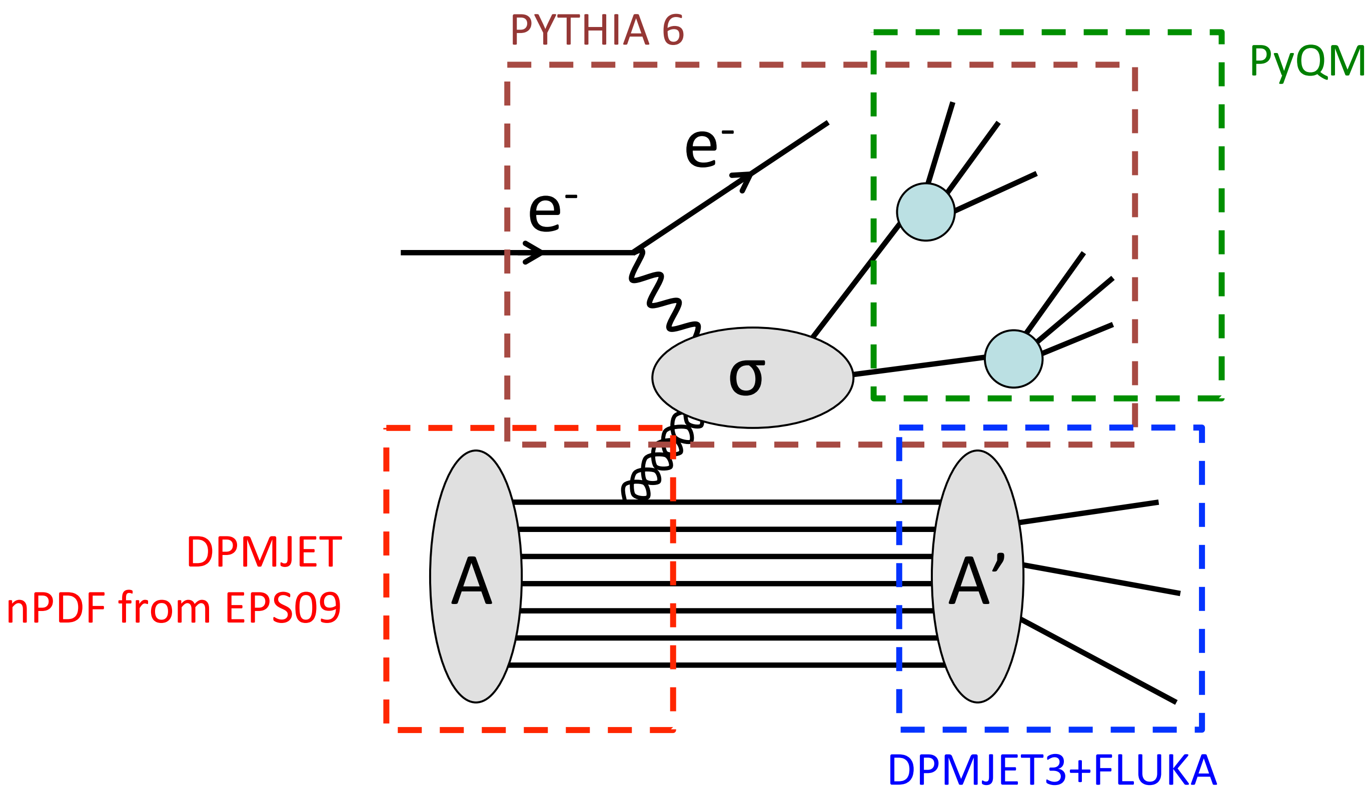
BeAGLE

- Benchmark eA Generator for Leptoproduction
- general purpose EIC eA Monte-Carlo generator



Quasi-Elastic scattering off SRC nucleons:
Generalized Contact Formalism (GCF)

https://wiki.bnl.gov/eic/index.php/BeAGLE

Contact Formalism and SRC universality

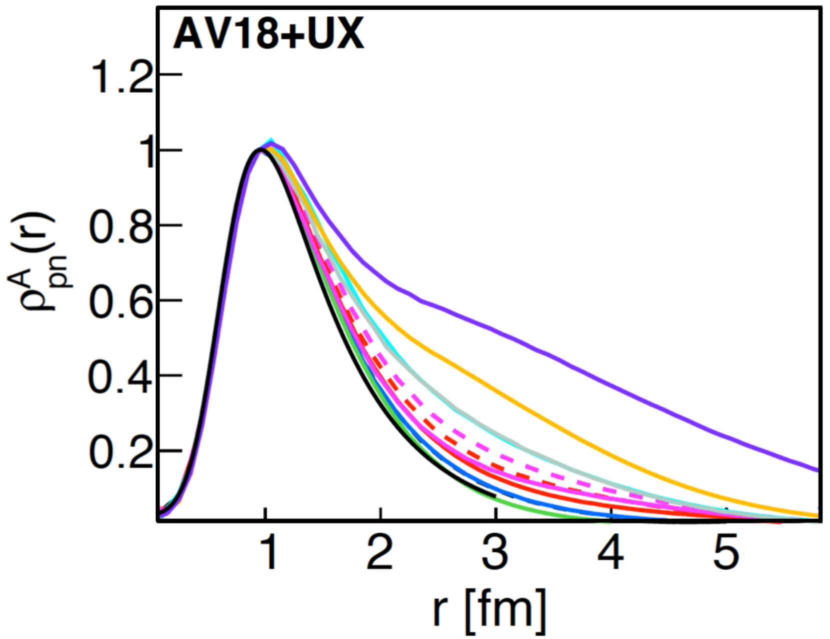
Reynier Cruz Torres

Exploring QCD with light nuclei at EIC

January 22nd, 2020

Summary & Conclusions

- GCF describes the many-body nuclear wave-function where SRCs dominate.



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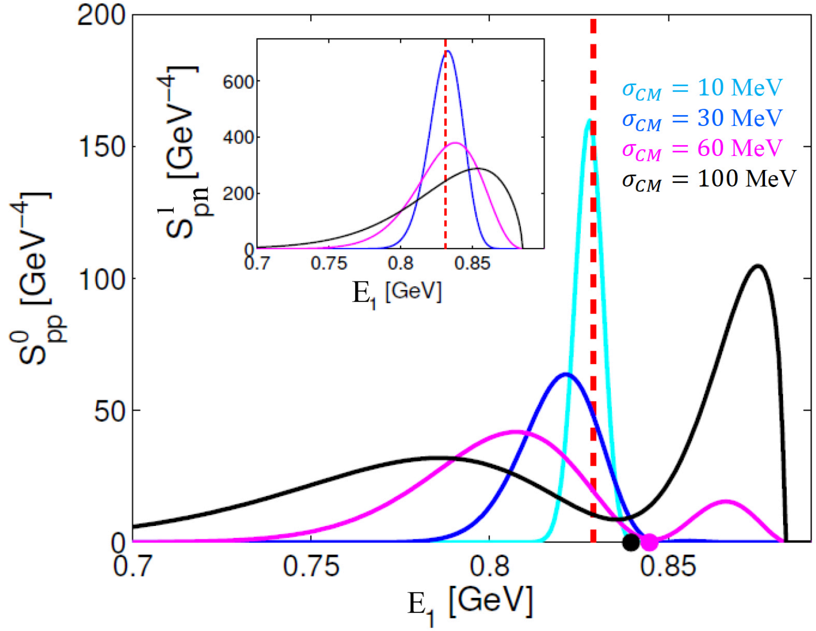
- GCF offers prescription for SRC spectral functions.



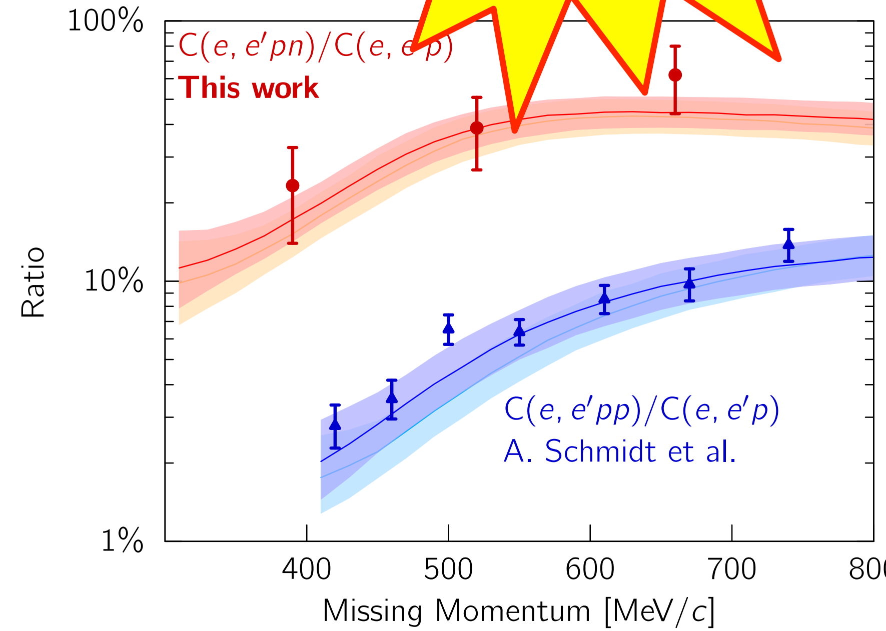
Summary & Conclusions

- GCF describes the many-body nuclear wave-function where SRCs dominate.

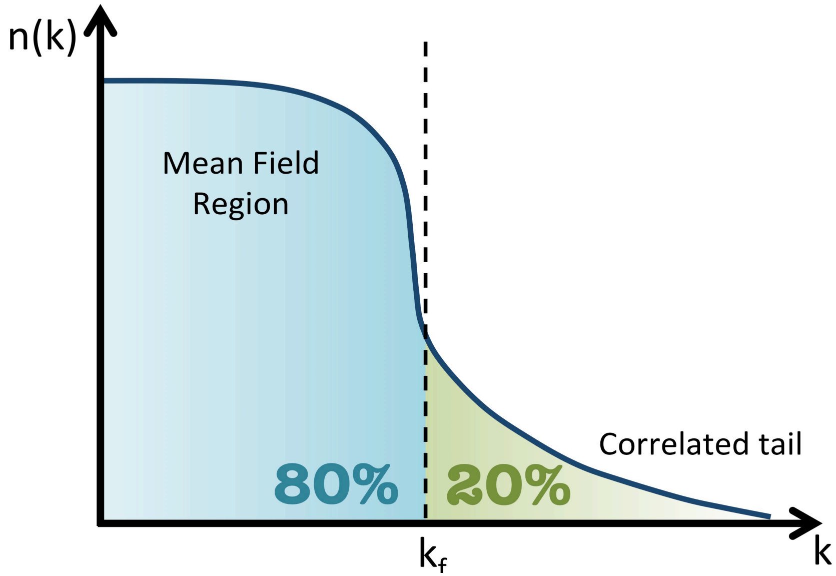
- GCF offers prescription for SRC spectral functions.

- This allows us to calculate QE electron-scattering cross sections and other observables.

see talks by J. Pybus and A. Denniston



SRC 101



O. Hen et al., Science 364 (2014) 614.
Korover et al., PRL 113 (2014) 022501.
N. Fomin et al., PRL 108, 092502 (2012).
R. Subedi et al., Science 320 (2008) 1476.
K. Sh. Egiyan et al., PRC 68, 014313 (2003).
H. Baghdasaryan et al., PRL 105, 222501 (2010).
O. Hen, L. B. Weinstein, E. Piasetzky, *et al.*, PRC 92, no. 4, 045205 (2015).

Account for ~20% of all nucleons in any nucleus.

Dominate the momentum distribution above the Fermi momentum (k_F).

Relative momentum >> center-of-mass and Fermi momenta.

Predominantly pn pairs.

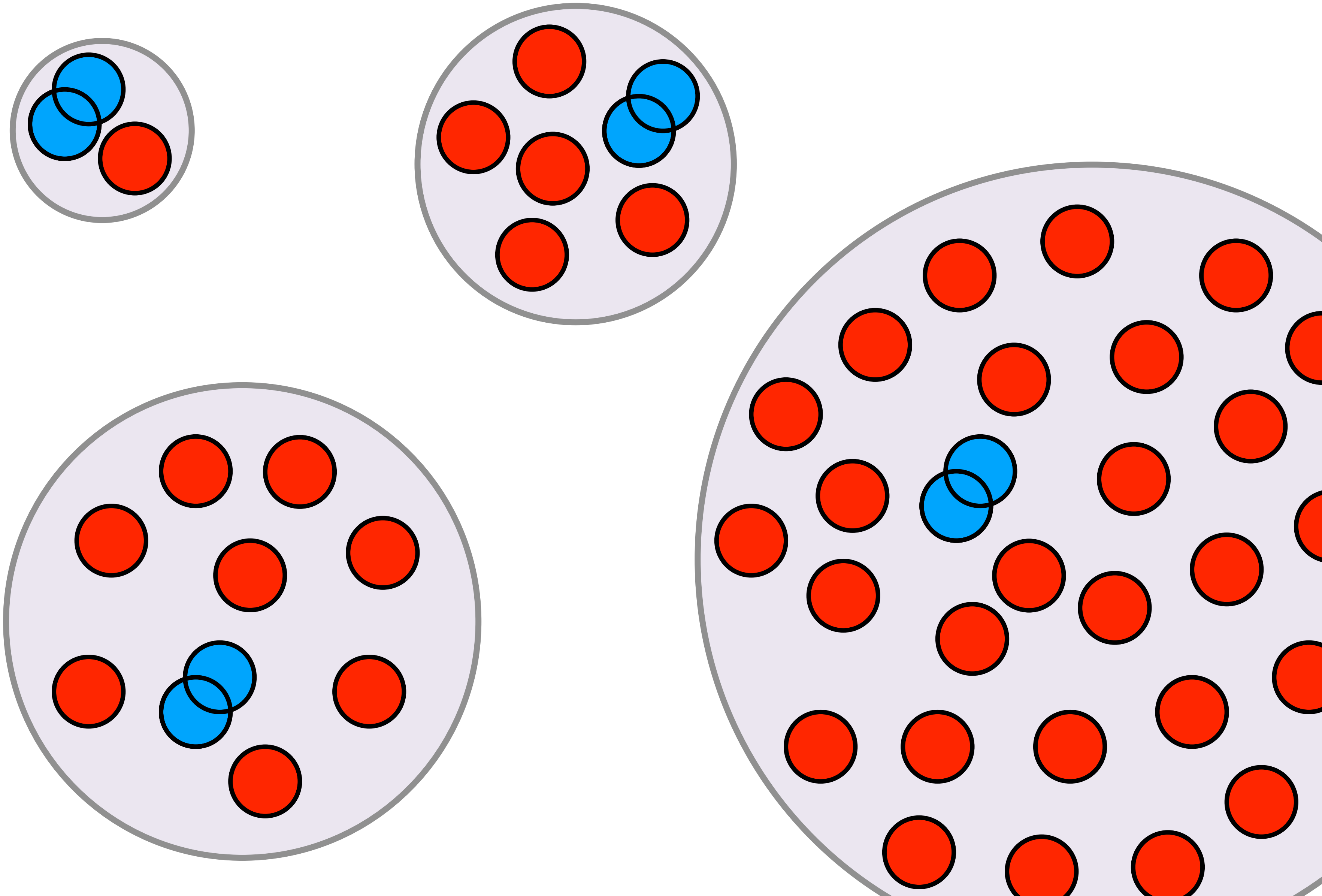
Why effective theories for SRC?

- Complicated NN interaction & large nuclear density

- Ab-initio calculations are limited to light-medium nuclei

- Mean-Field theories don't include SRCs

Scale Separation in Nuclear Systems



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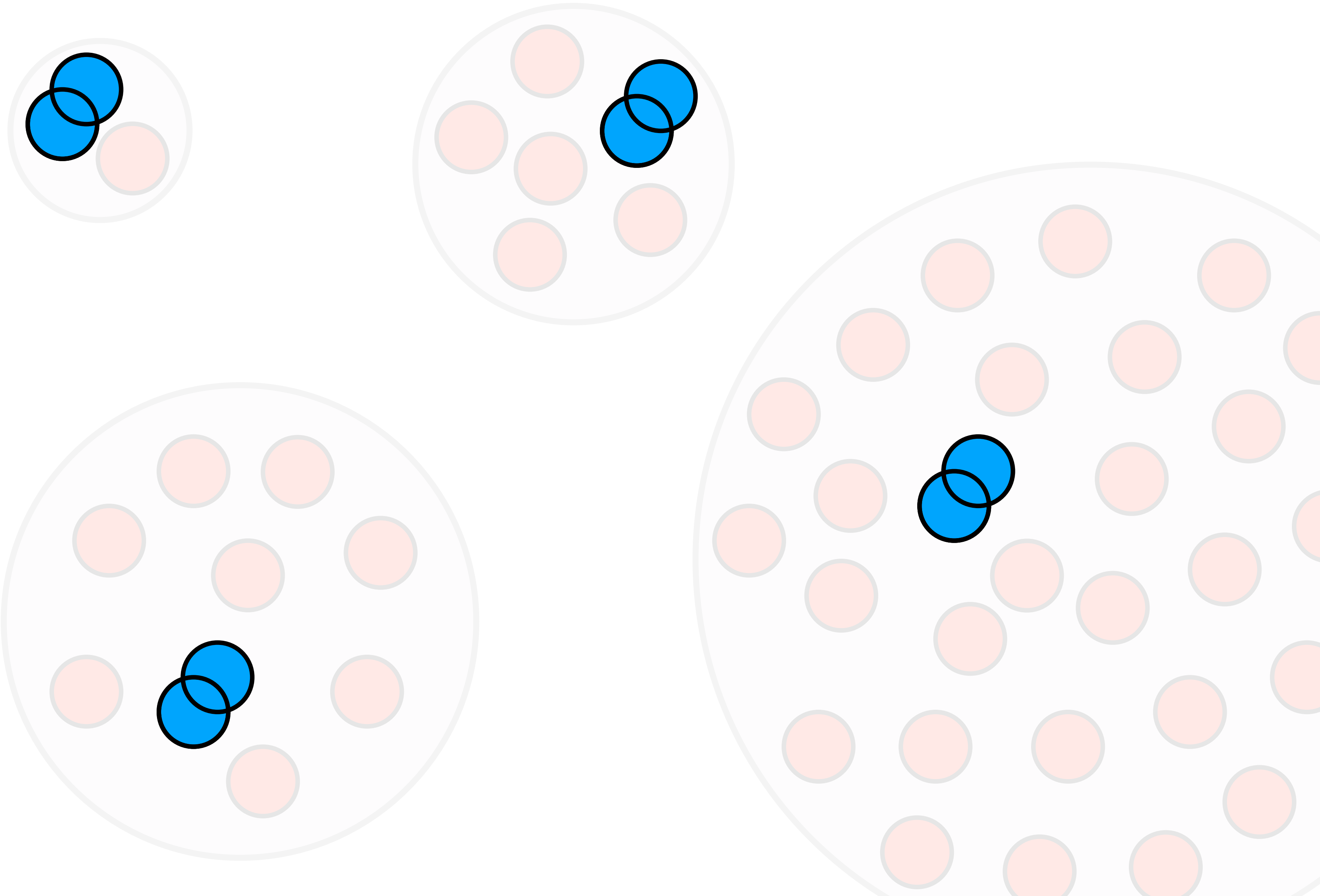
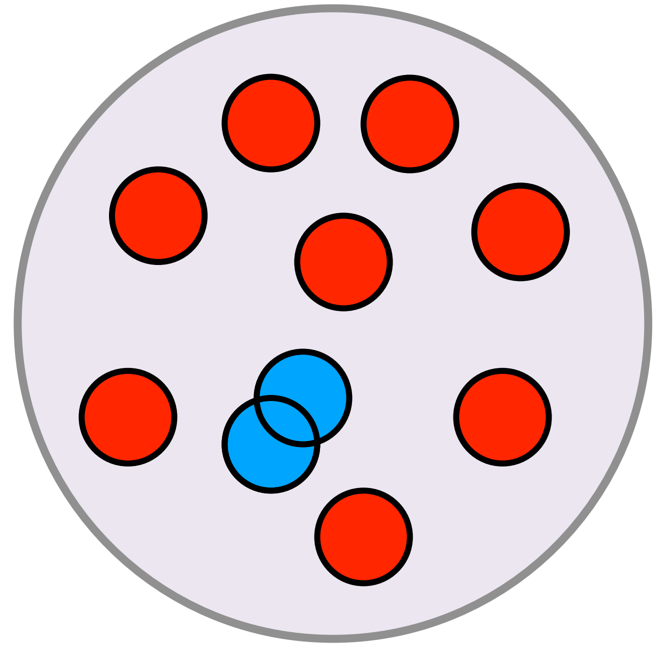


Factorization in nuclear systems

Scale separation at short distances

⇩

Factorization of the nuclear wavefunction



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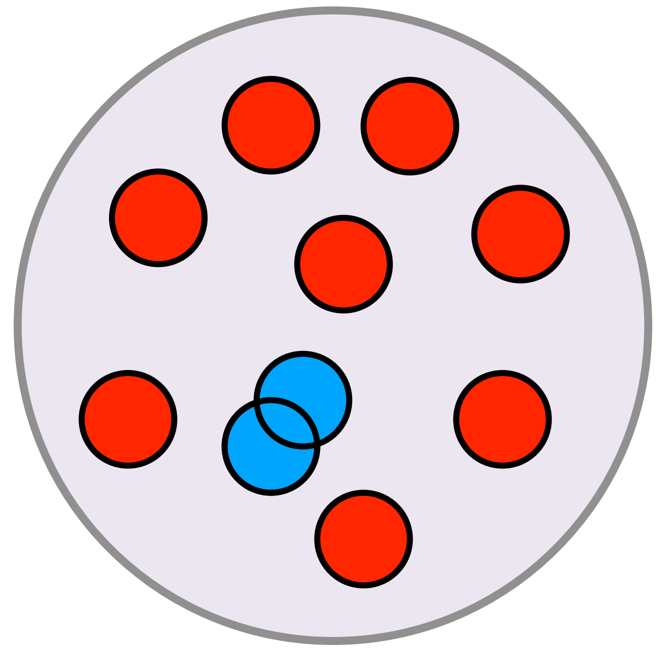


$$\Psi \xrightarrow{r_{ij} \to 0} \varphi(r_{ij}) \times A_{ij}(R_{ij}, \{r\}_{k \neq ij})$$

Many-body nuclear wave-function

two-body wave-function

A-2 residual system

Short-r 2-body density in the GCF

$$\rho_A^{NN,\alpha}(r) = C_A^{NN,\alpha} \times |\varphi_{NN}^{\alpha}(r)|^2$$

Short-r 2-body density in the GCF

$$\rho_A^{NN,\alpha}(r) = C_A^{NN,\alpha} \times |\varphi_{NN}^{\alpha}(r)|^2$$

Many-body density

constant

<u>Contacts</u>

(nucleus dependent)

2-body density

(universal)

High-k 2-body density in the GCF

$$\rho_A^{NN,\alpha}(r) = C_A^{NN,\alpha} \times |\varphi_{NN}^{\alpha}(r)|^2$$

$$\rho_A^{NN,\alpha}(q) = C_A^{NN,\alpha} \times |\varphi_{NN}^{\alpha}(q)|^2$$

Many-body density

constants
Contacts

(nucleus dependent)

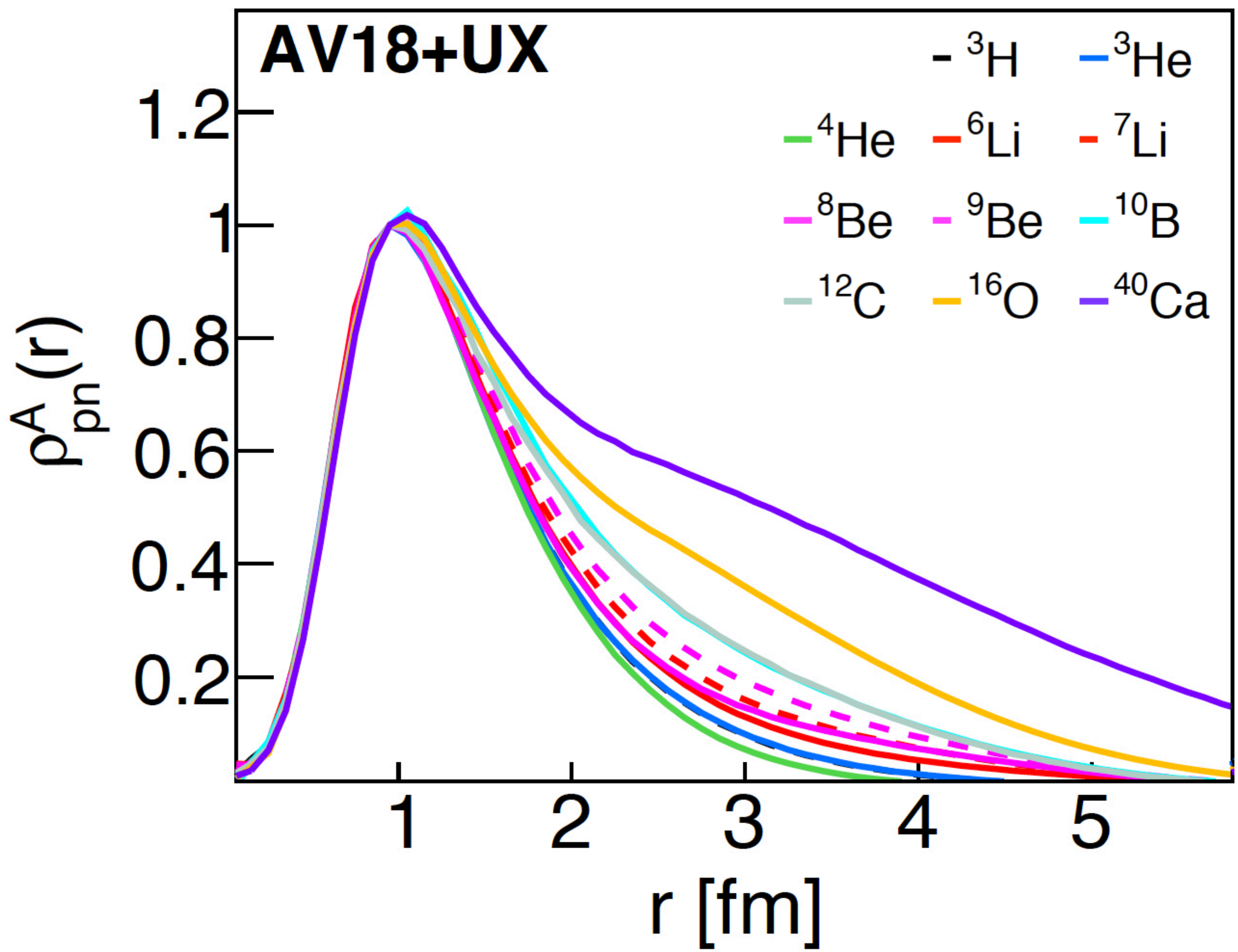
2-body density

(universal)

Small-r universality

$\rho_A^{NN,\alpha}(r)$

Many-body



Small-r universality

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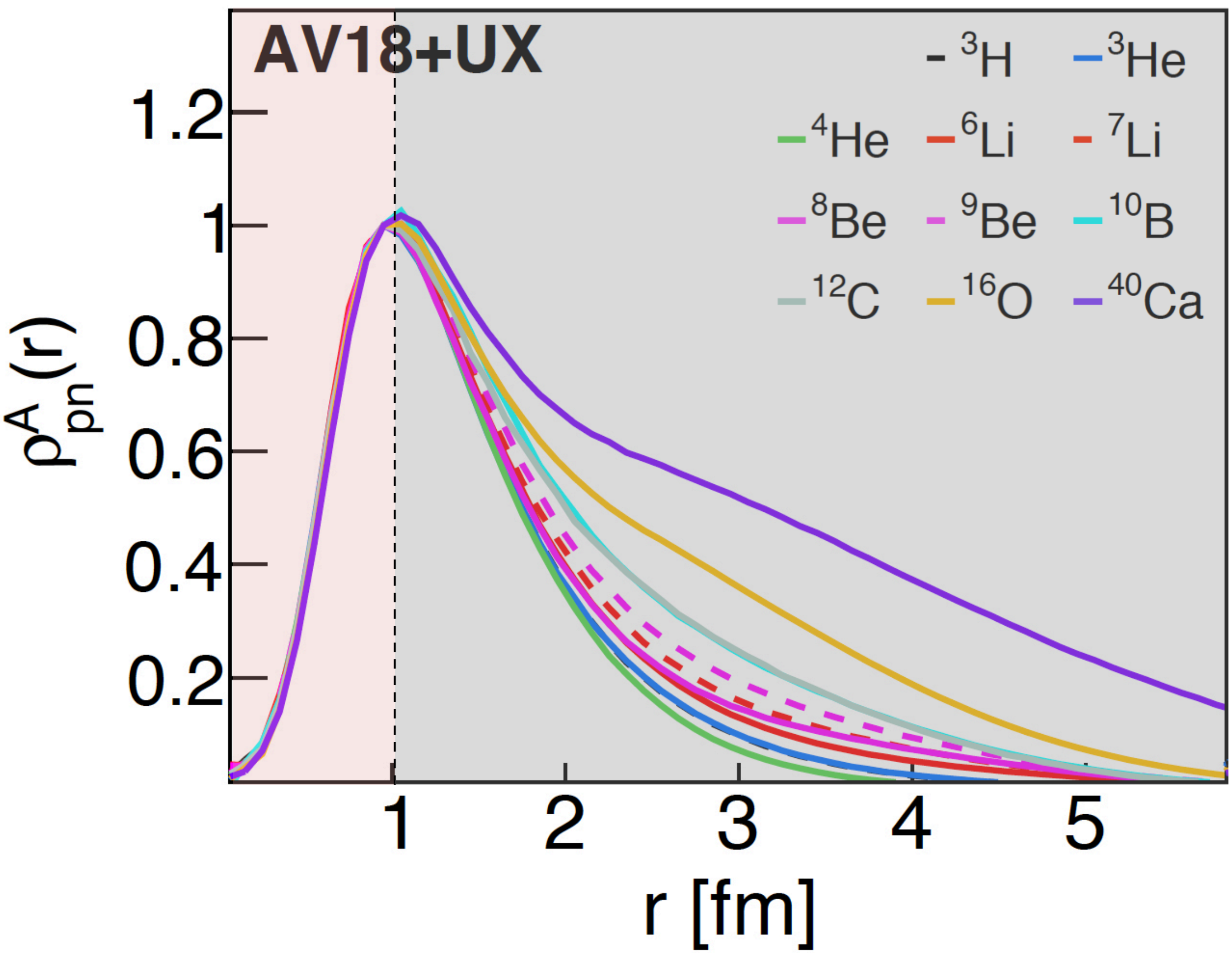
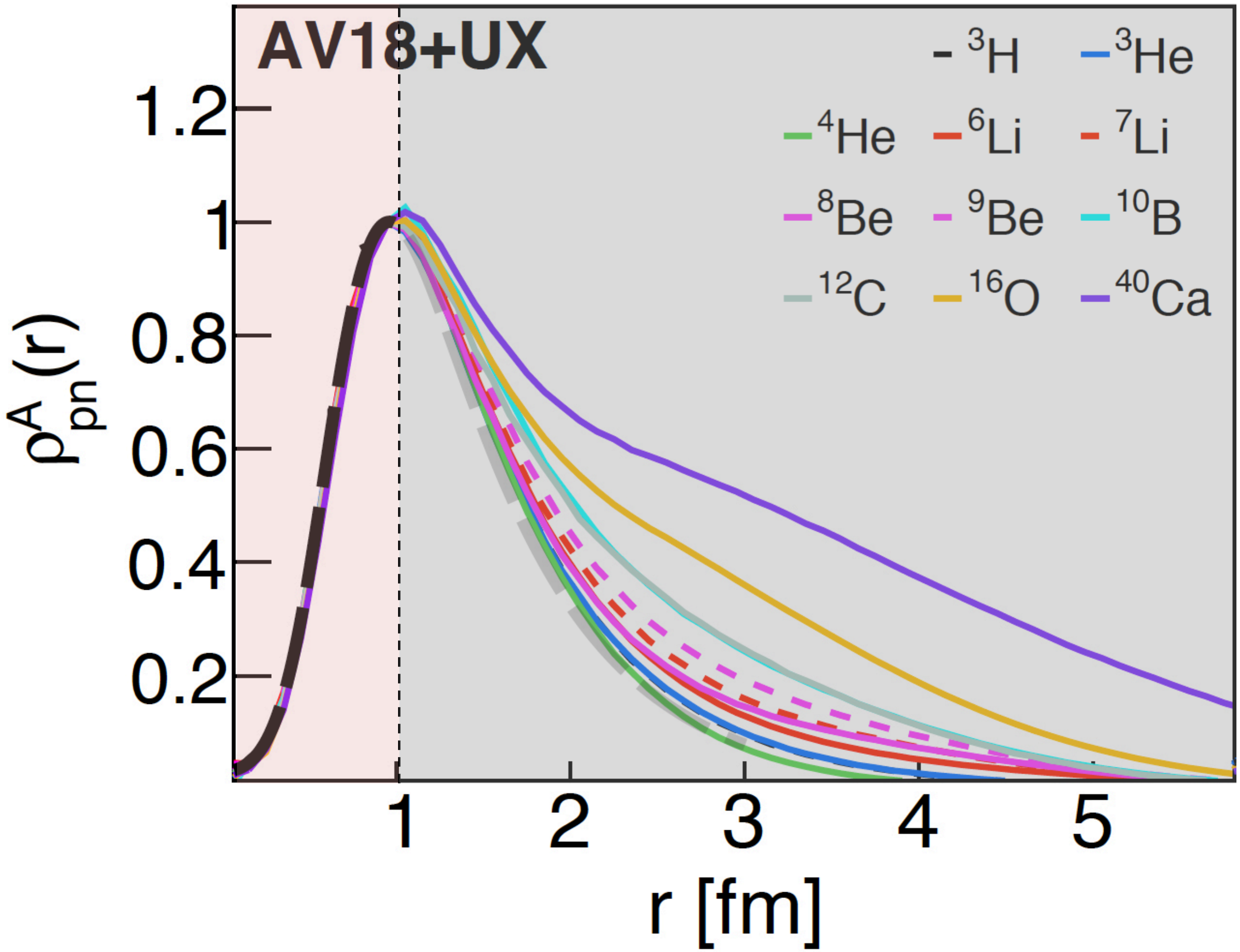


The Generalized Contact Formalism

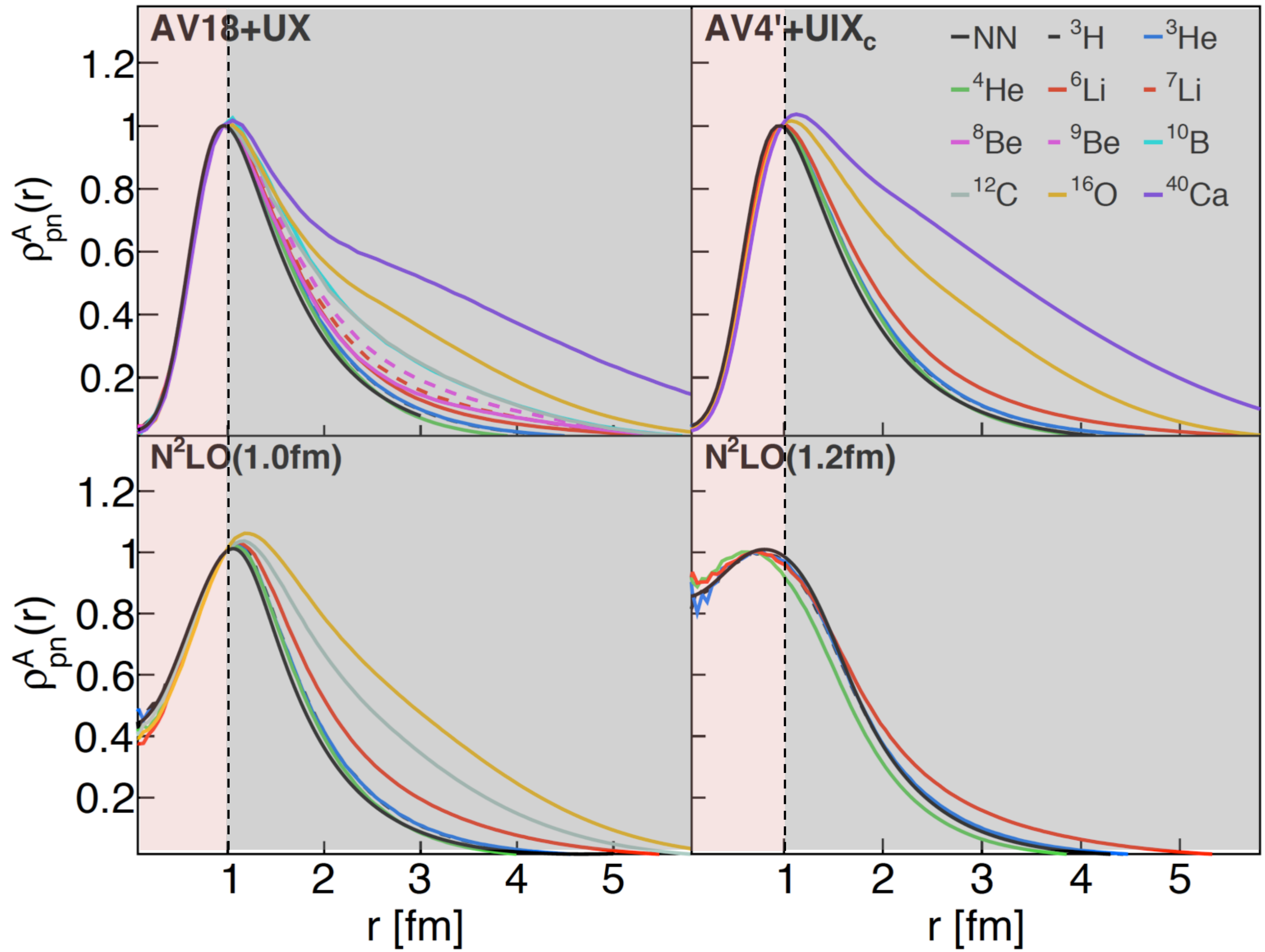
$$\rho_A^{NN,\alpha}(r) = C_A^{NN,\alpha} \times |\varphi_{NN}^{\alpha}(r)|^2$$

Many-body Constant Pair



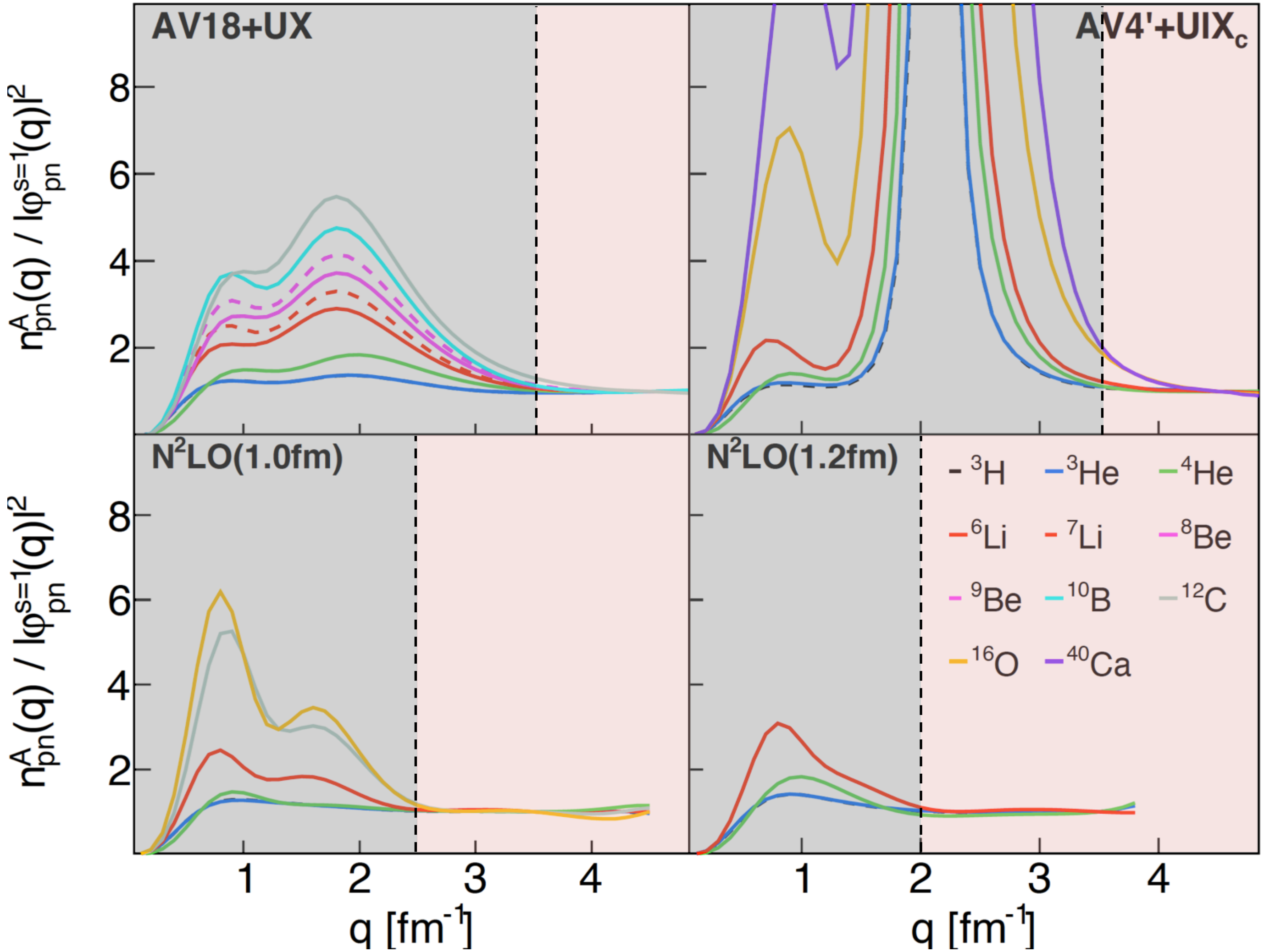
Small-r universality and the GCF

$$\rho_A^{NN,\alpha}(r) = C_A^{NN,\alpha} \times |\varphi_{NN}^{\alpha}(r)|^2$$



High-k universality and the GCF

$$\frac{\rho_A^{NN,\alpha}(q)}{|\varphi_{NN}^{\alpha}(q)|^2} = C_A^{NN,\alpha}$$



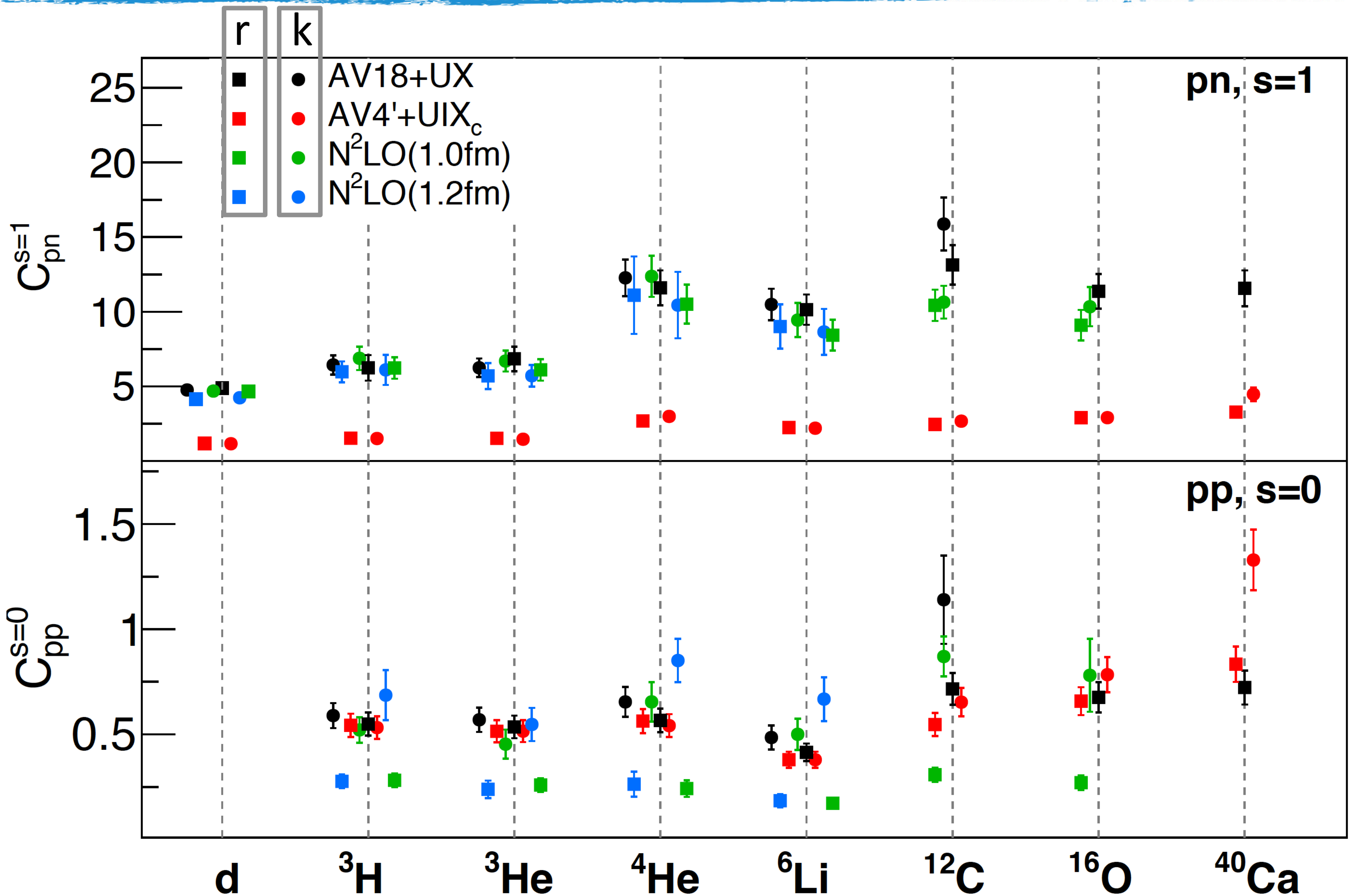
RW et al., Phys. Rev. C 92, 054311 (2015)

RW, **RCT** et al., PLB 780, 211 (2018)

RCT, et al., PLB 785 304 (2018)

RCT, et al., arXiv:1907.03658 (2019), under review for Nature Physics

Nuclear Contacts



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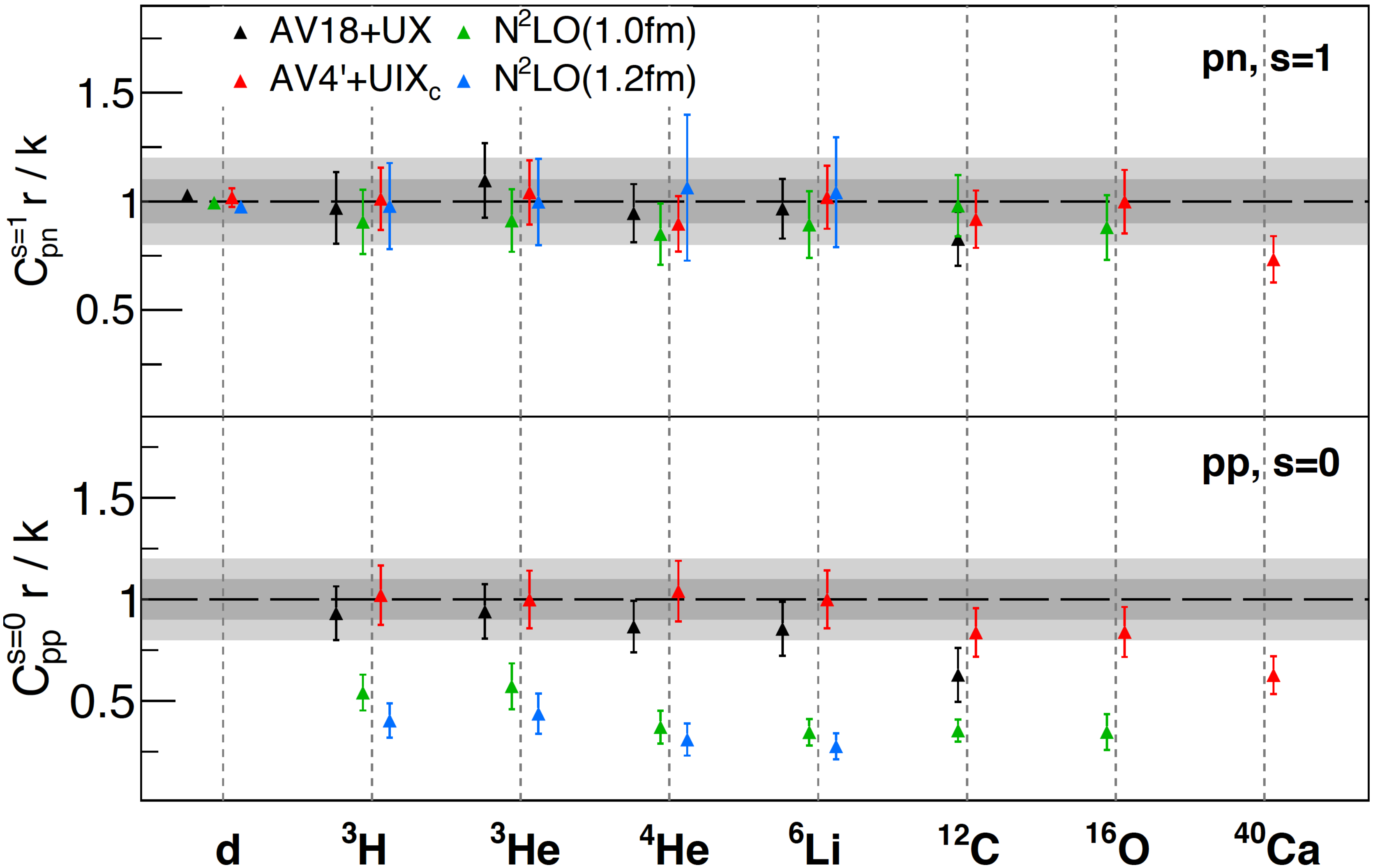
Coordinate – Momentum Equivalence



r/k ratio = 1 → coordinate-momentum equivalence

A/d: small-r and high-k scaling are IDENTICAL

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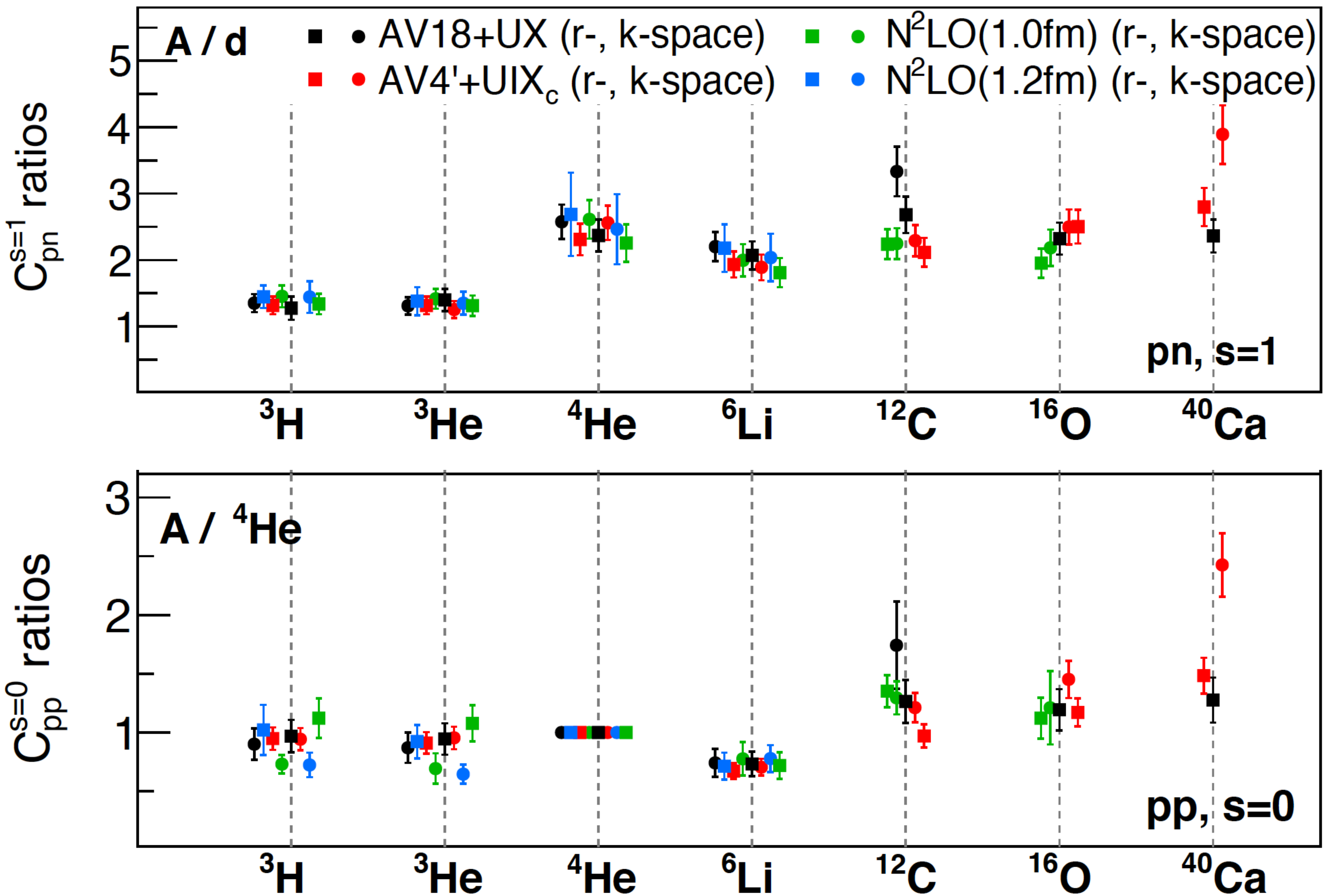

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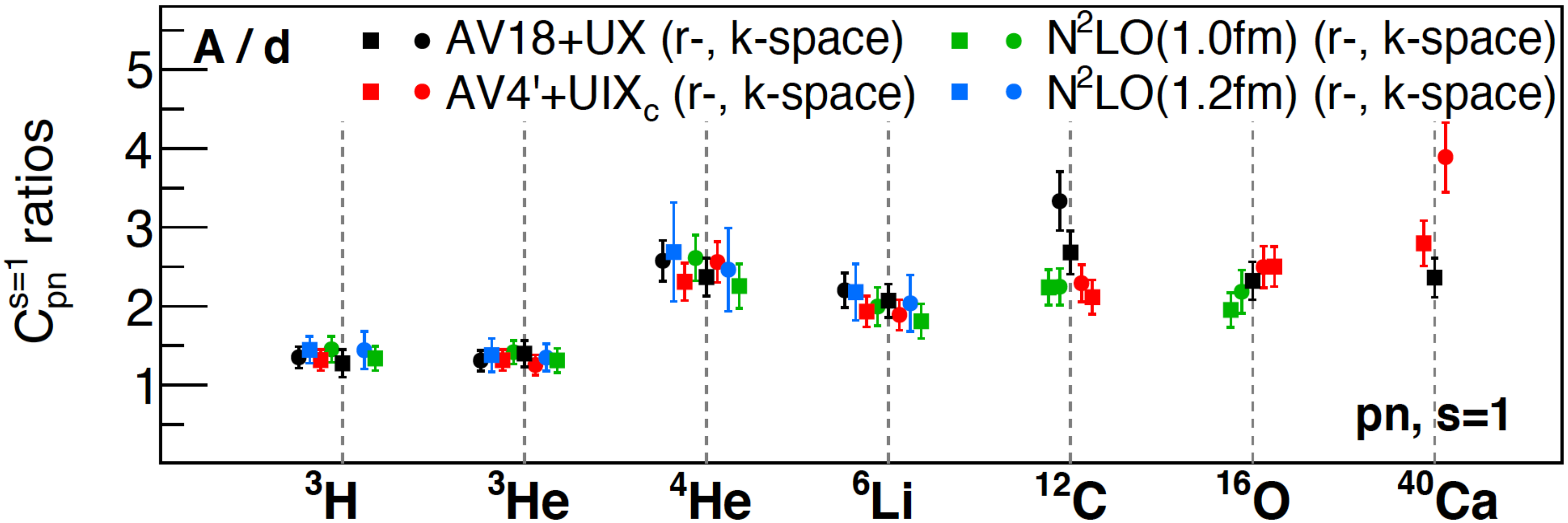

- SRC abundance is a Mean Field property.

Fomin et al., PRL 108, 092502 (2012).

B.Schmookler, et al., Nature 566, 354-358 (2019)

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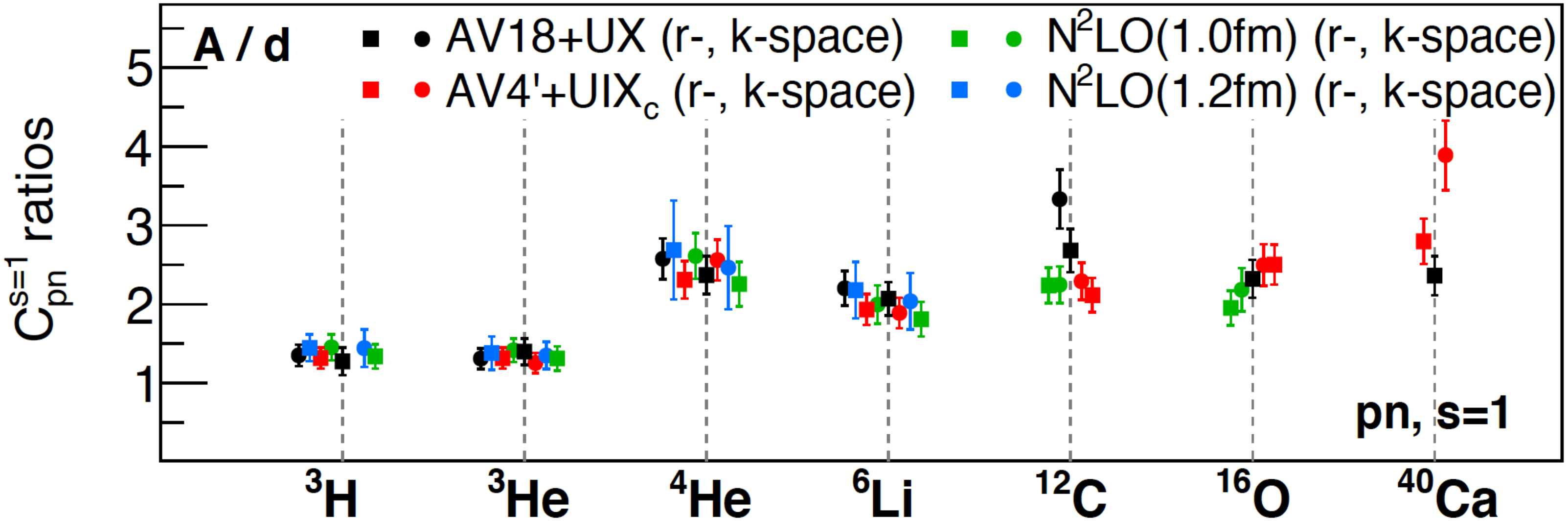
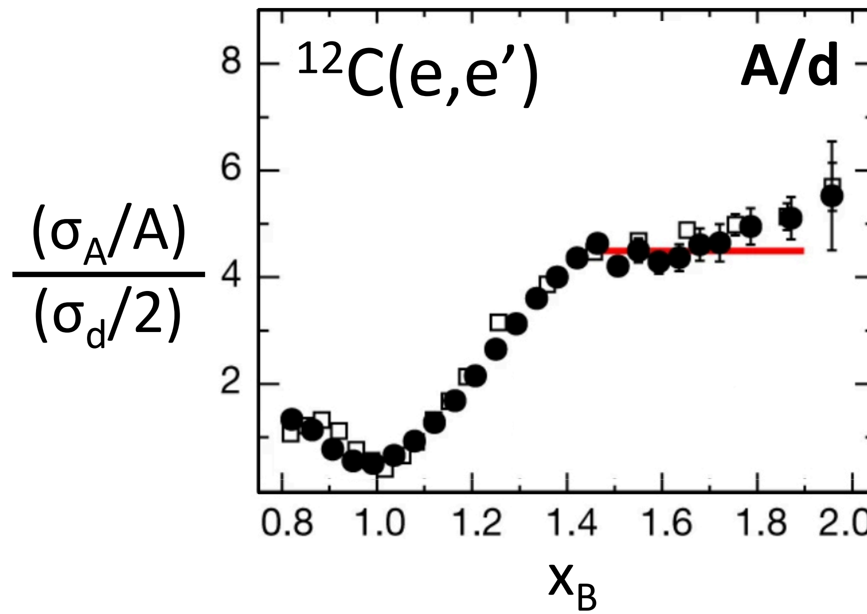


- SRC abundance is a Mean Field property.
- Inclusive ratios are insensitive to the NN interaction details at short distance.



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Applications of the GCF

Contact Formalism
PLB 780, 211 (2018)

Photo-absorption cross section
PRL 114 no.1, 012501 (2015)

Probing core of NN interaction
Nature, In-Press (2019)

Coulomb sum rule
Few-Body Syst 58, 9 (2017)

Nuclear Charge-Radii
PLB 790, 484 (2019)
PLB 793, 360 (2019)

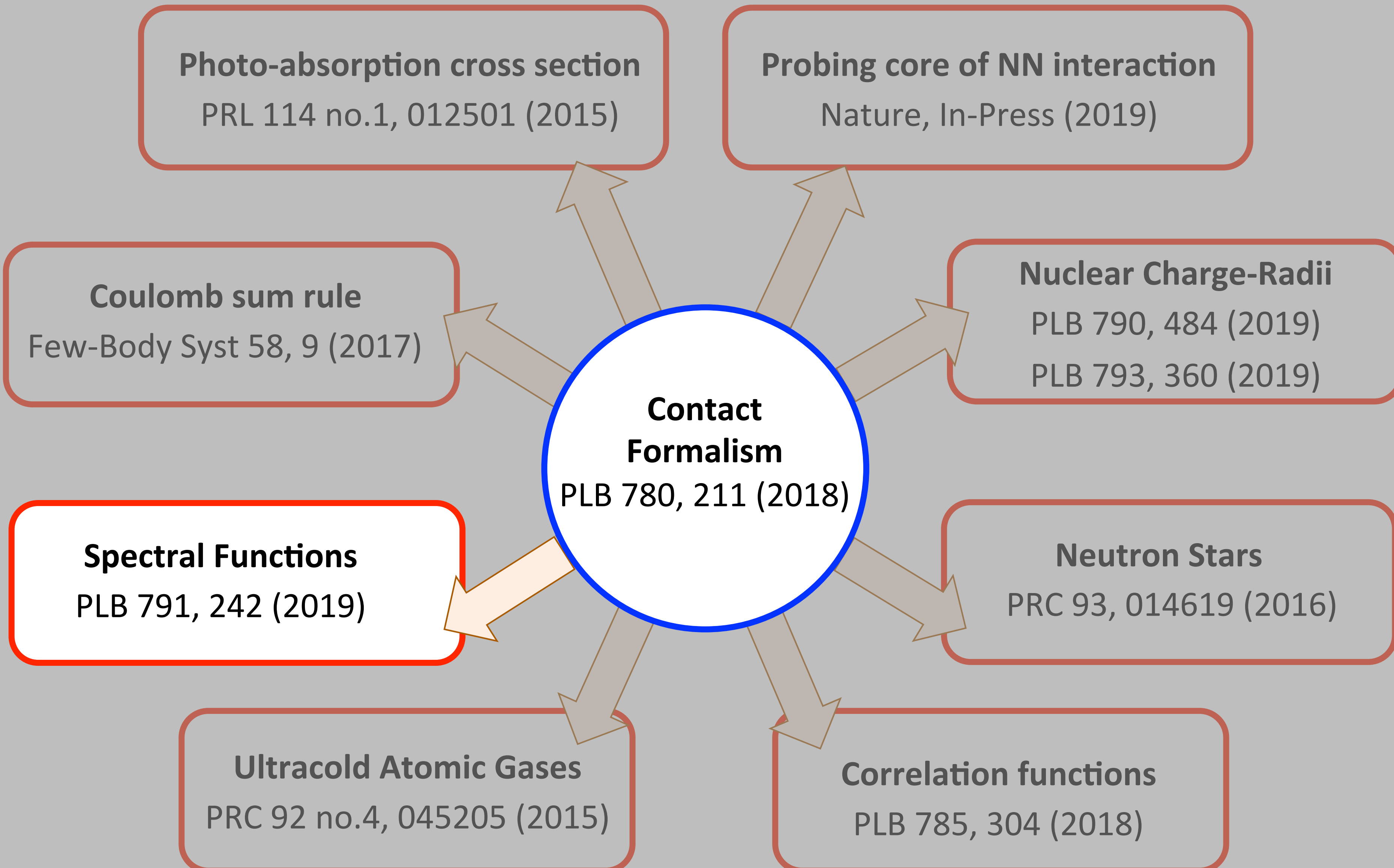
Spectral Functions
PLB 791, 242 (2019)

Neutron Stars
PRC 93, 014619 (2016)

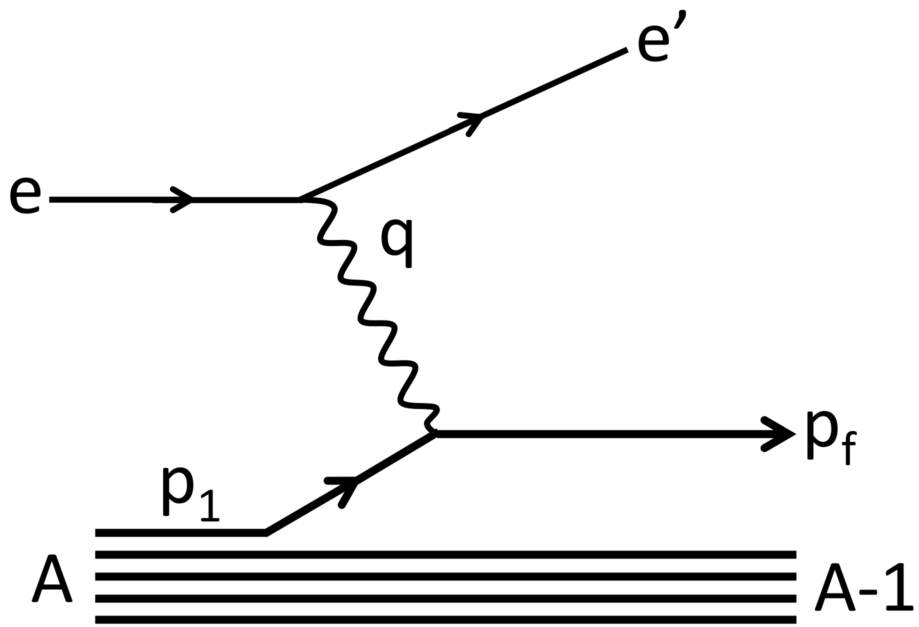
Ultracold Atomic Gases
PRC 92 no.4, 045205 (2015)

Correlation functions
PLB 785, 304 (2018)

Applications of the GCF



Plane-Wave Impulse Approximation (PWIA)



Missing momentum

$$\vec{p}_{miss} \equiv \vec{p}_f - \vec{q}$$

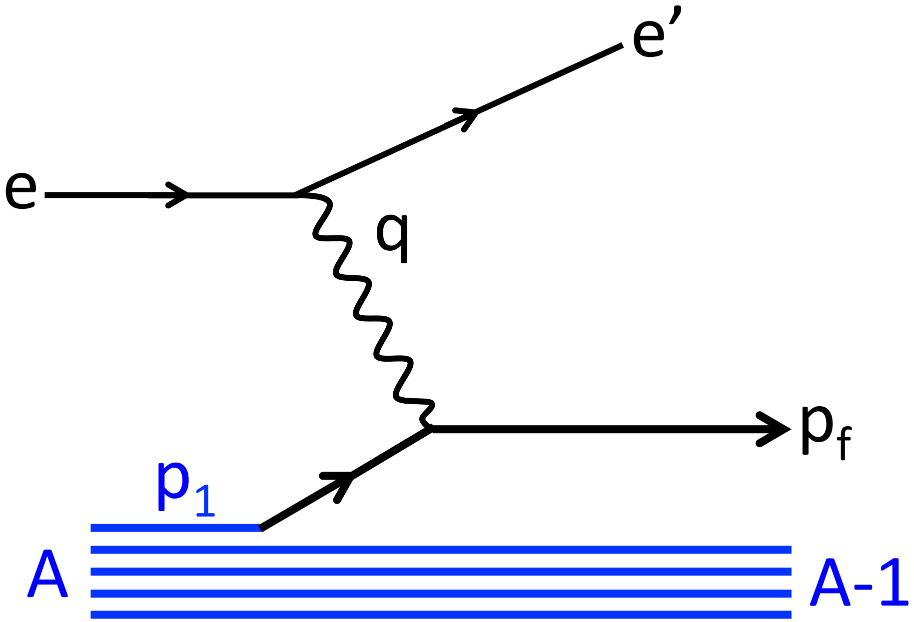
Assuming:

1) momentum transfer absorbed by a single nucleon.

2) knocked-out nucleon did not rescatter as it left the nucleus.

$$\vec{p}_{miss} = \vec{p}_1$$

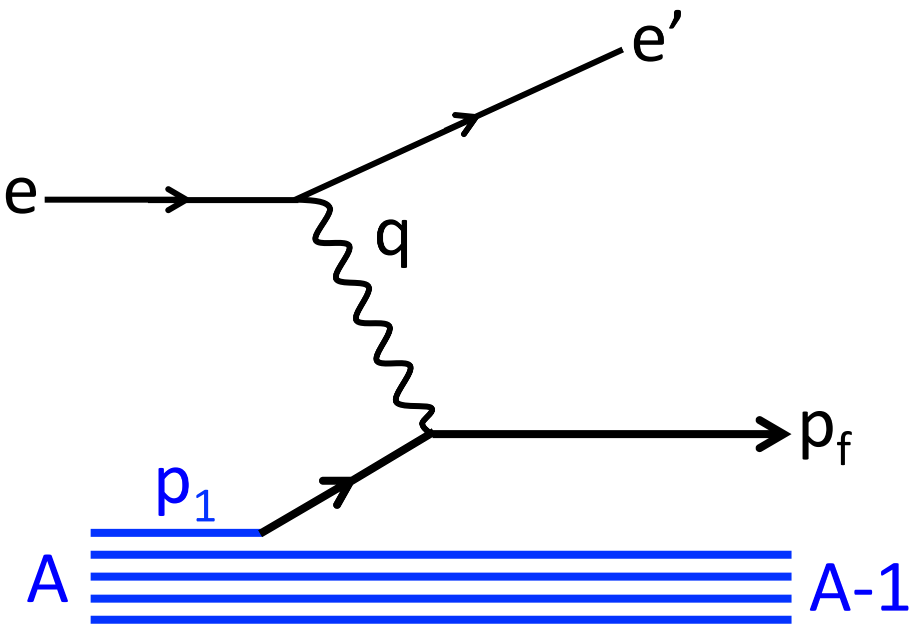
High-Energy Factorization



$$\sigma = \sigma_{eN} \cdot S(p_1, E_1)$$

Spectral function:
probability to find a nucleon with momentum p_1 and energy E_1

High-Energy Factorization



$$\sigma = \sigma_{eN} \cdot S(p_1, E_1)$$

Spectral function: probability to find a nucleon with momentum p_1 and energy E_1

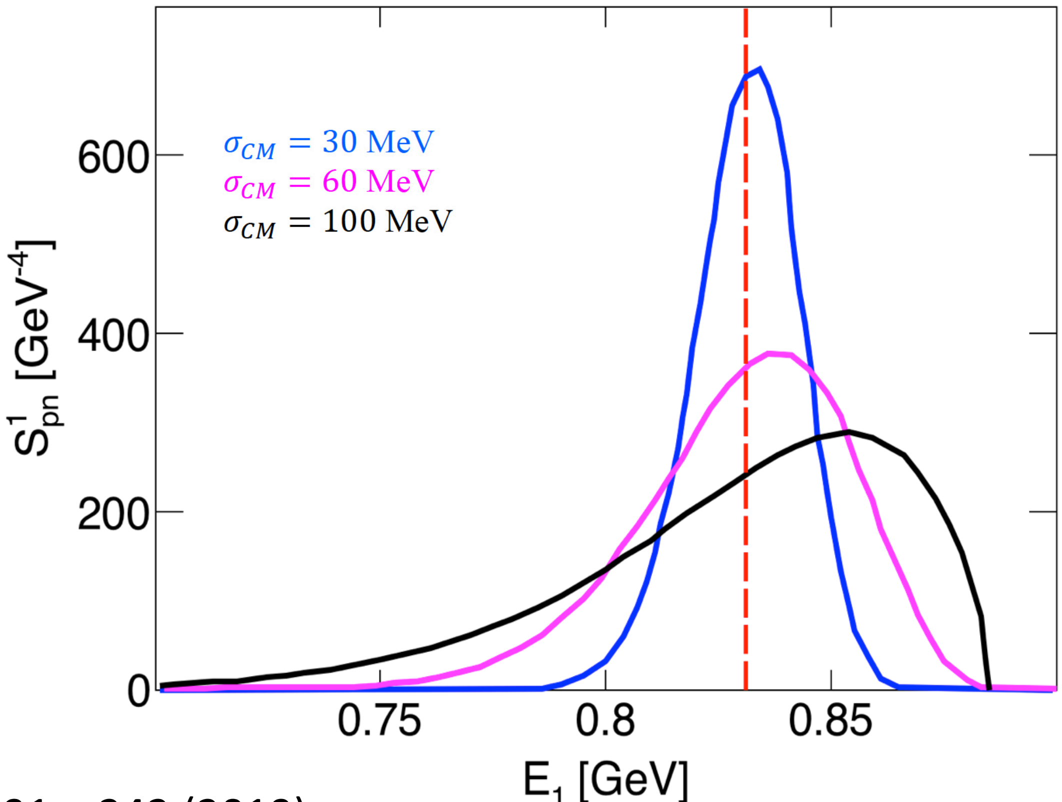
↓

Calculated from traditional effective models => lack SRC effects.

GFC (SRC) Spectral Function

$$\sigma = \sigma_{eN} \cdot S(p_1, E_1)$$

$$S(p_1, E_1) = \sum_{\alpha} C_A^{\alpha} \int \frac{d^3 p_2}{(2\pi)^3} |\varphi^{\alpha}(q)|^2 \, n(Q) \, \delta(f(p_2))$$



R. Weiss et al., PLB 791 p 242 (2019)

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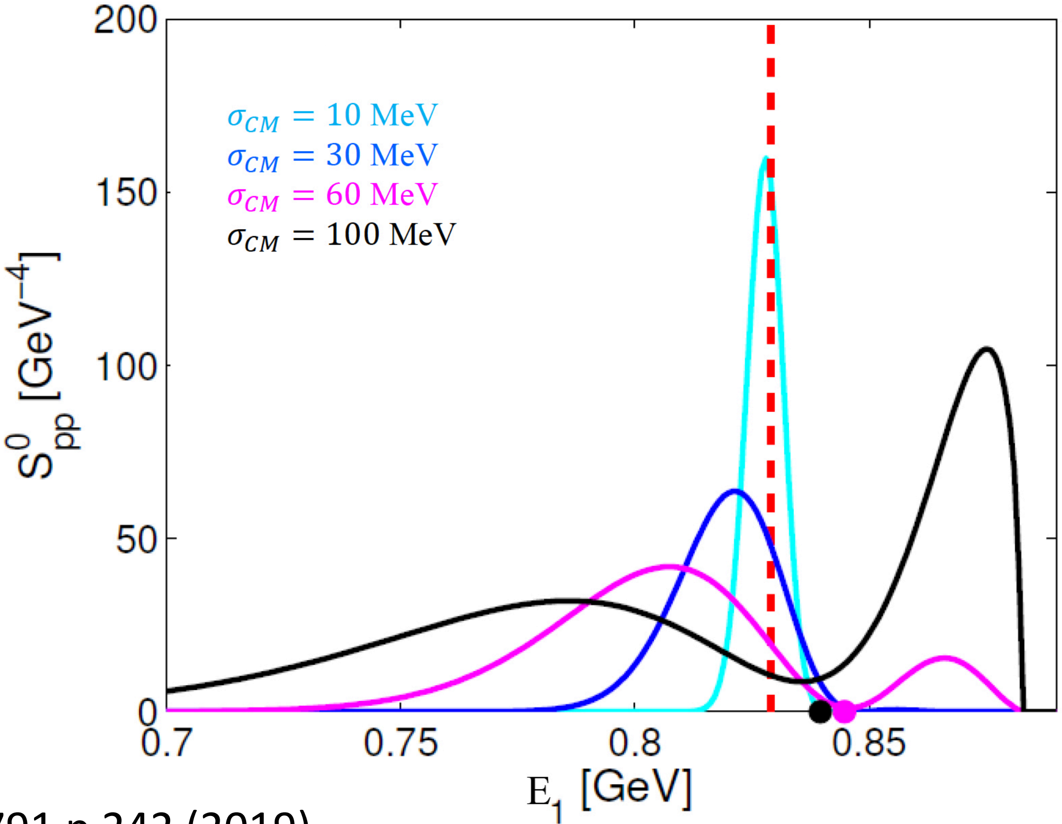

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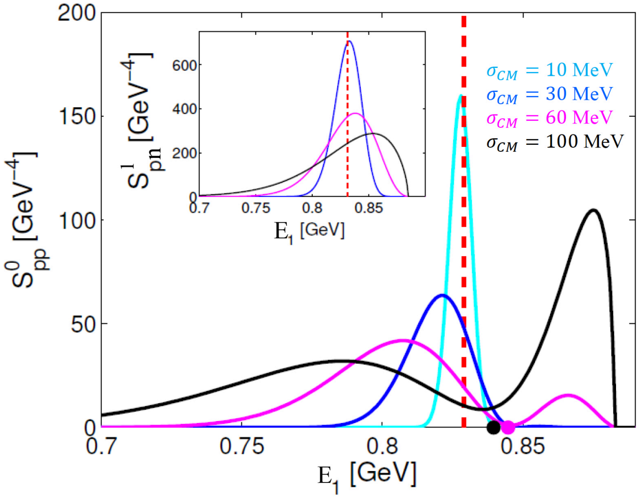
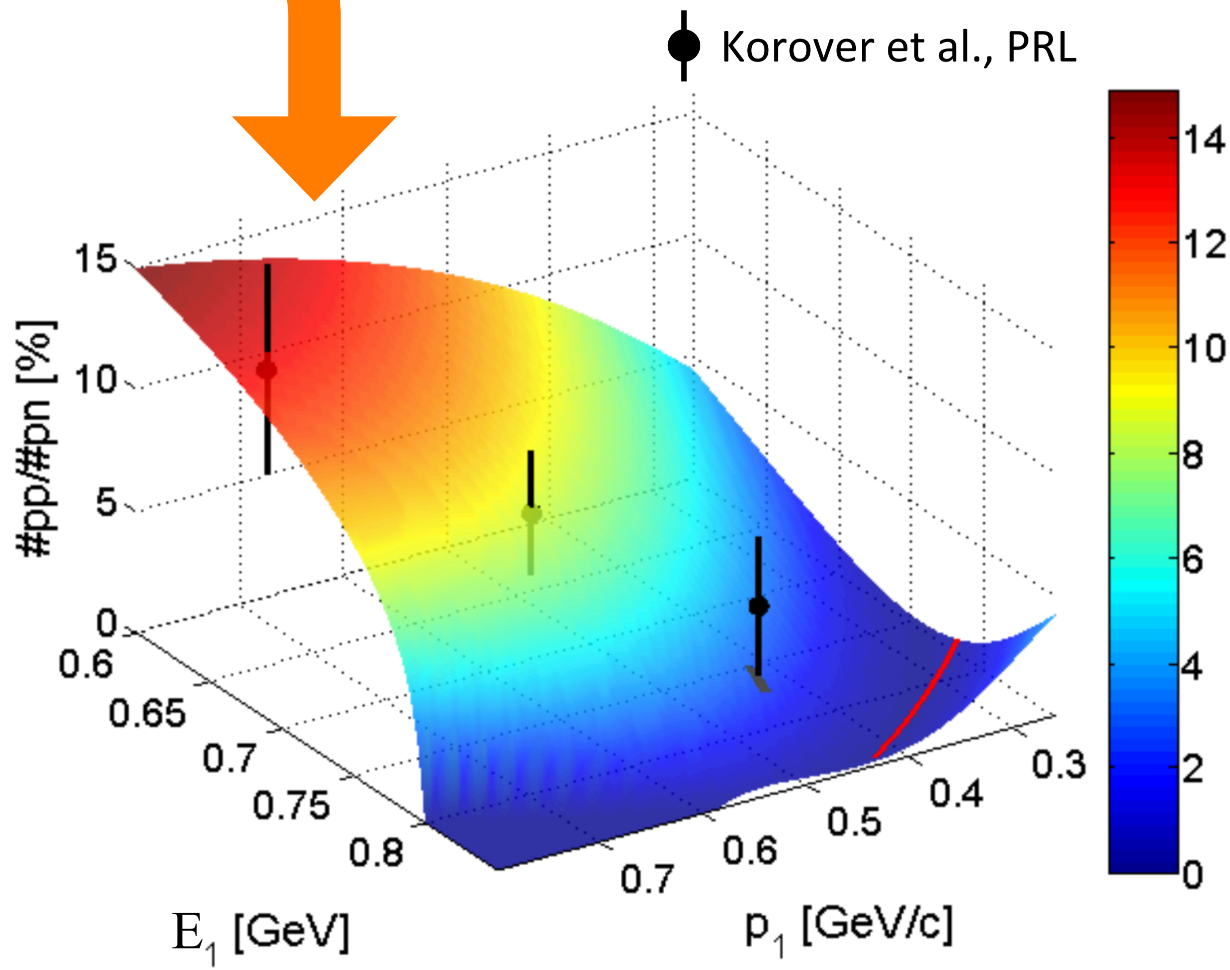


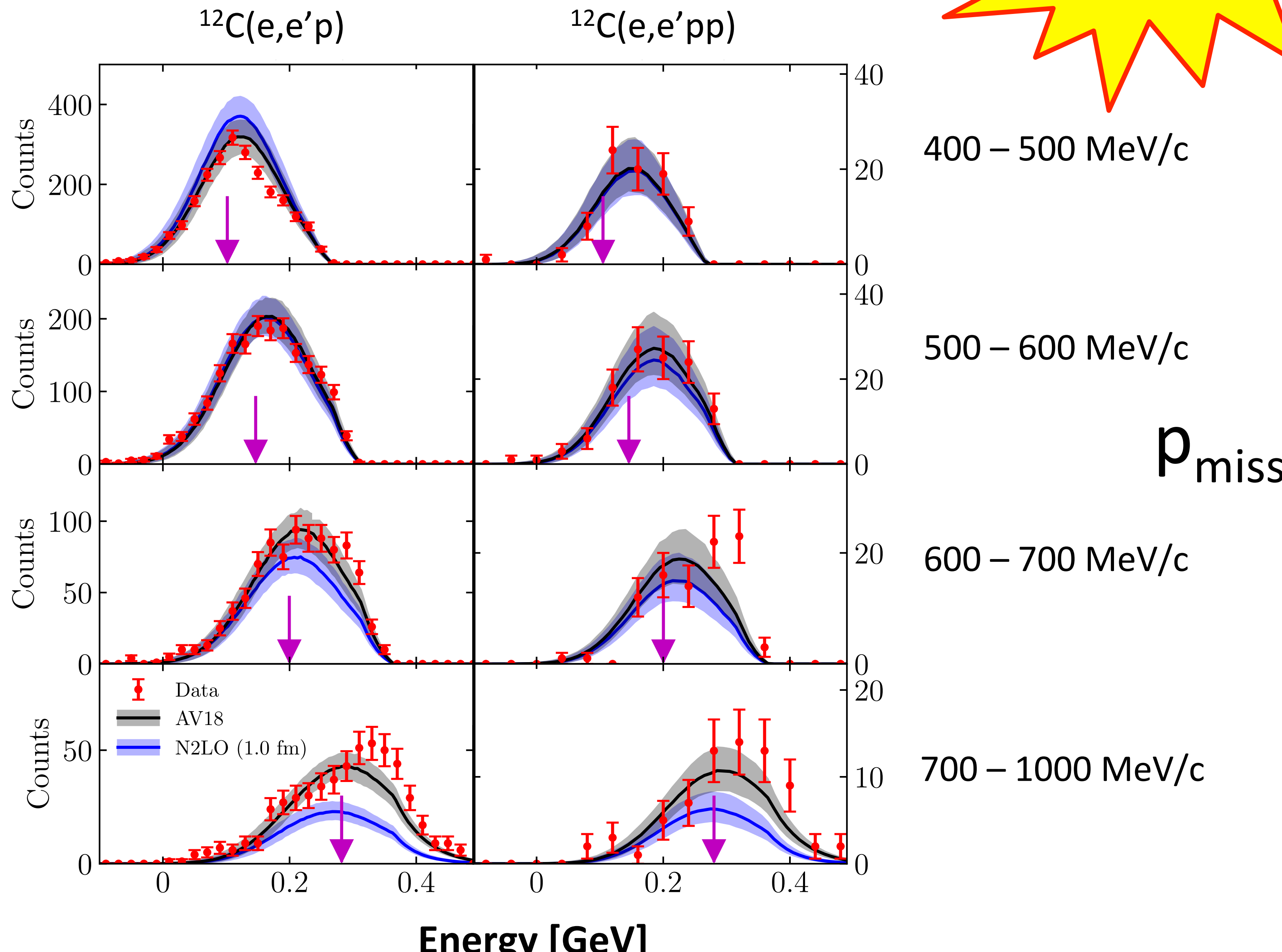


$$\frac{\#pp}{\#pn} = \frac{S_{pp}}{S_{pn}}$$

R. Weiss et al., PLB 791 p 242 (2019)

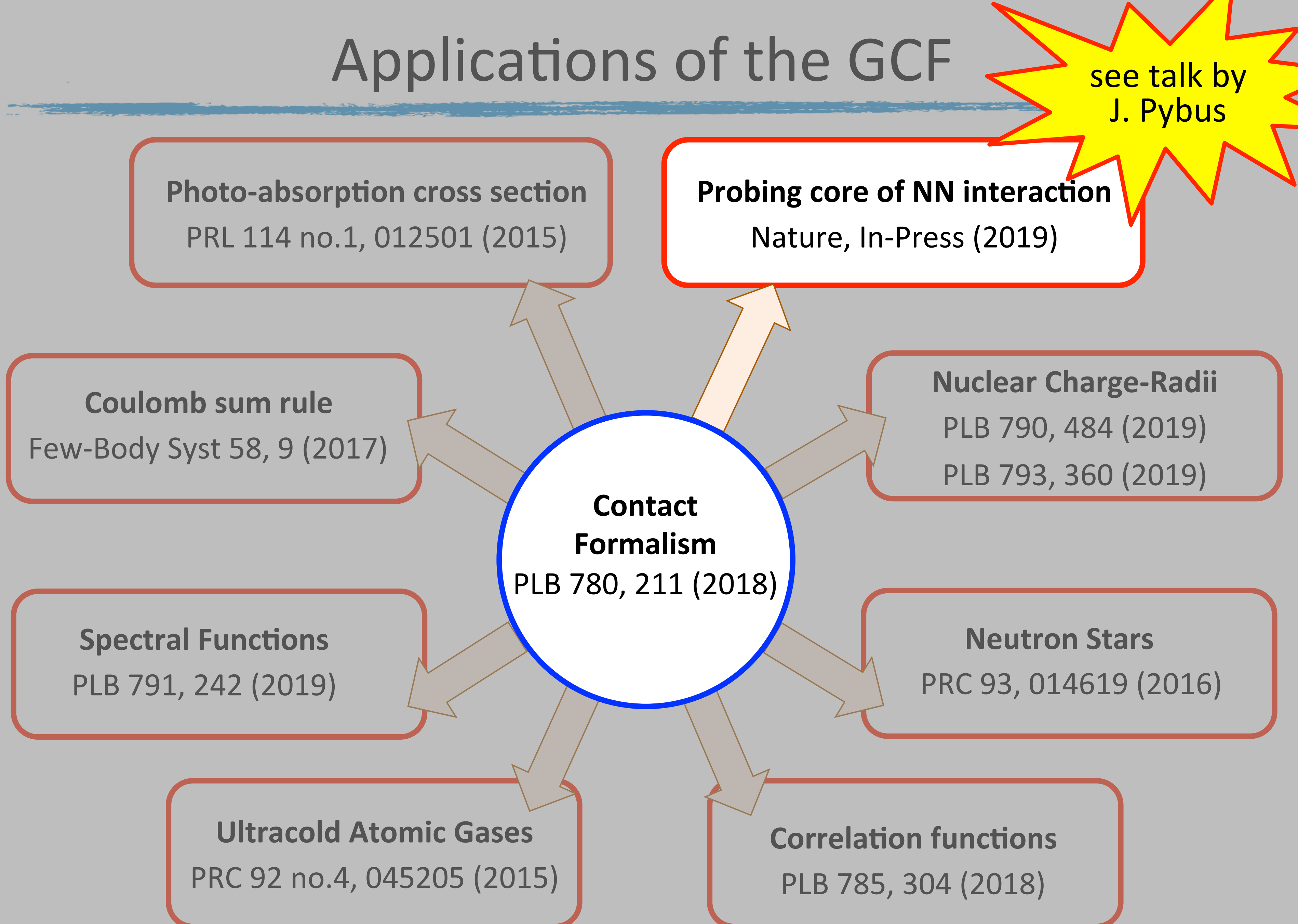
GFC (SRC) Spectral Function

see talk by J. Pybus



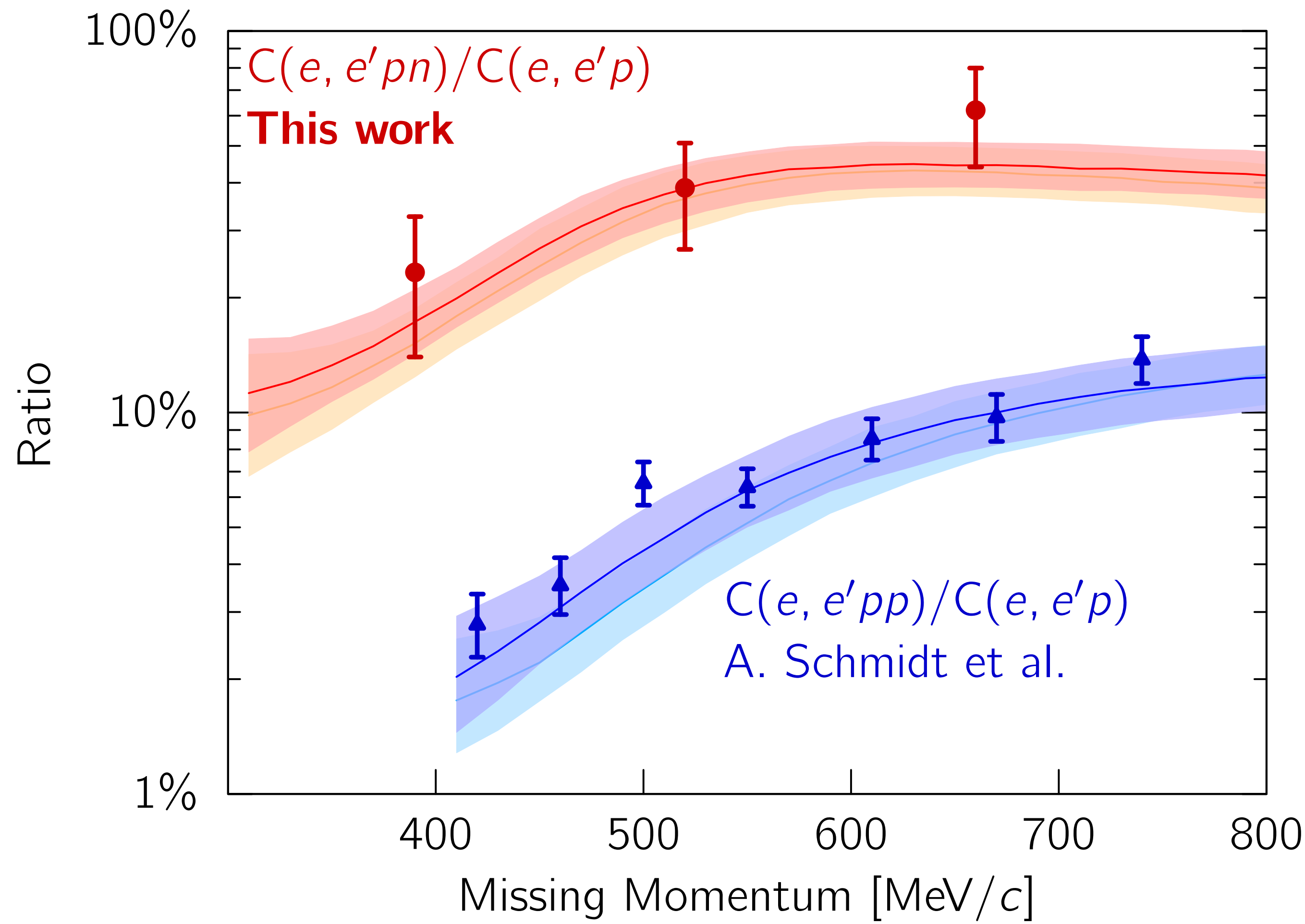
Schmidt et al., Nature In Press (2020)

Applications of the GCF



(e,e'pN)/(e,e'p) ratio

see talk by J. Pybus



Korover et al. (2020)

Summary & Conclusions

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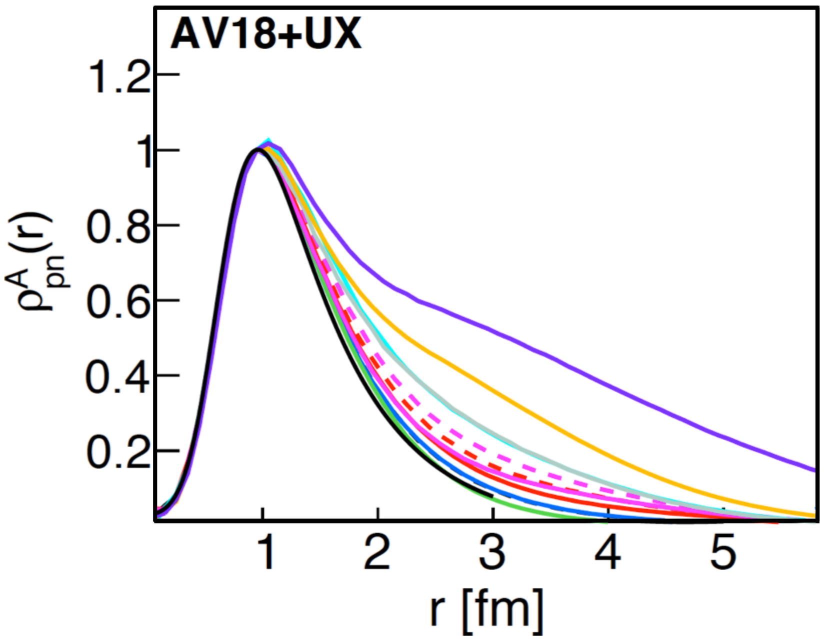

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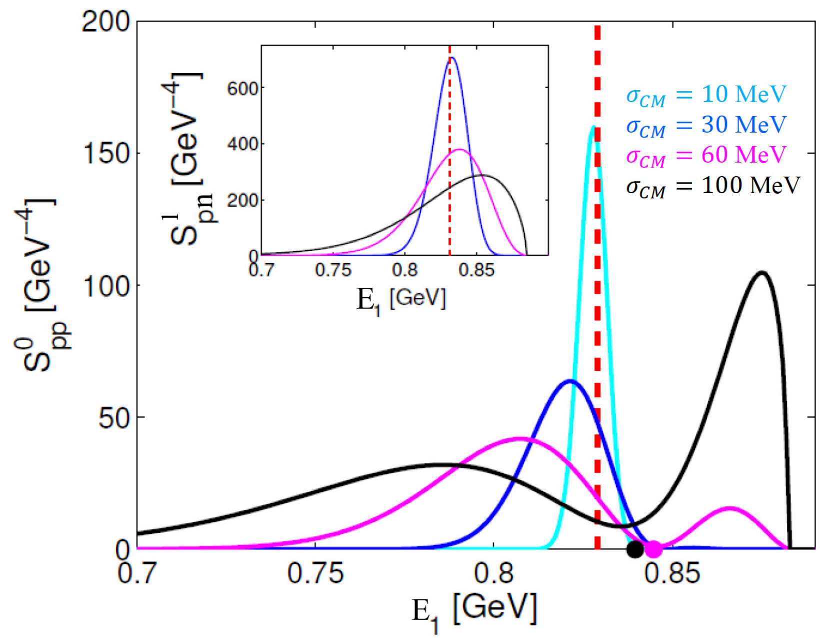

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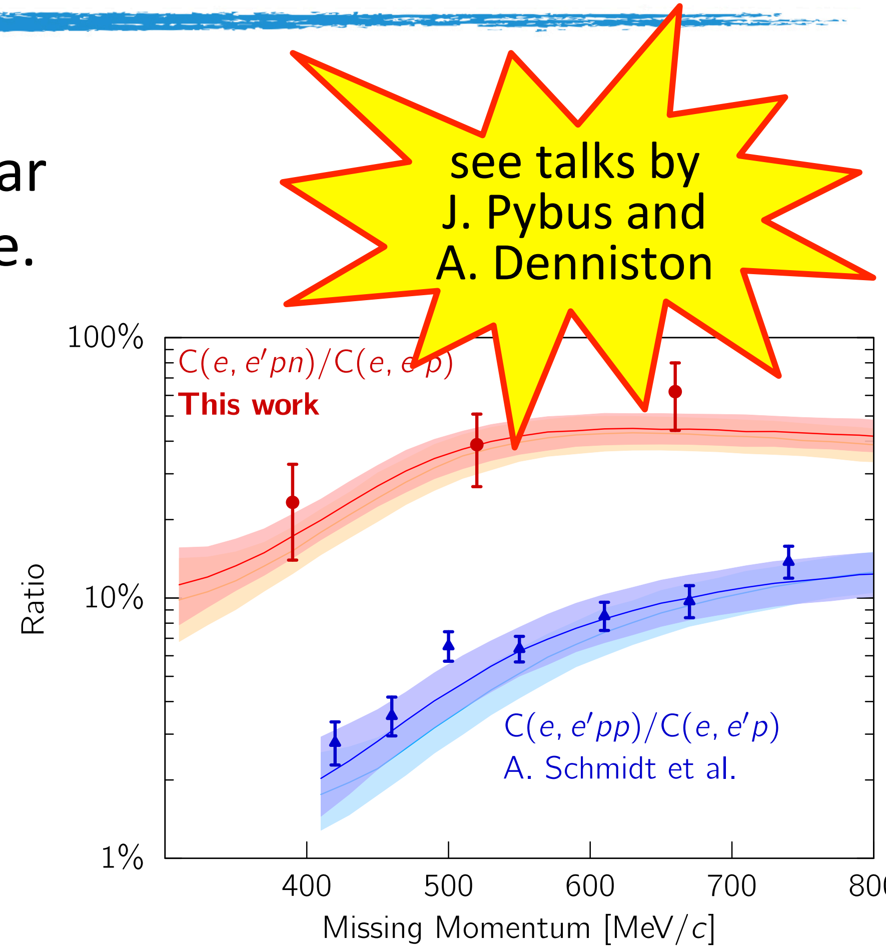
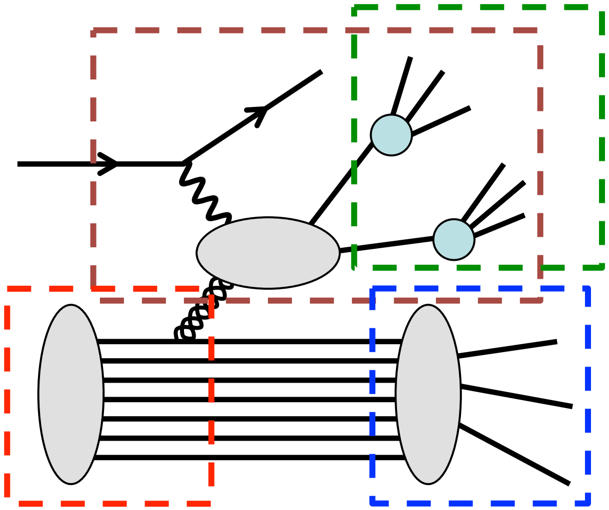
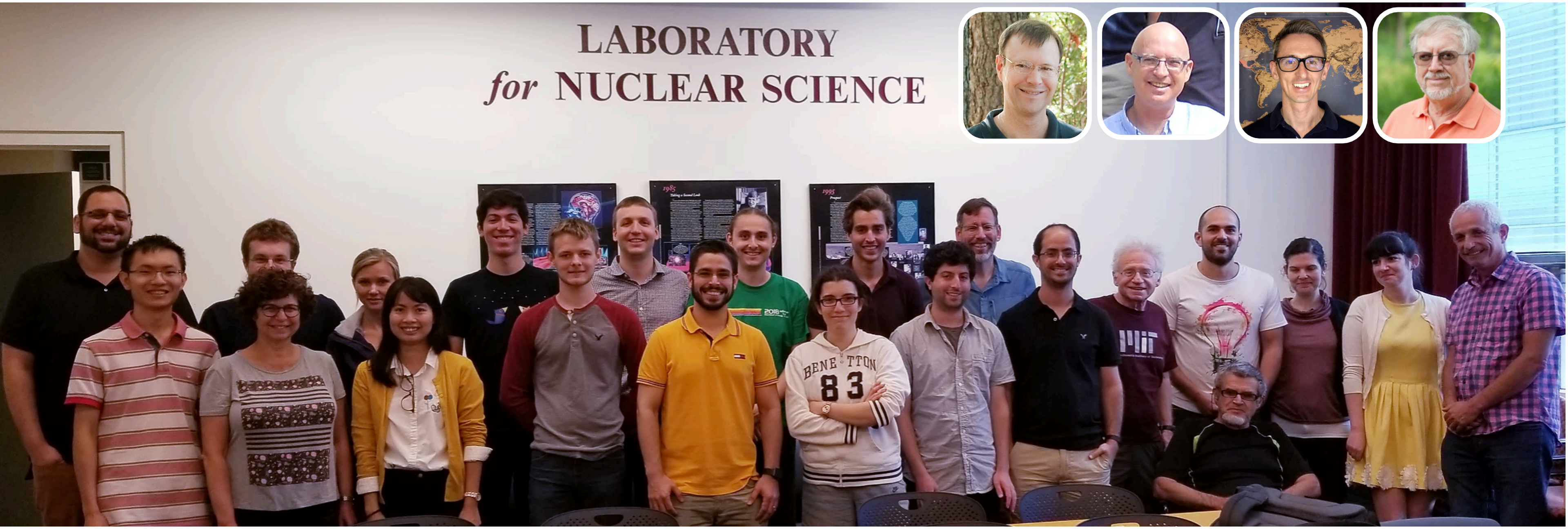


Summary & Conclusions

- GCF describes the many-body nuclear wave-function where SRCs dominate.
- GCF offers prescription for SRC spectral functions.
- This allows us to calculate QE electron-scattering cross sections and other observables.
- QE electron scattering off SRC nucleons implemented in EIC generator from GCF.



Thank you!



JL

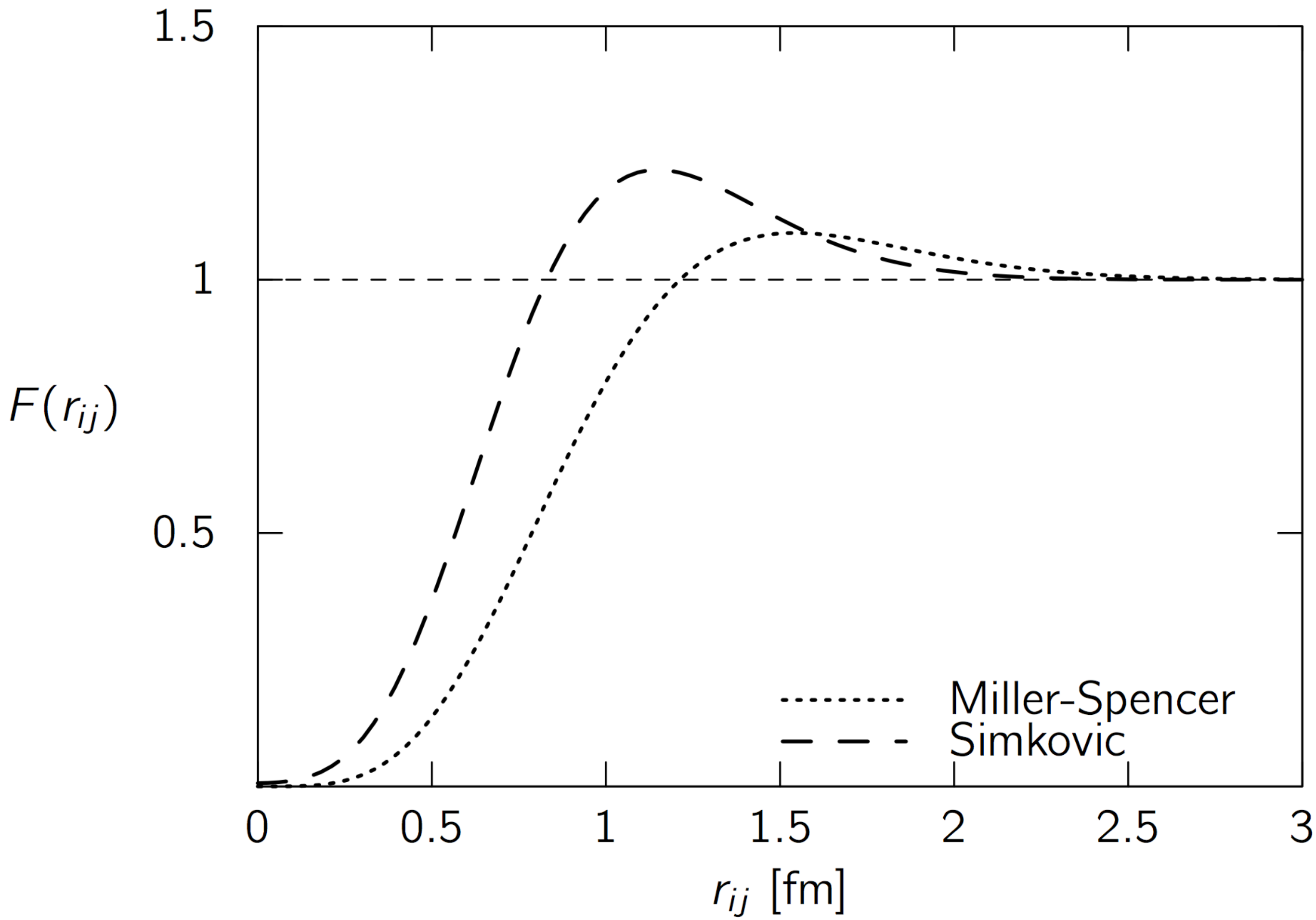
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MENS ET MANUS
1861

OLD DOMINION UNIVERSITY
1930

TEL AVIV UNIVERSITY

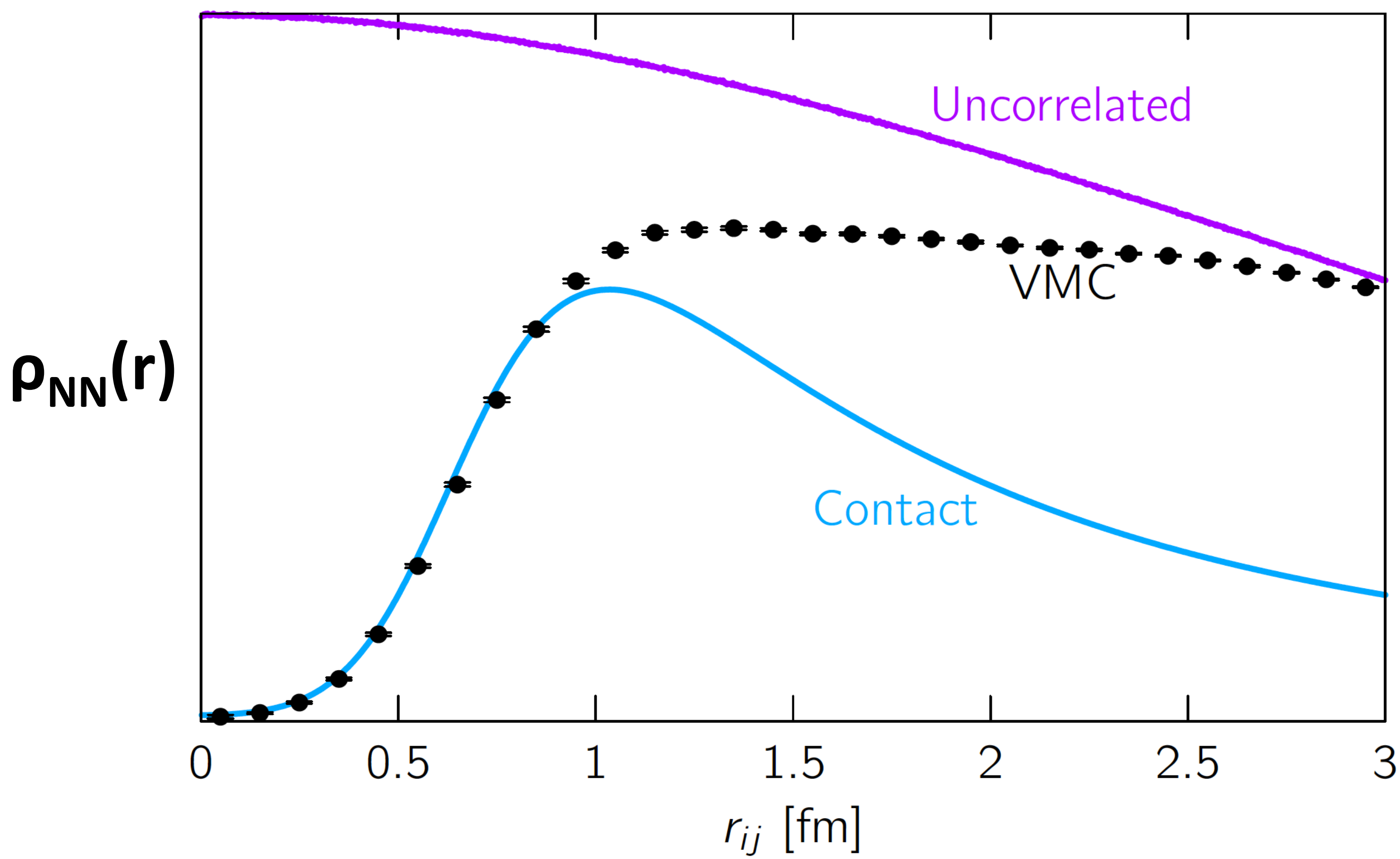
Backup

$$F(r) \equiv \frac{\text{Fully correlated}}{\text{Uncorrelated}}$$



2 Component Blending Model

$$\rho_{NN}(r) = g_{NN}(r)\rho_{NN}^{(contact)}(r) + \kappa(1 - g_{NN}(r))\rho_{NN}^{(Uncorrelated)}(r)$$



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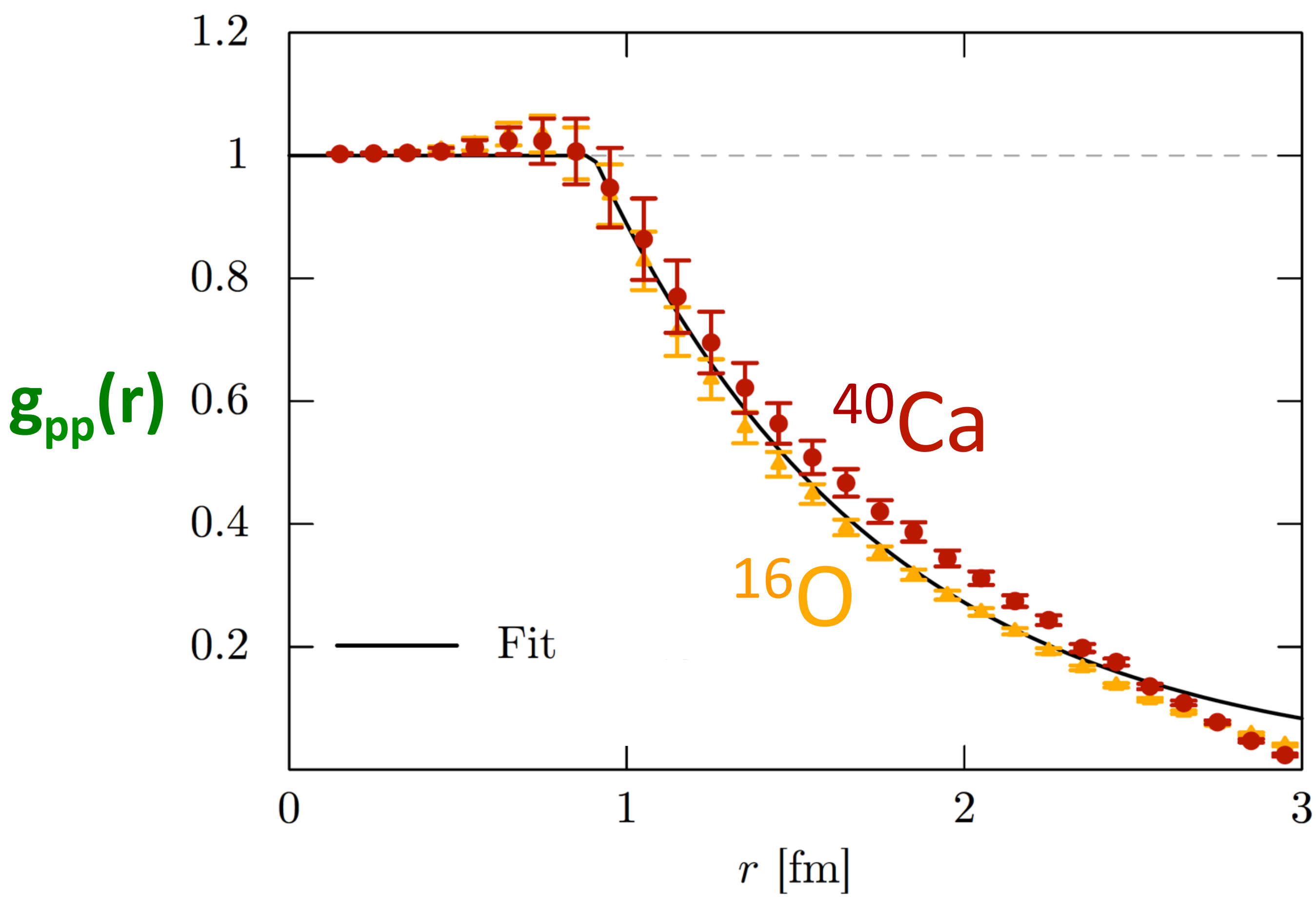
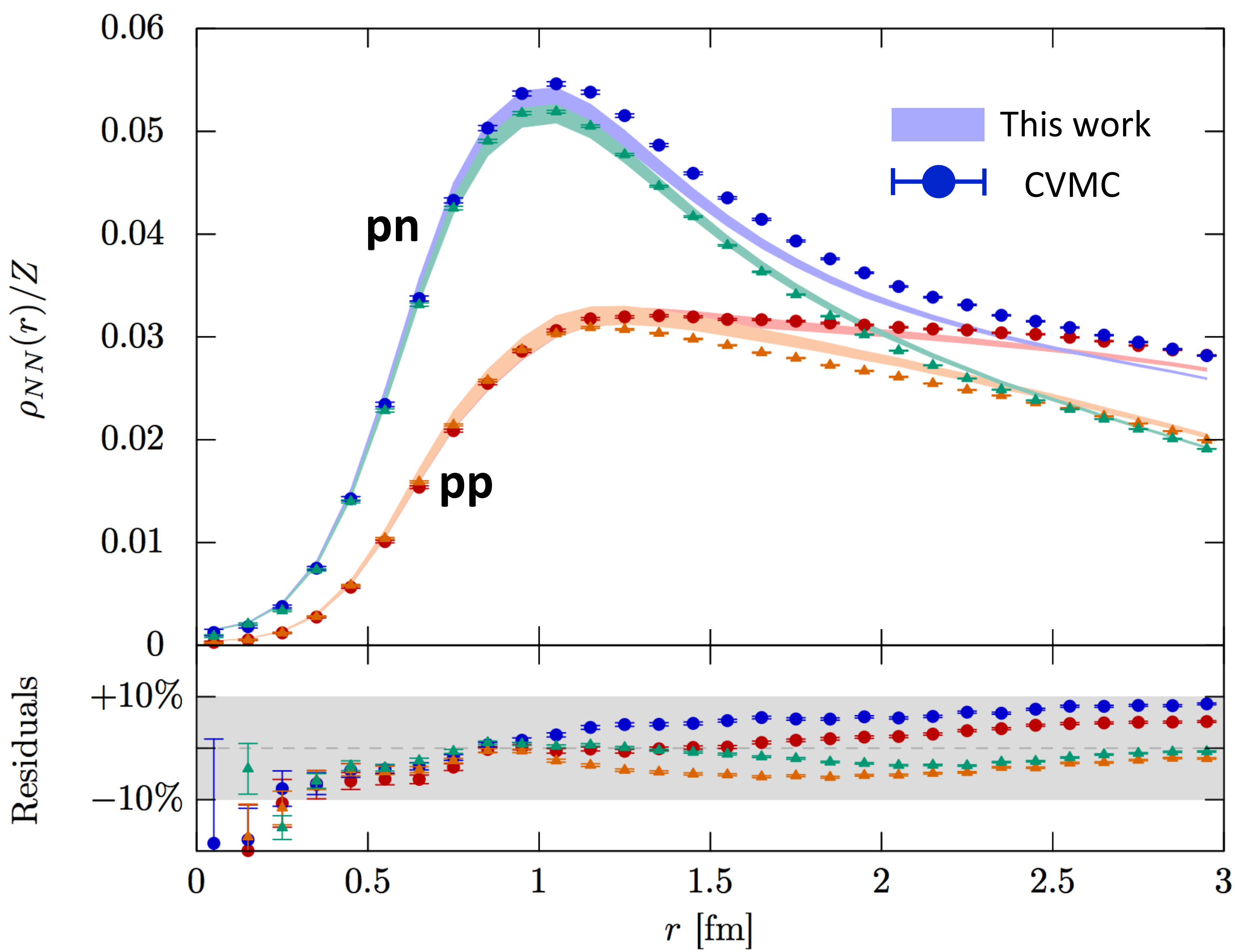
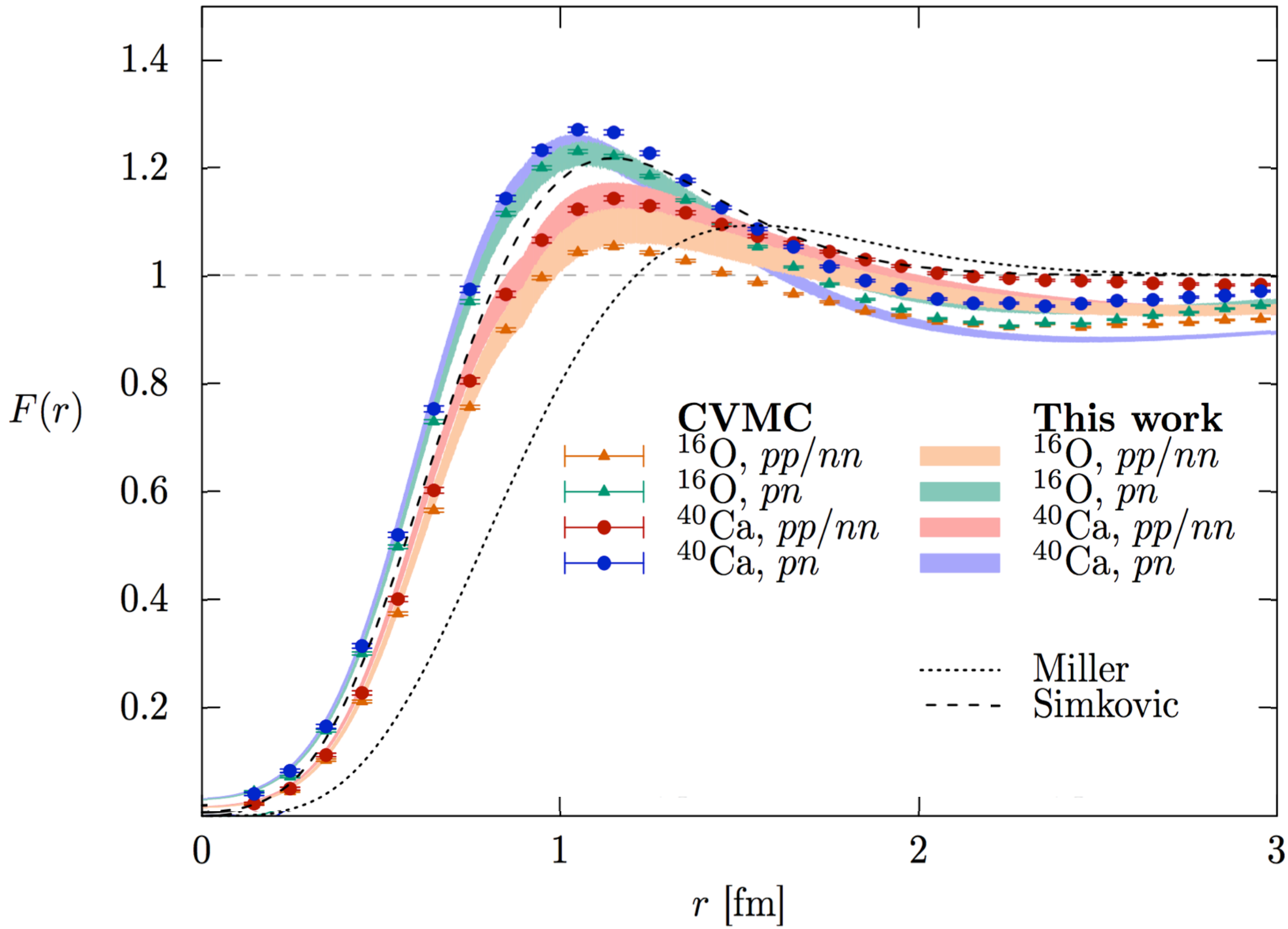


Test: 2-Body Density (A = 16 & 40)

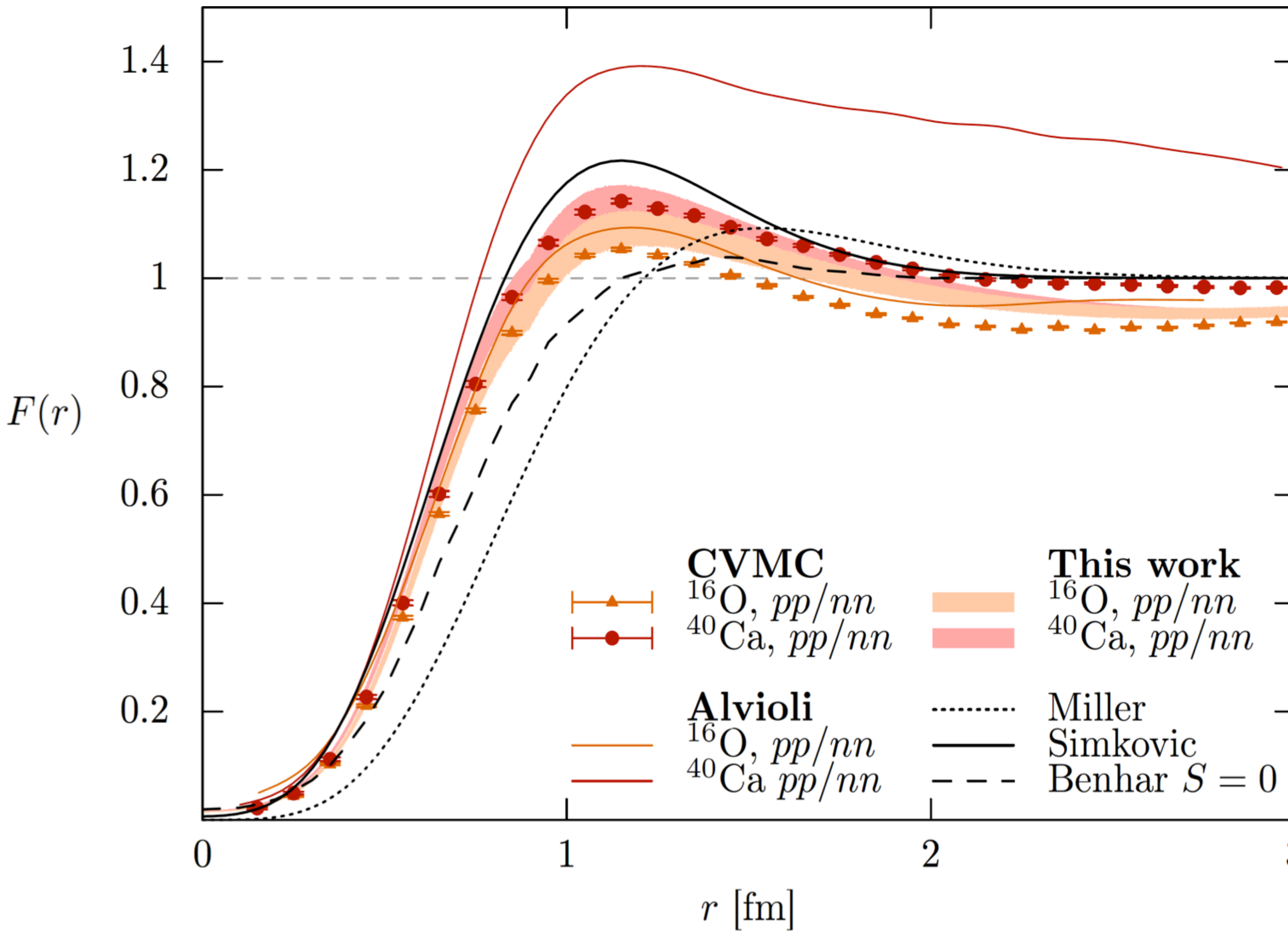


Correlation Functions



<u>Cruz-Torres</u> et al., Phys. Lett. B, In-Print (2018)

pp/nn Correlation Functions



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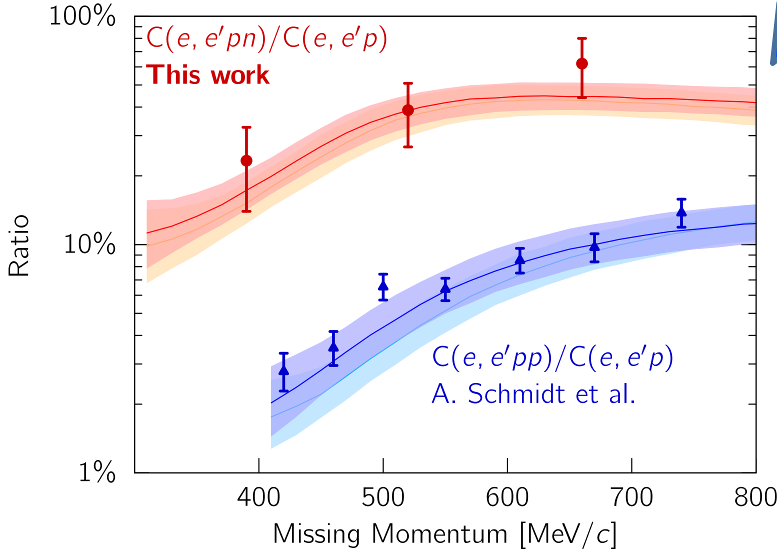
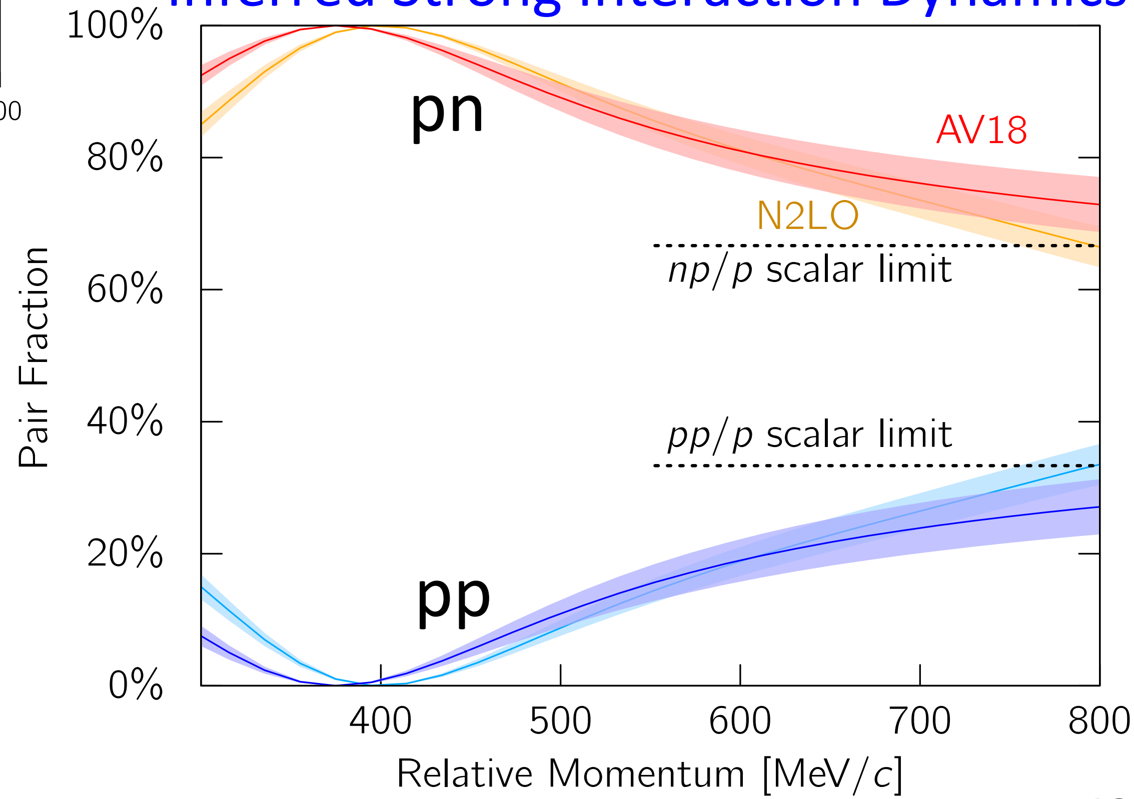


Inferred Strong Interaction Dynamics



Korover et al. (2020)