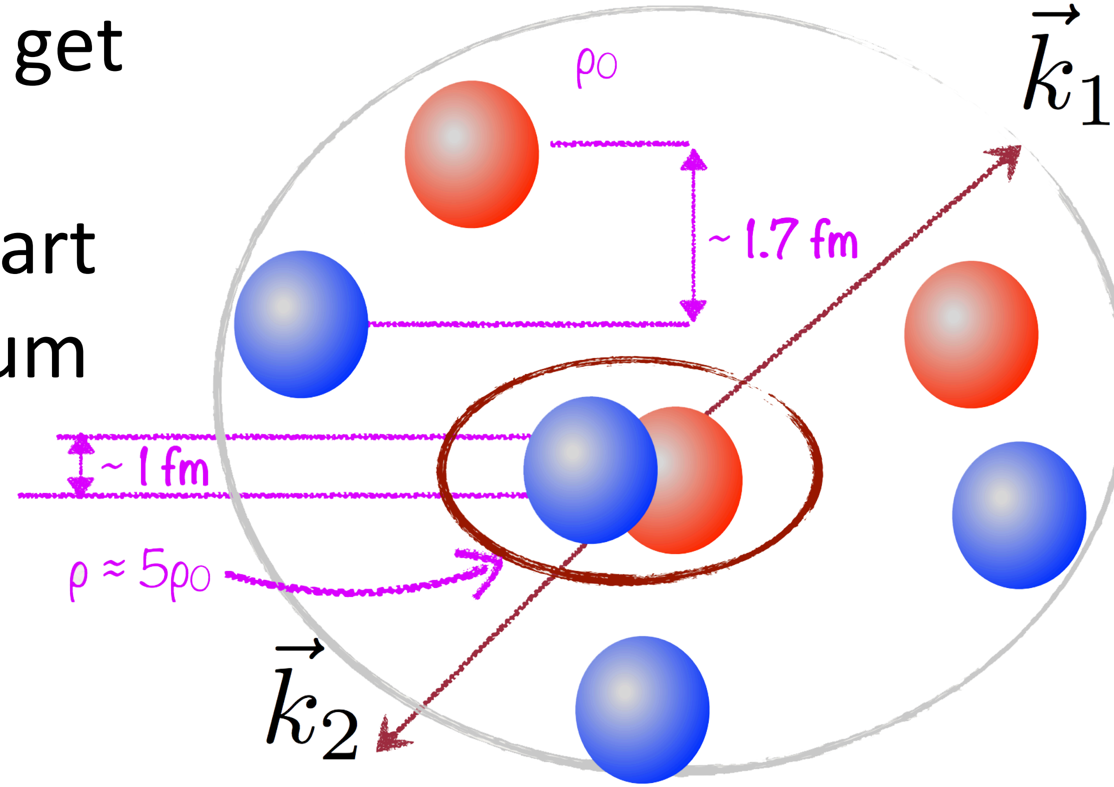
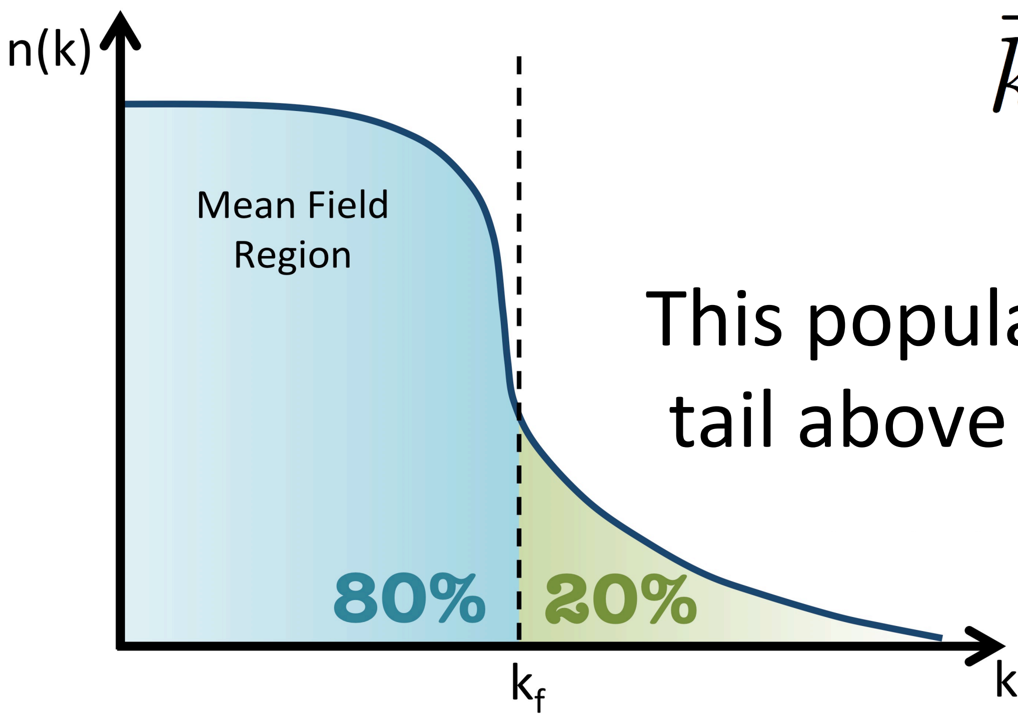
Short-Range correlations studies using the nuclear contact formalism

Reynier Cruz Torres - MIT

September 10, 2018

When two nucleons get close inside the nucleus, they fly apart with high momentum





This populates a high-momentum tail above the Fermi momentum

Why effective theories for SRCs?

- Complicated NN interaction & large nuclear density

- Mean-Field theories don't include SRCs

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

In this talk:

1. Contact formalism in nuclear systems

   R. Weiss & R. Cruz-Torres *et al*., Phys. Lett. B 780 211 (2018)

2. Nuclear Correlation Functions

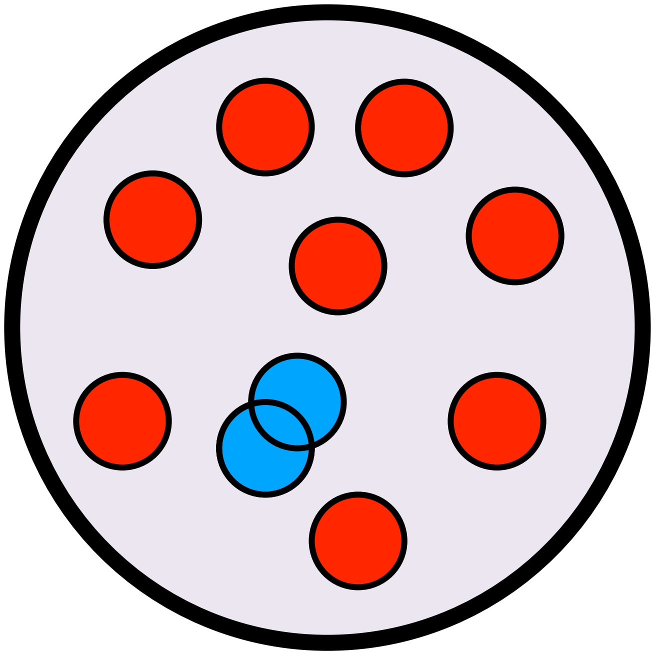
   R. Cruz-Torres *et al*., Phys. Lett. B In-Print (2018)

Factorization in nuclear systems

Scale separation at short distances

⇓

Factorization of the nuclear wavefunction

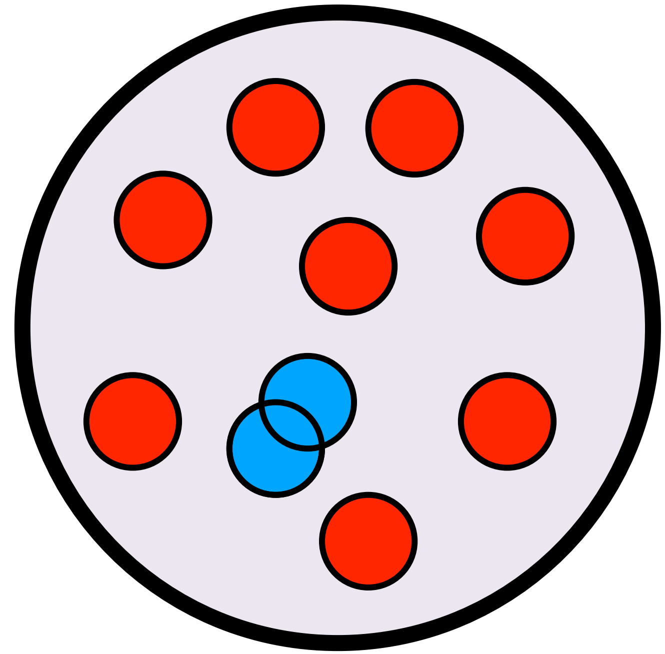


Factorization in nuclear systems

Scale separation at short distances

⇓

Factorization of the nuclear wavefunction



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

two-body function

A-2 residual system

Contact Formalism

High-k two-body densities:

$$\tilde{\rho}_2^{pp} = C_{pp}^{s=0} \left| \tilde{\varphi}_{pp}^{s=0}(k) \right|^2$$

Scaling constants called **Contacts**

(nucleus dependent)

zero-energy solution of 2-body Schrödinger equation

(universal)

Contact Formalism

High-k two-body densities:

$$\tilde{\rho}_2^{pp} = C_{pp}^{s=0} \left| \tilde{\varphi}_{pp}^{s=0}(k) \right|^2$$

$$\tilde{\rho}_2^{pn} = C_{pn}^{s=0} \left| \tilde{\varphi}_{pn}^{s=0}(k) \right|^2 + C_{pn}^{s=1} \left| \tilde{\varphi}_{pn}^{s=1}(k) \right|^2$$

Contact Formalism

High-k two-body densities:

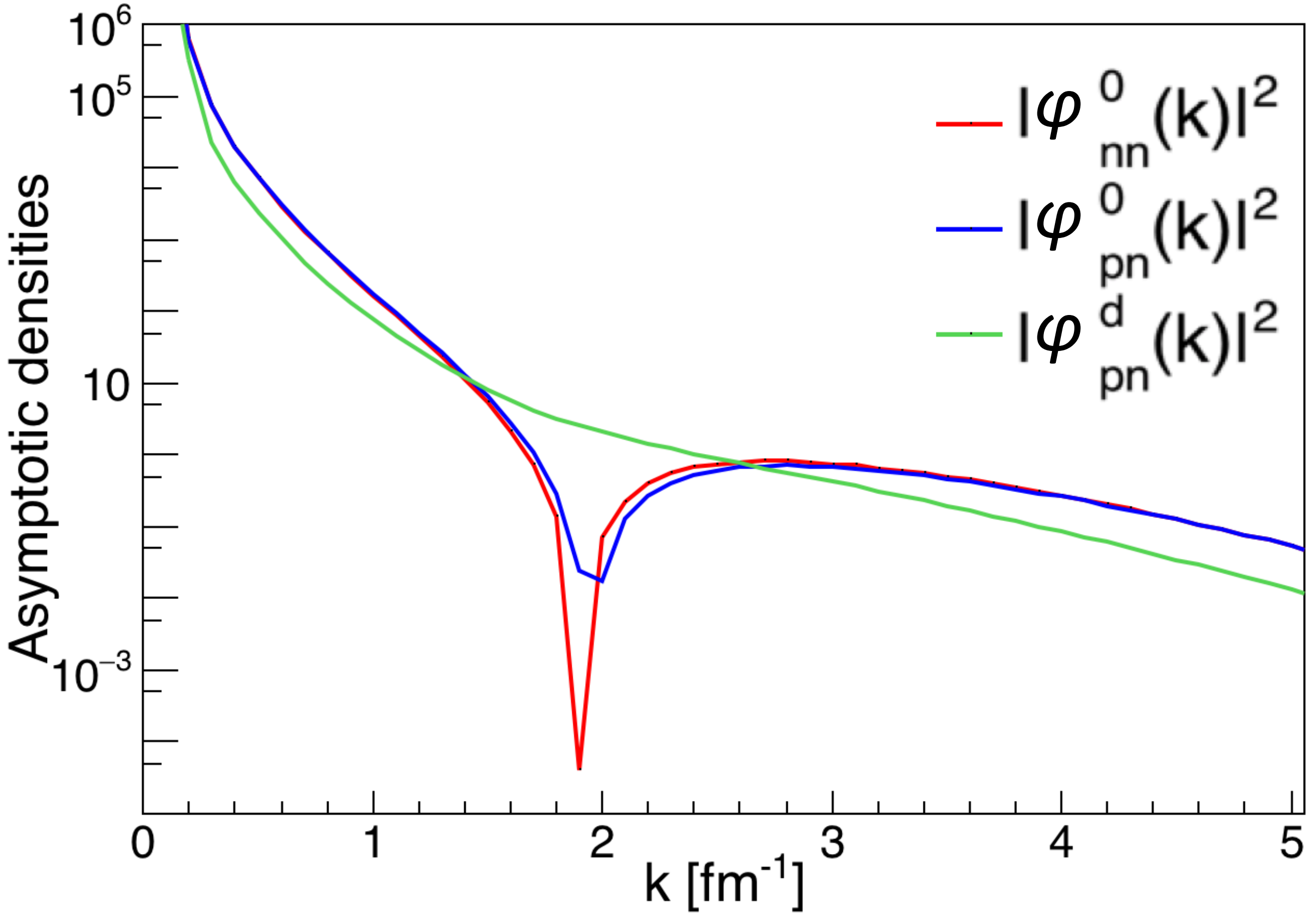
$$\tilde{\rho}_2^{pp} = C_{pp}^{s=0} \left| \tilde{\varphi}_{pp}^{s=0}(k) \right|^2$$

$$\tilde{\rho}_2^{pn} = C_{pn}^{s=0} \left| \tilde{\varphi}_{pn}^{s=0}(k) \right|^2 + C_{pn}^{s=1} \left| \tilde{\varphi}_{pn}^{s=1}(k) \right|^2$$

High-k one-body density:

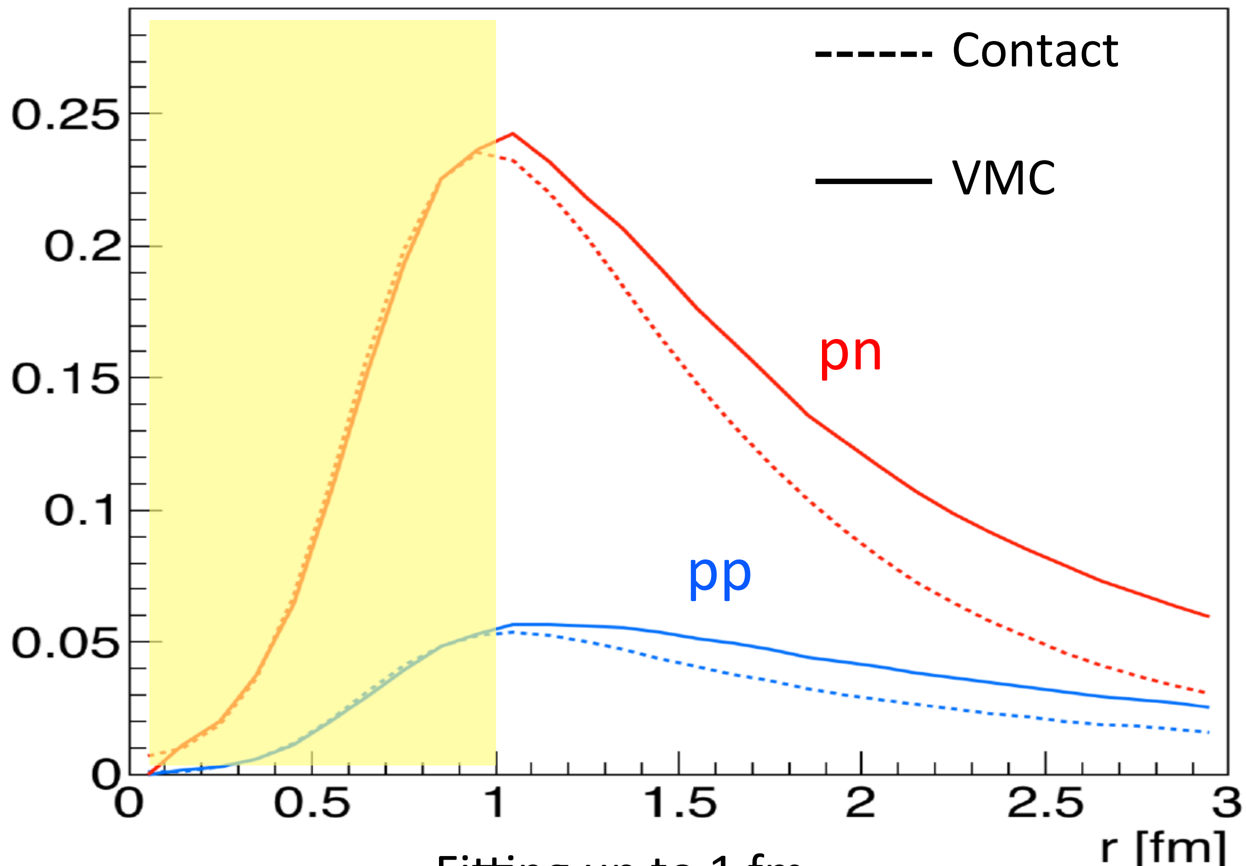
$$n(k) = 2C_{pp}^{s=0} \left| \tilde{\varphi}_{pp}^{s=0}(k) \right|^2 + C_{pn}^{s=0} \left| \tilde{\varphi}_{pn}^{s=0}(k) \right|^2 + C_{pn}^{s=1} \left| \tilde{\varphi}_{pn}^{s=1}(k) \right|^2$$

NN asymptotic wave-functions



Contact Extraction: 2-body densities

Coordinate Space

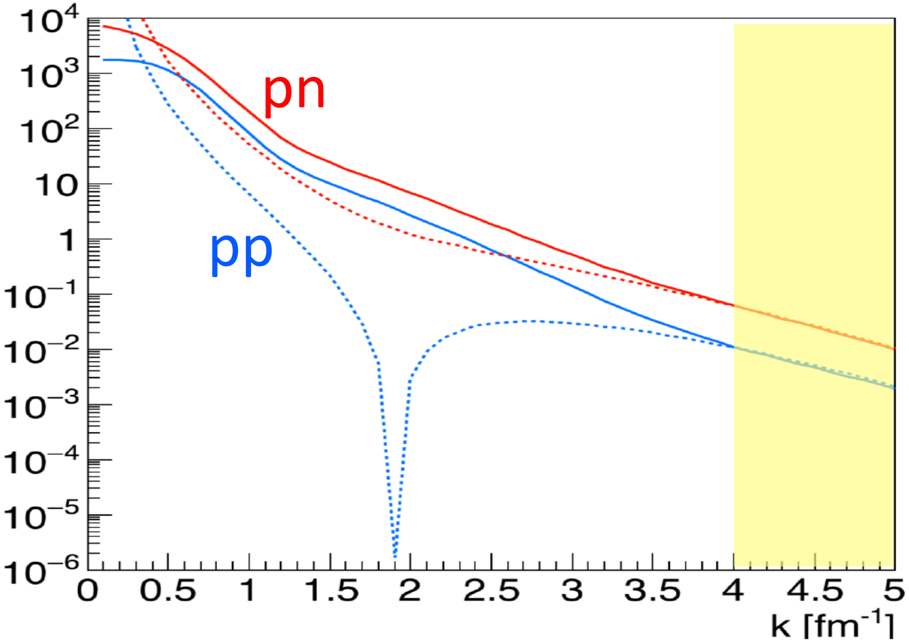


Fitting up to 1 fm

R. B. Wiringa *et al.*, PRC 89, 024305 (2014).

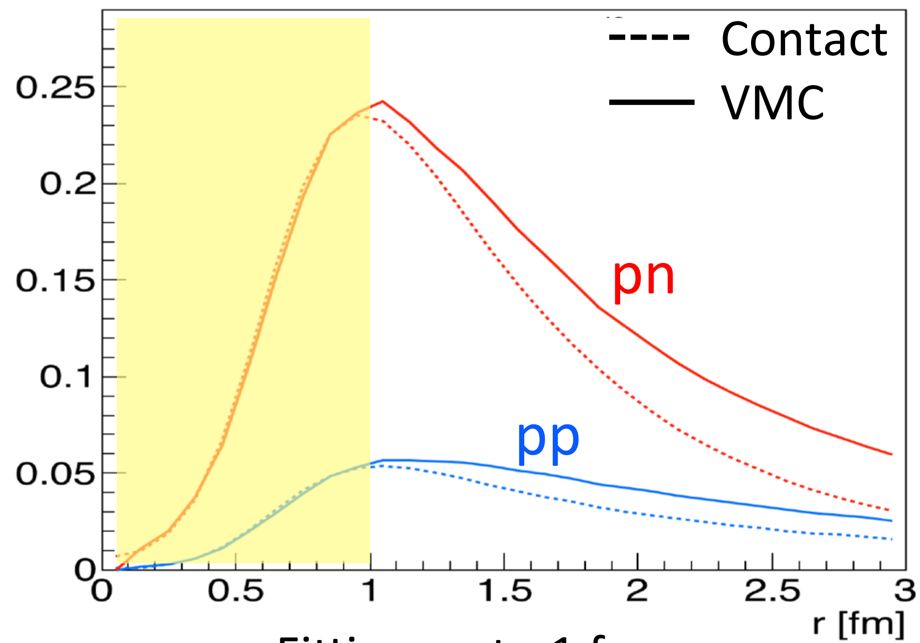
Contact Extraction: 2-body densities

Momentum Space



Fitting above 4 fm^{-1}

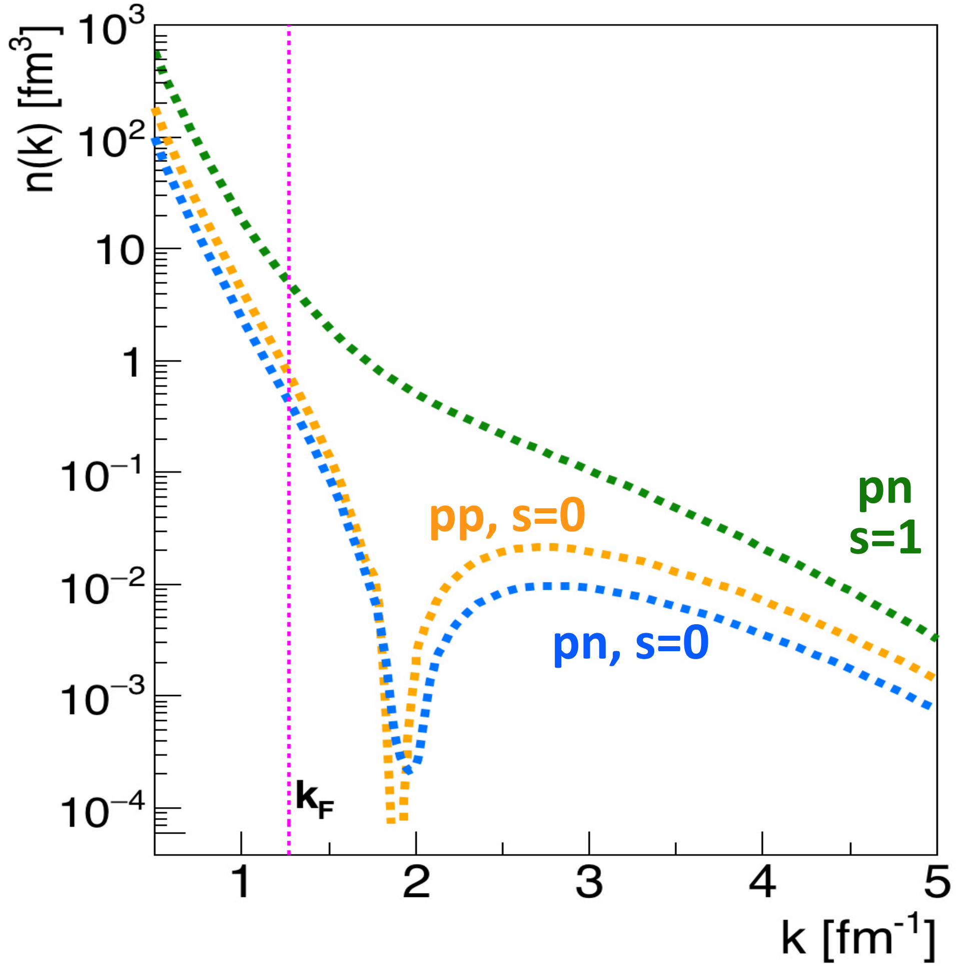
Coordinate Space



Fitting up to 1 fm

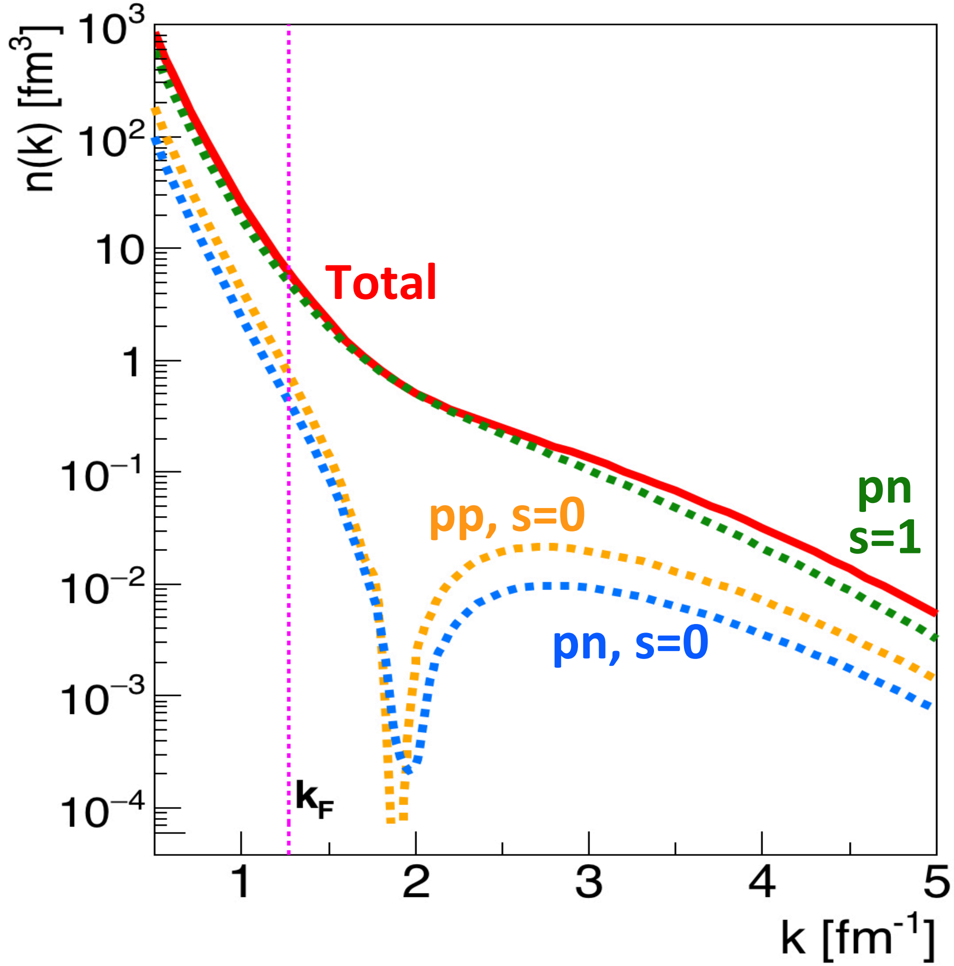
R. B. Wiringa *et al.*, PRC 89, 024305 (2014).

1-body distributions: A = 4



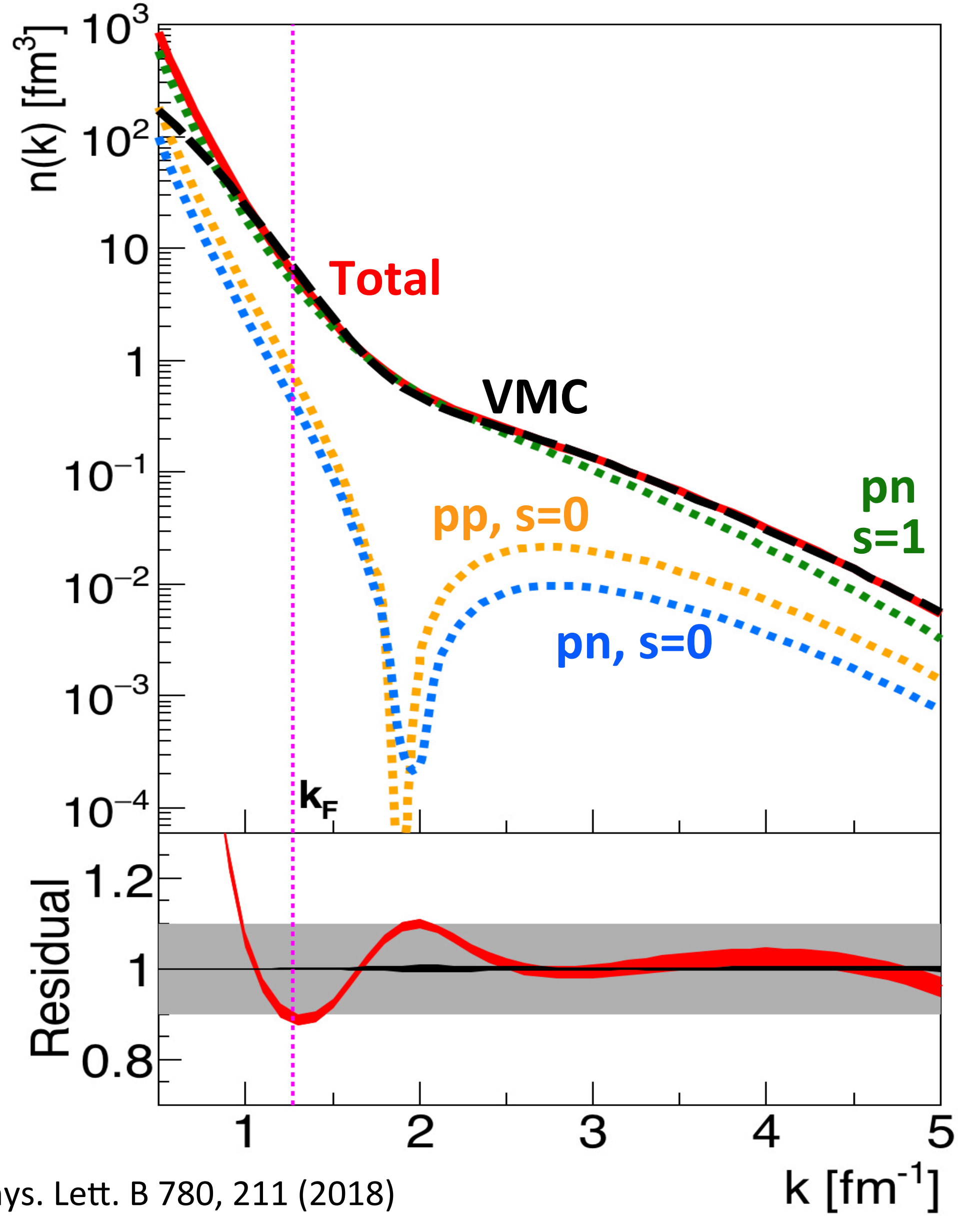
Weiss & **Cruz-Torres**, *et al.*, Phys. Lett. B 780, 211 (2018)
R. B. Wiringa *et al.*, PRC 89, 024305 (2014).

1-body distributions: A = 4



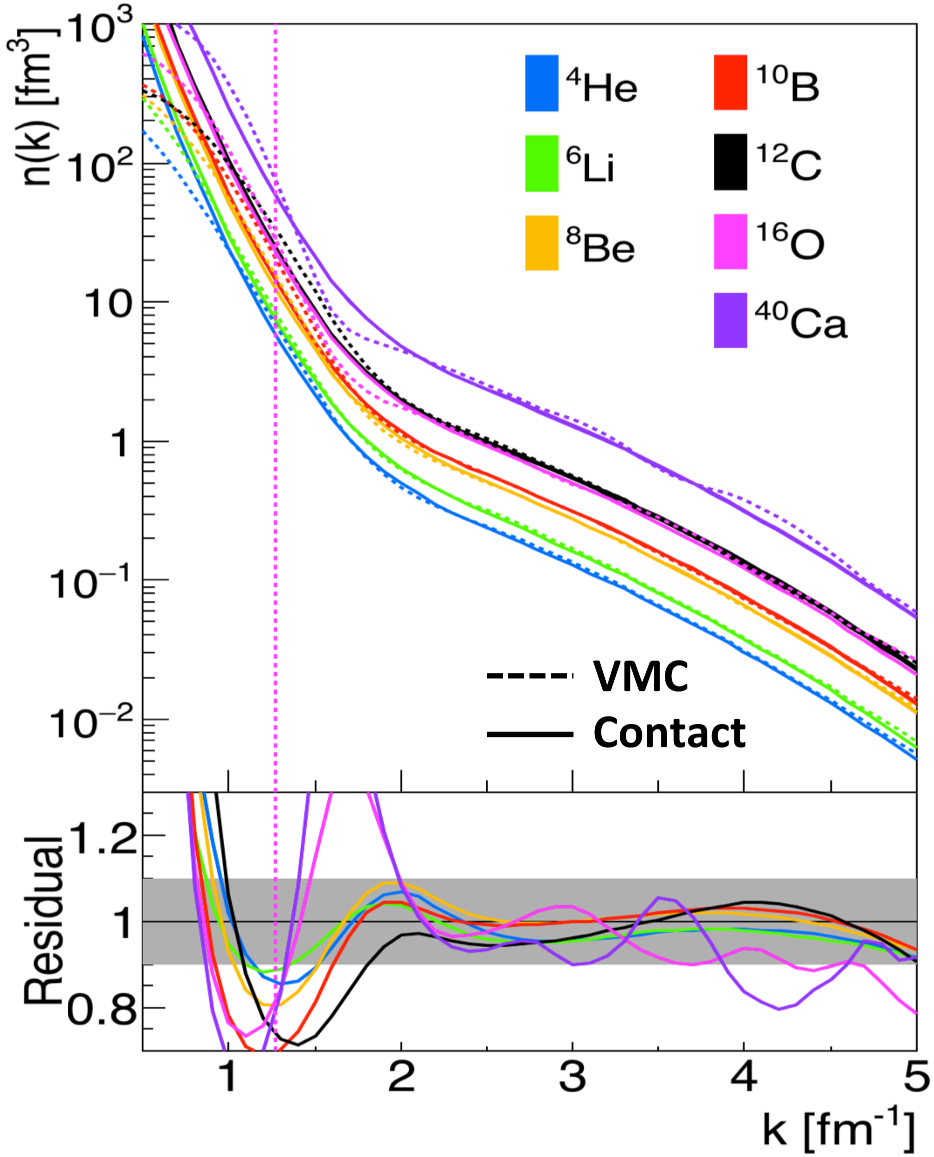
Weiss & **Cruz-Torres**, *et al.*, Phys. Lett. B 780, 211 (2018)
R. B. Wiringa *et al.*, PRC 89, 024305 (2014).

1-body distributions: A = 4



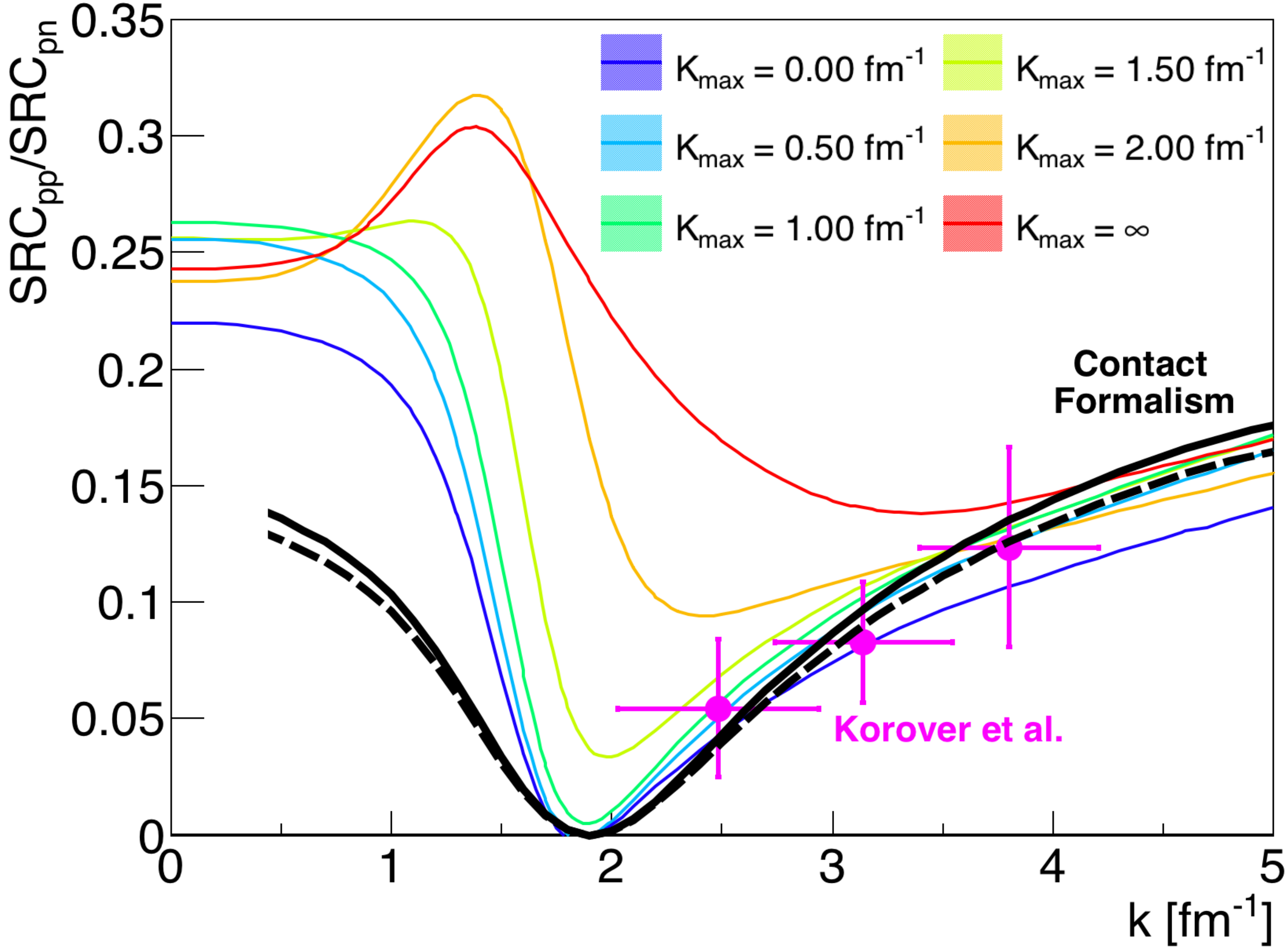
Weiss & **Cruz-Torres**, *et al.*, Phys. Lett. B 780, 211 (2018)
R. B. Wiringa *et al.*, PRC 89, 024305 (2014).

1-body distributions: A ≤ 40



Weiss & **Cruz-Torres**, *et al.*, Phys. Lett. B 780, 211 (2018)
R. B. Wiringa *et al.*, PRC 89, 024305 (2014).

pp/pn fraction: A = 4



Weiss & **Cruz-Torres** et al., Phys. Lett. B 780, 211 (2018)

Contact formalism is connected to:

Contact Formalism

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

Electron scattering
PRC 92, 045205 (2015)

Coupled-channels theory
arXiv:1705.02592 (2017)

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

Nuclear Charge-Radii
arXiv:1807.08677
arXiv:1805.12099

Spectral Functions
arXiv:1806.10217

Neutron Stars
PRC 93, 014619 (2016)

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

The EMC effect
arxiv 1607.03065 (2016)

Correlation functions
PLB In-Print (2018)
arXiv:1710.07966

Contact formalism is connected to:

Contact Formalism

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

Electron scattering
PRC 92, 045205 (2015)

Coupled-channels theory
arXiv:1705.02592 (2017)

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

Nuclear Charge-Radii
arXiv:1807.08677
arXiv:1805.12099

Spectral Functions
arXiv:1806.10217

Neutron Stars
PRC 93, 014619 (2016)

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

The EMC effect
arxiv 1607.03065 (2016)

Correlation functions
PLB In-Print (2018)
arXiv:1710.07966

Correlation Functions

Common method to Introduce two-body correlations in effective theories.

$$|\Psi_{cor.}> = \sqrt{F(r)}\,|\Psi_{MF}>$$

$$F(r) \equiv \frac{\text{Fully correlated 2-body density}}{\text{Uncorrelated 2-body density}}$$

Correlation Function find applications in…

Neutrino-less double beta decay.

Phys. Lett. B 647, 128 (2007)
Phys. Rev. C 75, 051303 (2007)
Phys. Rev. C 76, 024315 (2007)
Phys. Rev. C 79, 055501 (2009)
Phys. Rev. C 79, 064317 (2009)
…

Nuclear transparency & QE Scattering

Phys. Rev. C46, 761 (1992)
Nucl. Phys. A580, 595 (1994
Phys. Rev. D62, 113009 (2000)
Phys. Rev. C45, 1863 (1992)

Correlation Functions

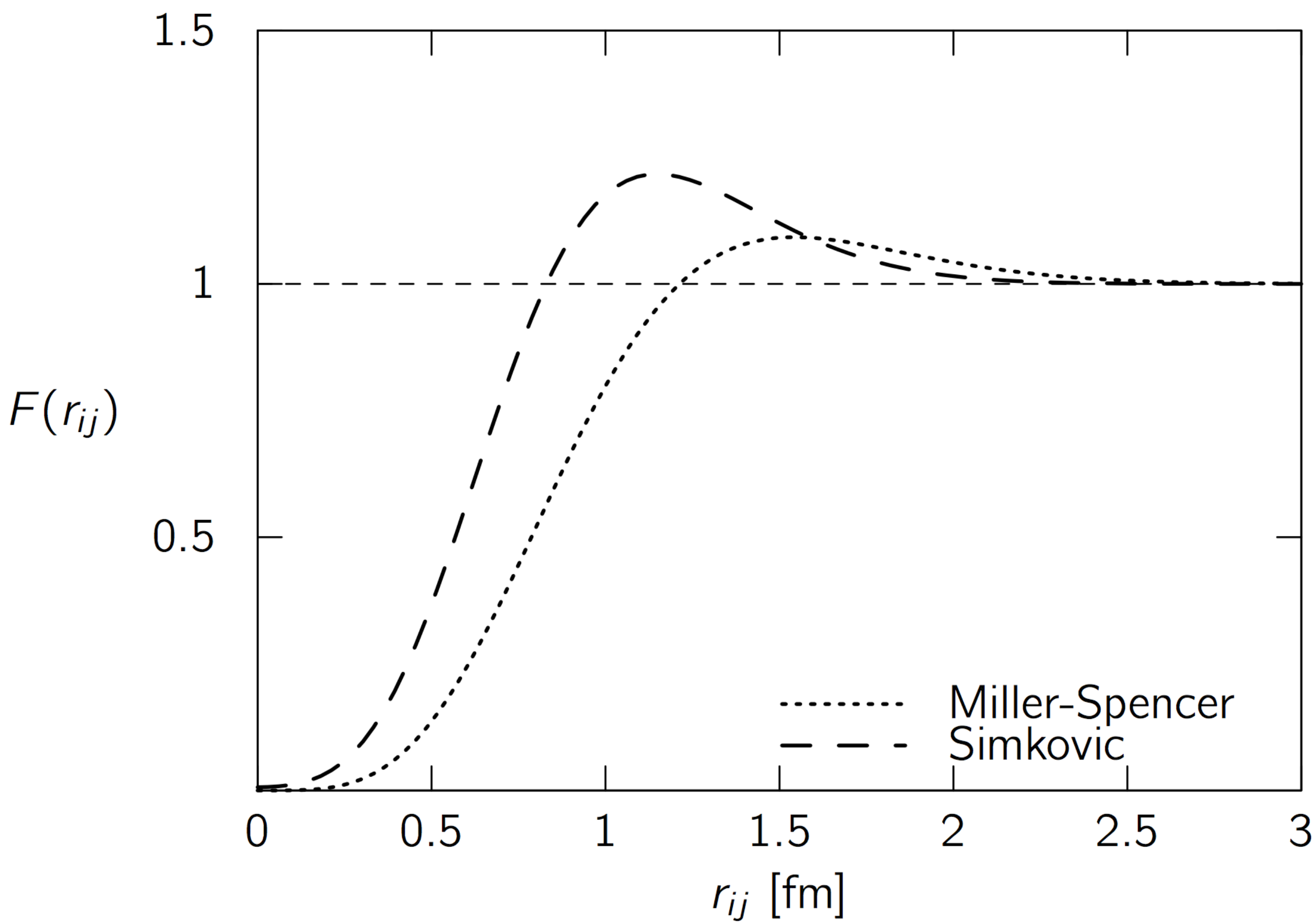
Shadowing in DIS

Phys. Rev. C 52, 1604 (1995)

Nuclear parity violation

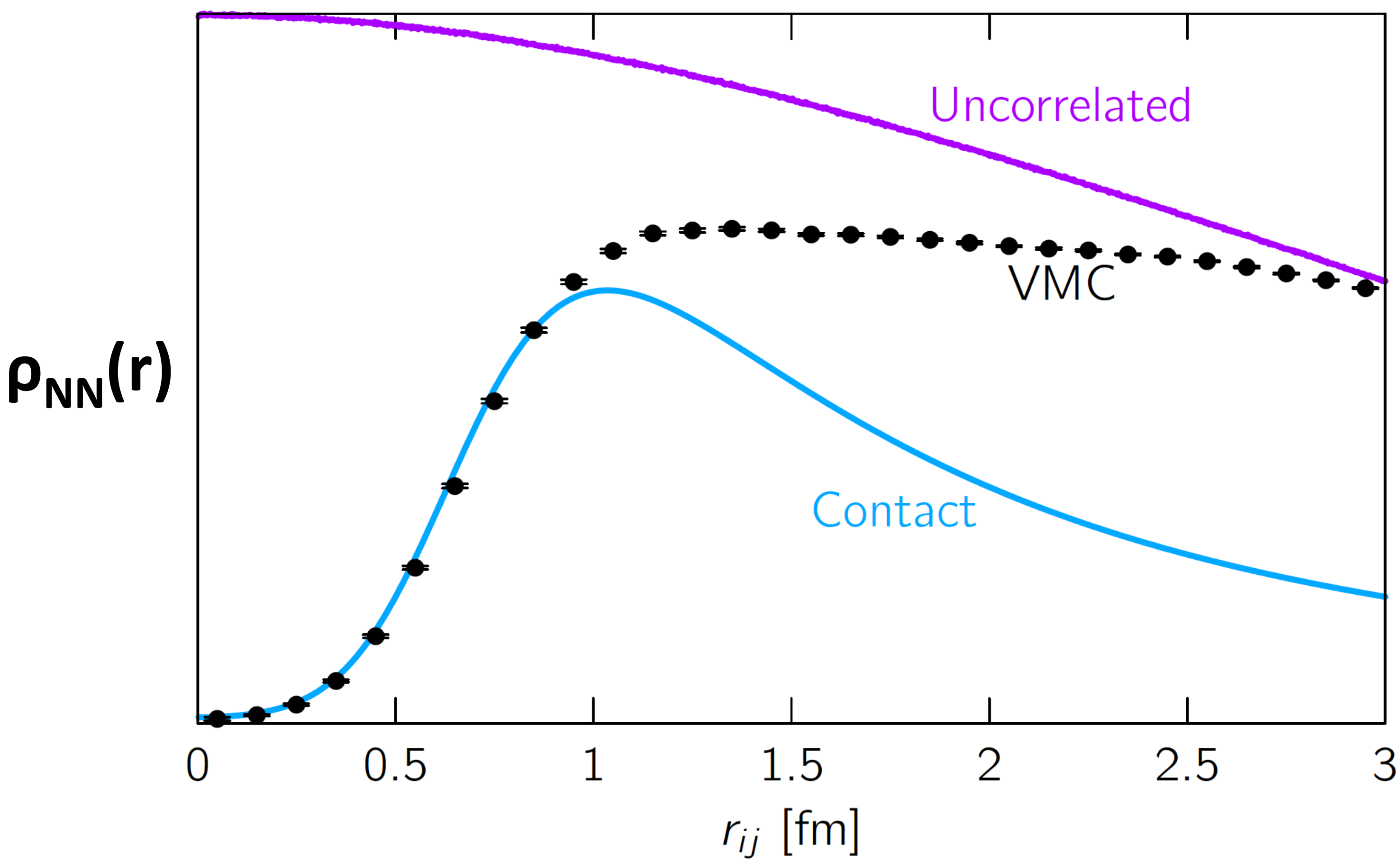
Ann. Rev. Nucl. Part. Sci. 35 501 (1985)

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



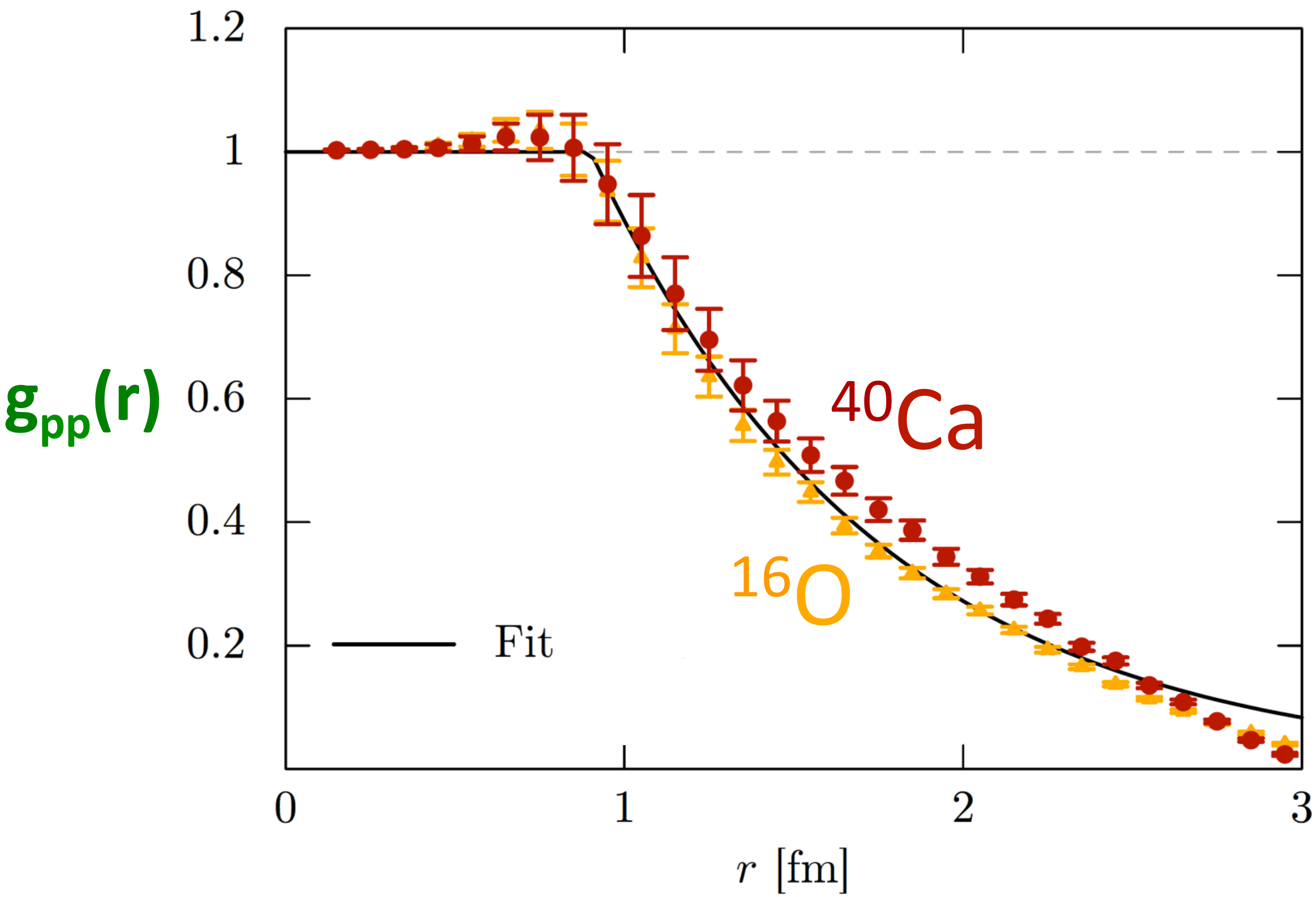
2 Component Blending Model

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

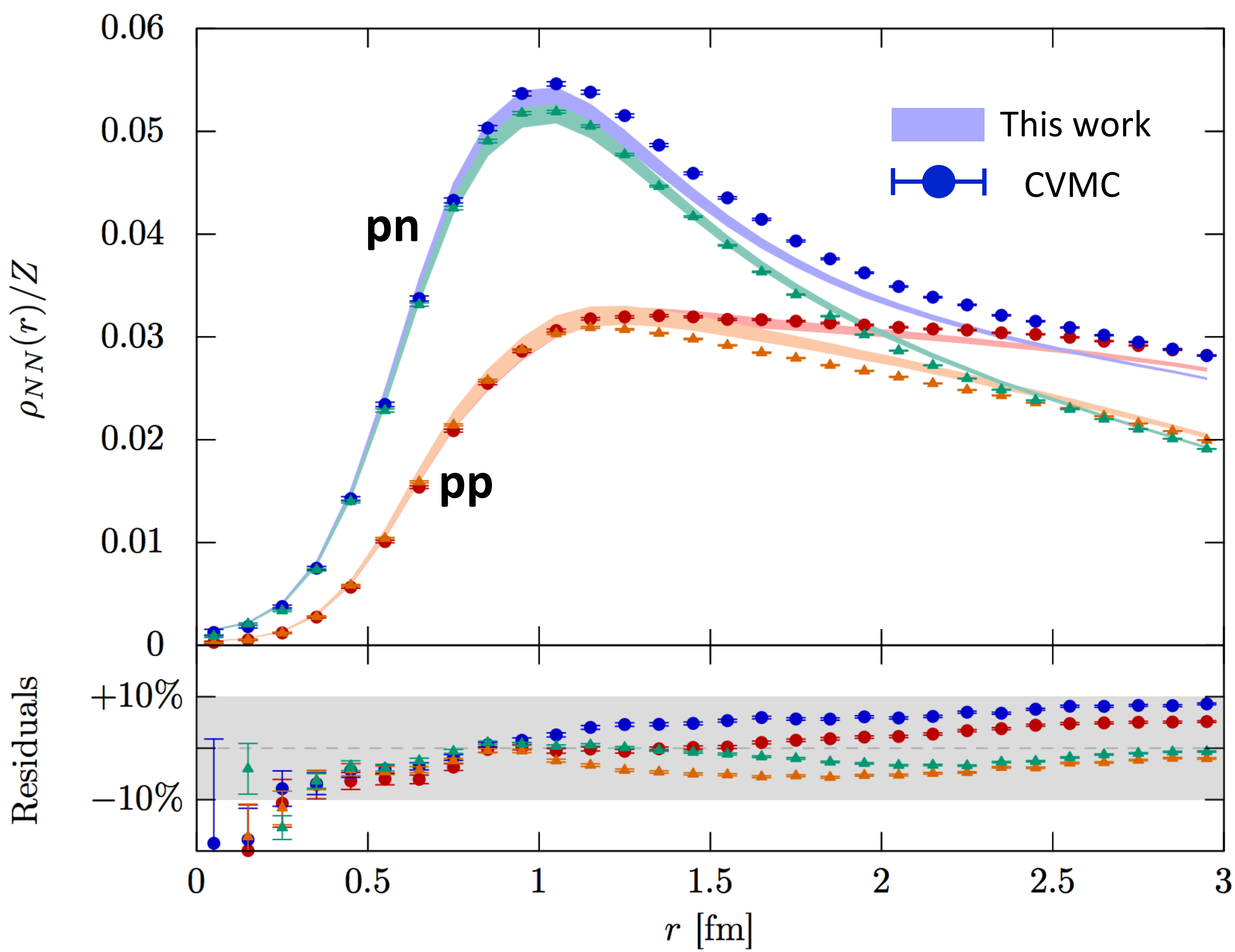


2 Component Blending Model

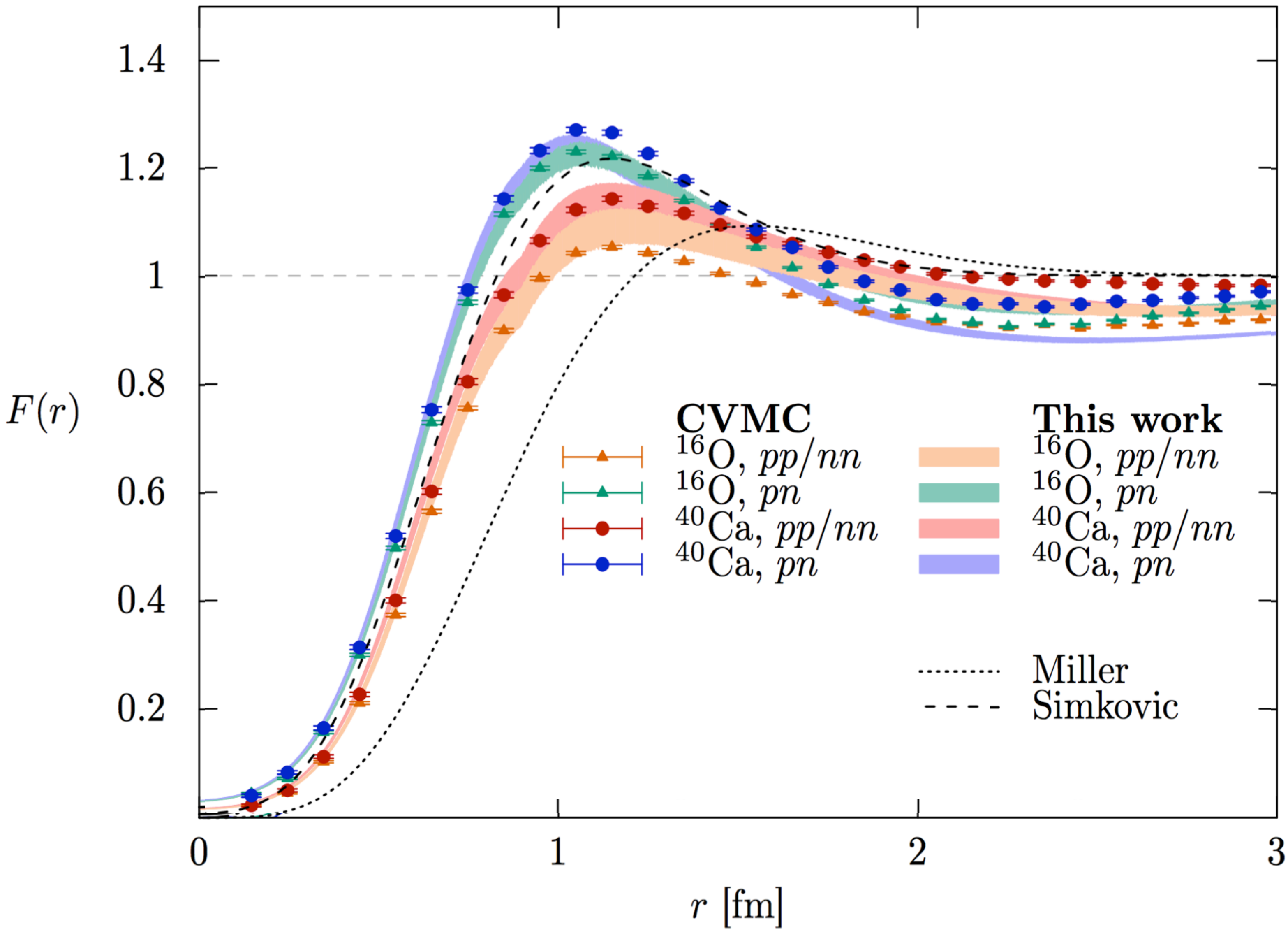
$$\rho_{NN}(r) = g_{NN}(r)\rho_{NN}^{(contact)}(r) + \kappa(1 - g_{NN}(r))\rho_{NN}^{(Uncorrelated)}(r)$$



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

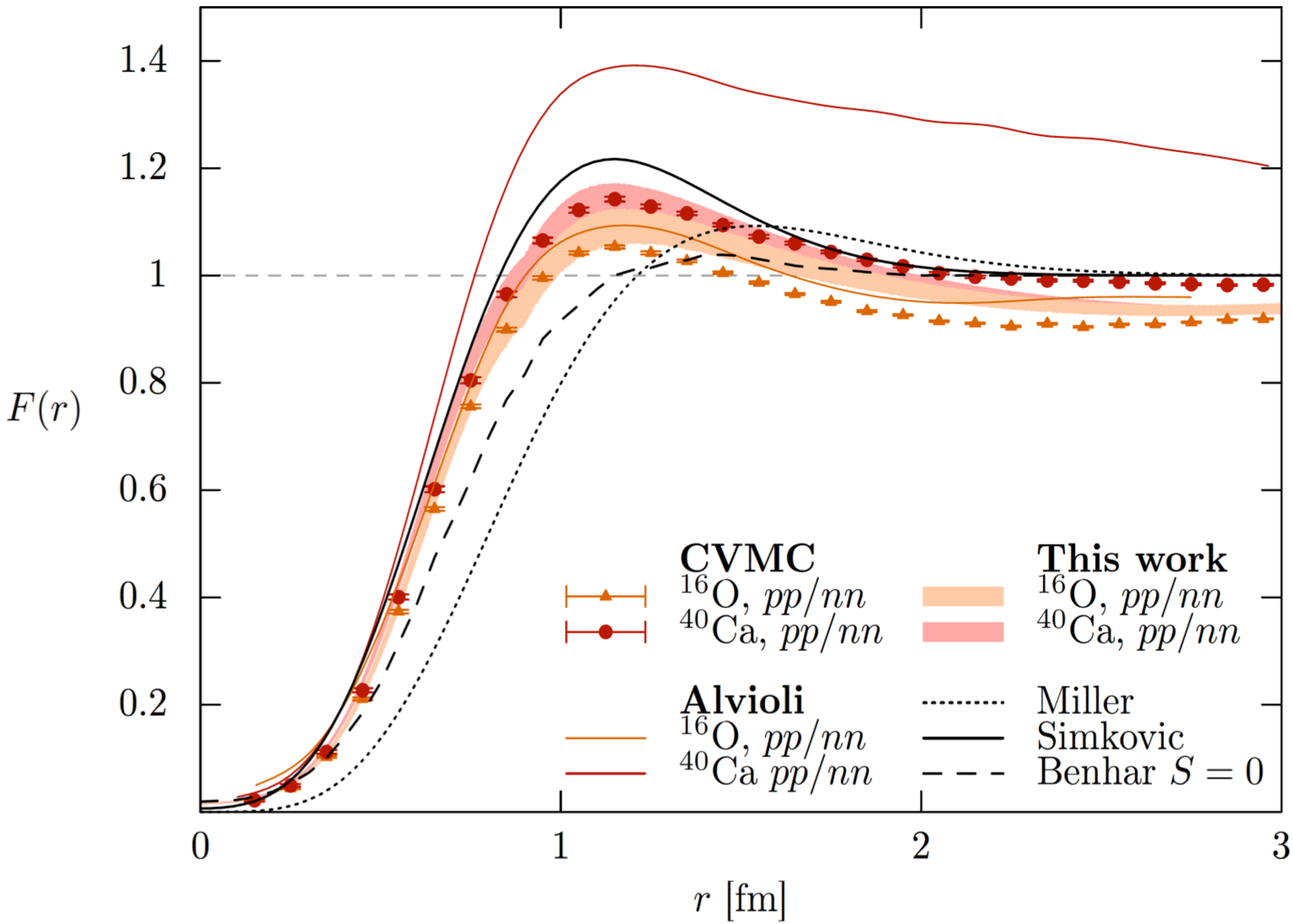


Correlation Functions



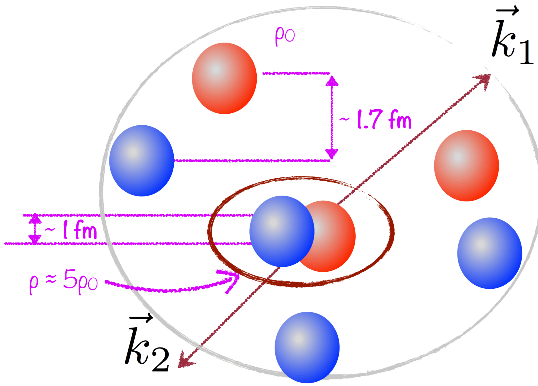
Cruz-Torres et al., Phys. Lett. B, In-Print (2018)

pp/nn Correlation Functions



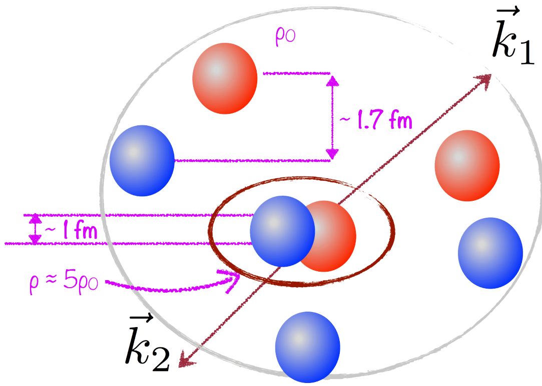
Cruz-Torres et al., Phys. Lett. B, In-Print (2018)

To Recap



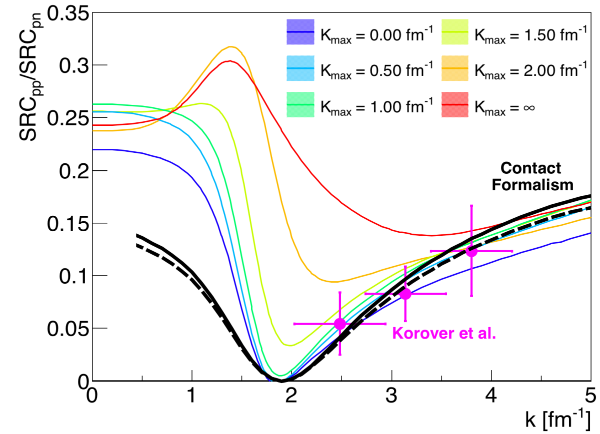
2-Nucleon Short-Range Correlations (SRC) are pairs of nucleons that interact at short distances and populate the high momentum states of the momentum distribution.

To Recap

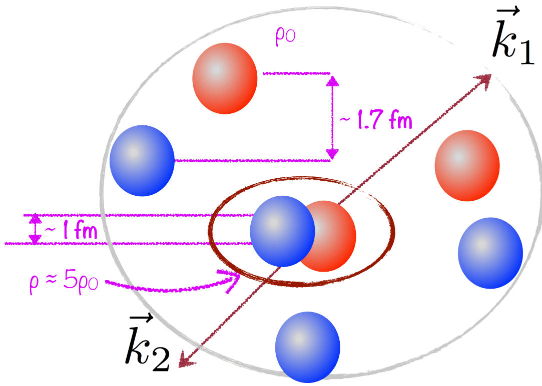


2-Nucleon Short-Range Correlations (SRC) are pairs of nucleons that interact at short distances and populate the high momentum states of the momentum distribution.

The Nuclear Contact Formalism is an effective theory that describes SRC by combining universal asymptotic wavefunctions with nucleus-dependent constants.

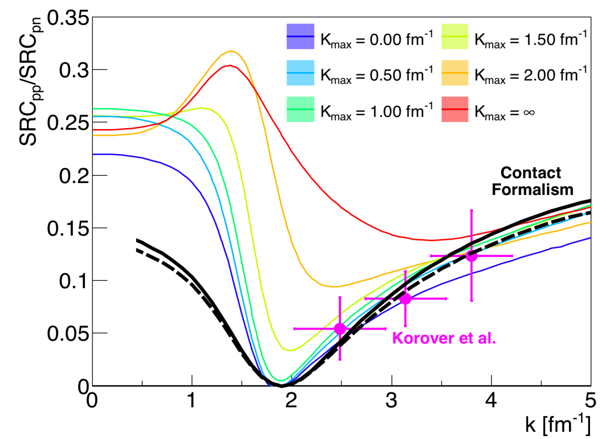


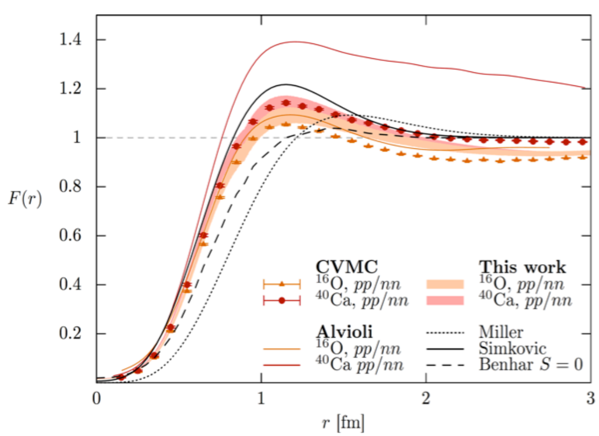
To Recap



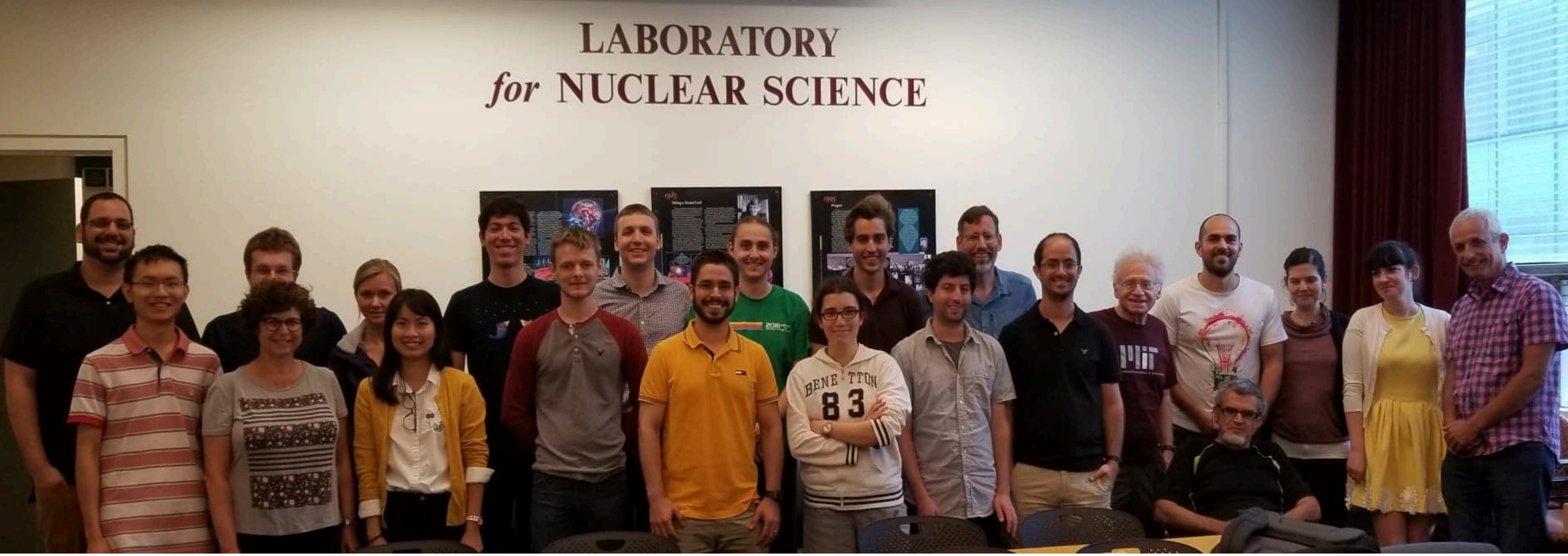
2-Nucleon Short-Range Correlations (SRC) are pairs of nucleons that interact at short distances and populate the high momentum states of the momentum distribution.

The Nuclear Contact Formalism is an effective theory that describes SRC by combining universal asymptotic wavefunctions with nucleus-dependent constants.





We have developed a Correlation Function model that combines Contact Formalism at short distances and uncorrelated densities at long distances.



^ SRC Collaboration Meeting August 2018

Contact Team:

N. Barnea, **R. Weiss**
G. Miller
E. Piasetzky
L. B. Weinstein
A. Schmidt, O. Hen

האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

Massachusetts Institute of Technology

אוניברסיטת תל-אביב
TEL AVIV UNIVERSITY

UNIVERSITY of WASHINGTON

OLD DOMINION UNIVERSITY