Fisica nucleare teorica
Iniziativa specifica MONSTRE

MOdeling
Nuclear
STructure and
REactions

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P. Klausner (Dott. XXXVIII)
F. Marino (Dott. XXXVII)

In Memoriam: Ricardo Americo Broglia (1939–2022)

Ricardo Americo Broglia

Ricardo Americo Broglia passed away in Milan on 4 October 2022. He was born in Cordoba, Argentina, in 1939. He started his master's studies at Instituto Balseiro of the University of Cuyo in Bariloche and then went to Buenos Aires to pursue his Ph.D. in nuclear structure theory under the supervision of Daniel R. Bès. Starting in 1965, he carried out intense research activity at the Niels Bohr Institute in Copenhagen. At the time, the institute was one of the most important centers in the world for the study of nuclear physics, with a group of theorists and experimentalists led by Aage Bohr and Ben Mottelson, who would be awarded the Nobel Prize in physics in 1975. Broglia embarked on a systematic study of two-nucleon transfer reactions, clarifying the role of pairing vibrations as elementary modes of excitations in closed shell nuclei and of pairing rotations in superfluid nuclei as well as establishing the parallel between pairing and surface vibrational modes. He carried out intense and important work on direct, deep inelastic and fusion reactions, developing a particularly close collaboration with Aage Winther. He was one of the main contributors to the development of nuclear field theory, a framework able to deal with the coupling between particles and the collective nuclear motion systematically.

Broglia's strong interest in the interplay between theory and experiment resulted in a close collaboration with the gamma spectroscopy groups in Copenhagen and in Milan led by Bent Herskind and Angela Bracco, in particular concerning the study of rotational motion in the quasi continuum as well as of giant resonances at finite temperature, working closely with Pier Francesco Bortignon. In 1985, Broglia joined the Department of Physics of the University of Milan and the Milano INFN Unit. A group developed around him. They applied many-body theory to the study of nuclear structure and direct nuclear reactions, striving to get a coherent description of the two fields, particularly in the case of loosely bound nuclei. Broglia investigated the link between nuclear and condensed matter superfluidity in an original way, studying in particular the contribution of many-body correlations to the pairing interaction, together with Francisco Barranco. His research activity in nuclear physics led to the publication of several monographs of which he was coauthor, some of which represent classic references in the field, like the book on heavy ion reactions written with Aage Winther, while the last one was published at the end of 2021, together with Gregory Potel.

With his vast and deep scientific culture and enthusiasm, Broglia brought continuous inspiration and encouragement to collaborators and students. For him, physics was a human activity not disconnected from art, philosophy, or music. He found it natural to work on different fields of physics, rapidly understanding the essentials and also the prospects for applications. Thanks to him, theoretical and experimental activities for the study and characterization of nanoaggregates began in Milan in the early 1990s, with the opening of a dedicated laboratory directed by Paolo Milani. For many years, Broglia was involved in the physics of proteins, in close collaboration with Guido Tiana. Among other things, he developed the idea of designing molecules that inhibit the activity of harmful proteins by binding and stabilizing disordered conformations, rather than by hitting their active conformation, as conventional inhibitors do.

Broglia taught nuclear structure theory for over 40 years and was the director of various international schools in Erice and Varenna. Several of his students now work as established researchers. His enthusiasm for physics sustained him right to the end. Researchers at the Legnaro Laboratories have just carried out an experiment stemming from one of his ideas concerning the Josephson effect, on which he kept working almost until the end of his life.

Thomas Døssing
Niels Bohr Institute, Copenhagen, Denmark

Enrico Vigezzi
Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Italy

INFN

MOdeling Nuclear STructure and REactions

Rappresentante Nazionale : E. Vigezzi

Strutture INFN — **Ricercatori:** 35 (23.4 FTE) -

BO CT LNS MI NA PD TIFP

Tradizionale collaborazione con i gruppi sperimentali

70% GAMMA:
C. Barbieri
G. Colò
X. Roca-Maza
E. Vigezzi (Osservatore di Comm. IV in Comm. III)

UNIVERSITÀ DEGLI STUDI DI MILANO

INFN
Istituto Nazionale di Fisica Nucleare

VIth Topical Workshop on Modern Aspects in Nuclear Structure

The Many Facets of Nuclear Structure

BORMIO 6 – 11 February 2023

Angela Bracco
Franco Camera
Gianluca Colò
Silvia Leoni

Local Organization Support
C. Barbieri, G. Benzoni, S. Bottoni, F. Crespi, A. Giaz, S. Laskar, B. Million, X. Roca-Maza, M. Polettini, E. Vigezzi, O.Wieland

4° Incontro Nazionale di Fisica Nucleare

Catania - Laboratori Nazionali del Sud

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The Galileo Galilei Institute For Theoretical Physics

Centro Nazionale di Studi Avanzati dell'Istituto Nazionale di Fisica Nucleare

Arcetri, Firenze

FNHP2023
FRONTIERS IN NUCLEAR AND HADRONIC PHYSICS

School at the Galileo Galilei Institute for Theoretical Physics
Florence, February 27 - March 10, 2023

ORGANIZERS

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DTP 2023 | AB INITIO METHODS AND EMERGING TECHNOLOGIES FOR NUCLEAR STRUCTURE

EURO-LABS EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES · UNIVERSITÀ DI TRENTO Dipartimento di Fisica · UNIVERSITÀ DEGLI STUDI DI MILANO DIPARTIMENTO DI FISICA · FRIB Theory Alliance

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EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

The Project

PROJECT ACRONYM: EURO-LABS – EUROpean Laboratories for Accelerator Based Science
PROGRAMME: Horizon EU (Research infrastructure services to support health research, accelerate the green and digital transformation, and advance frontier knowledge)
DURATION: September 2022- August 2026 (4 years)
TOTAL BUDGET: 14.5 M€
TOTAL EC CONTRIBUTION:14.2 M€
CONSORTIUM: 33 participants from 18 countries
PROJECT COORDINATOR: Paolo Giacomelli (INFN)

Theo4Exp virtual access infrastructure

IFJ PAN Krakow, University of Seville and University of Milano

HOME | EURO-LABS | MEANFIELD4EXP | REACTION4EXP | STRUCTURE4EXP | RESEARCH TEAM

About Theo4Exp

Theo4Exp virtual infrastructure will provide theoretical tools for the EuroLabs project as well as on the wider experimental nuclear physics community. It is designed as an open access platform, where key computer codes, as well as results of calculations, will be made accessible to the community.

Theo4Exp includes three installations:

1. MeanField4Exp (IFJ PAN Krakow)
2. Reaction4Exp (University of Seville)
3. Structure4Exp (University of Milano)

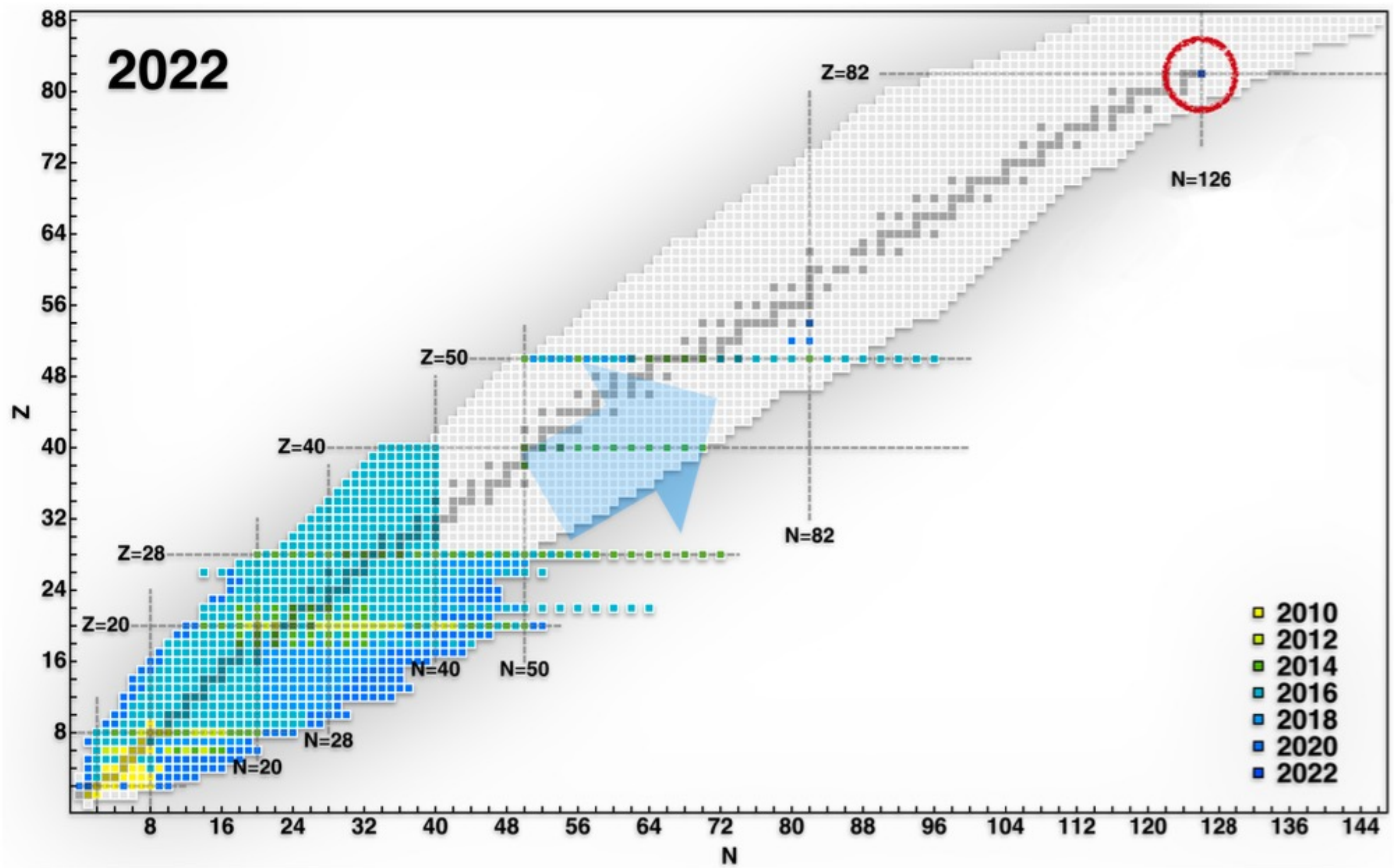
EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

Il gruppo si interessa principalmente di problemi teorici di struttura nucleare:

a) **dell'interazione forte che agisce in maniera efficace tra i nucleoni;**
b) **delle opportune tecniche per sistemi fermionici a molti corpi, che consentono di studiare e comprendere la ricca fenomenologia nucleare.**

Teoria del funzionali densita'
Teoria di campo nucleare
Eccitazioni collettive
Reazioni di trasferimento di nucleoni
Superfluidita' nucleare
Stelle di neutroni
Cattura elettronica, Risonanza di Gamow-Teller
e decadimento beta
Violazione di parita' , e-N scattering

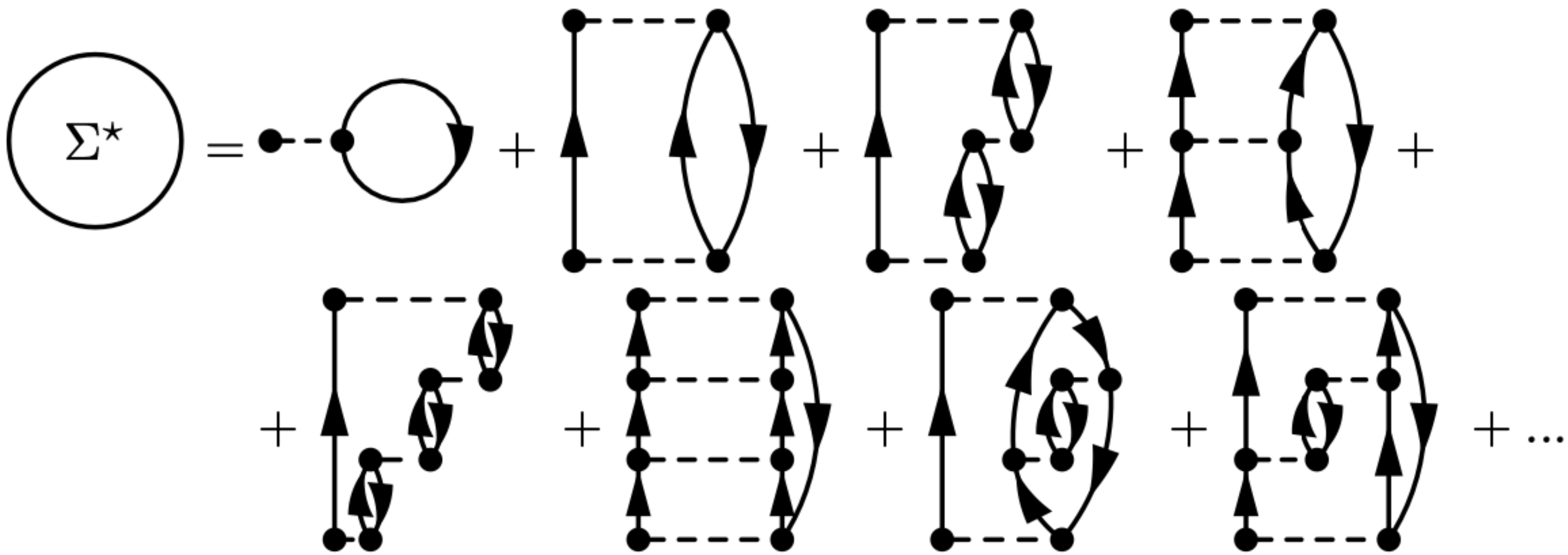
First principle calculations with Hamiltonians derived from QCD



Adapted from Hergert, *Frontiers in Physics* (2020)

The Green's function is found as the exact solution of the Dyson equation

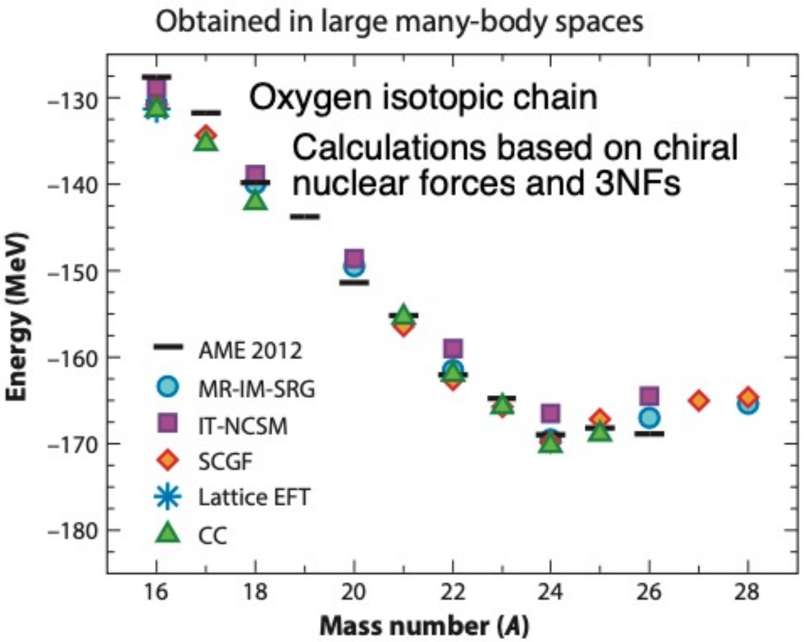
$$G_{\alpha\beta}(\omega) = G^{(0)}_{\alpha\beta}(\omega) + \sum_{\gamma\delta} G^{(0)}_{\alpha\gamma}(\omega)\, \Sigma^{\star}_{\gamma\delta}(\omega)\, G_{\delta\beta}(\omega)\,.$$



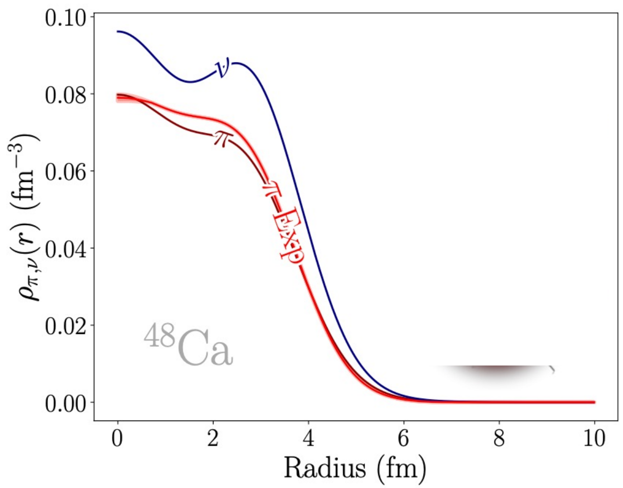
New techniques for sampling the relevant diagrams:
S. Brolli, Ph.D. project

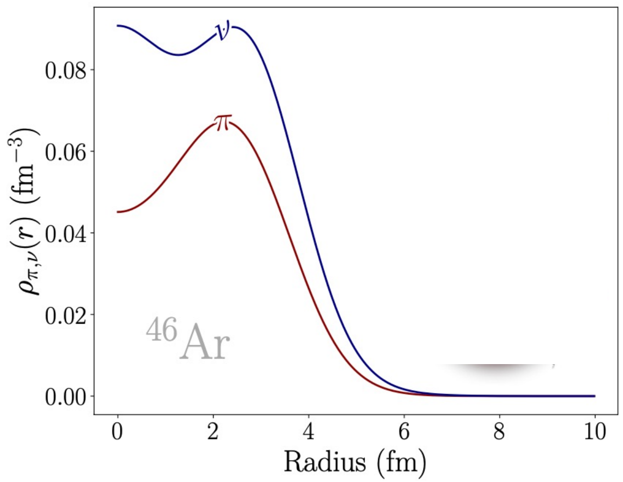
Ab initio calculation of energy and density

Energy of Oxygen isotopes up to the drip line



Bubble in the proton density of ^{46}Ar



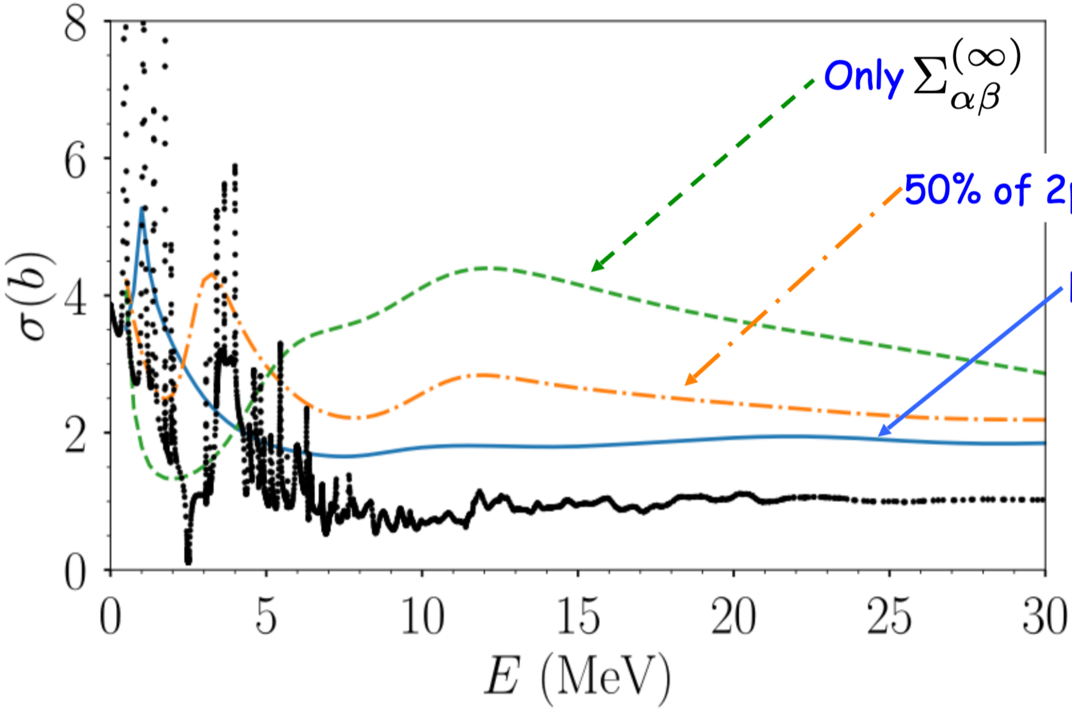


Ab initio calculation of optical potentials

Role of intermediate state configurations (ISCs)

[A. Idini, CB, Navrátil,
Phys. Rev. Lett. **123**, 092501 (2019)]

n-^{16}O, total elastic cross section



Only $\Sigma^{(\infty)}_{\alpha\beta}$

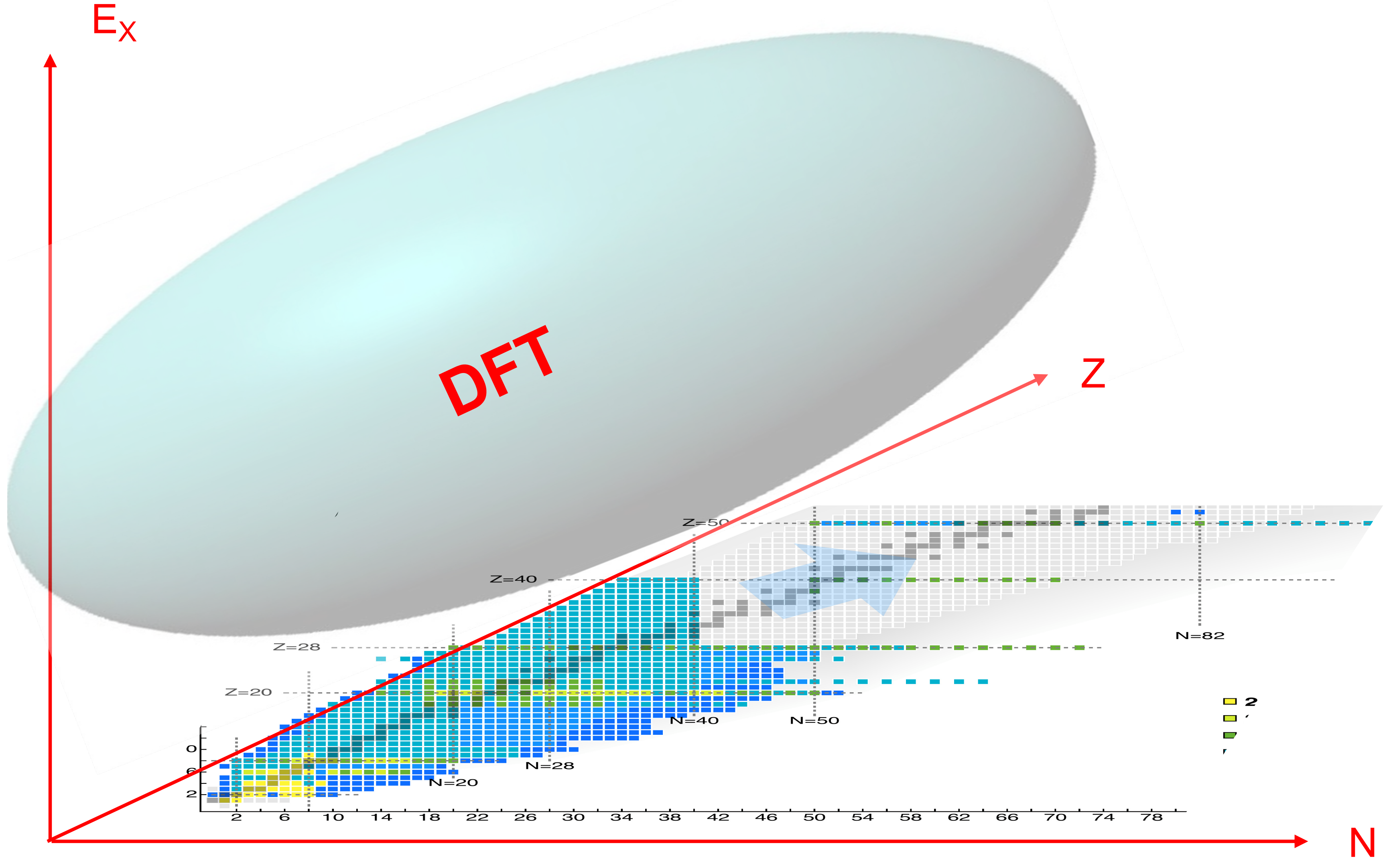
50% of 2p1h/2h1p poles suppressed

Full $\Sigma^{\star}_{\alpha\beta}(\omega)$ (all ISCs included)

High order configurations, or ADC(n>>3), to be critical for fully ab initio optical potentials

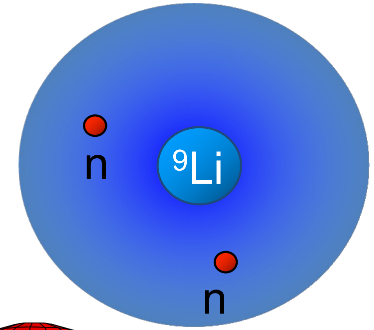
Density Functional Theory

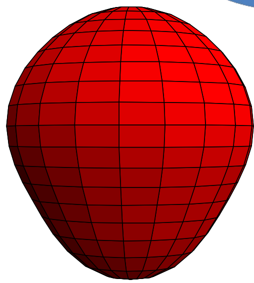
The theoretical framework for a global study of the properties of nuclei in the ground and escited states throughout the mass table

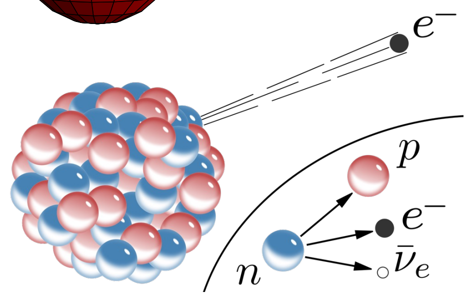


Status of nuclear DFT (very brief...)

- Error on **masses** of the order of 1 MeV.
- Predictions of **drip lines** and **super heavy** nuclei.
- Trends of **charge radii and deformations** fairly well reproduced.
- Advanced (multi-reference) techniques based on **symmetry restoration.**
- **Giant resonances, charge-exchange states and β-decay.**
- Current interest in **large amplitude motion, reactions** etc.







Skyrme (local) EDF

$$E = \int d^3r \ \left[\mathcal{E}^{\mathrm{kin}} + \mathcal{E}^{\mathrm{Skyrme}} + \mathcal{E}^{\mathrm{pairing}} + \mathcal{E}^{\mathrm{Coulomb}}\right]$$

Each term is an energy density, function of local densities.

$$\mathcal{E}^{\mathrm{Skyrme}} = C^{\rho\rho}[\rho]\rho^2 + C^{\rho\tau}\rho\tau + C^{J^2}\vec{J}^{\,2} + C^{(\nabla\rho)^2}\left(\vec{\nabla}\rho\right)^2 + C^{\rho\vec{\nabla}\cdot\vec{J}}\rho\vec{\nabla}\cdot\vec{J}$$

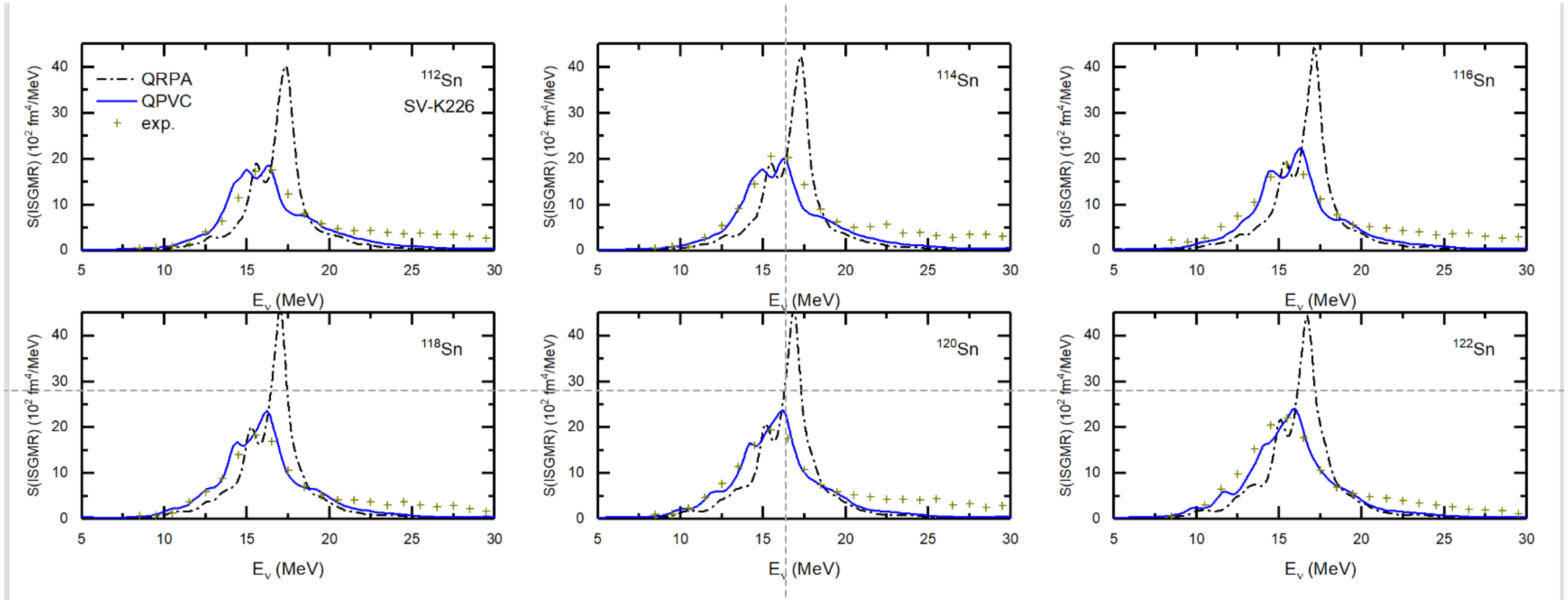
$$\tau = \sum_i |\vec{\nabla}\phi_i|^2 \qquad \vec{J} = \sum_{i,\sigma,\sigma'} \phi_i^\dagger \vec{\nabla}\phi_i \times \langle\sigma'|\vec{\sigma}|\sigma\rangle$$

Labels related to p, n omitted.

In principle all coupling constants could be, in turn, functions of the densities.

$$C^{\rho\rho}[\rho] = A + B\rho^\gamma$$

Systematic calculation of monopole resonance in Sn isotopes



Combining DFT and *ab initio*

Ab initio

- fundamental and unbiased

DFT

- universally applicable

Can we use *ab initio* to inform nuclear DFT ?

Ab initio → **Density functional theory**

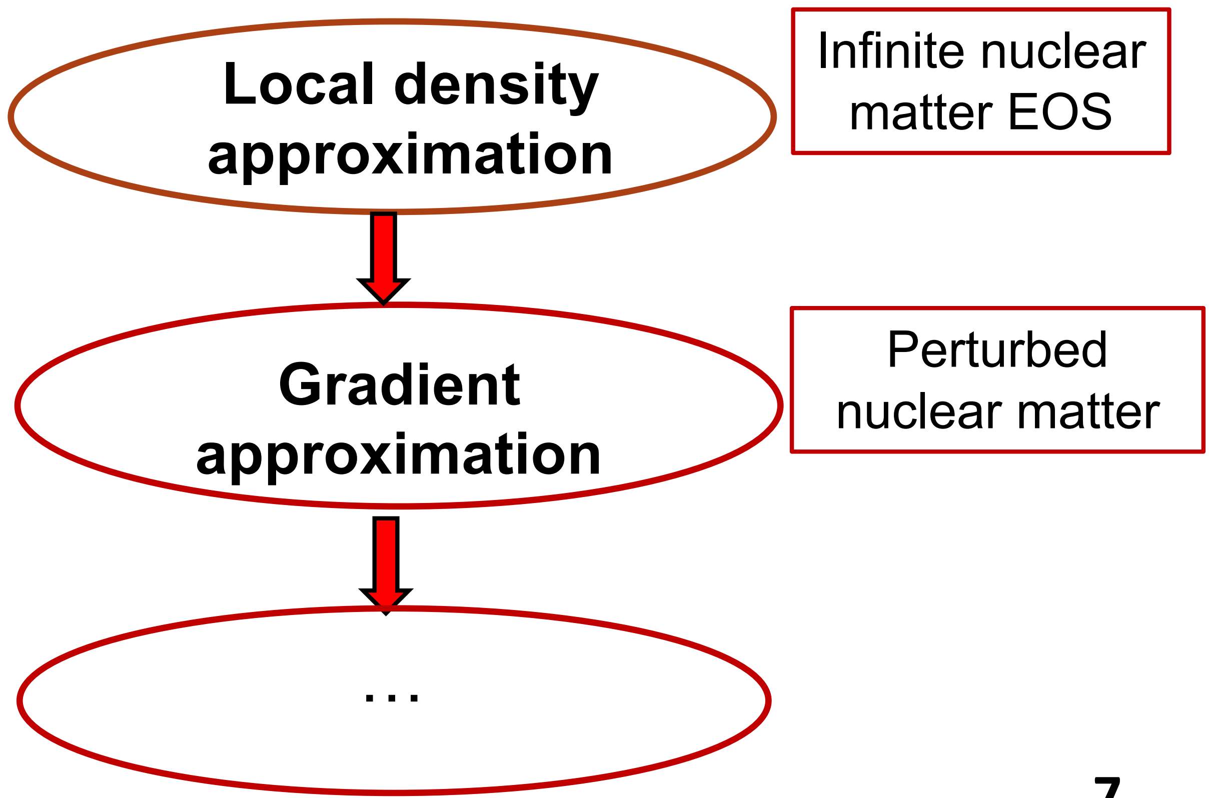
Our systematic strategy

Strategy inspired by the **«Jacob's ladder»** of condensed matter DFT

Two key principles

1. Follow a **step by step** approach

2. Use ***ab initio*** simulations of model systems as a **constraint** to the EDF



AFDMC 1

Diffusion Monte Carlo is an exact method for the many-body ground state

$$\Psi_0(X) = \lim_{\tau\to+\infty} \Psi(X,\tau) = \lim_{\tau\to+\infty} e^{-(\hat{H}-E_T)\tau}\,\Psi_T(X)$$

Imaginary-time **projection** of a trial state

$$E_0 = \lim_{\tau\to+\infty} \frac{\langle\Psi_T|\hat{H}|\Psi(\tau)\rangle}{\langle\Psi_T|\Psi(\tau)\rangle} = \frac{1}{M}\sum_{i=1}^{M}\frac{(H\Psi_T)(X_i)}{\Psi_T(X_i)}$$

Stochastic estimate of the energy

$$\Psi_T(X) = \prod_{i<j} f(r_{ij})\left(1 + \sum_{i<j}\sum_{p=1}^{4} f_p(r_{ij})O_{ij}^p\right)\Phi(X)$$

Jastrow correlations

Linear operator correlations

Mean field state

The AV4' interaction contains four operators $O_{ij}^p = 1, \sigma_i\cdot\sigma_j, \tau_i\cdot\tau_j, (\sigma_i\cdot\sigma_j)(\tau_i\cdot\tau_j)$

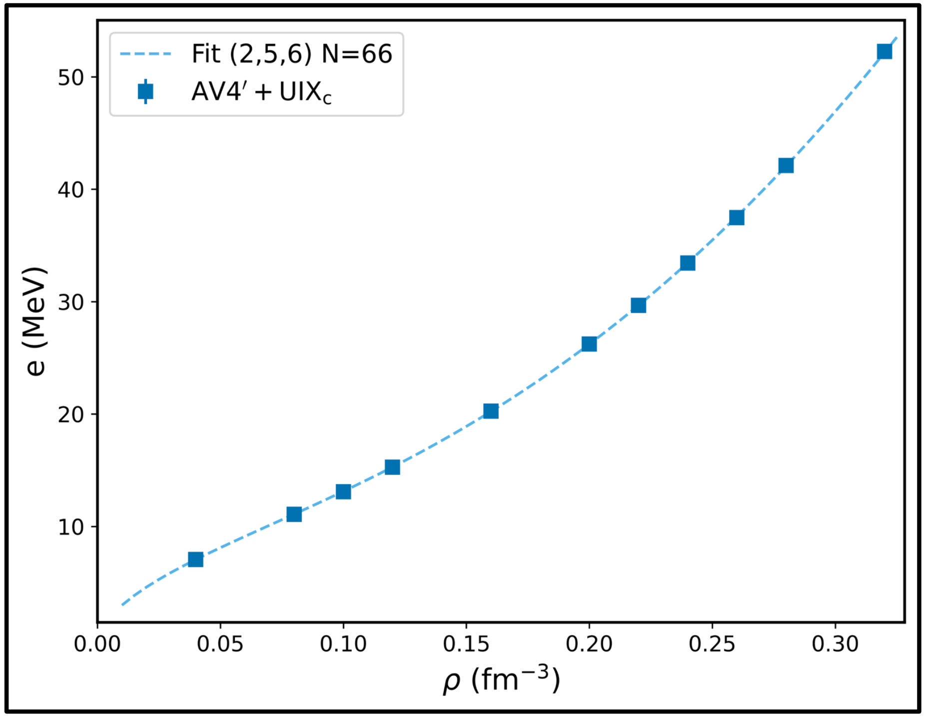
Gandolfi, Phys. Rev. C **90**, 061306 (2014)
Gezerlis, Phys. Rev. C **95**, 044309 (2017)

Results AFDMC 1

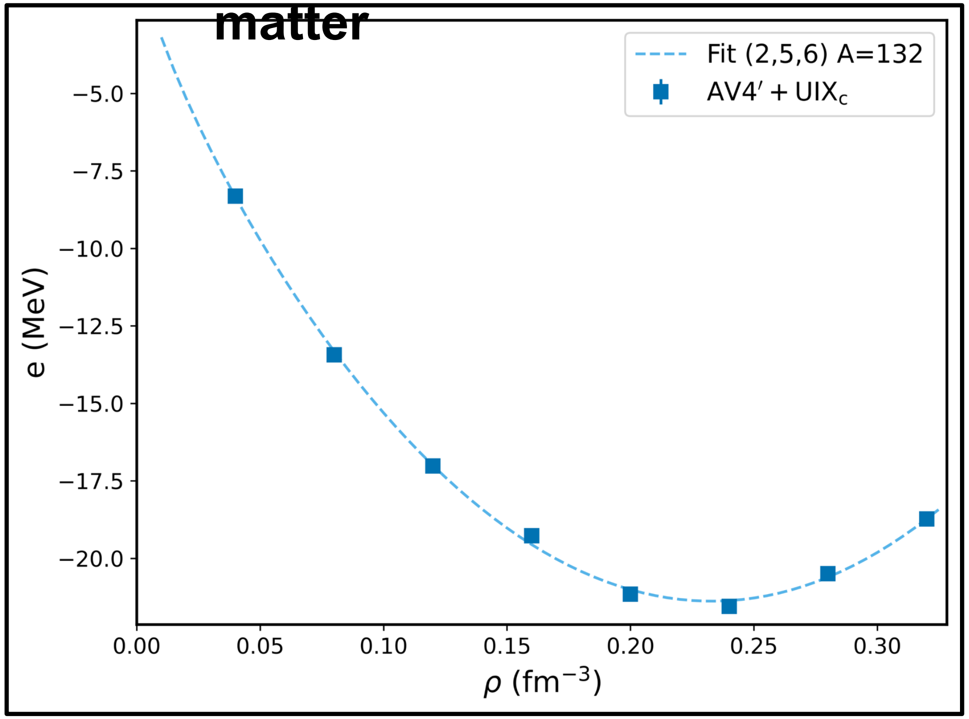
Equation of state

AV4'+UIX$_c$ interaction

Pure neutron matter

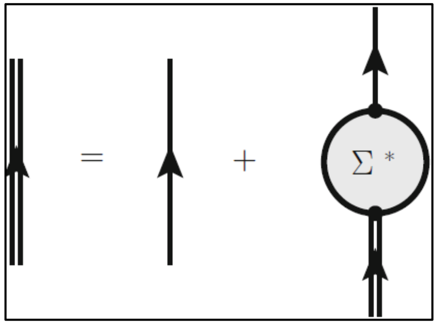


Symmetric nuclear matter



Self-consistent Green's functions

Dyson equation $g_{\alpha\beta}(\omega) = g^{(0)}_{\alpha\beta}(\omega) + \sum_{\gamma\delta} g_{\alpha\gamma}(\omega)\Sigma^{*}_{\gamma\delta}(\omega) g^{(0)}_{\delta\beta}(\omega)$

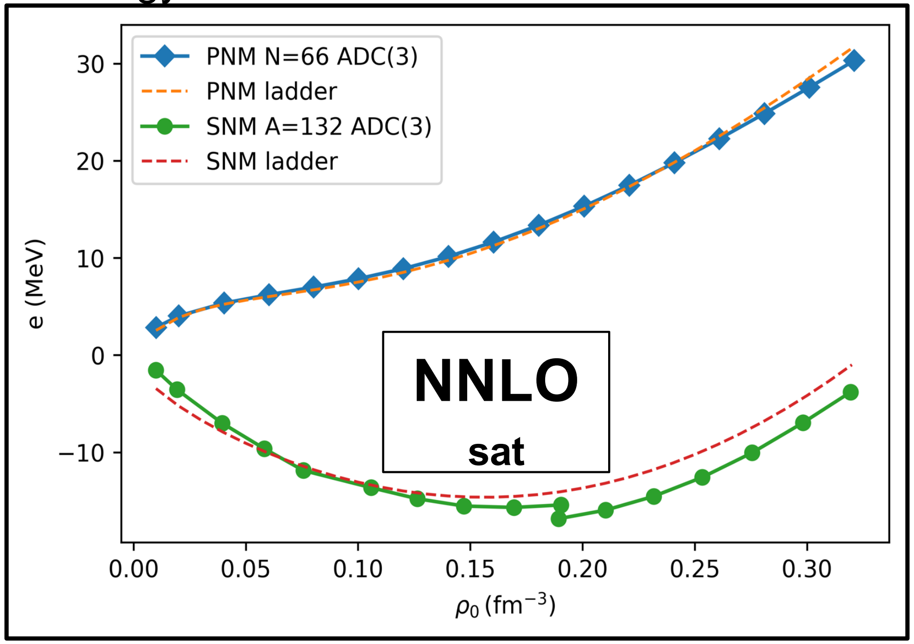


One-body propagator

Self-energy

$g_{\alpha\beta}(\omega)$ gives access to total energy, addition/removal energies, single-particle observables, spectral functions…

Currently implementing **ADC(3)** in infinite nuclear matter



Preliminary !

C. Barbieri and A. Carbone, Lect. Notes Phys. **936**, 571 (2017)

C. McIlroy, Ph.D. thesis, University of Surrey (2020)