MEG II実験のための背景ガンマ線同定用陽電子カロリーメーターの実機製作とその評価

Development status of low momentum e^+calorimeter to identify BG gamma ray from radiative μ^+ decay in MEG II experiment

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Ryoto Iwai, on behalf of MEG II collaboration

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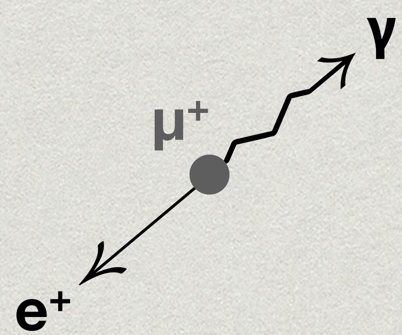
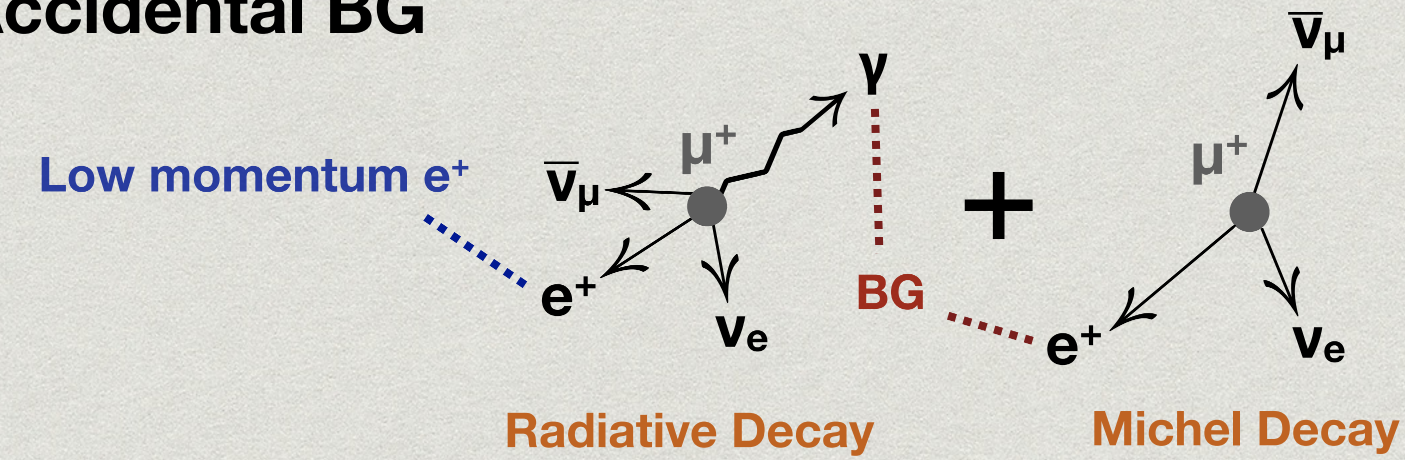
1. Introduction

- Accidental BG is the most dominant in $\mu^+ \to e^+\gamma$ search

Signal

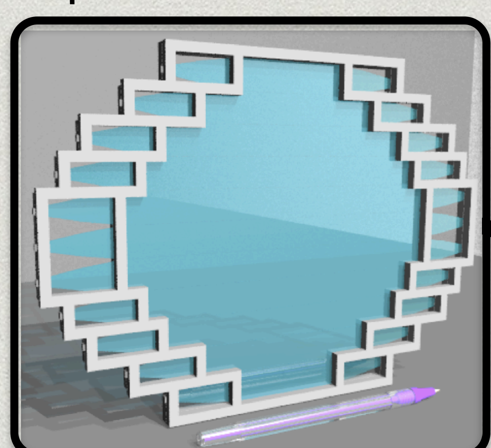


Accidental BG

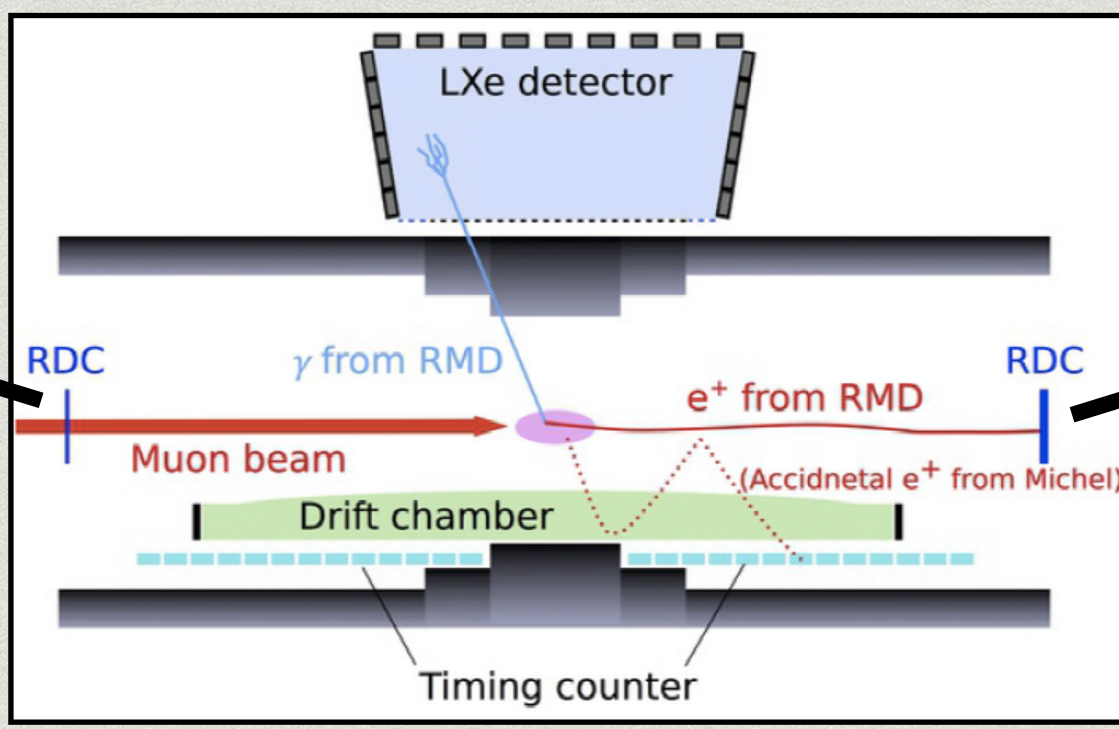


- RDC (Radiative Decay Counter) in MEG II experiment

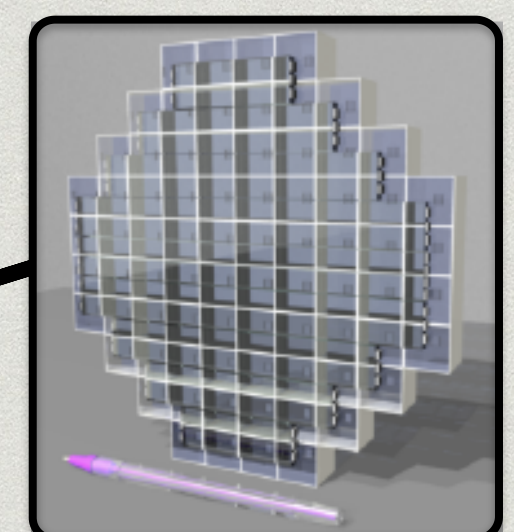
Upstream detector



Scintillation fibre



Downstream detector

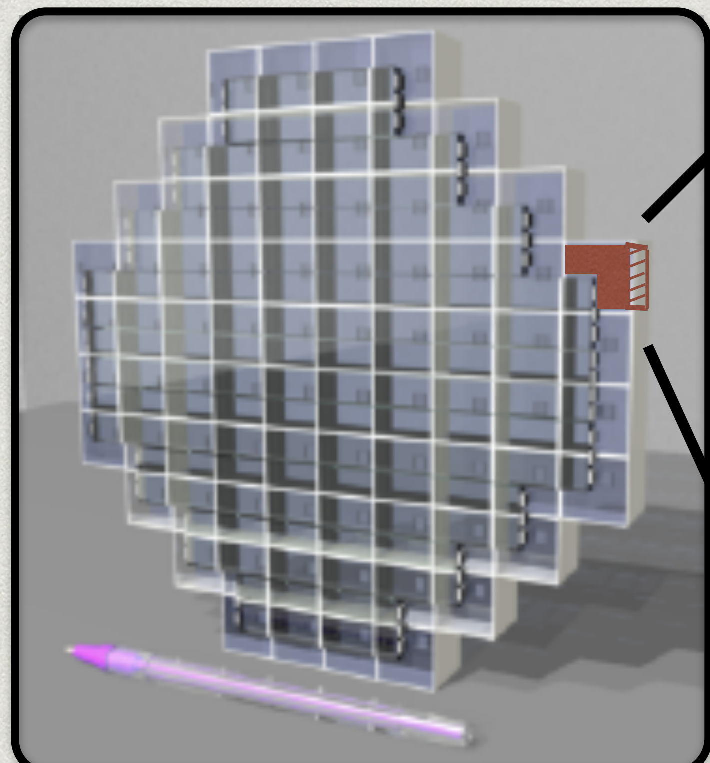


Plastic scintillator
+
LYSO calorimeter

Measuring energy to separate Radiative Decay from Michel Decay →

1. Introduction

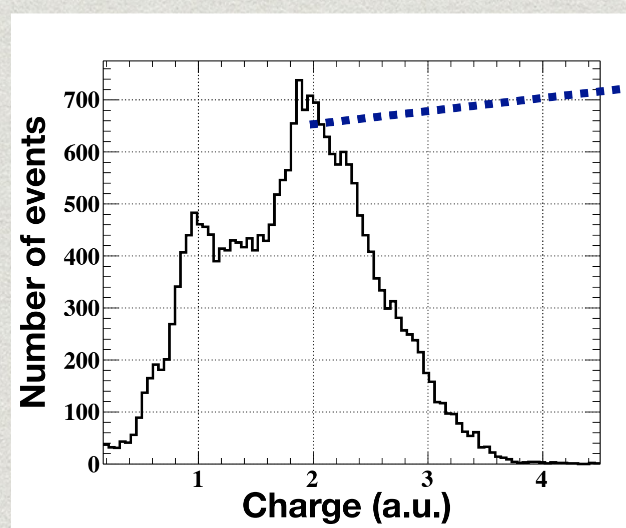
Calorimeter behind the plastic scintillator(76 channels)



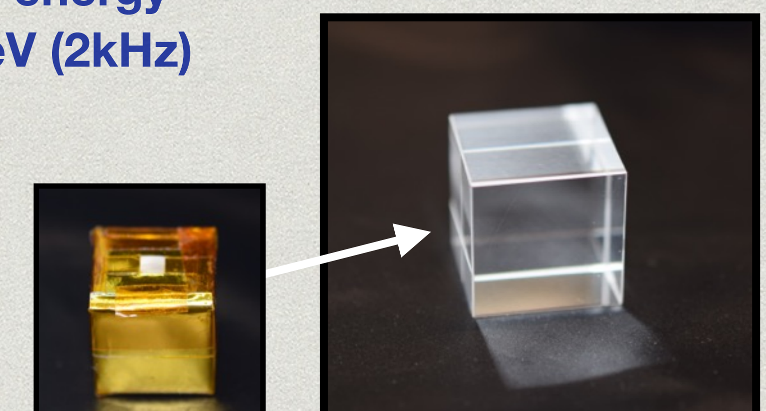
e^+ energy 2~5MeV(200~600kHz)

Desire resolution ~8% @1MeV

- **LYSO(Lutetium-Yttrium Oxyorthosilicate) crystal for scintillator**
  - → $2 \times 2 \times 2\,\mathrm{cm}^3$
  - → Great resolution, large light output
  - → <u>Quick decay time to prevent piling up e^+ signals</u>
  - → <u>Intrinsic radioactivity of Lu used for energy calibration</u>

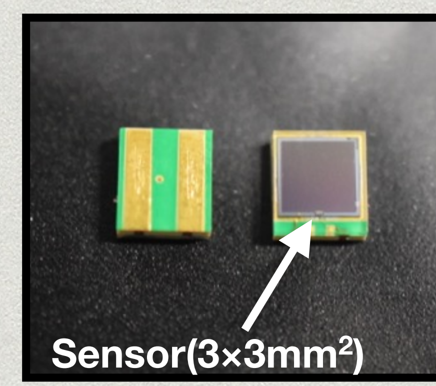


Typical energy ~600keV (2kHz)



With reflector

- **MPPC(Multi-Pixel Photon Counter) for reading out scintillation light**
  - → Hamamatsu, S12572-025P
  - → 25μm pixel pitch



2. Development status

- R&D
  - → **RDC prototype test**
  - → **MPPC & crystal selection**
  - → **Holder & PCB design**
  - → **LYSO mass test**

Remaining tasks

- → **Optical coupling test**
- → **Afterglow study**

- Assembling and operation test
  - → **Assembling the calorimeter**
  - → **Development of mover**
  - → **Operation test with plastic scintillator**

↓

MEG II engineering run / data taking in 2016

3. Optical coupling test

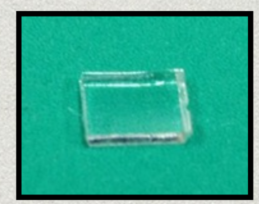
- Performance evaluation of optical coupling between MPPC & LYSO crystal

  → It can make energy resolution better

❶ No material

MPPC is directly attached

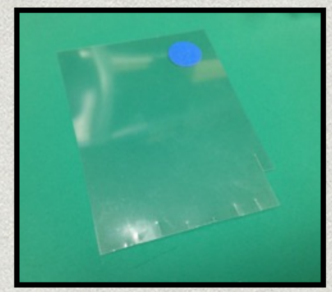
❷ Pad



t=1mm

Saint Gobain BC-634A

❸ Film



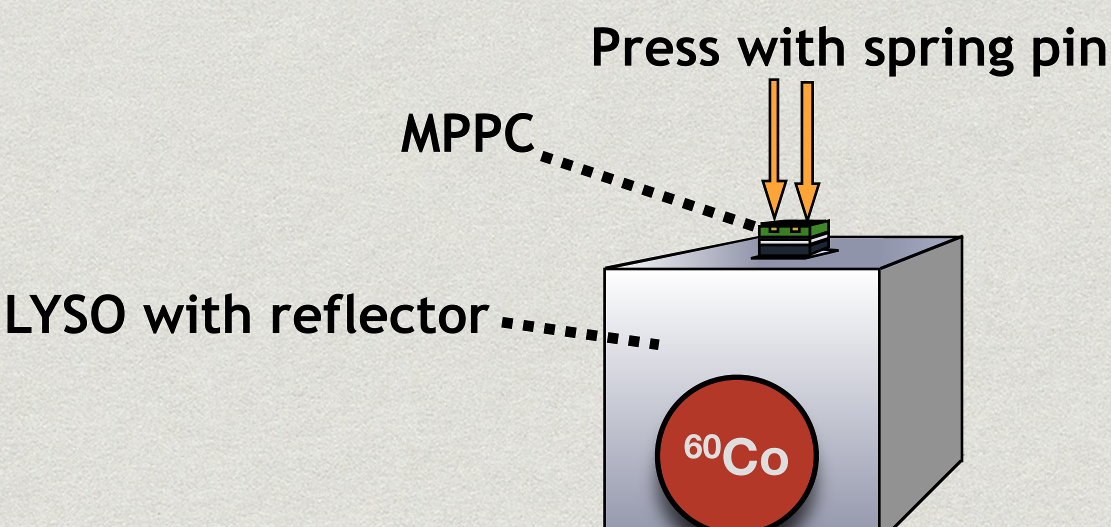
t=20μm

TOMOEGAWA FW-205

❹ Grease

Eljen technology EJ-550

- Experimental setup

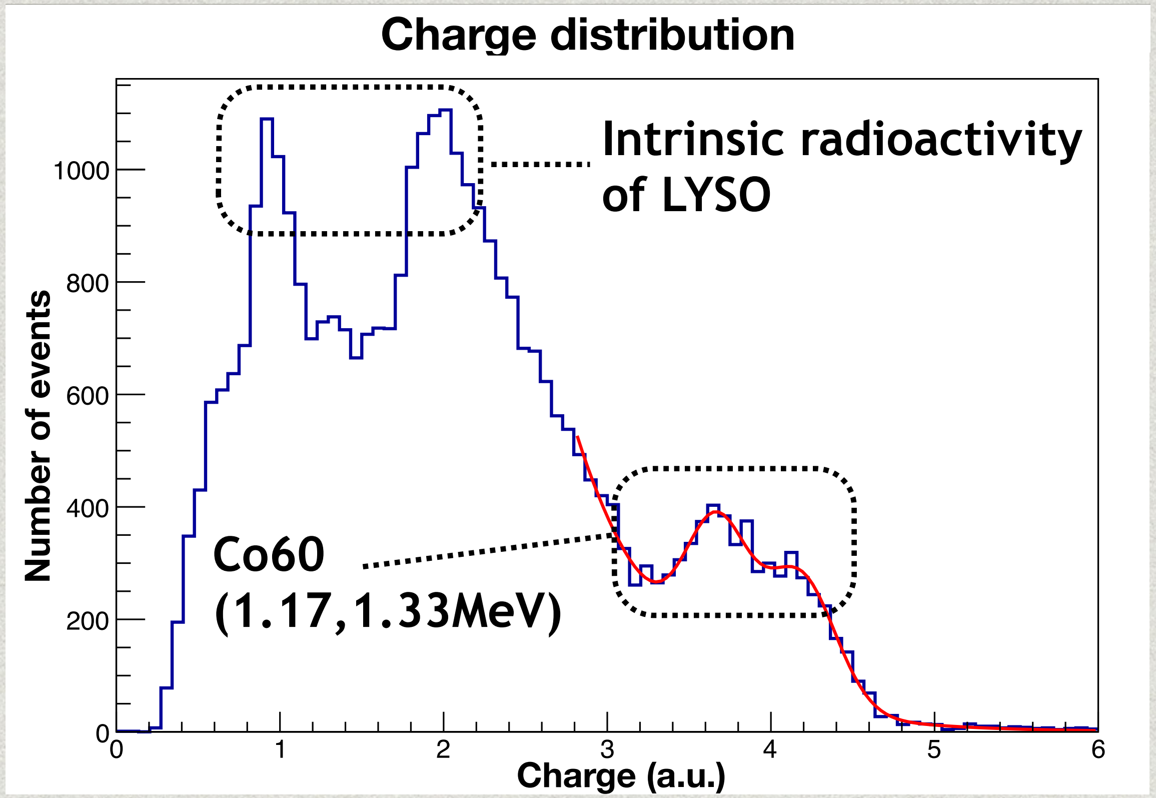


→ NIM amplifier

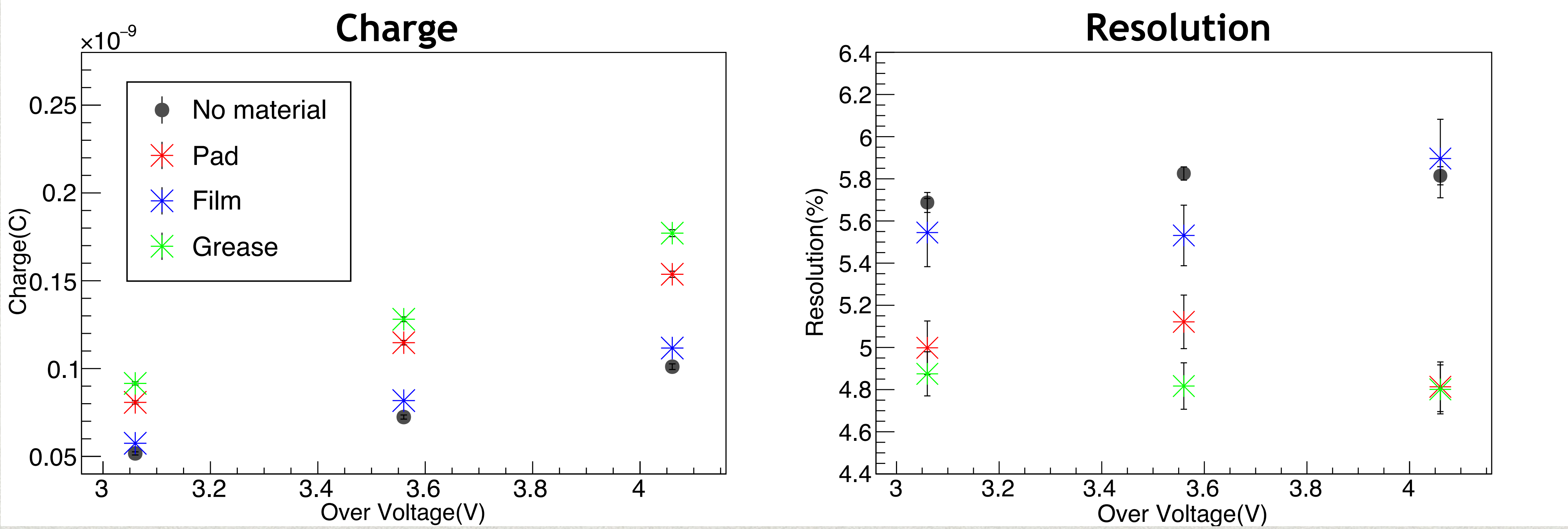
→ Waveform digitizer DRS (developed in PSI)

3. Optical coupling test

- Evaluation method
  - → Energy resolution calculated from the charge distribution

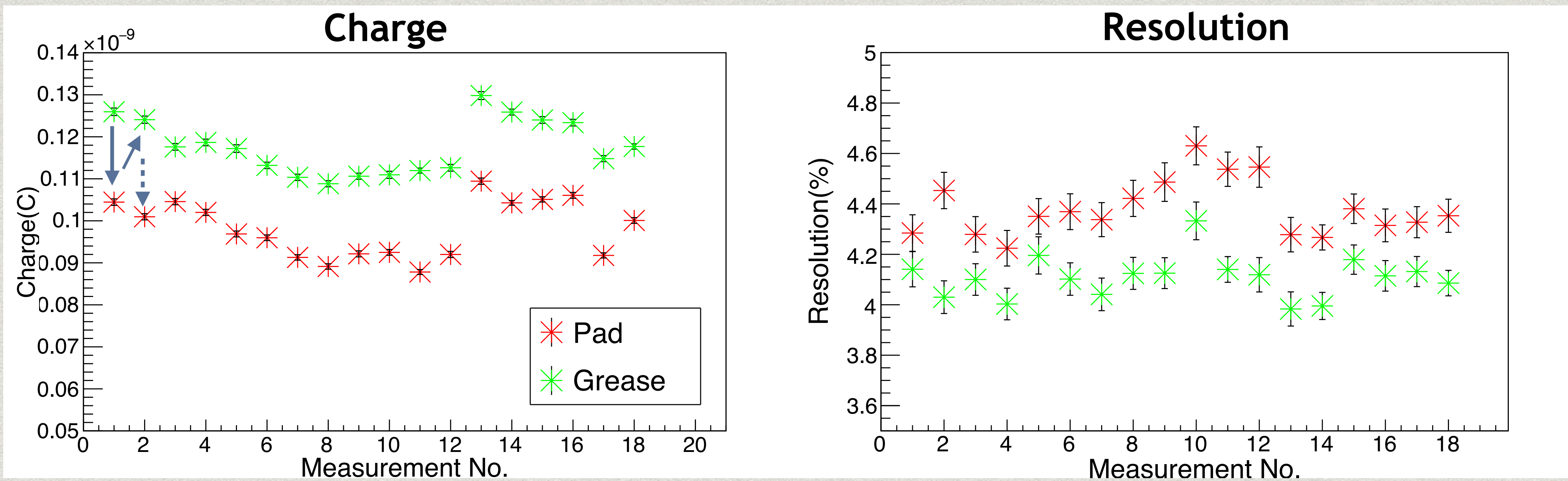


- Charge and energy resolution at 1.17MeV



3. Optical coupling test

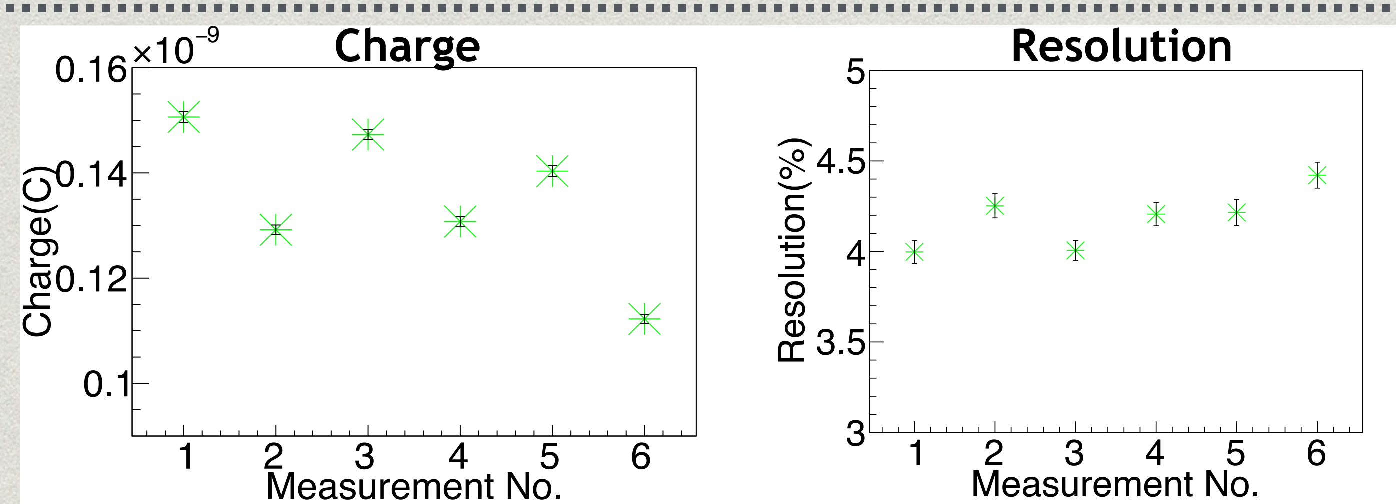
- Comparison of pad & grease
  → Over voltage = 3.56V



→ The performance changed little with reduced grease

→ Amount reduced by half in No.2,4,6

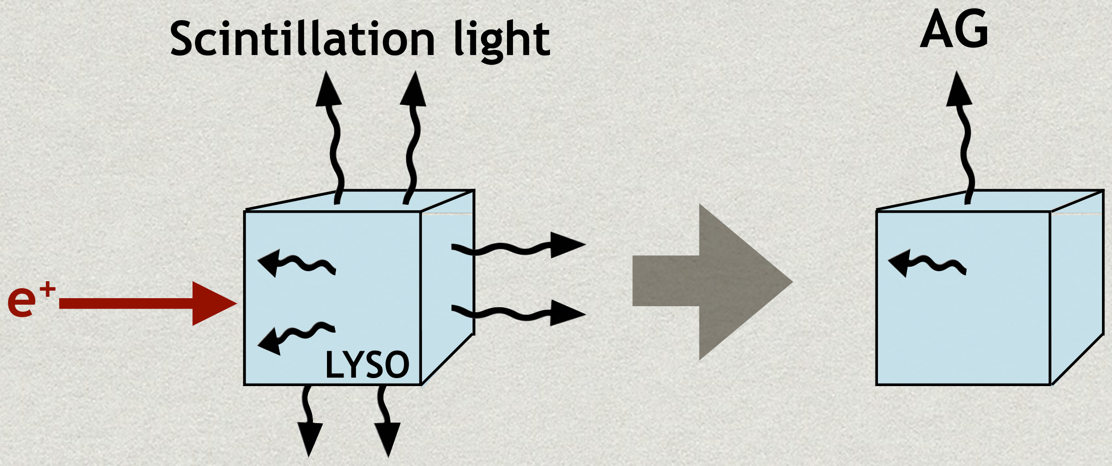
→ The performance becomes same as pad at worst



- We will use grease for optical coupling

4. Afterglow study

- LYSO crystal has afterglow(AG)
  - → Some excited e^- trapped in lattice defects
  - → Emitted late γ becomes noise
  - → Influence on current & energy resolution

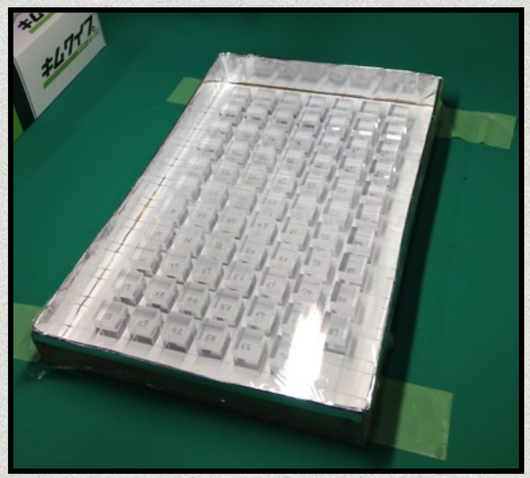


- AG is caused by both room light & radiation
  - → We want to check all crystals with radiation, but it takes long time

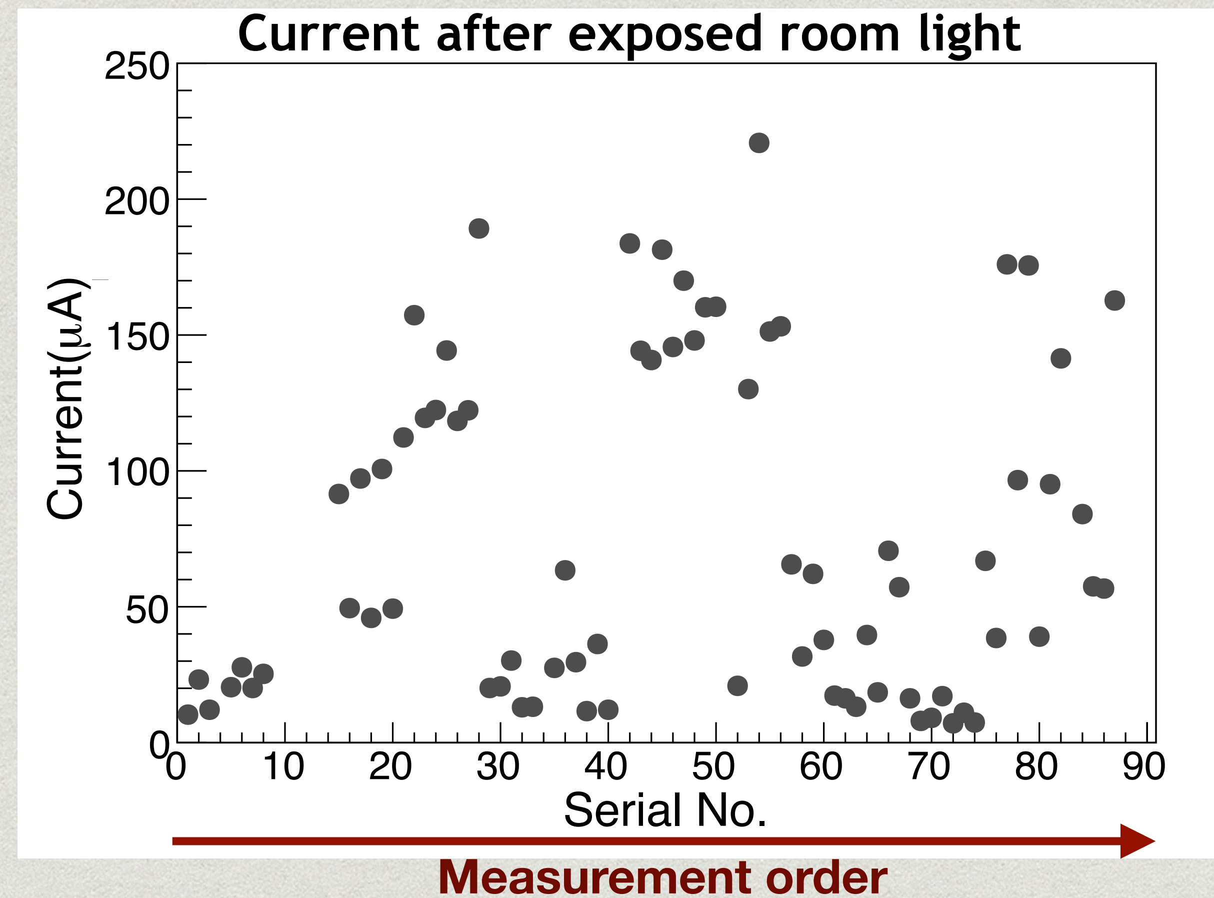
- So we checked all crystals with room light first
  - → Then check the correlation with radiation

4. Afterglow study

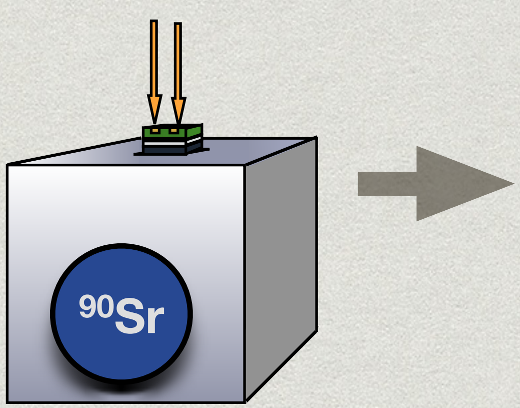
- Room light AG
  - → Current of MPPC was measured
  - → Over voltage = 4.02V
  - → Large individual difference was found (~5μA without AG)



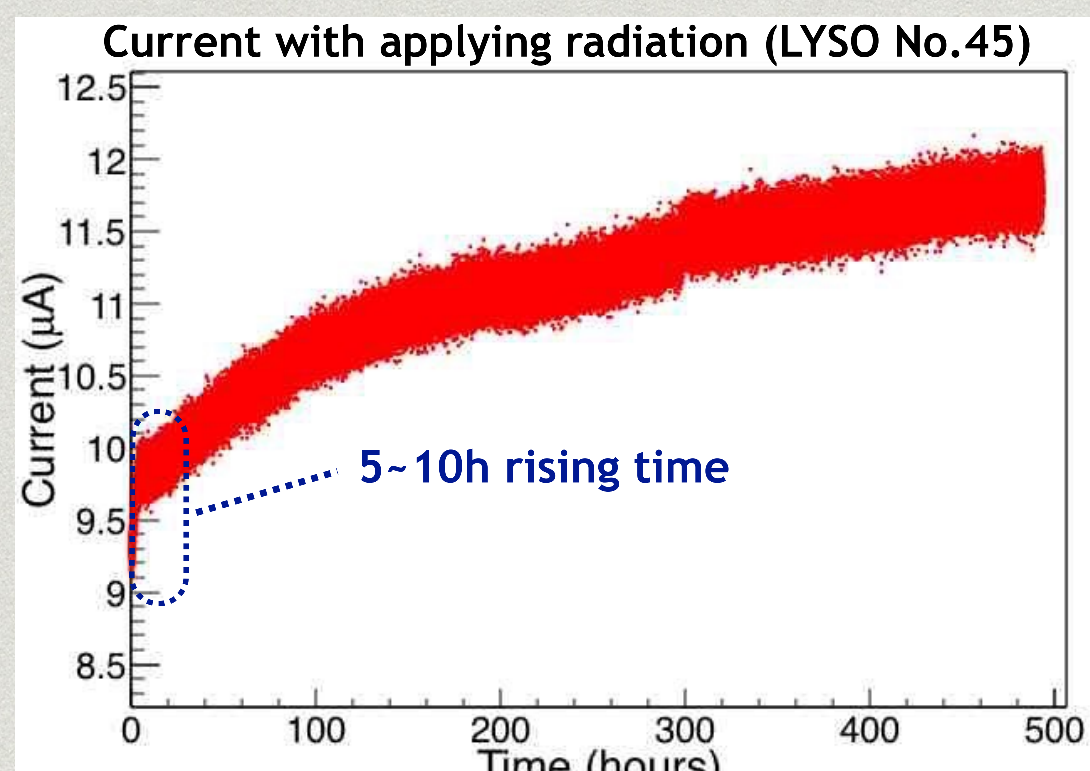
All LYSO crystals exposed to room light over 24h



- Current monitor with ^{90}Sr (~200kHz)
  - → Temperature was constant (26.0°C)
  - → Over voltage = 3.56V
  - → Current increased slowly (~30μA in 200days)

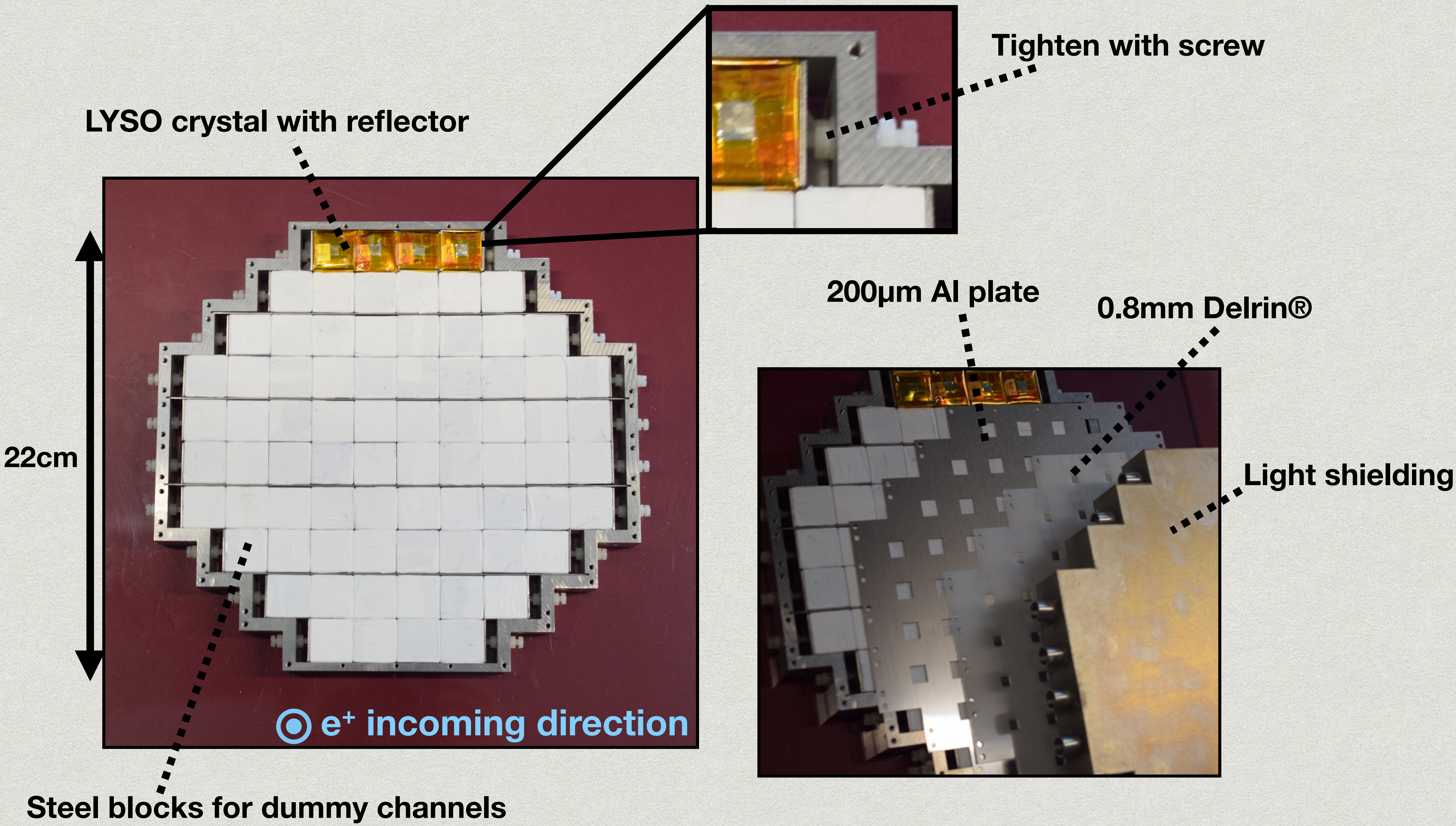


Current was measured in every 10sec



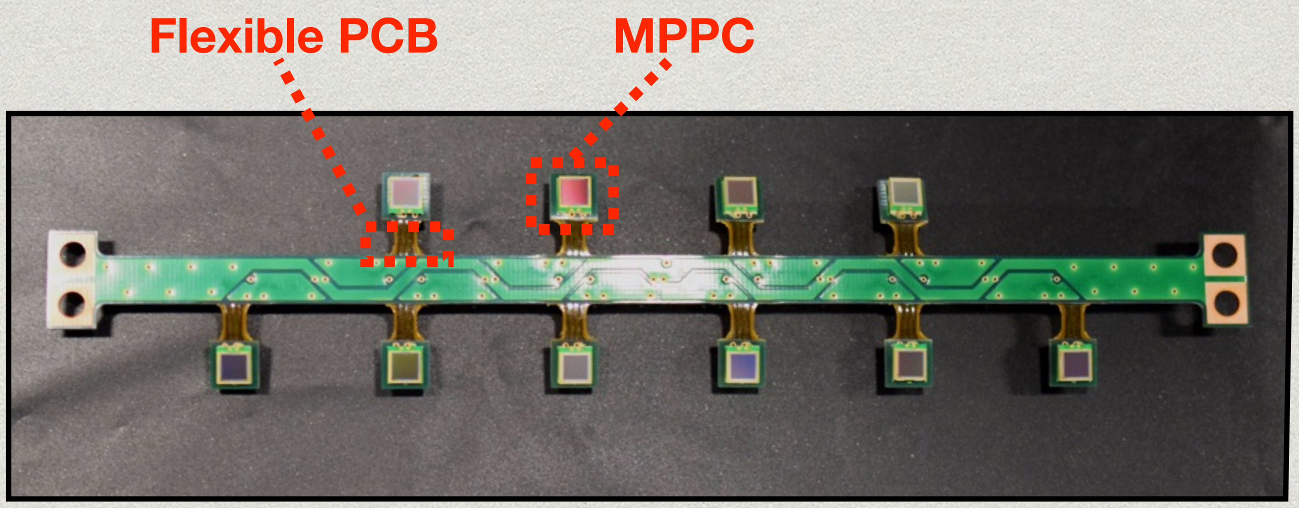
5. Assembling the calorimeter

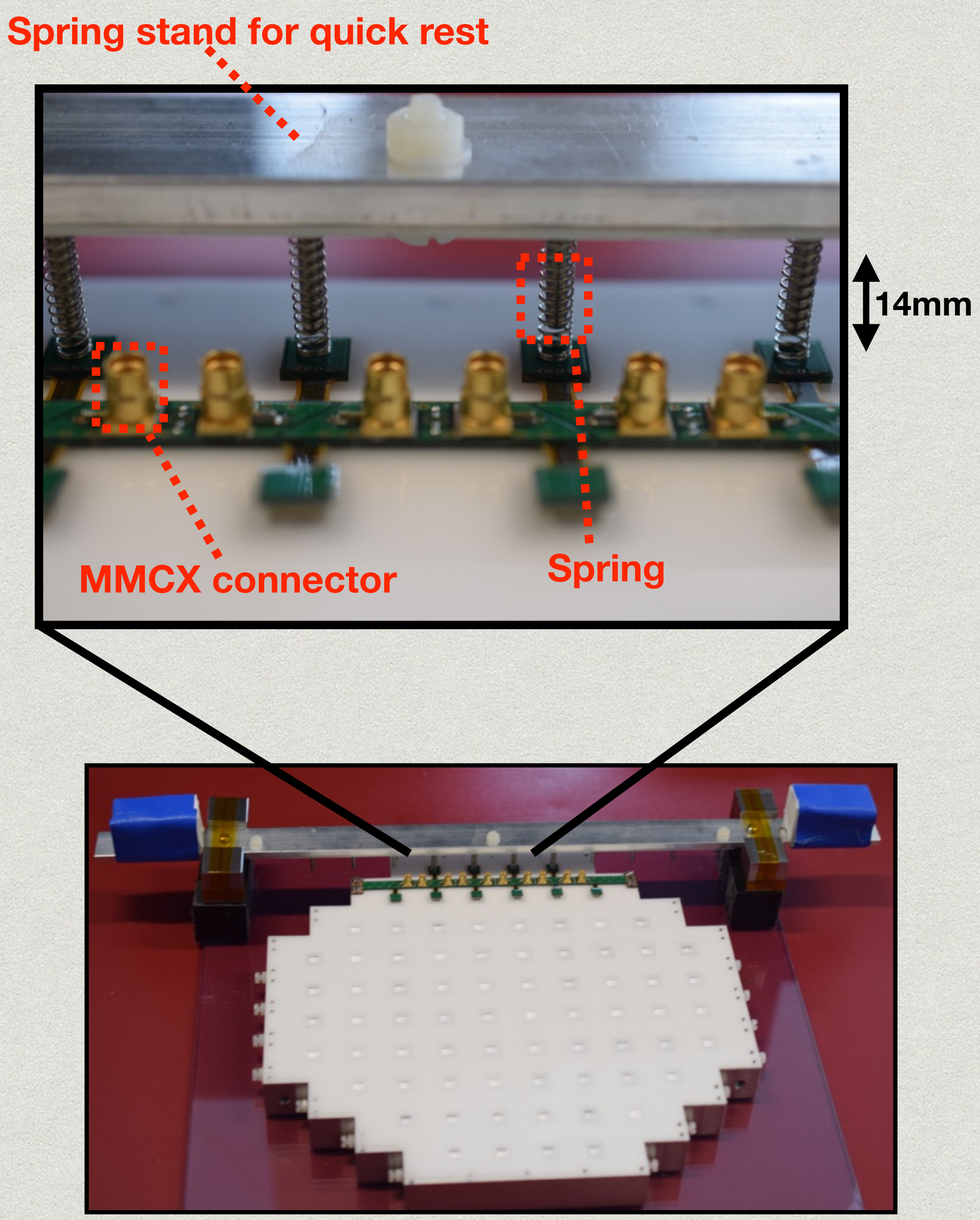
- Holder design



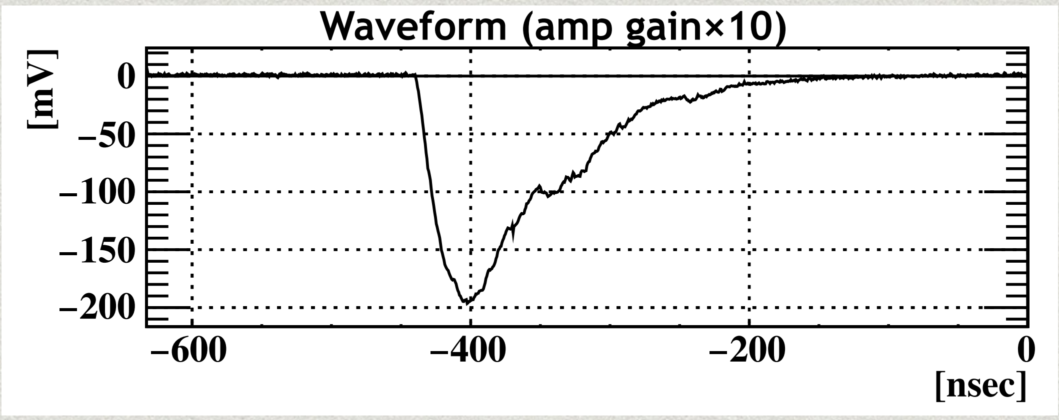
5. Assembling the calorimeter

- PCB design
  → MPPC are pressed with spring





- No dead channel was found in PCB
  → LYSO intrinsic radioactivity was obserbed in all channels



6. Summary

- **Optical coupling between MPPC and LYSO crystal was optimized**

  → We will use grease for optical coupling

- **Afterglow of LYSO crystal was studied**

  → All LYSO crystals were measured with room light

  → Increased current was observed with radiation

  → We should check correlation with AG from radiation and estimate effect on resolution

- **Construction of the calorimeter has just started**

  → No dead channel were found in PCB

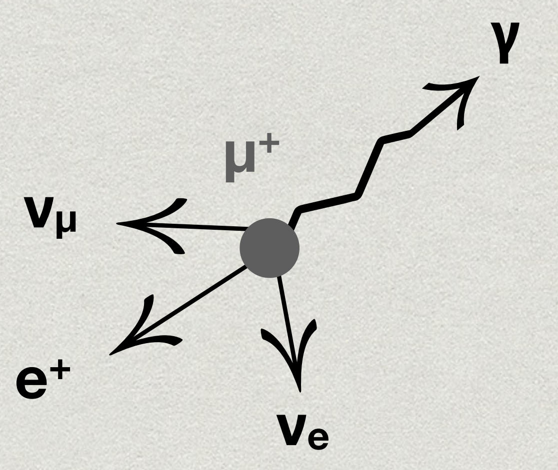
  → We should combine plastic scintillator and test

THE END

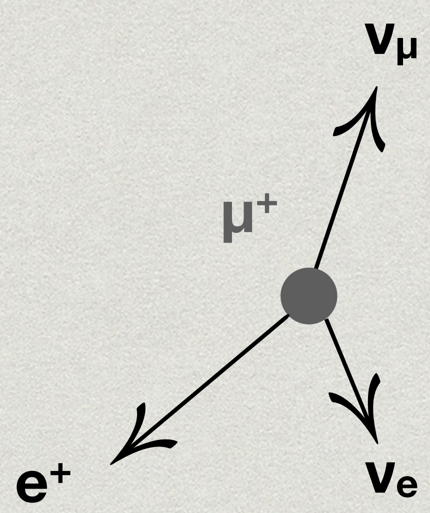
BACK UP

Michel Decay & Radiative Muon Decay

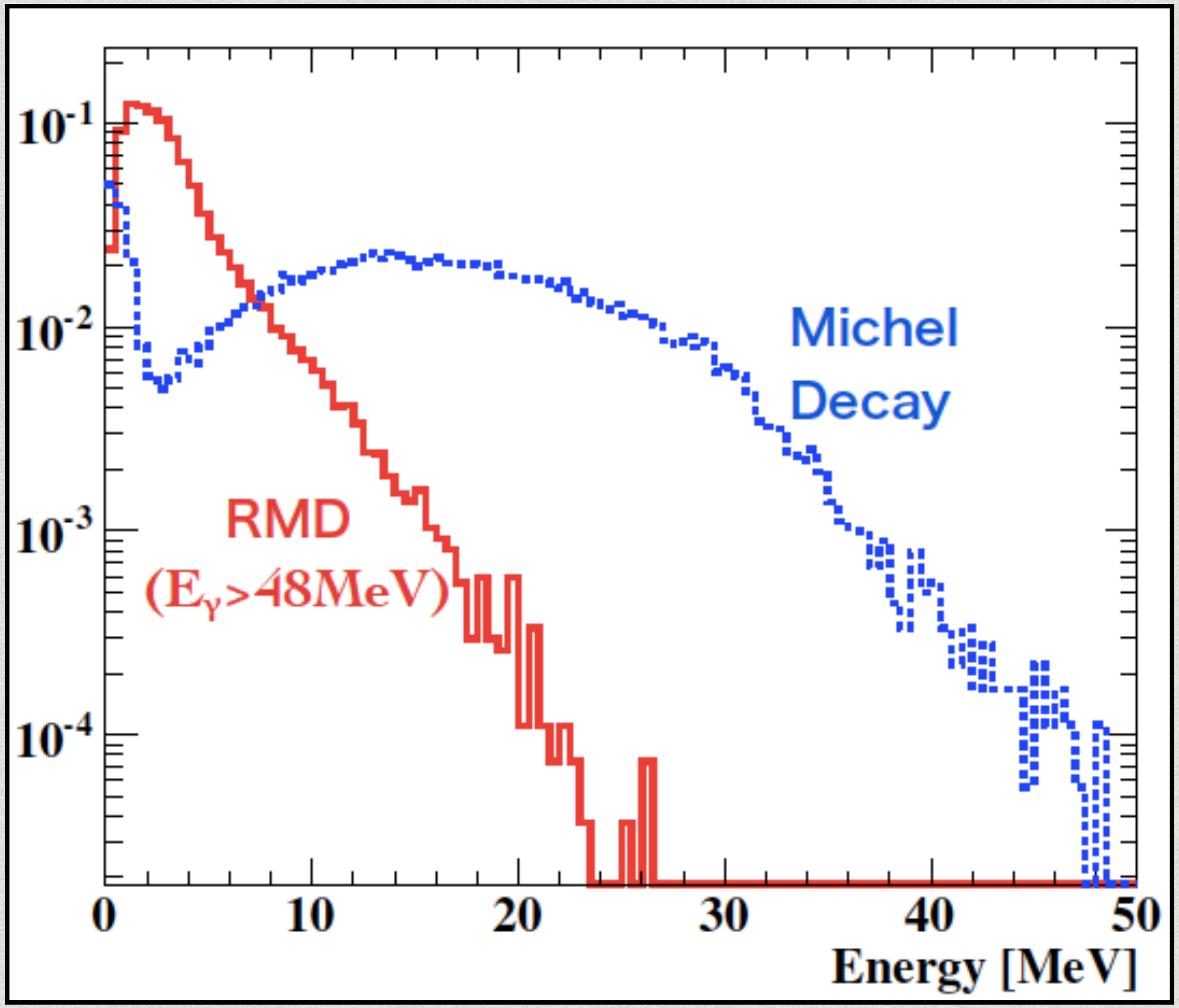
- e^+ energy deposit from simulation



Radiative Muon Decay



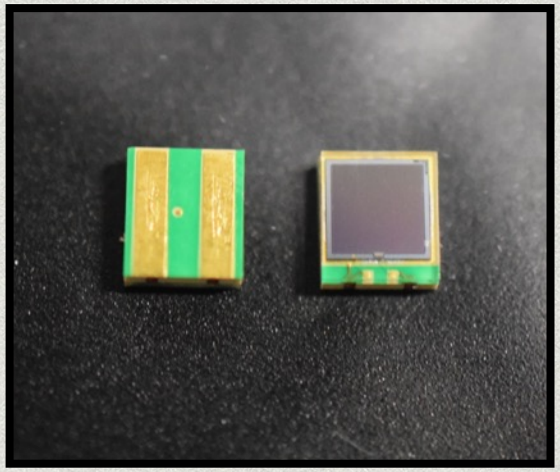
Michel Decay



MPPC selection

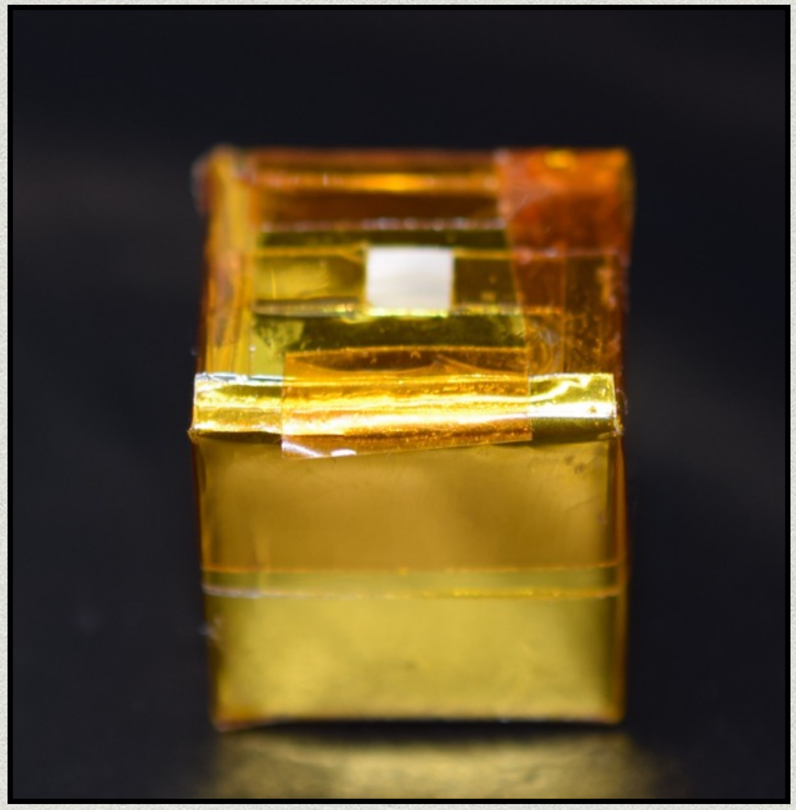
- Advantage of using 25μm pixel pitch compare to 50μm
  - → Crosstalk becomes smaller due to lower gain
  - → Saturation can be minimized
  - → Current also becomes smaller

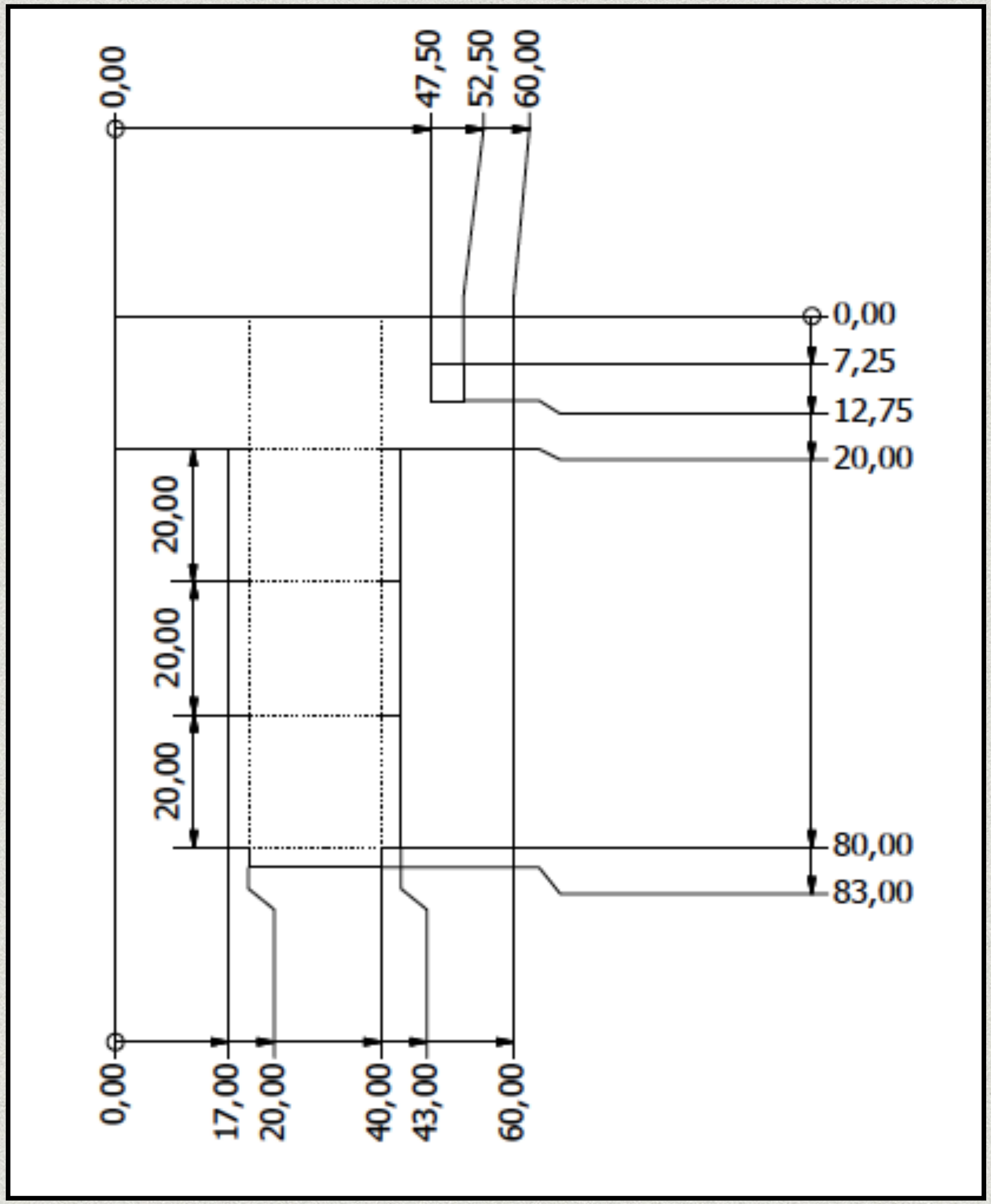
- 50μm pixel pitch is superior in S/N ration
  - → Signal can be seen more clearly
  - → But we can obtain desire resolution with 25μm pixel pitch



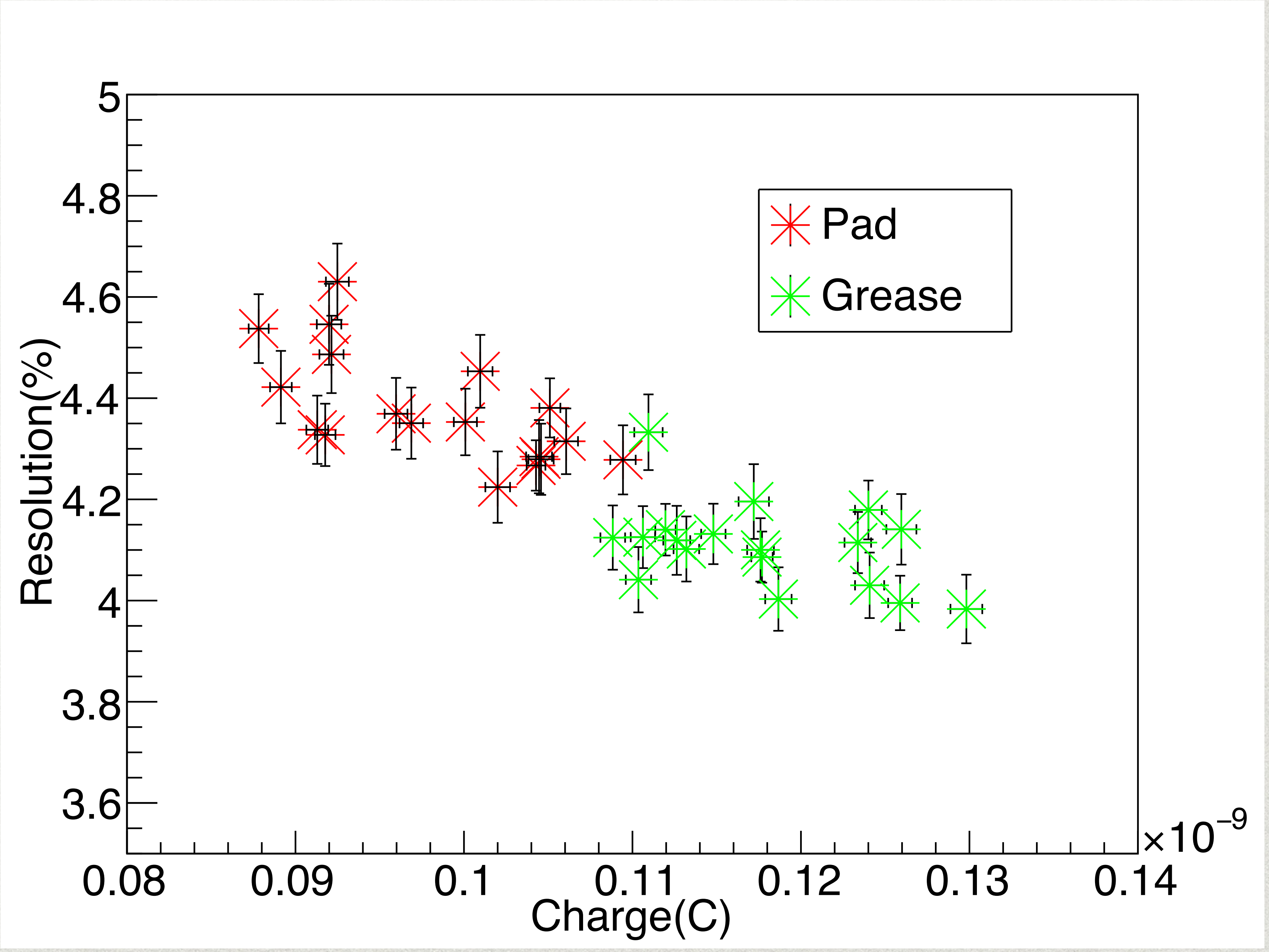
Reflector design

- Enhanced Specular Reflector Film (ESR)
  - → 65μm thickness

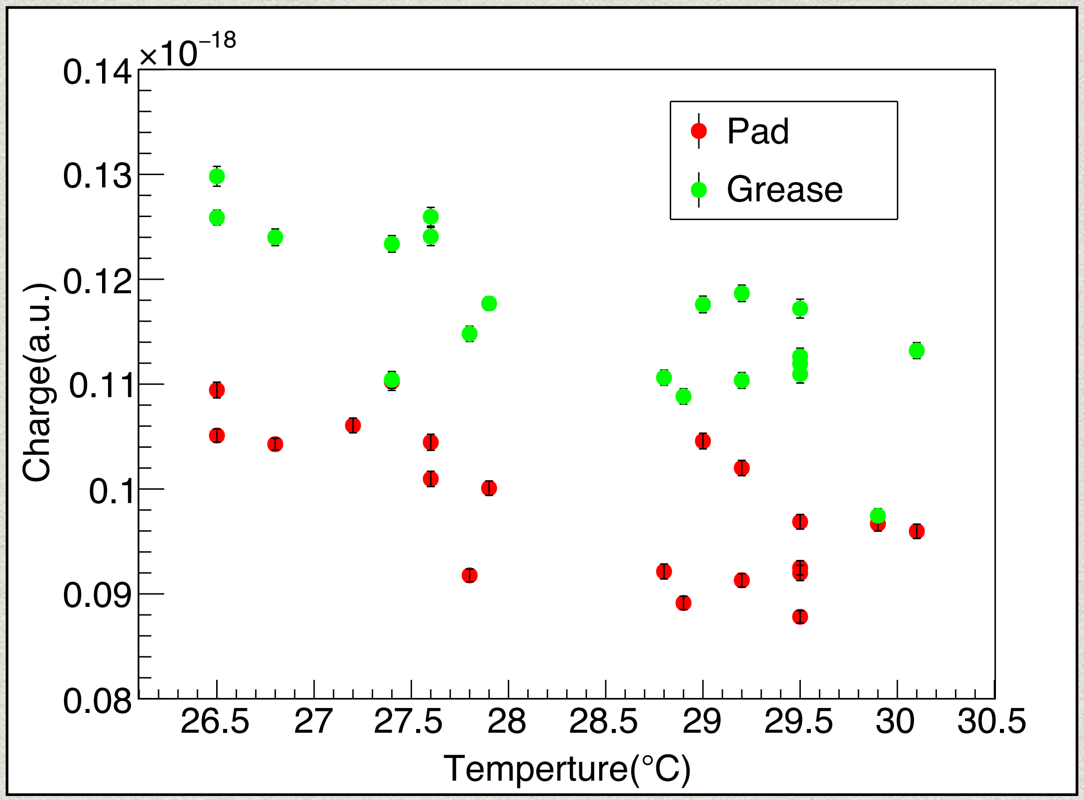


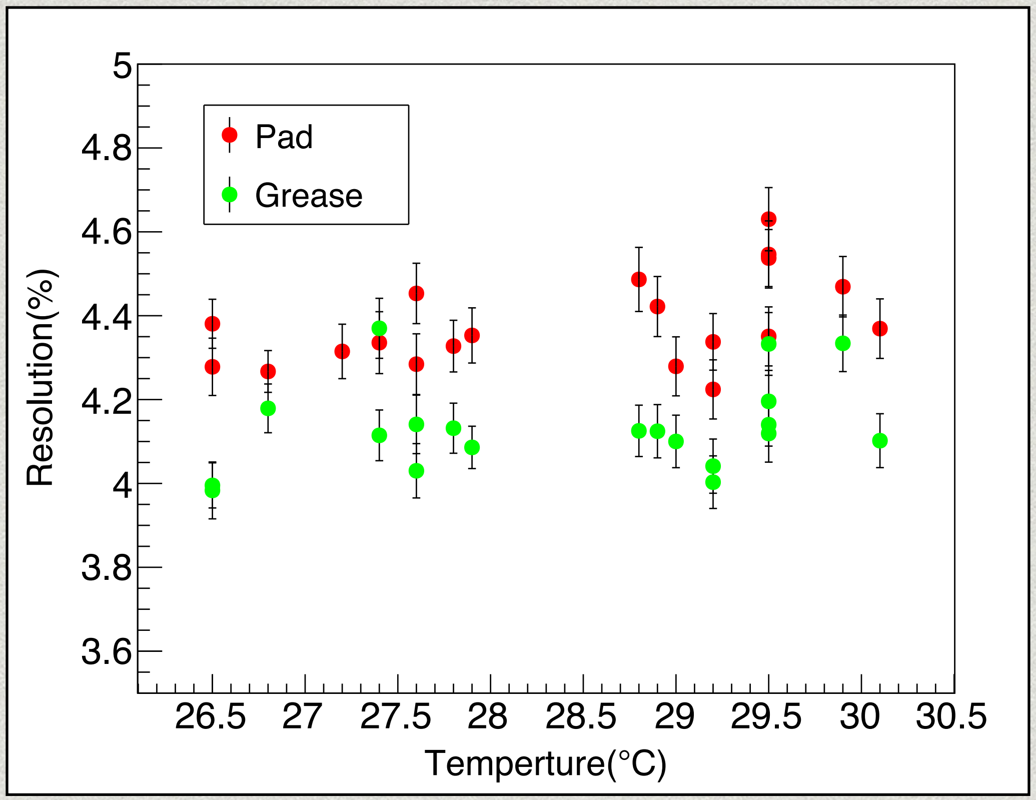


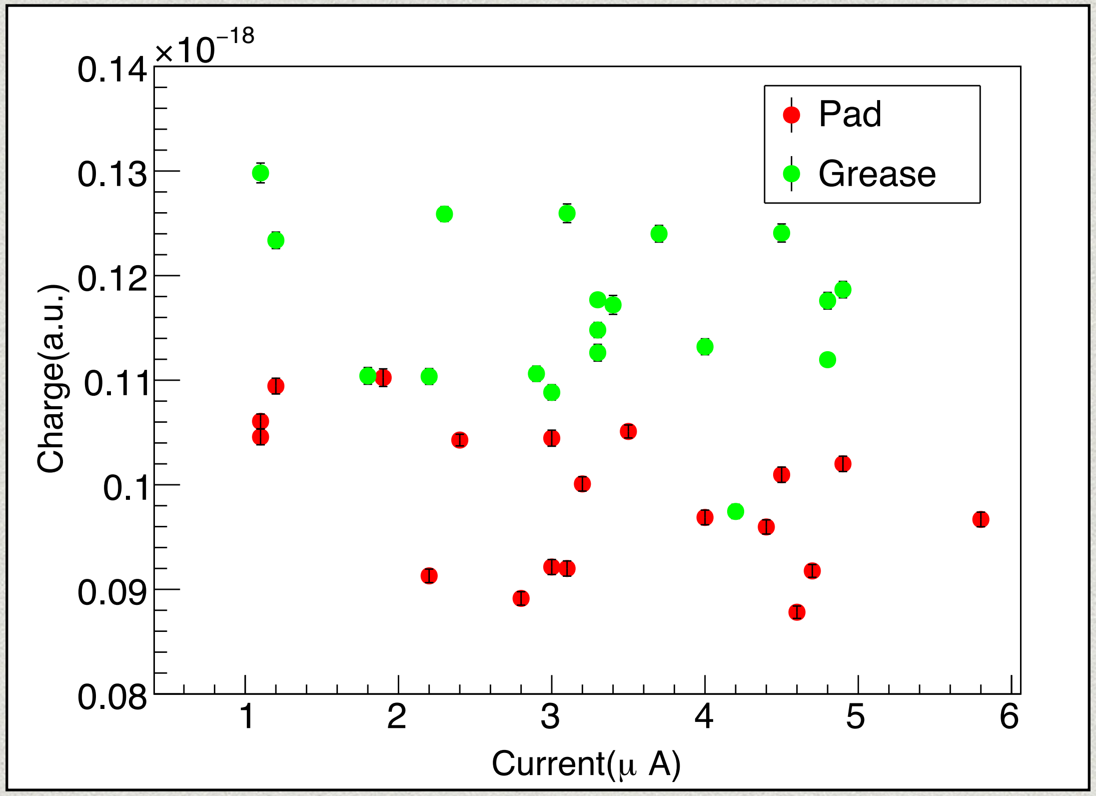
Charge vs Resolution

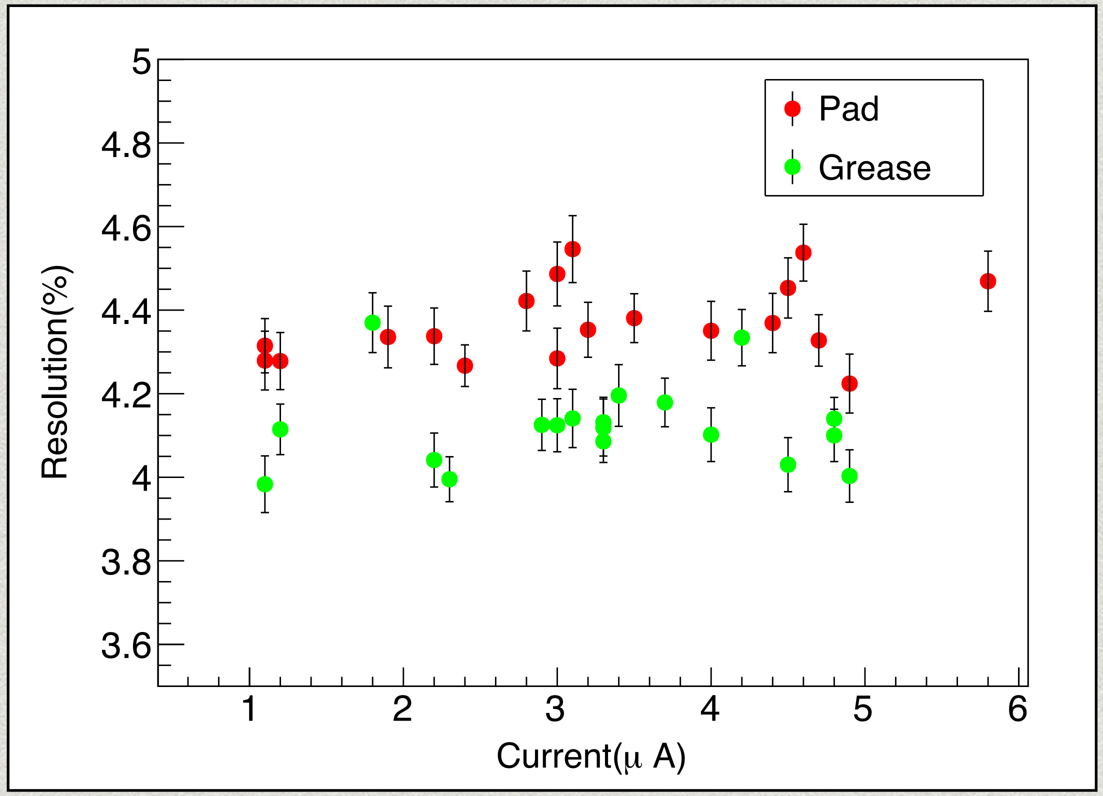


Temperature & current







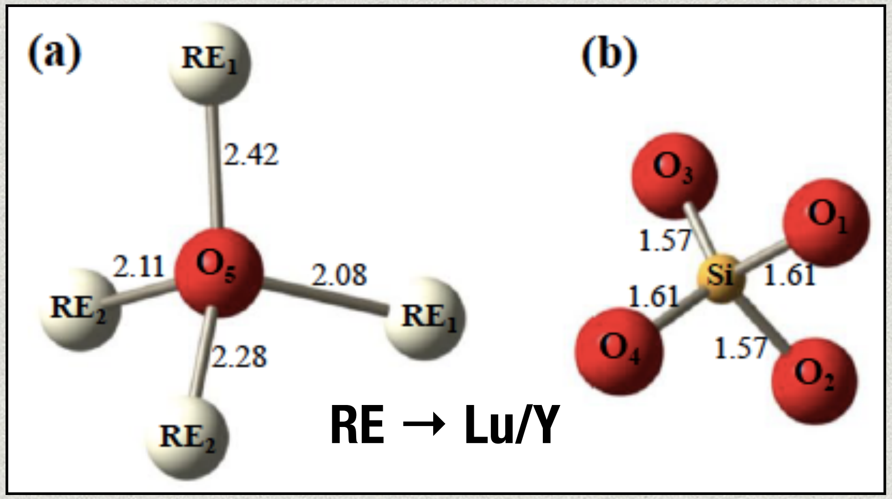


Afterglow mechanism

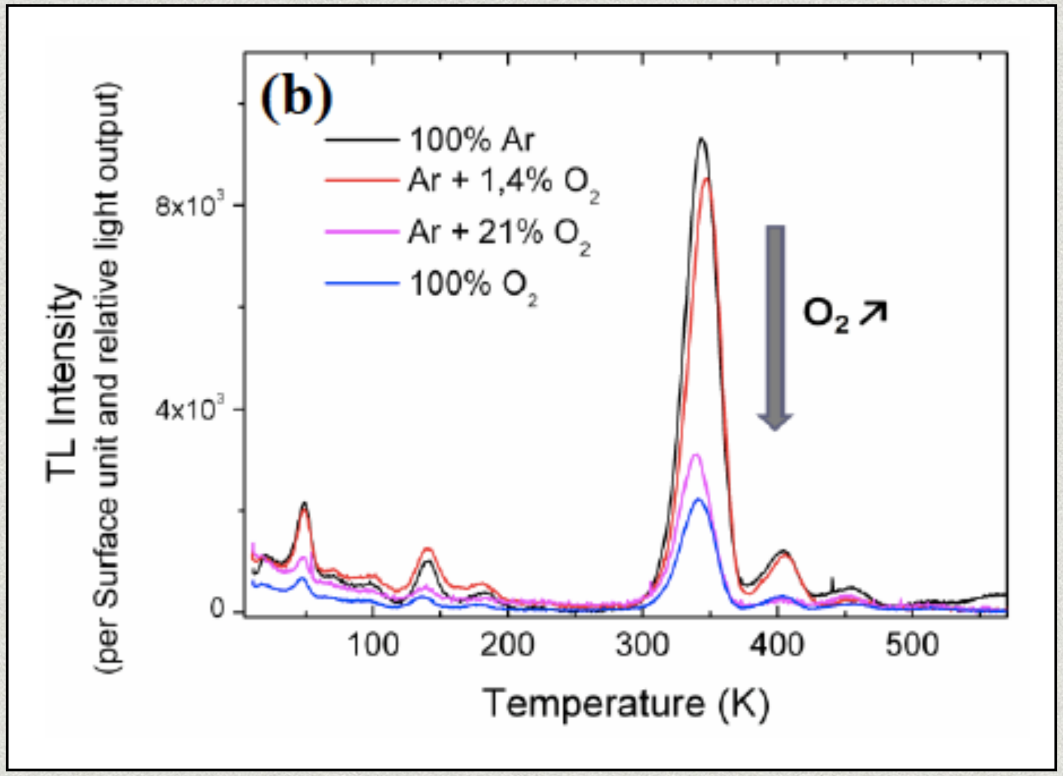
Reference

S. Blahuta et al.. 2011.
Defects identification and effects of annealing on Lu2(1-x)Y2xSiO5 (LYSO) single crystals for scintillation application,.
Materials,4, 1224

- LYSO crystal structure
  - → O_5 has the lowest formation energy
  - → Oxygen vacancies can be created during crystal growth due to the low oxygen content in the furnace atmosphere

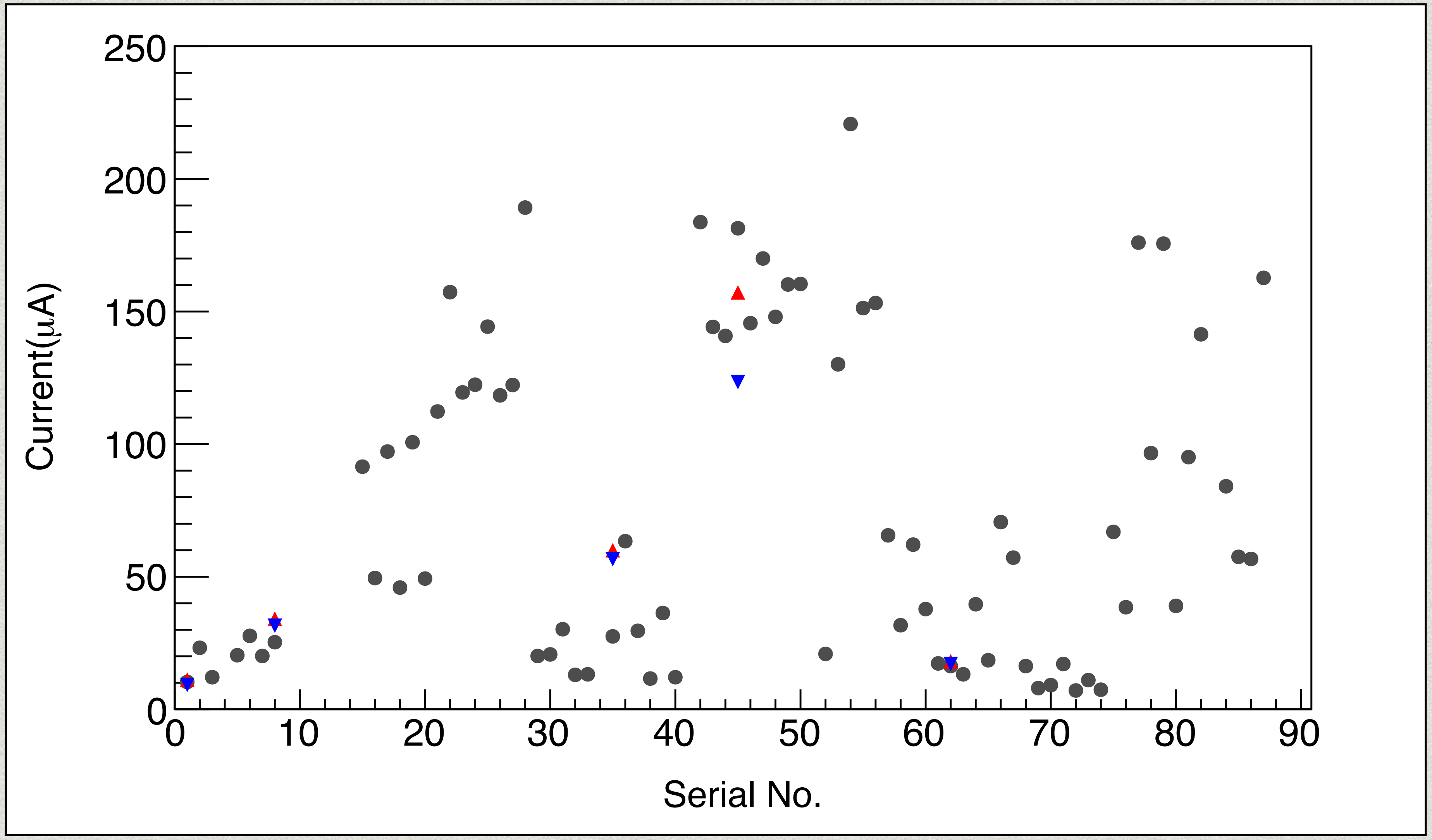


- Emission spectrum & Thermoluminescence
  - → Afterglow depends on its growth atmosphere
  - → Strong peak around 340K



Room light afterglow recheck

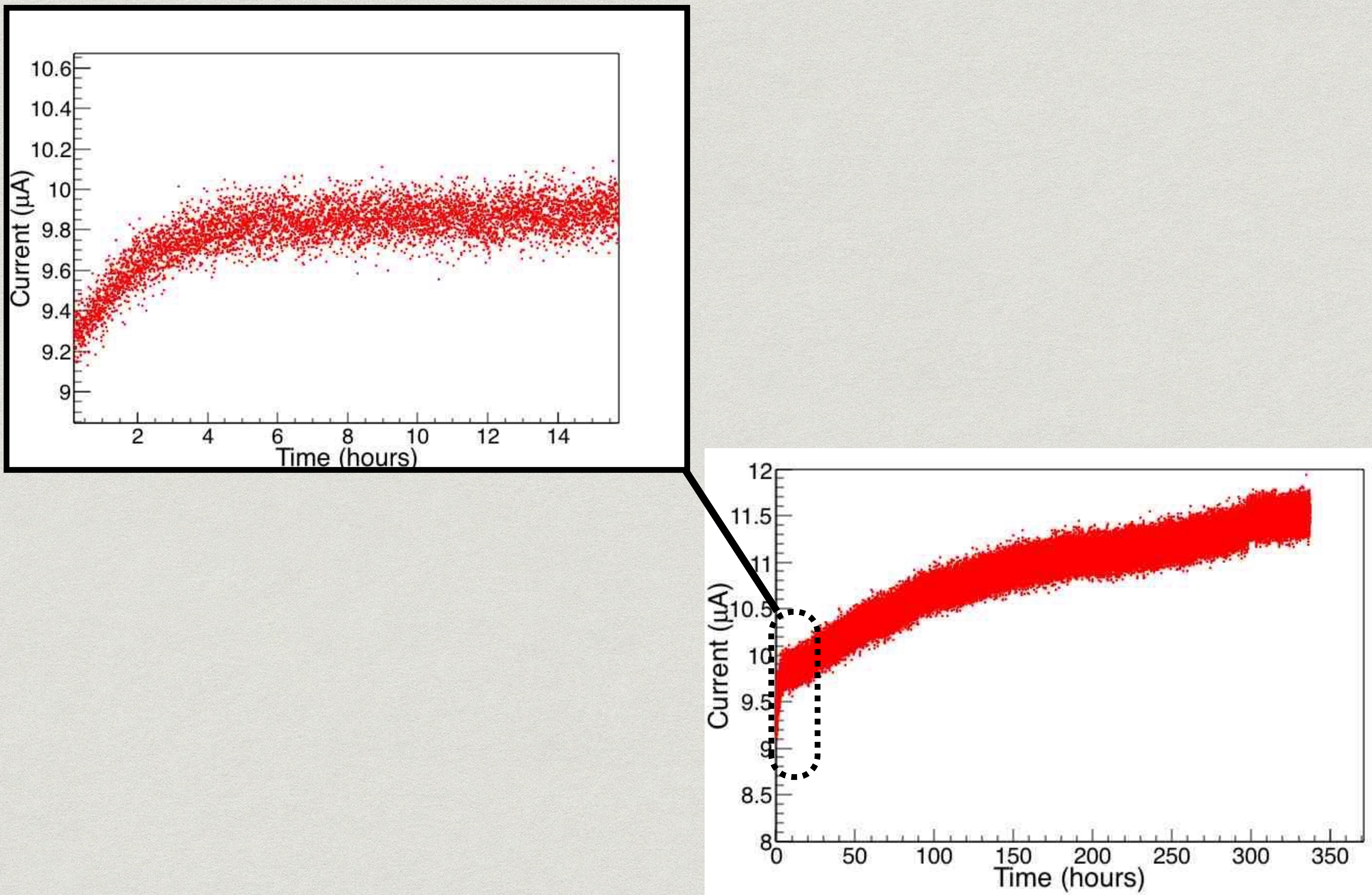
- Red & Blue plot shows another measurement results



→ Room light exposed over 48hours after light sheilding

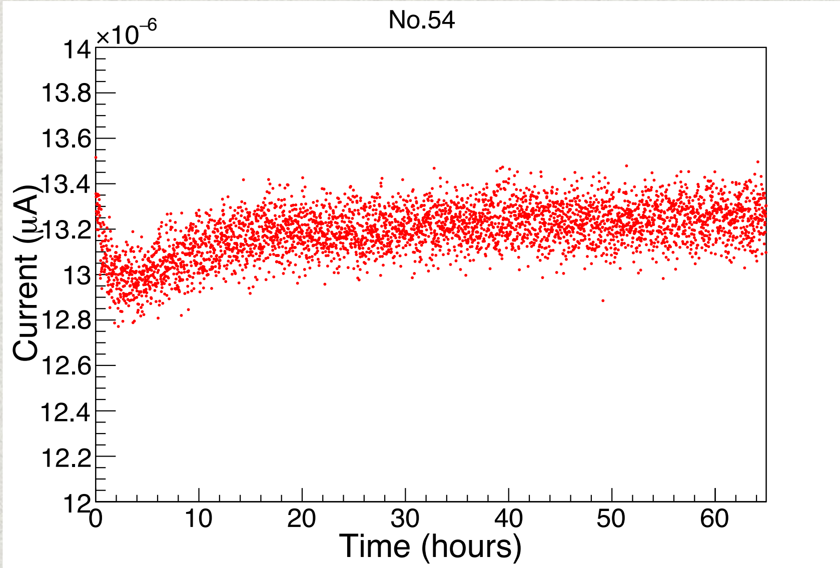
1 45 8 62 35

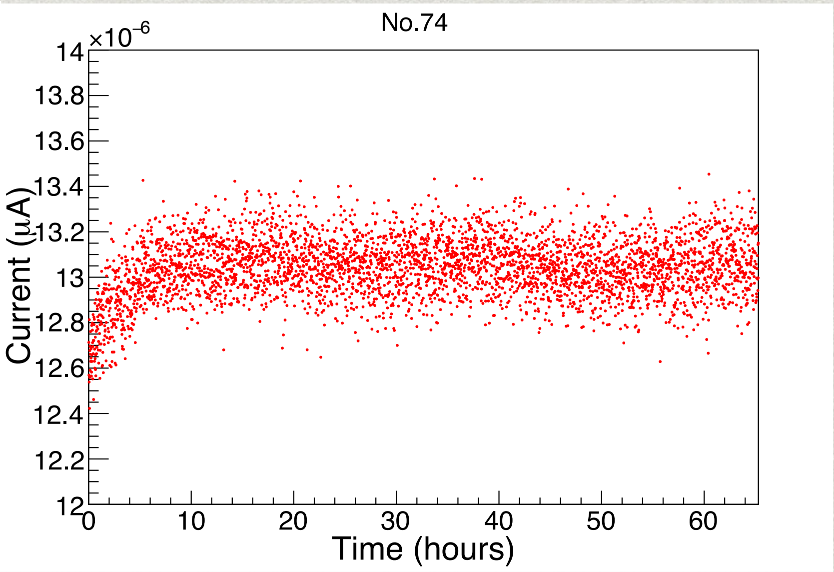
Afterglow study



Afterglow study

- We also checked other 2 crystals only for ~60h
  - → Over voltage = 3.56V





- Effect on energy resolution with rising of 50μA
  - → Statistical contribution from number of AG photoelectrons was calculated
  - → Single waveform contains $N_{\rm all} = N_{\rm sig} + N_{\rm AG}$

$$\mathrm{Resolution} = \frac{\sigma_{\rm all}}{N_{\rm sig}} = \frac{\sqrt{N_{\rm sig} + N_{\rm AG}}}{N_{\rm sig}} = \frac{1}{\sqrt{N_{\rm sig}}} + \underline{\mathrm{terms\ \ with\ \ N_{AG}}}$$

Assuming Poisson distribution

$$\sigma_{\rm all}{}^2 = \sigma_{\rm sig}{}^2 + \sigma_{\rm AG}{}^2$$
$$\sigma_{\rm sig} = \sqrt{N_{\rm sig}}$$
$$\sigma_{\rm AG} = \sqrt{N_{\rm AG}}$$

Measured $N_{\rm sig}$ & $N_{\rm AG}$

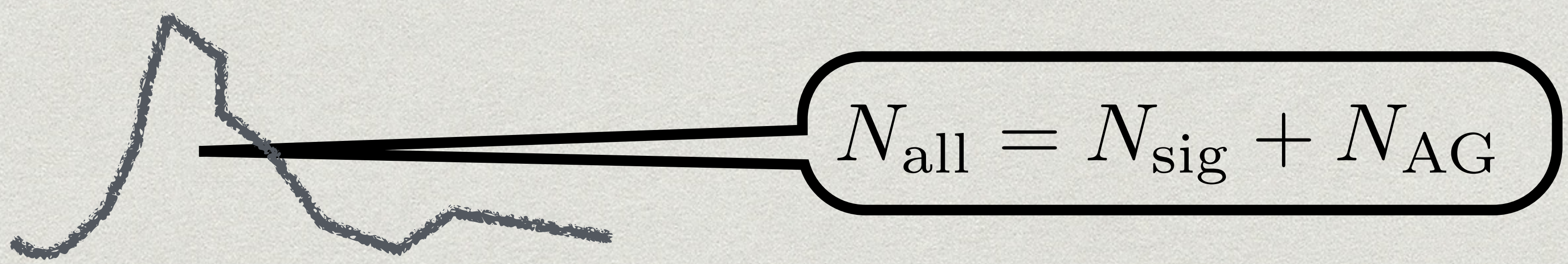
$$N_{\rm AG} \simeq 401$$
$$N_{\rm sig} \simeq 3090$$

This additional terms ~0.2%

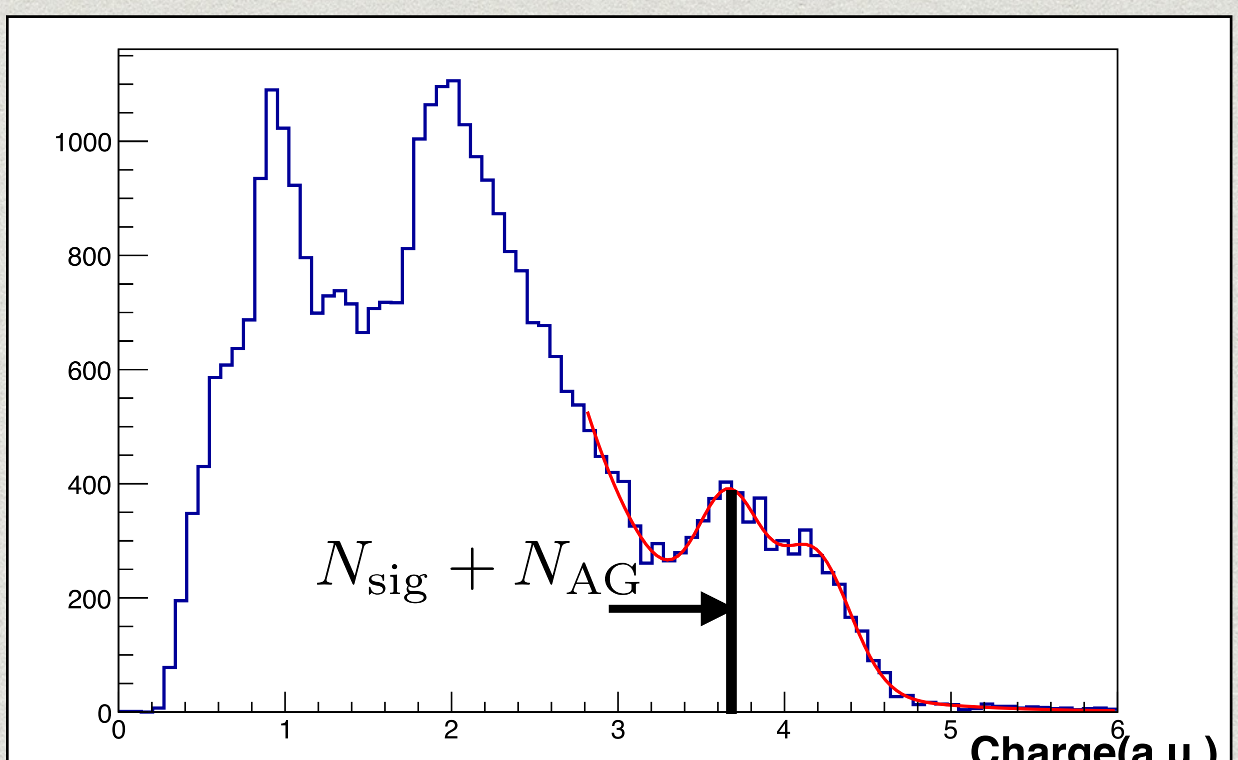
Energy resolution calculation

- How much resolution gets worse if p.e. from AG are increased
- 2 assumptions

1. Single waveform contains N_{all} photoelectons



2. N_{AG} shifts mean value in charge distribution



$$\mathrm{Resolution} = \frac{\sigma_{\mathrm{all}}}{N_{\mathrm{all}} - N_{\mathrm{AG}}} = \frac{\sigma_{\mathrm{all}}}{N_{\mathrm{sig}}}$$

Energy resolution calculation

$$N_{\text{all}} = N_{\text{sig}} + N_{\text{AG}}$$

$$\sigma_{\text{all}}{}^2 = \sigma_{\text{sig}}{}^2 + \sigma_{\text{AG}}{}^2$$

If it follows a Poisson distribution…

$$\sigma_{\text{sig}} = \sqrt{N_{\text{sig}}} \quad \sigma_{\text{AG}} = \sqrt{N_{\text{AG}}}$$

$$\rightarrow \sigma_{\text{all}} = \sqrt{N_{\text{sig}} + N_{\text{AG}}}$$

$$\begin{aligned} \text{Resolution} &= \frac{\sigma_{\text{all}}}{N_{\text{sig}}} \\ &= \frac{\sqrt{N_{\text{sig}} + N_{\text{AG}}}}{N_{\text{sig}}} \\ &= \frac{1}{\sqrt{N_{\text{sig}}}}\sqrt{1 + \frac{N_{\text{AG}}}{N_{\text{sig}}}} \\ &= \frac{1}{\sqrt{N_{\text{sig}}}} + \underline{\text{terms with } \text{N}_{\text{AG}}} \end{aligned}$$

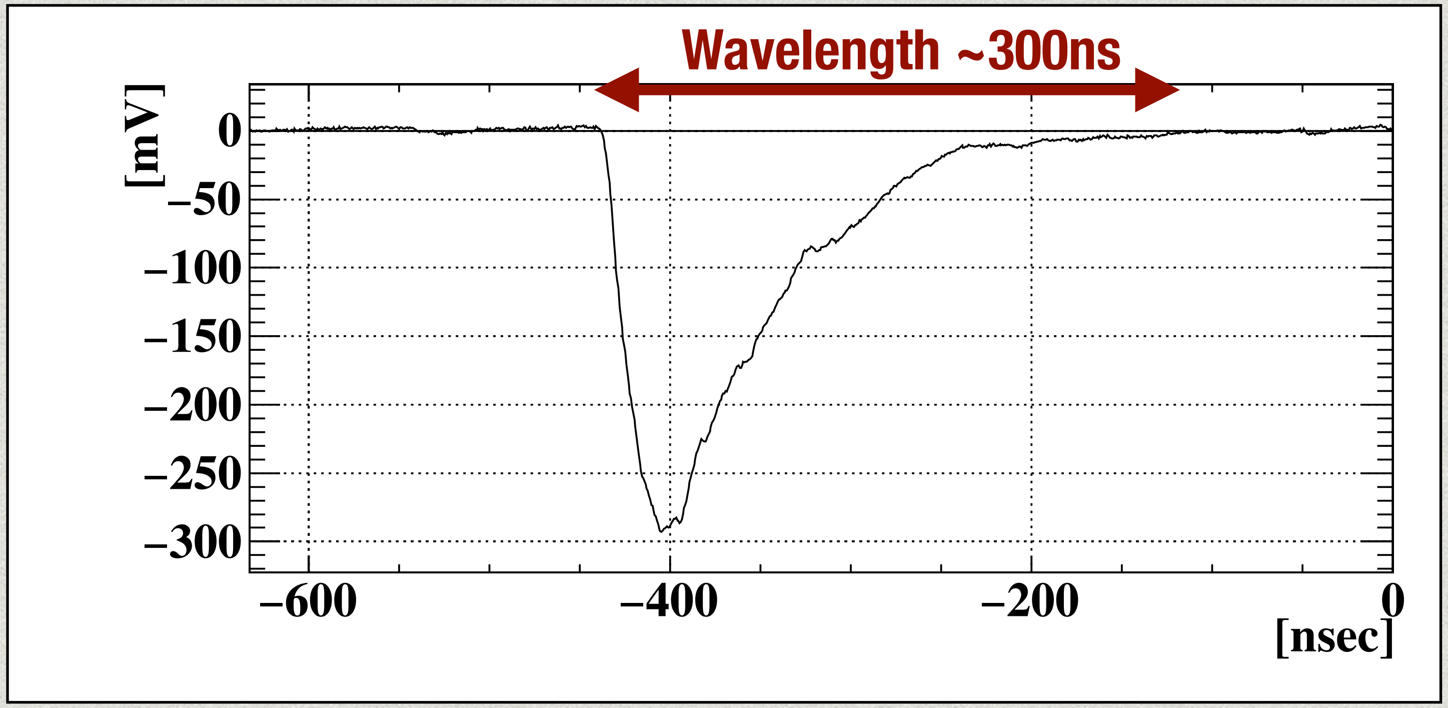
We can estimate additional terms from N_{sig} & N_{AG}

Energy resolution calculation

- Consider waveform of 1.17MeV Co60 peak

$$N_{\mathrm{AG}} = \frac{\mathrm{Current[c/s]} \times \mathrm{Wavelength[s]}}{\mathrm{Gain\ of\ MPPC} \times \mathrm{e[c]}}$$

$$N_{\mathrm{sig}} = N_{\mathrm{all}} - N_{\mathrm{AG}} = \frac{\mathrm{Charge\ at\ 1MeV}}{\mathrm{Charge\ at\ 1p.e.}} - N_{\mathrm{AG}}$$



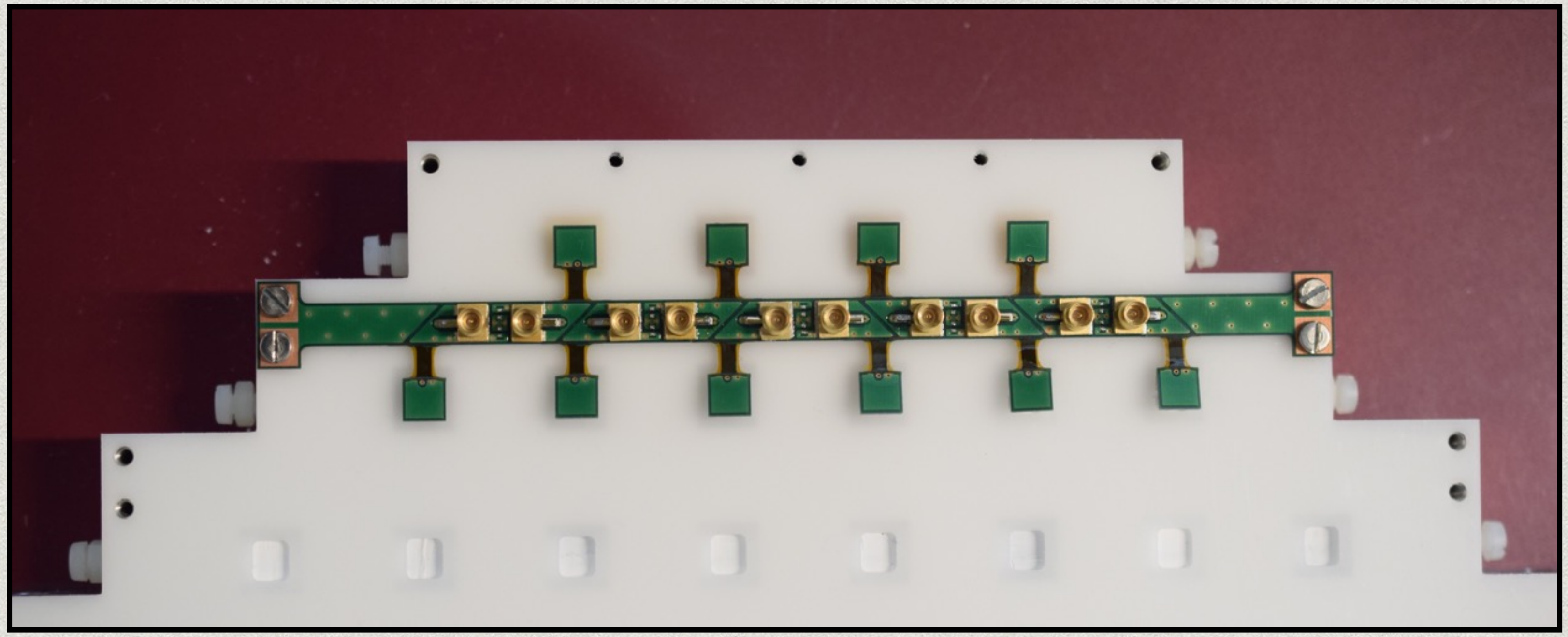
- If current is increased 50μA…

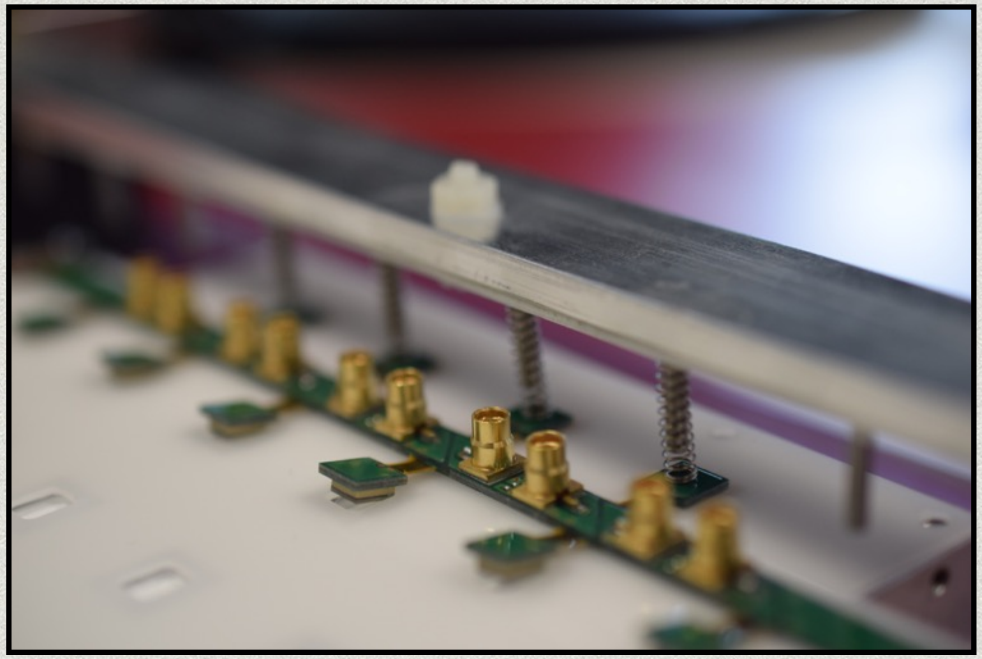
$$N_{\mathrm{AG}} \simeq 401$$

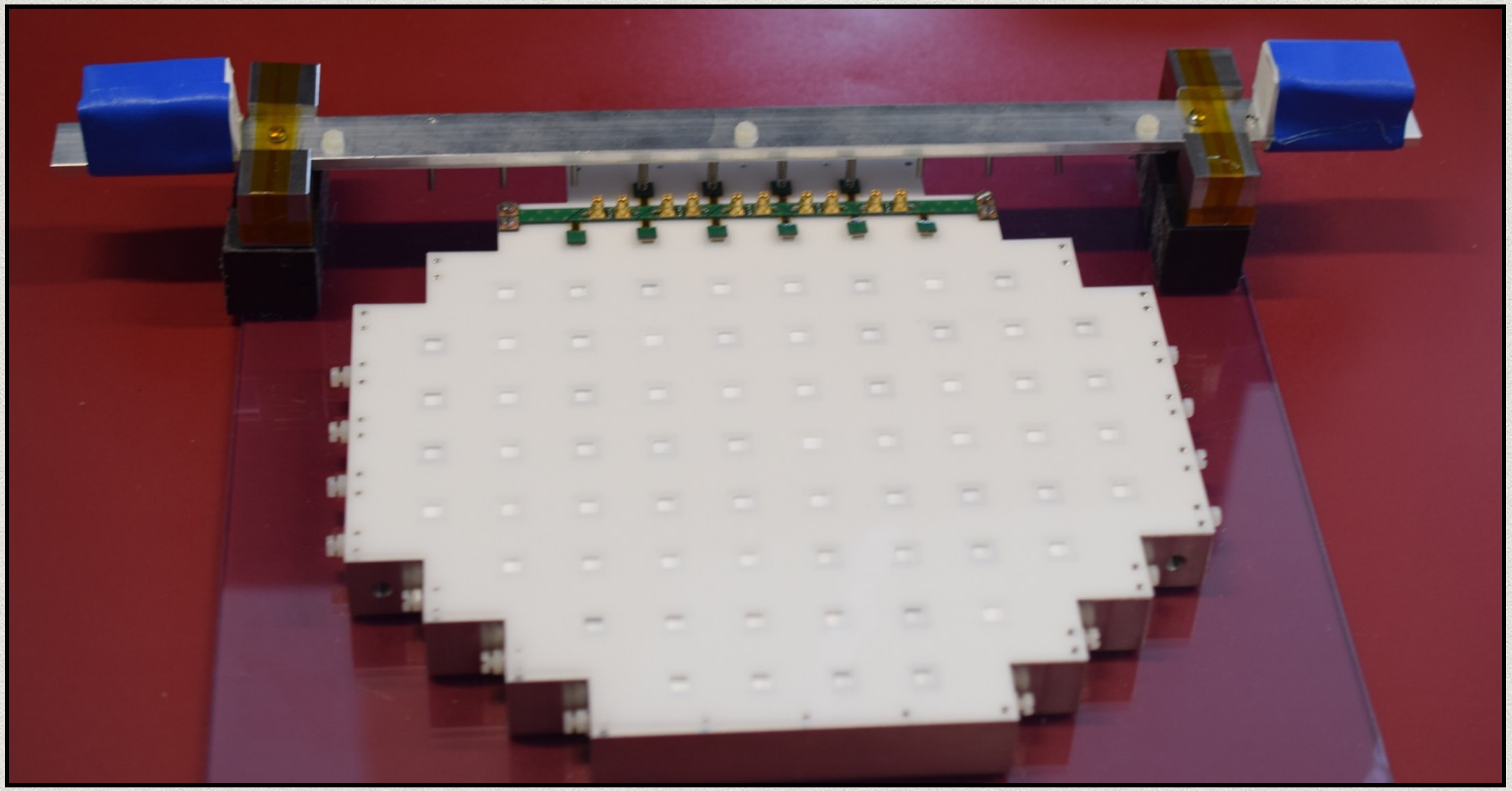
$$N_{\mathrm{sig}} \simeq 3491 - 401 = 3090$$

Resolution gets worse ~0.2%

Pictures of PCB







Springstand