INFN Istituto Nazionale di Fisica Nucleare

MOdeling Nuclear STructure and REactions

Enrico Vigezzi - INFN Milano

RICARDO A. BROGLIA

In memoriam

https://www.sif.it/riviste/sif/sag/ricordo/broglia

Ricardo Americo Broglia (1939-2022)

We started working with Ricardo in 1983- 1984, when we went to Copenhagen after our master's degree, and we have collaborated with him without interruption until his death on October 4th, 2022. In the following, we provide an outline of his scientific activity. This is not an easy task, because Ricardo coauthored around 500 papers, collaborating with around 150 theorists and with many experimentalists as well. A comprehensive curriculum can be found at the following link: https://home. mi.infn.it/broglia_CV.pdf

Ricardo Americo Broglia was born in Cordoba, Argentina, in 1939. He started his Master studies at Instituto Balseiro of the University of Cuyo in Bariloche and then went to Buenos Aires to pursue his Ph.D. under the supervision of Daniel R. Bès. This is how he later recollected those years:

Ricardo Americo Broglia was born in Cordoba, Argentina,
in 1939.

He graduated at Instituto Balseiro of the University of Cuyo and obtained his Ph.D. in Buenos Aires under the direction of Daniel Bes in 1965.

1.D.2

Nuclear Physics **80** (1966) 289—313; © *North-Holland Publishing Co., Amsterdam*

PAIRING VIBRATIONS

D. R. BÈS †

NORDITA, Copenhagen

and

R. A. BROGLIA

Facultad de Ciencias Exactas y Naturales, Buenos Aires

Received 30 September 1965

Abstract: We study the properties of the collective states (pairing vibrations) which are associated with fields changing the numbers of particles. In particular, we discuss which processes may be enhanced by the coherence in the pairing-vibration state.

The pairing vibration appears as a low-energy collective mode in the case of a residual two-body interaction such that the nucleus should be sufficiently close to the transition point between the single-particle and a superconducting system, and if there exists at least two well-defined groups of single-particle levels in such a way that the spread on energy within each group should be significantly smaller than the distance between the two groups.

The operator which specifically feels the coherence of the collective state corresponds to the two-body transfer processes.

In spherical nuclei, the most promising cases are the closed-shell nuclei. The main characteristic of the resulting spectrum is the existence of a low-energy 0^+ state which is populated with the same intensity as the ground state. Such spectrum appears to exist in ^{208}Pb although residual effects must have at least quantitative importance.

The Niels Bohr Institute, Copenhagen

Post-doc (1965-68) and then staff from 1970 after 2 years in Minnesota

The Bohrs: father and son

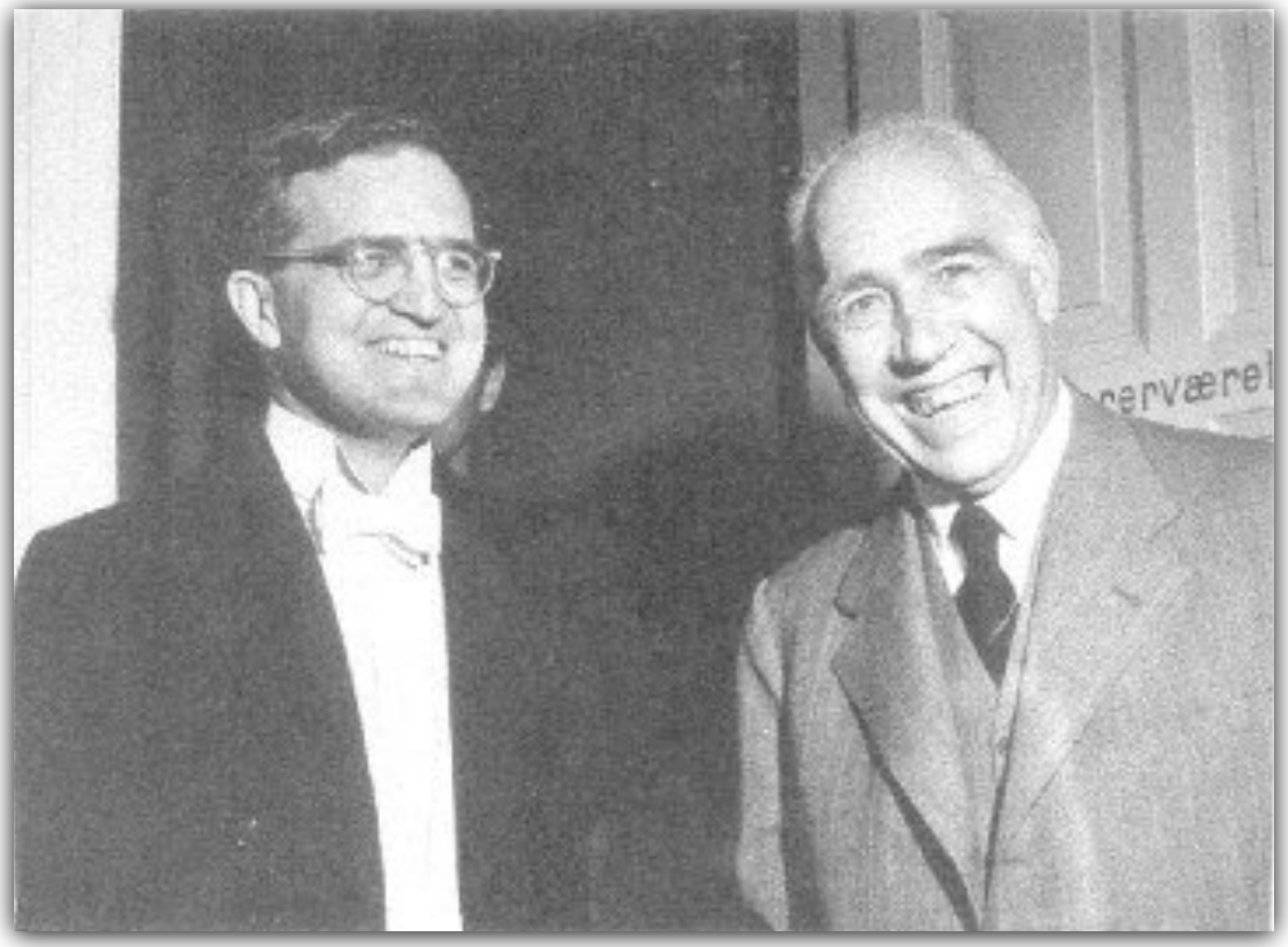
ROTATIONAL STATES OF ATOMIC NUCLEI

By

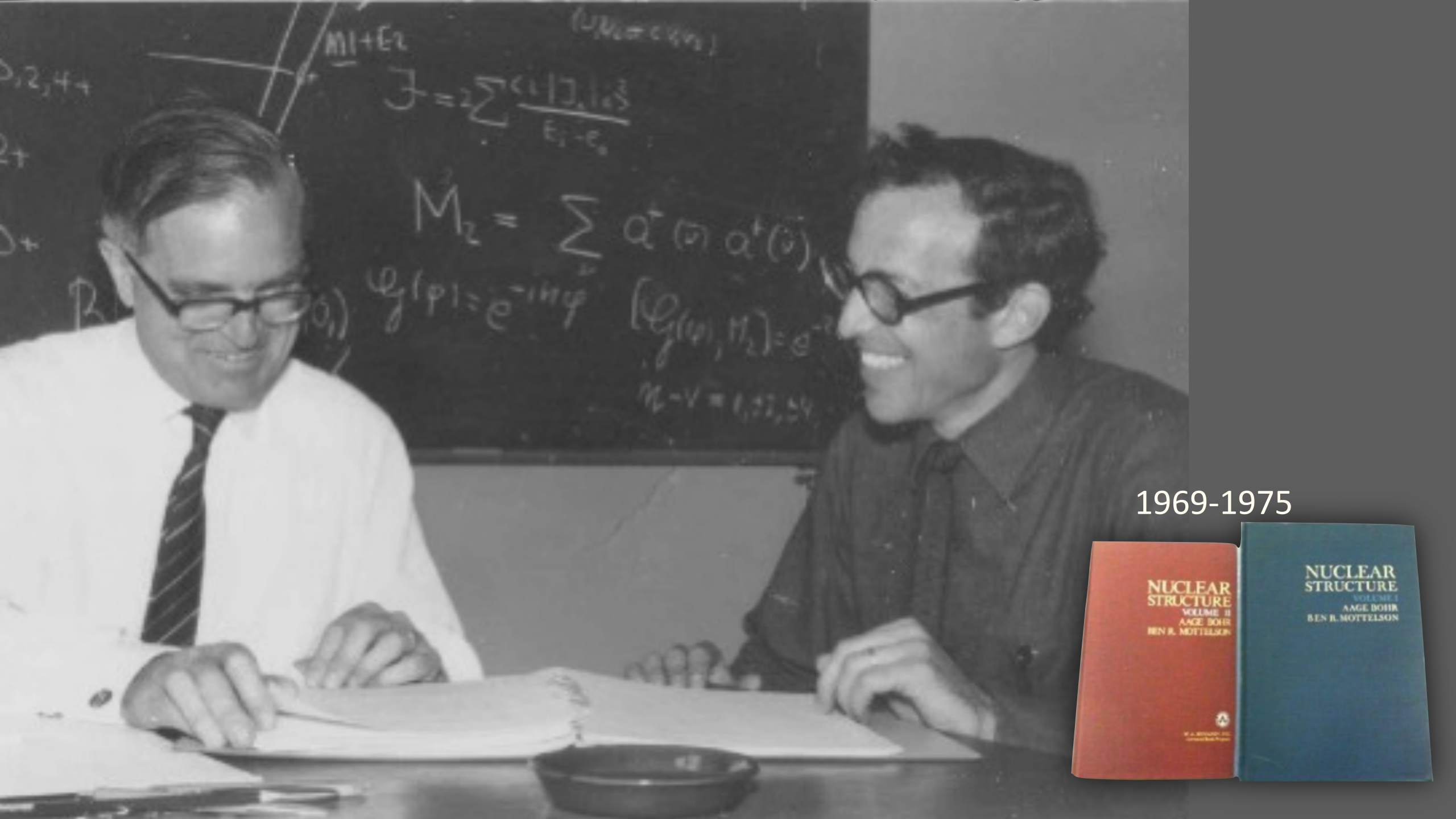
AAGE BOHR

Universitetets institut for teoretisk fysik

KØBENHAVN
EJNAR MUNKSGAARDS FORLAG
1954



Aage and Niels Bohr in Copenhagen in 1954, after Aage's thesis defence. Courtesy of Niels Bohr Archive, Copenhagen.

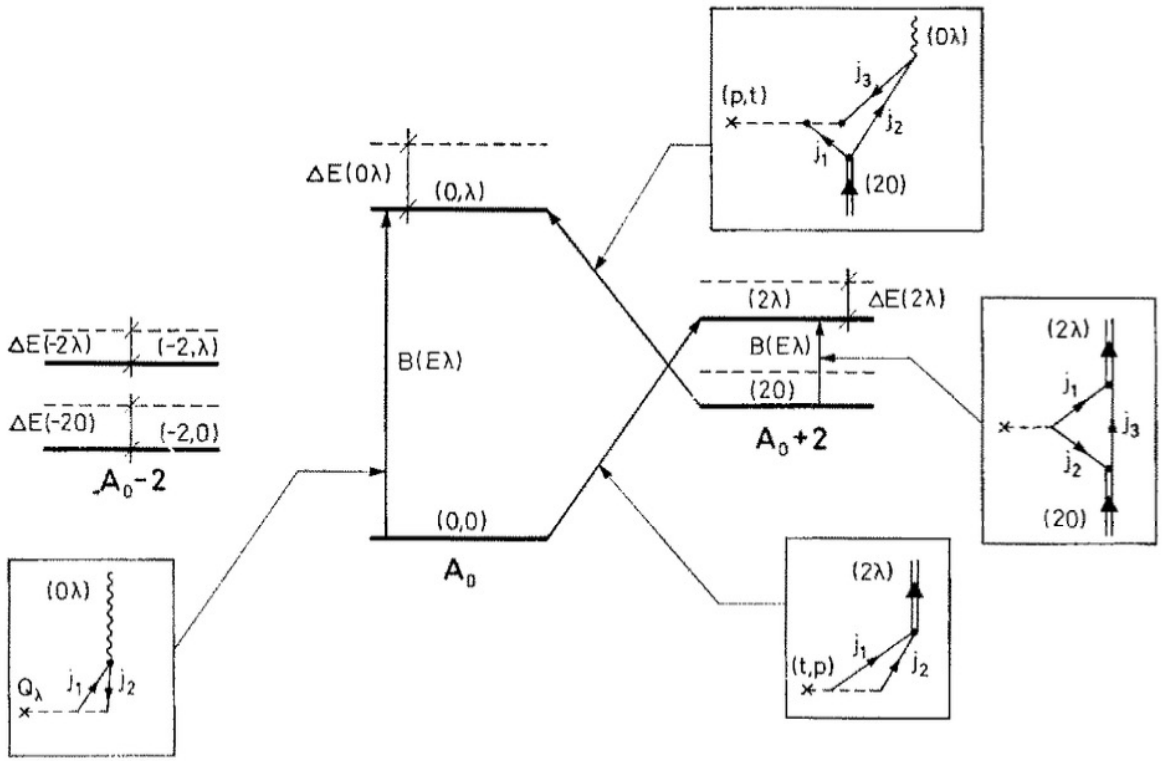

M1+E2
$J = 2\sum \frac{\langle 1 | D_1 | 3 \rangle}{E_1 - E_3}$
$M_2 = \sum_\nu a^+(\nu)\, a^+(\bar{\nu})$
$\varphi(p) = e^{-in\varphi}$
1969-1975
NUCLEAR STRUCTURE
VOLUME II
AAGE BOHR
BEN R. MOTTELSON
NUCLEAR STRUCTURE
VOLUME I
AAGE BOHR
BEN R. MOTTELSON

https://www0.mi.infn.it/~vigezzi/BHR/BrogliaHansenRiedel.pdf

Nuclear Physics **A169** (1971) 225—238;

COHERENCE PROPERTIES OF TWO-NEUTRON TRANSFER REACTIONS AND THEIR RELATION TO INELASTIC SCATTERING

R. A. BROGLIA
The Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
C. RIEDEL
Zentralinstitut für Kernforschung, Rossendorf near Dresden, Germany (DDR)
T. UDAGAWA
Center for Nuclear Studies, University of Texas, Texas 78712



Chapter 3

1973

TWO-NEUTRON TRANSFER REACTIONS AND THE PAIRING MODEL

Ricardo A. Broglia
The Niels Bohr Institute
University of Copenhagen, Copenhagen
Denmark

Ole Hansen
*Los Alamos Scientific Laboratory, University of California**
Los Alamos, New Mexico 87544

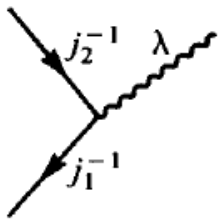
and

Claus Riedel
Zentralinstitut für Kernforschung, Rossendorf, D.D.R.
and
Physics Department, University of Karl Marx Stadt
Karl Marx Stadt, D.D.R.

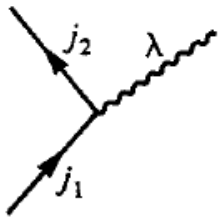
1. INTRODUCTION

The description of many-body systems at low energy in terms of "elementary modes of excitation" (see, e.g., Noz 65) is very useful in the case of nuclei (see BM 69). "Elementary modes of excitation" as used here comprise collective (rotations and vibrations) as well as quasiparticle excitations.

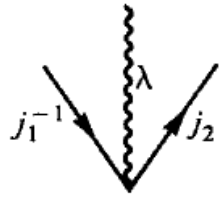
THE DEVELOPMENT OF NUCLEAR FIELD THEORY IN THE '70S



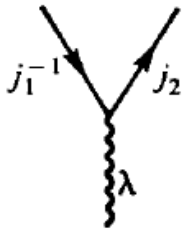
$-h(j_1,j_2\lambda)$



$h(j_1,j_2\lambda)$



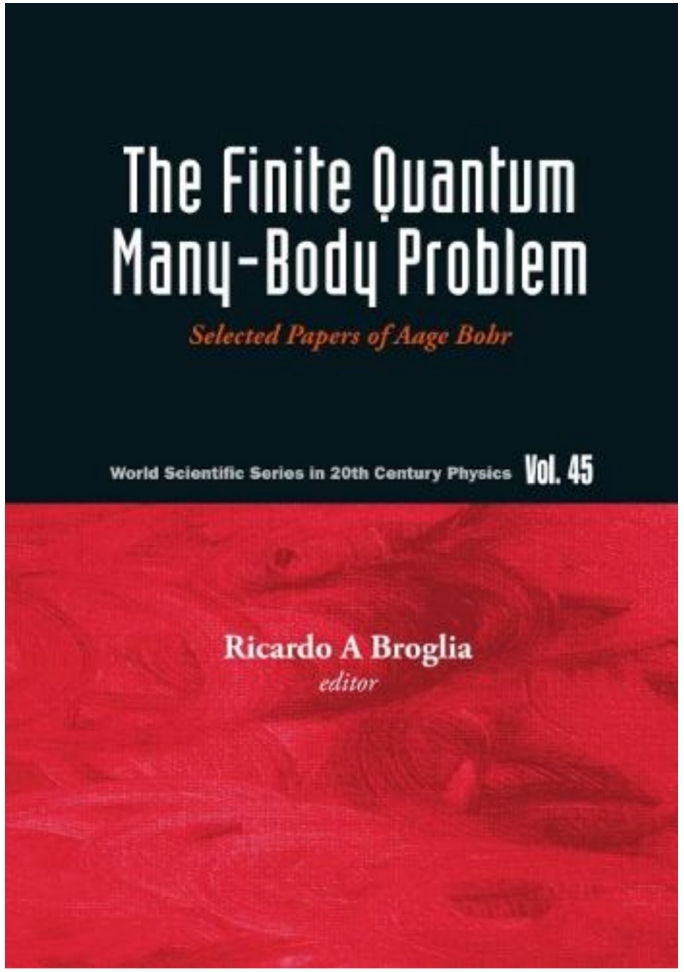
$-(2j_1+1)^{1/2}h(j_1,j_2\lambda)$



$$-\left(\frac{2j_1+1}{2\lambda+1}\right)^{1/2}h(j_1,j_2\lambda)$$

Nuclear Structure, Vol. II

In the preceding parts of Sec. 6-5, we have considered some of the consequences of the particle-vibration coupling in renormalizing the properties of the elementary modes of excitation and producing interactions between them. The systematic treatment of the particle-vibration coupling amounts to a nuclear field theory, which incorporates in a consistent manner the consequences arising from the fact that the quanta are built out of the same degrees of freedom as are the particle modes of excitation.



THE FERMION HAMILTONIAN IS MAPPED ON THE NUCLEAR FIELD THEORY HAMILTONIAN WHICH TREATS BOTH FERMIONIC (HF STATES) AND PHONONIC (RPA STATES) DEGREES OF FREEDOM

$$H = H_{sp} + H_{tb},$$

$$H_{sp} = \sum_J \varepsilon_J a_J^+ a_J,$$

$$H_{tb} = \tfrac{1}{4} \sum_{J_t} \langle J_1\, j_2 | V | j_3\, J_4 \rangle a_{J_1}^+ a_{J_2}^+ a_{J_4} a_{J_3}.$$

$$H_f = H_{sp} + H_{tb} + H_b + H_{pv},$$

$$H_{sp} = \sum_J \varepsilon_J a_J^+ a_J,$$

$$H_{tb} = \tfrac{1}{4} \sum_J \langle J_1\, j_2 | V | J_3\, j_4 \rangle a_{J_1}^+ a_{J_2}^+ a_{J_4} a_{J_3},$$

$$H_b = \sum_n \omega_n \Gamma_n^+ \Gamma_n,$$

$$H_{pv} = \sum_n \sum_{J_1 J_2} \{ \Lambda^*(j_1\, J_2\, n) \Gamma_n^+ a_{J_2}^+ a_{J_1} + \Lambda(J_1\, j_2\, n) \Gamma_n a_{J_1}^+ a_{J_2} \},$$

Nuclear Physics **A260** (1976) 77–94

ON THE MANY-BODY FOUNDATION OF THE NUCLEAR FIELD THEORY

D. R. BÈS †
Comisión Nacional de Energía Atómica, Buenos Aires, Argentina ††

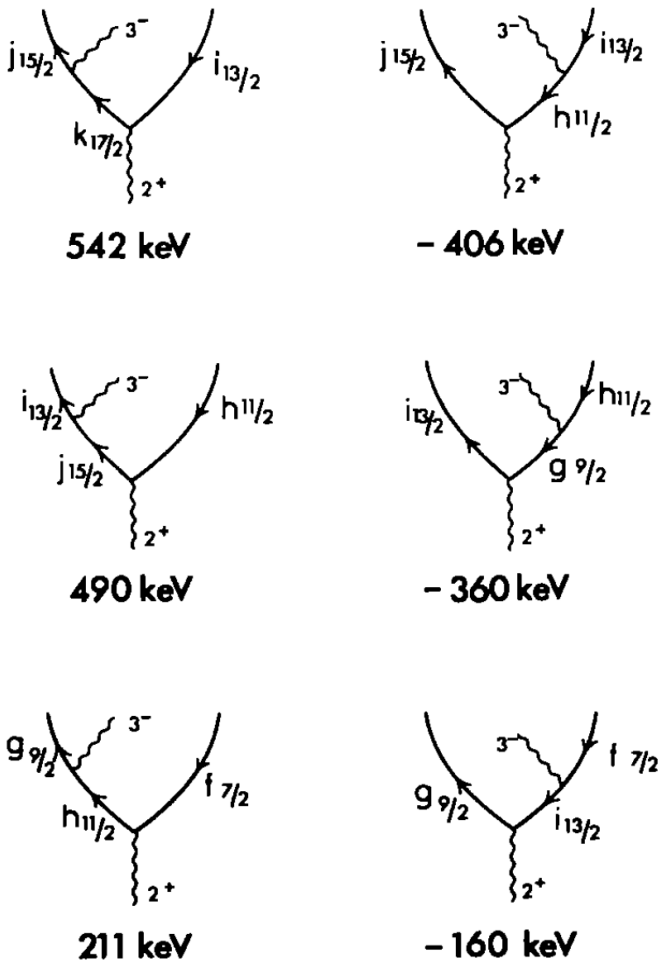
R. A. BROGLIA
Niels Bohr Institute, University of Copenhagen, Denmark

and

G. G. DUSSEL †, R. J. LIOTTA and R. P. J. PERAZZO †
Comisión Nacional de Energía Atómica, Buenos Aires, Argentina ††

A SET OF RULES IS DEFINED TO TAKE INTO ACCOUNT THE OVERCOMPLETENESS OF THE NFT BASIS AND TO RESPECT THE PAULI PRINCIPLE IN THE PERTURBATIVE EXPANSION

NFT IS APPLIED TO UNDERSTAND THE WIDTH OF COLLECTIVE GIANT RESONANCES:
THE COUPLING TO 2P-2H STATES



Nuclear Physics A371 (1981) 405–429

ROLE OF THE NUCLEAR SURFACE IN A UNIFIED DESCRIPTION OF THE DAMPING OF SINGLE-PARTICLE STATES AND GIANT RESONANCES

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University of Padova, Istituto di Fisica Galileo Galilei, Padova, and INFN, L. N. Legnaro, Italy

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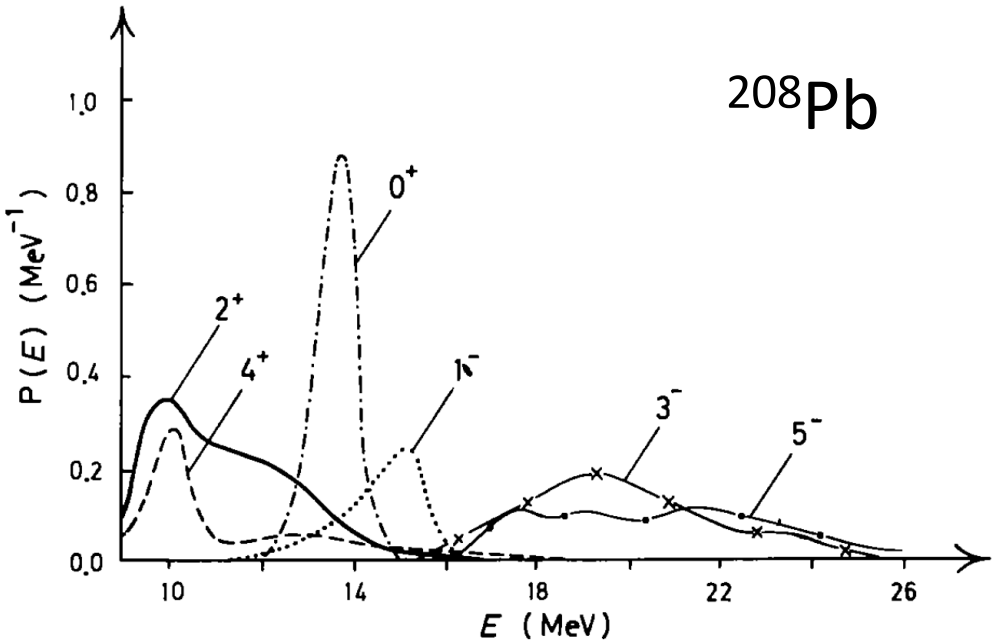

Reviews of Modern Physics, Vol. 55, No. 1, January 1983

Damping of nuclear excitations

G. F. Bertsch

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P. F. Bortignon

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R. A. Broglia

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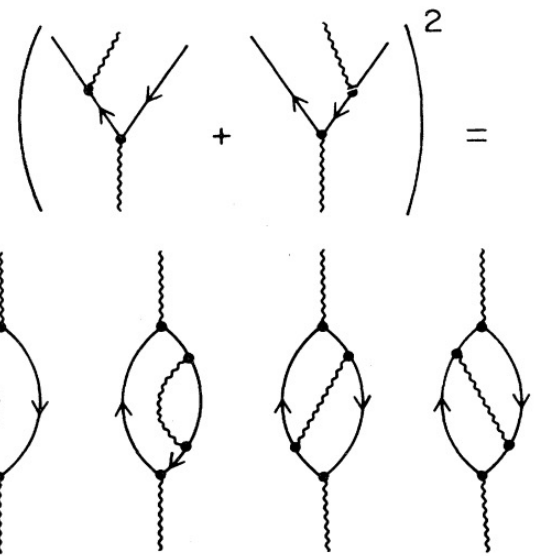
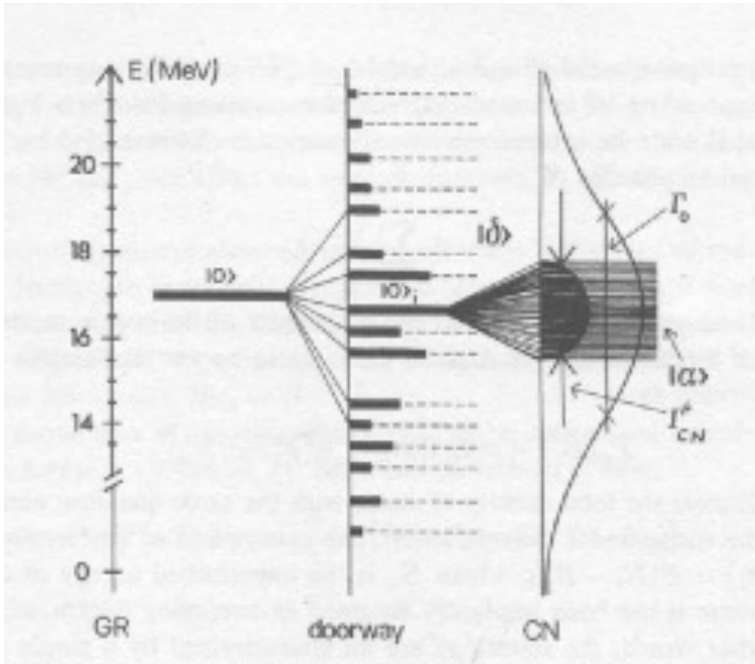
On a numerical level, the calculated widths are generally within a factor of 2 of the empirical values. However, there is a systematic tendency for the empirical damping to be underestimated by theory, showing that our understanding is not yet complete. The theoretical strength function often has much more structure than that observed experimentally. The doorways themselves must be strongly mixed with states of even higher complexity. A complete description of damping would require an understanding of the mixing at each level of complexity, but this remains for the future.





EXTENSIVE ANALYSIS OF THE EFFECTS OF THE COUPLING OF SINGLE-PARTICLE LEVELS TO OTHER MODES OF EXCITATION IN ^{3}HE, ELECTRON GAS, NUCLEAR MATTER AND NUCLEI

^{208}Pb

PHYSICS REPORTS 120, Nos. 1–4 (1985) 1–274.

DYNAMICS OF THE SHELL MODEL

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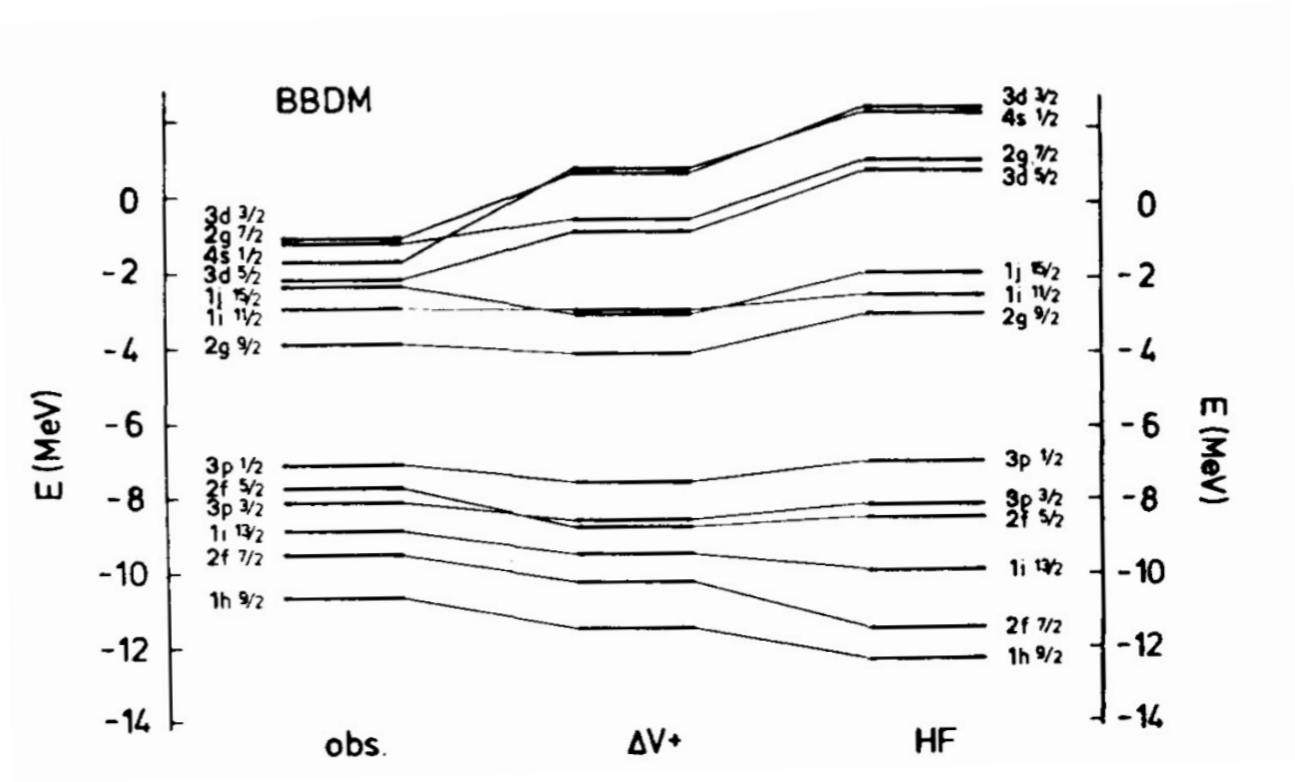

Nuclear Physics **A457** (1986) 61–83

DAMPING OF ROTATIONAL MOTION

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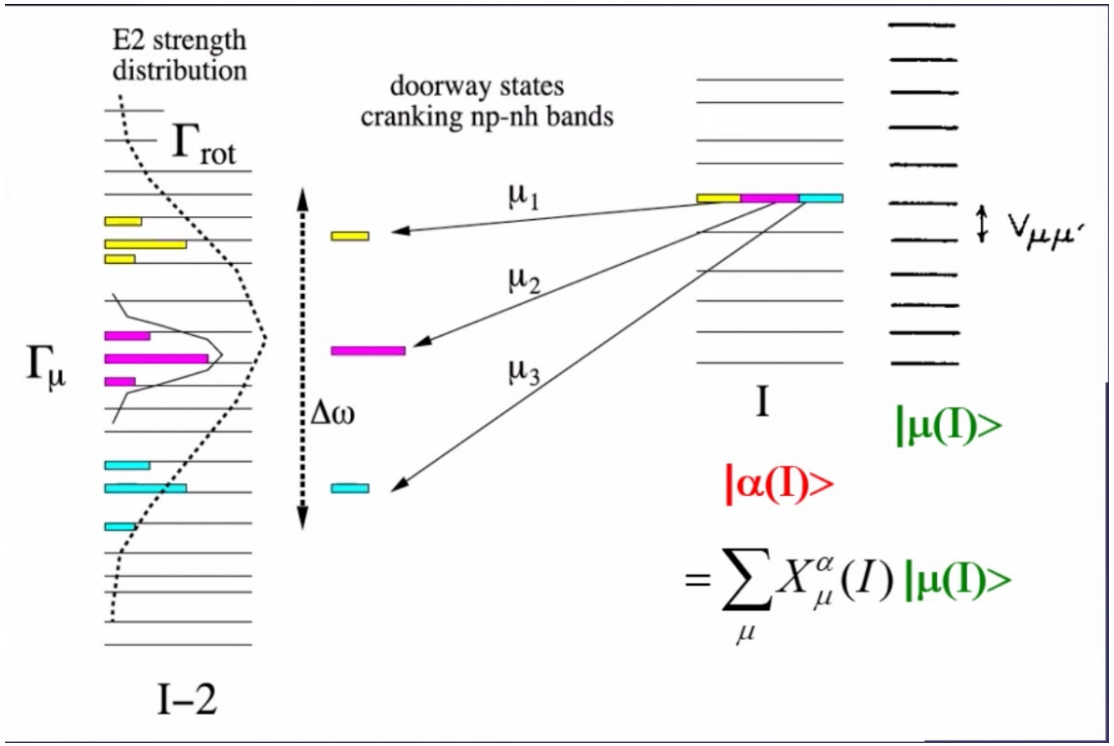
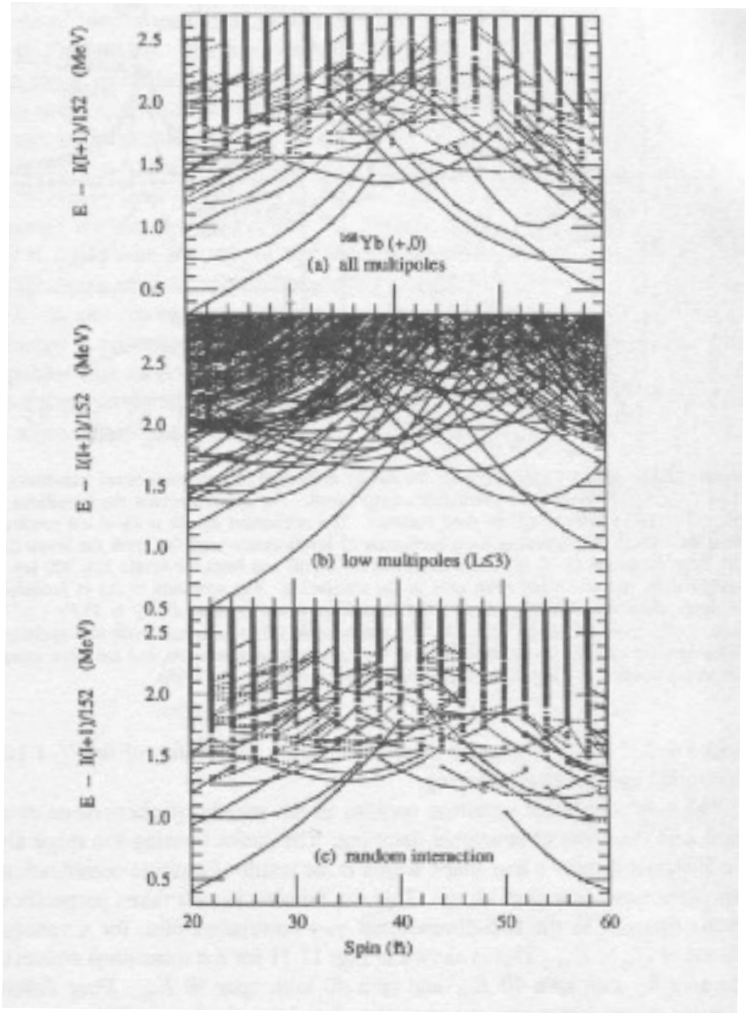
The Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark

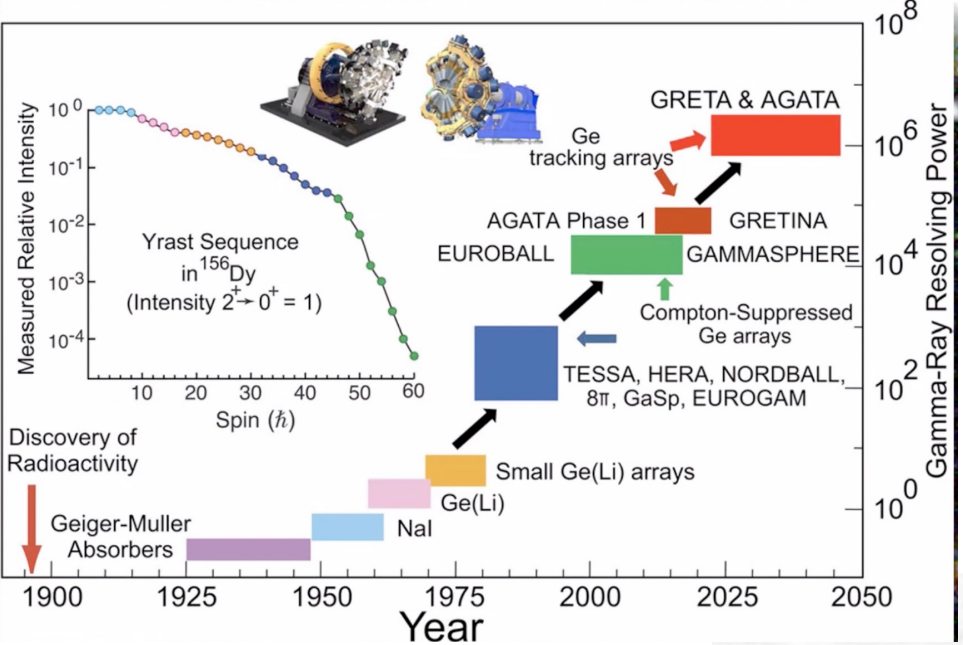
R.A. BROGLIA

The Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark
and
Dipartimento di Fisica, Universita di Milano, Via Celoria 16, and INFN Sez. Milano, 20133 Milano, Italy



UNDERSTANDING THE ROTATIONAL DECAY OF WARM NUCLEI: ROTATIONAL DAMPING





THE EUROBALL COLLABORATION

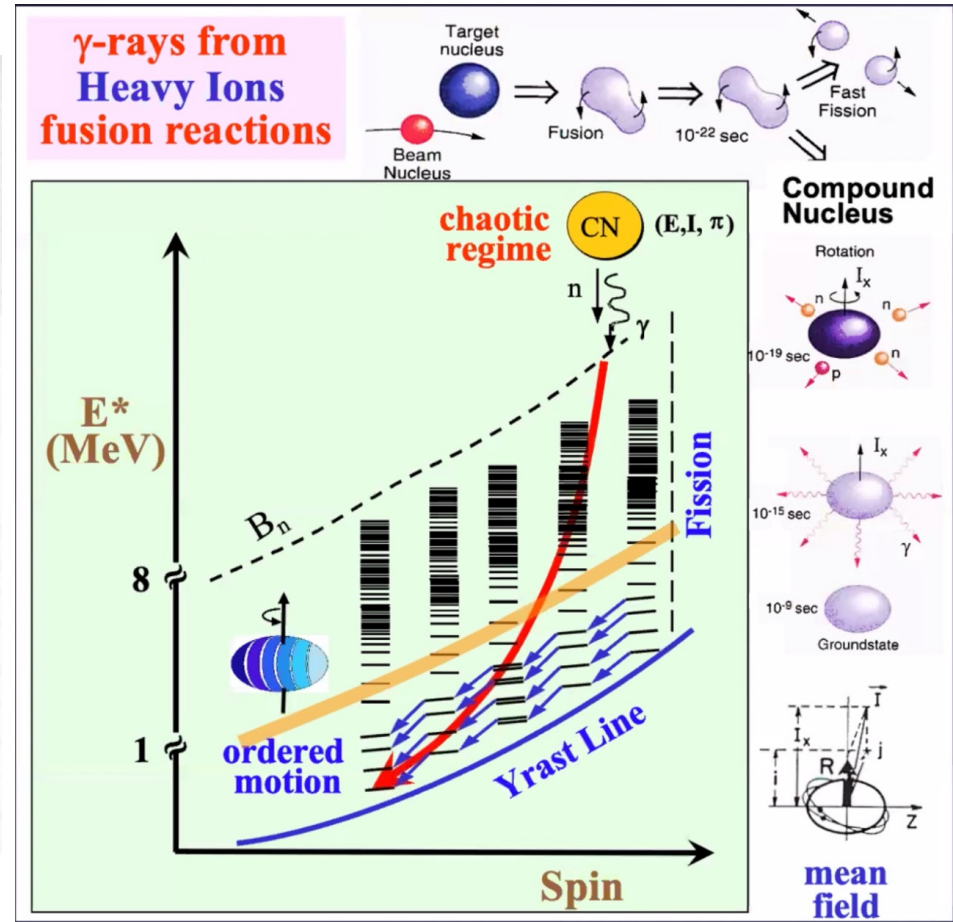
March 1990

The EUROBALL Steering Committee has reviewed the status of the project following the recommendations of July 1989 and considered the impact of a variety of events which have taken place in the past nine months.

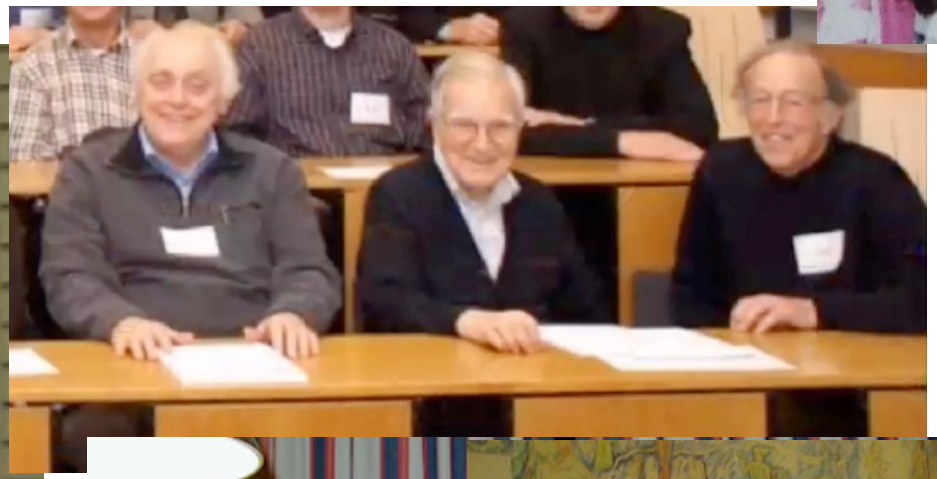
A three month Workshop held in Copenhagen last autumn was devoted to nuclear structure with large arrays. It elucidated some of the novel and exciting physics which are opened up by the EUROBALL project. The material produced during this workshop will be invaluable in preparing proposals to use current arrays and providing the scientific justification for the later phases of EUROBALL.

Francis Beck Ricardo Broglia Bent Herskind

Rainer Lieder Dirk Schwalm Peter Twin



A strong collaboration with the γ-spectroscopy community between Milano and Copenhagen and experimentalists and theoreticians

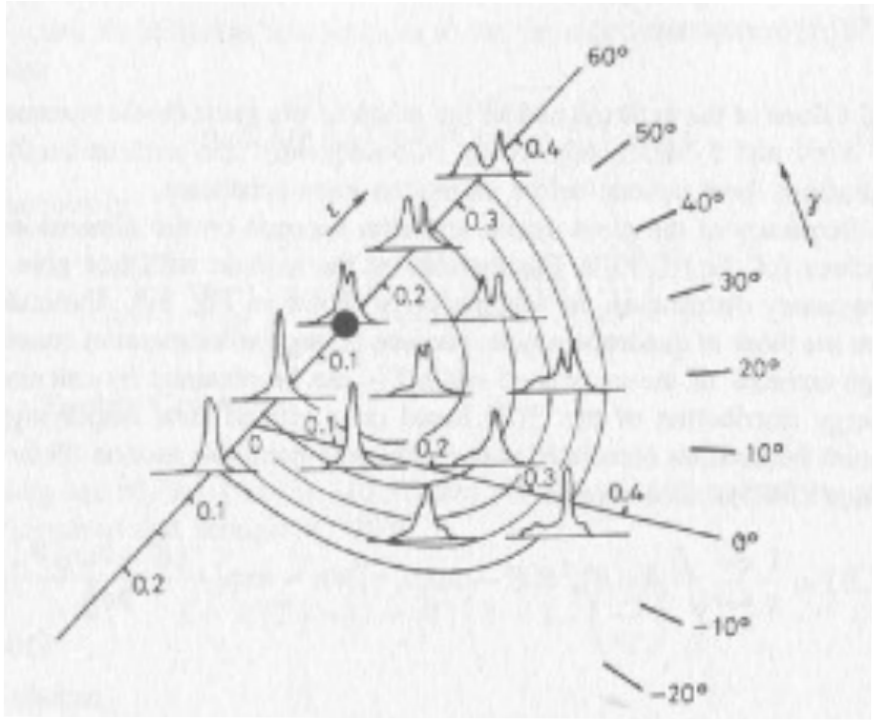


1985-2011: Full Professor at Milano University

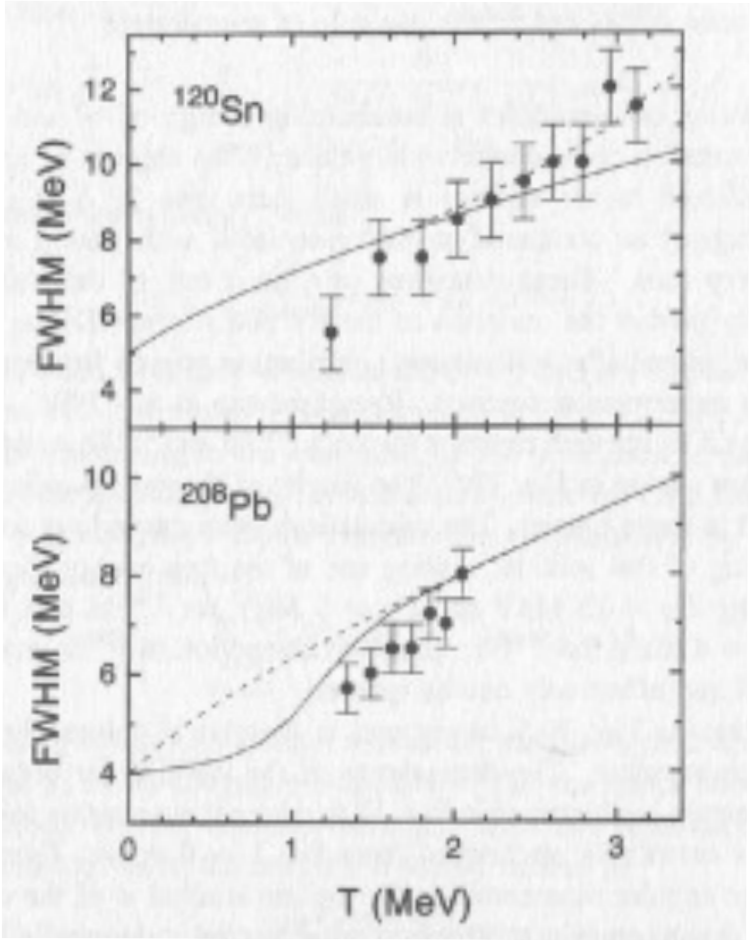
“It might seem unnatural that I have left what is one of the most prestigious physics institutes in the world (even though I have kept my research chair there) to create a new theoretical nuclear physics group in Milan.
Having learned in Copenhagen, from the school created by Niels Bohr, not only physics but above all what a great school of research and thought at the highest level was, I did not doubt back in 1986 that the time had come to move again.
Basic scientific research needs only one thing in order to develop: a positive atmosphere.
The antiscientific period that Denmark went through at that time was not the right one to be able to continue developing what was at the time the most important nuclear theoretical physics group in the world.
In particular, in a few years we had lost all the brightest young people to the United States for lack of research positions.

At the Department of Physics of the University of Milan I was able to create a theoretical nuclear physics group whose theoretical production places it today among the strongest in the world. Furthermore, I have been able to create an interdisciplinary group that deals with neutron stars, molecular aggregates, protein folding and the design of unconventional drugs.
Our group has gone from a dream (shared only with the late Prof. Francesco Resmini, former director of the Milanese superconducting cyclotron project) to a reality of great value.”

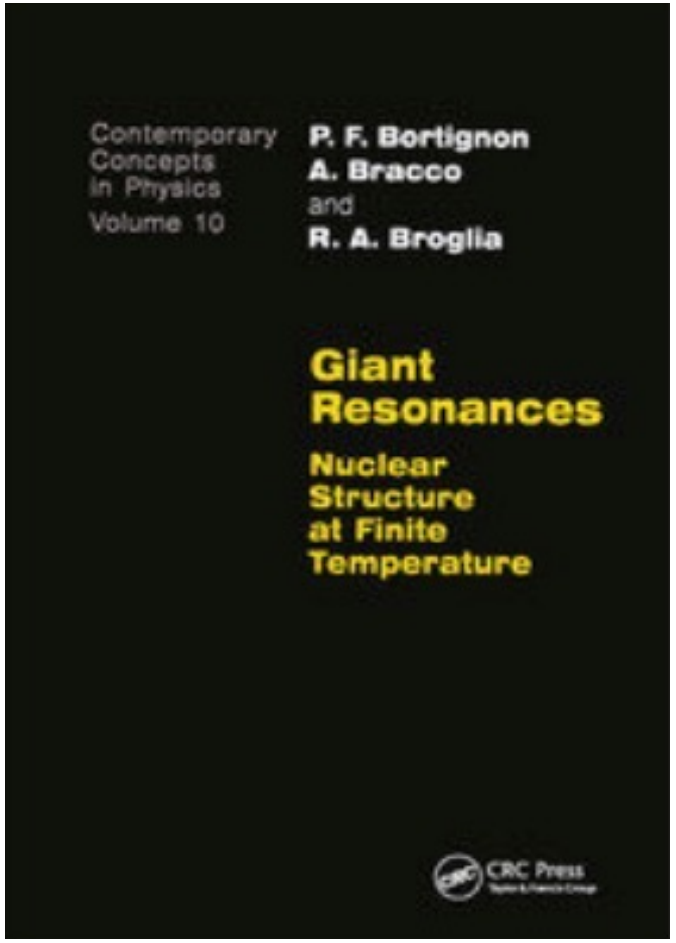
THE GIANT DIPOLE RESONANCE IN HOT NUCLEI



I. Gallardo, M. Diebel, T. Døssing, R.A. Broglia, Nucl. Phys. A443 (1985) 415



W.E. Ormand, P.F. Bortignon, R.A. Broglia, A. Bracco, Nucl. Phys. A614 (1997) 217



1998

Eur. Phys. J. A (2019) **55**: 222
DOI 10.1140/epja/i2019-12742-2

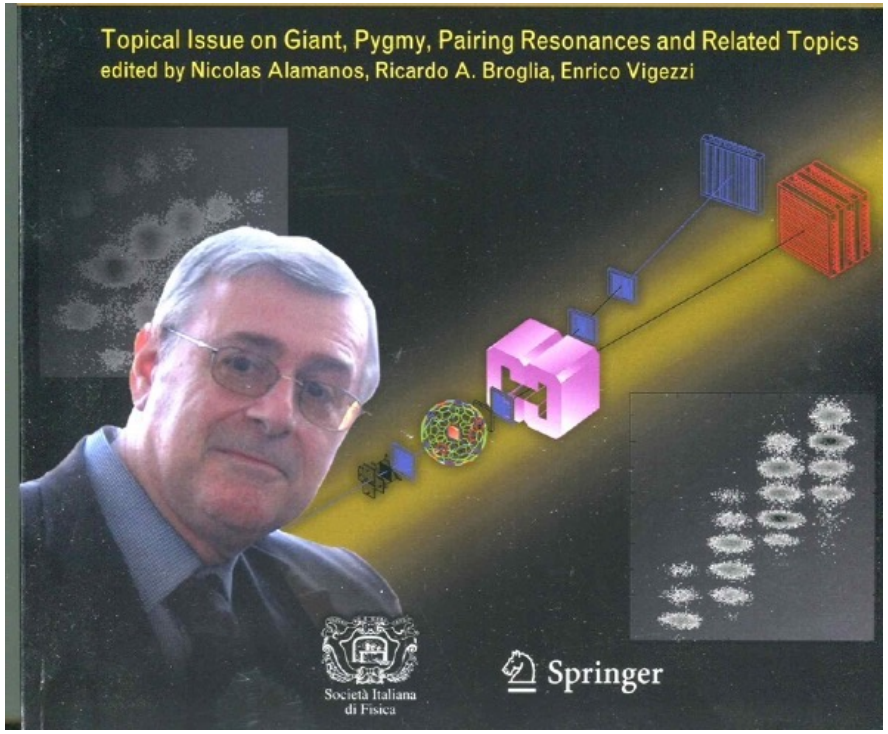
THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Theoretical Physics

Pier Francesco Bortignon as a scientist*

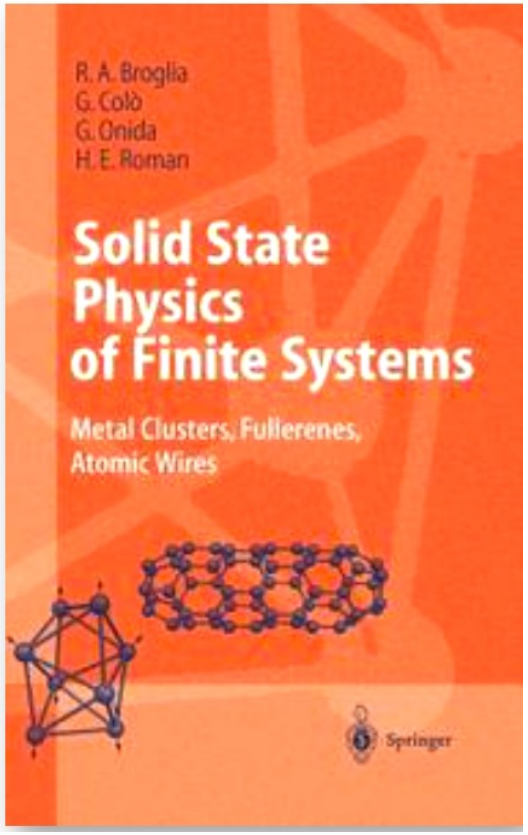
R.A. Broglia[1,2,a]

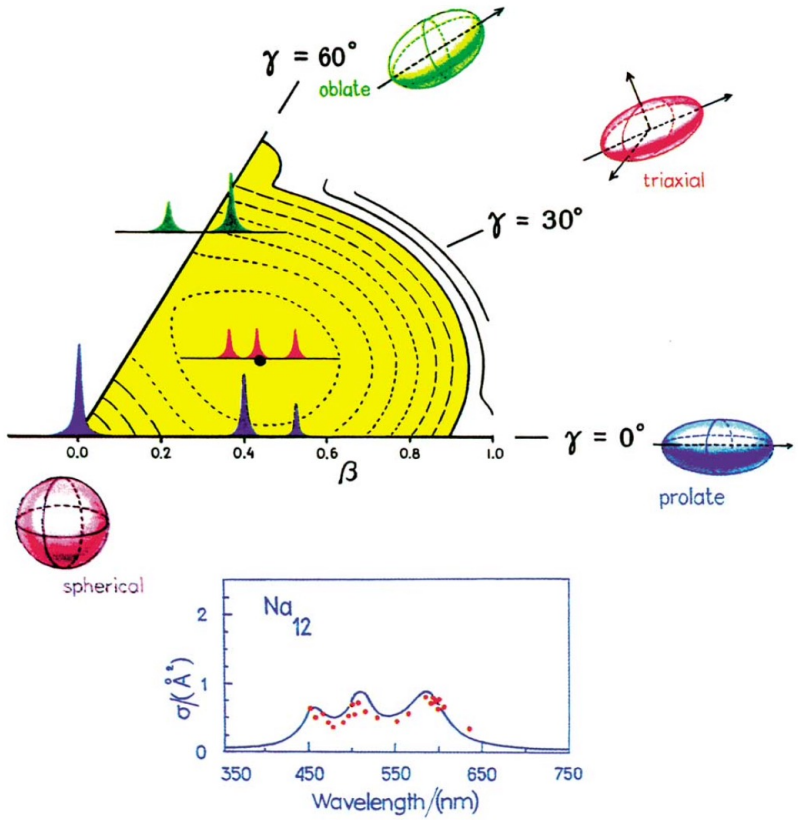
[1] Department of Physics, University of Milan, via Celoria 16, 20133 Milan, Italy
[2] The Niels Bohr Institute, Blegdamsvej 17, DK-2100 University of Copenhagen, Copenhagen, Denmark

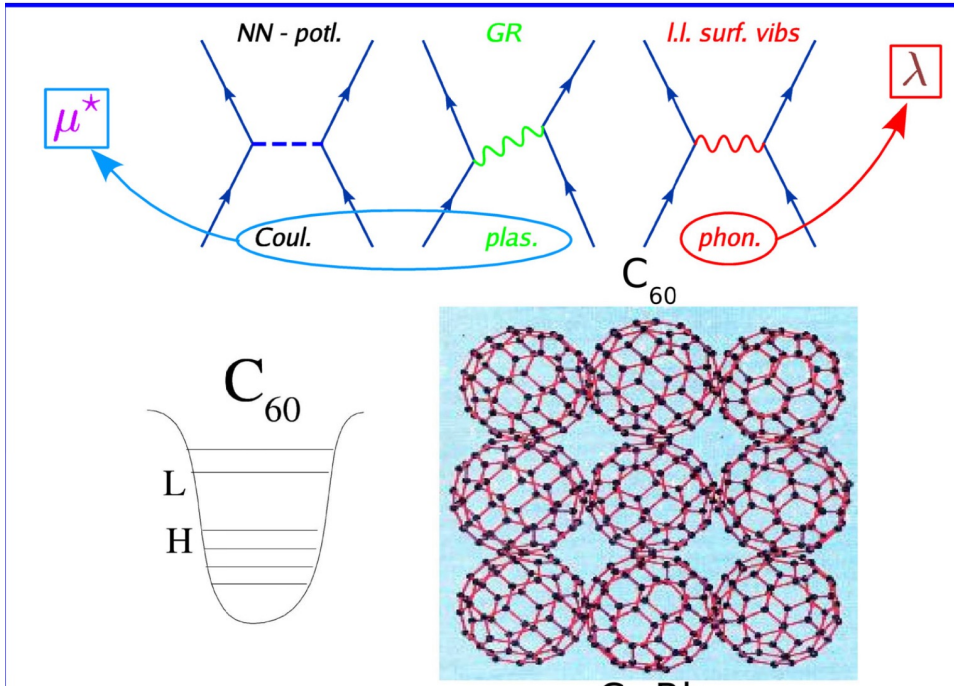


I vividly remember the summer of 1981 at Santa Barbara when we (Pier Francesco and myself) together with George Bertsch wrote the Review of Modern Physics paper on the damping of nuclear excitations. The initial remark of George regarding the project was something like "now there is something to review". He was referring to the recently published Nuclear Physics paper concerning the role of the nuclear surface on the damping of nuclear motion, a paper in which Pier Francesco had demonstrated his mastery in the subtleties of finite many-body techniques by identifying the doorway states to the compound nucleus, for both single-particle motion and giant resonances.

METAL CLUSTERS AND FULLERENES: ANALOGIES WITH ATOMIC NUCLEI







$$T_c = \frac{\langle \hbar\omega_{ph} \rangle}{1.2} \exp\left[-\frac{1.04(1+\lambda)}{\lambda - \mu^\star(1+0.62\lambda)} \right]$$

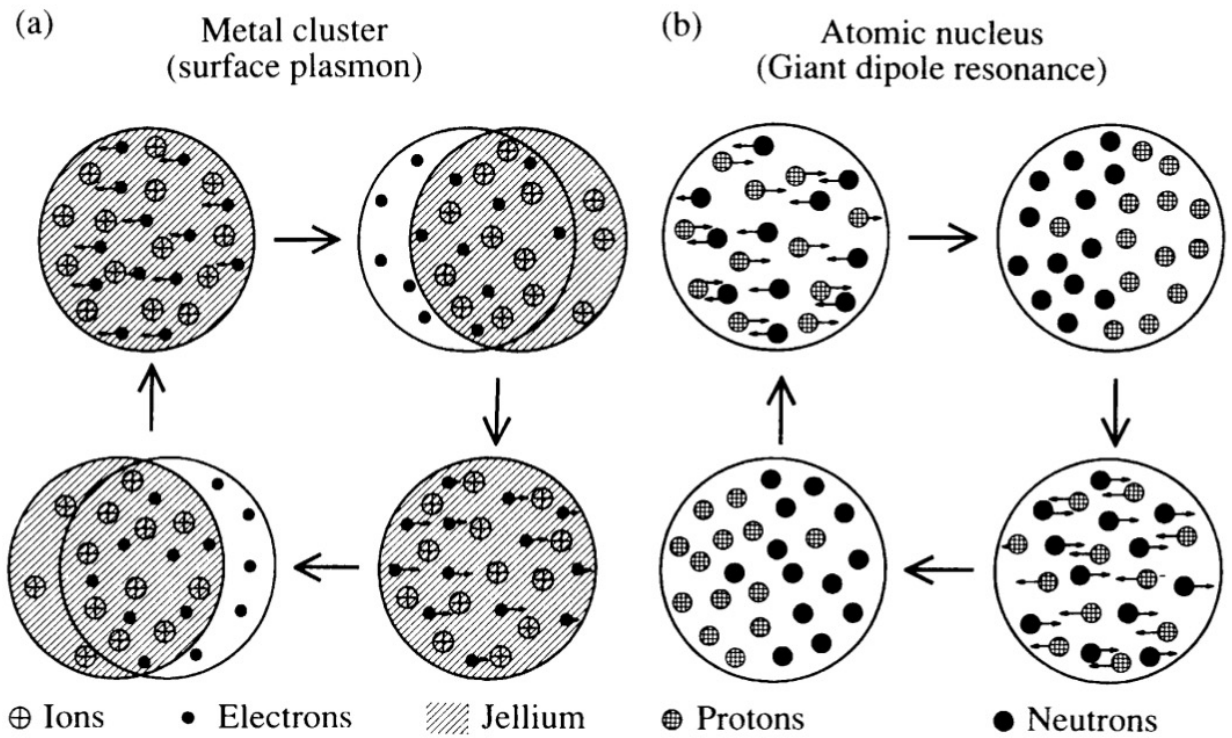
$$\lambda = 1.3, \quad \mu^\star \approx 0.3, \quad T_c \approx 29.5\ \mathrm{K}$$

ELSEVIER Surface Science 500 (2002) 759–792

The surfaces of compact systems: from nuclei to stars

R.A. Broglia [a,b,*]

The vibrations of the surface of finite many-body systems dress the single-particle motion, renormalizing its properties and consequently, the properties of the entire system. In fact, in their trajectories particles bounce, most of the time, elastically off the surface. From time to time, however, they set the surface into vibration, vibration which can be reabsorbed at a later time by the same particle or by another particle. In the first case the particle carries around a vibration and becomes effectively heavier, which thus modifies, among other things, the specific heat of the system. In the second case, the vibration becomes a messenger between two particles, and thus acts as a glue. The resulting interaction is particularly efficient in producing pairs of particles. These pairs of particles have properties that are very different from those of single particles. In particular they may behave collectively as a liquid without viscosity, or, if charged, without resistance. That is, as a superfluid or as a superconductor.

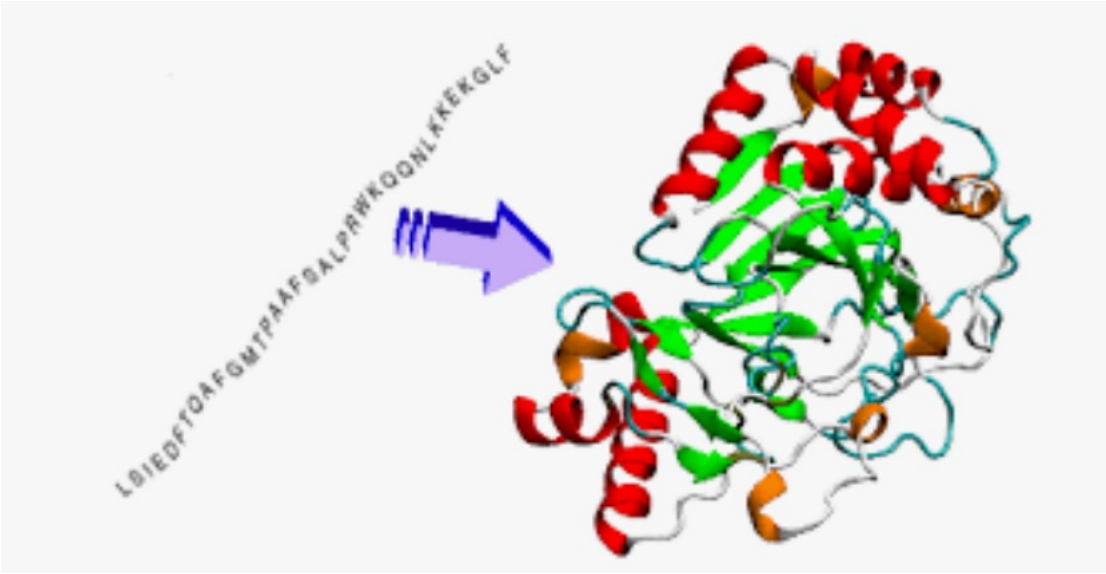


Protein folding

I have always done the same thing …

If you do something new, you have to play in Premier League…

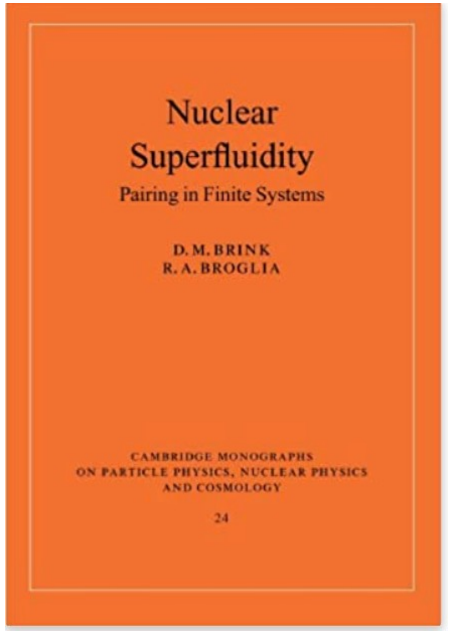
The protein folding problem

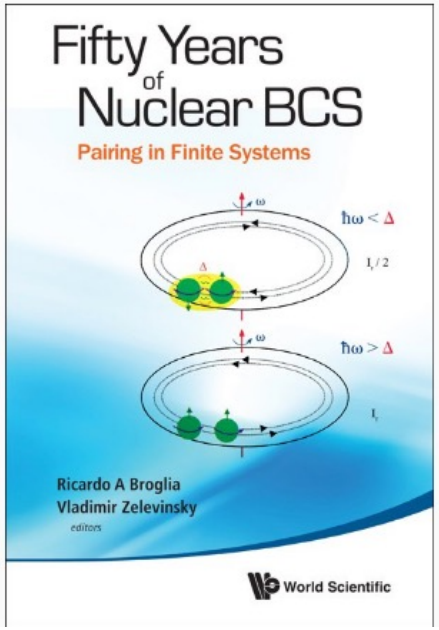


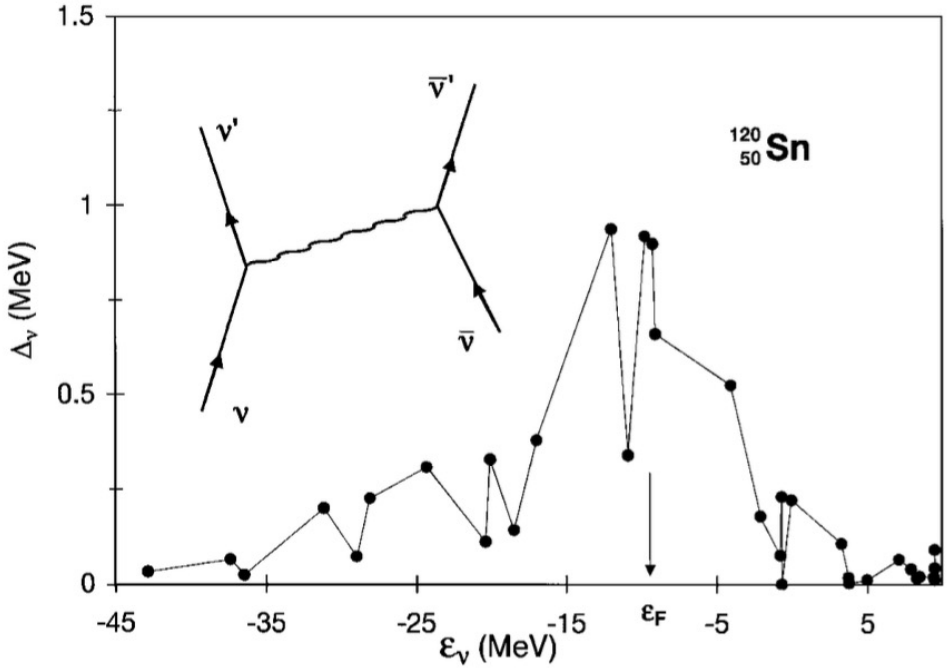
How can a linear sequence of aminoacids fold into a specific, biologically active, three-dimensional structure in a short time ?It is extremely difficult to answer with ‘ab initio’ molecular dynamics simulations

Broglia’s idea: there must exist specific, strongly interacting aminoacids that once in contact, determine the process. This is in analogy with the case of nuclei, where e a few ‘hot orbitals’ can determine a symmetry breaking phenomenon, like the transition from spherical to deformed shapes.

NUCLEAR SUPERFLUIDITY AND PARTICLE-VIBRATION COUPLING







J. Terasaki et al., Nucl.Phys. **A697**(2002)126;

F. Barranco et al, EPJ A21 (2004) 57

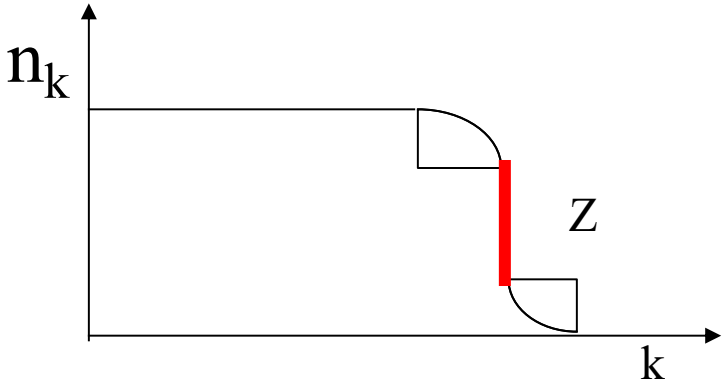
A. Idini et al. PRC 85 (2012) 014

cf. V. Soma' , C. Barbieri, T. Duguet,

PRC **84** (2011) 064317 ;PRC87 (2013) 011303

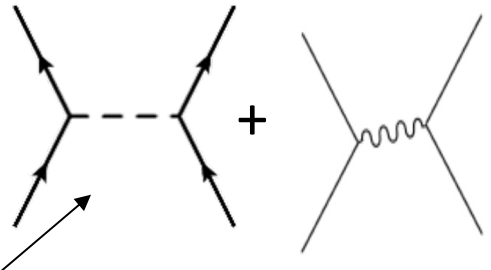
FROM 'BARE' TO RENORMALIZED PAIRING GAPS

Z=1 free Fermi gas
Z<1 correlated Fermi system



Bare+Induced interaction

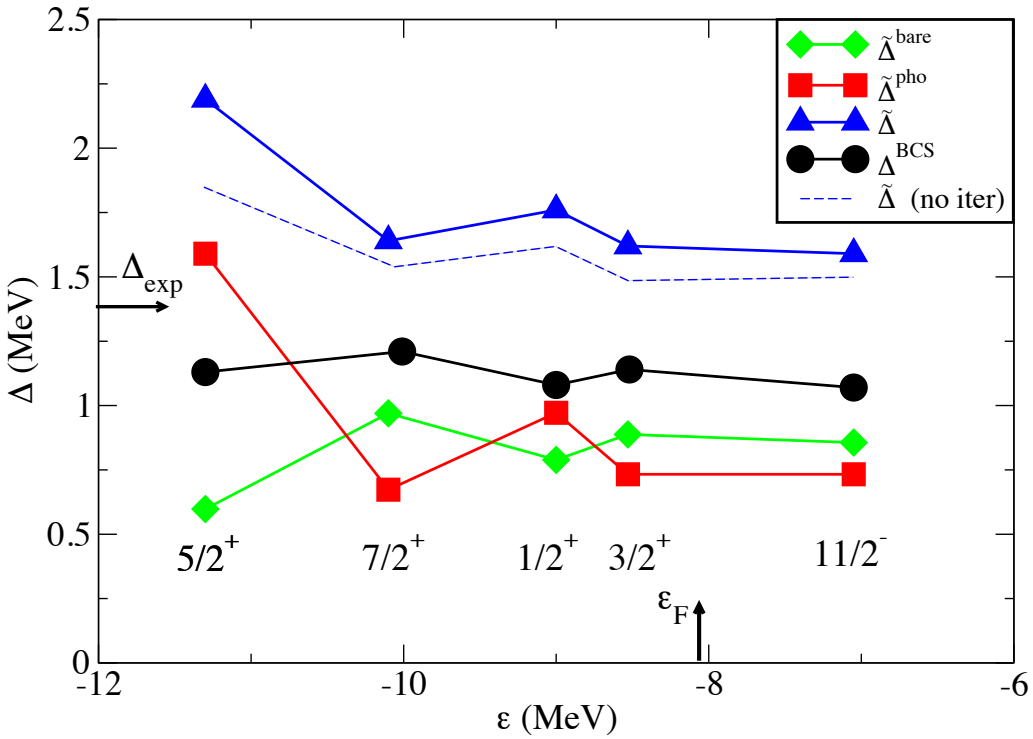
Quasiparticle strength <1



$$\Delta_p = -\frac{1}{2}\int d^3p' \frac{Z_p V_{pp'} Z_{p'}}{\sqrt{(\tilde{\varepsilon}_{p'} - \varepsilon_F)^2 + \Delta_{p'}^2}} \Delta_{p'}$$

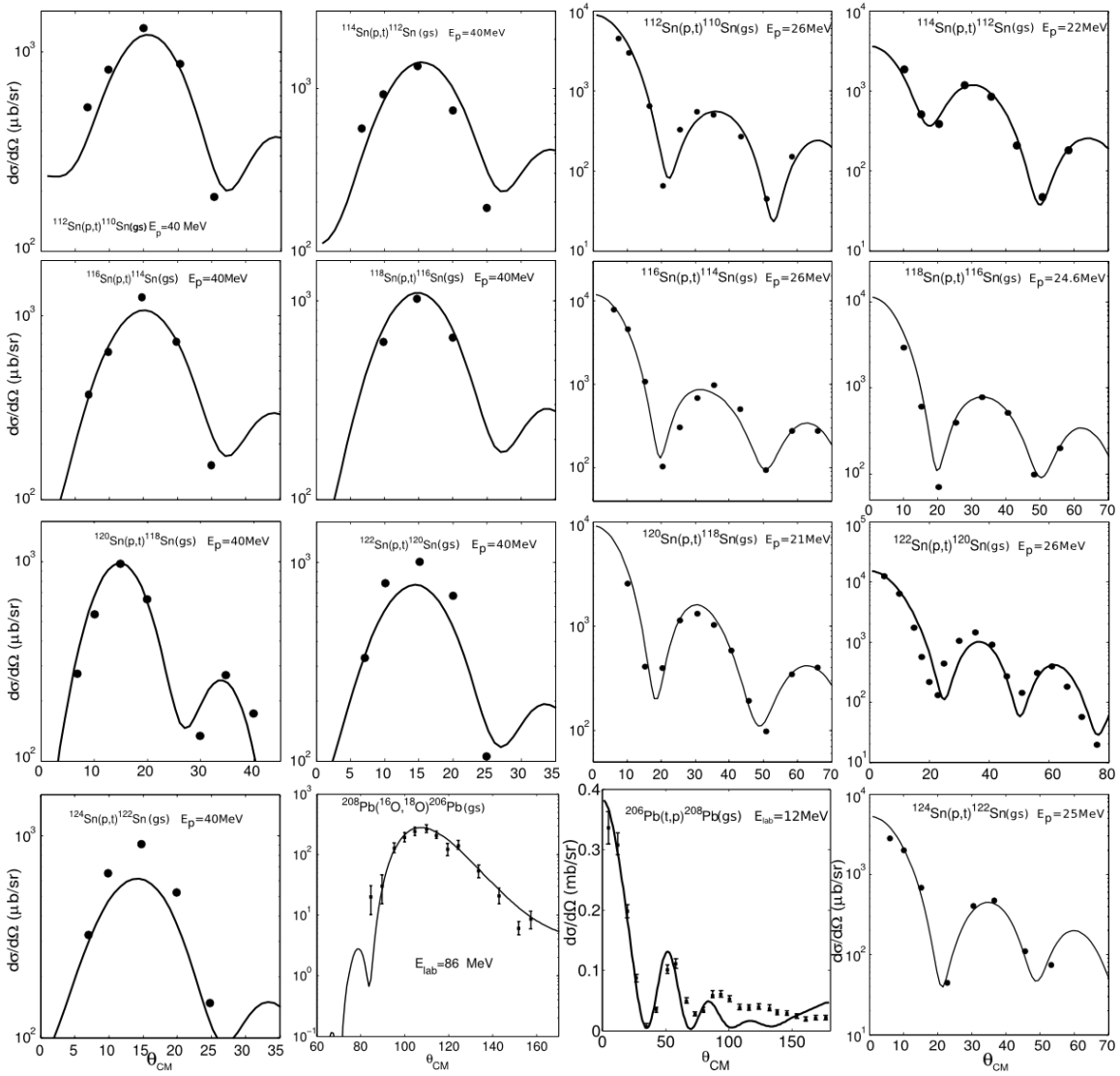
Renormalized s.p. energy

Bare interaction: Δ^{BCS}
Reduced occupation factor: $\Delta^{bare} = Z\ \Delta^{BCS}$
Induced pairing interaction: Δ^{ind}
Total gap : $\Delta^{bare} + \Delta^{ind}$



Software developed by Gregory Potel during his stay in Milano, following Ben Bayman's footsteps led to quantitative agreement between theoretical and experimental absolute cross sections with finite-range sequential DWBA

TWO-PARTICLE TRANSFER



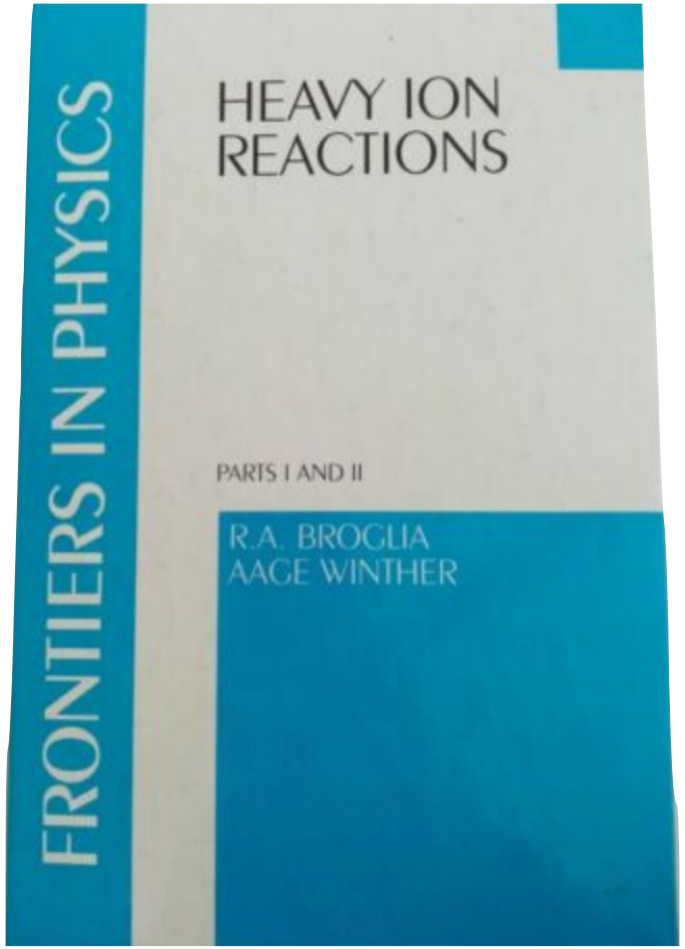
All along his career:
Structure and reactions, the two inseparable faces of the same medal

1965 (from later personal notes)

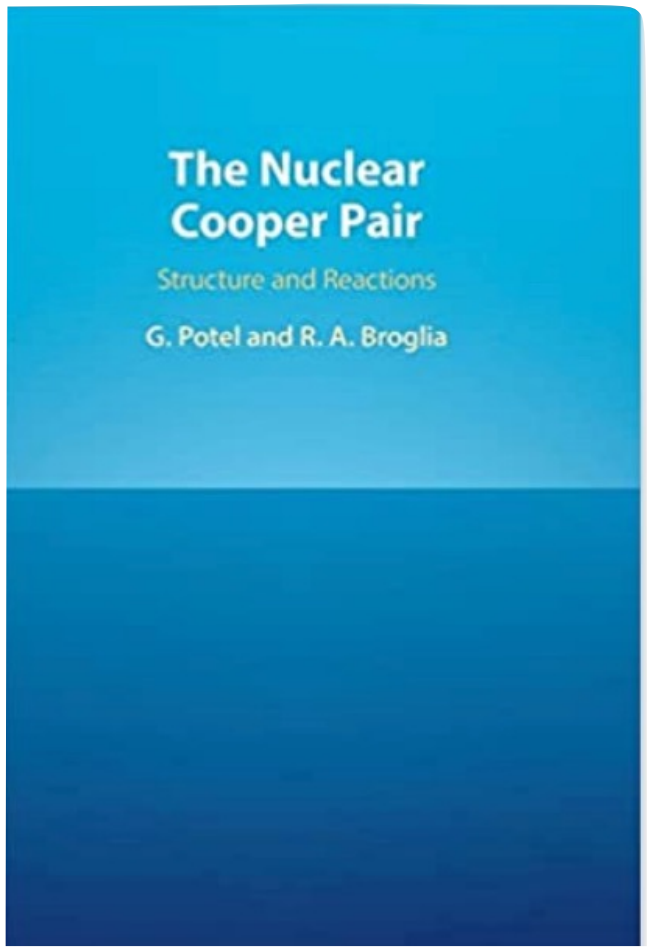
In the morning of 4th October 1965 , I (RAB) sat in a rather crowded auditorium A of the Niels Bohr Institute to attend the first of a series of lectures on nuclear reactions which were to be delivered by Ben Mottelson. In the following spring term, the Monday lectures were expected to deal with the subject of nuclear structure and the lecturer to be Aage Bohr, as it duly happened. After Ben's lecture, an experimental group meeting took place in which experimentalists, as it was the praxis, showed their spectra, likely not yet completely analyzed, while theoreticians attempted at finding confirmation of their predictions in connection with specific peaks of the spectra.

In the afternoon I would continue with the calculation of pairing vibrations I was carrying out in collaboration with Daniel Bès, as well as discuss with Claus Riedel on how to use this information to work out two-nucleon transfer differential cross sections for lead isotopes, quantities newly measured at the Aldermaston facility by Ole Hansen and co-workers. Within this context it did not seem surprising to me, nor to the rest of the attendees of Ben's lecture as far as I recall, that reactions and structure went hand in hand, to the extent that practitioners aimed at checking theory with experiment. Given this background, reinforced through the years by my association with Aage Winther and Daniel Bès, aside from that with Aage Bohr and Ben Mottelson, it is only natural that I view structure and reactions as the two inseparable faces of the same medal.

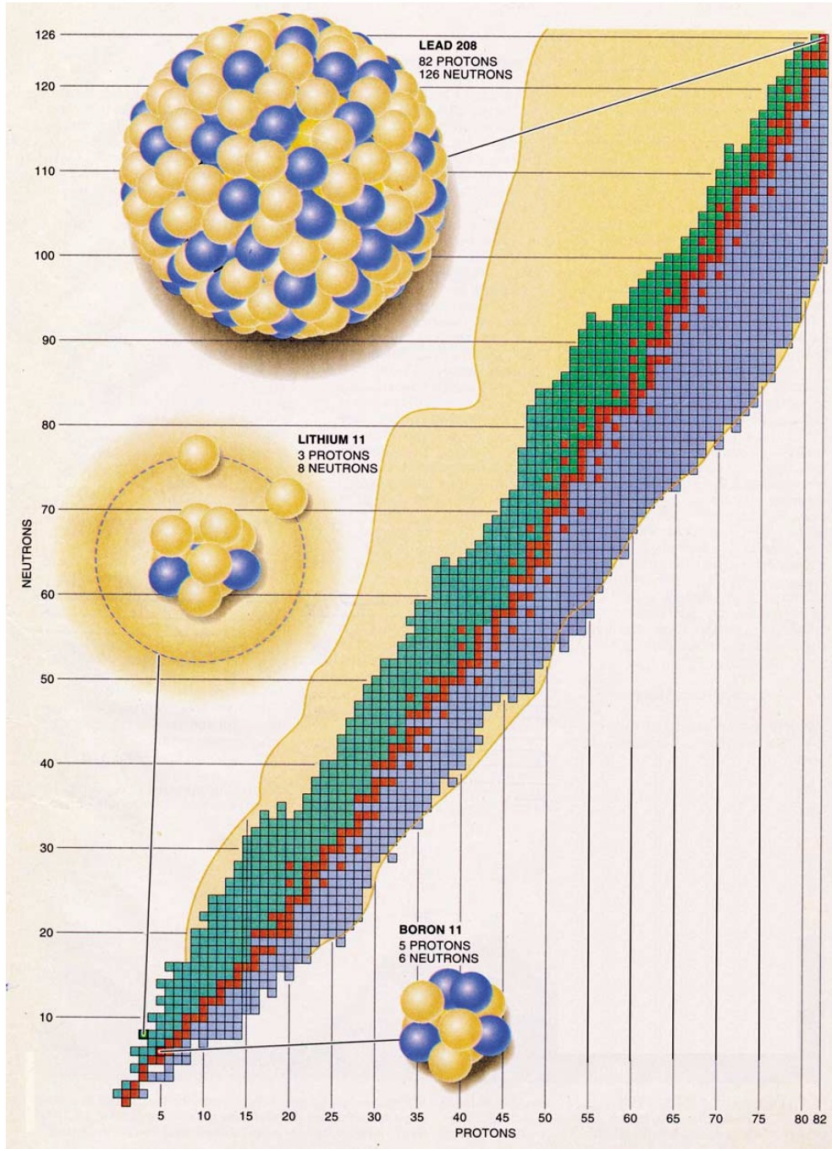
1991

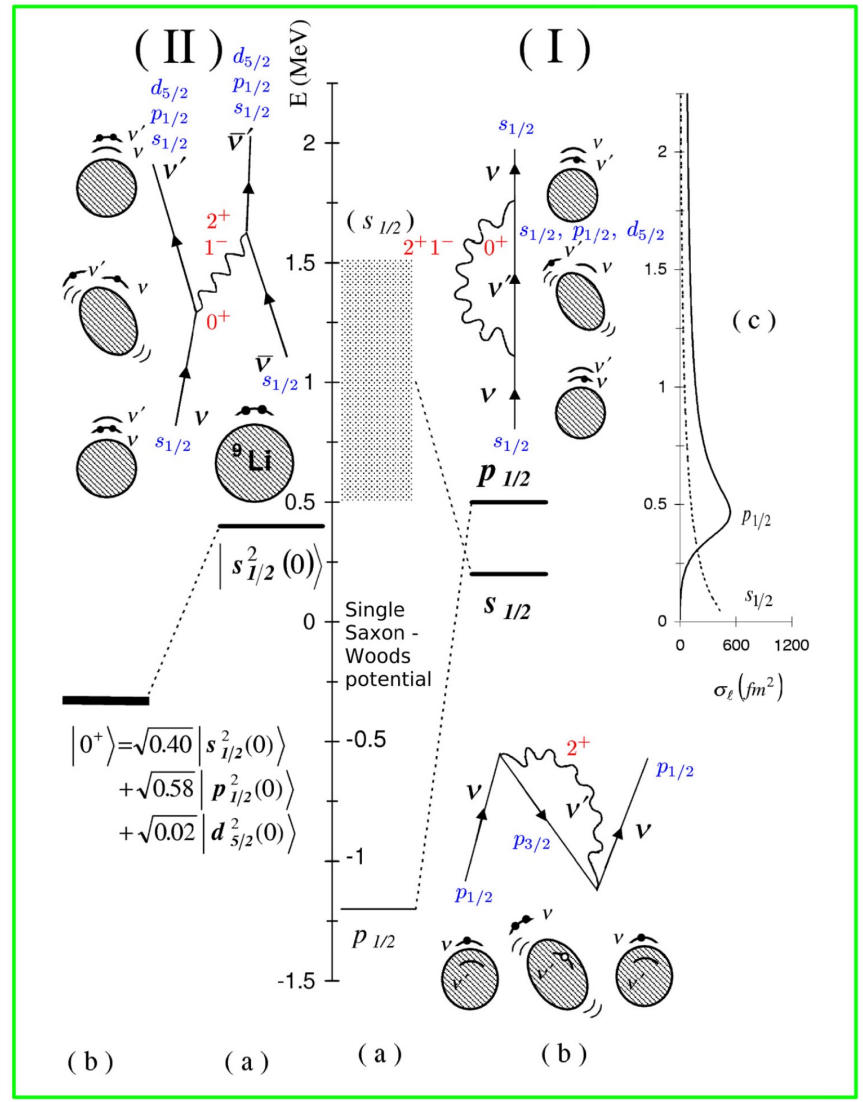


2021



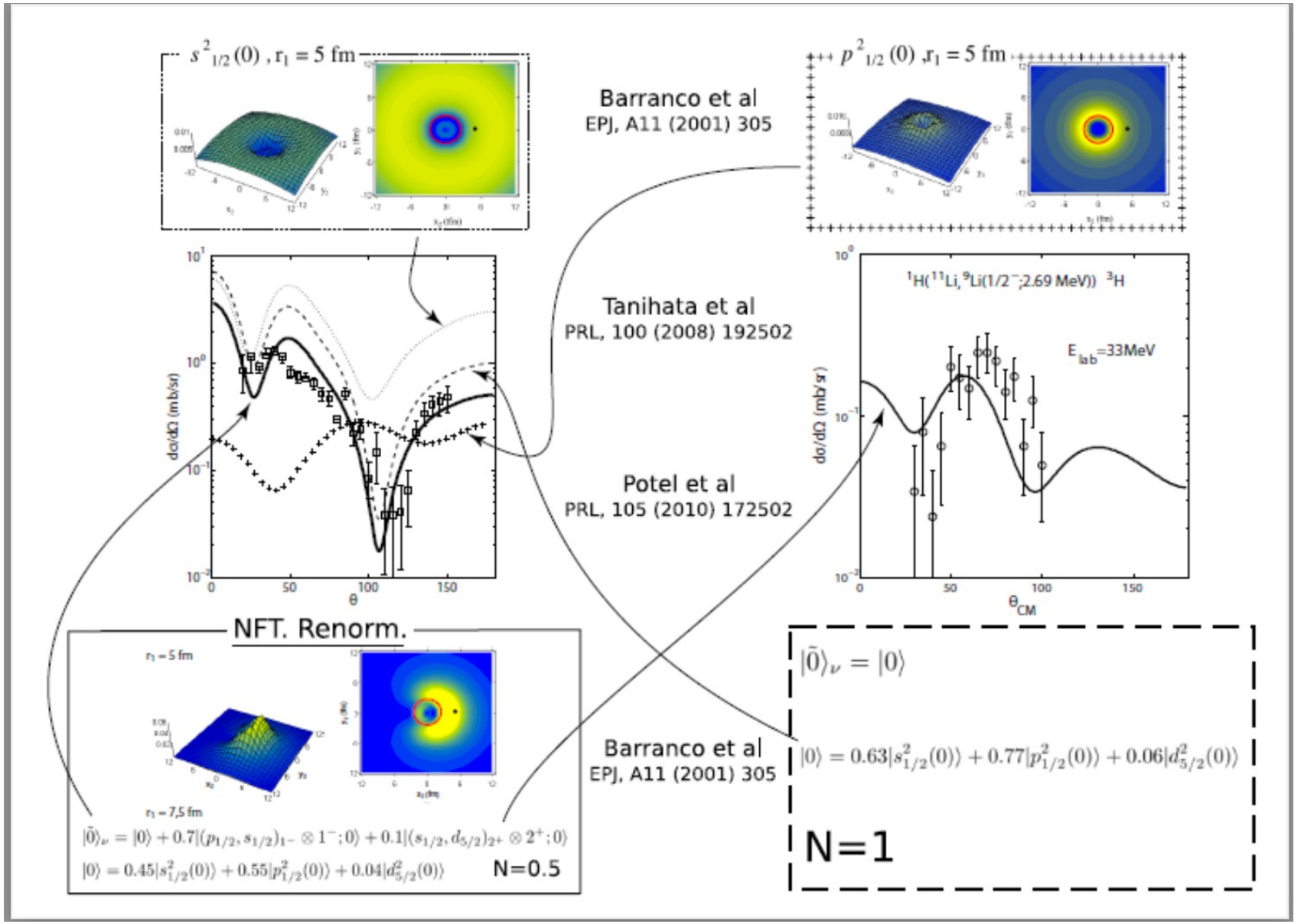
HALO NUCLEI: STRUCTURE AND REACTIONS OF ^{11}Li





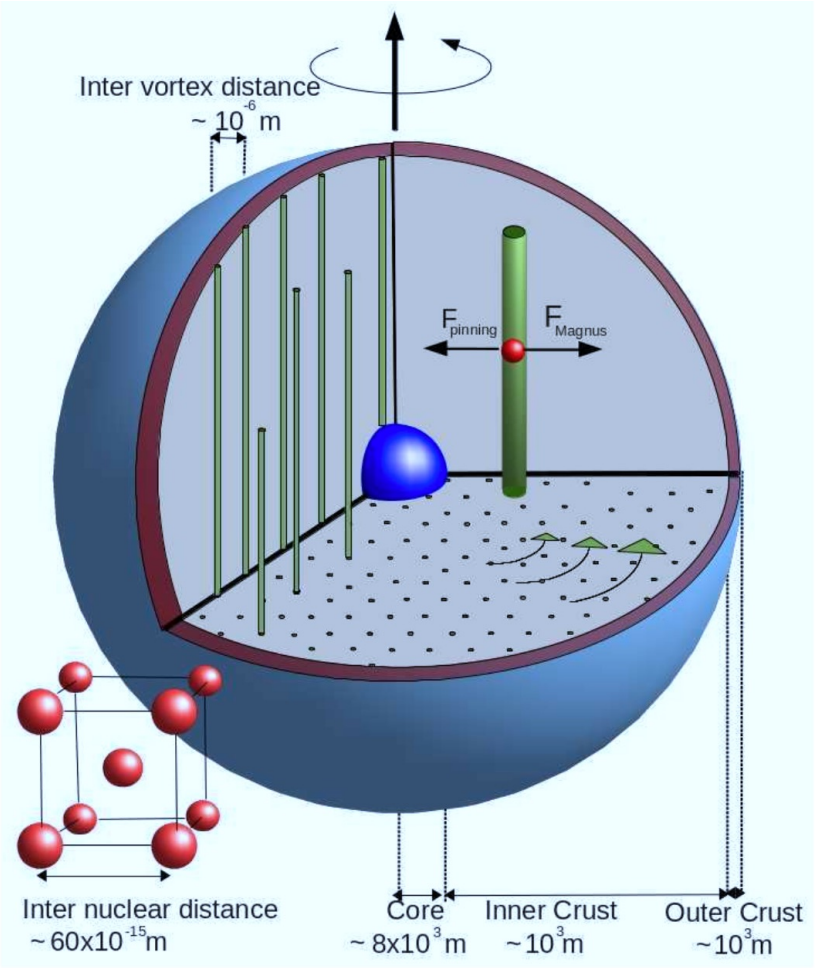
F. Barranco, P.F. Bortignon, R.A. Broglia, G. Coló and E. Vigezzi, *The halo of the exotic nucleus ^{11}Li: a single Cooper pair*, Eur. Phys. J. **A11** (2001) 385-392

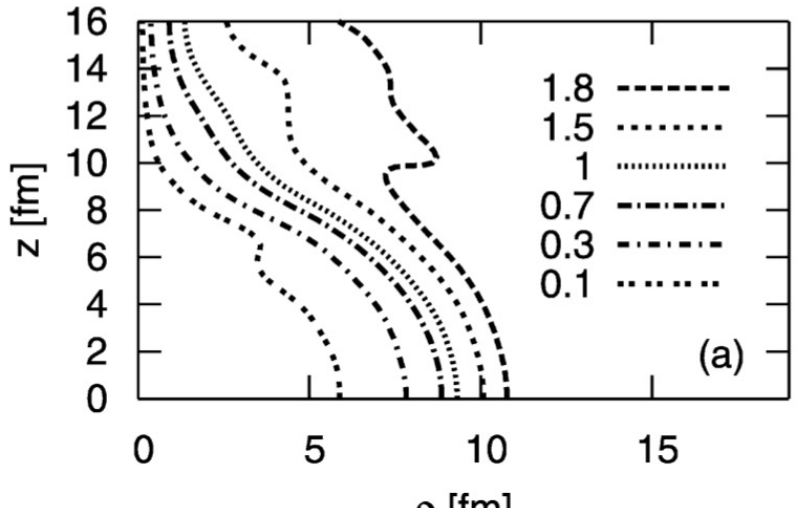
HALO NUCLEI: STRUCTURE AND REACTIONS OF ^{11}Li



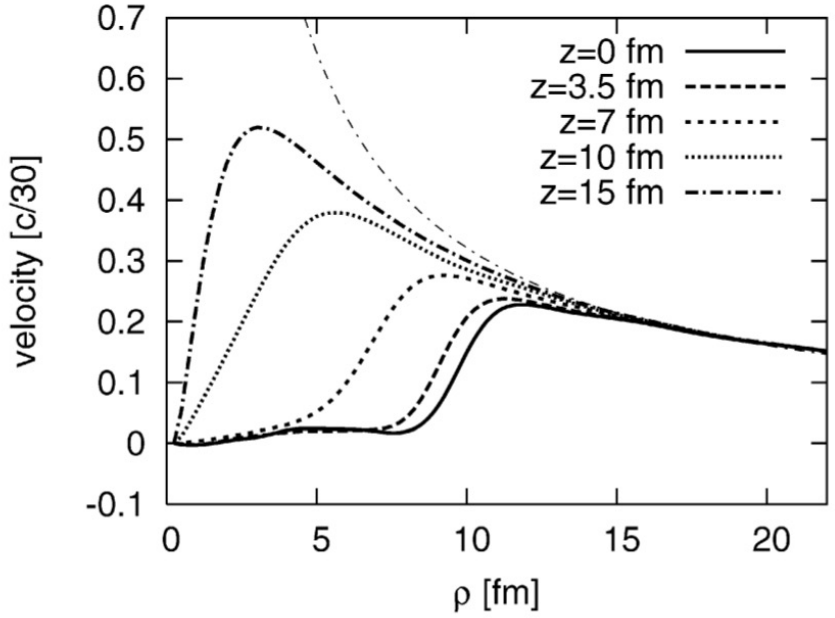
NEUTRON STARS: FIRST QUANTUM CALCULATION OF THE STRUCTURE OF VORTICES IN THE INNER CRUST

Nucl. Phys. A 811 (2008) 378





Pairing gap

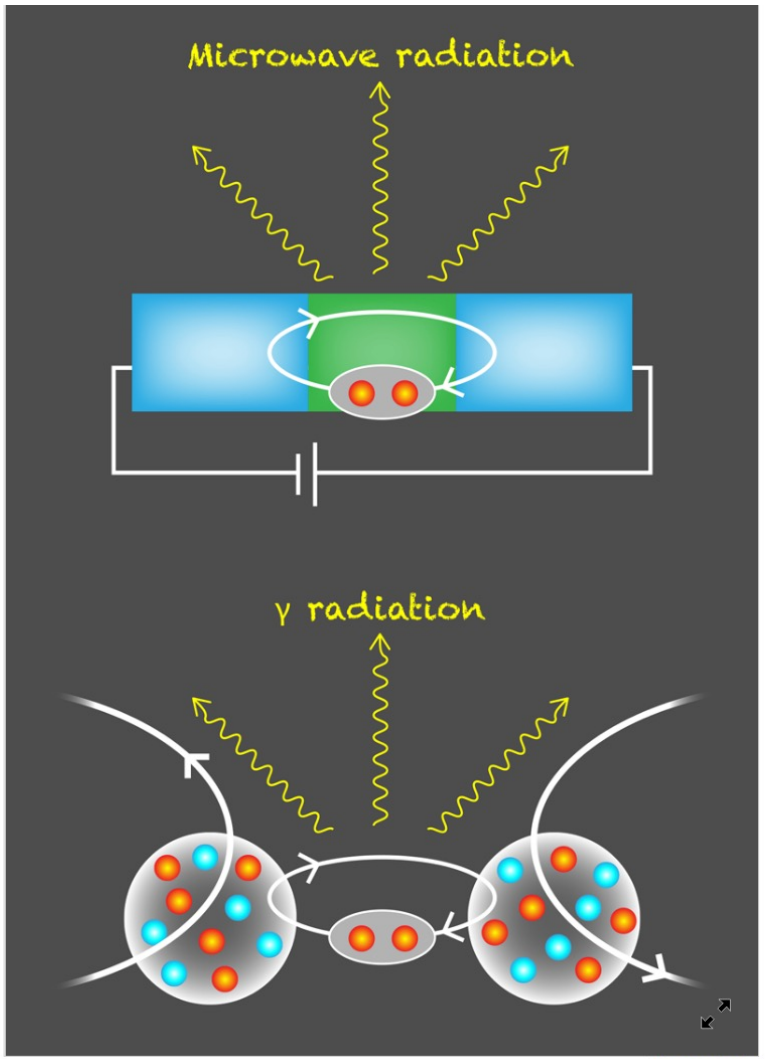


Velocity

Broglia worked almost up to the end of his life.
Recently an experiment at INFN Legnaro Laboratory has tested his idea, concerning the gamma-ray emission in coincidence with two-particle transfer between superfluid nuclei, in analogy to gamma-ray emission from Josephson junctions in condensed matter.
PRC 103 L021601 (2021)

The Tiniest Superfluid Circuit in Nature

Piotr Magierski

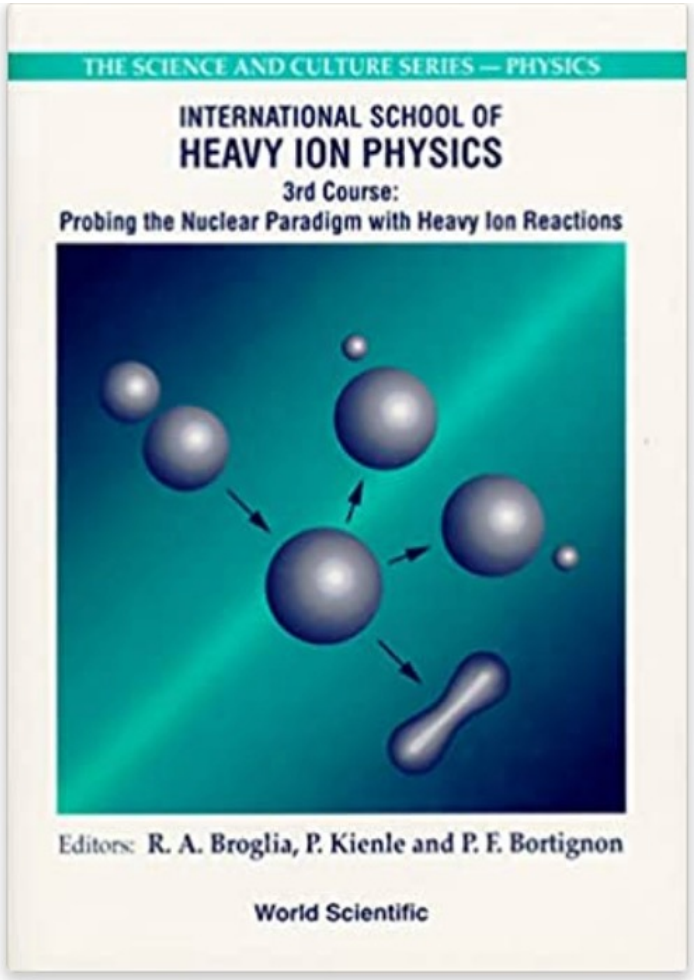


APS/Alan Stonebraker

Figure 1: (Top) Sketch of a Josephson junction, in which Cooper pairs tunnel through a barrier (green) between two superconductors (blue). In the ac Josephson effect, an applied dc voltage produces an oscillating, or ac, current, leading to the emission of microwave photons. (Bottom) Potel and co-workers have shown that a similar description applies to colliding nuclei [4]. As the nuclei approach, neutron pairs tunnel back and forth between them, causing the emission of gamma-ray photons. Show Less

P. Magierski
Physics 14, 27 (2021)

Co-director of 10 summer schools



Varenna 1987

1987
7 - 17 July

CIV COURSE

Directors: R.A. BROGLIA and J.R. SCHRIEFFER

Frontiers and borderlines in many-particle physics

E. MARINARI - The lattice strong interactions: an introduction.
A. J. LEGGETT - The quantum mechanics of a macroscopic variable: some recent results and current issues.
T. M. RICE - Heavy fermions.
R. A. BROGLIA - Theory of relaxation, phase transitions and tunneling in nuclei.
D. M. BRINK - Quantum effects in heavy ion reactions.
G. BERTSCH - Collective motion in Fermi droplets.
R. SCHRIEFFER, D.P. AROVAS - The quantum Hall effect.
P. W. ANDERSON - 50 years of the Mott phenomenon: insulators, magnets, solids and superconductors as aspects of strong-repulsion theory.
D. J. SCALAPINO - Numerical simulation of many electron condensed matter systems.
G. BAYM - Moments at the relativistic borderline: nuclei and rotating superconductors.

Nuclear structure and reactions from a broad perspective

An International School of Physics "Enrico Fermi" will be held in Varenna from 27 June to 2 July 2024 to honour the memory of Ricardo Broglia