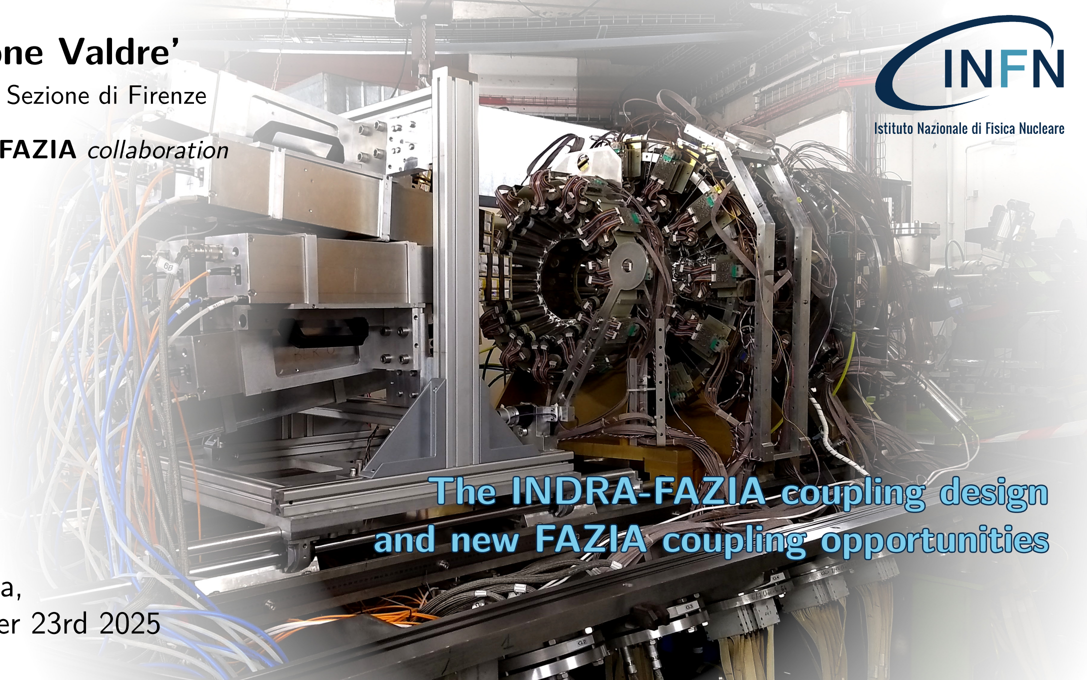
Simone Valdre'

INFN – Sezione di Firenze

for the **FAZIA** *collaboration*

INFN

Istituto Nazionale di Fisica Nucleare

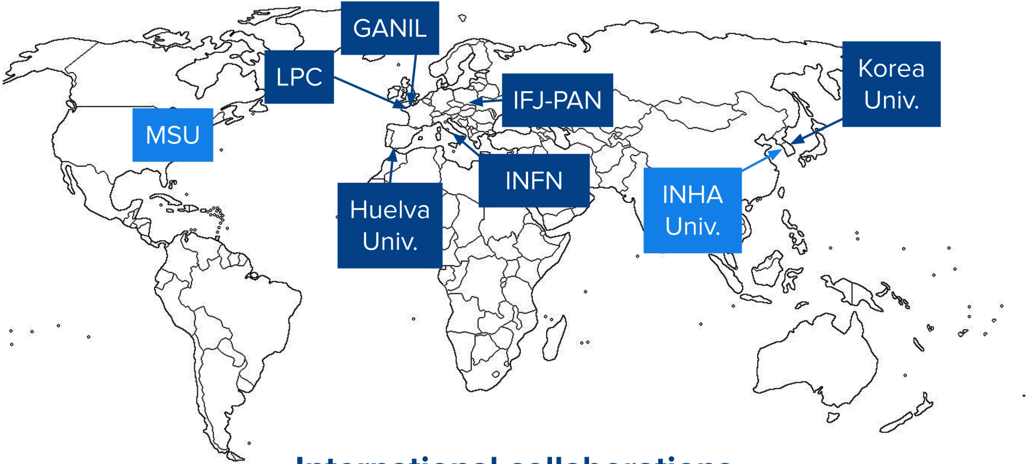


The INDRA-FAZIA coupling design and new FAZIA coupling opportunities

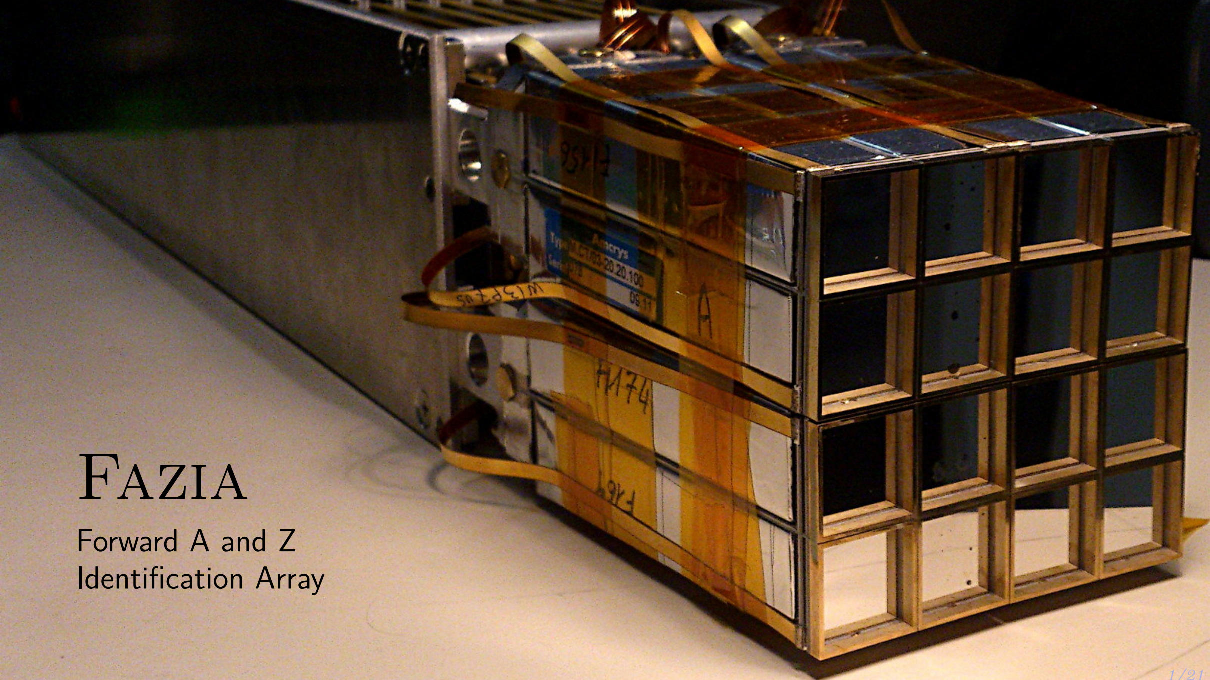
Catania,

October 23rd 2025

FAZIA collaboration

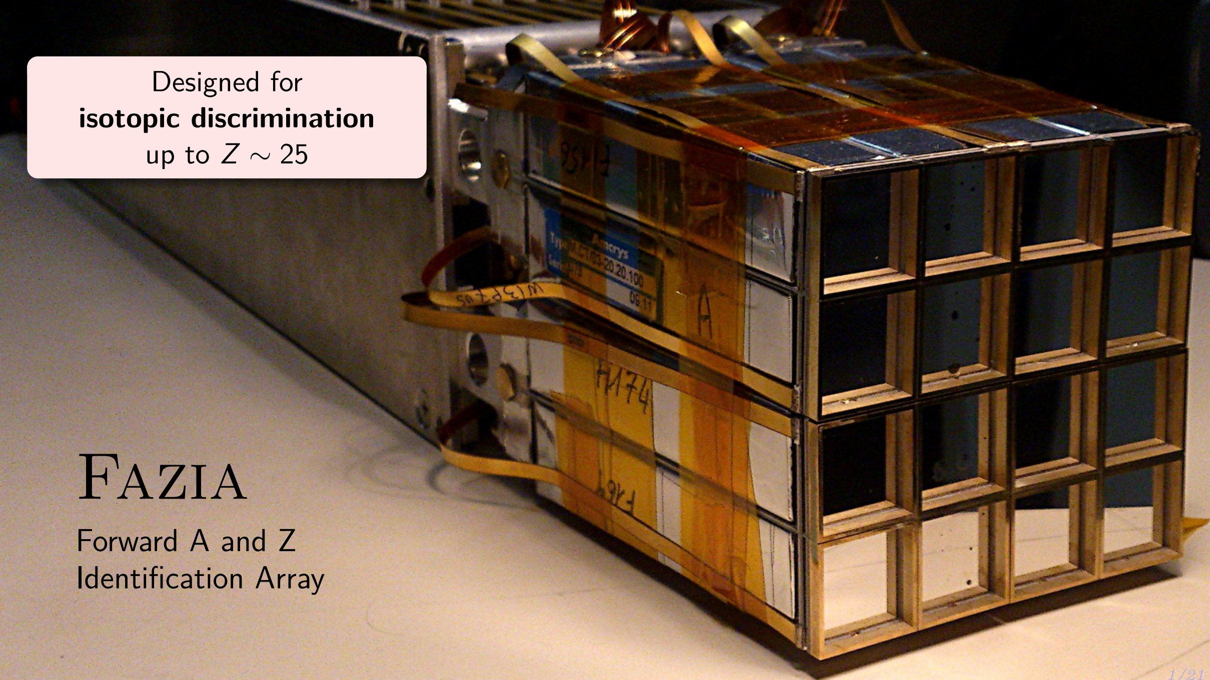


International collaborations in FAZIA MoU or FAZIA related



Fazia

Forward A and Z
Identification Array



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

FAZIA

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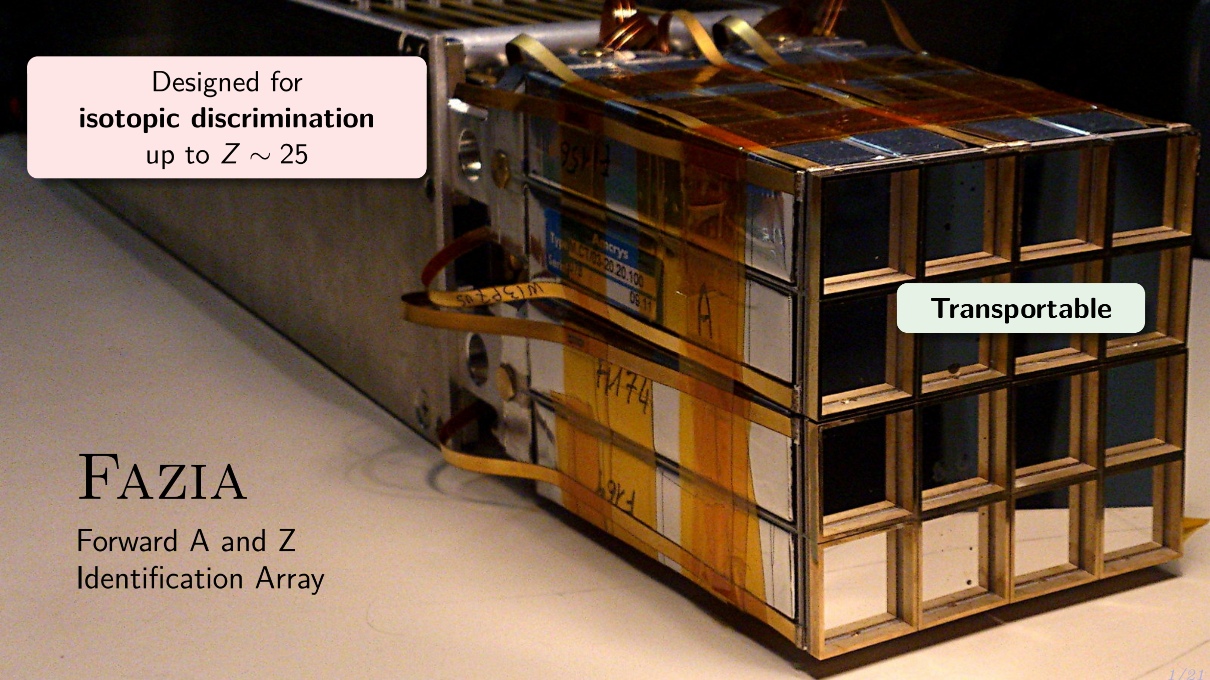

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FAZIA

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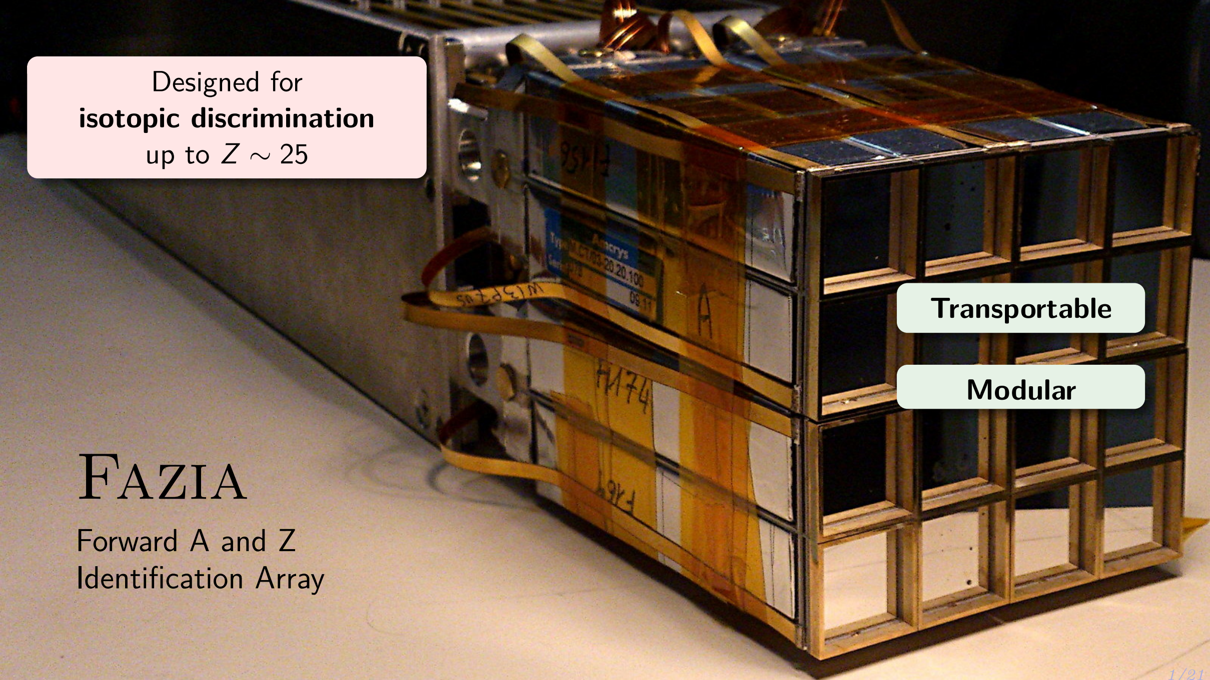

Designed for
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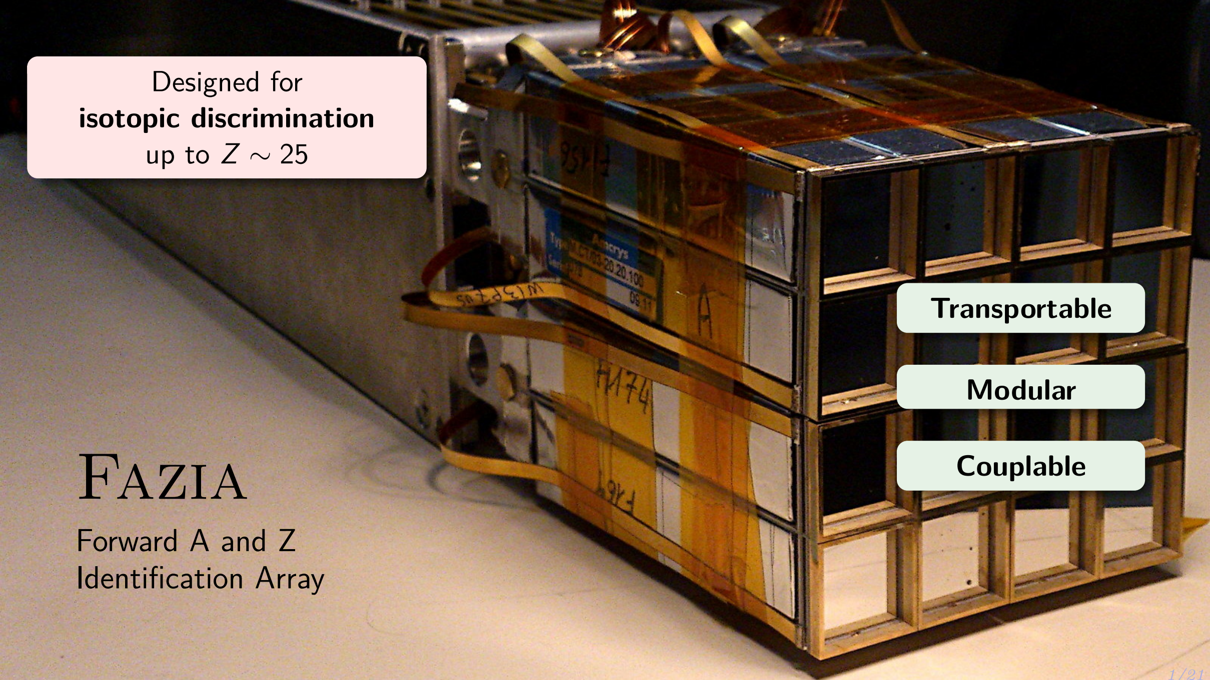
Transportable

Modular

Fazia

Forward A and Z
Identification Array



Designed for
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Transportable

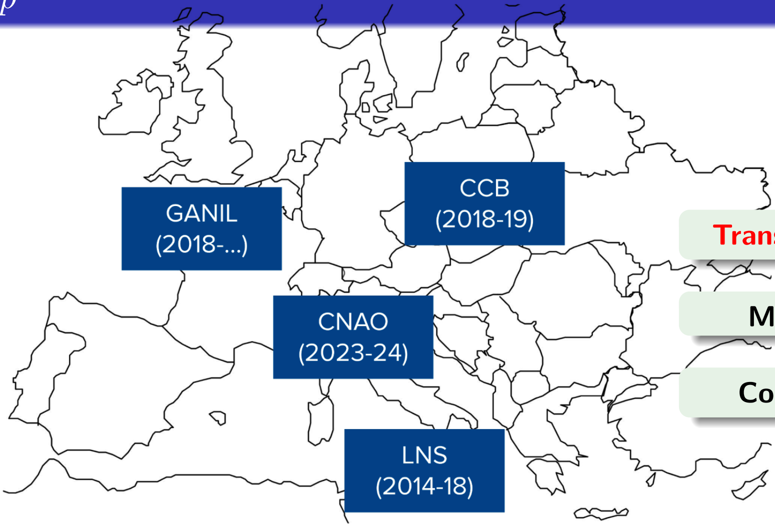
Modular

Couplable

FAZIA

Forward A and Z
Identification Array

FAZIA setup



Laboratories where FAZIA measured so far

- **Transportable**
- **Modular**
- **Couplable**

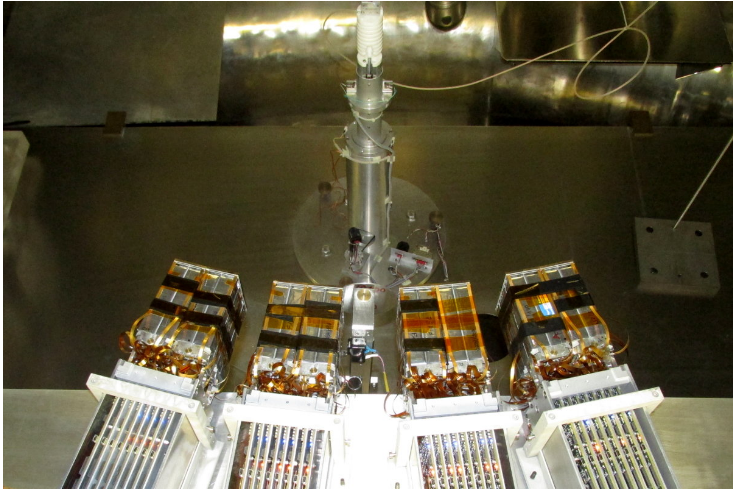
FAZIA setup

Transportable

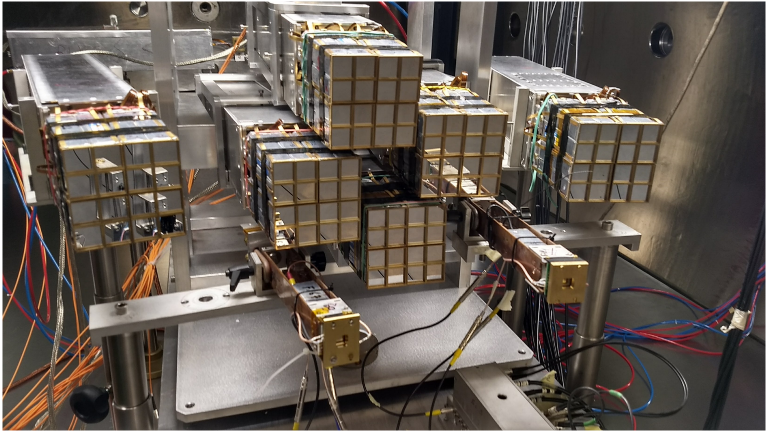
Modular

Couplable

INFN-LNS (Italy)
2014 – 2015



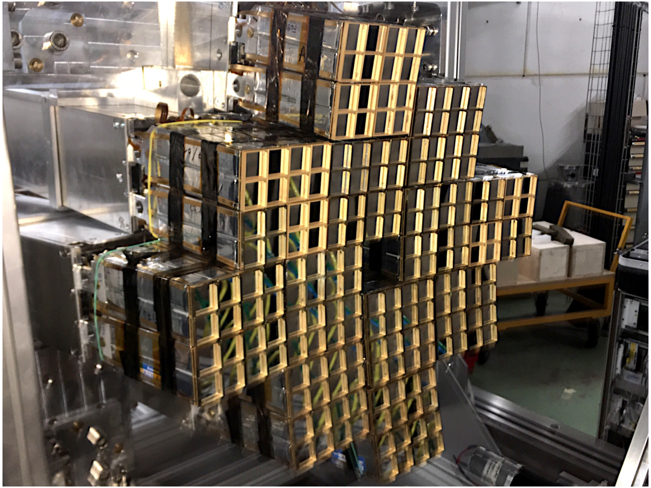
FAZIA setup



INFN-LNS (Italy)
2016 – 2018

FAZIA setup

GANIL (France)
2018 – today



FAZIA setup

GANIL (France)
2018 – today

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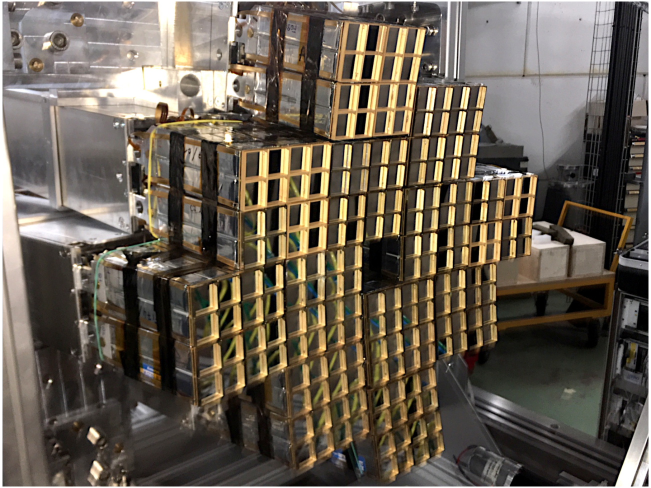
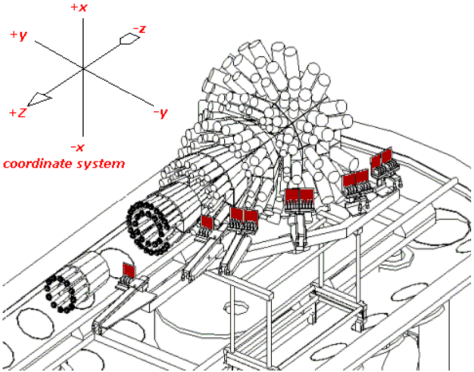


INDRA setup

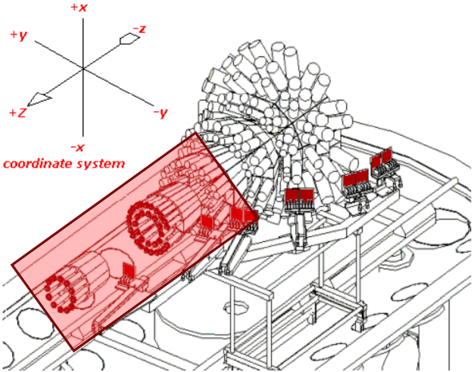


Original configuration (1992-2016)

- 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

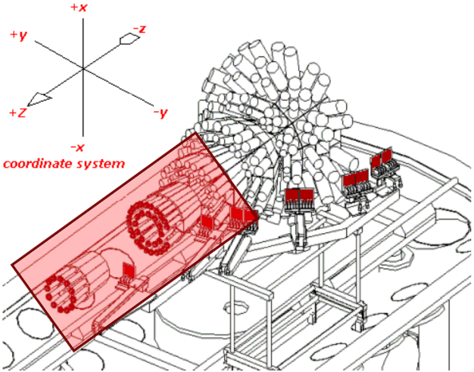
INDRA setup



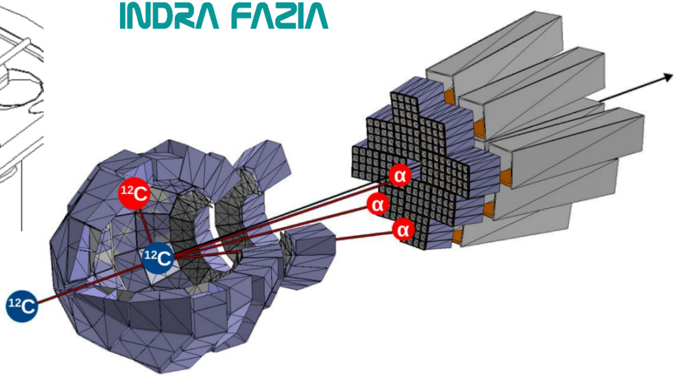
Present configuration (2017-today)

- 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

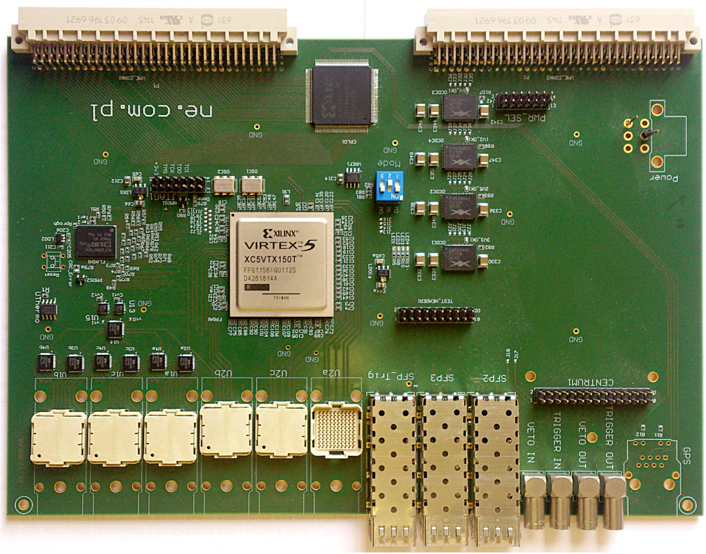
INDRA setup



INDRA FAZIA



Regional board



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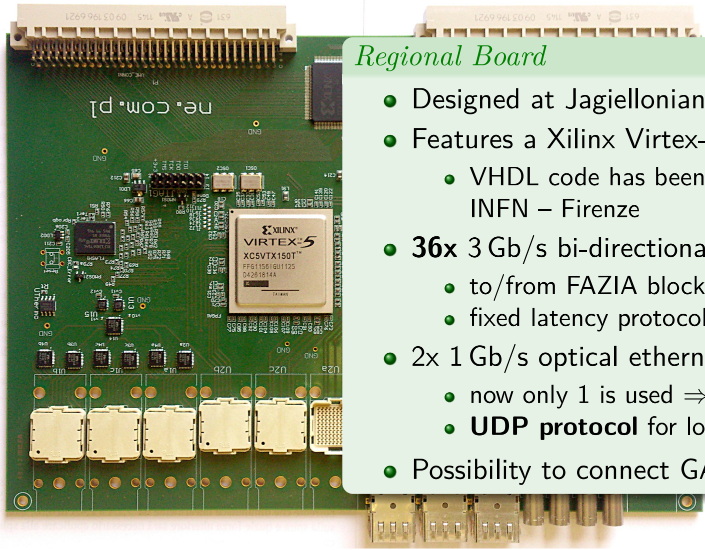

Regional Board

- Designed at Jagiellonian University, Krakow
- Features a Xilinx Virtex-5 FPGA
  - VHDL code has been written mainly at INFN – Napoli and INFN – Firenze
- **36x** 3 Gb/s bi-directional optical links
  - to/from FAZIA blocks
  - fixed latency protocol
- 2x 1 Gb/s optical ethernet links (1000Base-SX)
  - now only 1 is used ⇒ room for transmission speed increase
  - **UDP protocol** for low-latency transfer
- Possibility to connect GANIL **CENTRUM** module

Regional board

Regional Board tasks

- **Slow control** management of all the electronics
  - data transmission and slow control use the same optical fibre
- **Trigger board**:
  - multiple majority logic for trigger validation
  - trigger scaling by a settable factor
  - asynchronous or master/slave trigger operation (for coupling)
- **Event building** from data coming from all the blocks
  - it may add the CENTRUM timestamp to each event
- **Transmission** of acquired data to servers
  - maximum speed achieved: ~ 80 MB/s (~ 640 Mb/s)

Coupling with other apparatuses

FAZIA – INDRA coupling

FAZIA modularity makes coupling easy:

- CENTRUM[1] modules could be used for coupling
- FAZIA – INDRA coupled since 2018!

[1] developed at GANIL, Caen

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- Master/slave (common dead time)
- **Asynchronous mode (keeping common dead time)**

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CENTRUM operation

1. **Validation received** from one or both detectors
2. **Timestamp given** to both detectors

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- data merging using NARVAL[2]

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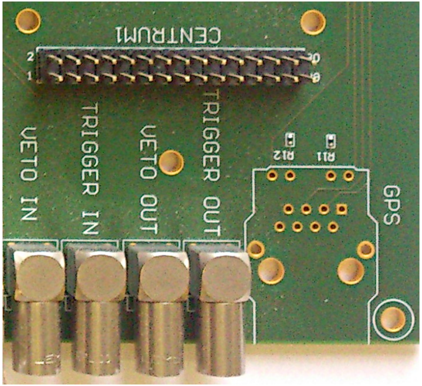
2. **Timestamp given** to both detectors

[1]developed at GANIL, Caen
[2]developed at IPN, Orsay

Trigger coupling (preserving common dead time)



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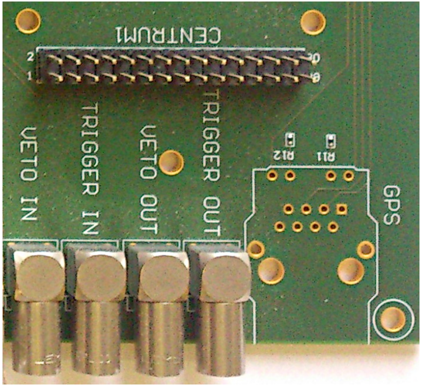

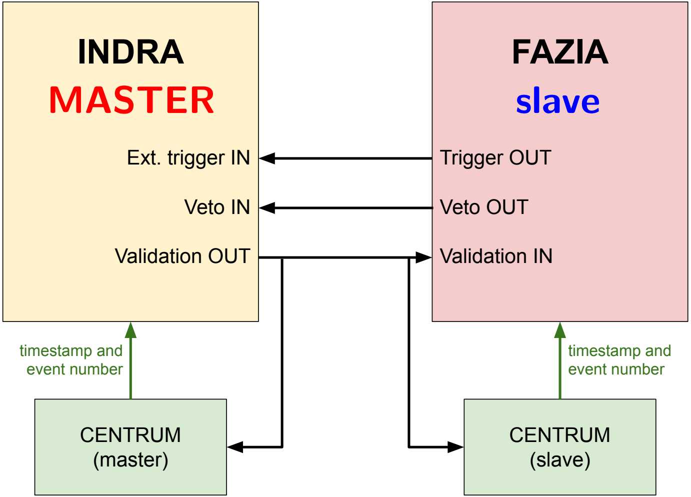

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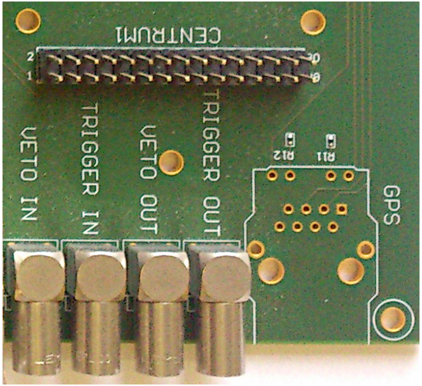
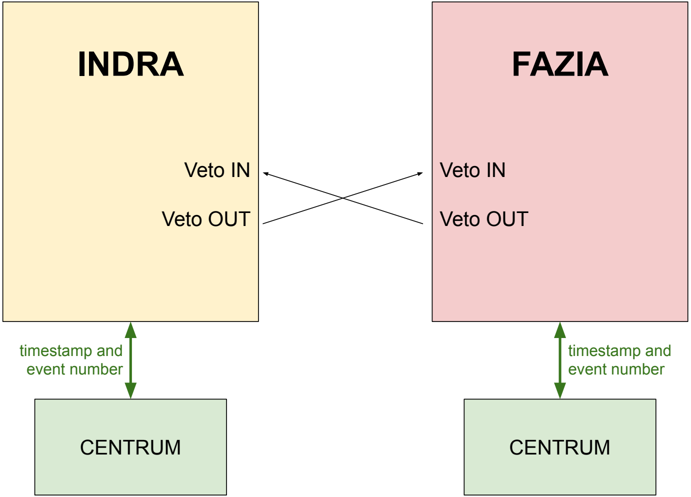
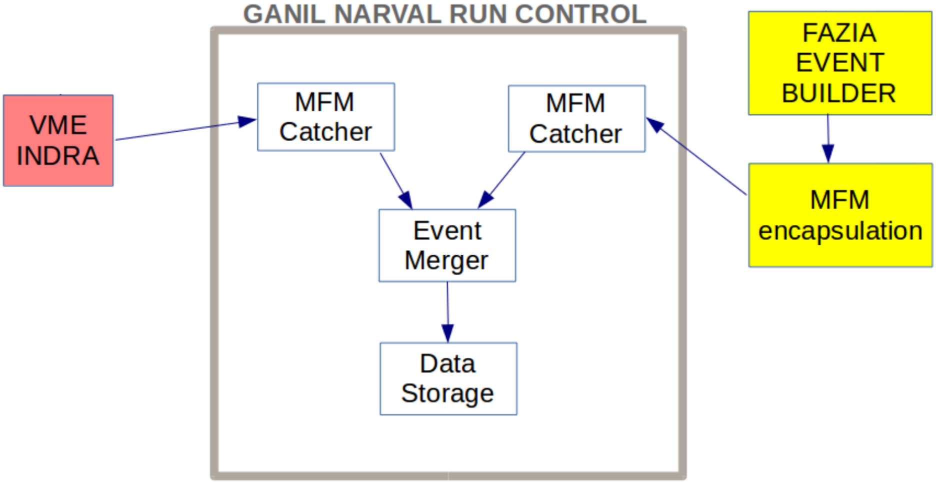




Asynchronous triggering

Data merging with NARVAL

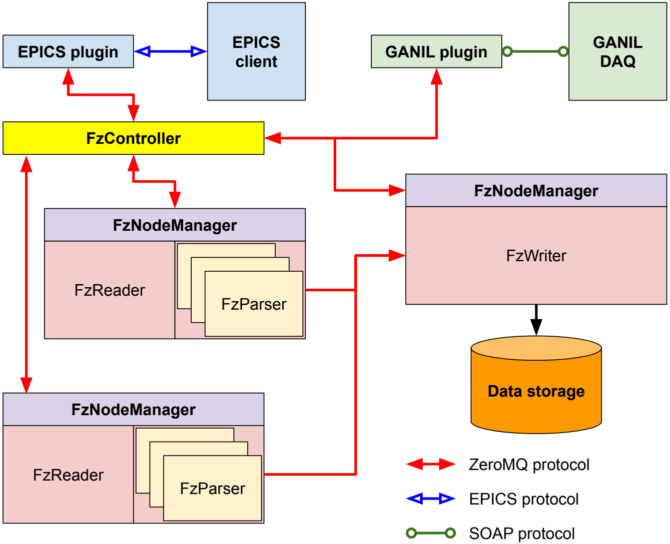


Acquisition and monitoring

Acquisition system

- Developed at INFN – Napoli
- Finite State Machine logic
- Multi-thread and **multi-machine**
  - controller sends machine IP addresses to regional board
  - regional board stores IP addresses inside a list
  - each event is sent to a different PC of the list sequentially
- Data merged and written to a data server.
- Monitoring software receives **live data** from the acquisition
- Data transfer between machines via **ZeroMQ** protocol
- NARVAL frame encapsulation implemented

Acquisition and monitoring



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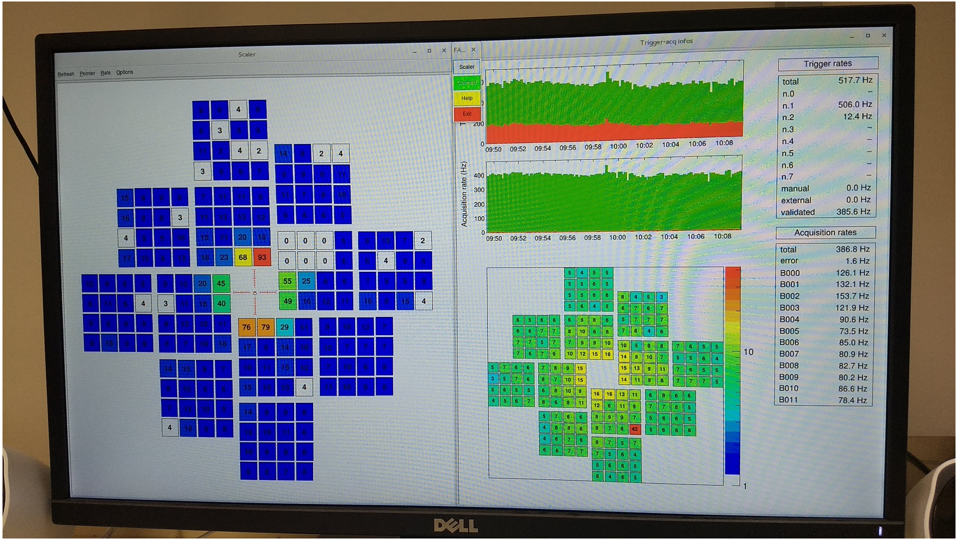

FAZIA now

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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- **Thicker** sensors with the same FAZIA electronics
- **New block** design with the same FAZIA acquisition protocols

FAZIA future

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- **Thicker** sensors with the same FAZIA electronics
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FAZIA technology will be fundamental for the future developments

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

DAQ and electronics

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

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- independent acquisition to store FAZIA data in the old format?
- Successful FAZIA@FRIB coupling test two weeks ago!

FAZIA@FRIB

FRIB DAQ coupling

- Common dead time by trigger coupling
- Timestamp (TS) generated from external clock
- TS reset is provided to all the coupled devices
- TS written in data flow
- FRIB DAQ extracts TS to merge data

FAZIA@FRIB

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FRIB veto signal in FAZIA for **common dead time**

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Timestamp coherency **verified!**

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Extra details from FRIB side in the next talk by **G. Cerizza**

Timestamp **clock** and **reset** signals are sampled by ReBo and written in data flow

FRIB veto signal in FAZIA for **common dead time**

Timestamp coherency **verified!**

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)

Developing a new detector...

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.

More details on the proposed AZIMUTH detector
could be found 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**

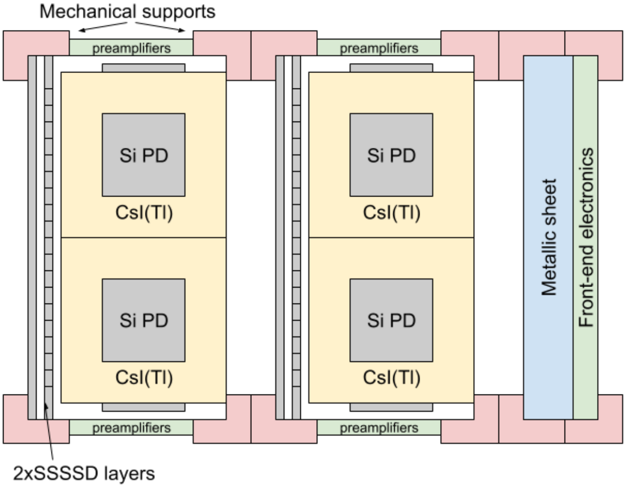
Universal

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

The AZIMUTH block



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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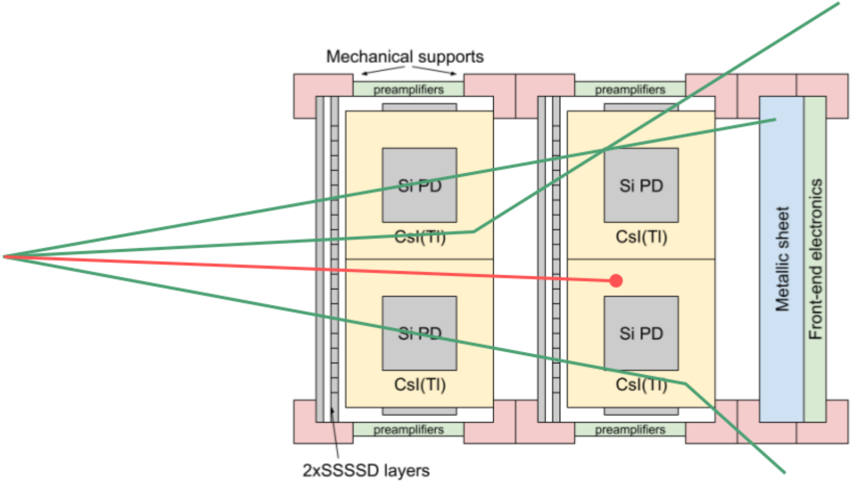
FAZIA

- 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)

Tracking features



Summary and future perspectives

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

INDRA FAZIA

INFN
Istituto Nazionale di Fisica Nucleare

Thanks for your attention

Backup slides

The FAZIA telescope

The telescope stages

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

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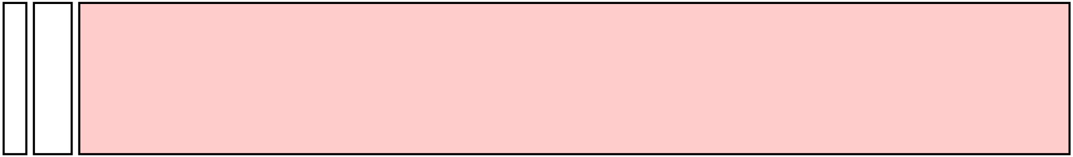


The FAZIA telescope

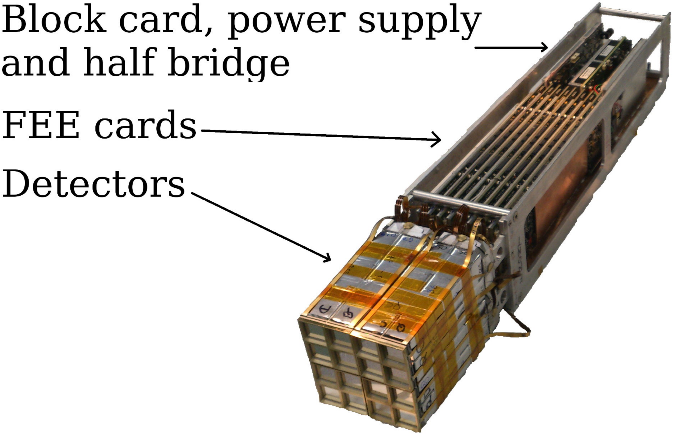
The telescope stages

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

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 %
    from 5 MeV to 4 GeV

S. Valdré *et al*, Nucl. Instr. and Meth. A 930 (27), 2019

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- common clock distribution for **synchronous** sampling

S. Valdré *et al*, Nucl. Instr. and Meth. A 930 (27), 2019

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$\Downarrow$

- Compactness and modularity
- Very good isotopic discrimination capabilities
- Thresholds ($\lesssim$10 MeV/u) suited for Fermi energies

S. Valdré *et al*, Nucl. Instr. and Meth. A 930 (27), 2019

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 %
      from 5 MeV to 4 GeV
- common clock distribution for **synchronous** sampling

$\Downarrow$

- Compactness and modularity
- Very good isotopic discrimination capabilities
- Thresholds ($\lesssim$10 MeV/u) suited for Fermi energies

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