Plans for Symmetry Energy research in INDRA-FAZIA

INDRA FAZIA

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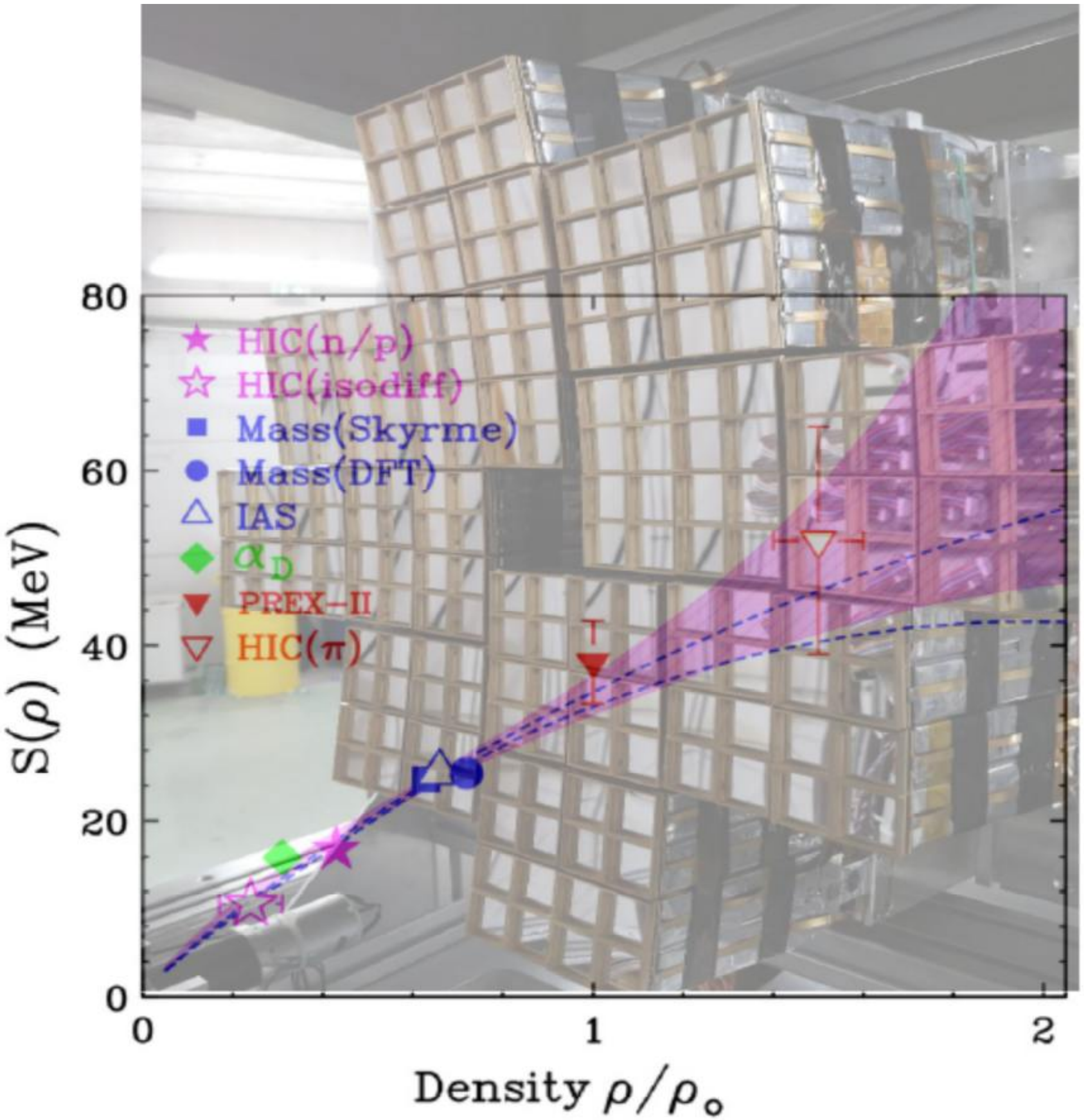
INFN Sezione di Firenze



Summary

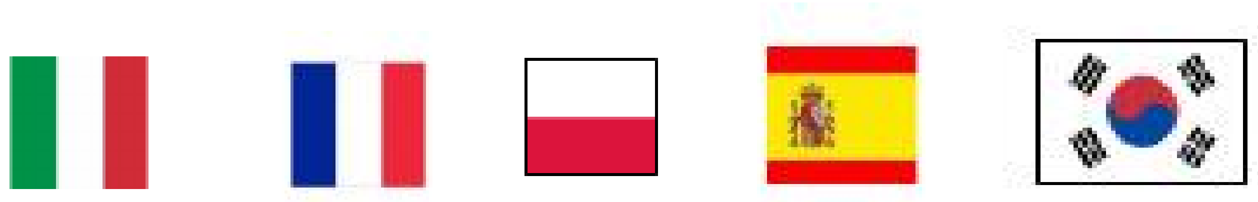
- The INDRA-FAZIA group
- The detector: sensors and electronics
- The performance: what we can contribute
- Ongoing activities and physics cases
  (for more: talks by Caterina and Alberto)
- New perspectives and R&D

The INDRA-FAZIA collaboration

Forward A and Z Identification Array

Born in 2006 with the goal to build an advanced solid-state detector array for identification of ions (Z,A), also exploiting the powerful opportunity of fast digital electronics for signal PSA.

After the R&D, the group built 12+4 modules of 3-stage telescopes to be used alone or coupled with other arrays. The priority is the coupling with INDRA at GANIL.



Since 2019 South Korea fully joined the collaboration, that was before only european.

Activities and plans included in a Memorandum of Understandings, now at its second edition.

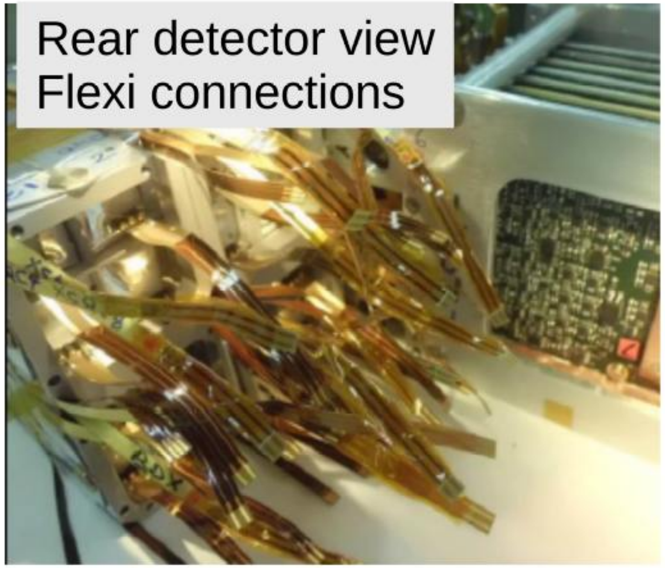
MoU n.1 2018-2022 End of R&D and first experiments

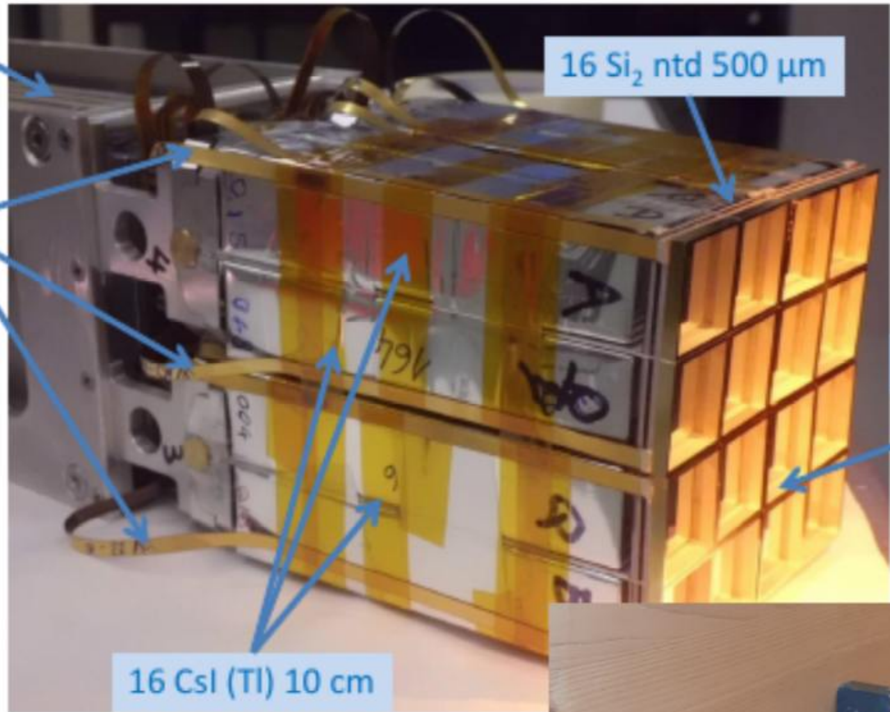
MoU n.2 2023-2027 Mature exploitation Phase

Human resources: about 30 physicists (among them: 3 PhD, 3 PostDOC)

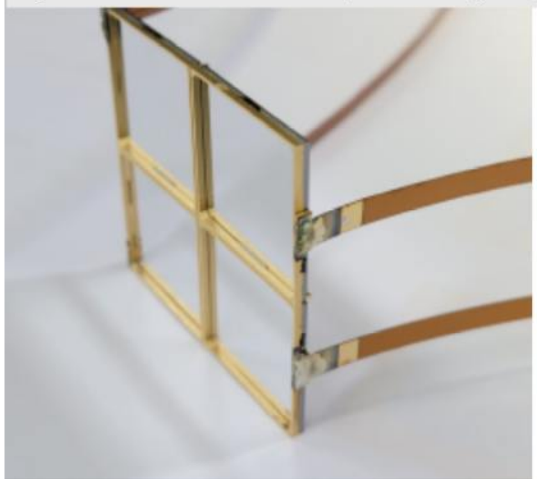
The FAZIA block

INDRA FAZIA



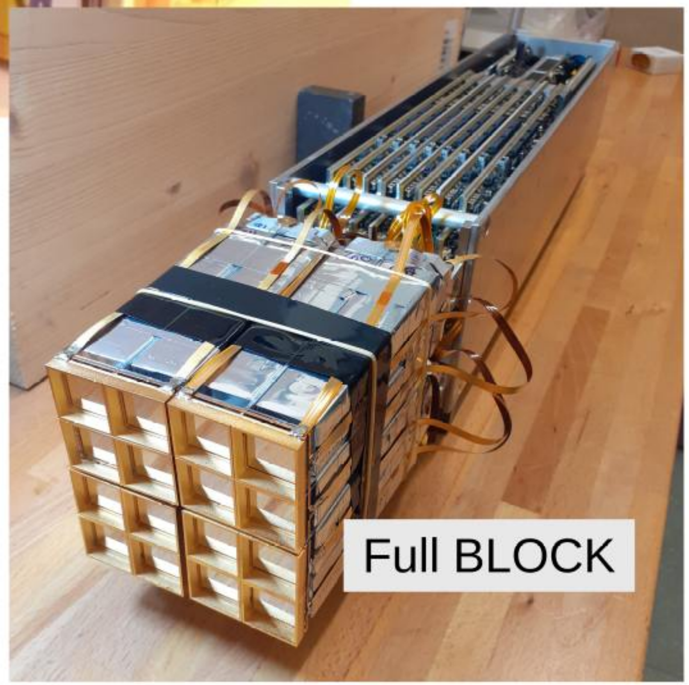


Gold plated ergal *quartetto* frame
(for a 4-silicon pad layer)



The complexity is confined under vacuum
The I/O connection is easy and needs only:

- Power supply DC 48V
- Optical fiber
- Two pipes for a water cooling system

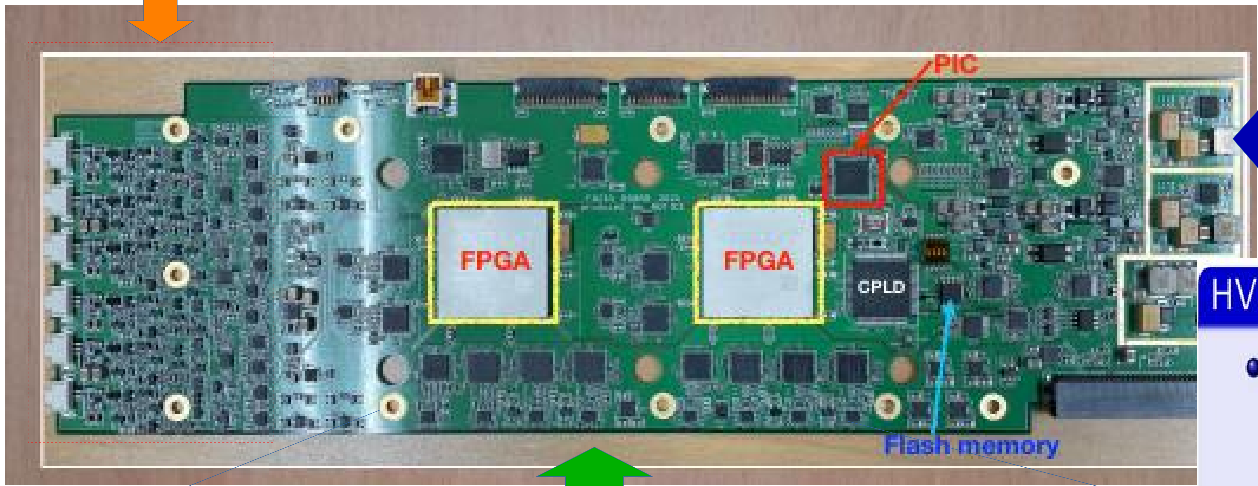


Electronics

S. Valdrè et al NIM A 930 2019

Analog chain (for each telescope)

- 3 fixed gain charge pre-amplifiers (8 V out dynamic range)
- High range signals are **attenuated** by a factor 4
- Low range signals are **amplified** by a factor 4
- Current signal by **analog differentiation** of charge signals



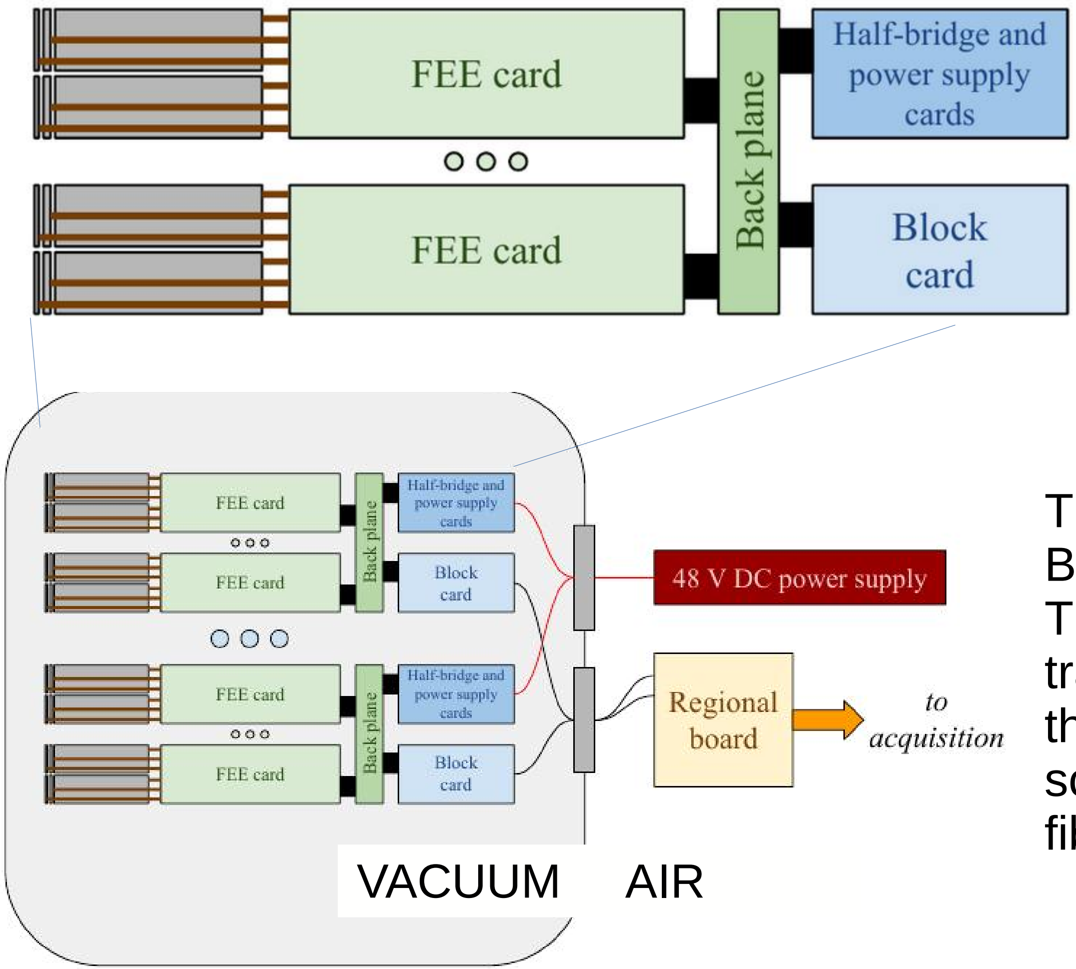
HV generation

- DC/DC converters produce the Si detectors **bias voltages**:
  - 0–200 V for Si1 (140 V depletion voltage)
  - 0–300 V for Si2 (290 V depletion voltage)
- CsI(Tl) photodiode bias voltage from the Power Supply card:
  - **optocoupler switch** on FEE card.

6 sampling ADCs per telescope

- 100 MHz, 14 bit (4 GeV full scale) [Si1 high range charge signal (QH1)]
- 250 MHz, 14 bit (250 MeV full scale) [Si1 low range charge signal (QL1)]
- 250 MHz, 14 bit [Si1 current signal (I1)]
- 100 MHz, 14 bit (4 GeV full scale) [Si2 charge signal (Q2)]
- 250 MHz, 14 bit [Si2 current signal (I2)]
- 100 MHz, 14 bit (4 GeV Si-equiv. full scale) [CsI(Tl) charge signal (Q3)]

Electronics layout

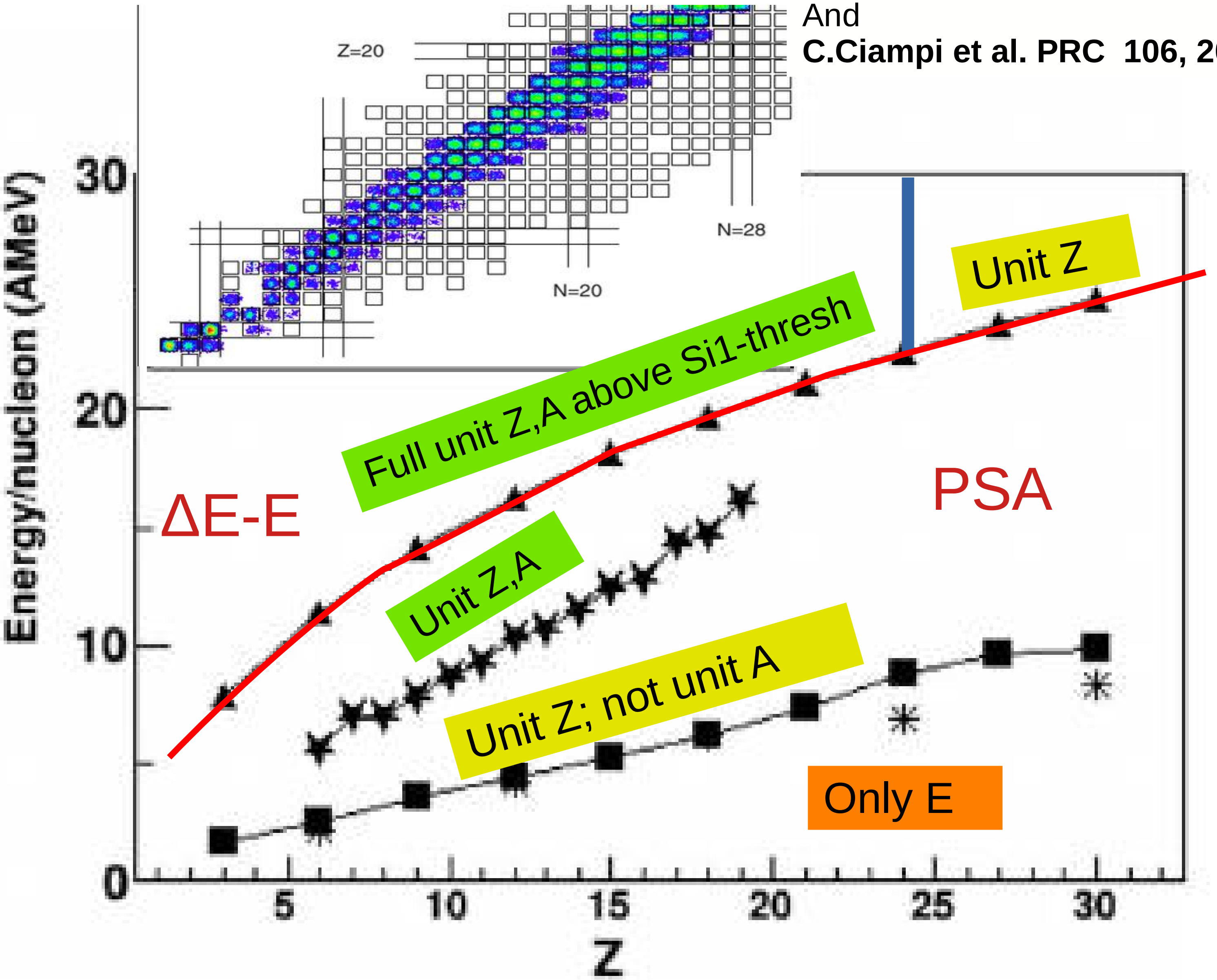


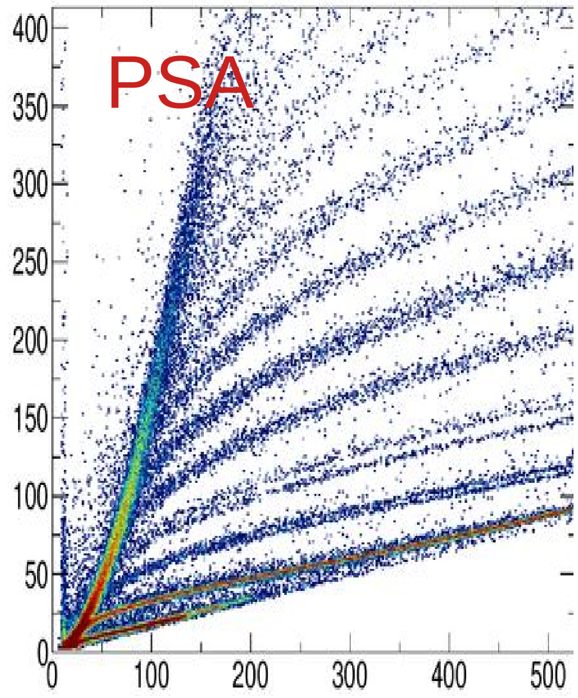
1 Block: 16 telescopes connected two-by-two to 8 FE boards

The 8 FE cards in a block are connected to Block Cards (BC) for the complete data transfer. The BC receives electrical signals/bits and transforms to optical packets, which are sent to the trigger Regional Board, outside the scattering chamber, through a full duplex 3Gb/s fiber link.

Present Z,A performance

Adapted from
G. Pastore et al. NIM A 860, 2017
And
C.Ciampi et al. PRC 106, 2022

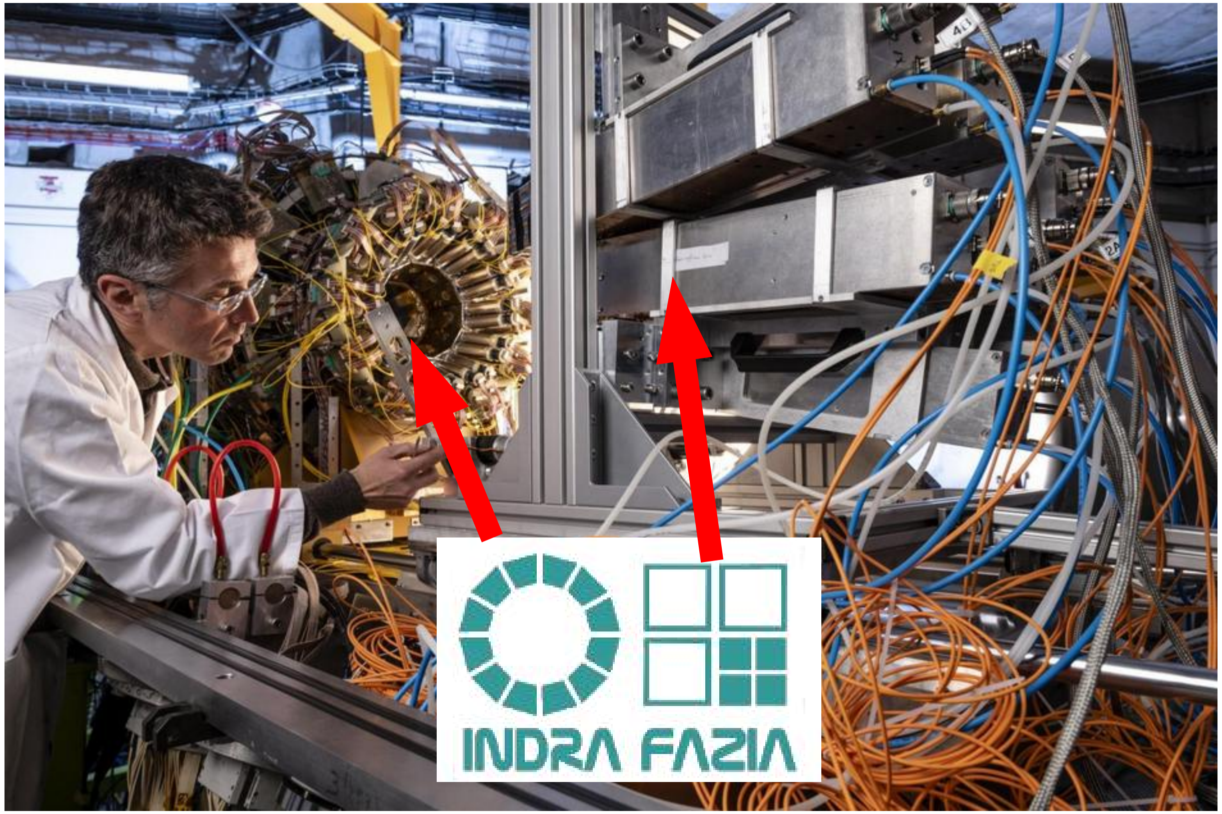




GANIL E818 2022

Results obtained from the first real experiment at LNS and then confirmed as average performance in the last INDRA-FAZIA experiments

Experiments at GANIL



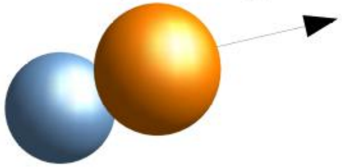
From 2019 we are performing experiments with INDRA-FAZIA

Physics: EOS at subsaturation via semiperipheral reactions at Fermi Energies

Specific field of interest, shared with other excellent groups (e.g. Texas-AM, MSU, LNS Catania)

Heavy-ion collisions can stimulate ‘isospin fluxes’ and also produce systems at subsaturation densities (e.g. V.Baran et al. N.Phys A 730 2004)

QP fragment



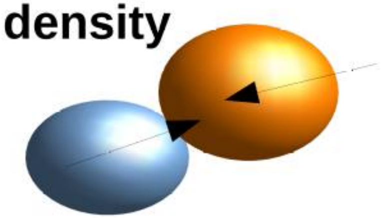
QT fragment

beam and target ions with different n/p

neutron-proton flux mainly governed by $E_{sym}(\rho=\rho_0)$

neck region low density

QP fragment



QT fragment

beam and target ions with equal n/p

Density gradients: neutron-proton flux also ruled by L_{sym}

- Often both processes are supposed to come into play
- Selective isospin-related quantities to evidence effects

Physics: EOS at subsaturation via semiperipheral reactions at Fermi Energies

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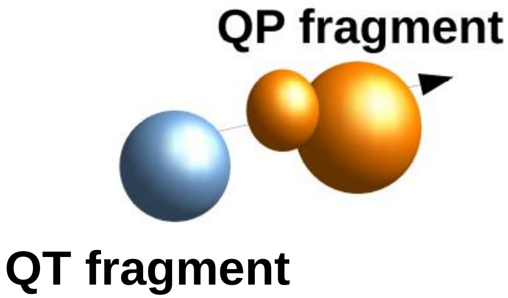
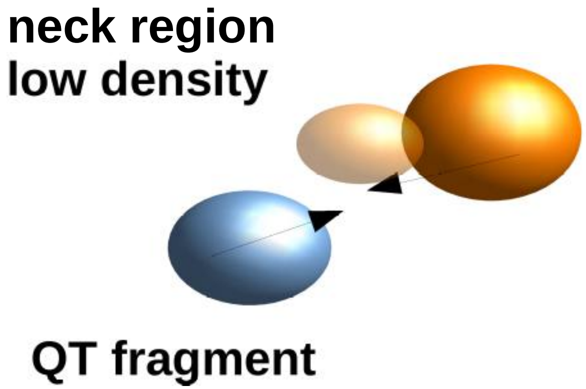


beam and target ions with different n/p

neutron-proton flux mainly governed by $E_{sym}(\rho=\rho_0)$



beam and target ions with equal n/p

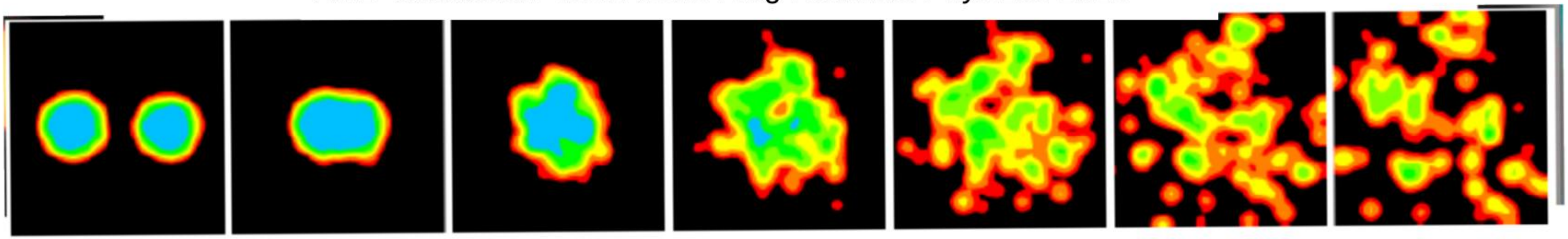
Density gradients: neutron-proton flux also ruled by L_{sym}

We are extending isotopic analysis to the BU channel:
S.Piantelli PRC 101 2020
Caterina Ciampi's Talk at Nusym23

other works, e.g. Jedele PRL 118 2017
Rodriguez-Manso PRC 102 2020

Physics: cluster formation and decay for EOS investigation

AMD calculation from A.Ono Prog Part Nucl Phys 105 2019



An active subject, studied in small to medium-size systems. In particular:

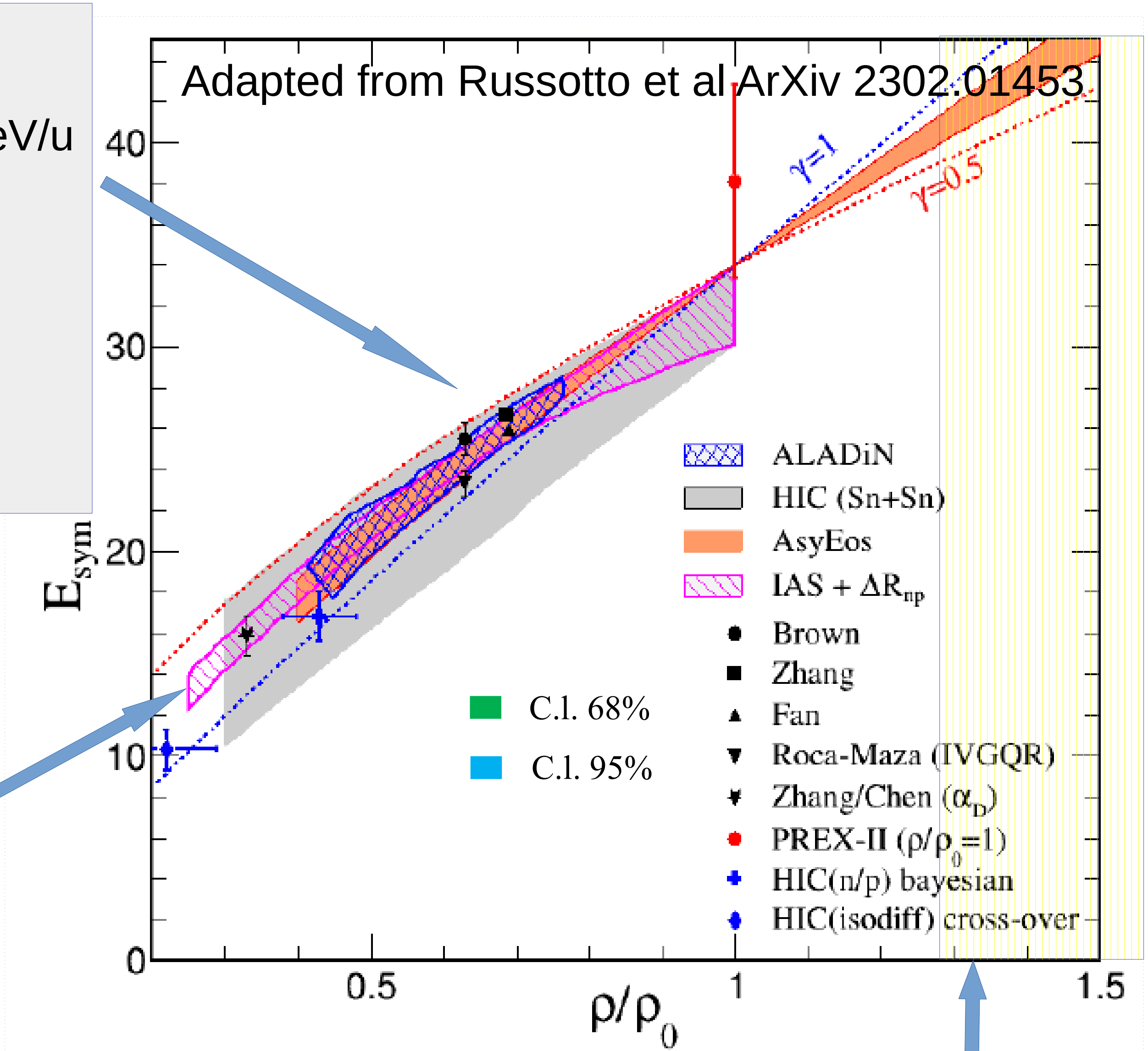
- cluster chemistry and abundances were measured in S,Ne+C and compared to AMD+Gemini prediction (Frosin et al. PRC 107 2023)
- the last experiment E818 (2022) is focused on the cluster dissolution vs. density (Mott transition) in hot diluted systems formed via central Ni+Ni collisions (analysis in progress)
- Byproduct of E818: Hoyle states and light nuclear resonances in C+C reactions (analysis next to the end)
- First correlation technique with FAZIA to get decay IMF resonances (Piantelli et al PRC 107 2023)

see: **Alberto Camaiani**'s talk at Nusym23

INDRA-FAZIA and the regions of the Esym

FAZIA activity (2010-2021)
LNS and GANIL
C,S,Ne,Ca, Ni,Kr beams from 25 to 52MeV/u

SEMIPERIPHERAL
QP vs IMF emissions
Neck chemistry and features
QP break-up channel
Fragment formation and emissions
Resonances reconstruction



INDRA FAZIA activity (2022)
Last exp at GANIL
Ni beams 74 MeV/u

CENTRAL
Mott transition up to Z=6-8 clusters
Equilibrium constants
In-medium effects

possible activity at
FRIB and RAON (2025-2035)

New opportunities: Raon in South Korea

Thanks to the korean partnership, there are plans at the RAON complex, next years

RAON
Phase 1: 2011-2022-->2024 (ISOL + KOBRA medium E beams)
Phase 2: 2023-2030 (H.E. SuperConducting Linac)

next TALK by Byungsik Hong

KEY FEATURES

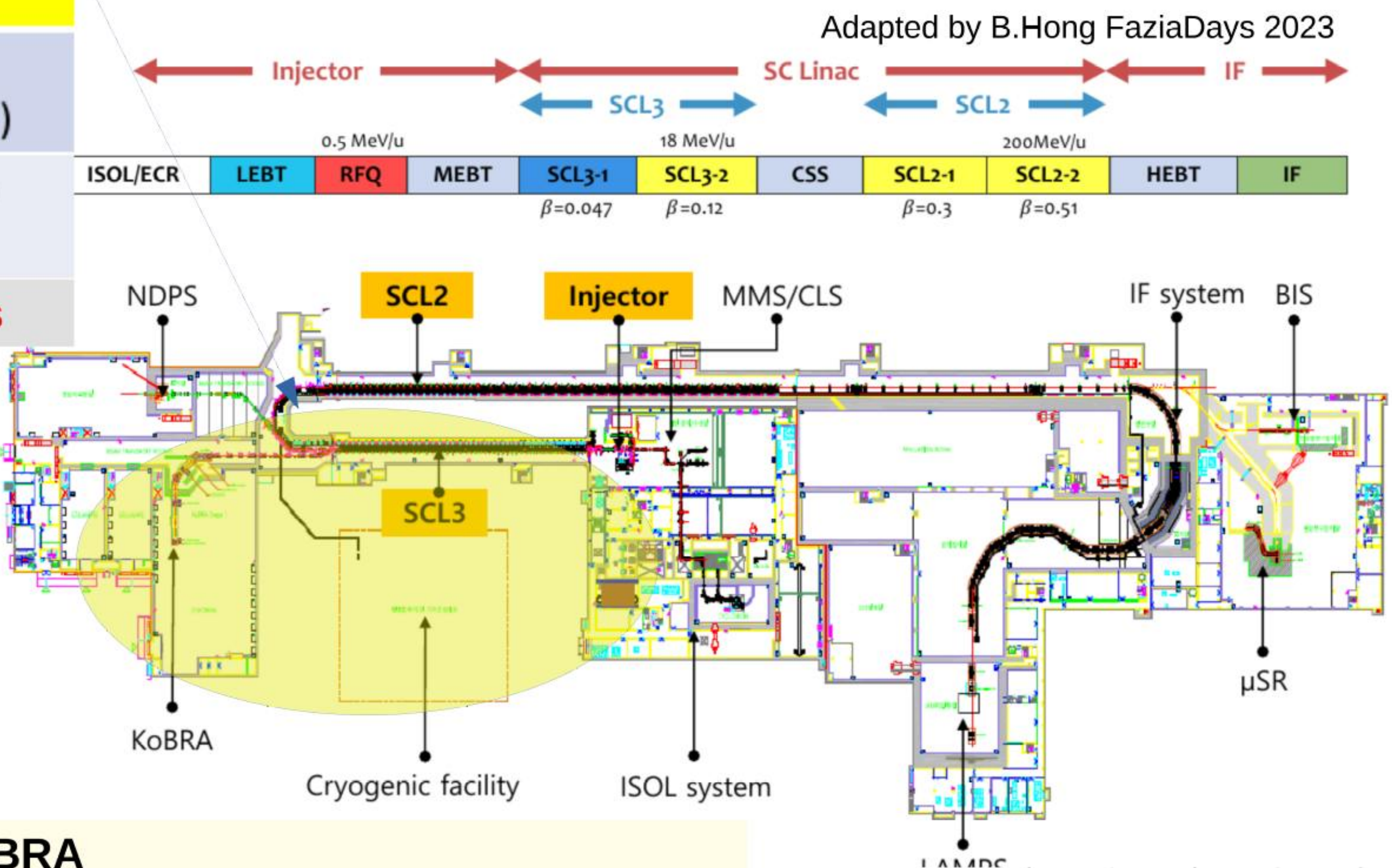
- High quality RI beams by **ISOL & IF**

ISOL: fission fragments from U by 70MeV protons
IF: SC linac system up to 200MeV/u Uranium beams 8pμA

- High-intensity n-rich beams
  e.g. **132Sn 250MeV/u up to 10^9 pps** for users
- Rich variety of exotic beams via combination of IF and ISOL

Mid-term FAZIA plans at RAON

KoBRA
ECR (SIB) → SCL3 → KoBRA Prod. Target (RIB)
Direct & multi-nucleon transfer reactions
≈20-30MeV/u beams



@KOBRA 31 -5- 2023
First Ar beam delivered on a Carbon target

FAZIA 2024-2029 at KOBRA

- Tests of new detectors-electronics
- Some experiments using the KOBRA facility (stable and exotic beams)

IFS: ^{238}U(200 Mev/u, 400 kW) + C

KOBRA: ^{40}Ar(30 MeV/u,12 kW) + Be

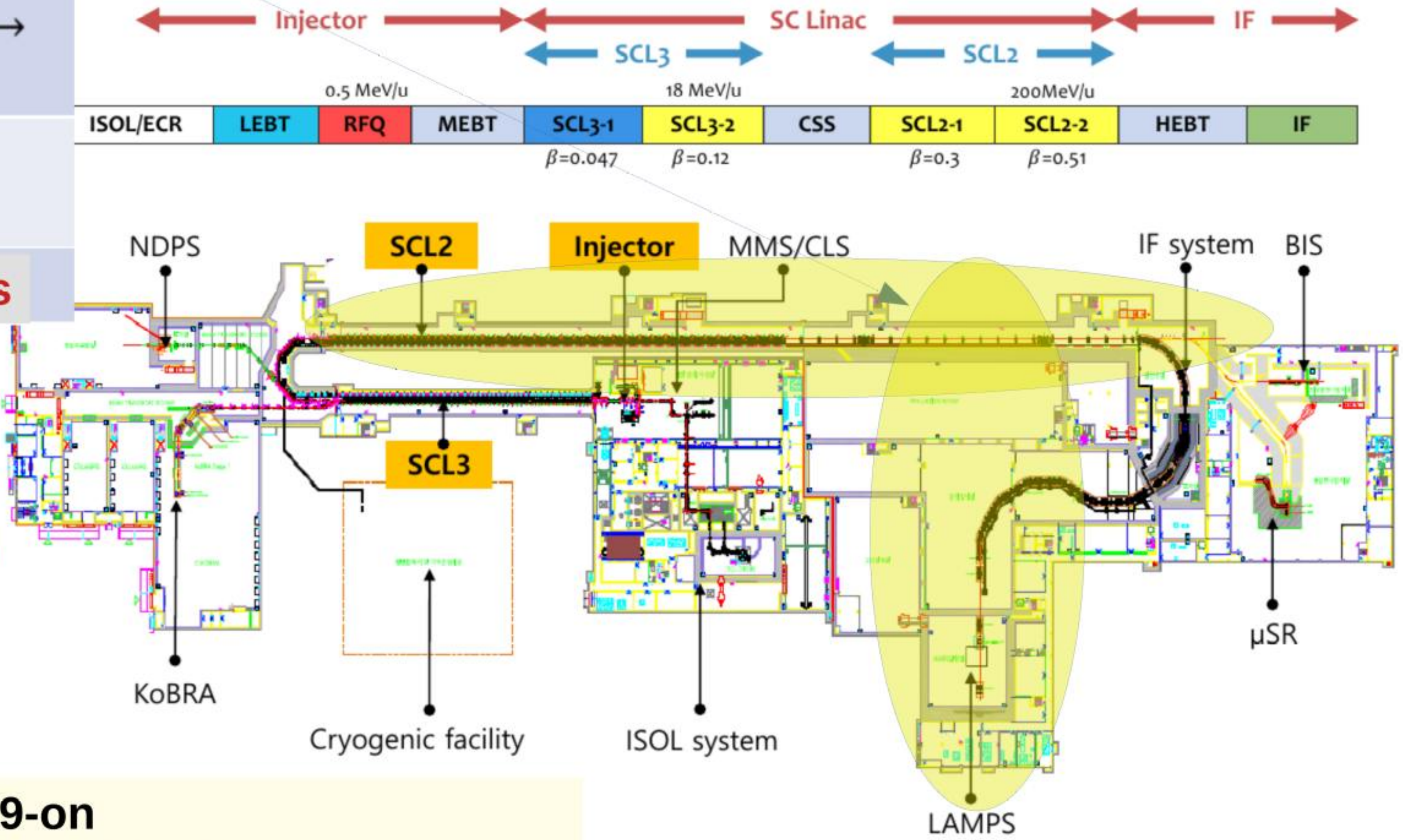
ISOL: p(70 MeV, 70 kW)+UC_x

ISOL+IF: ^{140}Xe(222 MeV/u, 1E+07 pps)+ C

Long-term FAZIA plans at RAON

IF separator
ECR (SIB) / ISOL (RIB) → SCL3 → SCL2 → IF (RIB)
PF, U fission
≈200-250MeV/u beams

Adapted by B.Hong FaziaDays 2023



The SC high-energy sector will be completed around 2029, at now.

FAZIA at LAMPS from 2029-on

- Very preliminary programs/intentions
- Use of FAZIA blocks for mid-velocity emissions and for target spectator fragmentation
- Energies around 250MeV/u;
- Reference beams: n-rich Xe,Sn

SYM23

IFS: ^{238}U(200 Mev/u, 400 kW) + C
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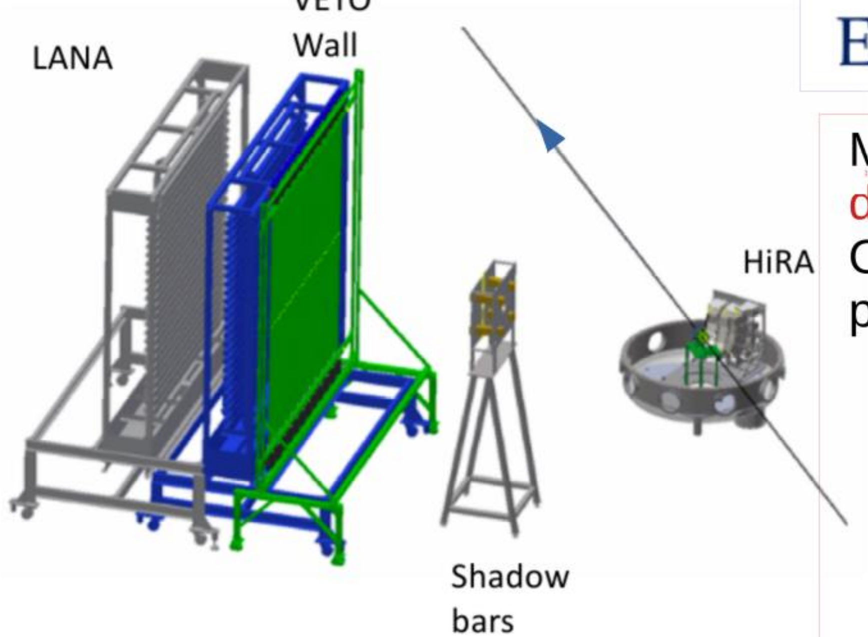
Perspectives at FRIB/MSU

- Longstanding contacts between members of FAZIA and MSU groups.
- Interactions favoured by an approved experiment, the first with exotic Ni-beams (exp 23058, in early 2025)
- Discussion on a collaboration scheme in phases

$^{56,70}\mathrm{Ni} + {}^{58,64}\mathrm{Ni}$

$E/A = 175$ MeV

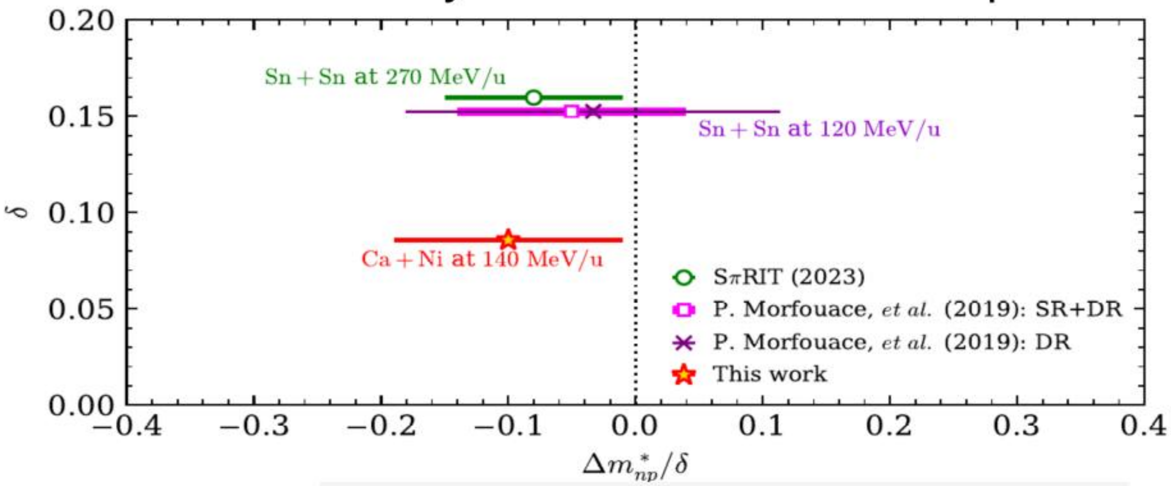
Exotic FRIB beams used



Models predict some sensitivity to effective p,n effective mass differences for high momentum particles.

Observables: Single Y(n/p) and Double Ratios (if beam-target poker combinations)

A recent systematics for effective n-p masses



G.Ca

Slight negative Δm^* emerging

Setup upgradings:

- LANA for neutron detection
- fiber bar (instead of MicroBall) for event and reaction plane selection

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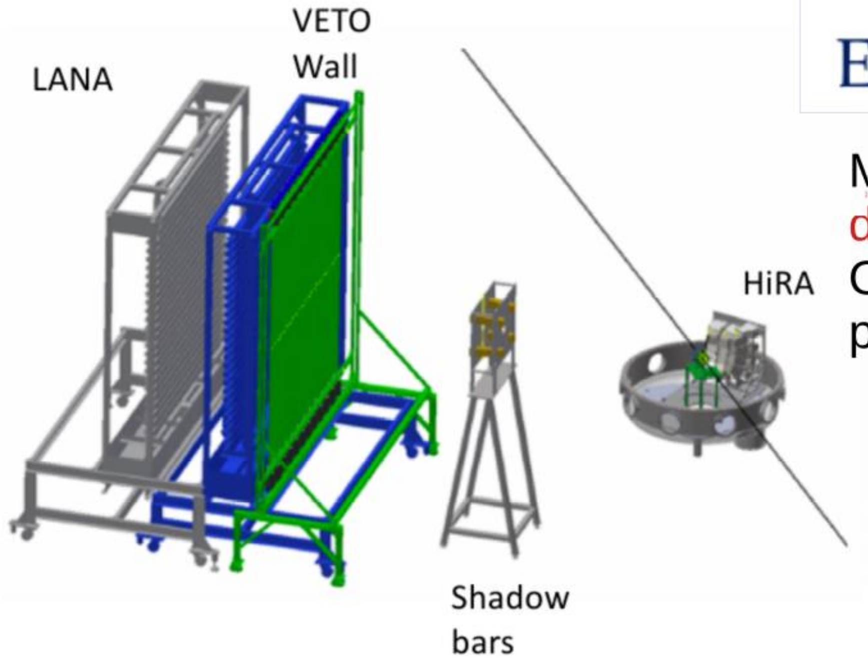
Exotic FRIB beams



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Setup upgradings:
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- fiber bar (instead of MicroBall) for event and reaction plane selection

FIRST PHASE (2023-2026)
INDRA-FAZIA participation to this experiment will permit to consolidate programs.
Some aspects to be investigated:
- Exotic beam diagnostics (chemistry and optics)
- Neutrons vs charged species balance for physics
- Isotopic separation for spectators (Z-range, E-thres.)
- Improve centrality and reac. plane selection

G.Ca

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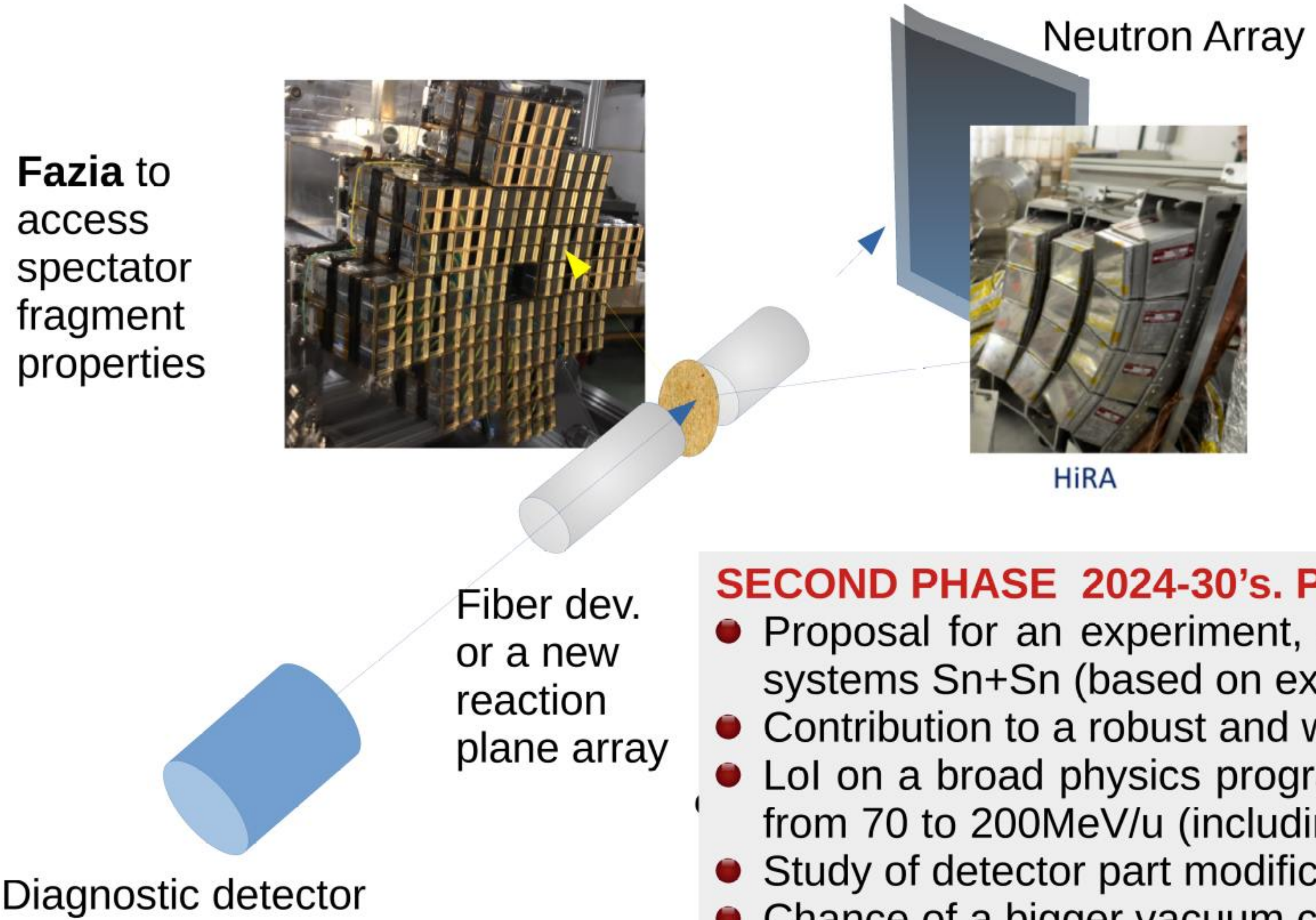


As a very preliminary hypothesis

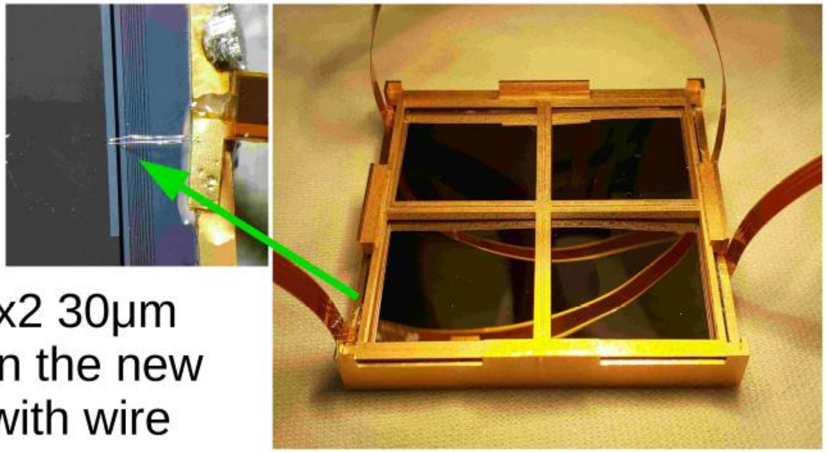
SECOND PHASE 2024-30's. Possible points:

- Proposal for an experiment, same Ni-energies but heavier systems Sn+Sn (based on exotic 132Sn beam)
- Contribution to a robust and wide test of models
- LoI on a broad physics program at FRIB with exotic beams from 70 to 200MeV/u (including clustering and QP breakup)
- Study of detector part modification or substitution
- Chance of a bigger vacuum chamber

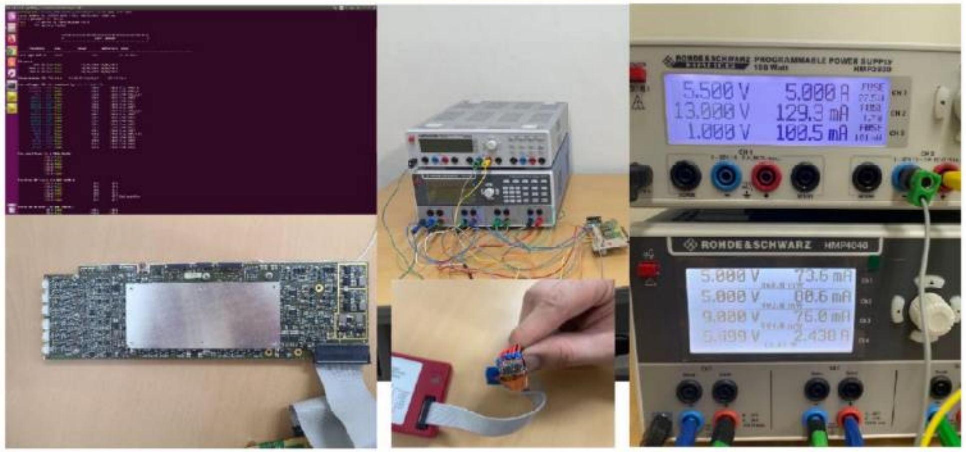
Sectors of R&D

Detectors

- Si1 stage: going thinner (20-30µm) for very low thresholds (Z-ident)
- Si2 stage: going thicker (750-1000µm) for above 70MeV/u (Z,A ident)
- CsI crystals: evaluate higher granularity
- Which detector for diagnostics?
- Timing detectors?



Florence lab:
Prototype of 2x2 30µm thick Sensor in the new FAZIA holder with wire bonding



South KOREA:
The new FAZIA lab and the new FEE

Electronics

- Fighting against obsolescence (FPGA and not only)
- Simplifying the design (space, components, heat production, firmware)
- Creating local labs for detectors and equipment tests (South Korea, GANIL)

INDRA FAZIA

Conclusions/Questions

- The INDRA-FAZIA collaboration obtained high-quality experimental data at Fermi Energies to investigate the EOS and the fragment/cluster formation and decay
- Focus on semiperipheral collisions: QP decay and "neck-like" emissions
- Activity at GANIL to be continued next years
- Opportunities given by the RAON and FRIB exotic beams also at suprasaturation density
- Our expertise on sensors and electronics can be shared for new initiatives

Questions Physics:

- at what extent neck and quasi-spectator emissions are important from 50 to 400MeV/u
- Clusters in dilute sytems (core-crust n-star interface): how to progress?

Questions Detectors:

- how to do a step forward in reac.plane and impact parameter determination?
- How crucial is diagnostics for RIB?

Spare SLIDES

INDRA-FAZIA and the regions of the Esym

FAZIA activity (2010-2021)
LNS and GANIL
C,S,Ne,Ca, Ni,Kr beams from 25 to 52MeV/u

SEMIPERIPHERAL
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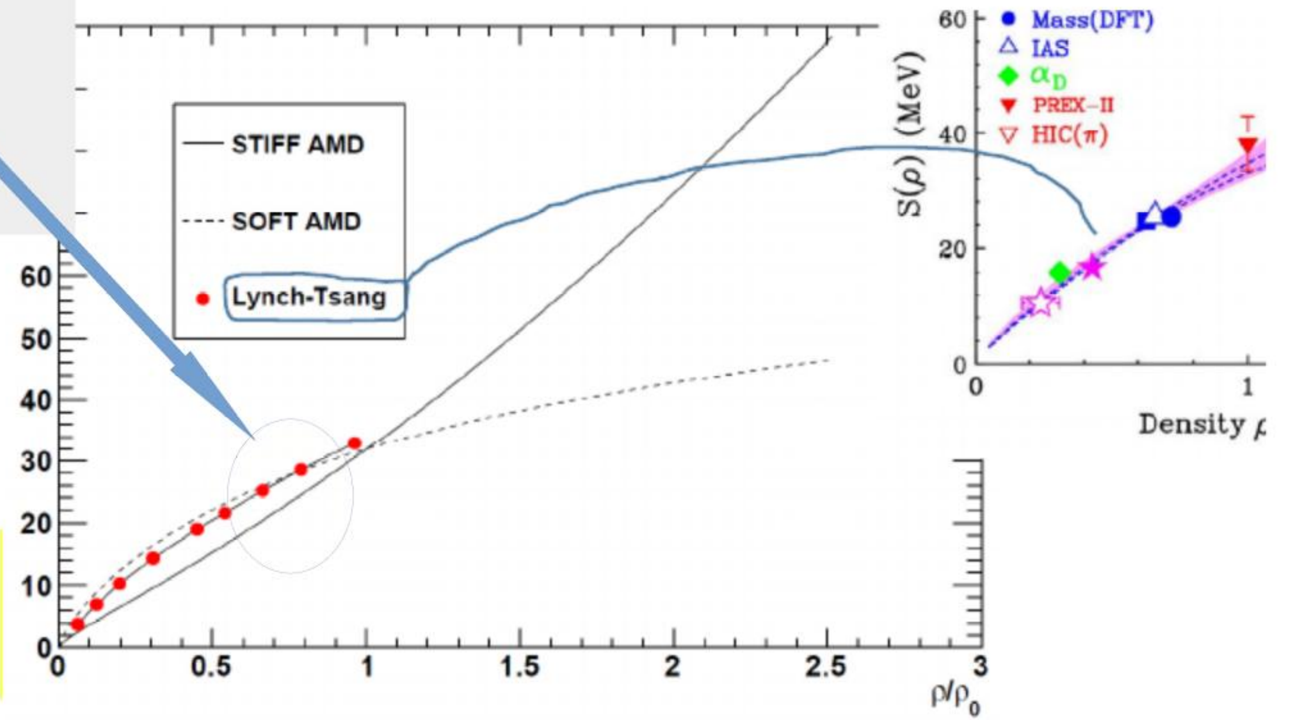
PL B 830 2022



PLOT L vs. rho in **AMD**
The two limiting asy-stiffness choices

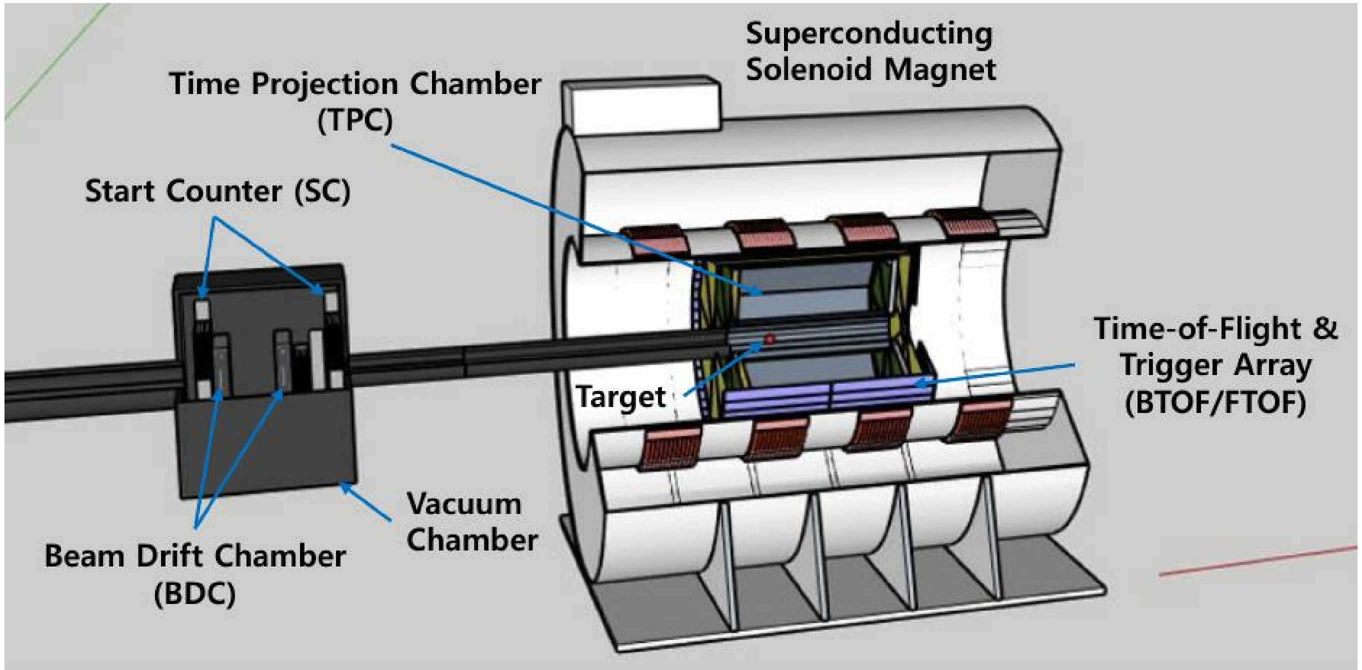
Findings by our experiments (based on average N/Z of fragments and 2nd moments)

- slight sensitivity to the Esym stiffness, at least within AMD
- weak overall tension toward a stiff choice but we are observing processes over a wide impact parameter range and it is difficult to define the region of density competing to the different bins.

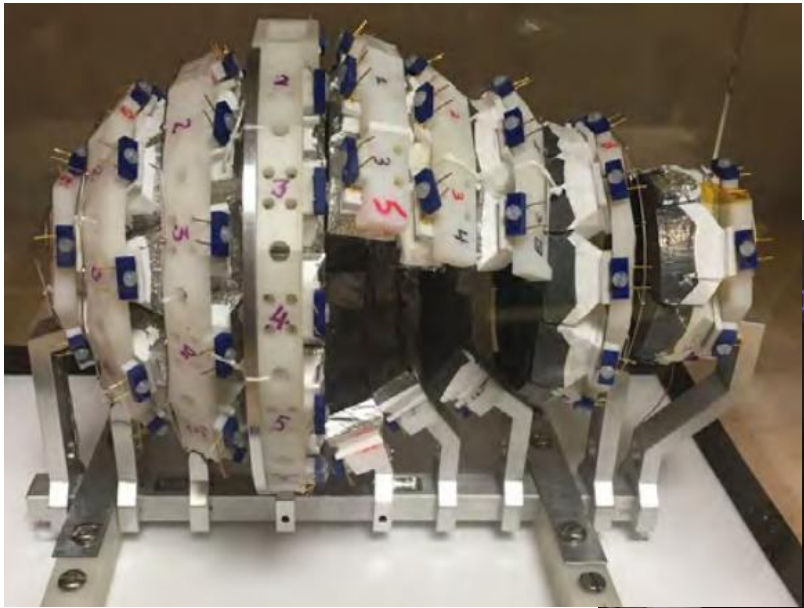
RAON: The high energy SECTOR

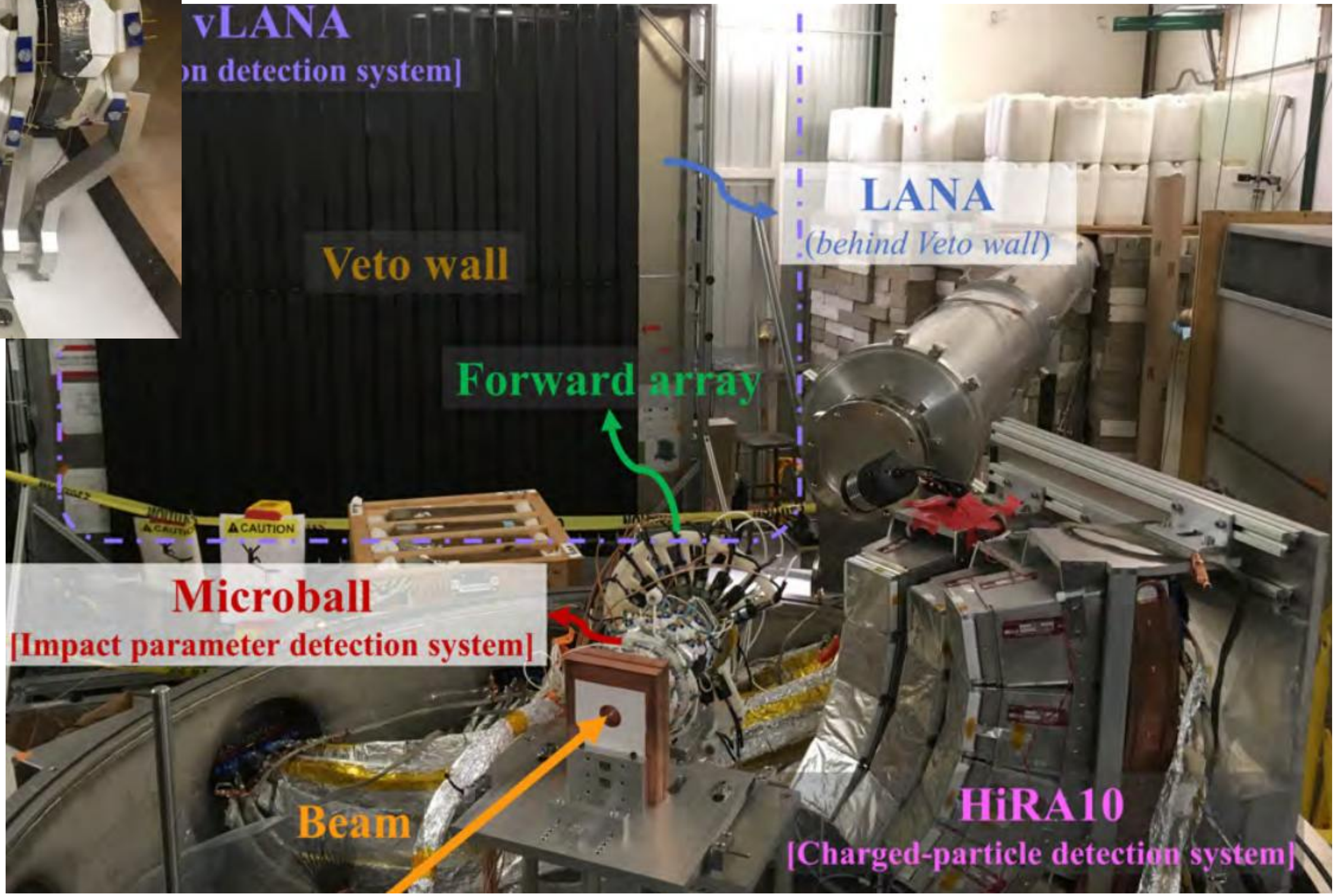
Large Acceptance Multi-Purpose Spectrometer

- Beam energies up to 250 MeV/u for ^{132}Sn with an intensity as large as 10^8 pps
- Comprehensive detector system to investigate the nuclear equation of state (EoS) and symmetry energy
- All detector components and magnet were already developed, manufactured, and assembled.
- Integration and commissioning of the whole LAMPS system is being planned at the end of 2023.



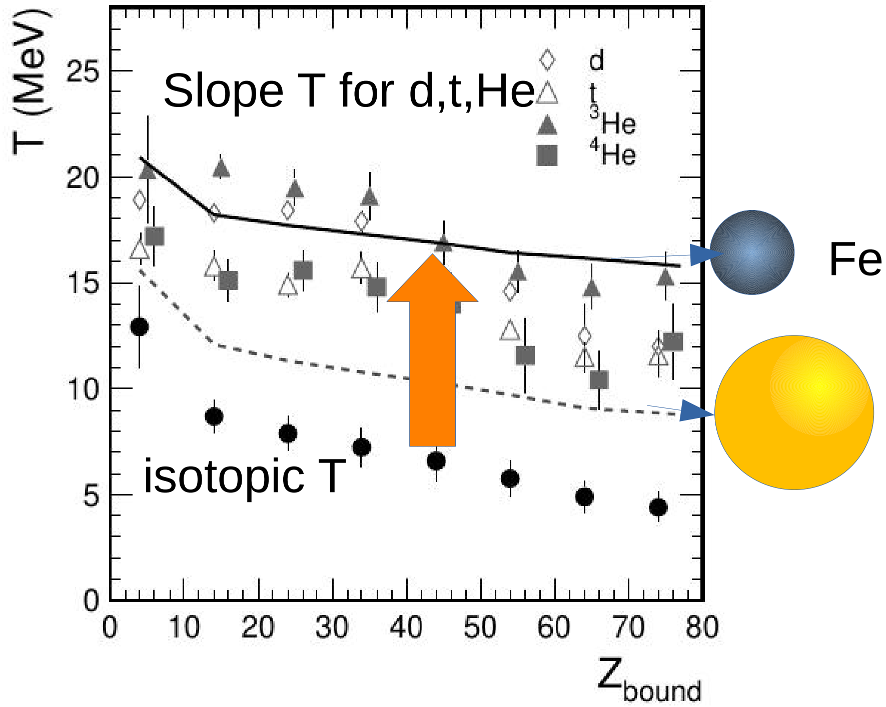
Set Up used in E15190 (2018)
Ca+Ni,Sn isotopes 56,140MeV/u stable beams





Some questions about thermal features in spectator fragmentation

Odeh PRL 84, 2000



AuAu1GeV/u

Fermi gas at saturation v=V0

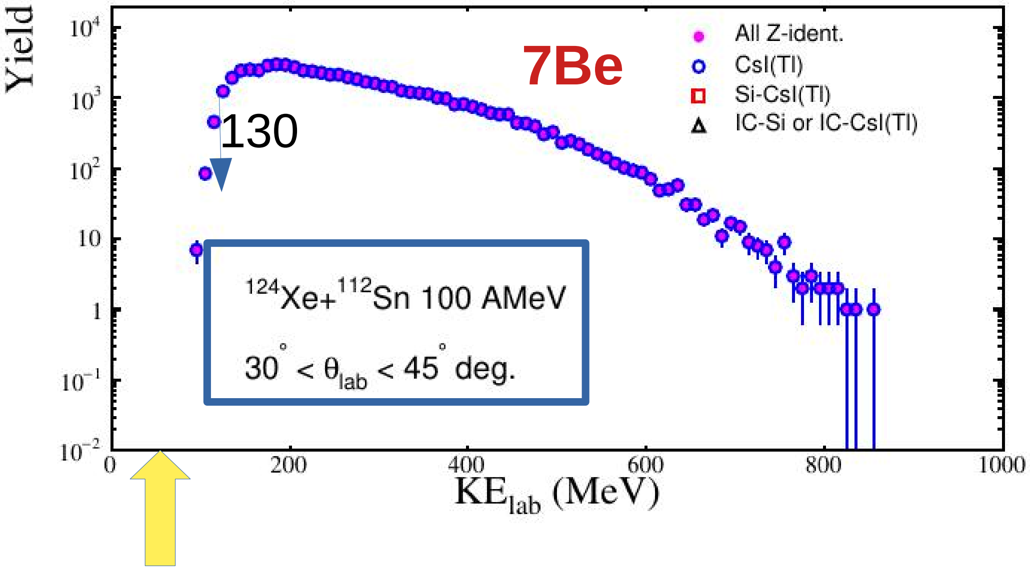
Expanded Fermi gas source v=3*V0

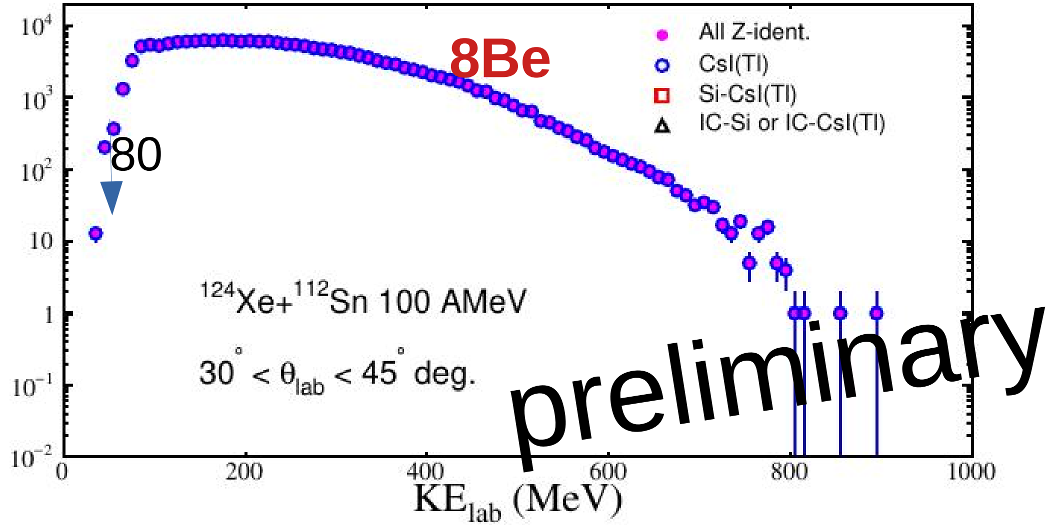
The disagreement between Slope T and Isotopic T can origin from the contribution of Fermi motion in early life of spectator fragments (depending on density)

OPEN POINTS

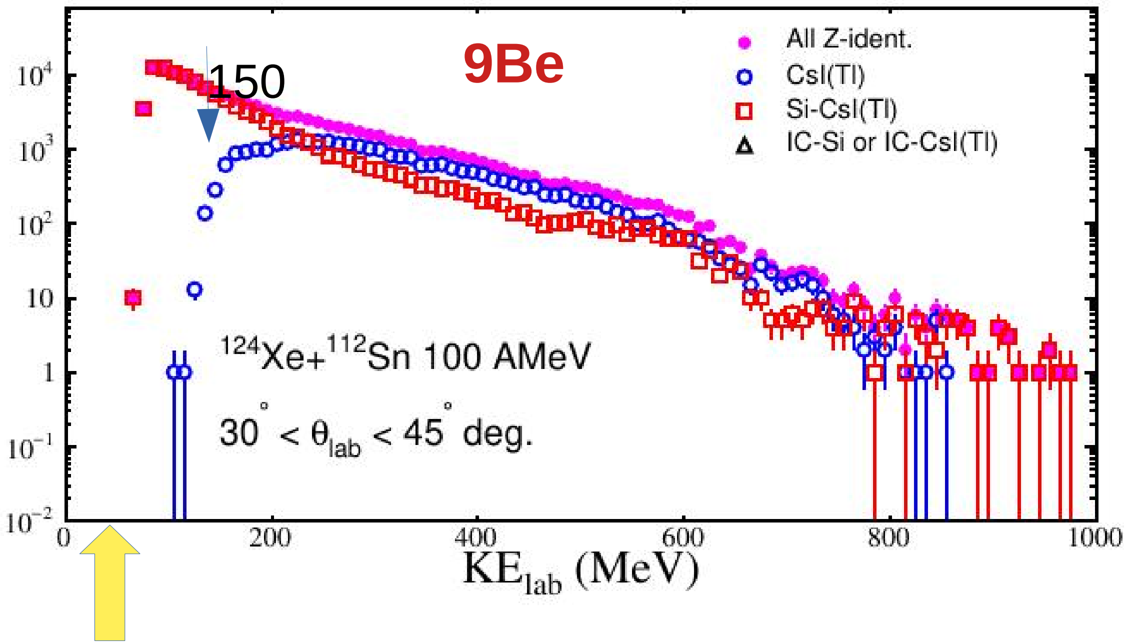
Never checked with fragments
Collective contribution not clarified
New insights about n-rich nuclei multifragmentation

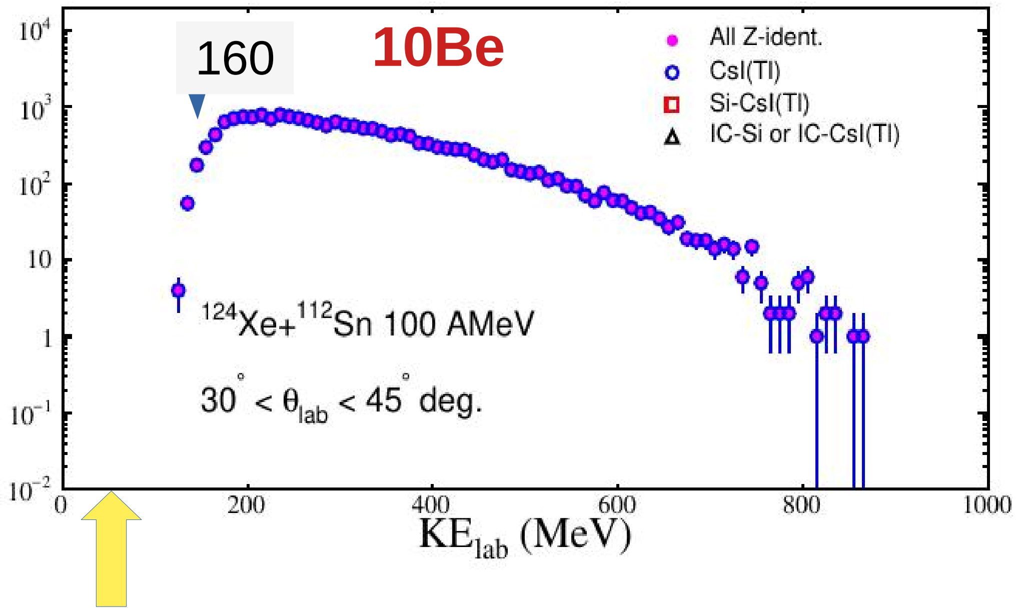
About target-spect fragments:
Compare old INDRA IMF data (GSI campaign)





Yellow arrow: thresholds for Be in FAZIA Z_{th}=14MeV A_{th} around 30MeV

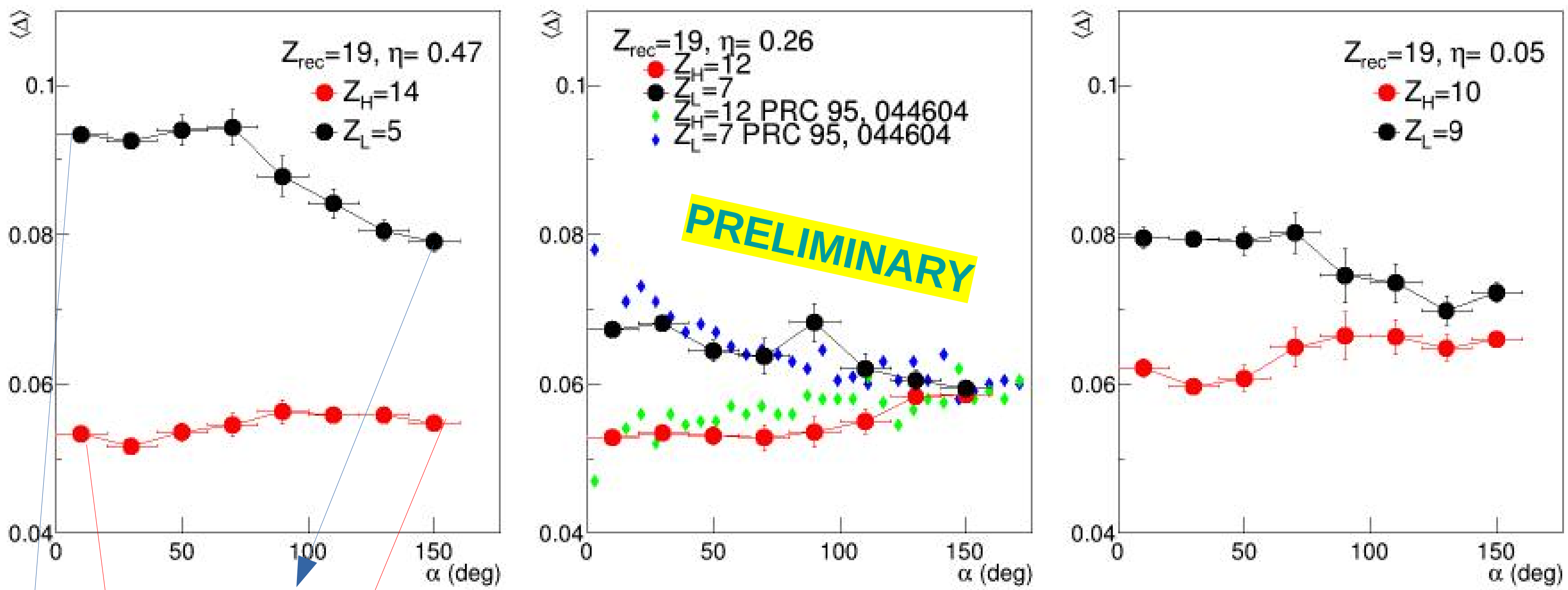


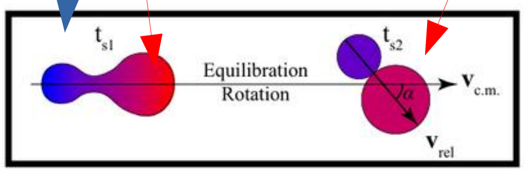


On going BU studies

- **Observables: n-content of both BU-fragments from QP (Ni-like)**
- **Confirmed exp results (US group) about trends in Zn+Zn**
- **Doubts on interpretation… further proposals at Ganil PAC**

$$^{58,64}\mathrm{Ni} + {}^{58,64}\mathrm{Ni}$$





C. Ciampi PhD Thesis 2022
C. Ciampi private comm.
Small symbols: Rodriguez-Manso PRC 95 2017

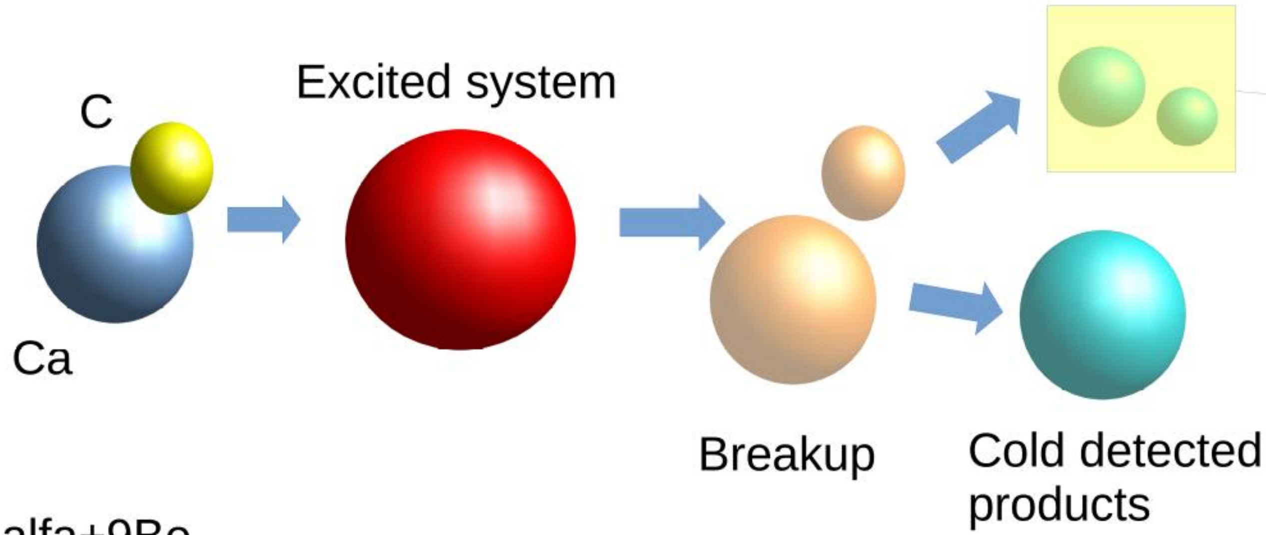
Aymmetric split

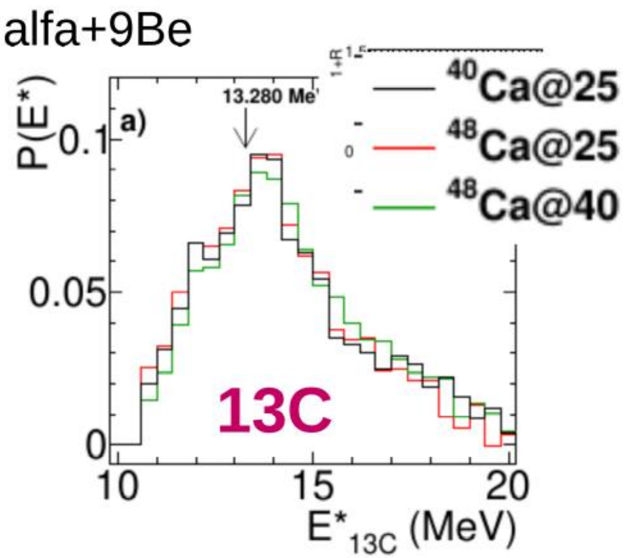
Symmetric split

FAZIA for decay resonances

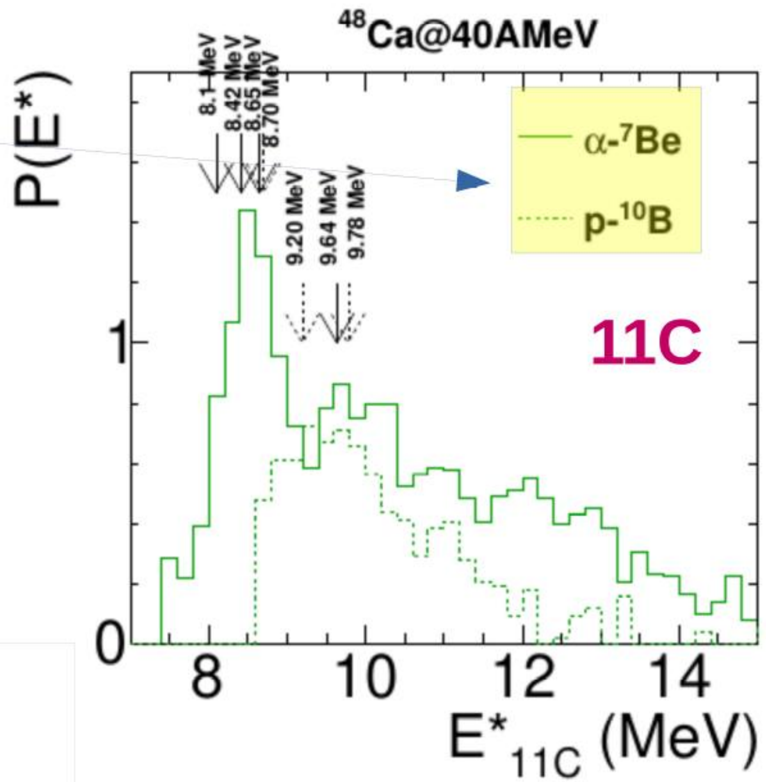
- **Checked the fair capability of FAZIA as a correlator due to its granularity (Δθ=+-0.6deg a 1m)**
- **Particle-fragments correlation studies**

S. Piantelli PRC 106 2023





- Phase space analogy for detected cold and resonant BU fragments
- Same BU process as origin
- Further studies to more quantitative results



E* spectrum of 11C reconstructed via two different decay channels