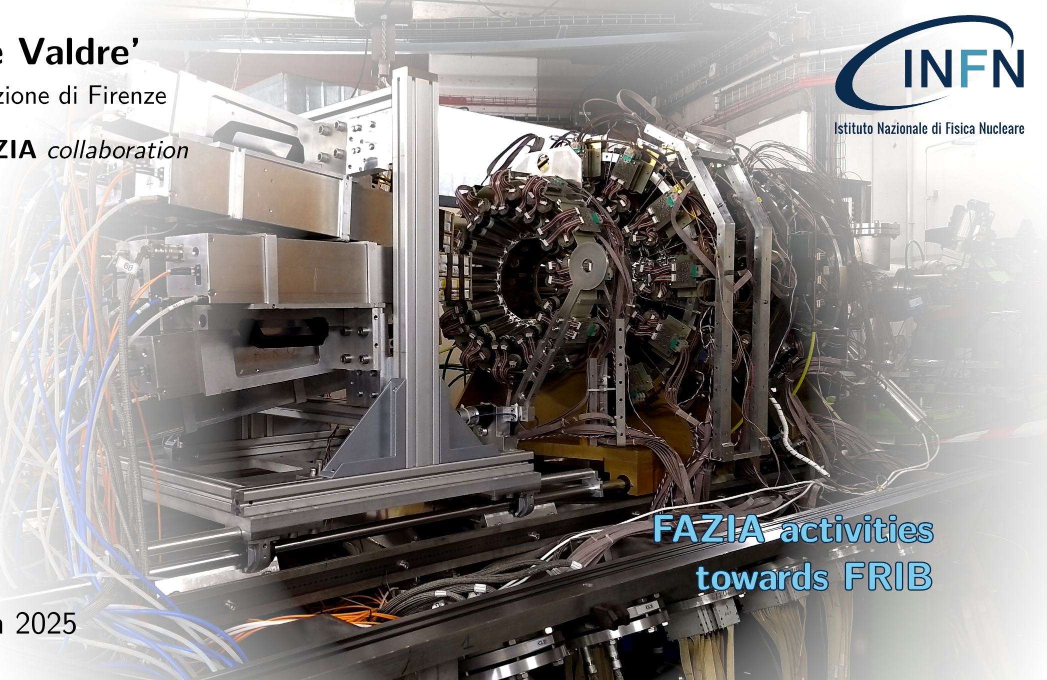
Simone Valdre'
INFN – Sezione di Firenze

for the **FAZIA** *collaboration*

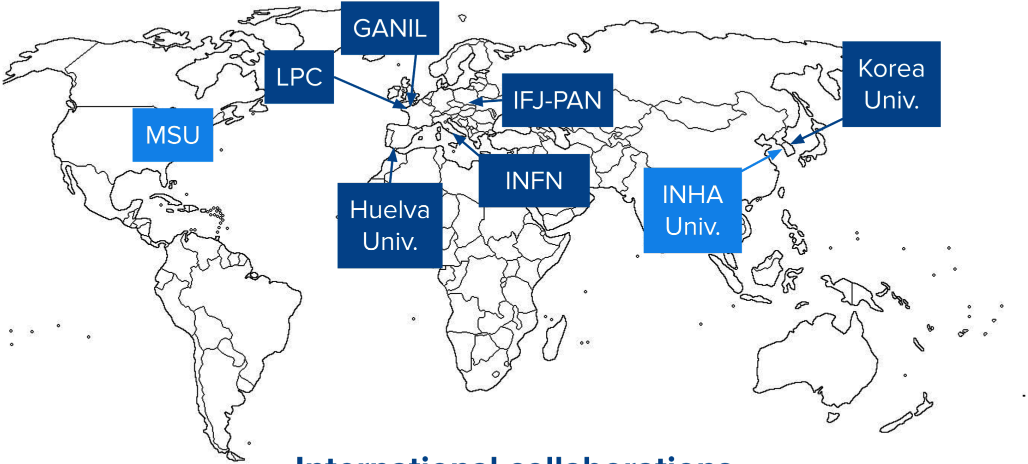
INFN
Istituto Nazionale di Fisica Nucleare



FAZIA activities towards FRIB

Caen,
June 26th 2025

FAZIA collaboration



International collaborations in FAZIA MoU or FAZIA related

Future of HIC

IN2P3 and INFN are going into the same direction

IRL-NPA

NUSDAF

Future of HIC

IN2P3 and INFN are going into the same direction

IRL-NPA

NUSDAF

⇓

Future of HIC is (also) at FRIB

SYMEOS initiative

Letter of Intent

INFN-NUSDAF (INFN - Nuclear Structure, Dynamics and Astrophysics at FRIB)

Giuseppe Verde[1], C. Agodi[2], M. Battaglieri[9], M. Bondì[1], M. Cavallaro[2], M. Colonna[2], D. Gambacurta[2], A. Gottardo[3], L. Lamia[4,2], S. Leoni[5,6], L. Marcucci[7] S. Pirrone[1], G. Pizzone[2,4], P. Russotto[2], S. Valdrè[8], J.J. Valiente[3], M. Viviani[7]

on behalf of the ASFIN, CHIRONE, EPIC, GAMMA, JLAB12, NUCL-EX, NUMEN, MONSTRE and NUCSYS groups of INFN (see Appendix 3 for detailed list of institutes)

Kyle Brown[10], Giordano Cerizza[10], Zbigniew Chajecki[11], Alexandra Gade[10], Dean Lee[10], Artemis Spyrou[10], Remco Zeger[10]

Local points of contact who agreed to collaborate and support these programs

[1]INFN Catania, [2]INFN Laboratorio Nazionali del Sud, [3]INFN Laboratori Nazionali di Legnaro, [4]University of Catania, [5]University of Milan, [6]INFN Milan, [7]INFN Pisa, [8]INFN Florence, [9]INFN Genova
[10]FRIB, Michigan State University, [11]Western Michigan University

SYMEOS initiative

Submitted to FRIB-PAC3

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INFN-NUSDAF (INFN - Nuclear Structure, Dynamics and Astrophysics at FRIB)

Six scientific initiatives

- *SYMEOS* EoS and E_{sym} with HIC
- *GASPEC* γ spectroscopy and Collective excitations
- *RIBDCE* RIB-induced Double Charge Exchange
- *NUSYC* NUcleoSYnthesis and Clustering
- *THEOF* THEOretical physics @ FRIB
- *SYSTERSE* SYnergic Stategy for future ElectRonics and Streaming rEadout solutions

SYMEOS initiative

Submitted to FRIB-PAC3

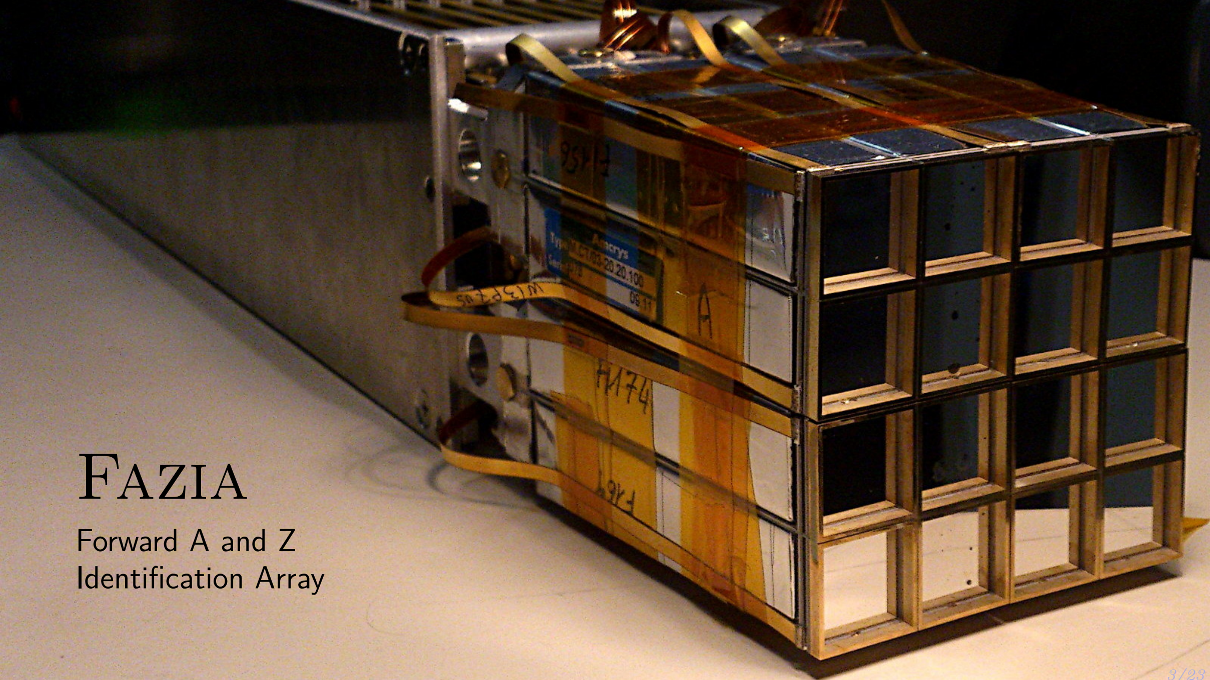
Letter of Intent

INFN-NUSDAF (INFN - Nuclear Structure, Dynamics and Astrophysics at FRIB)

Six scientific initiatives

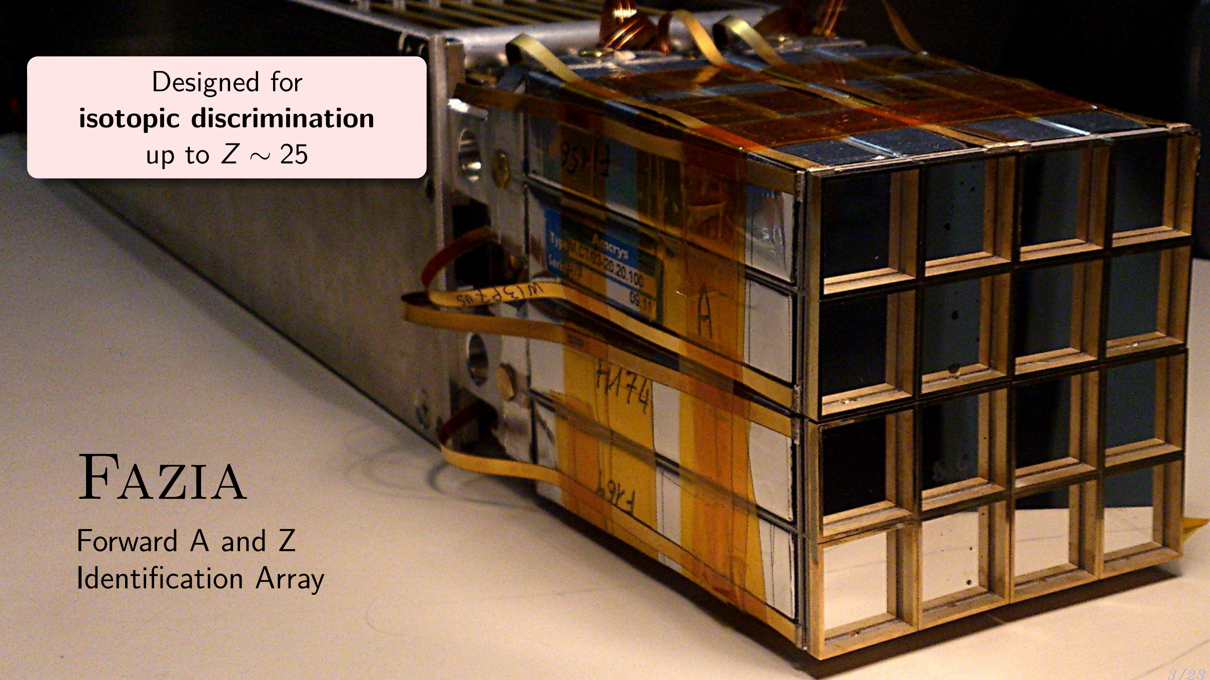
SYMEOS EoS and $E_{\rm sym}$ with HIC

more details already given by G. Verde's talk



Fazia

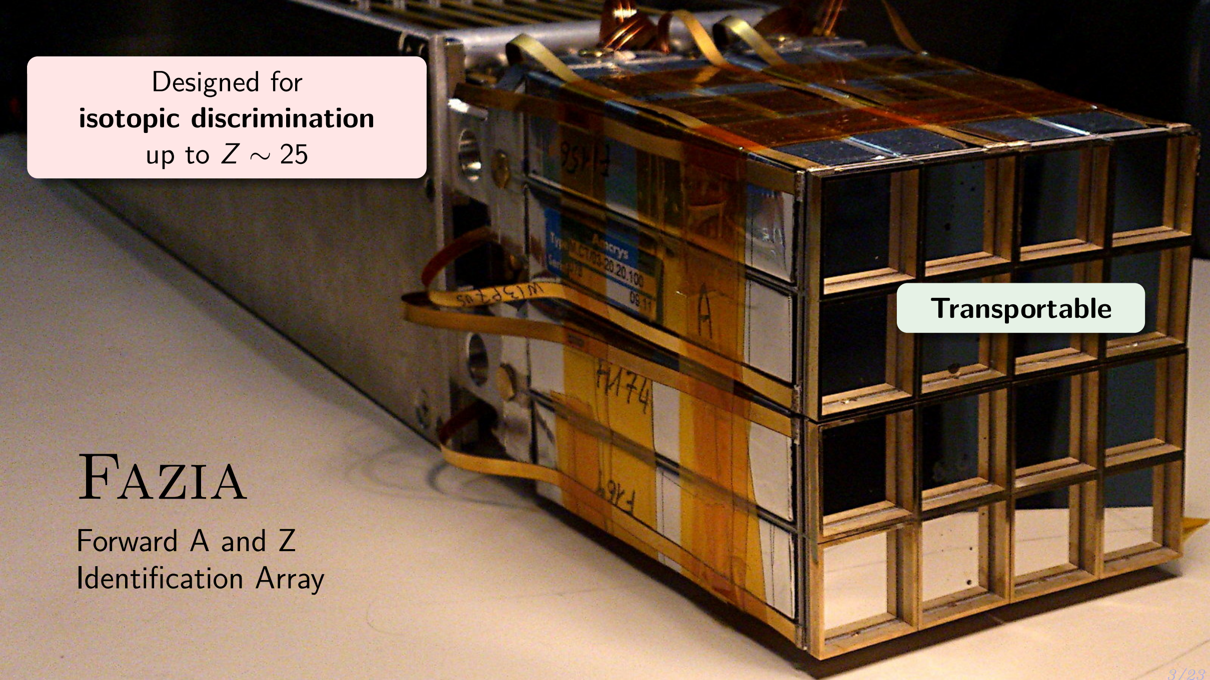
Forward A and Z
Identification Array



Designed for
isotopic discrimination
up to $Z \sim 25$

FAZIA

Forward A and Z
Identification Array



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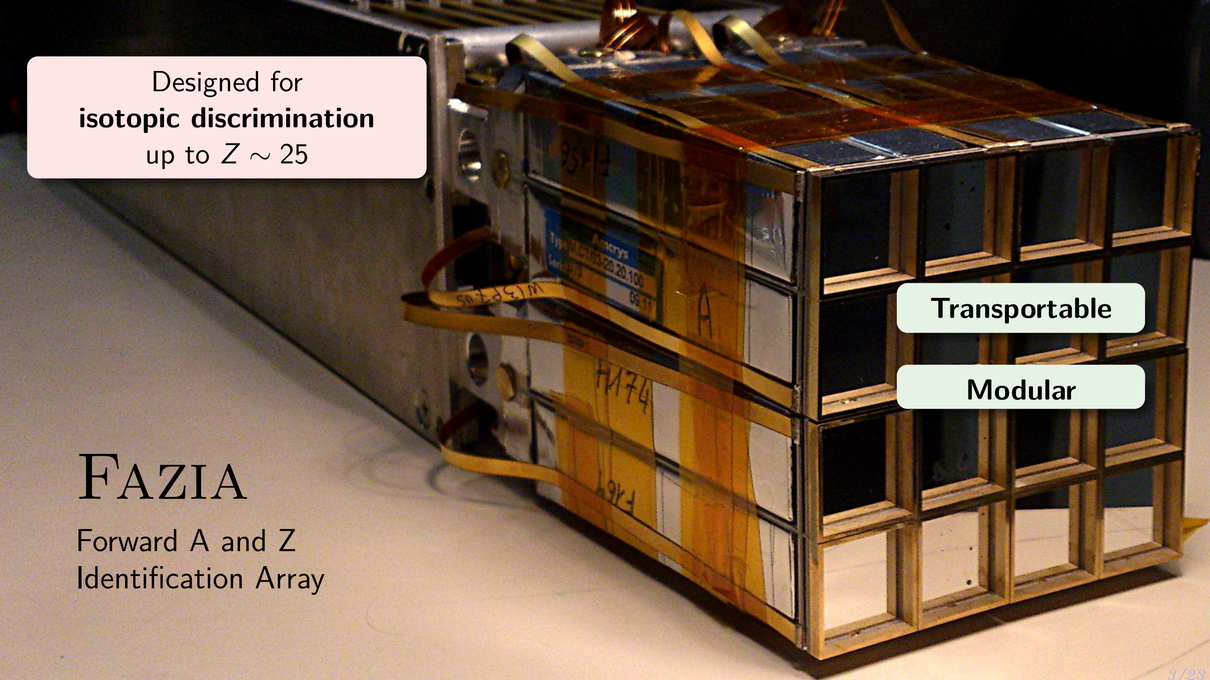

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Transportable

Modular

FAZIA

Forward A and Z
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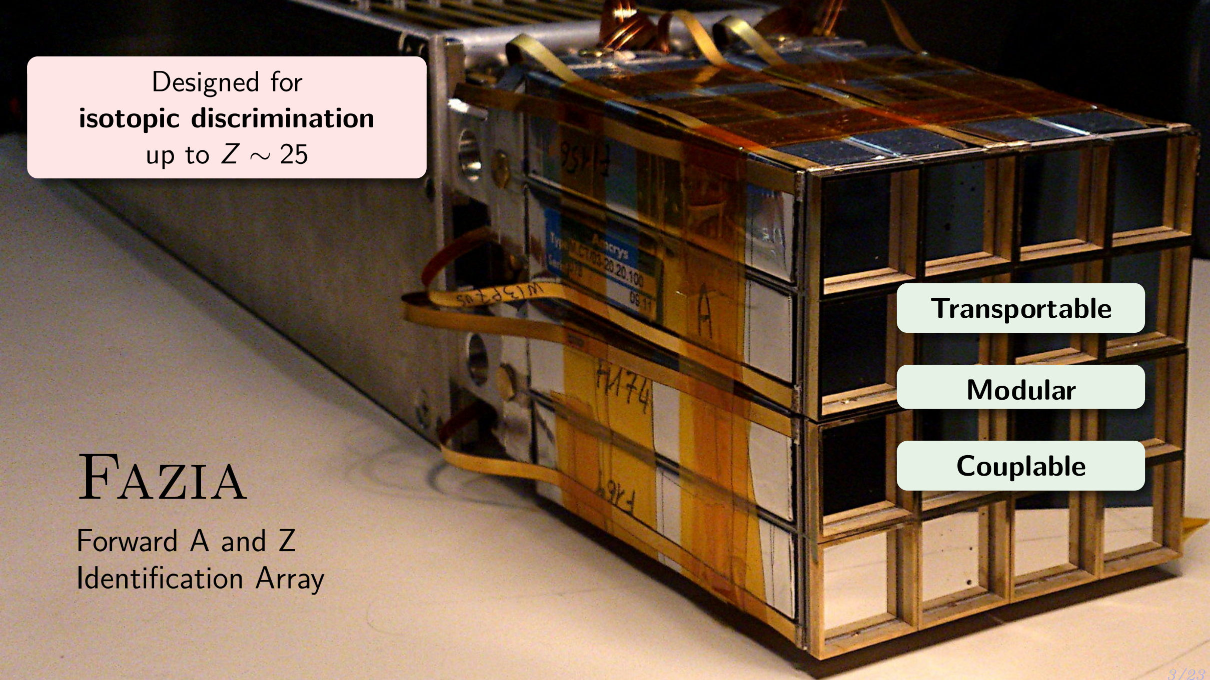

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Transportable

Modular

Couplable

FAZIA

Forward A and Z
Identification Array

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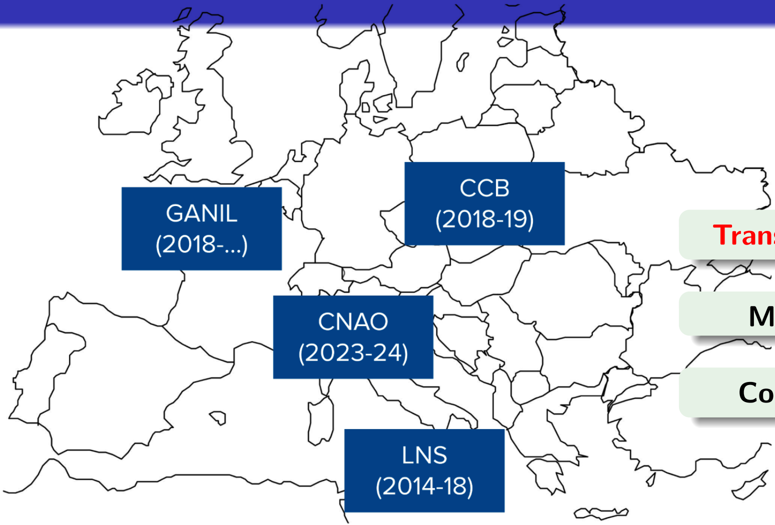


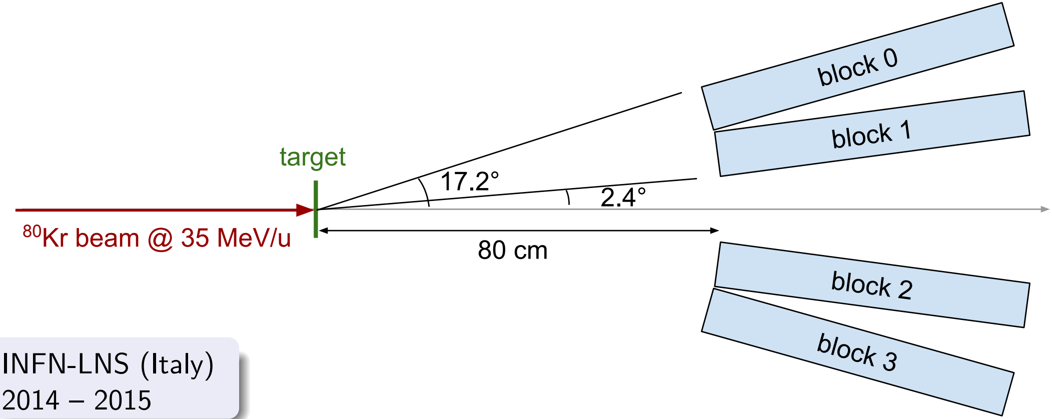
Transportable

Modular

Couplable

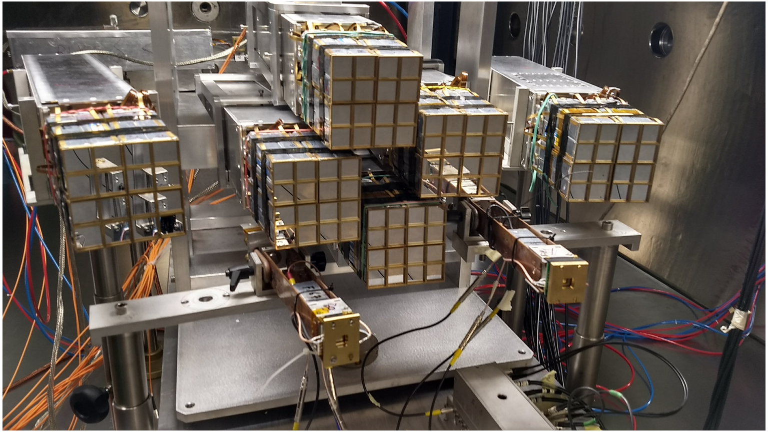
Laboratories where FAZIA measured so far

FAZIA modularity



INFN-LNS (Italy)
2014 – 2015

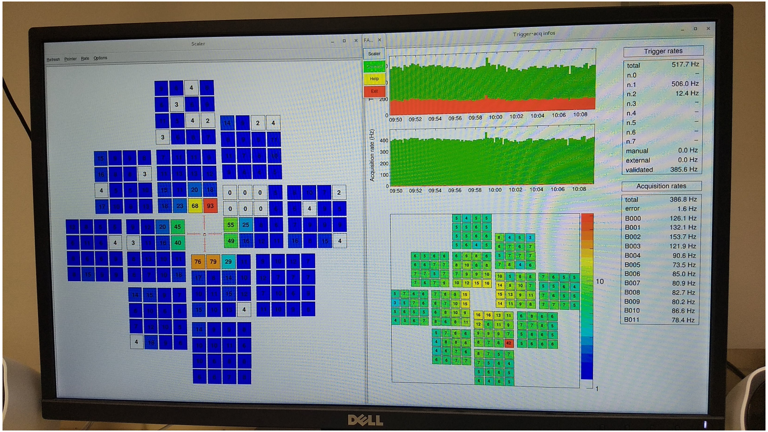
FAZIA modularity



INFN-LNS (Italy)
2016 – 2018

FAZIA modularity

GANIL (France)
2018 – today



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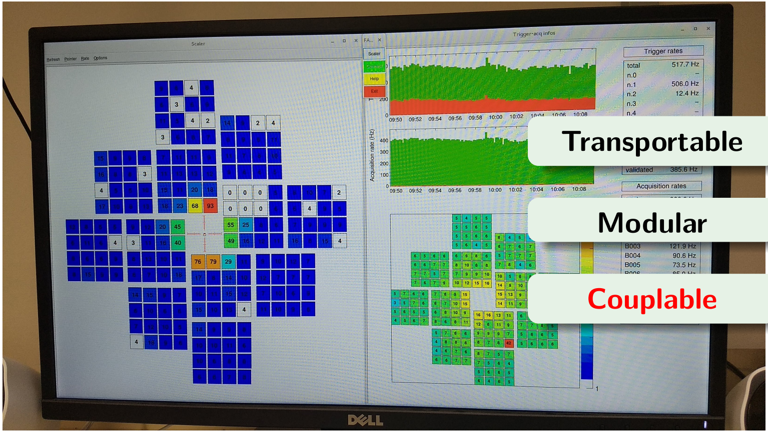
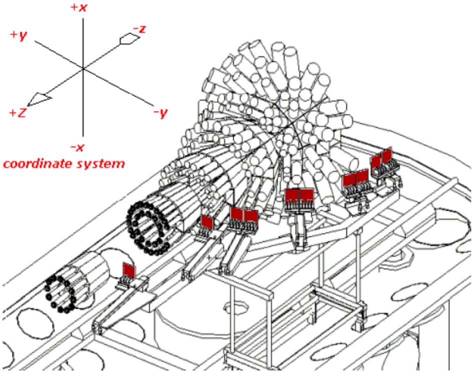


Transportable

Modular

Couplable

INDRA setup

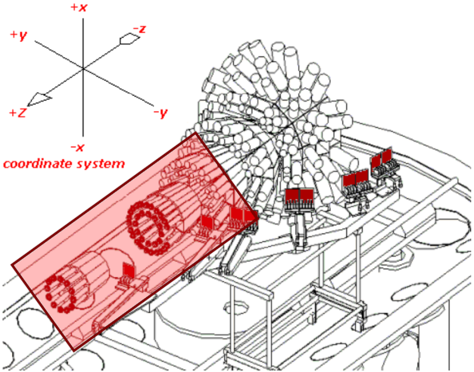


Original configuration (1992-2016)

- 90% of the solid angle covered
- 17 telescope rings (8-24 sectors per ring)
  - ring 1: IC + plastic scintillators
  - rings 2-9: IC-Si-CsI telescopes
  - rings 10-17: IC-CsI telescopes

J. Pouthas *et al*, Nucl. Instr. and Meth. A 357 (418), 1995

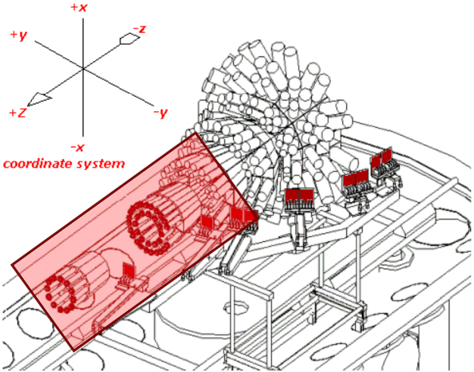
INDRA setup



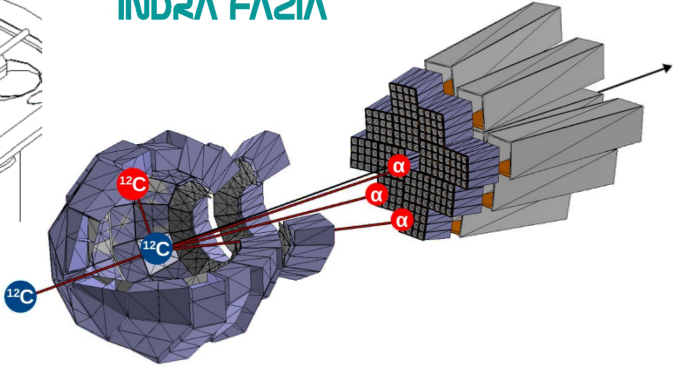
Present configuration (2017-today)

- FAZIA at forward angles!
- 12 telescope rings (8-24 sectors per ring)
  - rings 1-5: removed!
  - rings 6-9: IC-Si-CsI telescopes
  - rings 10-17: IC-CsI telescopes

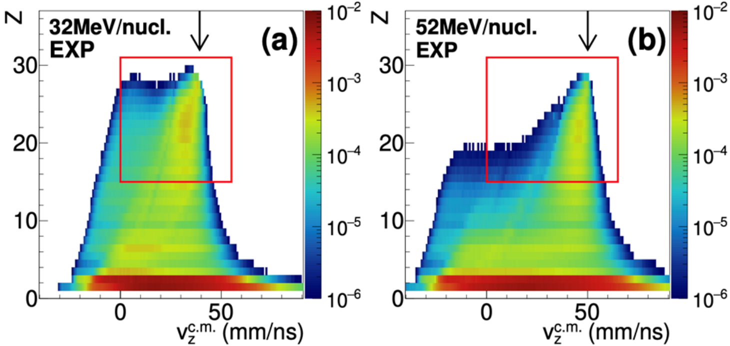
INDRA setup



INDRA FAZIA



Quasi-projectile "chemistry"



C. Ciampi *et al.* Phys. Rev. C **106**, 024603 (2022)

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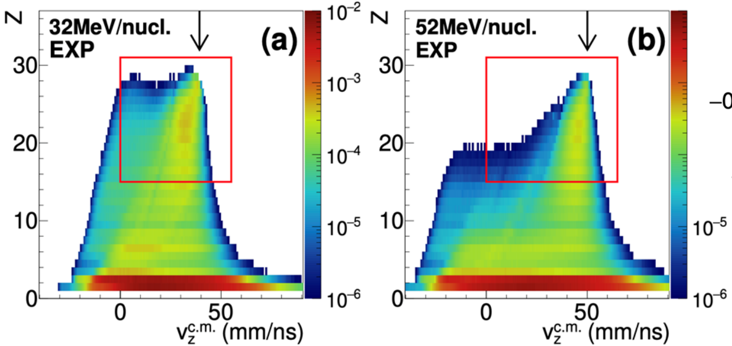
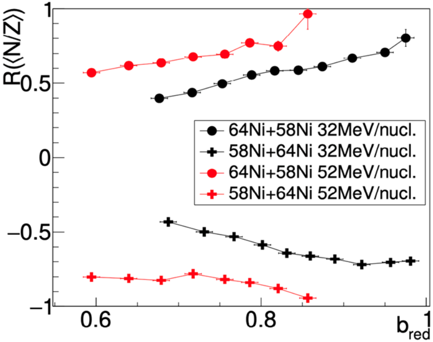




C. Ciampi *et al.* Phys. Rev. C **106**, 024603 (2022)

New results on Quasi-projectile breakup

Quasiprojectile breakup and isospin equilibration at Fermi energies: Potential indication of longer projectile-target contact times

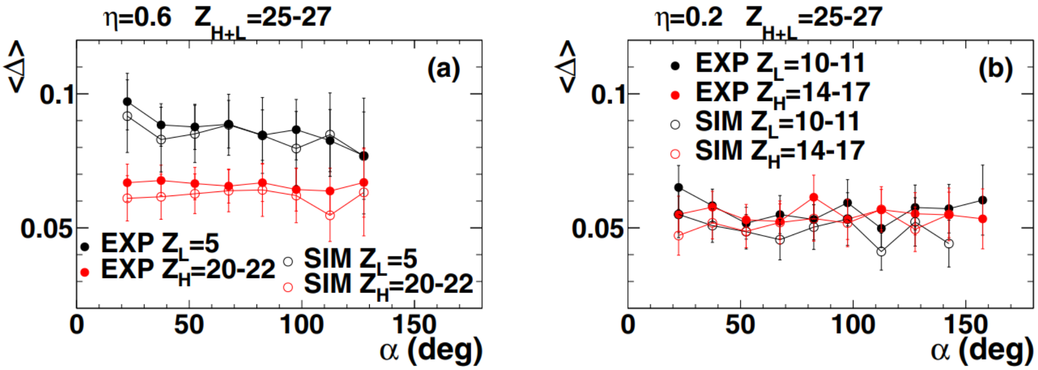
C. Ciampi [1,*], S. Piantelli [2], G. Casini [2], A. Ono [3], J. D. Frankland [1], L. Baldesi [2,4], S. Barlini [2,4], B. Borderie [5], R. Bougault [6] *et al.*
(INDRA-FAZIA Collaboration)

Show more

Phys. Rev. C **108**, 054611 – **Published 28 November, 2023**

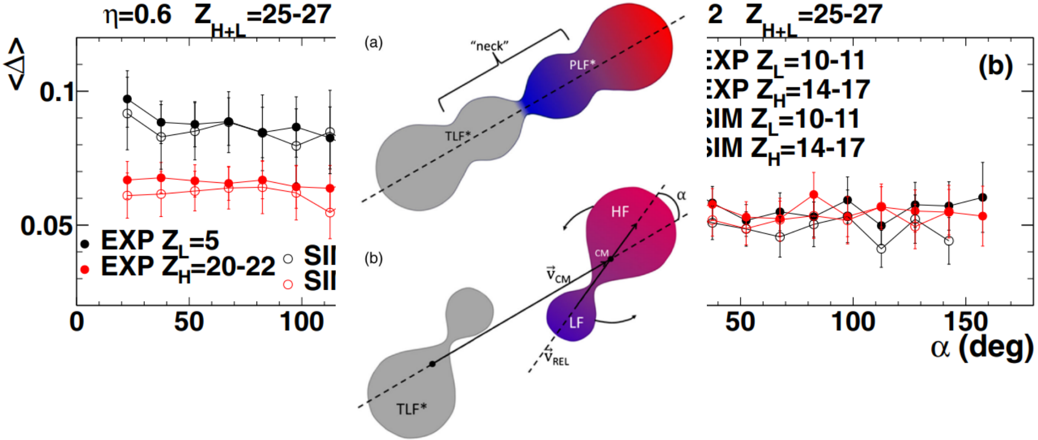
DOI: https://doi.org/10.1103/PhysRevC.108.054611

Quasi-projectile breakup



S. Piantelli *et al.* Phys. Rev. C **101**, 034613 (2020)
based on A. Jedele *et al.* Phys. Rev. Lett. **118**, 062501 (2017) and citations therein

Quasi-projectile breakup



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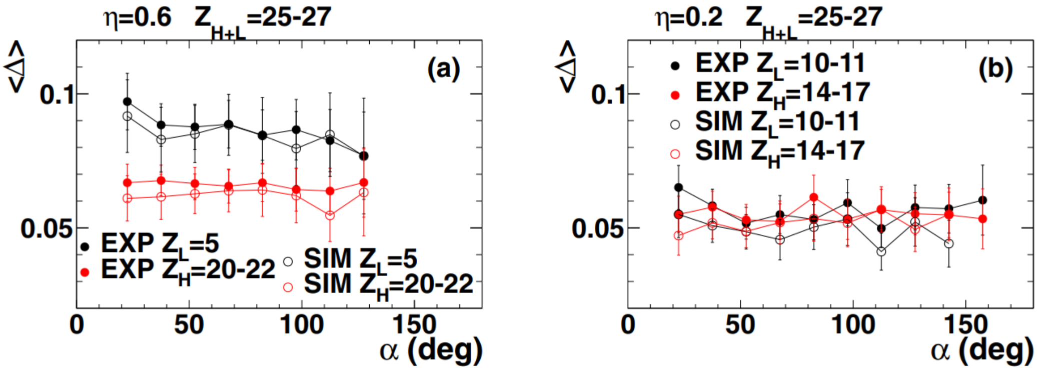
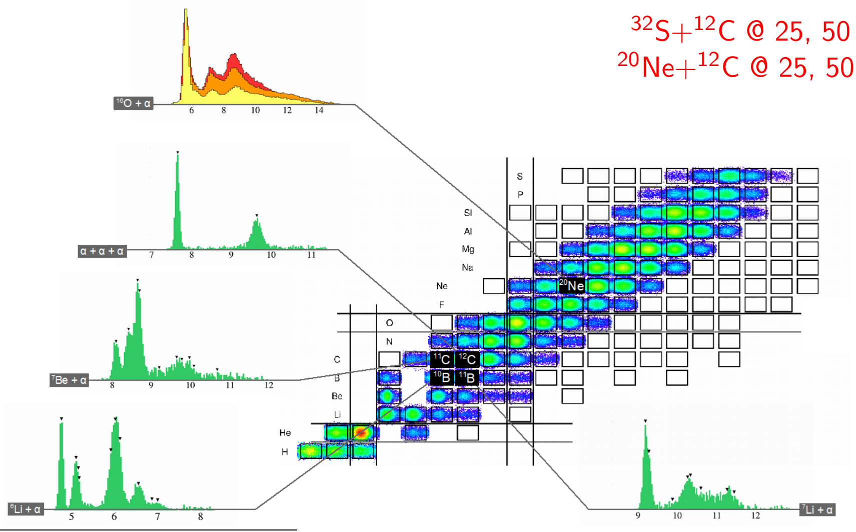


only 4 blocks (low statistics) but large-Z fragments could be isotopically identified

S. Piantelli *et al.* Phys. Rev. C **101**, 034613 (2020)
based on A. Jedele *et al.* Phys. Rev. Lett. **118**, 062501 (2017) and citations therein

Invariant mass spectroscopy

$^{32}S+^{12}C$ @ 25, 50 AMeV
$^{20}Ne+^{12}C$ @ 25, 50 AMeV



courtesy of D. Gruyer (FAZIACOR experiment)

FAZIA future

Present status

- FAZIA is a general purpose, modular and flexible apparatus
- almost full solid angular coverage achieved with INDRA+FAZIA coupling
- setup designed for **Fermi energies** (15–50 AMeV)

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Future at GANIL

There are still many physics cases to be explored

2 experiments just concluded in 2025!

1 experiment approved for 2026/27!

FAZIA future

Future challenges

Collaboration is planning to measure at higher energies (FRIB @ MSU) to explore the supra-saturation regime of the nuclear matter. We are considering many alternatives:

FAZIA future

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FAZIA future

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- **New block** design with the same FAZIA acquisition protocols

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FAZIA technology will be fundamental for the future developments

New observables

The next years will be crucial to find how to access observables to constraint EoS parameters with radioactive beams

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NUSDAF LoI proposals:

- Neutron and proton flow parameters
- Isospin diffusion, stopping and transparency
- Pygmy Dipole Resonances
- Femtoscopy
- Invariant Mass Spectroscopy

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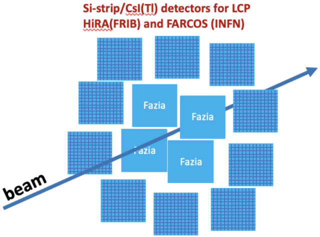
Femtoscopy and Invariant Mass Spectroscopy

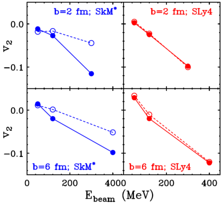
Experimental conditions

- medium charge ($Z < 30$) radioactive beam, close to the proton-drip line, on a light target
- decay by one or two-proton emission from its loosely bound ground state
- useful information on the structure, e.g. the one- or two-proton separation energies



- protons detected by silicon strips array (HiRA and/or FARCOS)
- heavier residue can be identified by FAZIA blocks
  - also providing a measurement of kinetic energy and angle

Simultaneous measurement of multiple observables



Elliptic flow

Flow parameters of free neutron and proton emissions are among the most sensitive probes of the symmetry energy

Choice of reactions in order to enhance isospin asymmetries

- ^{54,56}Ni+^{58}Ni and ^{70}Ni+^{64}Ni at $E/A = 150$ — 400 MeV
- ^{106}Sn+^{112}Sn and ^{132}Sn+^{124}Sn at $E/A = 150$ — 400 MeV

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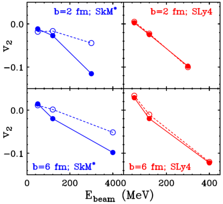

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at the same time FAZIA-like blocks can measure projectile spectators (extension of topics already measured at Fermi energies)

- breakup of projectile spectators
- isospin diffusion

FAZIA @ 23058

- As a first test, FAZIA will measure at FRIB coupled with other apparatuses
- We started a 2-weekly technical meeting cycle to prepare the setup

Mechanics

- The scattering chamber is too small to host FAZIA
- A "nose" will be build to host a FAZIA block at 80 cm distance from target
- Another block will measure in air, outside the chamber

DAQ and electronics

- FRIB experts received the full description of the FAZIA data flow protocol
- FAZIA data will be merged with other setups and handled by FRIB people
- independent acquisition to store FAZIA data in the old format

Developing a new detector. . .

- SYMEOS phase 2 will need **new kind of detectors**, optimized for FRIB energies
- Supra-saturation experiments will produce a broad variety of ejectiles:
  - Very energetic light particles from the fireball
  - Moderately excited fragments from spectator fragments
  - Very slow particles and fragment from spectators in peripheral collisions

Proposed solution in the LoI

- setups constituted by coupling INFN detector systems to equipment already operating at FRIB
- FAZIA upgrade without re-designing a new apparatus from scratch!
- complex setup which may introduce a bias

Developing a new detector...

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AZIMUTH solution

- A single apparatus with capabilities typical of correlators, $\Delta E - E$ telescopes, and particle trackers
- **Modular** and **portable** setup, capable to measure fragments emitted in collisions at E/A from 15 to 500 MeV/u
- Less bias (also thanks to **streaming readout** acquisition)

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European Research Council
Established by the European Commission

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- Less bias (also thanks to **streaming readout** acquisition)
- ~~Project submitted to ERC-CoG 2025!~~ **not funded!**

Even if not funded by ERC, we still may think to build
a FAZIA/AZIMUTH-like setup
for future measurements at FRIB and FAIR.

More details on the proposed AZIMUTH detector
could be found in my talk at previous FAZIAdays (March 12th, 2025)
and in “S. Valdré, J. Inst. **20**, C06060 (2025)”
I will summarize here the main characteristics.

AZIMUTH solution

A and Z Identification

the detector shall discriminate **in charge and mass** ions in a broad range of energies to guarantee the best isotopic discrimination ever achieved for a telescope-based detector

Modular

several telescope configurations shall be available, all of them with the **same connection standard** to front-end electronics and with the **same data acquisition protocol**

Universal

the apparatus shall be **multipurpose**, apt to measure multiple observables at the time, **couplable with other detectors**, and it shall also be used with a large variety of beams

Tracking Hodoscope

the telescopes shall implement **particle tracking** features through the layers in order to maximize the efficiency of light and energetic particle identification

AZIMUTH challenges

Main obstacles are related to fast particles energy loss profile

Energy straggling

energy loss of ions inside materials happens through a series of scatterings. The more interactions we have, the large variance in energy loss (straggling) we get[a]

[a] S. Kumar and P. K. Diwan, J Radiat Res Appl Sci **8**, 538 (2015)

Incomplete energy deposition (IED)

as ions react inside large volume crystals, or they scatter, punching-through the crystal surfaces, identification isn't feasible anymore[b]

[b] C. Frosin *et al.*, Nucl. Instrum. Meth. A **951**, 163018 (2020)

Tracking features

Energy loss + position tracking

- "multiple ΔE" measurement to track particle energy loss among layers
- position tracking thanks to SSSSD (or pixel detectors)

A lot of information per event to be analyzed by a neural network:

- training with simulation of reactions and elastic scattering inside sensors
- **reconstruction of trajectories**
- **reconstruction of original particle** E, Z, A

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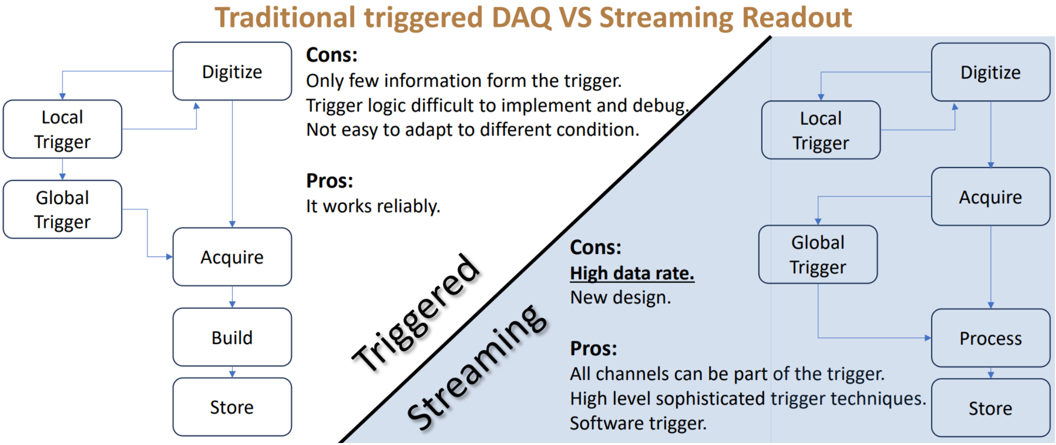
FAZIA

- 1x position (telescope)
- up to 3x partial energy release (Si-Si-CsI)

AZIMUTH

- up to 3x positions (3 stacked modules)
- up to 9x partial energy release (Si-Si-CsI-Si-Si-CsI-Si-Si-CsI)

Streaming readout



picture from F. Rossi's talk at SRO-XII workshop (2024)

Streaming readout

Streaming Readout Workshop SRO-XII

02–04 dic 2024
University of Tokyo
Asia/Tokyo fuso orario

Increased interest to SRO!
CERN, EIC, **JLAB**, **FRIB**, and SPADI alliance (Japan) involved

MSU-JLab Streaming Data Acquisition System Meeting

12 febbraio 2025
JLAB
US/Eastern fuso orario

AZIMUTH future

AZIMUTH

- **Telescope** approach + **tracking** features
- Position sensitive - good for **correlations**
- Designed for **elliptic flow** measurements and **invariant mass spectroscopy**
- Good for FRIB, but also for FAIR (full setup) or low energy Spiral2, SPES, and **LNS-FRAISE** beams (1- or 2-module blocks)

Next steps

- Start testing of sensor layers and tracking algorithms
- Improve the design after first FRIB experiments
- Strengthen sinergies among HIC collaborations

FRIB timeline

- IN2P3 created the IRL-NPA facility
- 9 INFN programs submitted a LoI which received appreciation by the PAC

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- A MoU between INFN and FRIB is currently been written
- Preparation of experiment 23058 is ongoing
- Implementing streaming readout acquisition
- Many plans for future detectors:
  - AZIMUTH / FAZIA-like detector
  - a new TPC

INDRA FAZIA

Thanks for your attention

Backup slides

Il telescopio FAZIA

The telescope stages

1. 300 µm reverse-mounted Si detector;
2. 500 µm reverse-mounted Si detector;
3. 10 cm CsI(TI) cristal read by a photodiode.

Il telescopio FAZIA

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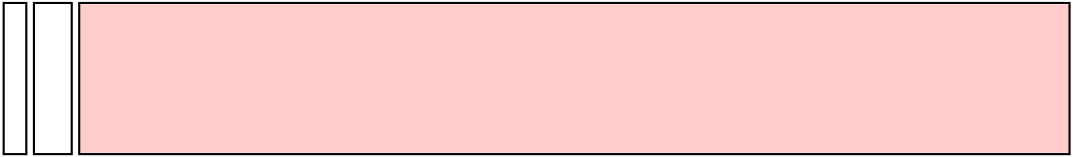

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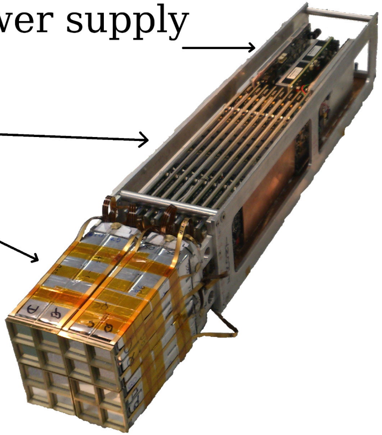
To achieve the best possible energy resolution and A and Z identification Si detectors come from a nTD ingot cut at random angle to avoid channeling effects.

R. Bougault *et al.*, Eur. Phys. J. A **50**, 47 (2014)

The FAZIA block



Transportable

Modular

Couplable

***16 telescopes**, together with **front-end electronics**,*
*form a **block** operating in **vacuum**.*

FAZIA front-end electronics

- Analogue chain: charge preamplifiers and anti-aliasing filters
- Signals are immediately digitized with **14-bit** ADCs:
  - on-line processed on FPGAs
  - energy resolution is better than 1 %
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S. Valdré *et al*, Nucl. Instr. and Meth. A 930 (27), 2019

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- Very good isotopic discrimination capabilities
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