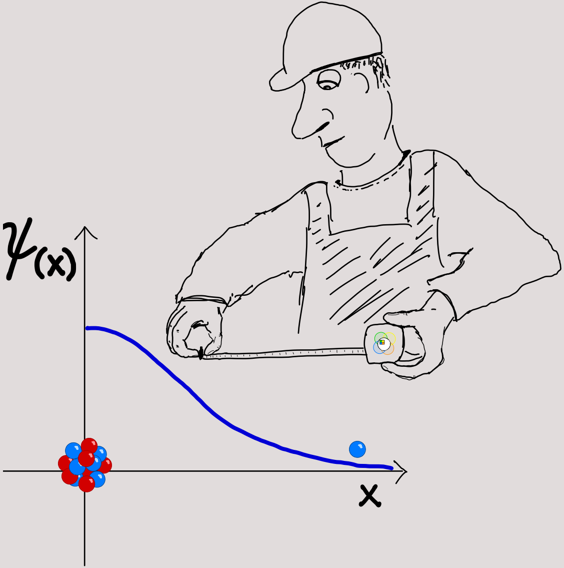
Nuclear Short-Range Correlations Part II:

Quenching, correlations, and currents from an ab initio perspective

Ragnar Stroberg

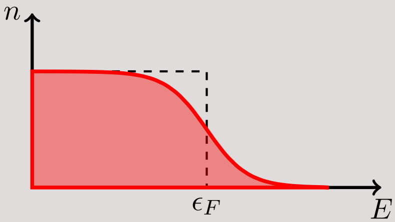
University of Washington

FRIB TA Nuclear Physics Dialogues
September 22, 2020



"Results from both theory and experiment...imply that only 2/3 of the time a nucleon acts as an independent particle bound in an average potential."

-Pandharipande, Sick, deWitt Huberts, RMP (1997)



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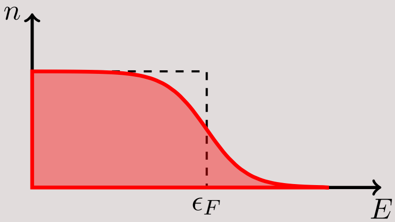


Overlap Function: $$O^{fi}(\vec{r}) = \langle \Psi_f^A | a^\dagger(\vec{r}) | \Psi_i^{A-1} \rangle$$

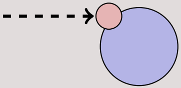
Spectroscopic Amplitude: $$\mathcal{A}_\alpha^{fi} = \int d\vec{r}\, O^{fi}(\vec{r}) \phi_\alpha(\vec{r}) = \langle \Psi_f^A | a_\alpha^\dagger | \Psi_i^{A-1} \rangle$$

Spectroscopic Factor: $$S_\alpha^{fi} = |\mathcal{A}_\alpha|^2 = |\langle \Psi_f^A | a_\alpha^\dagger | \Psi_i^{A-1} \rangle|^2$$

Occupation: $$n_\alpha^f = \sum_i S_\alpha^{fi} = \langle \Psi_f^A | a_\alpha^\dagger a_\alpha | \Psi_f^A \rangle$$

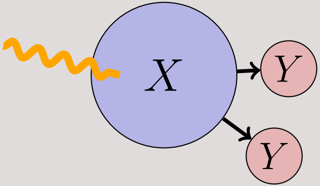
Caveat 1:

Can't populate bound state with "$a^\dagger$ beam"

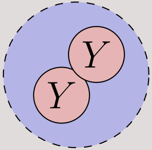


Caveat 2:

Whack X, Y comes out



X is made of Y



Questions for discussion

1. Can SFs be formulated in a model-independent way?
   - If not, can they still be useful, and is there a preferred scheme?

2. Can quenching of β decays inform quenching of SFs?

3. Is quenching of SFs a problem with structure theory, reaction theory, experiments, or the concept of SFs?

4. How do SRCs impact low-energy observables?

5. Can high-momentum tails be measured experimentally?

6. Can SRCs tell us something about high-density matter?

7. Is "observable" a discrete or continuous property?

SF=Spectroscopic Factor, SRC=Short Range Correlation

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Can spectroscopic factors be formulated in a model-independent way?

Physics Letters B 531 (2002) 203–208

Are occupation numbers observable?

R.J. Furnstahl, H.-W. Hammer

Department of Physics, The Ohio State University, Columbus, OH 43210, USA

Received 30 August 2001; accepted 21 December 2001

Editor: W. Haxton

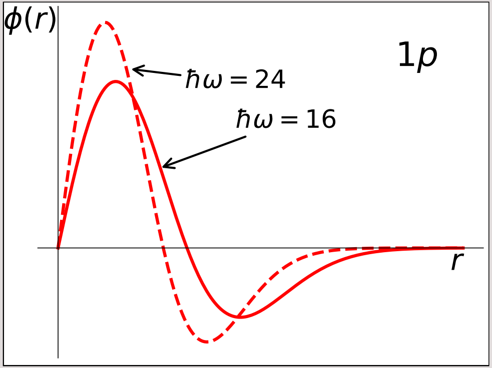
"In an EFT, observables are characterized by invariance under local field redefinitions."

"It is not only that the momentum distribution is difficult to extract but that it cannot be isolated in principle within a calculational framework based on low-energy degrees of freedom."

Can spectroscopic factors be formulated in a model-independent way?

$$S_{n\ell j} = |\langle \Psi^A | a^\dagger_{n\ell j} | \Psi^{A-1} \rangle|^2$$

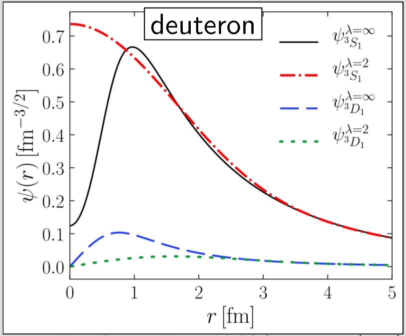
Depends on single-particle basis.



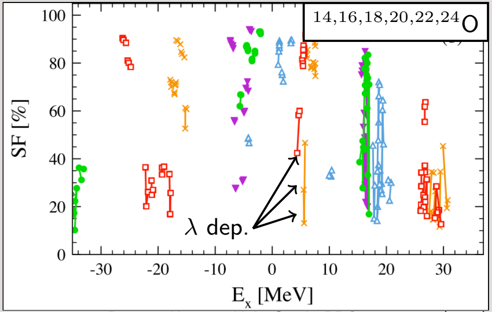
Can spectroscopic factors be formulated in a model-independent way?

$$S_{\ell j} = |\langle \Psi^A | \sum_n a^\dagger_{n\ell j} | \Psi^{A-1} \rangle|^2$$

Independent of single-particle basis, depends on resolution scale.



More, Bogner, Furnstahl, PRC 96 054004 (2017)



Duguet, Hergert, Holt, Somà, PRC 92 034313 (2015)

Can spectroscopic factors be formulated in a model-independent way?

$$S_{\ell j,\lambda} = |\langle\Psi^{A}|\sum_{n} a^{\dagger}_{n\ell j,\lambda}|\Psi^{A-1}\rangle|^{2}$$

Independent of single-particle basis, resolution-scale dependence explicit.

Can spectroscopic factors be formulated in a model-independent way?

$$S_{\ell j,\lambda} = |\langle\Psi^A| \sum_n a^\dagger_{n\ell j,\lambda} |\Psi^{A-1}\rangle|^2$$

Independent of single-particle basis, resolution-scale dependence explicit.

$$a^\dagger_\lambda = \underbrace{U_{\lambda,\lambda'}\; a^\dagger_{\lambda'}\; U_{\lambda',\lambda}}_{\text{“change of basis”}} \sim a^\dagger_{\lambda'} + a^\dagger_{\lambda'} a^\dagger_{\lambda'} a_{\lambda'} + a^\dagger_{\lambda'} a^\dagger_{\lambda'} a^\dagger_{\lambda'} a_{\lambda'} a_{\lambda'} + \ldots$$

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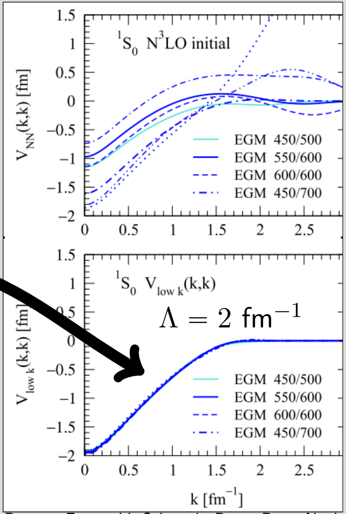
In *principle*, all many-body methods using an RG-equivalent H, should get the **same** $S_{\ell j,\lambda}$. But what λ should we use?

Can spectroscopic factors be formulated in a model-independent way?

Different potentials collapse to universal form at low resolution.

Is $S_{\ell j,\lambda\approx 2}$ a good choice?

Do we gain anything from this?



Bogner, Furnstahl, Schwenk, Prog. Part. Nucl. Phys. 65, 94 (2010)

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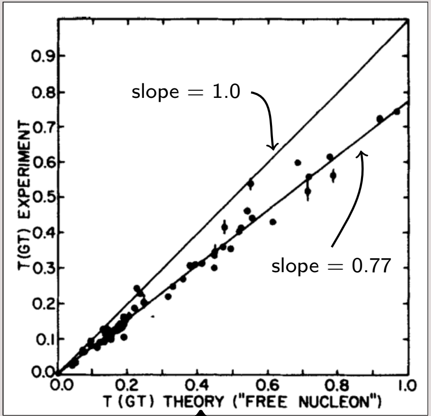
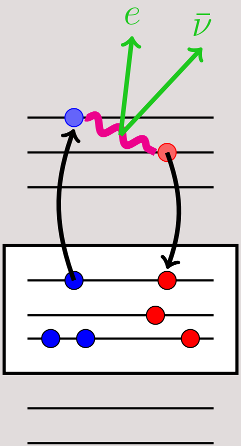
Quenching in Gamow-Teller β decays

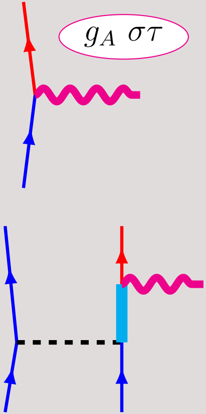


Brown, Wildenthal, At. Dat. Nucl. Dat. Tab. 33, 347 (1985)

(shell model with $\mathcal{O}_{GT} = g_A \sigma\tau$)

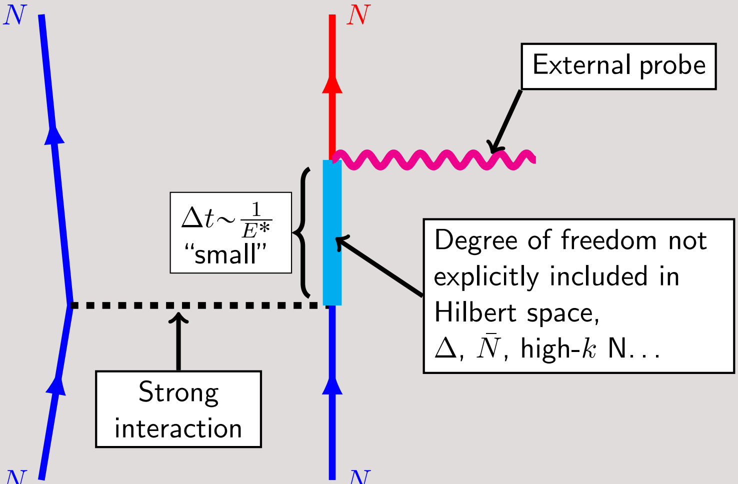


Correlations

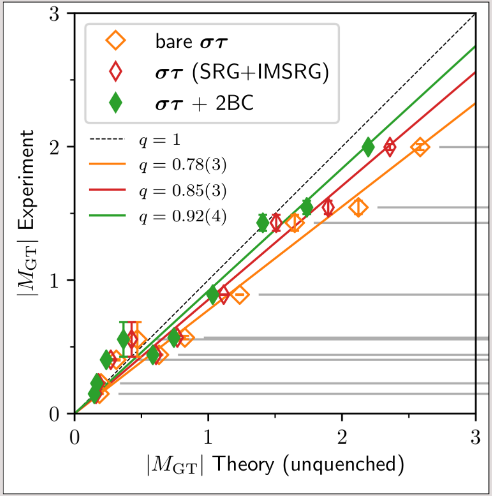


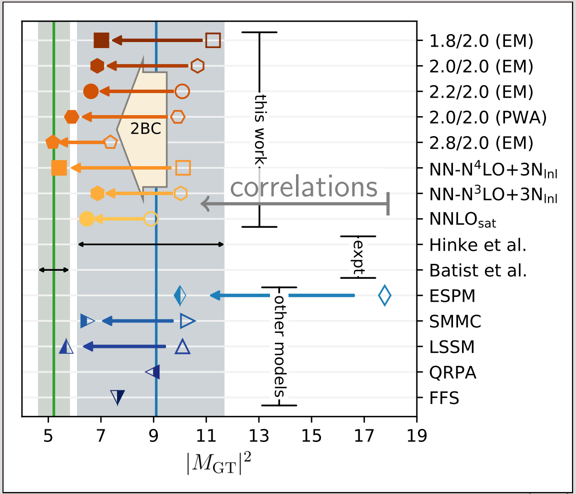
Currents

Two Body Current



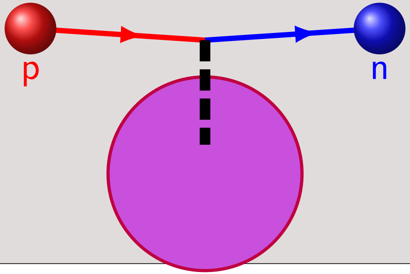
Quenching in Gamow-Teller β decays

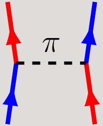




Gysbers et al. Nature Physics, 15 428 (2019)

Quenching in charge exchange reactions

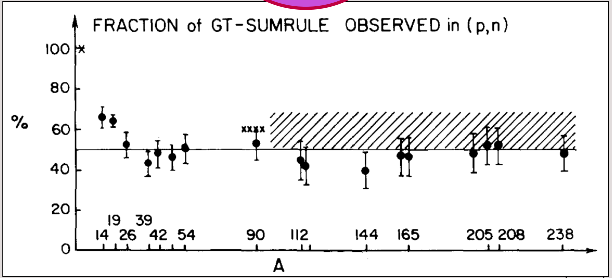




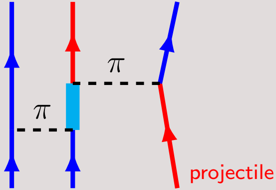
$$V_{1\pi} = -\frac{g_A^2}{4f_\pi^2}\tau_1\tau_2\frac{(\vec{q}\cdot\vec{\sigma}_1)(\vec{q}\cdot\vec{\sigma}_2)}{q^2+m_\pi^2}$$

$$\boxed{\sigma \underset{q\to 0}{=} \hat{\sigma}\, B(GT)}$$

Tadeucci et al., NPA 469 125 (1987)

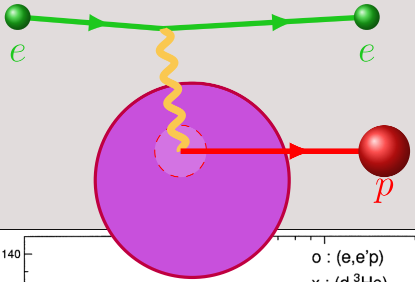


Gaarde Nuc. Phys. A 396 127c (1983)



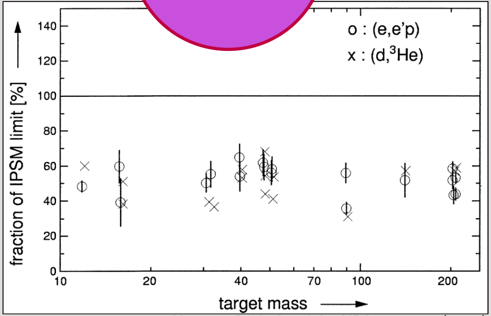
“Currents”

Quenching in $(e, e'p)$ reactions

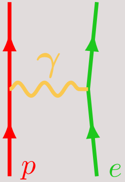


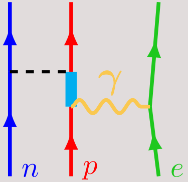
$$\boxed{\sigma \underset{\text{(PWIA)}}{=} k\sigma_{ep} S(E,p)}$$

$$S(E,p) = \left|\langle \Psi^A | a_p^\dagger | \Psi_E^{A-1} \rangle\right|^2$$



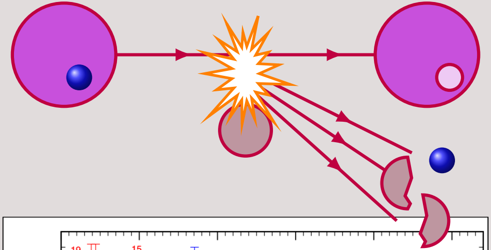
Kramer, Blok, Lapikás, NPA 679 267 (2001)



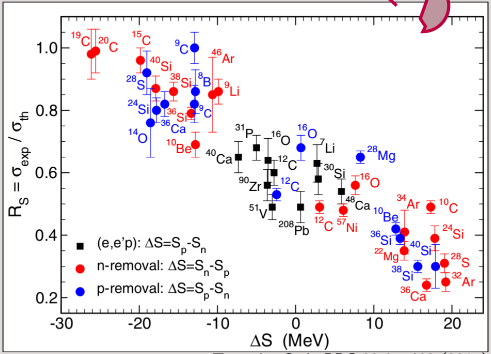


"Currents"

Quenching in hadronic knockout reactions

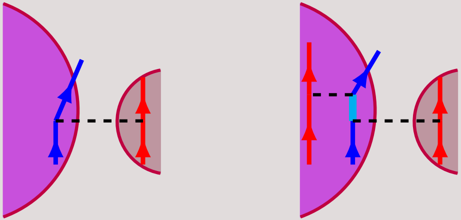


$$\sigma = \sigma_{\mathrm{sp}} \times S$$



Tostevin, Gade PRC 90 057602 (2014)

Double-folding optical potential:



"Currents"

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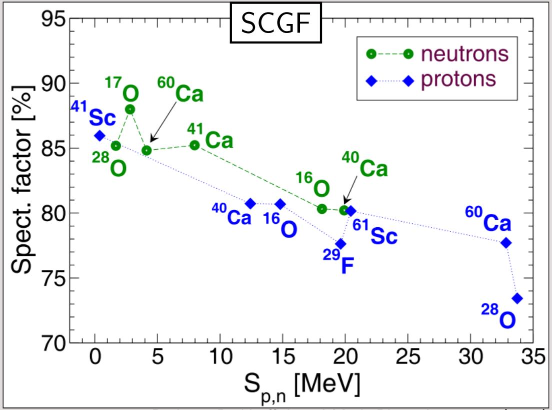
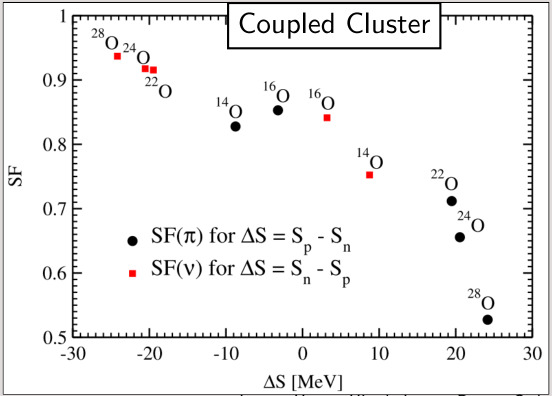
Is quenching of SFs a problem with structure theory?

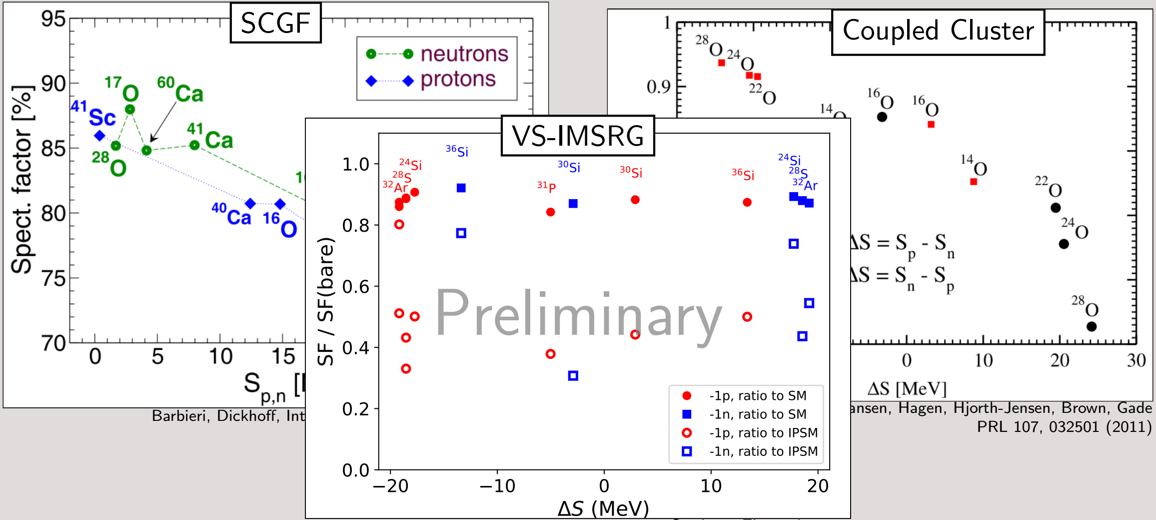


Barbieri, Dickhoff, Int. J Mod. Phys. A 24 2060 (2009)



Jansen, Hagen, Hjorth-Jensen, Brown, Gade
PRL 107, 032501 (2011)

Is quenching of SFs a problem with structure theory?

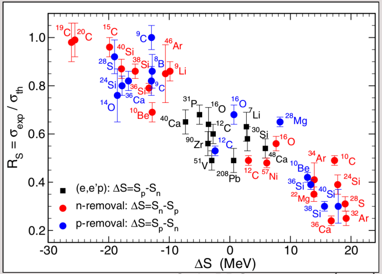


Barbieri, Dickhoff, Int

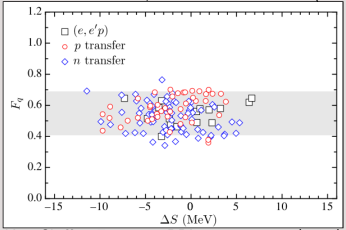
ansen, Hagen, Hjorth-Jensen, Brown, Gade
PRL 107, 032501 (2011)

Stroberg, Zhang, in prep.

Is quenching of SFs a problem with reaction theory?



Tostevin, Gade PRC 90 057602 (2014)

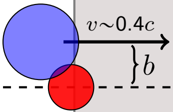


Kay, Shiffer, Freeman, PRL 111, 042502 (2013)

Hadronic knockout @ $\sim$ 50-100 MeV/nucleon

Possible sources of error:

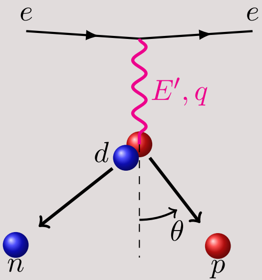
1. Eikonal approximation:
   - $V/E \sim [50 \text{ MeV}]/[100 \text{ MeV}] = 0.5 \ll 1$
   - $ka \gtrsim [2 \text{ fm}^{-1}][0.7 \text{ fm}] = 1.4 \gg 1$
2. Adiabatic approximation[1]:
   - $\omega_{fi}\Delta t \sim \left[\frac{\Delta E_{fi}}{20 \text{ MeV}}\right]\left[\frac{\Delta z}{4 \text{ fm}}\right] \ll 1$
3. Densities from Skyrme HF
4. Shell model SFs
5. Nucleus-Nucleus optical potential
   - Double-folding $\sim t\rho\rho$

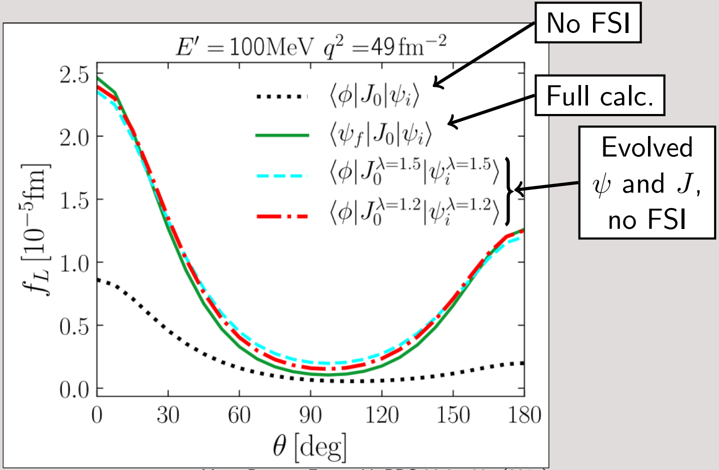


[1]see e.g. Flavigny et al. PRL 108 252501 (2012)

Is quenching of SFs a problem with the concept of SFs?

deuteron electrodisintegration





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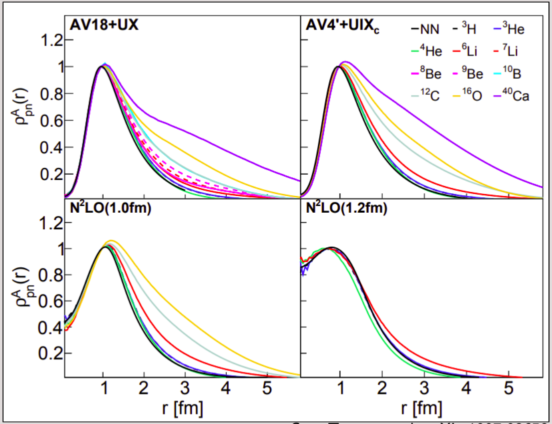
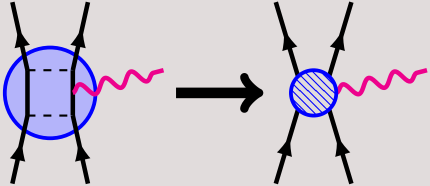


Cruz-Torrez, et al. arXiv:1907.03658

Generalized Contact Formalism[1]

$$\underbrace{\rho^A_{pn}(r)}_{\text{two body density}} \underset{r\to 0}{=} \underbrace{C^A_{pn}}_{\text{contact}} \times \underbrace{|\varphi_{pn}(r)|^2}_{\text{short distance, } A\text{-independent}}$$



 $\sim \int |\varphi(r)|^2 \, j(r)$

[1] see e.g. Weiss, Pazy, Barnea, Few-Body Syst. 58, 1 (2017); also Braaten, Platter PRL 100 205301 (2008)

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