“Evaluation of neutron resistivity of ECAL components”

2016/3/2
CALICE MTG @ Kyushu

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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

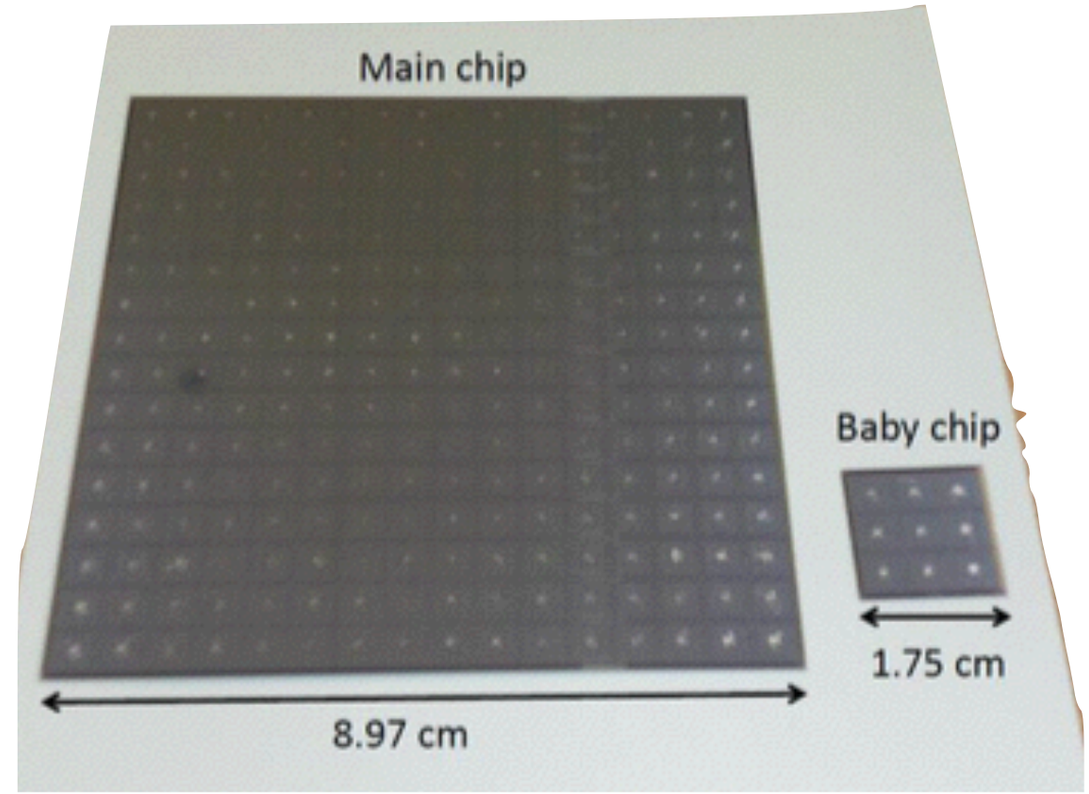
- Measurement of Radiation Damage
- Preliminary evaluation

ECAL parts [SiW]

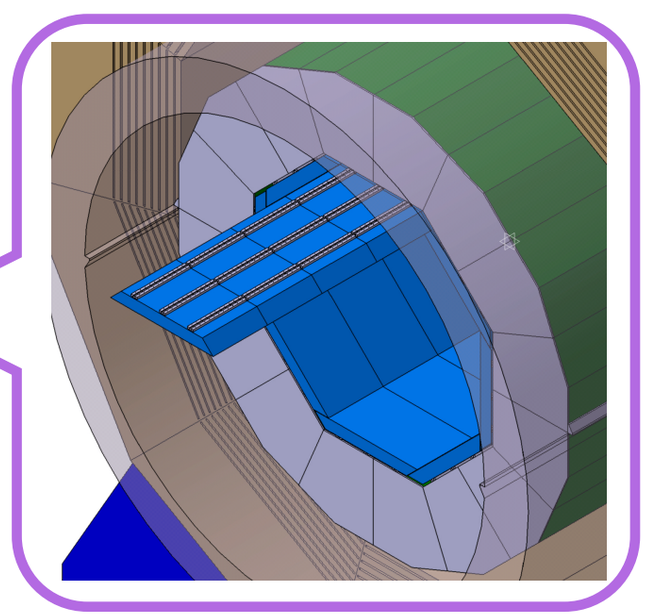
- **30 layers sandwiched calorimeter of Silicon PIN diode detector and W absorber**

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

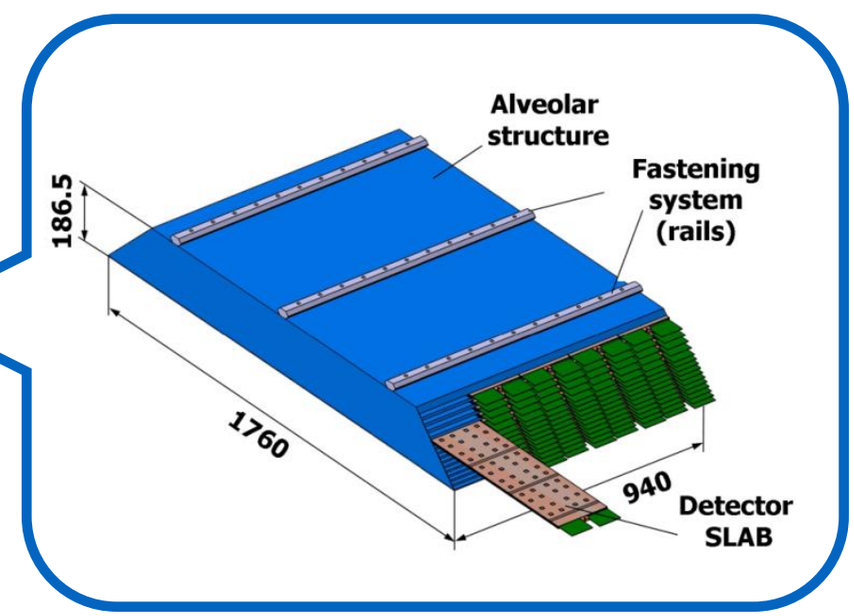
- **W absorber**
  - Small Molière Radius(R_M = 9mm)
  - Short Interaction Length(X_0 = 3.5mm)
  - Large ratio of them(λ/X_0 = 27.4)



ILD



ECAL



Si PIN diode+ W Sandwich CAL

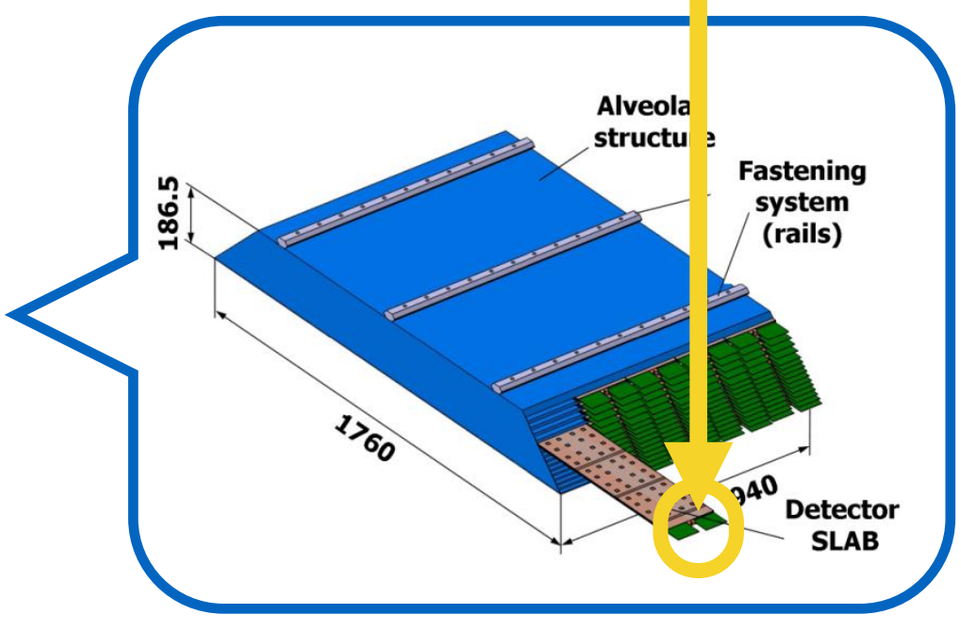
ECAL parts [super capacitor and glue]

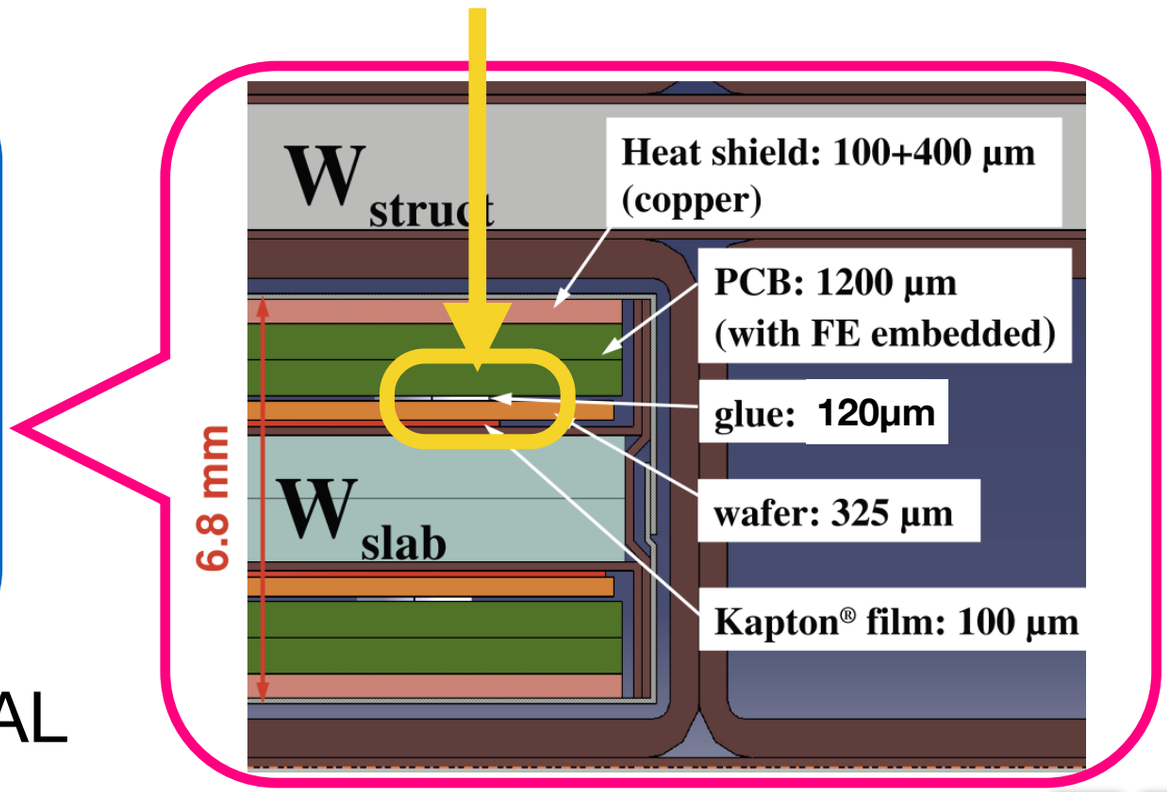
super capacitor

store power for power pulsing
of readout circuit

conductive glue

•adhere readout board and silicon
•Epoxy conductive glue

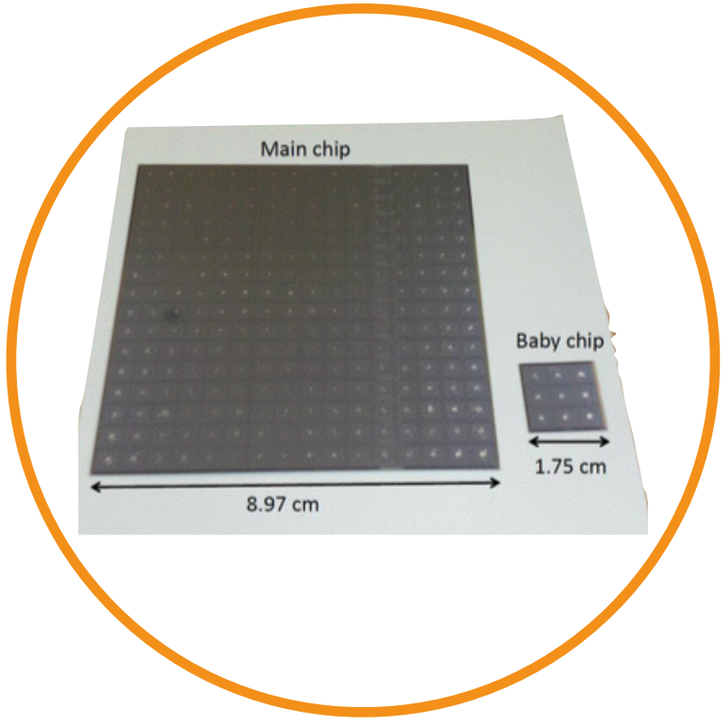




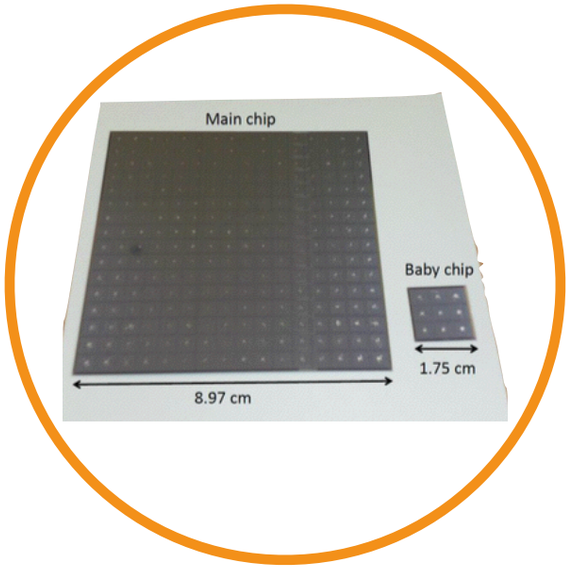
Si PIN diode + W Sandwich CAL

Research Purpose

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

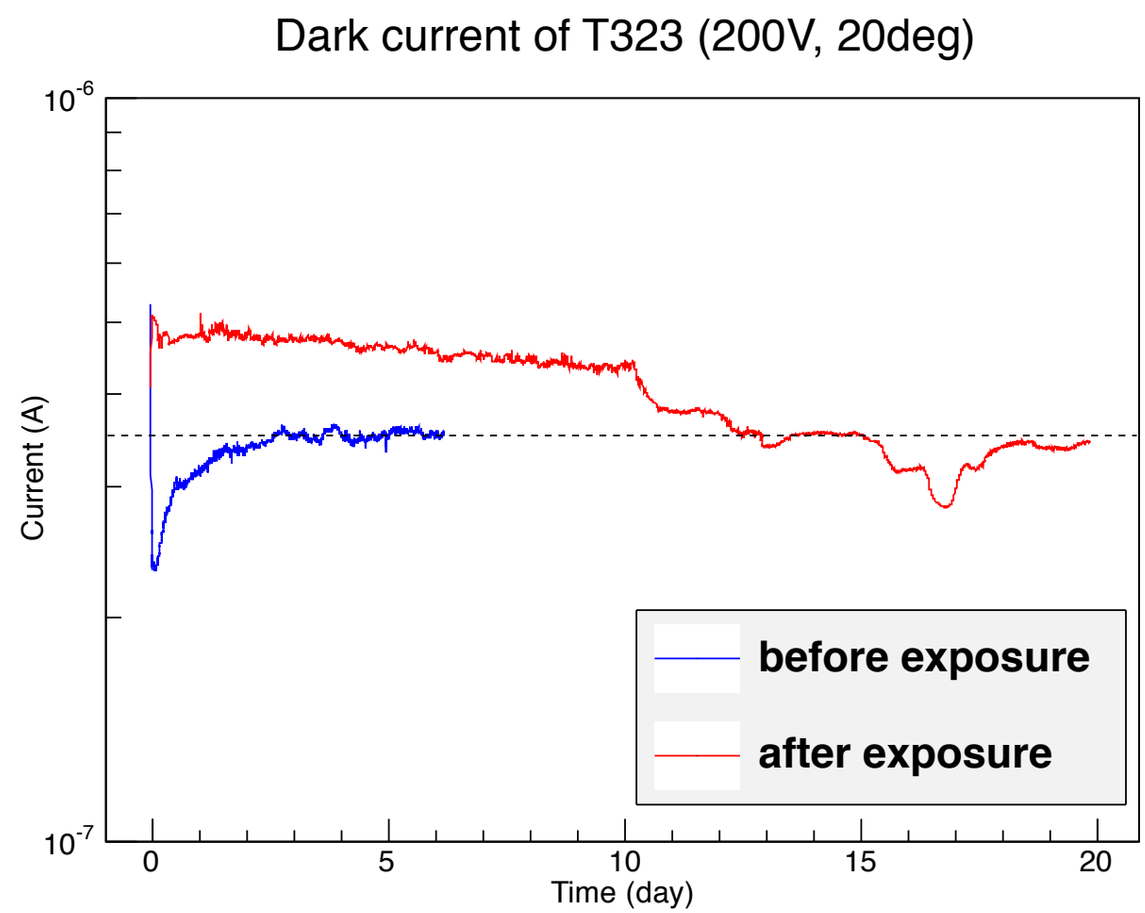


Radiation Damage in Silicon

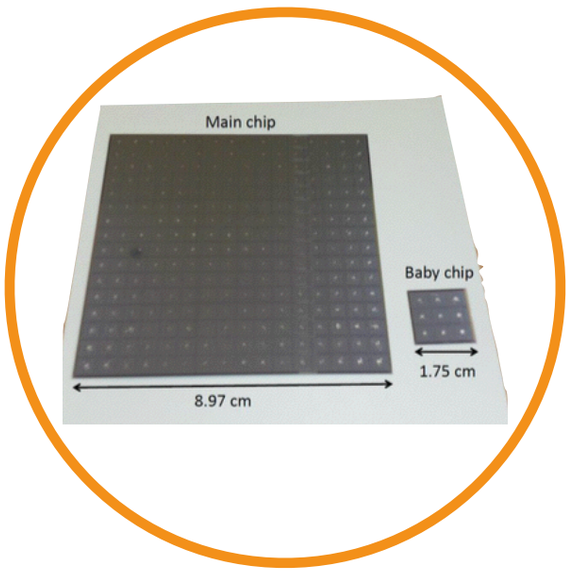


- **TID**(Total Ionising Dose Effect)
  Electromagnetic interaction by large radiation dose including photons. Creating fixed charge and border energy level aggravate properties.
- **DDD**(Displacement Damage Dose Effect)
  Particles create Frenkel defects in silicon crystal (**NIEL**) which degrade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

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



Radiation Damage in Silicon



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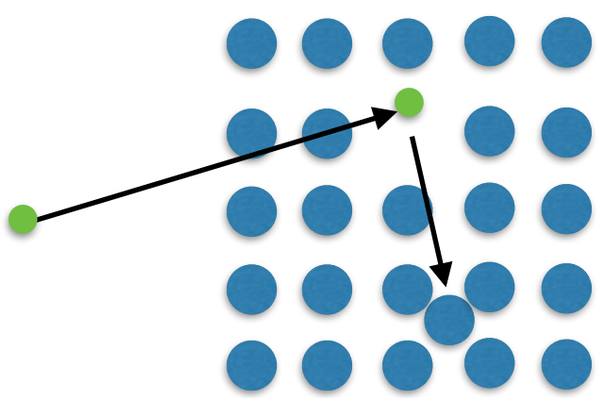
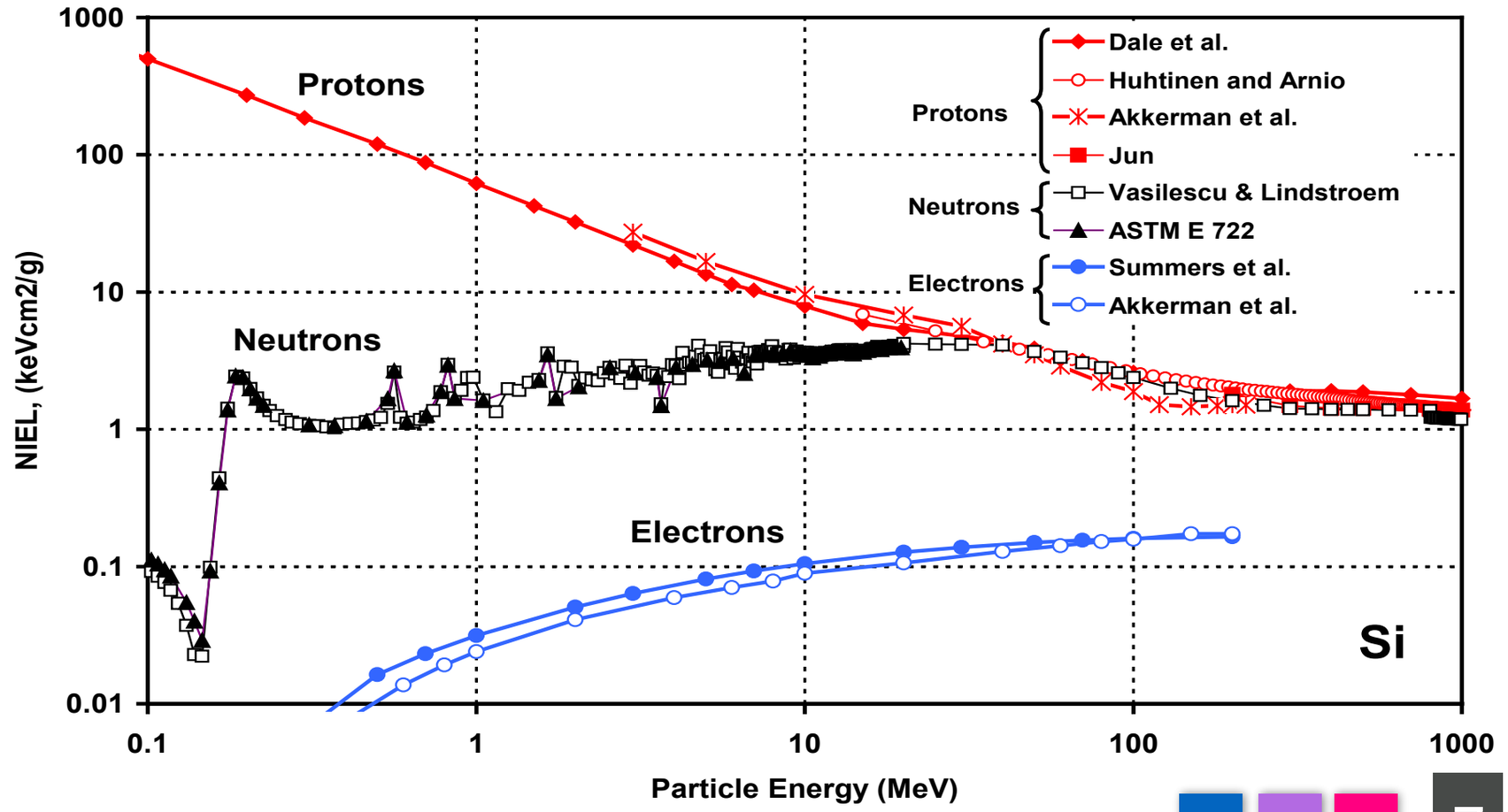
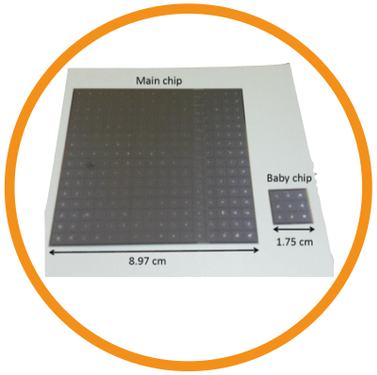
NIEL Damage Function





Radiation Damage and ILC requirement



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

- deterioration of conductivity and adherence

- change of capacitance

Required properties of ILD ECAL

1. Dark current is smaller than SKIROC2 design limit 20 nA / channel.
2. Effective volume does not change with operating voltage.
3. Collected charge is enough to detect ~ 0.2 MIPs.
4. continuity of conductivity and adherence
5. right action of electric circuit

Expected Radiation

- Radiation Sources are classified as BDS and IP.

IP(Interaction Point)

△ Photon: beamstrahlung photons

× Photon: **RBS(Radiative Bhabha Scattering)**
  × $e^- e^+$: **PC (Pair Creation)**
  × hadrons: **γ-γ scattering (Minijets)**

BDS(beam delivery system)

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

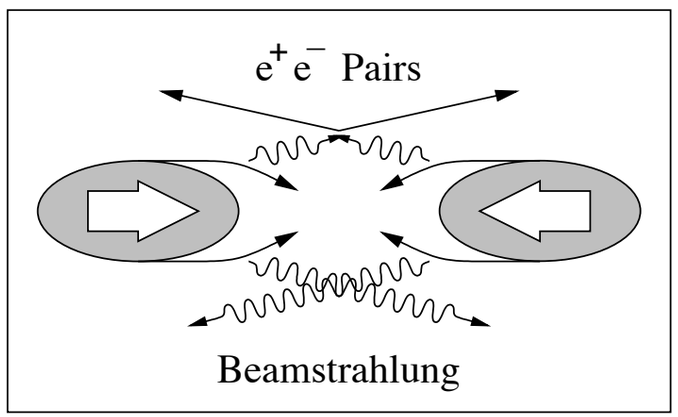
? Neutron: Beam dumps

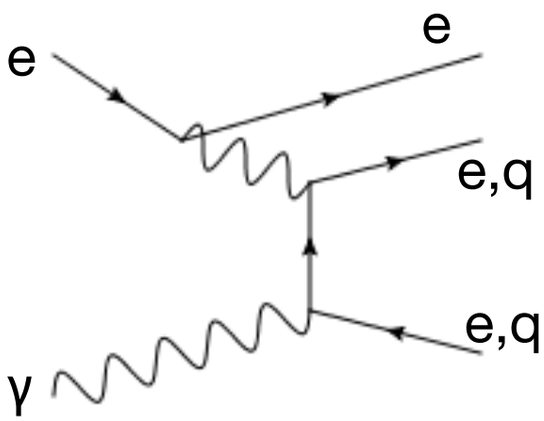
? others: Extraction Line Losses

- can ignore radiation damage
△ require appropriate evaluation

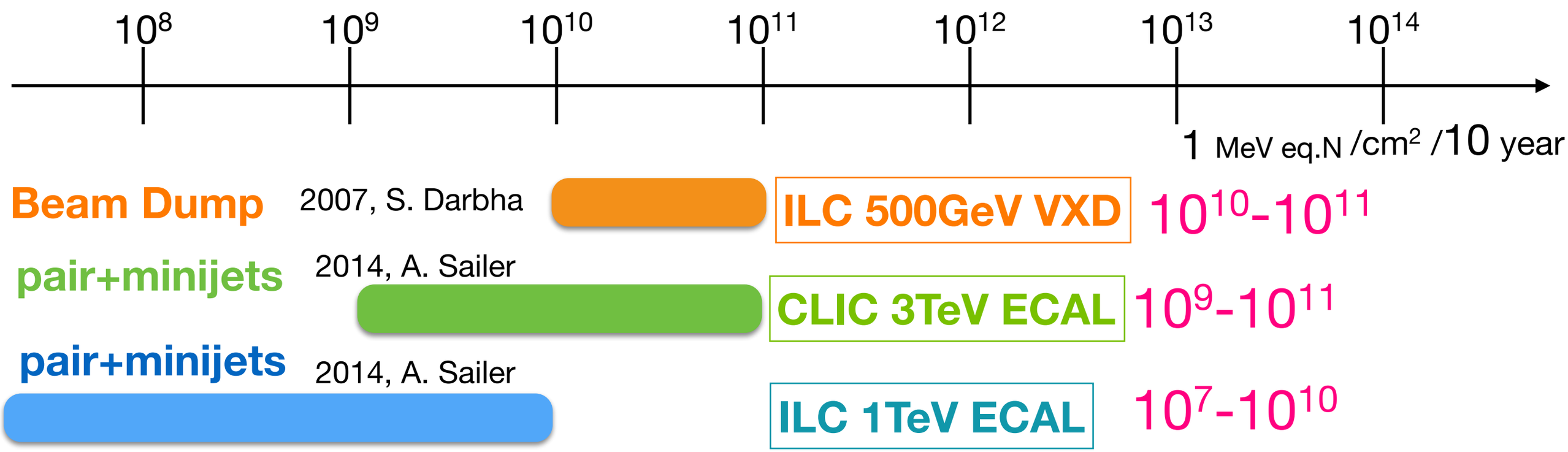
× can't ignore radiation damage
? require more detail

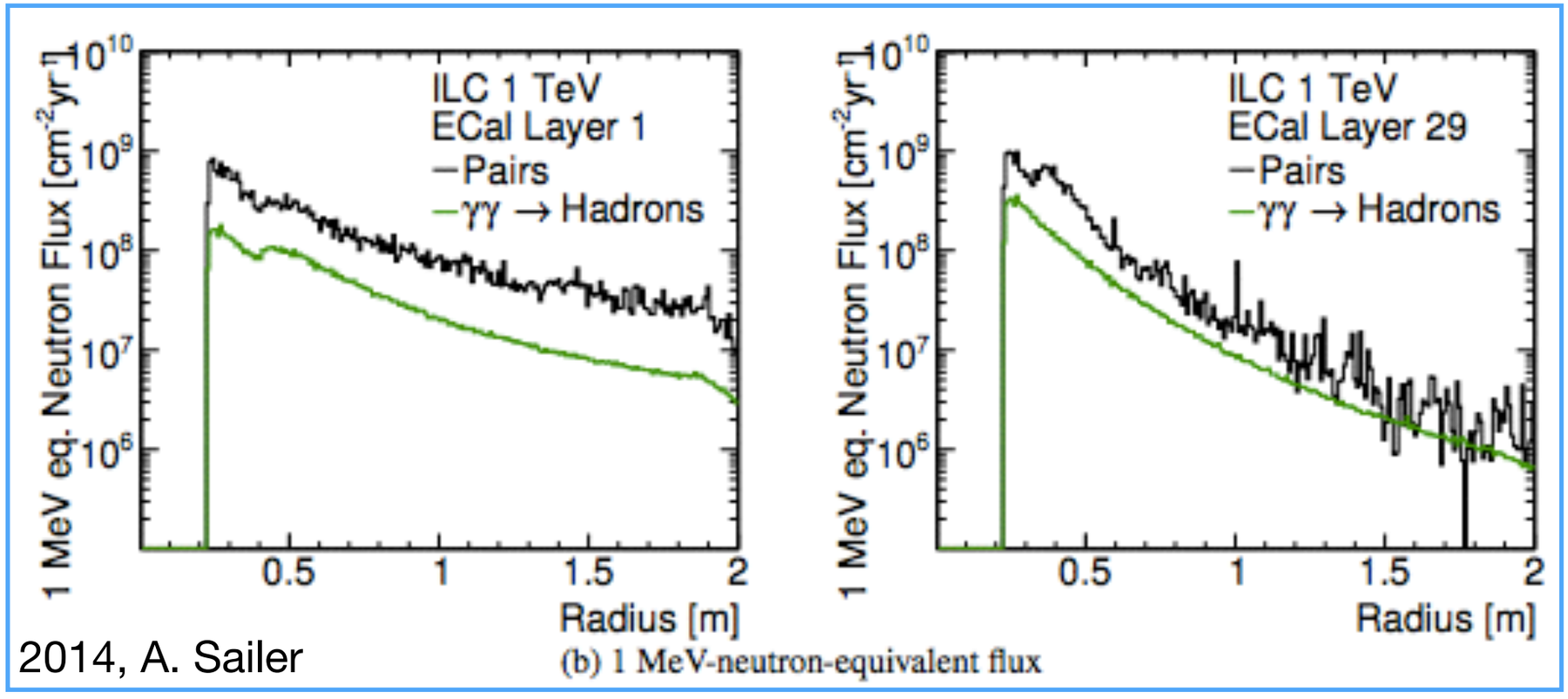
Spatial charge are attracted to each others by pinch effect and accelerated.





Expected Radiation





2014, A. Sailer

(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

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- Neutron Irradiation of ECAL parts

Evaluation

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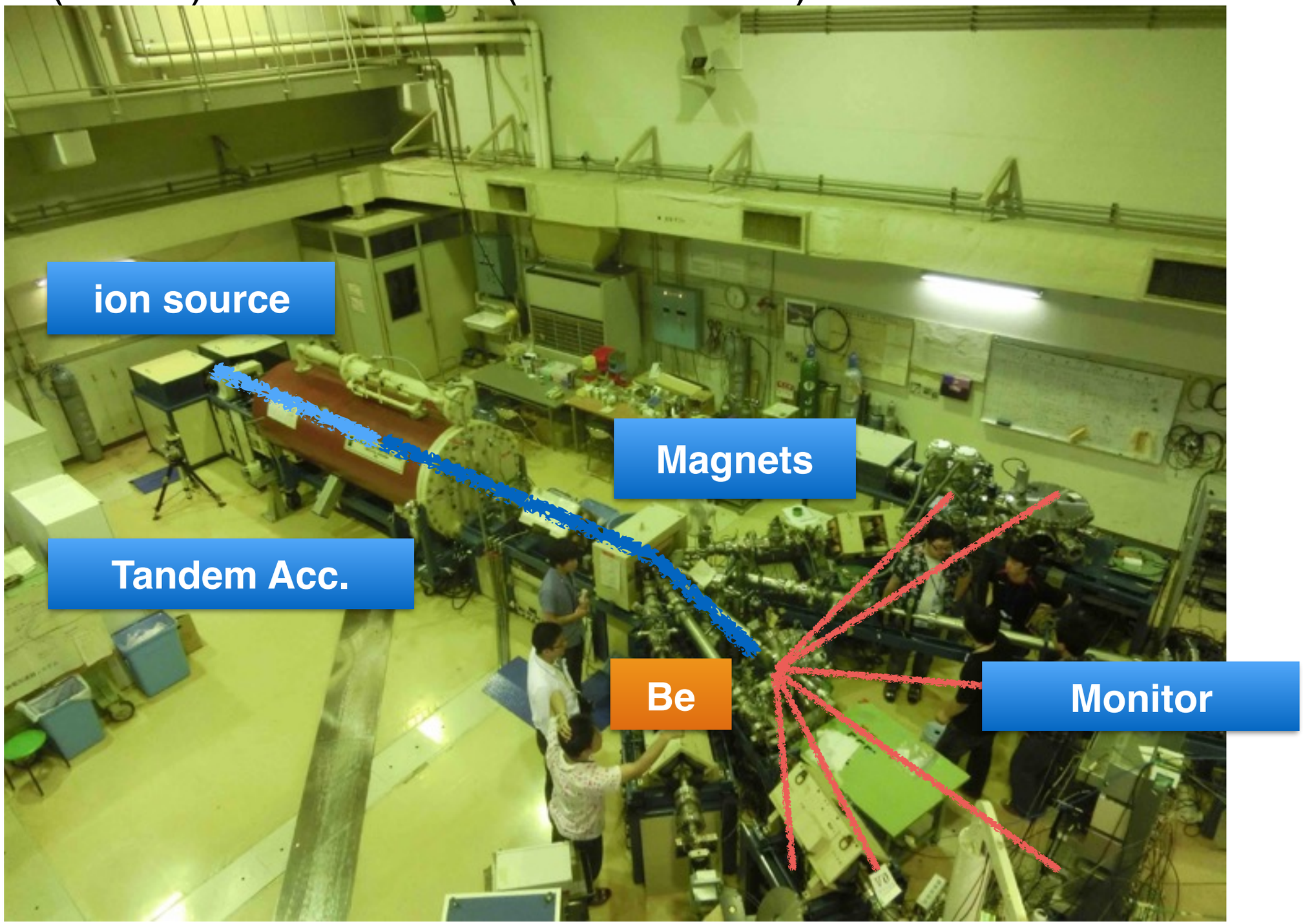
- Evaluation

Neutron Irradiation Test

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

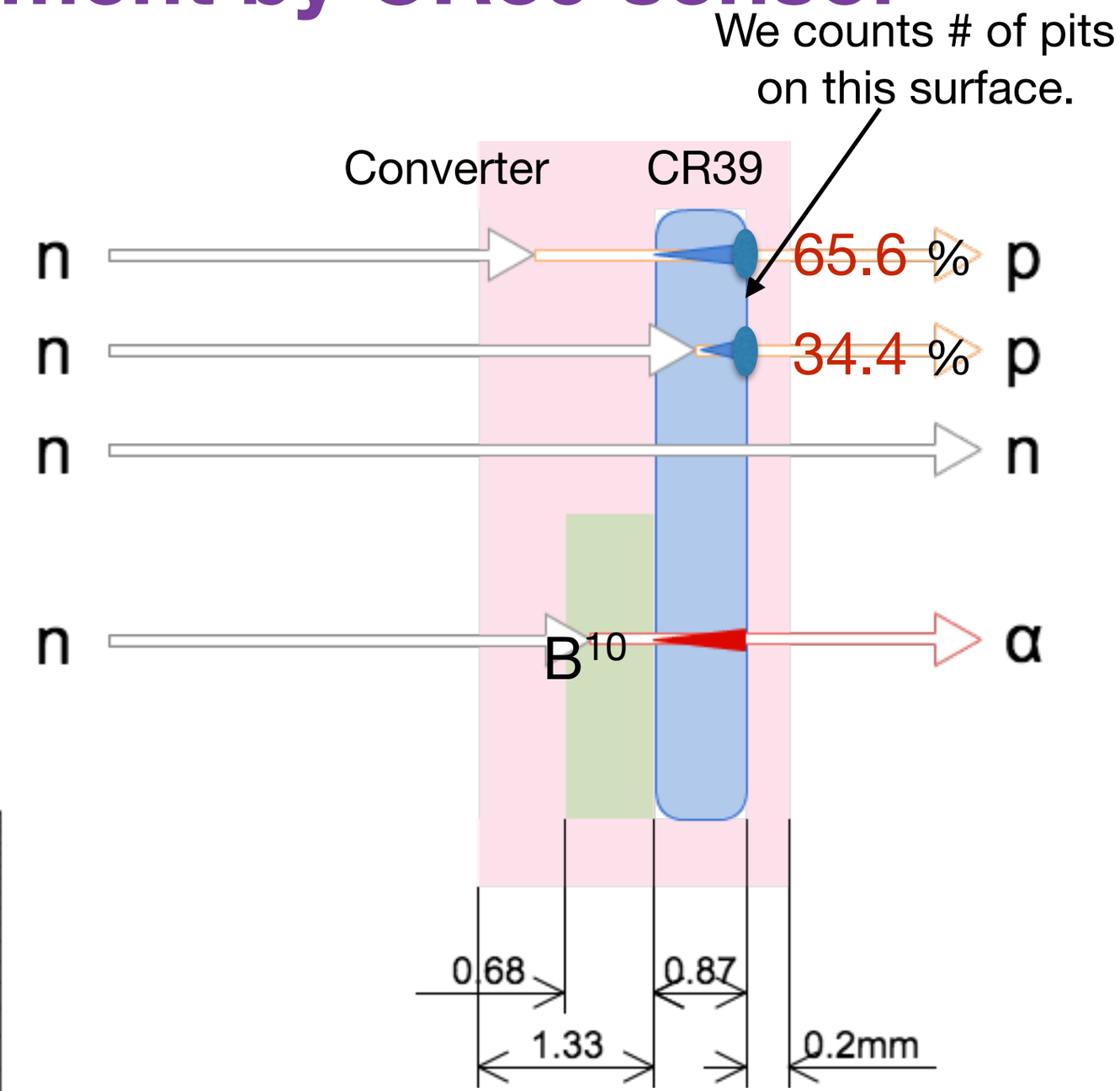
Thanks to Mr. Ochi(Kobe) and Mr. Ueno(KEK)

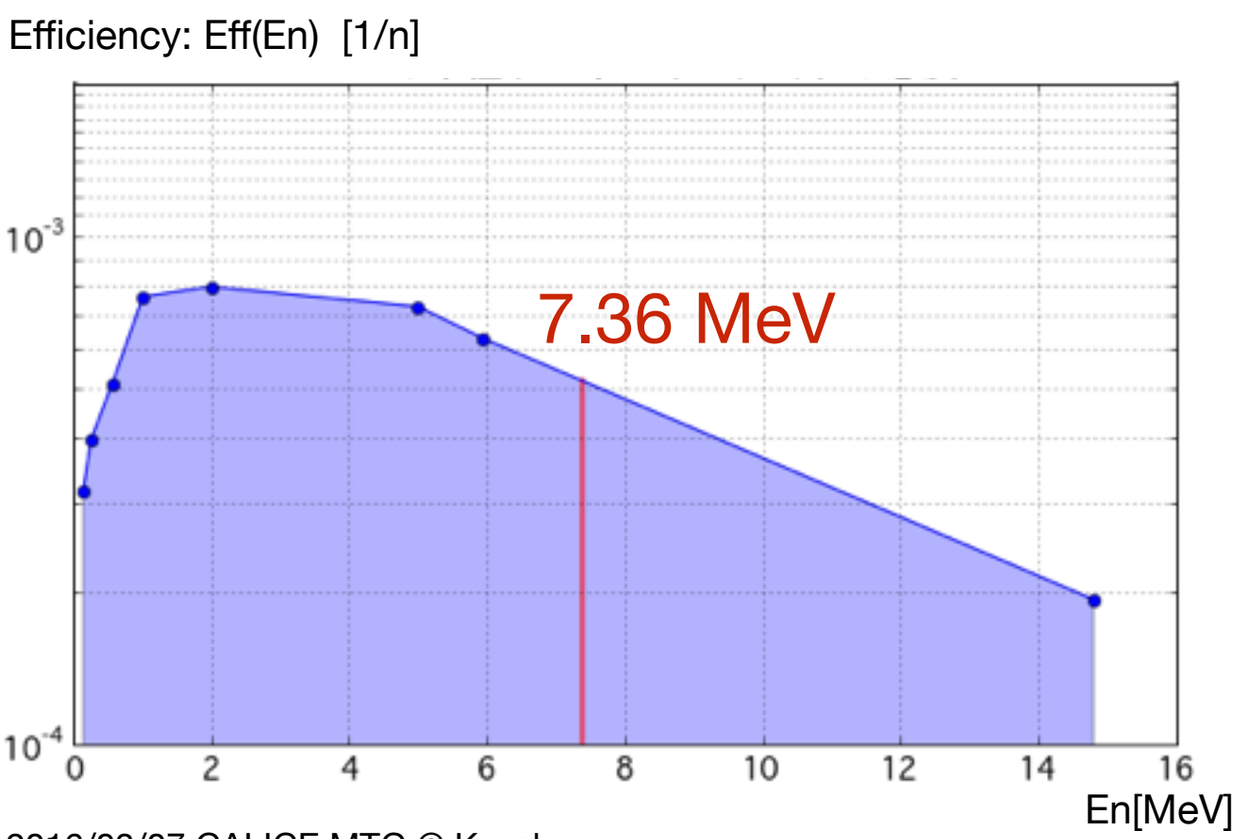


$E_{n,max}$ = **7.36** MeV

Neutron measurement by CR39 sensor

- Neutrons converted to protons, which damage CR39.
- The probability of detecting fast neutron is 10^{-4}.
- We know CR39 sensor's energy sensitivity in range 0.145~14.8 MeV.

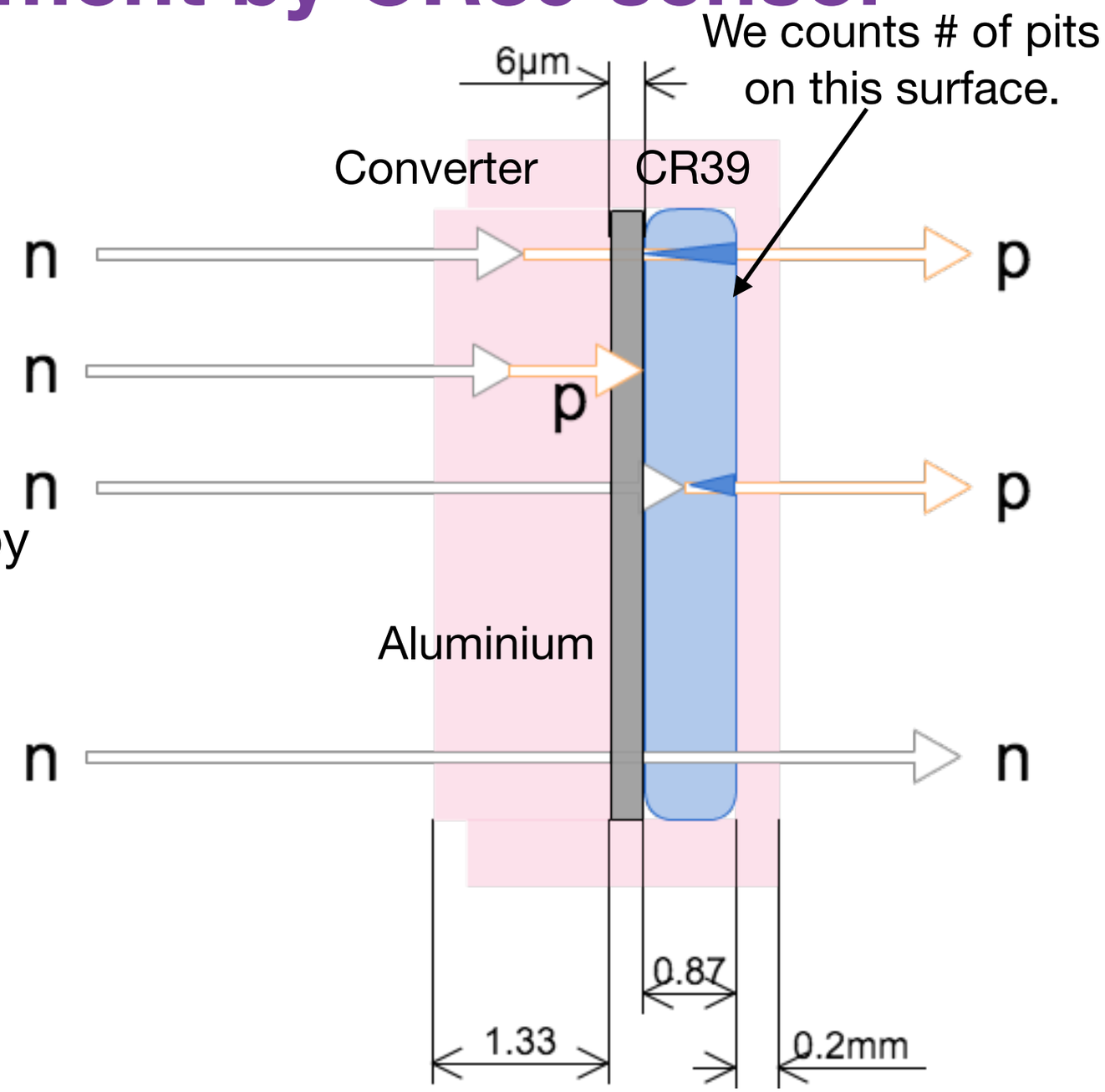


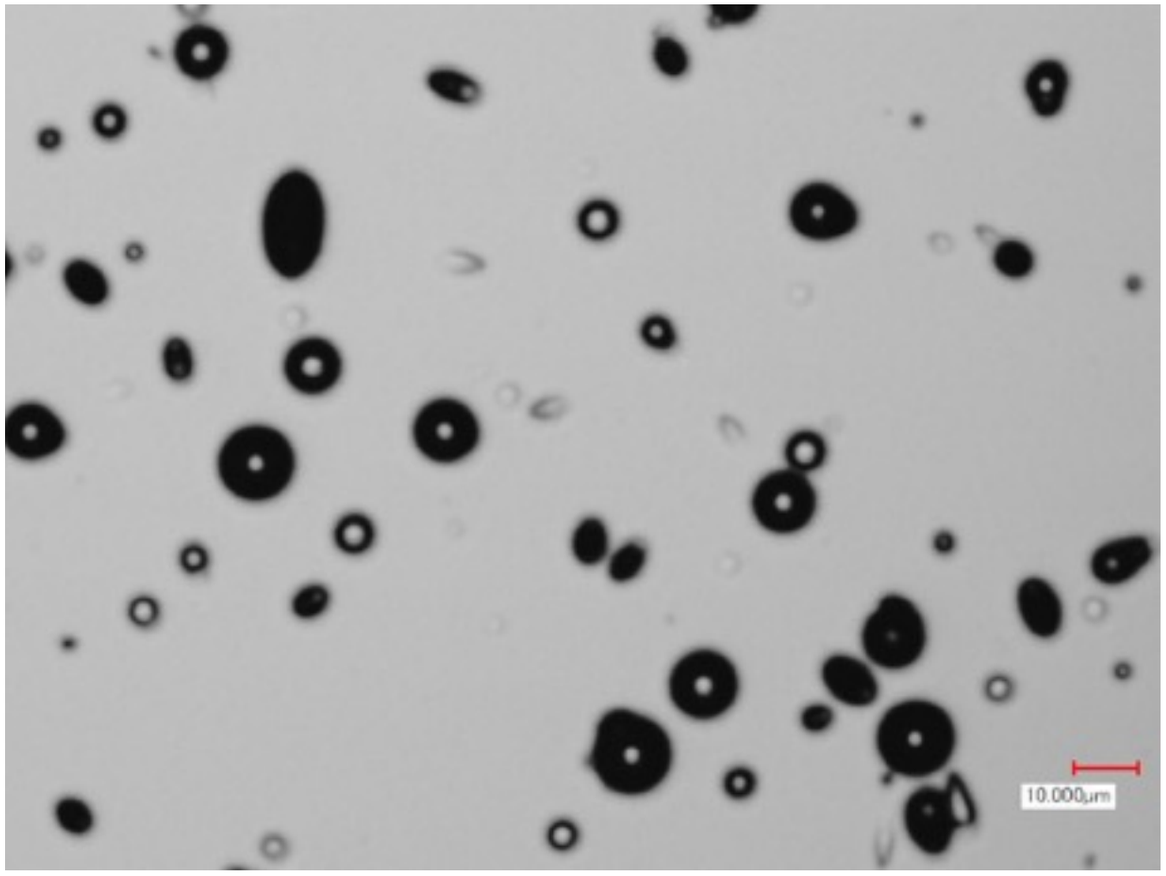


Calibrated by mono-energetic neutron in CYRIC(Tohoku)

Neutron measurement by CR39 sensor

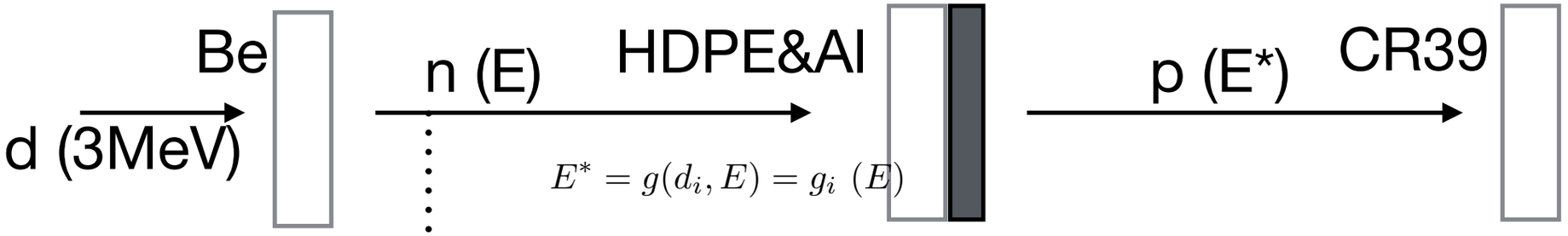
- By using different thickness of aluminium, converted protons were selected on energy threshold.
- Aluminium samples are 6, 24, 72, 204 μm.
- The pits on **CR39 sensor** are counted by eye. (9mm^2 area)



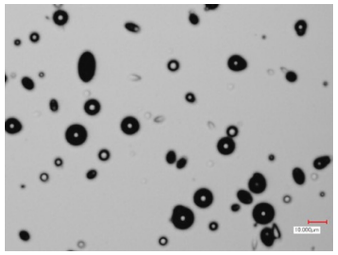


Neutron Energy Distribution

We counts # of pits on this surface.



$$E^* = g(d_i, E) = g_i\ (E)$$

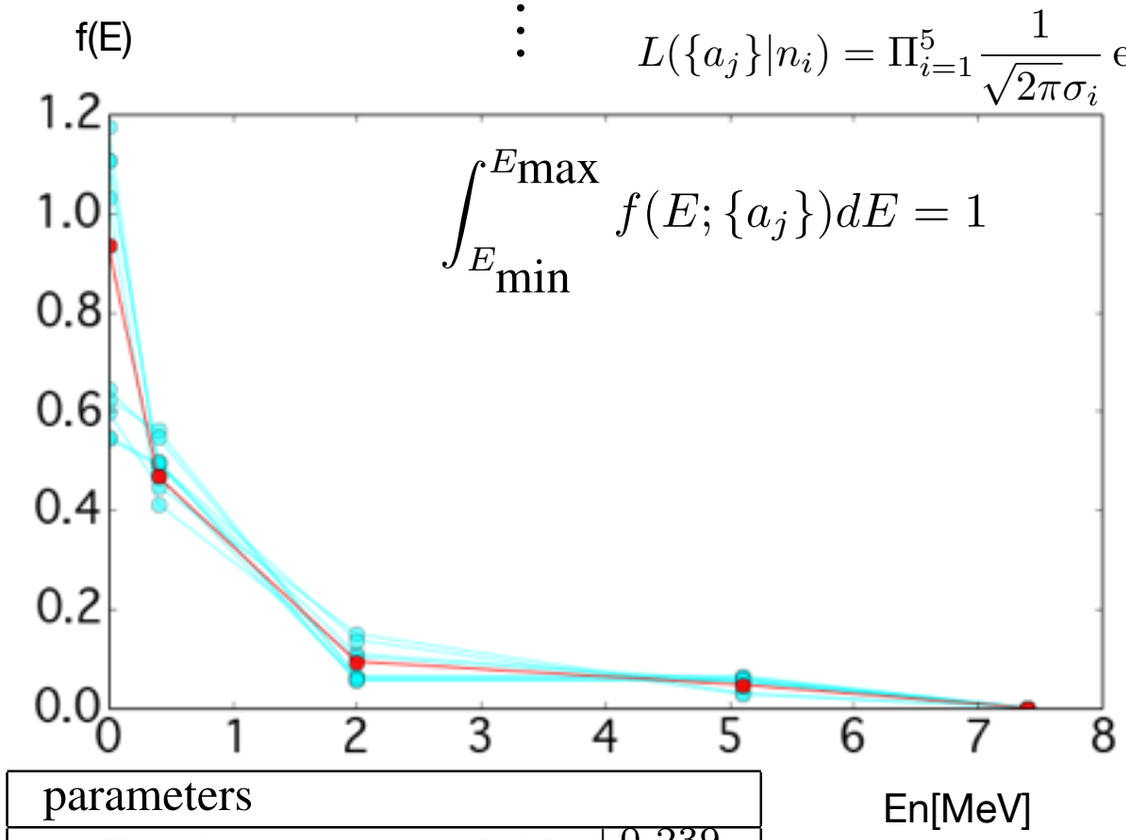


x_i [pit/μC/cm^2]

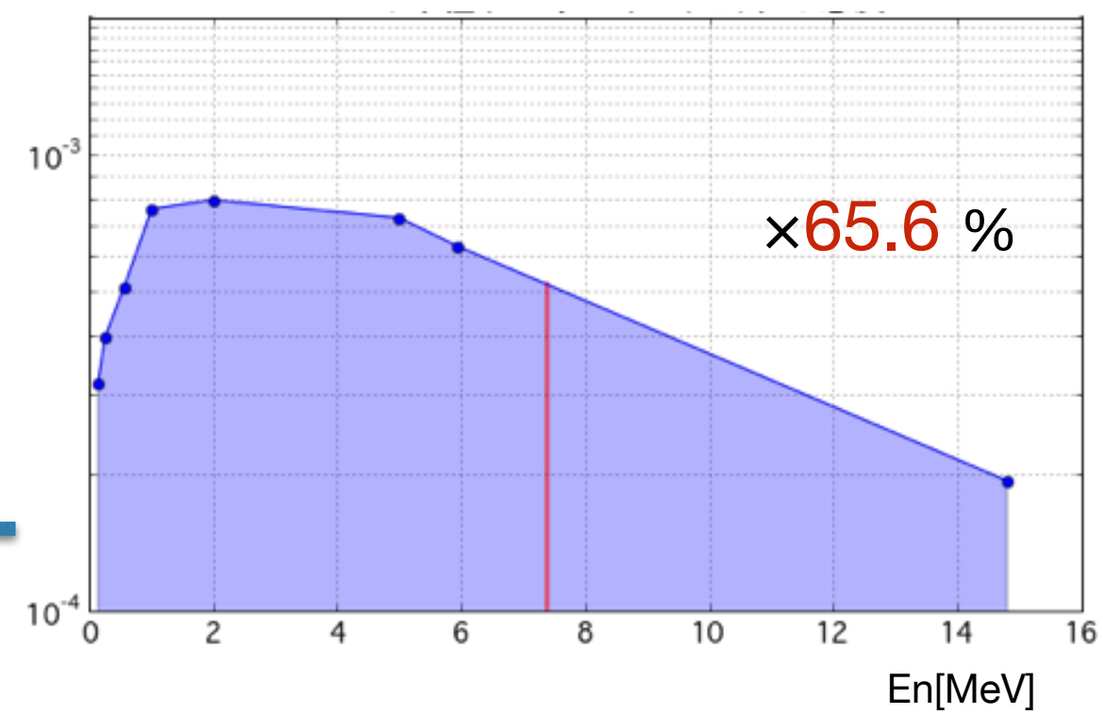
pits: $\mu_i(\{a_j\}) = \int \mathrm{Eff}(g_i(E))\ f(E;\{a_j\})\ \alpha\ dE$

$$L(\{a_j\}|n_i) = \Pi_{i=1}^{5} \frac{1}{\sqrt{2\pi}\sigma_i} \exp\left[-\frac{(x_i-\mu_i)^2}{2\sigma_i^2}\right]$$

Efficiency: Eff(En) [1/n]



$$\int_{E_{\min}}^{E_{\max}} f(E;\{a_j\})dE = 1$$



parameters	
a1(E = 0)	$0.934^{+0.239}_{-0.391}$
a2(E = 0.4)	$0.467^{+0.093}_{-0.055}$
a3(E = 2.0)	$0.093^{+0.056}_{-0.038}$
a4(E = 5.1)	$0.046^{+0.018}_{-0.019}$
a5(E = 7.36)	0
α	$(1.19^{+0.12}_{-0.15}) \cdot 10^6$
χ^2	2.217

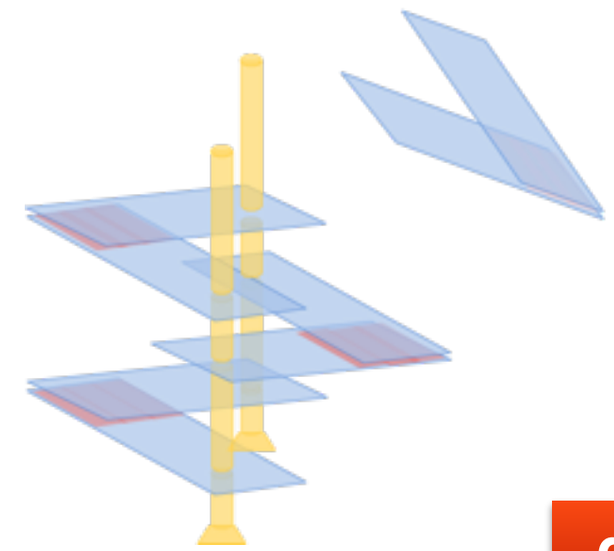
- Red line is optimised by likelihood function.

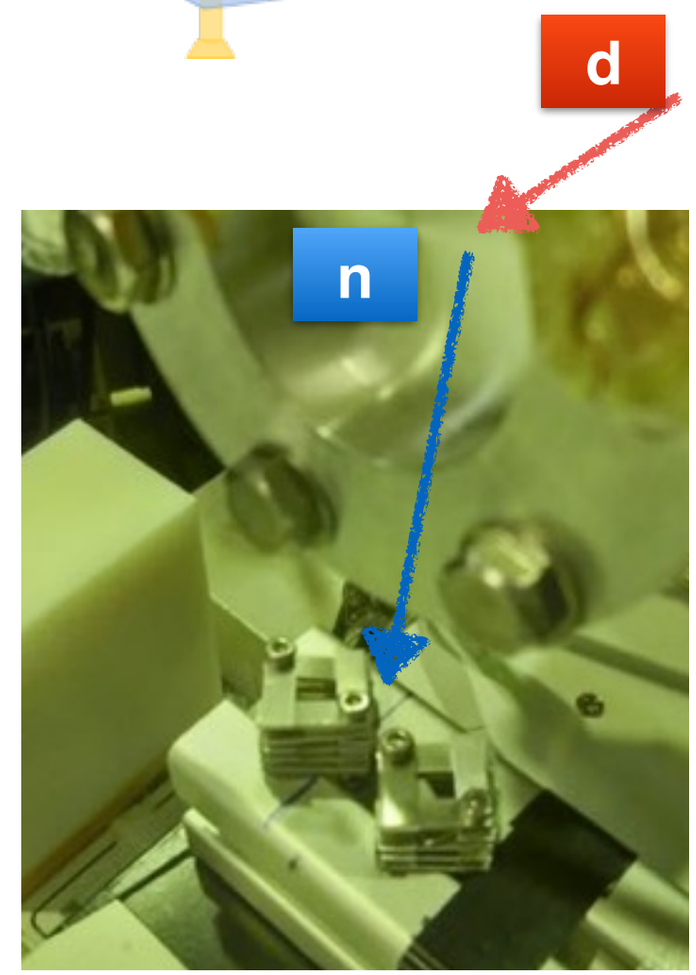
$$\chi^2/4 = 0.556 \quad \mathrm{SL} = 68\%$$

- Blue lines are satisfied with $\chi^2 = \chi^2_{\min} + 1$, which means 1σμ

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.





Recommended properties

	E4110	E4110-LV
23°C	×	×
40°C	✓	✓
60°C	✓	✓✓

Irradiation dose

sample	N_n n/cm^2
E4110	3.9E+09
E4110	5.3E+10
E4110	1.1E+12
E4110LV	3.9E+09
E4110LV	1.9E+11
E4110LV	1.1E+12

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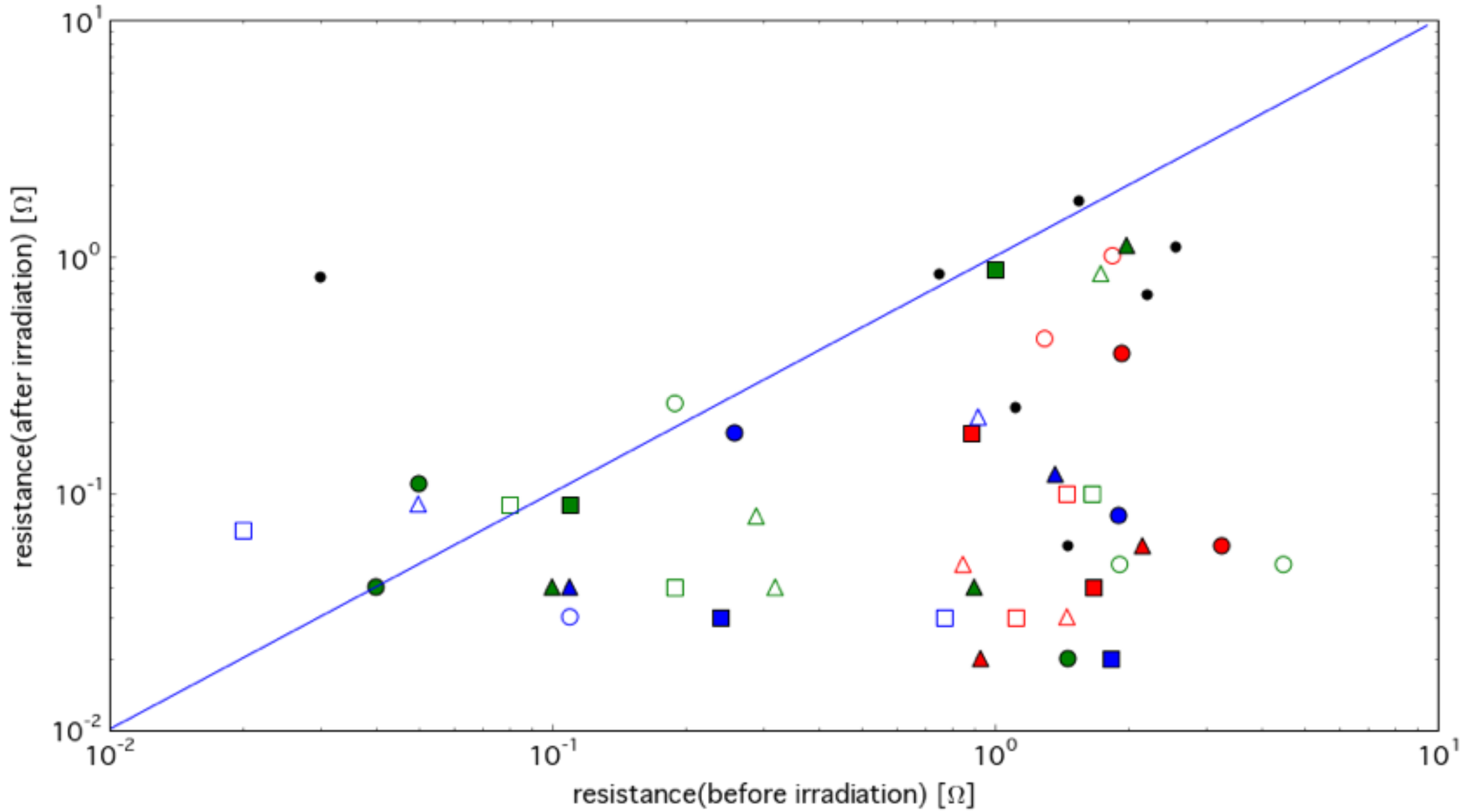
Resistance of Glue Samples

• 23°C • 40°C • 60°C

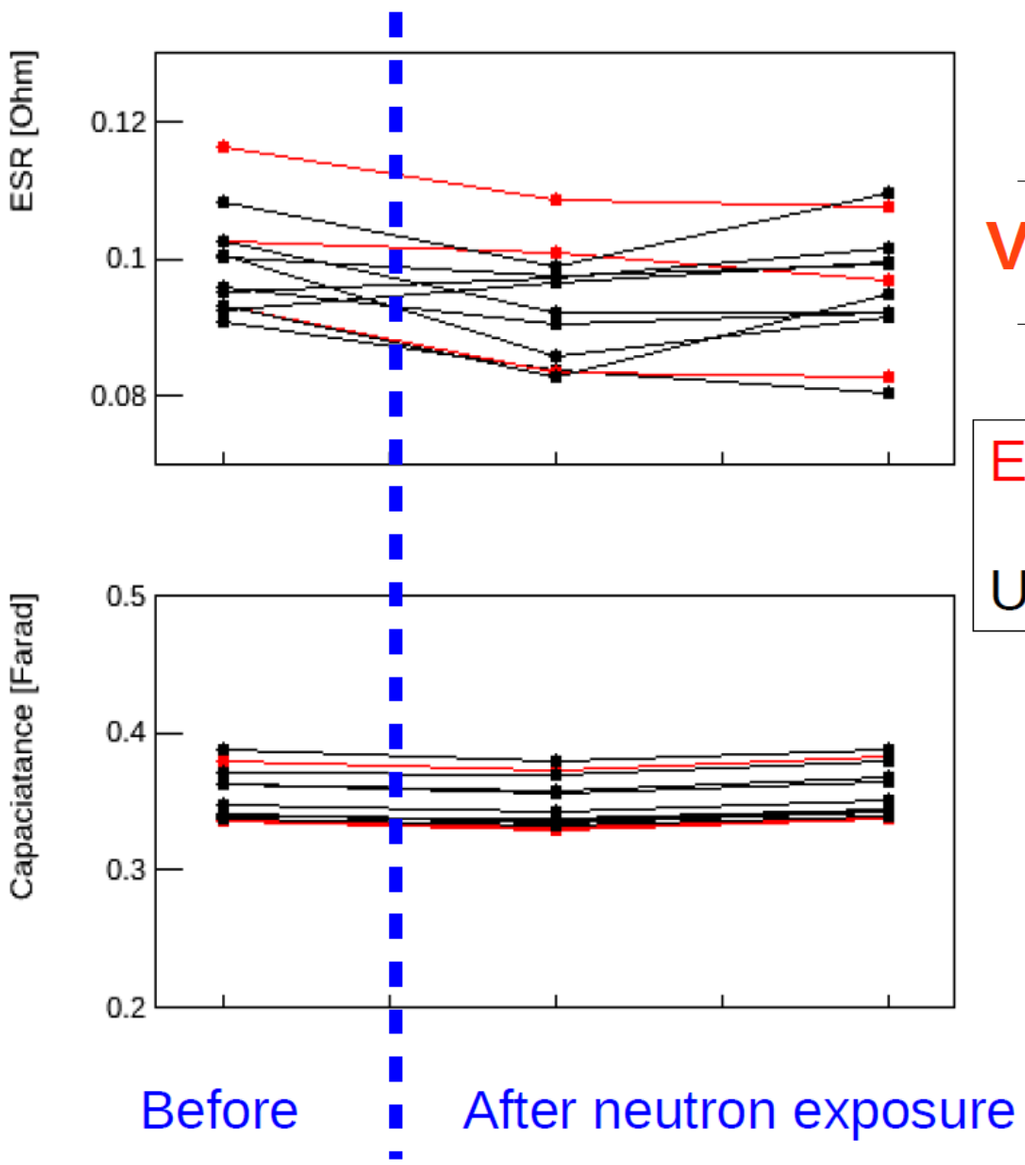
•**control** ◯ 10^9 n/cm^2 △ 10^{10} n/cm^2 ▫ 10^{12} n/cm^2

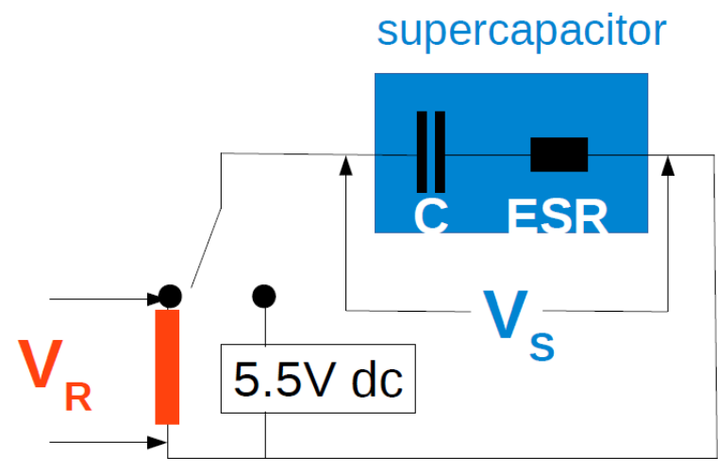


- couldn't understand big difference of resistance before irradiation.
- Every recipes has no sign of radiation damage up to around **10^{12}** n(1-MeV)/cm^2**.**

Thanks to
Kozakai-san

Super capacitor



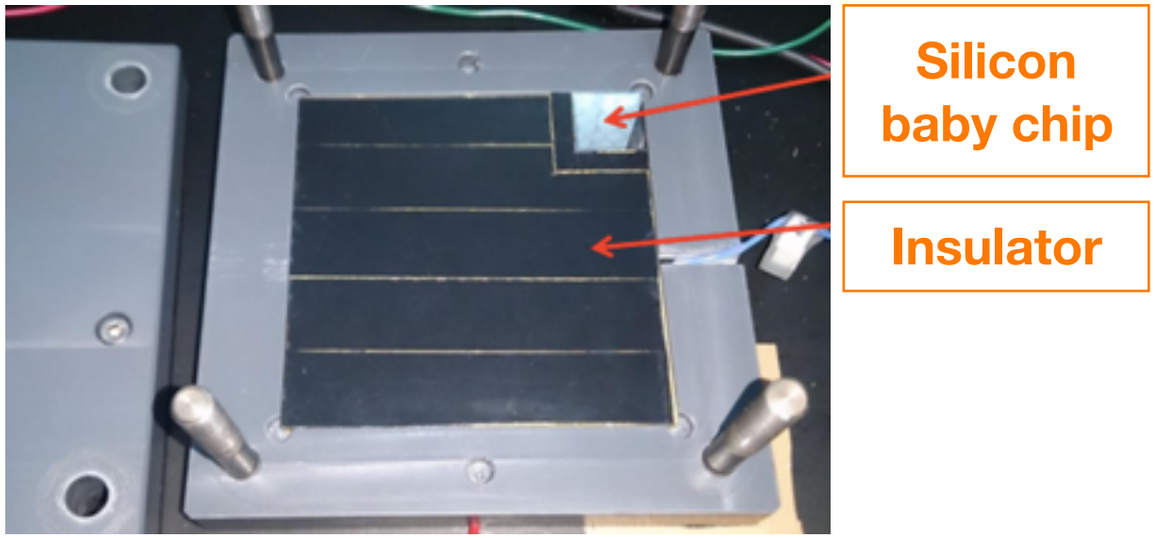


Exposed samples
Un-exposed

Super capacitor has radiation resistivity against $2.1 \cdot 10^{12}$ n/cm^2

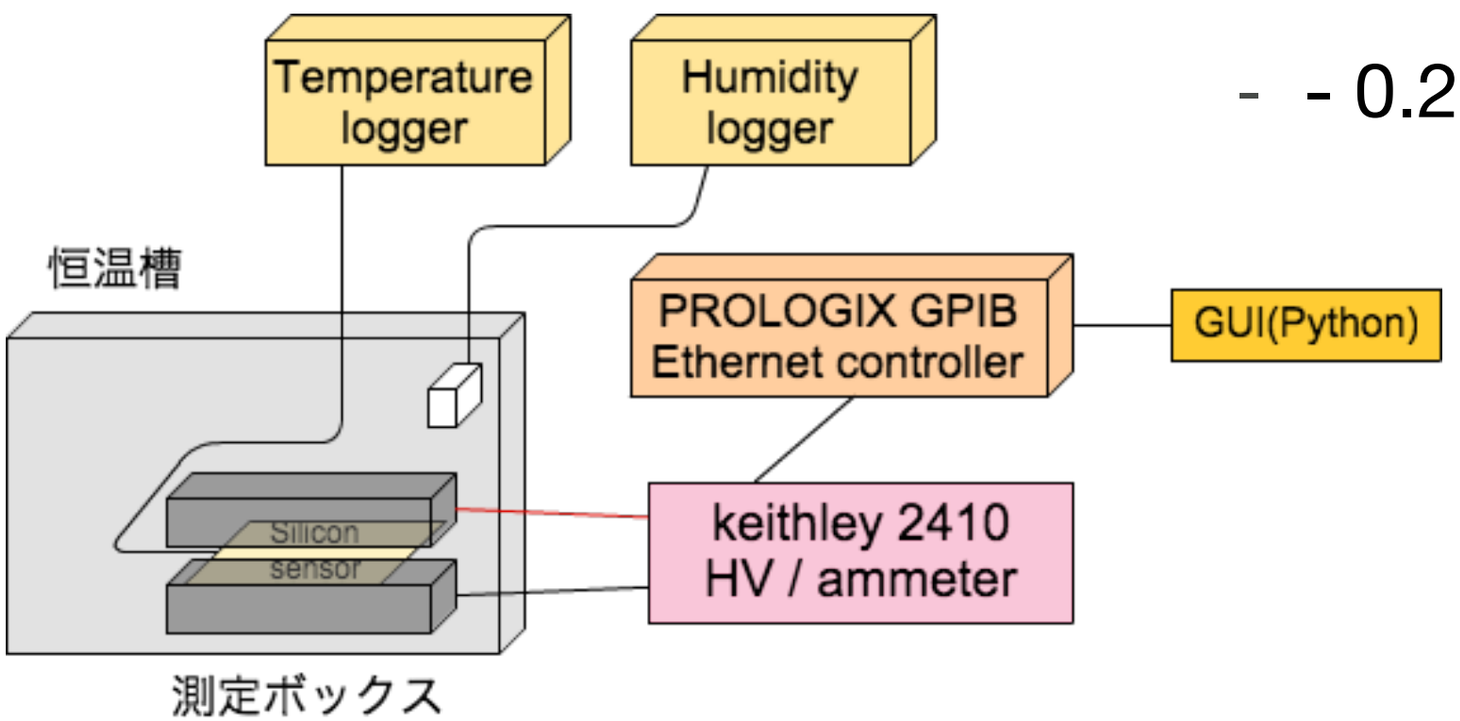
Current-Voltage characteristics

Checked increase of dark current before and after irradiation.



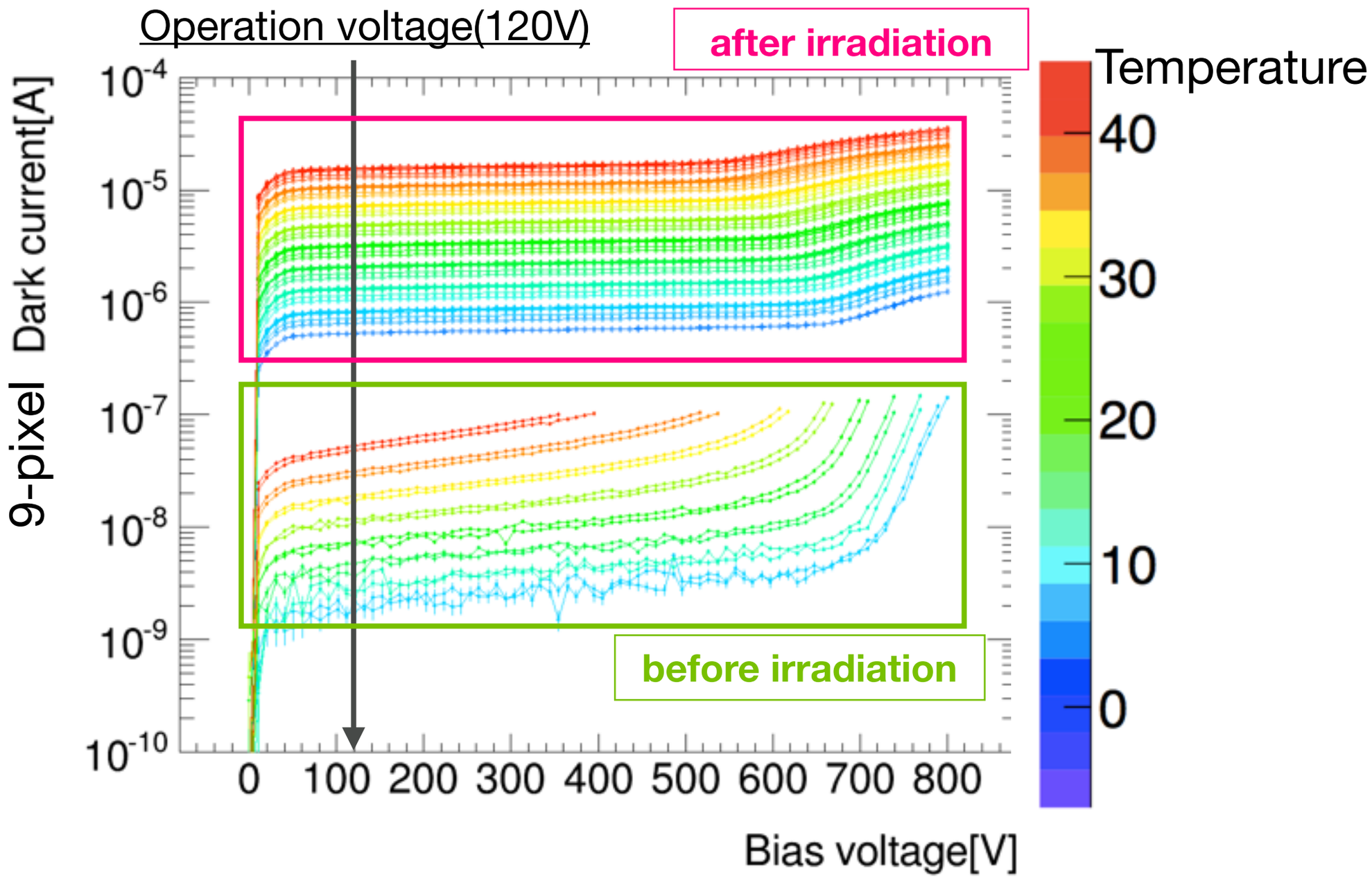
controlled voltage and temperature

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



Current-Voltage characteristics

- Large increase in dark current

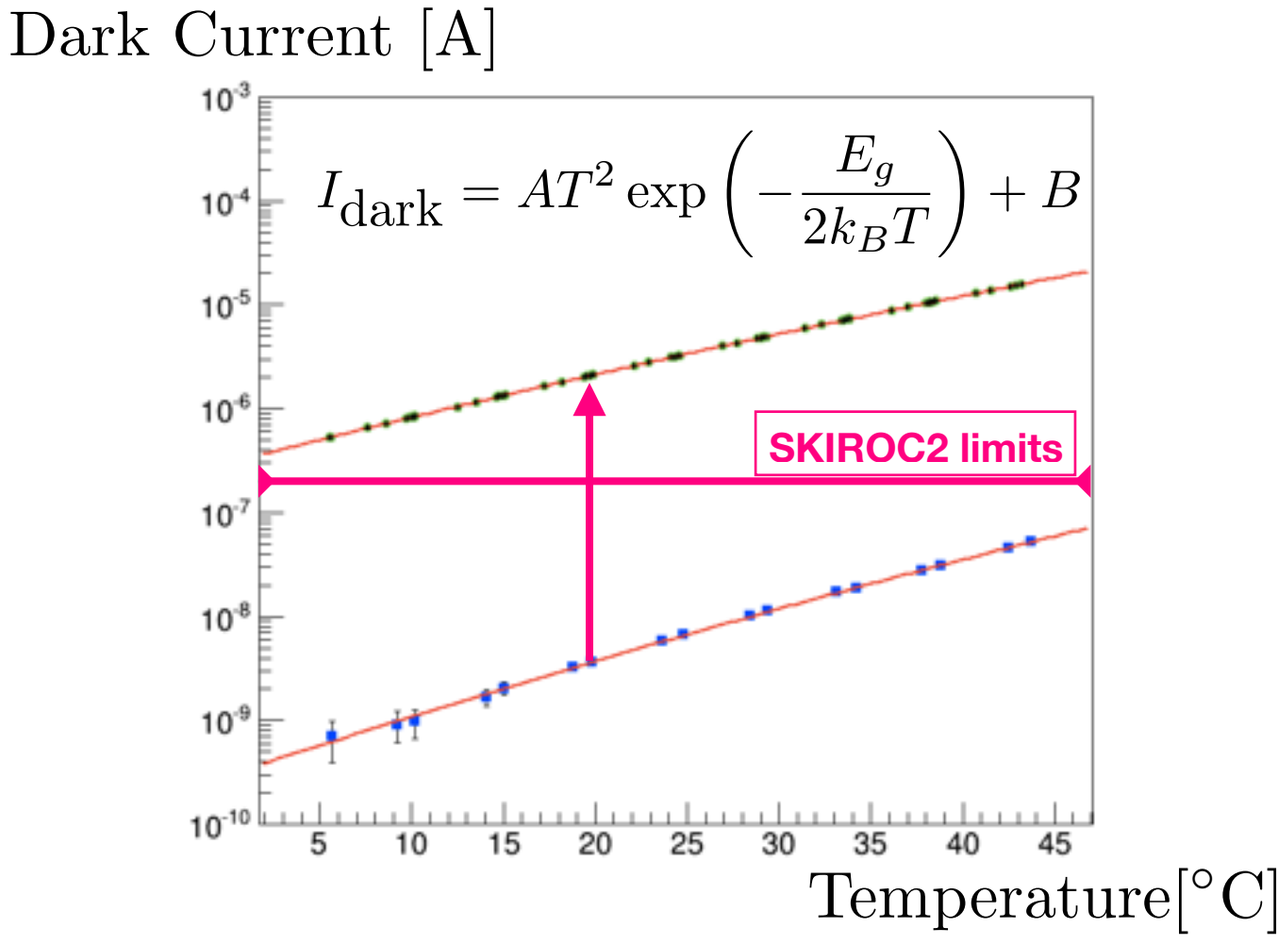


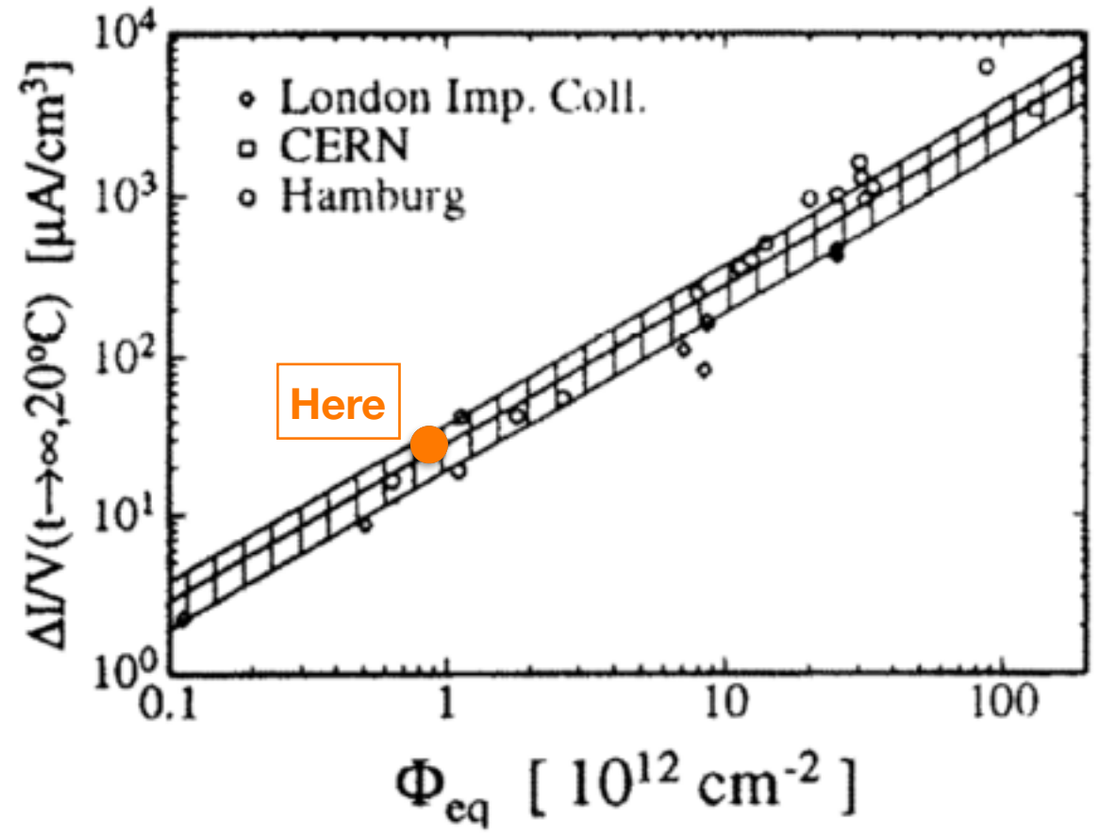
breakdown voltage

dark current @ operation voltage

Current-Temperature characteristics at 120 V

- measured temperature dependency of dark current at 120 V a long time after irradiation.





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

about 2μA increase @ 20°C

$$2\mu\mathrm{A}/(1.5\mathrm{cm} \times 1.5\mathrm{cm} \times 300\mu\mathrm{m}) = 30\mu\mathrm{A/cm}^3$$

equivalent neutron flux is around **9.2×10^{11} n(1-MeV)/cm^2**

Conclusion

- consistent with previous experiment.
- dark current reaches SKIROC2 design limit after **30 - 60 years**.

Conclusions

- Based on expected radiation dose on ILD ECAL,
  ECAL components are irradiated with neutrons.
- Neutron dose was measured using CR39 sensor. (still preliminary)
- Both **super capacitor** and **2 conductive glues** with several cooking recipes had also been tested up to around **10^{12} n(1-MeV)/cm^2. (100 years)**
- No significant degradation was seen for them and we can safely use them for the ILC project.
- As silicon, IV properties are significantly changed by irradiation.
  Our results is consistent with previous data.
- Silicon dark current expected to exceed **SKIROC2 design limit**,
  after **30 - 60 years of 1 TeV ILC** in inner part of ECAL endcap.

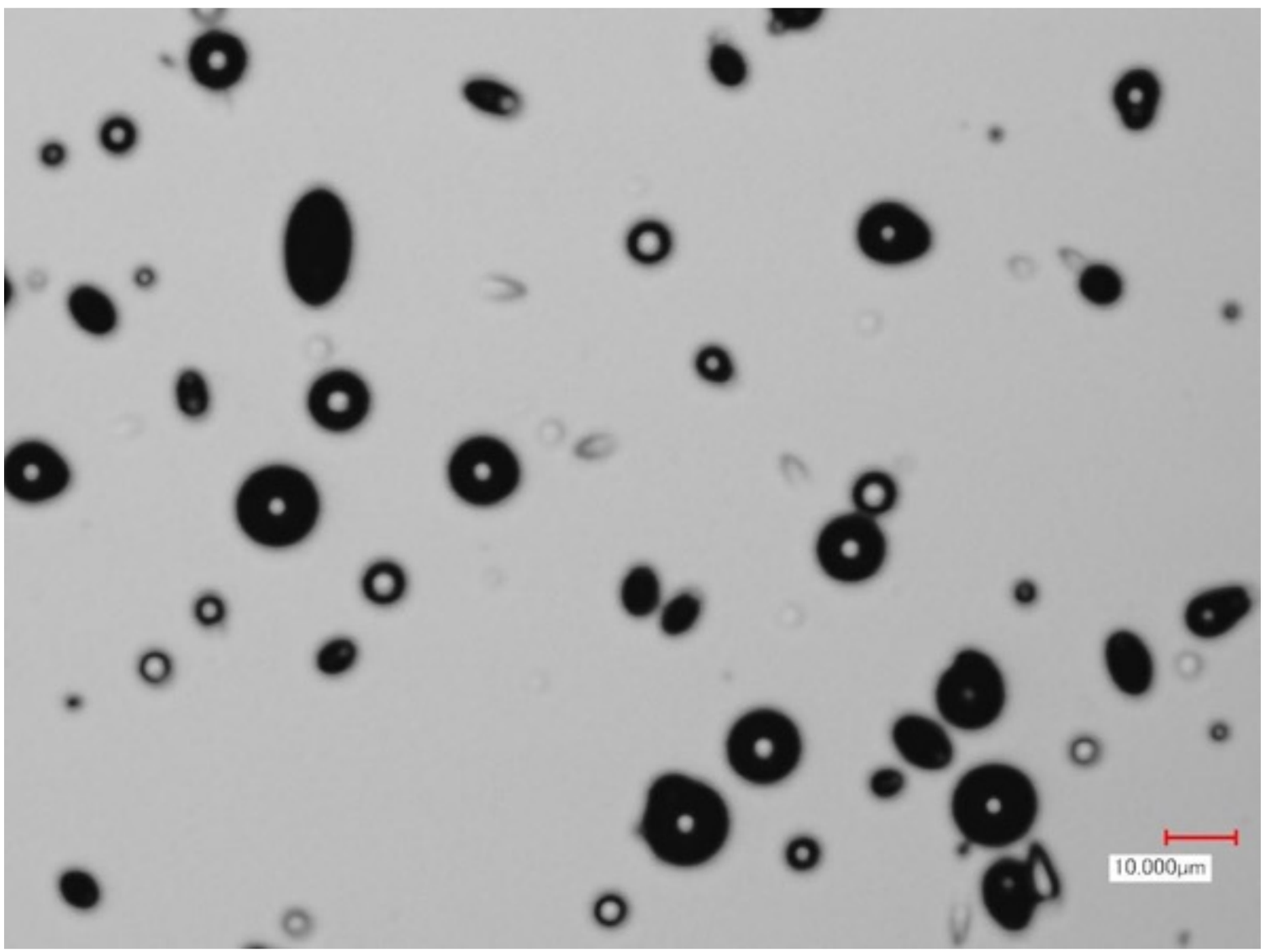
BackUp

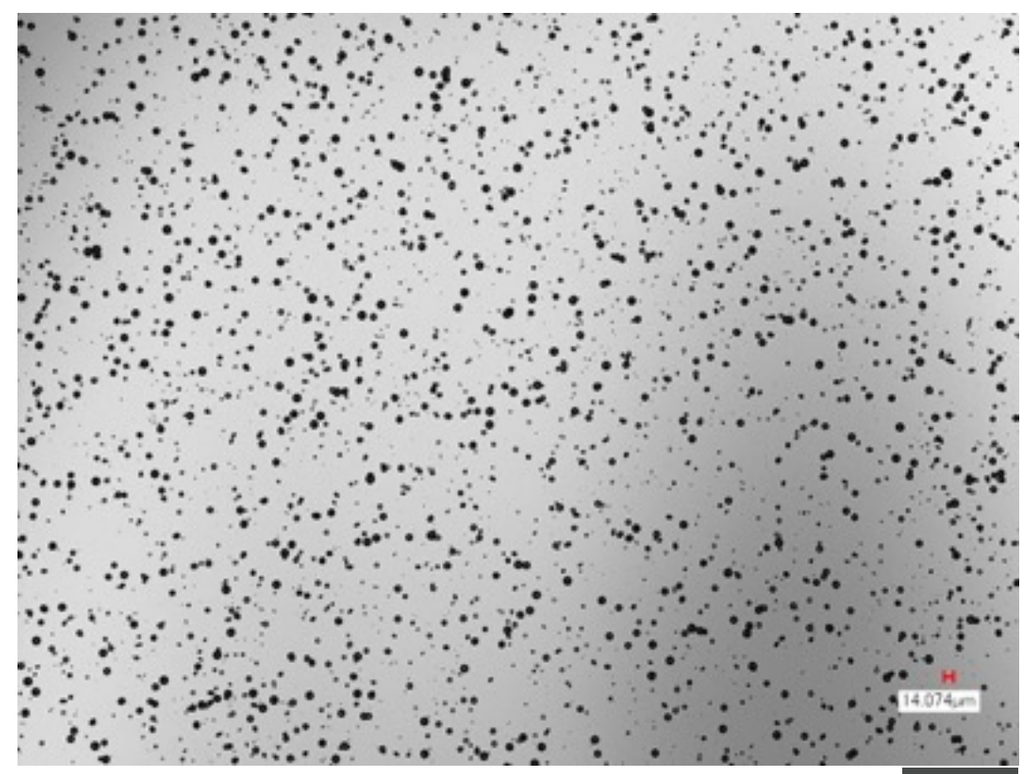
Hitoshi Nakanishi

December 9 , 2015

CR39 sensor pit count

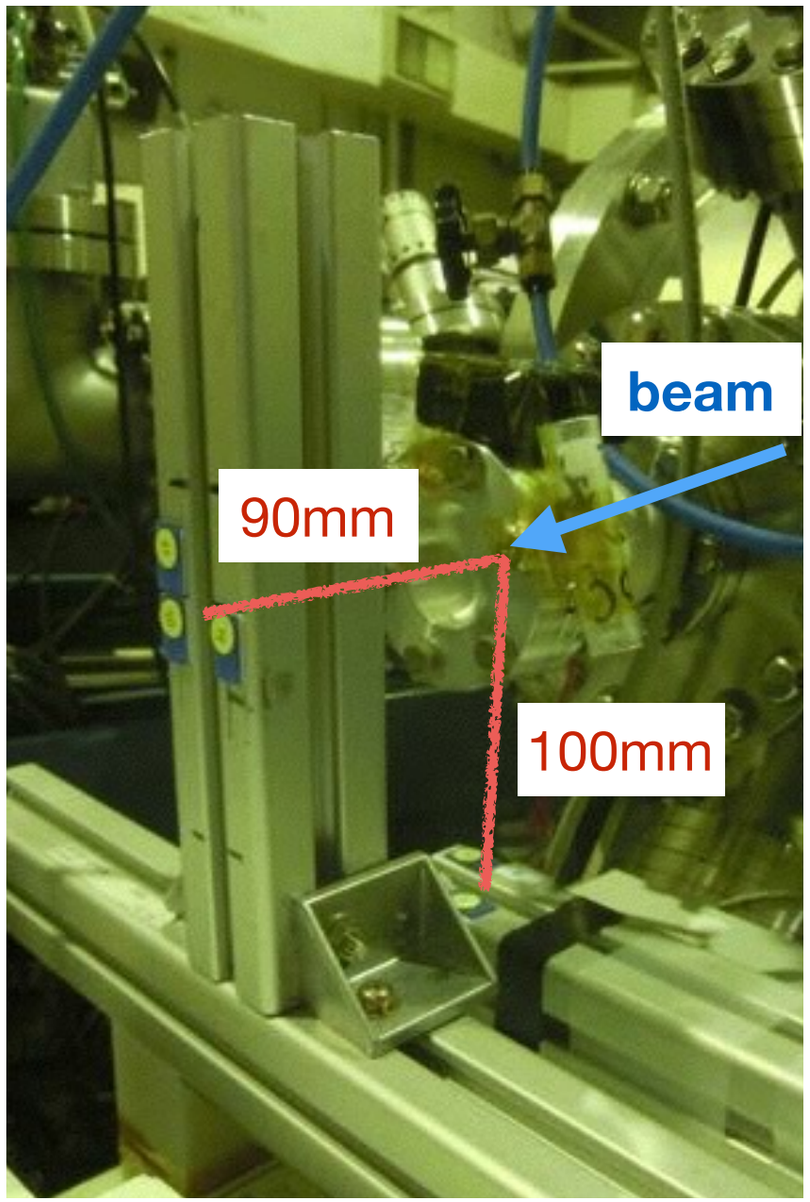
- The Landaua inc. evaluated neutron counts.
  - chemical edging by NaOH 10 [mol/L] 70°C, 6h
    - pit size is extended to10 μm.
  - The pits on **CR39 sensor** are counted by eye. (9mm^2 area)

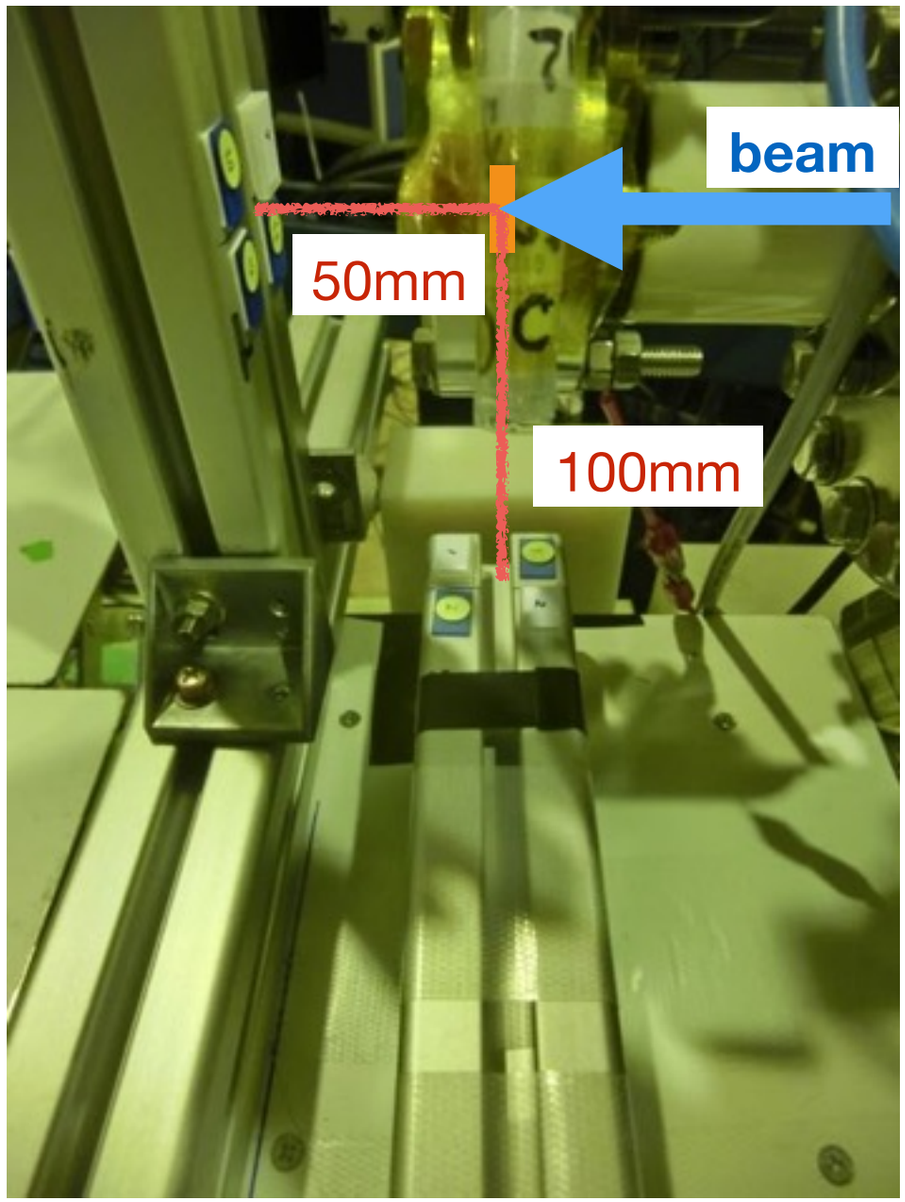




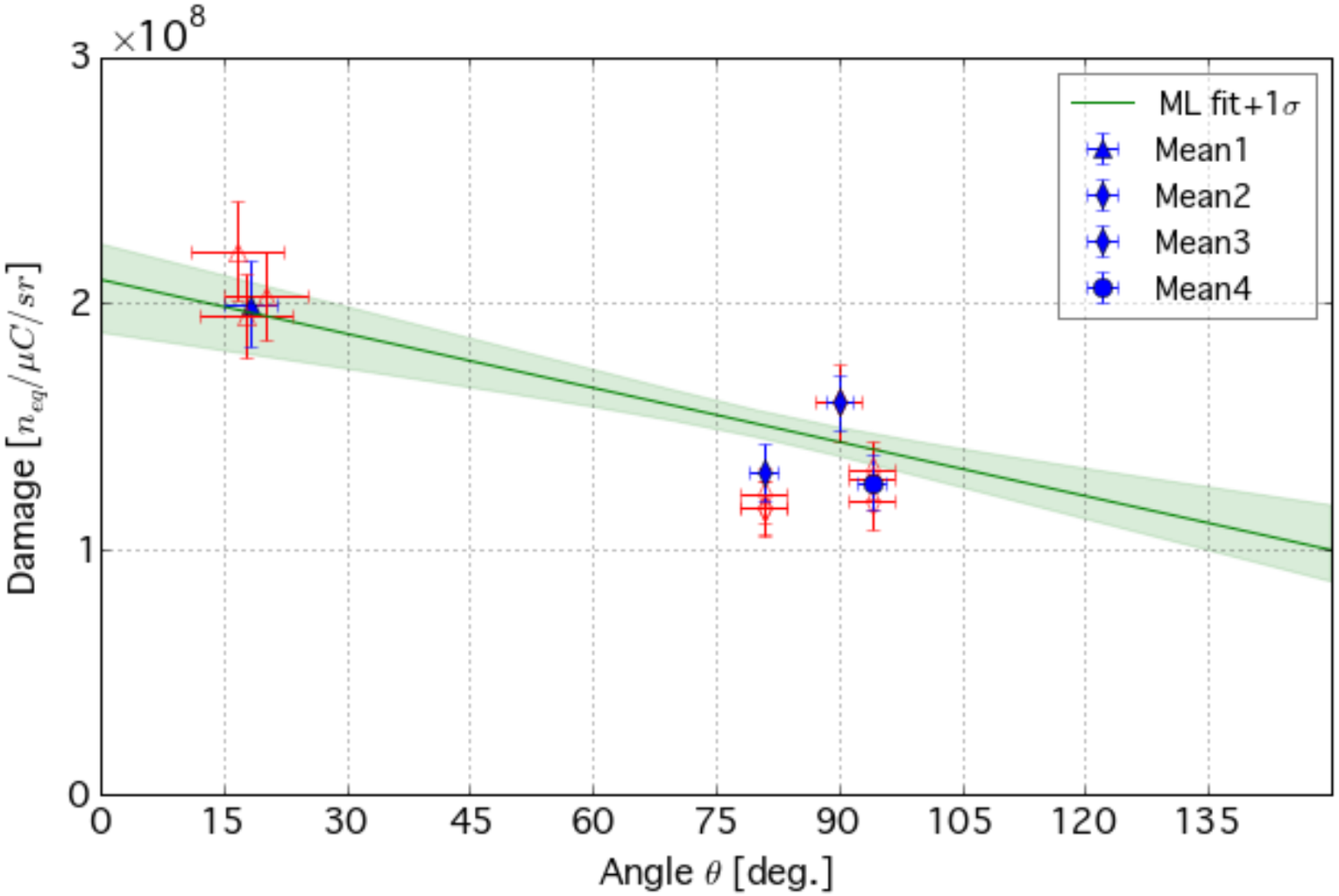
Neutron measurement by CR39 sensor

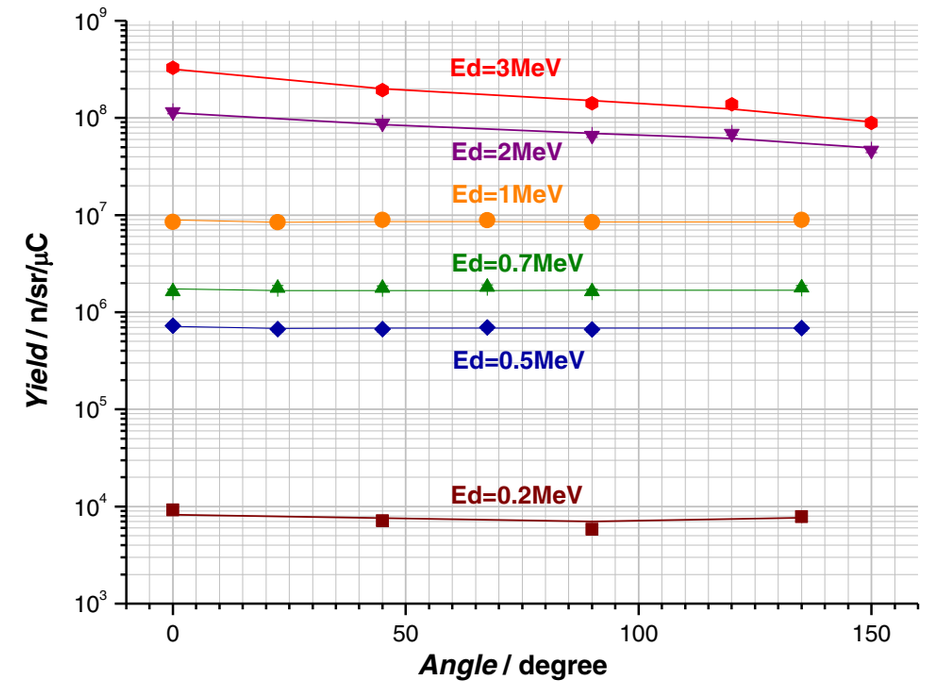
- **20 CR39 sensors**
- Fixed by Aluminium frame
- Position = Irradiation position of glue samples





Angular distribution of Neutron dose

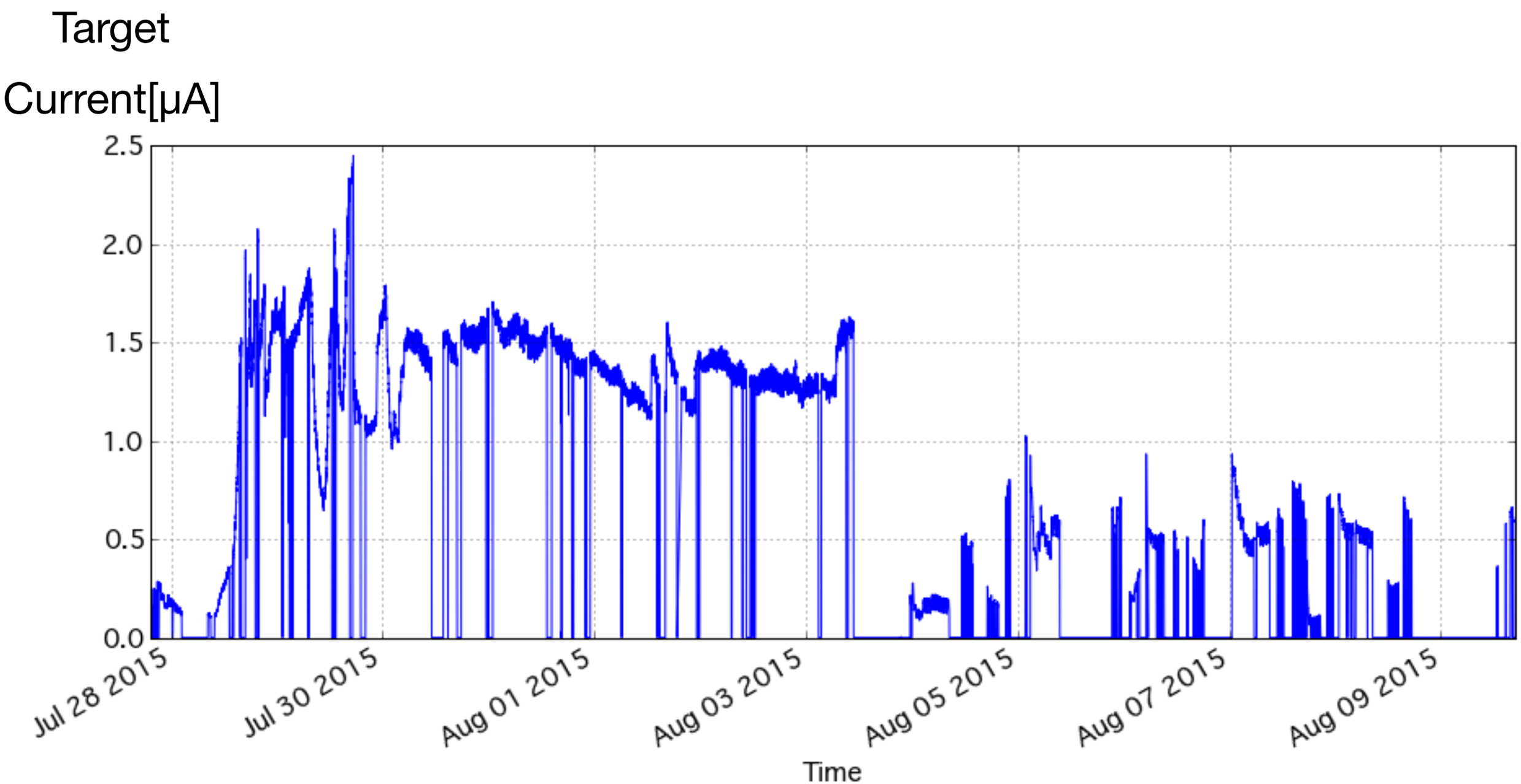




Yubin Zuo et al. / Physics Procedia 60 (2014) 220 – 227

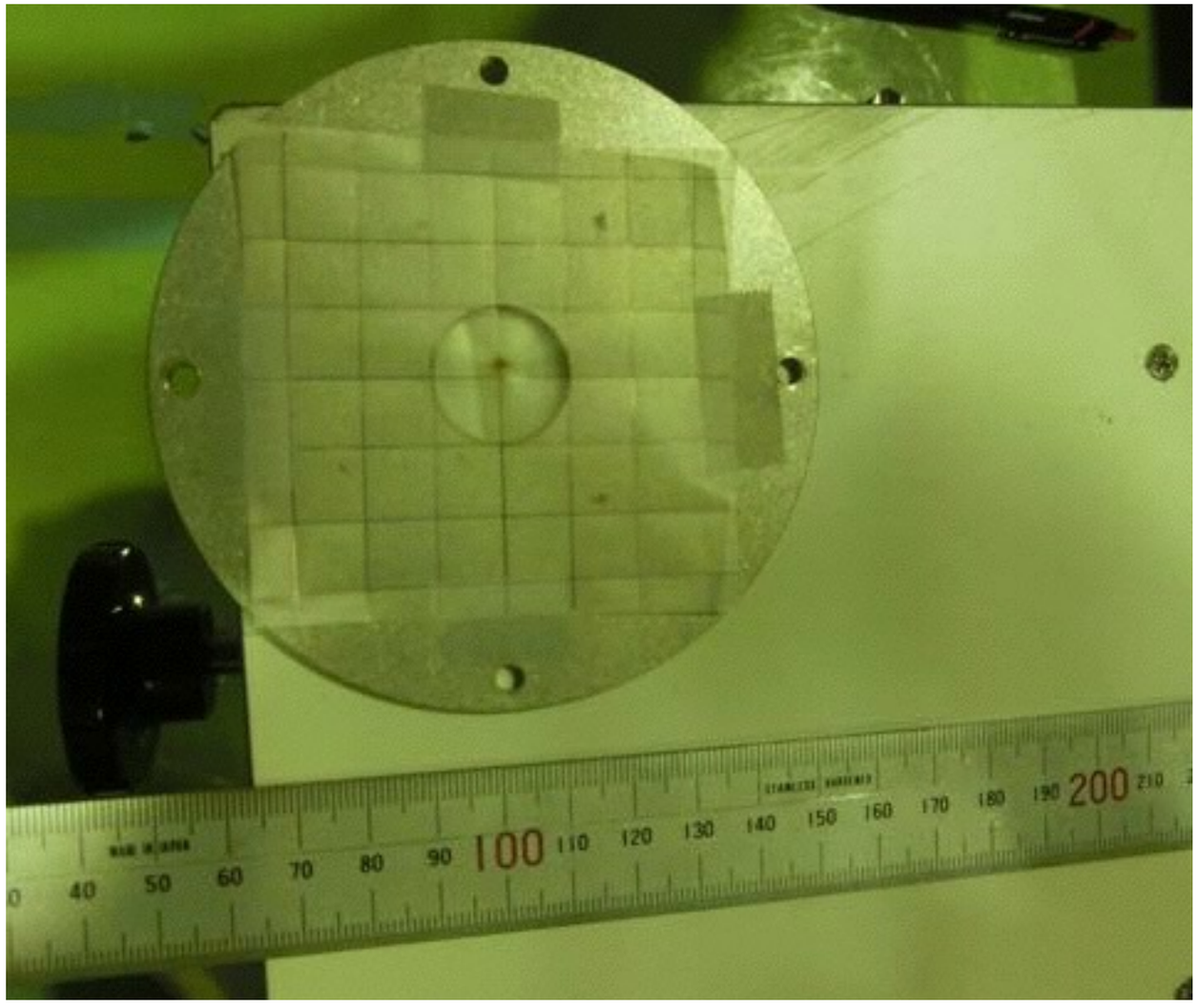
- Red points are measured data, and blue points are mean at each position.
- Straight line are assumed.
- Green line are optimised by ML methods and green band is 1σ.
- Damage function were convoluted. $\int D(E)f(E)dE = 0.873^{+0.026}_{-0.029(stat.)} \quad [n_{\text{1-MeV},eq}/n]$

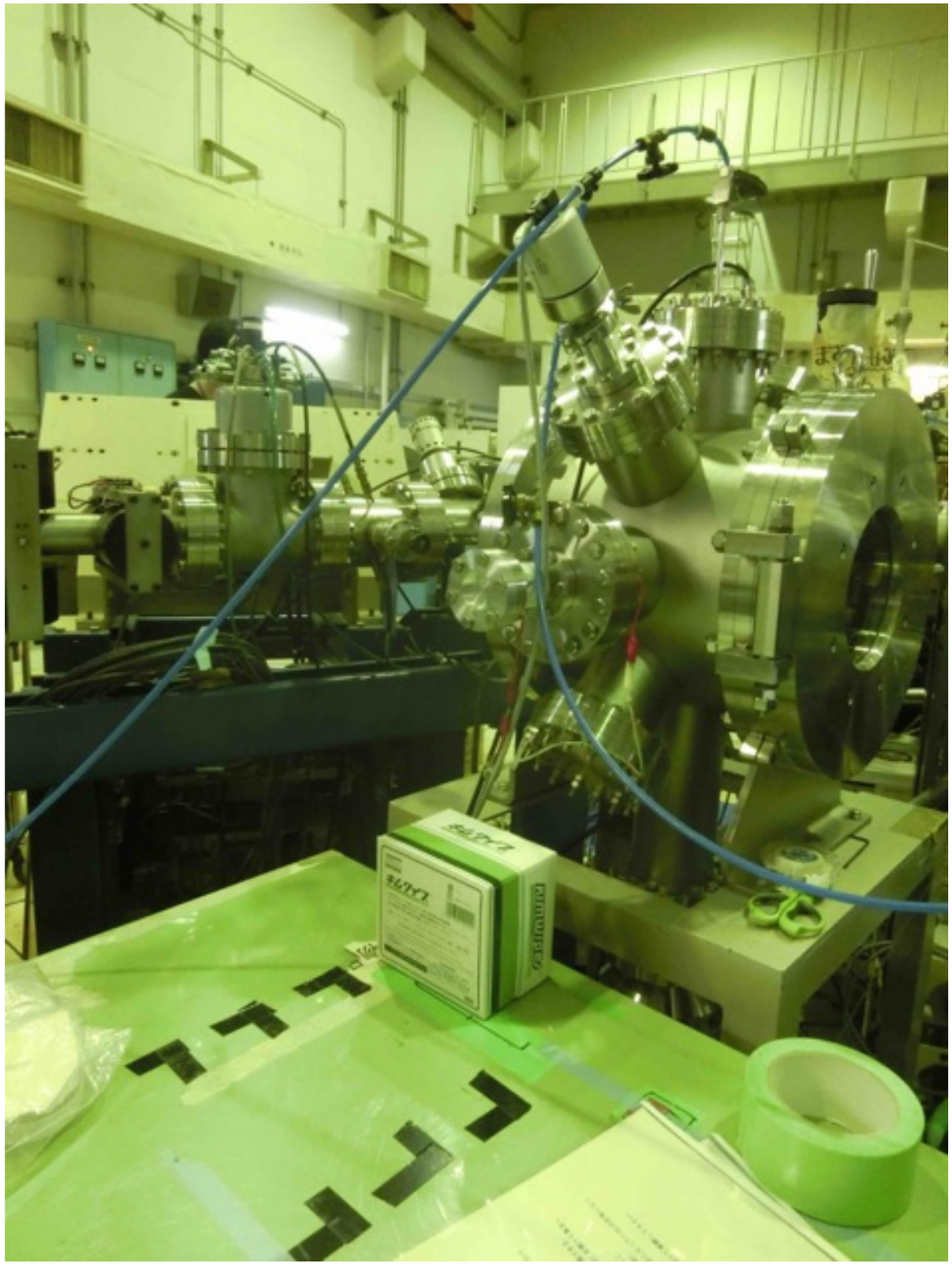
Beam Run: 7/27(Mon) ~ 8/9(Sun)



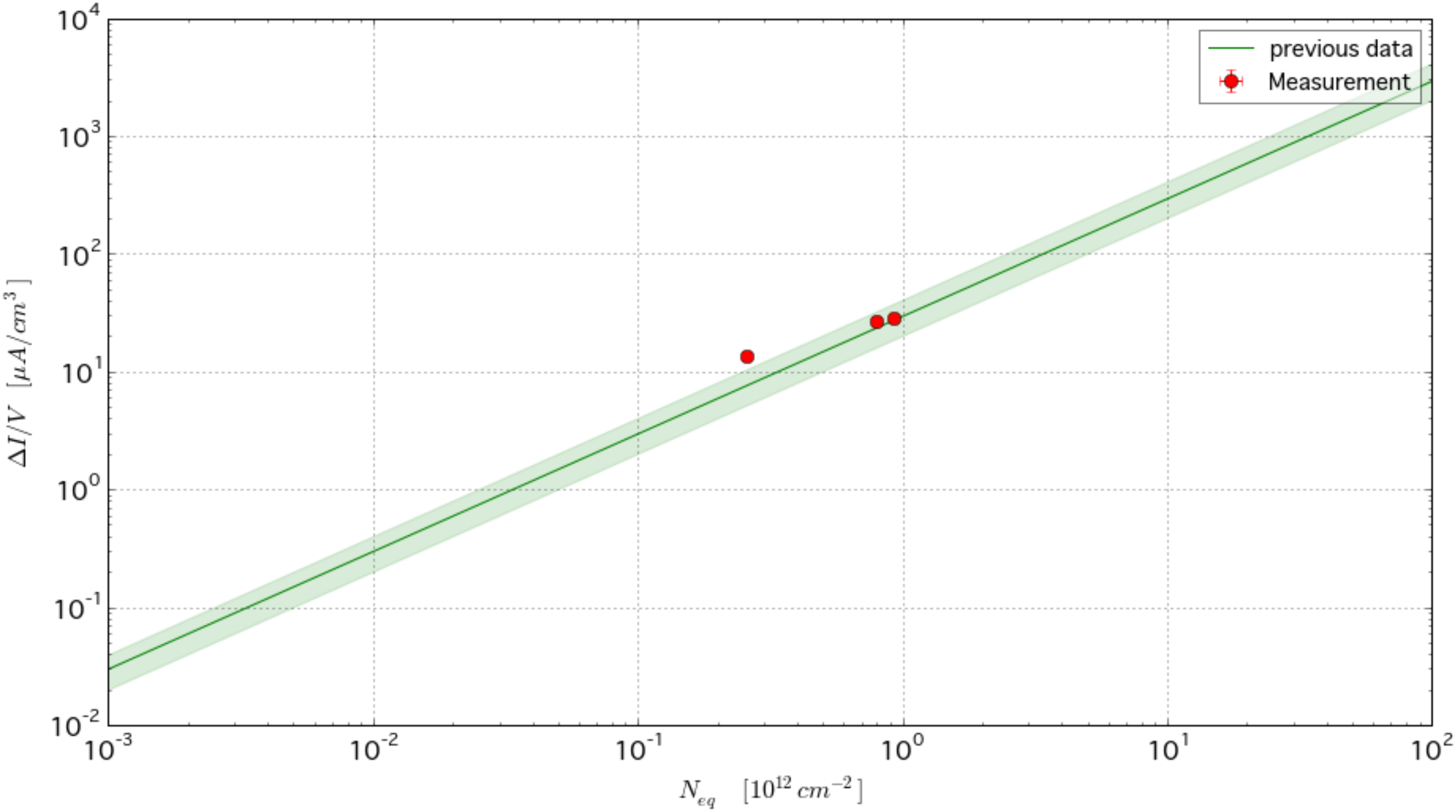
Neutron irradiation experiment (7/27)

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





Increase of leakage current and Neutron dose



- Red points are datum of irradiated silicon.
- 3 lines are drawn from previous data.