CIPANP 2022 Summary: Nuclear Forces and Structure, NN Correlations, and Medium Effects

* Slides presented by Shujie Li, Berkeley Lab

Session Conveners

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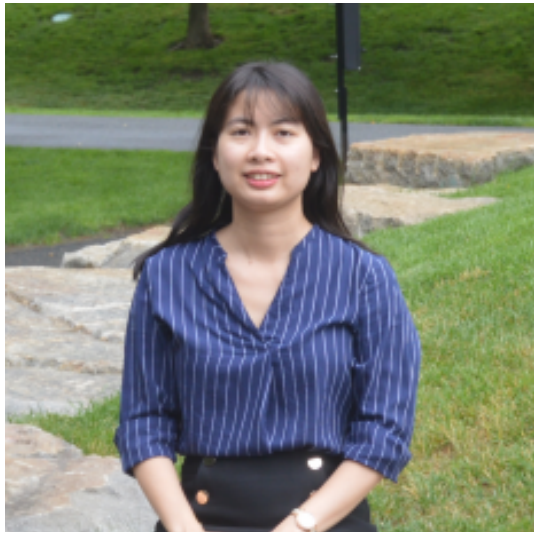

Dien Nguyen
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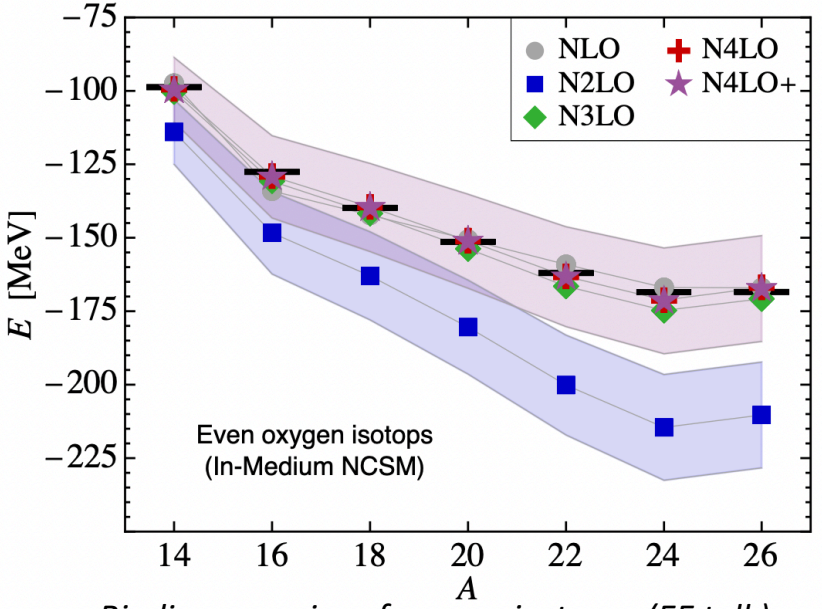
Topic 1: Constructing “bare” and “effective” nuclear Hamiltonians

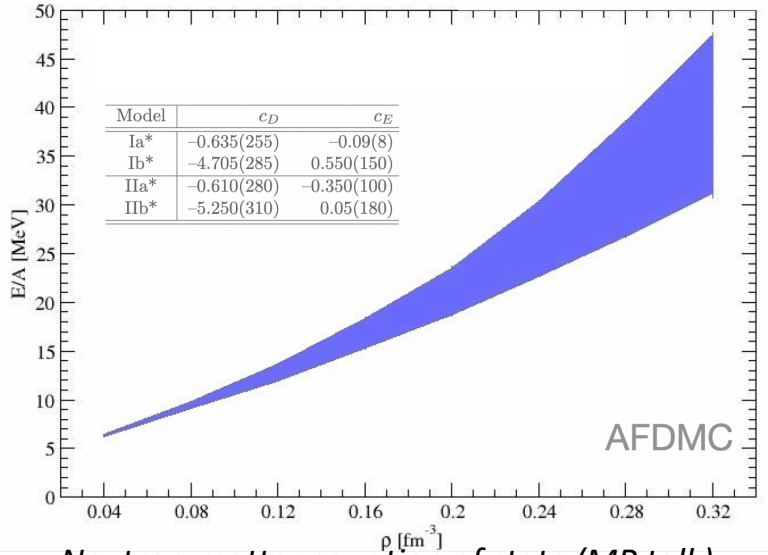
- ***Chiral effective field theory overview:*** **Evgeny Epelbaum** overviewed the status of chiral effective field-theories, highlighting the need for using symmetry-preserving regulator in three-nucleon forces and currents beyond N²LO. Selected results in nuclei up to the Oxygen chain show a remarkable predictive power of chiral-EFT although charge radii exhibit some differences with experiments. Precision calculations of the charge radii of A ≤ 4 nuclei are in excellent agreement with experiments.

- ***Analyzing the nuclear interaction: challenges and new opportunities:*** ***Maria Piarulli*** presented tremendous progress in ab-initio nuclear theory due to increased algorithms efficiency, benchmarks with rigorous uncertainty quantification. Despite this progress, she highlighted the need for a more quantitative connection between properties of finite nuclei and nuclear matter.

- ***Interactions between hyperons and nucleons from Lattice QCD:*** After a brief introduction to Lattice-QCD, **Marc Illa** discussed the importance and the robustness of using a variational approach to improve the accuracy of the calculations. He then showed the first steps taken to study these systems using quantum computers.



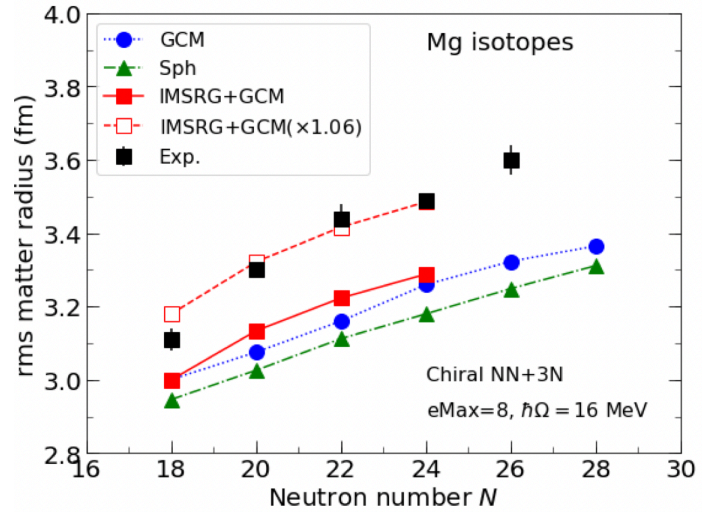
Binding energies of oxygen isotopes (EE talk)



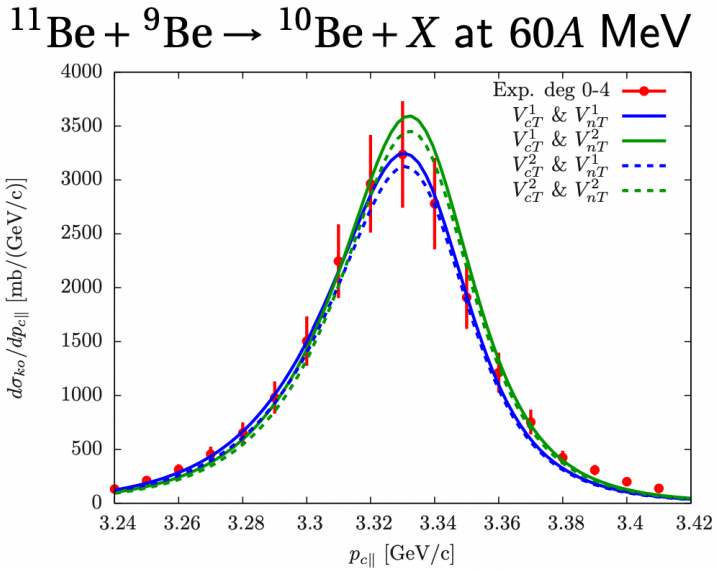
Neutron-matter equation of state (MP talk)

Topic 2: Probing nuclear forces: from light and medium-mass nuclei to the equation of state of nucleonic matter

- ***A Status Update on Ab Initio Calculations in Nuclear Physics:*** ***Heiko Hergert*** overviewed recent ab-initio results, including the first converged calculations of Pb-208 with two- and three-nucleon interactions from chiral EFT, and electroweak transitions of interest for fundamental symmetry program. He then looked ahead at the next round of challenges in improving the accuracy and expanding the reach of ab initio methods to deformed and more exotic nuclei.
- ***Analyzing the nuclear interaction: challenges and new opportunities:*** **Stefano Gandolfi** discussed several new results for quantum Monte Carlo calculations of nuclei up to A=16. He addressed several questions regarding the prediction power of local, chiral-EFT Hamiltonians, and issues related to regulators artifacts.
- ***Implications of PREX on the determination of the Nuclear Equation of State:*** **Jorge Piekarewicz** discussed the tension between the neutron skin thickness of 208Pb measured by the PREX collaboration and the tidal deformability of a 1.4 Msun neutron star reported by the LIGO-Virgo collaboration.
- ***One-neutron knockout reactions off halo nuclei and heavier neutron-rich projectiles as a probe for the neutron skin:*** ***Chloë Hebborn*** bridged ab initio predictions and one- neutron knockout observables combining effective field theory descriptions of halo nuclei with a few-body reaction formalism. She showed that one-neutron knockout cross sections of neutron-rich nuclei could be used to extract information about neutron skin thickness.



Mg isotopes radii (HH talk)



Halo knockout reaction (CH talk)

Topic 3: Rare Isotope Science

Progress in Rare Isotope Science has been impressive over the last decade and *the field is poised for major leaps forward*:

- ***(Plenary talk) FRIB*** **has just come online! Brad Sherrill** presented an overview of the technical and scientific aspects of the facility, and reviewed the overall science program to (1) develop a predictive model of atomic nuclei, (2) understand the nuclear reactions that drive explosive astrophysical environments and nucleosynthesis, (3) use isotopes for fundamental symmetries tests, and (4) explore societal applications.
- ***DMRG description of Neutron-rich light systems*** **at the very limits of nuclear stability** exhibit features common to all open quantum systems. They reveal qualitatively new information about the nuclear interaction due to their extreme neutron-to-proton ratios and emergent behaviors. Recent experiments observed unexpectedly large influence of continuum effects with 28, 29F isotope. That can be explained by state-of-the-art large-scale shell model calculations including continuum states (Green's function Monte Carlo, **Kevin Fossez**).
- ***CARIBU*** **at ATLAS Is being upgraded** with the n-rich isotopes from a ^{252}Cf fission source replaced by those from neutron-induced fission of ^{235}U, resulting in a 10-fold increase of intensity for research concentrating on precision mass measurements, decay studies and Coulomb excitation measurements of re-accelerated beams further away from stability (**Michael Carpenter**).
- ***ARUNA*** **facilities** (Association for Research at University Nuclear Accelerators) **provide essential complementary and often unique capabilities** such as mono-energetic neutrons and photon beams. They also offer unmatched opportunities for long-term experiments and programs not possible in the environment of national user facilities. They provide outstanding training opportunities for the next generation of nuclear scientists (**Ingo Wiedenhover**).
- **Recent studies of *light p-rich nuclei* at the limit of binding and beyond (Lee Sobotka)** led to the discovery of 7 new isotopes, some well beyond the drip line, herewith enabling tests of recent descriptions of resonant states and of the impact of the continuum. The experimental techniques also resolved the question of the cross section for nucleon-induced inelastic deexcitation of the Hoyle state, a path parallel to EM decay.

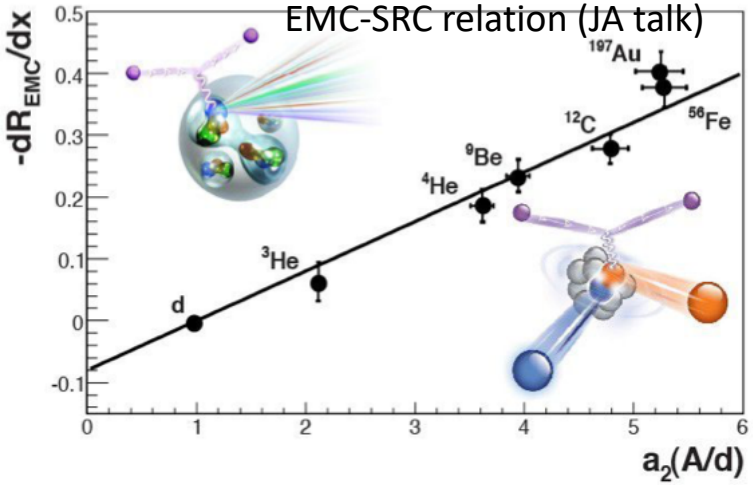
Topic 4: Short-Range Aspects of Nuclear Dynamics

EMC effect

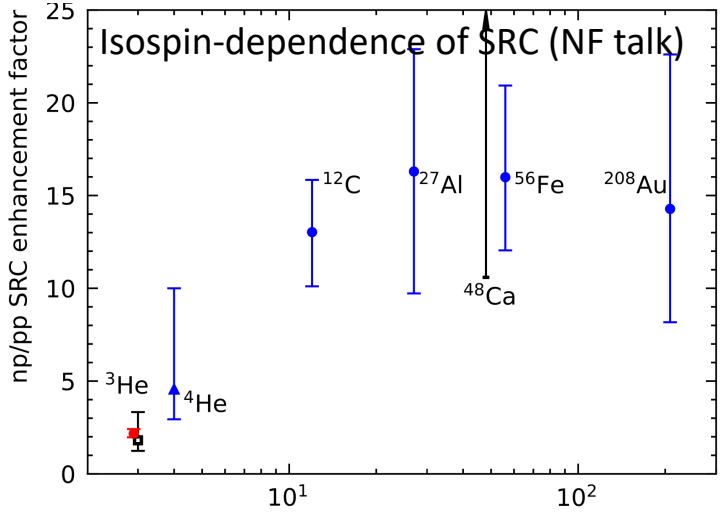
- Quark- and gluon-distributions are different for free nucleons and for bound nucleons inside nuclei.
- The EMC effect shows that nuclei are more than just protons, neutrons, and small binding and motion effects.

- **Despite renewed activity in recent years, e.g., studies of EMC effects in light nuclei (John Arrington), no consensus on origin of EMC effect.**
- **Connection between EMC effect and short-range correlations** (SRC, **Nadia Fomin, John Arrington**):
  - Tantalizing connection between 2N SRCs and EMC effect observed at Jefferson Lab 6 GeV.
  - *High virtuality picture*: Causal relationship, SRC isospin structure generates flavor-dependent EMC effect.
  - *Local density picture*: Common origin, may not have flavor dependence.
- **New observables required to provide more insight:**
  - Tagged DIS measurements (**Florian Hauenstein**): Study nucleon modification for high momentum nucleons
    - Directly probe EMC-SRC correlation and isospin dependence
    - First measurement of neutron-tagged DIS with CLAS12 + BAND
    - Preliminary ratios show large modification of deeply bound proton structure
  - EMC effect on polarized targets: Study nuclear effects,
  - Drell-Yan measurements with nuclear targets: Study contributions from antiquarks.
  - Parity-violating EMC measurements proposed for SoLID **(John Arrington)**: Study flavor dependence with high precision.

EMC-SRC relation (JA talk)



Isospin-dependence of SRC (NF talk)



Topic 5: Testing the Standard Model with Nuclei

- At present 0nbb is the only viable experimental technique to test the Majorana nature of neutrinos. Its observation would provide major new insights to the beyond-the-Standard-Model (BSM) physics. ***LEGEND*** is a ton-scale ^{76}Ge-based experiment with a discovery potential for a 0nbb half-life beyond 10^{28} years as well as for other searches for BSM physics (**Wenqin Xu**).

- The ***COHERENT*** collaboration searches for neutrino-nucleus interactions from elastic neutrino-nucleus scattering as well as from higher- energy charged and neutral current inelastic measurements. Results have implications for understanding coupling strengths, for searches for BSM physics, as well as for neutrino-nuclear astrophysics (**Kate Scholberg**).

- A universal fit to all available electron scattering data on C and O provide the best determination of the ***Inelastic Coulomb Sum Rule*** (CSR) as a function of q (momentum transfer). The longitudinal Quasielastic (QE) cross section is suppressed by a larger factor than expected from Pauli blocking only. The contribution of nuclear excitations to CSR can be as high as 30%. The extracted CSR values for Carbon are in good agreement with the “first principle Green’s function MC” calculations (**Arie Bodek**).

Topic 6: Medium Effects

- The role of quarks and gluons in nuclei is not well understood. Final state interactions (**FSIs**) in exclusive processes can be used to search for the **onset of color transparency** (CT), a QCD prediction. **Dipangkar Dutta** summarized the color transparency studies for meson and presented results from one of the first Jefferson Lab 12 GeV experiments that searched for the onset of color transparency for protons.
- **Wim Cosyn** discussed **final-state interactions in nuclear breakup measurements at Jefferson Lab and the upcoming EIC**. He presented theoretical work in how FSIs can be used to study QCD dynamics. The phenomenology of FSI is well understood for quasi-elastic and tagged DIS (deuteron) measurements but more experimental data is needed from other processes.
- High-energy reactions with nuclei can be interpreted using **in-medium parton showers**. **Ivan Vitev** introduced his theoretical work on in-medium splitting functions and how they can be implemented in higher order and resumed calculations. He showed the experimental verification of in-medium parton showers being softer and broader than the ones in the vacuum and discussed the significant effort that would be needed to implement in-medium splitting functions in Monte Carlo event generators.
- **Pia Zurita** presented her work on QCD phenomenology for **PDFs for nuclei** and showed how the broad kinematic coverage of DIS measurement at the upcoming Electron-Ion Collider will drastically improve our understanding of PDFs for nuclei. This data will help us deepen our understanding of in medium effects and nuclear dependence (see also Topic 4).

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We thank the 21 speakers in our 6 sessions for accepting our invitation and promoting the exciting science of *Nuclear Forces and Structure, NN Correlations, and Medium Effects*.

We thank Evgeny Epelbaum, Renee Fatemi, Kévin Fossez, Alexandra Gade, Stefano Gandolfi, and Alessandra Luca for their help with chairing the 6 sessions.

We thank Brendan Casey for inviting us to convene the topic of *Nuclear Forces and Structure, NN Correlations, and Medium Effects* and to show the intersections with other topics and fields.