Transverse Momentum Broadening in Nuclear Media at JLAB's CLAS

Esteban Molina C.
on behalf of the proponents

EX UMBRA IN SOLEM

CCTVal
CENTRO CIENTÍFICO TECNOLÓGICO DE VALPARAÍSO

Motivation

Transverse momentum broadening

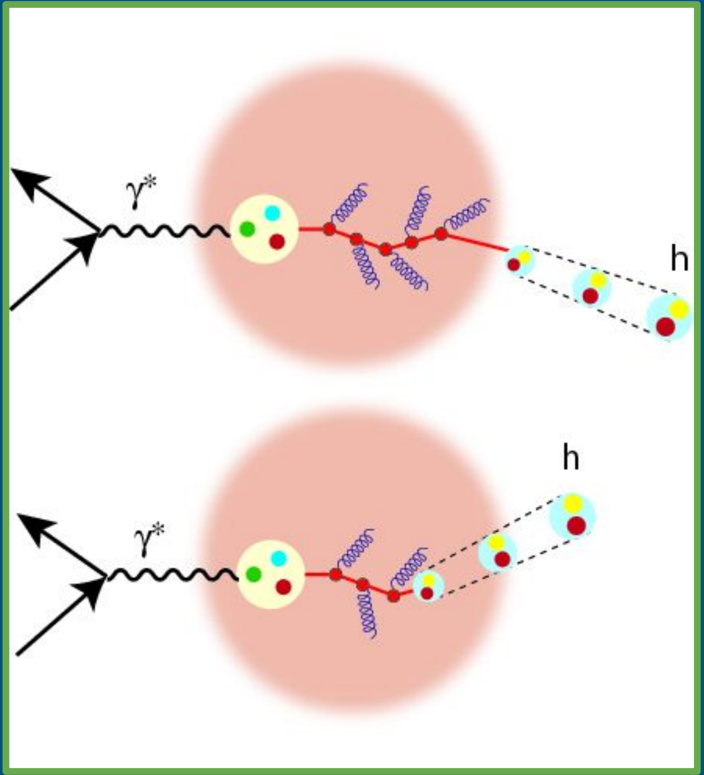


Diagram of hadronization in nuclear medium.
Phys. Rev. C 102, 045201

Nucleus can be used in the purpose of understanding the process of hadronization dynamics.
Nuclear Physics A 720 (2003) 131–156

Transverse momentum broadening

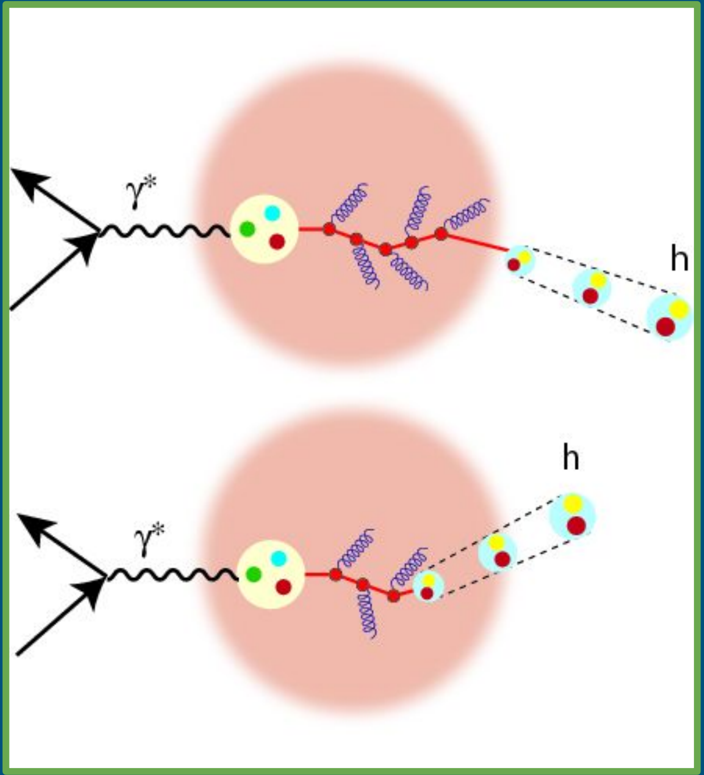


Diagram of hadronization in nuclear medium.
Phys. Rev. C 102, 045201

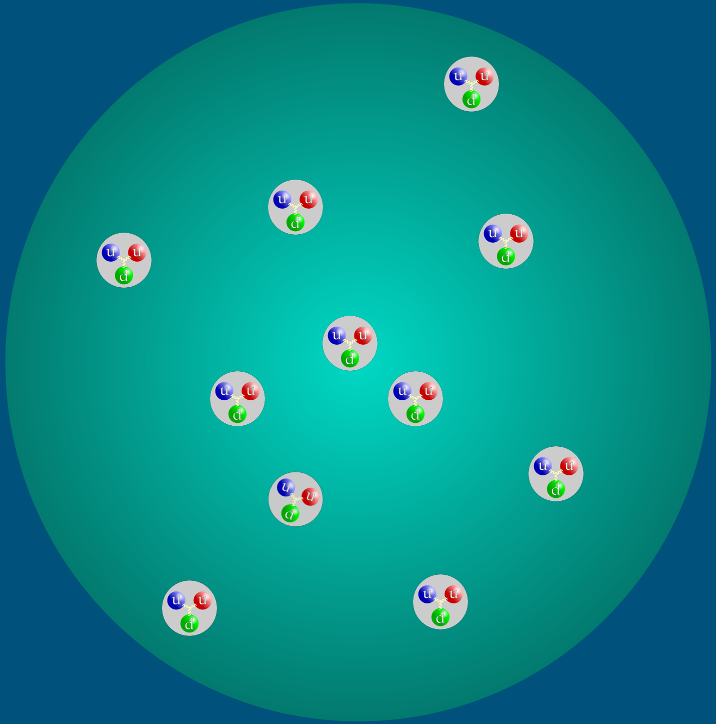
$$\Delta P_T^2 = \langle P_T^2 \rangle_A - \langle P_T^2 \rangle_D$$

$$\Delta P_T^2 \propto l_p$$

Nucl.Phys.B 484 (1997) 265-282

Broadening shows how **much/long** a struck out quark travels before hadronizing.

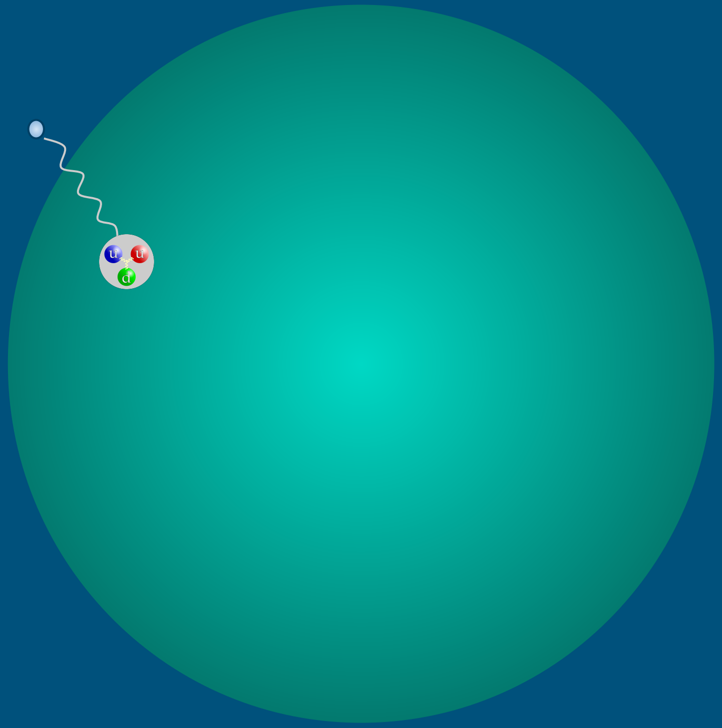
Transverse momentum broadening



Nucleus A

Using different nuclei, broadening can indicate **where** the energetic quark transitioned into a forming hadron.

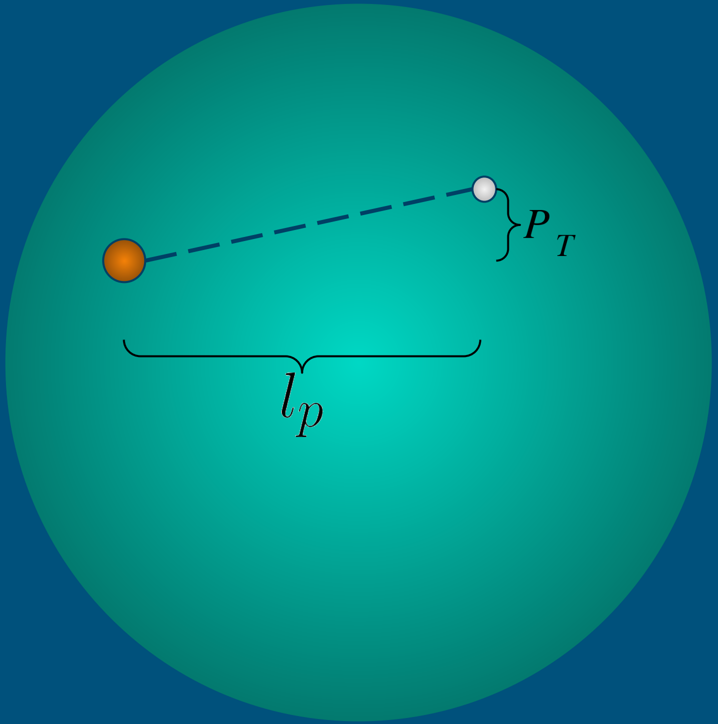
Transverse momentum broadening



Nucleus A

A deep inelastic scattering occurs!

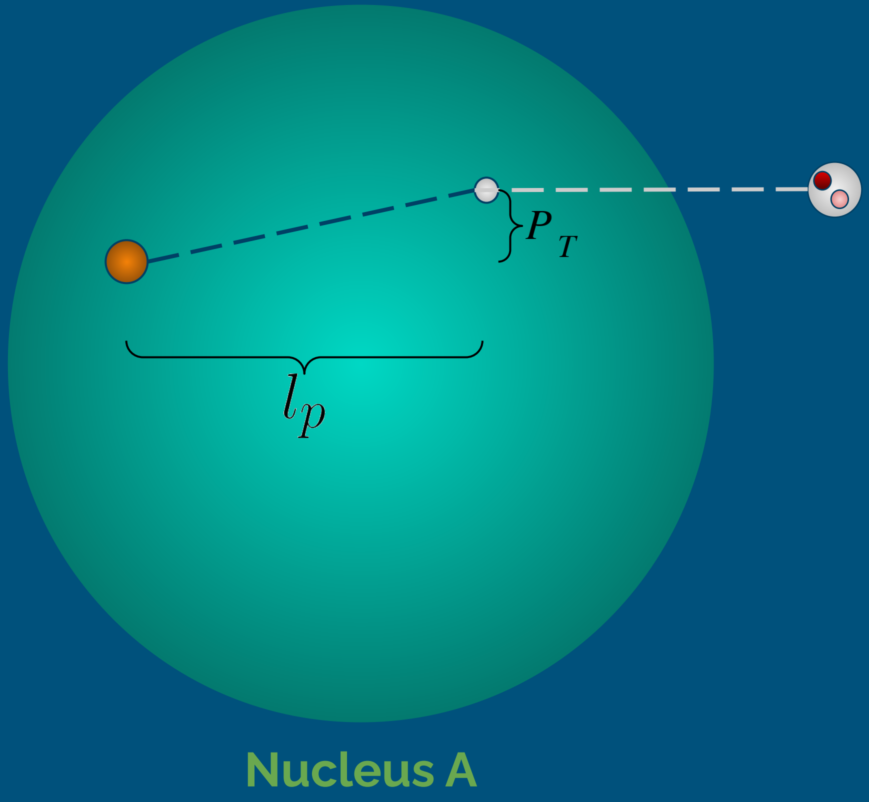
Transverse momentum broadening



Nucleus A

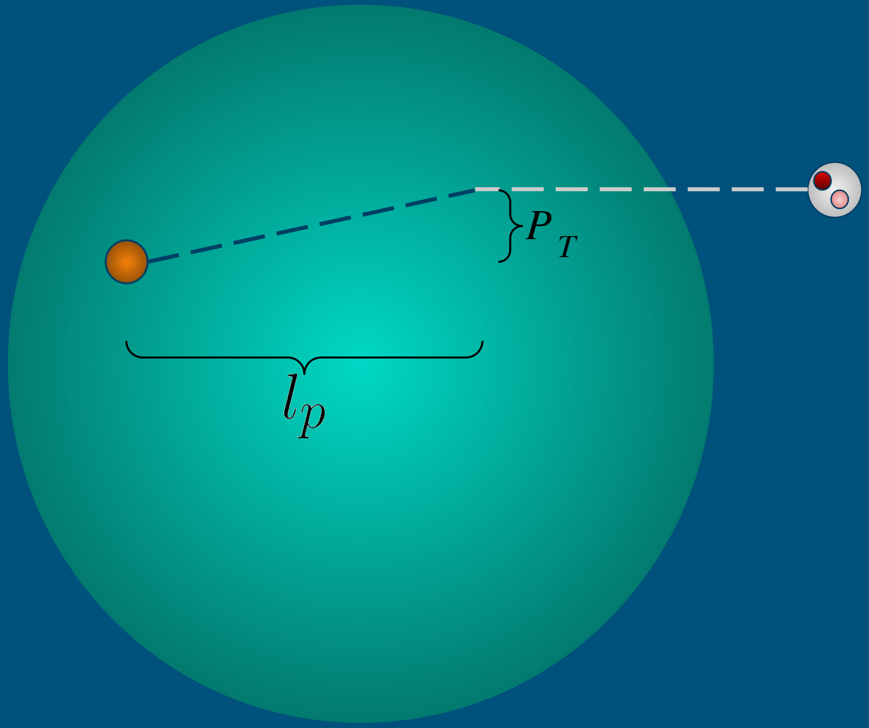
The struck quark travels a certain distance until color neutralization happens. **While traversing the nucleus it loses energy.**

Transverse momentum broadening



Color neutralized object travels another distance before hadronising.

Transverse momentum broadening



Nucleus A

$$\Delta P_T^2 \propto l_p$$

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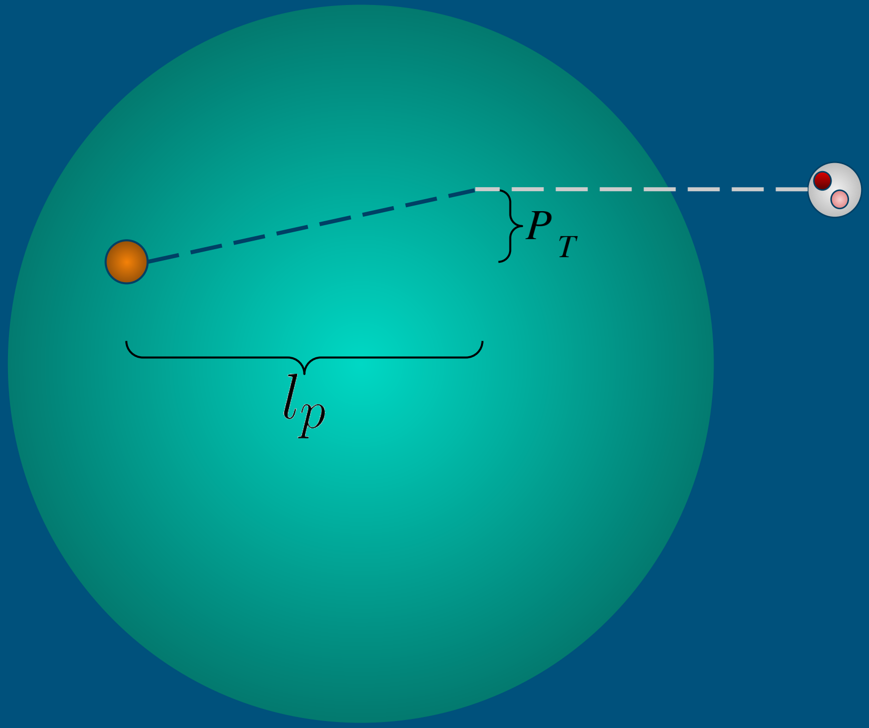
Transverse momentum broadening



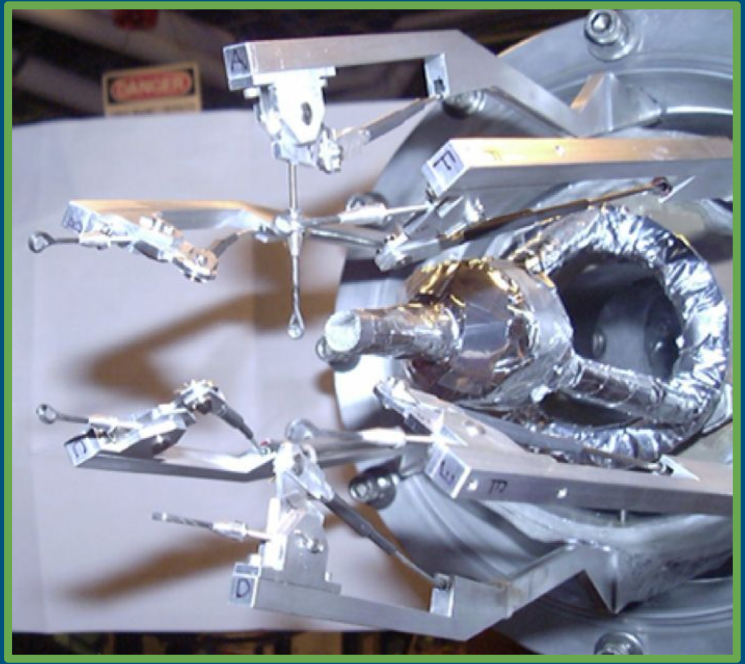
Nucleus A

Different nuclei can be used as **confinement landmarks** of the hadronizing energetic quarks.

Experimental Setup

CLAS and the EG2 run period (2004)

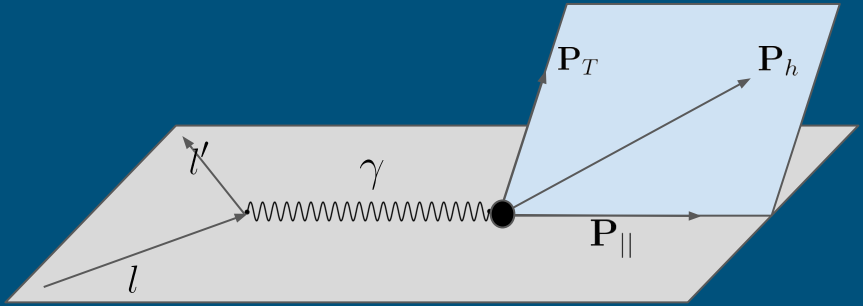
CLAS detector
Nucl.Instrum.Meth.A 503 (2003) 513-553



Double-target system
Nucl.Instrum.Meth.A 592 (2008) 218-223

Event selection

Semi-inclusive deep inelastic scattering



$$e(l)+N(p_N) \rightarrow e'(l')+h(p_h)+X(p_X)$$

Kinematical variables:

$$Q^2 = (l - l')^2$$

$$\nu = (E - E')$$

$$z_h = \frac{p_N \cdot p_h}{p_N \cdot q} = \frac{E_h}{\nu}$$

$$P_T^2 = P_h^2 - P_{||}^2$$

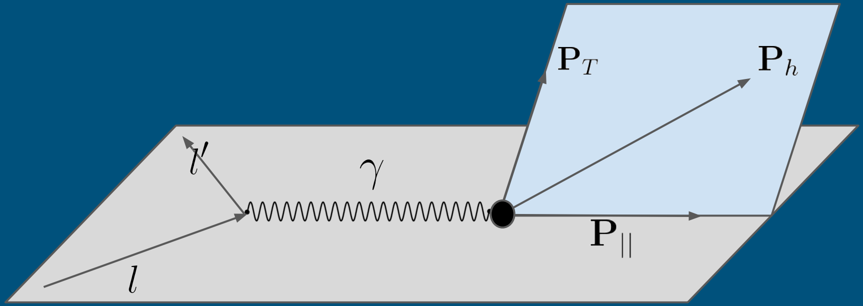
$$\phi_h = \text{angle(leptonic plane, hadronic plane)}$$

Additionally, we used:

$$x_f = \left(\frac{\mathbf{P}_{||}}{\mathbf{P}_{||_{max}}}\right)_{CM}$$

$$A^{1/3} = (\text{Mass Number})^{1/3}$$

Semi-Inclusive Deep Inelastic Scattering



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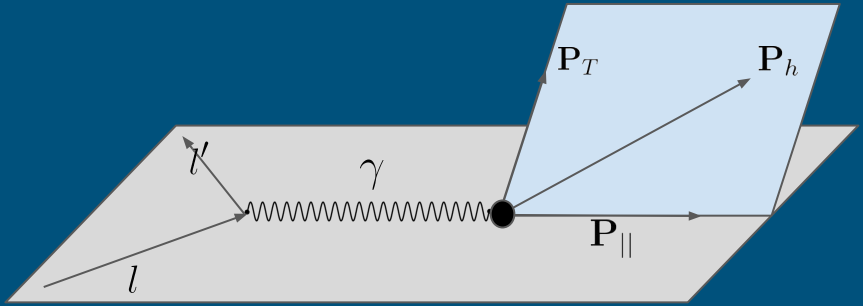

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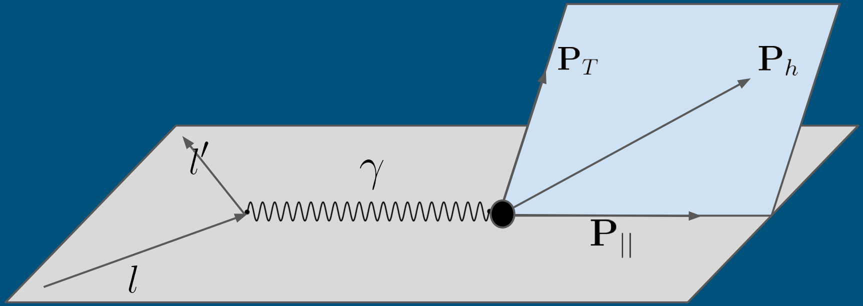

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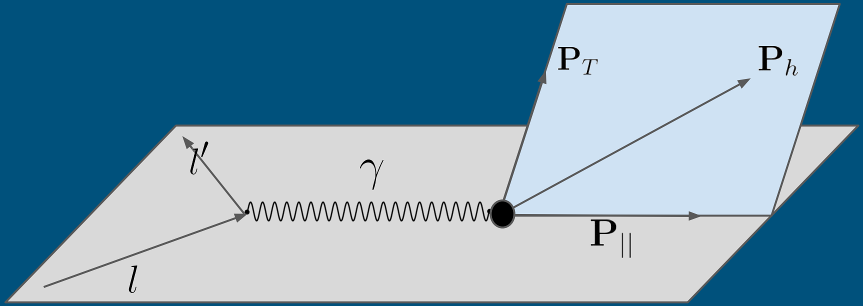
Hadronization where?
Nucl.Phys.A 825 (2009) 200-211

Semi-Inclusive Deep Inelastic Scattering



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Additionally, we used:

To emphasize certain fragmentation region ⟺ $$\boxed{x_f = \left(\frac{\mathbf{P}_{||}}{\mathbf{P}_{||max}}\right)_{CM}}$$

$$A^{1/3} = (\text{Mass Number})^{1/3}$$

Analysis overview

Overview

Positive pion sample
Phys. Rev. C 105, 015201

Corrections and background reduction

Systematic uncertainties

Final observable

Systematic uncertainties

We studied nine sources of systematic uncertainties:

- Pion Identification
- Vertex Selection
  - Vertex Cut
  - $|\Delta Z|$ cut variation
- Acceptance
  - Naccept
  - Acc
  - Different Pt2 binning
  - Closure Test
- Background Subtraction
- Radiative Corrections

Systematic uncertainties

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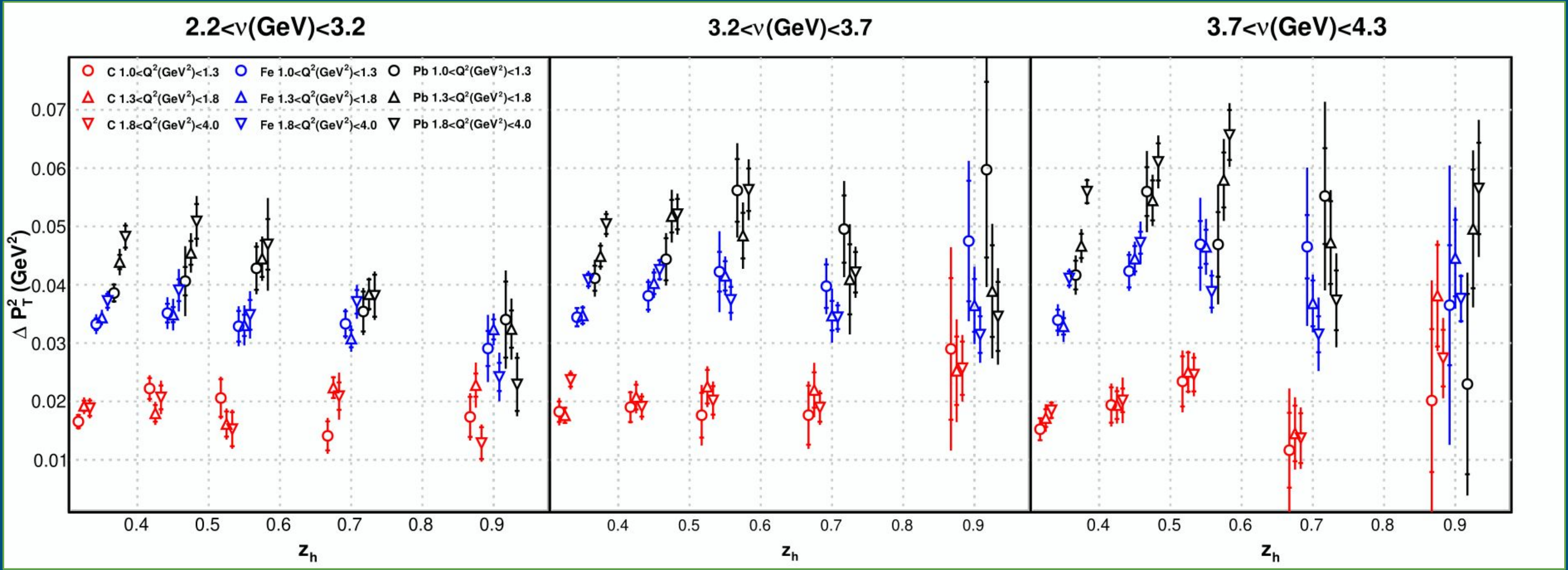
	No xF cut	xF>0
$\lvert\Delta Z\rvert$ cut variation	1%-3%	1%-3%
Naccept	<4%	1%-4%
Closure Test	1%-6%	1%-13%
Radiative Corrections	<6%	<13%

Results

Broadening of Pi+ (all fragmentation regions)



- Strong correlation of the observable with respect to the target size.
- Noticeable correlation of the observable with respect to zh.

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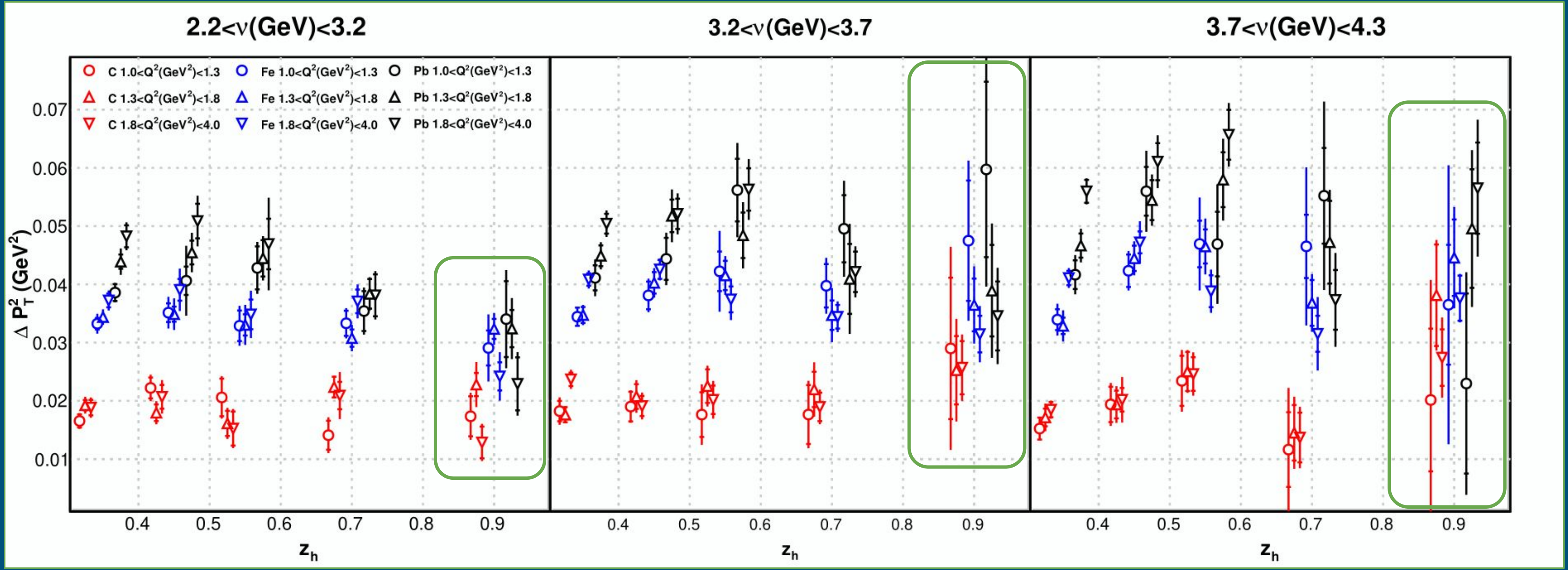
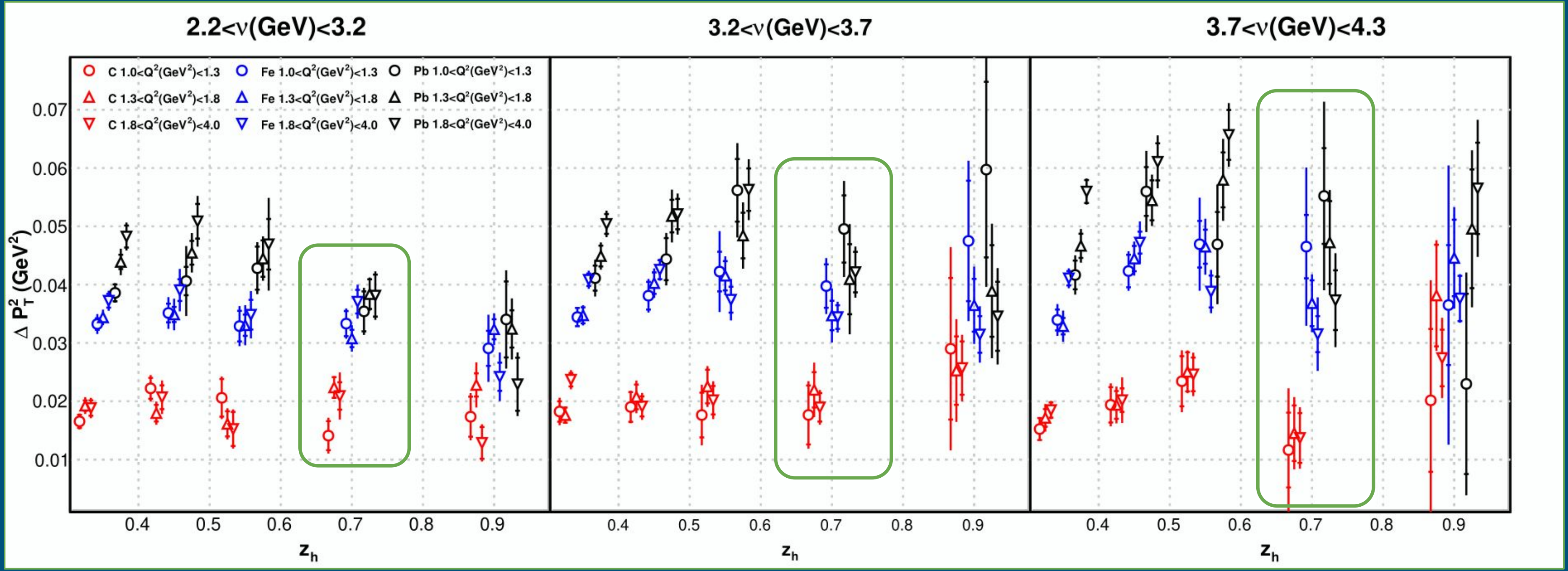


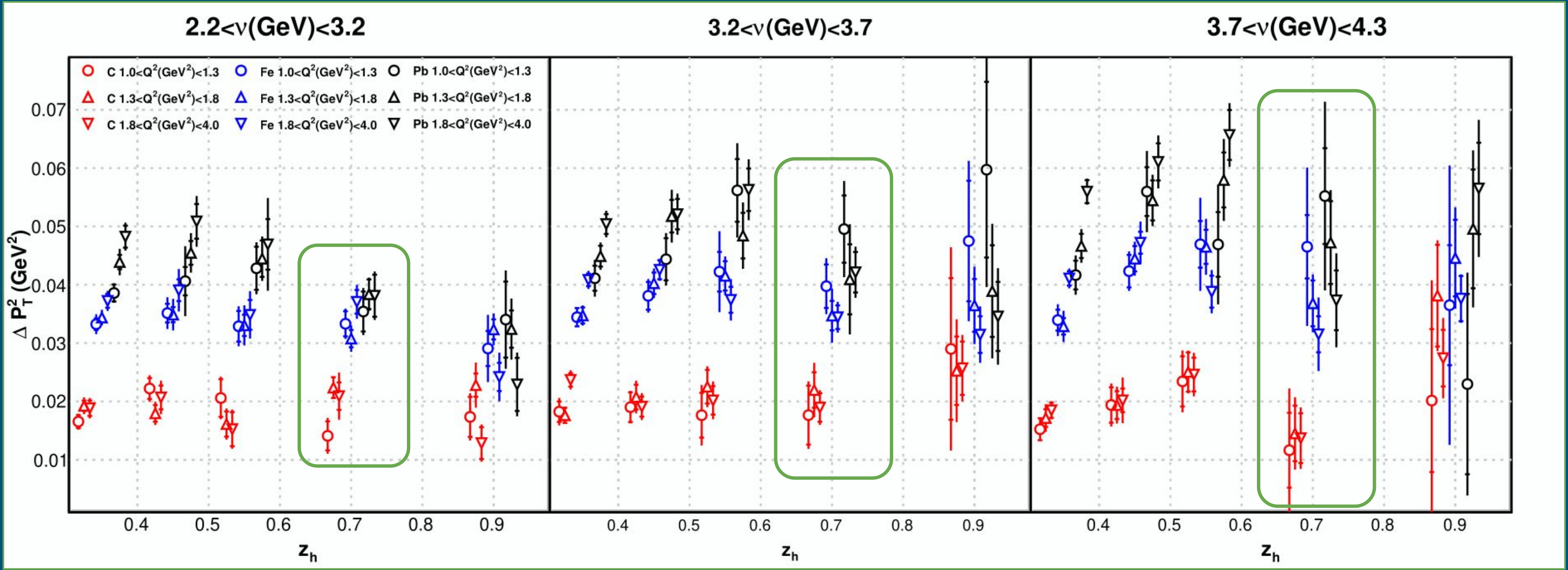
- Strong correlation of the observable with respect to the target size.
- Noticeable correlation of the observable with respect to zh.
- At zh->1, the broadening does not go to zero! Intrinsic quark momentum ?

Broadening of Pi+ (all fragmentation regions)



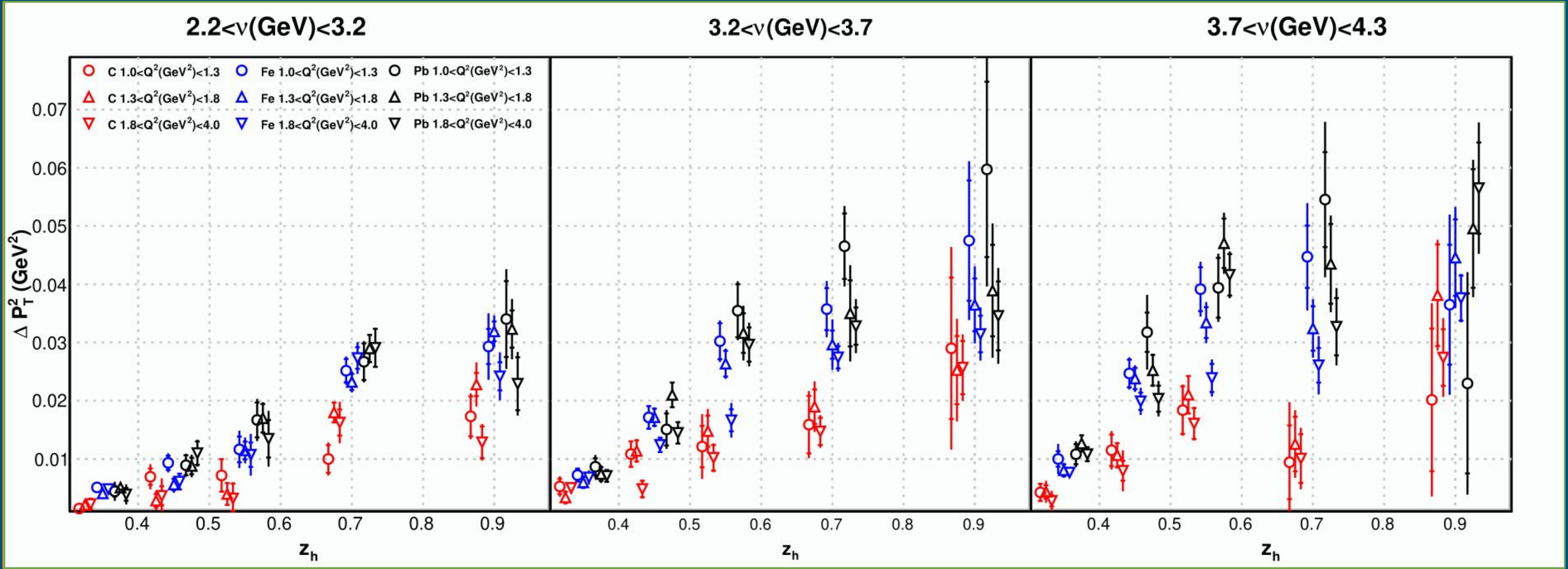
- Notice that the bigger the nucleus, a plateau starts to appear.

Broadening of Pi+ (all fragmentation regions)

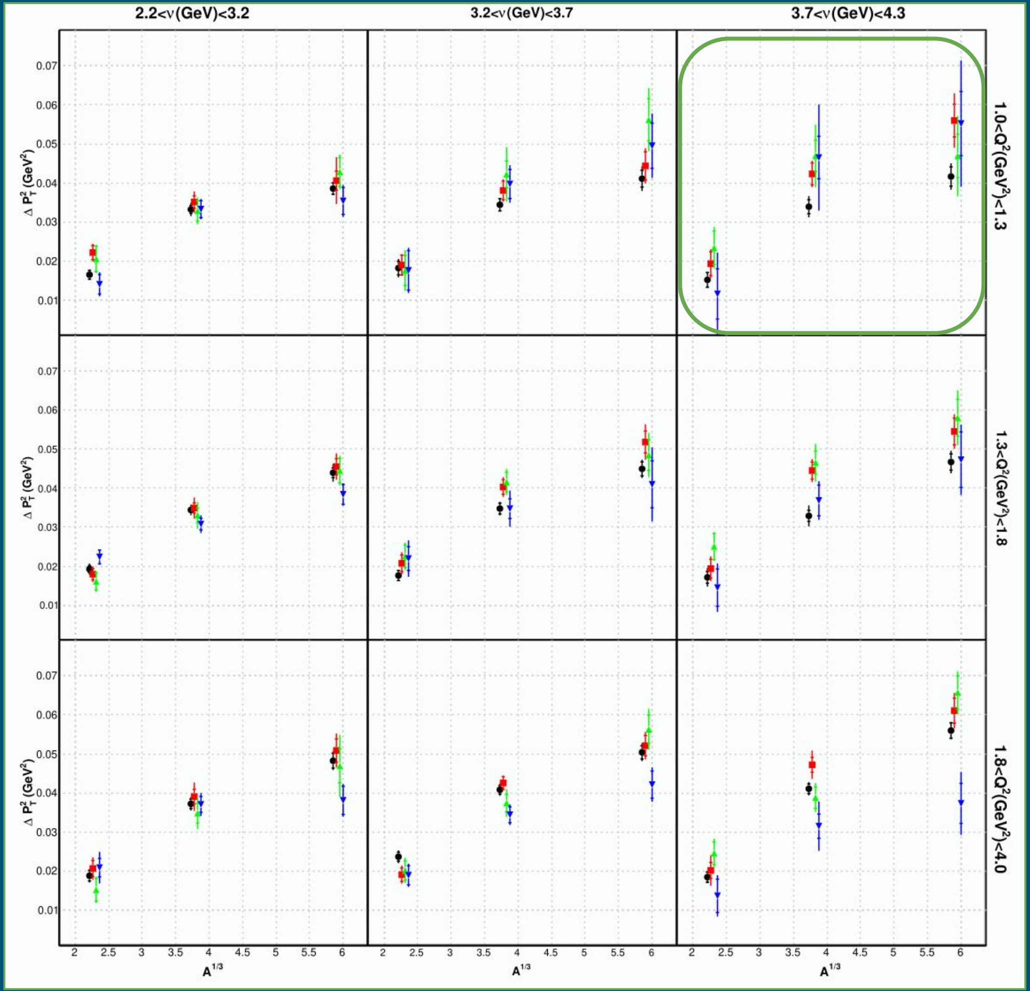


- Notice that the bigger the nucleus, a plateau starts to appear.
- **According to theoretical models, this is an indication that the quark starts its hadronization in a distance smaller than the size of Pb!**

Broadening of Pi+ (current fragmentation region)



- By emphasizing the current fragmentation region similar conclusions can be extracted!
  - With the exception of the emerging strong correlation w.r.t. zh.



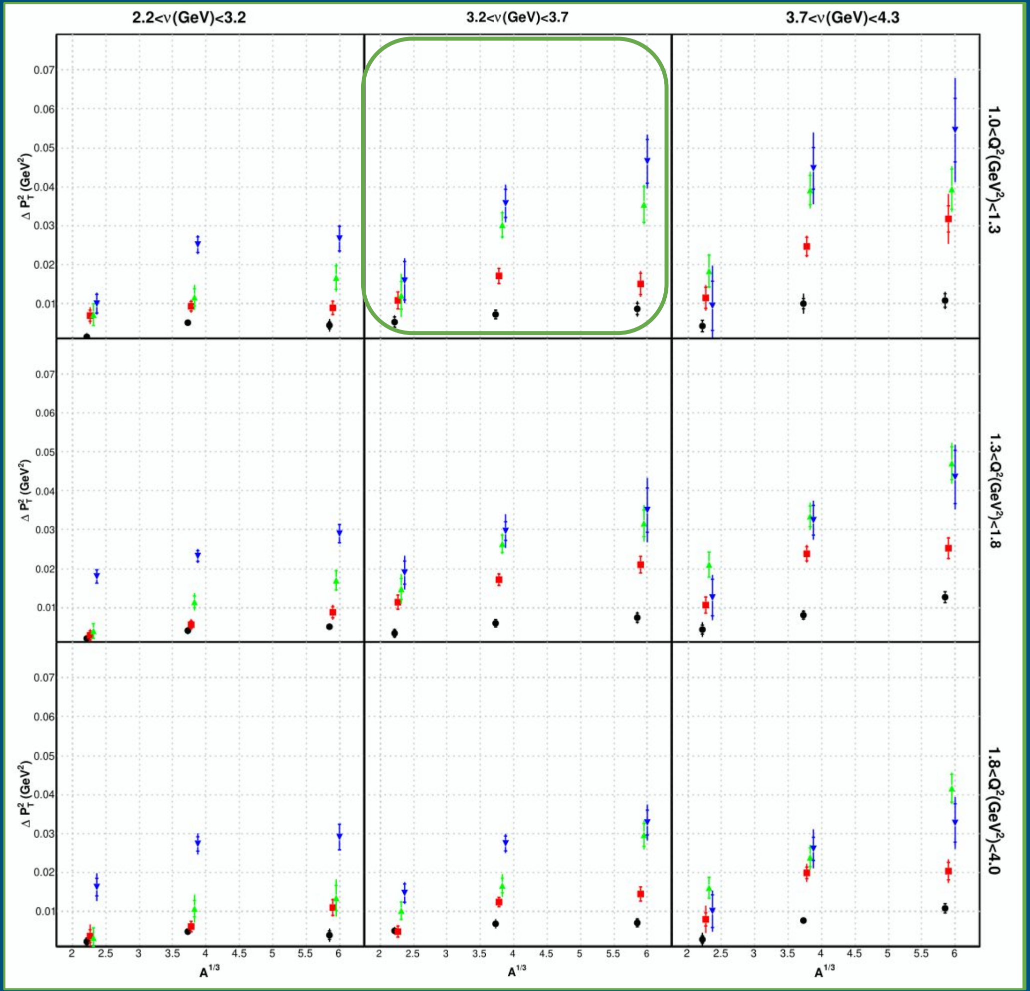
Results as a function of nuclear size

Legend:

- $0.4 < z_h < 0.5$
- $0.5 < z_h < 0.6$
- $0.6 < z_h < 0.8$
- $0.8 < z_h < 1$

Notice the curved behavior of the broadening as a function of the nuclear target.

- Indicative of hadronization inside nuclei.



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By emphasizing the current fragmentation region linear and curved behaviors are observed.

- Indicative of hadronization inside/outside nuclei.

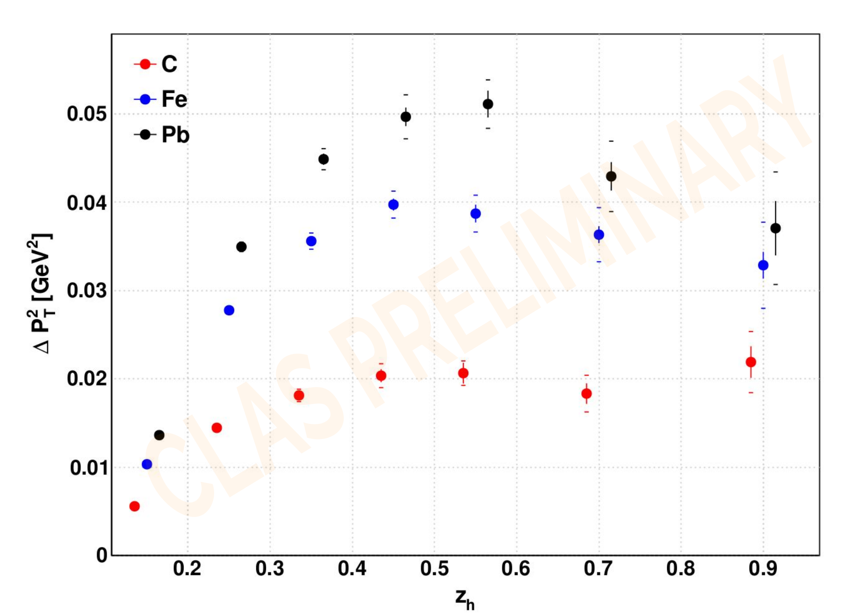
Conclusions

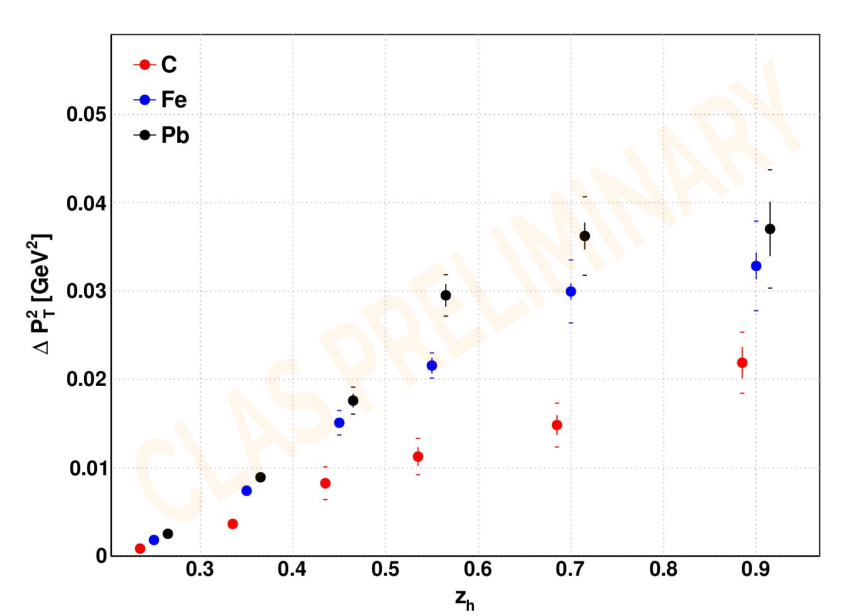
- Color neutralization distance is suggested to be in the order of nuclear sizes.
- At zh->1 the broadening does not vanish. This suggests a contribution coming from other process!
    - HERMES does not show such behavior.
- A strong correlation of the broadening with zh and the sizes of nuclei is observed in our results.
- A weak correlation of the broadening with Q2 and Nu is observed. However; it seems the latter has a stronger correlation.
- The fragmentation regions have a noticeable impact on the shape of the observable.

Thank you!

Backup Slides

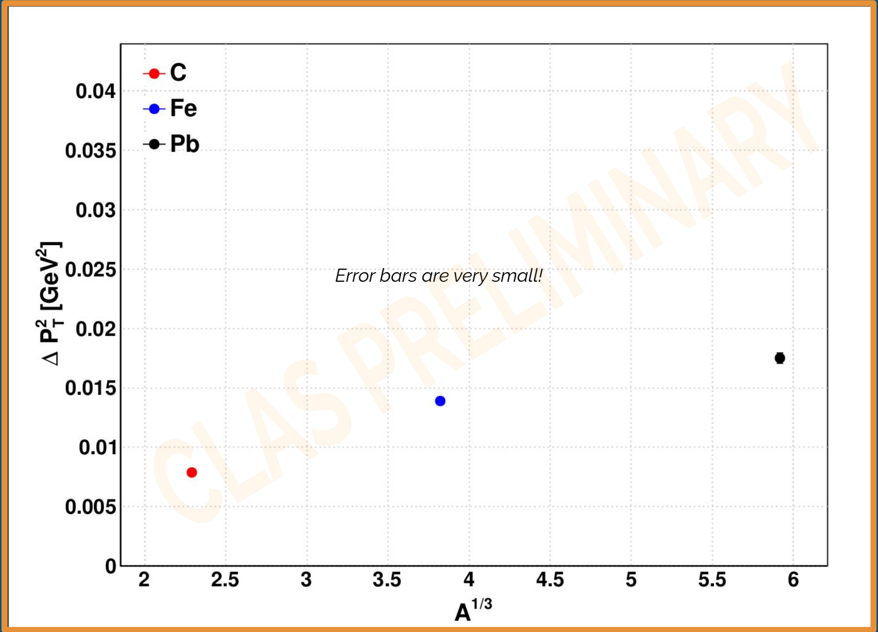
Transverse Momentum Broadening of Pi+

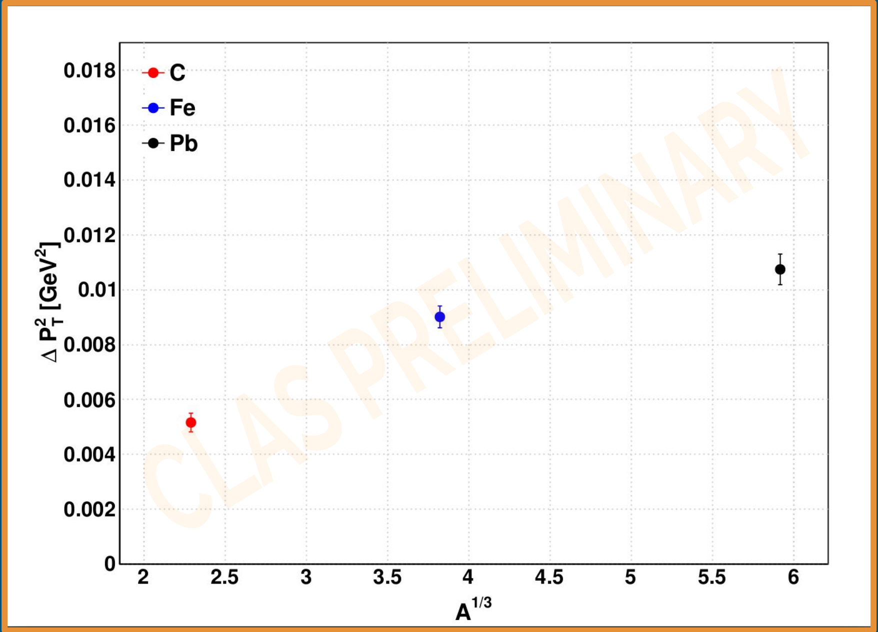




xf>0 cut applied.

Transverse Momentum Broadening of Pi+





xf>0 cut applied.

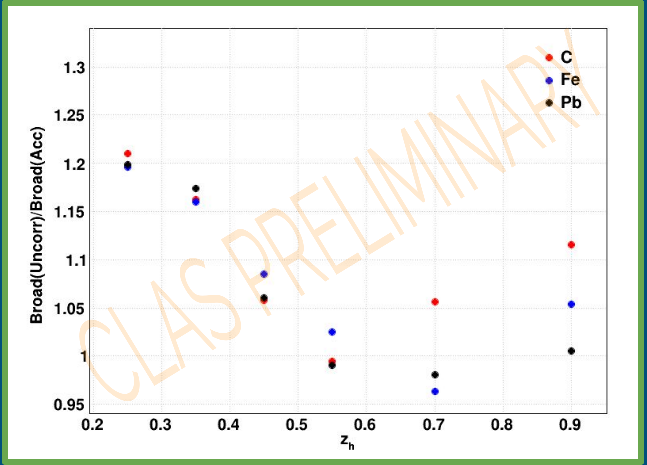
Corrections to Data: Acceptance Correction

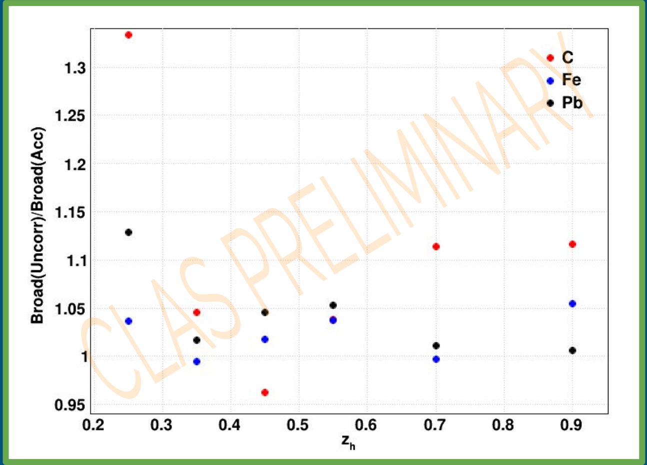
Acceptance correction is used to account for detector inefficiencies. Is defined as:

$$\mathrm{Acc}(Q^2, \nu, z_h, P_T^2, \phi_h) = \frac{N_{\mathrm{rec}}(Q^2, \nu, z_h, P_T^2, \phi_h)}{N_{\mathrm{thr}}(Q^2, \nu, z_h, P_T^2, \phi_h)}$$

$N_{\mathrm{rec}} \longrightarrow$ Geant3

$N_{\mathrm{thr}} \longrightarrow$ Pythia6





xf>0 cut applied.

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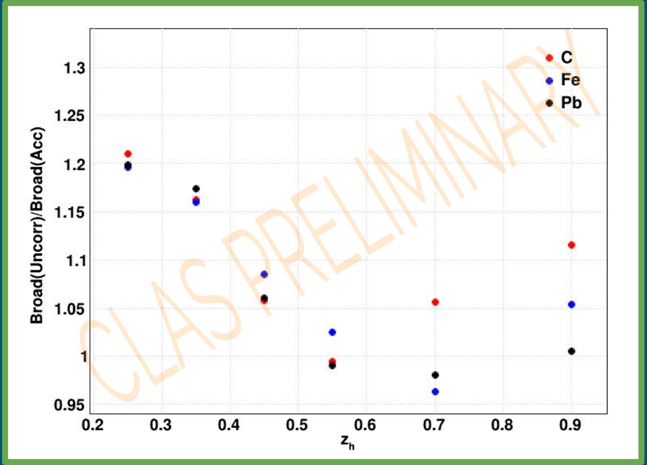
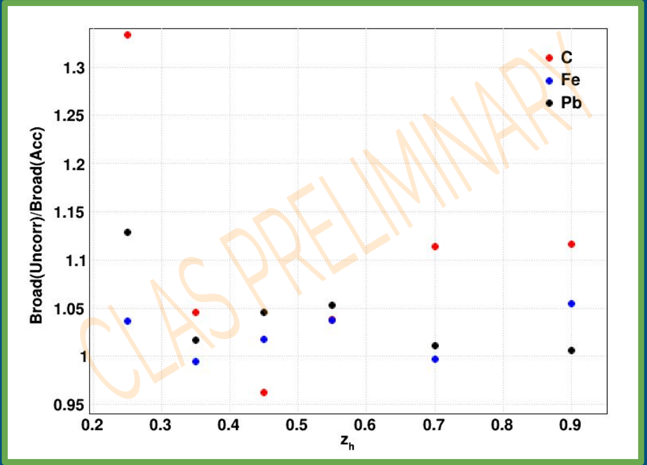
$$\text{Corrected } N_{\pi^+}(Q^2, \nu, z_h, P_T^2, \phi_h) = \frac{N_{\pi^+}(Q^2,\nu,z_h,P_T^2,\phi_h)}{\text{Acc}(Q^2,\nu,z_h,P_T^2,\phi_h)}$$

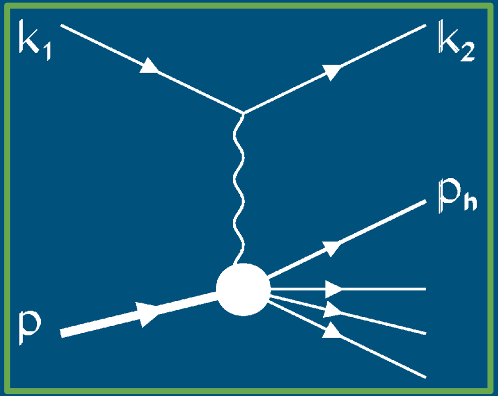




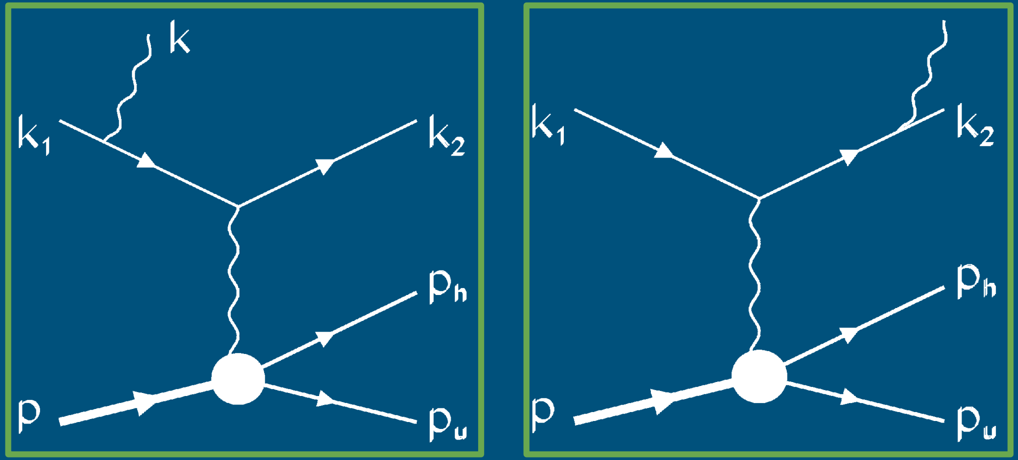
xf>0 cut applied.

Correction to Data: Radiative Corrections

Radiative correction accounts for events with real photon emission, among others:



Non-radiative SIDIS event



Radiative SIDIS events

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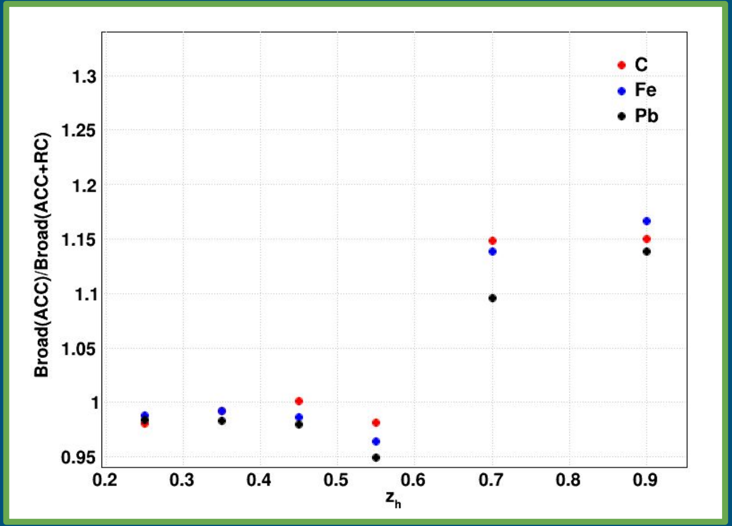

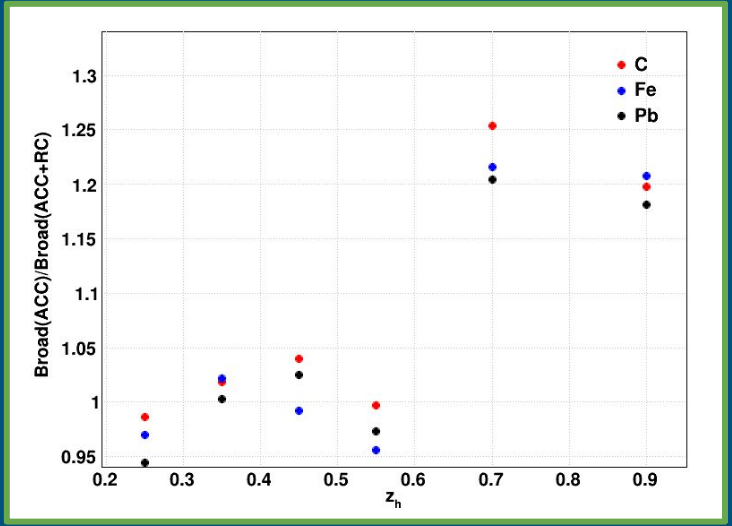

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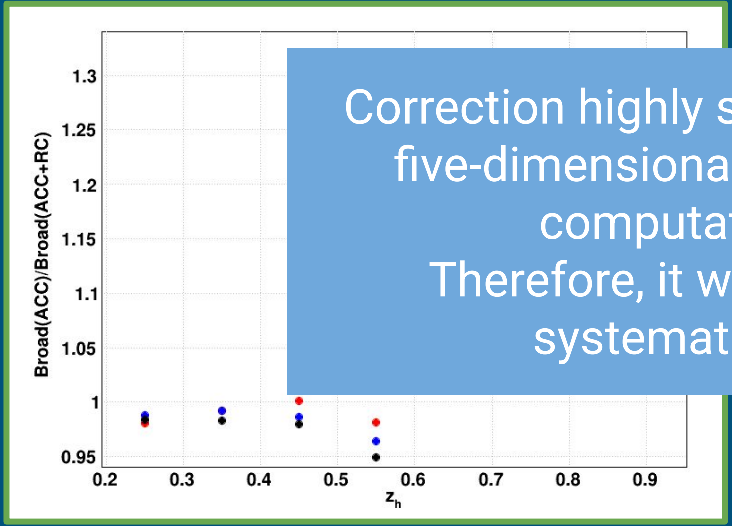
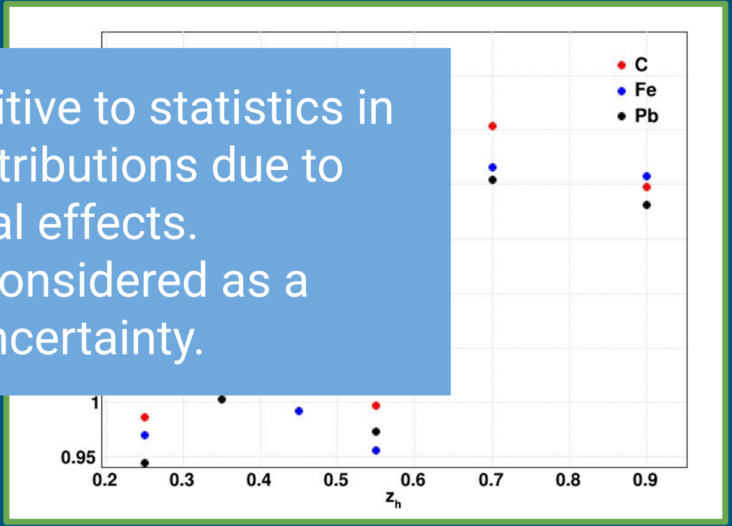
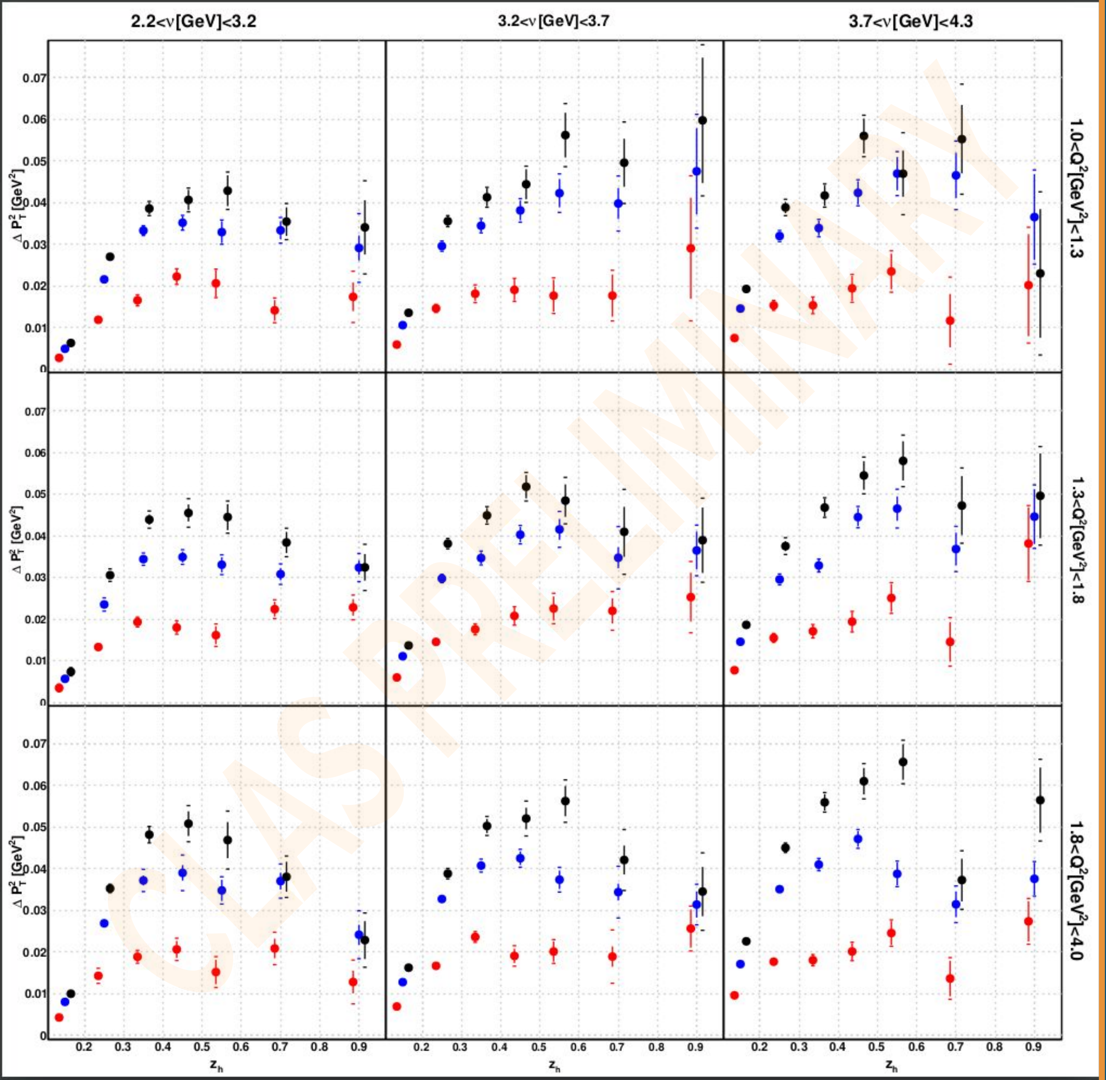




Correction highly sensitive to statistics in five-dimensional distributions due to computational effects.
Therefore, it was considered as a systematic uncertainty.

xf>0 cut applied.



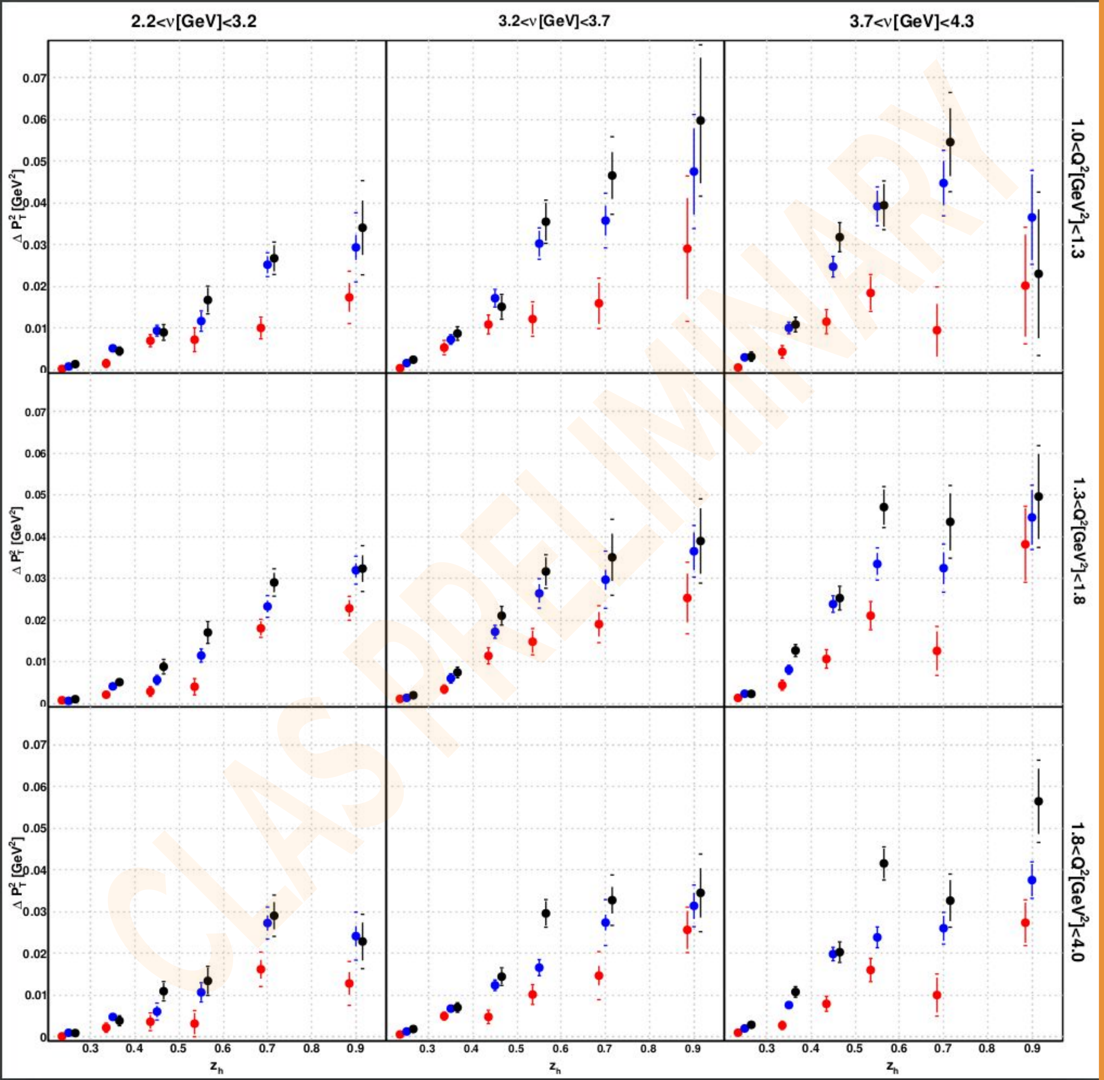
Three-dimensional Results

Legend:

- **Carbon**
- **Iron**
- **Lead**

Observations:

- Strong correlation with zh.
- Weak correlation with nu and Q^2.



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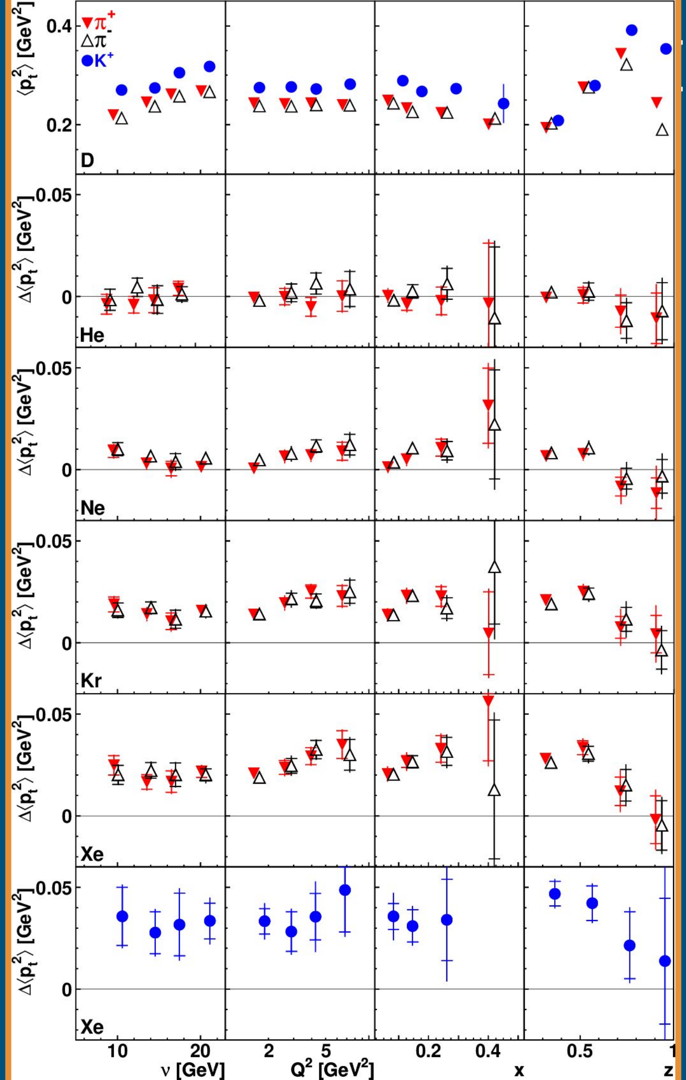
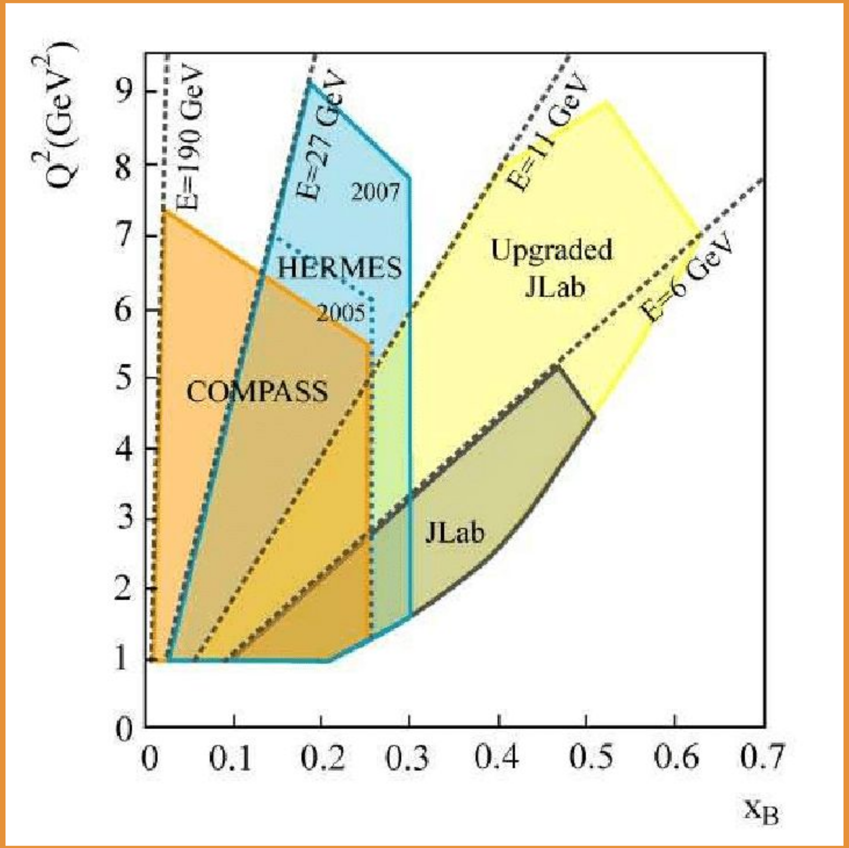
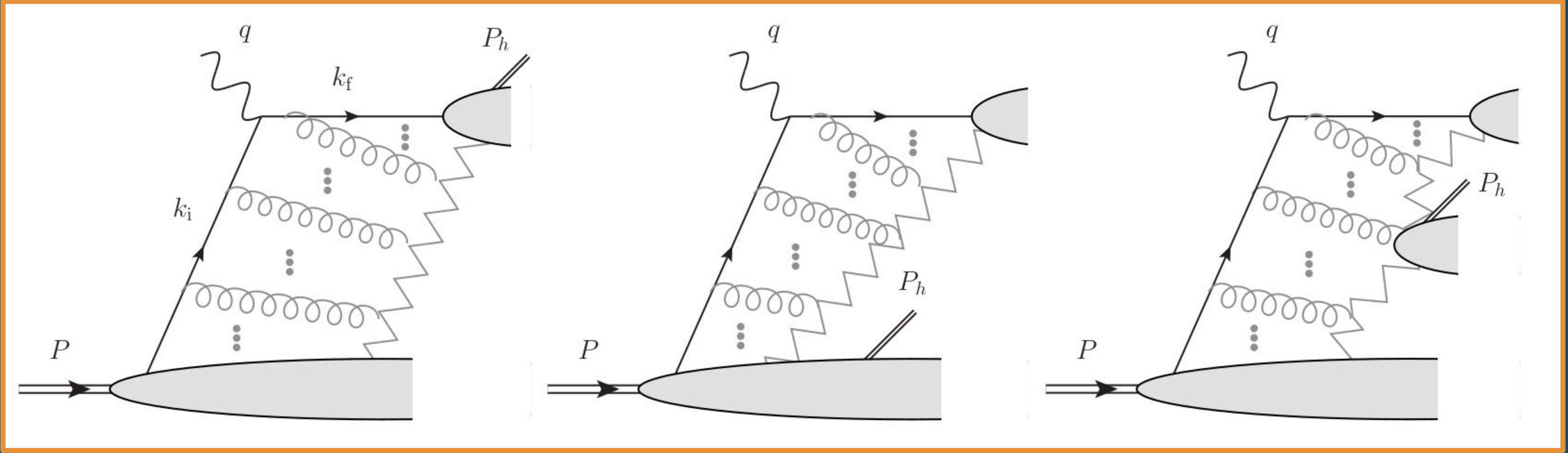
ES Broadening



Kinematic Coverage



Fragmentation Regions



Current Target Mixed

[-] **Boglione, M.; *et al.*** (2017). *Kinematics of current region fragmentation in semi-inclusive deep inelastic scattering.*