30th International Seminar on Interaction of Neutrons with Nuclei: Fundamental Interactions & Neutrons, Nuclear Structure, Ultracold Neutrons, Related Topics (ISINN-30)

Neutron Detection Using SiPMs: Performance and Applications

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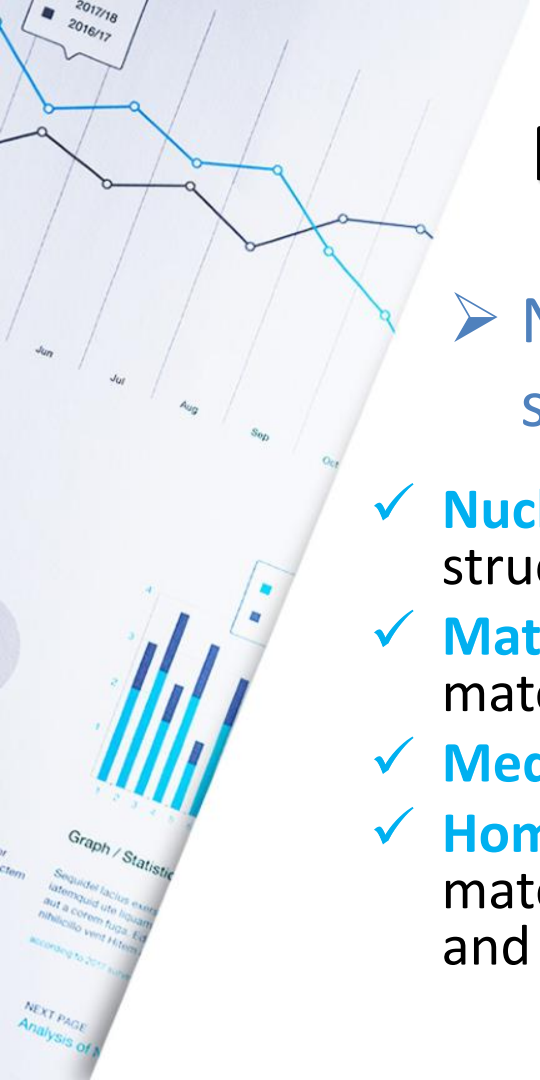


Neutron detection.

- Neutron detection is crucial for various scientific and technological fields e.g.,

✓ **Nuclear physics.** (Nuclear interactions and nuclear structure studies)

✓ **Material science.**(Passive, non-destructive technics for material composition investigation)

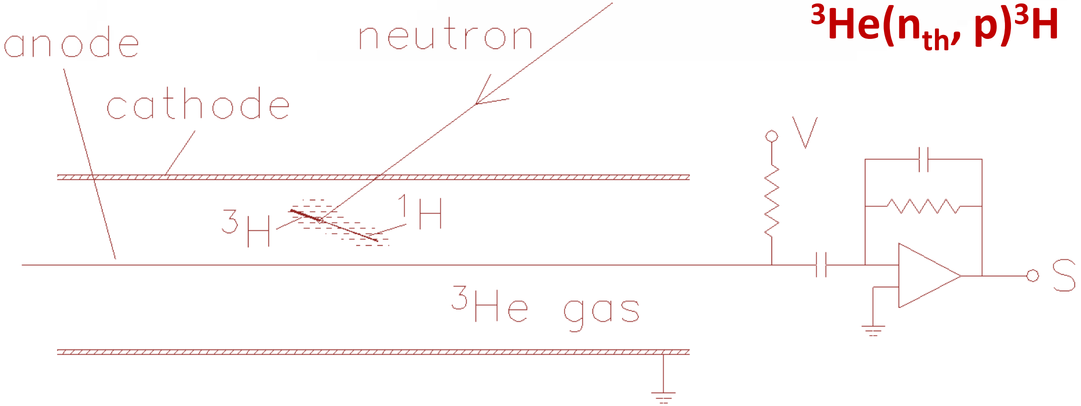
✓ **Medical physics.**(Nuclear imaging and therapy)

✓ **Homeland security.** (Detection of special nuclear materials like U-235, P-239 in the frame of nuclear and radiological threat prevention)

Neutron detection.

Gas Detectors.

- ^{3}He-based neutron detectors are the most commonly used systems.



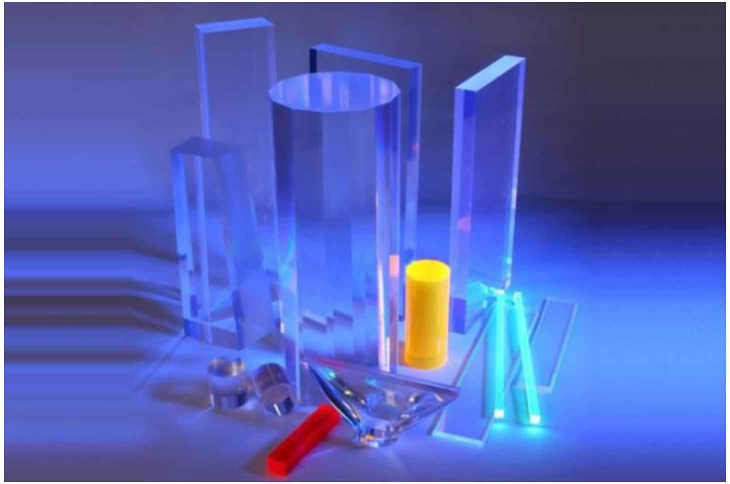
$^{3}He(n_{th}, p)^{3}H$

If voltage is high enough, electron collisions ionize gas atoms producing even more electrons gas amplification. Gas gains of up to a few thousand are possible.

Neutron detection.

Organic scintillators.

		plastic scint.
1.	Hydrogen / carbon ratio	≈ 1.1
2.	Scintillation efficiency	55 – 65 %
3.	Scintillation spectrum λ_{max}	370 – 490 nm
4.	Transparency	1 - 4 m
5.	Decay times	1.4 – 3 ns, 230 ns
6.	Pulse-shape discrimination	(yes)
7.	Doping for thermal sensitivity	yes

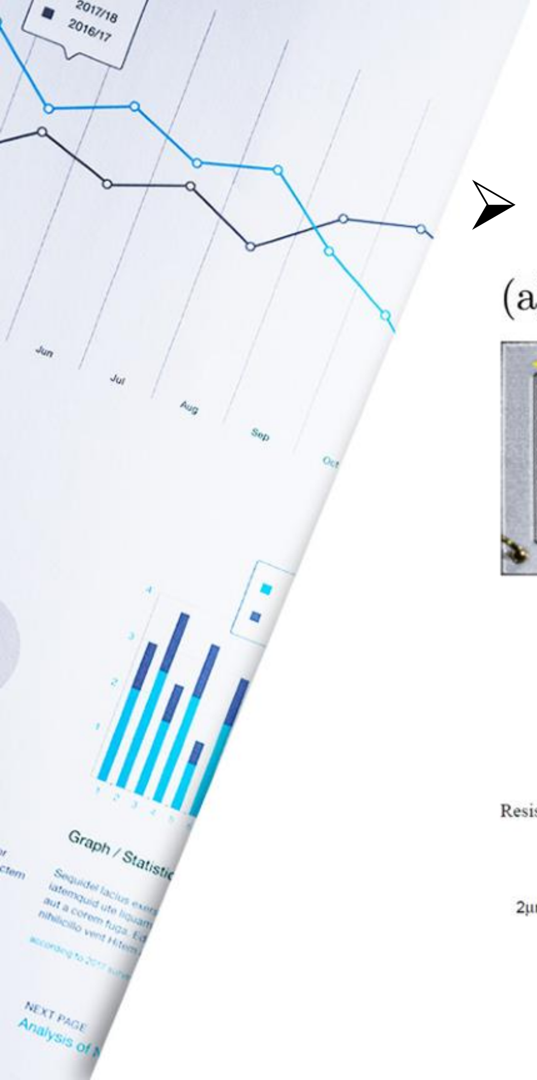


Plastic material that emits light when hit by radiation, ZnS, NaI, CsI, BaF2, BGO

Neutron detection.

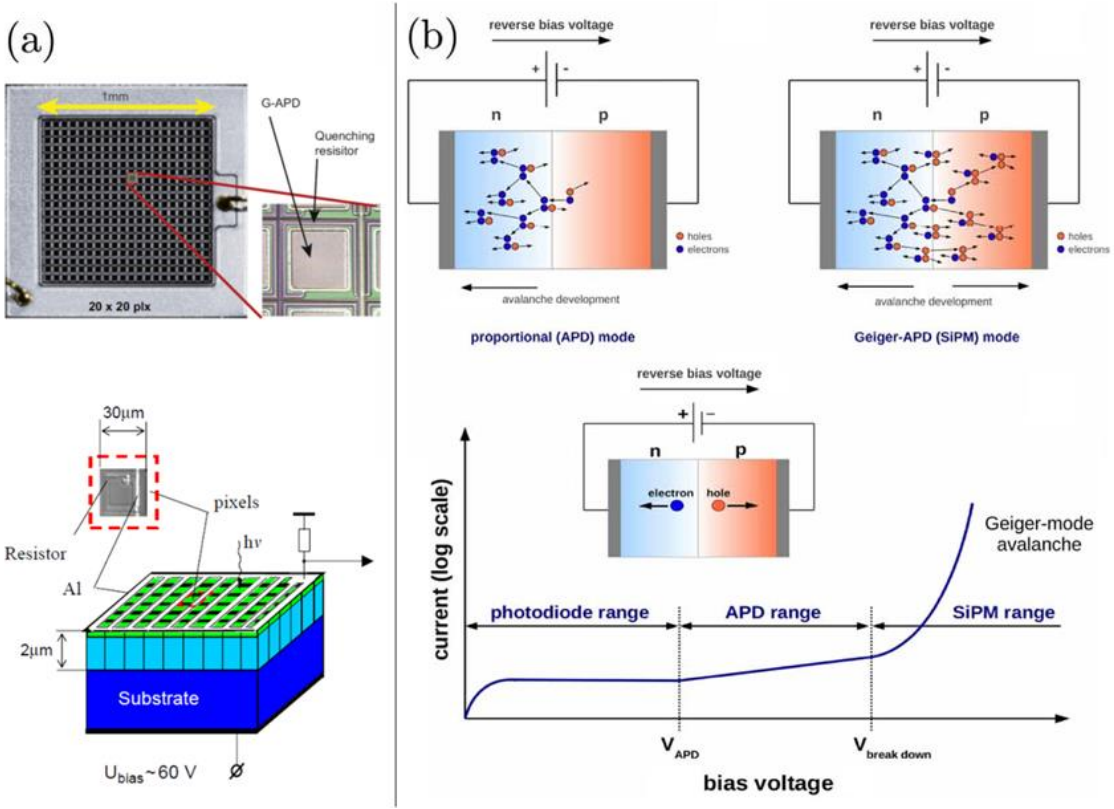
Photomultiplier tubes (PMTs).

- PMTs come with limitations
  - Large size and weight.
  - High operating voltage.
  - Magnetic field sensitivity.



Silicon Photomultipliers (SiPMs).

- Principle of operation.



Neutron detection.

on detection.

	PMTs	SiPMs
Gain	~ 10^6	$10^{5\sim6}$
PDE.	~ 0.20	~ 0.50
Response	fast	Very fast
Photon counting	Yes	Great
Bias voltage	1-2K	20 ~ 100 V
Size	Small	Compact (1-10 mm^2)
Magnetic Field	Sensitive	Insensitive (<15T)
Cost	Very expensive	Not expensive
Dynamic range	Good	good # Npix
Long-term Stability	Good	Unknown, presumably good
Noise	Quiet	Noisy (order of 100 kHz)

Neutron detection.

- ✓ Compared to PMTs, SiPMs offer the 'solid-state' advantages of ruggedness, lighter weight, high gain, fast timing, compactness, and lower operating voltages make them excellent candidates for different applications.

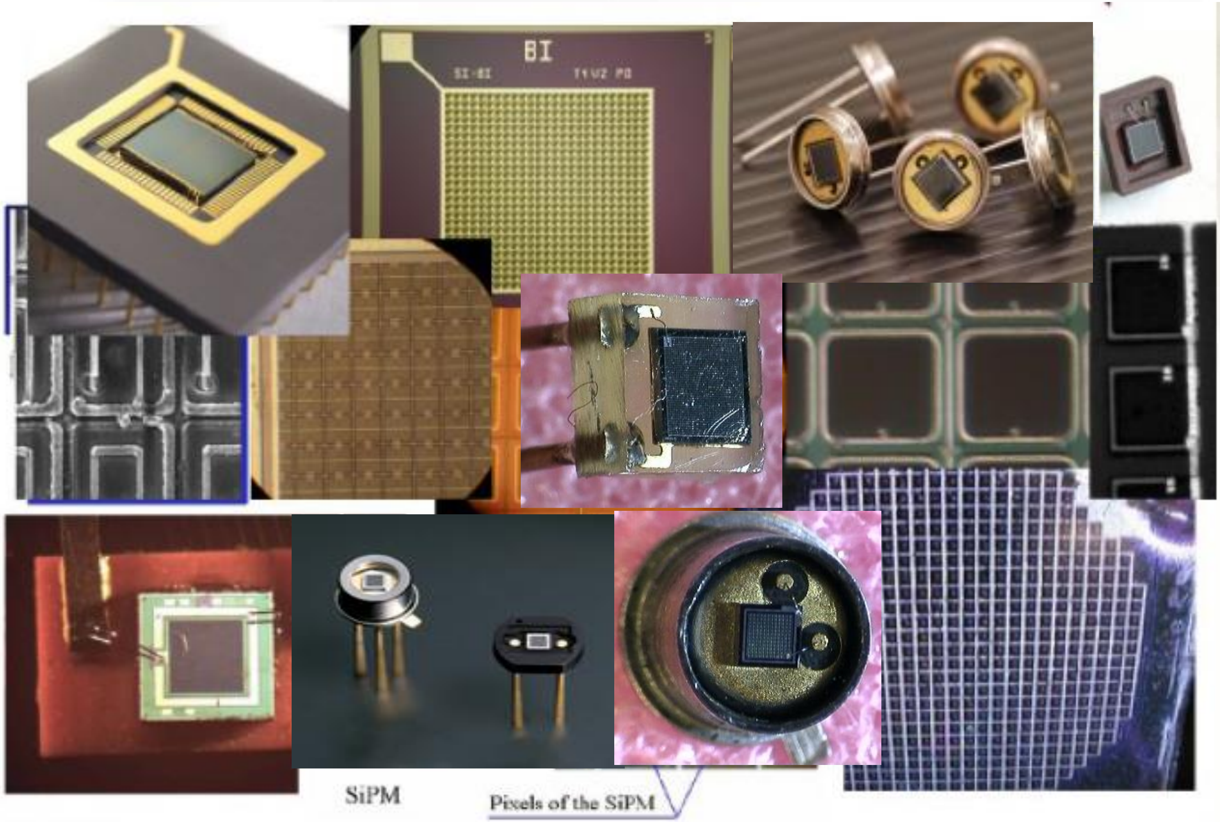
- ✓ SiPMs also have two key advantages over the PMT; these are insensitivity to magnetic fields (<15T) and are not damaged by exposure to high photon flux. The insensitivity to magnetic field, allowing operation in environments with varying magnetic field conditions

- ✓ The compact size and lightweight, enabling the development of portable and hand-held detector design . The low operating voltage, simplifying power supply and reducing detector design complexity.. In addition, the fast response time, enabling efficient discrimination between neutrons and other particles based on their interaction times with the detector material.

Neutron detection.

SiPMs manufacturers

- ✓ MEPhI/Pulsar (Moscow)
- ✓ CPTA (Moscow)
- ✓ Mikron (Moscow)
- ✓ Zecotek (Singapore)
- ✓ Amplification Technologies (Orlando)
- ✓ Hamamatsu Photonics (Hamamatsu, Japan)
- ✓ SensL (Cork, Ireland)
- ✓ AdvanSiD (former FBK-irst Trento, Italy)
- ✓ STMicroelectronics (Italy)
- ✓ KETEK (Munich)
- ✓ RMD (Boston, USA)
- ✓ MPI Semiconductor Laboratory (Munich)
- ✓ Novel Device Laboratory (Beijing, China)
- ✓ Philips (Netherlands)



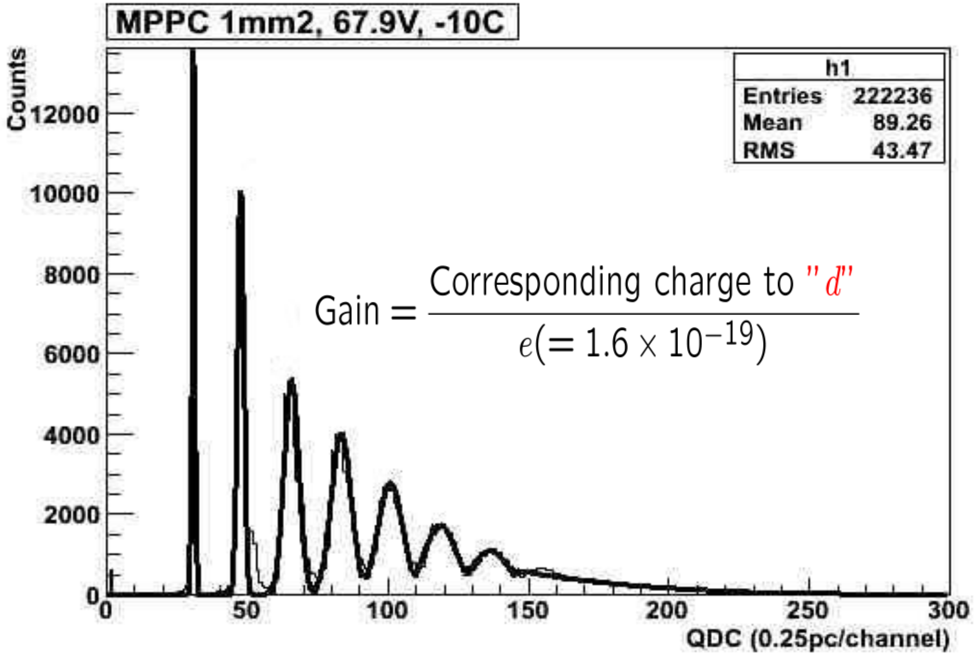
Neutron detection.

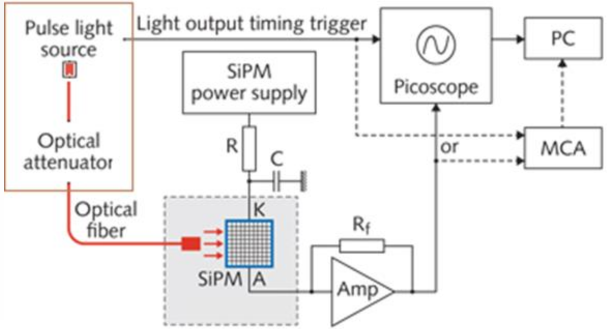
Characteristics.

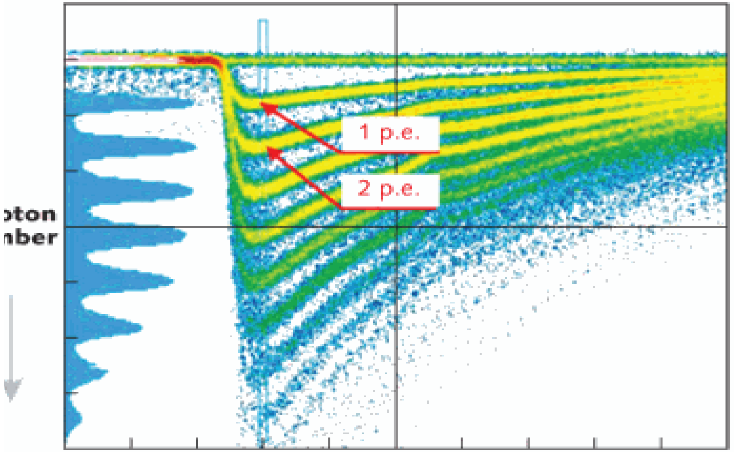
- Gain.
- Dark current.
- Operating voltage
- Photon counting
- Time resolution

Neutron detection.

SiPMs Characteristics. (Gain, Photon counting)



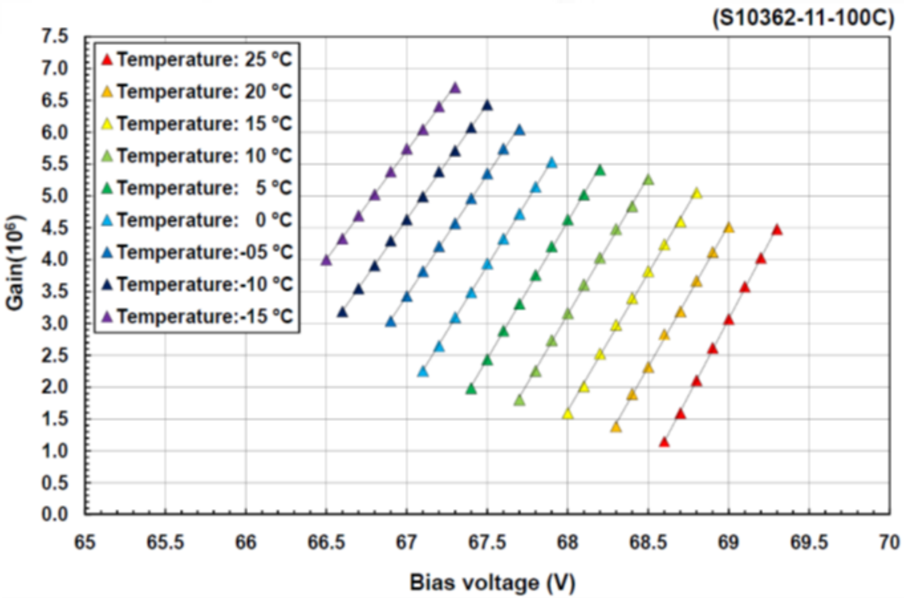


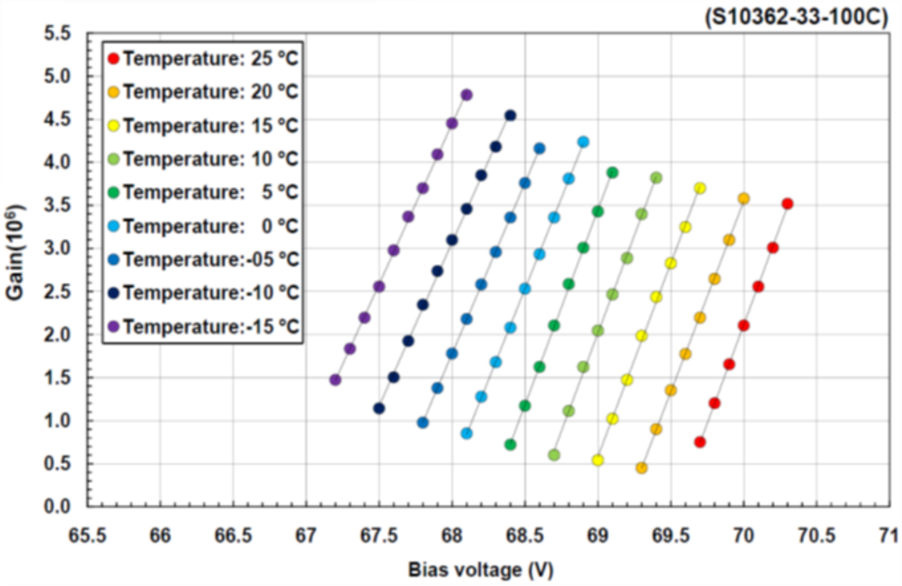


Excellent single photoelectron resolution

Neutron detection.

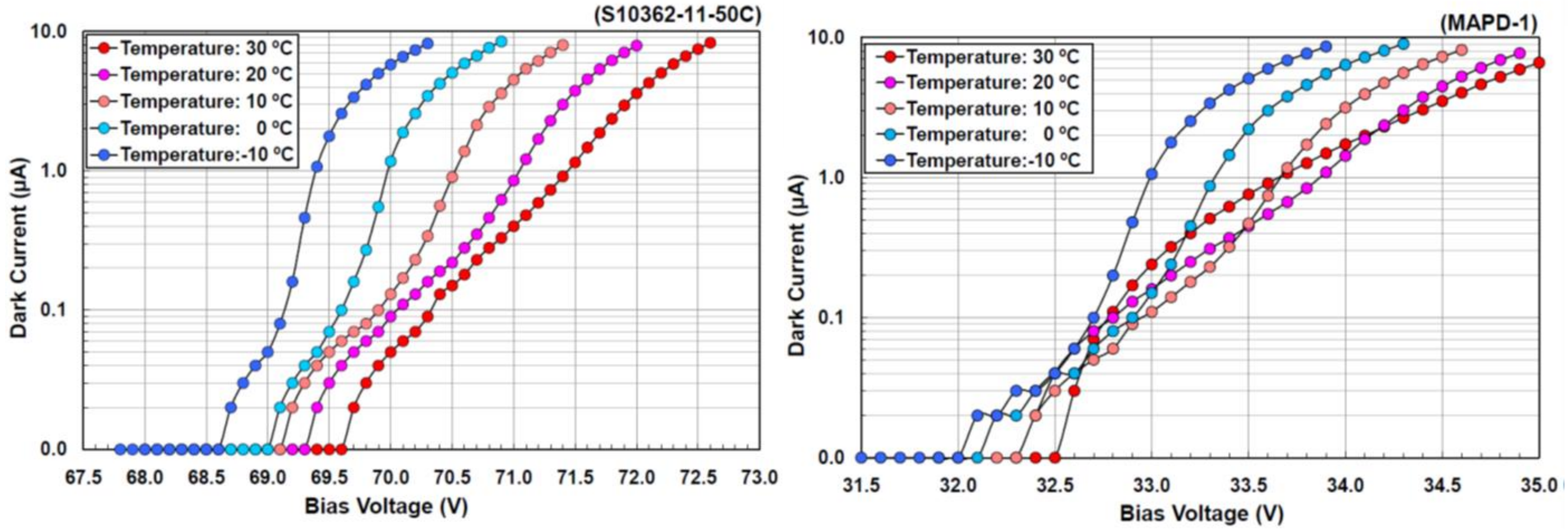
Gain as a function of the over-voltage at different operating temperature.





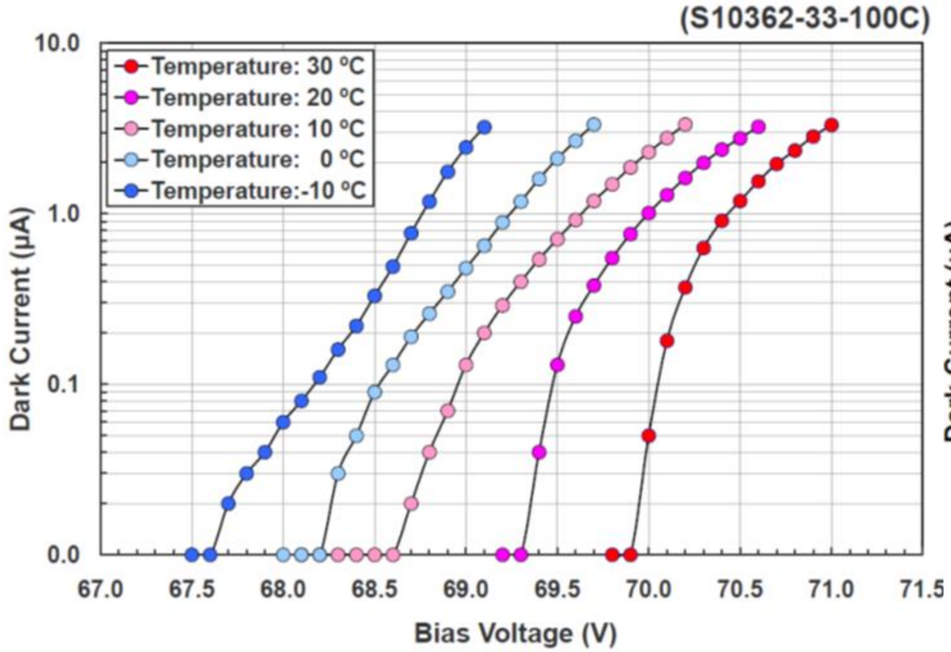
Neutron detection.

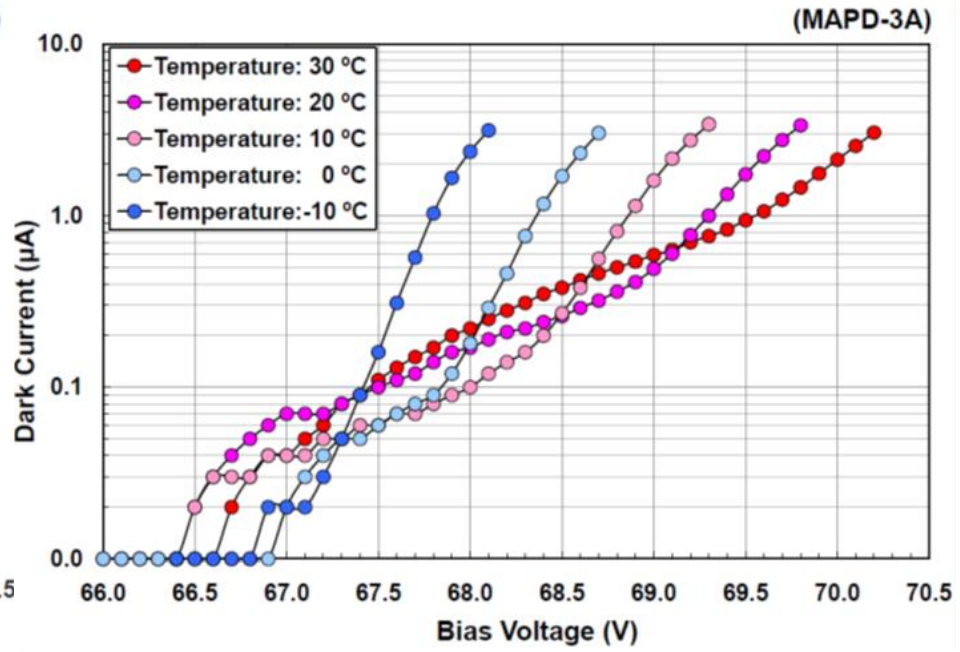
SiPMs Characteristics. (Dark current)



Neutron detection.

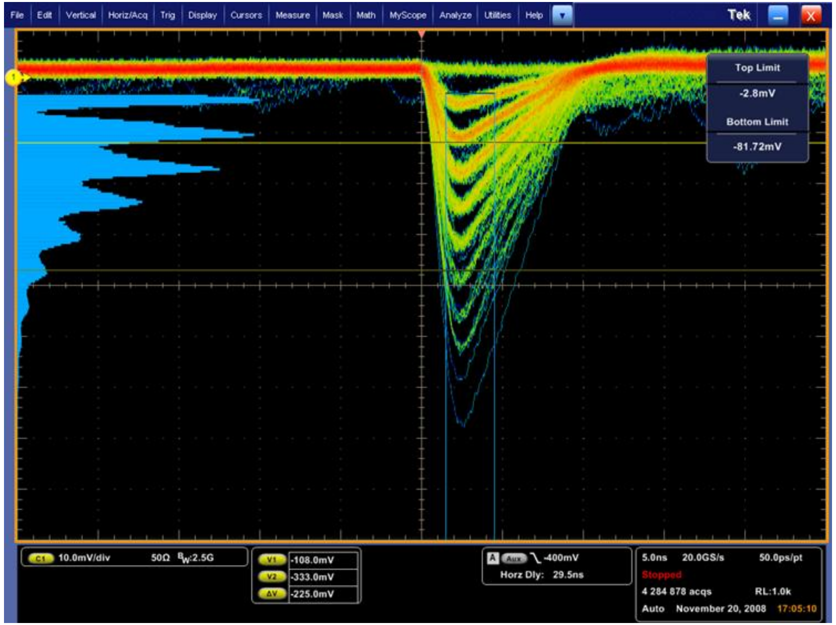
SiPMs Characteristics. (Dark current)

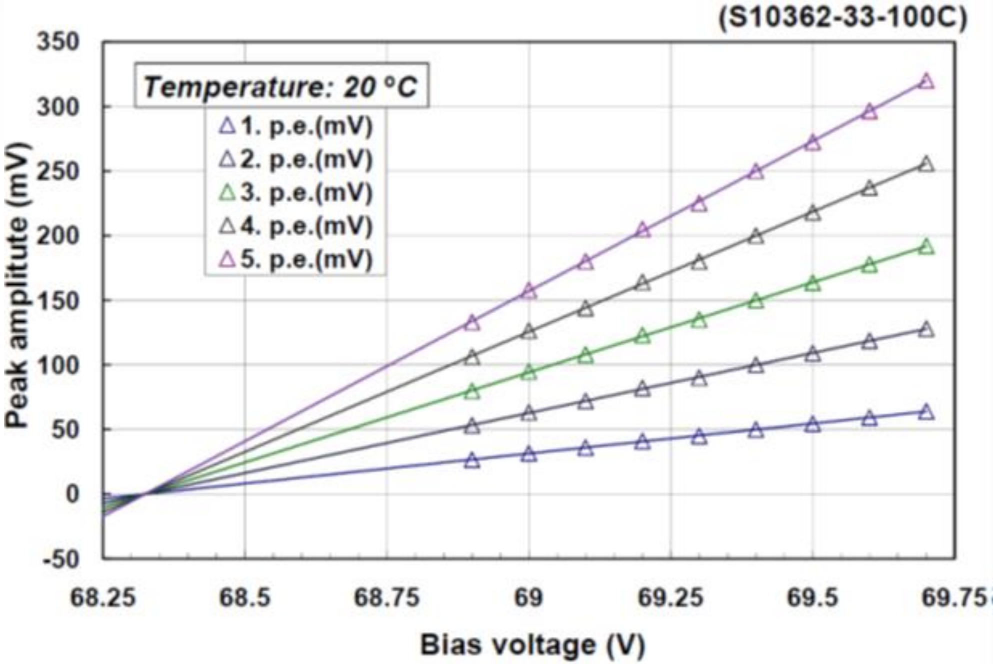




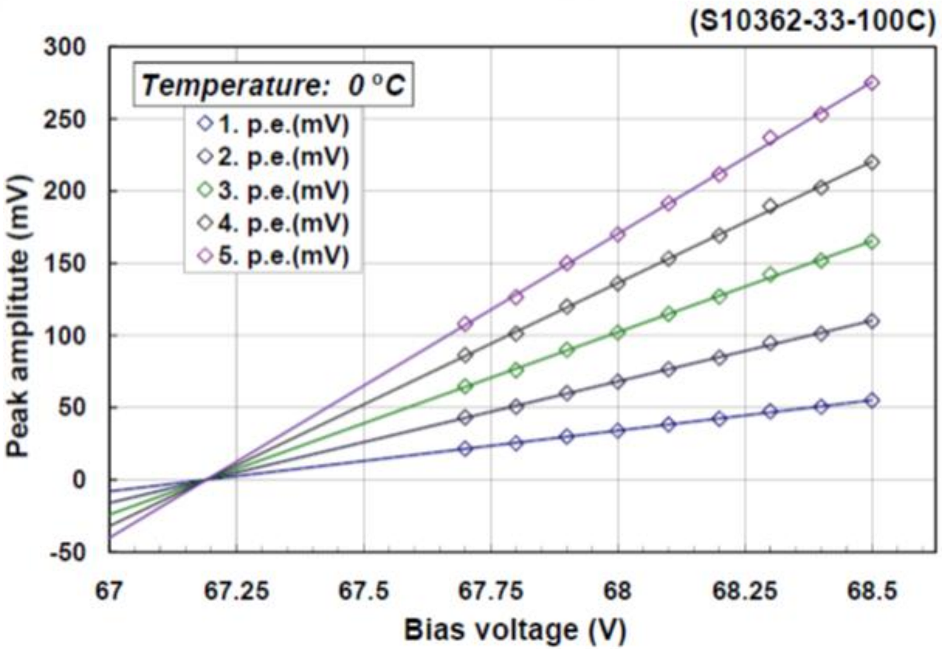
Neutron detection.

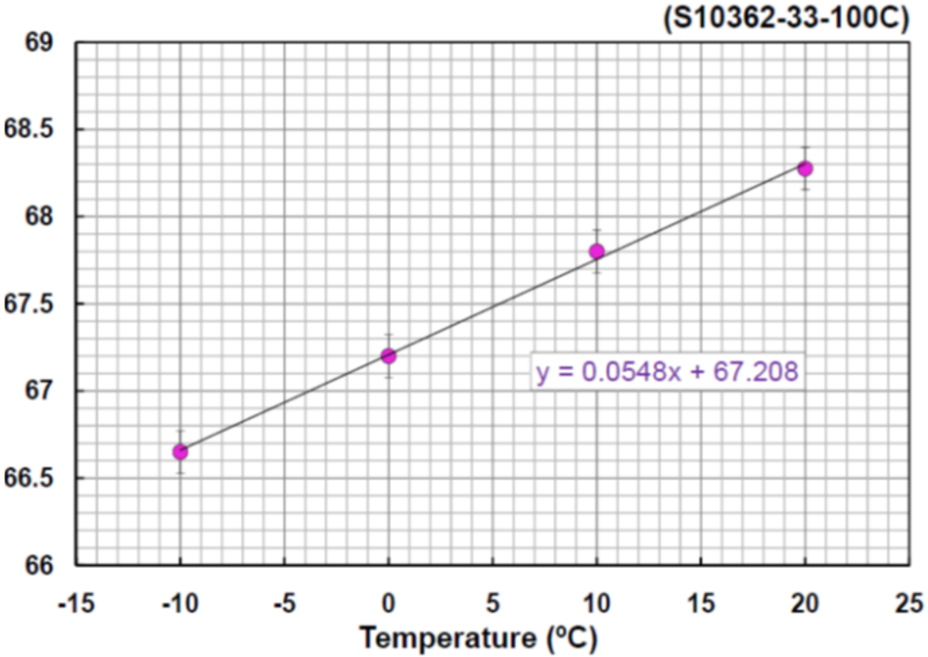
SiPMs Characteristics. (Operating voltage)





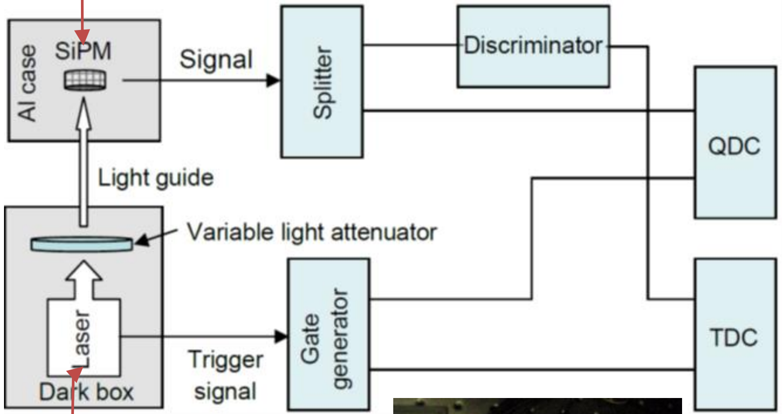
SiPMs Characteristics. (Operating voltage)

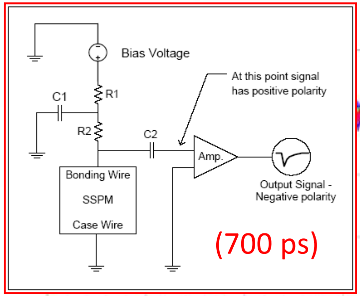




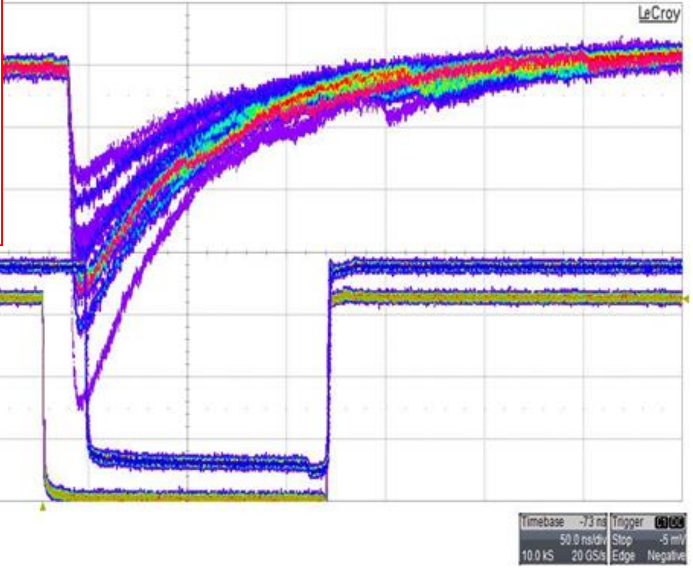
Neutron detection.

SiPMs Characteristics. (Time resolution)

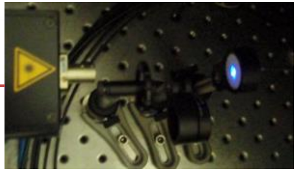




Photonique preamplifier (AMP-0611)

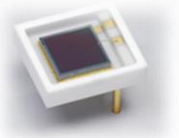


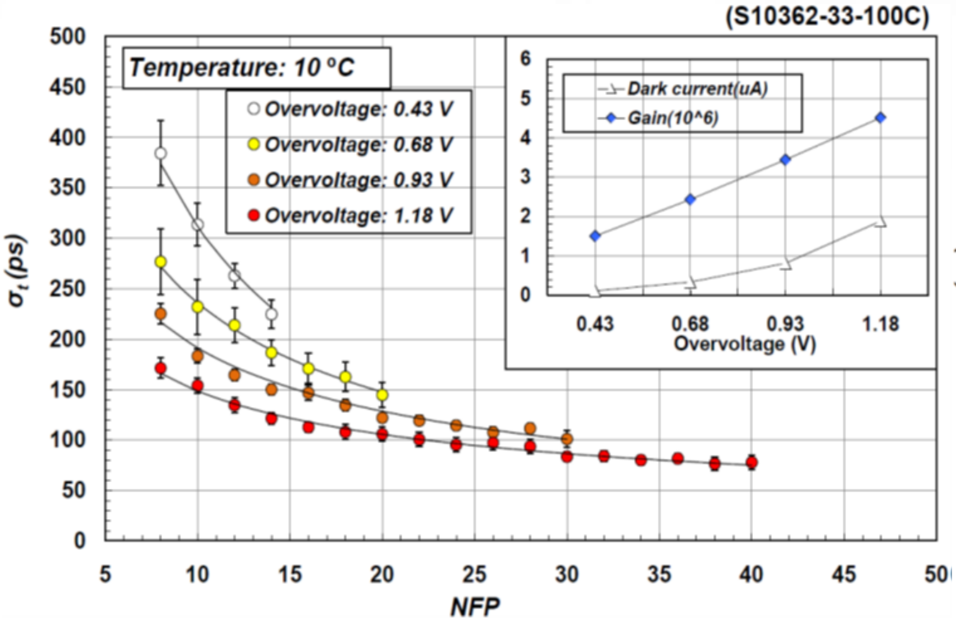
Laser light +Variable attenuator

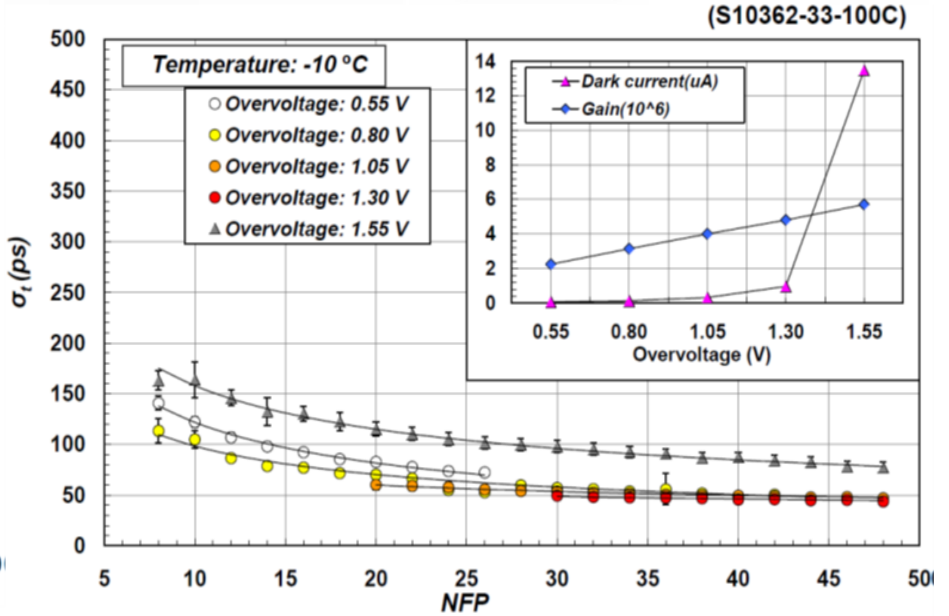


Neutron detection.

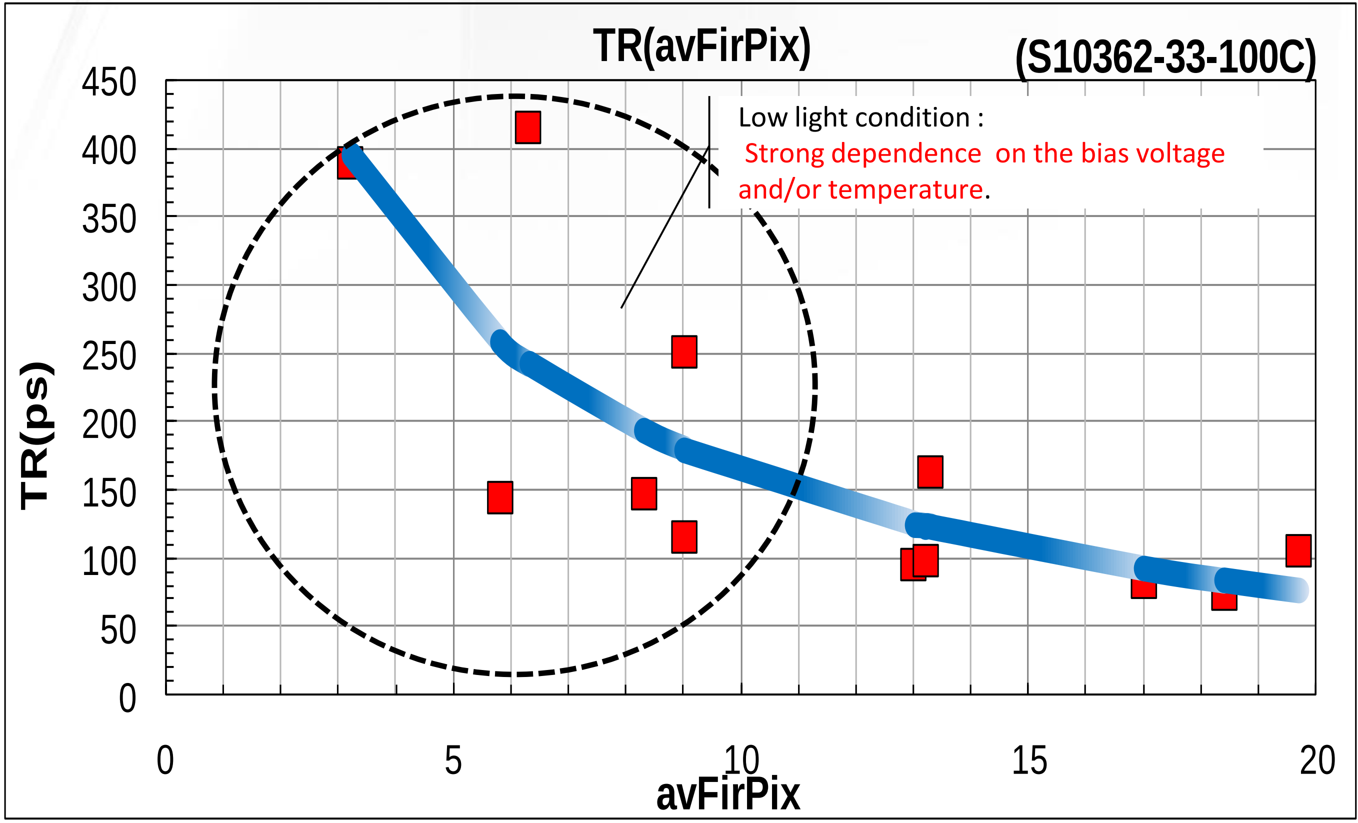
MPPC (3x3 mm^2, 900 pixels/mm^2) from Hamamatsu-Japan





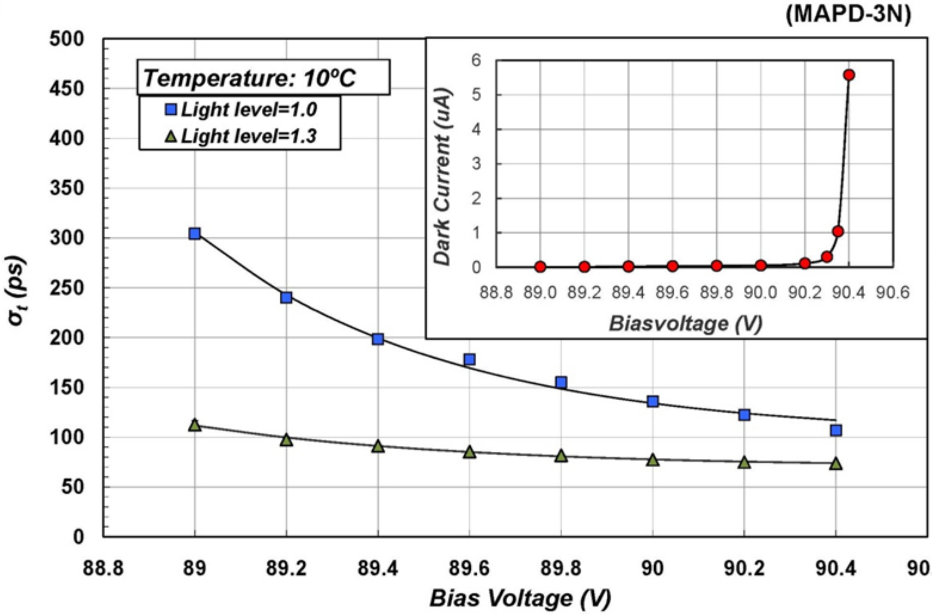


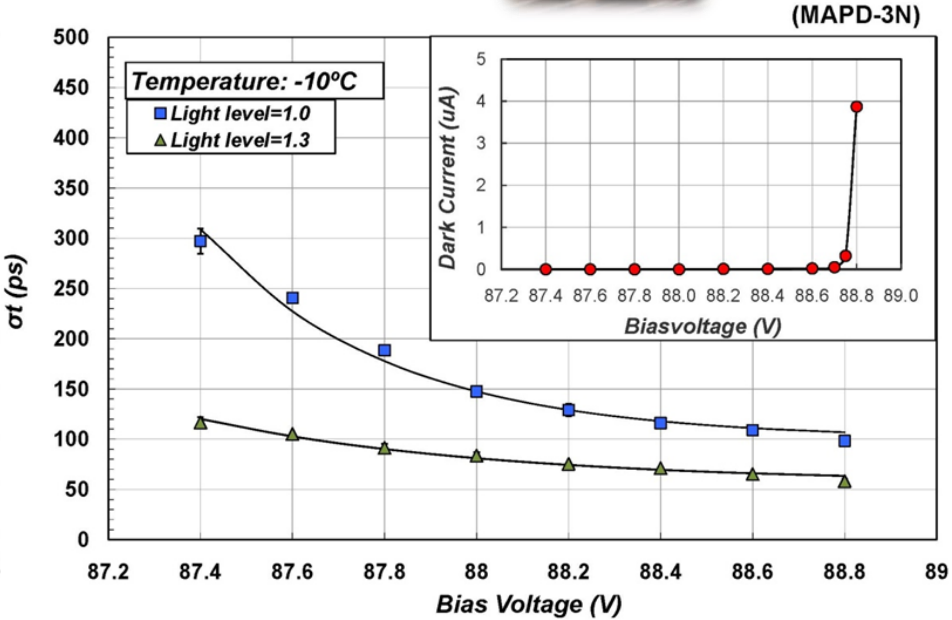
Hamamatsu (MPPC) 3x3mm^2, 100um pixels structure.



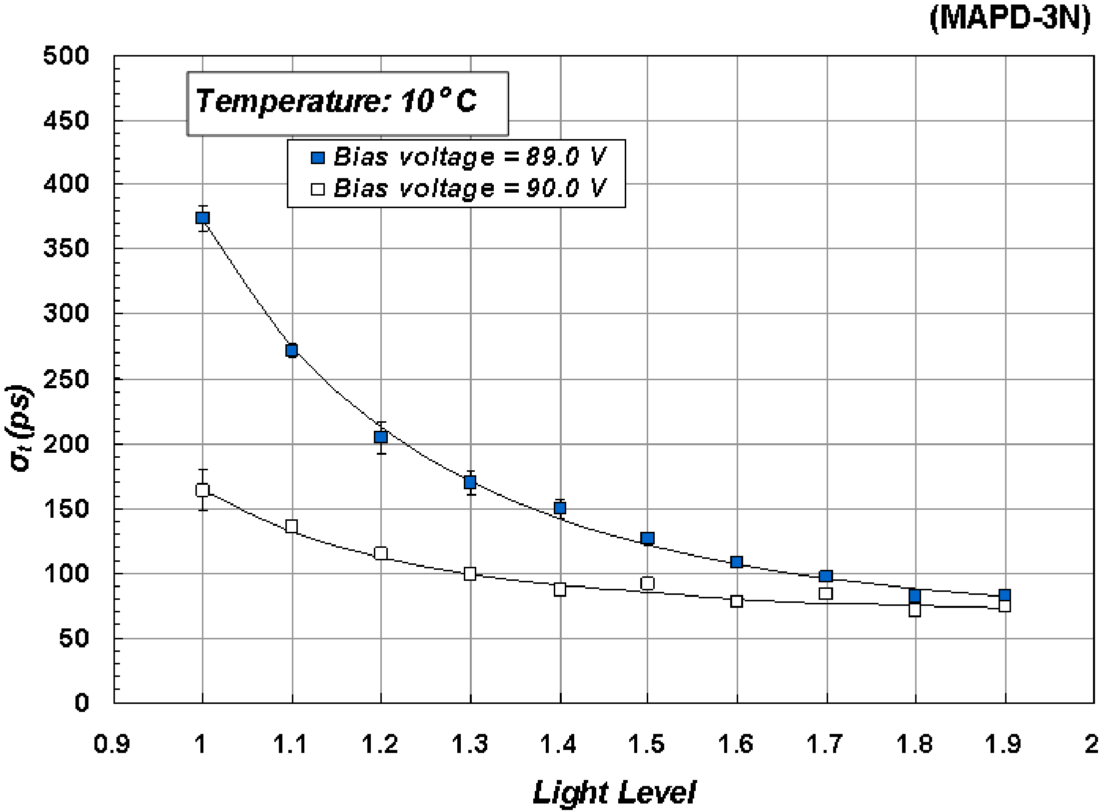
Neutron detection.

MAPD (3×3 mm^2 , 15k pixels/mm^2) from Zecotek-Singapore





Neutron detection.



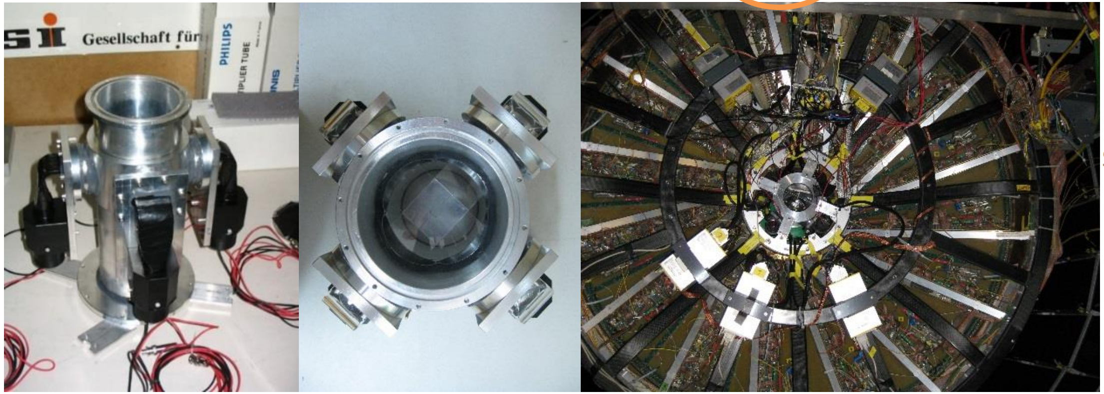
Neutron detection.

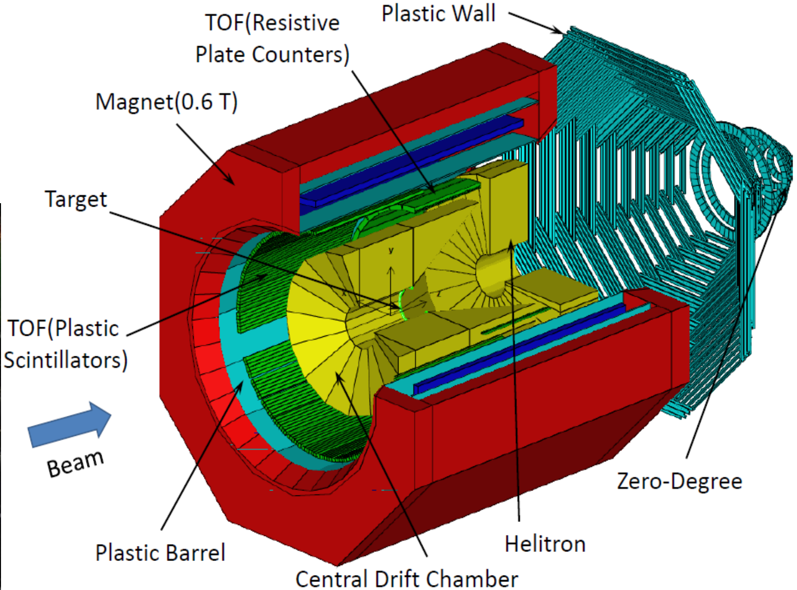
Hyperfine Interact
DOI 10.1007/s10751-011-0556-5

SiPM-based veto detector for the pion beam at FOPI

Gamal Ahmed · Pual Bühler · Olaf Hartmann · Johann Marton · Ken Suzuki · Johann Zmeskal

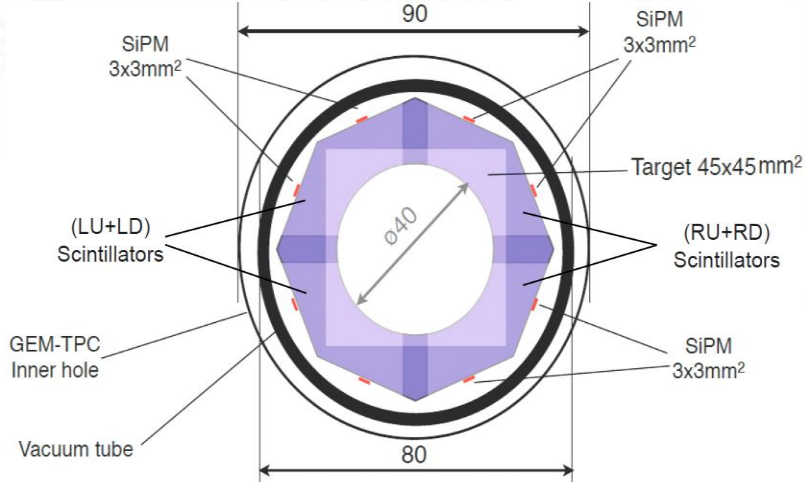
$$\pi^-(1.7\ \mathrm{GeV}/c) + A \rightarrow K^+K^- + X$$

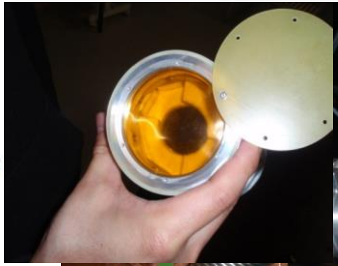


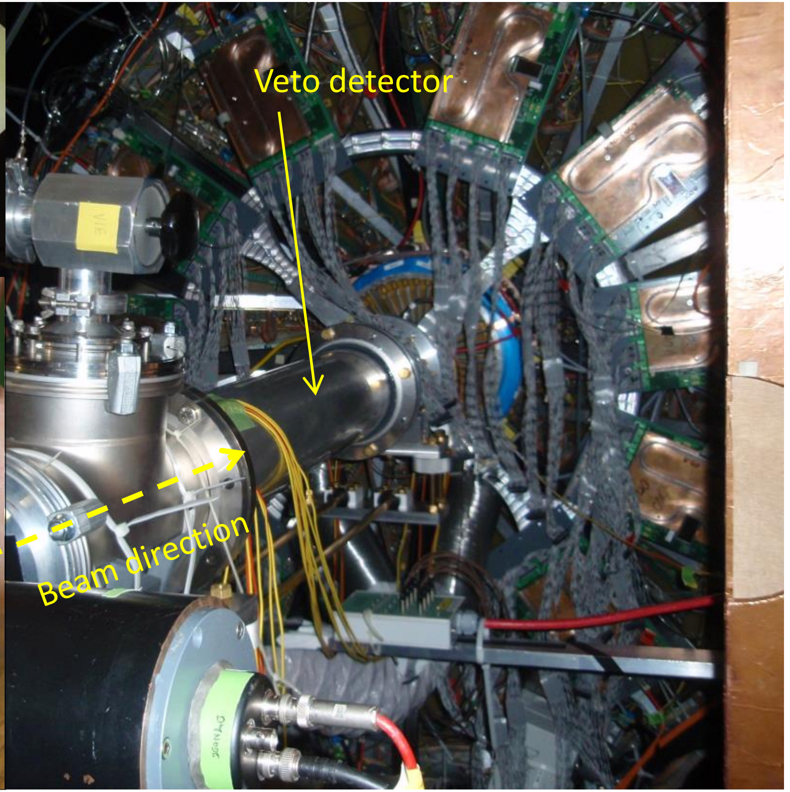


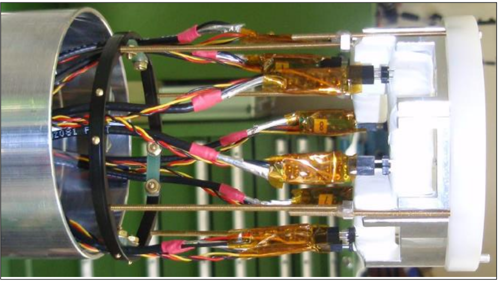

OSY-TOF
KFA
KFA

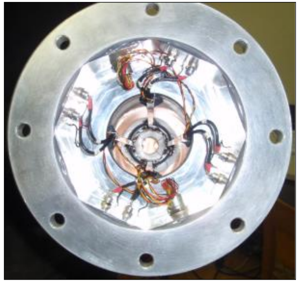
Neutron detection.



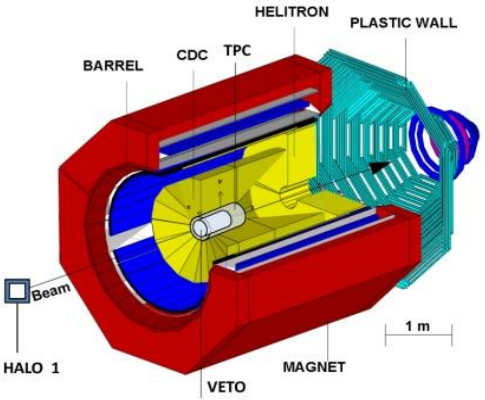


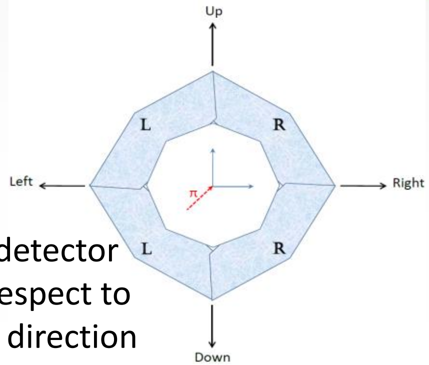




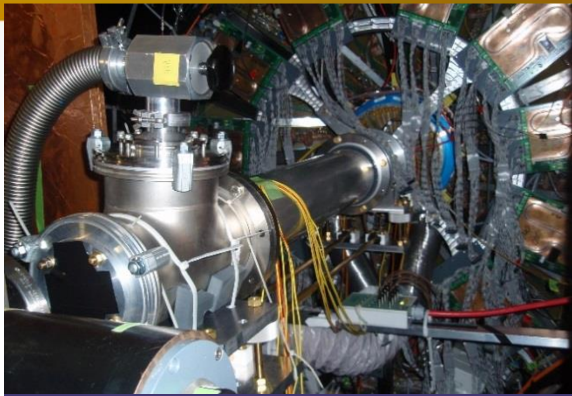


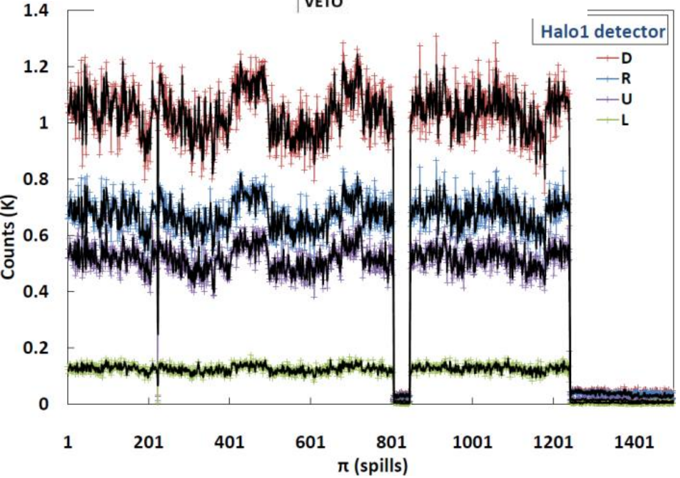
Neutron detection.

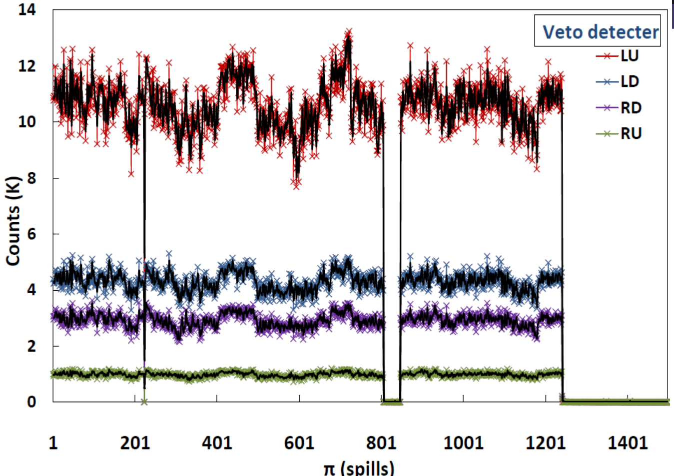


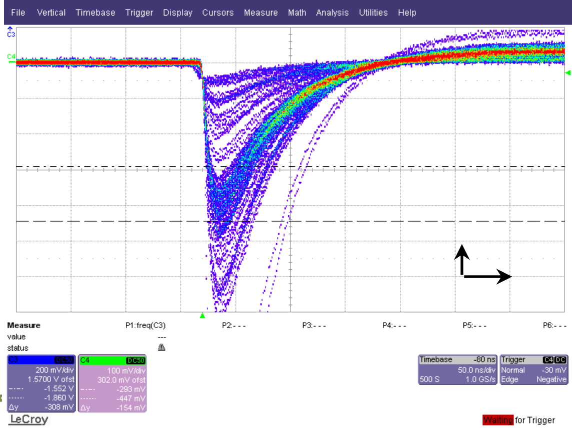


The veto detector setup in respect to the beam direction



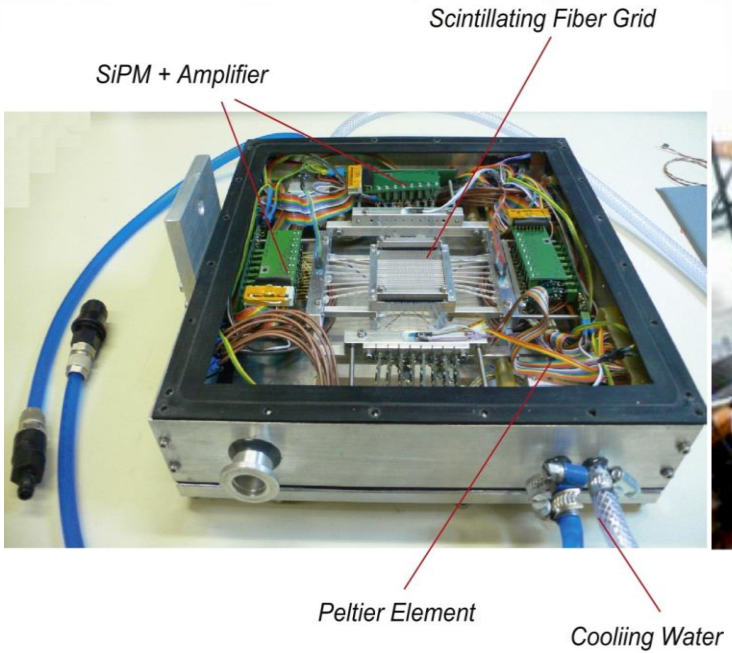


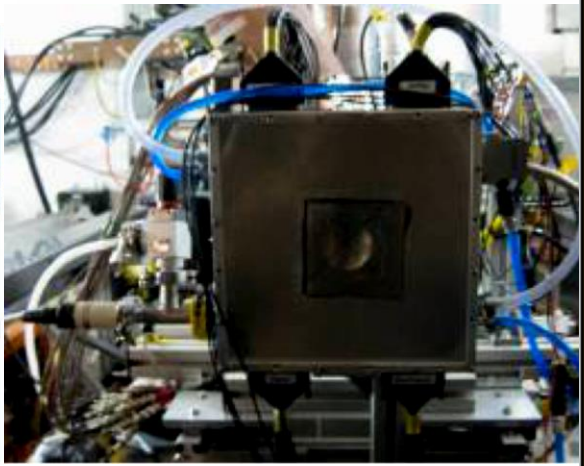


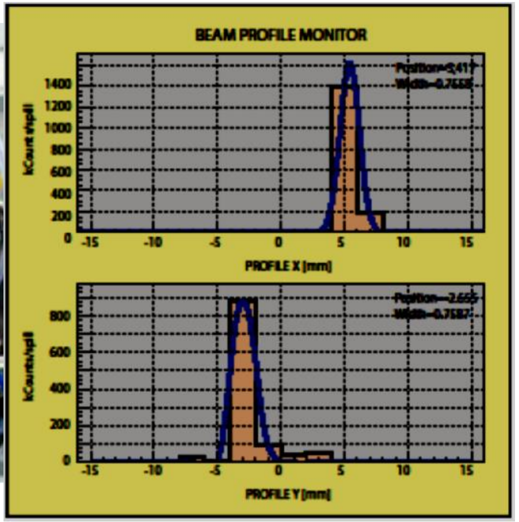


Neutron detection.

SiPMs based beam profile monitor.







K. Suzuki et al., Nucl. Instr. and Meth. A 610 (2009) 75.

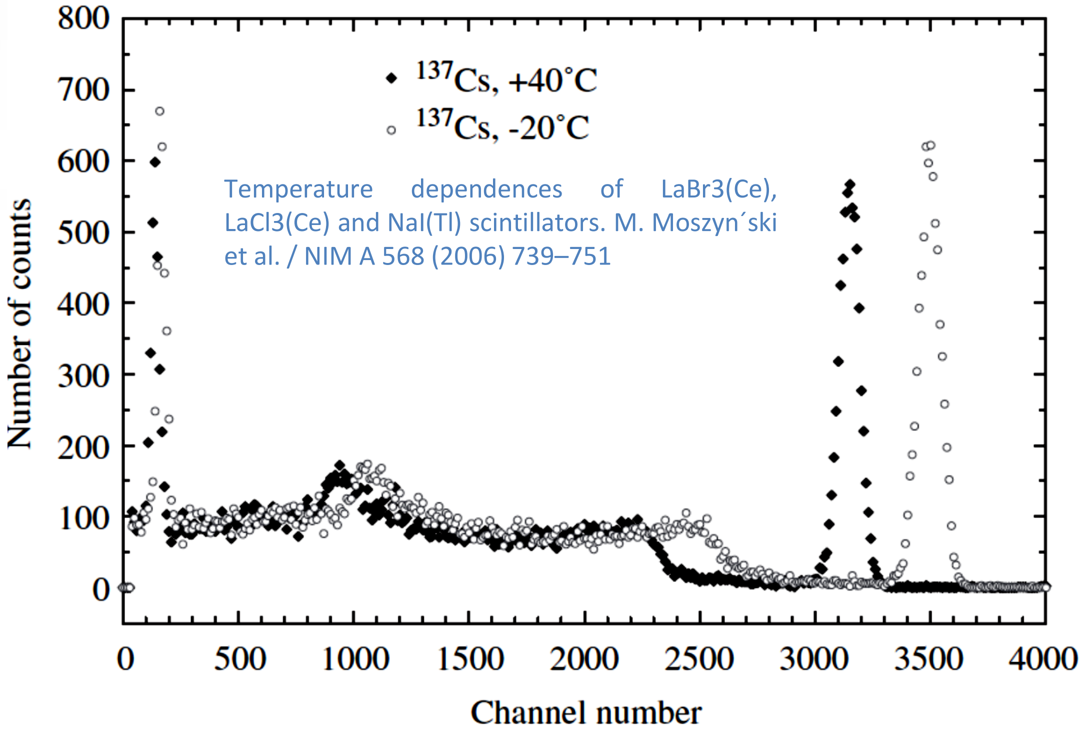
Neutron detection.

Hand-held neutron detector using SiPM.

➢ Scintillator Preparation

✓ Scintillator Light output as well as energy resolution shows strong temperature dependence.

✓ The energy spectra of g-rays from a ^{137}Cs measured with the LaBr3 crystal at different operating temperatures



Neutron detection.

Neutron Converters

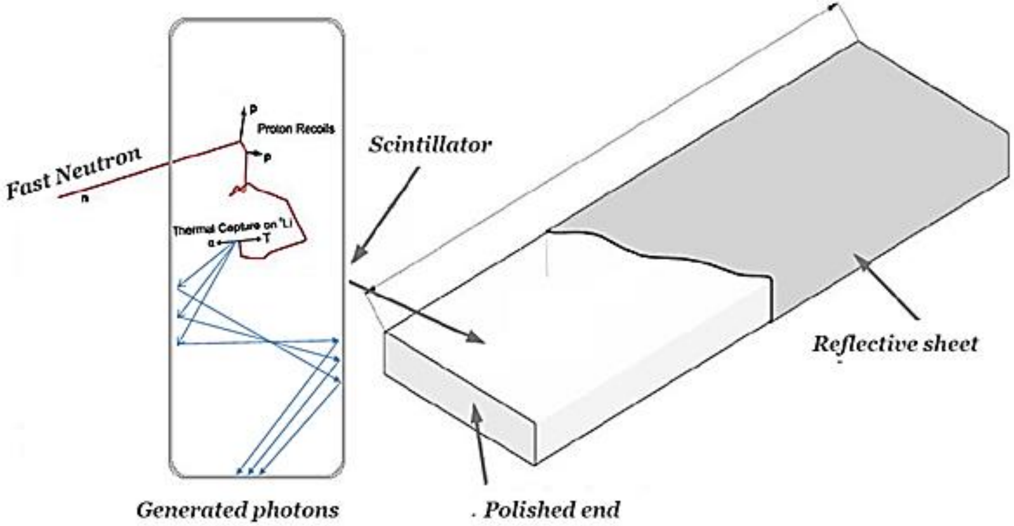
Interactions of interest for neutron detection and counting.

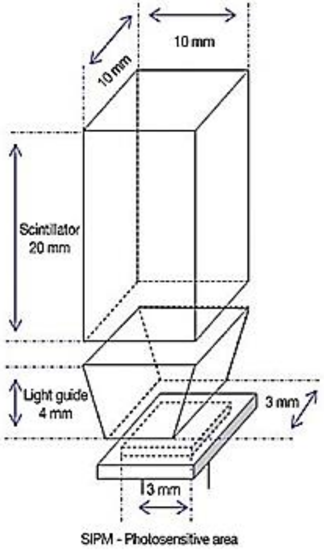
Interaction	Energy T_n	Cross section (b)	Q-value (MeV)	Products
$^{1}H(n, n')$	100 keV – 10 MeV	0.7–28	–	proton
$^{3}He(n, p)$	Thermal	5330	0.764	proton, triton
$^{10}B(n, \alpha)$	Thermal	3840	2.792	alpha, lithium ion
$^{6}Li(n, \alpha)$	Thermal	940	4.78	alpha, triton
$^{157}Gd(n, \gamma)$	Thermal	254000	7.937	photons, electrons
$^{155}Gd(n, \gamma)$	Thermal	60900	8.536	photons, electrons
$^{113}Cd(n, \gamma)$	Thermal	20600	9.04	photons, electrons

Neutron detection.

Hand-held neutron detector using SiPM.

- Assembly Process: Scintillator Preparation(fast neutrons)

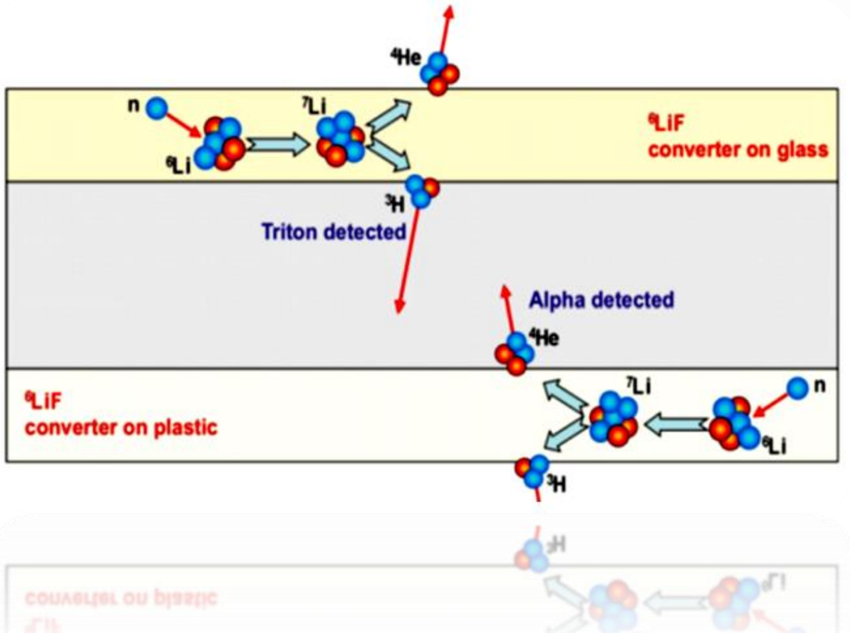




Neutron detection.

Hand-held neutron detector using SiPM.

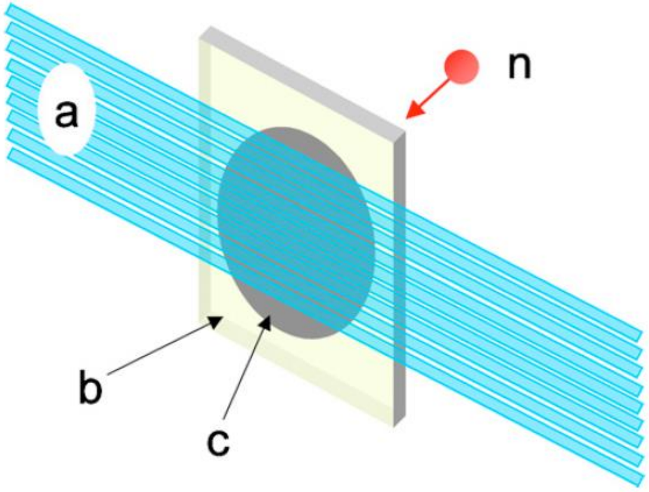
- ➢ Assembly Process: Scintillator Preparation (En = 25 meV)

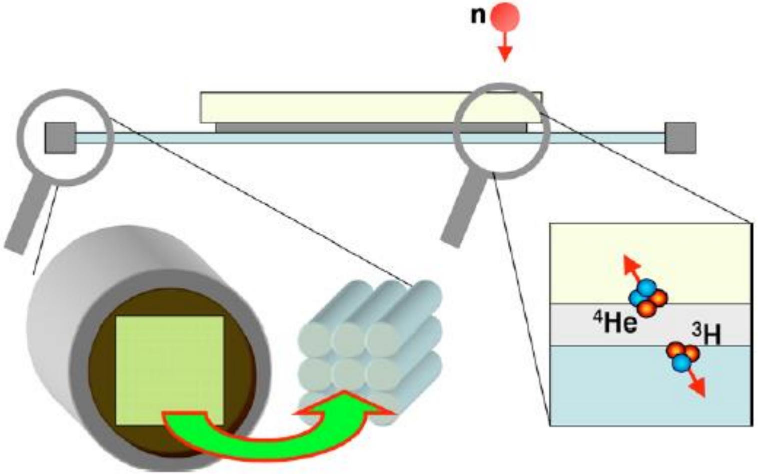


Neutron detection.

Hand-held neutron detector using SiPM.

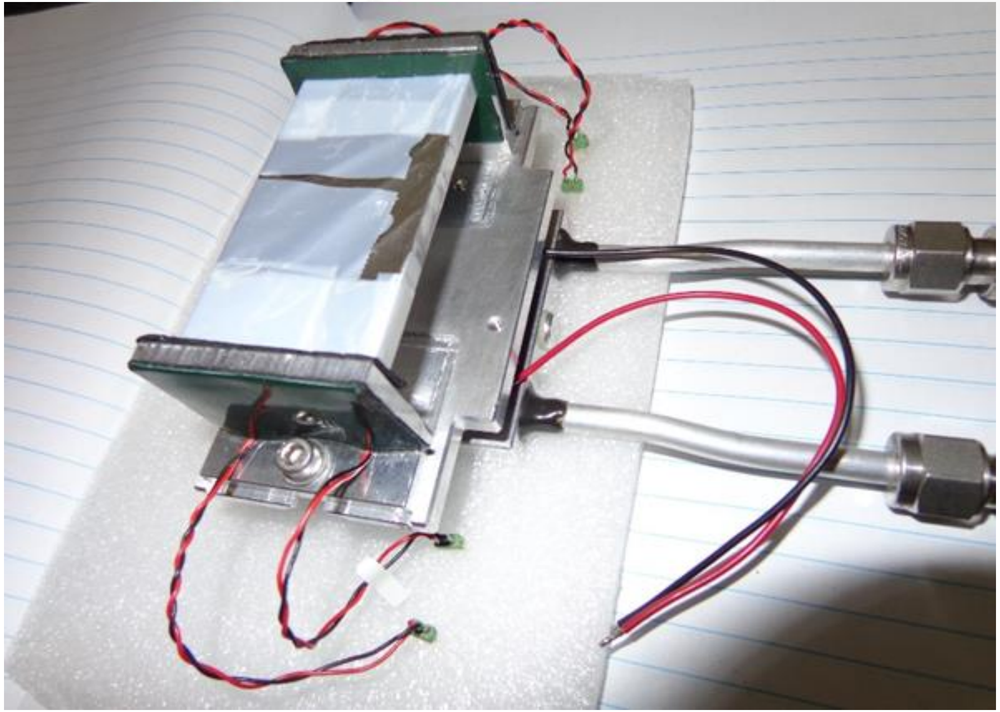
➢ Assembly Process: Scintillator Preparation (En = 25 meV)



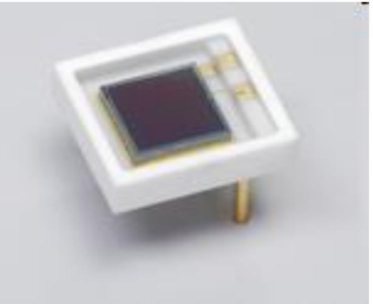


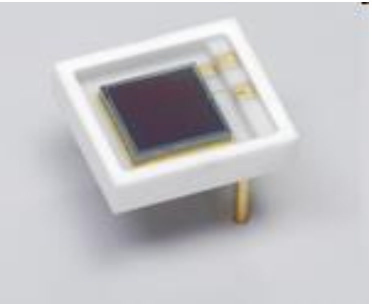
Neutron detection.

Organic plastic scintillator (EJ-204), 5 mm x 30 mm x 60 mm.



4 x (3x3 mm^2) MPPCs ((S10931-100P)





Neutron detection.

➢ Assembly Process: Read out electronics

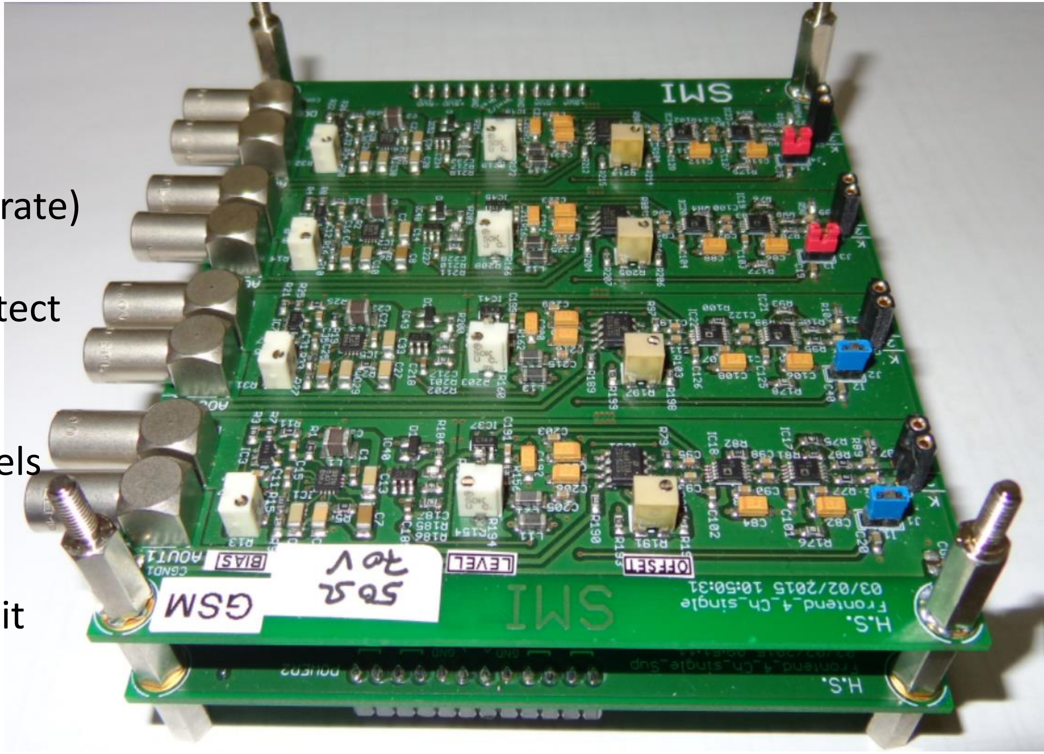
The PCB circuit board had built in:

1. Step-up power supply with an accurate bias voltage controller (needs around 12 volt to operate)

2. Incorporate maximum current control to protect SiPMs if it was inadvertently forward biased.

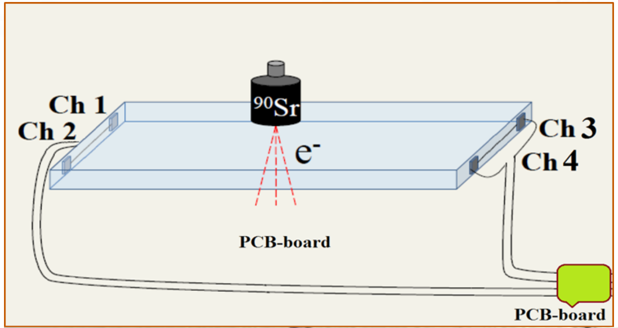
3. SiPM signals feed throw a built in four channels differential amplifier.

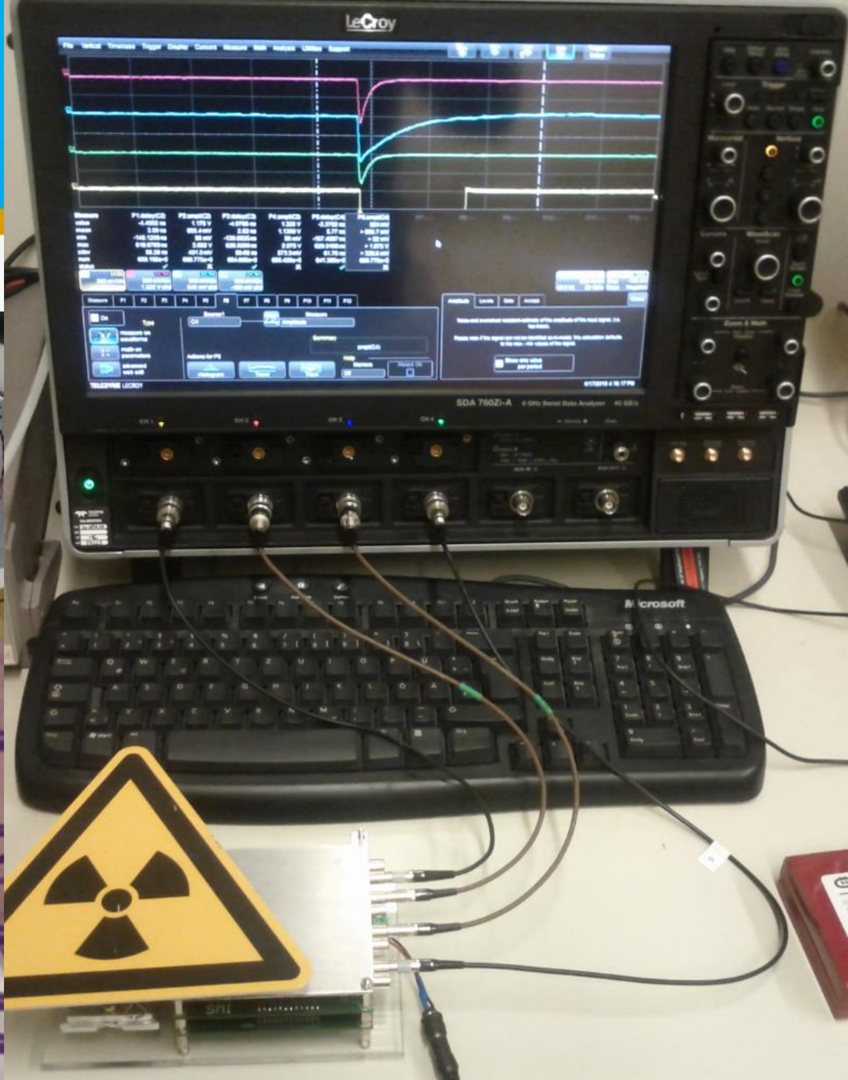
4. In addition a leading edge discriminator circuit featuring time over threshold.



Neutron detection.

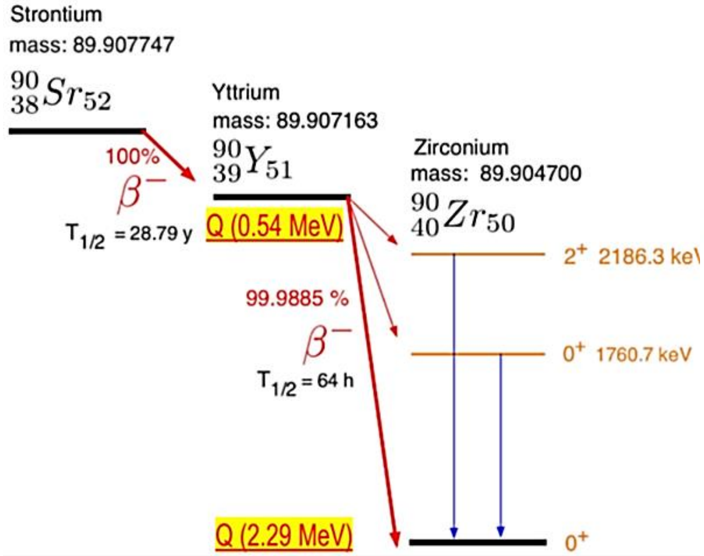
➢ Laboratory test and results;

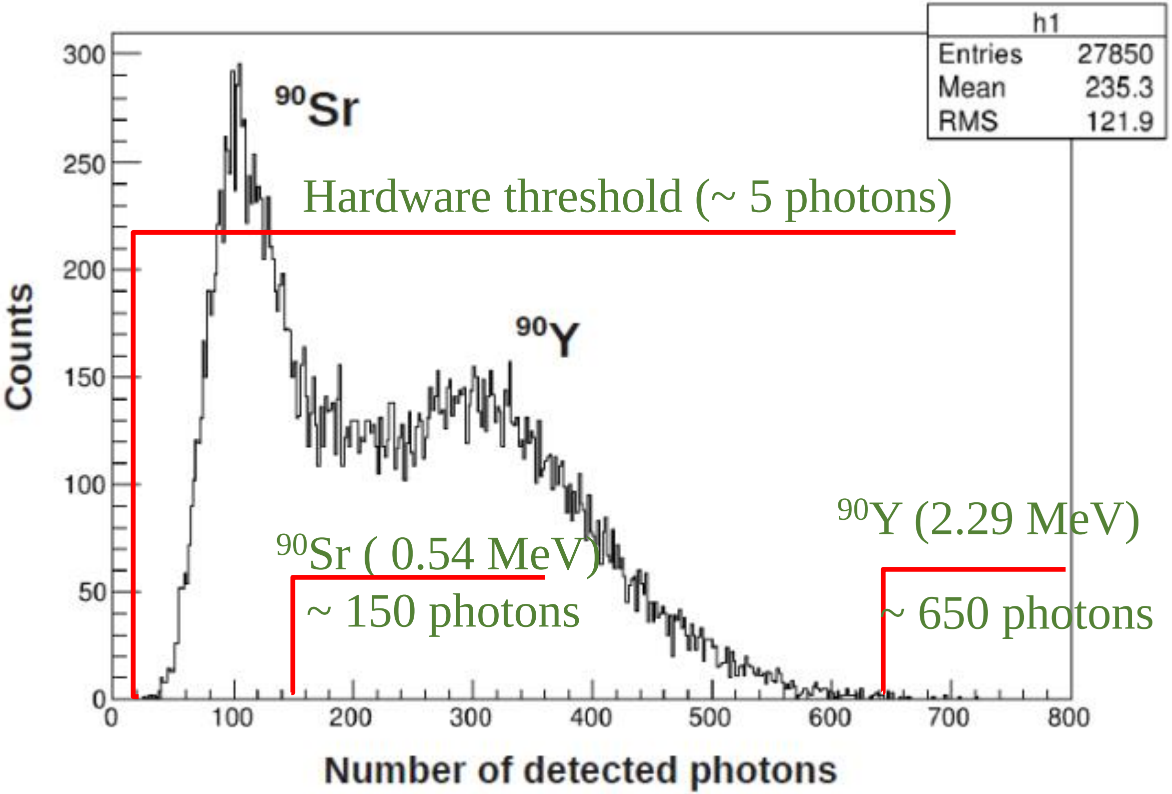




Neutron detection.

➤ Laboratory test and resu





Hand-held neutron detector using SiPM.

➢ Summary & Future work.

- Development of a compact SiPM based detection system has been successfully built and tested in the lab using Sr^{90} radioactive isotope.
- Next step is the performing of neutron detection using $^{241}Am/Be$ for fast neutrons.
- Design and build the necessary detector configuration for thermal neutron measurements.
- Design and machining aluminum and/or high-density polyethylene (HDPE) detector housing to provide both structural support and shielding against external light.


ON
OFF