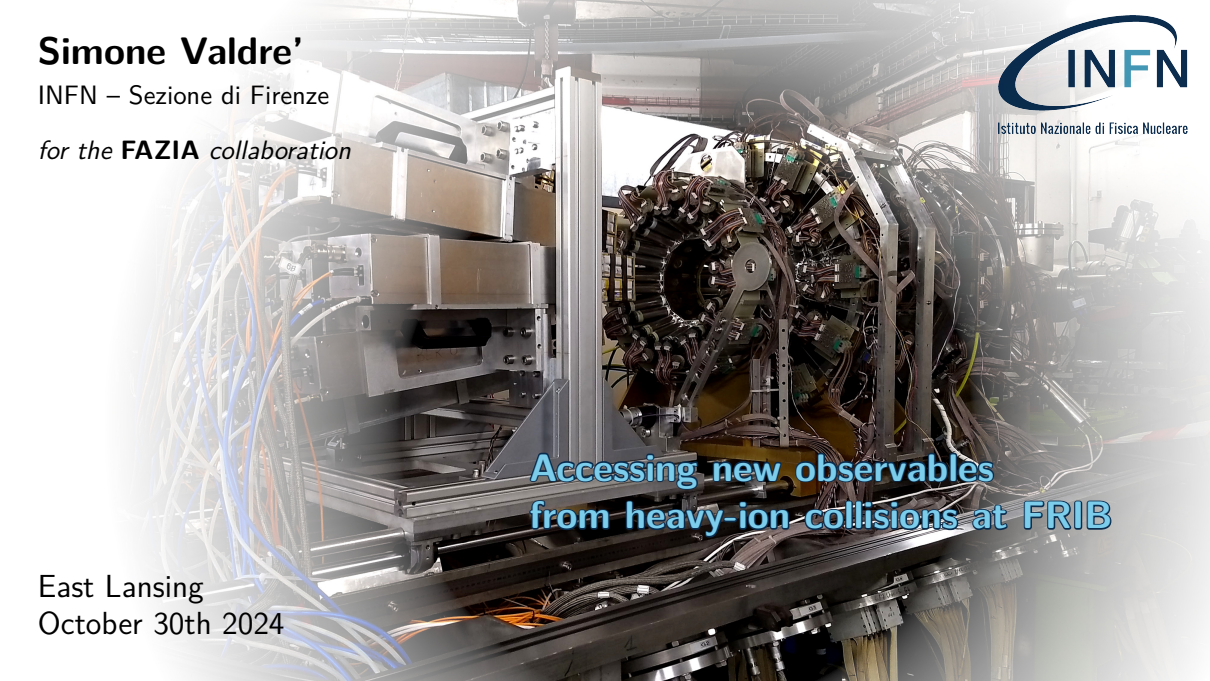
Simone Valdre'
INFN – Sezione di Firenze
for the **FAZIA** *collaboration*



Accessing new observables from heavy-ion collisions at FRIB

East Lansing
October 30th 2024

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 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

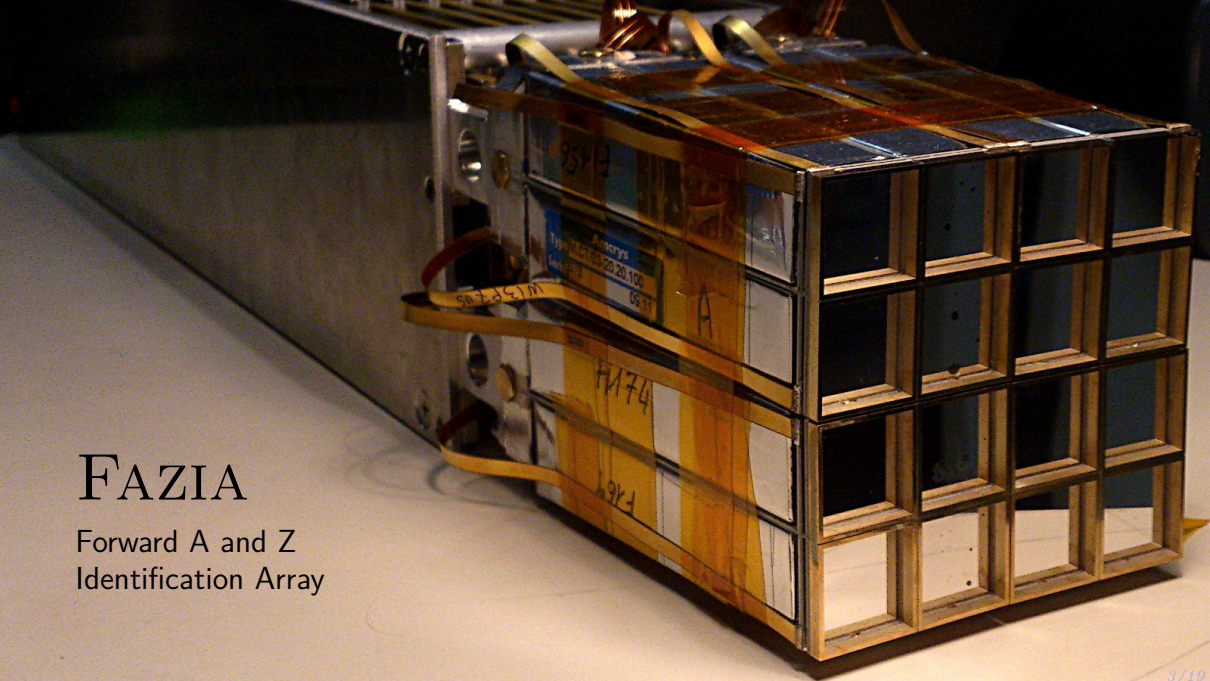
Letter of Intent

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

Six scientific initiatives

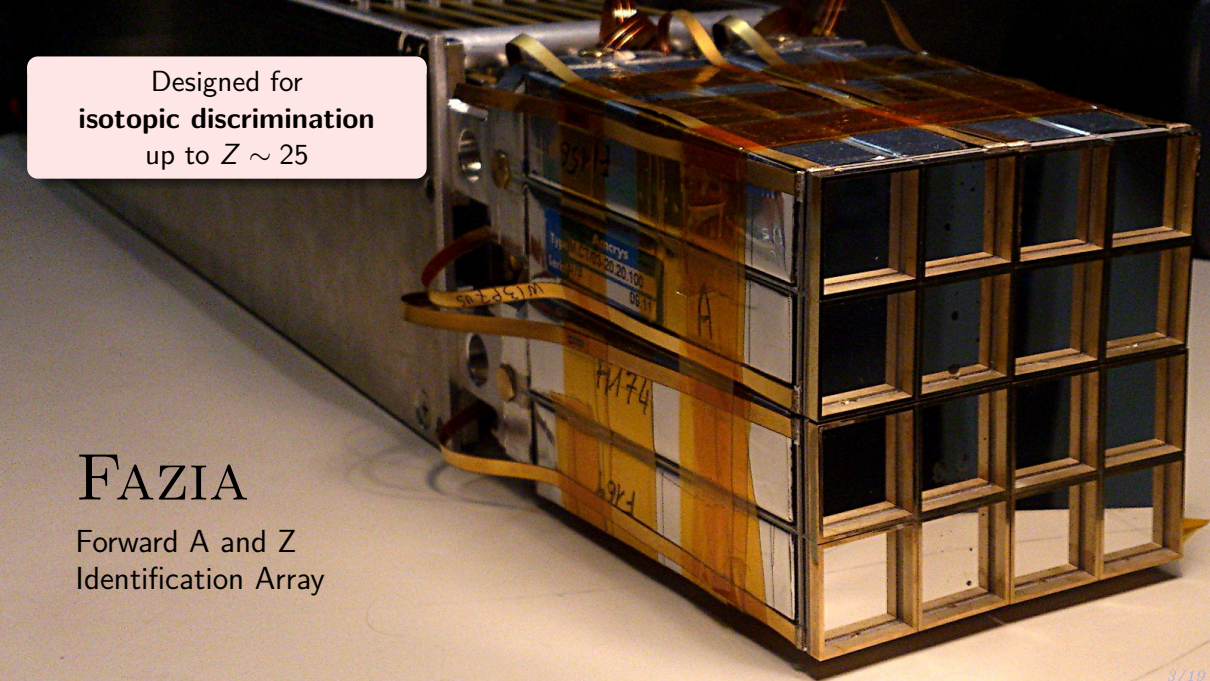
SYMEOS EoS and E_{sym} with HIC

more details during workshop group discussions



Fazia

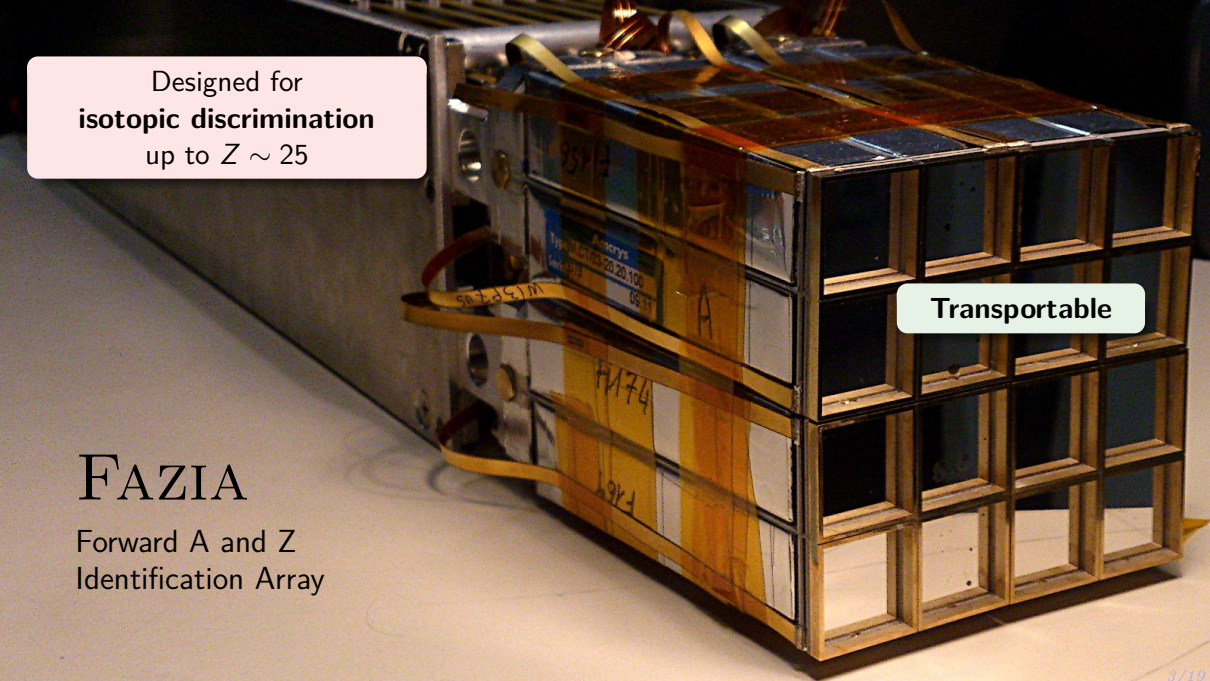
Forward A and Z
Identification Array



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

FAZIA

Forward A and Z
Identification Array



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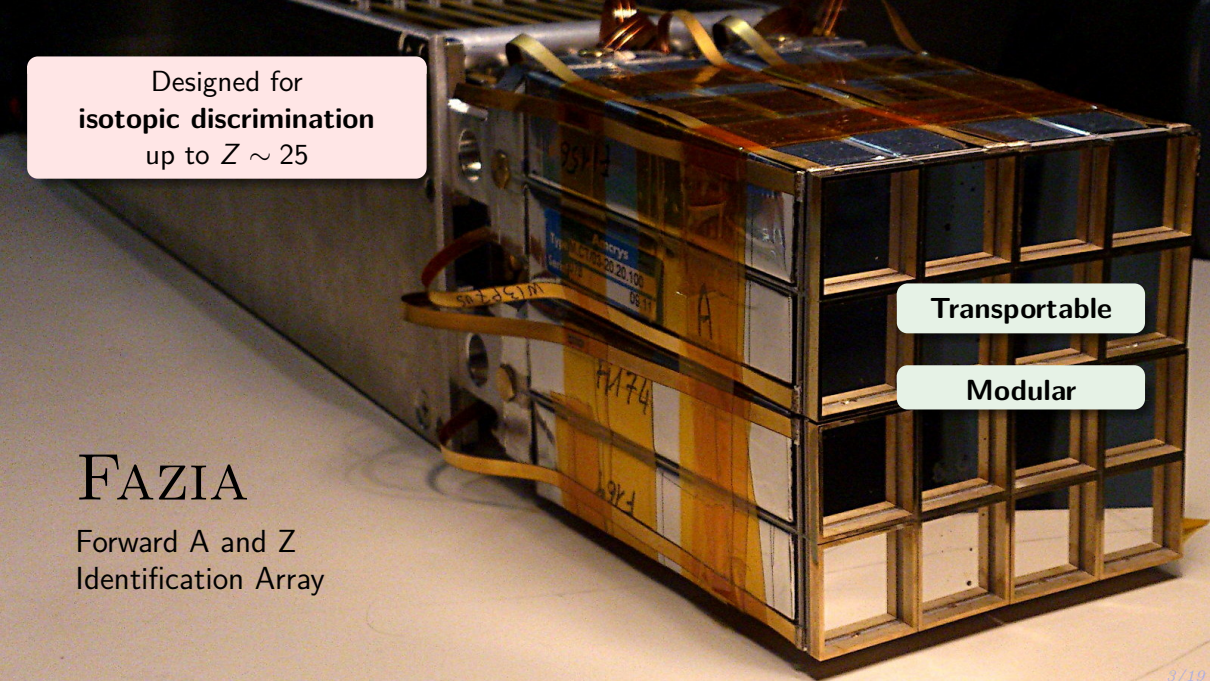
Transportable

FAZIA

Forward A and Z
Identification Array



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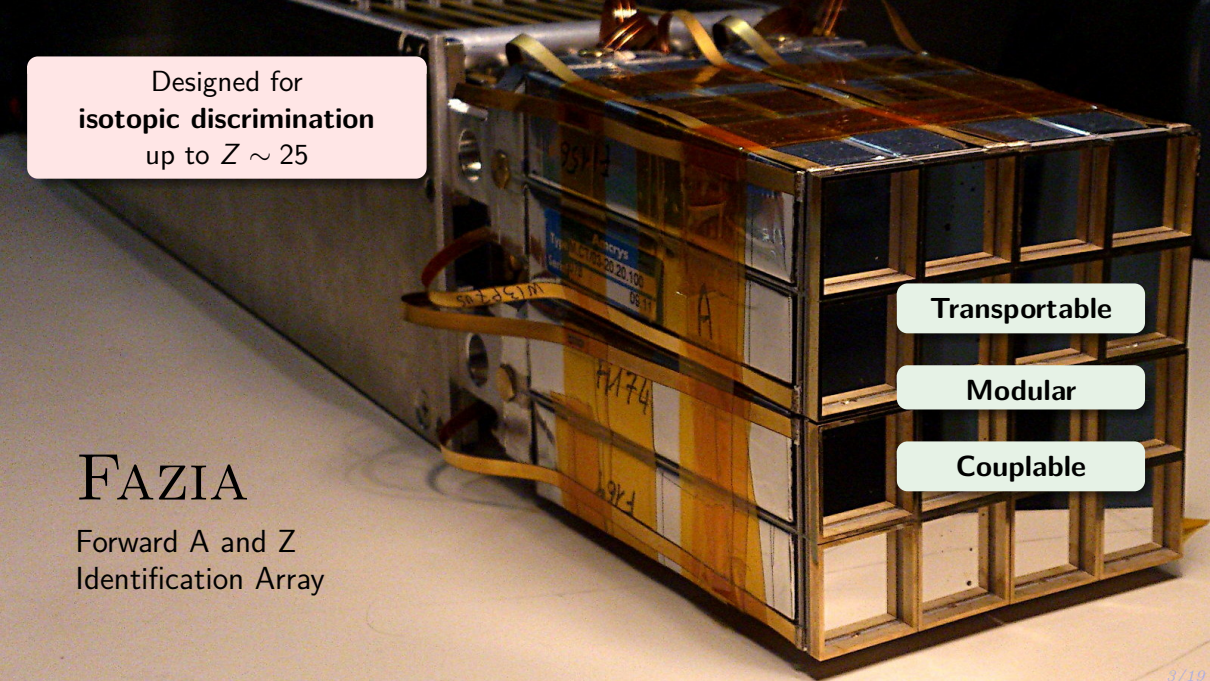
Transportable

Modular

FAZIA

Forward A and Z
Identification Array



Designed for
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Transportable

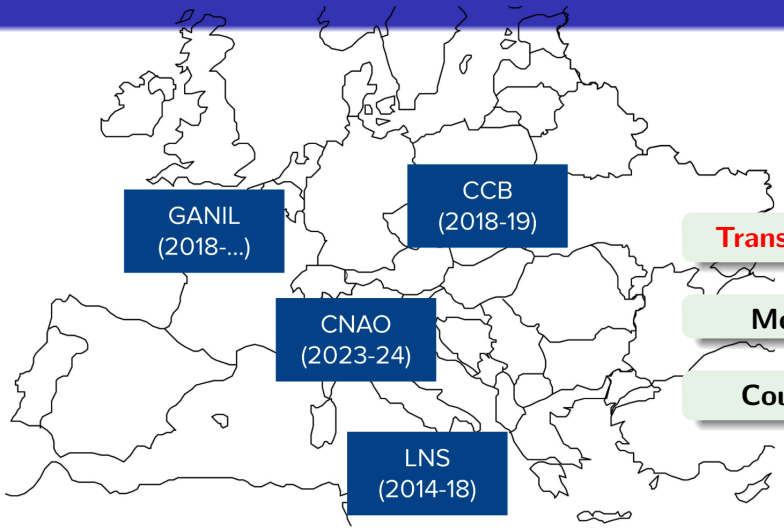
Modular

Couplable

FAZIA

Forward A and Z
Identification Array

FAZIA

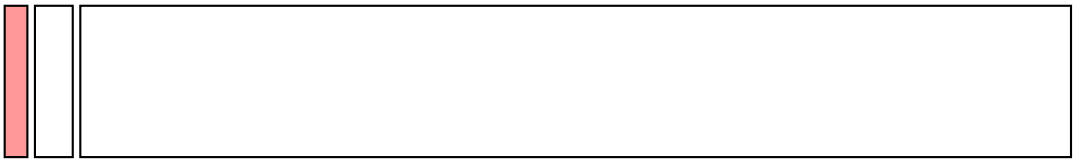


Laboratories where FAZIA measured so far

Il telescopio FAZIA

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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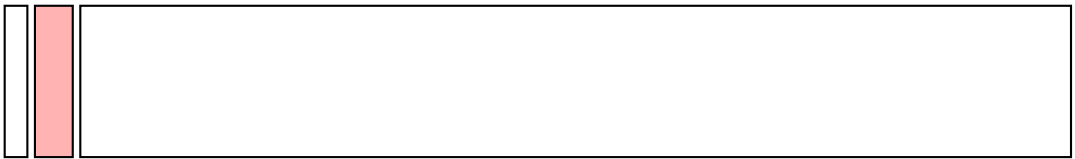

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Il telescopio FAZIA

The telescope stages

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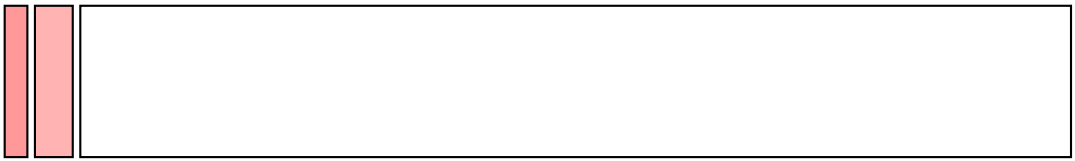
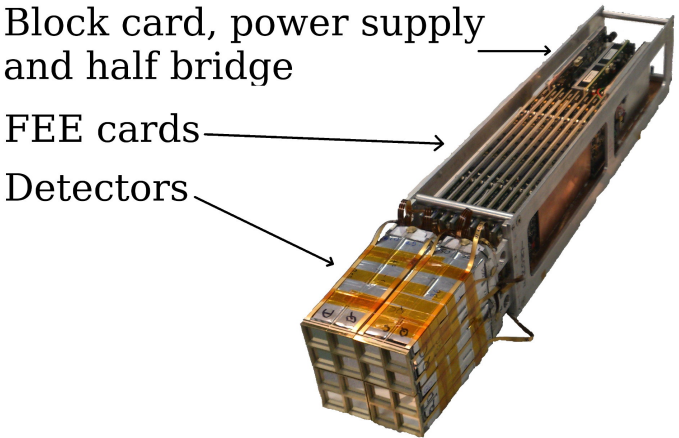
To achieve the best possible energy resolution and A and Z identification Si detectors come from a nTD ingot cut at random angle to avoid channeling effects.



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

The FAZIA block



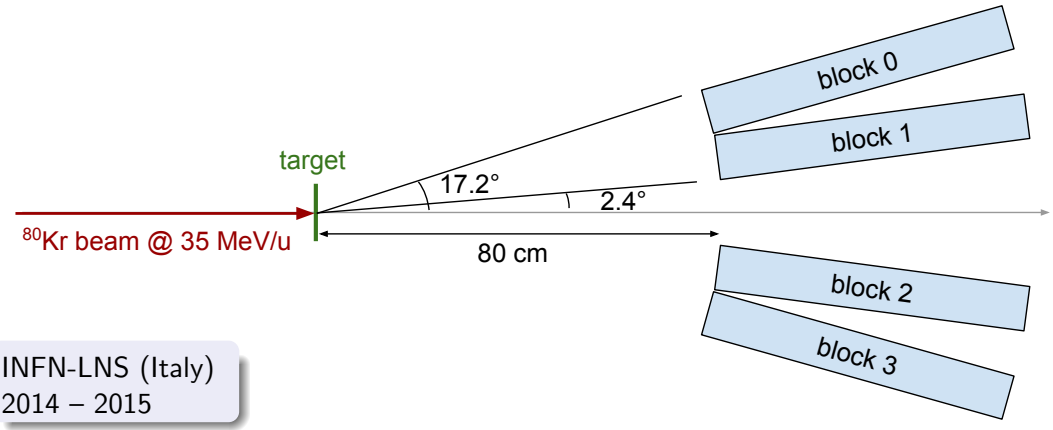
Transportable

Modular

Couplable

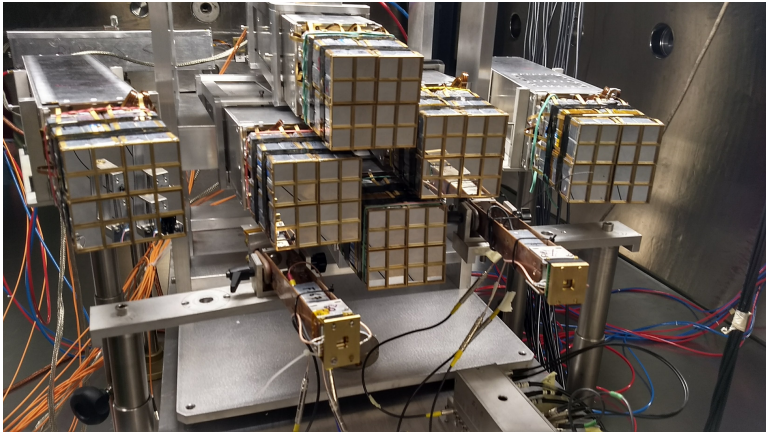
16 telescopes, *together with* ***front-end electronics***,
form a ***block*** *operating in* ***vacuum***.

FAZIA modularity



INFN-LNS (Italy)
2014 – 2015

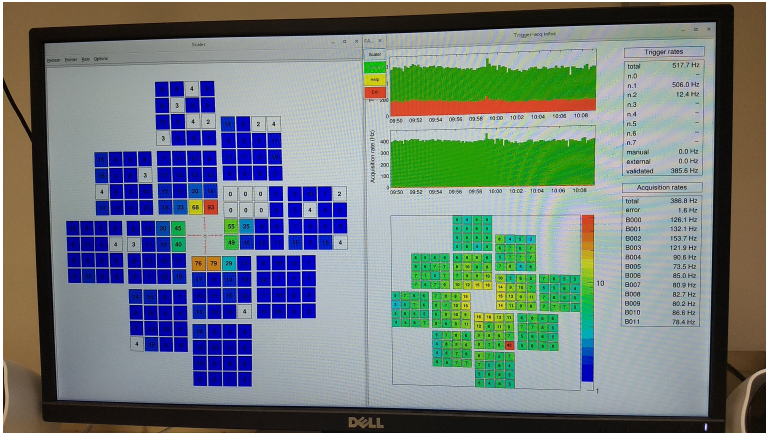
FAZIA modularity



INFN-LNS (Italy)
2016 – 2018

FAZIA modularity

GANIL (France)
2018 – today



FAZIA modularity

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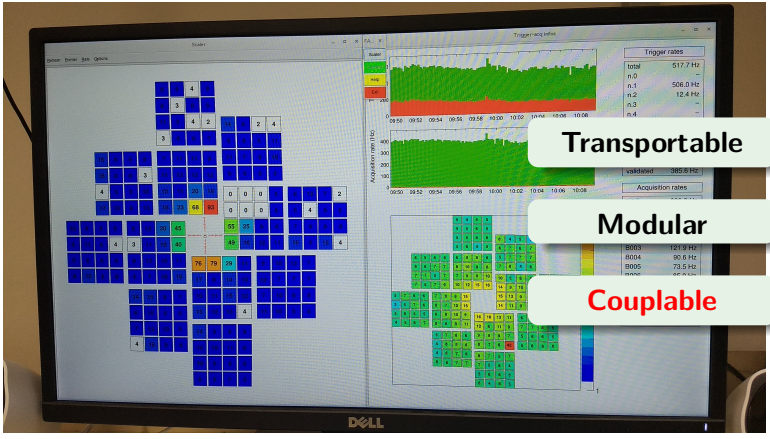
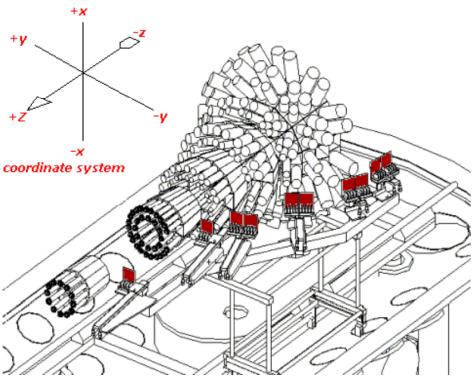


INDRA setup

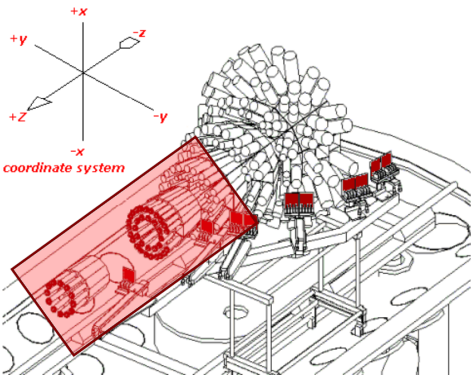


Original configuration (1992-2016)

- 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

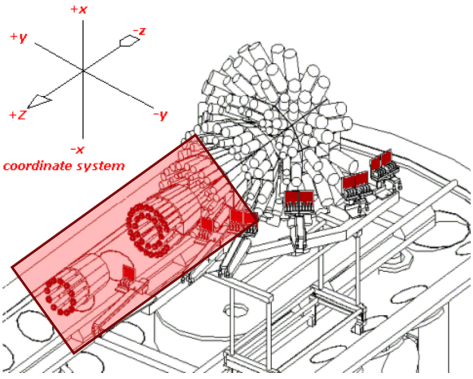
INDRA setup



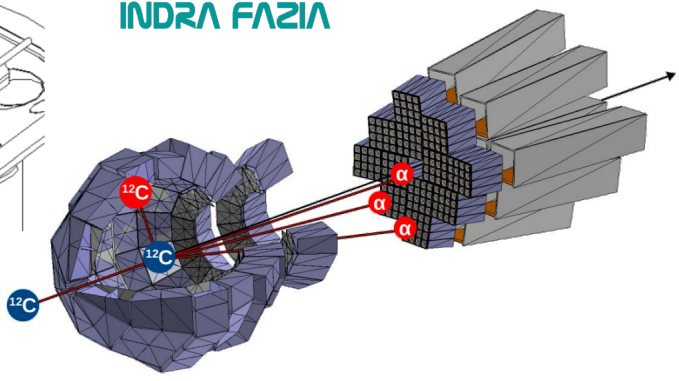
Present configuration (2017-today)

- 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

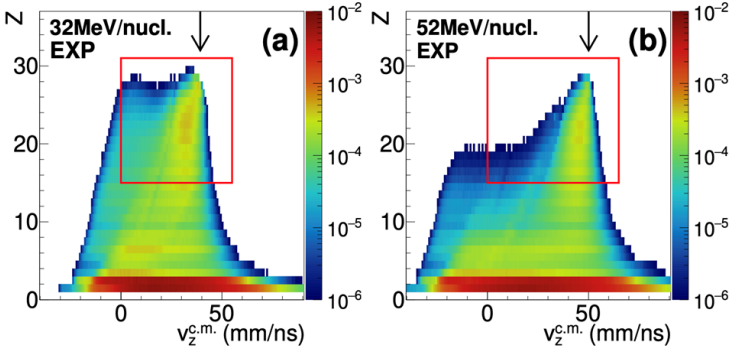
INDRA setup



INDRA FAZIA

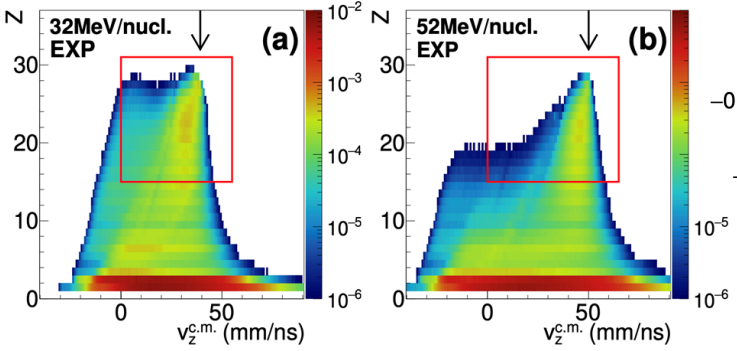


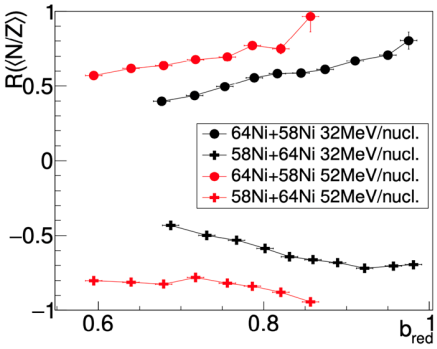
Quasi-projectile "chemistry"



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

Quasi-projectile "chemistry"

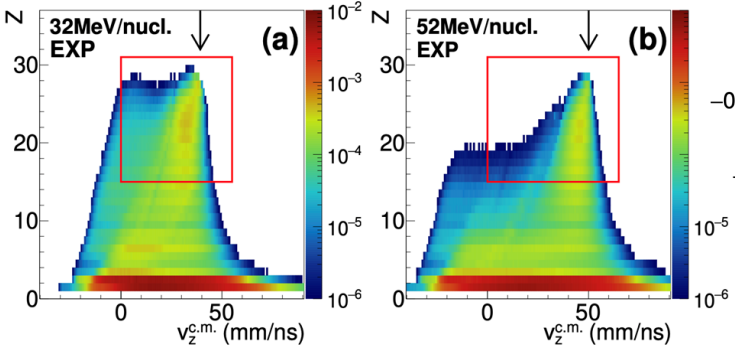


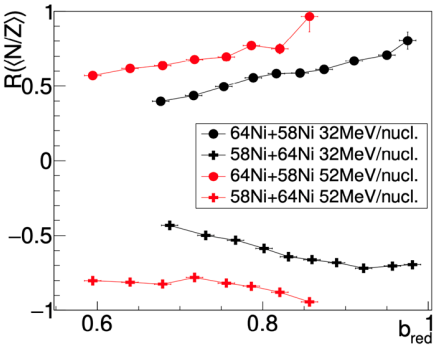


C. Ciampi *et al.* Phys. Rev. C **106**, 024603 (2022)

Quasi-projectile "chemistry"

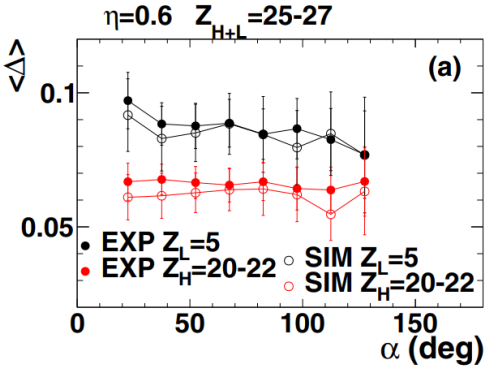
New results shown yesterday in C. Ciampi's talk!

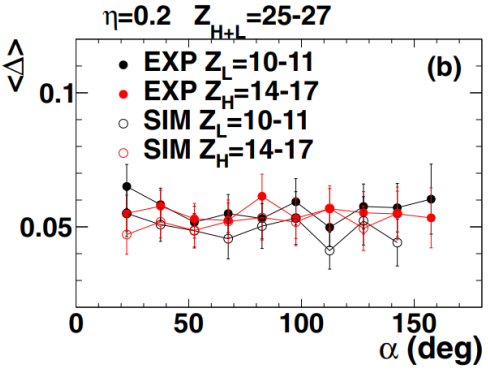




C. Ciampi *et al.* Phys. Rev. C **106**, 024603 (2022)

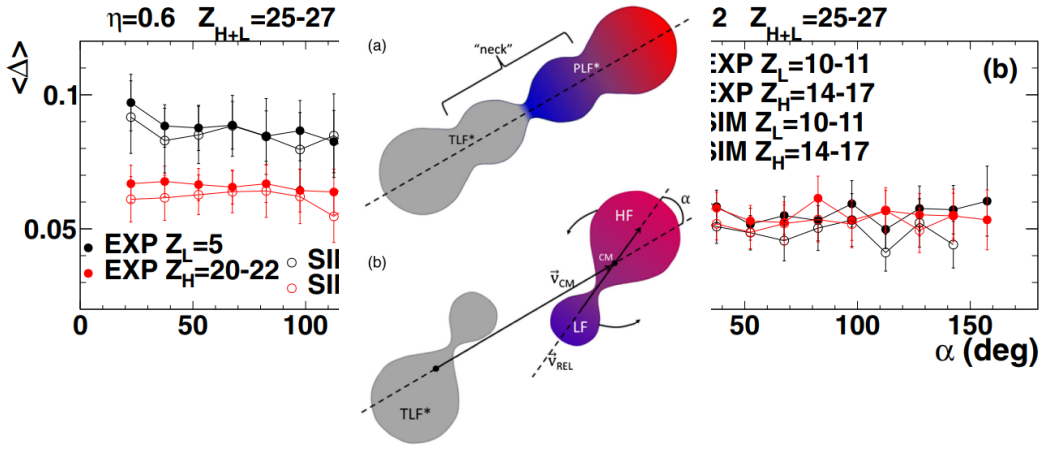
Quasi-projectile breakup





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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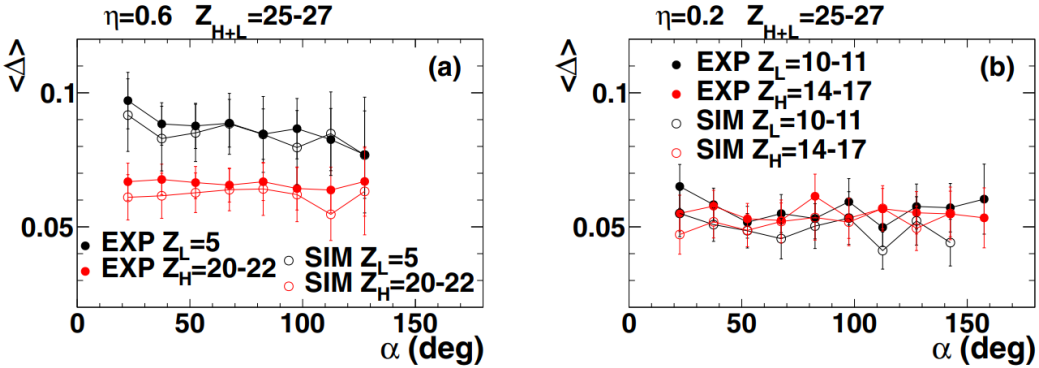
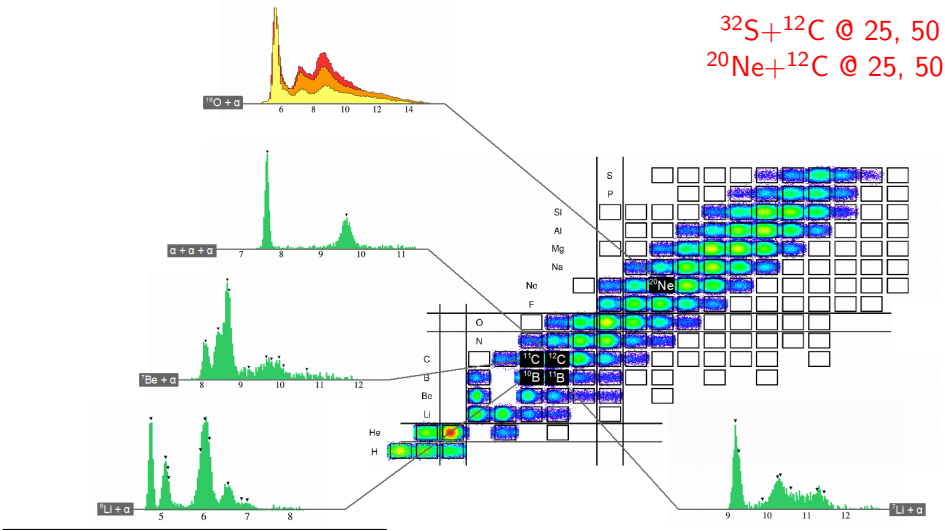


only 4 blocks (low statistics) but large-Z fragments could be isotopically identified

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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- setup designed for **Fermi energies** (15–50 AMeV)

Future at GANIL

There are still many physics cases to be explored

2 experiments approved for 2025!

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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- Thicker sensors with the same FAZIA electronics

FAZIA future

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- New block design with the same FAZIA acquisition protocols

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
- Full re-design of the apparatus based on the FAZIA expertise

FAZIA technology will be fundamental for the future developments

Aaa

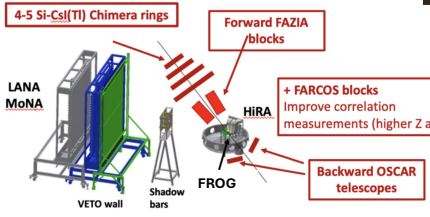
Short-term plans (coupling of existing detectors: FRIB + INFN)

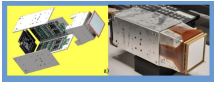
CHIMERA rings @ GSI

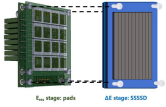
≈350 Si-CsI(Tl) telescopes
+ FROG
→ reaction plane, b, ...

FAZIA @ GANIL

12 blocks * 16 units each
→ 192 Si-Si-CsI(Tl) telescopes
→ Isotopic identification and low thresholds up to Z=25
→ Isospin diffusion/transparency, isotopic distributions from participants and spectators







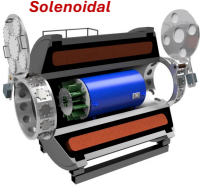
HiRA + FARCOS + OSCAR
DSSSD: Femtoscopy and Invariant Mass Spectroscopy

LANA and MoNA
Neutron detectors (flows, femtoscopy, invariant mass spectroscopy)

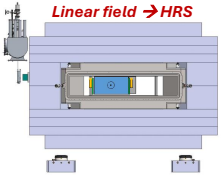
Aaa

Long-term solution: TPC + Ancillary detectors

Phase 1 – AT-TPC like
Solenoidal



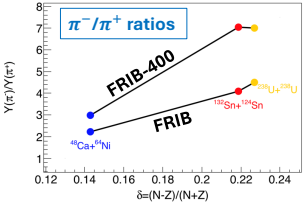
Phase 2 – Sπrit-like
Linear field → HRS



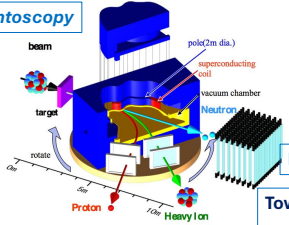
K. Brown and S. Hudan, P.I.s

Extend E_{sym}-sensitive observables

- π^-/π^+ ratios and flow
- neutron-proton femtoscopy
- ...others



n-p Femtoscopy



MoNA

FAZIA/FARCOS-like hodoscopes

Towards a common DAQ protocol:

- **Streaming readout**
- **Sinergy between FRIB and EIC experiments (i.e. EPIC)**

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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LoI proposals:

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

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LoI proposals:

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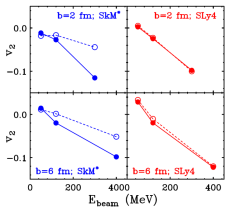
- Invariant Mass Spectroscopy

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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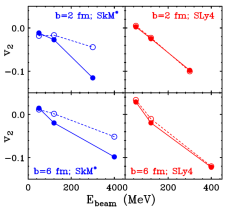

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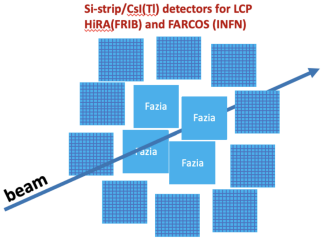
at the same time FAZIA-like blocks can measure projectile spectators (extension of topics already measured at Fermi energies)

- breakup of projectile spectators
- isospin diffusion

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

Conclusions

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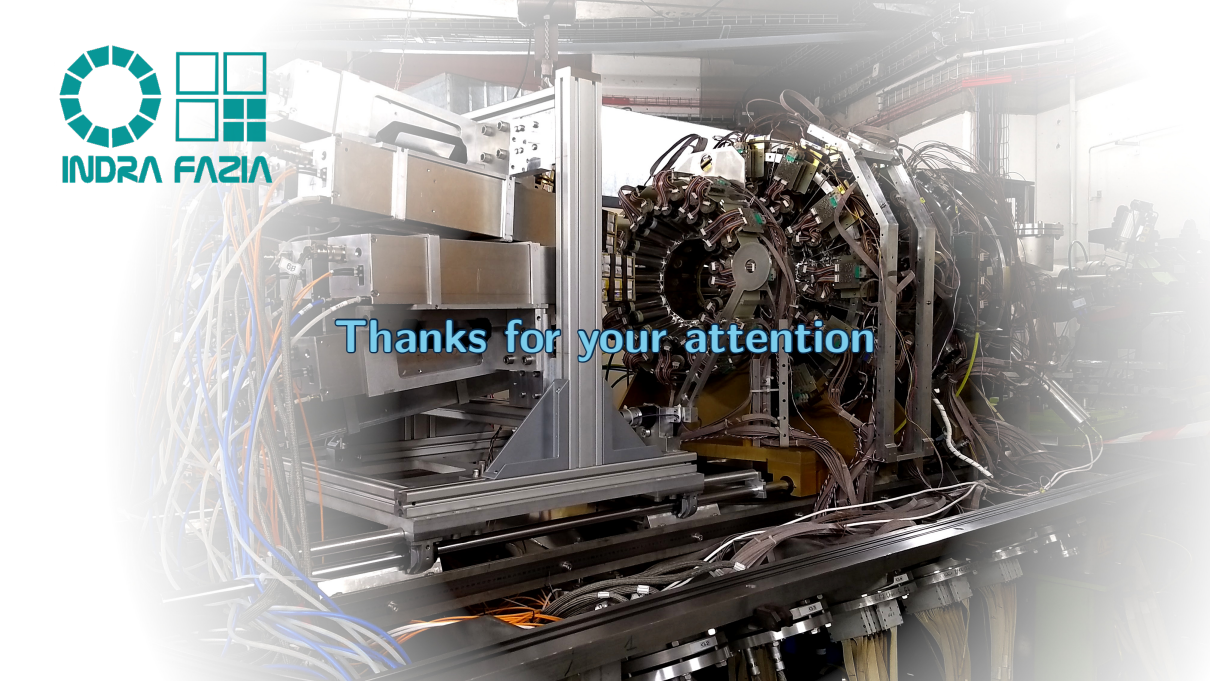
We submitted a letter of intents with some proposals of future experiments, suggested observables and hints on a new multipurpose apparatus. Discussions in this and future workshops will be fundamental to trace a route for the future of EoS investigations.


INDRA FAZIA
Thanks for your attention

Backup slides

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

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

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