

Status and analysis plan for nuclear symmetry energy using Ni+Ni collisions in INDRA-FAZIA experiment

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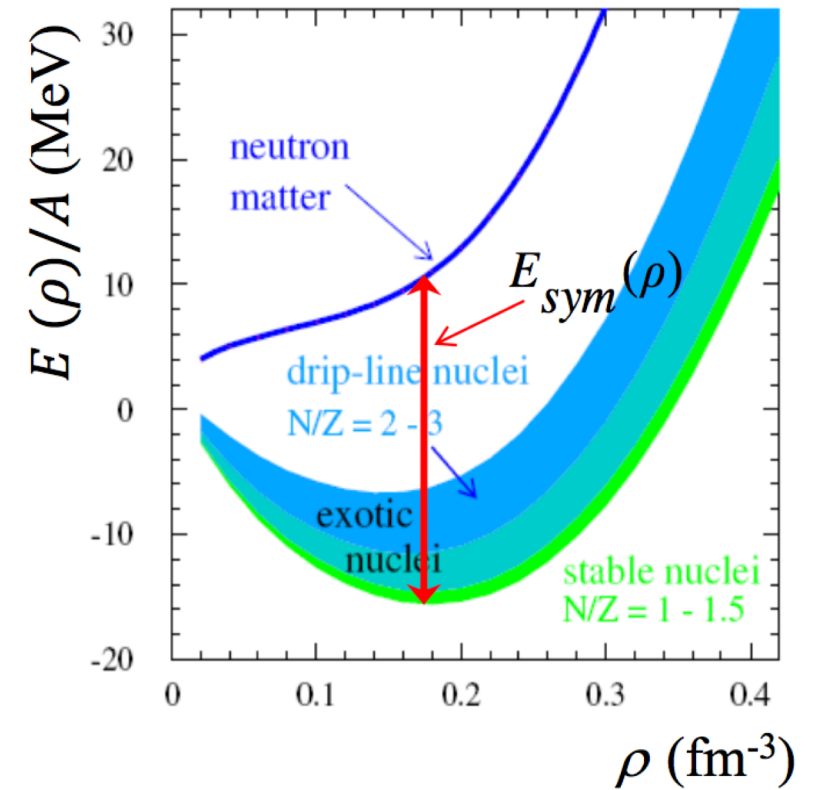
Nuclear Symmetry Energy

$$E(\rho, \delta)/A = \underbrace{E(\rho_n = \rho_p)}_{\text{Isoscalar}} + \underbrace{E_{\text{sym}}(\rho)\delta^2}_{\text{Isovector}}$$

$$E_{\text{sym}}(\rho) = \frac{1}{2} \frac{\partial^2 E}{\partial \delta^2} \approx E(\rho)_{\text{pure neutron matter}} - E(\rho)_{\text{symmetric nuclear matter}}$$

$$\text{with } \rho = \rho_n + \rho_p, \quad \delta = (\rho_n - \rho_p)/\rho$$

$$E_{\text{sym}}(\rho) = S + \frac{L_{\text{sym}}}{3} \left(\frac{\rho - \rho_0}{\rho_0} \right) + \frac{K_{\text{sym}}}{18} \left(\frac{\rho - \rho_0}{\rho_0} \right)^2 \dots$$





Physical Quantity and Observables

- The **isoscalar** part of EOS is well established from both experimental and theoretical study.

$$\rho_0 = 0.155 \pm 0.005 \text{ fm}^{-3}$$

$$E_0 = -15.8 \pm 0.3 \text{ MeV}$$

$$K_0 = 9\rho_0^2 \left(\frac{\partial^2 E_0}{\partial \rho^2} \right) \Big|_{\rho=\rho_0} = 240 \pm 20 \text{ MeV}$$

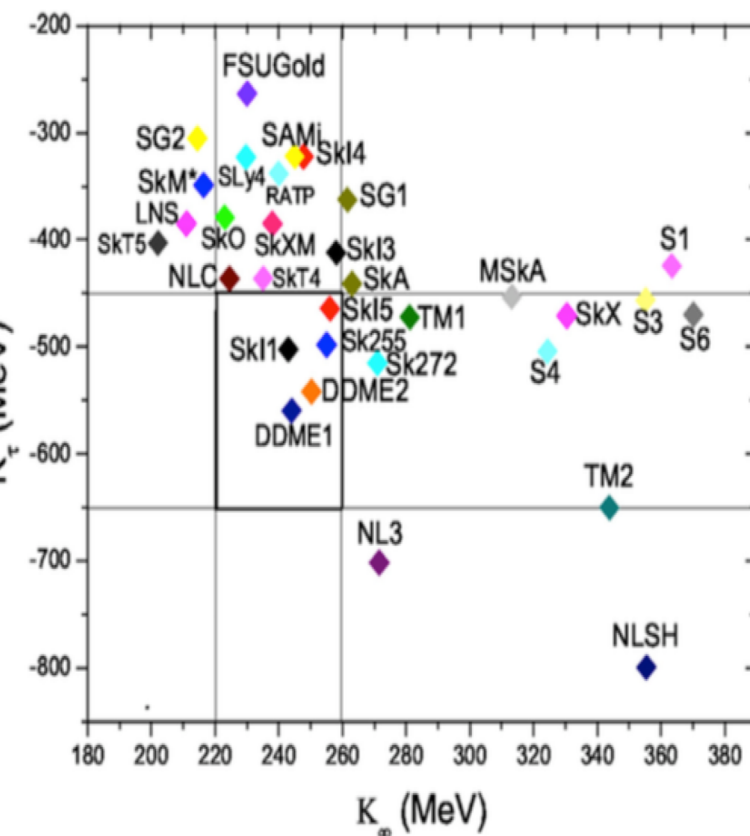
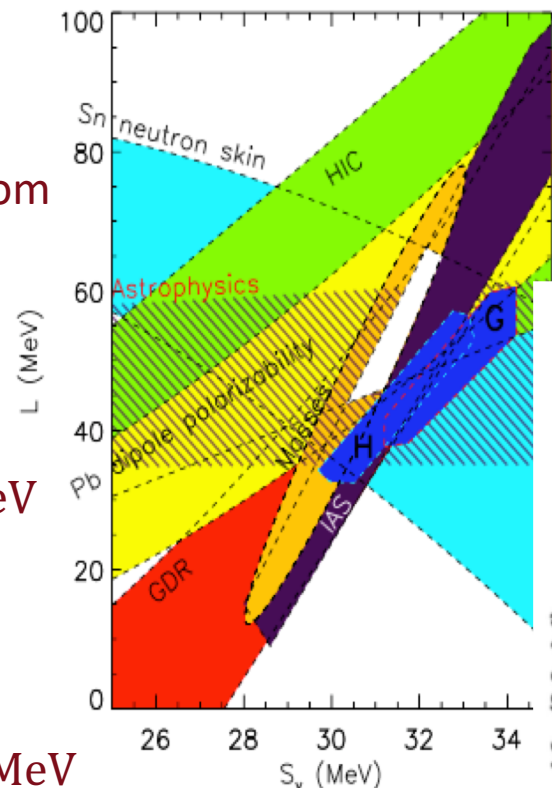
- The **isovector** part is less well known.

$$S = E_{\text{sym}}(\rho_0) = 32.7 \pm 1.5 \text{ MeV}$$

$$L_{\text{sym}} = 3\rho_0 \frac{\partial E_{\text{sym}}(\rho)}{\partial \rho} \Big|_{\rho=\rho_0} = 40 \sim 70 \text{ MeV}$$

$$K_{\text{sym}} = 9\rho_0^2 \left(\frac{\partial^2 E_{\text{sym}}}{\partial \rho^2} \right) \Big|_{\rho=\rho_0} = 0 \sim -200 \text{ MeV}$$

$$\text{where, } K_\tau = K_{\text{sym}} - 6L \approx -840 \sim -350 \text{ MeV}$$



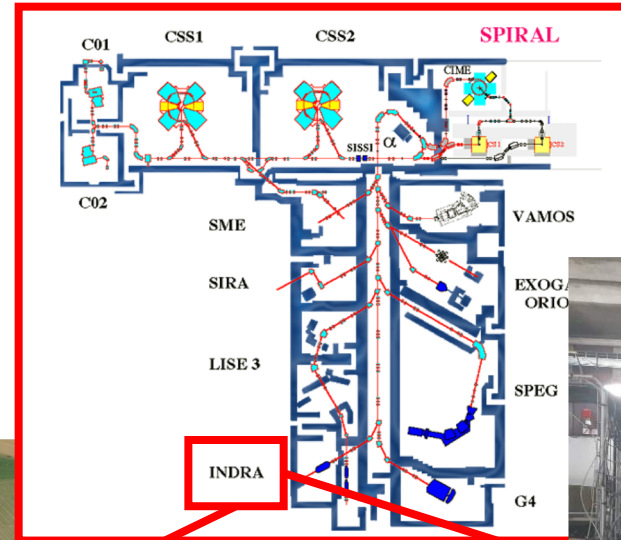
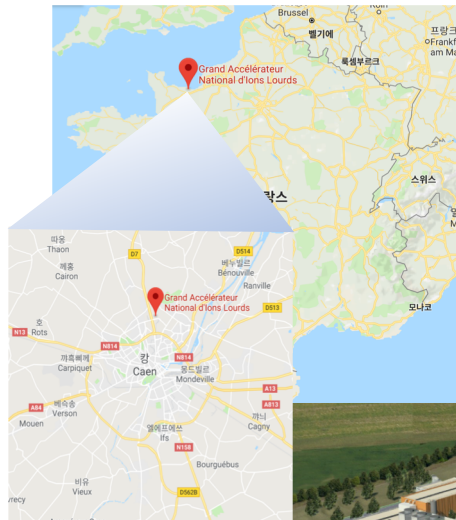


Heavy Ion Collision at Fermi energy

- Fermi energy level collision is proper to investigate thermal and mechanical property of nuclear matter.
- In this Energy region, Isospin Diffusion, Isospin Migration, Collective flow etc. are Important observables.
- Information of various kind produced particle is needed to more accurate investigation of nuclear symmetry energy.
- Experiment with detector with better resolution is needed.
- Last April to May, 32, 52 MeV/u Ni isotope beam - Ni isotope target collision experiment was done at GANIL using INDRA-FAZIA detector.

Introduce of GANIL

GANIL : Grand Accélérateur National d'Ions Lourds
(Large National Heavy Ion Accelerator)

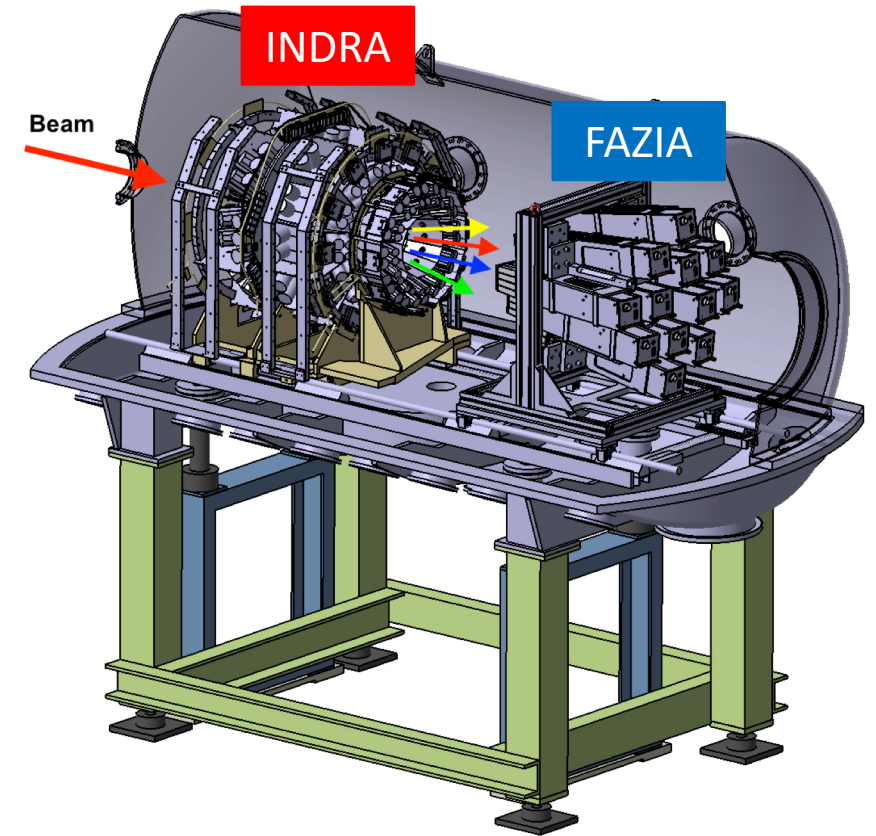


FAZIA and INDRA at D5

E789 Experiment using INDRA-FAZIA



- INDRA-FAZIA system cover 4π sr angle.
- 58, 64 Ni beam (32,52 AMeV) and 58, 64 Ni target
-> 8 separated beam time(about 30 hours /system)
- Beam intensity : $1.9 \cdot 10^8$ pps
- Pressure inside of chamber : $1.2 \cdot 10^{-5}$ mbar
- Each collision system statistics $\sim 30 \cdot 10^6$ events
->Total $\sim 240 \cdot 10^6$ events



INDRA & FAZIA Detectors



INDRA : Identification de Noyaux et Detection avec Resolutions Accrues
(Nucleus Identification and Detection with Increased Resolutions)

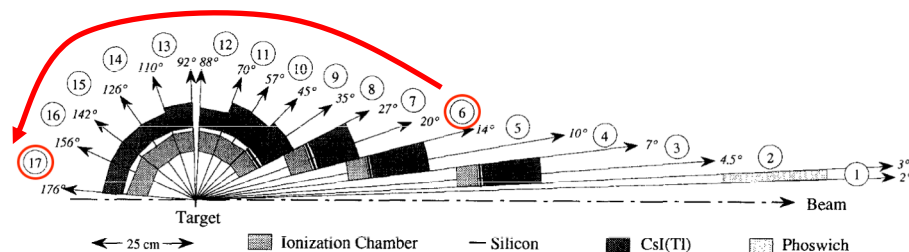
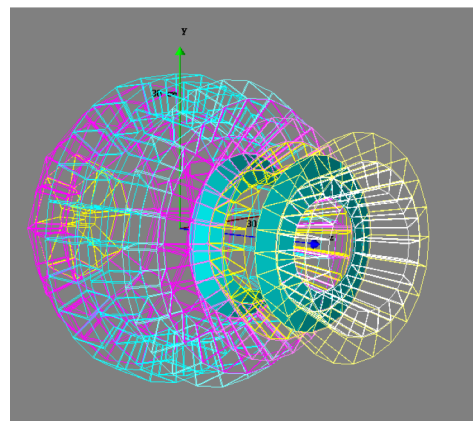
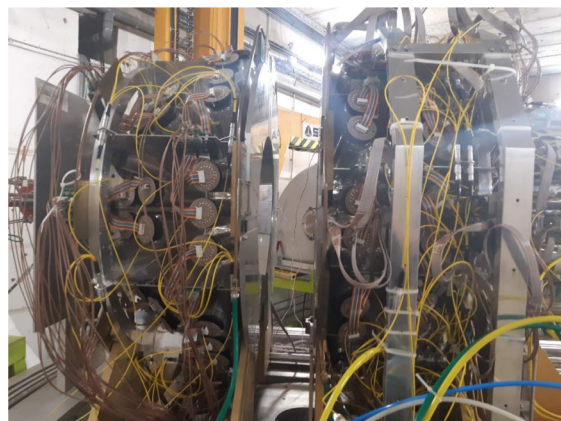
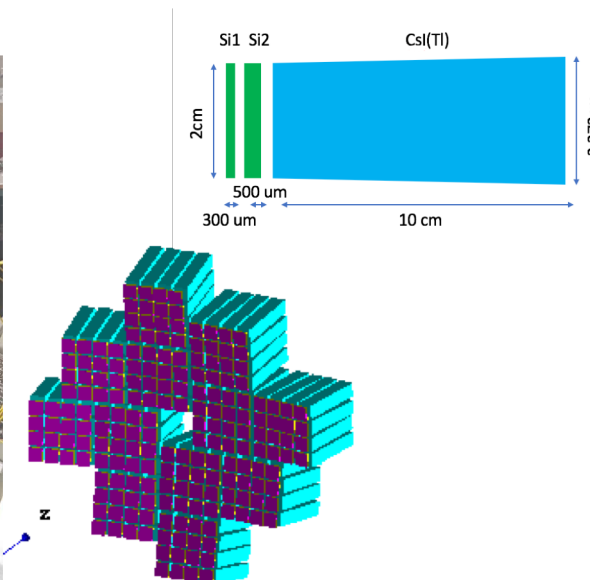


Fig. 3. Geometrical outline of the INDRA detector (cut along the beam axis). The detectors are arranged in 17 rings that are coaxial with the beam axis (see Table 1 for details).

240 CsI(Tl) Crystals and 96 Si silicon detectors

FAZIA : Four - π A – Z Identification Array



- 4 Telescopes in one Quad
- 4 Quads in one Block
- 12 Blocks -> 192 telescope
each telescope cover 0.2π sr
(1m from target)
- Polar angle coverage : $0^\circ \sim 14^\circ$

FAZIA Detector Electronics

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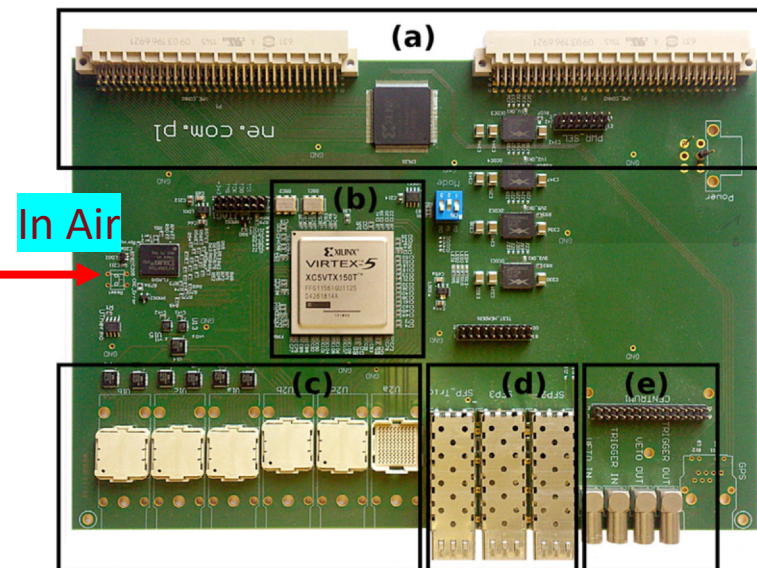
- Half-bridge and power supply : produce and monitor the voltage need to operate FAZIA blocks.
- Block Card : handle I/O operations using 3Gbit/s optical cable, merge data.

- FEE cards : each card processes signals from two telescope. pre-amp, ADC and FADC for signal processing are implemented

- Crystals :
Si1 : QH1(high range charge signal), QL1(Low range charge signal), I1(current signal)
Si2 : Q2(high range charge signal), I2(current signal)
CsI(Tl) : Q3(high range charge signal)



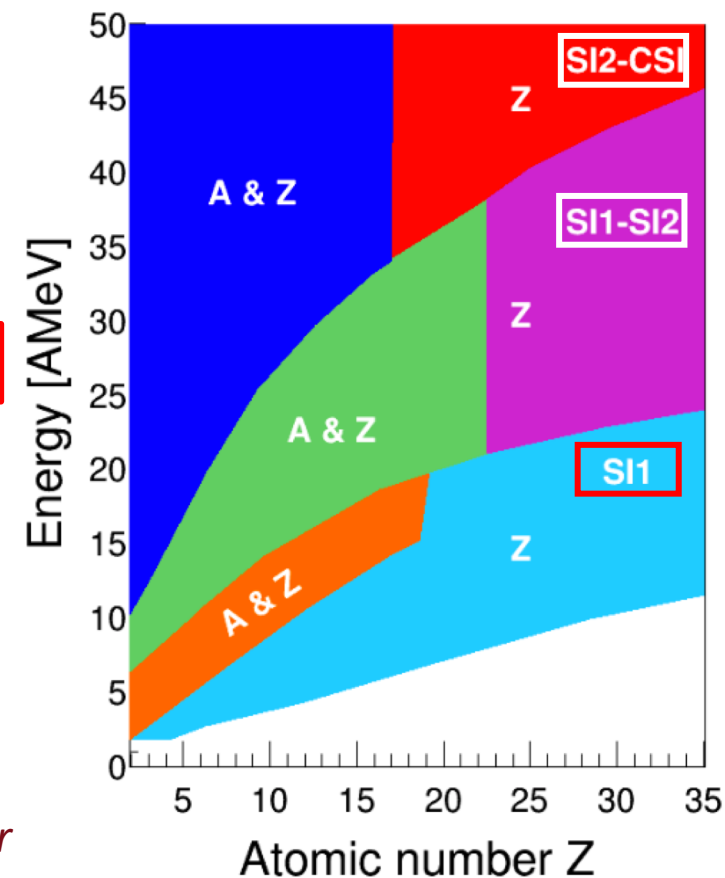
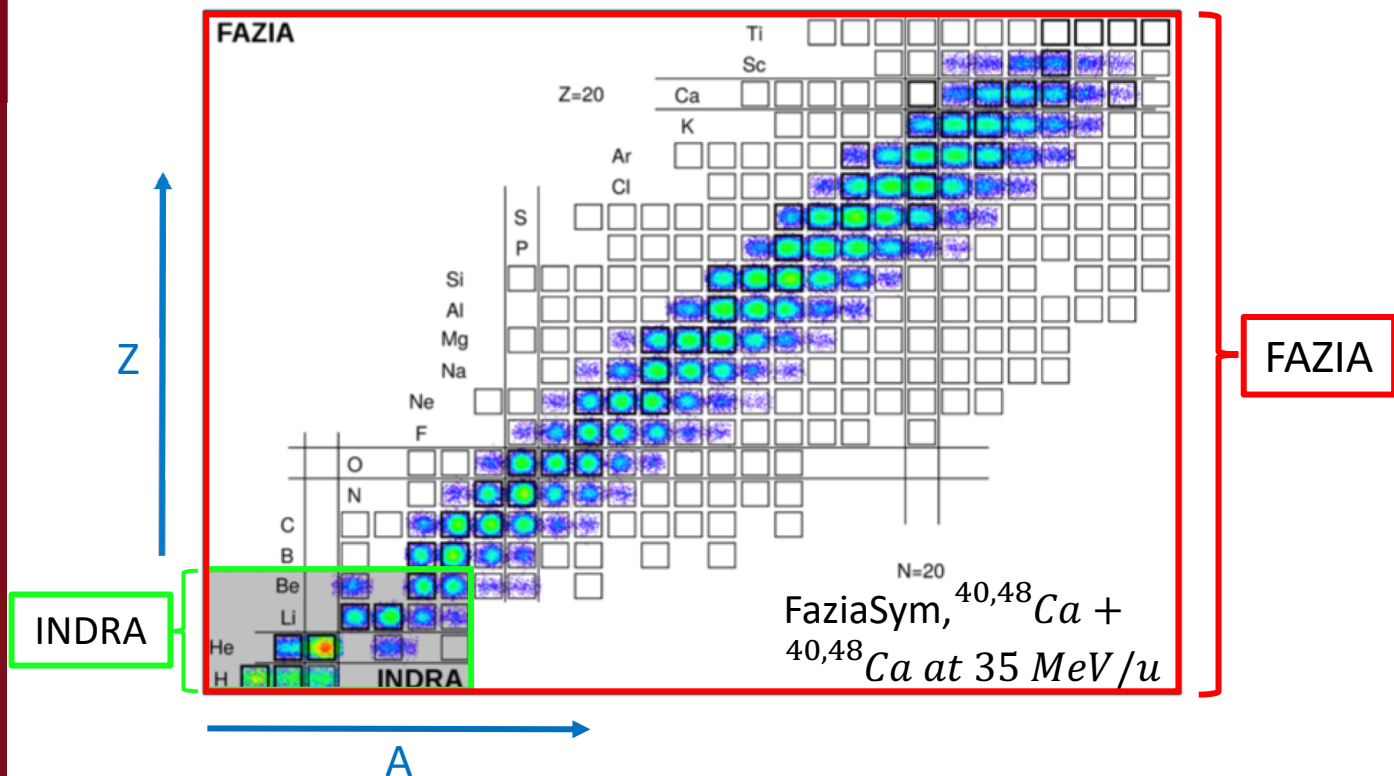
Regional Board



- Located in air and connected with block cards via optical fiber.
- Read data, form complete event, analyze the triggers from blocks and handle slow control from many PCs
-> Connect acquisition servers and detector

FAZIA Detector Performance

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*Z-N identification map obtained with FAZIA, on the bottom left corner (grey area),
the corresponding Z-N identification map obtained with INDRA.*

Current status and Future plans



- Current status
 - Studying analysis tool named KaliVeda
 - Working on event building processes using KaliVeda
 - Develop Geant4 simulation of E789 for check detector effect on analysis results.
- Future plan
 - Complete Geant4 simulation for theoretical model.
 - Participate detector calibration since early November.
-> FAZIA Si2, FAZIA Si-CsI id and INDRA Si.
 - Start particle flow analysis at GANIL since next late of January.

Summary



- Currently isovector property of Nuclear matter have big uncertainty.
- Collision at Fermi Energy region is important for study thermal and mechanical property of nuclear matter.
- From April to May in this year, Ni isotope beam (32&52 AMeV/u) -target collision experiment(E789) was done at GANIL.
- Calibration will be finished early of next year and analysis will be started after calibration.



Thank you

References

- X. Roca-Maza, N. Paar / Progress in Particle and Nuclear Physics 101 (2018) 96–176.
- Nuclear Instruments and Methods in Physics Research A 369 (1996) 222-247
- Nuclear Inst. and Methods in Physics Research, A 930 (2019) 27–36
- Proposal E789.
- FAZIA@GANIL PrePAC Meeting April 4th 2017 John Frankland.



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Back Up

Thesis Topic

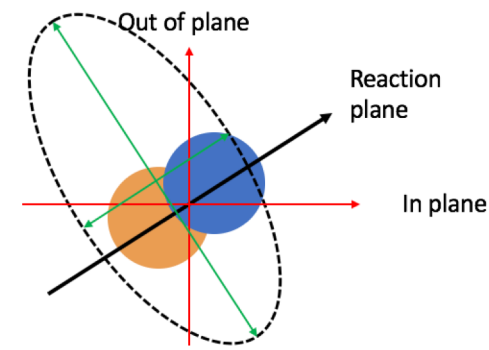
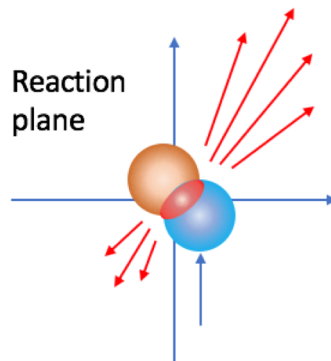
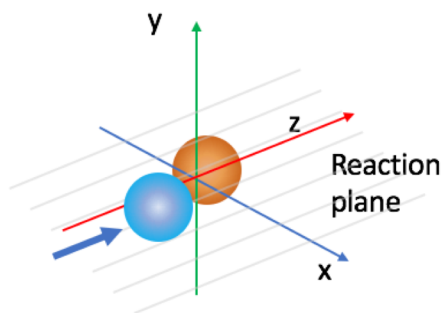
Collective Flow

- Angle distribution of produced particles are different with collision energy, isotope, Z number... .
- We can represent azimuthal distribution function using Fourier expansion.

$$\frac{dN}{d\phi} = c(1 + v_1 \cos(\phi) + v_2 \cos(2\phi) \dots)$$

v_n : n-type of flow

- v_1 : Direct flow = Overall shift of particles distribution.
- v_2 : elliptic flow = Eccentricity of particles distribution.



V1 attraction and repulsion schematic and data

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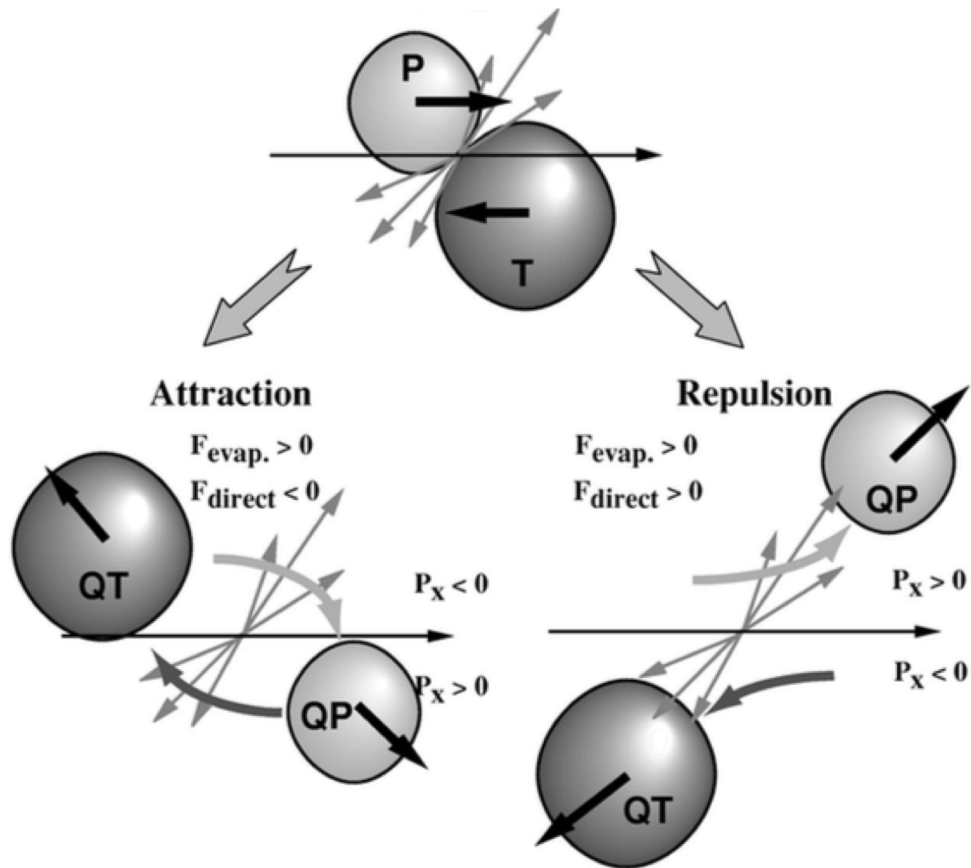
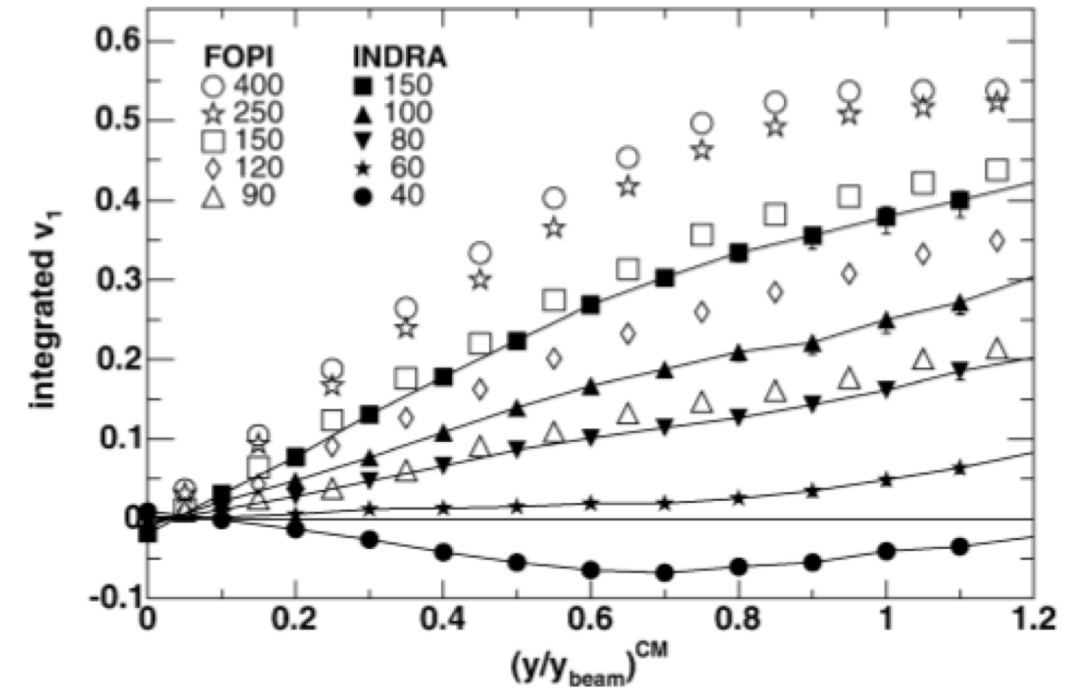


Figure from PHYSICAL REVIEW C **65** 044604

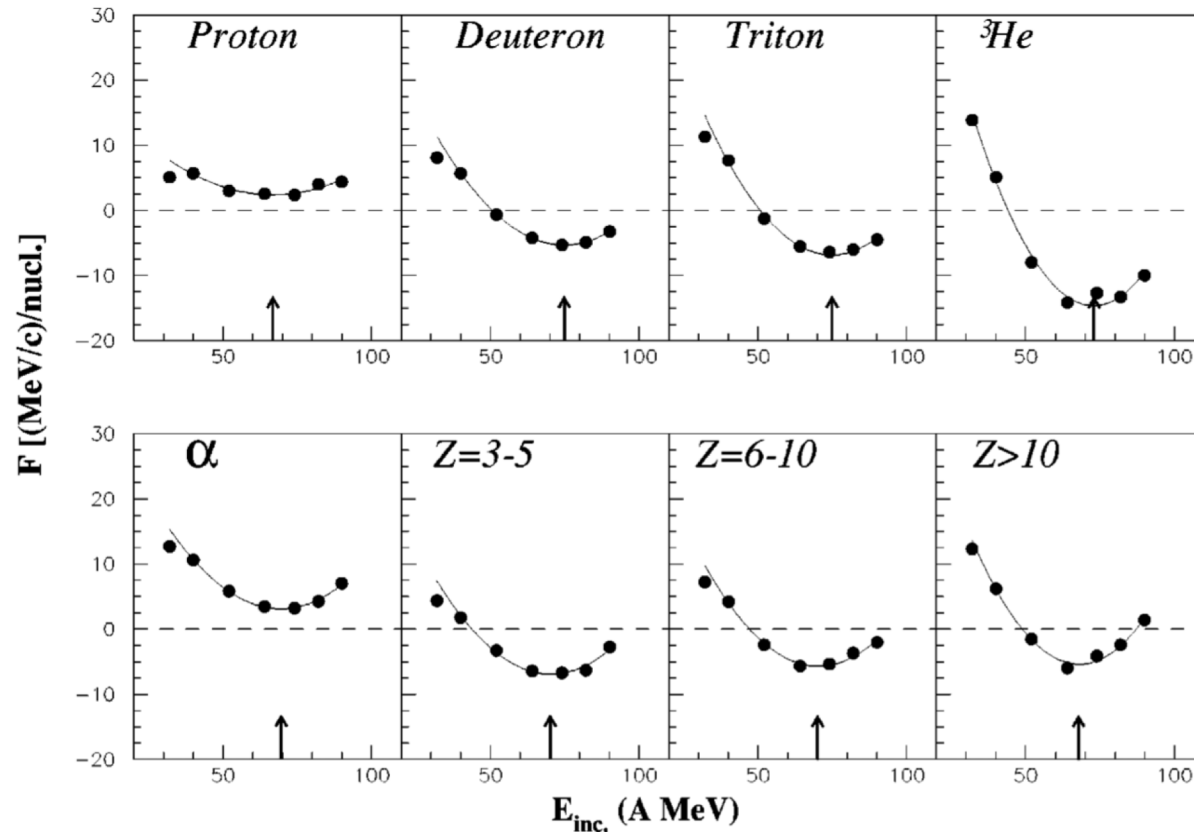


$^{197}\text{Au} + ^{197}\text{Au}$ collision data

Flow parameter v_1 for $Z = 2$ particles.
(mid-central collisions : 2 - 5.3 fm)

Data from FOPI and INDRA agree within a few percent.

Below 60 A MeV, sign of v_1 is changed



Flow parameter($Y_r = 0.5$) from $58\text{Ni}+58\text{Ni}$ at GANIL
using INDRA detector.

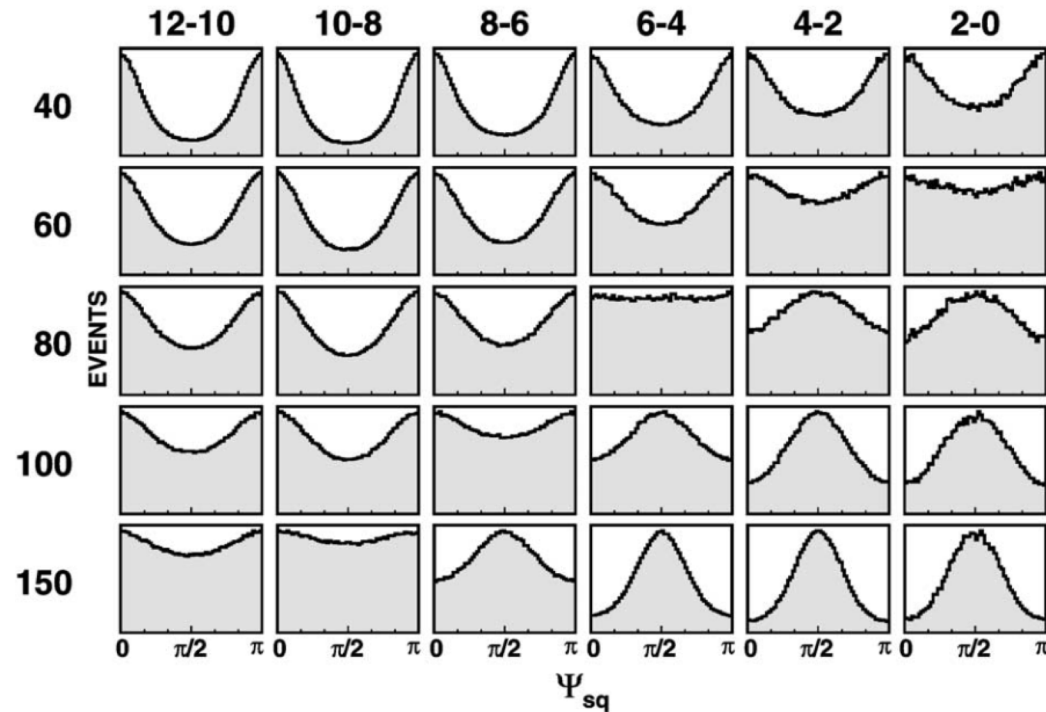
(PHYSICAL REVIEW C **65** (2002) 044604)

- Neutron detection is not available in INDRA system.
- Analysis of Isotope of Inter-Mass fragment will be possible using FAZIA detector.

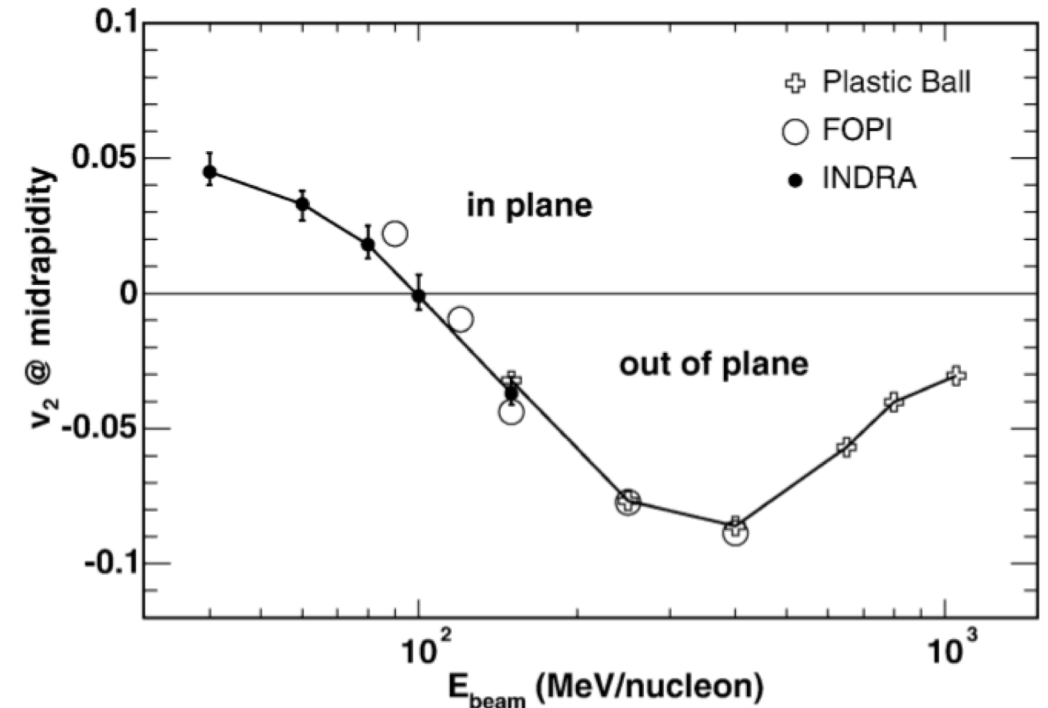
$$F = \frac{1}{2} \left(\frac{\partial \langle P_x / A \rangle}{\partial Y_r} \right) \quad Y_r = \frac{Y}{Y_{proj}}$$

V2 flow of 197Au+197Au collision at GANIL

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- In-plane, out of plane yield ratio(V_2) show sensitive change with different rapidity, impact parameter and energy.

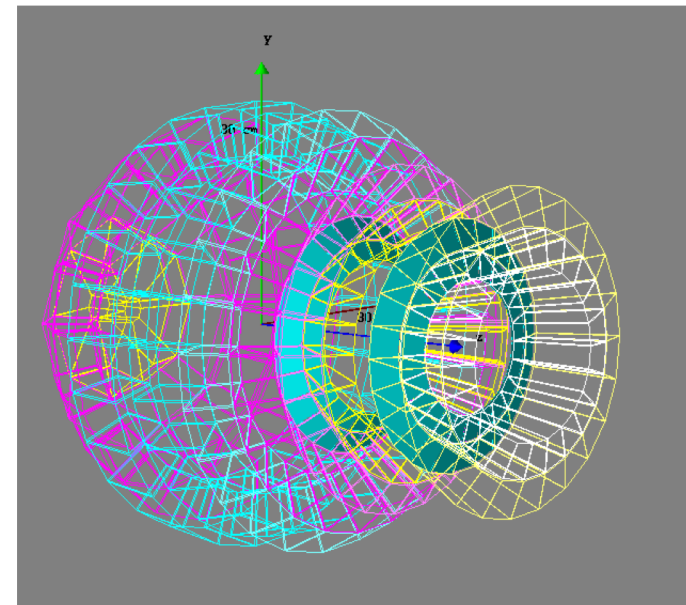
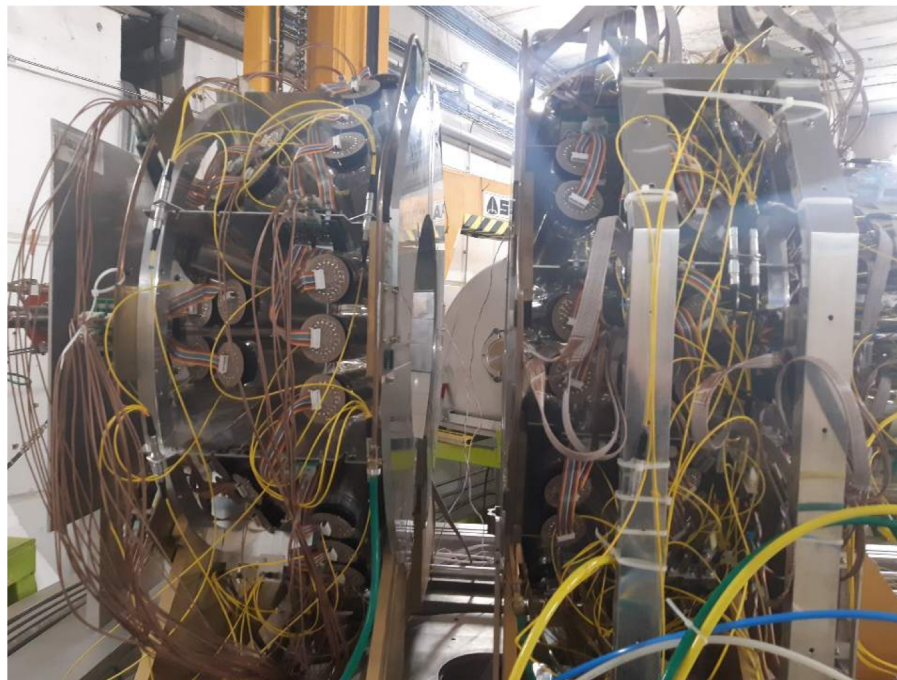
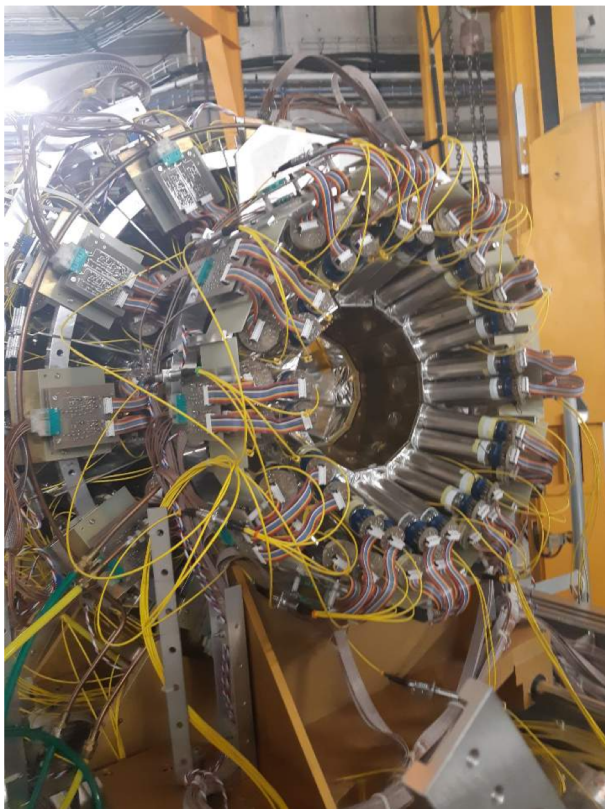


- Elliptic-flow parameter v_2 at mid-rapidity for $Z=2$ particles from mid-central collisions, in the rotated reference frame.
- The errors shown for the INDRA data are mainly systematic and caused by the uncertainty of b_{max} .

INDRA : Identification de Noyaux et Detection avec Resolutions Accrues

(Nucleus Identification and Detection with Increased Resolutions)

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- Pure INDRA has 17 CsI(Tl) detector rings, 8 Si detector rings and 9 Ionization chamber rings.
- In E789, we use **ring number 6 to 17** and **no Ionization chamber**.
- Target is placed center of INDRA using HV load.

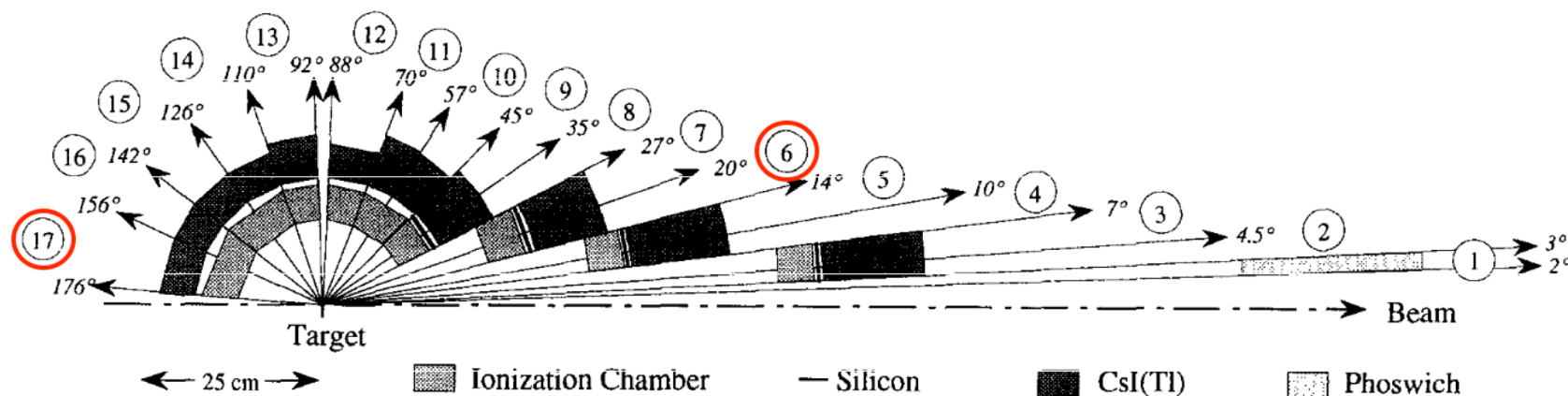


Fig. 3. Geometrical outline of the INDRA detector (cut along the beam axis). The detectors are arranged in 17 rings that are coaxial with the beam axis (see Table 1 for details).

Ring 6 ~ 13 : 24
Blocks

Ring 14,15 : 16
Blocks

Ring 16,17 : 8 Blocks

Ring 6 ~ 9 : 1
silicon detector
and CsI(Tl)
Scintillator

Ring 10~17 : CsI(Tl)
Scintillator

For PId, CsI signal
divided two part :

Fast part : 0 -> 400 ns
Slow part : 1400 ->
2900 ns

240 CsI(Tl) Crystals and 96 Si silicon detectors

Table 1

Geometrical arrangement of the INDRA detectors. N : number of detectors per ring, e : thickness of detector, $\Delta\Omega$: solid angle of detector, n : number of CsI(Tl) behind an ionization chamber, d : distance from target, θ : polar angle, ϕ : azimuthal angle

Phoswich NE102-NE115												
Ring No.	$\theta_{\min}$ [deg]	$\theta_{\max}$ [deg]	N	$\Delta\phi$ [deg]	e NE102 [mm]	e NE115 [mm]	$\Delta\Omega$ [msr]	d [cm]				
1	2	3	12	30	0.5	250	0.37	130				
CsI(Tl)							Si	ionization chamber				
Ring No.	$\theta_{\min}$ [deg]	$\theta_{\max}$ [deg]	N	$\Delta\phi$ [deg]	e [mm]	$\Delta\Omega$ [msr]	e [μm]	$\Delta\phi$ [deg]	N	n CsI(Tl)	d [cm]	$\Delta\Omega$ [msr]
2	3	4.5	12	30	138	0.74	300	30	12	3	65.4	2.9
3	4.5	7	24	15	138	1.01	300					
4	7	10	24	15	138	1.70	300	30	12	4	38.4	10.3
5	10	14	24	15	138	3.21	300					
6	14	20	24	15	97	7.01	300	30	12	4	25	37.7
7	20	27	24	15	97	11.2	300					
8	27	35	24	15	90	15.8	300	30	12	4	12	86.0
9	35	45	24	15	90	26.4	300					
10	45	57	24	15	76	39.6	none	30	12	4	12	183
11	57	70	24	15	76	50.3	none					
12	70	88	24	15	48	81.0	none	30	12	2	12	155
13	92	110	24	15	60	82.3	none	45	8	3	12	240
14	110	126	16	22.5	50	93.5	none	45	8	4	12	338
15	126	142	16	22.5	50	73.1	none					
16	142	157	8	45	50	91.2	none	45	8	2	12	144
17	157	176	8	45	50	50.9	none					

J. Pouthas et al. / Nucl. Instr. and Meth. in Phys. Res. A 369 (1996) 222-247

- Forward region granularity of Pure INDRA

Ring 1 : 0.37 sr

Ring 2 : 0.74 sr

Ring 3 : 1.01 sr vs FAZIA : 0.2π sr

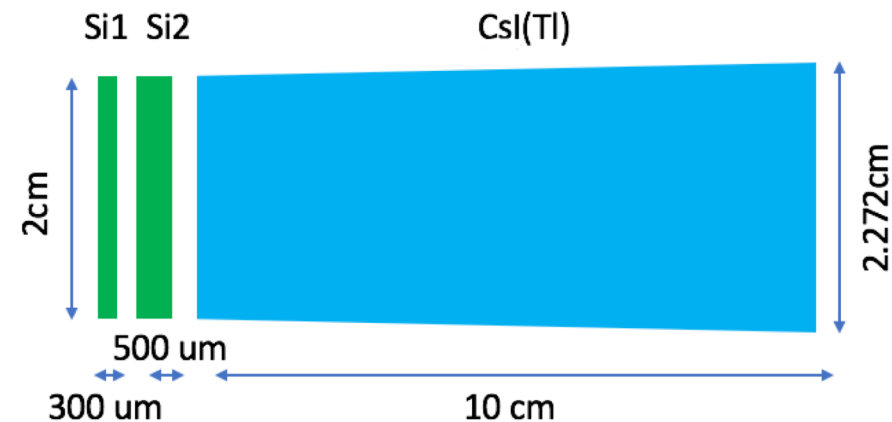
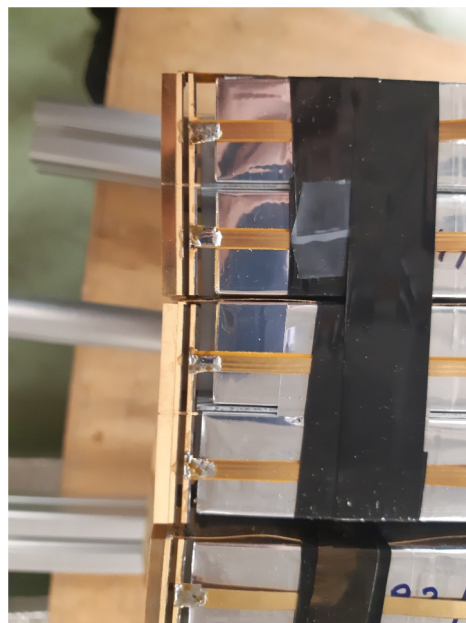
Ring 4 : 1.70 sr

Ring 5 : 3.21 sr

- Phoswich($2^\circ \leq \text{lab} \leq 3^\circ$) charge separation :
Z up to 30 ($E < 20$ AMeV).
- Isotopic separation :
Z = 3 – 4 in CsI(Tl) over the whole angular range ($3^\circ \leq \text{lab} \leq 176^\circ$) .
- Charge identification :
up to Z = 55 with Si ($3^\circ \leq \text{lab} \leq 45^\circ$) and up to Z = 20 in the backward region ($\text{lab} \geq 45^\circ$) .

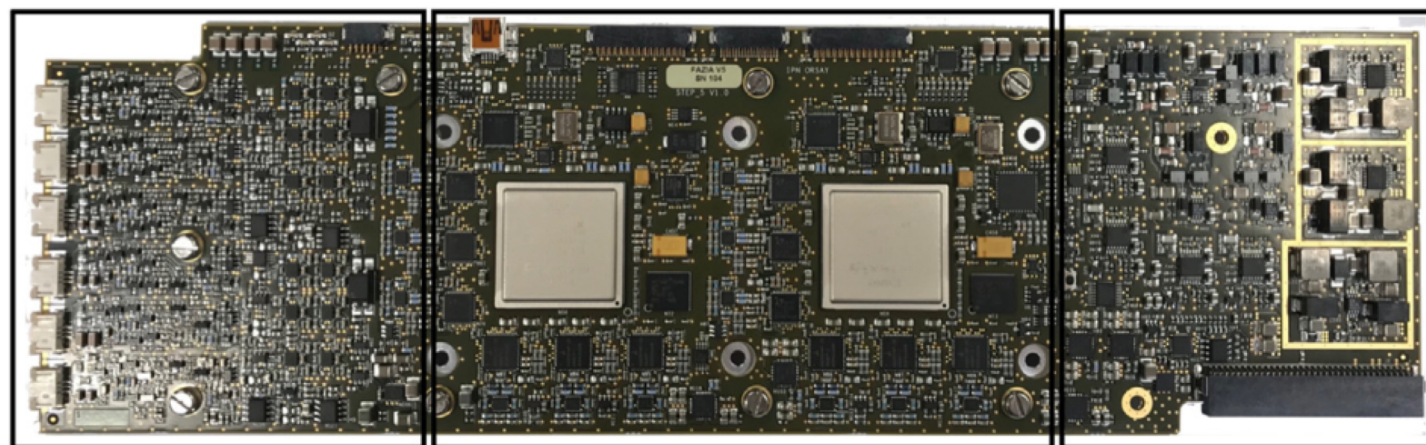
Crystals

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- Si1 : Bias voltage : 300 ± 0.1 V
Si2 : Bias voltage : 500 V
- Use nTD-Si for better resistivity uniformity (1-3%).
- For avoid channeling effect, random cut method is applied to Si crystals
- Photodiode is attached behind CsI(Tl).
- Two telescope are connected to a FEE card.

FEE Cards



Analogue stage

Digital Stage

Converters stage

Analogue stage

- Pre Amp
Si : dynamic range 8V
for energy 4 GeV
(2mV/MeV sensitivity)
Csl : dynamic range 8V
for energy 300MeV
(~26mV/MeV)
- Adapt to ADC
QH1, Q2, Q3 ->
attenuate to factor 4 for
2V dynamic range of
ADC
QL1 -> amplified factor 3

Digital Stage

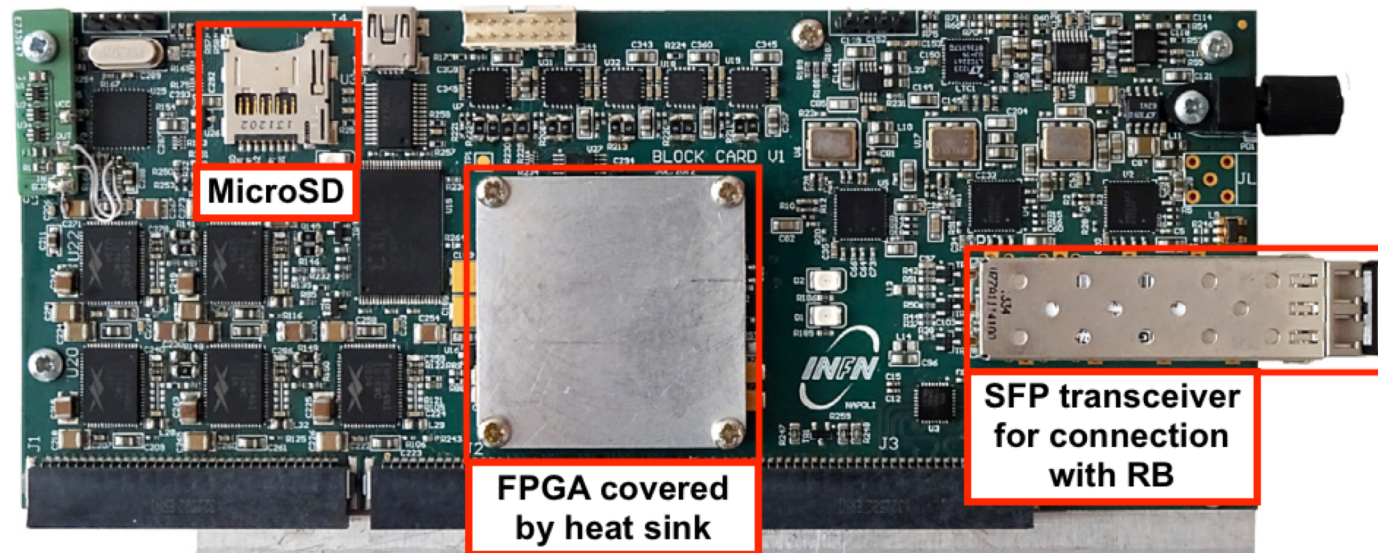
- ADC
QH1, Q2, Q3 -> 14-bit, 100MS/s ADCs with a 2V input
range.
Energy conversion factor of about 4.1 ADC units/MeV
for QH1 and Q2 signals.
QL1, I1, I2 -> 14-bit, 250 MS/s ADCs with a 1.5 V input
range.
- FPGA
Compute energy through digital filtering, generate local
triggers, data packing and transmission to the
acquisition.

Converters stage

- HV for Si
5.5V from High voltage
card
-> Si1 : 300 V $\pm$ 0.1 V
-> Si2 : 500 V

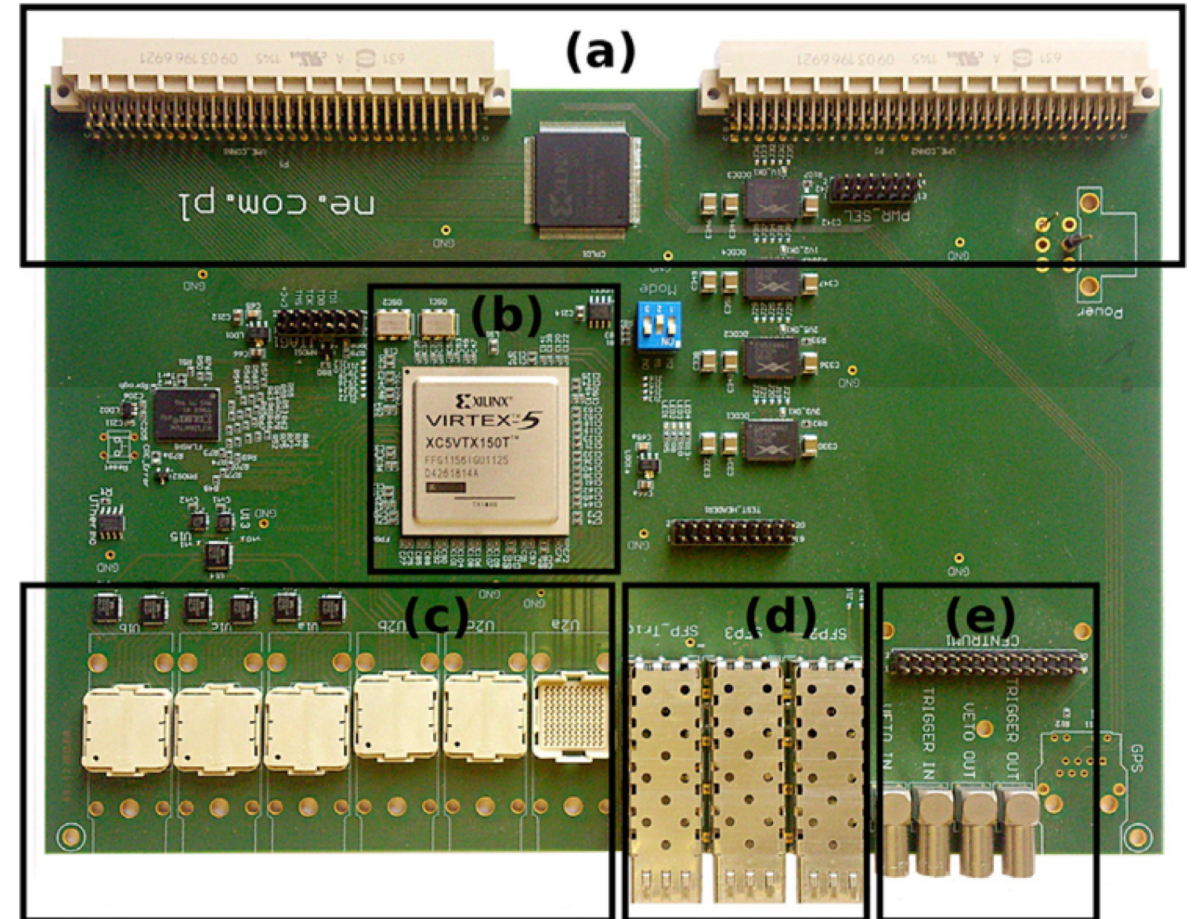
Block Card

- Retrieve data coming from the FEE cards.
- build partial event using data from FEE.
- Using SFP transceiver, 50MS/s ADC and photo diode, BC connected with Regional Board via 3Gbit/s optical link.
- MicroSD card give identity to each Block.
-> this make block changing easy.



Regional Board

- Located in air and connected with block cards via optical fiber.
- Read data, form complete event, analyze the triggers from blocks and handle slow control from many PCs
-> **Connect acquisition servers and detector**
- Each RB can connected with 36 blocks.
- Trigger coupling possible using LEMO connectors



(a) VME connectors and CPLD, (b) FPGA and crystal oscillators, (c) special connectors for block communication; (d) SFP slots; (e) LEMO connectors and CENTRUM port.

Coupling of 2 detectors

Coupling of two different detectors is done through 3 level:

1. Trigger level : ensure a common dead time between FAZIA and INDRA

2. CENTRUM module make absolute **time stamp** (48bits, 100MHz) and **event number** (32bits) and sent to both detectors .

3. NARVAL module receive data from both acquisition, **merge data with timestamp and producing global event.**

