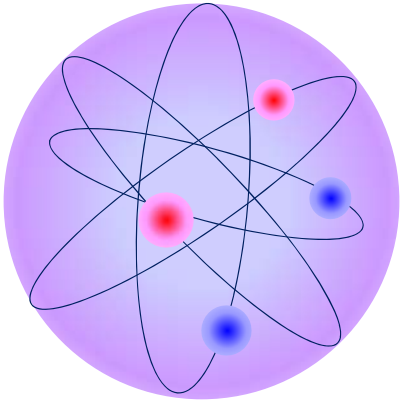
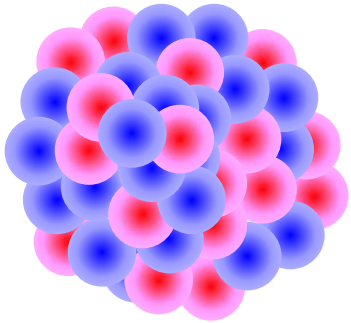
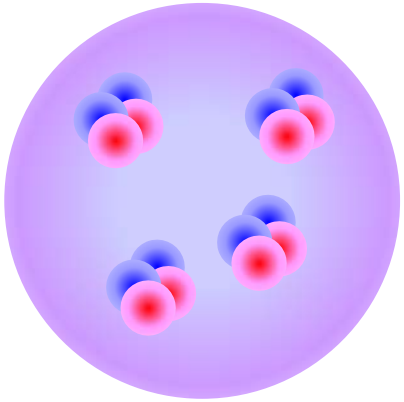
Microscopic reaction theory to probe several faces of nuclei

International Symposium in Honor of Professor Nambu

for the 10th Anniversary of his Nobel Prize in Physics







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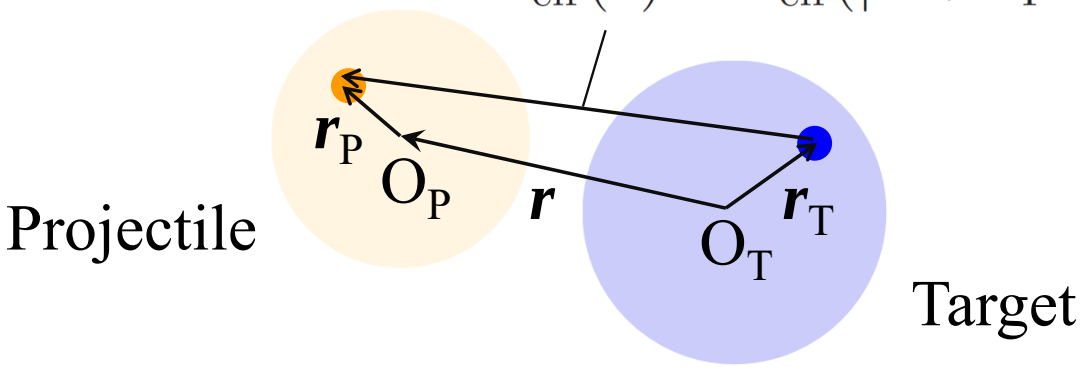
Microscopic Reaction Theory (framework)

The double-folding model potential

An "expectation value" of a nucleon-nucleon (*NN*) effective interaction

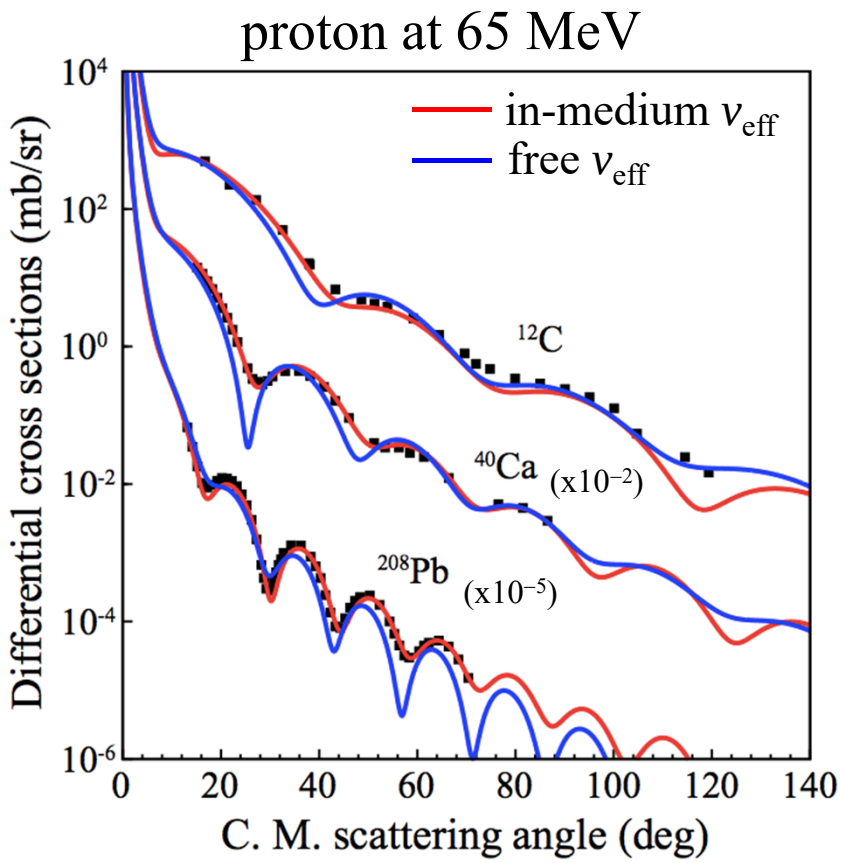
$$v_{\rm eff}(s) \equiv v_{\rm eff}(|\boldsymbol{r} + \boldsymbol{r}_{\rm P} - \boldsymbol{r}_{\rm T}|)$$

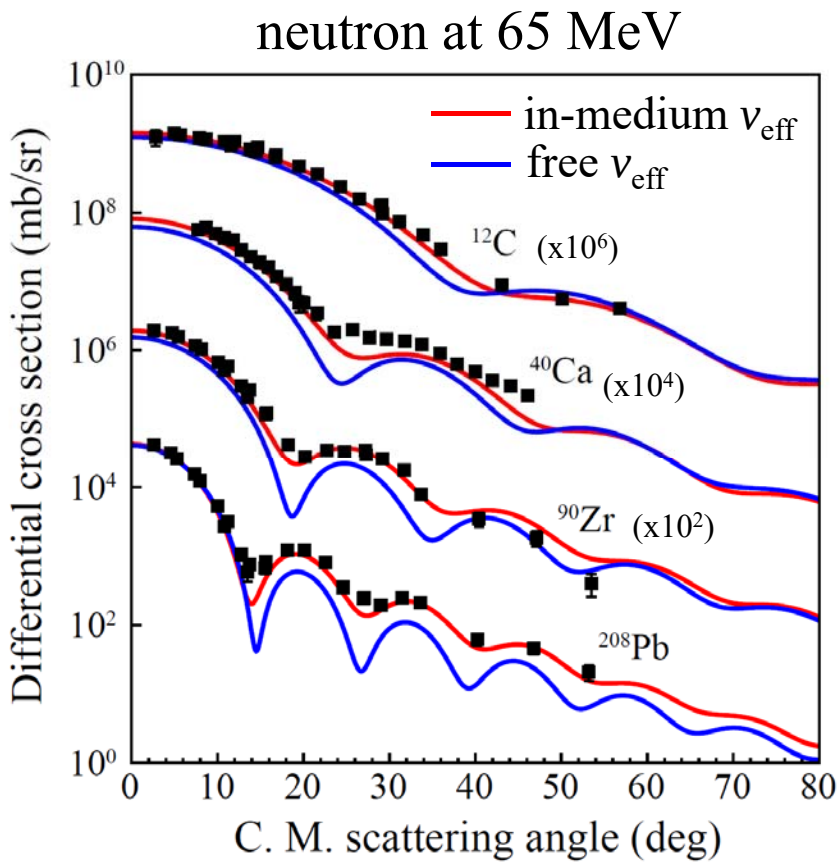


$$U(\boldsymbol{r}) = \int v_{\rm eff}(s)\rho_{\rm P}(\boldsymbol{r}_{\rm P})\rho_{\rm T}(\boldsymbol{r}_{\rm T})d\boldsymbol{r}_{\rm P}d\boldsymbol{r}_{\rm T}$$

one-body densities

Microscopic description of nucleon-nucleus scattering

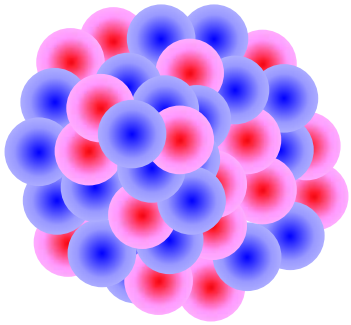




No free parameter ("prediction")

cf. K. Amos+, Adv. Nucl. Phys. ***25****, 275 (2000).*
T. Furumoto+, PRC ***78****, 044610 (2008).*
M. Toyokawa+, PRC ***92****, 024618 (2015).*

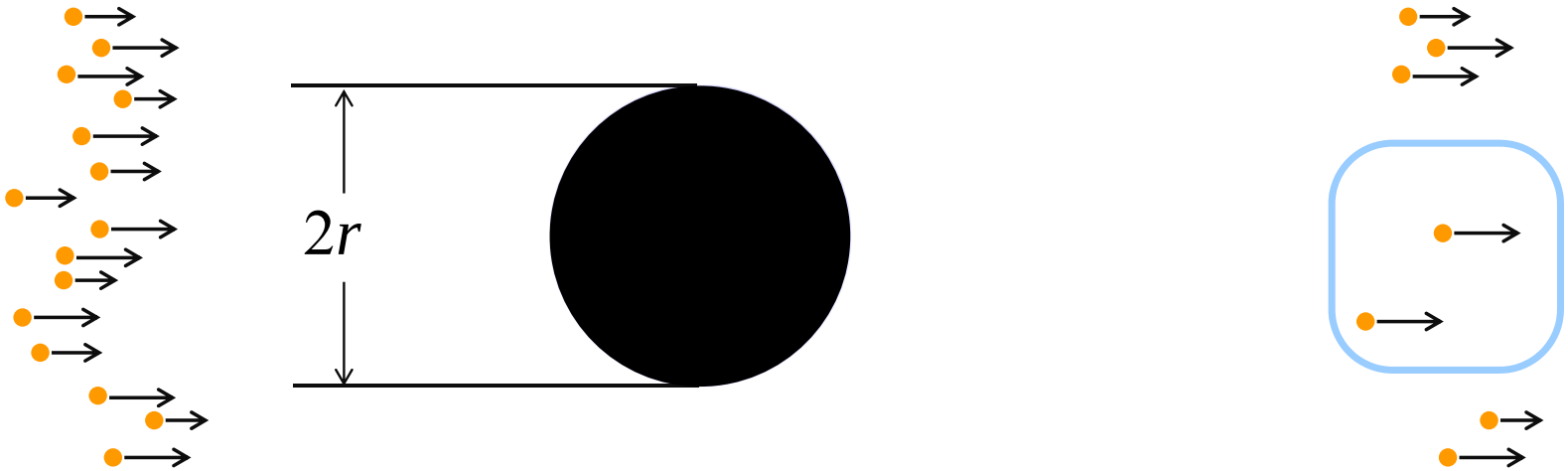
Nuclear size



$r = 1.2\ A^{1/3}$ (?)

$\rho_0 \sim 3.0 \times 10^{14}$ [g/cm^3]

The transmission method

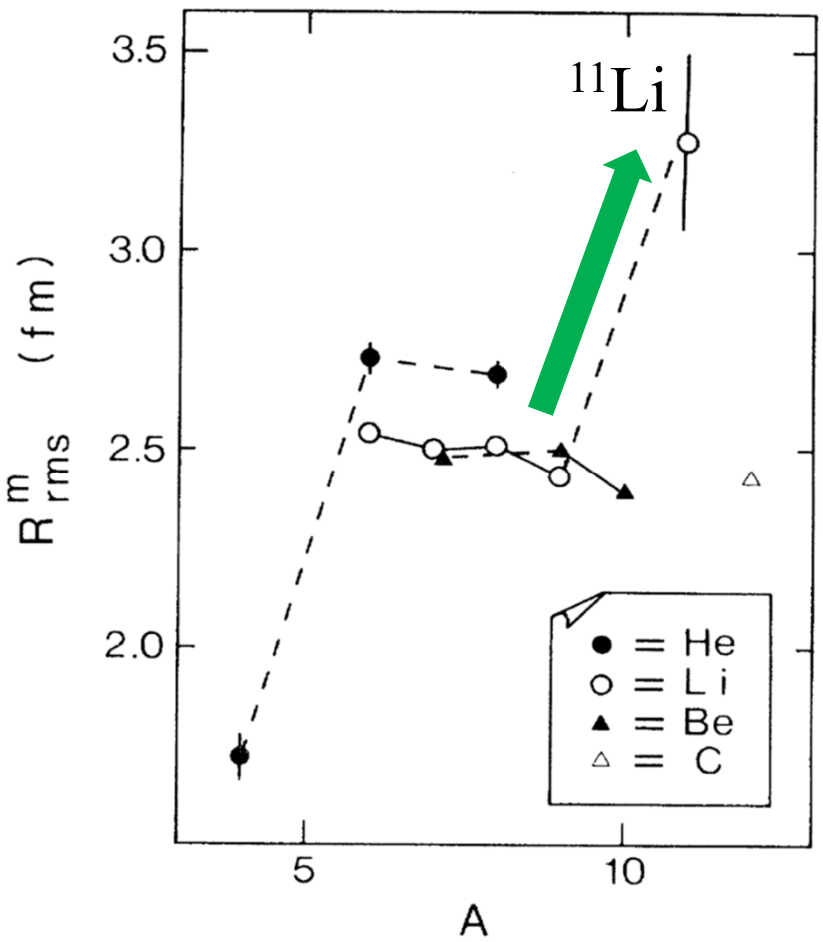


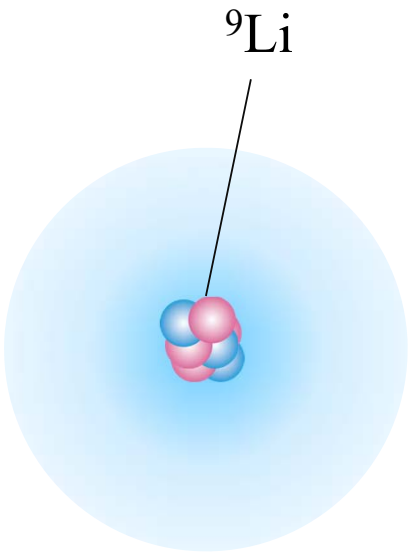
Because of the strong absorption the # of the survived incident particles represents the size (cross section) of the target nucleus.

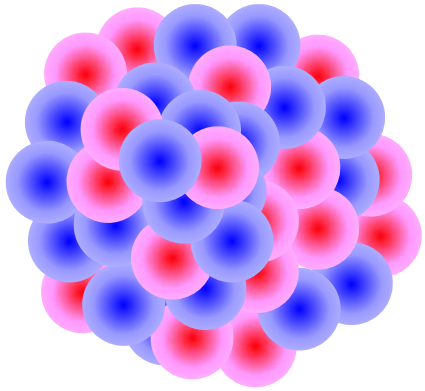
→ Total reaction cross section

Discovery of a halo nucleus

*I. Tanihata+, PRL **55**, 2676 (1985).*

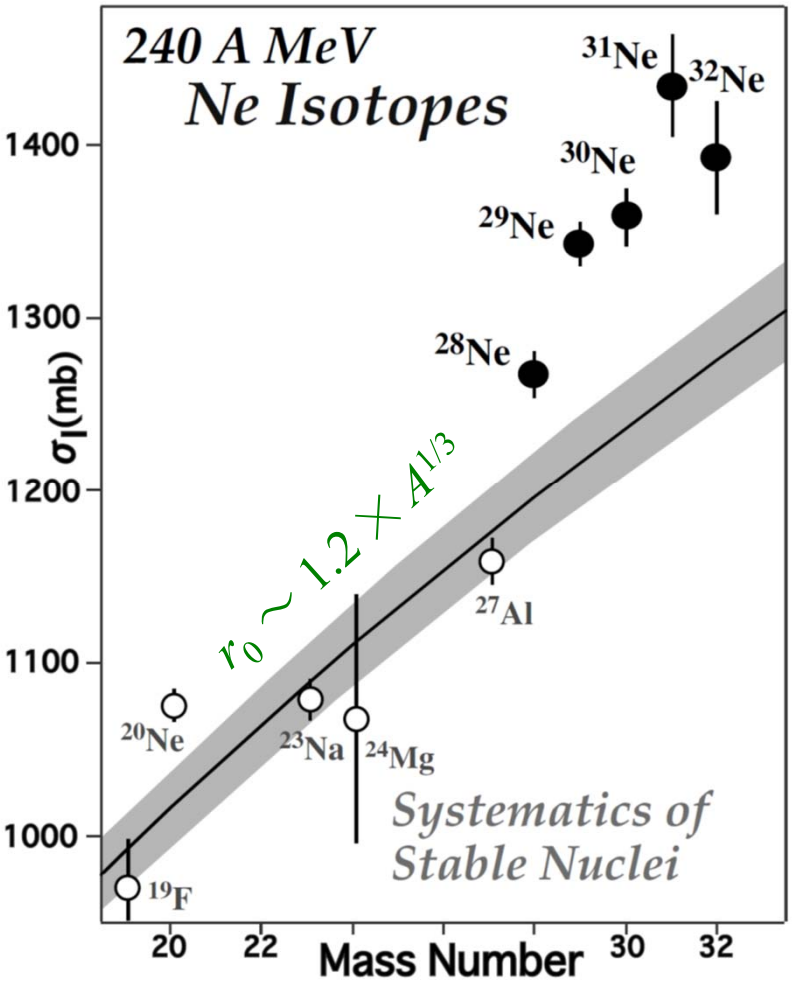






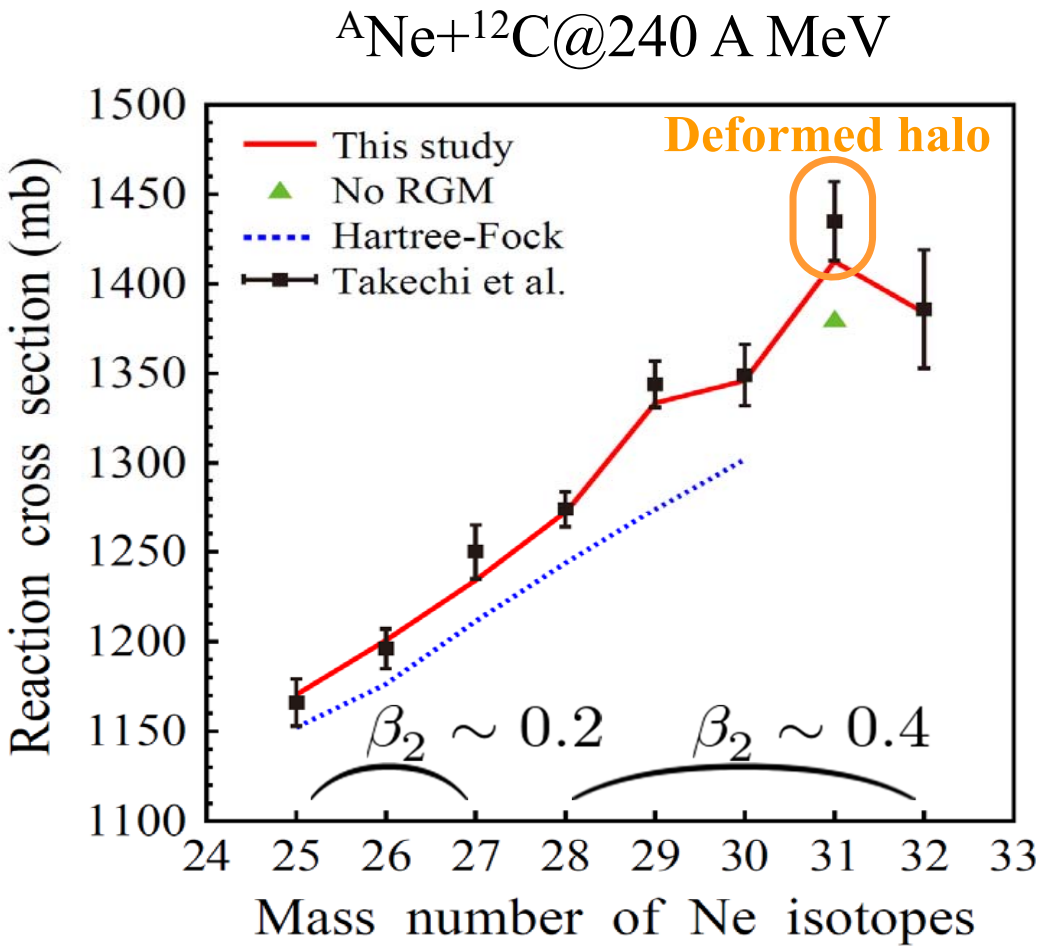
cf. Matsumoto, O, Tanaka, arXiv:1711.07209
(^{11}Li as a site of a Borromean Feshbach resonance)

Structure of neutron-rich Ne isotopes

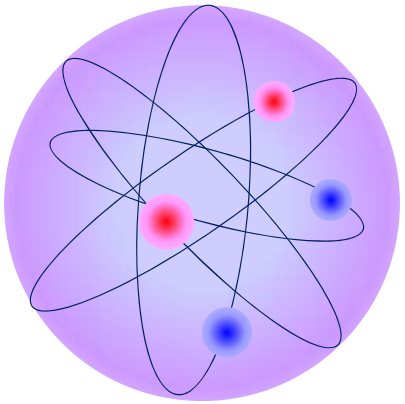


M. Takechi+, NPA**834**, 412c (2010).

K. Minomo, Sumi, Kimura, O, Shimizu, Yahiro, PRL **108**, 052503 (2012).

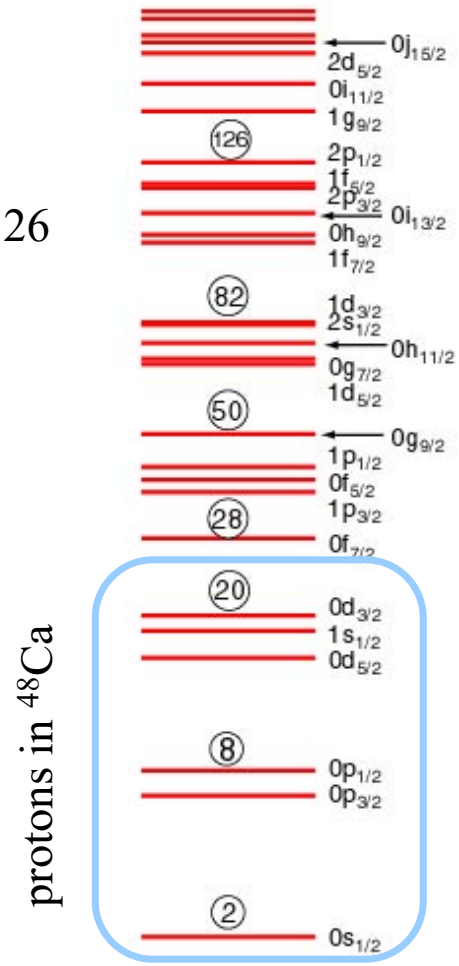


Single particle nature

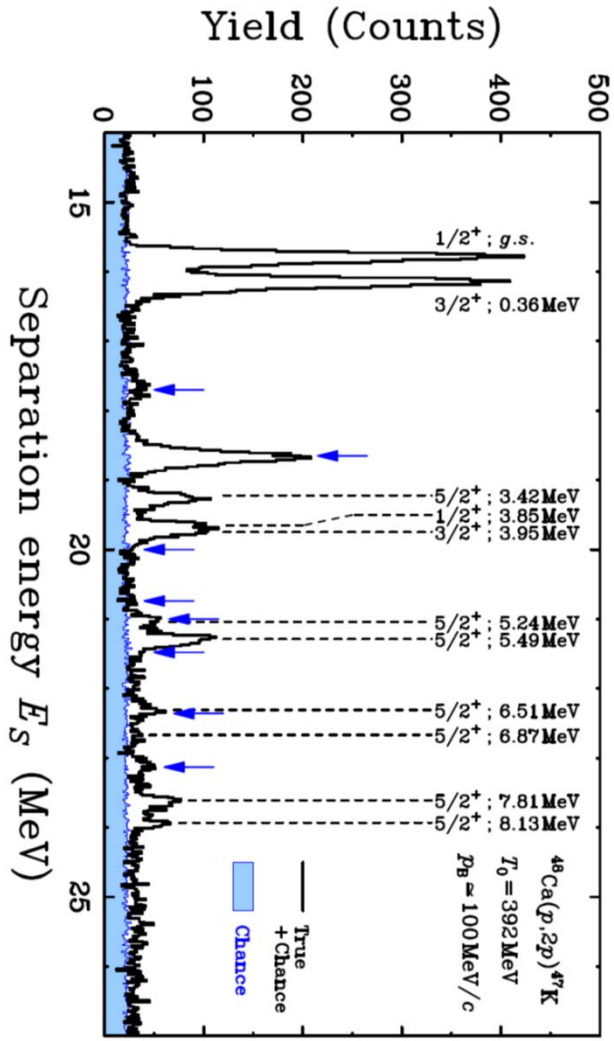


How far does the independent-particle picture hold?

Magic #
2, 8 20, 28, 50, 82, 126



(a naïve Shell Model)



T. Wakasa, KO, and T. Noro, PPNP **96**, 32 (2017).

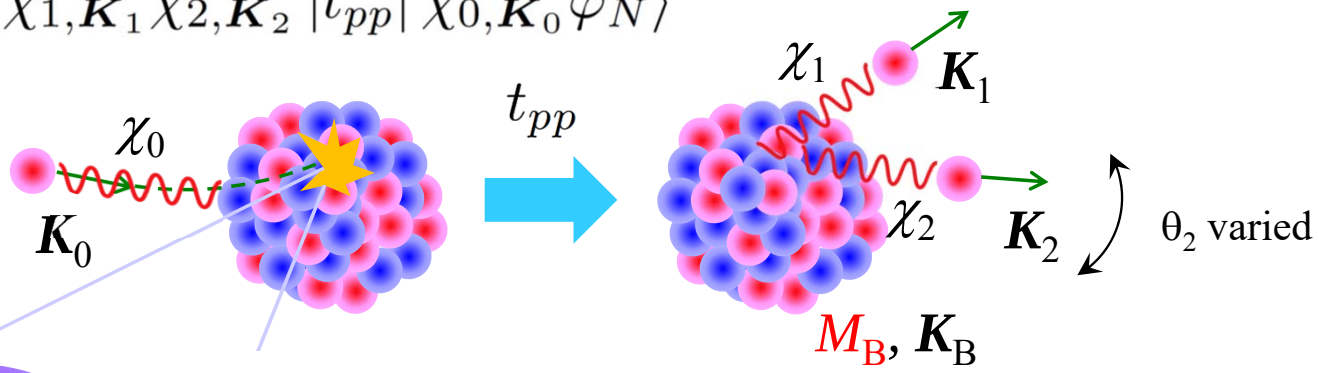
^{48}Ca(p,2p)^{47}K at 392 MeV (RCNP data)

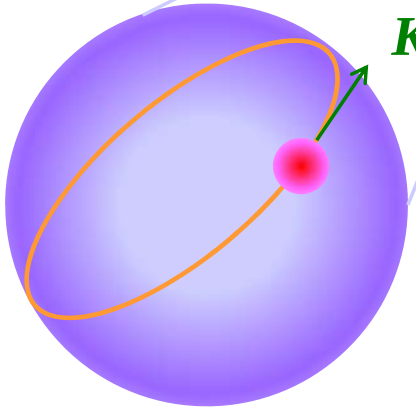
$\Delta E \sim 1/20000$

The (p,2p) reaction: a probe for s.p. structure

T. Wakasa, KO, and T. Noro, PPNP ***96****, 32 (2017).*

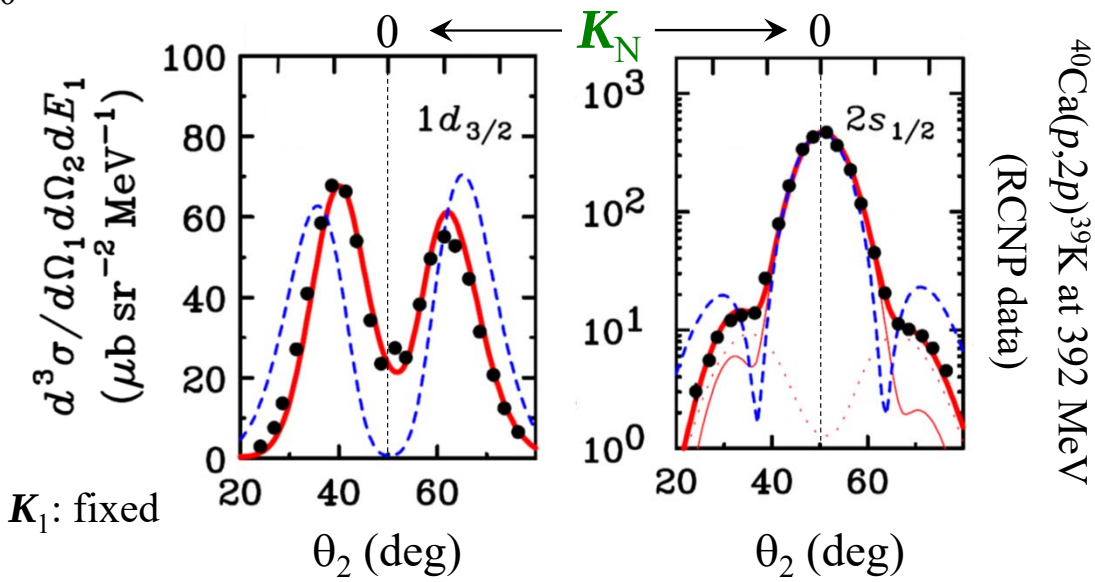
$$T = \langle \chi_{1,\boldsymbol{K}_1} \chi_{2,\boldsymbol{K}_2} | t_{pp} | \chi_{0,\boldsymbol{K}_0} \varphi_N \rangle$$





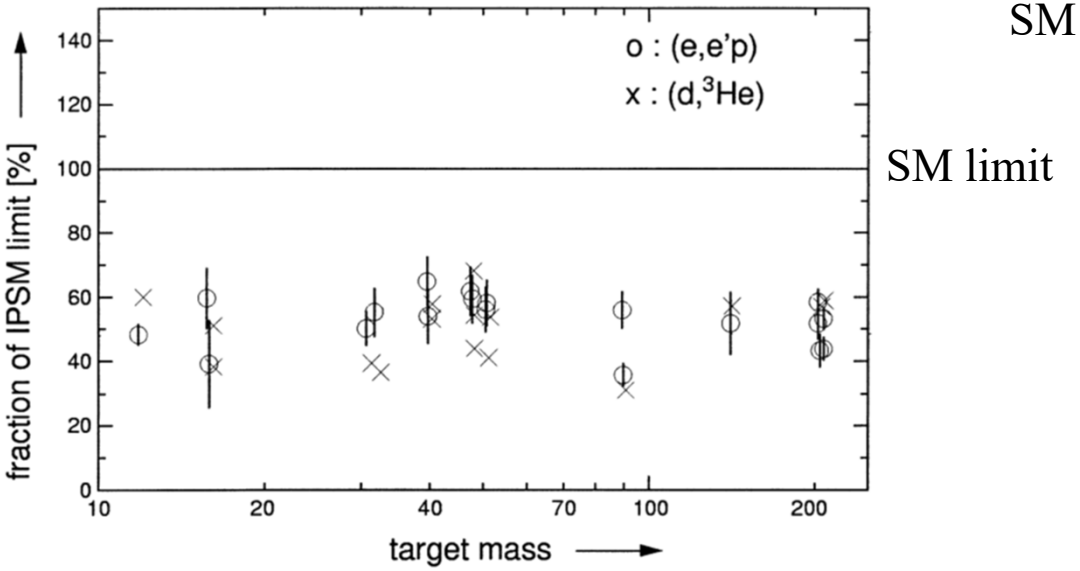
$K_N = K_1 + K_2 - K_0$

A "snapshot" of proton in a s.p. orbit in momentum space



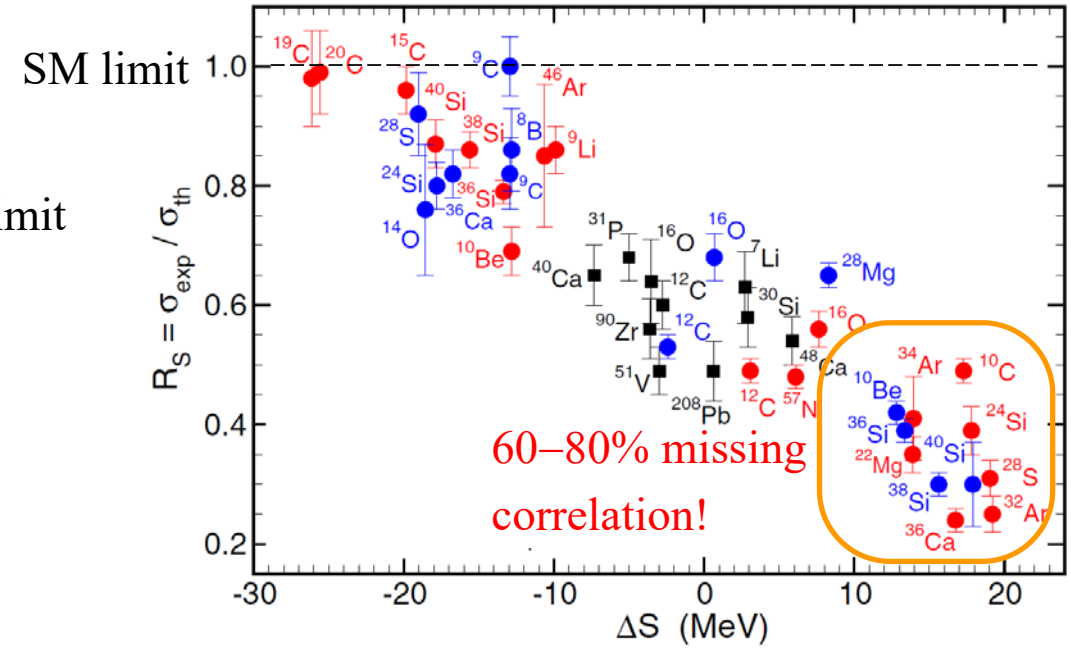
Missing correlation in the shell-model calculation

Stable nuclei



G. J. Kramer, H. P. Blok, L. Lapikas, NPA **679**, 267 (2001).

Unstable nuclei

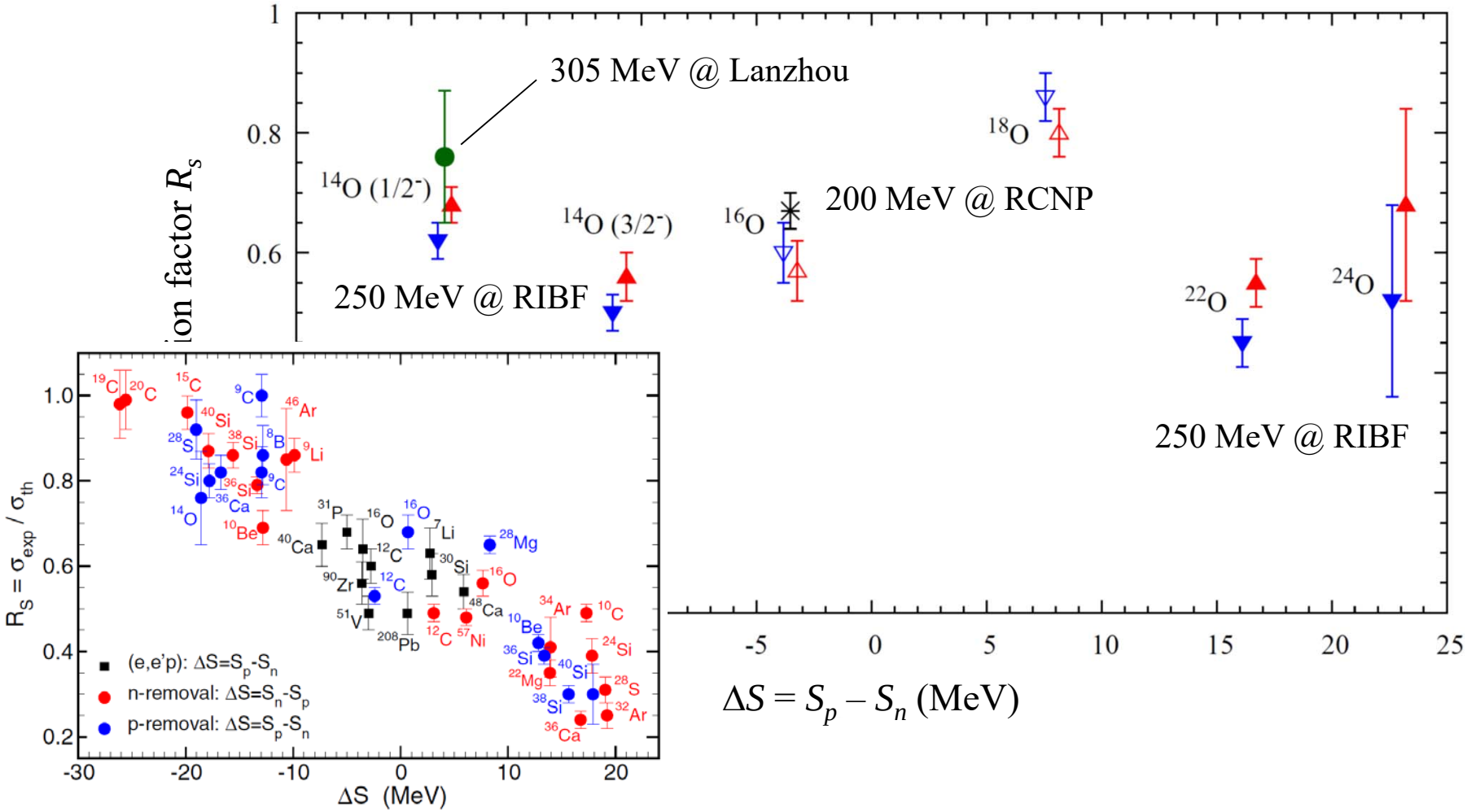


J. Tostevin and A. Gade, PRC **90**, 057602 (2014).

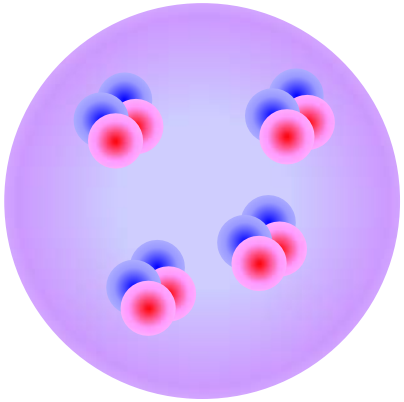
Nucleon knockout by a nucleus (not so clean)

Recent result from RIBF/RCNP

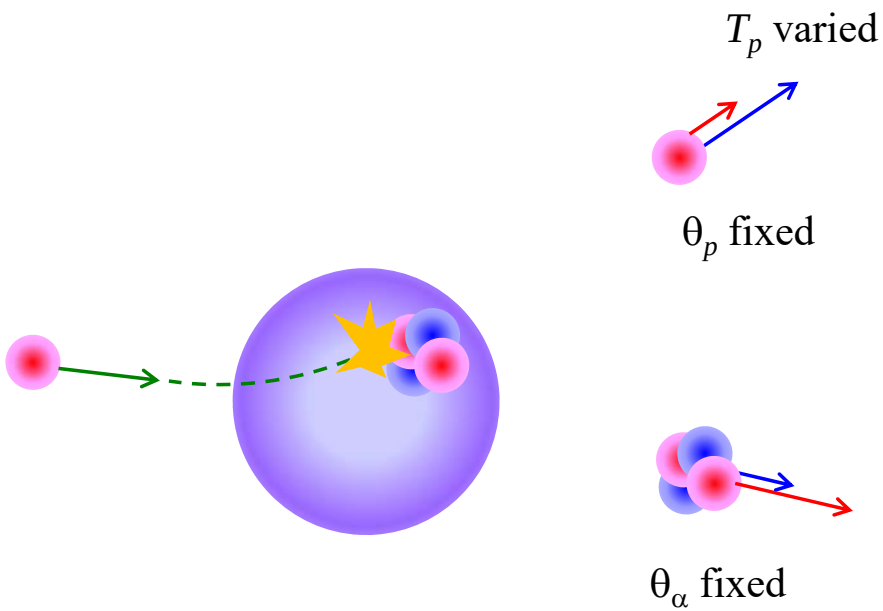
*S. Kawase+, PTEP **2018**, 021D01 (2018).*

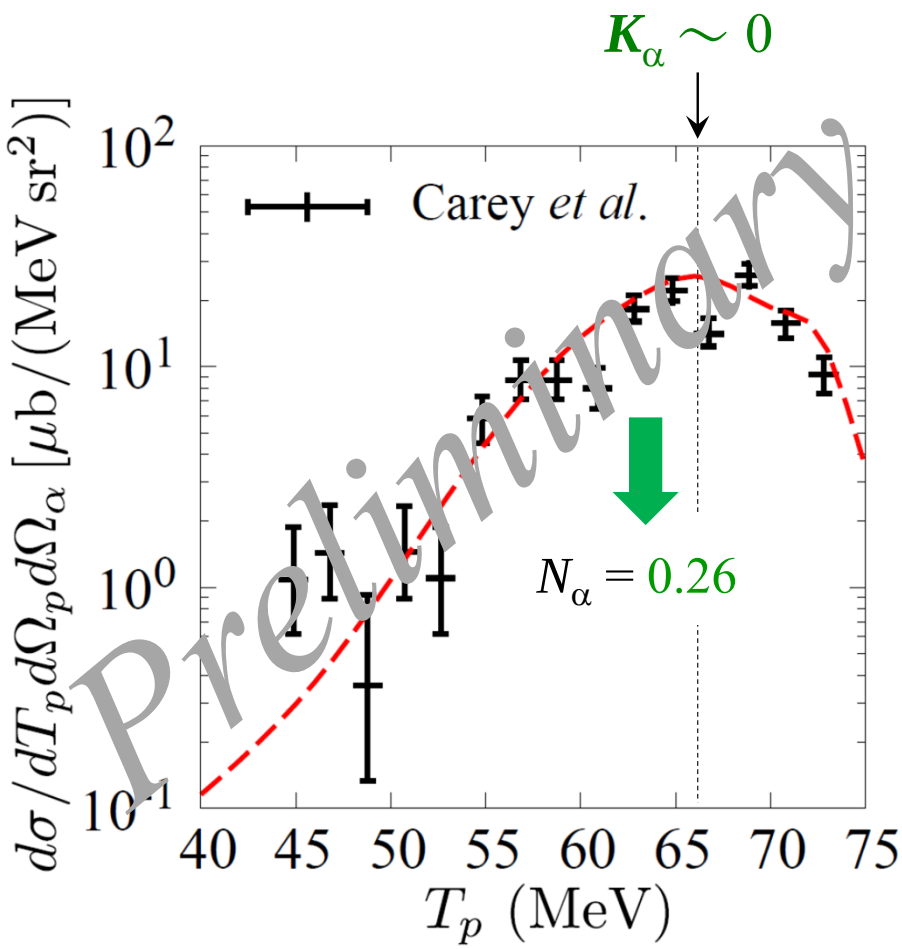


α clustering



^{20}Ne(p,pα) at 101.5 MeV

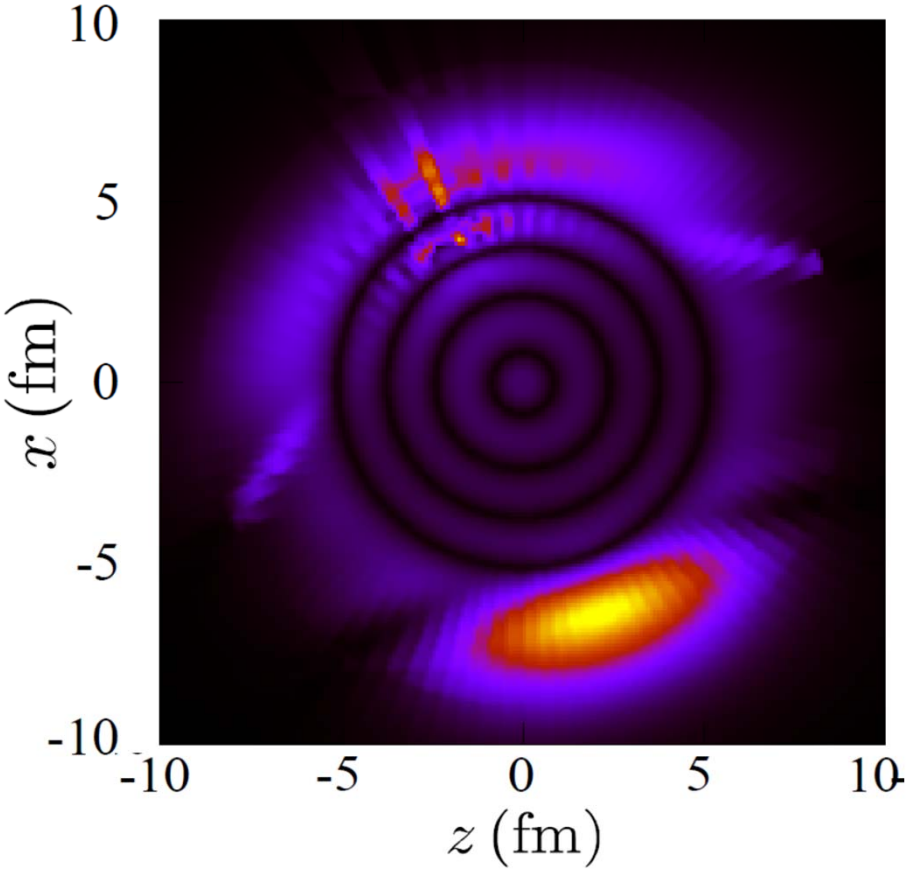


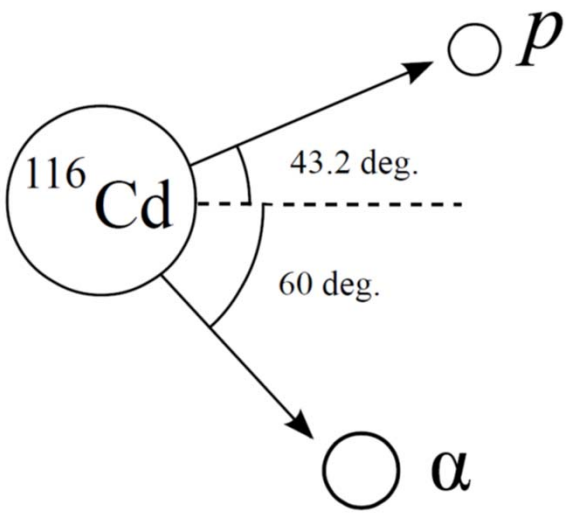


K. Yoshida, Chiba, Kimura, Taniguchi, Kanada-En'yo, O, in preparation.

^{120}Sn(p,pα)^{116}Cd

*K. Yoshida, K. Minomo, and KO, PRC **94**, 044604 (2016).*

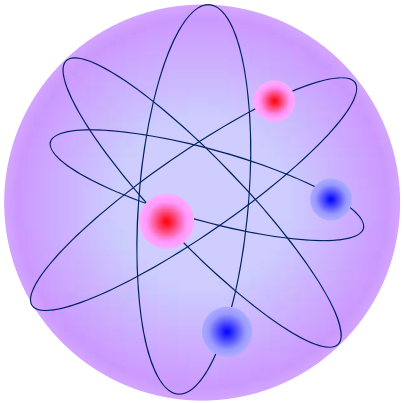


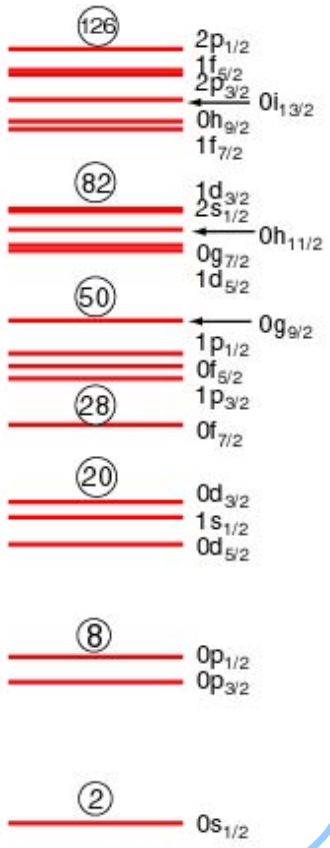


- (p,$p\alpha$) has a strong selectivity for the position of α inside a nucleus.
- Experimental data measured at RCNP will appear soon.

Instead of Summary

How much does the nuclear shell structure is robust?





How do the *NN* correlations break the shell structure?