# New Experimental Tools for Exploring In-Medium Parton Propagation in QCD

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    - Characteristic timescales
    - Partonic energy loss
    - Quantum interference effects
    - Current vs. target fragmentation
    - Partonic vs. hadronic interactions
    - Color transparency
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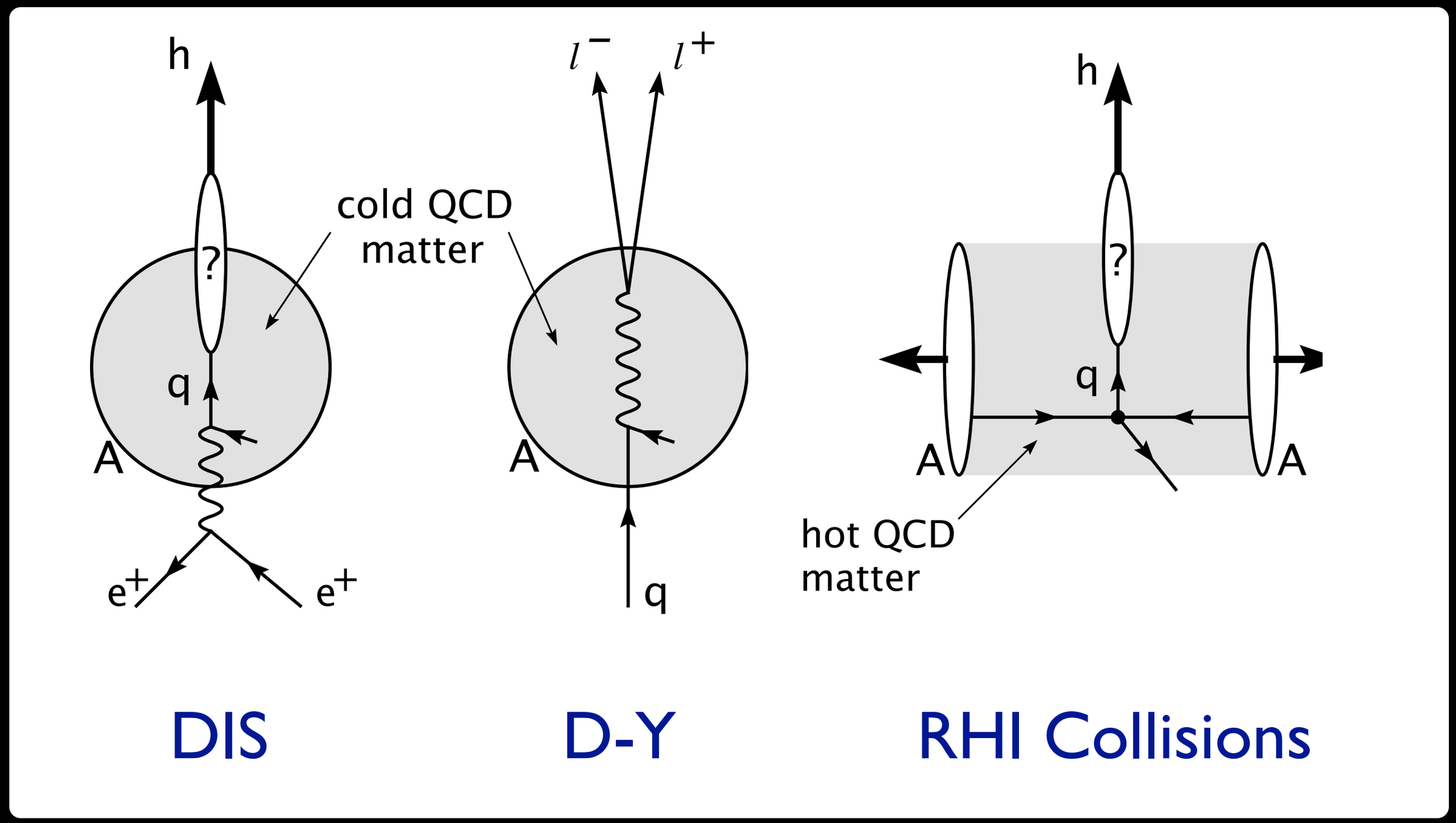
- *Unique kinematic window* at low energies
- *Simpler physical picture* at high energies

# Comparison of Parton Propagation in Three Processes




Accardi, Arleo, Brooks, d'Enterria, Muccifora Riv.Nuovo Cim.032:439-553,2010 [arXiv:0907.3534]
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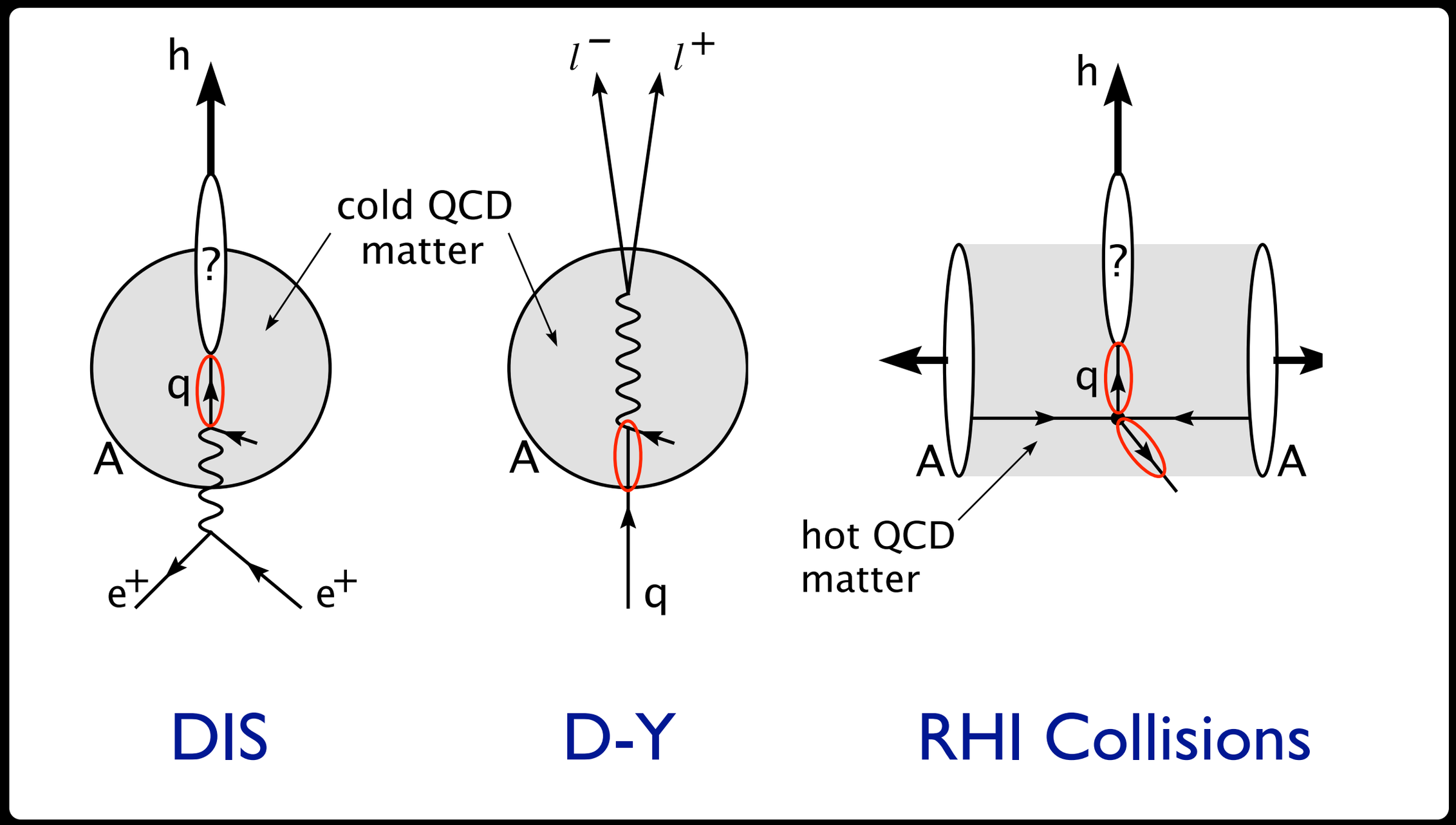


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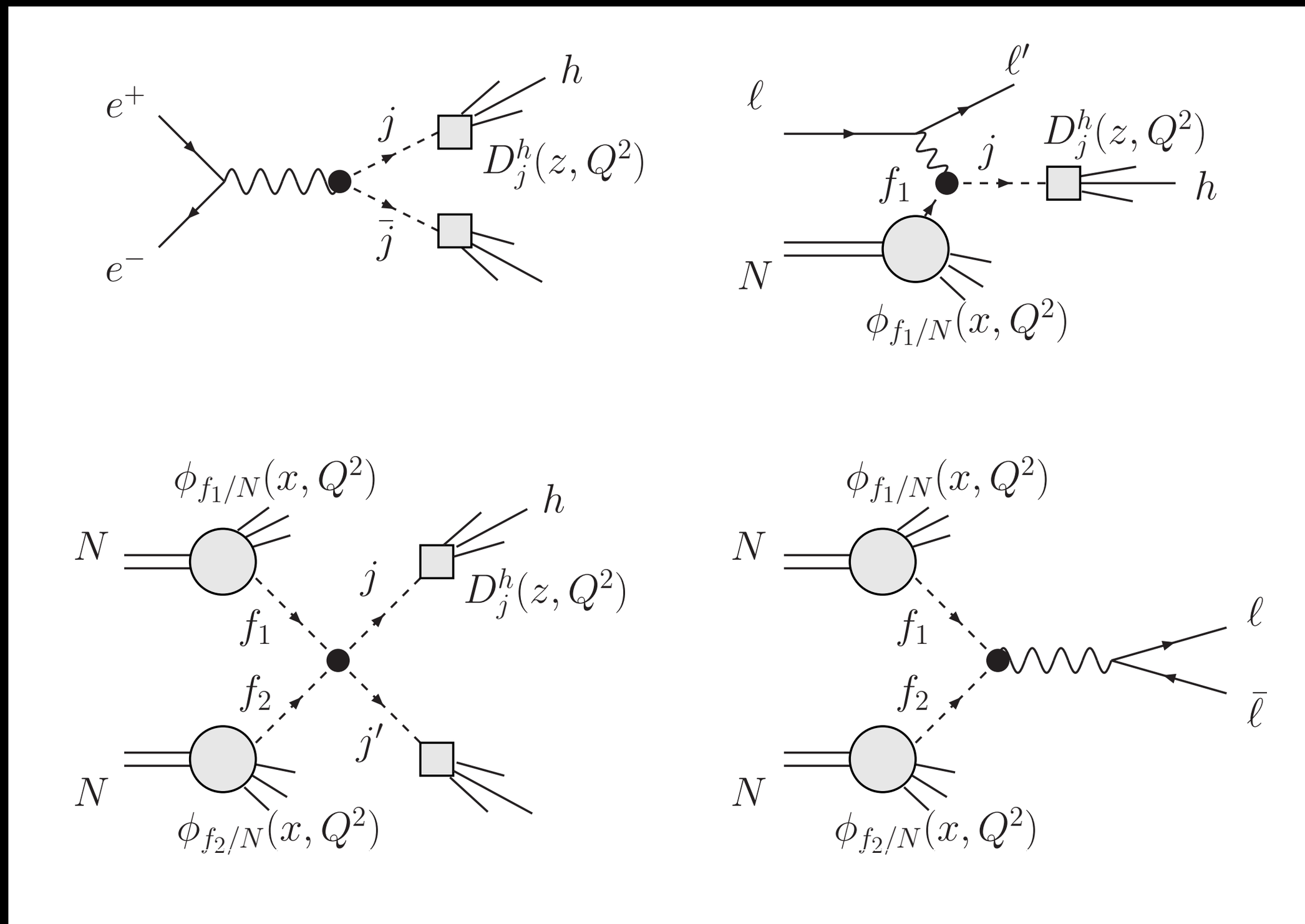
# Fundamental ingredients in perturbative picture




M. Voutilainen talk

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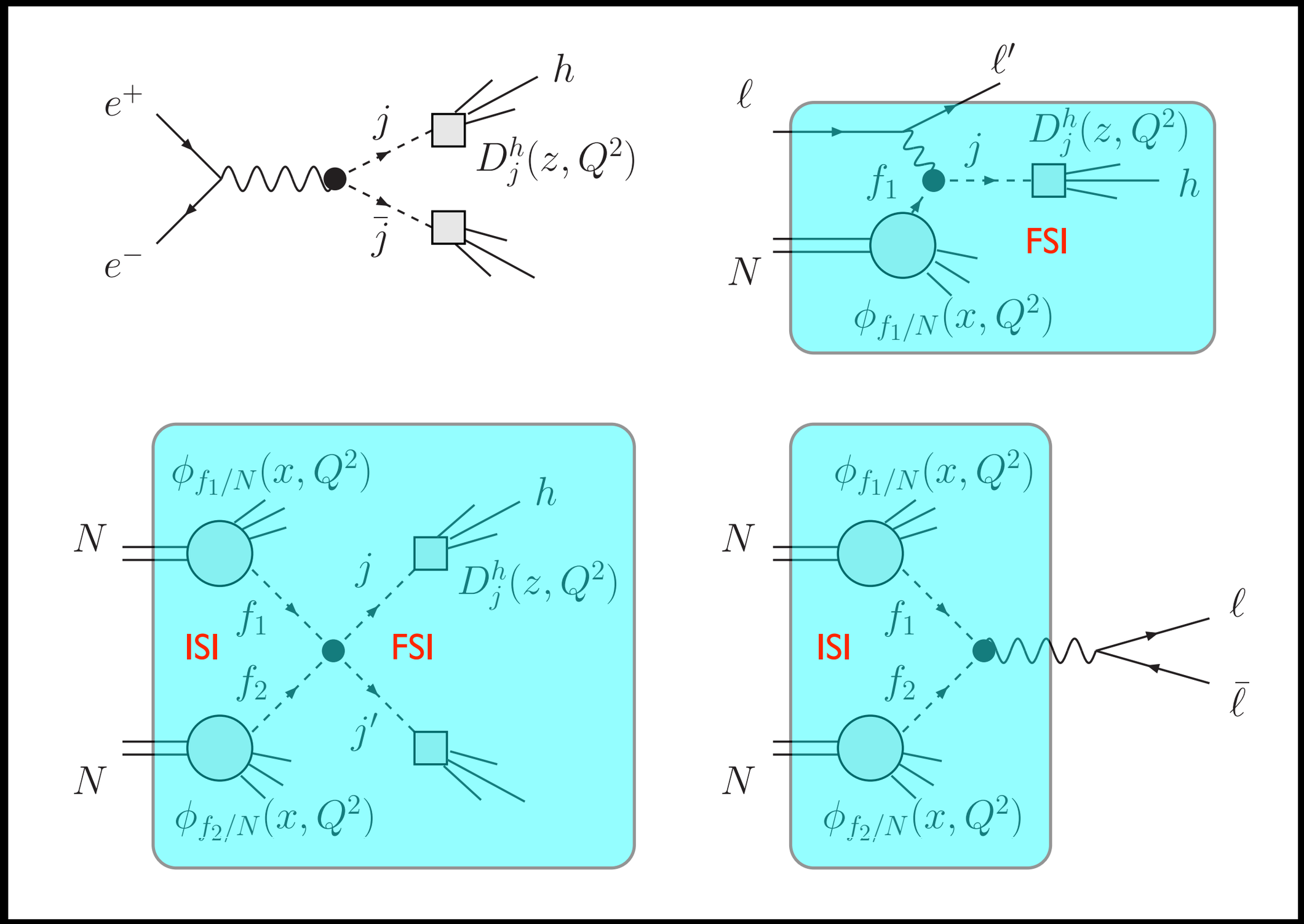
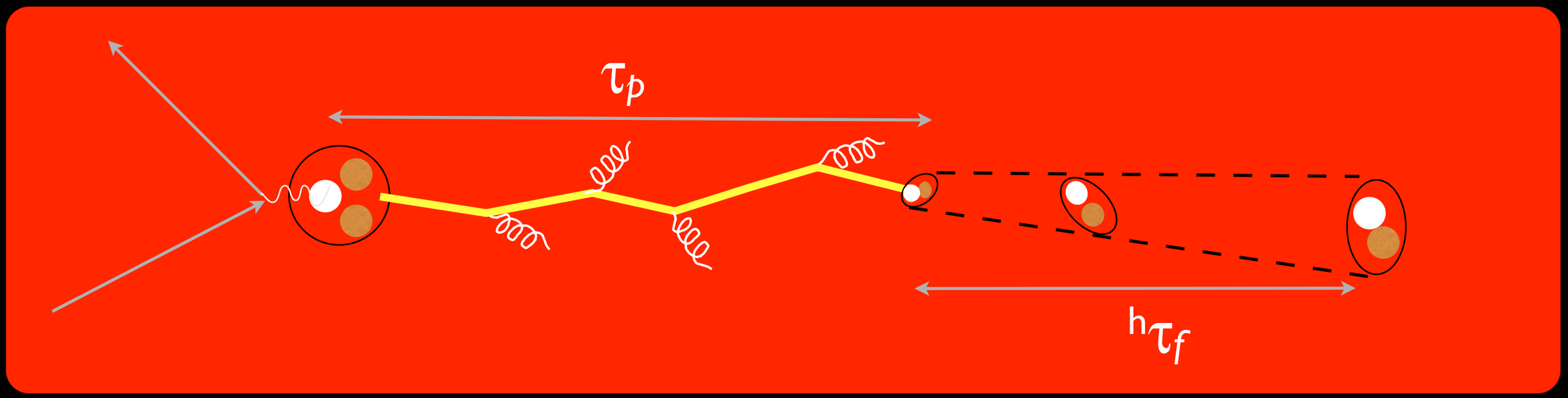



M. Voutilainen talk D. d'Enterria talk R. Holtzmann talk M. Rybar talk P. Kurt talk

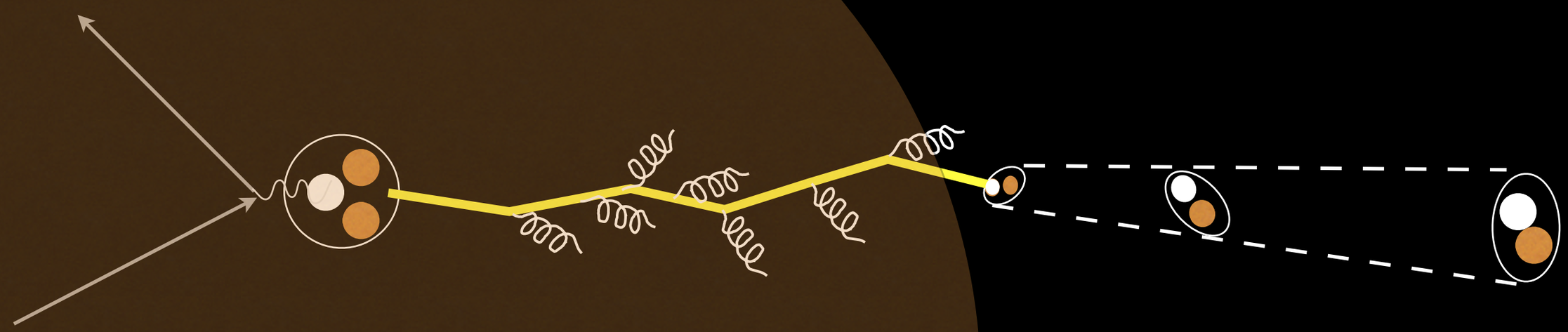
# Deep Inelastic Scattering - Vacuum




- *production time $\tau_p$* - propagating quark
- *formation time $^h\tau_f$* - dipole grows to hadron
- *partonic energy loss* - *dE/dx via gluon radiation in vacuum*

# Low-Energy DIS in Cold Nuclear Medium

Partonic multiple scattering:
*medium-stimulated*
gluon emission,
broadened $p_T$



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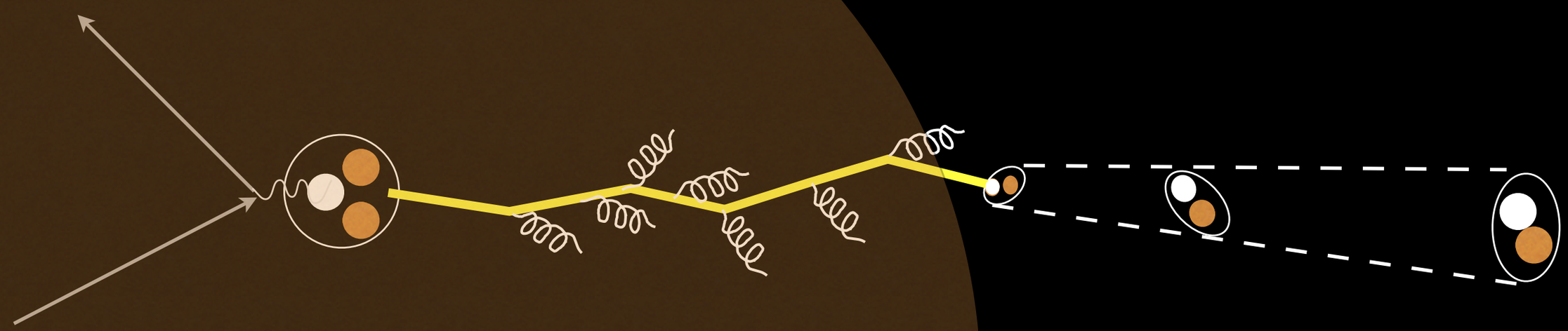
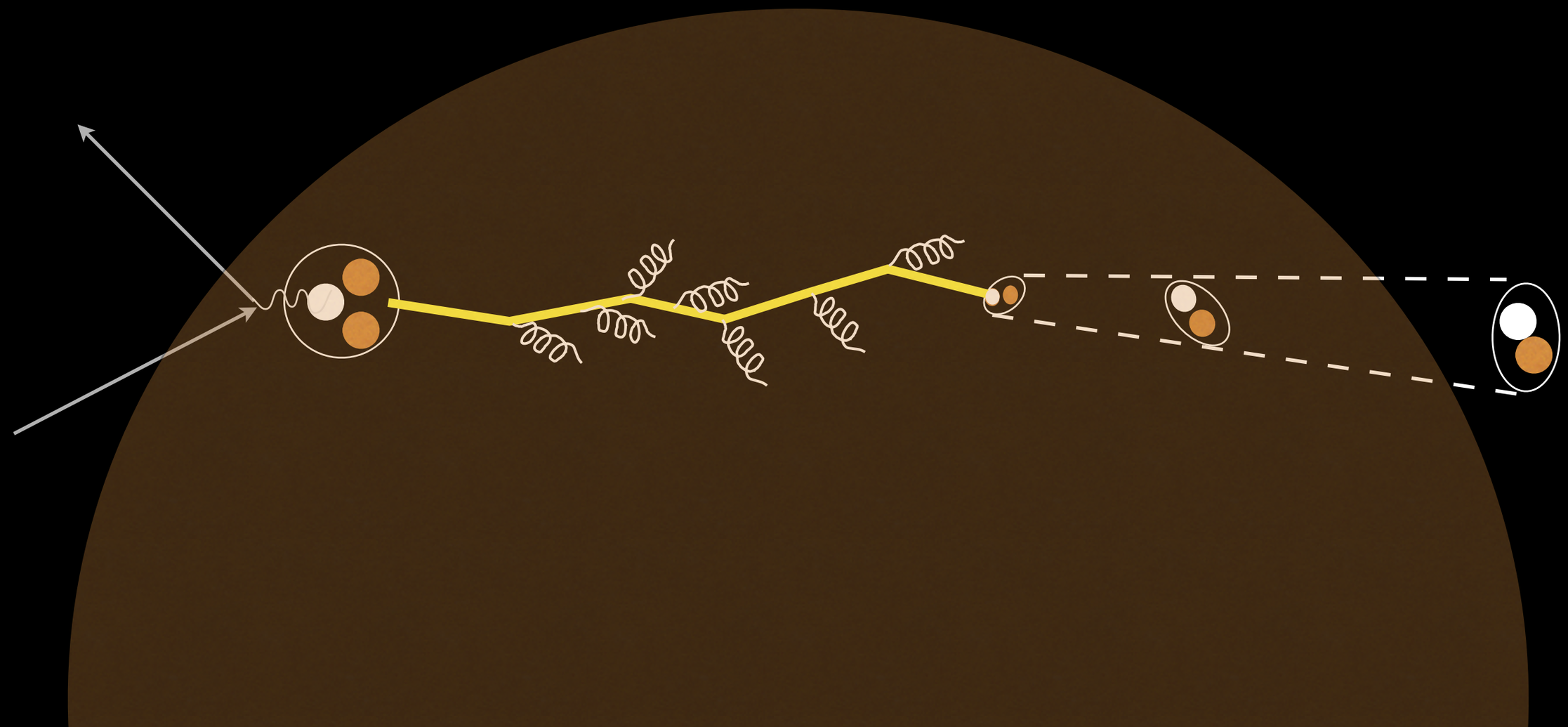


Hadron forms *outside* the medium; or....

# Low-Energy DIS in Cold Nuclear Medium

Hadron can form *inside* the medium; then also have prehadron/hadron interaction



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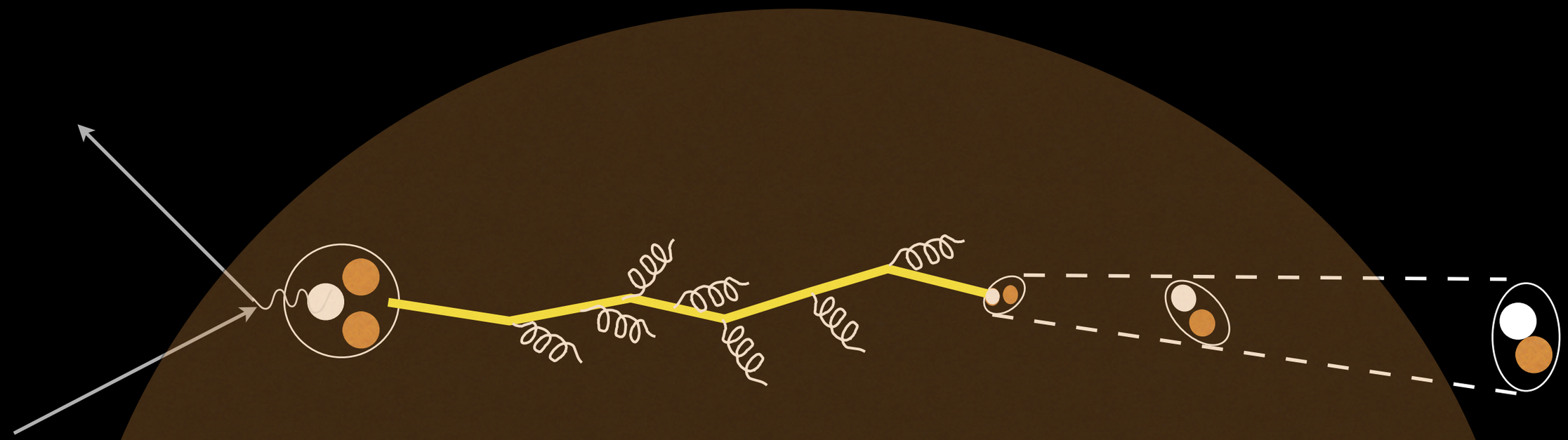


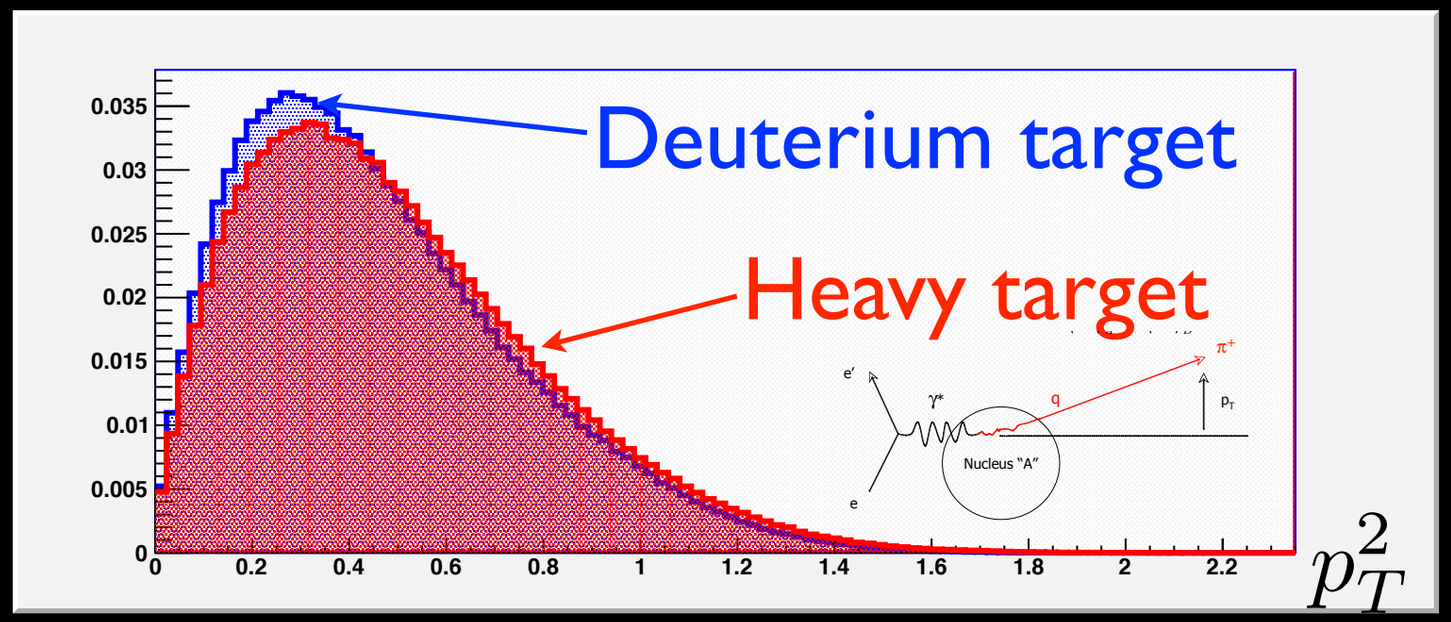
Amplitudes for hadronization *inside* and *outside* the medium can interfere

# *DIS Observables*

Transverse momentum broadening:

$$\Delta p_T^2 \equiv \langle p_T^2 \rangle_A - \langle p_T^2 \rangle_D$$

➪ ***partonic!***




(R. Dupré talk)

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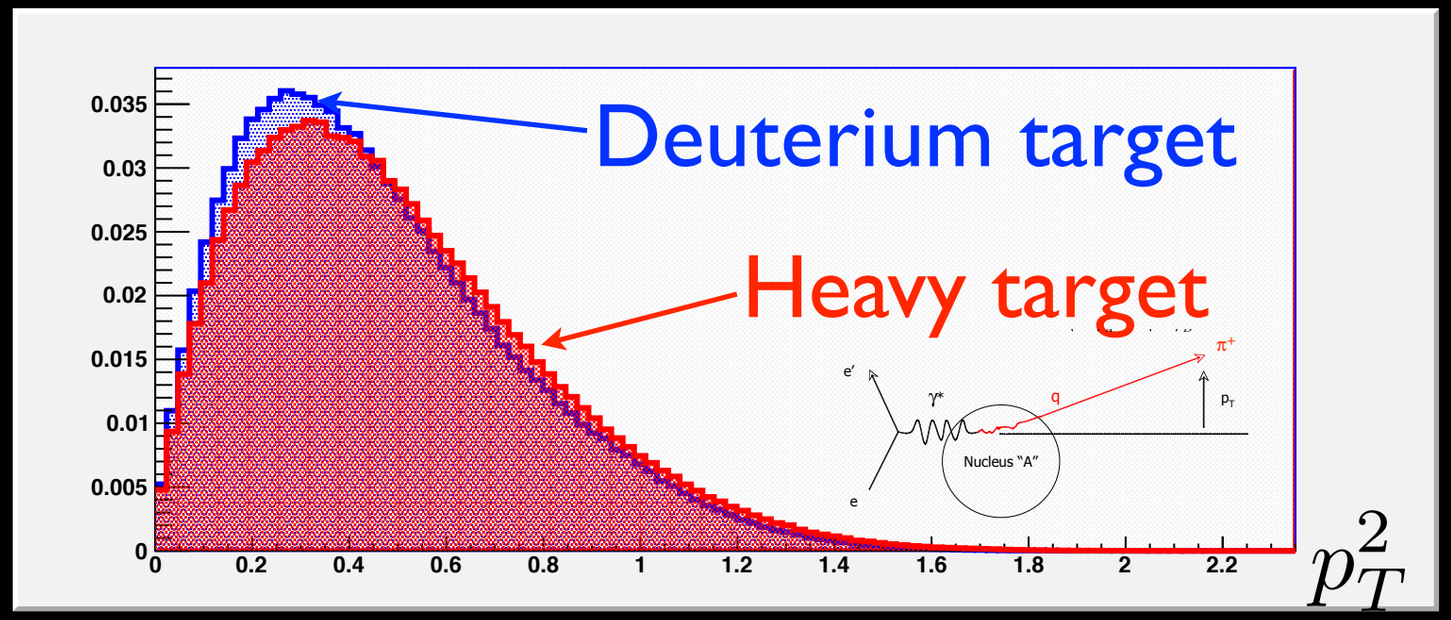



Hadronic multiplicity ratio (R. Dupré talk)

Multi-hadron multiplicity ratios

Hadron-photon correlations

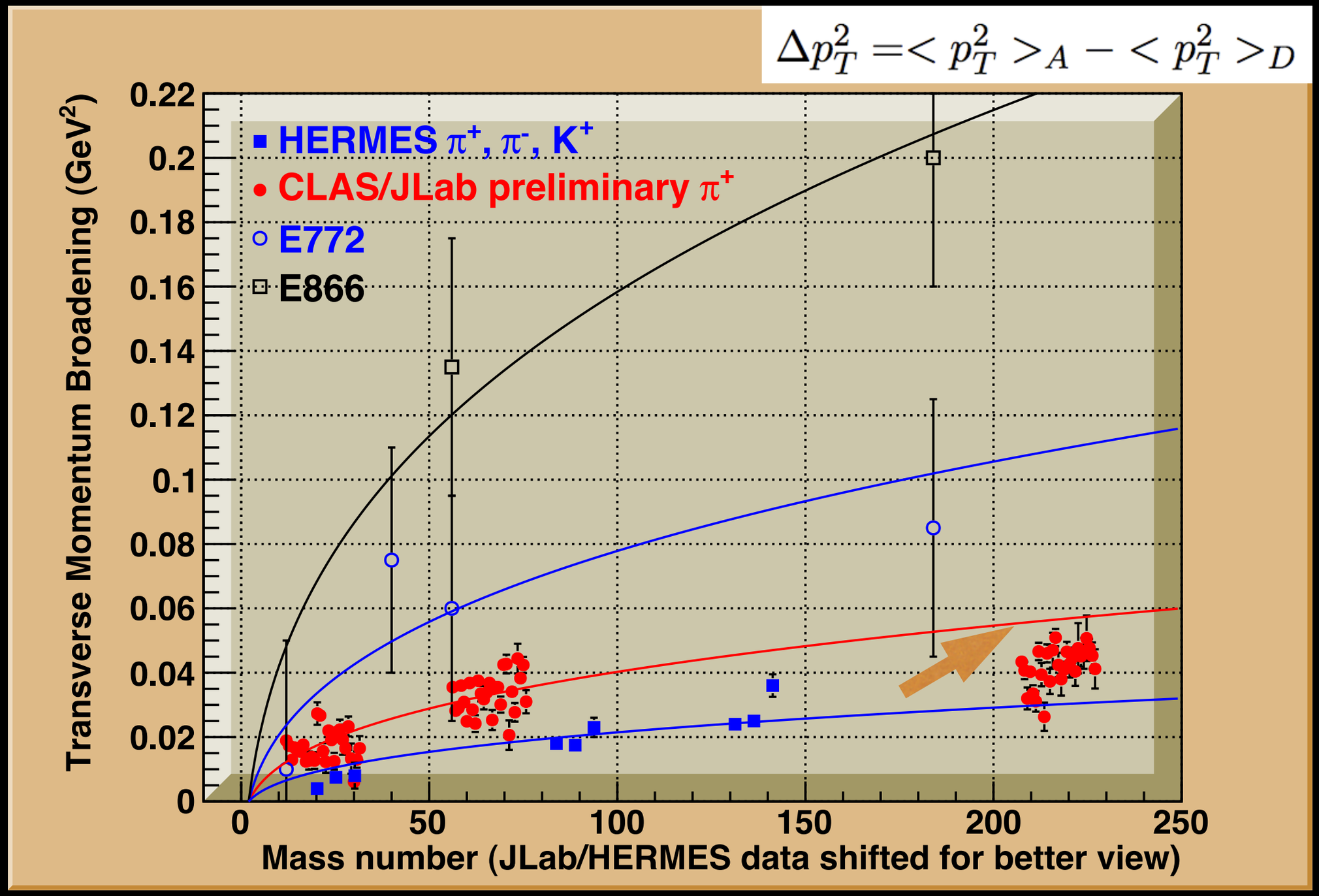
Bose-Einstein correlations

Centrality correlations

more....

not in this talk.....

# Comparison of $p_T$ broadening data - Drell-Yan and DIS

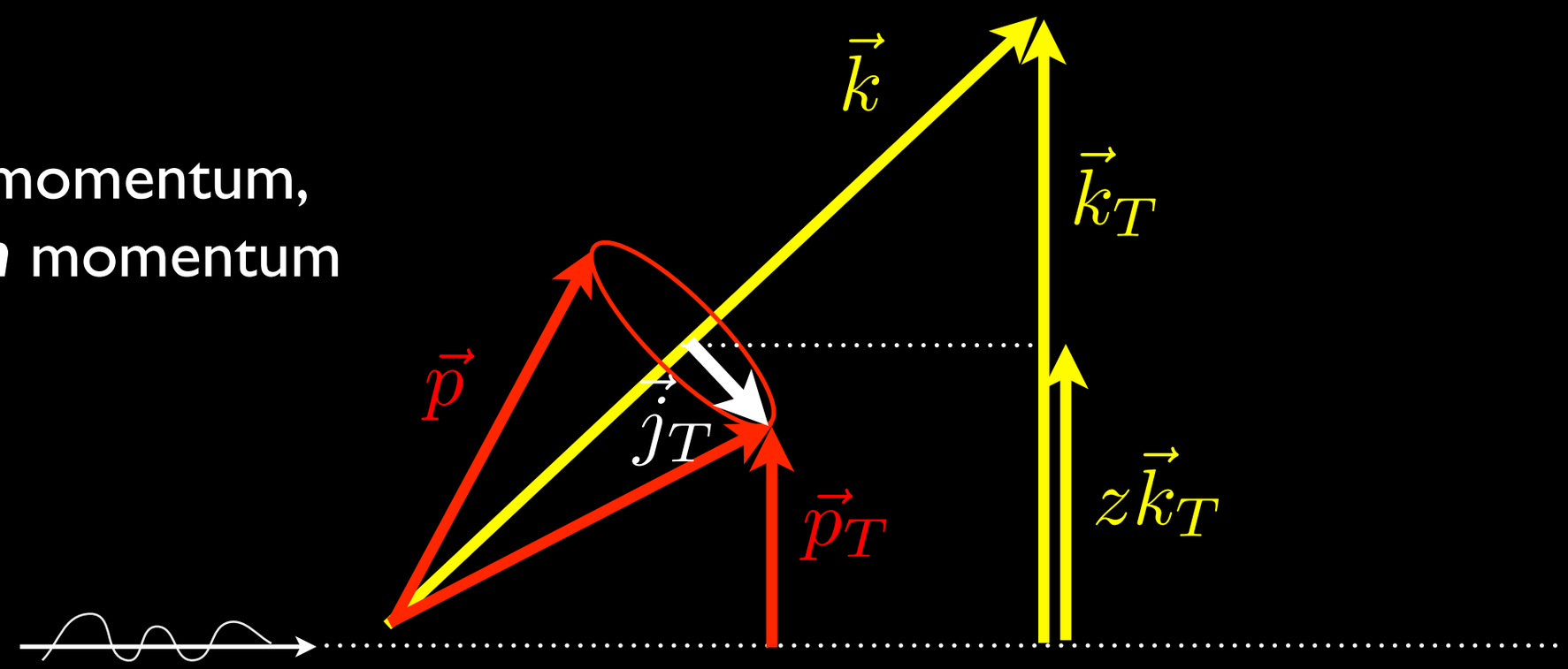



- New, high-precision data with identified hadrons!
- CLAS $\pi^+$: 81 four-dimensional bins in $Q^2$, $\nu$, $z_h$, and A

# *Quark* $k_T$ broadening vs. *hadron* $p_T$ broadening

The $k_T$ broadening experienced by a quark is "*diluted*" in the fragmention process

***k*** is the ***quark*** momentum,
***p*** is the ***hadron*** momentum




$$\vec{p}_T = z\vec{k}_T + \vec{j}_T$$

$$\langle p_T^2 \rangle = \langle z^2 k_T^2 \rangle + \langle j_T^2 \rangle$$

$$\Delta\langle p_T^2 \rangle = \Delta\langle z^2 k_T^2 \rangle + \cancel{\Delta\langle j_T^2 \rangle} \sim 0$$

$$\boxed{\Delta\langle p_T^2 \rangle \approx z^2 \Delta\langle k_T^2 \rangle}$$

Verified for pions to 5-10% accuracy for vacuum case, z=0.4-0.7, by monte carlo studies

Basic questions at low energies:

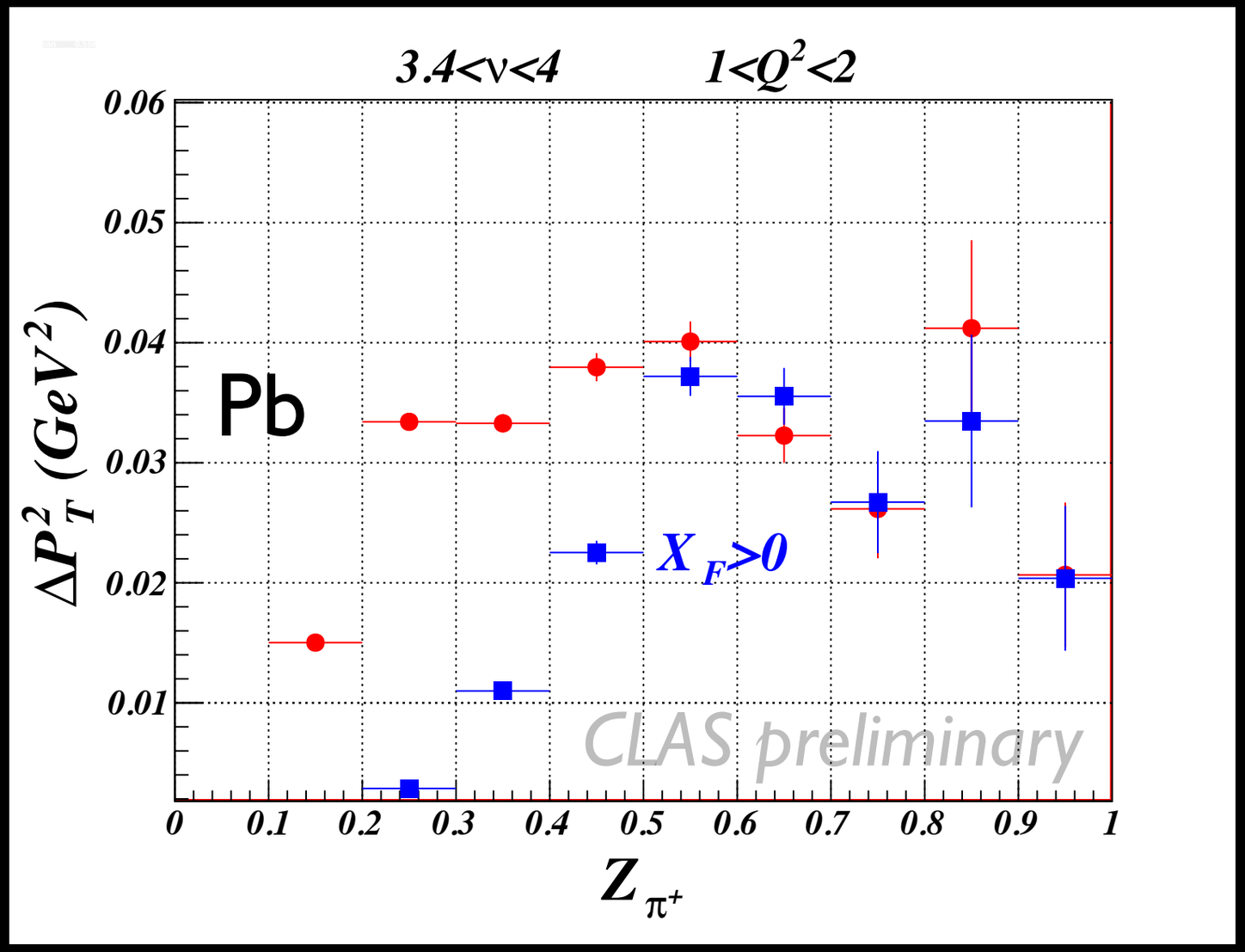
Partonic processes dominate, or hadronic? in which kinematic regime? classical or quantum?

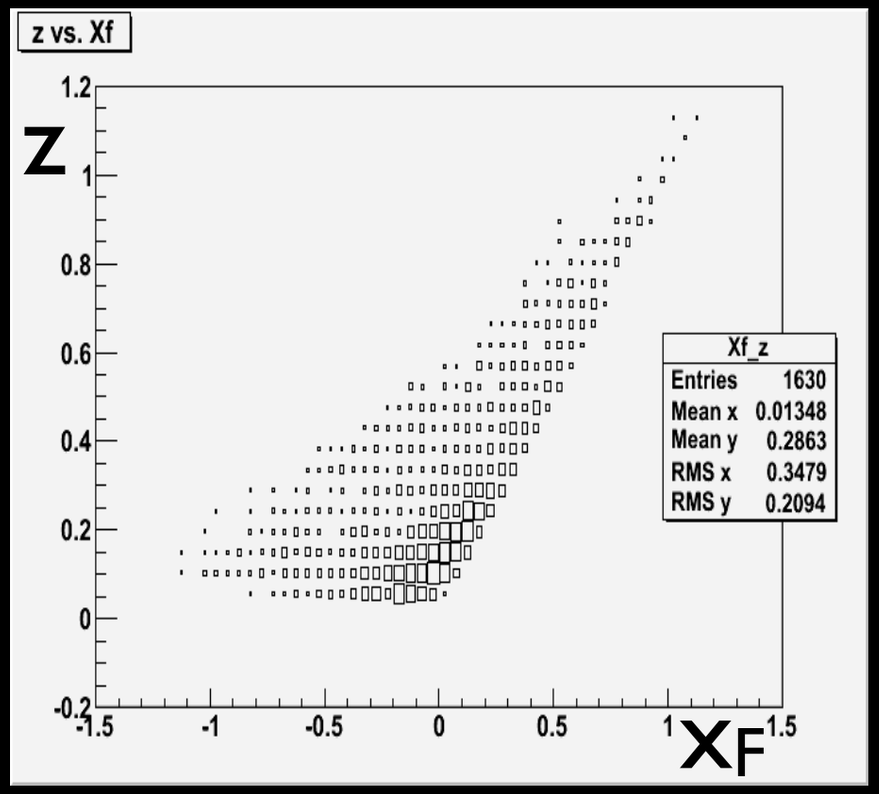
Can identify dominant hadronization mechanisms, uniquely? what are the roles of flavor and mass?

What can we infer about fundamental QCD processes by observing the interaction with the nucleus?

*If $p_T$ broadening uniquely signals the partonic stage, can use this as one tool to answer these questions*

# *New:* dependence of $p_T$ broadening on Feynman x




- $x_F$ and $z_h$ are partially correlated

- Feynman x is the fraction ${}^{\pi}p_L/\max\{{}^{\pi}p_L\}$ in the $\gamma^*$-N CM system
- Separate current ($x_F>0$) and target ($x_F<0$) fragmentation
- First observation that *$p_T$ broadening originates in both regimes*

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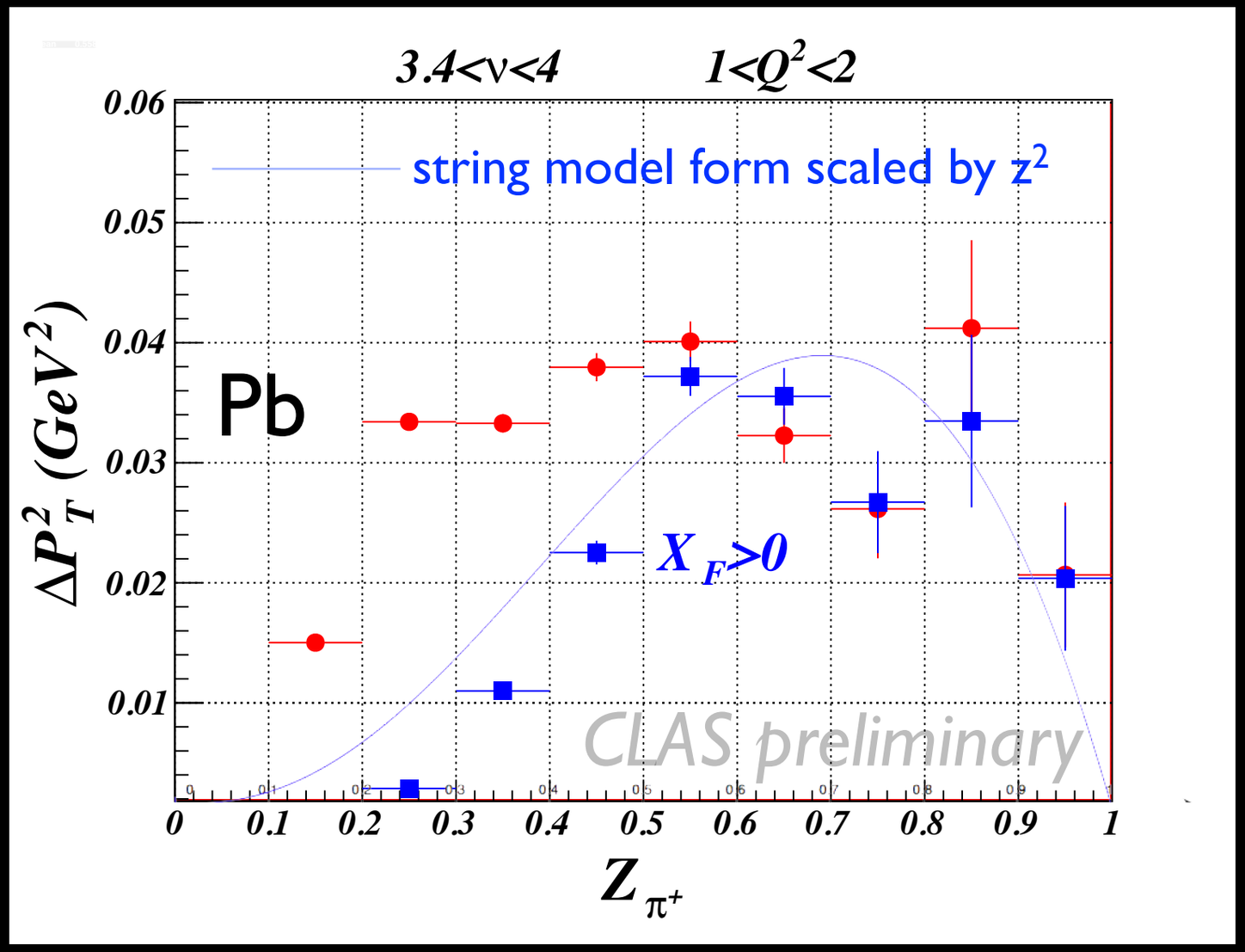


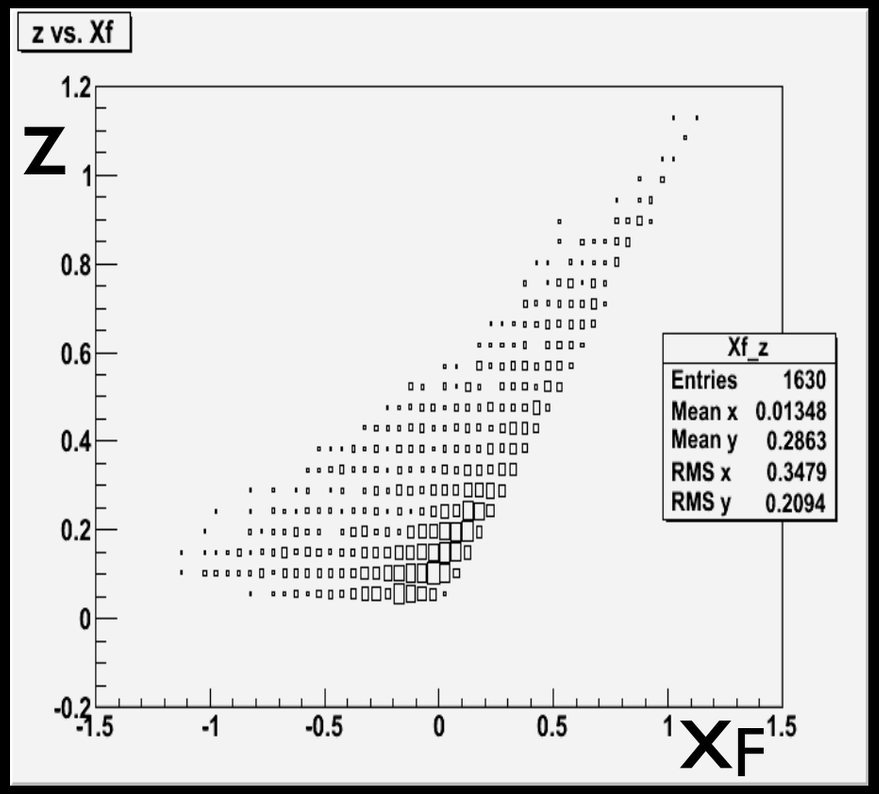


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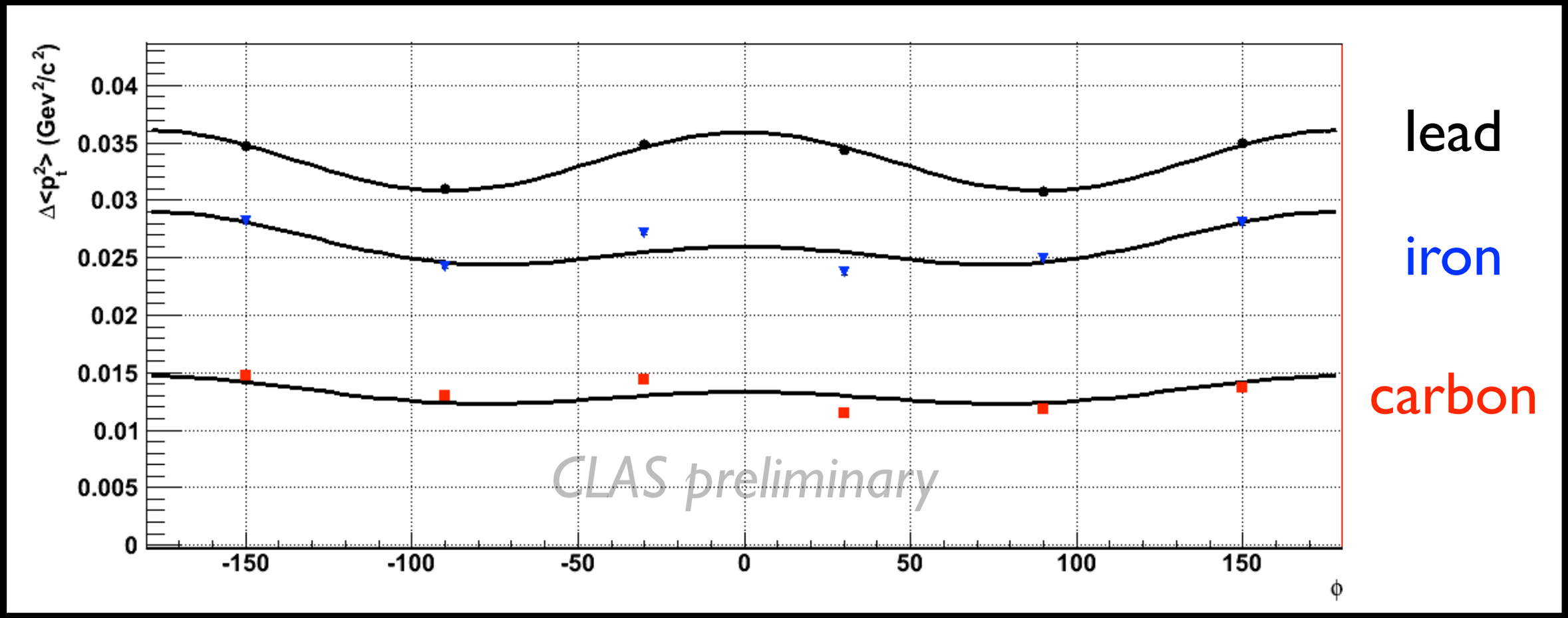
# *New:* dependence of $p_T$ broadening on $\phi_{pq}$

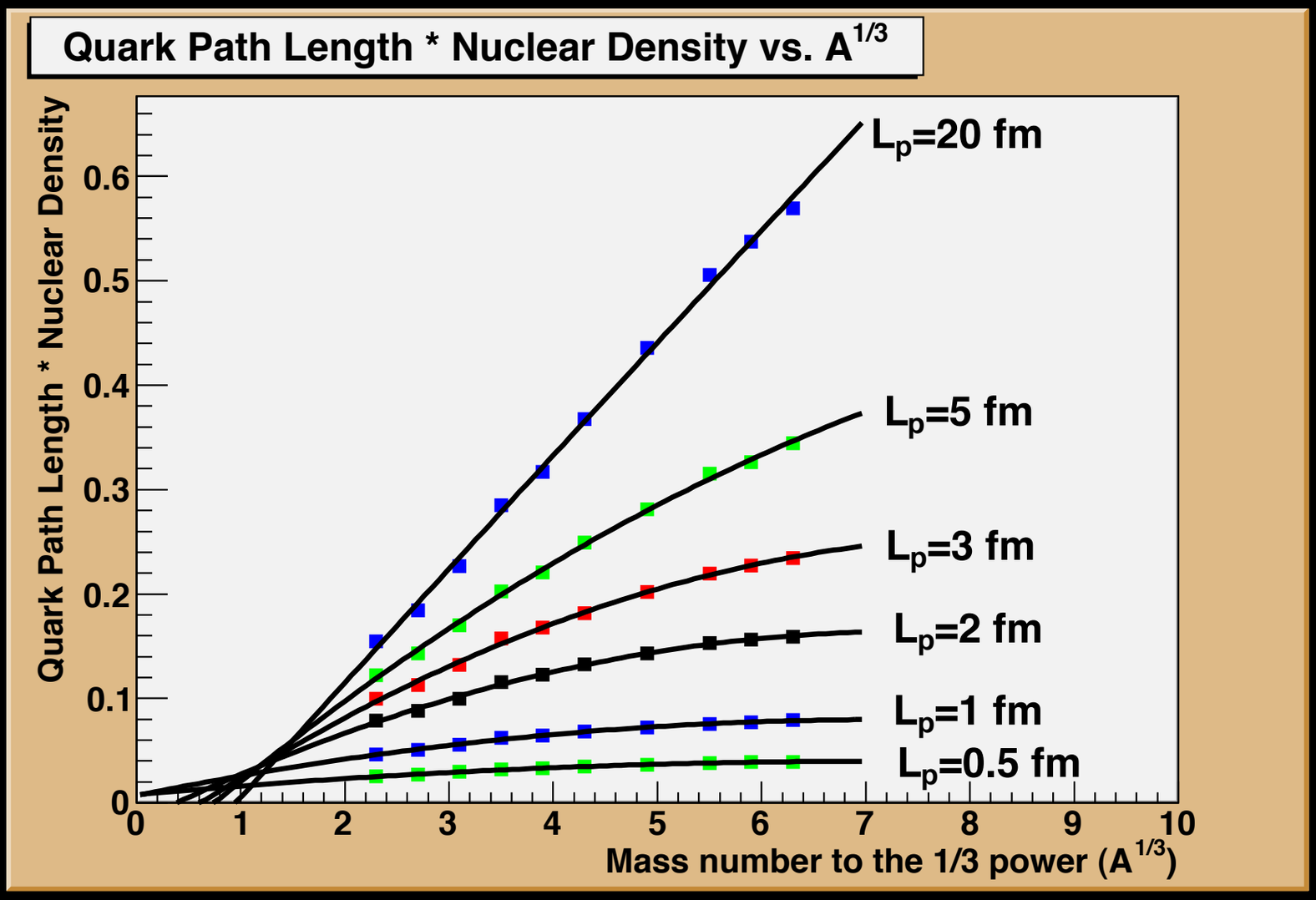



*curves shown contain terms in cos($\phi_{pq}$) and cos(2$\phi_{pq}$)*
*only statistical uncertainties shown*

- Expectation within classical picture: any distribution seen in carbon will become more 'washed out' in heavier nuclei
- Not seen! *first observation of quantum effect in $p_T$ broadening*

  - related to parton density fluctuations in larger nuclei? J. Qiu: Boer-Mulders TMD $\otimes D_j^h(z, Q^2)$ in presence of non-vanishing dipole moment

# Production Time Extraction - Geometrical Effects



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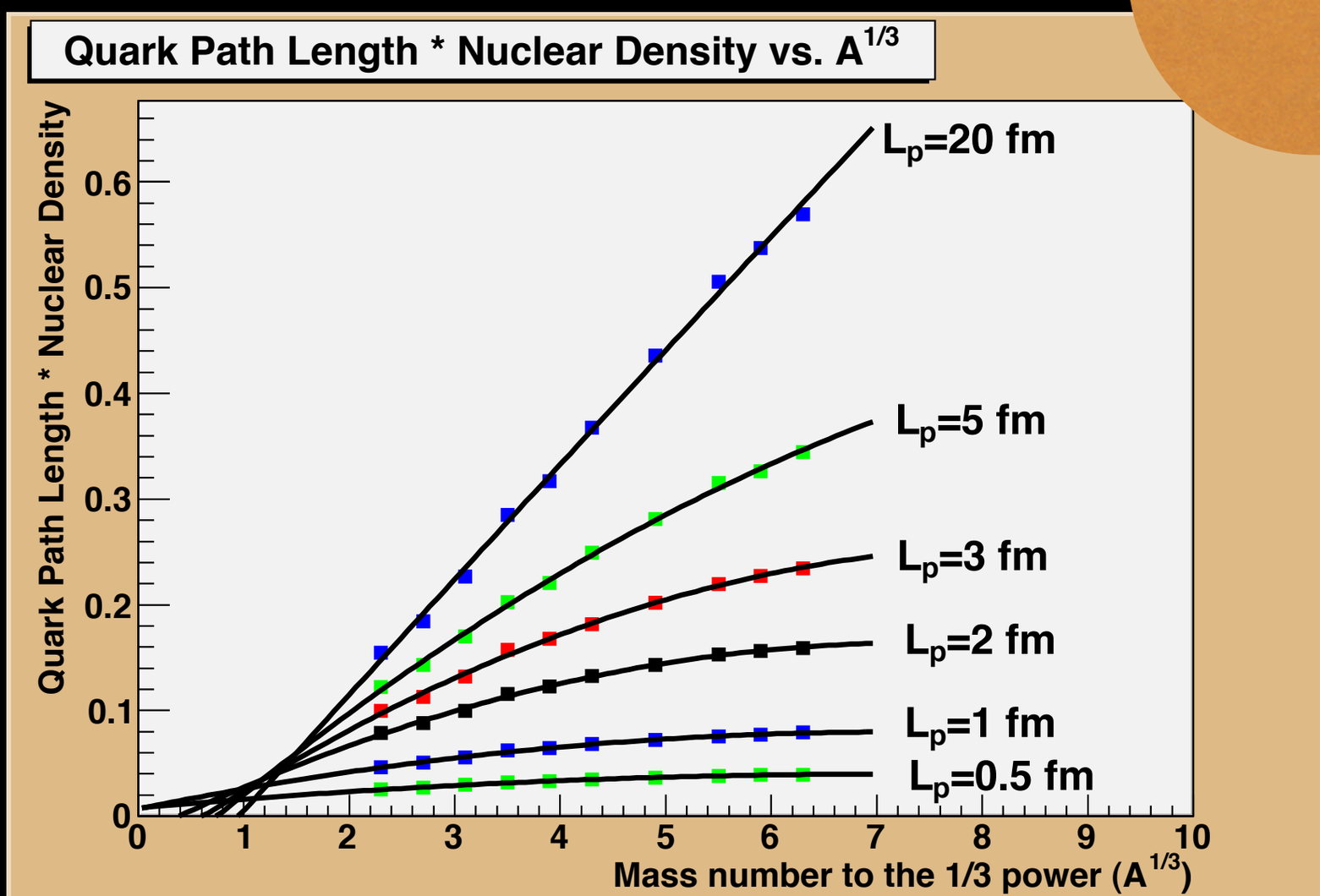

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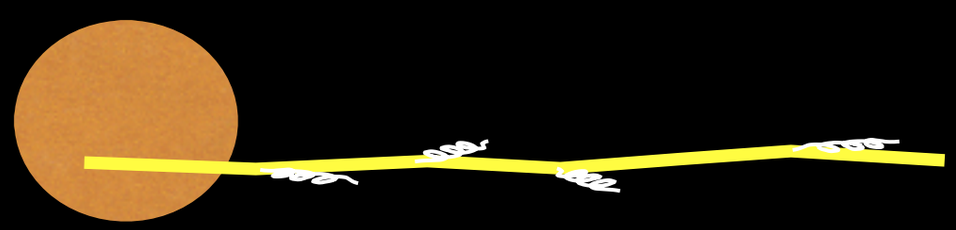

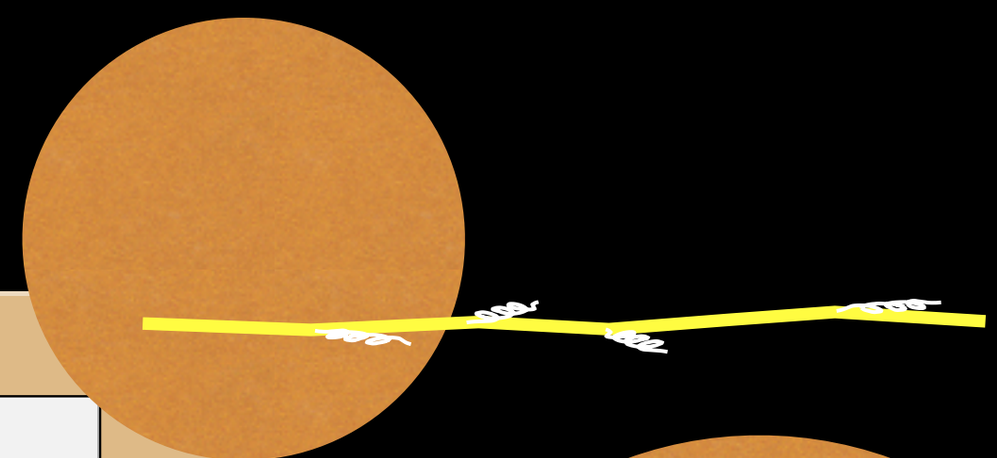

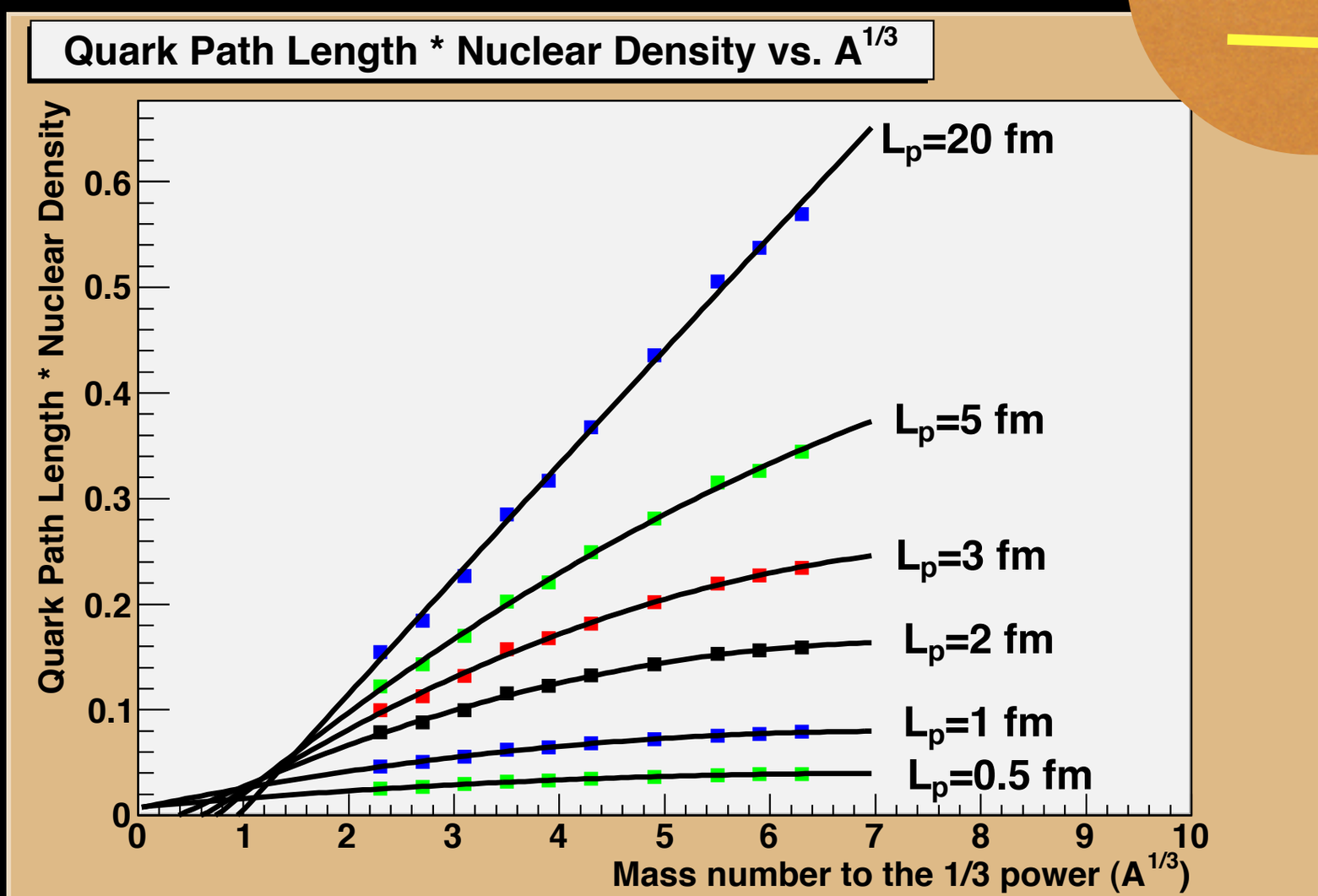


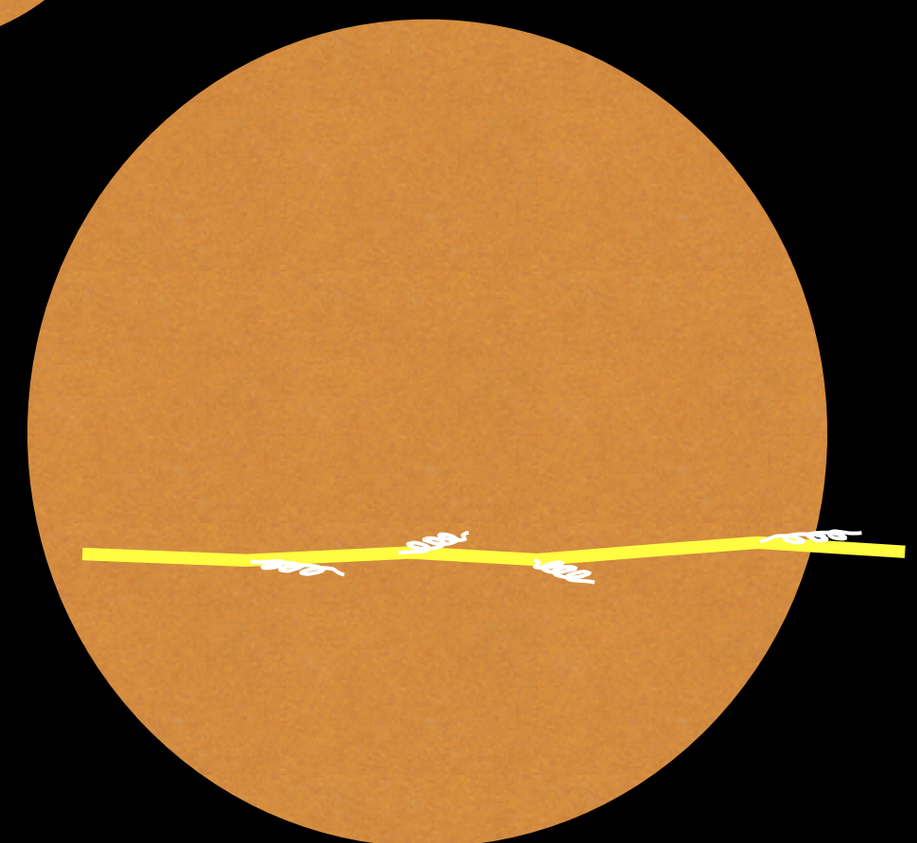

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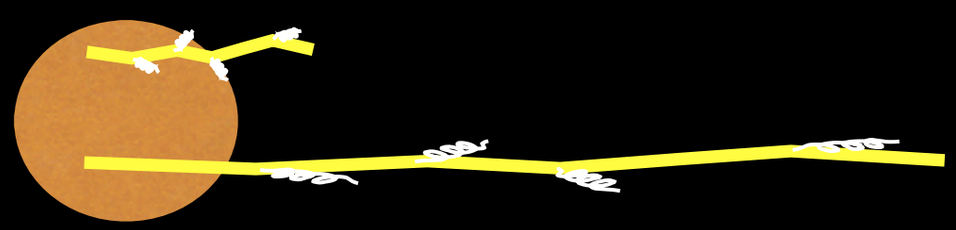

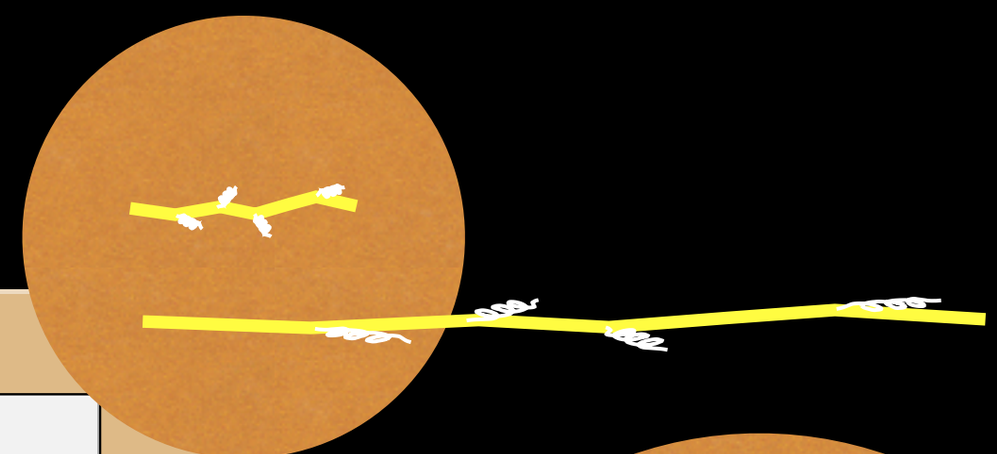

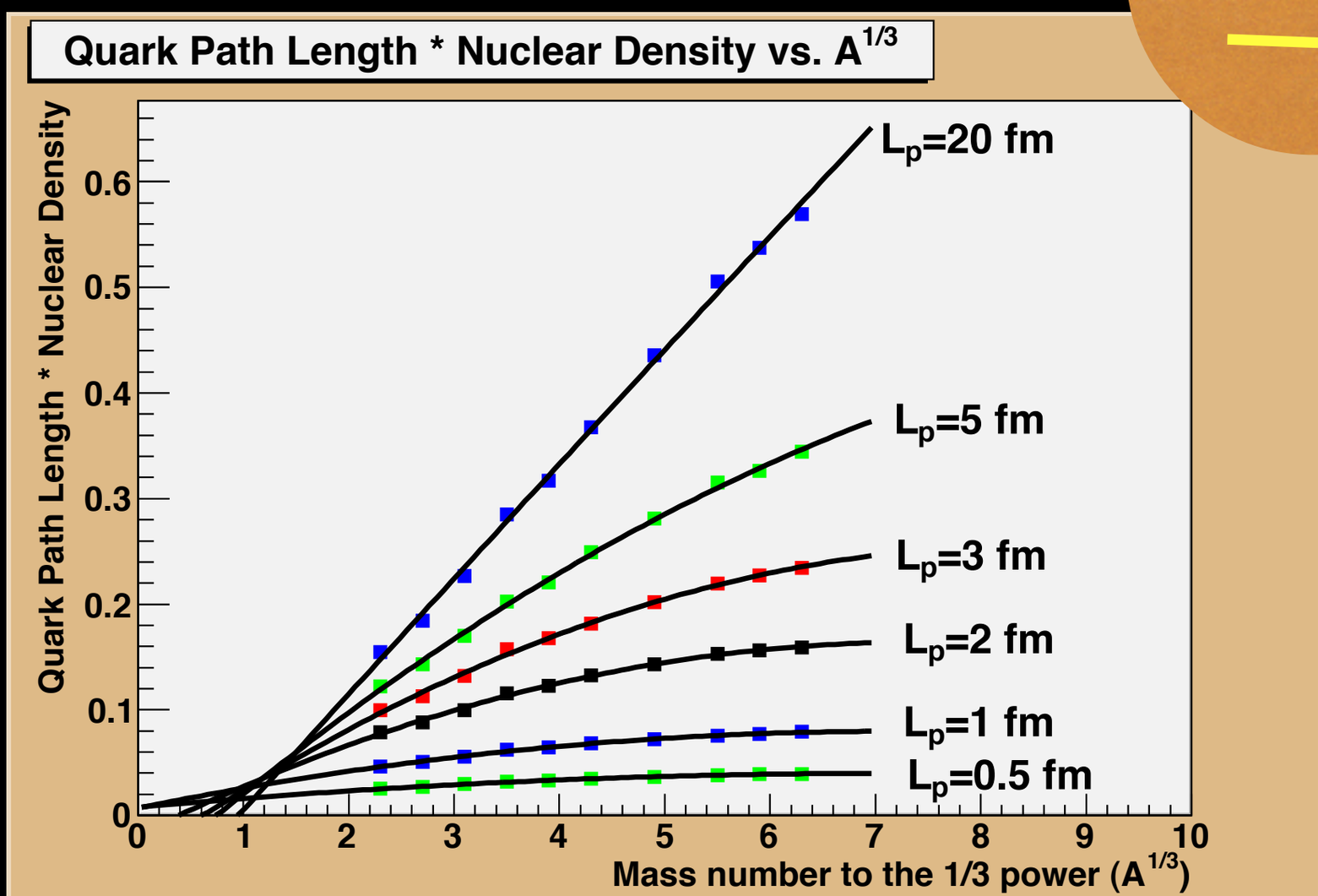


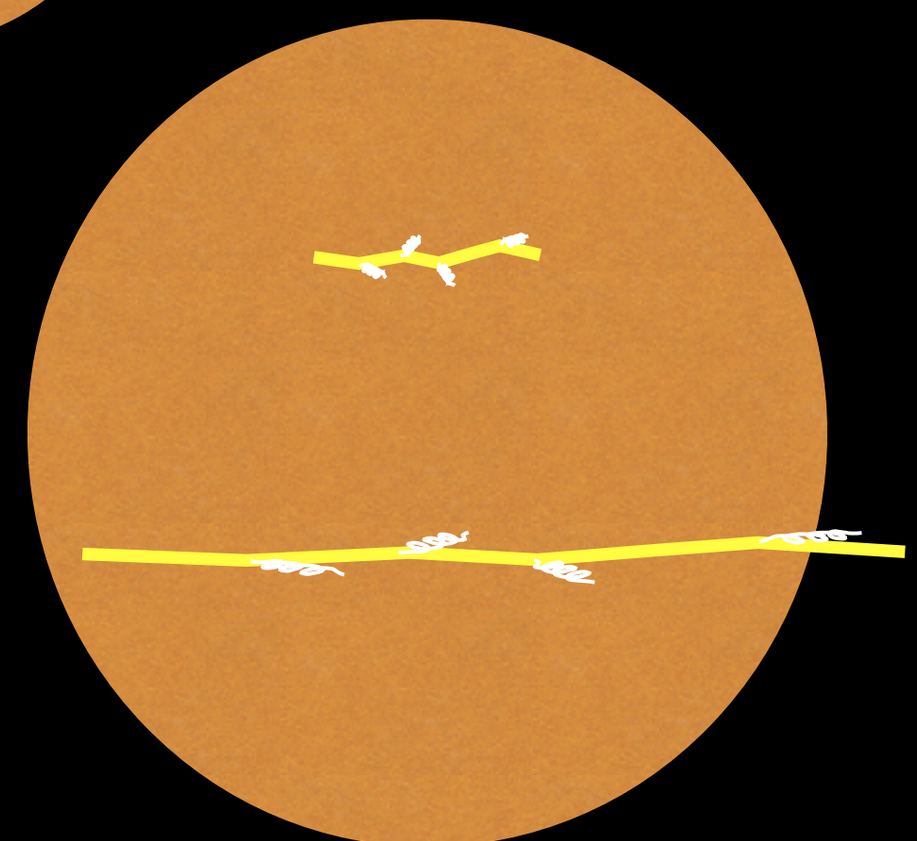

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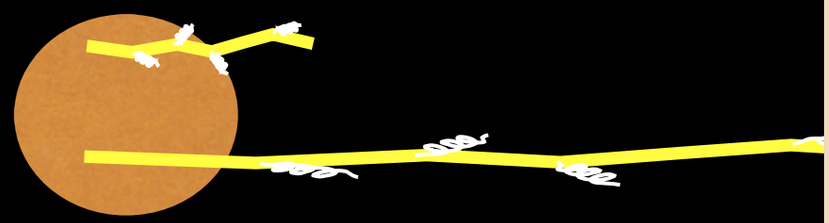

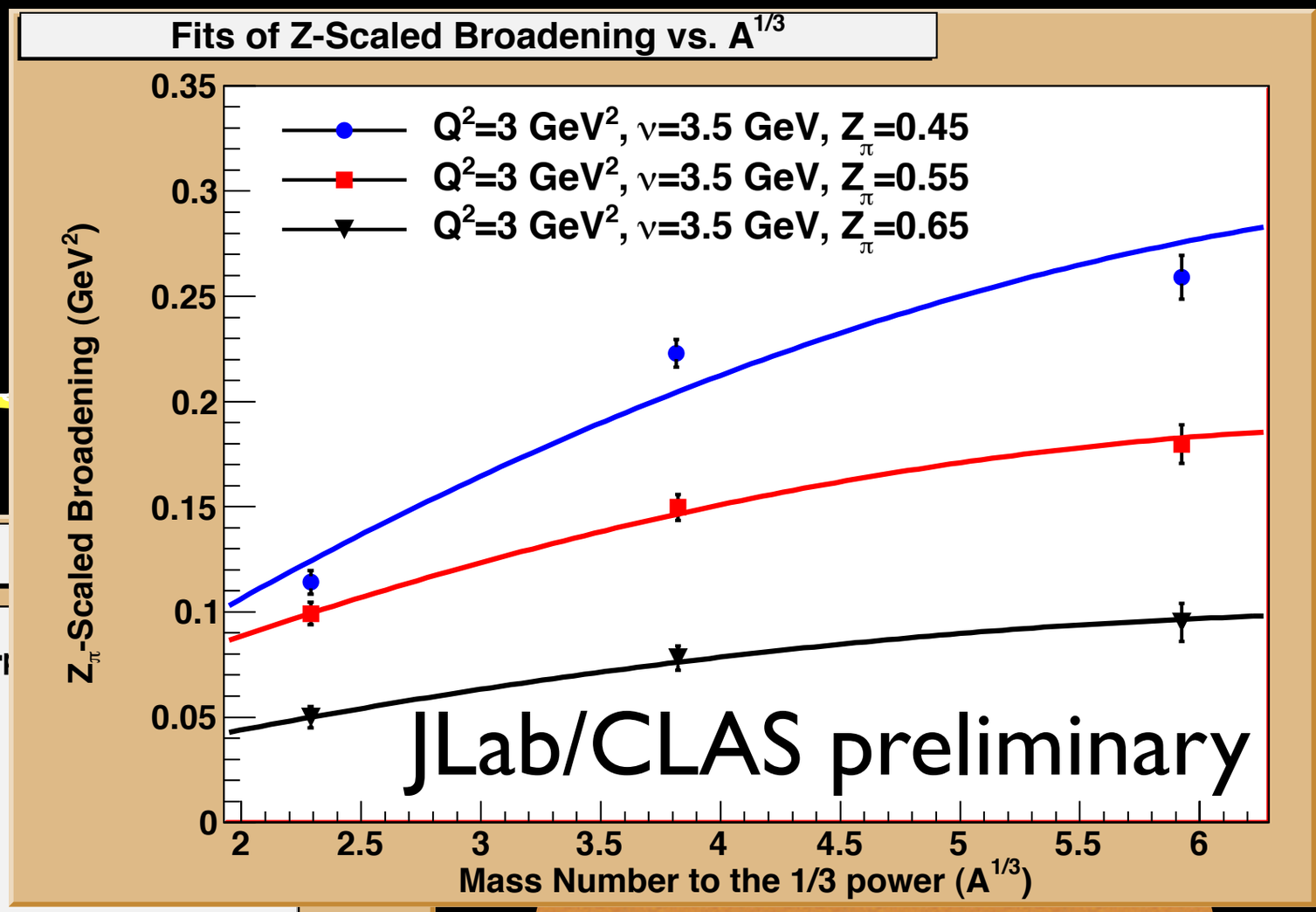


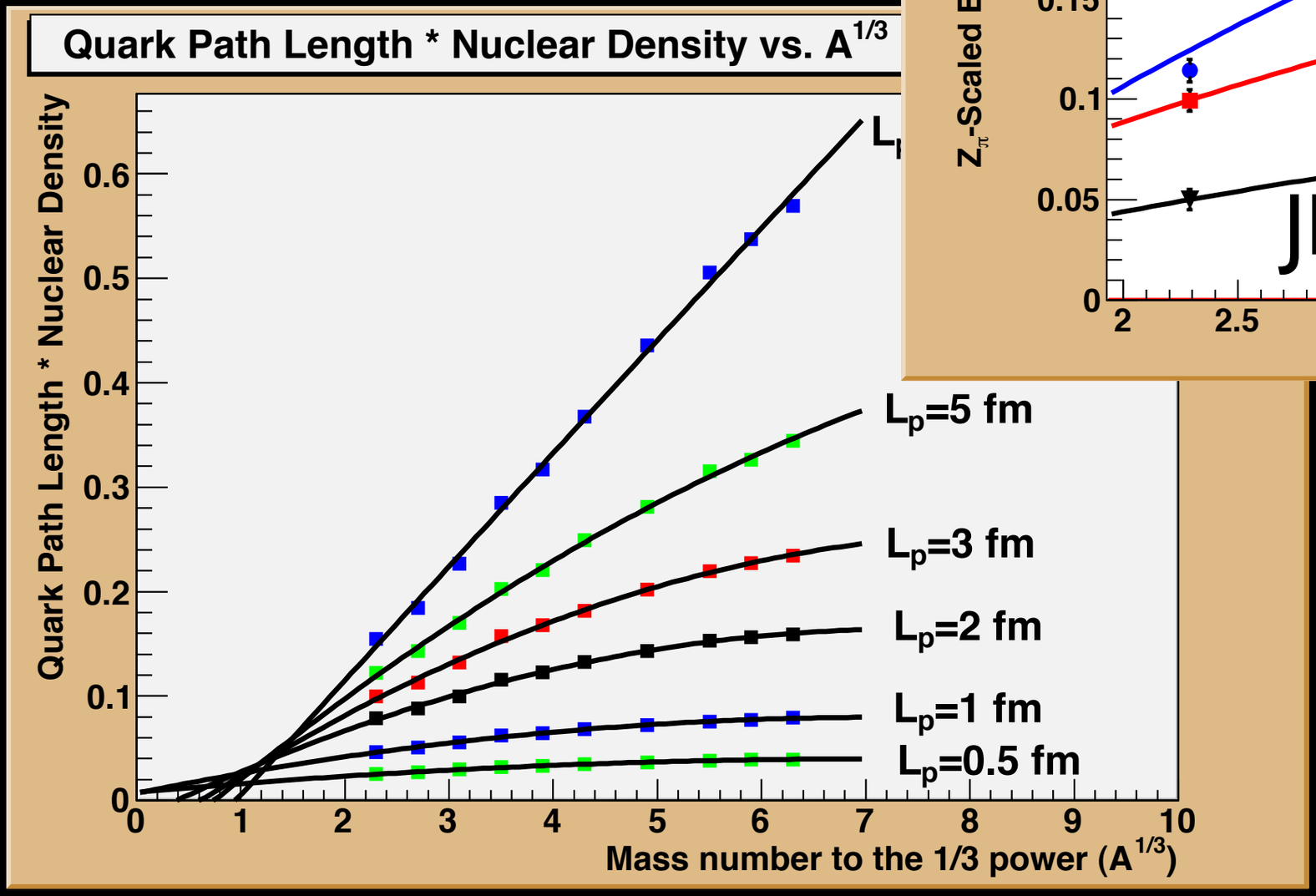


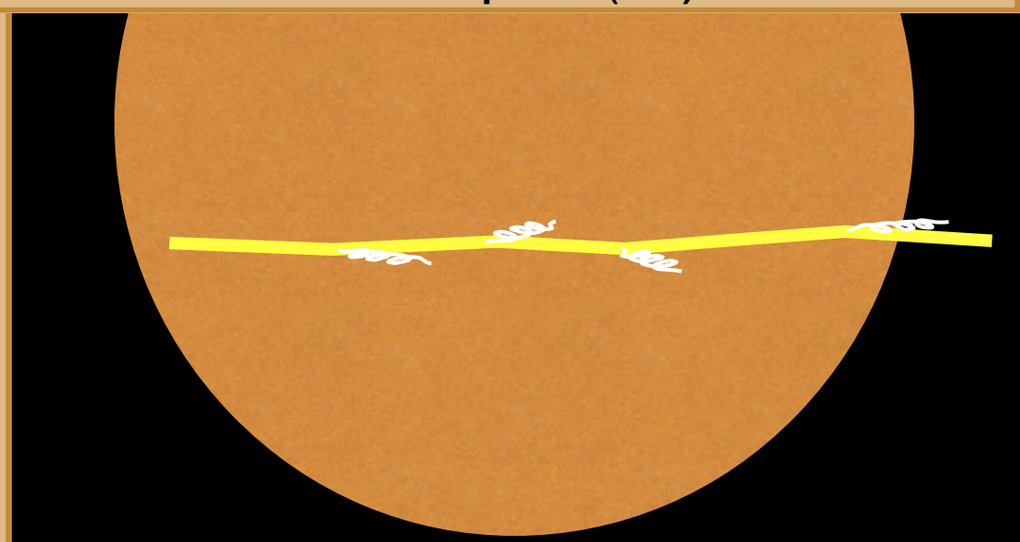

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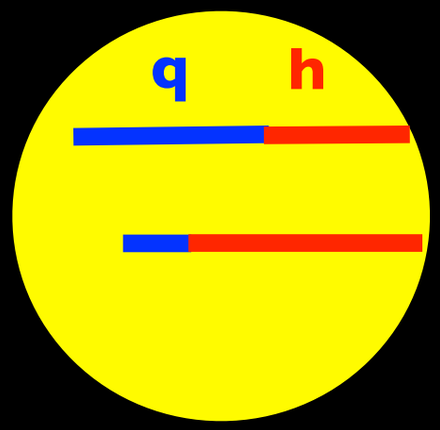

# Geometrical model

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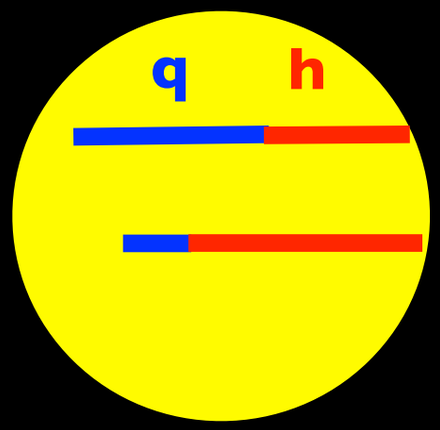

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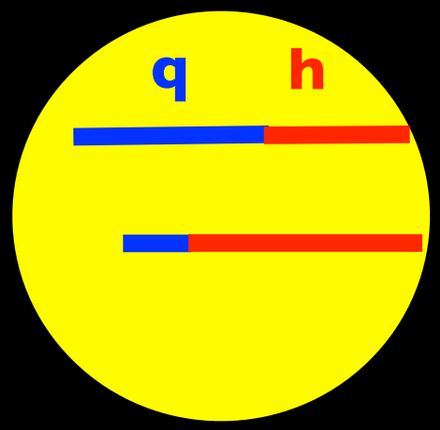

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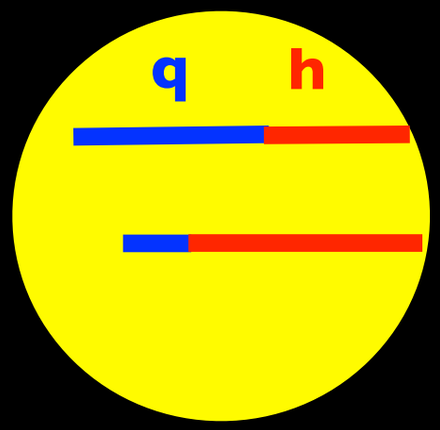

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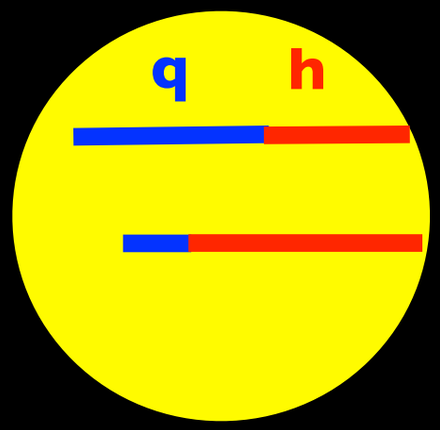
- Realistic nuclear densities



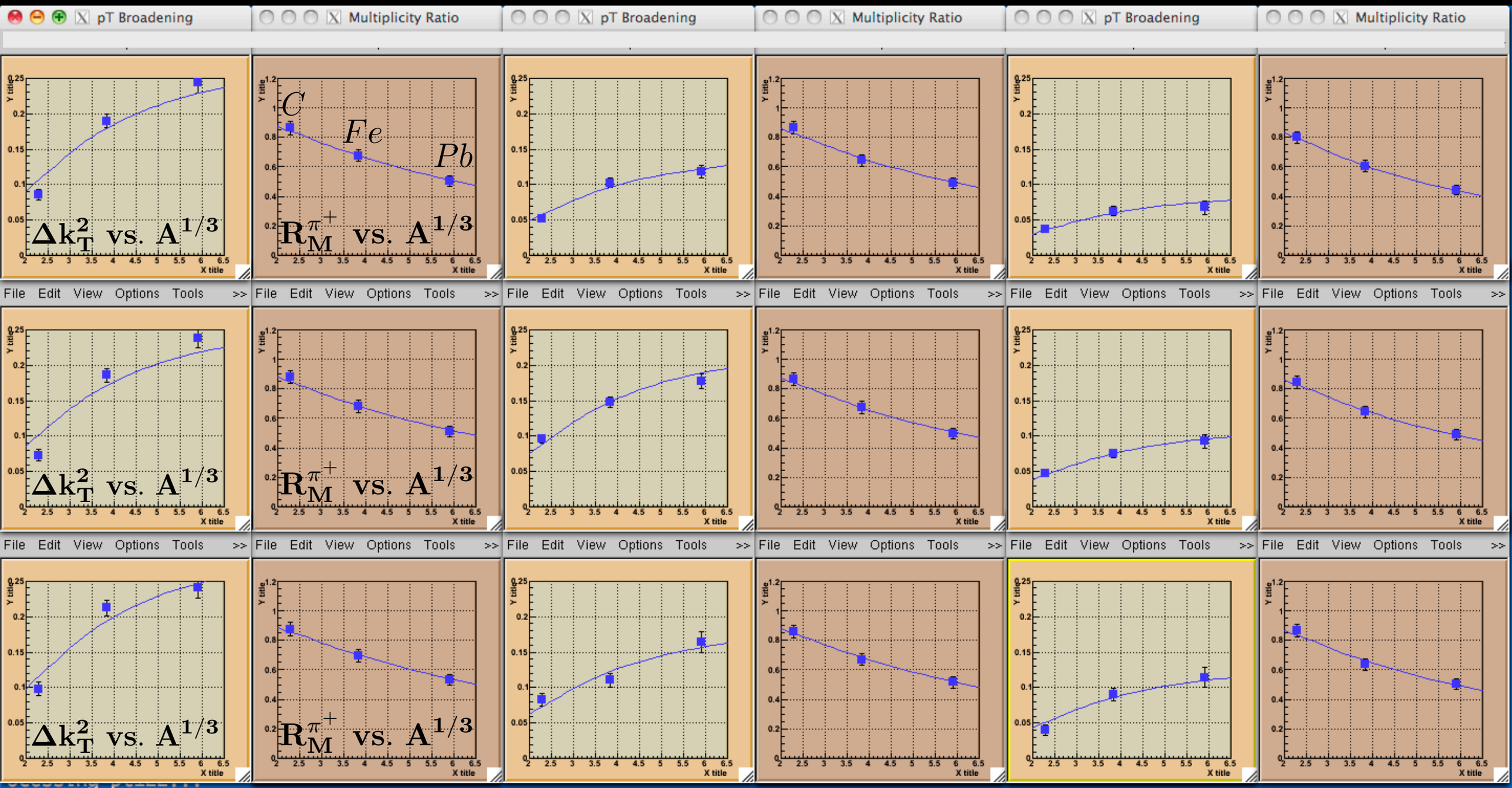

  - Path begins at point with probability proportional to density
  - Part of path is quark, part of path is (pre-) hadron

# Results from combined fit

## 3 or 4 parameter geometric model

## various bins in $Q^2$, $\nu$, and z

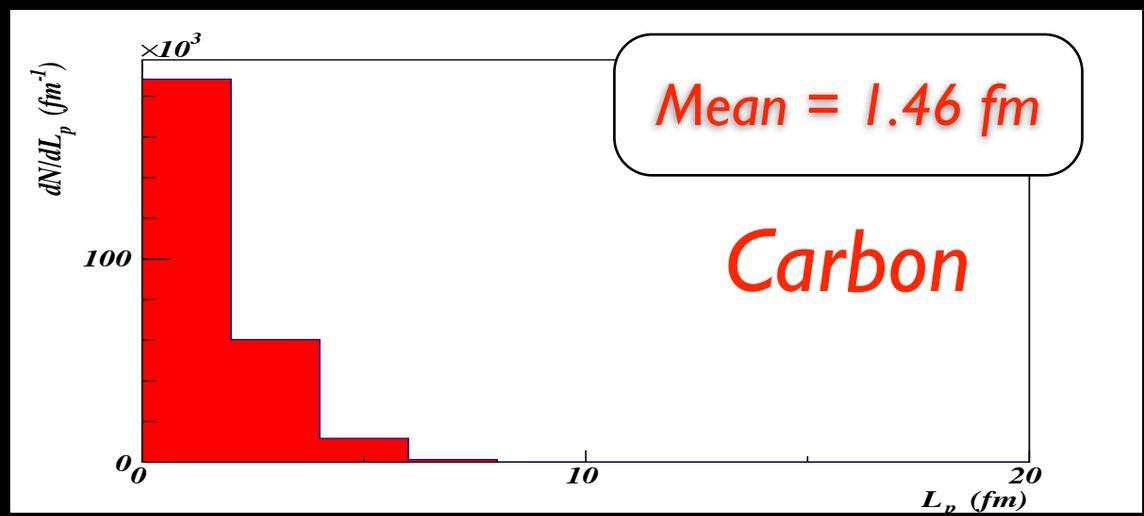
**fits are consistent with $\tau_p$=1.6 - 2 fm/c (<$R_{carbon}$/c)**

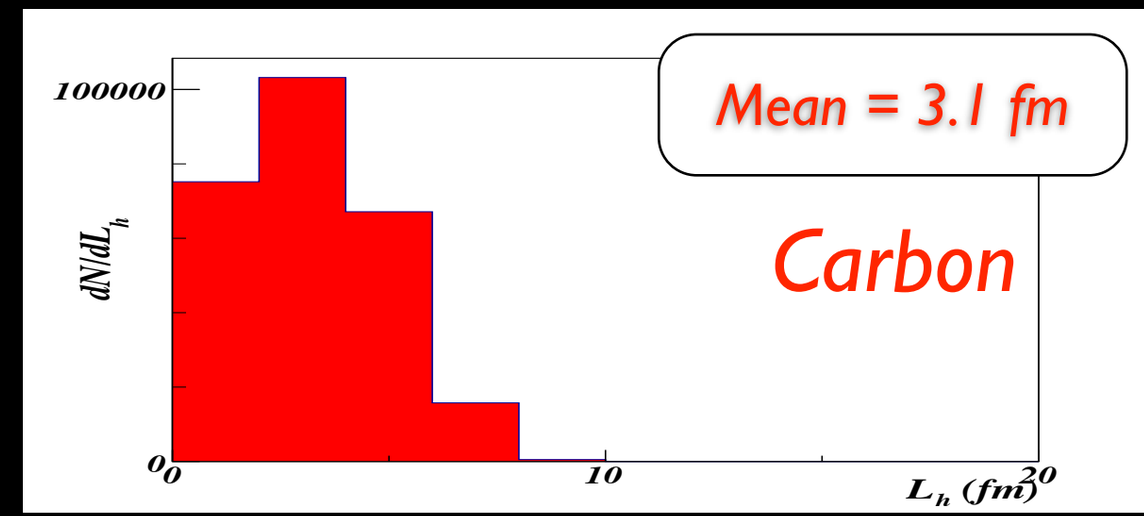


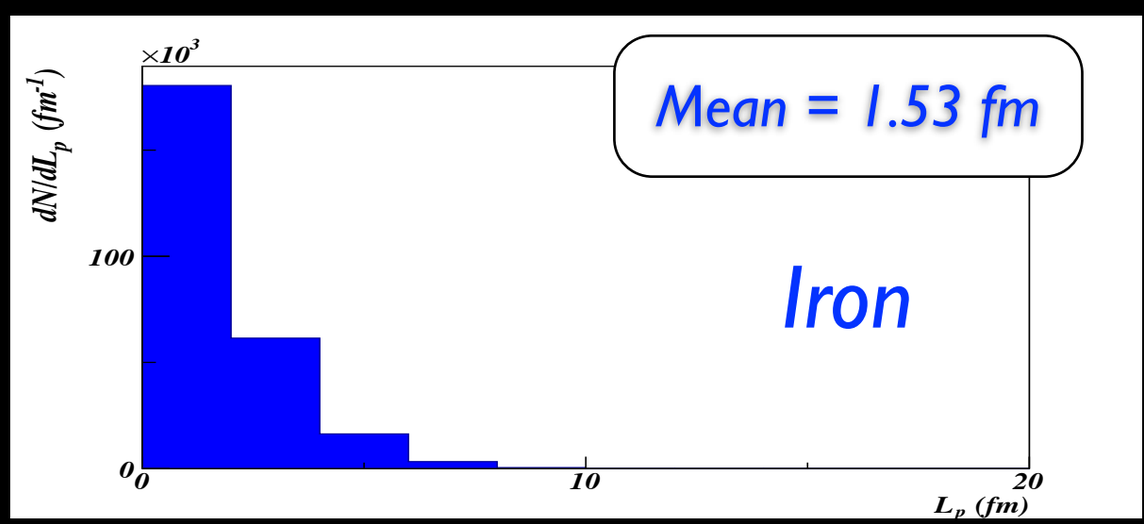
# *Distributions of lengths <u>within</u> the medium for $L_p$=1.6 fm*

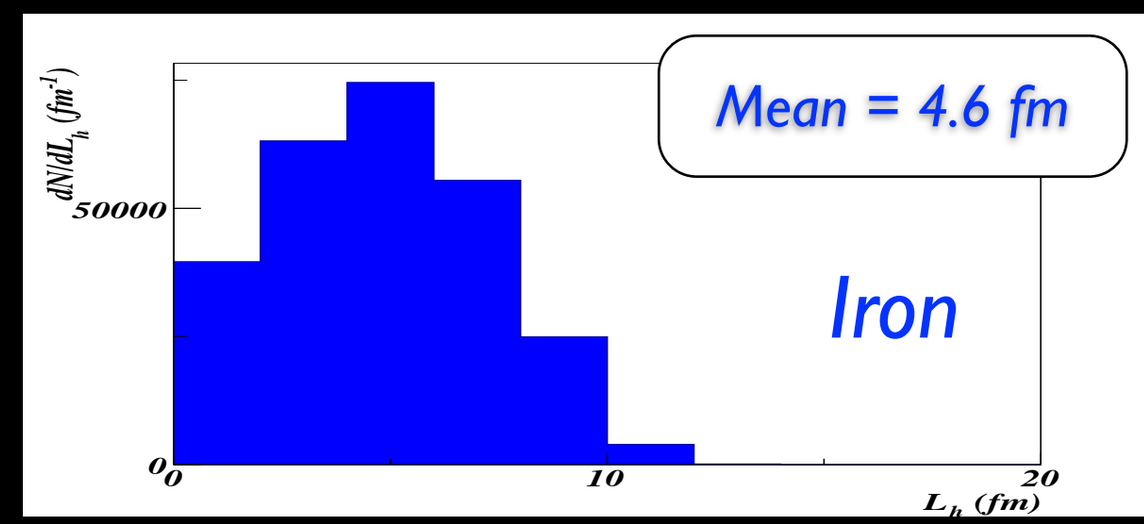
Partonic lengths

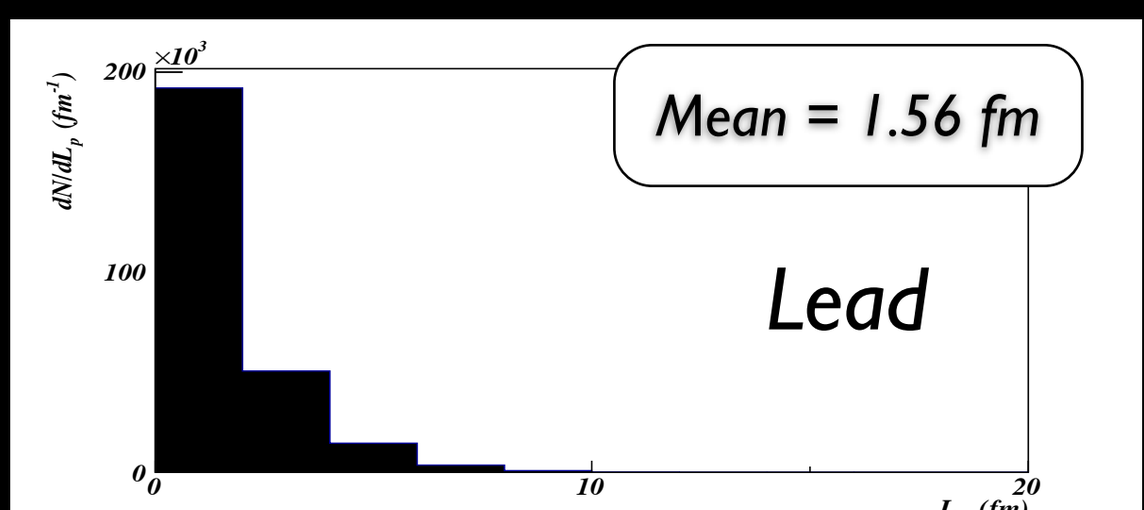
Hadronic lengths

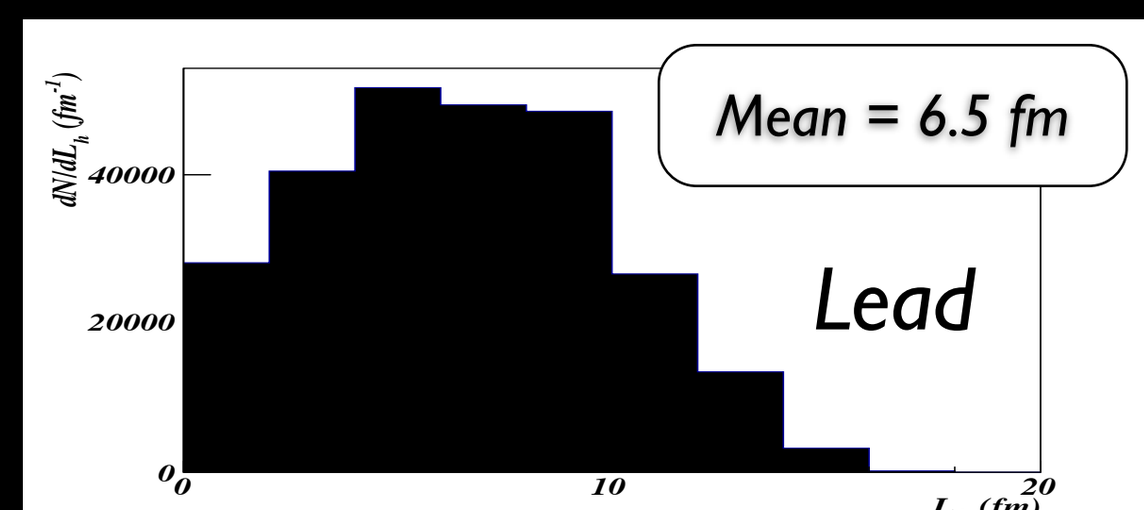


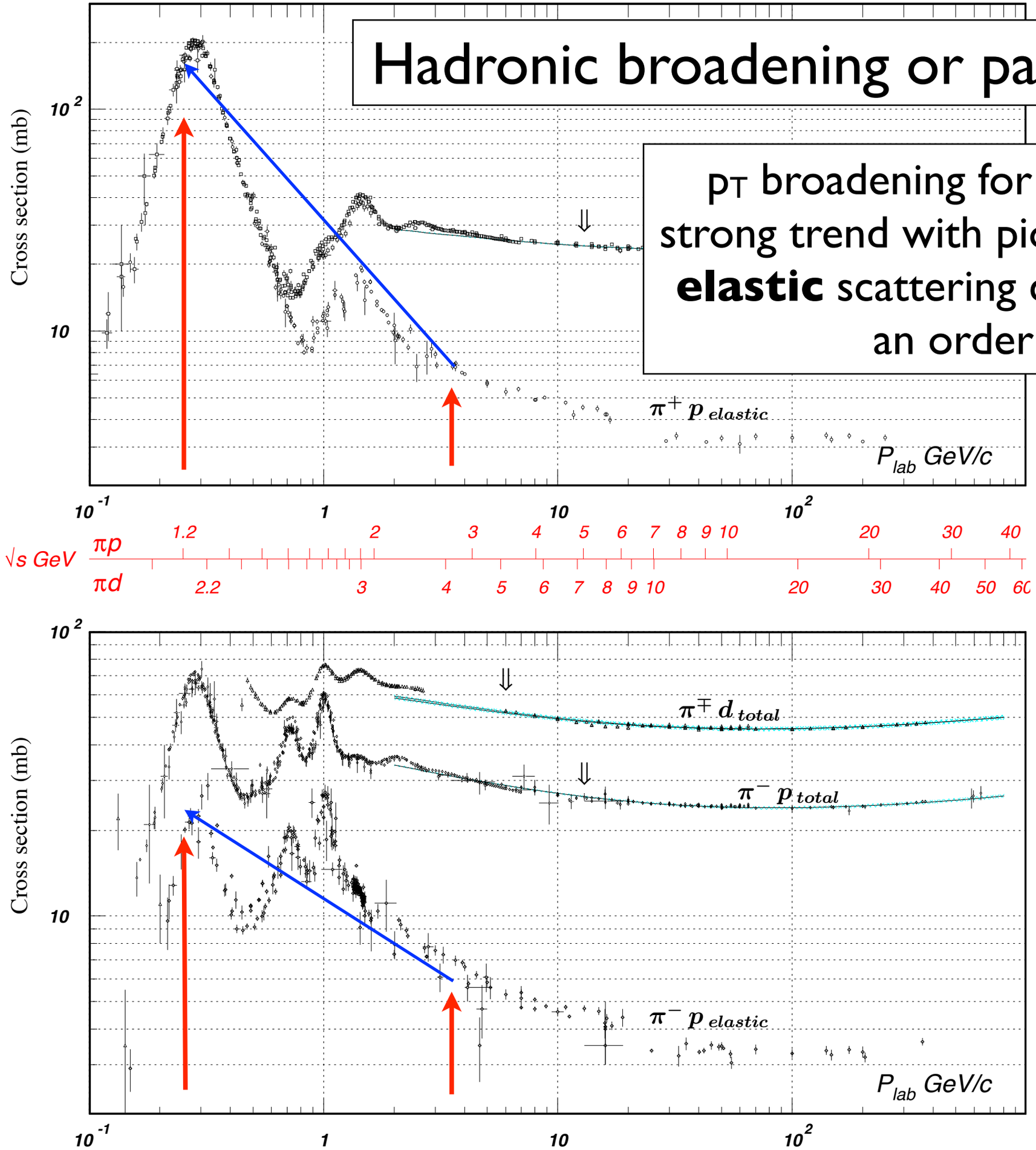



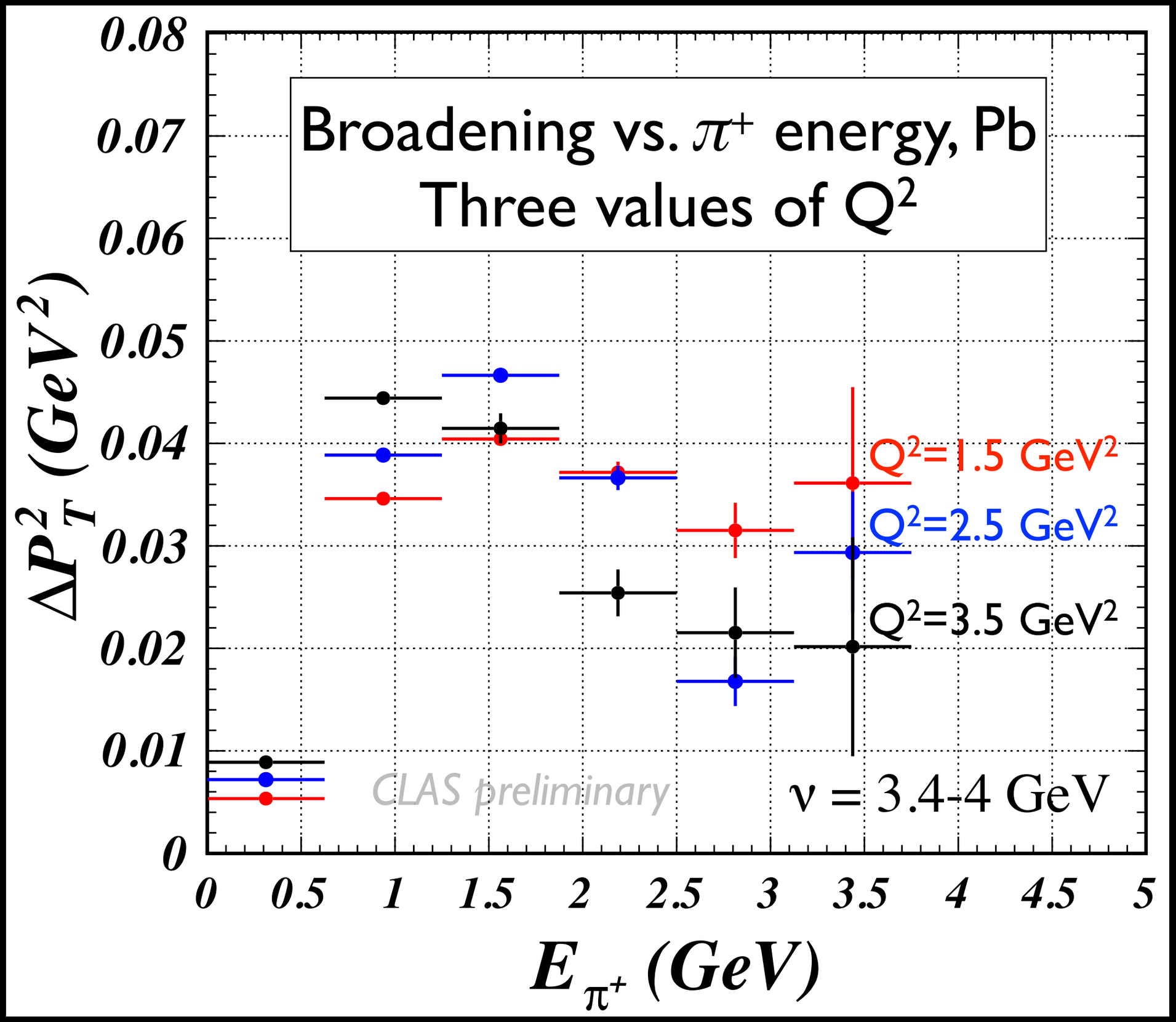



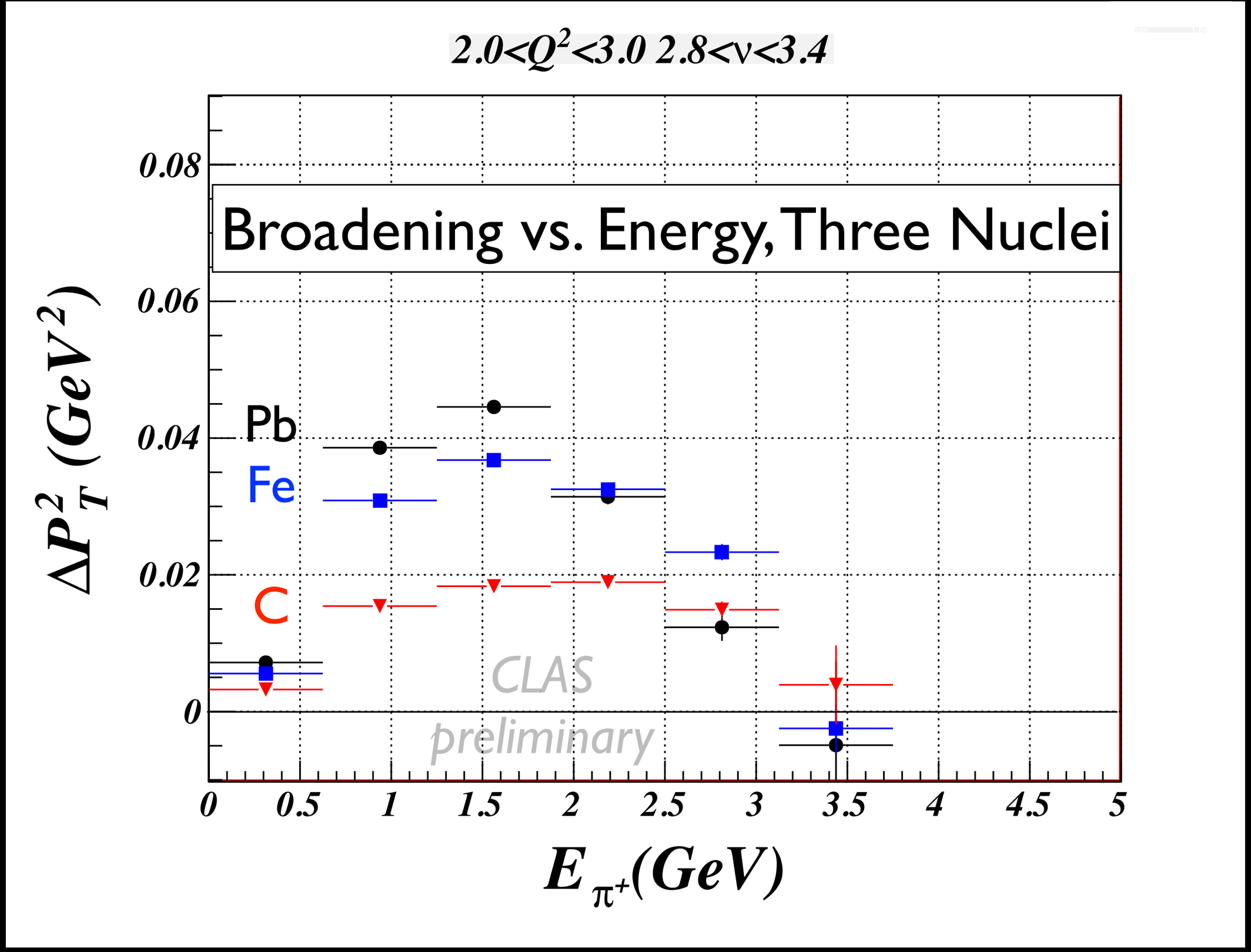
# Hadronic broadening or partonic broadening?

$p_T$ broadening for Pb does not show any strong trend with pion energy, while hadronic **elastic** scattering cross section changes by an order of magnitude






Expect some $Q^2$ dependence if there is partonic broadening



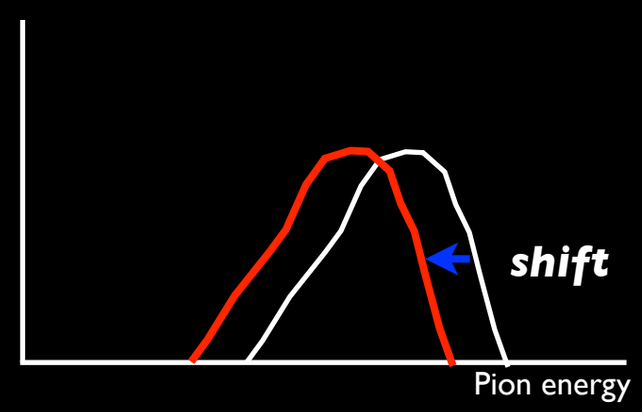

No evidence of hadronic broadening - no peak at low energies, and carbon (N=Z) flatter than lead (N>>Z)

## *New:* exploring a *direct measurement* of quark energy loss using $\pi^+$ energy spectrum

- Order of magnitude can be estimated from theory as ~100 MeV/fm, although factors of up to 10 are disputed
- Measurements of energy loss in cold nuclear matter have been attempted with 800 GeV protons
- 6 fm * 100 MeV/fm = **600 MeV** ...not easy to see with Drell-Yan muon pairs from 800 GeV protons on tungsten; but should be 'easy' to see with 2 GeV pions produced in DIS

# How to *directly* measure quark energy loss?

- Energy loss is predicted on very solid grounds to be *independent of energy* for a medium that is thin enough.
- "Thin enough" depends on energy, see next slide; if medium is thicker than "thin enough" it still loses energy
- If the energy loss is independent of energy, it will produce a ***shift*** of the energy spectrum, for higher energies.
- We can look for a ***shift*** of the Pb energy spectrum compared to that of the deuterium energy spectrum

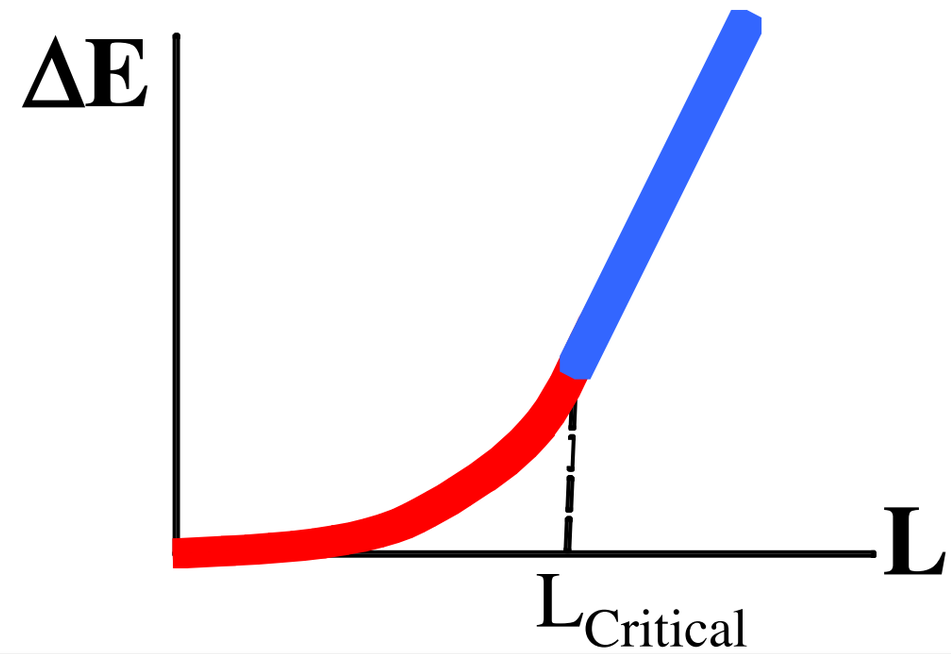


# Energy Loss in pQCD

(BDMPS-Z version)

$L < L_{Critical}$ $$-\frac{dE}{dx} \propto L\hat{q}$$

$L > L_{Critical}$ $$-\frac{dE}{dx} \propto \sqrt{E\hat{q}}$$




$$\text{at} \;\; \mathrm{L} = \mathrm{L}_{\mathrm{Critical}}, \;\; \mathrm{L}\hat{\mathrm{q}} \propto \sqrt{\mathrm{E_q} \cdot \hat{\mathrm{q}}} \;\; ; \quad \mathrm{L}_{\mathrm{Critical}} \propto \sqrt{\frac{\mathrm{E_q}}{\hat{\mathrm{q}}}}$$

$$\mathrm{E_q} \approx \nu \approx \;\; \text{few GeV}, \;\; \hat{\mathrm{q}} \approx 0.02 - 0.1 \;\; \mathrm{GeV}^2/\mathrm{fm},$$

$$\longrightarrow \quad \sqrt{\frac{\mathrm{E_q}}{\hat{\mathrm{q}}}} \approx \;\; \mathrm{R_{lead}} - \mathrm{R_{carbon}}$$

(multiplied by an unknown prefactor)

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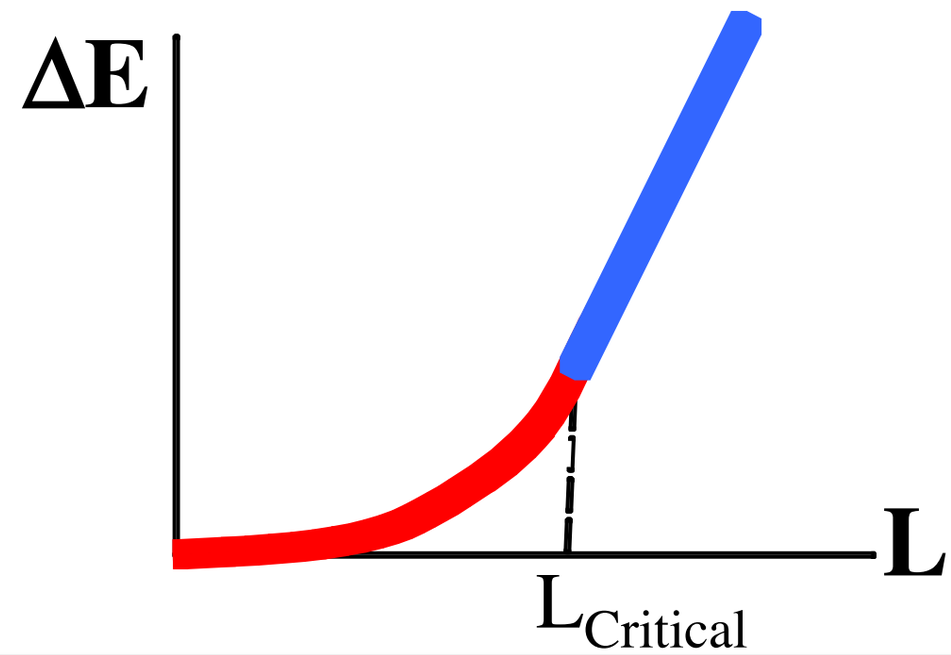


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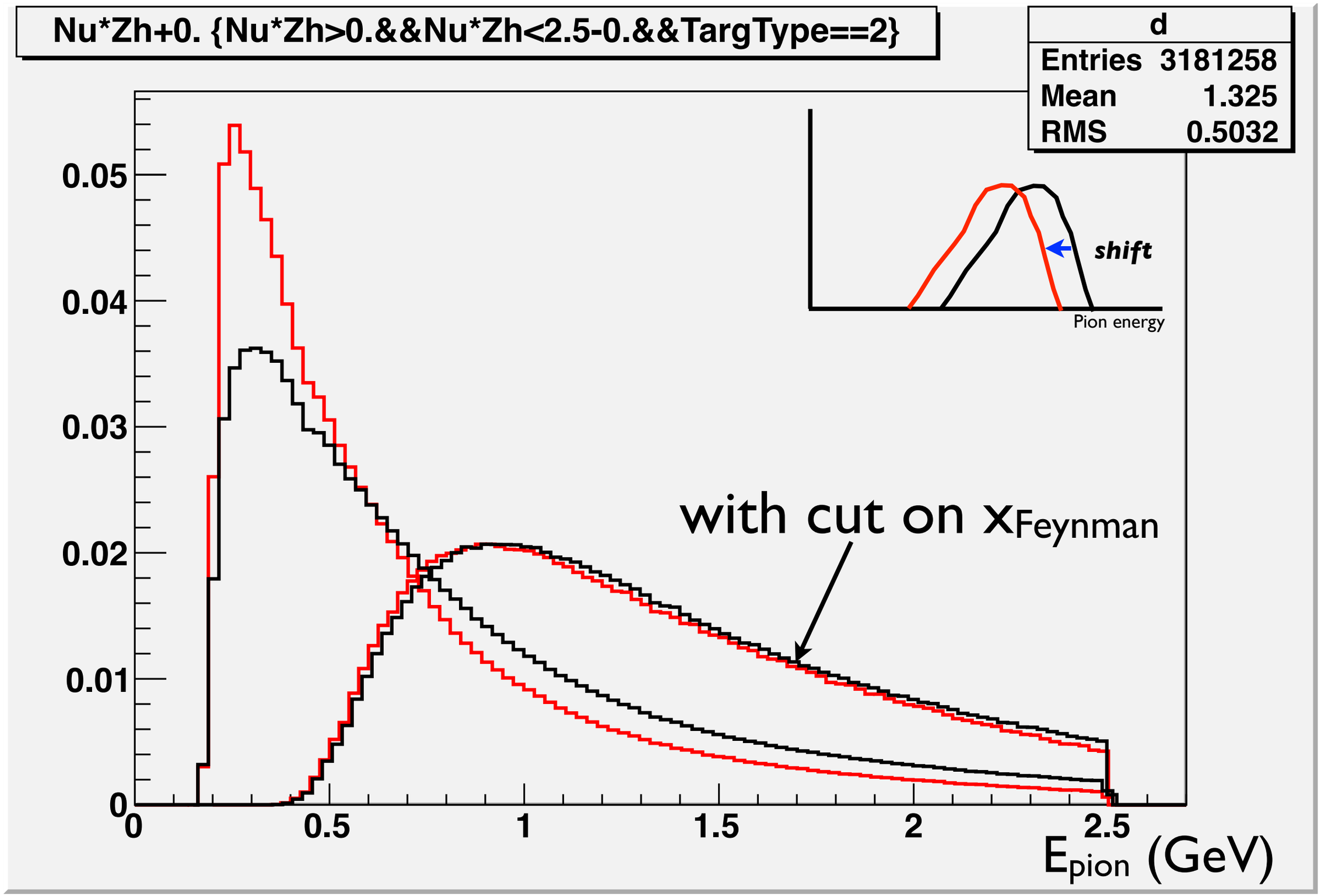
(H. Ma talk)
(P. Gossiaux talk) $\longrightarrow$ $$\sqrt{\frac{\mathrm{E_q}}{\hat{\mathrm{q}}}} \approx \;\; \mathrm{R_{lead}} - \mathrm{R_{carbon}}$$
(S. Peigne talk)

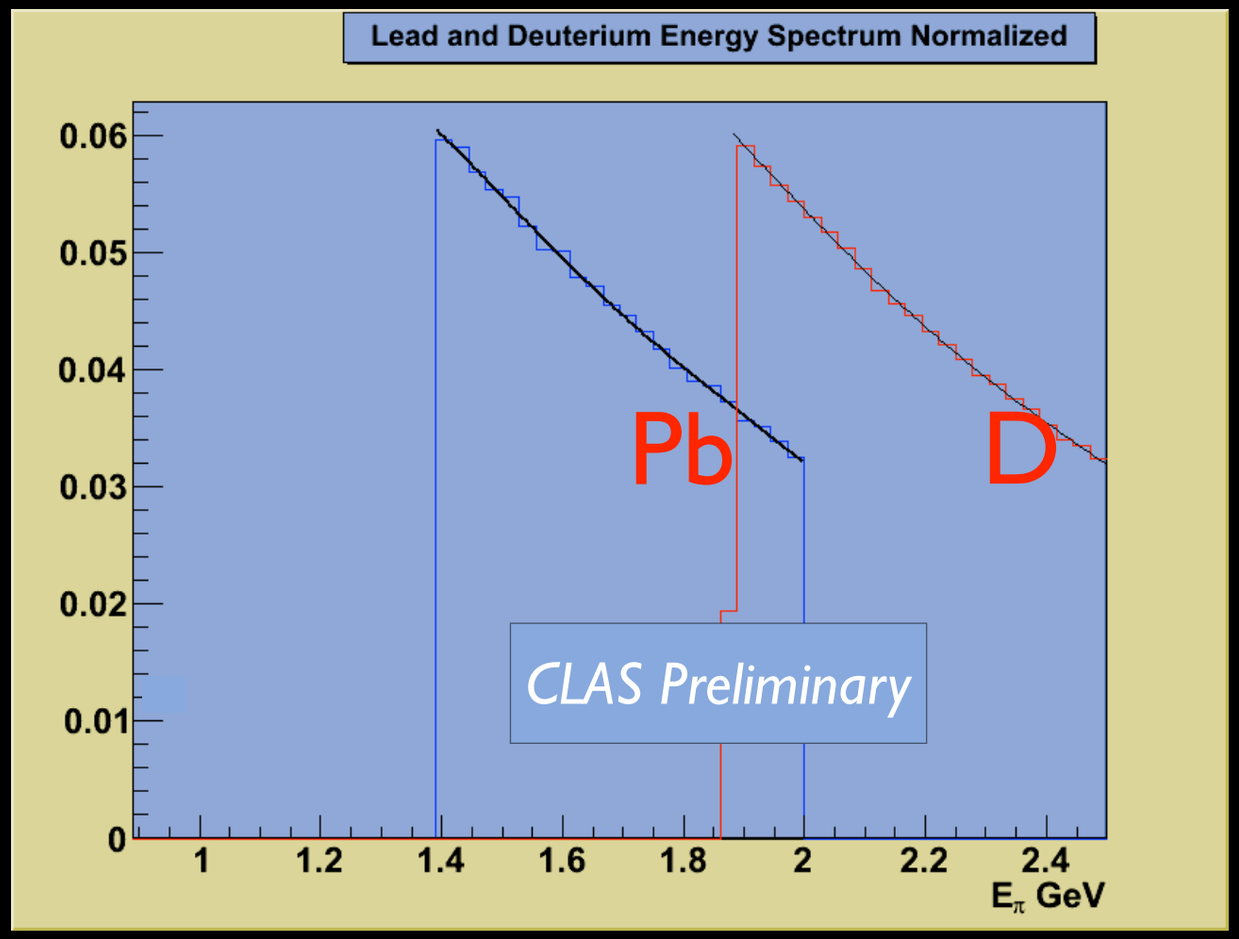
(multiplied by an unknown prefactor)

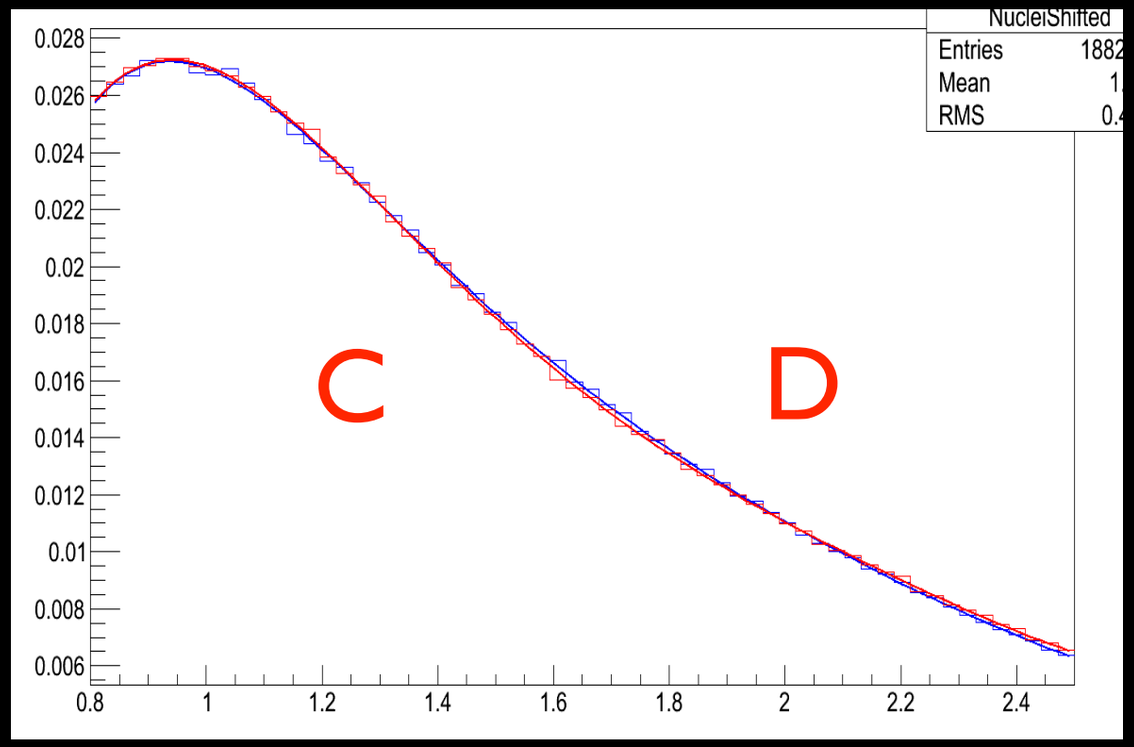
"Energy losses in relativistic plasmas: QCD versus QED," Peigne, Smilga, arXiv:0810.5702v2
"Coherent Radiative Parton Energy Loss beyond the BDMPS-Z Limit," Zapp, Wiedemann 1202.1192
"Medium-induced emissions of hard gluons," Apolinário, Armesto, Salgado 1204.2929

# Full lineshapes, deuterium and Pb (CLAS EG2 data) with and without cut on $x_{Feynman}$ (*normalized to area 1.0*)



# Minimize difference between shifted fitted spectra




Results look promising, but more systematic study of the shape analysis is needed

Early indications suggest that energy loss $\Delta E \leqq$ perturbative formula * $L_p$

$$-\frac{dE}{dx} = \frac{\alpha_s N_c}{4} \Delta p_T^2$$

# Future Prospects

- p-A in 2012:
  - *FNAL* - E906, 120 GeV fixed-target Drell-Yan, commissioning now, running ~2013 J-C Peng talk
  - *LHC:* ATLAS, CMS, ALICE, LHCb: currently Oct 31-Nov 23, 5 TeV per NN collision
- e-A:
  - *JLab* - 11 GeV upgraded CLAS12, ~2015-2018 R. Dupré talk
  - *EIC* - Electron-Ion Collider R. Ent talk
  - *LHeC*?
- A-A
  - *RHIC*, ongoing
  - *LHC*, 2015 (short run in 2012?)

# *New:* p-Pb at the LHC

- p-Pb collisions tentatively planned for 2012
- 2011 accelerator feasibility test successful
- hoping for luminosities at level $1.5 \times 10^{29}$ $cm^{-2}$ $s^{-1}$
- beyond baseline for heavy ions: rich physics program!
  - *Saturation of partonic densities at low x, e.g.* $R_{pPb}$
  - *Photon Drell-Yan*
  - *Cronin effect ('low'* $p_T$ *behavior of* $R_{pPb}$*)*
  - *Nuclear PDFs - jets (dijets, low energy?), EW bosons, prompt photons, quarkonia*
  - *Ultraperipheral collisions*
  - *Modification of jets/hadronization process in-medium*
  - *Cosmic-ray physics at ultra-high energies*

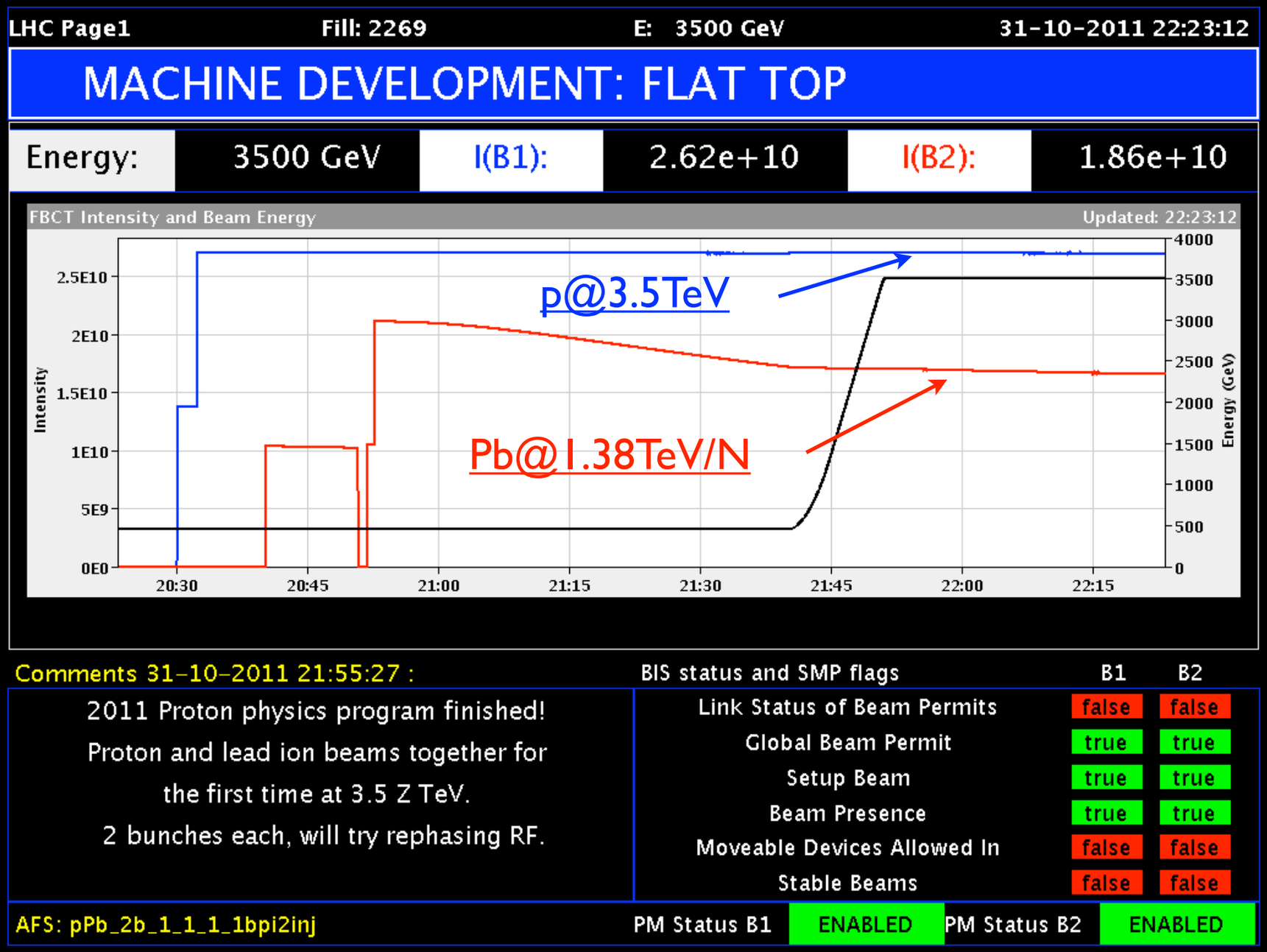
# LHC p-Pb feasibility test, October 31

Injected 2 bunches of protons, then 2 bunches of Pb ions

Ramped to full energy (4.4 TeV CM)

Forced both beams to same revolution frequency

Changed relative phase to synchronize collisions at the IPs




No collisions yet, but all ingredients proven to work!

# LHC p-Pb: Recent Papers
# (partial list: participants/organizers! apologies for omissions)

"Direct Photon Production in p-A and A-A Collisions," J. Cepila, J. Nemchik, 1106.0146; J. Nemchik talk

"Revisiting scaling properties of medium-induced gluon radiation," Arleo, Peigne, Sami, 1006.0818

"Nuclear suppression of J/Psi: from RHIC to the LHC," B.Z. Kopeliovich, I.K. Potashnikova, I. Schmidt

"Proton-Nucleus Collisions at the LHC: Scientific Opportunities and Requirements," C. A. Salgado (Editor), J. Alvarez-Muniz, F. Arleo, N. Armesto, M. Botje, M. Cacciari, J. Campbell, C. Carli, B. Cole, D. D'Enterria, F. Gelis, V. Guzey, K. Hencken, P. Jacobs, J. M. Jowett, S. R. Klein, F. Maltoni, A. Morsch, K. Piotrzkowski, J. W. Qiu, T. Satogata, F. Sikler, M. Strikman, H. Takai, R. Vogt, J. P. Wessels, S. N. White, U. A. Wiedemann, B. Wyslouch, M. Zhalov, http://arxiv.org/abs/1105.3919
and papers that refer to this paper

"Workshop: pA@LHC," CERN, 4-8 June 2012, Weidemann, Strikman, Salgado

"QCD saturation at the LHC: comparisons of models to p+p and A+A data and predictions for p +Pb collisions" Tribedy, Venugopalan 1112.2445

"Prompt photon production and photon-hadron correlations at RHIC and the LHC from the Color Glass Condensate," Jamal Jalilian-Marian, Amir H. Rezaeian, 1204.1319

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

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| *meson* | cτ | mass | flavor content |
|---|---|---|---|
| $\pi^0$ | 25 nm | 0.13 | $u\bar{u}d\bar{d}$ |
| $\pi^+, \pi^-$ | 7.8 m | 0.14 | $u\bar{d}, d\bar{u}$ |
| $\eta$ | 170 pm | 0.55 | $u\bar{u}d\bar{d}s\bar{s}$ |
| $\omega$ | 23 fm | 0.78 | $u\bar{u}d\bar{d}s\bar{s}$ |
| $\eta'$ | 0.98 pm | 0.96 | $u\bar{u}d\bar{d}s\bar{s}$ |
| $\phi$ | 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 | $d\bar{s}$ |
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| *baryon* | cτ | mass | flavor content |
|---|---|---|---|
| $p$ | stable | 0.94 | ud |
| $\bar{p}$ | stable | 0.94 | $\overline{ud}$ |
| $\Lambda$ | 79 mm | 1.1 | uds |
| $\Lambda(1520)$ | 13 fm | 1.5 | uds |
| $\Sigma^+$ | 24 mm | 1.2 | us |
| $\Sigma^-$ | 44 mm | 1.2 | ds |
| $\Sigma^0$ | 22 pm | 1.2 | uds |
| $\Xi^0$ | 87 mm | 1.3 | us |
| $\Xi^-$ | 49 mm | 1.3 | ds |

# 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 |
|---|---|---|---|
| $\pi^0$ | 25 nm | 0.13 | $u\bar{u}d\bar{d}$ |
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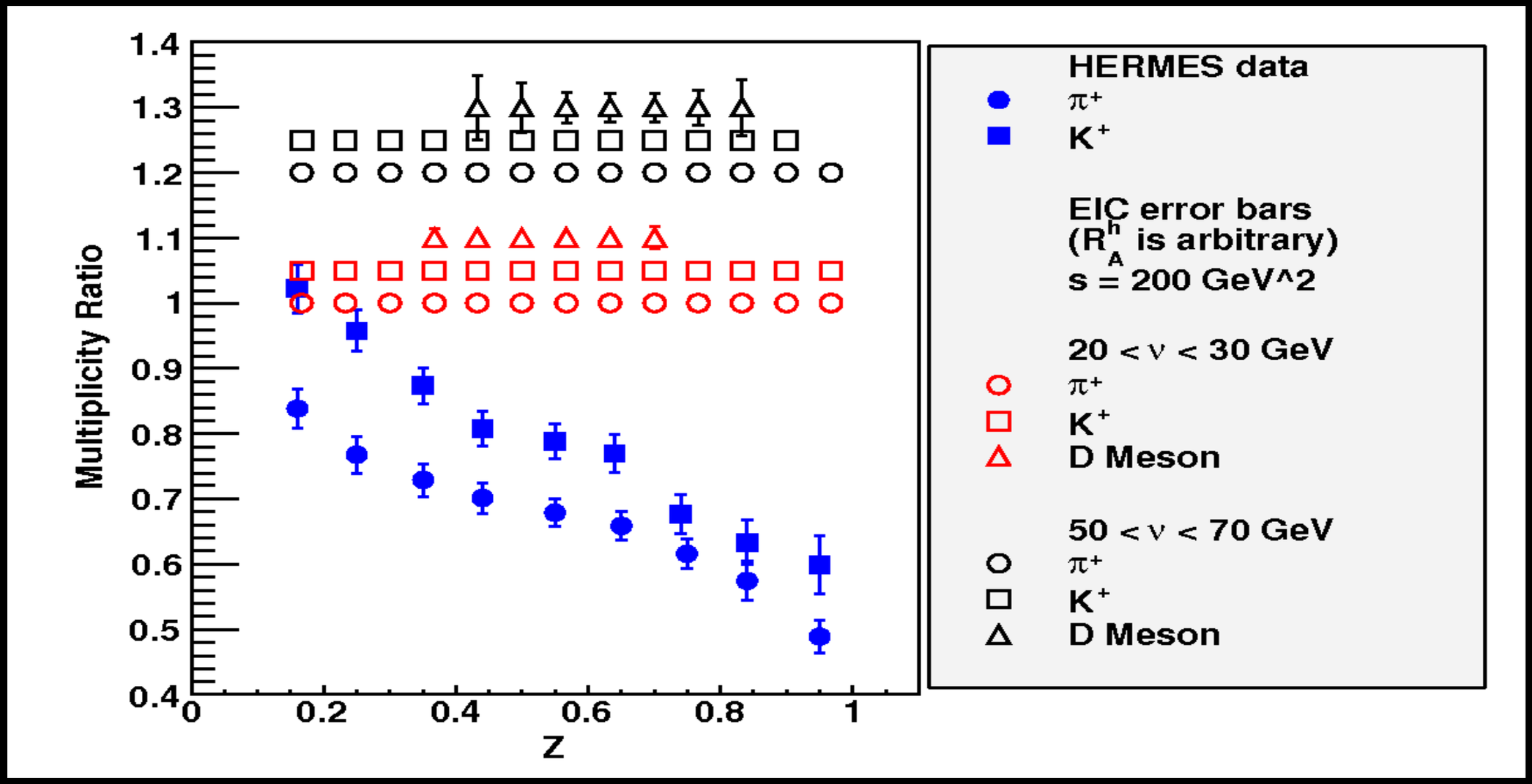
# Electron Ion Collider




Simulation by R. Dupre
more at http://arxiv.org/abs/1108.1713v2

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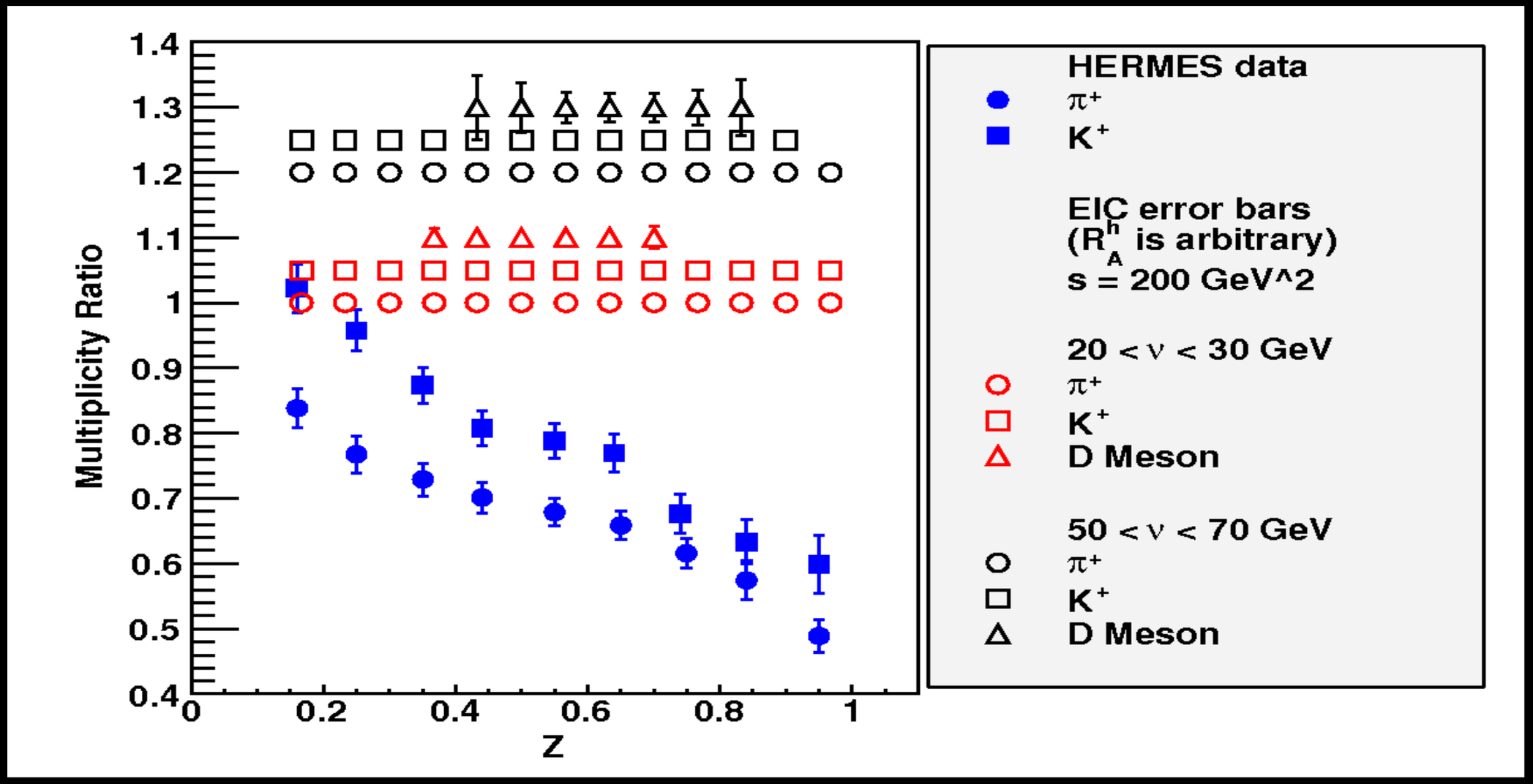


Example of one possibility at EIC - comparing partonic energy loss in light and heavy quark systems

Simulation by R. Dupre
more at http://arxiv.org/abs/1108.1713v2

# Conclusions

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- New tools:
  - $p_T$ broadening as *partonic* probe in nuclear systems
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- First observation of $\phi_{pq}$ dependence of $p_T$ broadening, suggesting a *quantum* description is necessary, and potentially probing partonic density fluctuations
- p-Pb collisions are coming this year at the LHC: parton propagation with TeV beams!

# Backup Slides

# Accessible energies and CM rapidities

Possible range of collision energies
Minimum p-Pb energy for equal revolution frequency.

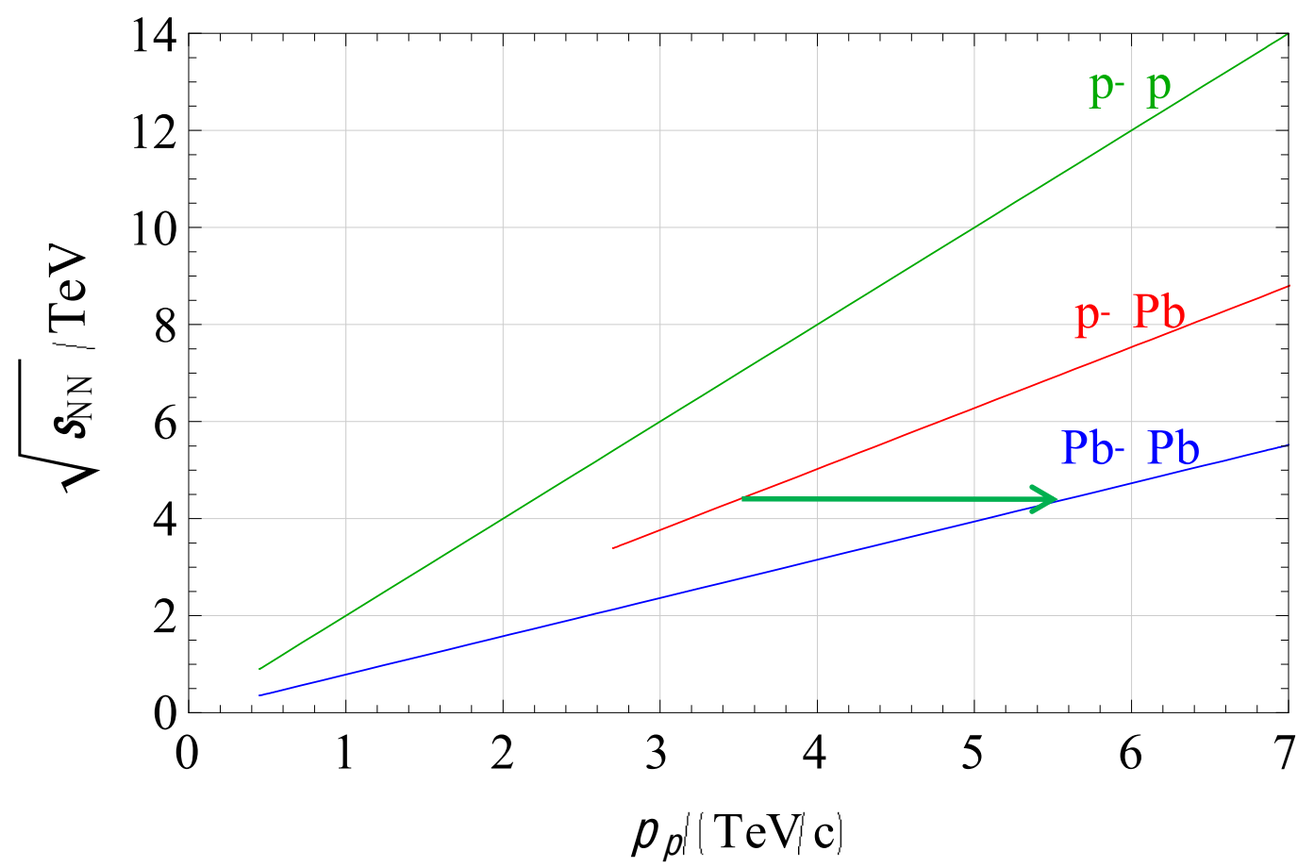
Relations between these numbers are a simple consequence of the two-in-one magnet design

| | p-p | Pb-Pb | p-Pb |
|---|---|---|---|
| $E/\mathrm{TeV}$ | 0.45-7 | 287-574 | (2.7-7,287-574) |
| $E_N/\mathrm{TeV}$ | 0.45-7 | 1.38-2.76 | (2.7-7, 1.38-2.76) |
| $\sqrt{s}/\mathrm{TeV}$ | 7-14 | 73.8-1148 | 48.9-126.8 |
| $\sqrt{s_{\mathrm{NN}}}/\mathrm{TeV}$ | 7-14 | 0.355-5.52 | 3.39-8.79 |
| $y_{\mathrm{CM}}$ | 0 | 0 | -2.20 |
| $y_{\mathrm{NN}}$ | 0 | 0 | +0.46 |

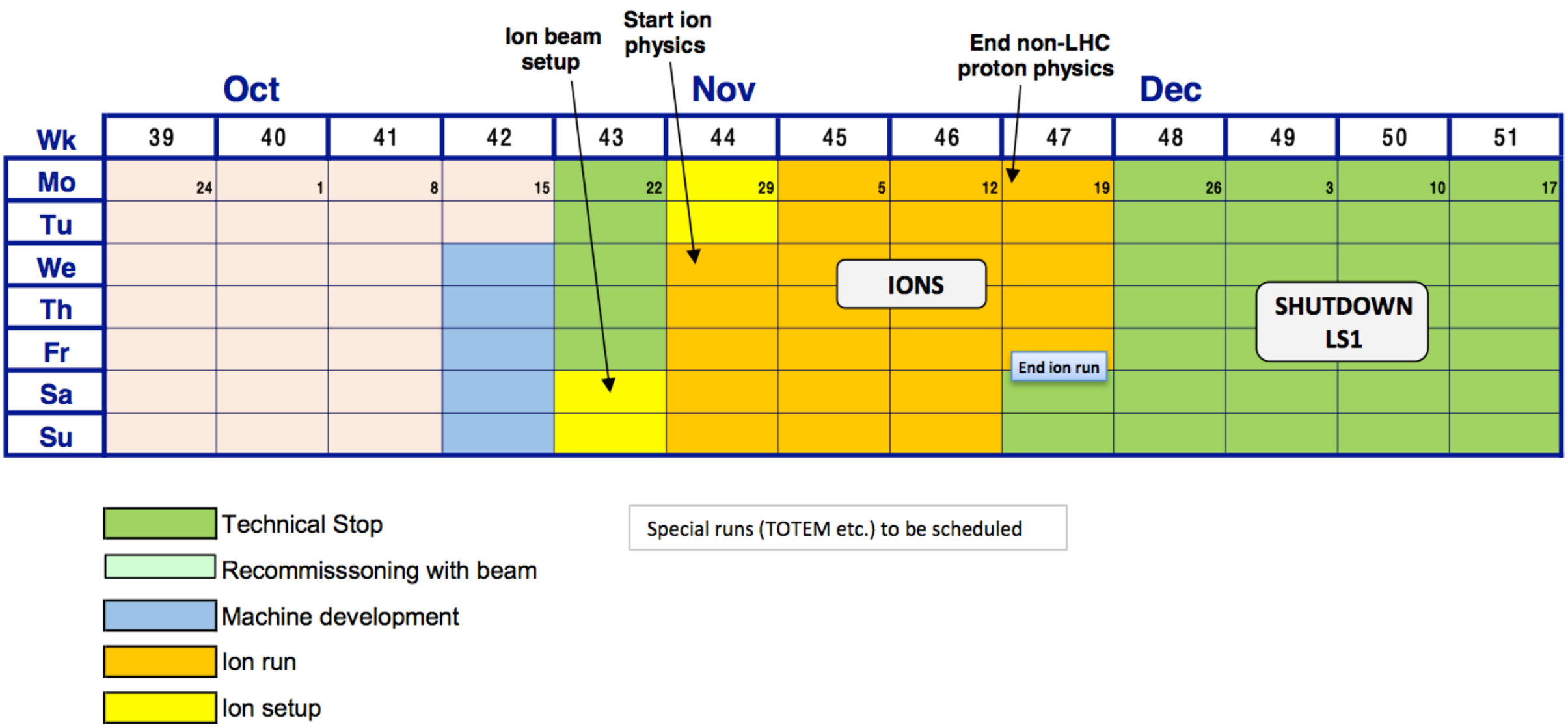
Charges $Z_1$, $Z_2$ in rings with magnetic field set for protons of momentum $p_p$

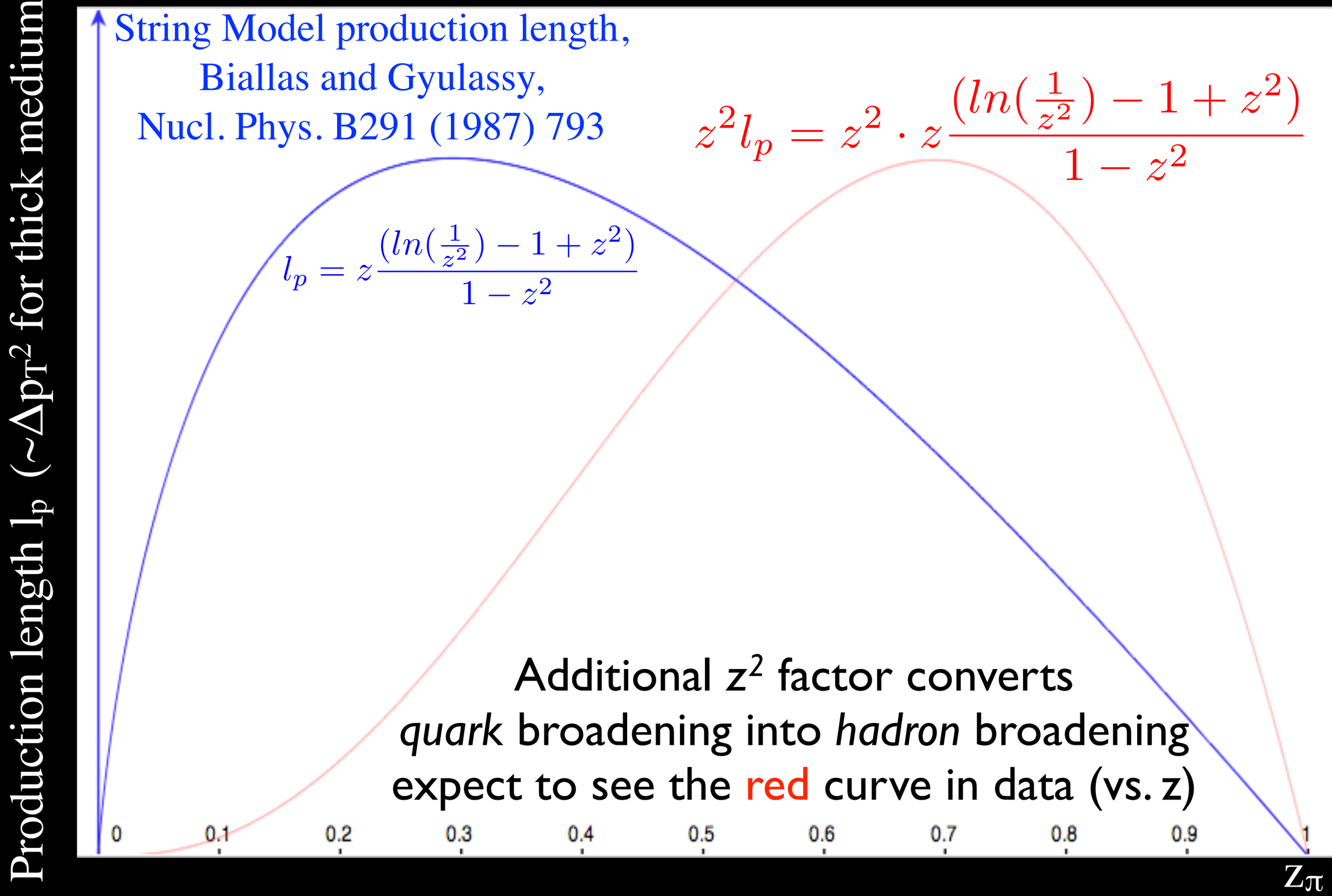
$$\sqrt{s_{NN}} \approx 2c\, p_p \sqrt{\frac{Z_1 Z_2}{A_1 A_2}},$$

$$y_{NN} = \frac{1}{2}\log\frac{Z_1 A_2}{A_1 Z_2}$$



# Preliminary 2012 LHC schedule for ion running

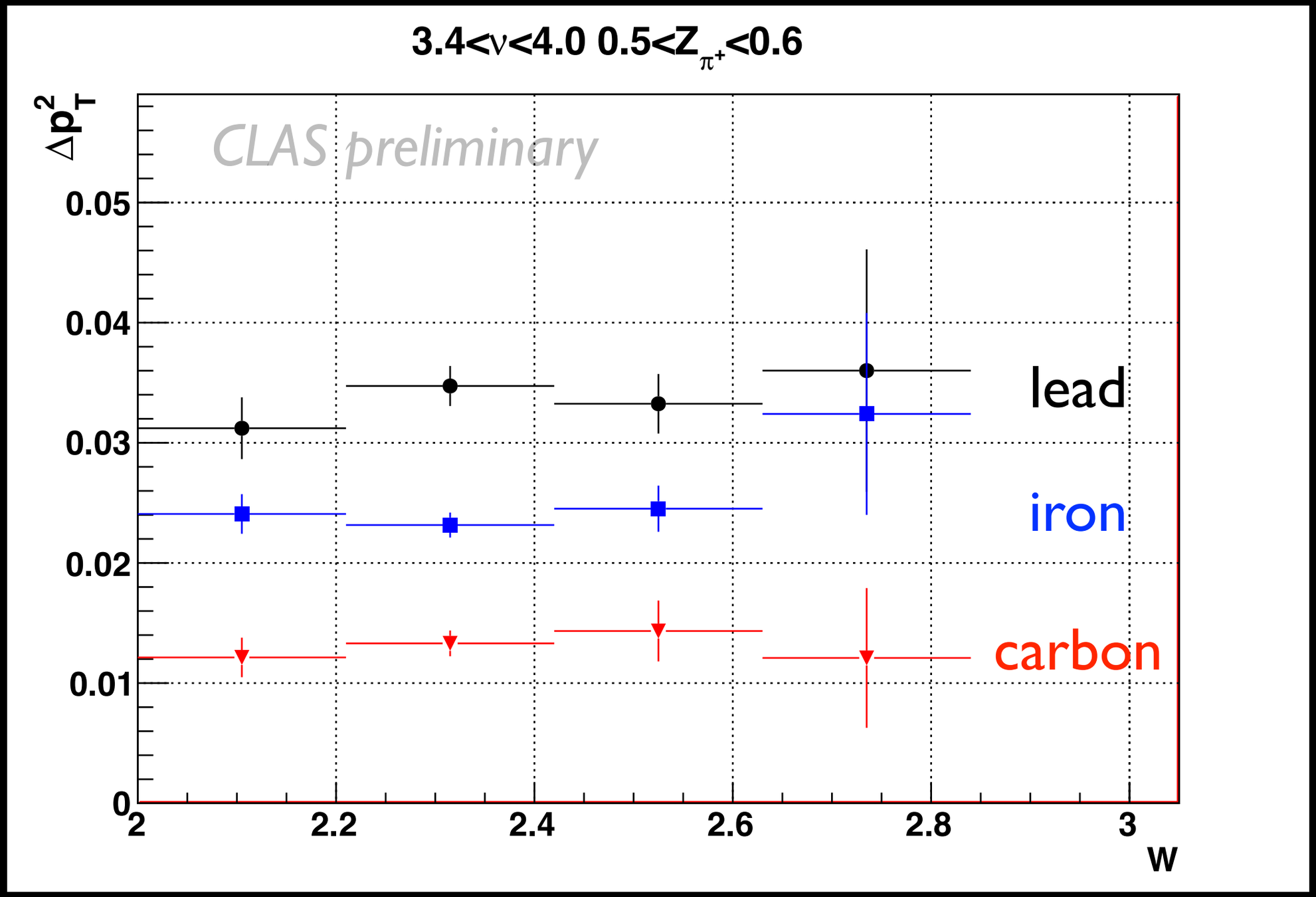



Production length $l_p$ ($\sim\Delta p_T^2$ for thick medium)
String Model production length,
Biallas and Gyulassy,
Nucl. Phys. B291 (1987) 793
$z^2 l_p = z^2 \cdot z \frac{(ln(\frac{1}{z^2}) - 1 + z^2)}{1 - z^2}$
$l_p = z \frac{(ln(\frac{1}{z^2}) - 1 + z^2)}{1 - z^2}$
Additional $z^2$ factor converts
*quark* broadening into *hadron* broadening
expect to see the red curve in data (vs. z)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
$z_\pi$

# Exploring a *direct measurement* of quark energy loss using $\pi^+$ energy spectrum - ***next steps***

- Radiative corrections
- Believe the results if:
  - robust, not sensitive to cuts
  - works over a wide energy range
  - the match in shape is extremely accurate
  - can't find any other explanation for the shift

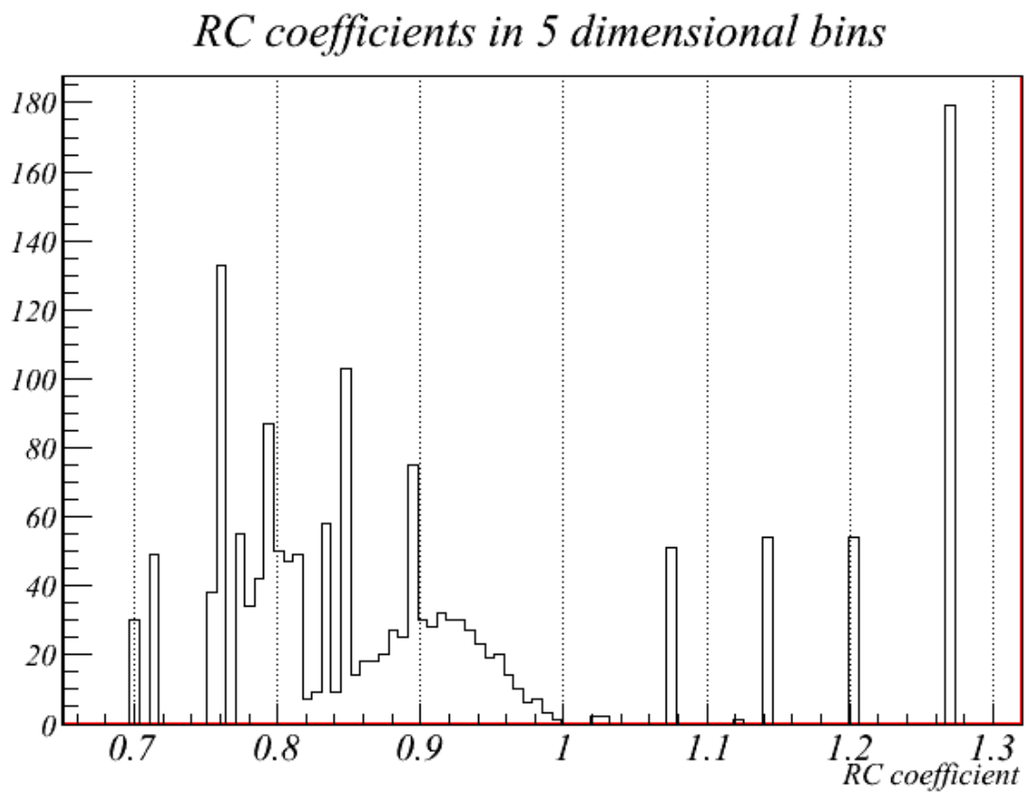
# Dependence of $p_T$ broadening on W




- Some variations, but no systematic evidence for influence of resonance region

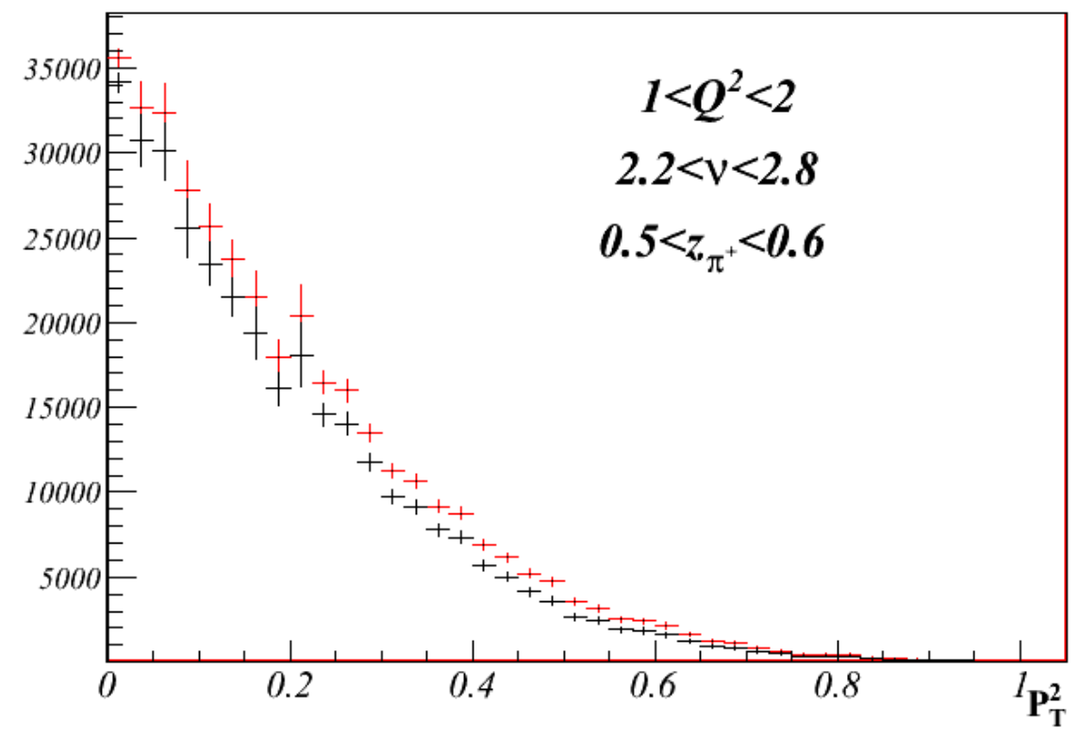
# Radiative Corrections

**HAPRAD_CPP** = HAPRAD(2) + Modified structure fnc from fit(x, $Q^2$, z, $p_T$, φ) to CLAS data




Distribution of the RC coefficients calculated for 3($Q^2$)x3(v)x3(z)x60($p_T$)xφ(12) equidistant points

$p_T^2$ without radiative correction (red) and the same with radiative correction (black)




HAPRAD_CPP code:
https://github.com/usm-data-analysis/HAPRAD_cpp


Radiative Effects in the Processes of Hadron Electroproduction. I.Akushevich, N.Shumeiko, A.Soroko. Eur. Phys. J. C10, 681-687 (1999).

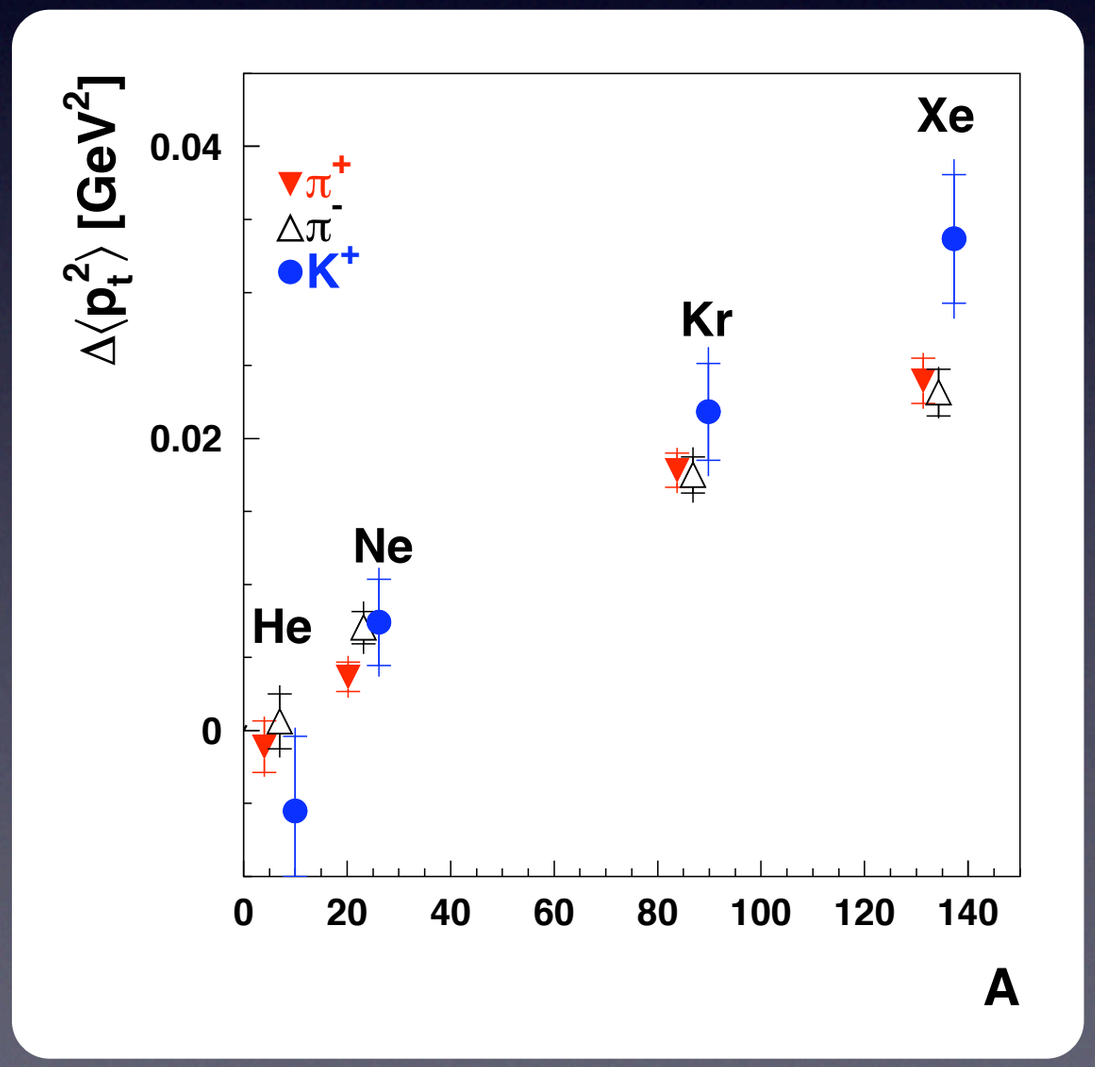
Lowest order QED radiative corrections to five-fold differential cross section of hadron leptoproduction. Phys. Lett. B 672 35-44 (2009).

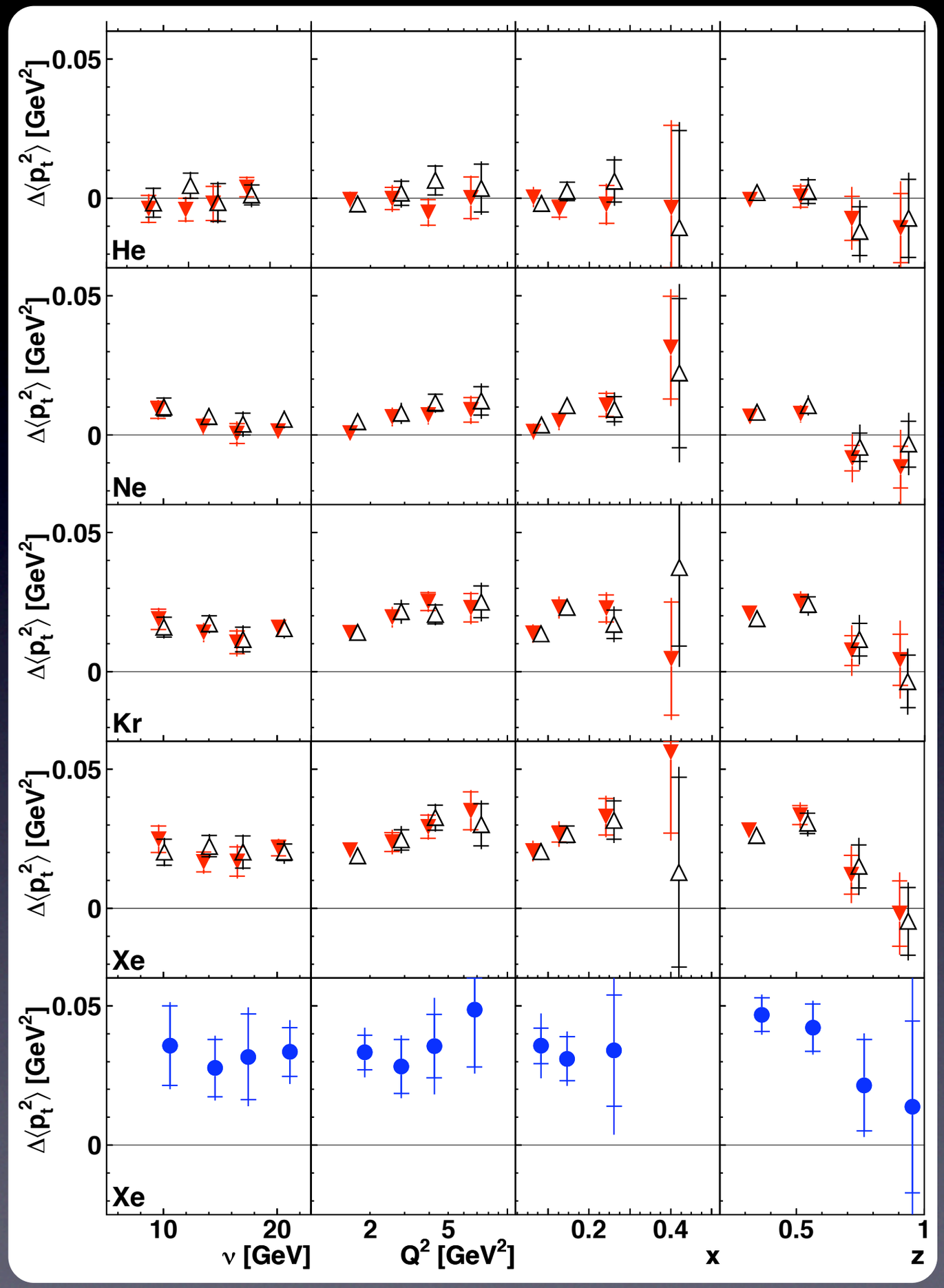


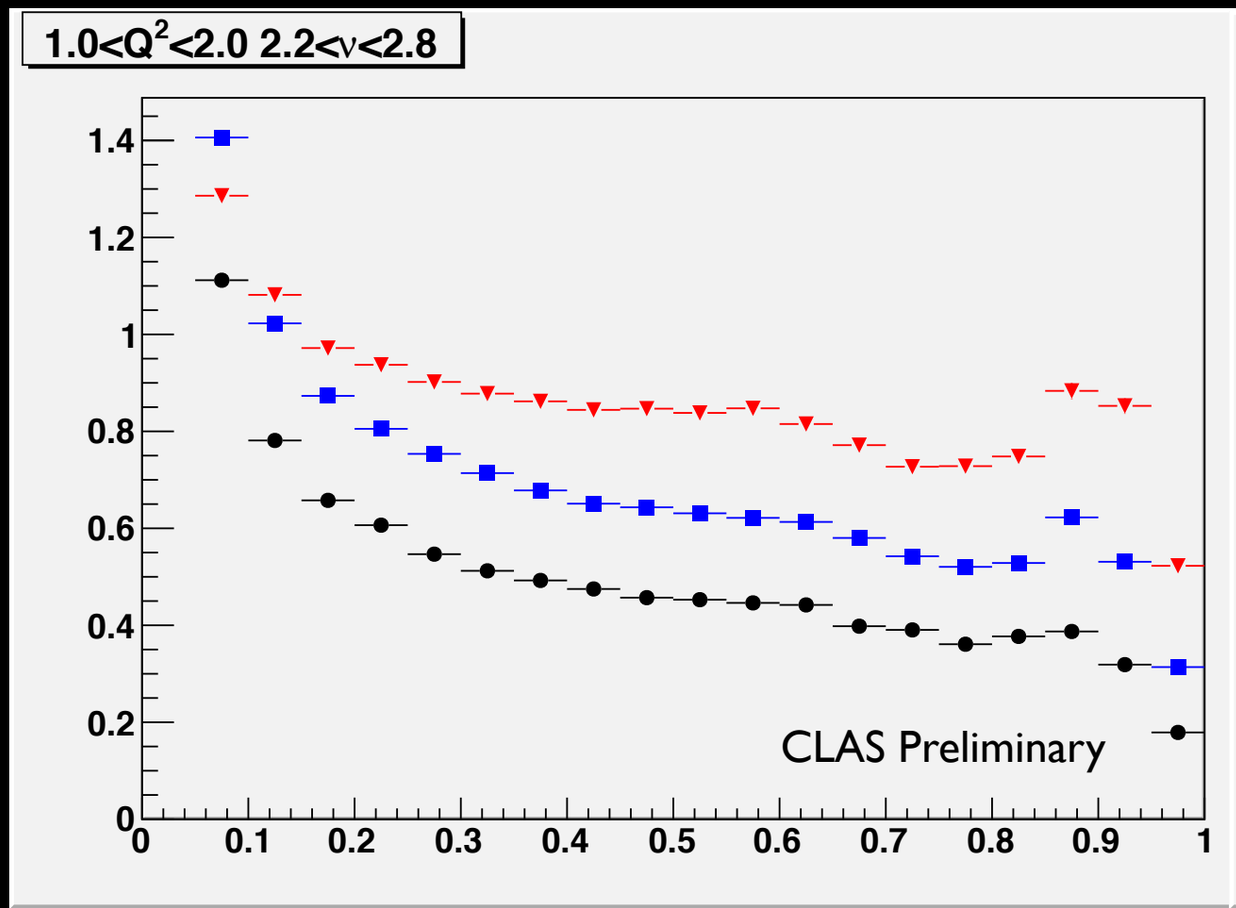
H.Hakobyan, Sebastián Mancilla, Ricardo Oyarzun

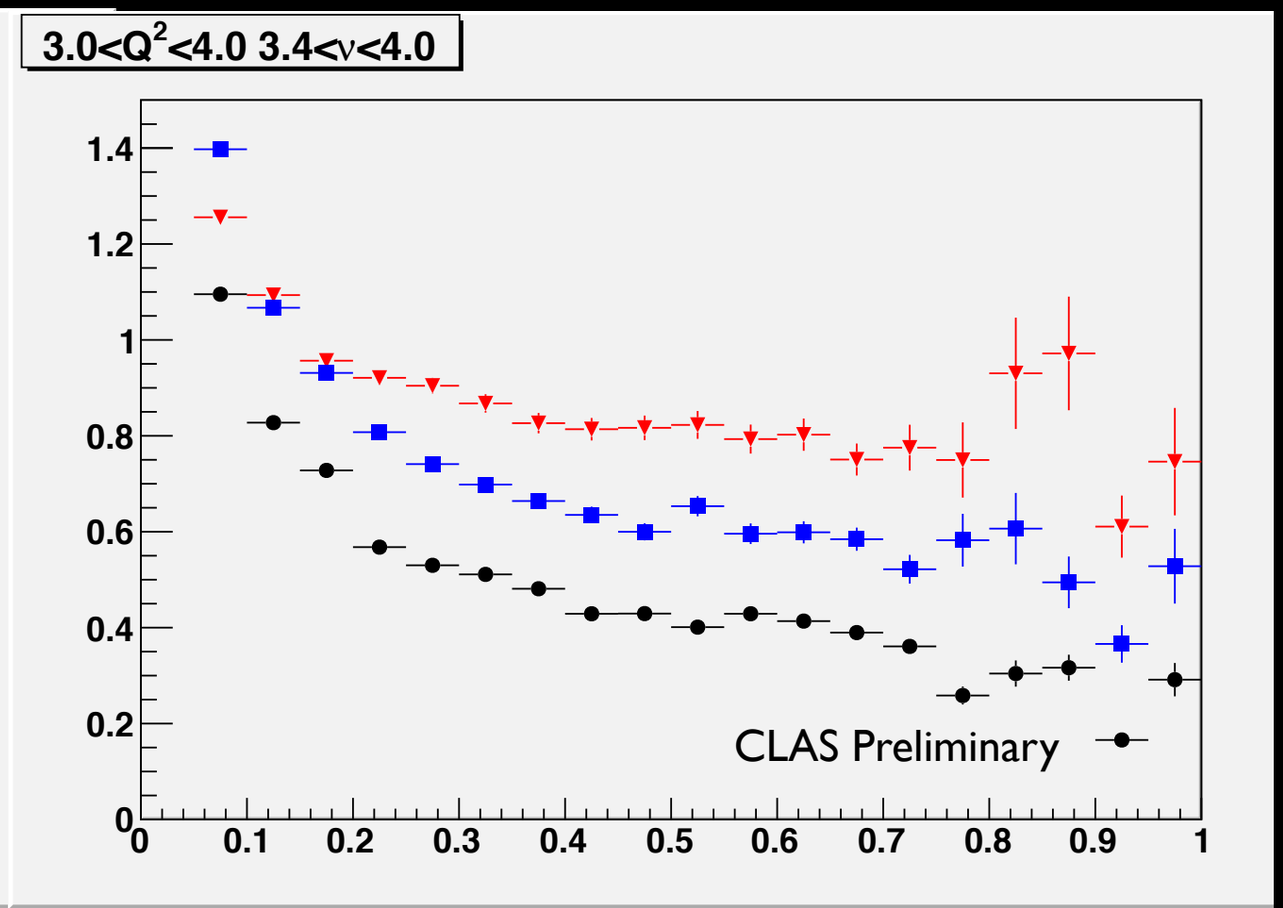
# Hermes $p_T$ broadening data

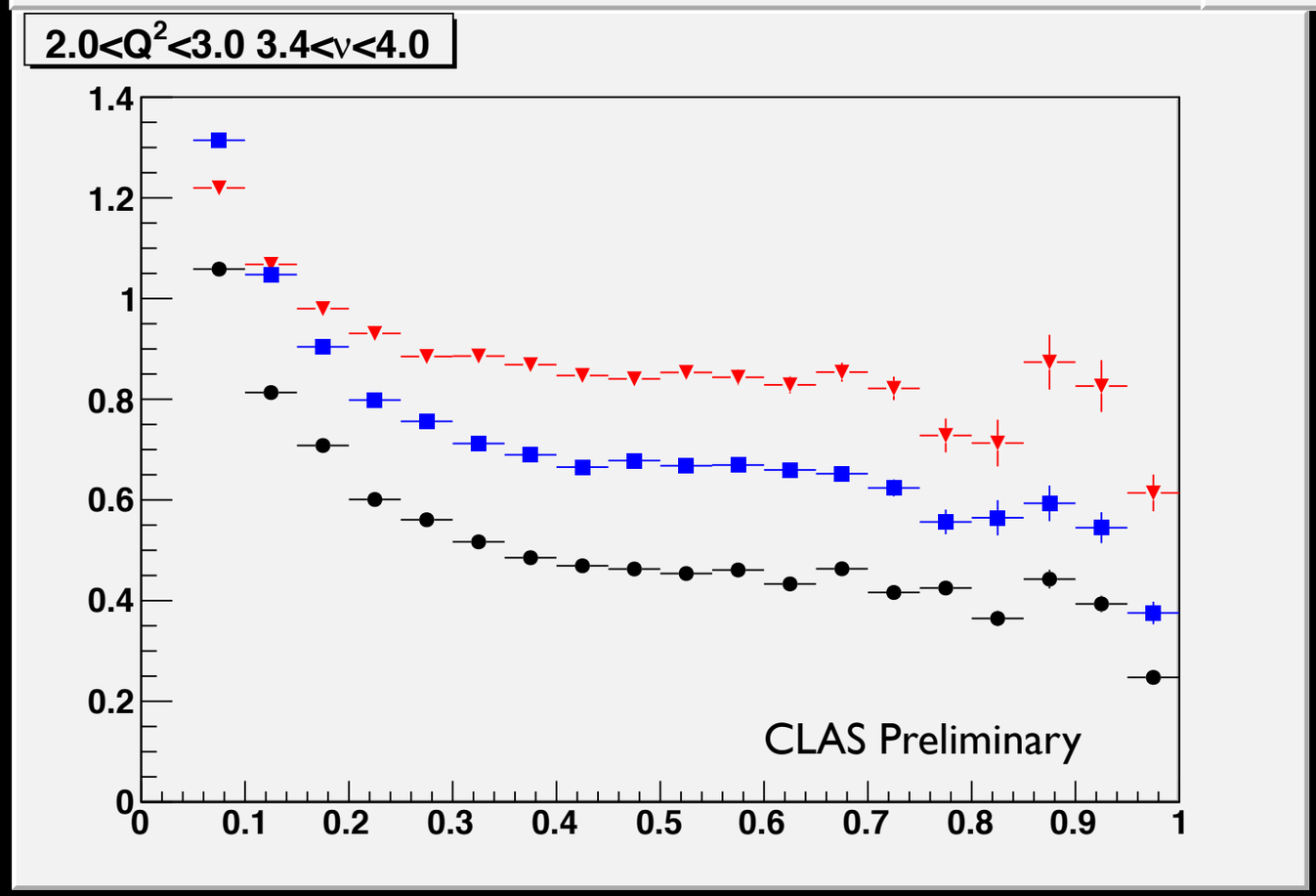
World's first comparison between pion and $K^+$ $p_T$ broadening



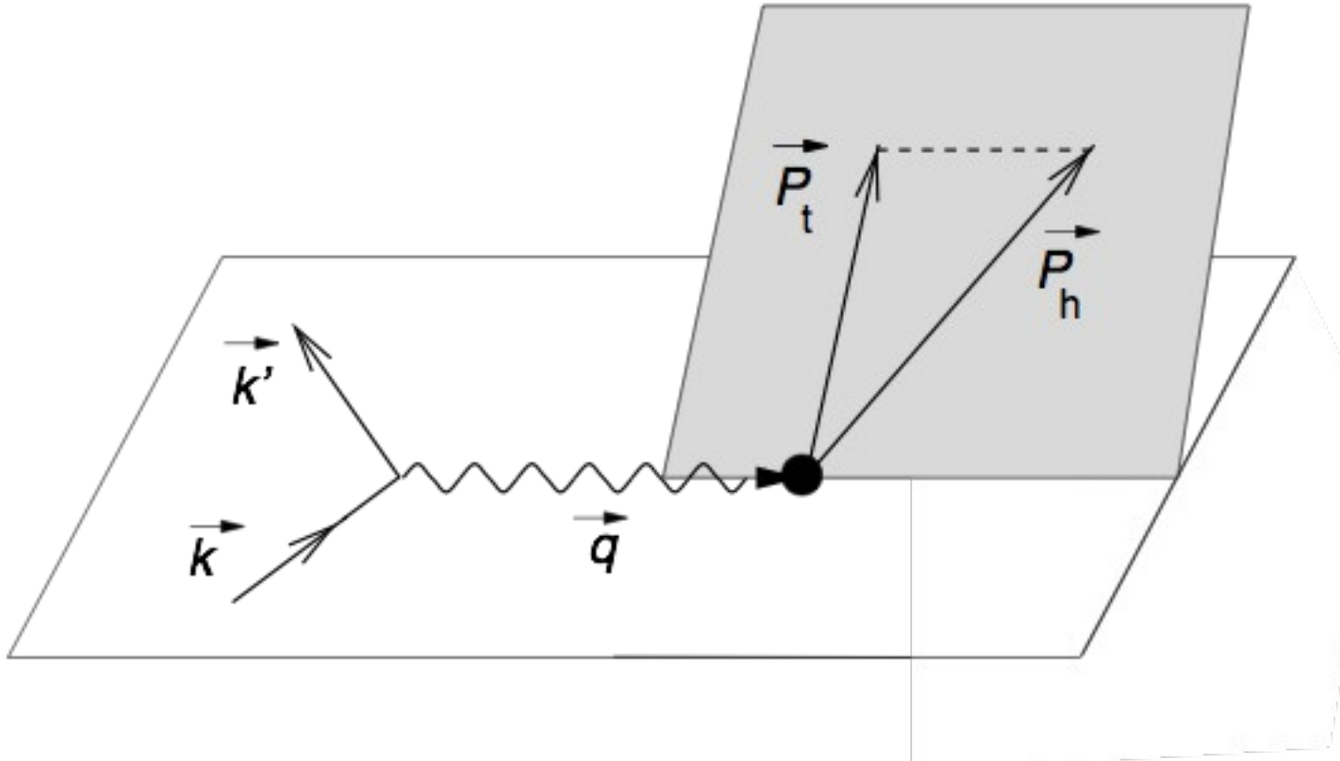



Multiplicity ratios,
fully corrected for radiative processes and acceptance,
normalized to target thicknesses,
not corrected for EMC effect

# SIDIS




**$Q^2$** = $-q^2$ four-momentum transferred by the electron (1-4)GeV$^2$;
**v** = $E$-$E'$ (lab) energy transferred by the electron (1-4.2)GeV;
**z** = $E_h/\nu$ fraction of initial quark energy carried by hadron;
**$p_T$** hadron momentum transverse to γ* direction;
**φ** angle between leptonic and hadronic planes

CLAS/DIS kinematics: $Q^2$>1 GeV$^2$, W >2 GeV ; 0.1<x<0.55, y<0.85

$E_{beam}$=5GeV

# Heuristic form for production length

$$\tau_{\mathrm{p}} \propto \frac{\nu \cdot \mathrm{z} \cdot (1 - \mathrm{z})}{\frac{\mathrm{dE}}{\mathrm{dx}}\Big|_{\mathrm{vacuum+medium}}}$$

$$\text{with } \mathrm{z} \equiv \mathrm{z}_{\mathrm{hadron}} = \mathrm{E}_{\mathrm{hadron}}/\nu$$

This form explicitly demonstrates the connection between the production length and the vacuum energy loss process

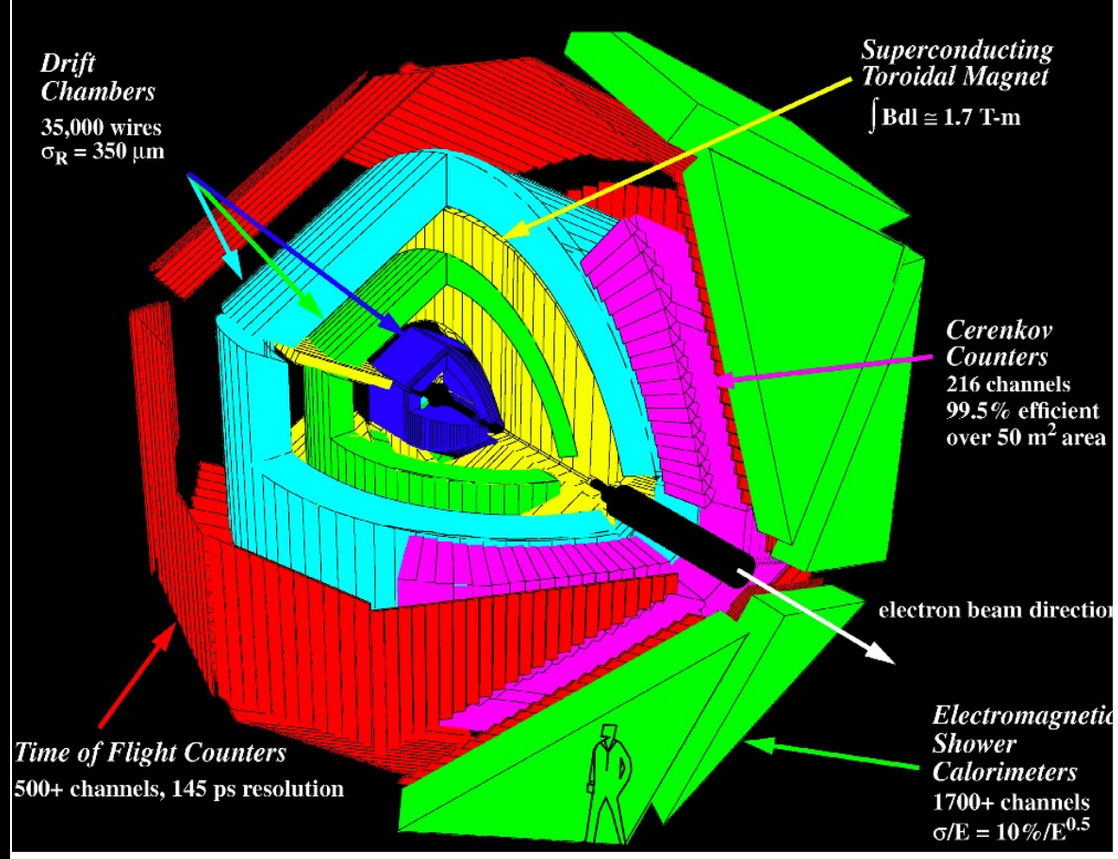
# Consistency between measured $\Delta E$ and the energy loss estimated from $p_T$ broadening

Pb: $\Delta E$ = 575 MeV
(uncorrected for acceptance and radiation)

Pb $p_T$ broadening ~0.04 $GeV^2$ for z=0.5
production length found is 1.6 fm

$$-\frac{dE}{dx} = \frac{\alpha_s N_c}{4} \Delta p_T^2$$

$$= \frac{0.5 \cdot 3}{4} \cdot \frac{0.04}{0.5^2} \text{ GeV}^2 \cdot 1.6 \text{ fm} \cdot \frac{1}{0.2 \text{ GeVfm}} = 0.5 \text{ GeV}$$

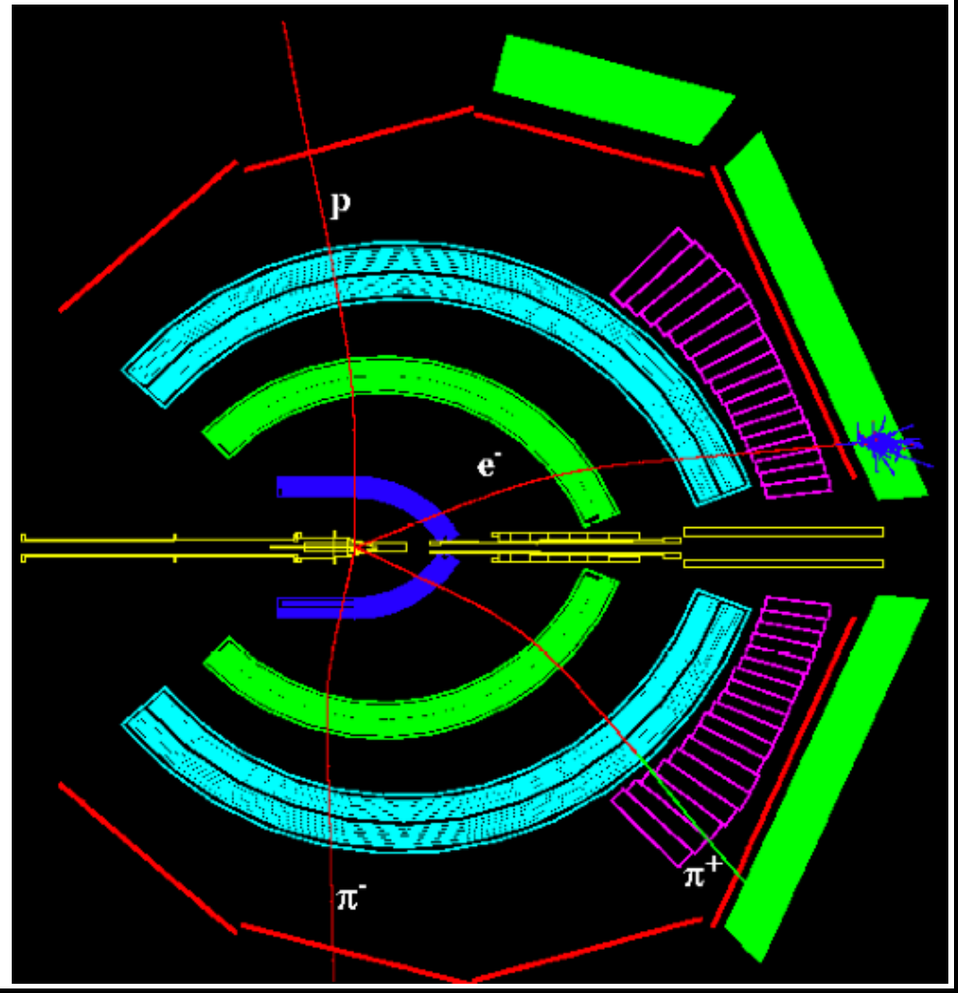



# CEBAF Large Acceptance Spectrometer

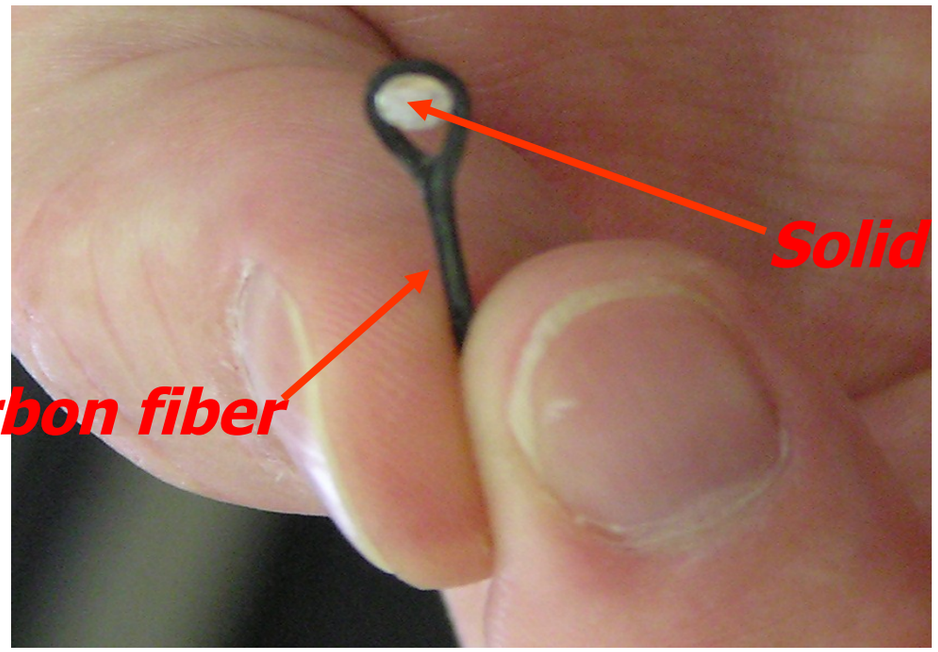
- Charged particles angles 8°-144°
- Neutral particles angles 8°-70°
- Identification of $e^+/e^-$,γ, p,n, $\pi^+/\pi^-$ ,$K^+/K^-$

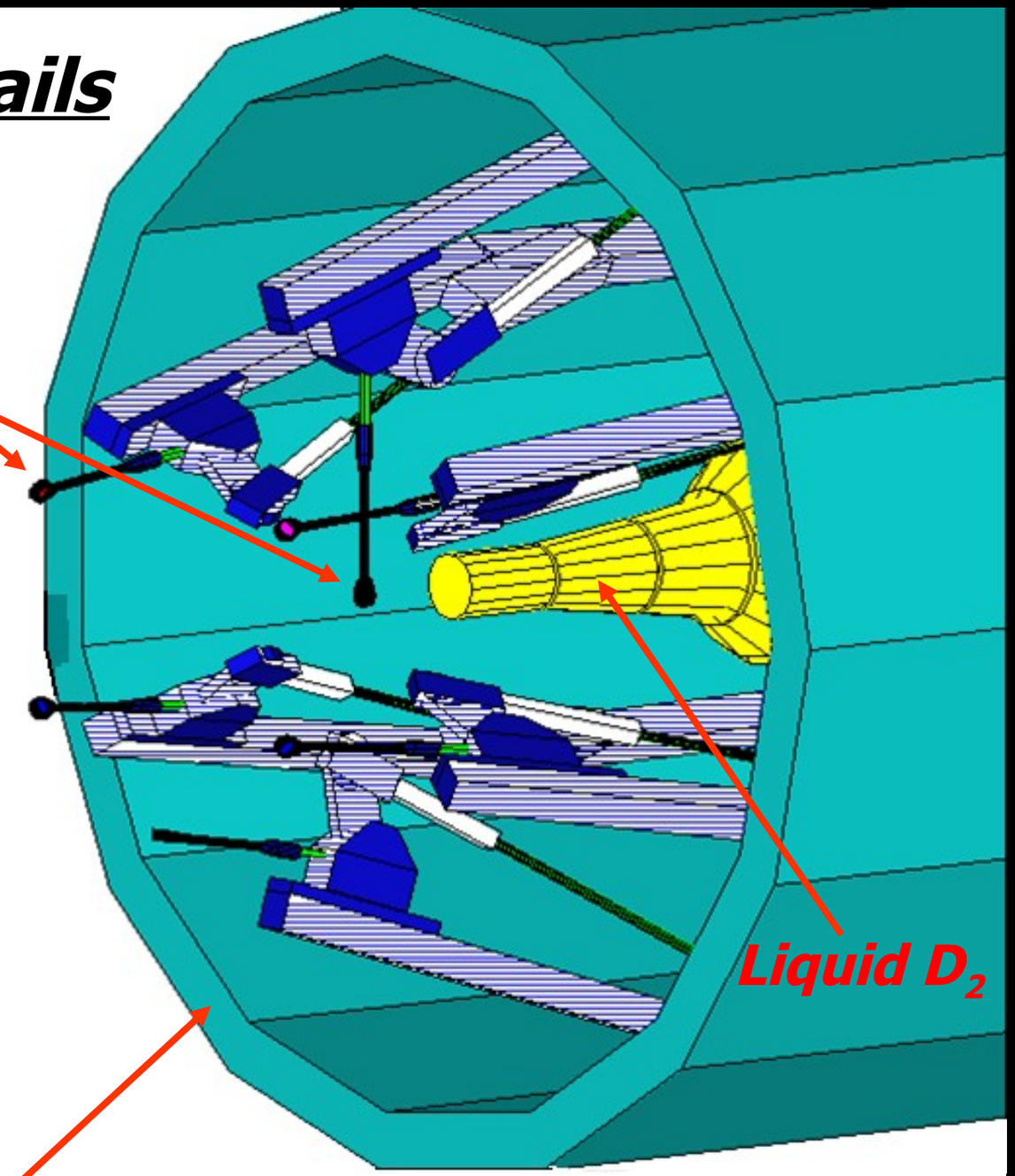
## CLAS EG2

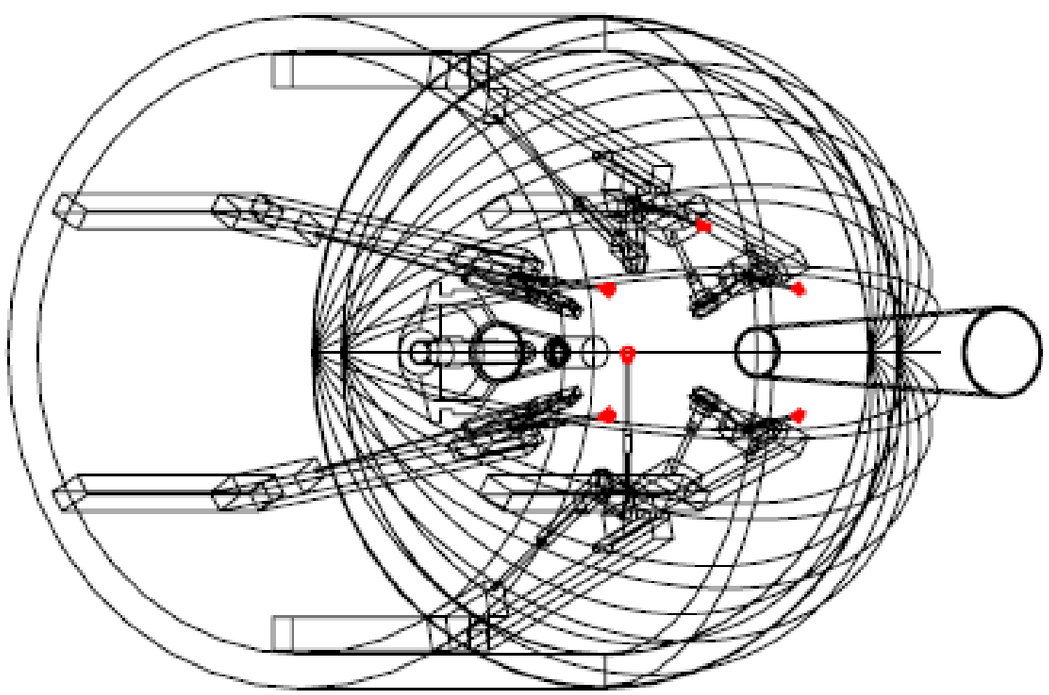
- Electron Beam 5.014 GeV
- Luminosity (1.3-2)$10^{34}$ 1/s●cm$^2$
- Targets $^2$H,$^{12}$C,$^{56}$Fe,$^{207}$Pb



# Experimental details



Rohacell foam scattering chamber

EG2 Experiment target in GEANT3
Solid (C, Al, Fe, Sn, Pb) target
simultaneously with deuterium target

H. Hakobyan, W. Brooks et al, Nucl. Instrum. and Meth. A592:218-223, 2008.

# Quark Propagation and Hadron Formation with 11 GeV Beam

*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*

# Quark Propagation and Hadron Formation with 11 GeV Beam

| *hadron* | cτ | mass | flavor content | limiting error (60 PAC days) |
|---|---|---|---|---|
| $\pi^0$ | 25 nm | 0.13 | $u\bar{u}d\bar{d}$ | 5.7% (sys) |
| $\pi^+, \pi^-$ | 7.8 m | 0.14 | $u\bar{d}$, $d\bar{u}$ | 3.2% (sys) |
| $\eta$ | 170 pm | 0.55 | $u\bar{u}d\bar{d}s\bar{s}$ | 6.2% (sys) |
| $\omega$ | 23 fm | 0.78 | $u\bar{u}d\bar{d}s\bar{s}$ | 6.7% (sys) |
| $\eta'$ | 0.98 pm | 0.96 | $u\bar{u}d\bar{d}s\bar{s}$ | 8.5% (sys) |
| $\phi$ | 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 | $\bar{u}\bar{d}$ | 5.9% (stat)** |
| $\Lambda$ | 79 mm | 1.1 | uds | 4.1% (sys) |
| $\Lambda(1520)$ | 13 fm | 1.5 | uds | 8.8% (sys) |
| $\Sigma^+$ | 24 mm | 1.2 | us | 6.6% (sys) |
| $\Sigma^-$ | 44 mm | 1.2 | ds | 7.9% (sys) |
| $\Sigma^0$ | 22 pm | 1.2 | uds | 6.9% (sys) |
| $\Xi^0$ | 87 mm | 1.3 | us | 16% (stat)* |
| $\Xi^-$ | 49 mm | 1.3 | ds | 7.8% (stat)* |

*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*

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| $\Xi^0$ | 87 mm | 1.3 | us | 16% (stat)* |
| $\Xi^-$ | 49 mm | 1.3 | ds | 7.8% (stat)* |

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

**in a bin in z from 0.6-0.7, integrated over all ν, $p_T$, $\phi_{pq}$, 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*

# Quark Propagation and Hadron Formation with 11 GeV Beam

| *hadron* | cτ | mass | flavor content | limiting error (60 PAC days) |
|---|---|---|---|---|
| $\pi^0$ | 25 nm | 0.13 | $u\bar{u}d\bar{d}$ | 5.7% (sys) |
| $\pi^+, \pi^-$ | 7.8 m | 0.14 | $u\bar{d}$, $d\bar{u}$ | 3.2% (sys) |
| $\eta$ | 170 pm | 0.55 | $u\bar{u}d\bar{d}s\bar{s}$ | 6.2% (sys) |
| $\omega$ | 23 fm | 0.78 | $u\bar{u}d\bar{d}s\bar{s}$ | 6.7% (sys) |
| $\eta'$ | 0.98 pm | 0.96 | $u\bar{u}d\bar{d}s\bar{s}$ | 8.5% (sys) |
| $\phi$ | 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) |
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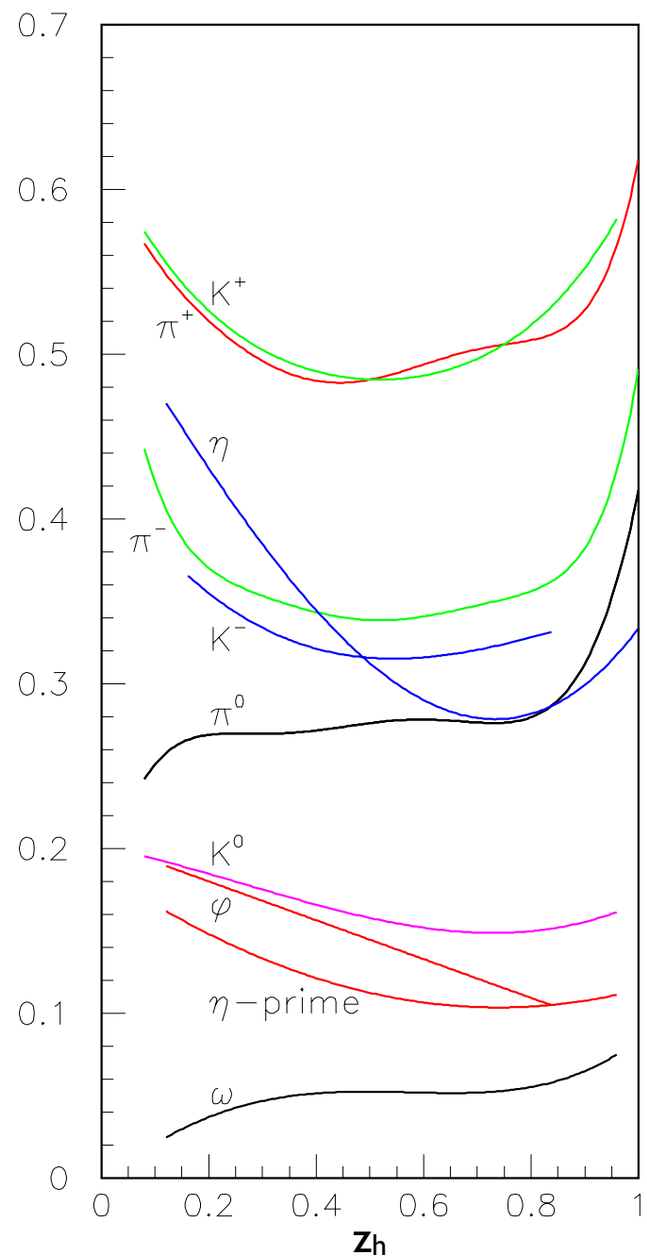
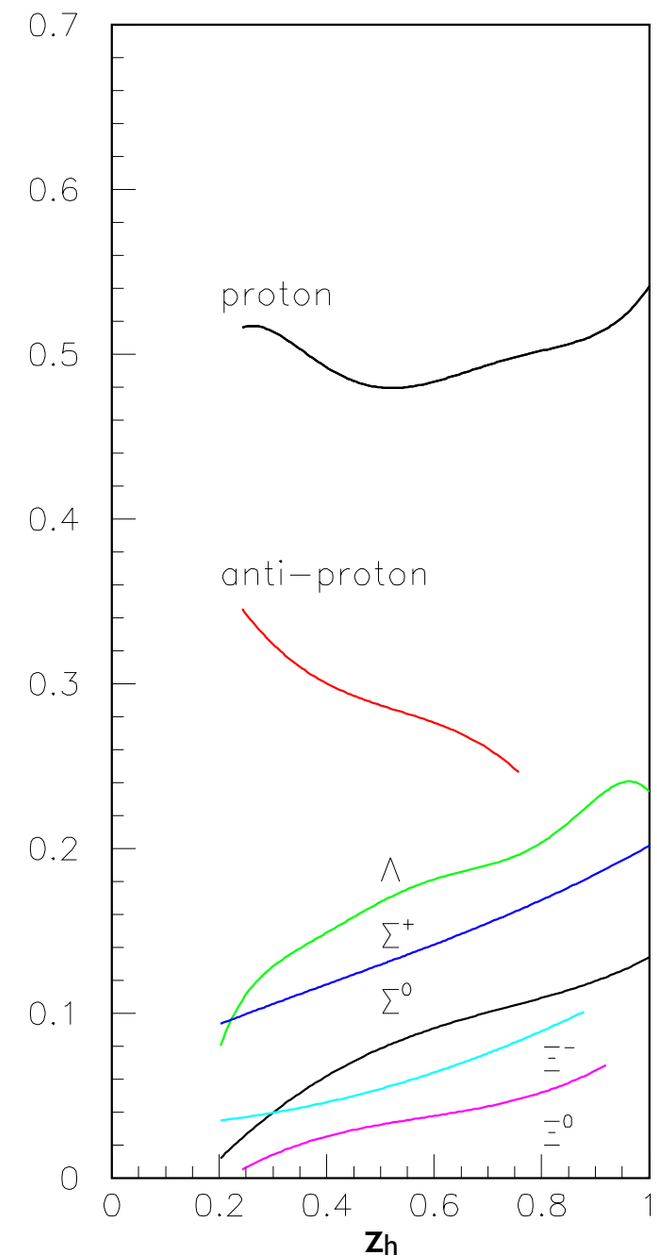
*in a bin in z from 0.7-0.8, integrated over all ν, $p_T$, $\phi_{pq}$, and $Q^2$>5 GeV$^2$

**in a bin in z from 0.6-0.7, integrated over all ν, $p_T$, $\phi_{pq}$, 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