Active Converter Study

W. Ootani

on behalf of UTokyo group

Jan. 25th, 2023

Pair Spectrometer with Active Converter

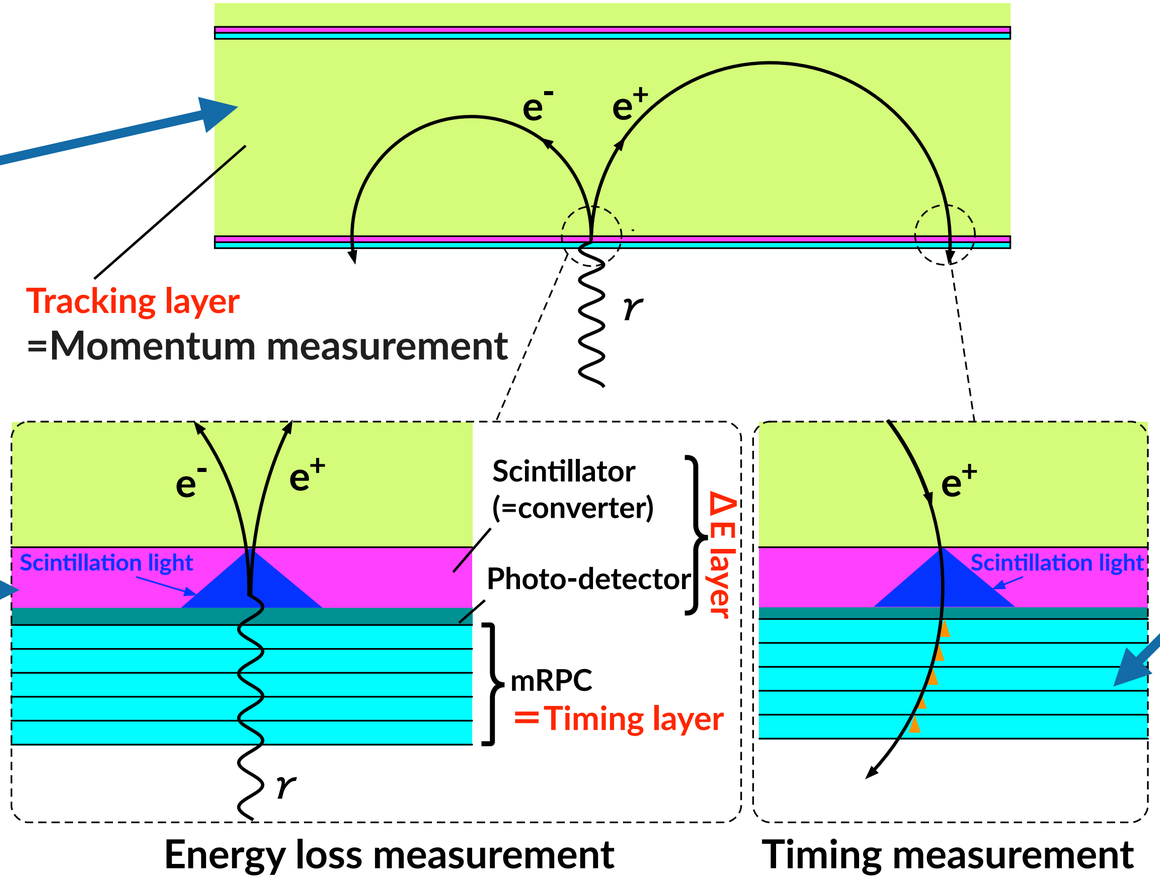
Reminder

Tracking layer

- Measure momentum of conversion pair
- Possible technologies
  - Drift chamber (a la MEG II CDCH)
  - Radial-TPC
  - Silicon detector

Active converter (ΔE layer)

- Thin active material to measure energy loss of conversion pair
- Possible technologies
  - Scintillator + photo-detector
  - Silicon detector



Timing layer

- Measure timing of returning conversion pair
- in front of active converter
- Possible technologies
  - Multi-layer RPC (mRPC)
  - Active converter = timing detector

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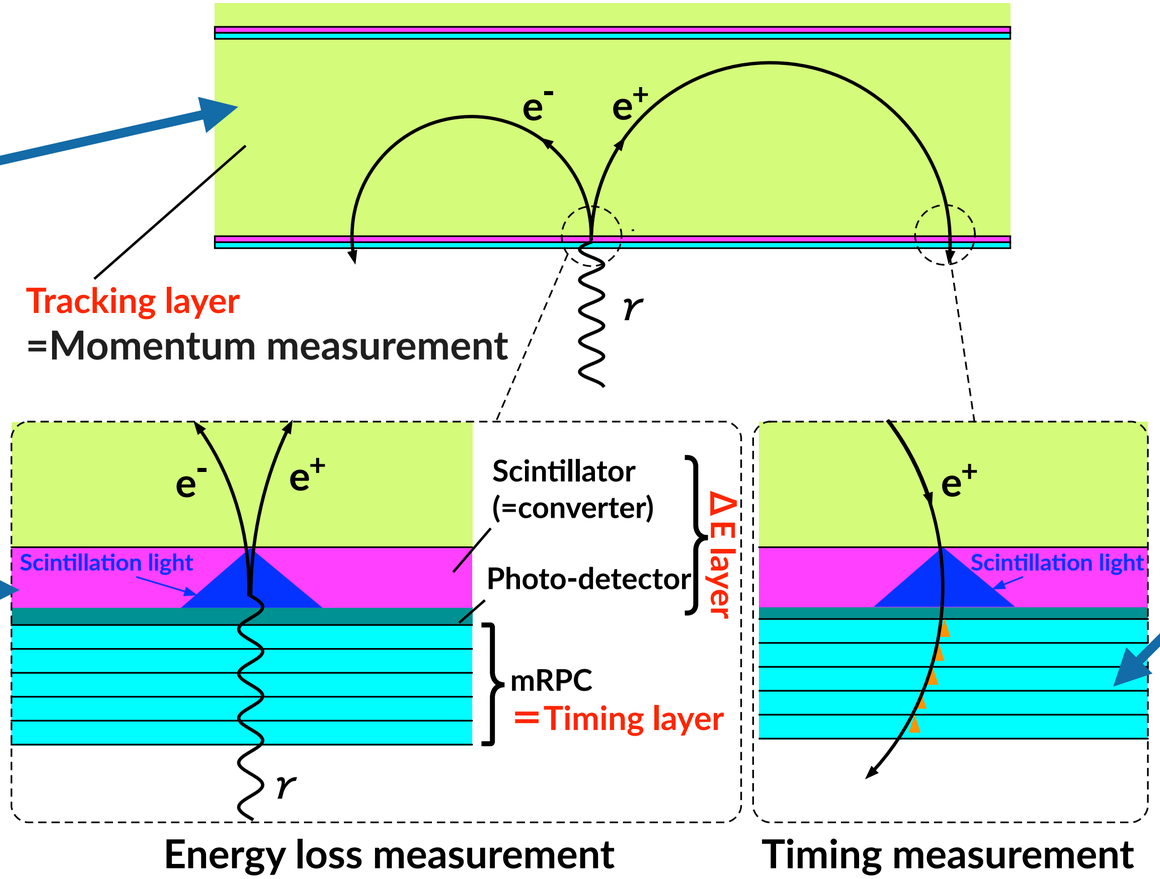

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Active Converter

Technology Options

- Scintillator as active converter material
  - Crucial parameters
    - Light yield → energy resolution
    - Decay time → high rate capability
    - Radiation length → detection efficiency
    - Critical energy → effect of bremsstrahlung (difficult to measure)
    - Cost
- Photo-sensor for scintillation readout
  - Requirements: high light detection eff. + low mass
  - Photo-detector under consideration
    - Gas PM
    - SiPM

Crystal	NaI	LYSO(Ce)	$LaBr_3$(Ce)	YAP(Ce)	Plastic scintillator	Silicon
Density [g/cm^3]	3.7	7.4	5.1	5.4	1.0	2.3
Light yield (relative to NaI)	100%	75%	160%	70%	30%	-
Peak Emission [nm]	415	420	380	370	400	-
Decay time [ns]	230	40	16	27	2-4	-
Radiation length [cm]	2.6	1.1	1.9	2.7	43	9.4
Critical energy* [MeV]	13	12	12	23	93	39
Hygroscopicity	Yes	No	Yes	No	No	-

* Critical Energy Ec: Ionisation ≲ Brems if E ≳ Ec

Active Converter

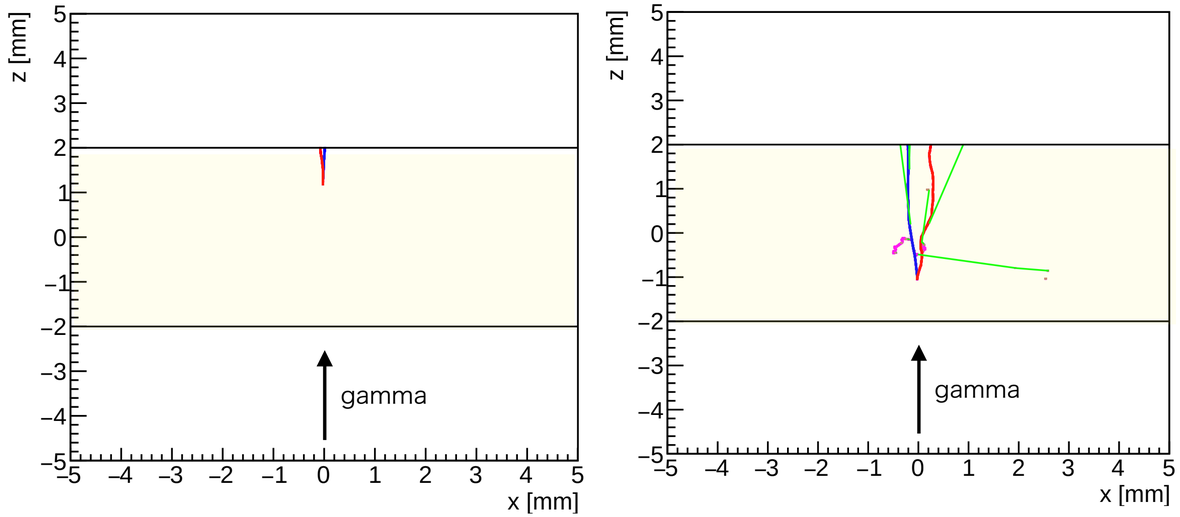
Simulation Study

S. Ban, R. Yokota

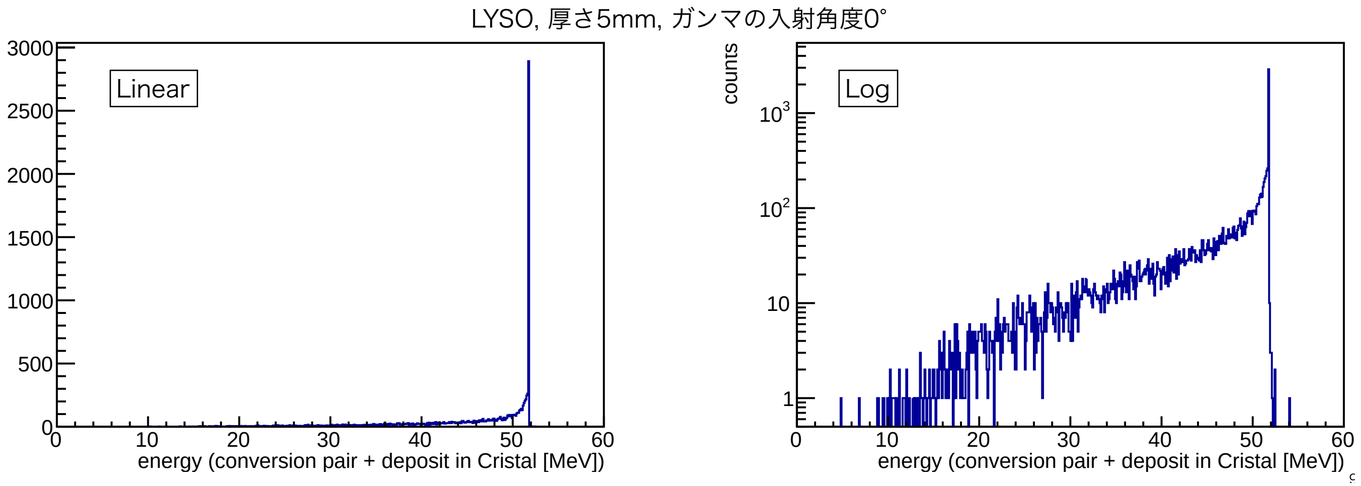
- Started simulation study with simple setup
- Estimate total energy which can be measured with converter + tracker
  - Efficiency is estimated with event fraction for

$$E > (52.8\,\mathrm{MeV} - 2 \times m_e) - \delta E$$

(Target energy resolution: $2\delta E = 0.2\,\mathrm{MeV}$)



blue : electron (conversion)
red : positron (conversion)
magenta : electron (ionization)
brown : electron (photo-absorption)
green : photon



Active Converter

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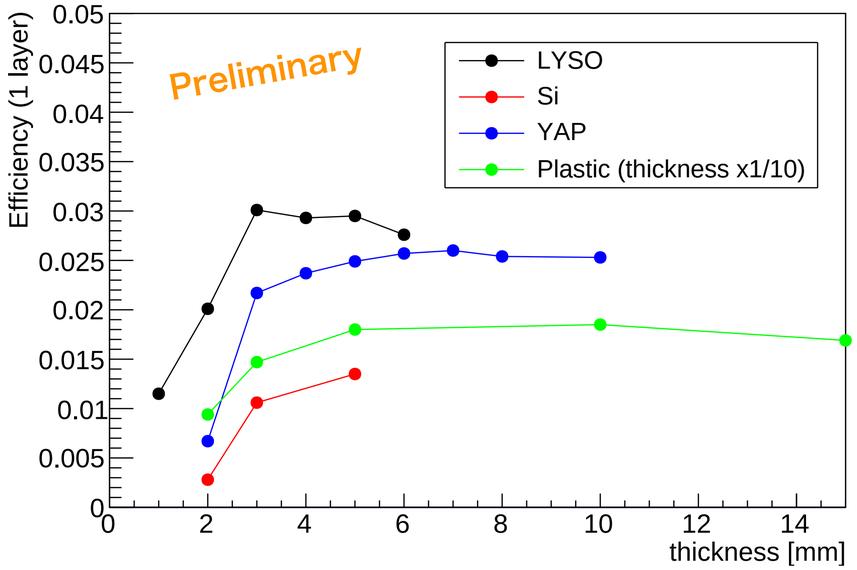
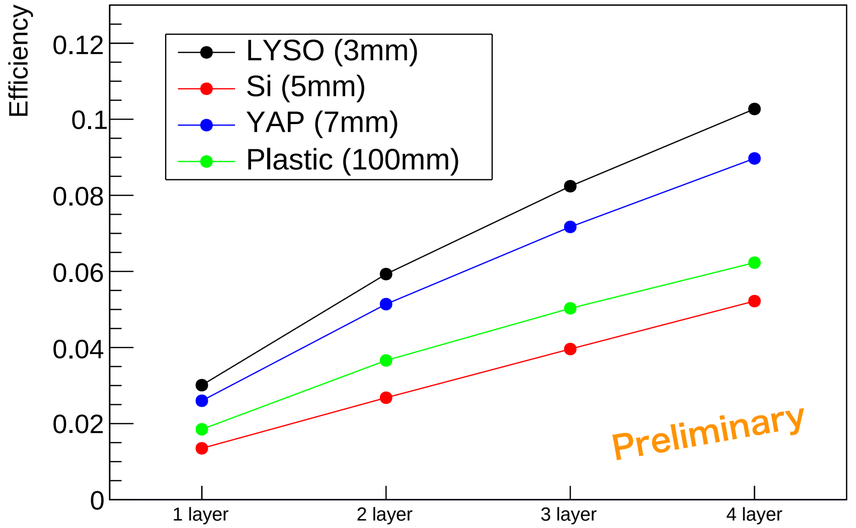
Simulation Study

- Efficiency
  - Efficiency saturates with increasing thickness due to energy escape by increasing bremsstrahlung and loss of conversion pair
  - Heavy crystal has a higher detection efficiency despite lower critical energy ← Some of bremsstrahlung can be absorbed in converter
  - 10% with 4 layers of LYSO(3mm-thick)

    (N.B. Effect of pileup hit of returning conversion pair is not taken into account)





Active Converter

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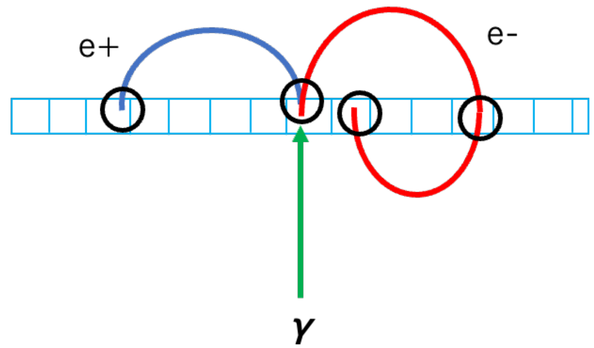
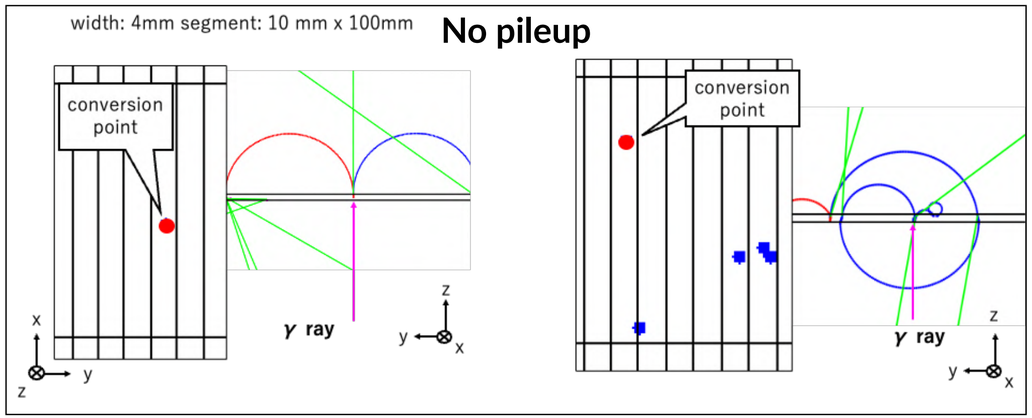
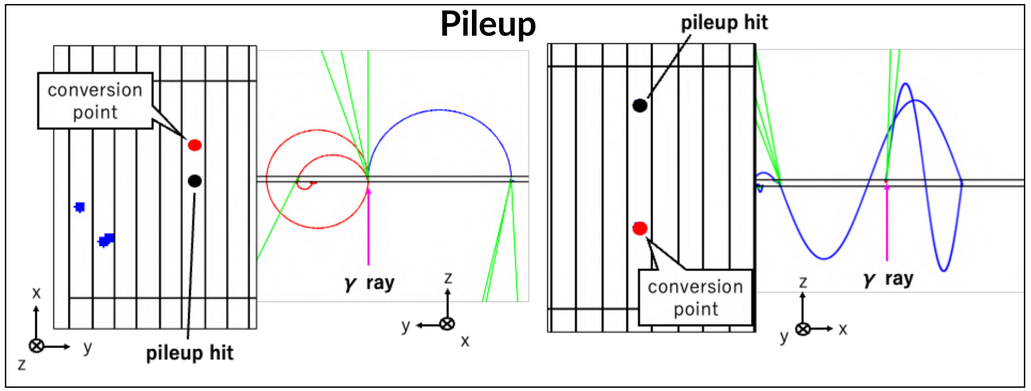
Simulation Study

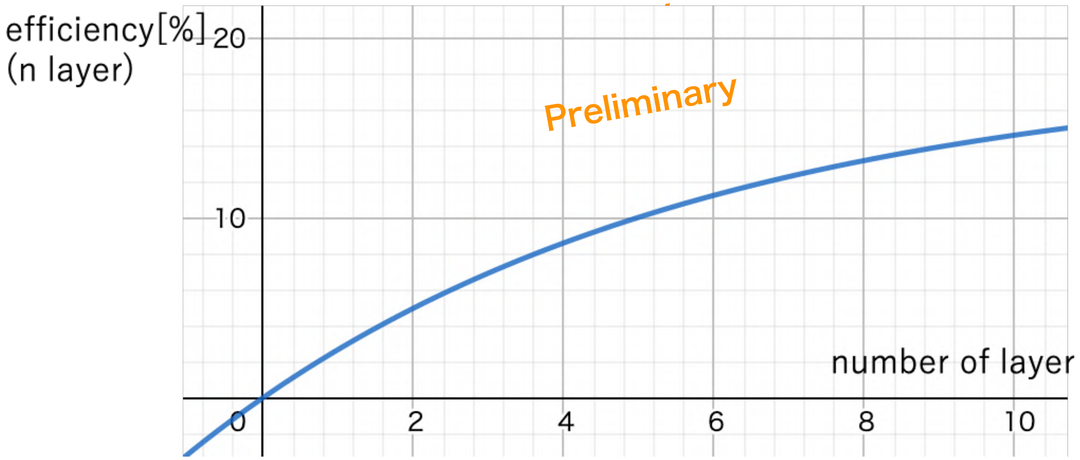


- Segmentation
  - Segmentation to best mitigate pileup by returning conversion pair
  - Optimisation of segmentation is in progress. Observed slight worsening of efficiency.





Segment size: $12.5 \times 25 \times 4\,\mathrm{mm}^3$



1 layer: efficiency = 2.7%
5 layer: efficiency = 10%
10 layer: efficiency = 15%

Active Converter

Energy Resolution

- Expected photoelectron statistics for LYSO + SiPM
  - Mean energy deposit for MIP (3mm-thick LYSO): 3.36MeV → 6.72MeV for conversion immediately after incidence
  - Light yield: $4 \times 10^4\,\mathrm{photons/MeV}$
  - 2200 p.e. measured with $30 \times 30 \times 4\,\mathrm{mm}^3$ and 2×SiPM (S13360-2050VE, $2 \times 2\,\mathrm{mm}^2$, $50\,\mu\mathrm{m}$)

    $\Rightarrow \sigma_E \sim 140\,\mathrm{keV}$ (p.e. statistics)

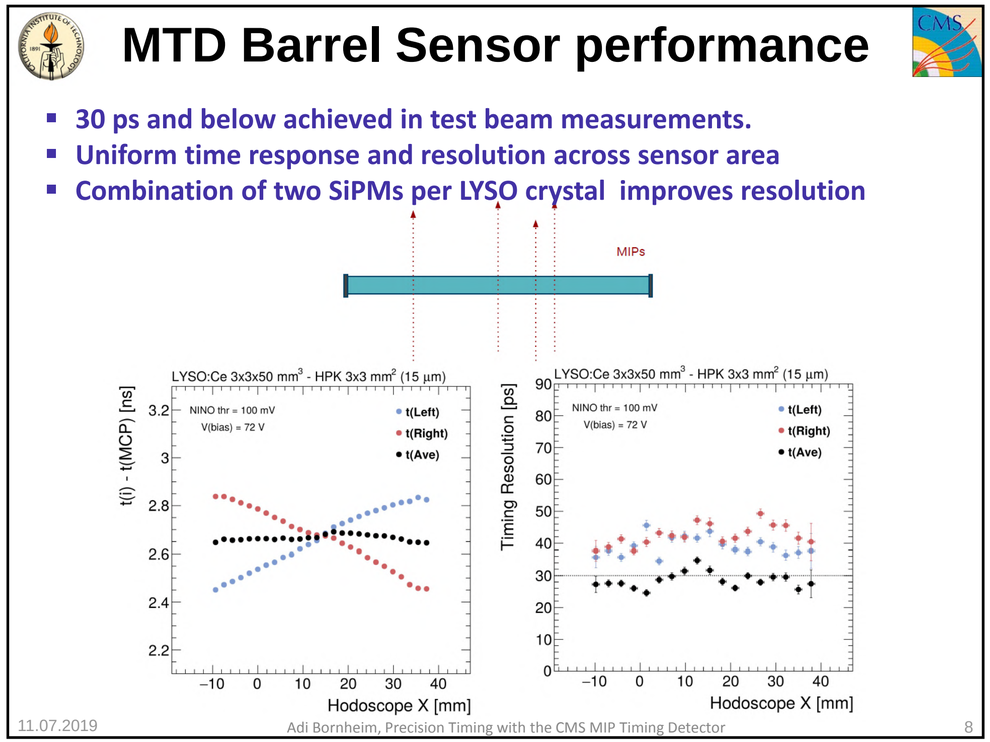
  - Photoelectron statistics should be enough

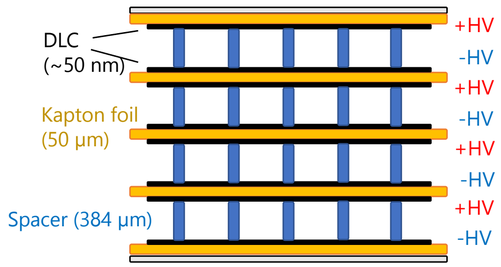
- Other potential contributions to energy resolution
  - Position dependence of photoelectron yield → not very large (a few $\%$). in any case, can be corrected with measured conversion position
  - dE/dx dependence of scintillation light yield → not very large

Timing Layer

Technology Options

- Target resolution: 40ps for MIP (→ 30ps for conversion pair)
- Technology options
  - Converter = Timing layer
  - mRPC as timing layer
- LYSO converter as timing layer F. Ikeda
  - CMS MIP Timing Detector HL-LHC: 30ps with LYSO bar ($3 \times 3 \times 50\ \mathrm{mm}^3$)
- multi-layer RPC (mRPC) W. Li
  - DLC-RPC technology developed for MEG II US-RDC
  - 110ps achieved for single layer RPC 194μm (not optimised for timing)
  - Optimisation for timing under study
    - Thinner gap
    - Higher efficiency and timing resolution with multi-layer

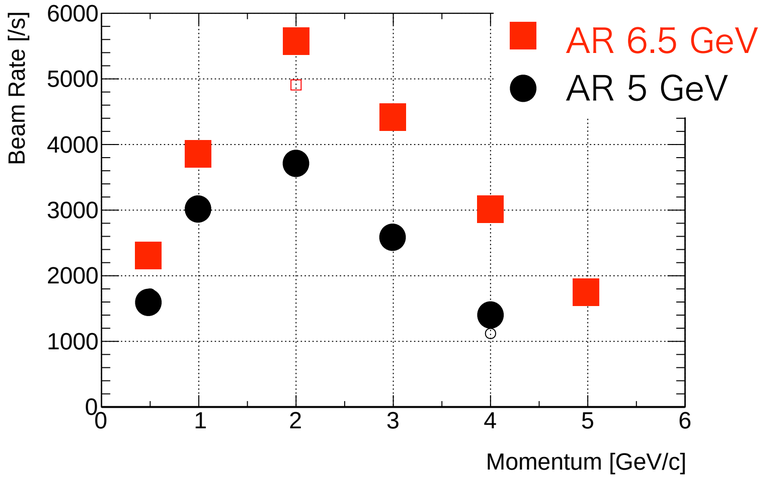




LYSO Beam Test

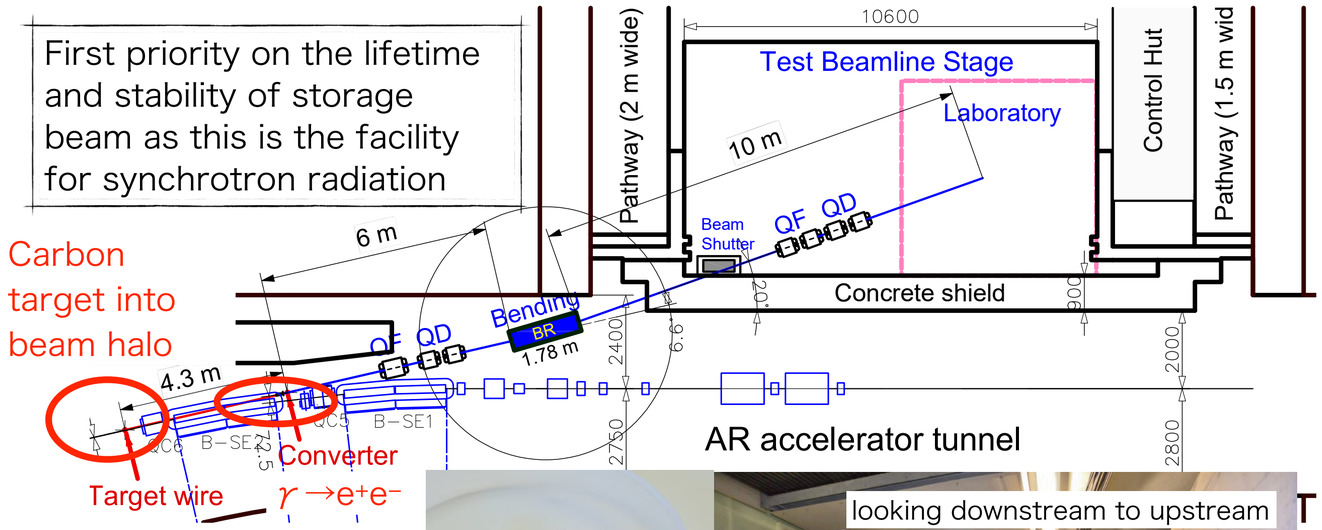
F. Ikeda, R. Yokota

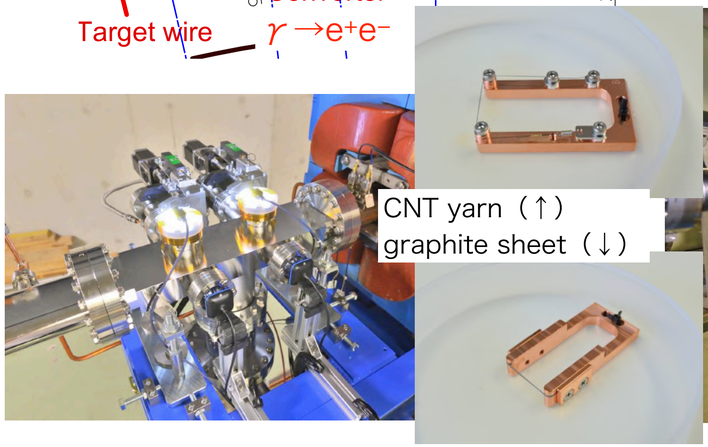
- Nov. 16-21, 2022@ KEK PF-AR test beam line
- Electron beam 0.5-5GeV



Overview of Test Beam Line

First priority on the lifetime and stability of storage beam as this is the facility for synchrotron radiation





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LYSO Beam Test

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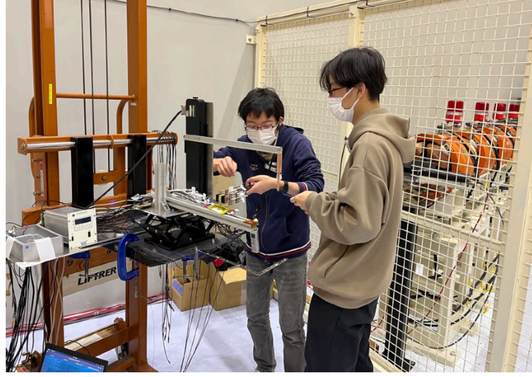
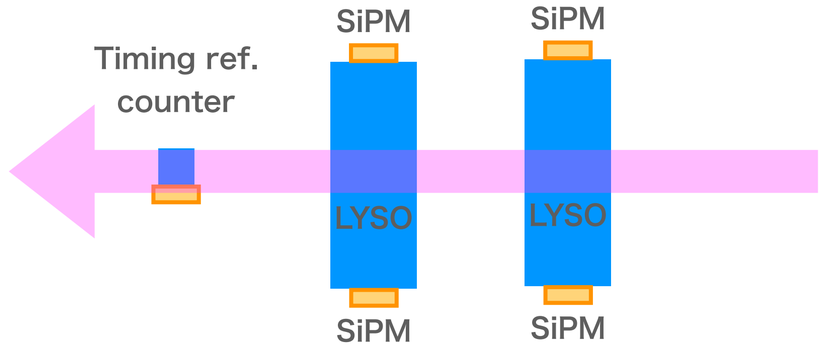
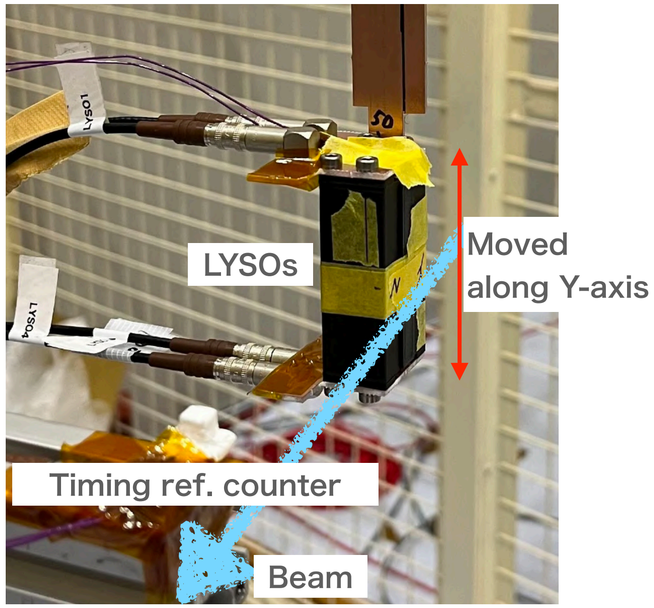
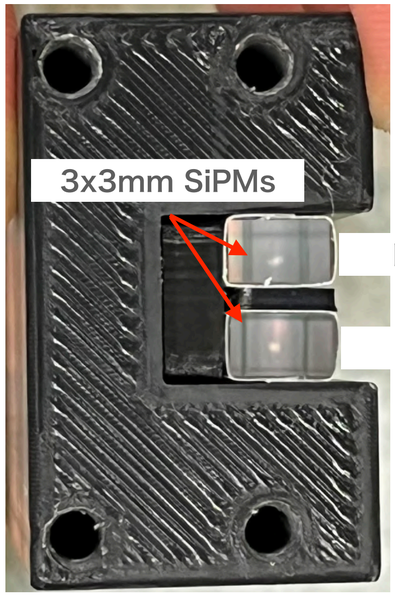
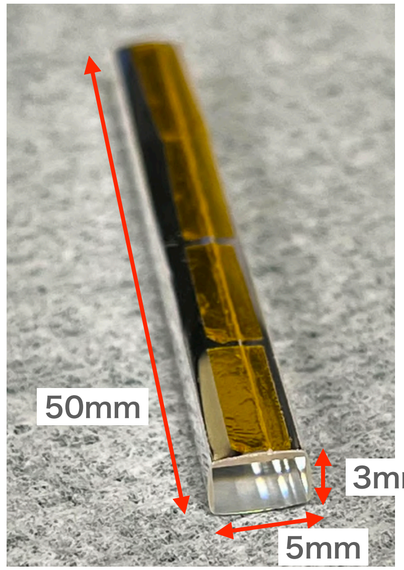


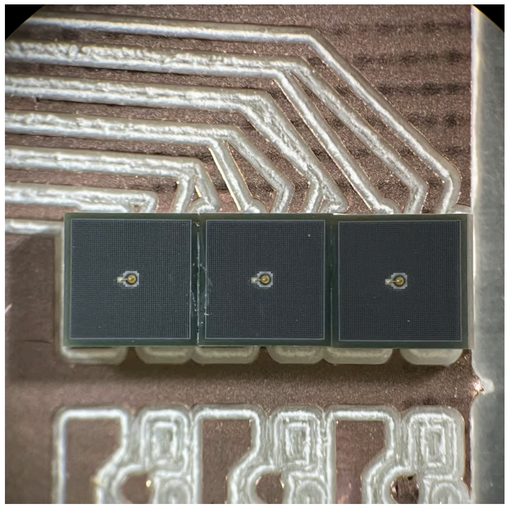
- Two types of LYSO
  - Standard LYSO, Fast LYSO (FTRL)
  - $3 \times 5 \times 50\ \mathrm{mm}^3$ wrapped with ESR
  - SiPM: S14160-3015PS ($3 \times 3\ \mathrm{mm}^2$, $15\ \mu\mathrm{m}$), S14160-3050HS ($3 \times 3\ \mathrm{mm}^2$, $50\ \mu\mathrm{m}$)
  - Waveform digitizer: DRS4 (1.6 GSPS)







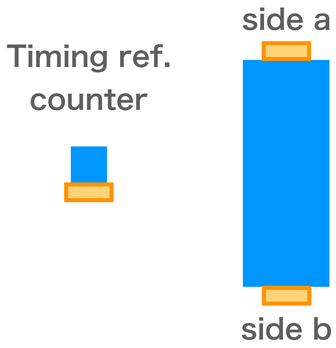


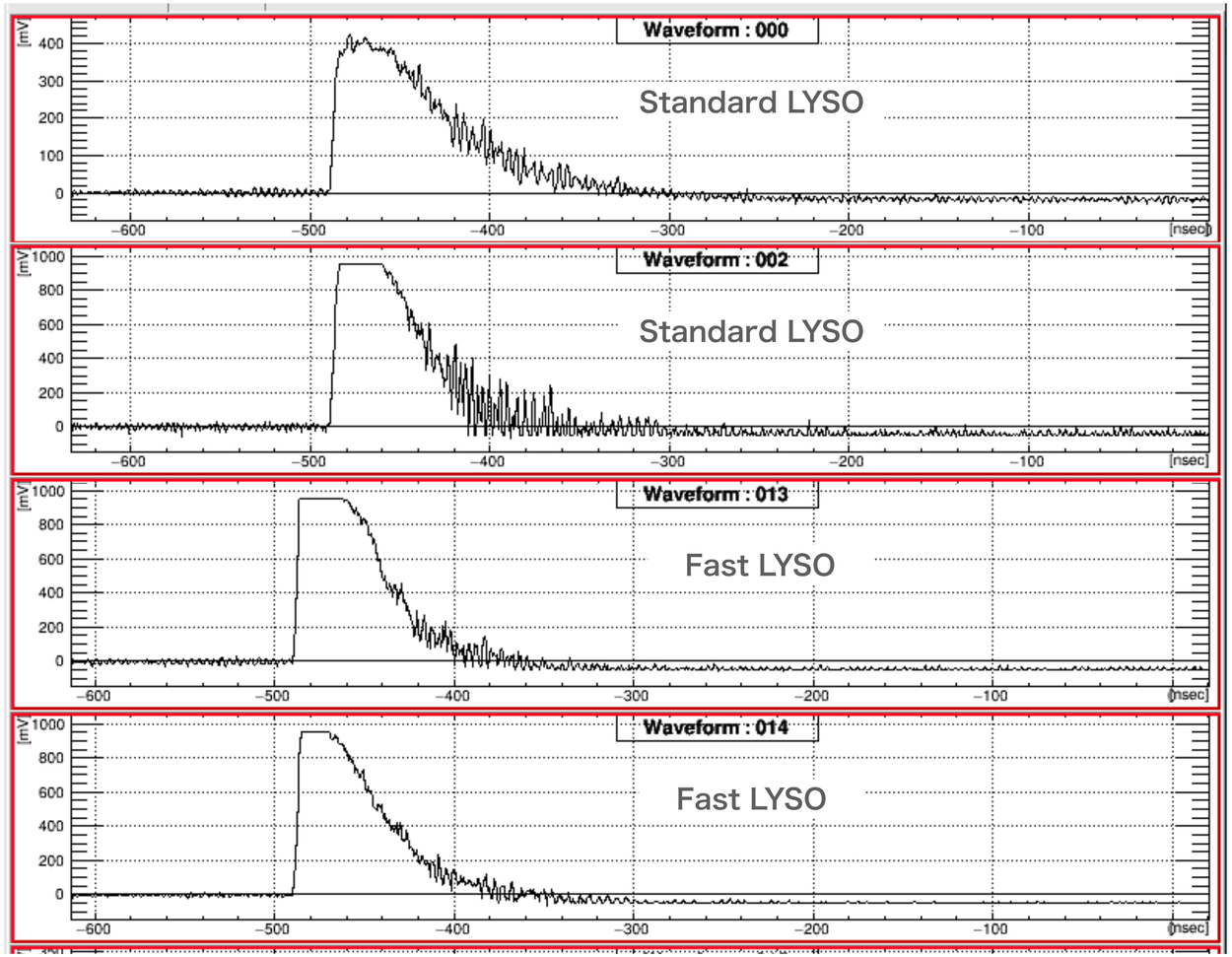


LYSO Beam Test

F. Ikeda, R. Yokota

- Analysis
  - Time pickup @ leading edge
  - Time-walk correction by TOT
  - Time resolution is estimated in two methods
    - $\sigma(t_{\text{side a}} - t_{\text{side b}})/2$
    - $\sigma((t_{\text{side b}} + t_{\text{side b}})/2 - t_{\text{timing ref. counter}})$





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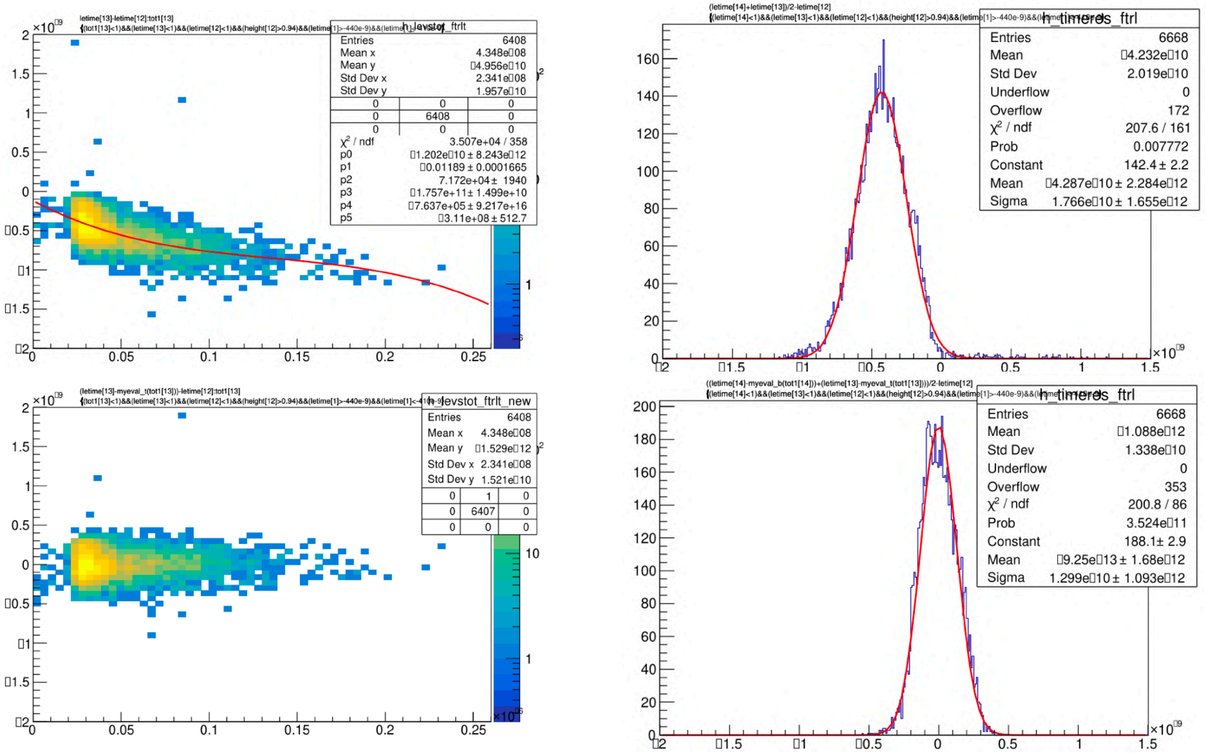
- Preliminary result for fast LYSO
  - Slight inconsistency between two methods. need further investigation
  - **Obtained excellent timing resolution of** $40 - 50\,\text{ps}$

Time-walk correction by TOT (Fast LYSO)



Summary

- Study on LYSO performance as a candidate material for active converter of pair spectrometer
- Highest efficiency expected compared to other materials despite its low critical energy, but still need optimisation of segmentation
- Target energy resolution should be achievable from viewpoint of photoelectron statistics thanks to its high light yield
- Performed beam test to measure the timing performance. The preliminary result already shows an excellent timing resolution of $40 - 50\,\mathrm{ps}$