Proposal for searching SRC in BESIII

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第一届中国电子离子对撞机相关物理年会

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Outline

- Introduction on short-range correlations (SRC)
- Searching SRC by photoproduction of ϕ in BESIII
- Searching SRC by πN scattering in BESIII
- Summary

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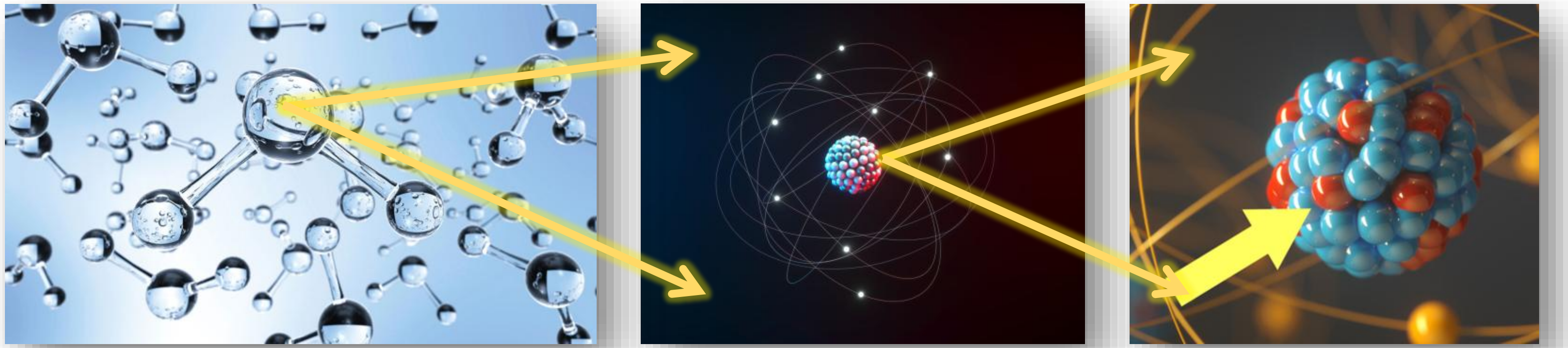
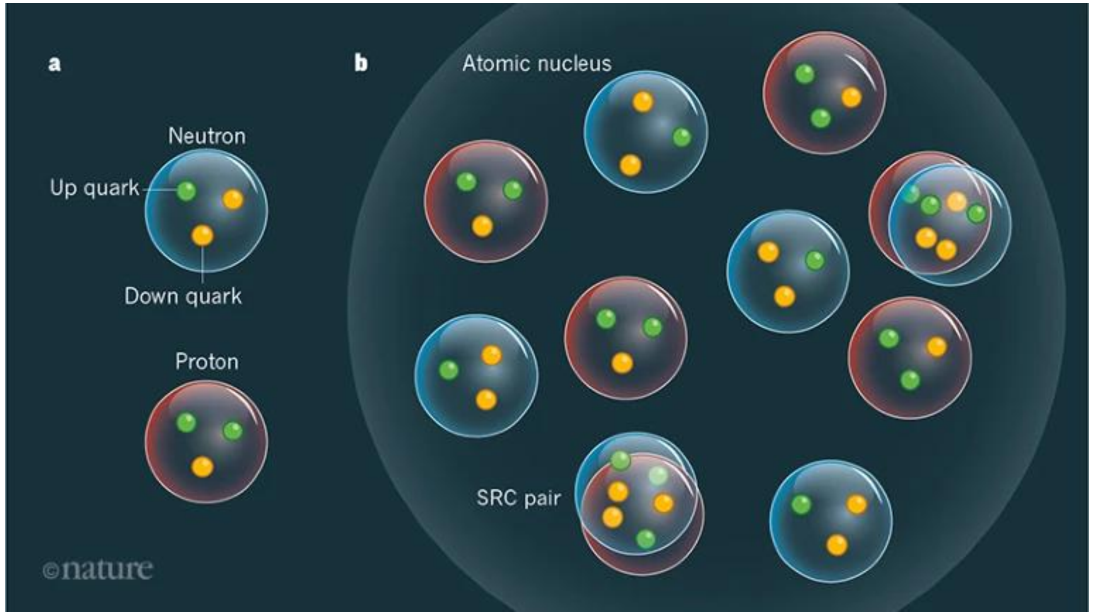
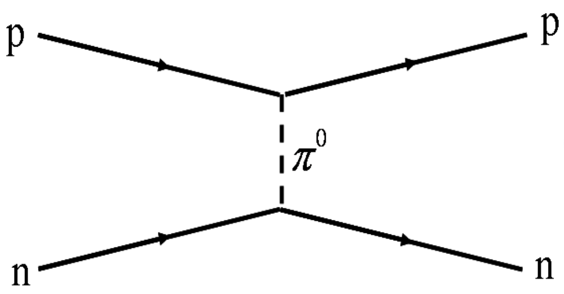
Introduction on SRC

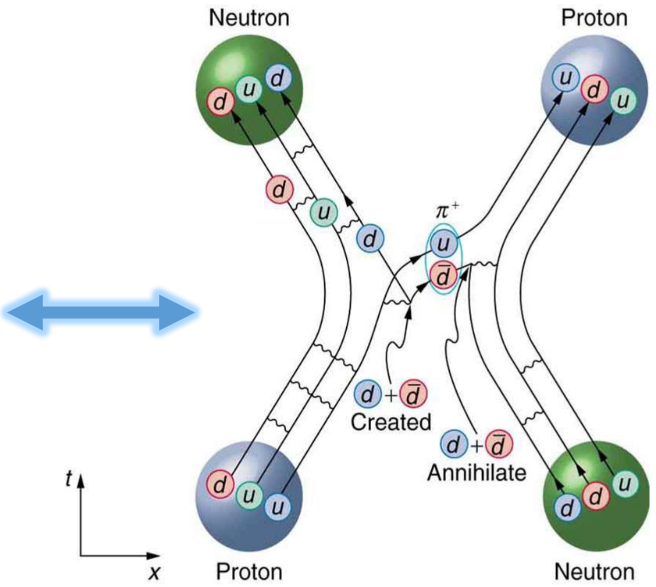
- The structure of the atomic nucleus is complex.



- The 2N-SRC pair.







Introduction on SRC

- The 2N-SRC is defined operationally in experiments as having small center-of-mass momentum and large relative momentum.

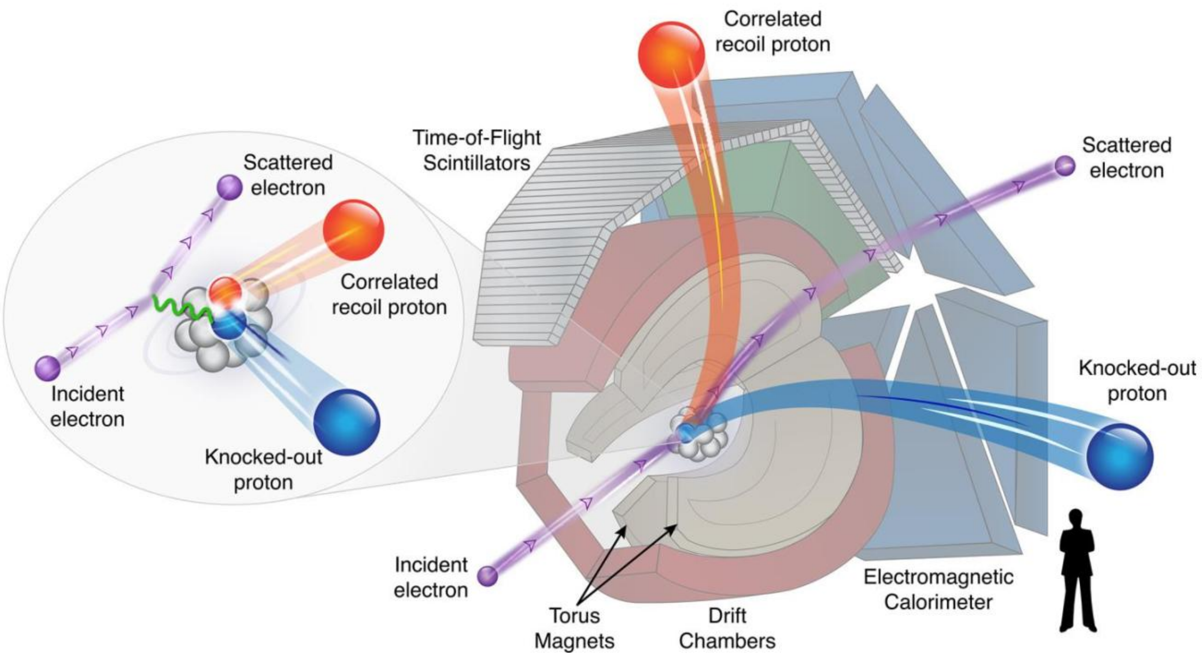


Illustration of a reconstructed two-proton knockout event.

[CLAS, Science 346 (2014)]
[CLAS, Nature 578 (2020)]
[CLAS, PRL 90 (2003)]

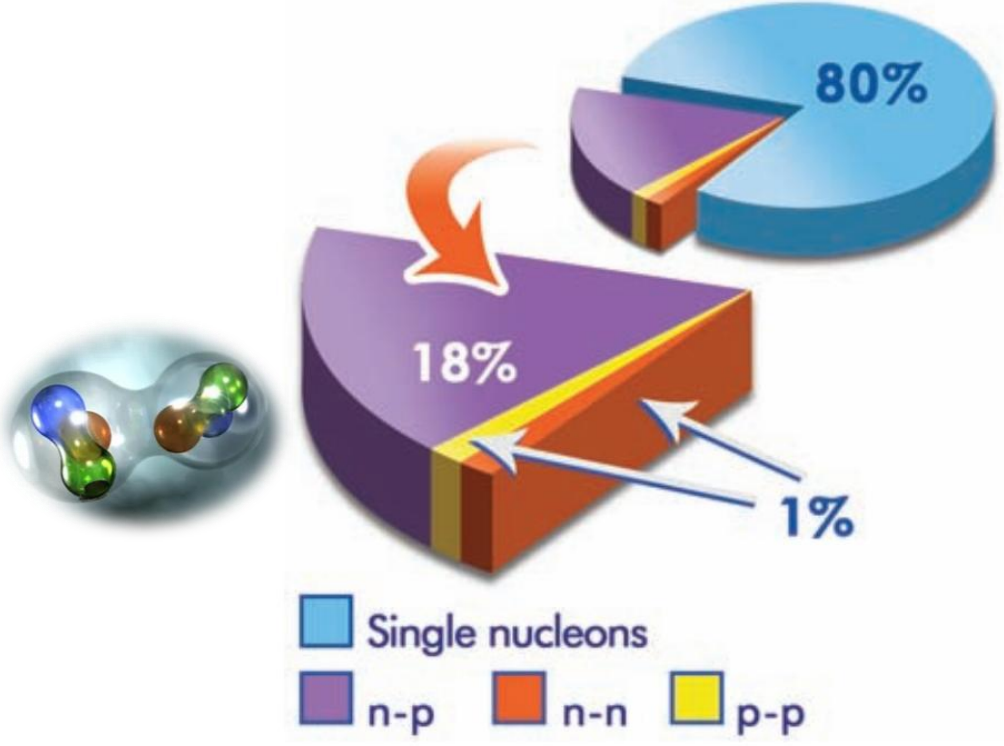
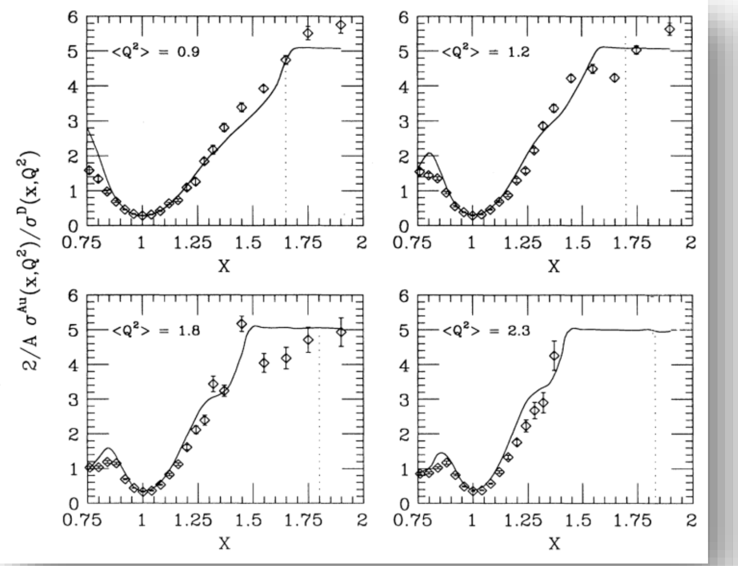


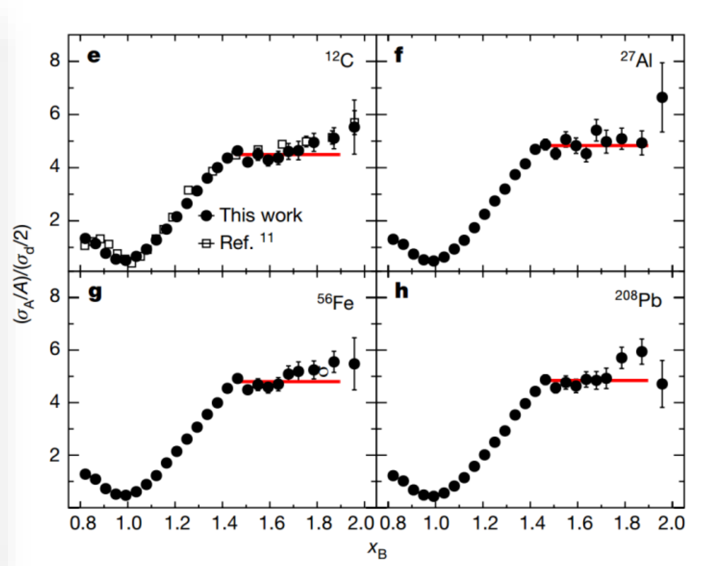
Fig. 3. The average fraction of nucleons in the various initial-state configurations of ^{12}C.

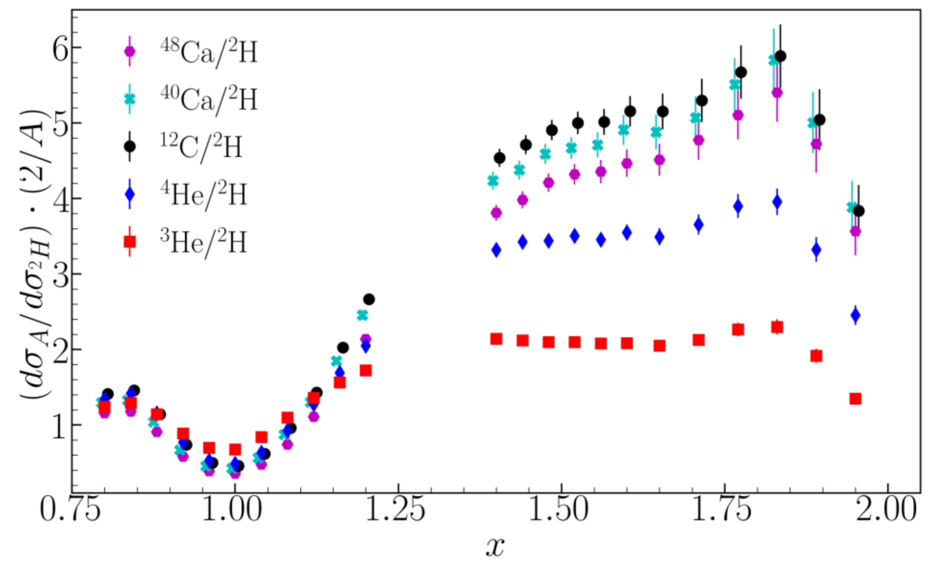
[CLAS, Science 320 (2008)]

Introduction on SRC

- The structure of SRCs is largely independent of the surrounding nuclear environment.
- In the region $Q^2 \sim 2-4\ \mathrm{GeV}^2$ and $x_p \geq 1.45-1.9,\ x_p = \frac{Q^2}{2p.q}$.







[Frankfurt et.al, PRC 48 (1993)]

[N.Fomin et.al, PRL 108 (2012)]

[CLAS, Nature 566 (2019)]

[S.Li et.al, Nature 609 (2022)]

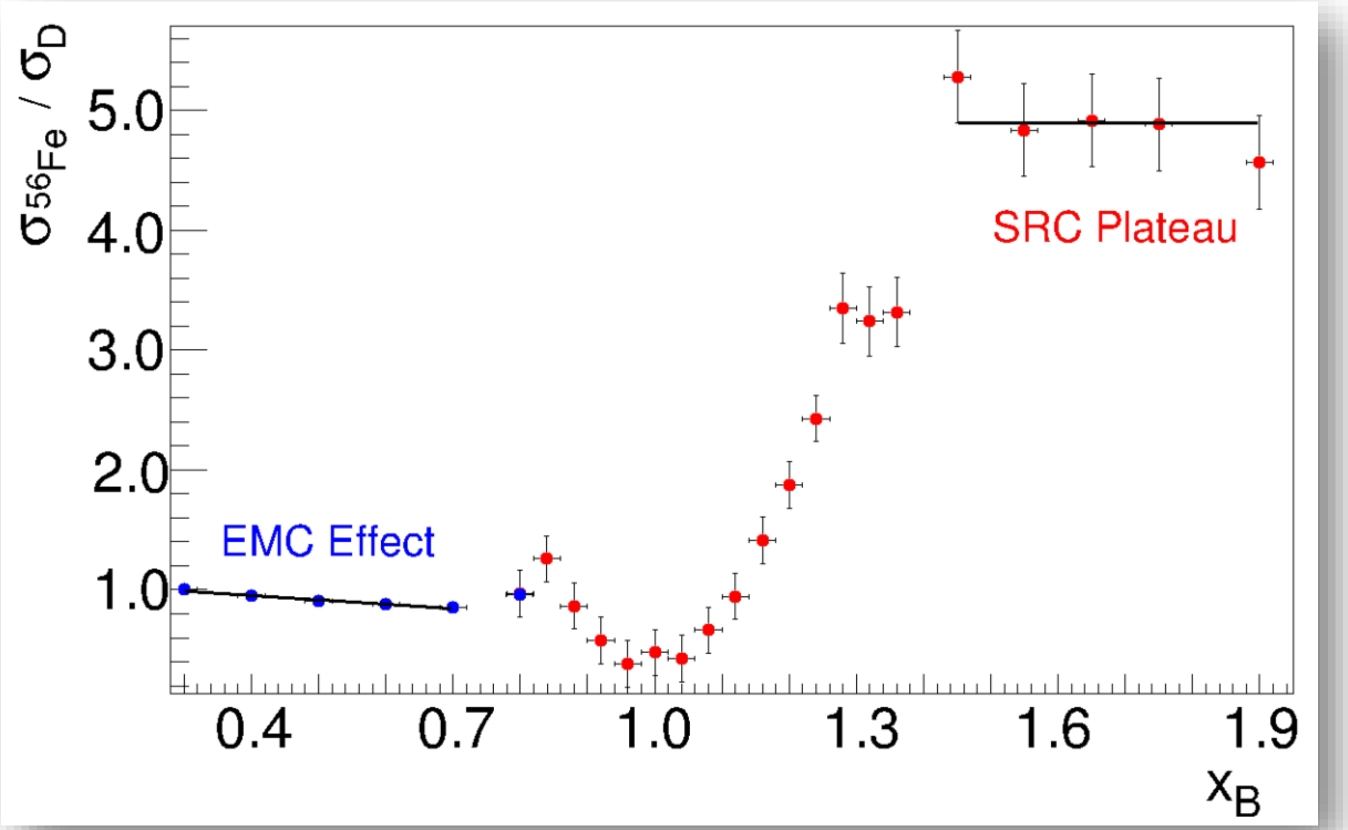
[Y.P.Zhang, Z.H.Ye et.al, PLB 872 (2026)]

[CLAS, PRL 96 (2006)]

Observation of a plateau in the cross-section ratio

The linear relation between EMC and SRC

➢ If we combine the EMC and SRC when considering the partonic structure of nucleon.

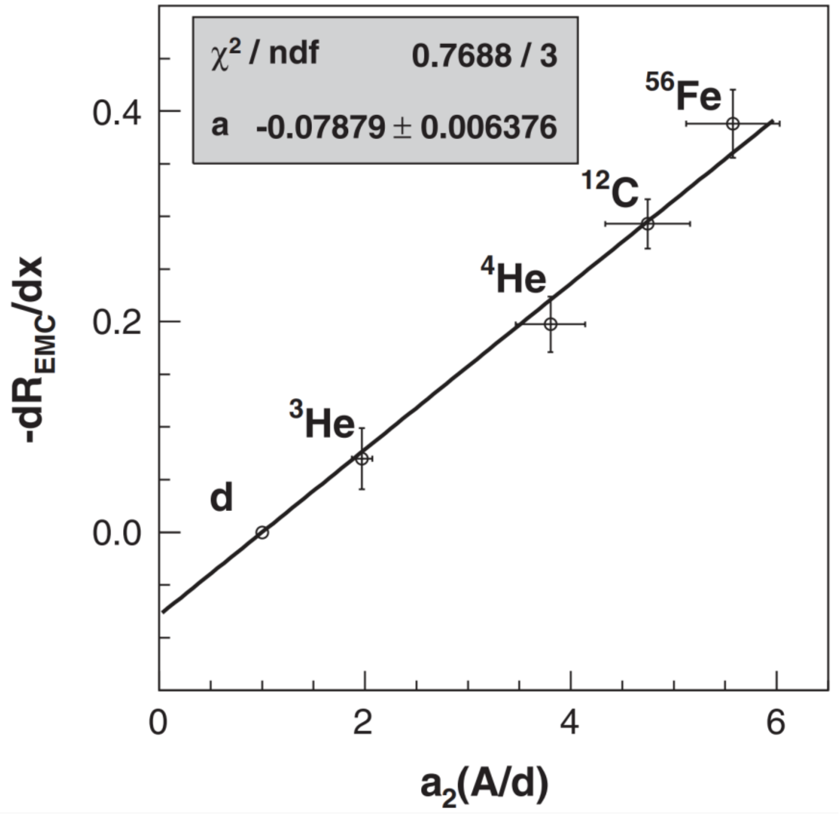


EMC effect: slope of the ratio dR_{EMC}/dx $(0.35 \leq x_p \leq 0.7)$.

SRC scale factor: ratio in the plateau region $a_2(A/d) = \frac{2}{A}[\sigma_A/\sigma_d]$ $(1.5 \leq x_p \leq 2.0)$.

The linear relation between EMC and SRC

- **Here comes the important observation.**



[Weinstein et.al, PRL 106 (2011)]

The linear relation between EMC and SRC

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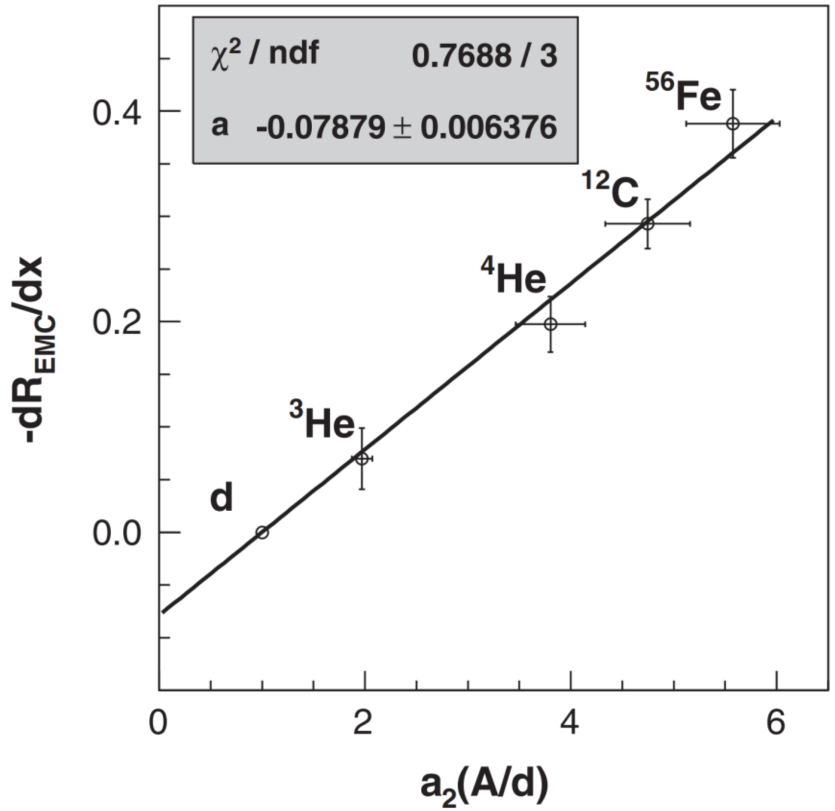
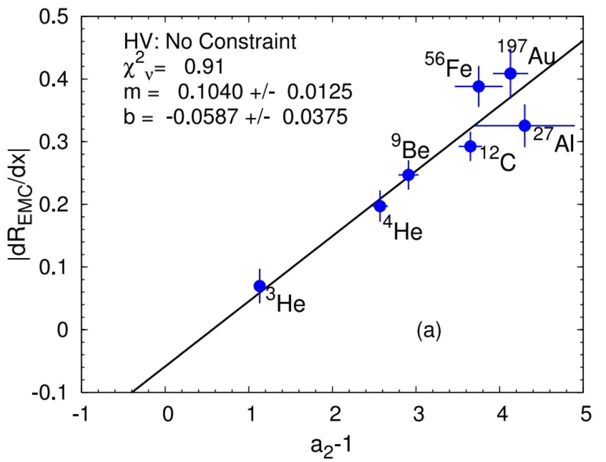
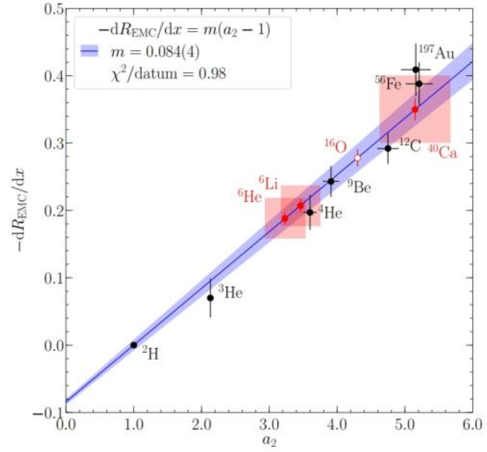


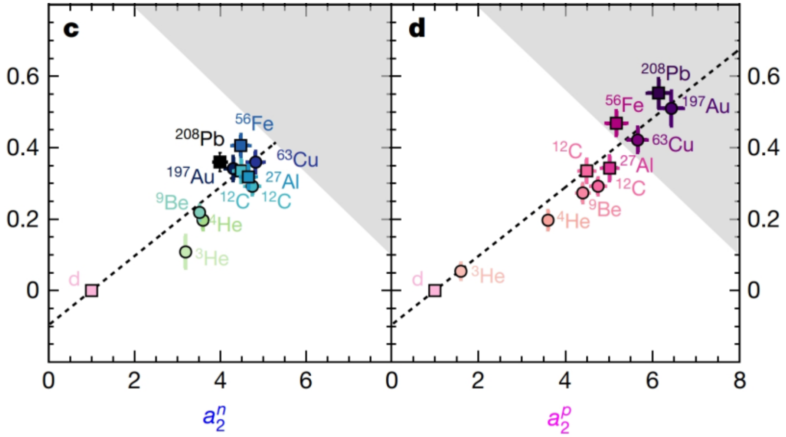
[Weinstein et.al, PRL 106 (2011)]



[Arrington et.al, PRC 86 (2012)]



[Lynn et.al, JPG 47 (2020)]

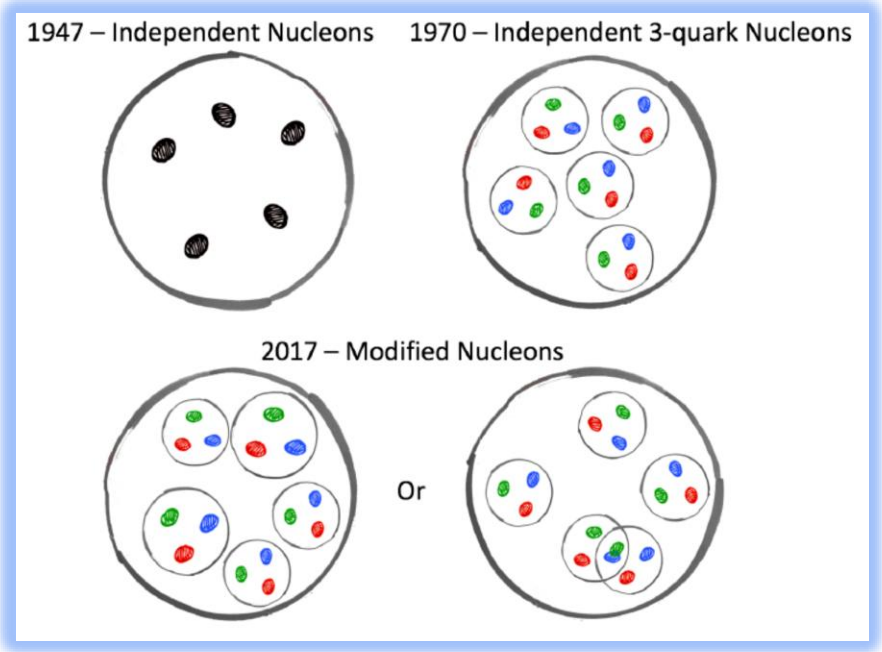


[CLAS, Nature 566 (2019)]

EMC and SRC are strongly linearly correlated

Introduction on SRC

- Progress in Quark Nuclear Physics:



[Or Hen et.al., Rev. Mod. Phys. 89 (2017)]

- The structure of bound nucleon is different from the free one.

$$F_2^A \neq Z \cdot F_2^p + N \cdot F_2^n$$

- If we only modify the PDFs of nucleons in SRCs.

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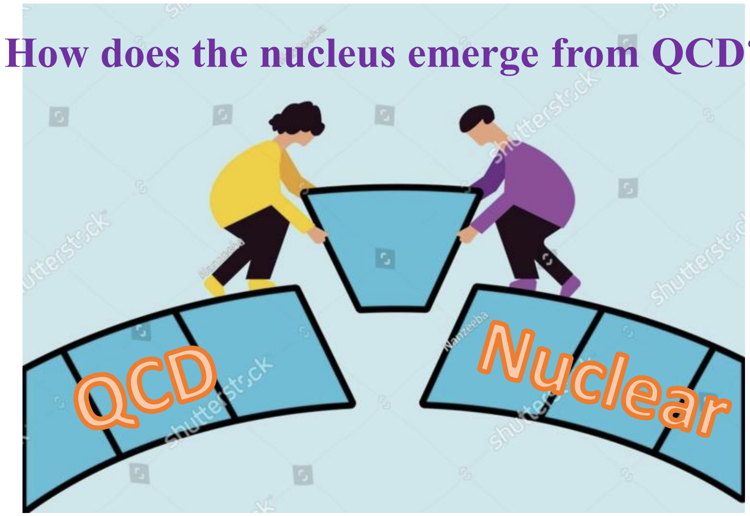
$$f_i^A(x,Q) = \frac{Z}{A}[(1-C_p^A)\times f_i^p(x,Q) + C_p^A \times f_i^{\mathrm{SRC}p}(x,Q)] + \frac{N}{A}[(1-C_n^A)\times f_i^n(x,Q) + C_n^A \times f_i^{\mathrm{SRC}n}(x,Q)].$$

[Denniston et.al., PRL 133 (2024)]



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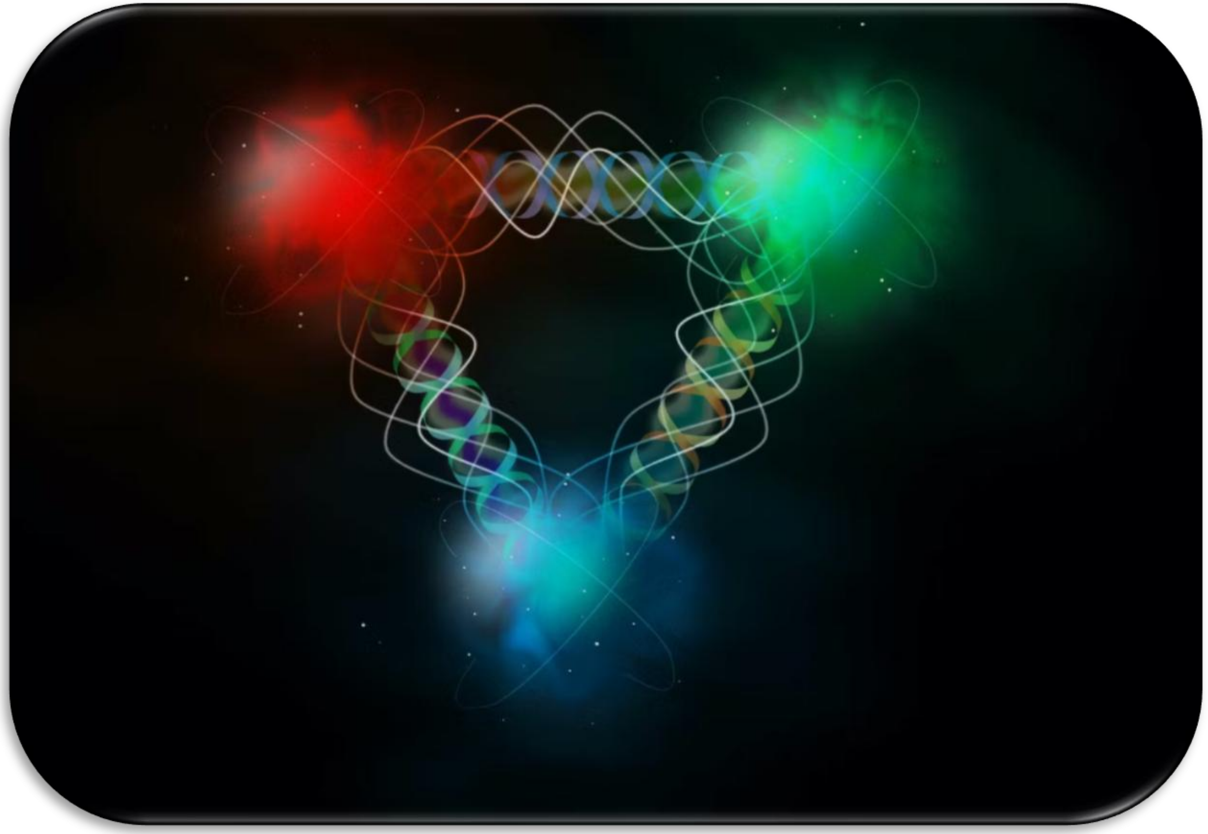
The gluons in nucleon

- The existing studies on the relation between EMC and SRC are mainly limited to the quark sector.

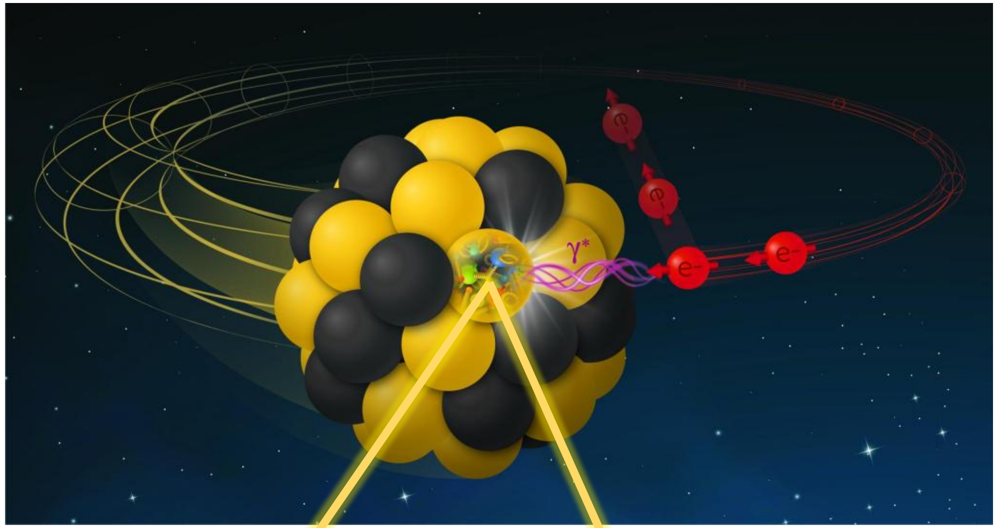


A proton is made up of three quarks tightly held together by the strong force.

How about the gluons?

EMC effect of gluons ?

- **Constraining the gluon nPDF** through the production cross section of heavy quark pair.



[Aschenauer et.al, PRD 96 (2017)]

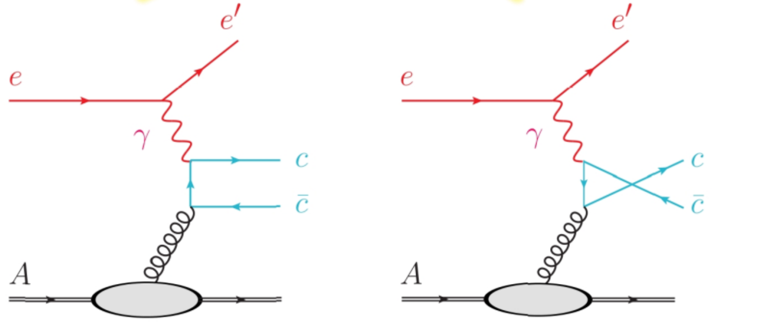


FIG. 1: Photoproduction of the heavy quark pair $c\bar{c}$ through photon-gluon fusion at leading order.

- The sub-threshold photoproduction of J/ψ.
- Assumed to be sensitive to the gluons bound in SRC.
- **For a free nucleon target,** the threshold photon energy to generate a J/ψ is $E_\gamma \sim 8.2$ GeV.
- **If the nucleon is bound in nucleus,** the production of J/ψ can occur at lower photon energy.

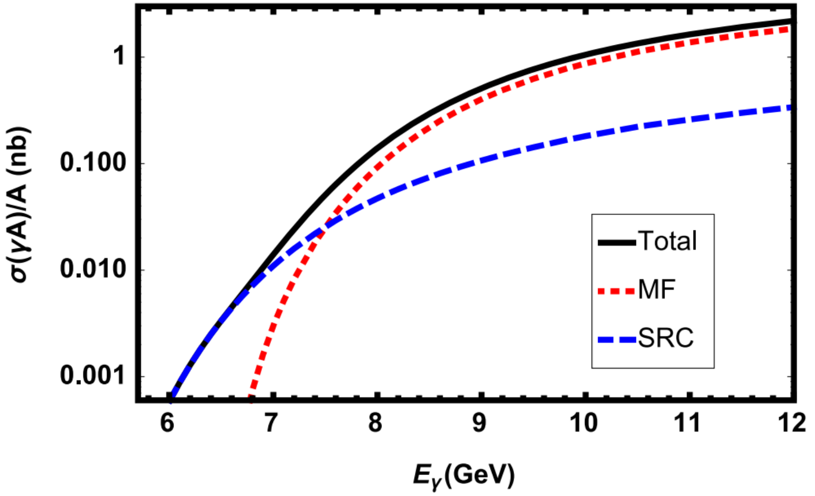


Fig. 3. Sub-threshold J/ψ production in photon-Carbon collisions as a function of incoming photon energy E_γ. We have estimated $P_{MF} = 0.84$ for the mean field normalization in Eq. (12).

[Hatta, Strikman, **J.X,** F.Yuan, PLB 803 (2020)]

Linear gluon EMC-SRC relation

- Utilizing chiral effective field theory analysis. [J.W.Chen et.al, PRL, 119 (2017)]

- A linear relation between the **magnitude of the gluon EMC effect** and the **sub-threshold J/ψ production cross section.**

- The Mellin moments of gluon nPDF

$$\langle A; p|\mathcal{O}_g^{\mu_0\cdots\mu_n}|A; p\rangle = \langle x_g^n\rangle_A(Q^2)p^{(\mu_0}\cdots p^{\mu_n)}\,.$$

$$\mathcal{O}_g^{\mu_0\cdots\mu_n} \rightarrow: \langle x_g^n\rangle_N M^n v^{(\mu_0}\cdots v^{\mu_n)} N^\dagger N\left(1+\delta_n N^\dagger N\right) + \ldots :$$

$$\langle x_g^n\rangle_A = A\langle x_g^n\rangle_N + \langle x_g^n\rangle_N \delta_n(\Lambda, Q^2)\langle A|:(N^\dagger N)^2:|A\rangle\,.$$

Linear gluon EMC-SRC relation

- The gluon nPDF can be divided

$$g_A(x,Q^2)/A \simeq g(x,Q^2) + g_2(A,\Lambda)\,\tilde{f}_g(x,Q^2,\Lambda)\,.$$

- Linear relation between $\left|dR_A^{c\bar{c}}/dx\right|$ and $g_2(A,\Lambda)$

$$\left|\frac{dR_A^{c\bar{c}}(x,Q^2)}{dx}\right| = C(x,Q^2)\,g_2(A,\Lambda)\,,$$

with $C\left(x,Q^2\right) = |d(\tilde{\sigma}(x,Q^2,\Lambda)/\sigma_{N,red}^{c\bar{c}}(x,Q^2))/dx|$.

Linear gluon EMC-SRC relation

- The ratio of $g_2(A,\Lambda)$ for different nuclei

$$\frac{g_2(A,\Lambda)}{g_2(A',\Lambda)} \simeq \left.\frac{\sigma_A^{sub}/A}{\sigma_{A'}^{sub}/A'}\right|_{E_\gamma\sim 7\,\mathrm{GeV}} .$$

- A non-trivial prediction from chiral EFT on gluon nPDF

$$\left|\frac{dR_A^{c\bar{c}}(x,Q^2)}{dx}\right| = \frac{C(x,Q^2)g_2(d,\Lambda)}{(\sigma_d^{sub}/2)}\left.(\sigma_A^{sub}/A)\right|_{E_\gamma\sim 7\,\mathrm{GeV}} .$$

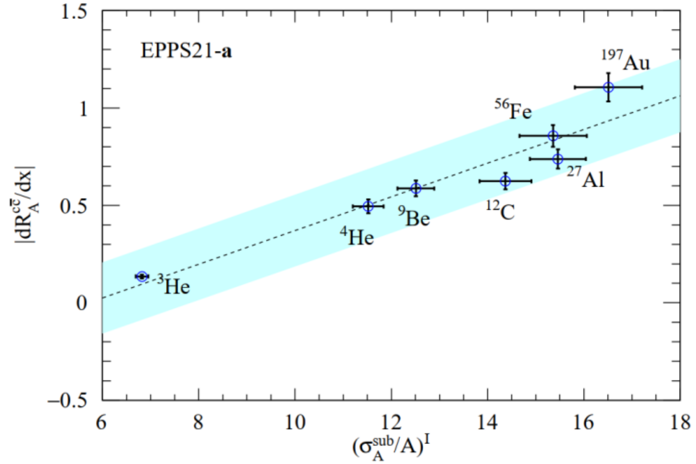
- One can examine the linear relation from the future experimental data.

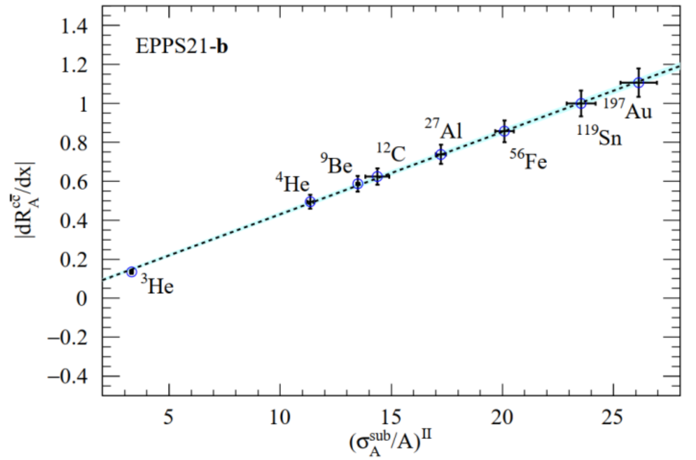
Gives a non-trivial prediction on gluon structure

Linear gluon EMC-SRC relation

➢ Utilize the global fits of nPDFs by EPPS21.

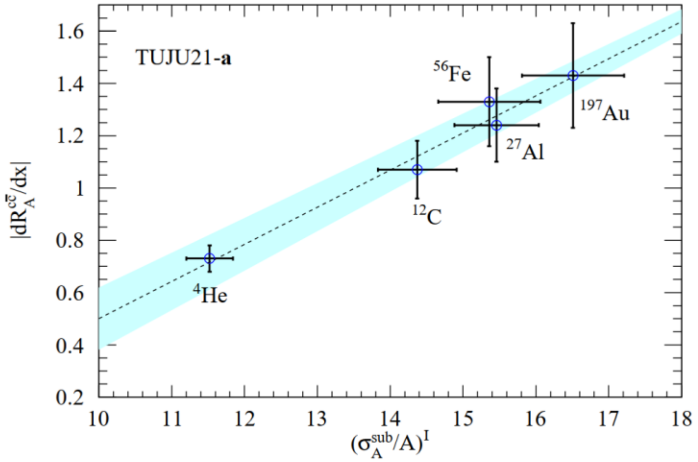
[EPPS21, EPJC 82 (2022)]

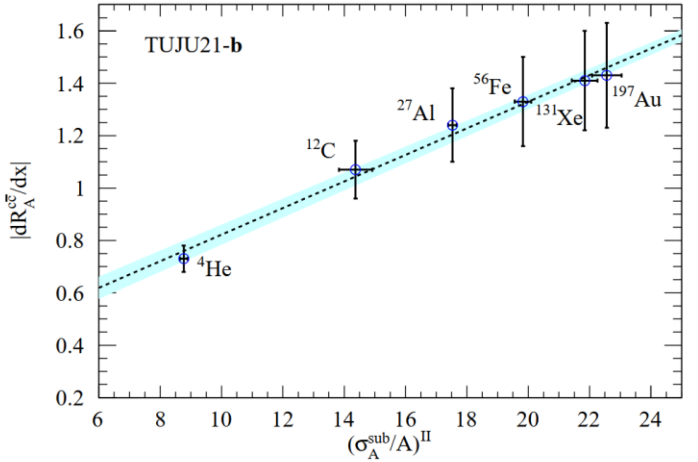




➢ Utilize the global fits of nPDFs by TUJU21.

[TUJU21, PRD 105 (2022)]





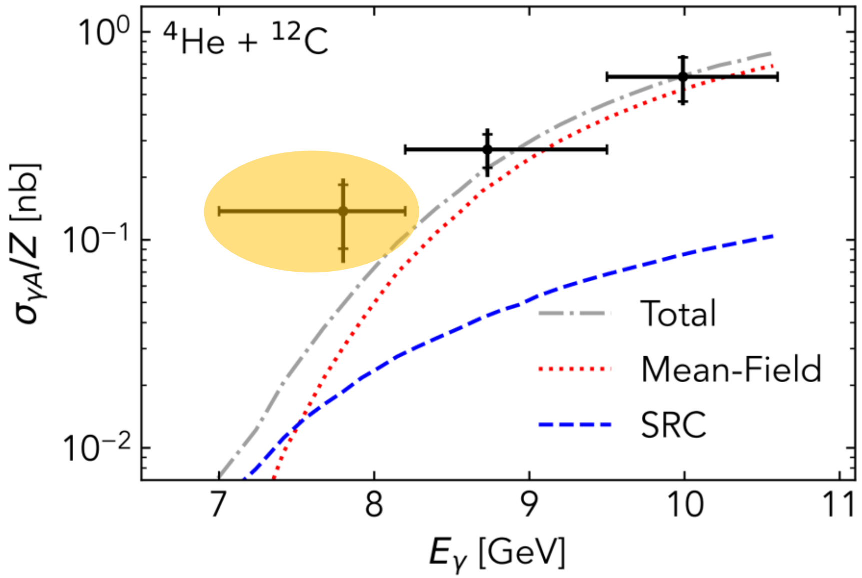
[W.Wang, **J.X,** X.H.Yang, S.Zhao, EPJA 61 (2025)]

Crucial to test this linear relation by future experimental data

The jury is till out

➢ **The cross section of sub-threshold production of J/ψ**

- Difficulties:
  - The cross section is pretty small, predicted from **0.003 ~ 1nb.**
  - Lack of experimental data.
    - Early attempts at $E_\gamma \sim 5.7$ GeV from a carbon target at Jefferson Laboratory did not yield any observed events. [Bosted et.al, PRC 79 (2009)]
    - Recent experiment reports on the first measurement below the energy threshold 8.2 GeV.



[Pybus et.al, PRL 134 (2025)]

How about sub-threshold photoproduction of ϕ ?

- Advantages:
  - As a pure $s\bar{s}$ state, ϕ is an excellent candidate with its narrow width of 4.3 MeV.
  - There have been measurements on near-threshold production (LEPS and CLAS Collaborations).
  - The cross section is relatively much larger, from **10 ~ 300 nb.**
  - The e^+e^- collision experiment such as **BESIII** and **STCF** might be suitable for this measurement.

[C.Z.Yuan et.al, PRL 127 (2021)] [H.B.Li et.al, CPC 48 (2024)]

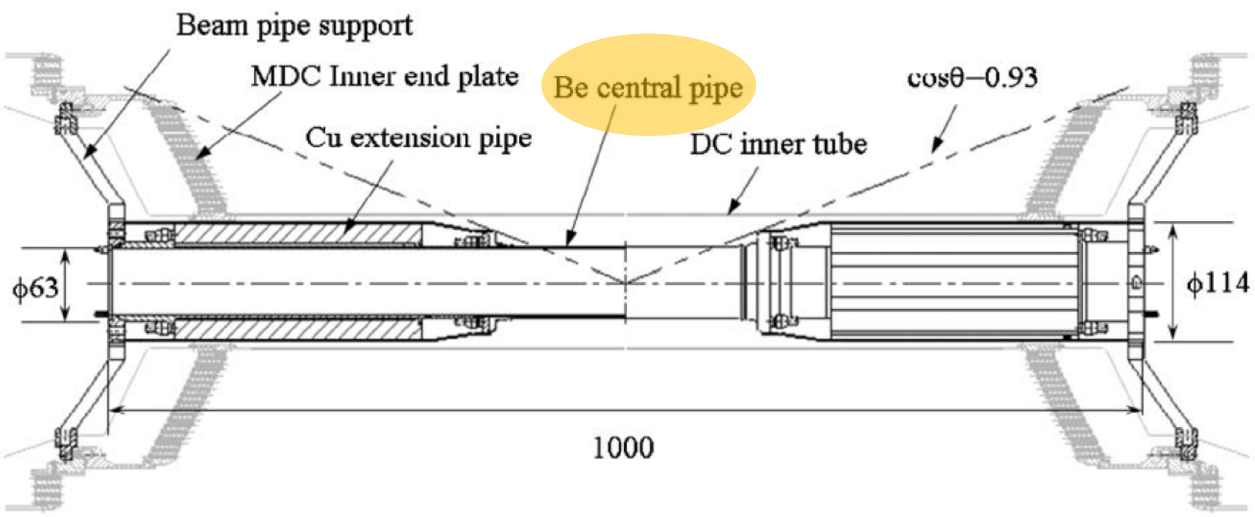


Fig. 3. Cross-sectional view of the beam pipe.

[BESIII, Nucl.Instrum.Meth.A 614 (2010)]

Source of photons from radiative decays of J/ψ and $\psi(3686)$

- **Source of photons**

Three-body

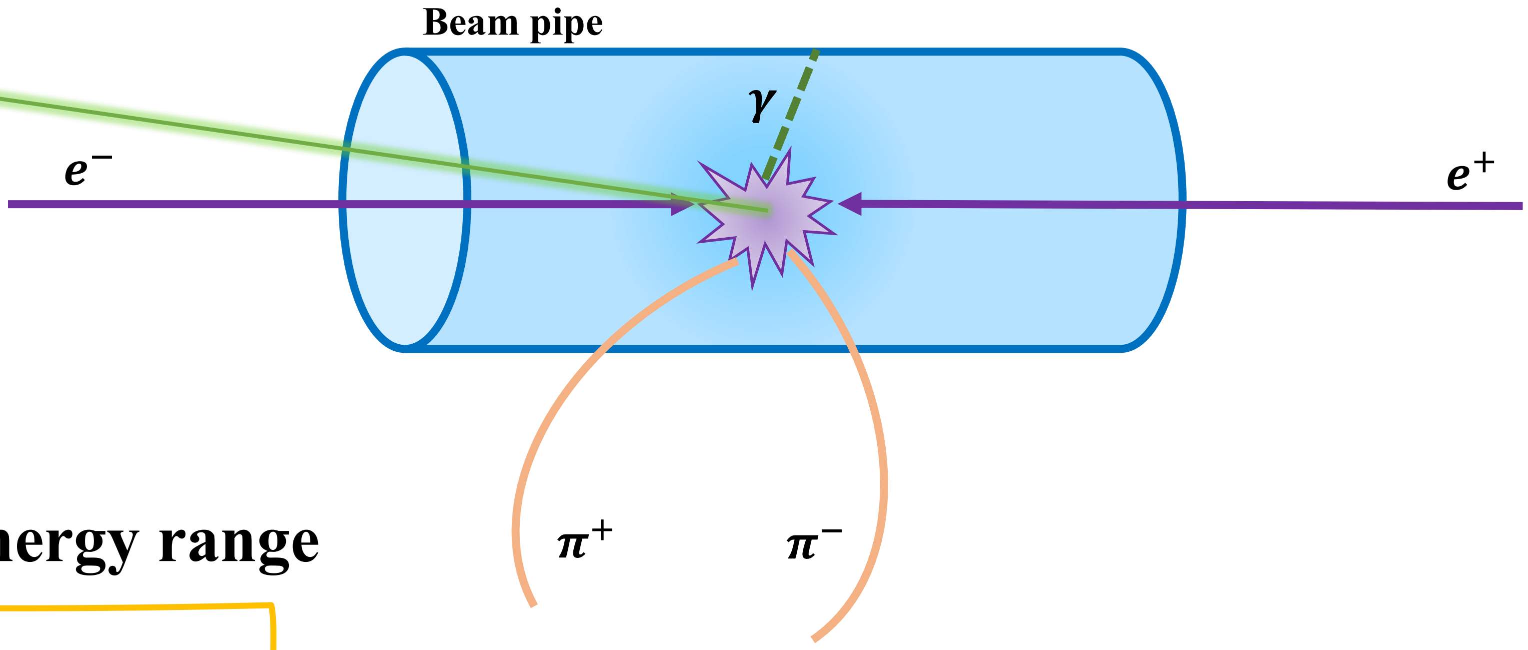
$$J/\psi \rightarrow \pi^+ + \pi^- + \gamma$$
$$J/\psi \rightarrow K^+ + K^- + \gamma$$
$$\psi(3686) \rightarrow \mu^+ + \mu^- + \gamma$$
$$e^+ + e^- \rightarrow e^+ + e^- + \gamma$$
$$e^+ + e^- \rightarrow \pi^+ + \pi^- + \gamma$$

… …

Two-body

$$J/\psi \rightarrow \eta(\eta') + \gamma$$
$$\psi(3686) \rightarrow \eta(\eta') + \gamma$$
$$J/\psi \rightarrow \rho + \pi$$

… …

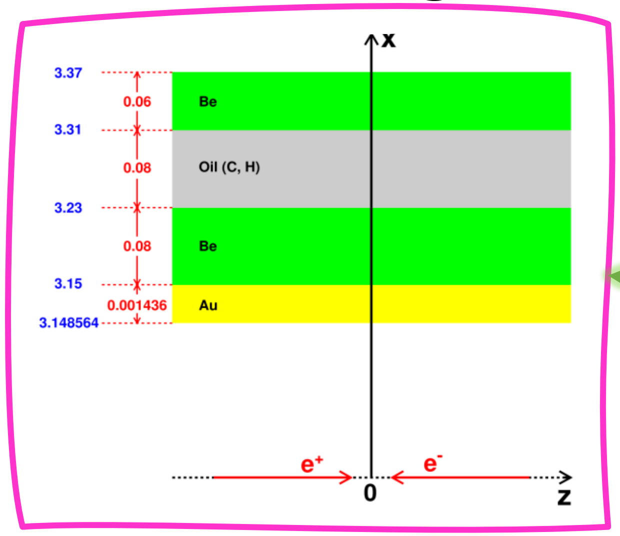


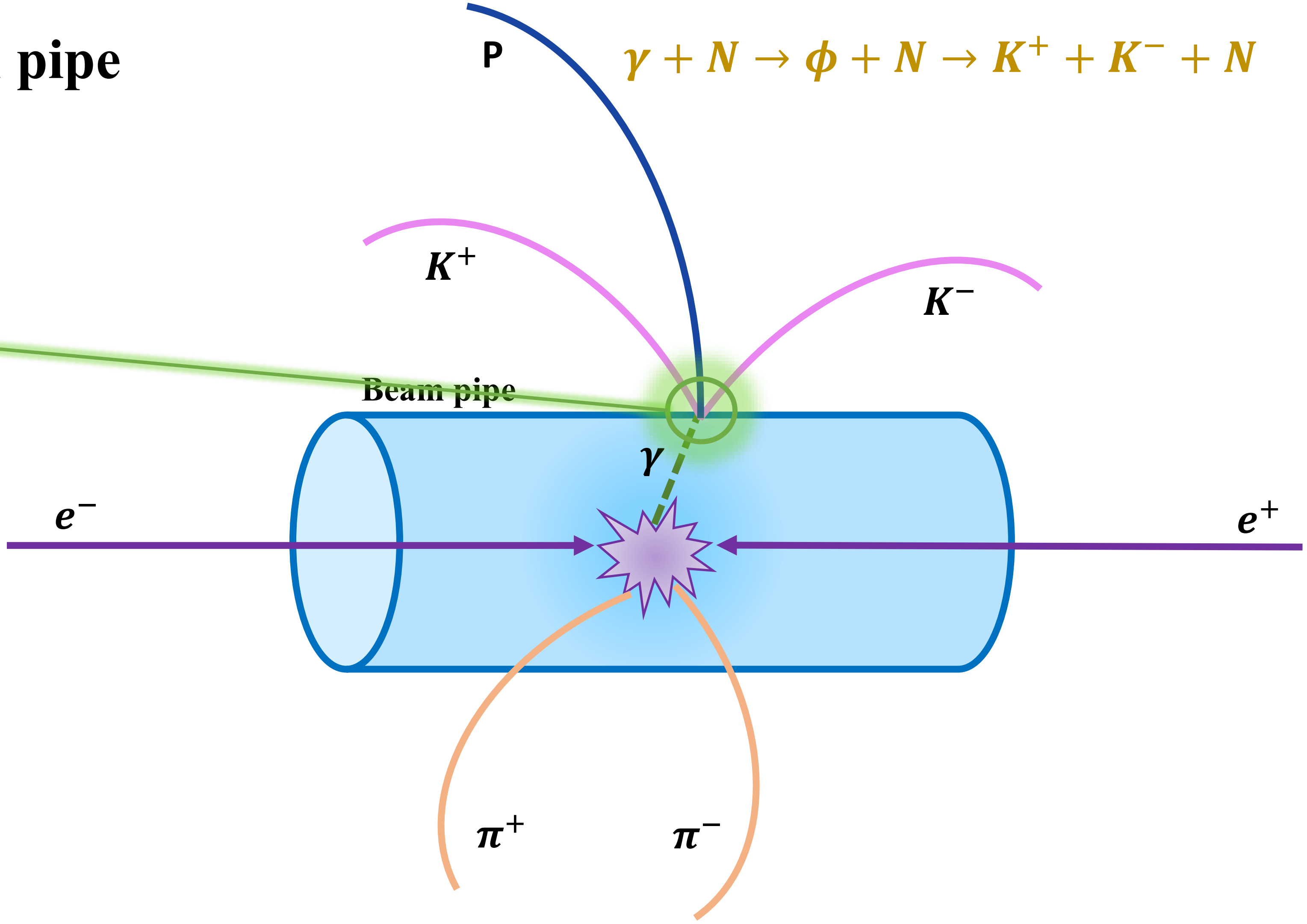
- **Provide photons with desired energy range**

✓ 1.30~1.57 GeV (Sub-threshold)
✓ 1.57~1.82 GeV (Near-threhold)

Production of ϕ

- Schematic diagram of the beam pipe





$$N^{\rm sig} = N^{\rm sig}_{\rm sub} + N^{\rm sig}_{\rm near}$$
$$= \mathcal{B}(\phi \to K^+K^-)\Big(\int_{1.30\,{\rm GeV}}^{1.57\,{\rm GeV}} dE_\gamma\, \sigma_{\gamma A\to\phi N(A-1)}(E_\gamma)\, \mathcal{L}_{\rm eff}(E_\gamma)$$
$$+ \int_{1.57\,{\rm GeV}}^{1.85\,{\rm GeV}} dE_\gamma\, \sigma_{\gamma A\to\phi N(A-1)}(E_\gamma)\, \mathcal{L}_{\rm eff}(E_\gamma)\Big)\,.$$

$$\mathcal{L}_{\rm eff}(E_\gamma) = \Big(\rho_{J/\psi\to\gamma\pi\pi}(E_\gamma) + \rho_{\rm 2body}(E_\gamma) + \rho_{\rm Bha.}(E_\gamma)$$
$$+\rho_{\pi\pi\gamma_{\rm ISR}}(E_\gamma)\Big) \times \int_a^b N(x)\, dx\,.$$

- The predicted signal can reach a dozen

[W.Wang, **J.X,** X.H.Yang, S.Zhao, Y.T.Zhang, PLB 875 (2026)]

Fresh opportunities in BESIII

- This proposed study opens fresh opportunities for applications in particle and nuclear physics.
  - Opportunities:
    - Testing the contribution of gluon SRC.
    - The strangeness content of the nucleon.
    - Various nuclear, particle, and astrophysics measurements…
  - For instances:
    - We can prob neutrons without having to detect them in the final state: $\gamma\, n \rightarrow \pi^{-}\, p$, $\gamma\, n \rightarrow \rho^{-}\, p$.
    - The momentum distribution of proton can be investigated by: $\gamma\, p \rightarrow \pi^{0}\, p$, $\gamma\, p \rightarrow \rho^{0}\, p$.
    - The quasi-elastic scattering $\Lambda\, p \rightarrow \Lambda\, p$.
    - The quasi-elastic $e\, p$ and $e\, n$ scattering.
    - The $\pi\ N$ and $K\ N$ scattering.

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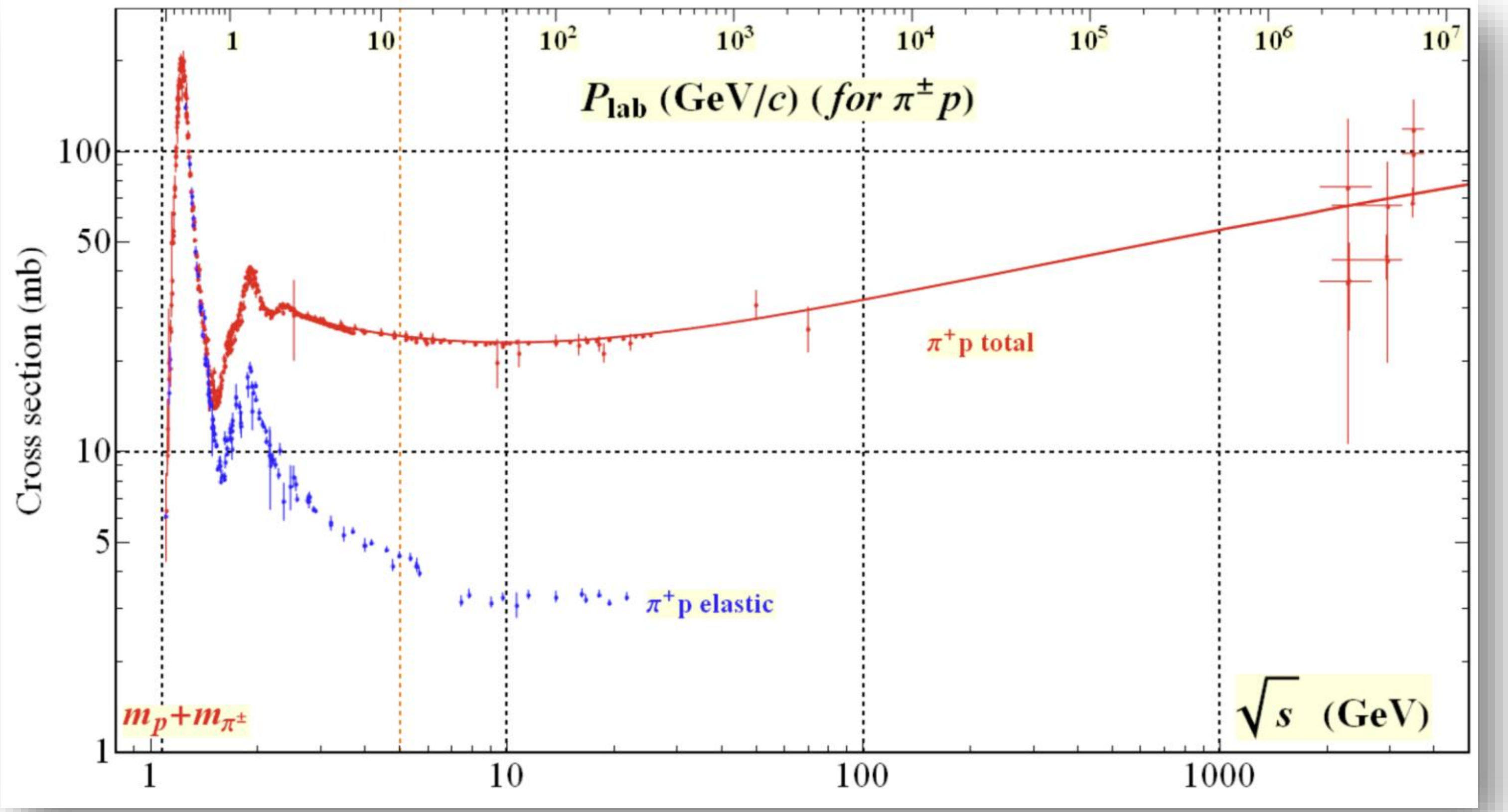
Searching SRC by π N scatterring

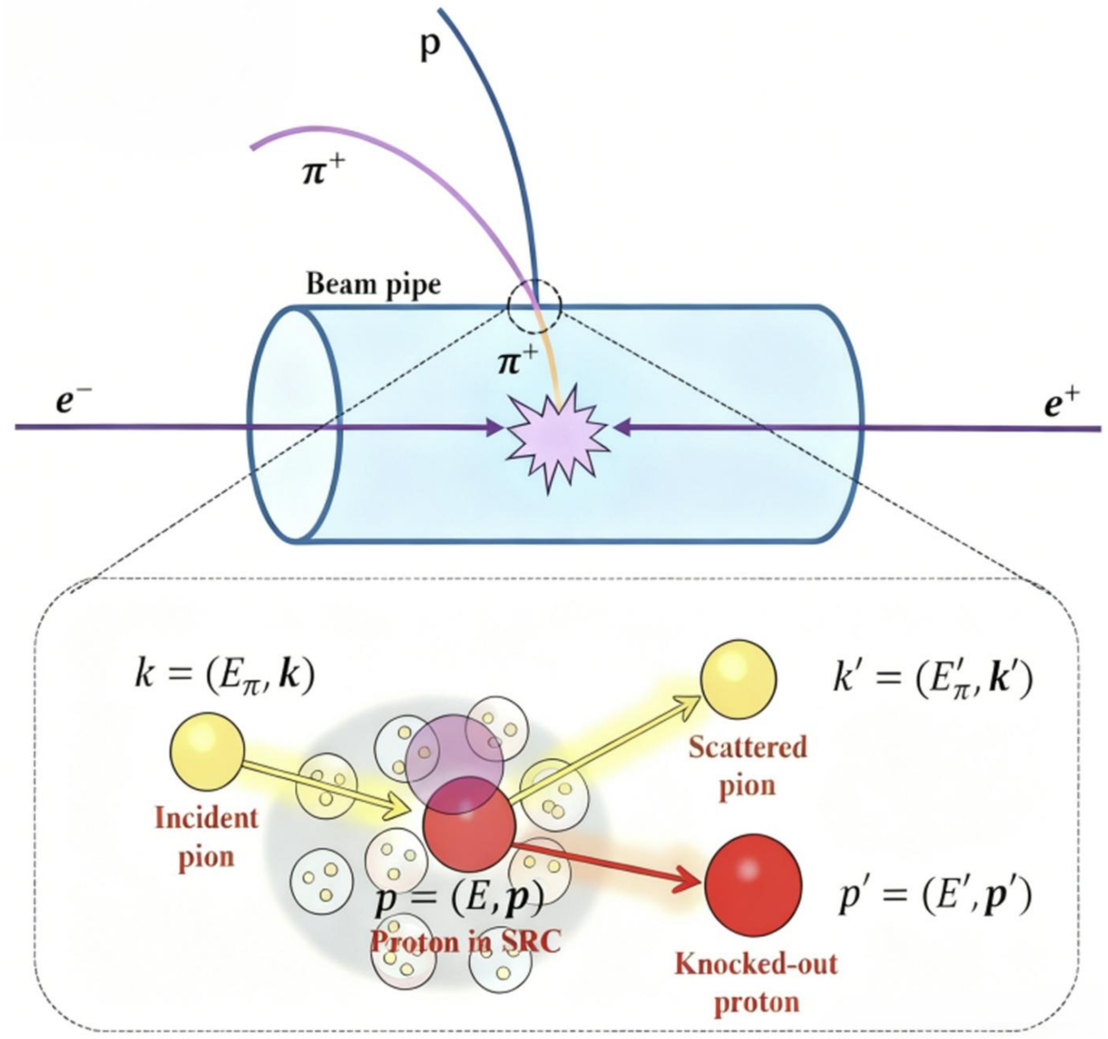
- π N scattering has been intensively studied with a long history in theory and experiment.



- However, the data on π N (bound in nuclei) scattering is limited.

Searching SRC by π N scatterring

- This process can be precisely measured at BESIII.



- ✓ The typical cross section is ~10 mb.
- ✓ Tens of thousands of events can be expected.
- ✓ Essential complementary information on beryllium.
- ✓ First attempt to study SRC by a meson beam.
- ✓ First experiment investigating nuclear corrections at BESIII.

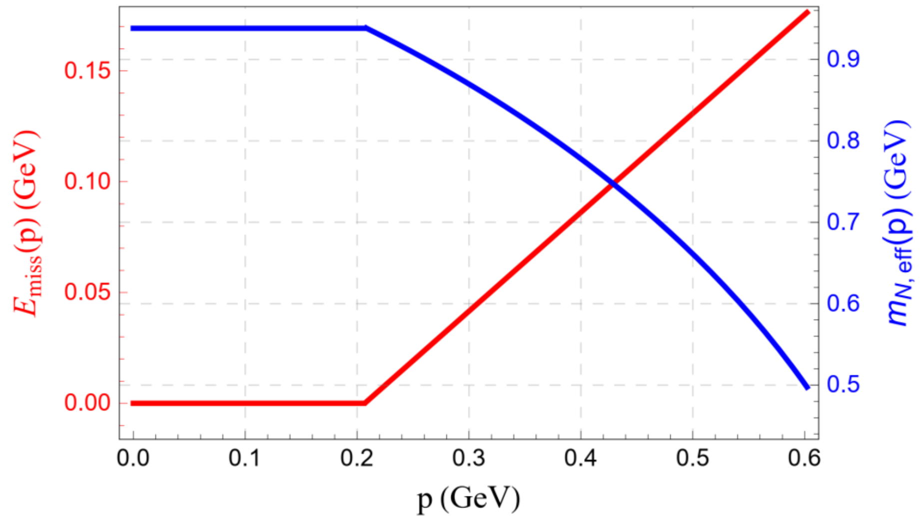
Searching SRC by πN scatterring

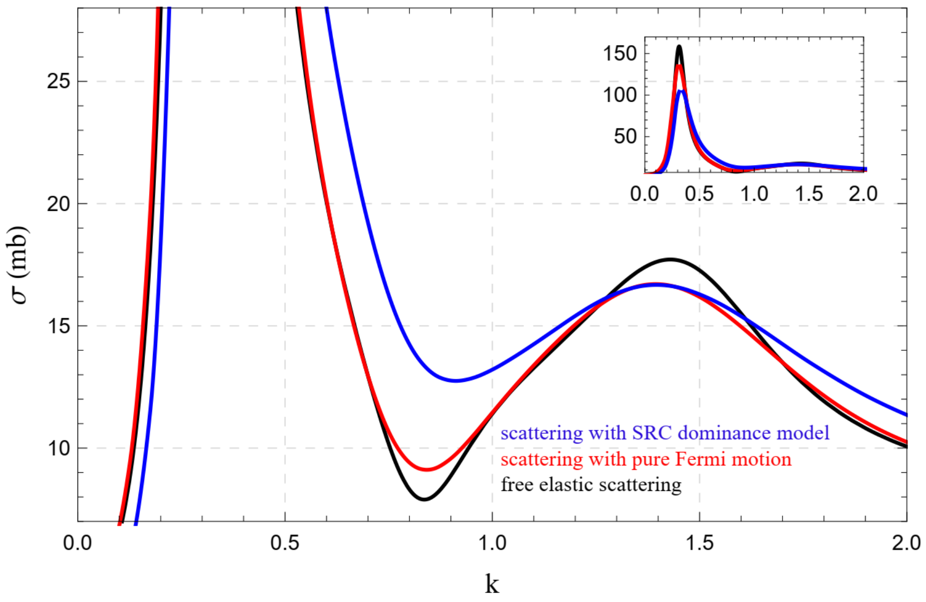
- Two straightforward and experimentally accessible observables.

  [CLAS, Nature 578 (2020)]

- The difference in quasielastic cross section between π^+-bound proton and π^+-free proton scattering.

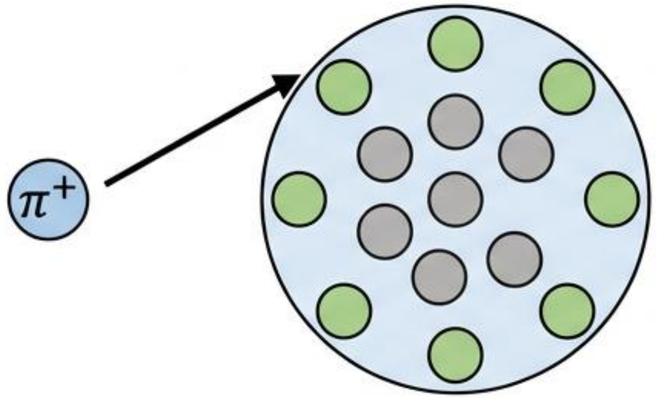
  [W.Wang, **J.X,** Y.T.Zhang, X.R.Zhou, ePrint: 2512.12293]





Searching SRC by π N scatterring

- **Effective Number of Nucleons**

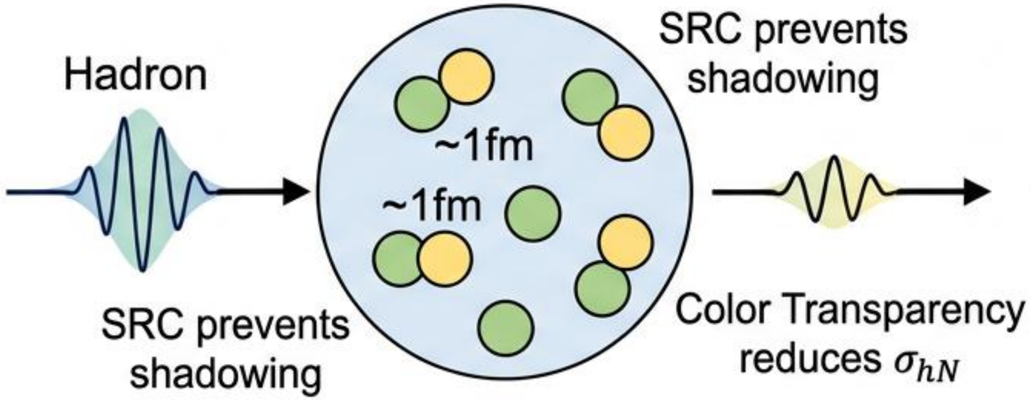


Due to strong π-N interaction, pions mainly scatter from nuclear surface, which leads to $A_{\text{eff}}<A$.

$A_{\text{eff}} \propto A^{0.42}$ (for pions) vs $A_{\text{eff}} \approx A$ (for electrons)

[Fujii et.al, PRC 64 (2001)]

- **Nuclear Transparency & Glauber Effect**



SRC enhances transparency by preventing nucleon shadowing. Color transparency further reduces hadron-nucleon cross section.

[Das, PRC 107 (2023)]

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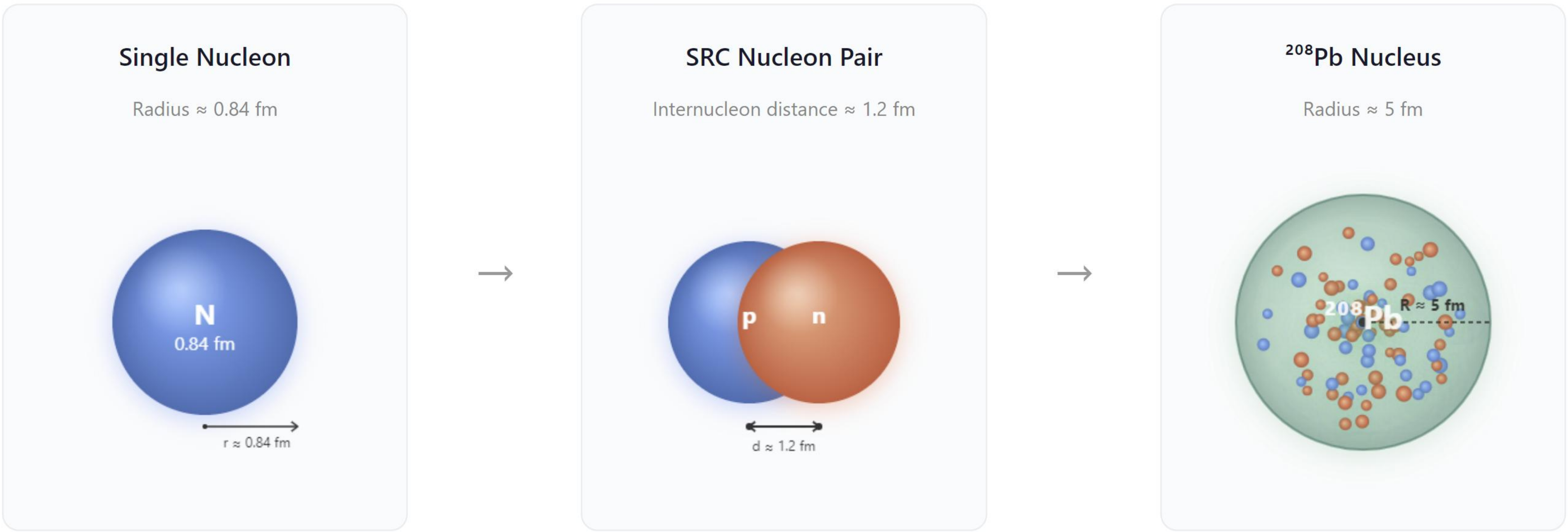
Scale Hierarchy in Nuclear Structure

From individual nucleons to heavy nuclei — the role of Short-Range Correlations



- The SRCs are related to nucleon and quark structure of nucleus.
- We derive a linear relation of gluons in nucleus similar to the observed quark linear relation.
- We propose to search for SRCs at BESIII in different processes, which offers an independent test of universal influence of SRCs.

Thanks!

BACK UP

Evidence for the existence of SRC

- There is much indirect and direct evidence for the existence of nucleon-nucleon SRCs),.
  - (i) High-energy $(e, e'pN)$ and $(p, 2pN)$ reactions show that two-nucleon correlations exist in nuclei, dominate the high-momentum $(k \geq k_F)$ tail of the nuclear momentum distribution, and are dominated, at certain nucleon momenta, by np pairs.
  - (ii) High-energy (e, e') reactions at large values of x_B (the Bjorken scaling variable) show that all nuclei have similar momentum distributions at large momentum, consistent with the direct observation that strongly correlated two-nucleon clusters exist in the nuclear ground state.
  - (iii) A consequence of the np-SRC dominance is the possible inversion of the kinetic energy sharing in nuclei with $N > Z$ (i.e., that protons might have more kinetic energy than neutrons in neutron-rich nuclei).
  - (iv) This leads to a dynamic model of nuclei where SRC pairs are temporary large fluctuations in the local nuclear density.

Nuclear density vs EMC effect

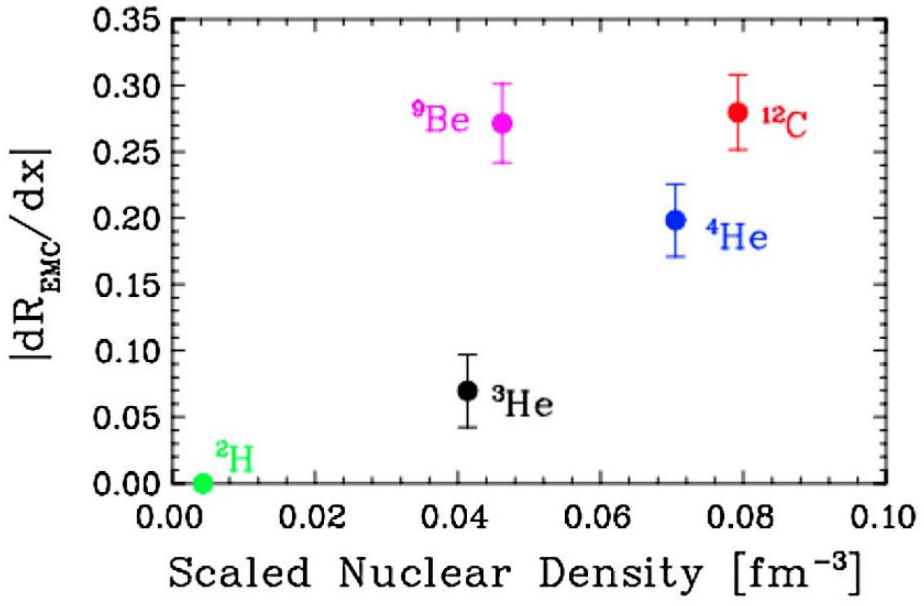
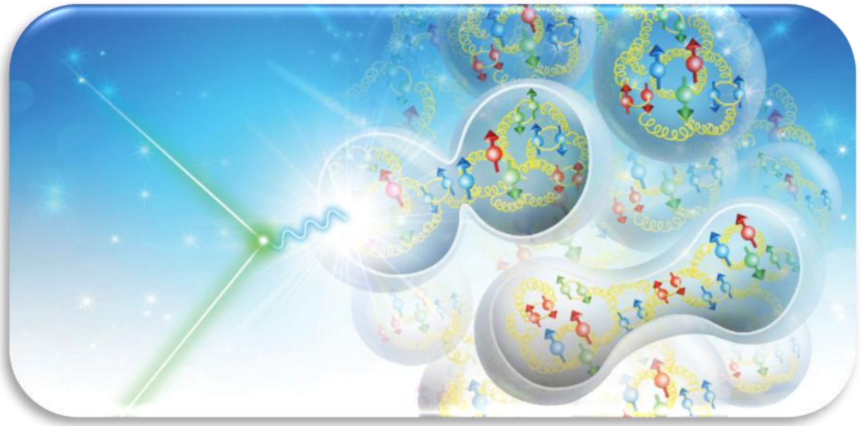


FIG. 23. The slope of the EMC effect for $0.35 \leq x_B \leq 0.7$ plotted vs the average nuclear density for various light nuclei as measured at Jefferson Lab. From Seely *et al.*, 2009.

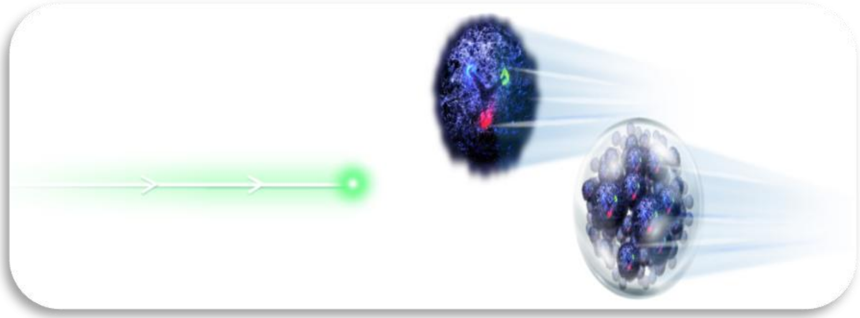
The EMC effect

- Proton's inelastic structure function,

$$F_2^p\left(x_p, Q^2\right) = x_p \sum_q e_q^2 \cdot \left(q^p\left(x_p\right) + \bar{q}^p\left(x_p\right)\right) \; .$$



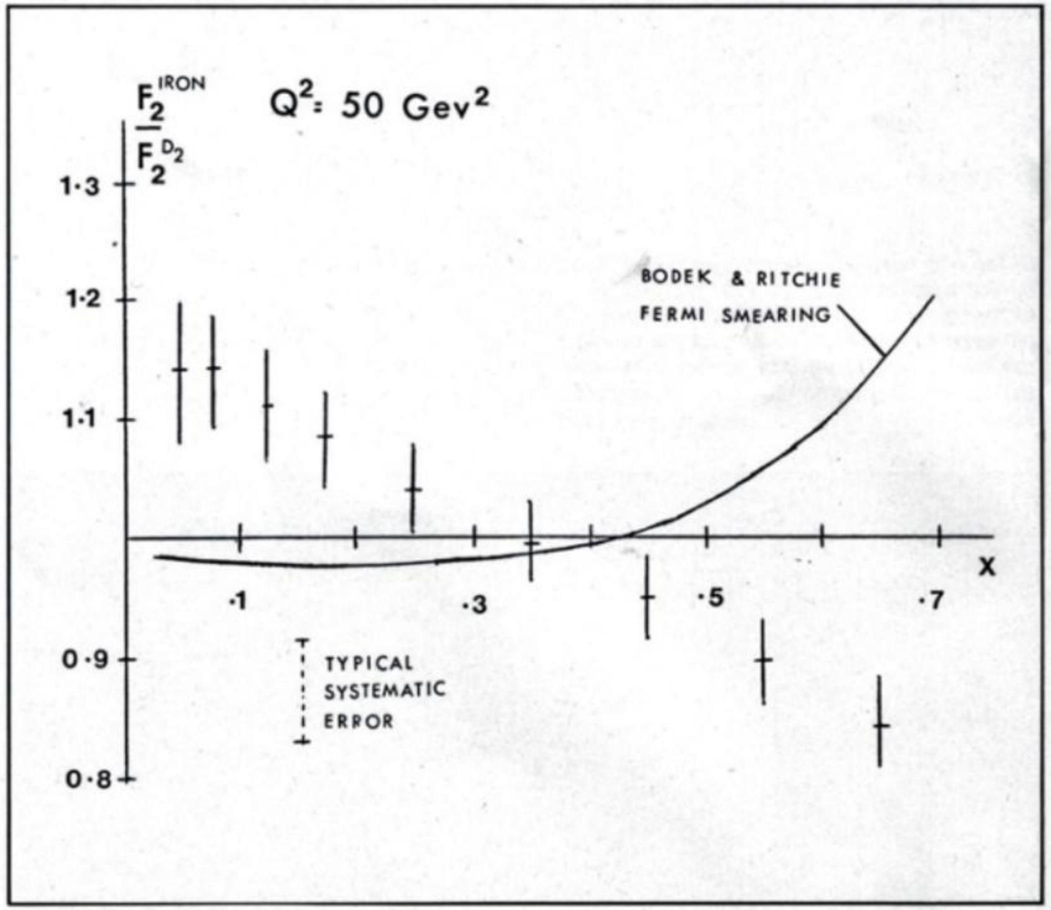
EIC Yellow Report, NPA 1026 (2022)



The Present and Future of QCD, ePrint:2303.02579

People once believed DIS would give the same result for all nuclei.

The EMC effect



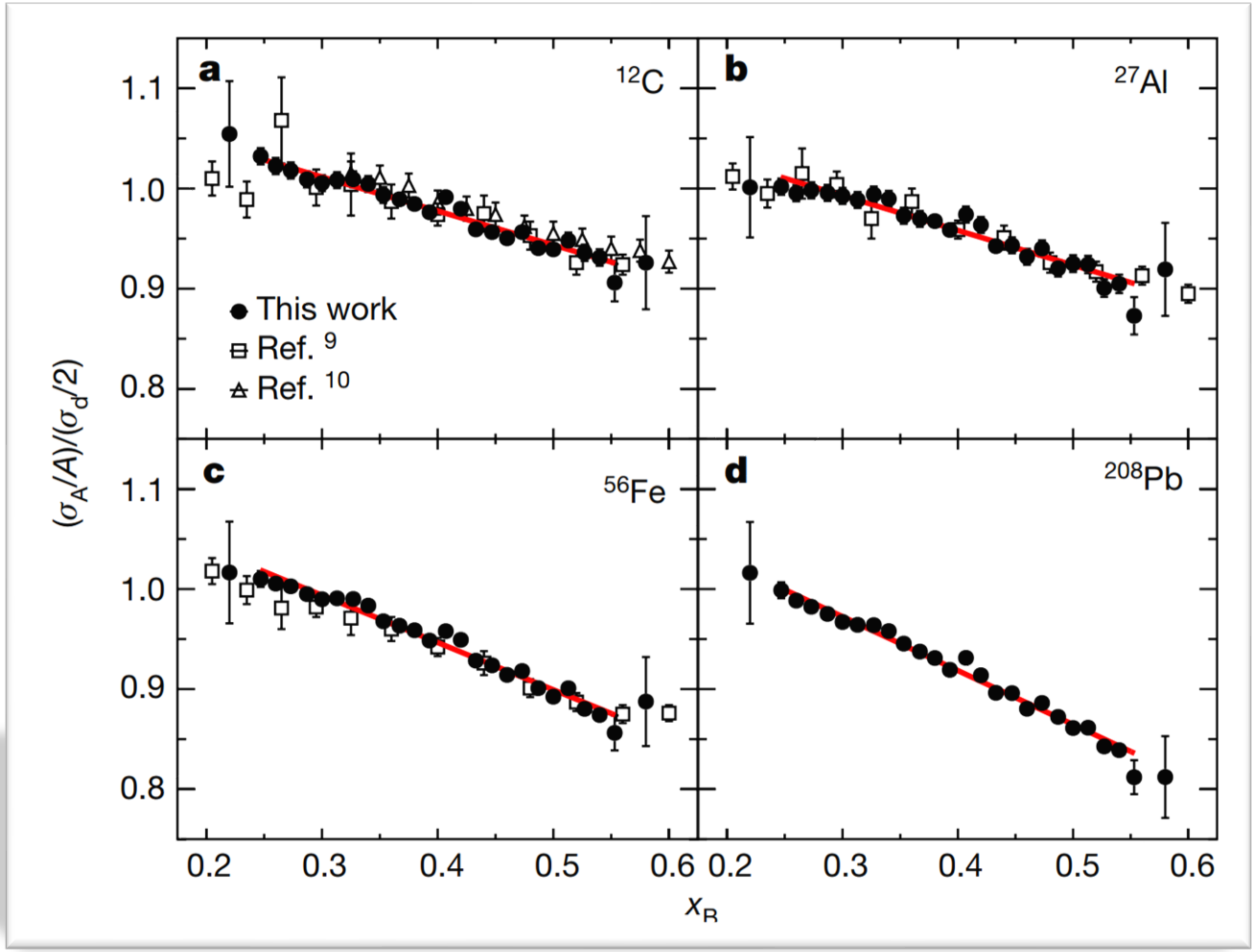
European Muon Collaboration (EMC)

But, things are not this simple !

The EMC effect

- Soon confirmed by other groups. [CLAS Collaboration, PRD 49, 4348 (1994); NMC Collaboration, NPB 3, 441 (1995)]

- Recent results from CLAS Collaboration. [CLAS Collaboration, Nature 566 (2019)]



The Linear relation between EMC and SRC

- **Support:**

  - **Short Range Correlations and the EMC Effect in Effective Field Theory, Phys.Rev.Lett. 119 (2017):**
    "The empirical linear relation … is a natural consequence of scale separation and it can be derived using effective field theory."

- **Suspicion:**

  - **Do short-range correlations cause the nuclear EMC effect in the deuteron? Phys.Rev.Lett. 125 (2021):**
    "… this analysis does not support the hypothesis that there is a causal connection between nucleons residing in SRCs and the EMC effect."

This issue is controversial.

EMC (vertical axis): reduced cross section

- Constraining the gluon nPDF through the production cross section of heavy quark pair.
  [Phys.Rev.D 96 (2017)]

$$\sigma^{c\bar{c}}_{A,red}(x, Q^2) \equiv \left(\frac{d\sigma^{c\bar{c}}_{A}}{dx dQ^2}\right) \frac{xQ^4}{2\pi\alpha^2[1 + (1-y)^2]} .$$

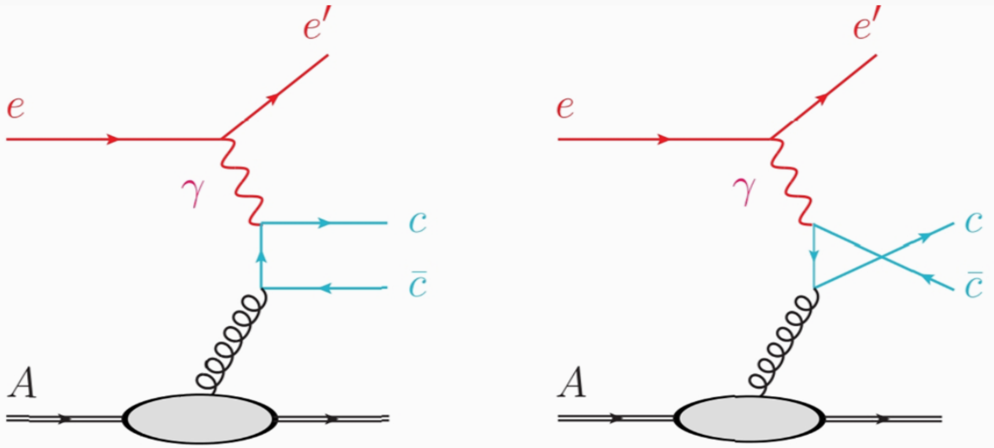


FIG. 1: Photoproduction of the heavy quark pair $c\bar{c}$ through photon-gluon fusion at leading order.

EMC (vertical axis): reduced cross section

$$\sigma^{c\bar{c}}_{A,red}(x,Q^2) \equiv \left(\frac{d\sigma^{c\bar{c}}_A}{dxdQ^2}\right)\frac{xQ^4}{2\pi\alpha^2[1+(1-y)^2]}$$
$$= \frac{2}{[1+(1-y)^2]}\left(xy^2F^{c\bar{c}}_{1,A}(x,Q^2)+(1-y)F^{c\bar{c}}_{2,A}(x,Q^2)\right), \quad (1)$$

In the collinear factorization framework, one can express the charm structure function in terms of the perturbative partonic cross section $f_{1/2}$ and the gluon nPDF g_A:

$$F^{c\bar{c}}_{1,A}(x,Q^2) = \int_{\tau x}^{1}\frac{dz}{z}g_A(z,\hat{s})\,f_1(\frac{x}{z},Q^2),$$
$$F^{c\bar{c}}_{2,A}(x,Q^2) = \int_{\tau x}^{1}\frac{dz}{z}z\,g_A(z,\hat{s})\,f_2(\frac{x}{z},Q^2). \quad (2)$$

We utilize the results from global analysis of nPDFs presented by EPPS21 in which the gluon nPDFs $g_A(x,Q^2)$ can be expressed as the product of a factor R^A_g and the gluon PDF in a free proton [25]

$$g_A(x,Q^2) = AR^A_g(x,Q^2)g(x,Q^2). \quad (3)$$

The specific expression for R^A_g can be found in [20].

We defined the factor $R^{c\bar{c}}_A$ to quantitatively assess the nuclear modification as the ratio below

$$R^{c\bar{c}}_A(x,Q^2) = \frac{\sigma^{c\bar{c}}_{A,red}(x,Q^2)}{A\sigma^{c\bar{c}}_{N,red}(x,Q^2)}, \quad (4)$$

EMC (vertical axis): reduced cross section

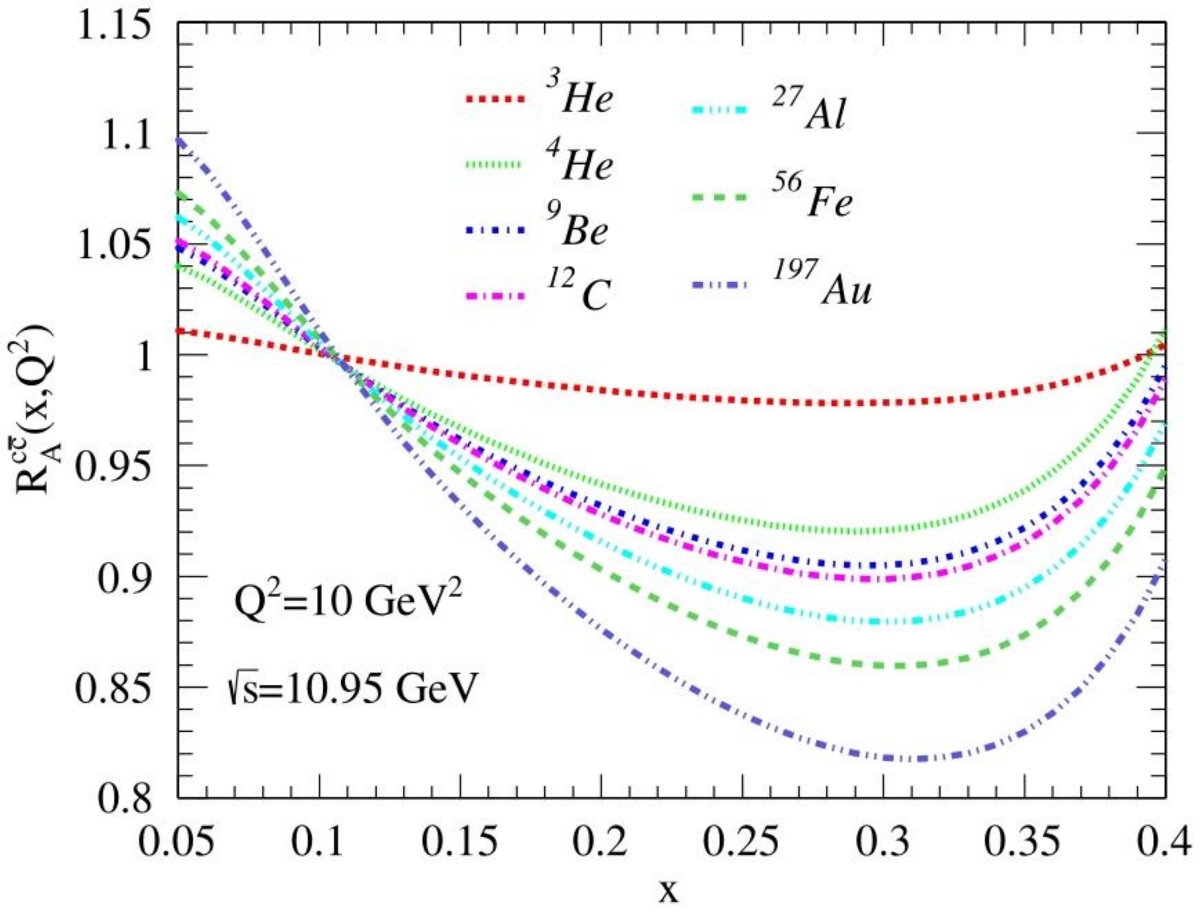
- The gluon nPDF can be parameterized through the gluon PDF in a free proton

[Eur.Phys.J.C 82 (2022)]

$$g_A(x,Q^2) = AR_g^A(x,Q^2)g(x,Q^2)\,.$$

- Define the nuclear modification

$$R_A^{c\bar{c}}\left(x,Q^2\right) = \frac{\sigma_{A,red}^{c\bar{c}}\left(x,Q^2\right)}{A\sigma_{N,red}^{c\bar{c}}\left(x,Q^2\right)}\,.$$



EMC (vertical axis): reduced cross section

- Quantify the strength of the gluon EMC effect for nucleus A by the slope of $R_A^{c\bar{c}}$, i.e., $\left|dR_A^{c\bar{c}}/dx\right|$.

Nucleus	$\lvert dR_A^{c\bar{c}}/dx \rvert$	$(\sigma_A^{sub}/A)^{\mathrm{I}}$	$(\sigma_A^{sub}/A)^{\mathrm{II}}$
^{3}He	0.152 ± 0.013	6.82 ± 0.13	3.31 ± 0.06
^{4}He	0.555 ± 0.046	11.52 ± 0.32	11.35 ± 0.14
^{9}Be	0.659 ± 0.053	12.51 ± 0.38	13.49 ± 0.07
^{12}C	0.699 ± 0.056	14.37 ± 0.54	14.37 ± 0.54
^{27}Al	0.828 ± 0.065	15.46 ± 0.58	17.23 ± 0.23
^{56}Fe	0.961 ± 0.075	15.36 ± 0.70	20.09 ± 0.42
^{197}Au	1.241 ± 0.097	16.51 ± 0.70	26.13 ± 0.82

SRC (horizontal axis): sub-threshold J/ψ production

- **For a free nucleon target,** the threshold photon energy to generate a J/ψ is $E_\gamma \sim 8.2$ GeV.

- **If the nucleon is bound in nucleus,** the production of J/ψ can occur at lower photon energy.

[Phys.Lett.B 498 (2001)]

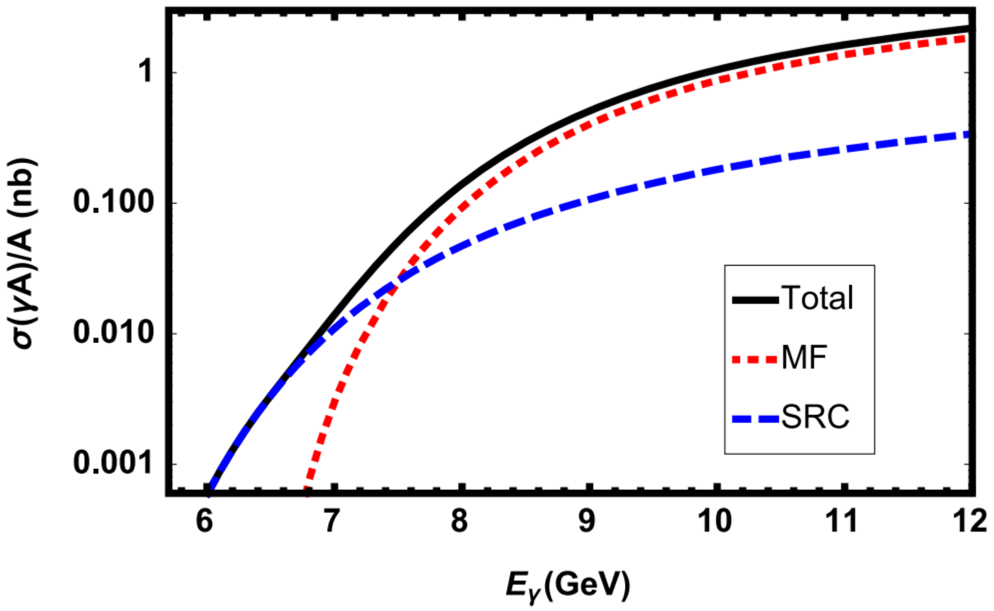


Fig. 3. Sub-threshold J/ψ production in photon-Carbon collisions as a function of incoming photon energy E_γ. We have estimated $P_{MF} = 0.84$ for the mean field normalization in Eq. (12).

[Phys. Lett. B 803 (2020)]

Linear gluon EMC-SRC relation

Strategy I

- Making use of the SRC scaling factor a_2. [Nature 566 (2019); Phys.Rev.C 85 (2012)]

- It is likely that a_2 is roughly equals to $g_2(A)/g_2(d)$ if the gluon nPDF is affected by the SRCs in about the same way as quarks.

Strategy II

- Making use of the parameterization in EPPS21

$$\frac{g_2(A,\Lambda)}{g_2(A',\Lambda)} = \frac{R_g^A(x,Q^2)-1}{R_g^{A'}(x,Q^2)-1}\,.$$

Linear gluon EMC-SRC relation

- The cross sections (picobarn) per nucleon for sub-threshold J/ψ production.

Nucleus	$\lvert dR_A^{c\bar{c}}/dx \rvert$	$(\sigma_A^{sub}/A)^{\mathrm{I}}$	$(\sigma_A^{sub}/A)^{\mathrm{II}}$
^{3}He	0.152 ± 0.013	6.82 ± 0.13	3.31 ± 0.06
^{4}He	0.555 ± 0.046	11.52 ± 0.32	11.35 ± 0.14
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Opportunities in BESIII

- This proposed study opens fresh opportunities for applications in particle and nuclear physics.
  - Opportunities:
    - Testing the contribution of gluon SRC.
    - Study the $\phi - N$ bound state.
    - The strangeness content of the nucleon.
    - Quasi-elastic e^+N scattering.
    - Various nuclear, particle, and astrophysics measurements…
  - Difficulties:
    - BEPC is not specifically built for this kind of process. [Phys.Rev.Lett. 127 (2021) 1, 012003]
    - The cross section may still not be large enough ($10 \sim 300$ nb). [Phys.Rev.Lett. 130 (2023) 25, 251902]
    - The kinds of target nuclei that can be studied are limited (Be and C).
- But still worth trying, because the rewards are substantial !

$$\sigma_{\text{bound}}(|\mathbf{k}|) = \int \frac{d^3\mathbf{p}}{(2\pi)^3}\,\sigma_{\text{free}}(\sqrt{s})\,\rho_p(|\mathbf{p}|)\,, \qquad (2)$$

here $\sigma_{\text{free}}(\sqrt{s})$ is the free cross section with

$$\sqrt{s} = m_N^2 + m_\pi^2 + E_{\text{miss}}^2 - E_{\text{miss}}(2m_N + 2E_\pi) + 2m_N E_\pi$$
$$-|\mathbf{p}|^2 - 2|\mathbf{k}||\mathbf{p}|\cos\theta\,.$$

$$\rho_p(|\mathbf{p}|) = \begin{cases} \eta \cdot \rho_p^{\text{MF}}(|\mathbf{p}|)\,, & |\mathbf{p}| < k_F \\ \frac{A}{2Z} \cdot a_2(\text{Be}/d) \cdot \rho_d(|\mathbf{p}|)\,, & |\mathbf{p}| > k_F \end{cases}\,. \quad (3)$$

$$E_{\text{miss}}(|\mathbf{p}|) = \begin{cases} 0\,, & |\mathbf{p}| < k_F \\ 0.446\,|\mathbf{p}| - 0.098\,, & |\mathbf{p}| > k_F \end{cases}\,, \quad (1)$$

TABLE I: The energy distribution of photon numbers $\rho(E_\gamma)$ for various processes.

E_γ	$\rho_{\text{Bha.}}$	$\rho_{\pi\pi\gamma_{\text{ISR}}}$	$\rho_{J/\psi\to\gamma\pi\pi}$	$\rho_{J/\psi\to\rho\pi}$	$\rho_{J/\psi\to\gamma\eta}$	$\rho_{J/\psi\to\gamma\eta'}$	$\rho_{\psi(3686)\to\gamma\eta}$	$\rho_{\psi(3686)\to\gamma\eta'}$
1.30 GeV	5.50×10^7	8.01×10^4	1.11×10^6	5.02×10^6	0	0	0	0
1.35 GeV	5.25×10^7	8.96×10^4	1.91×10^6	4.67×10^6	0	0	0	0
1.40 GeV	4.80×10^7	1.03×10^5	8.50×10^5	4.19×10^6	0	5.28×10^7	0	0
1.45 GeV	4.64×10^7	1.16×10^5	1.87×10^5	2.22×10^6	0	0	0	0
1.50 GeV	4.68×10^7	1.28×10^5	5.60×10^4	2.37×10^5	1.09×10^7	0	0	0
1.55 GeV	4.22×10^7	1.44×10^5	3.97×10^4	3.17×10^3	0	0	0	0
1.60 GeV	4.08×10^7	1.91×10^5	0	0	0	0	0	0
1.65 GeV	3.83×10^7	3.17×10^5	0	0	0	0	0	0
1.70 GeV	3.49×10^7	5.96×10^5	0	0	0	0	0	2.23×10^5
1.75 GeV	3.27×10^7	1.59×10^6	0	0	0	0	0	1.18×10^5
1.80 GeV	2.88×10^7	1.04×10^7	0	0	0	0	2.48×10^3	0
1.85 GeV	1.99×10^7	3.36×10^6	0	0	0	0	0	0

Fresh opportunities in BESIII

- This proposed study opens fresh opportunities for applications in particle and nuclear physics.

  - Opportunities:
    - Testing the contribution of gluon SRC.
    - Study the $\phi - N$ bound state.
    - The strangeness content of the nucleon.
    - Quasi-elastic e^+N scattering.
    - Various nuclear, particle, and astrophysics measurements…

  - For instances:
    - We can prob neutrons without having to detect them in the final state: $\gamma\, n \to \pi^-\, p,$ $\gamma\, n \to \rho^-\, p$.
    - The momentum distribution of proton can be investigated by: $\gamma\, p \to \pi^0\, p,$ $\gamma\, p \to \rho^0\, p$.
    - The cross section is relatively much larger, about 300 μb.