“Evaluation of radiation resistivity for ECAL parts through measurement of neutron irradiation”

2011/12/10
Tokusui Meeting

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Daniel Jeans, Sachio Komamiya
The University of Tokyo

Outline

Expected Radiation

- ILC & ILD (ECAL) Structure
- Expected Radiation
- Radiation Damage and Requirement

Neutron irradiation Test

- Kobe Tandem
- CR39 sensor: Neutron Measurement
- Neutron Irradiation of ECAL parts

Evaluation

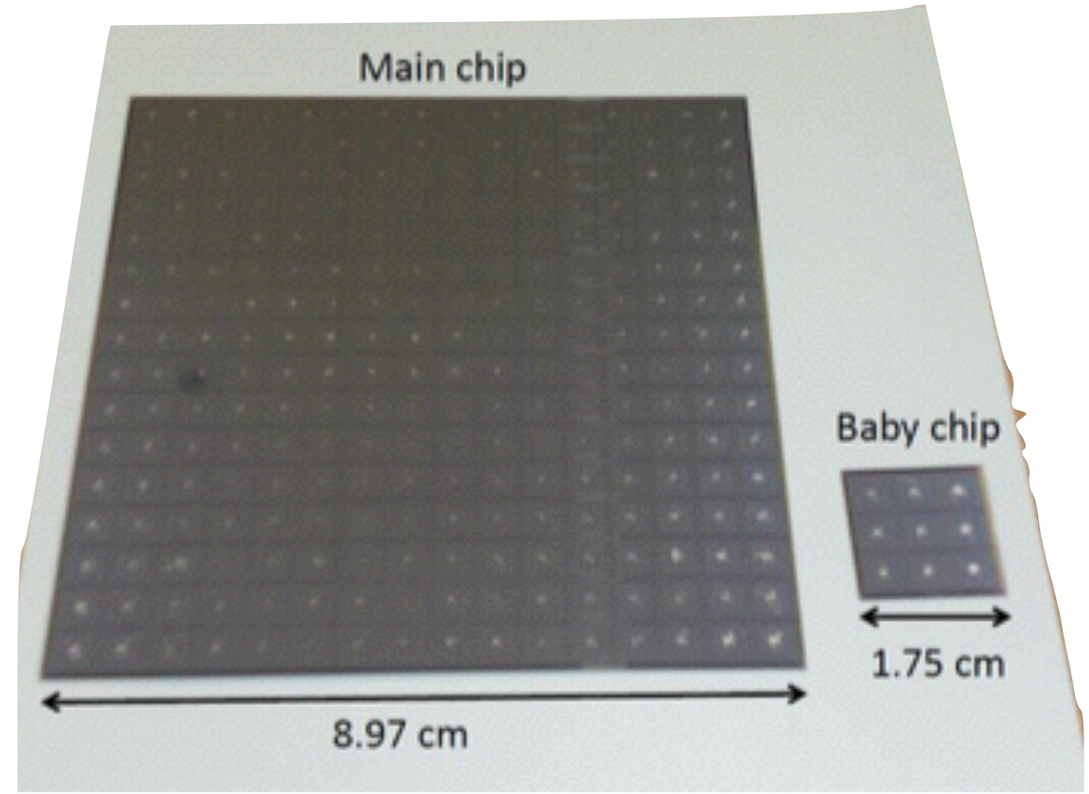
- Measurement of Radiation Damage
- Evaluation

ECAL parts [SiW]

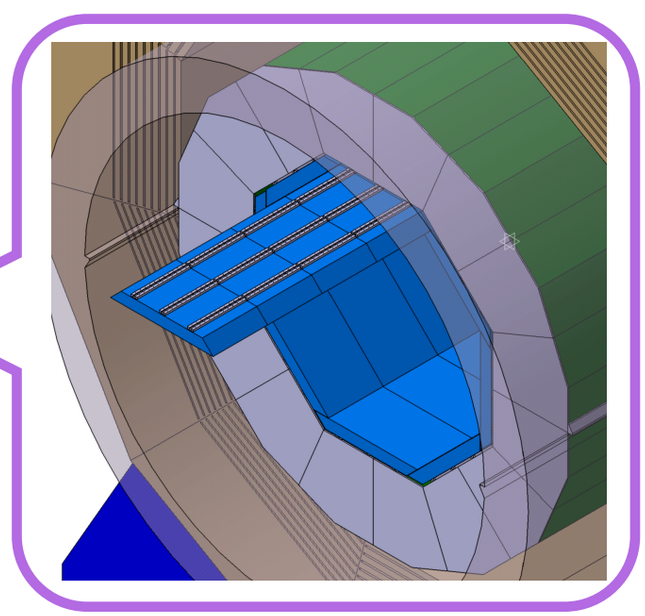
- **30 layers sandwiched calorimeter of Silicon PIN diode detector and W absorber**

- **Silicon PIN diode**
  - 5×5 mm^2 pixel
  - **325** μm width

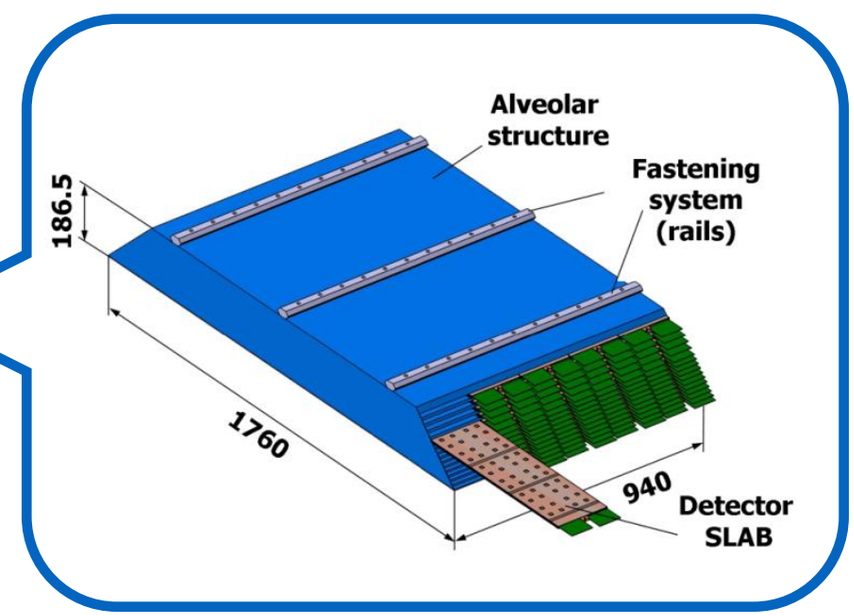
- **W absorber**
  - Small Molière Radius(R_M = 9mm)
  - Short Interaction Length(X_0 = 3.5mm)
  - Big ratio of them(λ/X_0 = 27.4)



ILD



ECAL



Si PIN diode+ W Sandwich CAL

ECAL parts [super capacitor and glue]

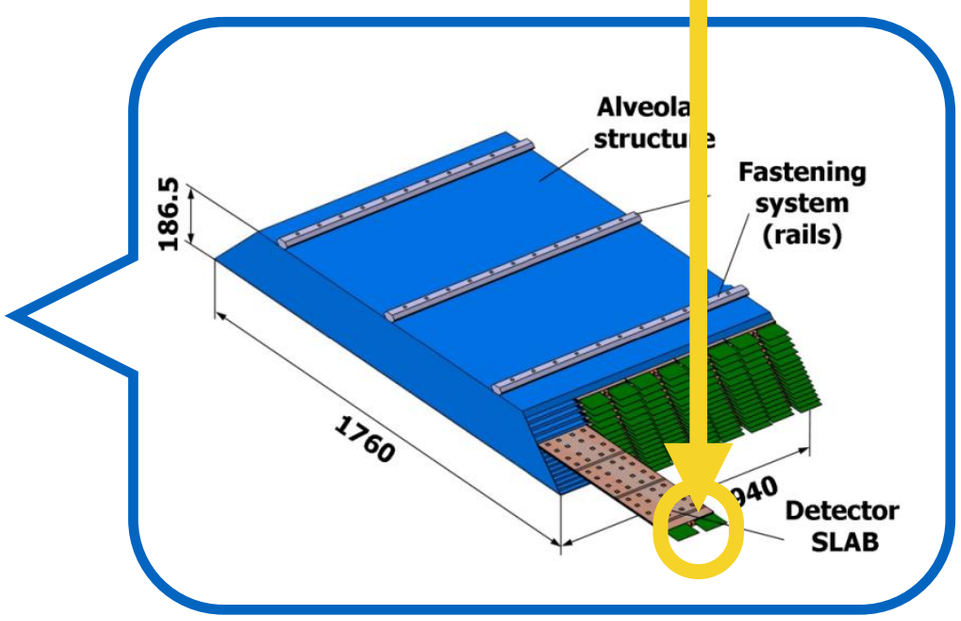
super capacitor

conductive glue

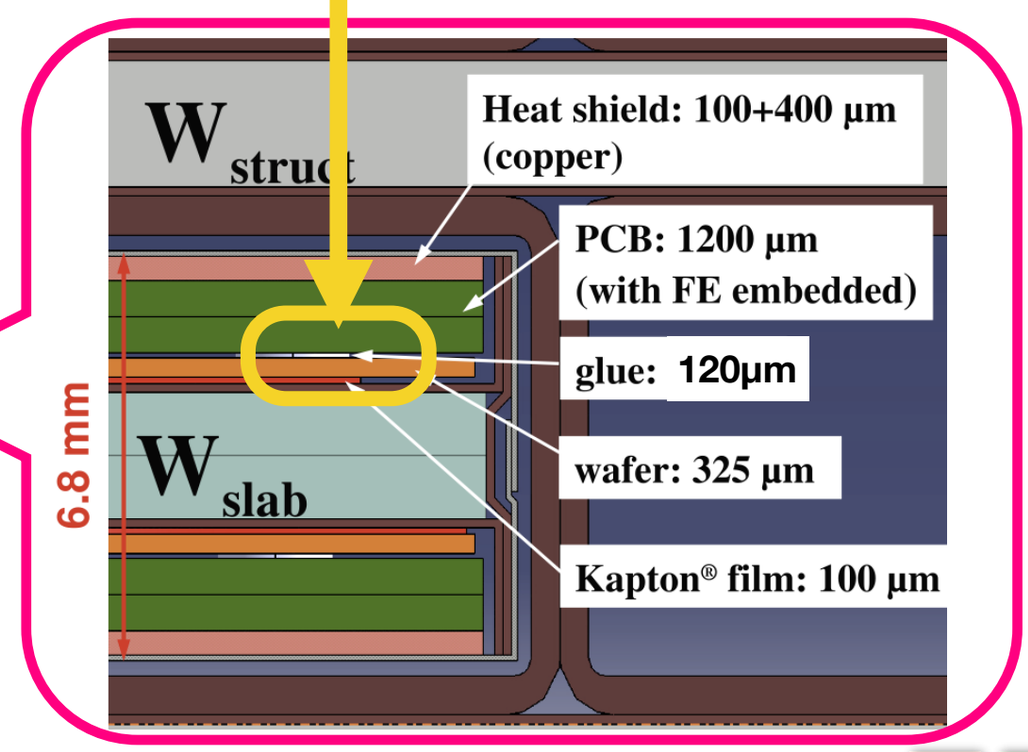
ON/OFF switching of readout circuit by power pulsing

•adhere readout board and silicon

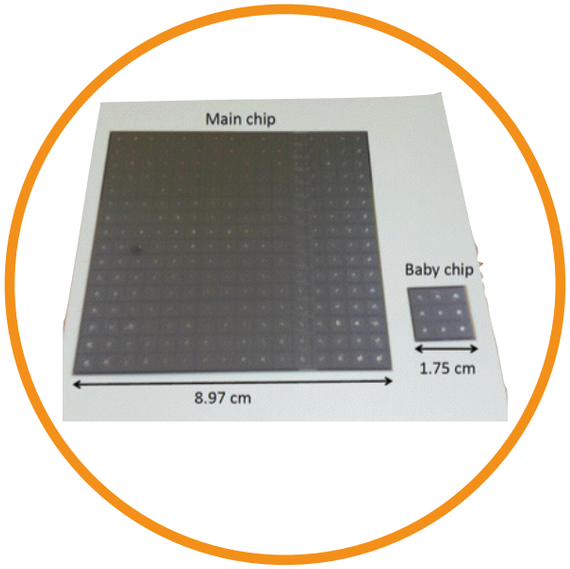
•Epoxy conductive glue



Si PIN diode+ W Sandwich CAL

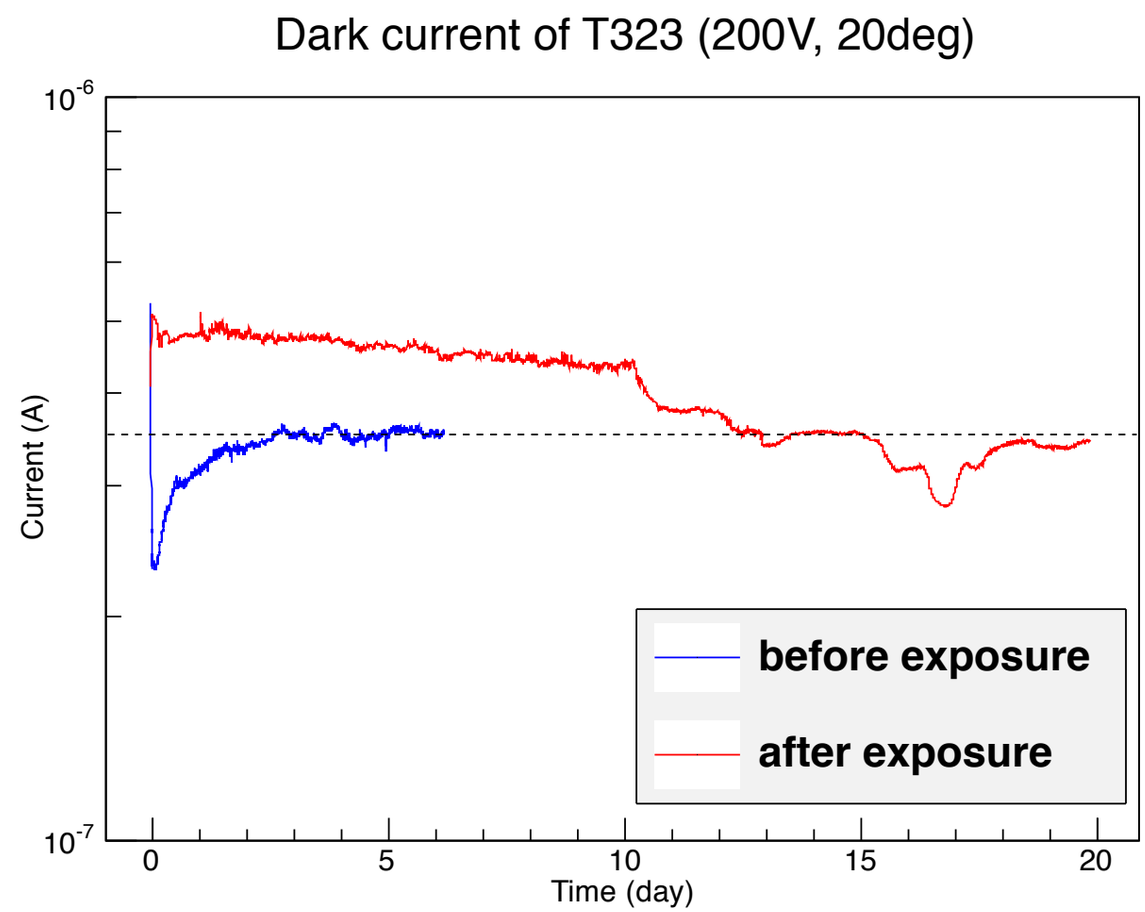


Radiation Damage

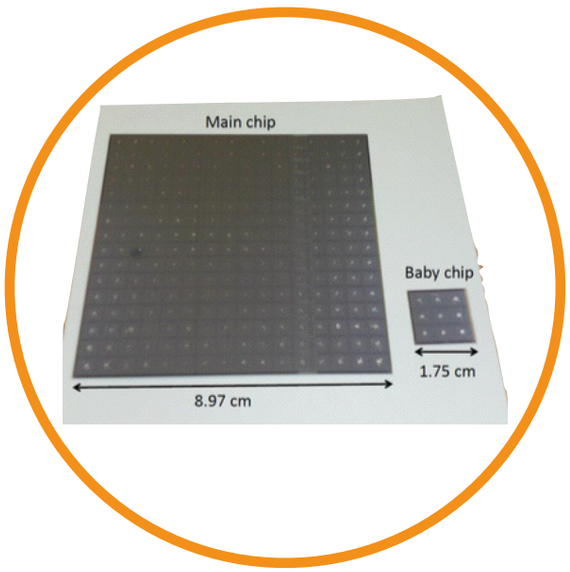


- **TID**(Total Ionising Dose Effect)
  Electromagnetic interaction by large radiation dose including photons. Creating fixed charge and border energy level aggravate features.
- **DDD**(Displacement Damage Dose Effect)
  Hadrons creates defects in silicon crystal.(**NIEL**)
  Frenkel defects create new energy and aggravate it.

Kyushu group researched and evaluated **TID** through **γ-ray irradiation of 100Gy(ILC: 1M year)**



Radiation Damage



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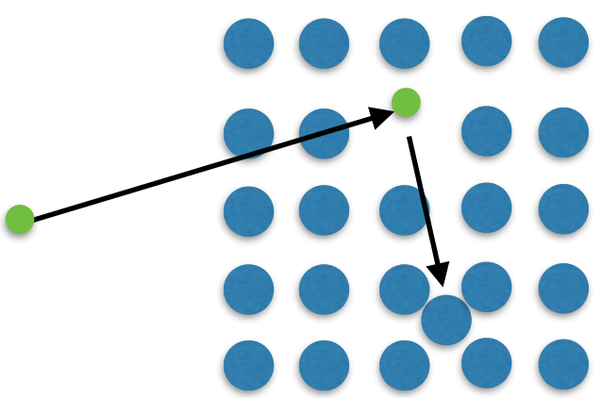
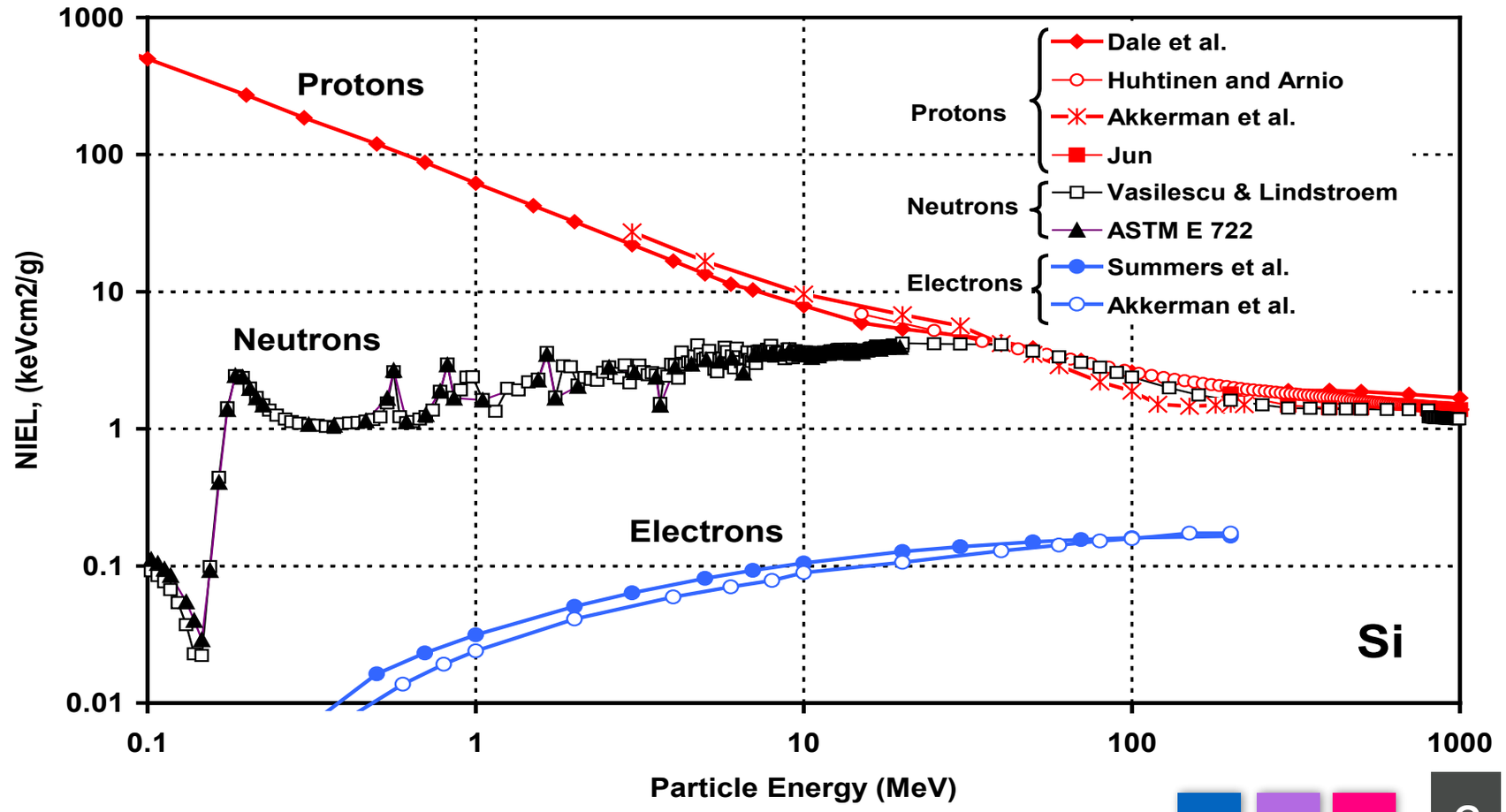
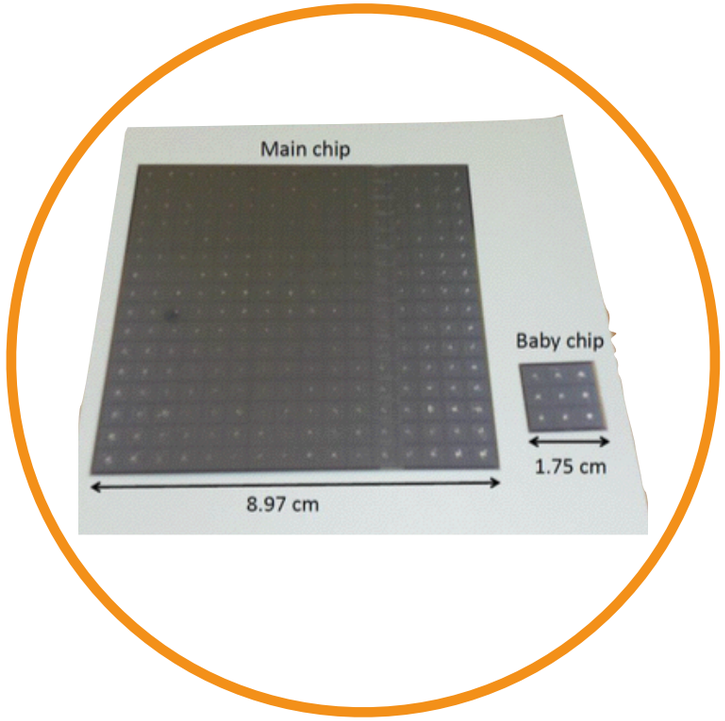
NIEL Damage Function



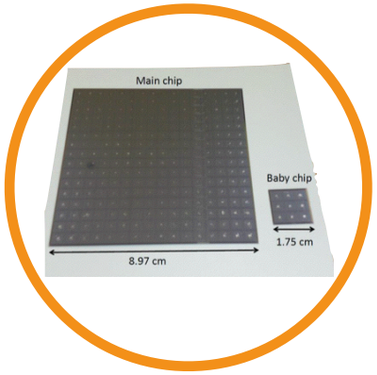


Research Purpose

- **Evaluation of neutron resistivity** about ECAL parts of silicon, conductive glue, and super capacitor.
- Evaluation of lifetime and measurement accuracy, compared with the requirement of **ILD ECAL**.



Radiation Damage and ILC requirement



- increase of dark current
- change of full depletion voltage
- collected charge decrease

- deterioration of conductivity and adherence

- change of capacitance

Required properties of ILD ECAL

1. Dark current is smaller than readout board SKIROC2 (0.2 μA).
2. Effective volumes dose not change on operating voltage.
3. Collected charge is enough to detect 0.1 MIPs - 2500 MIPs.
4. continuity of conductivity and adherence
5. right action of electric circuit

Expected Radiation

- Radiation Sources are classified as bean pipe and Interaction point.

IP(Interaction Point)

△ Photon: beamstrahlung photons

× Photon: **RBS(Radiative Bhabha Scattering)**
- $e^- e^+$: CPC (Coherent Pair Creation)
- × $e^- e^+$: **IPC (Incherent Pair Creation)**
- × hadrons: **γ-γ scattering (Minijets)**
- × others: backscattering particles

BDS(beam delivery system)

- Photon: synchrotron radiation
  - Neutron: γ-N scattering(beam pipe)
  - Charged particle: Beam-Gas Interaction
- μ: Beam Halo Muons

? Neutron: Beam dumps

? others: Extraction Line Losses

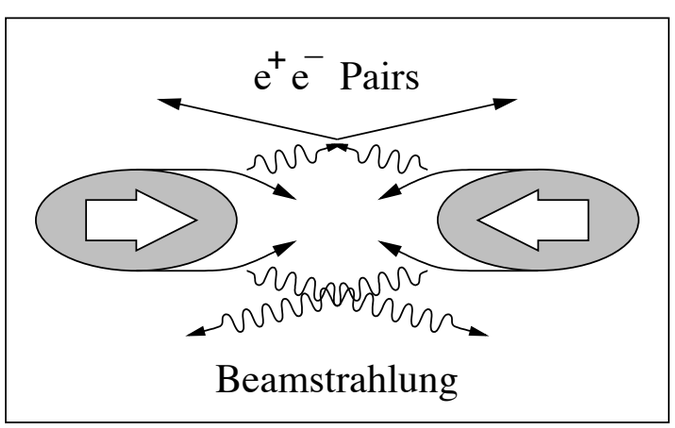
- can ignore radiation damage

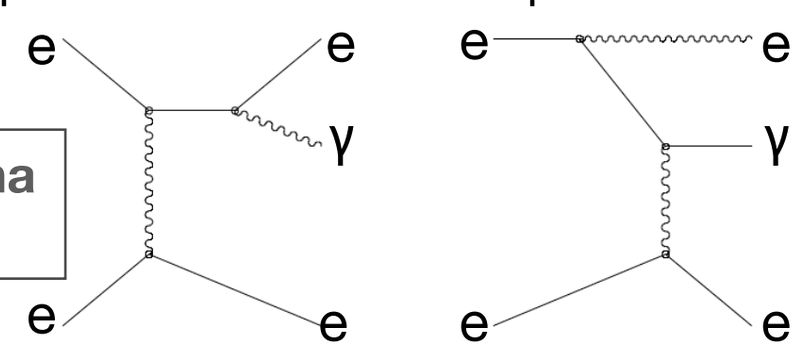
△ require appropriate evaluation

× can't ignore radiation damage

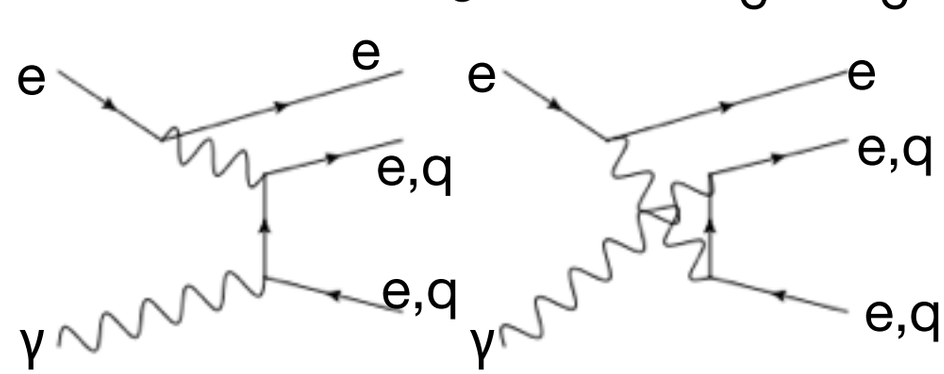
? require more detail

Spatial charge are attracted to each others by pinch effect and accelerated.



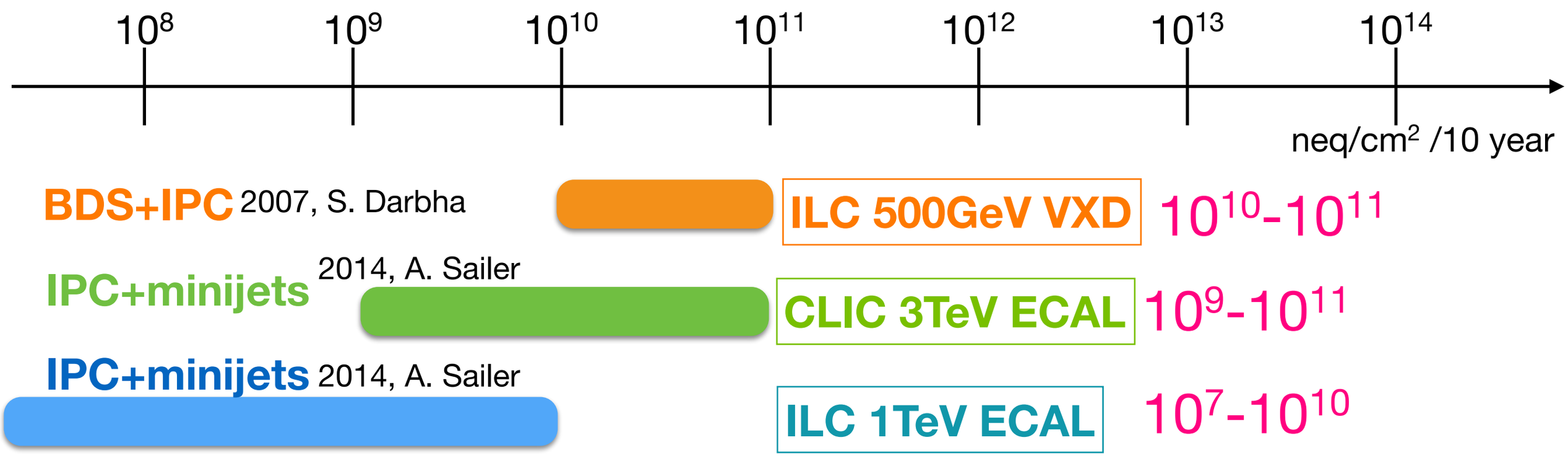


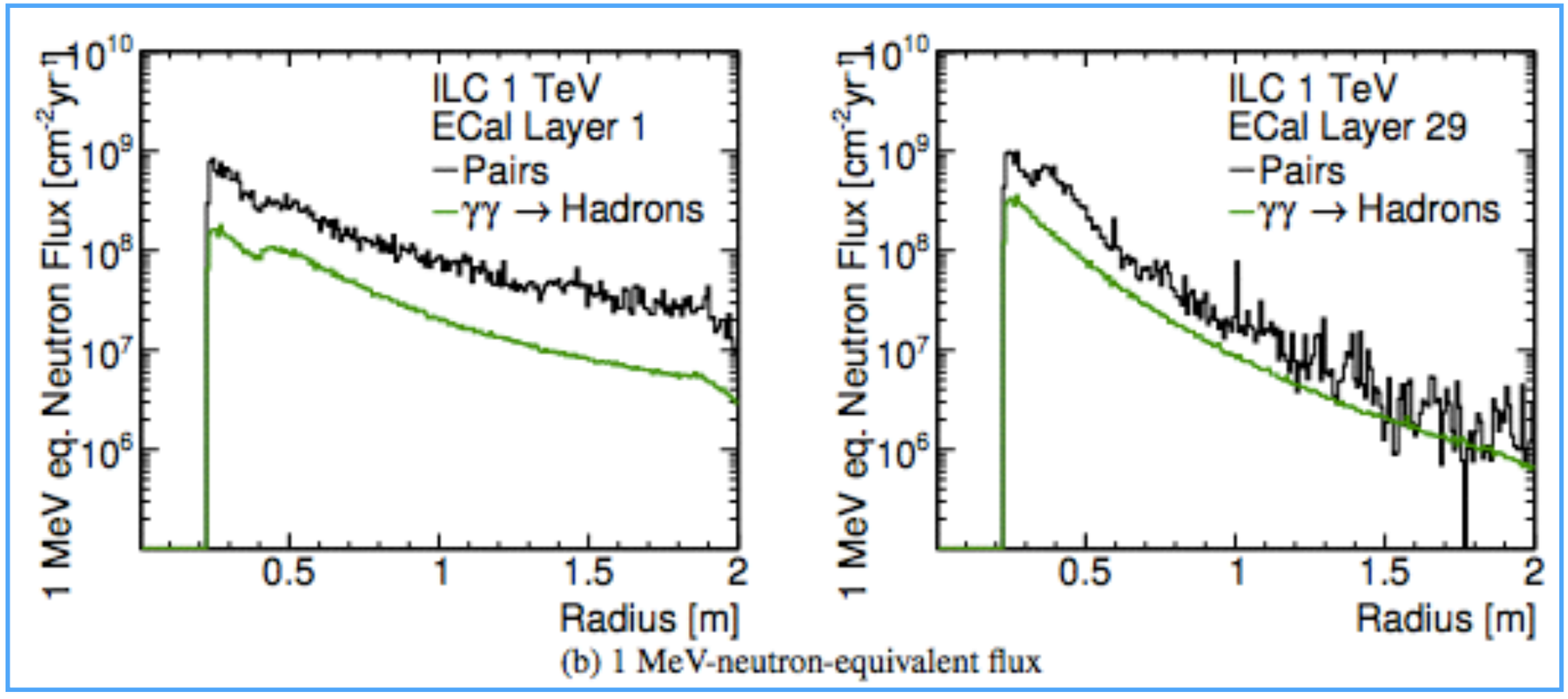
radiative Bhabha scattering



Bethe-Heiter process

Expected Radiation





(b) 1 MeV-neutron-equivalent flux

Neutron irradiation test was conducted by about $10^{10\text{-}11}$ n_{eq}/cm^2

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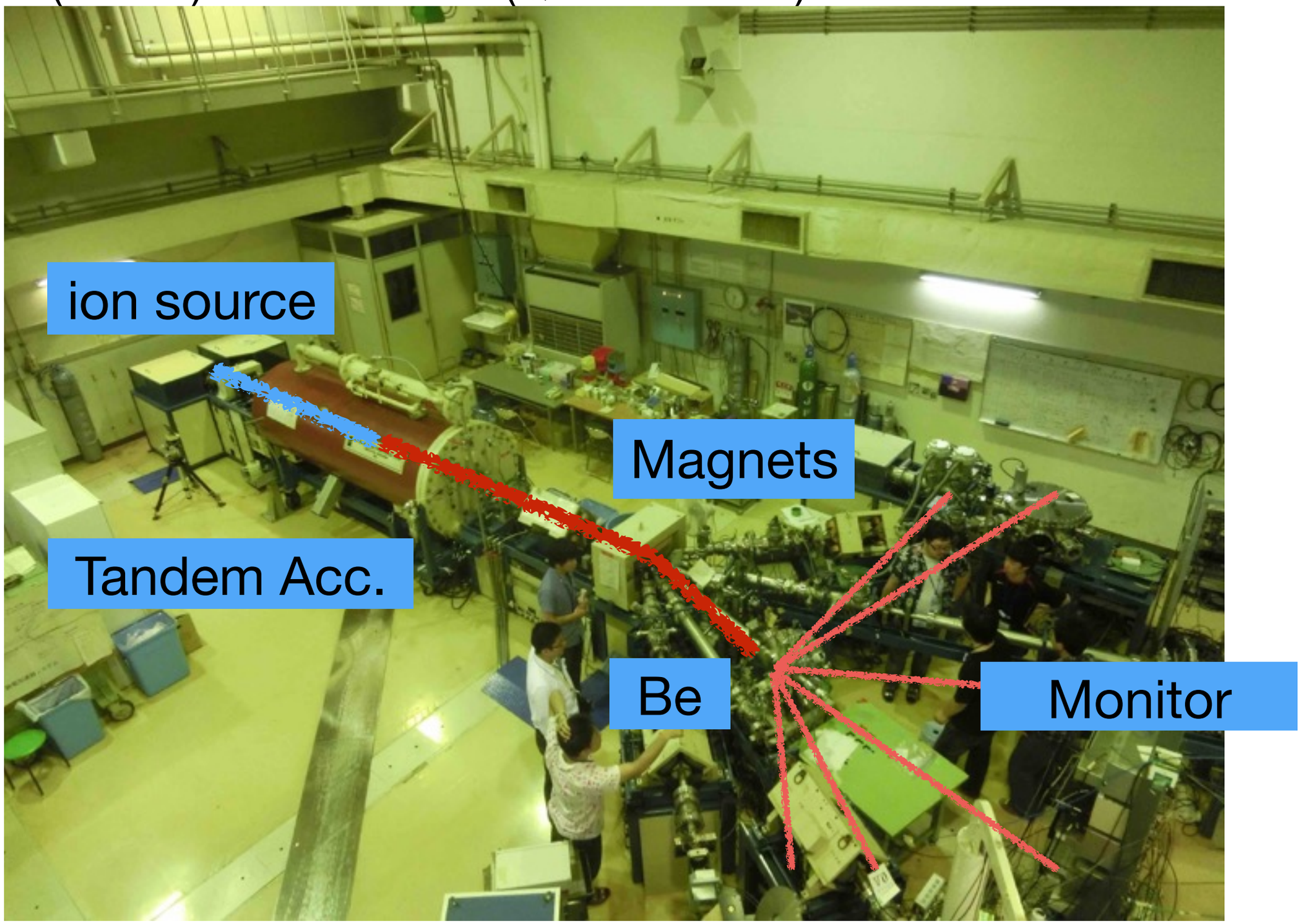
Neutron Irradiation Test

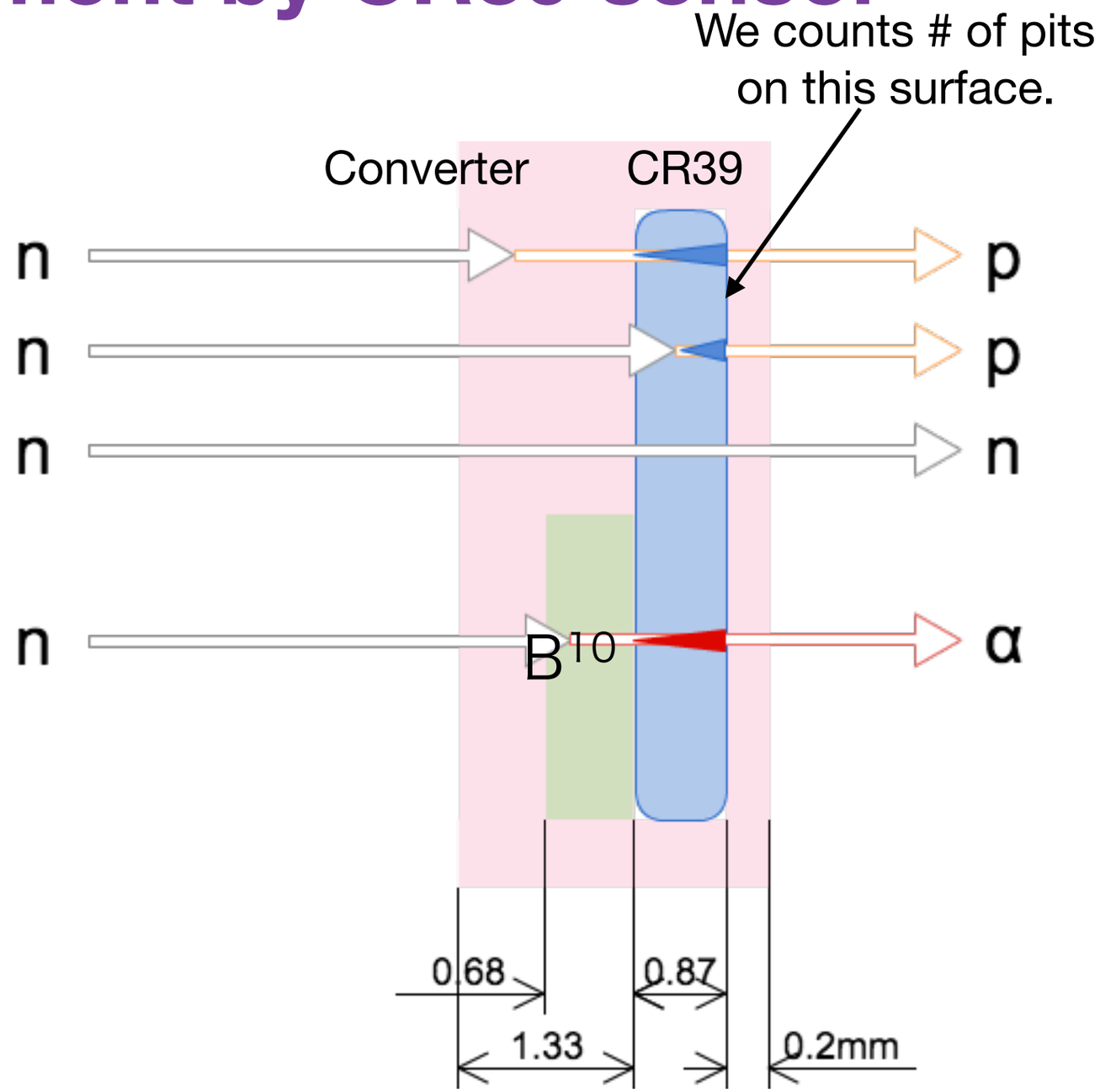
Thanks to Mr. Ochi(Kobe) and Mr. Ueno(KEK)

- Kobe tandem accelerator
  d(3 MeV) + Be → B + n (Q = 4.36 MeV)



Neutron measurement by CR39 sensor

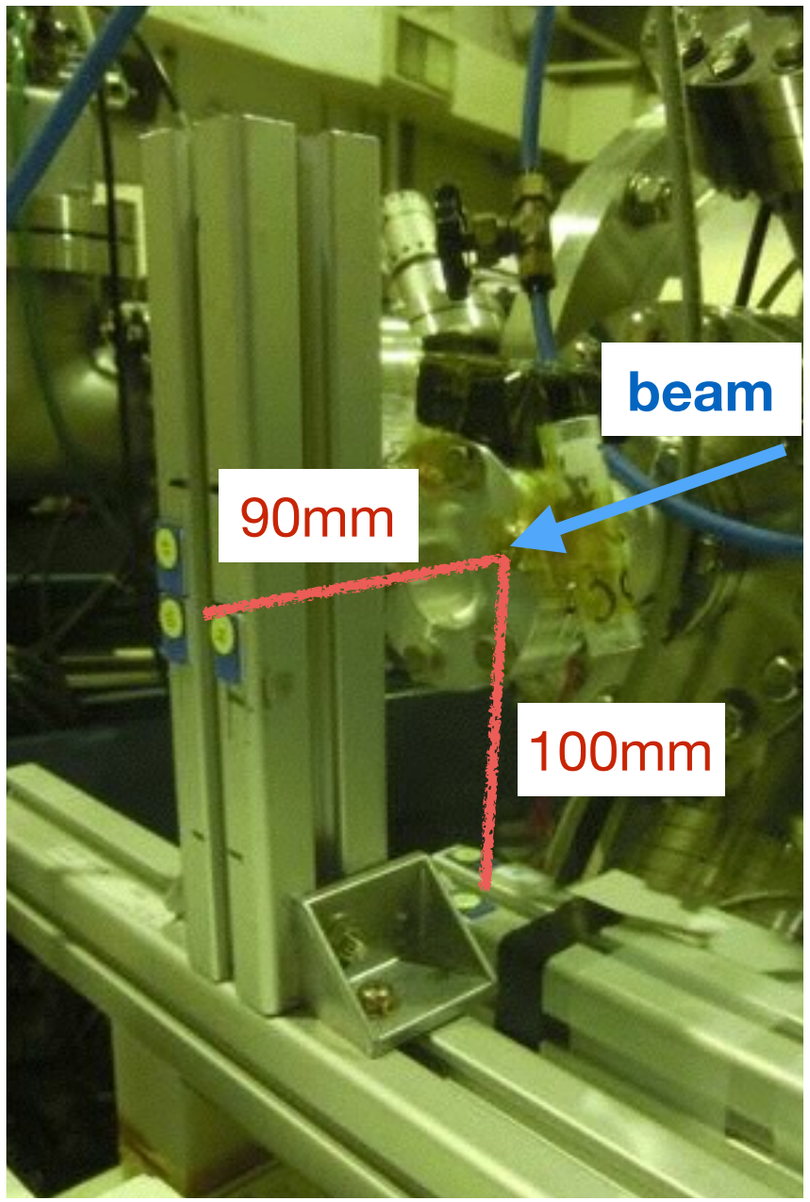
- The probability of detecting fast neutron is 10^{-4}.
- We know CR39 sensor's energy sensibility as 0.145 MeV ~ 14.8 MeV.

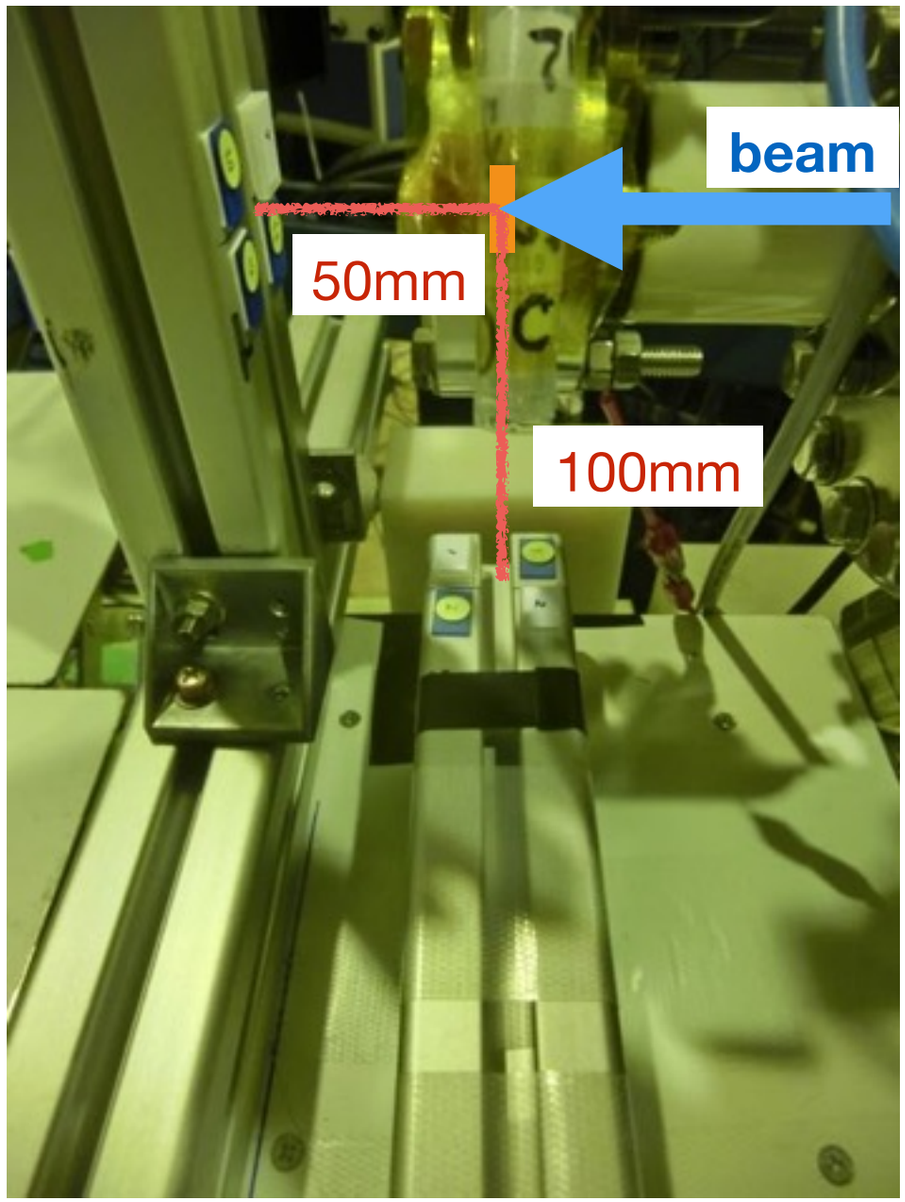


Calibrated by mono-energetic neutron in CYRIC(Tohoku)

Neutron measurement by CR39 sensor

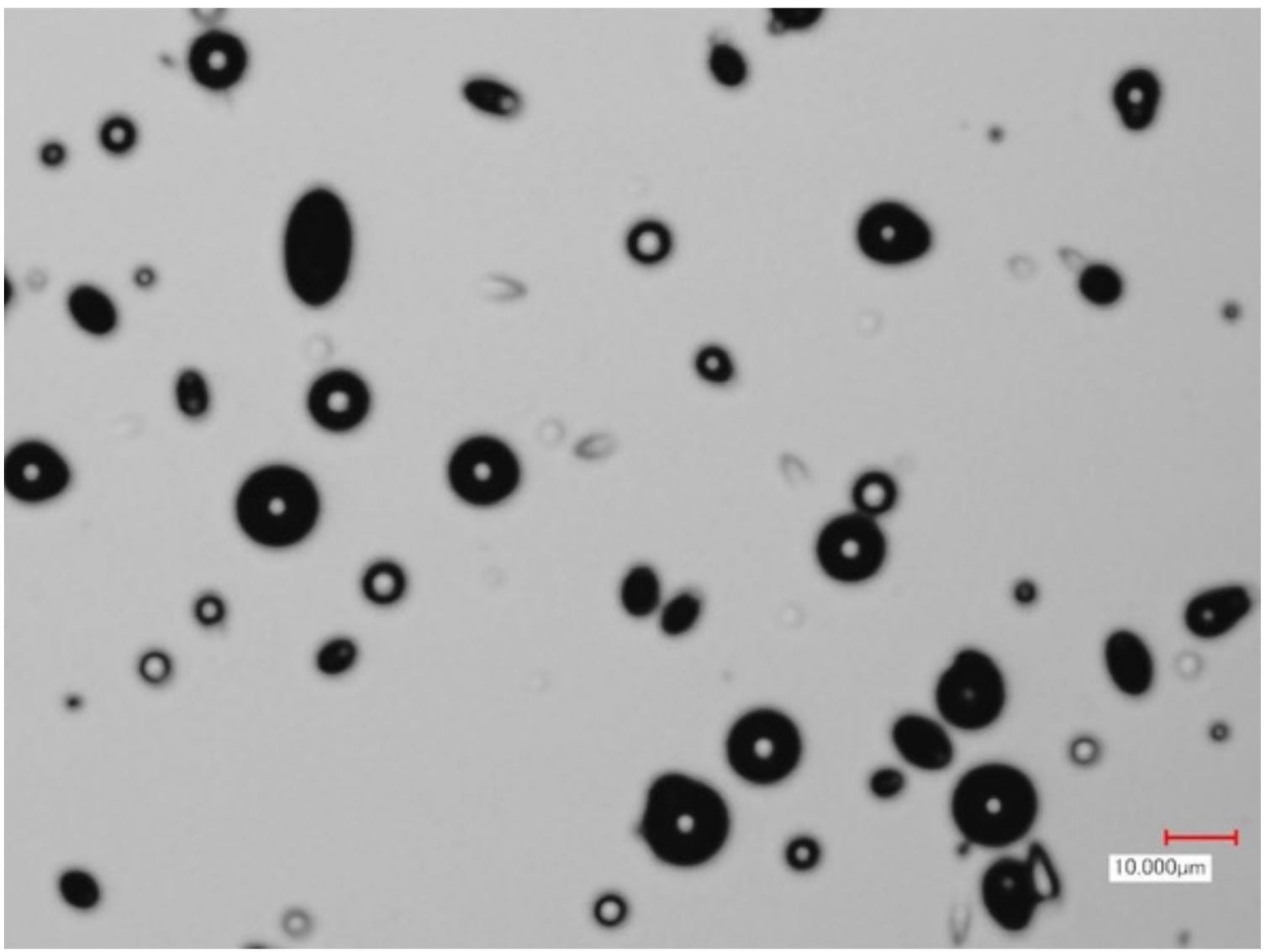
- **20 CR39 sensors**
- Fixed by Aluminium frame
- Position = Irradiation position of glue samples

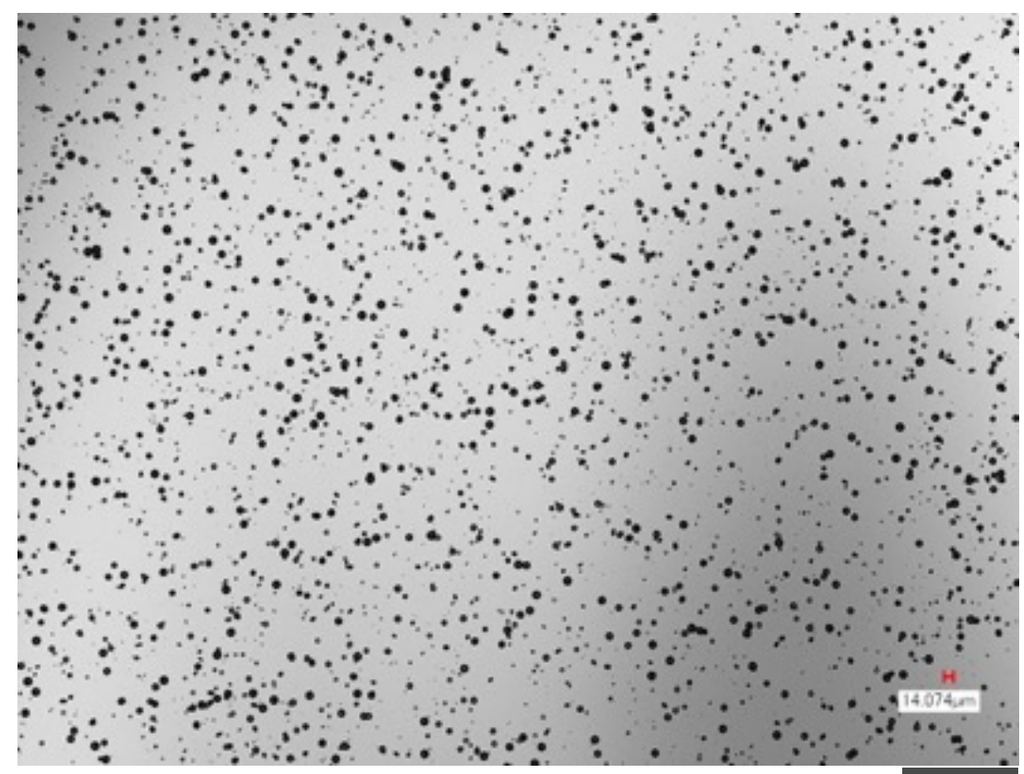




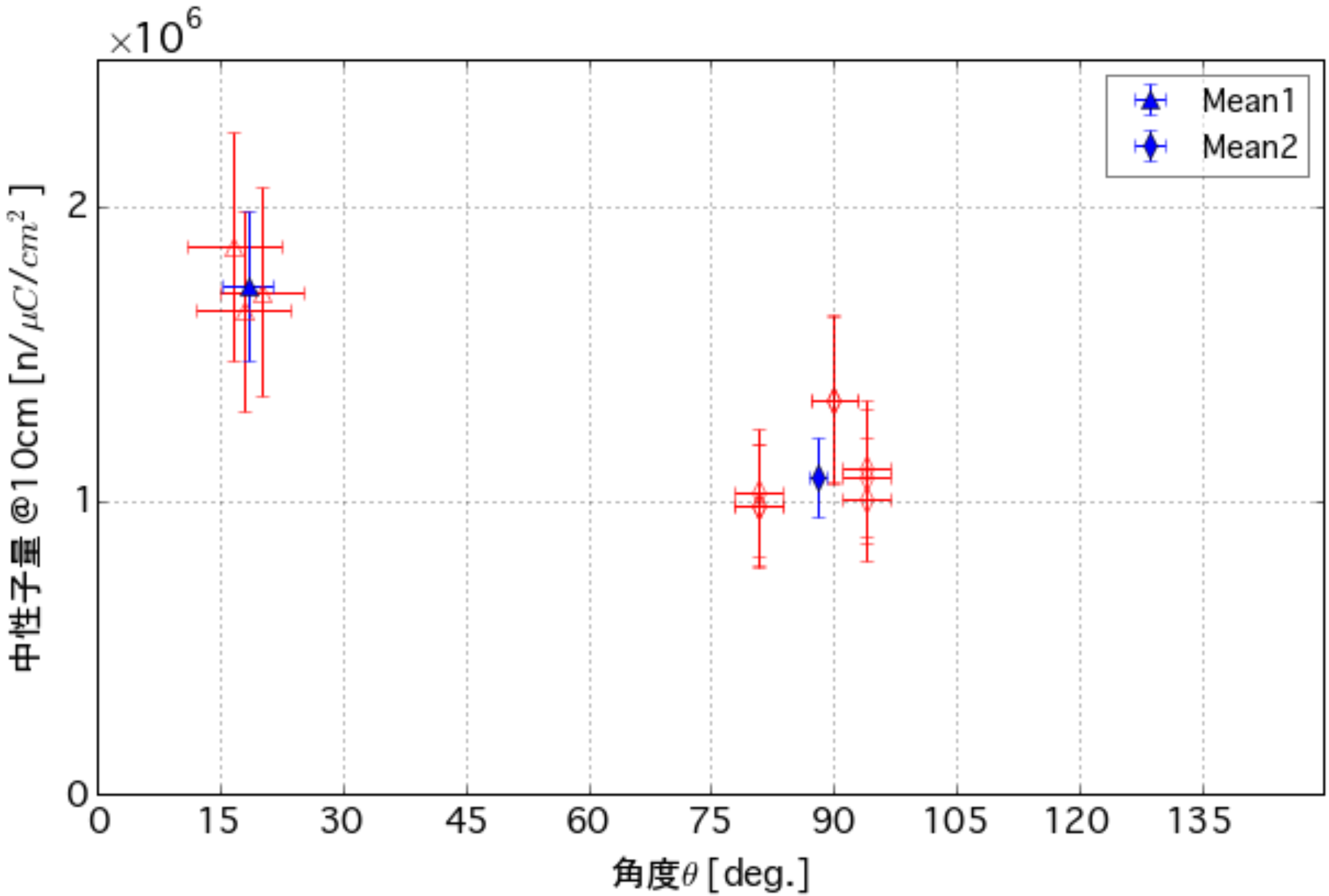
CR39 sensor pit count

- The company Landaua evaluated neutron counts.
  - chemical edging by NaOH 10 [mol/L] 70°C, 6h
    - pit size is extended to10 μm.
  - The pits on **CR39 sensor** is counted by direct eyes. (9mm^2 area)





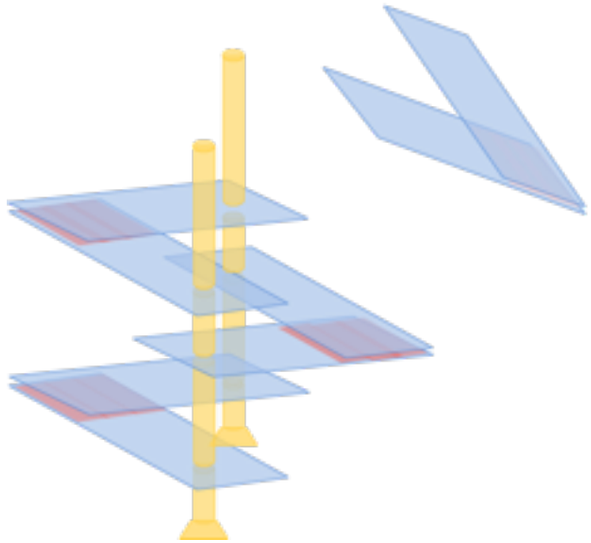
Angular distribution of Neutron dose



- Blue points are mean data on each position.

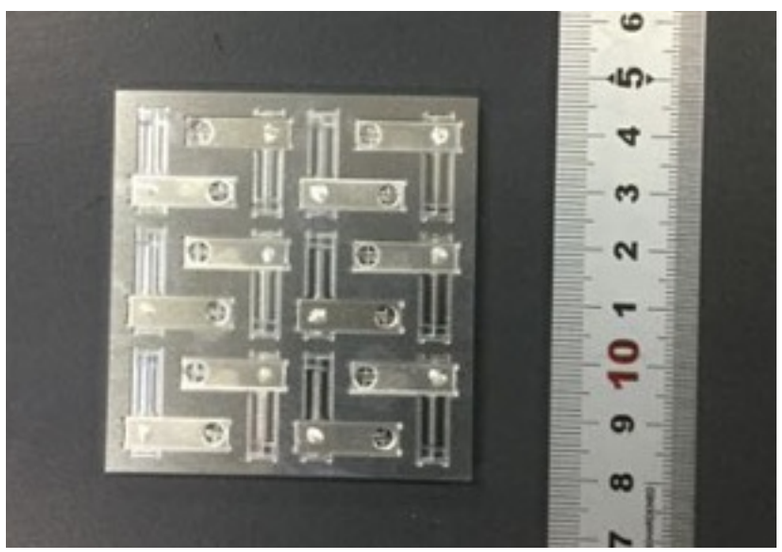
Neutron irradiation for Glue samples

- 2 types of conductive glues(E4110, E4110LV) are targeted.
  3 way of adherence are tested.
  - Recipe A: 60°C-6h (company recommended),120μm
  - Recipe B: 40°C-24h (France groups), 120μm
  - Recipe C: 23°C-3h (company recommended), 120μm
- These samples are irradiated by around 10^{12} n(1-MeV)/cm^2.

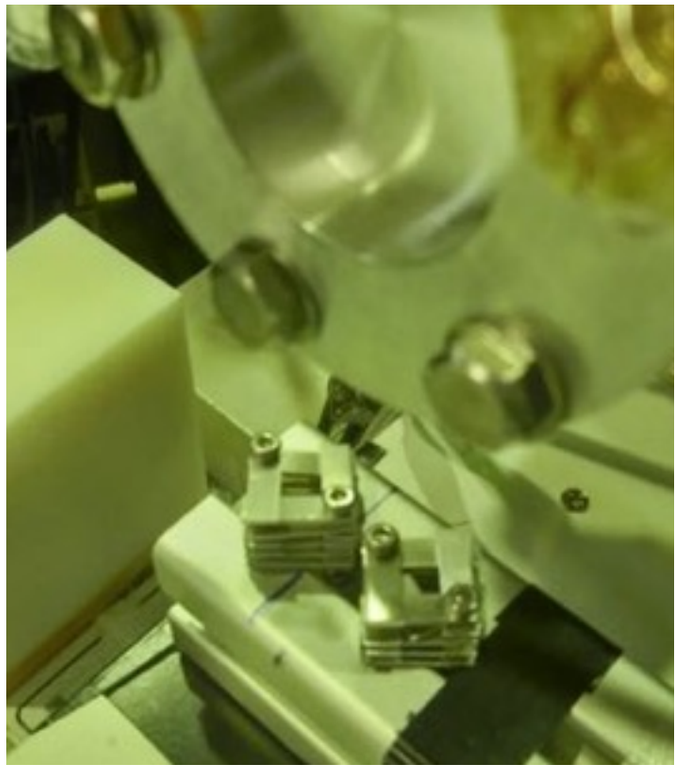


Expected properties

	E4110	E4110-LV
23°C	△	△
40°C	○	○
60°C	○	◎



sample	N_n n/cm^2
E4110	4.5E+09
E4110	3.5E+10
E4110	1.2E+12
E4110LV	4.5E+09
E4110LV	2.2E+11
E4110LV	1.2E+12



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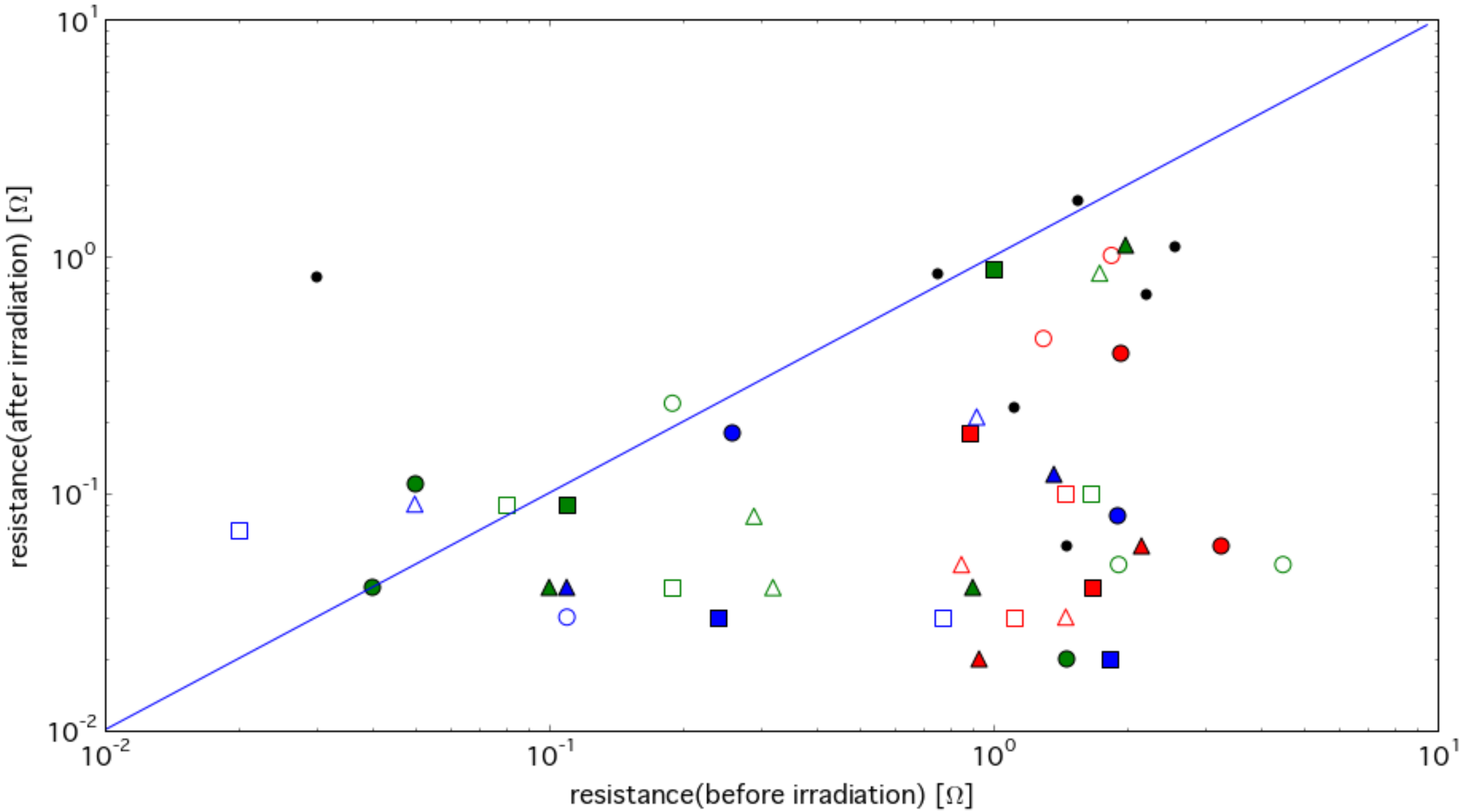
Resistance of Glue Samples

• 23°C • 40°C • 60°C

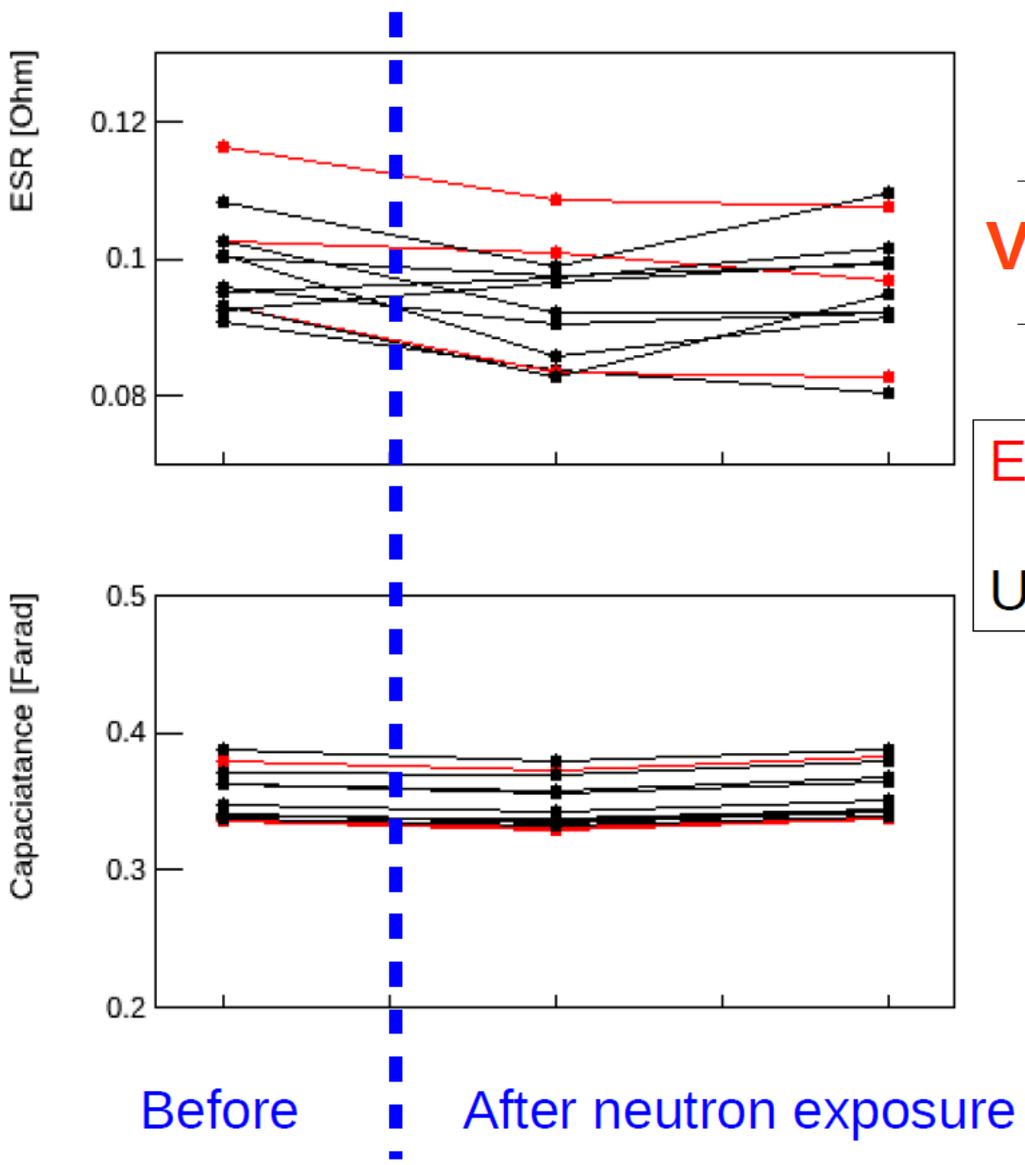
•**controll** ◯ 10^9 n/cm^2 △ 10^{10} n/cm^2 ▫ 10^{12} n/cm^2

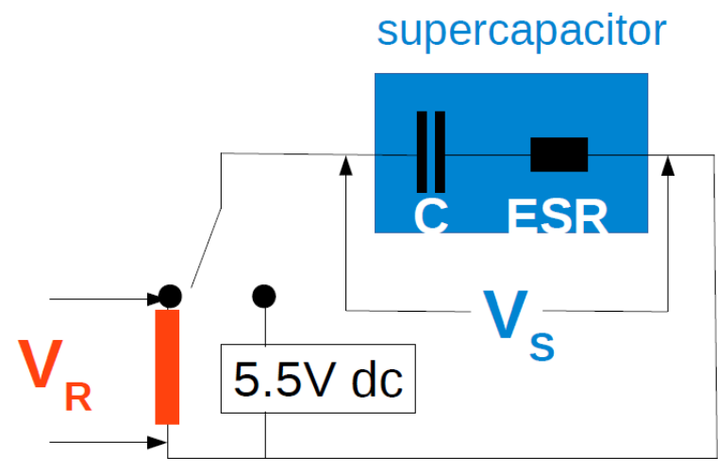


Every recipes of 2 types has radiation resistivity up to around **10^{12}** n(1-MeV)/cm^2**.**

Thanks to
Kozakai-san

Super capacitor



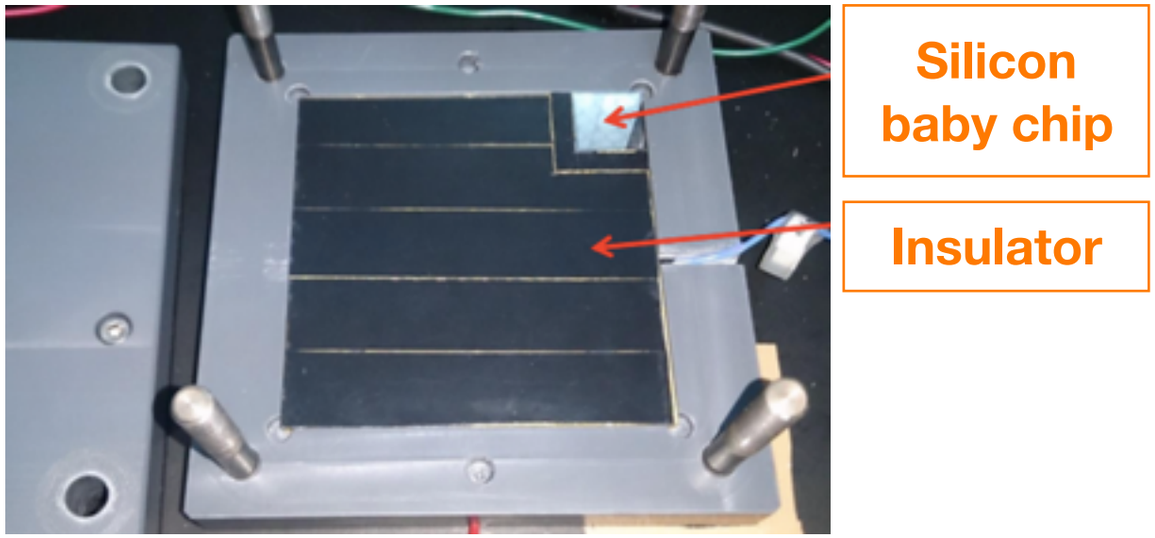


Exposed samples
Un-exposed

Super capacitor has radiation resistivity against $1.4 \cdot 10^{12}$ n/cm^2

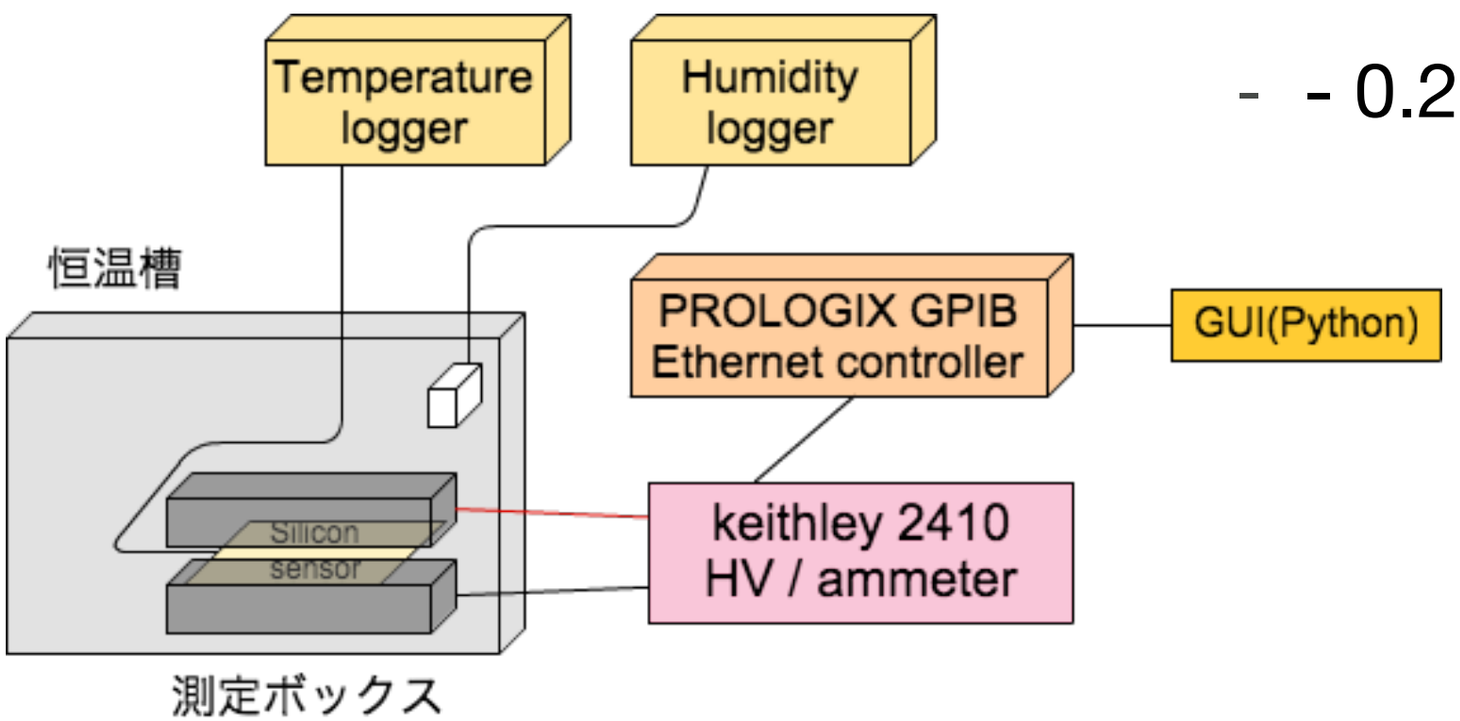
Current-Voltage characteristics

Checked increase of dark current before and after irradiation.



controlled voltage and temperature

- Temperature: maintainer
  - 5 °C ~ 45 °C
- Voltage: source meter
  - 0 V ~ 800 V
  - - 0.2 V ~ 0.2 V



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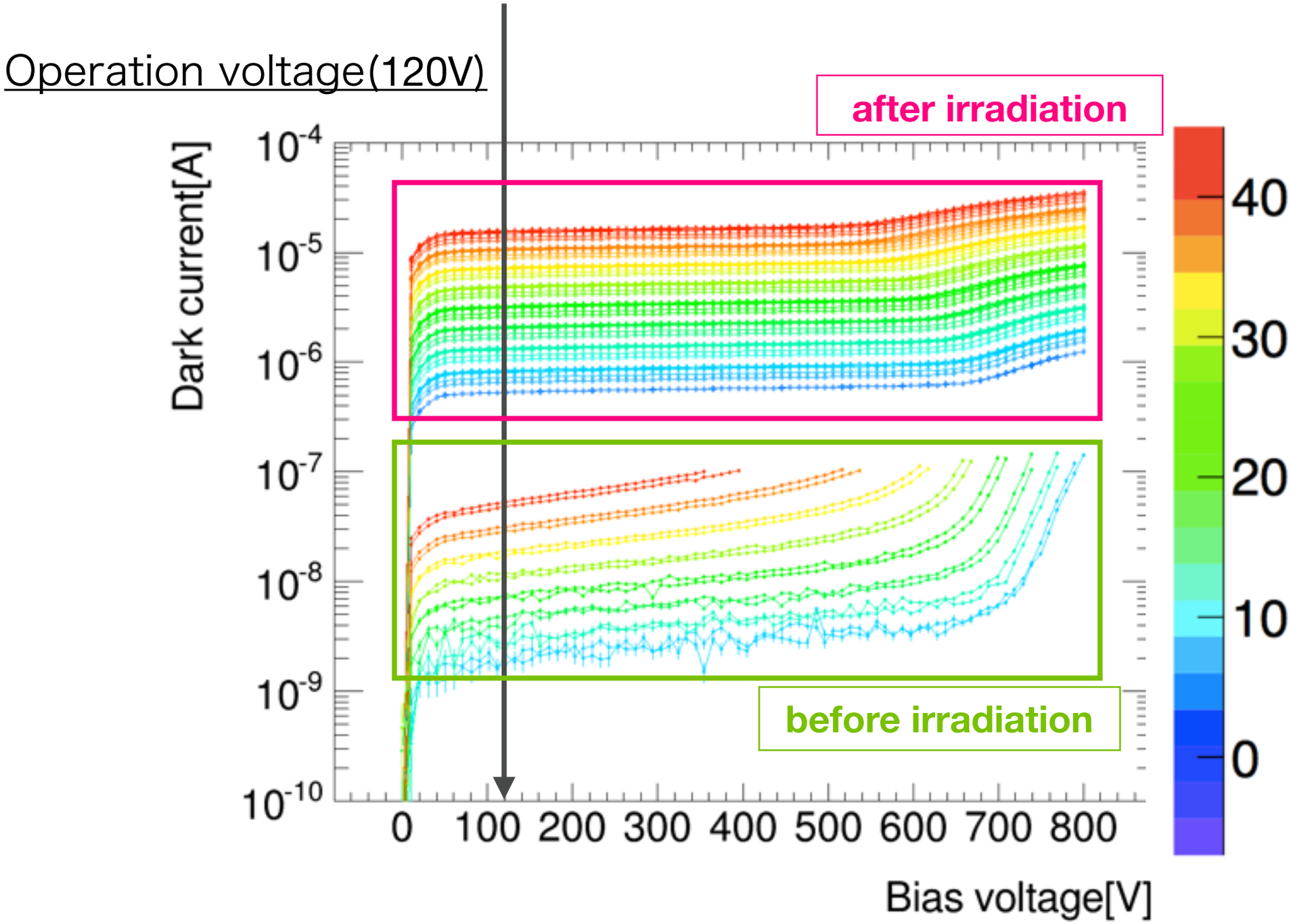


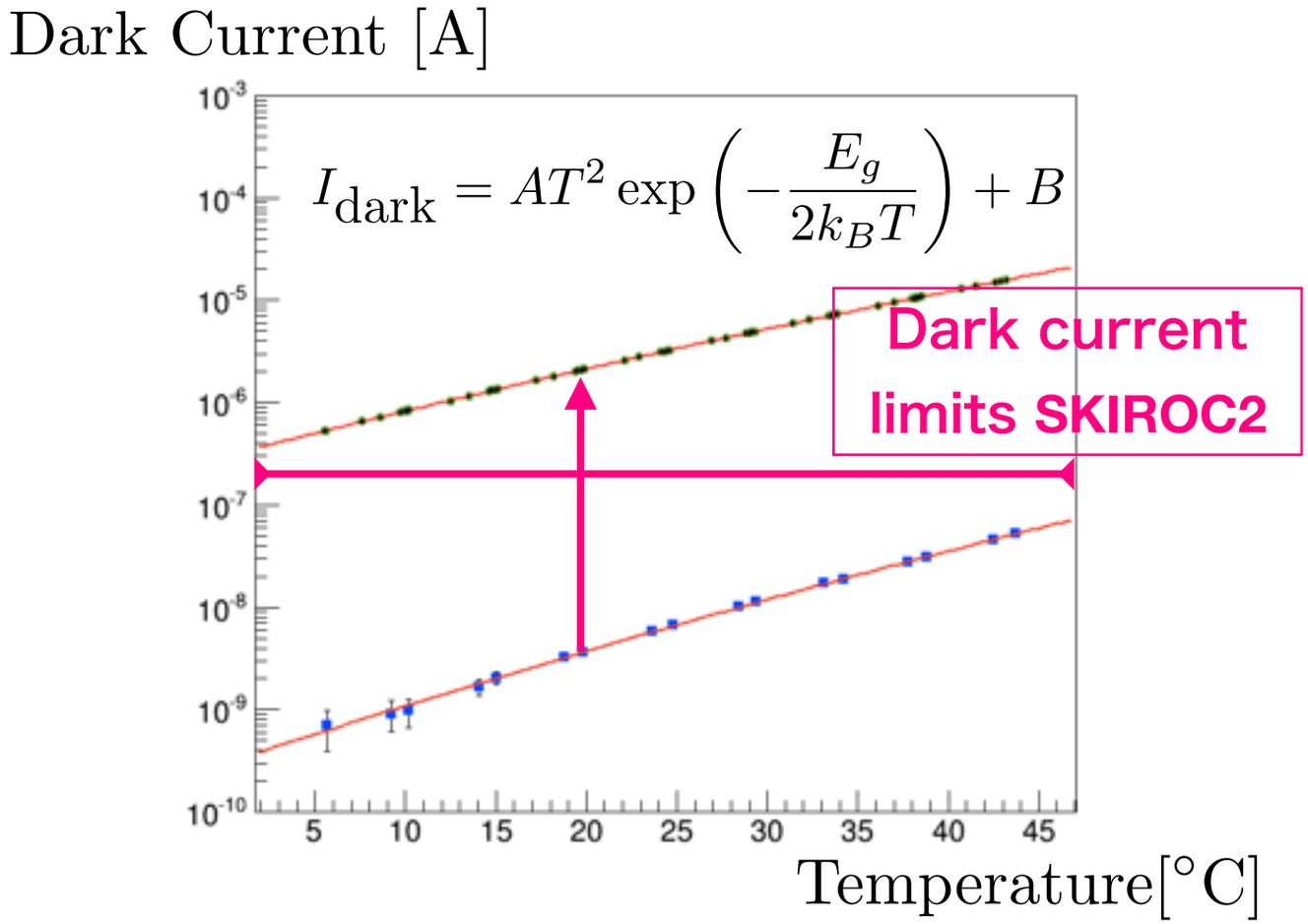
breakdown voltage

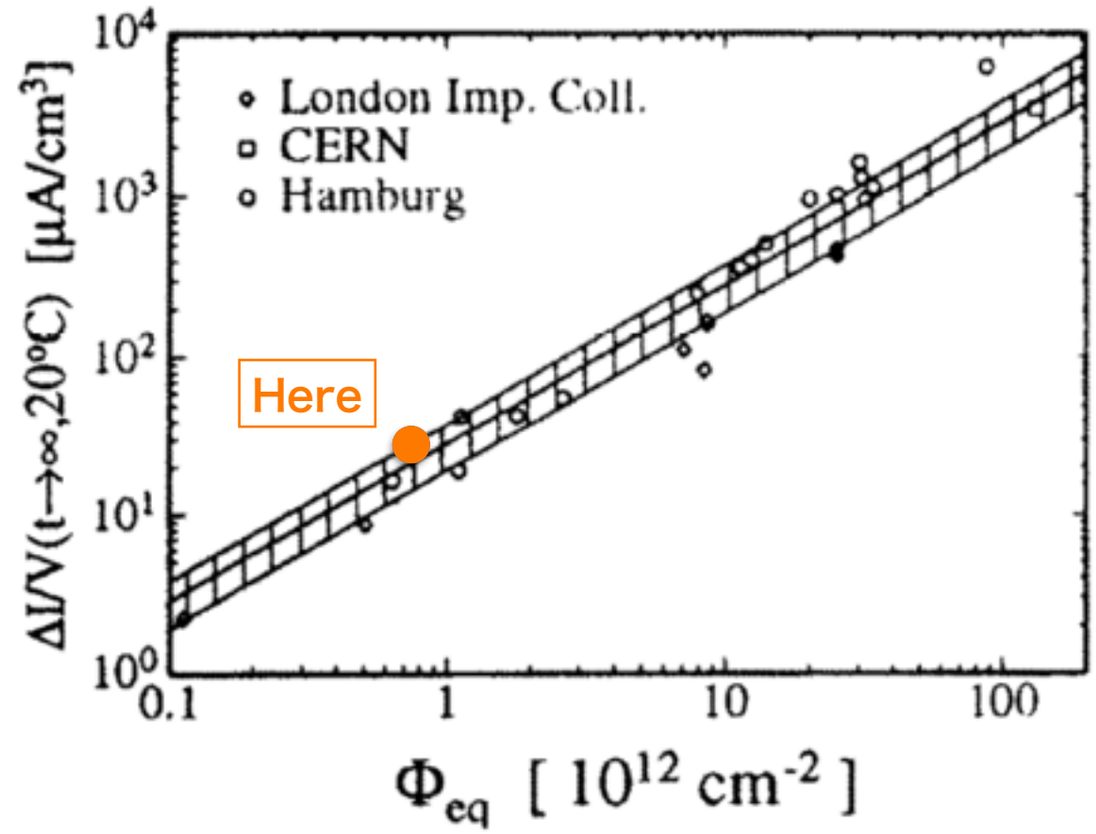
dark current @ operation voltage

diode properties @ low voltage

Current-Voltage characteristics on 120 V

- measured temperature dependency of dark current on 120 V long period after irradiation.





A. Chilingarov et al, Nucl. Instrm. Methods Phys. Res. A 360 (1995) 432 - 437

about 2μA increase @ 20°C

$$2\mu\mathrm{A}/(1.5\mathrm{cm} \times 1.5\mathrm{cm} \times 300\mu\mathrm{m}) = 29.6\mu\mathrm{A/cm}^3$$

equivalent neutron flux is around **7.5×10^{11} n(1-MeV)/cm^2**

Conclusion

- consistent in LHC & Hamburg experiment.
- From upper limit SKIROC2 dark current, it's safe during **30 - 60 years**.

Conclusions

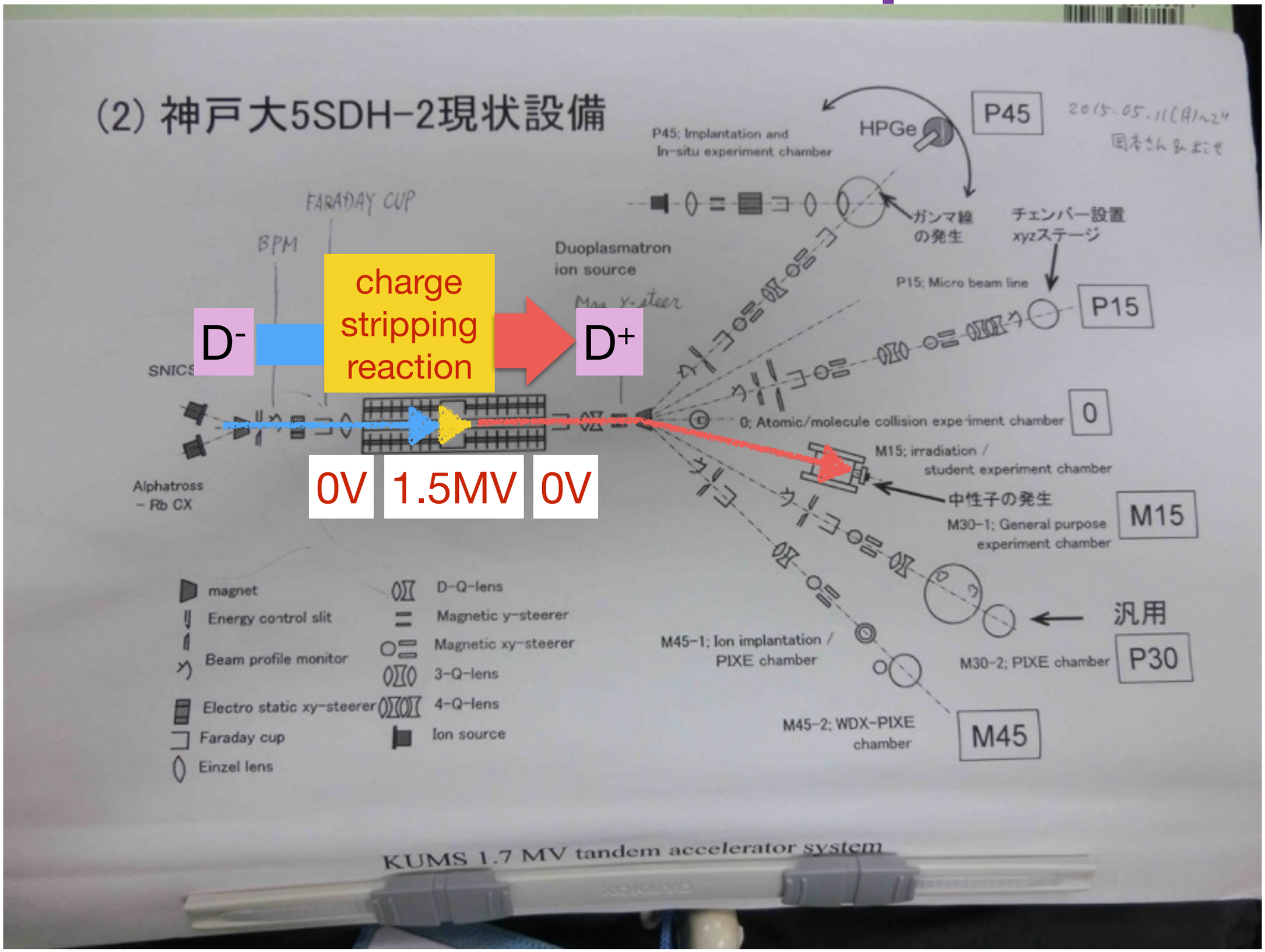
- Based on expected radiation dose on ILD ECAL,
  it's conducted to irradiate ECAL parts by Tandem neutron.
- Neutron dose is measured by CR39 sensor and
  the angular dependence.
- Both **super capacitor** and **2 conductive glues** with several cooking recipes had also been tested up to up to around **10^{12} n(1-MeV)/cm^2.**
- No significant degrade was found for them and we can safely use them for the ILC project.
- As silicon, IV properties are changed before and after irradiation.
  It's consistent with other silicon datum.
- From dark current of **upper limit SKIROC2**, it's safe during **30 - 60 years**.

BackUp

Hitoshi Nakanishi

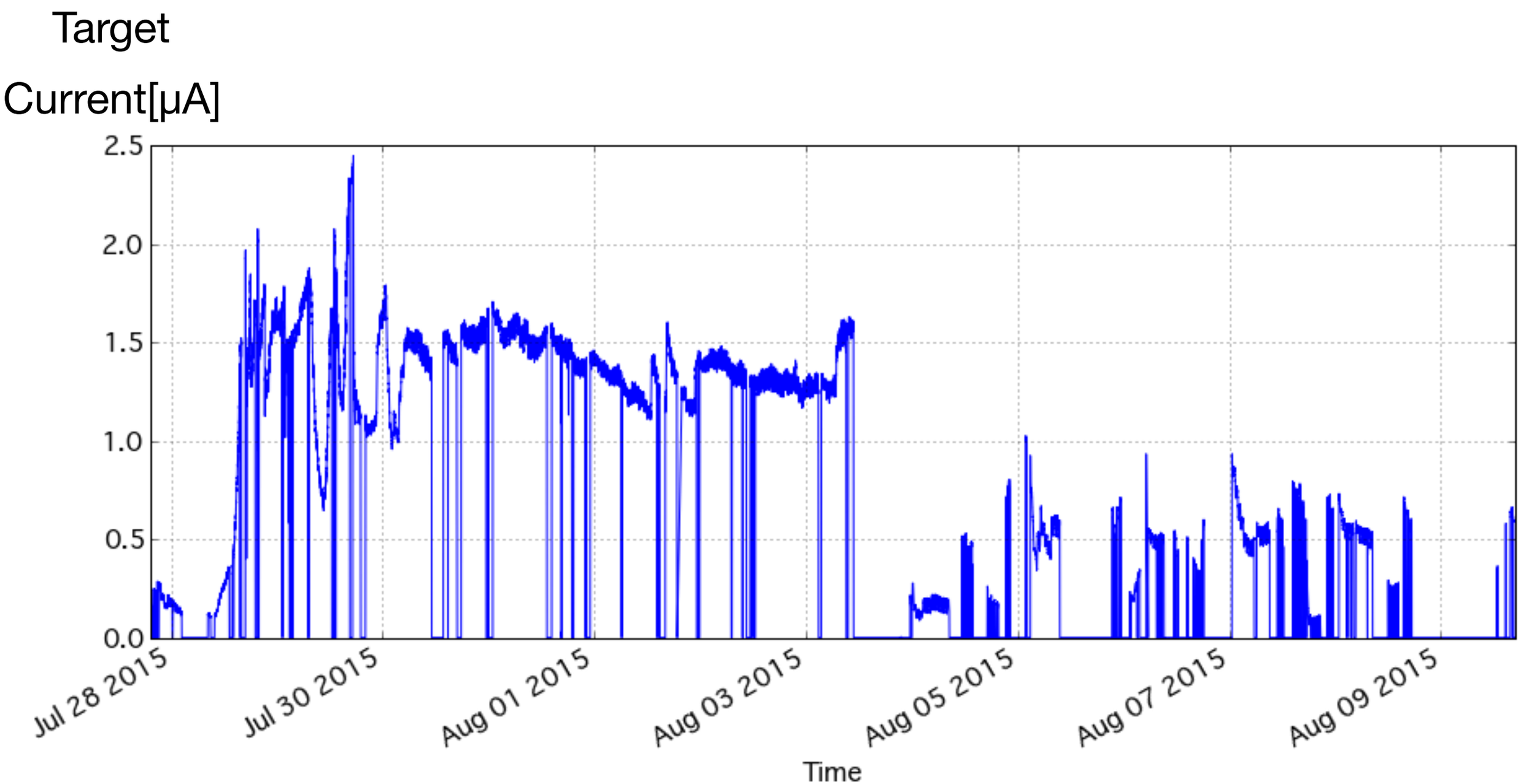
December 9 , 2015

Neutron irradiation experiment



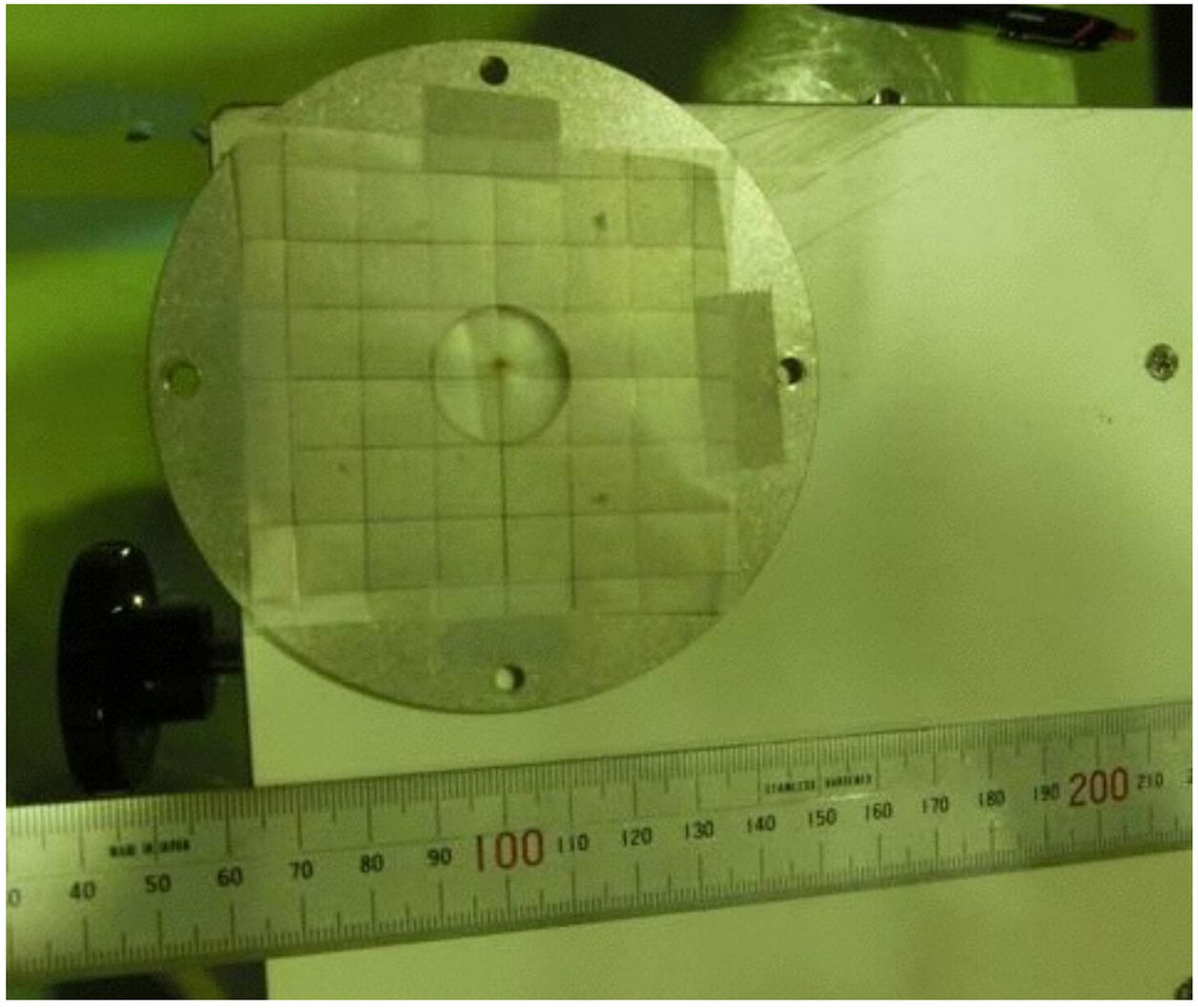
- keyword: tandem accelerator, charge stripping reaction

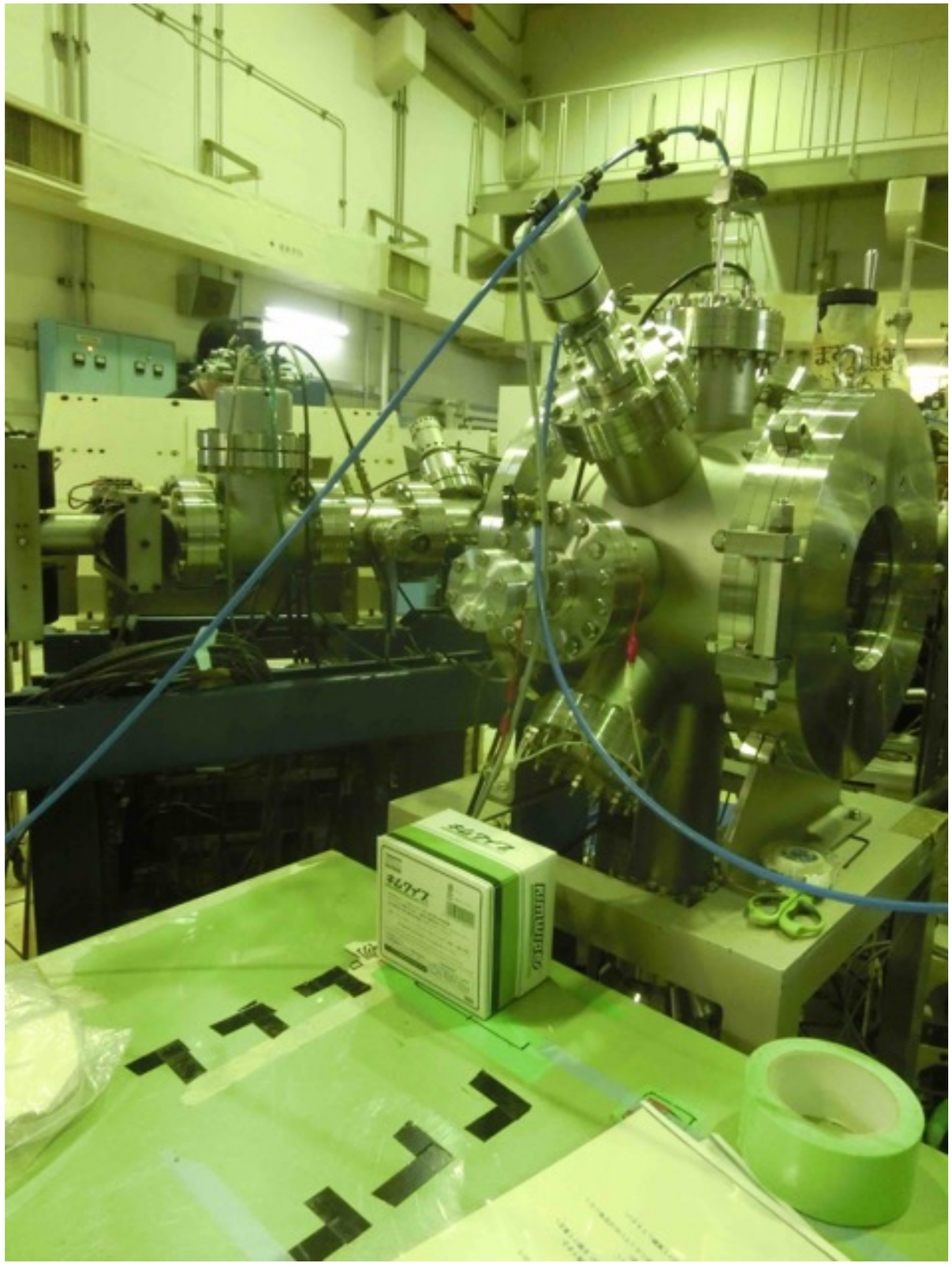
Beam Run: 7/27(Mon) ~ 8/9(Sun)



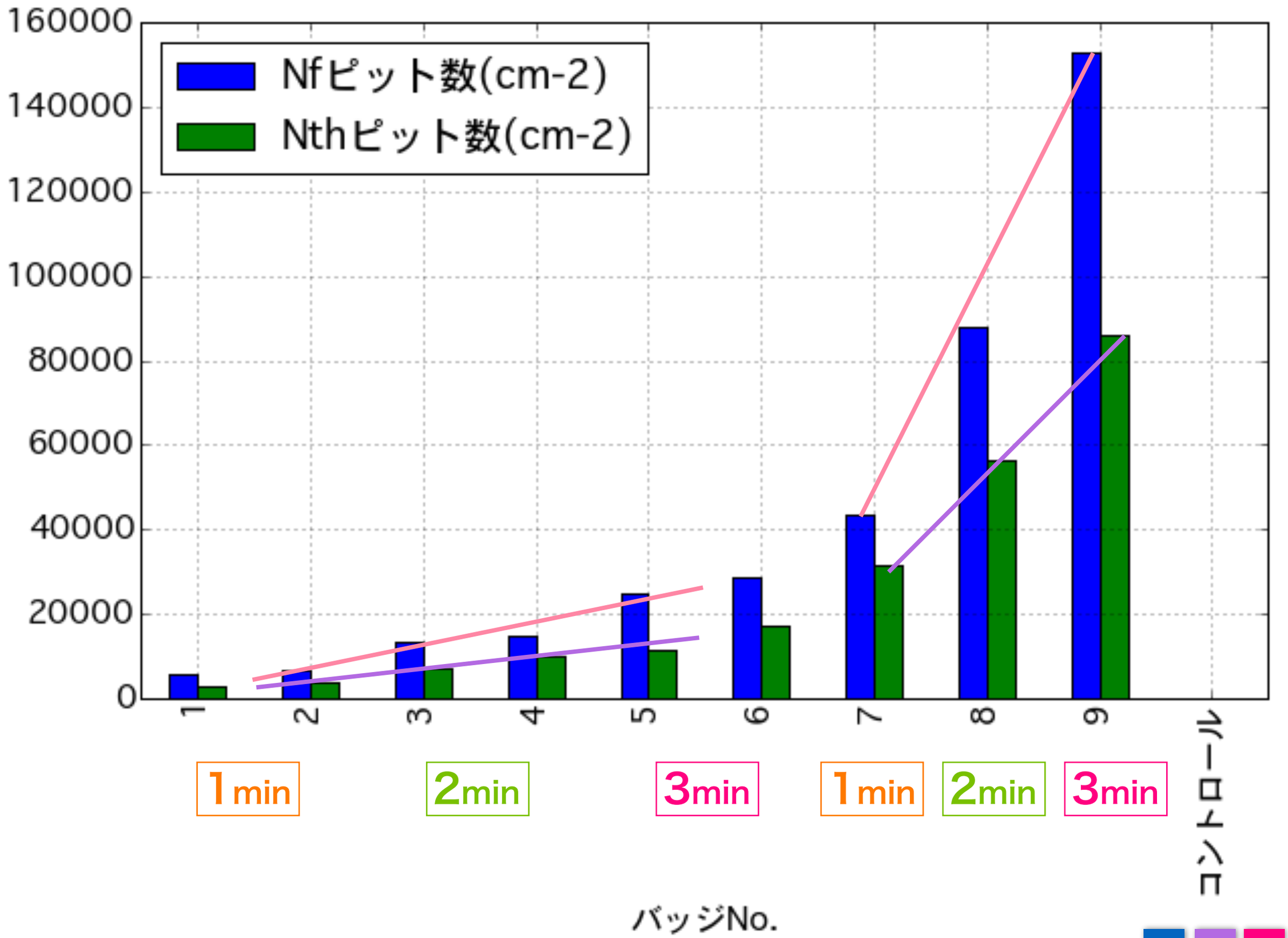
Neutron irradiation experiment (7/27)

- Be target: ϕ20 × 1.5 mm
- deuteron beam:
  size: < 4mm
- beam alignment were done.

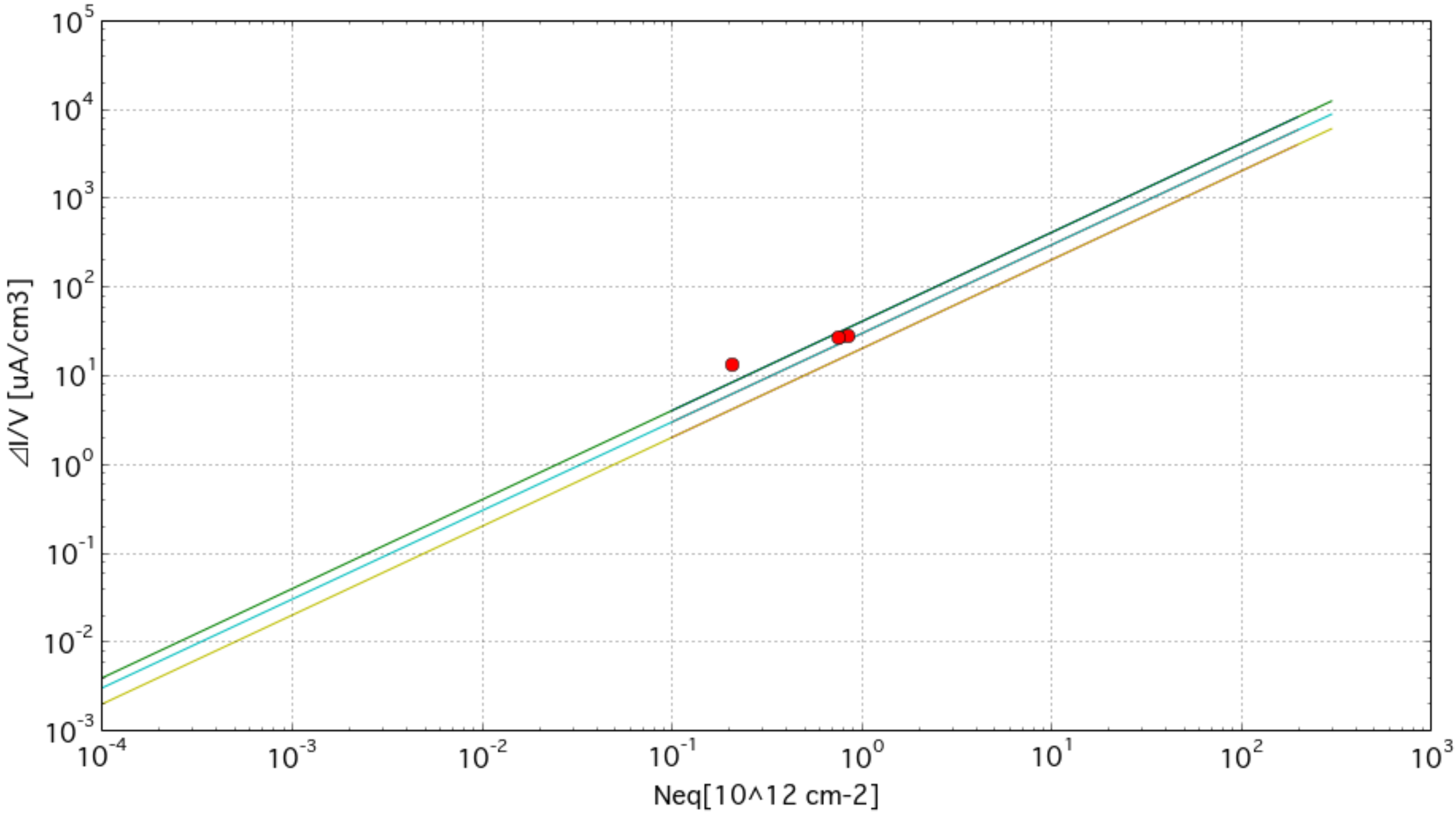




Neutron monitor by CR39 sensor



Angular distribution of Neutron dose



- Red points are datum of irradiated silicon.
- 3 lines are drawn from datum of LHC & Hamburg teams.