



兰州大学

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UNIVERSITY

# Proposal for Searching SRC in BESIII

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2026. 07. 16 @ 广州

第十二届全国会员代表大会暨学术年会

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# Outline

- Introduction on short-range correlations (SRC)
- The gluon linear relation between SRC and EMC
- Opportunities in BESIII and STCF
- Summary

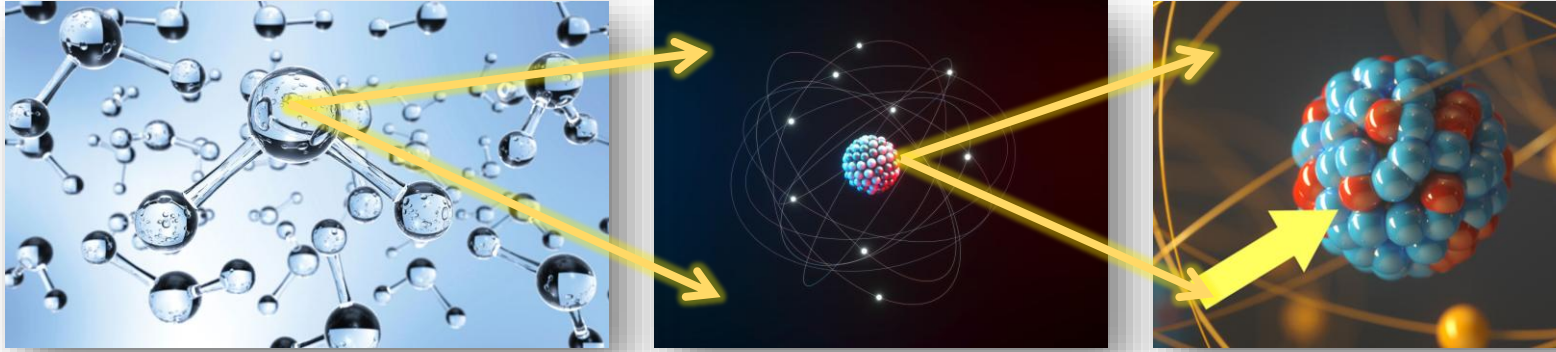


# Outline

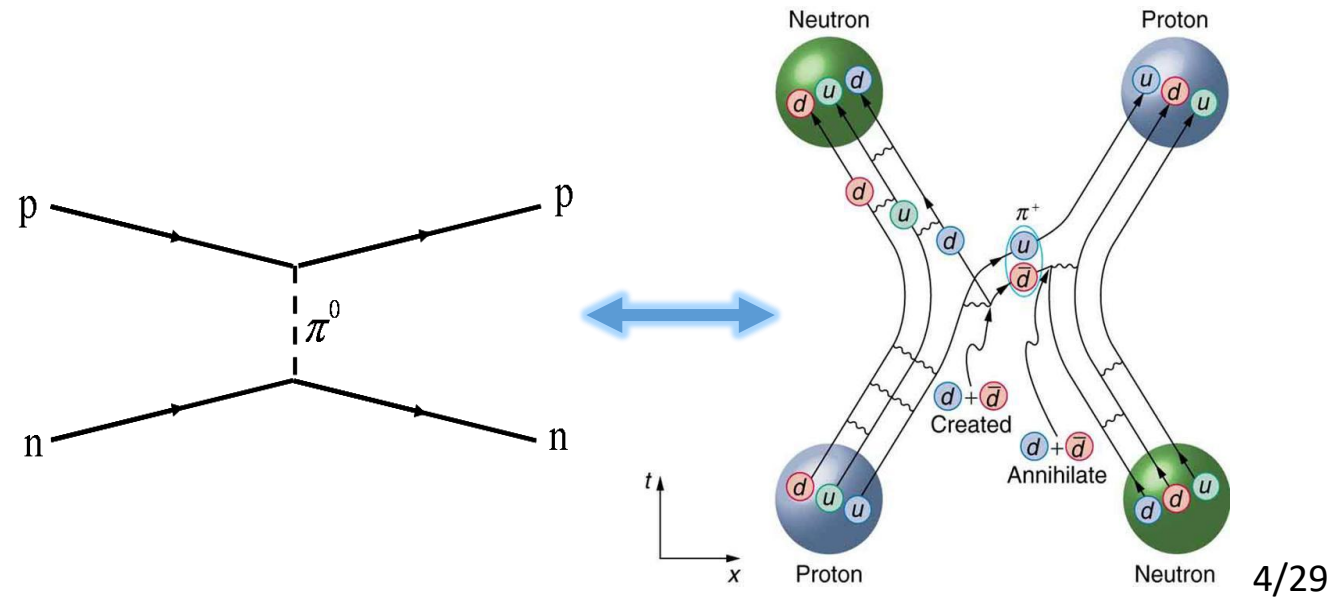
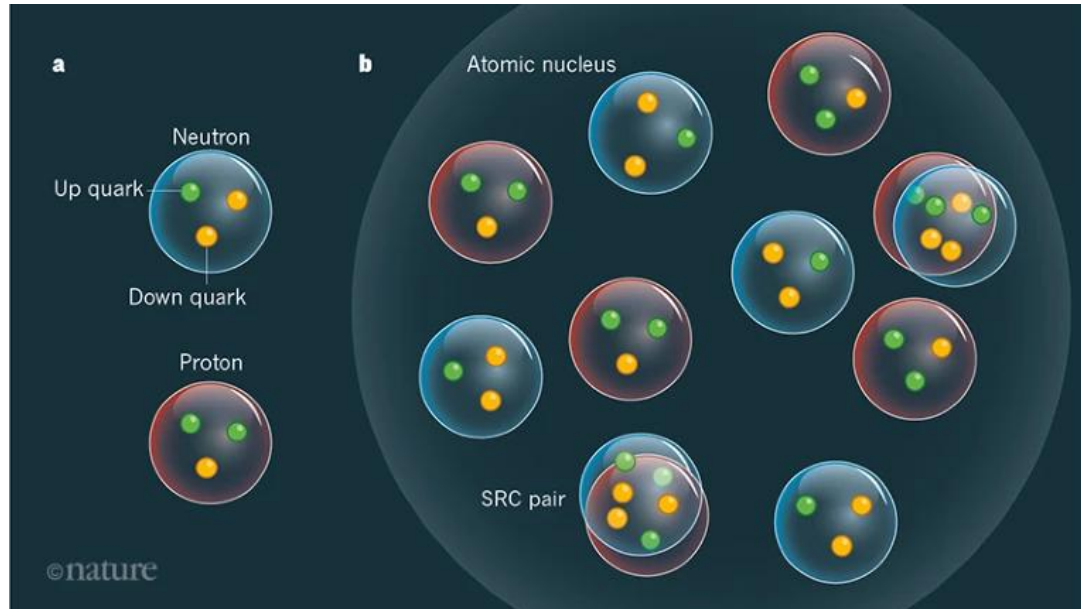
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# Introduction on SRC

- 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.

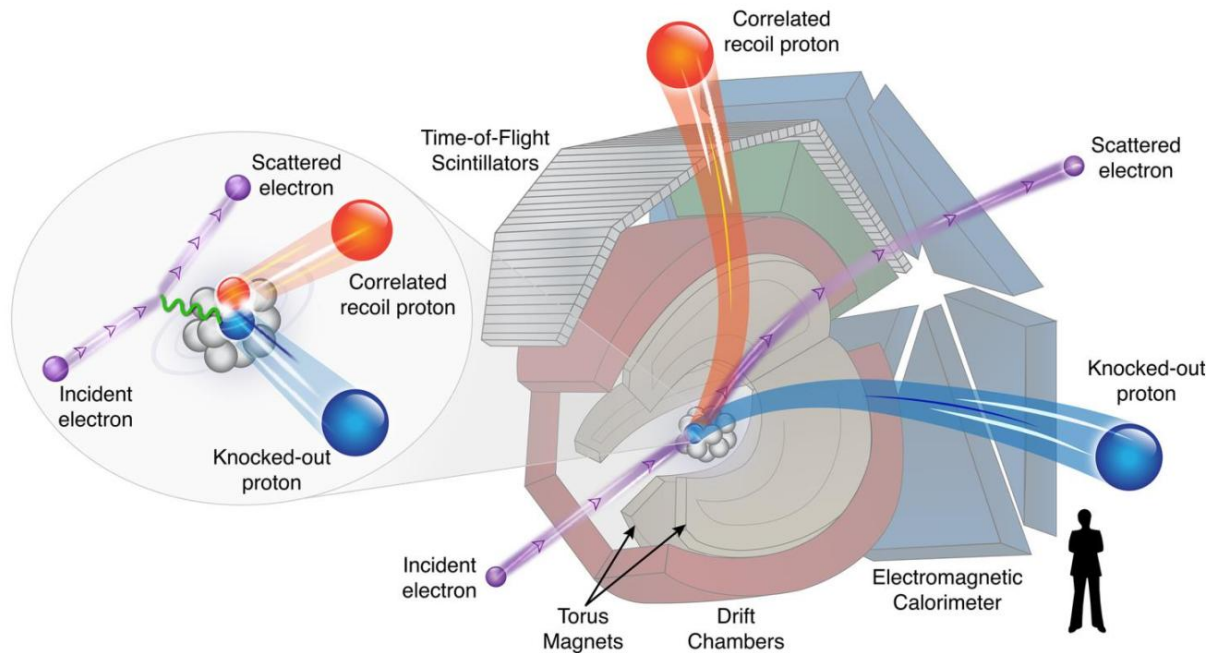


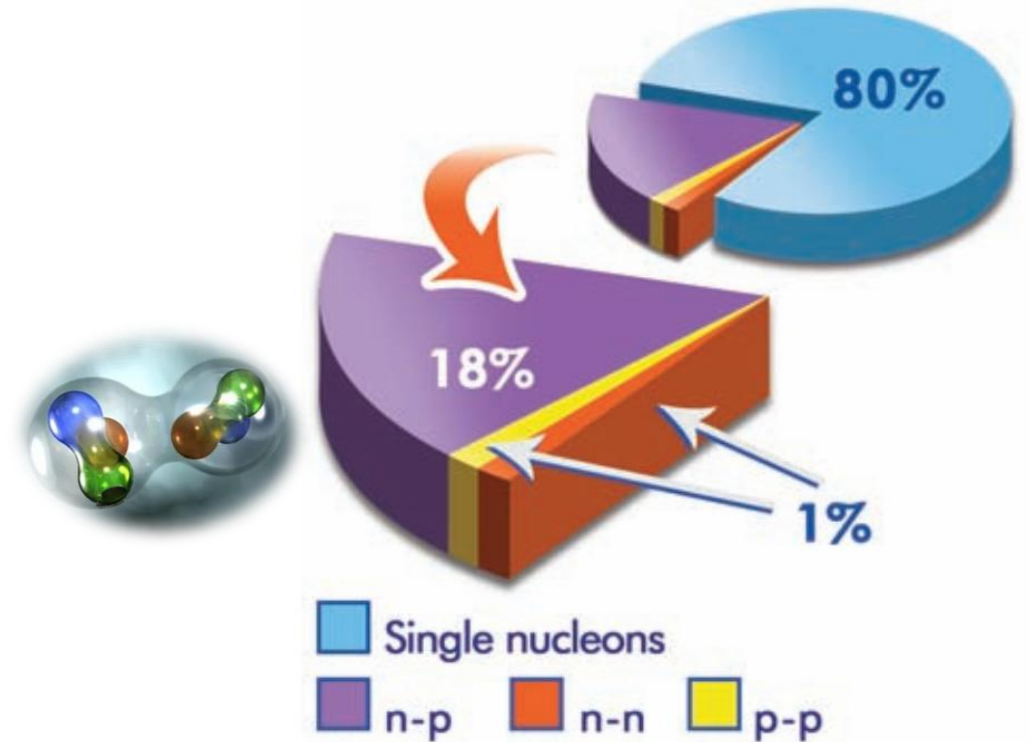
Illustration of a reconstructed two-proton knockout event.

[CLAS, Science 346 (2014)]

[CLAS, Nature 578 (2020)]

[CLAS, PRL 90 (2003)]

[Nguyen et.al, Nature 654 (2026)]

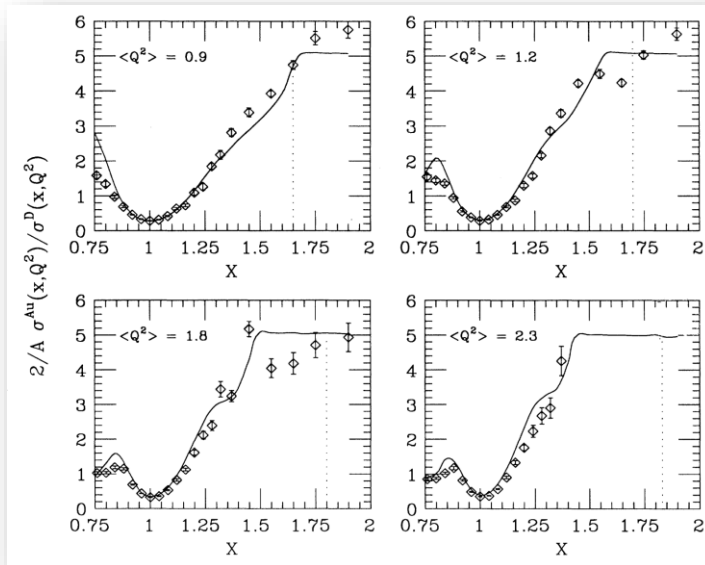


**Fig. 3.** The average fraction of nucleons in the various initial-state configurations of  $^{12}\text{C}$ .

[CLAS, Science 320 (2008)]

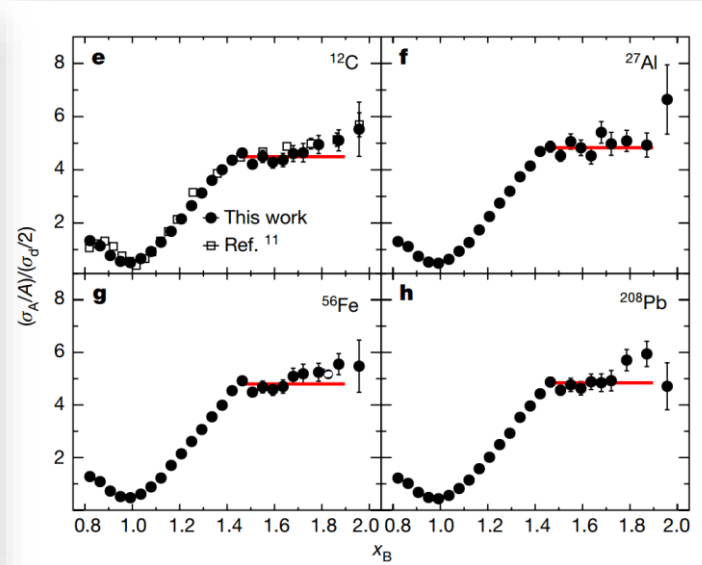
# Introduction on SRC

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



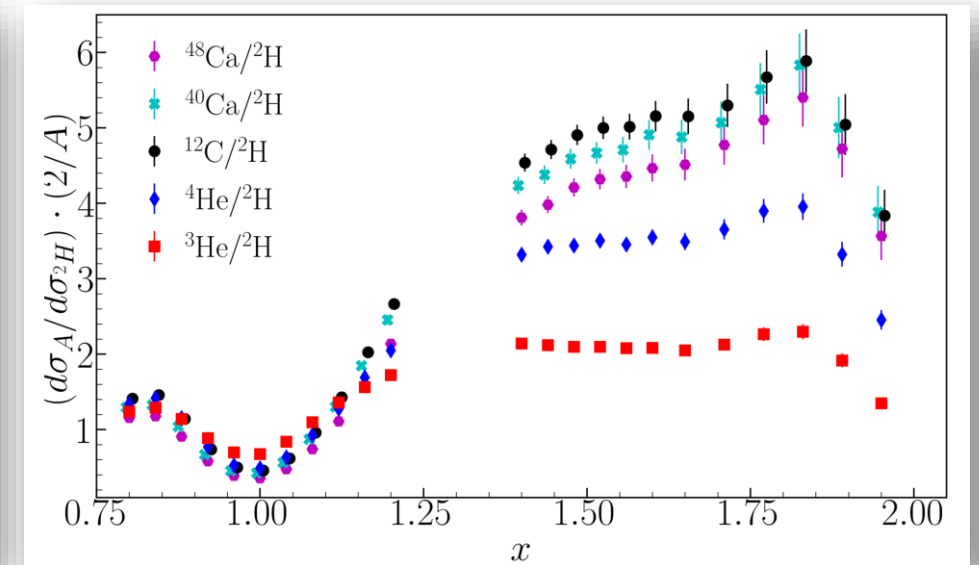
[Frankfurt et.al, PRC 48 (1993)]

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



[CLAS, Nature 566 (2019)]

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



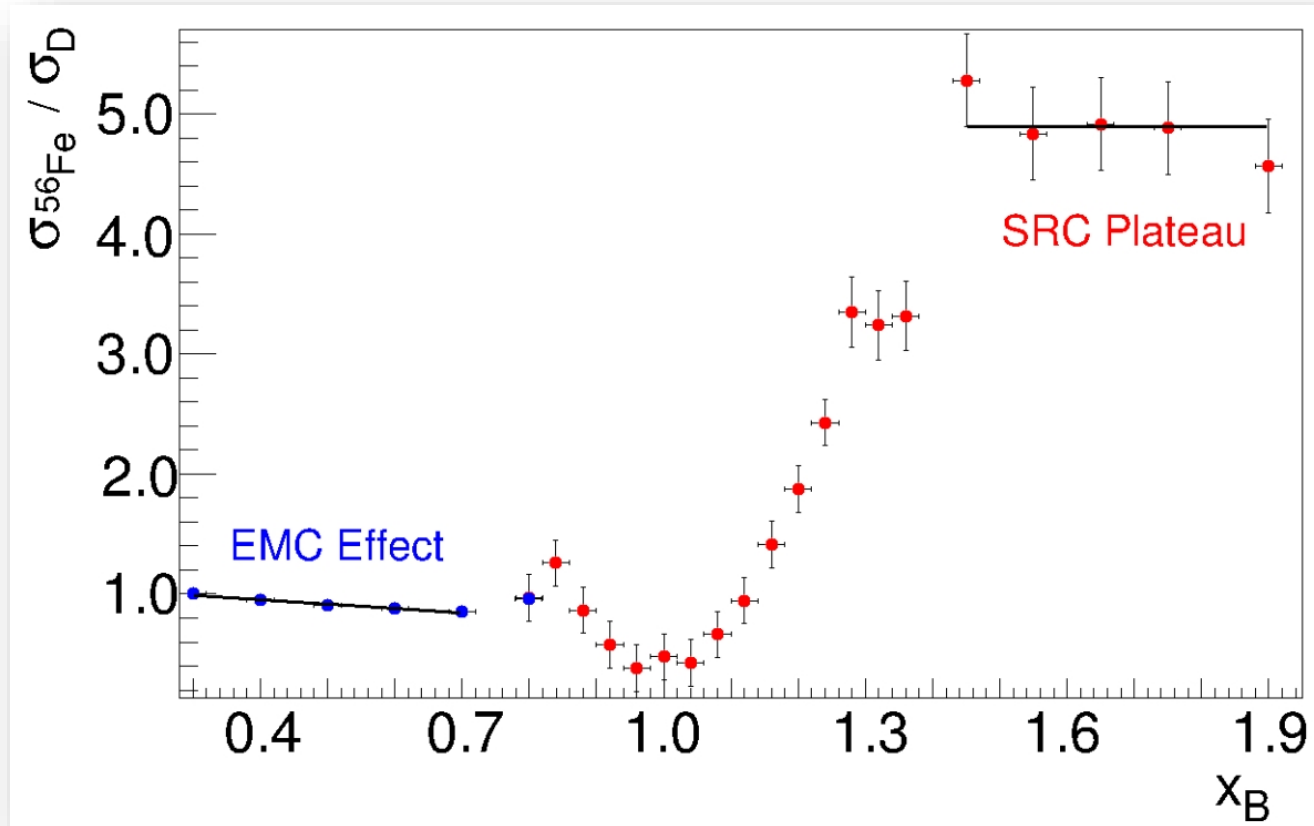
[Y.P.Zhang, Z.H.Ye et.al, PLB 872 (2026)]

[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.

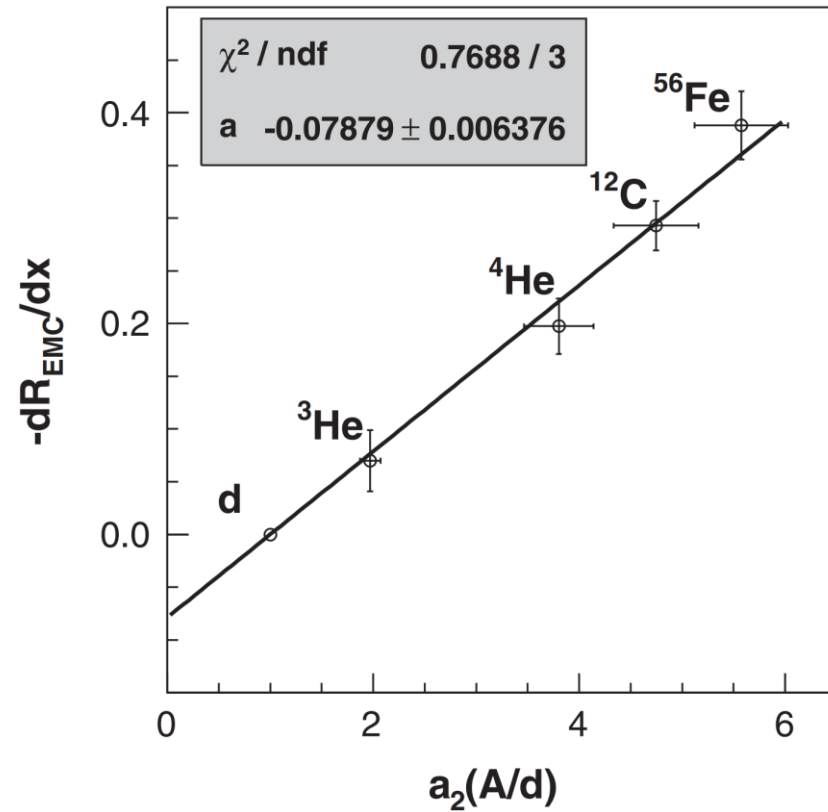


**EMC effect:** slope of the ratio  $dR_{EMC}/dx$  ( $0.35 \leq x_p \leq 0.7$ ).

**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

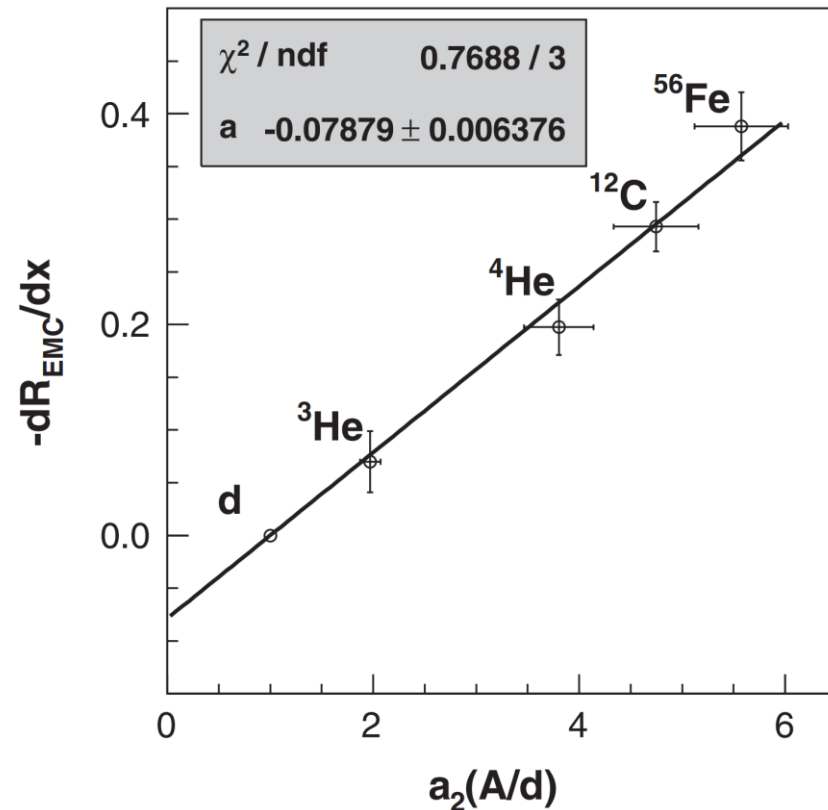
- Here comes the important observation.



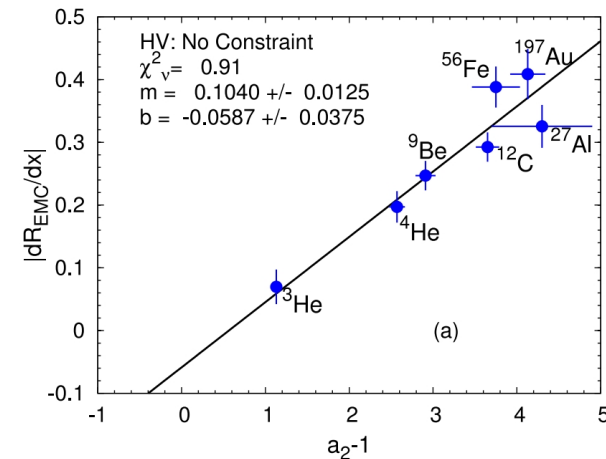
[Weinstein et.al, PRL 106 (2011)]

# The linear relation between EMC and SRC

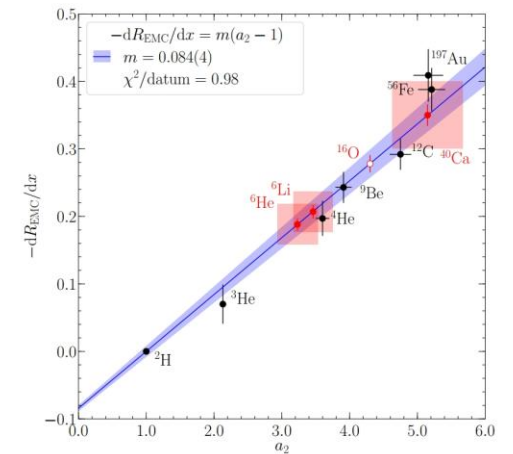
- Here comes the important observation.



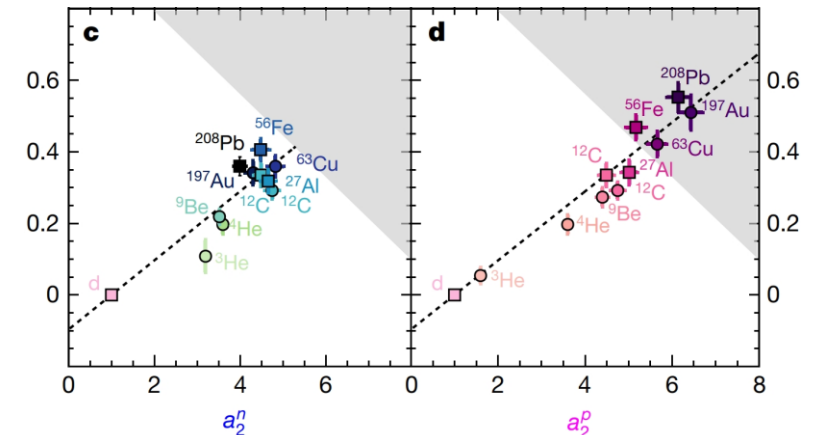
[Weinstein et.al, PRL 106 (2011)]



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



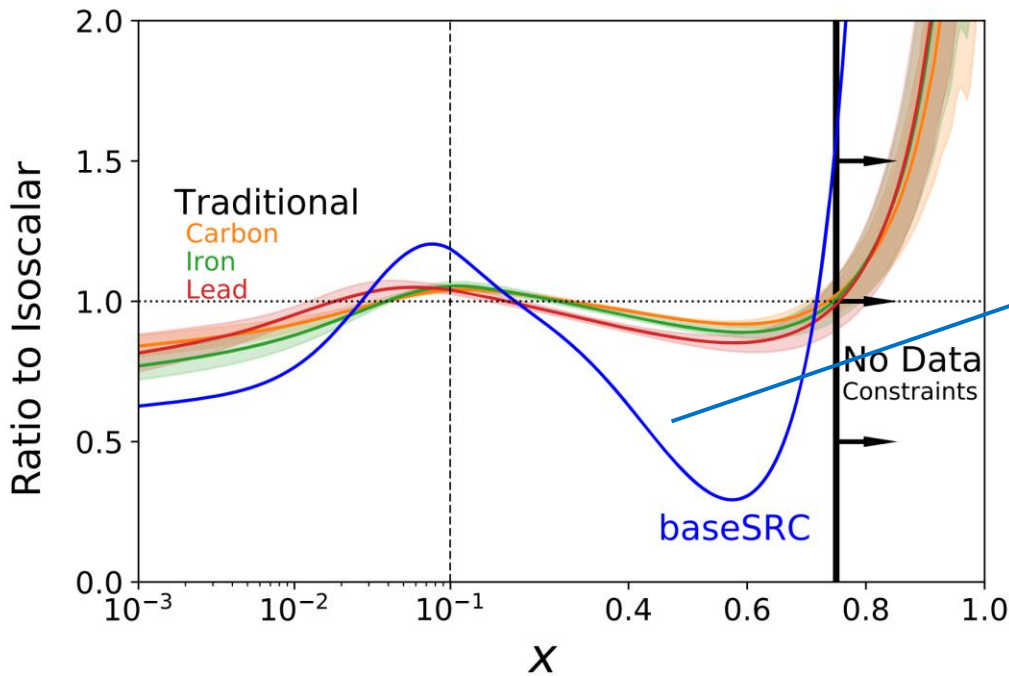
[Lynn et.al, JPG 47 (2020)]



[CLAS, Nature 566 (2019)]

**EMC and SRC are strongly linearly correlated**

# Introduction on SRC

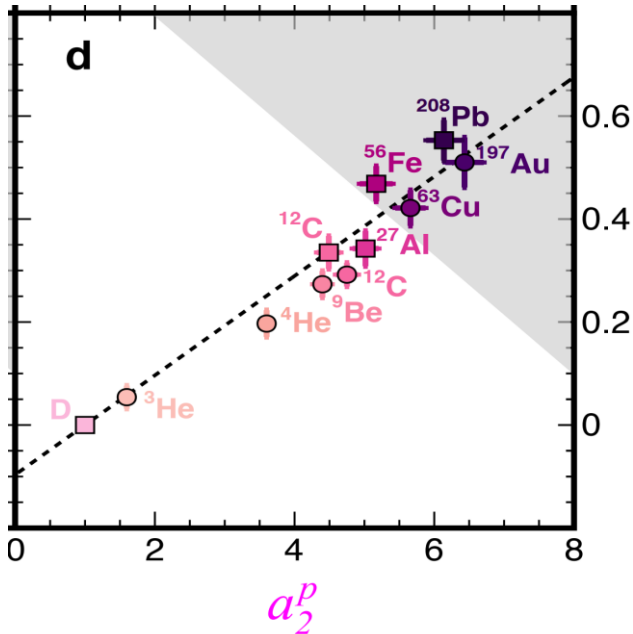


[Denniston et.al., PRL 133 (2024)]

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

nCTEQ:  $\frac{dR_{EMC}}{dx} \Big|_{SRC} = -(1.8 \sim 2.2)$

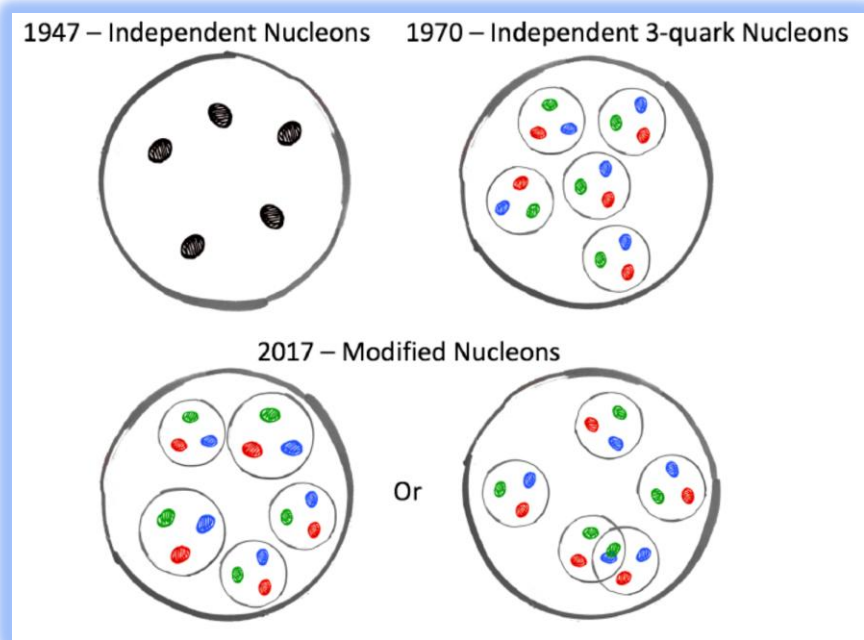
CLAS:  $\frac{dR_{EMC}}{dx} \Big|_{SRC} = -(1.7 \sim 2.1)$



[CLAS, Nature 566 (2019)]

# Introduction on SRC

- Progress in Quark Nuclear Physics:

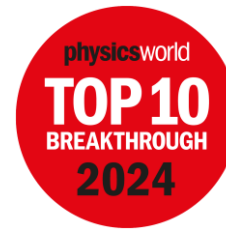


[Or Hen et.al., Rev. Mod. Phys. 89 (2017)]

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

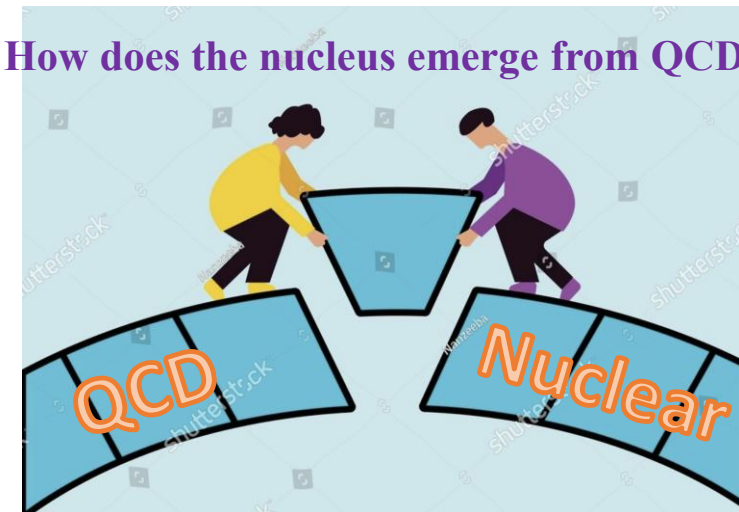
$$F_2^A \neq Z \cdot F_2^p + N \cdot F_2^n$$

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



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

How does the nucleus emerge from QCD?



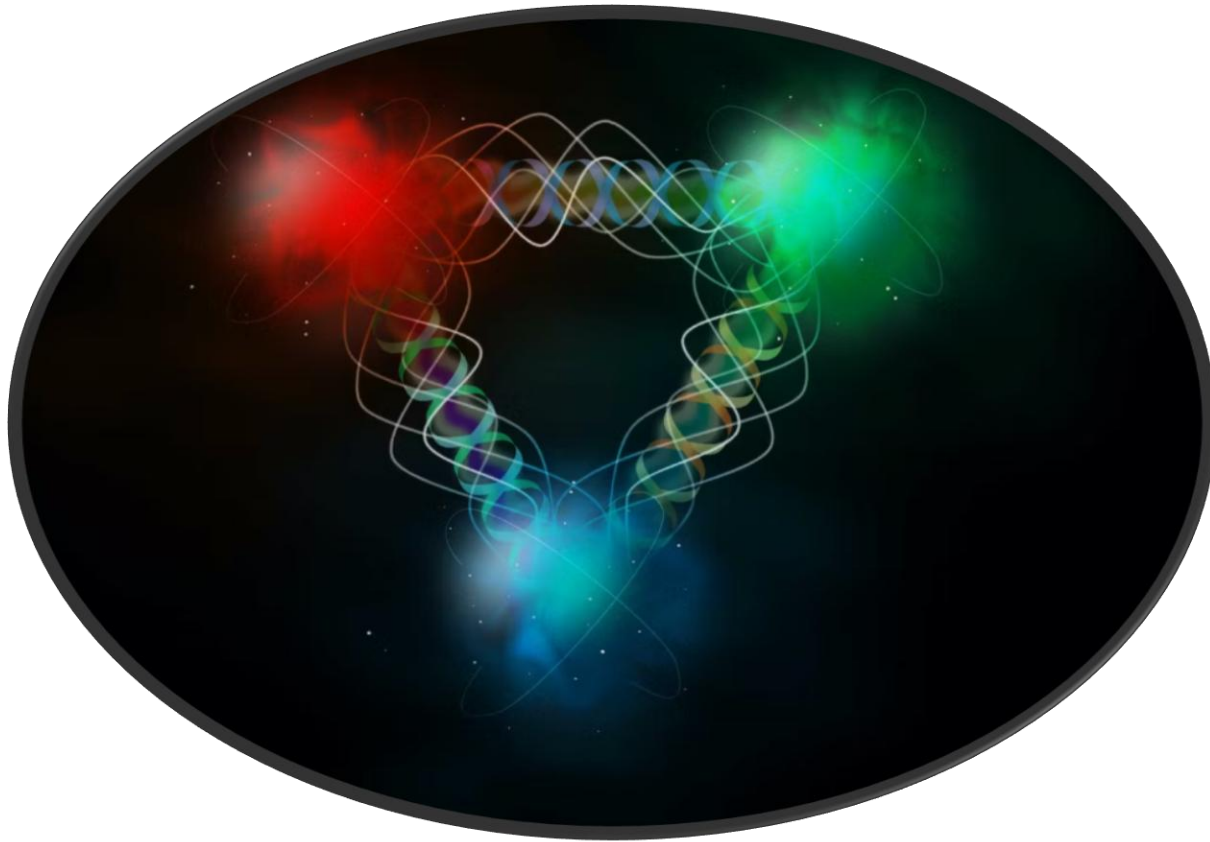


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# The gluons in nucleon

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

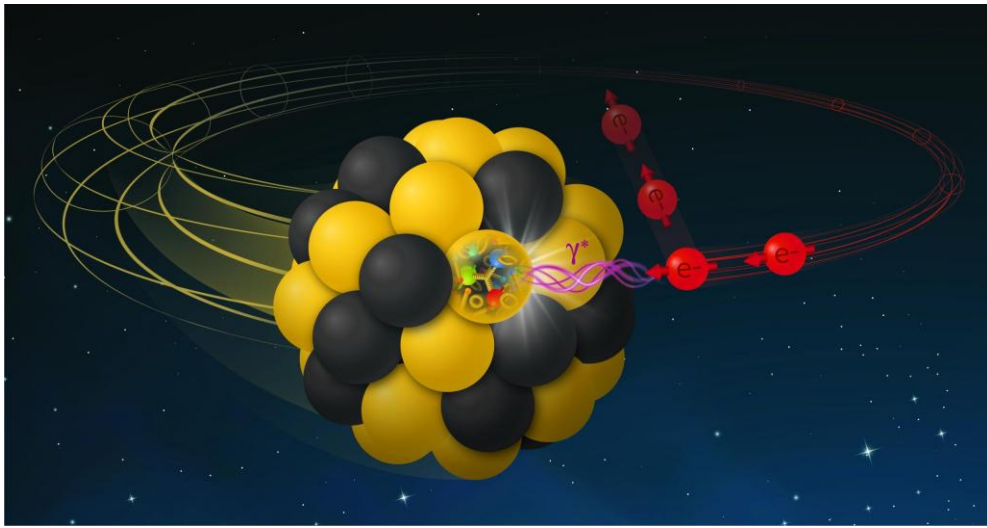


**How about the gluons?**

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

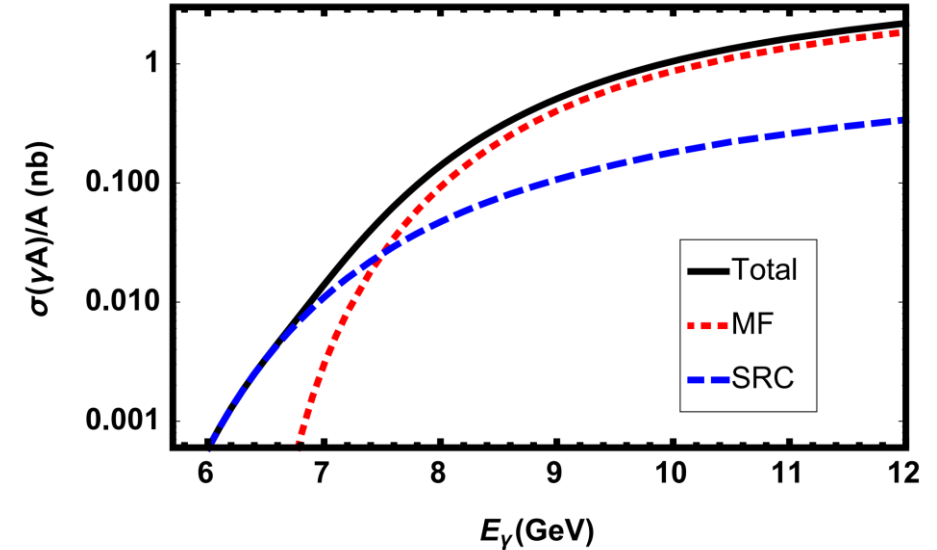
# EMC effect of gluons ?

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



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

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



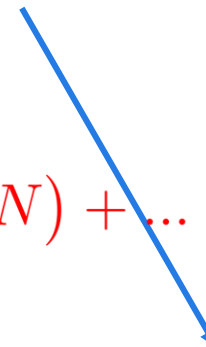
[Hatta, Strikman, **J.X.**, F.Yuan, PLB 803 (2020)]

# 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  $J/\psi$  production cross section**.
- The Mellin moments of gluon nPDF

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


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


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

# Linear gluon EMC-SRC relation

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

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

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

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

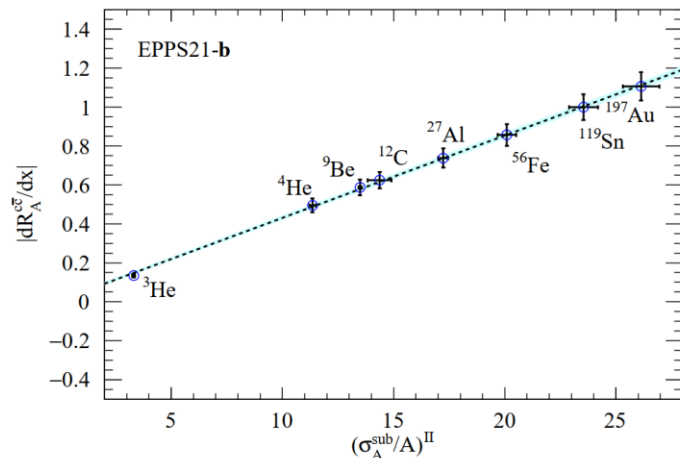
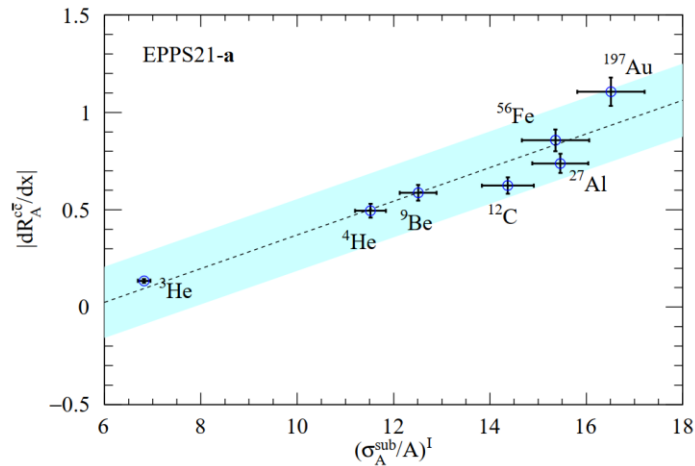
- One can examine the linear relation from the future experimental data.

**Gives a non-trivial prediction on gluon structure**

# Linear gluon EMC-SRC relation

- Utilize the global fits of nPDFs by EPPS21.

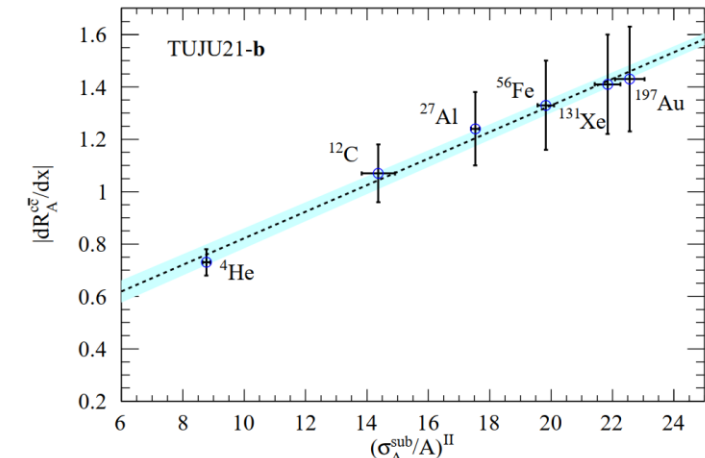
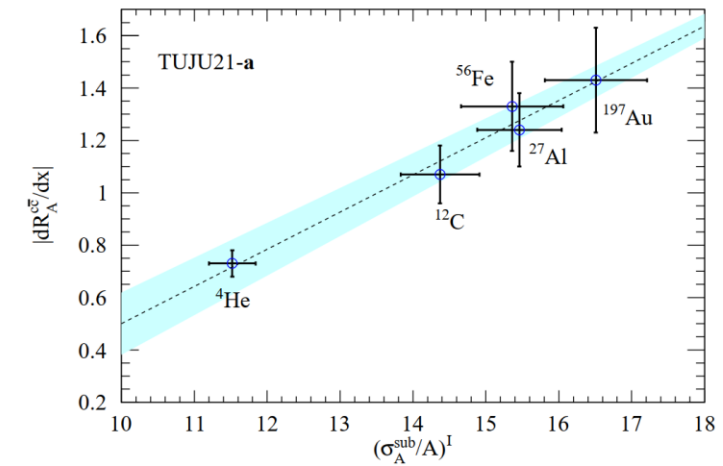
[EPPS21, EPJC 82 (2022)]



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

- Utilize the global fits of nPDFs by TUJU21.

[TUJU21, PRD 105 (2022)]



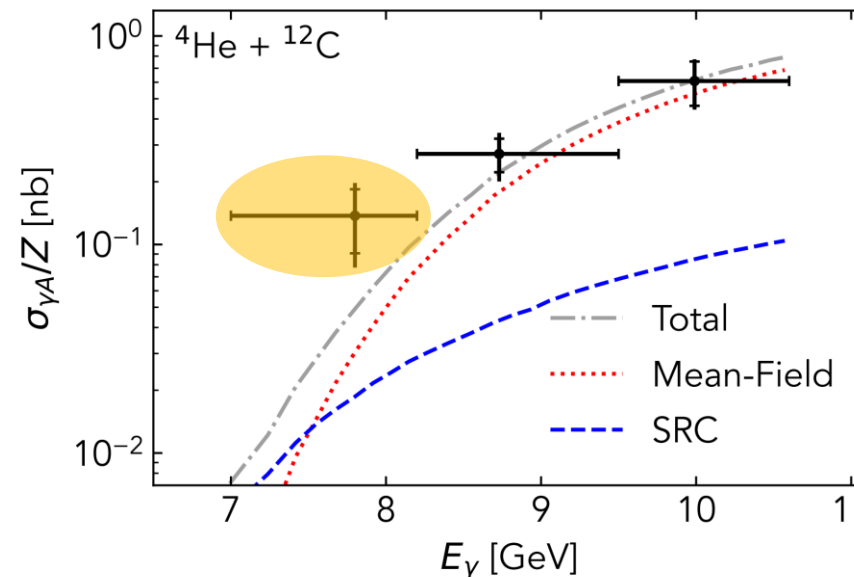
**Crucial to test this linear relation by future experimental data**

# The jury is still out

## ➤ The cross section of sub-threshold production of $J/\psi$

### □ 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)]



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# BESIII can be viewed as a fixed-target nuclear experiment

## □ Advantages:

- ◆ As a pure  $s\bar{s}$  state,  $\phi$  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)]

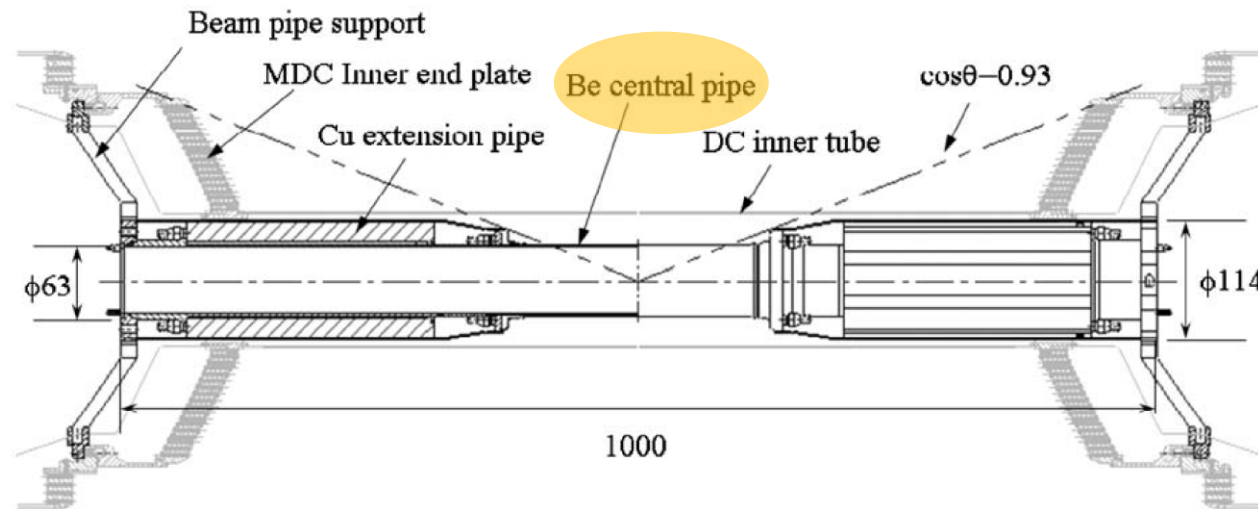


Fig. 3. Cross-sectional view of the beam pipe.

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

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

## ➤ Source of photons

### Three-body

$$J/\psi \rightarrow \pi^+ + \pi^- + \gamma$$

$$J/\psi \rightarrow K^+ + K^- + \gamma$$

$$\psi(3686) \rightarrow \mu^+ + \mu^- + \gamma$$

$$e^+ + e^- \rightarrow e^+ + e^- + \gamma$$

$$e^+ + e^- \rightarrow \pi^+ + \pi^- + \gamma$$

... ..

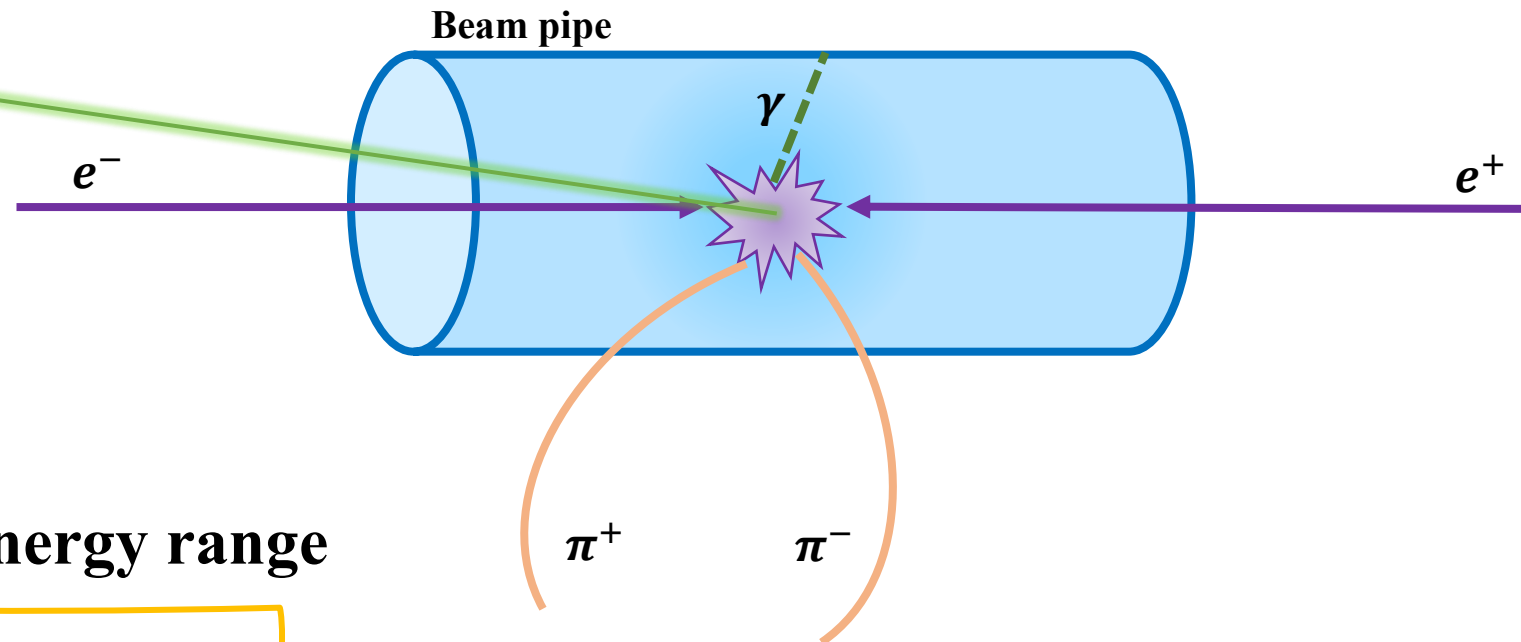
### Two-body

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

$$\psi(3686) \rightarrow \eta(\eta') + \gamma$$

$$J/\psi \rightarrow \rho + \pi$$

... ..



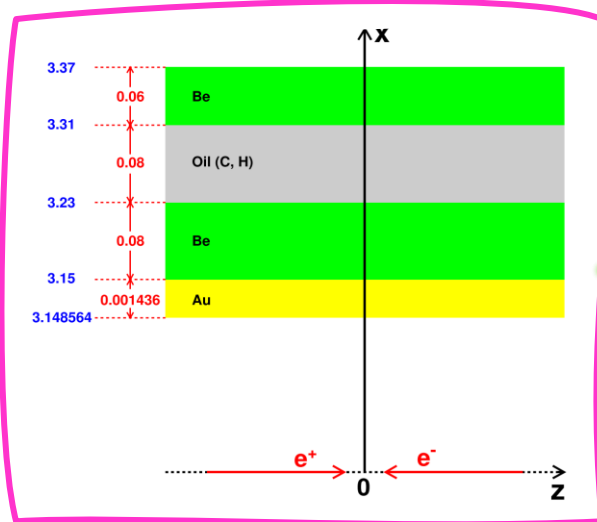
## ➤ Provide photons with desired energy range

✓ 1.30~1.57 GeV (Sub-threshold)

✓ 1.57~1.82 GeV (Near-threshold)

# Production of $\phi$

## ➤ Schematic diagram of the beam pipe



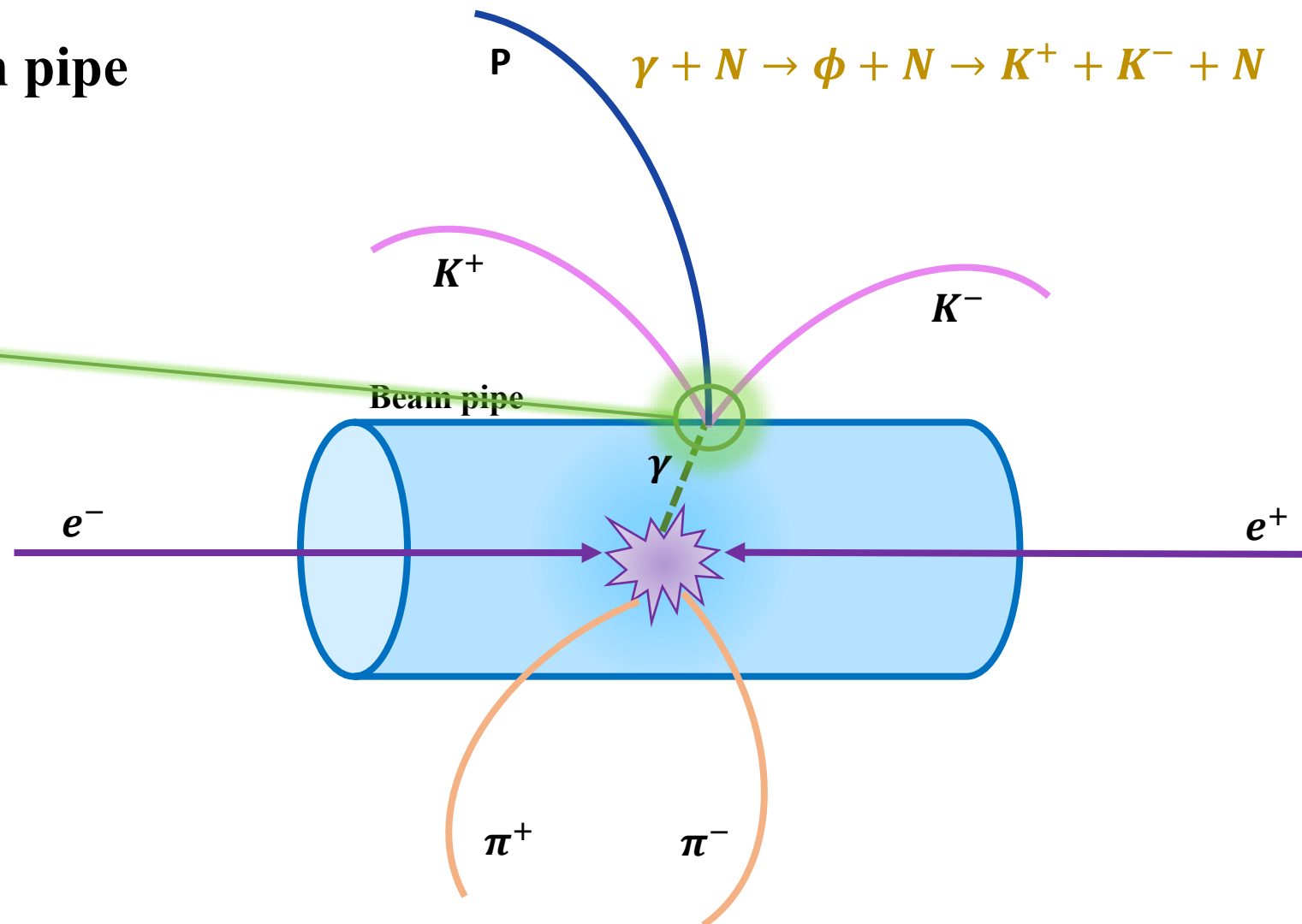
$$N^{\text{sig}} = N_{\text{sub}}^{\text{sig}} + N_{\text{near}}^{\text{sig}}$$

$$= \mathcal{B}(\phi \rightarrow K^+ K^-) \left( \int_{1.30 \text{ GeV}}^{1.57 \text{ GeV}} dE_\gamma \sigma_{\gamma A \rightarrow \phi N(A-1)}(E_\gamma) \mathcal{L}_{\text{eff}}(E_\gamma) \right. \\ \left. + \int_{1.57 \text{ GeV}}^{1.85 \text{ GeV}} dE_\gamma \sigma_{\gamma A \rightarrow \phi N(A-1)}(E_\gamma) \mathcal{L}_{\text{eff}}(E_\gamma) \right).$$

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

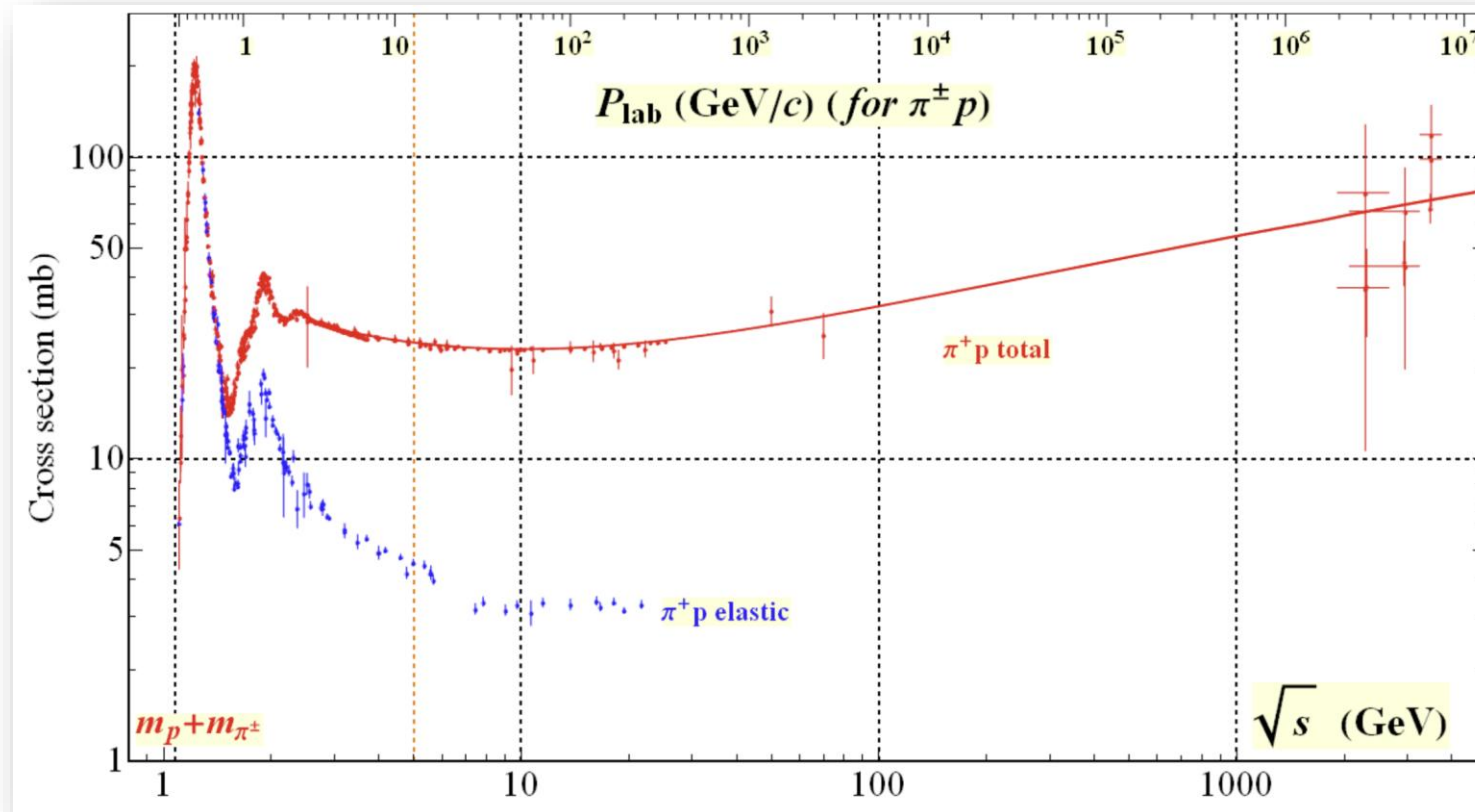
## ➤ The predicted signal can reach a dozen

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



# Searching SRC by $\pi N$ scattering

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

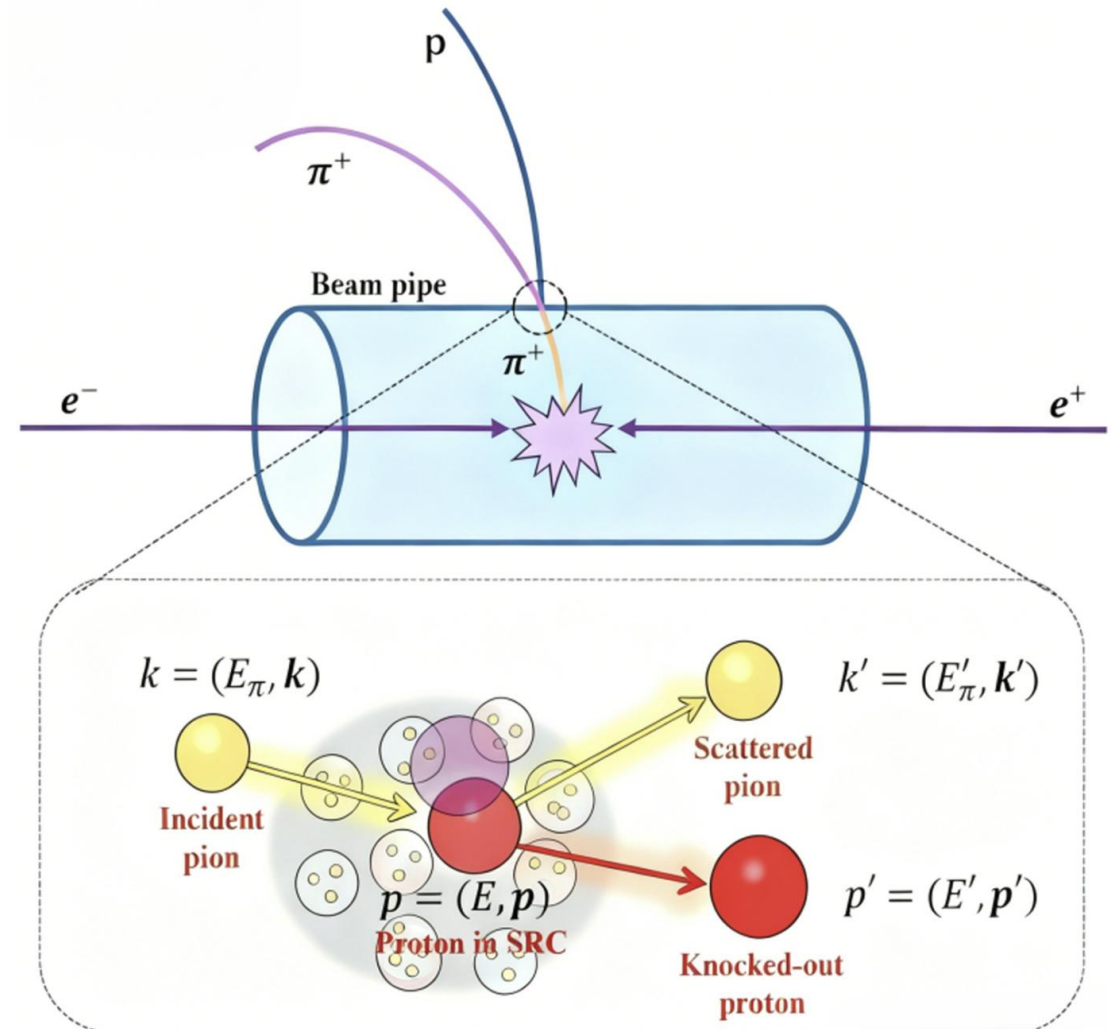


- However, the data on  $\pi N$  (bound in nuclei) scattering is limited.

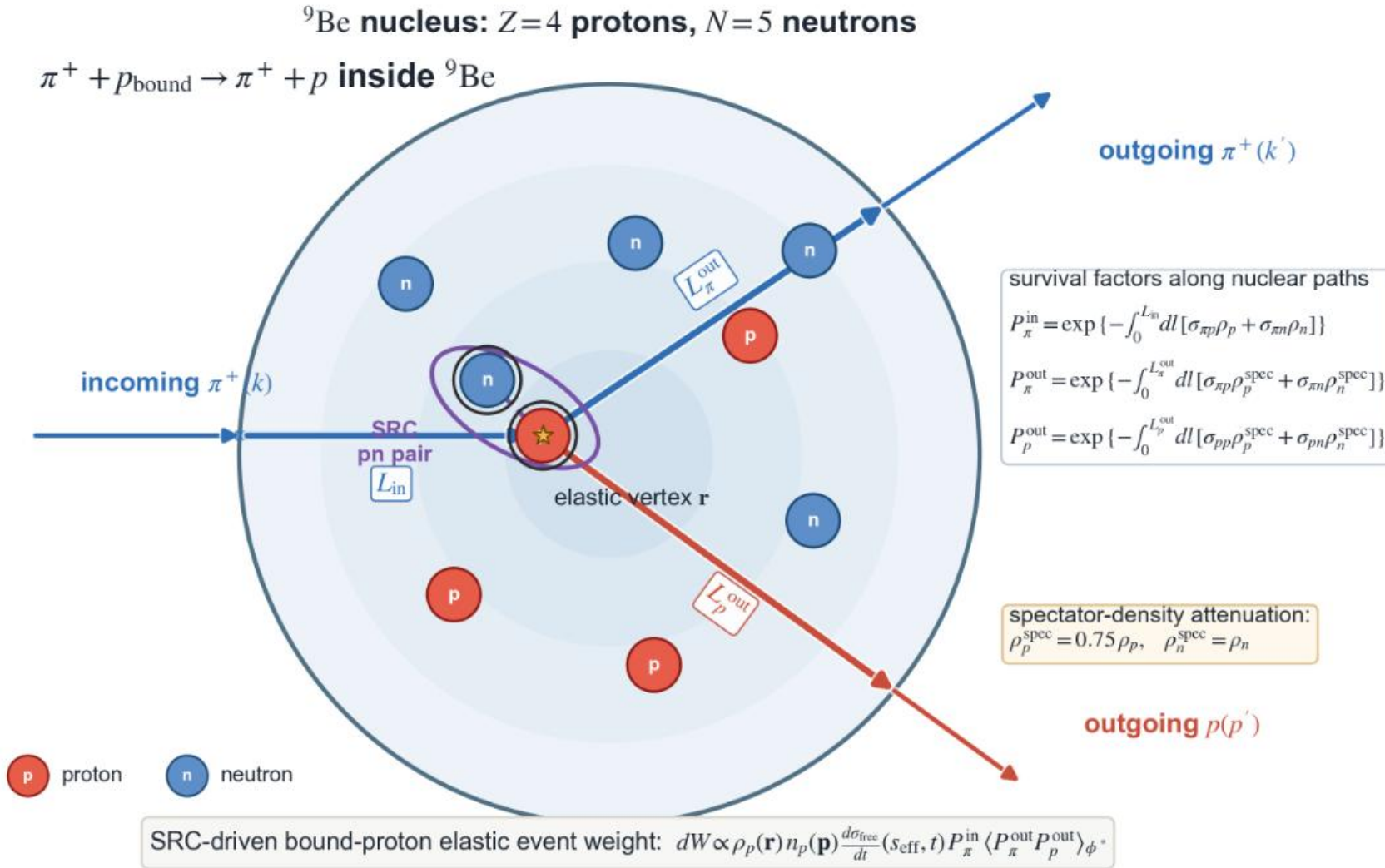
# Searching SRC by $\pi N$ scattering

➤ This process can be precisely measured at BESIII.

- ✓ The typical cross section is  $\sim 10$  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 $\pi N$ scattering

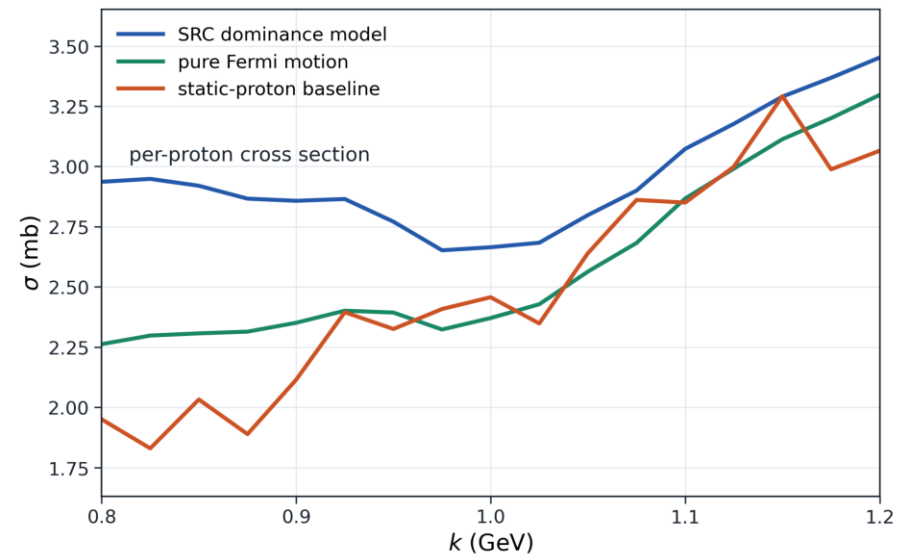
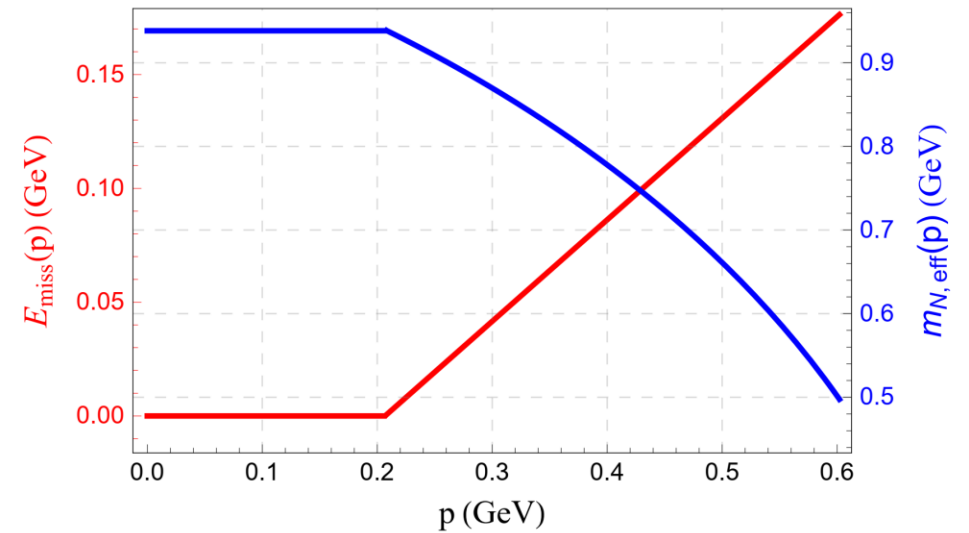


$$\sigma_{\text{bound}}(|\mathbf{k}|) = \int d^3\mathbf{r} \hat{\rho}_p(\mathbf{r}) \int \frac{d^3\mathbf{p}}{(2\pi)^3} \rho_p(|\mathbf{p}|) \int dt \frac{d\sigma_{\text{free}}}{dt}(\sqrt{s}, t) \times P_{\pi}^{\text{in}}(\mathbf{r}, \mathbf{k}) P_{\pi}^{\text{out}}(\mathbf{r}, \mathbf{k}') P_p^{\text{out}}(\mathbf{r}, \mathbf{p}') .$$

# Searching SRC by $\pi N$ scattering

- Two straightforward and experimentally accessible observables.
- The difference in quasielastic cross section between  $\pi^+$ -bound proton and  $\pi^+$ -free proton scattering.

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



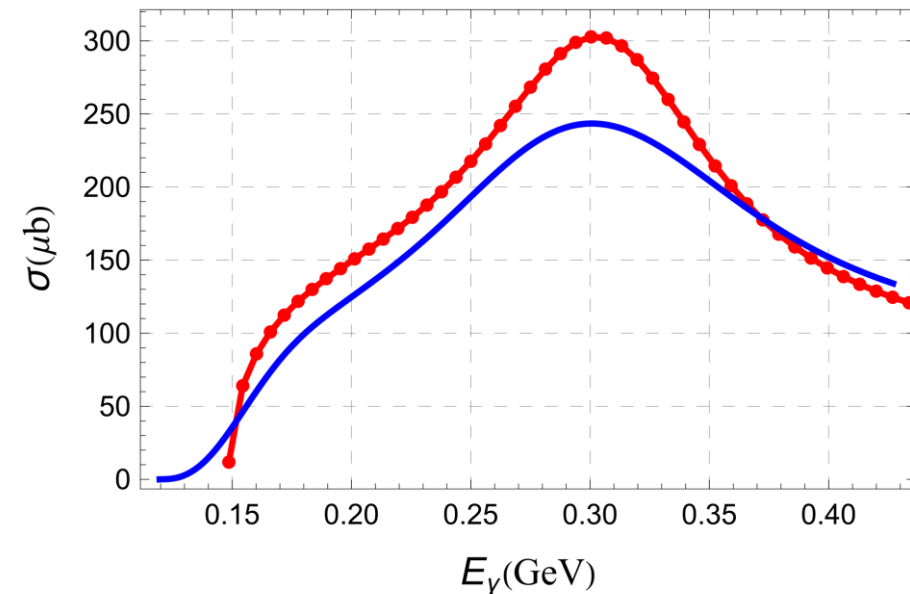
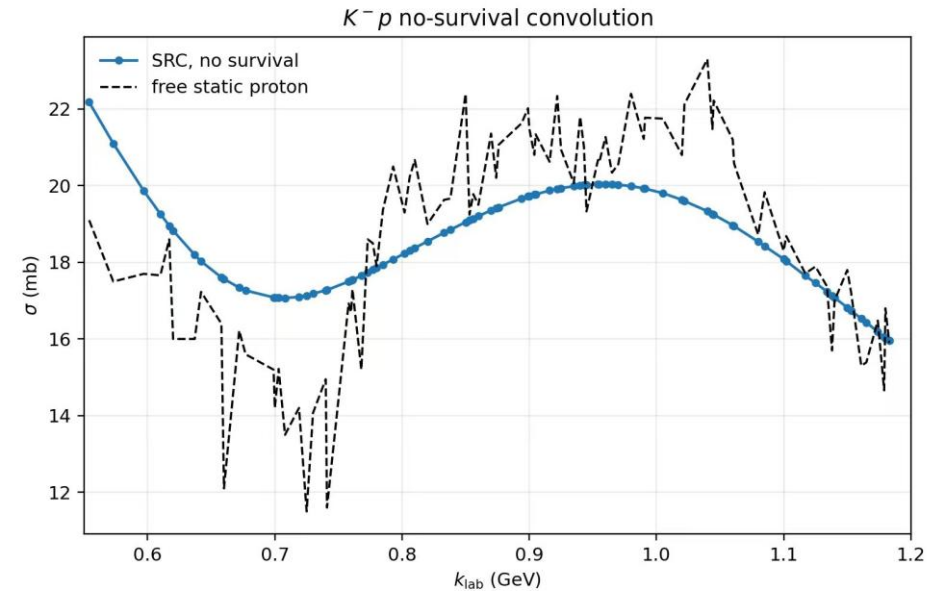
# Searching SRC by $K N$ scattering and $\gamma n \rightarrow \pi^- p$

- Similarly, the  $KN$  can also be utilized to investigate SRC.

$$K^- p \rightarrow K^- p$$

- The photoproduction of pion can also be utilized to investigate the momentum distribution of neutrons.

$$\gamma n \rightarrow \pi^- p$$





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# Summary

- 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

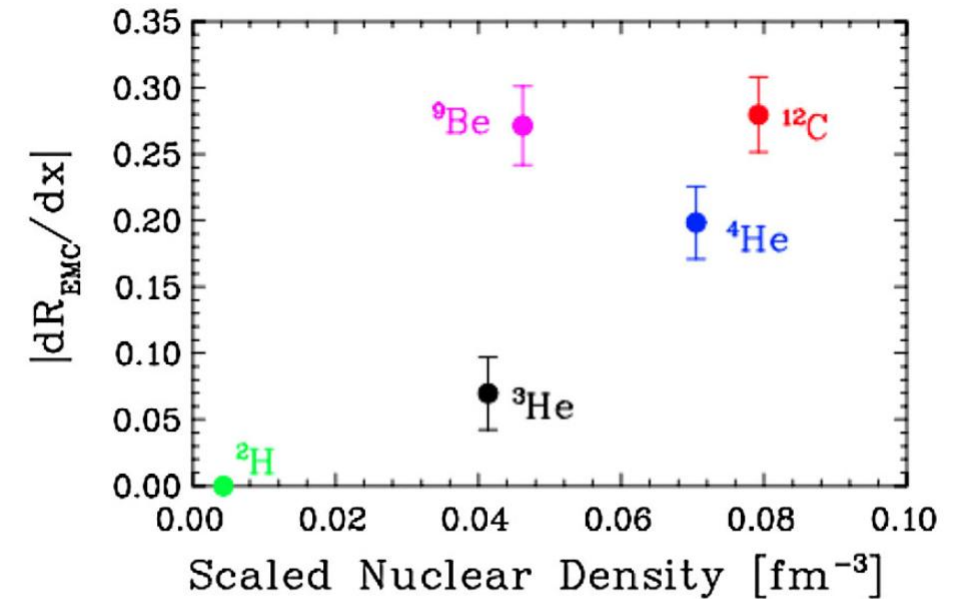
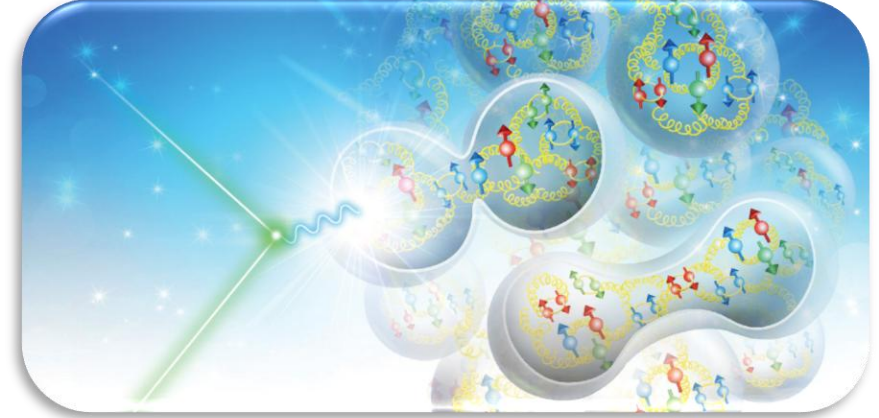


FIG. 23. The slope of the EMC effect for  $0.35 \leq x_B \leq 0.7$  plotted vs the average nuclear density for various light nuclei as measured at Jefferson Lab. From [Seely \*et al.\*, 2009](#).

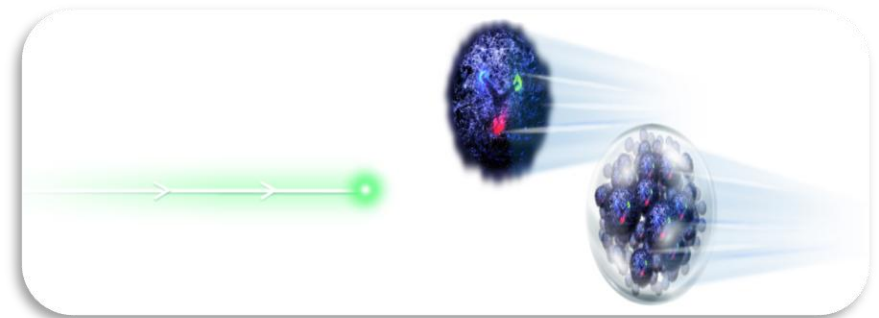
# The EMC effect

➤ Proton's inelastic structure function,

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



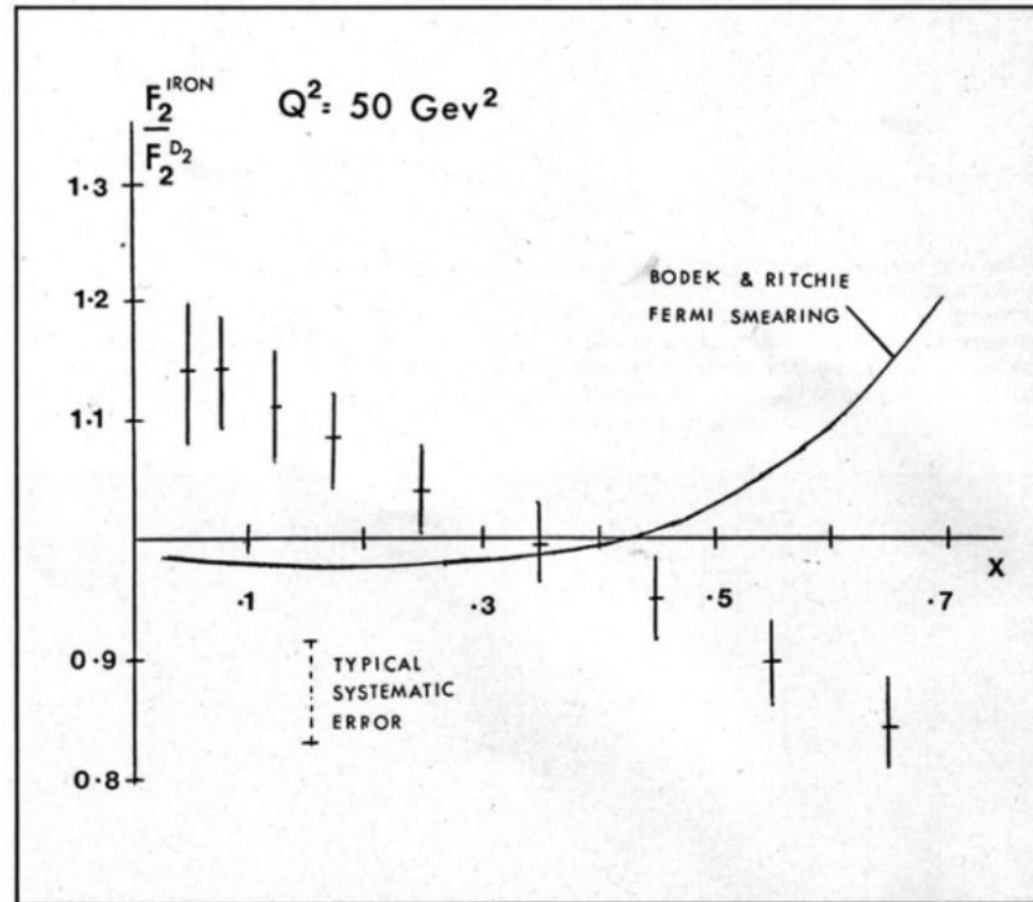
EIC Yellow Report, NPA 1026 (2022)



The Present and Future of QCD, ePrint:2303.02579

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

# The EMC effect

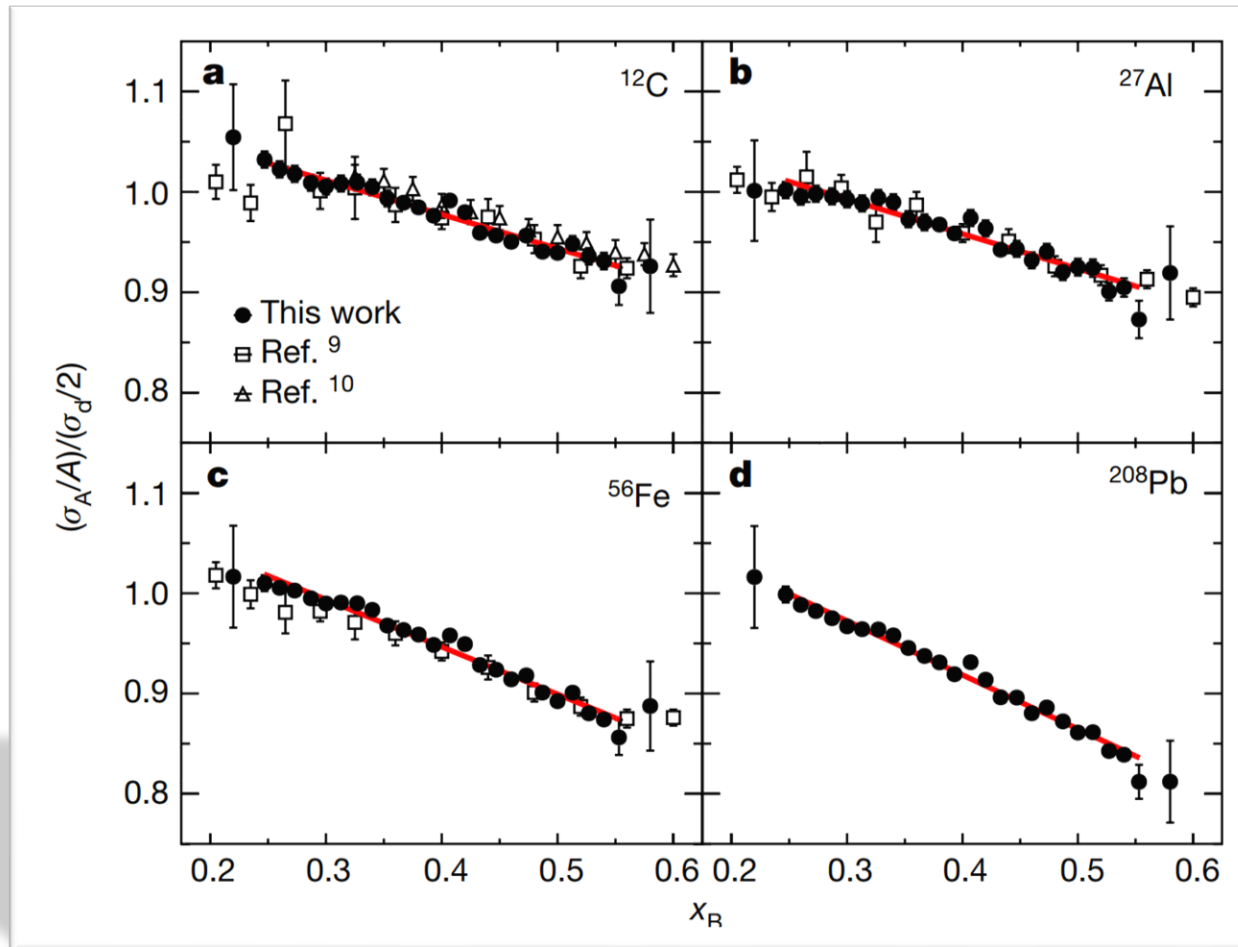


European Muon Collaboration (EMC)

**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)]

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

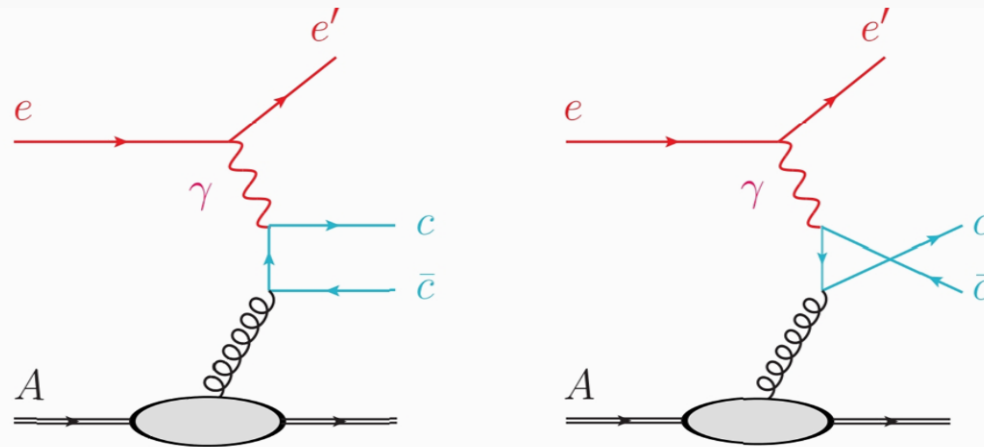


FIG. 1: Photoproduction of the heavy quark pair  $c\bar{c}$  through photon-gluon fusion at leading order.

# EMC (vertical axis): reduced cross section

$$\begin{aligned}\sigma_{A,red}^{c\bar{c}}(x, Q^2) &\equiv \left( \frac{d\sigma_A^{c\bar{c}}}{dx dQ^2} \right) \frac{xQ^4}{2\pi\alpha^2[1 + (1 - y)^2]} \\ &= \frac{2}{[1 + (1 - y)^2]} (xy^2 F_{1,A}^{c\bar{c}}(x, Q^2) + (1 - y)F_{2,A}^{c\bar{c}}(x, Q^2)) ,\end{aligned}\tag{1}$$

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  $g_A$ :

$$\begin{aligned}F_{1,A}^{c\bar{c}}(x, Q^2) &= \int_{\tau x}^1 \frac{dz}{z} g_A(z, \hat{s}) f_1\left(\frac{x}{z}, Q^2\right), \\ F_{2,A}^{c\bar{c}}(x, Q^2) &= \int_{\tau x}^1 \frac{dz}{z} z g_A(z, \hat{s}) f_2\left(\frac{x}{z}, Q^2\right).\end{aligned}\tag{2}$$

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  $R_g^A$  and the gluon PDF in a free proton [25]

$$g_A(x, Q^2) = AR_g^A(x, Q^2)g(x, Q^2).\tag{3}$$

The specific expression for  $R_g^A$  can be found in [20].

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

$$R_A^{c\bar{c}}(x, Q^2) = \frac{\sigma_{A,red}^{c\bar{c}}(x, Q^2)}{A\sigma_{N,red}^{c\bar{c}}(x, Q^2)},\tag{4}$$

## EMC (vertical axis): reduced cross section

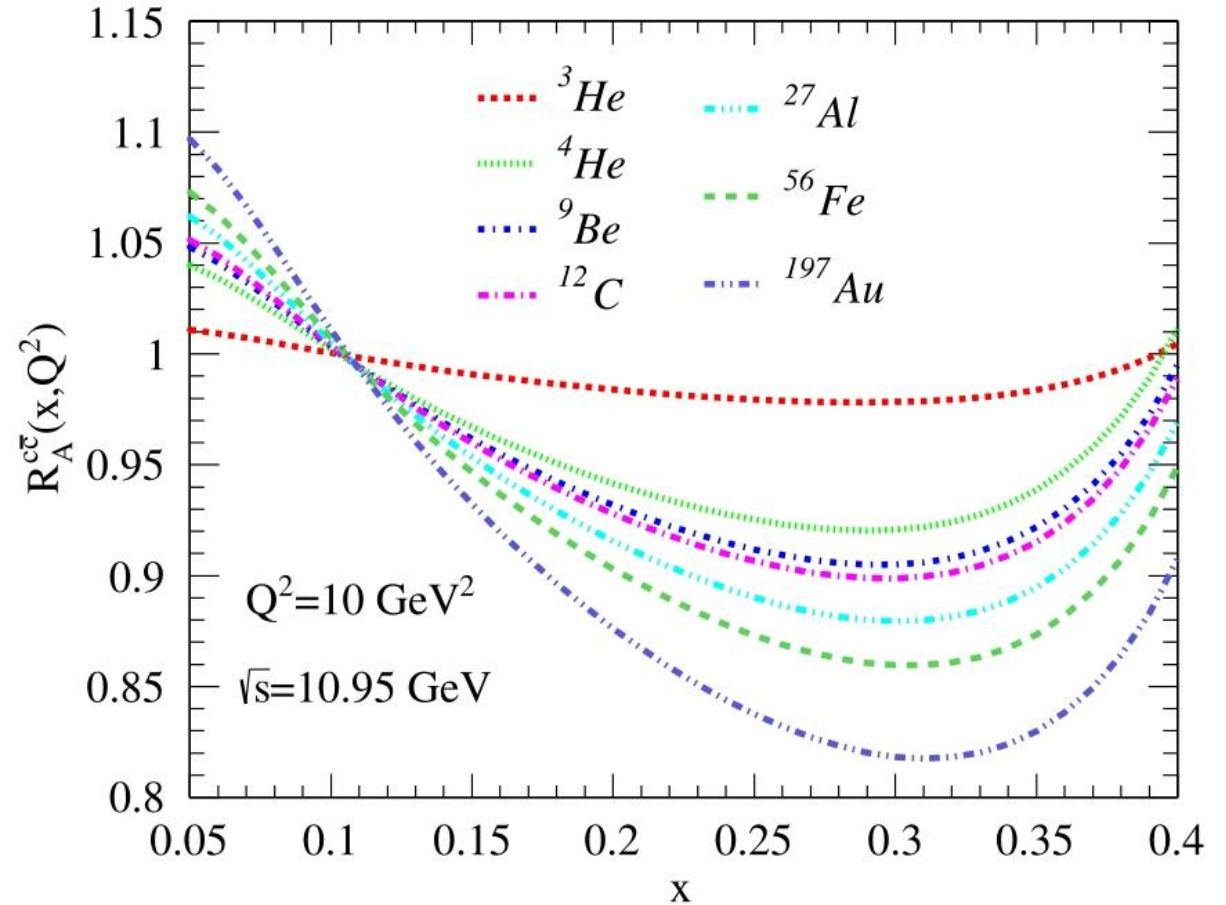
- The gluon nPDF can be parameterized through the gluon PDF in a free proton

[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

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



## EMC (vertical axis): reduced cross section

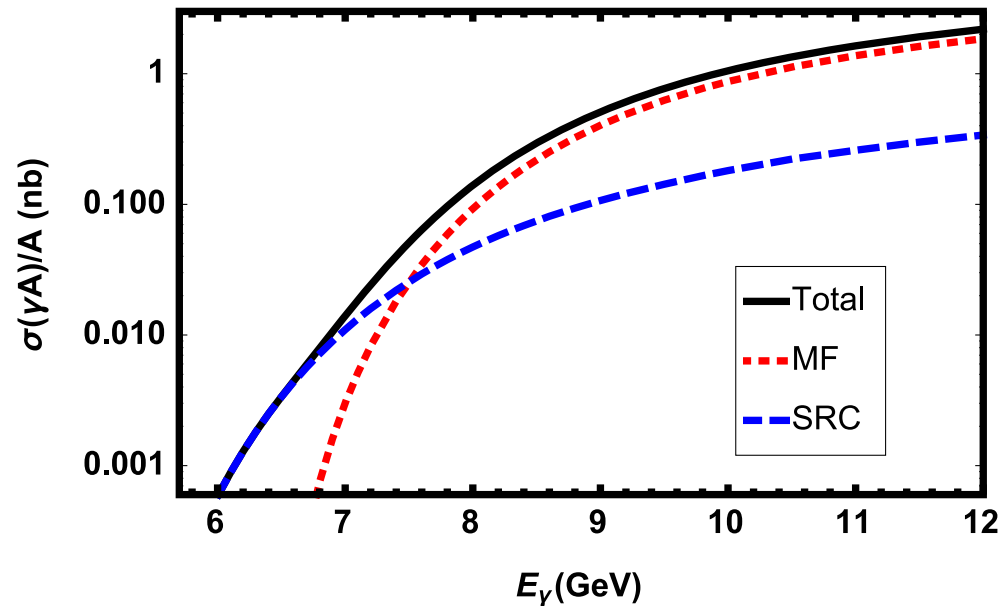
➤ Quantify the strength of the gluon EMC effect for nucleus  $A$  by the slope of  $R_A^{c\bar{c}}$ , i.e.,  $|dR_A^{c\bar{c}}/dx|$ .

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

## SRC (horizontal axis): sub-threshold $J/\psi$ production

- For a free nucleon target, the threshold photon energy to generate a  $J/\psi$  is  $E_\gamma \sim 8.2$  GeV.
- If the nucleon is bound in nucleus, the production of  $J/\psi$  can occur at lower photon energy.

[Phys.Lett.B 498 (2001)]



**Fig. 3.** Sub-threshold  $J/\psi$  production in photon-Carbon collisions as a function of incoming photon energy  $E_\gamma$ . 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 III

- 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  $J/\psi$  production.

| Nucleus           | $ dR_A^{c\bar{c}}/dx $ | $(\sigma_A^{sub}/A)^I$ | $(\sigma_A^{sub}/A)^{II}$ |
|-------------------|------------------------|------------------------|---------------------------|
| $^3\text{He}$     | $0.152 \pm 0.013$      | $6.82 \pm 0.13$        | $3.31 \pm 0.06$           |
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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 ~ 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 !

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

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

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

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

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

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

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

# Fresh opportunities in BESIII

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- ◆ Various nuclear, particle, and astrophysics measurements...

## □ For instances:

- ◆ We can probing 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 cross section is relatively much larger, about 300  $\mu\text{b}$ .

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

