2023 Joint Workshop of FKPPL and TYL/FJPPL
Ochanomizu University, Tokyo, Japan (Online) 9-11 May 2023

FAZIA French-Korean Collaboration

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and
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for
FAZIA-FKC

Brief history of French-Korean Collaboration in FAZIA

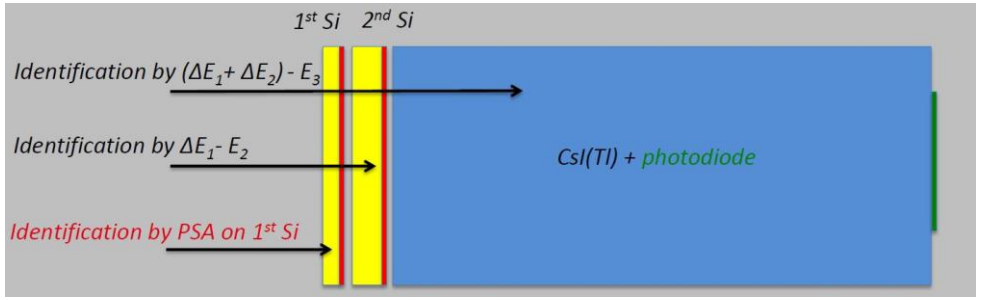
- Before 2019:
  - The Korean group (part of LAMPS Collaboration) was designing the Si-CsI telescope for the low-energy (a few tens MeV per nucleon) nuclear collision experiments at RAON, which is the new radioactive-ion beam facility being built in Korea.
  - The International Advisory Committee of RAON reviewed the status of the detector development and suggested to collaborate with FAZIA in Europe, because it had been operating the most advanced Si-CsI detector system for nuclear physics.
  - We started the discussion with some FAZIA members to join the Collaboration in various Conferences and meetings.
- In 2019
  - A group of Korean researchers visited GANIL in May 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 2019 and presented the application to officially join the Collaboration.
- MoU
  - The Center for Extreme Nuclear Matters (CENuM), representing the whole Korean group, signed on the MoU in 2020.
  - Signed the new MoU for 2023-2027

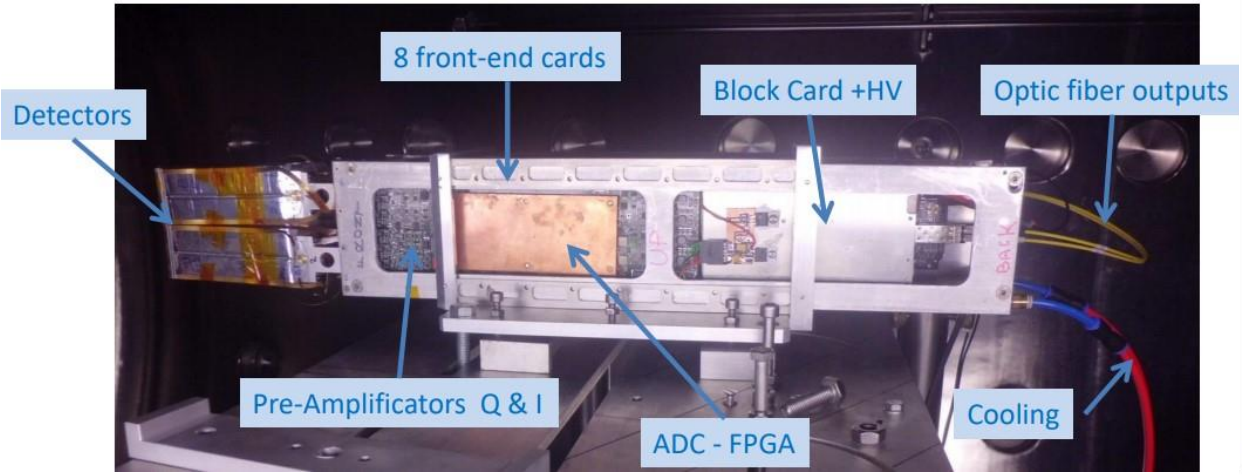
FAZIA 101

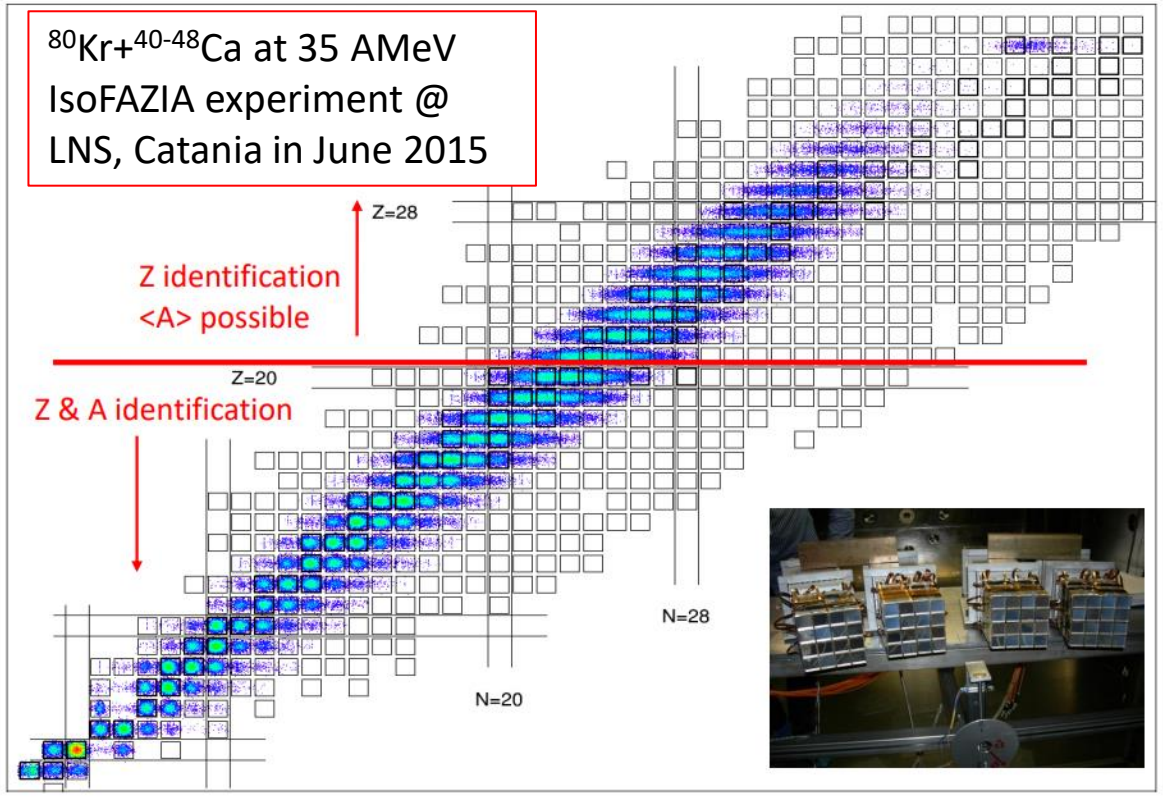
- FAZIA: a charged-particle detector system for heavy-ion collision studies at intermediate beam energies
- Collaboration status
  - 5 countries (France, Italy, Korea, Poland, Spain)
  - ~30 physicists & ~10 students

FAZIA 101

- One FAZIA block consists of 16 Si_1+Si_2+CsI telescopes with a cross-section of 2X2 cm^2.
  - Si_1(nTD): 300 μm thick, Si_2(nTD): 500 μm thick, CsI: 10 cm thick (photodiode readout)
  - Refining Pulse-Shape Analysis (PSA) techniques for identification in a single detector
  - Excellent isotopic resolution for charged particles in heavy-ion collisions at the beam-energy range from 15 to 100 AMeV, which is mandatory for the radioactive ion beam experiments.

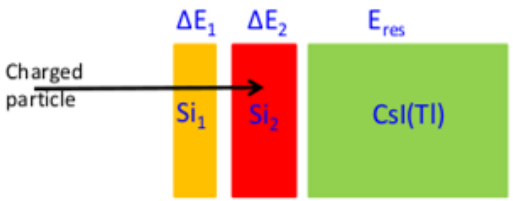


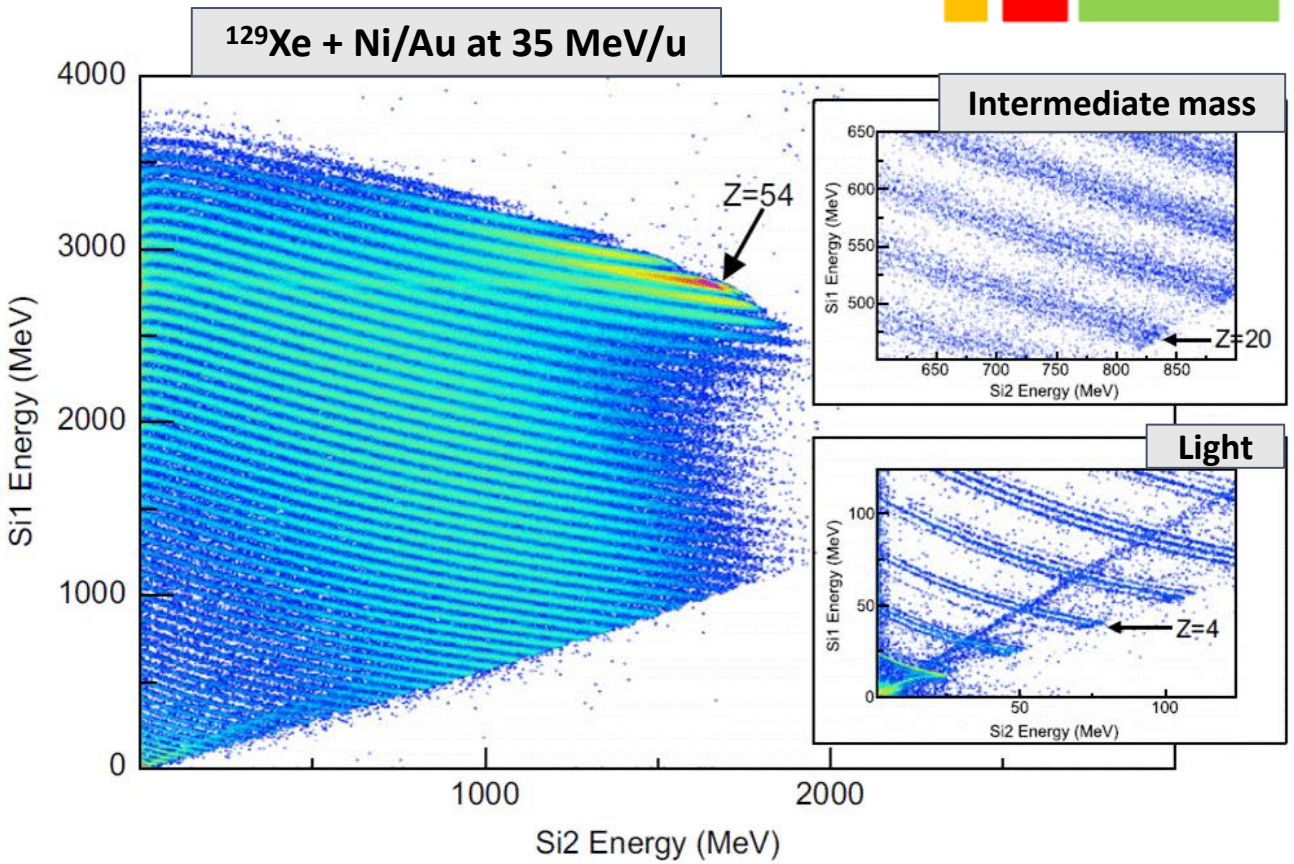


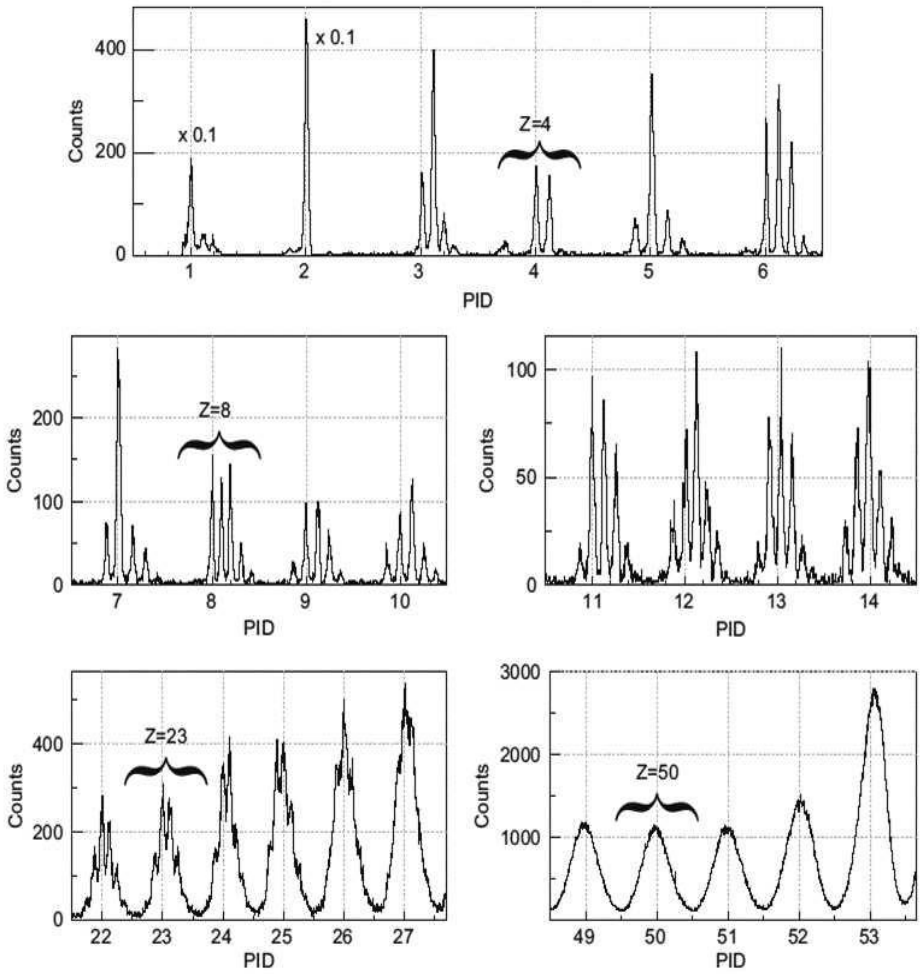


FAZIA 101

- PID: EPJA 50, 47 (2014)







- Charge identification tested up to Z=54 & mass discrimination up to Z~26

FAZIA 101

- Scientific goal
  - Detailed understanding of the nuclear Equation of State (EOS) and the nuclear symmetry energy for both microscopic (nuclei) and macroscopic (neutron stars) objects
- Physics experiments
  - E789 (2019): Isospin transportation and the density dependence of the symmetry energy
  - E818 (2022): Characteristics of the warm dense nuclear matter in low-density region
- Future
  - Extension of the particle identification capability
  - Exploration of the flexible installation scheme in the limited space of vacuum chamber
  - Application of the modern technology to the next generation detectors and FEE
  - Manufacturing more FAZIA blocks in Europe and Korea for more comprehensive measurements
- Goal of FAZIA-FKC
  - R&D and production of new FAZIA blocks (today's focus)
  - Analysis on the directed and elliptic flow using INDRA and FAZIA data set

Participants

French side			Korean side		
Name	**Position**	**Affiliation**	**Name**	**Position**	**Affiliation**
Leader: **Le Neindre, Nicolas**	CR	LPC Caen CNRS IN2P3 & University	**Leader:** **Hong, Byungsik**	Professor	Korea University (CENuM)
Bonnet, Eric	CR	Subatech Nantes CNRS IN2P3	**Kweon, Minjung**	Professor	Inha University (CENuM)
Borderie, Bernard	Emeritus	IPNO Orsay CNRS IN2P3 & University	**Kim, Jiyoung**	PostDoc	Korea Univ. (CENuM) & Inha Univ.
Bougault, Rémi	DR	LPC Caen CNRS IN2P3 & University	**Lee, Jong-Won**	PostDoc	Korea University (CENuM)
Chbihi, Abdou	DR	GANIL	**Nam, Seon Ho**	Student	Korea University (CENuM)
Fable, Quentin	Postdoc	L2IT Toulouse CNRS IN2P3	**Park, Jeonghyeok**	Student	Korea University (CENuM)
Frankland, John	CR	GANIL	**Kim, Giyoung**	Student	Inha University (CENuM)
Genard, Tom	Student	GANIL	**Hahn, Kevin Insik**	Professor	CENS, IBS
Gruyer, Diego	CR	LPC Caen CNRS IN2P3 & University	**Kim, Sunji**	PostDoc	CENS, IBS
Lemarié, Julien	Student	GANIL			
Lopez, Olivier	DR	LPC Caen CNRS IN2P3 & University			
Rebillard, Alex	Student	LPC Caen CNRS IN2P3 & University			
Vient, Emmanuel	EC	LPC Caen CNRS IN2P3 & University			

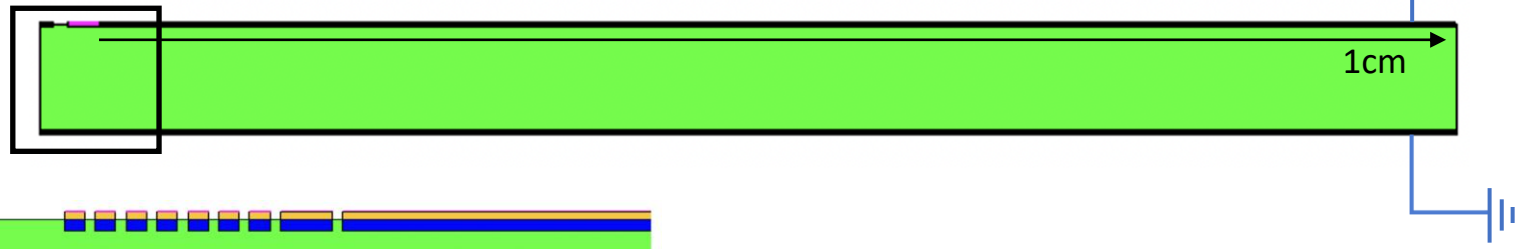
Synopsys TCAD (Technology Computer Aided Design)

Simulation setup for PiN sensor

Half of cross section of 2 × 2 cm^2 chip

V_0 , reverse bias voltage

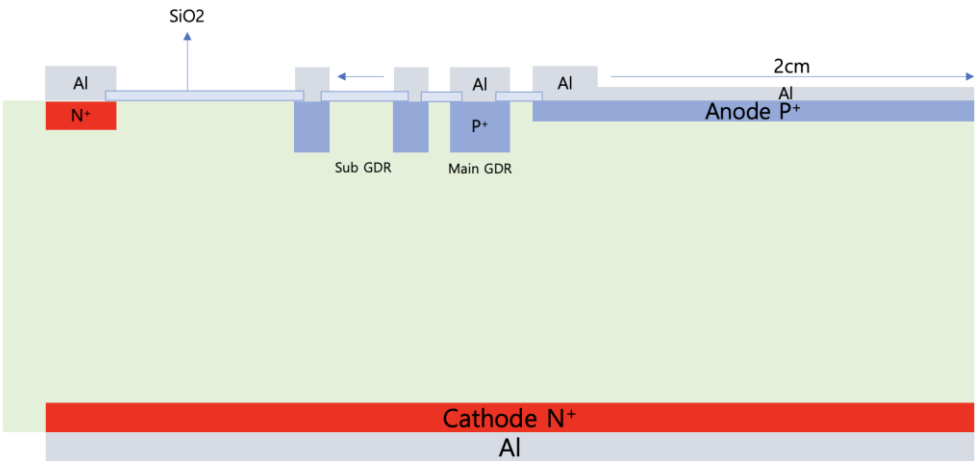
Thickness: 720 μm



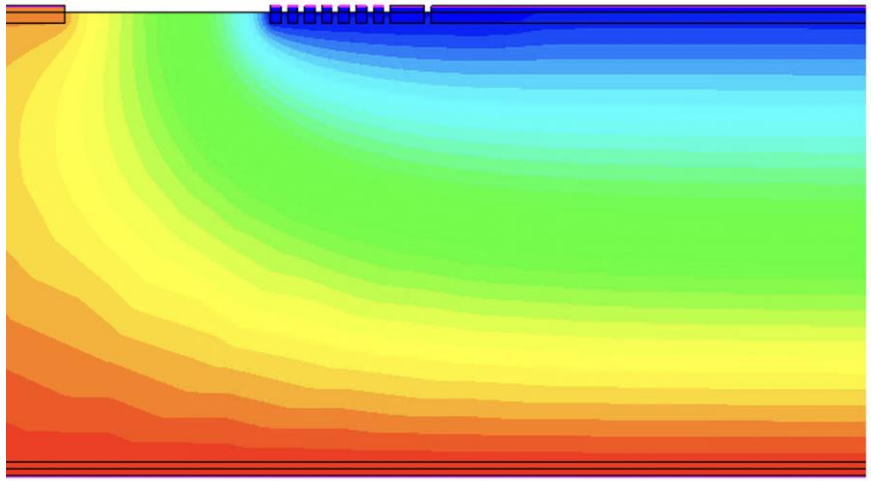
Edge of silicon sensor

Input parameter				
Temperature	300 K		Doping density	
Bias voltage	0 ~ -700 V			P^+ Boron
Carrier lifetime	electron	1×10^{-4} s^{-1}		N^- Phosphorus
	hole	3×10^{-4} s^{-1}		N^+ Phosphorus

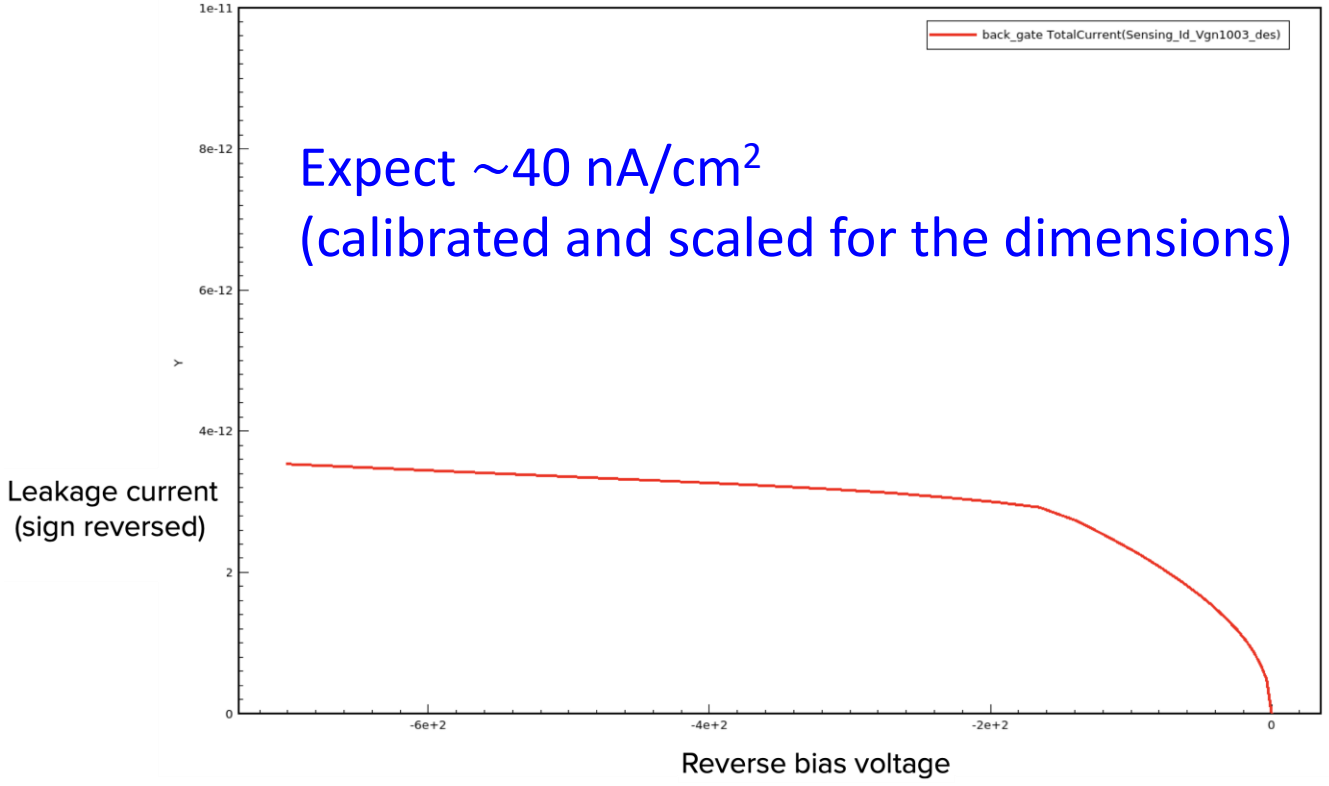
TCAD simulation



Cross sectional view of electric potential

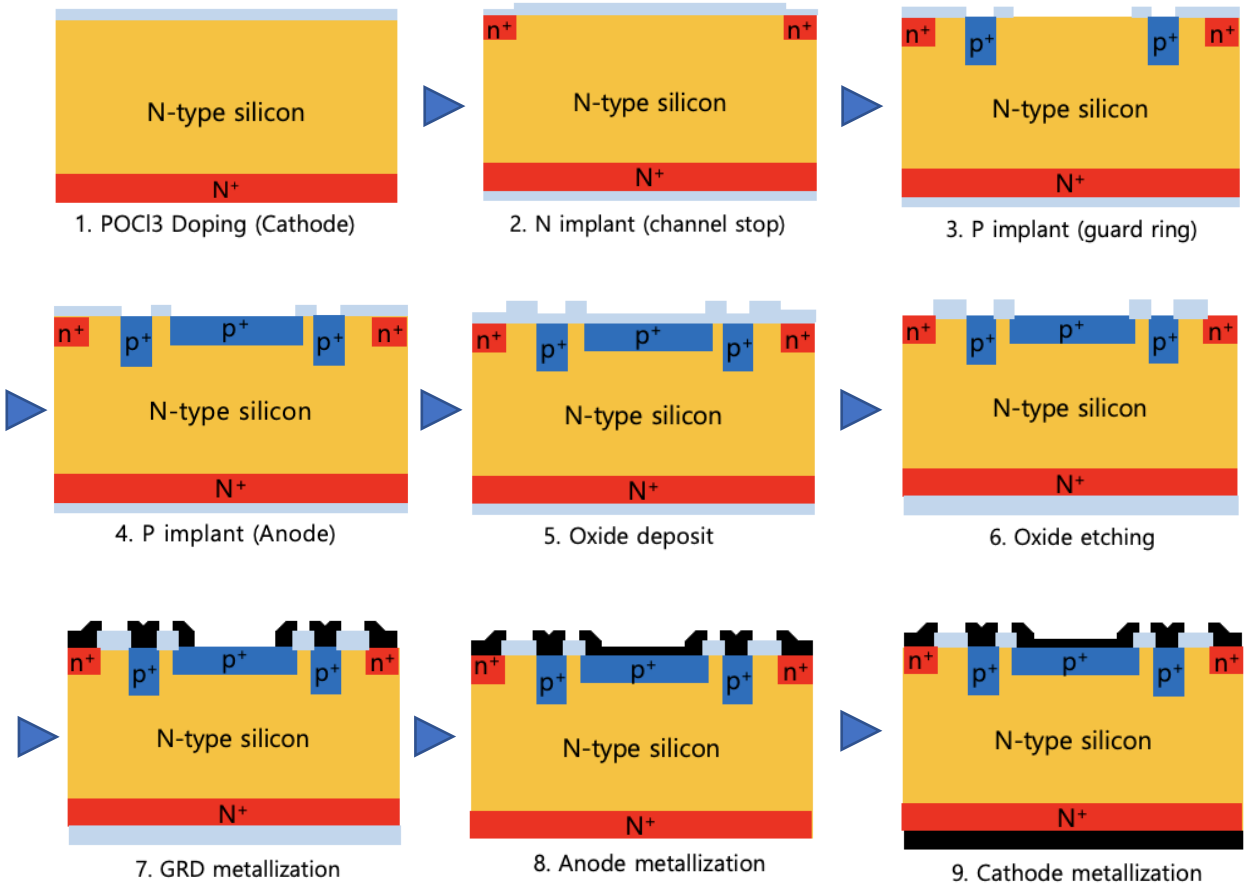


- Calculation of the leakage current for the final design based on the calibrated parameters

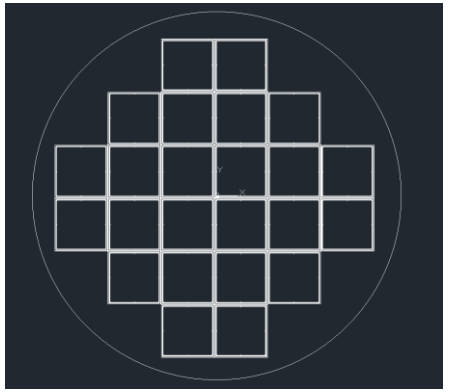


Expect ~40 nA/cm^2
(calibrated and scaled for the dimensions)

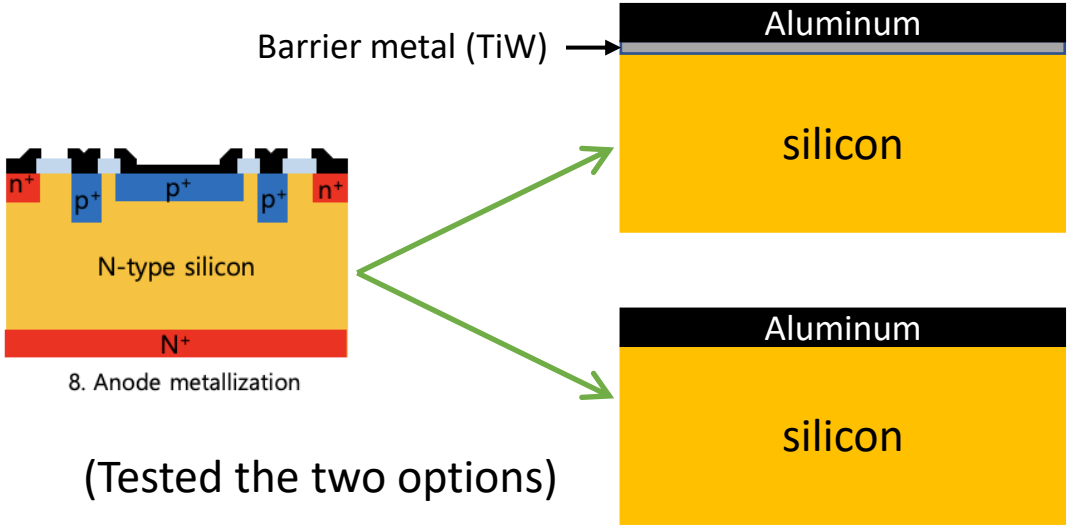
Sensor fabrication



Part of the silicon process flow



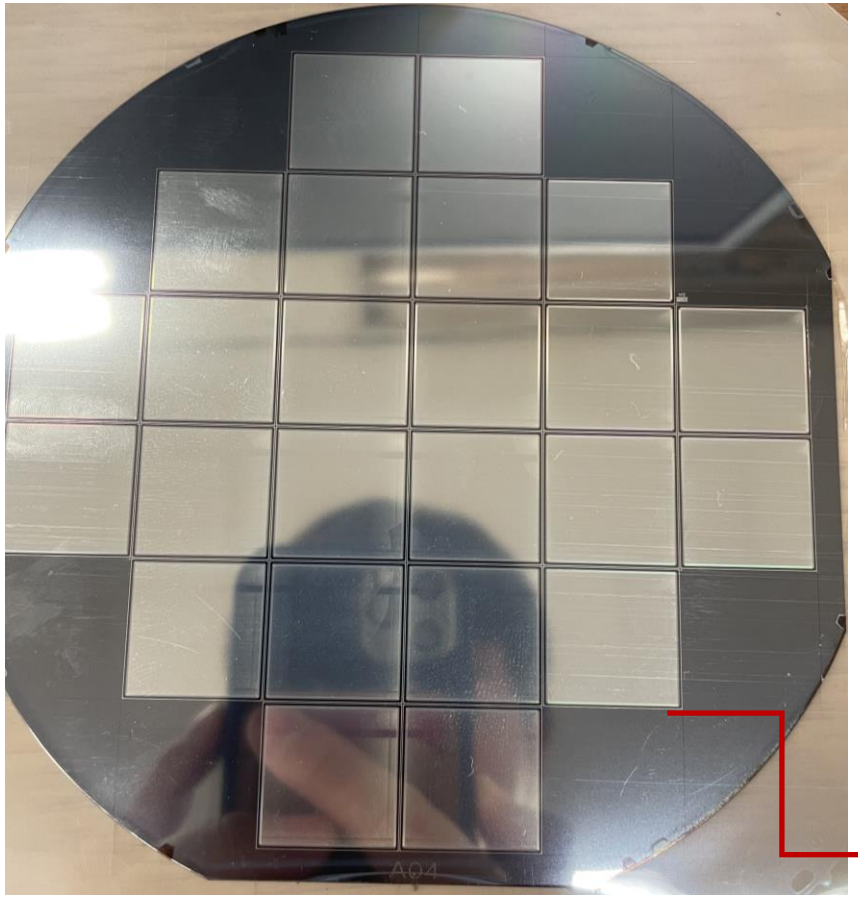
Photomask design



(Tested the two options)

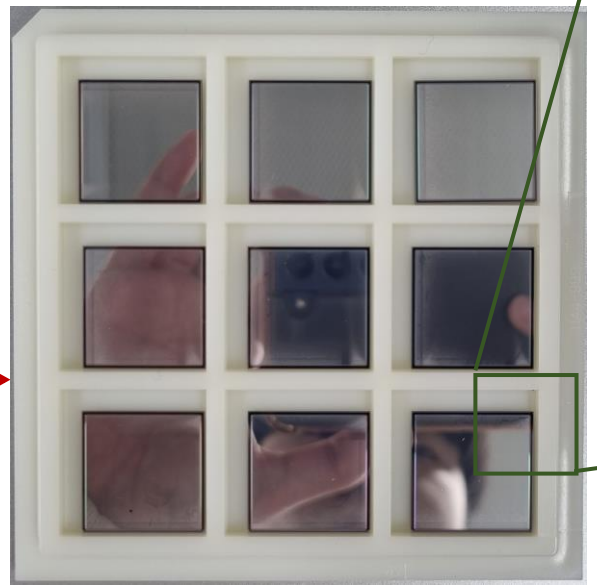
- Tested the two options for the anode structure: with and without metallization
- Sensor fabrication was done at ETRI

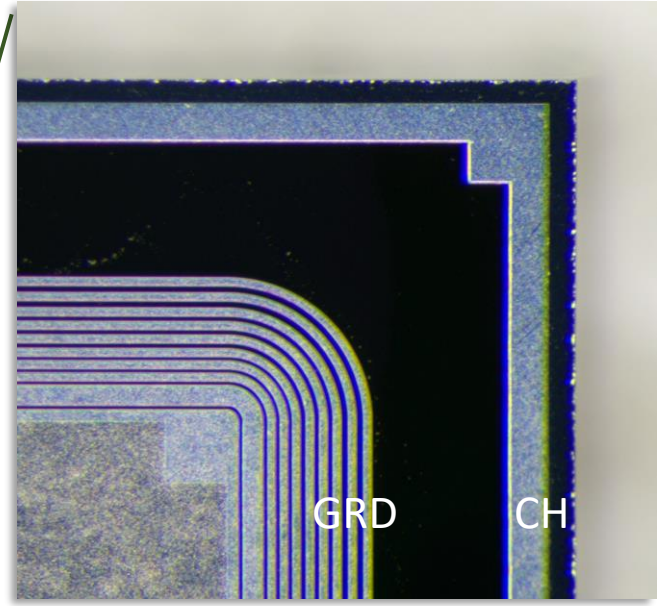
Processing results at ETRI



Sawing silicon wafers

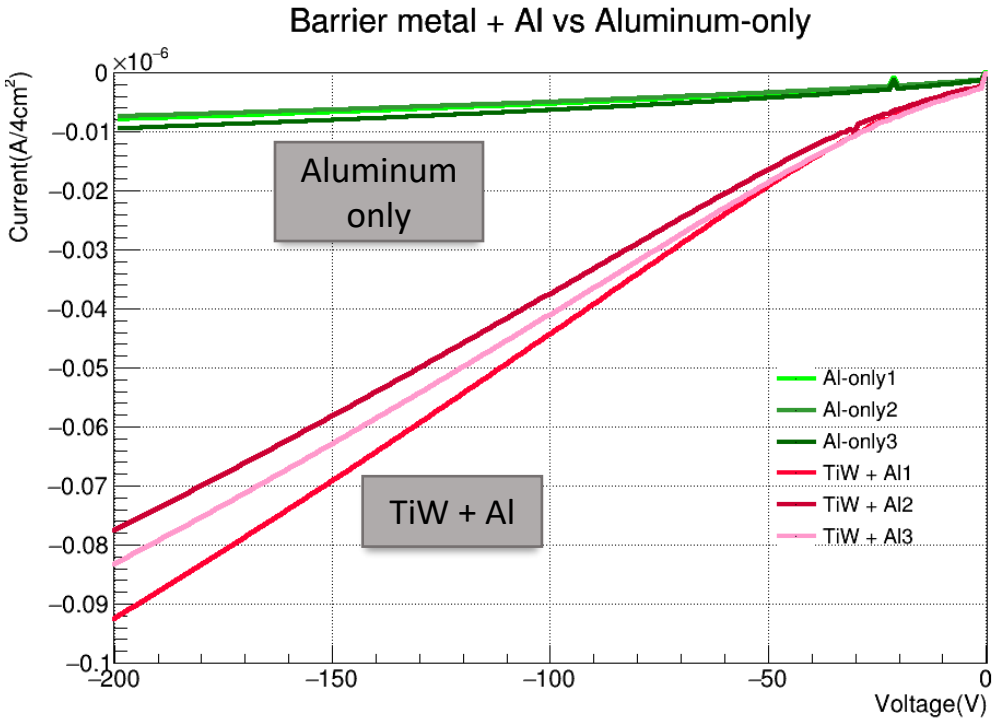
- Patterning the 8 guard rings and 1 channel stop of the silicon sensor structure

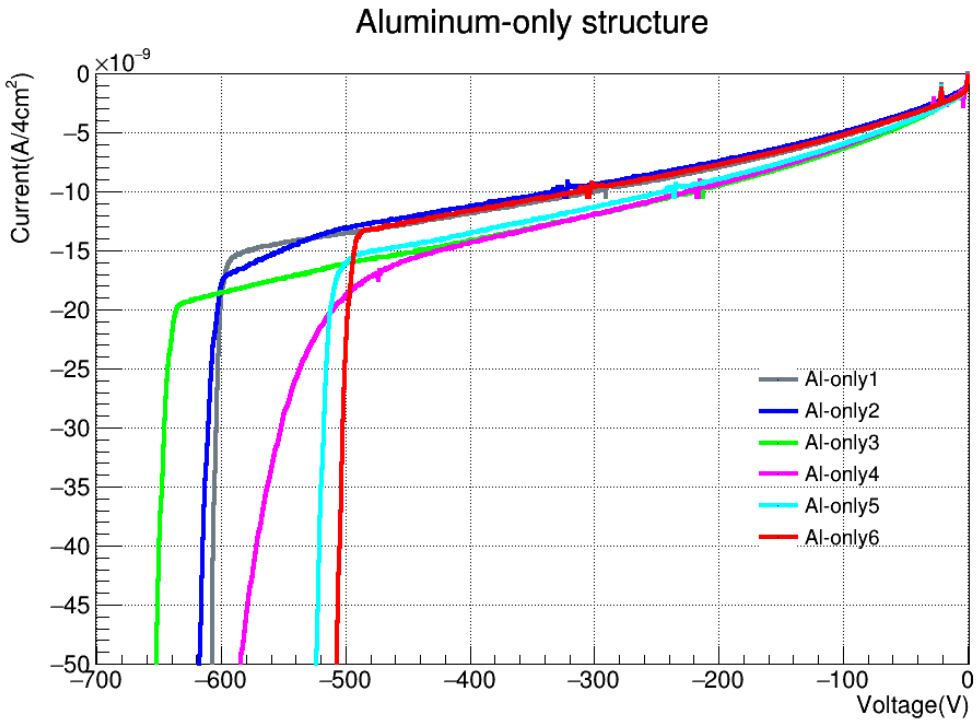




Extended view

Characterization



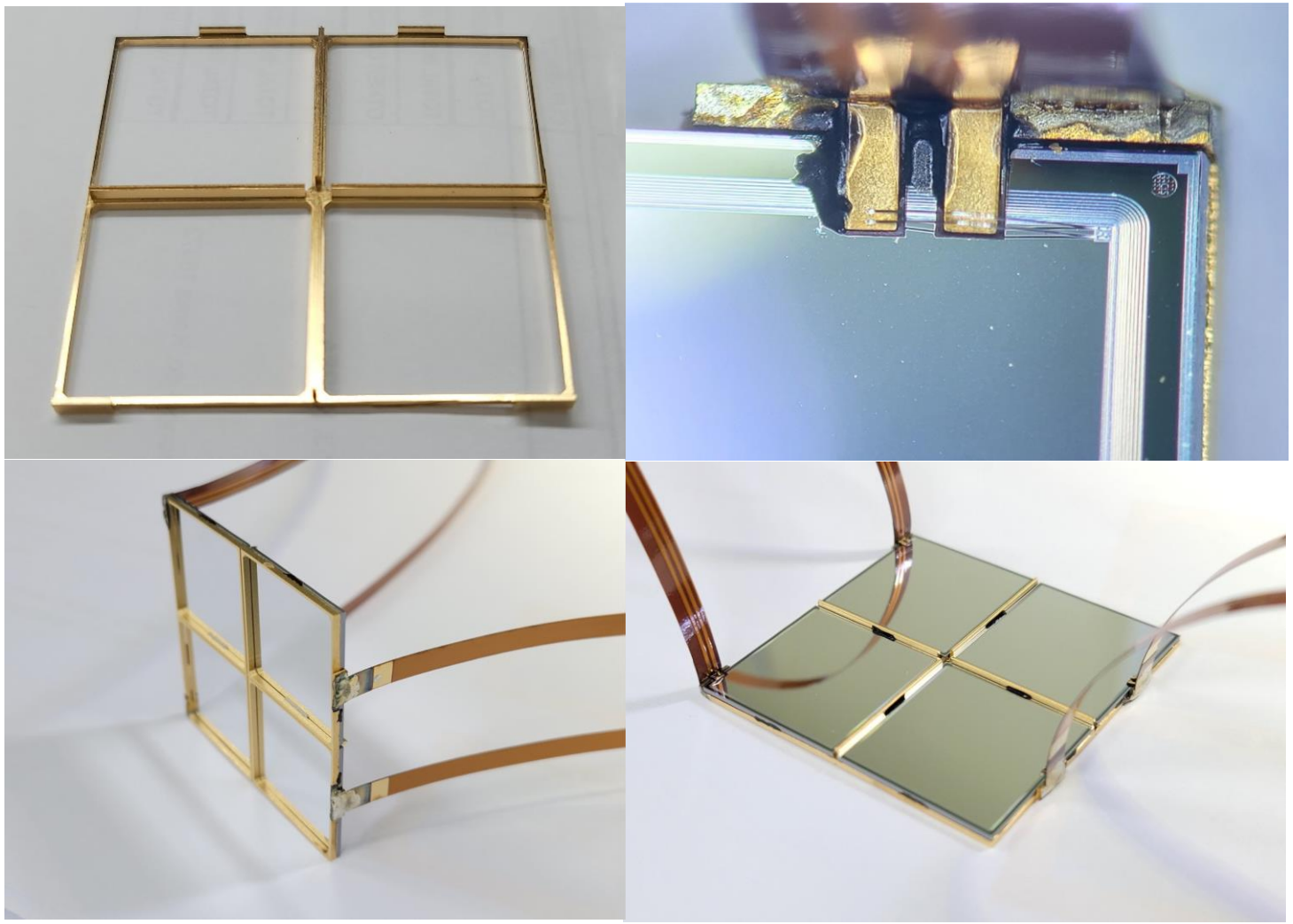


- About 10 times higher leakage current was observed with the barrier metal + aluminum structure

- Breakdown voltage point is close to -600 V
- Enough to reach full depleted voltage

$$W_{scr} = 0.53\sqrt{\rho V_0} \;\triangleright\; V_0 = 400\ \text{V}$$

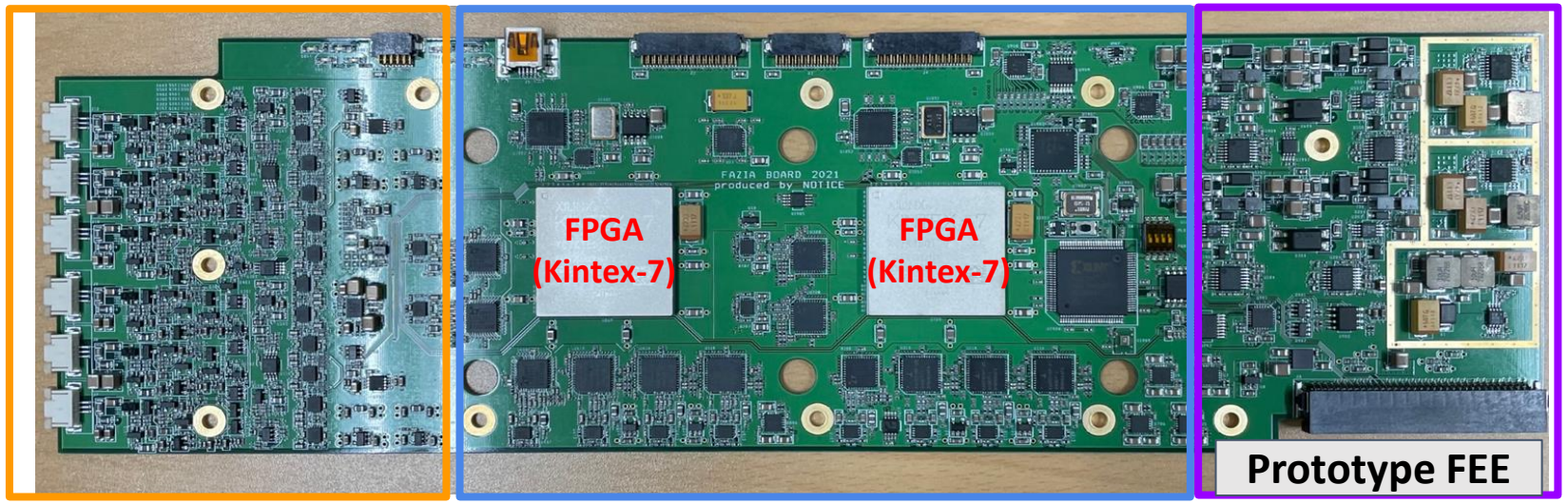
Preparation of chip assembly



- Quartetto (chip frame)
  - 4 chips mounted in each quartetto frame
  - Backside of the sensor connected for grounding
  - Wire-bonding connection to apply the reverse-bias voltage to the sensors
  - Successful production of the required components in Korea
  - We are working on the production of the first Korean modules.

R&D of Front-end electronics board

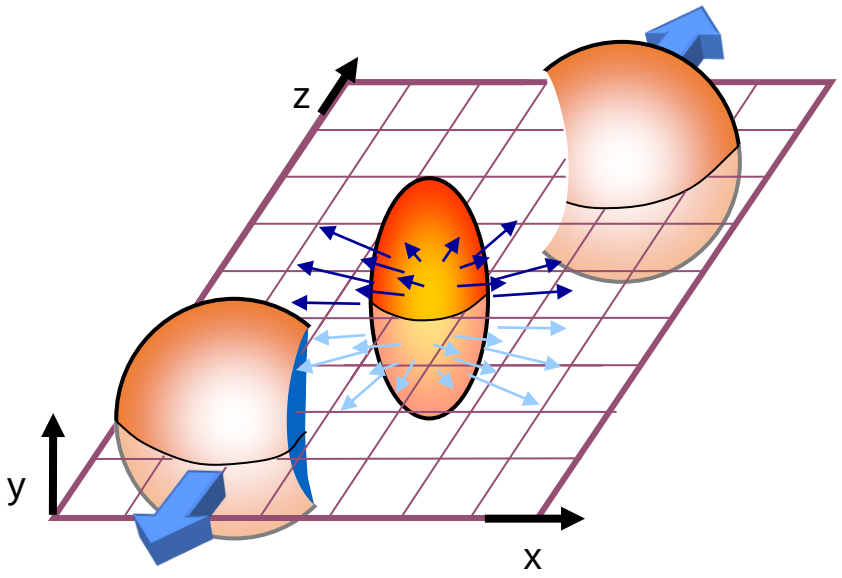
- Two prototype FEBs were produced by the Korean vendor, NOTICE.
  - We started with the original design of the FAZIA FEB.
  - The out-of-dated digital parts were replaced (For example, FPGA: Vertex-5 → KINTEX-7).
  - New FPGA chips → Development of the new VHDL code
  - Performance test at GANIL and INFN-Firenze: No major issue
    - Plan to design the second prototype, employing one FPGA



- **Analog part**:
  To amplify analog signals
  from the detector
- **Digital part**:
  Signal processing
  (analog to digital conversion)
- **Conversion part**:
  Power distribution
  Application of the bias voltage

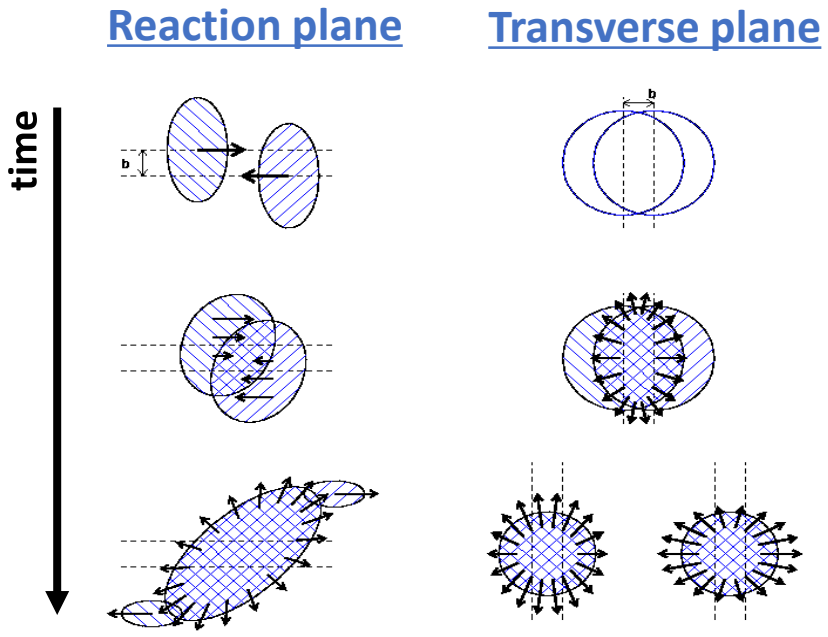
Analysis of collective flow

- Data sets
  - INDRA: ^{129,124}Xe + ^{124,112}Sn @ 100 AMeV
  - FAZIA+INDRA: ^{58,64}Ni + ^{58,64}Ni @ 32 and 52 AMeV



$$\frac{d^3N}{p_t dp_t dy d\phi} \propto 1 + 2v_1\cos(\phi) + 2v_2\cos(2\phi) + \ldots$$

with $\phi \equiv \phi_{meas} - \Psi_R$



Directed (Sideward) flow
$v_1 < 0 \quad v_1 > 0$
$v_1 = \langle p_x/p_t \rangle$

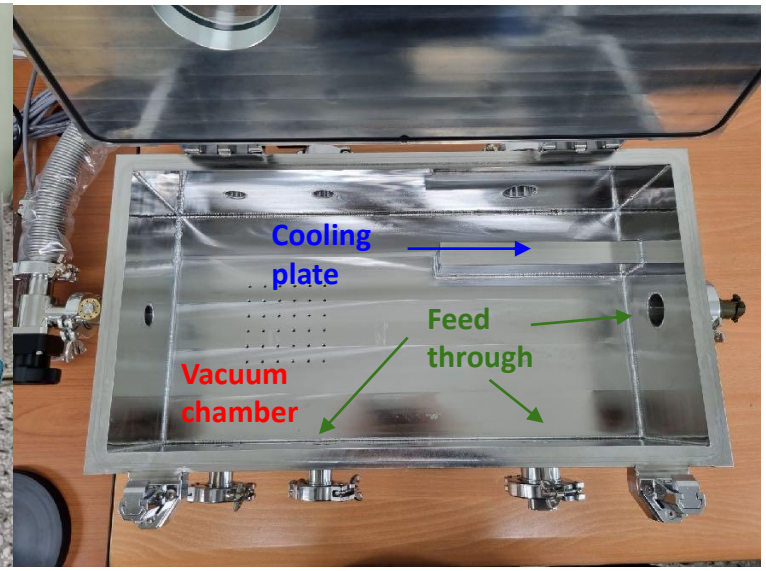
Elliptic flow
$v_2 < 0 \quad v_2 > 0$
$v_2 = \langle (p_x^2 - p_y^2)/p_t^2 \rangle$

The approved results will come soon!

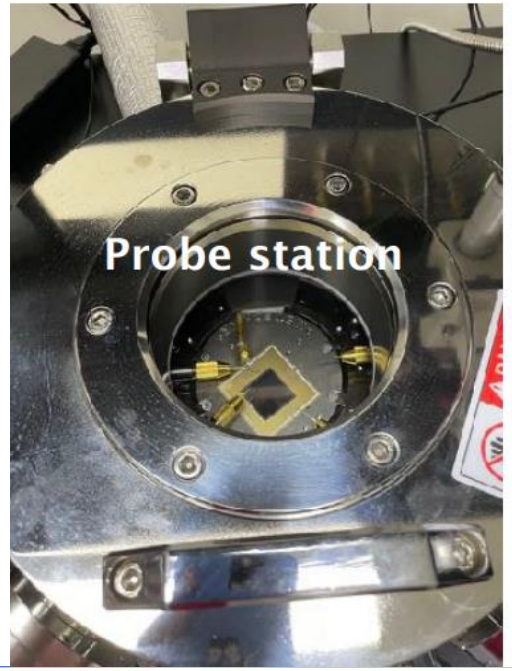
Plan in 2023-2024

- ☐ Set up the Lab. testing system with radiation sources
  - Vacuum chamber and cooling system are ready.
- ☐ Test with proton beams at KOMAC
  - Radiation hardness of sensors
- ☐ Next round of sensor fabrication
  - Improve the design for better I-V characteristics
  - Thinner(~150 μm) and thicker(~1 mm) sensors
- ☐ Assembly of complete FAZIA module
  - CsI and other necessary parts for assembly will be provided by FAZIA.

Water cooling machine



Vacuum chamber



Merci Beaucoup.

감사합니다.

どうもありがとうございます.

Thank you very much.