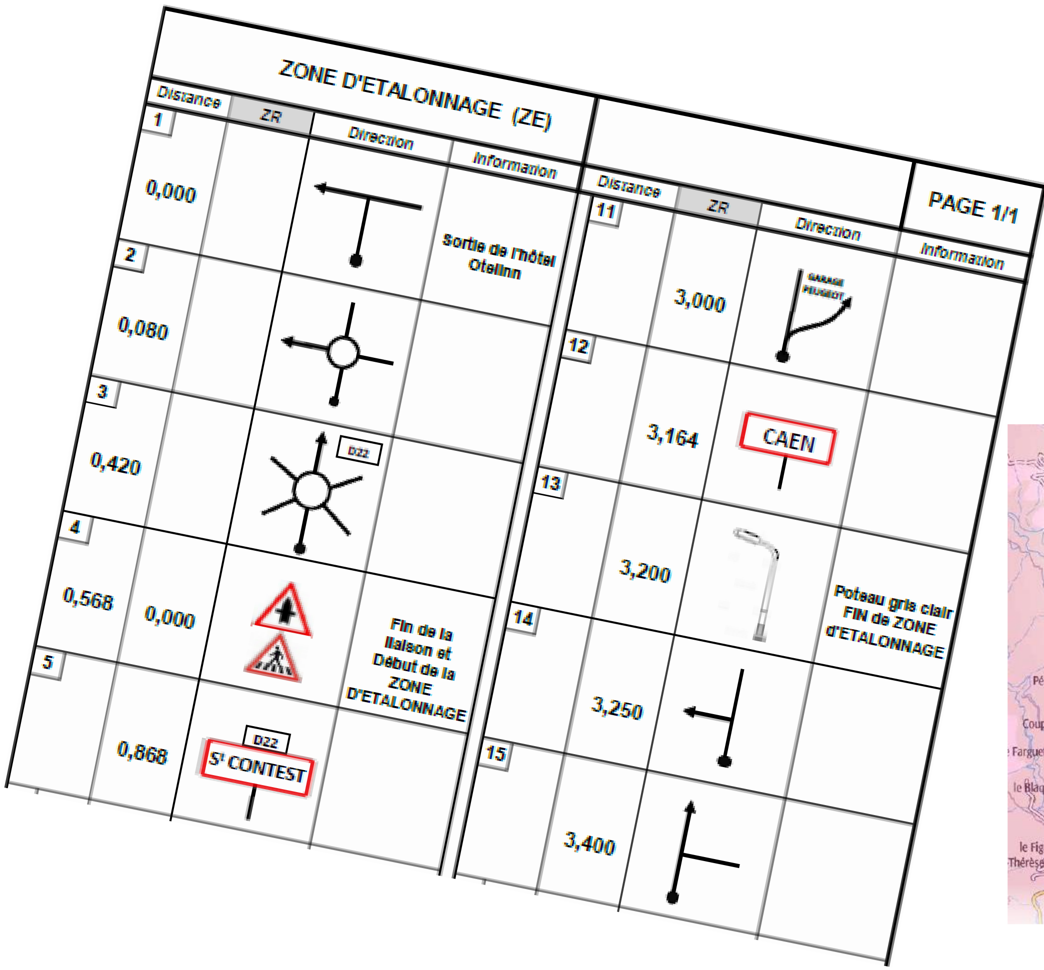
FAZIA roadmap at GANIL

Nicolas Le Neindre for the INDRA-FAZIA collaboration

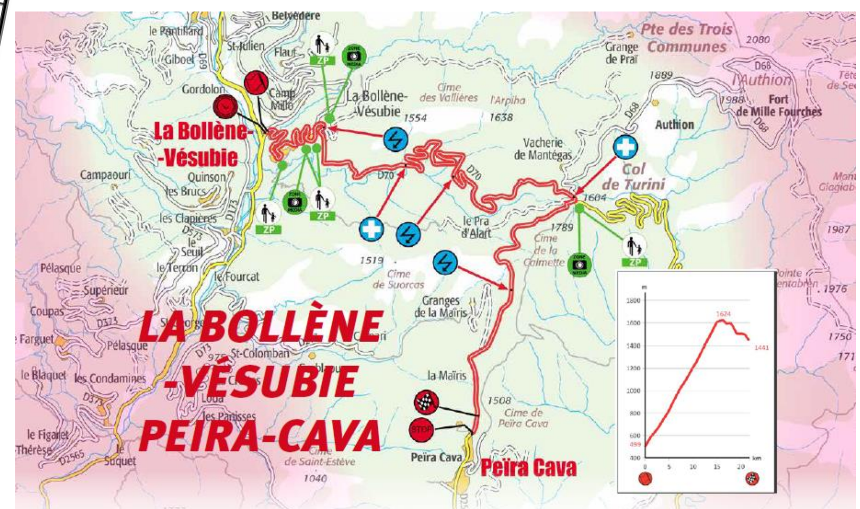


ZONE D'ETALONNAGE (ZE)

	Distance	ZR	Direction	Information
1	0,000			Sortie de l'hôtel Otelinn
2	0,080			
3	0,420		D22	
4	0,568	0,000		Fin de la liaison et Début de la ZONE D'ETALONNAGE
5	0,868		D22 S^t CONTEST	

PAGE 1/1

	Distance	ZR	Direction	Information
11	3,000		GARAGE PEUGEOT	
12	3,164		CAEN	
13	3,200			Poteau gris clair FIN de ZONE d'ETALONNAGE
14	3,250			
15	3,400			



FAZIA collaboration

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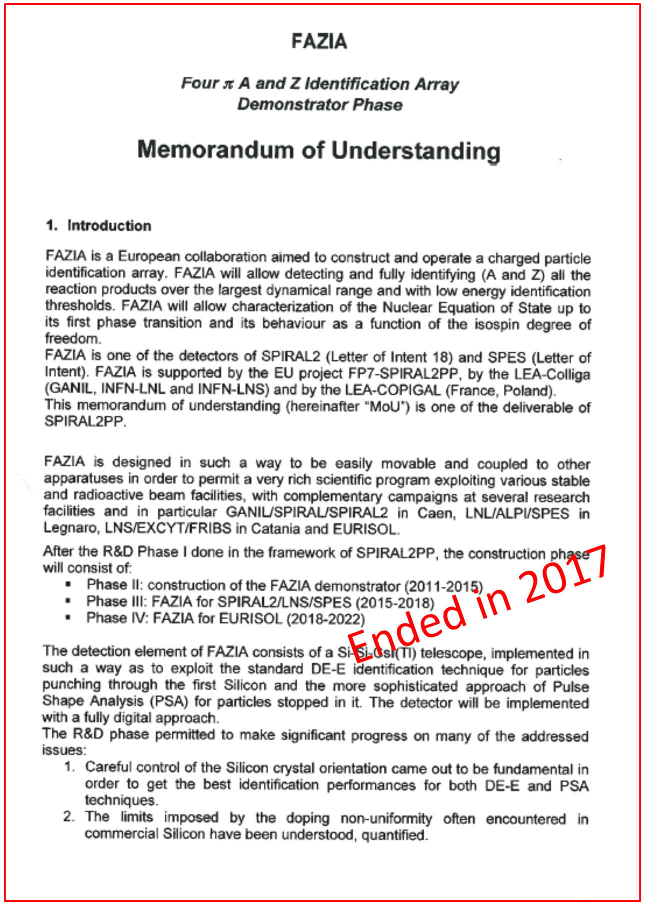
Spokesperson: Giovanni Casini (INFN Florence) co-spokesperson: Nicolas Le Neindre (LPC Caen)

Memorandum of Understanding

First MoU 2011


FAZIA

Four π A and Z Identification Array
Demonstrator Phase

Memorandum of Understanding

1. Introduction

FAZIA is a European collaboration aimed to construct and operate a charged particle identification array. FAZIA will allow detecting and fully identifying (A and Z) all the reaction products over the largest dynamical range and with low energy identification thresholds. FAZIA will allow characterization of the Nuclear Equation of State up to its first phase transition and its behaviour as a function of the isospin degree of freedom.
FAZIA is one of the detectors of SPIRAL2 (Letter of Intent 18) and SPES (Letter of Intent). FAZIA is supported by the EU project FP7-SPIRAL2PP, by the LEA-Colliga (GANIL, INFN-LNL and INFN-LNS) and by the LEA-COPIGAL (France, Poland).
This memorandum of understanding (hereinafter "MoU") is one of the deliverable of SPIRAL2PP.

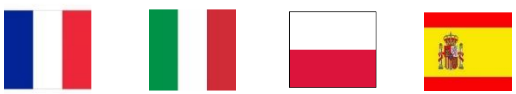
FAZIA is designed in such a way to be easily movable and coupled to other apparatuses in order to permit a very rich scientific program exploiting various stable and radioactive beam facilities, with complementary campaigns at several research facilities and in particular GANIL/SPIRAL/SPIRAL2 in Caen, LNL/ALPI/SPES in Legnaro, LNS/EXCYT/FRIBS in Catania and EURISOL.

After the R&D Phase I done in the framework of SPIRAL2PP, the construction phase will consist of:

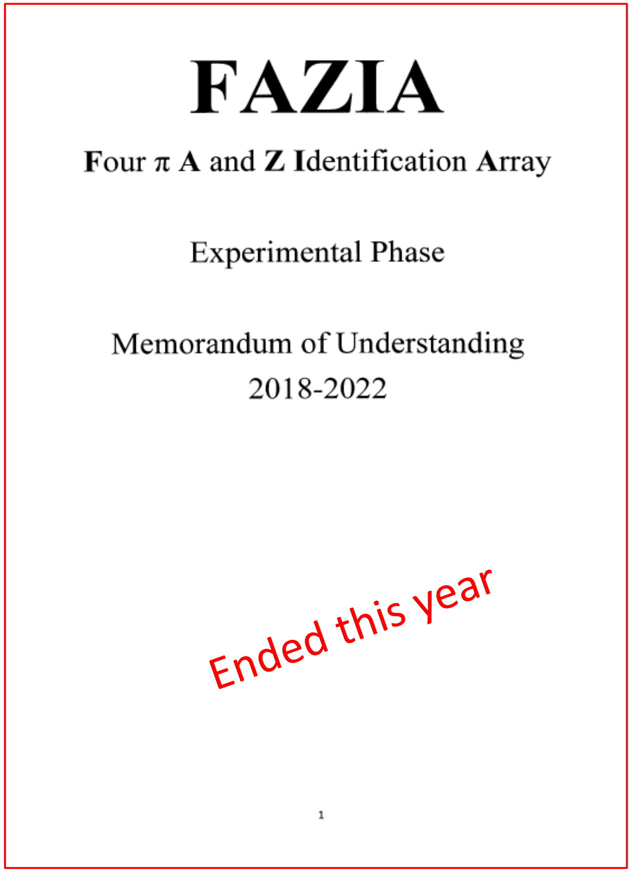
- Phase II: construction of the FAZIA demonstrator (2011-2015)
- Phase III: FAZIA for SPIRAL2/LNS/SPES (2015-2018)
- Phase IV: FAZIA for EURISOL (2018-2022)

The detection element of FAZIA consists of a Si-Si-CsI(Tl) telescope, implemented in such a way as to exploit the standard DE-E identification technique for particles punching through the first Silicon and the more sophisticated approach of Pulse Shape Analysis (PSA) for particles stopped in it. The detector will be implemented with a fully digital approach.
The R&D phase permitted to make significant progress on many of the addressed issues:

1. Careful control of the Silicon crystal orientation came out to be fundamental in order to get the best identification performances for both DE-E and PSA techniques.
2. The limits imposed by the doping non-uniformity often encountered in commercial Silicon have been understood, quantified.



Second MoU 2018

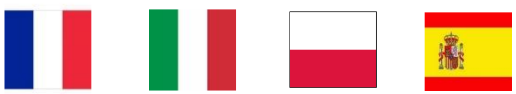

FAZIA

Four π A and Z Identification Array

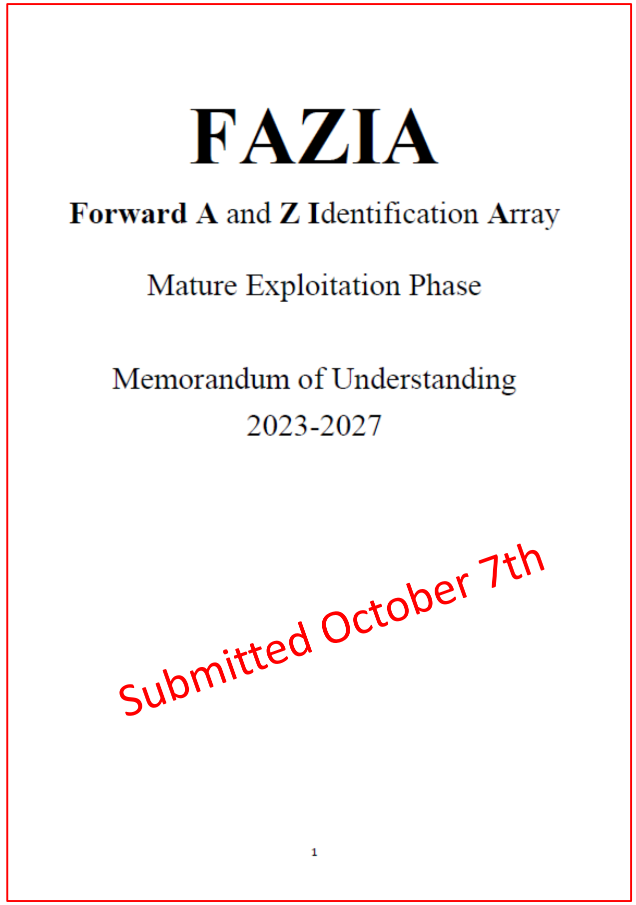
Experimental Phase

Memorandum of Understanding
2018-2022

1



Third MoU 2023

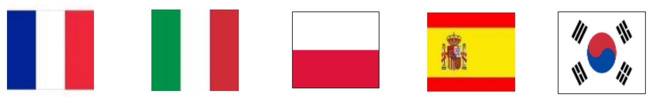

FAZIA

Forward A and Z Identification Array

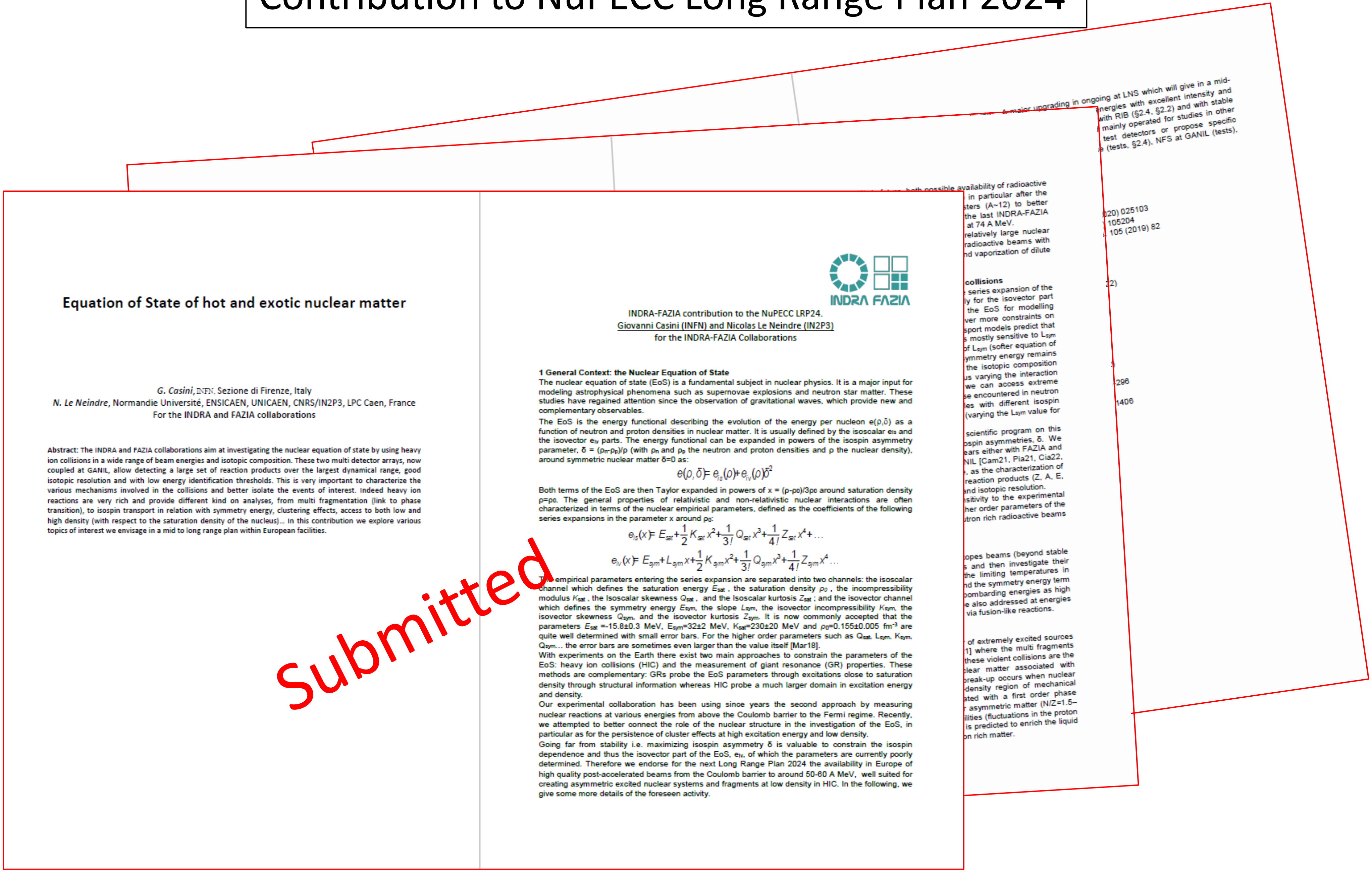
Mature Exploitation Phase

Memorandum of Understanding
2023-2027

1



Contribution to NuPECC Long Range Plan 2024



Equation of State of hot and exotic nuclear matter

G. Casini, INFN, Sezione di Firenze, Italy
N. Le Neindre, Normandie Université, ENSICAEN, UNICAEN, CNRS/IN2P3, LPC Caen, France
For the INDRA and FAZIA collaborations

Abstract: The INDRA and FAZIA collaborations aim at investigating the nuclear equation of state by using heavy ion collisions in a wide range of beam energies and isotopic composition. These two multi detector arrays, now coupled at GANIL, allow detecting a large set of reaction products over the largest dynamical range, good isotopic resolution and with low energy identification thresholds. This is very important to characterize the various mechanisms involved in the collisions and better isolate the events of interest. Indeed heavy ion reactions are very rich and provide different kind on analyses, from multi fragmentation (link to phase transition), to isospin transport in relation with symmetry energy, clustering effects, access to both low and high density (with respect to the saturation density of the nucleus)… In this contribution we explore various topics of interest we envisage in a mid to long range plan within European facilities.

Submitted

INDRA FAZIA

INDRA-FAZIA contribution to the NuPECC LRP24.
Giovanni Casini (INFN) and Nicolas Le Neindre (IN2P3)
for the INDRA-FAZIA Collaborations

1 General Context: the Nuclear Equation of State

The nuclear equation of state (EoS) is a fundamental subject in nuclear physics. It is a major input for modeling astrophysical phenomena such as supernovae explosions and neutron star matter. These studies have regained attention since the observation of gravitational waves, which provide new and complementary observables.

The EoS is the energy functional describing the evolution of the energy per nucleon $e(\rho,\delta)$ as a function of neutron and proton densities in nuclear matter. It is usually defined by the isoscalar e_{is} and the isovector e_{iv} parts. The energy functional can be expanded in powers of the isospin asymmetry parameter, $\delta = (\rho_n - \rho_p)/\rho$ (with ρ_n and ρ_p the neutron and proton densities and ρ the nuclear density), around symmetric nuclear matter δ=0 as:

$$e(\rho,\delta) = e_{is}(\rho) + e_{iv}(\rho)\delta^2$$

Both terms of the EoS are then Taylor expanded in powers of $x = (\rho-\rho_0)/3\rho_0$ around saturation density $\rho=\rho_0$. The general properties of relativistic and non-relativistic nuclear interactions are often characterized in terms of the nuclear empirical parameters, defined as the coefficients of the following series expansions in the parameter x around ρ_0:

$$e_{is}(x) = E_{sat} + \frac{1}{2}K_{sat}x^2 + \frac{1}{3!}Q_{sat}x^3 + \frac{1}{4!}Z_{sat}x^4 + \dots$$

$$e_{iv}(x) = E_{sym} + L_{sym}x + \frac{1}{2}K_{sym}x^2 + \frac{1}{3!}Q_{sym}x^3 + \frac{1}{4!}Z_{sym}x^4 \dots$$

The empirical parameters entering the series expansion are separated into two channels: the isoscalar channel which defines the saturation energy E_{sat}, the saturation density ρ_0, the incompressibility modulus K_{sat}, the Isoscalar skewness Q_{sat}, and the Isoscalar kurtosis Z_{sat}; and the isovector channel which defines the symmetry energy E_{sym}, the slope L_{sym}, the isovector incompressibility K_{sym}, the isovector skewness Q_{sym}, and the isovector kurtosis Z_{sym}. It is now commonly accepted that the parameters E_{sat} =-15.8±0.3 MeV, E_{sym}=32±2 MeV, K_{sat}=230±20 MeV and ρ_0=0.155±0.005 fm^{-3} are quite well determined with small error bars. For the higher order parameters such as Q_{sat}, L_{sym}, K_{sym}, Q_{sym}… the error bars are sometimes even larger than the value itself [Mar18].

With experiments on the Earth there exist two main approaches to constrain the parameters of the EoS: heavy ion collisions (HIC) and the measurement of giant resonance (GR) properties. These methods are complementary: GRs probe the EoS parameters through excitations close to saturation density through structural information whereas HIC probe a much larger domain in excitation energy and density.

Our experimental collaboration has been using since years the second approach by measuring nuclear reactions at various energies from above the Coulomb barrier to the Fermi regime. Recently, we attempted to better connect the role of the nuclear structure in the investigation of the EoS, in particular as for the persistence of cluster effects at high excitation energy and low density.

Going far from stability i.e. maximizing isospin asymmetry δ is valuable to constrain the isospin dependence and thus the isovector part of the EoS, e_{iv}, of which the parameters are currently poorly determined. Therefore we endorse for the next Long Range Plan 2024 the availability in Europe of high quality post-accelerated beams from the Coulomb barrier to around 50-60 A MeV, well suited for creating asymmetric excited nuclear systems and fragments at low density in HIC. In the following, we give some more details of the foreseen activity.

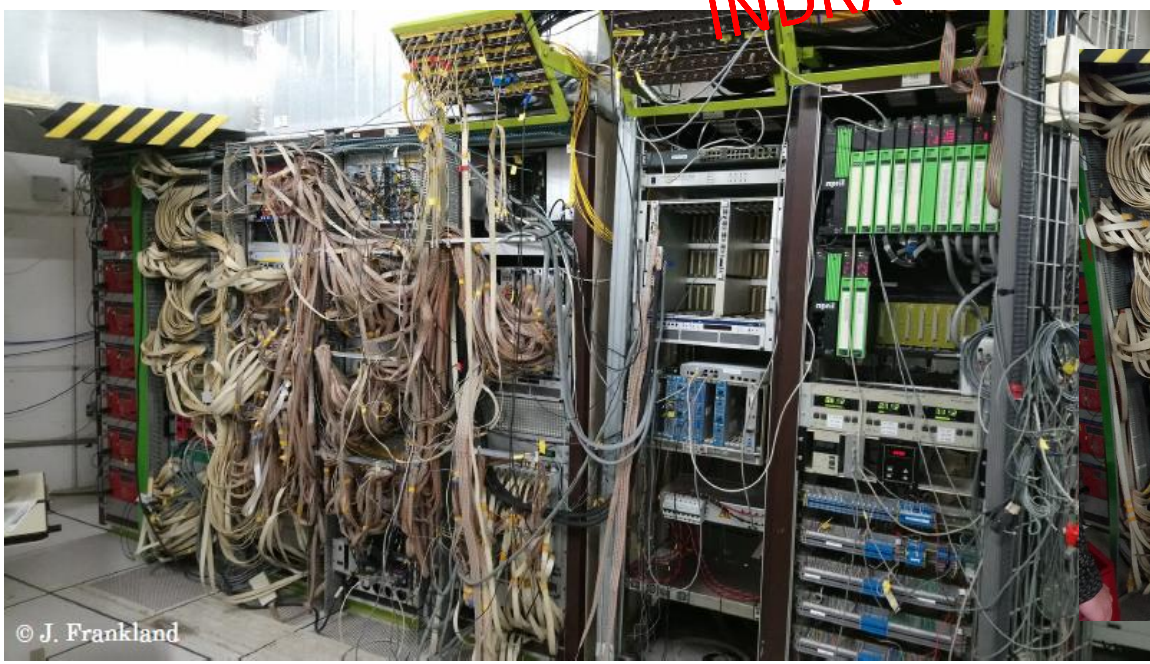
Recent news from 2022

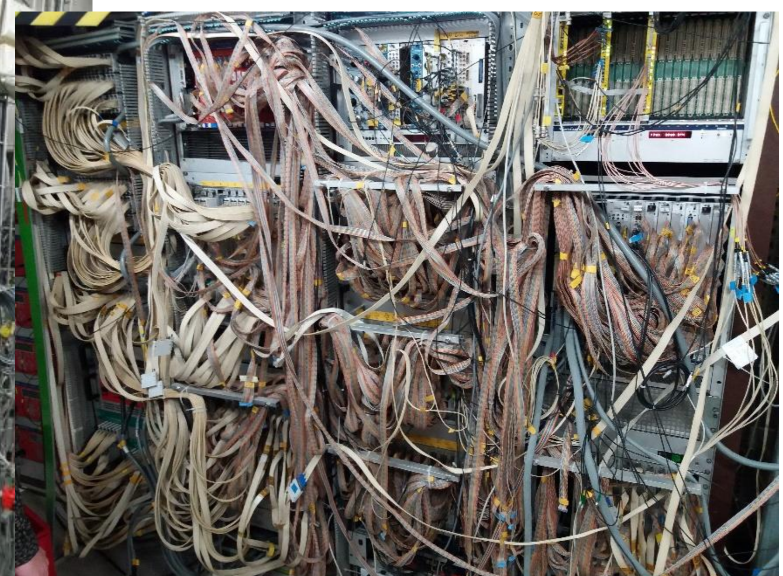
UPDATE of INDRA electronics

Budget Réseaux d'Intérêts Normands RIN GIF 330 k€

- New acquisition electronics: MESYTEC
- New power supply HV/LV: CAEN
- New cabling network (cables & boites de distribution)
- New electronics support and host (cooled bay)

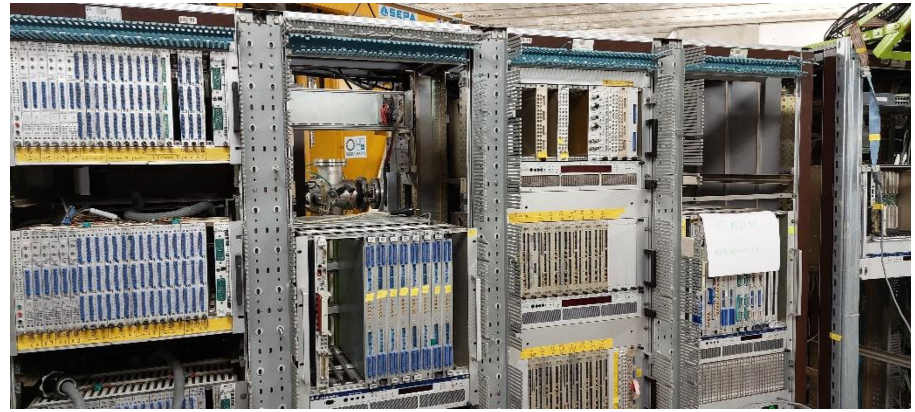
INDRA since 1993 in D5

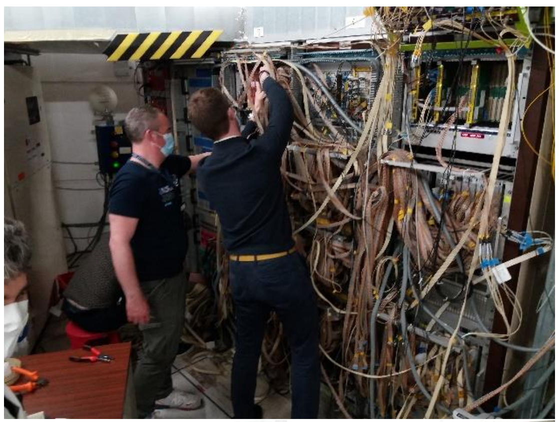


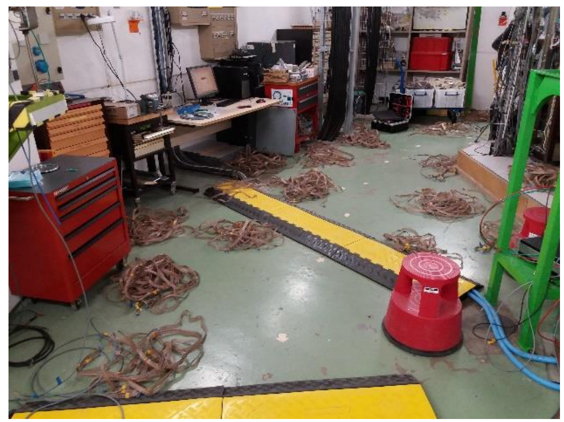


Let's go to 21st century now!

In May 2021 we dismounted everything, really everything!
(outside the vacuum chamber)







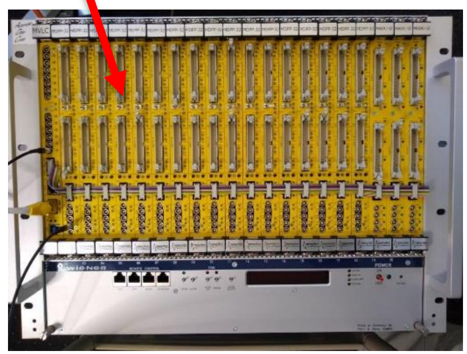
GANIL SPIRAL2
laboratoire commun CEA/DRF CNRS/IN2P3

In autumn 2021 we rebuilt everything from scratch

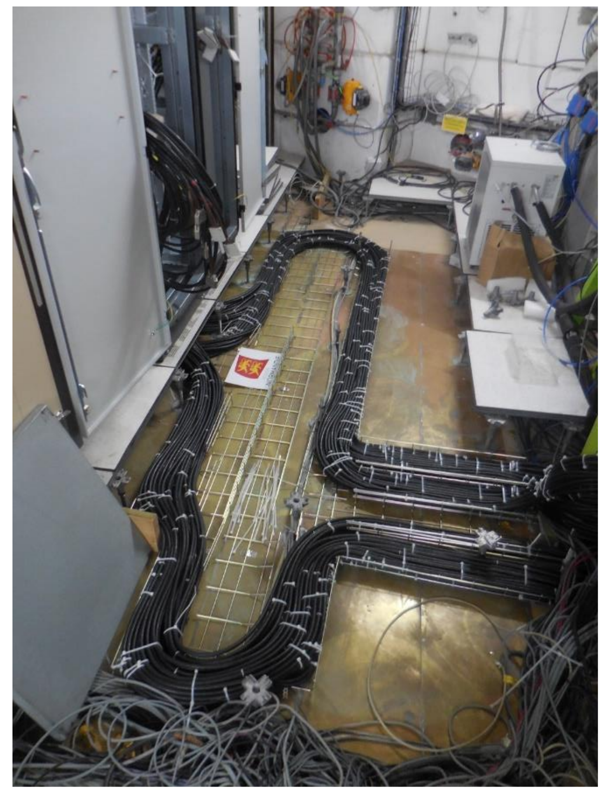
ATOS Bayeux

Mesytec electronics for CI, Si & CsI

CAEN power supply HV &LV



tpc caen



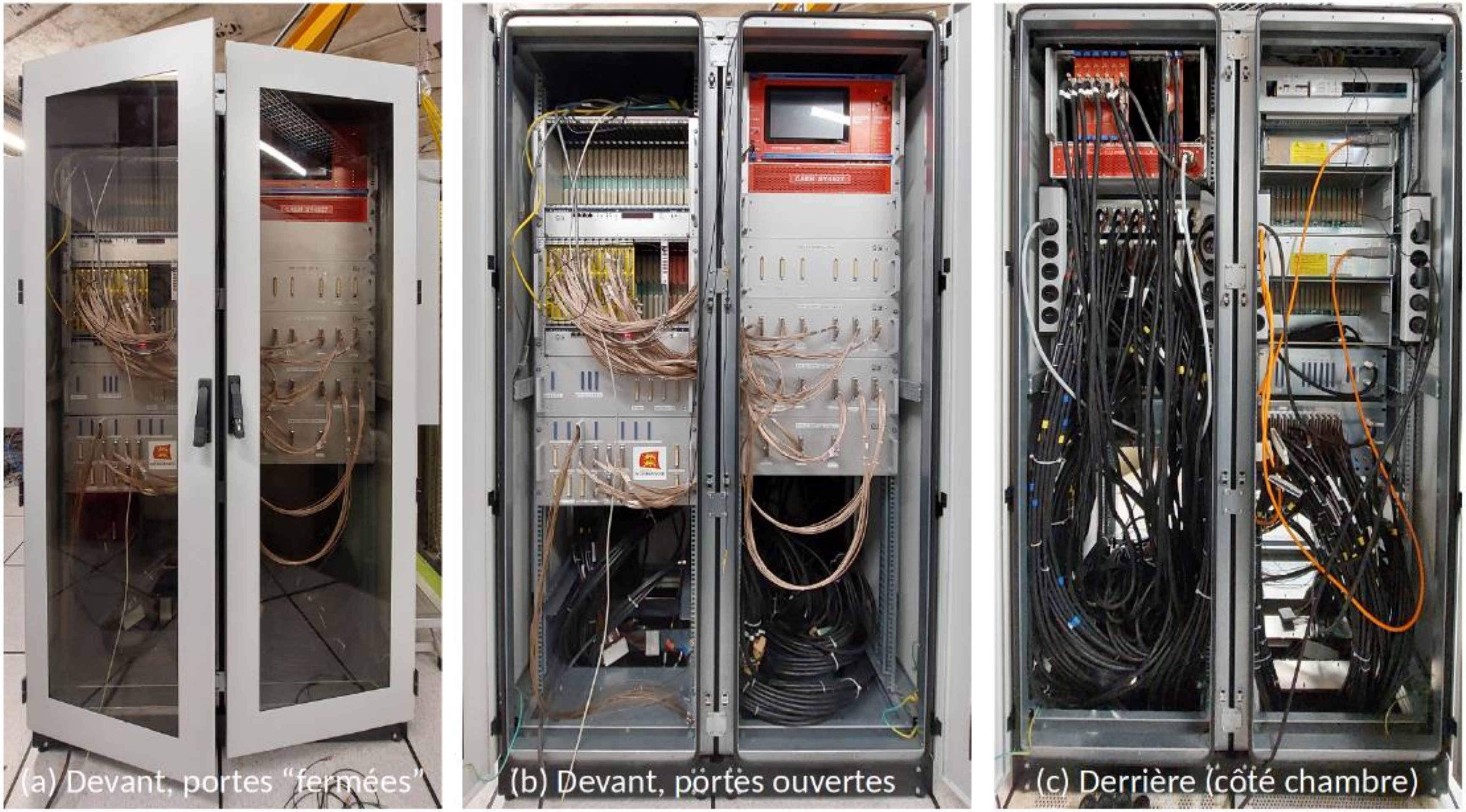
RÉGION NORMANDIE

By January 2022 we switched on everything and we observed cosmic rays in INDRA rings

New digital INDRA electronics

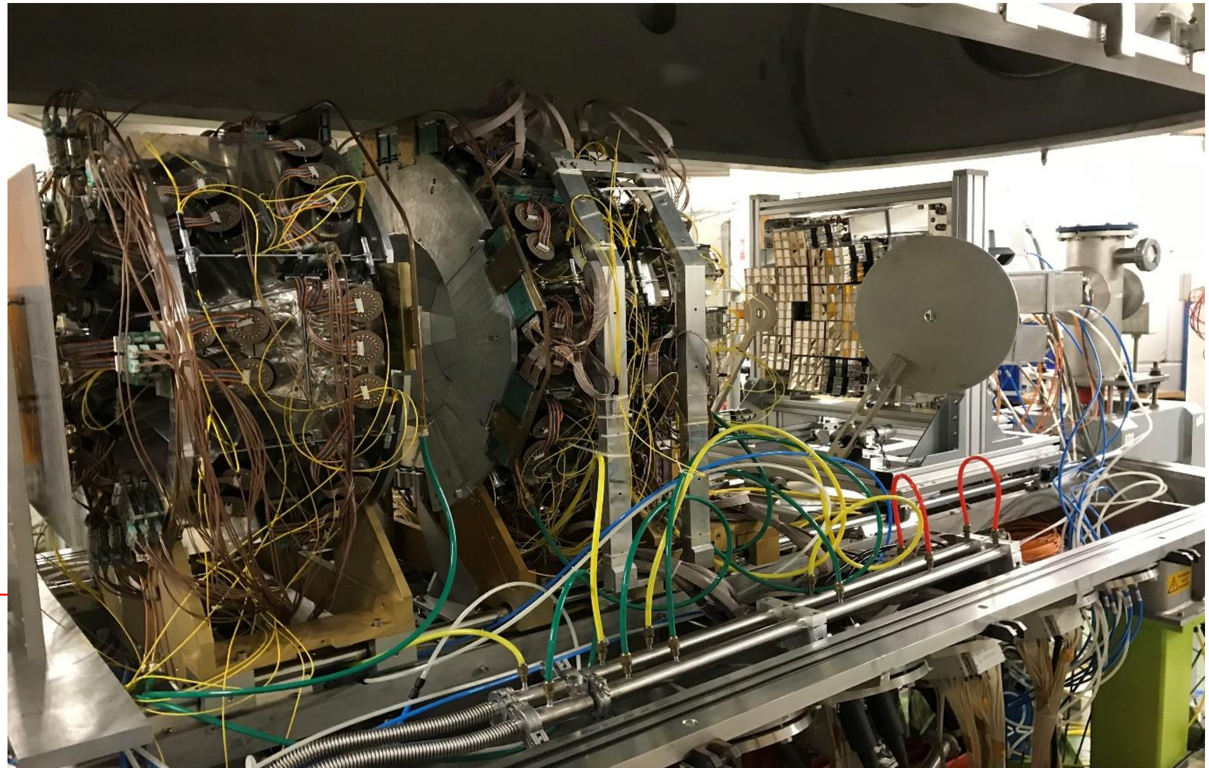
- Digitizer Mesytec, 32 channels, 16 bytes
- Dedicated firmware for ADC, QDC, PSA CsI
- Trigger control Mesytec MVLC

Front view closed doors — Front view opened doors — Back view opened doors



In April-May 2022 with the new INDRA electronics we performed the second INDRA-FAZIA campaign at GANIL E818

2nd INDRA-FAZIA campaign



INDRA FAZIA

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

System	Energy	
^{36}Ar + ^{58}Ni	74 A MeV	E818
^{58}Ni + ^{58}Ni	74.25 A MeV	E818
^{84}Kr + ^{124}Sn	67.6 A MeV	Test
^{12}C + ^{197}Au	8.75 & 13.75 A MeV	Calibrations

E818:extending our knowledge of warm nuclear matter in the low density region

2nd INDRA-FAZIA campaign

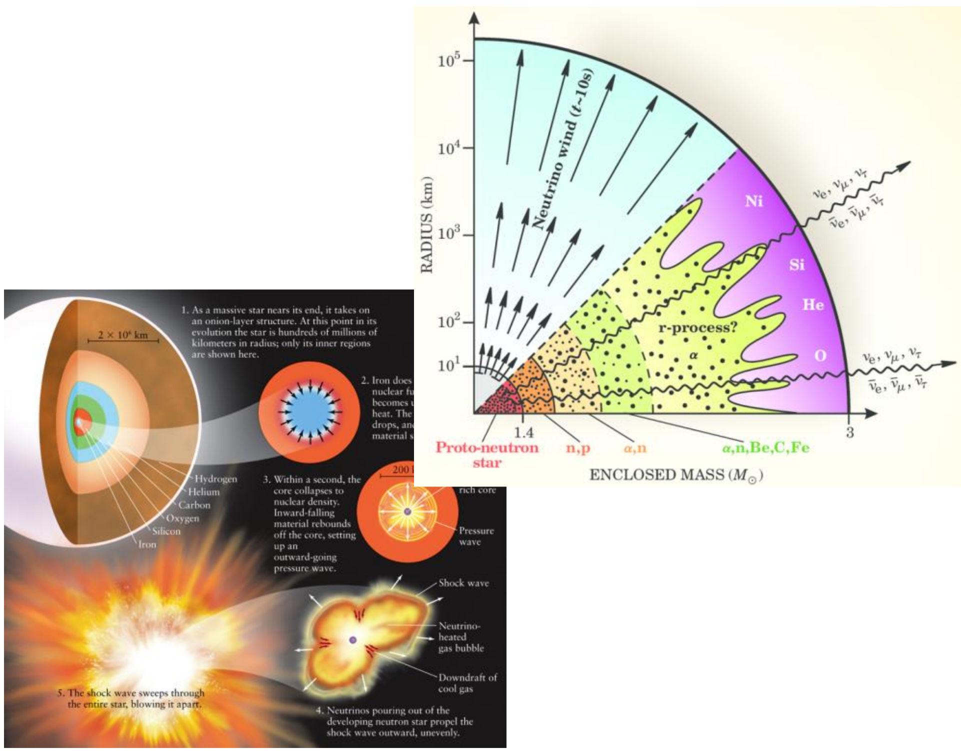
Spokespersons: Rémi Bougault (LPC Caen), Giovanni Casini (INFN Florence)

Warm and diluted nuclear matter is found in:

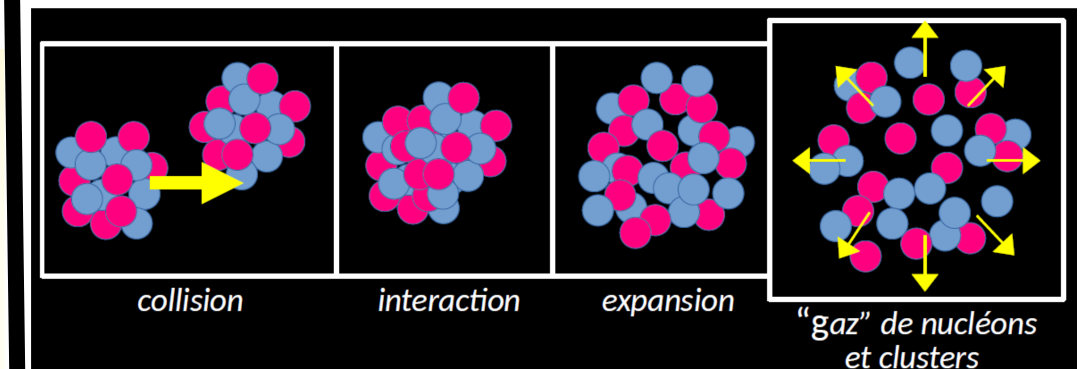
- Explosion of giant stars (supernova)
- External crust on neutron stars

Its composition in cluster/nucleons determines:

- Neutrinos transport (dynamical explosion of supernova)
- External structure of the crust of neutron star



In heavy ion collisions at beam energies > 30 A MeV



Courtesy of John Frankland

To better characterize the warm and diluted gas of cluster and nucleons:

⇒ Detection and resolution of all products (INDRA+FAZIA 4π)

⇒ Reconstruction of the « gas » for each collisions

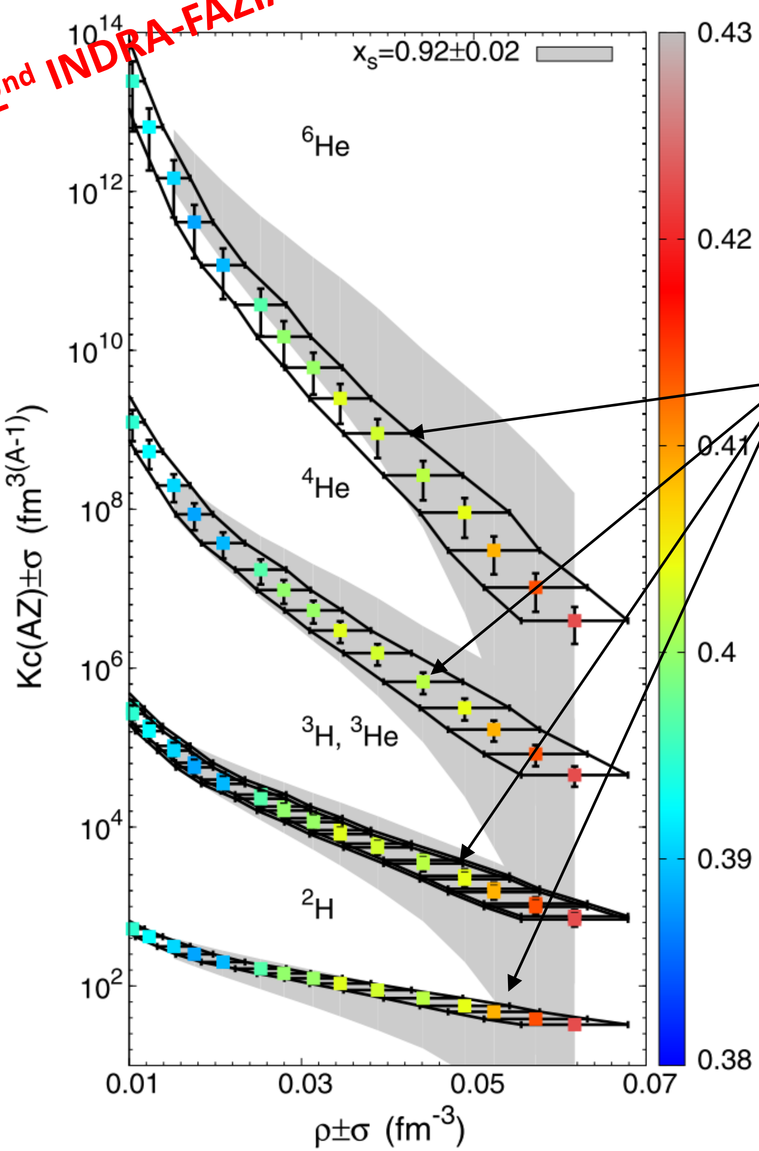
⇒ Millions of events: Statistical ensemble for thermodynamical studies

INDRA FAZIA

E818:extending our knowledge of warm nuclear matter in the low density region

2nd INDRA-FAZIA campaign

Spokespersons: Rémi Bougault (LPC Caen), Giovanni Casini (INFN Florence)



Pais, Bougault et al. Phys. Rev. Let. 125 (2020) 012701

Collaboration PESSOA *PHC 47833UB*
Theory <-> Experiment
H. Pais, C. Providência, M. Ferreira +PhDs
University of Coimbra

So far with INDRA data Xe+Sn (2001)

Yields of light clusters as a function of ρ (thermodynamical studies of kinematical and multiplicities of the detected particles in the medium)

Relative mean field calculations

The grey area: nucleon interact all together but also with the ones bound in clusters (medium effect, binding reduction)

Experimental data constraint the cluster-medium interaction in the model

X_s reduced to 0,92 to reproduce the experimental points

But possible only for light clusters ^{2}H, ^{3}H, ^{3}He, ^{4}He & ^{6}He by the time (2001)

⇒ E818: use of FAZIA for full isotopic resolution of all clusters produced in the reactions, constraints on larger clusters

E818:extending our knowledge of warm nuclear matter in the low density region

<u>New data were needed</u>

It is essential to be able to confront the calculation with a larger set of masses…ideally up to $^{12,13,14}C$

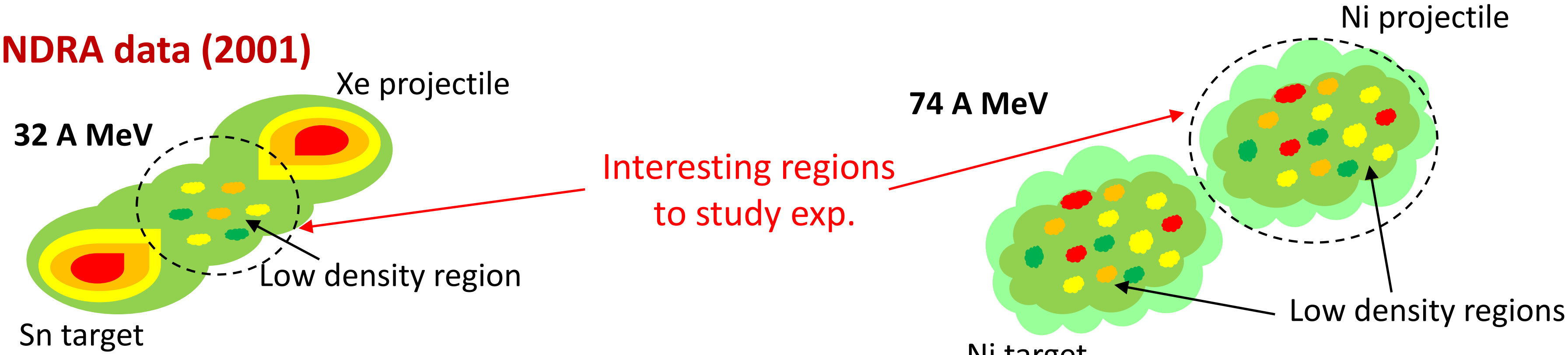
The previous mid rapidity source-based study is limited in terms of cluster diversity.

⇒ We propose to extend the in medium measurements to:

- Projectile vaporization like sources where nuclear matter state is compatible with a gaseous phase composed only of clusters
- Using FAZIA multi detector for (A,Z) identification up to Z~20

INDRA-FAZIA (2022)

INDRA data (2001)



Previous analysis
Mid velocity source

New analysis
Vaporization like sources

Same experimental set-up as E789, full 4π coverage

Beam	Target	BTU
^{58}Ni at 74 A MeV	^{58}Ni	30 Uts-10 days
^{36}Ar at 74 A MeV	^{58}Ni	10 Uts-3,3 days

2nd INDRA-FAZIA campaign

A. Rebillard-Soulié PhD in 2024

2022: Not only an update of the INDRA electronics

E818 focused on light clusters:
But we had a test beam too…

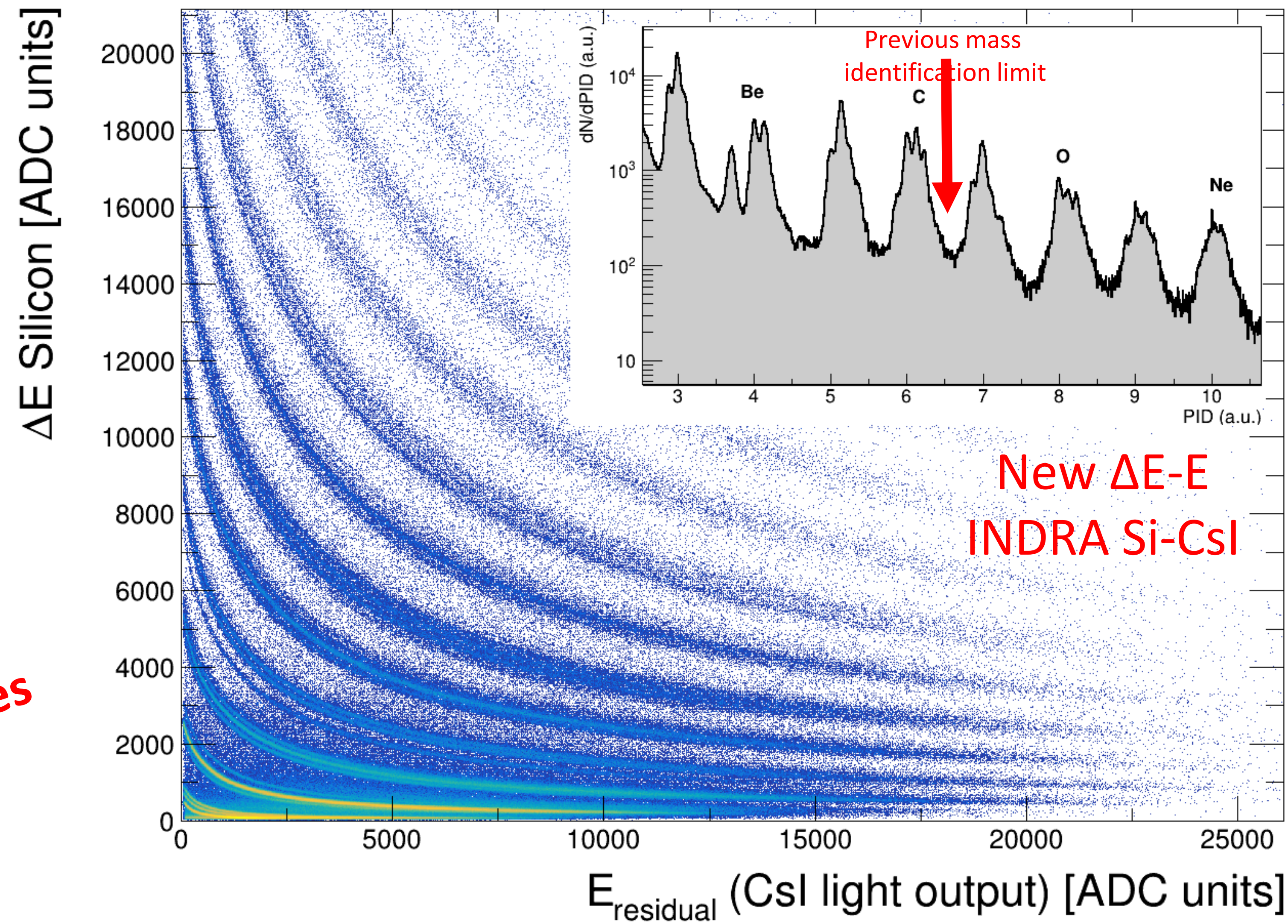
INDRA upgrade:
- New digital electronics & from 12 bytes to 16 bytes
- -> Pushing the PA gain
- New cabling
- New silicons detectors

=>upgrade of INDRA
Better isotopic resolution
From Z=6 to Z=10-12

A resolution:
FAZIA: 1.8-13.5°
INDRA: now 14°-45°

New perspectives

^{84}Kr + ^{124}Sn @ 68 A MeV test beam May 2022



New proposal at next GANIL PAC in December 2022

New proposal for 2023
3rd INDRA-FAZIA campaign

EVIDENCING NEUTRON ENRICHMENT AT MID RAPIDITY BY ISOTOPIC MEASUREMENTS OF LIGH/MEDIUM CLUSTERS

SOMEONE[1], SOMEBODY[2]

FOR THE FAZIA COLLABORATION:

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[13] *Institute of Nuclear Physics PAN, Warsaw, Poland.*
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[16] *CENS, institute for basic science, Daejeon 34126, Republic of Korea.*
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Abstract: We propose here to measure with a better isotopic resolution the isospin content of light/medium fragments produced at mid velocities in the course of the collision of heavy ions. Transport model calculations have always predicted a neutron enrichment in this low density region between the two main partners of the collision and indeed it has been observed so far mainly with light particles. In addition to enlarge this study to larger clusters, recent BLOB data have shown that these fragments are also sensitive to the symmetry energy term of the EoS of nuclear matter. Thanks to the recent INDRA upgrade and the powerfull coupling with FAZIA we can now extend such isotopic analyses towards a larger angular coverage with a more powerfull event by event selection than the previous analyses done.

1 Scientific motivation and method

Heavy ion collisions in the Fermi energy regime (30-70 A MeV) are a common tool to study the properties of nuclear matter. A variety of outputs emerge from the reactions, mostly depending of its centrality (from peripheral to central reactions). Many efforts have been dedicated to the study of the isotopic composition of the products of heavy ion reactions, aiming to look for the details of the microscopic mechanism in relation with the nuclear Equation of State (EoS) and more specificaly the symmetry energy term. Such studies assume that nucleon exchange processes taking place during the interaction phase of the reaction between the entrance channel nuclei are at the origin of the kinetic energy dissipation into internal degrees of freedom and of the evolution towards their equilibration. Among these latter, a special focus has been put on the isospin transport phenomena [1]. Two main experimental observations in the field of isospin dynamics have been widely recognized by the scientific community: the process of isospin equilibration between reacting nuclei having different initial neutron-to-proton ratio N/Z [2], [3], and the neutron enrichment of the midvelocity emissions [4], [5], [6], [7], [8], [9], [10]. An interpretation of these two phenomena can be found in the framework of the nuclear equation of state (EoS). The isospin equilibration between asymmetric projectile and target can be ascribed to the isospin diffusion mechanism, which is driven by an isospin gradient and depends on the contact time between the two colliding nuclei [11], [12], which in turn varies as a function of the bombarding energy and of the impact parameter of the collision [13]. For a long enough interaction time, a full isospin equilibration, i.e., a homogeneous distribution of the isospin content among the reaction products, could be expected. However, the neutron enrichment at midvelocity has been associated with the isospin drift (or migration), an effect driven by the presence of a nuclear density gradient, leading to a net neutron flux towards low-density regions [14]. A neutron enrichment can be therefore expected for the diluted intermediate neck region, formed in the separation of the projectile-target system, and hence for

System	Beam energy
$^{78}Kr + ^{112}Sn$	35 & 45 A MeV
$^{86}Kr + ^{124}Sn$	35 & 45 A MeV

Why measuring the isospic content is important?

- Isospin transport arises because n and p are subject to different forces

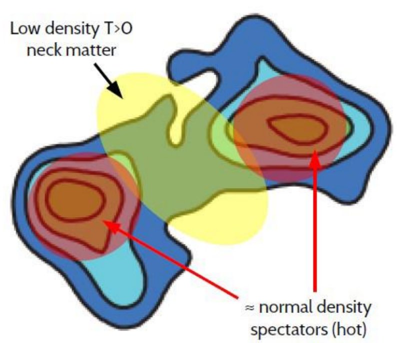
$$j_n - j_p \propto S(\rho)\nabla I + \frac{\partial S(\rho)}{\partial \rho} I \nabla \rho$$

Difference between the neutron and proton currents

V.Baran et al., Phys. Rep. 410 (2005) 335
M.DiToro et al., J.Phys.G 37 (2010) 083101

- The isospin gradient ∇I between target and projectile (in isospin asymmetric reactions) is responsible of the isospin diffusion process, sensitive to S(ρ)

- The density gradient ∇ρ between the QP/QT region (at normal density) and the more diluted neck zone (both in symmetric and asymmetric reactions), is responsible of the isospin drift/migration, sensitive to ∂S/∂ρ



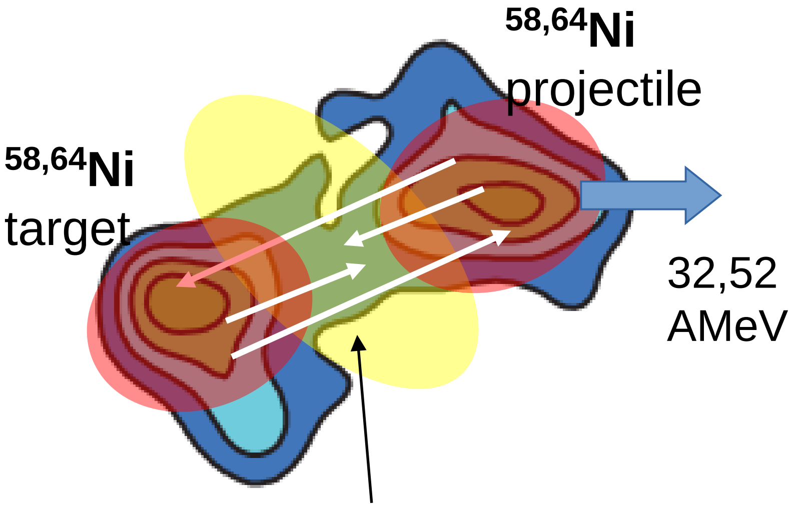
Isospin transport phenomena depend on the **symmetry energy S(ρ)** term of the nuclear equation of state; S(ρ) is not well known far from normal conditions

E789 : Isospin Transport and the Density Dependence of the Symmetry Energy

O. Lopez (LPC Caen) & S. Piantelli (INFN Florence)

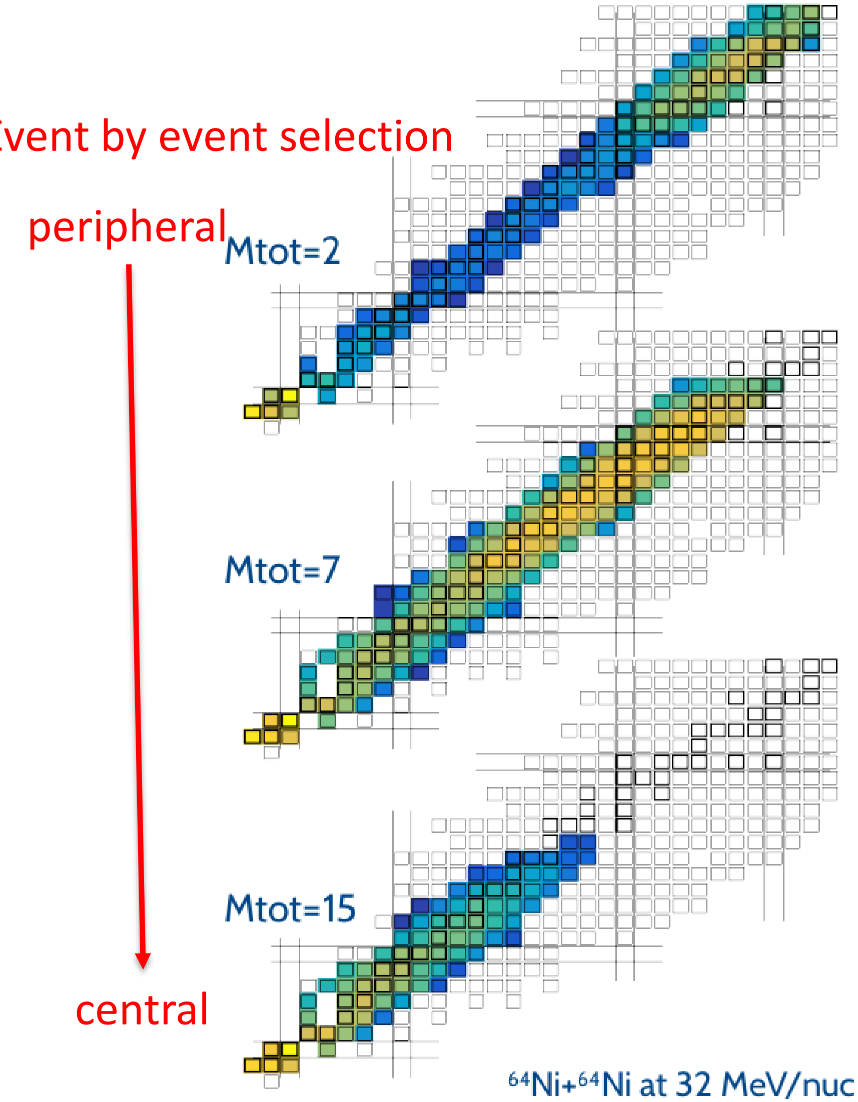
1st INDRA-FAZIA campaign

INDRA FAZIA



Isospin transport :
redistribution of neutrons & protons
between projectile/target & neck
during reaction time (10^{-22}-10^{-20} sec.)

Event by event selection



2019: first INDRA-FAZIA campaign at GANIL with old INDRA electronics

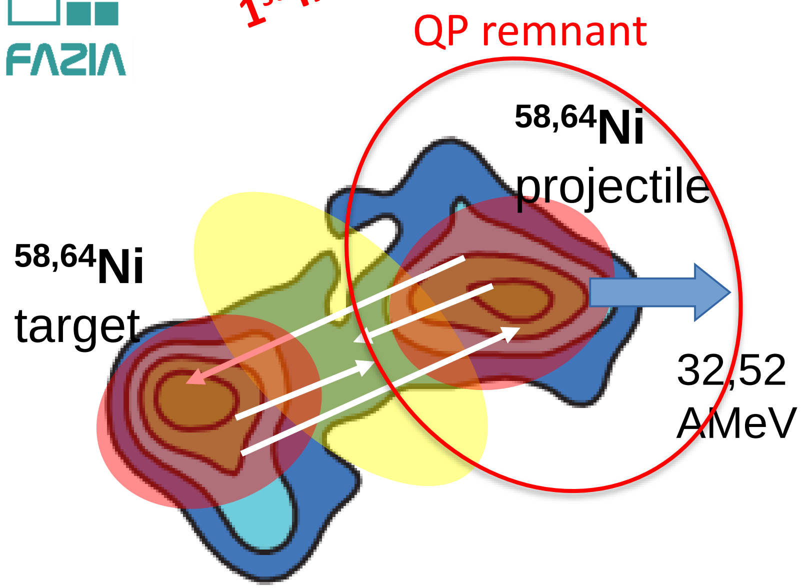
Courtesy of Diego Gruyer LPC Caen

E789 : Isospin Transport and the Density Dependence of the Symmetry Energy

O. Lopez (LPC Caen) & S. Piantelli (INFN Florence)

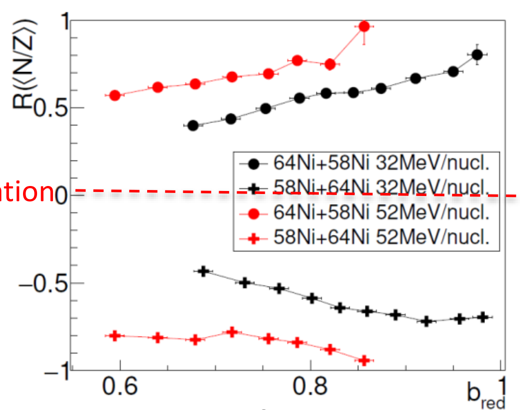
Projectile	Energy	Target	Events
^{58}Ni	32AMeV	**^{58}Ni**	27 764 899
		^{64}Ni	34 085 718
	52AMeV	**^{58}Ni**	42 533 432
		^{64}Ni	39 563 517
^{64}Ni	32AMeV	**^{58}Ni**	34 297 052
		^{64}Ni	34 283 433
	52AMeV	**^{58}Ni**	29 896 441
		^{64}Ni	30 296 143

1st INDRA-FAZIA campaign

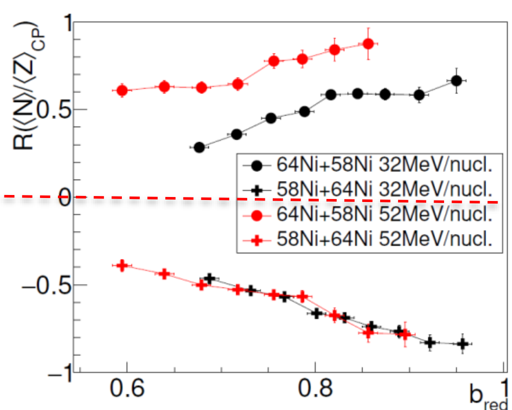


$R(\delta) = (2X_i - X_1 - X_2)/(X_1 - X_2)$ with $X_i = f(Z,N) = \delta$

equilibration



Measured QP remnant



Complex particles H, He…Be

In e789 (so far) mainly the forward part of the emitted particles has been studied
To benefit from the large isotopic capabilities of FAZIA (1.5°-13° in the lab)

⇒ But now INDRA is able to better A identification too

Caterina Ciampi et al. PRC 106 (2022) 024603

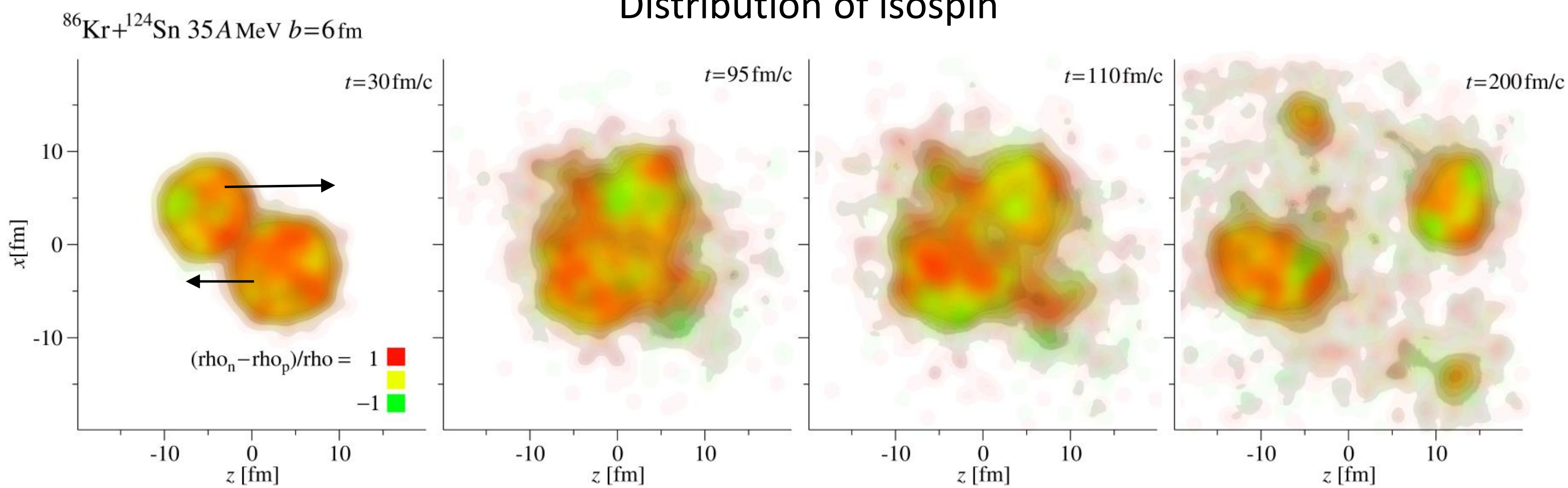
New proposal for 2023
3rd INDRA-FAZIA campaign

Transport model calculations: BLOB

Stochastic event Kr+Sn at 35 A MeV

- Matter drift outward but the flow is along the reaction plane
- A large disk of low density (ρ~ρ_{sat}/4) neutron rich matter forms
- From the disk fragments and clusters arise at mid velocity and are emitted with a dominant perpendicular component

Distribution of isospin

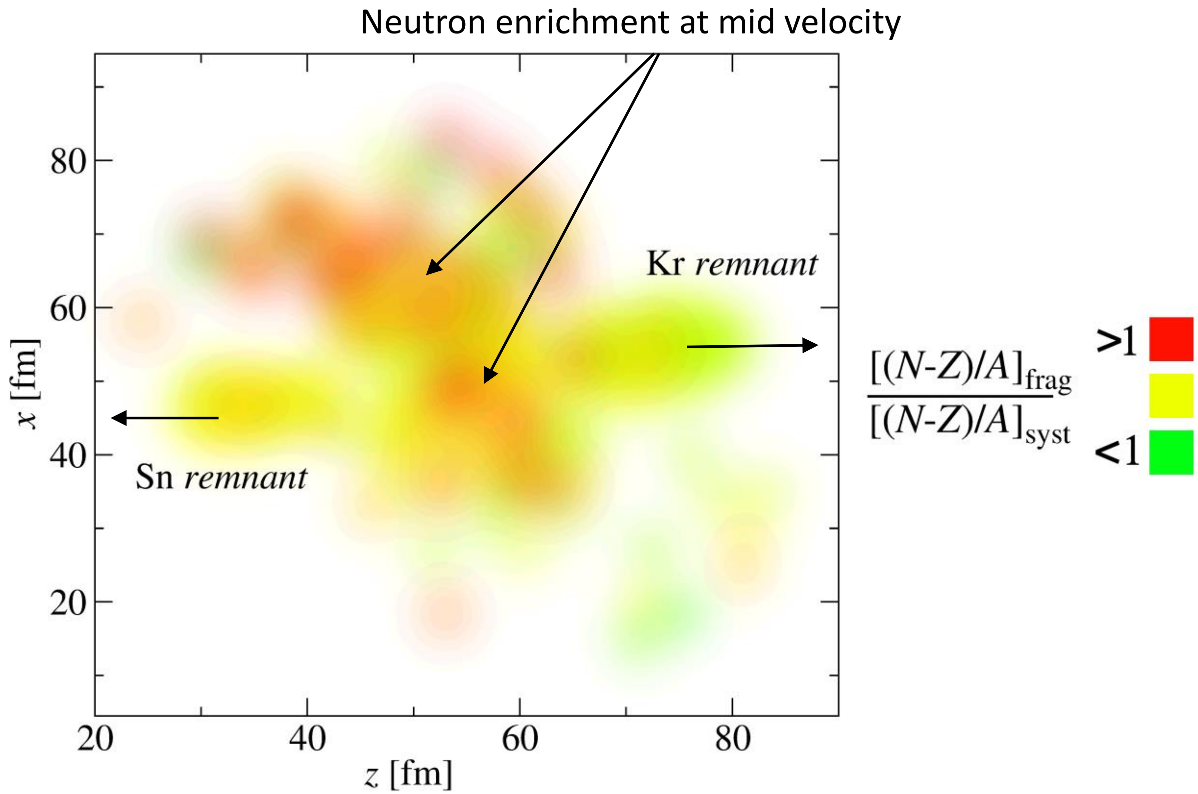


Courtesy of Paolo Napolitani, NUSYM Catania September 2022

New proposal for 2023

Transport model calculations: BLOB

Kr+Sn at 35 A MeV with BLOB (500 stochastic events at 300 fm/C)
Isotopic composition of arising fragments

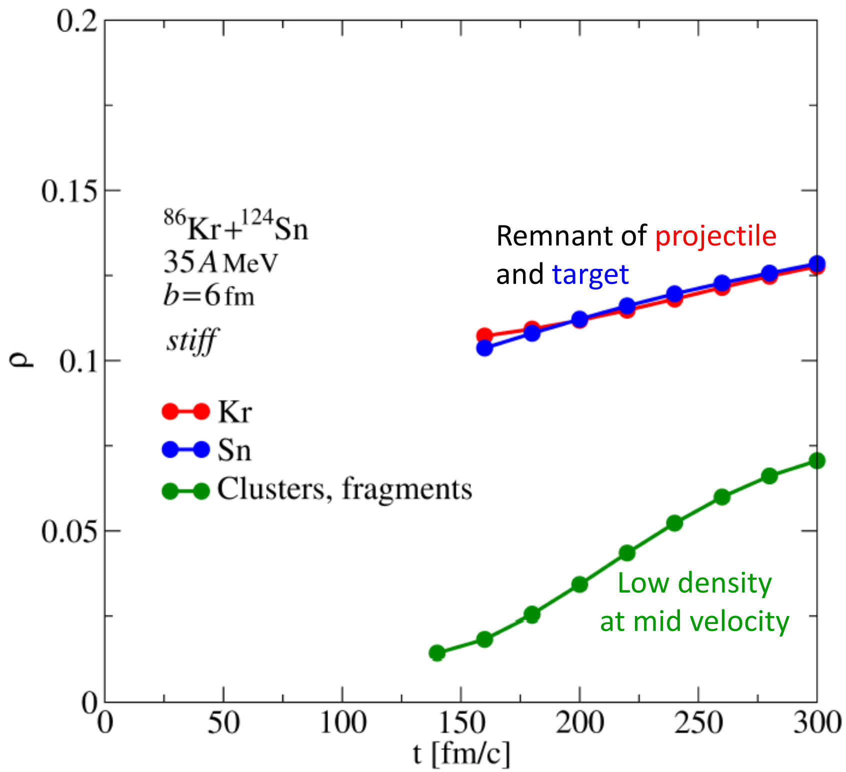


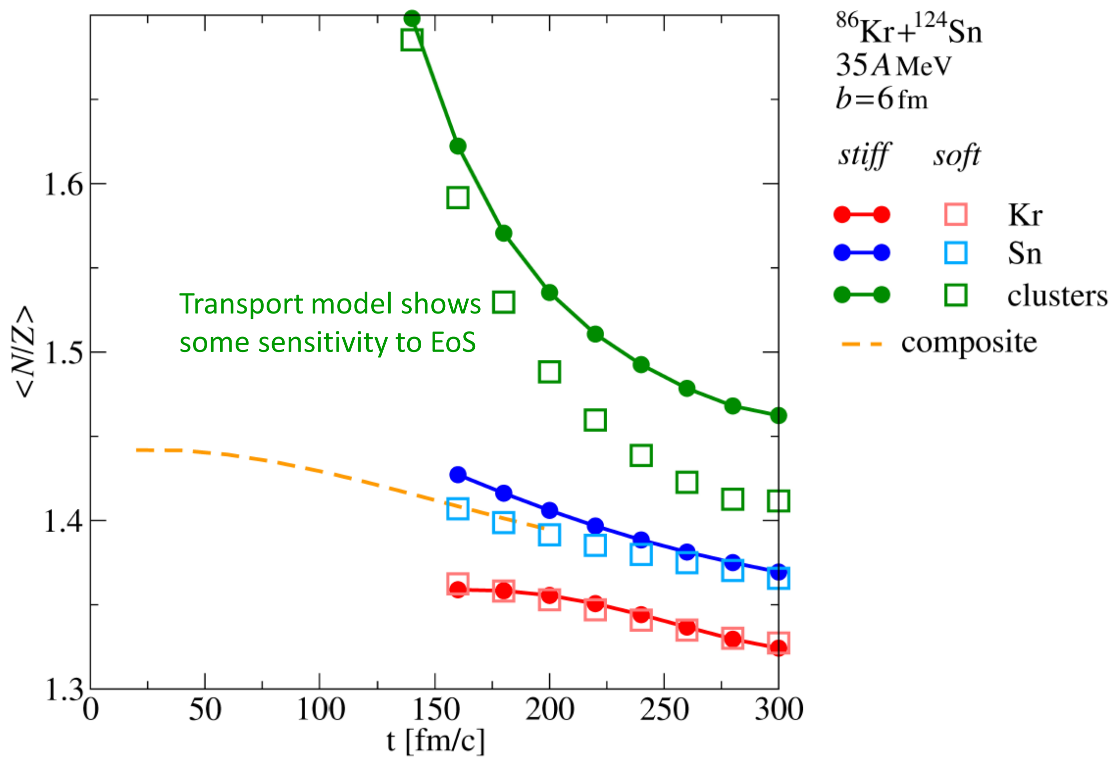
Courtesy of Paolo Napolitani, NUSYM Catania September 2022

New proposal for 2023

Transport model calculations: BLOB

^{86}Kr+^{124}Sn at 35 A MeV with BLOB



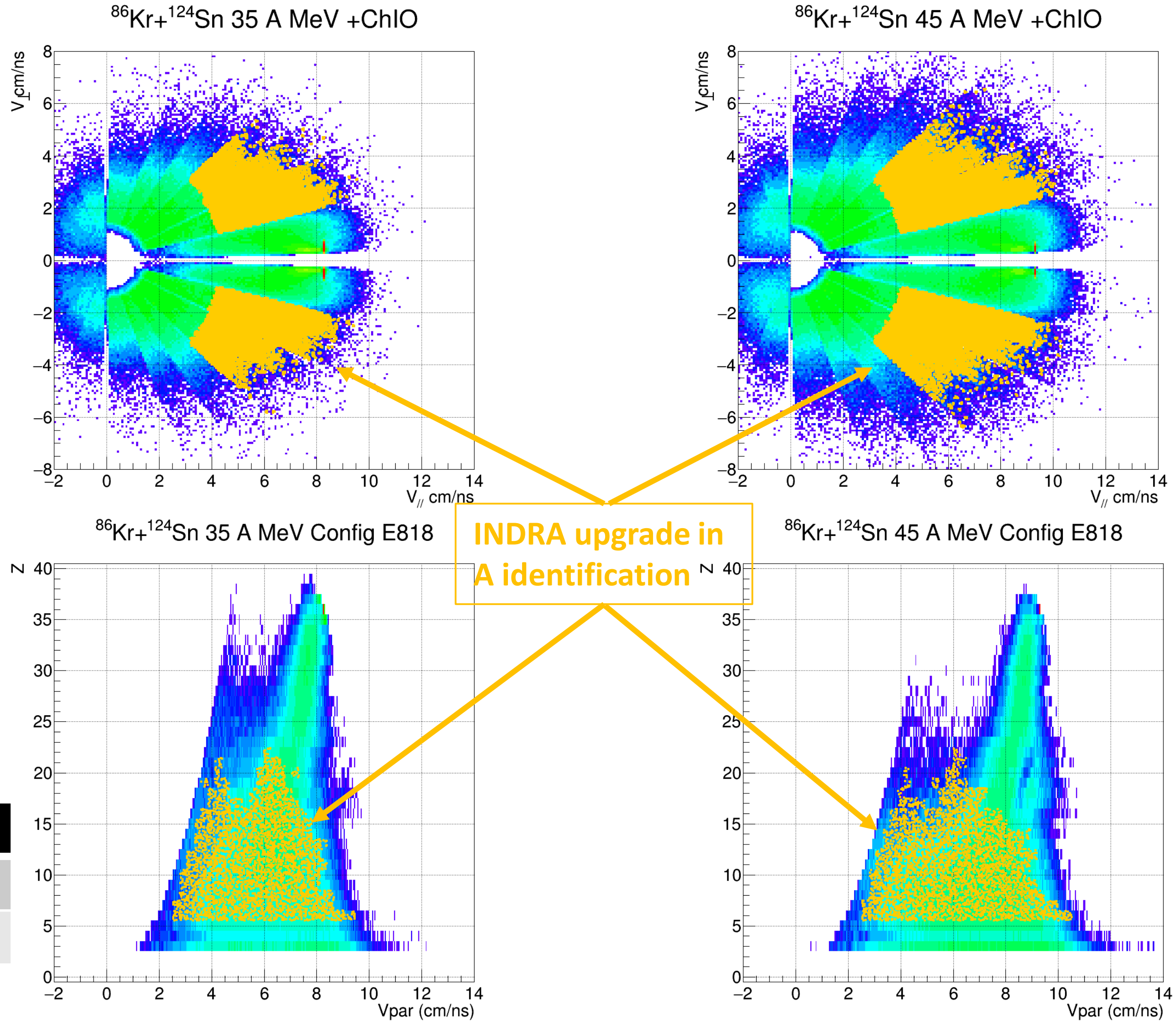


Courtesy of Paolo Napolitani, NUSYM Catania September 2022

HIPSE simulations for ^{86}Kr+^{124}Sn at 35 & 45 A MeV

New proposal for 2023

Filtred events with the INDRA-FAZIA set-up



INDRA FAZIA

System	Beam energy
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^{86}Kr + ^{124}Sn	35 & 45 A MeV

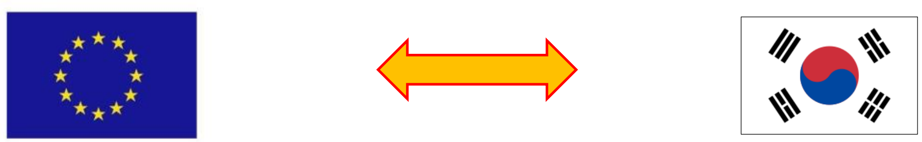
We verified with simulations that indeed the INDRA-FAZIA set-up is able to isotopically resolves the mid velocity clusters produced in the course of the reaction

What next?

- So far we have 12 complete FAZIA blocks in D5 (and in the world)
  + 2 spare blocks
- To extend our geometrical efficiency and to do experiments elsewhere => more blocks
- The FEE FAZIA cards are already obsolete (and difficult to repair/maintain)
- Difficult also to buy new silicon detectors (nTDs wafers)

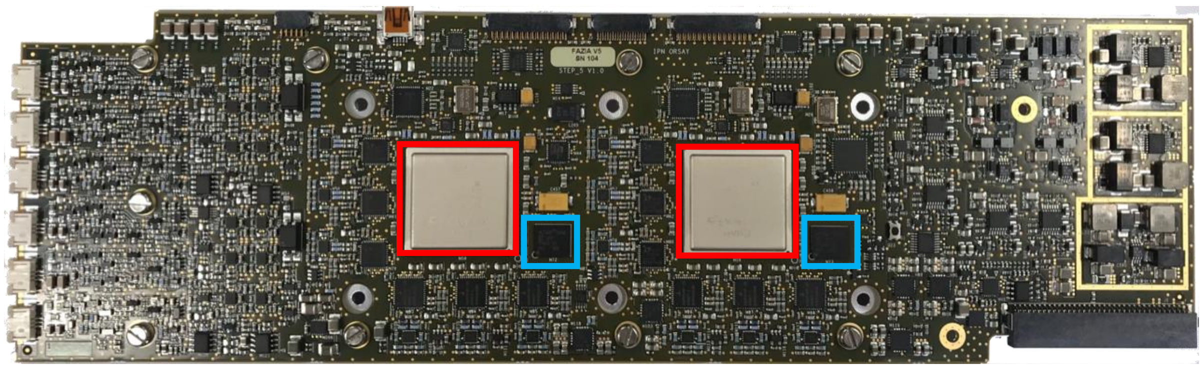
⟹ Ending of the road map?

No, thanks to our new colleagues from Korea since 2019



Future developments

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

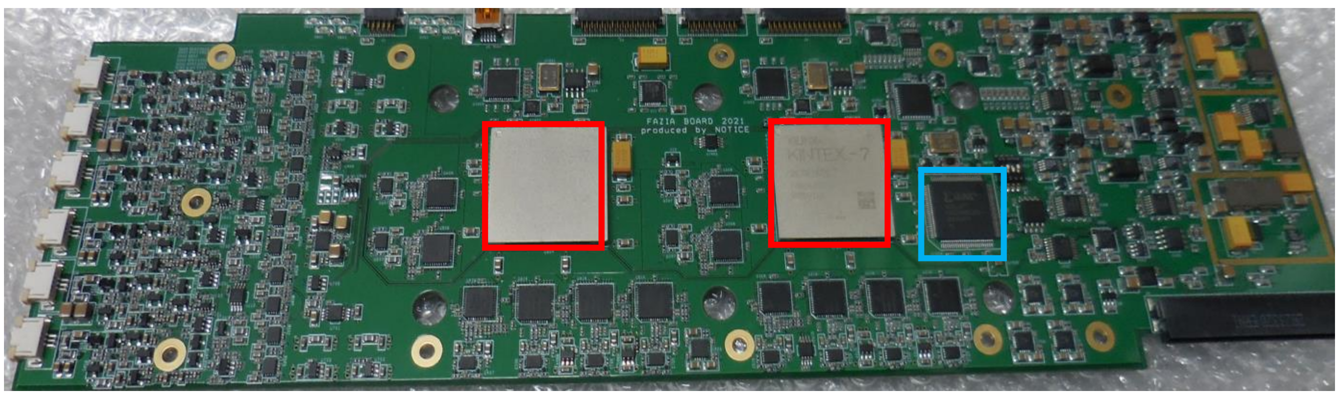


Analog stage Digital stage Converters stage

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

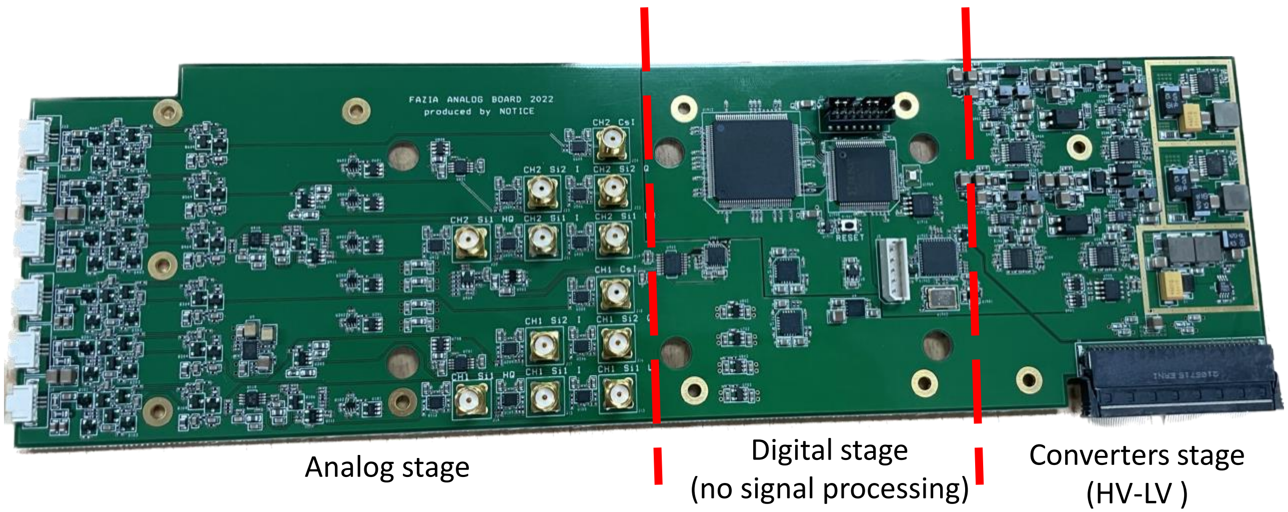
Update of the components

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

Future developments

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



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감사합니다
Thank you

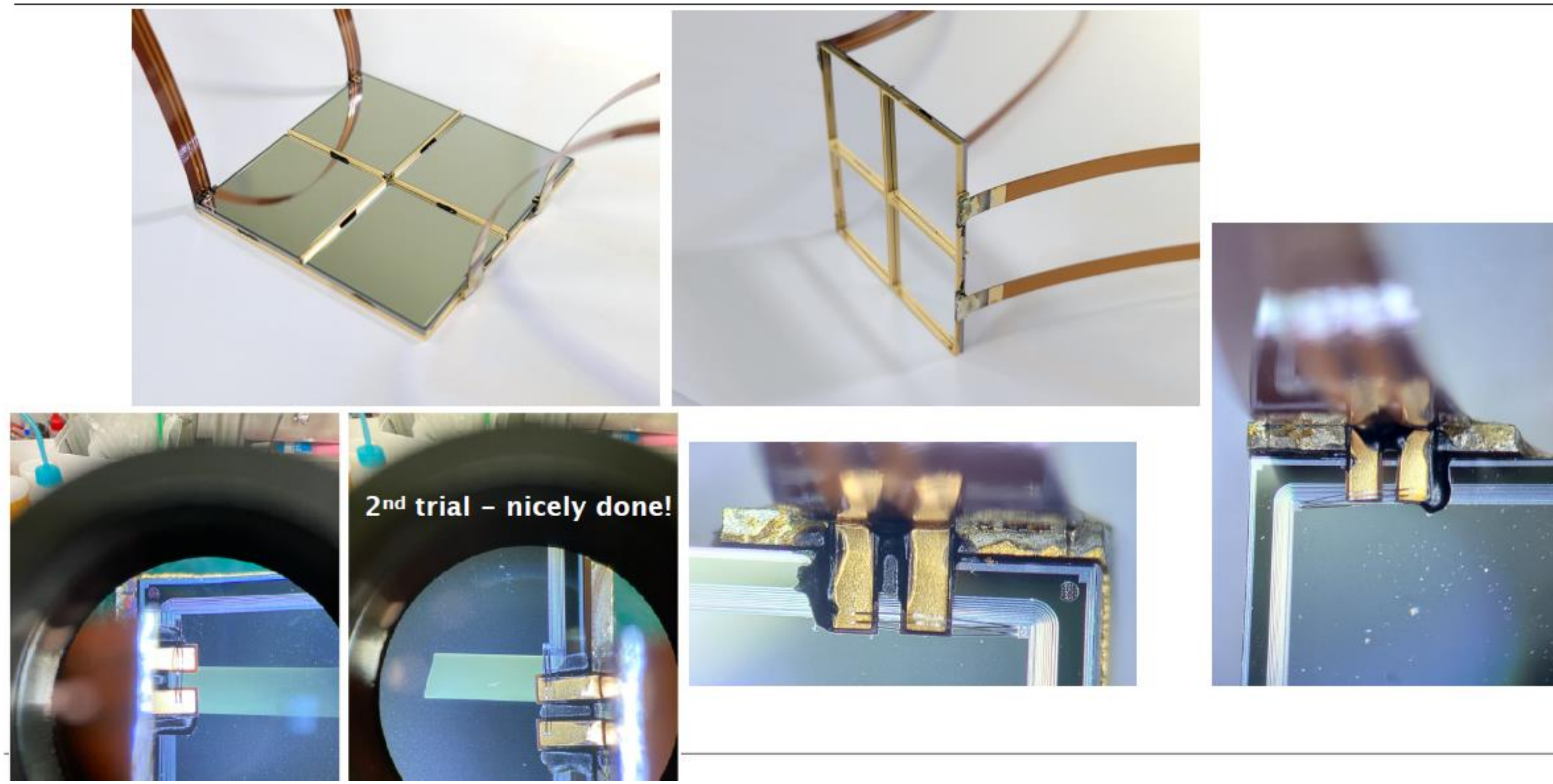
This initiative brings new developments towards simpler FAZIA block

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

Future developments

- 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

Conclusions

- For the forthcoming years the FAZIA collaboration is still involved at GANIL to complete our scientific program in relation with the study of the nuclear EoS with heavy ion reactions. (phase transition, symmetry energy, clustering effects…)
- INDRA was renewed completely and is operational as good as it was in 1993.
- More oriented structure experiments too (LISE ZDD, ACTAR, cluster sub-structure…)
- In the mean while radioactive beam facilities will start too (SPIRAL2, FRAISE, SPES…) and we would do some tests there too.
- In Korea the RAON project is starting as well. The goal here is to replicate the FAZIA set-up with many (at least 4) blocks (new electronics, new detectors…)

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30 anniversary of the first INDRA experiment at GANIL in 2023
=> Join the party

FAZIA publication and PhD lists

FAZIA publication list:

- H. Hamrita et al. NIM A 531 (2004) 607
- S. Barlini et al. NIM A 600 (2009) 644
- L. Bardelli et al. NIM A 602 (2009) 501
- L. Bardelli et al. NIM A 605 (2009) 353
- M. Parlog et al. NIM A 613 (2010) 290
- H. Hamrita et al. NIM A 642 (2011) 59
- L. Bardelli et al. NIM A 654 (2011) 272
- S. Carboni et al. NIM A 664 (2012) 251
- G. Pasquali et al. European Physics Journal A 48 (2012) 158
- N. Le Neindre et al. NIM A 701 (2013) 145
- S. Barlini et al. NIM A 707 (2013) 89
- S. Barlini et al. Physical Review C 87 (2013) 054607
- S. Piantelli et al. Physical Review C 88 (2013) 064607
- R. Bougault et al. European Physics Journal A 50 (2014) 47
- G. Pasquali et al. European Physics Journal A 50 (2014) 86
- A.J. Kordyasz et al. European Physics Journal A 51 (2015) 15
- F. Salomon et al. Journal of Instrumentation (2016) Vol. 11, JINST 11 C01064
- D. Gruyer et al. NIM A 847 (2017) 142
- G. Pastore et al. NIM A 860 (2017) 42
- S. Valdré et al. NIM A 930 (2019) 27
- C. Frosin et al. NIM A 951 (2020) 163018
- S. Piantelli et al. Physical Review C 101 (2021) 034613
- S. Piantelli et al. Physical review C 103 (2021) 014603
- A. Camaiani et al. Physical Review C 103 (2021) 014605
- C. Ciampi et al. Physical Review C 106 (2022) 024603
- C. Frosin et al. submitted to Physical Review C

PhD Thesis

- L. Bardelli (2005)
- H. Hamrita (2005)
- S. Carboni (2012)
- G. Pastore (2017)
- A. Camaiani (2019)
- P. Ottanelli (2019)
- J. Quicray (2021)
- C. Frosin (2021)
- C. Ciampi (2022)
- S. Upadhyaya (2022)
- J. Lemarié (2022)
- S.H. Nam (2023)
- T. Génard (2023)
- A. Rebillard-Soulié (2024)
- L. Baldesi (2025)
- A. Valente (2025)

http://fazia.in2p3.fr