Nuclear medium modifications of bound nucleon generalized parton distributions

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Outline

- Introduction: A short review of nuclear medium modifications of properties of bound nucleons

- Bound nucleon generalized parton distributions and incoherent deeply virtual Compton scattering with nuclei

  V.Guzey, A.W. Thomas, K. Tsushima, PLB 673, 9 (2009)

- Medium modifications of the bound nucleon spin sum rule

  V.Guzey, A.W. Thomas, K. Tsushima, 0902.0780 [hep-ph]

- Summary

Nuclear modifications of bound nucleons

Properties of bound nucleons in a nuclear medium are expected to be modified:

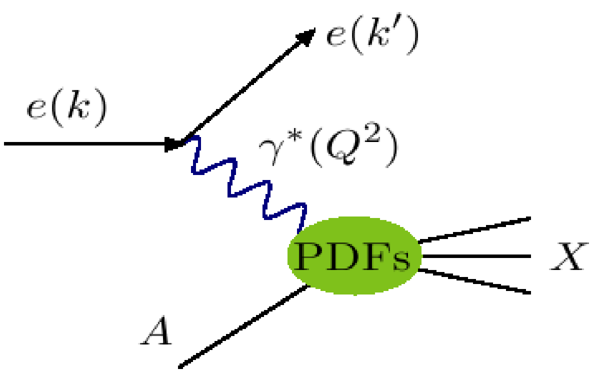
- structure function $F_{2N}^{*}(x,Q^2) \neq F_{2N}(x,Q^2)$ in deep inelastic scattering with nuclear targets
- elastic form factors $F_1^{*}(t) \neq F_1(t)$ and $F_2^{*}(t) > F_2(t)$ in quasi-elastic scattering on nuclei
- axial coupling constant $g_A^{*} < g_A$ in nuclear beta decay
- various static properties (masses, magnetic moments)

DIS with nuclei: EMC effect

The story of medium modifications started with the EMC effect:

$F_{2A}(x,Q^2) < AF_{2N}(x,Q^2)$ for $0.7 > x > 0.2$

European Muon Collaboration (EMC), CERN
J.J. Aubert et al. Phys. Lett. B123, 275 (1983)



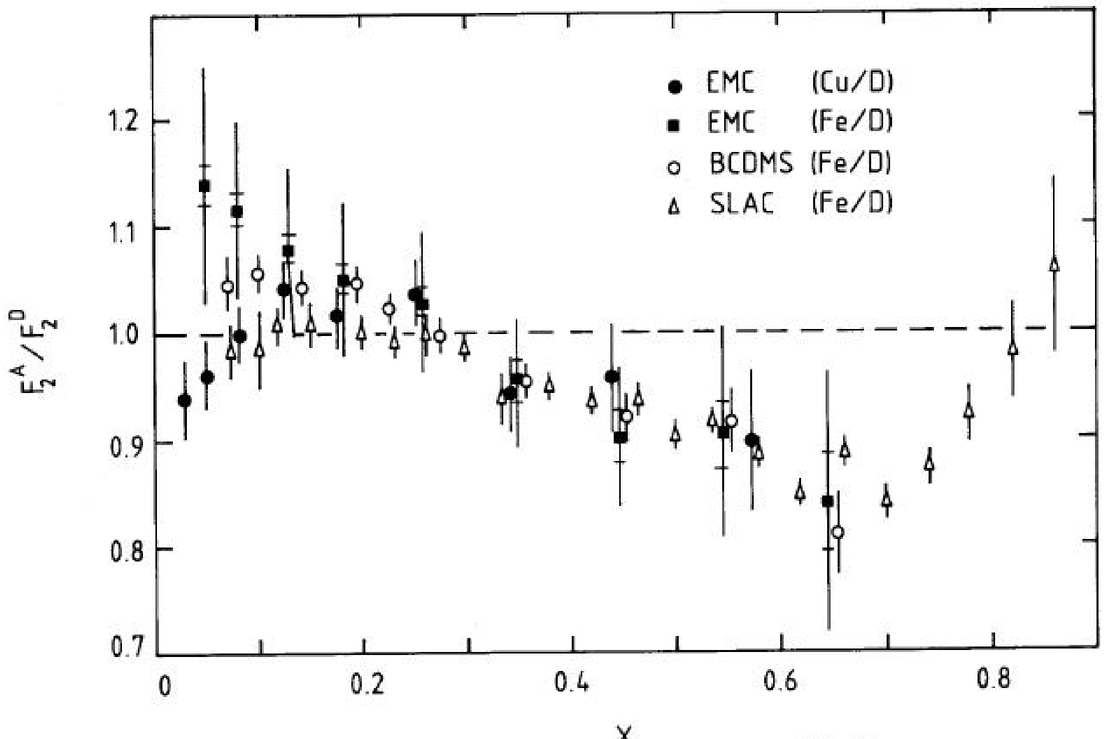
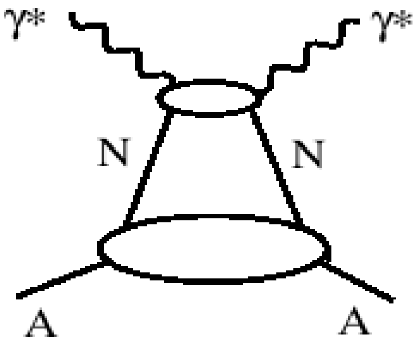


FIG. 3

Naive expectation: $F_{2A}(x,Q^2)=AF_{2N}(x,Q^2)$ since $Q^2 \gg$ nuclear scales

Interpretation of EMC effect

The EMC effect cannot be explained by assuming that the nucleus consists of unmodified nucleons



$$\frac{1}{A}F_{2A}(x) = \int_x^A dy f_N(y) F_{2N}^*\left(\frac{x}{y}\right)$$

$y = A\frac{k^+}{p_A^+}$ is the light-cone fraction of the nucleus carried by the nucleon

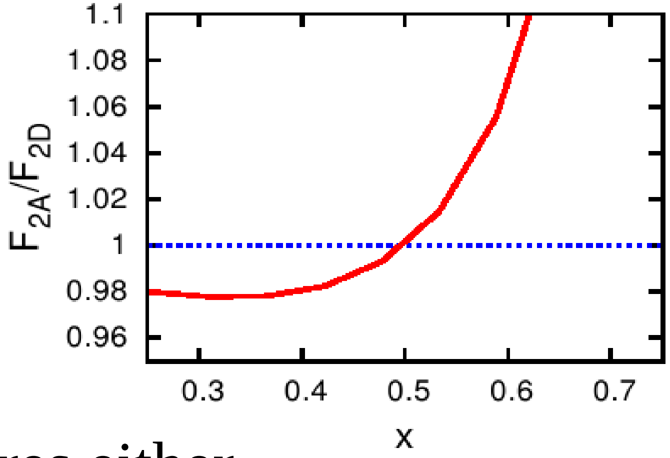
$f_N(y)$ is the probability to find the nucleon with given y

Interpretation of EMC effect

$f_N(y)$ is peaked around y≈1

$$\frac{1}{A}F_{2A}(x) = F^*_{2N}(x) + \frac{\langle T \rangle}{3m_N}\left(2xF^{*\prime}_{2N}(x) + x^2 F^{*\prime\prime}_{2N}\right)$$

Assuming that $F^*_{2N}(x)=F_{2N}(x)$ →



An explanation of the EMC effect requires either

1) medium modifications, $F^*_{2N}(x,Q^2) \neq F_{2N}(x,Q^2)$,

L. Frankfurt, M. Strikman, Phys. Rept. 160, 235 (1988)

2) explicit non-nucleonic degrees of freedom (pion excess models)

M. Ericson, A.W. Thomas, Phys. Lett. B128, 112 (1983)

Interpretation of EMC effect

A particular realization of $F_{2N}^{*}(x,Q^2) \neq F_{2N}(x,Q^2)$ is the Quark-Meson coupling model,

K. Saito, K. Tsushima, A.W. Thomas, Prog. Part. Nucl. Phys. 58, 1 (2007)

QMC model:

- nucleus=collection of non-overlapping nucleon bags
- quarks in the bags interact with the scalar and vector fields, which provide nuclear binding
- coupling constants tuned to reproduce properties of nuclear matter

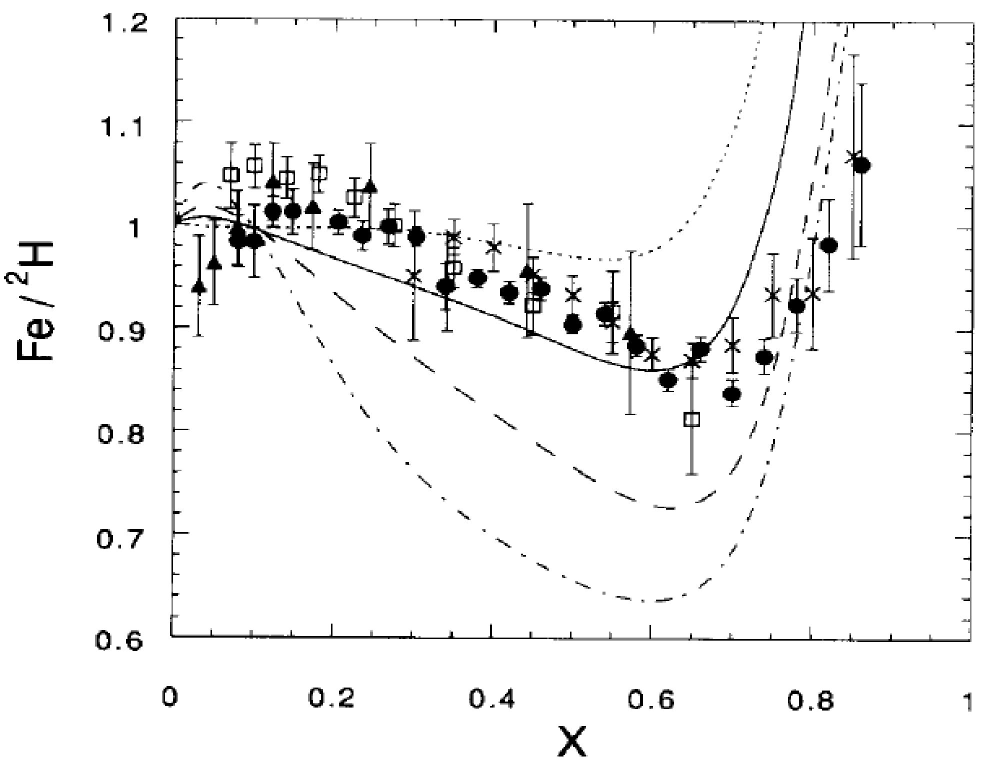
↓

Successful description of nuclear structure (level structure, charge form factors, binding energies, etc.)

Interpretation of EMC effect

QMC model semi-quantitatively explains the EMC effect

K. Saito, A.W.Thomas, Nucl. Phys.A 574, 659 (1994)



Quasi-elastic scattering

Medium modifications the bound nucleon can be also probed in quasi-elastic scattering on nuclei.

Recent Jefferson Lab experiment measured proton recoil polarization in the reaction $^4He(\vec{e},e'\vec{p})^3H$

S. Strauch et al. PRL 91, 052301 (2003)
S. Malace at al, 0807.2252 [nucl-ex]

- The polarization transfer ratio measures the ratio of elastic form factors

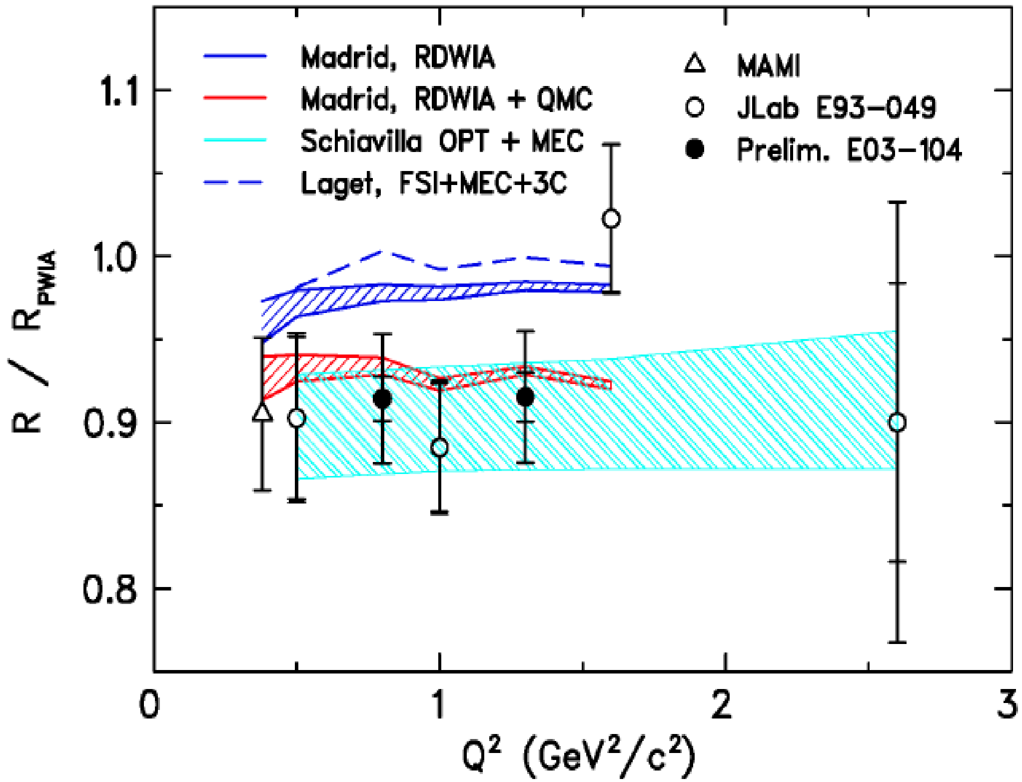
$$\frac{P'_x}{P'_z} \propto \frac{G_E}{G_M}$$

- The super-ratio R probes medium modifications of the bound elastic form factors

$$R = \frac{(P'_x/P'_z)_{^4\mathrm{He}}}{(P'_x/P'_z)_{^1\mathrm{H}}} = \frac{(G_E/G_M)_{^4\mathrm{He}}}{(G_E/G_M)_{^1\mathrm{H}}}$$

Quasi-elastic scattering

S. Malace at al, 0807.2252 [nucl-ex]



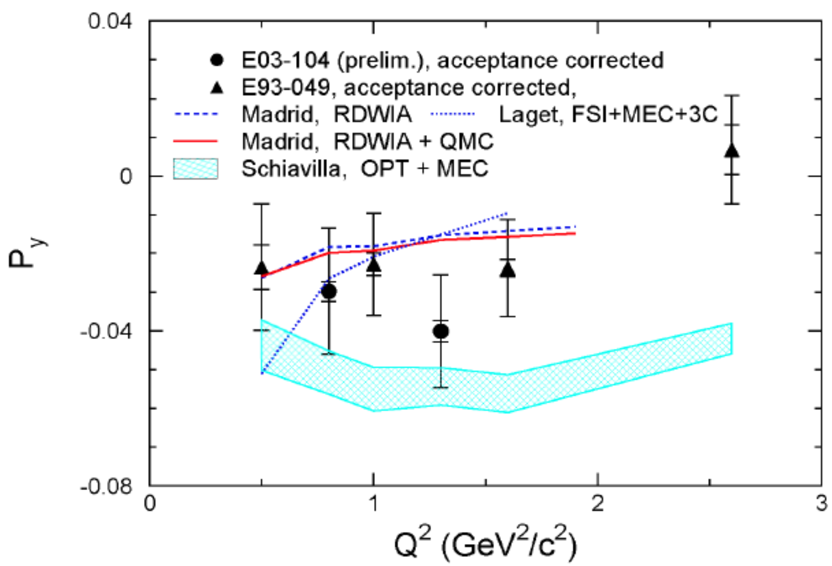
Can be explained either by

- medium modifications

or

- very strong charge-exchange FSI

However, very strong charge exchange FSI contradict induced polarization P_y



Bound nucleon GPDs

Generalized parton distributions (GPDs) interpolate between parton distributions and form factors

$$\int_{-1}^{1} dx H^q(x, \xi, t) = F_1^q(t)$$

$$\int_{-1}^{1} dx E^q(x, \xi, t) = F_2^q(t)$$

→ GPDs of the bound nucleon should also be modified by the nuclear medium.

Bound nucleon GPDs

Natural model for GPDs of the bound nucleon:

V.Guzey, A.W. Thomas, K. Tsushima, PLB 673, 9 (2009)

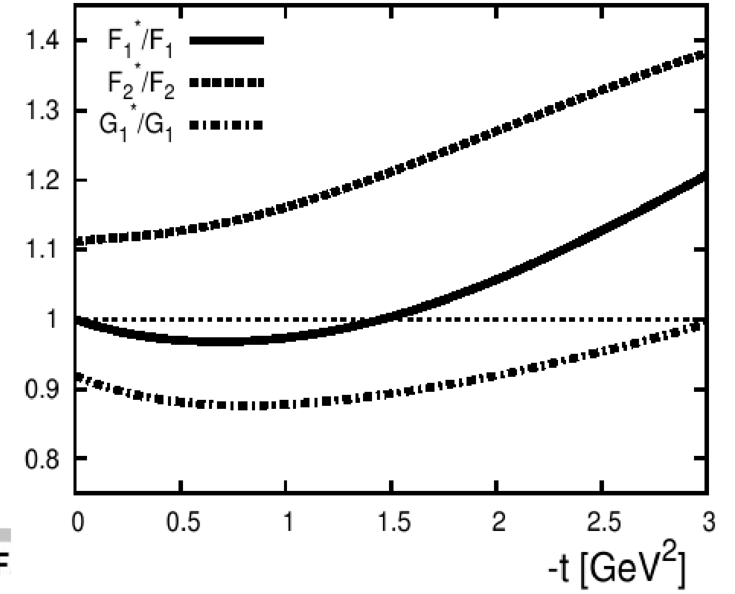
$$H^{q/N^*}(x,\xi,t) = \frac{F_1^{q/N^*}(t)}{F_1^{q/N}(t)} H^{q/N}(x,\xi,t)$$

$$E^{q/N^*}(x,\xi,t) = \frac{F_2^{q/N^*}(t)}{F_2^{q/N}(t)} E^{q/N}(x,\xi,t)$$

Double distribution model for GPDs,

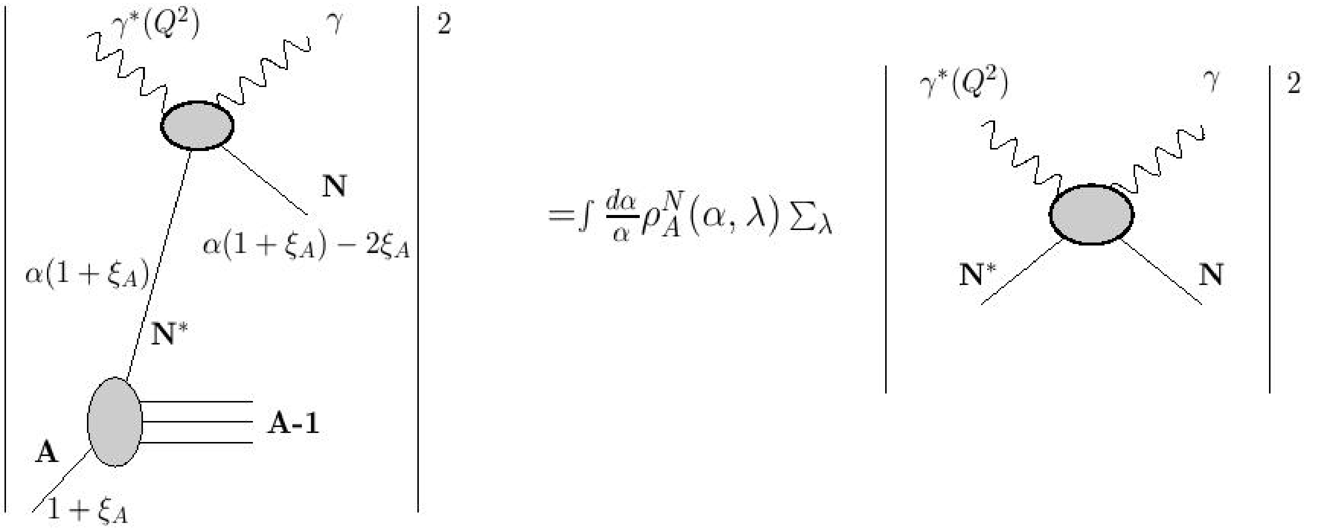
M. Guidal et al, PRD 72, 054013 (2005)

QMC for ^{4}He



Incoherent nuclear DVCS

GPDs of the bound nucleon can be probed in incoherent deeply virtual Compton scattering (DVCS) with nuclear targets

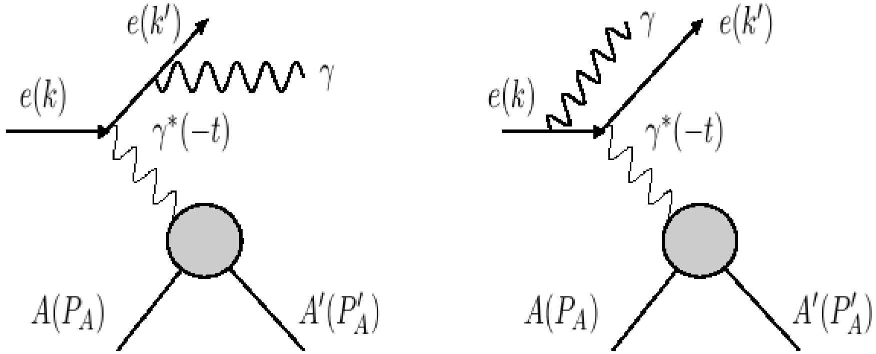


Ignoring Fermi motion:

$$|\mathcal{T}_{\mathrm{DVCS}}^{^4\mathrm{He}}|^2 = \sum_{\lambda} |\mathcal{T}_{\mathrm{DVCS}}^{p^*}|^2$$

Incoherent nuclear DVCS

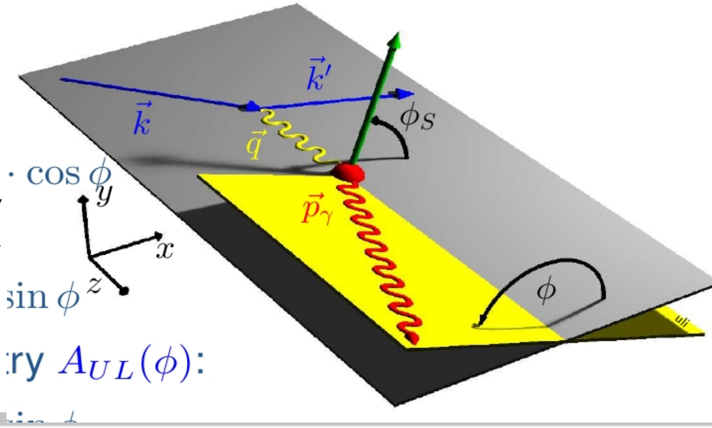
DVCS interferes with Bethe-Heitler (BH) process



In fixed-target kinematics, BH » DVCS. One extracts information on DVCS and GPDs by measuring cross section asymmetries, which are proportional to the interference between DVCS and BH.

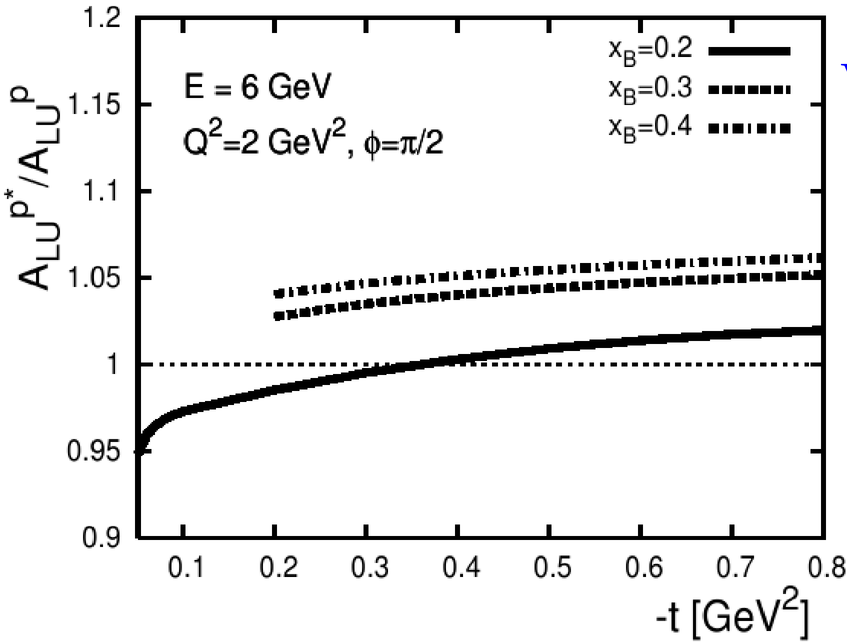
Beam-spin asymmetry (polarized beam)

$$A_{\mathrm{LU}}(\phi) = \frac{\overrightarrow{\sigma} - \overleftarrow{\sigma}}{\overrightarrow{\sigma} + \overleftarrow{\sigma}} \propto \sin\phi F_1(t) Im\mathcal{H}$$



Incoherent nuclear DVCS on ^{4}He

$$A_{\mathrm{LU}}(\phi) \propto \mathrm{Im}\left(F_1^{p^*}\mathcal{H}^{p^*} - \frac{t}{4m_N^2}F_2^{p^*}\mathcal{E}^{p^*}\right)\Big/ f(F_1^{p^*}, F_2^{p^*})\sin\phi$$



V.Guzey, A.W. Thomas, K. Tsushima, PLB 673, 9 (2009)

- will be tested by the approved JLab at 6 GeV experiment

  H.Egyian, F.Girod, K.Hafidi, S.Liuti, E.Voutier, E08-024 (2008)

- our predictions are very different from the only other existing model

  S.Liuti, S.K.Taneja, PRC72, 032201 and 034902 (2005)

Bound nucleon spin sum rule

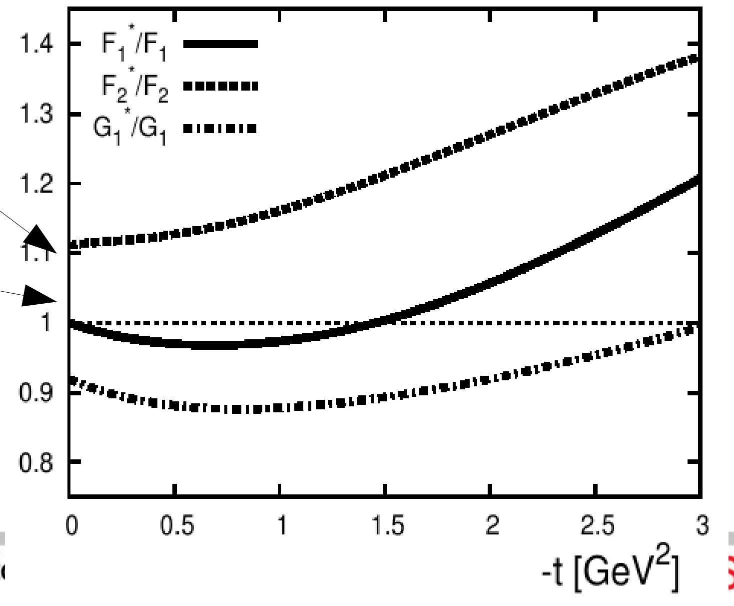
Medium modifications of bound nucleon GPDs lead to modifications of Ji's spin sum rule

$$J^{q^*} = \lim_{t,\xi\to 0} \frac{1}{2} \sum \int_{-1}^{1} dx\, x \left(H^{q/N^*}(x,\xi,t) + E^{q/N^*}(x,\xi,t)\right)$$

$$> \lim_{t,\xi\to 0} \frac{1}{2} \sum_q \int_{-1}^{1} dx\, x \left(H^{q/N}(x,\xi,t) + E^{q/N}(x,\xi,t)\right) = J^q$$

$F_1^*(0) = F_1(0)$

$F_2^*(0) > F_2(0)$



QMC for ^{4}He

Bound nucleon spin sum rule

- Separate J^q into quark helicity $\Delta\Sigma$ and quark angular momentum L^q

$$\Delta\Sigma^* = \frac{1}{2}\sum_{q=u,d,s}\int_0^1 dx(\Delta q^*(x) + \Delta\bar{q}^*(x))$$

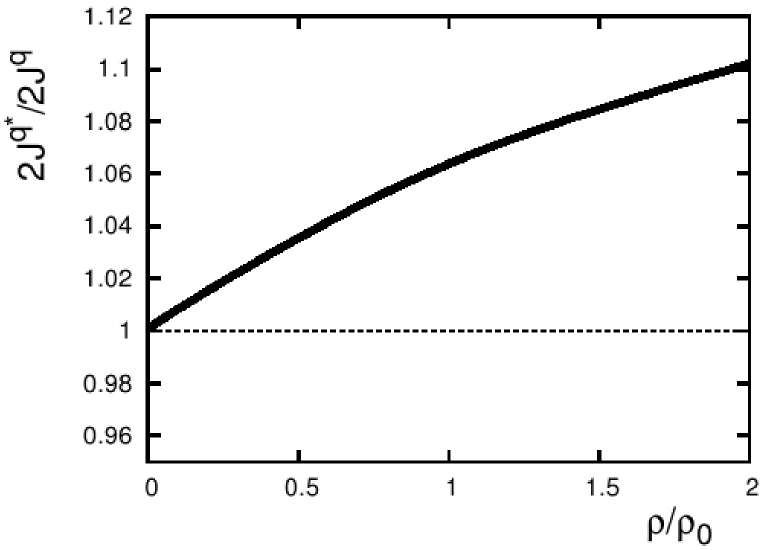
- In QMC model, the mechanism of suppression of the axial coupling constant, $g_A^* < g_A$, does not depend on isospin.

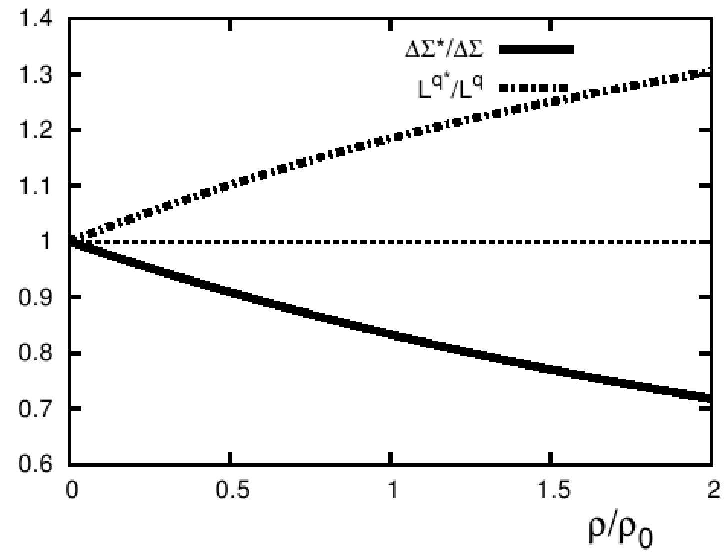
$$g_A^* < g_A \quad \longrightarrow \quad \Delta\Sigma^* < \Delta\Sigma$$

- Since $J^{q^*} > J^q$ and $\Delta\Sigma^* < \Delta\Sigma \longrightarrow L^{q^*} > L^q$

Bound nucleon spin sum rule

V.Guzey, A.W. Thomas, K. Tsushima, 0902.0780 [hep-ph]





Conclusions

- On very general grounds one expects that GPDs of the bound nucleon should be different from that of the free nucleon.

- Assuming that bound nucleon GPDs are modified in proportion to the corresponding elastic form factors, as predicted by QMC, we calculate beam-spin asymmetry in incoherent DVCS on ^{4}He.

- The deviation from the free proton case is as large as 6%, will be tested by a dedicated JLab experiment.

- Modified GPDs lead to the modification of the Ji's spin sum rule for quarks: $J^{q^*} > J^q\,,\ \Delta\Sigma^* < \Delta\Sigma\,,\ L^{q^*} > L^q$

Can be explained by the enhancement of lower component of the quark spinor in nuclear medium.