Plans for symmetry energy research within the INDRA-FAZIA collaborations

INDRA FAZIA

http://fazia.in2p3.fr

Nicolas Le Neindre for the INDRA & FAZIA Collaborations

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NUSYM 2024, XIIth International Symposium on Nuclear Symmetry Energy, September 9th-13th 2024, Caen

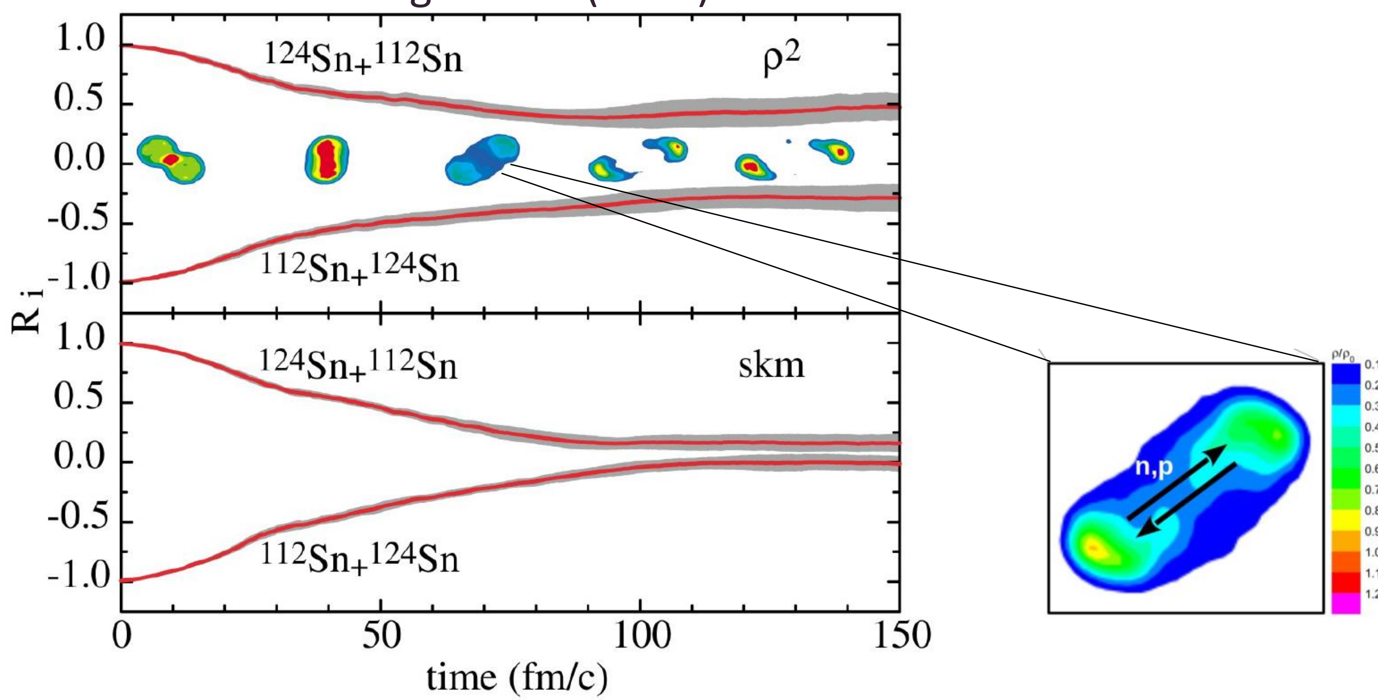
INTRODUCTION

In heavy ions collisions, during peripheral reactions, projectile and target interact and exchange nucleons.
Isospin equilibration: projectile and target with different neutron to proton ratio equilibrate their N/Z over time.
Different interactions, leading to different EoS, produce different equilibration path.

Any experimental measurements of the isospin equilibration rate would constraint the EoS
-> See C. Ciampi, A. Jedele, S. Mallik, R. Bougault, A. Le Fèvre and many other talks

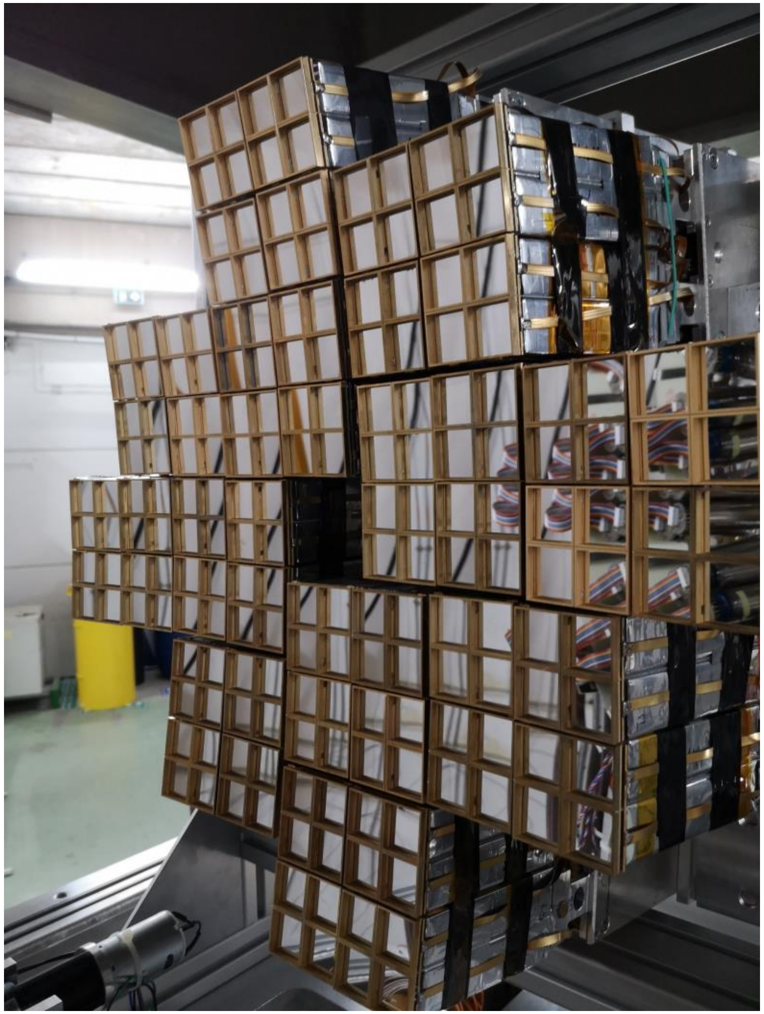
Critical role of clustering at low density

Tsang PRL 92 (2004) 062701

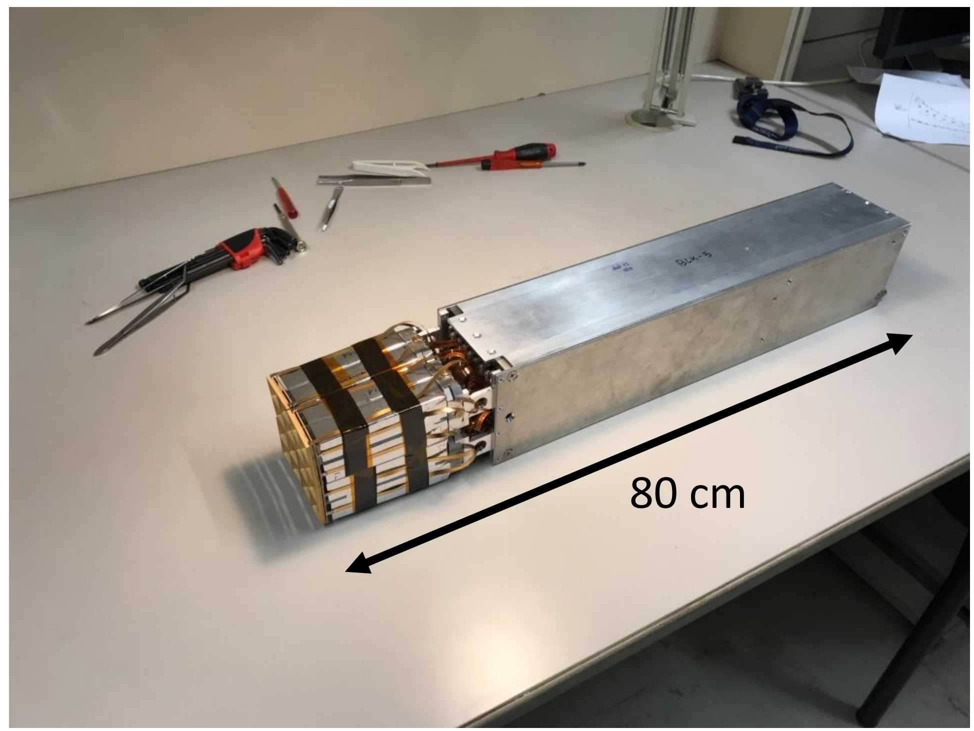


From Diego Gruyer IWM 2024

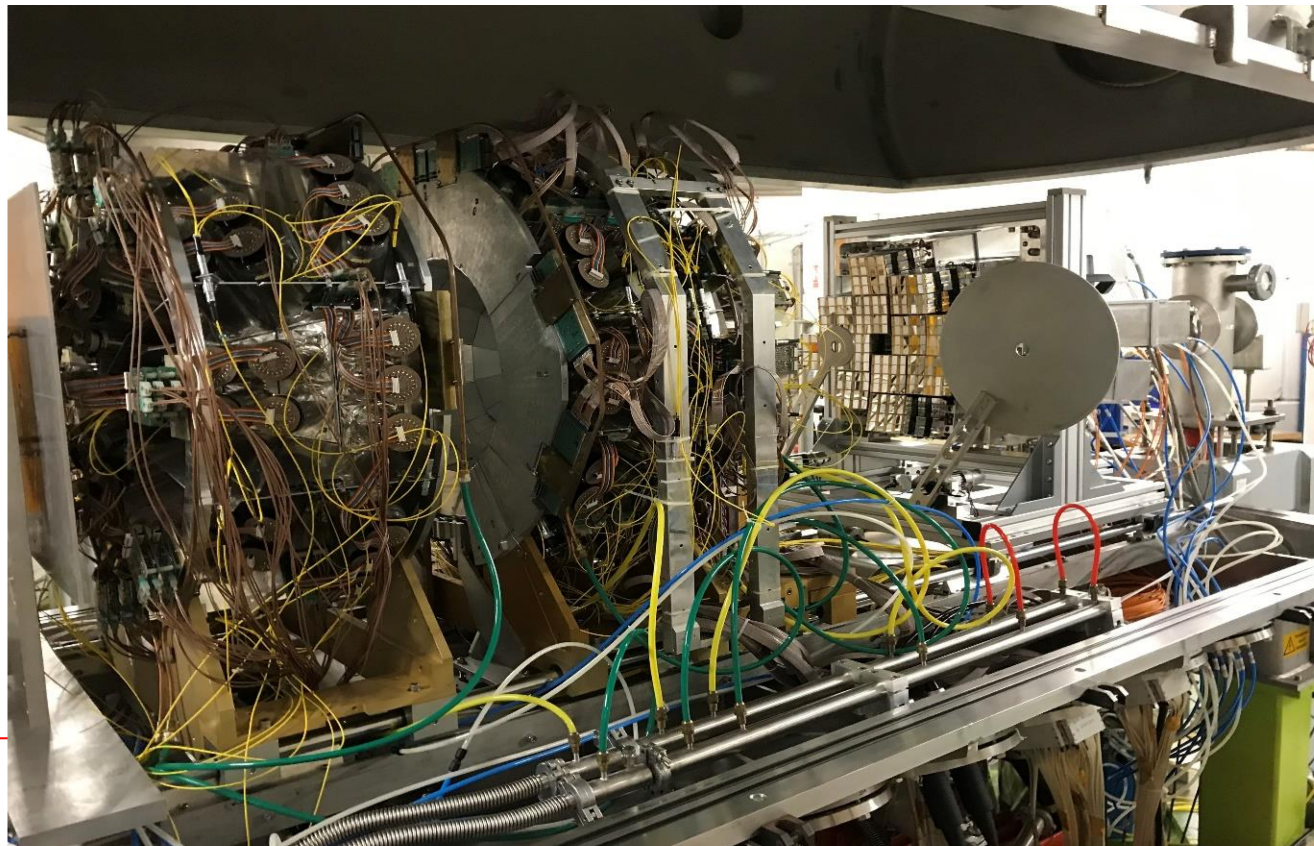
What is FAZIA?



FAZIA at GANIL:
12 blocks 1,8°-13,5°
192 telescopes Si-Si-CsI(Tl)
Z identification 1-54
A resolution Z~20 PSA
& Z~25 ΔE-E



INDRA & FAZIA at GANIL in 2024



FAZIA:
12 blocks 1,8°-13,5°
192 telescopes Si-Si-CsI(Tl)
Z identification 1-54
A resolution Z~20 PSA Z~25 ΔE-E

INDRA:
12 rings 14°-176°
240 CsI(Tl)
96 Si detectors
Z identification 1-54
A resolution Z=1-4 CsI, Z=1-6 Si-CsI

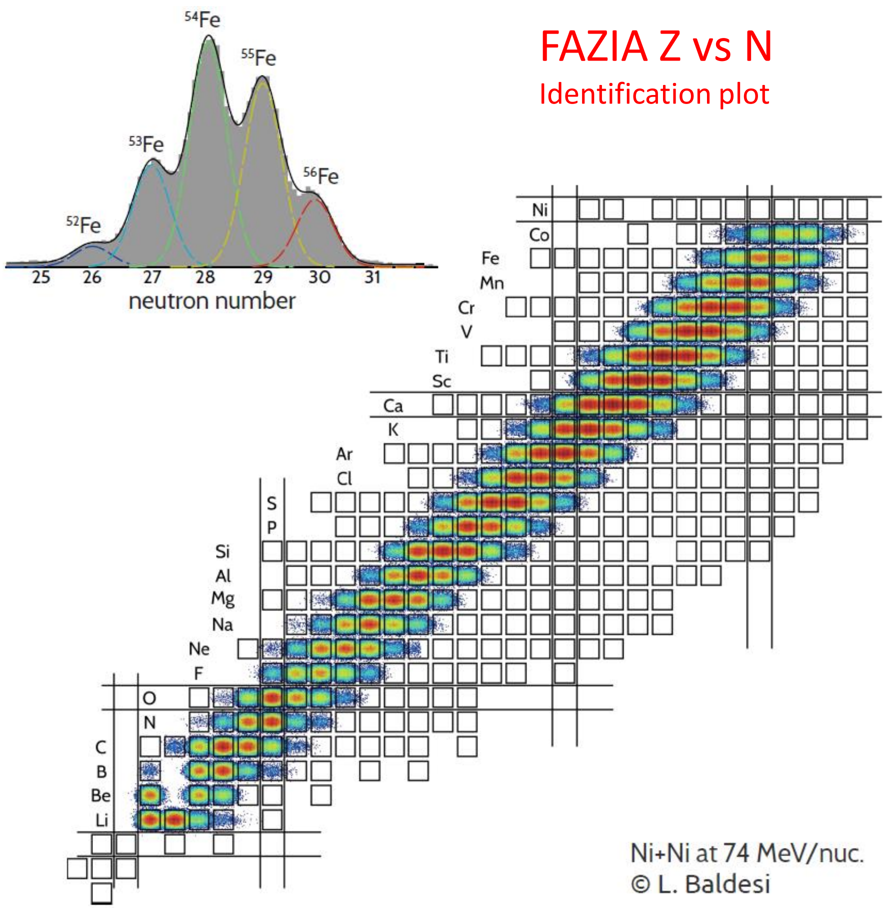
Why INDRA and FAZIA for symmetry energy research?

- Very good isotopic identification on a large scale
- Large angular isotopic resolution with INDRA upgrade ->45°
- Good acceptance and low thresholds -> good event characterization
- 192 telescopes for FAZIA and 240 for INDRA -> high multiplicity
- Full digital electronics, low dead time and high acquisition rate

INDRA FAZIA

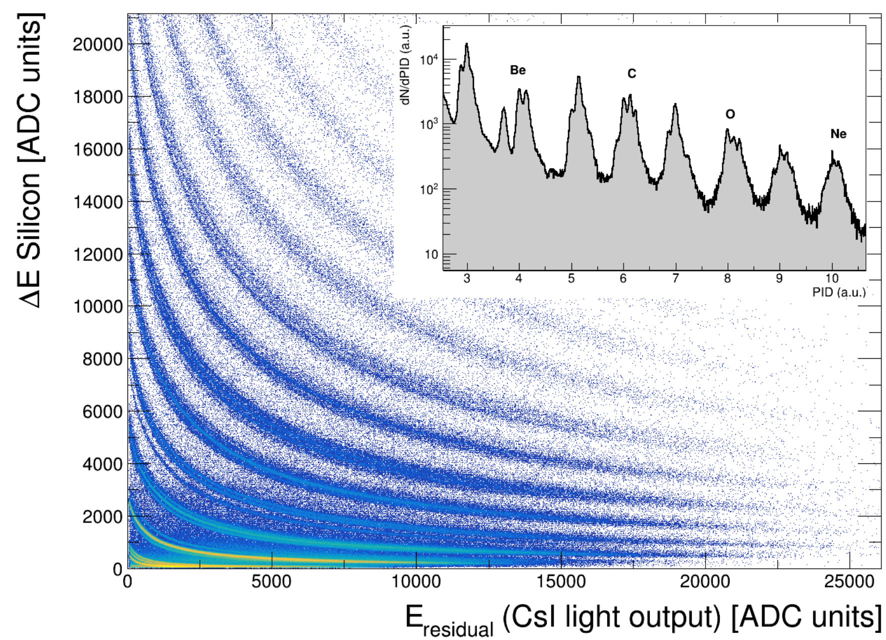
FAZIA Z vs N

Identification plot



Ni+Ni at 74 MeV/nuc.
© L. Baldesi

INDRA upgrade



So far, what have been done?

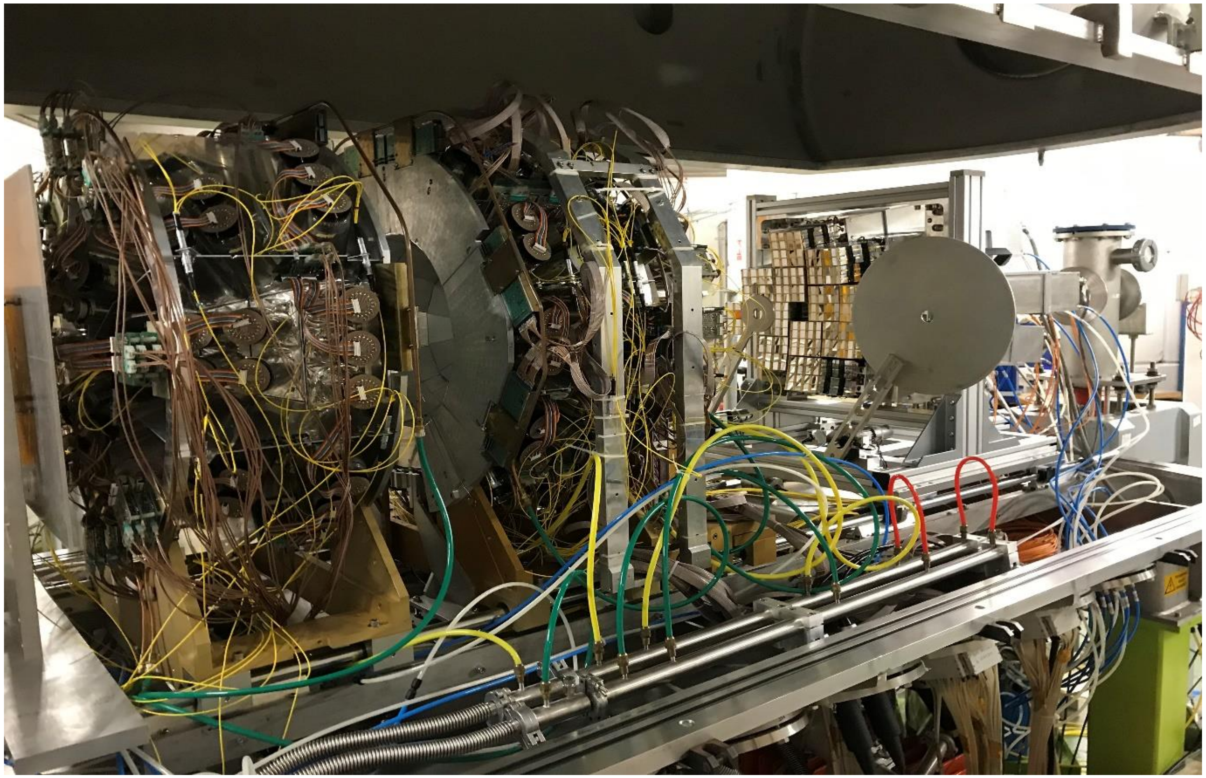
INDRA-FAZIA at GANIL

- E789 – 2019 : $^{58-64}$Ni + $^{58-64}$Ni @ 32 & 52 A MeV
- E818 - 2022 : ^{36}Ar + ^{58}Ni @ 74 A MeV & ^{58}Ni + ^{58}Ni @ 74 A MeV

To come soon (2025)

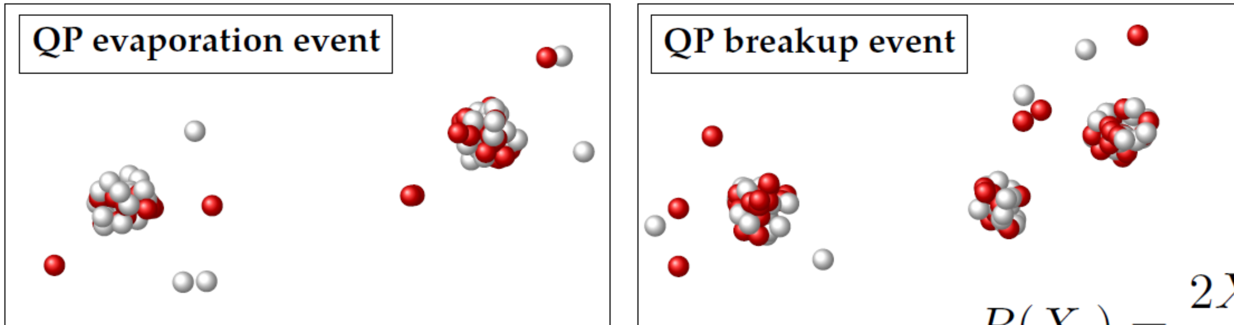
- E884 - 2025 : ^{70}Zn + ^{27}Al,^{70}Zn,^{208}Pb @ 35 A MeV

INDRA FAZIA

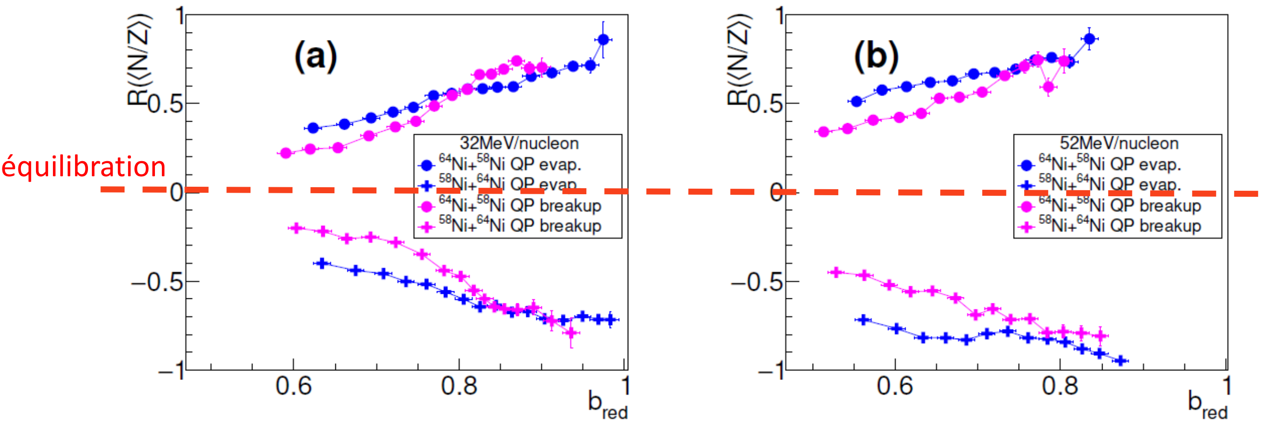


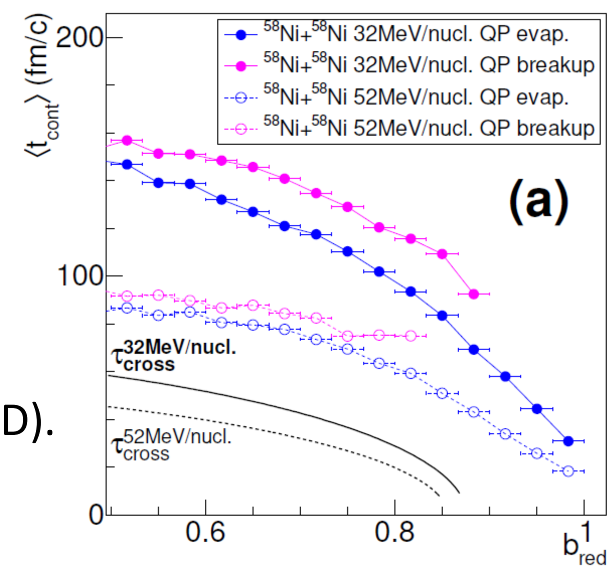
E789: Studies on isospin transport ratio with $^{64\text{-}58}$Ni+$^{64\text{-}58}$Ni @ 32 & 52 A MeV

- C. Ciampi et al. Physical Review C 106 (2022) 024603
- C. Ciampi et al. Physical Review C 108 (2023) 054611



$$R(X_i) = \frac{2X_i - X_{6464} - X_{5858}}{X_{6464} - X_{5858}}$$

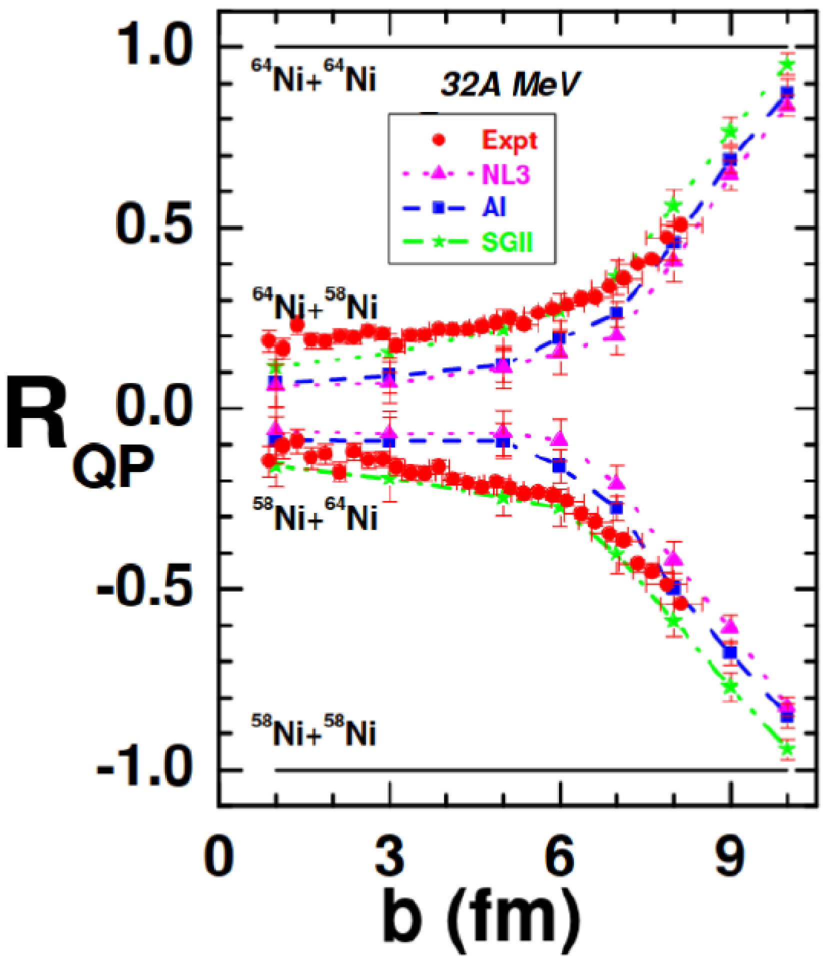




Contact time extraction via comparison with transport models (AMD).
Longer contact time for break-up respect to QP evaporation.
+time = more isospin equilibration

E789: Studies on isospin transport ratio with $^{64-58}$Ni+$^{64-58}$Ni @ 32 & 52 A MeV

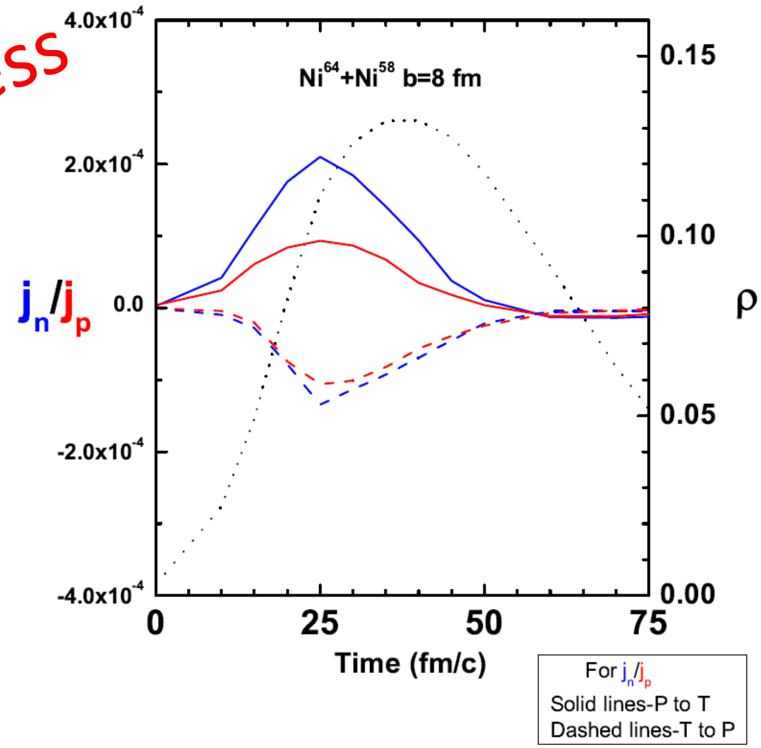
Constraining the parameters of the nuclear EoS



© Caterina Ciampi

In progress

Coll. FAZIA+ F. Gulminelli & Swagata Mallik (Kolkata)
BUU calculations with differents equation of state vs Exp.



© Swagata Mallik

Next INDRA-FAZIA campaign at GANIL

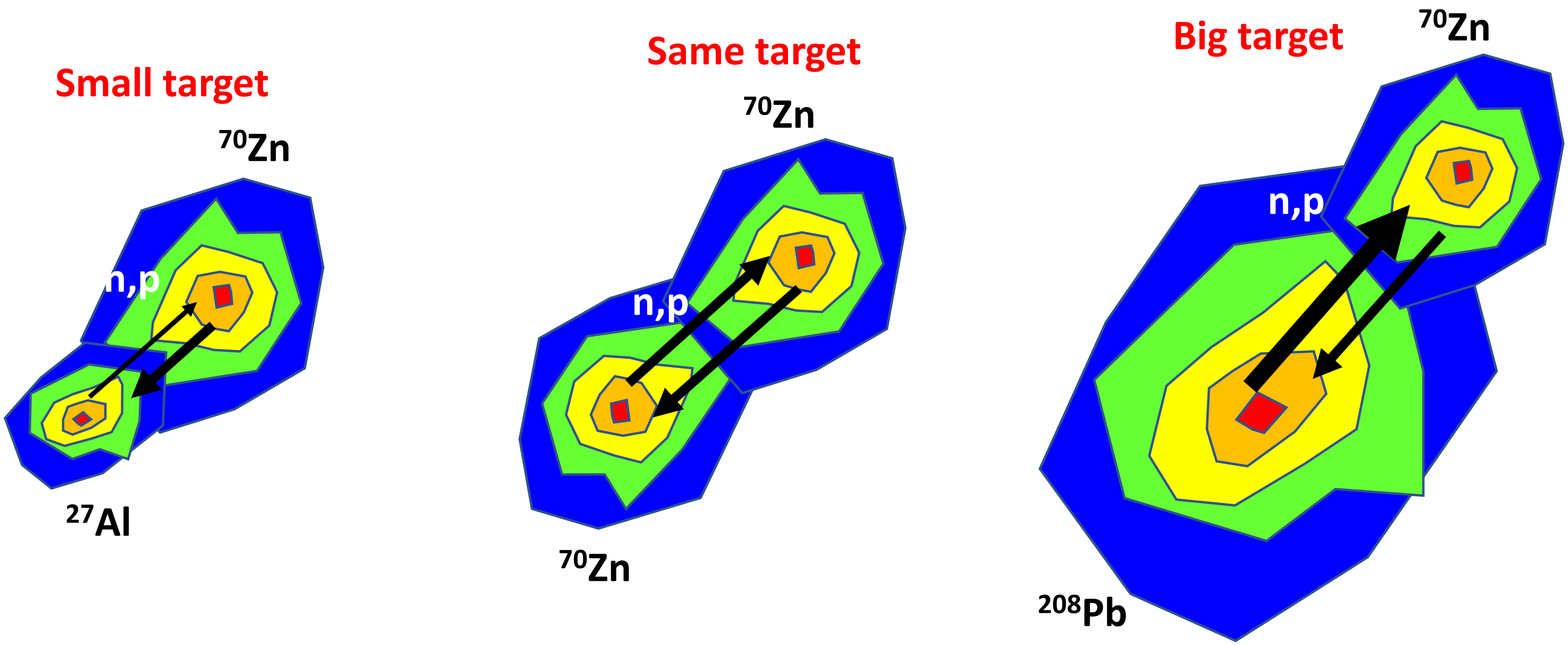
E884 - 2025 : ^{70}Zn + ^{27}Al, ^{70}Zn, ^{208}Pb @ 35 A MeV

"Impact of projectile-target size asymmetry on the isospin equilibration rate extracted From quasi projectile break-up reactions."

We have seen in previous analyses how isospin transport evolves according to QP decay (evaporation vs break-up) see C. Ciampi et al.

What is the role of the target?

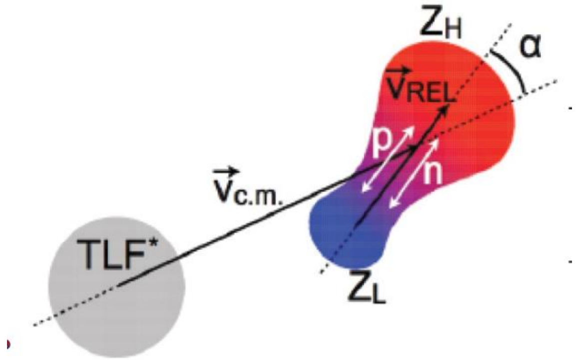
Target as an isospin reservoir and size influence on QP evolution.



Next INDRA-FAZIA campaign at GANIL

E884 - 2025 : ^{70}Zn + ^{27}Al, ^{70}Zn, ^{208}Pb @ 35 A MeV

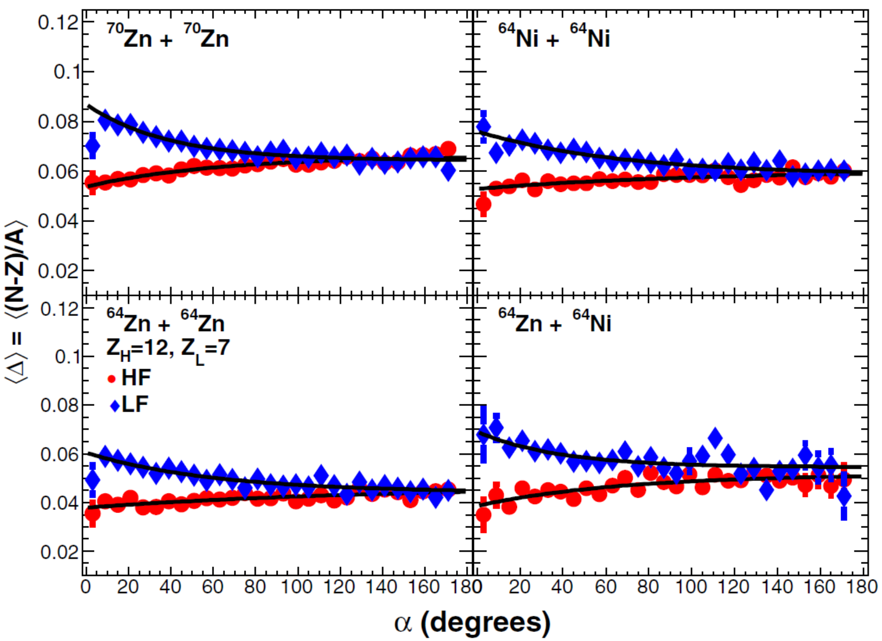
"Impact of projectile-target size asymmetry on the isospin equilibration rate extracted From quasi projectile break-up reactions."

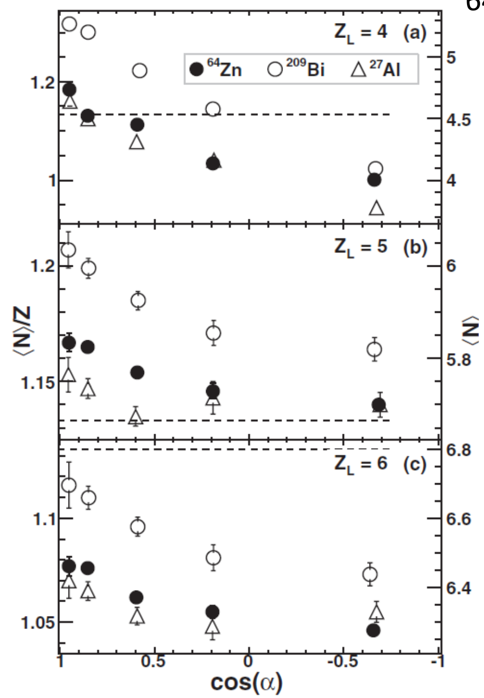


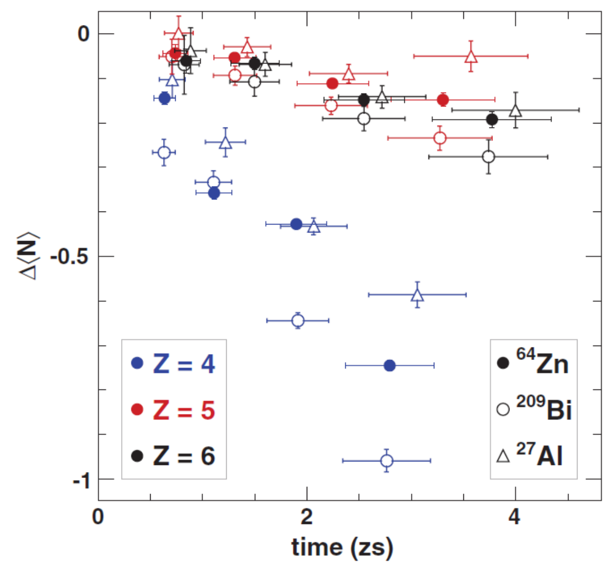
α angle between the QP-QT separation axis and the break-up axis can be used as a « clock » for the breakup time scale.

- Such interpretation is still debated
- As well the target role is contrasted in literature.

^{64}Zn + ^{27}Al, ^{64}Zn, ^{209}Bi @ 45 A MeV







A. Rodriguez-Manso et al. PRC 95 (2017) 044604

K. Brown et al. PRC 87 (2013) 061601

Experimental campaigns at GANIL: INDRA+FAZIA

In addition to symmetry energy studies

E881

Measurement of the ^{12}C Hoyle state radius via double-excitation inelastic scattering

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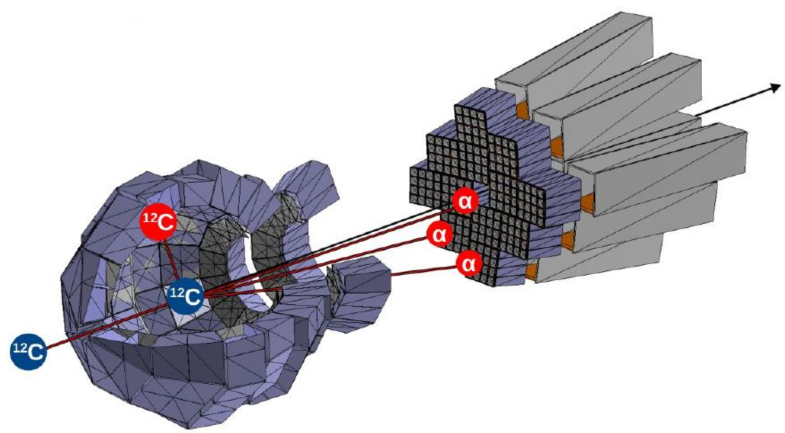
(INDRA and FAZIA Collaborations)

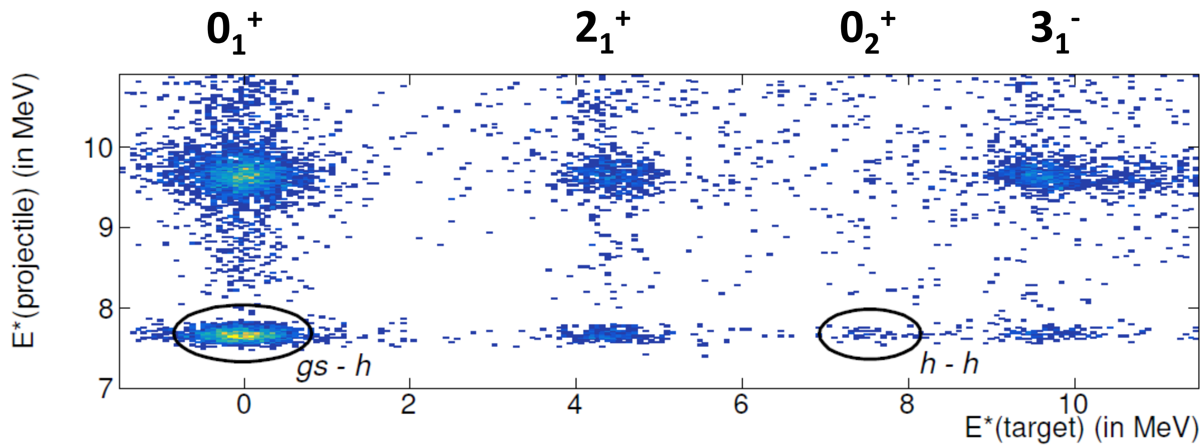
The detailed properties of the ^{12}C second 0^+ excited state, known as the Hoyle state, are both a challenge for nuclear structure theory and have a key role in the synthesis of the elements. We propose to measure the mean matter radius of this state by analyzing the diffraction structure of single- and double-excitation in ^{12}C+^{12}C inelastic scattering at 105 MeV beam energy. The experimental setup will consist in the FAZIA detector.

In 2022 during E818 campaign, we had calibration beams ^{12}C at 8,75 and 13,75 A MeV. After having completed calibrations, during 6 hours we put a C target . For fun…



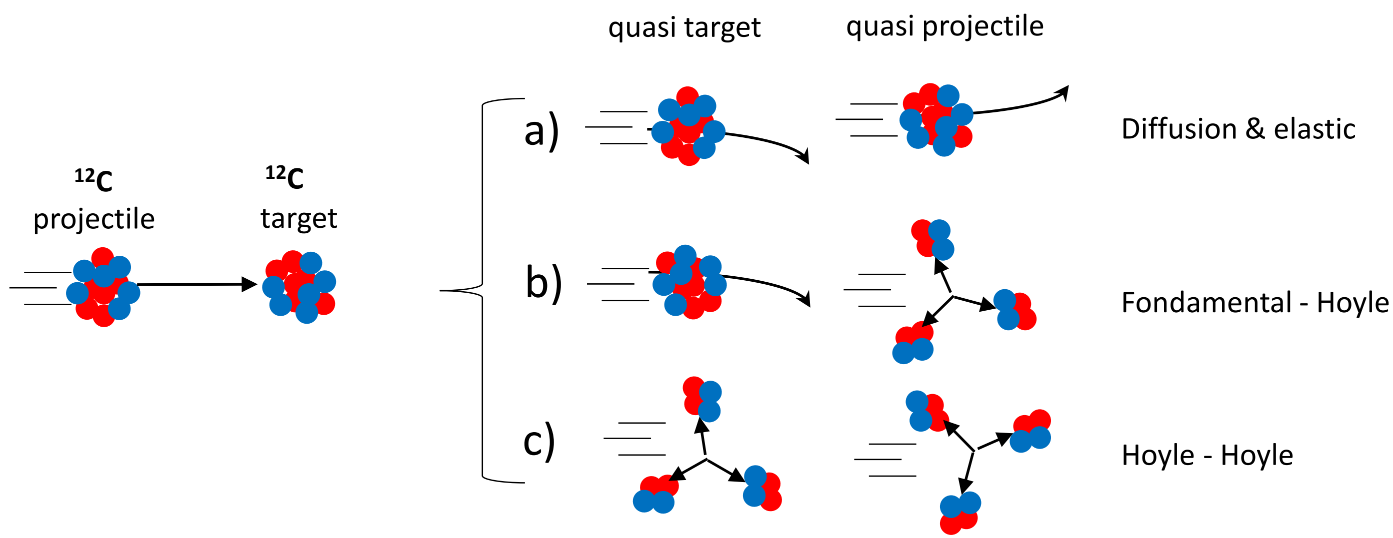
Experimental campaigns at GANIL: INDRA+FAZIA

In addition to symmetry energy studies



experimental data
6 hours of beam test

© Diego Gruyer



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High energies - high density aspects of nuclear EoS

Dense Nuclear Matter Equation of State from Heavy-Ion Collisions *

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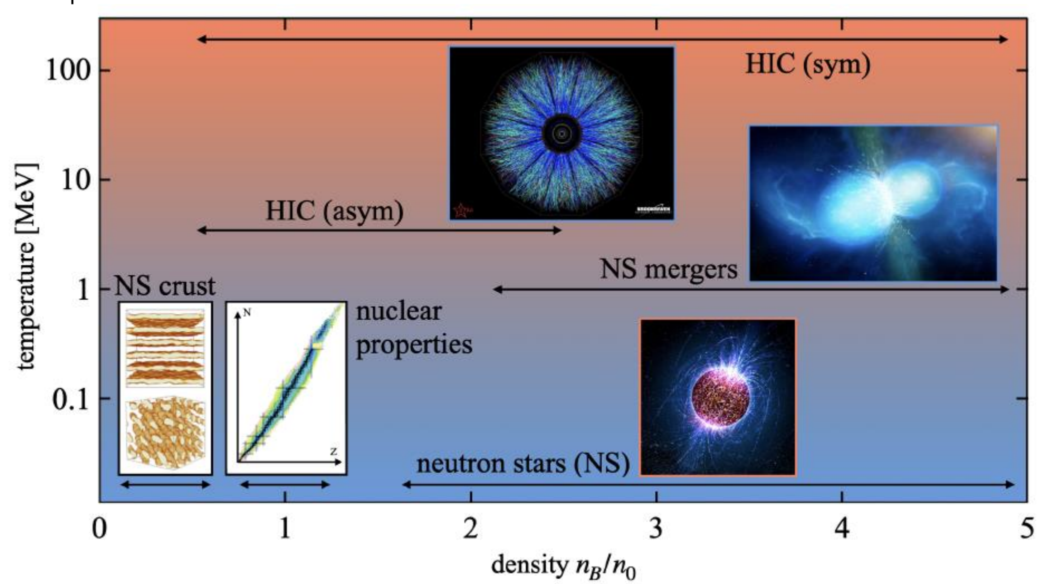
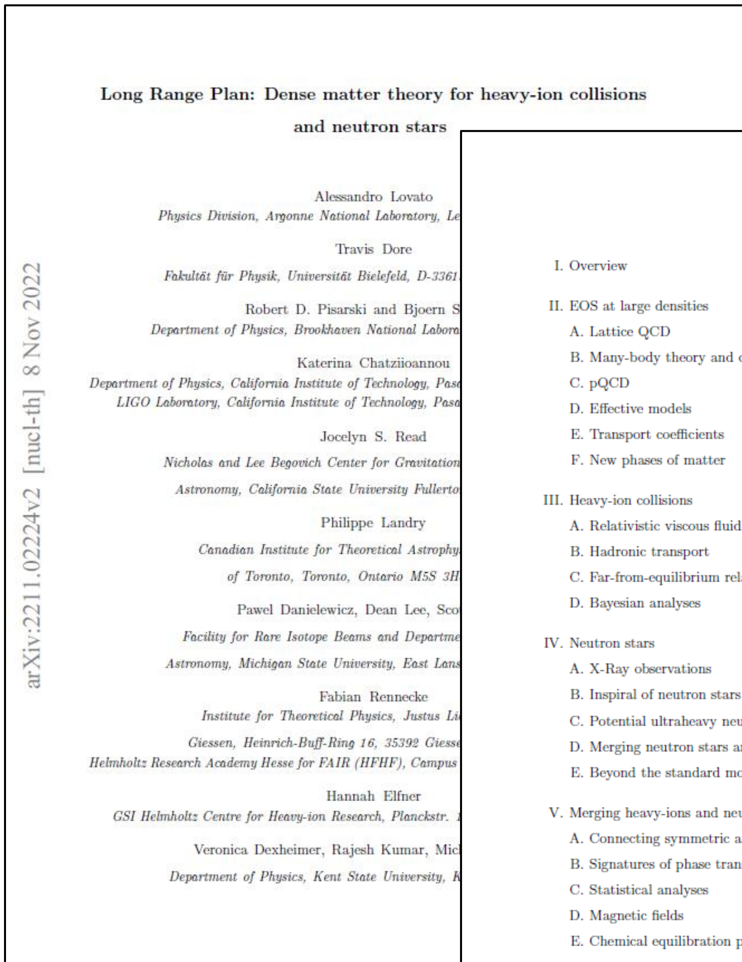
Long Range Plan: Experimental side



High E radioactive beams, for larger ρ, T & isospin

High energies - high density aspects of nuclear EoS

Long Range Plan: Theory side



Long Range Plan: Dense matter theory for heavy-ion collisions and neutron stars

arXiv:2211.02224v2 [nucl-th] 8 Nov 2022

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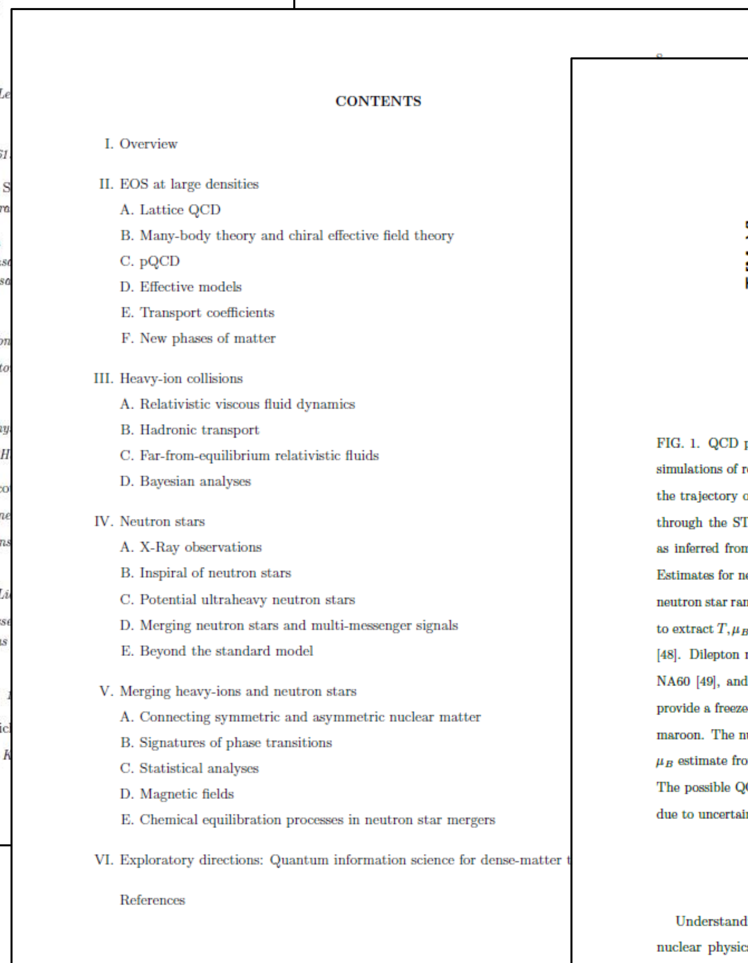

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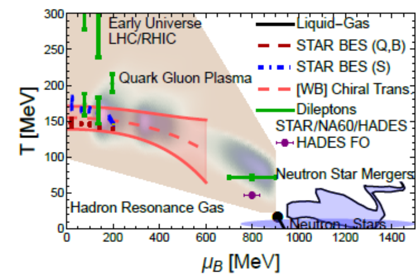


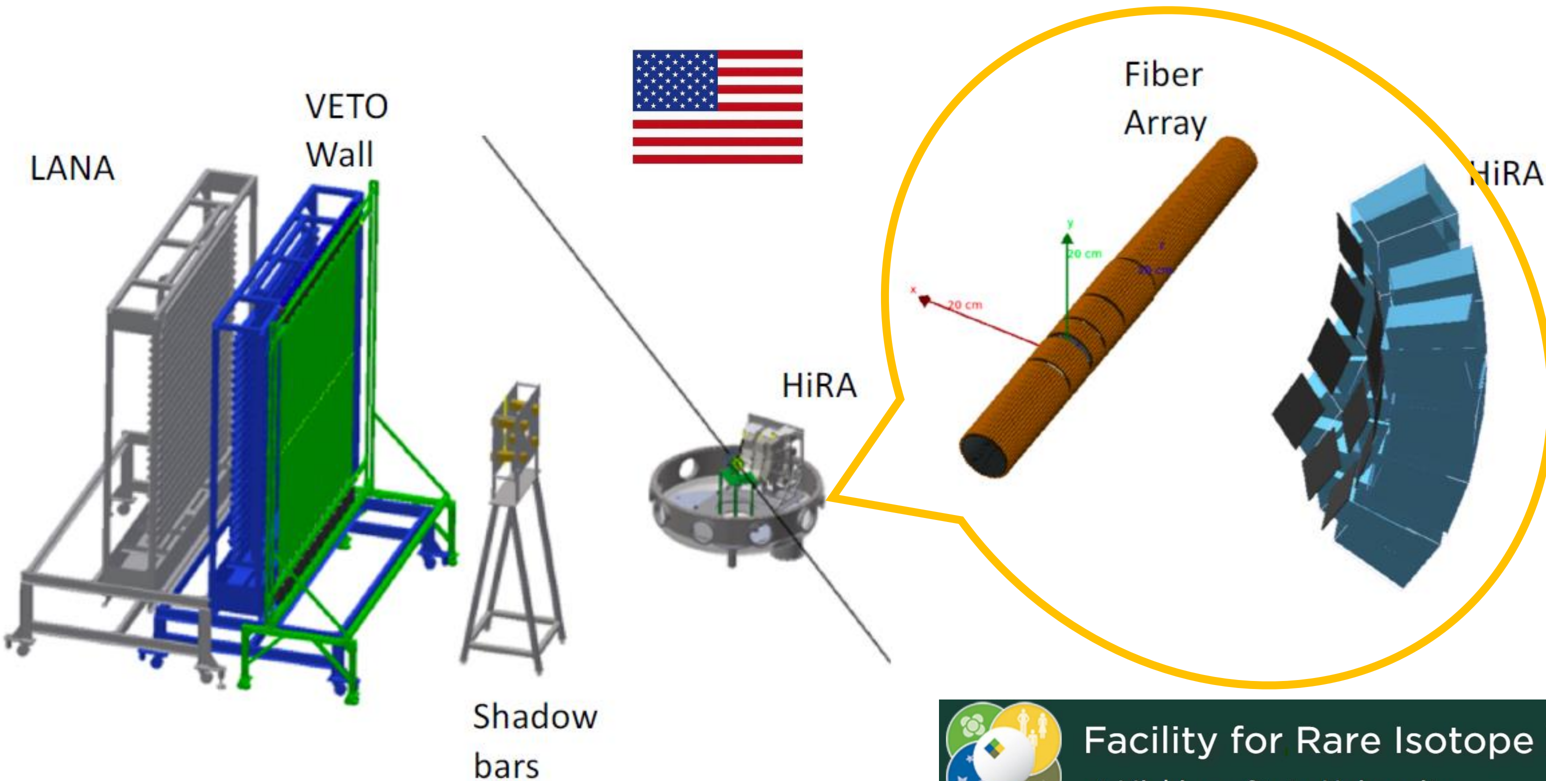
FIG. 1. QCD phase diagram with the latest interpretation of experimental data and dynamical simulations of regions probed by various systems. The zero baryon chemical potential axis follows the trajectory of the early universe and coincides with the Large Hadron Collider (LHC). RHIC, through the STAR BESII and fixed target (FXT) programs, explores the brown shaded region as inferred from relativistic viscous hydrodynamic simulations [46] for $\sqrt{s_{NN}} = 3, 7.7, 27$ GeV. Estimates for neutron star mergers comes from numerical relativity simulations [47] and the $T = 0$ neutron star range comes from various EOS estimates. Net-proton, K, π data from STAR were used to extract T, μ_B of light particles at freeze-out (red) and net-K, Λ for strange particles (blue) from [48]. Dilepton measurements of temperatures within the quark-gluon plasma phase from STAR, NA60 [49], and HADES [6] are shown in green. Thermal model fits to HADES particle yields provide a freeze-out estimate for $\sqrt{s_{NN}} = 2.4$ GeV [50] (some ambiguity still exists [51]), shown in maroon. The nuclear liquid-gas phase transition is based on experimental data from [52] and the μ_B estimate from [53]. The chiral transition (light red) comes from lattice QCD calculations [54]. The possible QCD critical point and the associated 1st-order phase transition line are not shown due to uncertainty, which STAR BESII and FXT aim to reduce.

I. OVERVIEW

Understanding the behavior of dense baryonic matter is one of the central problems in nuclear physics. Dense matter in this context is any nuclear system that contains a net

American set-up foreseen so far for an approved experiment at FRIB (end 2025?)

^{56,70}Ni+^{58,64}Ni @ 175 A MeV



Facility for Rare Isotope Beams
at Michigan State University

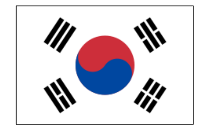
Possible FAZIA involvements at FRIB

- Bringing some FAZIA blocks to join/complete the set-up?
- Imagine our own set-up? Of course with local support.
- LoI for PAC3 at FRIB?

=> Everything is open, let's discuss and collaborate.

Building additional FAZIA blocks for RAON 2024-….

RAON Rare isotope Accelerator complex for ON-line experiments



Two production methods: Separation on line (ISOL) and in flight fragmentation (IF):

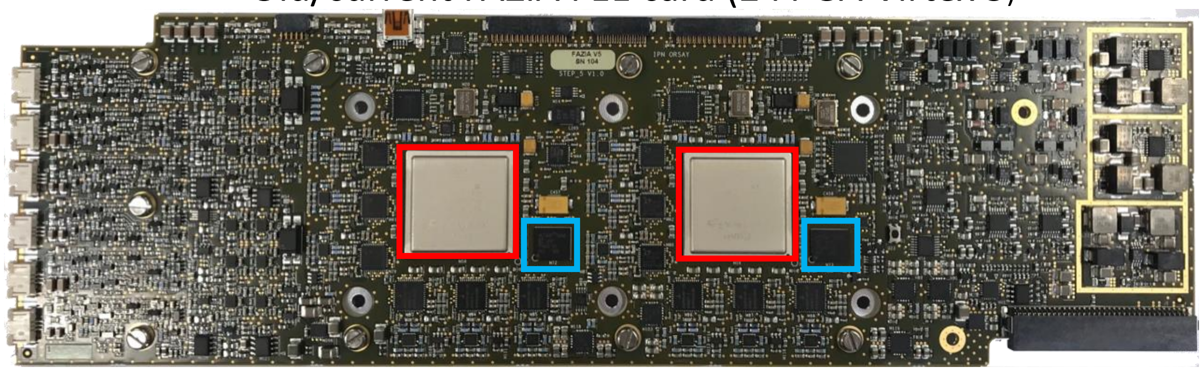
- ISOL: ^{238}U fission by proton beam at 70 MeV
- IF: ^{238}U beam at 200 A MeV (8,3p µA)

Final project associates a large variety of radioactive beams with a big range of beam energies.
For example ^{132}Sn at 250 A MeV with 10^9 pps!
But not before 2030 after building SCL2!

New developments for the future

FAZIA Front End Electronics update in South Korea

Old/current FAZIA FEE card (2 FPGA Virtex 5)

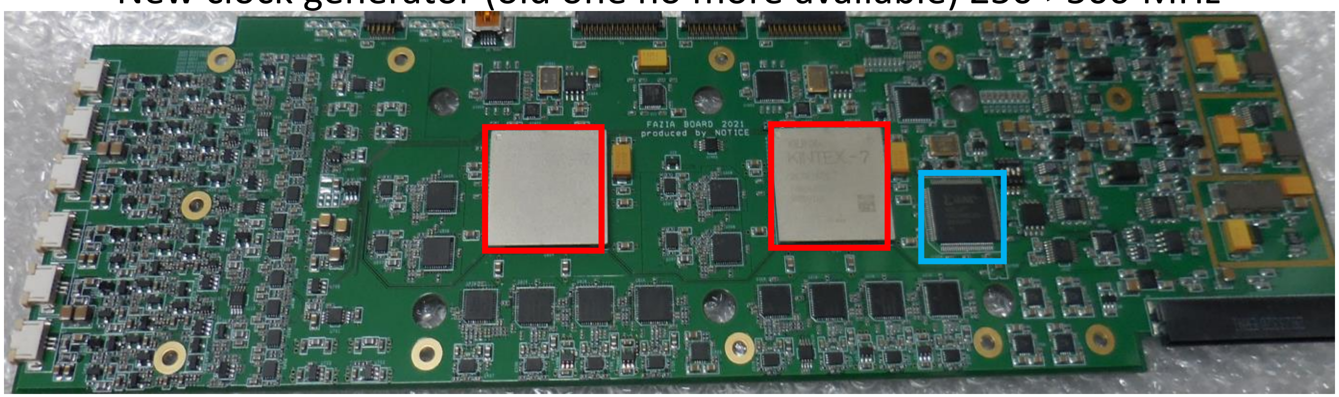


Analog stage Digital stage Converters stage

IJCLab Orsay
Naples

Courtesy of Minjung Kweon, Jiyong Kim & Simone Valdré

New prototypes FAZIA FEE card (FPGA Virtex 5->Kintex 7)
One Complex Programmable Logic Device chip (VHDL) makes two FPGAs
New clock generator (old one no more available) 250->500 MHz



NOTICE Co
Korea

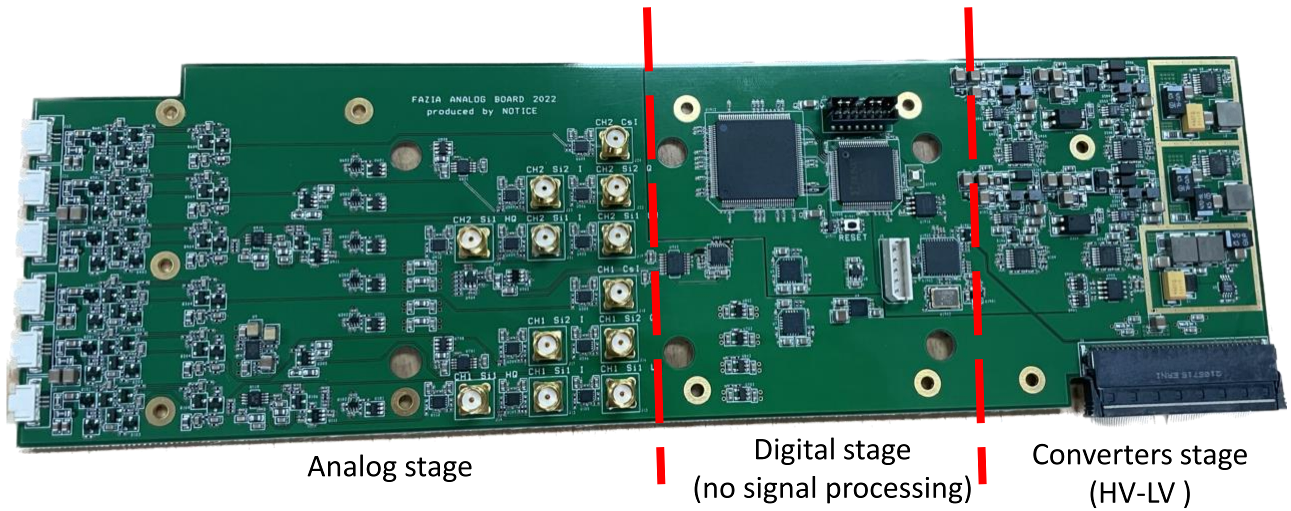
Update of the components

After a series of tests during summer 2022 and 2023: the two new prototypes were validated!

New developments for the future

FAZIA Korean initiative: a simpler version of the FEE
Development of a “small” card with mainly the analog part (PreAmp)
=> Coaxial outputs

Courtesy of Minjung Kweon & Jiyong Kim



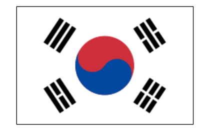
NOTICE Co
Korea

This initiative brings new developments towards simpler FAZIA block

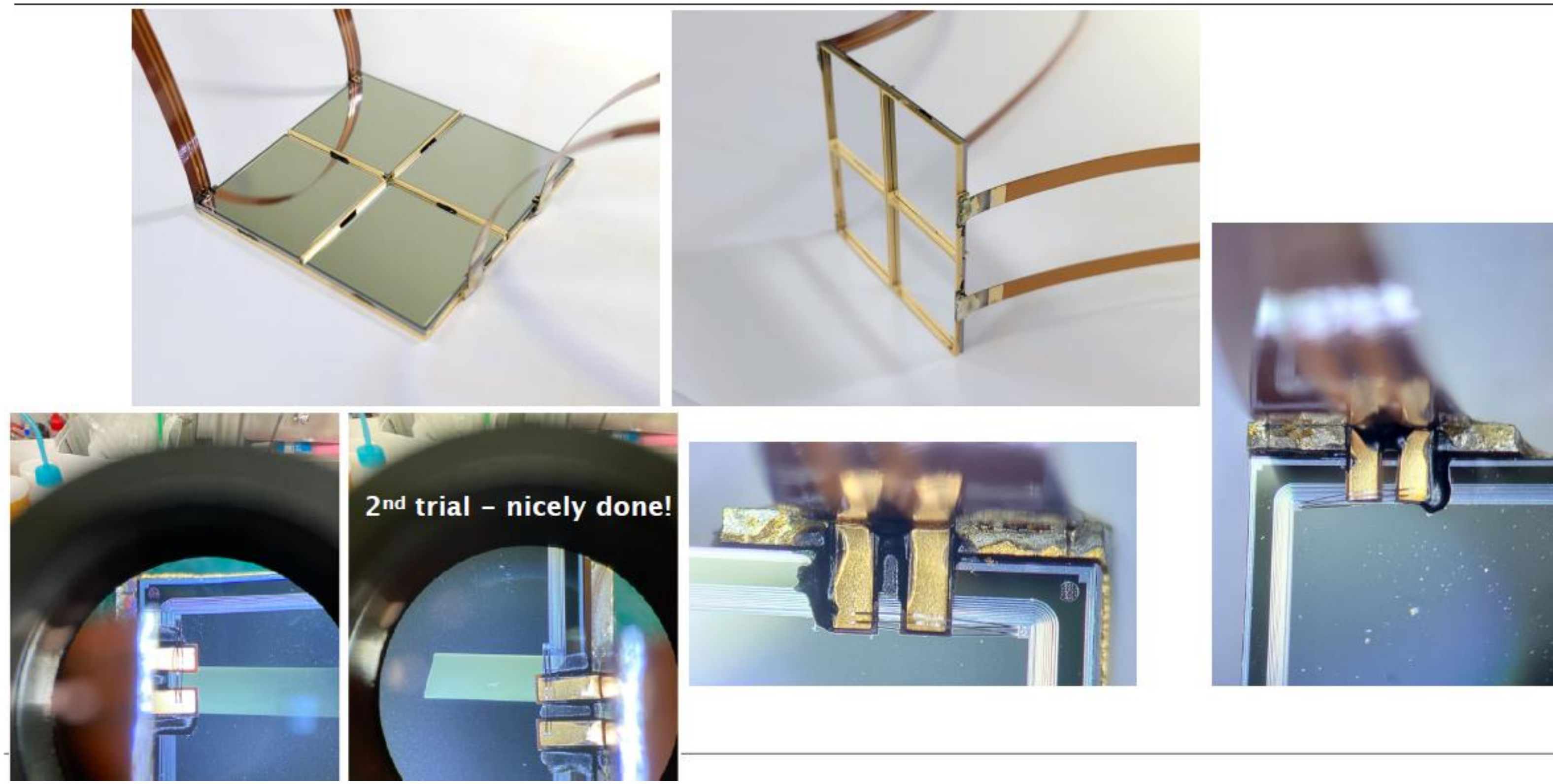
- Increasing the angular coverage especially at larger angle (mid velocity) or backward
- More versatile for experiments with other groups (LISE, ACTAR, FRIB…)

New developments for the future

- Korean colleagues already delivered 500 and 750 µm thick for FAZIA at GANIL
- New silicon chip detectors for FAZIA developed in Korea as well (100 to 1000 µm)
- Better partnership between them and the detector companies too



Quartetto produced by MEMSPACK (chip mounting & wire-bonding)



Courtesy of Minjung Kweon

First step: The low energy RI beams (GANIL SPIRAL 2, SPES, RAON)

For low energy experiments (radioactive ion beams SPES, Spiral 2, FRAISE…) we must lower the identification thresholds => Thin silicon prototypes (20-30 µm).

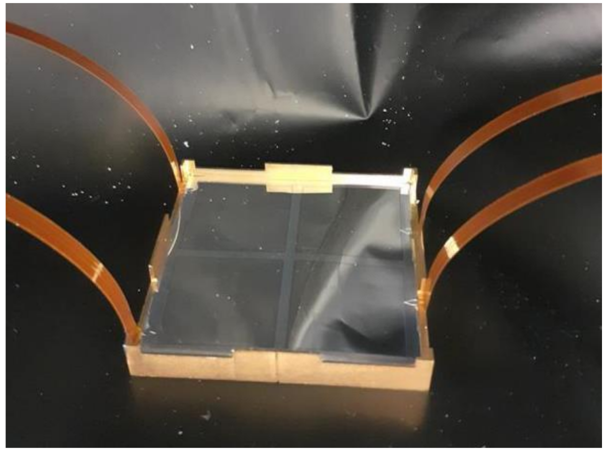
INFN budget 20 k€ in 2023 + IN2P3

⇒ Ordering 4 protos at Micron semi-conductor.

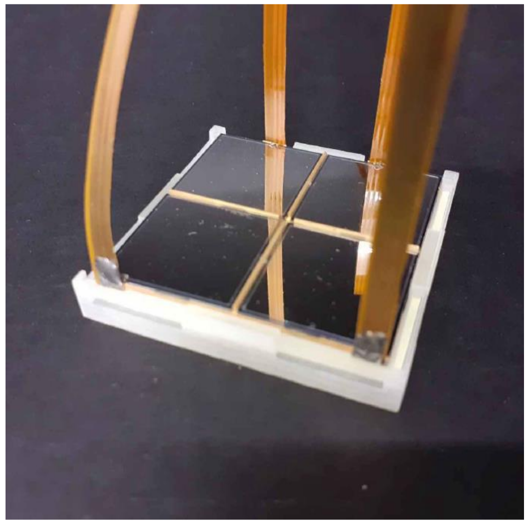
⇒ Beam test at LNS Legnaro 2024? GANIL 2025?

⇒ Interesting developments to lower the dead zone for other silicon detectors.

New quartet:
1 silicium/4 20 µm



Quartet standard:
4 siliciums 500 µm



Conclusions

Plans for symmetry energy researches.

Now

Experimental program at GANIL with INDRA & FAZIA (in parallel with other thematic)

- Complete maintenance + improvements on electronics and detectors.

Future

Development of additional FAZIA blocks in Korea for RAON.

- New updated electronics FEE boards.
- More simple electronic cards for better versatility.
- New silicon detectors of various thicknesses according to beam energies and studies.

Participation to experiments at FRIB.

- First as partner, with some spare blocks added to existing devices.
- As a whole device??