Precision Fitting Function for HPMT Spectra

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Abstract:

Hybrid Photomultiplier tubes are an ideal tool for detecting small numbers of photons. However, as the number of photons increases, the probability of one or more of the resultant photo-electrons backscattering from the diode increases and eventually the individual photon peaks are no longer resolved. The spectra obtained are complex and the extraction of precise results depends on fitting the a complex distribution. A function has been developed that provides an excellent fit to HPMT data and allows the extraction of precision results for the light collection uniformity from lead tungstate crystals for the CMS electromagnetic calorimeter end-caps.

Keywords: HPMT, CMS, Crystals, Lead-tungstate

The small taper of the lead tungstate crystals in the CMS calorimeter leads to a non-uniformity in the light collection along the length of the crystal. This effect must be reduced to less than 0.35% per radiation length in order that it does not dominate the constant term of the detector resolution. In the barrel detector, one of the long faces of the crystals is de-polished to randomize the scattering angle of the light and remove the non-uniformity. However, this also leads to a large light loss that must be recovered by a highly reflective wrapping. In the end-cap detector, the larger crystal size reduces the relative effect of the taper and the remaining non-uniformity is close to the limit required. It is highly desirable to avoid the complicated process of de-polishing the end-cap crystals and of finding a reflective wrapping that can withstand the doses of up to 100 times that in the barrel. In addition, the hermeticity of the end-caps is improved if the wrapping can be avoided.

In order to investigate the light-collection uniformity in the end-cap crystals, a rig was developed at Imperial College based on a 40mm ϕ HPMT from DEP. The crystal is optically coupled and sits vertically on top of the tube (it is mounted horizontally and the crystal and tube rotated to the vertical position to help ensure a reproducible coupling and to avoid the risk of damaging the quartz window). The crystal is excited by a weak (20Kbq) Co^{60} point source mounted on a linear stage to allow movement along the length of the crystal. The experiment is performed in a temperature controlled, light-tight box. The output from the integrated HPMT pre-amplifier is amplified 100x by an Ortec 672 spectroscopic amplifier with a shaping time of 0.5 μs. The data is acquired and the experiment controlled by a LabView application. A single photoelectron resolution of

16% FWHM is obtained with 15KV applied across the tube and a diode bias of 60V. Up to the 17 photoelectron peaks are visible in the spectra.

To extract information on light collection uniformity along the length of the crystal, it is necessary to extract the mean number of photons from each spectrum with considerable accuracy. To achieve this, a detailed fitting function was developed from first principles and used within the Minuit fitting programme. Photons from the Co^{60} source at 1.2 and 1.3 MeV are prone to Compton scattering, leaving just part of their energy in the crystal. Thus, the starting point for the fit is a Poisson distribution around the mean number of photons, convoluted with the effect of Compton scattering. The photons are detected by the HPMT cathode are converted, with some efficiency, to photoelectrons that are accelerated by the 15KV field towards the diode. Although the majority of the photoelectrons are fully absorbed by the diode, some are backscattered, leaving a variable fraction of their energy. For the first photoelectron peak, this generates a low-side tail but for the higher peaks the result becomes complicated, as all the combinations have to be considered. Indeed, this effect gives rise to the continuum background under the discrete photoelectron peaks and eventually limits the number of peaks that can be observed.

The basic fitting function developed incorporates the Compton scattering and the backscattering. However, to obtain a good fit to the data, the fit must include the backgrounds and pile-up. The backgrounds arise from the dark-current (observed from the biased tube without a crystal) and cosmic rays (observed when a crystal is mounted but no source is present). In practice, scans of the Co^{60} source along the crystal are preceded and followed by spectra taken with the source parked in a shielded position. A background is subtracted from each of the data spectra based on an interpolation between these two background spectra. The interpolation uses the measured time-dependence of the dark current as weighting. Although the source is extremely weak, pile-up is evident in the data spectra. This is included in the fit by allowing source-source and source-background pile-up contributions. Including the calibration constants there are a total of nine parameters in the fit. They are: An amplitude; the Compton fraction; the average light yield; the resolution; the backscattering fraction; two calibration constants; the pile-up fraction; and a shape parameter for the backscattering function. This number of degrees of freedom can be fairly catastrophic when trying to converge on a fit so a number of strategies are tried, using various sequences of fits. The final fit to obtain the light yield is performed with the amplitude, Compton fraction, resolution, and pile-up fraction also allowed to float. Crystals with high light-yields (~12 photoelectrons/MeV) can give χ^2 as low as 1.0. Typical values are around 1.4 and the fit is deemed to have failed if values greater than 2.1 are obtained. Average light-yields below 7 photoelectrons/MeV are hard to fit without fixing the Compton fraction, though in principle this should only vary at the very ends of the crystals where the containment is slightly worse.

The CMS end-cap crystals have been investigated using this technique at Imperial College. The precise results have shown that the light-collection uniformity of crystals in the carbon fibre support structure is better than for crystal in a reflective wrapping and slightly worse than for completely unwrapped crystals. In addition, it has allowed the development of a method for the mildly improving the uniformity based on shading in the first 6cm of the chamfered edges of the crystals with an ordinary pencil. We now hope

that the CMS end-cap crystals will not need de-polishing as for the barrel and that no wrapping will be needed.

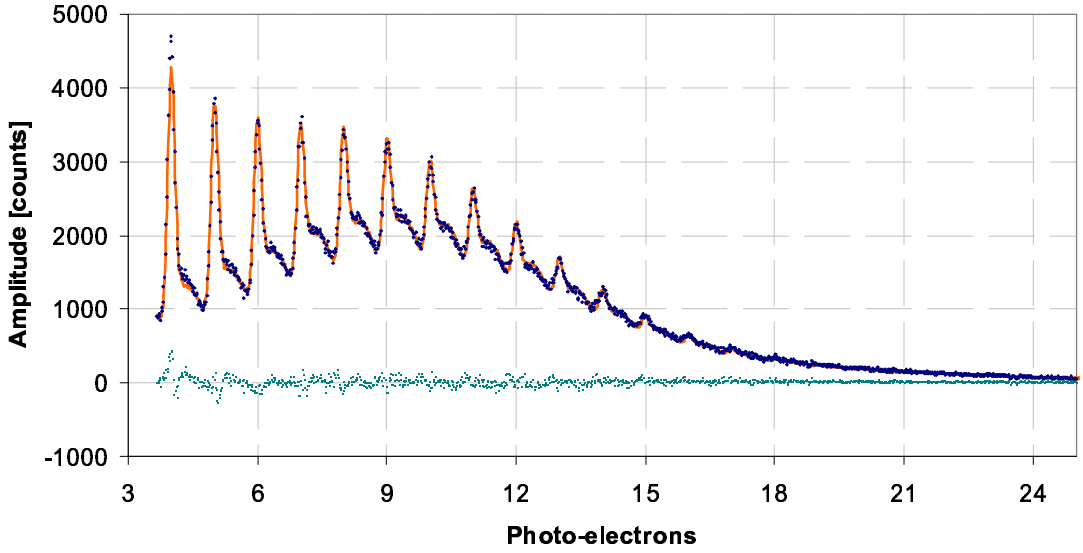

Figure-1: HPMT spectrum showing data, fit and residuals.