Von Schalen, Clustern und Halos

- Neue Konzepte zur Lösung des nuklearen Vielteilchenproblems -

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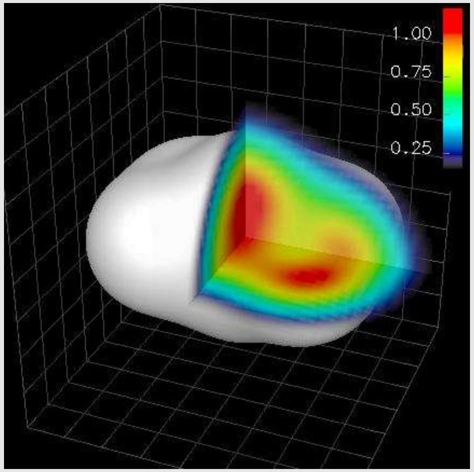
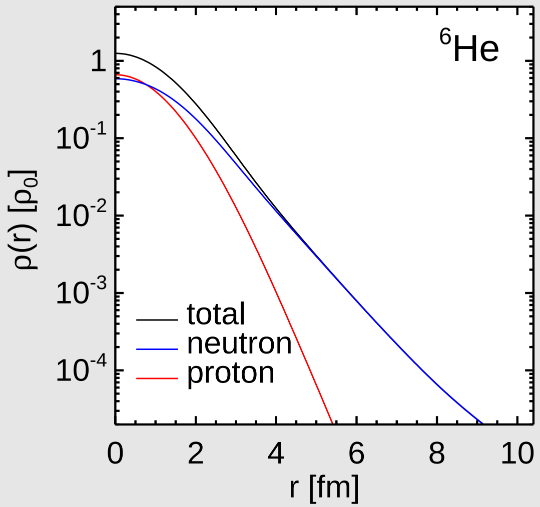


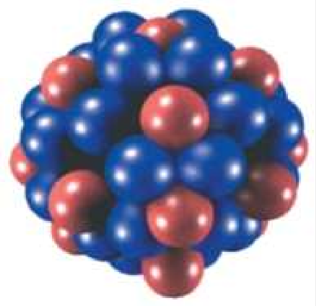


Von der QCD zur Kernstruktur

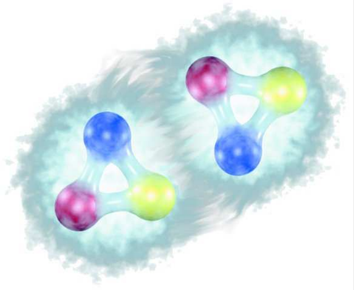
mehr Auflösung / fundamentaler

Quantum Chromo Dynamics

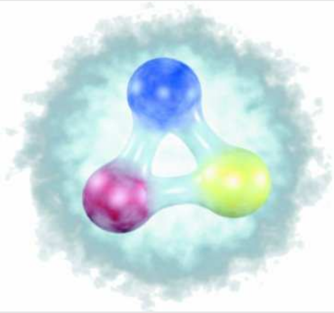
Kernstruktur



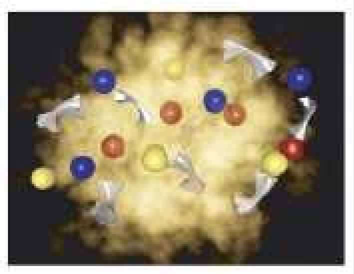
- Atomkerne



- Wenig-Nukleonen-Systeme
- Nukleon-Nukleon-Potential



- Hadronenstruktur



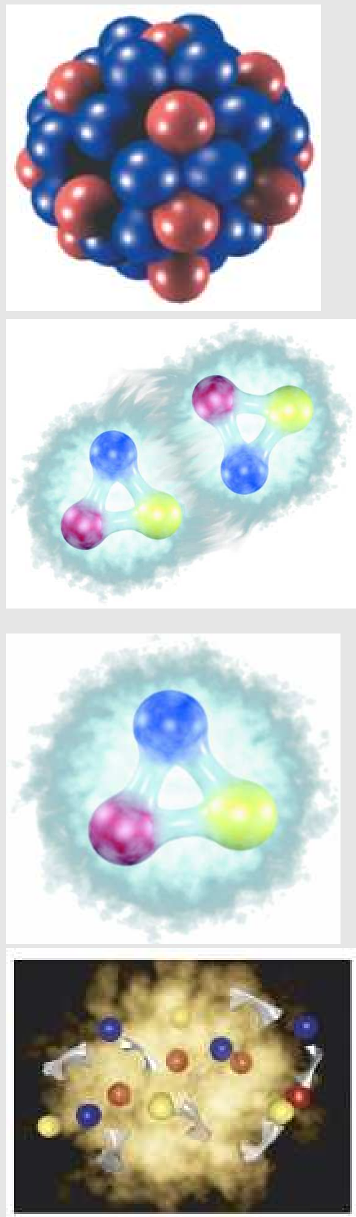
- Quarks & Gluonen
- Deconfinement

Von der QCD zur Kernstruktur

mehr Auflösung / fundamentaler

Quantum Chromo Dynamics

Kernstruktur



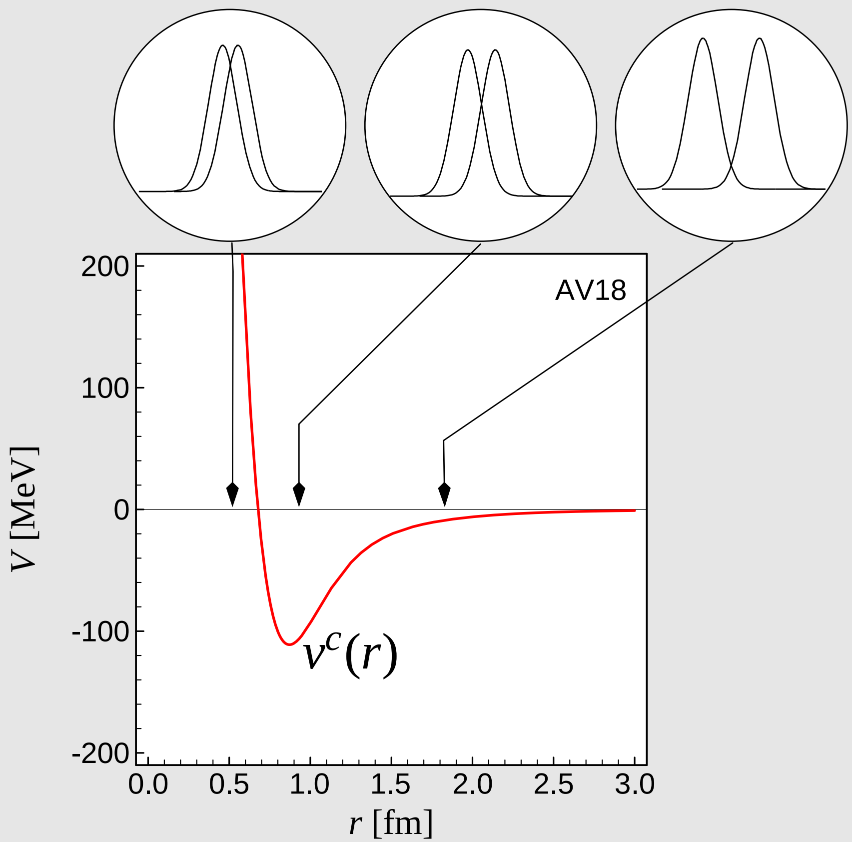
löse
das wechselwirkende nukleare Vielteilchenproblem

konstruiere
realistische Nukleon-Nukleon Wechselwirkung aus der QCD

Potential und Größe des Protons

Proton Ladungsradius $\sqrt{\langle r^2 \rangle_e} \approx 0.86)$ fm

Proton Ladungsverteilung und S=0, T=1 Potential



- Proton Durchmesser nicht klein gegen Reichweite der Wechselwirkung
- Halbdichte-Überlapp bei maximaler Anziehung, Ausläufer berühren sich noch bei mittlerem NN-Abstand in Kernmaterie
- V_{NN} nicht elementar ähnlich wie Atom-Atom-Potential
- erwartet Dreikörperkräfte

Realistic Nucleon-Nucleon Interaction

Realistic NN Potential

- describes phase shifts and deuteron properties
- central, spin-orbit, tensor, momentum dependent

$$\underset{\sim}{V}_{NN}(\mathbf{r}_{12}, \mathbf{p}_{12}, \sigma_1, \sigma_2, \tau_1, \tau_2)$$

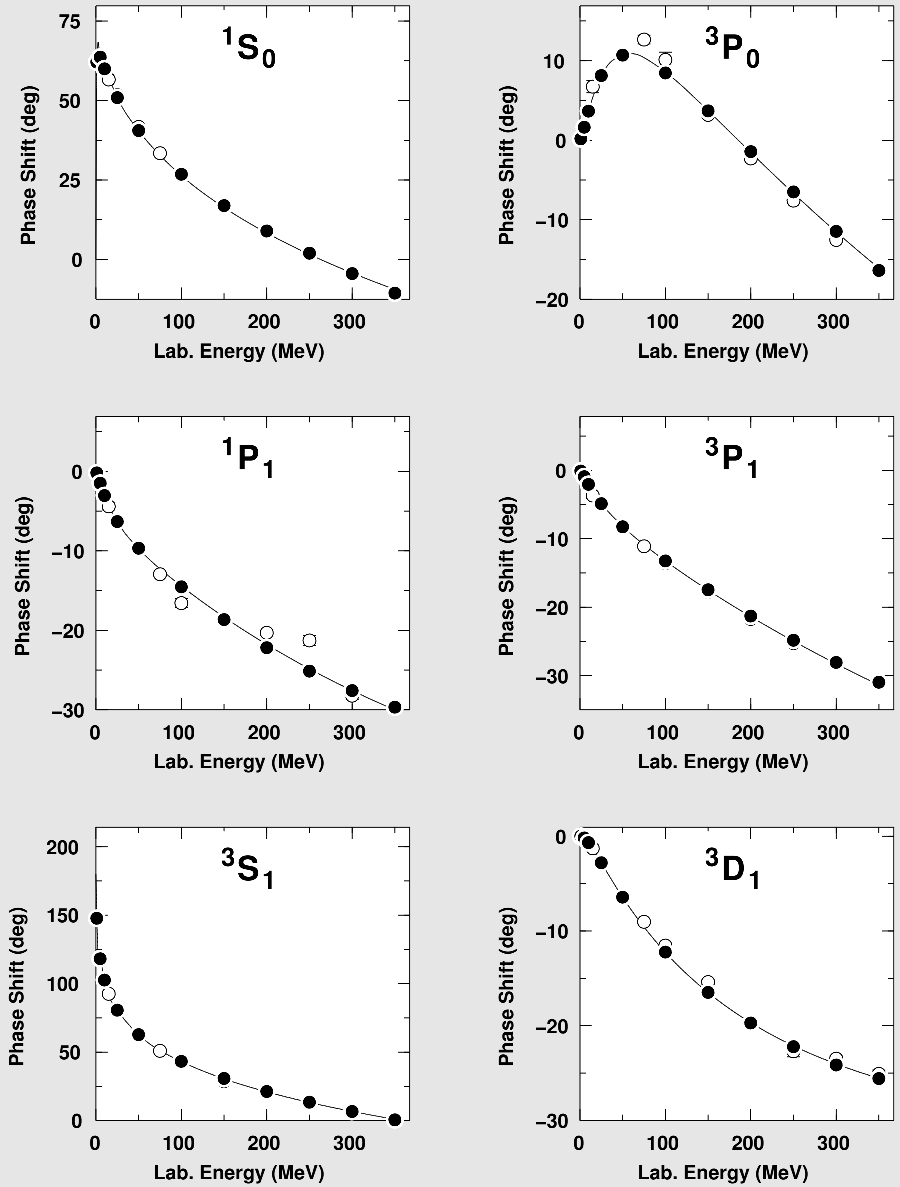
different realistic NN interactions describe scattering data

e.g.

- chiral effective field theory
  (pion exchange & contact terms)
- Bonn potential
  (pion & heavier meson exchange)
- Argonne potential
  (pion exchange & phenomenological short range terms)

NN scattering data

$^{2S+1}L_J$



Ab Initio Nuclear Structure Calculations

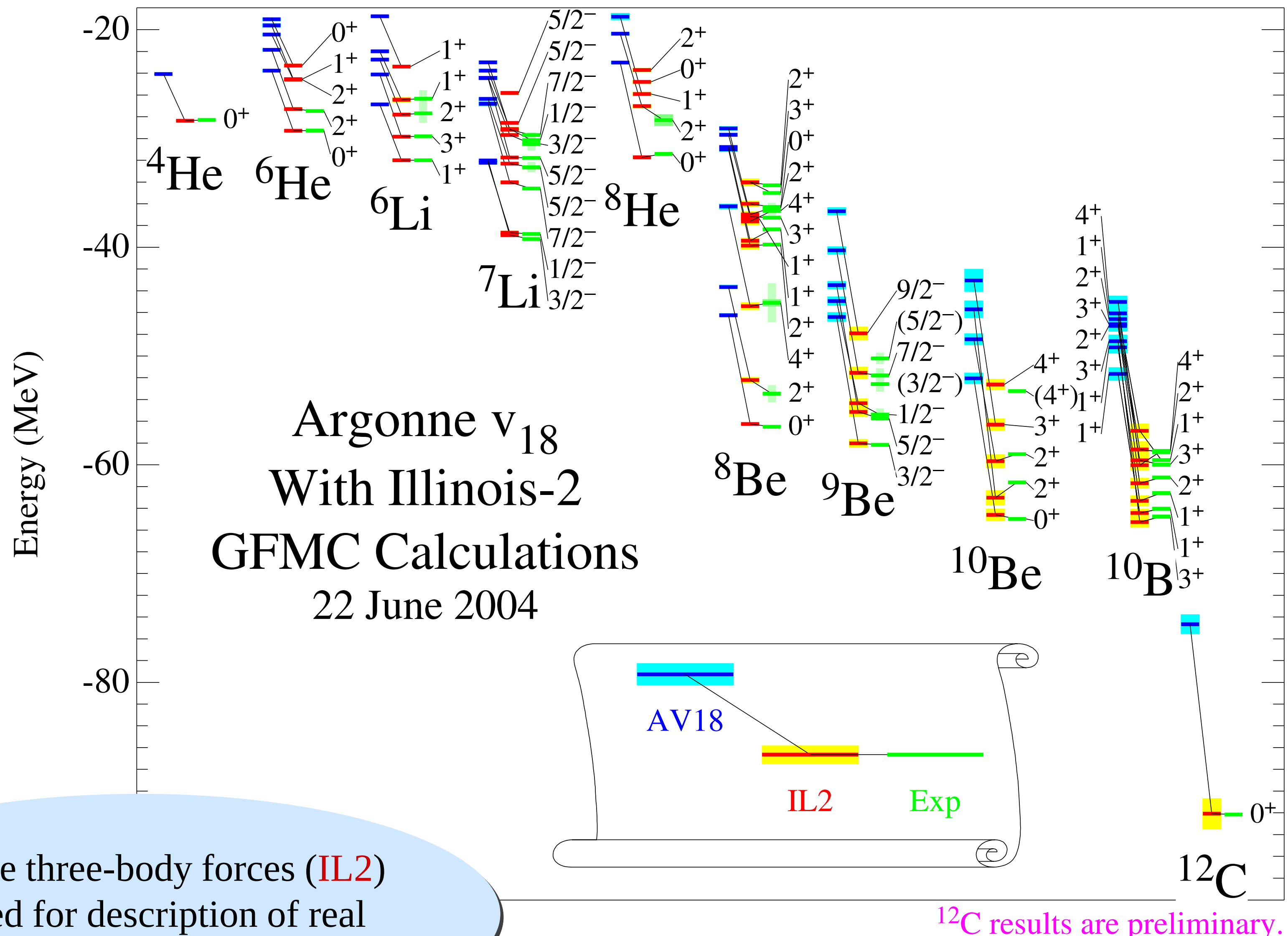
Aim

describe basic properties of nuclear many-body system
in terms of a realistic nucleon-nucleon interaction $\underset{\sim}{H}$ and a many-body state $\left|\,\hat{\Psi}\,\right\rangle$
$\left\langle\, \mathbf{r}_1, \sigma_1, \tau_1; \mathbf{r}_2, \sigma_2, \tau_2; \ldots; \mathbf{r}_A, \sigma_A, \tau_A \,\middle|\, \hat{\Psi} \,\right\rangle$

➨ solve $$\underset{\sim}{H} \left|\,\hat{\Psi}_n\,\right\rangle = E_n \left|\,\hat{\Psi}_n\,\right\rangle$$

by means of Green Function Monte Carlo Method (GFMC)

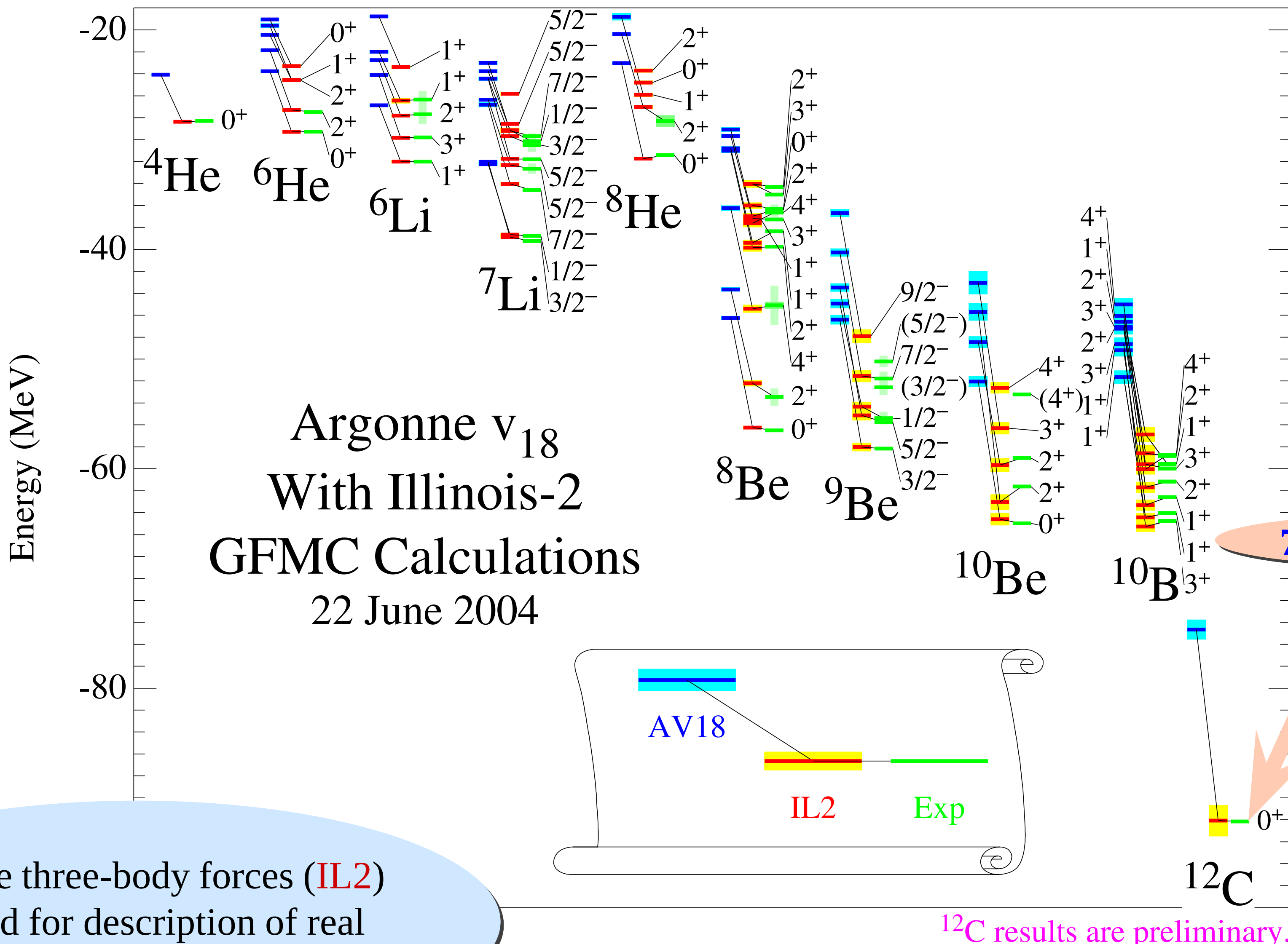
GFMC calculations (”exact” numerical solution)



genuine three-body forces (IL2) needed for description of real nuclei

Wiringa, Pieper, PRL **89** (2002) 182501

GFMC calculations (”exact” numerical solution)



75000 CPU-hours

genuine three-body forces (IL2) needed for description of real nuclei

Wiringa, Pieper, PRL **89** (2002) 182501

Ab Initio Kernstruktur

GFMC Ergebnis:

$$\left\langle \mathbf{r}_1, \sigma_1, \tau_1; \mathbf{r}_2, \sigma_2, \tau_2; \ldots; \mathbf{r}_A, \sigma_A, \tau_A \,\middle|\, \hat{\Psi}_n \right\rangle$$

ist sehr kompliziert für
realistische Nukleon-Nukleon-Potentiale.

WARUM?

Inhalt

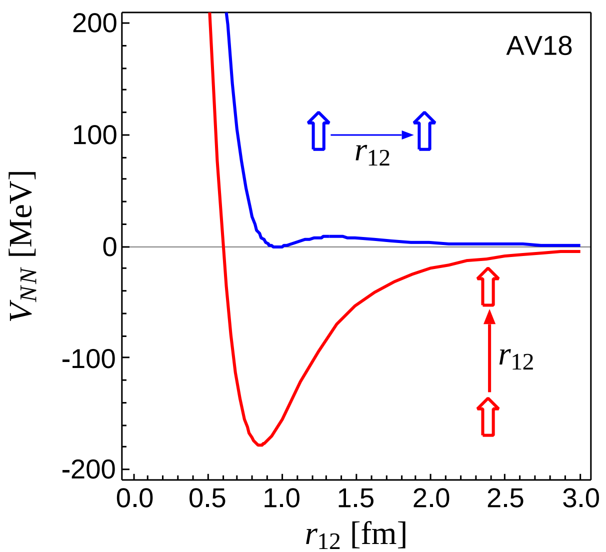
- ✔ Wo liegt das Problem?
- Unitary Correlation Operator Method
  realistischer $\longrightarrow$ korrelierter Hamiltonian
- Anwendungen:

  No-Core Schalenmodell

  Fermionische Molekular Dynamik
- Zusammenfassung und Ausblick

Realistic NN-potential

$V_{NN}(\mathbf{r}_{12}, \mathbf{p}_{12} = 0, \sigma_1, \sigma_2, T = 0)$



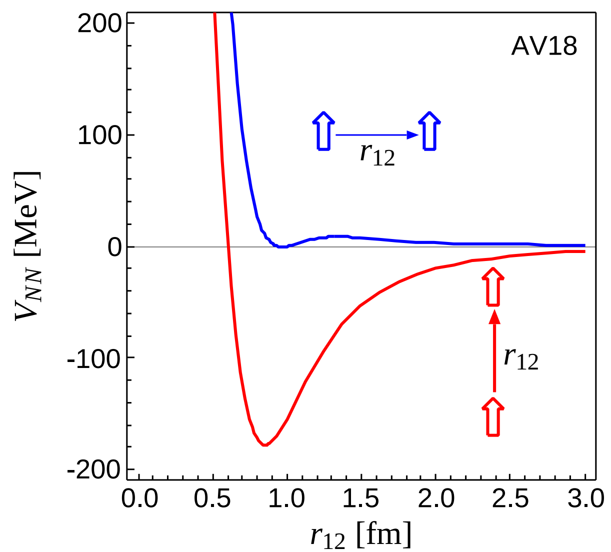
Argonne potential

- $\underset{\sim}{V}_{NN}$ repulsive at small distances
  - strong short-range central correlations
    nucleons cannot get closer than $\approx$ 0.6 fm
- $\underset{\sim}{V}_{NN}$ depends strongly on orientation of σ_1, σ_2 with respect to $\mathbf{r}_{12}$
  - tensor correlations
    protons and neutrons want to align their spins with $\mathbf{r}_{12}$

Problem:
Slater determinants cannot describe these correlations

Realistic NN-potential

$V_{NN}(\mathbf{r}_{12}, \mathbf{p}_{12} = 0, \sigma_1, \sigma_2, T = 0)$



Argonne potential

- $\underset{\sim}{V}_{NN}$ repulsive at small distances
  - ➨ strong short-range central correlations
    nucleons cannot get closer than ≈ 0.6 fm
- $\underset{\sim}{V}_{NN}$ depends strongly on orientation of σ_1, σ_2 with respect to $\mathbf{r}_{12}$
  - ➨ tensor correlations
    protons and neutrons want to align their spins with $\mathbf{r}_{12}$

Problem:
Slater determinants cannot describe these correlations

Solution: include short-range correlations by unitary transformation (UCOM)

$$\left|\hat{\Psi}\right\rangle = \underset{\sim}{C}\left|\Psi\right\rangle = \underset{\sim}{C}_{\Omega}\,\underset{\sim}{C}_{r}\left|\Psi\right\rangle$$

- $\underset{\sim}{C}_r$ central correlator shifts nucleons out of repulsive core
- $\underset{\sim}{C}_\Omega$ tensor correlator aligns spins along $\mathbf{r}_{12}$

Unitary Correlation Operator Method (UCOM)

Correlation Operator

introduce short-range correlations by means of a unitary transformation with respect to the relative coordinates of all pairs

$$\underset{\sim}{C} = \exp[-i\,\underset{\sim}{G}] = \exp\Big[-i \sum_{i<j} \underset{\sim}{g}_{ij}\Big] \qquad (1)$$

$$\underset{\sim}{G}^\dagger = \underset{\sim}{G}$$

$$\underset{\sim}{C}^\dagger \underset{\sim}{C} = 1$$

Correlated States

$$|\hat{\Psi}\rangle = \underset{\sim}{C}\,|\Psi\rangle$$

Correlated Operators

$$\hat{\underset{\sim}{O}} = \underset{\sim}{C}^{-1}\ \underset{\sim}{O}\ \underset{\sim}{C}$$

$$\langle \hat{\Psi} | \underset{\sim}{O} | \hat{\Psi}' \rangle = \langle \Psi | \underset{\sim}{C}^{-1}\, \underset{\sim}{O}\, \underset{\sim}{C} | \Psi' \rangle = \langle \Psi | \hat{\underset{\sim}{O}} | \Psi' \rangle$$

Central and Tensor Correlators

$$\underset{\sim}{C} = \underset{\sim}{C}_\Omega \, \underset{\sim}{C}_r$$

Central Correlator $\underset{\sim}{C}_r$

- radial distance-dependent shift in the relative coordinate of a nucleon pair

$$\underset{\sim}{g}_r = \frac{1}{2}[s(\underset{\sim}{r})\,\underset{\sim}{q}_r + \underset{\sim}{q}_r\,s(\underset{\sim}{r})]$$

$$\underset{\sim}{q}_r = \frac{1}{2}[\frac{\underset{\sim}{\mathbf{r}}}{\underset{\sim}{r}} \cdot \underset{\sim}{\mathbf{q}} + \underset{\sim}{\mathbf{q}} \cdot \frac{\underset{\sim}{\mathbf{r}}}{\underset{\sim}{r}}]$$

Tensor Correlator $\underset{\sim}{C}_\Omega$

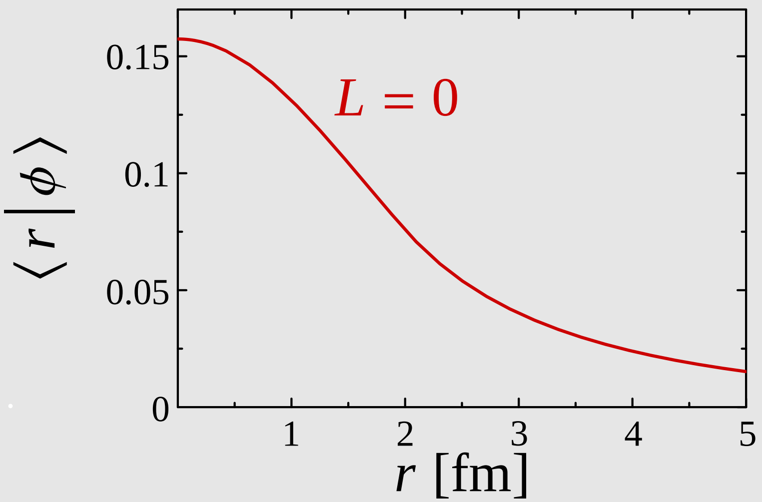
- angular shift depending on the orientation of spin and relative coordinate of a nucleon pair

$$\underset{\sim}{g}_\Omega = \frac{3}{2}\vartheta(\underset{\sim}{r})[(\underset{\sim}{\sigma}_1 \cdot \underset{\sim}{\mathbf{q}}_\Omega)(\underset{\sim}{\sigma}_2 \cdot \underset{\sim}{\mathbf{r}}) + (\underset{\sim}{\mathbf{r}} \leftrightarrow \underset{\sim}{\mathbf{q}}_\Omega)]$$

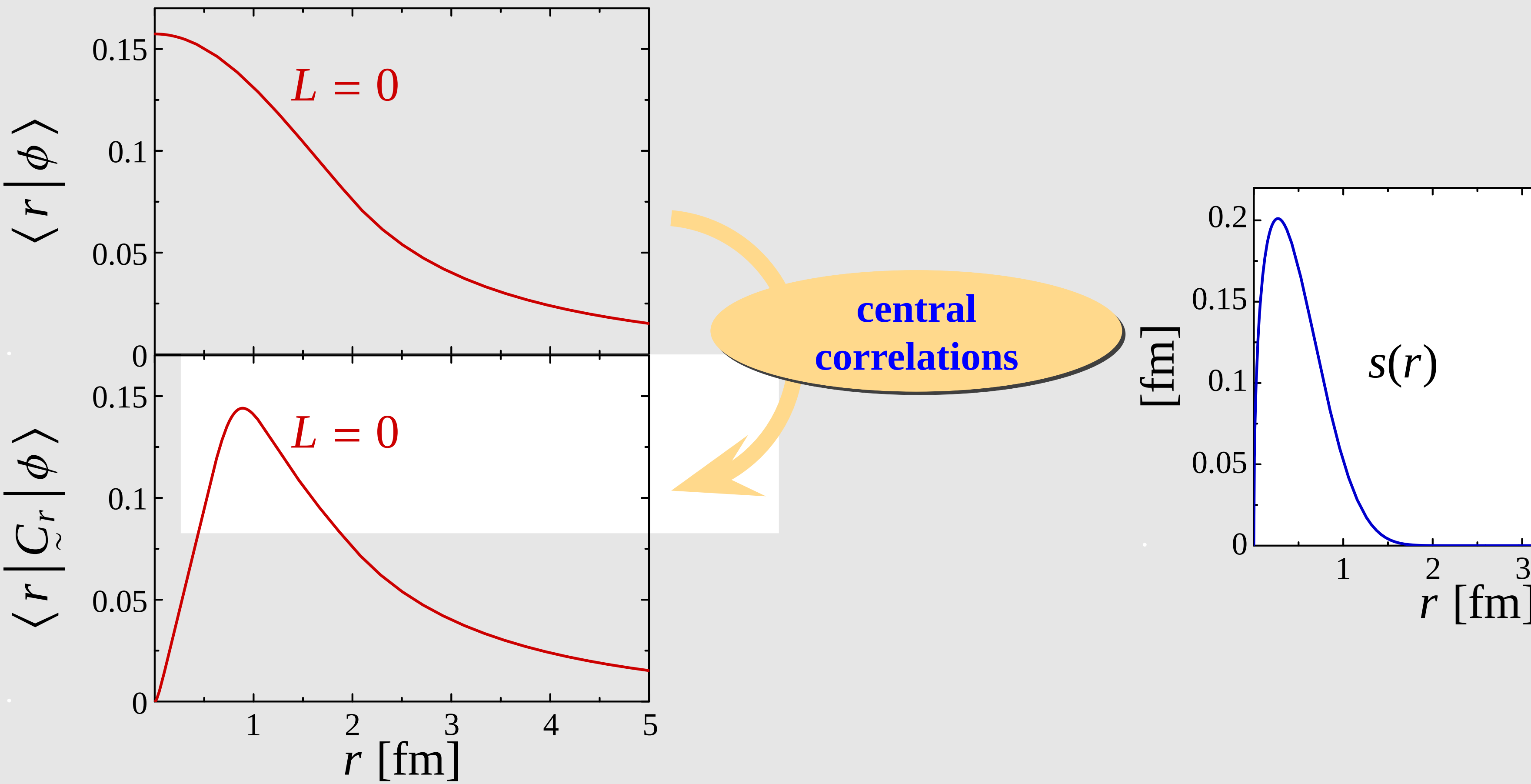
$$\underset{\sim}{\mathbf{q}}_\Omega = \underset{\sim}{\mathbf{q}} - \frac{\underset{\sim}{\mathbf{r}}}{\underset{\sim}{r}}\,\underset{\sim}{q}_r$$

$s(r)$ and $\vartheta(r)$
for given potential determined
in the two-body system

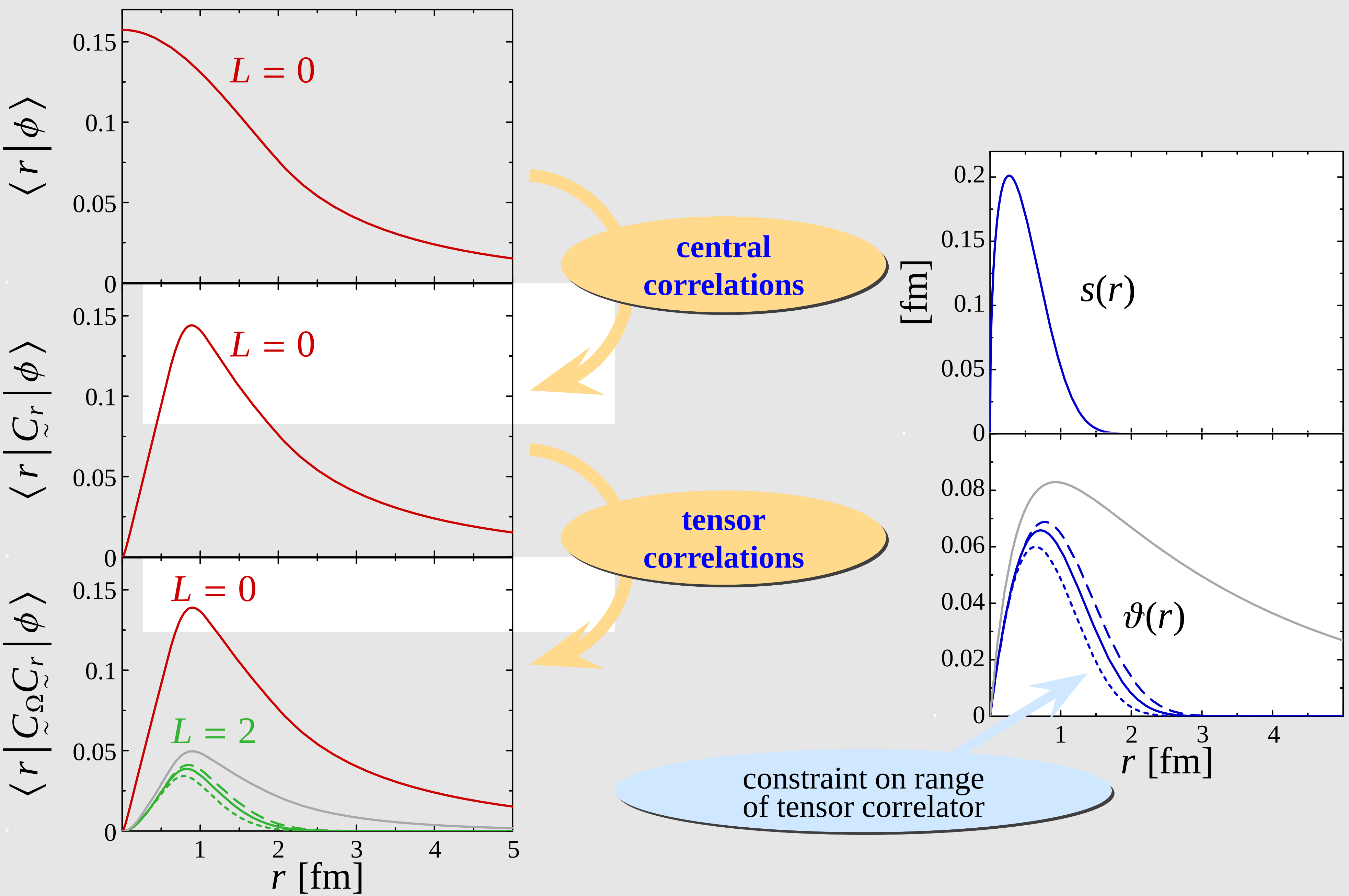
Correlated States: The Deuteron



Correlated States: The Deuteron

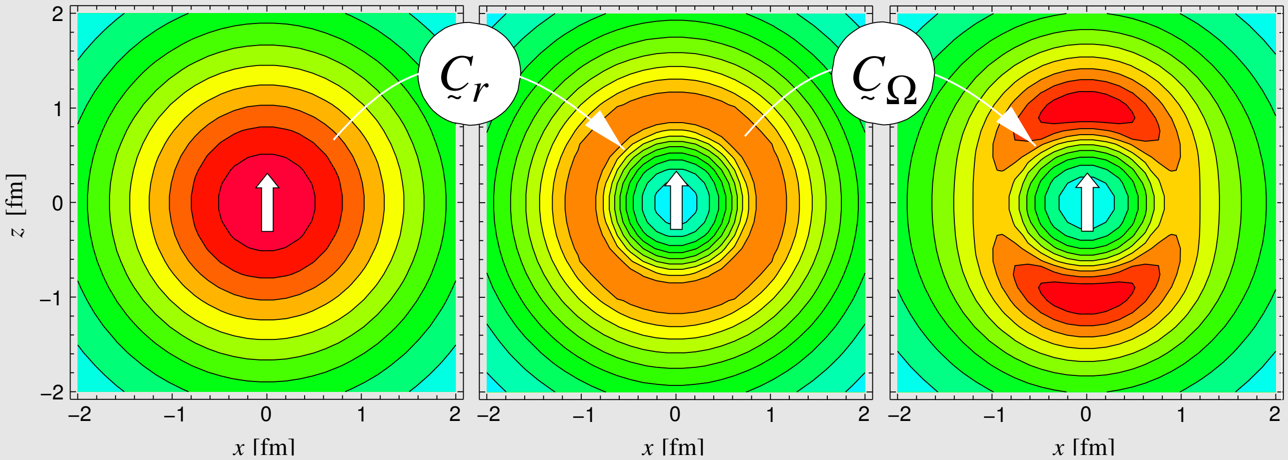


Correlated States: The Deuteron



Correlations in Nuclei

two-body densities

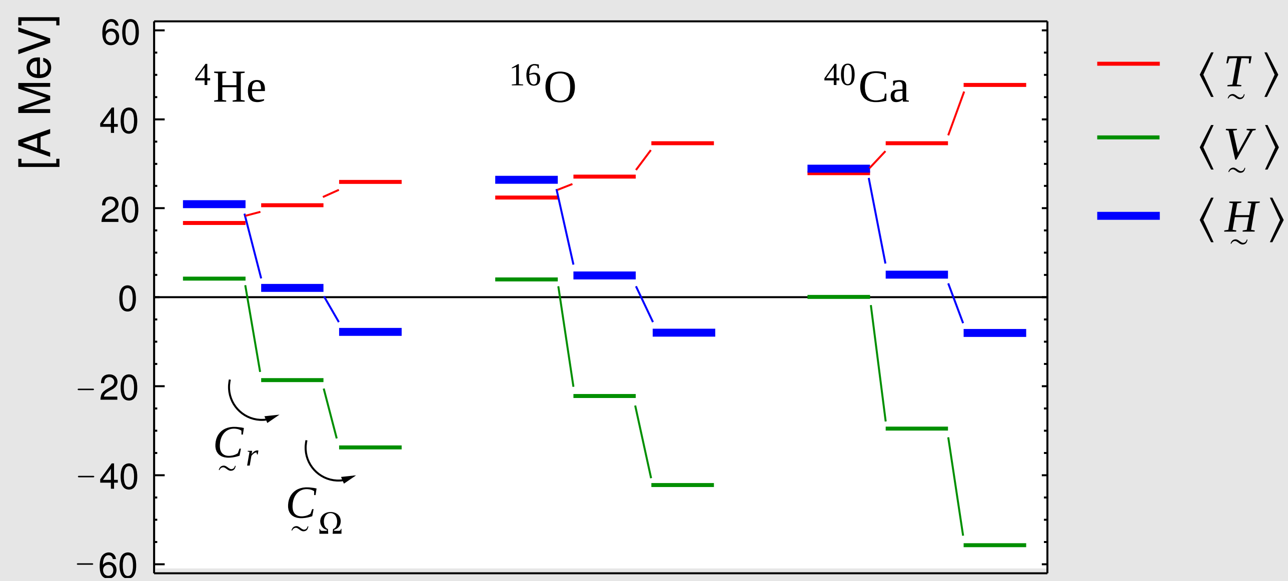


$$\rho^{(2)}_{S,T}(\mathbf{r}_1 - \mathbf{r}_2) \quad S = 1, M_S = 1, T = 0$$

- radial correlator shifts density out of the repulsive core
- tensor correlator aligns density with spin orientation

- both radial and tensor correlations are essential for binding

energies



Correlated Interaction – V_{UCOM}

$$\underset{\sim}{\hat{H}} = \underset{\sim}{T} + \underset{\sim}{V}_{\mathrm{UCOM}} + \underset{\sim}{V}^{[3]}_{\mathrm{UCOM}} + \cdots$$

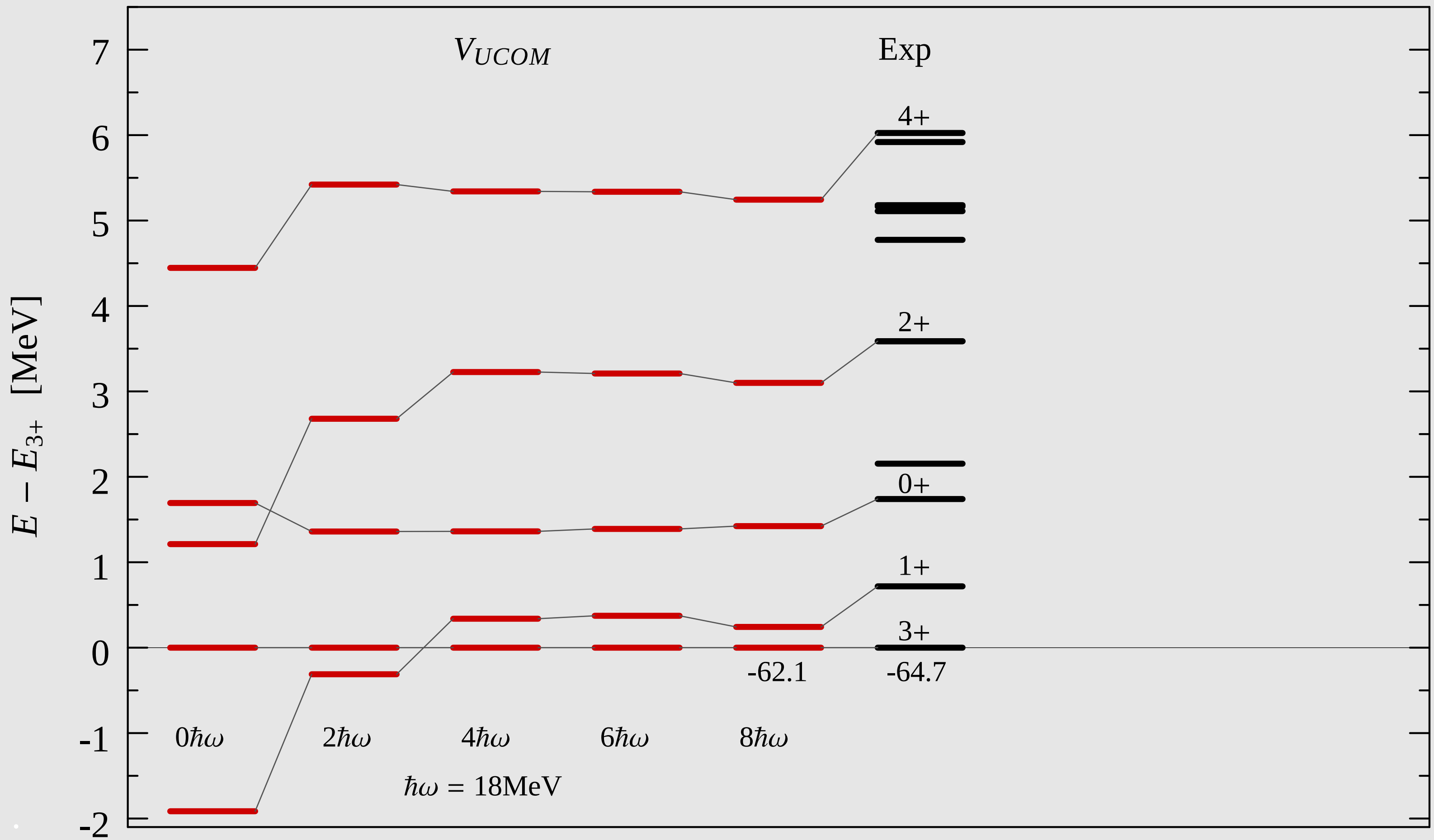
- **closed operator expression** for the correlated interaction $\underset{\sim}{V}_{\mathrm{UCOM}}$ in two-body approximation
- correlated interaction and original NN-potential are **phase shift equivalent** by construction
- unitary transformation results in a **pre-diagonalisation** of Hamiltonian

Anwendung 1

No-Core Shell Model

Benchmarking V_{UCOM} for ^{10}B:

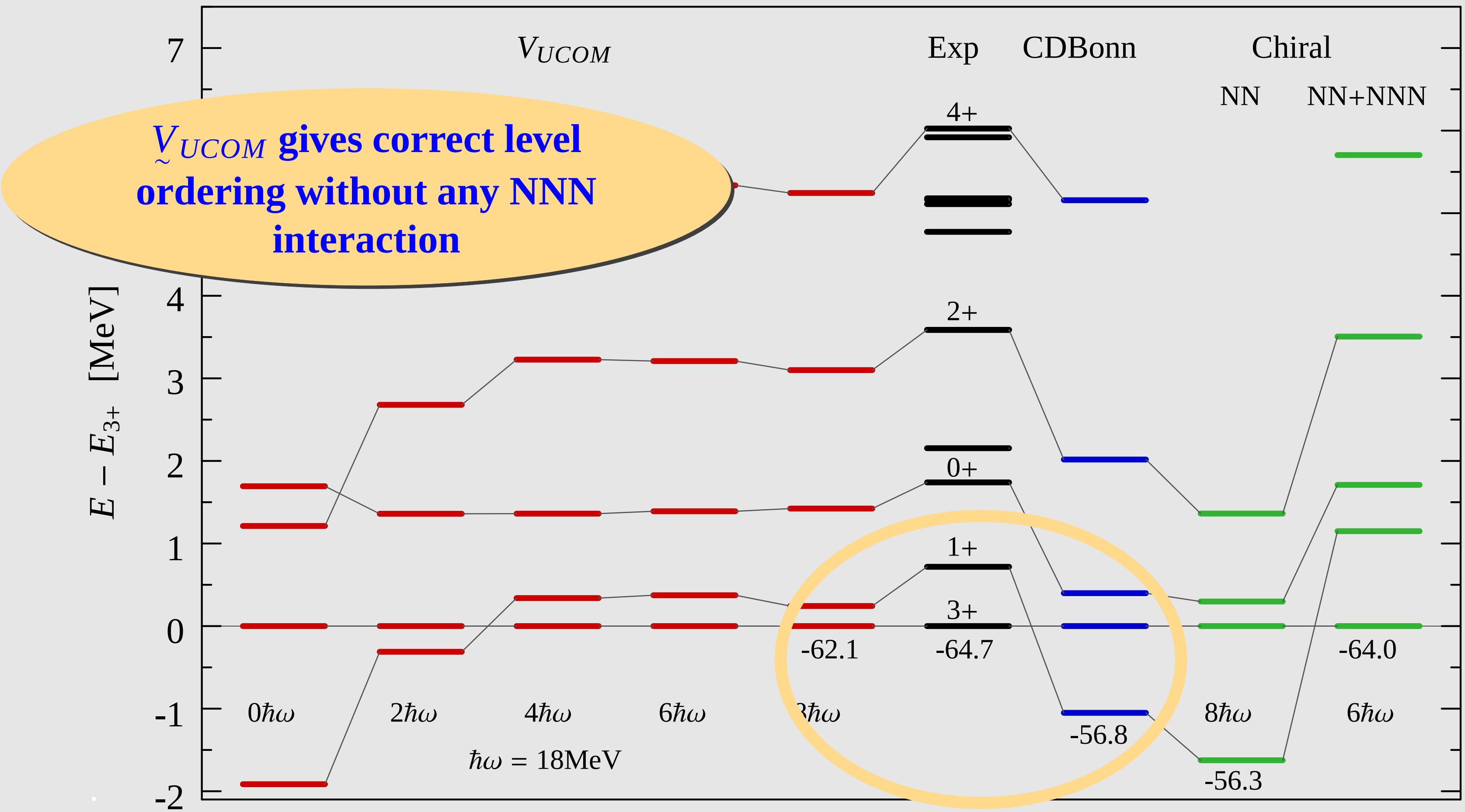
- large-scale NCSM calculations troughout the p-shell in progress



calculations by Petr Navrátil – preliminary

Benchmarking V_{UCOM} for ^{10}B:

- large-scale NCSM calculations troughout the p-shell in progress



calculations by Petr Navrátil – preliminary

Anwendung 2

Fermionic Molecular Dynamics

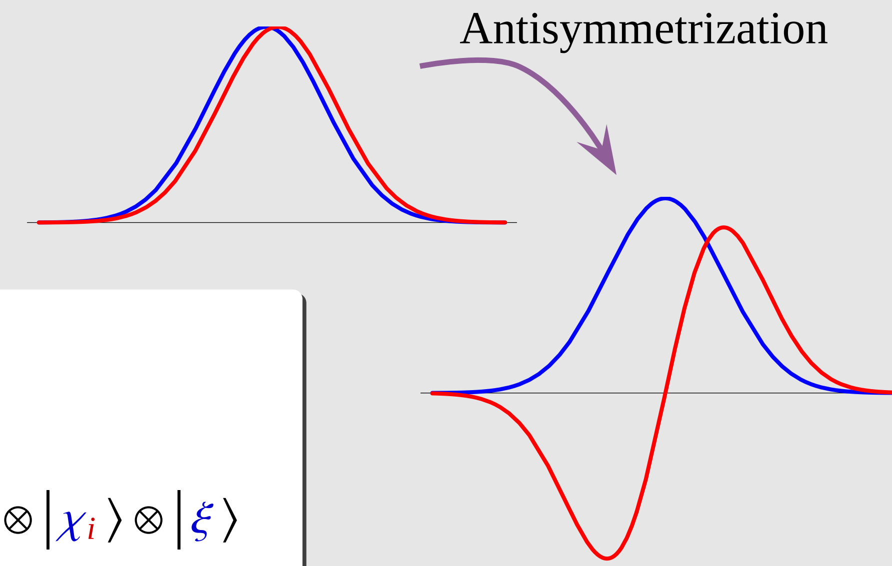
Hilbert Space: Fermionic Molecular Dynamics

Fermionic

Slater determinant

$$\left| Q \right\rangle = \underset{\sim}{\mathcal{A}}\Big(\left| q_1 \right\rangle \otimes \cdots \otimes \left| q_A \right\rangle \Big)$$

➨ antisymmetrized A-body state



Molecular

single-particle states

$$\langle \mathbf{x} | q \rangle = \sum_i c_i \exp\left\{ -\frac{(\mathbf{x} - \mathbf{b}_i)^2}{2a_i} \right\} \otimes \left| \chi_i \right\rangle \otimes \left| \xi \right\rangle$$

➨ Gaussian wave-packets in phase-space,
spin is free, isospin is fixed

➨ Hilbert space contains
shell-model, clusters, halos

Dynamics in Hilbert space

spanned by one or several non-orthogonal $\left| Q^{(a)} \right\rangle$

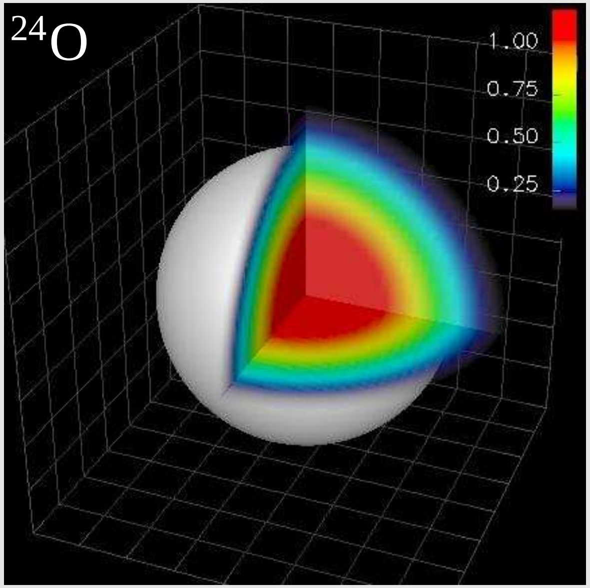
$$\left| \Psi \right\rangle = \sum_a \psi_a \left| Q^{(a)} \right\rangle$$

variational principle $\rightarrow$ $Q^{(a)} = \{ q_\nu^{(a)}, \nu = 1 \cdots A \},\ \psi_a$

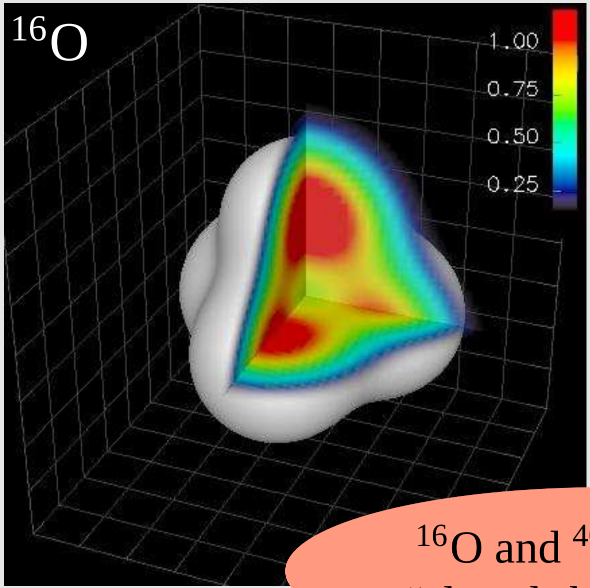
Effective Correction to the Interaction

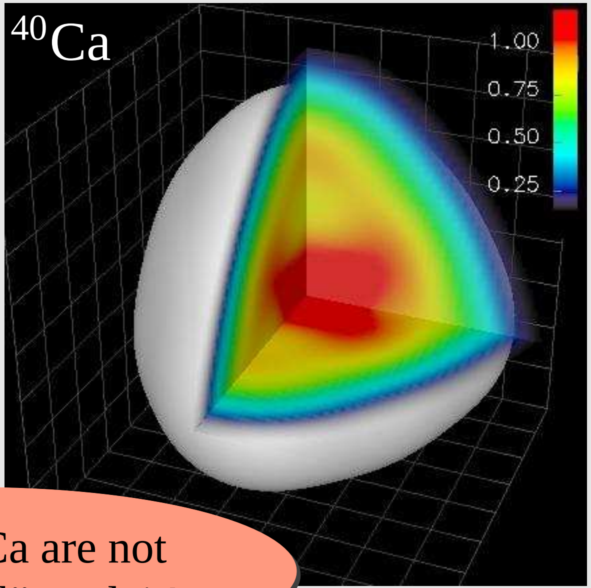
Effective two-body interaction

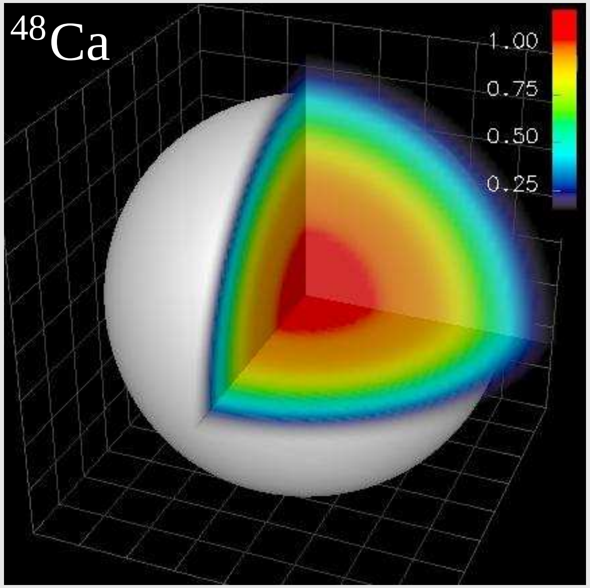
- correlated two-body interaction $\underset{\sim}{\hat{H}} = \underset{\sim}{C}^{\dagger}\, \underset{\sim}{H}\, \underset{\sim}{C}$ is lacking three-body forces
- instead of three-body force use additional momentum-dependent and spin-orbit two-body correction term
- fit correction term to binding energies and radii of "closed-shell" nuclei
- altogether a **15%** correction to the *ab-initio* two-body potential



$\rho^{(1)}(\mathbf{r})\ [\rho_0]$



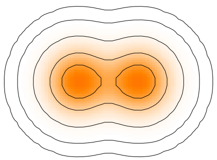




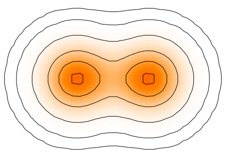
^{16}O and ^{40}Ca are not "closed shell" nuclei !

FMD - Projection, Variation after Proj., Multiconfiguration

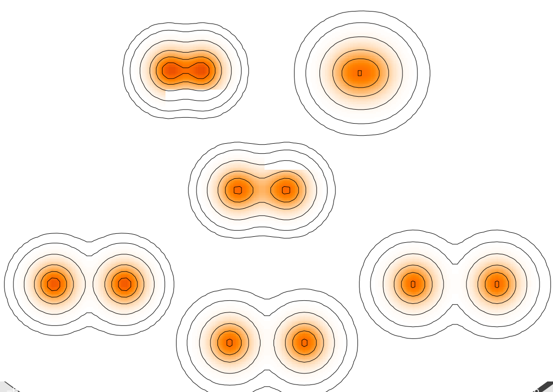
PAV



VAP

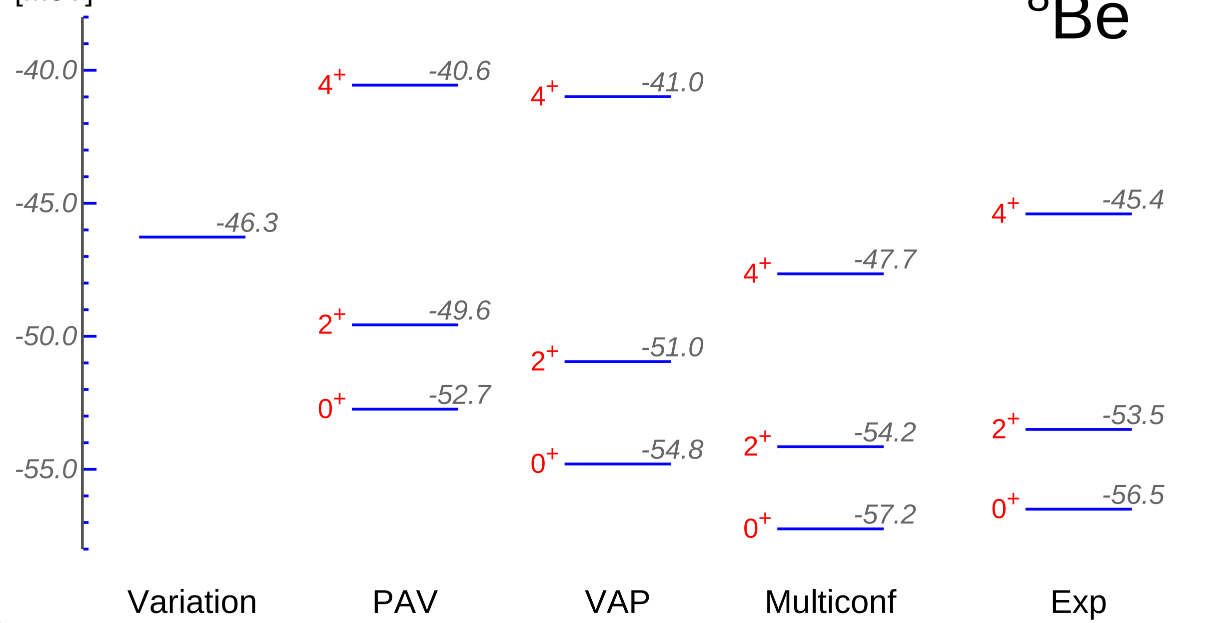


Multiconfig

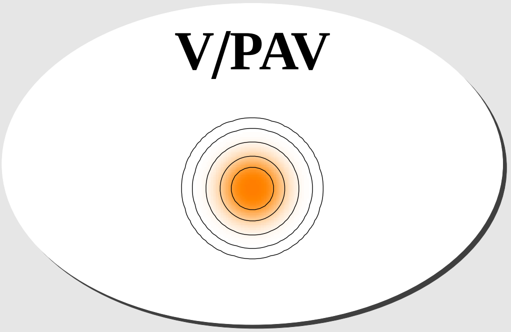


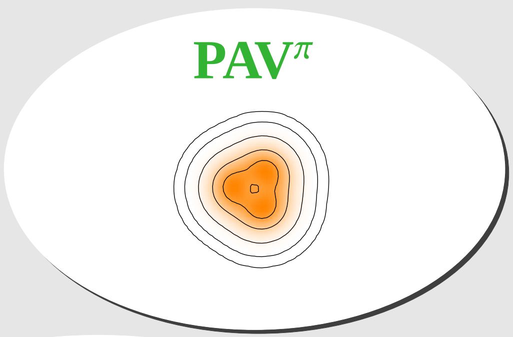
Radius and Quadrupole Moment as Generator Coordinates

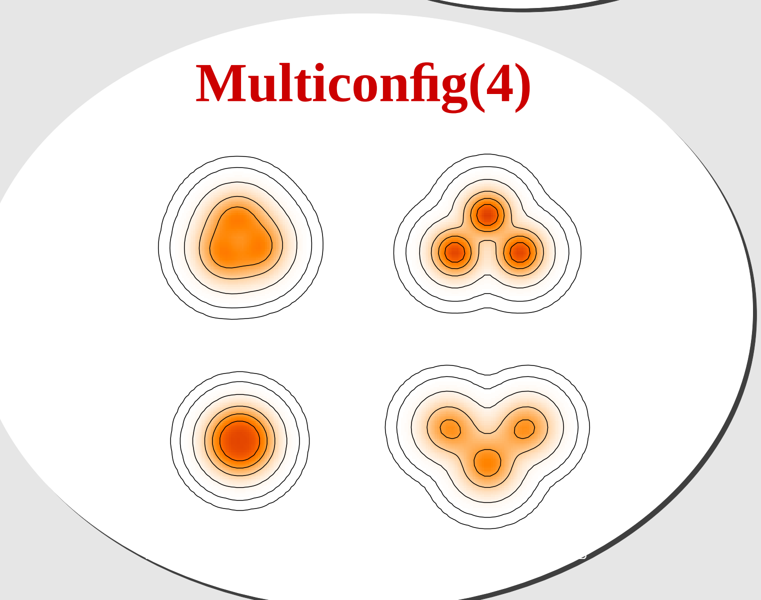
	r_{charge} [fm]	Q [fm^2]	$B(E2)$ [e^2fm^4]
PAV	2.39	-6.25	9.31
VAP	2.49	-8.02	15.36
Multiconfig	2.74	-11.88	30.39



FMD - Variation, PAV$^{\pi}$, Multiconfig.

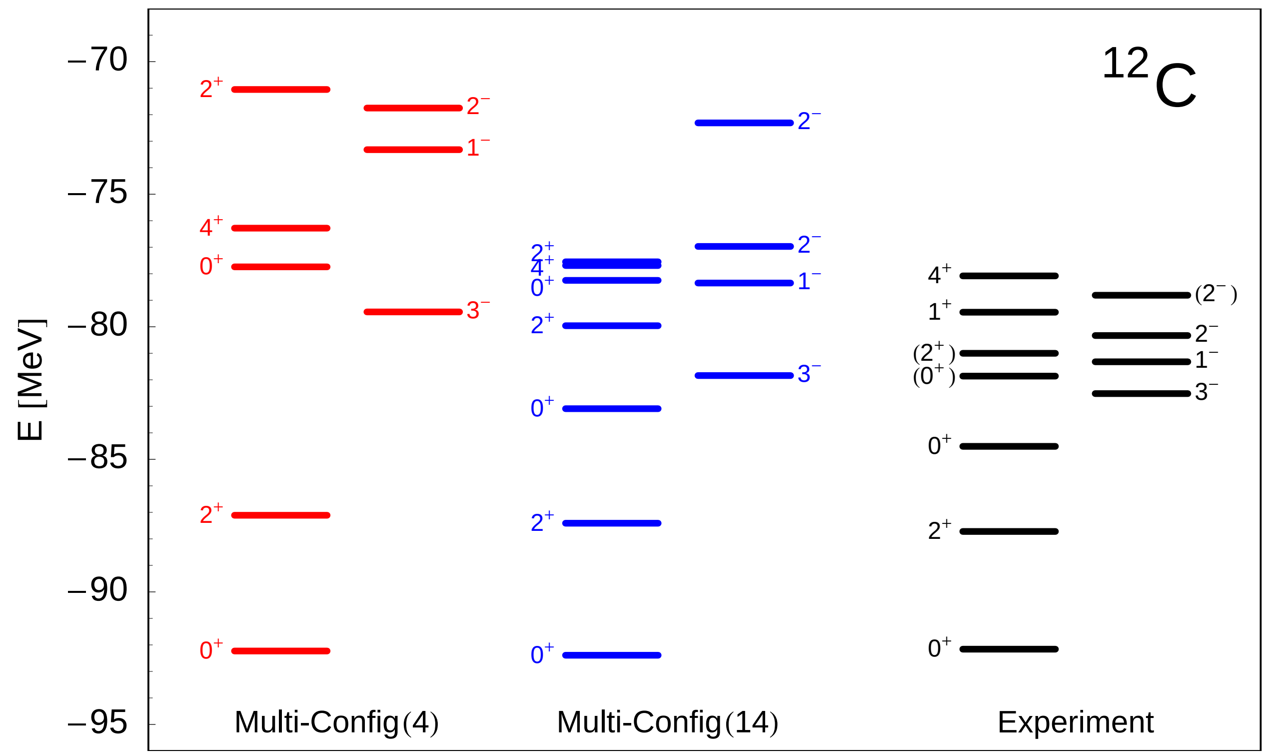




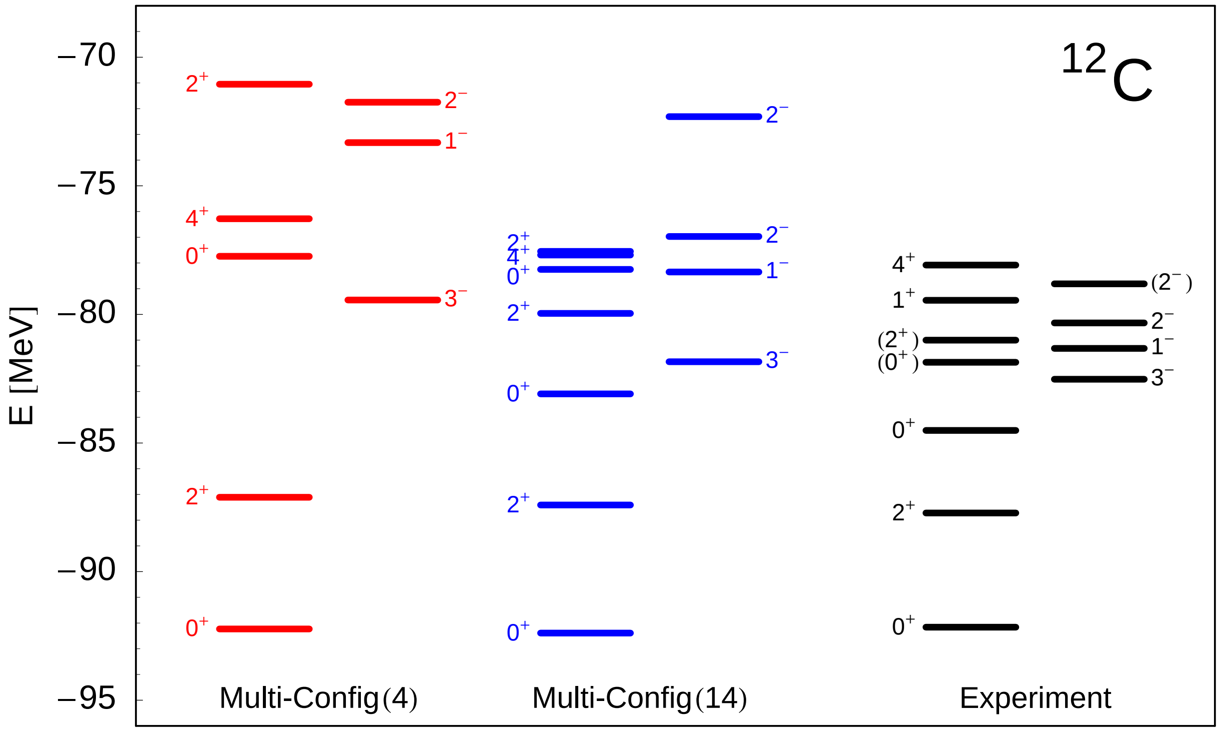


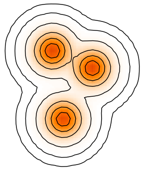
^{12}C

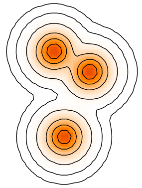
	E [MeV]	r_{charge} [fm]	$B(E2)$ [e^2fm^4]
V/PAV	-81.4	2.36	-
PAV$^{\pi}$	-88.5	2.51	36.3
Multiconfig(4)	-92.2	2.52	42.8
Multiconfig(14)	-92.4	2.52	42.9
Exp	-92.2	2.47	39.7 ± 3.3

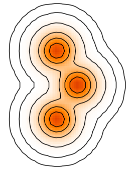


Structure of the Carbon – Hoyle State

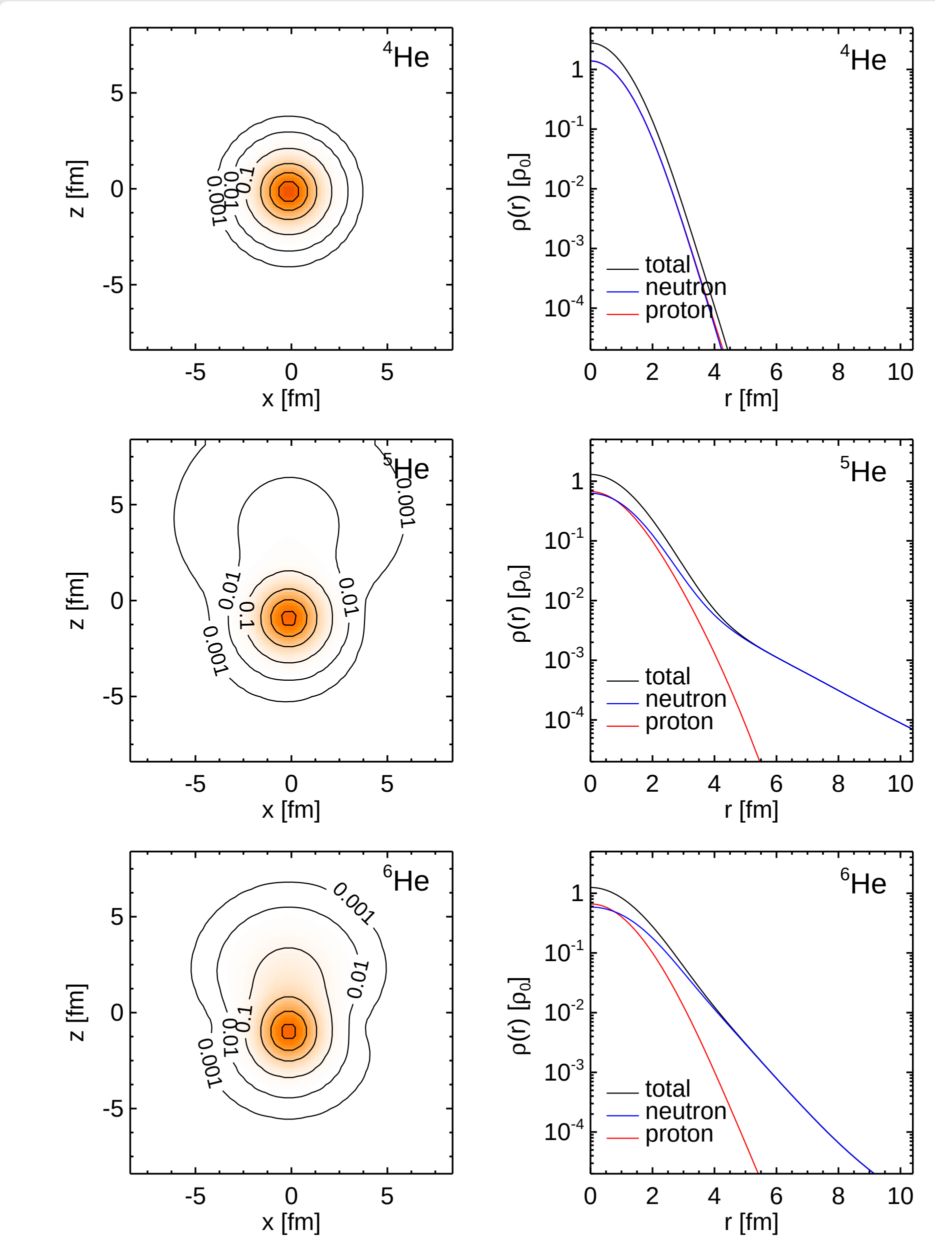


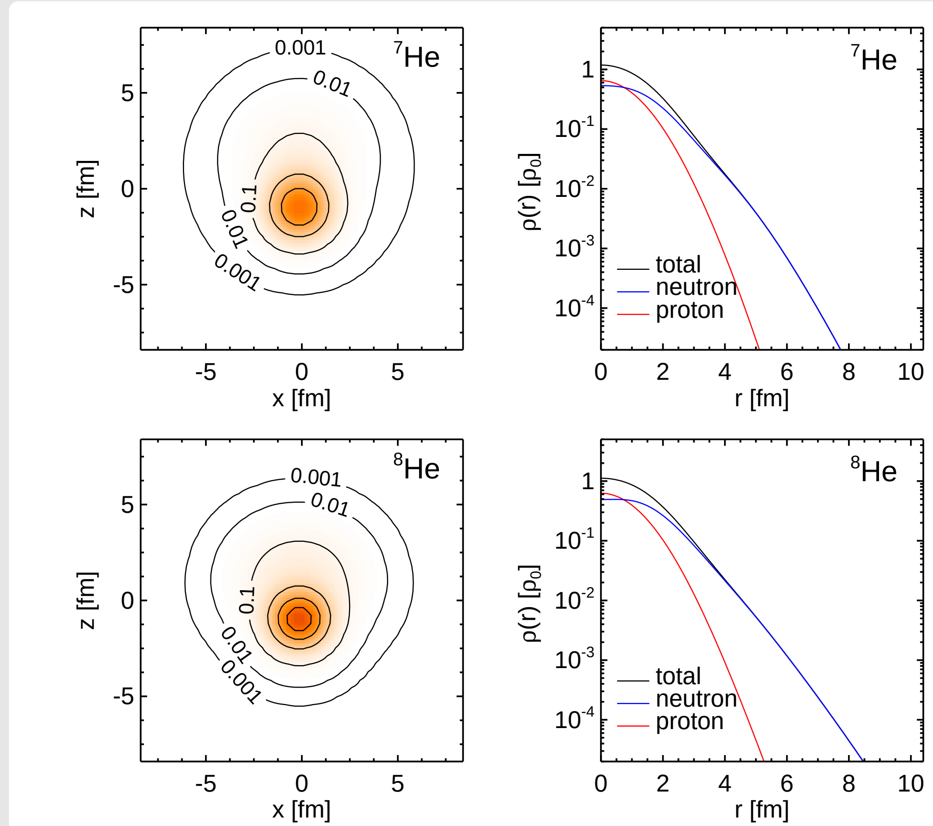
$\Big|\langle$  $|0_2^+\rangle\Big| = 0.76$

$\Big|\langle$  $|0_2^+\rangle\Big| = 0.71$

$\Big|\langle$  $|0_2^+\rangle\Big| = 0.50$

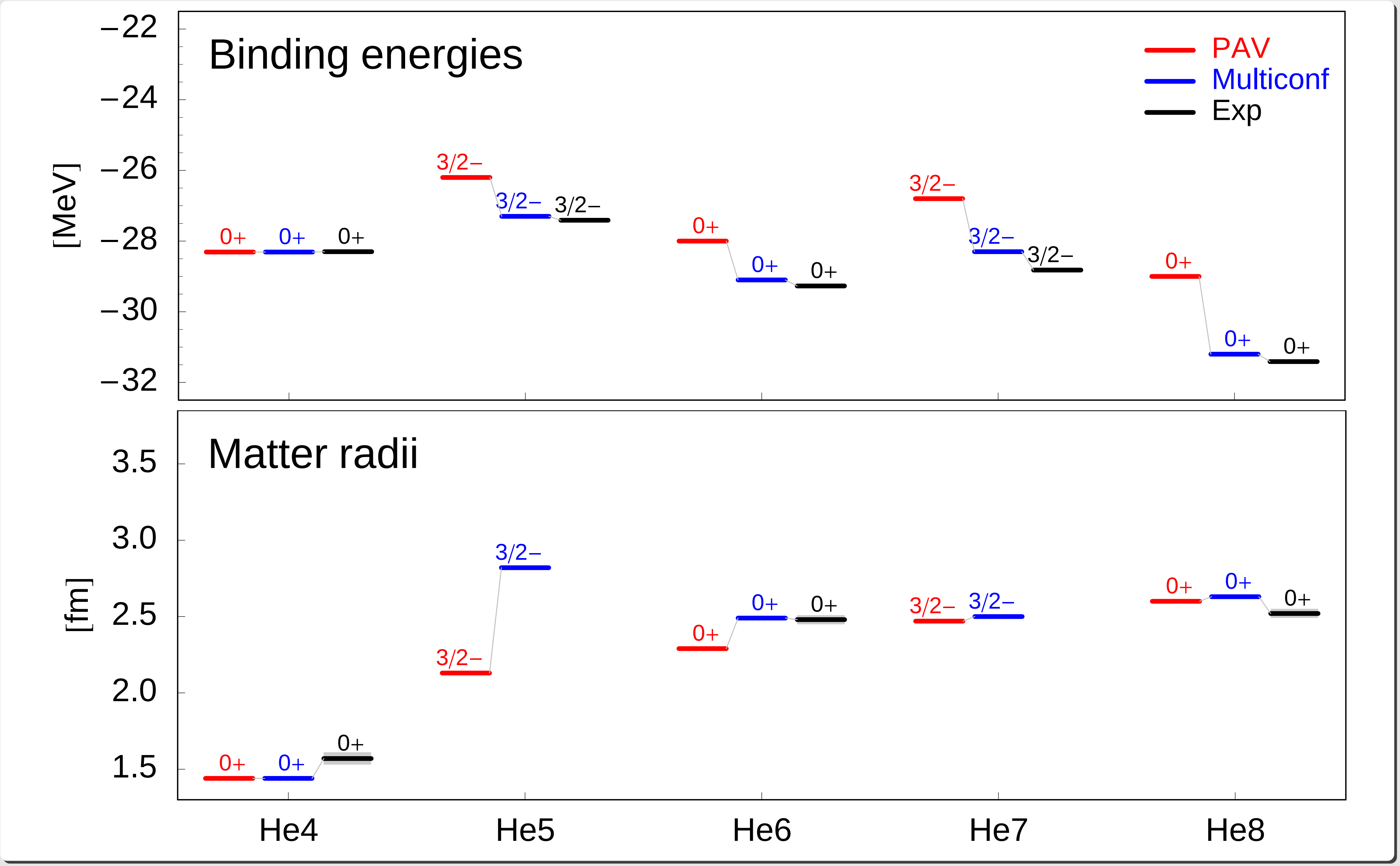
Helium Isotopes





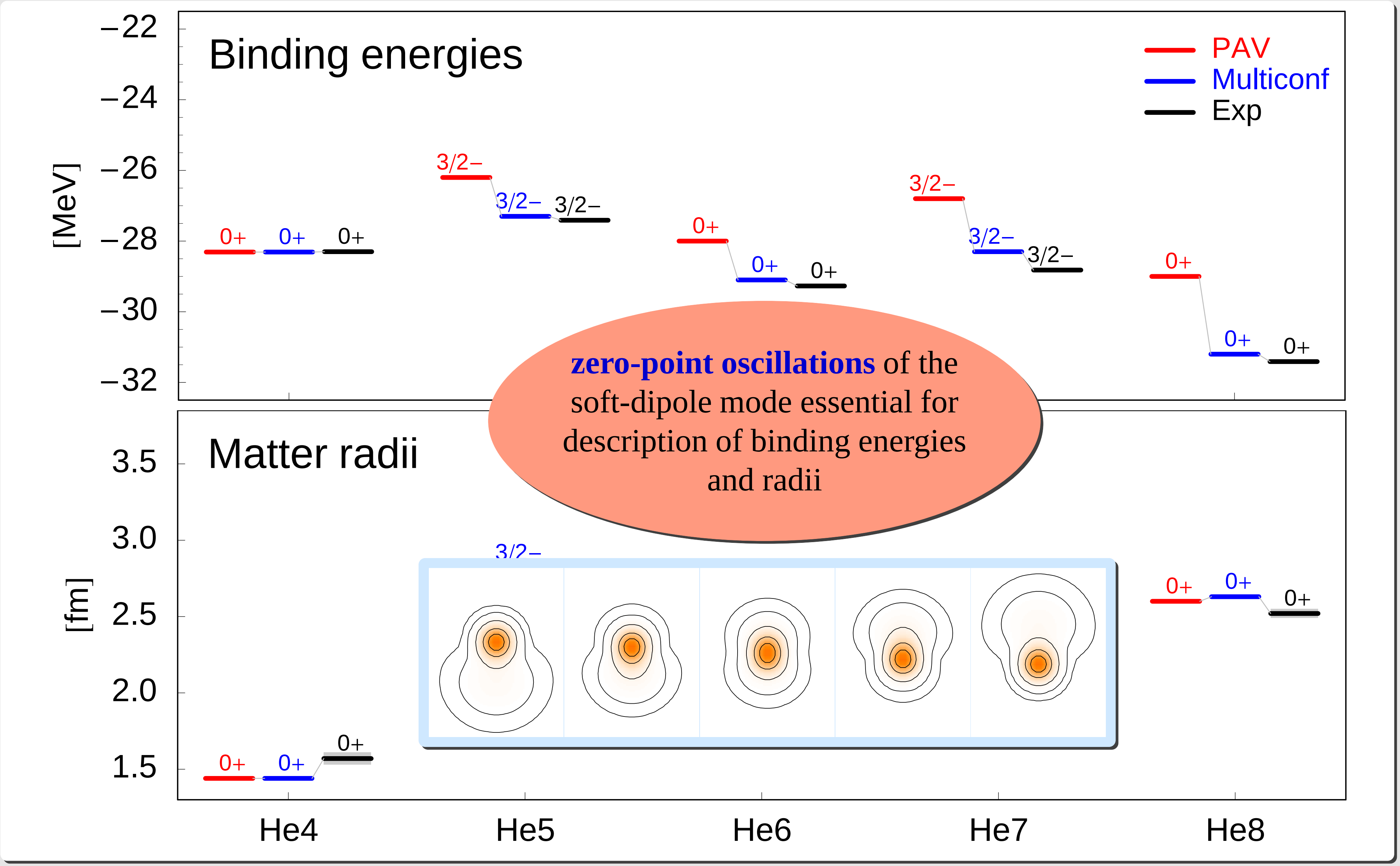
soft-dipole mode
neutrons are oscillating against α-core

Helium Isotopes



Exp: Ozawa,Suzuki,Tanihata, NP**A693**(2001)32; Raman,Nestor,Tikkanen, Atomic Data and Nucl. Data Tables **78**(2001)1

Helium Isotopes



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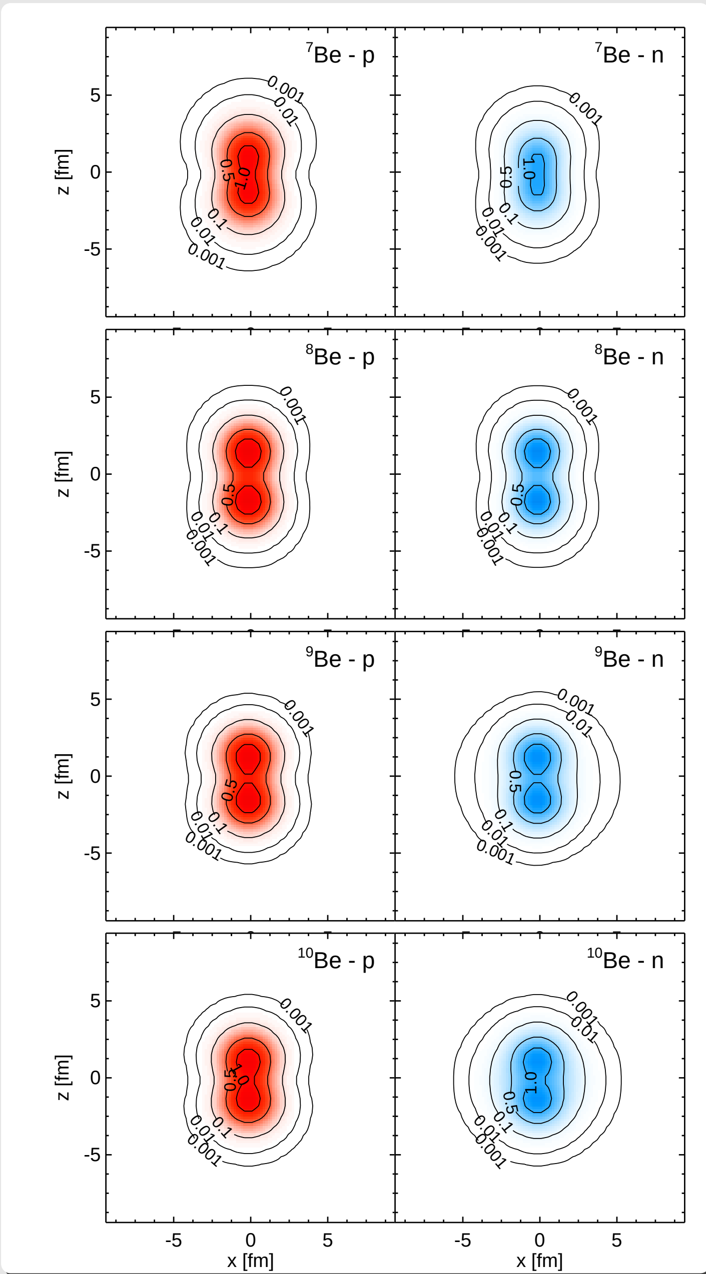
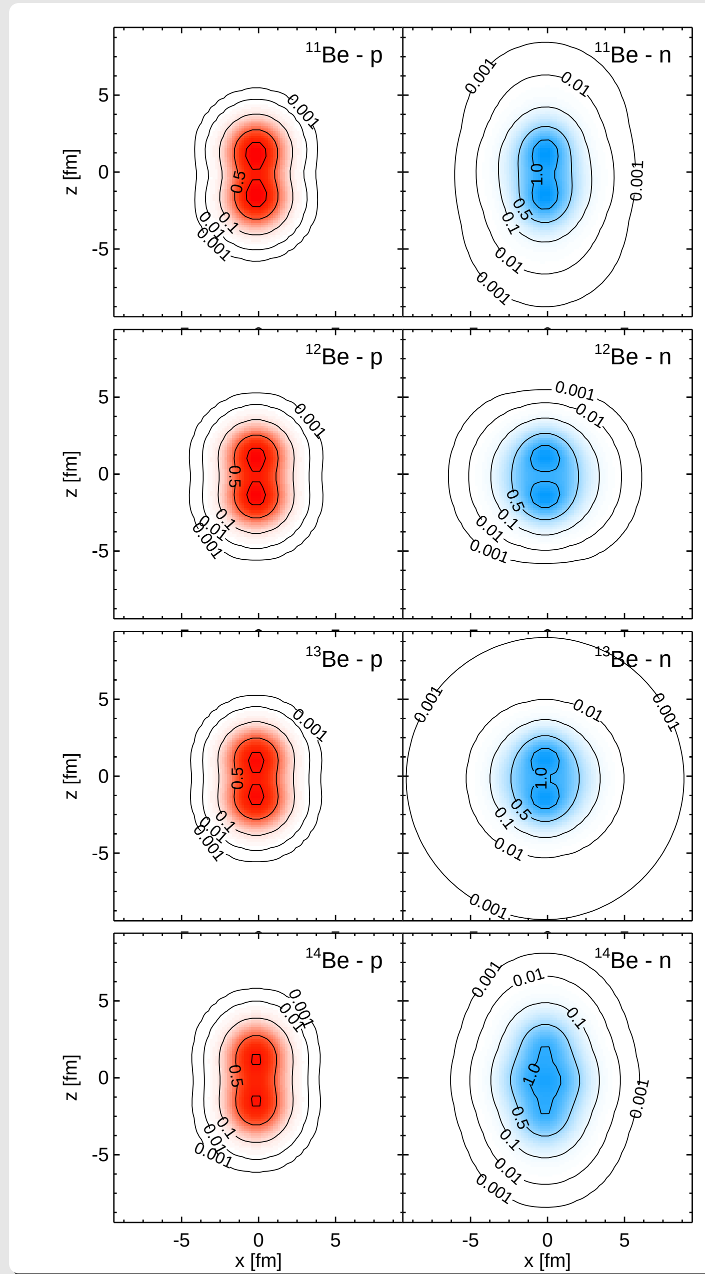
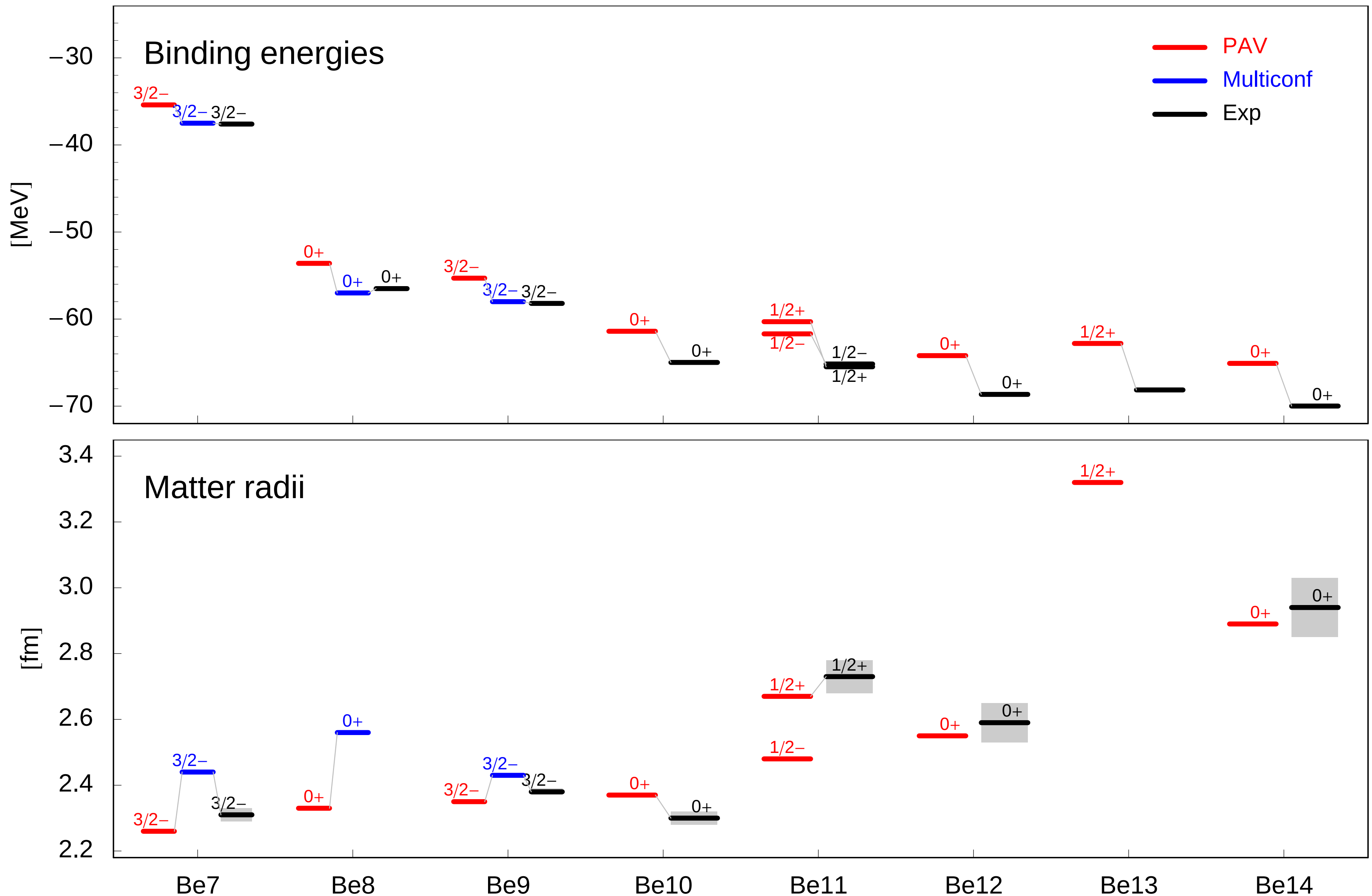
Beryllium Isotopes





cluster structure changes with addition of neutrons

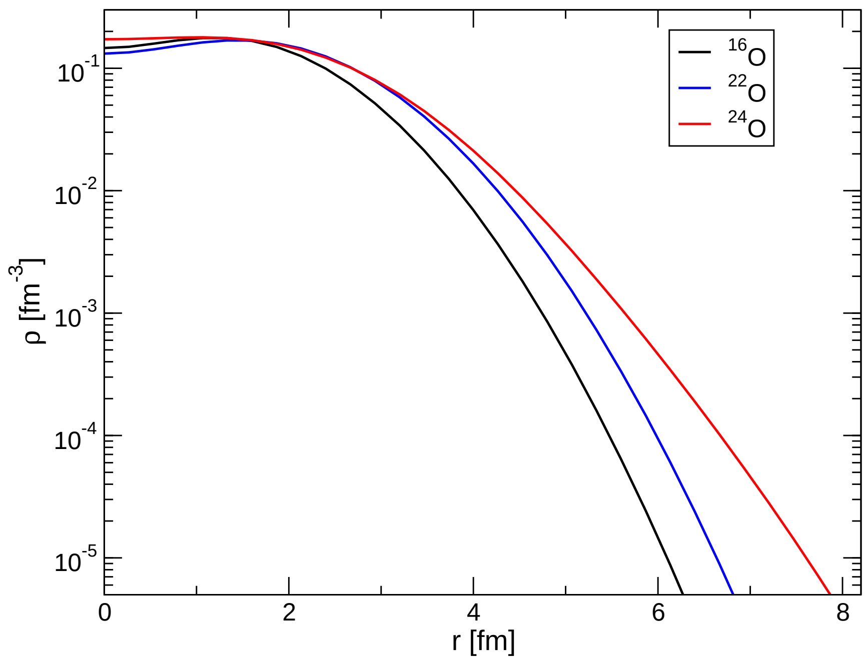
Beryllium Isotopes



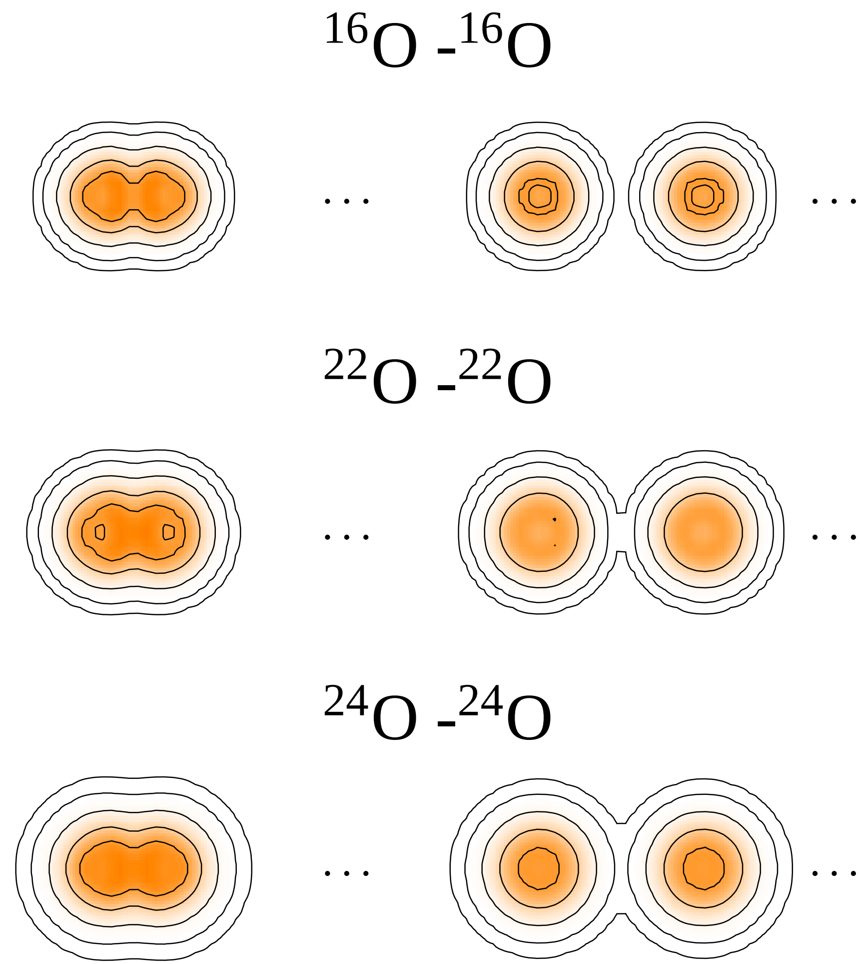
Exp: Ozawa,Suzuki,Tanihata, NP**A693**(2001)32; Raman,Nestor,Tikkanen, Atomic Data and Nucl. Data Tables **78**(2001)1

Mikroskopische Kern-Kern-Potentiale

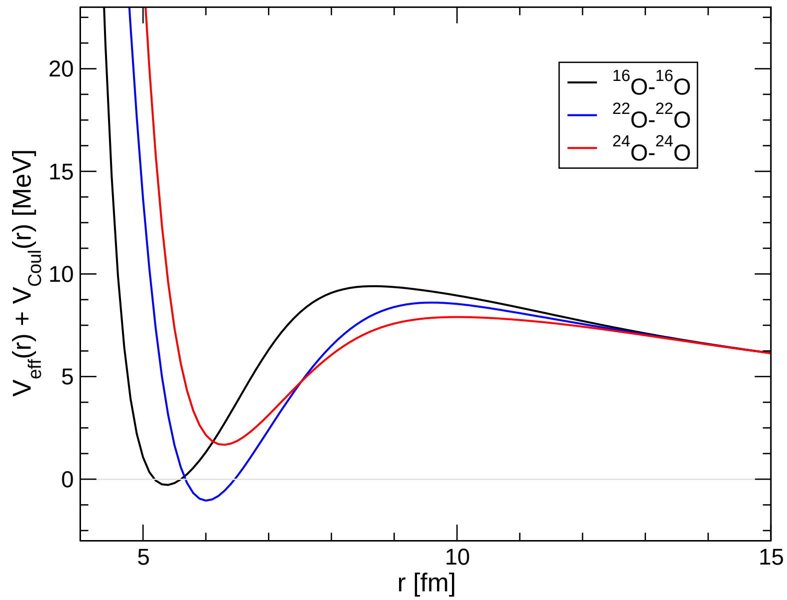
- Vielteilchenzustände:
  Fermionische Molekulardynamik (FMD)
- Effektive *NN*-Wechselwirkung:
  abgeleitet von der realistischen Argonne-V18 *NN*-Wechselwirkung (UCOM)



Massendichten



Potentiale & Astrophysikalische S-Faktoren

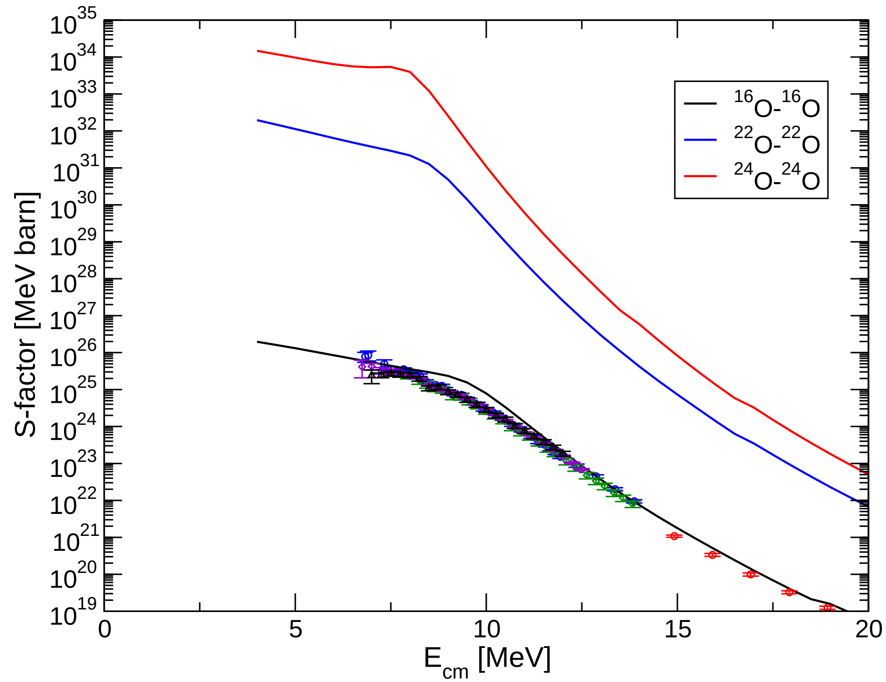


Mikroskopisch berechnete
Kern-Kern-Potentiale

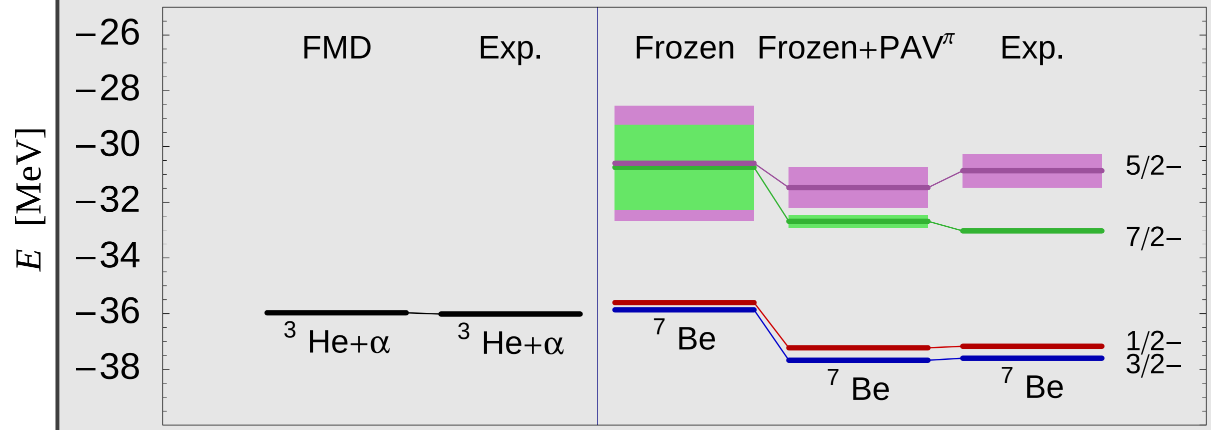
Astrophysikalischer S-Faktor

$$S(E) = \sigma_{\text{fusion}}(E)\, E\, e^{2\pi\eta}$$

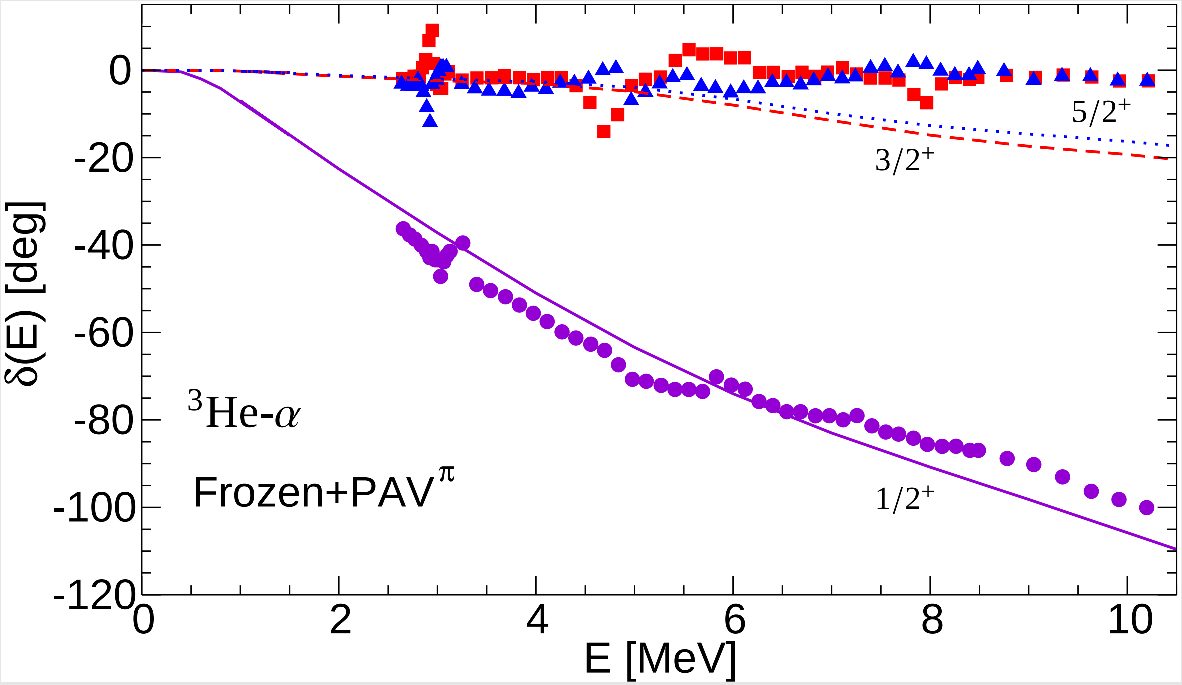
η=Sommerfeld-Parameter



Outlook: Resonances & Scattering in FMD



- collective coordinate representation as tool for the description of continuum states in FMD

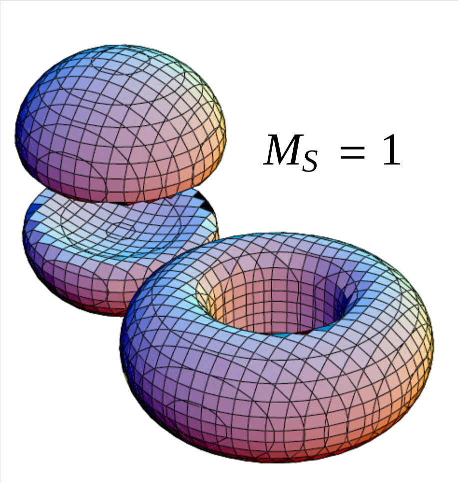


first steps towards fully microscopic and consistent description of **structure and reactions**

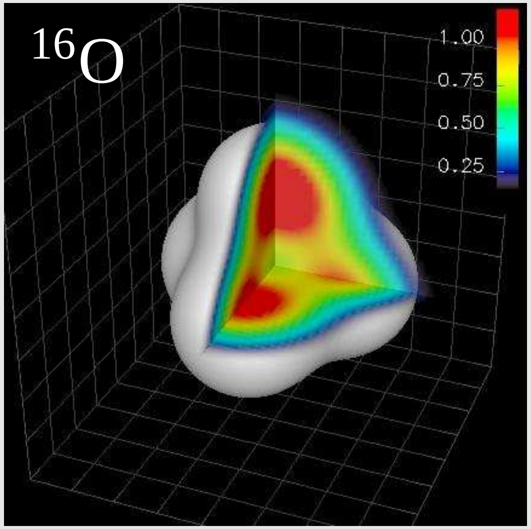
Zusammenfassung und Ausblick

Neue Ära der Kernstruktur

- Unitary Correlation Operator Method
  beschreibt kurzreichweitige radiale und tensorielle Korrelationen
- UCOM erzeugt ab-initio korrelierte Wechselwirkung $\hat{H}$
  für Vielteilchenmethoden wie HF, Shalenmodell, FMD
- Observablen müssen und können auch korreliert werden
- no-core Schalenmodell Rechnungen für leichte Kerne
- FMD Rechnungen mit demselben $\hat{H}^{C2}+\hat{H}^{corr}$ für $3 \leq A \leq 60$
- Ein mikroskopisches Modell für:
  Bindungsenergien, Radien, Spektren, Übergänge,
  Kontinuum, Resonanzen, Reaktionen



$M_S = 0$



Ausblick

- "ab initio" Idee weiter verfolgen → Vorhersagekraft
- Vorhersagen für viele exotische leichte Kerne (vor Messung)
- Korrelierte Übergänge: M1, β-Zerfall, quenching
- Ab-initio korrelierte WW in HF, RPA oder ähnlichem für $A > 60$
- Langreichweitige Tensorkorr. – 3-Teilchenkräfte
- …

Epilogue

- **thanks to my group & my collaborators**

- A. Cribeiro, K. Langanke
  Gesellschaft für Schwerionenforschung (GSI)

- T. Neff
  NSCL, Michigan State University

- R. Roth, H. Hergert, N. Paar, P. Papakonstantinou, A. Zapp
  Institut für Kernphysik, TU Darmstadt

supported by the DFG through SFB 634
“Nuclear Structure, Nuclear Astrophysics and Fundamental Experiments...”

How to improve ?

Projection After Variation (PAV)

- mean-field may break symmetries of Hamiltonian
- restore reflection and rotational symmetry by parity and angular-momentum projection $\underset{\sim}{P}^{J\pi}_{MK}$

$$\sum_{K'} \langle\, Q \,|\, \underset{\sim}{H}\underset{\sim}{P}^{J\pi}_{KK'} \,|\, Q \,\rangle \cdot c_{K'} = E^{J\pi}_{K} \sum_{K'} \langle\, Q \,|\, \underset{\sim}{P}^{J\pi}_{KK'} \,|\, Q \,\rangle \cdot c_{K'}$$

Variation After Projection (VAP)

- effect of projection can be large
- perform VAP applying **constraints** on radius, dipole moment, quadrupole moment or octupole moment and minimize the energy in the projected energy surface

Multiconfiguration Calculations

- diagonalize Hamiltonian in a set of projected intrinsic states

$$\left\{ \underset{\sim}{P}^{J\pi}_{KK'} \,\middle|\, Q^{(a)} \right\rangle , \quad a = 1, \cdots , N \right\}$$

Unitary Correlation Operator Method, UCOM

Two-Body Correlations

- ➨ two-body generator

$$\underset{\sim}{C} = e^{-i\underset{\sim}{G}}, \qquad \underset{\sim}{G} = \underset{\sim}{G}^{\dagger} = \sum_{i<j} \underset{\sim}{g}_{ij}$$

Correlator $\underset{\sim}{C}$

should conserve translational, rotational and Galilei invariance
short ranged

Cluster Expansion

correlated operators $\hat{\underset{\sim}{A}} = \underset{\sim}{C}^{\dagger}\underset{\sim}{A}\underset{\sim}{C}$ are no longer operators with definite particle number

- ➨ decompose correlated operator into irreducible k-body operators

$$\hat{\underset{\sim}{A}} = \underset{\sim}{C}^{\dagger}\underset{\sim}{A}\underset{\sim}{C} = \hat{\underset{\sim}{A}}^{[1]} + \hat{\underset{\sim}{A}}^{[2]} + \hat{\underset{\sim}{A}}^{[3]} + \cdots$$

Two-Body Approximation

$$\hat{\underset{\sim}{T}}^{C2} = \hat{\underset{\sim}{T}}^{[1]} + \hat{\underset{\sim}{T}}^{[2]}, \qquad \hat{\underset{\sim}{V}}^{C2} = \hat{\underset{\sim}{V}}^{[2]}$$

- ✘ correlation range should be smaller than mean distance of nucleons (to avoid 3-body terms)

Unitary Correlation Operator Method, UCOM

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✘ correlation range should be smaller than mean distance of nucleons (to avoid 3-body terms)

Spin-Isospin Dependence

nuclear interaction strongly depends on spin and isospin

$$\underset{\sim}{V} = \sum_{S,T} \underset{\sim}{v}_{ST} \underset{\sim}{\Pi}_{ST}$$

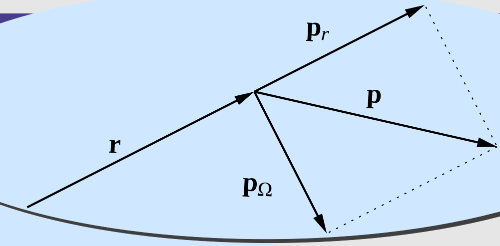
➨ different correlations in the respective channels

$$\underset{\sim}{g} = \sum_{S,T} \underset{\sim}{g}_{ST} \underset{\sim}{\Pi}_{ST}$$

➨ correlated interaction in two-body space

$$\hat{\underset{\sim}{V}} = \sum_{S,T} (e^{i\underset{\sim}{g}_{ST}} \underset{\sim}{v}_{ST} e^{-i\underset{\sim}{g}_{ST}}) \underset{\sim}{\Pi}_{ST}$$

Radial and Tensor Correlations



$$\underset{\sim}{C} = \underset{\sim}{C}_\Omega \underset{\sim}{C}_r = e^{-i\underset{\sim}{G}_\Omega} e^{-i\underset{\sim}{G}_r}$$

$$\mathbf{p} = \mathbf{p}_r + \mathbf{p}_\Omega$$

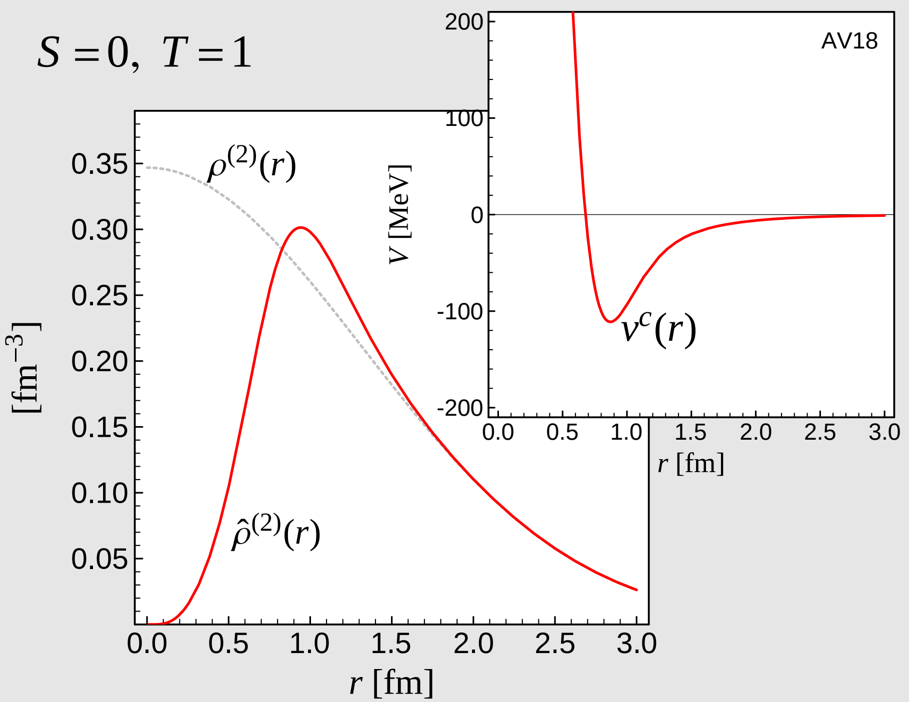
$$\mathbf{p}_r = \frac{1}{2}\left\{\frac{\mathbf{r}}{r}\left(\frac{\mathbf{r}}{r}\mathbf{p}\right) + \left(\mathbf{p}\frac{\mathbf{r}}{r}\right)\frac{\mathbf{r}}{r}\right\}, \qquad \mathbf{p}_\Omega = \frac{1}{2r}\left\{\mathbf{l} \times \frac{\mathbf{r}}{r} - \frac{\mathbf{r}}{r} \times \mathbf{l}\right\}$$

Radial Correlator

$$\underset{\sim}{G}_r = \frac{1}{2}\{\underset{\sim}{p}_r\, s(\underset{\sim}{r}) + s(\underset{\sim}{r})\,\underset{\sim}{p}_r\}$$

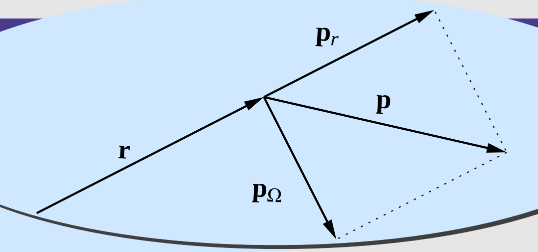
➨ probability density shifted out of the repulsive core

$S = 0,\ T = 1$



Manfred Ristig Z.Physik **199** (1967) 325

Radial and Tensor Correlations



$$\underset{\sim}{C} = \underset{\sim}{C}_\Omega \underset{\sim}{C}_r = e^{-i\underset{\sim}{G}_\Omega} e^{-i\underset{\sim}{G}_r}$$

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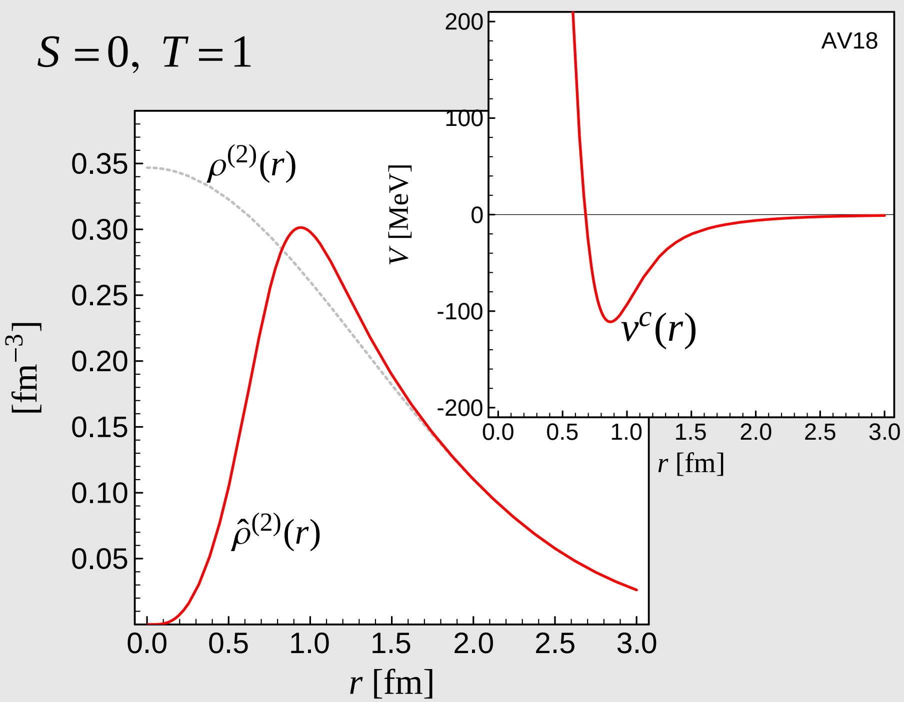

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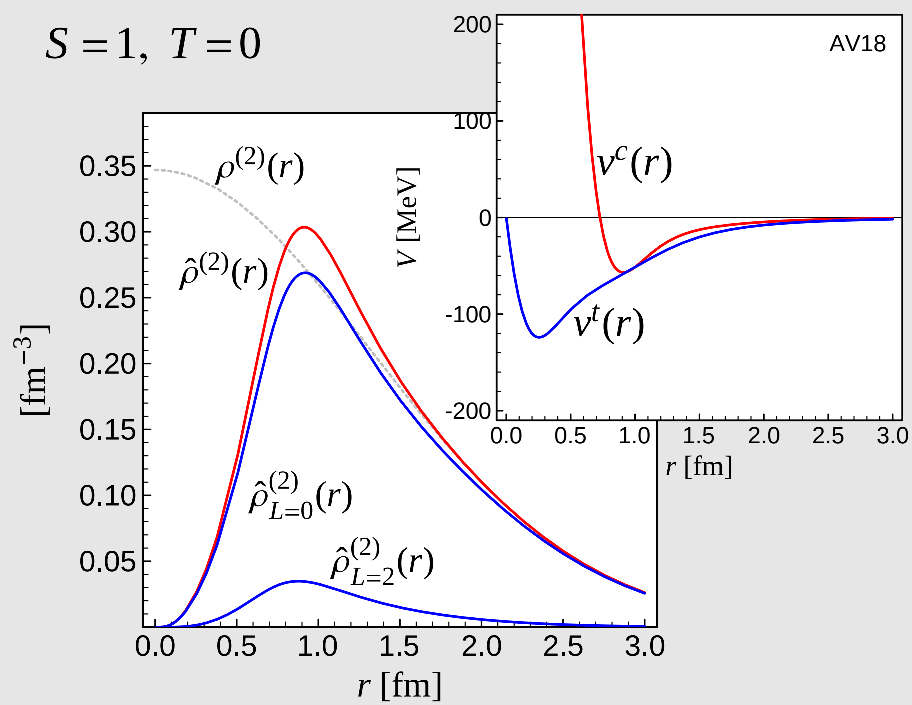
Tensor Correlations

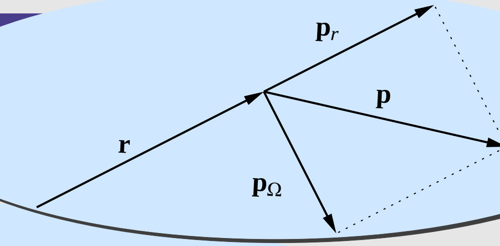
$$\underset{\sim}{G}_\Omega = \vartheta(\underset{\sim}{r})\frac{3}{2}\left\{(\underset{\sim}{\boldsymbol{\sigma}}_1\cdot\underset{\sim}{\mathbf{p}}_\Omega)(\underset{\sim}{\boldsymbol{\sigma}}_2\cdot\underset{\sim}{\mathbf{r}}) + (\underset{\sim}{\boldsymbol{\sigma}}_1\cdot\underset{\sim}{\mathbf{r}})(\underset{\sim}{\boldsymbol{\sigma}}_2\cdot\underset{\sim}{\mathbf{p}}_\Omega)\right\}$$

➨ tensor force admixes other angular momenta

$S = 1,\ T = 0$



Radial and Tensor Correlations



$$\underset{\sim}{C} = \underset{\sim}{C}_\Omega \underset{\sim}{C}_r = e^{-i\underset{\sim}{G}_\Omega} e^{-i\underset{\sim}{G}_r}$$

$$\mathbf{p} = \mathbf{p}_r + \mathbf{p}_\Omega$$

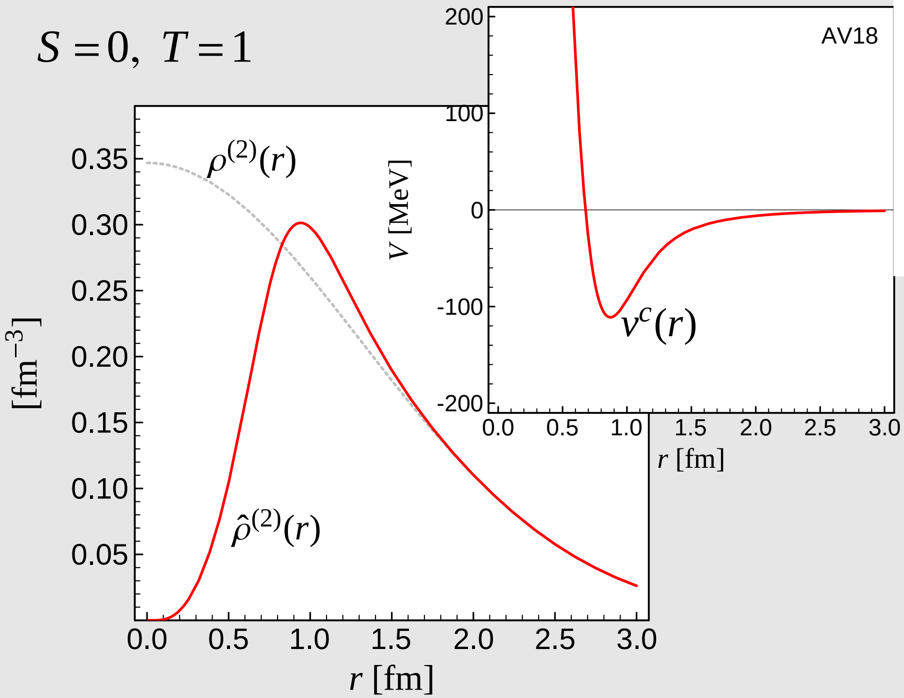
$$\mathbf{p}_r = \frac{1}{2}\left\{\frac{\mathbf{r}}{r}\left(\frac{\mathbf{r}}{r}\mathbf{p}\right) + \left(\mathbf{p}\frac{\mathbf{r}}{r}\right)\frac{\mathbf{r}}{r}\right\}, \qquad \mathbf{p}_\Omega = \frac{1}{2r}\left\{\mathbf{l} \times \frac{\mathbf{r}}{r} - \frac{\mathbf{r}}{r} \times \mathbf{l}\right\}$$

Radial Correlator

$$\underset{\sim}{G}_r = \frac{1}{2}\{\underset{\sim}{p}_r s(\underset{\sim}{r}) + s(\underset{\sim}{r})\underset{\sim}{p}_r\}$$

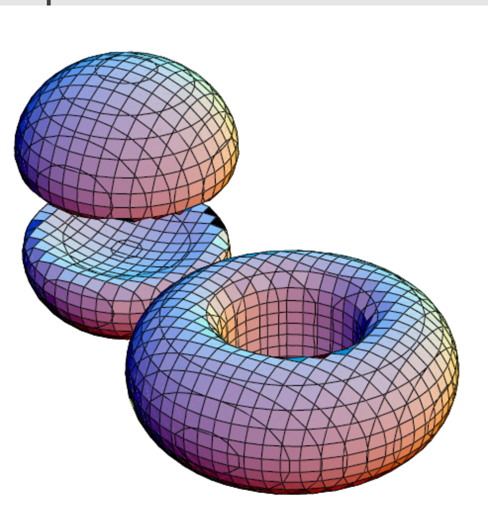
- probability density shifted out of the repulsive core

$S = 0, \; T = 1$



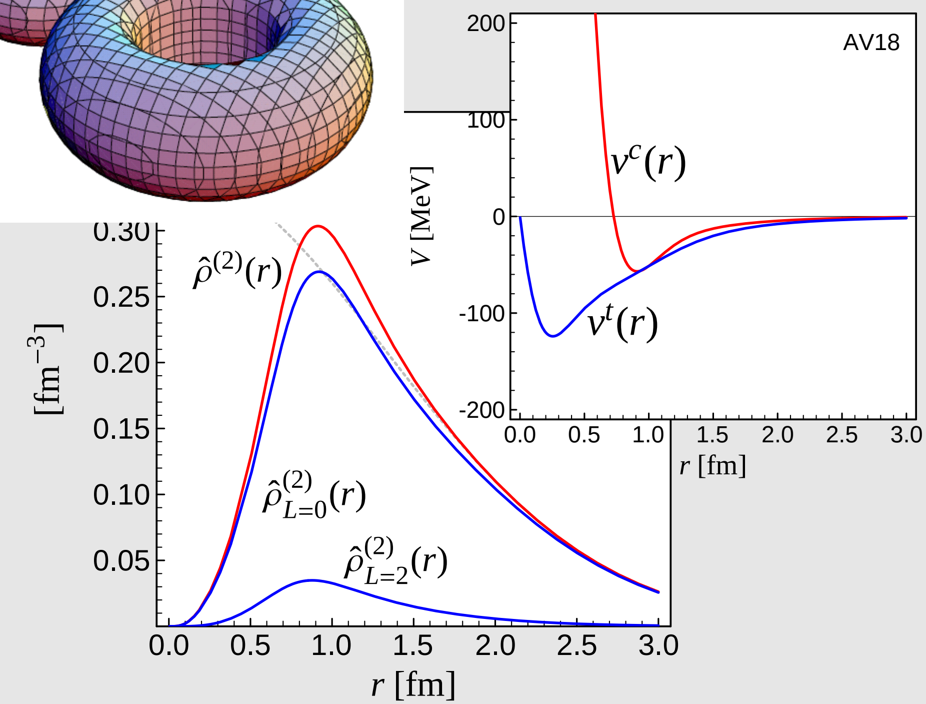
Manfred Ristig Z.Physik **199** (1967) 325

Tensor Correlations



$$\ldots_\Omega)(\underset{\sim}{\sigma}_2\cdot\underset{\sim}{\mathbf{r}}) + (\underset{\sim}{\sigma}_1\cdot\underset{\sim}{\mathbf{r}})(\underset{\sim}{\sigma}_2\cdot\underset{\sim}{\mathbf{p}}_\Omega)\}$$

…xes other angular momenta

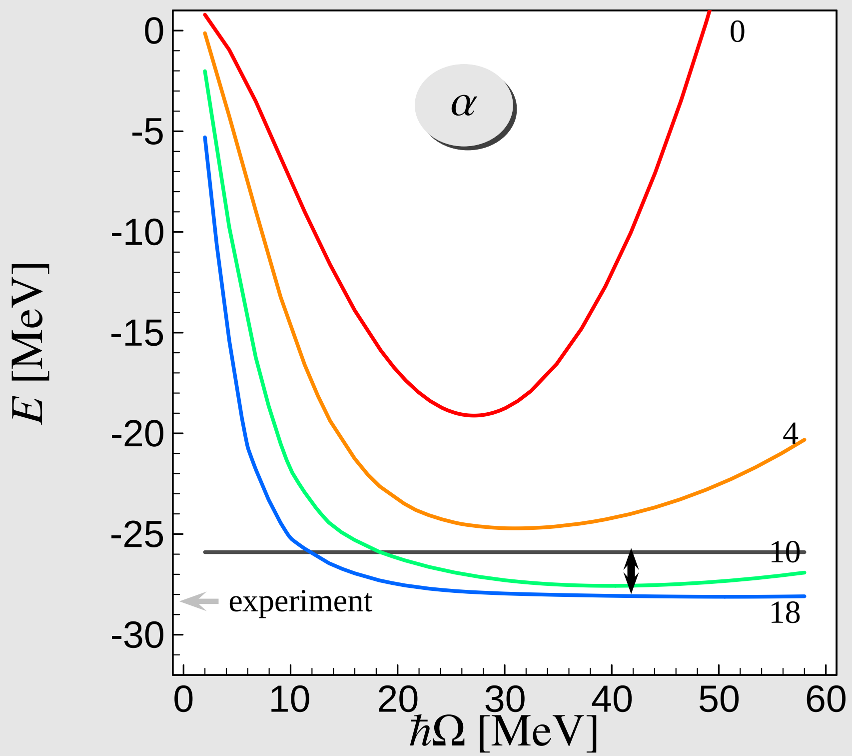


AV8’ Interaction

No-Core Shell Model Calculations

preliminary

^{4}He



test of two-body approximation

Quasi-exact calculations for light nuclei possible

exact result from PR**C64** (2001) 044001

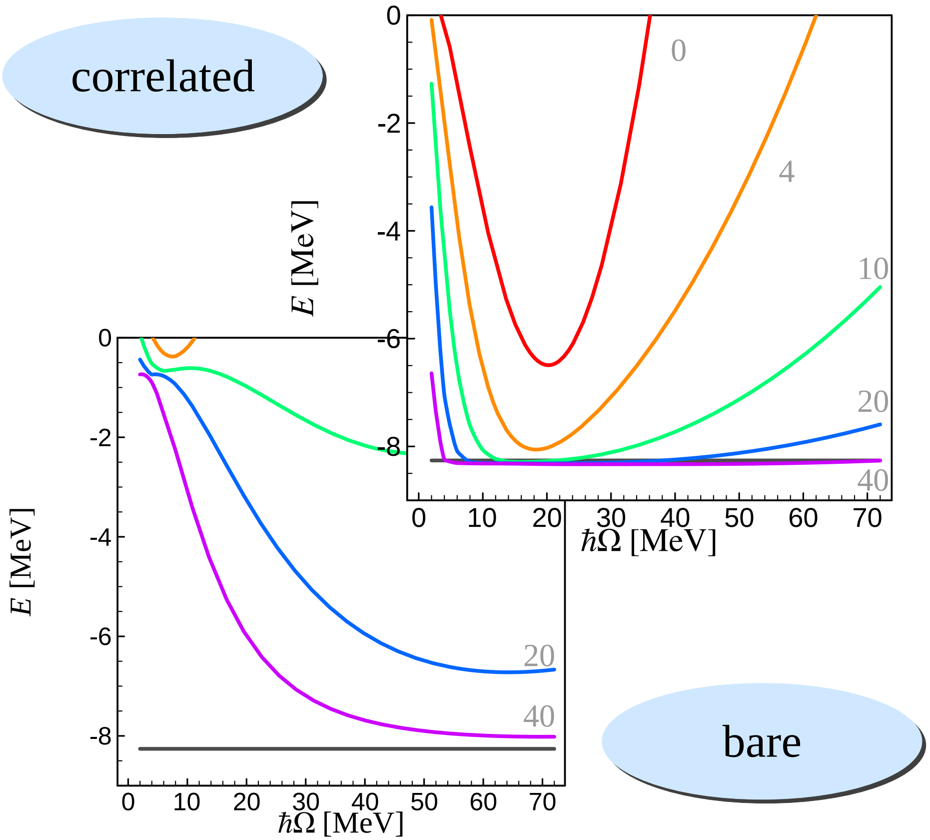
- use no-core shell model code from Petr Navratil (LLNL)

➨ neglected 3-body correlated terms same order as genuine 3N interactions

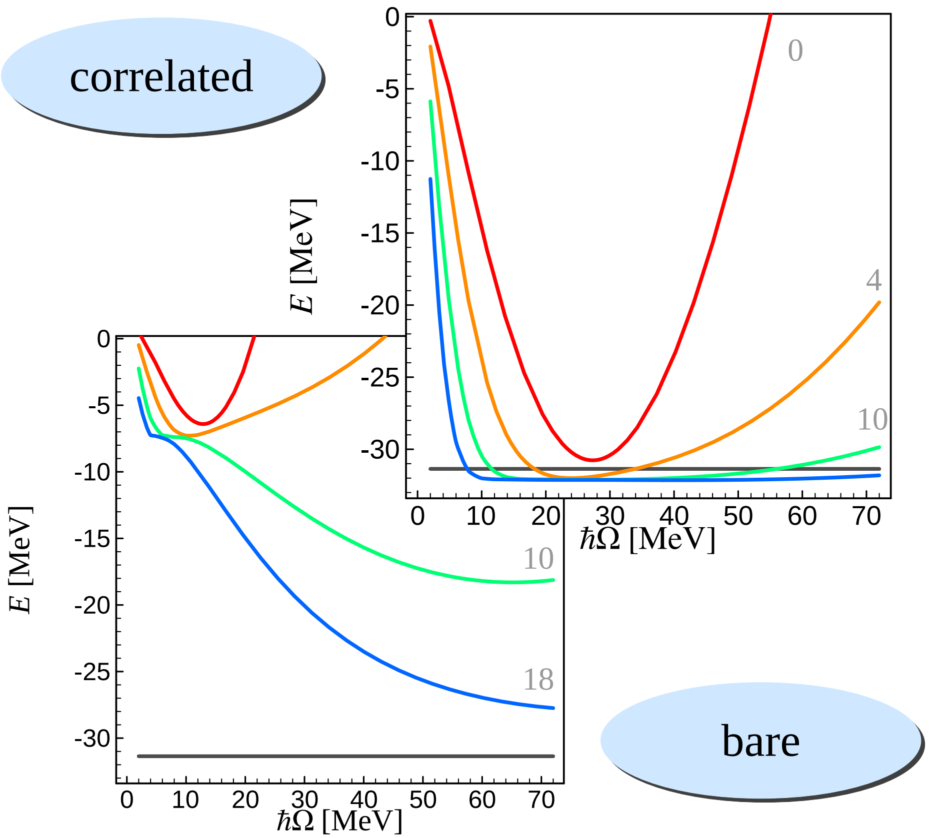
➨ more investigations needed

MTV Interaction
No-Core Shell Model Calculations

^{3}He



^{4}He



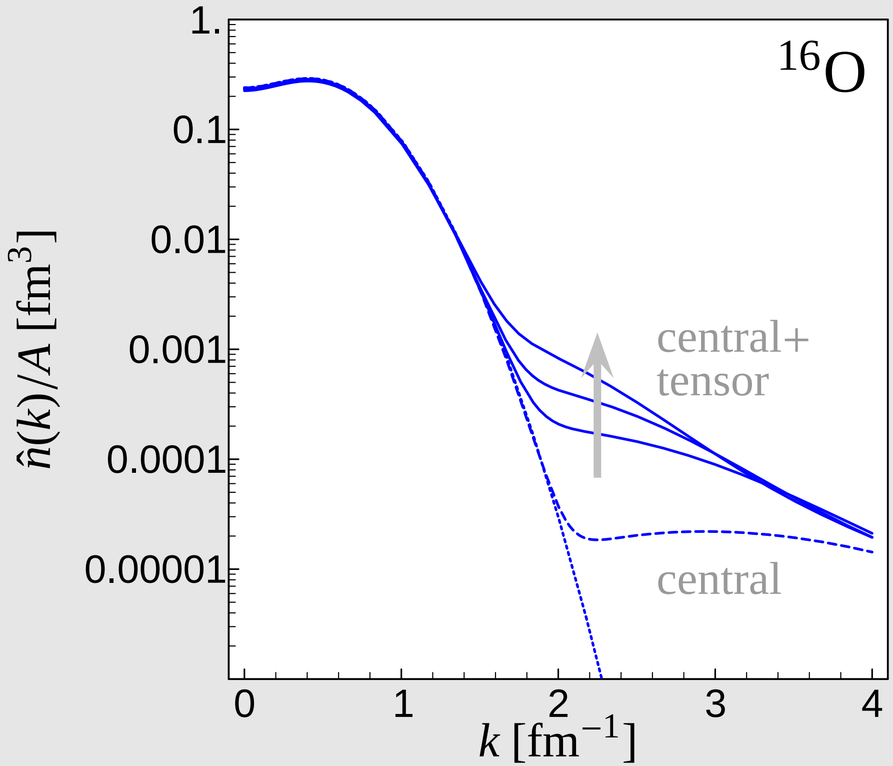
exact results from PR**C52** (1995) 2885

only radial correlations

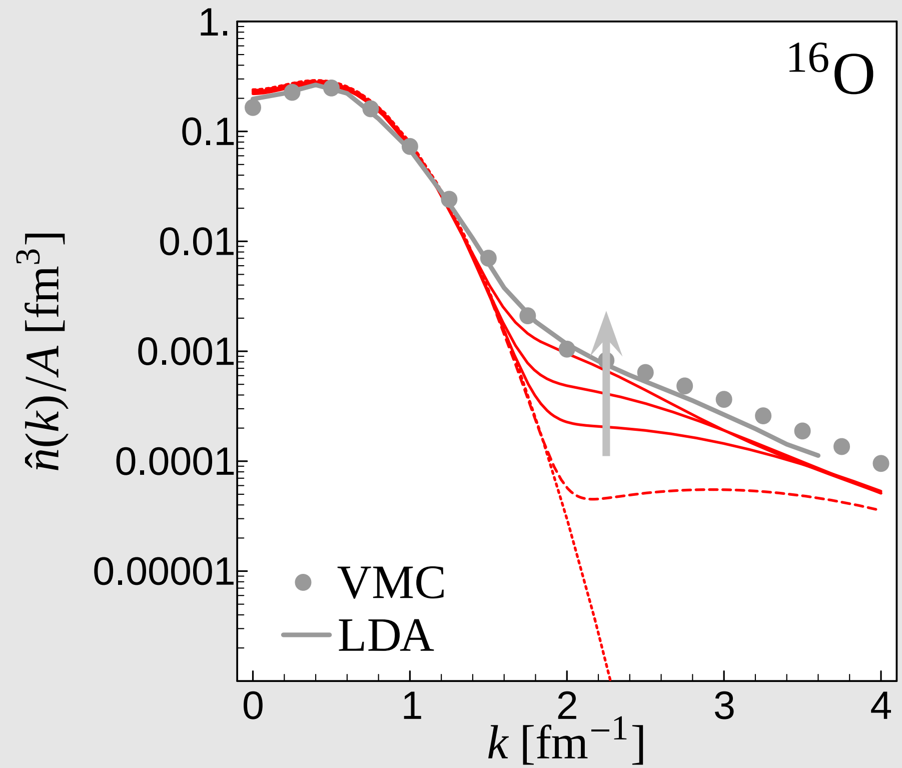
- use no-core shell model code from Pétr Navratil (LLNL)

Nucleon Momentum Distributions

Bonn-A



Argonne V18

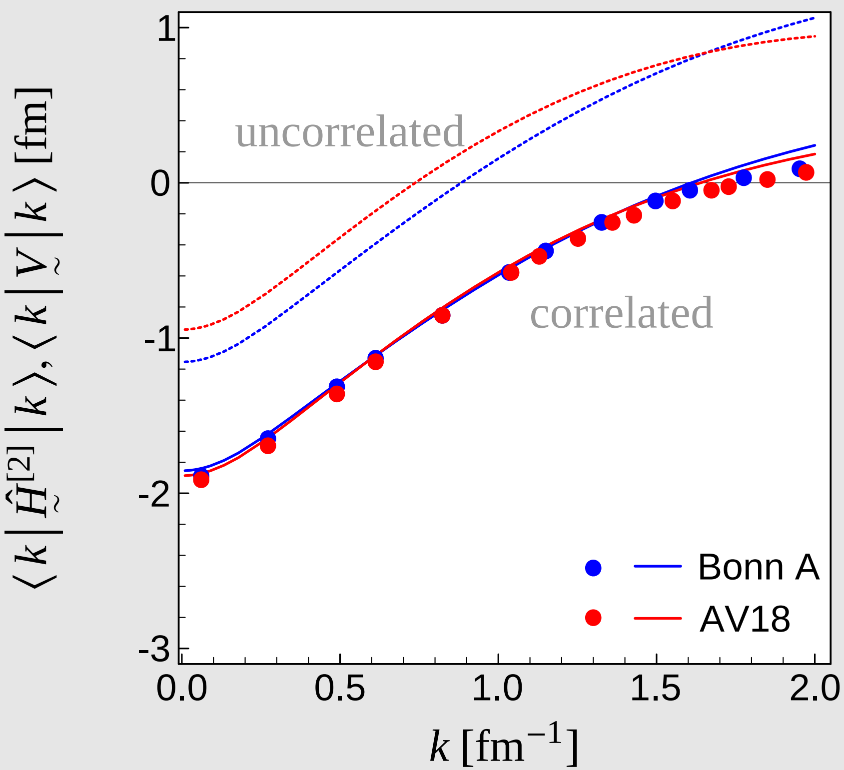


- correlations induce high-momentum components
- contributions of tensor correlations very big
- different correlator ranges relevant especially at the fermi surface

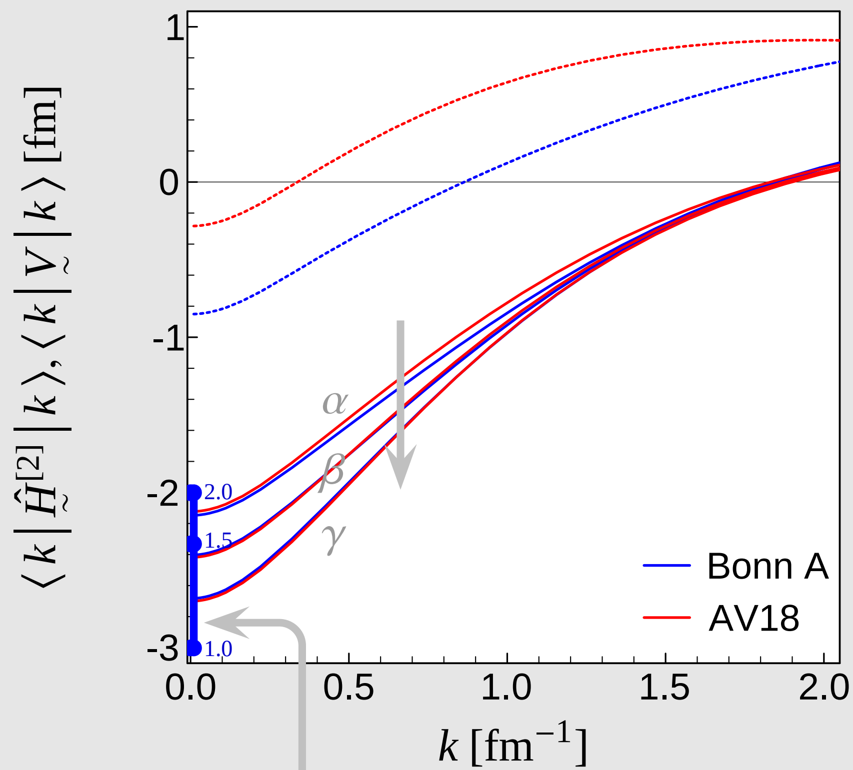
Interaction in Momentum Space

$$\langle\, klm \,|\, \underset{\sim}{\hat{H}}^{[2]} \,|\, k'l'm' \,\rangle = i^{l'-l} M \int \mathrm{d}^3x\; Y^{\star}_{lm}(\hat{\mathbf{x}})\, j_l(kx) \langle\, \mathbf{x} \,|\, \underset{\sim}{\hat{H}}^{[2]} \,|\, \mathbf{x} \,\rangle\, j_{l'}(k'x) Y_{l'm'}(\hat{\mathbf{x}})$$

$^1S_0$ channel



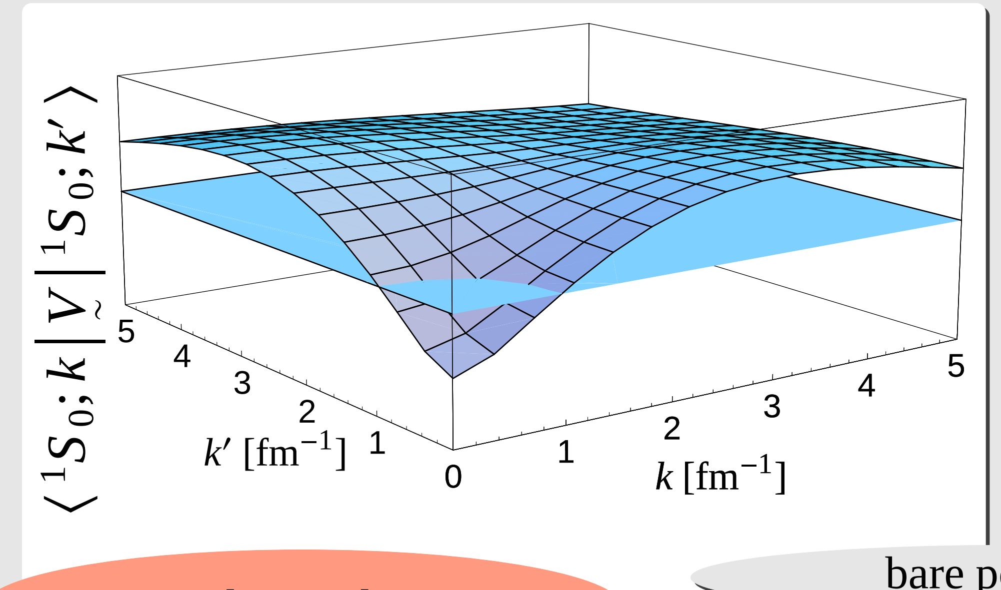
$^3S_1$ channel

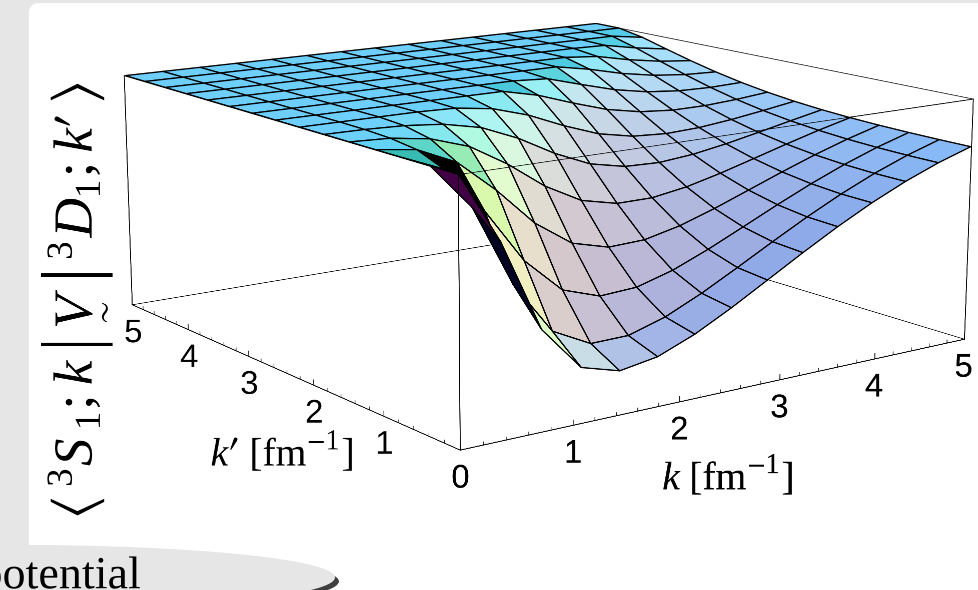


- unique effective potential – identical to V_{lowk}
  Kuo, Schwenk, nucl-th/0108041

- V_{lowk} Cutoff $\Lambda = 1.0 - 2.0\ \mathrm{fm}^{-1}$

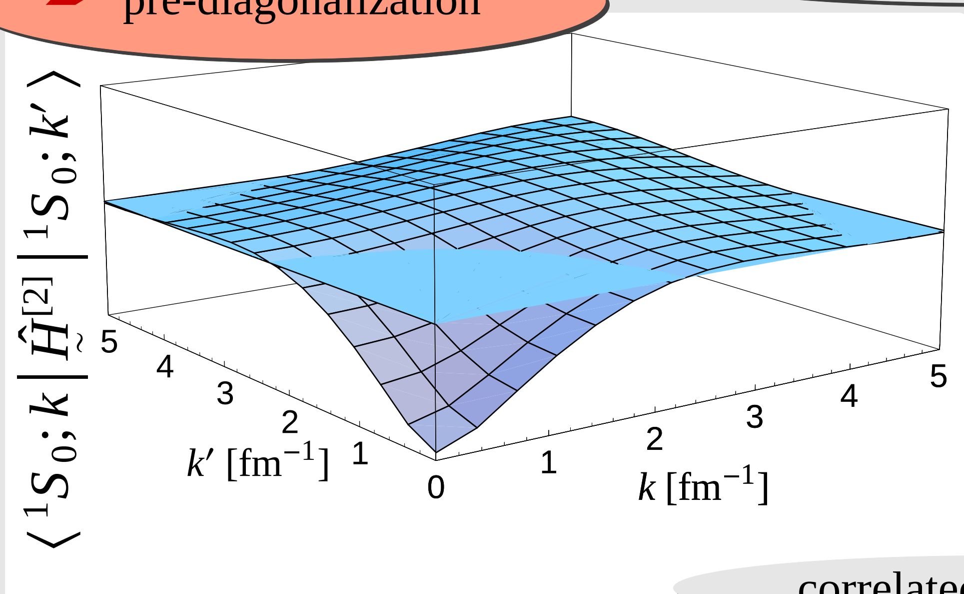
Off-diagonal Matrix Elements

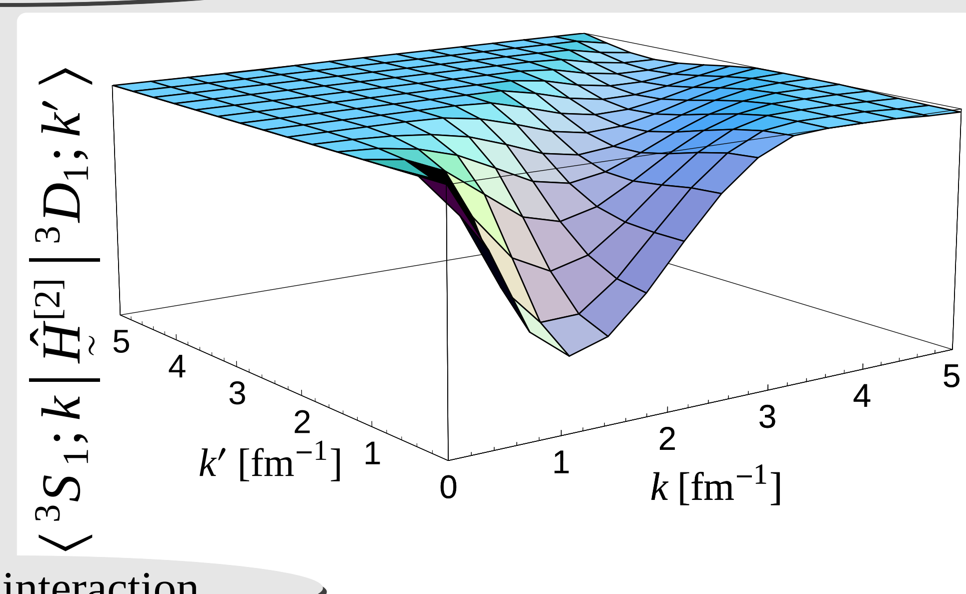




bare potential

➨ “pre-diagonalization”





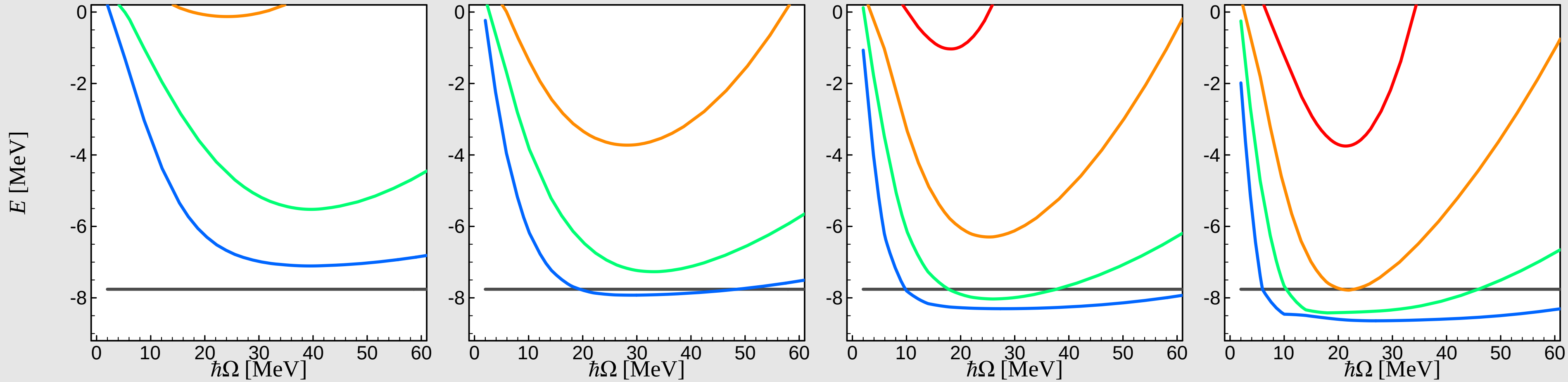
correlated interaction

No-Core Shell Model Calculations

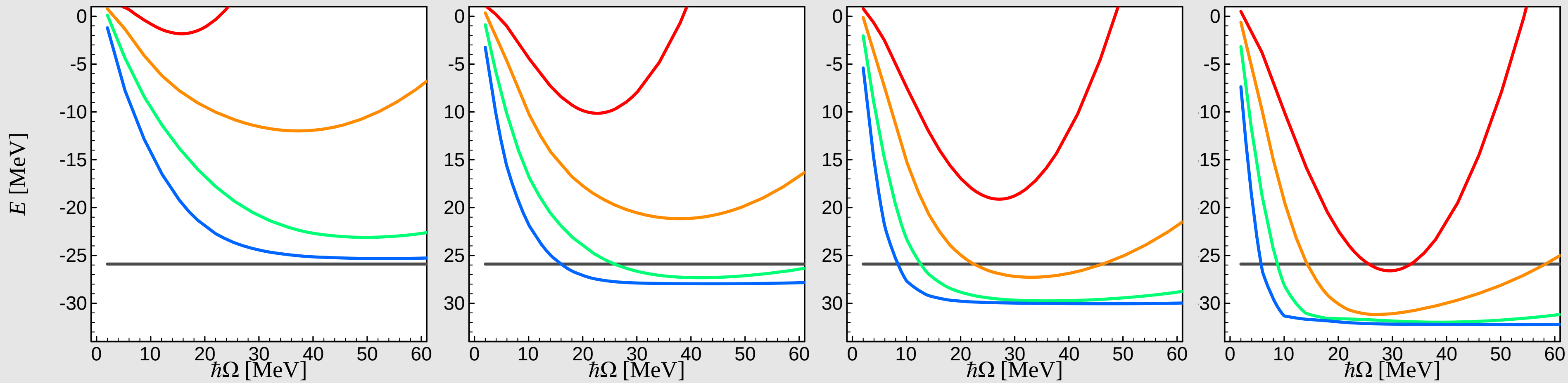
preliminary

Increasing range of tensor correlator

^{3}He

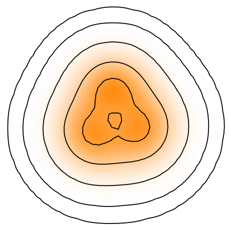


^{4}He



^{11}B (^{3}He, *t*) ^{11}C – Gamov-Teller transitions

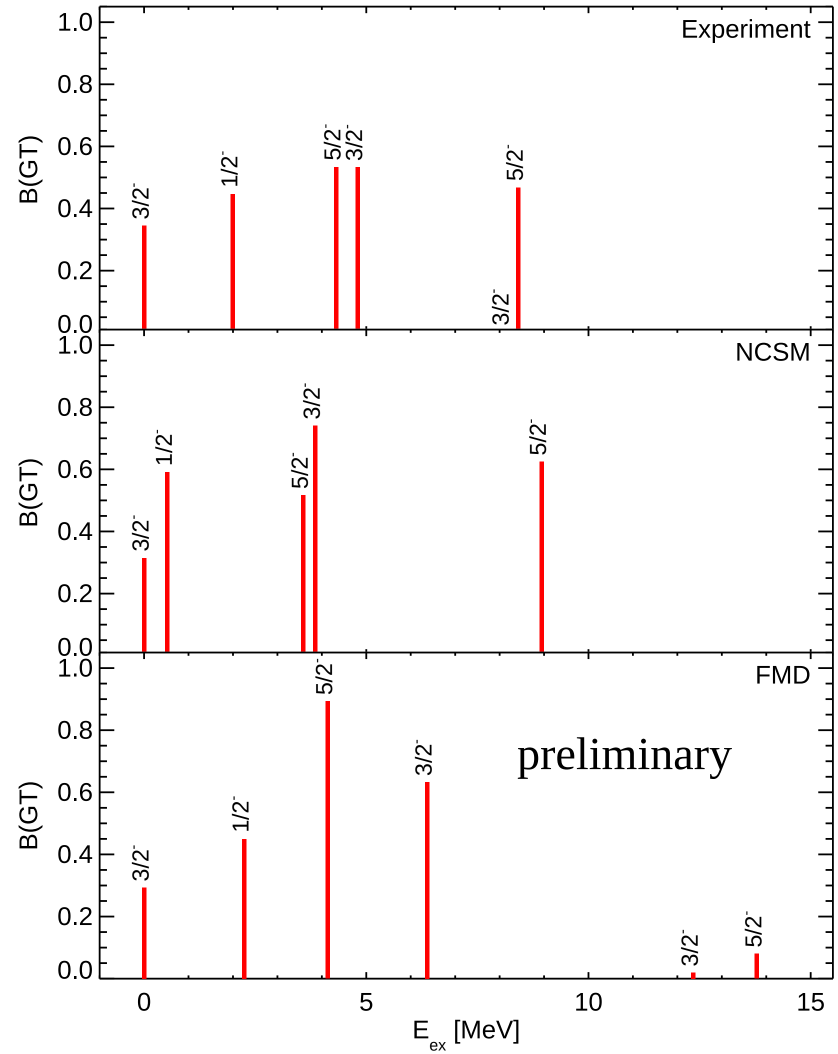
^{11}B



transition: $\underset{\sim}{C}_{\Omega}^{-1}\ \sigma\tau_{+}\ \underset{\sim}{C}_{\Omega}$
up to now only: $\sigma\tau_{+}$

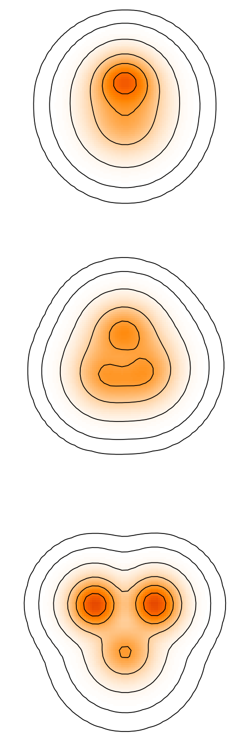
NCSM: Navrátil, Ormand
no core shell model with 3-body force, PRC 68(2003)
third $3/2^{-}$ missing

FMD with configuration mixing



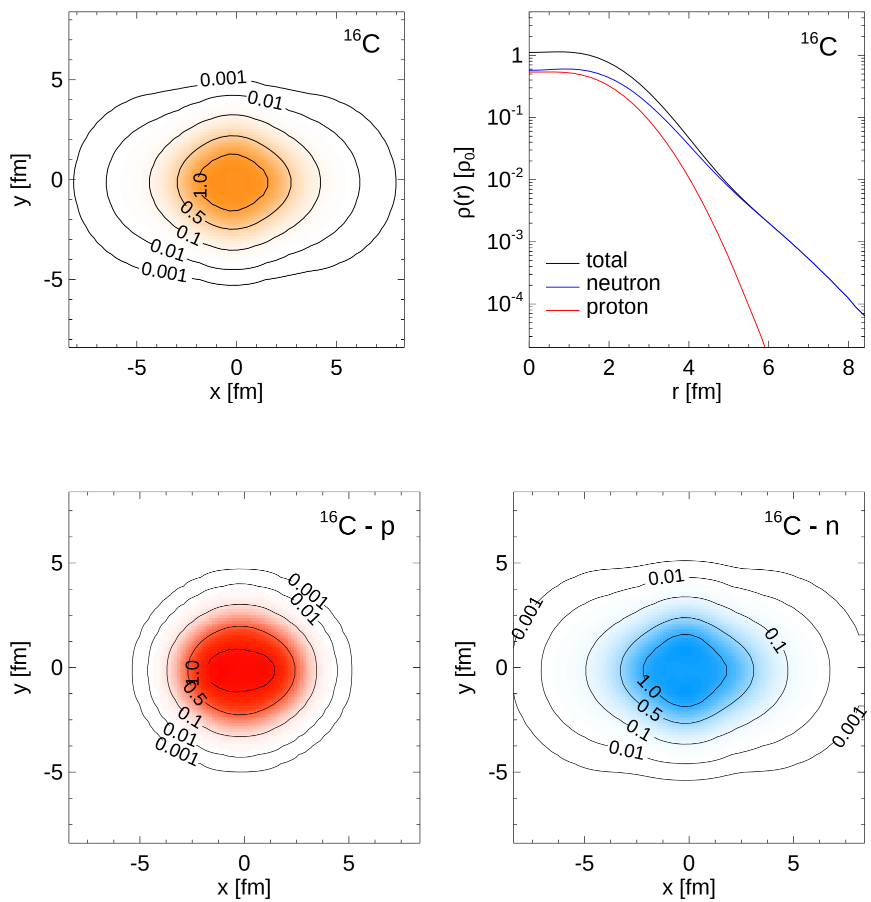
Exp.: Y. Fujita, P. von Brentano et al.
Phys. Rev. C 70, 011306(R) (2004)

^{11}C



^{16}C PAV only

Variation



	E_b [MeV]	r_{charge} [fm]	r_{matter} [fm]
PAV 1g	99.1	2.52	2.88
PAV	105.0	2.49	2.60
Exp	110.8		2.70 ± 0.03
			2.76 ± 0.06

	E_{2^+} [MeV]	$B(E2)$ [e^2fm^4]
PAV	1.29	4.6
Exp	1.77	3.15 ± 0.95
Global Best Fit[1]	1.77	82 ± 14

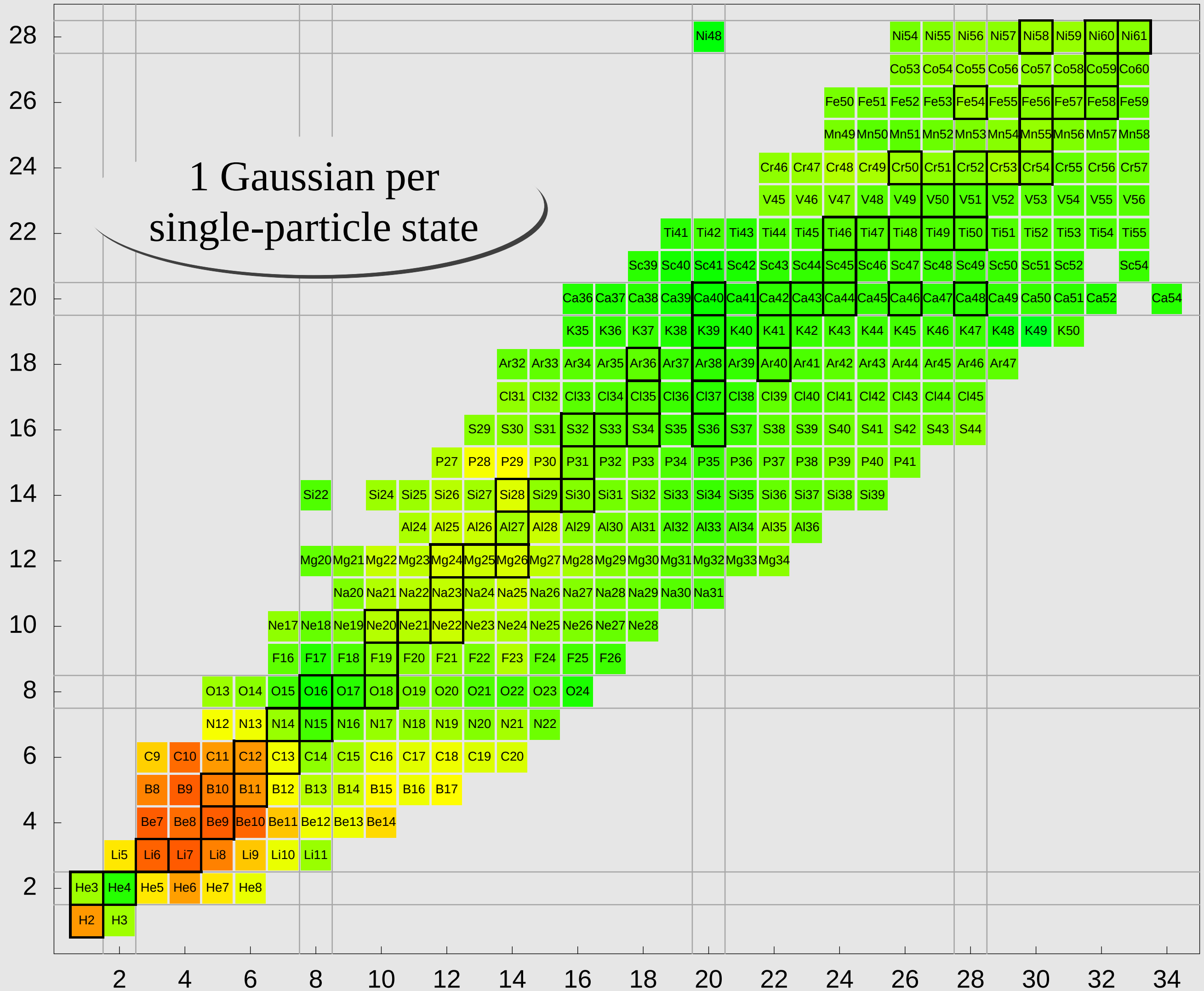
[1] Raman *et al*, Atomic Data and Nuclear Data Tables **78** (2001) 1

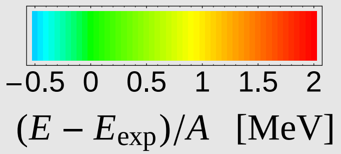
- calculated B(E2) consistent with anomalously long lifetime of 2^+ state measured at RIKEN

  Imai *et al*, PRL in print

FMD, Variation

Nuclear Chart

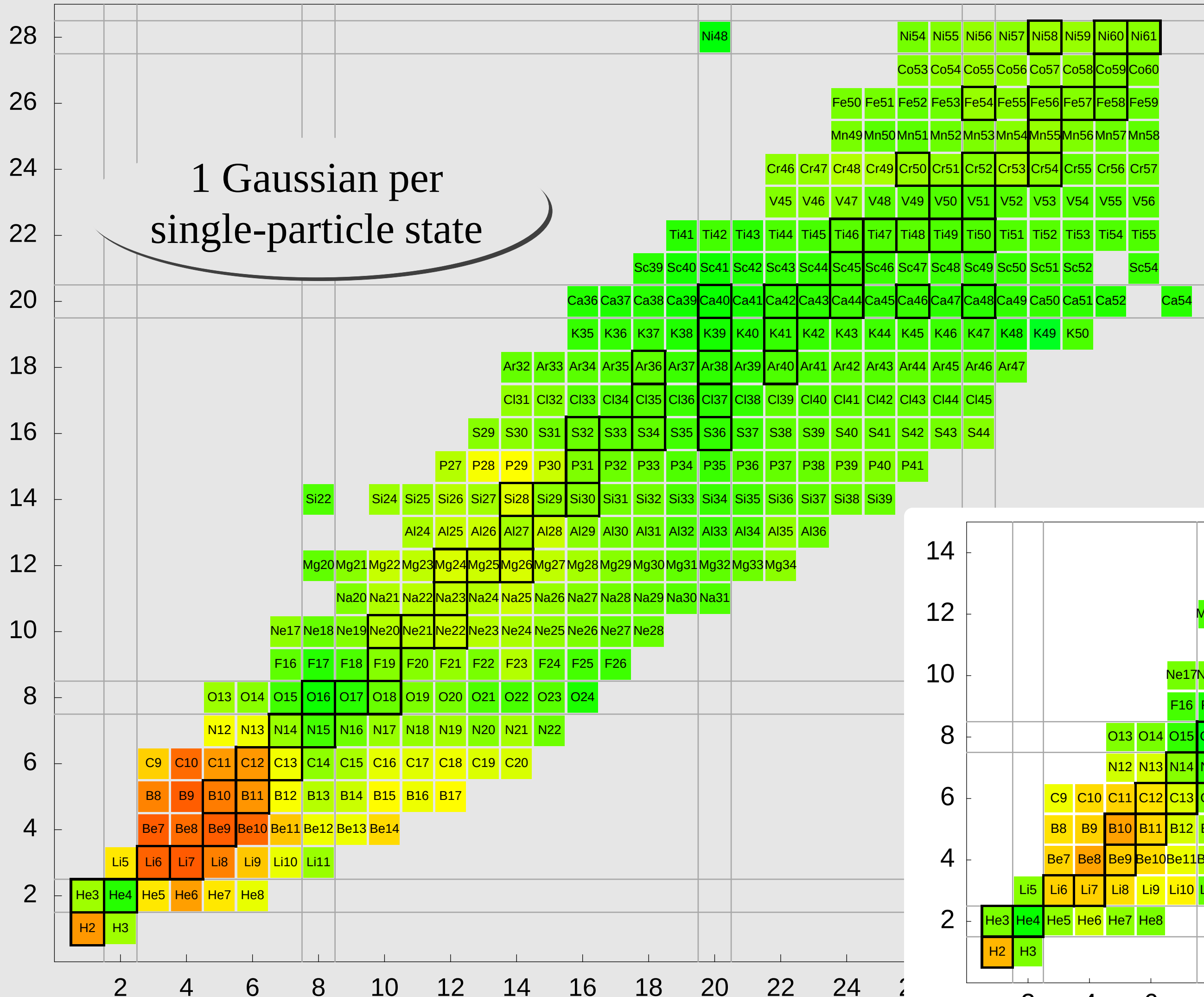


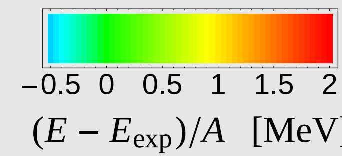


correlated $AV18 + \widehat{\underset{\sim}{H}}^{corr}$

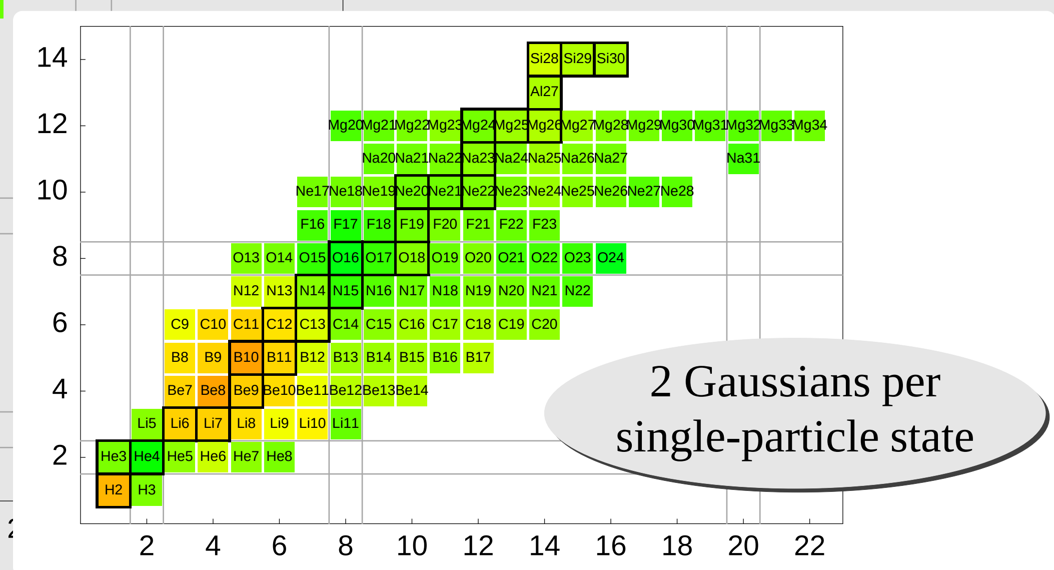
FMD, Variation

Nuclear Chart

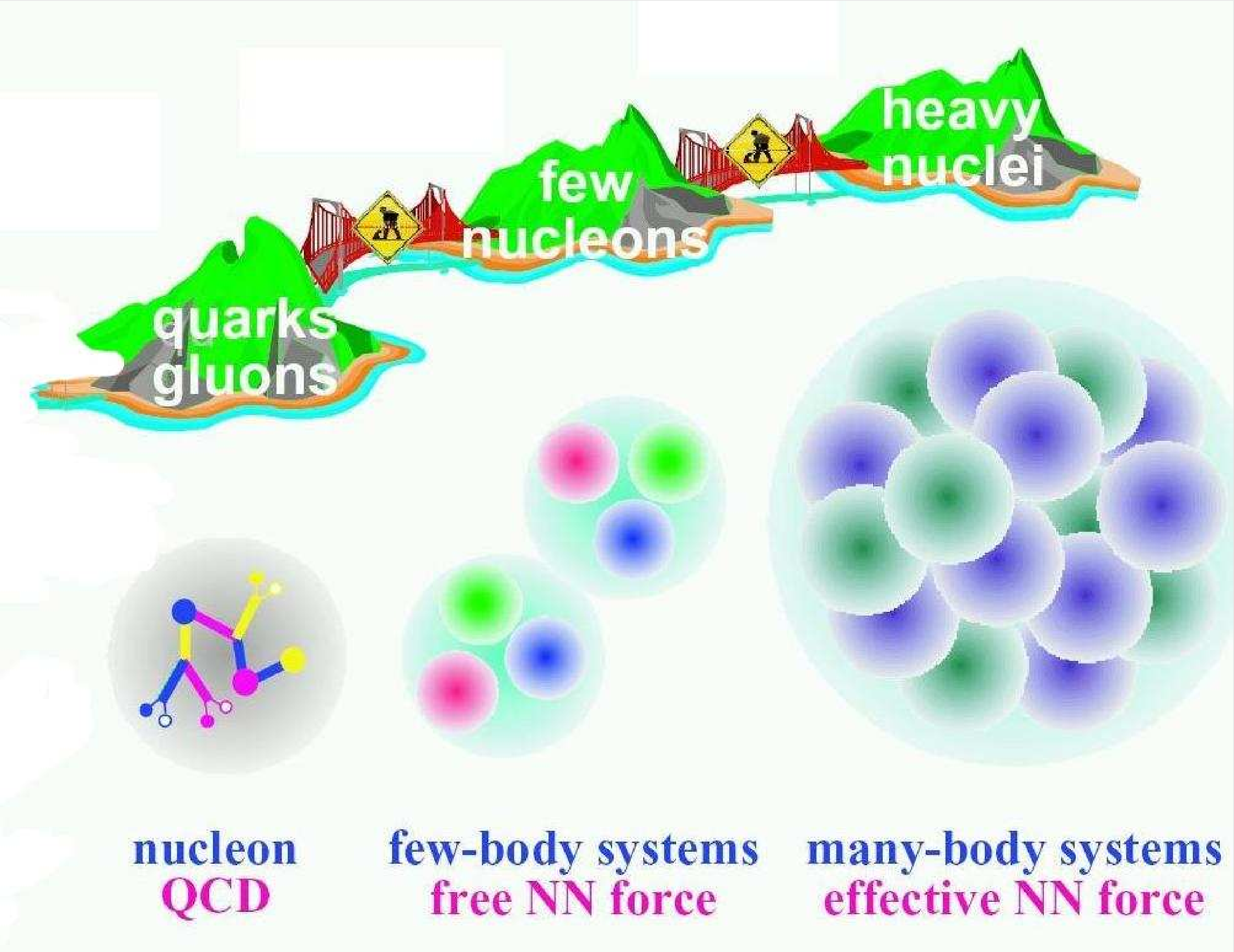




correlated $AV18 + \widetilde{\widehat{H}}^{corr}$



Nuclear Degrees of Freedom



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