Development of Active Converter for Pair Spectrometer
MIP Electron Beam Test at KEK 2024

Fumihito IKEDA
Future μ → eγ Meeting 2024-12-12

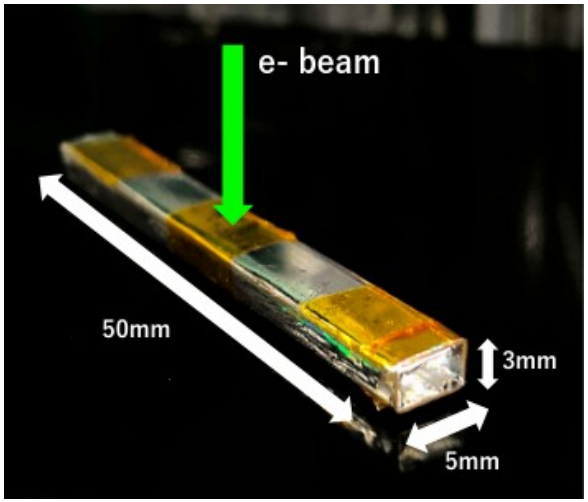
LYSO Bar as Active Converter Prototype
MIP Electron Beam Test at KEK (2023)

Purpose: Energy and timing performance evaluation

Require pair spectrometer to ΔE/E < 0.4% at 52.8 MeV && Δt < 30 ps

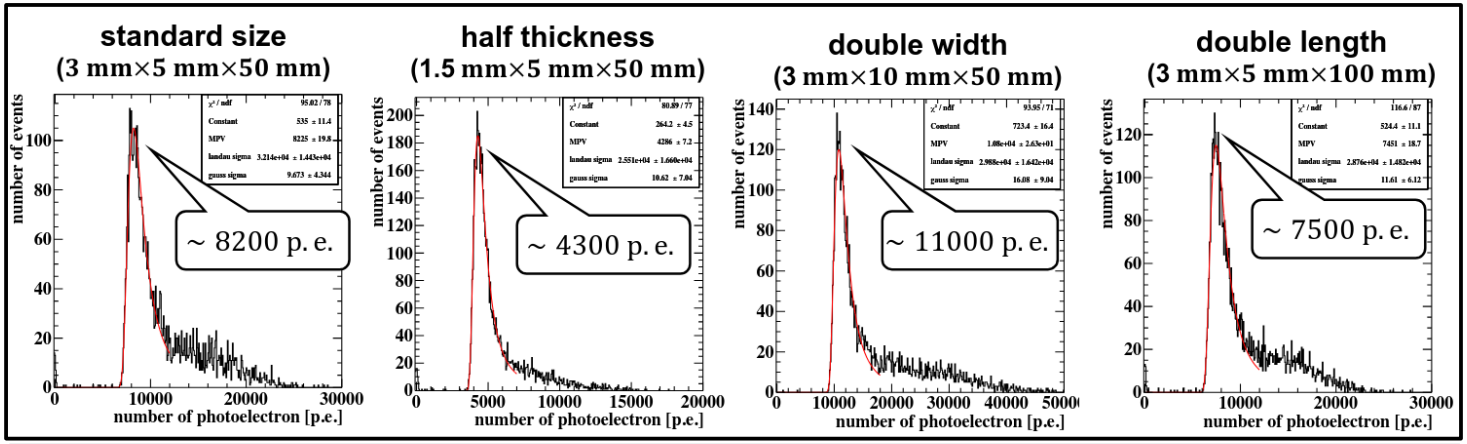
→ Require 1 segment of active converter to **Np.e. > 670p.e.** (t = 3 mm) && **Δt < 40 ps for 1MIP**

Note: 670p.e. ignoring tracker energy res. && the minimum number required from photo-electron statistics



LYSO bar

Readout by SiPM(s) from both sides



	Standard size (3 mm×5 mm×50 mm)	Half thickness (1.5 mm×5 mm×50 mm)	Double width (1.5 mm×5 mm×50 mm)	Double length (3 mm×5 mm×100 mm)
Independent readout	27.0 ps	36.1 ps	26.5 ps	30.4 ps
Series readout	29.4 ps	(no data taken)	27.6 ps	(no data taken)

Reported by Sakakibara-san, "R&D on an active photon converter" at last meeting 2nd Oct.

Basic requirements have already been achived, but there are things that have yet to be done....

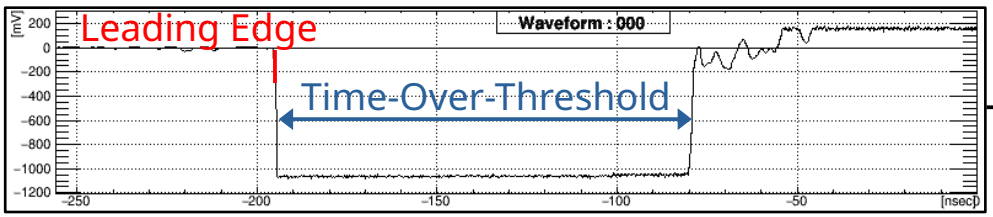
- **Simultaneous measurement of energy and timing**
- Fine position/angle scan

LYSO Bar as Active Converter Prototype
MIP Electron Beam Test at KEK (2024)

Purpose: Energy and timing performance evaluation

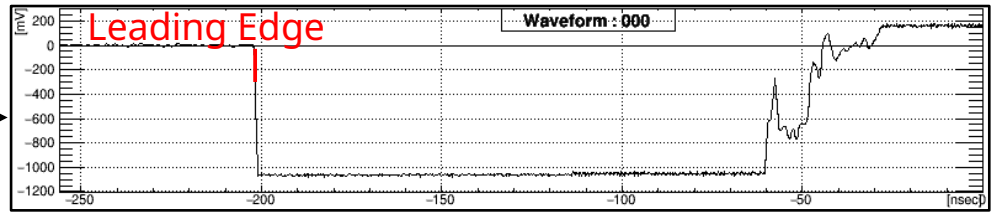
- Upgrade from 2023 beam test
  - **Simultaneous readout with high-gain (timing) and low-gain (energy)**
    - Use **high-gain** waveforms **for time-picking by leading-edge**
    - Use **low-gain** waveforms **for charge information**
  - **Position and angle scans with finer steps**
  - VETO-ing multi-particle events (generated upstream)
    - Misjudge energy deposited in LYSO (and affects time resolution)

2023

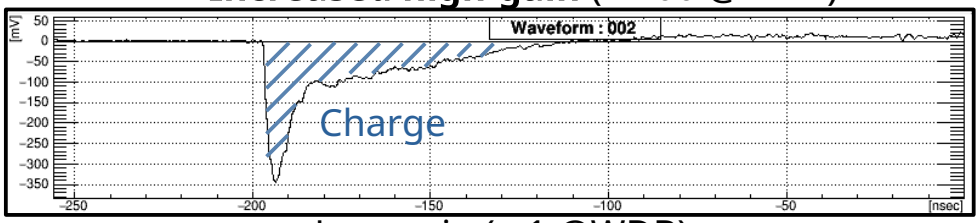


High-gain (= 50 @WDB) only

2024



Increased high-gain (= 100 @WDB)



Low-gain (= 1 @WDB)

Example of MPPC waveforms on one side of LYSO
3x5x50 ㎣ LYSO + 3x3 ㎟ MPPC x3 in series, 4 GSPS @WDB

PF-AR Test Beam Line@KEK

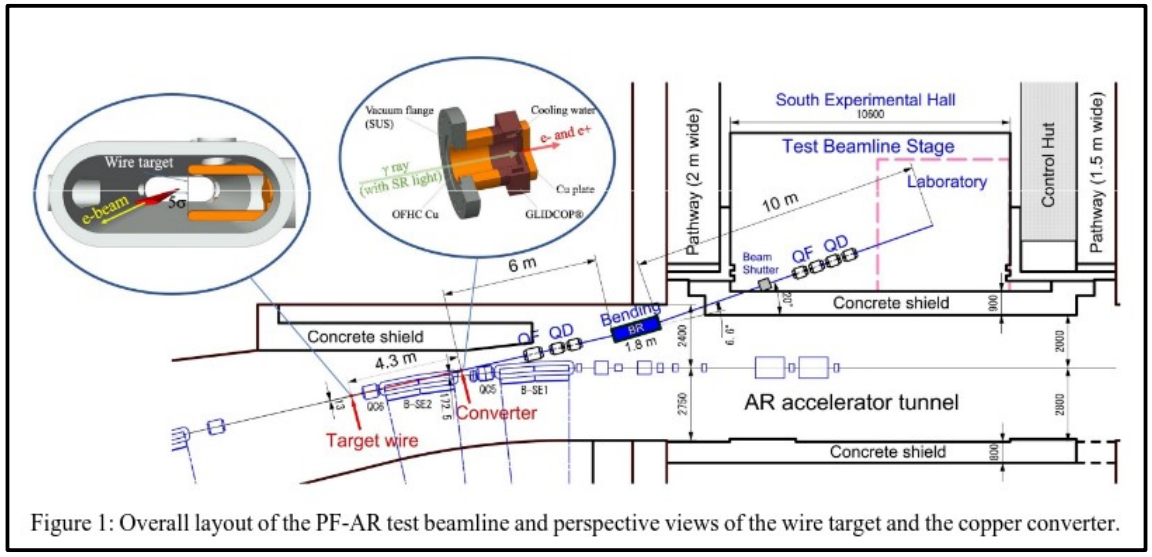
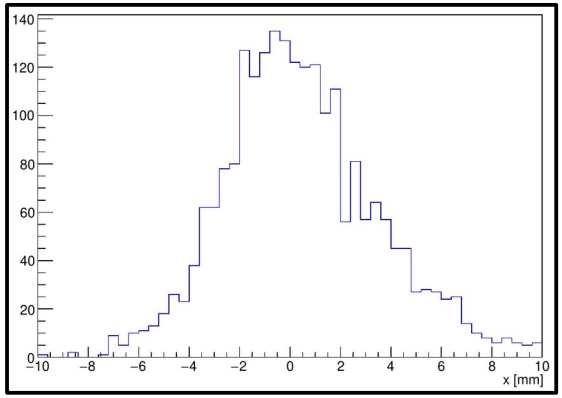
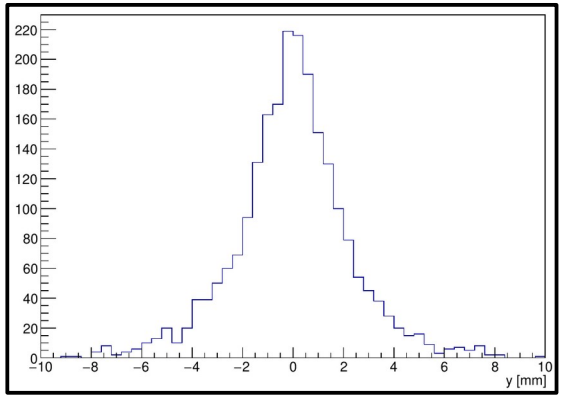


Figure 1: Overall layout of the PF-AR test beamline and perspective views of the wire target and the copper converter.

T.Honda et al., PASJ2021 MOP049 (2021), “DESIGN OF THE GeV RANGE TEST BEAM LINE AT THE PF-AR”

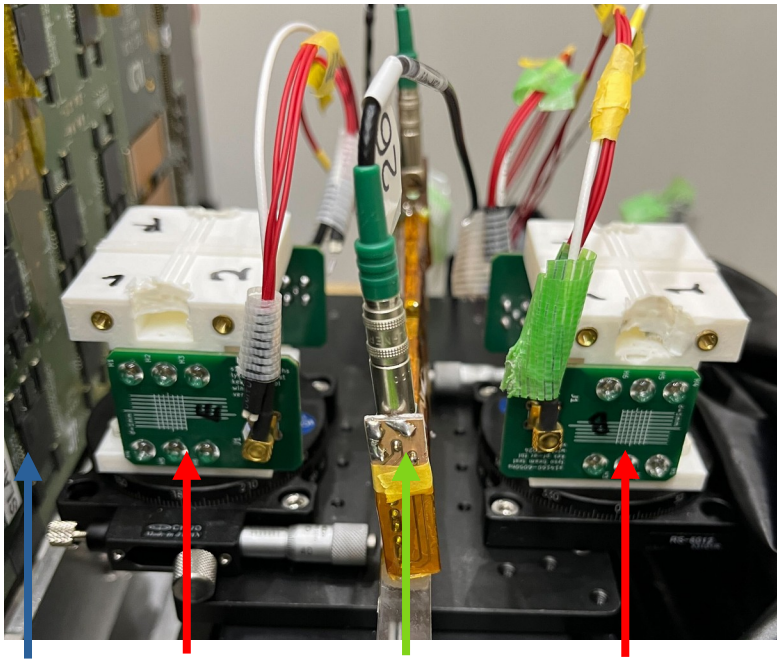


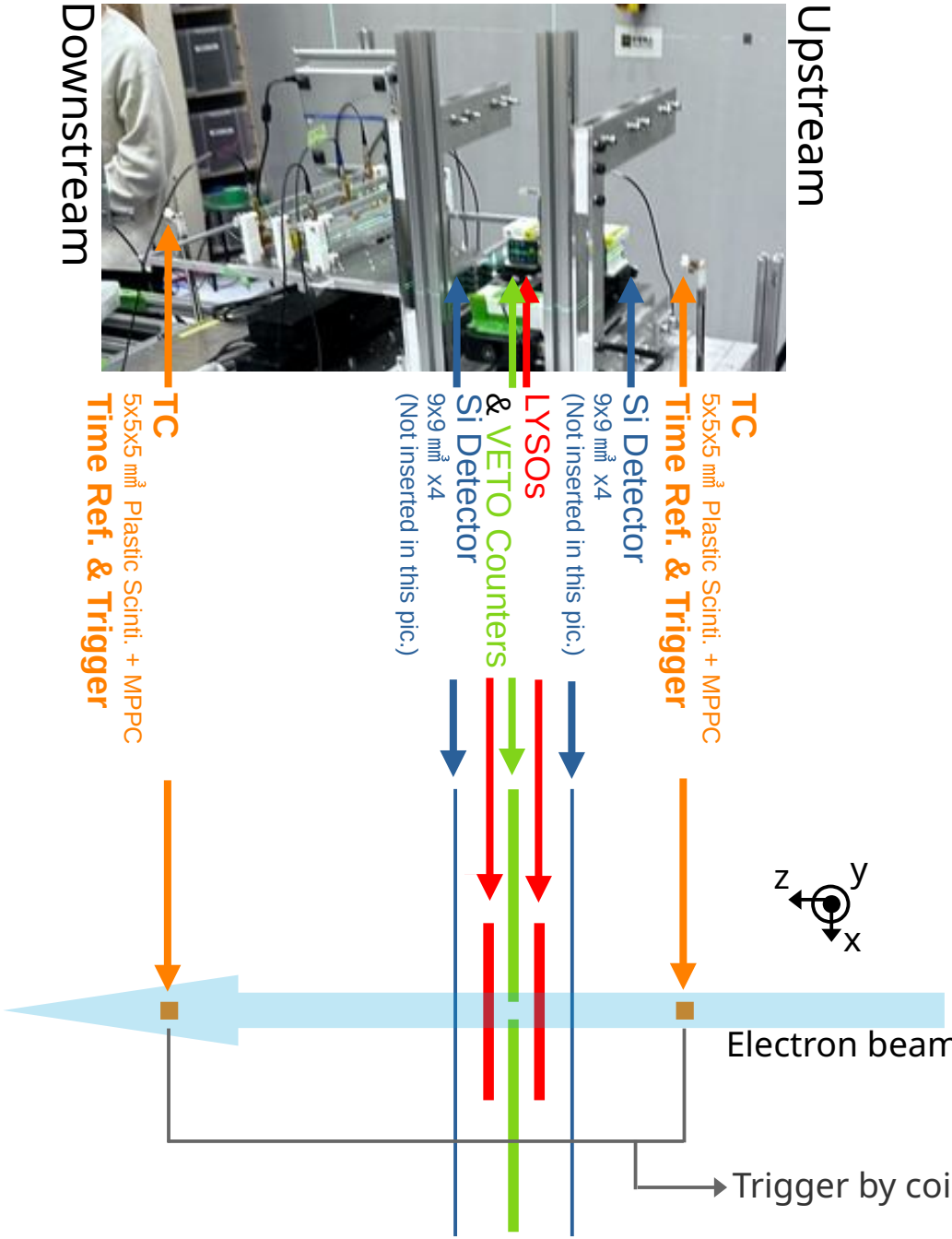


Beam profile exmaple with PF-AR 6.5GeV && TBL 3GeV
https://wiki.kek.jp/display/artbl/AR+Test+Beam+Line+Home

- **Same as 2023 beam test**
- **Beam time = 24th Nov. - 5th Dec.**
- **MIP electron beam** (**Beam momentum ~** 2, **3** or 5 **GeV/c** during our beamtime)
- **Beam rate ~ 3 kHz** at 3 GeV/c with the entire beam profile

Setup



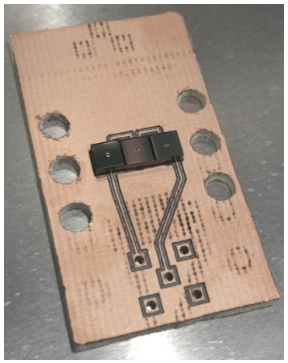


All counters' waveforms except Si recorded by WDB
Sampling frequency = 4 or 5 GHz

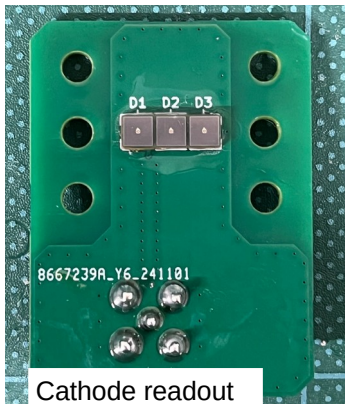
SiPMs

Newly designed readout boards for better quality

Impedance matching, Better S/N, Better frequency characteristics, Smaller gaps between SiPMs

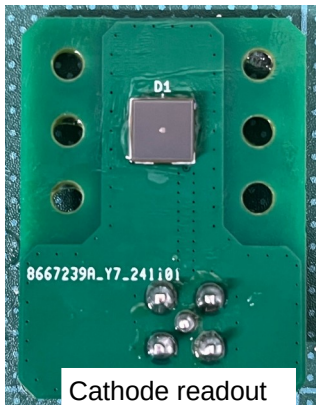


2023 board



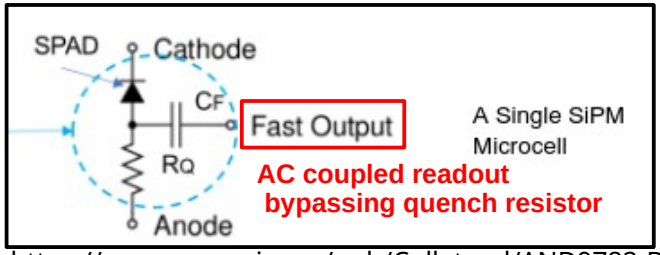
Cathode readout output & +HV

S14160-3050HS
Hamamatsu
3x3 ㎟ / 50 um pitch
x3 in series connection
Also used in 2023 beam test

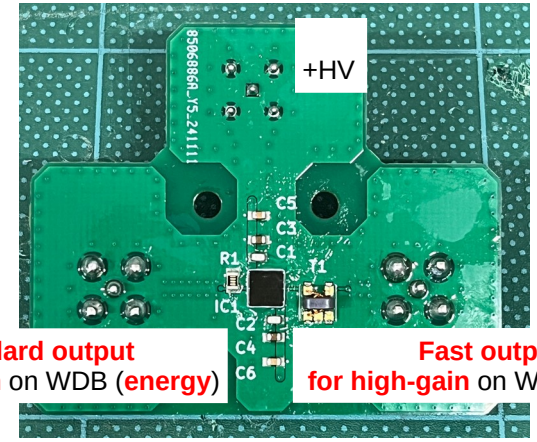


Cathode readout output & +HV

S14160-6050HS
Hamamatsu
6x6 ㎟ / 50 um pitch
100% coverage readout



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

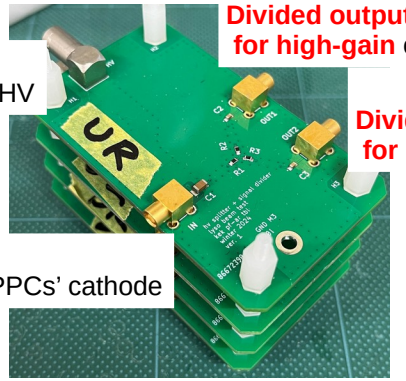


MICROFJ-40035-TSV-TR1
Onsemi
4x4 ㎟ / 35 um pitch
Fast output for timing measurements

3x5x50 ㎥ LYSO with 3x3 ㎟ MPPCs

3x5x50 ㎥ LYSO with 6x6 ㎟ MPPC

3x5x50 ㎥ LYSO with 4x4 ㎟ SiPM



Biasing & Signal Dividing Baord for MPPCs

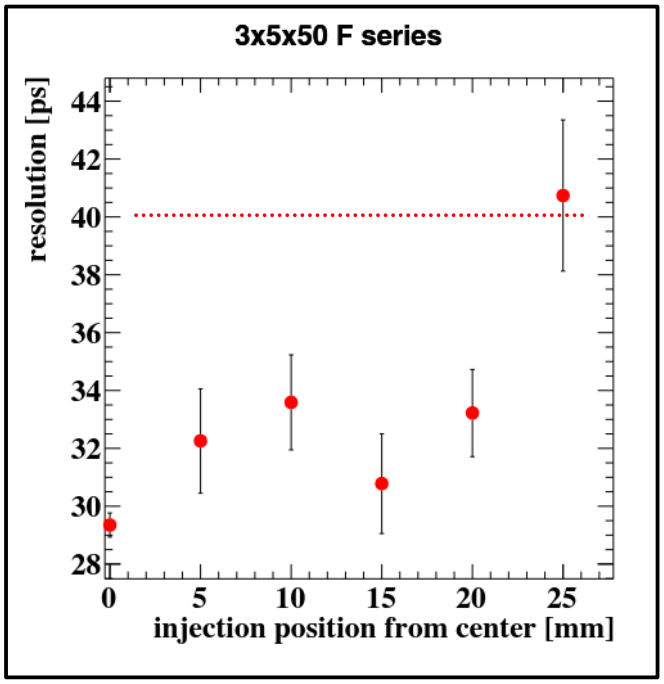
Data

		3x5x50 ㎣ 3x3 ㎟ MPPC	3x5x50 ㎣ 6x6 ㎟ MPPC	3x5x50 ㎣ 4x4 ㎟ SiPM	1.5x5x50 ㎣ 6x6 ㎟ MPPC
Beam on	Vop scan	○ 1 V step	○ 1 V step	○ 1 V step	X Same Vop as 3x5x50 ㎣
	Position scan w/ optimized Vop	○ 2.5 mm step	○ 5.0 mm step	○ 2.5 mm step	○ 2.5 mm step
	Angle scan w/ optimized Vop	○ 10° step	○ 10° step	X	○ 10° step
Beam off	Self-radiation daq	X	○	X	○
	Noise daq w/ acc. trig.	○	○	○	○
	Dark daq w/ periodic trig.	○	○	○	○

Preliminary Results Compared to 2023
3x5x50 ㎣ LYSO + 3x3 ㎟ MPPC x3 in series

2023 Beam Test

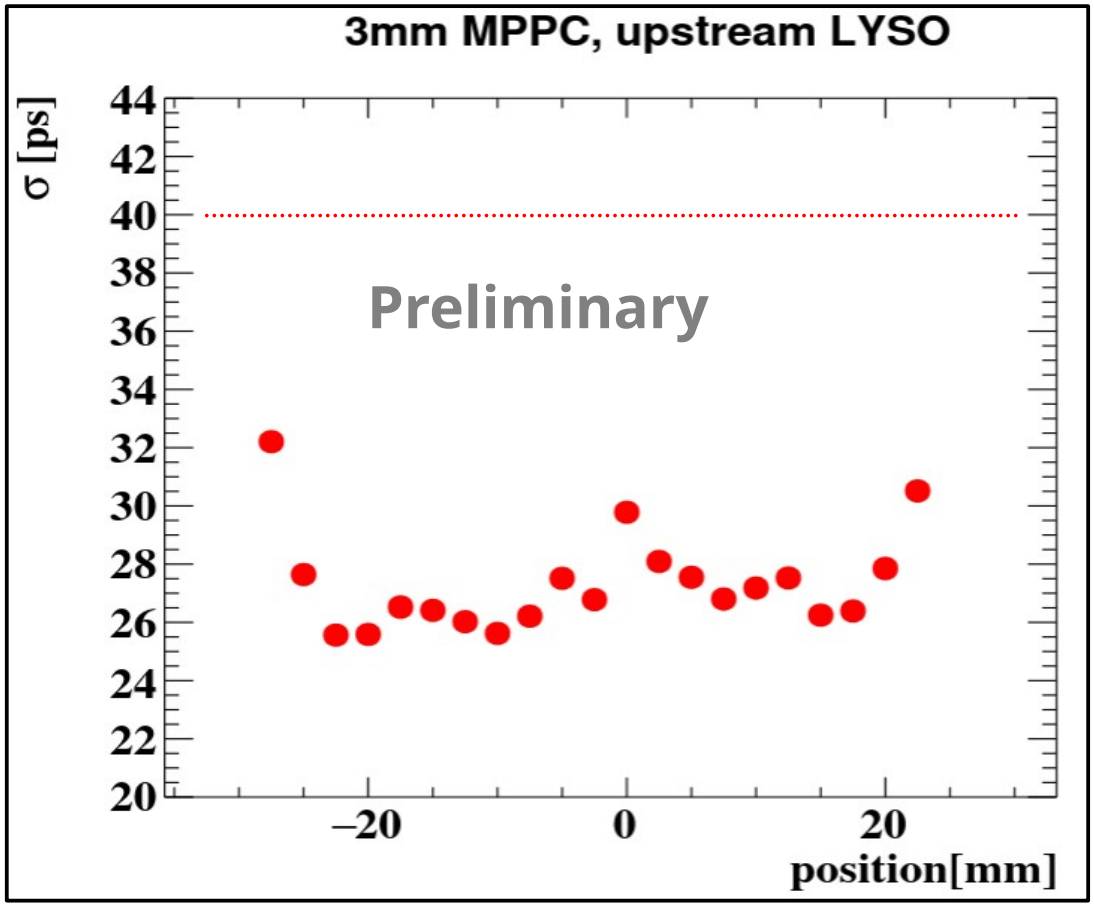
Readout gain = 50
Walk is corrected using the TOT of the saturated waveform itself



by Sakakibara-san @JPS Autumn 2024
https://meg.icepp.s.u-tokyo.ac.jp/docs/talks/JPS/2024a/sakakibara_jps2024a.pdf

2024 Beam Test

Readout high-gain= 100 low-gain = 1
Walk is corrected using the charge of the low-gain waveform



→ **Roughly uniform across the entire region with good time res.**
(Discrepancies in behavior near the center are not yet understood.)

Items to be Analysed

- **Energy**
  - **Uniformity of light yield** vs. beam position
  - **Comparison of light yield**
    - vs. ingection angle, vs. LYSO thickness, vs. SiPM type
  - **Estimation of absolute value of deposited energy** by camparing charge with MC sim.
    - To calibrate, compare LYSO self-rad. charge with its spectrum to convert Np.e. → Energy
      Source dependence of LYSO light output (i.e., MIP, few MeV e-/e+, self-rad.) needs to be understood
  - Effect of using TOT of high-gain ch instead of charge of low-gain ch on energy res.
    - If only high-gain waveform is sufficient, the number of chs can be 1/2
- **Timing**
  - **Uniformity of time resolution** vs. beam position
  - **Comparison of time resolution**
    - vs. injection angle, vs. LYSO thickness, vs. SiPM type
  - Consistency of the time res. when using TC as time ref. and when using time diff. between left and right
  - Investigation of tail components in time diff. distribution
  - Effect of using TOT of high-gain ch instead of charge of low-gain ch for walk correction on time res.
  - **Noise reduction** by waveform analysis for better time res.
- Other
  - Estimation of hit pos. using chage ratio or time diff. between the two sides

Summary & Prospect

- Active converter using LYSO bar + SiPM is under development
- MIP electron beam test in 2023
  had already shown that energy and timing performance requirment to 1 segment of active converter could be achieved
- **MIP electron beam test in 2024**
  were newly conducted to further detail energy and timing performance
  - Simultaneous **high-gain (timing) and low-gain (energy) readouts** were performed
  - Preliminary result show **good time res. of ~ 25-30 ps across the entire bar region**
- Detailed analyses of energy and time resolution are planned
  - For energy performance,
    - Comparison of **light yield under various conditions** (pos., angle, LYSO thickness, SiPM type)
    - Estimation of absolute value of deposited energy by comparison with simulation
  - For timing perfomance,
    - Comparison of **time res. under various conditions** (pos., angle, LYSO thickness, SiPM type)
    - Seek further time res. by improving waveform analysis