Study and Development of a PET detector with position resolution of 0.1 mm using Wavelength Shifting Fibers

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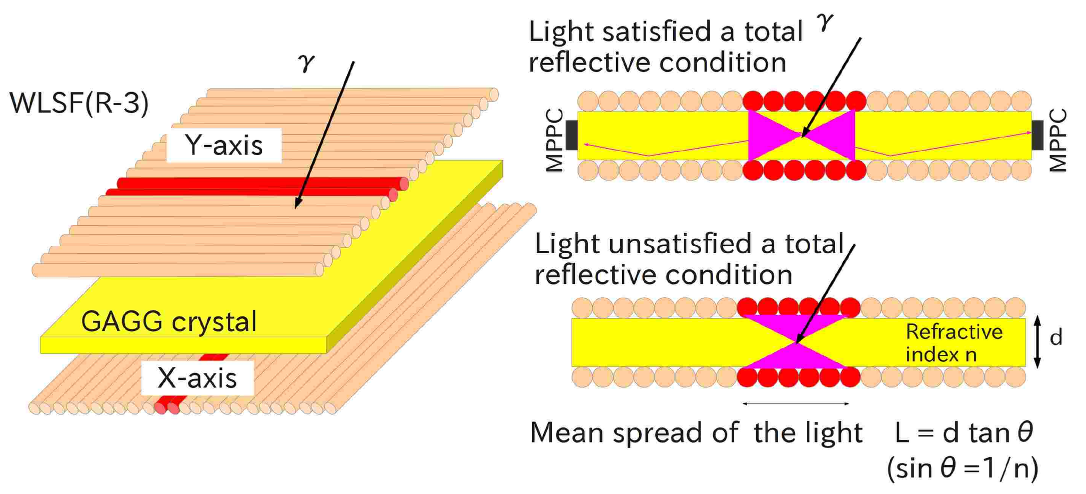
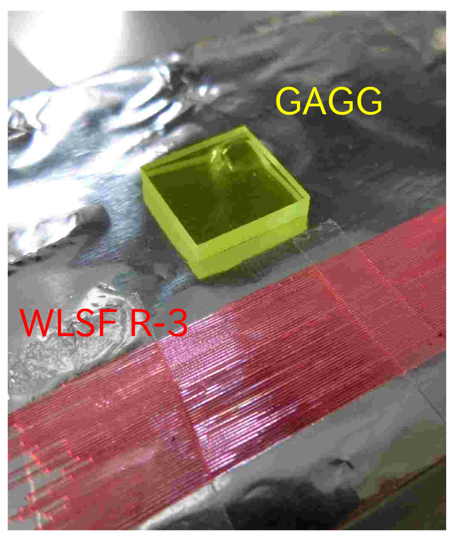
PET detector using WLSF





An approach for narrow position resolution in PET detection is using thiner scintillator crystals sandwiched with wavelength shifting fiber (WLSF) sheets and reading XY coordinates by photo-device [1], e.g. MPPC or photomultiplier.

The coordinates of interaction position is determined by photo-device read out the fibers which absorbed the light entering from the crystal. And the position resolution depends on the fiber size and the thickness of crystal [2, 3, 4], e.g. the resolution is allowed 0.2 mm by using the fiber of Φ0.2 mm. Anger Logic is known as a method of reconstruction position which calculated by weight of photoelectrons. In this way, the resolution is expected less than 0.1 mm.

GAGG (C&A Co. Ltd.)
size 10 x 10 x d mm³ ··· (d = 0.5, 1, 2 mm), polish 2 face, 57,000 ph./MeV, 520 nm [5]

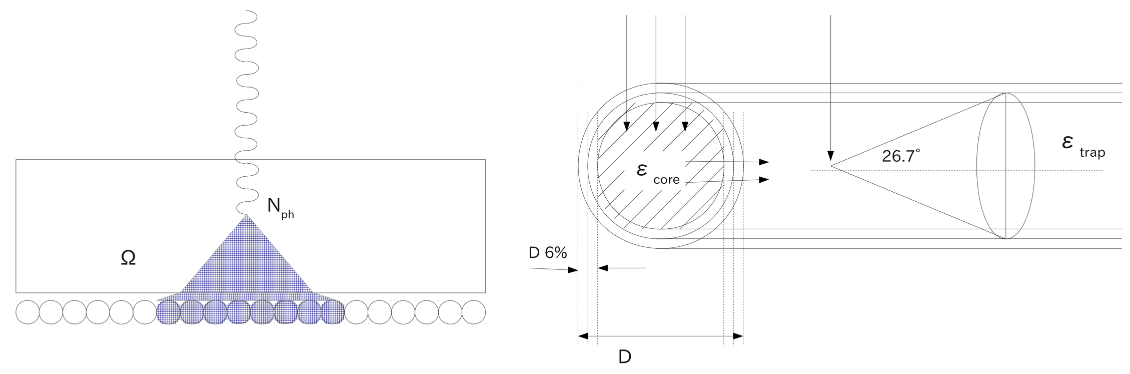
WLSF R-3(Kuraray Co. Ltd.)
size ϕ0.2 mm, absorption 500 - 550 nm, emission peak 560 - 600 nm, trapping efficiency of 0.054 [6].

WLSF Readout system

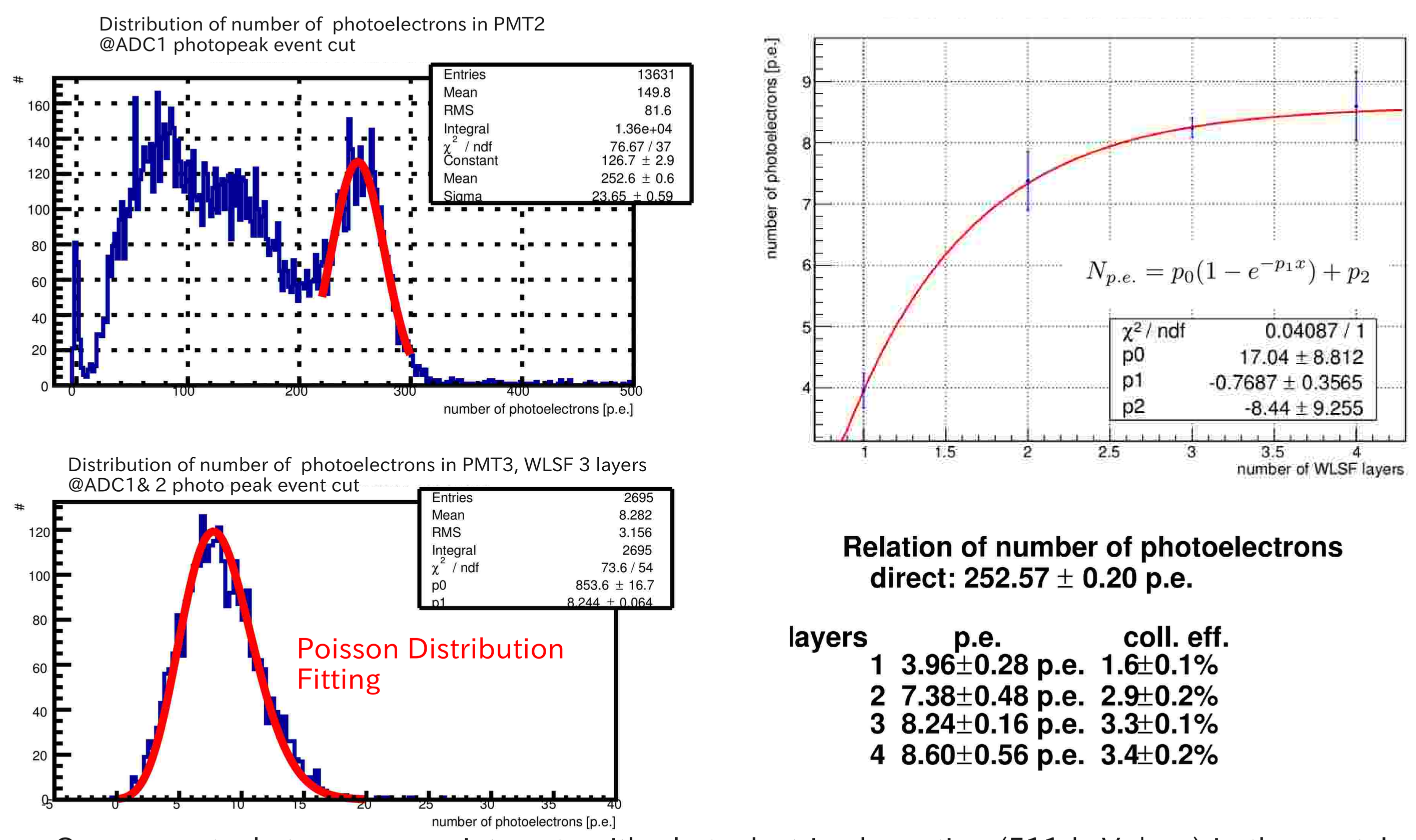
A Number of photoelectrons measured via WLSF by PMT is given as,

$$N_{p.e.} = \int \frac{N_{ph}(\lambda)}{MeV}\Omega(\lambda)\varepsilon_{core}(\lambda)\varepsilon_{trap}(\lambda)\varepsilon_{PMT}(\lambda)d\lambda,$$

where N_{ph} notes number of photons emitted from the crystal per unit deposited energy, Ω is ratio of incident light into WLSF's core and the emitted light, ε_{core}, ε_{trap} and ε_{PMT} represent, respectively, wavelength shifting efficiency in the core, trapping efficiency defined from a total reflection condition between core and cladding [6] and quantum efficiency.



WLSF Collection Efficiency



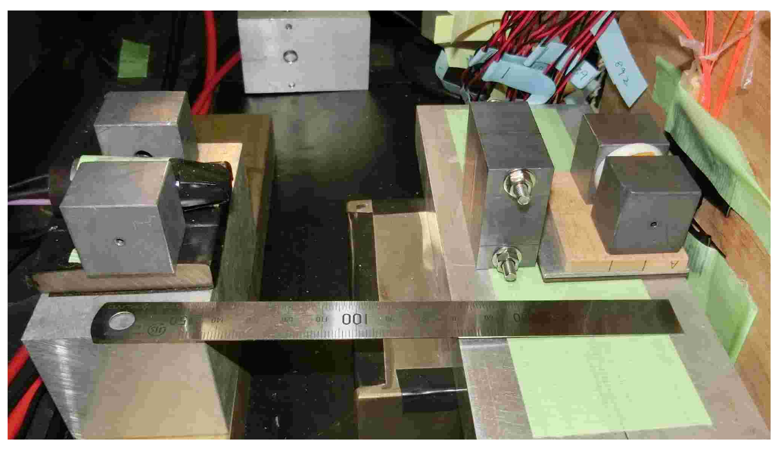
Relation of number of photoelectrons
direct: 252.57 ± 0.20 p.e.

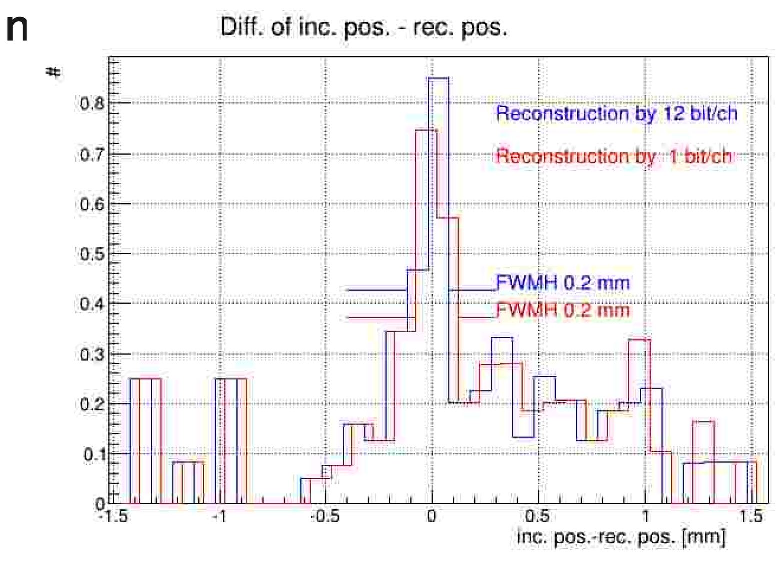
layers	p.e.	coll. eff.
1	3.96±0.28 p.e.	1.6±0.1%
2	7.38±0.48 p.e.	2.9±0.2%
3	8.24±0.16 p.e.	3.3±0.1%
4	8.60±0.56 p.e.	3.4±0.2%

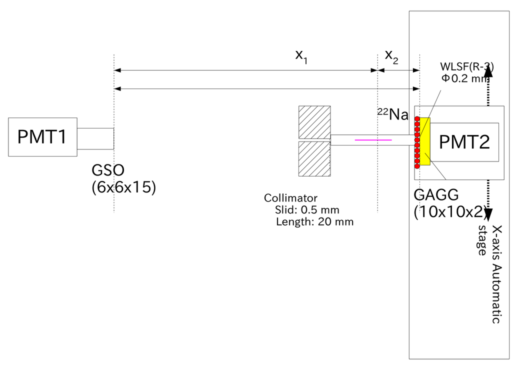
On an event what gamma-ray interacts with photoelectric absorption (511 keV ± σ) in the crystal, a relation between number of photoelectrons via WLSFs and number of fiber layers is shown in the right graph, where the WLSFs connected to side of the crystal. Mean number of photoelectrons is estimated by Poisson distribution fitting. The relation has exponential function toward saturation. This saturation number of photoelectrons means the WLSF's core absorbing approximately all photons in incident to the fibers from the crystal.

Collection efficiency of WLSF is estimated by comparing with a number of photoelectrons observed from the crystal directly. As the result, ε_{core} = 0.63 ± 0.04 is obtained by ratio of the collection efficiency on the saturation condition and trapping efficiency.

Measurement of Position Resolution





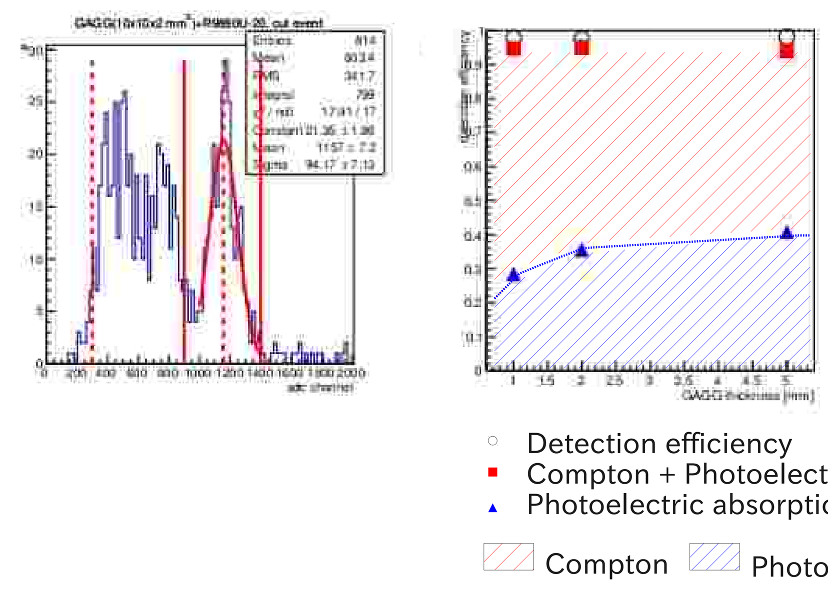


Difference of incident position and reconstruction position of the interaction in the crystal is shown in the right figure. The reconstruction position (X) is given as,

$$X = \begin{cases} \frac{1}{Q}\sum_i x_i N_i,\ Q = \sum_i N_i & \text{(12 bit/ch)} \\ \frac{1}{D}\sum_i x_i n_i,\ D = \sum_i n_i & \text{(1 bit/ch)} \end{cases}$$

where x_i is x-coordinate of the fiber connected i^{th} MPPC, N_i presents number of photoelectrons of i^{th} channel at 12 bit and n_i denotes 1 or 0 to detect photons at i^{th} channel. As result, both operation method of reconstruction achieved FWHM 0.2 mm of resolution in x-axis.

Detection Efficiency

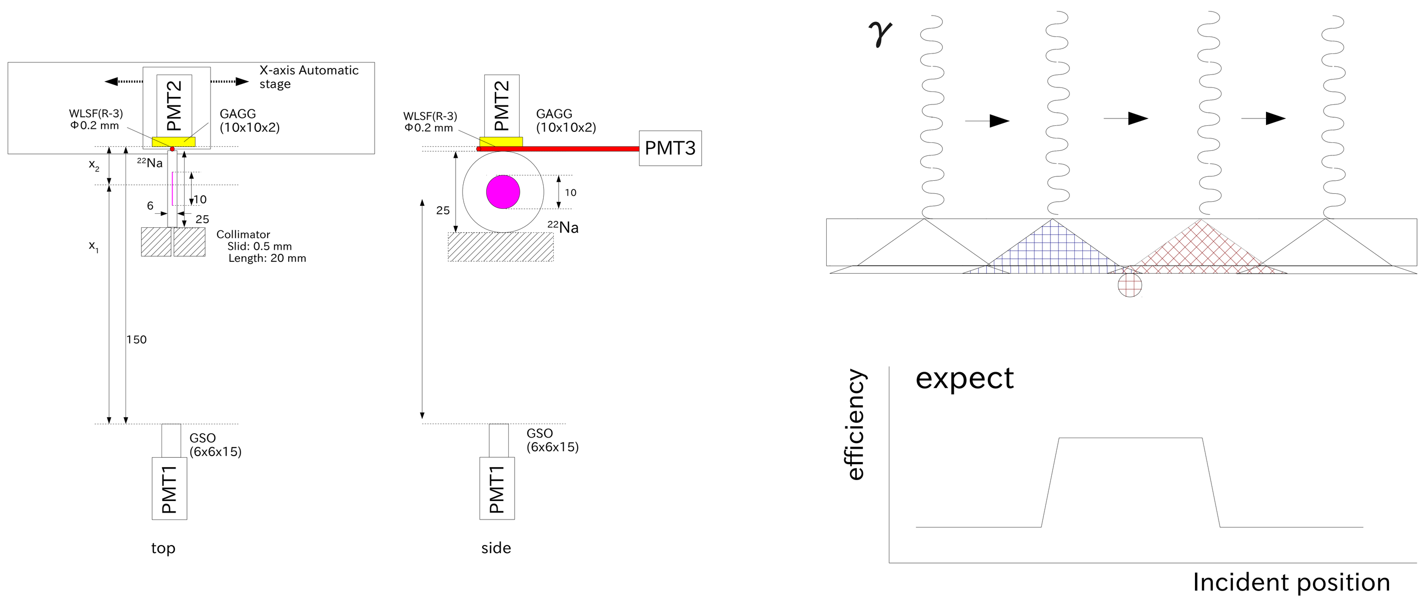


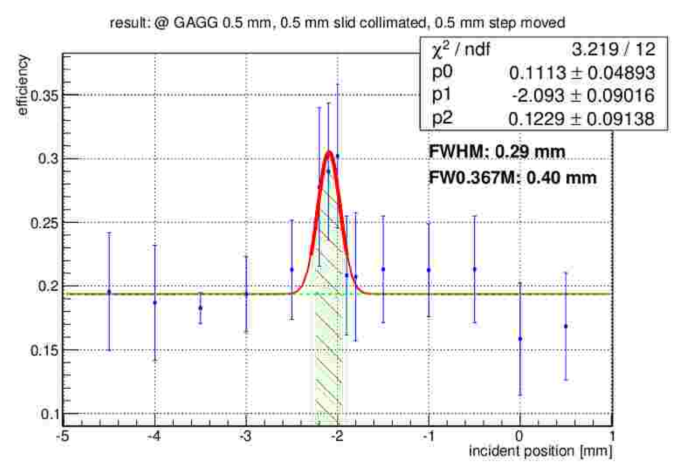
Detection Efficiency depending on GAGG's thickness

d =	1 mm	2 mm	5 mm
Total eff:	0.977	0.975	0.982
$eff_{Comp.}$:	0.662	0.595	0.532
$eff_{phe.}$:	0.285	0.356	0.409

A percentage of photoelectric absorption event increases according with the crystal's thickness. Detection efficiency of a conventional PET detector is based on method of simultaneous measurement of photoelectric absorption events. The system using WLSF improves to 5-10 times of detection efficiency than conventional, because it can analyze also Compton scattering events.

Demonstration of Parallel γ-Beam System





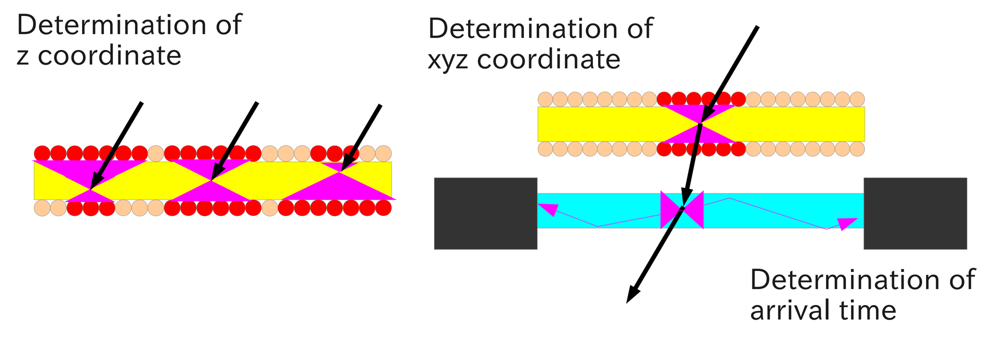
A collimated read allows to irradiate parallel γ-beam with width of 0.1 mm, where the slid width is 0.5 mm (setup is shown in the left top figure). The spread of incident light to the fiber depends on the crystal thickness. When an incident position of gamma-ray move minute, detection efficiency similar rectangular shapes would expect to obtain. As the result, detection efficiency peak with FWHM 0.29 mm was obtained by using the thickness of 0.5 mm. This result corresponds with average value of the spread light from the crystal.

Conclusion & Future outlook

The system using WLSF achieved the position resolution of FWHM 0.2 mm for gamma-ray detector. It is characterized possible to use any crystals if the absorption spectrum of WLSF overlap with the emitted spectrum of a crystal and the number of emission photon from the crystal is enough, e.g. GAGG and WLSF (R-3).

As the future outlook, the system would be include to read out interaction position in 3-dimensions, where z coordinate in the crystal is determined by ratio of the number of the absorbed fibers over and under the crystal. Adding differential crystal to pray function reading with higher timing resolution in the system, it would allows to break through a dilemma on the compromise of position resolution at about 0.2 mm and timing resolution less than 100 ps [9].

Compton scattering event analyzed for the system allows to improve detection efficiency to 5-10 times than convention, and it can suppress to explosion for patient or improve imaging resolution at same time of convention scanning.



Acknowledgment

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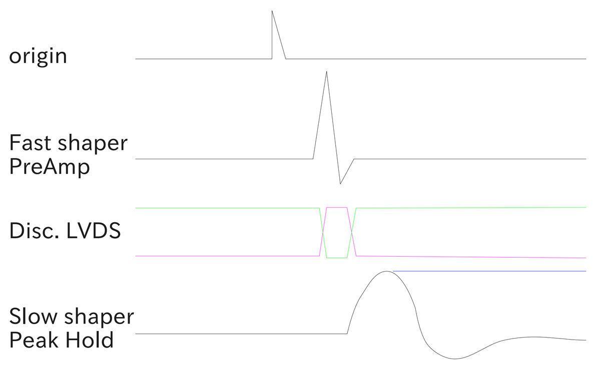
MPPC(R) & EASIROC module Readout system

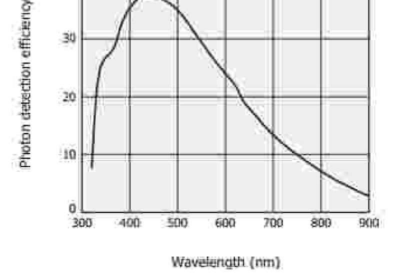
MPPC: S12572-100P

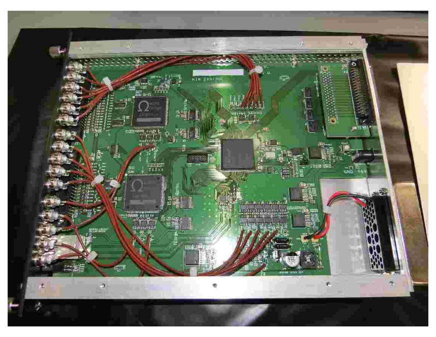
- Multi-Pixel Photon Counter
- Made by HAMAMATSU PHOTONICS K.K.
- Size: □ 3 mm
- Photon Detection Efficiency for GAGG [7]: 25 – 28% @550 – 600 nm
- Dark Count: 1000 kcps (Typ.)

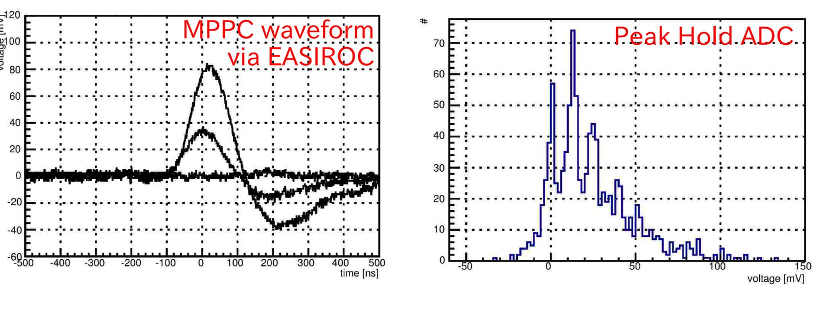
EASIROC module

- Extended Analogue Silicon pm Integrated Read Out Chip [8]
- Developed by Tohoku Univ. & KEK
- Installed two EASIROC chips (Ω group)
- Max 64 ch/mod. Supply Voltage Readout ADC (Peak Hold type ADC)
- NIM or AC supply Unit









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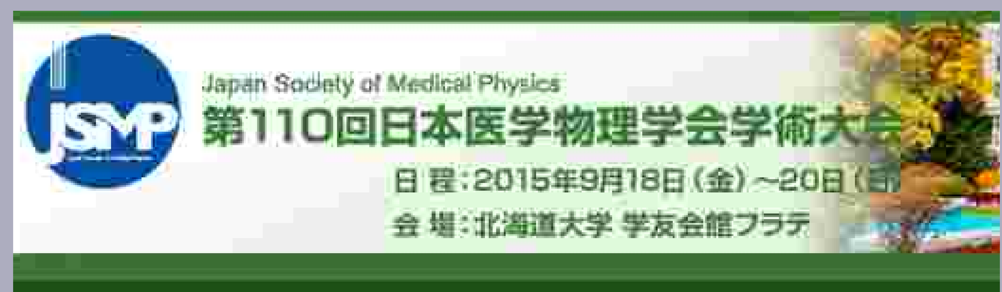

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