CLOSING REMARKS

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Giuseppina Orlandini
Dipartimento di Fisica - Universita' di Trento - Italy

- A few impressions conference
- The discussion about the field
- Where is the future

About the conference

- many new, high quality physical results
- clear talks (*most of them with good overview of the "work of others"!)*
- clearifying discussions
- friendly atmosphere
- smooth organization

.

A few interesting results

(from a very personal point of view!)

PHYSICAL REVIEW C **85**, 064003 (2012)

Di-neutron and the three-nucleon continuum observables

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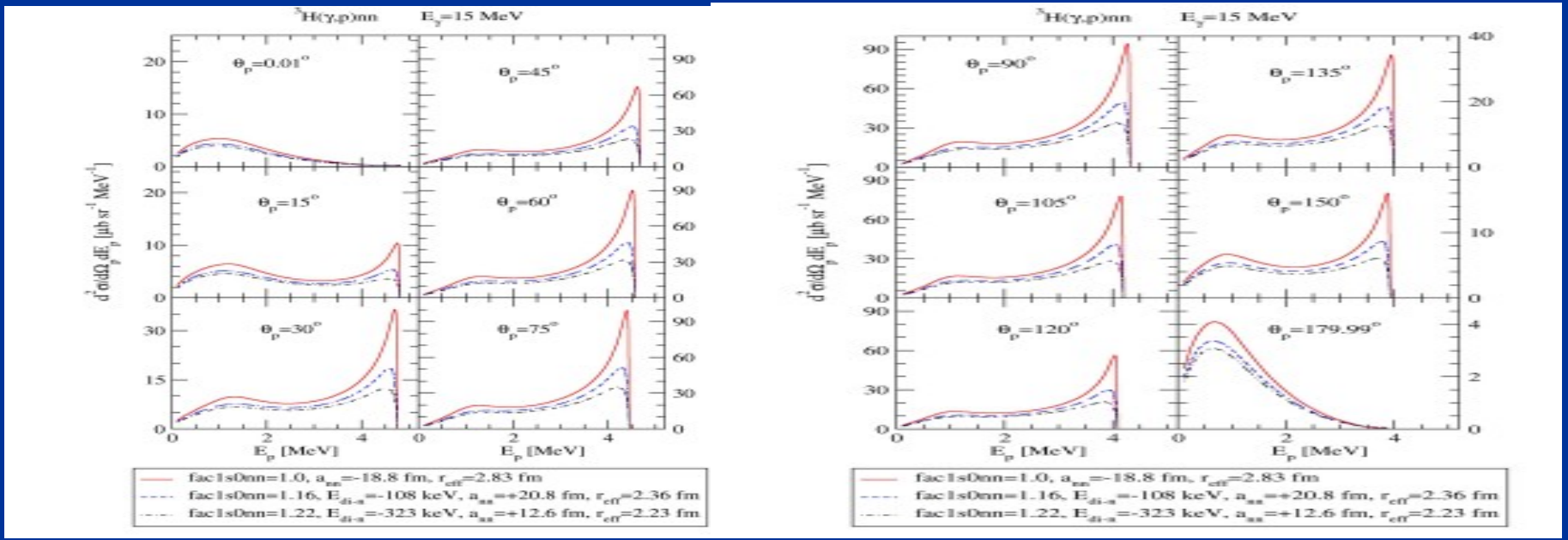
(Received 24 April 2012; published 25 June 2012)

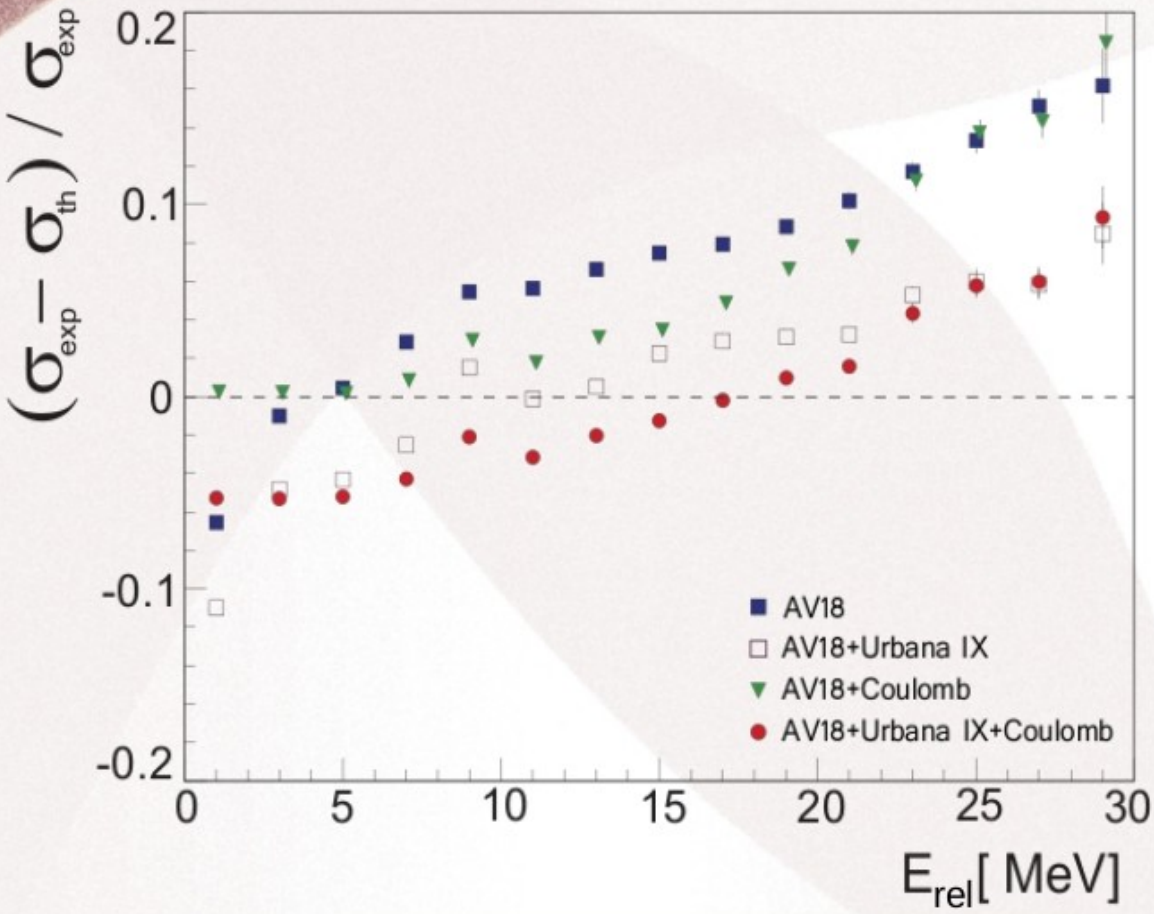
We investigate how strongly a hypothetical $^1S_0$ bound state of two neutrons would affect observables in neutron-deuteron reactions. To that aim we extend our momentum-space scheme of solving the three-nucleon Faddeev equations and incorporate in addition to the deuteron also a $^1S_0$ di-neutron bound state. We discuss effects induced by a di-neutron on the angular distributions of the neutron-deuteron elastic scattering and deuteron breakup cross sections. A comparison to the available data for the neutron-deuteron total cross section and elastic scattering angular distributions cannot decisively exclude the possibility that two neutrons can form a $^1S_0$ bound state. However, strong modifications of the final-state-interaction peaks in the neutron-deuteron breakup reaction seem to disallow the existence of a di-neutron.

Photon induced three-body breakup of ^{3}H > n +n +p



Conclusions

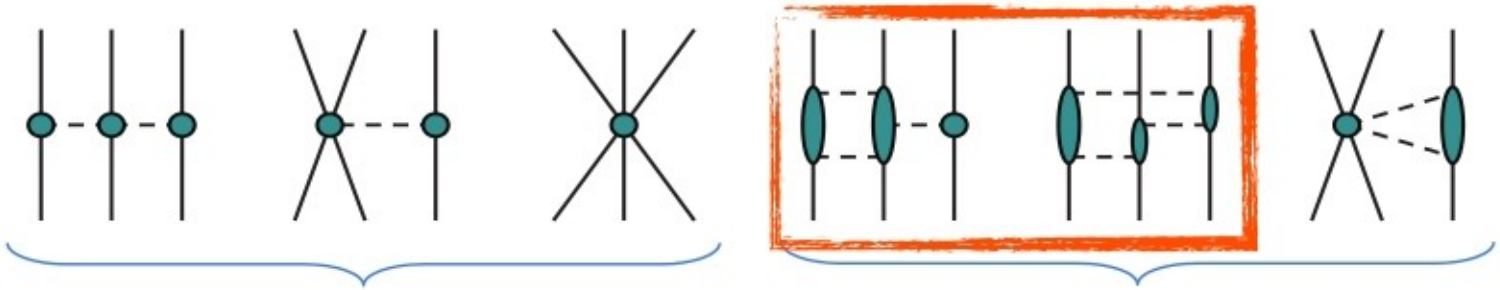
Coulomb Force & 3NF



Coulomb force + 3NF gives much better agreement with the data !

3N force beyond N²LO

3NF topologies (up to N⁴LO)



Q^3 (N^2LO) + Q^4 (N^3LO) + Q^5 (N^4LO) + ... Q^4 (N^3LO) + Q^5 (N^4LO) + ...

- N^2LO contributions (leading 3NF) nowadays included in most few-/many-body calculations
- First corrections (N^3LO)

  Ishikawa, Robilotta, PRC76 (07); Bernard, EE, Krebs, Meißner, PRC77 (08); PRC84 (11)
  - parameter-free, rich spin-momentum structure (especially from ring diagrams)
  - intermediate-range contributions not converged (effects of **Δ**(1232) are missing...)

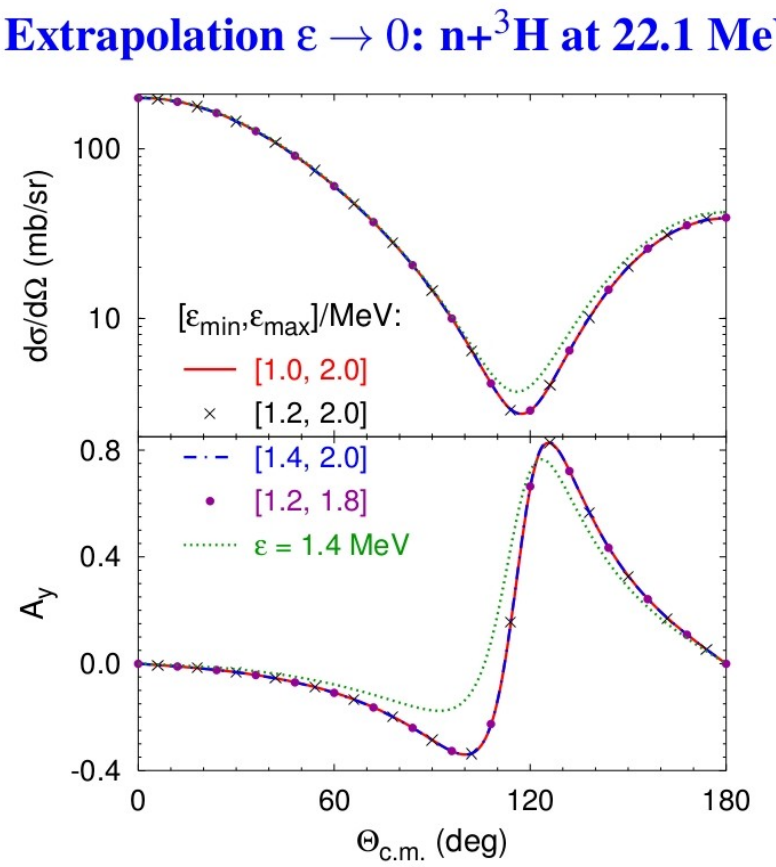
subleading loop corrections (N^4LO) in the **Δ**-less theory

Krebs, Gasparyan, EE '12,'13

leading loop corrections (N^3LO) in EFT with explicit **Δ**

Krebs, Gasparyan, EE, to appear

The solution of the 4-body problem in the continuum for realistic interactions

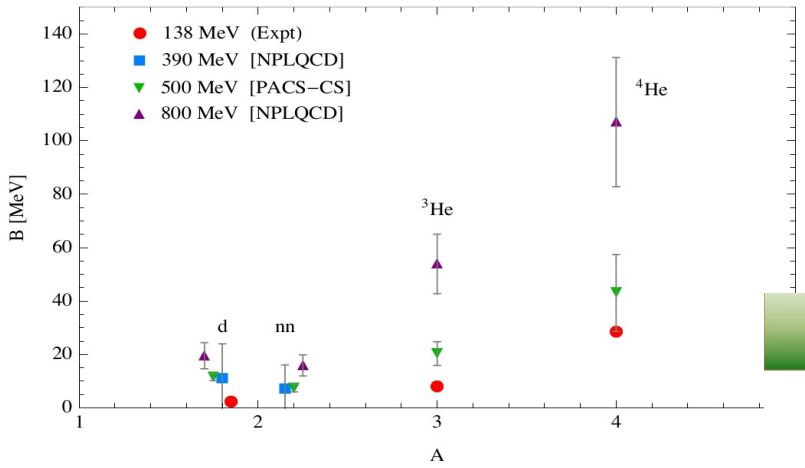


H. Kamada, Y. Koike, and W. Gl¨ockle, Prog. Theor.Phys.109, 869L (2003).

A. Deltuva, A.C. Fonseca
Phys. Rev. C 86, 011001(R) (2012)

LATTICE QCD - LATTICE EFT

QCD Periodic Table



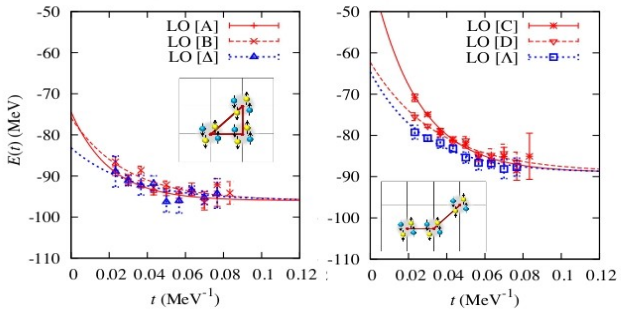
The Hoyle state

EE, Krebs, Lähde, Lee, Meißner, PRL 106 (2011) 192501; PRL 109 (2012) 252501

Lattice results for low-lying even-parity states of ^{12}C

	0_1^+	$2_1^+(E^+)$	0_2^+	$2_2^+(E^+)$
LO	−96(2)	−94(2)	−89(2)	−88(2)
NLO	−77(3)	−74(3)	−72(3)	−70(3)
NNLO	−92(3)	−89(3)	−85(3)	−83(3)
Exp	−92.16	−87.72	−84.51	−82(1)

Probing (α-cluster) structure of the 0_1^+, 0_2^+ states



RMS radii and quadrupole moments

	LO	Experiment
$r(0_1^+)$ [fm]	2.2(2)	2.47(2) [26]
$r(2_1^+)$ [fm]	2.2(2)	–
$Q(2_1^+)$ [e fm^2]	6(2)	6(3) [27]
$r(0_2^+)$ [fm]	2.4(2)	–
$r(2_2^+)$ [fm]	2.4(2)	–
$Q(2_2^+)$ [e fm^2]	−7(2)	–

New Horizons in Ab Initio Nuclear Structure Theory

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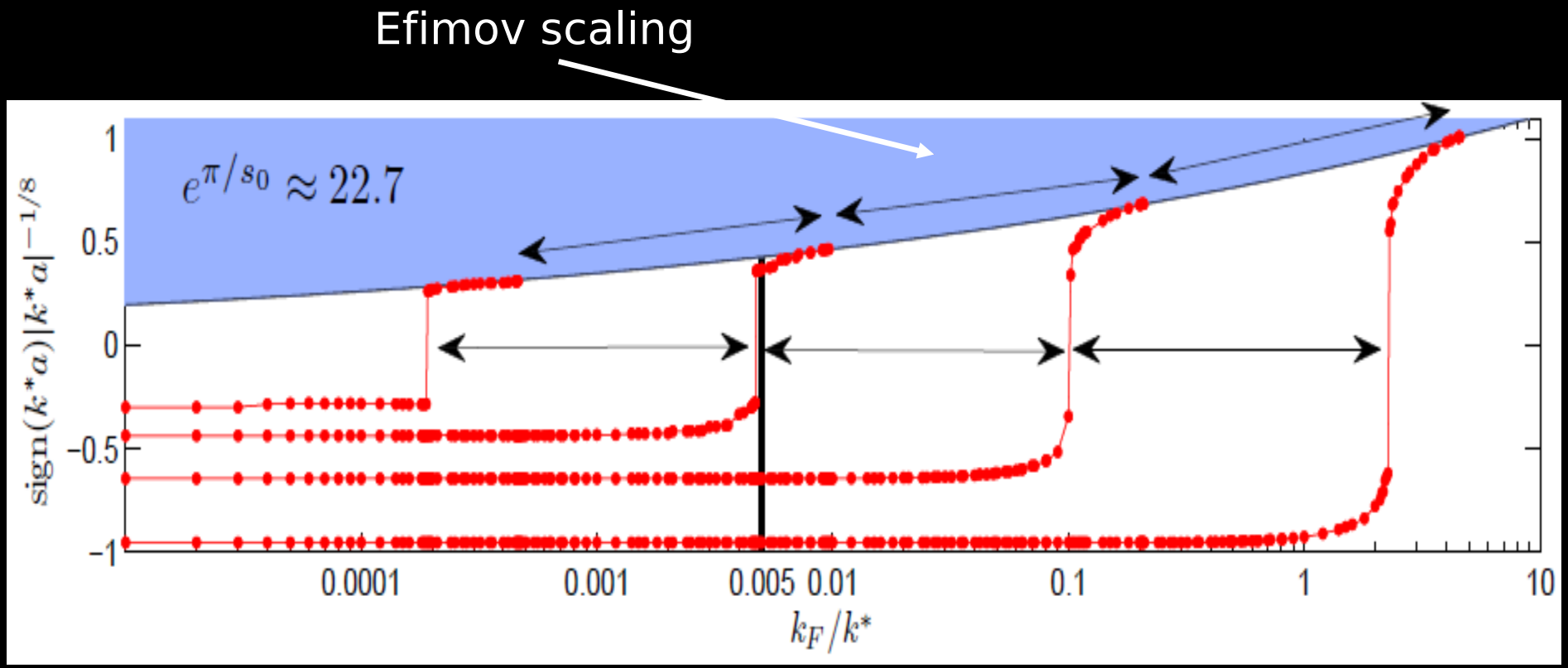
Low-energy nuclear theory has entered an era of ab initio nuclear structure and reaction calculations based on input from QCD. One of the most promising paths from QCD to nuclear observables employs Hamiltonians constructed within chiral effective field theory as starting point for precise ab initio studies. However, the full inclusion of chiral two- plus three-nucleon (NN+3N) interactions in exact and approximate many-body calculations beyond the few-body domain poses a challenge. I discuss recent breakthroughs that allow for ab initio calculations for ground states and spectra of nuclei throughout the p- and the lower sd-shell with full 3N interactions using consistent Similarity Renormalization Group (SRG) transformations and the Importance-Truncated No-Core Shell Model (IT-NCSM) [1,2]. This framework allows for predictions of nuclear structure phenomena of experimental relevance from QCD input as well as for a validation of the fundamental theoretical ingredients by confrontation with experimental nuclear structure data. I present a few highlights illustrating this two-way link between QCD and nuclear structure. Moreover, I discuss extensions of these ab initio calculations to heavy nuclei within coupled-cluster theory [3,4], to low-energy reactions of astrophysical relevance, and to p-shell hypernuclei.

Supported by the Deutsche Forschungsgemeinschaft through SFB 634, by the Helmholtz International Center for FAIR (HIC for FAIR), and by the BMBF through NUSTAR.de (BMBF-FSP 302) and 06DA7047I.

Scaling in a background

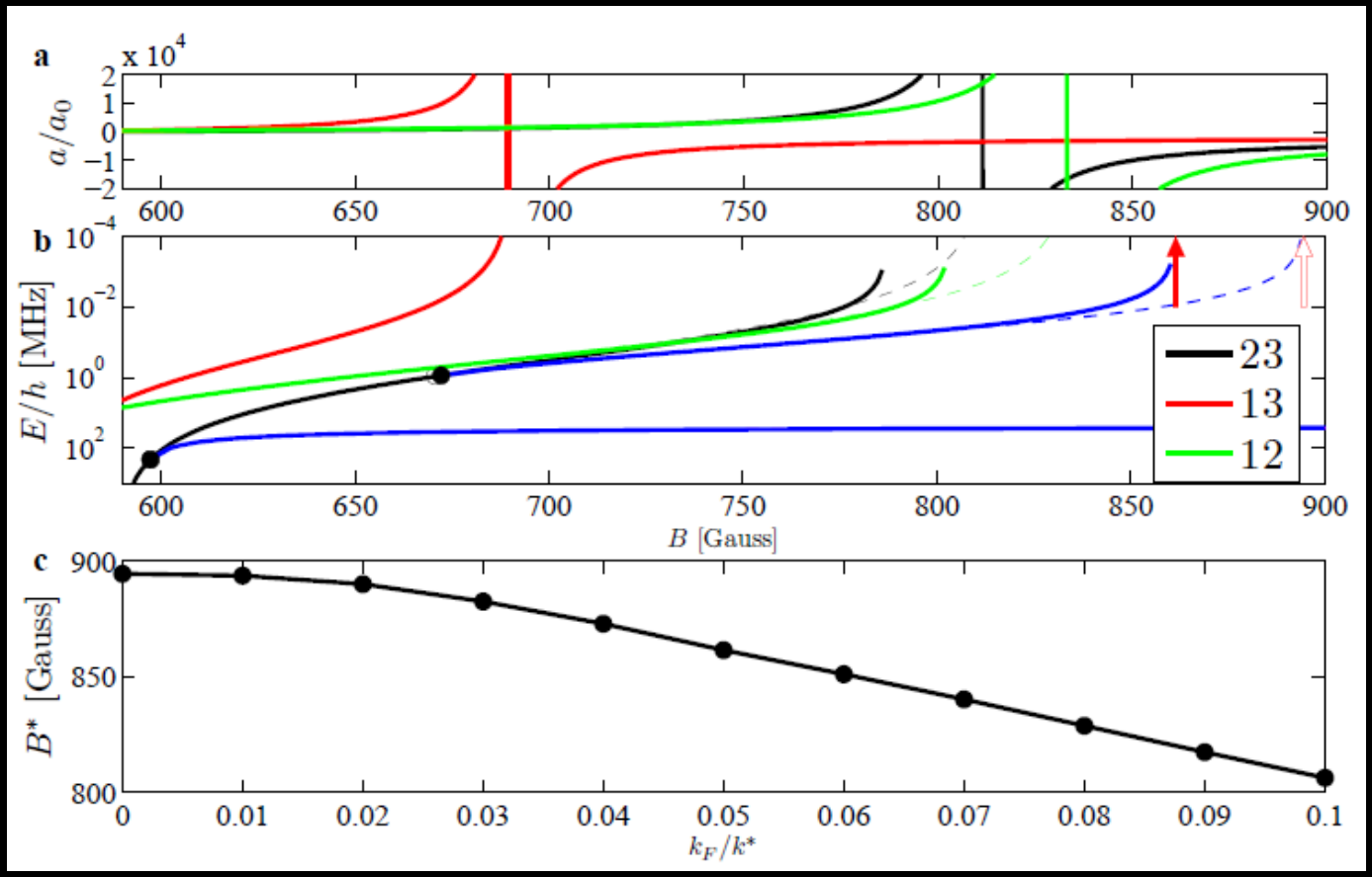
We find many-body Efimov scaling!



N.G. Nygaard and N.T. Zinner, arXiv:1110:5854

Real three fermion systems

Experimentally realized three-component Fermi gas with three-body states. T. Lompe et al. Science **330**, 940 (2010)



N.G. Nygaard and N.T. Zinner, arXiv:1110:5854

PHYSICAL REVIEW A **87**, 052719 (2013)

Universal nature and finite-range corrections in elastic atom-dimer scattering below the dimer breakup threshold

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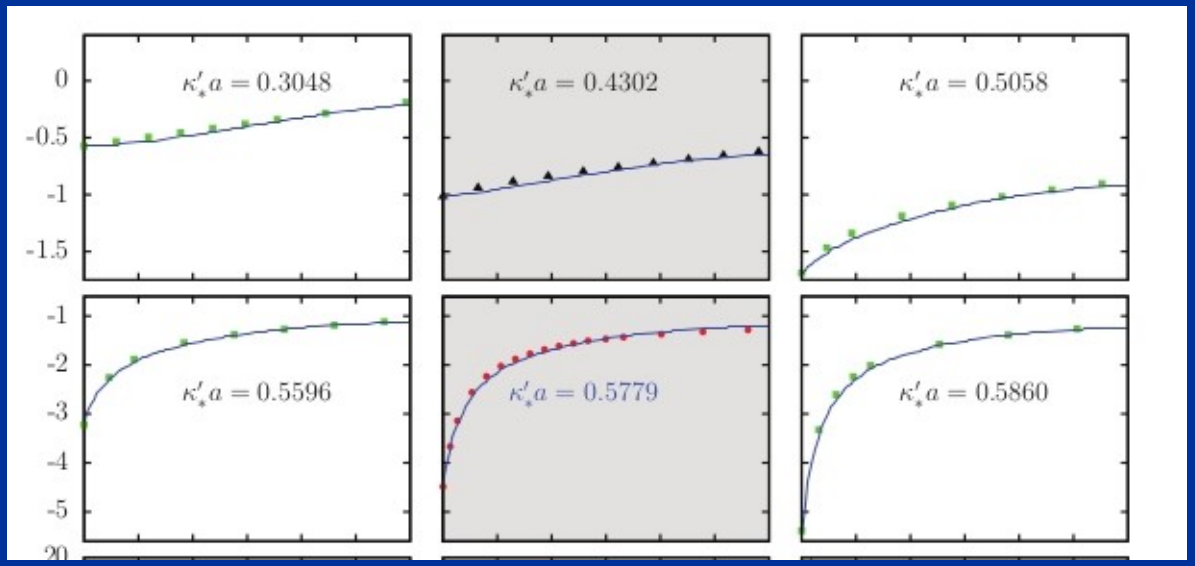
[2]*Université de Nice-Sophia Antipolis, Institut Non-Linéaire de Nice, CNRS, 1361 route des Lucioles, 06560 Valbonne, France*

(Received 14 December 2012; revised manuscript received 26 March 2013; published 31 May 2013)

We investigate universal behavior in elastic atom-dimer scattering below the dimer breakup threshold calculating the atom-dimer effective-range function $ak\cot\delta$. Using the He-He system as a reference, we solve the Schrödinger equation for a family of potentials having different values of the two-body scattering length a and we compare our results to the universal zero-range form deduced by Efimov, $ak\cot\delta = c_1(ka) + c_2(ka)\cot[s_0\ln(\kappa_* a) + \phi(ka)]$, for selected values of the three-body parameter κ_*. Using the parametrization of the universal functions c_1, c_2, ϕ given in the literature, a good agreement with the universal formula is obtained after introducing a particular type of finite-range corrections. Furthermore, we show that the same parametrization describes a very different system: nucleon-deuteron scattering below the deuteron breakup threshold. Our analysis confirms the universal character of the process, and relates the pole energy in the effective-range function of nucleon-deuteron scattering to the three-body parameter κ_*.



The discussion on the field:

- . still concentrated mainly on N=2 and 3 but is also moving fast to larger N (6-12-16-22...
- has many facets (interdisciplinary," "instrumental" to other fields)
- still NP dominated, but is looking more and more outside (fascinated by Universality!)
- has built a "culture" (precision, ab initio, ...)
- is a school of "aggressive innovation" but also "patience and modesty"

About the future

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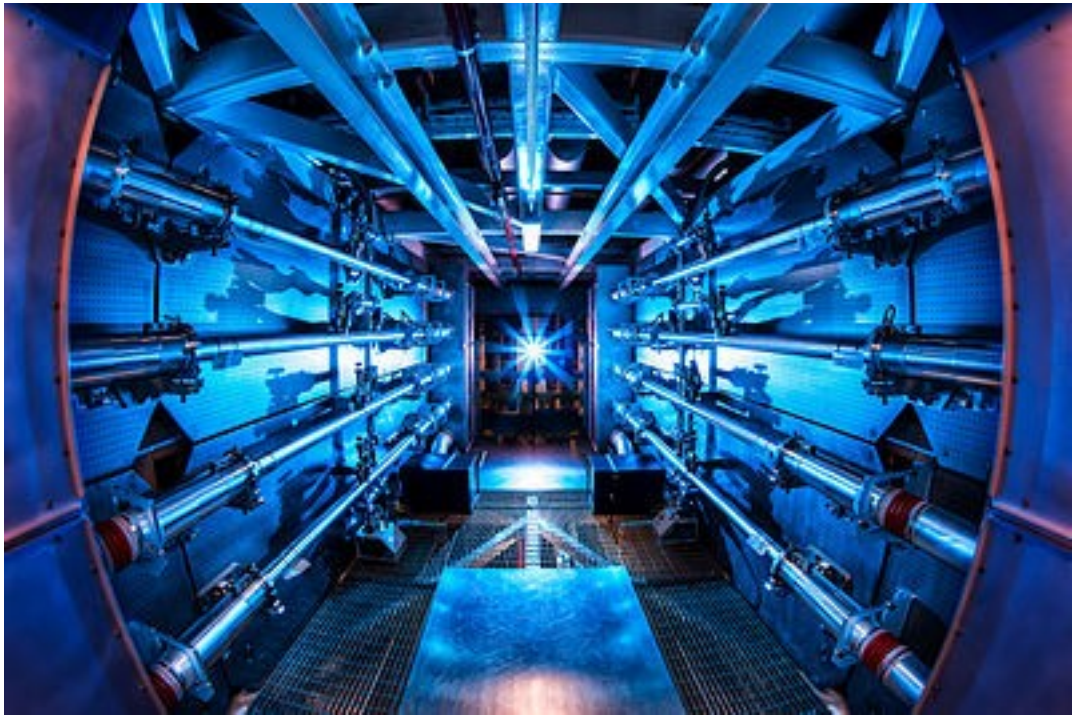
New machines & new experiments will drive the field

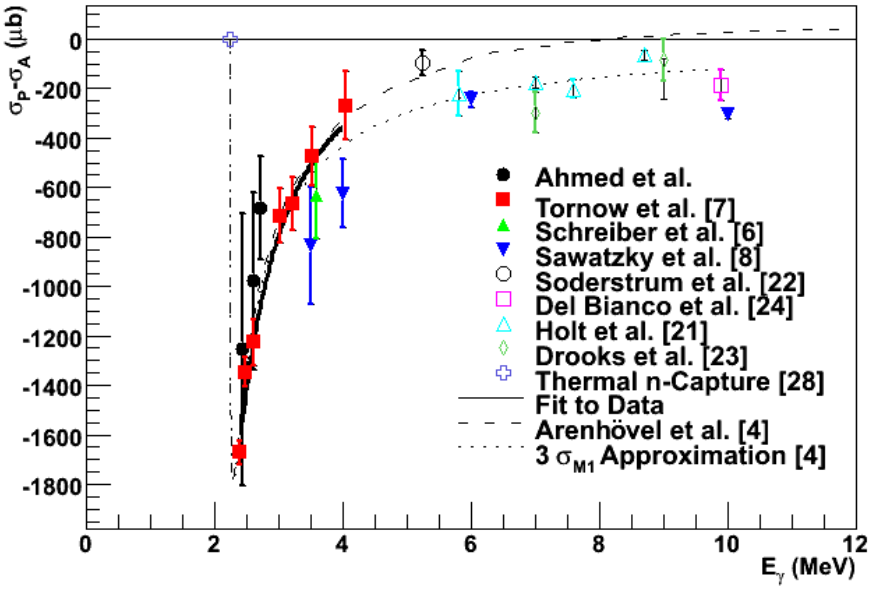
National Ignition Facility (NIF) at LLNL

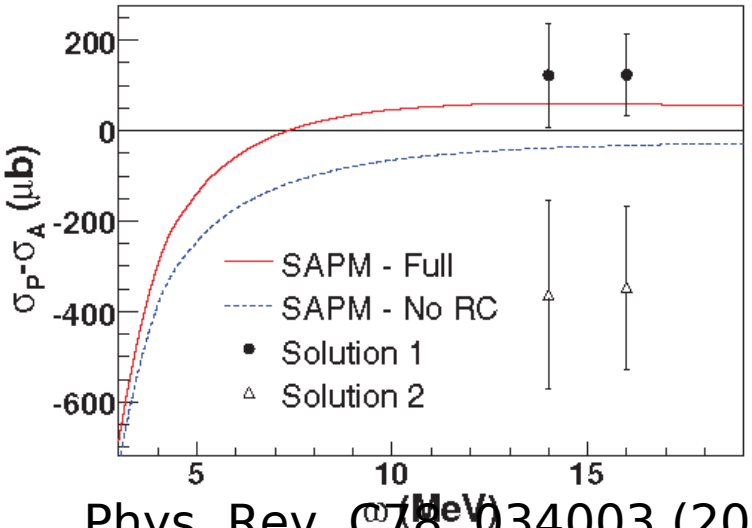


Inertial Confinement Fusion, 192 laser beams, DT capsule in hohlraum

Few-Body Physics Studies at HIGS

- HIGS is currently mounting the GDH experiment on the deuteron
- Installation of the HIGS Frozen Spin Target (HIFROST) is ongoing
- The majority of data taking will be completed by the end of 2013 between 4 and 6 MeV





Phys. Rev. C78, 034003 (2008)

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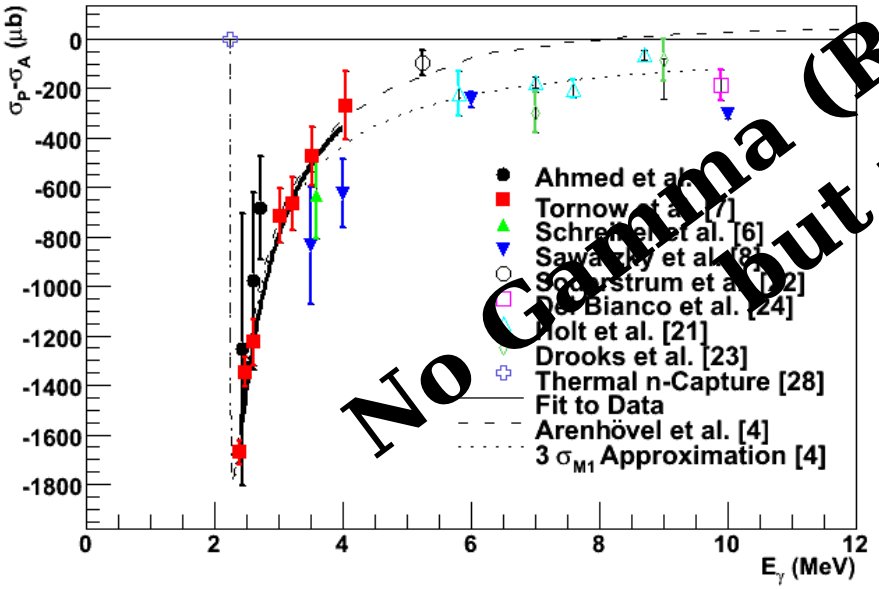
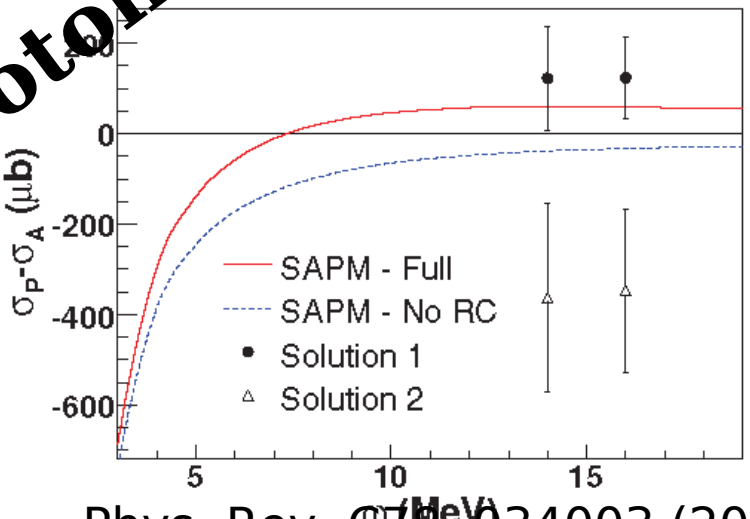
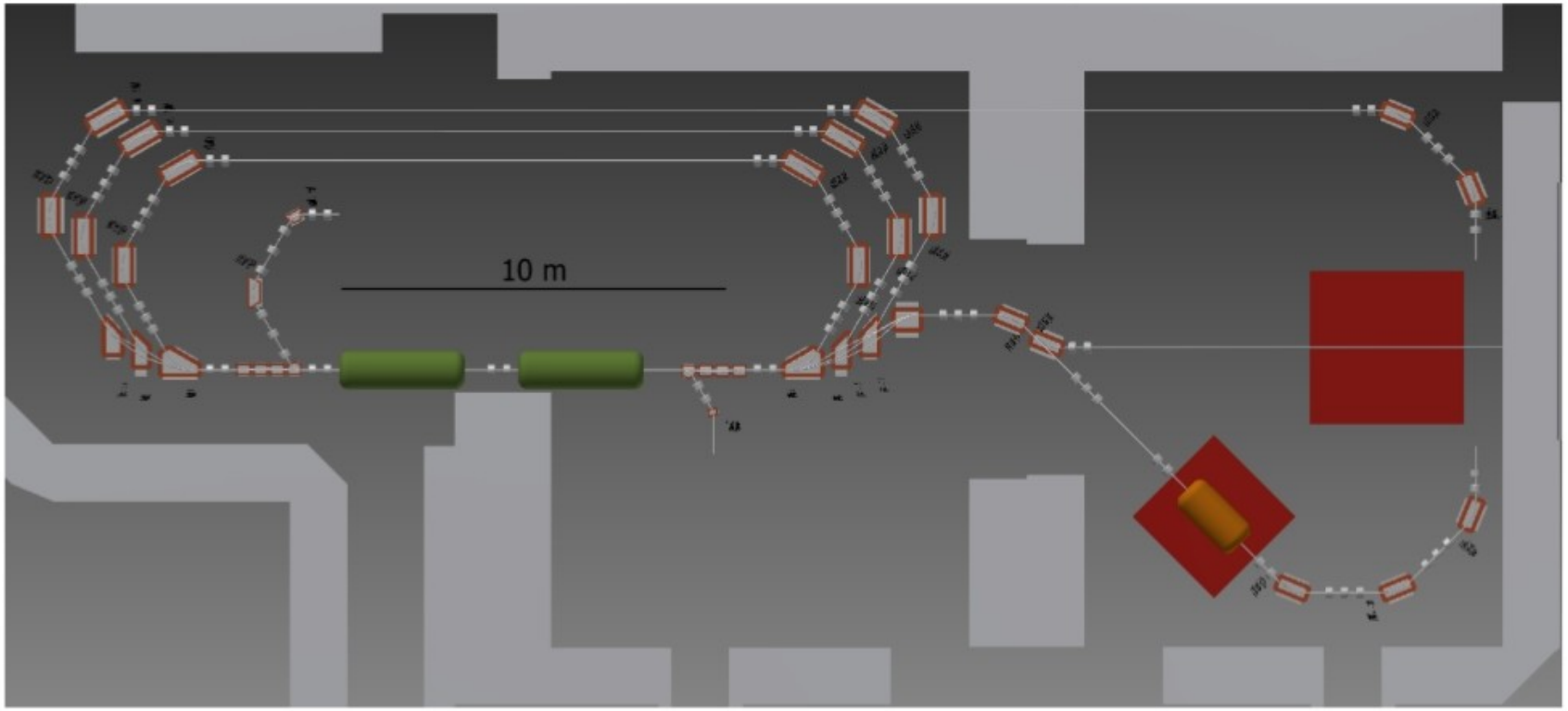




Phys. Rev. C78, 034003 (2008)

No Gamma (Rutherford 1903) but photons!

MESA: Mainz Energy recovering Superconducting Accelerator

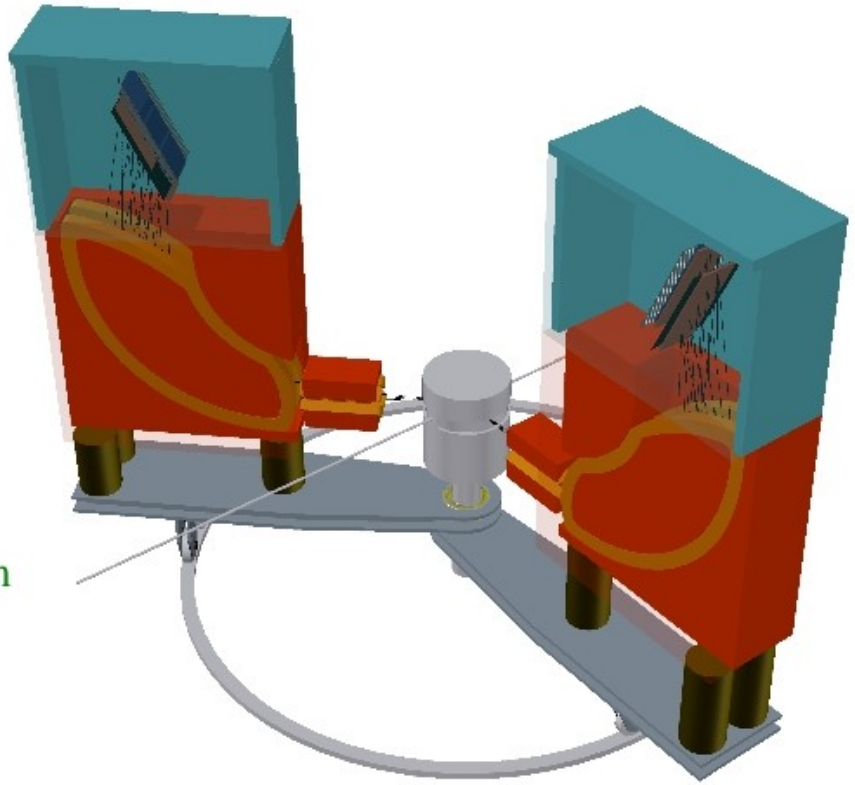


- Superconducting LINAC
- Three recirculation arcs for external beam
  high external current for "next generation" parity violation experiments
- Energy recovery mode (half wave-length recirculation) for *internal target* experiments

	Current	Energy	Luminosity
External Beam Mode:	150 μA	200 MeV	10^{39} cm^{-2}s^{-1}
Energy Recovery Mode:	10 mA	150 MeV	10^{36} cm^{-2}s^{-1}

Low Momentum Spectrometers

- Target: Atomic beam source
  - High polarization possible
  - High luminosity due to beam quality
  - Window-less, low multiple scattering



- High resolution spectrometers
  - Momentum resolution $\delta p/p \approx 10^{-4}$
  - Low momentum $\rightarrow$ modest size $r < 3\,\mathrm{m}$

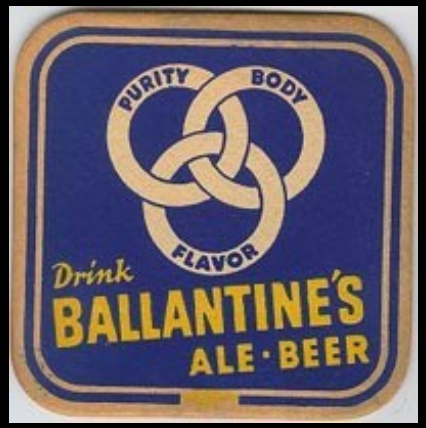
Physics Book:

- Searches for dark photons
- Hadron Physics: e.g. magnetic radius of the proton via double polarization
- Polarization observables in few body physics
- ...

New ground state of 2D gas

Assume no two-body bound state

For three bosonic polar molecules there will be a bound **three-body** state
A Borromean system!



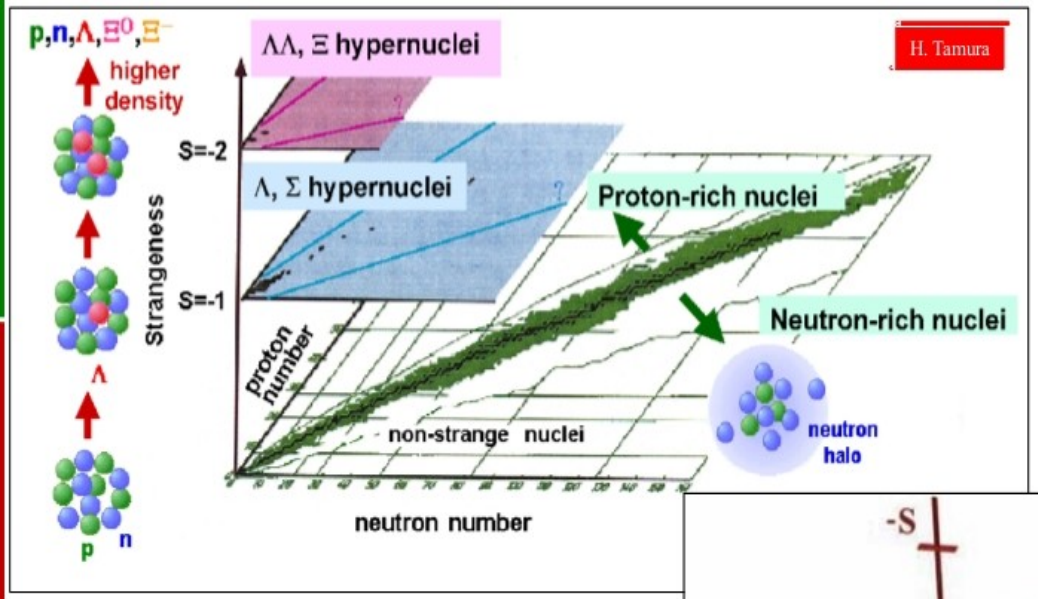
TO BE SEARCHED

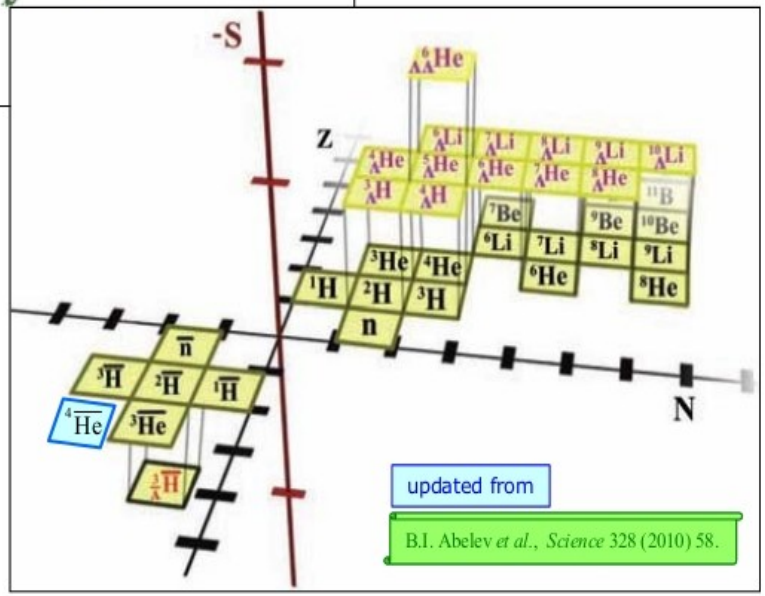
Two-component fermionic molecules are more complicated due to the Pauli principle

The many-body physics should be controlled by the three-body bound state. A **trion** quantum gas!

H. Lee, A.G. Volosniev *et al.*

Expanding the horizon...





Hypernuclei

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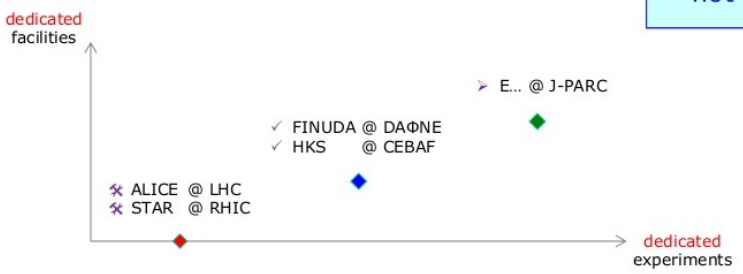
Summary

a good wealth of interesting and sometime unexpected hypernuclear physics results has been recently produced

no longer running or not dedicated experiments



we are now looking forward for new and exciting world class results

@ J-PARC

RIB Facilities

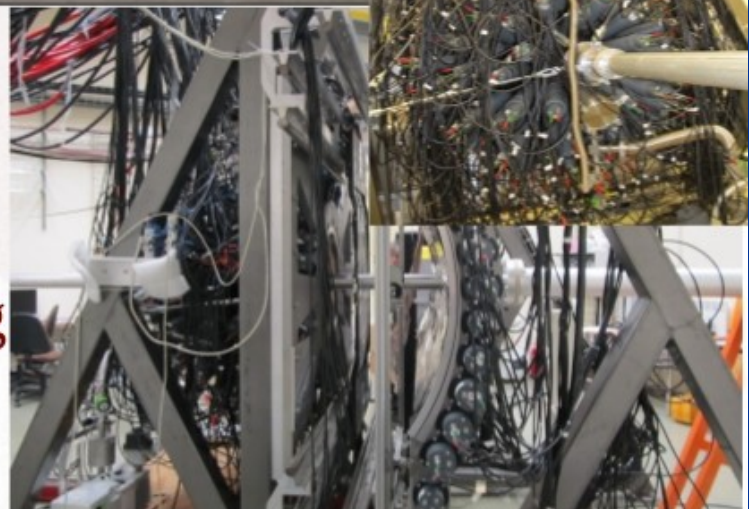
- FAIR
  GANIL
  KEK
  RIKEN
  ..

Outlook: BINA @ CCB Cracow

IFJ PAN

CYCLOTRON CENTER BRONOWICE

- proton beam energy: 70 - 230 MeV
- energy resolution: $\Delta E/E < 0.7\%$
- intensity: 500 - 0.1 nA
  (3.3×10^{12} - 6.6×10^{8} p/s)



GENERAL RESEARCH PROGRAM

- feasibility studies
- measurements of elastic scattering and breakup reactions – systematic and consistent data base for investigating of the 3N continuum at medium energies
- development of the detection system

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Each one is bringing his tessera to the whole mosaic to see the whole picture...

Universality and Pointilism

TECHNISCHE UNIVERSITÄT DARMSTADT

- Painting at the limit of resolution of the human eye
-

G. Seurat, A Sunday on La Grande Jatte

Each one is bringing his tessera to the whole mosaic to see the whole picture…**but we also want to get the picture in all details** ….

Universality and Pointilism

TECHNISCHE UNIVERSITÄT DARMSTADT

- Painting at the limit of resolution of the human eye

Each one is bringing his tessera to the whole mosaic to see the whole picture...**but we also want to get the picture in all details, because**

"the devil hides in the details !"

Announcement:

The 23d European Few-Body Conference will take place in Aahrus (Denmark) in 2016

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Organized by

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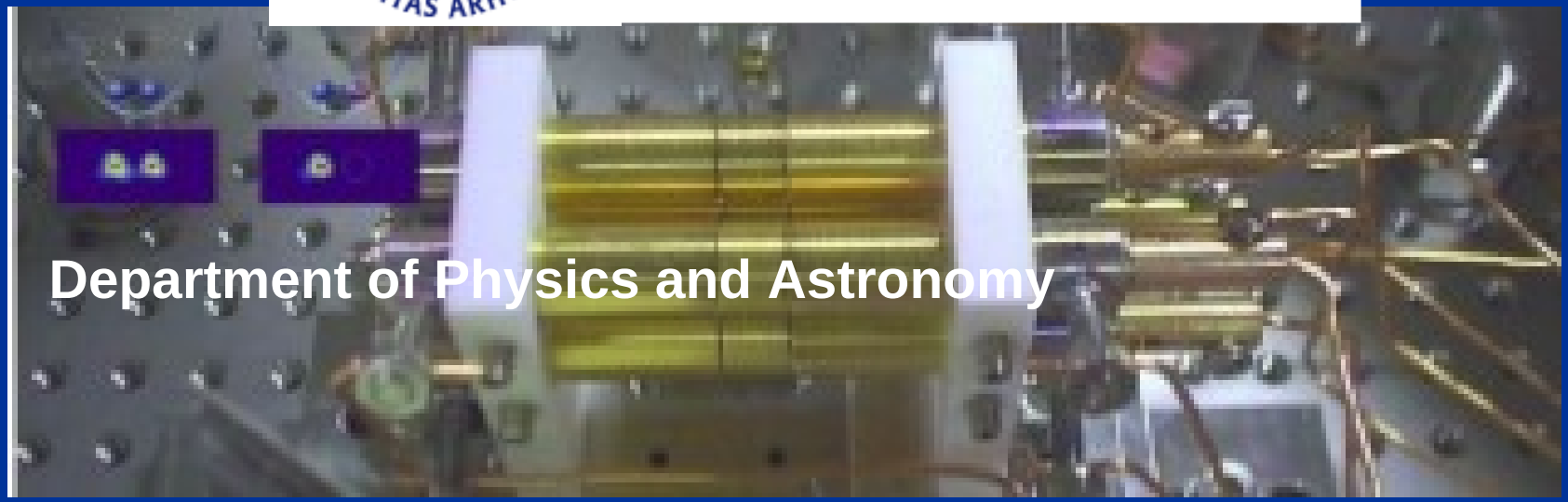
Aarhus University



Dmitri Fedorov Hans Fynbo et al. Nikolaj Thomas Zinner

EFB23 2016

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