Measuring Flavor Dependence of the EMC Effects

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Mississippi State University

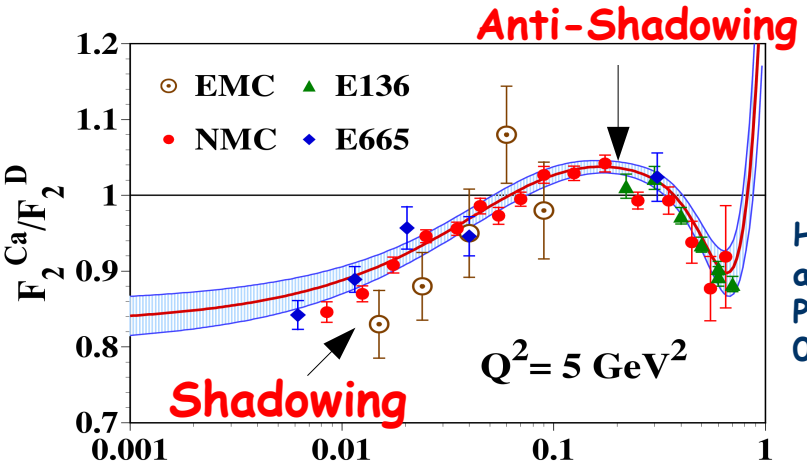
Workshop on Nuclear Chromo-Dynamic Studies
with a Future Electron Ion Collider
Argonne National Laboratory, April 7 - 9, 2010

Outline

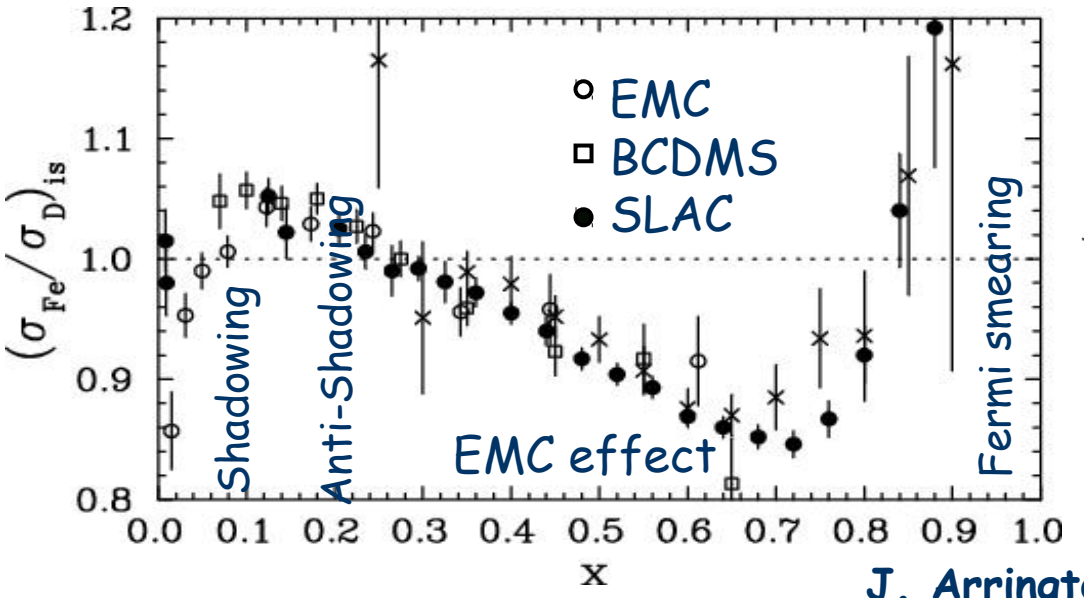
- Introduction
- Flavor tagged EMC effect, anti-shadowing and shadowing
- EMC program @ 12 GeV Jlab
  - quark flavour dependence of the EMC effect
  - PVDIS
  - EMC on Calcium
- New possibilities at an EIC

Introduction

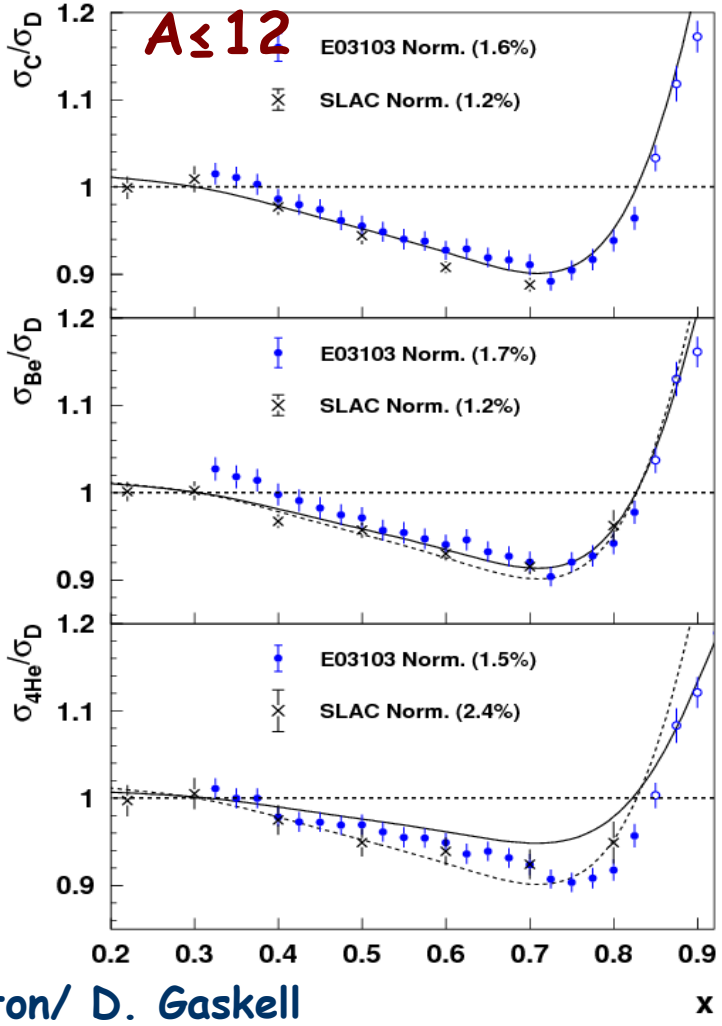
Over 25 years of experiments



Hirai, Kumano and Nagai, PRC 70, 044905 (2004)



JLabE03-103: A≤12



J. Arrington/ D. Gaskell

Origins of the EMC Effect

- **Traditional Models**

  -Fermi motion + binding + nuclear pions

  (uses realistic description of nucleons in the nucleus)

- **Quark Models**

  -Multiquark clusters

  (convolution over nucleons and multi-quark clusters)

  -Dynamical rescaling

  $$F_2^A(x,Q^2) = F_2^N(x,\xi_A(Q^2)\cdot Q2)$$

  -Quark-meson coupling inspired models

  (covariant quark-diquark eq. in NJL model light-cone nucleon distributions)

Review of EMC effect: Geesaman, Saito and Thomas, Ann. Rev. of Part. Sci. 45, 377 (1996)
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Need new handles to understand the origins

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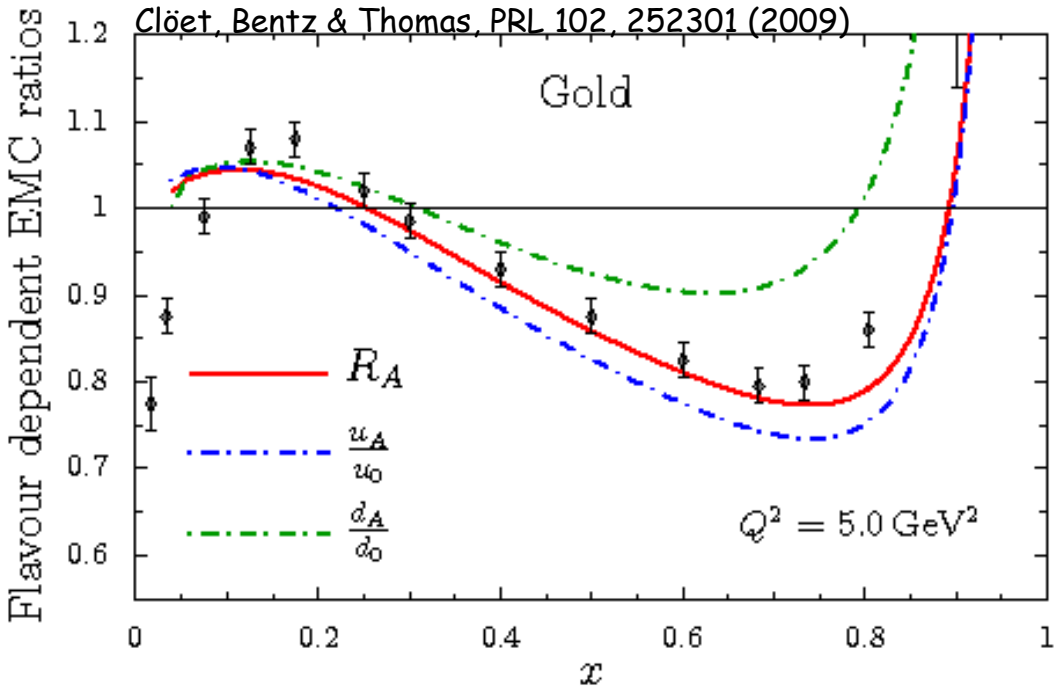
Flavor Dependence of the EMC effect

Some models predict a significant flavor dependence for asymmetric nuclei such as gold.

The isovector-vector mean field (ρ^0) causes an *u* (*d*) quark to feel an additional vector attraction (repulsion) in N ≠ Z Nuclei.



medium modified quark distributions

$$u_A = \frac{Z\tilde{u}_p + N\tilde{d}_p}{A}, \quad d_A = \frac{Z\tilde{d}_p + N\tilde{u}_p}{A}$$

nucleon quark distributions

$$u_0 = \frac{Zu_p + Nd_p}{A}, \quad d_0 = \frac{Zd_p + Nu_p}{A}$$

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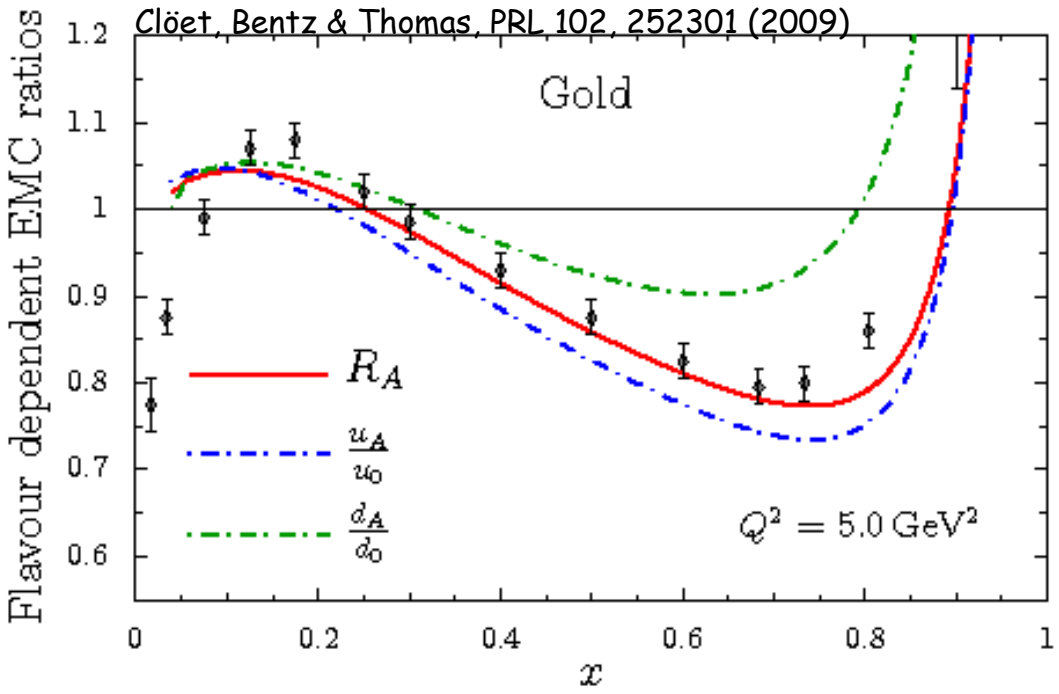

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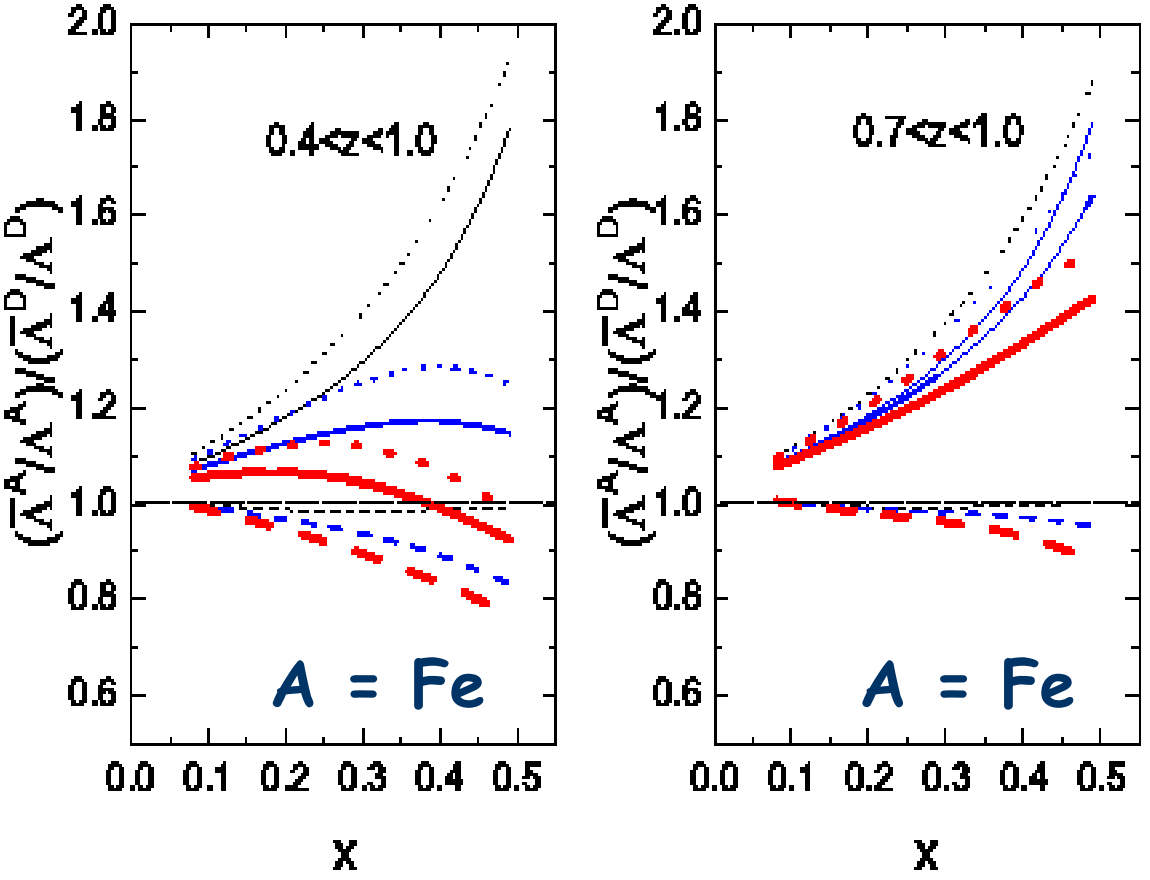
Experimentally, the flavor dependence of the EMC effect is as yet completely unexplored.

Sea Quark Flavor Dependence of EMC effect

It has been shown that models of the EMC effect can be distinguished based on their prediction for the sea content of nuclei

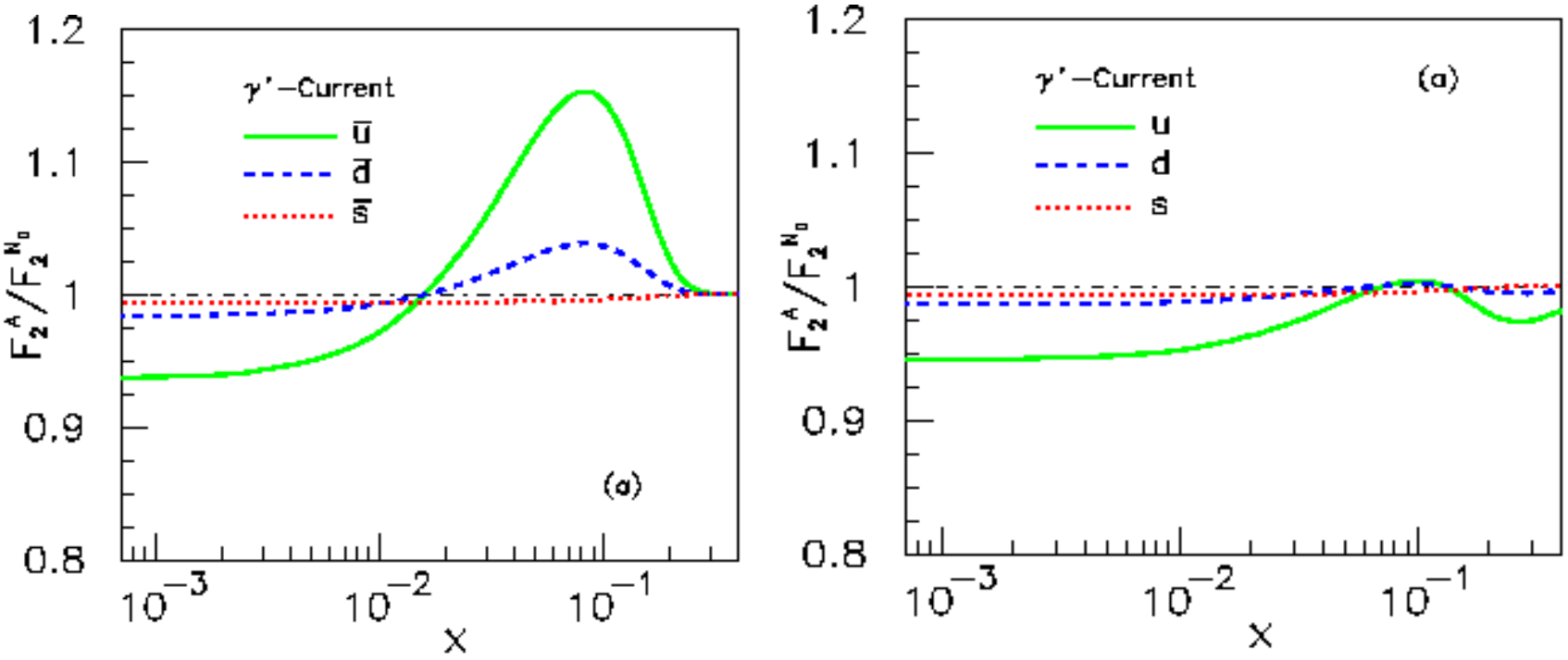


The colors correspond to different options for the unfavored fragmentation functions

B. Lu and B.-Q. Ma
Phys. Rev. D 74, 055202 (2006)

Flavor Dependence of Shadowing and Anti-Shadowing

Other models predict a significant flavor dependence of the anti-shadowing and shadowing effects.

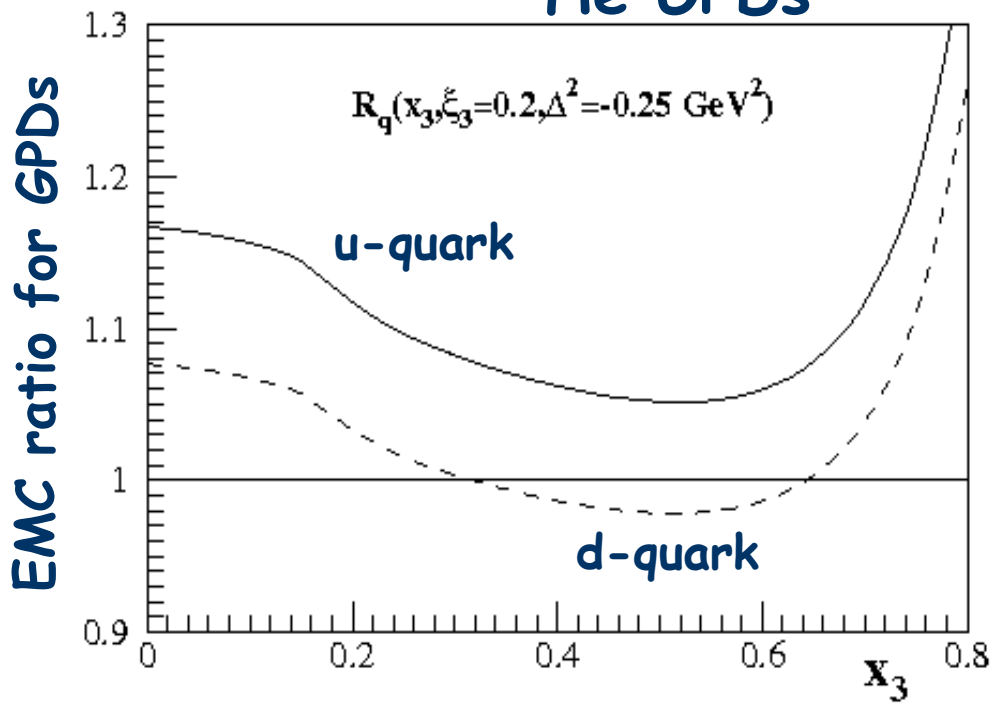


S. J. Brodsky, I. Schmidt and J. J. Yang,
Phys. Rev. D 70, 116003 (2004)

Flavor Dependence of EMC effect for GPDs

EMC effect for off-forward GPDs is strongly flavor dependent

^{3}He GPDs



EMC ratio for ^{3}He GPDs

$$R_q = \frac{H_q^3(x,\xi,\Delta)}{2H_q^{3,p}(x,\xi,\Delta)+H_q^{3,n}(x,\xi,\Delta)}$$

$\Delta = P' - P$ = 4-momentum transfer to the hadron

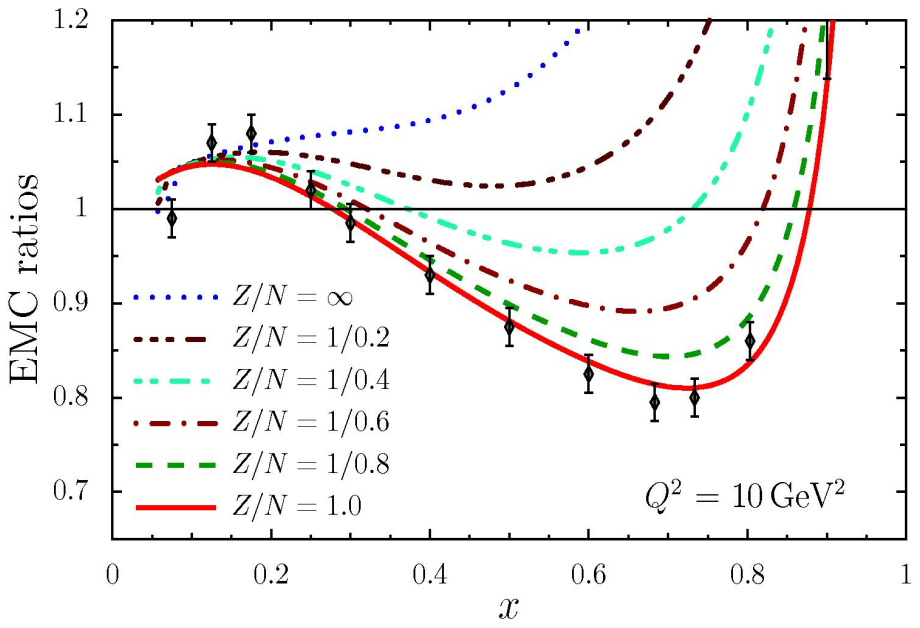
$\xi \sim x/(2-x)$ = skewedness

$\Delta = \xi = 0$, is the "forward" limit

S. Scopetta,
Phys. Rev. C 79, 025207 (2009)

Can be accessed via nuclear DVCS in off-forward kinematics

Existing Data Do Not Constrain Flavor Dependence



Clöet, Bentz & Thomas, PRL 102, 252301 (2009)

Different EMC effect for u and d quarks

Inclusive DIS data unlikely to constrain this model.

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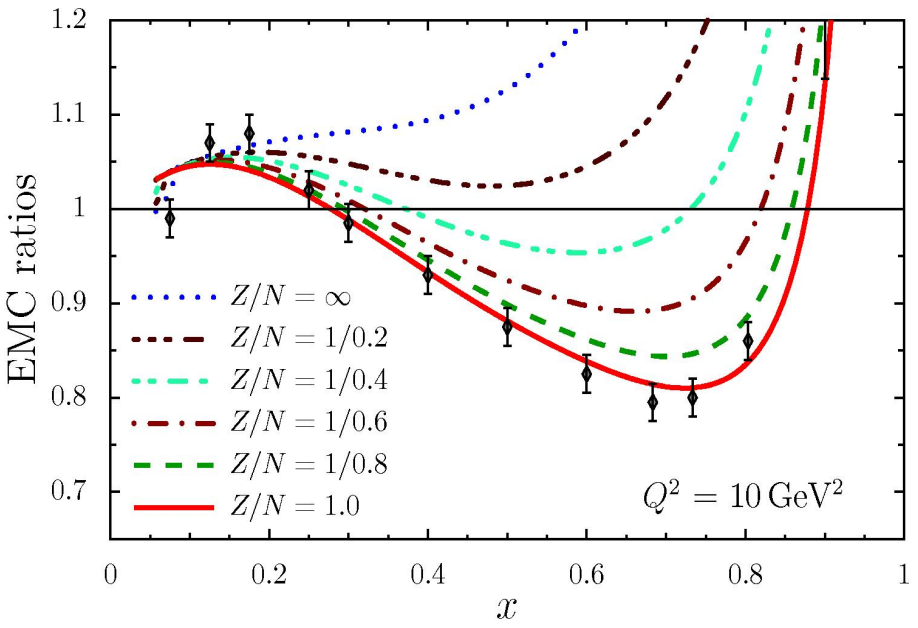

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Different anti-shadowing and shadowing for u, d, ū and đ quarks

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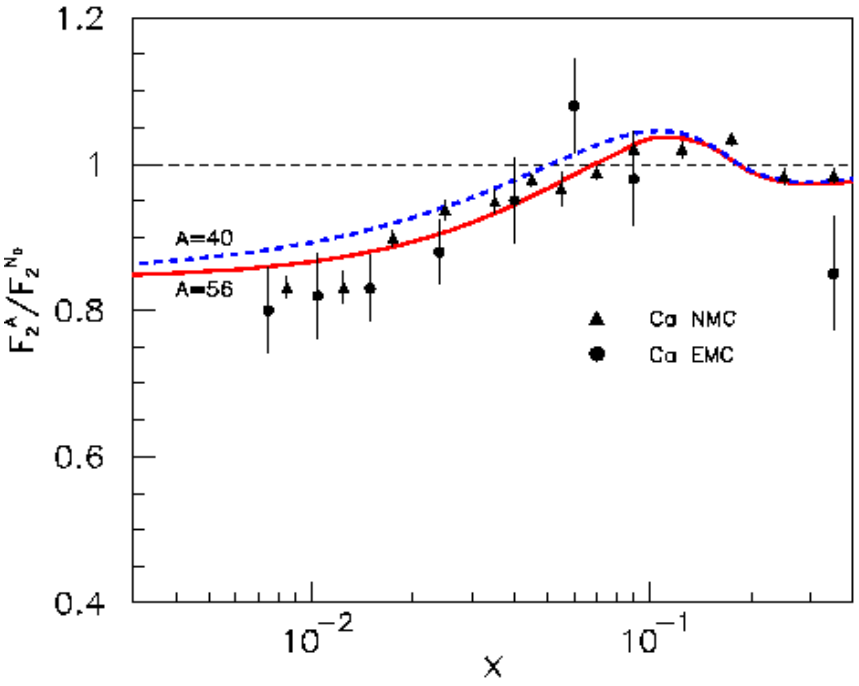
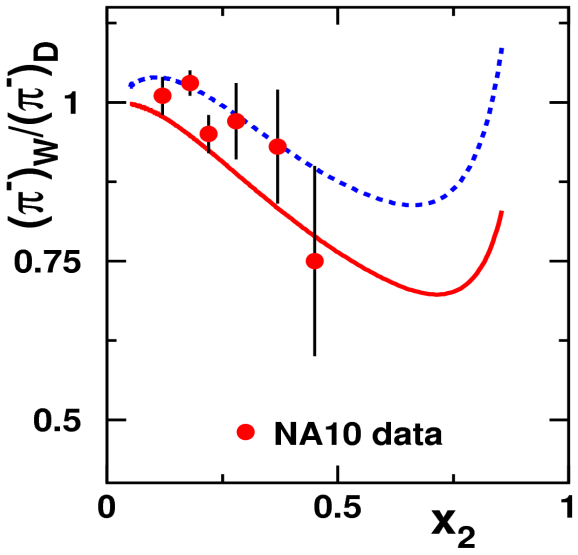
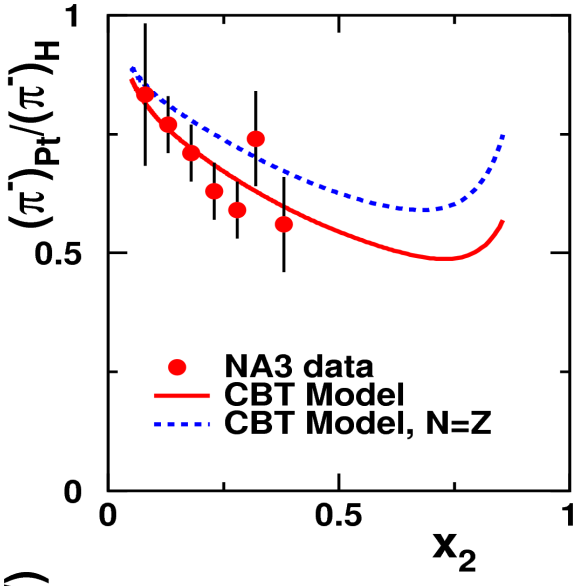
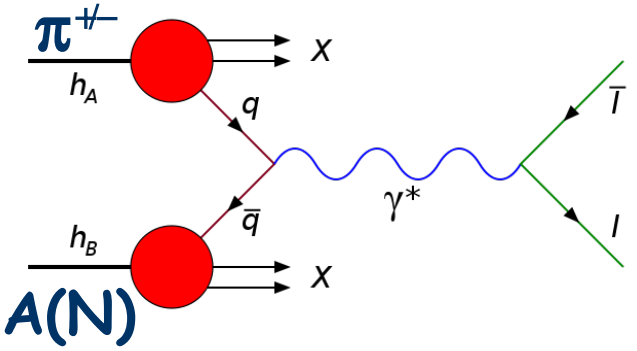
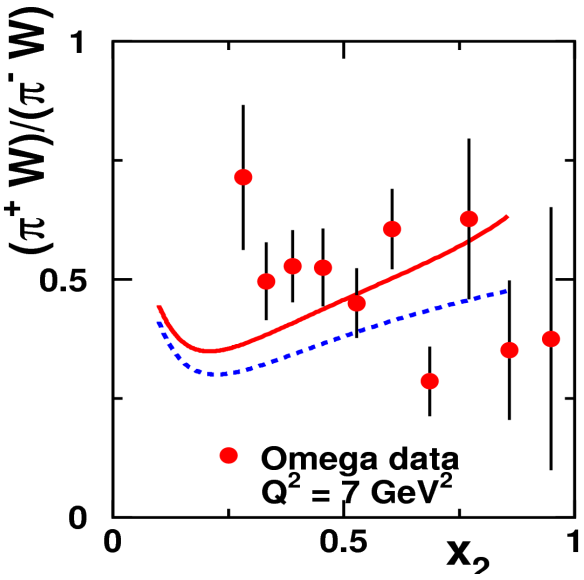


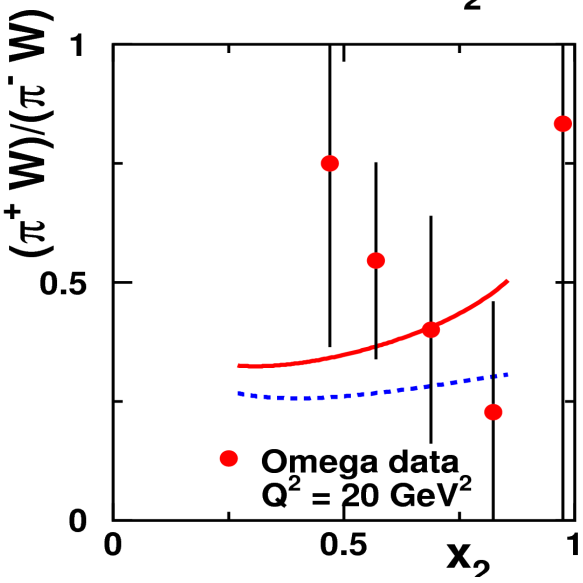
Existing Data Is Not Sufficient









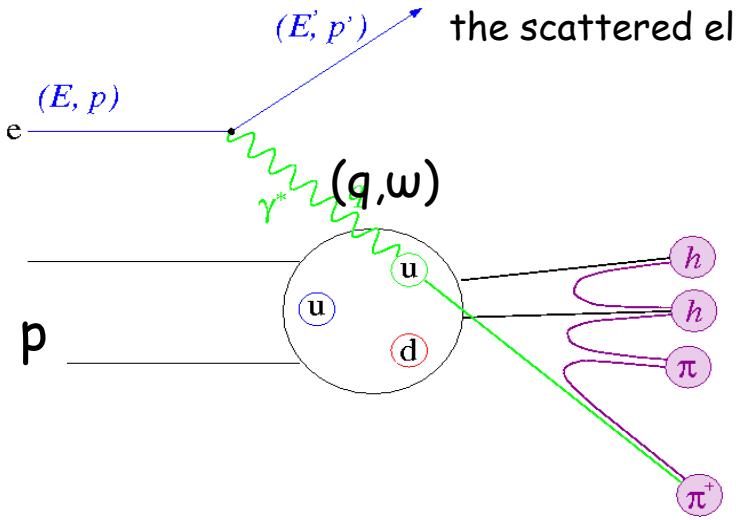


Pionic Drell-Yan data cannot constrain flavor dependence of EMC effect

Dutta, Gaskell, Peng and Clöet
In preparation

Semi-Inclusive DIS

SIDIS @ high luminosity machines is one possibility



the scattered electron is detected

Tags the struck quark (flavor tagging)

at least one hadron is detected in coincidence

quark distribution

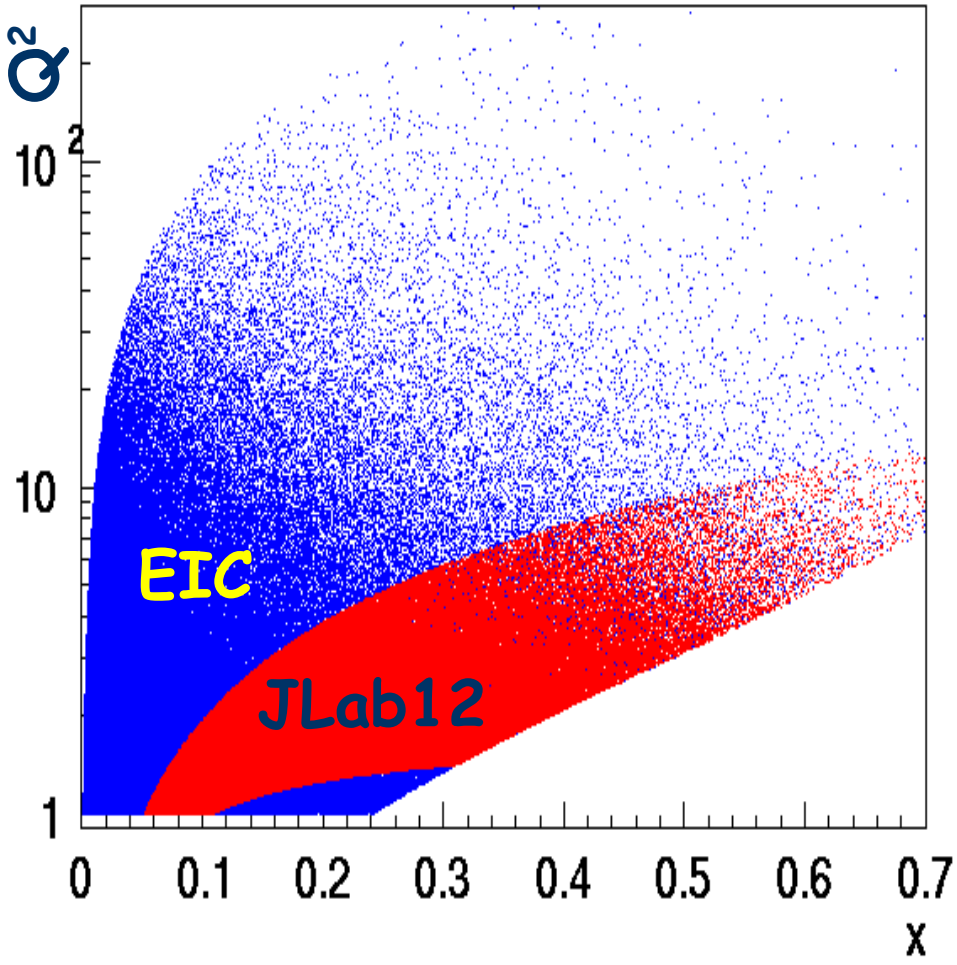
Fragmentation function
(probability of find quark 'f' in the hadron h)

$$\frac{d\sigma}{dx\,dQ^2\,dz} = \frac{\sum_f e_f^2 q_f(x,Q^2)\, D_f^h(z,Q^2)}{\sum_f e_f^2 q_f(x,Q^2)} \left(\frac{d\sigma}{dx\,dQ^2} \right)$$

Inclusive DIS cross section

Q^2 = 4-momentum transfer, x = fraction of proton's momentum carried by quark,
z = fraction of energy transfer carried by outgoing hadron

SIDIS @ Jlab → EIC



Flavor dependence of EMC effect, anti-shadowing and shadowing is important on its own right as a step in understanding the strong force in terms of QCD

Measurement of flavor dependence of these phenomena would help distinguish between the plethora of models and help understand the origins of the EMC effect.

Flavor dependence has been proposed as part of the explanation for the for the anomalous measurement of the Weinberg angle by NuTeV

Overlap between Jlab12 and EIC is Critical for this program

Jefferson Lab

Jlab → JLab@12GeV

$0.1 < x_B < 0.7$

valence quarks

EIC

EIC $10^{-4} < x_B < 0.3$

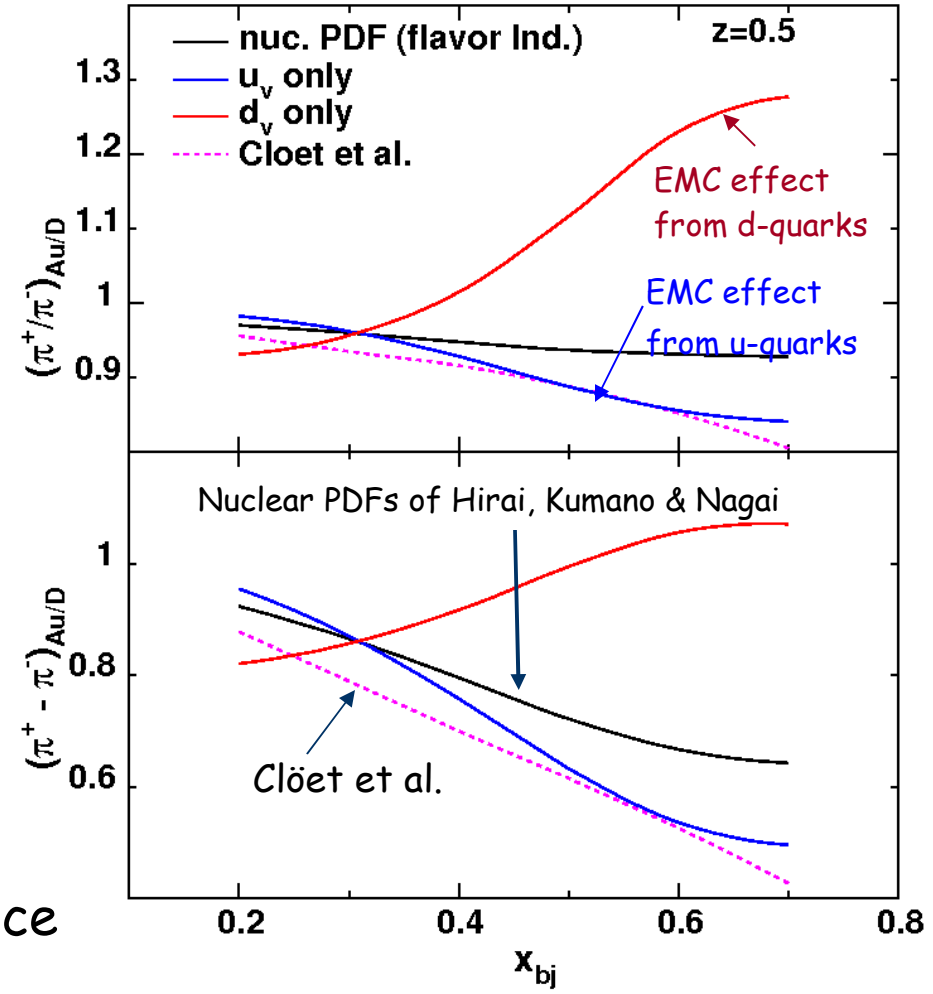
A New EMC Measurement

- New Observables

Super ratio $\dfrac{Y^{\pi+}_{Au} / Y^{\pi-}_{Au}}{Y^{\pi+}_{D} / Y^{\pi-}_{D}}$

&

Difference ratio $\dfrac{Y^{\pi+}_{Au} - Y^{\pi-}_{Au}}{Y^{\pi+}_{D} - Y^{\pi-}_{D}}$



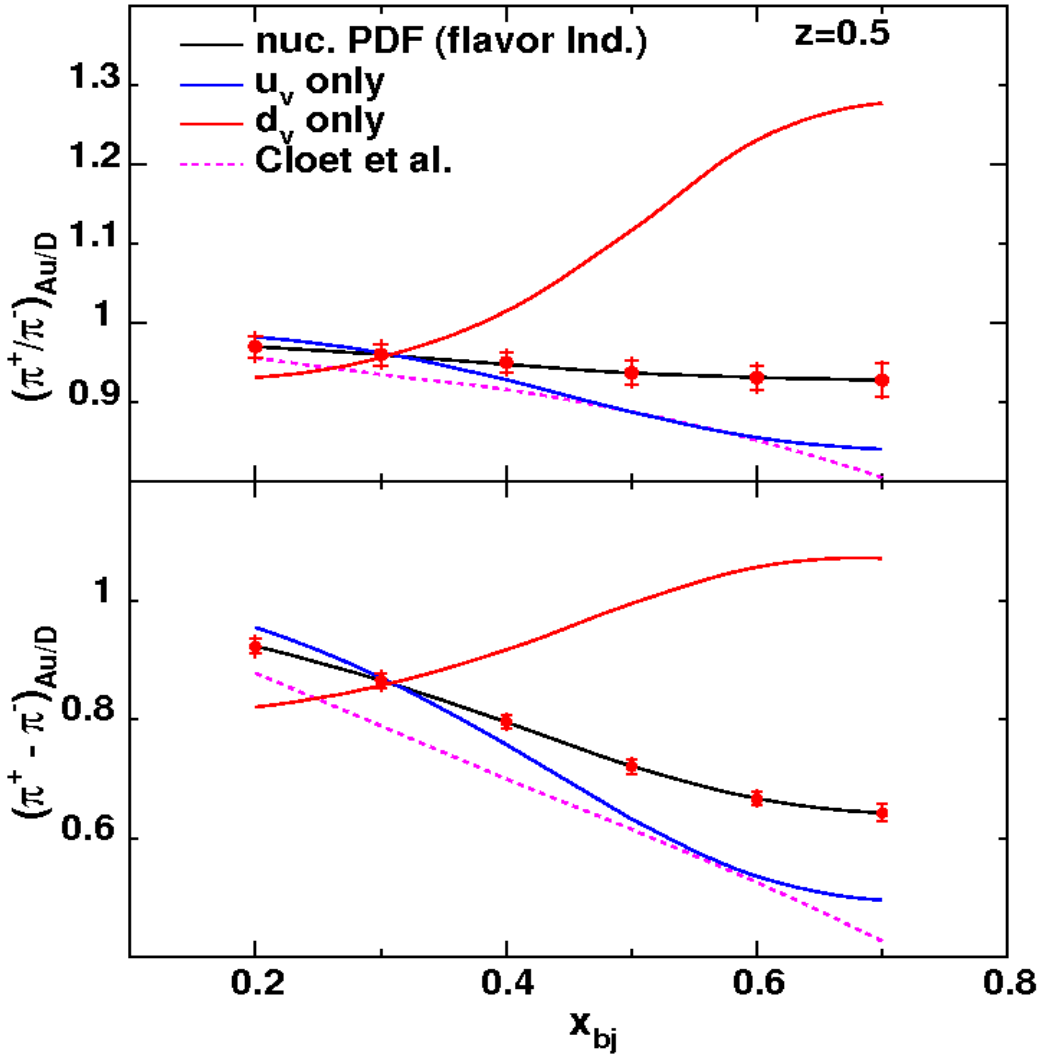
Test sensitivity to flavor dependence of the EMC effect with toy model

u_v only: EMC effect due to modification of u_A only

d_v only: EMC effect due to modification of d_A only

} F_2^A remains unchanged

Projected Results



Measure $A(e,e'\pi^{\pm})X$ on ^2H and ^{197}Au with E_e = 11 GeV.

$Q^2 > 1.0$ GeV^2, $W^2 > 4.0$ GeV^2 and $W'^2 > 2.5$ GeV^2, $P_T \sim 0$

Spokespersons:
D. Dutta, D. Gaskell & K. Hafidi

x = 0.2 to 0.6 in steps of 0.1, at a fixed z = 0.5

Both observables can be measured with sufficient precision to verify and/or set stringent limits on the flavor dependence of EMC effect

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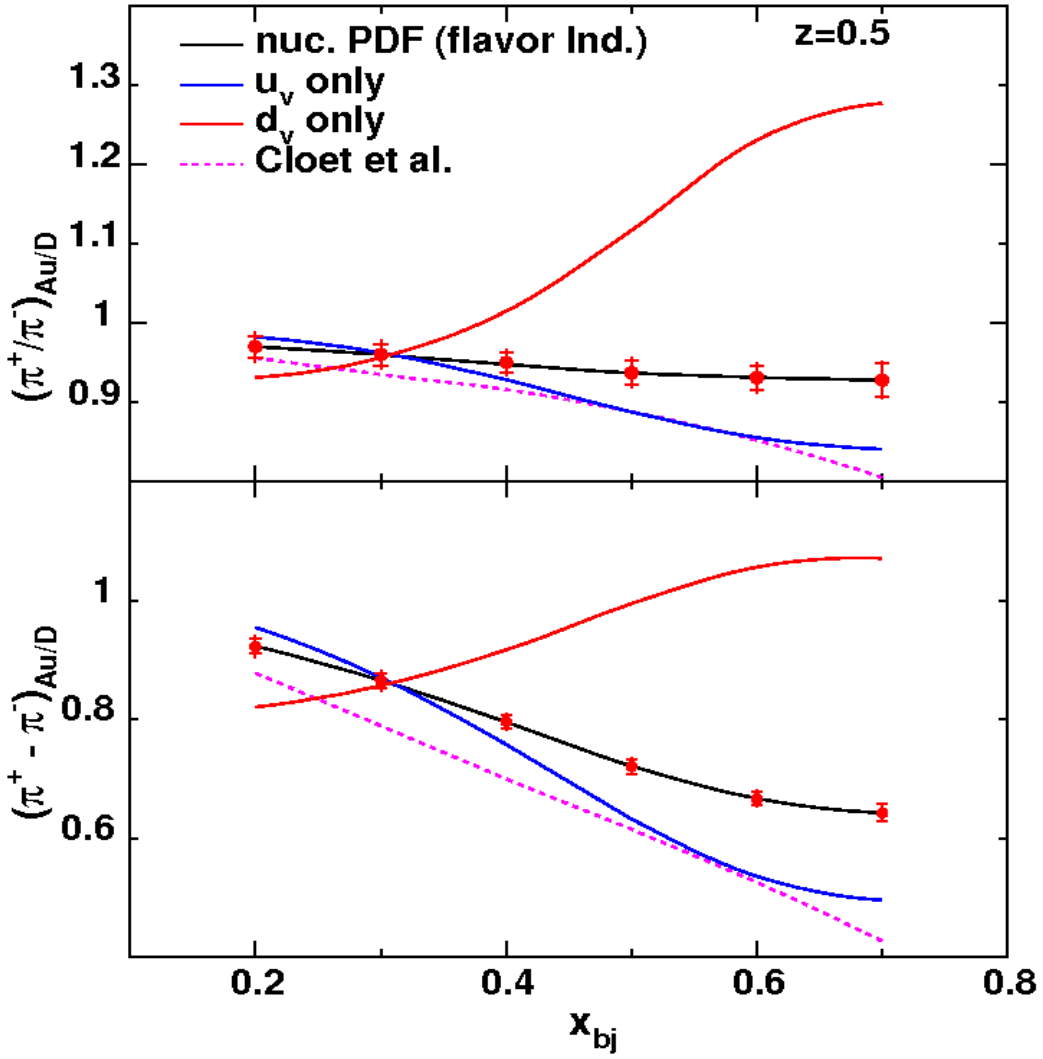

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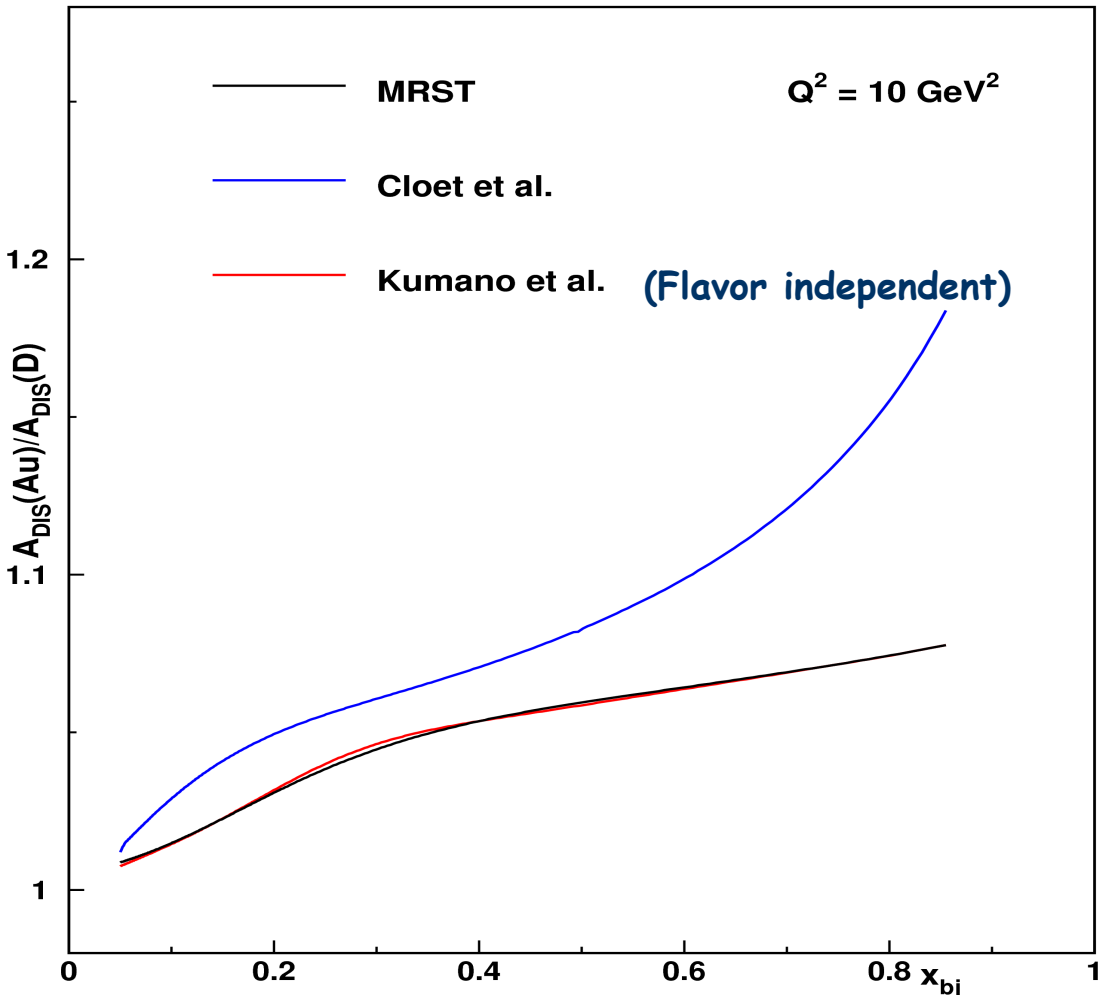
a CLAS experiment for SIDIS pion/kaon production was approved.

Both observables can be measured with sufficient precision to verify and/or set stringent limits on the flavor dependence of EMC effect

Parity- Violating DIS

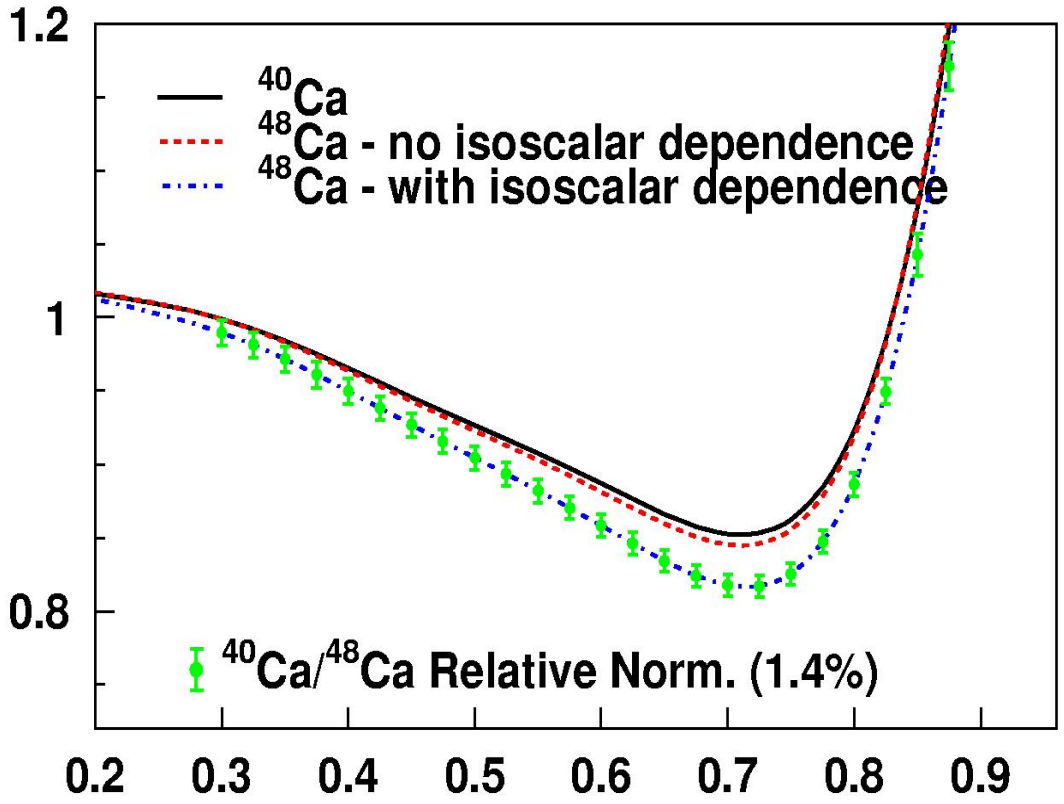


Two 12-GeV experiments already approved.

One should concentrate on heavy targets

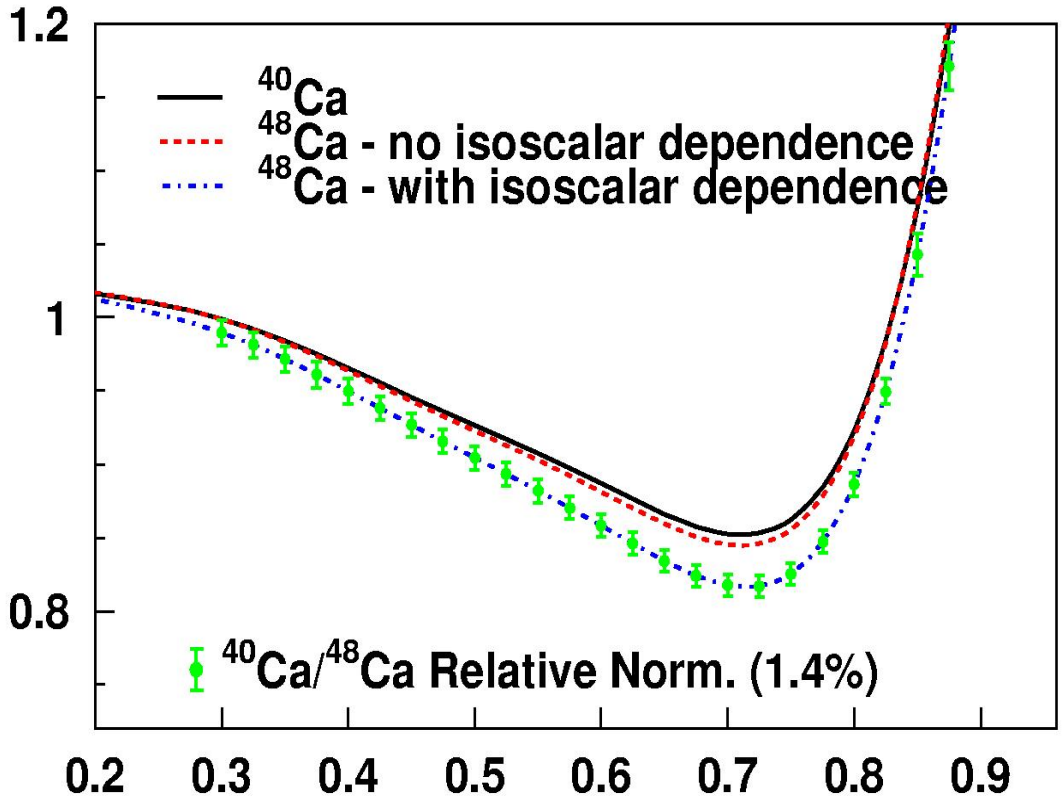
~ 5% effect at x =0.7

DIS experiment @ 12 GeV



E10-008
Spokespersons:
Arrington, Gaskell and Daniels

DIS experiment @ 12 GeV



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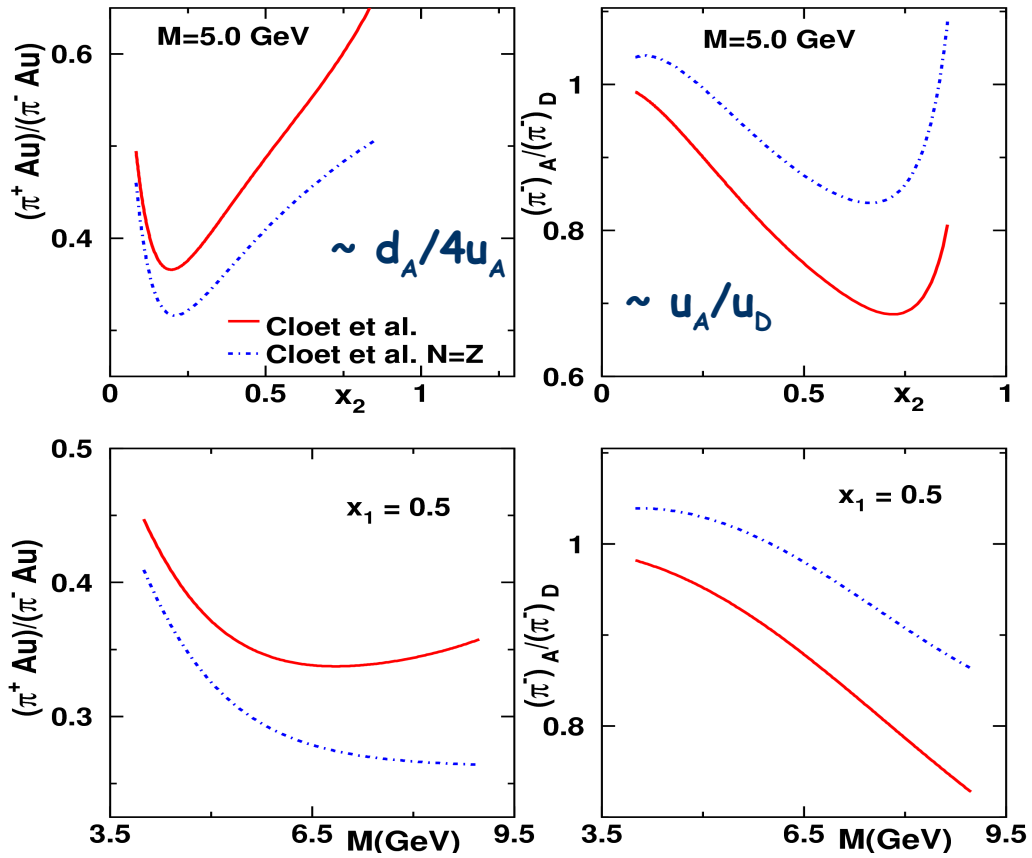
High precision measurements @ Jlab 12 GeV will cover the EMC region with a variety of experiments

Other Opportunities



Pionic Drell-Yan

160 GeV pions on Gold target

can be accessed at COMPASS

Dutta, Gaskell, Peng and Clöet
In preparation

$$\frac{d\sigma^2}{dx_1 dx_2} = \frac{4\pi\alpha^2}{3s}\frac{1}{3}\sum_i \frac{e_i^2}{x_1 x_2}\left[f^1_{q_i}(x_1) f^2_{\bar{q}_i}(x_2) + f^1_{\bar{q}_i}(x_1) f^2_{q_i}(x_2) \right]$$

x_{pion} $x_{nucleon}$

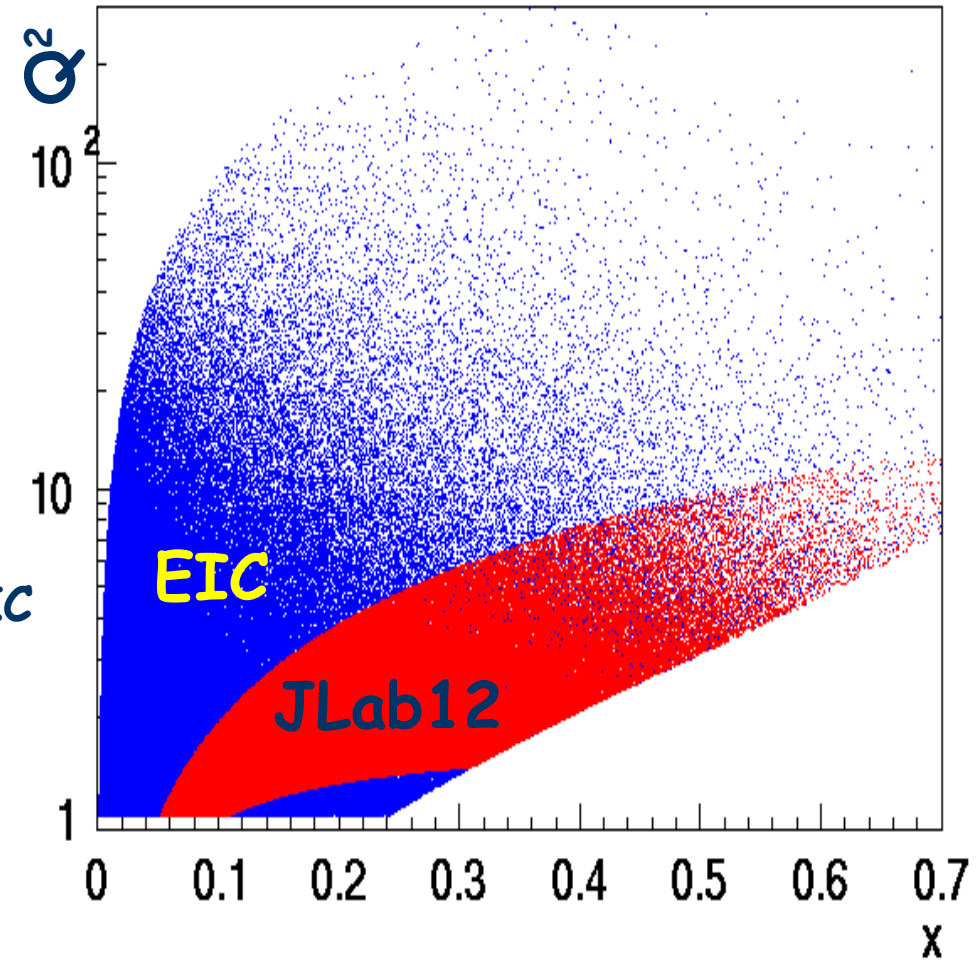
quark/antiquark distributions

SIDIS @ Jlab → EIC

4 GeV e → ← p 60 GeV

SIDIS kinematics

$Q^2>1GeV^2$
$W^2>4\ GeV^2$
$y<0.85$
$M_X>2GeV$

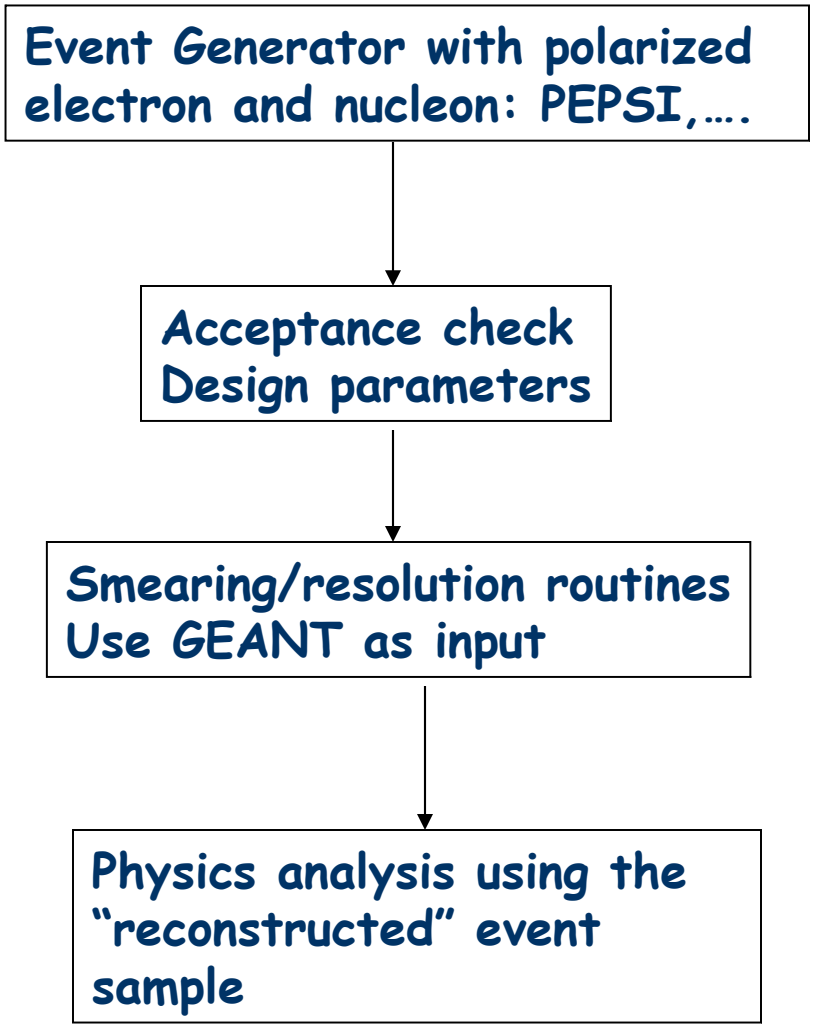


Overlap between Jlab12 and EIC is critical for this program

Jlab → JLab@12GeV
$0.1<x_B<0.7$
valence quarks

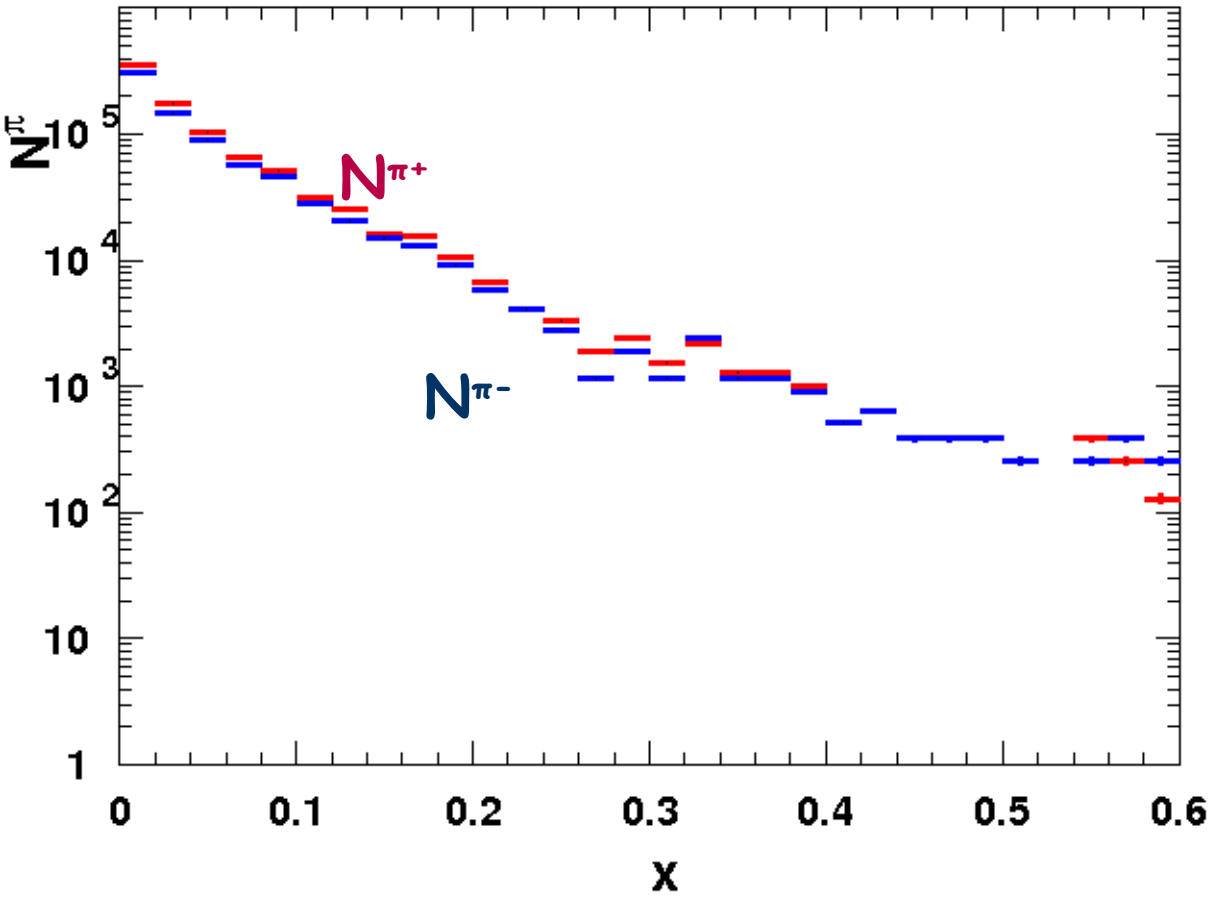
EIC $10^{-4}<x_B<0.3$

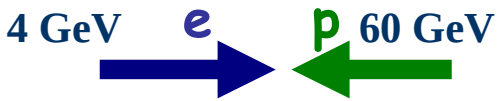
Fast MC for EIC



Written by
Harut Avakian

Pion Production in SIDIS



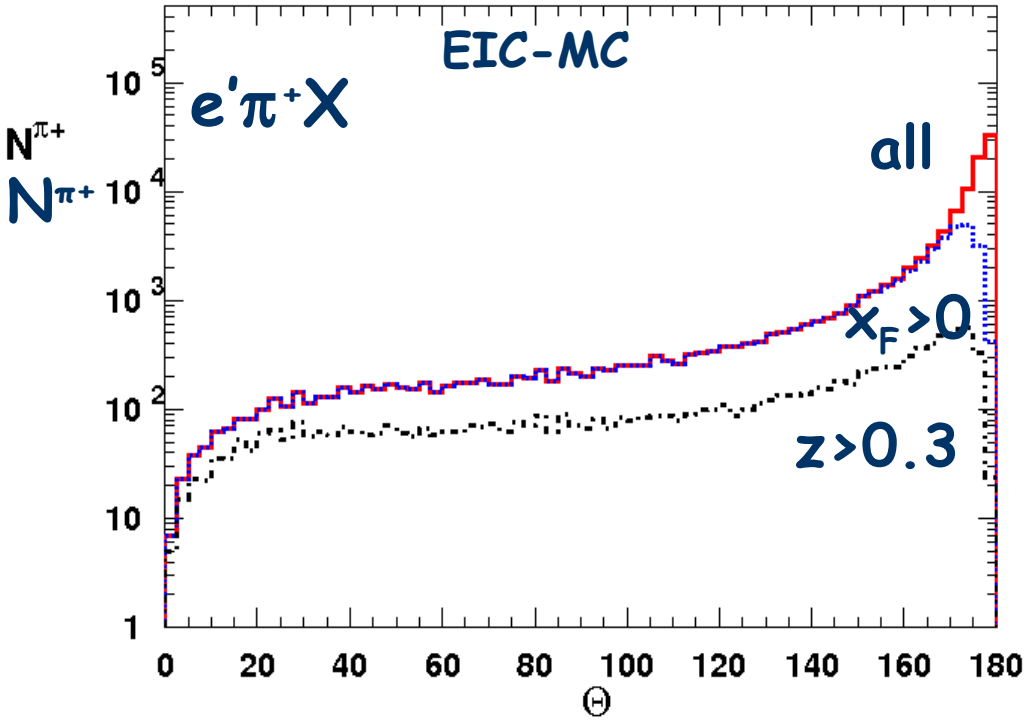


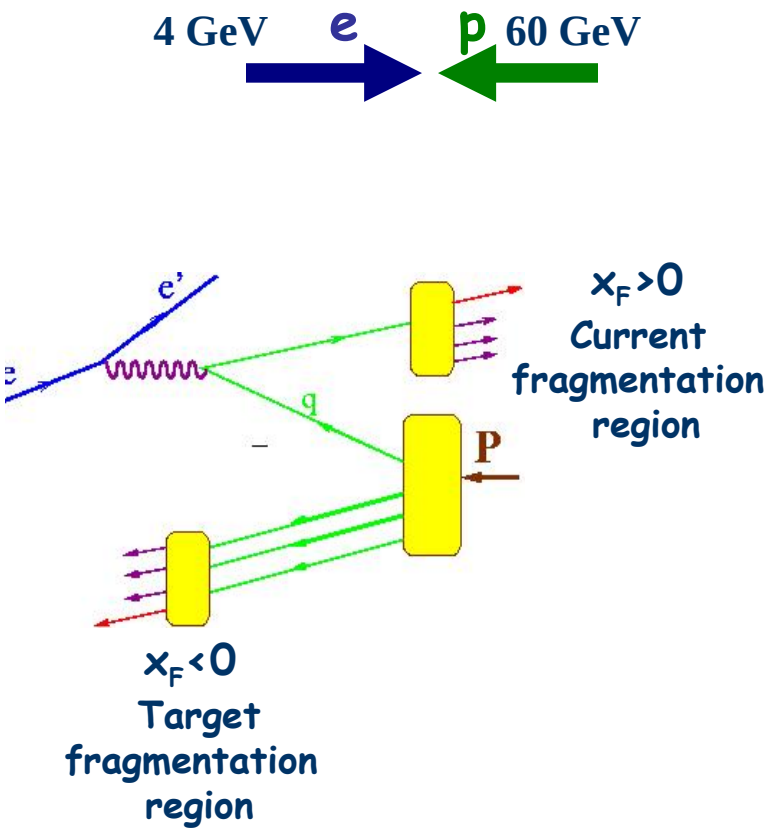
$L = 10^{33}\ cm^{-2}\ s^{-1}$

100 hrs

Using Fast-MC
From Harut Avakian

EIC Kinematic Coverage





Major part of current particles are at large angles in Lab frame (PID at large angles crucial).

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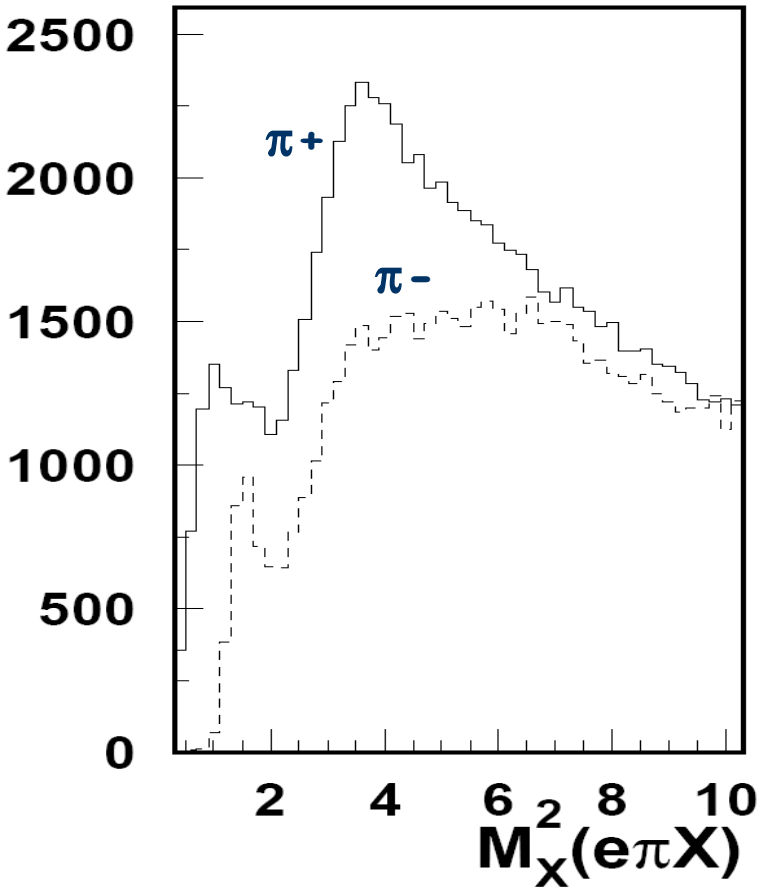
Pion Production in SIDIS



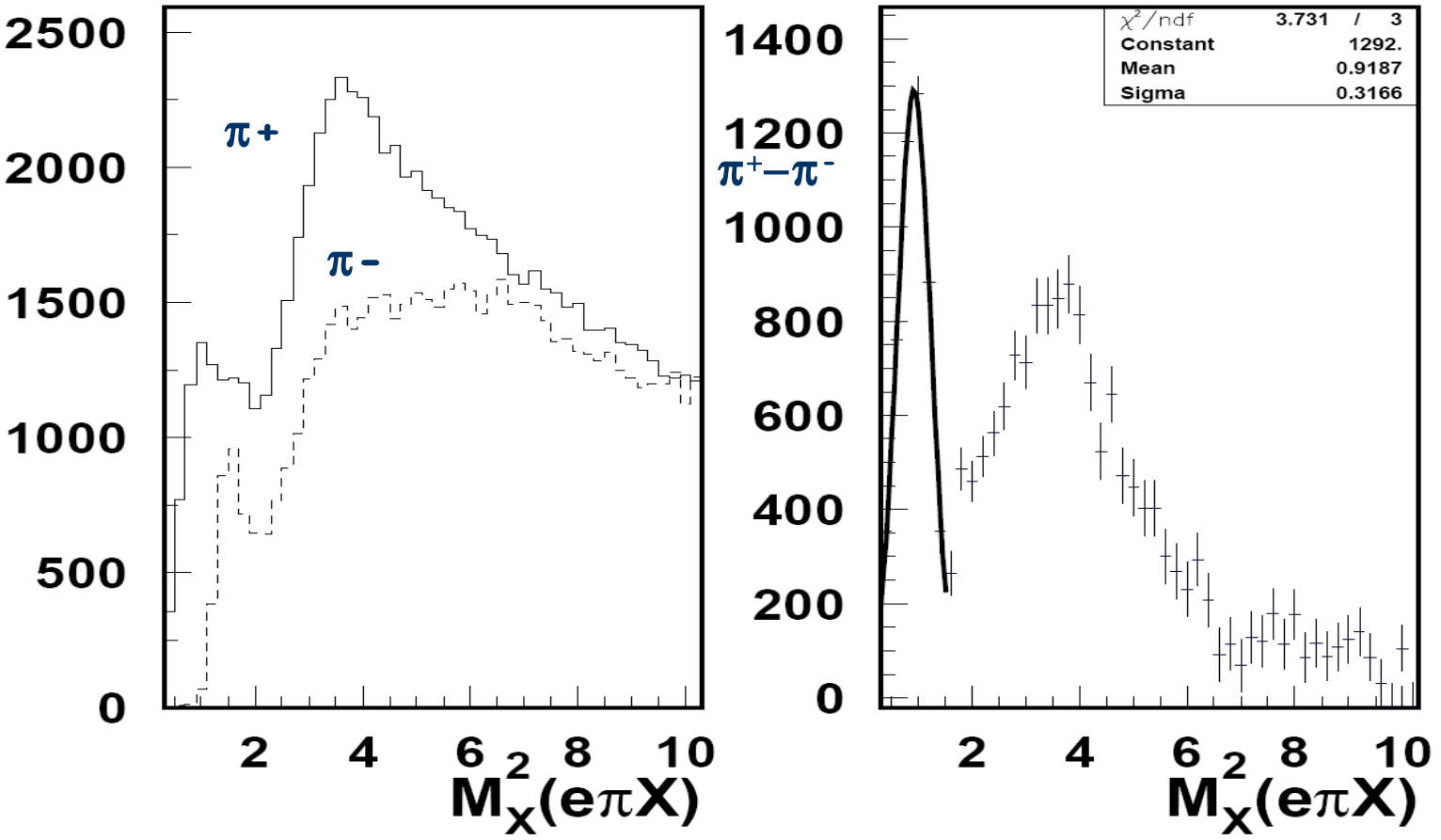
$\sigma(p) = 0.05 + 0.06*p\ [GeV]\ \%$[1]

Good resolution essential to identify exclusive events

[1] Rolf Ent priv. comm.

From Harut Avakian

Pion Production in SIDIS



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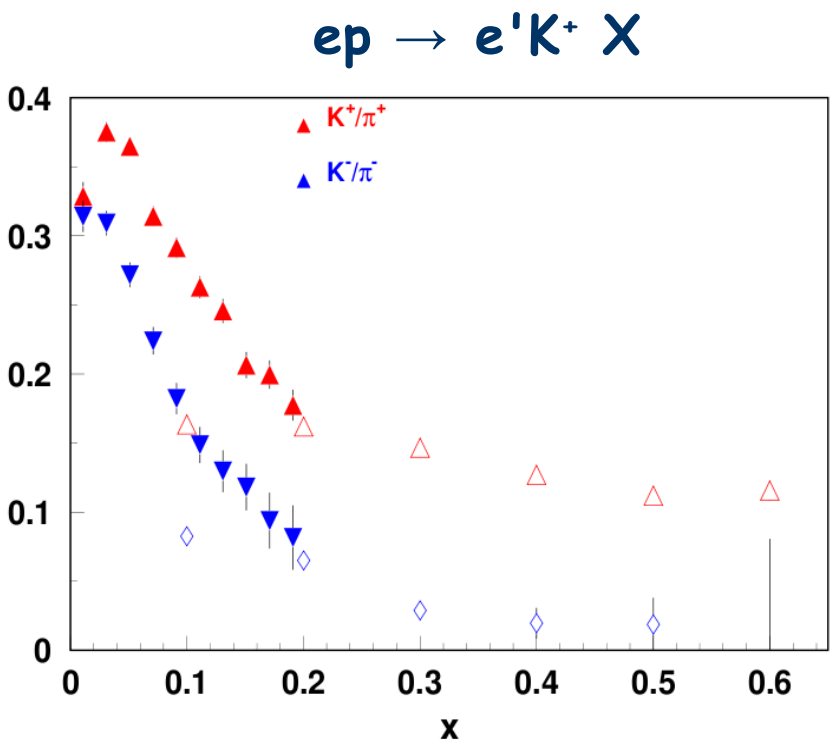
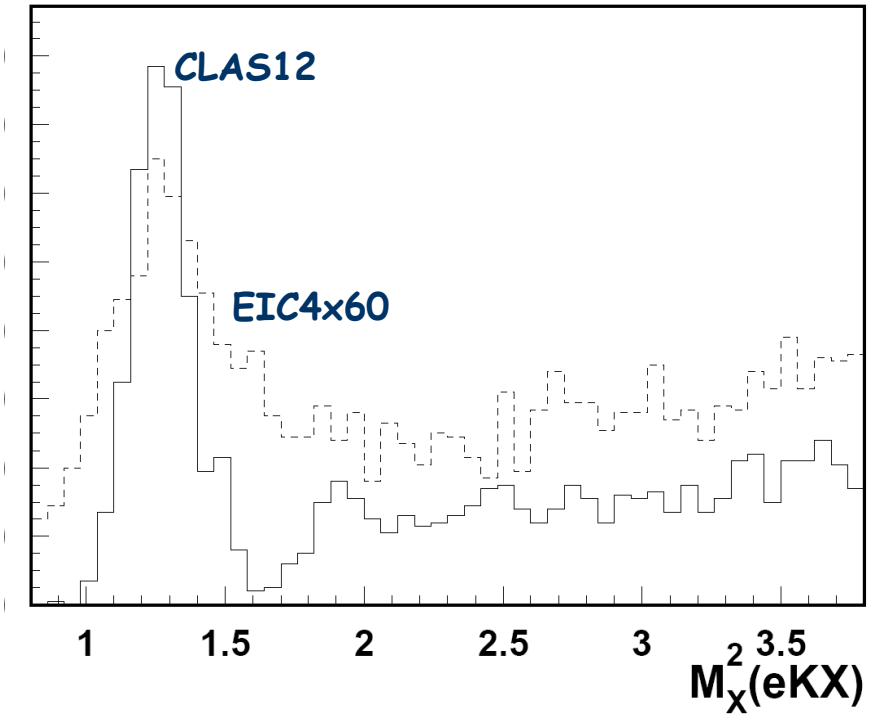
From Harut Avakian

Kaon Production in SIDIS





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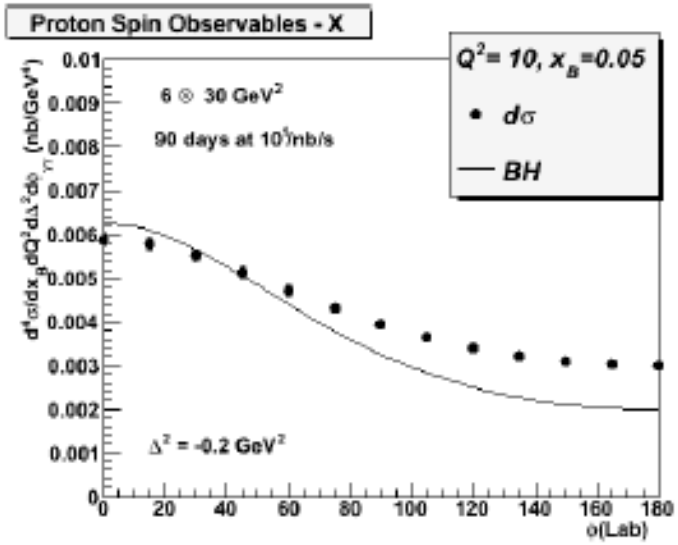
Identification using the missing mass may be possible

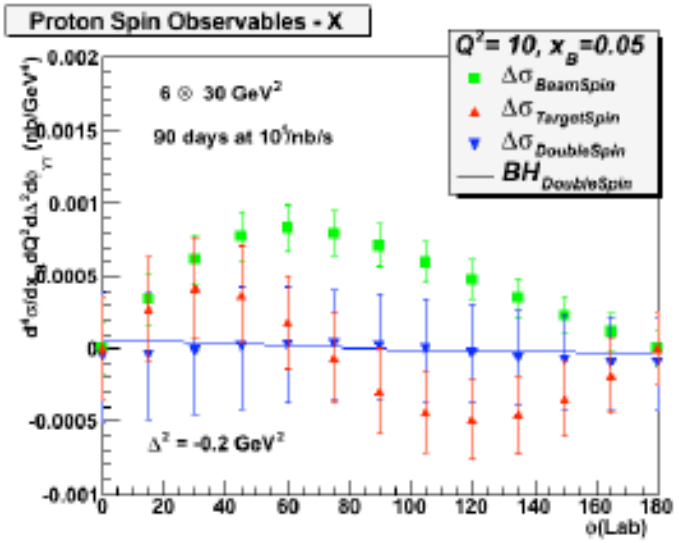
[1] Rolf Ent priv. comm.

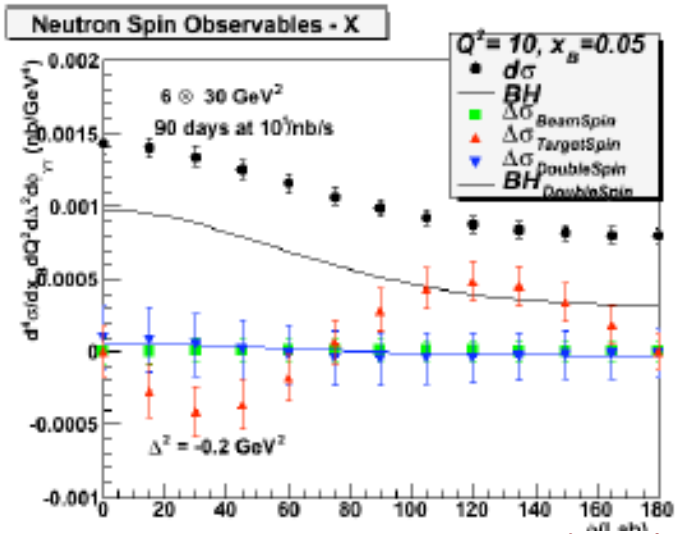
From Harut Avakian

Nuclear DVCS

Sample Count Rates







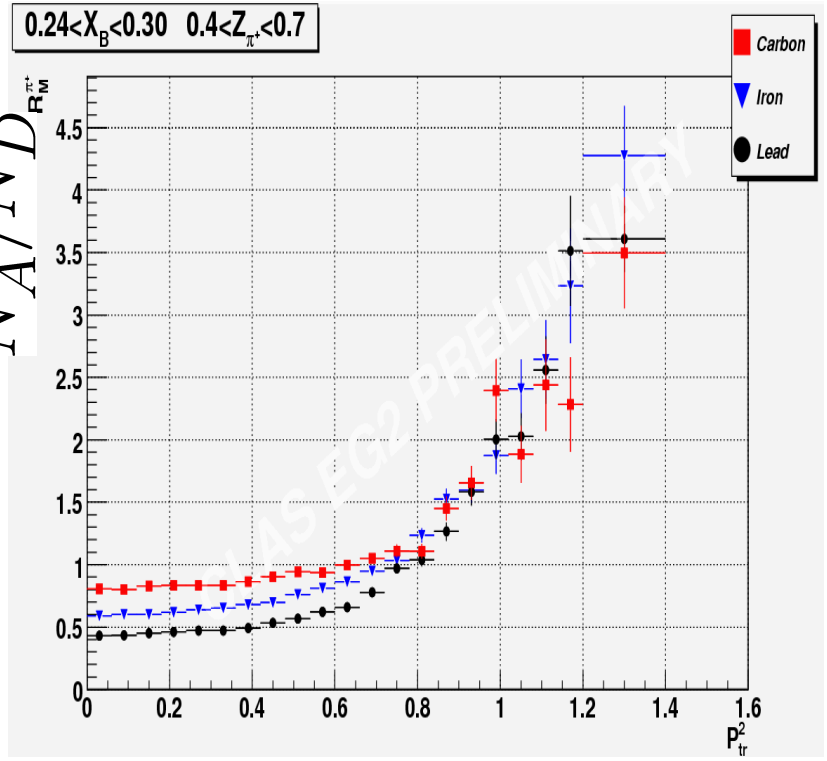
- L=10^{34}/cm^2/s
- $\Delta Q^2 = 0.4\ Q^2$
- $\Delta x_B = x_B/\sqrt{2}$
- Δt = 0.1 GeV^2.
- VGG code M. Guidal
  - Twist-2 only

From Charles Hyde

Summary

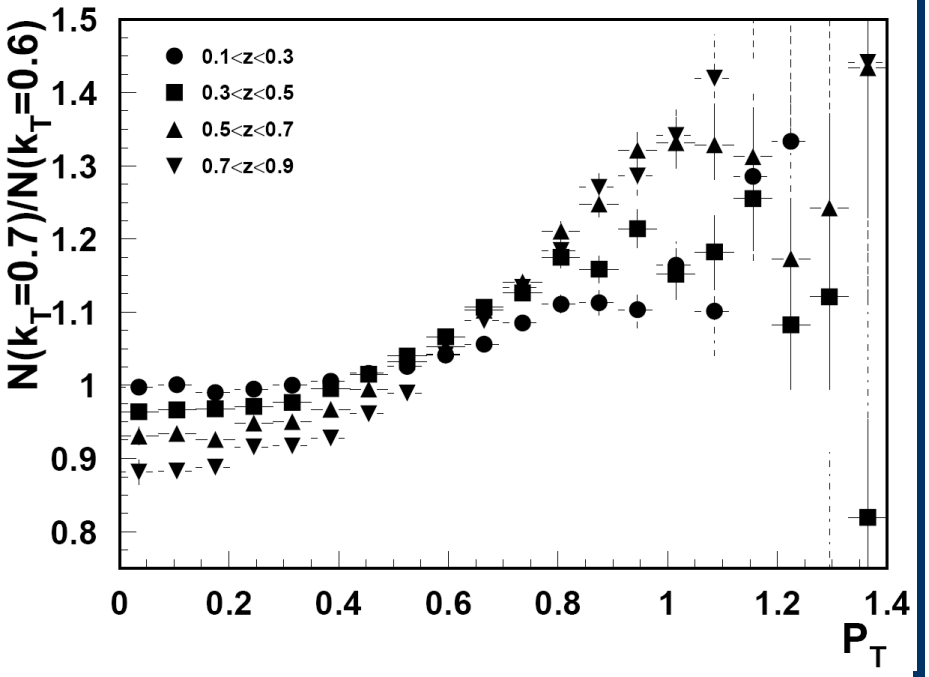
- A new handle is essential to make progress in our understanding of the EMC effect
- Flavor dependence of the EMC effect and anti-shadowing and shadowing presents just such a handle
- SIDIS and PVDIS at the upgraded Jlab can used to probe flavor dependence of EMC effect.
- While a high luminosity EIC would enable us to probe the flavor dependence of anti-shadowing, shadowing and EMC effect for GPDs
- To build a consistent and coherent program to study the quark distributions in nuclei, an overlap between the kinematics of Jlab @12 GeV and the EIC is essential.

Quark distributions at large k_T



bigger effect at large z

$P_T = p_\perp + z\, k_T$

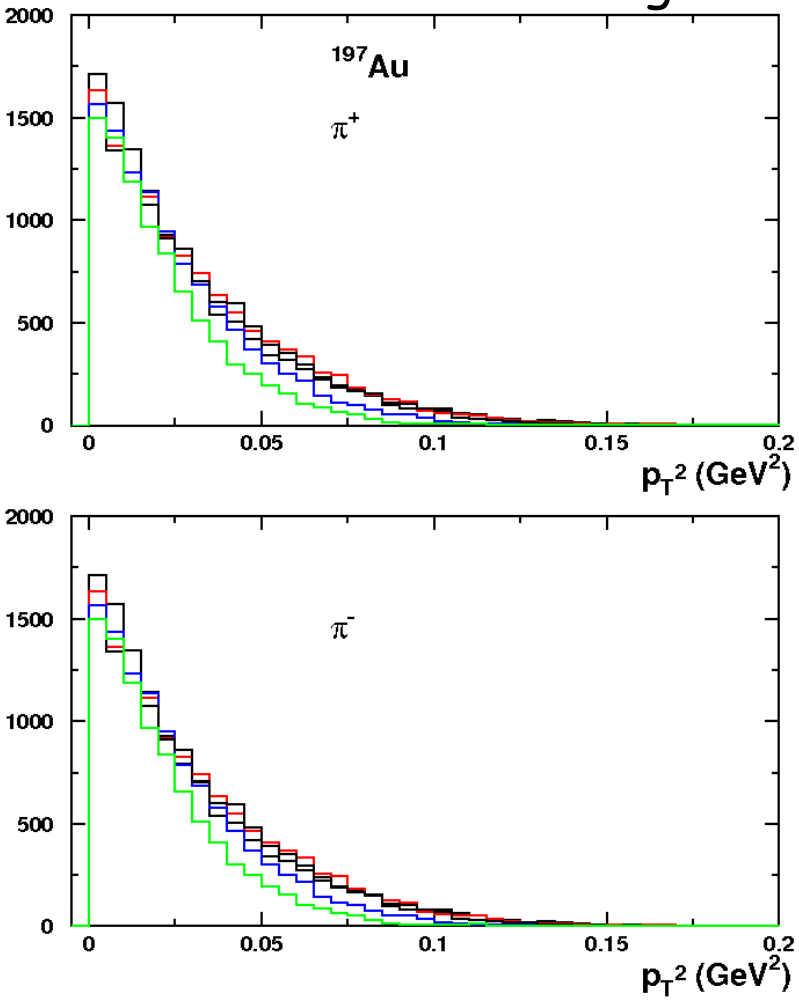


Higher probability to find a hadron at large P_T in nuclei

k_T-distributions may be wider in nuclei?

P_t Coverage

P_t coverage virtually identical at all settings.



HERMES shows hadronization varies very slowly with p_t