VNiVERSiDAD D SALAMANCA

800 AÑOS

1218 ~ 2018

Pion multiplicities from CLAS at Jefferson Lab

Taisiya Mineeva

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EX UMBRA IN SOLEM

clas

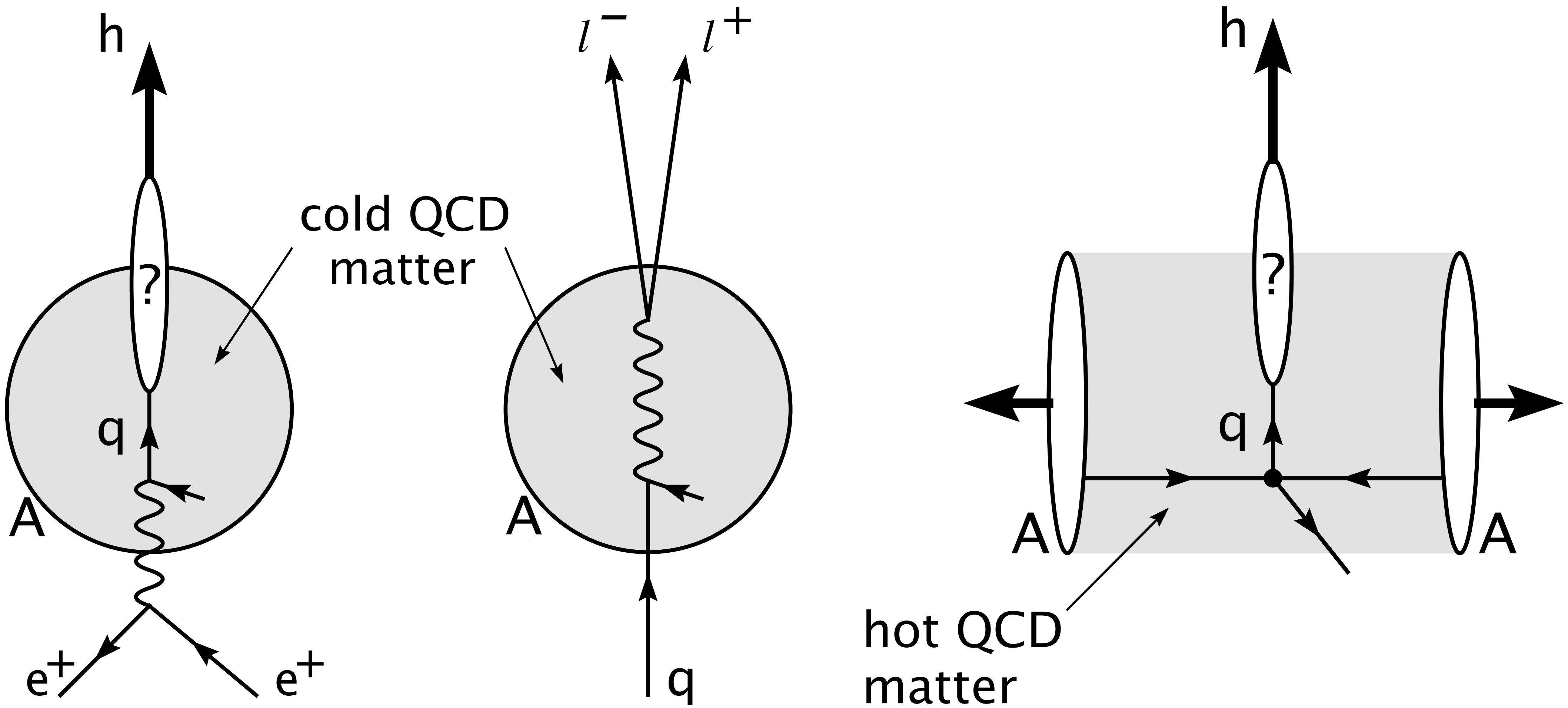
QCD and Hadronization

How all the color from initial parton is neutralized into colorless hadrons?
>> Dynamical enforcement of confinement <<

Goal: study dynamics of parton propagation in QCD
explore hadron formation mechanisms
characteristic timescales of these processes

How: embed the process in nuclei with known properties
and use the nuclei of varying size as a spatial ruler

Parton propagation in three processes



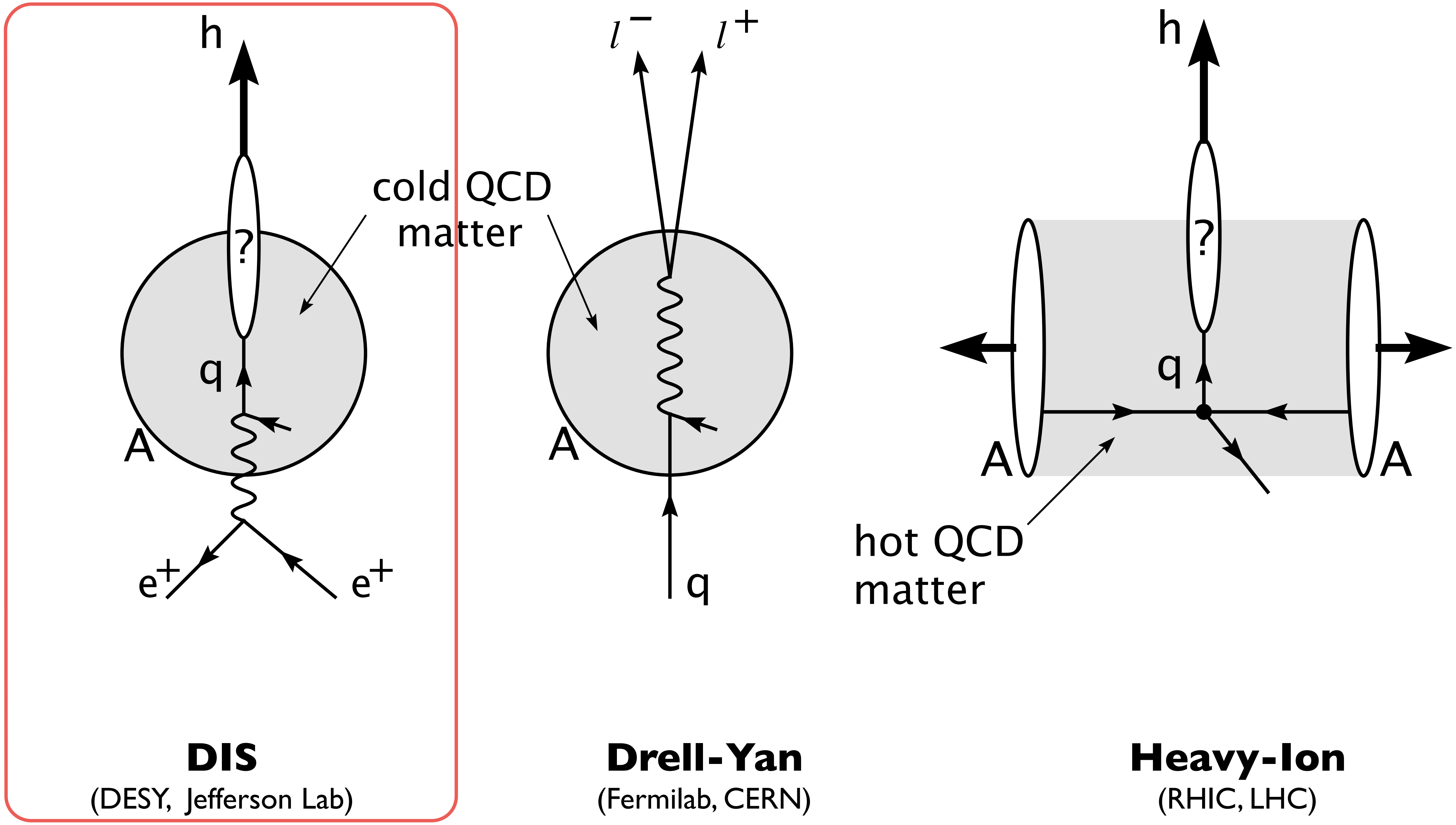
DIS
(DESY, Jefferson Lab)

Drell-Yan
(Fermilab, CERN)

Heavy-Ion
(RHIC, LHC)

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

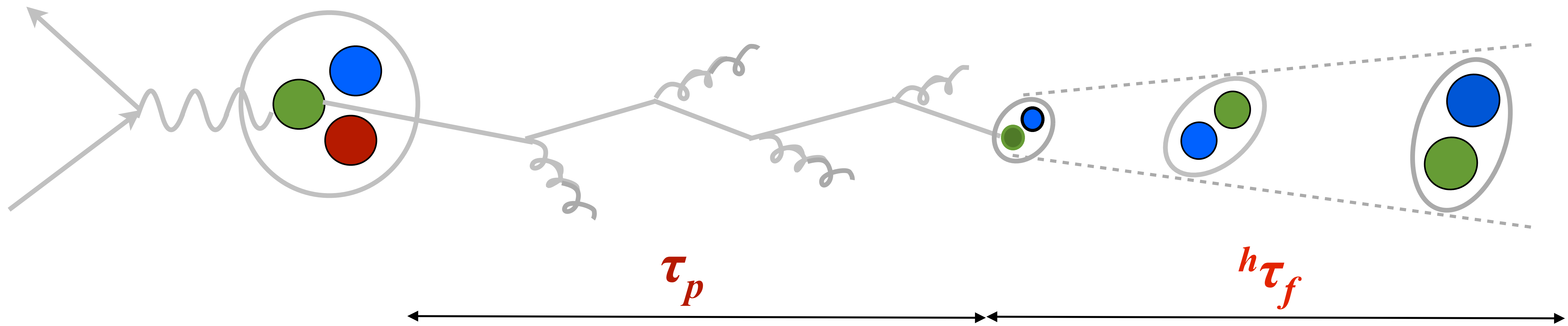
Parton propagation in three processes



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

Deep Inelastic Scattering: vacuum

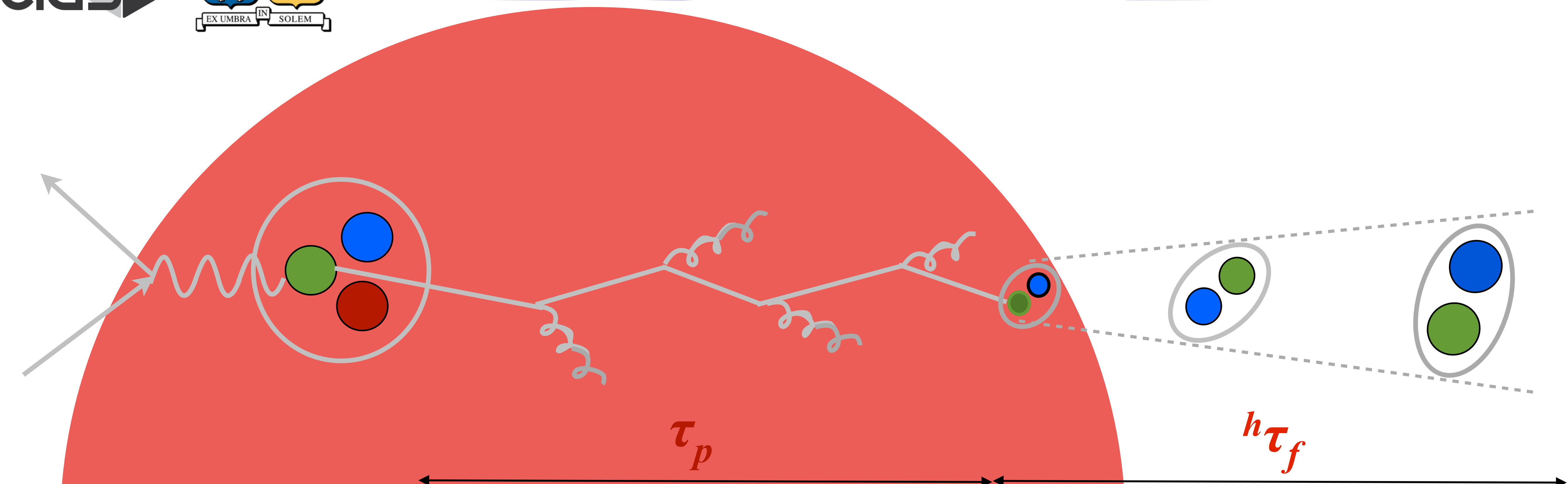
Hadronization is the process by which energetic q and g evolve into hadrons



- Quark propagation τ_p: in hard hadronic processes, energetic partons can be temporarily liberated from hadrons; distribution of the color charge over an extended volume.

- Hadron formation $^h\tau_f$: color charge is neutralized into color singlet hadrons.

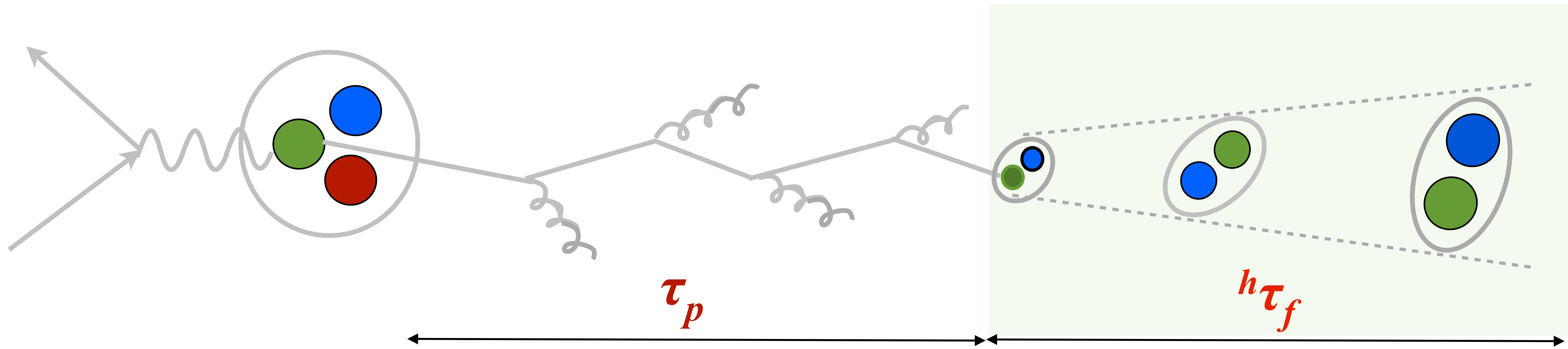
Deep Inelastic Scattering: medium



Nuclear medium acts as a ruler

- partonic multiple scattering
- medium-stimulated gluon emission
- quark energy loss
- additional prehadron interaction

Observable: hadronic multiplicity ratio



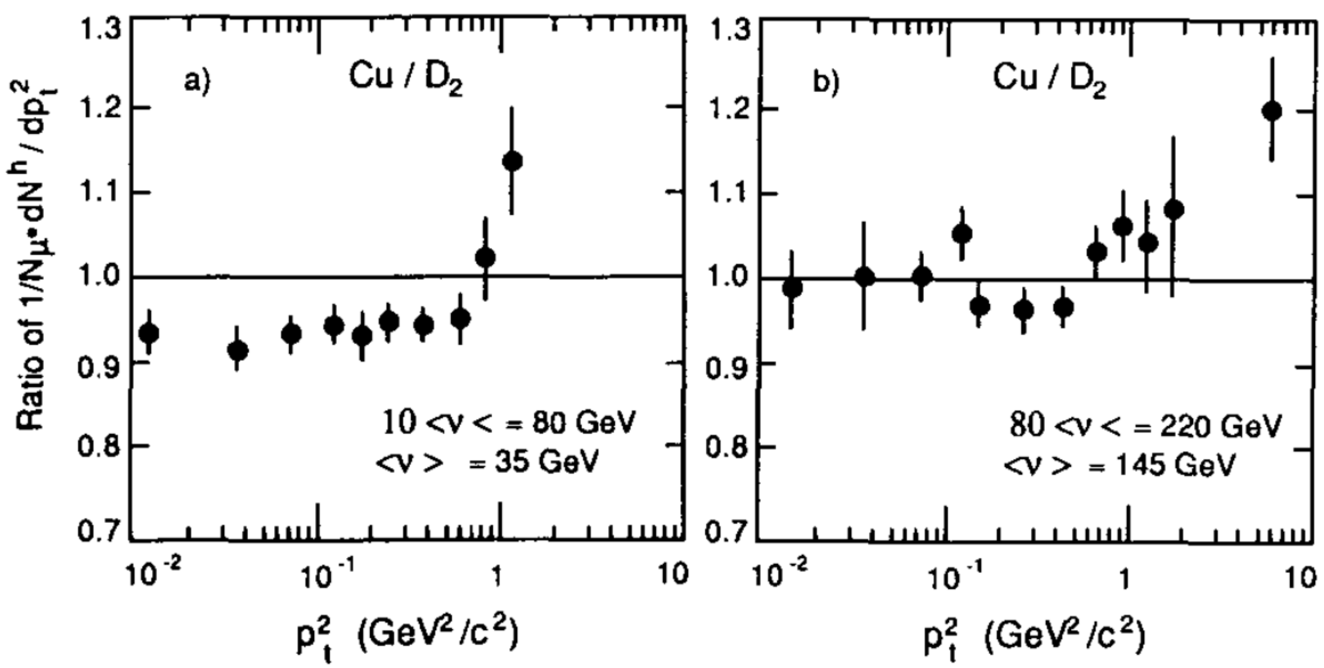
Connects to hadronic phase:

- how long it takes to form full hadron?
- space-time description of hadronization

$$R_A^h(\nu, Q^2, z, p_T) = \frac{\left.\frac{N_h(\nu,Q^2,z,p_T)}{N_e(\nu,Q^2)|_{DIS}}\right|_A}{\left.\frac{N_h(\nu,Q^2,z,p_T)}{N_e(\nu,Q^2)|_{DIS}}\right|_D}$$

Early results

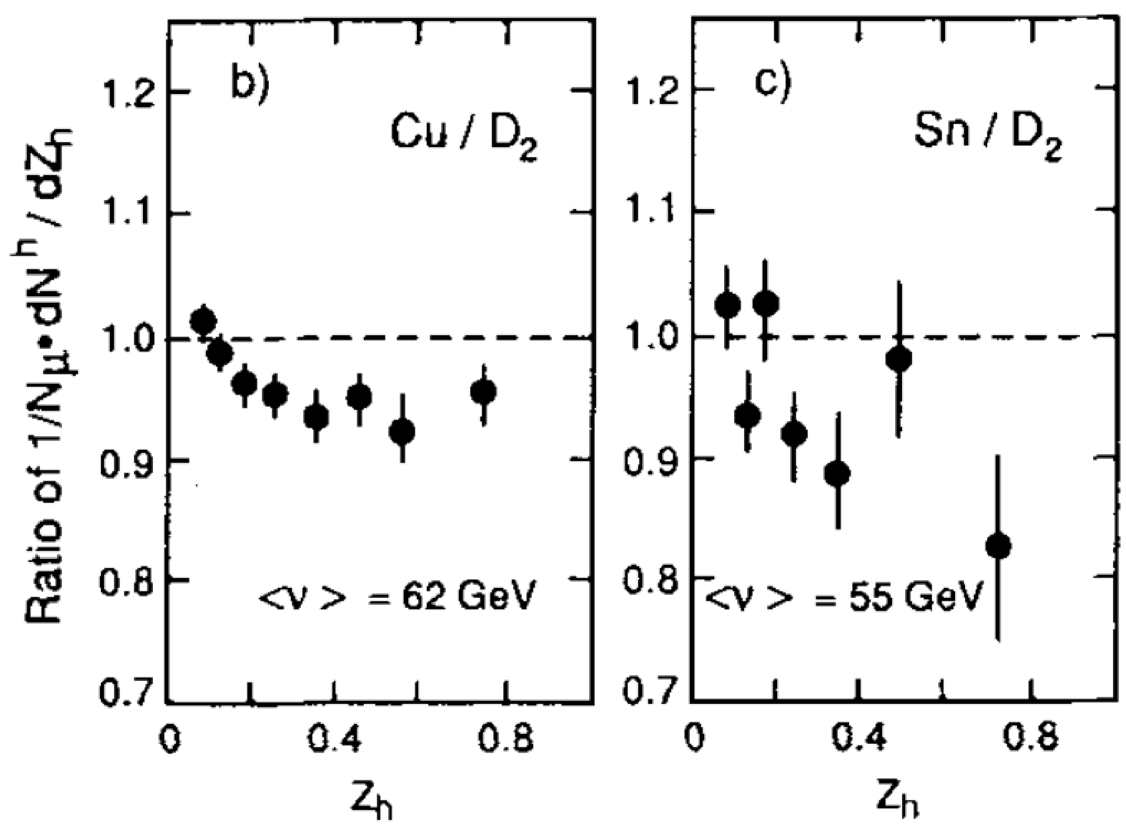
Quarks in nuclei: EMC data



J. Ashman *et al*. *Comparison of forward hadrons produced in muon interactions on nuclear targets and deuterium*. Z.Phys., vol. C52 (1991)

Hadronization data from the EMC

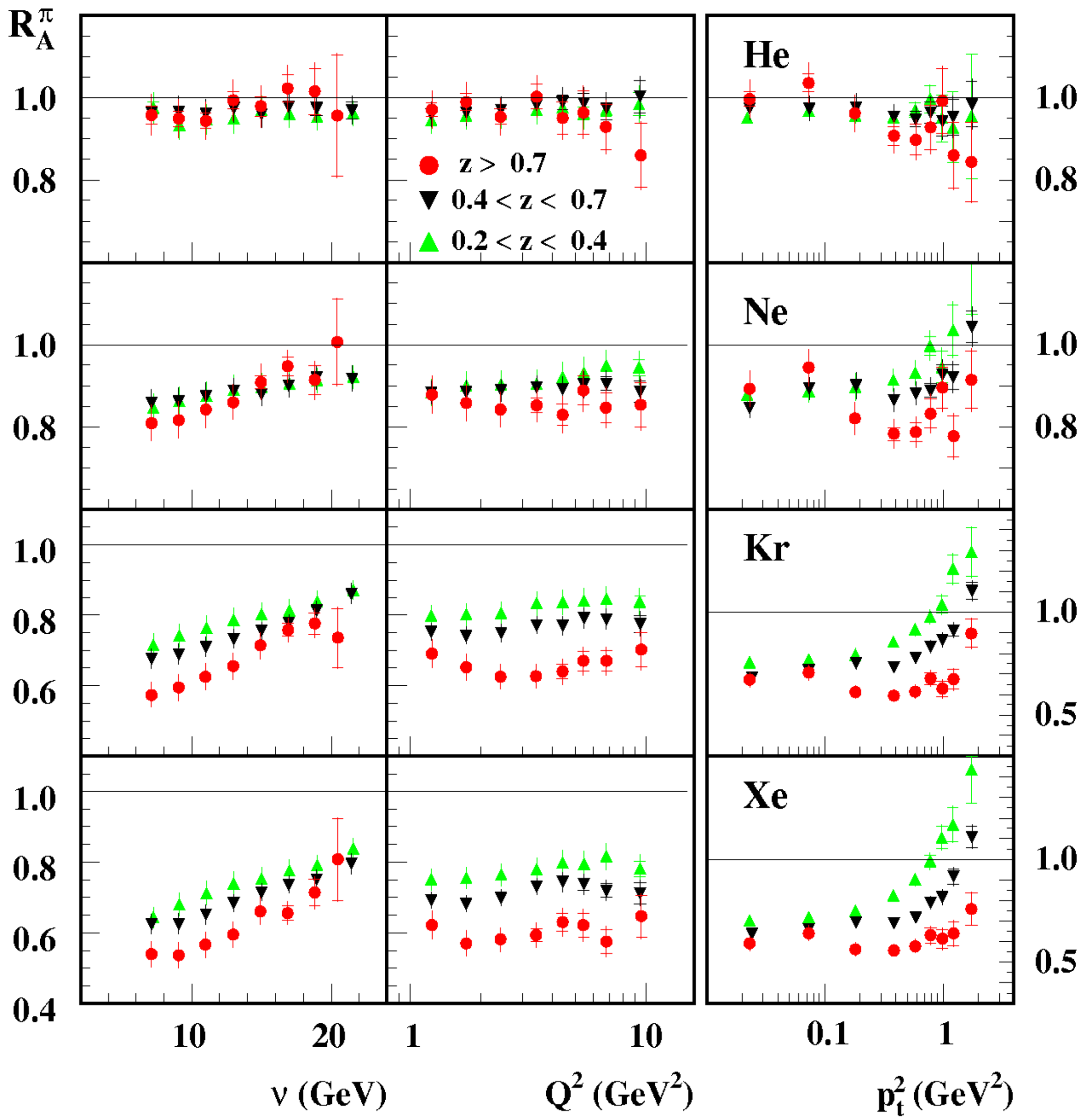
Muon beam: 100 to 280 GeV
Targets: D, C, Cu, Sn



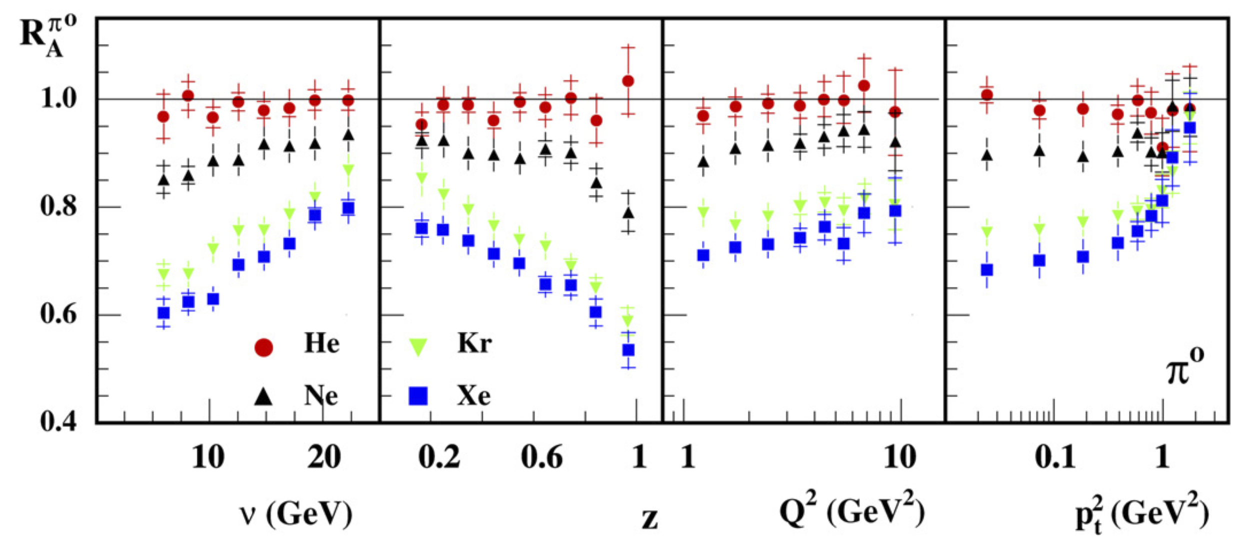
- Increase of multiplicity ratio at high p_T^2
- Attenuation at high z

Quarks in nuclei: HERMES data

Multiplicity ratios for charged pions in varios z bins



Multiplicity ratios for neutral pions in ν, z, $Q2$, p_T^2 bins



Electron beam: 27 GeV
Targets: He, Ne, Kr, Xe

- $\pi^{\pm}$, π^0, $K^{\pm}$, p, $\bar{p}$ multiplicities
- 2D multiplicities for $\pi^{\pm}$
- 1D multiplicities for π^0

A.Airapetian *et al*. *Hadronization in semi-inclusive deep inelastic scattering on nuclei*. Nucl.Phys., vol. B780 (2007)

Quantitative agreement with EMC results

Glimpse on available models

Based on HERMES data, models can not discriminate two proposed mechanisms: partonic energy losses vs prehadron absorption.

Authors	References	Model Description	Multiplicity Results	$p_\perp^2$ Broadening Results
Accardi *et al.*	[Accardi 2003]	Q^2 rescaling of FF + hadron absorption	Few comparisons with HERMES & EMC	None
Arleo	[Arleo 2003b]	BDMPS based parton energy loss (quenching weight calculation)	Scarce comparison with HERMES	$\hat{q} = 0.75$ GeV/fm^2 too large for HERMES
Deng *et al.*	[Deng 2010] [Deng 2011]	Modified DGLAP evolution	Few comparisons with HERMES	$\hat{q} = 0.015$ GeV^2/fm coherent with HERMES
Falter *et al.* (GiBUU)	[Falter 2004] [Gallmeister 2005] [Gallmeister 2008]	Pure hadron/prehadron absorption	Extensive comparison with HERMES & EMC	None
Gyulassy and Plümer	[Gyulassy 1990]	Medium modified FF using string-flip model	Comparison with old data (EMC & SLAC)	None
Kopeliovich *et al.*	[Kopeliovich 2004] [Domdey 2009] [Ciofi degli Atti 2005]	Q^2 rescaling of FF, energy loss and prehadron absorption	Extensive comparison with HERMES & EMC	Extensive comparison with HERMES
Salgado and Wiedemann	[Salgado 2002] [Salgado 2003]	BDMPS based parton energy loss (quenching weight calculation)	Few comparisons with HERMES	Extensive comparison with HERMES
Wang and Wang	[Wang 2002]	Pure parton energy loss	Few comparisons with HERMES	None

Glimpse on available models

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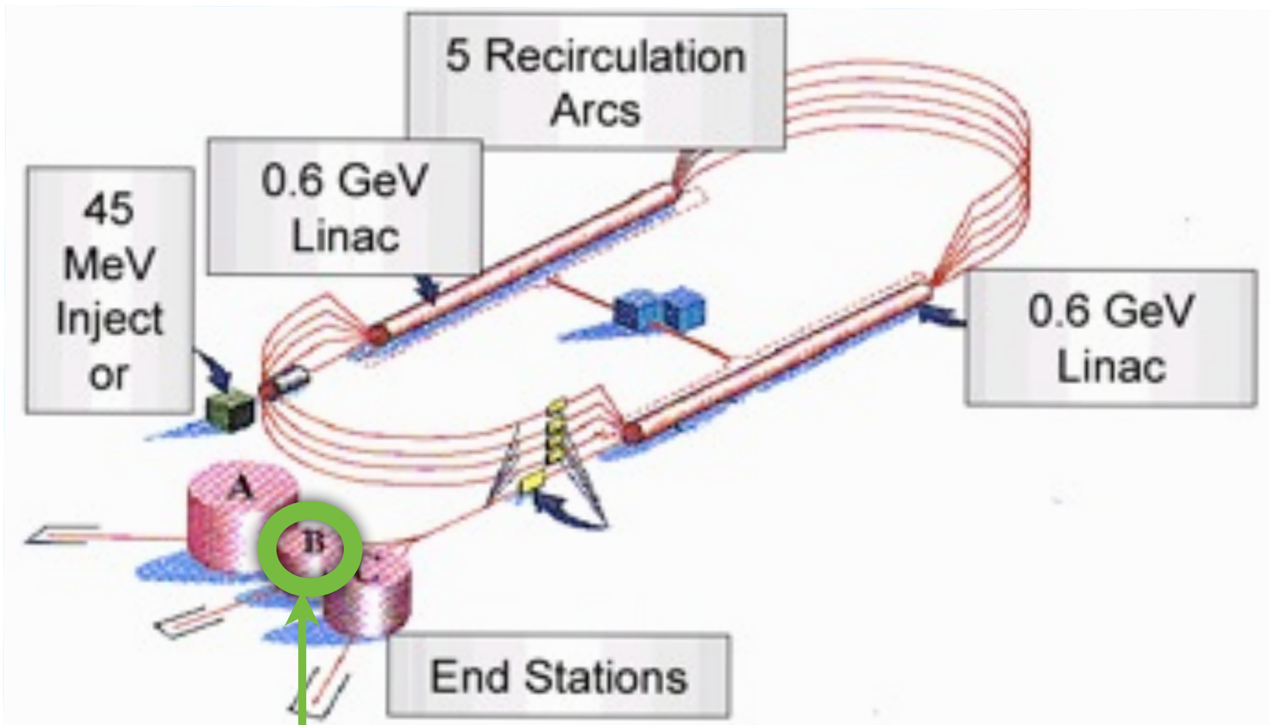
Need higher precision data!

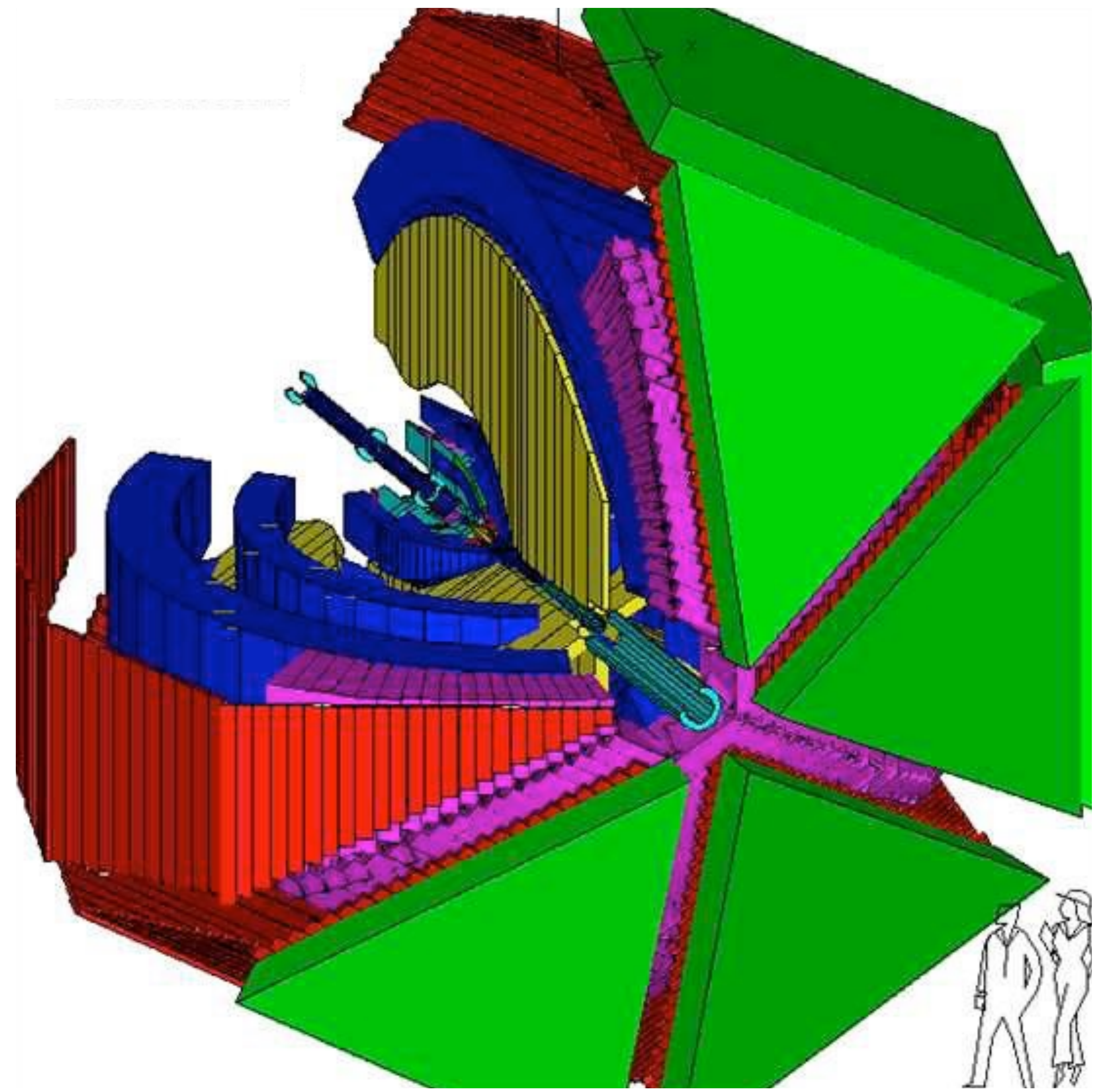
Experiment

CEBAF and CLAS @ 6 GEV

Jefferson Lab



Hall B CLAS



N. A. Mecking *et al.*, *The CEBAF large acceptance spectrometer (CLAS)*, Nucl. Inst. and Meth. A 503, 513 (2003).

CLAS **EG2** experimental conditions:

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

State of the art radiative corrections for the processes on *nuclear targets*

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

State of the art radiative corrections for the processes on *nuclear targets*

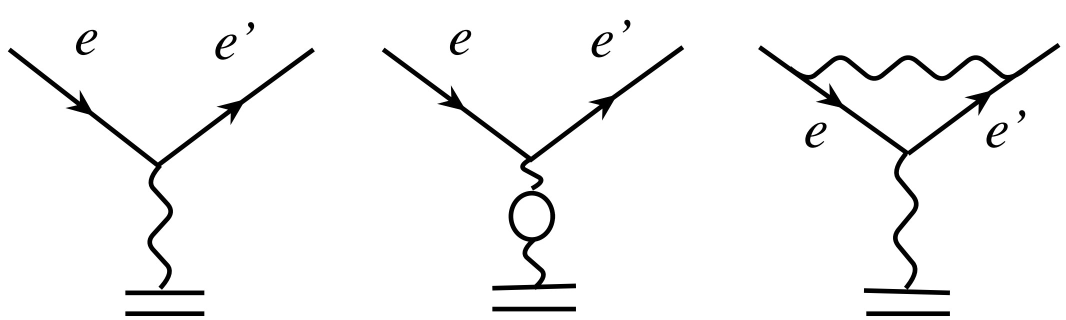
$$R_{\mathrm{A}}^{h}\left(\nu, Q^{2}, z, p_{T}\right)=\frac{\left.\frac{N_h(\nu,Q^2,z,p_T)}{N_e(\nu,Q^2)|_{\mathrm{DIS}}}\right|_{\mathrm{A}}}{\left.\frac{N_h(\nu,Q^2,z,p_T)}{N_e(\nu,Q^2)|_{\mathrm{DIS}}}\right|_{\mathrm{D}}}$$

Inclusive e⁻ radiative corrections (eA→e′X)

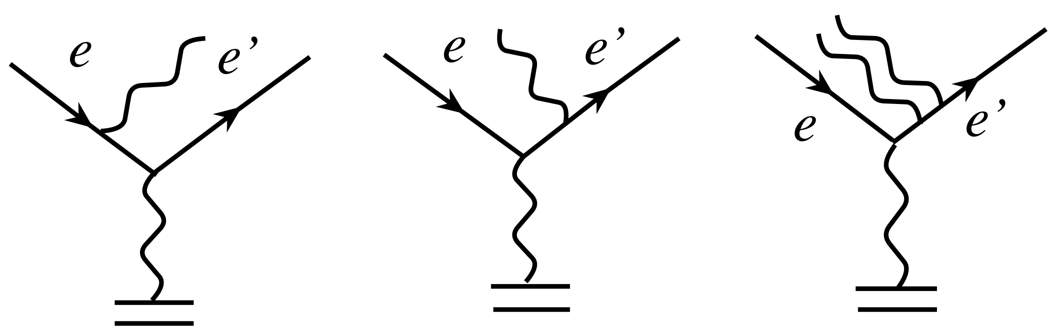
Formalism: Mo&Tsai (SLAC Pub-0848, 1971)

Code EXTERNALS provided by D.Gaskell

First order QED RC to Born c.s.

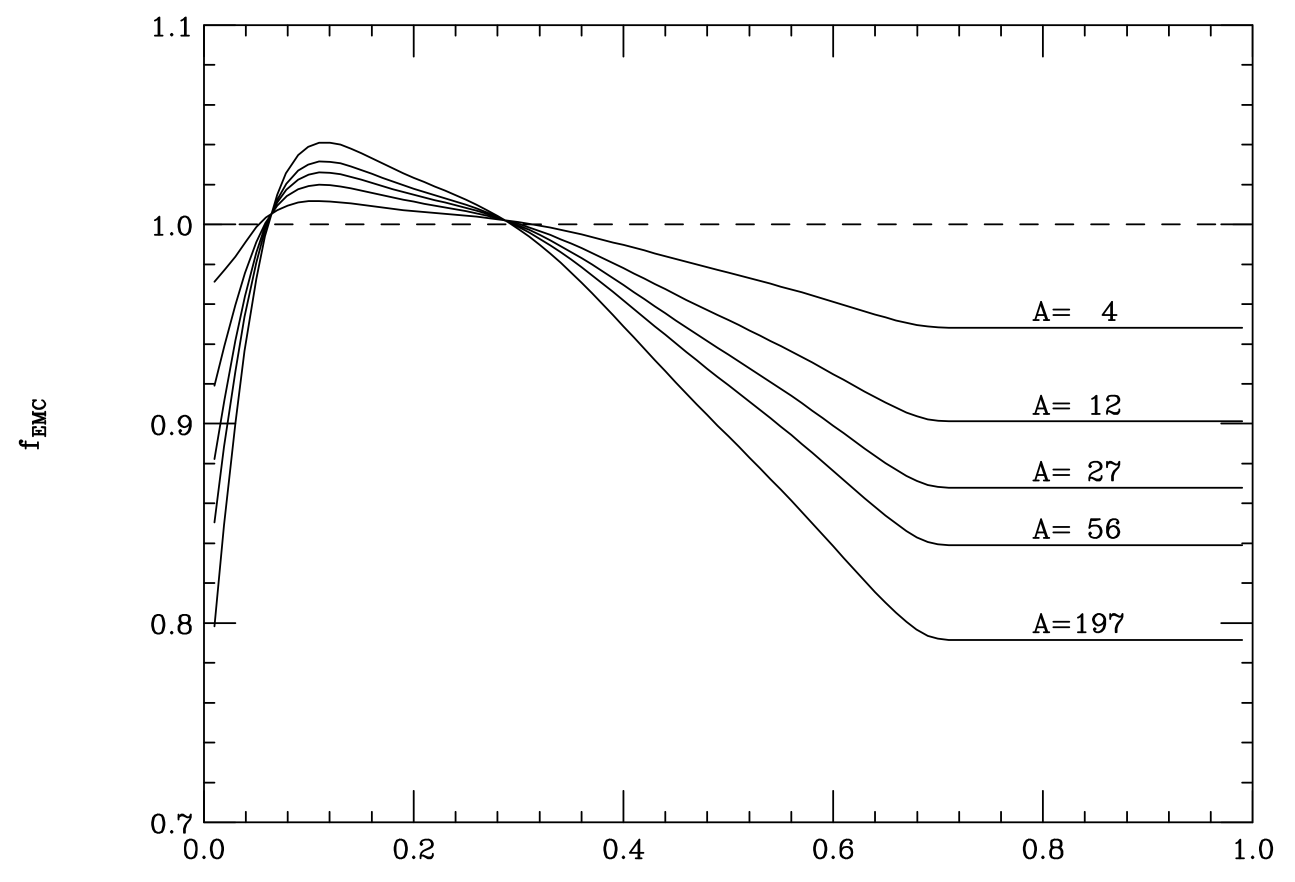


a) Born *b) Vacuum Polarization* *c) Vertex Correction*



d) Bremsstrahlung *e) Multi−Photon Emission*

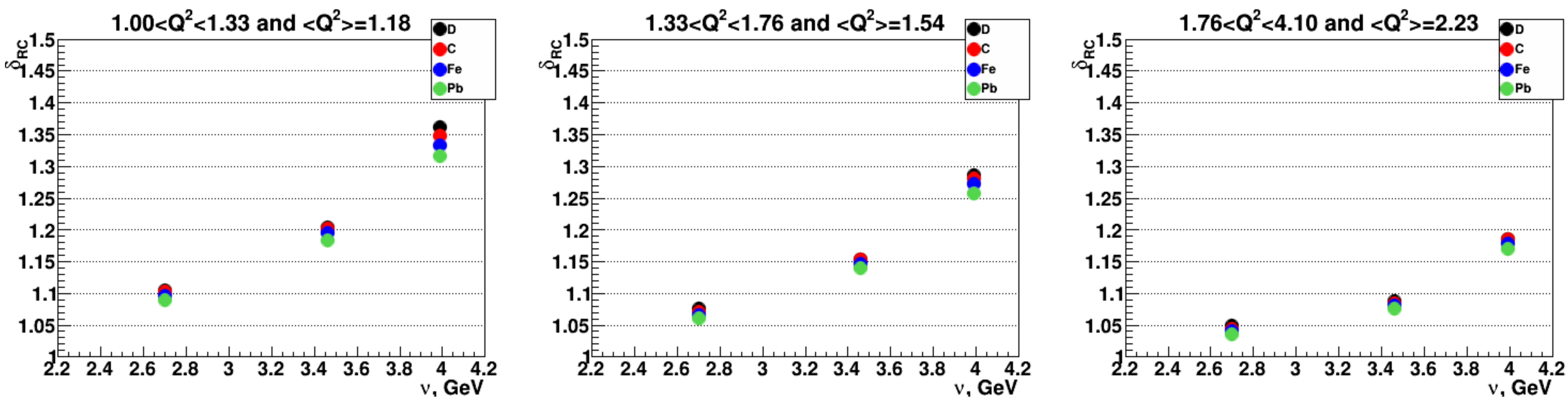
A-dependence of structure functions is based on parametrization of world data



P.Bosted, V.Mamyan "Empirical fit to electron-nucleus scattering" arXiv:1203.2262v2

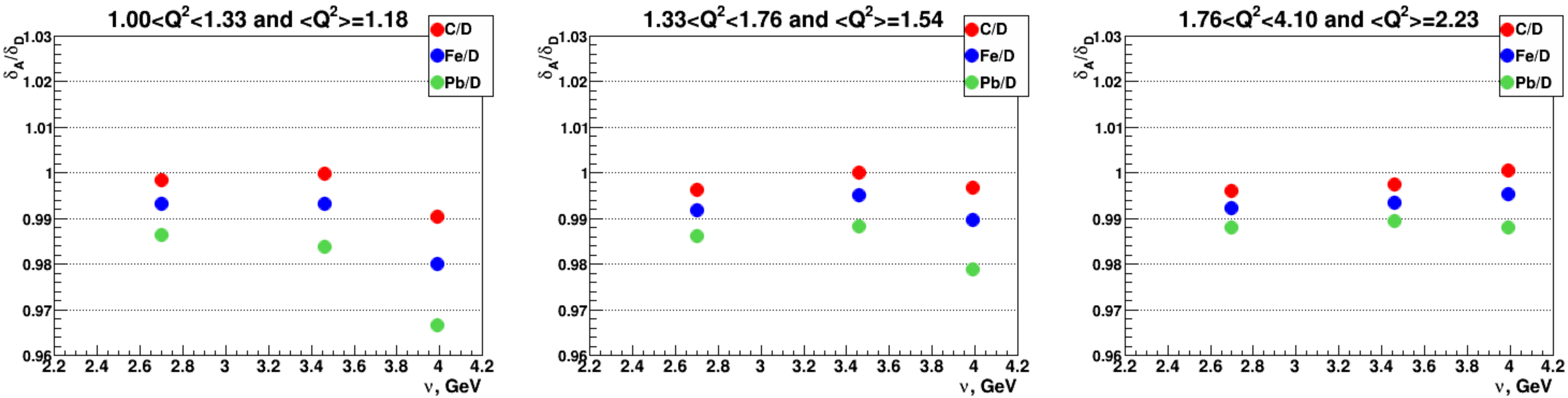
Inclusive e⁻ radiative corrections (eA→e′X)

Radiative factor $\delta_{RC} = \sigma_{Rad} / \sigma_{Born}$



Inclusive e$^-$ radiative corrections (eA→e′X)

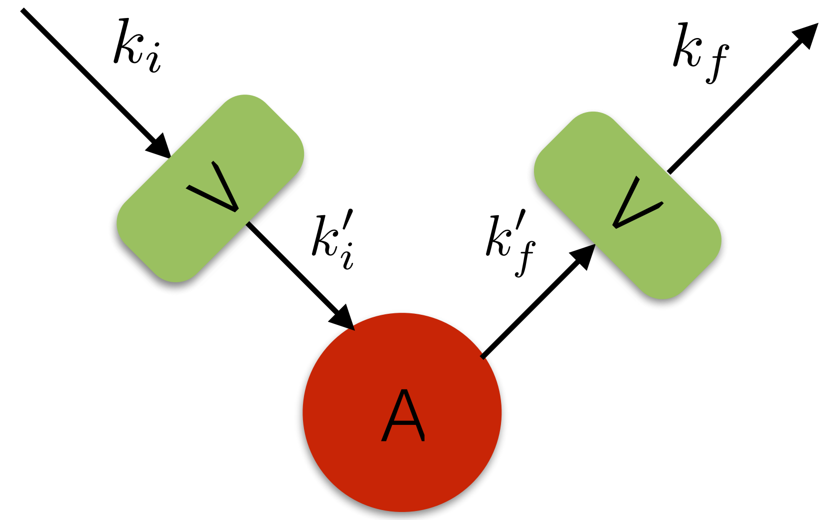
Ratio of RC factors $\boldsymbol{\delta}_{RC}$ on A to D: up to 3.5% correction



Coulomb corrections (eA→e'X)

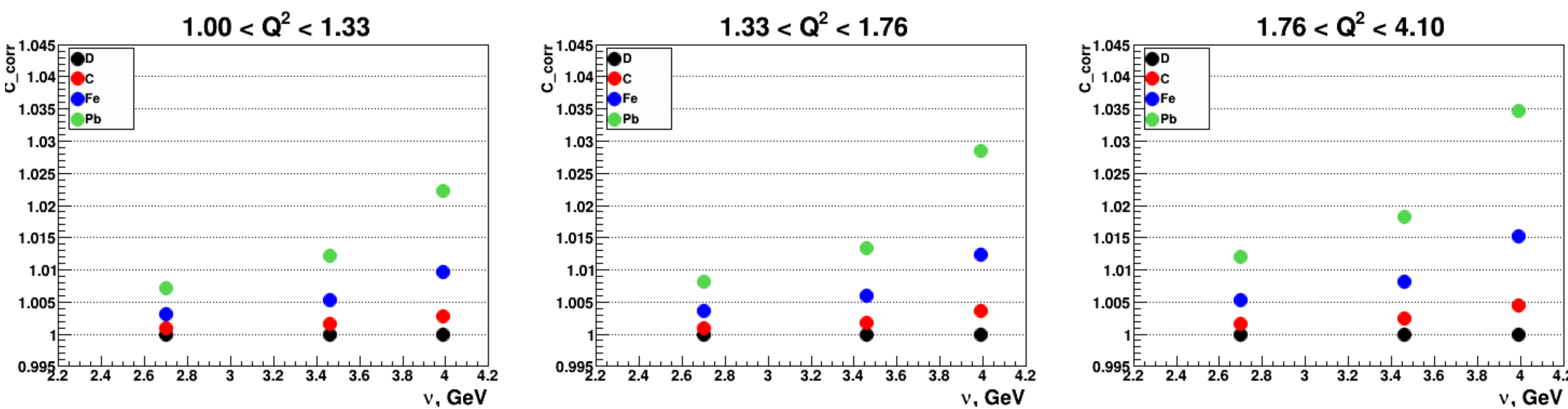
Formalism: Effective Momentum Approximation (Aste *et al*)

Code EXTERNALS provided by D.Gaskell



C_corr ~ σ_{Born_QE} / $\sigma_{Coulomb}$

C_corr is up to 3.5%



State of the art radiative corrections for the processes on *nuclear targets*

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

RC to SIDIS process (eA→e′π⁰X)

Formalism: convolution of leptonic and hadronic tensors (I.Akushevich et al)

Code: modified version of original HAPRAD (HAPRAD_cpp)

$$\sigma_{SIDIS} = \sigma_{SIDIS}(\mathcal{H}_1, \mathcal{H}_2, \mathcal{H}_3, \mathcal{H}_4)$$

$$\mathcal{H}_1 = \sum_q e^2 f_q D_q \mathcal{G}$$

$$\mathcal{H}_2 \approx \mathcal{H}_1$$

$$\mathcal{H}_3 = f(x, Q^2, z)|_{cos(\phi)} \sum_q e^2 f_q D_q \mathcal{G}$$

$$\mathcal{H}_4 = f(x, Q^2, z)|_{cos(2\phi)} \sum_q e^2 f_q D_q \mathcal{G}$$

$$\mathcal{G} = \frac{1}{2\pi\sigma} \cdot \exp - \frac{(p_T - \mu)^2}{2\sigma^2}$$

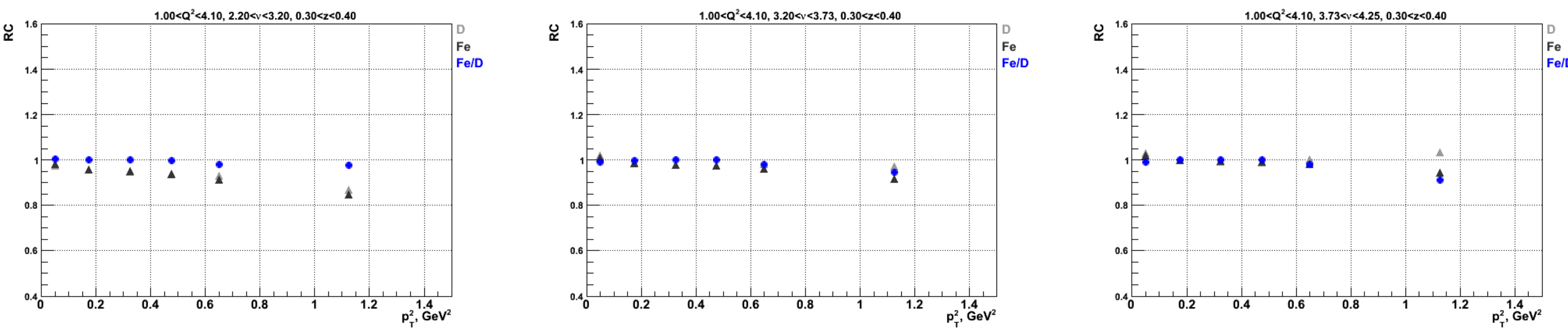
A-dependence is accounted in structure functions based on the fits to our data

φ- dependence of σ_{SIDIS}

G is hadron **transverse momentum** distribution

RC to SIDIS process (eA→e′πX)

Radiative factor $\delta_{RC} = \sigma_{Rad} / \sigma_{Born}$ and its ratioFe/D: up to <u>10%</u> correction



A slice in the kinematics on the example of π^0

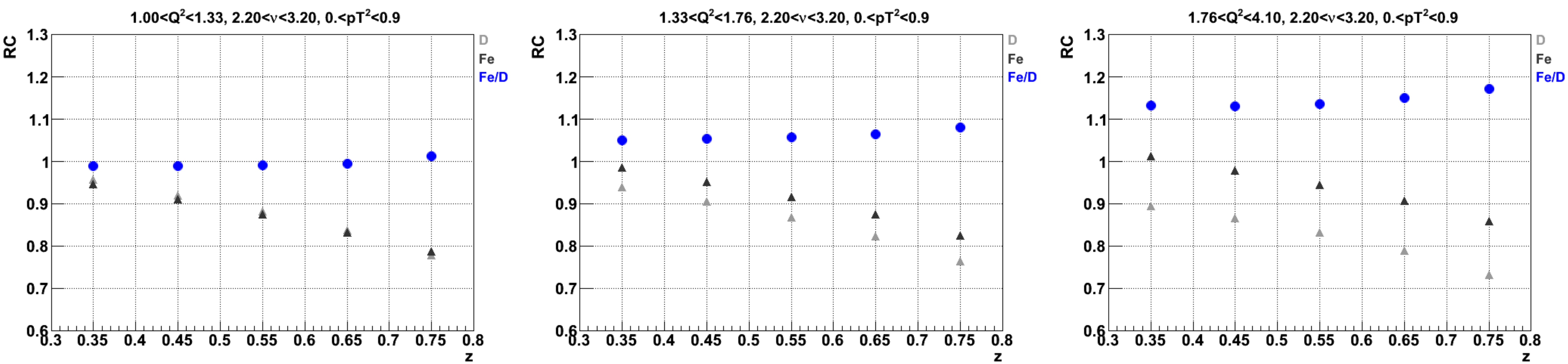
RC to exclusive process (eA→e′πA)

Formalism: convolution of leptonic and hadronic tensors (I.Akushevich et al)

Code: HAPRAD_cpp with MAID parametrization for **π±** and CLAS data for ***π⁰***

Total RC factor $\delta_{RC} = \delta_{INCL} + \delta_{EXCL}$ on the example of π^0

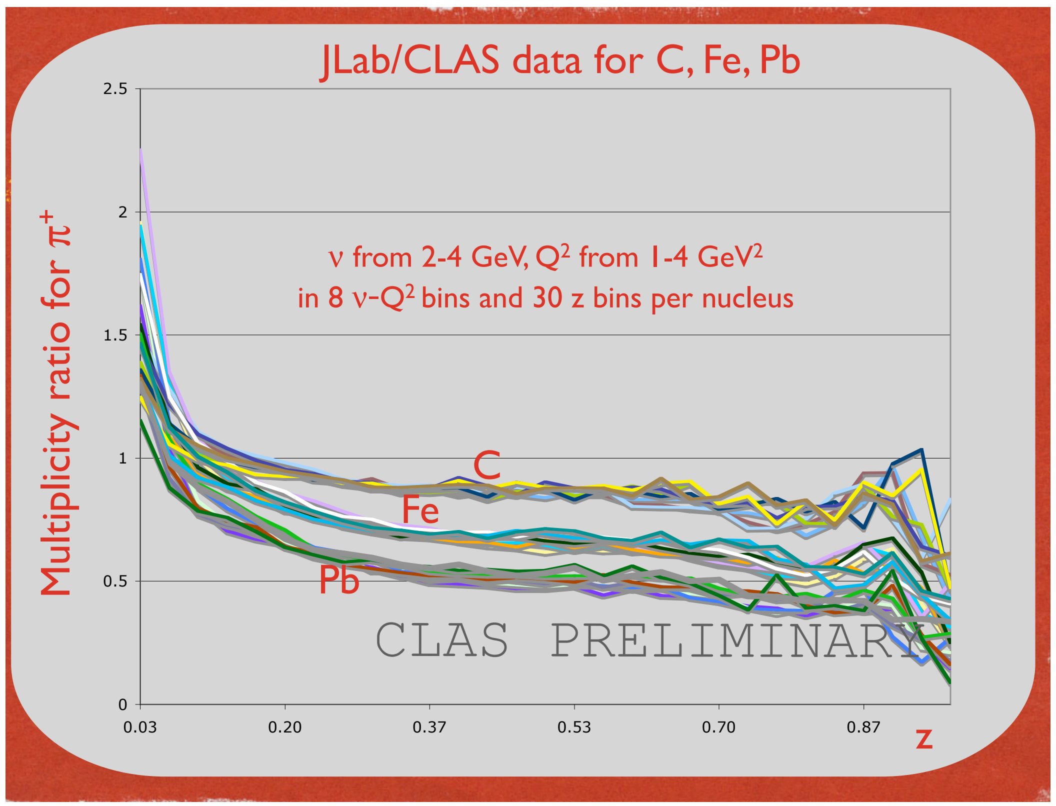
In ratioFe/D correction is up to <u>18%</u>



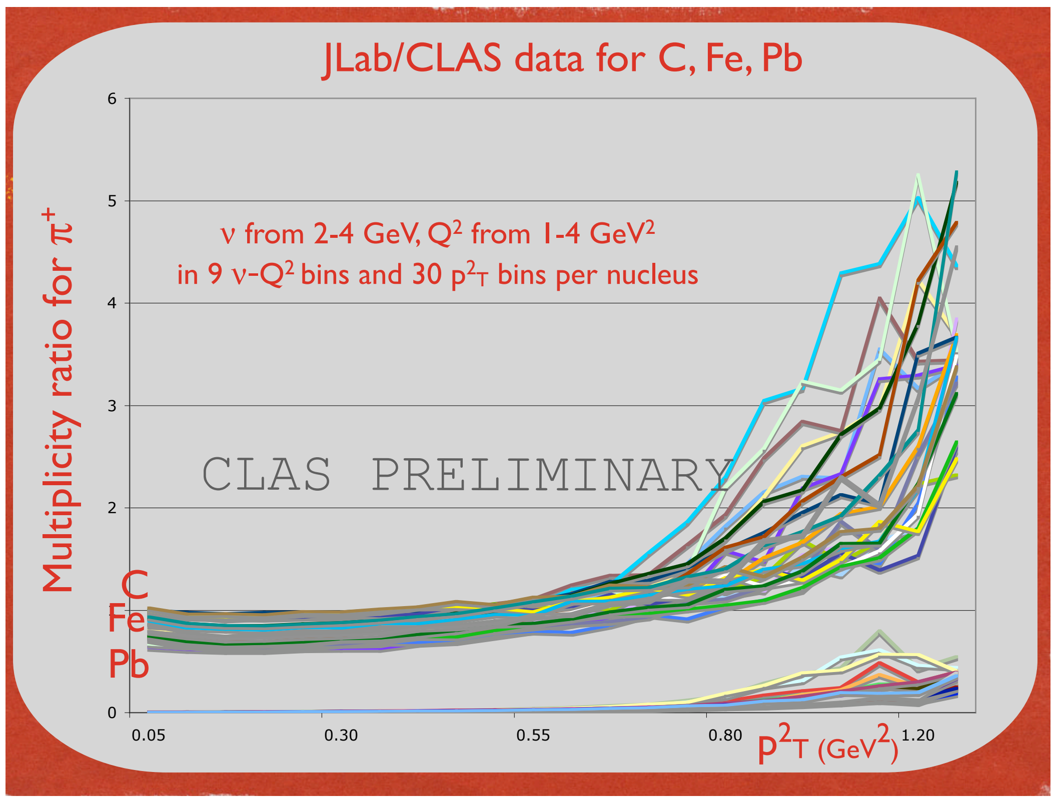
Results

3D π^+ Multiplicities on $^{12}C, ^{56}Fe, ^{207}Pb$ to D

$R_{\pi+}$ in (Q^2, ν, z) integrated over p_T^2



$R_{\pi+}$ in (Q^2, ν, p_T^2) integrated over z

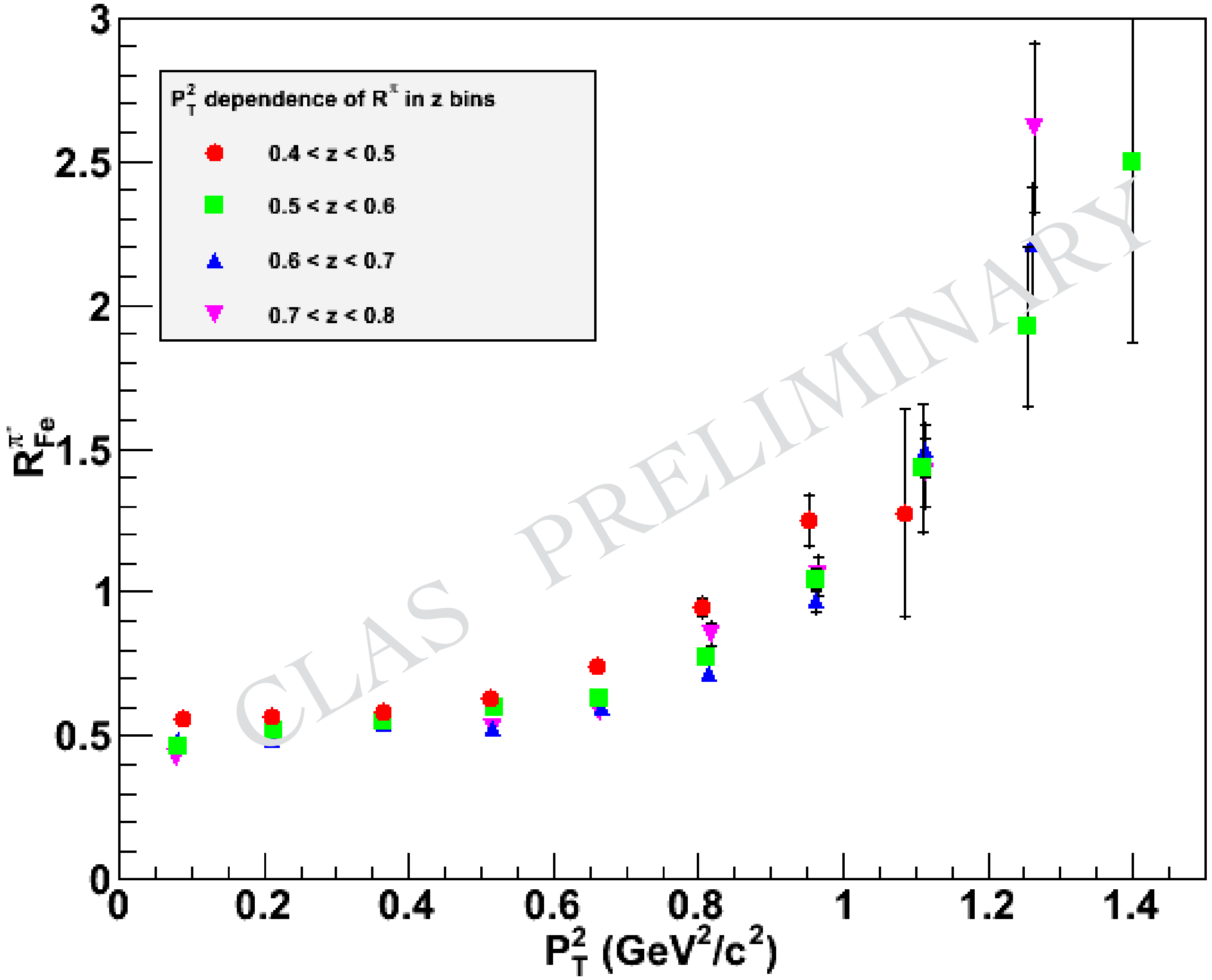


Hayk Hakobyan

- Attenuation depends on nuclear size
- Increase of hadrons at low z, attenuation at high z
- Bears resemblance to Cronin effect at high p_T^2
- Quantitative behavior compatible with Hermes

2D π^- Multiplicities on ^{12}C, ^{56}Fe, ^{207}Pb to D

R_{π^-} in (z, p_T^2) integrated over ν, Q^2



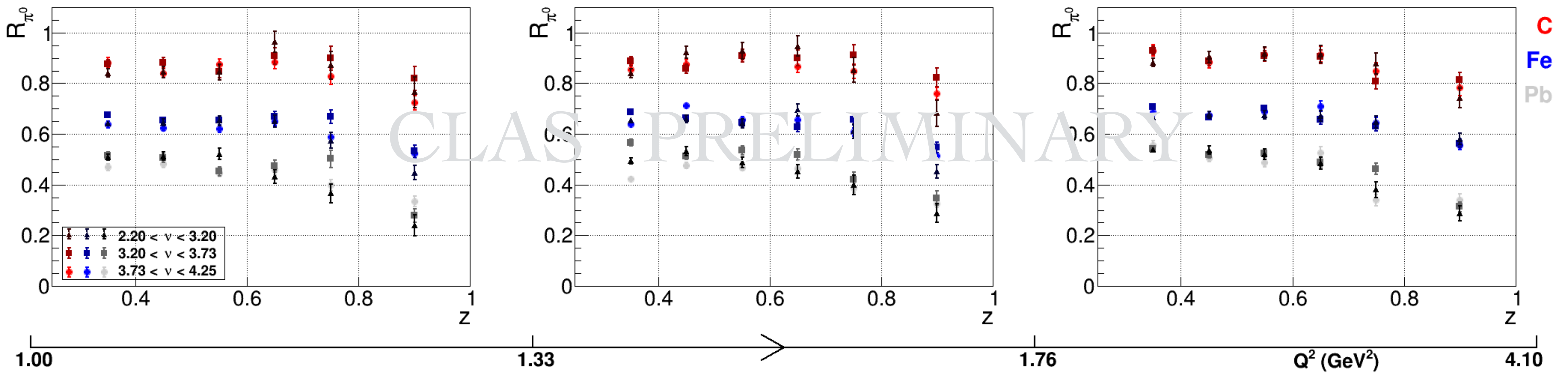
Raphael Dupré

Analysis under review

3D π^0 Multiplicities on $^{12}C, ^{56}Fe, ^{207}Pb$ to D

$R_{\pi 0}$ in (Q^2, ν, z) integrated over p_T^2

Results are acceptance corrected only. Statistical uncertainties included. Systematics: 3-6%.



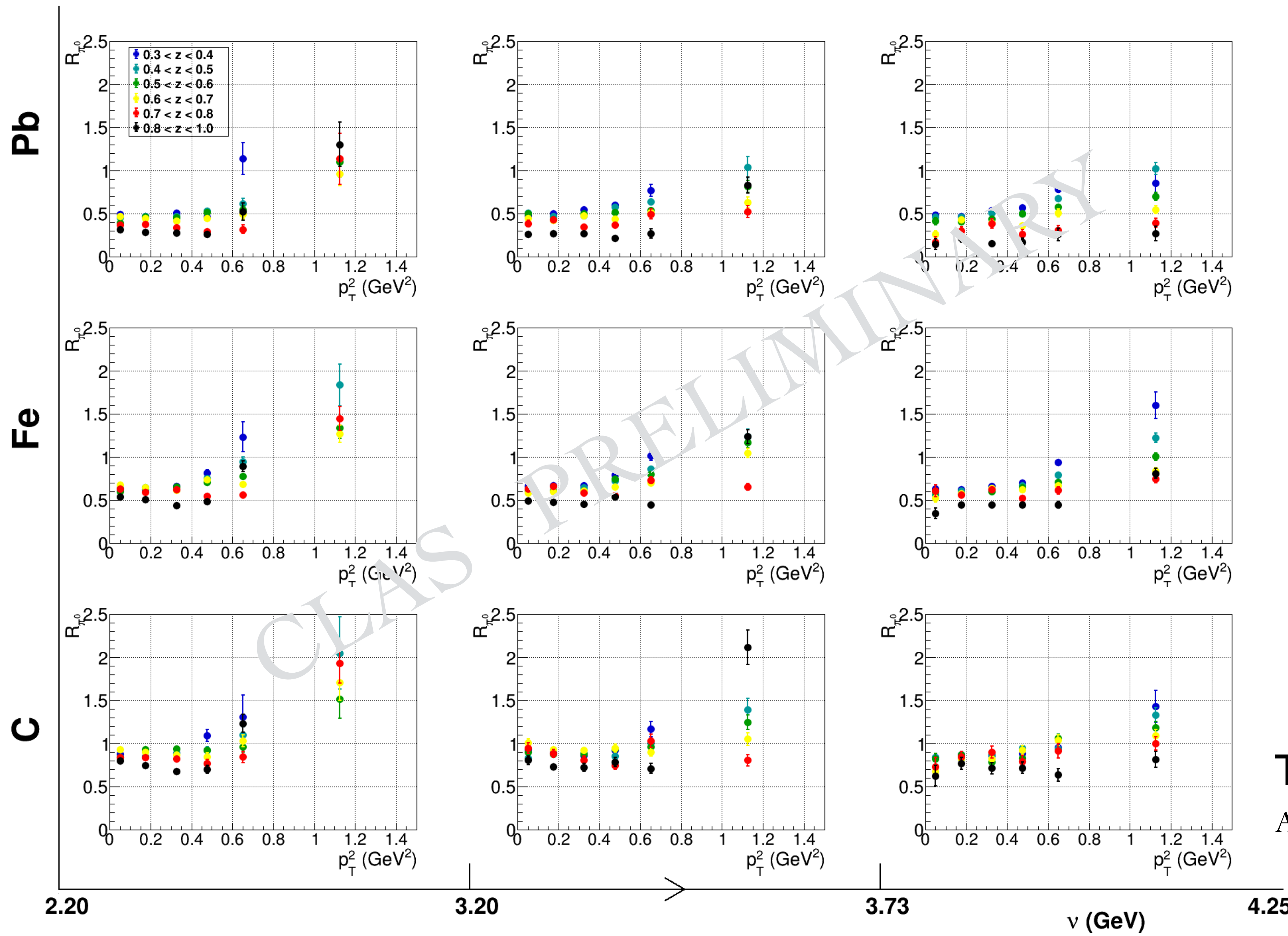
Taisiya Mineeva

Analysis under review

3D π^0 Multiplicities on $^{12}C, ^{56}Fe, ^{207}Pb$ to D

$R_{\pi 0}$ in (ν, z, p_T^2) integrated over Q^2

Results are acceptance corrected only. Statistical uncertainties included. Systematics: 4-6%.



Taisiya Mineeva

Analysis under review

Summary

- The microscopic information on space-time dynamics of hadronization can be accessed via DIS using nuclear medium as an analyzer.

- Propagation time of quasifree quark can be related to its transverse momentum broadening and formation time of final state hadron is related to hadronic multiplicity ratio.

- CLAS high luminosity data on ^{2}H, ^{12}C, ^{56}Fe, ^{207}Pb
- Extraction of multidimensional multiplicities and momentum broadening
- State-of-the art radiative corrections for processes in heavy target
- Analysis under review

- Future program with CLAS12 (E12-06-117) will provide by far the best experimental access to medium-stimulated parton energy loss and enable extraction of 4D multiplicities for a large spectrum of hadrons.

7 th International Conference on High Energy Physics in the LHC era

8-12 January 2018

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Astroparticle Physics
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Non Perturbative QCD
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Particle Detectors and Instrumentation
Beyond the Standard Model Physics
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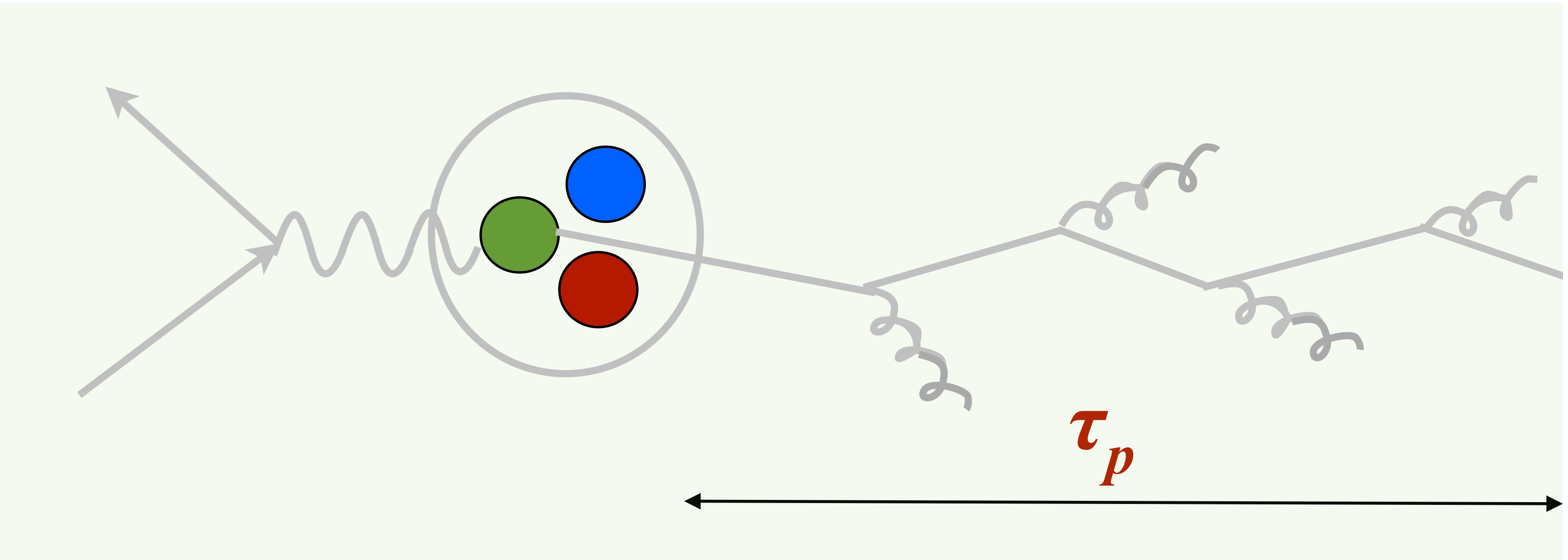
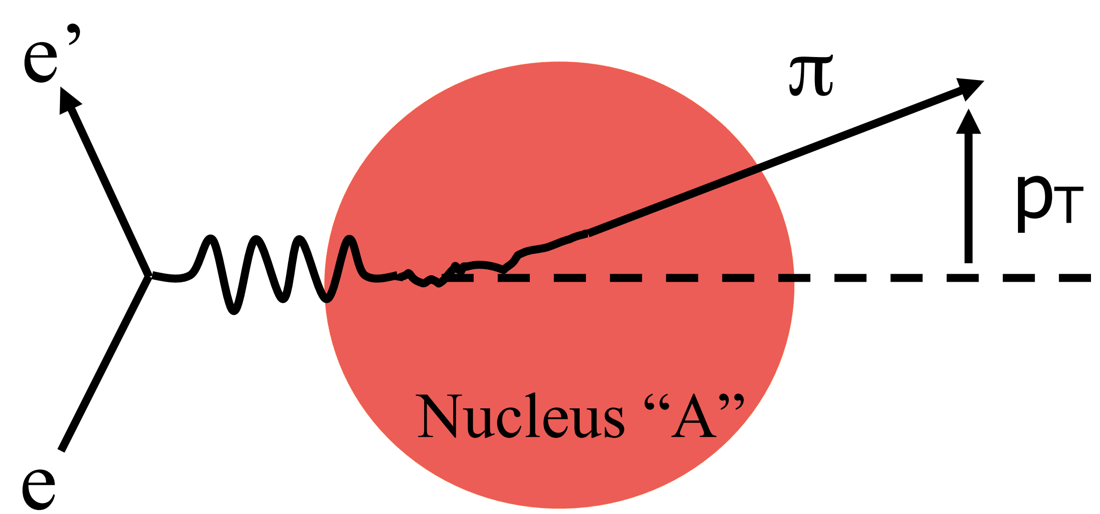
Transverse momentum broadening



Transverse momentum broadening

$$\Delta p_T^2 = < p_T^2 >_A - < p_T^2 >_D$$



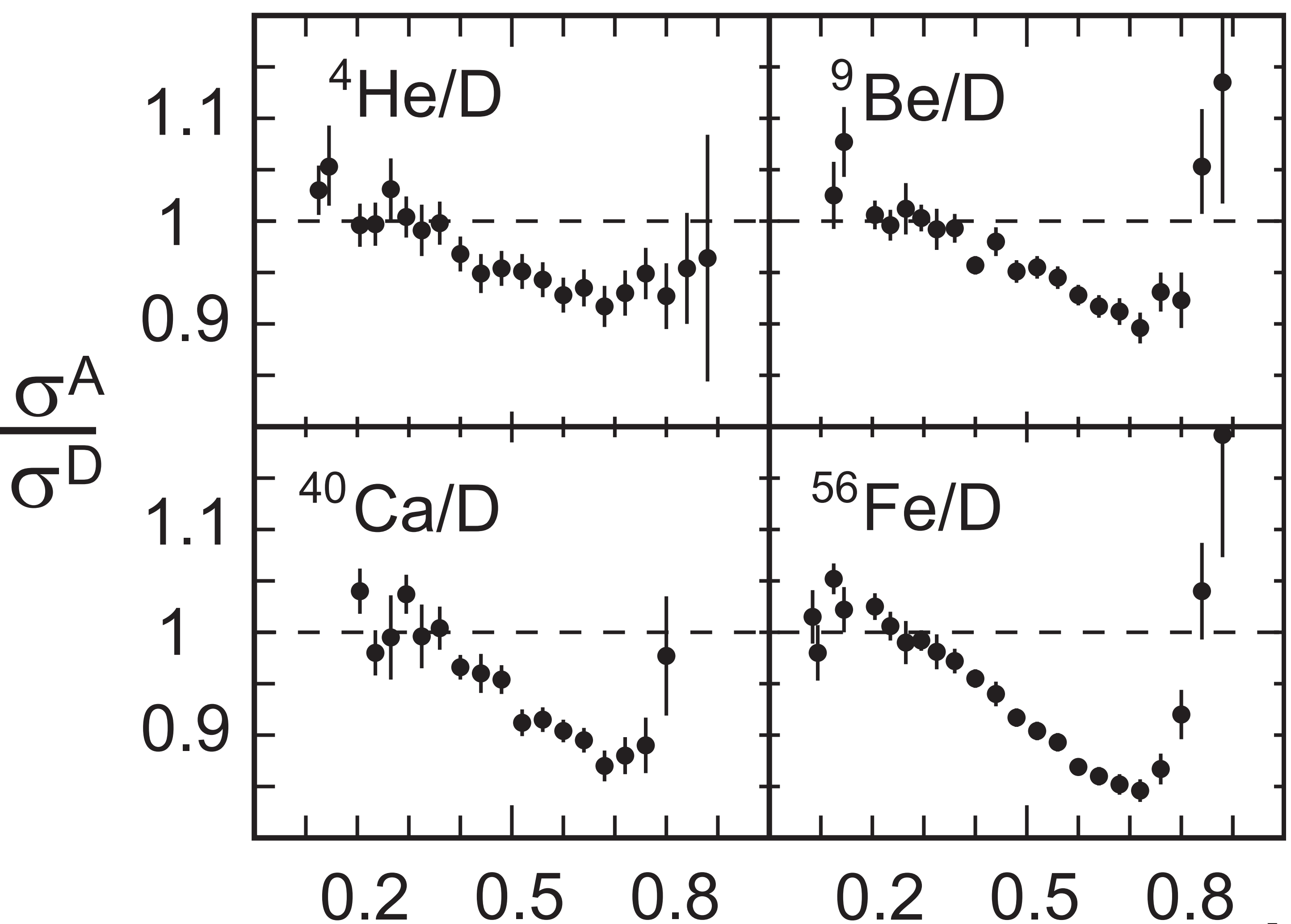
Connects to partonic phase

- in-medium scattering
- quark energy loss
- access to production time τ_p

Quarks in nuclei: EMC effect

EMC effect (1983): structure function F_2 is modified when nucleons are embedded in a nucleus (from measurement F_2^{Fe}/F_2^{D})

The ratio σ^A/σ^D as a function of x for various nuclei



SLAC E139 (1994) confirmed EMC effect on wide range of A

Reduction of per-nucleon cross section σ^A compared to 'free' one σ^D

Universal x-dependence for all nuclear targets

. J. Gomez et al. (SLAC-E139), Phys. Rev. D 49 (1994) 4348

HERMES @DESY and CLAS @Jefferson Lab

- HERMES has higher beam energy (27 GeV and 12 GeV, vs. 5 GeV)
- HERMES can identify a wider range of particle species
- CLAS has higher luminosity (10^{34}/cm2/s, ~factor 100)
  – Can do 3 and 4-fold differential binning (vs. 1-D or 2-D for HERMES)
  – Access to higher Q2 (good statistics for 4 GeV2) and higher pT2
- CLAS can use solid targets – Access to heaviest nuclei (^{207}Pb vs. ^{131}Xe)

	ν (GeV)	Q^2 (GeV^2)	z	pT^2 (GeV^2)
CLAS	2.2 - 4.2	1.0 - 4.1	0,3 - 1.0	0 - 1.5
HERMES	7 - 23	1.0 - 10	0.2 - 1.0	0 - 1.1