'Two-Template-Fit' analysis: R133 Soudan Ba data.

05 August 2014 -- Updated 13 August

Abstract

The *Two-Template-Fit* is a new method of extracting information from our phonon pulses, motivited by the observed pulse shapes and their variations. Instead of a single template we generate two templates, one that describes the average pulse, and one that describes the deviation of the individual channel pulses from the average (the *residuals template*). In this note we describe our first application of this method to iZIP data from Soudan.

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1. Introduction

So far we use two different fitting methods to extract information from our phonon pulses: the first is the 'Optimal Filter' (OF), where a fixed template is fit to the individual phonon traces, ignoring differences in pulse shape (this is the method that we also used in CDMS); the second is the 'Non-stationary Optimal Filter' (NSOF) where single template is fit to the sum of all traces from an individual event, but the part of the pulse where differences in pulse shape between events are significant is de-weighted in the fit. The first method leads to a poor energy resolution but maintains position information, while the second method improves the energy resolution considerably by minimizing the position dependence.

The new method proposed here, the *Two-Template-Fit* (2T fit) is still an optimal filter method (template fit in frequency space), but we fit two different templates to each individual pulse trace: one describing the average pulse and one describing the typical variation between the average and an individual pulse (the 'residuals template'). The fit parameters are a common start time for the two templates and two amplitudes (see fig.0). The average (or 'slow') template amplitude is our energy estimator while the amplitude of the residuals (or 'fast') template contains position information.

We earlier tested the 2T fit on data acquired with a special detector (phonon readout only on one side of the detector) operated in the Queen's Test Facility (2T-QueesData). Now we have processed some Ba calibration data from Soudan Run 133 and compared the performance of our new quantities to the OF and NSOF parameters to investigate if the new method brings any benefits.

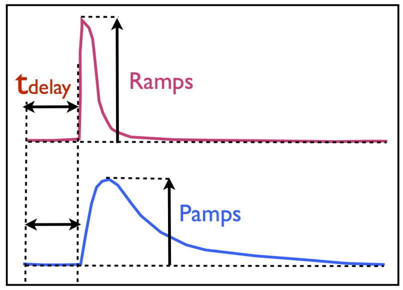

fig.0: A graphic that shows the 3 fit parameters, namely: the slow template amplitude (Pamps), the residual template amplitude (Ramps) and a single delay common to both fast and slow templates (t_{delay}).

- **Detector:** For this study we only looked at detector T3Z1
- **Data used:** Barium series:
  - Template generated using series: 01120924_0832, 01120924_1201
  - Series analyzed: 01120924_1201, 01120919_0948, 01120920_1108, 01120921_1111
  - OF and NSOF quantities are used from the standard R133 processing 'Prodv5-3_June2013' data release.
- **Cuts used:**
  - Good events cut: cGoodEv_v53
  - Bulk events selection: cQsym_v53
  - Energy range: inrange(ptNF,10,450)

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2. Templates

The slow templated (which gives the phonon amplitude, thus 'PT') is just the average of a number of good pulses. To generate the residuals template ('RT') we subtract from each individual pulse trace the PT template scaled to the tail of the pulse. Residual traces with a negative amplitude are flipped before the residuals are average to produce the residuals template. Some more details on the generation of the templates can be found in the 2T-QueesData note. Figure 1 shows the two templates.

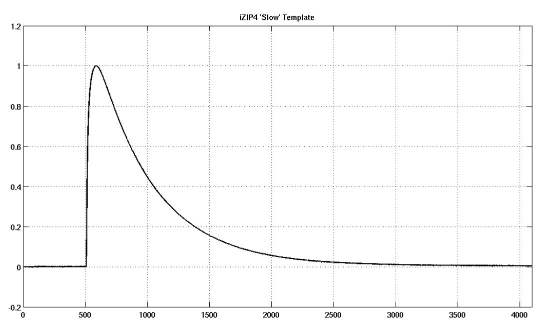

fig:1.a: Average template (PT)

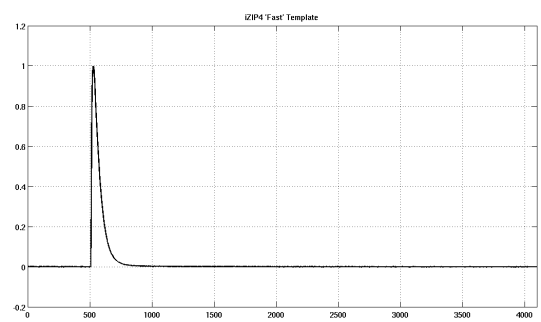

fig:1.b: Residuals template (RT)

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3. Example fits

Here we show a few example fits selected from different regions in the detector.

Select Event Class: Side 1 surface events Side 2 surface events Bulk events
View pulses from: Side 1 channels Side 2 channels

Select Pulses

P1
P2
P3
P4
P5
P6
P7
P8
P9
P10

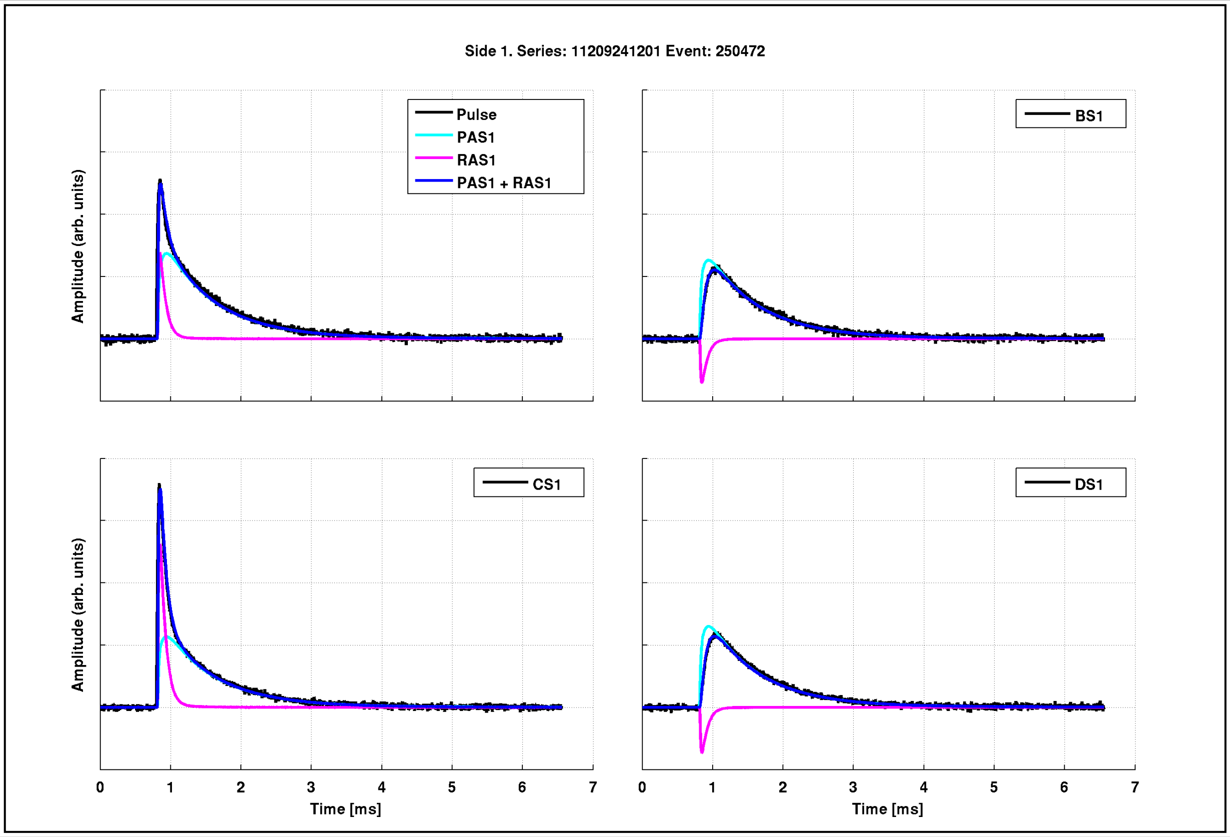

Fig:2: Example fits to pulses from the two surfaces and the bulk. The y-scales are identical for all channels in a given event and hence the relative sizes of the pulses are just as they are in the raw data. Random events with ptNF in the range {10,400} are selected.

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4. Energy Estimator

The energy estimater for the 2T fit is derived from the PT amplitudes. In the plots below (Fig. 3) we chose the simplest way of combining the amplitudes from the eight individual traces for each event which is just the sum (we did try other combinations such as weighting by the relative phonon calibration factors or by the pre-pulse standard deviation of each trace, but the outcome is essentially identical).

More explicitly the new energy quantity **PSUM2T = PA1 + PA2 + PB1 +PB2 + PC1 +PC2 + PD1 +PD2** without relative calibration. **PSUM2Tc** is the scaled version of PSUM2T with the Barium 356 keV line at 356. Similarly **PTNFc** is the scaled version of PTNFamps so that the 356 keV line is at 356.

In figures 3.a and b we compare the new energy estimator with tbe best prviously available phonon energy estimator from the NSOF fit, ptNF. The new energy estimator produces a better energy resolution for the 356 keV peak from the Ba calibration than the old one.

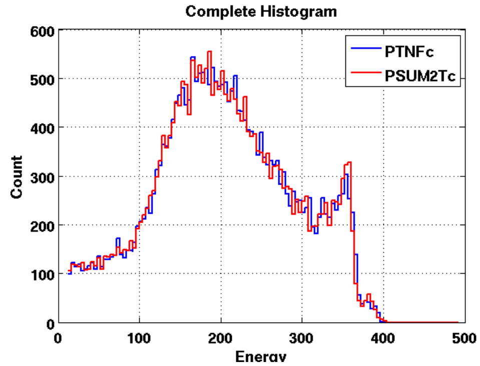

fig:3.a: Histogram of all good bulk events.

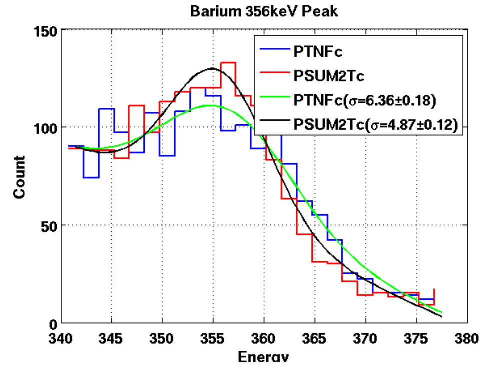

fig:3.b: Barium 356 keV peak in phonon energy.

In the previous note we explored two different ways of generating the Residuals Template and found some influence on the energy resolution, but the changes were less than we observe here for the difference between the NSOF and the 2T energy estimators.

NOTE: We have not applied any Luke correction - yet, the position dependence due to the Luke phonons makes a signficant contribution to the overall resolution of the 356 keV line. Future studies will have to disentangle this and show that the improvement we see here is real an not due to an accidnetal cancellation of position dependencies.

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5. Postion Information

In this section we explore the position information from the new fit procedure. We compare quantities derived from the RT amplitudes from the new fit with the OF quantities.

In the first set of plots we just plot the RT amplitudes (normalized by the total energy derived from the 2T fit) versus the OF amplitudes (normalized by ptNF). To first order we observe a simple linear relationship indicating that the basic information content is very similar. However, there is some noticeable spread; in particular in the lower left corner of each plot there is a population which has a fairly narrow distribution in RT but a wide spread in OF. We have not investigated yet if there is anything to be learned from this population, but by construction of the quantities, the events that appear in the lower left corner in one of the channels must be higher up in the distribution in at least one of the other channels.

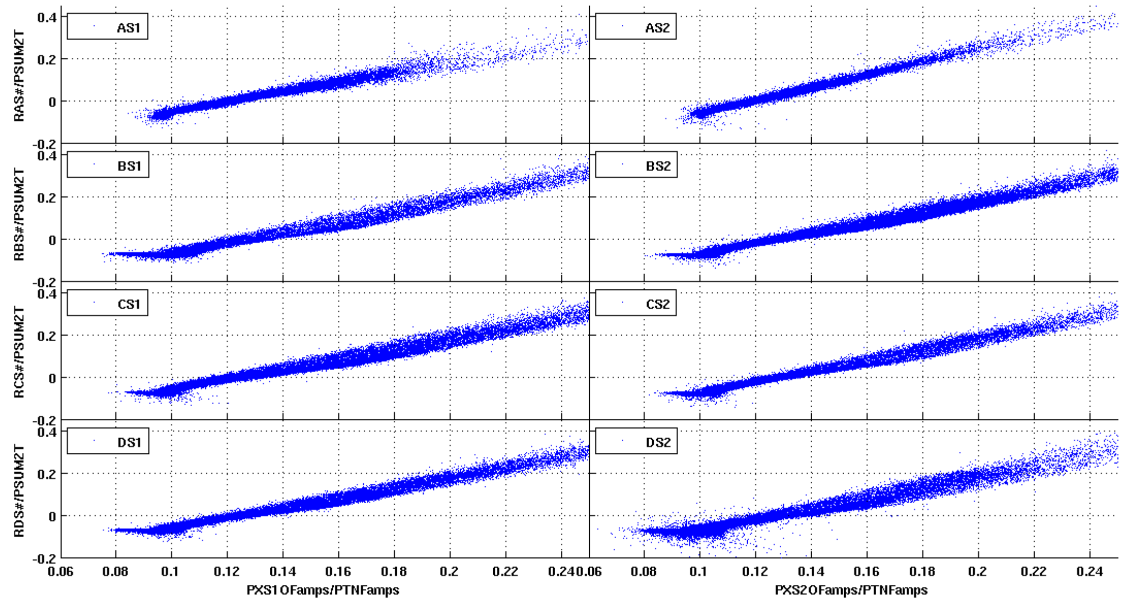

fig 4: RT amplitude of each channel normalized by the total phonon energy derived from the 2T fit
versus the OF amplitude normalized by total energy from the NSOF fit.

Next we have produced position quantities to measure the radial- and z-position and compare those to the OF and charge information. While the definition of the z-partition is straight forward, the radial partition is more complicated. We translated the standard definition of the phonon radial partition with OF quantities (prpartOF = PAOF/psumOF) into a definition using the new parameters (see below), but it is not obvious that this is the most appropriate way to define a radial partition. So we also defined a new quantity for both OF and the new parameters and we investigate both. The quantities are defined as follows:

- prpartR = (A1 + A2 + 2*offset)/(A1+B1+C1+D1+A2+B2+C2+D2+8*offset)
  All amplitudes are RT amplitudes; the offset is the same in numerator and denominator. It is needed since the RT amplitudes can be negative. We chose the offset such that the minimum RT amplitudes (besides a few outliers) are just above zero. (Individual side quantities are defined correspondingly)
- prpart = (3*(A1+A2)-(B1+C1+D1+B2+C2+D2))/3*PT,
  where X1 and X2 are the phonon amplitudes for channel X on side 1 and side 2 respectively (either the RT or the OF amplitudes); The qunatity is called prpart2T in case of 2T fit and prpartOF_new in case of OF.
  PT is the total phonon energy (either from the 2T or the NSOF fit). All the idividual OF and 2T-residual amplitudes are relative calibrated.
- pzpart = ((A1+B1+C1+D1) - (A2+B2+C2+D2))/PT
  (definition of quantities as above)
- qzpart is defined as usual: (qsum1-qsum2)./(qsum1+qsum2)

Whereever we use residual amplitudes, we also use the proper relative phonon calibration.

It can be seen that from both phonon radial position (figures 5, using our new definition of radius) and phonon z position (figures 6) that the 2T quantities provide quite similar information as the OF quantities do. However, these types of plots don't provide a clear answer as to which sets of quantities provide higher quality information.

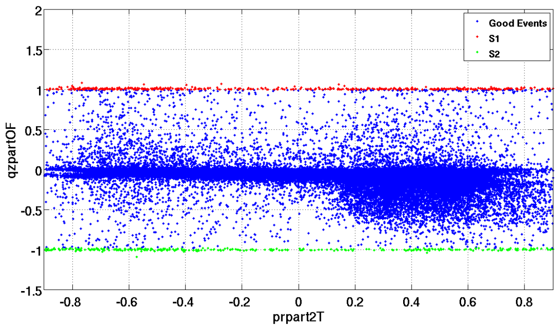

fig 5.a: Charge z partition vs Phonon radial partition (2T)

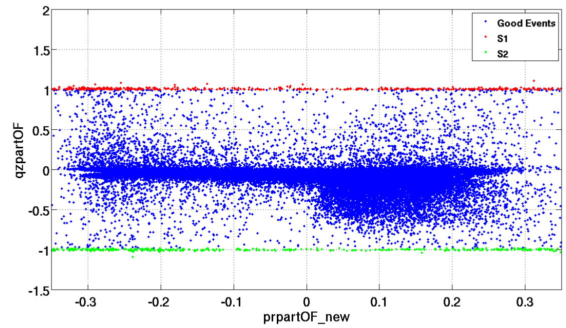

fig 5.b: Charge z partition vs Phonon radial partition (OF)

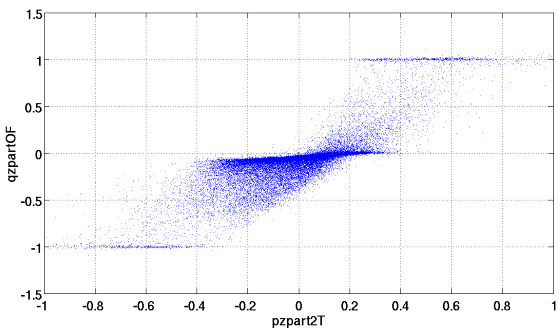

fig 6.a: Charge z partition vs Phonon z partition (2T)

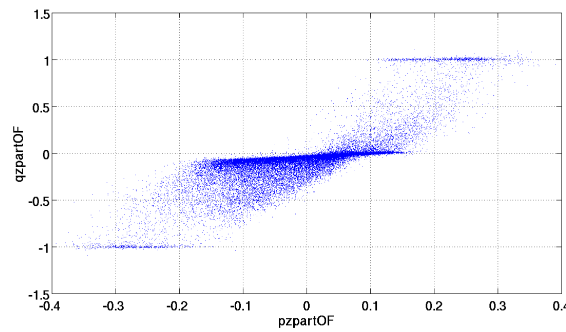

fig 6.b: Charge z partition vs Phonon z partition (OF)

Quantification

In order to find some quantification of the quality of position information, we start with a phonon independent position quantity. The quantity we use is a charge based radial quantity. We start with the standard side specific charge radial partition (qrpart#OF). We then add them in quadrature as shown in figure 7 to generate a single charge based radial variable.

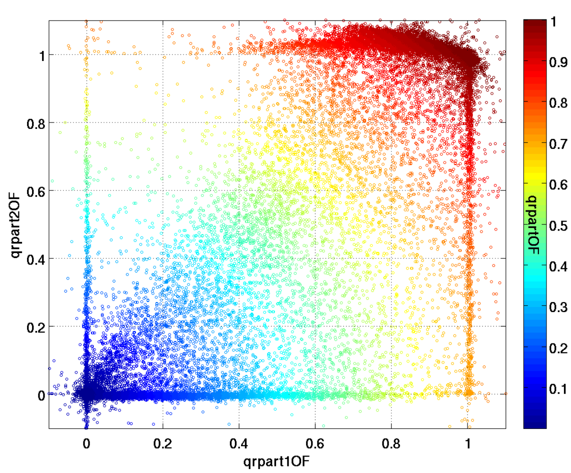

fig 7: Charge radial partition of side 2 vs. side 1.
The color coding indicates how we defined a combined charge partition.

In figure 8 we show the radial partition quantities extracted from the phonon quantities. For the phonons we generated a combined radial partition by just adding the radial partition quantities from the two sides. In figure 8 a and b we use the new radial definition, while figure 8 c and d show prparOF and our adaptation of this quantity for the RT amplitudes. Note that for all following plots we have lowered the energy threshold to 2 keVee (based on the 2T energy) with no upper limit.

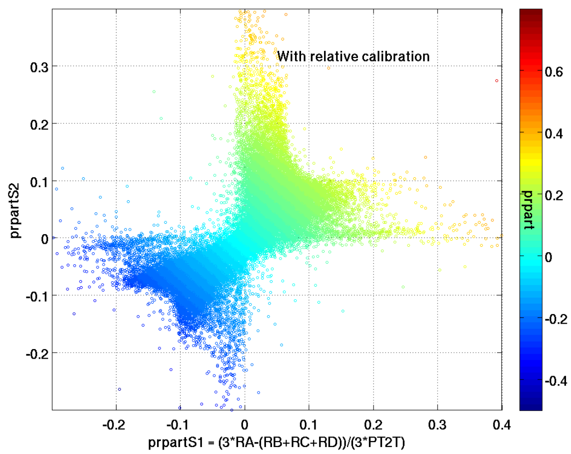

fig 8.a Phonon partition from 2T fit; new definition.

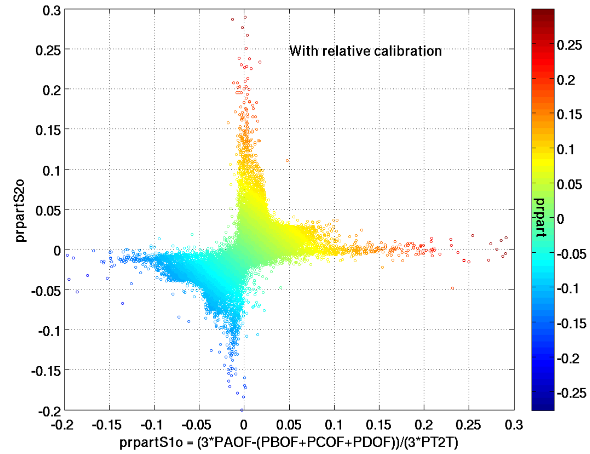

fig 8.b Phonon partition from OF fit; new definition.

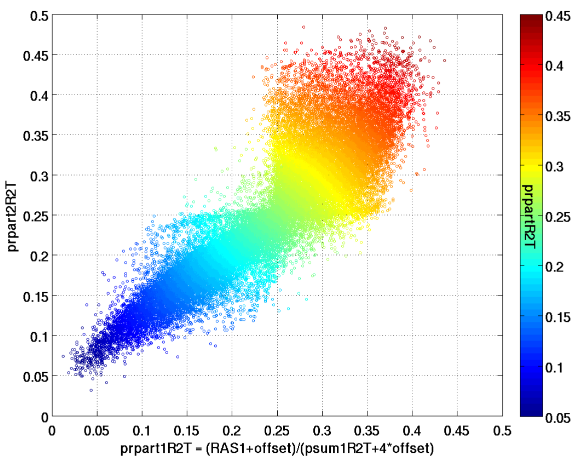

fig 8.c Phonon partition from 2T fit; adaptation of prpartOF definition, see above.

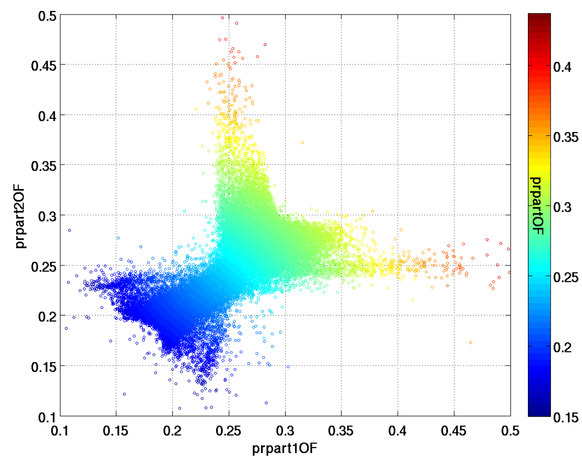

fig 8.d Phonon partition from OF fit; stnadard definition (prpartOF).

The horizontal and vertical structure in these plots comes from the fact that the phonon radial partition on a given side is quite good for events close to that side, but almost completely disappears for events on the opposite side.

Finally, in figure 9 we study the efficiency of a radial cut based on phonon quantities, assuming that the charge based cut (on the combined qrpartOF, see fig. 7) is a good measure for the actual radial position. For four different charge based radial cuts we calculate the efficiency of a phonon based cut (fraction of 'good' events selected by the charge based cut that are also selected by the phonon based cut) as well as its inefficiency (fraction of 'bad' events, rejected but the charge based cut, that pass the phonon based cut). We calculated those quantities for all good events as well as for charge symmetric events (using the standard cQsym_v53 cut).

Figure 9 a shows this plot for our new definition of the radial quantities; for most of the parameter space, the 2T fit based quantities provide a noticeably lower inefficiency for a given efficiency. Only at very high efficiency values the curves are essentially identical. In some of the cases there is a reversal for a small range of efficiency, but the difference in this range is very small.

In figure 9 b we show the same for the standard prpartOF and our adaptation for the RT amplitudes. Here the situation is not as clear cut. For 'all good events' (aka without the cQsym cut) the OF curves are very similar to those in figure 9 a; for charge symmetric events the OF situation seems to improve for the looser of the qrpart cuts. The 2T quantities still perform better for efficiencies below ~70 %, but for the looser cuts and efficiencies above 70 % the new quantities seem to perform worse. However, it needs to be remembered that we base our study on the assumption that the qrpartOF cut gives us a 'true' measure of good and bad events, but in particular for the looser cuts in qrpartOF this might not be the best assumption.

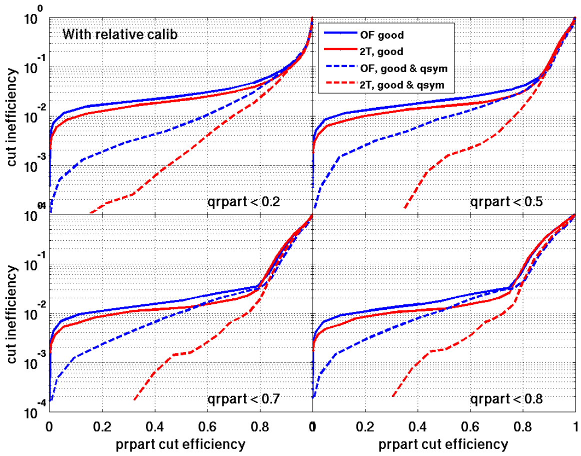

fig 9.a: Cut efficiency and inefficiency of phonon based radial cuts (new definition) when compared to charge based radial cuts.
In essentically all cases the radial quantity based on the 2T fit provides better a discrimination than the OF based quantity.

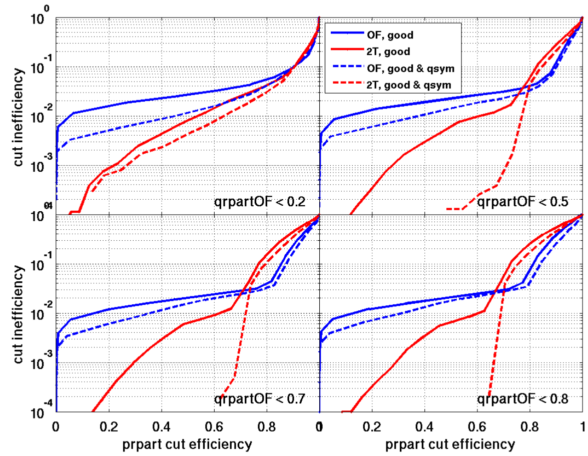

fig 9.b Same as 9.a, except with the standard definition of radial partition for OF and our adaptation for the RT amplitudes.
The conclusion here is the same as for 9.a for efficiencies below ~70 %. For higher efficiencies the OF cuts have smaller leakage - see text for more discussion.

Out of curiosity we have performed the same calculations using the positions quantities out of the box, without relative calibrations. The results are very similar.

6. Conclusion

The Two Template Fit algorithm with the template generation as implemented here leads to an improvement in energy resolution compared to the NSOF algorithm and the position information seems to have higher quality than the position information we get from the OF quantities. This together with the fact that opposed to the NSOF algorithm, the 2T algorithm does not need relative calibrations for processing (and the relative calibration can be very easily extracted from the PT amplitudes in the different channels afterwards) makes a strong case for implementing this algorithm in the next round of data processing. The algorithm is already implemented in CDMSBATS and is ready to be used after some minor adjustments.

Credits to Carlos who first wrote and implemented the code into CDMSBATS and to Oleg who helped debugging it.

Queen's Crew:
Antoine, Nikita, Kedar, Wolfgang