Fitting of the Source Calibration Response

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1 Introduction

This note documents the development of an algorithm to fit the output from the calorimeter's source calibration system. This system provides an absolute calibration across all crystals. References [**?**] provide detailed overviews of the hardware employed. Essentially, neutrons from a Starfire Deutrium-Tritium generator irradiate a fluorine-based compound (FC770). This produces the following:

$$^{19}F + n \rightarrow^{16} N + \alpha \tag{1}$$

$$^{16}N \rightarrow^{16} O^* + \beta(t_{1/2} = 7s) \tag{2}$$

$$^{16}O^* \rightarrow^{16} O + \gamma(6.13MeV) \tag{3}$$

The FC770 flows around the front plate of each of the disks periodically. The resulting 6.13 MeV γ acts as our absolute calibration point.

1.1 Key Performance Requirements

The calorimeter is vital for providing particle identification, a fast online trigger filter, and accurate timing information for background rejection and for seeding track reconstruction. To achieve this the calorimeter must have:

- Energy resolution of $\mathcal{O}(5\%)$,
- Timing resolution requirement of < 0.5 ns at 100 MeV.
- Position resolution of order 1 cm.

2 Fitting the response

As part of our calibration procedure, we must fit each SiPMs photon response. To understand how to do this a simulation was carried out.

Within the Mu2e/Offline framework, 10^7 calibration photons were generated across each disk. The resulting spectra were fitted in a similar way to how we will fit the raw ADC response.

In the reconstructed crystal hits a series of peaks can be identified:

1. The 6.13 MeV photon peak E_{full};
2. The 1st escape peak corresponding to $E_{full} - m_e$;
3. The 2nd escape peak corresponding to $E_{full} - 2m_e$;
4. A background continuum to represent electronic noise.

The energy spectra are fitted offline to three crystal ball functions centered around the 6.13 MeV peak and the two escape peaks and a fourth function that incorporates the background. Each crystal ball function has four parameters: peak energy, peak width, α, and n. The latter two parameters have the standard definitions within a crystal ball parameterization.

We parameterize the logistic background and electronic noise as:

$$\frac{1}{(1 + e^{\frac{(E-C)}{\beta}})} \tag{4}$$

where E is the photon energy, C is a constant, and β which is the inverse of the growth rate.

When applied to the raw response the peak value can be combined to ADC counts per MeV and a resolution can be calculated from the width of the peaks.

Two cuts were enforced to improve fit quality:

1. Energy deposited in the target crystal larger than 80% of the total energy deposited
2. Time difference $\Delta T < 4$ ns required for different hits

The fit was carried out using RooFit. The following are the outputs of the fit:

- C - noise constant parameter
- β - noise beta parameter
- α - for crystal ball functions
- n - for crystal ball functions
- F_{full} - fraction of events in full peak

- F_{first} - fraction of events in first escape peak
- F_{second} -fraction of events in second escape peak
- $Peak$ - peak position of combined fit
- σ- peak width for combined fit
- σ_{first} - peak width for first peak
- σ_{second} - peak width for second peak

Figure 1 shows three example fits to a selection of crystals in the second disk. The yellow line is the crystal ball for the 6.13MeV line, the magenta is the crystal ball function for the first escape peak and the cyan is that for the second escape peak. The violet line is the electronic noise contribution. The red line shows the combined fit.

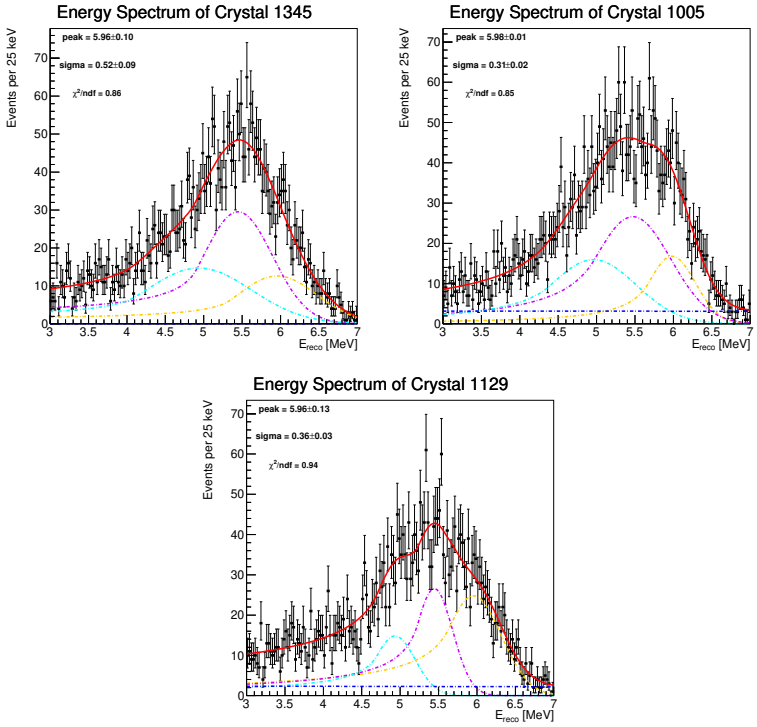

Figure 1: A few examples fits to single crystals. The red is the combined RooFit plot. The magenta and cyan distributions are the crystal ball functions for the first and second peaks. The violet line is the electronic noise contribution.

Figure 2 shows the distributions of the full peak, full width and χ^2/ndf for the combined fit.

The resolution is defined as $100 \times \sigma_{full}/Peak$ is shown in Fig. 3

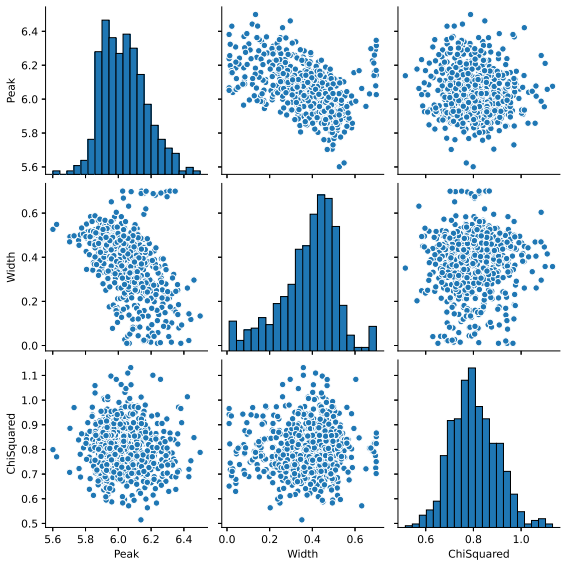

Figure 2: Pairplot showing distributions and correlations between fit parameters and χ^2 of the fit

3 Where is this the code?

The current fitting routines lives in: https://github.com/Mu2e/CaloCalibration. We plan to move away from RooFit in the coming weeks and move to a python based routine which we will further optimize.

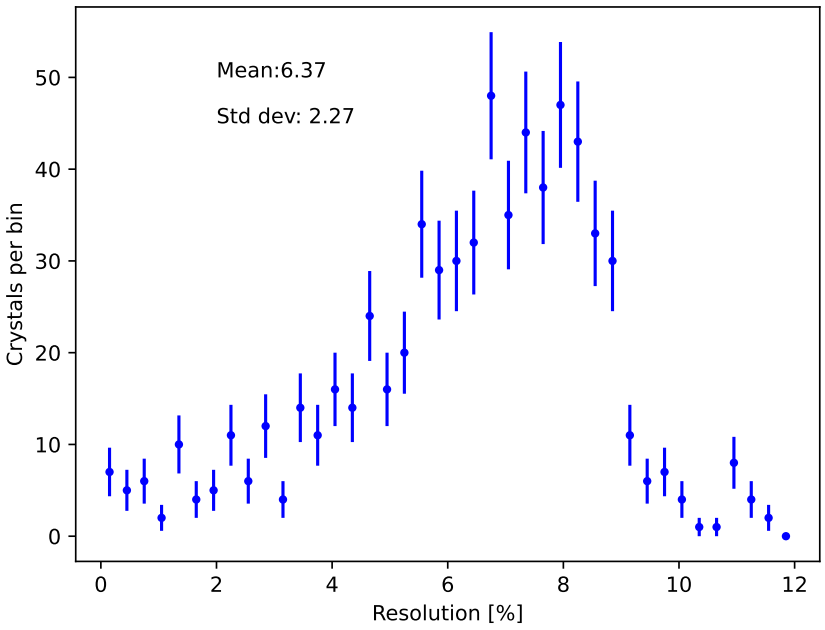

Figure 3: Resolution of the fit defined in terms of a percentage