Performance evaluation of fast $LaBr_3(Ce)$ crystals equipped with fast photomultiplier tubes

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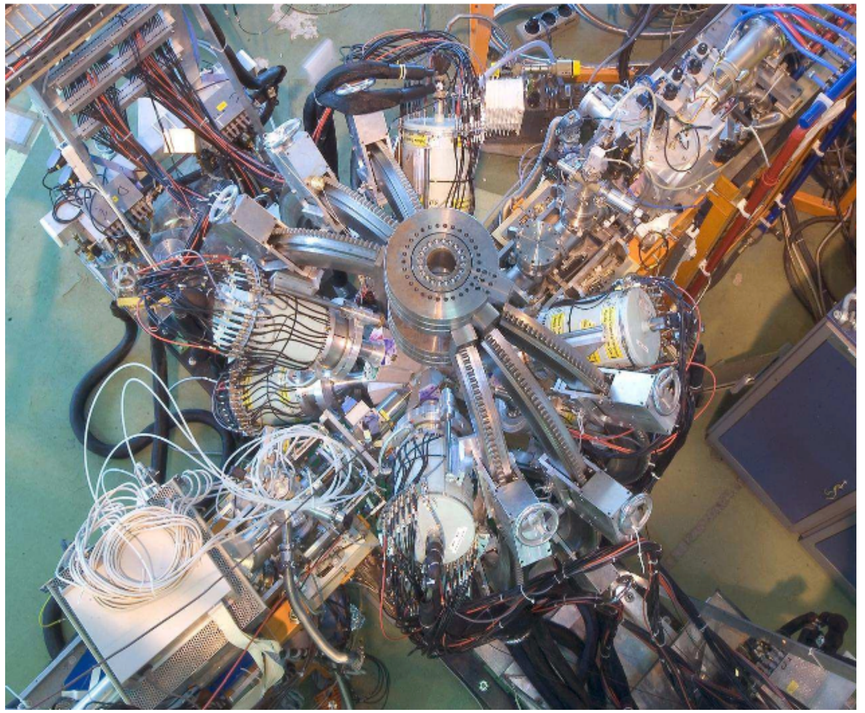
Introduction

- Purpose: Characterization of the time resolution, time walk, energy resolution and linearity of four Hamamatsu photomultiplier tubes (PMTs).
- Objective: To determine which PMT could perform best for the upcoming γ-ray array in the HIE-ISOLDE Timing Array for Reaction Studies (HISTARS) project.
- Experimental method and setup: The PMTs were coupled to a $LaBr_3(Ce)$ [1][2][3] crystal with the shape of a truncated cone. A time-delayed setup was employed to perform measurements of time resolution and time walk.

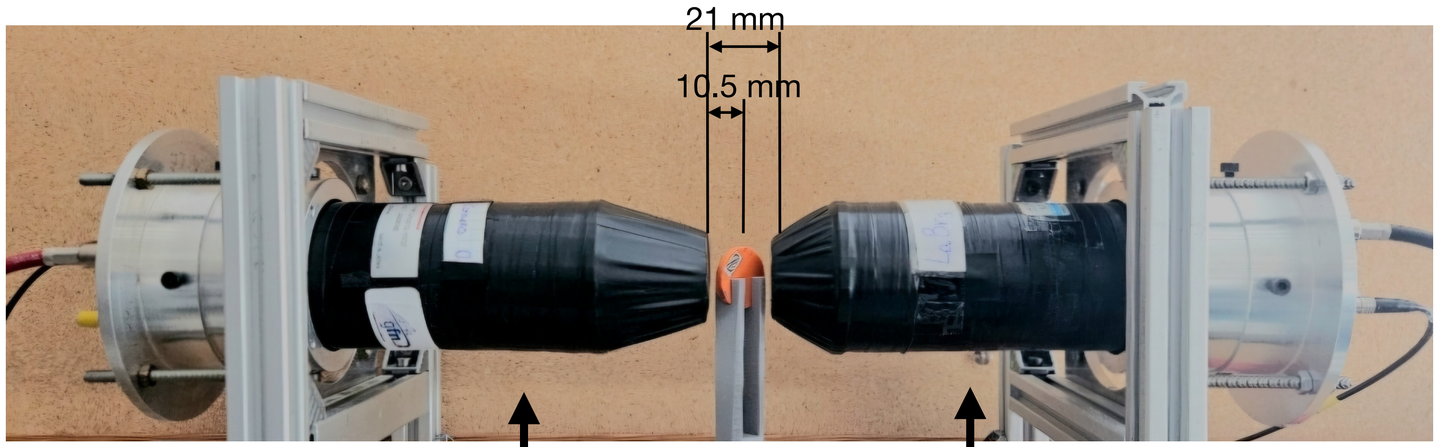


[1] V. Vedia, H. Mach, L. Fraile, J. Udías, S. Lalkovski, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 795, 144 (2015). DOI https://doi.org/10.1016/j.nima.2015.05.058. URL https://www.sciencedirect.com/science/article/pii/S0168900215007172

[2] V. Vedia, M. Carmona-Gallardo, L. Fraile, H. Mach, J. Udías, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 857, 98 (2017). DOI https://doi.org/10.1016/j.nima.2017.03.030. URL https://www.sciencedirect.com/science/article/pii/S0168900217303704

[3] L. Fraile, V. Sánchez-Tembleque, J. Benito, M. García-Díez, J. Udías, V. Vedia, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 463, 394 (2020). DOI https://doi.org/10.1016/j.nimb.2019.04.044. URL https://www.sciencedirect.com/science/article/pii/S0168583X19302289

Experimental setup



Detector to test

Reference detector

Time-delayed setup for the CRT measurements.

Experimental method

Detectors to test and reference detector

Detectors to test

Crystal

LaBr3(Ce) with the shape of a truncated cone 1.5” in height and with bases of 1.5” and 1” in diameter.

Newer PMTs

- Hamamatsu R13089 [4] with the assembly H13719-Y006: 2” of diameter and 8 stages.
  ➜ **The longest one**
- Hamamatsu R13089 with the assembly H13719-Y007: 2” of diameter and 8 stages.
  ➜ **The shortest one**
- Hamamatsu R13408-Y006 [4]: 1.5” of diameter and 8 stages. It is smaller than the crystal.
  ➜ **The smallest one**

All of them have a bialkali photocathode.

Reference detector

For timing measurements.

- Crystal: cylindrical LaBr3(Ce) of 1” × 1”.
- PMT: Hamamatsu R9779 [5] with the assembly H10570 operated at -1275 V. Its diameter sizes 2”, it has 8 stages and a bialkali photocathode.
  ➜ **The oldest one**

Main characteristics of the PMTs

PMT	τ_{rise}	FWHM TTS (ps)	Sensitivity		Dark current (nA)
			Cathode (μA/lmF)	Blue (μA/lmF)	
R9779	1.8	250	95	11	15
R13089	1.9	230	95	10	3
R13408	1.2	190	95	10	10

[4] Hamamatsu. Hamamatsu Photonic Systems R13478, R13449,R13408,R13089 and R15608 datasheet. URL https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/etd/R13478_R13449_R13408_R13089_R15608_TPMH1363E.pdf

[5] Hamamatsu. Hamamatsu Photonic Systems R9779 datasheet. URL https://www.digchip.com/datasheets/parts/datasheet/190/r9779-pdf.php

DAQ and signal processing

DAQ

PSI DRS digitizer [6].
For timing measurements, an internal logical AND trigger was used to record only events in coincidence at 5.12 GS/s.

Signal processing

For timing measurements.

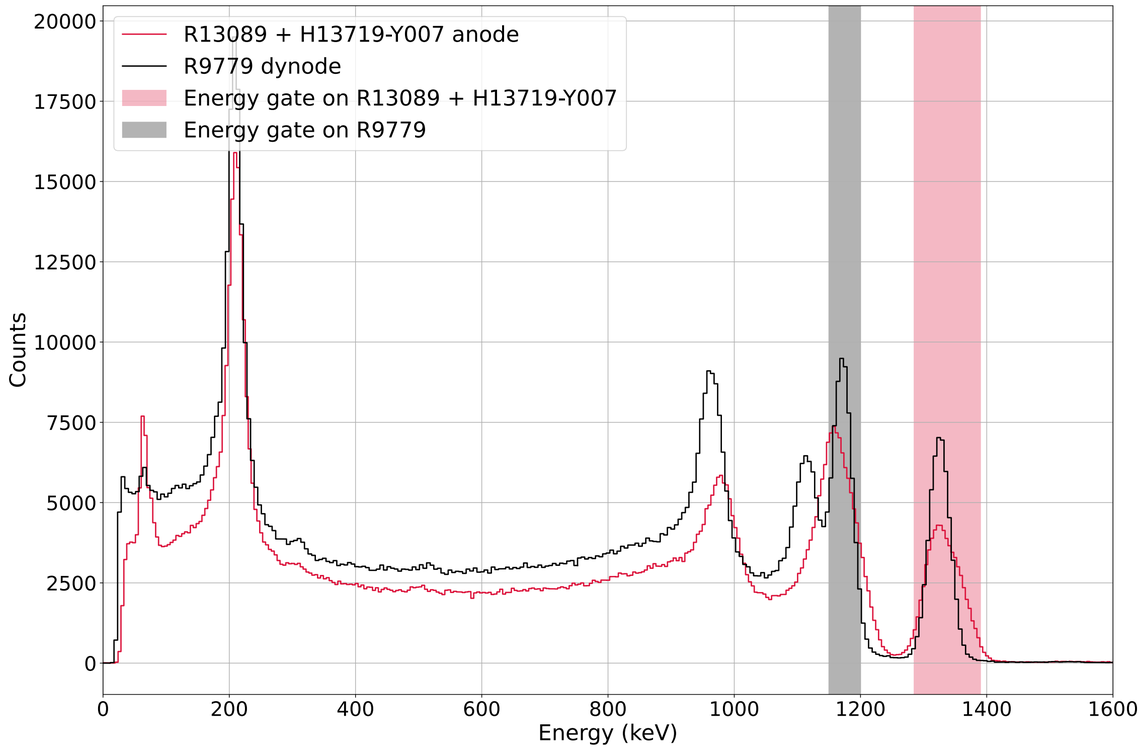
- Digital Constant Fraction Discrimination (D-CFD) [7].
- First-order recursive filter where RC and CR are particular cases [7].
- Genetic algorithm to optimize the parameters from the filter and the D-CFD [7].

[6] P.S. Institute. Drs chip home page. URL https://www.psi.ch/en/drs
[7] V. Sánchez-Tembleque, V. Vedia, L. Fraile, S. Ritt, J. Udías, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 927, 54 (2019). DOI https://doi.org/10.1016/j.nima.2019.02.017. URL https://www.sciencedirect.com/science/article/pii/S0168900219301925

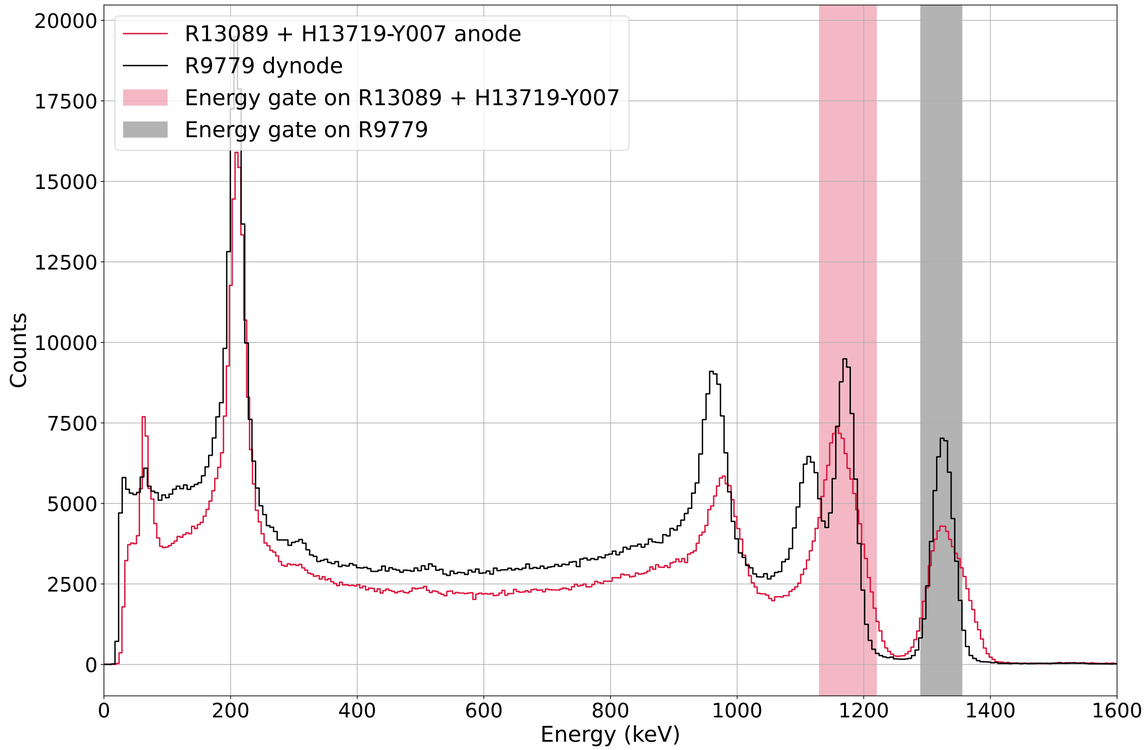
How to calculate time resolutions with a ^{60}Co source.

First step: To choose the energy windows. This results in two time spectra.

First pair of energy windows



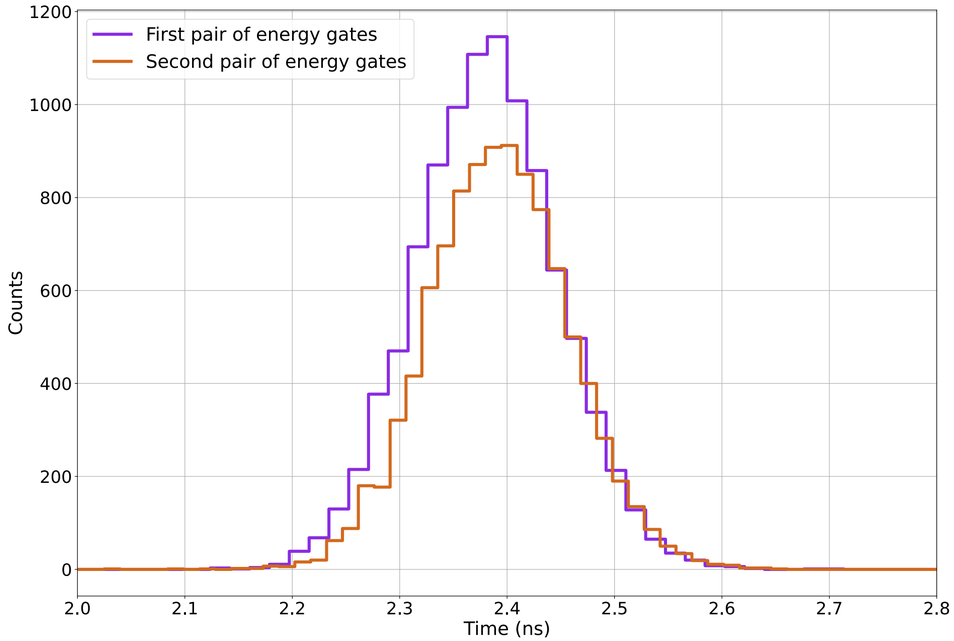
Second pair of energy windows



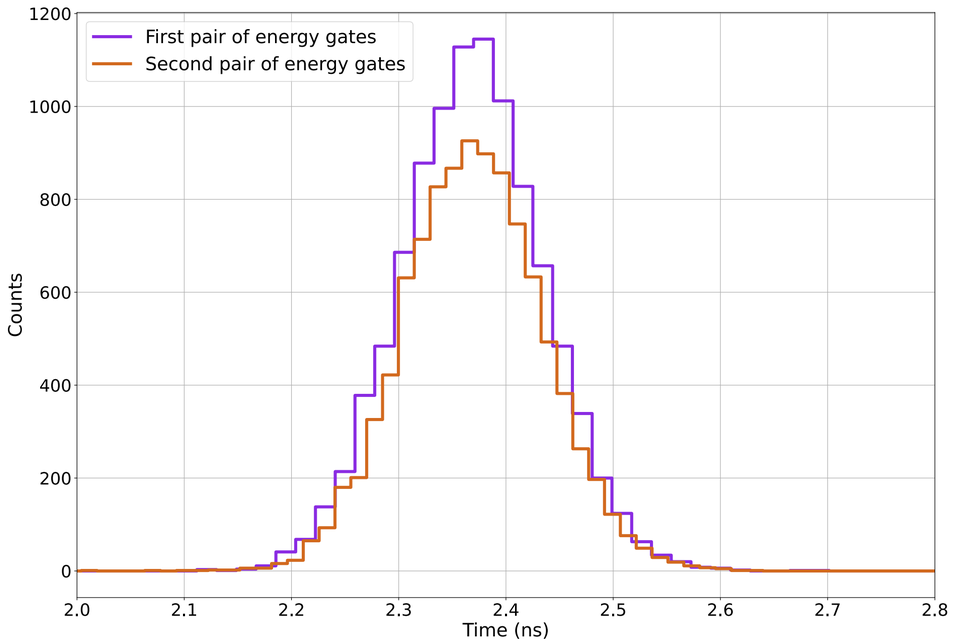
How to calculate time resolutions with a ^{60}Co source.

Second step: To correct by the energy-time walk.

Time spectra without correction



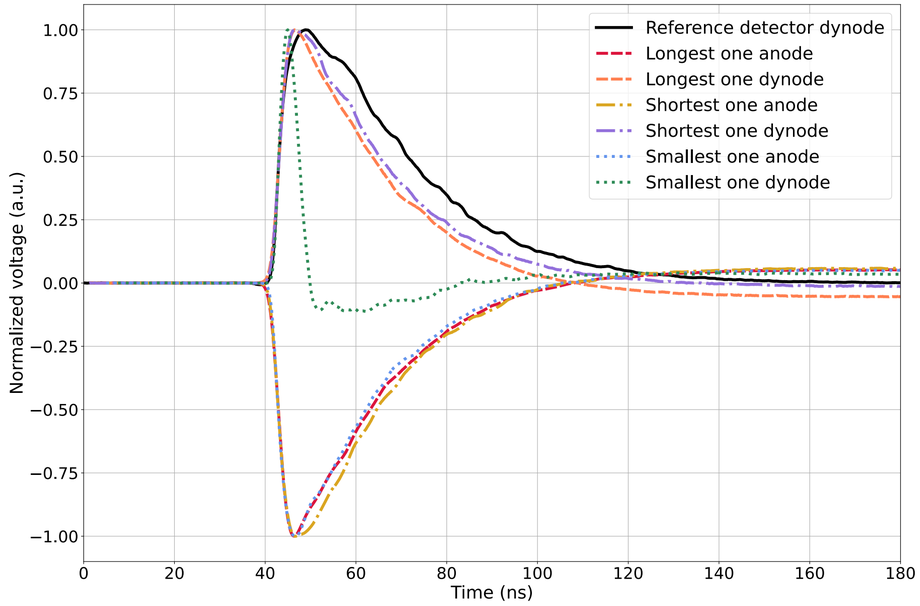
Corrected time spectra



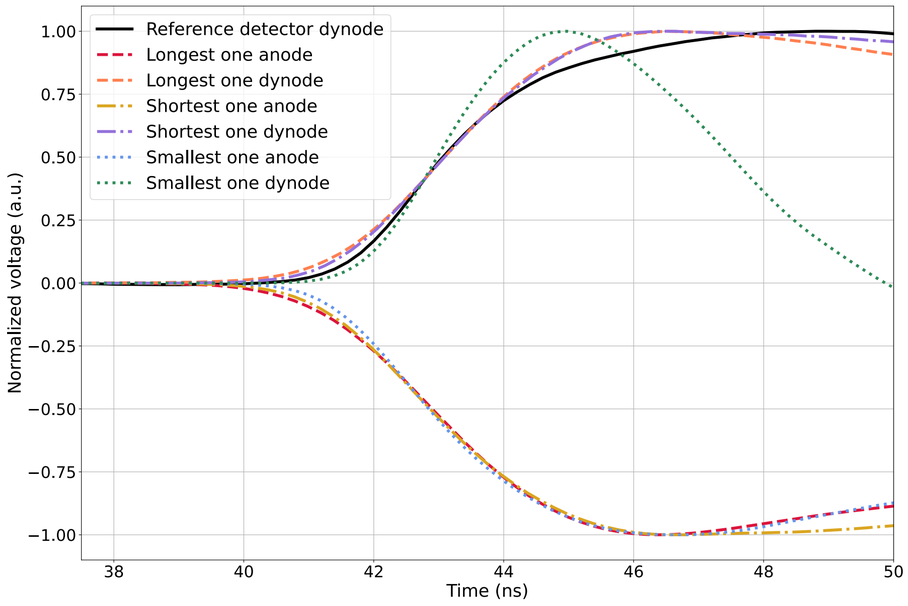
Final step: To add both time spectra and to get the FWHM, so the CRT is measured.

Pulse shapes

At original scale



Zoomed in



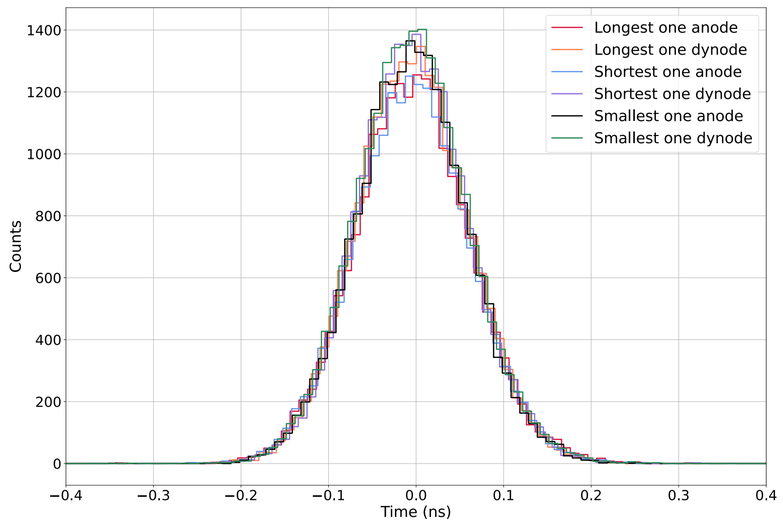
R13408 dynode has an undershoot and the shortest rise time.

PMT	Polarity	Voltage (V)	Rise time (ns)
Reference detector	Dynode	-1275	3.6
The oldest one	Dynode	-1275	4.3
The longest one	Anode	-1575	3.4
The longest one	Dynode	-1350	3.4
The shortest one	Anode	-1500	3.8
The shortest one	Dynode	-1300	3.3
The smallest one	Anode	-1100	3.4
The smallest one	Dynode	-1250	2.2

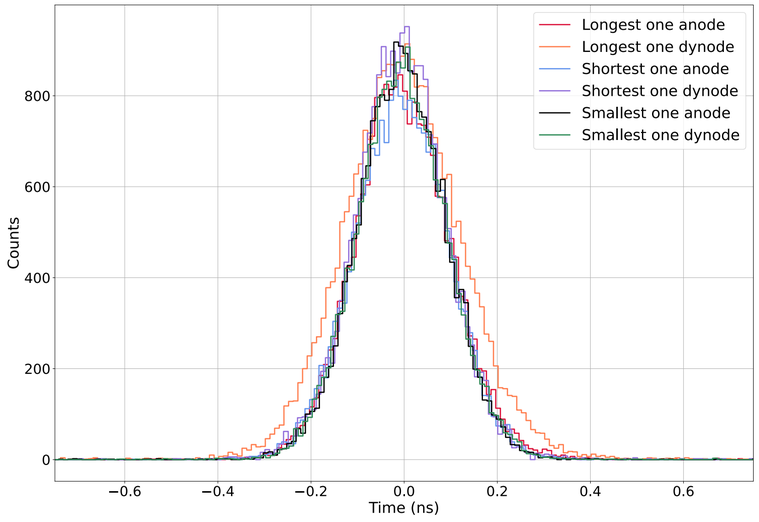
Results

Time resolutions and time walks

Time spectra for ^{60}Co



Time spectra for ^{22}Na



Reference detector

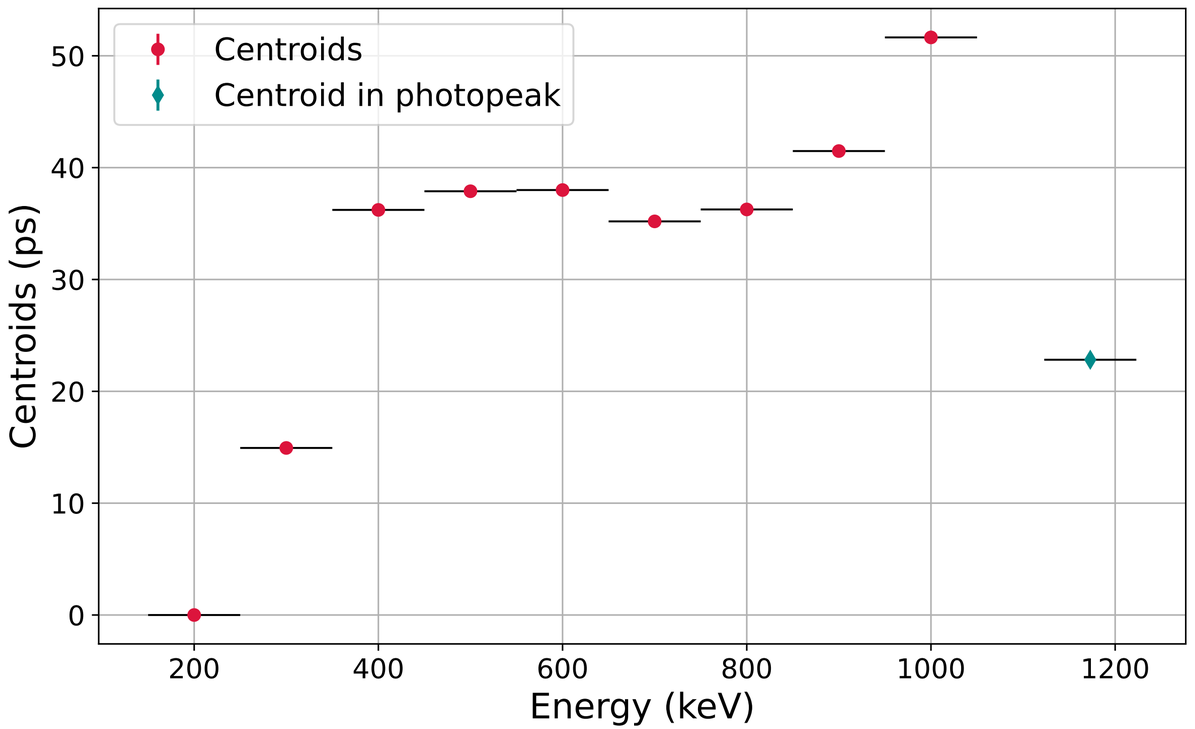
PMT	Polarity	Voltage (V)	Time resolution at ^{60}Co energies (ps)			Time resolution at ^{22}Na energies (ps)		
Reference detector	Dynode	-1275	81	±	4	129	±	2

Detectors to test

PMT	Polarity	Voltage (V)	Time resolution at ^{60}Co energies (ps)			Time resolution at ^{22}Na energies (ps)		
The oldest one	Dynode	-1275	111	±	1	156	±	2
The longest one	Anode	-1575	128	±	3	197	±	4
The longest one	Dynode	-1350	126	±	3	251	±	3
The shortest one	Anode	-1500	129	±	3	196	±	4
The shortest one	Dynode	-1300	120	±	3	179	±	4
The smallest one	Anode	-1100	122	±	3	177	±	4
The smallest one	Dynode	-1250	124	±	3	182	±	3

Time resolutions and time walks

Example time walk plot



- All of the PMTs have small time walk values.
- The energy gate in the reference detector was set at 1332 keV.
- The energy gates in the detector to test go from 150 keV to 1050 keV.
- The centroid of the photopeak is included.

Results

Energy resolutions and linearities

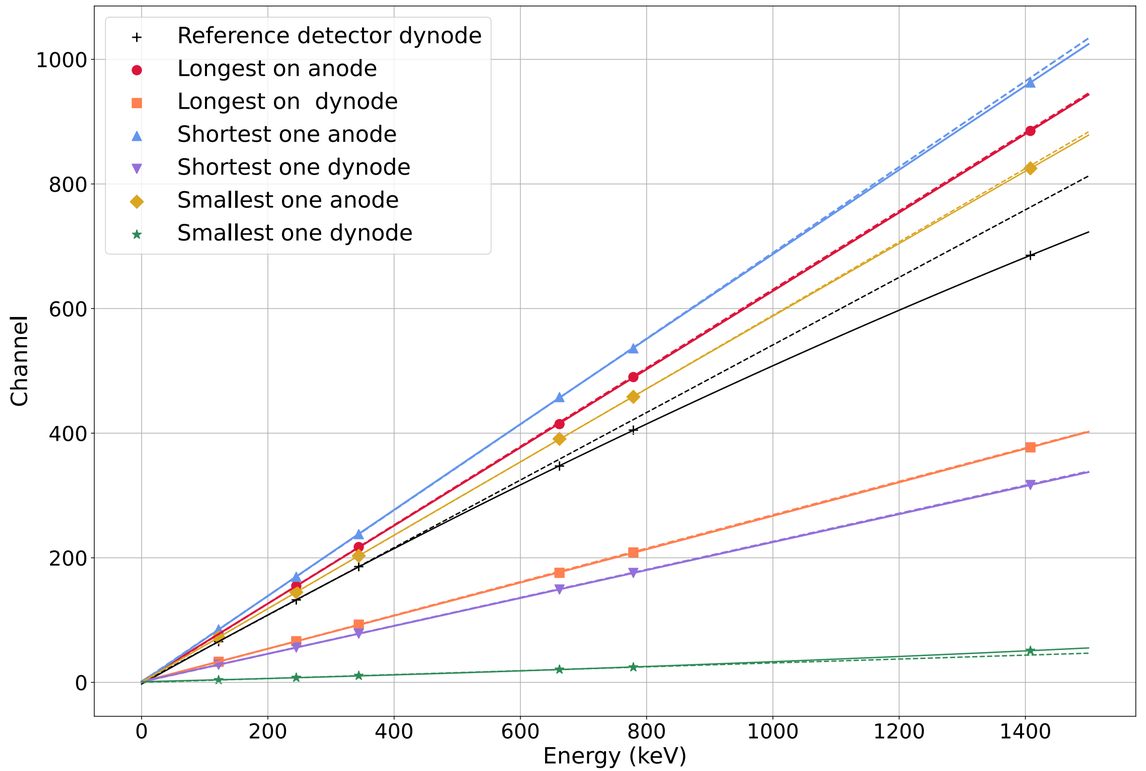
Reference Detector

PMT	Polarity	Voltage (V)	Energy resolution at 662 keV energies (%)
Reference detector	Dynode	-1275	3.0

Detectors to test

PMT	Polarity	Voltage (V)	Energy resolution at 662 keV energies (%)
The oldest one	Dynode	-1275	4.1
The longest one	Anode	-1575	4.7
The longest one	Dynode	-1350	4.8
The shortest one	Anode	-1500	4.7
The shortest one	Dynode	-1300	4.5
The smallest one	Anode	-1100	5.9
The smallest one	Dynode	-1250	8.8

Linearity



Conclusions

What PMT should we choose?

- The dynode R13408-Y006 (the smallest one) signal has an undershoot that worsens the energy resolution. This is enough reason to discard this one.

- R13089, with the assembly H13719-Y006 (the longest one) and H13719-Y007 (the shortest one), has similar energy resolutions, but with H13719-Y007 it can provide better time resolutions.

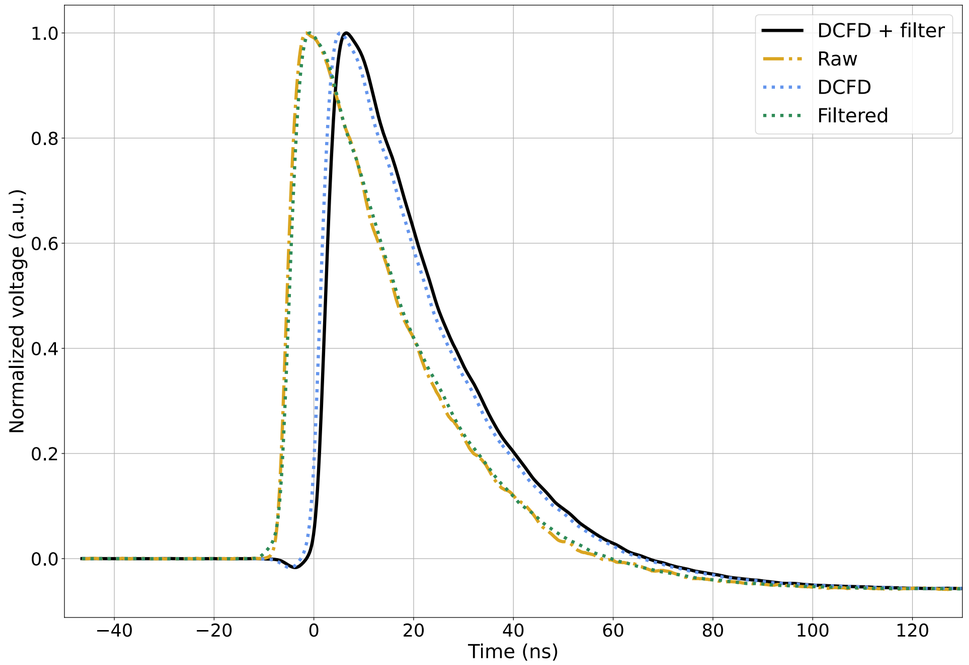
My answer: I would choose R13089 with the assembly H13719-Y007.

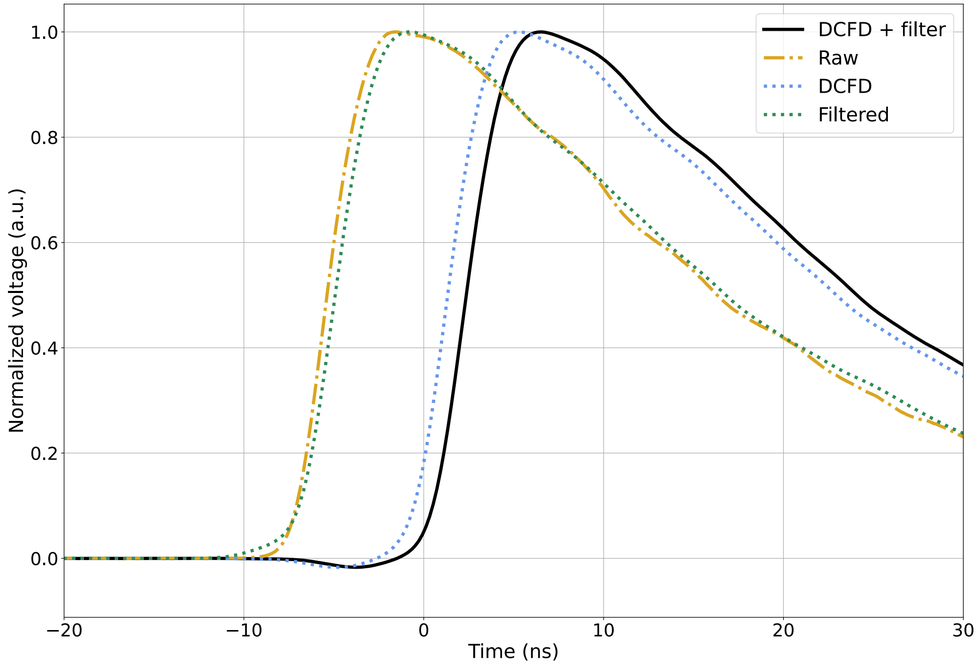
Remarkably, the newer PMTs results do not match the results acquired with the old Hamamatsu R9779.

The end

Thank you for your attention

DAQ and signal processing





First order recursive filter: $Y[n] = A \cdot [y-1] + B \cdot x[n] + C \cdot x[n-1]$