Investigation of Timing Characteristics using LYSO+SiPM system

International Conference on Technology &

Instrumentation in Particle Physics (TIPP)

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Outline of the talk

- Introduction
- Estimation of timing resolution
  - Using Analogue electronics
  - Using Digital electronics
- Summary and Future Outlook

1. Introduction

Lutetium–Yttrium oxyorthosilicate $[Lu_{(1-x)}Y_x]_2SiO_5 : Ce)$

Properties of LYSO Crystal

- High density (**7.1 g/cm³**) [absorb more photons in a smaller volume, improving detection efficiency.]
- High light output (~ **33,000 photons/MeV**) [Higher light output → more photons per event → smaller statistical fluctuations → sharper photopeaks]
- Fast decay time (~ **36 ns**) [6 times faster decay time than BGO] [Fast decay → signal ends quickly → detector is ready for the next event → Less Pile up]
- Radiation hardness. (less radiation damage)

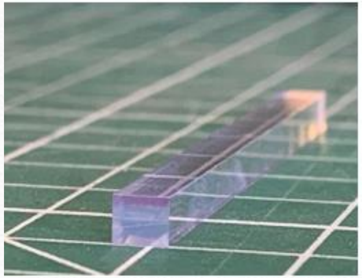
Due to these properties, LYSO has many application (including PET scanning): e.g. in CMS experiment as MIP Timing Detector where timing resolution of 30 ps is required for HL-LHC era.

F.M. Addesa et al 2022 JINST 17 P08028

2. a) Estimation of timing resolution (from Analogue electronics)

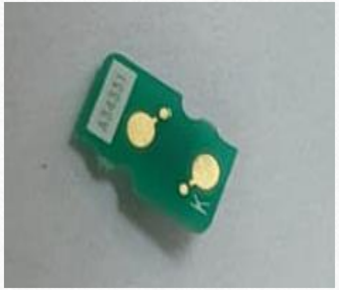
Components used in detector setup

Dimension of LYSO Crystal used: 56 mm x 3mm x 3mm

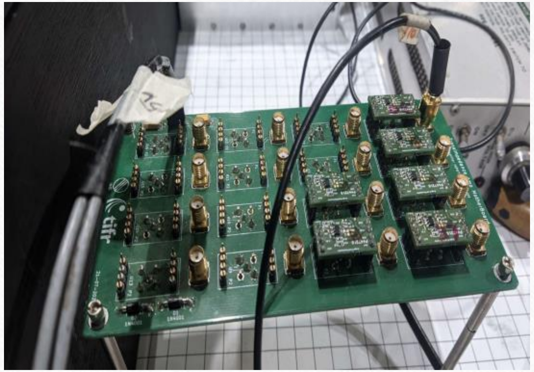


LYSO Crystal

Acetal Casing



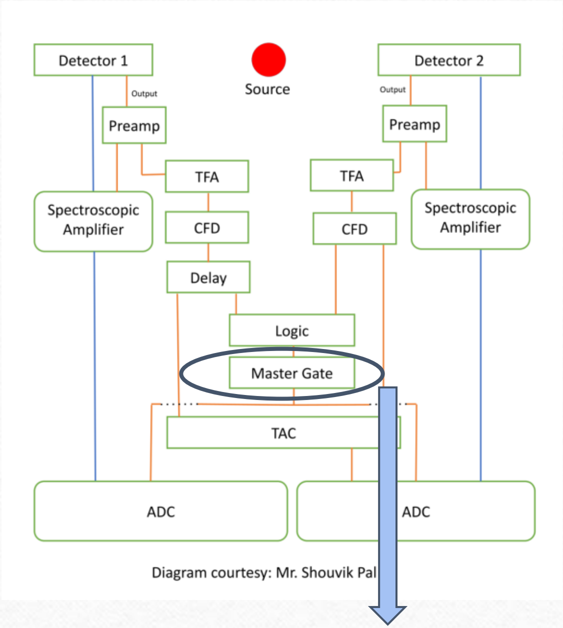
SiPM Mounting PCB



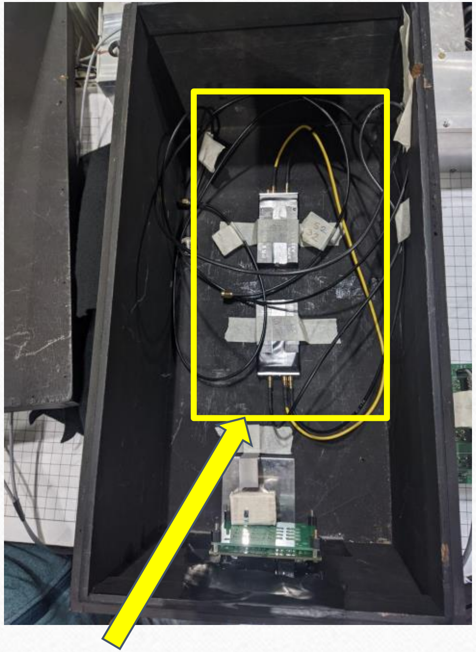
Transimpedance Amplifier (TIA)

Analogue data is acquired using *LAMPS (Linux Advanced MultiParameter System)* software [Data acquisition and analysis package that supports VME and a number of CAMAC controllers. Also used for offline data analysis.]

Schematic Circuit Diagram

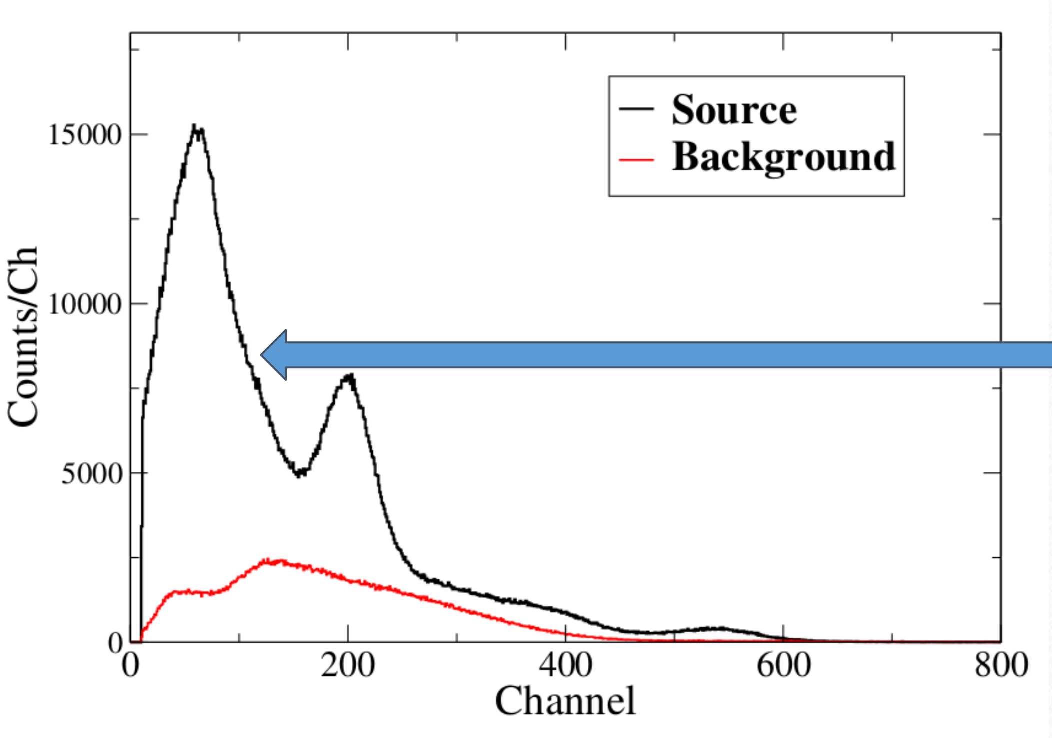


The master gate ensures the events are recorded only when two detectors got signal within a certain time window. This is later used for gating.



LYSO + SiPM coupled (air coupling)
(SiPM bias voltage = 53.4 Volt)

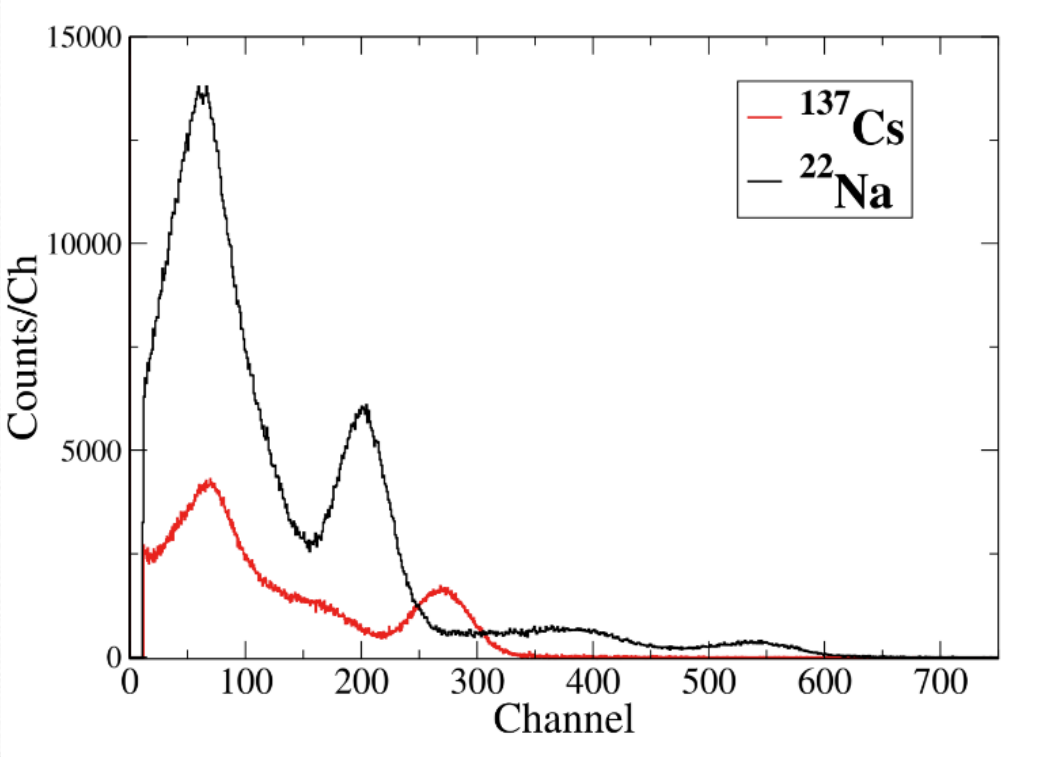
Typical spectrum and background from LYSO + SiPM



Energy Resolution at 511 KeV ~ 4.8% for crystal size 3 X 3 X 56 mm^3

The low channel peak corresponds to the backscatter peak (~ 170 KeV for 511 KeV)

Different monoenergetic γ-sources for calibration

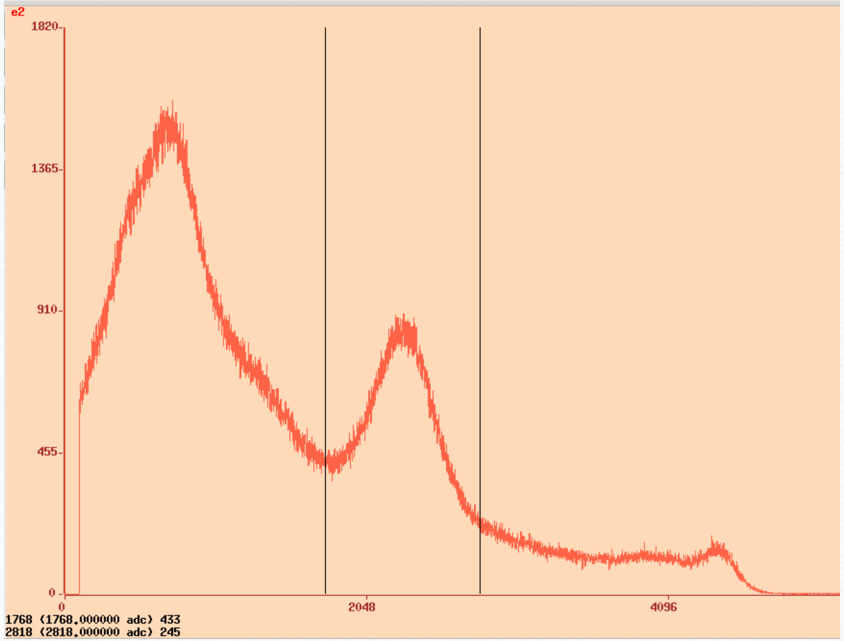


γ-rays of known energies are used to calibrate the detectors.

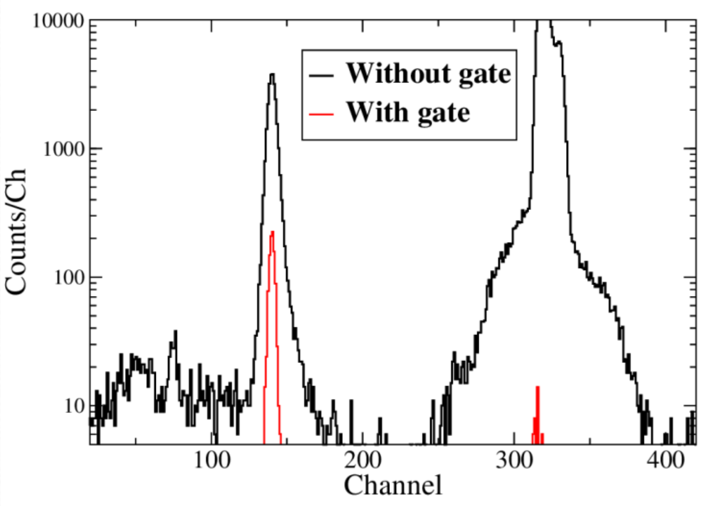
^{137}Cs → 662 keV
^{22}Na → 511 keV

Calibration ~ 0.46(1) KeV/Ch

Use of gating



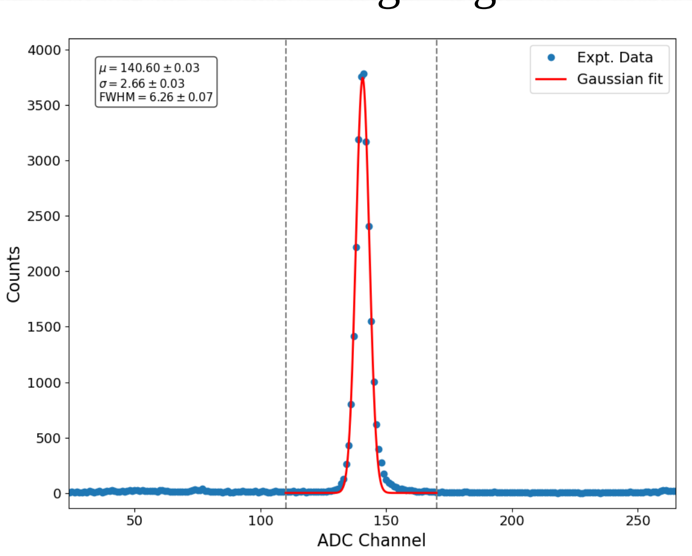
Putting gate on energy using AND condition.



Putting a gate improves resolution

Estimation of Timing Resolution

Without gating

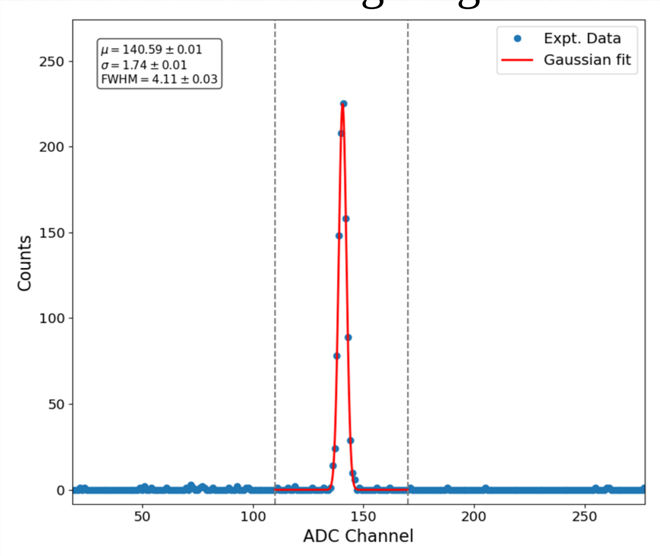


FMHM (2 crystals) : 835 (15) ps

σ_t [~ FWHM/2.35] (2 crystals) : **355 (7) ps**

σ [= $\sigma_t/\sqrt{2}$] (1 crystal) : **251 (5) ps**

With gating



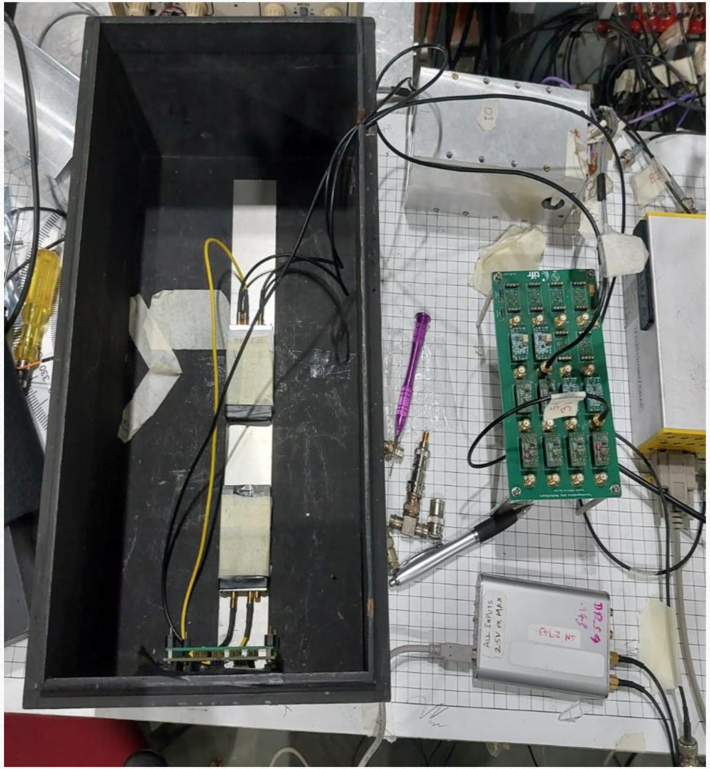
FWHM (2 crystals) : 516 (9) ps

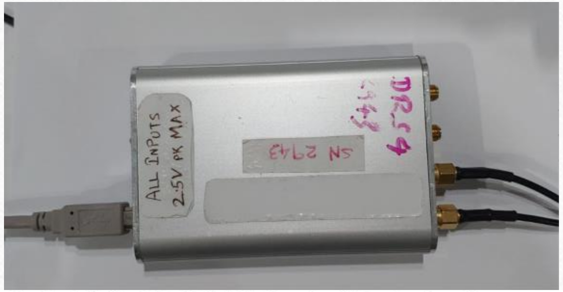
σ_t [~ FWHM/2.35] (2 crystals) : **151 (4) ps**

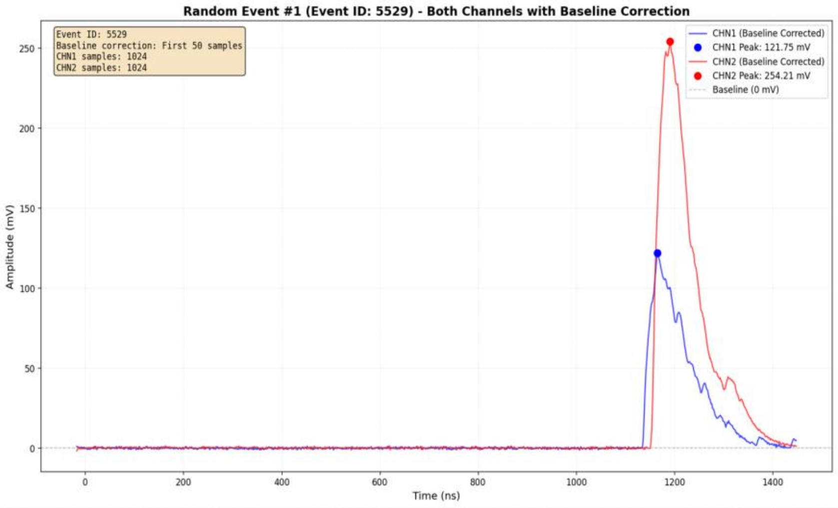
σ [= $\sigma_t/\sqrt{2}$] (1 crystal) : **107 (3) ps**

2. b) Estimation of Timing Resolution (from Digital electronics)

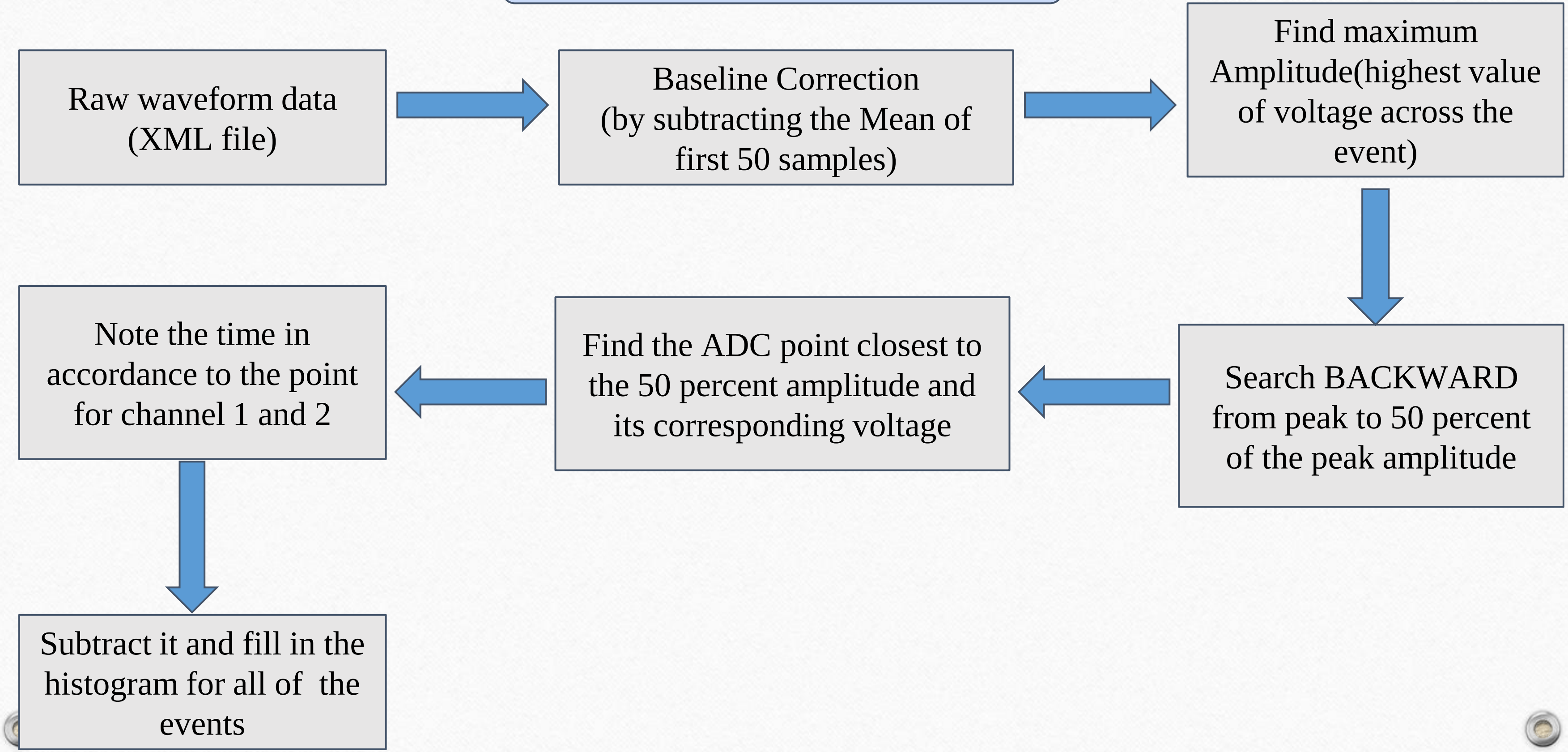
Components used in detector setup







Data Processing Workflow



Amplitude-Dependent Resolution

WHY BIN ANALYSIS?

Timing resolution typically improves with higher signal amplitude

⇨ Study $\sigma(\Delta t)$ as function of amplitude

For each event:

1. Find A_max,CH1 and A_max,CH2
2. *Check if highest peak amplitude of both the channels are falling under the same bin, then only consider the event.*
3. Classify into appropriate bin using [a,b)
4. Calculate Δt for that event
5. Accumulate statistics per bin

AMPLITUDE BINS (Using Min Peak)

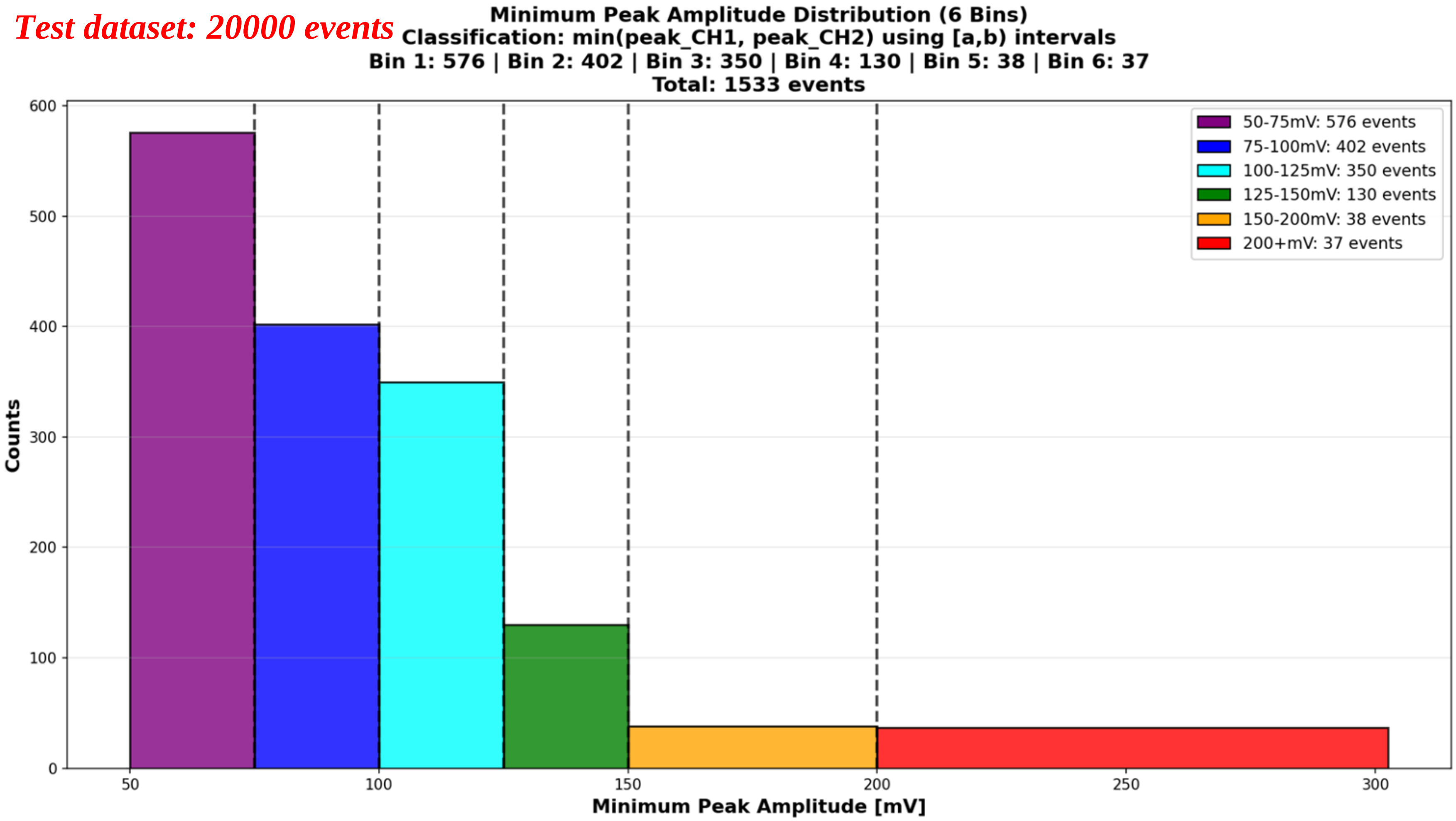
Bin 1	[50, 75) mV
Bin 2	[75, 100) mV
Bin 3	[100, 125) mV
Bin 4	[125, 150) mV
Bin 5	[150, 200) mV
Bin 6	[200, ∞) mV

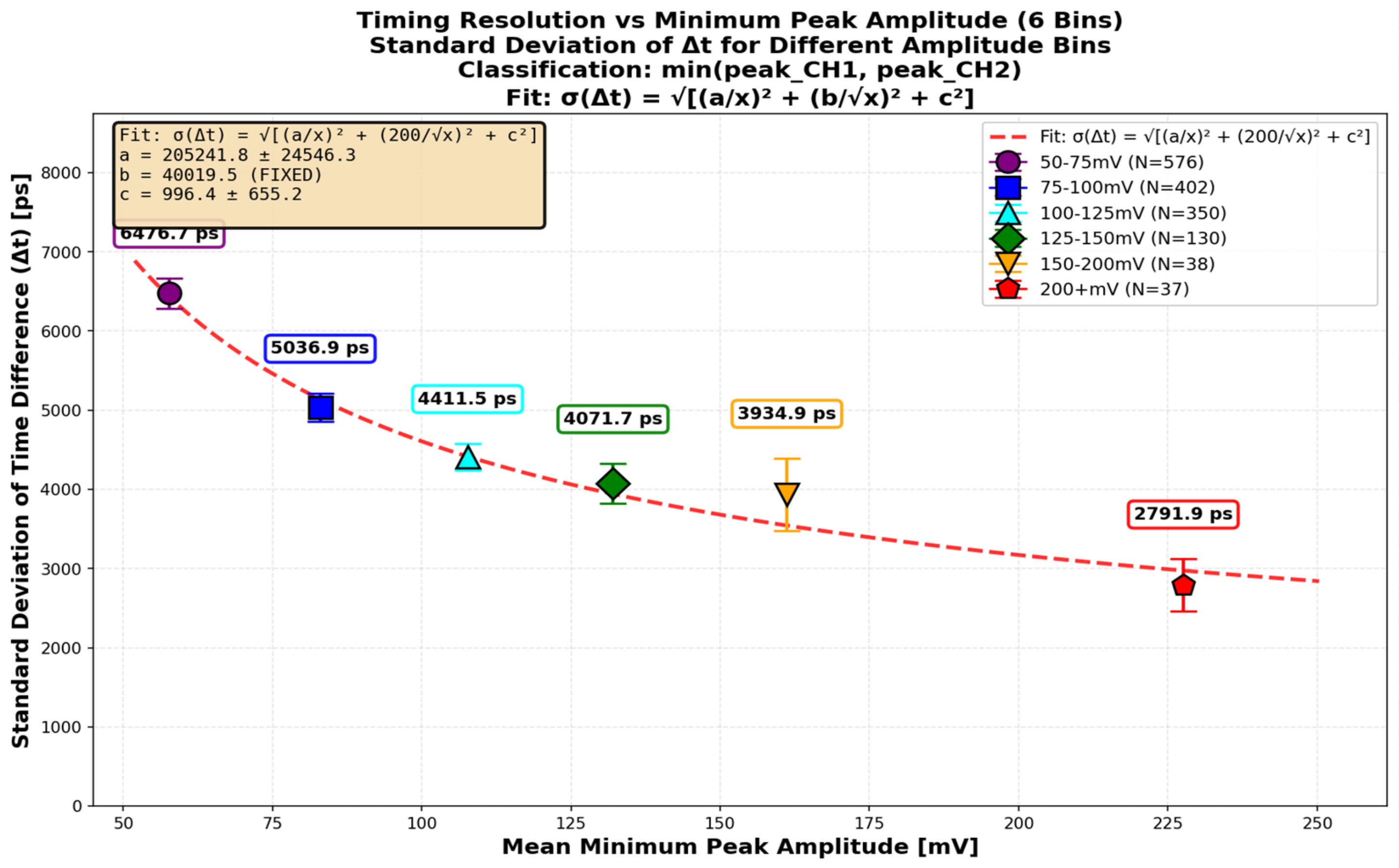
Classification Method:

A_bin = min(A_max,CH1, A_max,CH2)

Using left-inclusive intervals [a,b)

Test dataset: 20000 events





Timing Resolution vs Minimum Peak Amplitude (6 Bins)
Standard Deviation of Δt for Different Amplitude Bins
Classification: min(peak_CH1, peak_CH2)
Fit: σ(Δt) = √[(a/x)² + (b/√x)² + c²]
Fit: σ(Δt) = √[(a/x)² + (200/√x)² + c²]
a = 205241.8 ± 24546.3
b = 40019.5 (FIXED)
c = 996.4 ± 655.2
6476.7 ps
5036.9 ps
4411.5 ps
4071.7 ps
3934.9 ps
2791.9 ps
Fit: σ(Δt) = √[(a/x)² + (200/√x)² + c²]
50-75mV (N=576)
75-100mV (N=402)
100-125mV (N=350)
125-150mV (N=130)
150-200mV (N=38)
200+mV (N=37)
Standard Deviation of Time Difference (Δt) [ps]
Mean Minimum Peak Amplitude [mV]
0
1000
2000
3000
4000
5000
6000
7000
8000
50
75
100
125
150
175
200
225
250

Summary and Future Outlook

- Initial studies done with LYSO crystal using ^{22}Na and ^{137}Cs source
- From the analogue setup, we observe a timing resolution of 107 (4) ps
    - Scope of improvement at several places (e.g. Instead of air coupling between SiPM and LYSO, one can use optical grease)
- We also looked at the timing resolution in bins of amplitude using TIA
    - Pulse analysis algorithm needs to be optimised to obtain better time resolution [704 (463) ps].
    - In the process of understanding and making improvements to the setup.

References

- Pallavi Singh et. al. *ACS Nano*, **18**, 14029−14049 2024
- O. Beesley et. al. *NIM A*, **1075,** 170320, June 2025
- J. Chen et. al. *IEEE Transactions On Nuclear Science*, Vol. **52**, No. 6, December 2005
- A Yu Barnyakov et al *J. Phys.: Conf. Ser.* **1561** 01 2018

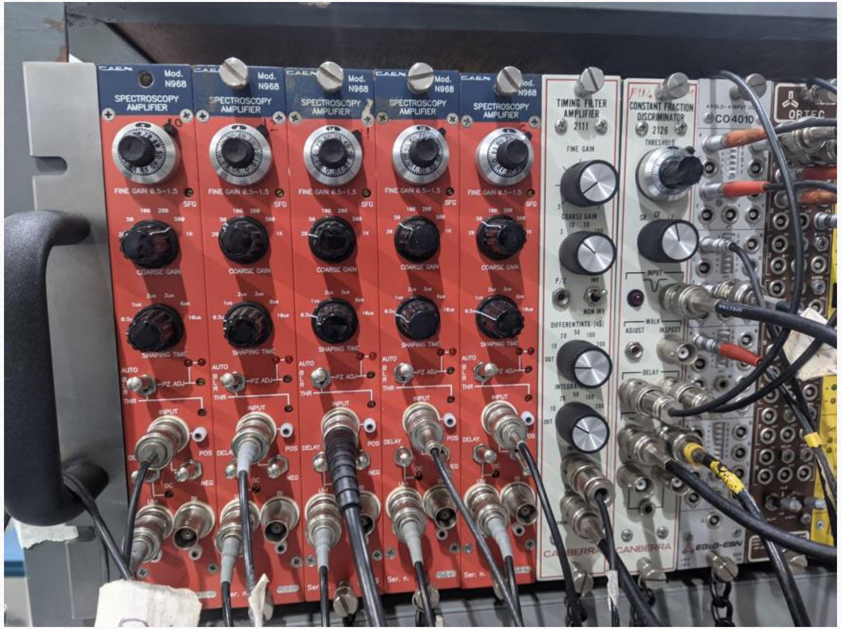
Acknowledgement

Thanks to Riccardo Paramatti from CMS for providing LYSO crystals

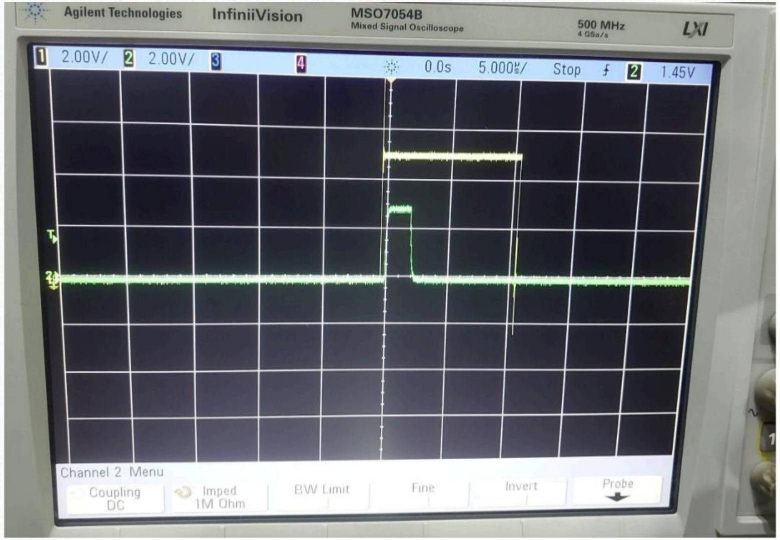
Thank you…!

BACKUP Slides

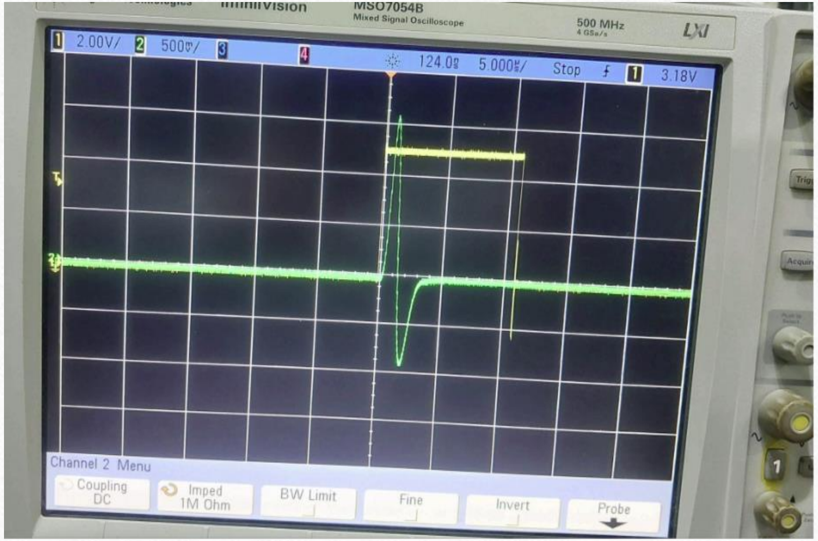
Electronic modules



Setting up the *Master Gate*



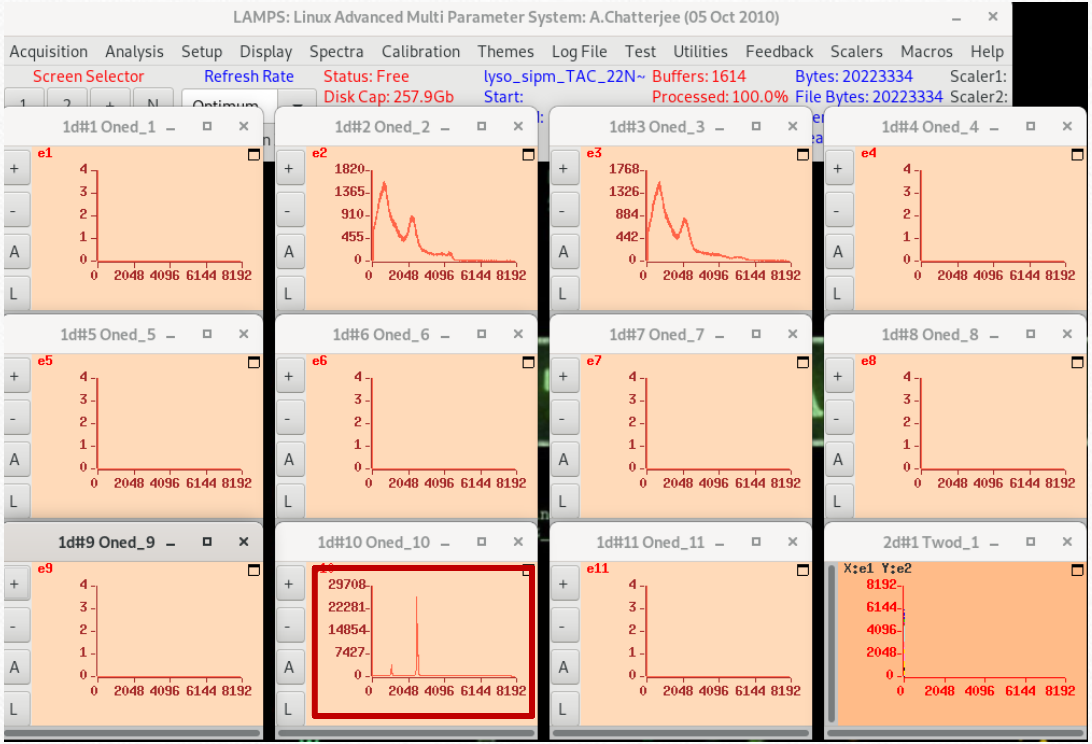
CFD output



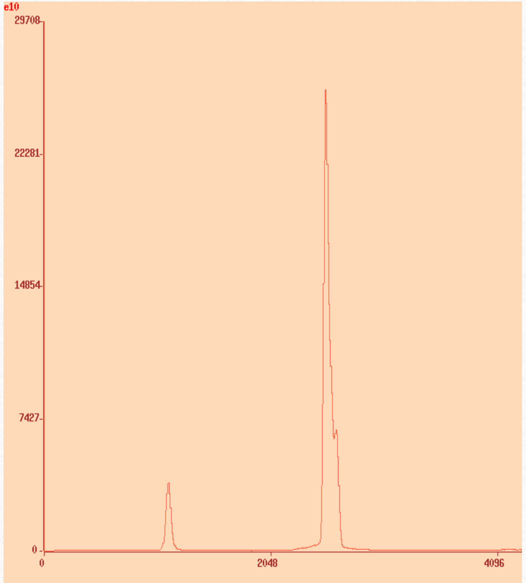
Spectroscopic amplifier output

First, we have to set master length such that CFD and Spectroscopic Amplifier outputs falls within that length.

TAC Spectrum



But, what are the two peaks in TAC spectrum?



How to improve?

- Instead of air coupling between SiPM and LYSO, one can use optical grease (Can reduce the timing FWHM by 100 ps)
- Optimize CFD fraction and delay
- With these optimisations, one can aim at ***200 - 250 ps*** time resolution.

Pallavi Singh et. al. ACS Nano 2024, 18, 14029−14049

O. Beesley et. al. NIM A, 1075, 170320, June 2025

J. Chen et. al. IEEE Transactions On Nuclear Science, Vol. 52, No. 6, December 2005

A Yu Barnyakov et al 2020 J. Phys.: Conf. Ser. 1561 01 2018