Performance evaluation of LYSO as active converter

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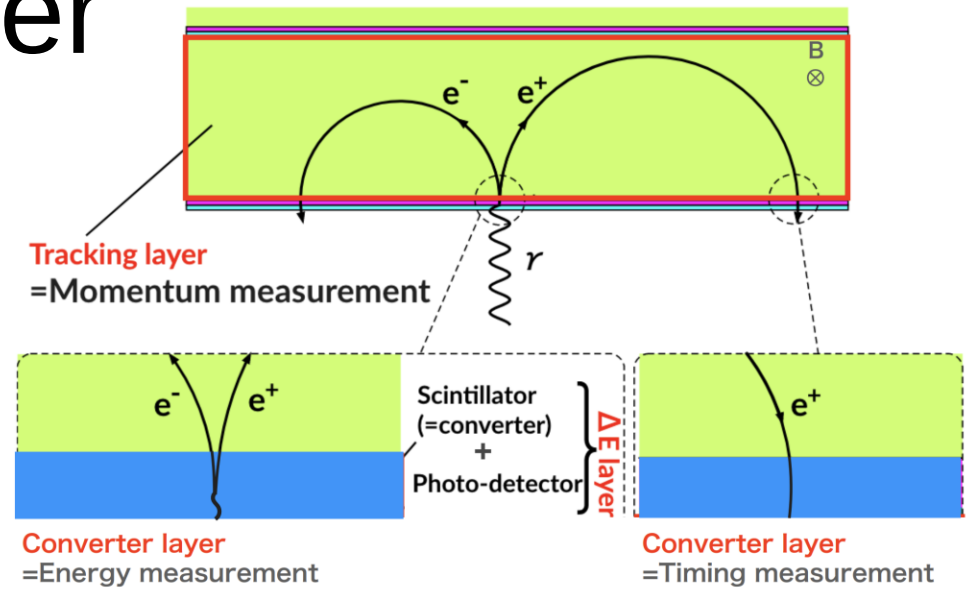
Pair spectrometer with active converter



- Photon pair spectrometer is considered as a high-performance gamma-ray detector.
- By making the converter layer an active material, the energy loss in the converter, which is a drawback of the pair spectrometer, can be measured to achieve high energy resolution.
  Active converter can work as timing detector too.

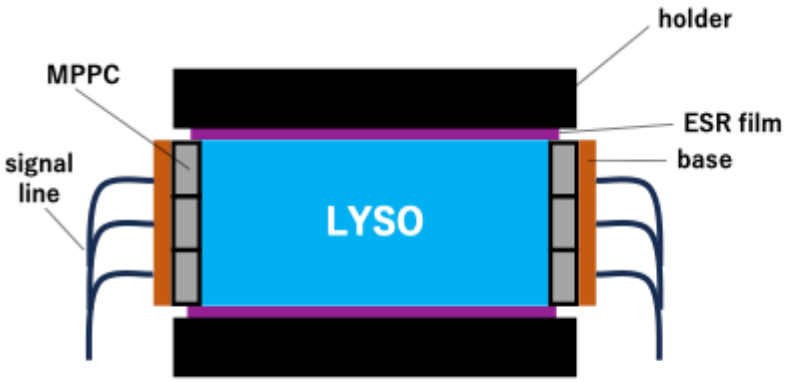
Performance requirement

- **Target performance for pair spectrometer**
  : $\Delta E_\gamma = 200\ \mathrm{keV}, \Delta t_\gamma = 30\mathrm{ps},\ \Delta x_\gamma = 0.2\mathrm{mm}$
- **Required performance for active converter (3mm, LYSO crystal)**
  : $\Delta E_\gamma = 200\ \mathrm{keV}$ → 500 photo-electrons per electron (positron)
  $\Delta t_\gamma = 30\mathrm{ps}$ → 42ps per electron (positron)

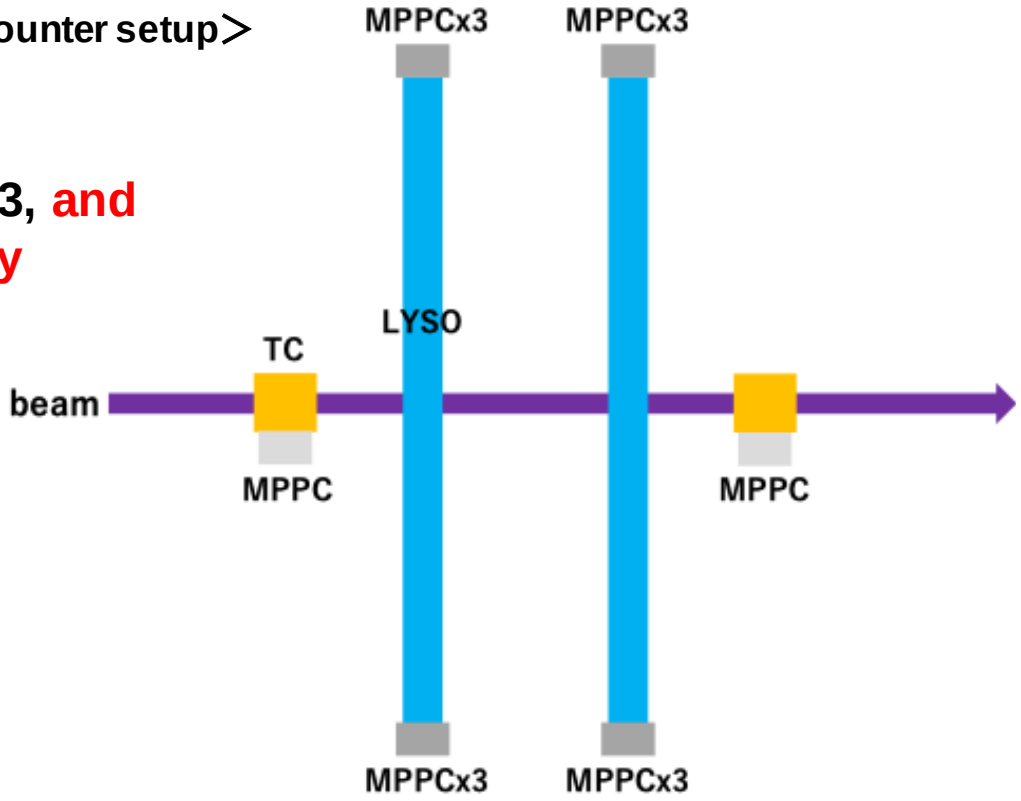
→ We measured the performance of the LYSO converter at electron beam 3GeV/c at KEK PF-AR test beamline

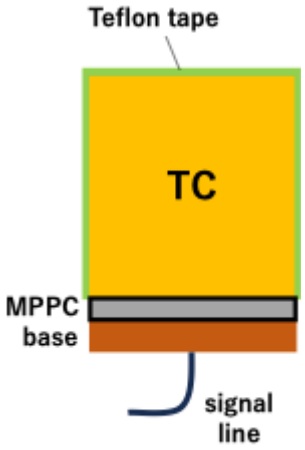
Setup

The test period is 12/10-12/17, 2023, and the results for this time and energy resolution are preliminaries.



＜counter setup＞

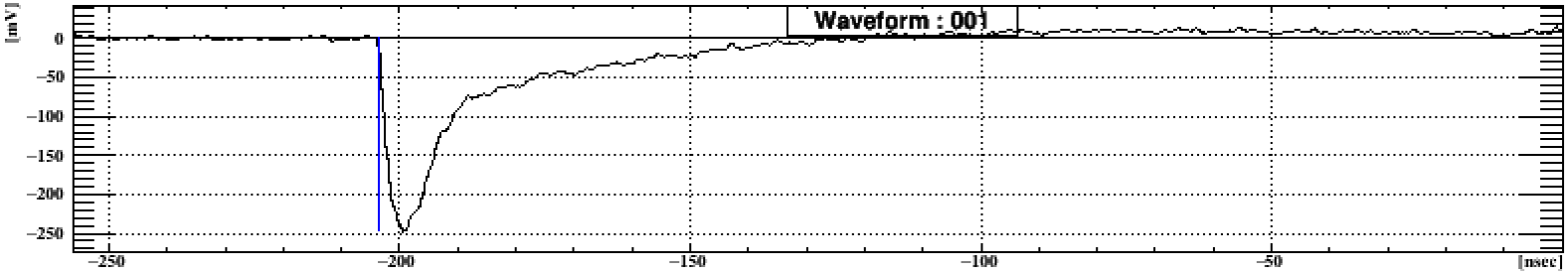




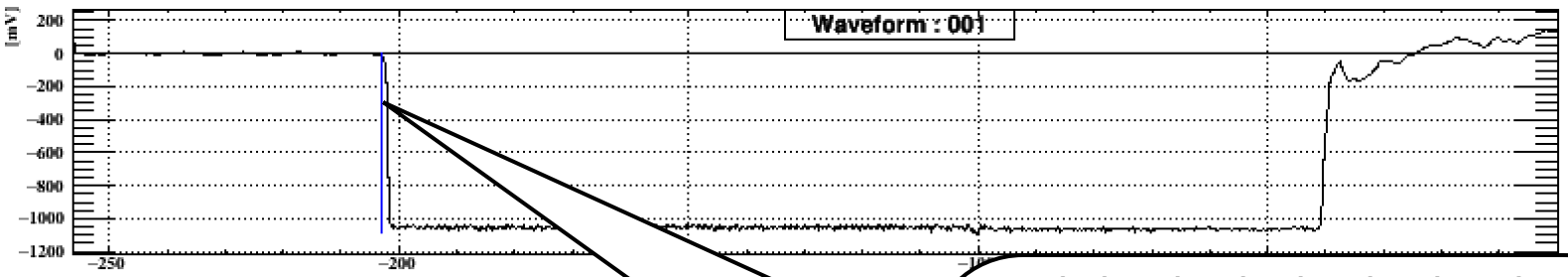
- - Configuration
  - LYSO size: 3x5x50, 1.5x5x50, 3x10x50, 3x5x100
  - LYSO type: NORMAL, FTRL
  - MPPC
    - pixel pitch: S14160-3050HS, S14160-3010PS(3015PS)
    - Connection: independent, series
  - Position scan: ±50mm(100mm), length direction
  - Angle scan: 30 ~ 90(vertical) deg

Timing measurement

- **3x5x50, gain 0.5**



- **3x5x50, gain 50**



- **Key Points for Timing Measurement**
  - **Scintillation light arrives at MPPC with a certain time width**
  - **For good time resolution, we want to focus on early arrival photons.**
- **DAQ Approach**
  - **Amplify the waveform and focus on the EARLY arrival photon**

- Timing is obtained using the **LE method**
- The LE method defines the rise time of a signal as the time it exceeds a certain threshold
- Timing resolution:

$$\sigma_{t_{LYSO}} = \sigma\left(\frac{t_{right} - t_{left}}{2}\right)$$

  - $t_{right/left}$: Time taken at the right (left) end of LYSO

Photoelectron statistics for energy loss measurement

- The light intensity for all LYSO sizes was sufficient to meet the required light intensity of 500 p.e. (130 p.e. at 1.5 mm) and the energy resolution of 200 keV for active converters

▪ Type

	[p.e.]	σ(E) [keV]
3x5x50(FTRL)	1720	130
3x5x50(NORMAL)	2160	120

NORMAL light intensity was greater than FTRL.

▪ Thickness

	[p.e.]	σ(E) [keV]
3x5x50(FTRL)	1720	130
1.5x5x50(FTRL)	978.0	110

At 1.5 mm thickness, light intensity decreased in proportion to thickness

▪ Length

	[p.e.]	σ(E) [keV]
3x5x50(FTRL)	1720	130
3x5x100(FTRL)	1560	140

100m length may have low light intensity due to scintillation light attenuation

▪ Width

	[p.e.]	σ(E) [keV]
3x5x50(FTRL)	1720	130
3x10x50(FTRL)	2210	120

The 10 mm width has a small MPPC insensitive area ratio to LYSO sides. Also, the light intensity may be higher due to the wider width and higher light collection ratio

Timing resolution

- The 3 mm LYSO (FTRL) achieved a time resolution of 42 ps for all sizes
- The results for the different sizes were generally consistent with the light intensity
  - LYSO is a material with high luminous flux and good time resolution due to its large p.e. number.

・Type

	time resolution[ps]
3x5x50(FTRL)	37
3x5x50(NORMAL)	45

FTRL had better time resolution than NORMAL

・Thickness

	time resolution[ps]
3x5x50(FTRL)	37
1.5x5x50(FTRL)	51

Light intensity is reduced compared to 3 mm thickness, and time resolution is also deteriorated.

・Length

	time resolution[ps]
3x5x50(FTRL)	37
3x5x100(FTRL)	40

Time resolution is thought to be deteriorated by light attenuation in the longitudinal direction

・Width

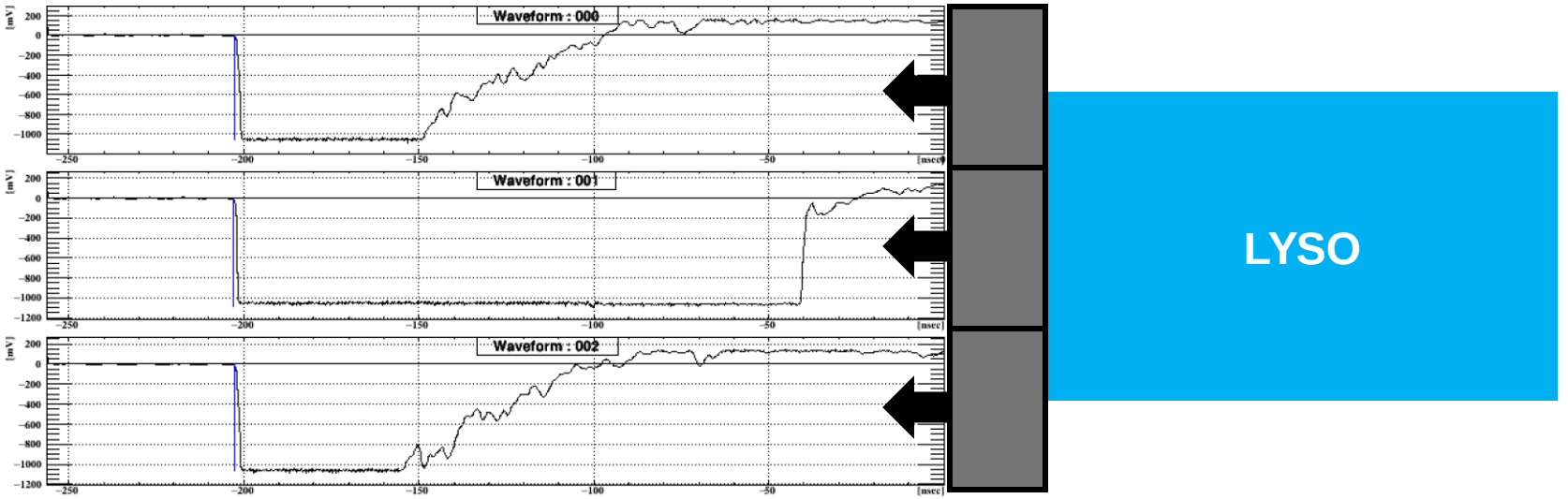
	time resolution[ps]
3x5x50(FTRL)	37
3x10x50(FTRL)	29

Time resolution is considered to be good due to the small ratio of the MPPC insensitive area to the LYSO side and the high light collection rate.

Timing resolution

3x5x50(FTRL)	independence[ps]	series[ps]
10um	68.2	56.8
15um	42.8	38.8
50um	28.6	26.4

- The best readout method was a combination of 50um pixel size with large gain & series connection with good time response.
- Also, the series connection has less influence on time walk than independent readout because there is no variation in waveform size (however, this may not change depending on time walk correction).



independent readout

Summary

- **Time resolution: 25 ps**
- **Energy resolution: 120 keV (2200p.e.)**

  → **Satisfies requirements well**

[Measurement status]

- 3GeV electron beam vertically injected into the center of LYSO
- LYSO(FTRL type): 3x10x50[mm^3] size
- Light detection method: MPPC(S14160-3050HS) connected in series with 3 channels on the side of LYSO

→ Time resolution is calculated from the time difference between the two sides

It was found that
sufficient performance could be achieved in future experiments.