Electromagnetic properties of the nuclei: a fingerprint of their structure

A. Goasduff
Università degli studi di Padova - INFN, Sezione di Padova

Ricci90 Symposium
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The nucleus: A laboratory to explore the fundamental interactions

The nucleus $\leftrightarrow$ A quantum many-body object where all interactions are at work:

- the strong force $\Longrightarrow$ NN, NNN, ...
- the weak interaction $\Longrightarrow$ β-decay
- the Coulomb interaction
- (Gravitation)

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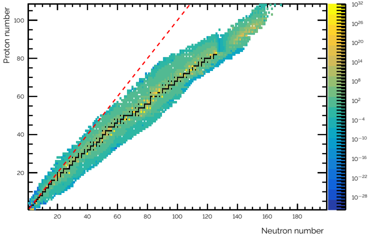
However:

- **the nuclear force is short range** ($<$ radius of most nuclei)
  $\Longrightarrow$ 1 nucleon interacts $\sim$ the 10 closest nucleons
- **the Coulomb force is long range**:
  $\Longrightarrow$ each proton interacts with all the other ones



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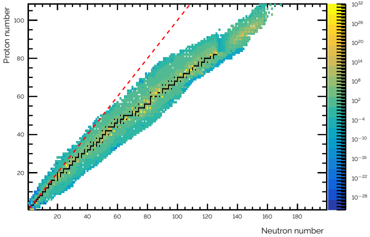
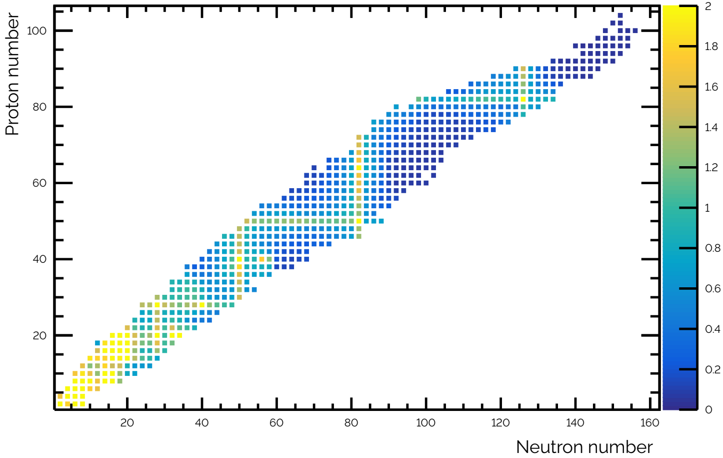


There should be a limit where eventually Coulomb $\geq$ nuclear force

A first glance to the nuclear structure: the energy of the first 2^+ in even-even nuclei



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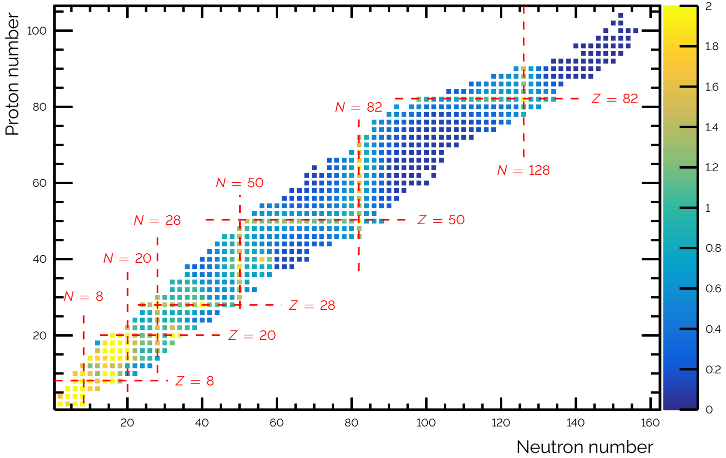

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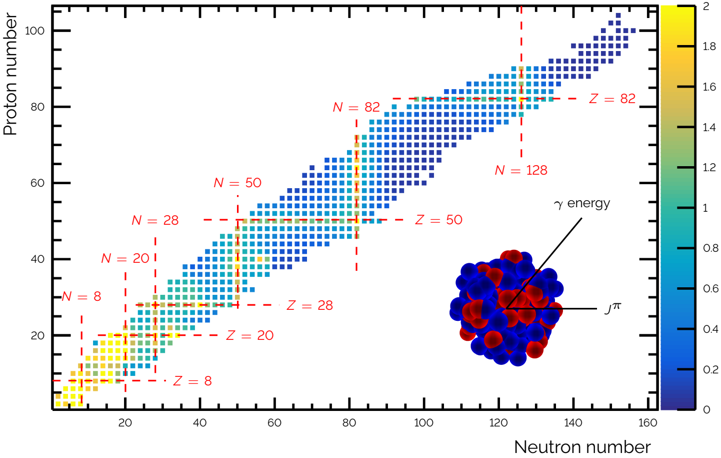

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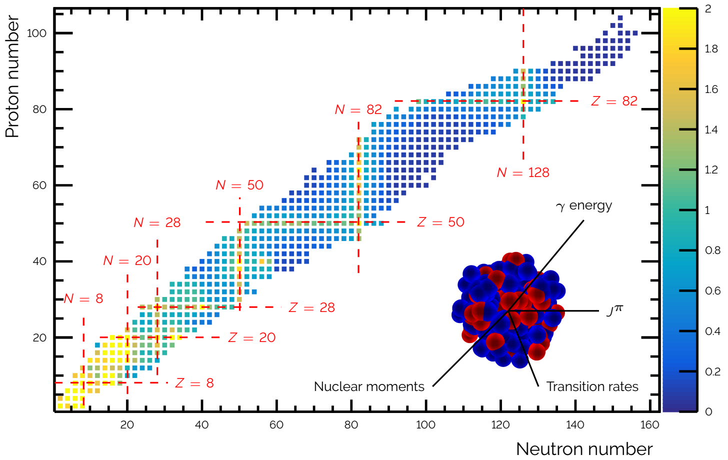

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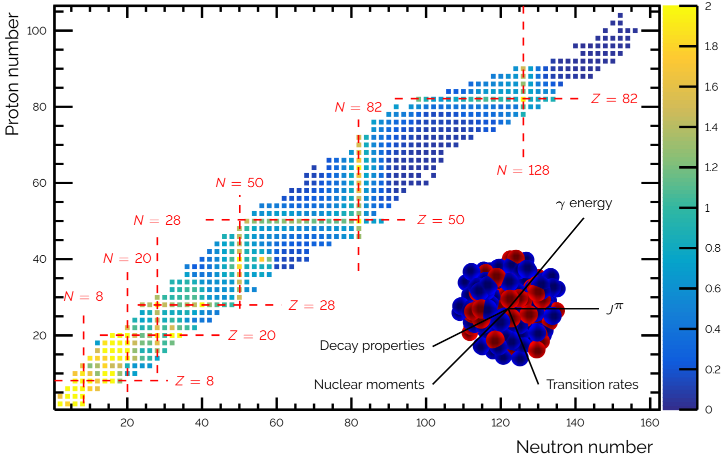
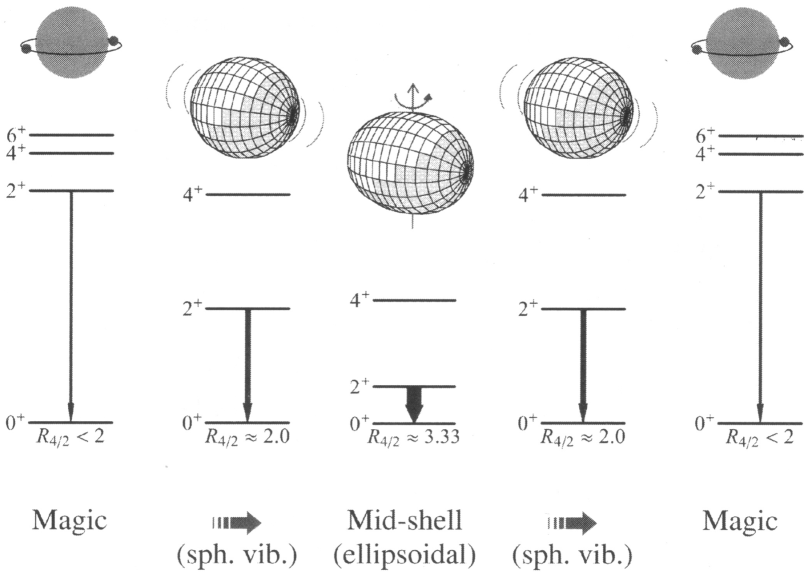


Evolution of the nuclear structure



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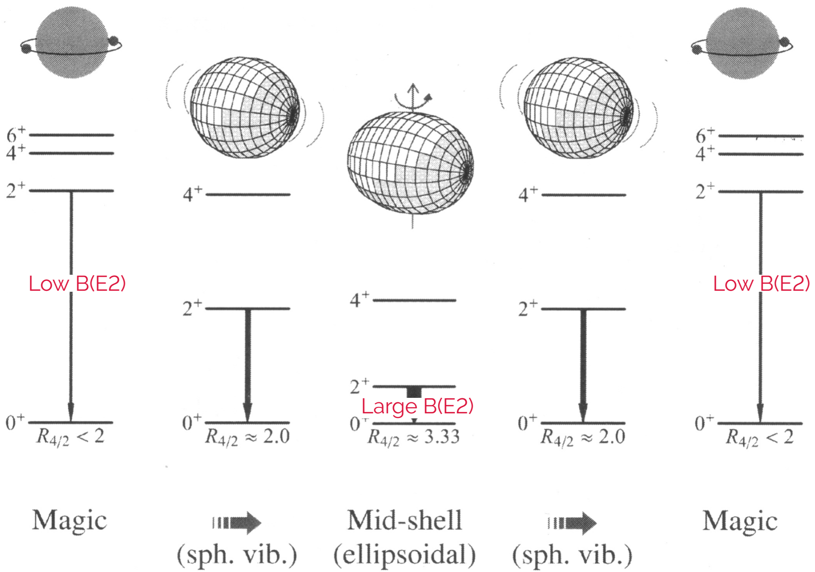

How can we study the nuclear structure?

One of the easiest way to study the nucleus $\Longrightarrow$ γ-spectroscopy:

- Relatively simple and well-known operator
- In a first (and good) approximation: 1-body operator

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- But generally limited efficiency
- Based on semi-conductor
- Low to medium energy γ-rays
- Complex low energy structure

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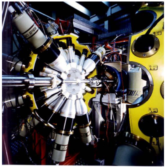
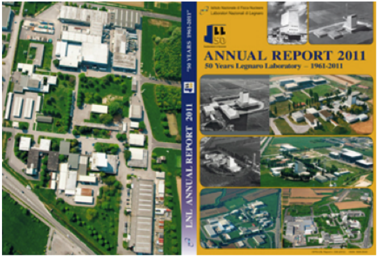
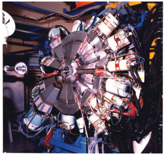
New devices reuniting the two aspects:
The AGATA tracking array

γ-spectroscopy at LNL - A long story (short)



GASP





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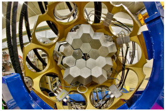
CLARA

- 80 % of nuclear physics research
- 50 % γ-ray spectroscopy



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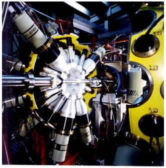

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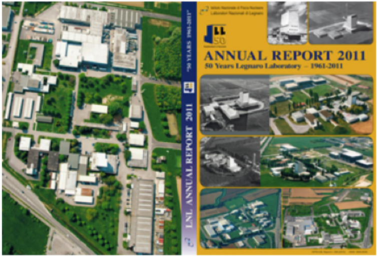

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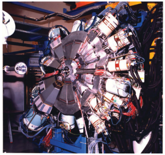
- 50 % γ-ray spectroscopy
- Neutron-deficient and neutron-rich nuclei



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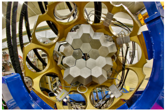

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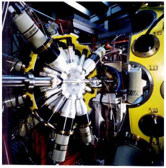

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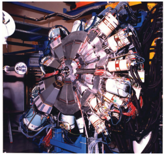

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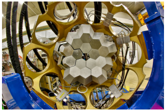

AGATA

Exploring the low energy structure of the nuclei

VOLUME 74, NUMBER 6   PHYSICAL REVIEW LETTERS   6 FEBRUARY 1995

$N = 40$ Neutron Subshell Closure in the ^{68}Ni Nucleus

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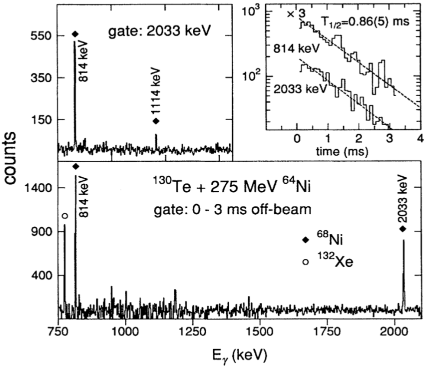

GASP experiment
Deep-inelastic reaction ^{64}Ni + ^{130}Te

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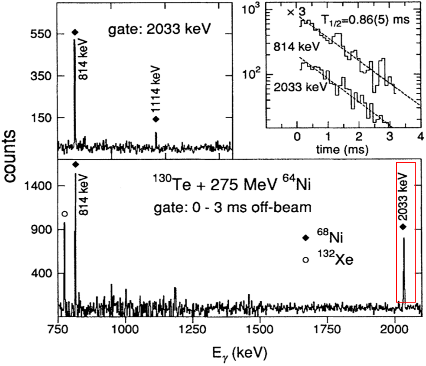

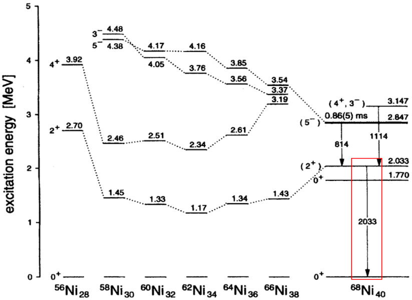

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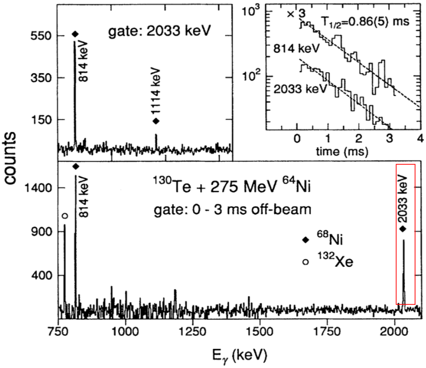

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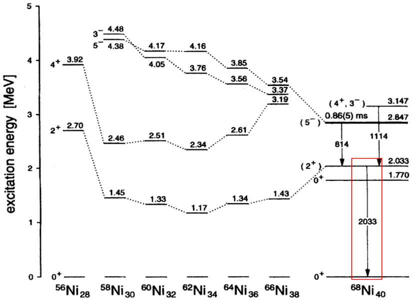

Large increase of the E(2^+) at $N = 40$
→ subshell closure
→ Evolution of the magicity far from stability

Coupling the γ-spectrometer with complementary setup

Deep-inelastic and multi-nucleon transfer reaction $\Longrightarrow$ Population of moderately neutron-rich nuclei BUT:

- Identification in thick target experiment is limited
- Doppler-broadening
- What to do with weak reaction channel?

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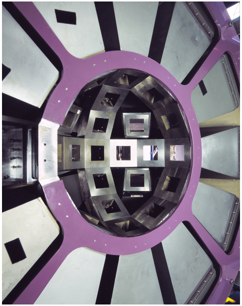
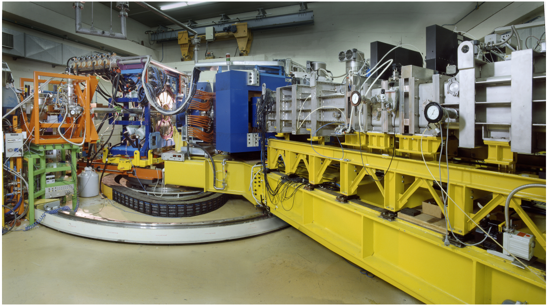


CLARA γ-ray array
25 Compton-suppressed Ge Clovers
$\epsilon = 3\%$ for single 1 MeV γ



PRISMA Magnetic spectrometer
$\Omega = 80$ msr
Z, A, q clean identification of the fragments

From the $N = 40$ subshell closure down to an island of deformation

PHYSICAL REVIEW C **76**, 034303 (2007)

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[3]*National Institute for Physics and Nuclear Engineering, Bucharest, Romania*
[4]*Dipartimento di Fisica dell' Università and INFN Sezione di Firenze, Firenze, Italy*
[5]*Schuster Laboratory, University of Manchester, Manchester, United Kingdom*
[6]*Laboratoire Pluridisciplinaire Hubert Curien, CNRS-IN2P3/ULP Strasbourg, Strasbourg, France*
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[8]*Ruđer Bošković Institute, Zagreb, Croatia*

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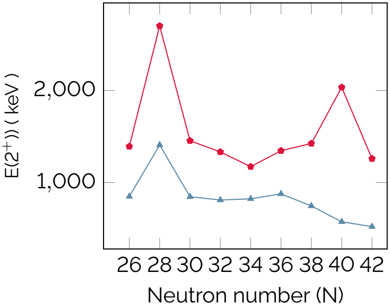

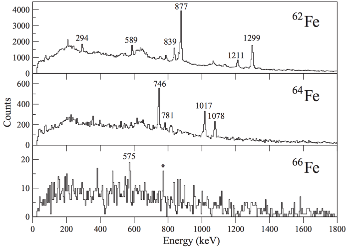

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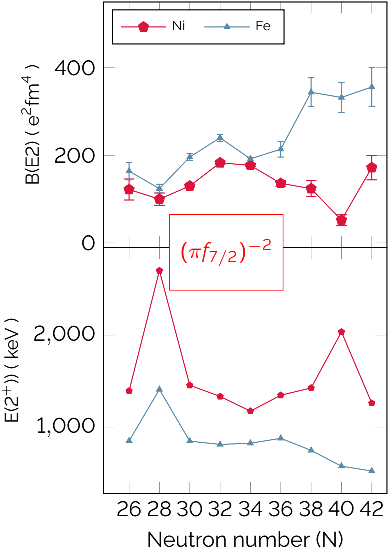

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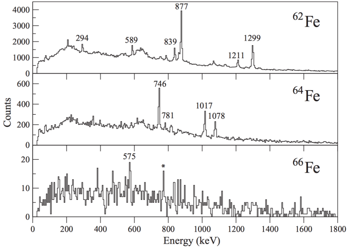

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Going deeper into the nuclear structure with the electromagnetic moment measurement

PRL 117, 062501 (2016)   PHYSICAL REVIEW LETTERS   week ending 5 AUGUST 2016

Superdeformed and Triaxial States in ^{42}Ca

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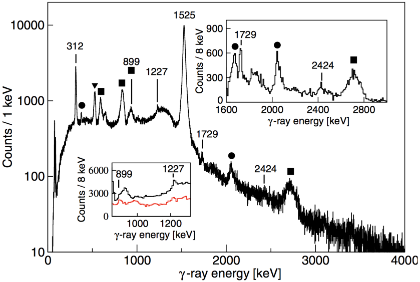

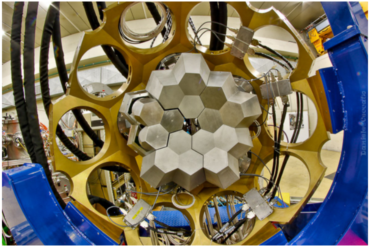

Going deeper into the nuclear structure with the electromagnetic moment measurement

PRL 117, 062501 (2016) PHYSICAL REVIEW LETTERS week ending 5 AUGUST 2016

Superdeformed and Triaxial States in ^{42}Ca

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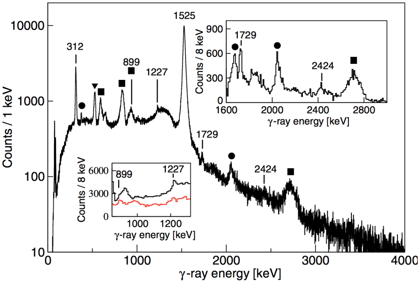

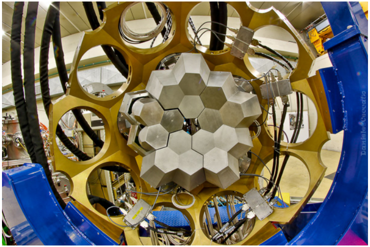

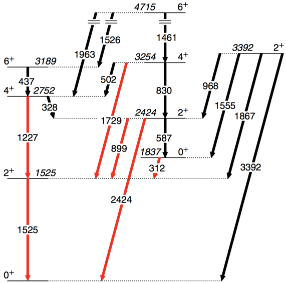

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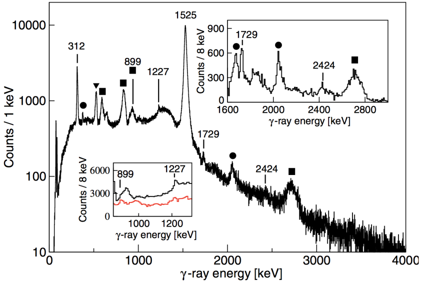
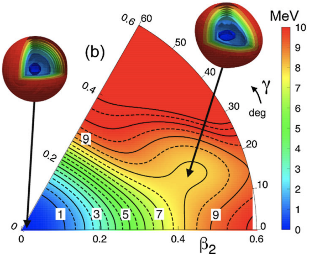
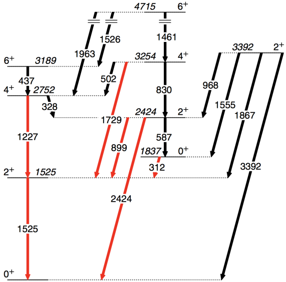
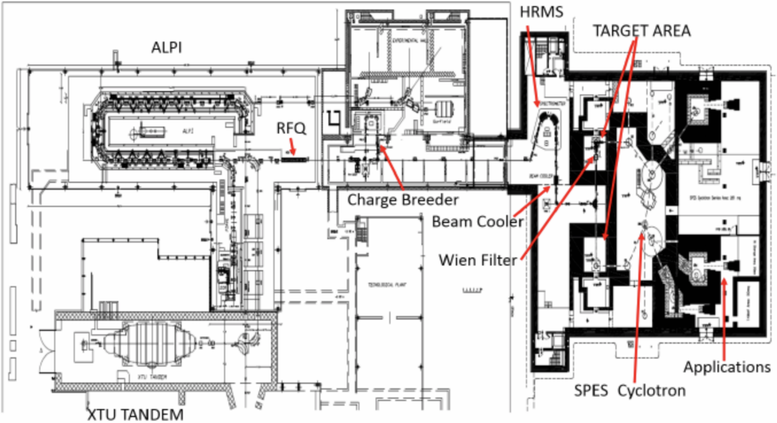






The future of the γ-spectroscopy with the SPES radioactive beams



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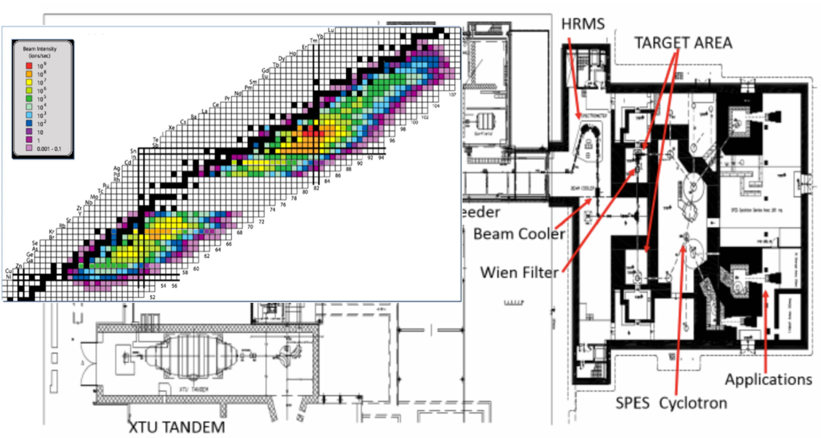
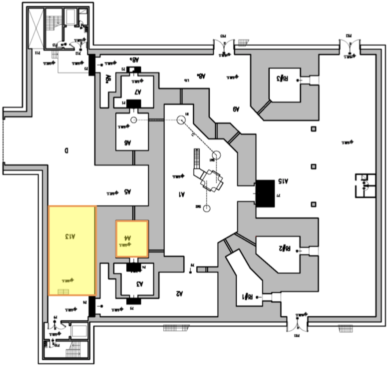


SPES
exotic beams for science

Can we do something with beams of 75 keV?

We can study the decay of the fission fragments:



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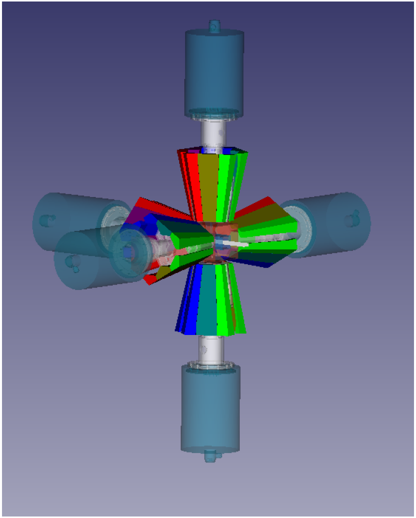

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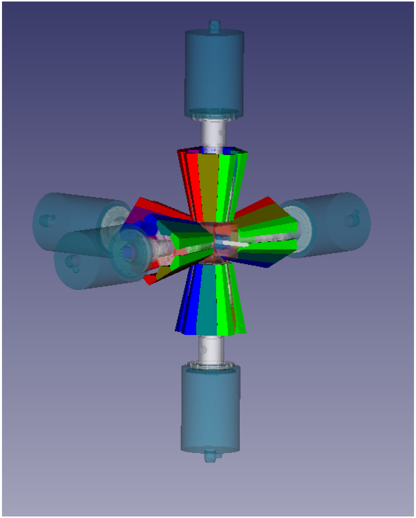
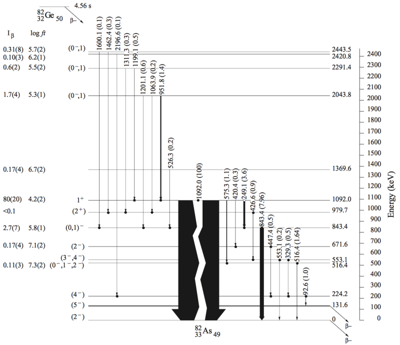


PHYSICAL REVIEW C **91**, 064317 (2015)

Low-lying intruder and tensor-driven structures in ^{82}As revealed by β decay at a new movable-tape-based experimental setup

A. Etilé,[1] D. Verney,[2] N. N. Arsenyev,[3] J. Bettane,[2] I. N. Borzov,[3,4] M. Cheikh Mhamed,[2] P. V. Cuong,[5] C. Delafosse,[2] F. Didierjean,[6] C. Gaulard,[1] Nguyen Van Giai,[2] A. Goasduff,[1] F. Ibrahim,[2] K. Kolos,[2,*] C. Lau,[2] M. Niikura,[2,†] S. Roccia,[1] A. P. Severyukhin,[3] D. Testov,[2,7] S. Tusseau-Nenez,[2] and V. V. Voronov[3]



Post-accelerated radioactive ion beams: A new and bright future

42 Letter of Intent presented from around the world. In particular for the γ-spectroscopy on:

- Lifetime measurements
- Coulomb excitation measurements
- Transfer reaction
- Collective excitation
- ...

For which we have to be ready (and we are working hard)

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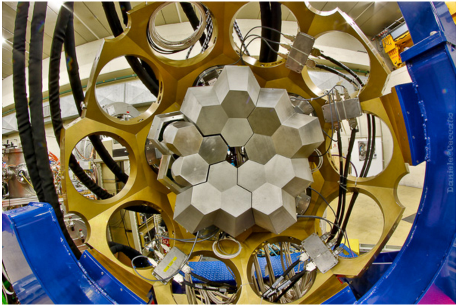

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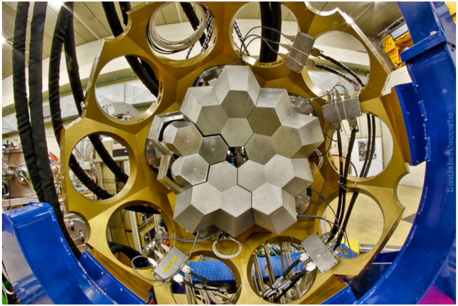

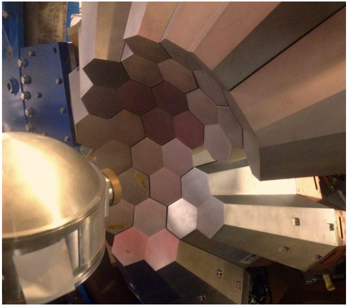

The phase II the GALILEO array

The GALILEO phase II consists of:

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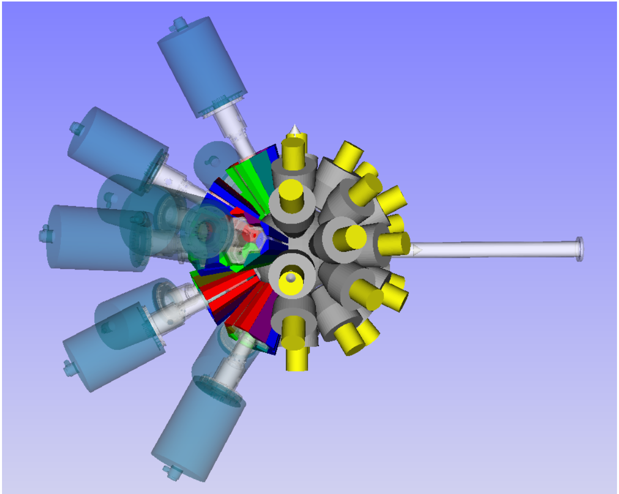
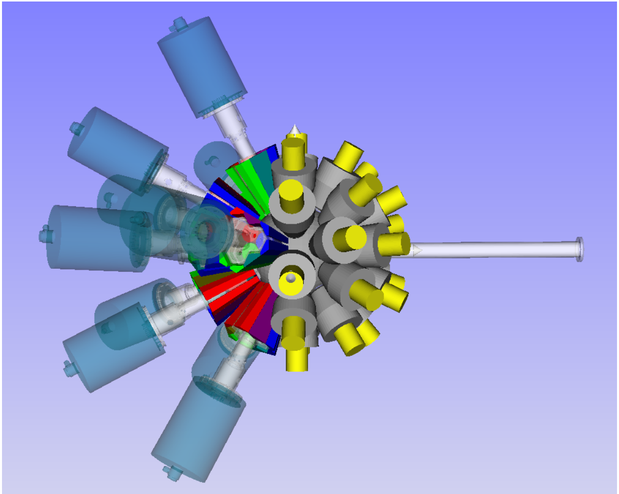


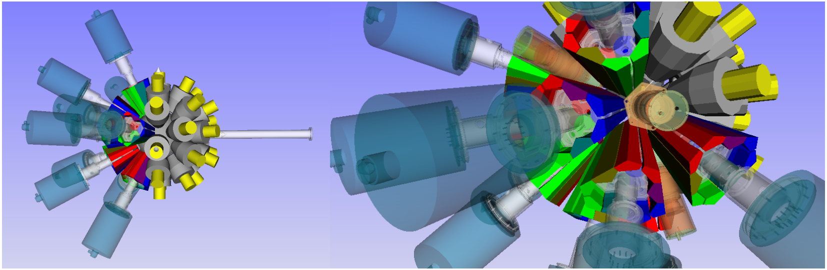
The phase II the GALILEO array

The GALILEO phase II consists of:

- GALILEO phase I (**25 HPGe detectors** with **AC shield**)
- **10 Triple clusters** with **AC shield** (GTC)
- Fully digital electronics using the developments made for AGATA



The complementary detectors of the GALILEO and AGATA array



- Light charged particle detectors
  Euclides, TRACE
- Neutron detector
  NeutronWall, NEDA
- Lifetime measurements
  Dedicated IKP-LNL plunger
- Heavy-ion detectors:
  Spider, RFD, Segmented plastic

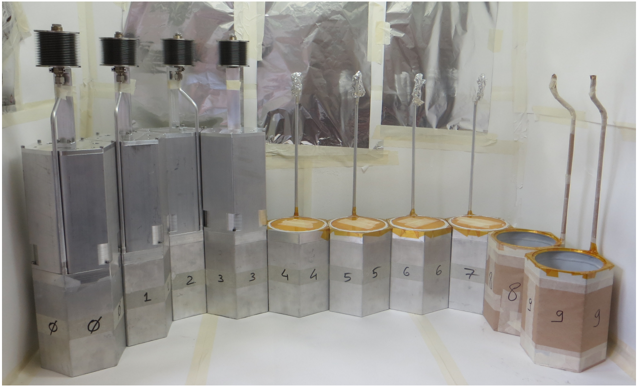
- Fast timing/high-energy γ-ray detector
  $LaBr_3$ detectors, PARIS, FATIMA
- Electron spectrometer
  MiniOrange
- Beam quality for RIBs
  FASTIC?

Commissioned dets

Future dets

Developing the necessary complementary detectors: For neutrons

NEDA



FIRB 2010-2014 and Spiral2 – Prep. Phase
First physics campaign with AGATA at GANIL with stable beams in 2018
International collaboration

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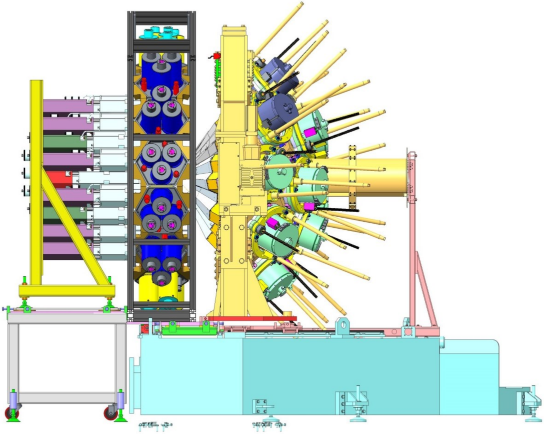

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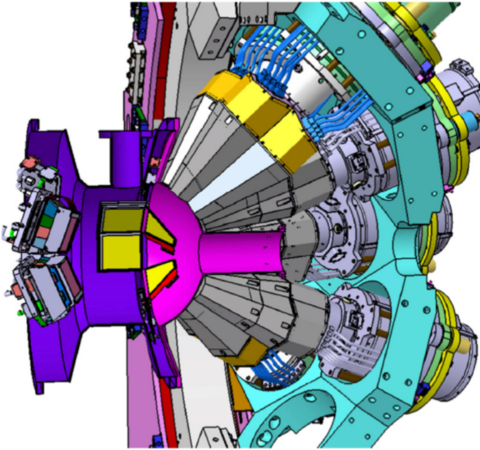
Developing the necessary complementary detectors: For charge particles

Identification of $A \sim 10$ mass ions at low kinetic energy, by PSA analysis



FIRB 2010-2014 and CaRiPaRo
International collaboration
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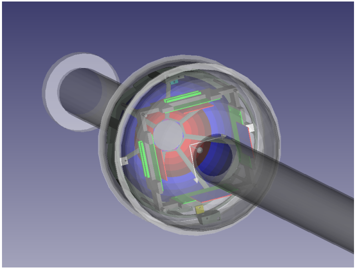

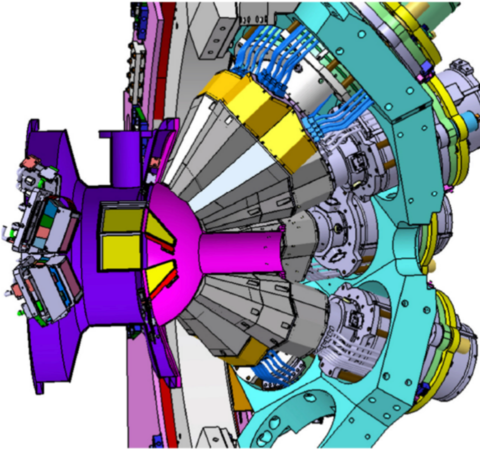

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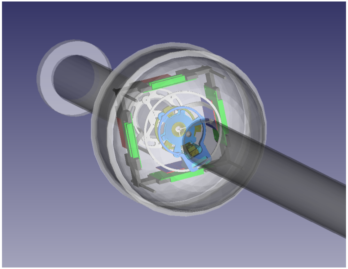

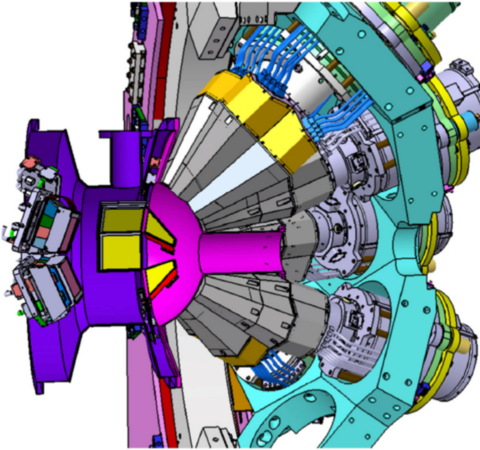

Conclusion and perspectives

- High resolution γ-ray spectroscopy shed light on new phenomenons
- Strong collaborations between experimental and theoretical nuclear physicists allow to deepen our understanding of the nuclear interaction:
  - Tensor force
  - Key role of the 3N force
  - Importance of the continuum for the description of weakly bound nuclei
- The *terra incognita* is now getting closer and closer:
  - Pushing back the technical limits of the detection setup (counting rate, efficiency, ...)
  - Radioactive ion beams facility like SPES
- But we should not forget the stable beams:
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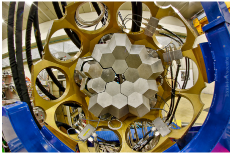
  - Exploring the high energy structure of stable nuclei to look for exotic structures

SPES

exotic beams for science



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