Massachusetts Institute of Technology

TEL AVIV UNIVERSITY אוניברסיטת תל אביב

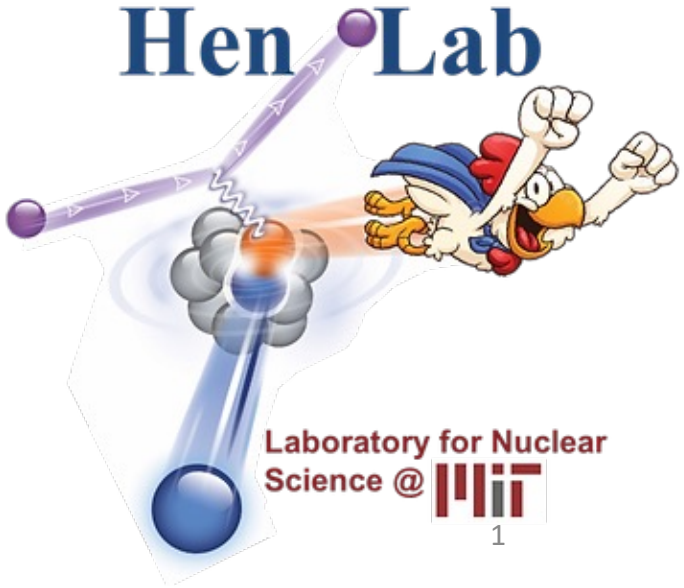
The Onset of Short Range Correlation (SRC)

LNS Laboratory for Nuclear Science

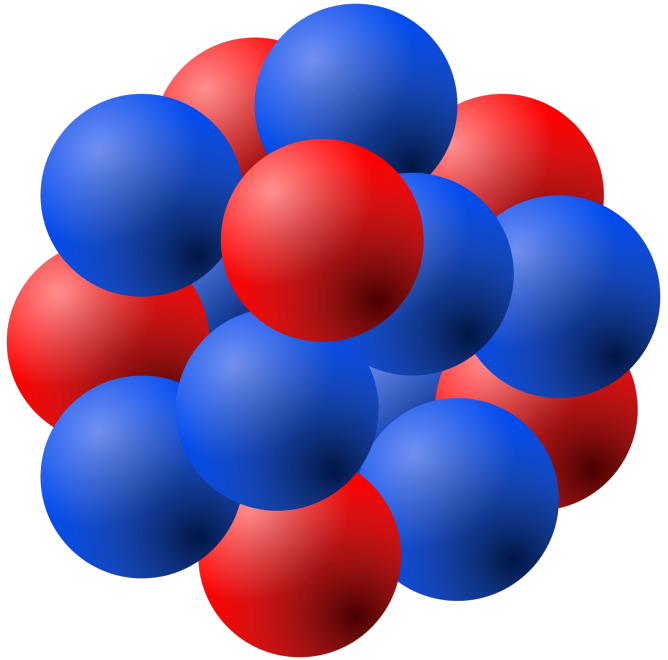
Igor Korover

2024 JLUO Annual Meeting

June 10, 2024



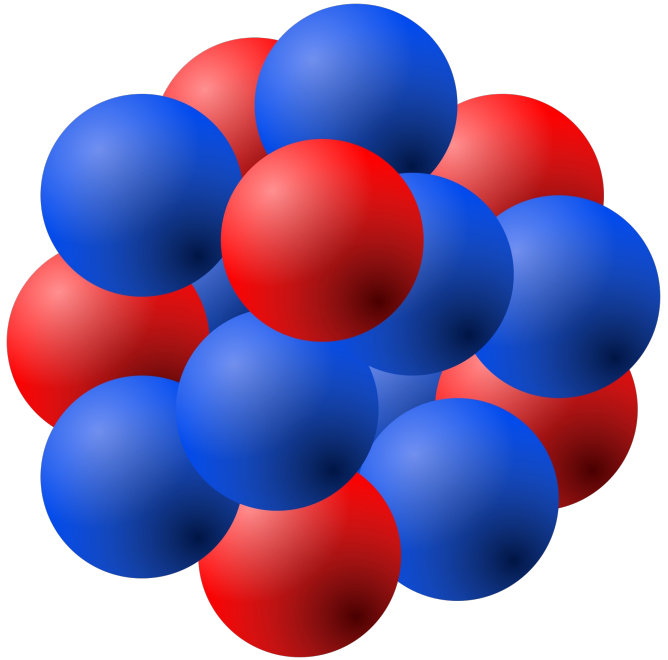
The Nuclear Challenge



1. Many-body problem

$$\sum_i \left\{ -\frac{\hbar^2}{2m_i} \nabla_i^2 \Psi(\vec{r}_1, \ldots, \vec{r}_N, t) \right\} + U(\vec{r}_1, \ldots, \vec{r}_N) \Psi(\vec{r}_1, \ldots, \vec{r}_N, t) = i\hbar \frac{\partial}{\partial t} \Psi(\vec{r}_1, \ldots, \vec{r}_N, t)$$

The Nuclear Challenge



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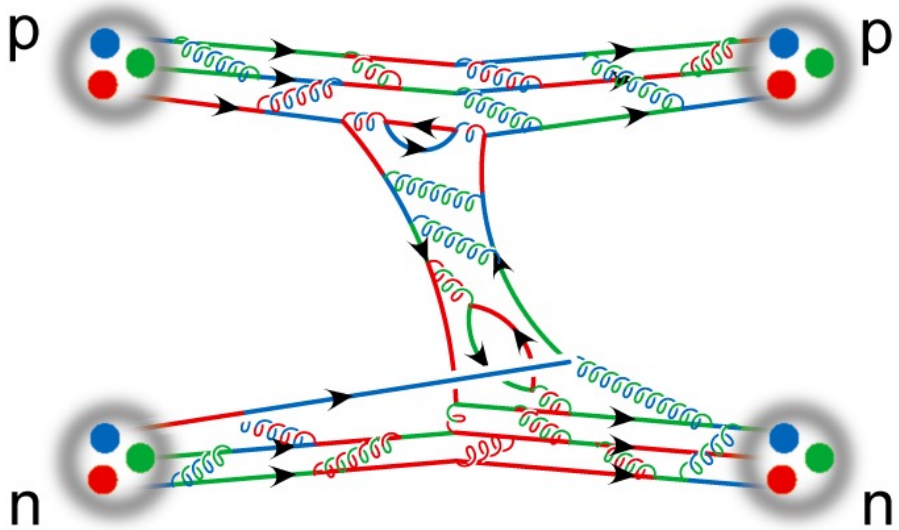
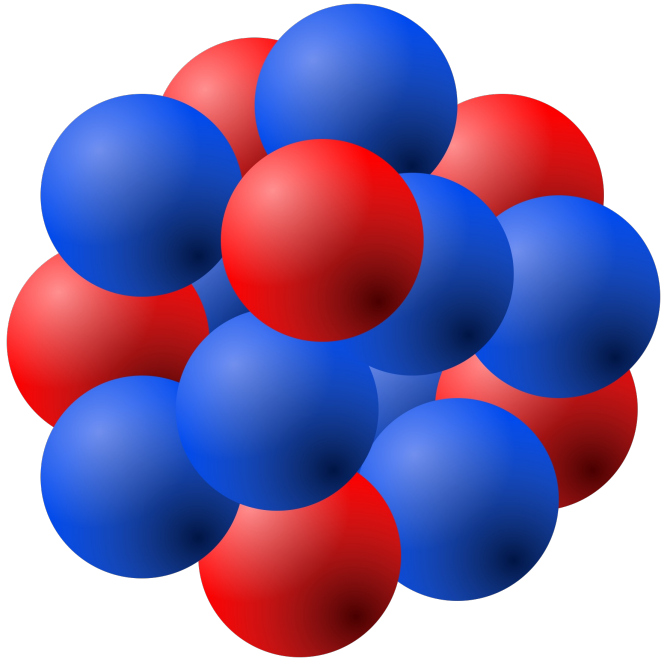
2. Complex QCD interaction



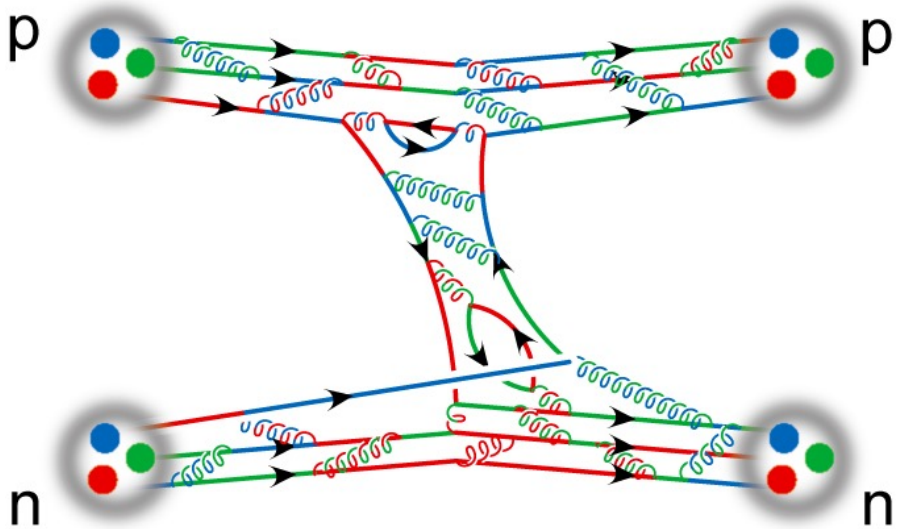
The Nuclear Challenge



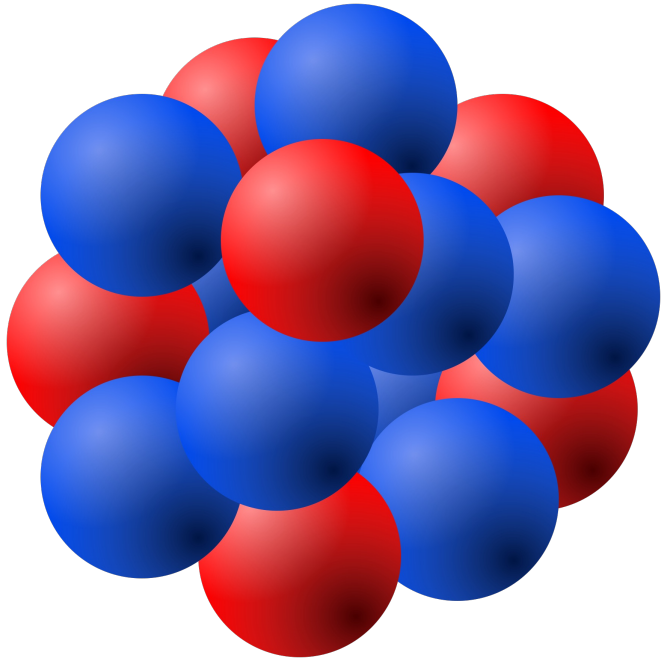
1. Many-body problem

   ➔ **Numerical Technics** (Quantum Monte Carlo, Lattice …)

2. Complex QCD interaction



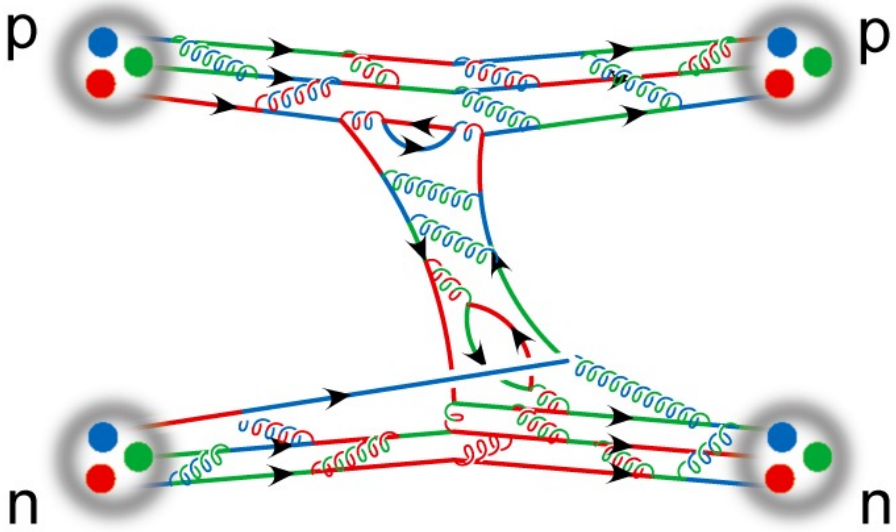
The Nuclear Challenge

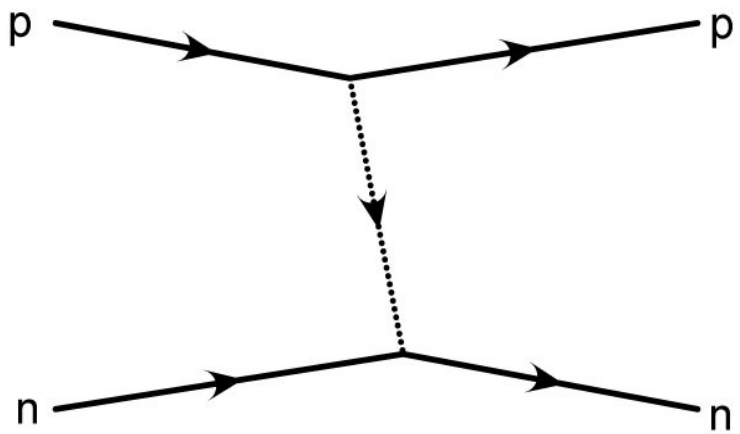


1. Many-body problem

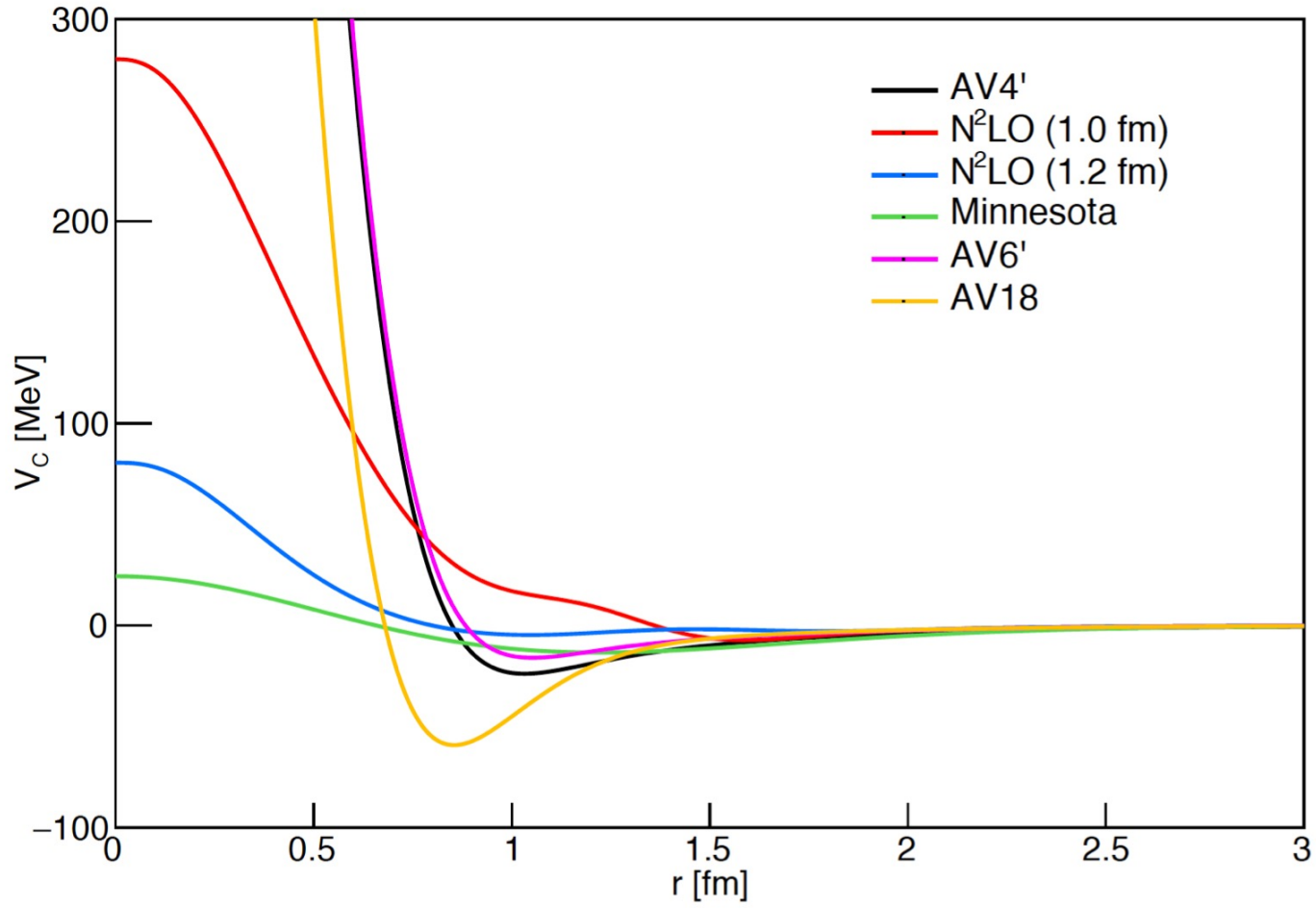
   ➔ **Numerical Technics** (Quantum Monte Carlo, Lattice …)

2. Complex ~~QCD~~ **Effective interaction**

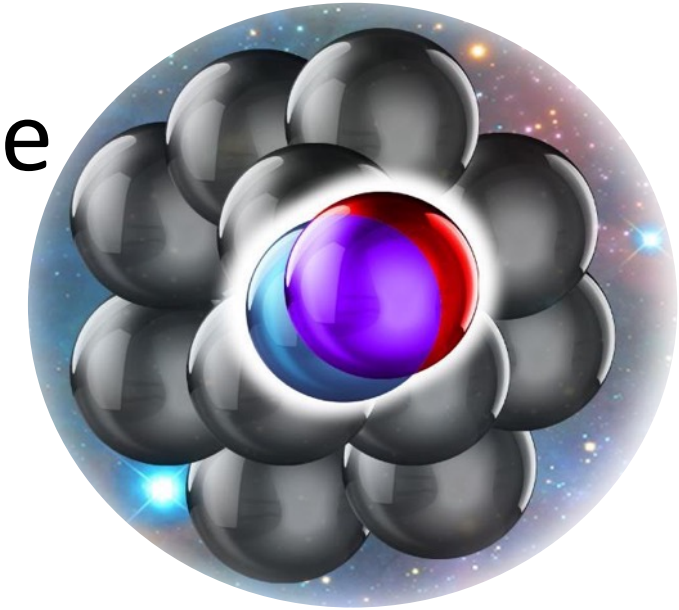




NN interaction is highly uncertain at short distance.

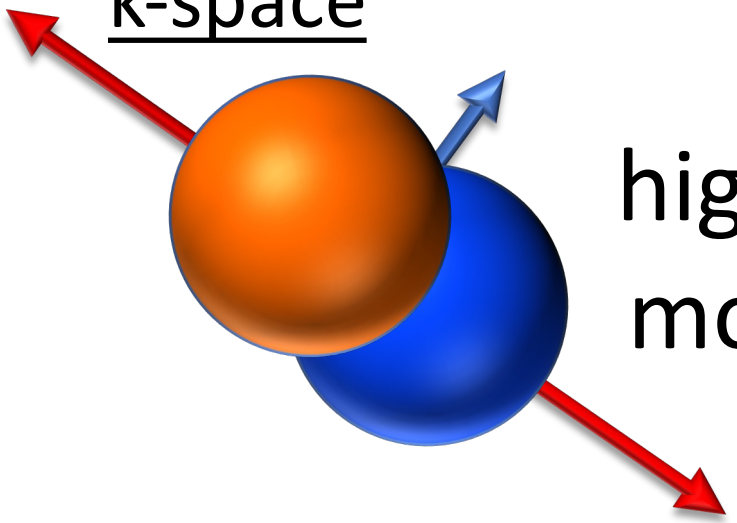


r-space



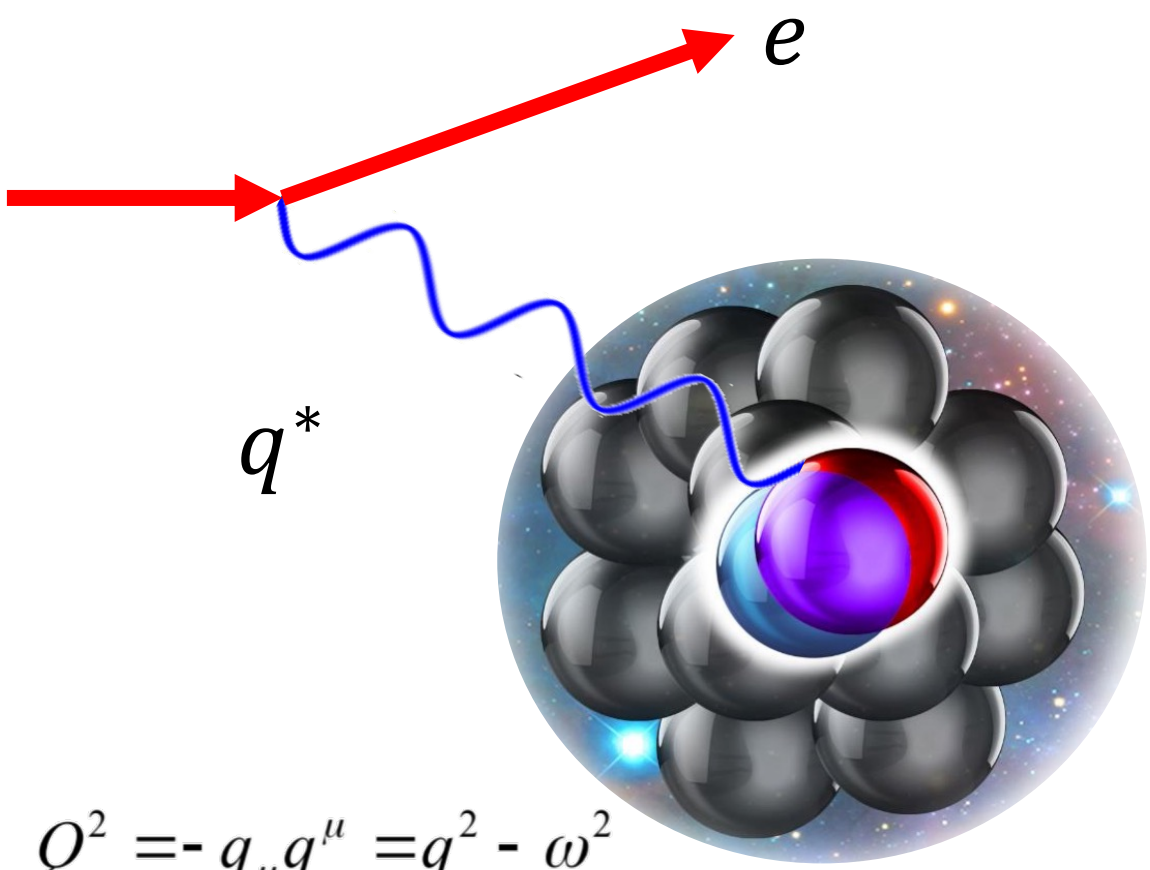
Nucleon pairs that are close together in the nucleus

k-space



high ***relative*** and lower ***c.m.*** momentum compared to k_F

2N – SRC measurements



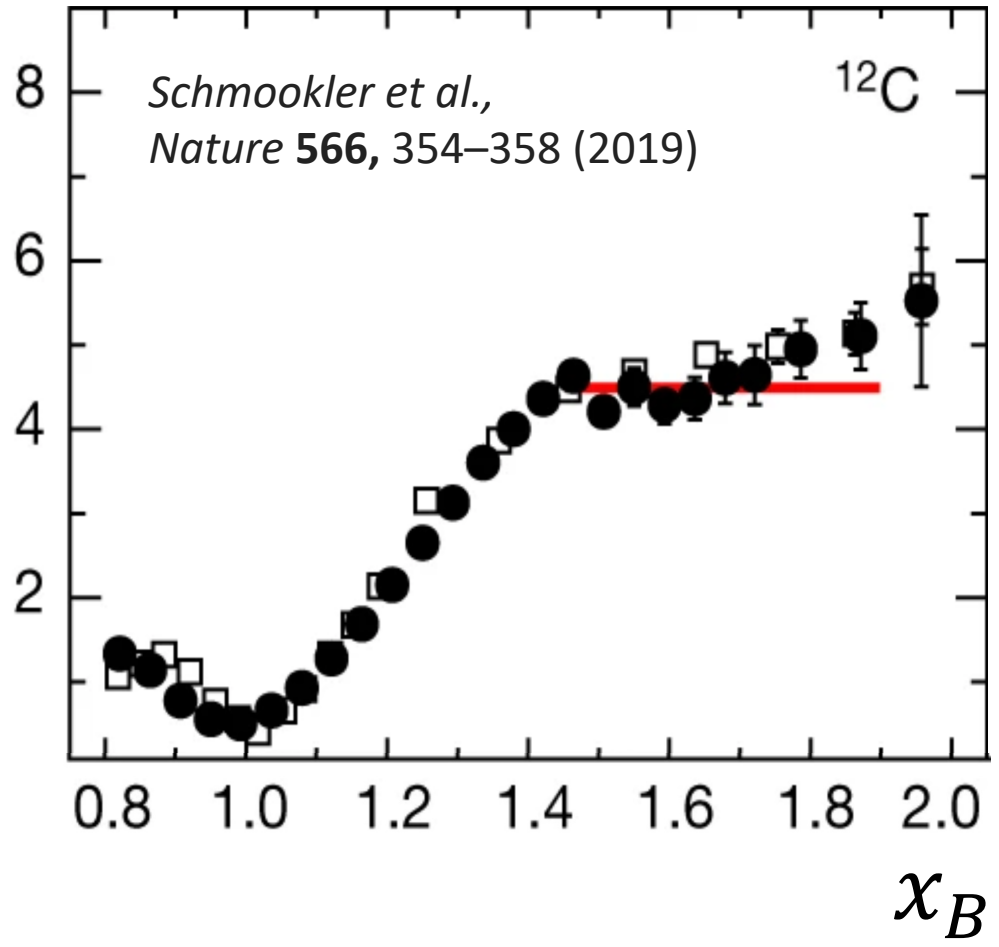
$$Q^2 = -q_\mu q^\mu = q^2 - \omega^2$$

$$\omega = E' - E$$

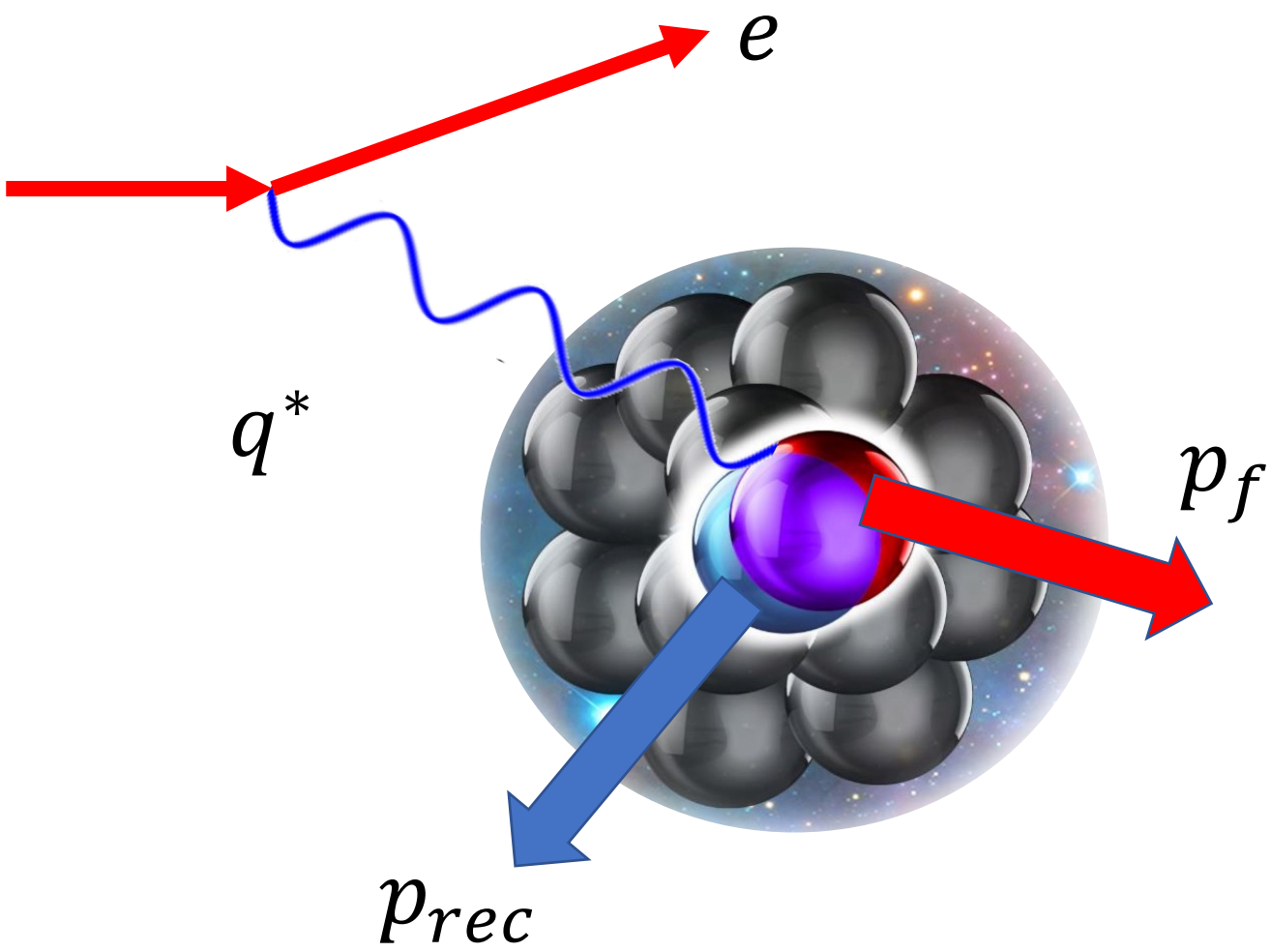
$$x_B = \frac{Q^2}{2m\omega}$$

Inclusive Scattering

$$R = \frac{\sigma_A(x_B)/A}{\sigma_d(x_B)/2}$$

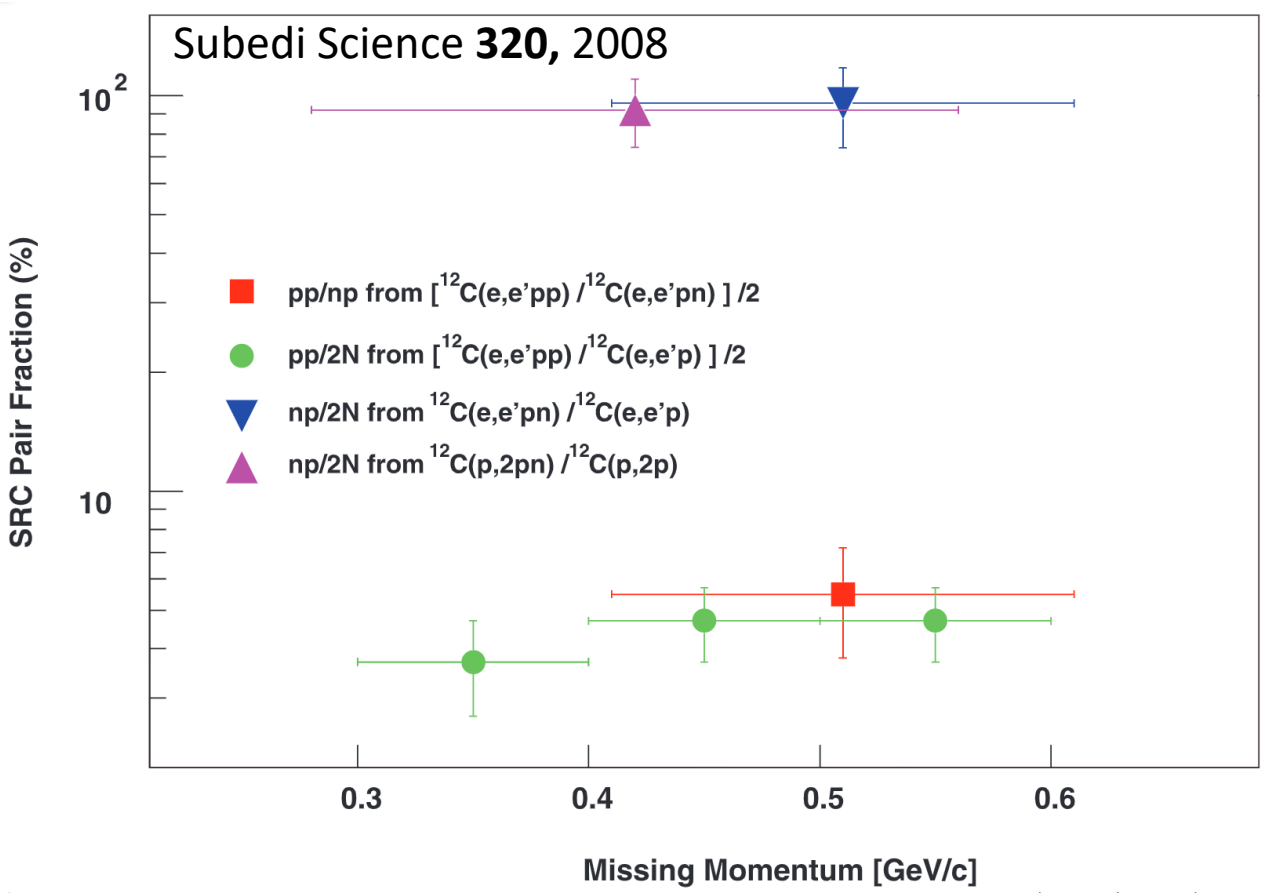


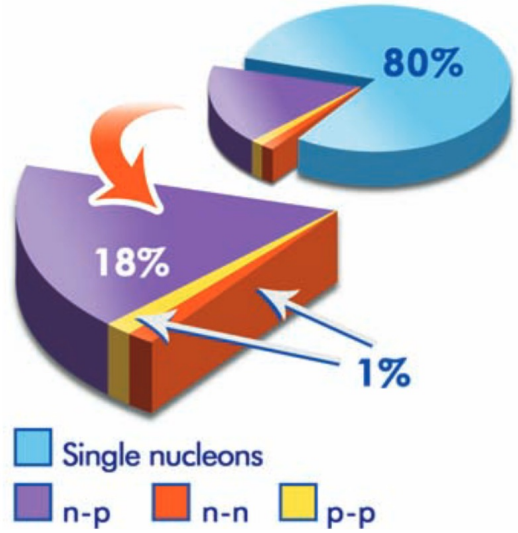
2N – SRC measurements: Exclusive scattering

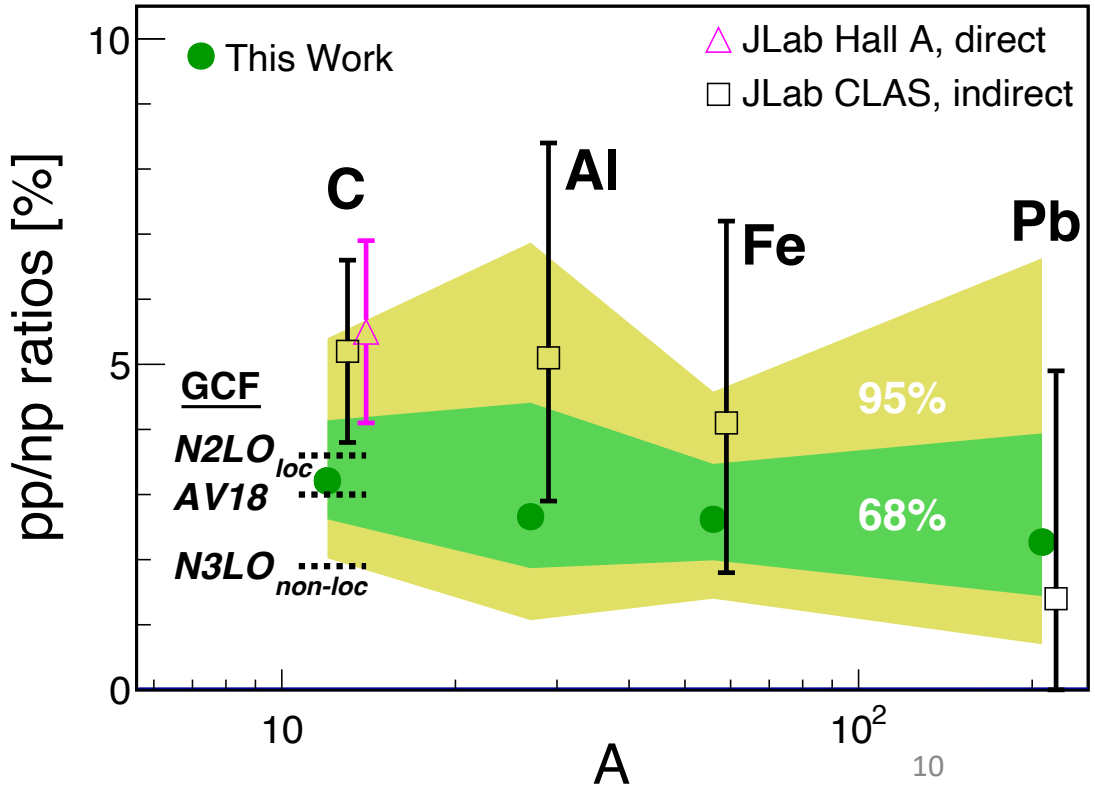


$$p_{missing} = p_f - q$$

Exclusive Scattering



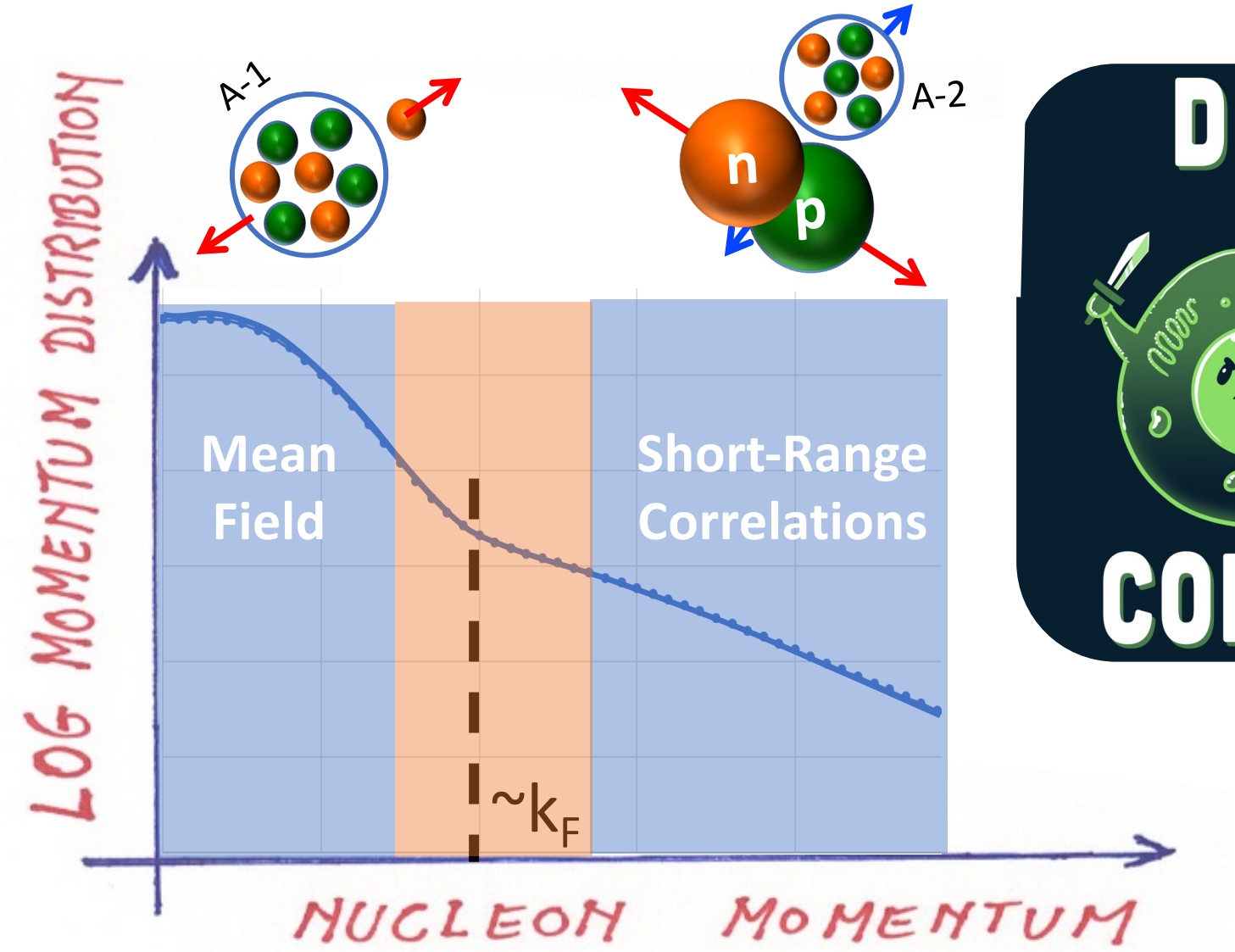




Dominance of np 2N-SRC pairs

Duer, PRL (2019); Duer, Nature (2018); Hen, Science (2014); Korover, PRL (2014); Subedi, Science (2008); Shneor, PRL (2007); Piasetzky, PRL (2006); Tang, PRL (2003);

High-Resolution nuclear wave function



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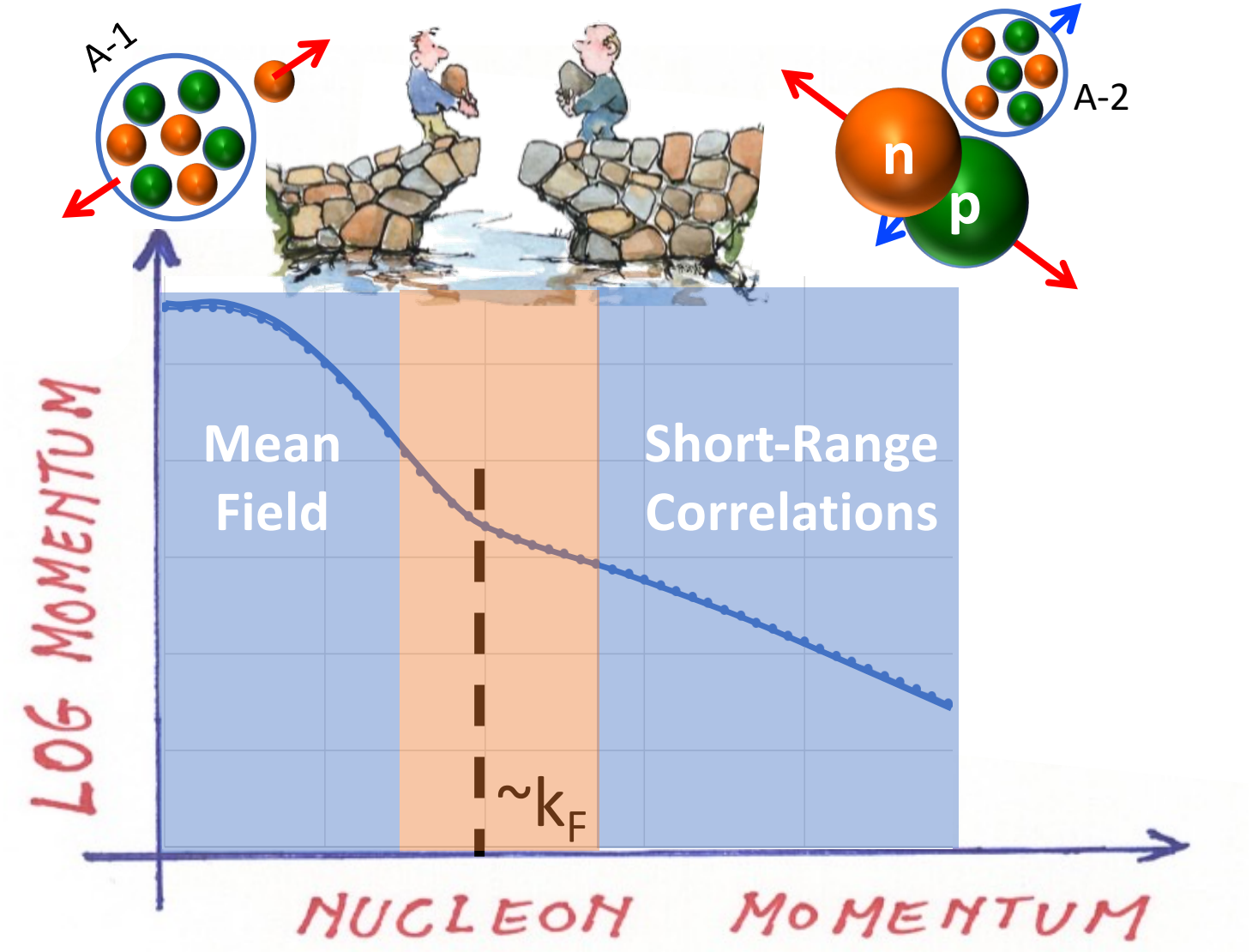
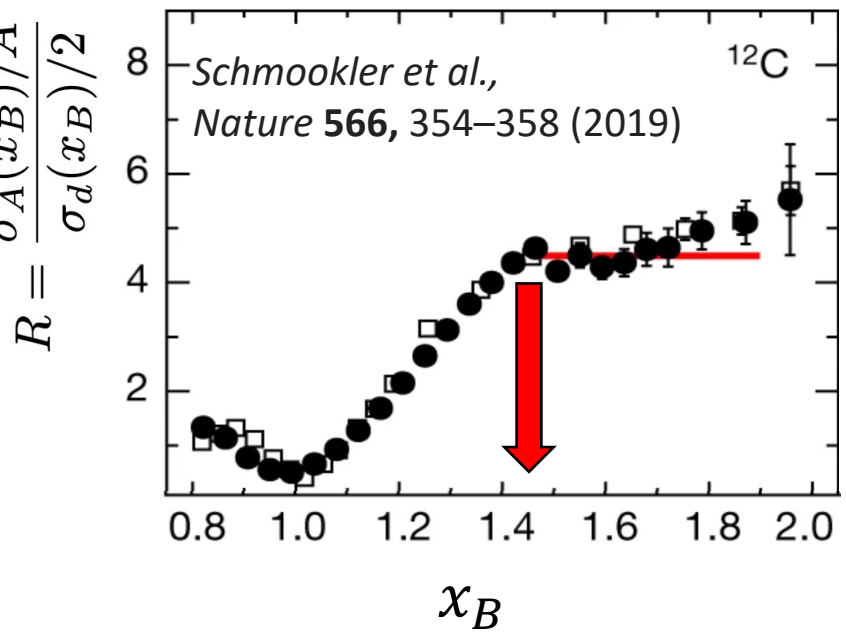


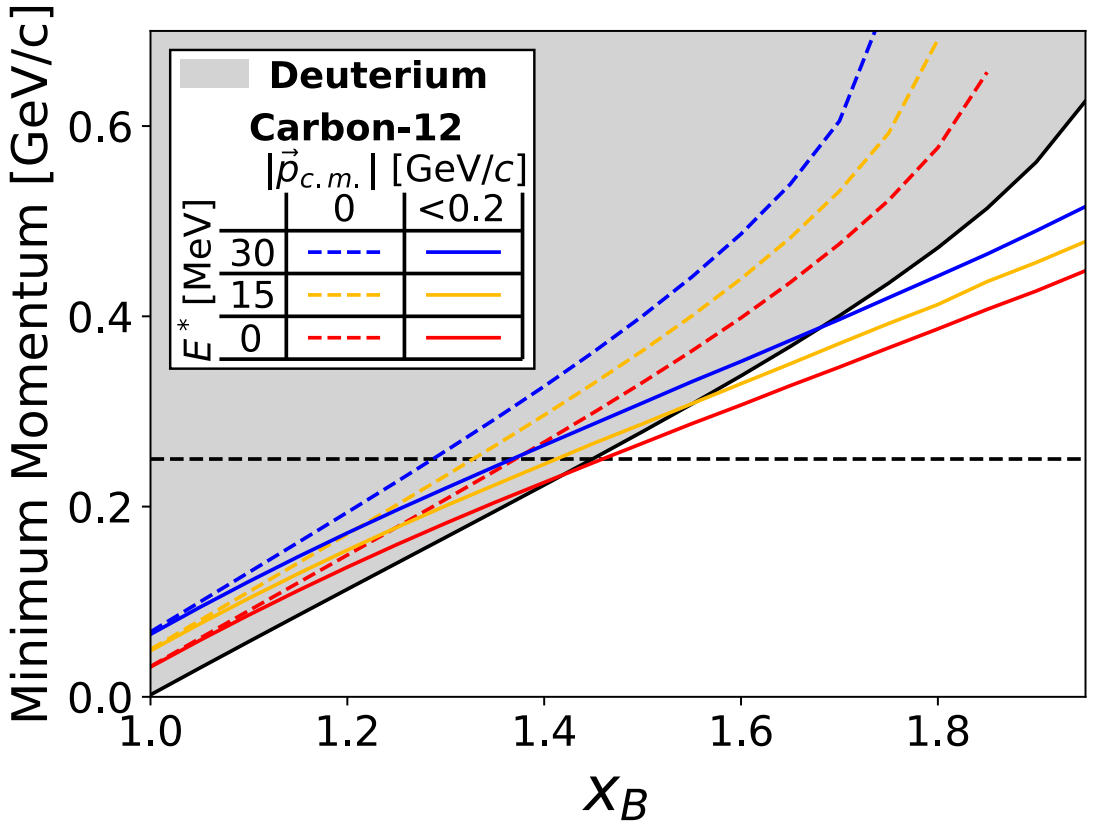
Inclusive scattering



Using energy-momentum conservation

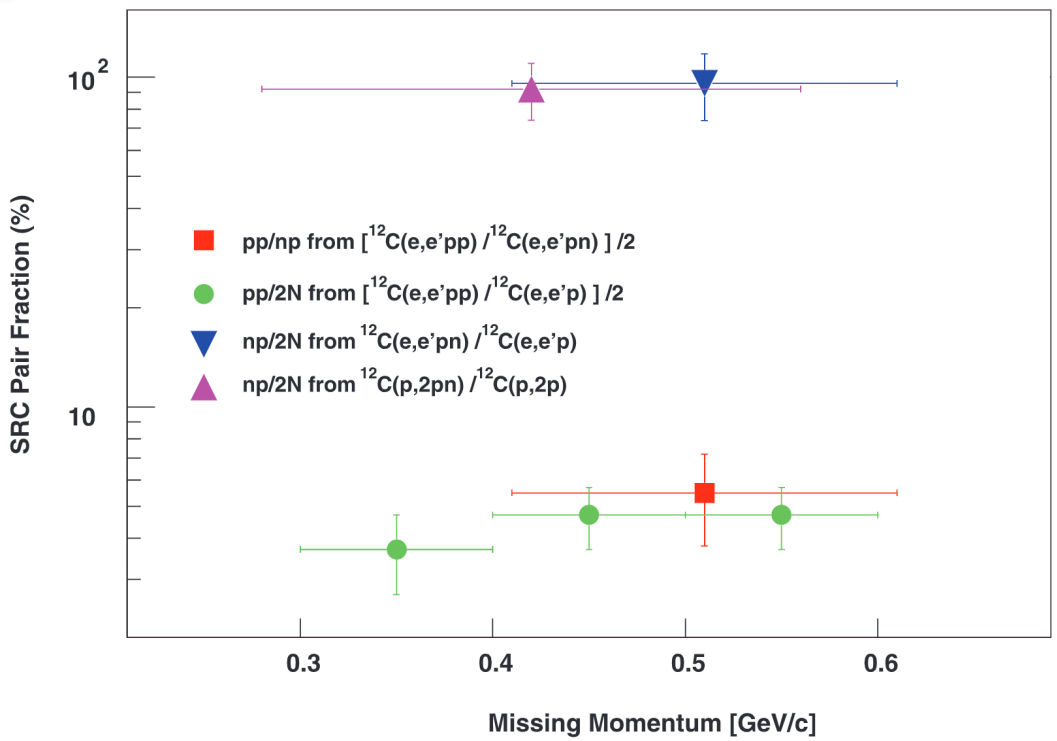
SRC Interpretation is model-dependent

[Excitation energy and pair CM motion]



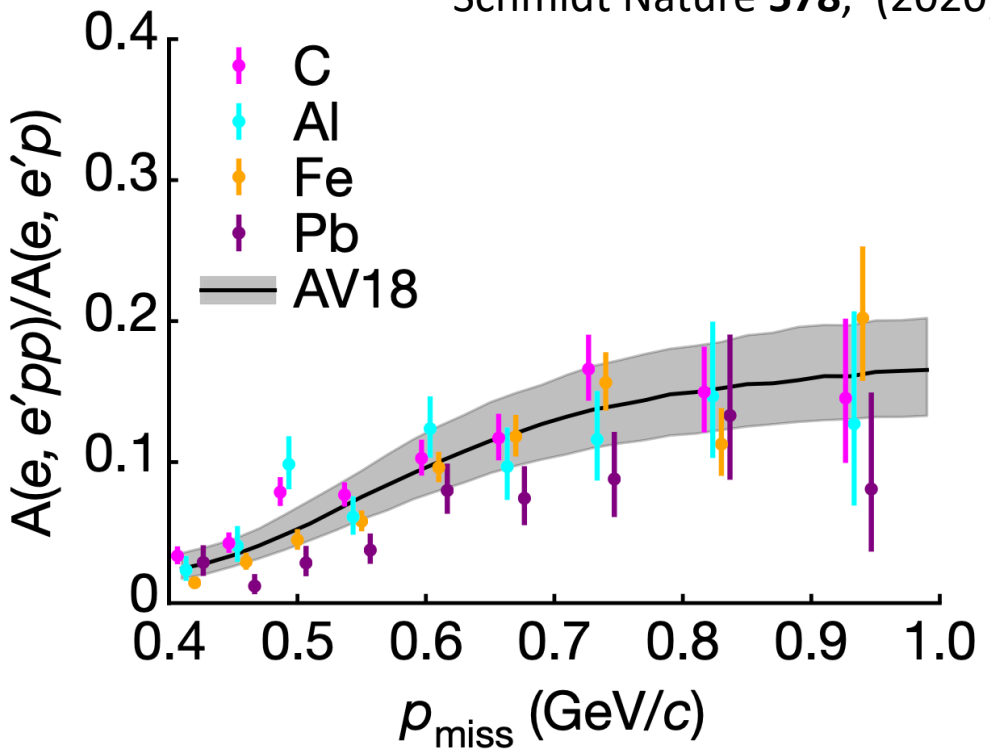
Phys. Rev. C Lett. **103**, L031301 (2021)

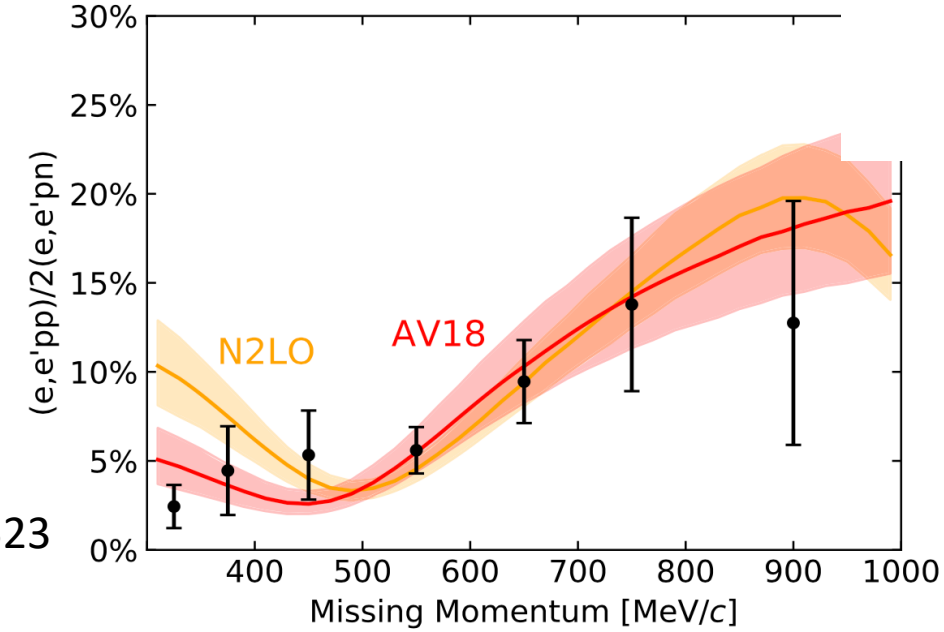
Exclusive Scattering



Subedi Science **320,** 2008

Schmidt Nature **578**, (2020)

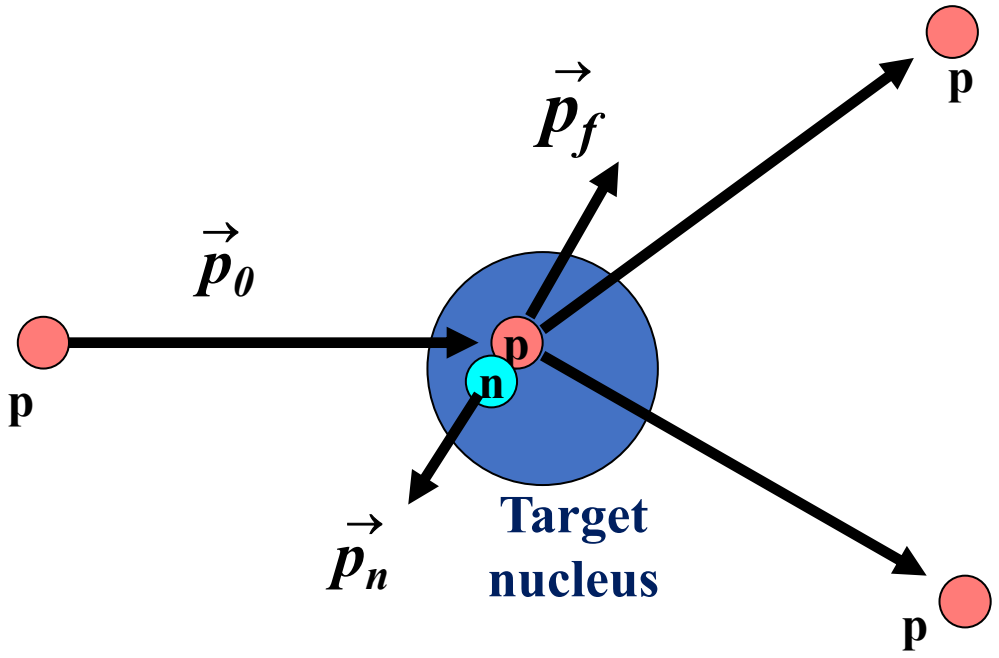


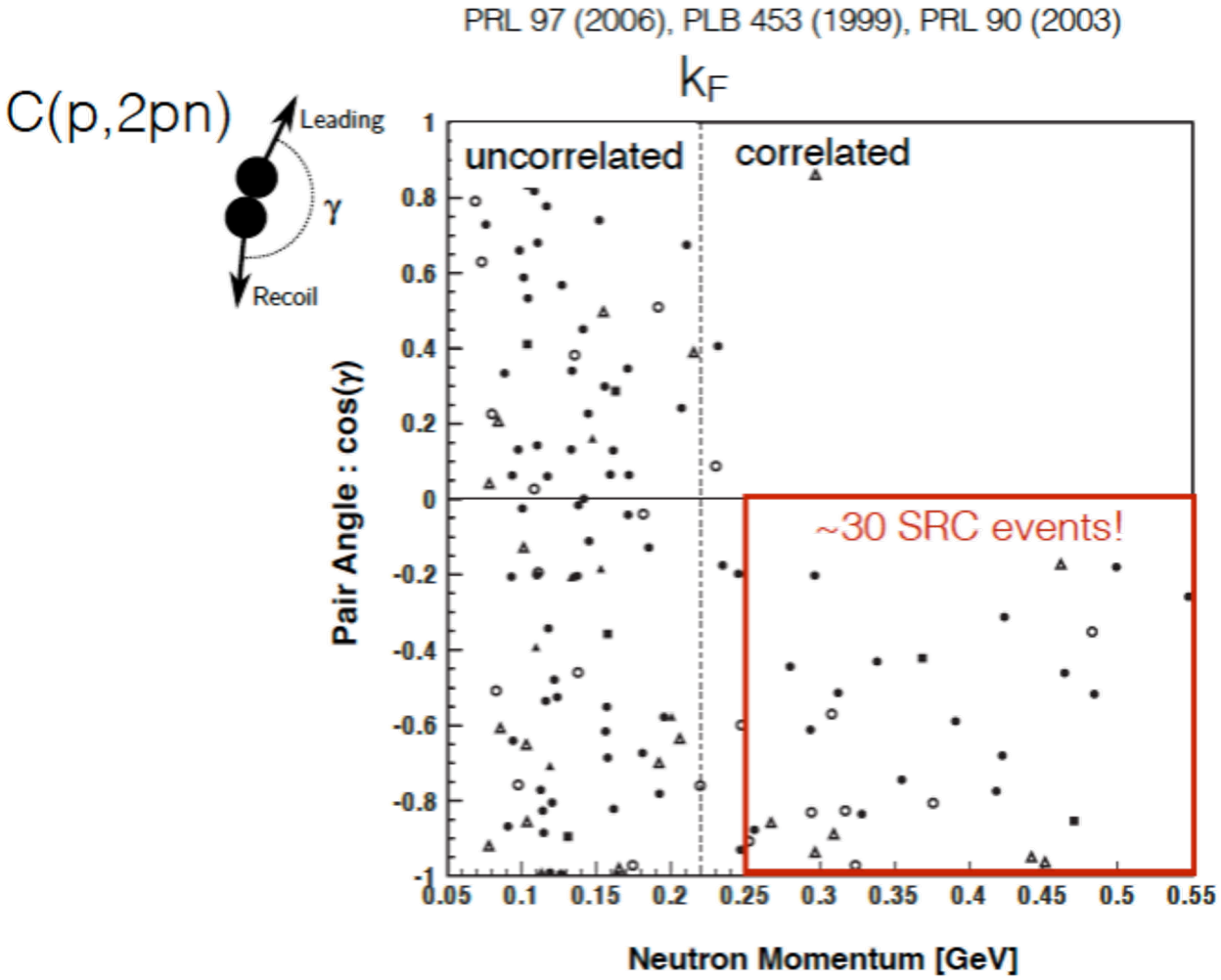


Korover, PLB **820**, (2021) 136523

SRC onset observation using proton beams

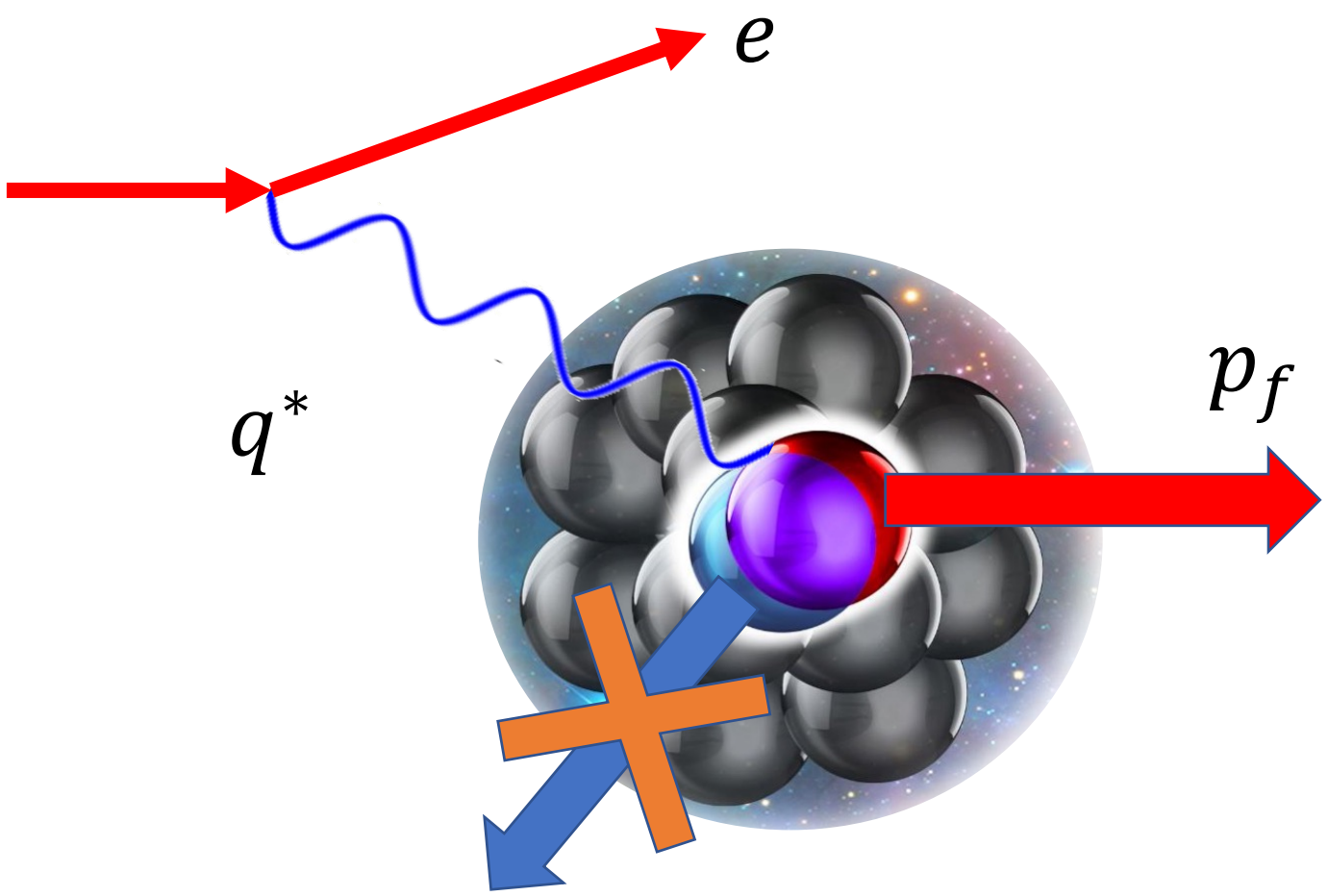
Limited statistics





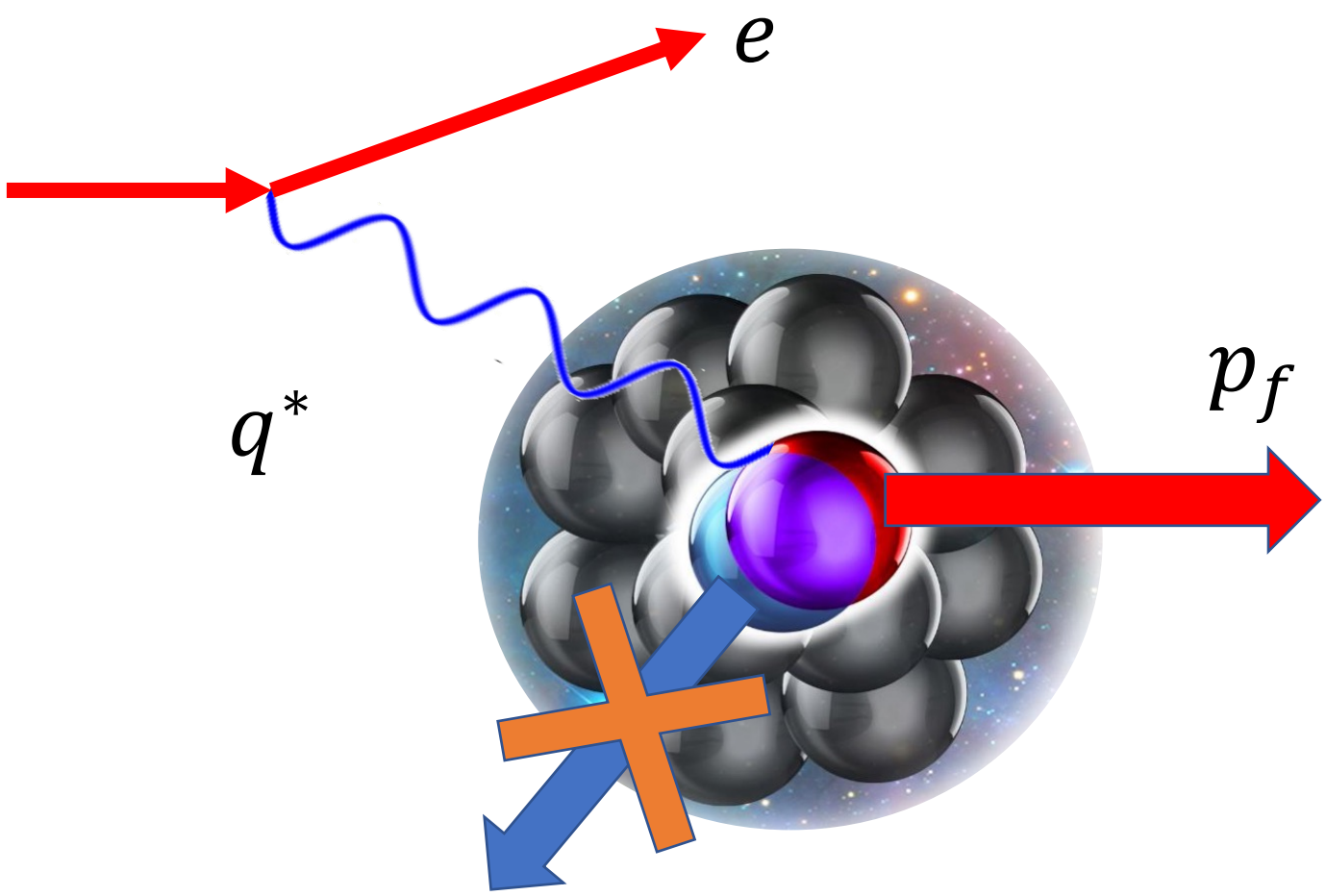
More details in Julian talk on Wednesday

2N – SRC measurement using electron scattering

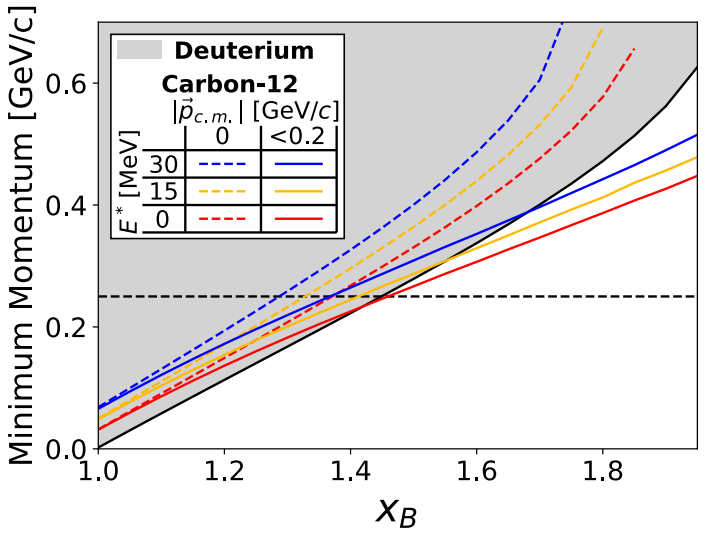


Semi-Inclusive A(e,e'p)

2N – SRC measurement using electron scattering



Semi-Inclusive A(e,e'p)



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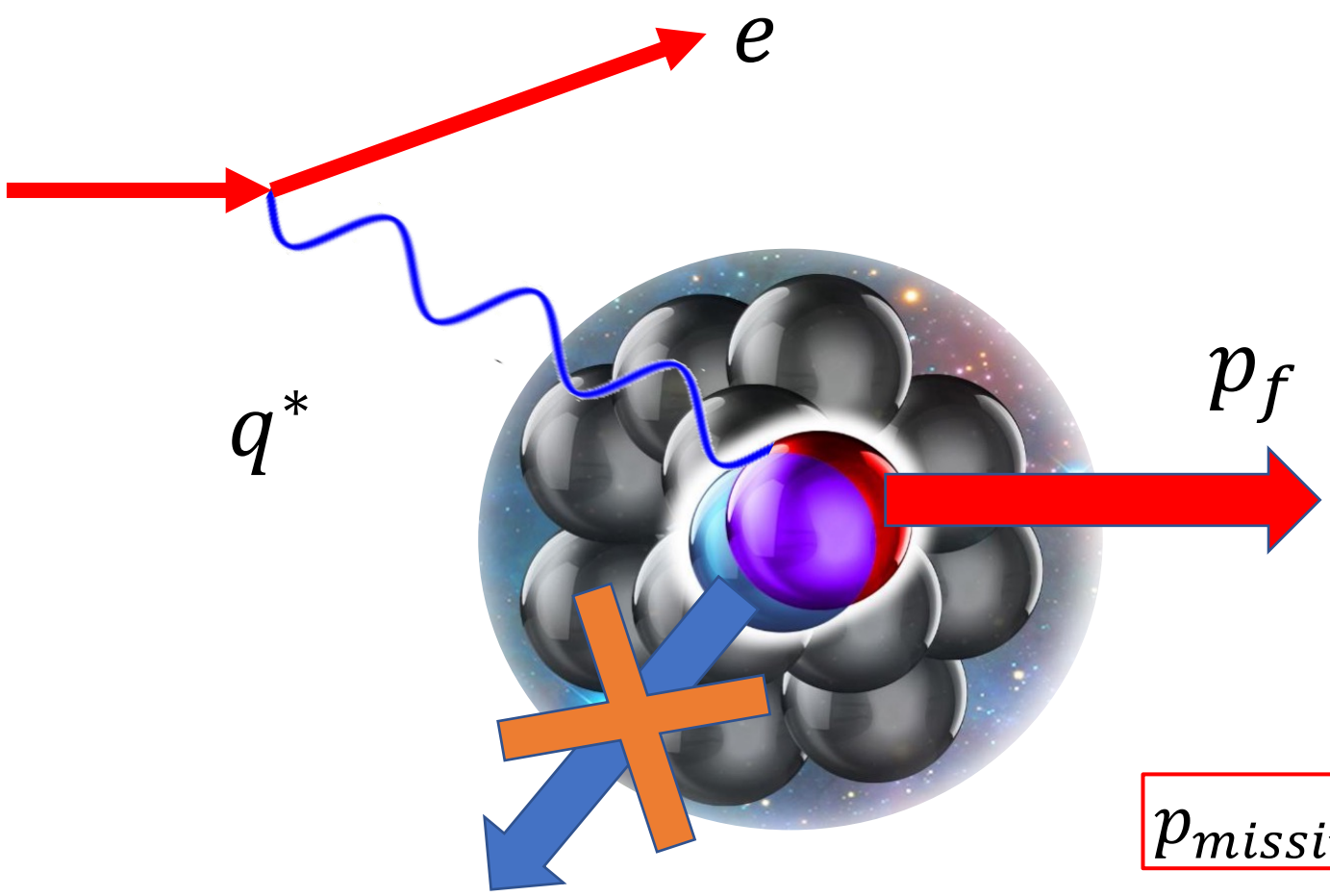

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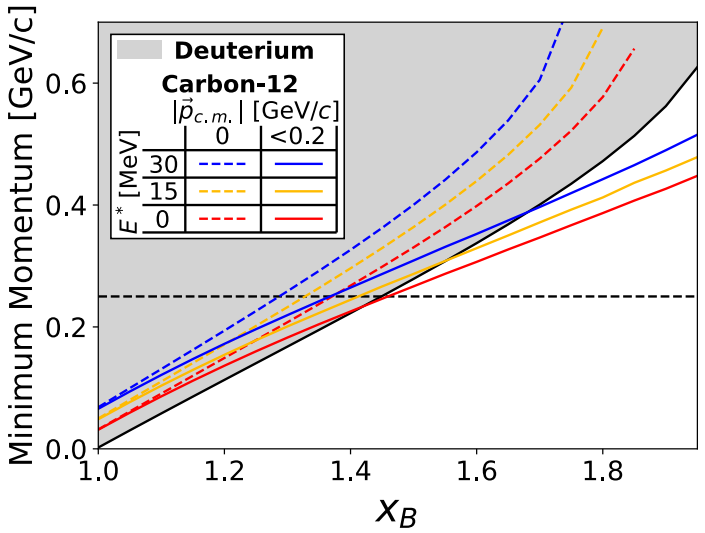
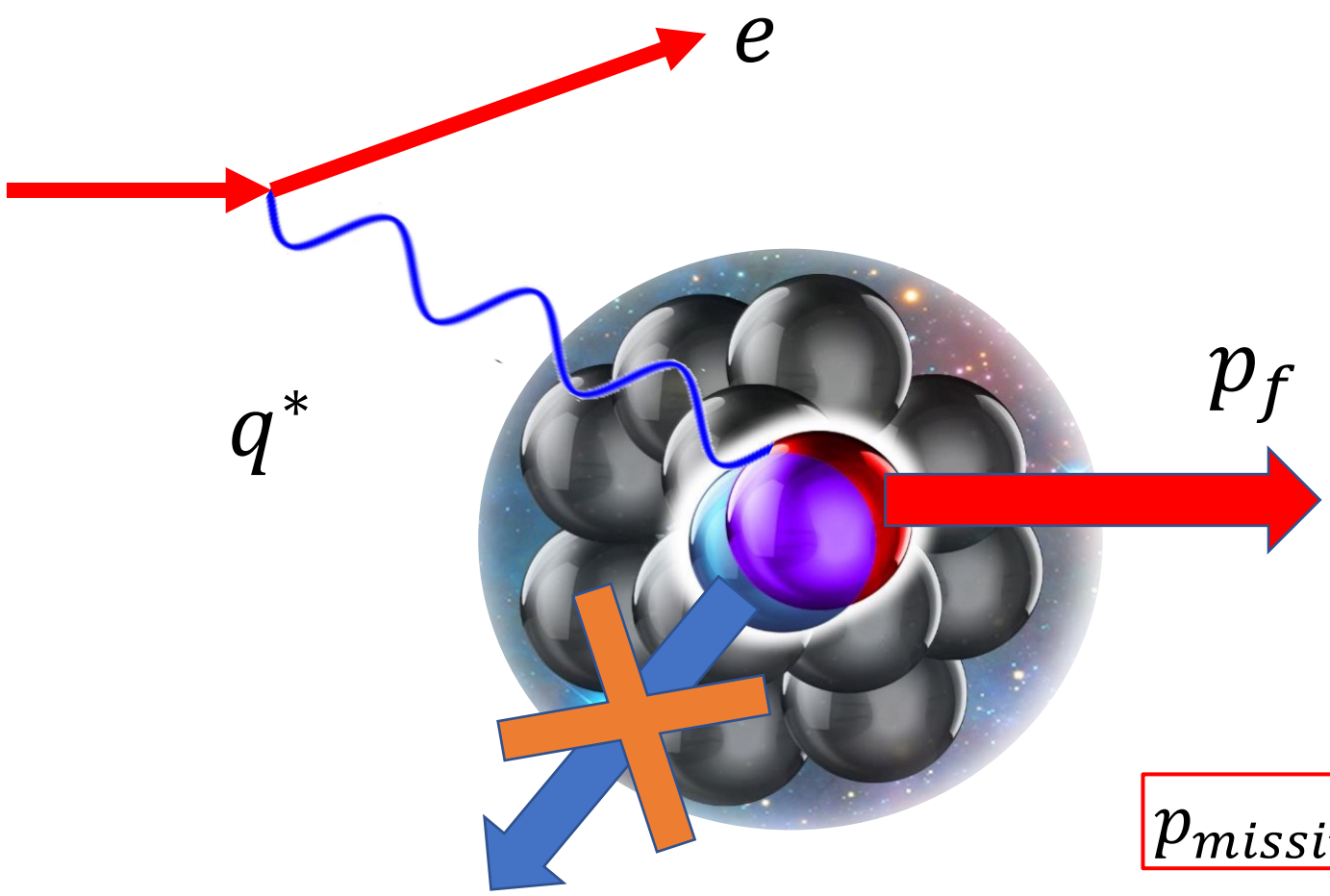


$$p_{missing} = p_f - q$$

2N – SRC measurement using electron scattering



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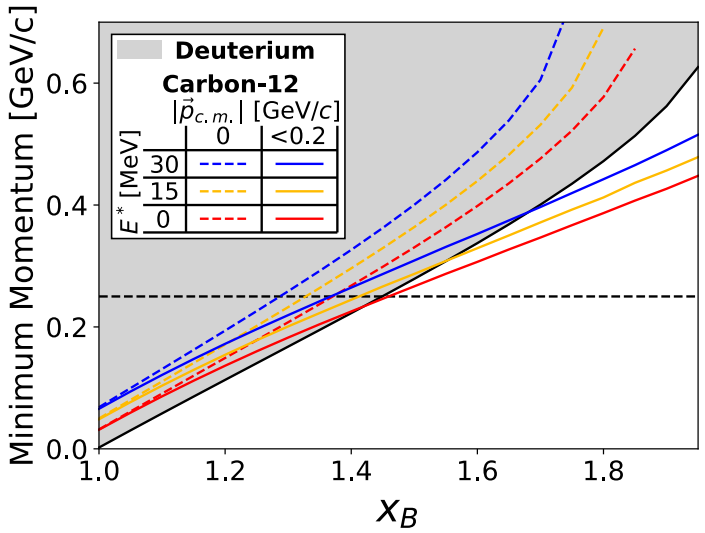
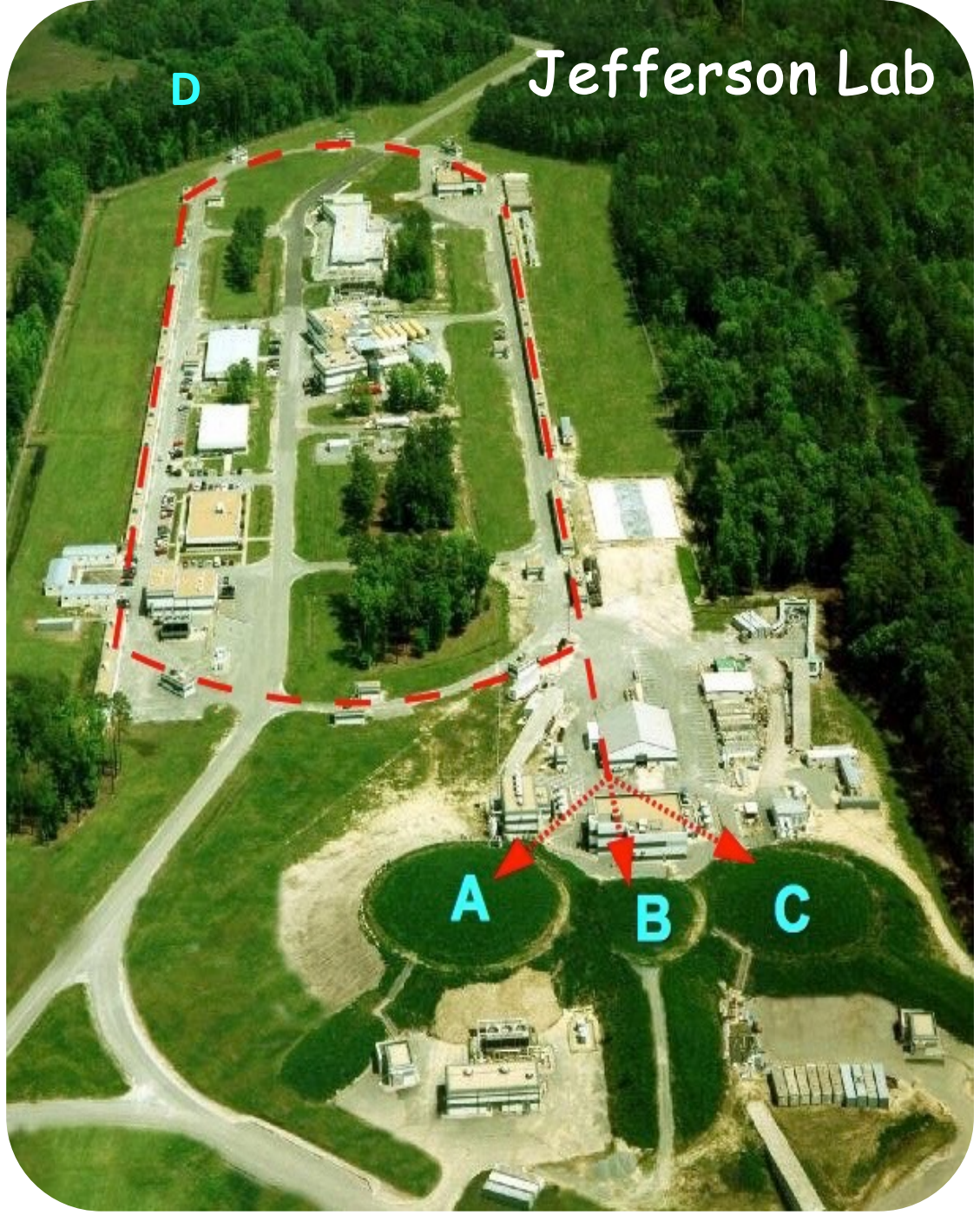
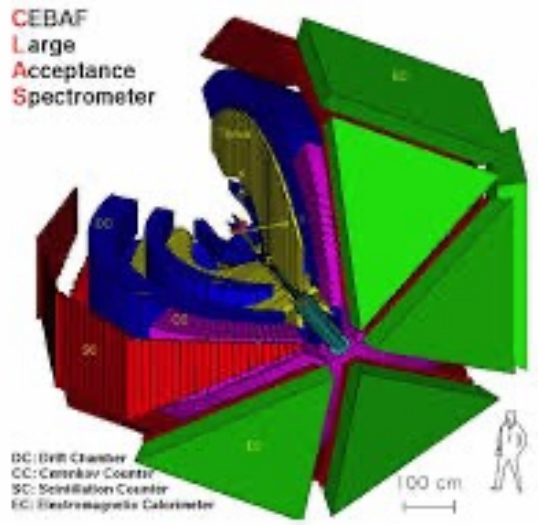


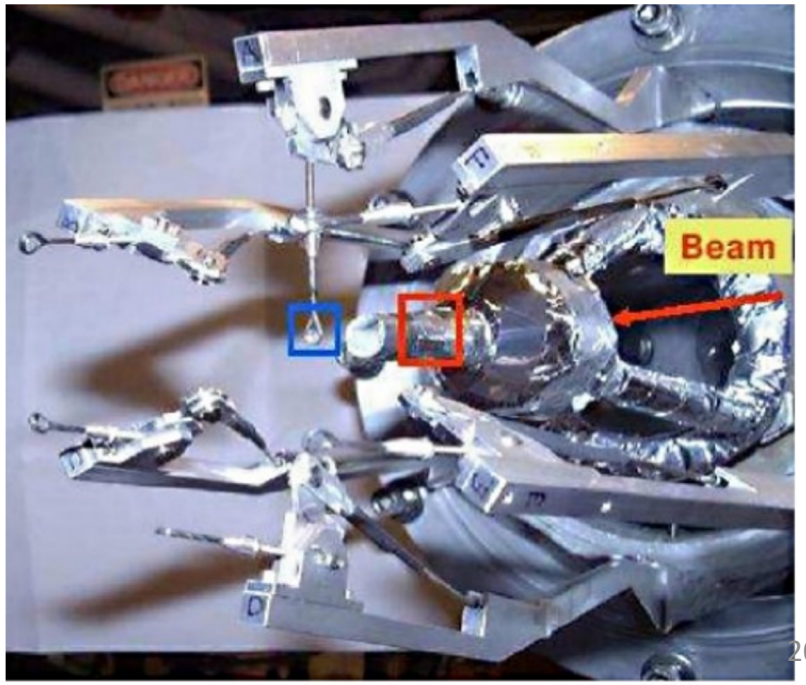
$$p_{missing} = p_f - q$$

$$M_{mass} = \sqrt{(\omega + m_d - E_f)^2 - (\vec{q} - \vec{p}_f)^2}$$



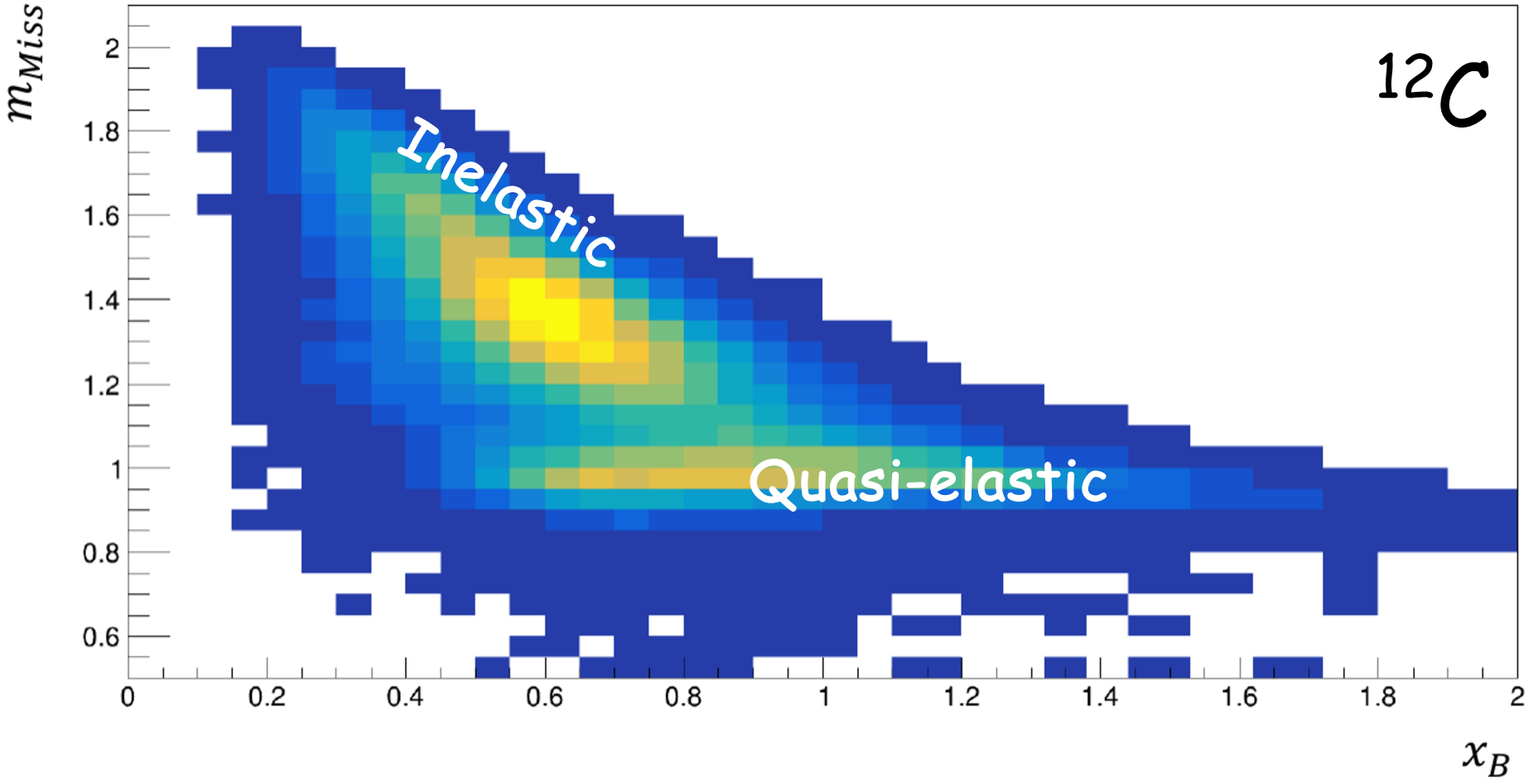


Solid Targets: Carbon, Al, Fe, Pb



Missing Mass vs X_B

$$M_{mass} = \sqrt{(\omega + m_d - E_f)^2 - (\vec{q} - \vec{p}_f)^2}$$



$$0.3 < p_{miss} < 0.6[GeV/c]$$

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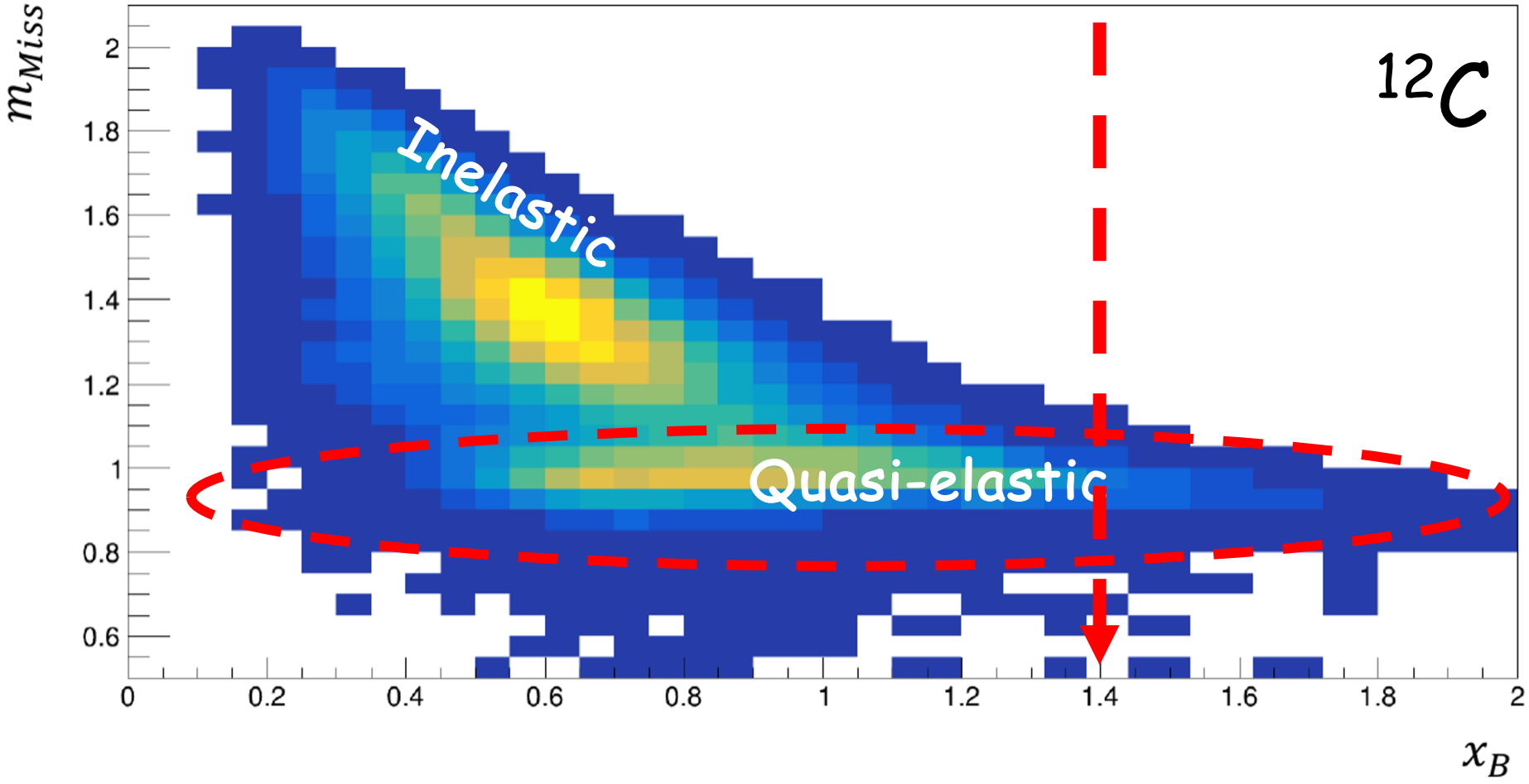

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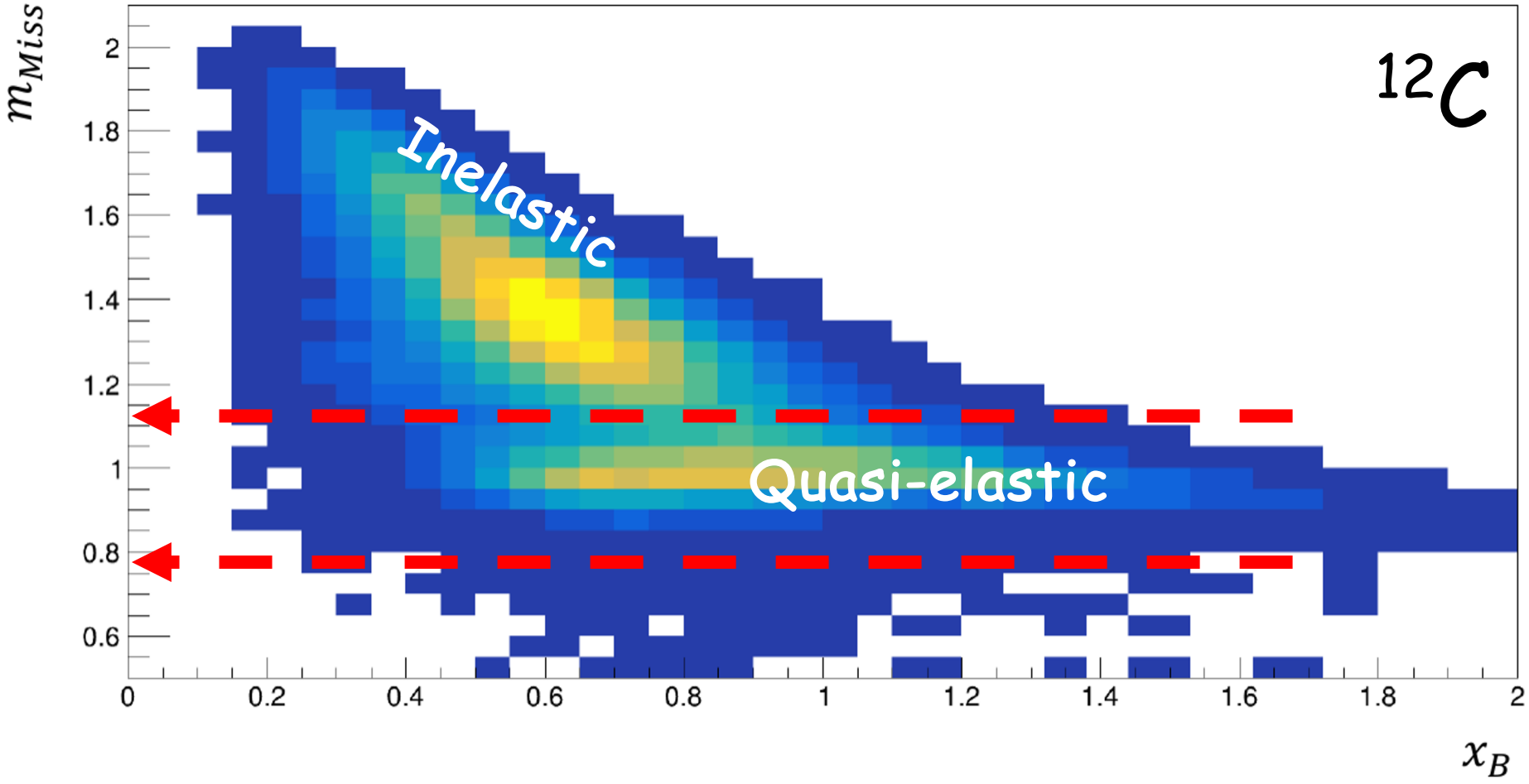
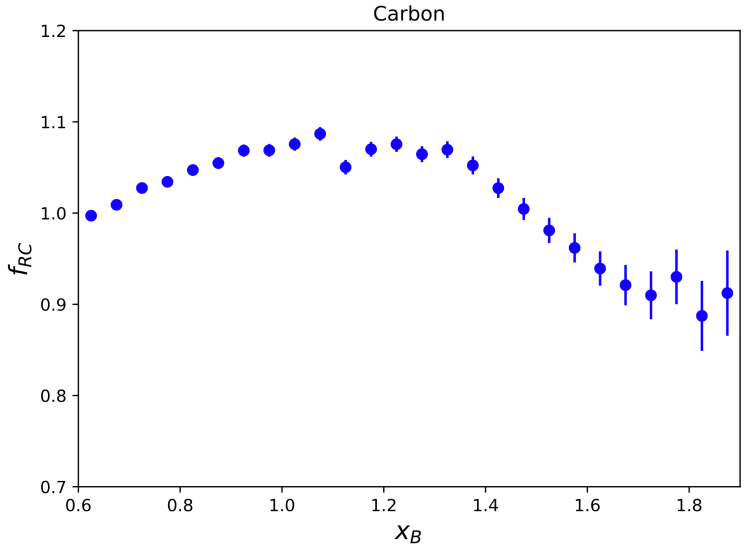


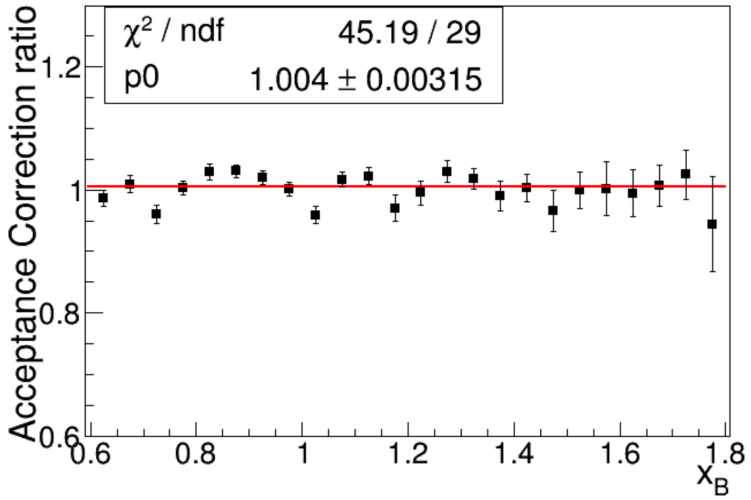
$$0.3 < p_{miss} < 0.6[GeV/c]$$

From yields to cross sections ratio

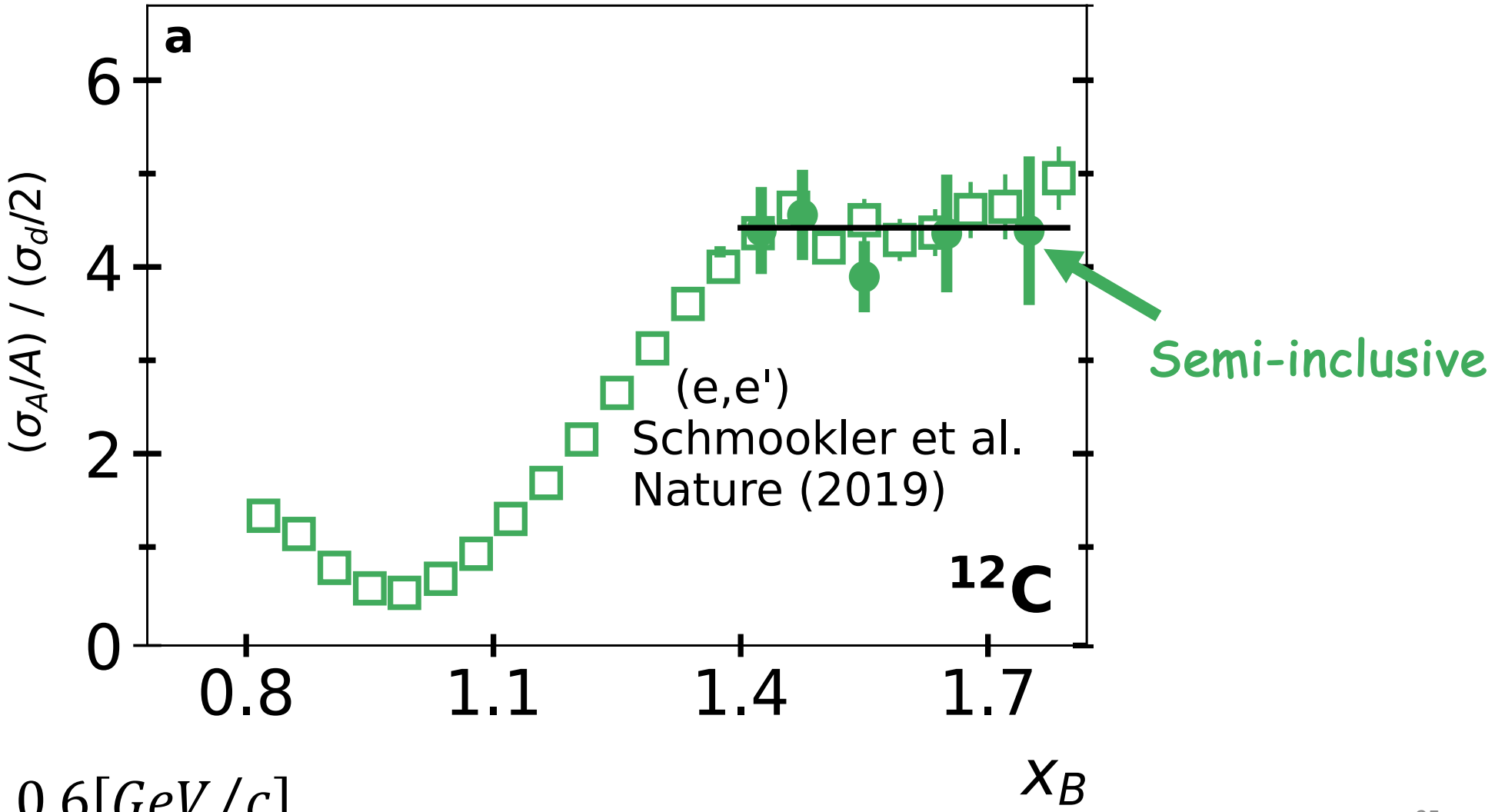
$$R = \frac{\sigma_A(x_B)/A}{\sigma_d(x_B)/2} = \frac{Yield_A^{corr}(x_B)}{Yield_d^{corr}(x_B)} \cdot \frac{RC_A(x_B)}{RC_d(x_B)} \cdot W(x_B) \cdot \frac{T_{deuteron}}{T_{solid}}$$



- Acceptance correction
- Radiative Correction
- Luminosity
- Liquid target cell background

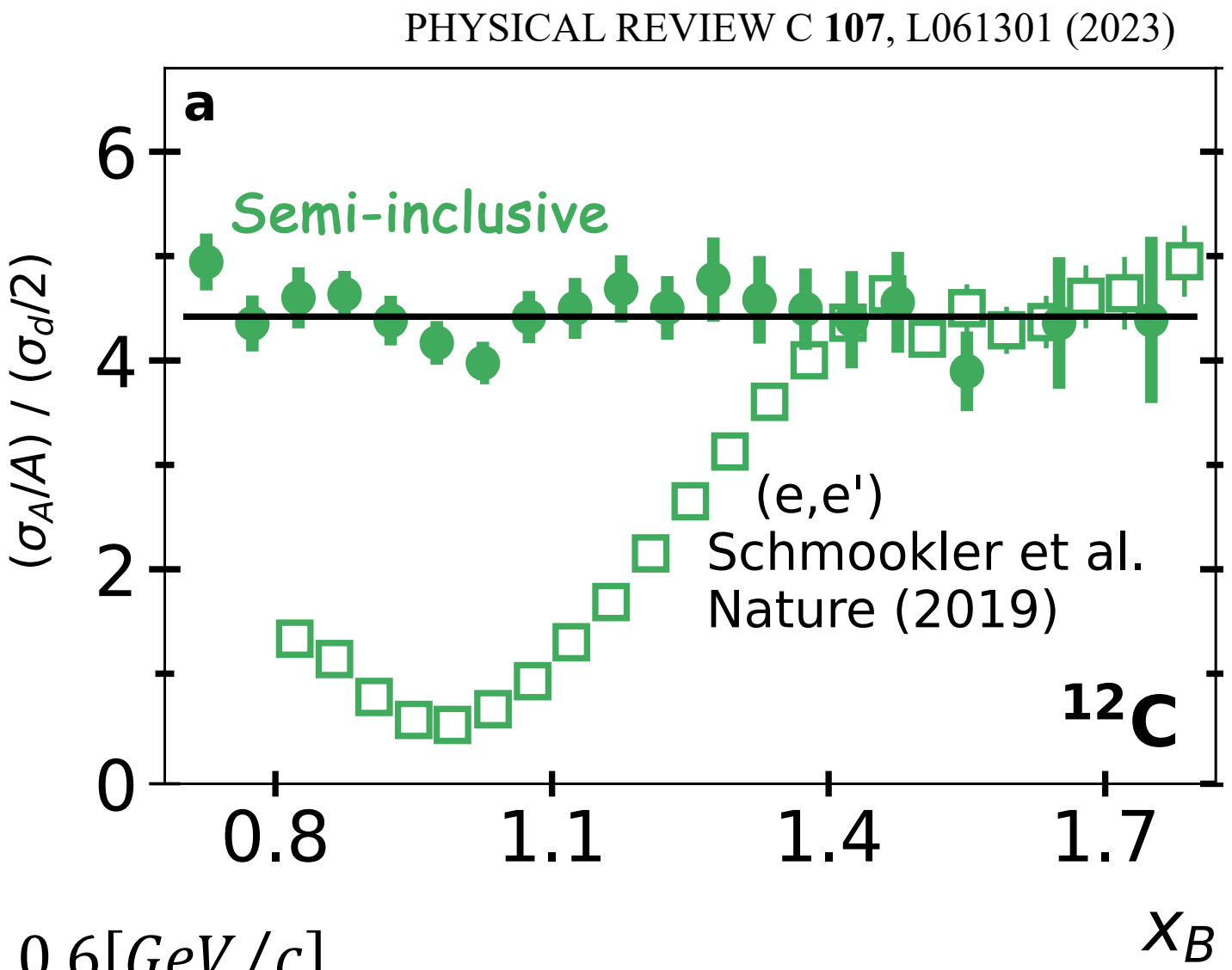


Experimental identification of 2N-SRC



$0.3 < p_{miss} < 0.6[GeV/c]$

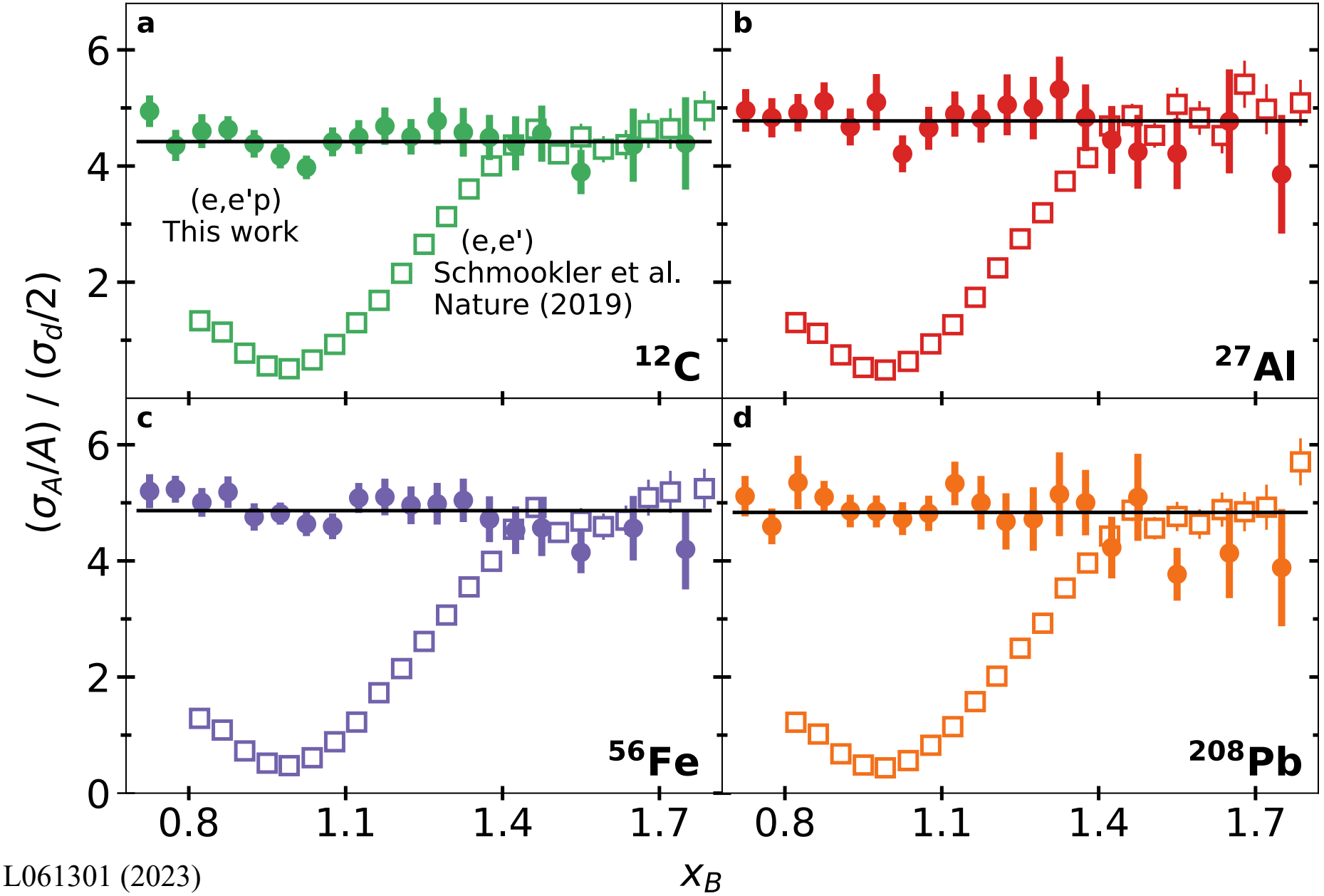
Experimental identification of 2N-SRC



$0.3 < p_{miss} < 0.6[GeV/c]$

Scaling Universality

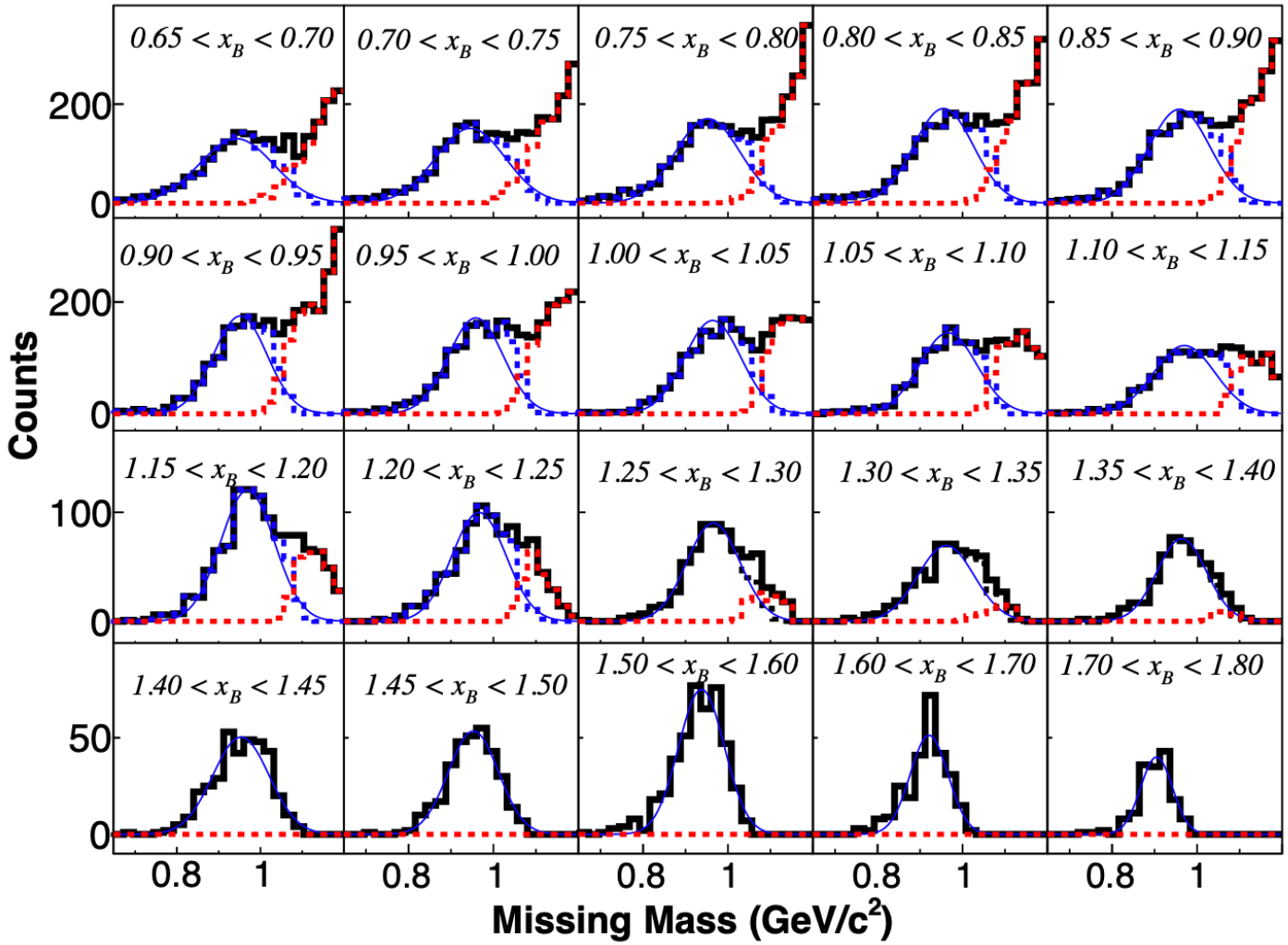
$$0.3 < p_{miss} < 0.6 [GeV/c]$$



Korover PRC **107**, L061301 (2023)

Measuring CM using only one nucleon

Exact for deuteron, but CM smear this distribution for other nuclei



$$\sigma_{cm} = \sqrt{\sigma^2_{A,measured} - \sigma^2_{d,measured}}$$

Histogram: experimental data
Different lines: two Gaussian fit

PRC **107**, L061301 (2023)

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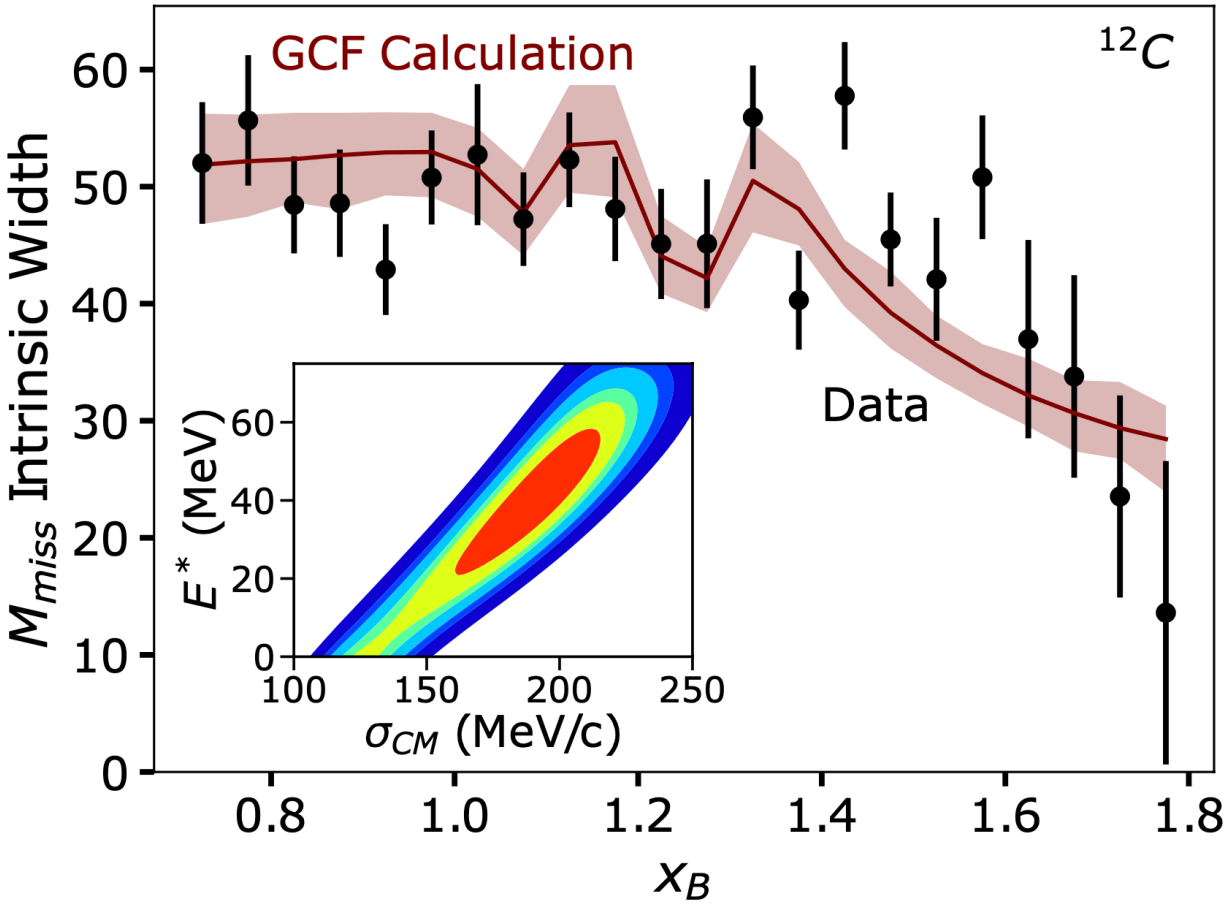


PRC **107**, L061301 (2023)

$$\sigma_{cm} = \sqrt{\sigma^2_{A,measured} - \sigma^2_{d,measured}}$$

$$\sigma_{CM} = 170 \pm 20\ MeV/c$$

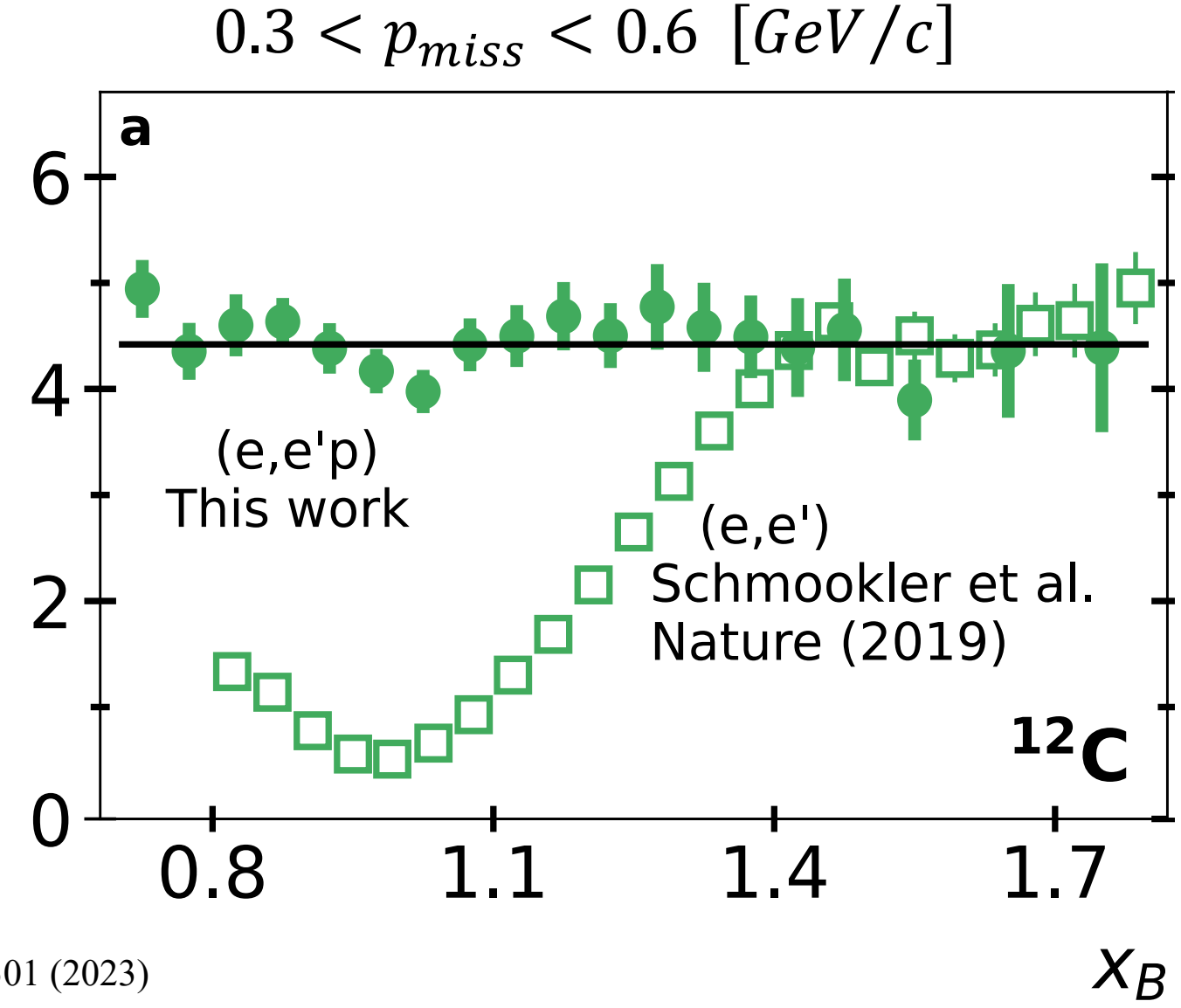
See Julian talk on Wednesday

σ = (156 ± 27) MeV/c

Details on GCF:
R. Cruz-Torres, Nature Physics **17,** 306 (2021)

From Scaling to Mean Field

$$R = \frac{\sigma_A(x_B)/A}{\sigma_d(x_B)/2}$$



Variation of the missing momentum

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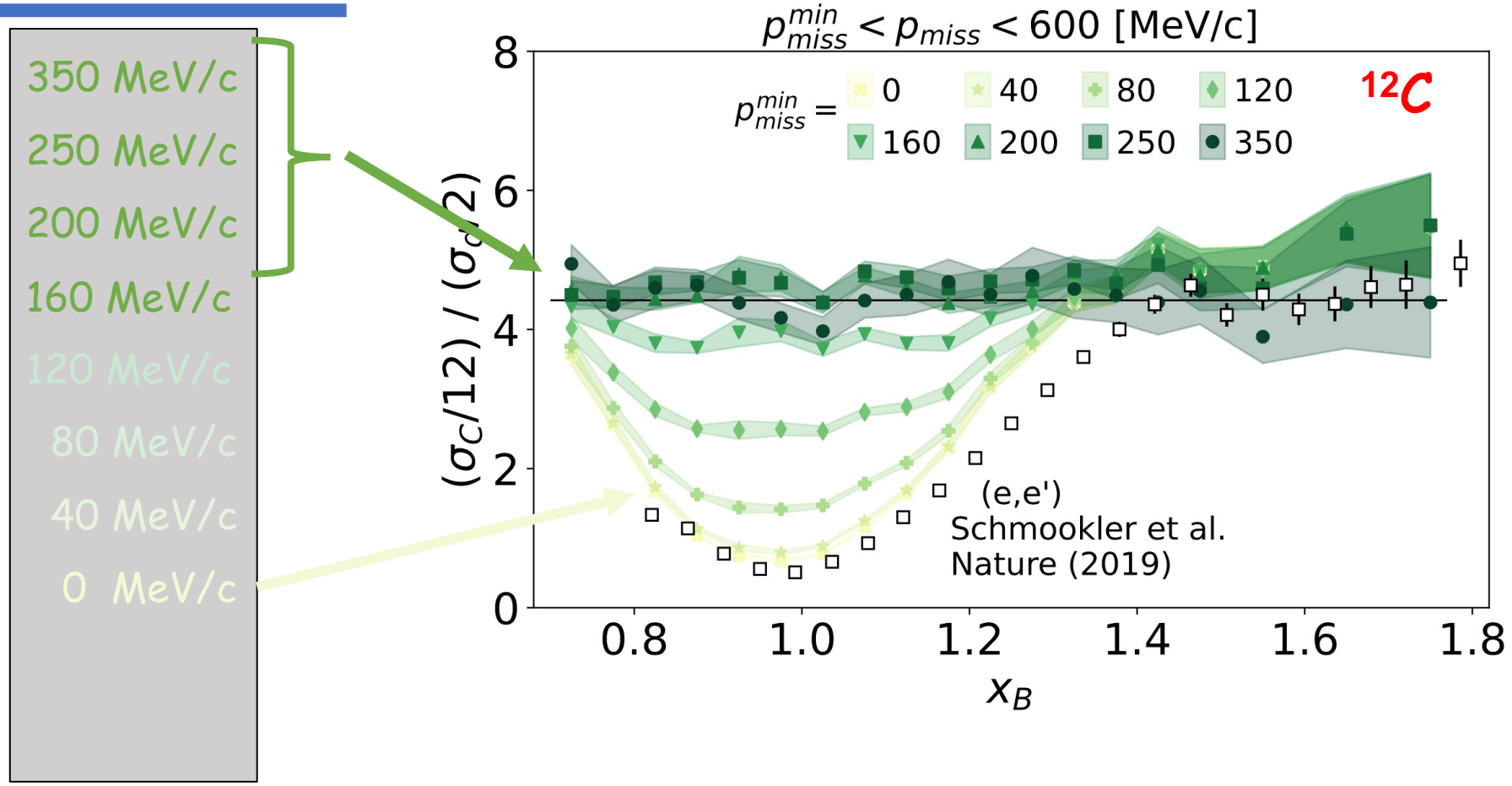
From Scaling to Mean Field

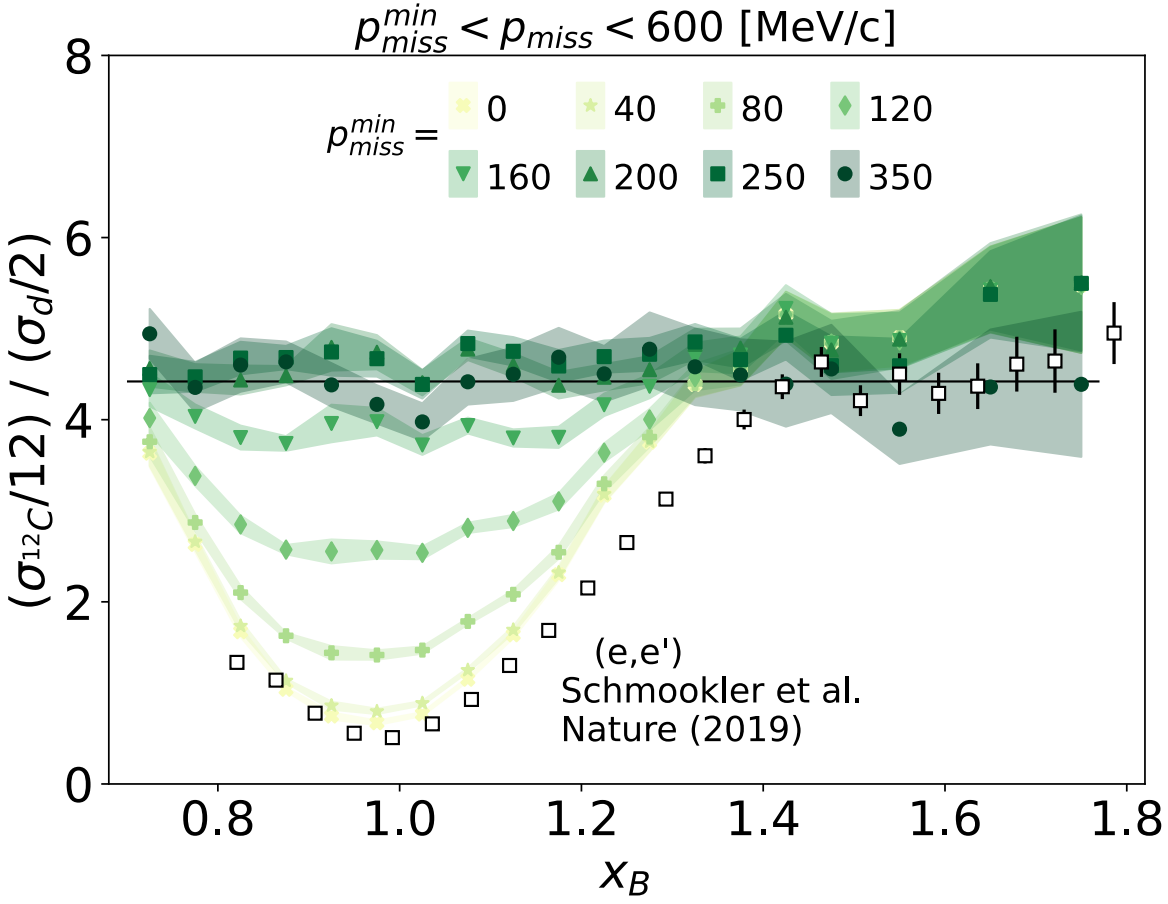
$$R = \frac{\sigma_A(x_B)/A}{\sigma_d(x_B)/2}$$

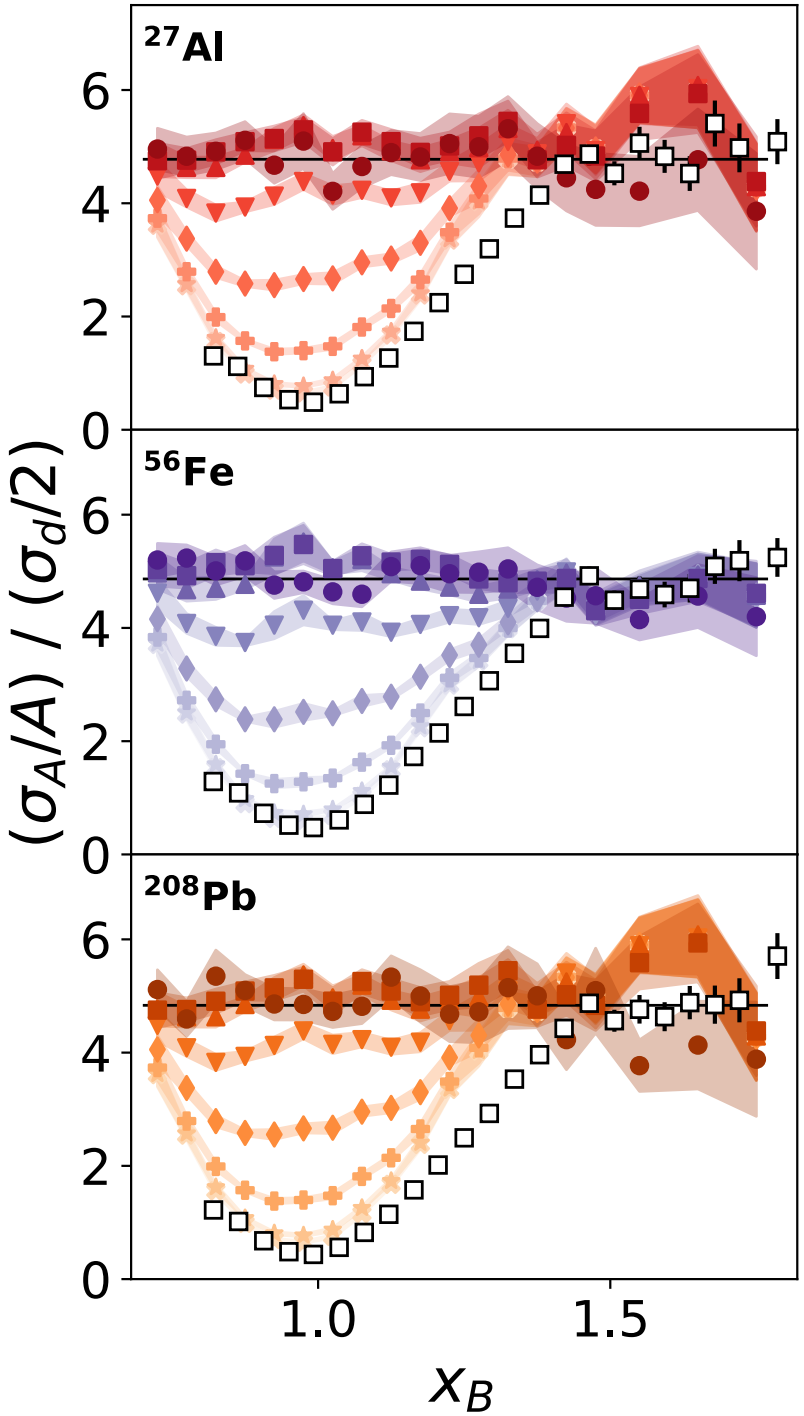
P_{miss}^{min}



Korover PRC **107**, L061301 (2023)

From Scaling to Mean Field

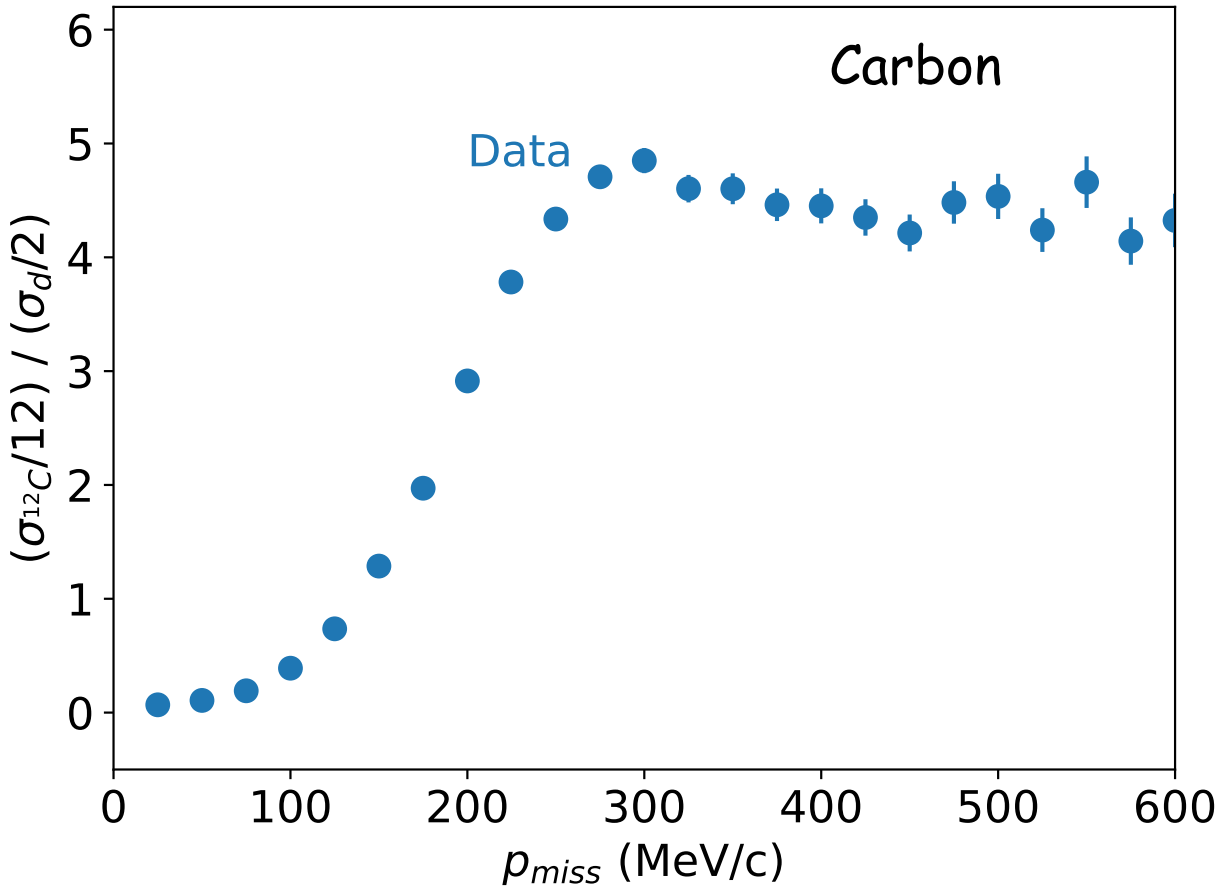




Korover PRC **107**, L061301 (2023)

From Mean Field to SRC

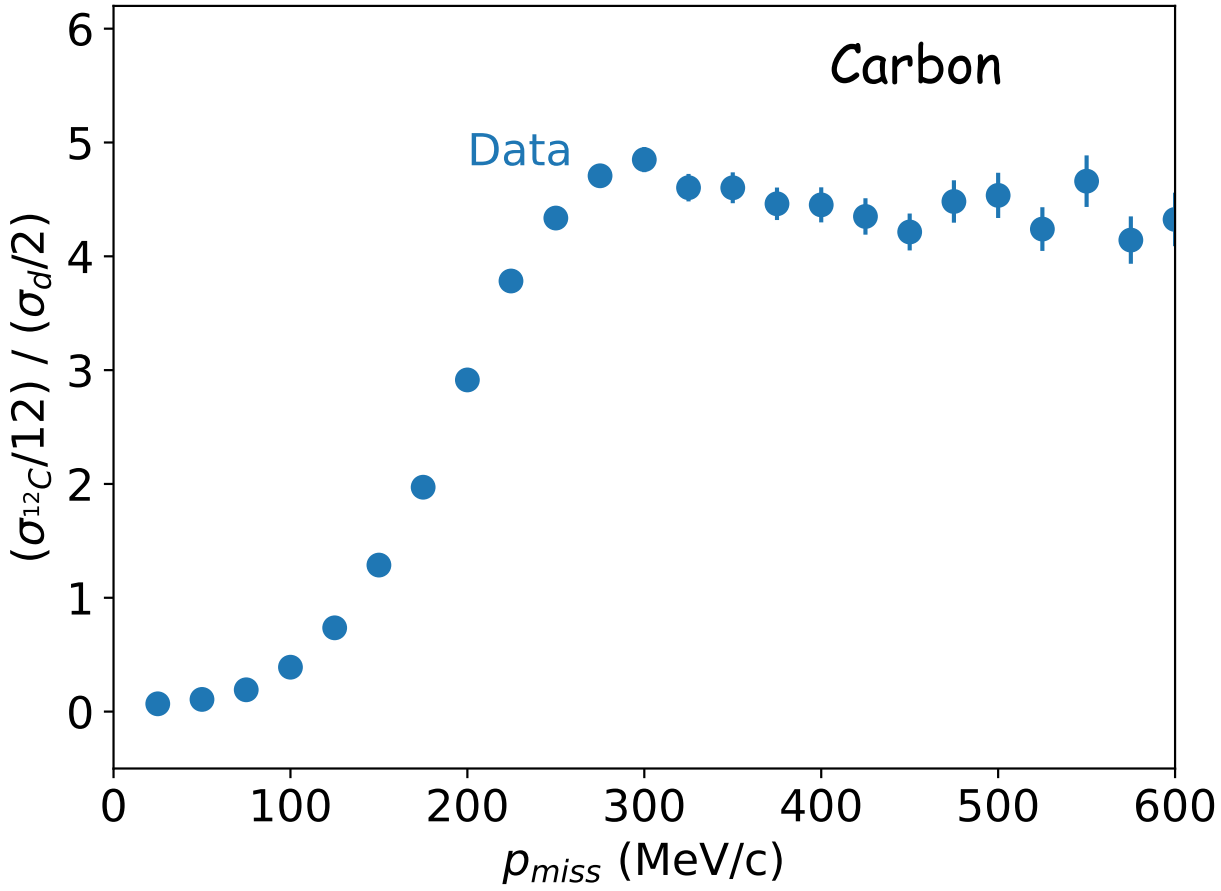
$0.8 < x_B < 1.8$

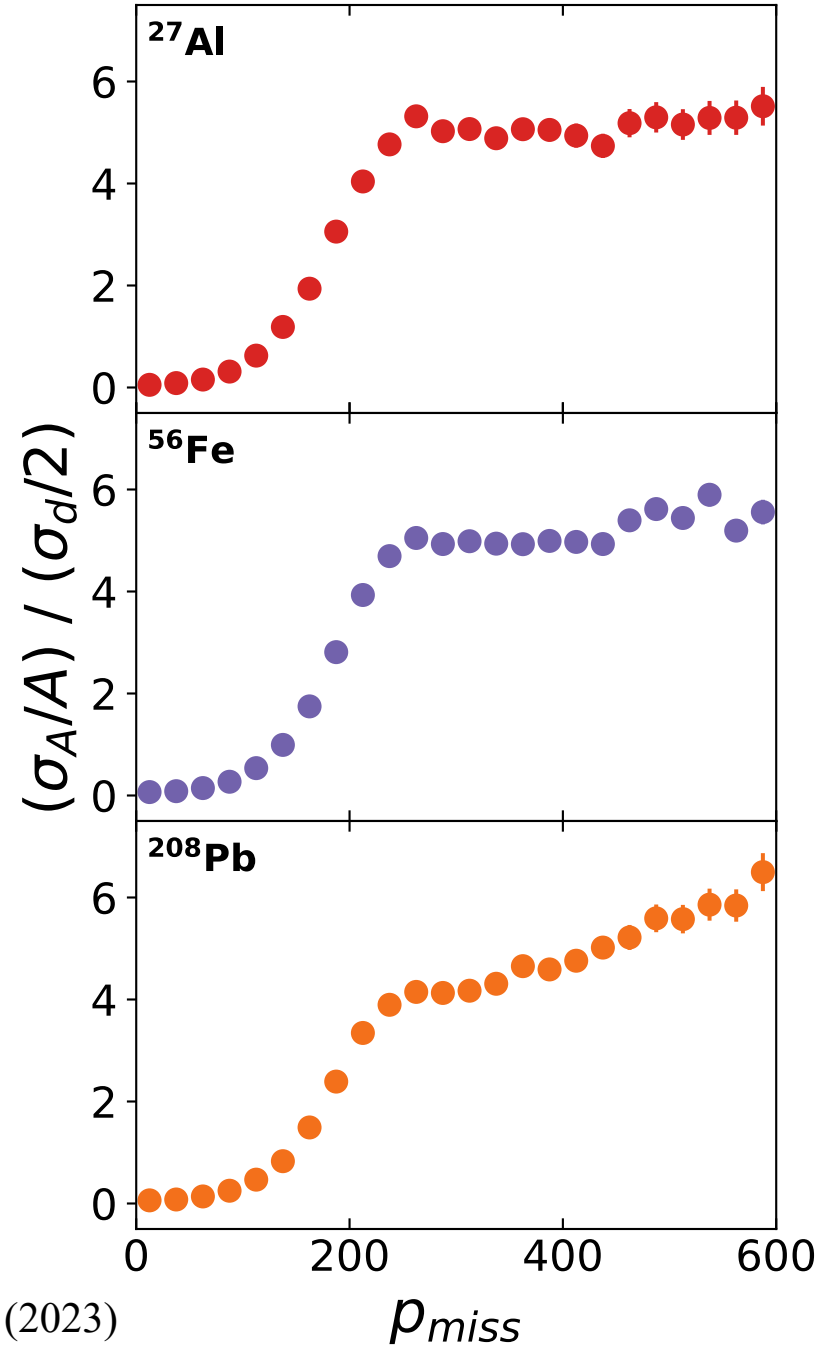


From Mean Field to SRC

Similar behavior for all nuclei

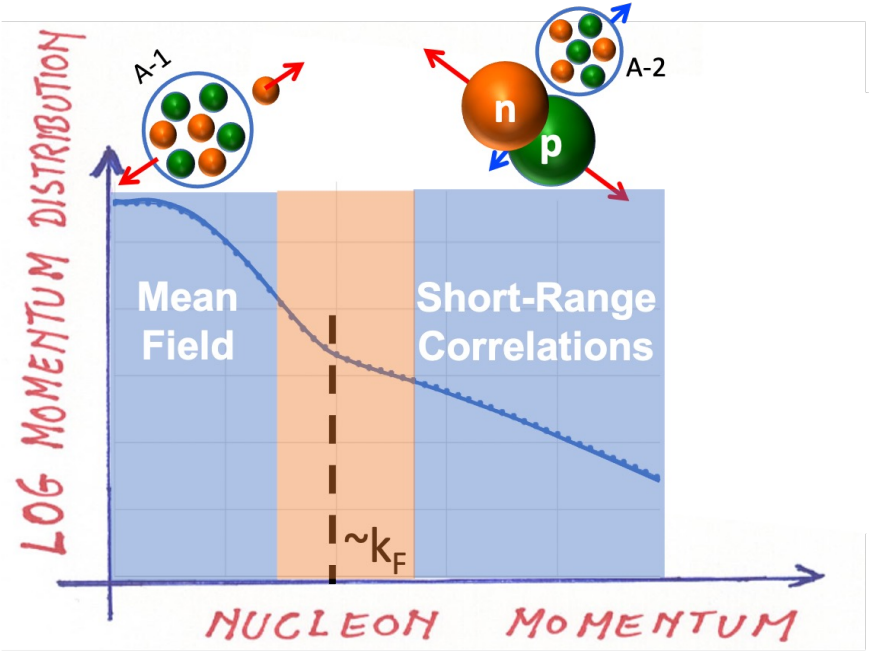
$0.8 < x_B < 1.8$

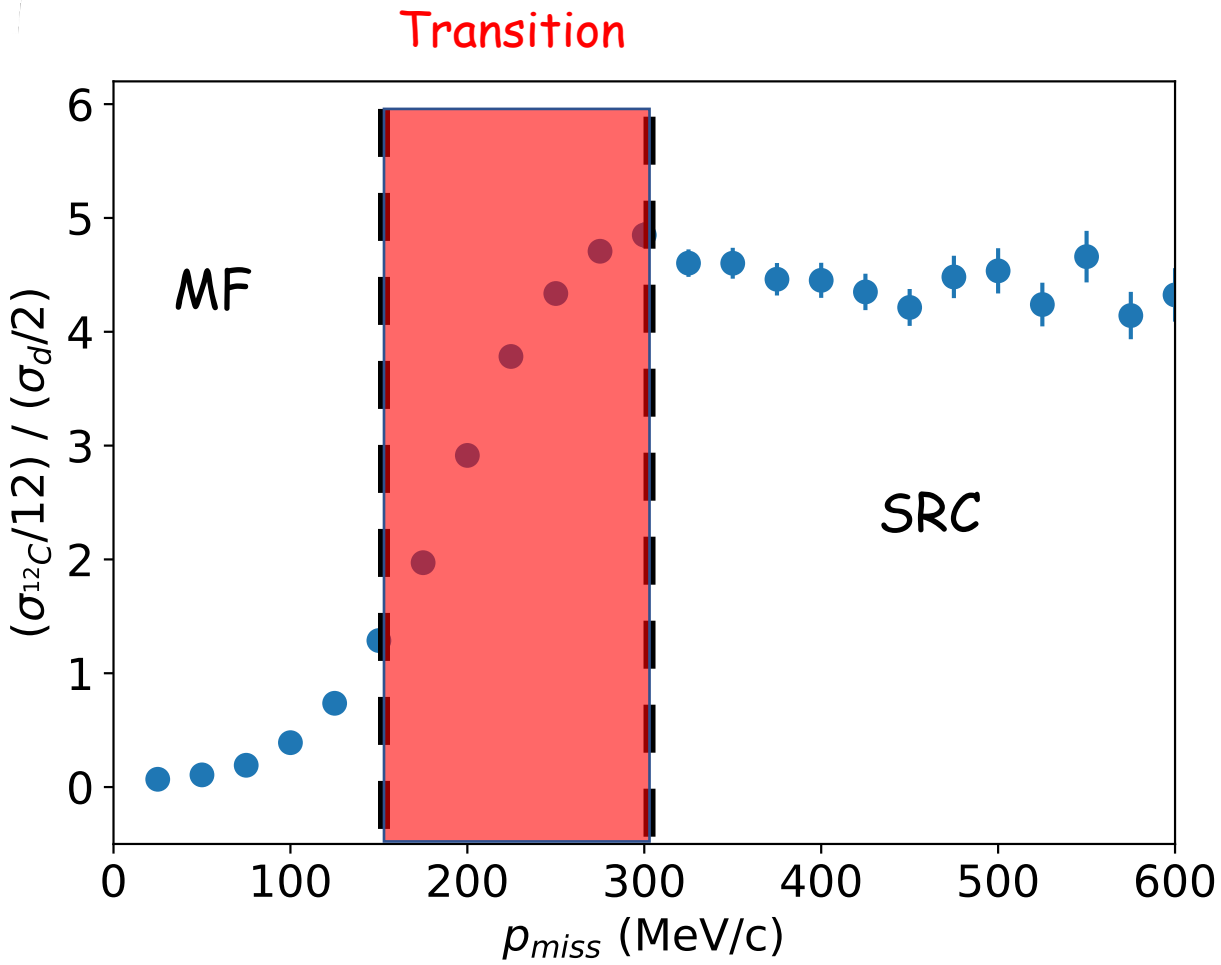




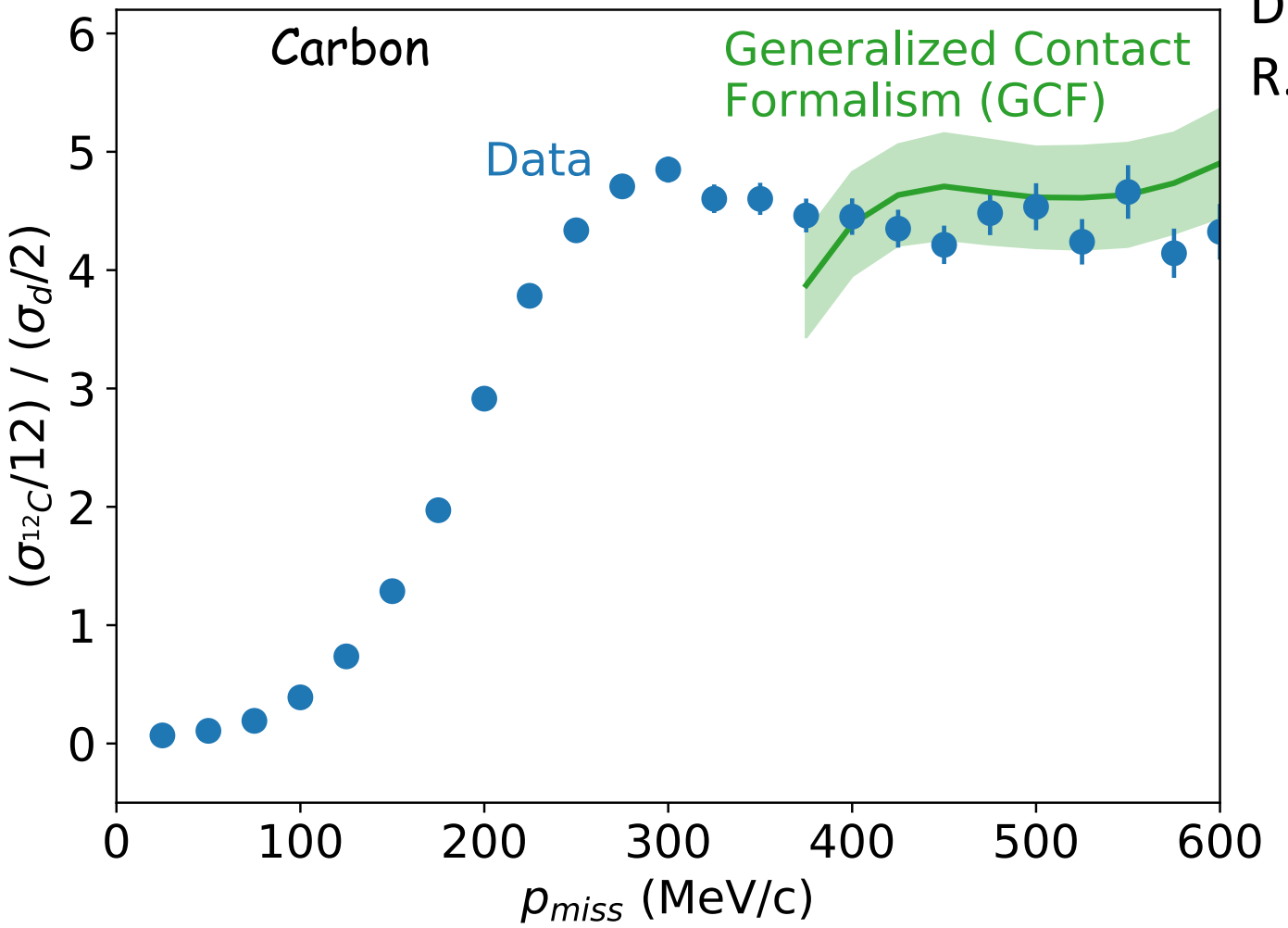
Korover PRC **107**, L061301 (2023)

Quantifying the transition





Mean Field to SRC transition



Details on GCF:
R. Cruz-Torres, Nature Physics **17,** 306 (2021)

- AV18 two nucleon interaction
- CM motion width 150 ± 20 MeV/c
- A-2 excitation energy of 0 – 30 MeV
- SRC abundance from contact terms

Mean field calculations

(e,e'p) knockout for high Q^2 reaction modeled assuming PWIA

$$\frac{d\sigma_{A(e,e'p)}}{d\Omega_{k'}dE_{k'}d\Omega_p dE_p} = p_p E_p \sigma_{ep} S_A^N(p_{miss}, E_{miss})$$

Single nucleon spectral function:

IPSM was modeled using Woods-Saxon.

Phys. Lett. B **351**, 87 (1995)
Phys. Rev. Lett. **72**, 1986 (1994)

Skyrme with five different functionals

Phys. Rev. C **19**, 1983 (1979)
Nucl. Phys. A **635**, 231 (1998)

Calculations quenched to agree with data (at low missing momentum)

QMC many-body calculations of the overlap between the ^{12}C and ^{11}B + proton wave functions

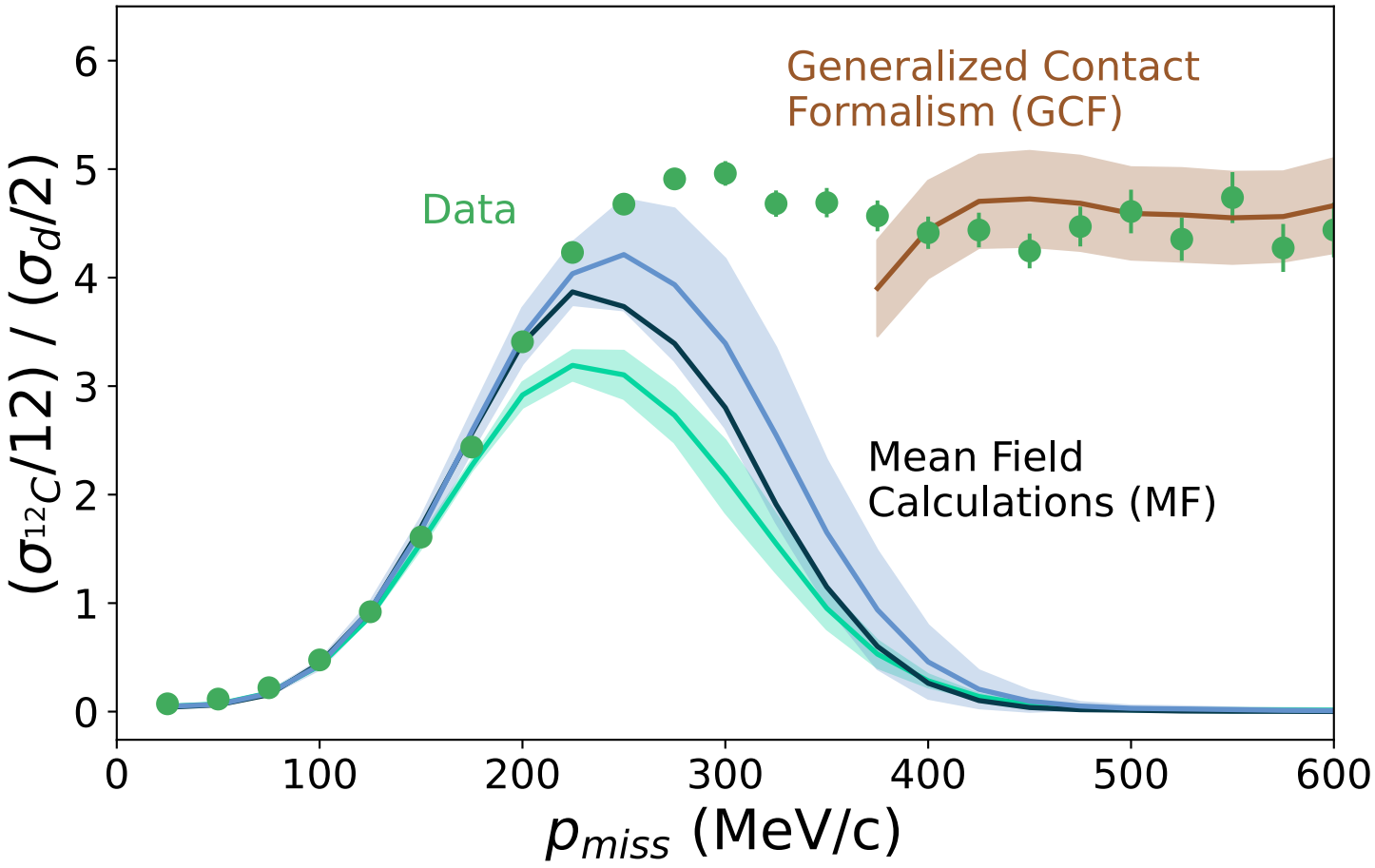
Mean Field to SRC transition

Mean Field Models

QMC (teal)

IPSM (black)

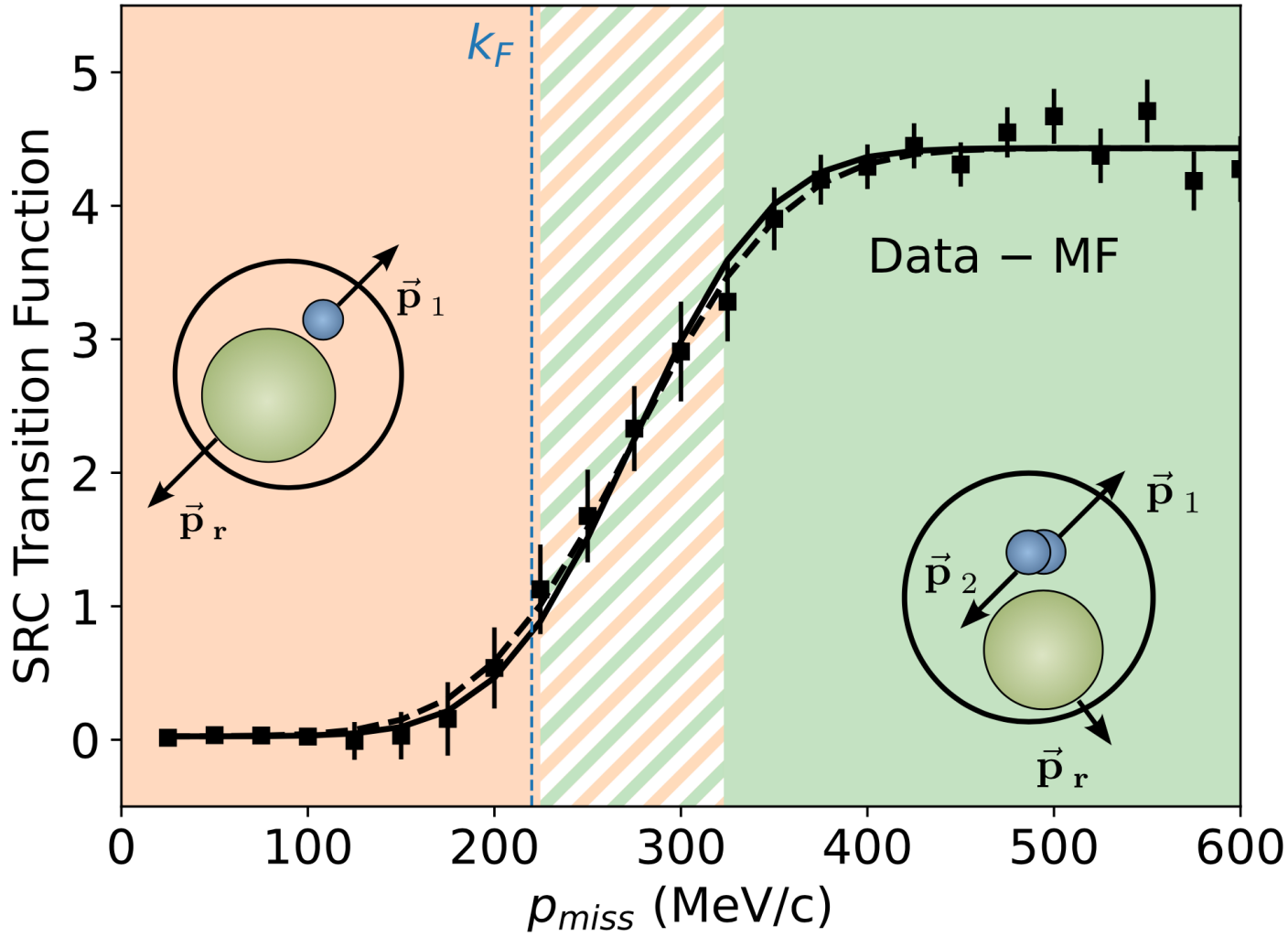
Skyrme (azure)



Mean Field to SRC transition

Centered around 270 ± 2MeV/c

Width of 57 ± 4 MeV/c



Summary

New experimental technique to study 2N-SRC

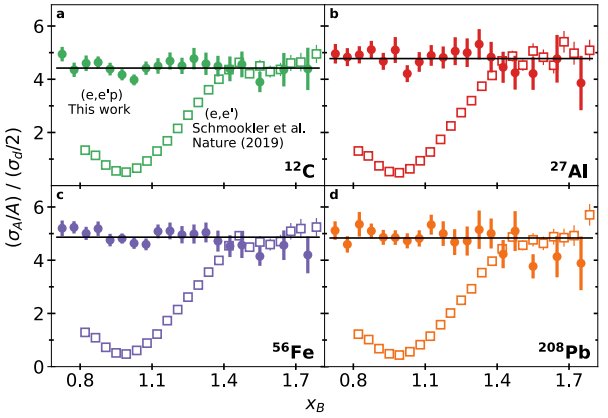
Experimental measurement of scaling over extended x Bjorken range

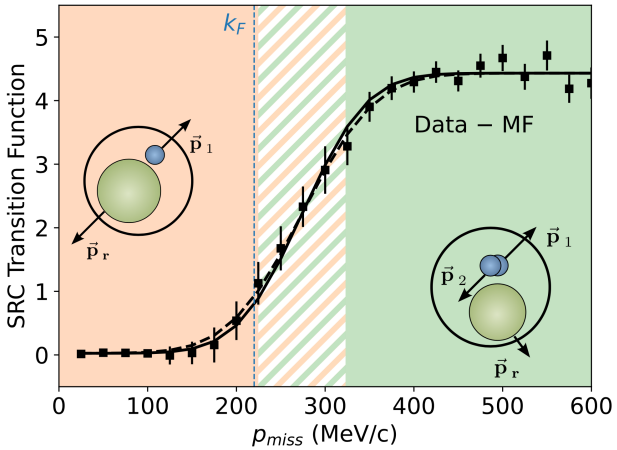
Dividing the nucleus into 3 regions
- Mean Field
- High Momenta (SRC)
- Transition

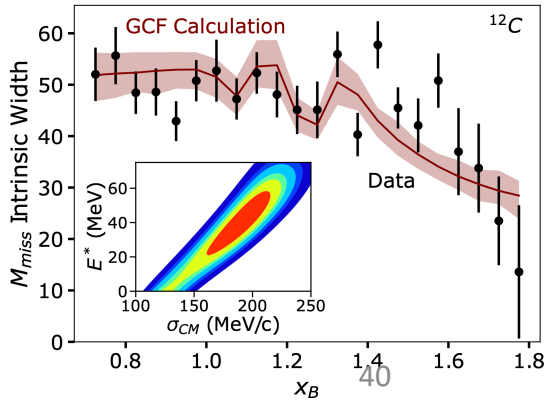
Quantitative measurement of transition region

Transition mean: 270 ±2 MeV/c (Larger than Carbon Fermi momentum ~220 MeV/c)

The width of the transition indicates that the overlap region where both long-range and short-range dynamics contribute is overall narrow.







A .Denniston

Thank you.