Physics in Electron-Ion Collider Experiments

V: Parity Violating e-N and More

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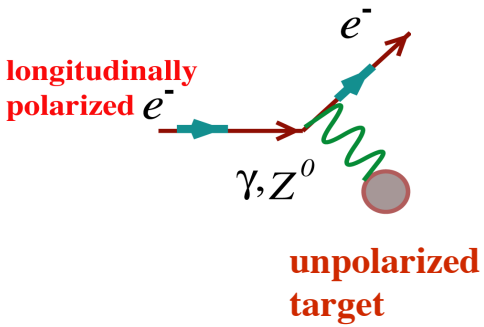
Huada School on QCD 2016: QCD in the EIC Era , May 23 – June 3, 2016

- Parity Violating e-N : Precision test of SM

  JLab 6 GeV results, Planned SoLID Measurement
- Quark-gluon Structure of Nuclei
- EIC Programs

Parity-Violating (PV) Electron Scattering



$$\sigma \;\alpha\; |A_\gamma + A_{weak}|^2 \quad \sim |A_{EM}|^2 + 2A_{EM}A^*_{weak} + \ldots$$

$$-A_{LR} = A_{PV} = \frac{\sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow}}{\sigma_{\uparrow\downarrow} + \sigma_{\uparrow\uparrow}} \sim \frac{A_{weak}}{A_\gamma} \sim \frac{G_F Q^2}{4\pi\alpha} g$$

$$g = g_A^e g_V^T + \beta\, g_V^e g_A^T$$

$$A_{PV} \sim 10^{-5} \cdot Q^2 \quad \text{to} \quad 10^{-4} \cdot Q^2$$

- *g_V and g_A are function of $\sin^2\theta_W$*
- *β is a kinematic factor*
- *Q^2 is the 4-momentum transfer*
- *g^T affected by QCD physics*

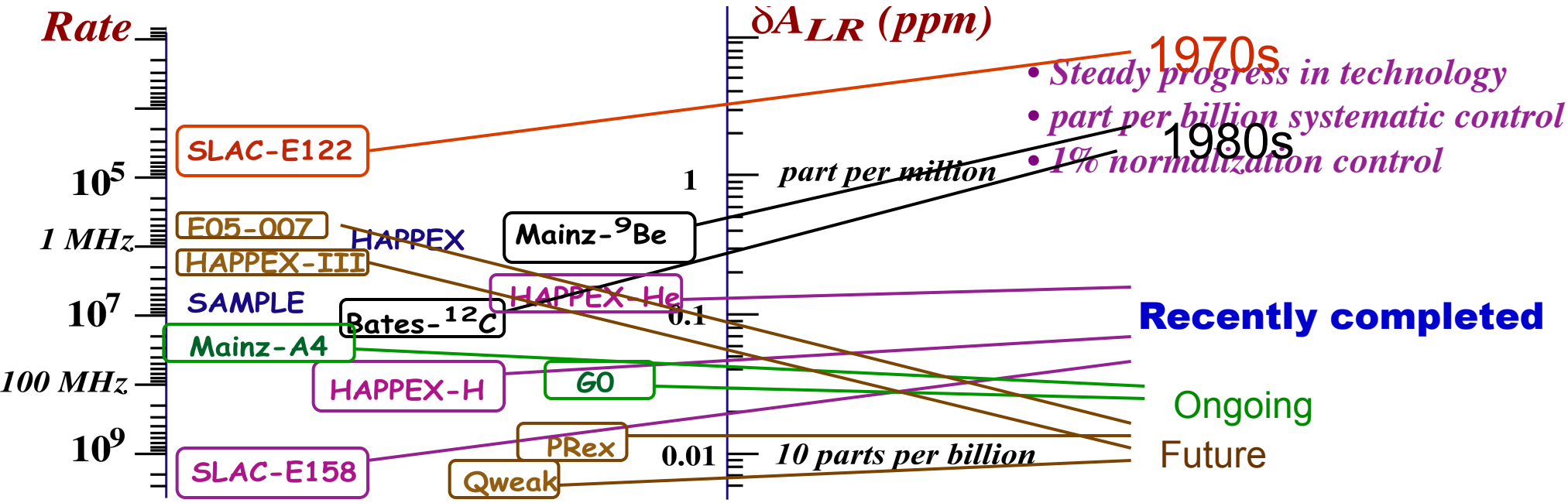
A_{PV} in Deep Inelastic Scattering off liquid Deuterium: $Q^2 \sim 1$ (GeV)^2

E122 at the Stanford Linear Accelerator Center (SLAC) (1978)

20 GeV polarized electron beam on a 30 cm LD_2 target

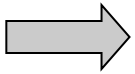
- *Established experimental technique: $\delta(A_{PV}) < 10$ ppm*
- *Cleanly observed weak-electromagnetic interference*
- *$\sin^2\theta_W = 0.224 \pm 0.020$: same as in neutrino scattering*

MeV to TeV Physics



Parity-violating electron scattering has become a precision tool

- ***Search for New TeV Physics***
- ***Nucleon Structure Physics***
- ***Valence Quark Physics***
- ***Many-Body Nuclear Physics***



Address fundamental physics issues over a large range of energy scales

Parity Violating Deep-Inelastic Scattering

Precision Test of Standard Model

Unique Information on Nucleon Structure

Signature of Neutral Weak Interaction in Electron Scattering – Parity Violation Asymmetry

- In the Standard Model,
  - weak interaction current = V(vector) minus A(axial-vector)
- PV comes from the product VxA
- In DIS: $A_{PV} = -\left(\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\right)\left[a_1 Y_1 + a_3 Y_3\right]$

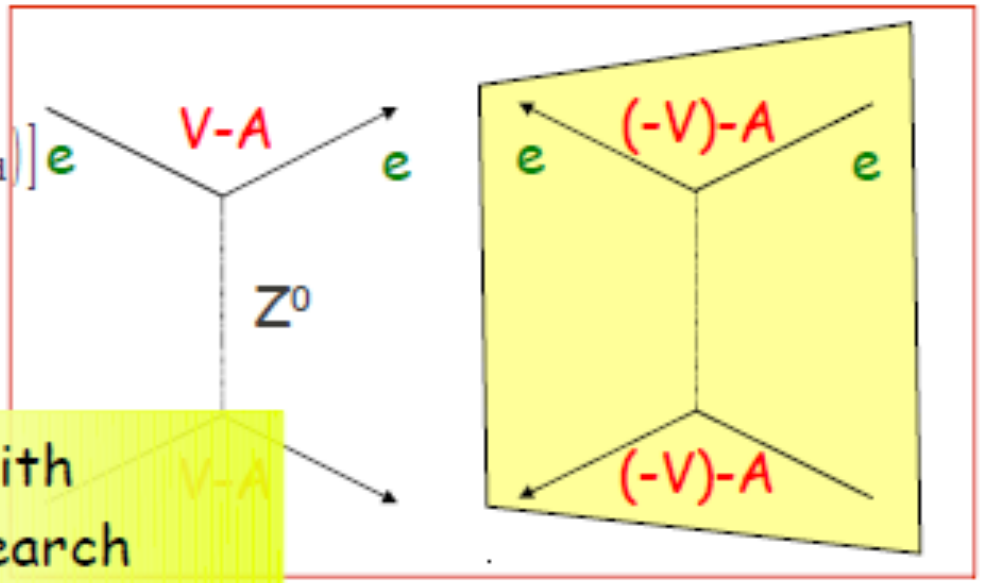
fermions	$g_A^f = I_3$	$g_V^f = I_3 - 2Q\sin^2\theta_W$
ν_e, ν_μ	$\frac{1}{2}$	$\frac{1}{2}$
e-, μ-	$-\frac{1}{2}$	$-\frac{1}{2}+2\sin^2\theta_W$
u, c	$\frac{1}{2}$	$\frac{1}{2}-\frac{4}{3}\sin^2\theta_W$
d, s	$-\frac{1}{2}$	$-\frac{1}{2}+\frac{2}{3}\sin^2\theta_W$

- In the valence quark region:

$$a_1 = \frac{6}{5}\left[2C_{1u} - C_{1d}\right] \qquad a_3 = \frac{6}{5}\left[\left(2C_{2u} - C_{2d}\right)\right]$$

$$C_{1q} \equiv 2 g_A^e g_V^q, \quad C_{2q} \equiv 2 g_V^e g_A^q$$

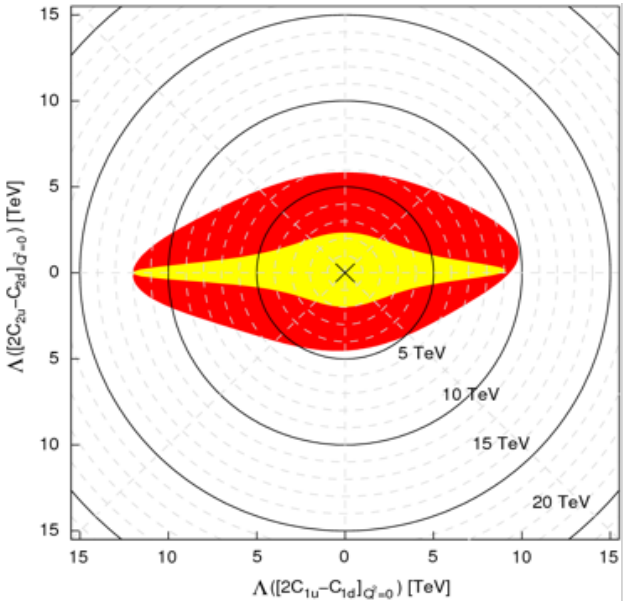
e-q contact terms, both with potential in new physics search

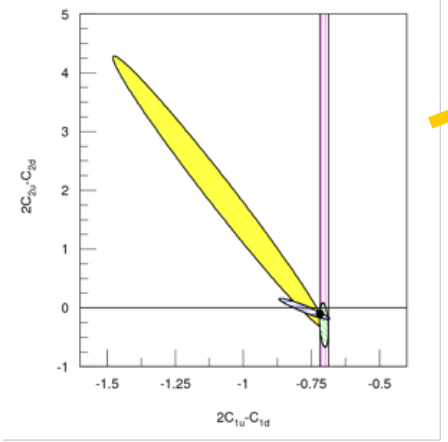


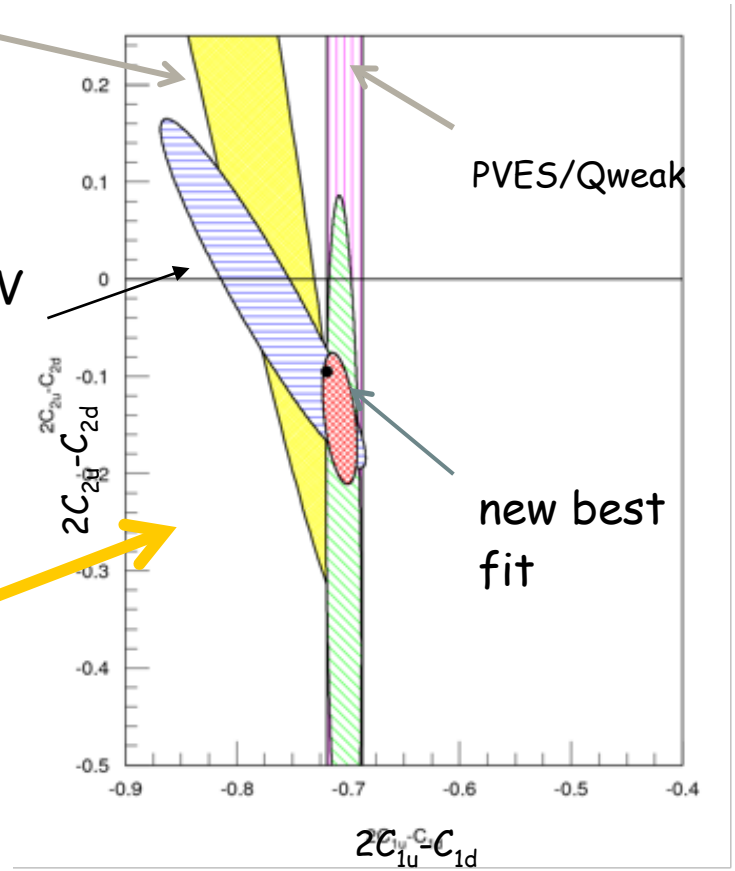
JLab 6 GeV PVDIS Results

nature International weekly journal of science

D. Wang et al., Nature 506, no. 7486, 67 (2014)

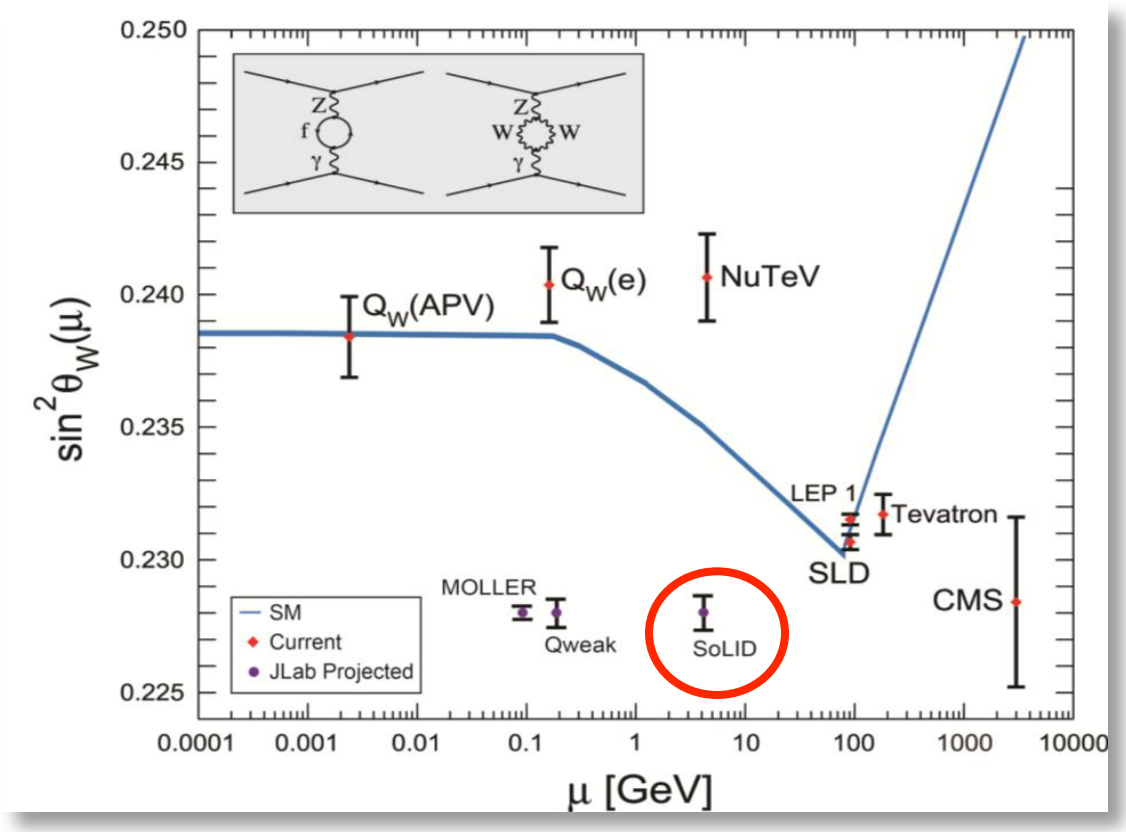


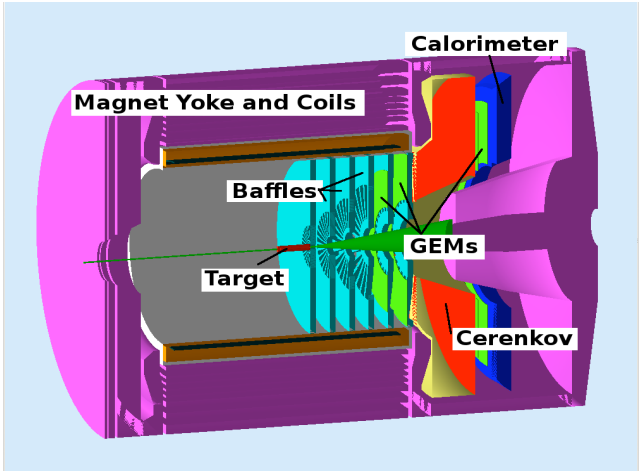




first experimental determination that an axial quark coupling combination is non-zero (as predicted)

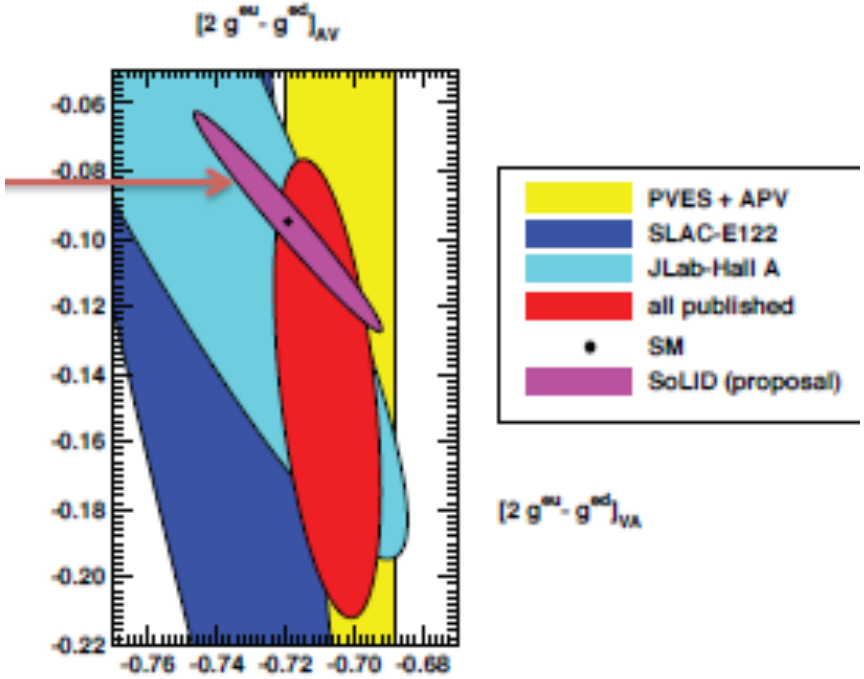
PVDIS with SoLID @ JLab12

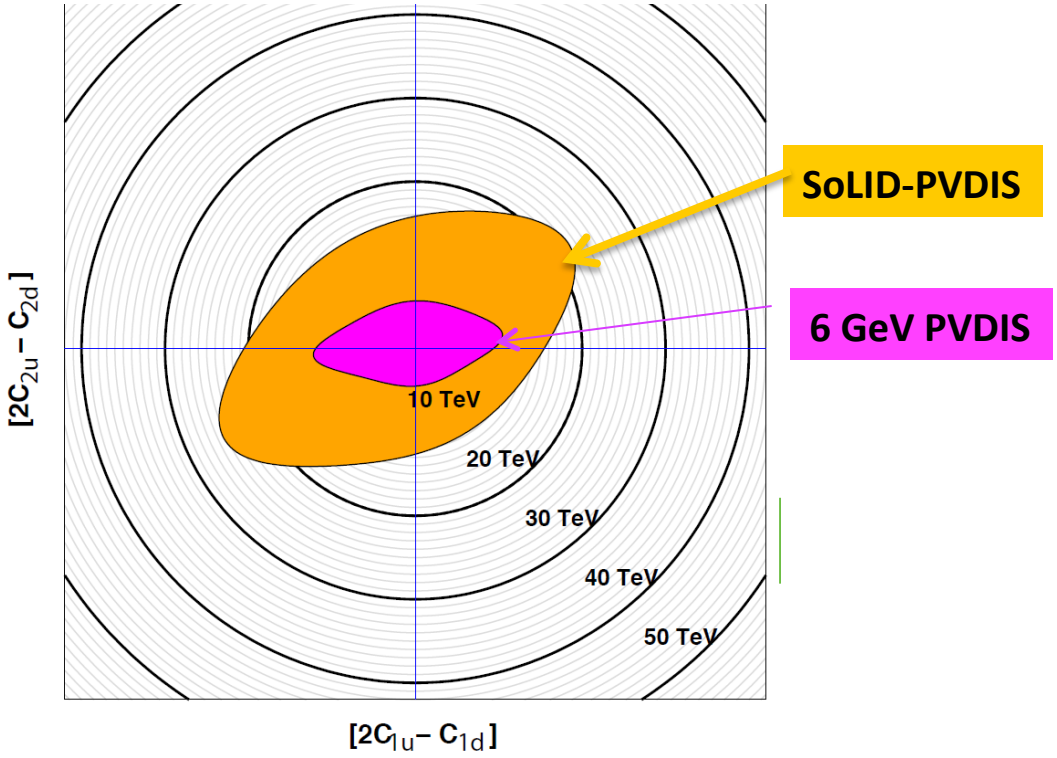




- High Luminosity on LD2 and LH2
- Better than 1% errors for small bins over large range kinematics
- Test of Standard Model
- Quark structure:
  - charge symmetry violation
  - quark-gluon correlations
  - d/u at large-x

Parity Violation with SoLID





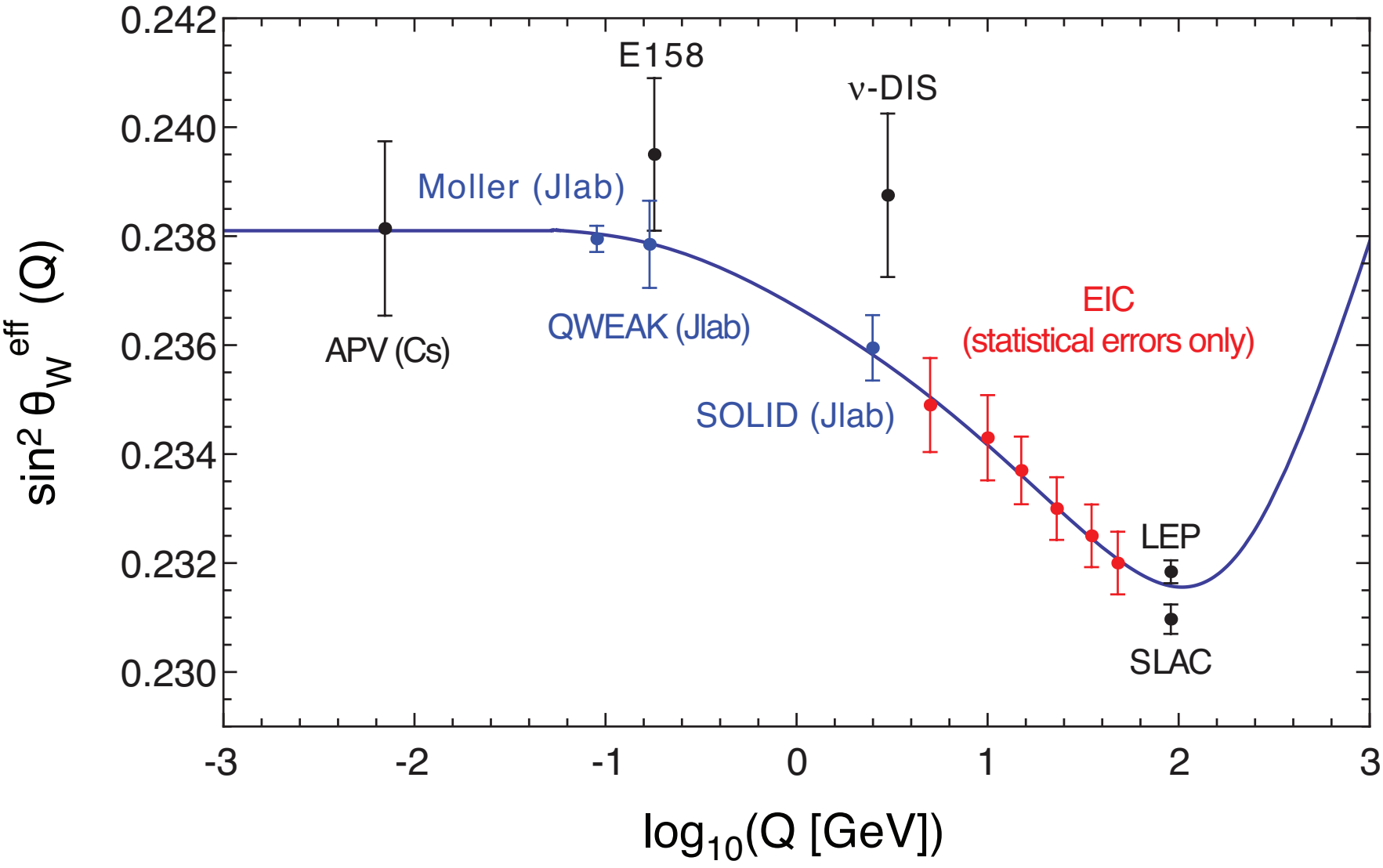
PVDIS asymmetry has two terms:

1) $\mathbf{C_{2q}}$ weak couplings, test of Standard Model

2) Unique precision information on **quark structure of nucleon**

Mass reach in a composite model, SoLID-PVDIS ~ 20 TeV, sensitivity match LHC reach with complementary Chiral and flavor combinations

Parity Violation with EIC



Quark-gluon Structure of Nuclei

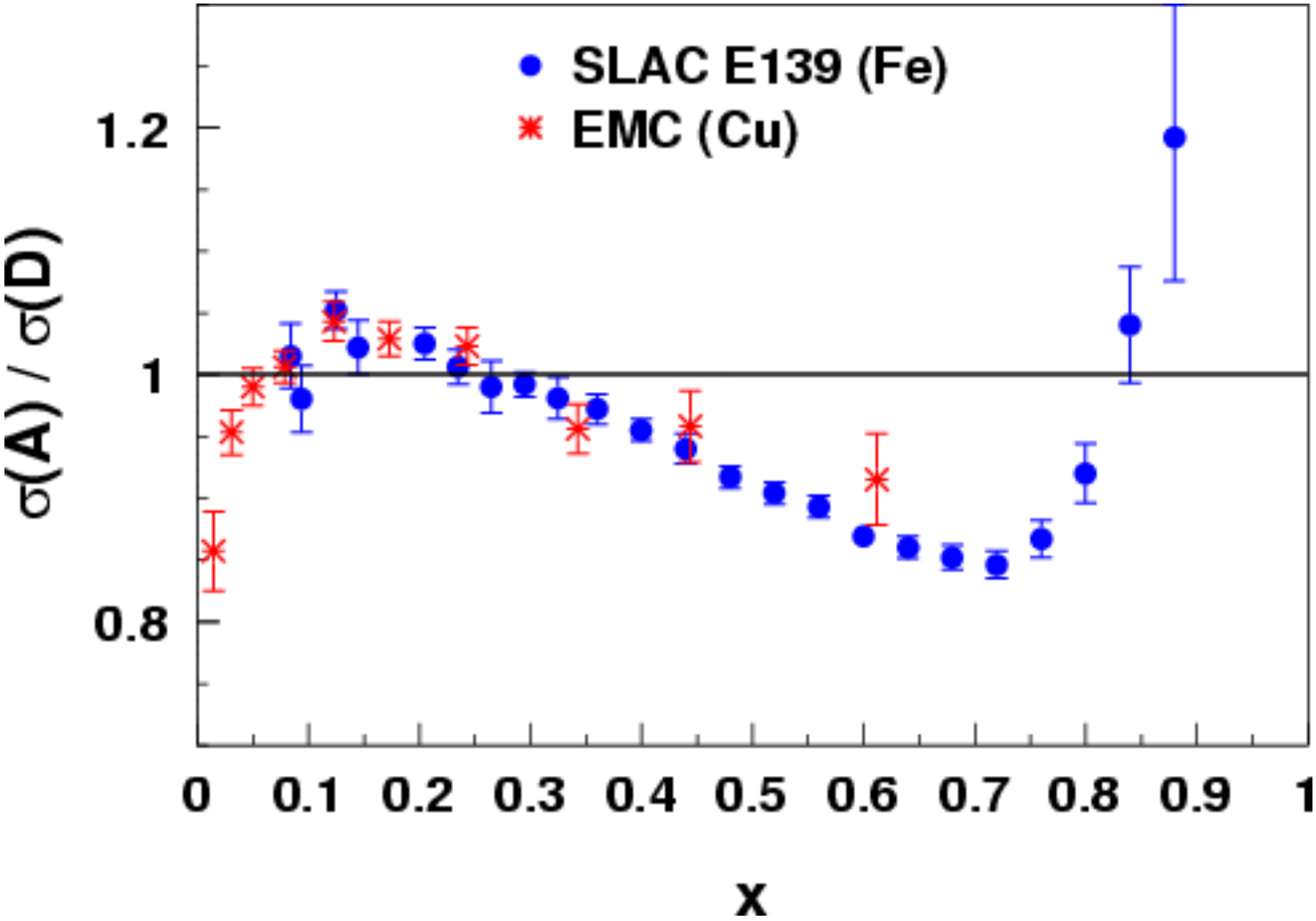
Nuclear Medium as a Laboratory to Study QCD

QCD and Nuclei

- **Most of the strong interaction confined in nucleon, only residual strong interaction remains among nucleons in a nucleus**
  - **Effective N-N interaction with meson exchanges**
- **Study QCD with nuclei**
  - **Short range not well understood**
  - **Nuclei at extreme conditions: QGP, CGC (gluon saturation)**
  - **Nuclear medium effects**
    - **EMC effect**
    - **Nucleon Property in Nuclear medium**
    - **Short range correlations**
    - **Quark propagation in cold nuclear matter**

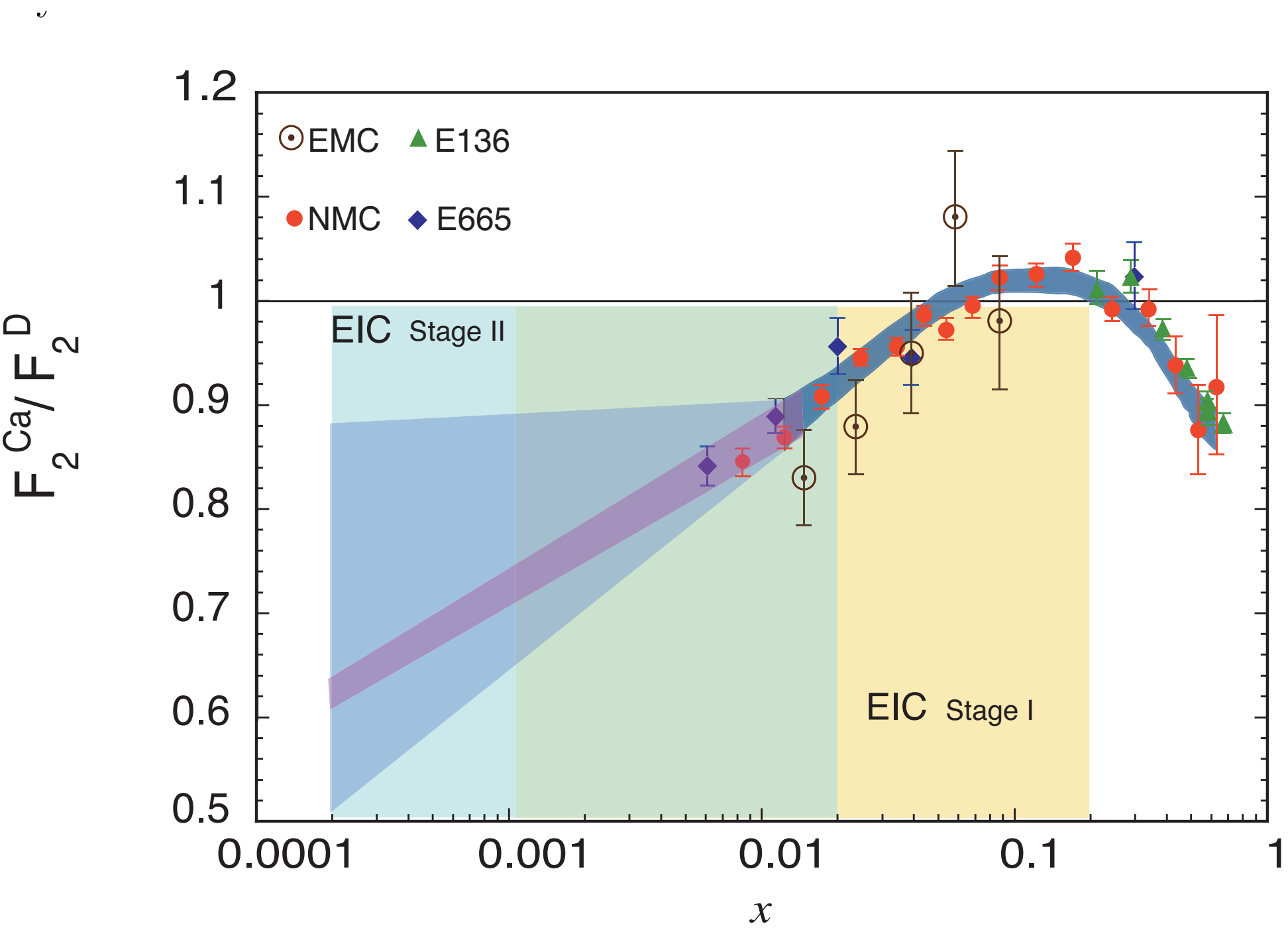
Nuclear Medium Effects: EMC Effects

- **EMC effects, shadowing and anti-shadowing**



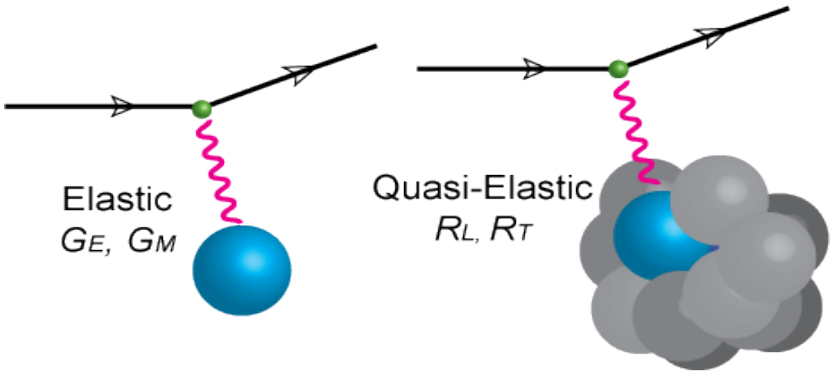
J. Ashman *et al.*, Z. Phys. **C57**, 211 (1993)

J. Gomez *et al.*, Phys. Rev. **D49**, 4348 (1994)


EMC
E136
NMC
E665
EIC Stage II
EIC Stage I
F_2^{Ca}/F_2^D
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.0001
0.001
0.01
0.1
1
x

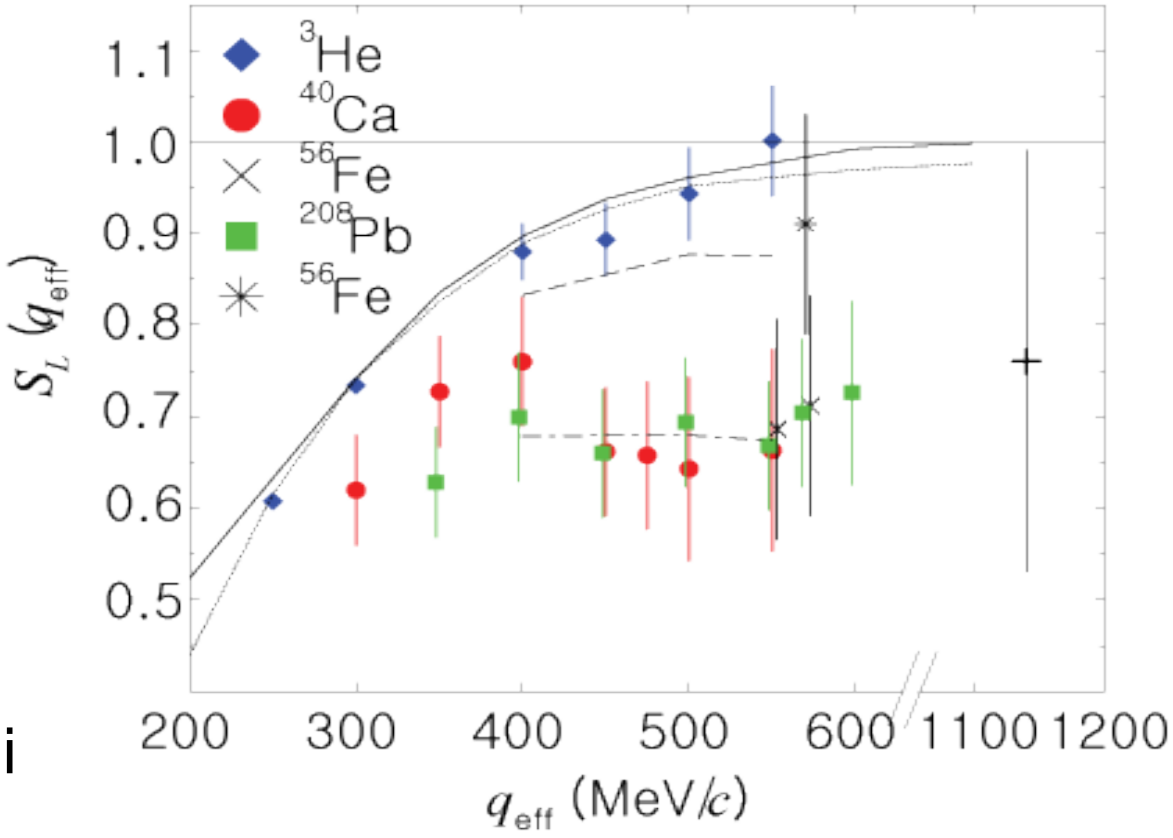
Nuclear Medium Effects: Coulome Sum Rule

$$S_L(q) = \frac{1}{Z}\int_{0+}^{\infty} \frac{R_L(q,\omega)}{[(G_E^p + N/ZG_E^n)\zeta]^2} d\omega \;=\; 1\,?$$



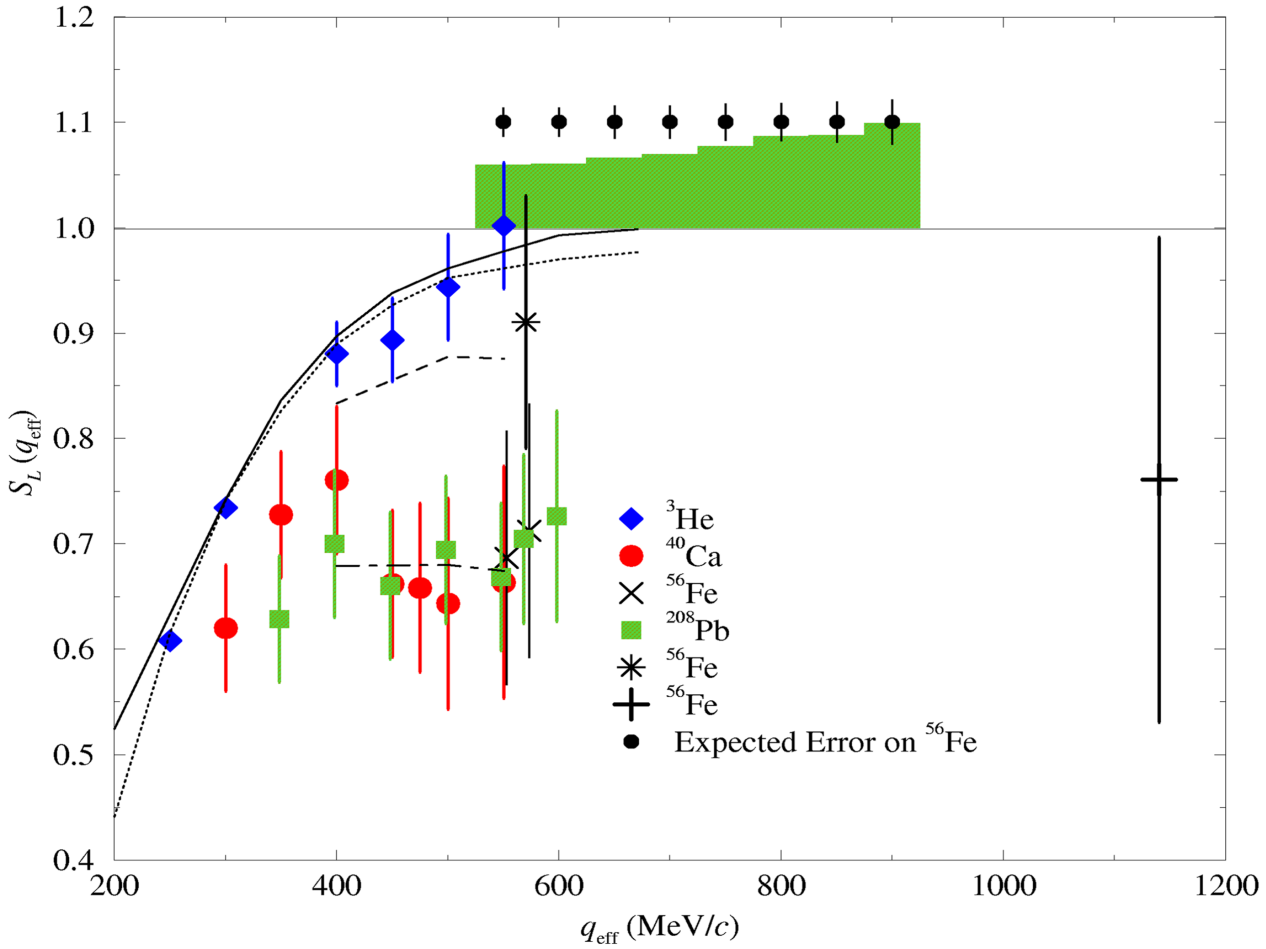
Probing a nucleon inside a nucleus

Possible modification of the nucleons' property inside nuclei



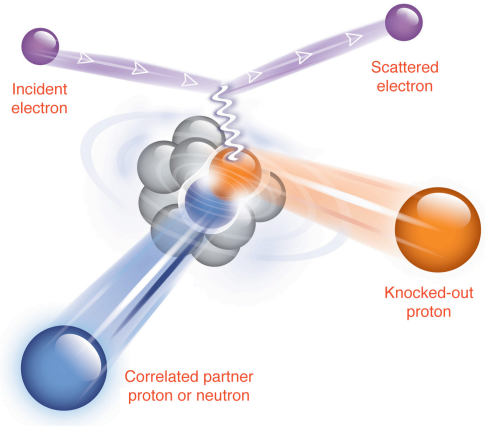
JLab E01-015
Precision Measurement of Coulomb Sum at q=0.5-1 GeV/c

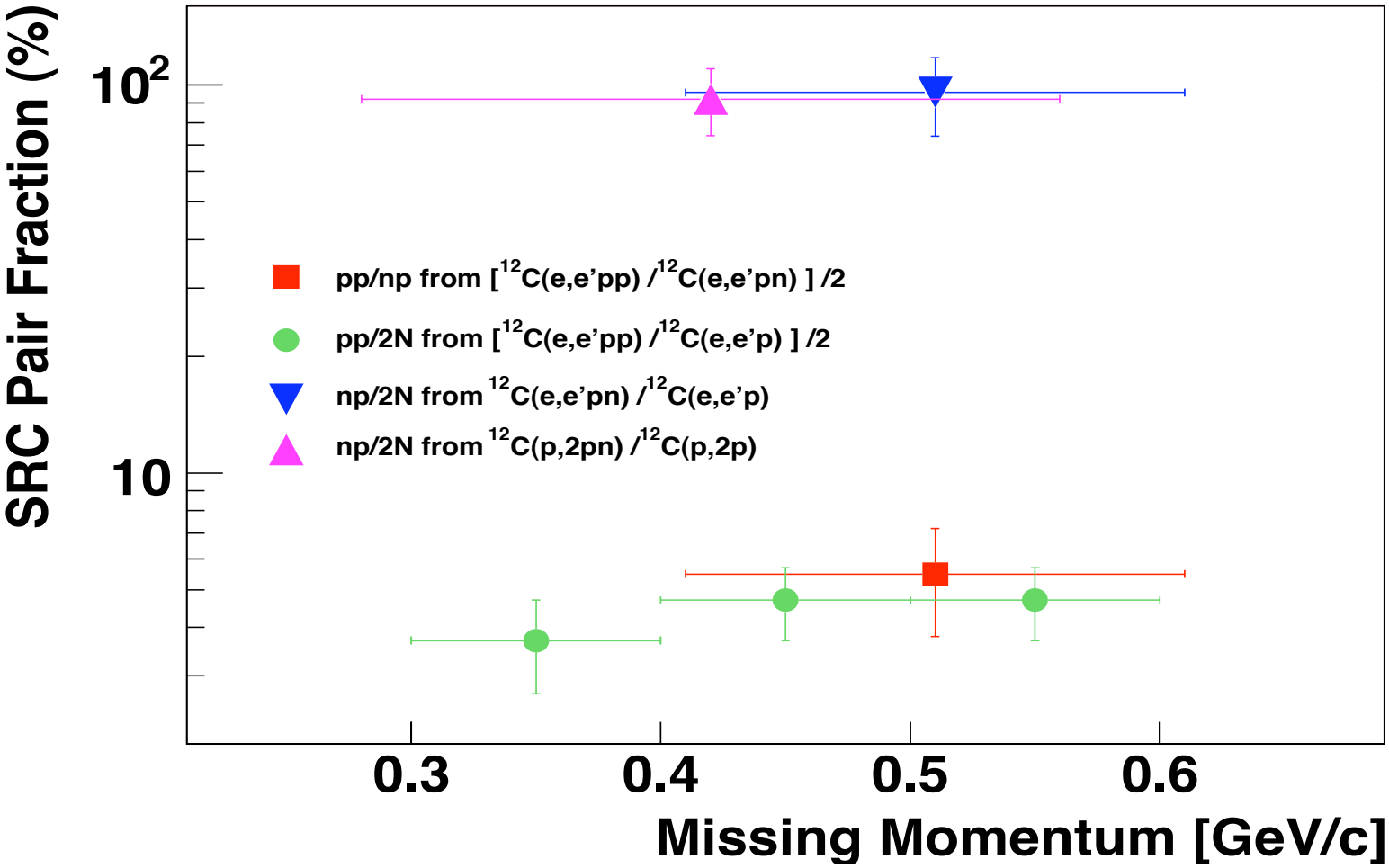
- New NaI detector for ♪ background control♪
- Data taking last year♪
- Analysis well underway♪
- Expect preliminary ♪ results in a few months♪



Short-Range Correlation Pair Factions

R. Subedi *et al.*, Science **320** (2008) 1476).

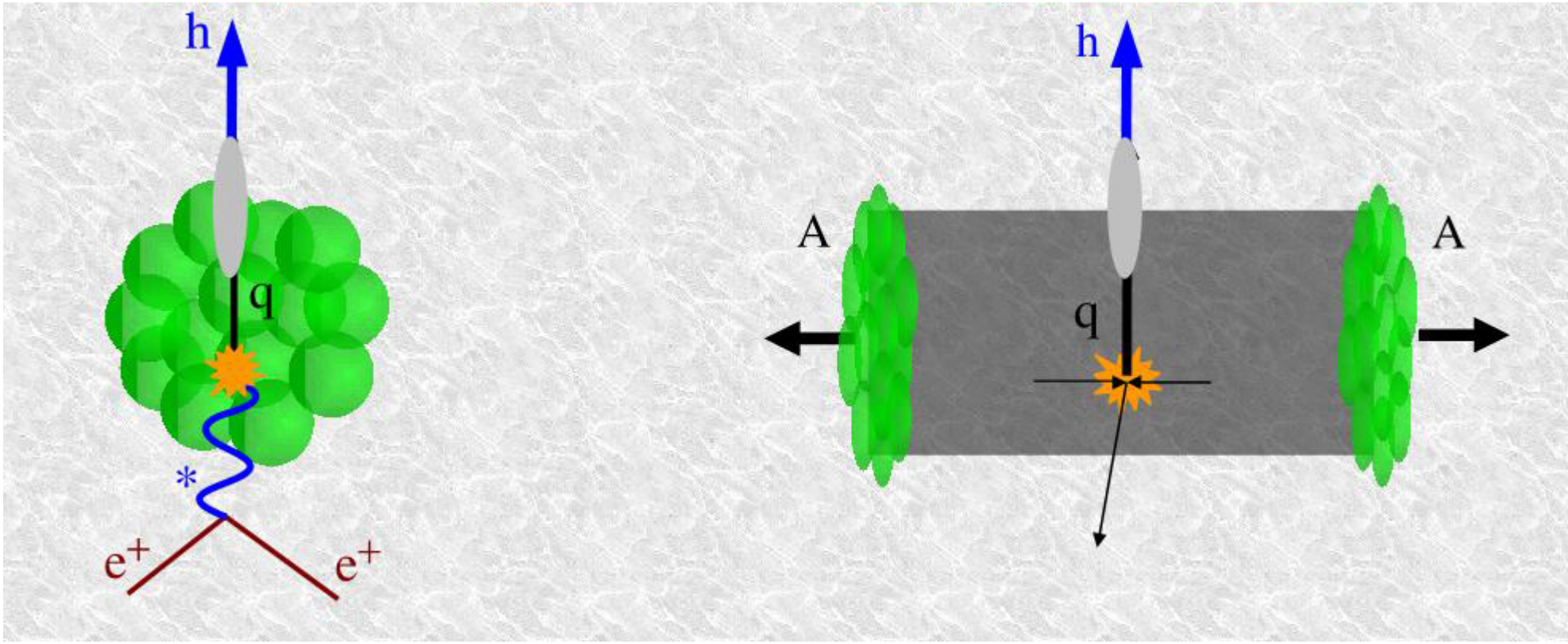




Nuclear Medium Effect: Quark Propagation

- **Quark propagation in cold and hot matter**

SIDIS **A-A Collision**

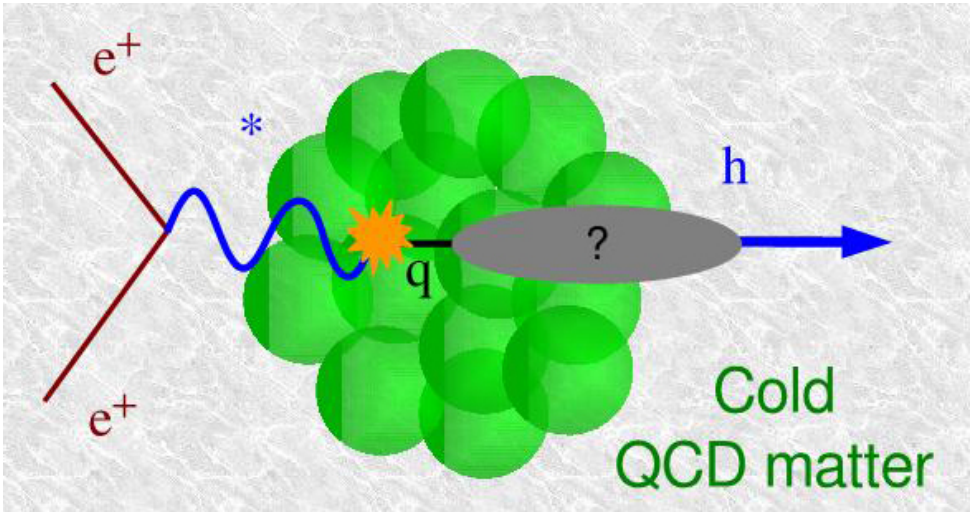


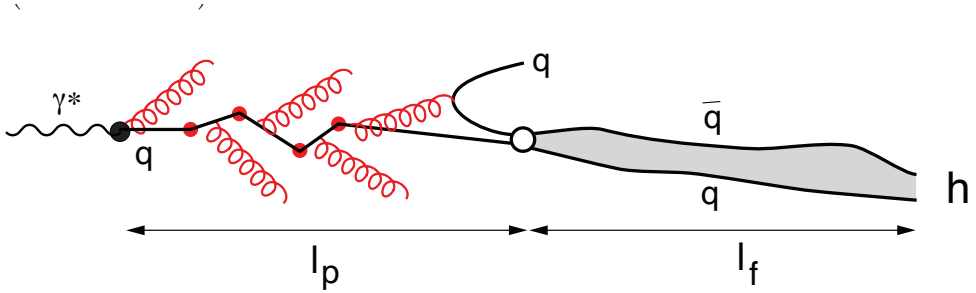
$E_h = z\nu \sim 2 - 20$ GeV
(HERMES/JLab)

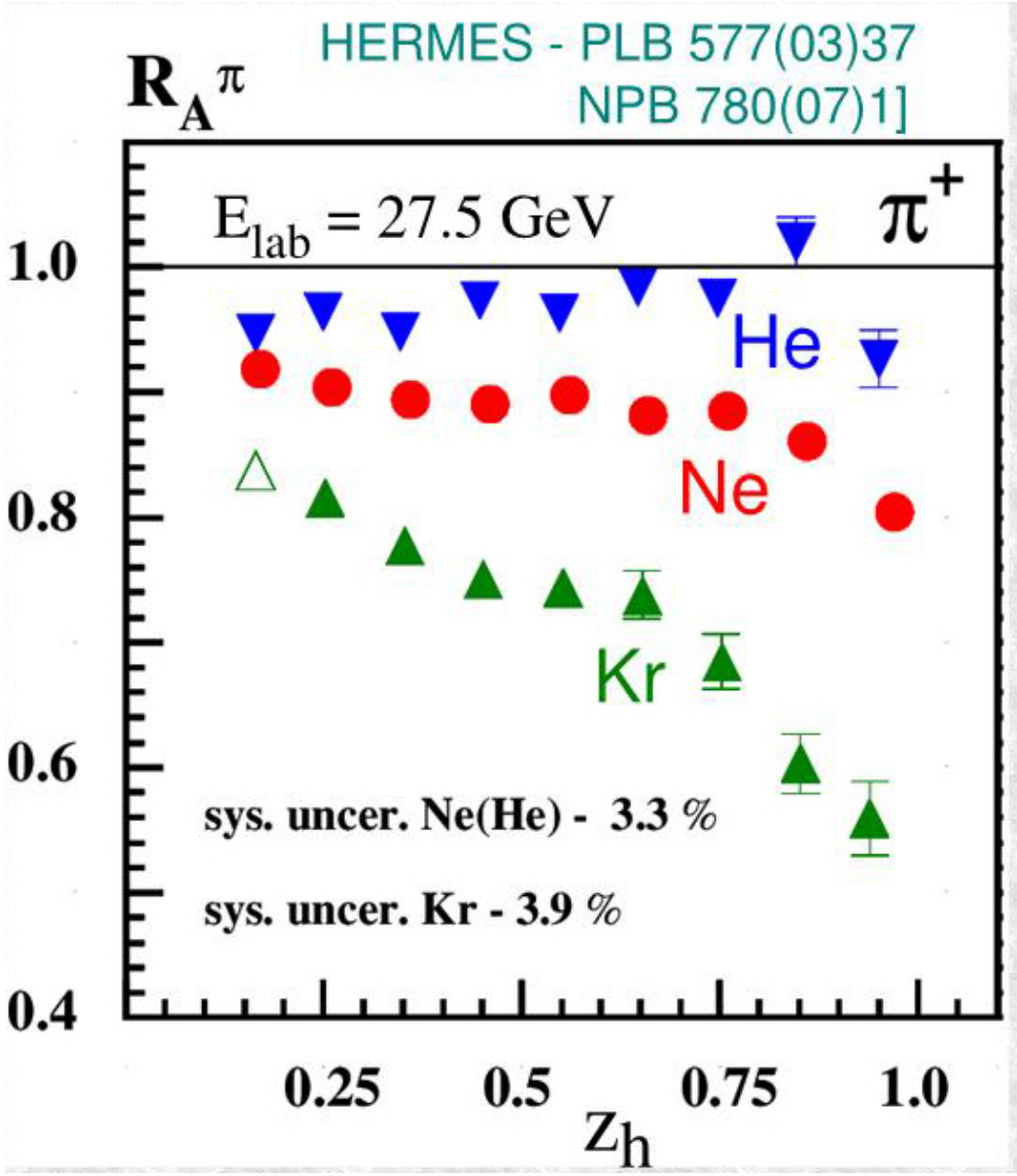
$E_h = p_T \sim 2 - 20$ GeV
(RHIC)

SIDIS to study hadronization

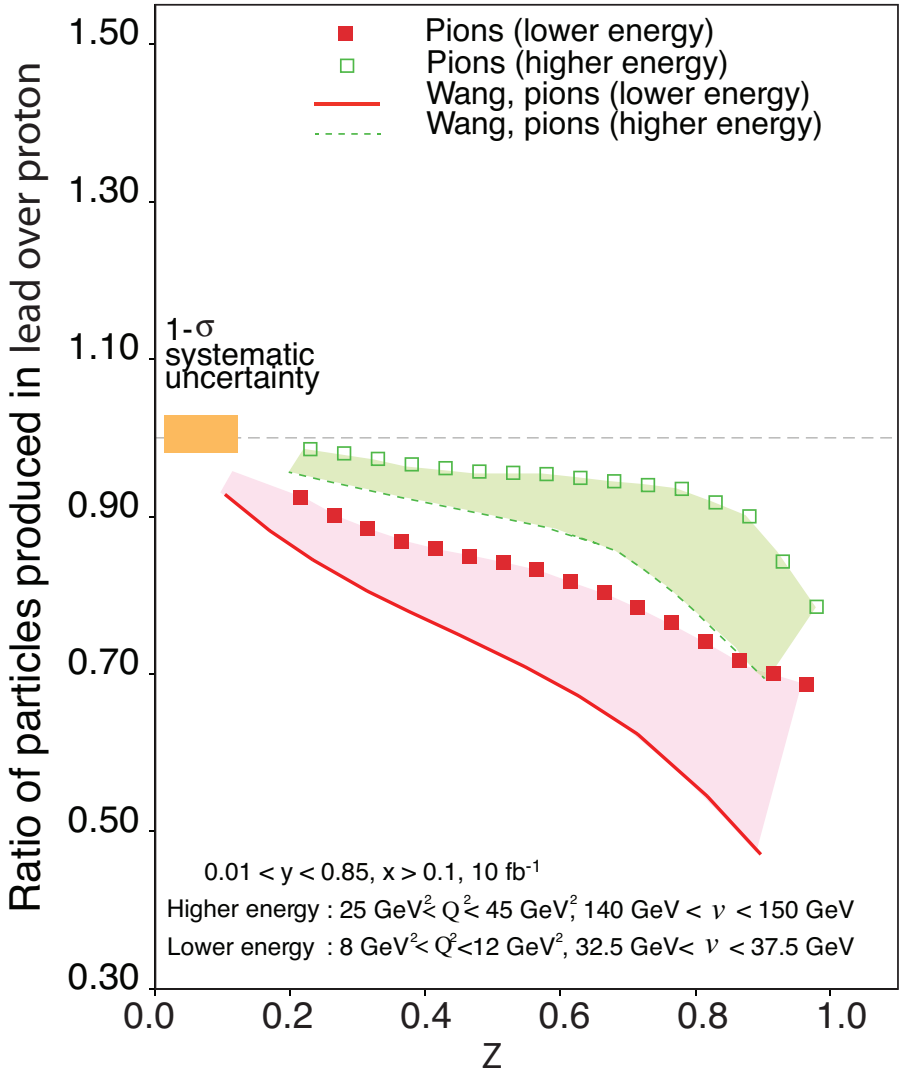
- **Quark propagation**

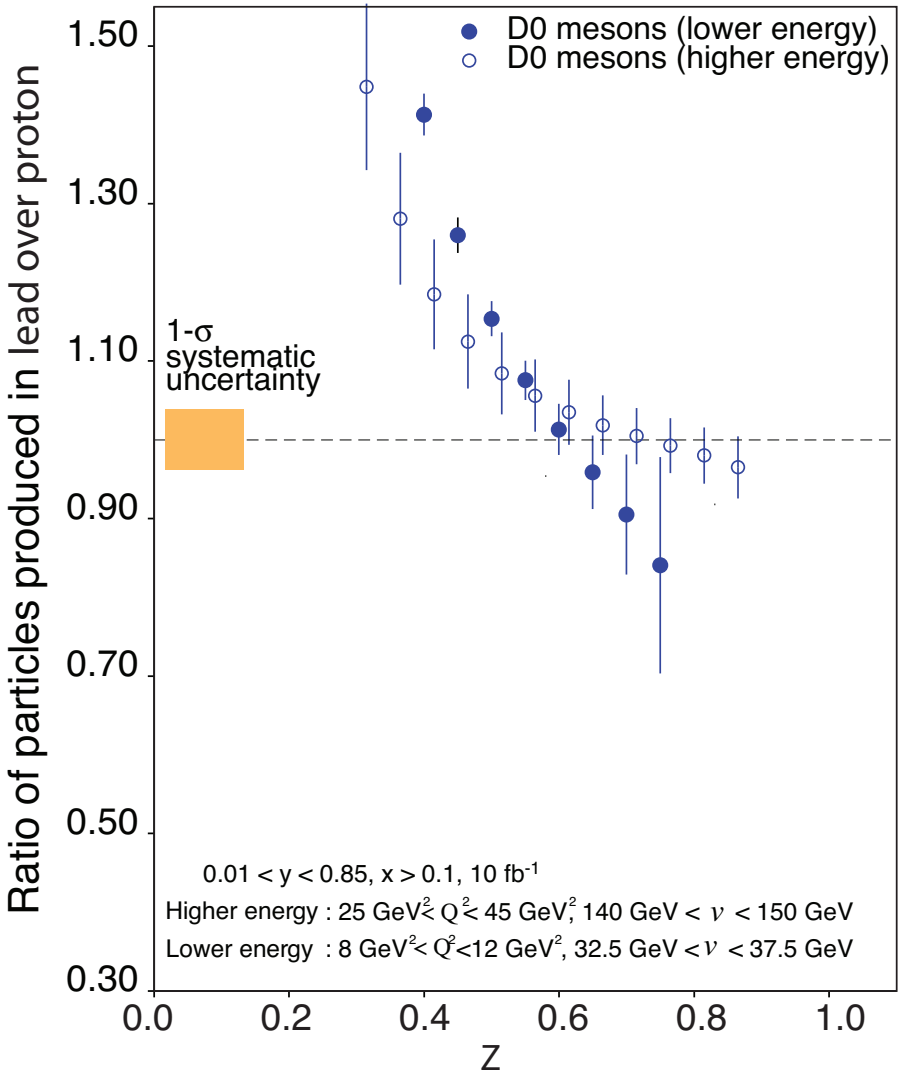






EIC Projections: SIDIS Ratio for π and D





Summary

- **Partity Violating e-N: a precision tool to test Standard Model**
  - **JLab 6 GeV results**
  - **Planned SoLID measurement**
  - **EIC projections**

- **Quark-gluon in nuclear medium**
  - **EMC Effects, shadowing**
  - **Nucleon property in nuclear medium**
  - **Short Range Correlations**
  - **Quark propagation and hadronization**