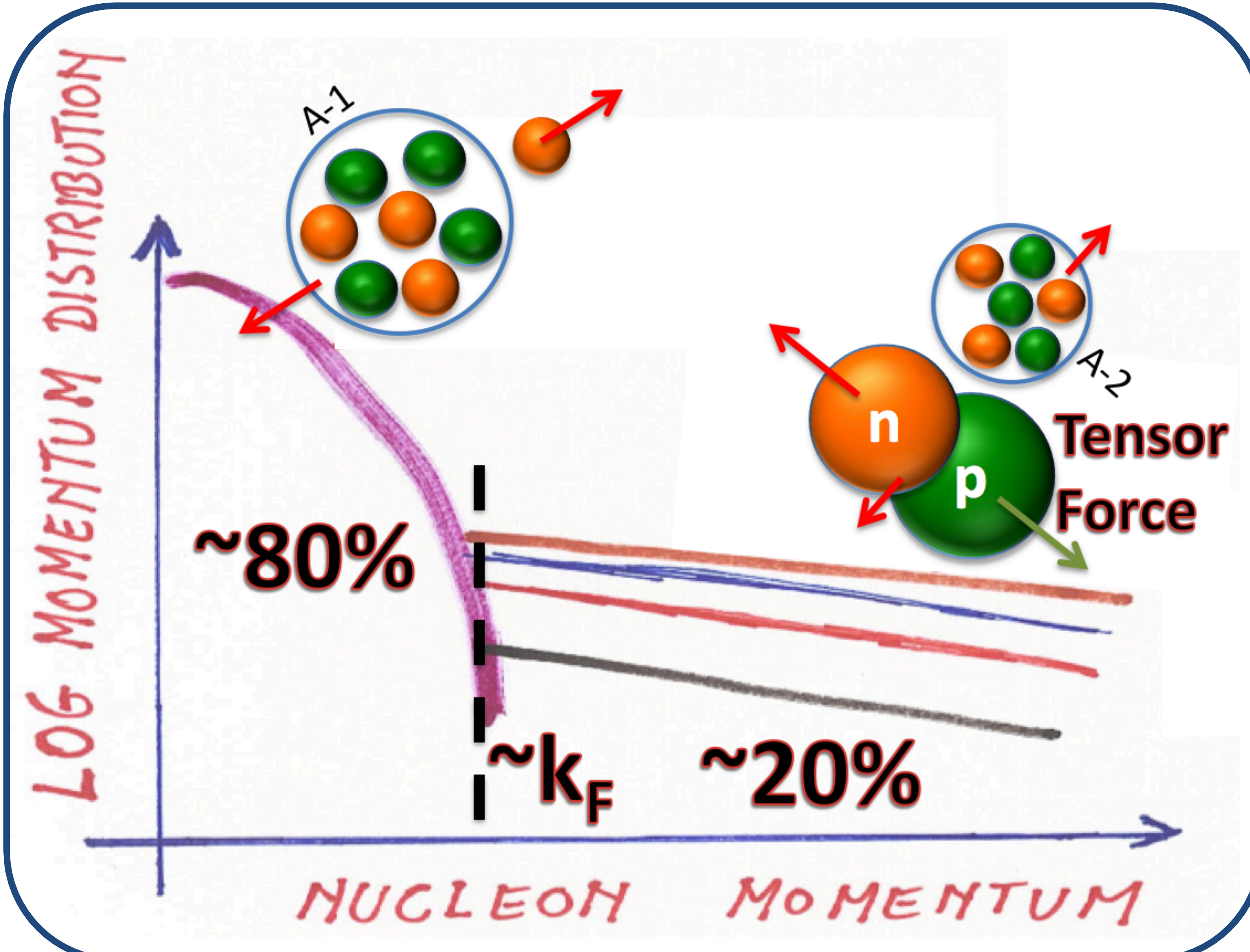
# Factorization and Universality

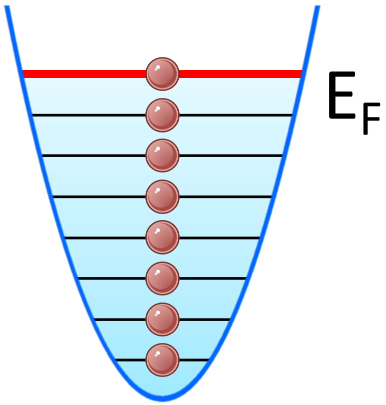
Or Hen – MIT


Quantitative Challenges in EMC and SRC Research, December $2^{nd}$ 2016

# Universal Nuclear Structure

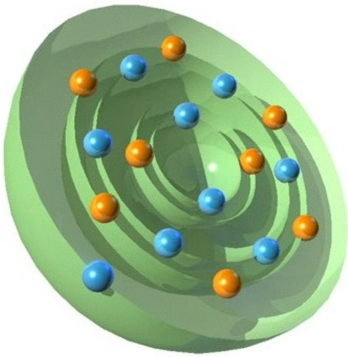


Fermi Gas Model

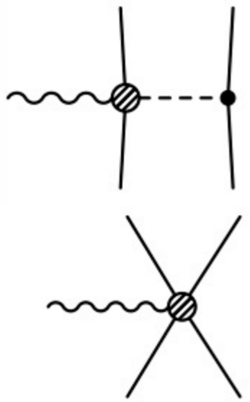



Liquid Drop Model

Shell Model



Chiral Perturbation Theory



# Challenge of Correlations

Whole is different from the sum of parts!

$$n_{2N}(k_1, k_2) \neq n_N(k_1) \cdot n_N(k_2)$$
$$\rho_{2N}(\vec{r}_1, \vec{r}_2) \neq \rho_N(\vec{r}_1) \cdot \rho_N(\vec{r}_2)$$

Specifically, in coordinate space:

SRC: $\rho_{2N}(\vec{r}_1, \vec{r}_2) \neq 0$ for $|\vec{r}_1 - \vec{r}_2| \approx R_N$

LRC: $\rho_{2N}(\vec{r}_1, \vec{r}_2) \neq 0$ for $|\vec{r}_1 - \vec{r}_2| \approx R_A$

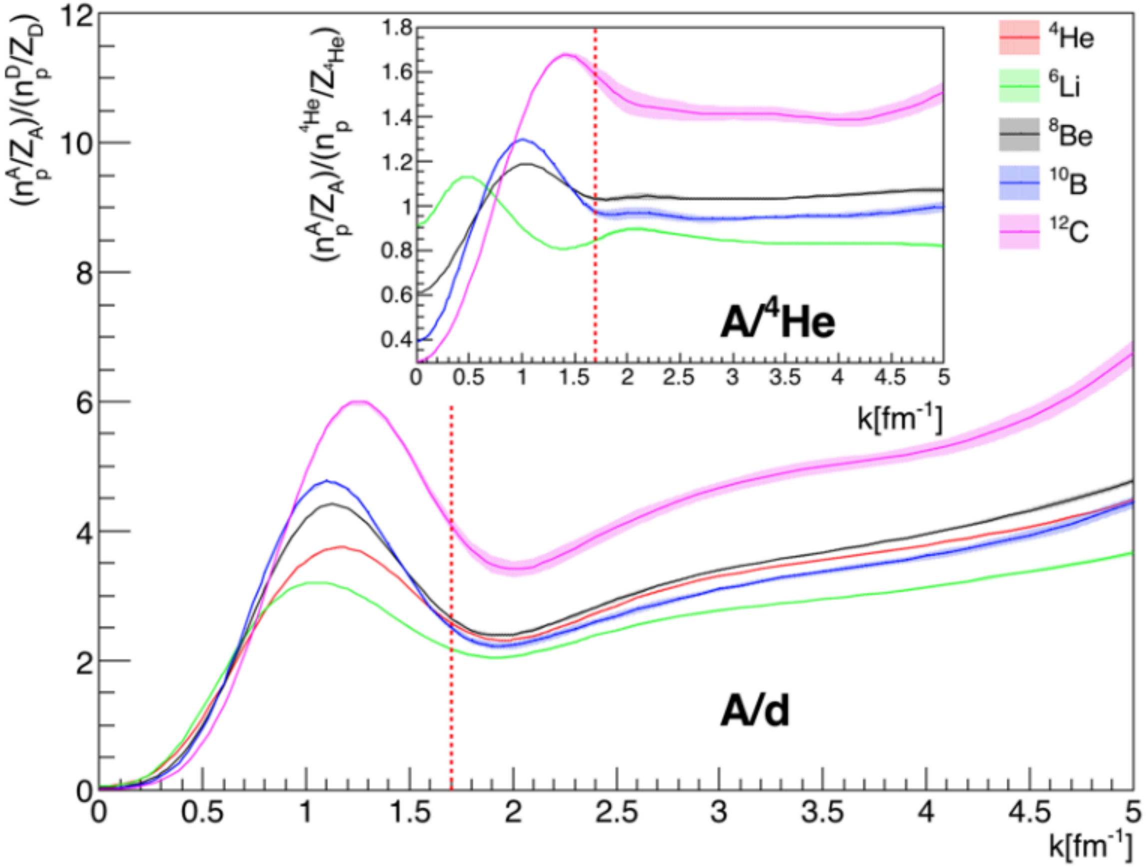
(Some) Interesting questions:

Is there a way to factorize the two-body density? Can we separate the 'mean-field' and 'SRC' effects? Are the SRC effects universal?

# Hints from Many-Body (VMC) ?

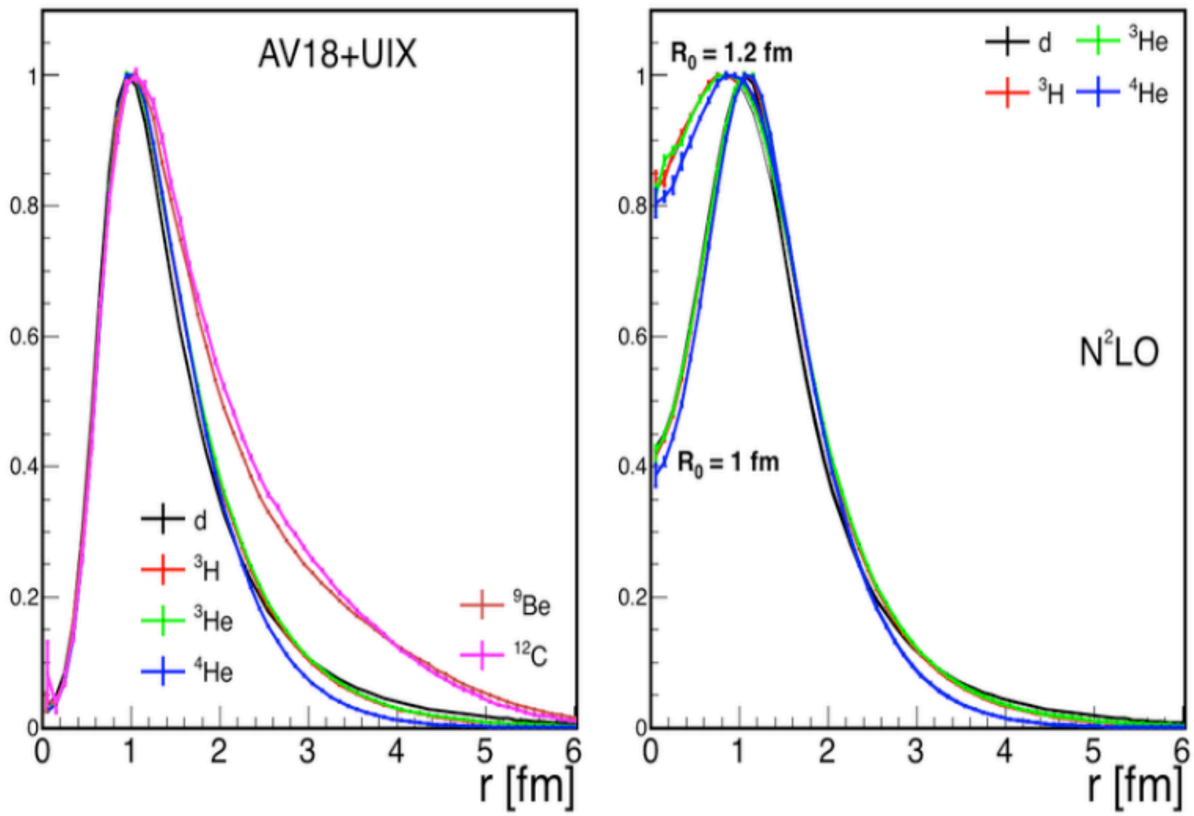
- One body momentum distribution scales above $k_F$.
- Good scaling relative to $^4$He NOT deuteron.

=> Importance of non-deuteron pairs? c.m. motion? Both?



# Hints from Many-Body (VMC) ?

Short-Range coordinate space density also scales
(See talk by Joel Lyn)



# Jan Ryckebusch's approach

Shift complexity from the wave-function to the operators:

- Start with a mean-field slater determinant.
- Introduce SRCs using correlation operators (Central, Tensor, Spin-Isospin).
- Act with the correlation operator only on $^1S_0$ ($^3S_0$) mean-field pairs.

Note: Correlation operators are universal! Main thing that is changing for different nuclei is the number of mean-field pairs!

# Jan Ryckebusch's approach

- Shift complexity from wave functions to operators

$$| \Psi\rangle = \frac{1}{\sqrt{\mathcal{N}}}\widehat{\mathcal{G}} \mid \Phi\rangle \qquad \text{with,} \qquad \mathcal{N} \equiv \langle \Phi \mid \widehat{\mathcal{G}}^{\dagger}\widehat{\mathcal{G}} \mid \Phi\rangle$$

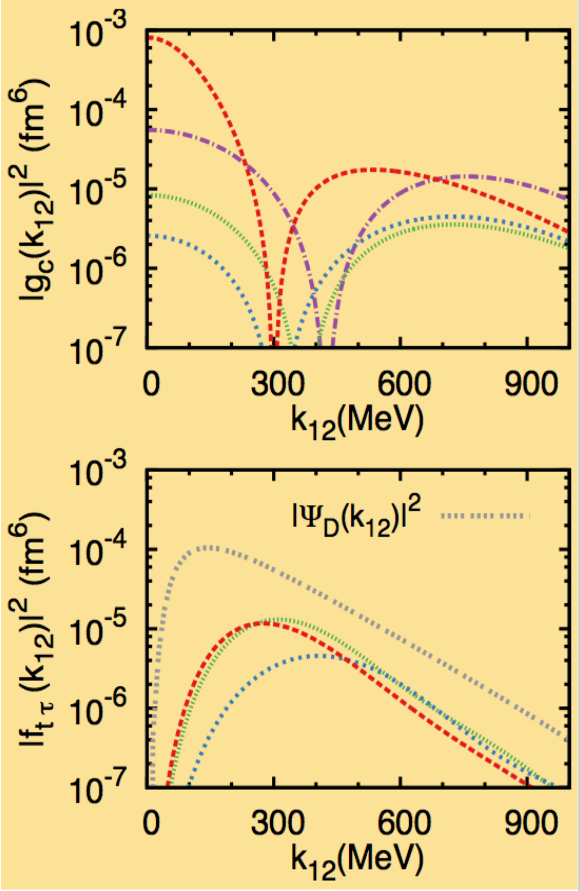
$| \Phi\rangle$ is an IPM single Slater determinant

- Nuclear correlation operator $\widehat{\mathcal{G}}$

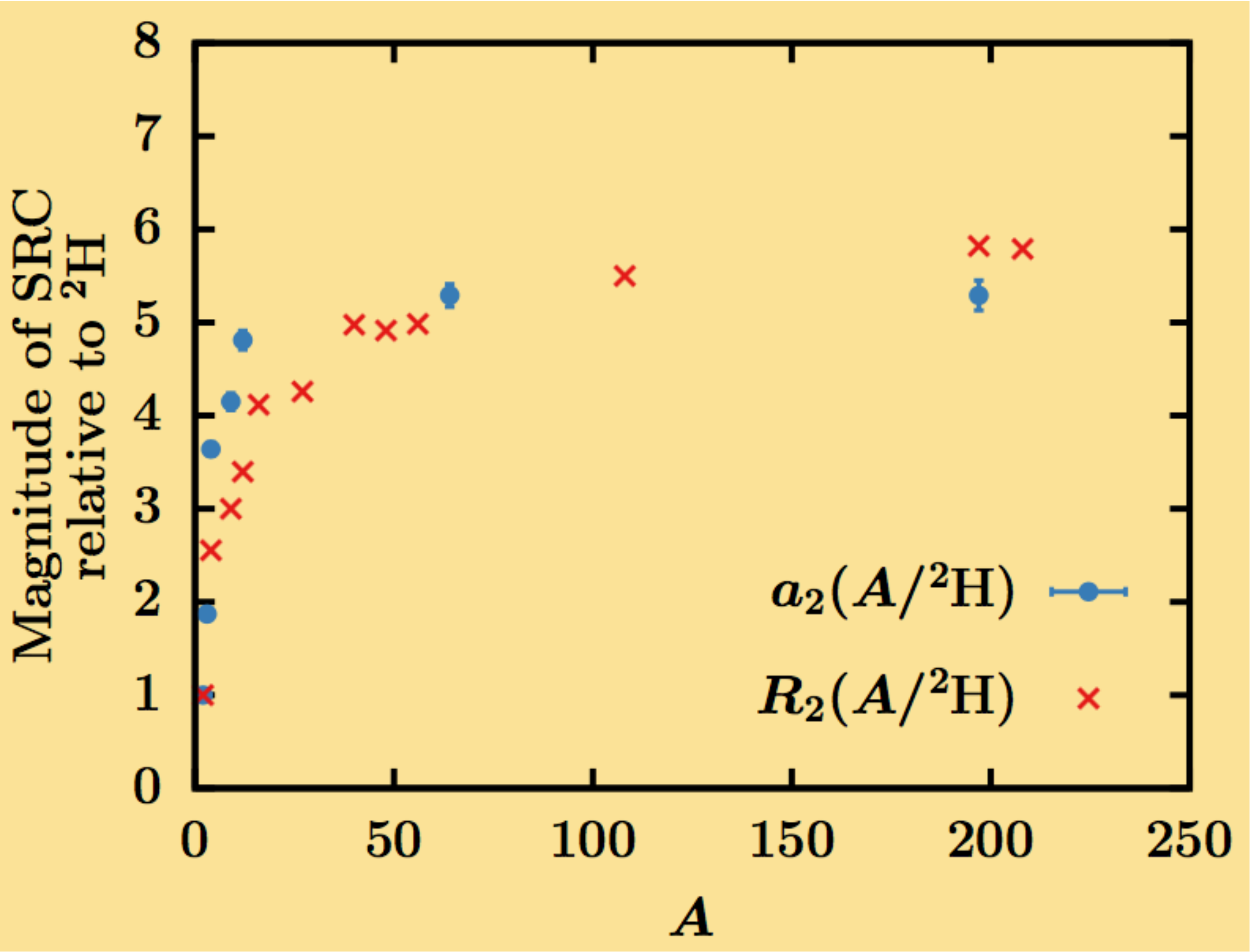
$$\widehat{\mathcal{G}} \approx \widehat{\mathcal{S}} \left( \prod_{i<j=1}^{A} \left[ 1 + \hat{l}(i,j) \right] \right) ,$$

- Major source of correlations: central (Jastrow), tensor and spin-isospin

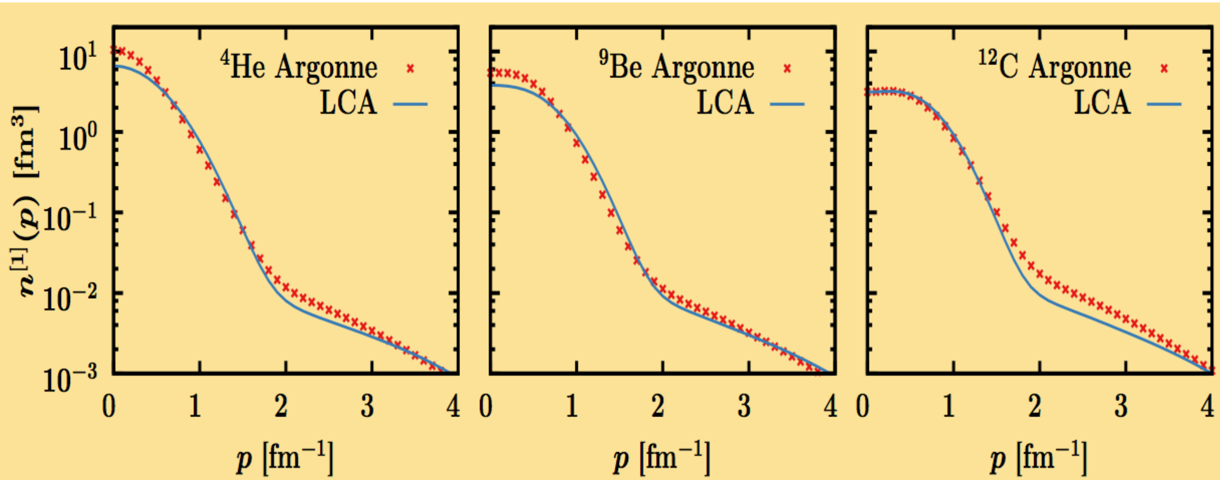
$$\hat{l}(i,j) = -g_c(r_{ij}) + f_{\sigma\tau}(r_{ij})\vec{\sigma}_i \cdot \vec{\sigma}_j \vec{\tau}_i \cdot \vec{\tau}_j + f_{t\tau}(r_{ij})\widehat{S}_{ij}\vec{\tau}_i \cdot \vec{\tau}_j \ .$$

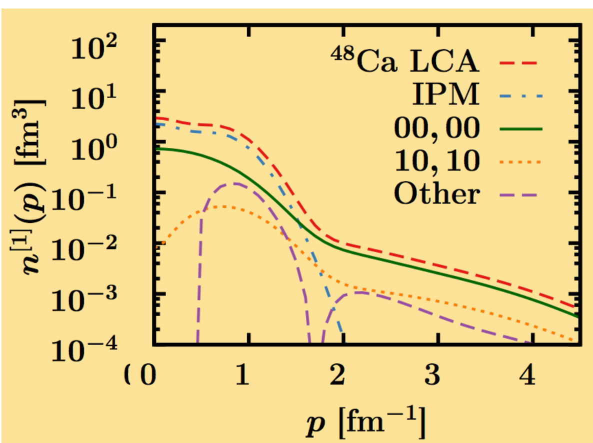


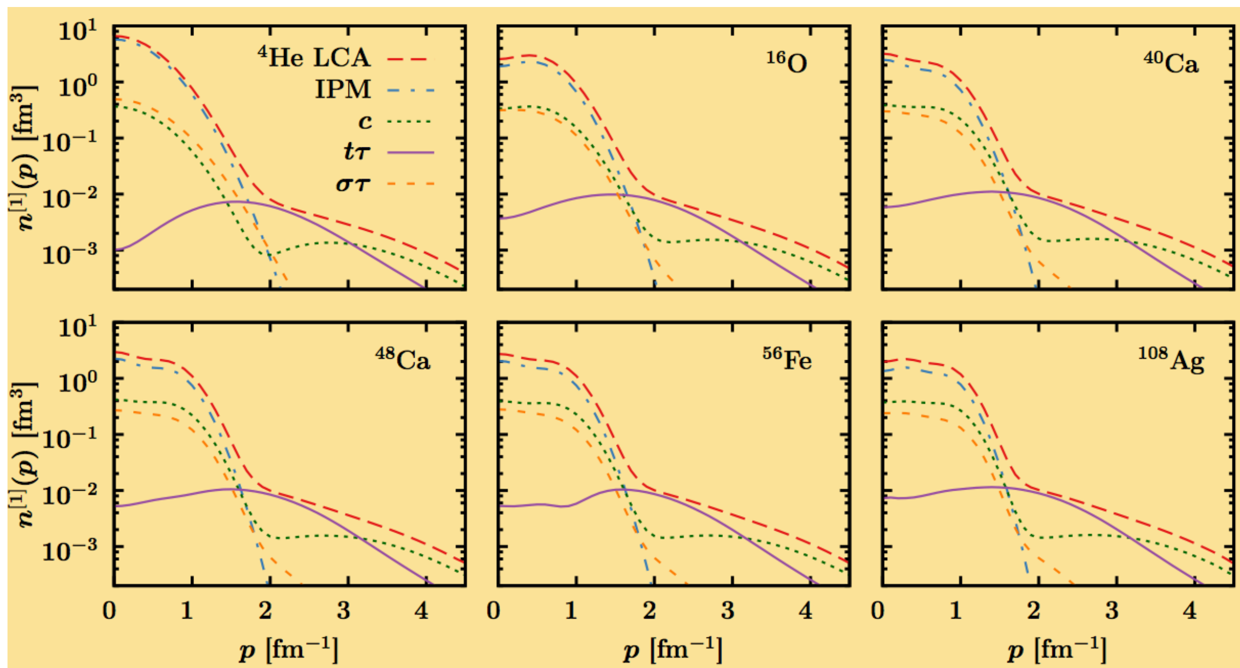
# SRC Pair Counting



# One-Body Momentum Distribution

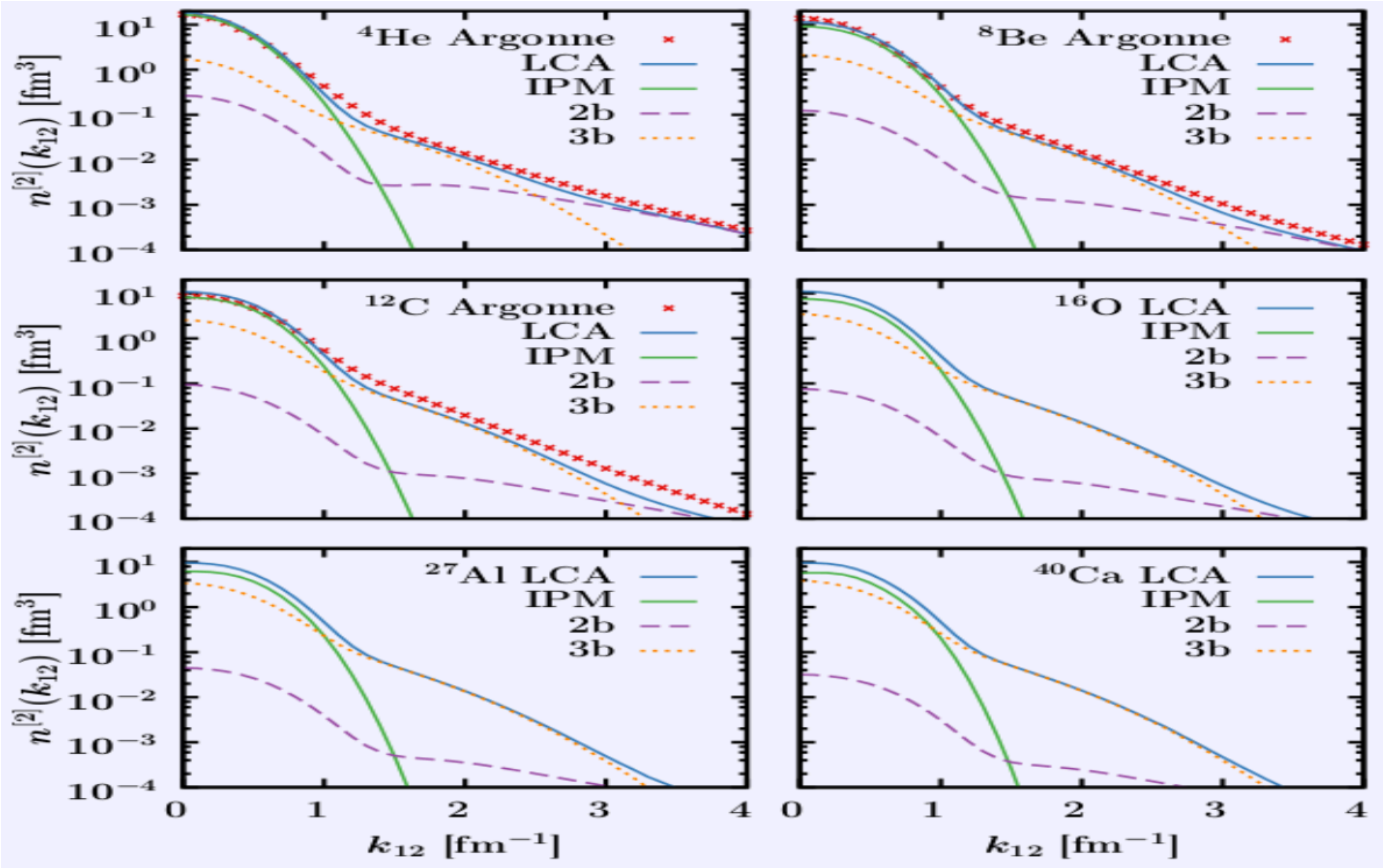



*Quantum numbers BEFORE action of correlation operators

# Two-Body Momentum Distribution




Two-Body density (integrated over c.m. momentum) not sensitive to pairs until VERY large relative momentum (See talk by Reynier)

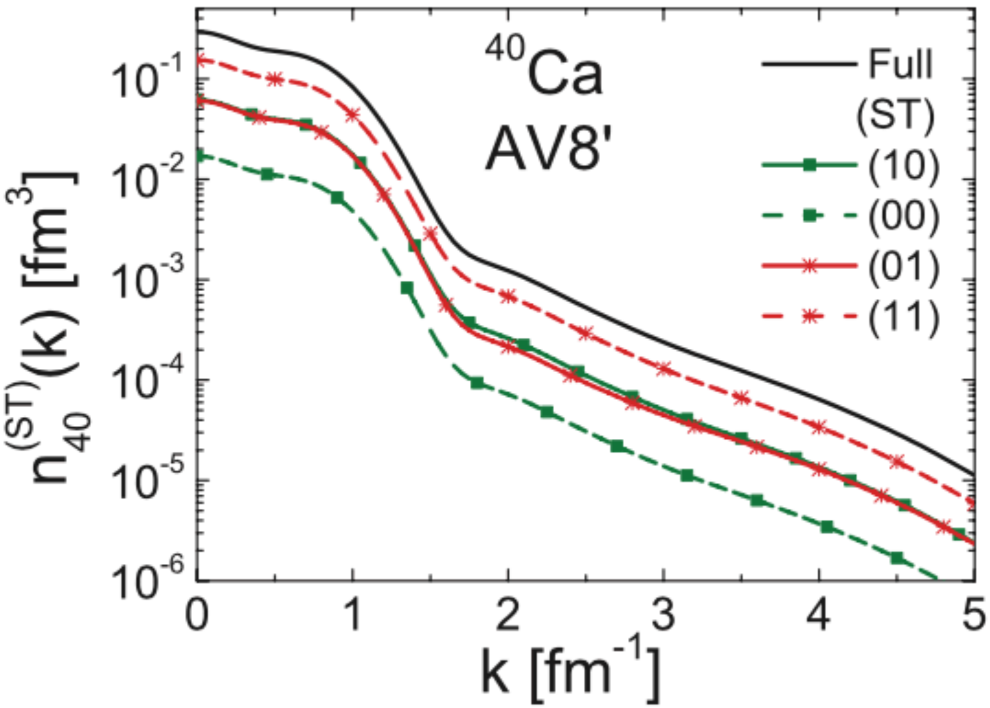
# Alvioli and Ciofi

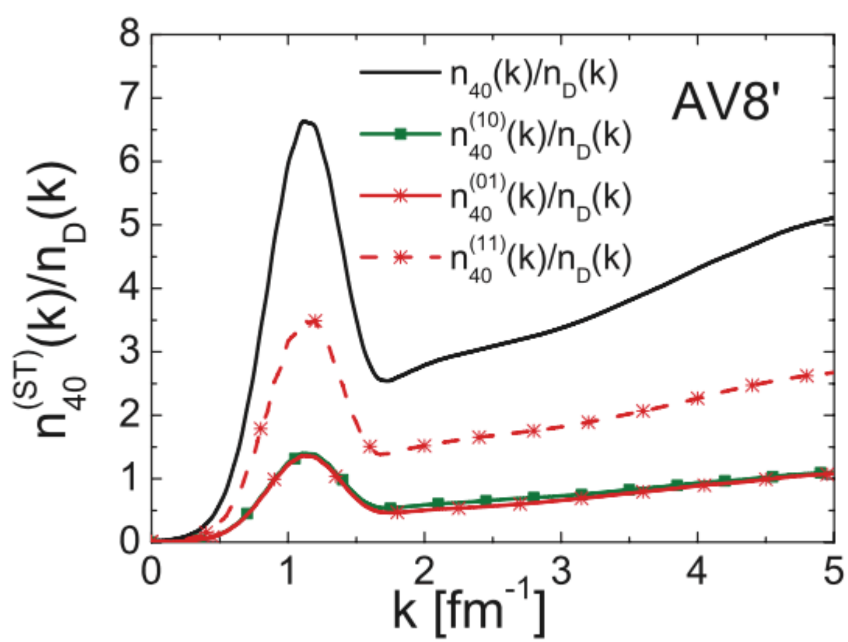
$$n_T^{(N_1N_2)}(\boldsymbol{k}_1) = \frac{1}{N_T^A}\int n_T^{N_1N_2}(\boldsymbol{k}_1,\boldsymbol{k}_2)\,d\boldsymbol{k}_2$$

$$n_{T=0}^{(N_1N_2)}(\boldsymbol{k}_1) = \left[n_{(00)}^{N_1N_2}(\boldsymbol{k}_1) + n_{(10)}^{N_1N_2}(\boldsymbol{k}_1)\right]$$

$$n_{T=1}^{(N_1N_2)}(\boldsymbol{k}_1) = \left[n_{(01)}^{N_1N_2}(\boldsymbol{k}_1) + n_{(11)}^{N_1N_2}(\boldsymbol{k}_1)\right]$$

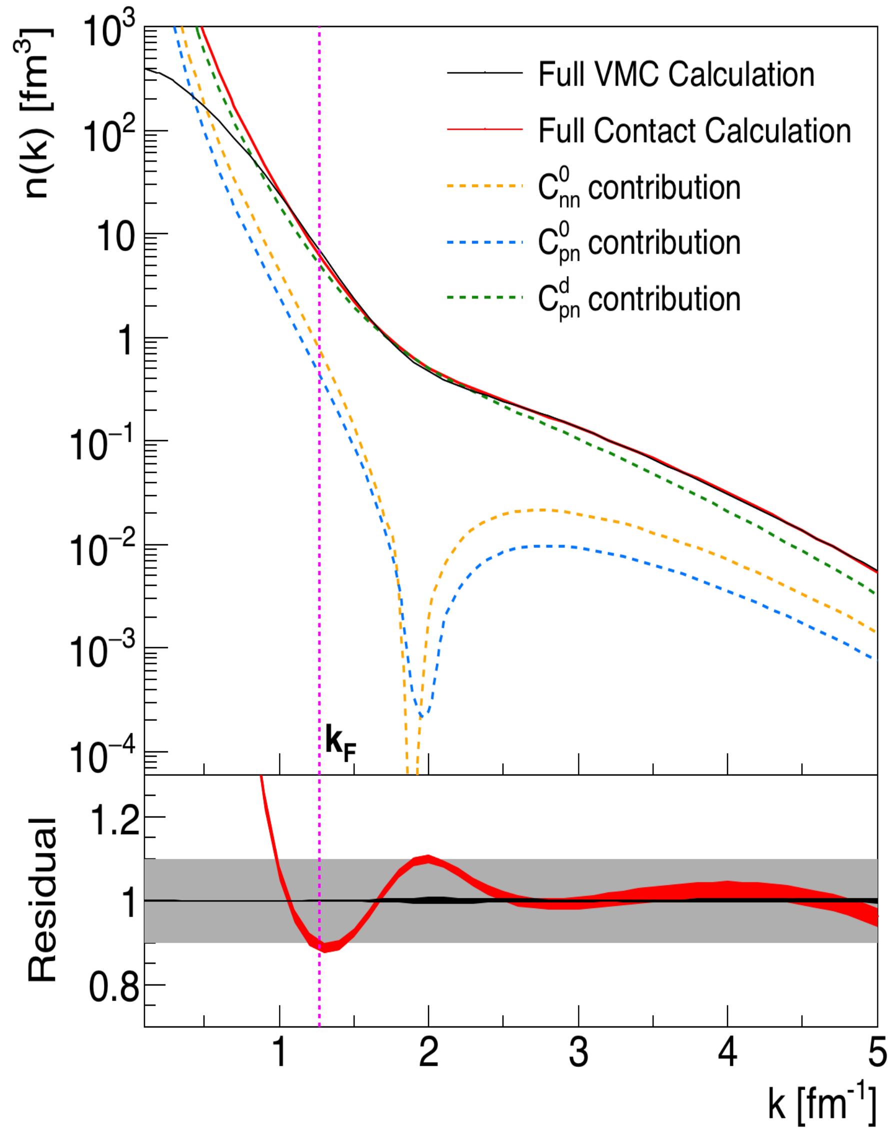
$$n_A^{N_1}(\boldsymbol{k}_1) = n_A^{(10)}(\boldsymbol{k}_1) + n_A^{(00)}(\boldsymbol{k}_1) + n_A^{(01)}(\boldsymbol{k}_1) + n_A^{(11)}(\boldsymbol{k}_1)$$



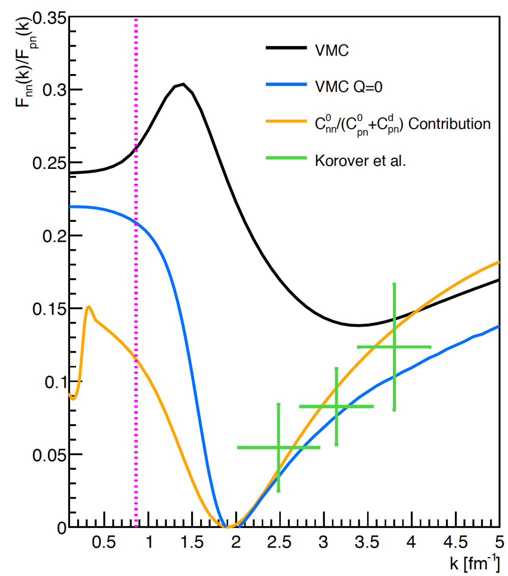

See talk by Alvioli

# Contact Approach




Generalized contact theory allows reproducing one-body densities using universality to 10-20% accuracy! (See talk by Ronen Weis)

Nuclear contacts can be calculated AND extracted from experiment!




Wiess, Cruz-Torez, Barnea, Piasetzky, Hen

# Universal Nuclear Structure

Can universality help describe the SRC phase of the nucleus in both coordinate and momentum space WITHOUT relaying on many-body calculations? (seems like the answer is YES)