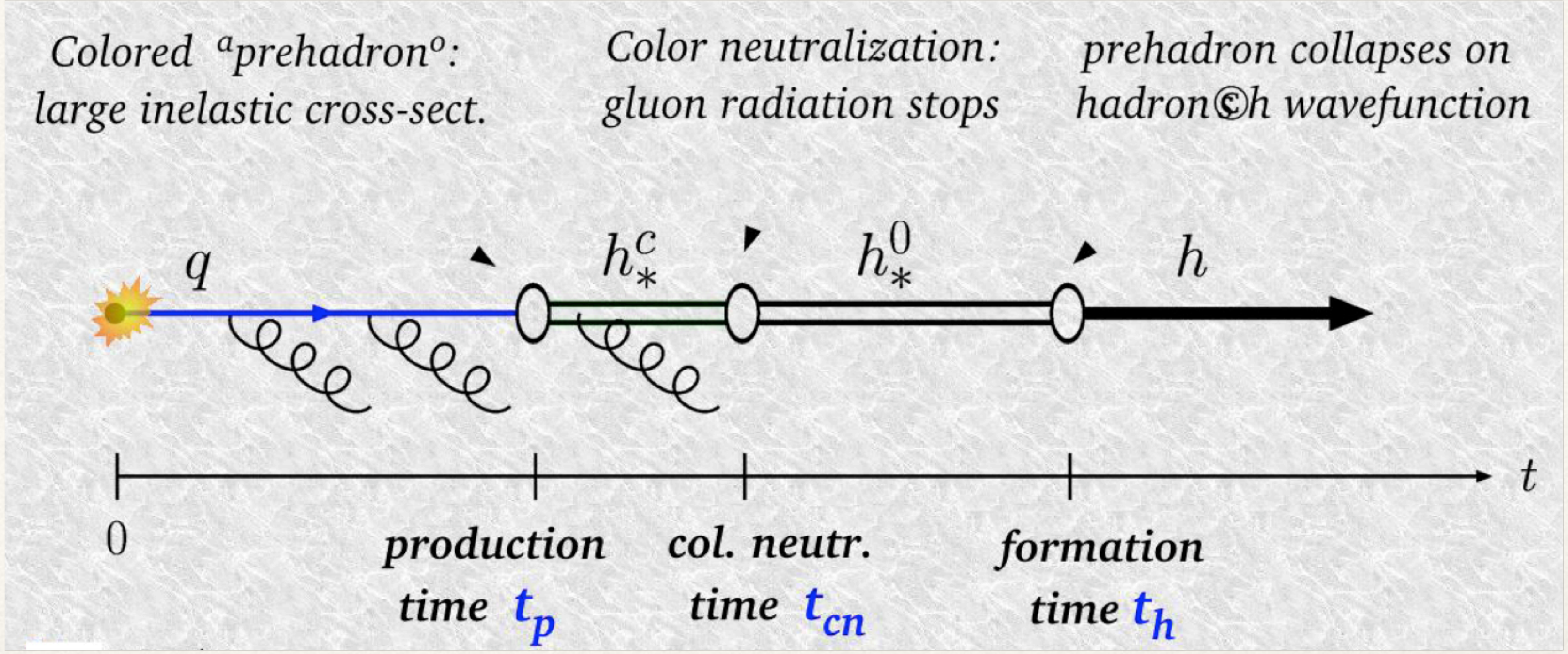


Correlations in Partonic and Hadronic Interactions 2020

Present and Future Studies of Color Transparency and Hadronization in Hall B

Michael H. Wood for the
CLAS Collaboration
Canisius College, Buffalo, NY,
USA

Canisius College

Jefferson Lab
Thomas Jefferson National Accelerator Facility

clas
CEBAF Large Acceptance Spectrometer

Outline

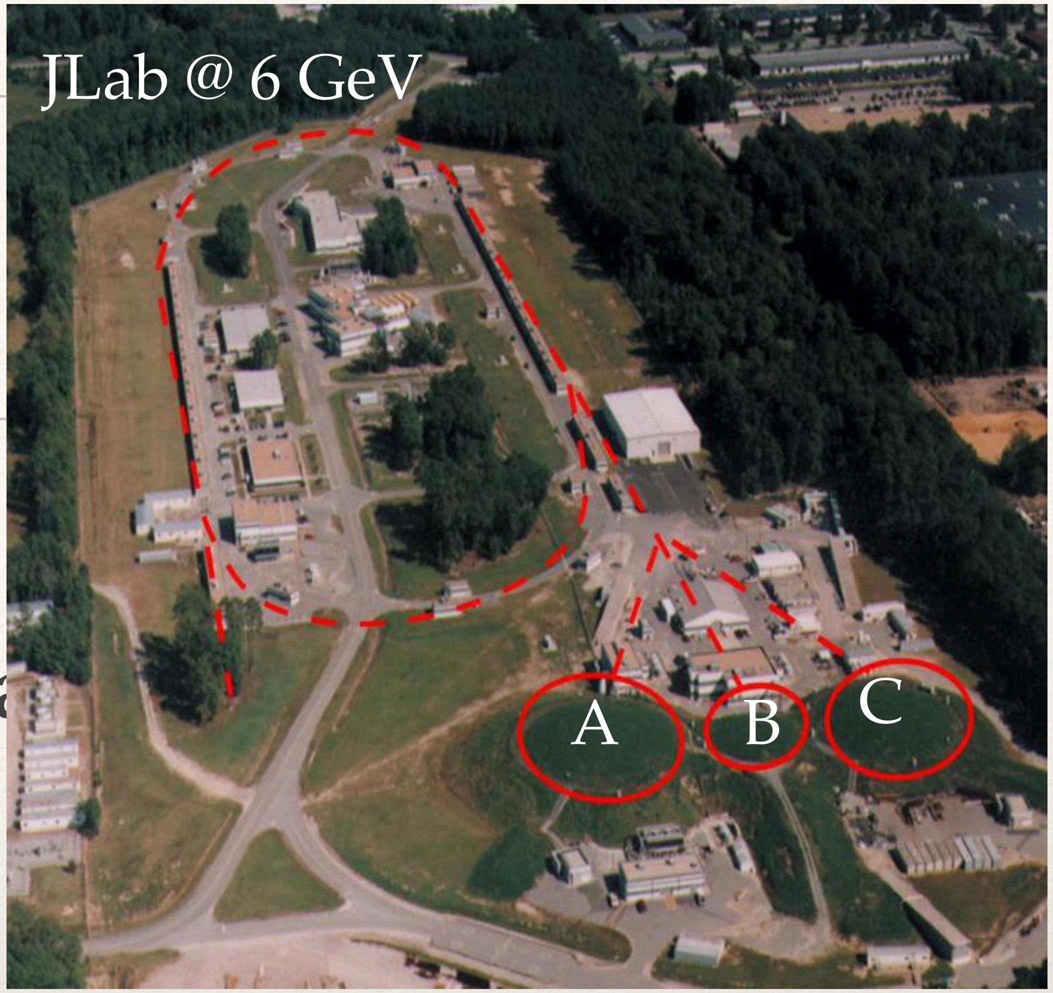
The Question: How does a colored, bare quark evolve into a fully dressed (color neutral) hadron?

To address this:

- Brief introduction
- Highlights of Color Transparency and Hadronization Studies
  - CLAS6 analyses
  - CLAS12 experiments
- Summary

Outline

The Question: How does a colored,
into a fully dressed (color neutral) ha



To address this:

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- Summary

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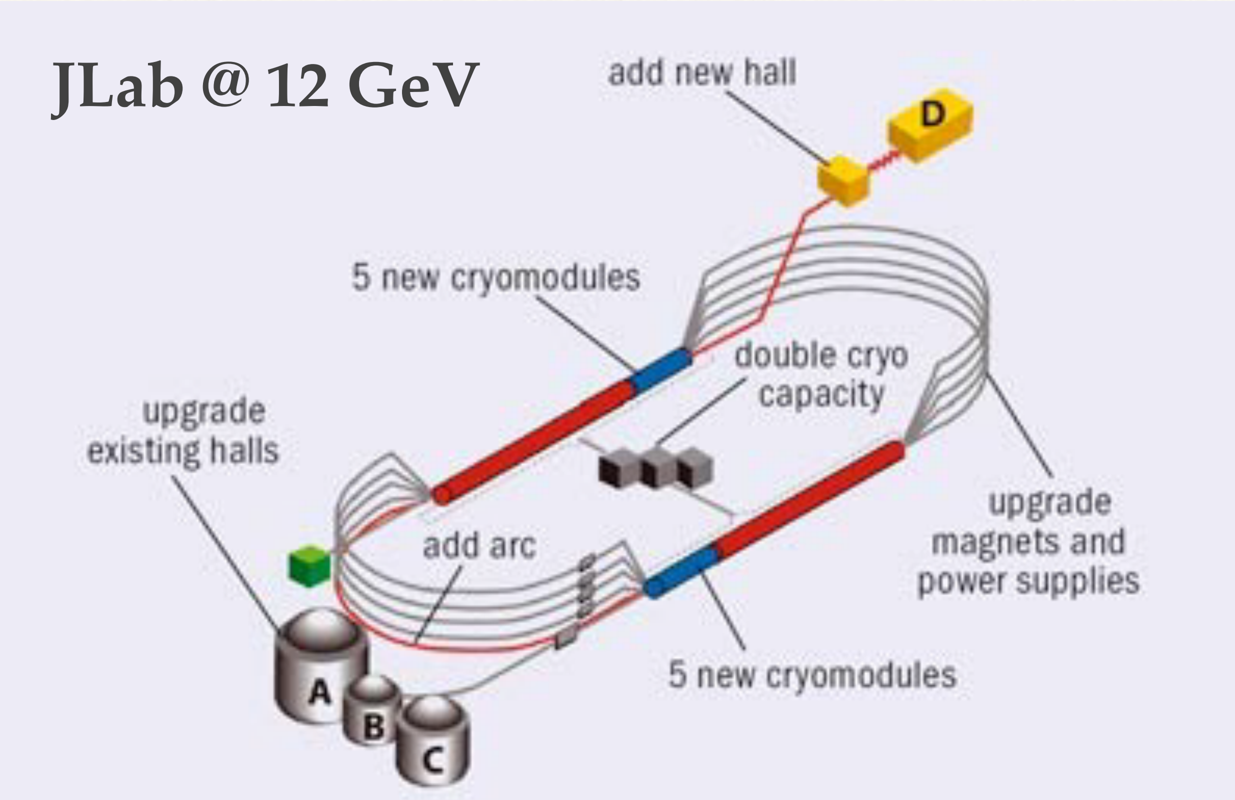
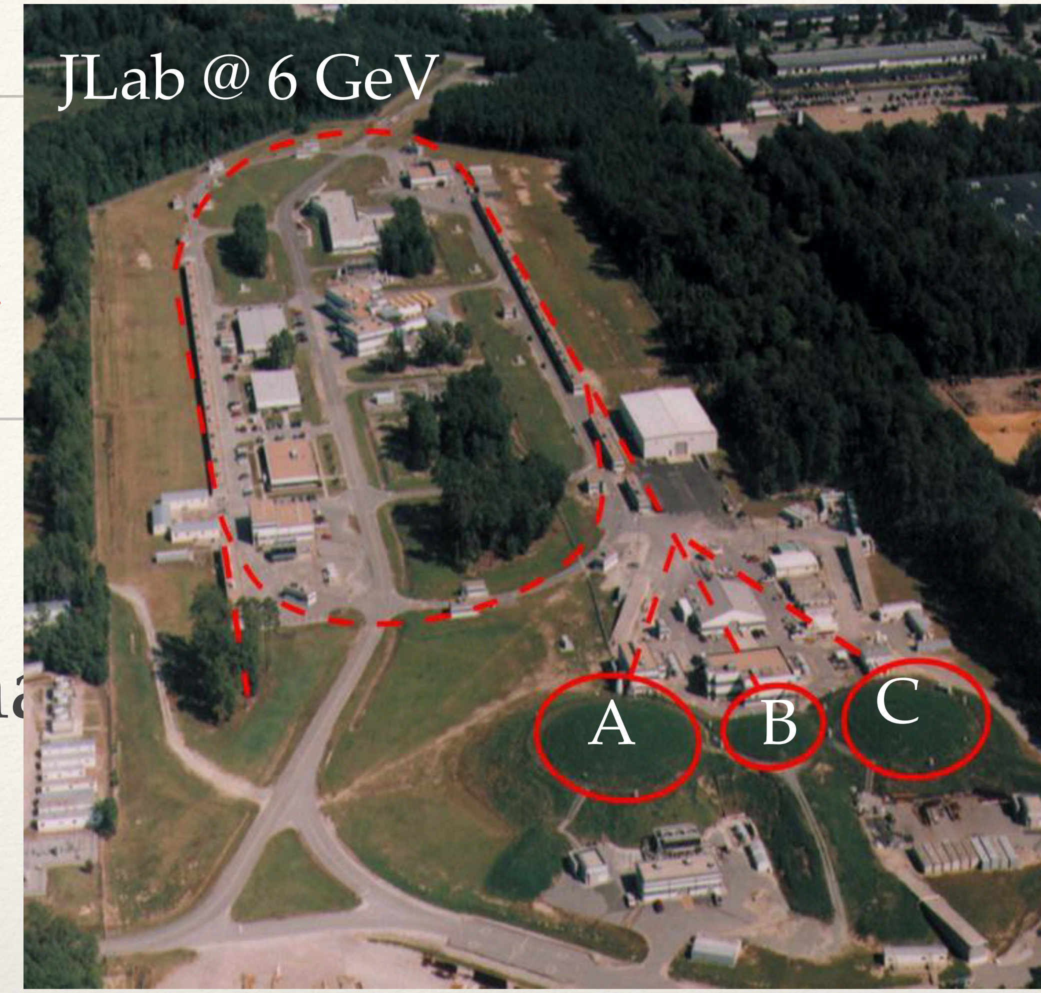
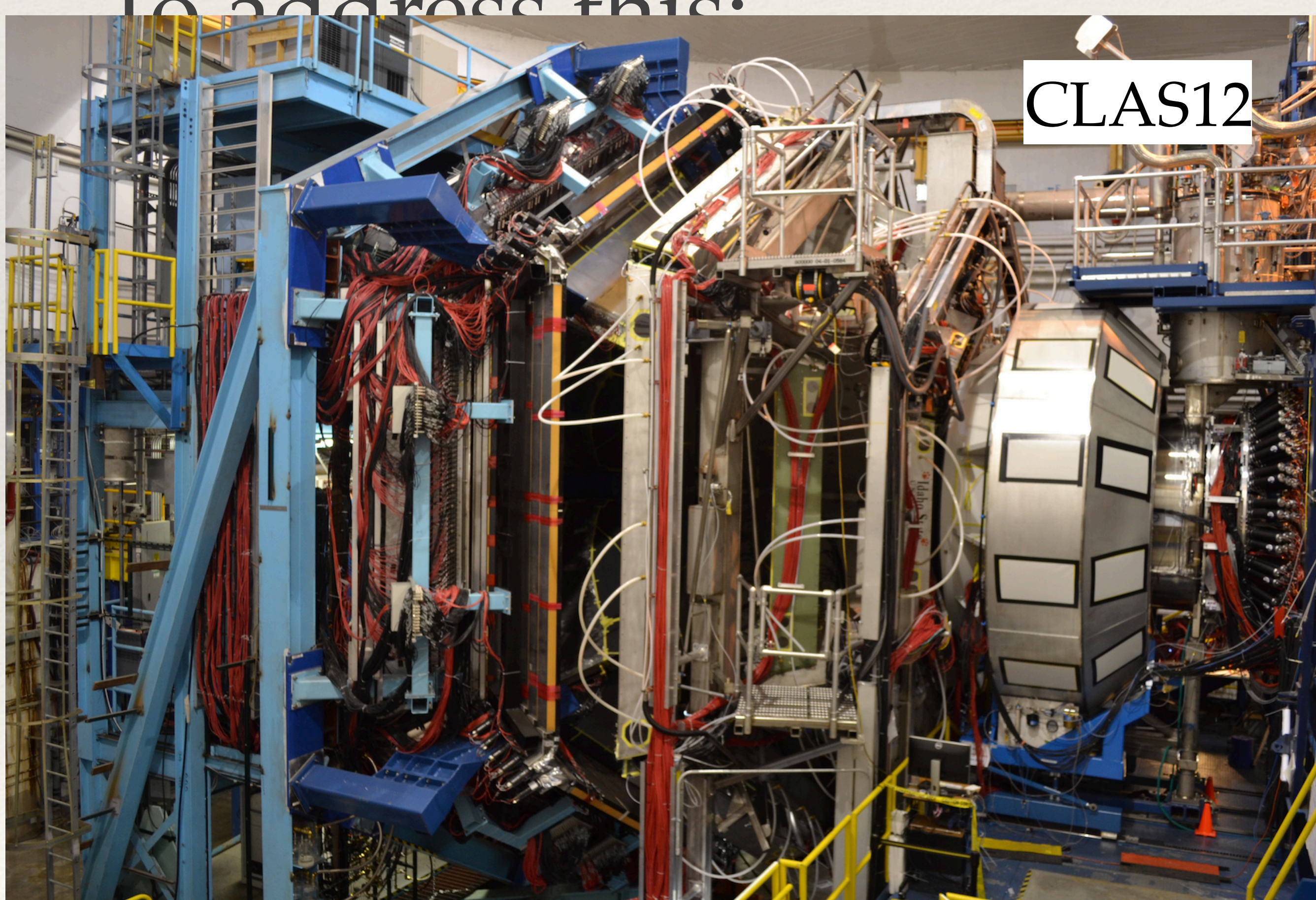
To address this:





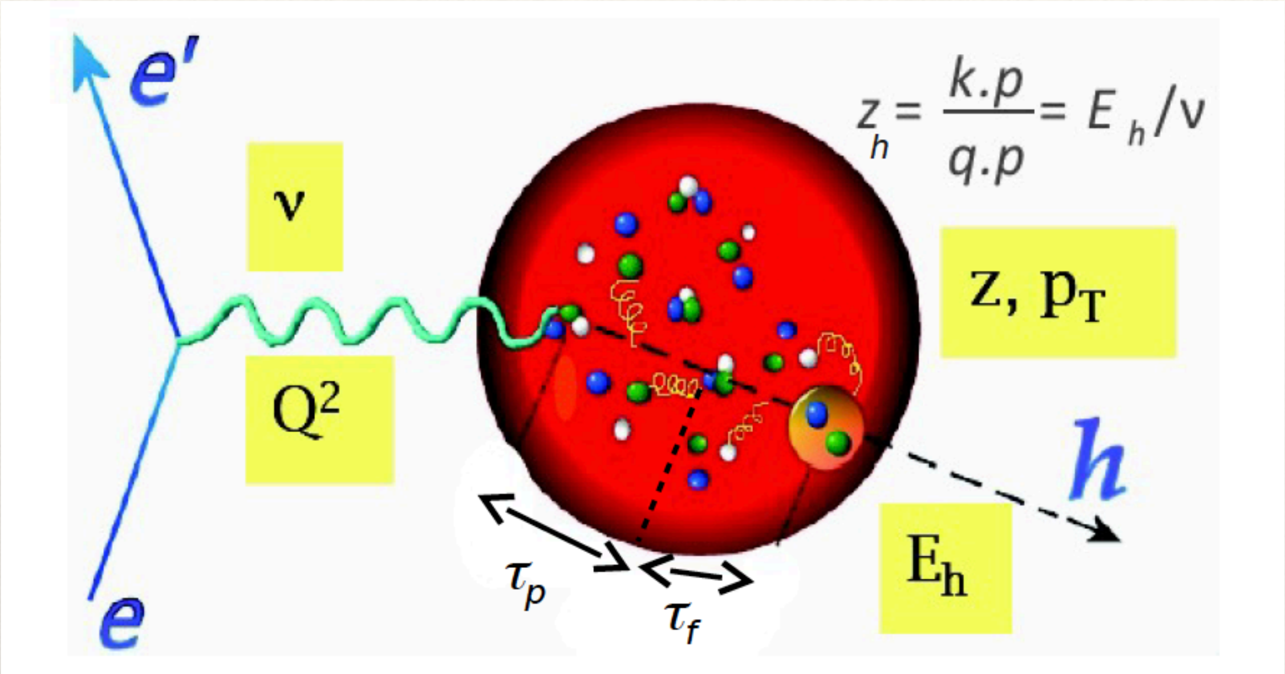


a

Hadronization

Study hard processes in nuclei to probe the QCD confinement dynamics:

Color propagation (CP) and fragmentation - **Hadronization process**



Motivation - E_{e+}=27 GeV studies of pions and kaons by Hermes

Production time τ_p: Time spent by a deconfined quark to neutralize its color charge. Stimulated by energy loss to the medium by gluon exchange.
Observable: transverse momentum broadening.

$$\Delta p_T^2 = < p_A^2 > - < p_D^2 >$$

Formation time τ_f: Time required to form a regular hadron. Interactions with hadron cross sections.
Observable: multiplicity ratios

$$R_M^h = \frac{\left[\frac{N_h^{DIS}}{N_e^{DIS}}\right]_A}{\left[\frac{N_h^{DIS}}{N_e^{DIS}}\right]_D}$$

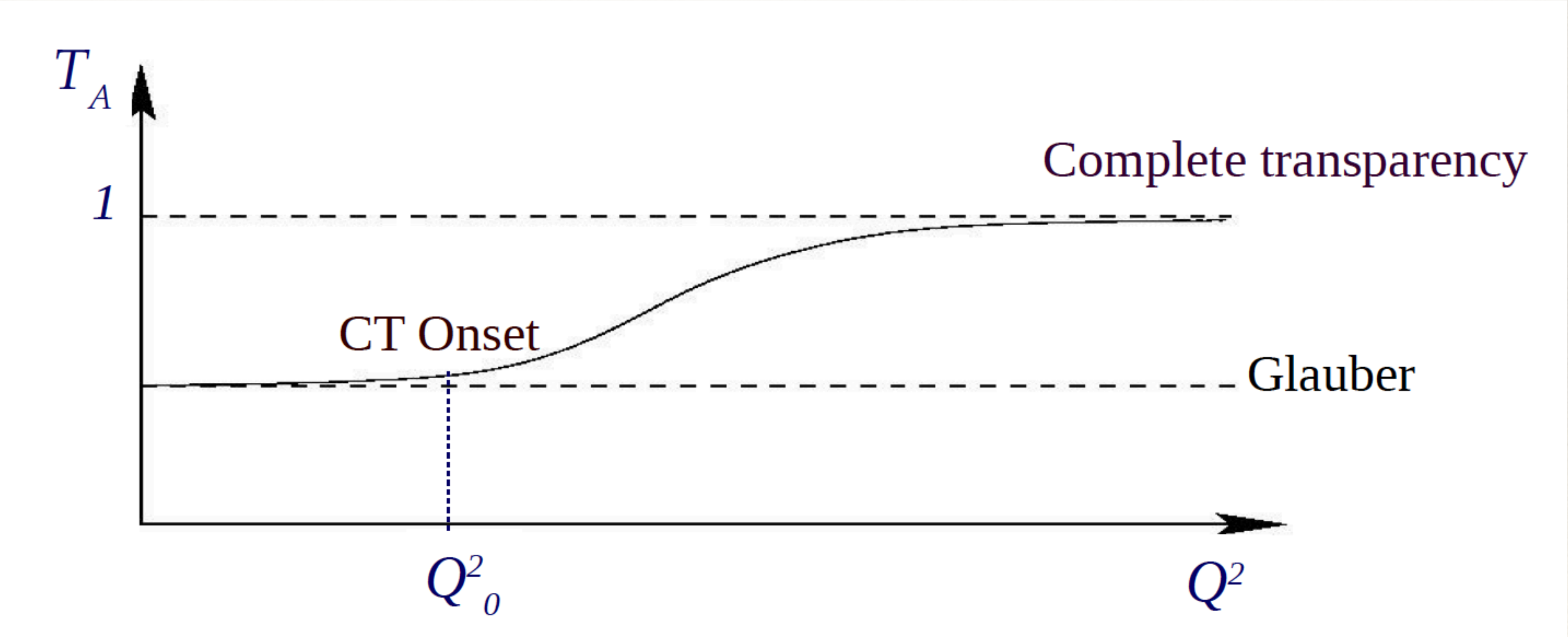
Color Transparency

- Creation of Small Size Configuration (SSC) in hard and exclusive reactions
- SSC experiences reduced attenuation before evolving to the fully dressed hadron
- In QCD, the color field of singlet objects vanishes as their size is reduced
- The CT signature is the increase of the medium "nuclear" transparency as a function of Q^2.

$$T_A = \frac{\sigma_A}{A\sigma_N}$$

$\sigma_A \rightarrow$ nuclear cross section

$\sigma_N \rightarrow$ free (nucleon) cross section



Color Transparency

Proton measurements:

- A(p,2p)

A. Leksanov et al. PRL 2001

- A(e,e'p)

SLAC

N. C. R. Makins et al. PRL 72, 1986 (1994)

G. Garino et al. PRC 45, 780 (1992)

JLab

D. Abbott et al. PRL 80, 5072 (1998)

K. Garrow et al. PRC 66, 044613 (2002)

Disagreement between results

Hall C in 12 GeV Era

Experiment E12-06-107: Spokespersons - D. Dutta & R. Ent

Collected 10 days of the A(e,e'p) proton knockout data - 3.5 days @ 8.8 GeV and 6.5 days @ 11 GeV beam energy.

Meson measurements:

- A(π,di-jet) FNAL

Aitala et al., PRL 86, 4773 (2001)

- A(e,e'π^+) JLab Hall C

B. Clasie et al. PRL 90, 10001 (2007)

X. Qian et al., PRC 81, 055209 (2010)

- A(e,e'ρ^0)

DESY - Airapetian et al. PRL 90, 052501 (2003)

JLab Hall B - L. El Fassi et al. PLB 712, 2012

Small size is more probable in two-quark systems.
Onset of CT expected at lower Q^2.

The Collaboration

CT and CP Collaboration

K. Joo (U. Connecticut) K. Hicks (Ohio U.) J. Gilfoyle (U. Richmond)

W. Armstrong, K. Hafidi, B. Mustapha (ANL) R. Dupre* (IPN-Orsay)

T. Chetry, L. El Fassi*, C. Segbefia (Mississippi State U.)

M. Holtrop, L. Zana* (U. New Hampshire) L. Weinstein (Old Dominion U.)

W. Brooks, A. El Alaoui, H. Hakobyan*, T. Mineeva*, O. Soto*, A. Borquez*, S. Moran*
(UTFSM, Chile)

I. Niculescu, G. Niculescu (James Madison U.) M. Wood (Canisius College)

CLAS6 CT or CP spokespersons

CLAS12 CT and/or CP spokespersons

* Former CLAS6 CT or CP graduate student

* Current CLAS6 CP graduate student

The Program

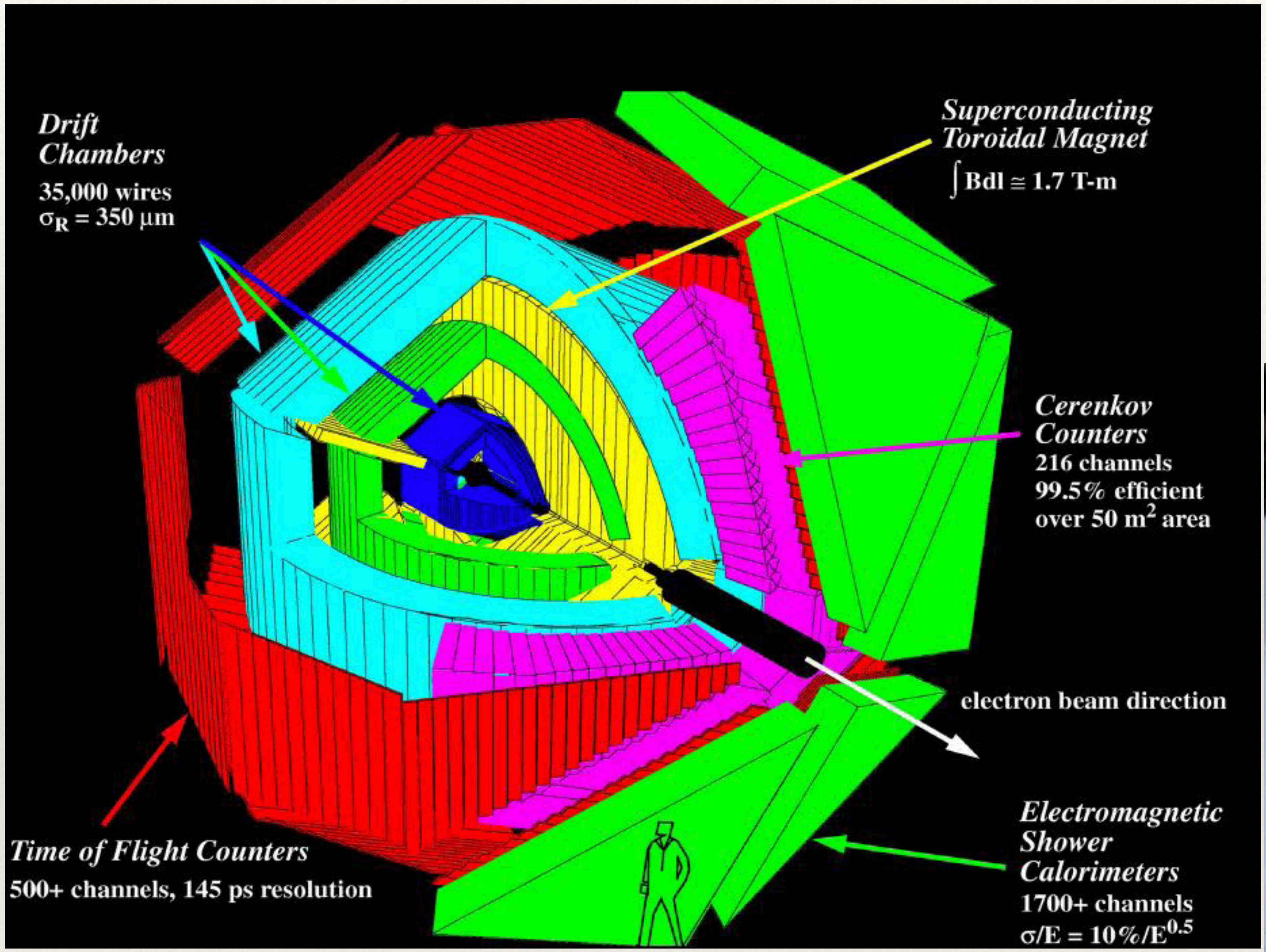
DIS channels: *stable* hadrons, accessible with 11 GeV
JLab experiment PR12-06-117

Actively underway with existing 5 GeV data

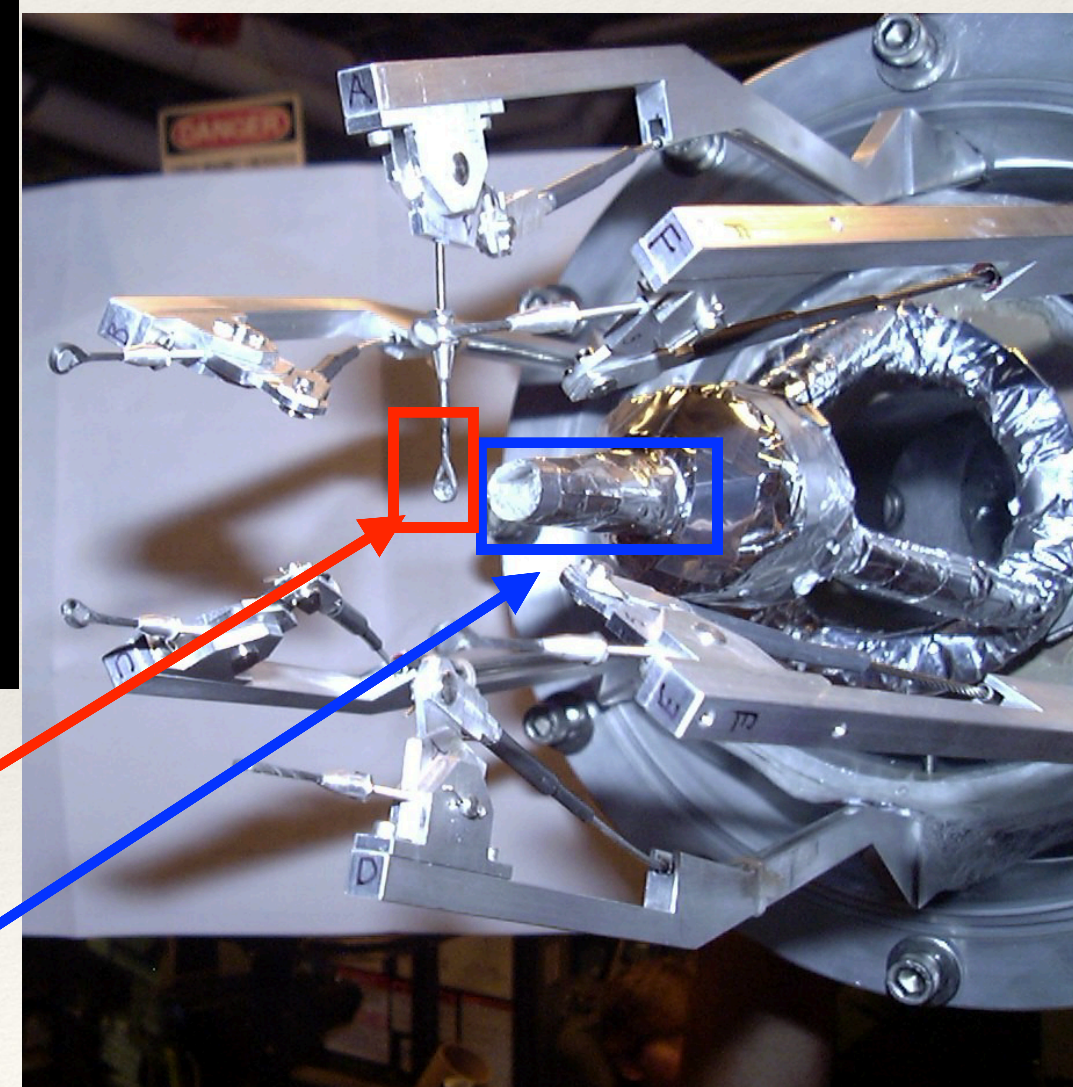
meson	cτ	mass	flavor content
π^0	25 nm	0.13	$u\bar{u}d\bar{d}$
π^+, π^-	7.8 m	0.14	$u\bar{d}$, $d\bar{u}$
η	170 pm	0.55	$u\bar{u}d\bar{d}s\bar{s}$
ω	23 fm	0.78	$u\bar{u}d\bar{d}s\bar{s}$
η'	0.98 pm	0.96	$u\bar{u}d\bar{d}s\bar{s}$
ϕ	44 fm	1.0	$u\bar{u}d\bar{d}s\bar{s}$
f1	8 fm	1.3	$u\bar{u}d\bar{d}s\bar{s}$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

CLAS6 - The Present



CLAS-6 E-02-104 (CT) & E-02-110 (CP) experiments were run as a single measurement.



Solid target
(C, Fe, Pb)

Liquid deuterium

Color Propagation SIDIS Kinematics

Q^2: Four-momentum transfer,

> 1 GeV², to probe the intrinsic structure of nucleons

$y = \frac{\nu}{E_h}$: Electron energy fraction transferred to a struck quark,

< 0.85, to reduce the size of the radiative effects on multiplicity ratios

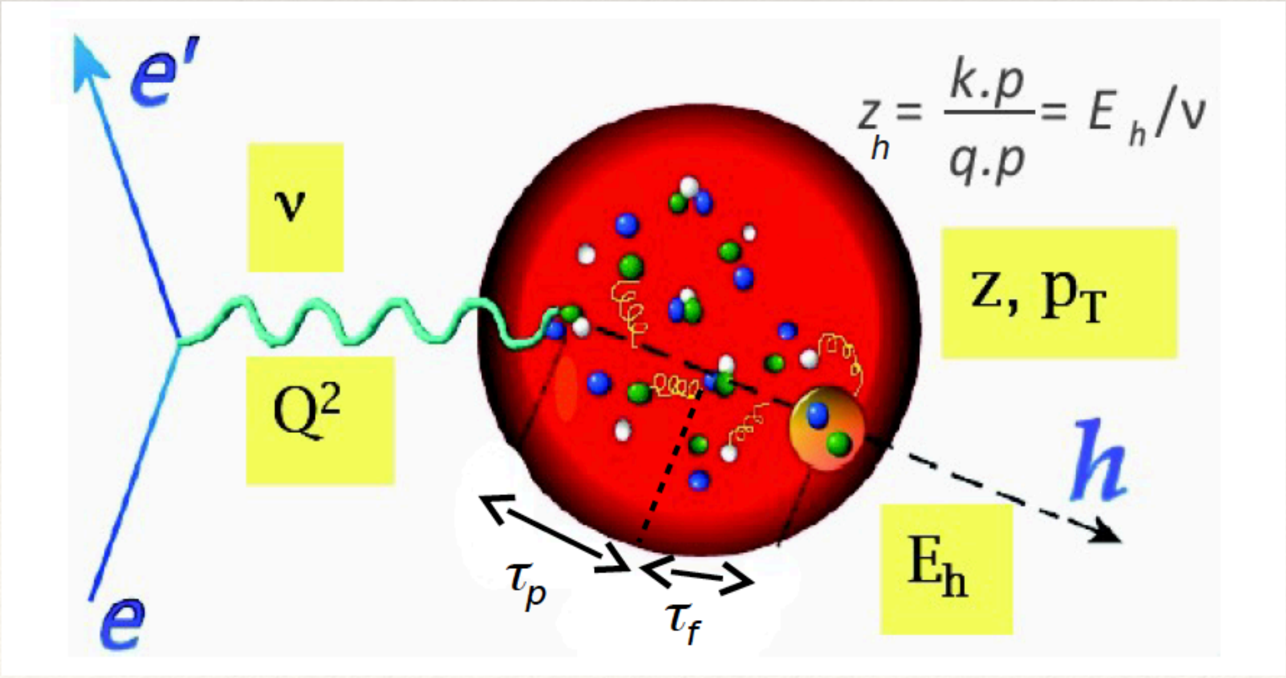
$W = \sqrt{M_N^2 + 2\nu M_N - Q^2}$: mass of the total hadronic final state (nucleon mass M_N)

> 2 GeV, to avoid a contamination from the resonance region

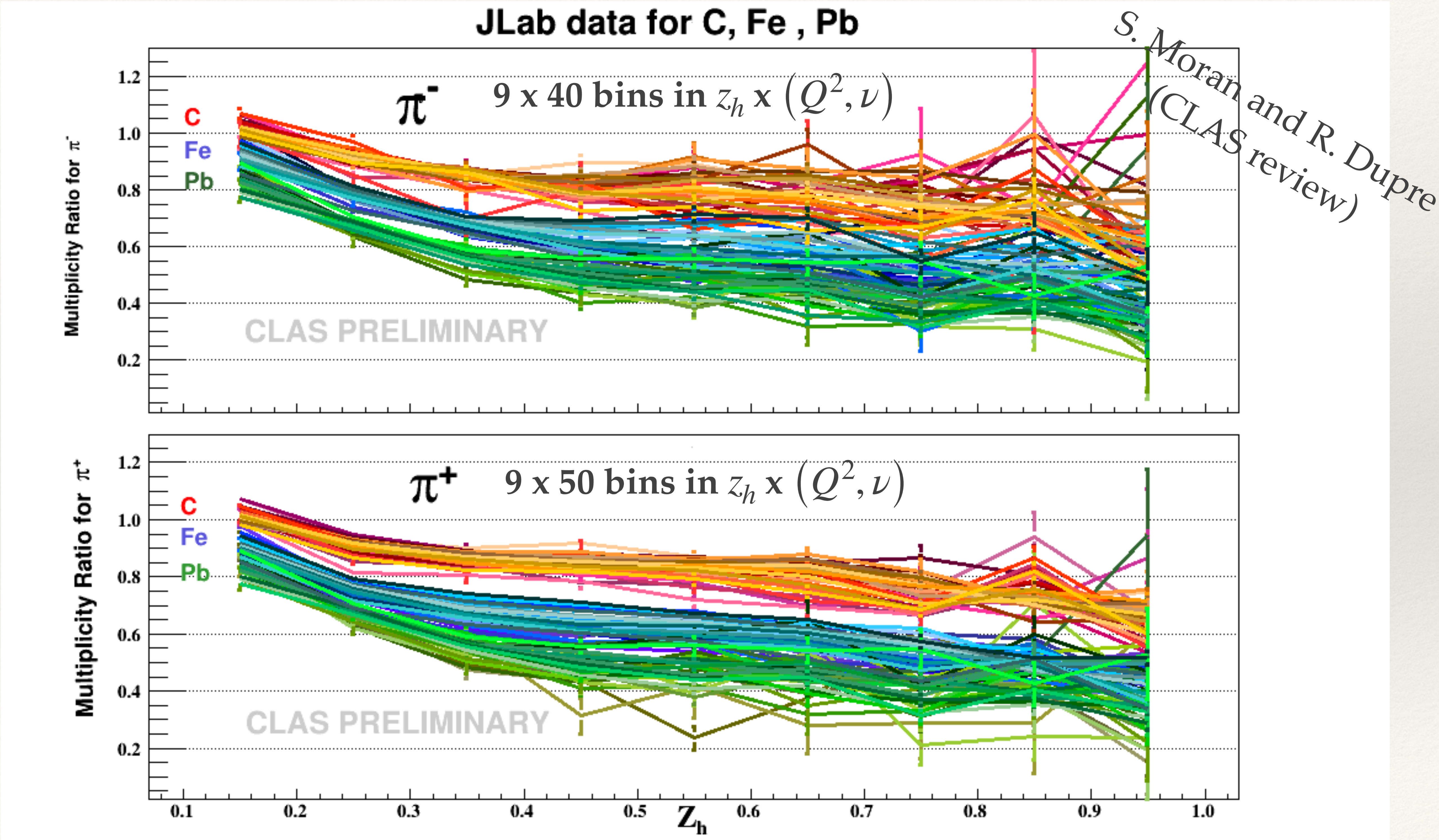
x_F : Fraction of the CM longitudinal momentum carried by the observed hadron.

> 0, selects the current fragmentation region.

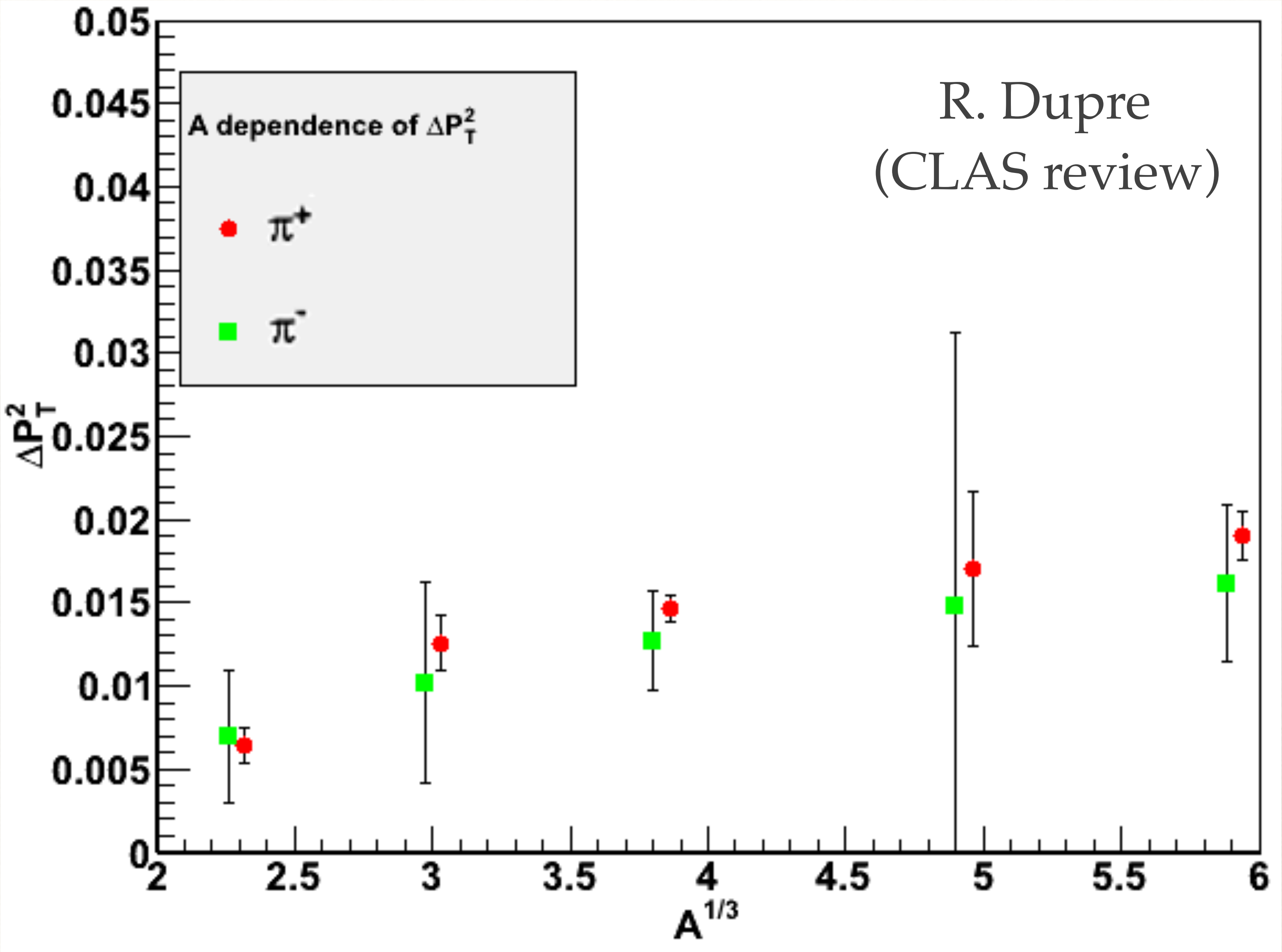
< 0, selects the backward (target-remnant) fragmentation region.



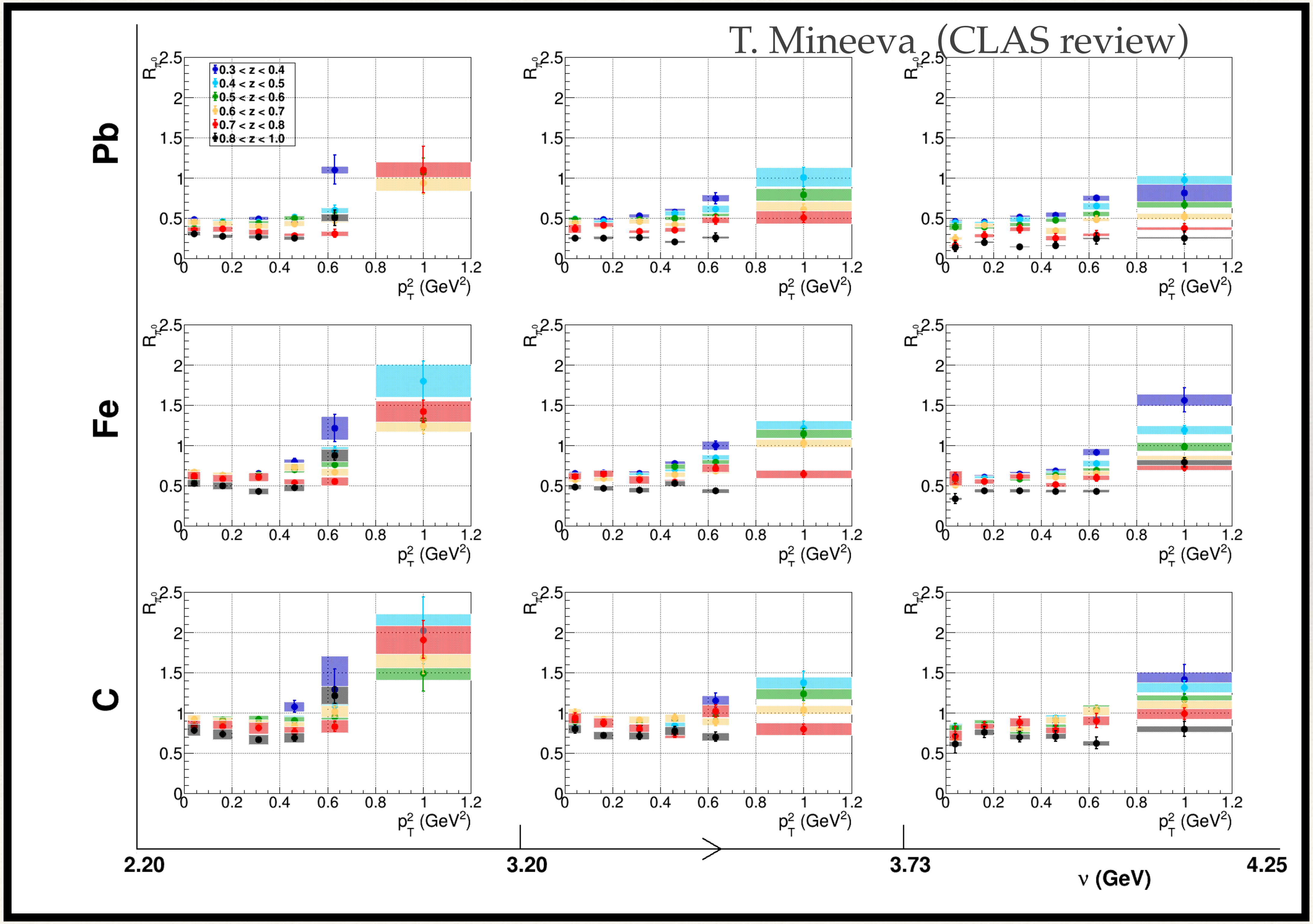
Charged Pion Multiplicity Ratios



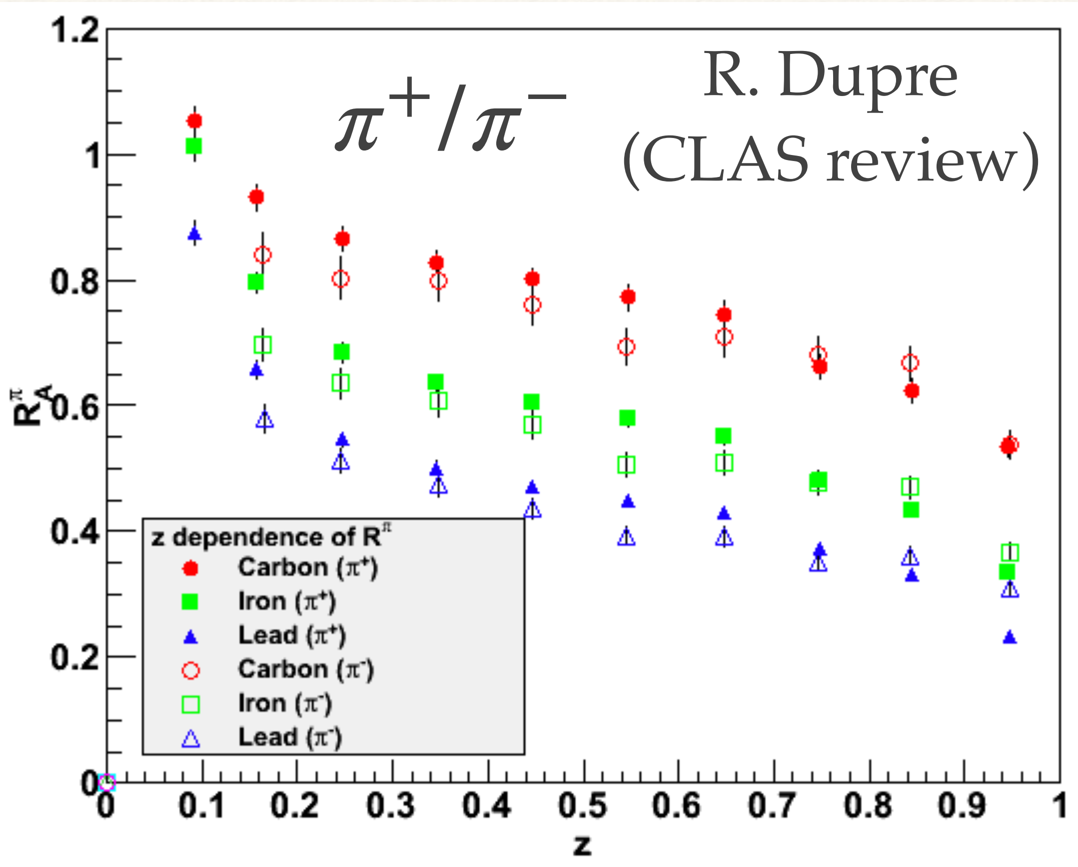
Charged Pion Multiplicity Ratios

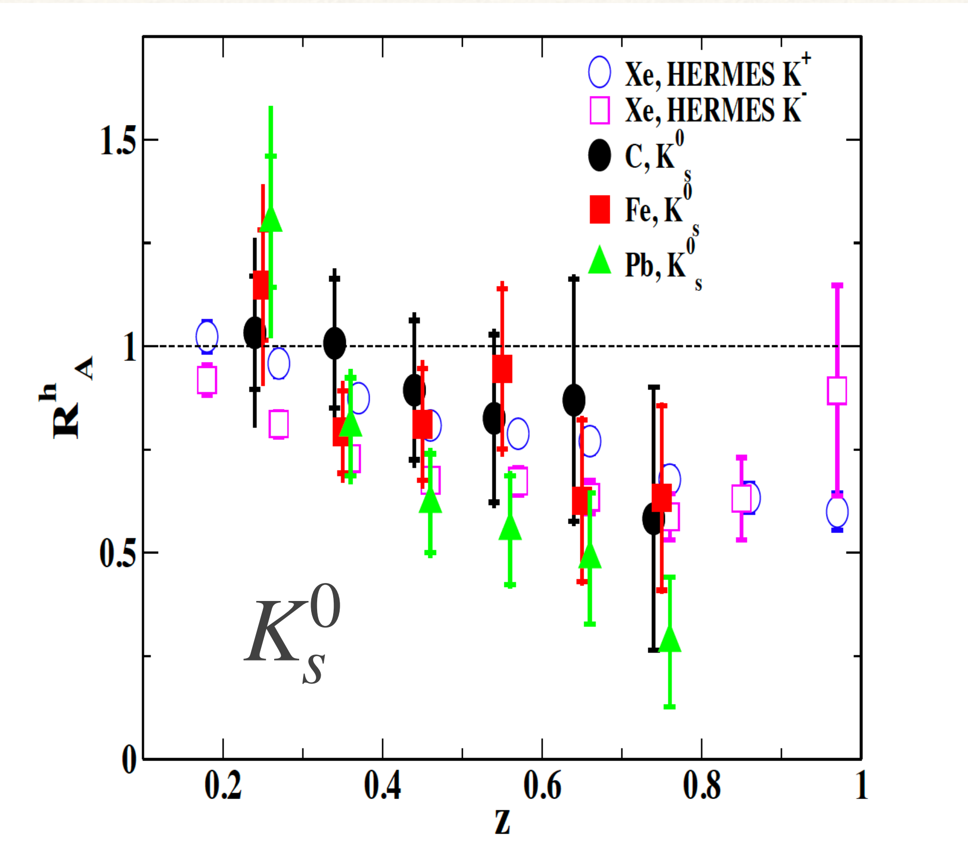


Neutral Pion Multiplicity Ratios



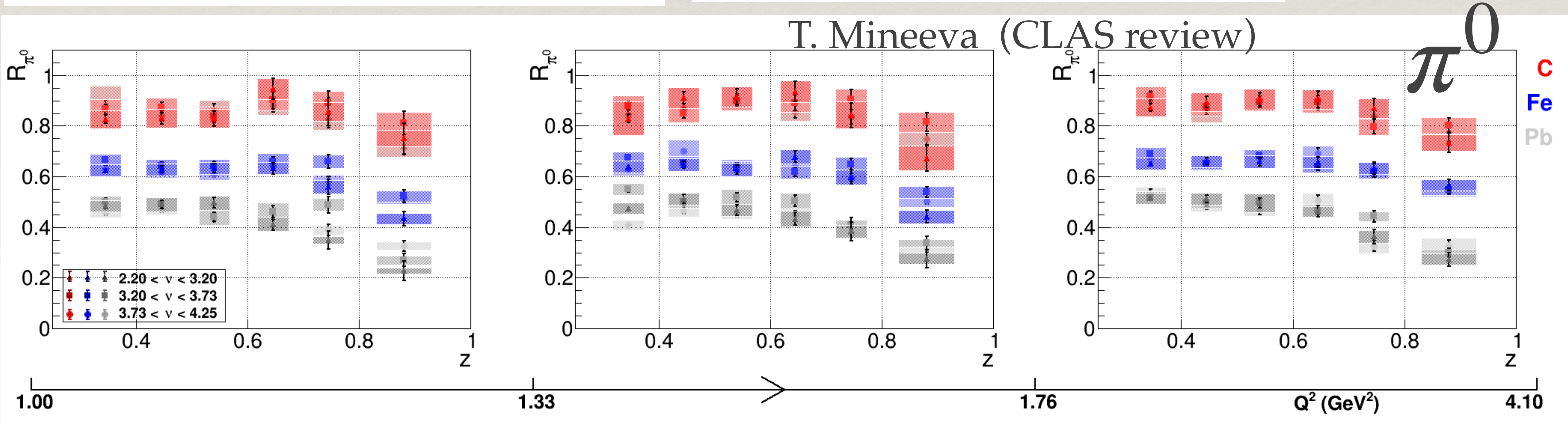
Multiplicity Ratios - Comparison





Hermes -
A. Airapetian, *et al.*, Nucl. Phys. B 780 (2007) 1.

CLAS6 -
A. Daniel *et al.*, PLB 706 (2011) 26.



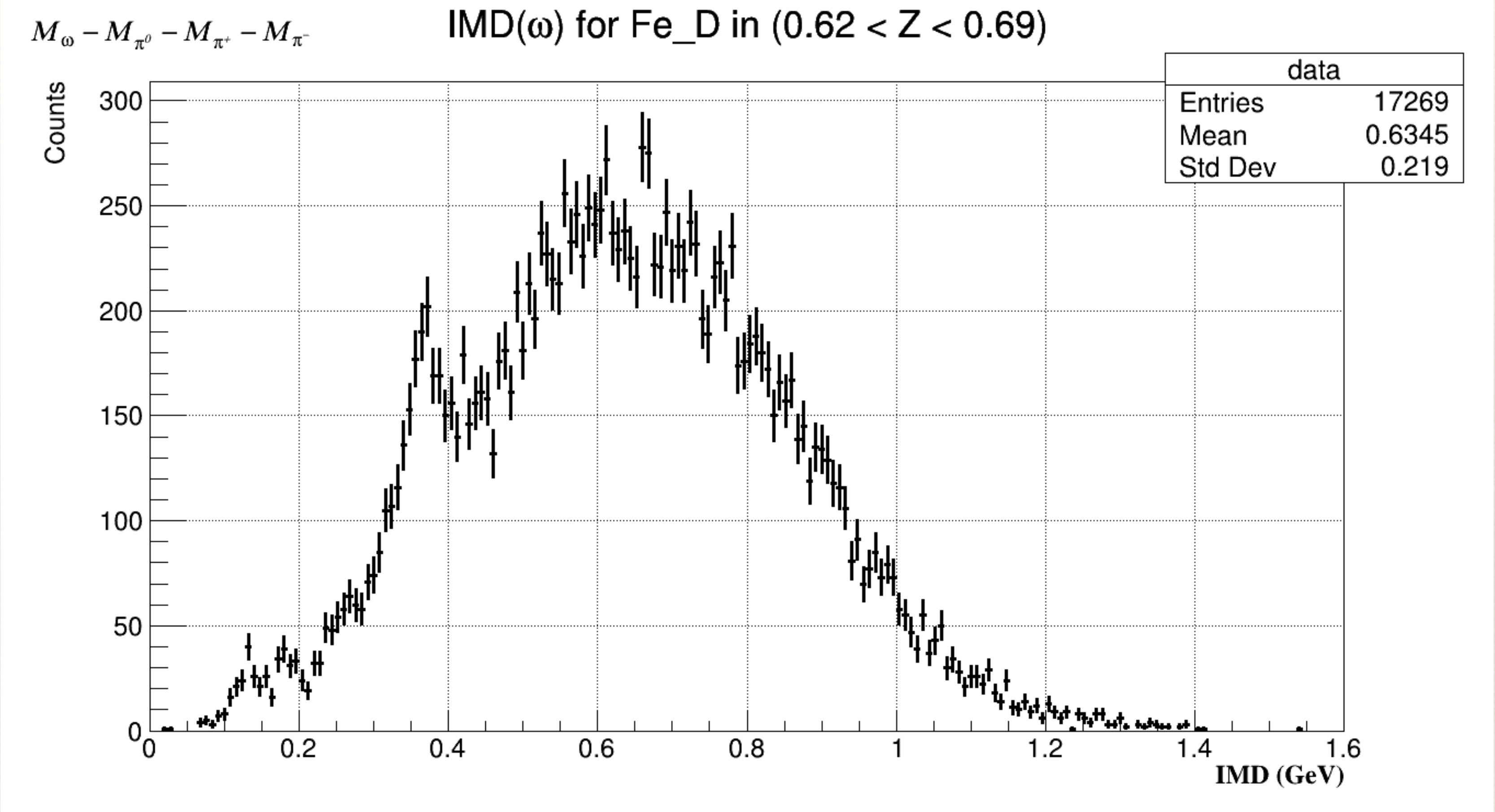
ω Meson Multiplicity Ratios

Thesis of A. Borquez (UTFSM grad. Student)

Supervised by

H. Hakobyan (UTFSM) and M. Wood (Canisius College)

Mass Diff. - G. Aad et al. (ATLAS), PRD 85, 052005 (2012)



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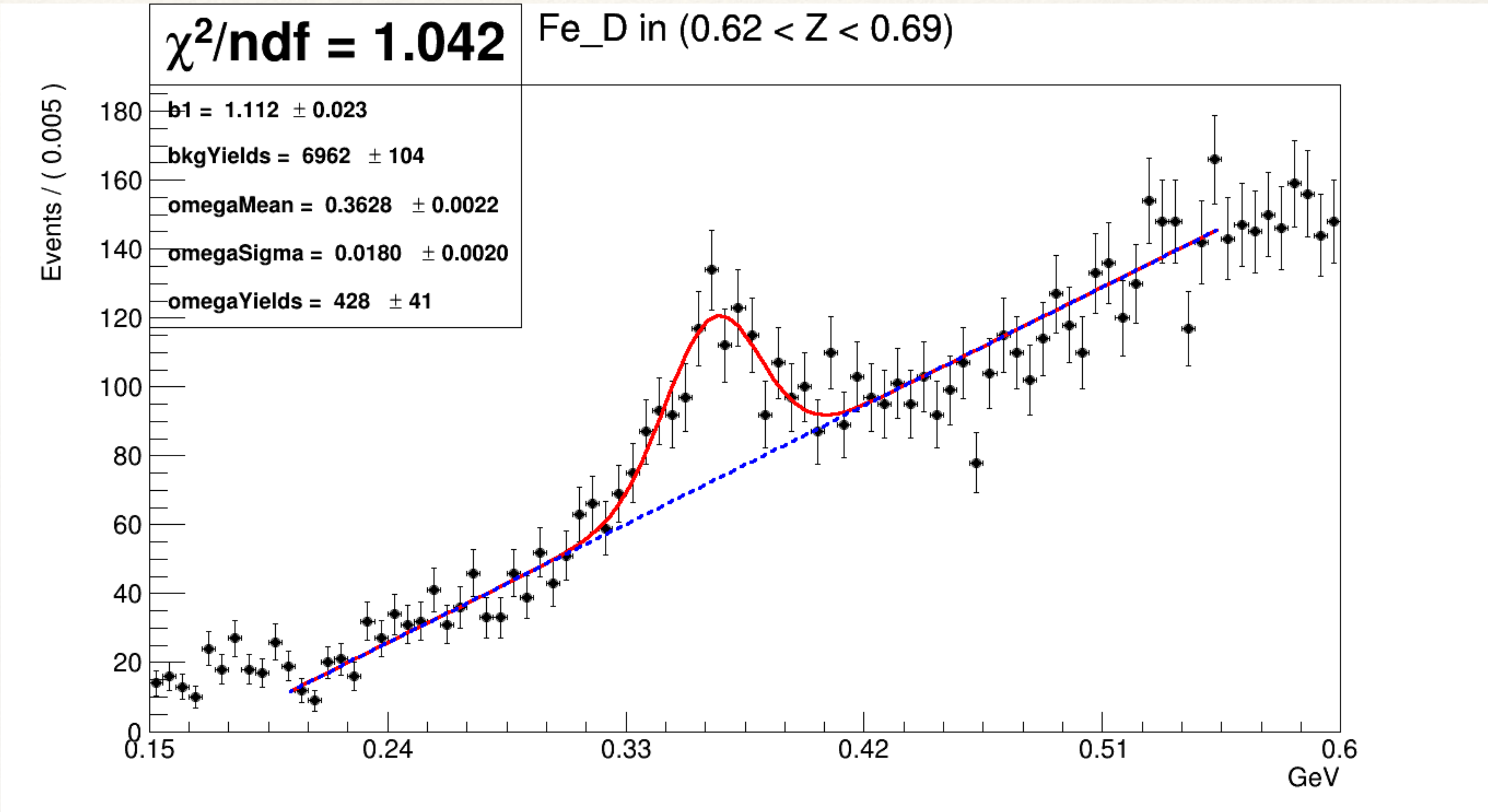

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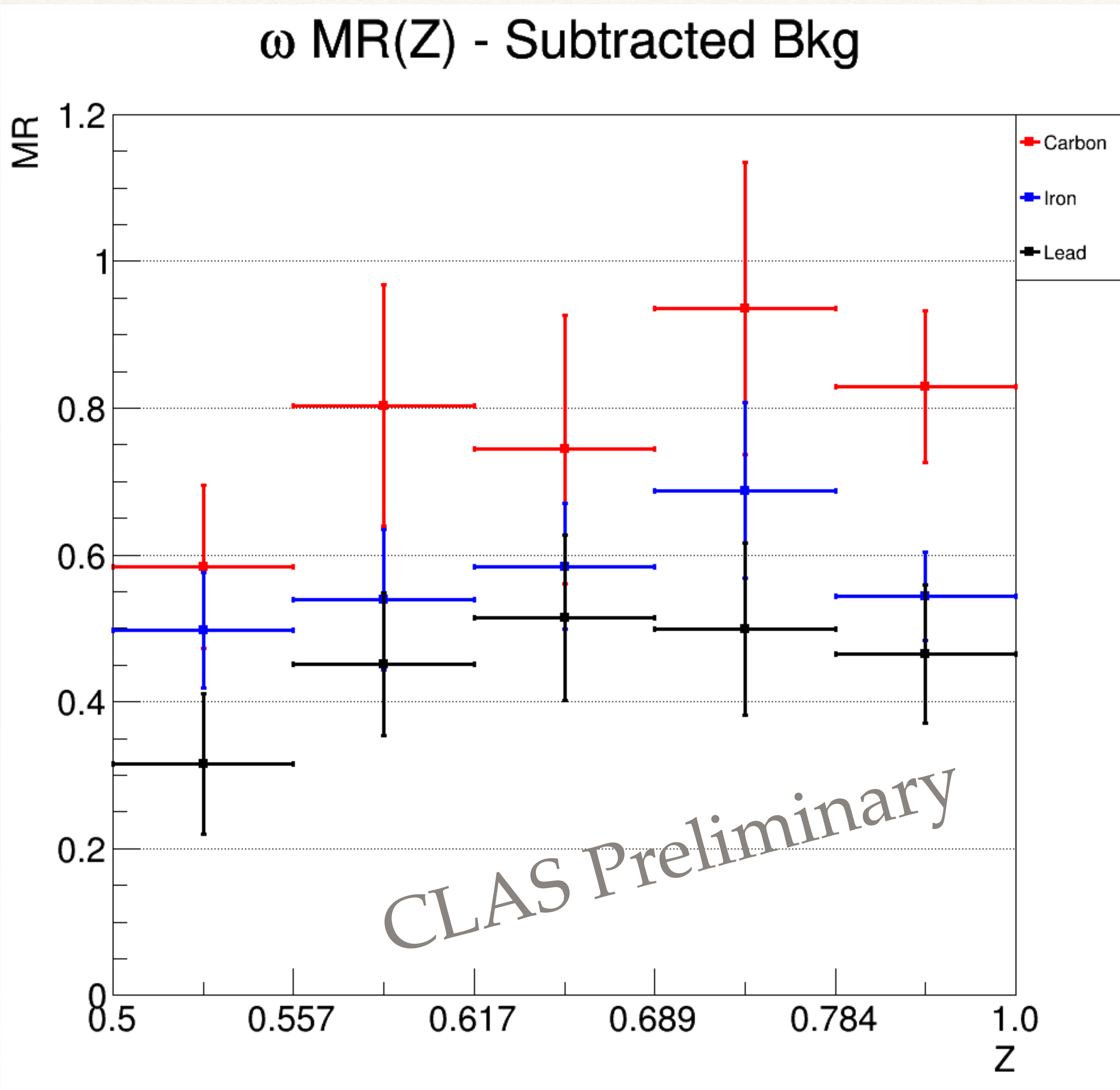
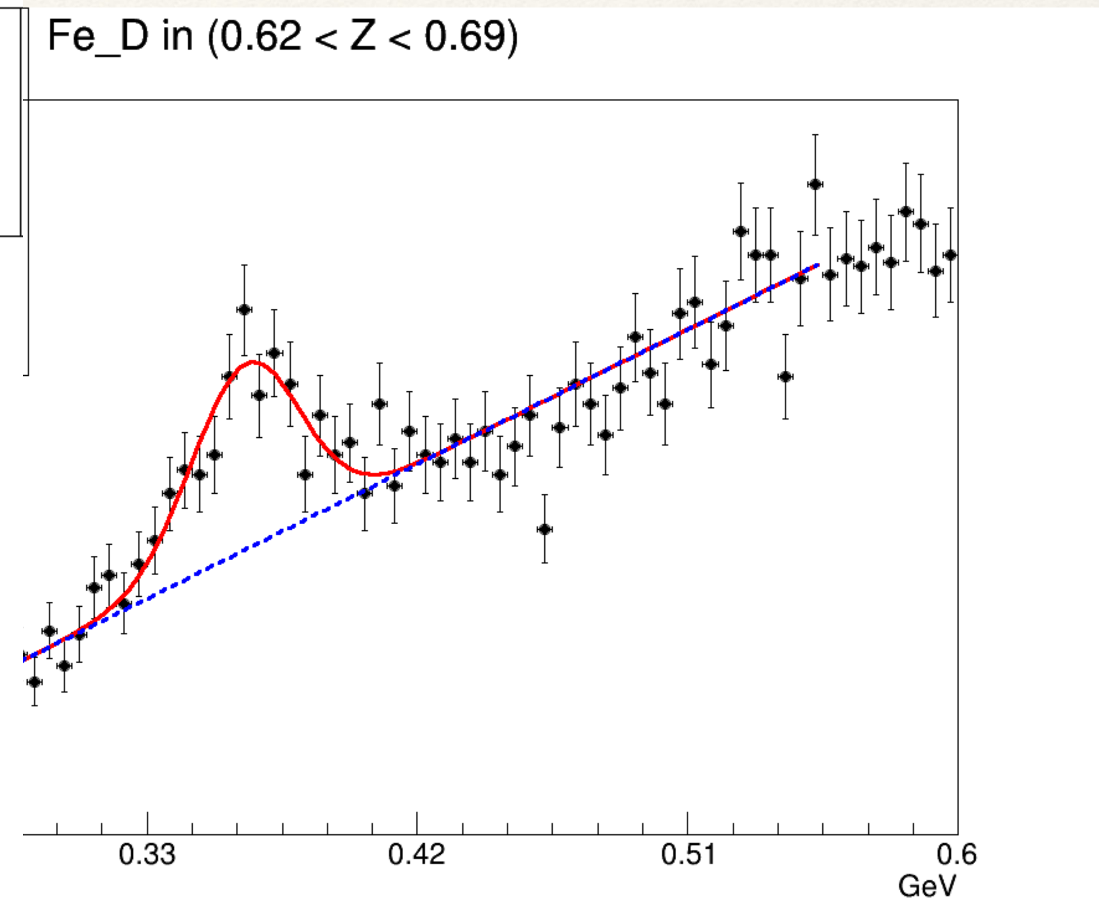


iff. - G. Aad et al. (ATLAS), PRD 85, 052005 (2012)

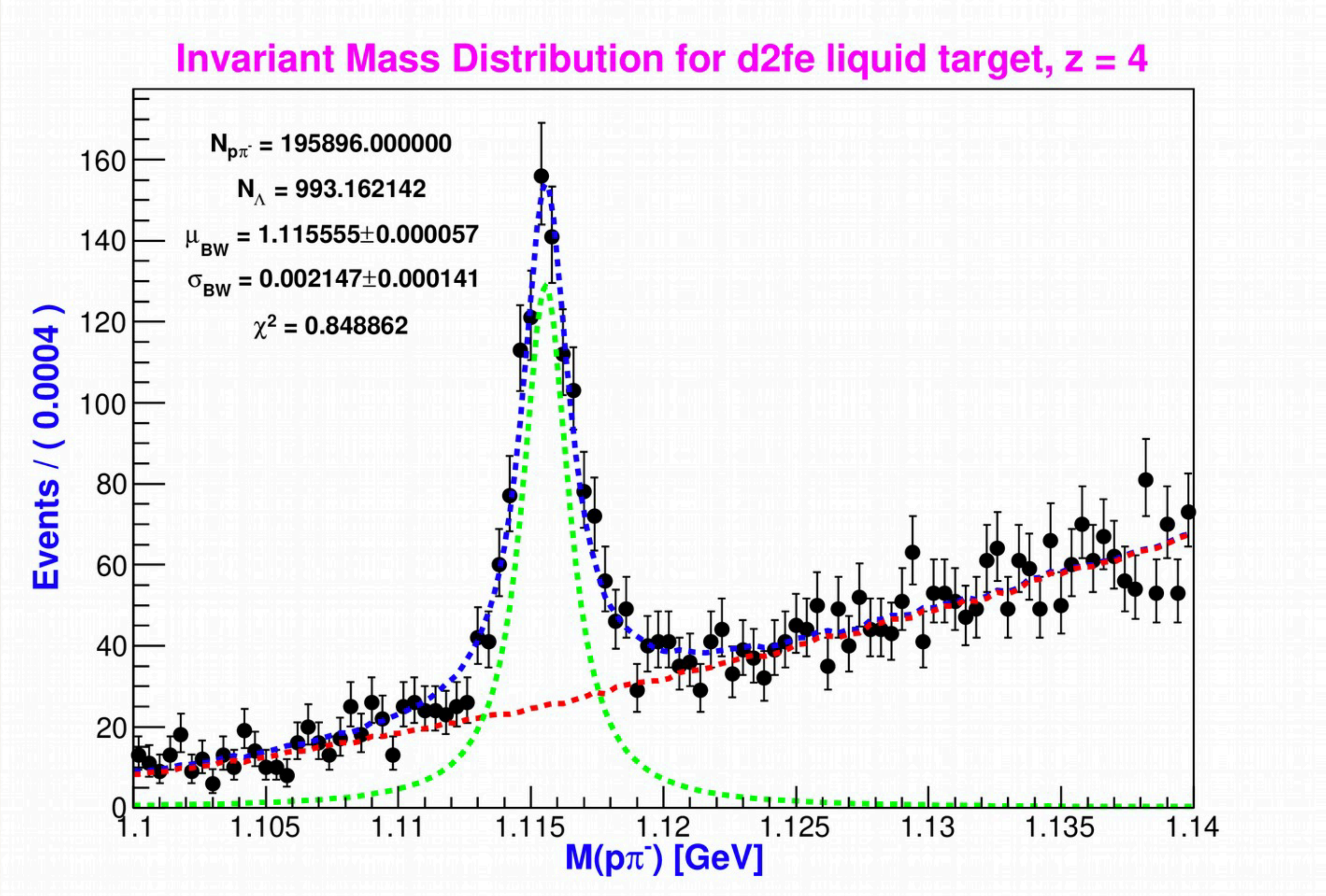


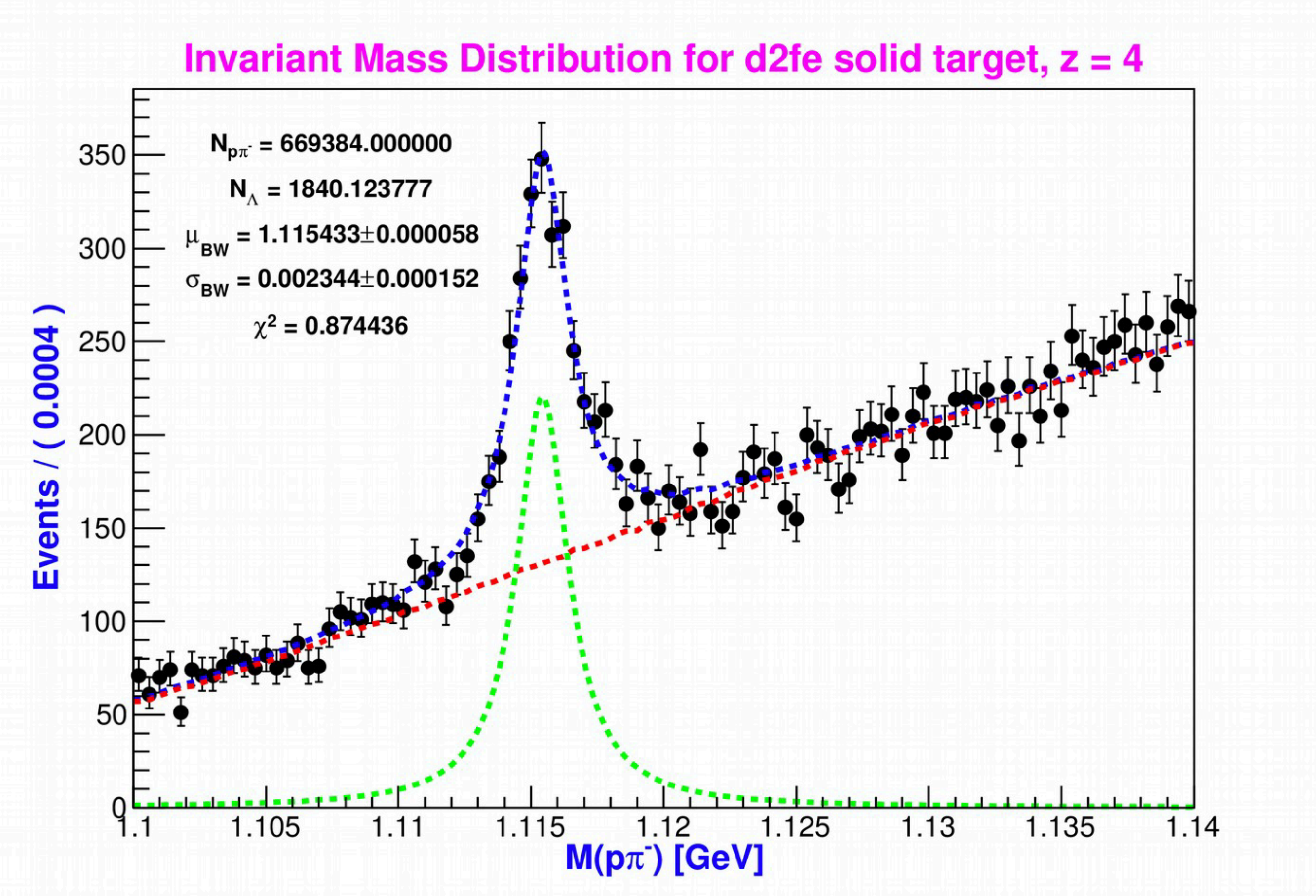
No acceptance or radiative corrections applied.

First results on ω meson hadronization,

Λ^0 Analysis - Don't Forget the Baryons

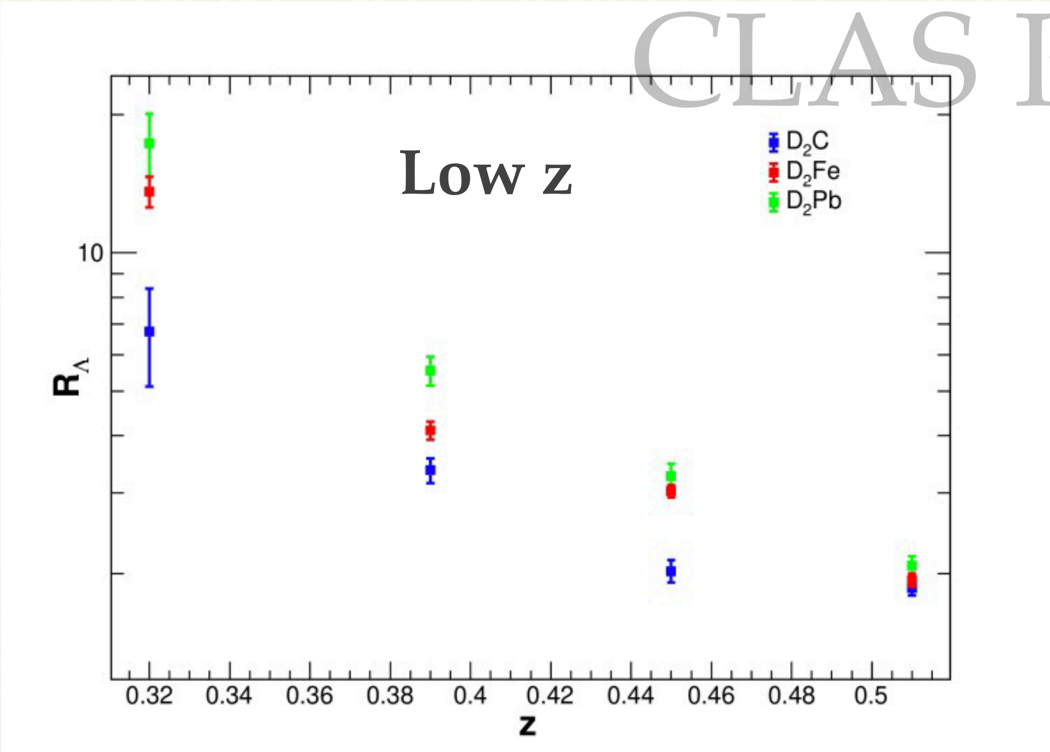
- First ever study of the hadronization process of Λ^0hyperon which probes the forward (current) and backward (target) fragmentation regions.
- Identify Λ^0 via its decay particles, π^- and p.
- Use the event mixing technique to subtract the combinatorial background.

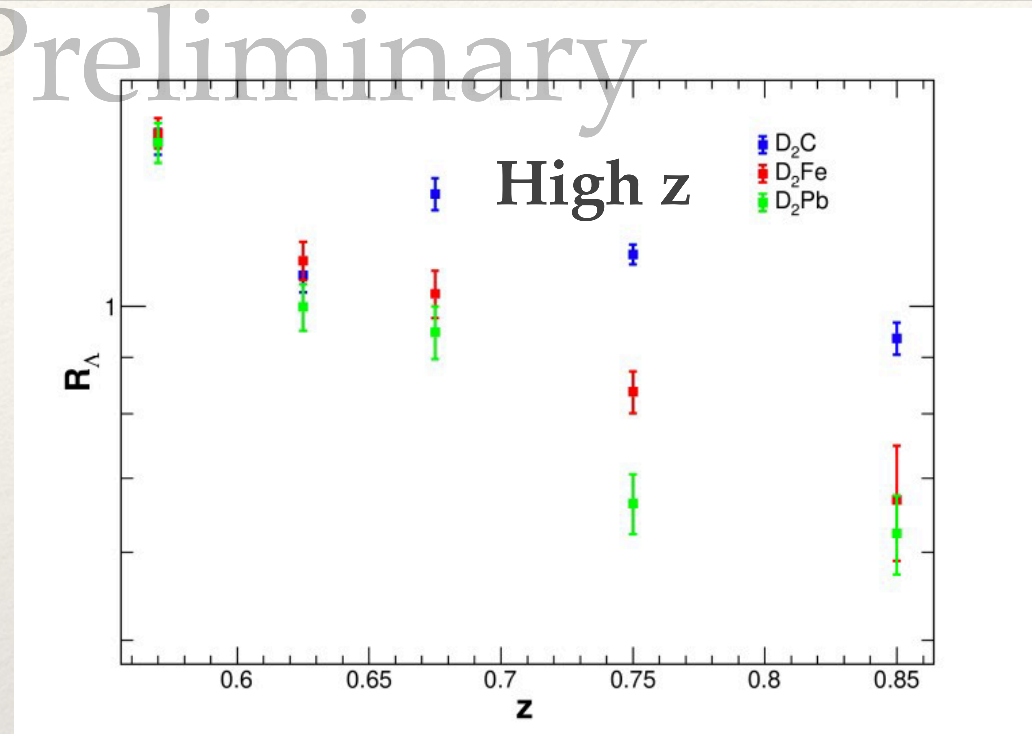


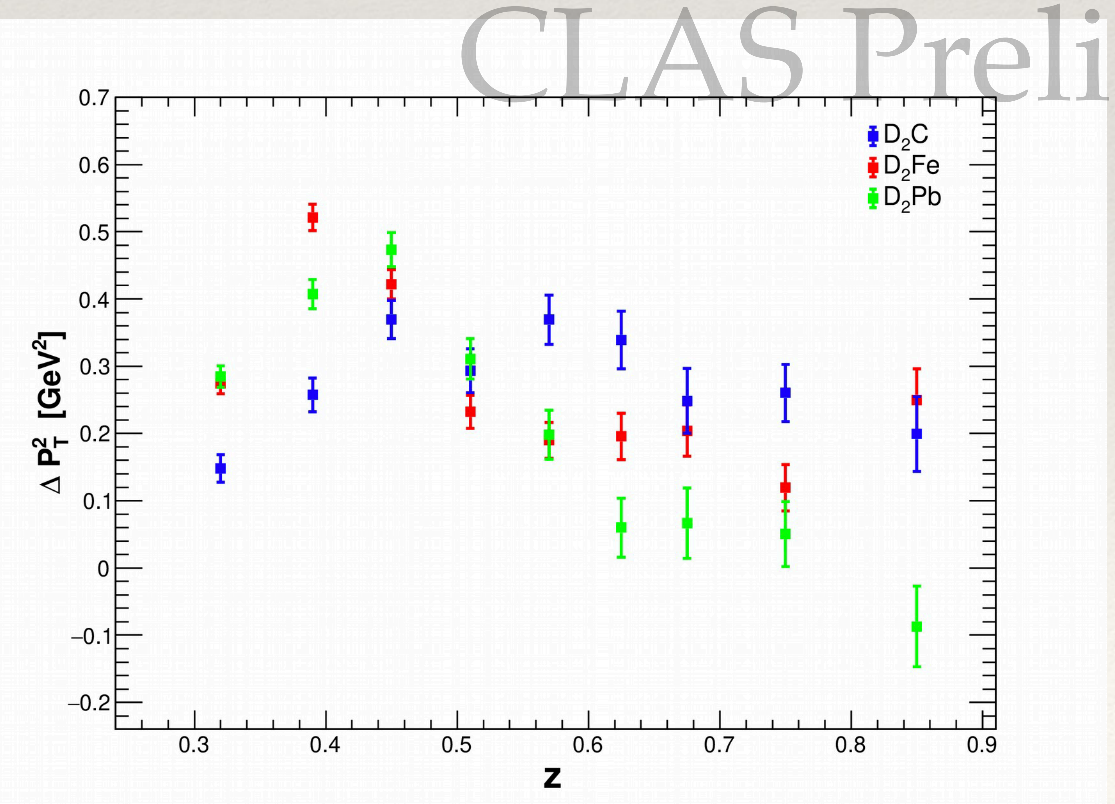


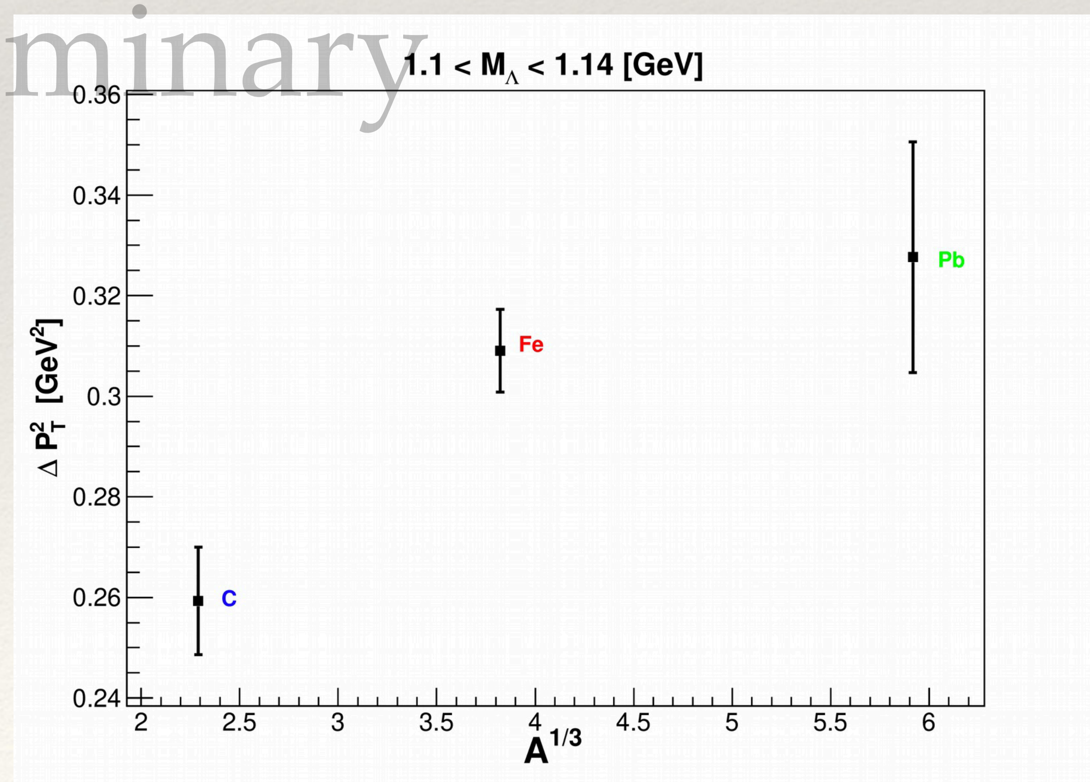
T. Chetry and L. El Fassi, Preliminary Analysis

Λ^0 Multiplicity Ratios and Δp_T^2

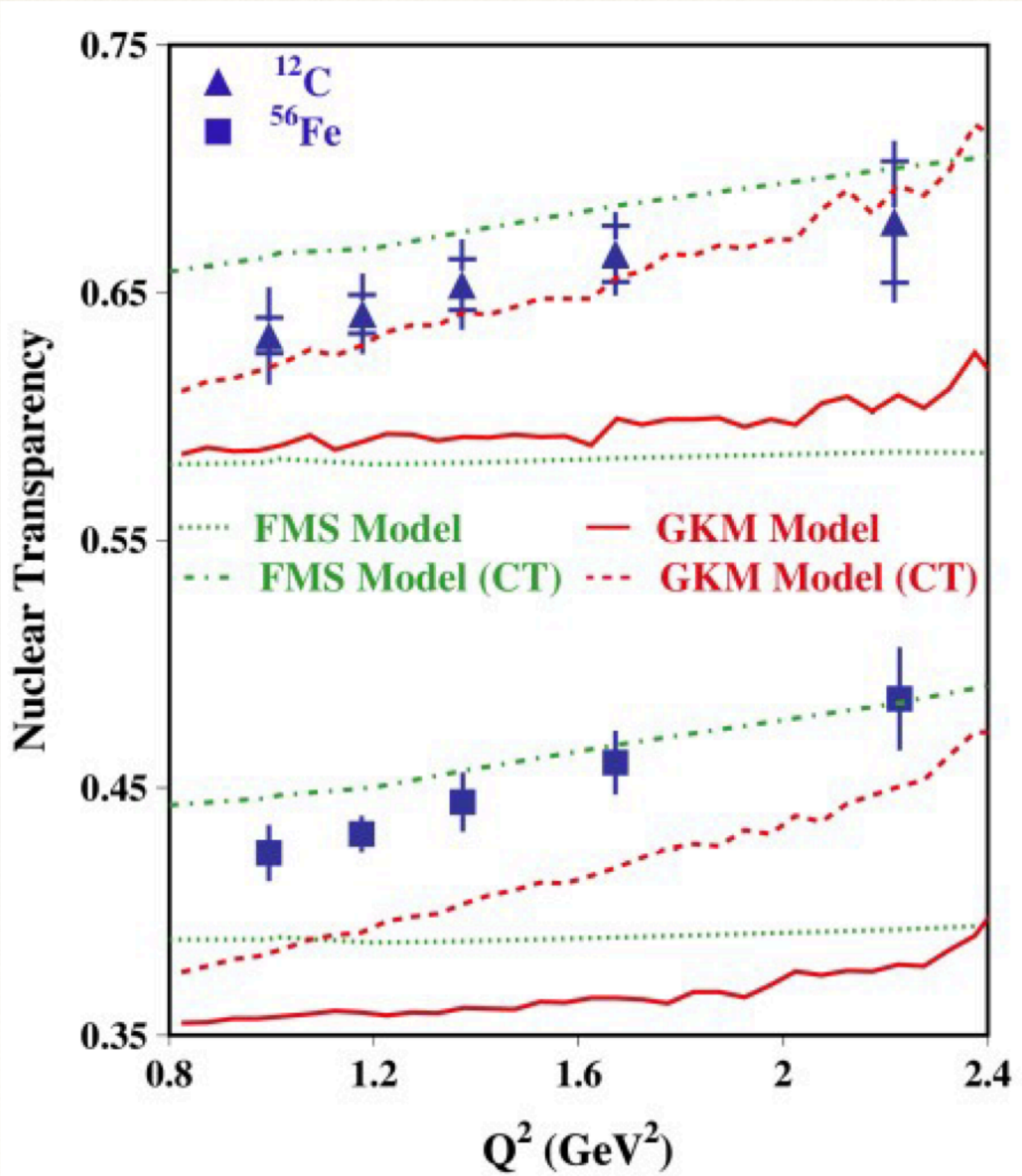








Color Transparency - ρ Meson



L. El Fassi et al. PLB 712, 2012

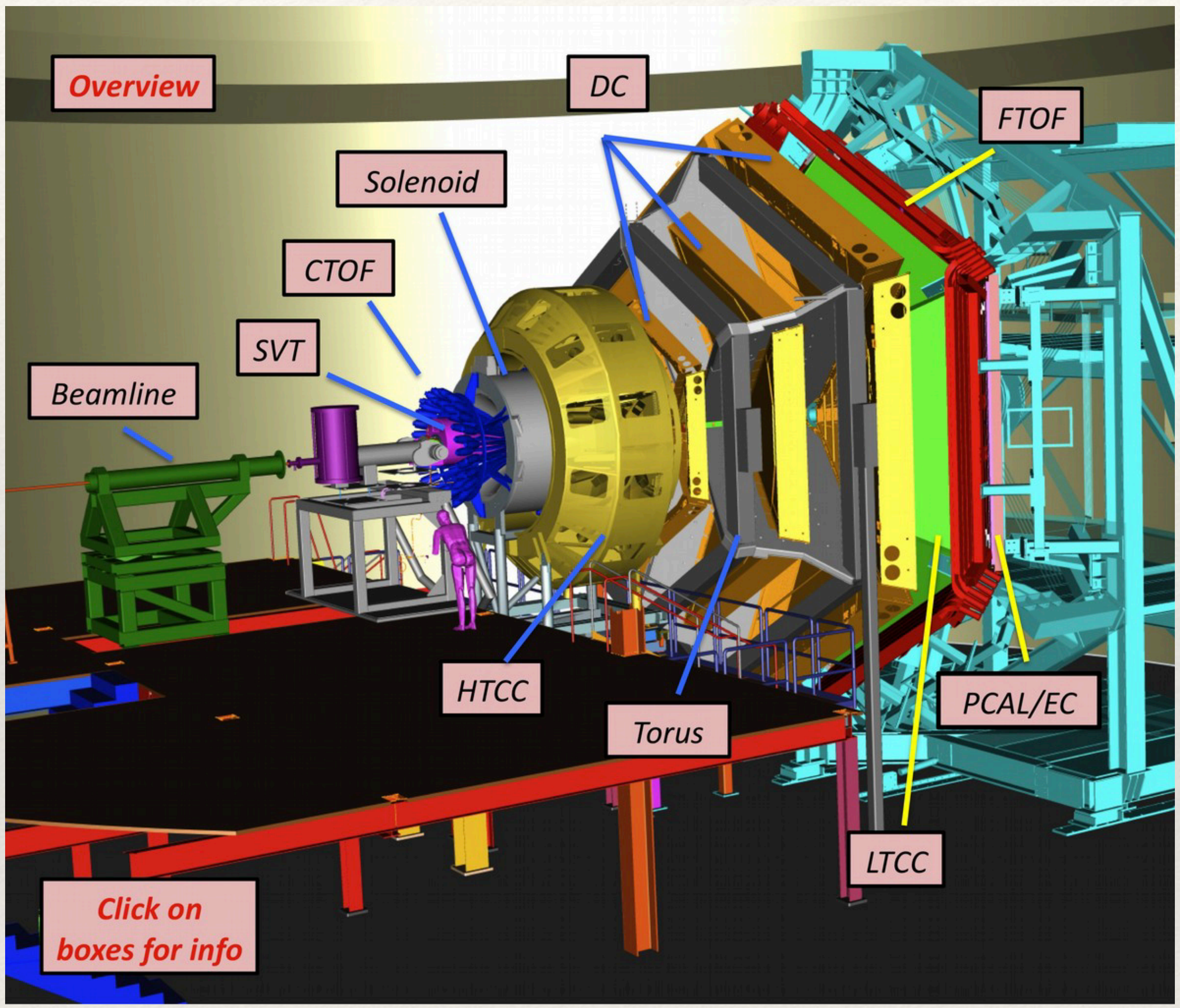
Selection

$W > 2$ GeV : avoid resonance region
$-t < 0.4$ GeV^2 : select diffractive process
$-t > 0.1$ GeV^2 : exclude coherent production
$z_h \geq 0.9$: select elastic channel

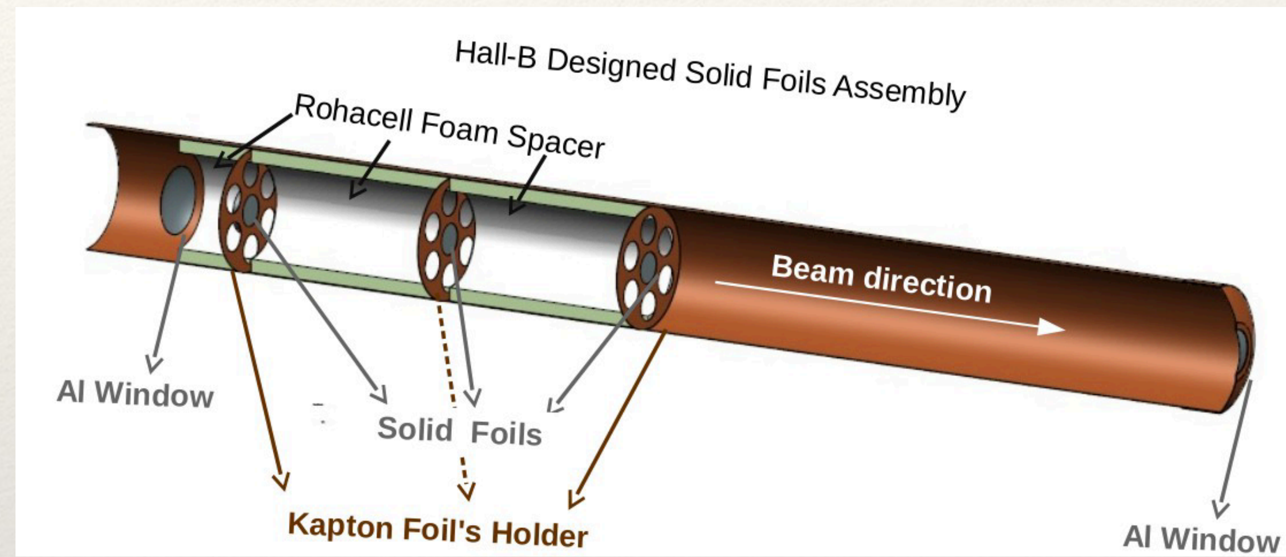
FMS Model - semi-classical Glauber formalism based on quantum diffusion model.
Dot-dashed line includes CT effects and FSI interactions.
Frankfurt, Miller & Strikman, PRC 78 (2008)

GKM: Transport Model (GiBUU)
Dashed curve includes CT effects for ρ^0produced in DIS regime only!
Gallmeister, Kaskulov & Mosel, PRC 83, 015201 (2011)

CLAS12 - The Future



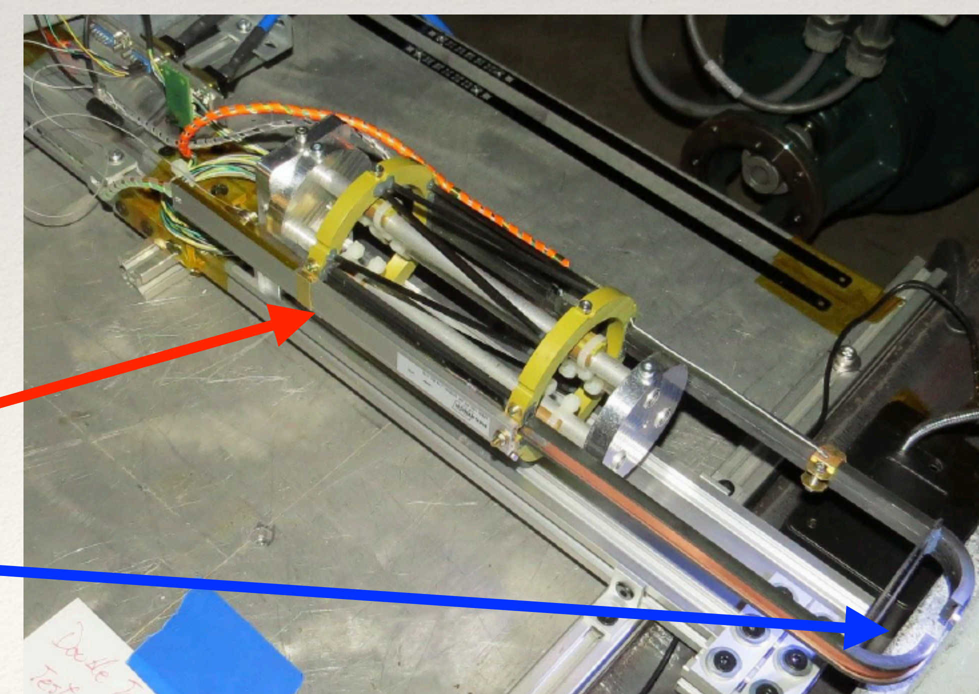
CT STudy: PR12-06-106



CP STudy: PR12-06-117

Liquid target

Solid target



CLAS12 - The Future

- Span a wider range of nuclei masses Better understanding of the A dependence,
- Study the production of a variety of hadrons Improve our understanding of hadron's formation mechanism
- Cover much larger kinematical coverage,
- 10 times higher luminosity compared to CLAS6 (1000 higher than Hermes)
- Determine the two hadronization timescales.

CLAS12 - Color Propagation

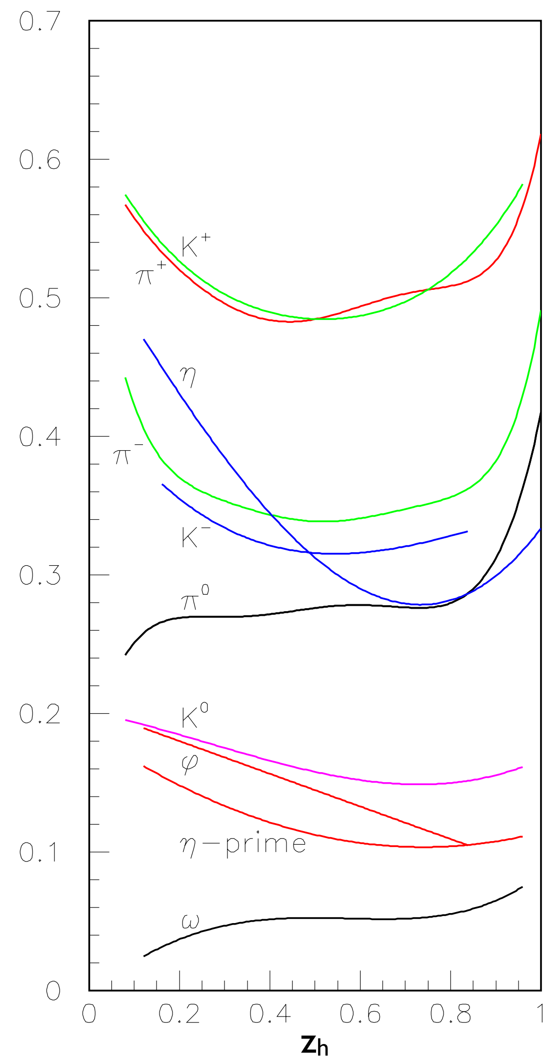
Quark Propagation and Hadron Formation

hadron	cτ	mass	flavor content	limiting error (60 PAC days)
π^0	25 nm	0.13	$u\bar{u}d\bar{d}$	5.7% (sys)
π^+, π^-	7.8 m	0.14	$u\bar{d}$, $d\bar{u}$	3.2% (sys)
η	170 pm	0.55	$u\bar{u}d\bar{d}s\bar{s}$	6.2% (sys)
ω	23 fm	0.78	$u\bar{u}d\bar{d}s\bar{s}$	6.7% (sys)
η'	0.98 pm	0.96	$u\bar{u}d\bar{d}s\bar{s}$	8.5% (sys)
ϕ	44 fm	1.0	$u\bar{u}d\bar{d}s\bar{s}$	5.0% (stat)*
f1	8 fm	1.3	$u\bar{u}d\bar{d}s\bar{s}$	-
K^0	27 mm	0.50	$d\bar{s}$	4.7% (sys)
K^+, K^-	3.7 m	0.49	$u\bar{s}$, $\bar{u}s$	4.4% (sys)
p	stable	0.94	ud	3.2% (sys)
$\bar{p}$	stable	0.94	$\overline{ud}$	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	us	6.6% (sys)
Σ^-	44 mm	1.2	ds	7.9% (sys)
Σ^0	22 pm	1.2	uds	6.9% (sys)
Ξ^0	87 mm	1.3	us	16% (stat)*
Ξ^-	49 mm	1.3	ds	7.8% (stat)*

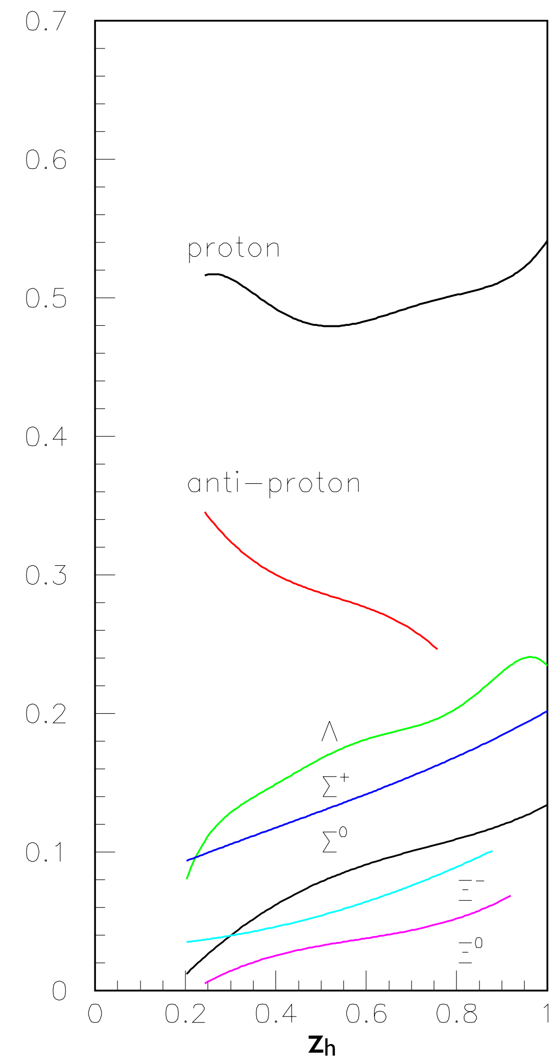
*in a bin in z from 0.7-0.8, integrated over all ν, p_T, ϕ_{pq}, and Q^2>5 GeV^2

**in a bin in z from 0.6-0.7, integrated over all ν, p_T, ϕ_{pq}, and Q^2>5 GeV^2

Dependency of observables (and thus derived quantities, such as production time, formation times, transport coefficient, in-medium cross section, etc.) on mass, flavor, and number of valence quarks



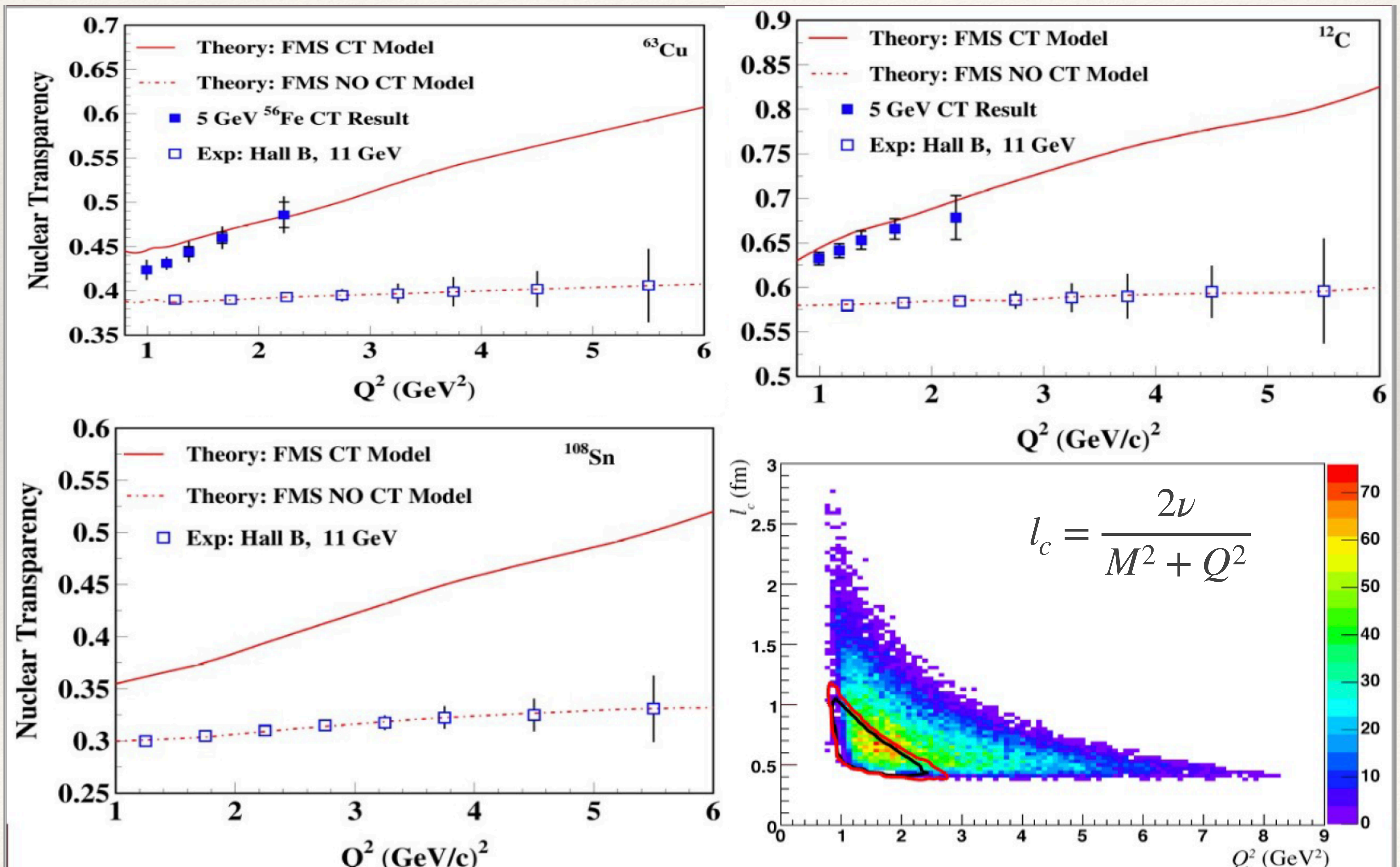
CLAS12 Acceptance for Mesons



CLAS12 Acceptance for Baryons

CLAS12 - Color Transparency

CT Study with ^{12}C, ^{63}Cu and ^{118}Sn: Experiment PR12-06-106



Summary

Color Transparency

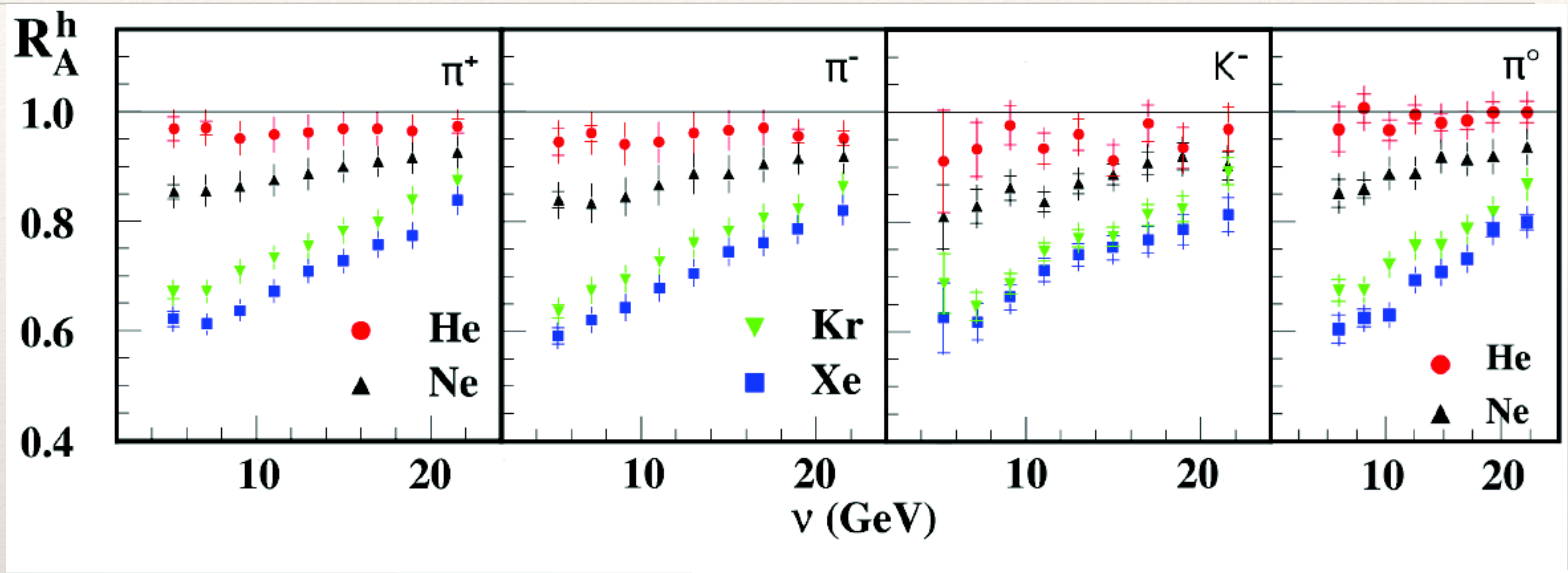
- Strong evidence for the onset of CT using ρ^0electroproduction off nuclei: CLAS-6 5 GeV dataset showed $11 \pm 2.3\%$ ($12.5 \pm 4.1\%$) decrease in the absorption of ρ^0 in iron (carbon).
- SSC expansion time with FMS model were found to be between 1.1 fm and 2.4 fm for ϱ0 momenta between 2 and 4.3 GeV.
- At intermediate energies, CT provides unique probe of the space-time evolution of special configurations of the hadron wave function.
- Future CLAS12 measurement will allow to disentangle different CT effects (SSC creation, its formation and interaction with the nuclear medium)

Color Propagation

- The hadronization study is a complementary probe of the QCD confinement in cold and hot nuclear matter.
- A detailed comprehension of its mechanism helps constraining the existing theoretical models.
- CLAS6 - Large (3D) data set for pions. First measurements on ω and Λ^0.
- The future CLAS12 experiment will provide the multi-dimensional data needed to extract the production and formation time-scales.

Backup Slides

CLAS6 CP Motivation

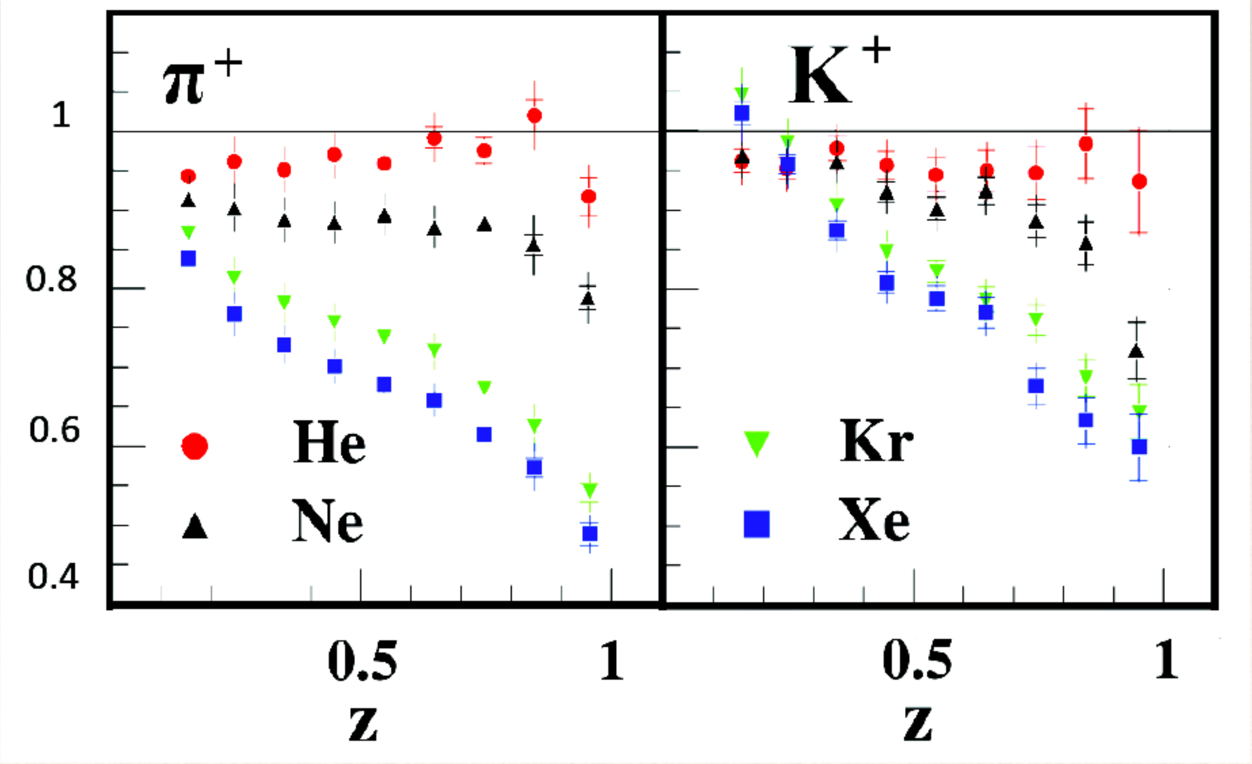


<u>Hermes results</u>

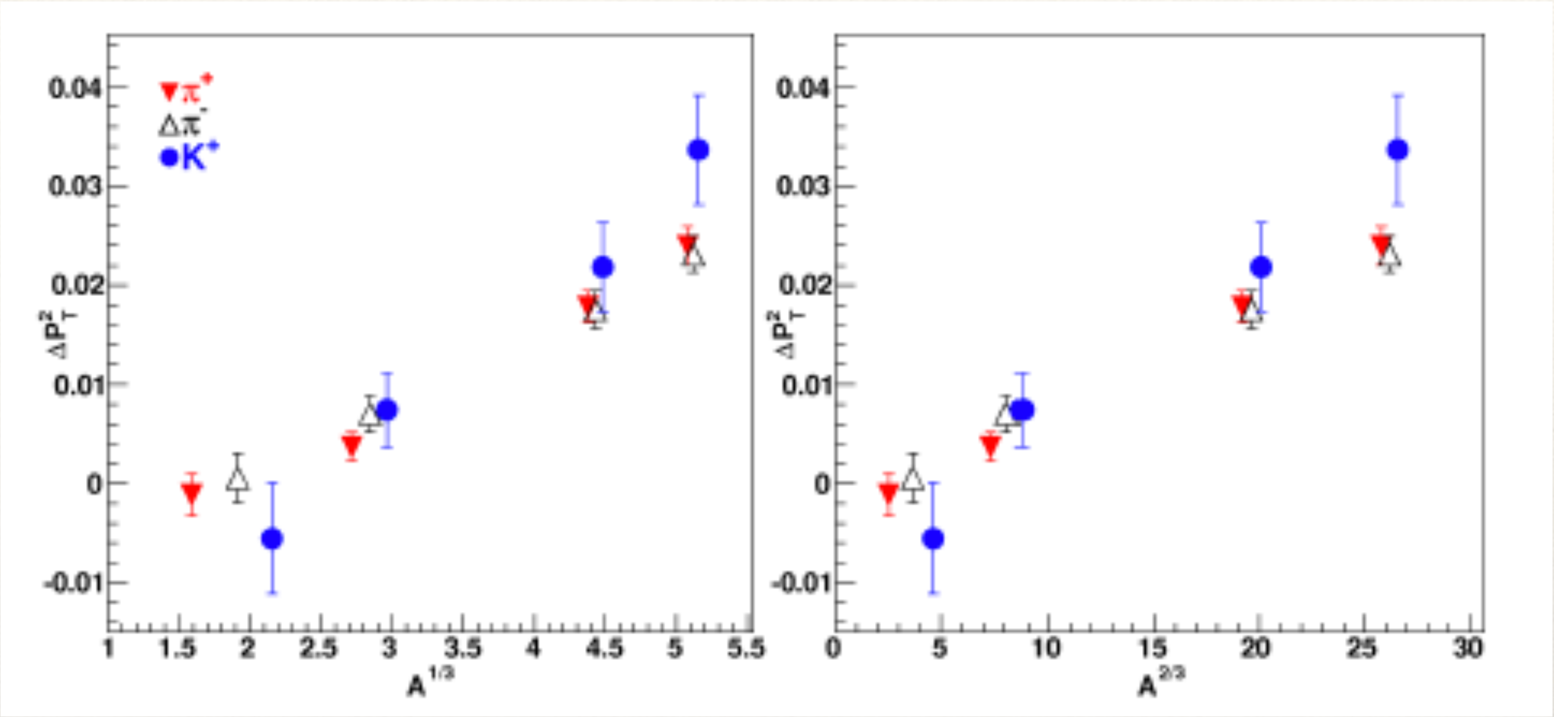
A. Airapetian, *et al.*, Nucl. Phys. B 780 (2007) 1.

E= 27 GeV; Positron beam

Pions and kaons give similar attenuation

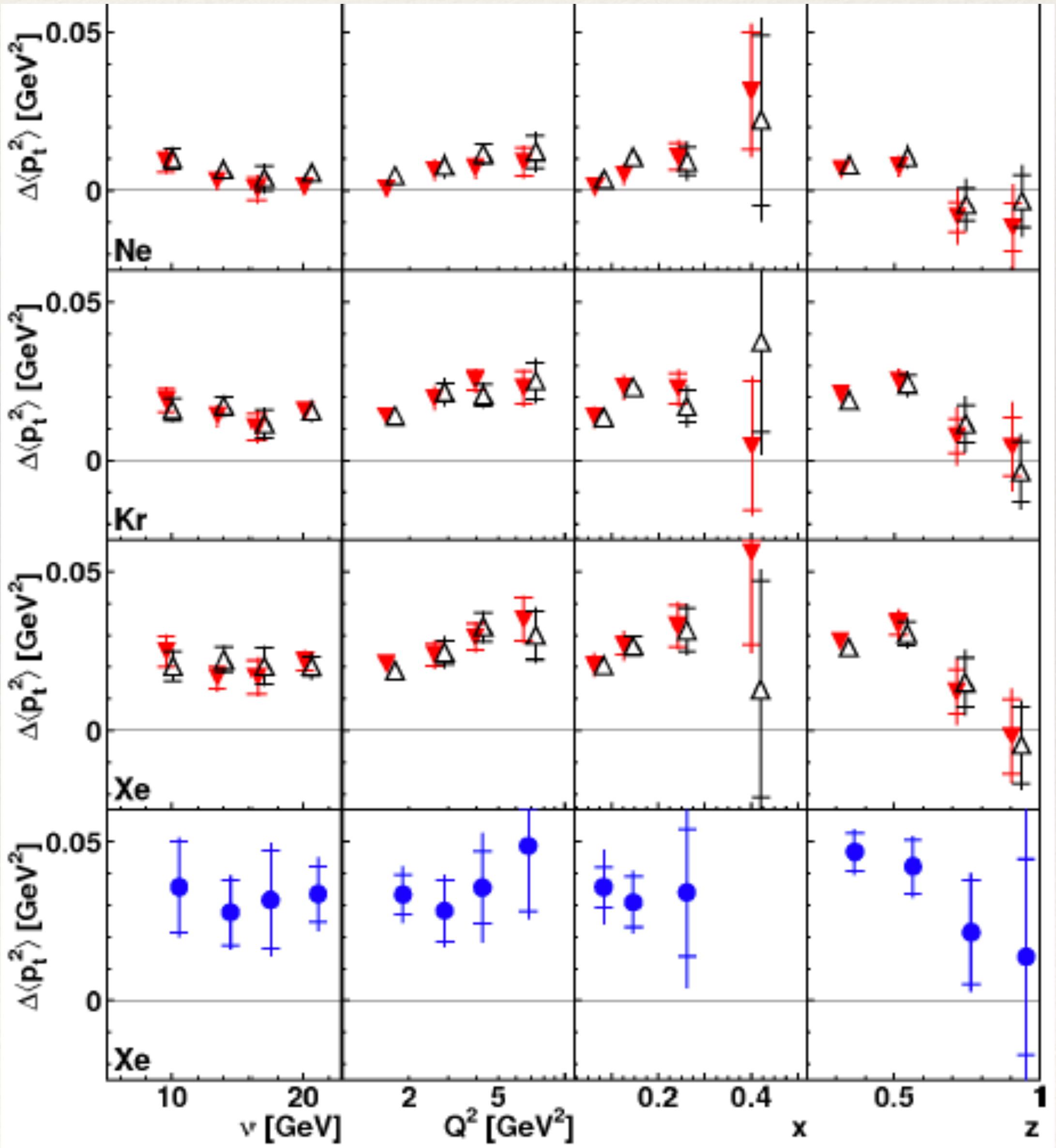


CLAS6 CP Motivation



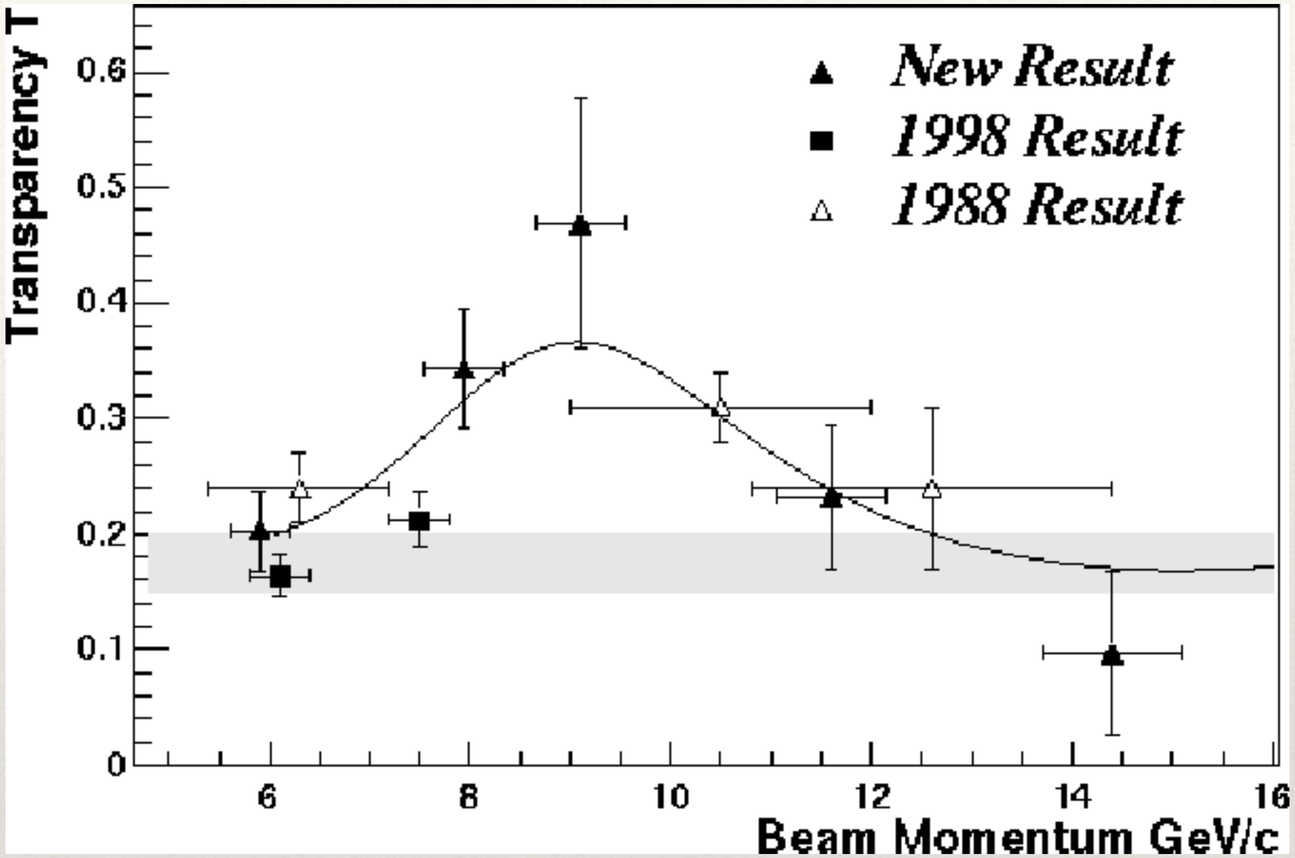
Hermes data on momentum broadening

E= 27 GeV; Positron beam

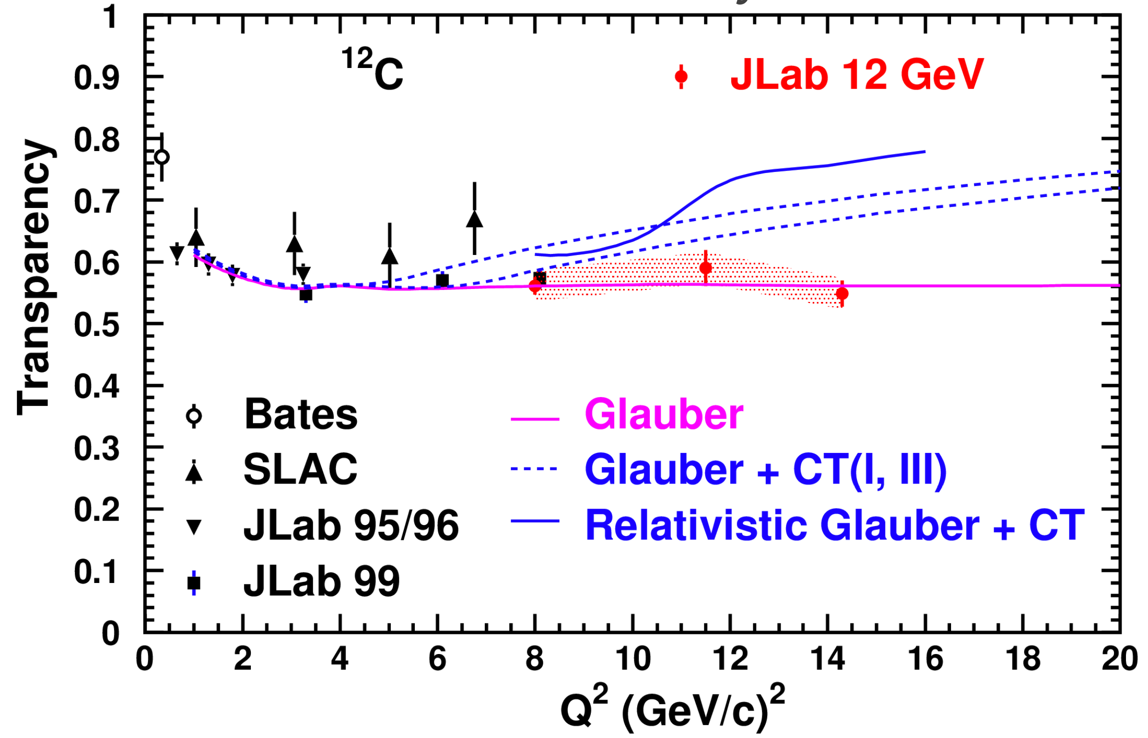


CT Study: BNL and Hall C 12 GeV

BNL Result



Preliminary



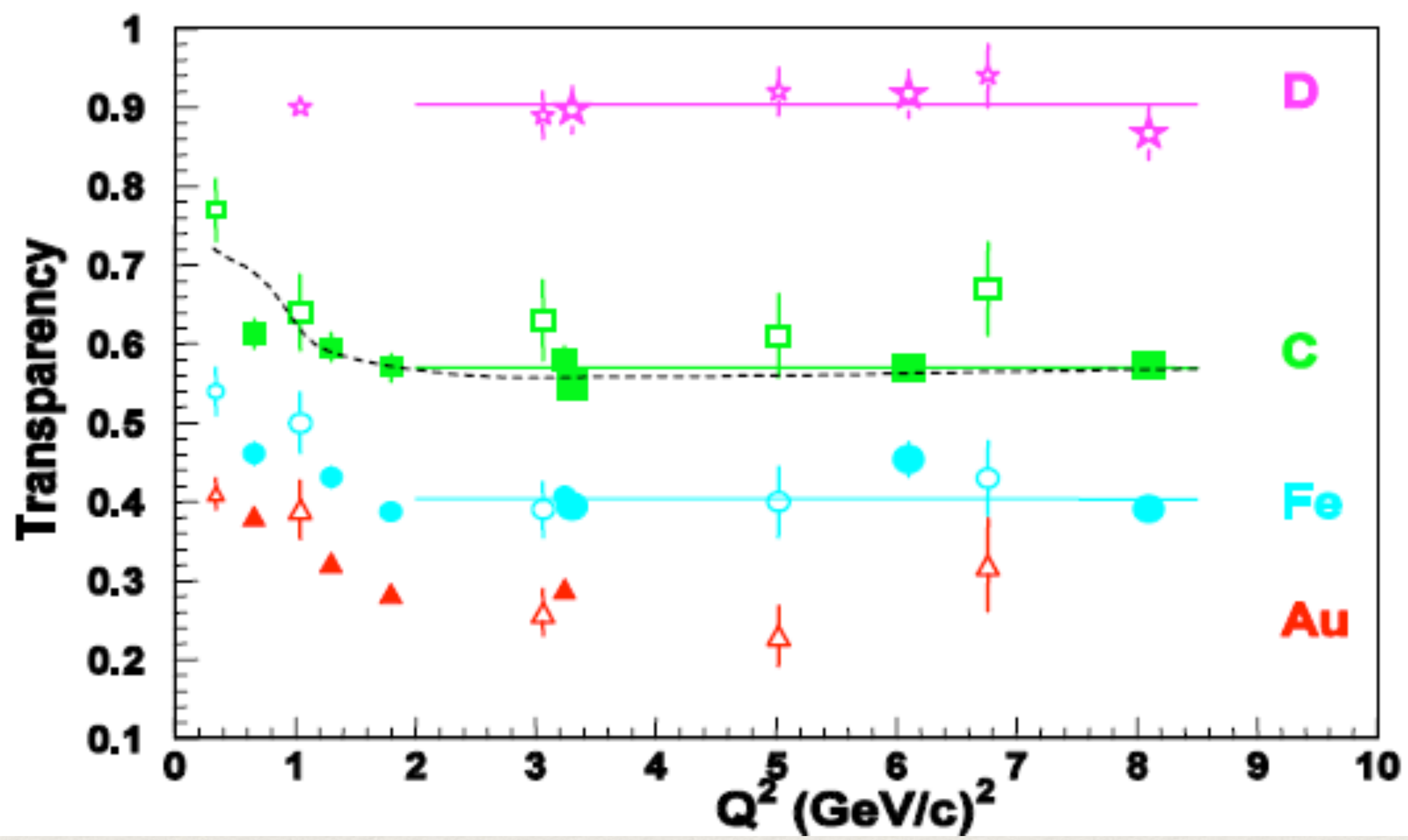
Preliminary 12 GeV
Hall C Result

CT Study with A(e,e’p)

Solid points - JLab Hall C
Open points - non-JLab

Constant value fit for $Q^2 > 2$ (GeV/c)^2 has $\chi^2/\text{ndf} \approx 1$.

No evidence for CT.



N. C. R. Makins et al. PRL 72, 1986 (1994)
G. Garino et al. PRC 45, 780 (1992)
D. Abbott et al. PRL 80, 5072 (1998)
K. Garrow et al. PRC 66, 044613 (2002)