Alpha particle scintillation detector based on micro pixel avalanche photodiode and LYSO crystal

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24-th International Seminar on Interaction of Neutrons with Nuclei: **«Fundamental Interactions & Neutrons, Nuclear Structure, Ultracold Neutrons, Related Topics»**

Dubna, Russia, May 23 – 27, 2016

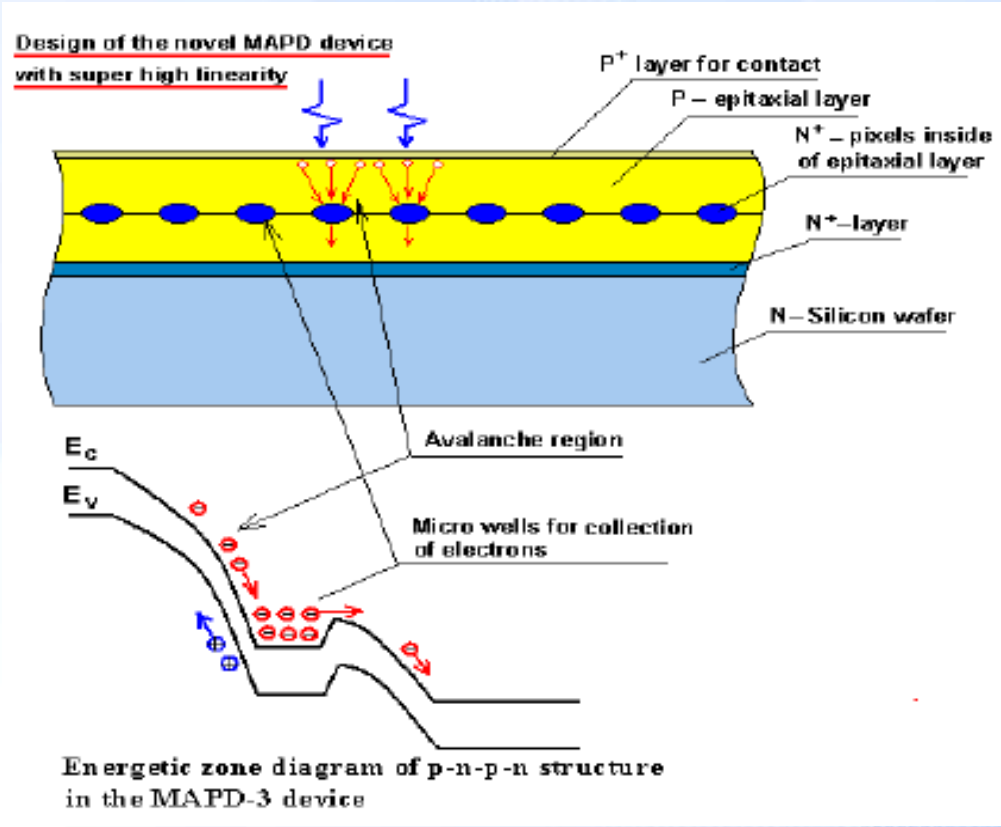
Outline

- Micro pixel avalanche photo diode (MAPD)
- LYSO scintillator
- The method of tagged neutrons
- Alpha particle detector based on MAPD array and LYSO scintillator
- Conclusion

Micro pixel avalanche photo diode

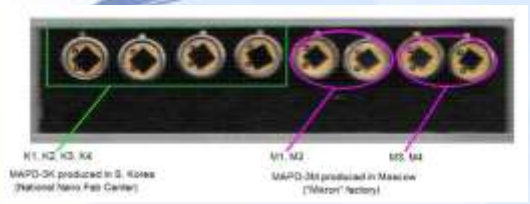
Silicon photomultipliers are nowadays considered a promising alternative to conventional vacuum tube photomultipliers. MAPD is one successful type of the silicon photomultipliers. Micro-pixel avalanche photodiode manufactured by Zecotek Photonics Inc.

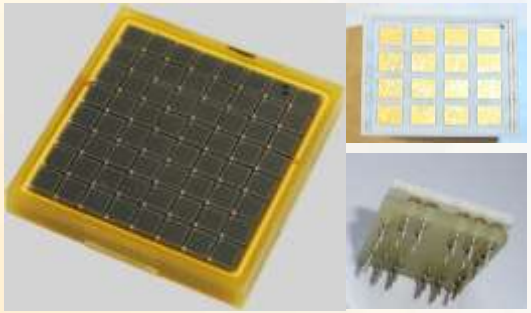
- PDE (~40%)
- High gain (~10^6)
- Low operation voltage (~90)
- High pixel density ($1*10^4$-$4*10^4$ pix./mm^2)
- Insensitive to magnetic field
- very compact
- very robust

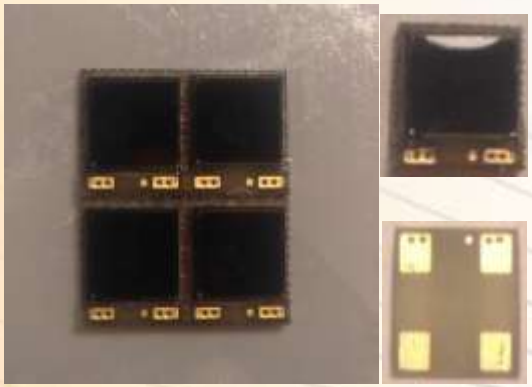


Design and operational principle of MAPD

MAPD from Zecotek Photonics Inc.







MAPD	3A	3B	3N	3N1P	K0
Pixel density-pix/mm^2	15000	40000	15000	15000	40000
Size,mm ^{2}	3x3	3x3	3x3	3x3	3.7x3.7
PDE, % (450-550)	~13	~13	~30	~30	~40
Gain-10^5	2	1	5	5	5
Voltage	~66	~70	~90	~90	~90

LYSO (Lutetium-yttrium oxyorthosilicate) scintillator

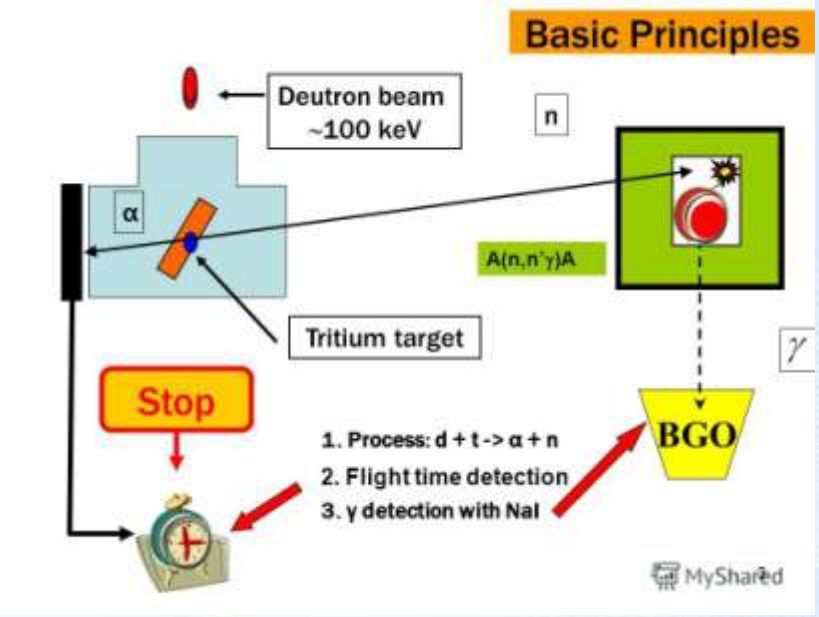
Material	NaI(Tl)	BGO	YAP	LYSO
Density(g/cm3)	3.67	7.13	5.55	7.3
Light output (%)	100	7-12	35-40	75
Decay time, (ns)	235	300	27	50
Peak emis, (nm)	410	480	350	428
Radiation Hardness (rad)				$>10^6$

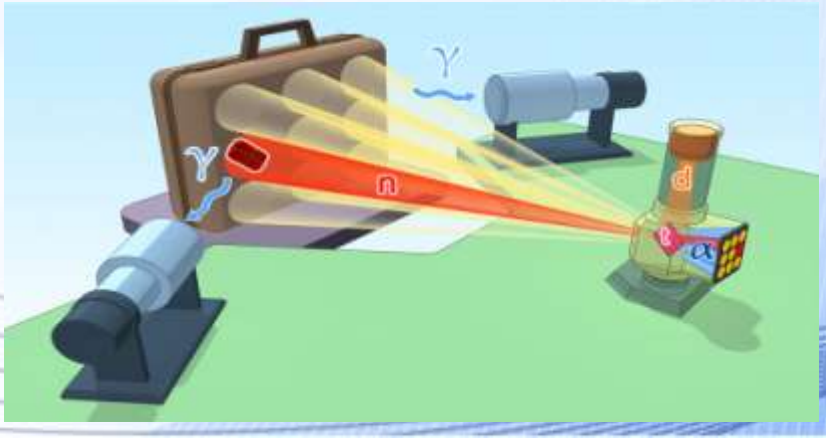
The method of tagged neutrons

The method of tagged neutrons uses fast monochromatic neutrons with the energy of 14.1 MeV produced in binary reaction d+t→4He+n. In this reaction the α particle with the energy of 3.5 MeV flights back-to-back with the neutron. By measuring the α -particle trajectory the direction of the corresponding neutron is determined.

DVIN-2 SETUP

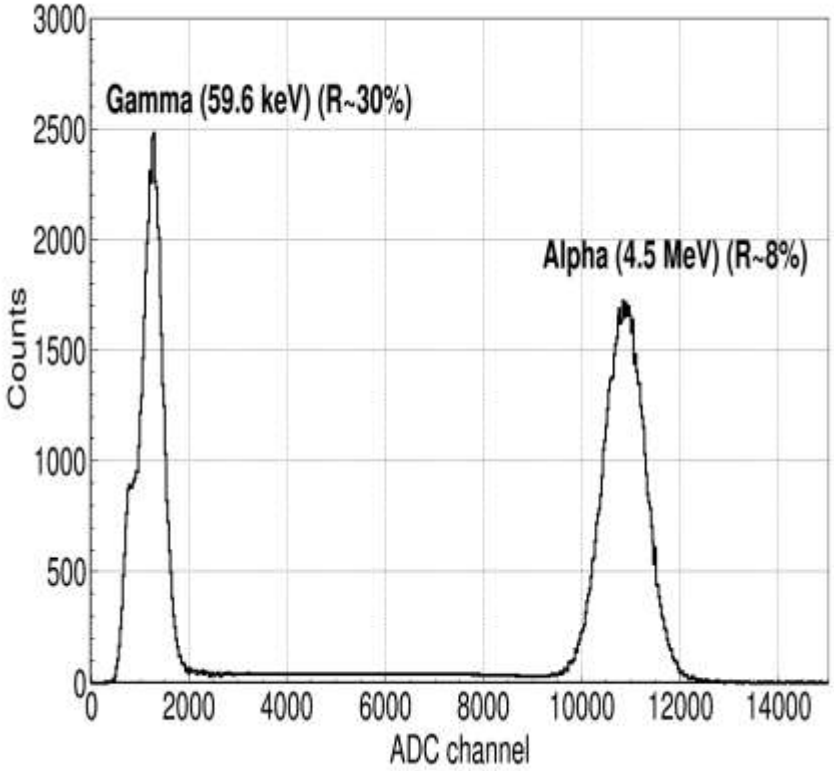
(1) a portable neutron generator with a built-in α detector;
(2) γ detectors based on BGO crystals;
(3) data acquisition electronics;
(4) biological shielding from the neutron radiation created by the neutron generator;
(5) a sample stage with moving support for the studied object;
(6) power supply units for the neutron generator and α and γ detectors;
(7) a PC-based operator interface with a data processing program block.



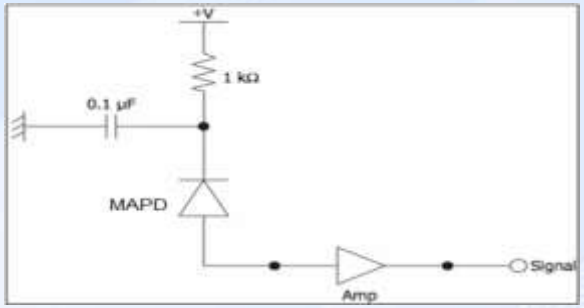


Scintillation detector based on MAPD and LYSO scintillator

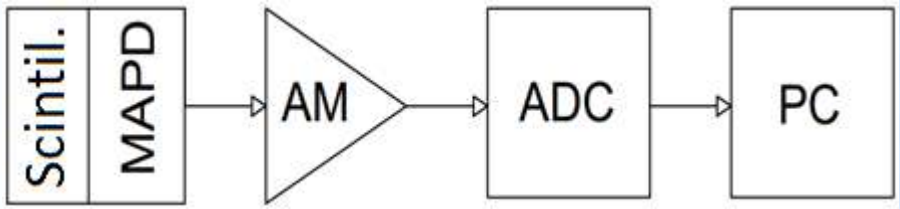
In order to measure alpha particle spectra, LFS scintillator (3*3*2 mm) was placed on top of MAPD (3*3 mm) separated from it by a thin layer of optical grease. Edges of the scintillator were covered with a 6-μm thick aluminum foil. An ^{241}Am alpha particle source with ~5.5 MeV energy was used in the experiment. The distance between the MAPD-1P diode and the alpha particle source was 1 cm. Energy loss for alpha particle was about 1 MeV in 1 cm of air was taken into account.



Pulse-height spectrum of ^{241}Am alpha-gamma source



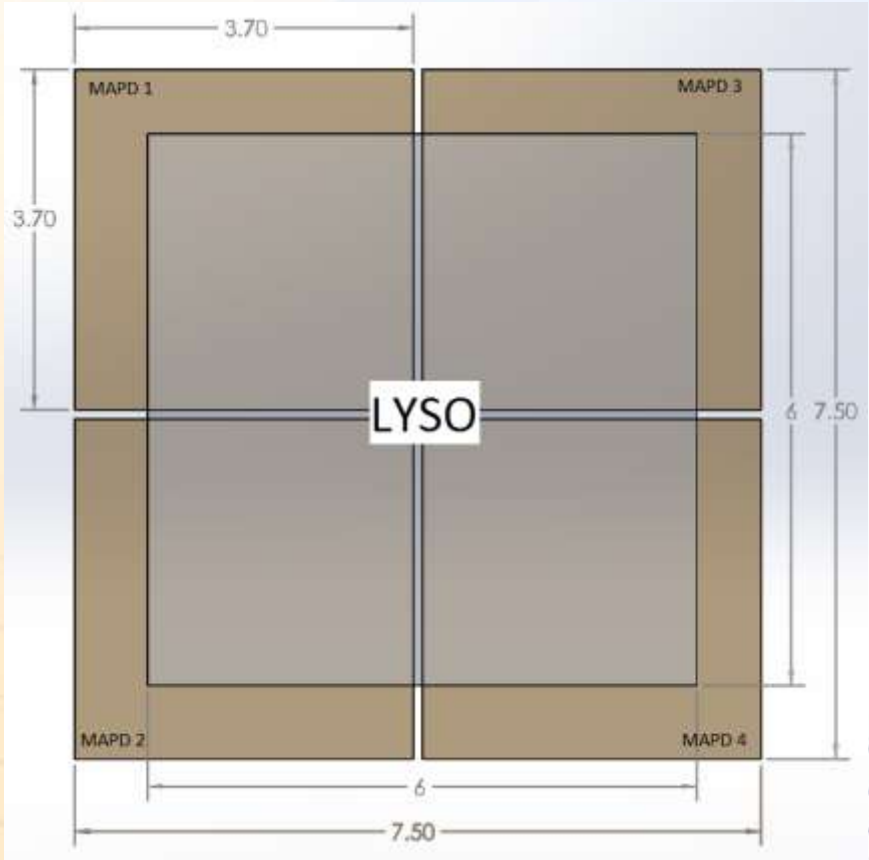
A basic electrical circuit for operating an MAPD

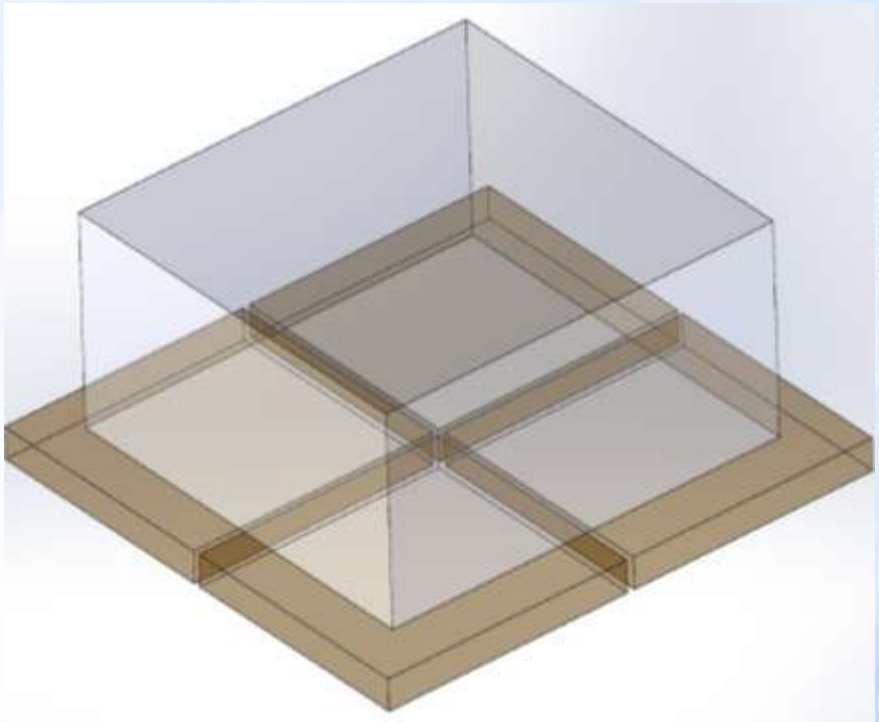


Block diagram of the experimental setup

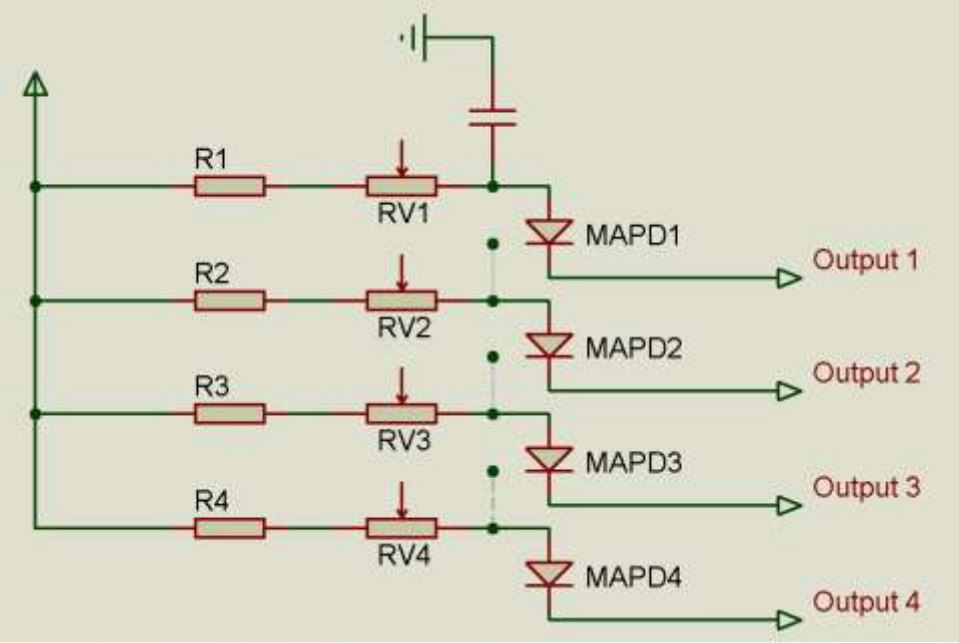
Scintillation detector based on MAPD array and LYSO crystal

Scintillation detector consist of LYSO scintillator and MAPD array. Size of the scintillator is 6*6*2 mm^3. 4 MAPD diodes in size of (3.7*3.7 mm^2) are used for MAPD array.

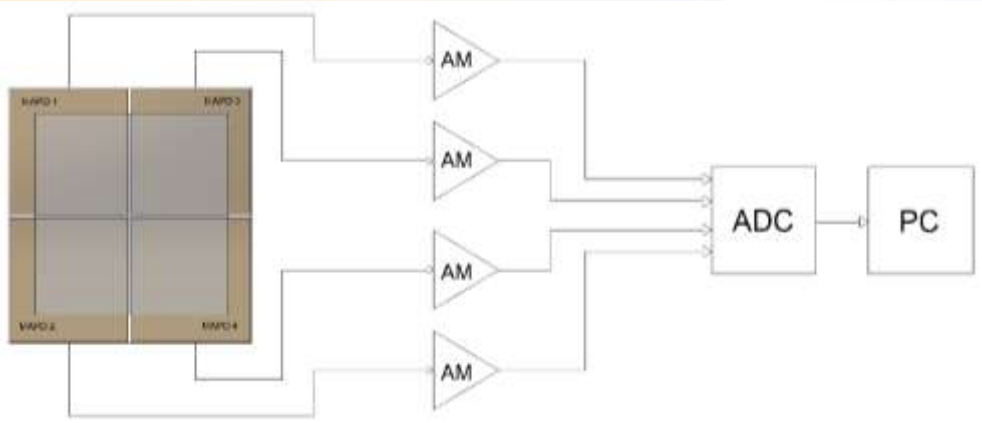




Scintillation detector based on MAPD and LYSO scintillator

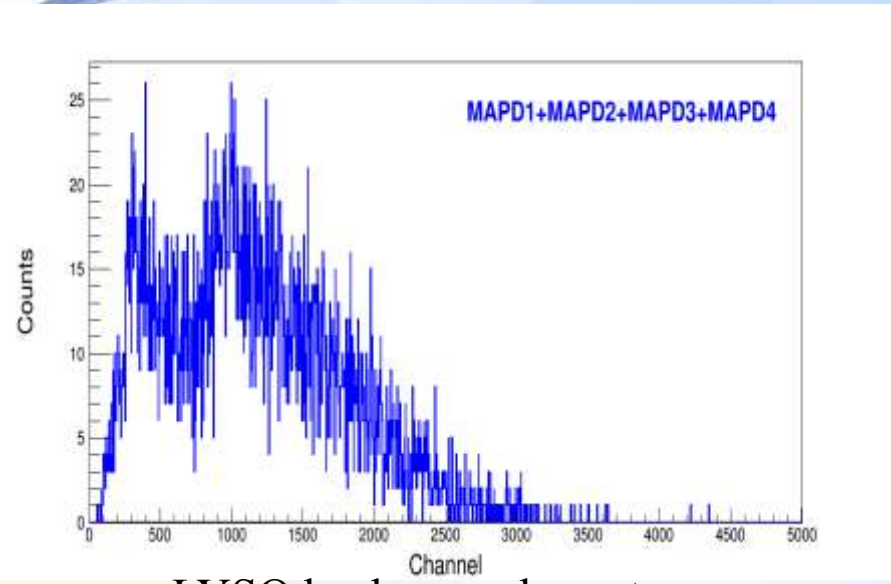


A basic electrical circuit for operating MAPDs



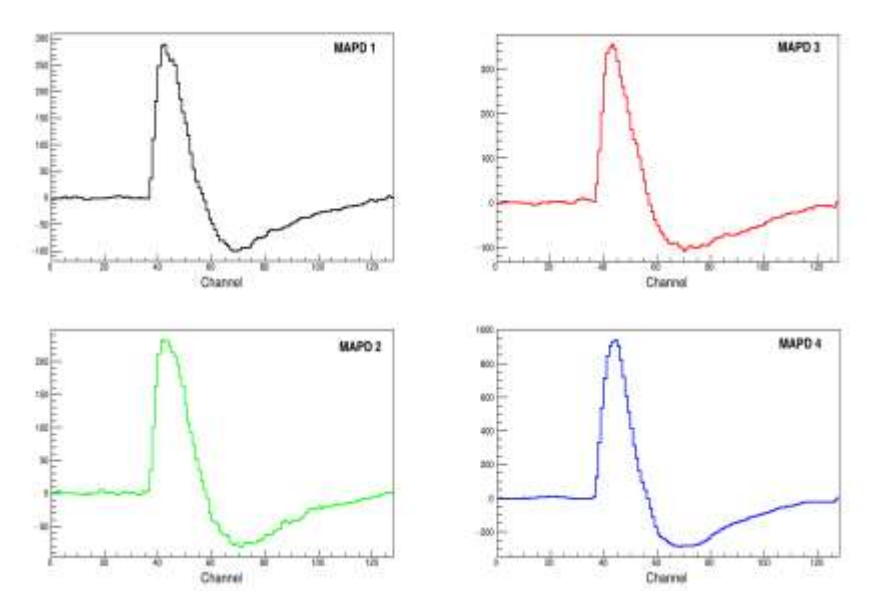
Block diagram of the experimental setup

Spectra of LYSO background

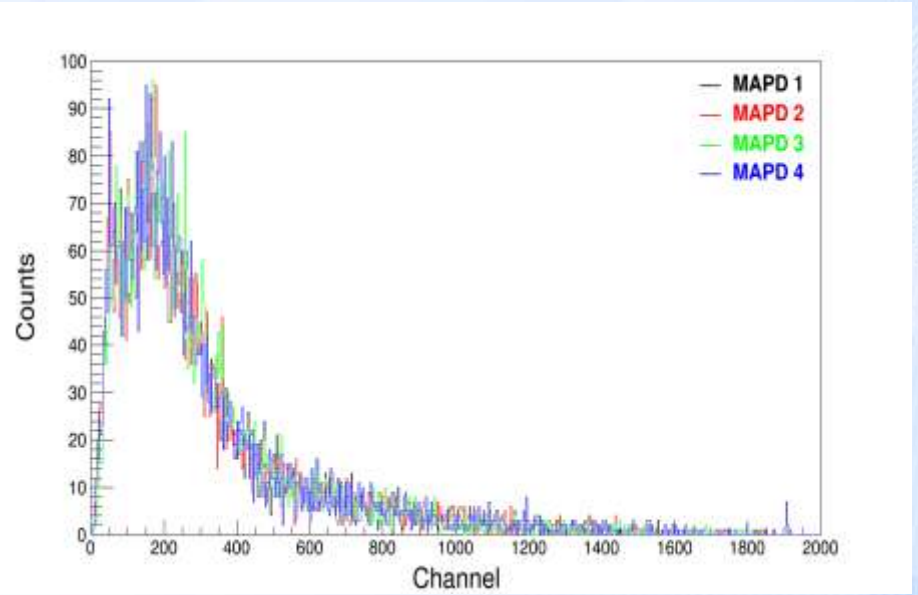


LYSO background spectrum

The LYSO crystals feature intrinsic radioactivity due to lutetium β decay with a maximum electron energy of 596 keV 176Lu→176Hf followed by emission of three prompt gammas with energies of 88, 202 and 307 keV.



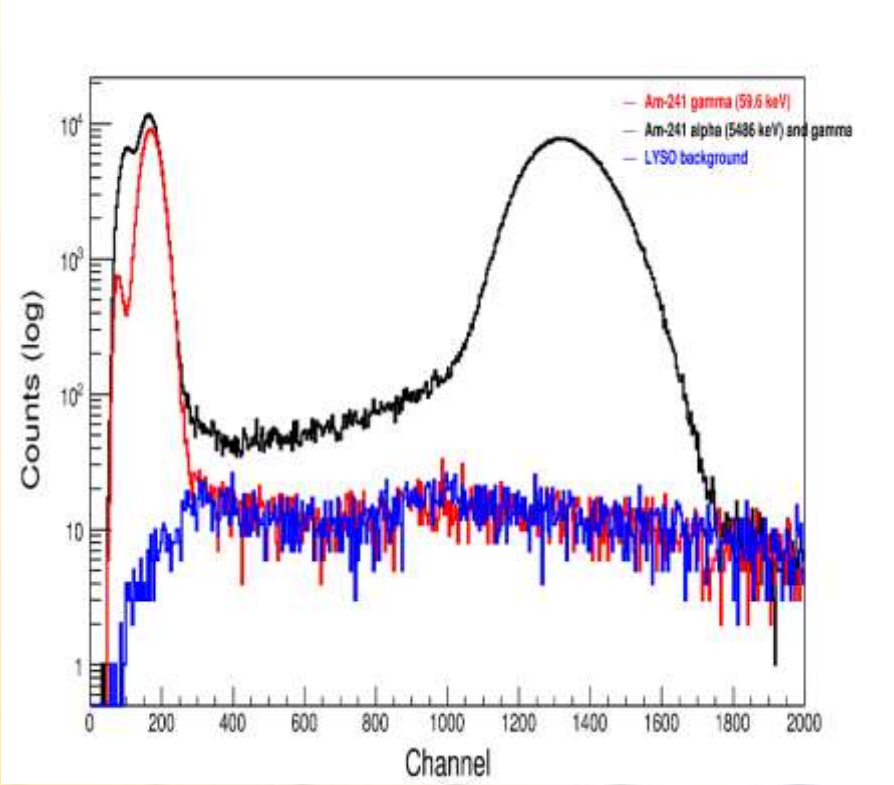
Waveforms from MAPDs

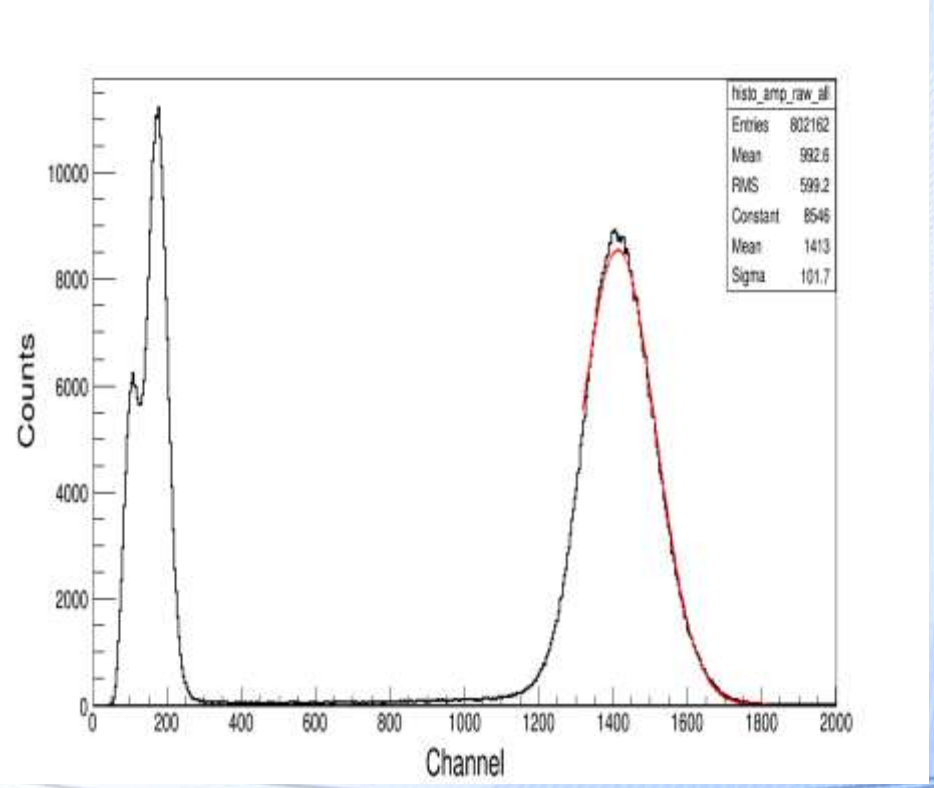


LYSO background spectra from every MAPDs

Pulse height spectra of LYSO background, gamma and alpha from Am-241 source

In order to measure alpha particle spectra, LYSO scintillator (6*6*2 mm) was placed on top of MAPD array (7.5*7.5 mm) separated from it by a thin layer of optical grease. ^{241}Am alpha particle source with ~5.5 MeV energy was used in the experiment. The distance between the MAPD array and the alpha particle source was 1.5 cm. Energy loss for alpha particle was about 1.5 MeV in 1.5 cm of air was taken into account.





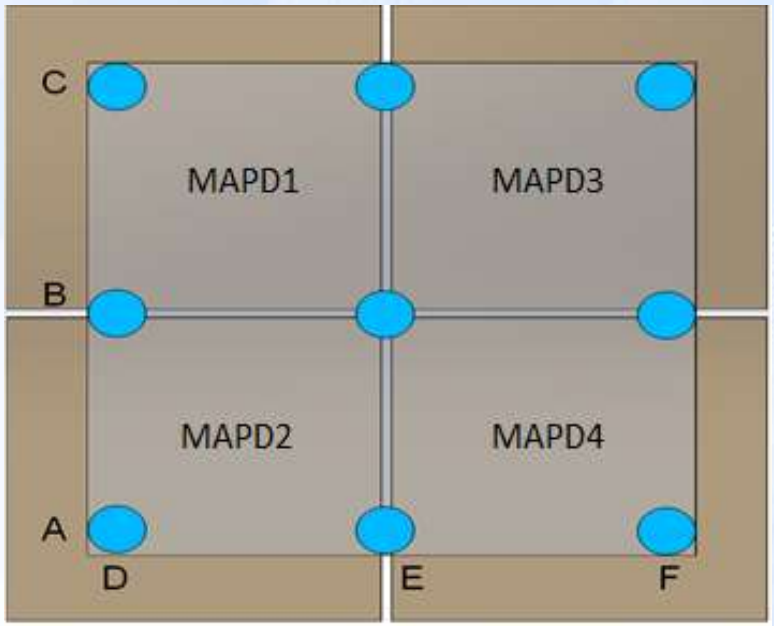
Pulse height spectra from Am-241 source

Algorithm for position

Anger's positioning algorithm was used to find positions. The algorithm combines only the signals from all MAPDs to determine an X and Y position and is expressed as follows:

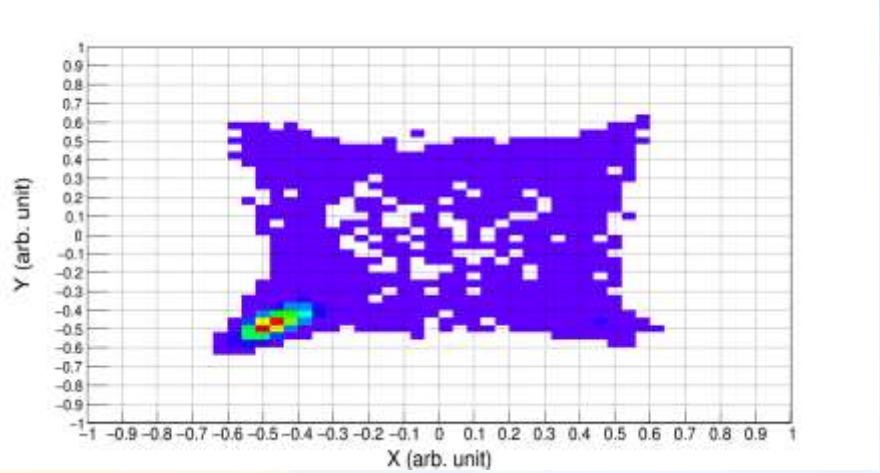
$$X = \frac{(A_{MAPD1} - A_{MAPD3}) + (A_{MAPD2} - A_{MAPD4})}{A_{MAPD1} + A_{MAPD2} + A_{MAPD3} + A_{MAPD4}}$$

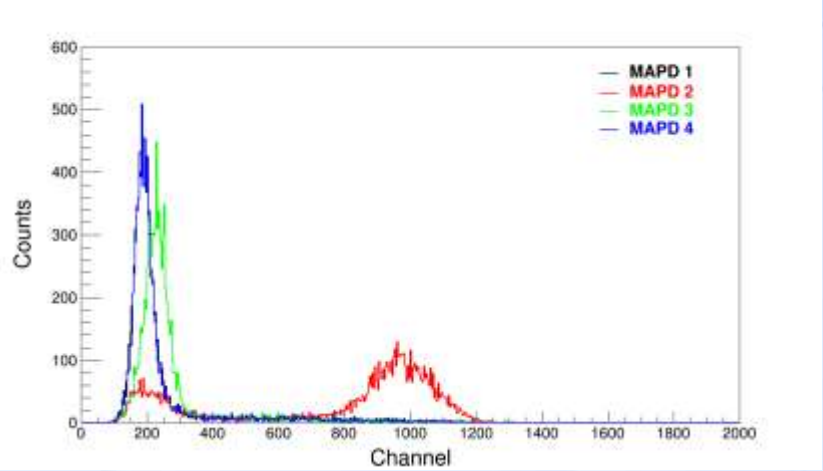
$$Y = \frac{(A_{MAPD1} - A_{MAPD2}) + (A_{MAPD3} - A_{MAPD4})}{A_{MAPD1} + A_{MAPD2} + A_{MAPD3} + A_{MAPD4}}$$



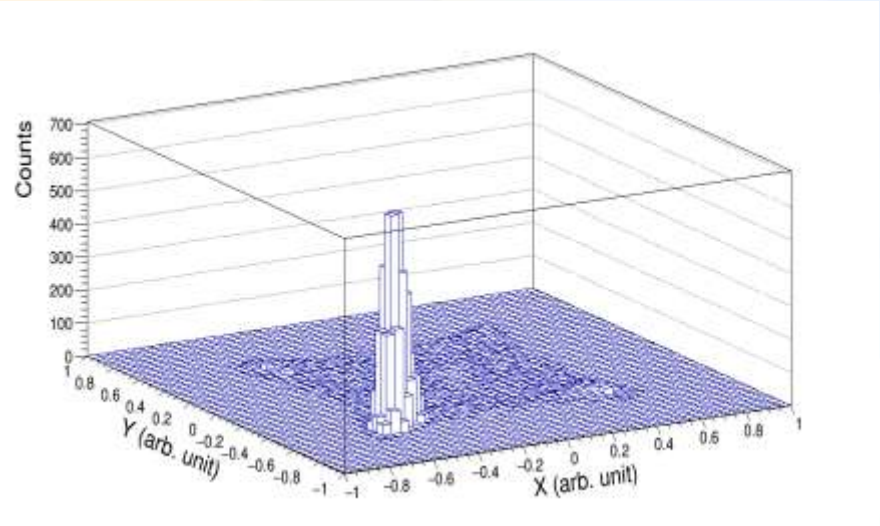
Pattern of positions where measurements were made with Am-241 source

Testing position sensitivity (AD point)

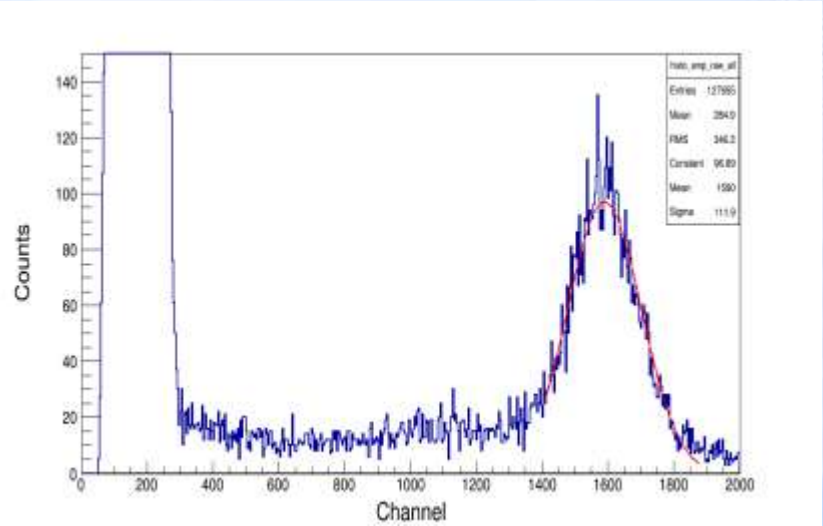




Pulse height spectra from all MAPDs

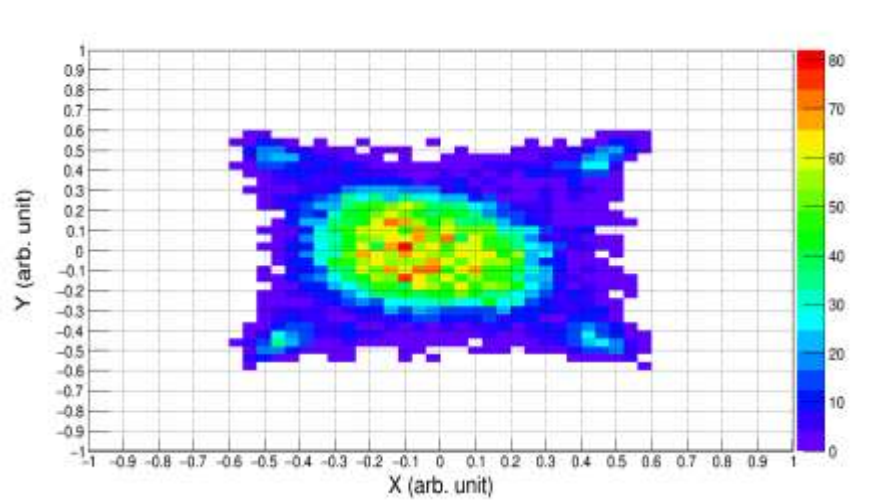


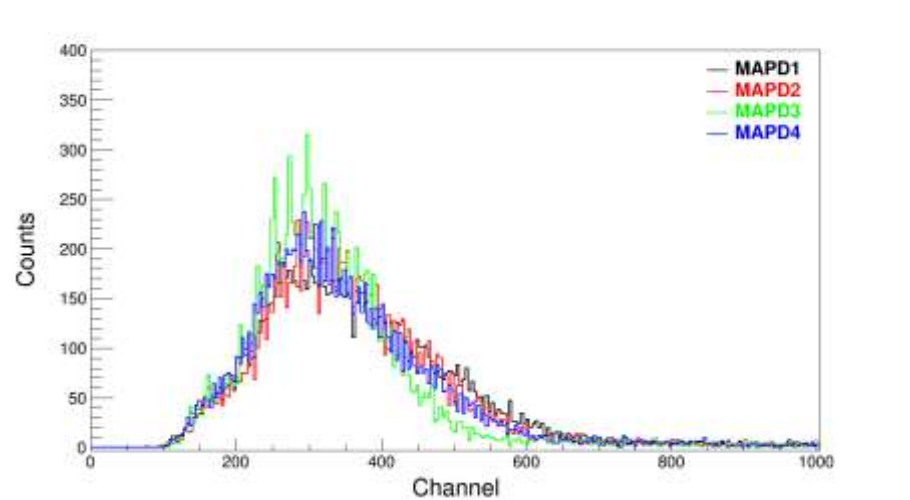
2D (up) and 3D (down) histograms (50 bin) correspond to AD position



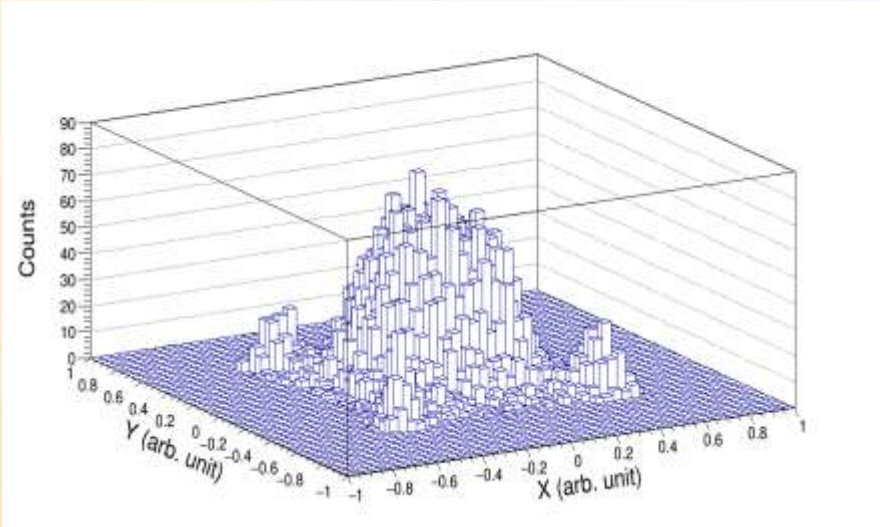
Pulse height spectrum from the detector

Testing position sensitivity (BE position)

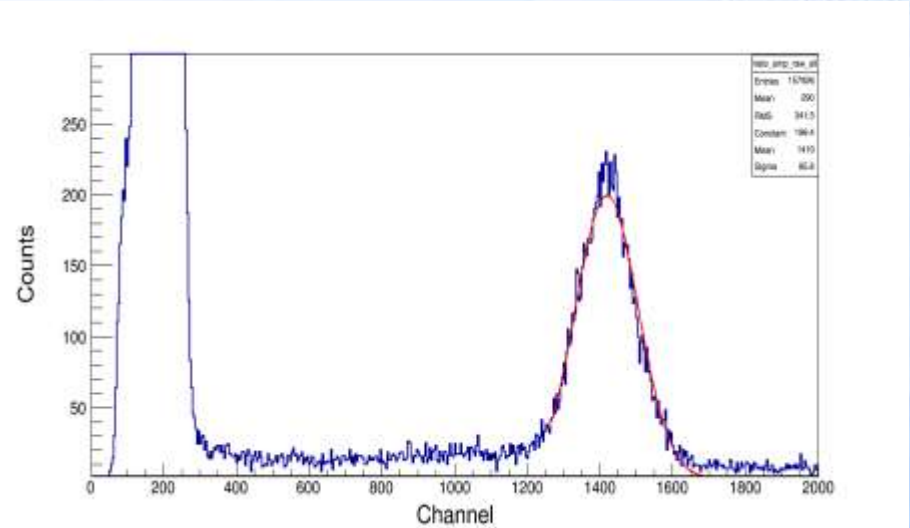




Pulse height spectra from all MAPDs

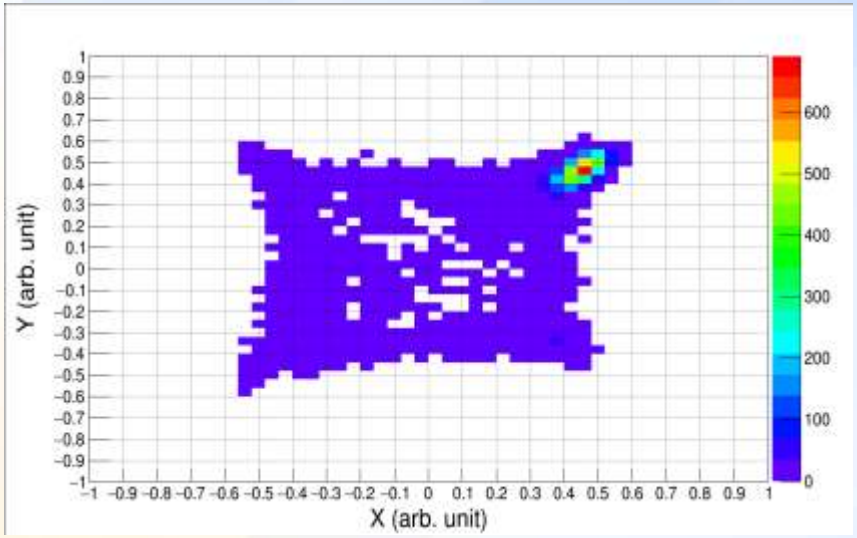


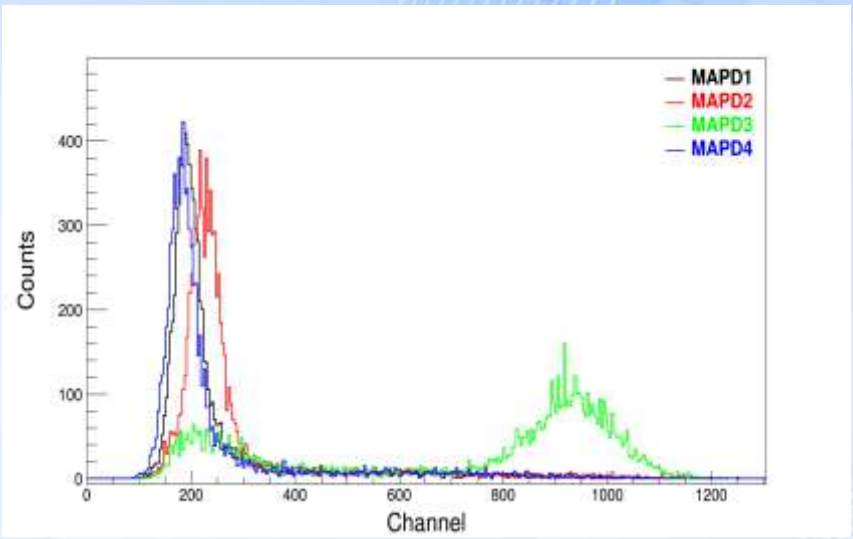
2D (up) and 3D (down) histograms (50 bin) correspond to BE position



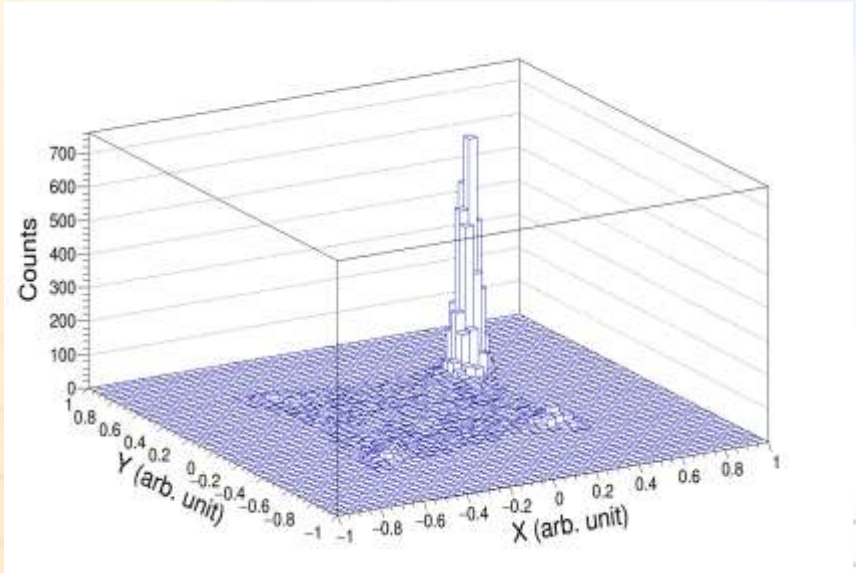
Pulse height spectrum from the detector

Testing position sensitivity (CF position)

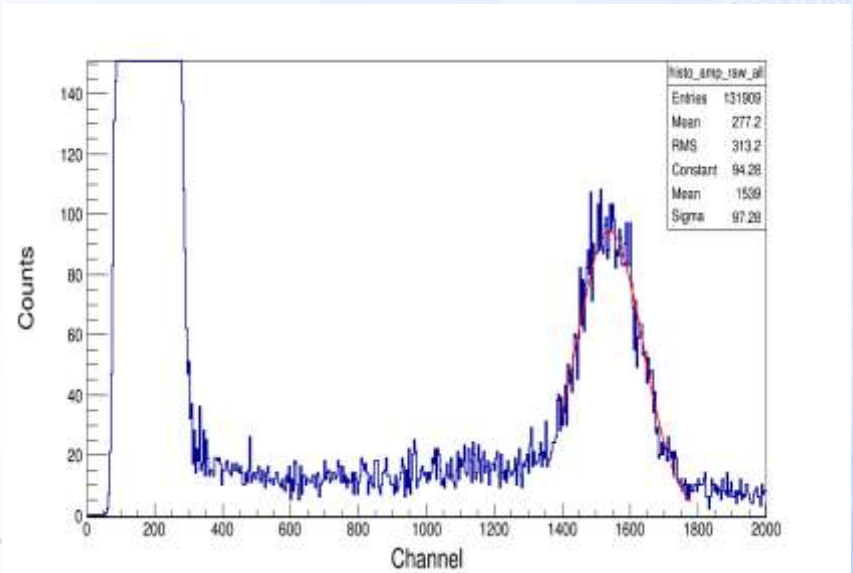




Pulse height spectra from all MAPDs



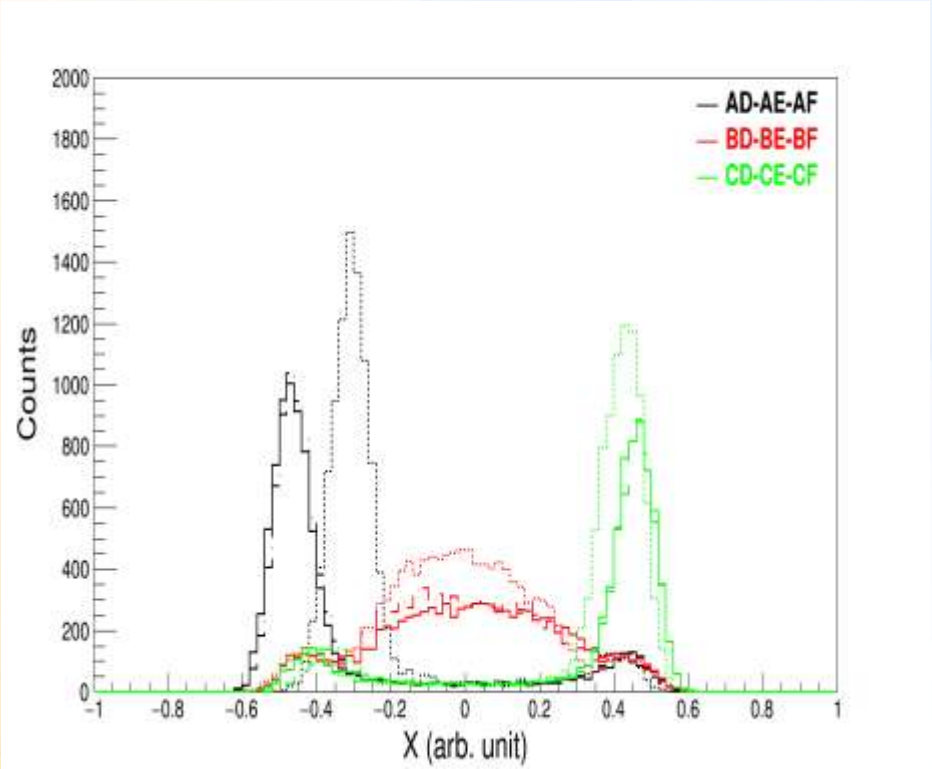
2D (up) and 3D (down) histograms (50 bin) correspond to CF position

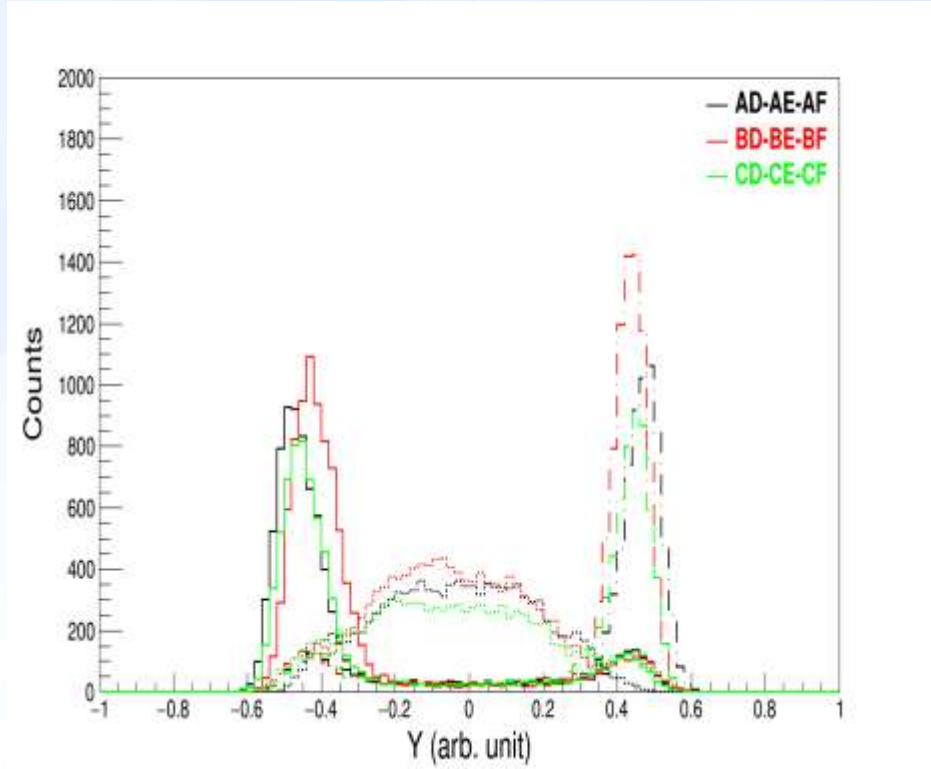


Pulse height spectrum from the detector

Testing position sensitivity (all positions)

Position distribution on X (left) and Y (right) measured when the Am-241 source was placed at the given locations.





Conclusions

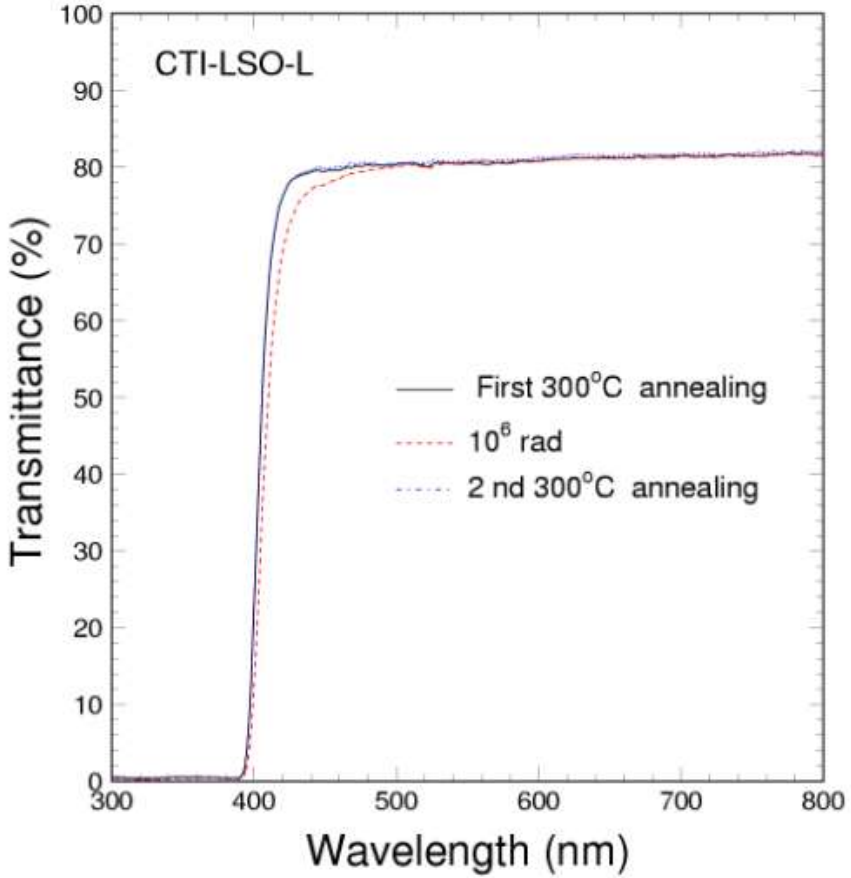
- Radiation hardness of the scintillation detector is better than Si detector
- Minimum obtained position sensitivity is <3 mm and is required additional studies for better results

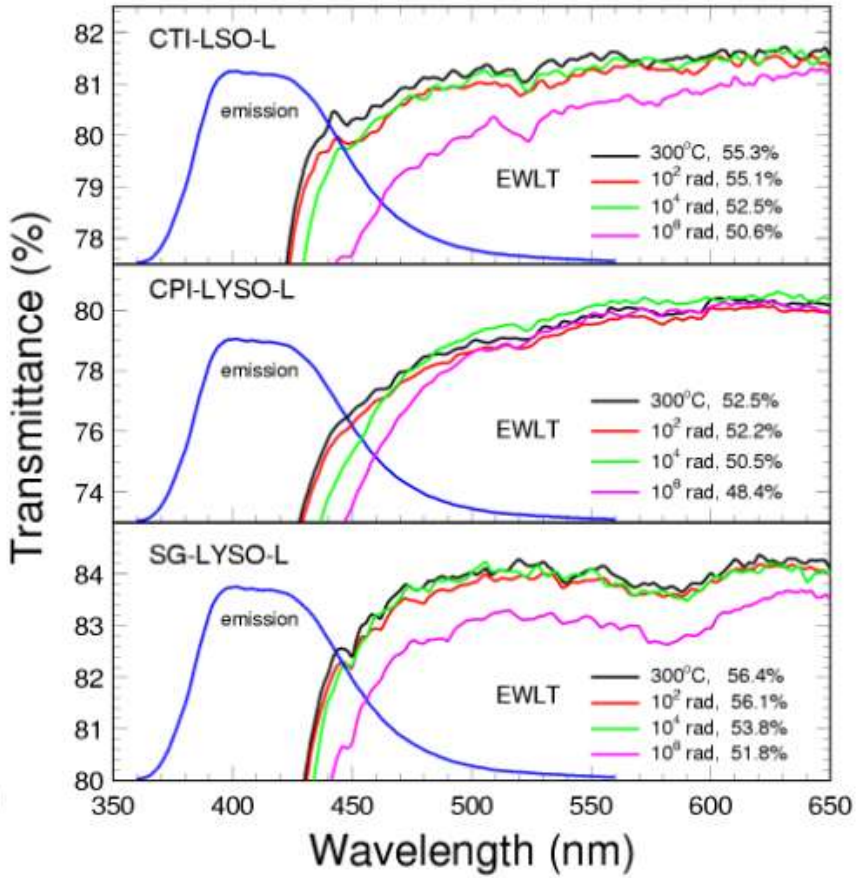
Thank you very much for your attention!

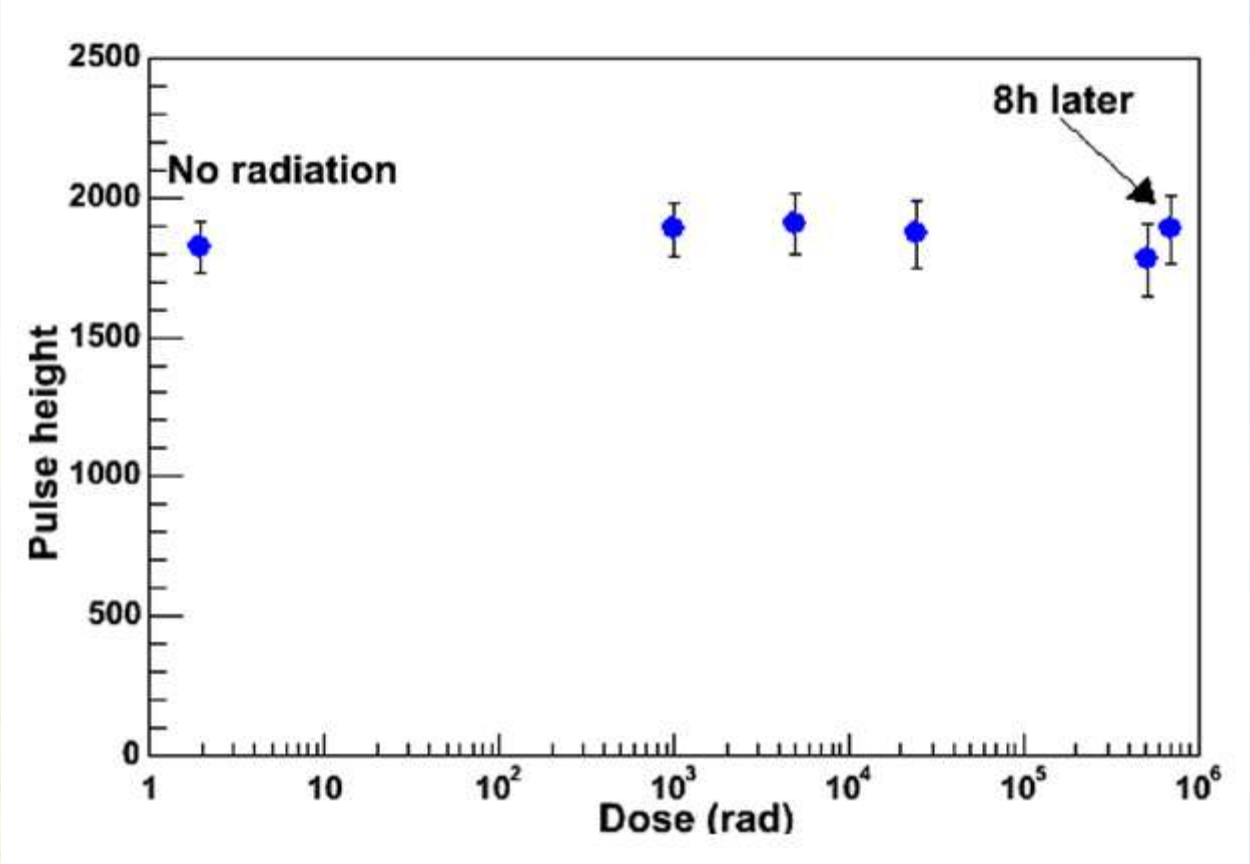
γ-Ray Induced Transmittance Damage

300°C thermal annealing effective

LT damage: 8% @ 1 Mrad






2500
2000
1500
1000
500
0
Pulse height
No radiation
8h later
1
10
10^2
10^3
10^4
10^5
10^6
Dose (rad)