FAZIA type Si-CsI detector R&D status

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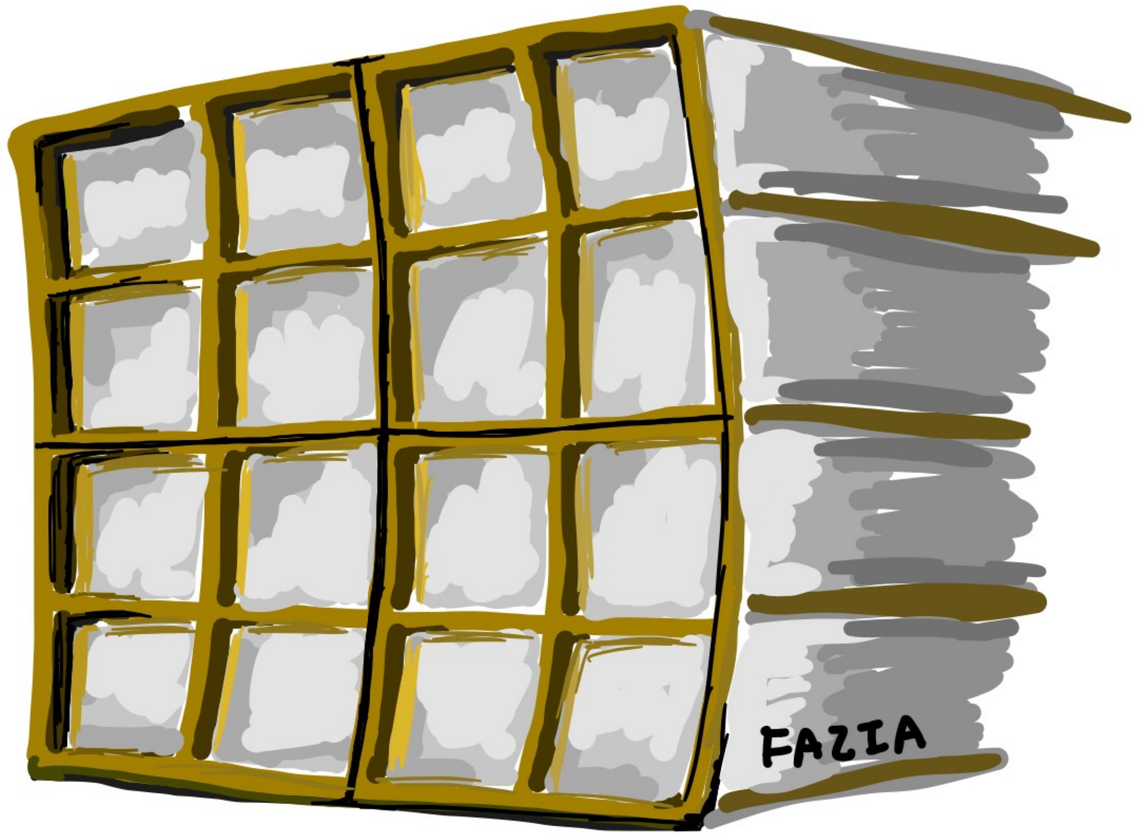
2022. 9. 3, CENuM workshop

FAZIA type Si-CsI detector development status;
ONLY talk about detector R&D



Korea in FAZIA: Brief history

Description of prof. Hong

Before 2019

- The Korean group (part of LAMPS Collaboration) was designing the **Si-CsI** telescope detector for the low-energy (a few tens MeV per nucleon) nuclear collision experiments at **RAON.**
- The International Advisory Committee of RAON reviewed the status of the detector development and suggested us to collaborate with **FAZIA** in Europe, because it had been operating the most advanced Si-CsI detector system for nuclear physics.
- Therefore, to join the Collaboration, we started the discussion with some FAZIA members in several Conferences & meetings

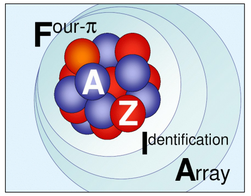
In 2019

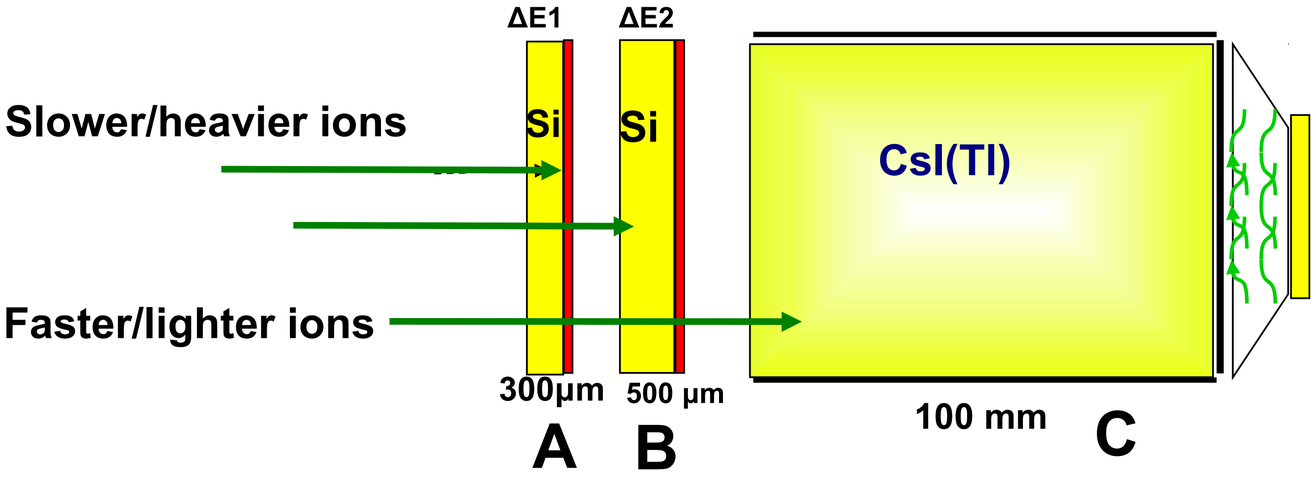
- Even before officially joining the FAZIA Collaboration, a group of interested Korean researchers visited GANIL in May 2019 and participated in the E789 experiment.
- Three professors (**B. Hong @ Korea Univ., M. Kweon @ Inha Univ., I. Hahn @ Ewha Womans Univ.**) attended the FAZIA Workshop at GANIL in September and presented the application to join the Collaboration.

Then, MOU in 2020

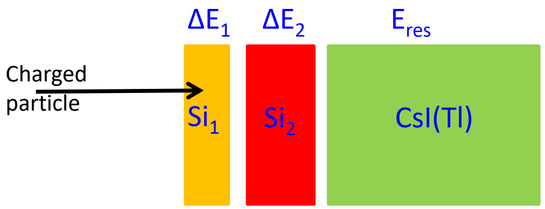
Addendum of MOU for FAZIA, adding Korea with CENuM (Center for Extreme Nuclear Matters directed by B. Hong) the national representative, was signed by CENuM (Korea), INFN (Italy), CNRS/IN2P3 (France), GANIL (France), COPIN (Poland), UHU (Spain) on November 6, 2020.

The FAZIA telescope

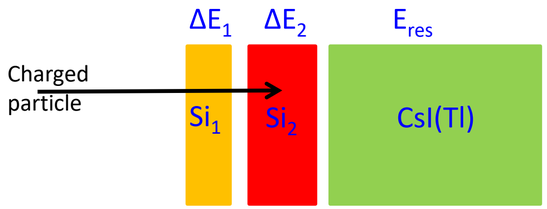




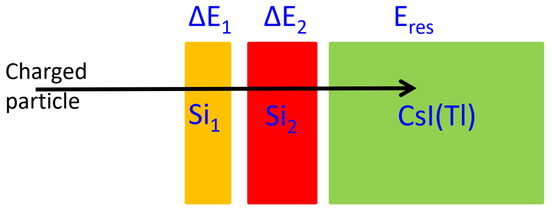
Pulse shape for stopped particles



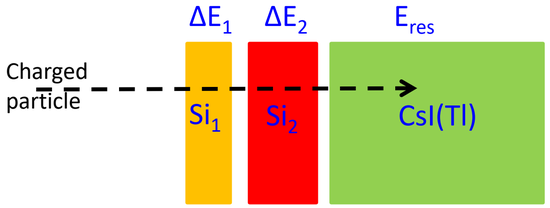
ΔE-E method



ΔE-E method



Pulse shape for energetic particles

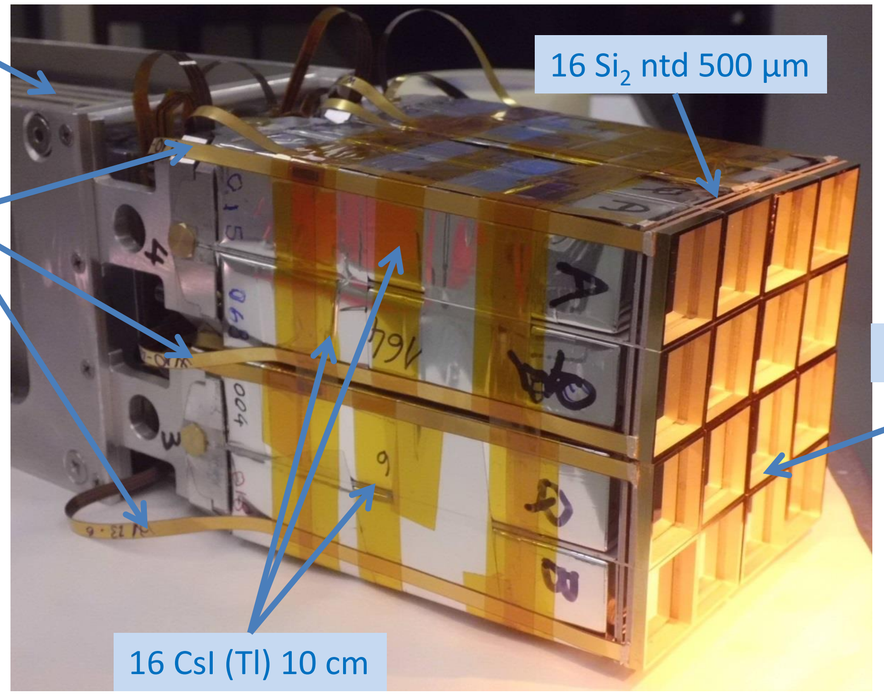


Identification threshold
~ 50 µm penetration

The FAZIA telescope

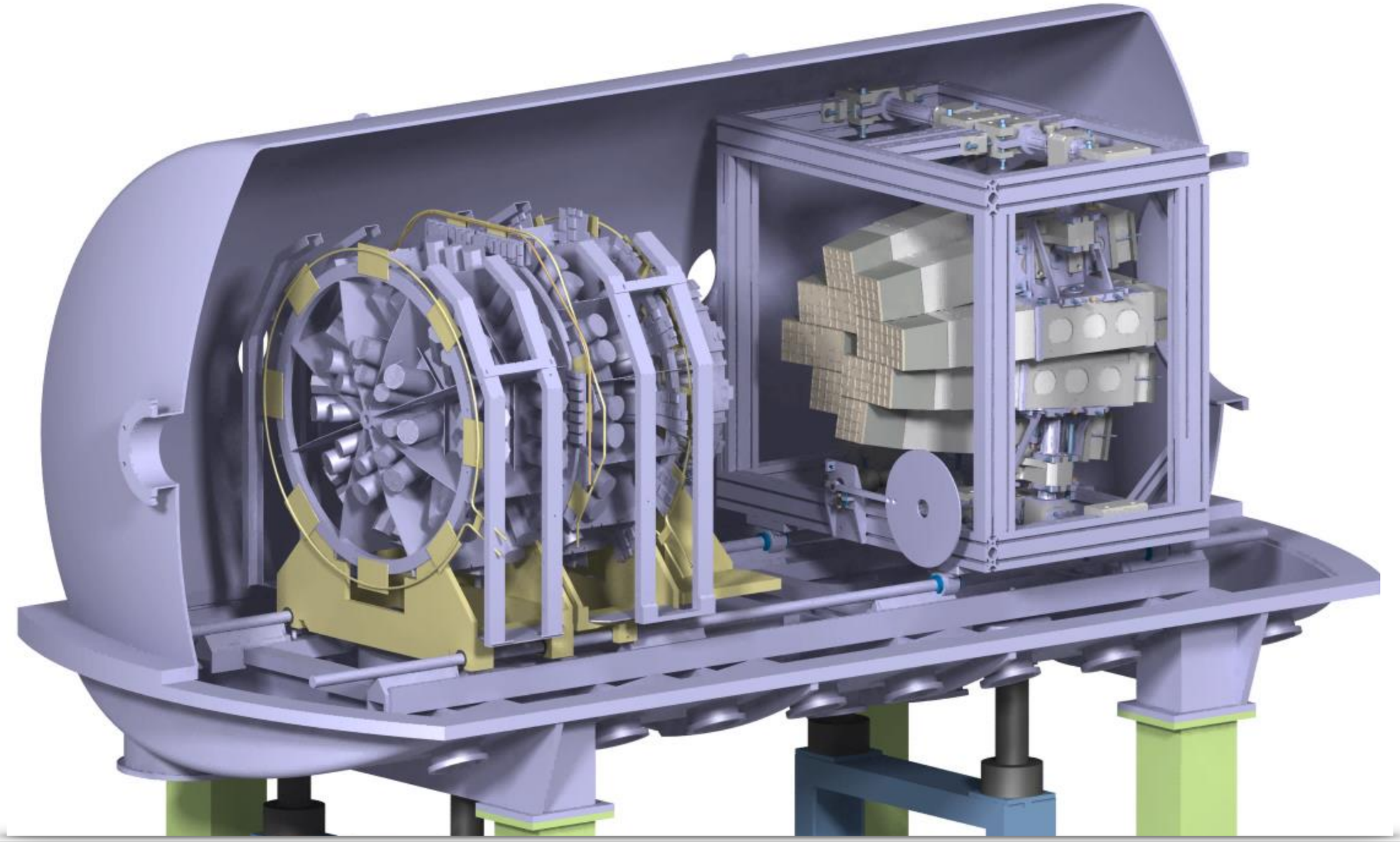
Front-end cards

One Fazia block is 16 telescopes Si_1-Si_2-CsI 20x20 mm²

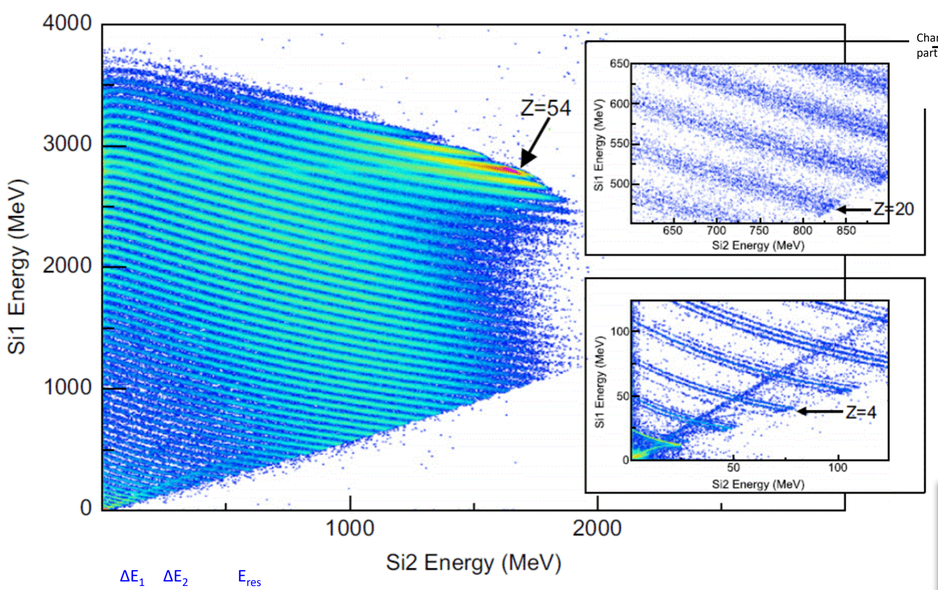


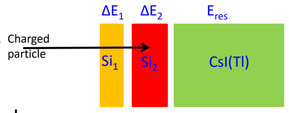
FAZIA: 12 blocks, 192 telescopes Si-Si-CsI
covering from 1,5°-12,5°
Z identification up to 50
A identification up to ~Z=20

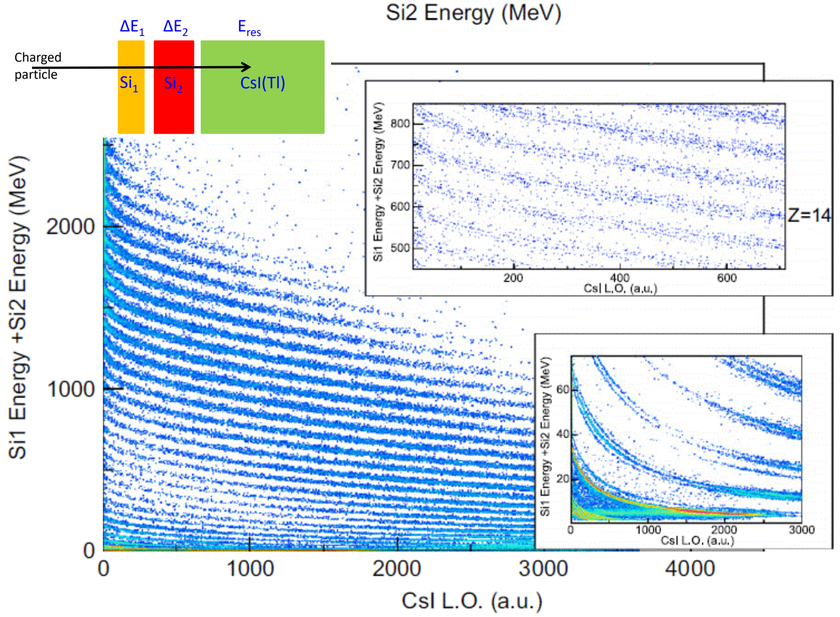
The FAZIA-INDRA in vacuum chamber

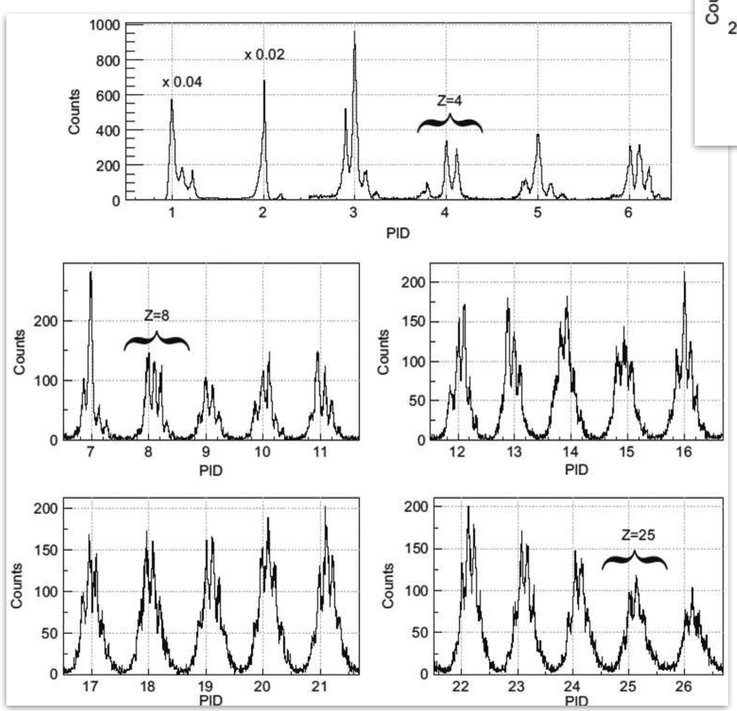


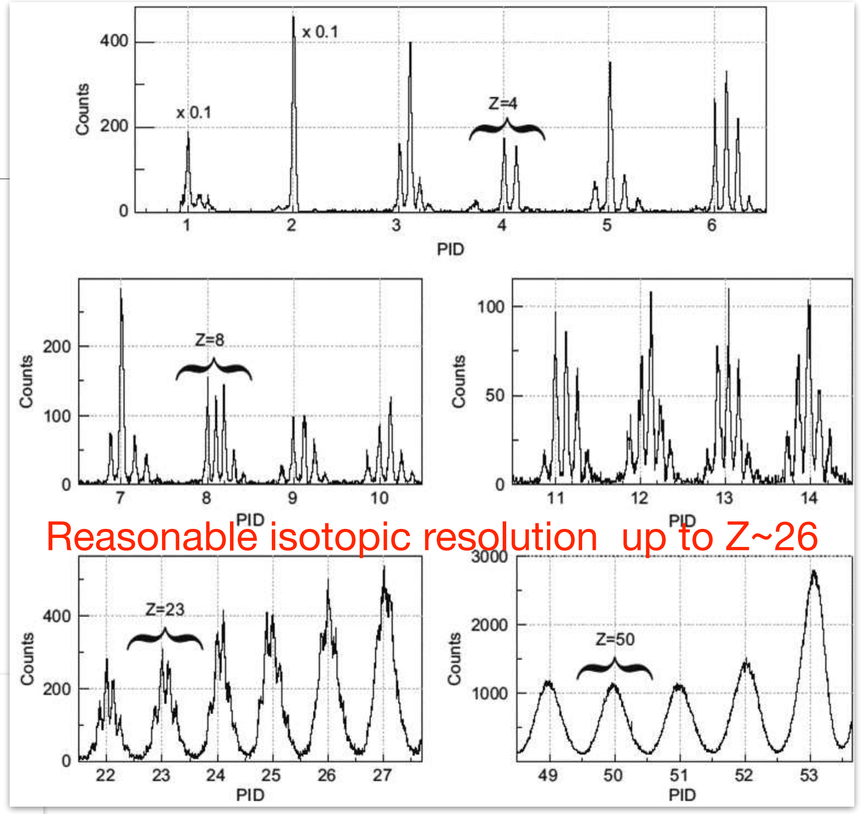
PID performance











Reasonable isotopic resolution up to Z~26

for Z = 6

- charge identification from 2 MeV/u

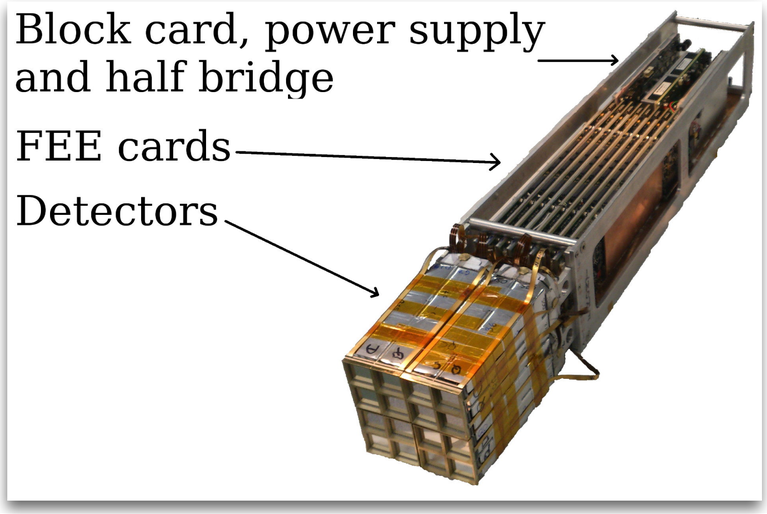
- isotopic discrimination from 5 MeV/u

Eur. Phys. J. A (2014) 50: 47

The FAZIA-type detector development for RAON

- Joined FAZIA detector upgrade project in 2019
  - Development of 750 μm thickness chips
  - New FEE board R&D and prototype production including test

- R&D for RAON: targeting producing one FAZIA-type block
  - Development of 1 mm & 150 μm thickness chips
  - New FEE board R&D
  - Production of supporting structures with the help of FAZIA team



1st visit in May/2019

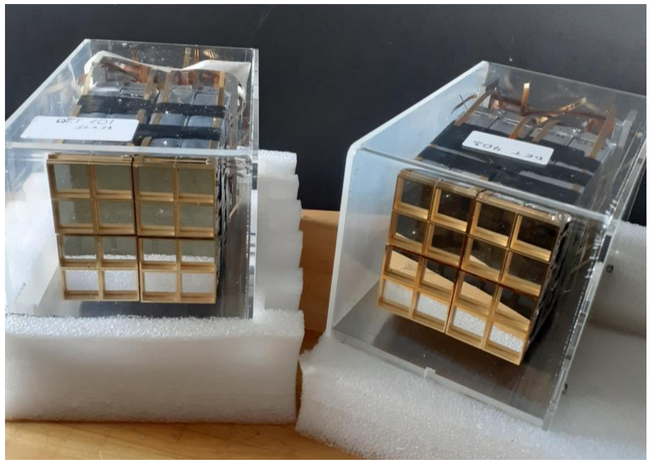
- Several Korean researchers from Ewha, Inha and Korea university visited FAZIA experiment (during beam time). at the end of May, and discussed where we can contribute as (potential) new collaborators

- Korean group starts to investigate
  - ✣ if there is a factory in Korea providing thin & ultra high purity Si sensors
  - ✣ if there is a company in Korea to produce the electronics for FAZIA-INDRA detector upgrade (similar/cheaper and smaller board)

Korean participating Institutes: Inha, Korea, Ewha university supported by CENuM

Si chip development

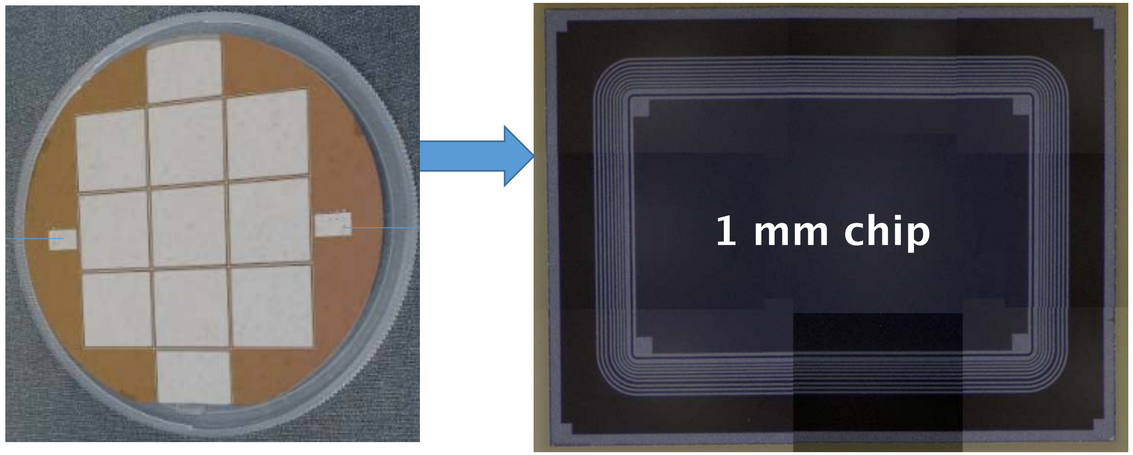
- 750 μm thickness chip
  - wafer investigation: 750 μm wafer was supplied from Korea
  - chip processing was done in Germany and tested by FAZIA team

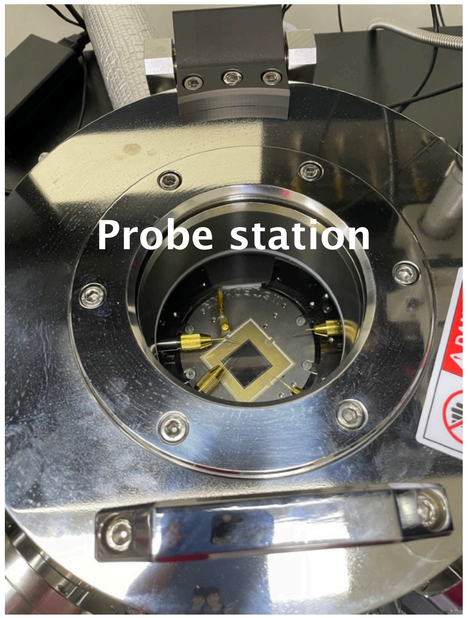


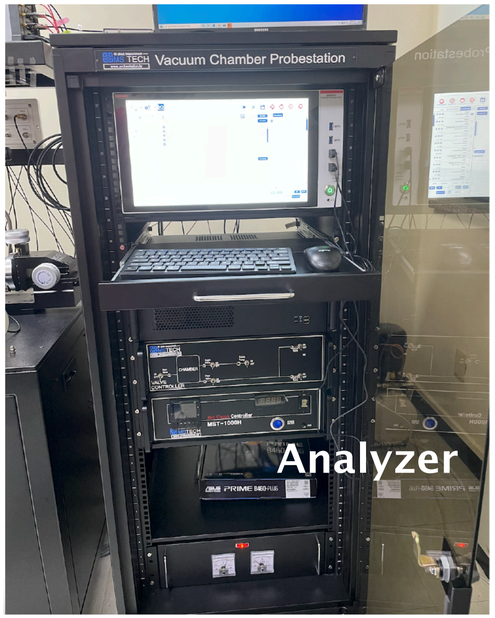
quartetto	batch	wafer	pad	rev curr. @340V CIS	internal reference (neglect)	date of test	bias voltage	rev current Florence	geometry Reverse o Direct	pulser width (ch)	241Am peak pos (ch)	241Am peak width (ch)	Resolution %
7501	401778	7	6	13,5	III	7-1-2021	300	12	r	8.2	3131,7	16,2	5,17E-01
7501	401778	7	8	0	II	7-1-2021	300	10	r	7.7	3135,4	13	4,15E-01
7501	401778	7	5	10,5	IV	7-1-2021	300	10	r	8.6	3135,9	13,1	4,18E-01
7501	401778	7	5	10,5	IV	7-1-2021	330	11	r	8.6	3140,2	13,3	4,24E-01
7501	401778	7	7	13,4	I	7-1-2021	300	2000	r	0	0	0	-

  - Assembled by the Italian (INFN @ Florence) group & included for the beam test during E818 Exp.

- 1 mm thickness chip (1st trial)
  - Chips produced by Pohang Nanofab. & tested in our lab.
- 150 μm thickness chip
  - produced & tested

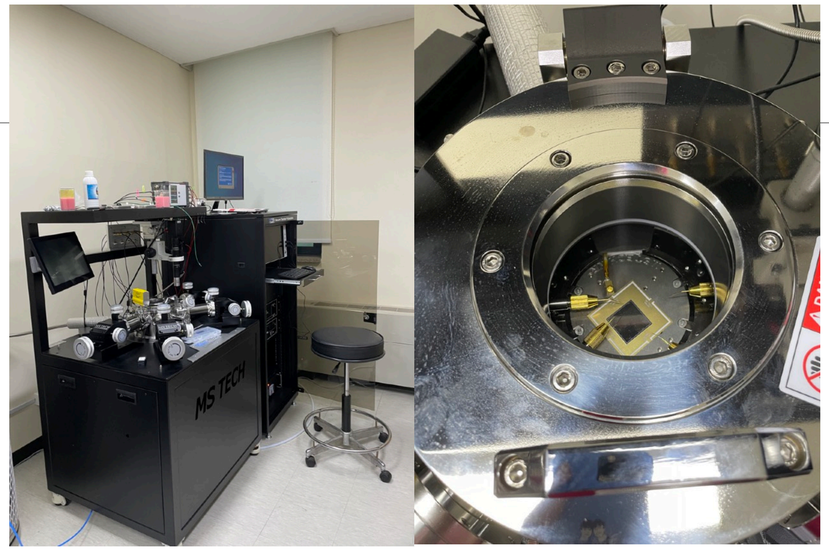




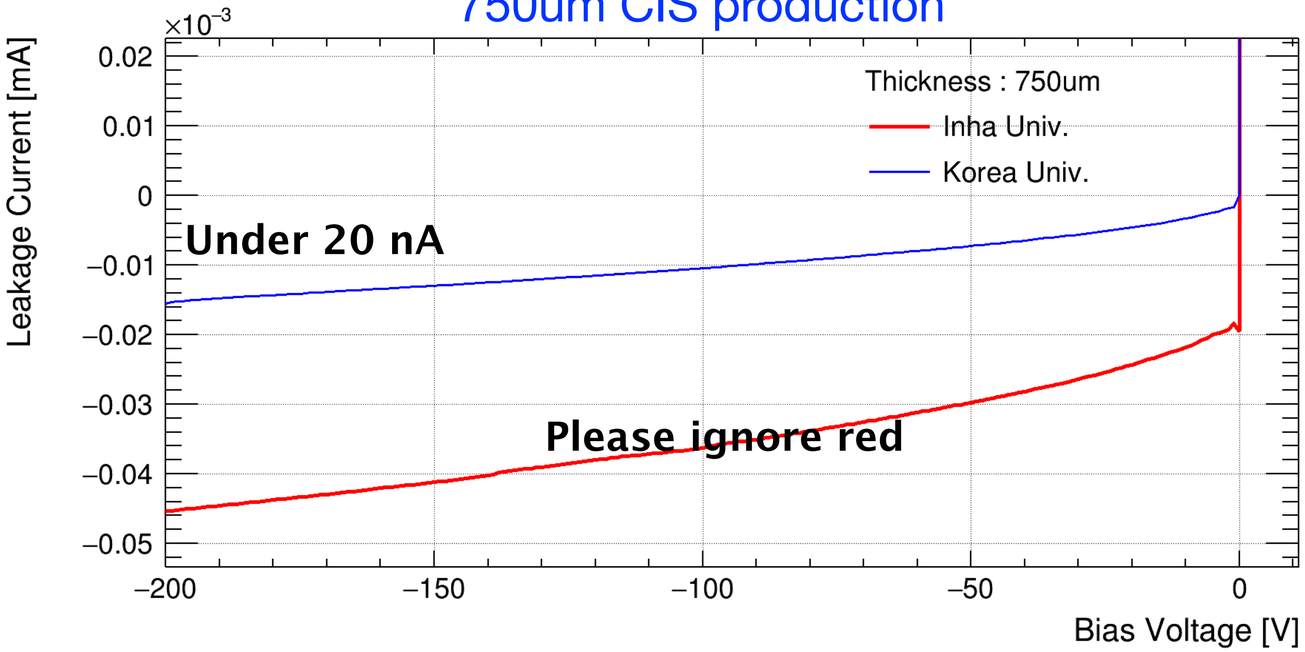


Leakage current of 750 μm vs. 1 mm

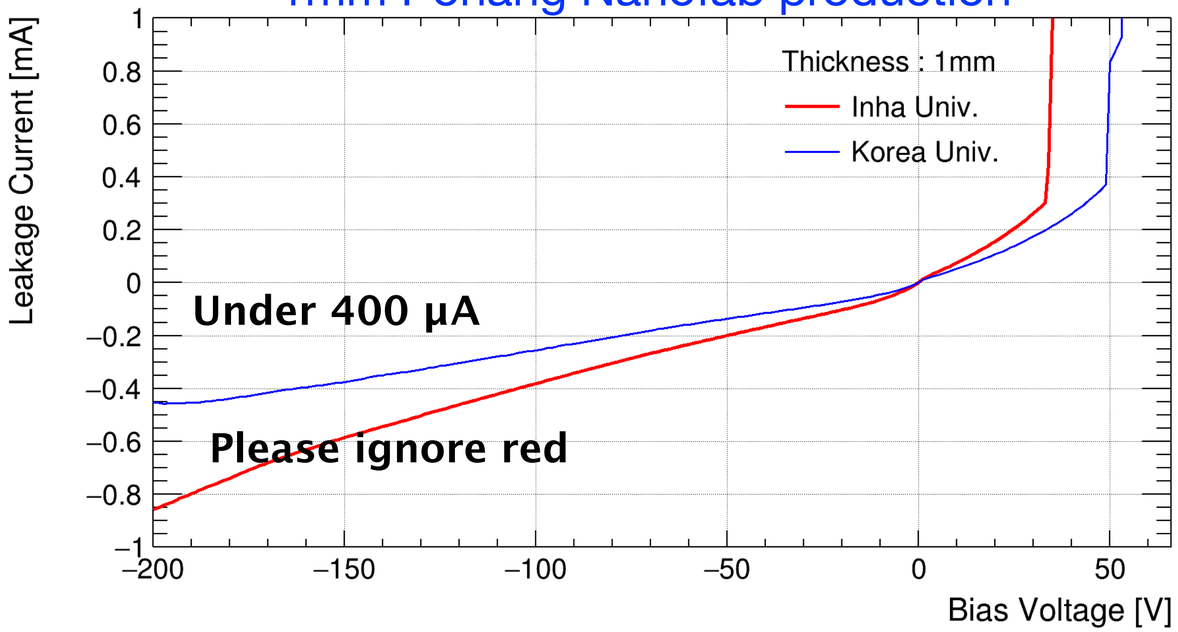
- 1 mm chips were tested (0 ~ 200 V)
  - 750 μm nominal chip: < 25 nA leakage current up to 200 V
  - 1 mm nominal chip: 0.1 mA ~ 1 mA between 50 V ~ 200 V
  - ➡ Doesn't satisfy the qualification



750um CIS production

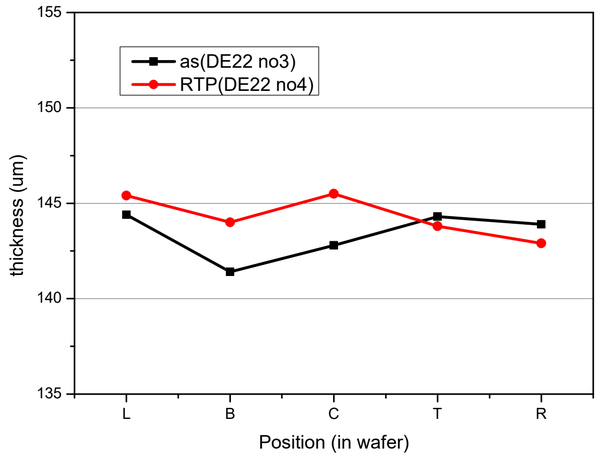


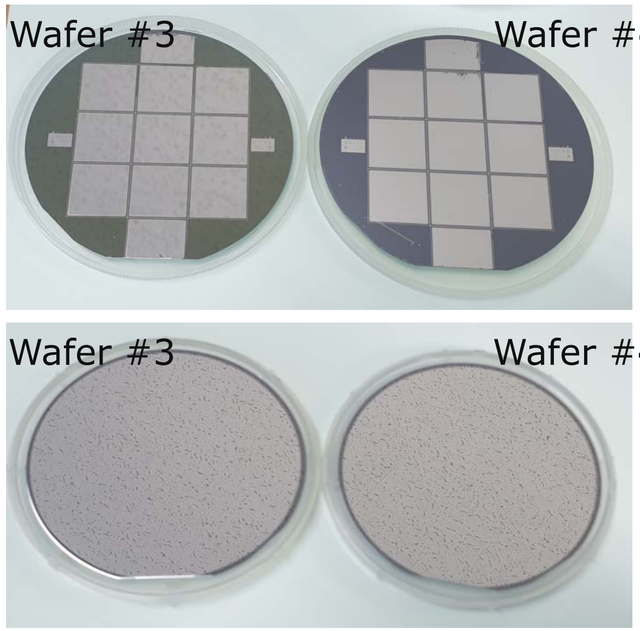
1mm Pohang Nanofab production



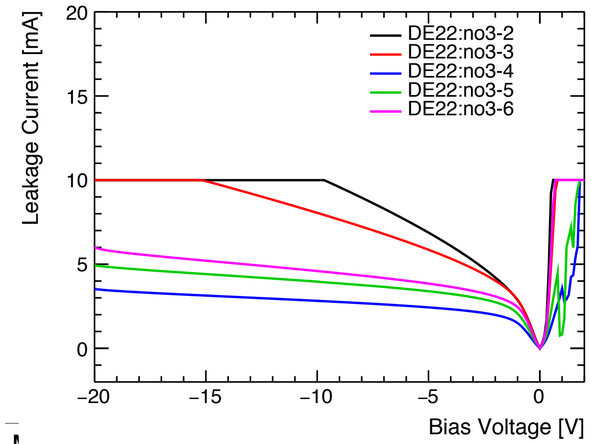
150 μm chip produced :), Jan/2022

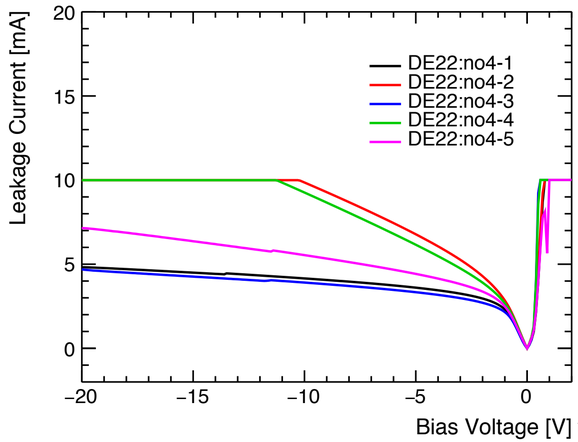
- 300 μm wafer was thinned into 150 μm after the fabrication





(150um: 5ea) (150um: 5ea)





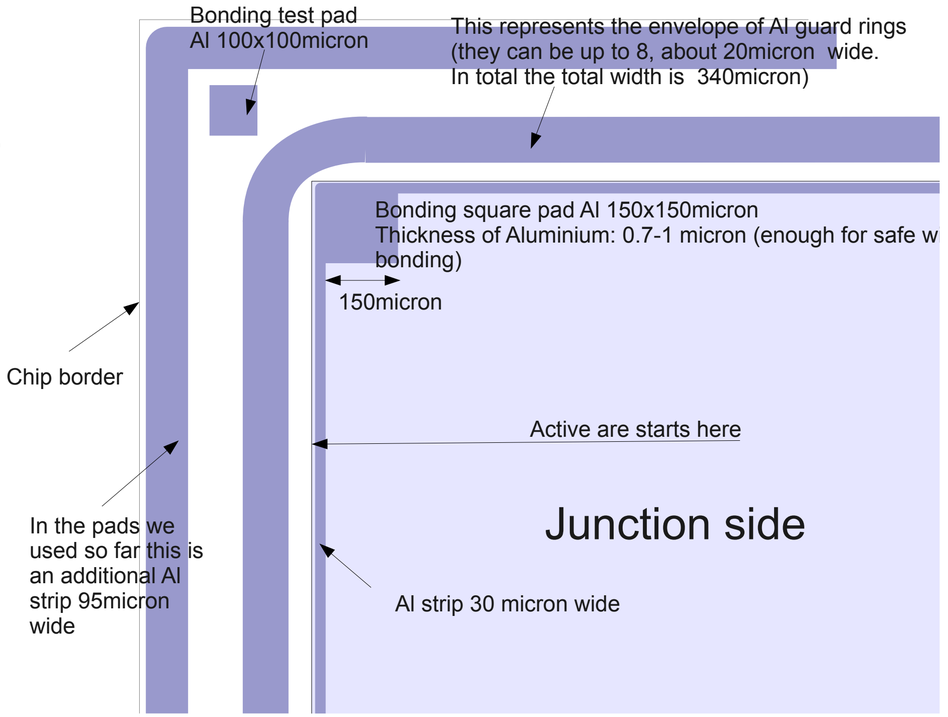
- 150 μm chips also don't satisfy the qualification

Design and construction of the new thick Si detectors

- Chip production with Pohang Nanofab was not successful.

- National Nanofab Center (NNFC) 나노종합기술원 in 대전
  - Help out chip design by….
  - Chip fabrication with 8 inch wafer (same qualification as the previous production): planned

- Fabrication with ETRI (6 inch wafer)
  - Chip design has been done
  - Flow chart has been prepared
  - Run sheet is on progress
  - Expect to start fabrication on September

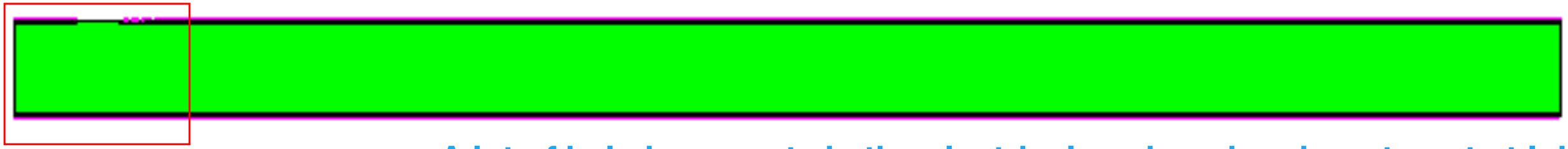


Learn a lot through trail and error!

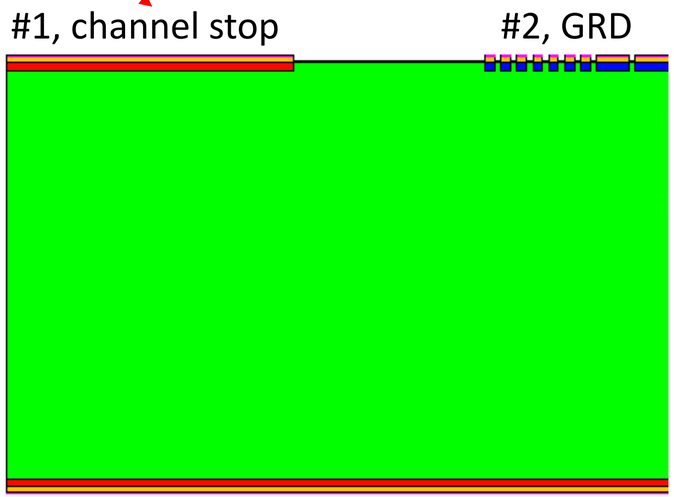
+

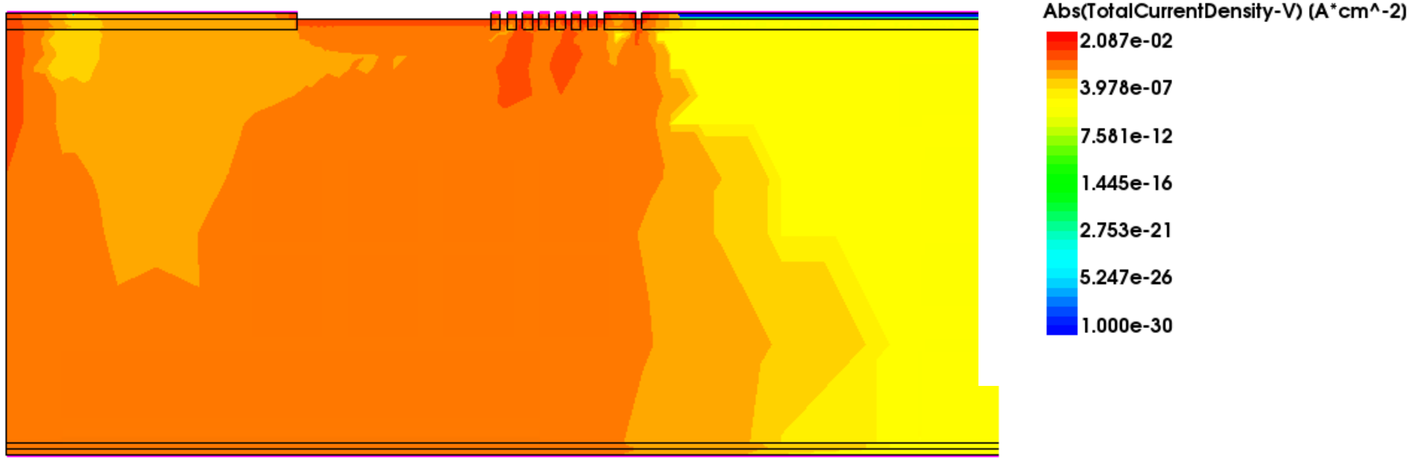
Further investigation!

Chip design & TCAD simulation (Synopsys)



A lot of help by experts in the electrical engineering department at Inha

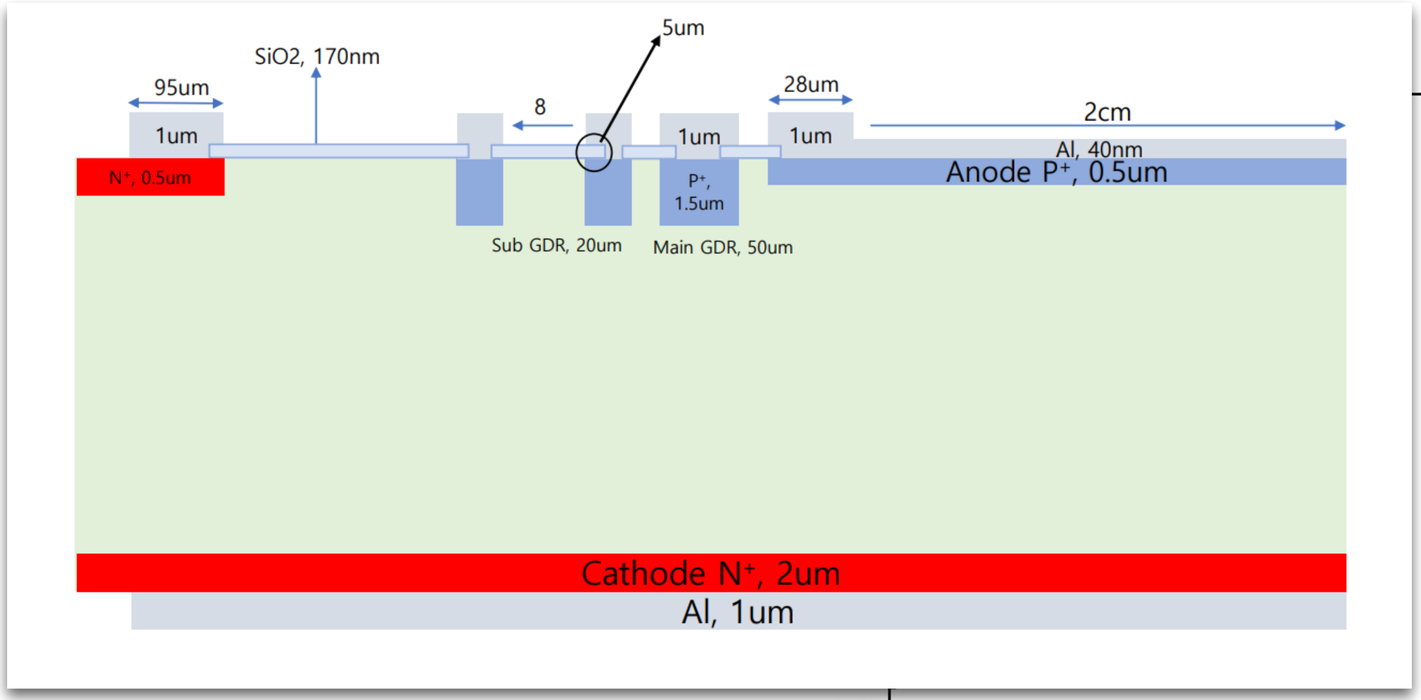


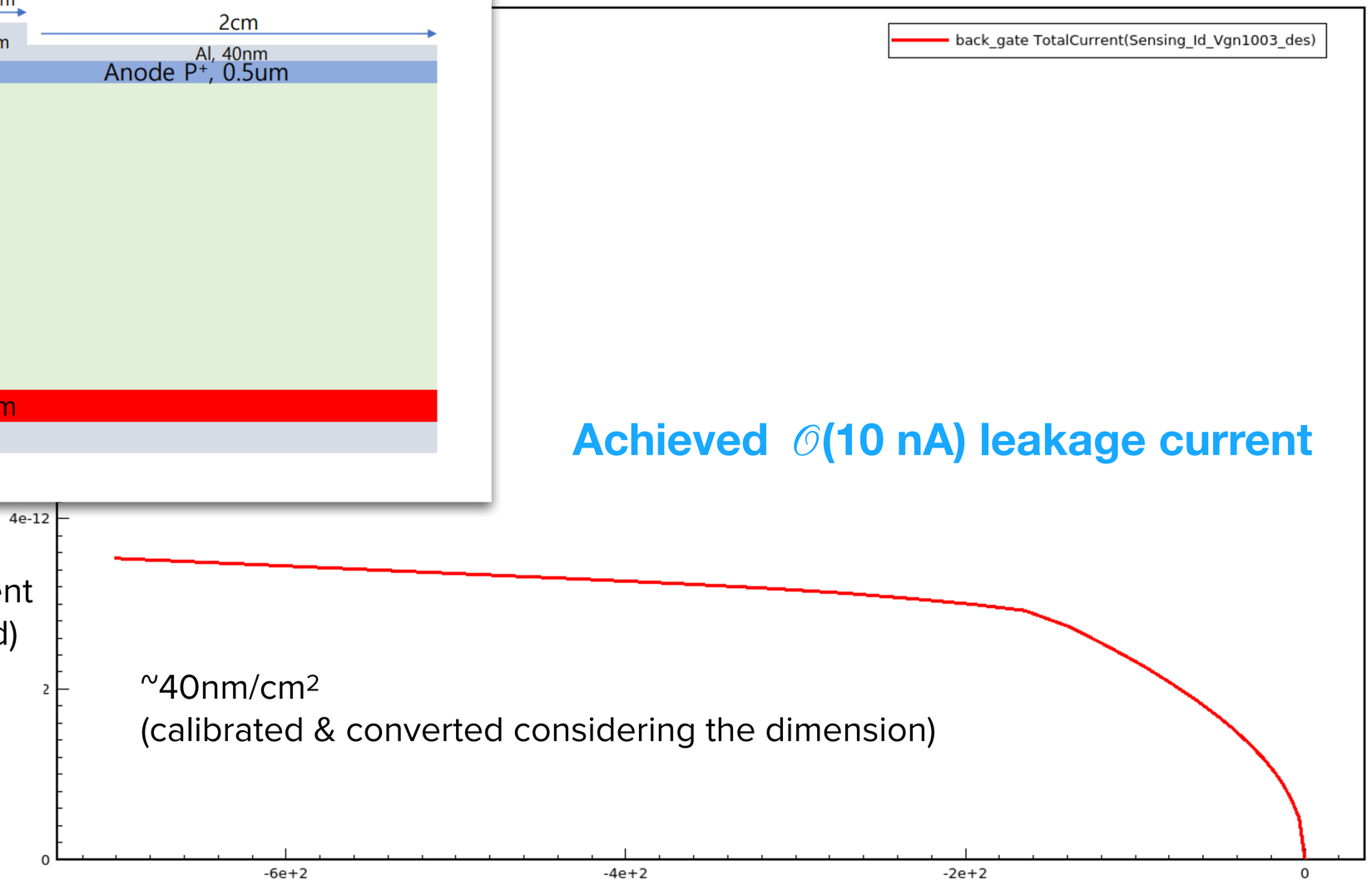


2D simulation on a side region of the chip
Current density distribution from 2D simulation

Structure, dimensions
Doping profile…. & ion-implantation energy, dose, incident angles ….

Leakage current simulation based on the final design



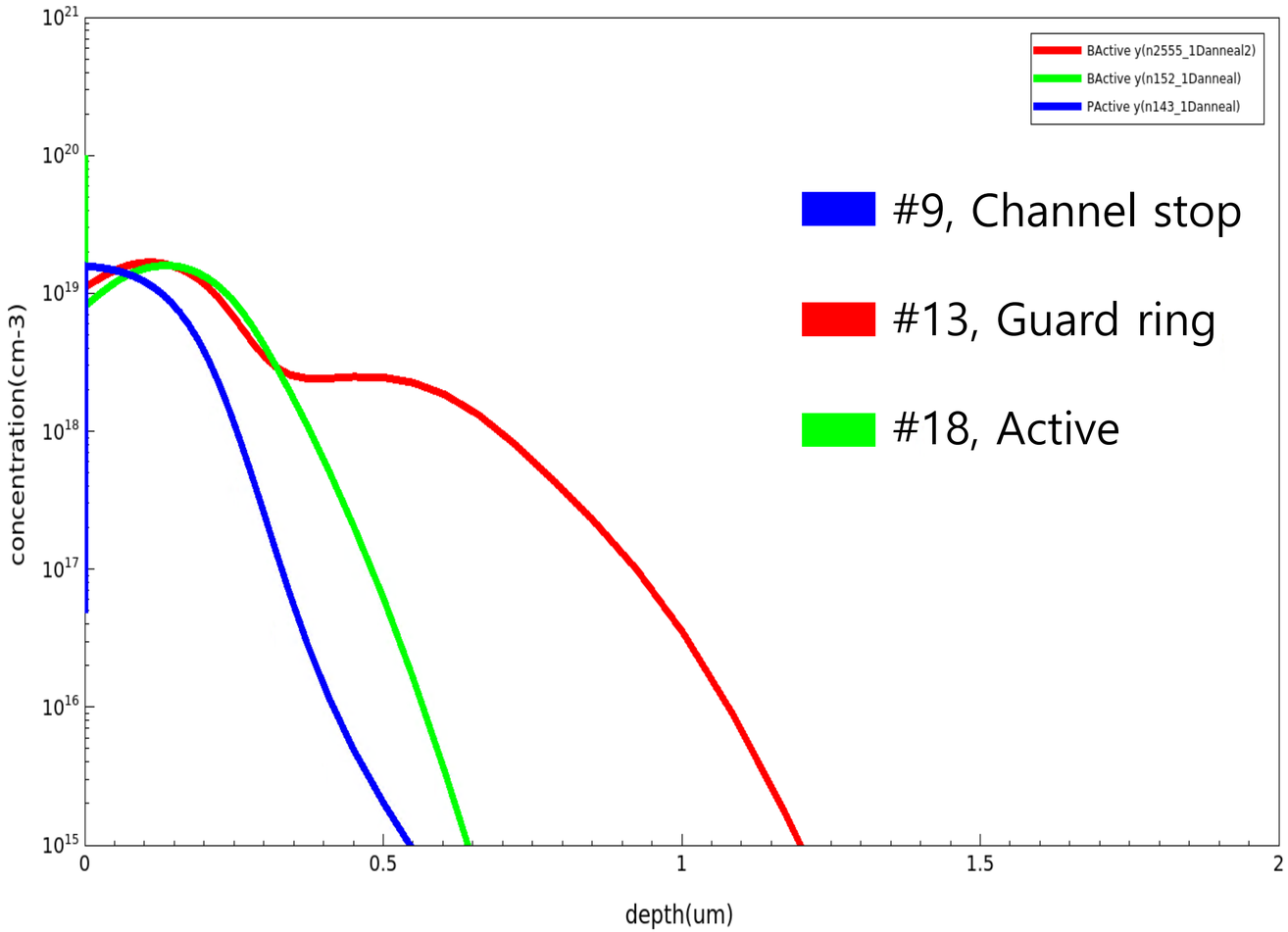


Achieved $\mathcal{O}$(10 nA) leakage current

~40nm/cm^2
(calibrated & converted considering the dimension)

Doping profile based on TCAD process simulation

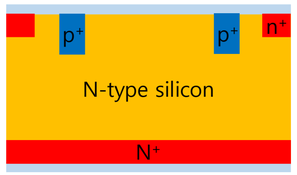
Doping profile



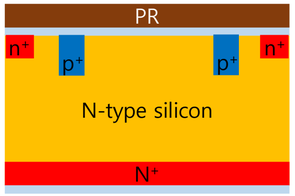
Simulated with specific energy, dose, activation condition

PIN sensor fabrication

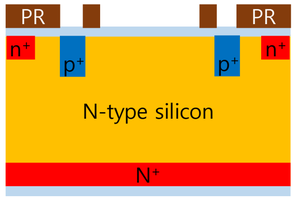
Flow charts prepared



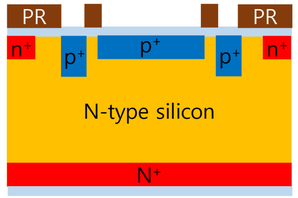
16. activation[1]



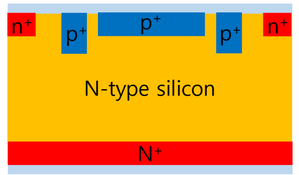
17. PR coating



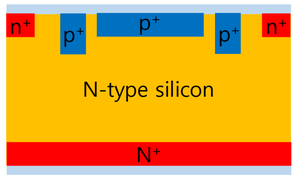
18. PR develop



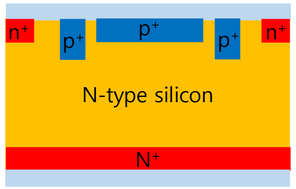
19. P+ implant [active]



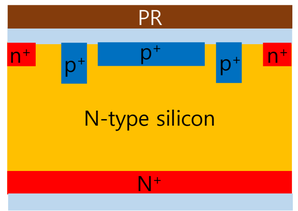
20. PR strip



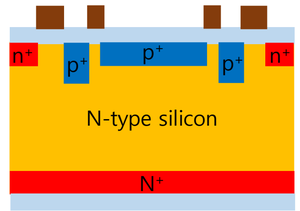
21. activation[2]



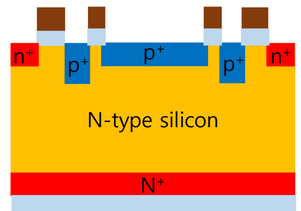
22. Oxidation [1700Å]



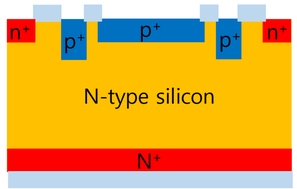
23. PR coating



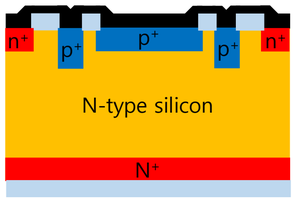
24. PR develop [oxide etch]



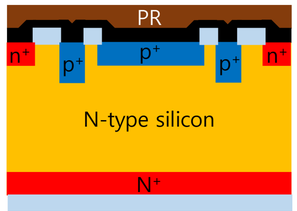
25. oxide etching



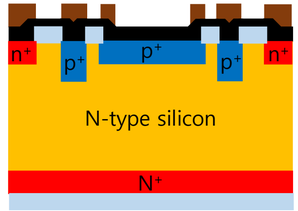
26. PR strip



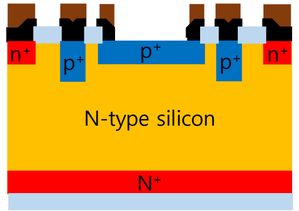
27. metal deposit [10000Å]



28. PR coating

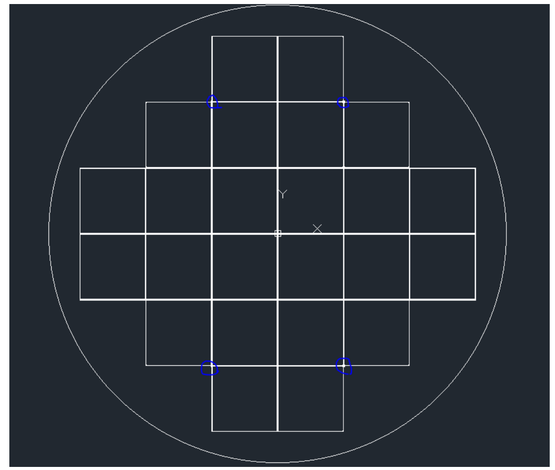


29. PR develop [GRD metal]

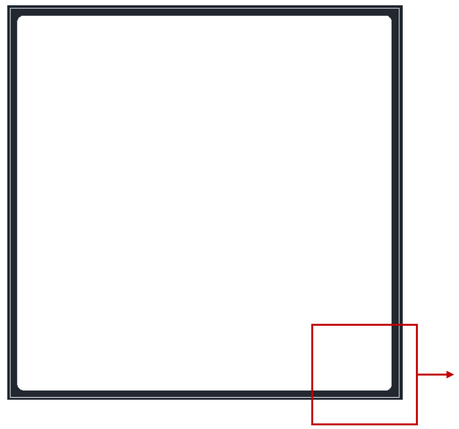


30. metal etching

Mask designed



#3 active

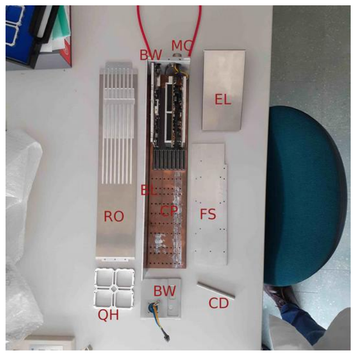


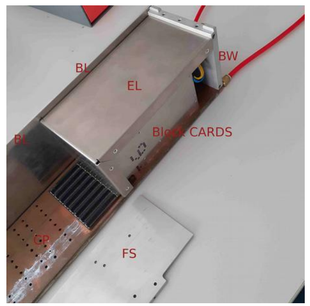
Run sheet for the fabrication is under preparation.
Hope the production done until the end of October.

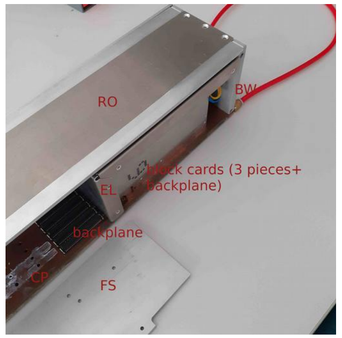
Building blocks including Quartteto

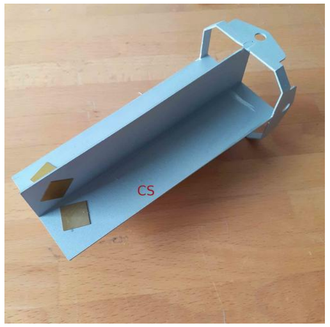
Supporting structures

- FAZIA team will provide supporting structures as much as possible
- For the mass production in the future, plan to produce them locally in Korea → plan changed considering cost
- Wire bonding on the frame in ergal is done by the company (MEMSPACK)

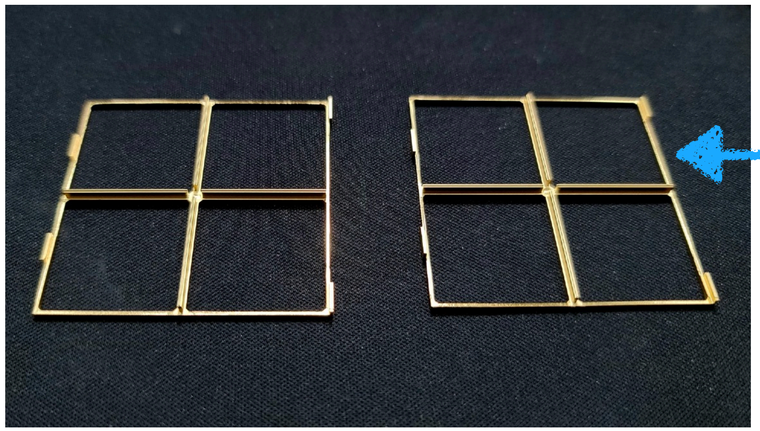


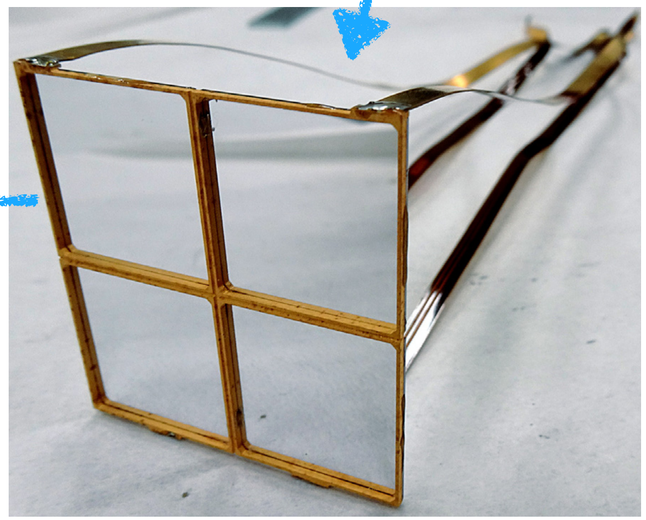






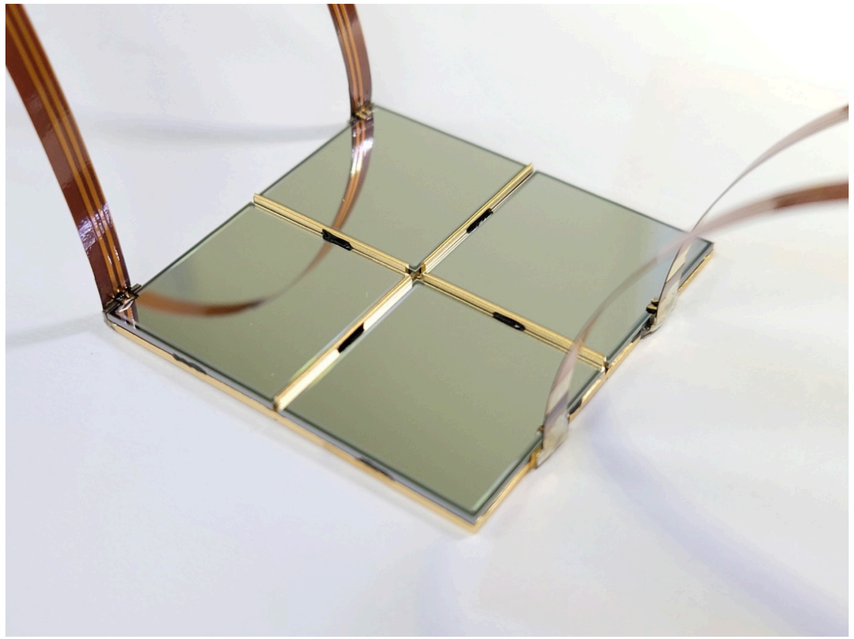
Quartteto frame

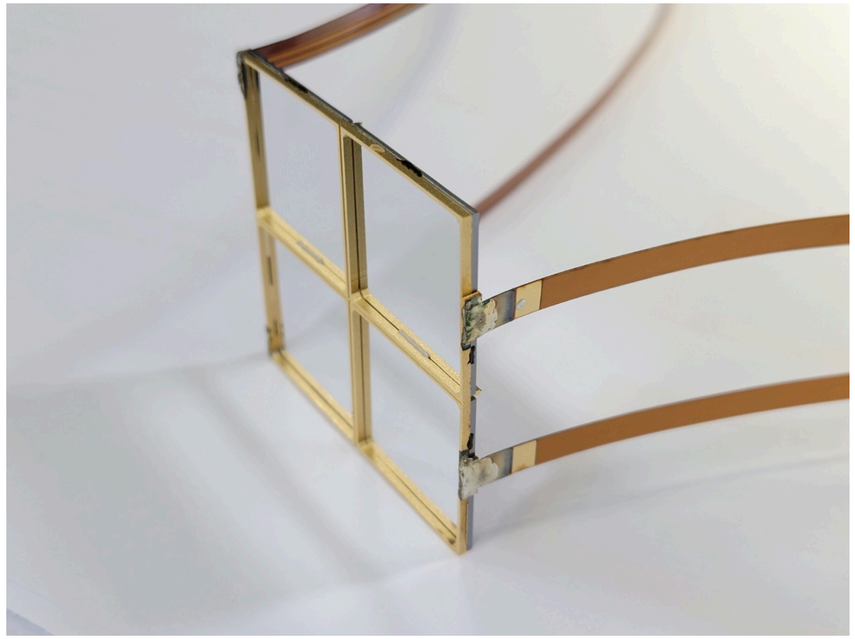


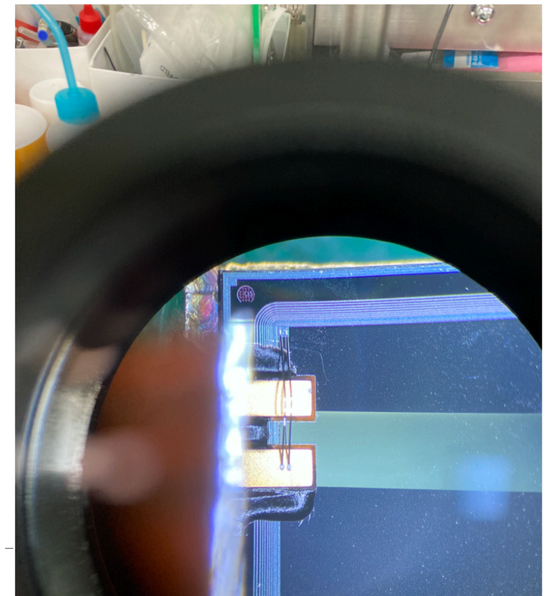


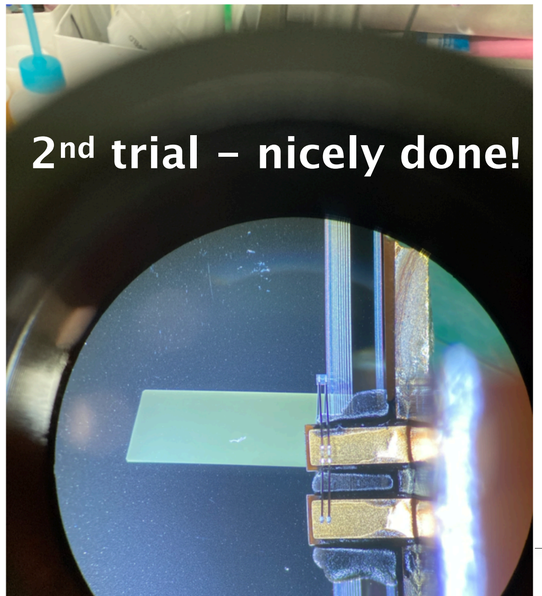
- CsI+diode for the 1st block will be also supported by FAZIA

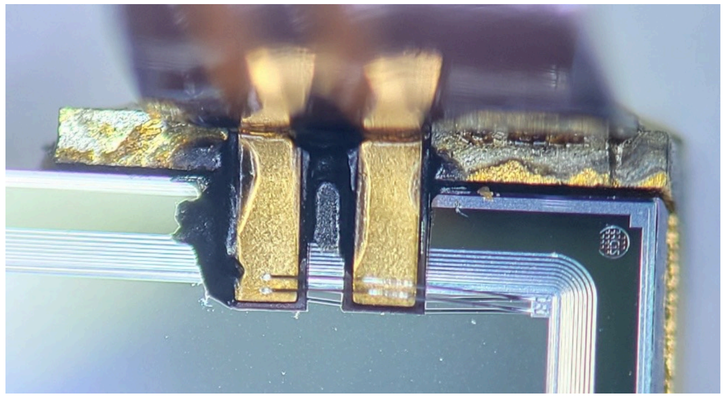
Quartetto produced by MEMSPACK (chip mounting & wire-bonding)

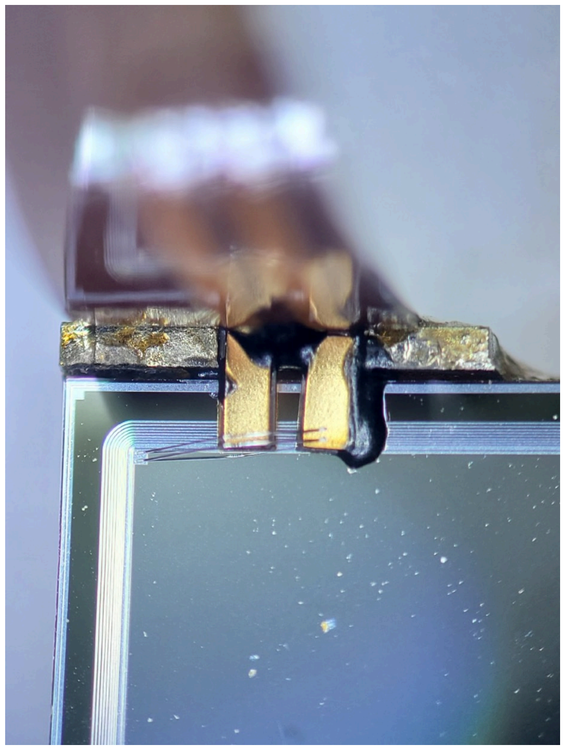




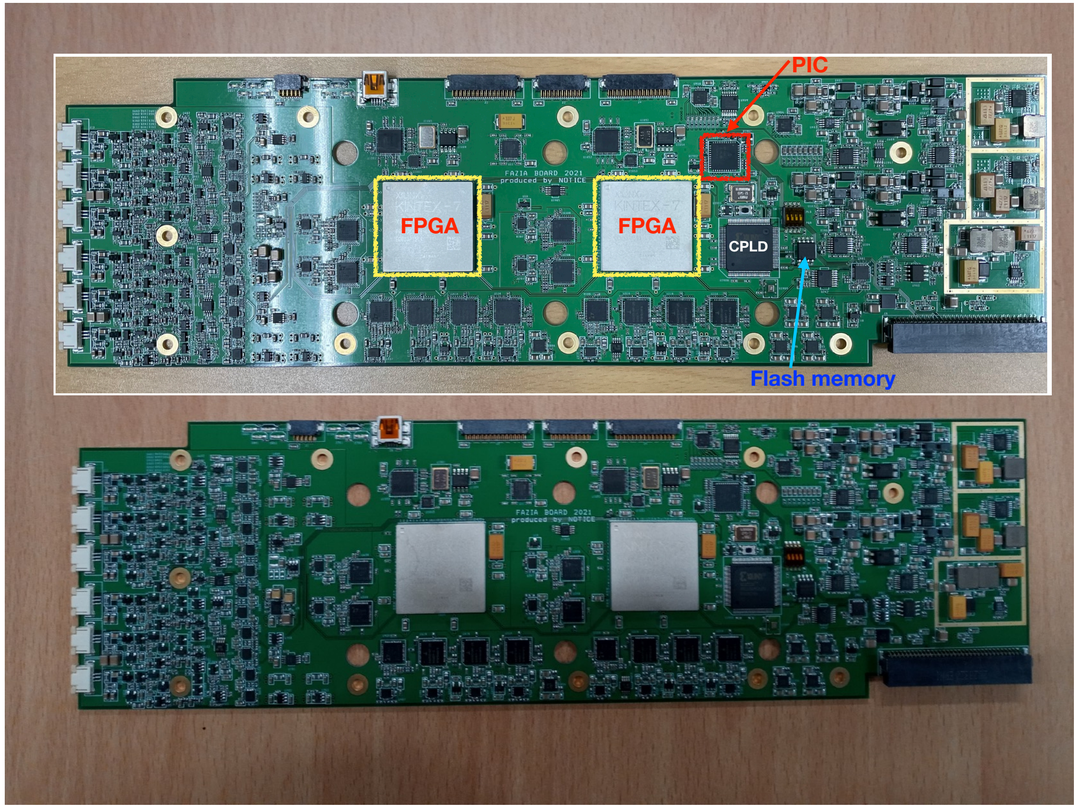




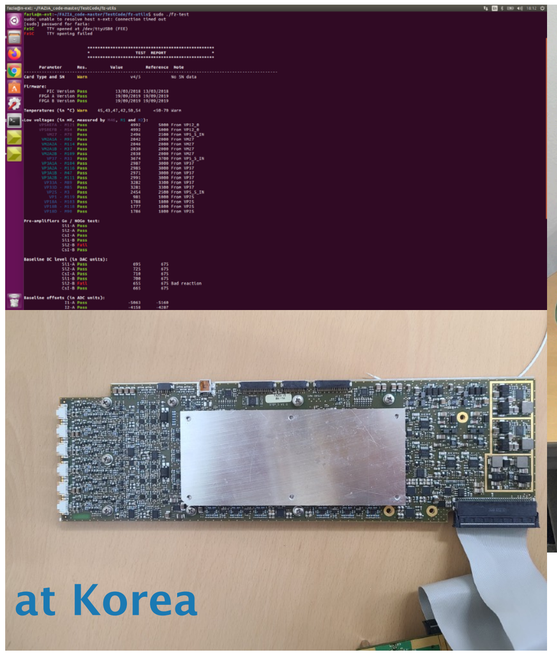


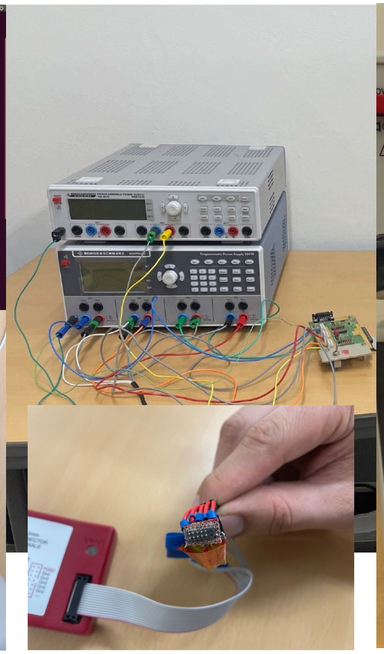


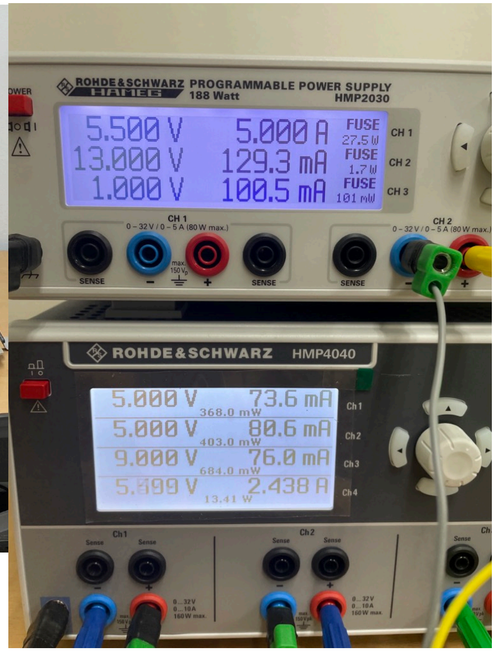
FEE development & production



- Two prototype boards were produced by NOTICE
  - Out of dated digital parts → replaced
  - New FPGA chips → new VHDL software developed (quite some work!!!)
- Tested at GANIL; seems there is no major issue, need minor debugging on (likely) firmware
- Discussion ongoing for the next version of the board with one FPGA chip & reduced board size (together with NOTICE)







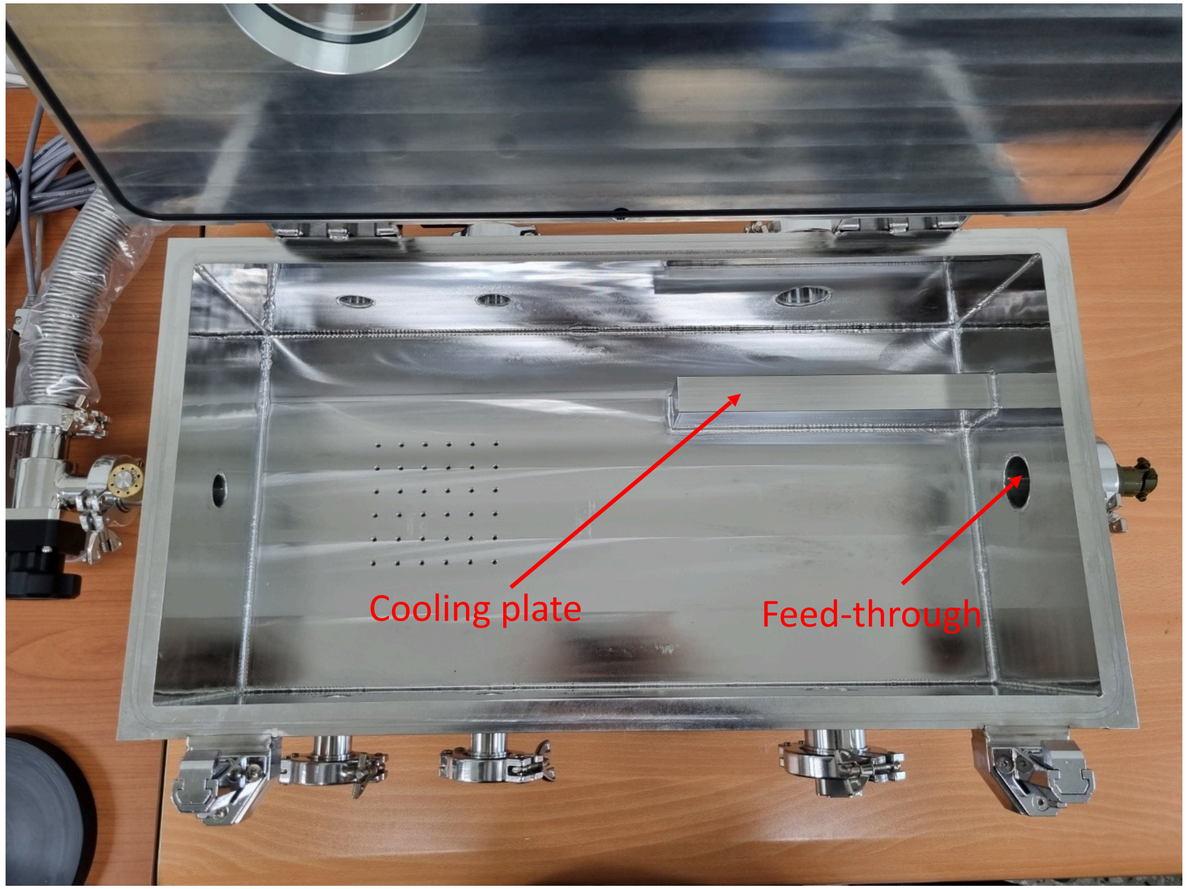
Test setup prepared at Korea

Alpha source test setup

Construct lab. test system for Si chip characterization

Cooling machine

Vacuum chamber



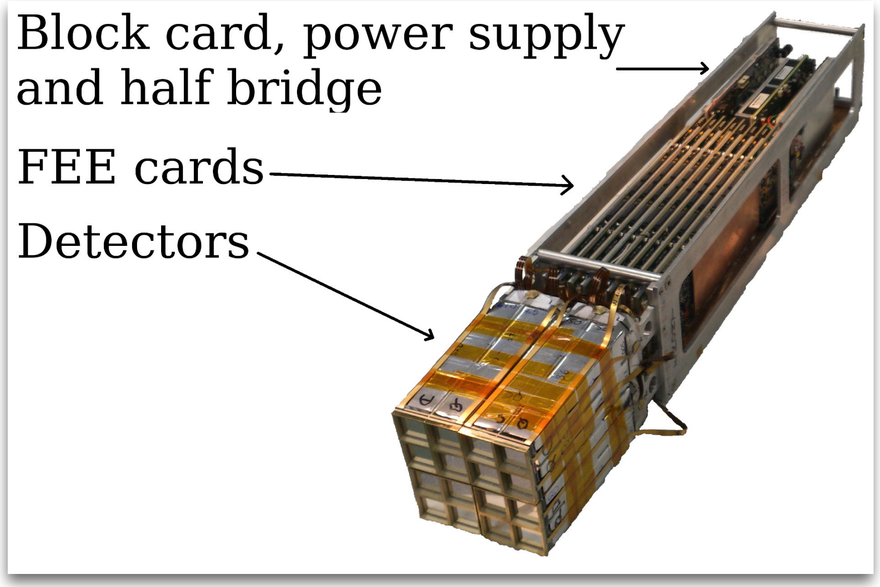
Vacuum chamber interior

Vacuum pump

Special boards with preAmp ONLY were produced for the source test.

Outlook

- Target to produce the 1st block within 2 years (?)
- Plan to prepare several blocks (at least 4 blocks) but it depends on funding, need further internal discussions



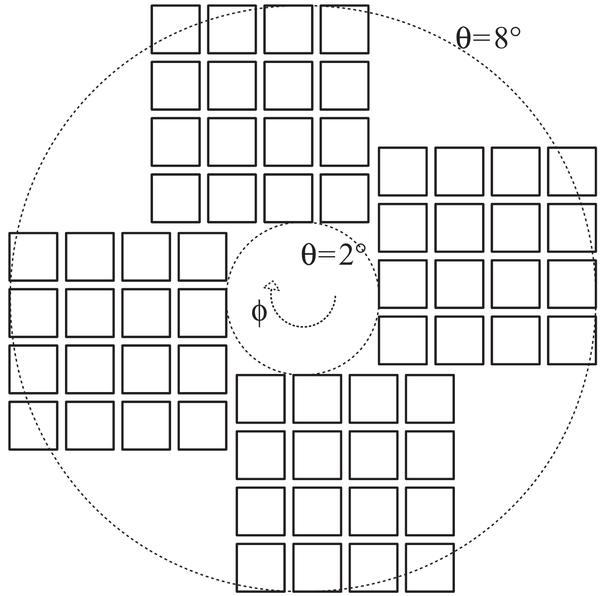


FIG. 1. Schematic polar representation of the apparatus geometry. The beam axis passes through the symmetry center. View from the target.

FAZIA will use the detector blocks constructed in Korea in the commissioning phase of RAON. Later, FAZIA can also use the Korean blocks for the RIB experiments not only at RAON but also at GANIL & other accelerator facilities.

Something with one block? FAZIA commissioning: stable ^{84}Kr beam

FAZIA commissioning phase at LNS Catania 2013-2018

FAZIA May 2013
1 block + telescopini
84Kr at 35A MeV

FAZIA December 2014
2 blocks horizontal plane 10 UTs
^{84}Kr + ^{58}Ni, ^{93}Nb & $^{112-124}$Sn at 24.75 A MeV

ONE block!
called test run!

FAZIA 2015
4 blocks horizontal plane 25 UTs
^{40}Ar at 35 A MeV & ^{80}Kr + $^{40-48}$Ca at 35 A MeV

FAZIASYM December 2015
4 blocks wall configuration
$^{40-48}$Ca + $^{40-48}$Ca at 35 A MeV

FAZIACOR March 2017
4 blocks wall configuration
^{20}Ne & ^{32}S + ^{12}C at 25 & 50 A MeV

FAZIAPRE test October 2017 experim
4 blocks wall configuration, plus 2 late
$^{40-48}$Ca + ^{12}C at 25 & 40 A MeV + few r

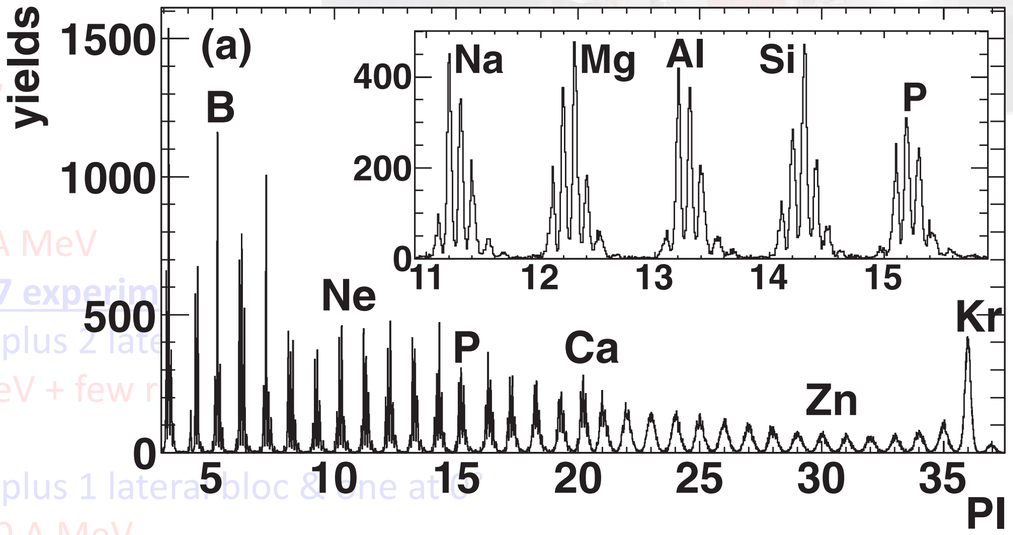
FAZIAZERO July 2018
4 blocks wall configuration, plus 1 lateral bloc & one at
^{12}C + ^{12}C & $(CH_2)_n$ at 62 & 80 A MeV

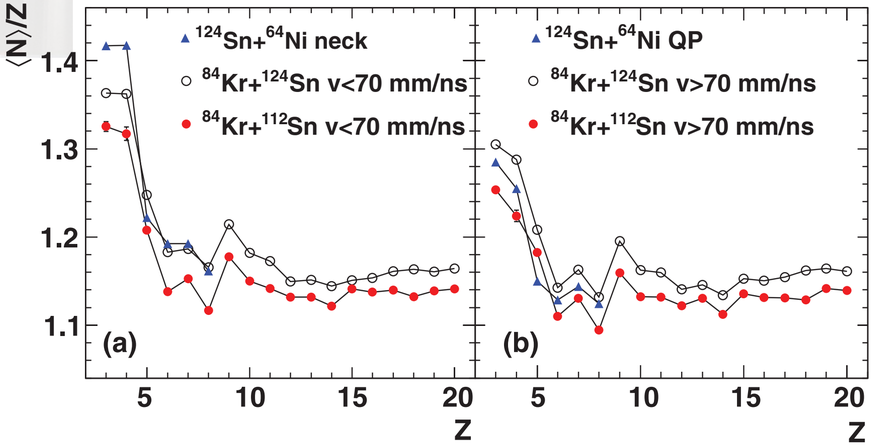
Example!

PHYSICAL REVIEW C **87**, 054607 (2013)

Isospin transport in ^{84}Kr + ^{112,124}Sn collisions at Fermi energies

Isotopically resolved fragments with $Z \lesssim 20$ have been studied with a high-resolution telescope in a test run for the FAZIA Collaboration. The fragments were produced by the collision of a ^{84}Kr beam at 35 MeV/nucleon with a neutron-rich (^{124}Sn) and a neutron-poor (^{112}Sn) target. The fragments, detected close to the grazing angle, are mainly emitted from the phase-space region of the projectile. The fragment isotopic content clearly depends on the neutron richness of the target and this is direct evidence of isospin diffusion between projectile and target. The observed enhanced neutron richness of light fragments emitted from the phase-space region close to the center of mass of the system can be interpreted as an effect of isospin drift in the diluted neck region.



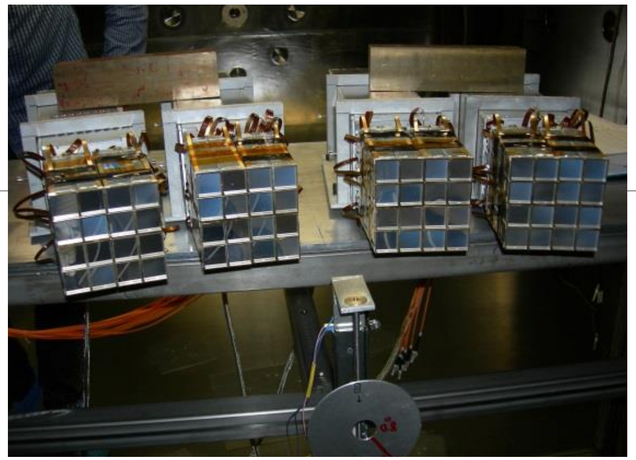


identified fragments (Z >= 3) that are stopped in the second silicon layer or in the CsI(Tl), isotope resolution up to Z ~ 20

Extra Slides

Beam & detector used for FAZIA commissioning

FAZIA commissioning phase at LNS Catania 2013-2018



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1 block + telescopini
84Kr at 35A MeV

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2 blocks horizontal plane 10 UTs
^{84}Kr + ^{58}Ni, ^{93}Nb & $^{112\text{-}124}$Sn at 24.75 A MeV

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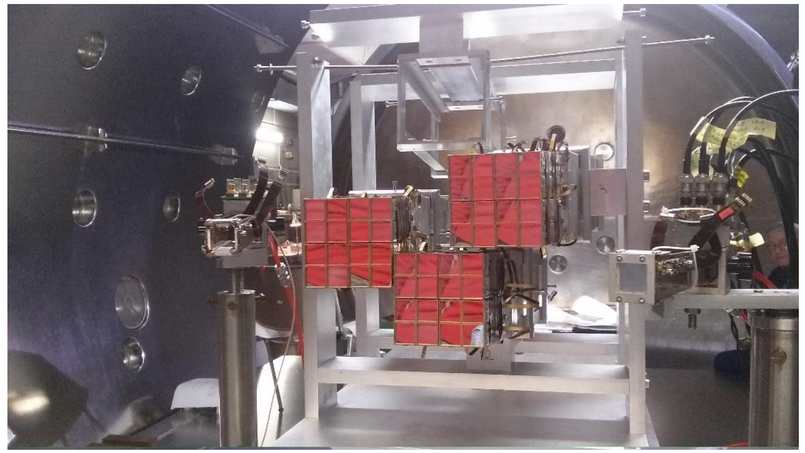
4 blocks wall configuration
$^{40\text{-}48}$Ca + $^{40\text{-}48}$Ca at 35 A MeV

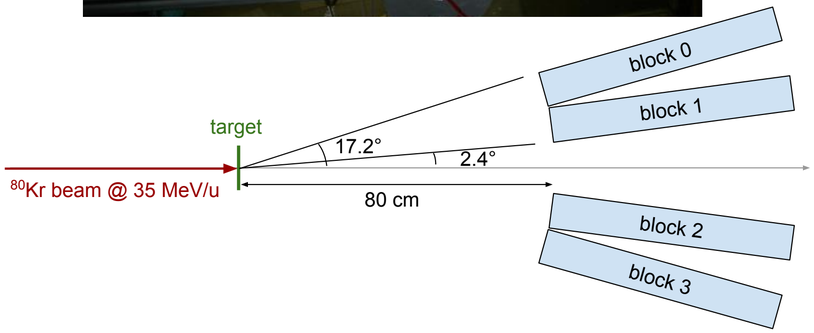
FAZIACOR March 2017
4 blocks wall configuration
^{20}Ne & ^{32}S + ^{12}C at 25 & 50 A MeV

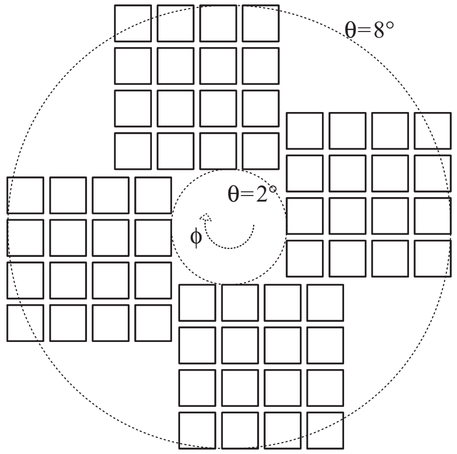
FAZIAPRE test October 2017 experiments in February & May 2018
4 blocks wall configuration, plus 2 lateral blocks
$^{40\text{-}48}$Ca + ^{12}C at 25 & 40 A MeV + few runs with ^{27}Al & ^{40}Ca

FAZIAZERO July 2018
4 blocks wall configuration, plus 1 lateral bloc & one at 0°
^{12}C + ^{12}C & $(CH_2)n$ at 62 & 80 A MeV

1st physics oriented experiment







Courtesy of Nicolas Le Neindre, LPC CAEN