# Performance of a CsI(Tl) detector with APD readout

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## Introduction

CsI(Tl) detectors coupled to photo-diodes have been routinely used to detect light-charged particles such as *protons* and α-*particles* generated in heavy-ion-induced reactions. These light ion measurements are generally performed along with the gamma rays for nuclear structure studies. They also have applications in γ-ray multiplicity measurements in fusion-fission studies, where closed-packed arrays around the target (at vacuum) with higher granularity are required. CsI(Tl) detectors can intrinsically discriminate between light-charged particles such as *protons*, α-*particles*, γ-*rays*, etc., according to their different decay times. The signal strengths from the photo-diode are weak, which restricts their use to *protons* and α-*particles* of energies ⩾5 *MeV*. Some physics cases, such as low energy charged particle emission from extremely deformed states, require detecting these light particles with energies ranging from a few hundred *keV* onwards. The same cannot be realized with CsI(Tl) detectors coupled to photo-diodes due to the weak signal strength of low-energy particles. It is required to increase the strength of the signal. This can be achieved with the use of either photo-multiplier tubes or with the use of avalanche photo-diodes (APD). The inherent gains of APD are higher by a factor of 10 – 50 times (function of applied potential) compared to normal photo-diode (unity gain). The performance of a CsI(Tl) crystal coupled to APD is reported.

## Description of the detector system

For test measurements, a CsI(TI) crystal of thickness 3 *mm* having an active area of 20 *mm* x 20 *mm*. This was coupled to an APD (Hamamatsu S8664-1010) via a 7 *mm* thick plexi-glass light guide. This assembly is identical to the existing CsI(Tl) based charged particle arrays at IUAC [1] & TIFR [2] where CsI(Tl) crystal is coupled to a photo-diode. This photo-diode operates with a bias voltage of 30 – 40 V. APD requires a bias voltage ranging from 250 – 400 V while maintaining linearity and resolution.

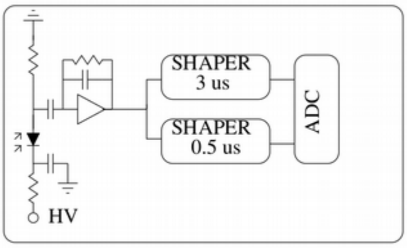


**Fig.1:** Schematic of signal processing for APD

## Detector Instrumentation

Fig.1 shows the schematic diagram of the readout scheme of the CsI-APD detector system. The APD, coupled to a CsI(TI) detector, is read by conventional charge-sensitive pre-amplifiers (CSPA) developed in-house. The APD is coupled to the CSPA with a sensitivity of 90 *mV/MeV* (*Si* equi.) and dynamic range of – 1 *V*. More about the CSPA can be found in Ref. [3]. The CSPA output is further amplified and shaped using spectroscopy amplifiers with shaping times of 0.5 μs and 3 μs for realizing the ballistic deficit technique.

## Measurements

The APD-CsI(Tl) detector was tested with various radioactive sources such as $^{137}$Cs, $^{60}$Co, $^{241}$Am and $^{229}$Th. Measurements were also made with CsI(Tl)–photo-diode combination and comparison was made in terms of signal strength. The signal strength in case of photo-diode remains constant whereas in case of APD it increases somewhat linearly between 200 V and 400 V. Table I compares the charge sensitivity (CS) of the same CSPA connected to both APD and photo-diode. Due to the multiplication of charges, gains are higher in

APD. Comparisons were also made with a standard NaI(Tl) detector coupled to a PMT.

**Table I**

| **CS (photo-diode)** | **CS (APD 300 V)** | **CS (APD 350 V)** |
|---|---|---|
| 10 *mV/MeV* (for γ-rays) | 200 *mV/MeV* (for γ-rays) | 300 *mV/MeV* (for γ-rays) |
| 6 *mV/MeV* (α- *particles*) | 120 *mV/MeV* (α- *particles*) | 180 *mV/MeV* (α- *particles*) |

A maximum potential of 400 V can be applied to APD. At such high potentials, saturation of signals in CSPA is observed for α-*particles* along with higher dark currents and background from cosmic particles. There is no appreciable change in resolutions observed while increasing the APD bias voltage from 300 *V* to 400 *V*. At the same time, rise times of the signals observed from the CSPA in both photo-diode and APD were identical. Rise times are functions of decay times in the of the light output in the CsI crystal. The rise times observed are 2 μs and 1.3 μs for γ-rays and α-*particles* respectively. Another interesting observation made is that in case of APD, there is no significant change in energy resolution while changing shaping times of spectroscopy amplifier from 0.5 μs to 3 μs. In contrast, energy resolutions are severely degraded at shorter shaping times (0.5/1 μs) for the photo-diodes. Table II shows the energy resolutions observed with 3 μs shaping time.

**Table II**

| Energy | Photo-diode (Resolution) | APD (Resolution) |
|---|---|---|
| 59 *keV* γ-rays | Not observed | 18 *keV* |
| 662 *keV* γ-rays | 65 *keV* | 45 *keV* |
| 1332 *keV* γ-rays | 72 *keV* | 56 *keV* |
| 8.37 *MeV* α-*particles* | 300 *keV* | 300 *keV* |

For low energy γ-rays, resolutions are better with APD. Energies as low as 59 *keV* could be detected with APD while it could not be observed with the photo-diode. Resolutions for 662 *keV* and 1332 *keV* γ-rays are at par with the NaI(Tl) detector. For 59 *keV* γ-rays, a resolution of 10 *keV* was observed with the NaI(Tl) detector. The lower threshold limit for photon detection in the APD-CsI(Tl) combination was estimated at around 50 *keV*.

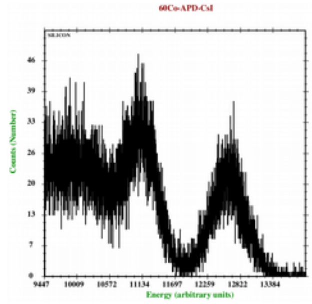


**Fig.2:** γ-ray spectrum of $^{60}$Co with APD-CsI

Fig.2 displays the energy plot of γ- rays from $^{60}$Co. The peak to valley ratio is superior for APD in comparison to photo-diode. The resolutions are identical to NaI detector.

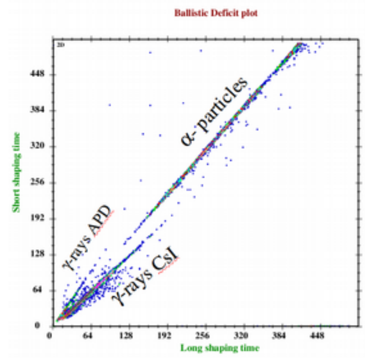


**Fig.3:** BD plot with α- *particles* and γ-*rays* using APD-CsI(Tl) detector.

Fig.3 shows the ballistic deficit (BD) plot with APD showing different slopes for α- *particles* *($^{229}$Th)* and γ-*rays* *($^{60}$Co)*. We plan to perform further tests with beams from accelerator to observe lower energy threshold for particle separation between protons and α-*particles*. It is also planned to increase the dynamic energy range of CsI-APD detector with lower gain CSPA.

**References:**

[1] A. Jhingan et al., Proc. DAE Symp. Nucl. Phys. 66 (2022) 1100.
[2] R. Palit et al., Proc. DAE Symp. Nucl. Phys. 62 (2017) 1058.
[3] A. Jhingan et al., Nucl. Inst. & Meth. Phys. Res. A 786 (2015) 51.