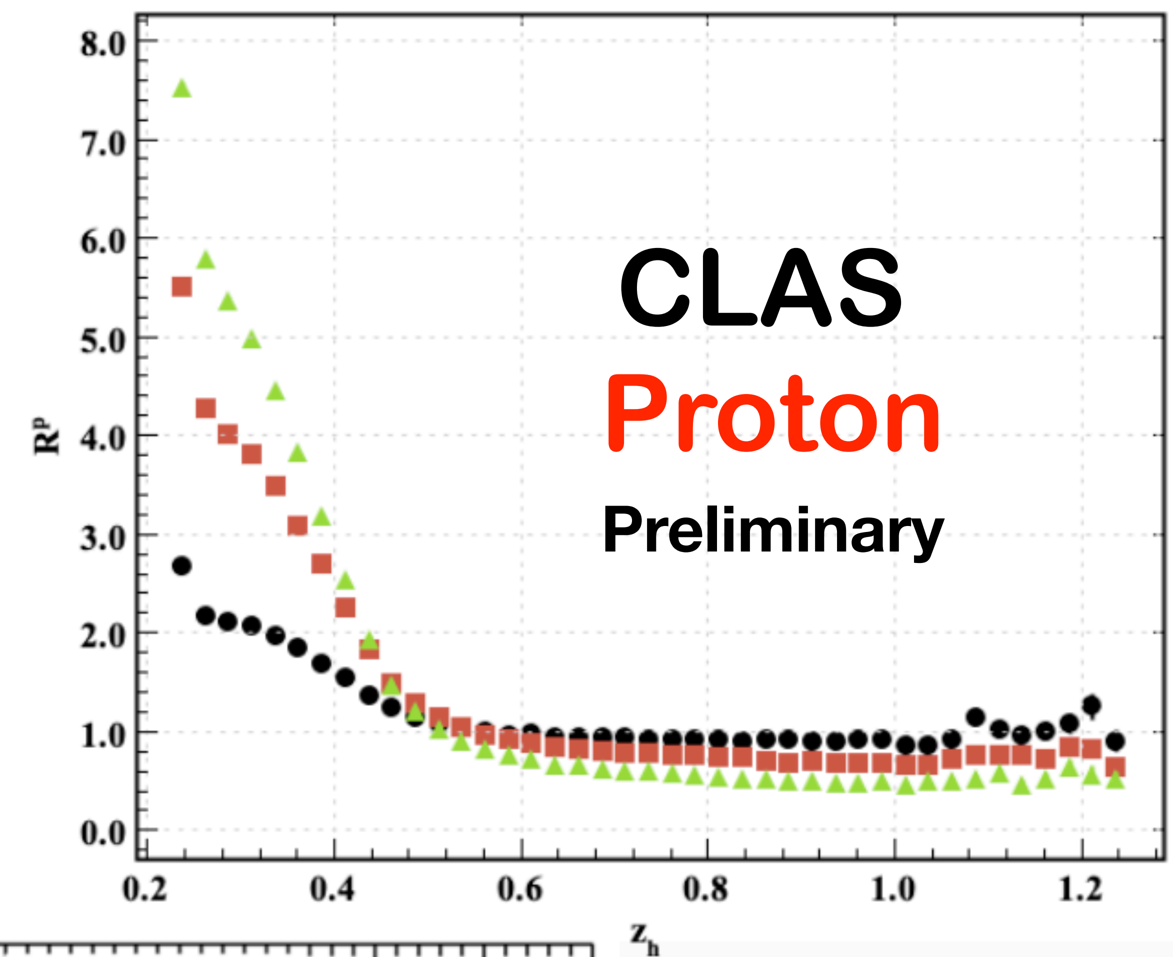
Prediction: proton (neutron) and lambda will behave similarly; the others will be different.

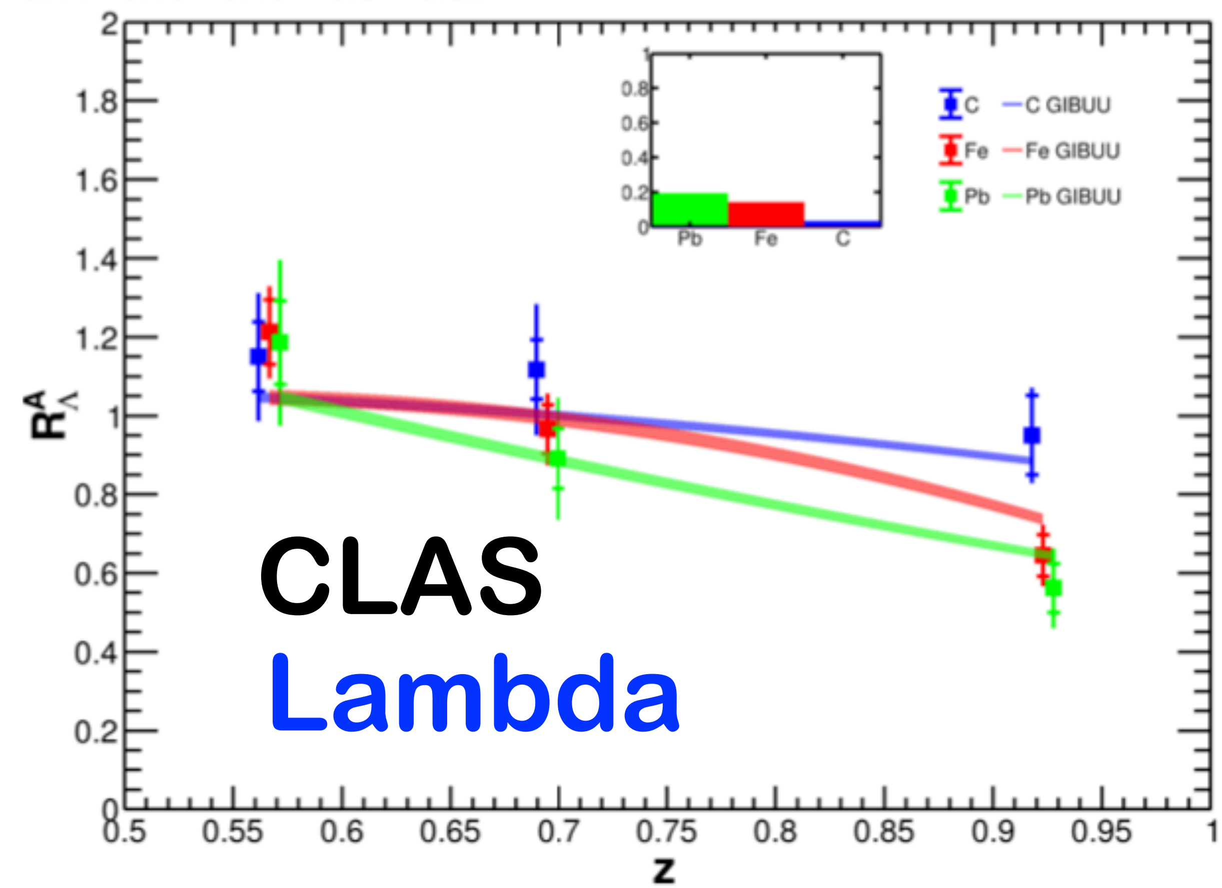
Proton multiplicity ratio



Inversion of ordering seen
Maximum value 7.5
The same number as for the lambda!

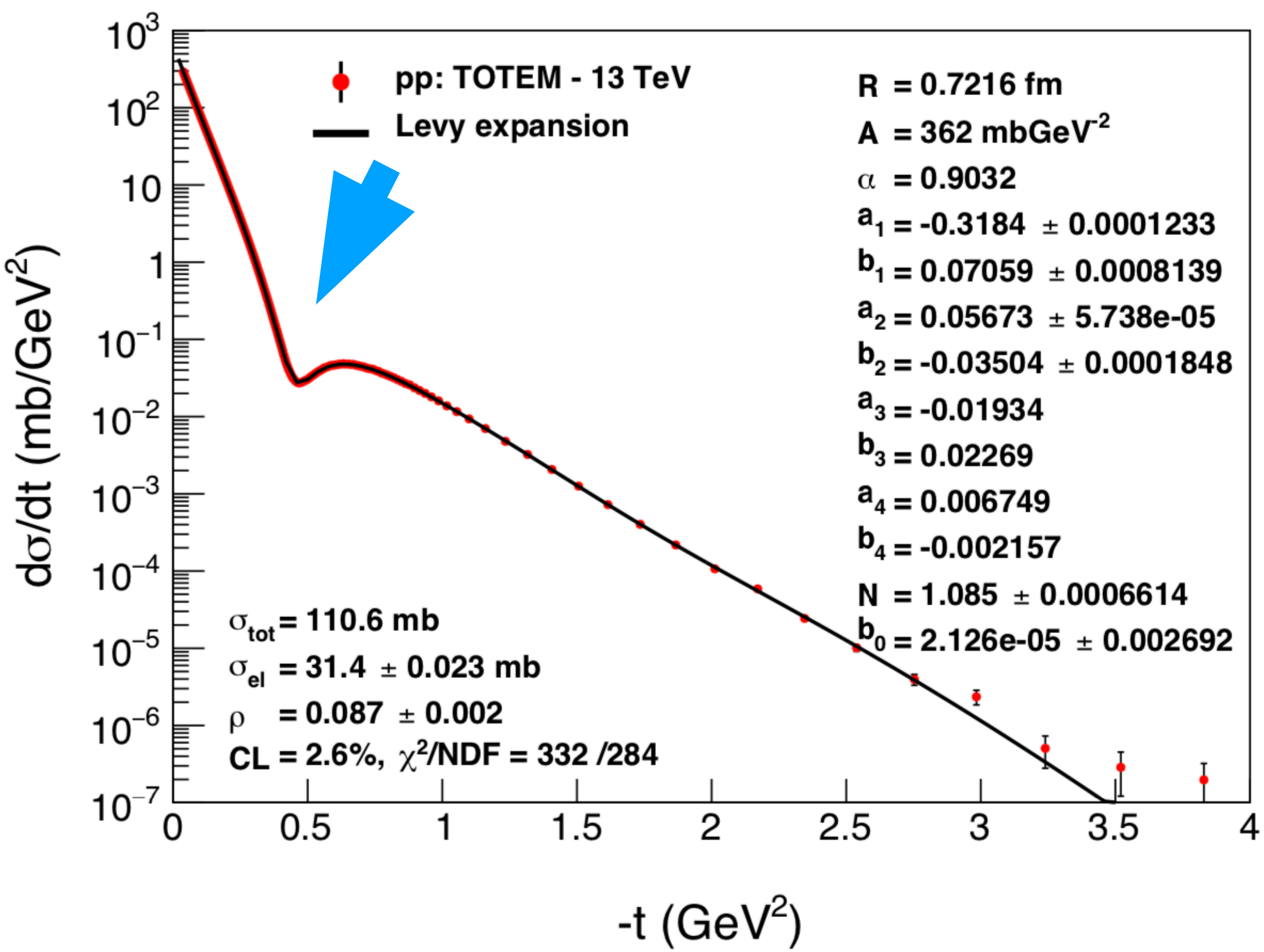

CLAS
Lambda
C
C GIBUU
Fe
Fe GIBUU
Pb
Pb GIBUU
Pb
Fe
C
R^A_Λ
z


CLAS
Proton
Preliminary
R^p
z_h


CLAS
Lambda
C
C GIBUU
Fe
Fe GIBUU
Pb
Pb GIBUU
Pb
Fe
C
R^A_Λ
z

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

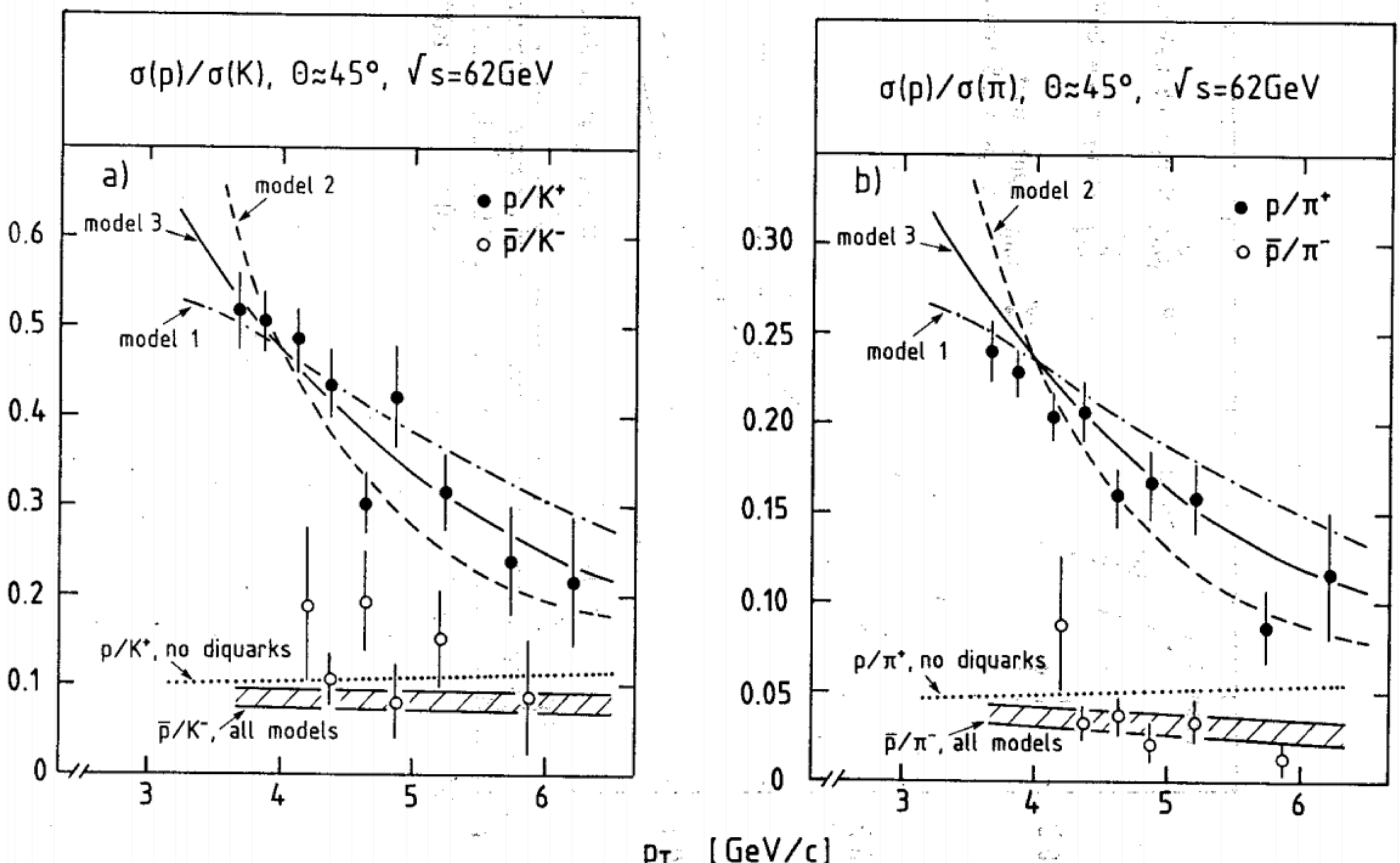
A DIQUARK SCATTERING MODEL FOR HIGH p_T PROTON PRODUCTION IN pp COLLISIONS AT THE ISR

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

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 current models of diquarks.
- More theoretical work is needed to determine the feasibility and plausibility of this interpretation.
- 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:

ANID PIA/APOYO AFB180002 (Chile) - Center for Science and Technology of Valparaíso (CCTVal).

ANID - Millennium Science Initiative Program - ICN2019_044 (Chile) - Millennium Institute for SubAtomic Physics at the HIgh energy frontieR (SAPHIR).

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

Backup slides

P_T broadening for positive pions in CLAS

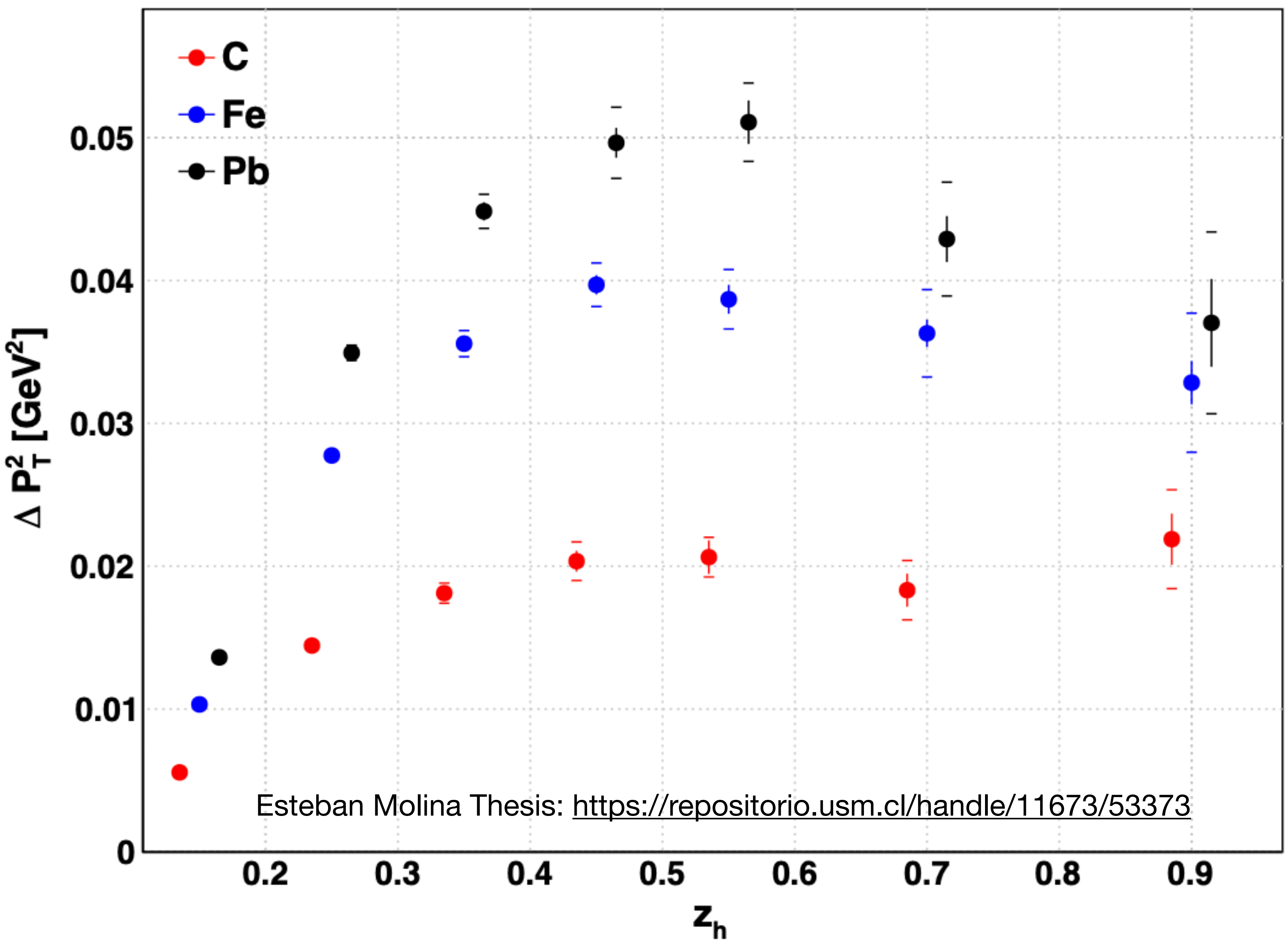


Figure B.63: ΔP_T^2 with all variables integrated except z_h.

P_T broadening for positive pions in CLAS

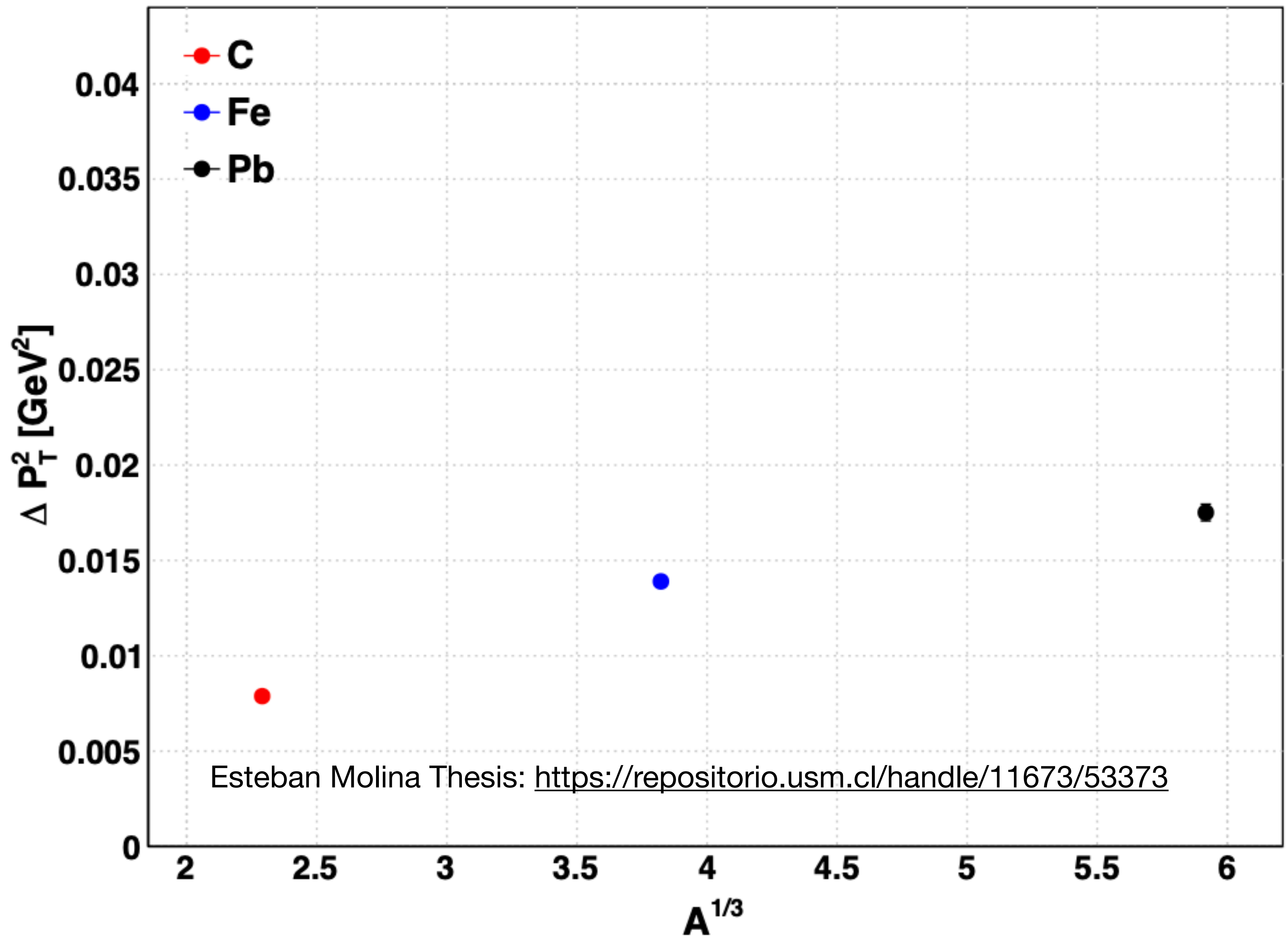


Figure B.59: ΔP_T^2 with all variables integrated and no x_f cut.