The EMC effect of light-nuclei within the light-front Hamiltonian dynamics

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Sezione di Perugia

STRONG 2020

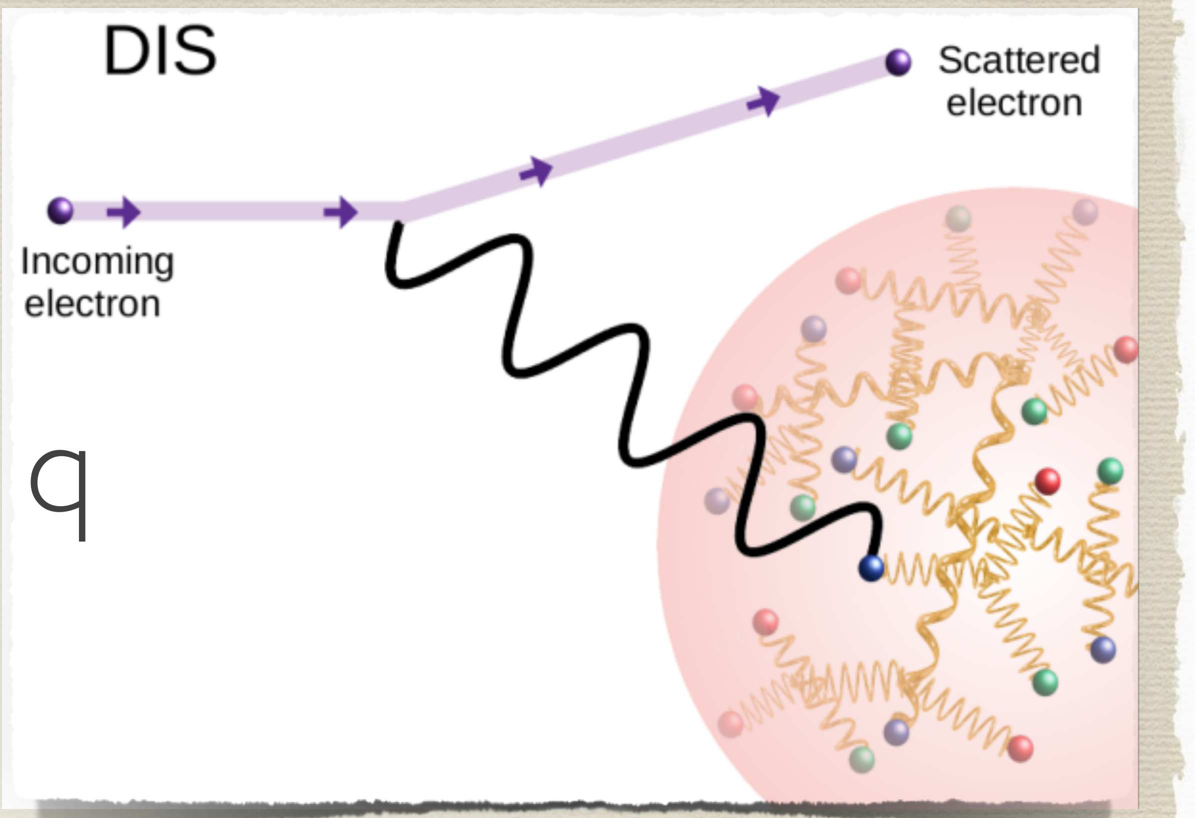
Outline

- The EMC effect
- The Light-Front Poincaré covariant approach
- Nuclear Structure Functions (SFs) with Relativistic Hamiltonian Dynamics
- Numerical results for the EMC effect
- Numerical results for the ^{3}He Spin dependent SFs
- Conclusions

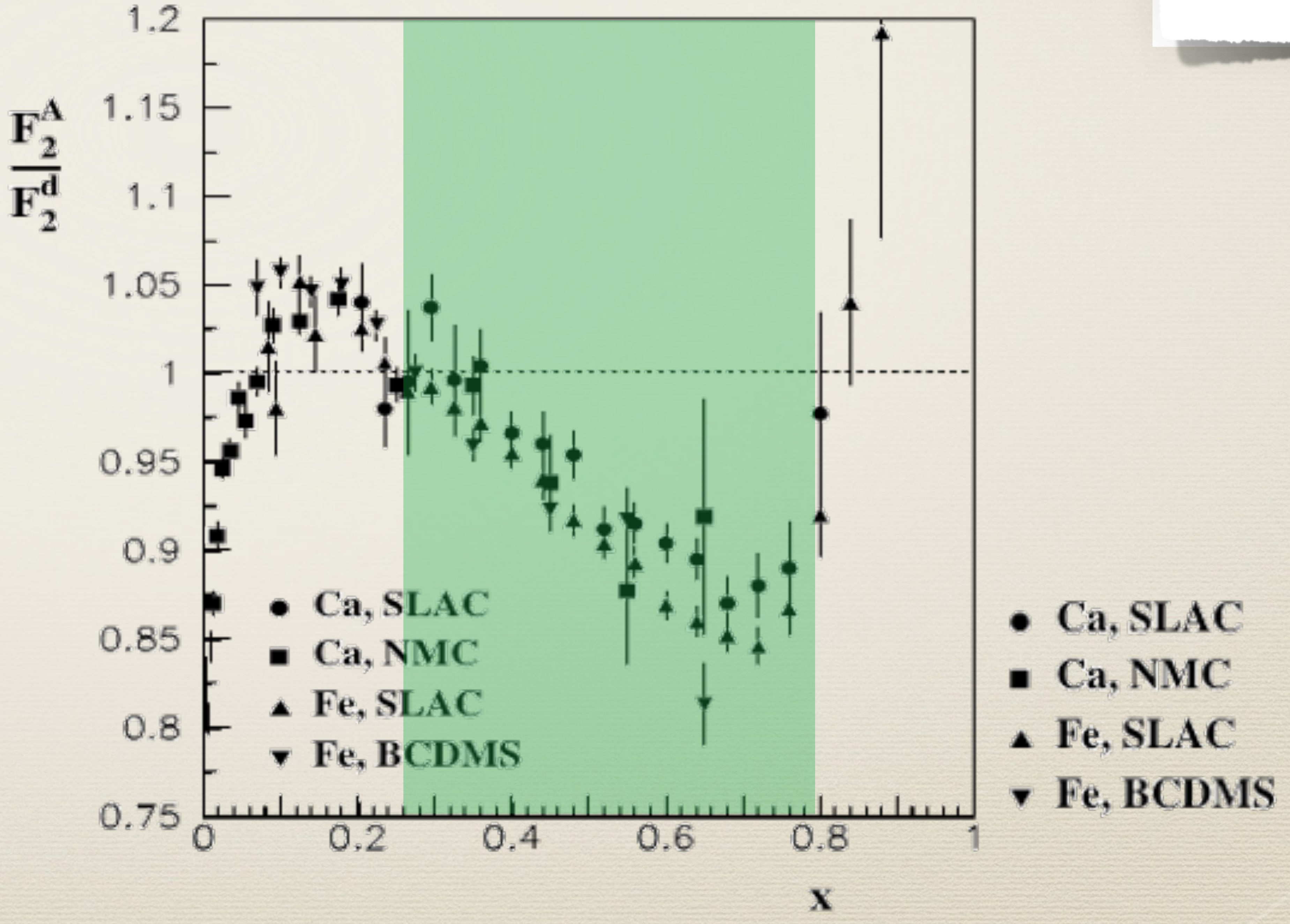
The EMC effect

In DIS off a nuclear target with A nucleons: $\frac{d\sigma}{d\Omega dE'} \propto F_2^A(x)$

$$0 \le x = \frac{Q^2}{2M\nu} \le \frac{M_A}{M} \simeq A$$



$0.2 \le x \le 0.8$ "EMC (binding) region":
mainly valence quarks involved



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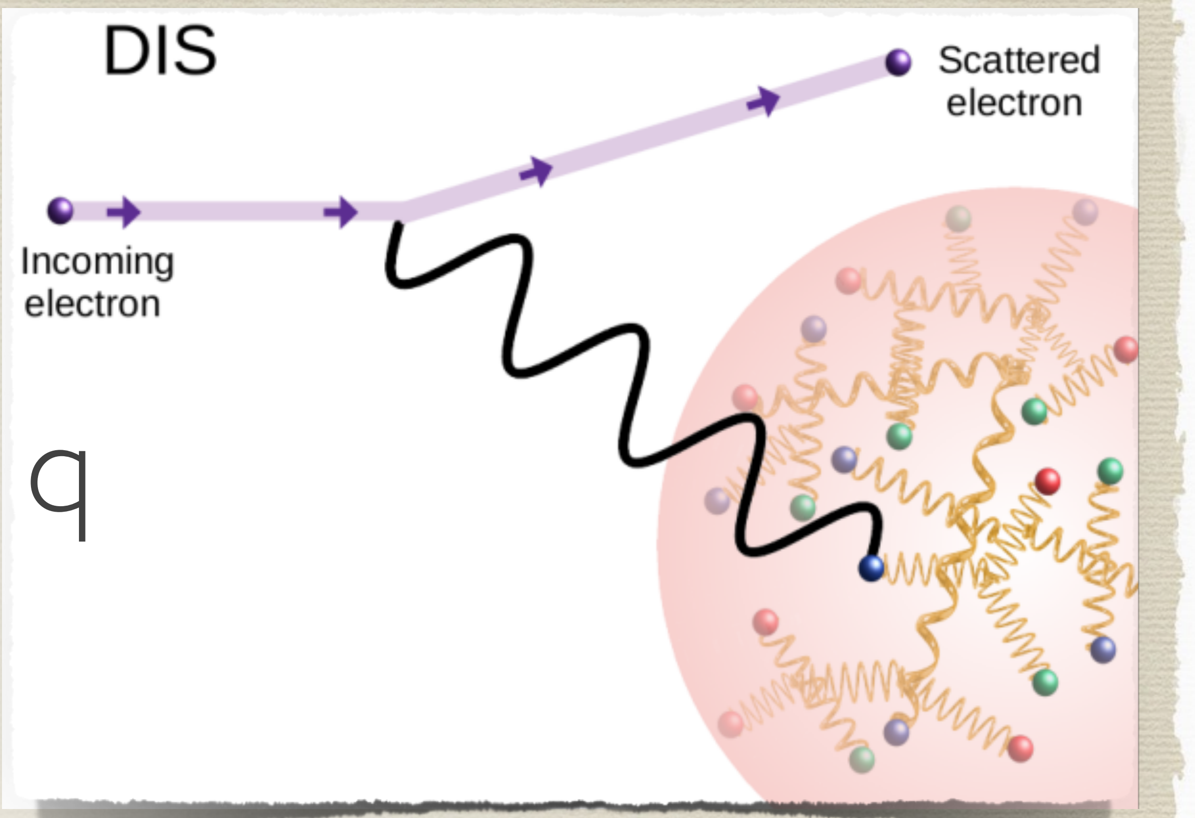

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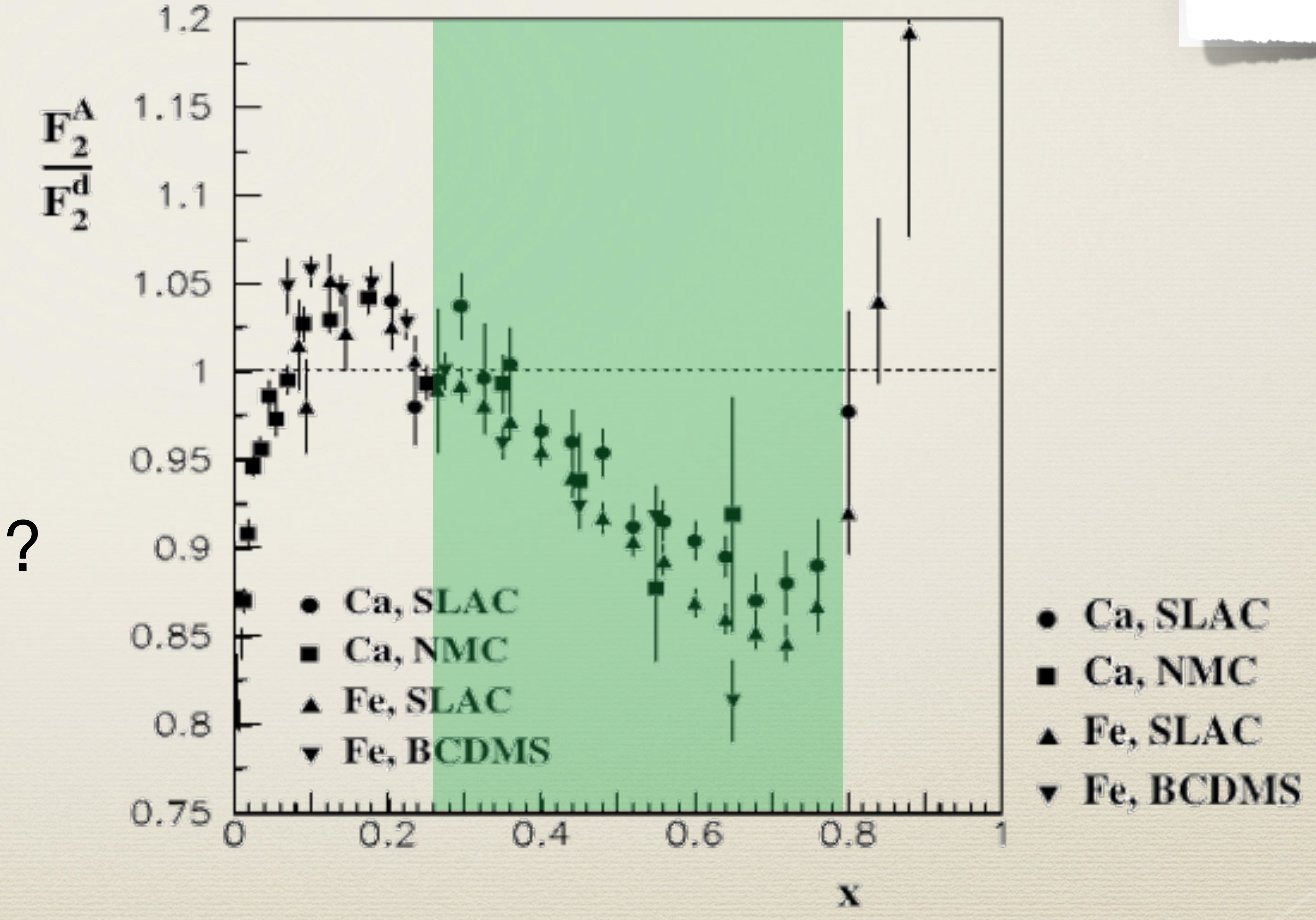
Naive parton model interpretation:

"Valence quarks, in the bound nucleon, are in average slower that in the free nucleon"

Is the bound proton bigger than the free one??



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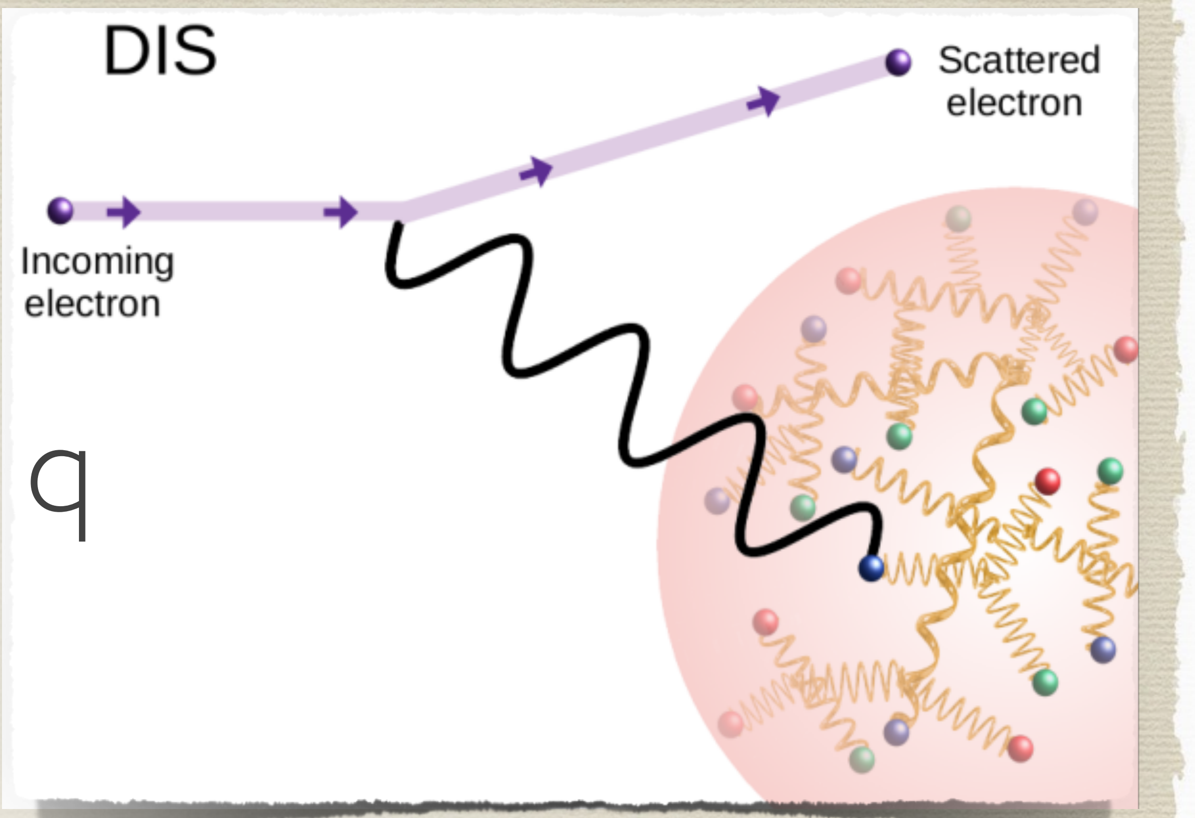

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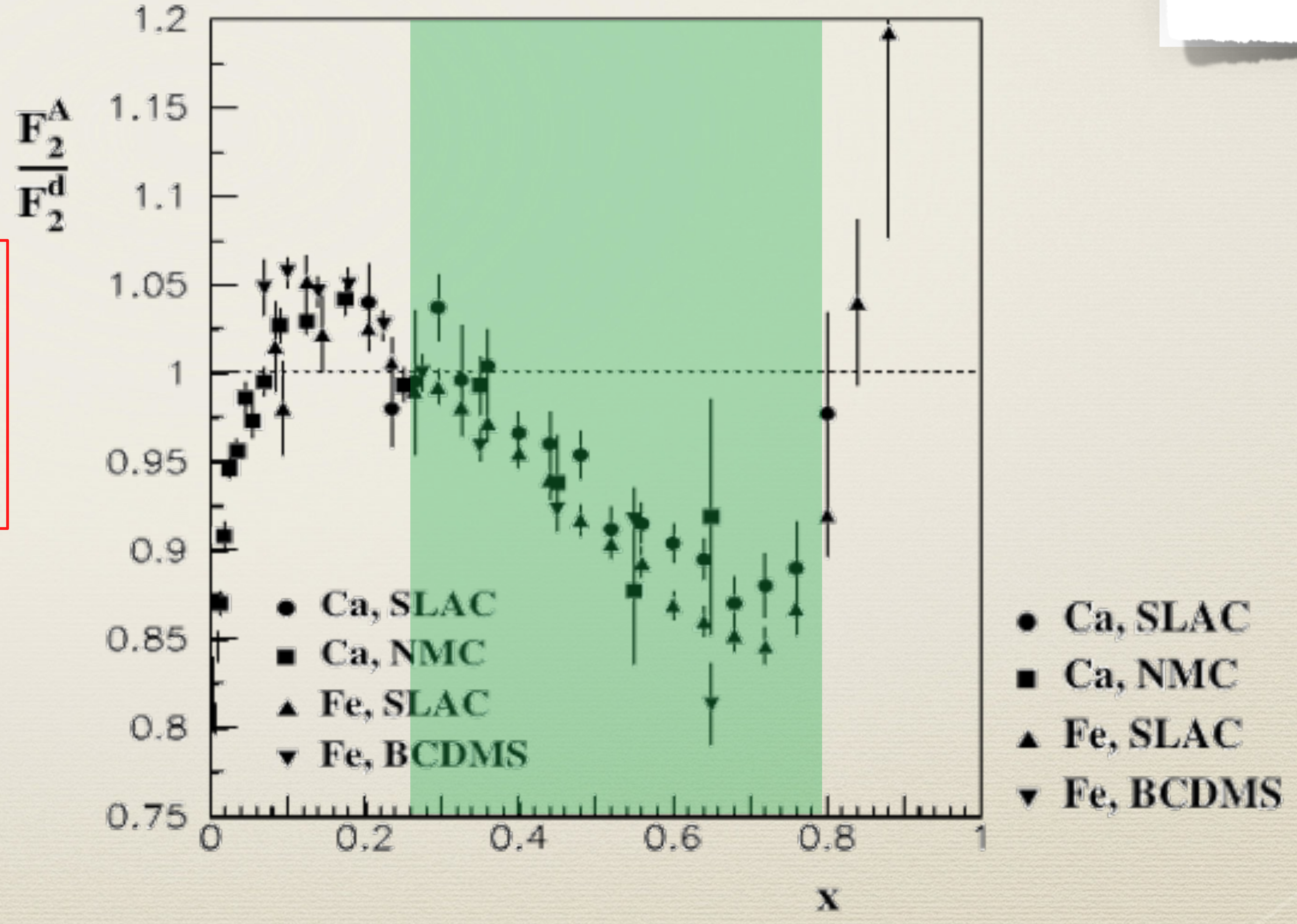
main features: universal behavior independent on Q^2; weakly dependent on A; Scales with the density ρ → global property?
Or due to SRC → local property?



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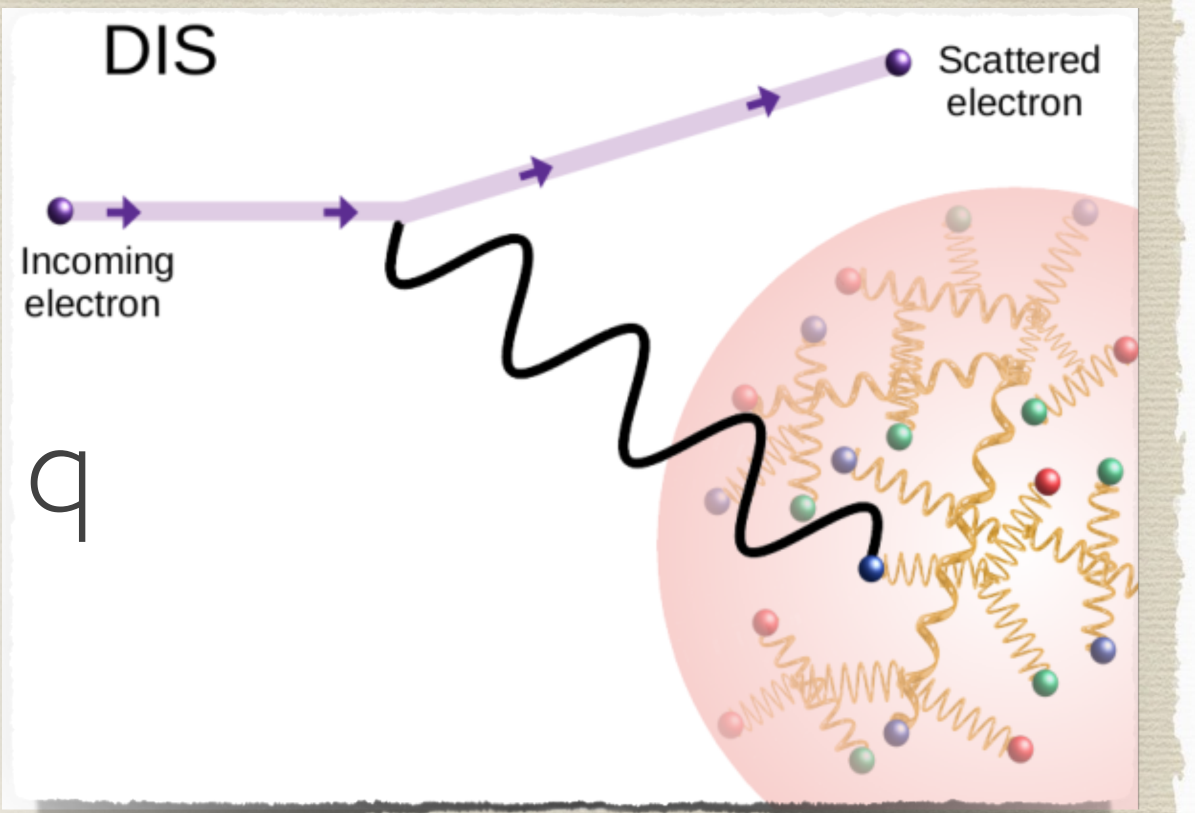

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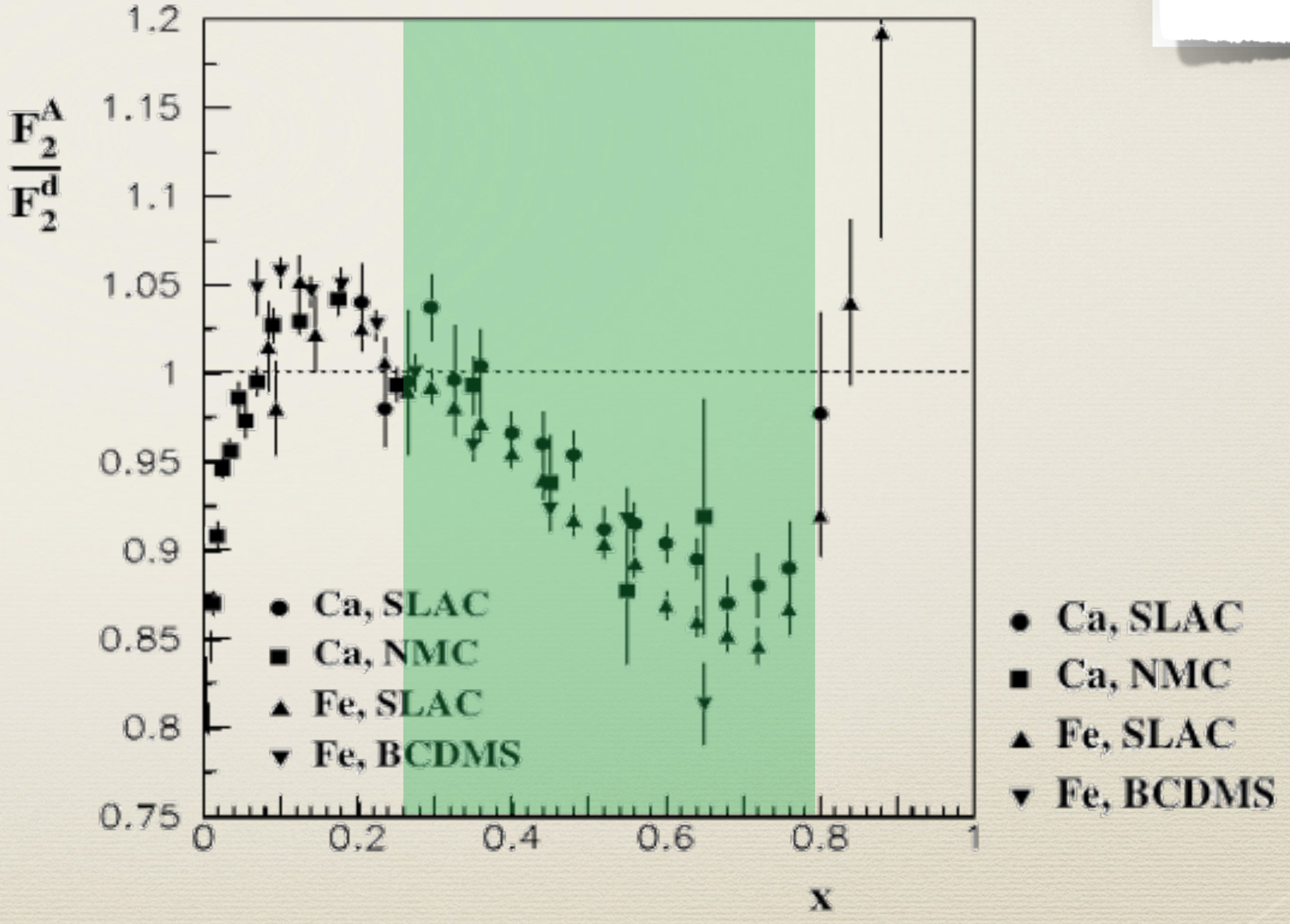
Explanation (exotic) advocated: confinement radius bigger for bound nucleons, quarks in bags with 6, 9,..., 3A
quark, pion cloud effects... Alone or mixed with conventional ones...



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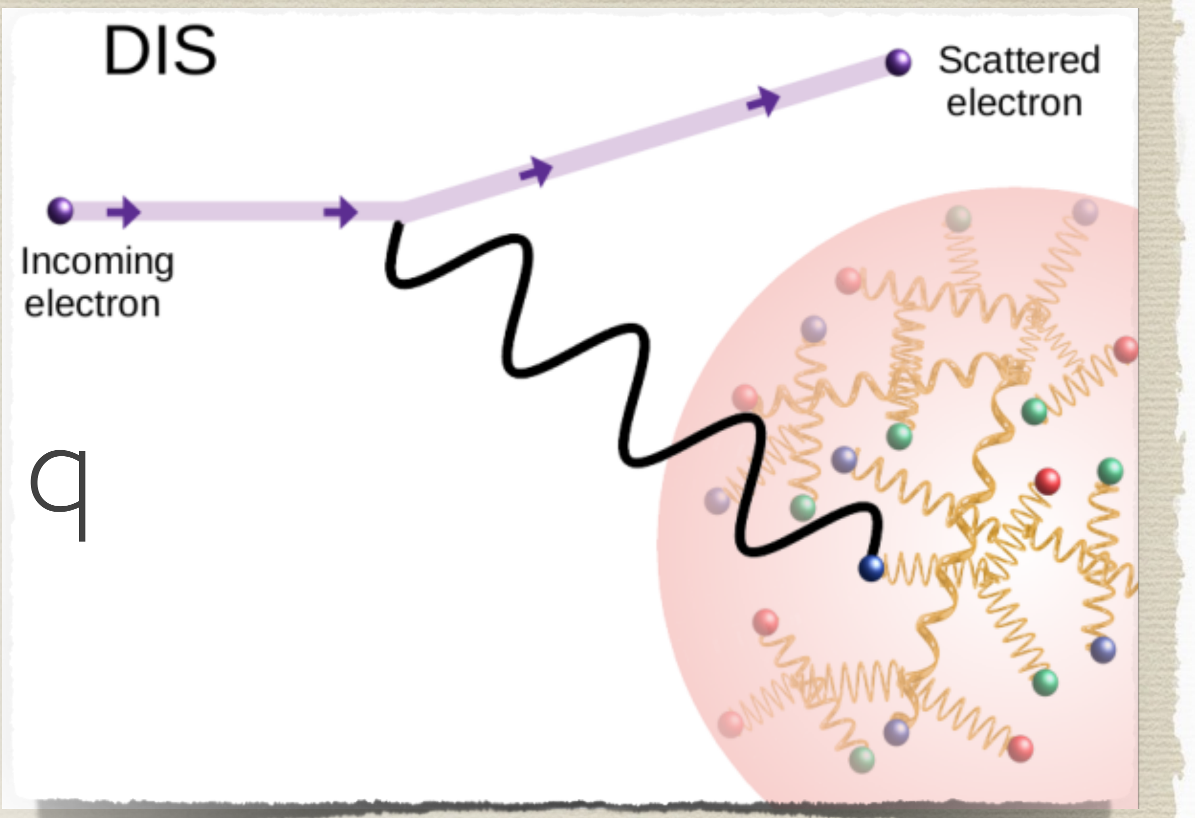

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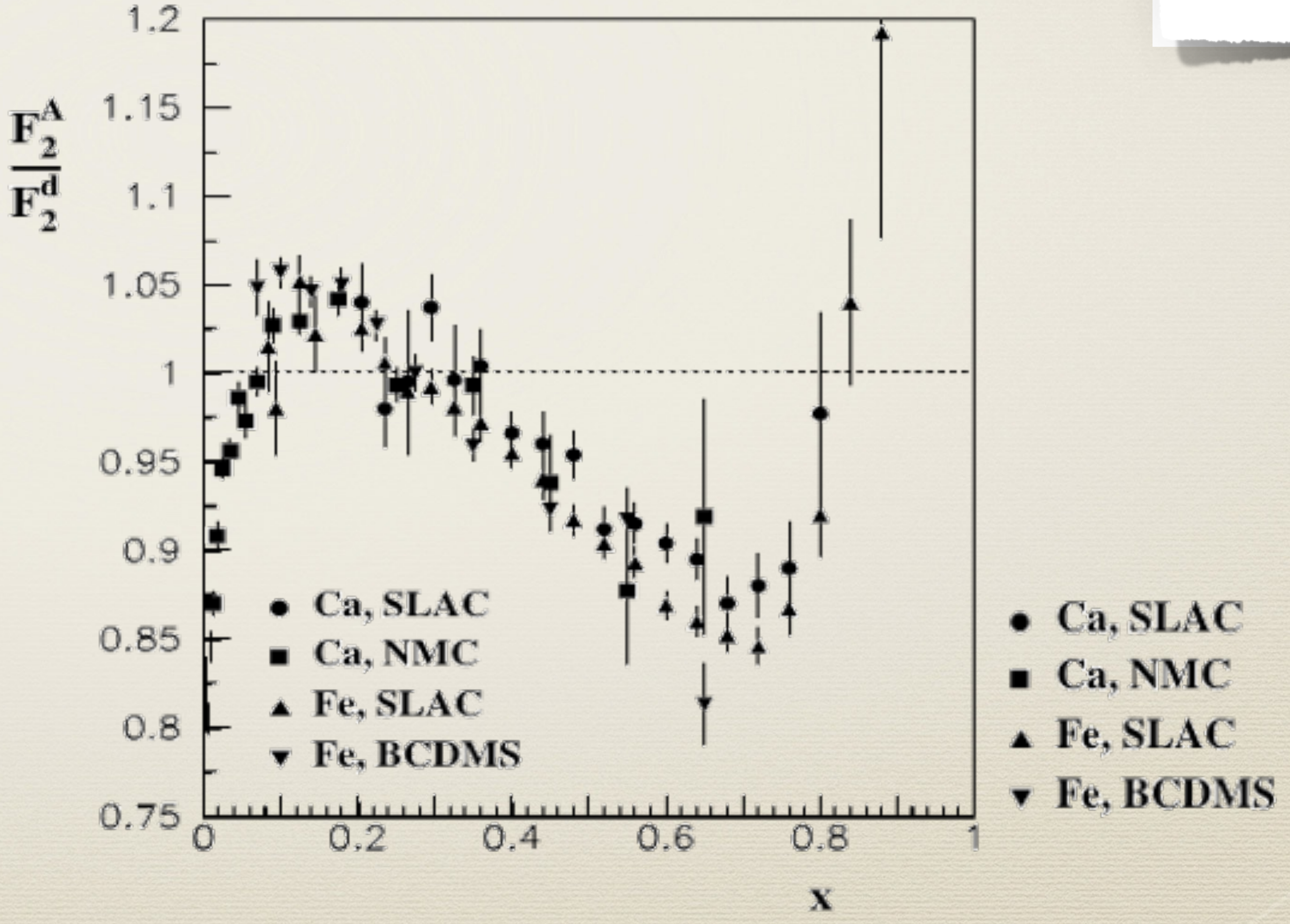

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Conventional calculations:

✔ Qualitative agreement

No fulfillment of both particle and momentum sum rules ✘

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In general, the lack of the **Poincarè covariance** and **macroscopic locality*** generates **biases for the study of genuine QCD effects** (nucleon swelling, exotic quark configurations …)

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In general, the lack of the **Poincarè covariance** and **macroscopic locality*** generates **biases for the study of genuine QCD effects** (nucleon swelling, exotic quark configurations …)

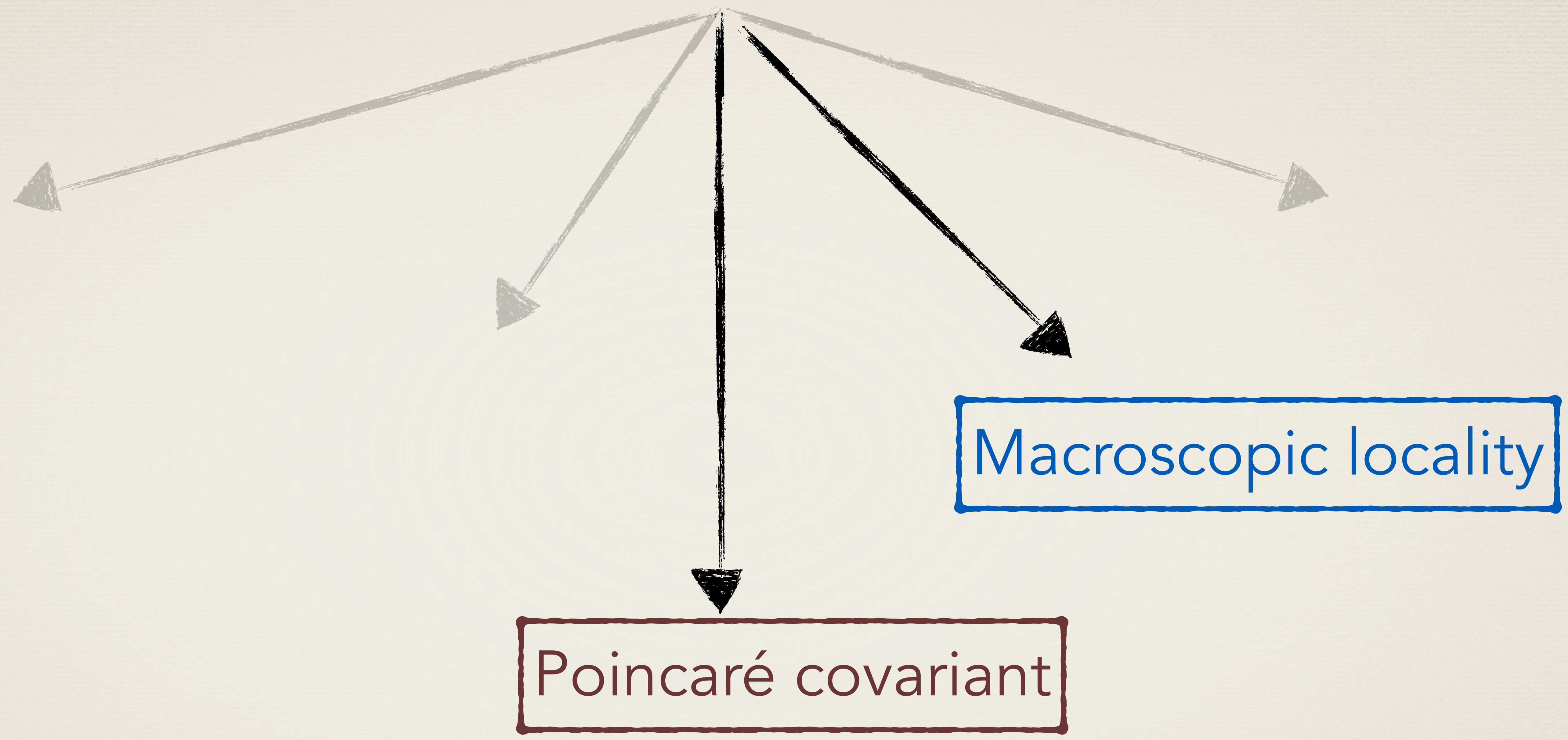
Macroscopic locality (= **cluster separability** (relevant in nuclear physics)): i.e. observables associated to different space-time regions must commute in the limit of large space like separation (i.e. causally disconnected).

In this way, when a system is separated into disjoint subsystems by a sufficiently large space like separation, then the subsystems behave as independent systems

B.D.Keister and W.N.Polyzou, Adv.Nucl.Phys. 20 (1991), 225-479

The EMC effect

Our approach (Light-Front + Bakamjian-Thomas)



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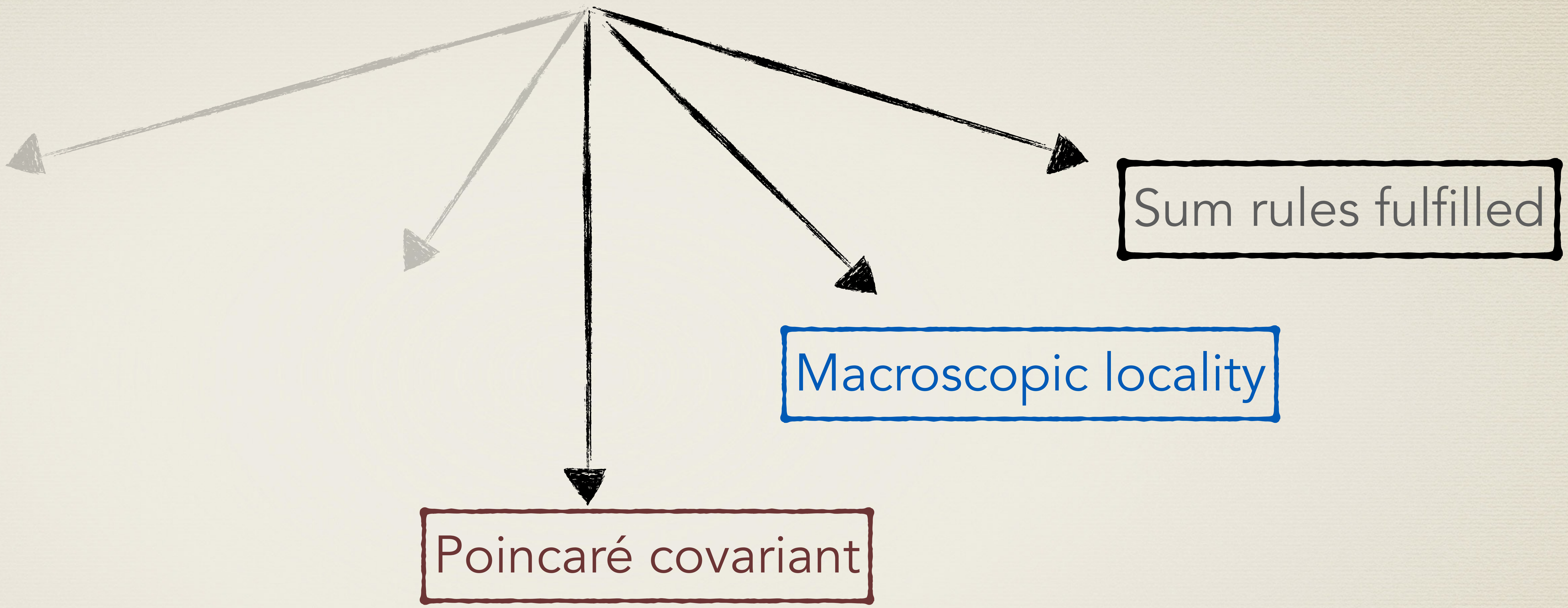

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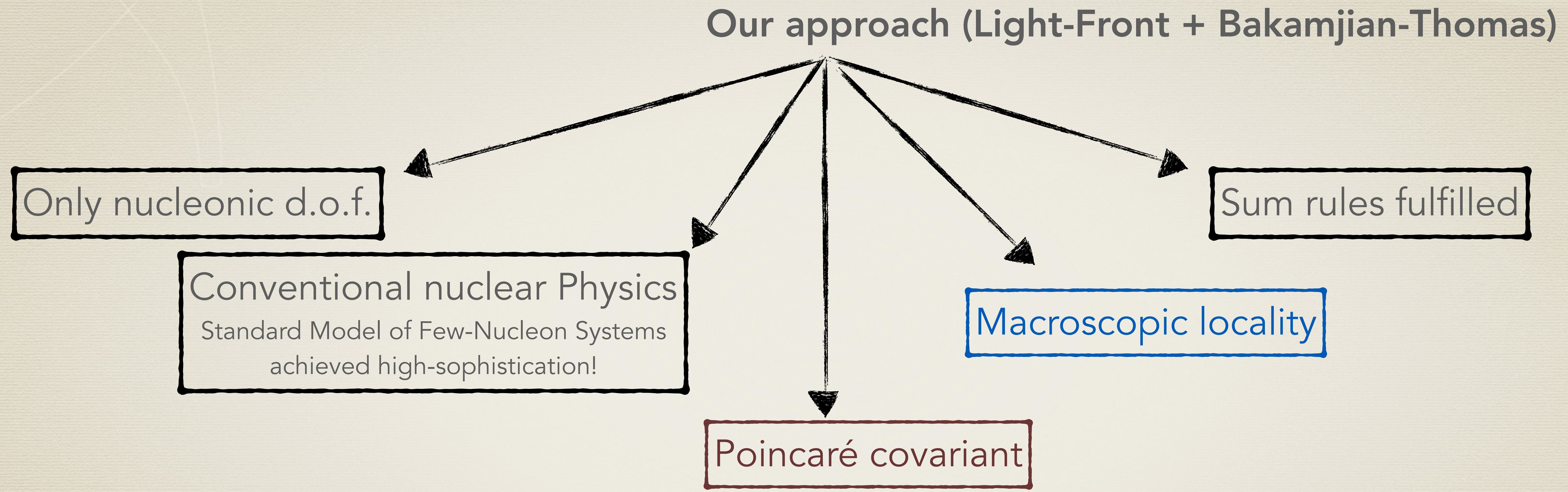

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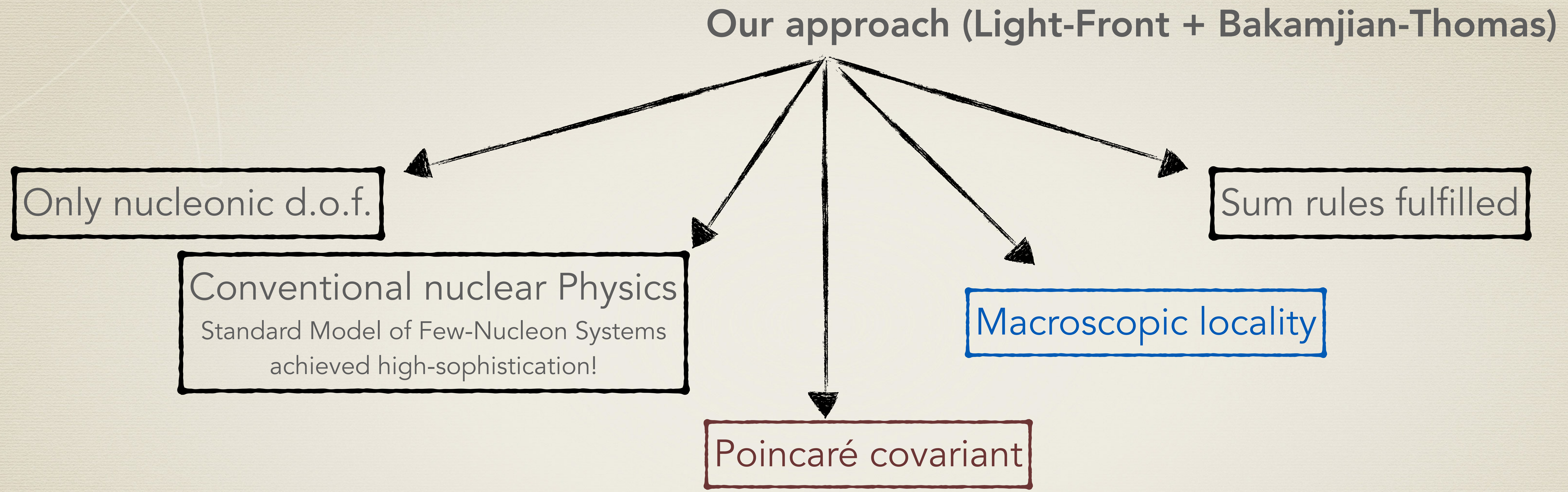

- We provide a **reliable baseline for the calculation of the nuclear SFs** where only the well known nuclear part is considered

- This relativistic treatment is needed for the kinematics of the **JLab12, JLab22 and EIC**

LF approach in pills

Poincaré covariance → Find 10 generators:

$P^\mu \to 4D$ displacements and $M^{\nu\mu} \to$ Lorentz transformation, that fulfill:

$$[P^\mu, P^\nu] = 0; [M^{\mu\nu}, P^\rho] = -i(g^{\mu\rho}P^\nu - g^{\nu\rho}P^\mu)$$
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- **7 Kinematical generators** (max n°): i) 3 LF boosts (in instant form they are dynamical!) ; ii) $\tilde{P} = (P^+ = P^0 + P^3, \mathbf{P}_\perp)$; iii) Rotation around the z-axis
- The LF boosts have a subgroup structure: **trivial separation of intrinsic and global motion, as in the NR case**
- $P^+ \geq 0 \to$ meaningful Fock expansion, once massless constituents are absent
- **The infinite-monentum frame (IMF) description of DIS is easily included**

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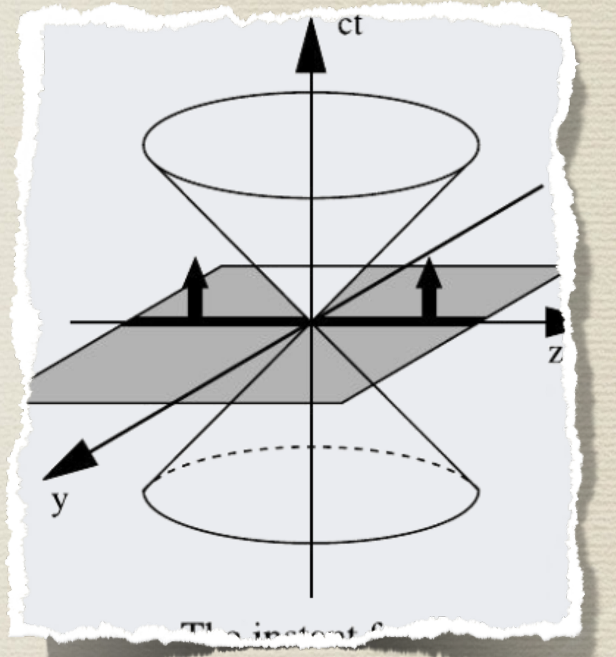

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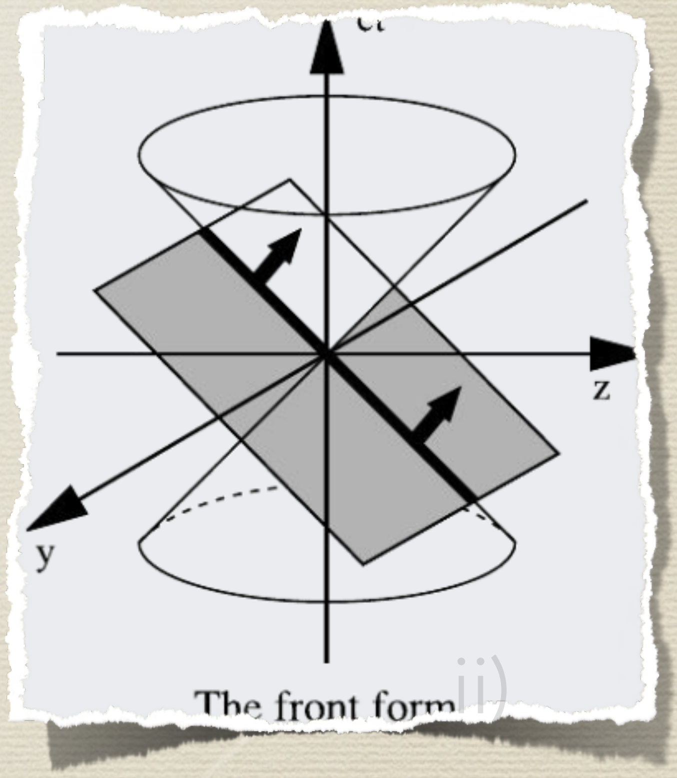

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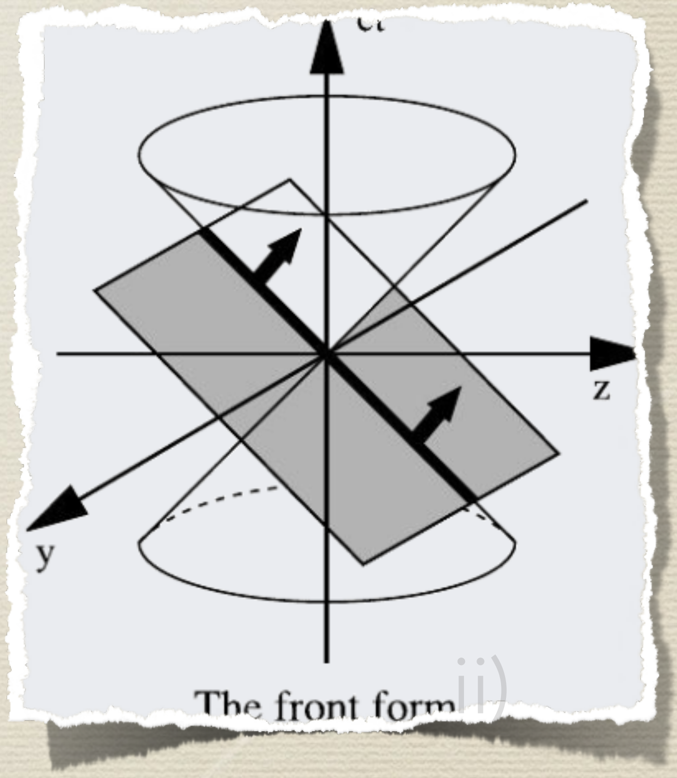

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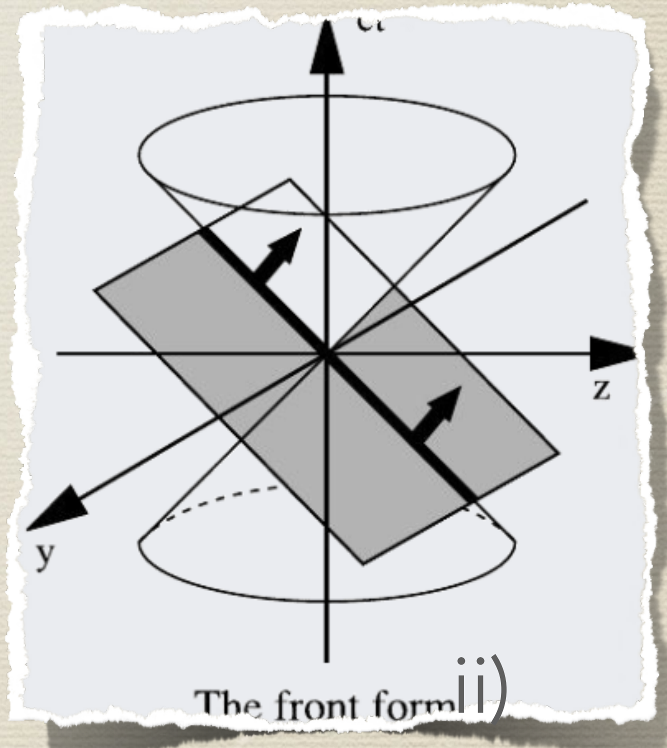

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LF + Bakamjian-Thomas construction

BT properly constructed the 10 Poincaré operators in presence of interactions following this scheme:

i) Only the mass operator M contains the interaction

ii) It generates the dependence of the 3 dynamical generators (P^- and LF transverse rotations)

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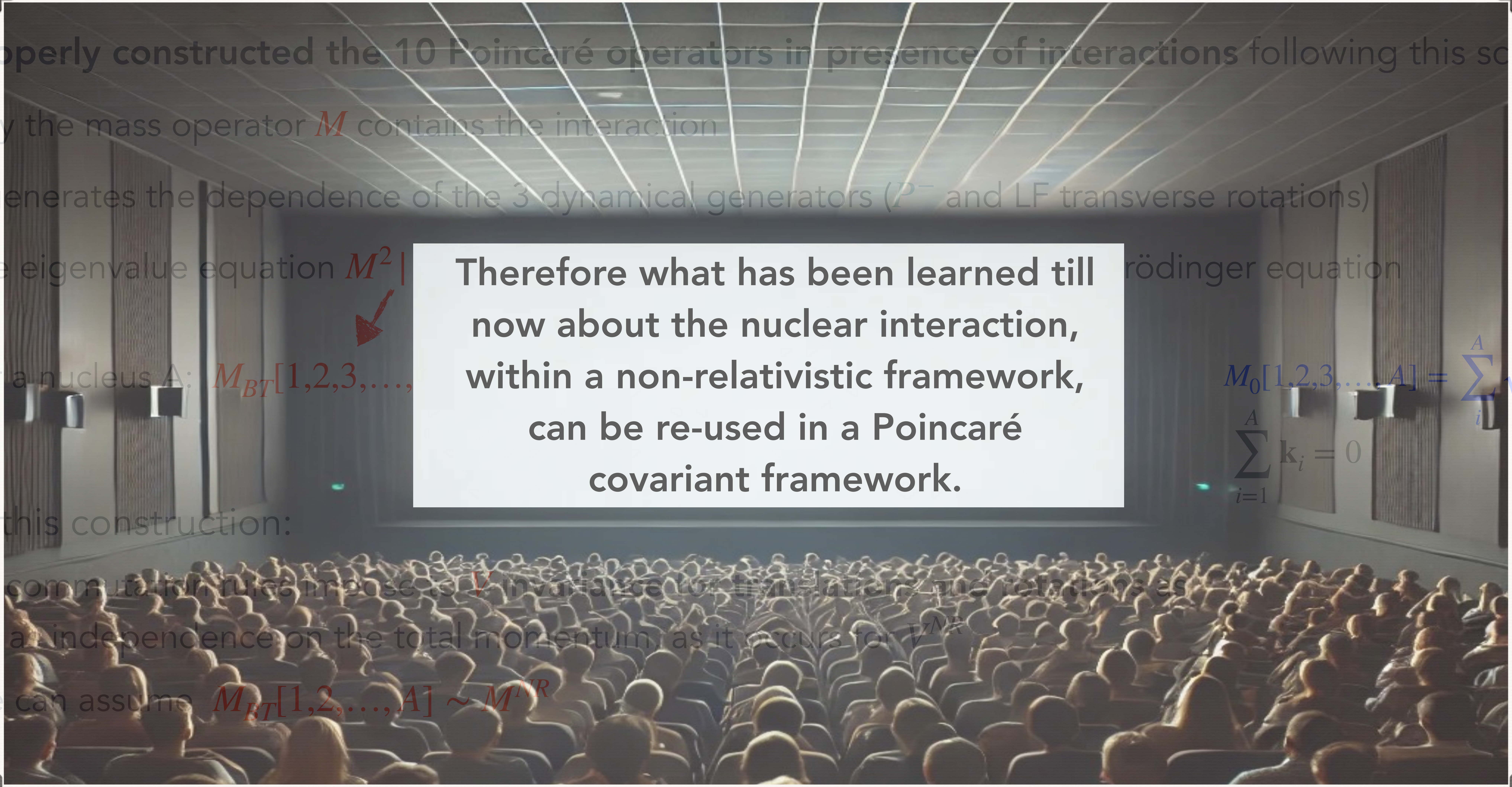

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Our approach: Reference frames

In order to implement **macro-locality**, it is crucial to distinguish between different frames:

- The Lab frame, where $\tilde{P} = (M_{BT}, \mathbf{0}_\perp)$
- The intrinsic LF frame of the whole system, $[1,2,\ldots,A]$, where $\tilde{P} = (M_0[1,2,\ldots,A], \mathbf{0}_\perp)$ with $k_i^+ = \xi_i M_0[1,2,\ldots,A]$ and $M_0[1,2,\ldots,A] = \sum_{i=1}^{A} \sqrt{m^2 + \mathbf{k}_i^2}$
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  $\tilde{P} = (\mathscr{M}_0[1;2,3,\ldots,A-1]), \mathbf{0}_\perp)$ with
  $k^+ = \xi \mathscr{M}_0[1;2,3,\ldots,A-1]$ and $\mathscr{M}_0[1;2,3,\ldots,A-1] = \sqrt{m^2+\kappa^2} + \sqrt{M_s^2+\kappa^2}$

$M_s = (A-1)m + \epsilon$ is the mass of the fully interacting spectator system

While $\mathbf{p}_\perp^{LAB} = \mathbf{k}_{1\perp} = \kappa_\perp$

Our approach: LF spectral function I

Since we use an **impulse approximation** assumption, we rely on the **spin-dependent LF spectral function** $P^{\tau}_{\sigma'\sigma}(\tilde{\kappa}, \epsilon, \mathbf{S}, M)$

$$P^{N}_{\sigma'\sigma}(\tilde{\kappa}, \epsilon, \mathbf{S}, M) = \sum_{JJ_z} \sum_{TT_z} \rho(\epsilon)_{LF} < tT; \alpha, \epsilon; JJ_z; \tau\sigma', \tilde{\kappa} \,|\, \Psi_{JM}; \mathbf{S}, T_A T_{Az} > < \Psi_{JM}; \mathbf{S}, T_A T_{Az} \,|\, _{LF} tT; \alpha, \epsilon; JJ_z; \tau\sigma, \tilde{\kappa} >_{LF}$$

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$|\, tT; \alpha, \epsilon; JJ_z; \tau\sigma', \tilde{\kappa} >_{LF}$ is the **tensor product** of the plane wave of the struck nucleon and the state of the fully interacting spectator system $[2,\ldots, A-1]$ in the intrinsic reference frame of the cluster $[1; 2,3,\ldots, A-1]$ when the spectator system has energy ϵ. It fulfills the macrolocality*

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$|\,\Psi_{JM}; \mathbf{S}, T_A T_{A_z} >_{LF}$ is the eigenstate of $M_{BT}[1,\ldots, A] \sim M^{NR}$ in the intrinsic frame of the system $[1,2,\ldots, A]$

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$|\Psi_{JM}; \mathbf{S}, T_A T_{Az} >_{LF}$ is the eigenstate of $M_{BT}[1,\ldots,A] \sim M^{NR}$ in the intrinsic frame of the system $[1,2,\ldots,A]$

The LF spectral function contains the determinant of the Jacobian of the transformation between the intrinsic frames $[1;2,3,\ldots,A-1]$and $[1,2,\ldots,A]$, connected each other by a LF boost

Our approach: LF spectral function II

$$P^N_{\sigma'\sigma}(\tilde{\kappa},\epsilon,\mathbf{S},M) = \sum_{JJ_z}\sum_{TT_z}\rho(\epsilon)_{LF} < tT;\alpha,\epsilon;JJ_z;\tau\sigma',\tilde{\kappa}\,|\,\Psi_{JM};\mathbf{S},T_A T_{Az} > < \Psi_{JM};\mathbf{S},T_A T_{Az}\,|\,_{LF}tT;\alpha,\epsilon;JJ_z;\tau\sigma,\tilde{\kappa} >_{LF}$$

How do we deal with LF states?

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How do we deal with LF states?

1) We can express the LF overlap in terms of the IF overlap using **Melosh rotations**:

$$< tT;\alpha,\epsilon;JJ_z;\tau\sigma',\tilde{\kappa}\,|\,\Psi_{JM};\mathbf{S},T_AT_{Az} >_{LF} \rightarrow \; < tT;\alpha,\epsilon;JJ_z;\tau\sigma'_c,\kappa\,|\,\Psi_{JM};\mathbf{S},T_AT_{Az} >_{IF}$$

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2) Then we can approximate the IF overlap into a NR overlap by using the **NR wave function for the nucleus**, thanks to the BT construction:

$$< tT; \alpha, \epsilon; JJ_z; \tau\sigma'_c, \kappa | \Psi_{JM}; \mathbf{S}, T_A T_{Az} >_{IF} \; \sim \; < tT; \alpha, \epsilon; JJ_z; \tau\sigma'_c, \kappa | \Psi_{JM}; \mathbf{S}, T_A T_{Az} >_{NR}$$

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Poincarè covariance preserved but using the successful NR phenomenology

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Poincarè covarian

We used wave functions of $^2H, ^3H, ^3He, ^4He$ calculated through 3 different potentials: **Av18+UIX*** and 2 versions of the **Norfolk χEFT interactions NVIa+3N**** and **NVIb+3N****

*R. B. Wiringa, V. G. J. Stoks, R. Schiavilla, **Phys. Rev. C 51 (1995) 38–51;** R. B. Wiringa et al., **Phys. Rev. Lett. 74 (1995) 4396–4399**

M.Viviani et al., **Phys. Rev. C 107 (1) (2023) 014314; M. Piarulli et al.,**Phys. Rev. Lett. 120 (5) (2018) 052503;** M. Piarulli, S. Pastore, R. B. Wiringa, S. Brusilow, R. Lim,**Phys. Rev. C 107 (1) (2023) 014314**

Nuclear SFs and EMC ratio

To calculate the EMC ratio $R^A_{EMC}(x) = \dfrac{F_2^A(x)}{F_2^d(x)}$ for any nucleus A, we need the nuclear SFs.

Within our approach we have:

$$F_2^A(x) = \sum_N \int_{\xi_{min}}^1 d\xi \; F_2^N\left(\frac{mx}{\xi M_A}\right) \; f_A^N(\xi)$$

*ξ = longitudinal momentum fraction carried by a nucleon in the nucleus

Since our approach **fulfill both macro-locality and Poincaré covariance** the LC momentum distribution satisfies 2 essential sum rules at the same time ():

$A = \int_0^1 d\xi [Z f_1^p(\xi) + (A-Z) f^n(\xi)]$: **Baryon number SR**;

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Unpolarized LF spectral function:

$$P^N(\tilde{\kappa}, \epsilon) = \frac{1}{2j+1} \sum_{\mathcal{M}} P^N_{\sigma\sigma}(\tilde{\kappa}, \epsilon, \mathbf{S}, \mathcal{M})$$

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2) The free nucleon SFs E.Pace, M.Rinaldi, G.Salmè and S. Scopetta, **Phys. Scr. 95, 064008 (2020)**:

a) we choose a **parametrization** for $F_2^p(x)$

b) we use the **MARATHON data** (MARATHON Coll., **Phys. Rev. Lett 128 (2022) 13,132003**)

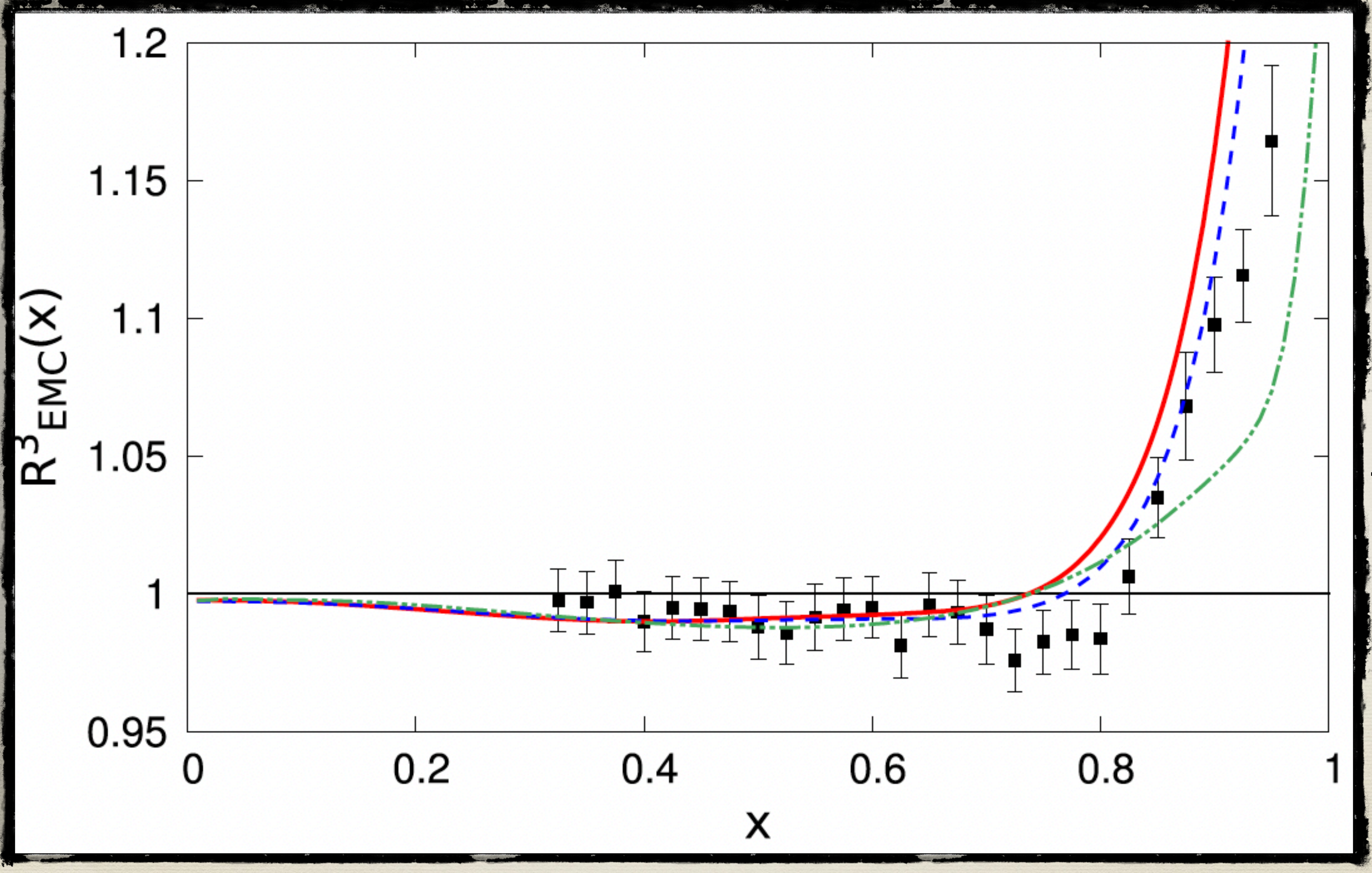
for the parametrization of the ratio $\dfrac{F_2^n}{F_2^p}$ to get F_2^n

The EMC effect for ^{3}He

E.Pace, M.R. G.Salmè and S.Scopetta, Phys. Lett. B 839(2023) 127810

[1] J. Arrington, et al, **Phys. Rev. C 104 (6) (2021) 065203**

[2] S. A. Kulagin and R. Petti, **Phys. Rev. C 82, 054614 (2010)**



Solid line: Av18/UIX + SMC*
Dashed line:Av18 + SMC*
Dotted-dashed: Av18/UIX +CJ15**

Full squares: JLab data from experiment E03103 [1] **as reanalyzed in** [2]

****[B. Adeva, et al., Phys. Lett. B 412 (1997) 414–424.]***

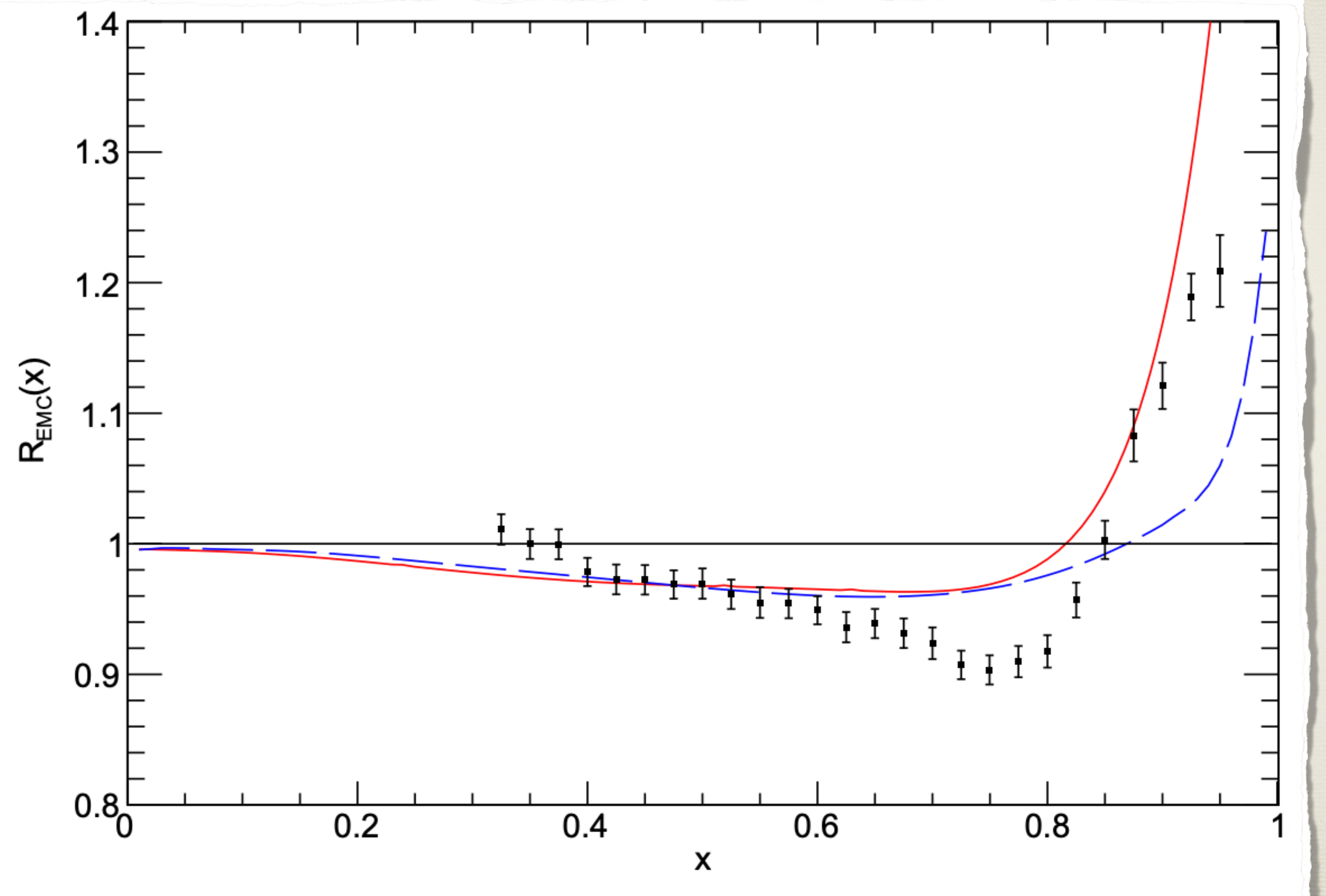
****[A. Accardi, L. T. Brady, W. Melnitchouk, J. F. Owens, N. Sato, Phys. Rev. D 93 (11) (2016) 114017]**

Small but **solid** effect, comparable to the experimental data

The EMC effect for ^{4}He

F.Fornetti, E.Pace, M.R., G.Salmè, S.Scopetta and M.Viviani, **Phys.Lett.B** 851 (2024) 138587

Full squares: JLab data from experiment E03103



Both lines calculated with Av18/UIX

Solid line: SMC parametrization of F_2^p *

Dashed line: CJ15 +TMC Parametrization of F_2^p**

F_2^n extracted from MARATHON data

[B. Adeva, et al., Phys. Lett. B 412 (1997) 414–424.]

****[A. Accardi, L. T. Brady, W. Melnitchouk, J. F. Owens, N. Sato, Phys. Rev. D 93 (11) (2016) 114017]**

The dependence on the choice of the **free nucleon SFs** is largely under control in the **properly EMC region**

The EMC effect for ^{4}He

F.Fornetti, E.Pace, M.R., G.Salmè, S.Scopetta and M.Viviani, **Phys.Lett.B** 851 (2024) 138587

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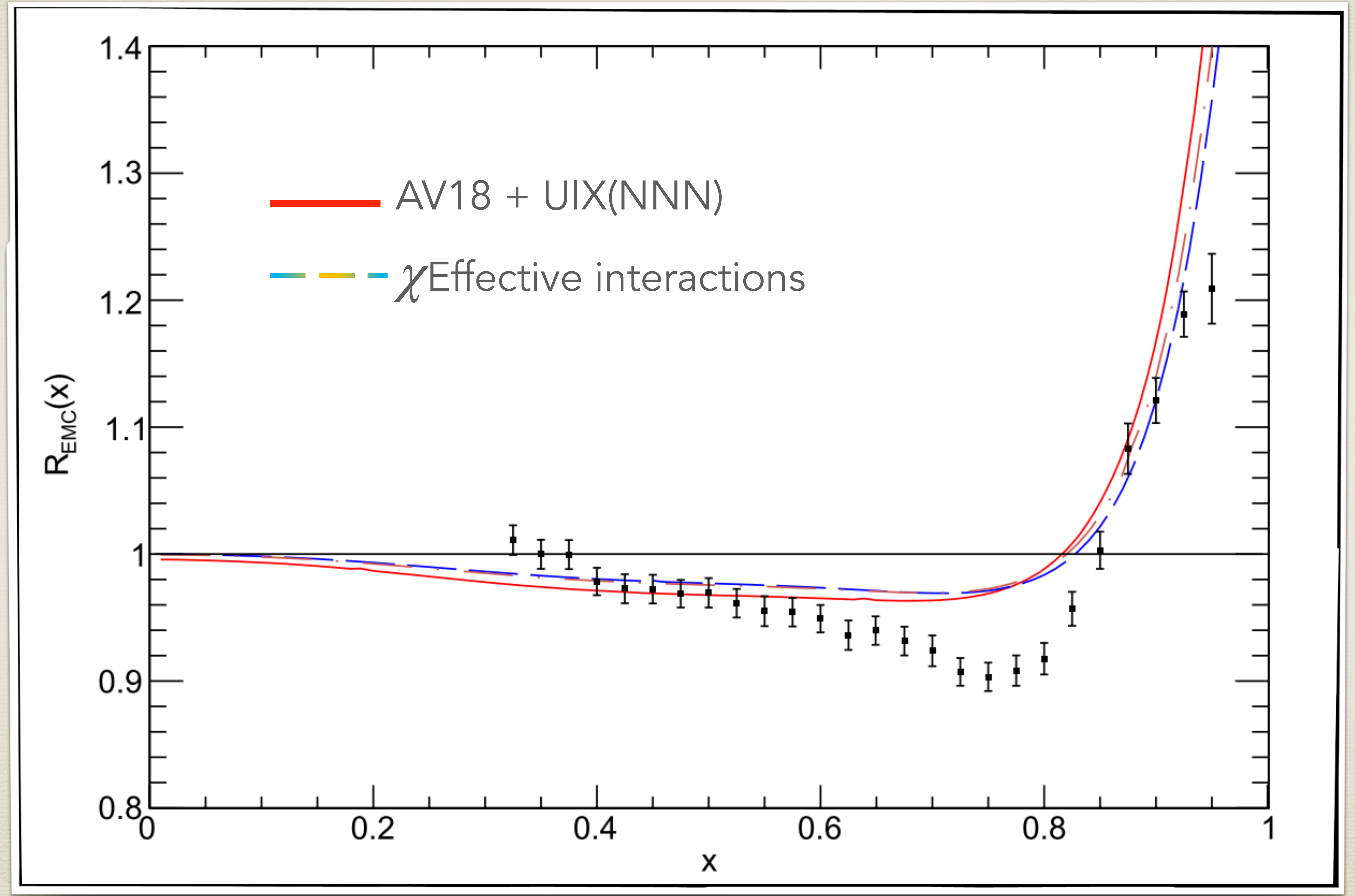

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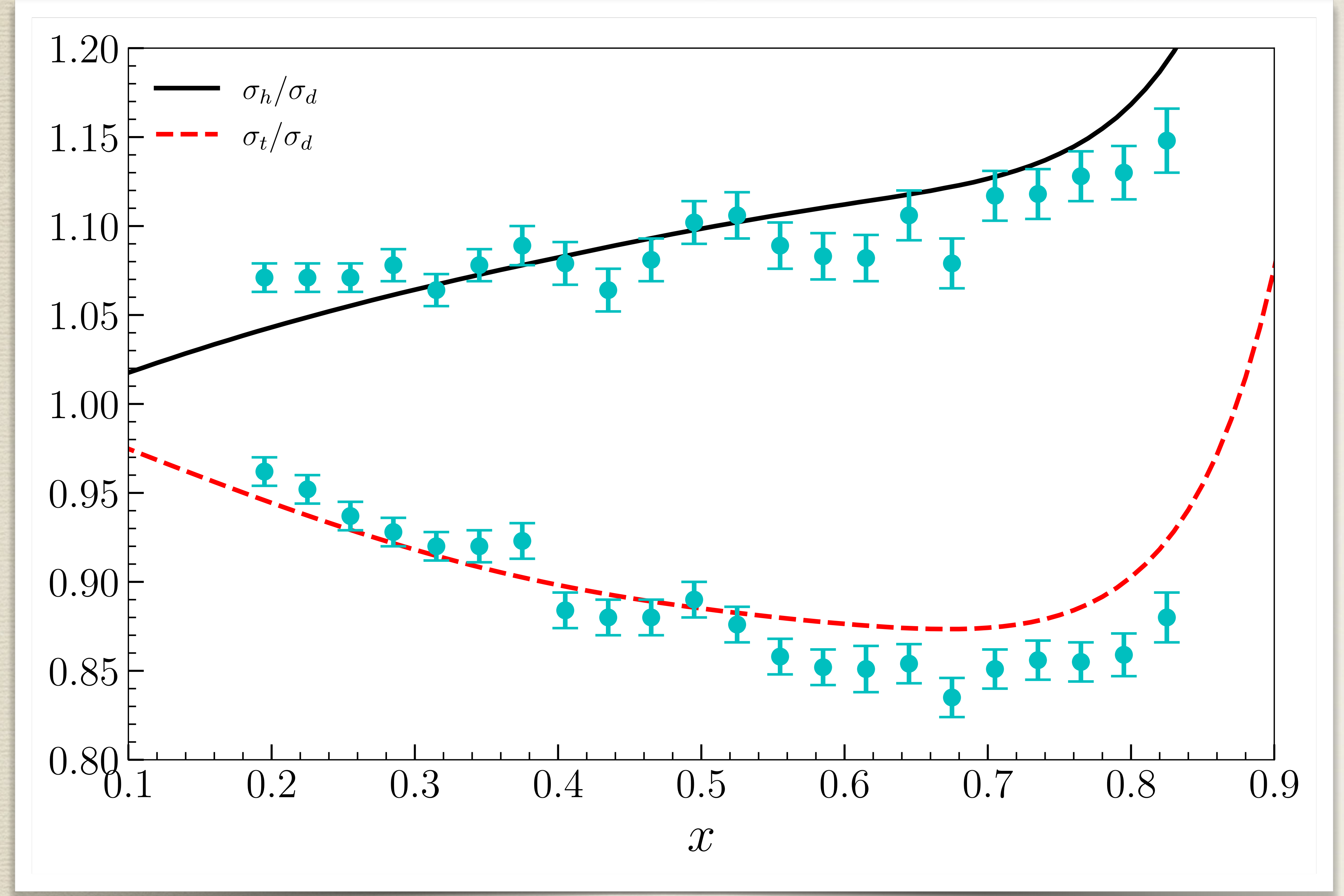
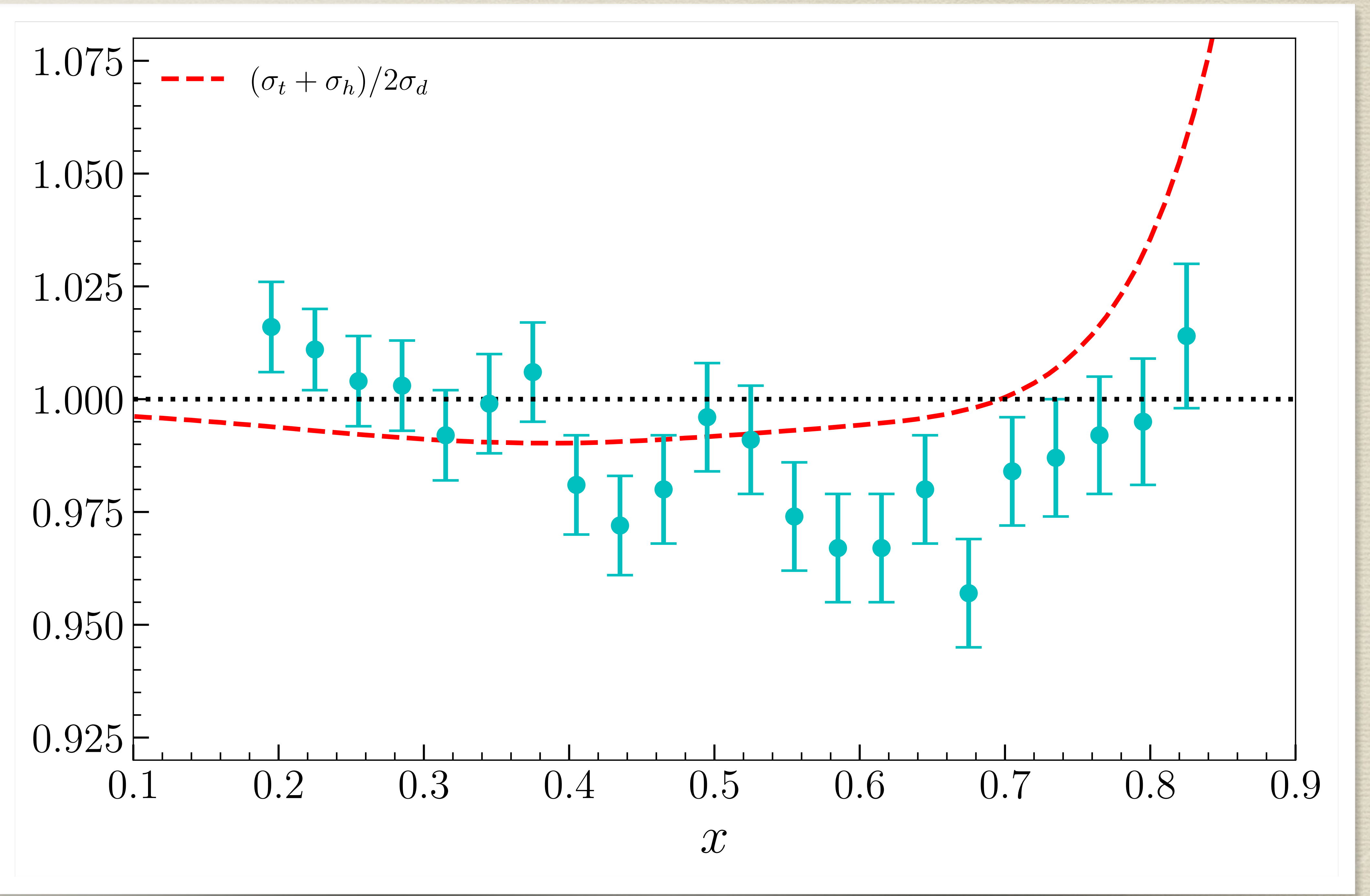
****[B. Adeva, et al., Phys. Lett. B 412 (1997) 414–424.]***

Recent (ongoing) calculations





Data from:

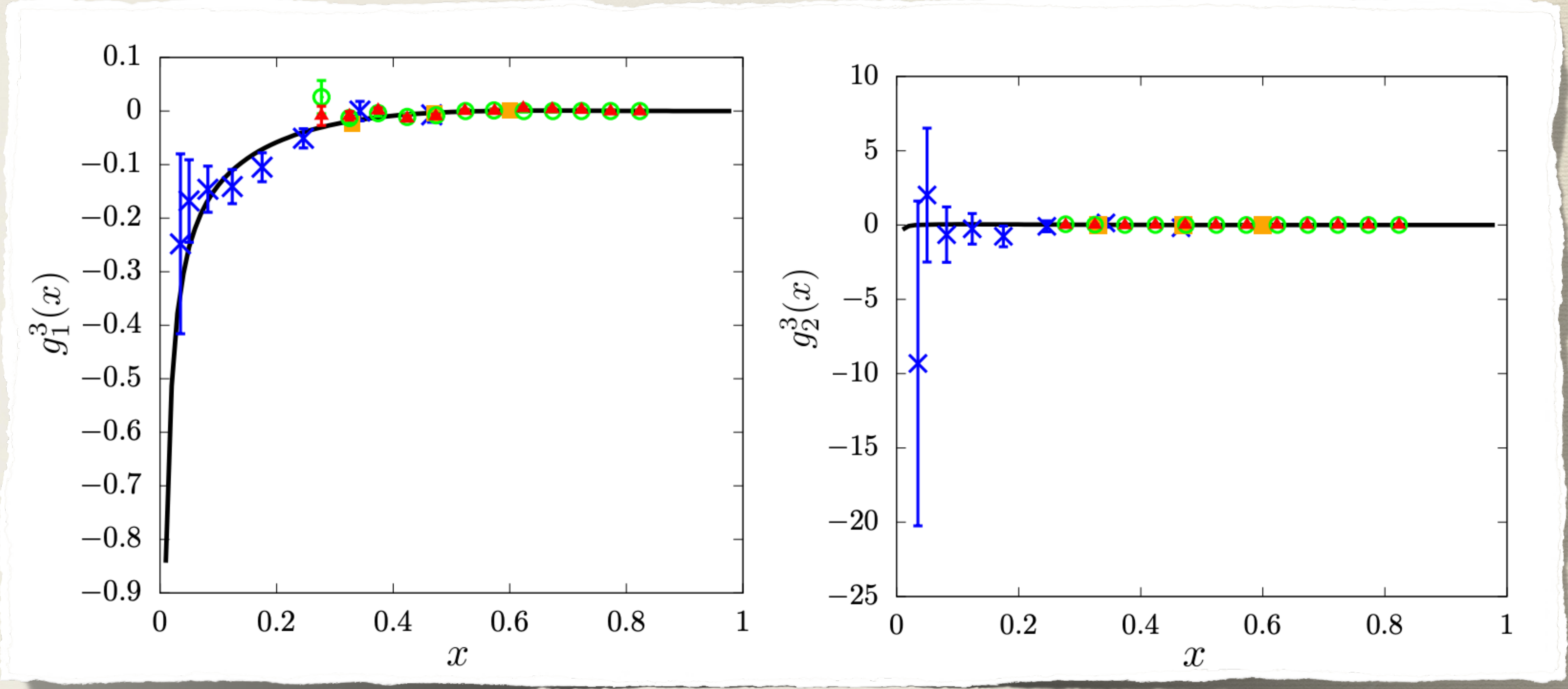
D. Abrams, H. Albataineh, B.~S. Aljawrneh,...,et al,
``The EMC Effect of Tritium and Helium-3 from the JLab MARATHON Experiment,''
[arXiv:2410.12099 [nucl-ex]].

Some recents works…

F. Fornetti, E. Proietti…, M. R. et al, PRC 110 (2024), 3, L031303

Calculation of the spin dependent ^{3}He structure functions within the Light-Front covariant approach:

Also in this case there are no free parameters and the ^{3}He w.f. corresponding to the Av18 potential has been used



Some recents works…

F. Fornetti, E. Proietti…, M. R. et al, PRC 110 (2024), 3, L031303

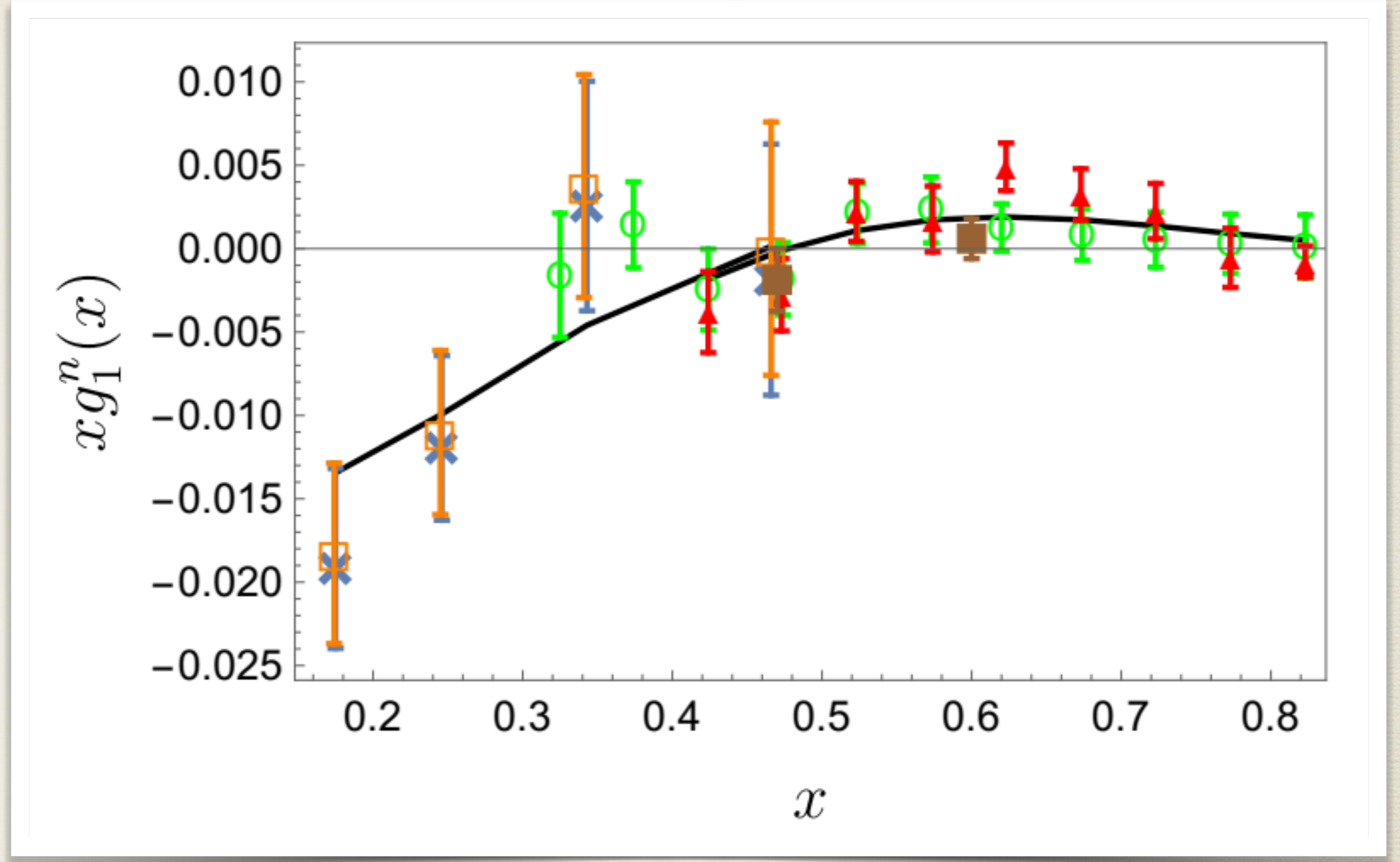
Extraction of the neutron spin dependent structure from ^{3}He data:

$$\bar{g}_j^n(x) = \frac{1}{p_j^n}\left[g_j^3(x) - 2p_j^p g_j^p(x)\right] \quad (j = 1, 2)$$

with the effective polarizations obtained from the ^{3}He w.f.

$$p_1^n \simeq 0.873 \qquad p_2^n \simeq 0.873$$

$$p_1^p \simeq -0.0230 \qquad p_2^p \simeq -0.0245$$



Points: extracted from ^{3}He data using our formula

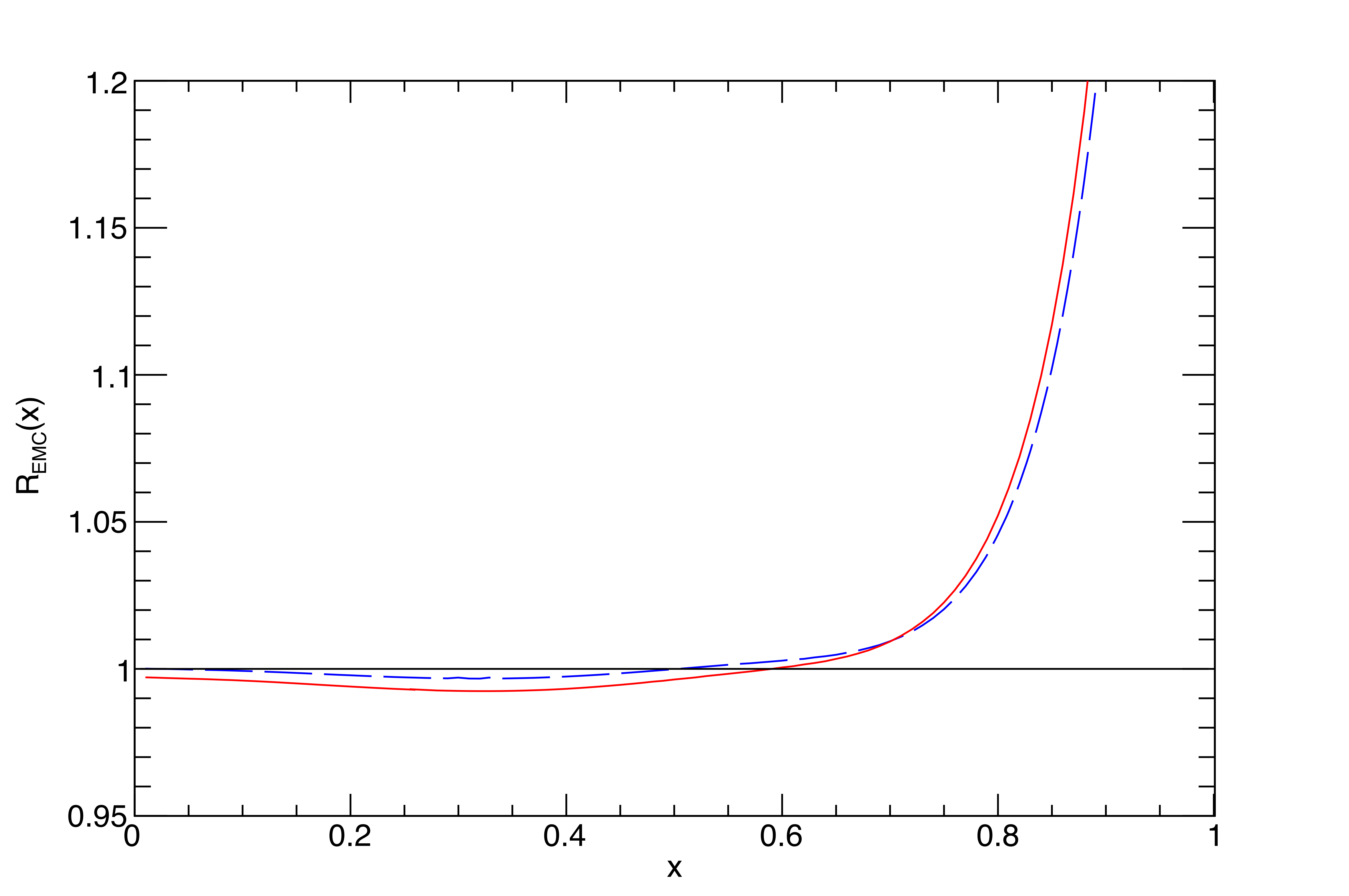
Line: M. Gluck, et al, Phys. Rev. D 63, 094005 (2001).

The ^{3}He spin structure is makes this nucleus unique to extract the neutron distributions!

Conclusions

- **EMC of light-nuclei within a Poincaré covariant LF approach**
  - ☑ We developed a rigorous formalism for the calculation of nuclear SFs (also for TMDs) involving only nucleonic DOF with the conventional nuclear physics
  - ☑ For ^{3}He we obtain results in agreement with experimental data for the EMC effect. Useful analysis for planned experiments in future facilities
  - ☑ For the deviations from experimental data could be ascribed to genuine QCD effects: **our results provide a reliable baseline to study exotic phenomena**
- **To do next**
  - ☐ Inclusion of the fully Poincaré relativistic approach to Generalized Parton Distributions
  - ☐ Include off-shell effects
  - ☐ Application of the approach to heavier nuclei (^{6}Li starting project)
  - ☐ Studying Double Parton Distributions of light-nuclei (in preparation)

Backup slides



Results similar to ^3He and ^4He

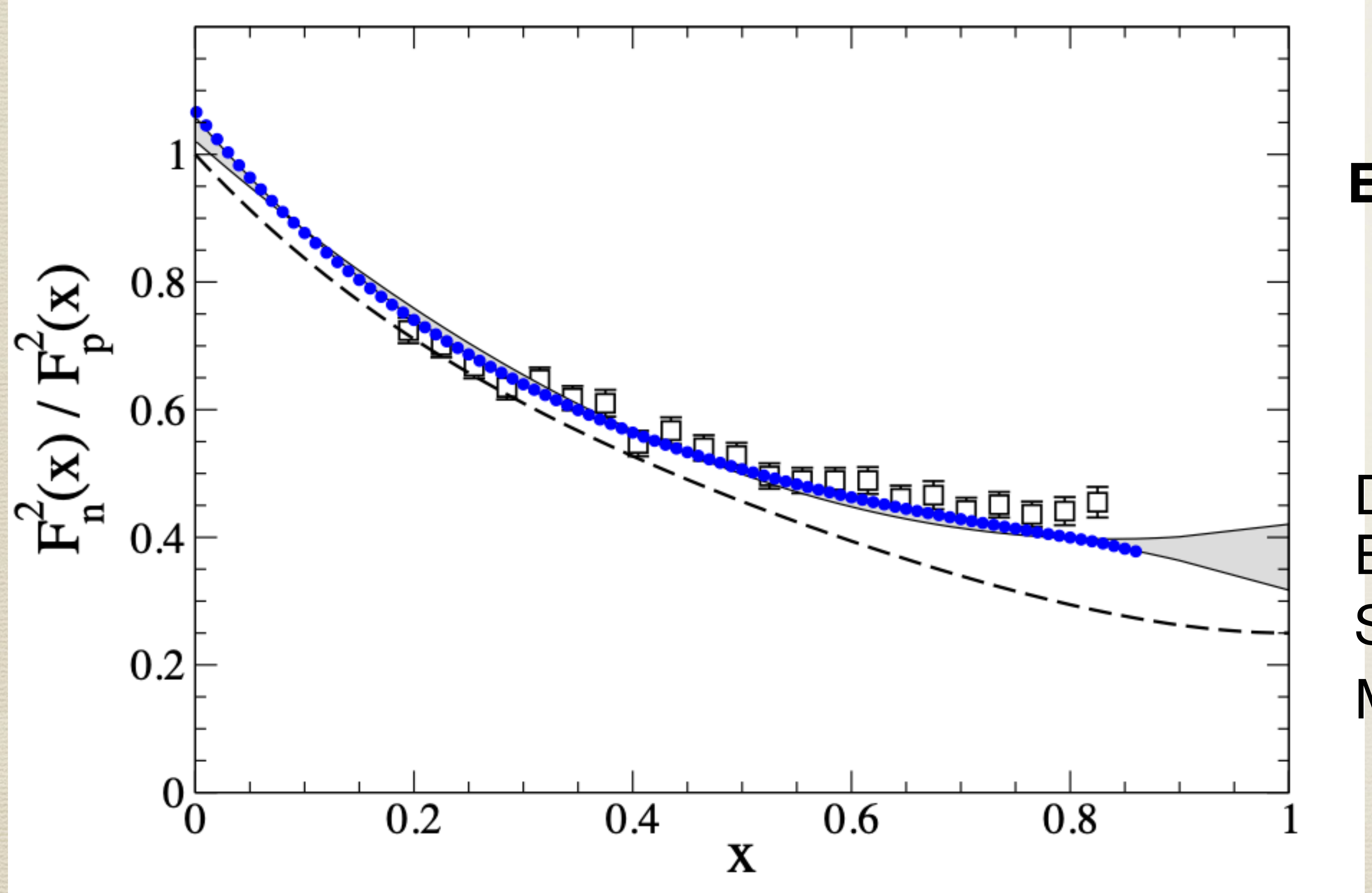
Solid line: Av18/UIX; Dashed-line: NVIb/UIX

Backup slides

MARATHON coll. : experimental data of the super-ratio $R^{ht}(x) = F_2^{^3He}(x)/F_2^{3H}(x)$

^3He: 2p + n; ^3H: n + 2p

Is possible to extract the ratio $F_2^n(x)/F_2^p(x)$ through the super-ratio



E.Pace, M.Rinaldi, G.Salmè and S.Scopetta Phys. Lett. B 839(2023) 127810

Dashed line: ratio from SMC collaboration
Empty squares: MARATHON extraction
Solid line: cubic and conic extractions from F_2^p SMC parametrization, fitted to MARATHON data

Backup slides

- In Instant form (initial hyperplane t=0), one can couple spins and orbital angular momenta via Clebsch-Gordan (CG) coefficients. In this form the three rotation generators are independent of the the interaction.
- To embed the CG machinery in the LFHD one needs unitary operators, the so-called Melosh rotations that relate the LF spin wave function and the canonical one. For a particle of spin (1/2) with LF momentum

$$\tilde{\mathbf{k}} \equiv \{k^+, \vec{k}_\perp\}$$

$$|\mathbf{k}; \frac{1}{2}, \sigma\rangle_c = \sum_{\sigma'} \underbrace{D^{1/2}_{\sigma',\sigma}(R_M(\tilde{\mathbf{k}}))}_{\text{Wigner rotation for the J=1/2 case}} |\tilde{\mathbf{k}}; \frac{1}{2}, \sigma'\rangle_{LF}$$

Wigner rotation for the J=1/2 case

- $R_M(\tilde{\mathbf{k}})$ is the Melosh rotation connecting the intrinsic LF and canonical frames, reached through different boosts from a given frame where the particle is moving

$$D^{1/2}[R_M(\tilde{\mathbf{k}})]_{\sigma'\sigma} = \chi^\dagger_{\sigma'} \frac{m + k^+ - \imath\boldsymbol{\sigma}\cdot(\hat{z}\times\mathbf{k}_\perp)}{\sqrt{(m+k^+)^2 + |\mathbf{k}_\perp|^2}} \chi_\sigma = {}_{LF}\langle\tilde{\mathbf{k}}; s\sigma'|\mathbf{k}; s\sigma\rangle_c$$

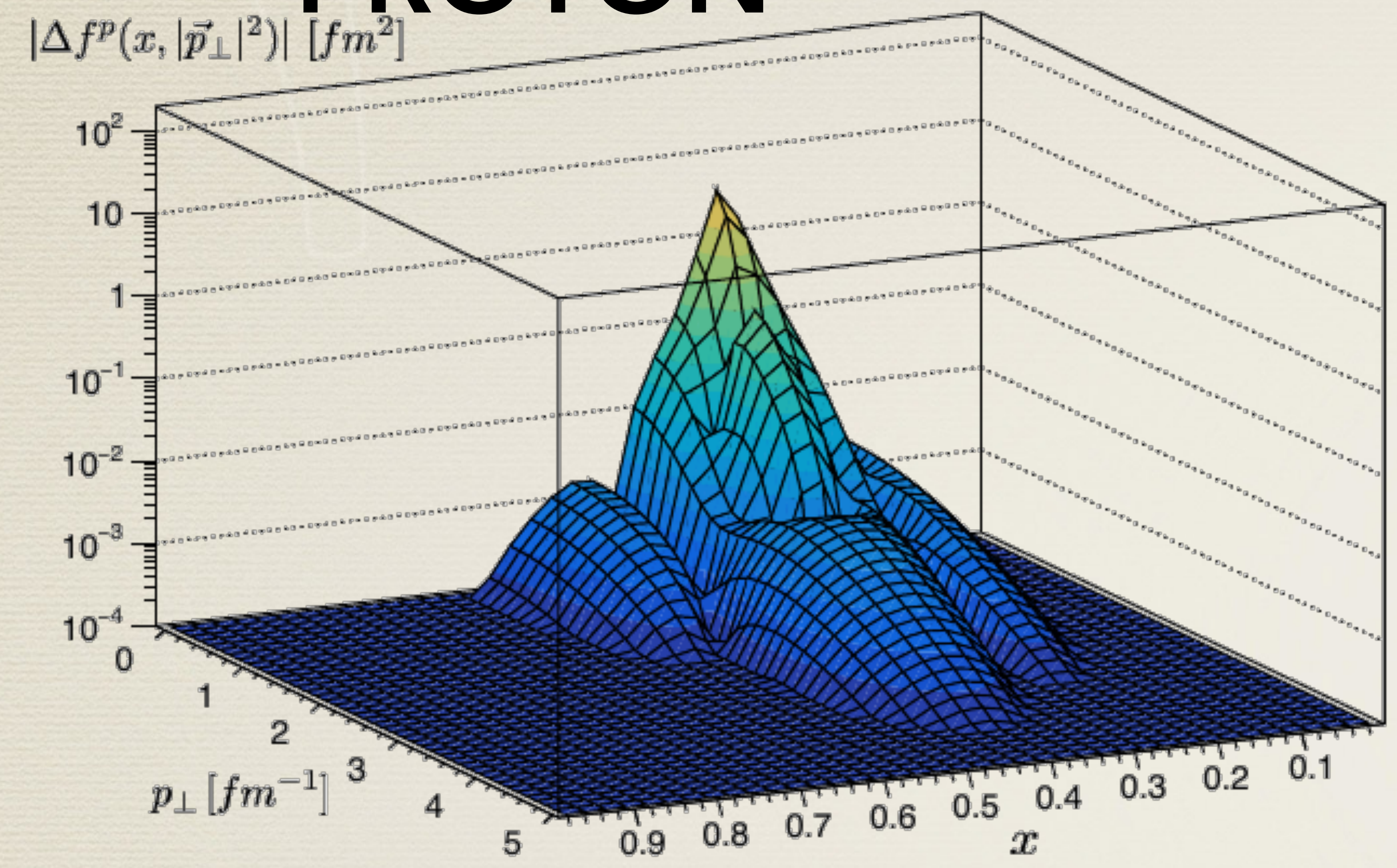
χ_σ → **two-dimensional spinor**

N.B. If $|\mathbf{k}_\perp| << k^+, m \longrightarrow D_{\sigma'\sigma} \simeq I_{\sigma'\sigma}$

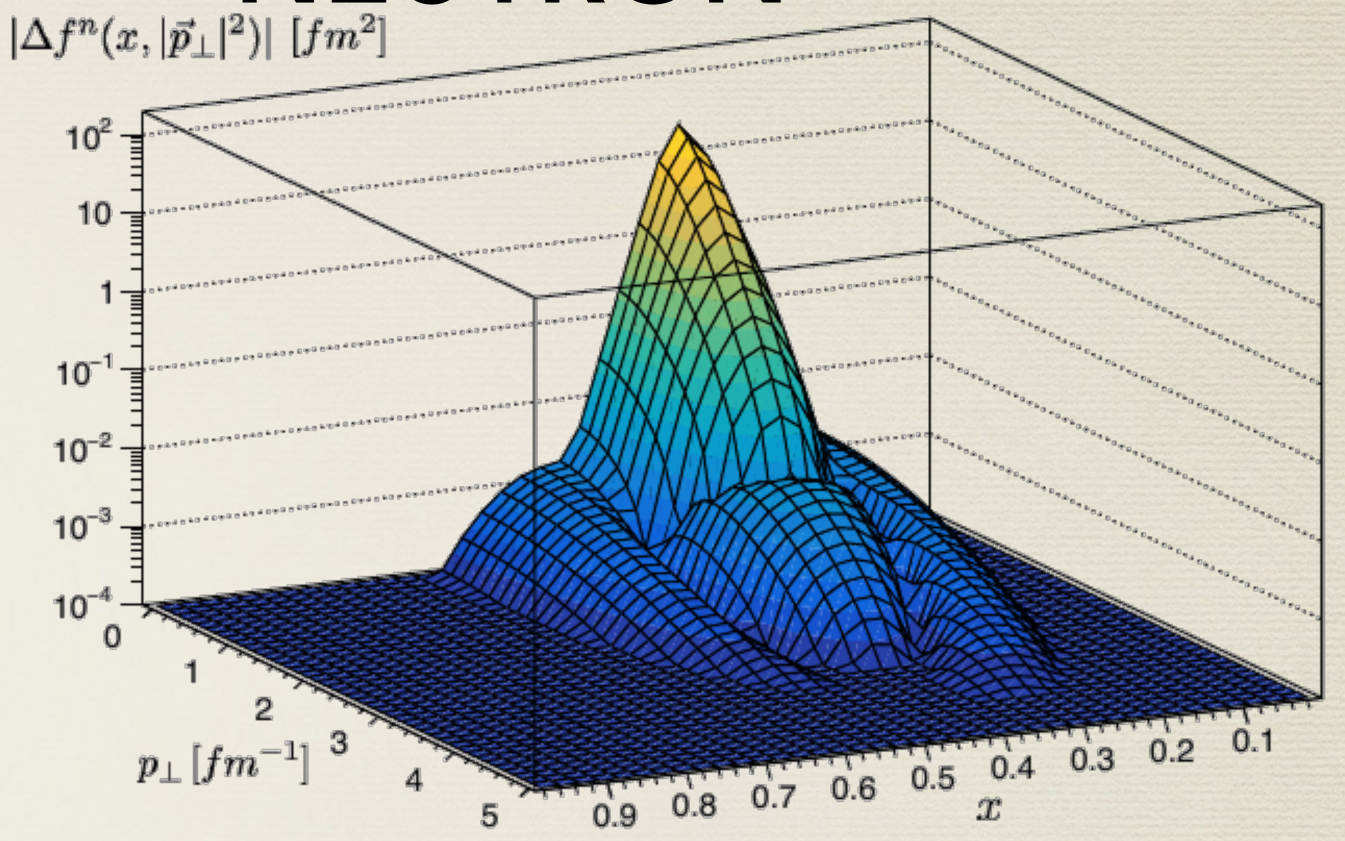
Backup slides

Numerical results A. Del Dotto, E. Pace, G. Perna, A. Rocco, G. Salmè and S. Scopetta, Phys.Rev.C 104 (2021) 6, 065204)

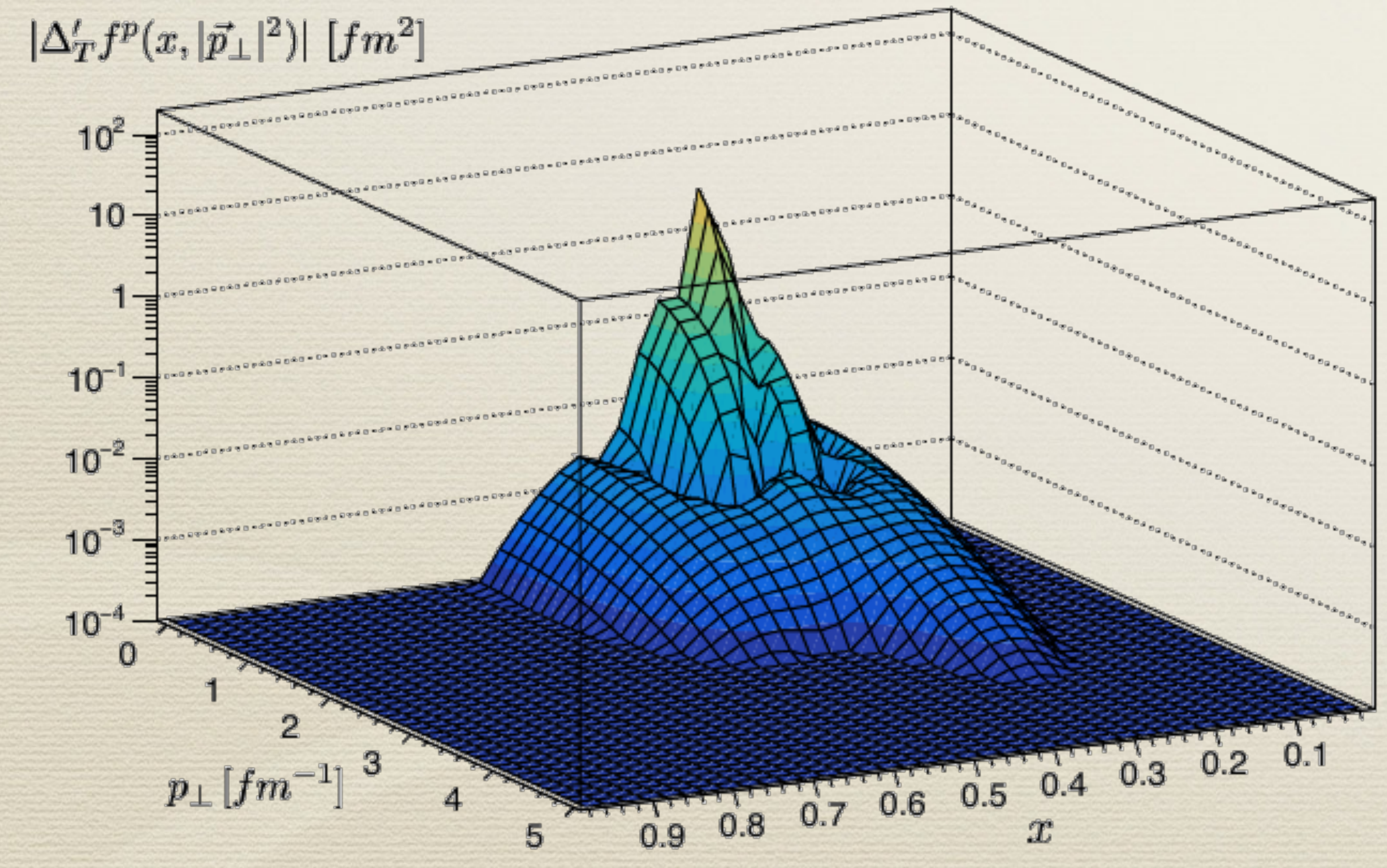
PROTON



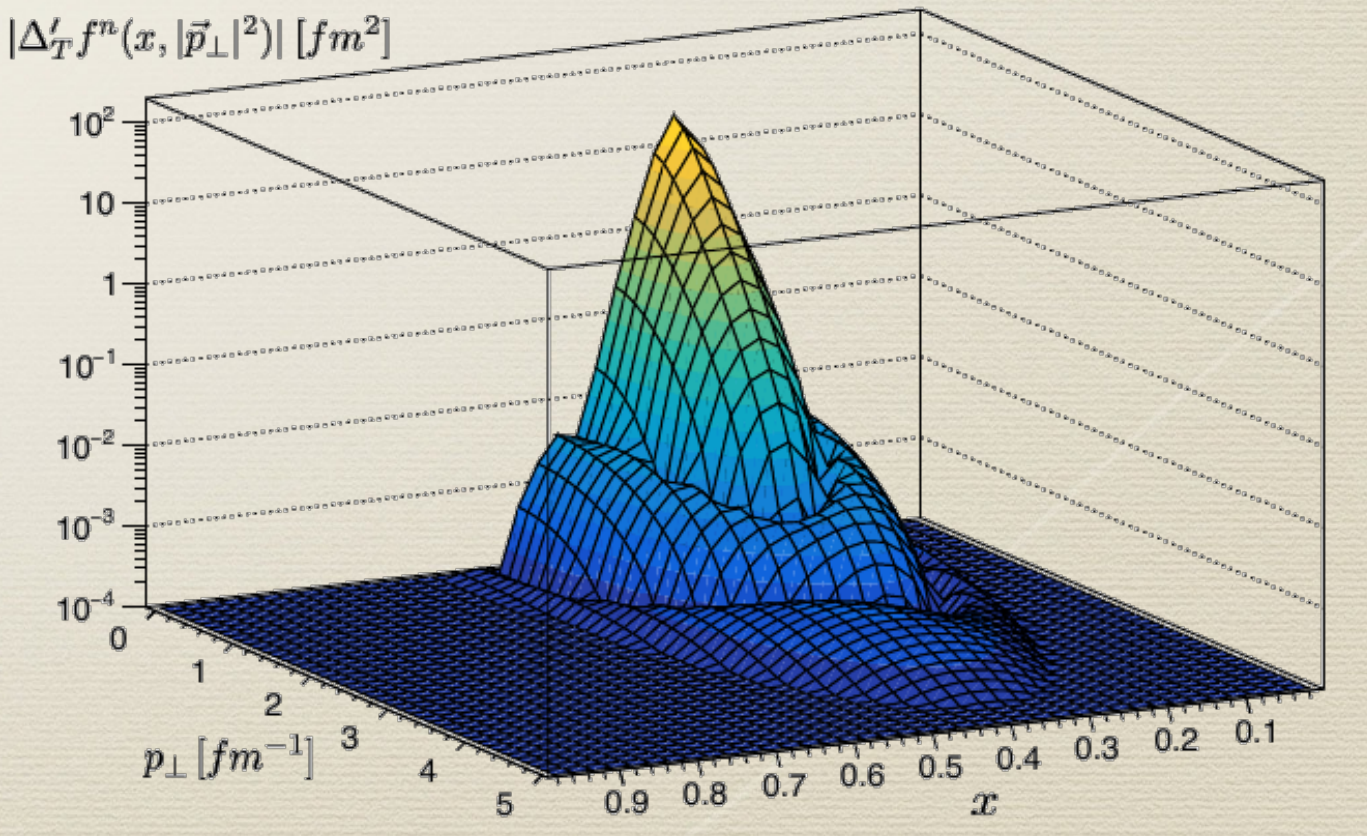
NEUTRON



$\Delta f^{\tau}(x, |\mathbf{p}_\perp|^2)$



$\Delta'_T f^{\tau}(x, |\mathbf{p}_\perp|^2)$

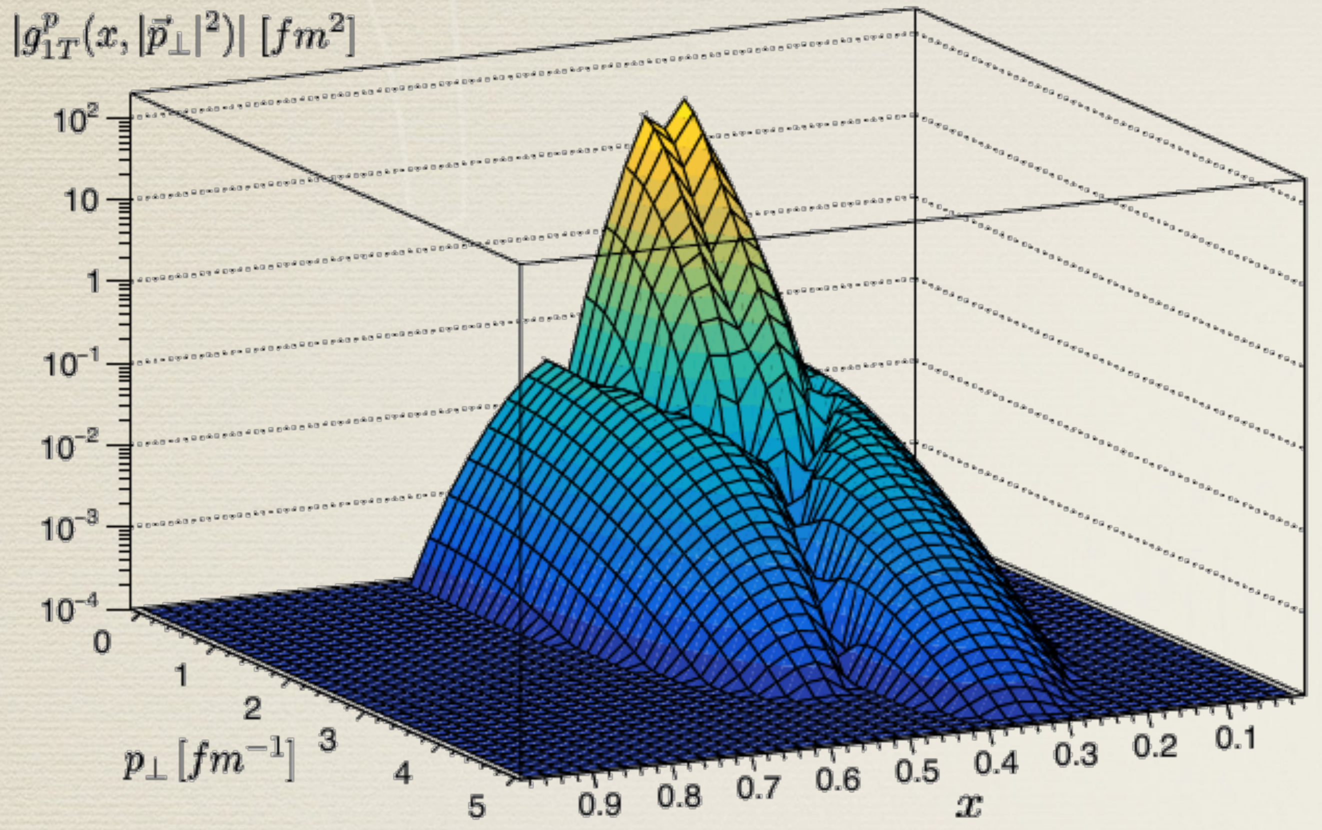


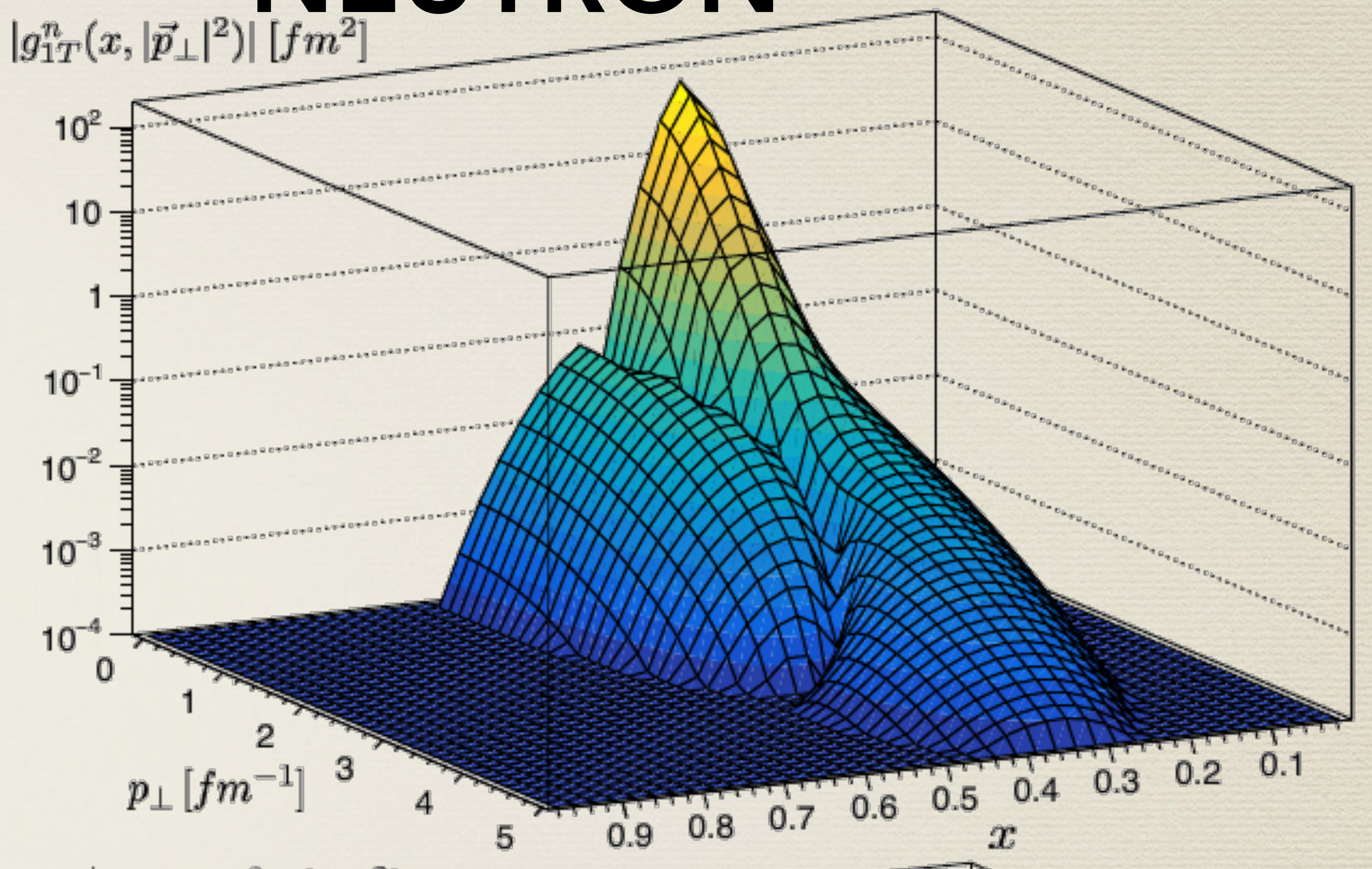
Backup slides

Numerical results A. Del Dotto, E. Pace, G. Perna, A. Rocco, G. Salmè and S. Scopetta, Phys.Rev.C 104 (2021) 6, 065204)

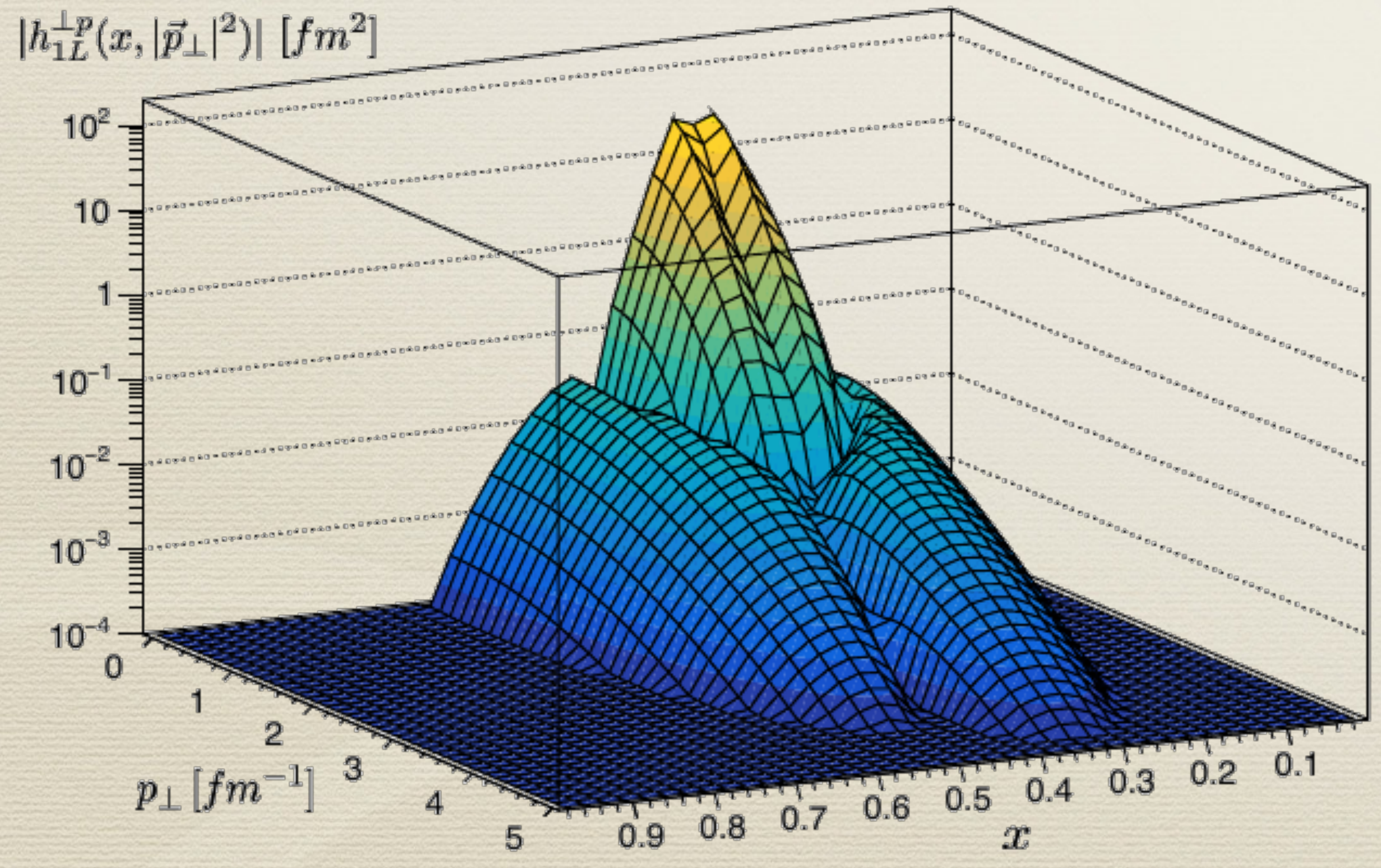
PROTON

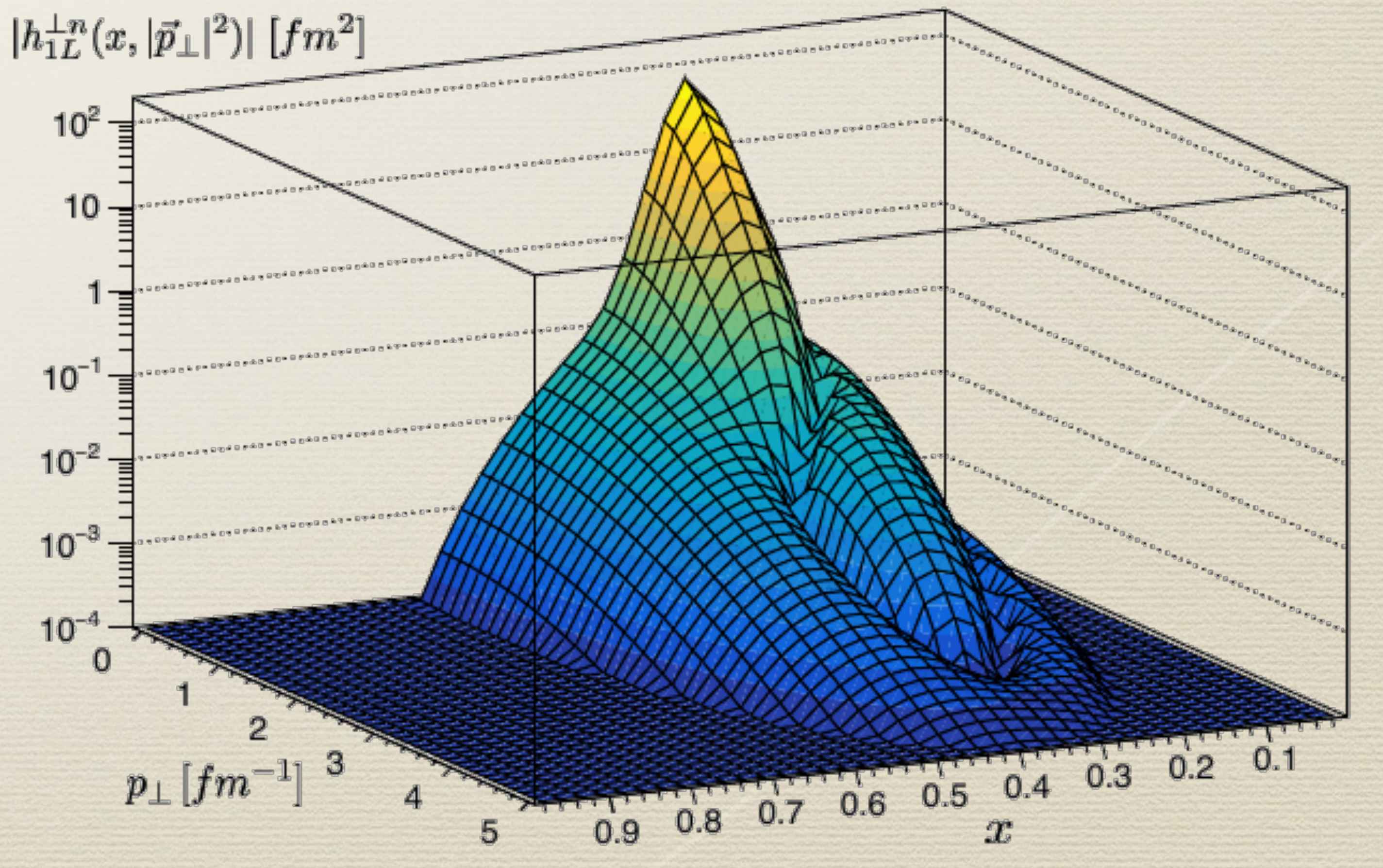
NEUTRON





Absolute value of the nucleon longitudinal-polarization distribution, $g^{\tau}_{1T}(x, |\mathbf{p}_\perp|^2)$, in a transversely polarized ^{3}He.





Absolute value of the nucleon transverse-polarization distribution, $h^{\perp\tau}_{1L}(x, |\mathbf{p}_\perp|^2)$ in a longitudinally polarized ^{3}He.

Backup slides

* E.Pace, M.Rinaldi, G.Salmè and S. Scopetta, **Phys. Scr. 95, 064008 (2020)**

$$W_A^{s,\mu\nu} = \sum_N \sum_\sigma \oint d\epsilon \int \frac{d\kappa_\perp d\kappa^+}{2(2\pi)^3\kappa^+} \frac{1}{\xi} P^N(\tilde{\kappa},\epsilon) \; w_{N,\sigma}^{s,\mu\nu}(p,q)$$

hadronic tensor of the nucleon

Unpolarized LF spectral function:

$$P^N(\tilde{\kappa},\epsilon) = \frac{1}{2j+1} \sum_{\mathcal{M}} P^N_{\sigma\sigma}(\tilde{\kappa},\epsilon,\mathbf{S},\mathcal{M})$$

$W_A^{s,\mu\nu}$ is parametrized by the SFs $F_2^A(x)$ and $F_1^A(x)$:

$$F_2^A(x) = -\frac{1}{2} x g_{\mu\nu} W_A^{s,\mu\nu} = \sum_N \sum_\sigma \int d\epsilon \int \frac{d\kappa_\perp}{(2\pi)^3} \frac{d\kappa^+}{2\kappa^+} P^N(\tilde{\kappa},\epsilon) F_2^N(z)$$

Free nucleon SF

Where $x = \dfrac{Q^2}{2P_A \cdot q}$ and $\xi = \dfrac{\kappa^+}{\mathcal{M}_0[1;2,3,\ldots,A-1]}$ with $z = \dfrac{Q^2}{2p\cdot q} = \dfrac{p}{P_A^+}\dfrac{x}{\xi}$

Backup slides

* A. Del Dotto, E.Pace, G. Salmè and S.Scopetta, **Phys. Rev. C 95,014001 (2017)**

$$F_2^A(x) = -\frac{1}{2} x g_{\mu\nu} W_A^{s,\mu\nu} = \sum_N \sum_\sigma \int d\epsilon \int \frac{d\kappa_\perp}{(2\pi)^3} \frac{d\kappa^+}{2\kappa^+} P^N(\tilde{\kappa}, \epsilon) F_2^N(z)$$

In the Bjorken limit $\int d\epsilon \int d\kappa^+ = \int d\kappa^+ \int d\epsilon$ so we can use the **light-cone momentum distribution** (LCMD) instead of the **LF spectral function** *

$$\textbf{LCMD}: f_1^N(\xi) = \sum \int d\epsilon \int \frac{d\kappa_\perp}{(2\pi)^3} \frac{1}{2\kappa^+} P^N(\tilde{\kappa}, \epsilon) \frac{E_s}{1-\xi} = \int d\mathbf{k}_\perp n^n(\xi, \mathbf{k}_\perp)$$

LF momentum distribution:

$$n^N(\xi, \mathbf{k}_\perp) = \frac{1}{2\pi} \int \prod_{i=2}^{A-1} [d\mathbf{k}_i] \; \left| \frac{\partial k_z}{\partial \xi} \right| \; \mathcal{N}^N(\mathbf{k}, \mathbf{k}_2, \ldots, \mathbf{k}_{A-1})$$

Squared nuclear wave function. **Thanks to the BT construction, one is allowed to use the NR one**

Determinant of the Jacobian matrix. **LF boost: effect of a Poincaré covariance approach**

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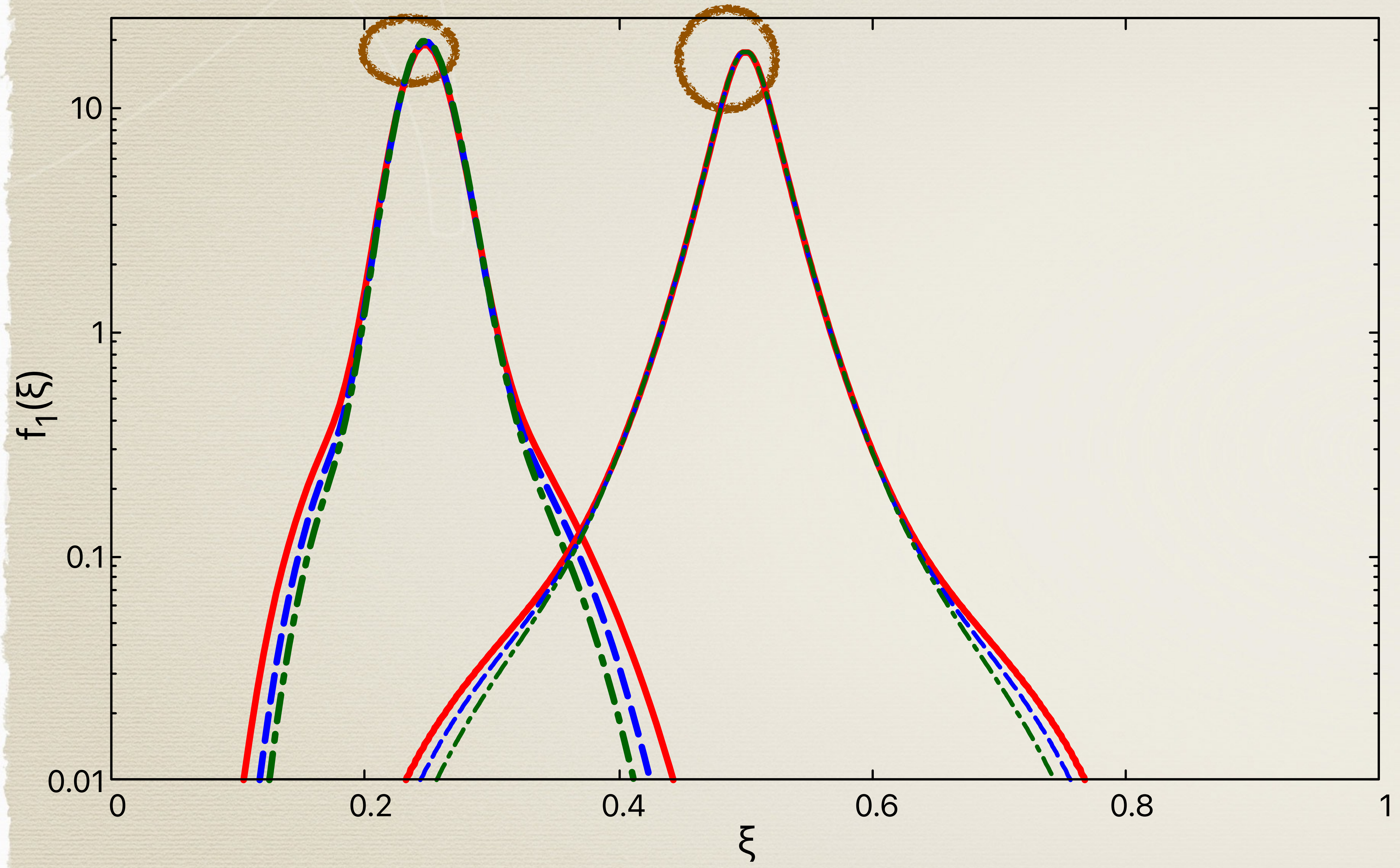
The distributions are peaked at 1/A with an accuracy of 1/1000:



- The tails of the distributions are generated by the **short range correlations (SRC)** induced by the potentials (i.e the high-momentum content of the 1-body momentum distribution)
- The tails of the LC momentum distribution calculated by the Av18/UIX potential is larger than the ones obtained by the χEFT potentials for both ^4He and deuteron

F.F, E.Pace, M.Rinaldi, G.Salmè, S.Scopetta and M.Viviani, ***Phys.Lett.B*** **851 (2024)**

LC momentum distribution for ^4He (peaked at 0.25) and deuteron (peaked at

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For the **polarized DIS** we need to calculate the **antysimmetric** part of the **hadronic tensor**:

$$W_A^{a,\mu\nu} = \sum_N \sum_\sigma \oint d\epsilon \int \frac{d\kappa d\kappa^+}{2(2\pi)^3\kappa^+} \frac{1}{\xi} P_\sigma^N(\tilde{\kappa}, \epsilon, \mathbf{S}, \mathcal{M}) \; w_{N,\sigma}^{a,\mu\nu}(p,q)$$

hadronic tensor of the nucleon

Spin-dependent LF spectral function

$W_A^{a,\mu\nu}$ is parametrized by the the **spin-dependent SFs (SSFs)** $g_1^A(x,Q^2)$ and $g_2^A(x,Q^2)$

As for the unpolarized case, in the **Bjorken limit** we can write a **convolution formula** for the **SSFs**:

$$g_j^A(x) = \sum_N \int_{\xi_m}^1 d\xi \left[g_1^N(z) l_j^N(\xi) + g_2^N(z) h_j^N(\xi) \right], j = 1{,}2$$

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$$g_j^A(x) = \sum_N \int_{\xi_m}^1 d\xi \left[g_1^N(z) l_j^N(\xi) + g_2^N(z) h_j^N(\xi) \right], j = 1,2$$

The spin-dependent **LCMD** $l_j^N(\xi)$ and $h_j^N(\xi)$ are related to the **transverse momentum-**

We used the **TMDs** for ^3He calculated with the **Av18** potential in Ref. **[1]**

GRSV parametrization [2] for the $g_1^N(x)$ SSF

$g_2^N(x)$ extracted by $g_1^N(x)$ with the **Wandzura-Wilczek** formula [3]:

$$g_2^N(x) = - g_1^N(x) + \int_x^1 dy \frac{g_1^N(y)}{y}$$

[1] R.Alessandro, A.Del Dotto, E.Pace, G.Perna, G.Salmè and S.Scopetta, **Phys.Rev.C 104(2021) 6,065204**

[2] M. Glück, E. Reya, M. Stratmann, and W. Vogelsang, **Phys. Rev. D 63, 094005 (2001)**

[3] S. Wandzura and F. Wilczek, **Phys. Lett. B 72, 195 (1977)**

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$$g_j^A(x) = \sum_N \int_{\xi_m}^1 d\xi \left[g_1^N(z) l_j^N(\xi) + g_2^N(z) h_j^N(\xi)\right]$$

One can **approximate** this equation using that $l_j^N(\xi), h_j^N(\xi)$ are **peaked** around $\xi \simeq 1/A$ and so

$$g_j^{\bar{n}}(x) = \frac{1}{p_j^n}\left[g_j^{^3He}(x) - 2p_j^p g_j^p(x)\right]$$

Where the **effective polarization** p_j^N are **integral** of the **TMDs** $\Delta f(\xi, k_\perp)$ **and** $\Delta_T' f(\xi, k_\perp)$*

$$p_1^N = \int_0^1 d\xi \int d\mathbf{k}_\perp \Delta f(\xi, k_\perp) \text{ and } p_2^N = \int_0^1 d\xi \int d\mathbf{k}_\perp \Delta_T' f(\xi, k_\perp)$$

We compared our extraction of the **neutron SSFS** with the one of the **GRSV parametrization** and with the **NR extraction**, obtained through the effective polarizations calculated from a NR