Active converter for pair-spectrometer 2024 beam test

12 Feb. 2025

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Overview of electron beam test of active converter

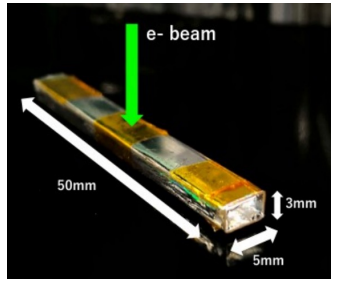
- Reported in detail at last meeting

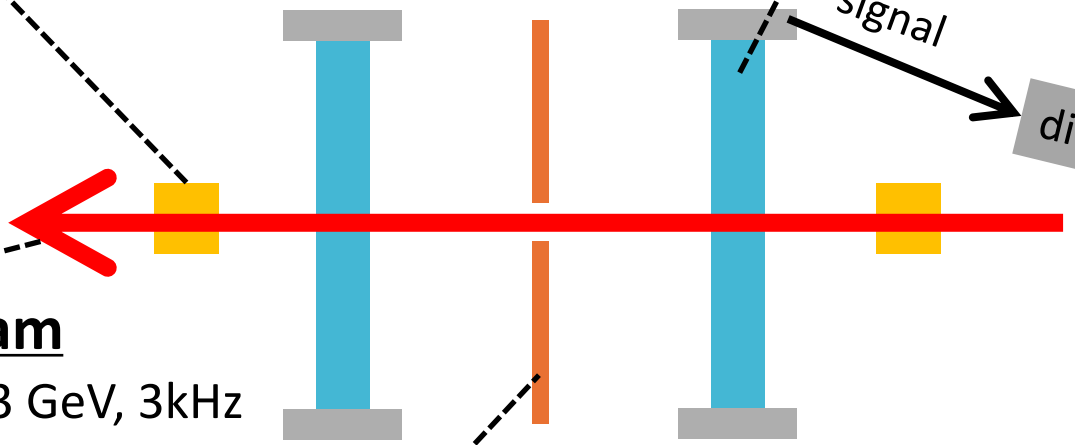
Reference Counter

- for DAQ trigger & time reference
- 5 mm cube plastic scintillator + SiPM

Active converter prototype

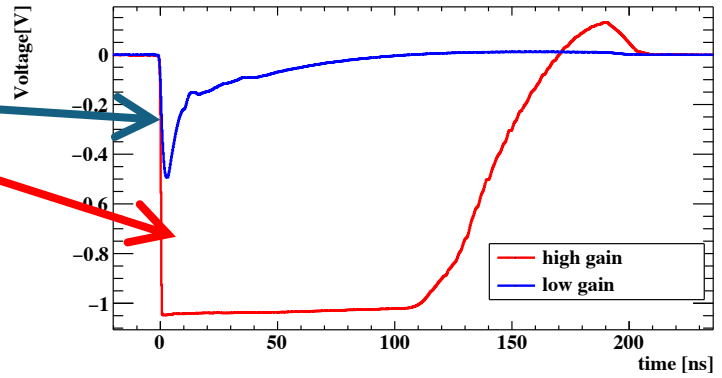
- LYSO + SiPM readout on both edge
- 3 types of SiPMs
- LYSO dimension:
  T=3(1.5) mm, W=5 mm, L=50 mm





DAQ

typical waveform



- WaveDREAM Board (4-5 GHz sampling
- Divide signal and record with high&low gain at the same time

electron beam

- about 3 GeV, 3kHz
- at KEK

VETO counter

- for offline analysis (veto multiparticle events)
- plastic scintillator + SiPM

Time resolution analysis

- Time pick up by leading edge method on high-gain channel
  - Threshold is scanned to find the optimal value

- Time walk correction using charge on low-gain channel

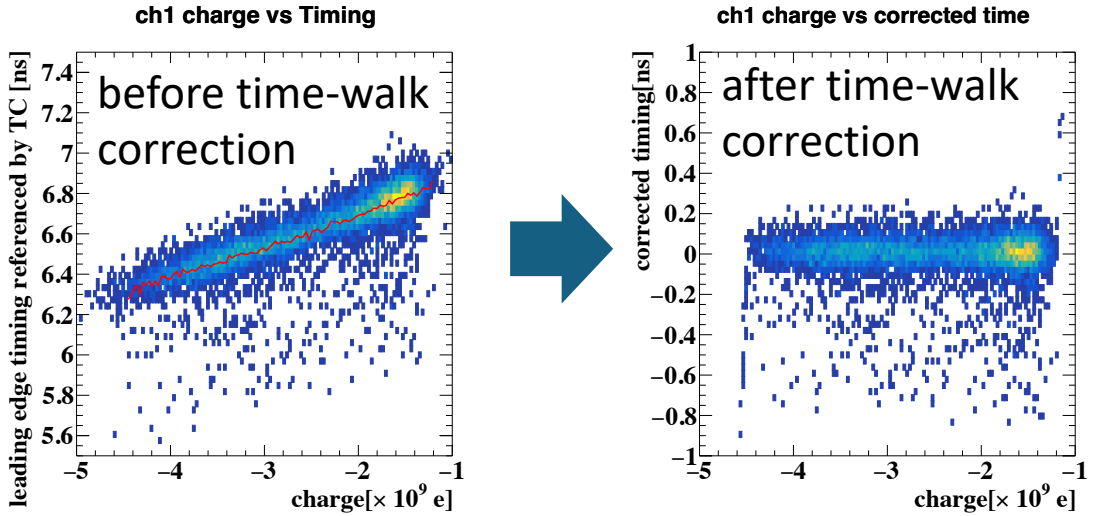
- single counter time resolution

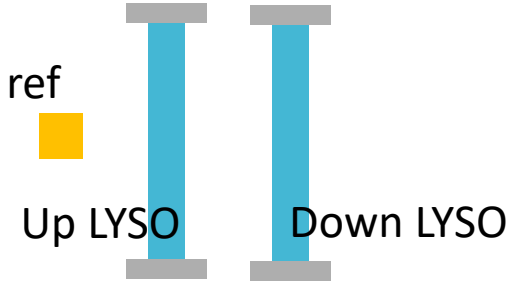
$$\sigma(t_{up\ LYSO} - t_{ref}) = \sqrt{\sigma(t_{up\ LYSO})^2 + \sigma(t_{ref})^2}$$

$$\sigma(t_{down\ LYSO} - t_{ref}) = \sqrt{\sigma(t_{down\ LYSO})^2 + \sigma(t_{ref})^2}$$

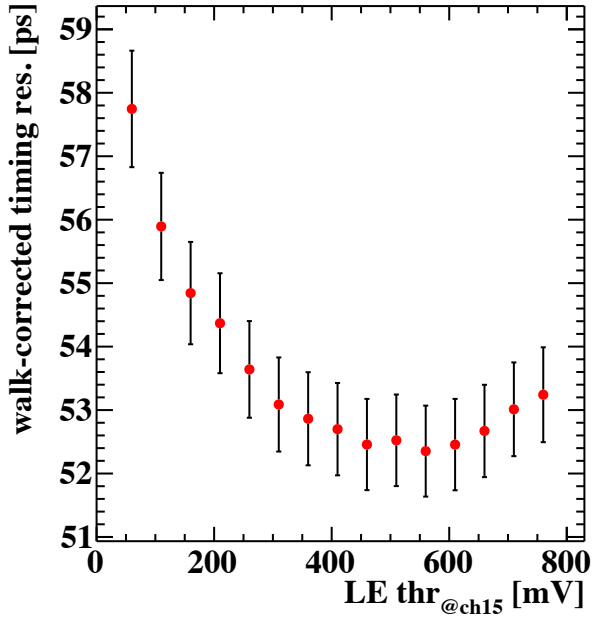
$$\sigma(t_{up\ LYSO} - t_{down\ LYSO}) = \sqrt{\sigma(t_{up\ LYSO})^2 + \sigma(t_{ref})^2}$$

➡ Solve and obtain $\sigma(t_{up\ LYSO}), \sigma(t_{down\ LYSO}), \sigma(t_{ref})$

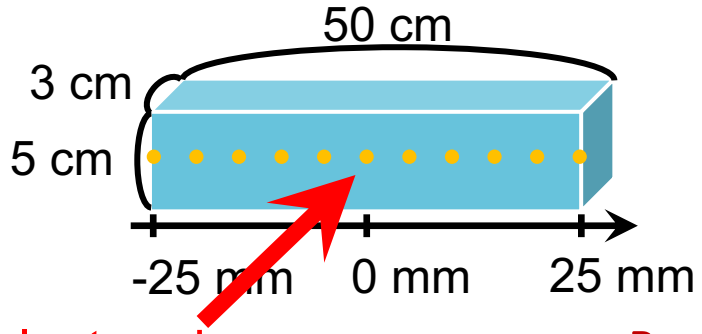


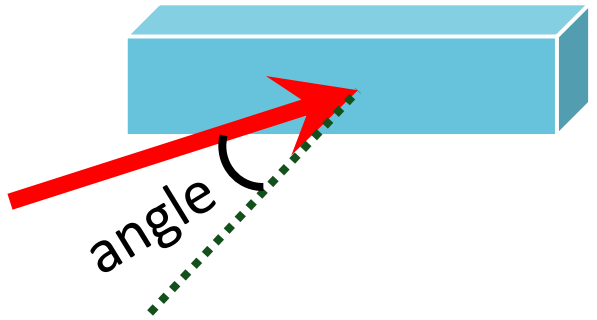


example of leading-edge threshold scan

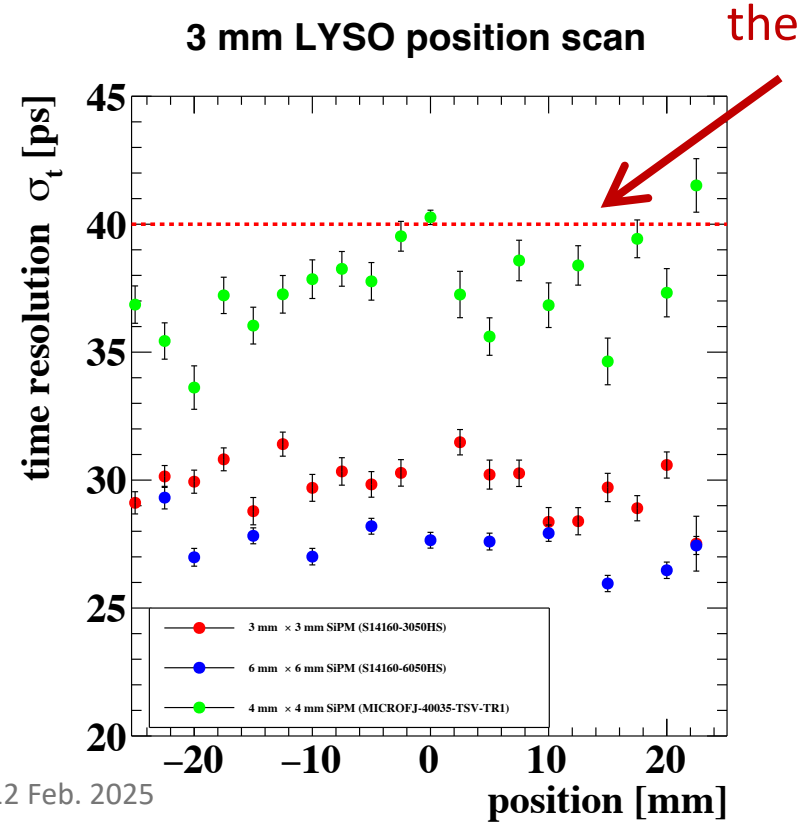


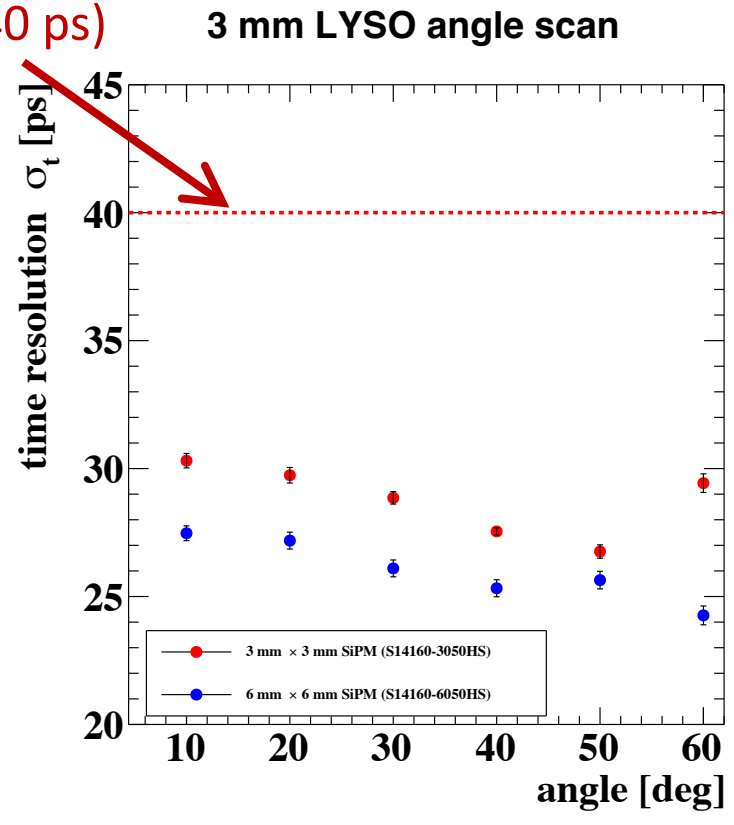
Time resolution results



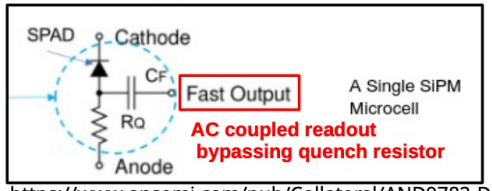


Requirement for
the future experiment (40 ps)





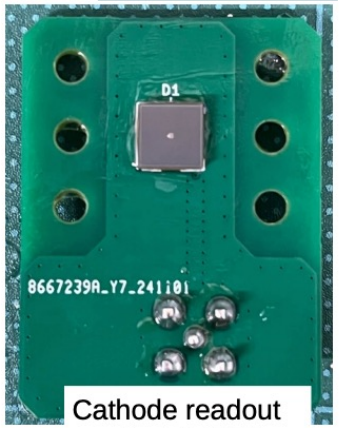
Comparison of readout SiPMs



https://www.onsemi.com/pub/Collateral/AND9782-D.PDF

6 mm × 6 mm 50 μm pitch Hamamatsu MPPC

S14160-6050HS

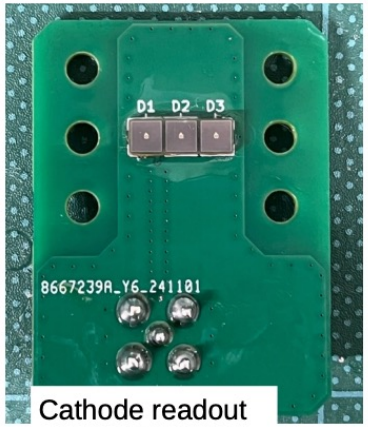


3x5x50 ㎣ LYSO with 6x6 ㎟ MPPC

- 100 % coverage of LYSO crystal crossection
- Best resolution (<30 ps)

3 mm × 3 mm 50 μm pitch Hamamatsu MPPC

S14160-3050HS

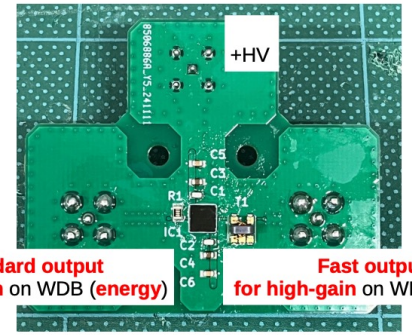


3x5x50 ㎣ LYSO with 3x3 ㎟ MPPCs

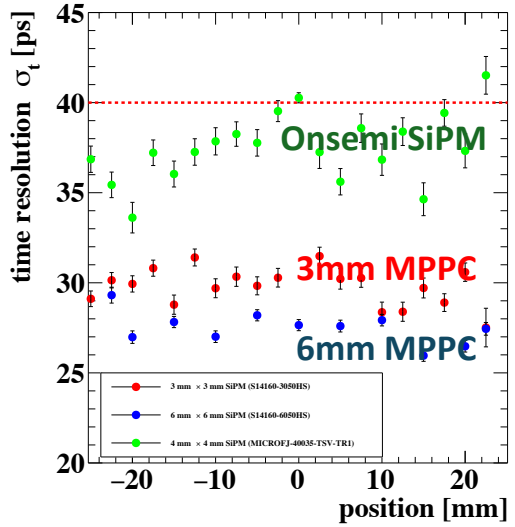
- Connected in series
- Small inactive area (gap between MPPCs)
- Best resolution (<30 ps)

4 mm × 4 mm 35 μm pitch Onsemi SiPM

MICROFJ-40035-TSV-TR1



MICROFJ-40035-TSV-TR1
Onsemi
4x4 ㎟ / 35 um pitch
Fast output for timing measurements



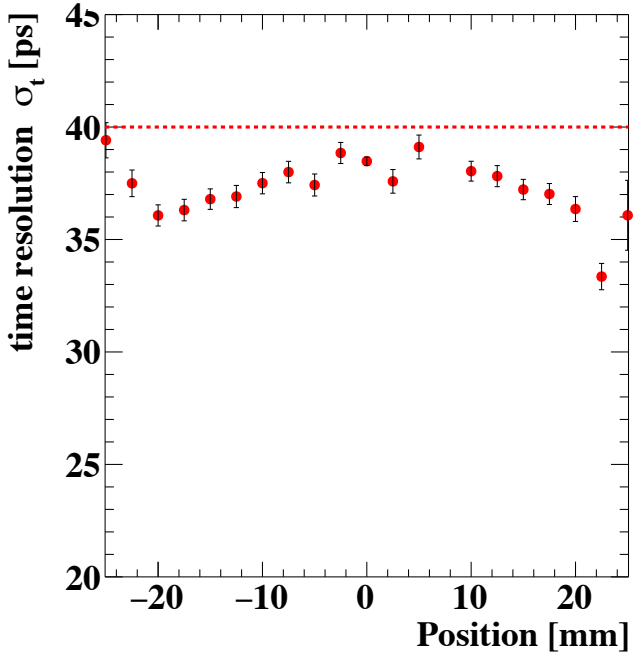
3x5x50 ㎣ LYSO with 4x4 ㎟ SiPM

- Unique feature of having “fast output”
- However, time resolution was the worst among three

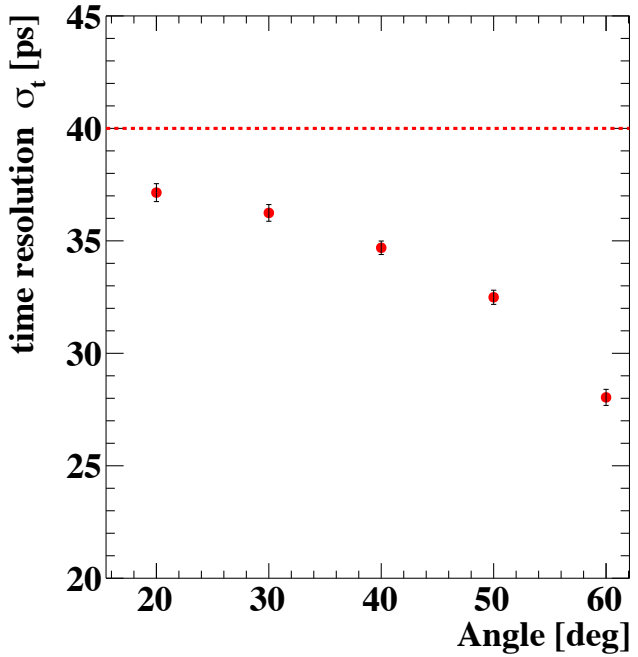
Time resolution with half thickness LYSO

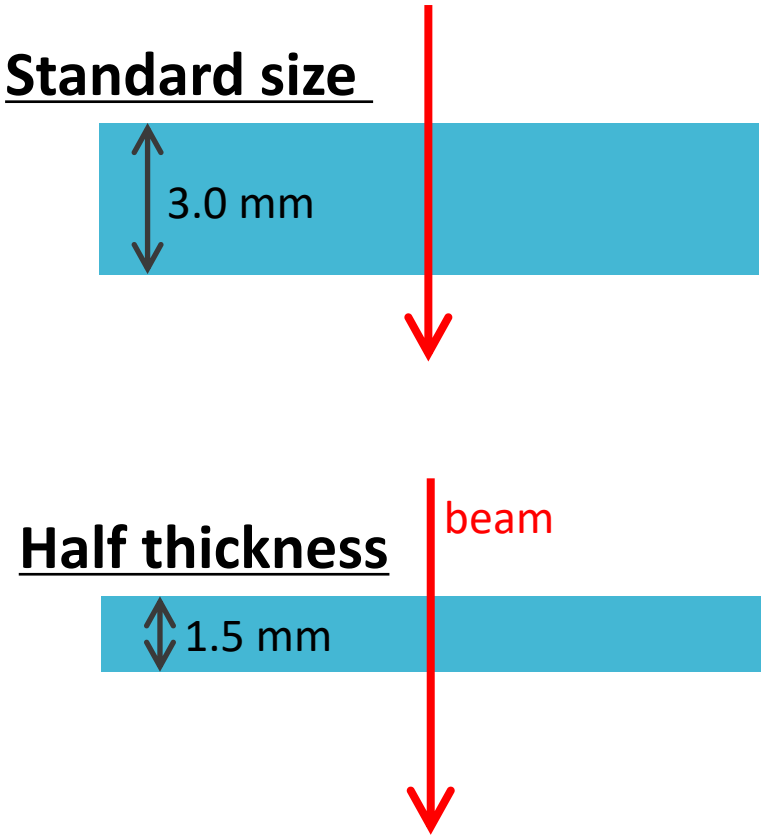
- Also tested with LYSO of half thickness (1.5 mm)
  - worse resolution due to the less light yield
- 40 ps time resolution was still achieved over all beam injection position & angle

position scan



angle scan



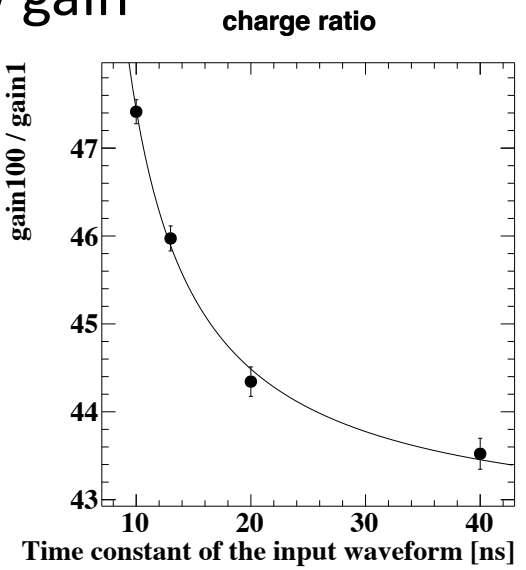


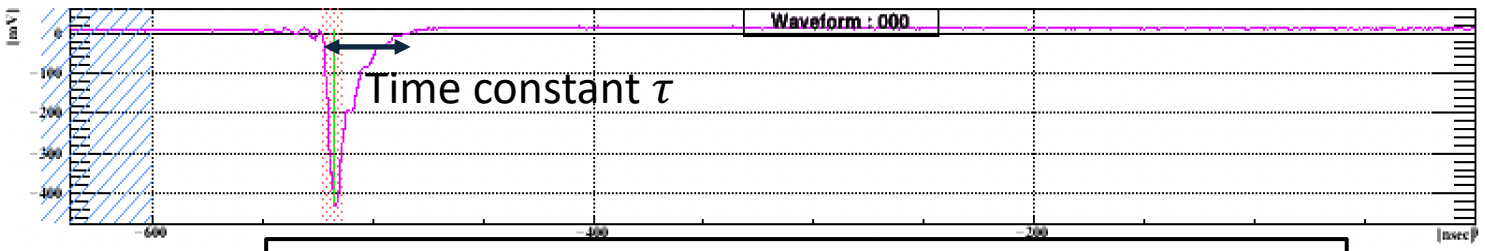
Light yield analysis

- Conversion from charge Q -> photoelectron $N_{\mathrm{p.e.}}$

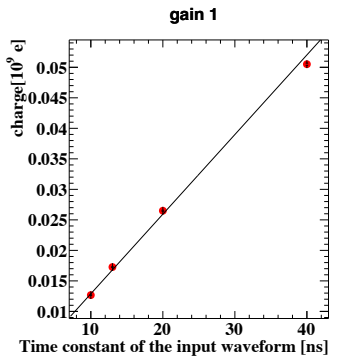
$$N_{\mathrm{p.e.}} = \frac{Q \text{ at WDB low gain}}{\text{single photoelectron gain WDB high gain}} \times \frac{\text{WDB high gain}}{\text{WDB low gain}}$$

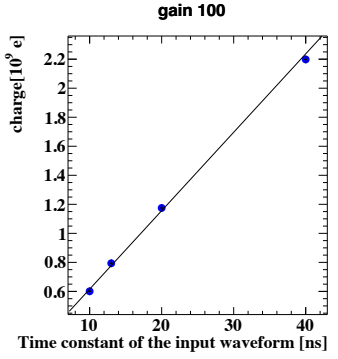
- WDB high-gain/low-gain
  - Nominal value : low-gain = 1, high-gain = 100
  - Measured actual high/low ratio with function generator exponential waveform input
  - Found to be frequency dependent … high/low = 34 ~ 42





Exponential waveform made with function generator

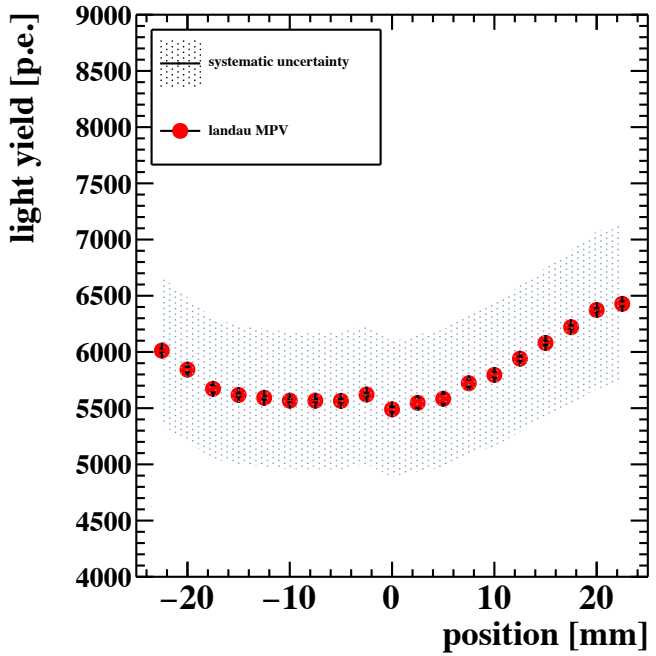


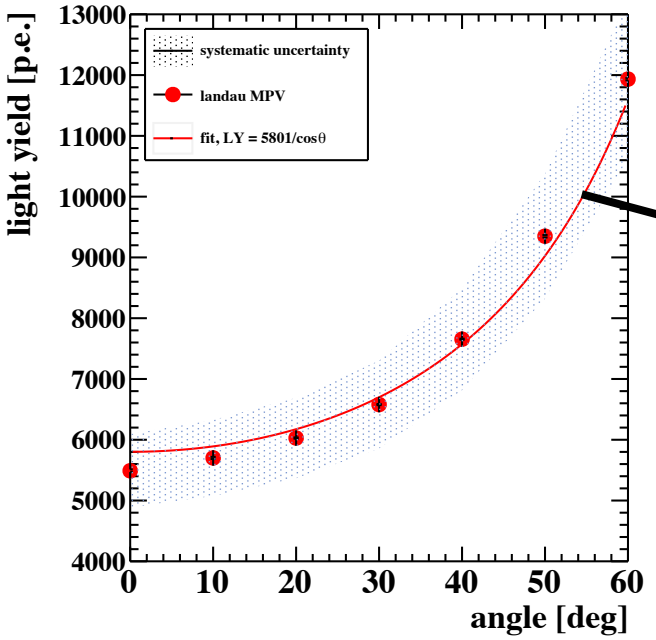


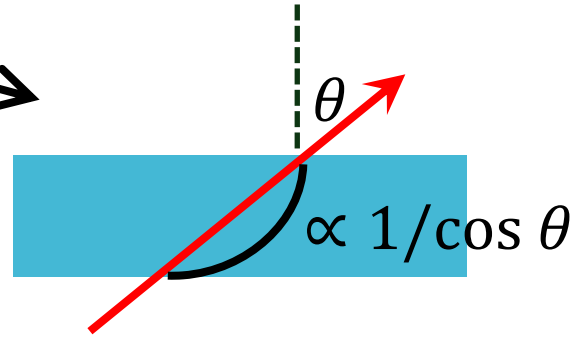
Light yield results

- Result with 3 mm MPPC : $N_{p.e.} = 5000 - 7000$ over all crystal region (perpendicular injection)
- Requirement for future experiment

$$\frac{\Delta E}{E} = \frac{E_{\gamma,\mathrm{sig}}(=52.8\ \mathrm{MeV}) \times 0.4\%}{2 \times E_{e^{\pm}\mathrm{deposit}}(\simeq 3\ \mathrm{MeV})} > \frac{1}{\sqrt{2 \times N_{p.e.}}} \Rightarrow N_{p.e.} > 500$$



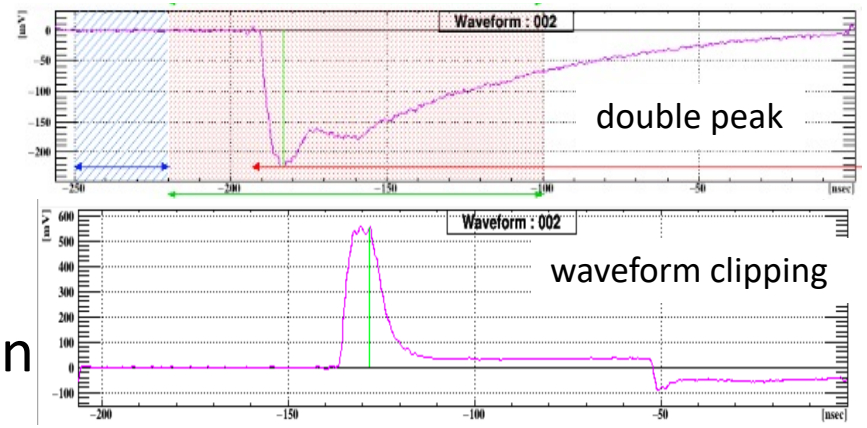




Summary & prospect

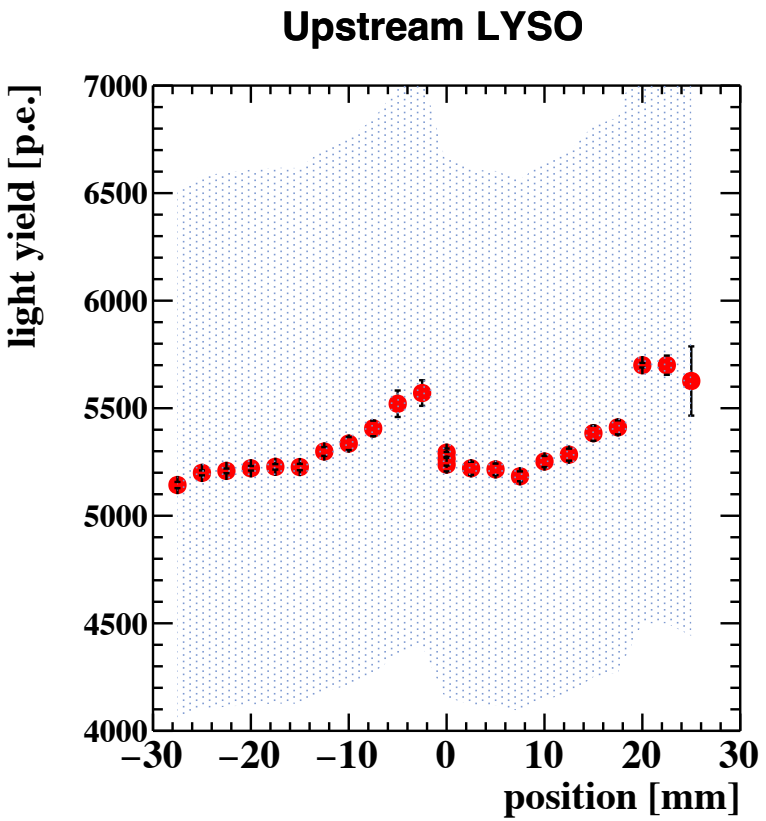
- 3 GeV Electron beam test with active converter was done.
- Time resolution
  - 25-35 ps was achieved with 3mm thickness LYSO + Hamamatsu MPPC readout
  - 1.5 mm thickness could still achieve 40 ps goal
- Light yield
  - 5000 - 7000 photoelectron achieved with 3 mm thickness LYSO
    → enough for future μ→eγ energy resolution requirement for gamma (0.4 % at 52.8 MeV)
- Prospect
  - Strange waveform observed with some SiPM data
    - Causing unreasonably large charge
    - WDB characteristics(e.g. pole-zero cancellation, amplification) seems to be related
      → Further investigation needed
  - Evaluation of actual energy deposit using LYSO self-radiation

Example of strange waveform

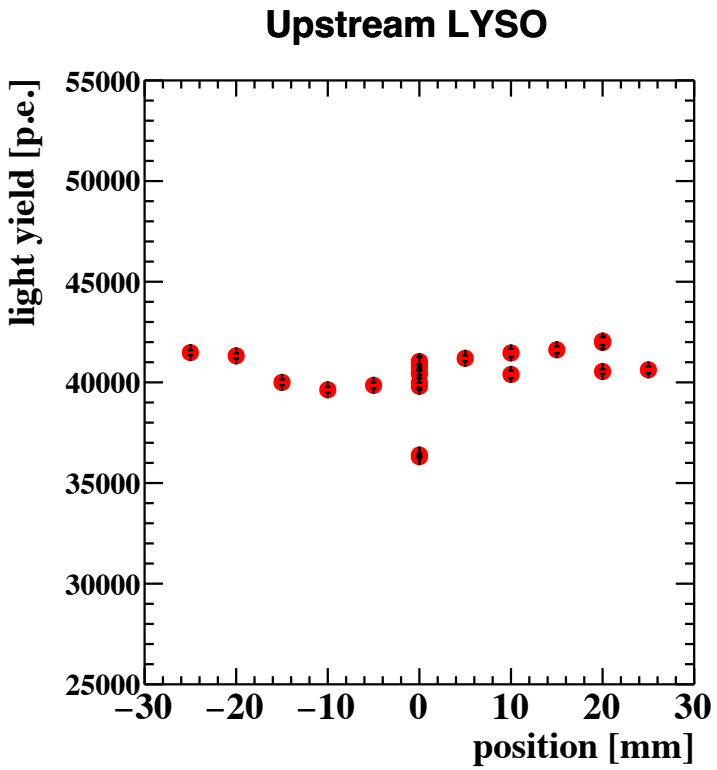


backup

4 mm Onsemi SiPM

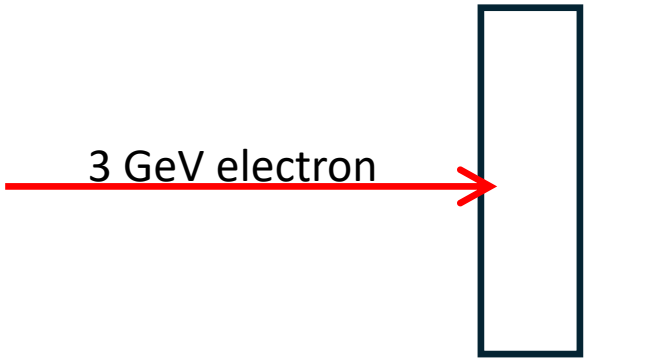


6 mm MPPC

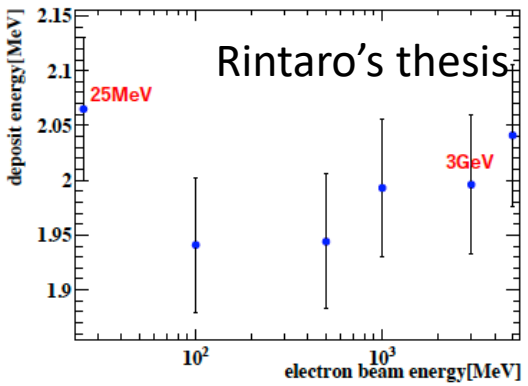


Expected number of photoelectrons

- Total energy deposit by 3 GeV electron beam
  - Simulation (I did in the new PIONEER based framework) : 2.76 MeV
  - Simulation result in Rintaro's thesis : ~ 2 MeV
  - Literature value 1.12 MeV/mm ->3.36 MeV
- Light output for FTRL LYSO : $30000 \pm 10\%$ Ph/MeV
- PDE : ~ 50% (catalog value)



- Therefore, the expected number of photoelectrons is $45000 \times$ (light collection efficiency)
  - For 3 mm MPPC, 4500 pe observed -> light collection efficiency = 10 %
  - For 6 mm MPPC, 40000 pe observed -> light collection efficiency = 89 % … not realistic



(a) シミュレーションによって算出した LYSO に対する入射電子のエネルギーごとの電子のデポジットエネルギー (平均) の分布。横軸は対数スケール。