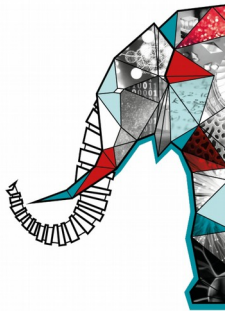
INDRA FAZIA

GANIL laboratoire commun CEA/DRF – spiral2 – CNRS/IN2P3

25e Congrès Général de la Société Française de Physique



Étude de l'équation d'état de la matière nucléaire : INDRA-FAZIA, un dispositif expérimental innovant au GANIL

M. Henri
Pour les collaborations INDRA & FAZIA

cnrs dépasser les frontières

DE LA RECHERCHE À L'INDUSTRIE cea

RÉGION NORMANDIE

INDRA & FAZIA collaborations

GANIL
LPC Caen
IPN Orsay
SUBATECH Nantes

INFN Sez. di Firenze
Univ. di Firenze
INFN LNS, Catania
INFN Sez. di Catania
INFN LNL, Legnaro
INFN Sez. di Napoli
Univ. di Napoli
INFN Sez. di Bologna
Univ. di Bologna

Jagellonian Univ.
Univ. of Warsaw

Univ. of Huelva

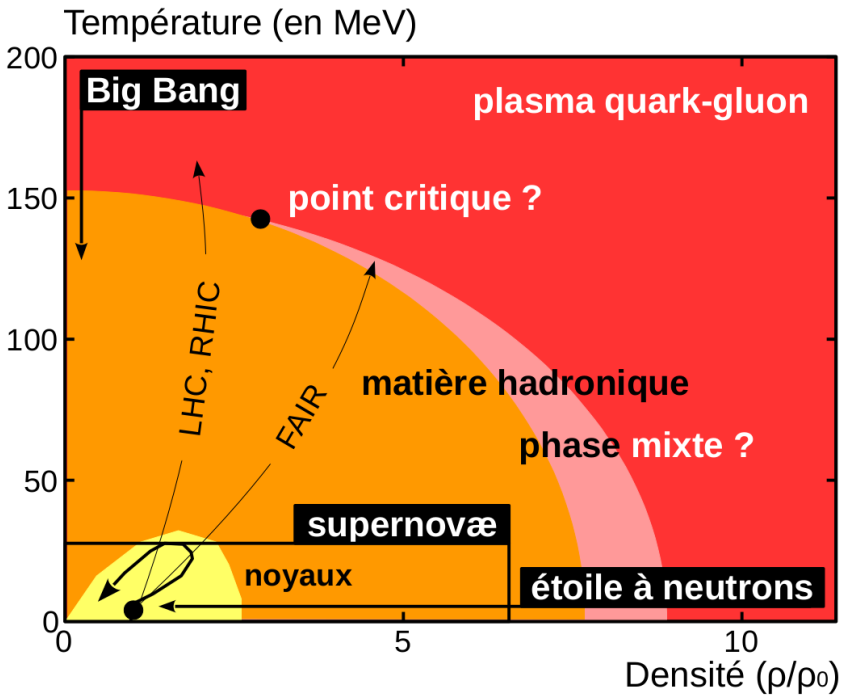
Univ. of Ewha
Univ. of Inha
Univ. of Korea

Studying the **nuclear matter equation of state**: INDRA-FAZIA, an innovative experimental device at GANIL

- Nuclear matter:
  - infinite system of interacting protons and neutrons
  - coulomb interaction and surface effects are neglected

- Describe by its Equation of State (EoS): e(T,ρ,δ)

- Dense matter phase diagram:
  - composition of the nuclear matter in the different regions
  - astrophysical and cosmological implications



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- Dense matter phase diagram:
  - composition of the nuclear matter in the different regions
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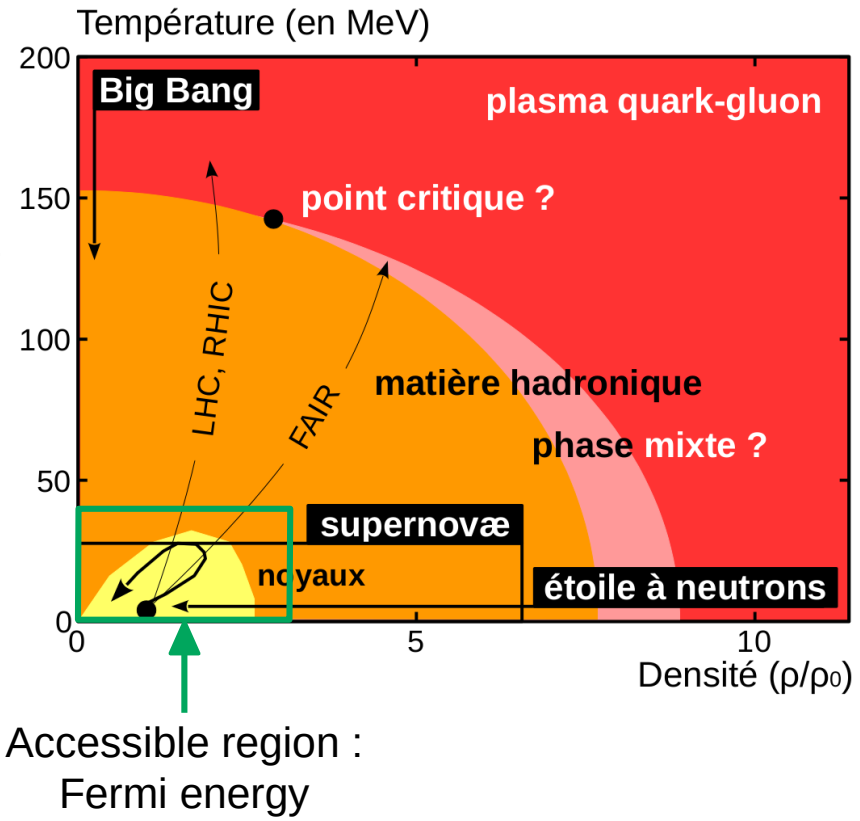
- How to explore this diagram?
  - through Heavy Ion Collisions (HIC)

- Zone of interest:
  - the one of the nucleus
  - degrees of freedom: the nucleons



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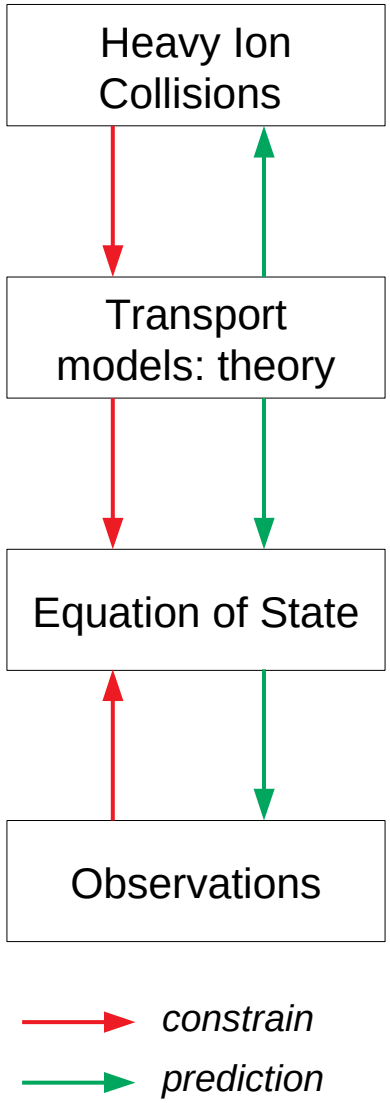
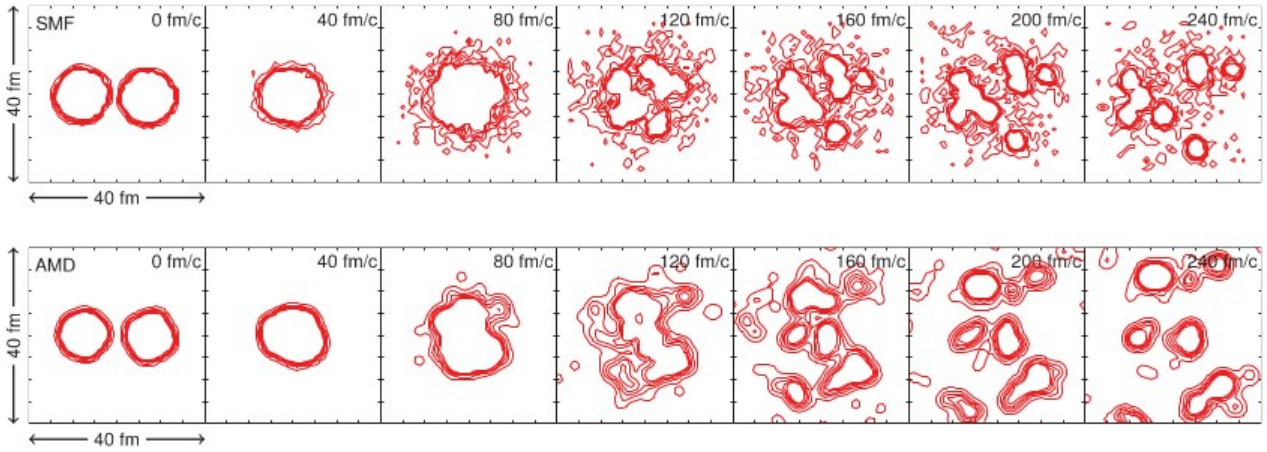


Studying the **nuclear matter equation of state**: INDRA-FAZIA, an innovative experimental device at **GANIL**

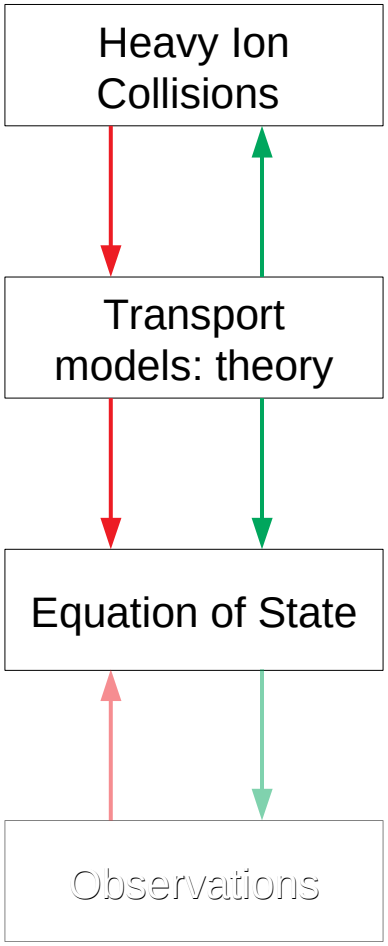
Description of heavy ion collisions :

- Tools = transport models
- Goal = constrain the parameters of the models
  - constrain the EoS of asymmetric nuclear matter

^{112}Sn + ^{112}Sn à 50 MeV/nucleon



Ref: M. Colonna *et al.*, *Phys. Rev. C*, **82**, 054613 (2010)



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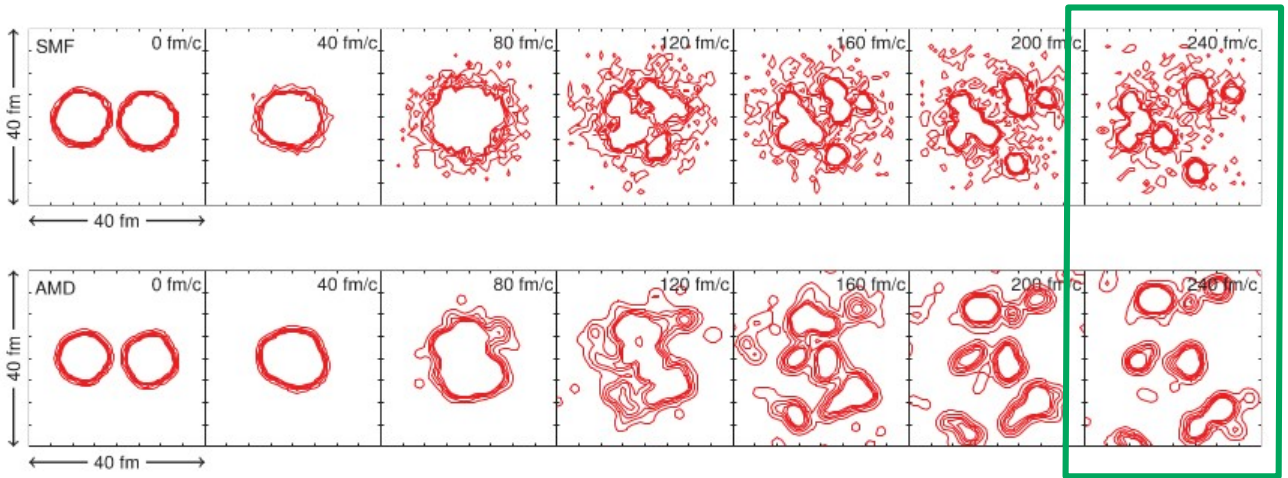

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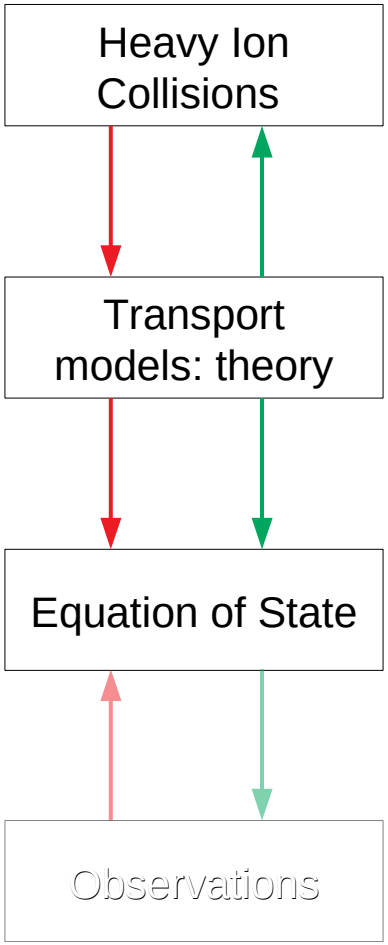
Big amount of reaction products : multi-detector

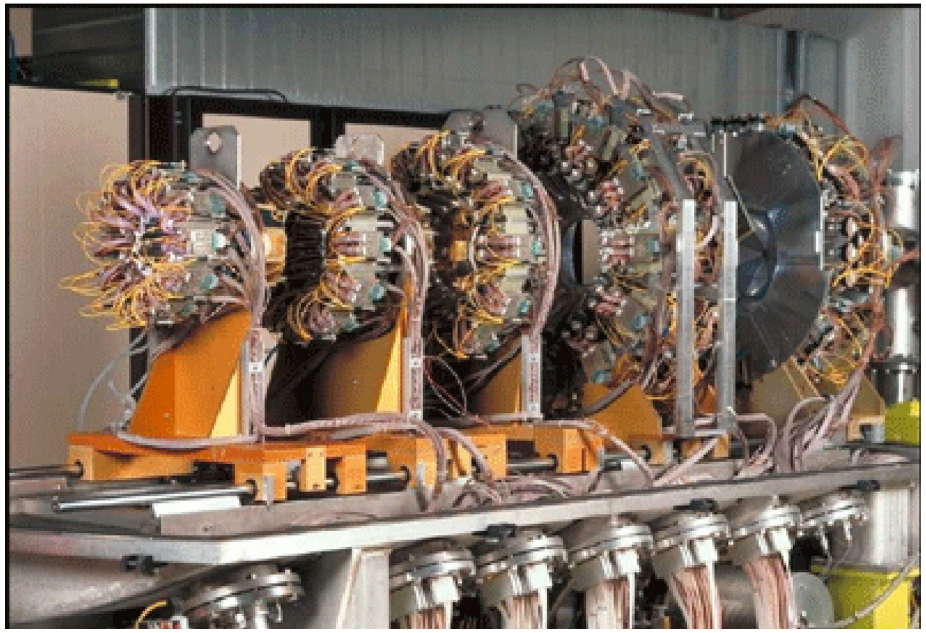


Studying the nuclear matter equation of state:
INDRA-FAZIA, **an innovative experimental device at GANIL**

INDRA : *Identification des Noyaux et Détection à Résolution Accrues*

Multi-detector of charged particles « resident » at GANIL :

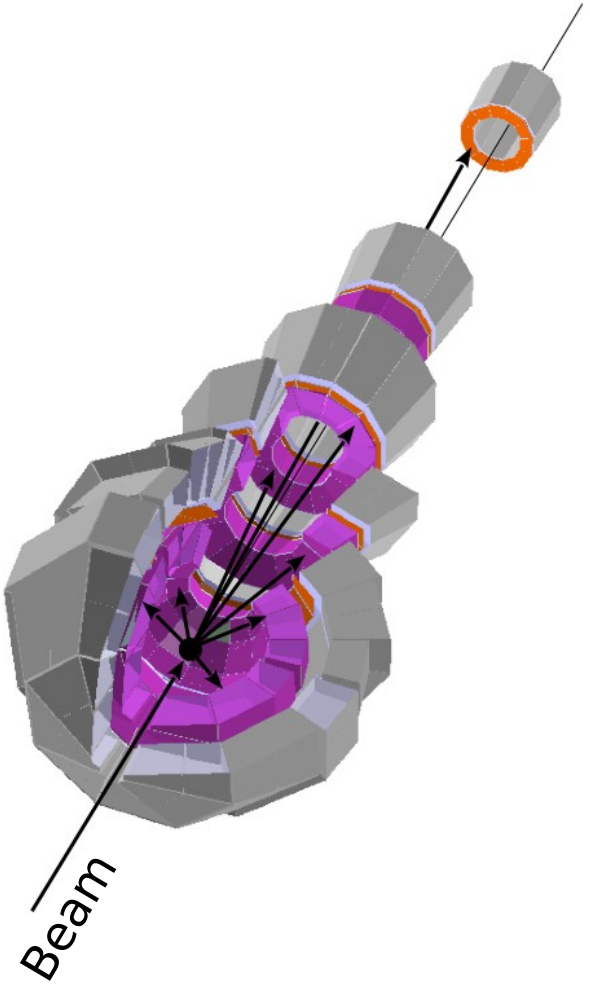
- First experiment in 1993
- Today, database of over 40 combinations projectile/target/energy
  - from 15 to 150 MeV/nucleon
  - from ^{36}Ar + KCl to ^{197}Au + ^{197}Au
- Still working (last experiment April/May 2019)



INDRA : *Identification des Noyaux et Détection à Résolution Accrues*

What is INDRA ?

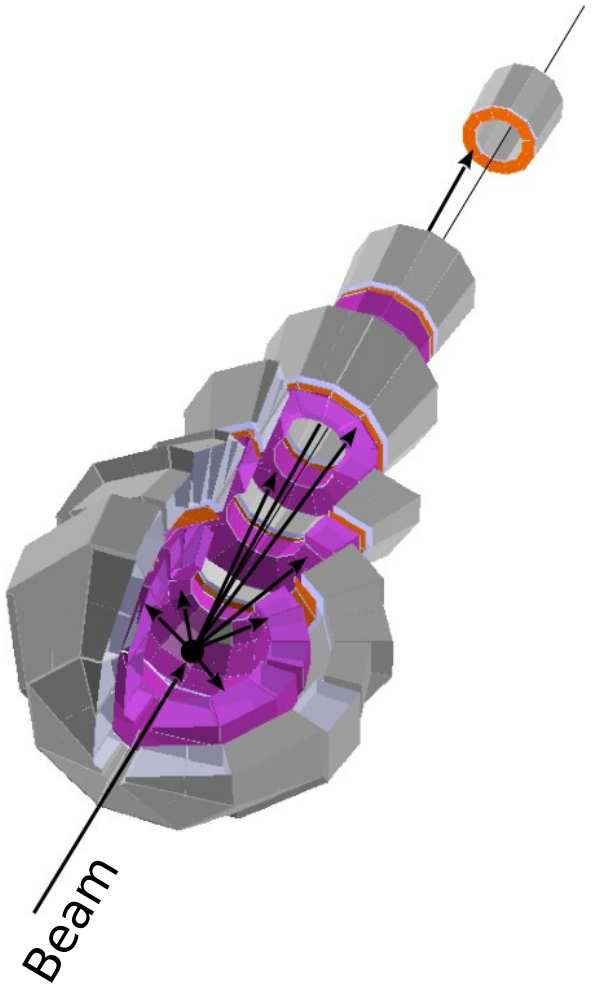
- 336 modules of detections (564 detectors in total)
- Three types of detector:
  - ionisation chamber (IC)
  - silicon (Si)
  - caesium iodide (CsI(Tl))
- 1 detection module = 1 telescope
  - Si – CsI(Tl)
  - IC – Si – CsI(Tl)
  - IC – CsI(Tl)
- 17 rings, cylindrical symmetry around the beam axis
- Wide angular coverage: 90% of 4π



INDRA : *Identification des Noyaux et Détection à Résolution Accrues*

What are its performances?

- Detection of almost all the reaction products
- Low detection threshold (1 MeV/nucleon – IC)
- Identification :
  - in Z – up to Z=92
  - in Z & A – up to Z≤4 (1993), Z≤8 (2001)



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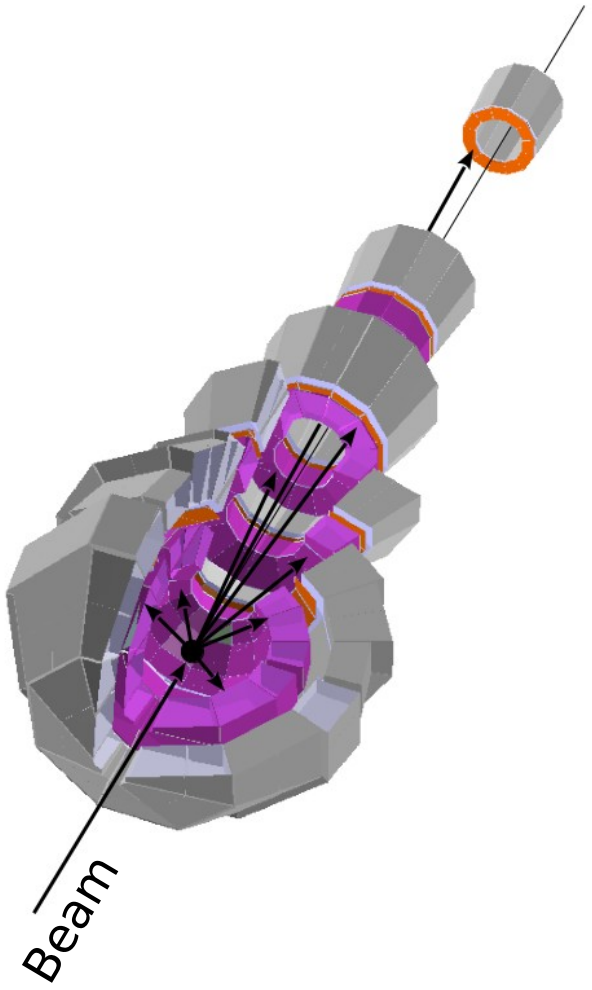
However:

- Fully analogical electronics (old, hard to maintain)
- Complete identification (Z&A) only for Z≤8



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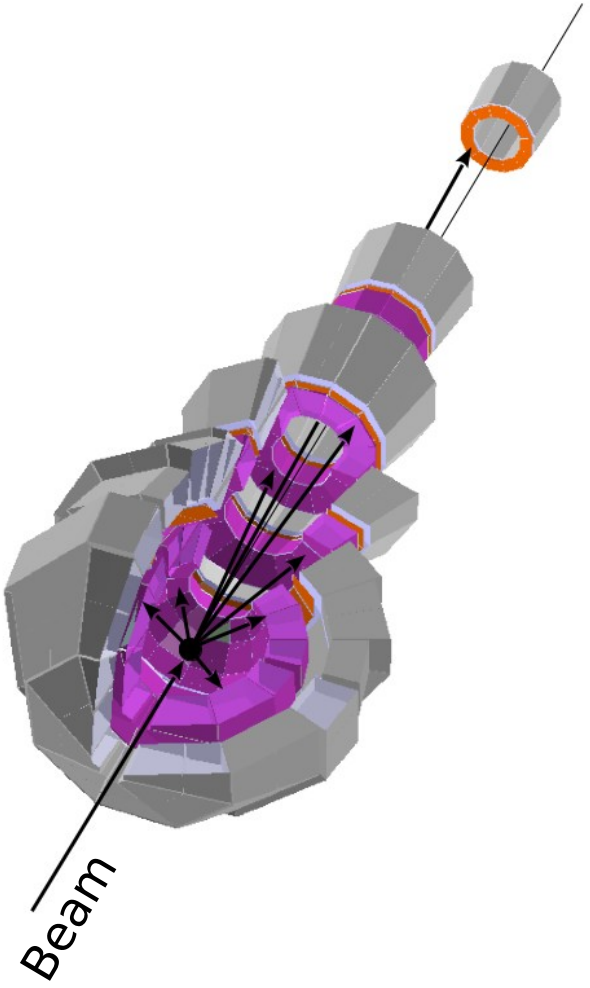
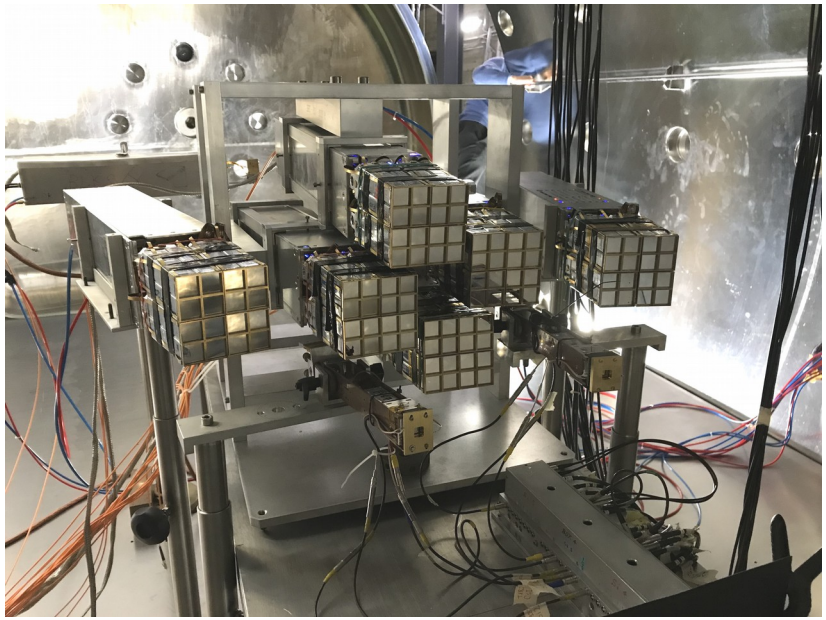
Improvements? **FAZIA !**



FAZIA : *Forward Z&A Identification Array*

New generation of charged particles detection array:

- 10 years of R&D (detectors & electronics)
- First experiment: June 2015, IsoFazia @ LNS Catania (Italie)
- Demonstrator installed in GANIL since the beginning of 2019

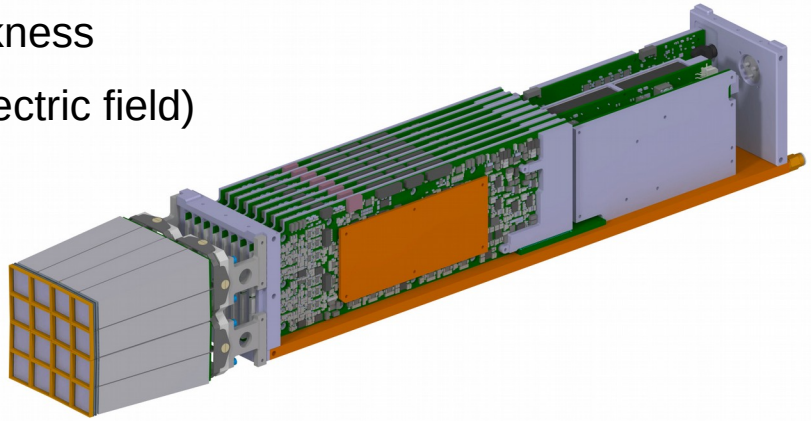


FaziaPre experimental setup, $^{40,48}Ca + ^{12}C$ @ 25,40 MeV/nucleon (LNS Catania, Italy)

FAZIA : *Forward Z&A Identification Array*

What is FAZIA?

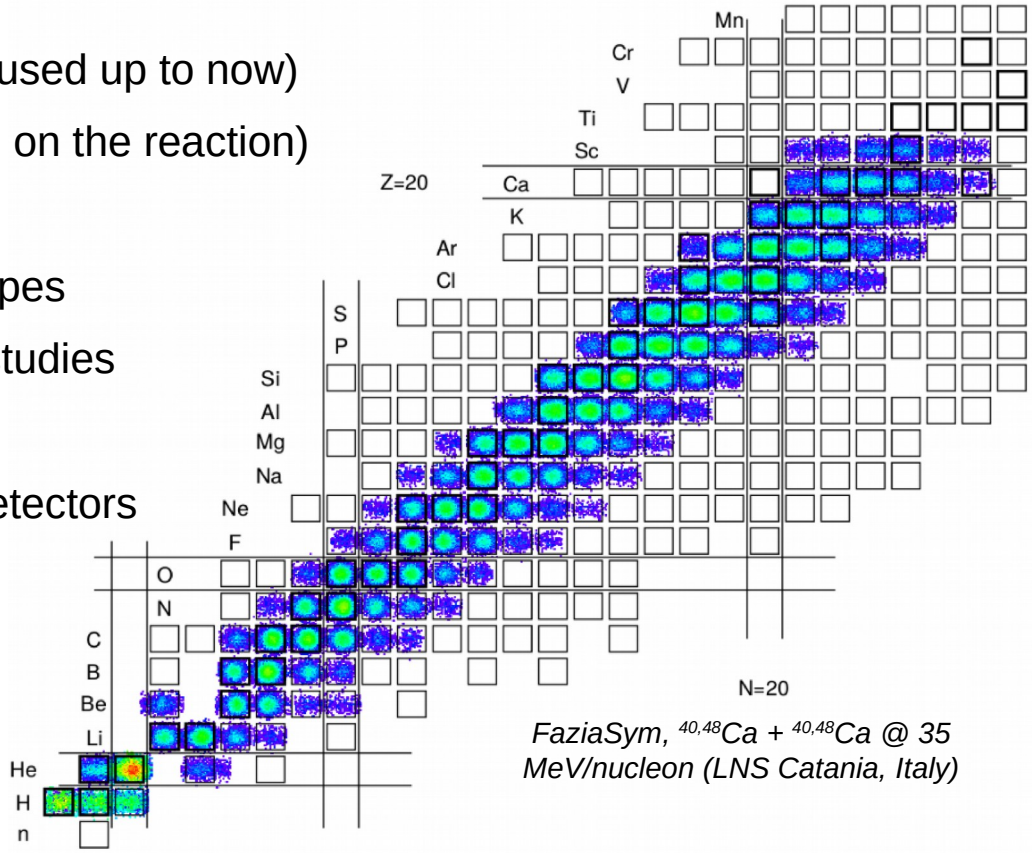
- Modular multi-detector with a block configuration
- 1 bloc = 16 telescopes Si (300 µm) – Si (500 µm) – CsI(Tl) (10 cm)
- Digital electronics, embedded under vacuum (11 cards per block)
  - control of the detectors high voltages, thresholds, ...
  - signals are sampled close to the detectors and their preamplifiers
  - slow control
- Silicon(2x2 cm^2):
  - tilted with respect to the main crystal axis
  - uniform resistivity (nTD process), uniform thickness
  - reverse mounted (particles enter by the low electric field) to enhance the signal dynamic range



FAZIA : *Forward Z&A Identification Array*

What are its performances?

- Identification
  - in Z – up to Z=54 (heavier projectile used up to now)
  - in Z & A – up to Z≤20-25 (depending on the reaction)
- Spatial resolution
  - high granularity : 16 2x2 cm^2 telescopes
  - very good resolution for correlation studies
- Digital electronics
  - Pulse Shape Analysis (PSA) in all detectors
  - lower the detection threshold



FaziaSym, ^{40,48}Ca + ^{40,48}Ca @ 35 MeV/nucleon (LNS Catania, Italy)

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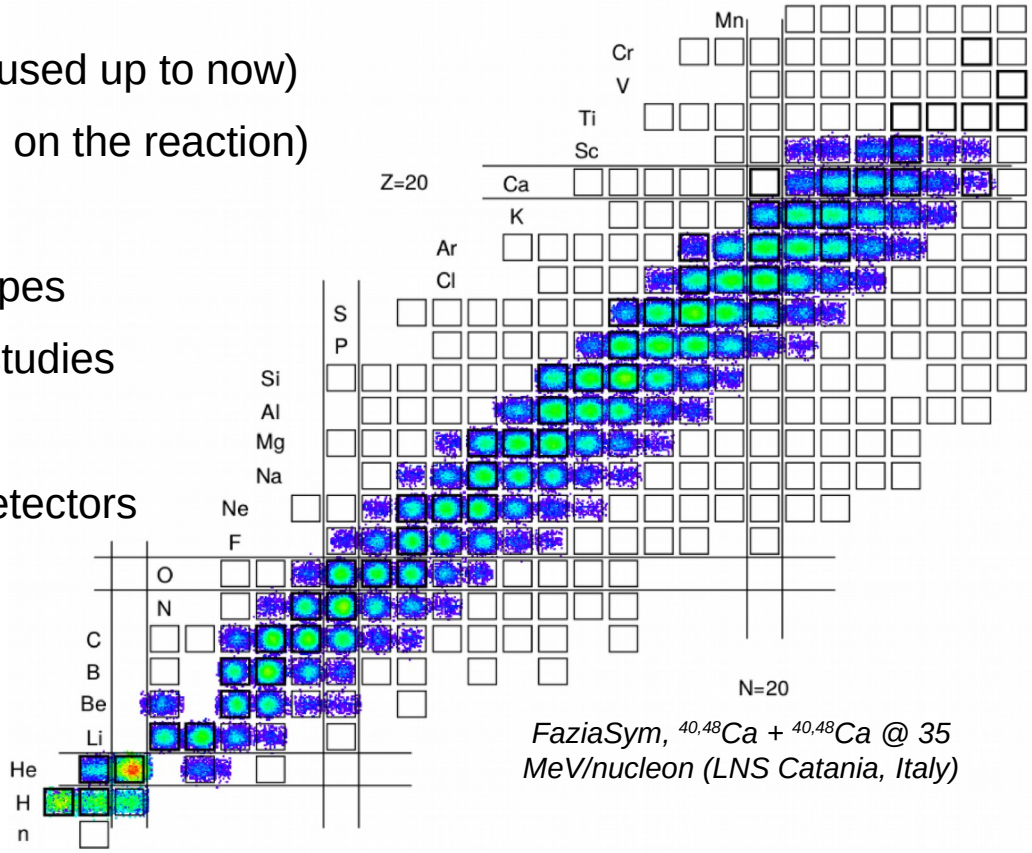
What could become a problem:

- 1 block: (70x10x10) cm^3 & 15 kg



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INDRA-FAZIA: a unique tool

To probe the nuclear matter EoS we need:

INDRA-FAZIA: a unique tool

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- to detect all the products of the reaction

INDRA

Wide angular coverage

INDRA-FAZIA: a unique tool

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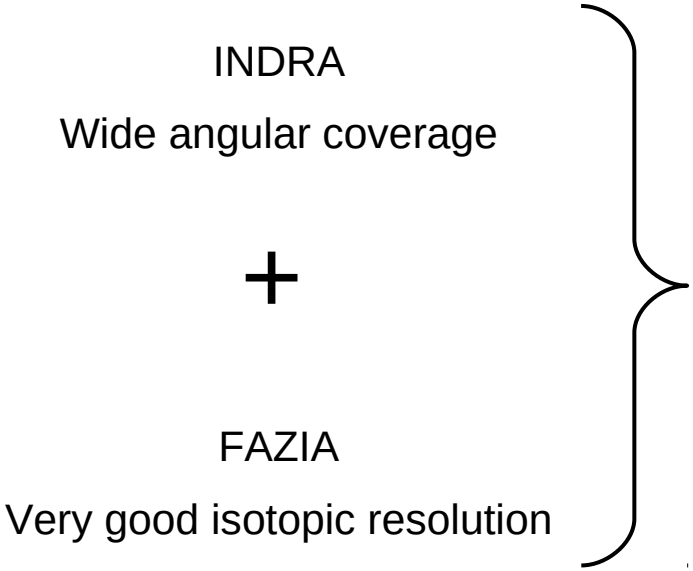
- to detect all the products of the reaction
- to know their charge Z and mass A



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INDRA

Wide angular coverage

+

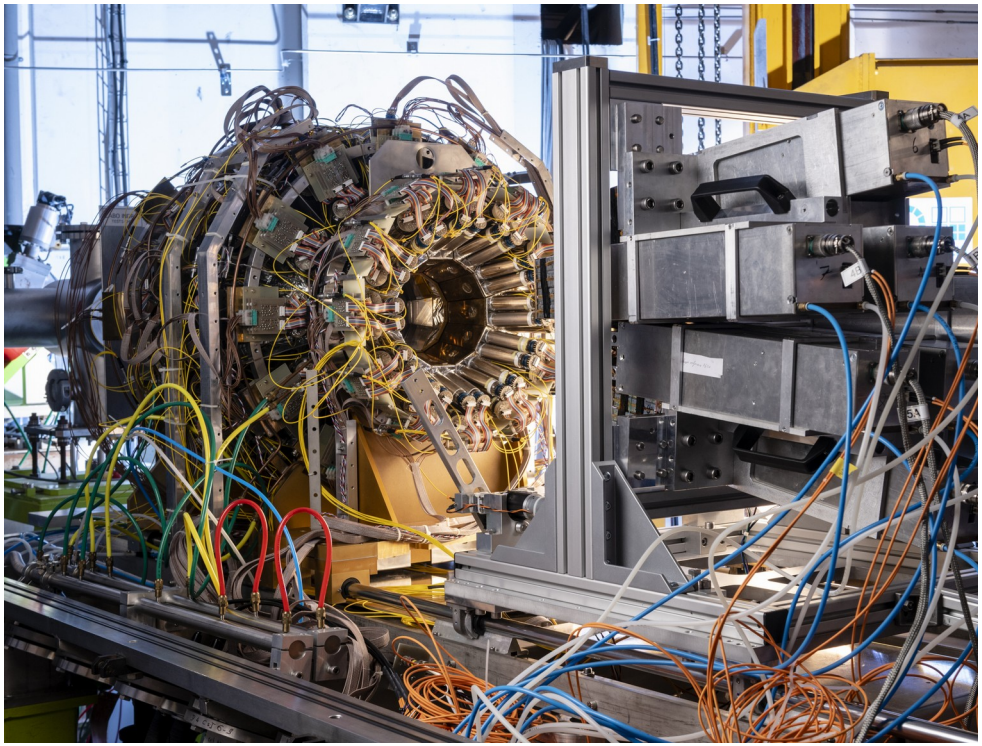
FAZIA

Very good isotopic resolution

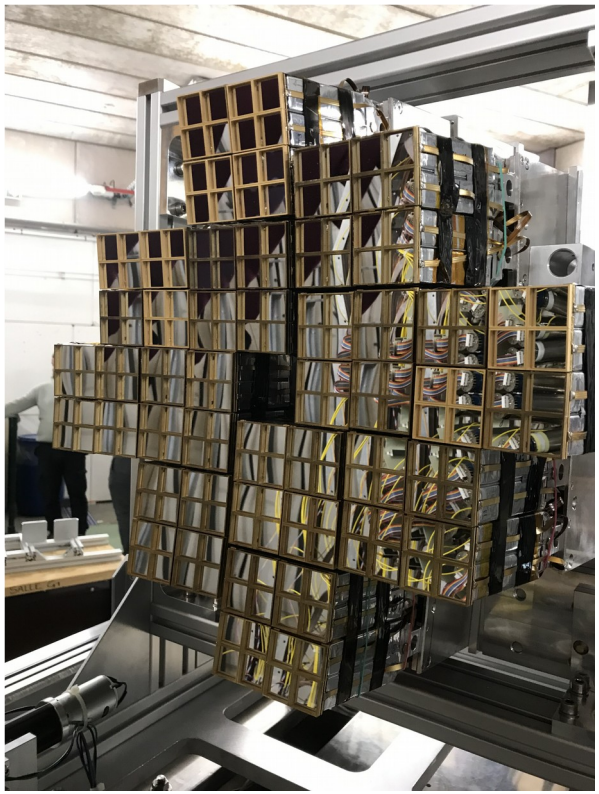
INDRA-FAZIA: a unique tool

What is INDRA-FAZIA?

- INDRA: rings 6 to 17 (14° to 178°)
  - Si – CsI(Tl) up to ring 9 (45°)
  - CsI(Tl) from ring 10 to 17



- FAZIA demonstrator (12 blocks):
  - Si – Si – CsI(Tl) from 1.5° to 12.5°



INDRA-FAZIA: a unique tool

Acquisition coupling:

- To construct the physical events we need a universal clock – the CENTRUM (10 ns cadenced clock)

INDRA acquisition (VXI,VME)	CENTRUM	FAZIA acquisition (Regional board)

INDRA-FAZIA: a unique tool

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→ *Trigger conditions fulfilled – request of a timestamp*

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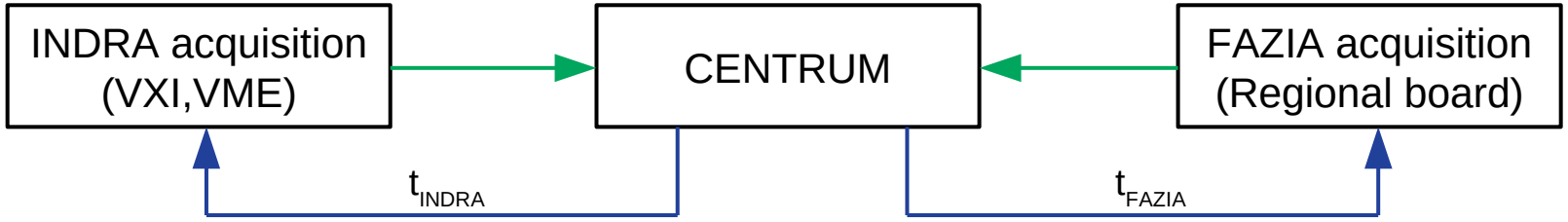

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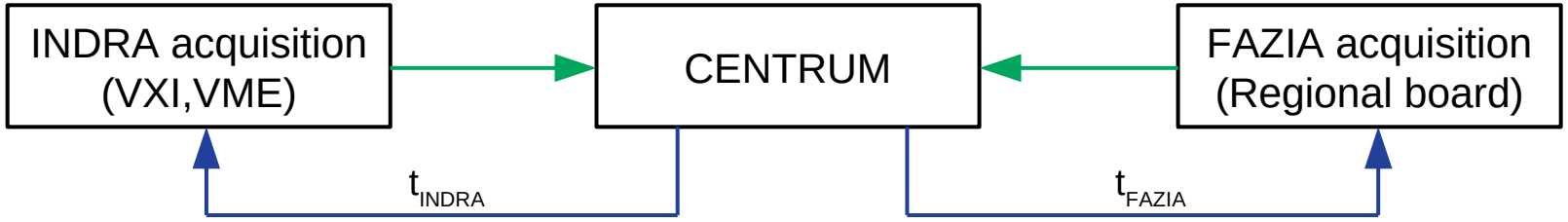

Trigger conditions fulfilled – request of a timestamp

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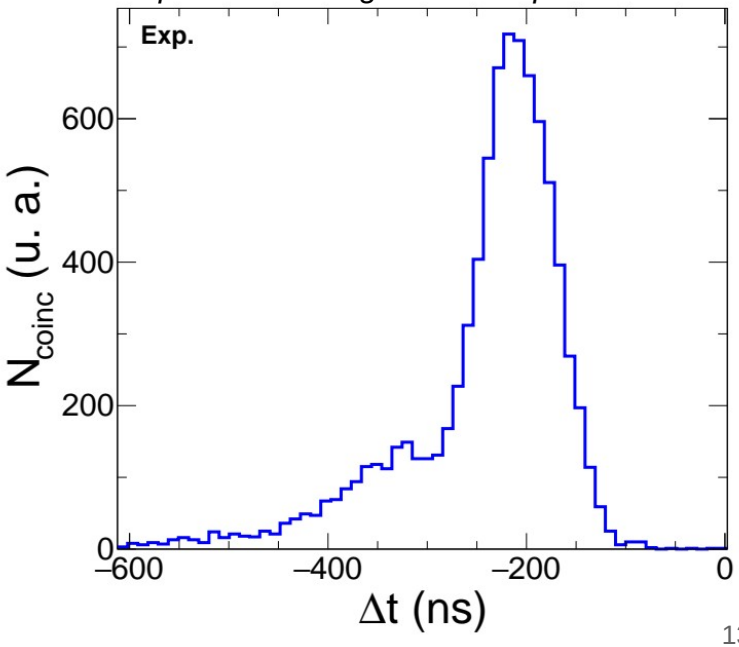
Test beam: ^{13}C + ^{58}Ni @ 50 MeV/nucleon
Experiment configuration – April 2019



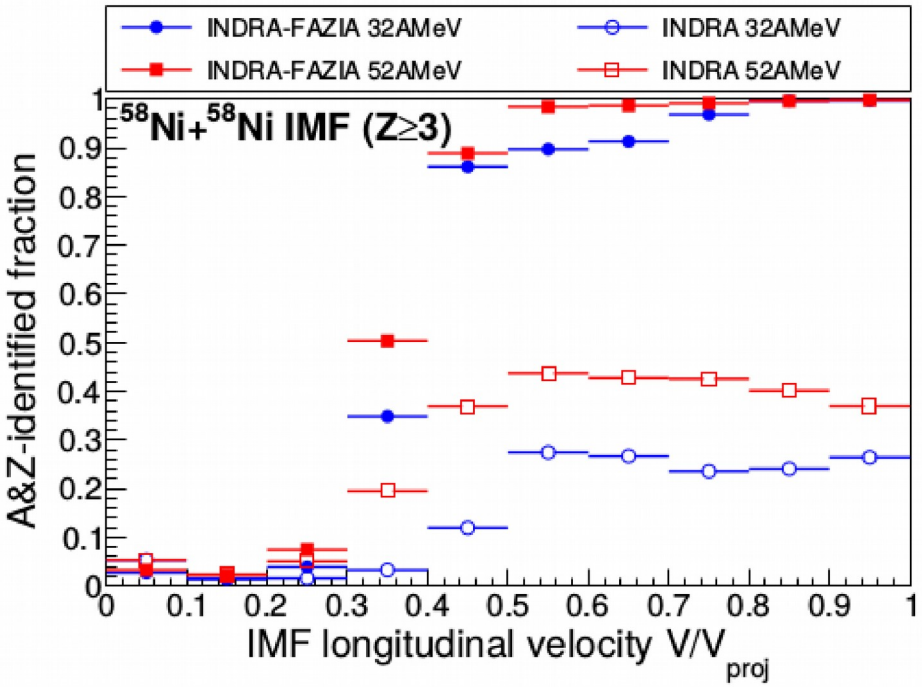
This coupling allows to work in different modes:

- Experiment: if (t_{INDRA} – t_{FAZIA}) is in the coincidence window – same physical event, data storage on disk in one event
- Free: no coincidences required (for detector calibrations) – data storage on disk in separated events

INDRA-FAZIA: a unique tool

Expected performances (example)?

- Thanks to the INDRA wide angular coverage:
  - information all along the velocity range
- Thanks to the FAZIA isotopic identification:
  - big enhancement of the IMF (Intermediate Mass Fragments) identified fraction respect to INDRA solo



Ref: INDRA-FAZIA collaborations. Proposal for the GANIL PAC : Isospin transport and the density dependence of the Symmetry Energy. GANIL PAC, 2018

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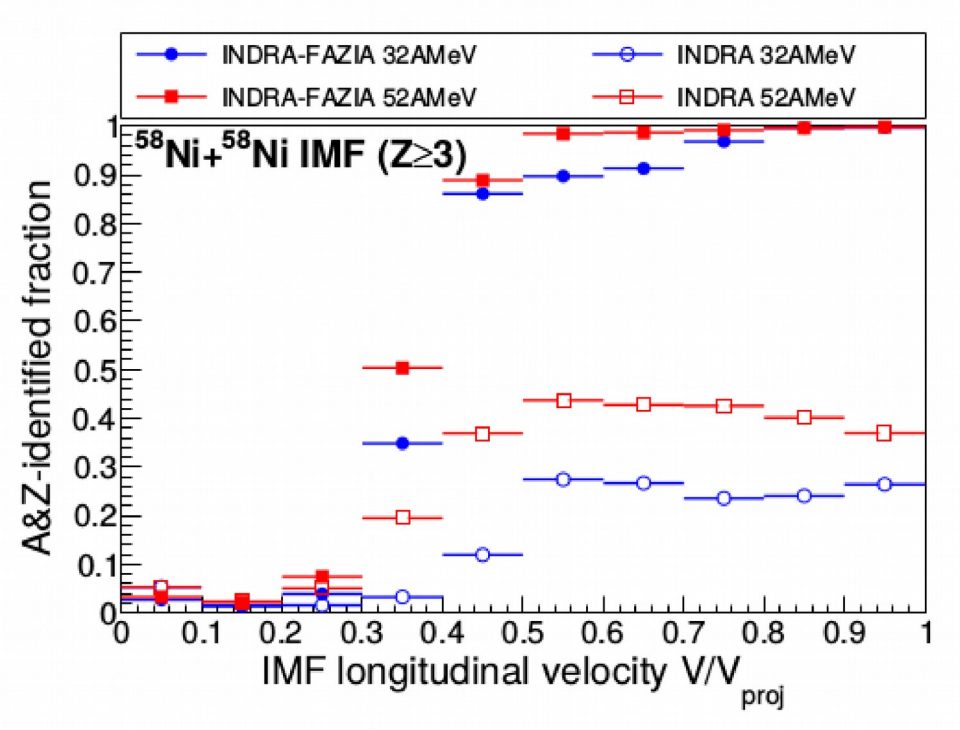
INDRA-FAZIA is thus, a **unique tool** to **study tiny effects** that can be **linked to the nuclear matter EoS !!**



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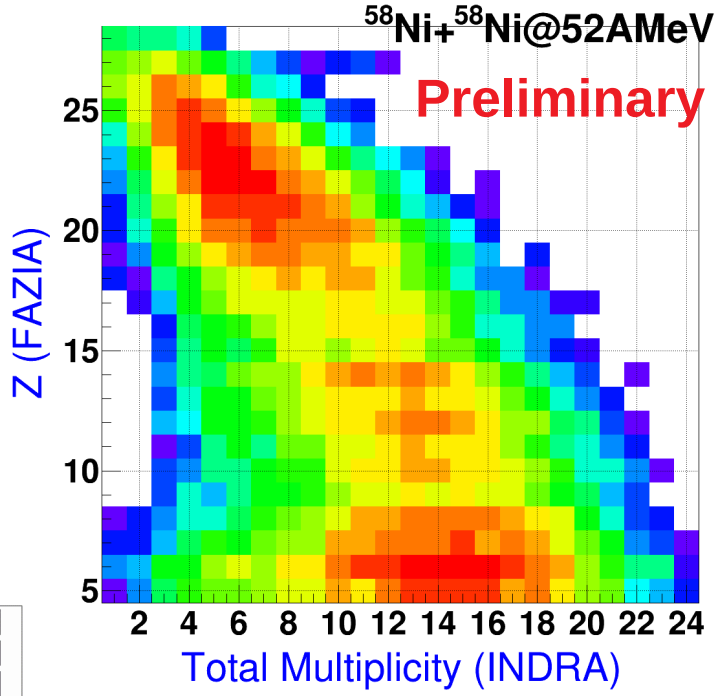
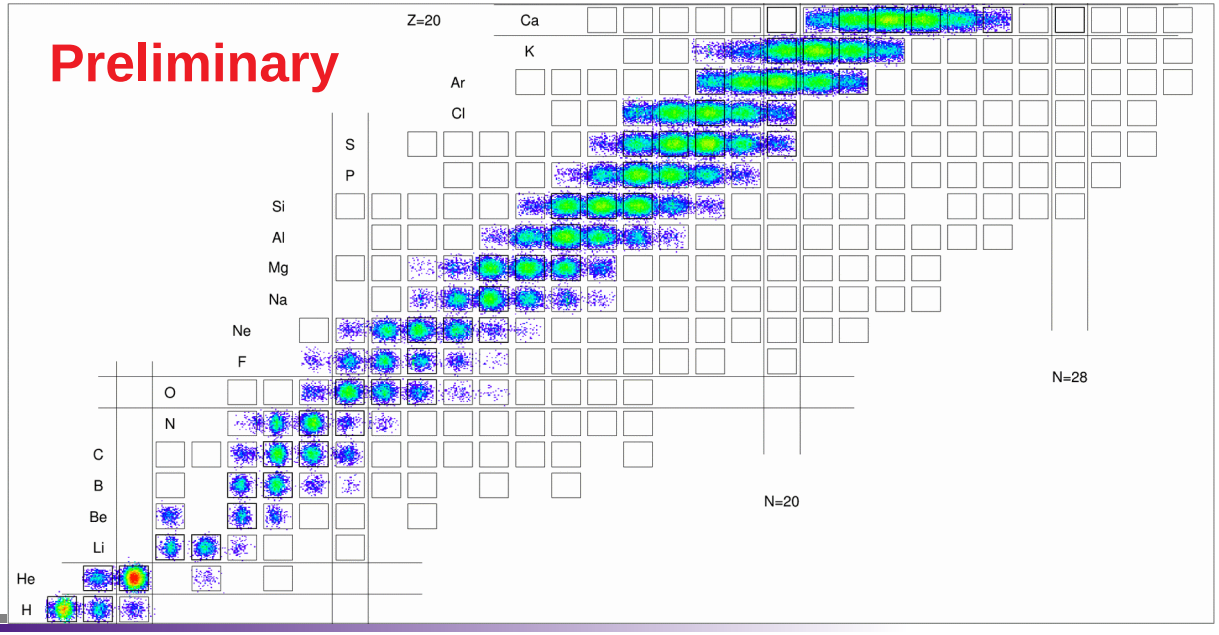
Before conclusion, nothing better than experimental data!!

- E789, first INDRA-FAZIA experiment in GANIL
- Probe the density dependance of the nuclear matter EoS
- ^{58,64}Ni + ^{58,64}Ni @ 32,52 MeV/nucleon
- April/May 2019
- 38 BTUs of data taking
- 8 systems studied, at least 30M events for each one
- Data reduction in progress



Correlation between charge of fragments detected in FAZIA & violence of collisions (multiplicity) measured by INDRA



Typical Z & A identification obtained with FAZIA during the experiment

Conclusion

Nuclear matter EoS

- Describe how nuclear matter evolves in various conditions (T, ρ, δ,...)
- Important ingredients for astrophysics
- Can be studied through Heavy Ion Collisions (HIC)

INDRA-FAZIA detection arrays in GANIL: a unique tool to study the EoS

- wide angular coverage (80% of 4π)
- full isotopic identification (Z&A) in FAZIA
- mechanism selection (collisions sorting)

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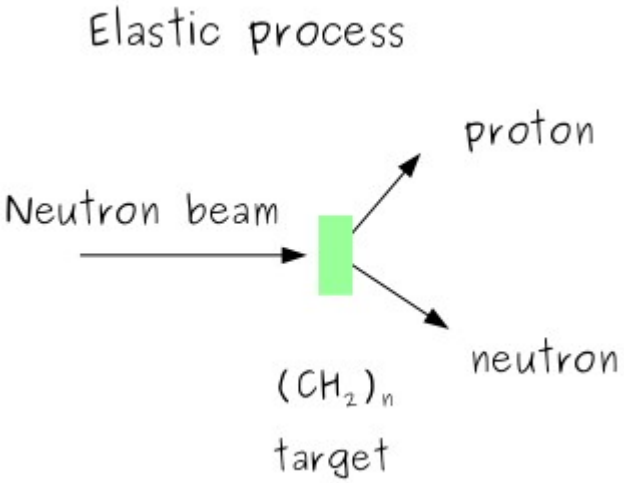
Other topics of interest than “only” the EoS

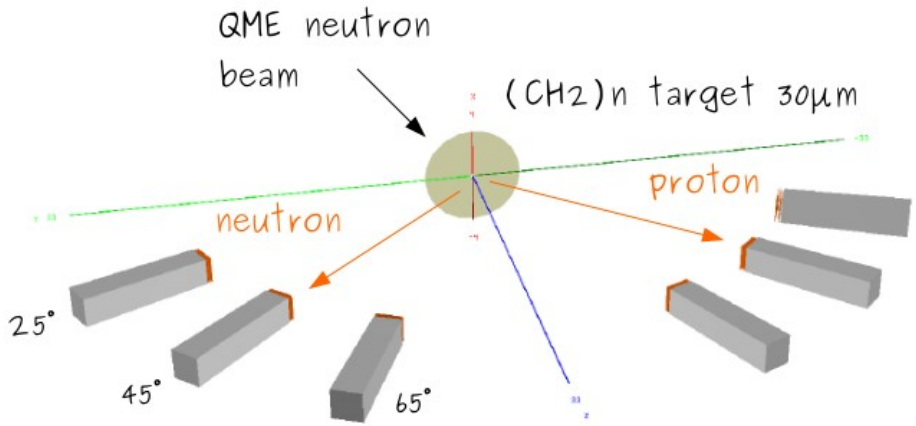
- Hot, dilute, asymmetric nuclear matter
  - transport properties
  - clusterization in dilute nuclear medium
- In medium nuclear structure and reactions

FAZIA @ NFS

INDRA & FAZIA are charged particles detectors: what about the neutrons?

- Approved experiment for FAZIA @ NFS (SPIRAL 2) : E720
  - what is the neutron signal in the Si – Si – CsI(Tl) telescopes of FAZIA?
  - what is the efficiency of such process for the FAZIA telescopes?





- How to do that?
  - by looking at the signal observed in the CsI(Tl) associated to a proton detection

Ref: FAZIA collaboration. Proposal for the GANIL PAC : Measurement of the absolute neutron detection efficiency of FAZIA telescopes. GANIL PAC, 2016