Crystal Tests, Joint NRL and École Polytechnique

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Bogaert and Debraine visited NRL on 6–9 December 2000 to perform joint experiments on CsI(Tl) enclosures and readouts, and to observe NRL's light tapering method.

The first aim of these experiments was to agree on appropriate gain calibration methods to ensure that both labs derive consistent and comparable numbers for scintillation light yield.

The second aim was to perform a common study of the yield obtained with various crystal wrappings or sleeve linings. We studied Tyvek, Tetratek, and 3M birefringent-polymer multilayer optical material wraps, and composite sleeve linings of the 3M material applied to the sleeve with two different methods.

The third aim was to study the effect of light tapering on the mean light yield. We measured the yield from a polished Crismatec crystal immediately before and after tapering under the same readout conditions.

Experimental setup

Ecole Polytechnique supplied one Crismatec crystal, 370 × 30 × 23 mm, with a fine polish on all surfaces, three triplets of composite crystal sleeves with various reflective linings, and a mounting structure to hold the sleeves and PIN photodiodes in place. The three sets of sleeves were lined with silver-coated Mylar, the 3M birefringent-polymer multilayer optical material applied during the sleeve layup (which we called the "3M hot" cell), and the 3M birefringent optical material applied to the sleeves with spray adhesive after they were baked (which we called the "3M cold" cell). We did not test the silver cell.

NRL supplied the data acquisition system, from analog front end to data storage and analysis, and the GLAST crystal testing station with PMT readout. NRL also supplied Tyvek and Tetratek wraps, an Amcrys H crystal 370 × 30 × 23 mm, and Hamamatsu dual PIN photodiodes. NRL cut the Amcrys crystal, ID number U-02-49, from a 400 mm crystal received on 15 April 1999, and NRL polished all six faces.

Studies of the relative light yields for wraps and composite-sleeve linings were performed using a crystal mounting structure manufactured at Ecole Polytechnique. This structure supports up to three crystals either wrapped or in a composite sleeve. A single crystal can be read out with the custom dual-PIN diode at each end. The diodes were held on a movable fixture and optically coupled to the. In all cases, the crystal end face was covered in a Tyvek window mounted nearly flush with the PIN. As the tests progressed, the windows became wet with optical grease, which certainly degraded their whiteness to some degree. We encased the crystal mount in a large chassis box and connected the 1-cm^2 PINs to eV Products 5092 preamplifiers via short, twisted pigtails. The chassis box provided optical and EMI shielding.

Optical contacts were somewhat troublesome with the composite cell structures manufactured for the test. All of the experiments listed in Table 2 – with the exception of the 3M hot cell (run th3mhot2.dat) – used solely Dow-Corning Q2 3067 optical grease. We originally avoided optical grease because of the mess of application and the need for repeated cleaning of the crystal ends. We began the experiments with Sylgard elastomeric pads ~2.5 mm thick coupling the diodes to the crystals, first completely dry, and then with optical grease. Unfortunately, the 3M hot cell run in Table 2 used the Sylgard pads and is therefore not strictly comparable with the other runs.

Studies of the light tapering were performed in NRL's GLAST Crystal Testing Station, which houses a single CsI crystal above a collimated ^{22}Na source in a lead pig. The source was translated along the length of the crystal under computer control. The crystal was read out at each end with a Hamamatsu R669 red-sensitive 2" PMT. The crystal was wrapped as desired, then mounted with its end faces in dry contact with

Sylgard elastomeric optical pads on the PMT faces. The PMT outputs were fed directly into shaping amplifiers.

The data acquisition system consisted of a Mechtronics dual shaping amplifier [CR-$(RC)^2$ shaping, 2 μs shaping time, 4.4 μs peaking time] and two Canberra 8075 ADCs with serial readout into a PC running NRL's custom Homer or Marge data logging systems in list mode. The configurations are summarized in Table 1. Although the Table lists the typical ADC LLD setting of 0.20 for the PIN tests, some runs used lower or higher discriminators. In particular, after the Crismatec crystal was exposed to bright lights during the surface sanding, we were forced to raise the discriminator to 0.30.

	Left side				Right side			
	Bias	Coarse gain	Fine gain	LLD	Bias	Coarse gain	Fine gain	LLD
PMT tests	-1200V	x10 x50	8.5	0.20	-970V	x10 x50	0.0	0.20
PIN tests	45V	x10 x10	5.0	0.20	45V	x10 x10	5.0	0.20

Table 1: Data acquisition configurations

Calibration

We investigated three methods to calibrate the electronic gain scale: we illuminated the PIN directly with an ^{241}Am source; we injected charge into a calibrated Ortec capacitor attached to the signal input on the eV 5092 preamp; and we injected charge into the test input of the preamp. The capacitor on the preamp test input is rated nominally at 1 pF, but it is not calibrated.

Photopeak interactions of the 60-keV X-ray from ^{241}Am in the Si photodiode are well resolved, and the peak is easy to fit. Since the energy to liberate an electron-hole pair in Si is 3.6 eV, the gain scale is

$$= \frac{\quad}{e\ (\quad - \quad)}$$

where = 59.5 keV, ε_{Si} = 3.6 eV/e, is the ^{241}Am peak in raw ADC bins, and is the pedestal in ADC bins. We measured the Am peak to be in bin 430 (datafile am3mhot1.dat), and the pedestal to be -90 bins; from which we conclude a gain of 31.8 e per bin. We note the caveat, as always, that Si has a much faster rise time than CsI(Tl), so this gain calibration may not be appropriate for CsI(Tl) pulses (although, see final paragraph of this section).

To measure the pedestal, we injected charge into the test capacitor with a BNC 9010 pulse generator and stepped through the range of pulse heights measured in the light yield tests below. A linear fit to the two points bracketing the range gave a pedestal of –90 bins. Directly injecting pulses into the Canberra ADCs confirms that they are rather linear and have zero intercept, i.e. zero pedestal. The offset we observed here resulted from the Mechtronics shapers. We have some concern about the stability of the pedestal with time, temperature, and noise environment. The pedestal measurement we report here was made several days after the other tests were complete.

We attached a calibrated 2 pF capacitor from Ortec to the preamp's signal input with 100Ω to ground. We injected tail pulses from a BNC 9010 pulse generator's 50Ω output (100 Hz rep rate, width 10 μs, rise time 0.05 μs, fall time 1000 μs, amplitude 100 mV, attenuation x2 x10 in), and measured 3.1 mV into 1 MΩ. This corresponds to 3.1×10^{-3} V $\times$ 2×10^{-12} F $\times$ 6.25×10^{18} e/C = 39,000 electrons. The pulser peak appeared in bin 1130 – (-90) (data file frpul3.dat), from which we derive a gain of 32.0 e per bin. This is consistent with the Am gain to better than 1%.

We injected charge into the test input of the preamp with the same pulse generator. The precise value of the hybrid test capacitor is not known, but it is nominally 1 pF. Our preamp motherboards have 50Ω to ground on the test input. With a measured amplitude of 4.6 mV teed into 1 MΩ, the pulser peak appears in bin 1235 – (-90) (data file frpul2.dat). This gives a gain of 43.7 e per bin. Changing the risetime to 2 μs has only a small effect on the derived gain, dropping the peak to bin 1170 – (-90) (data file frpul1.dat), which corresponds to 45.9 e per bin. Note that changing the pulse rise time from comparable to Si (i.e. fast) to comparable to CsI (i.e. slow) changed the calibration by only ~5%, which indicates that the very fast rise time of the Am calibration does not significantly bias the absolute light yield numbers we derive. This is also consistent with our report in "Americium calibration of electron yields in BTEM crystals", NRL SEM 2000-01, by Grove and Sandora, 14 Sep 2000.

Note that both of these values are ~3/2 of the values derived with the calibrated capacitor and the ^{241}Am source. This discrepancy is consistent with that reported in NRL SEM 2000-01. Because the calibrated capacitor and ^{241}Am methods are robust and in excellent agreement with each other, and this method relies on a nominal value for a capacitor, it seems likely that the actual value for the test input capacitance is about 1.5 pF. We conclude that calibration through the test input will not be reliable until we the test input capacitance is measured.

Absolute light yield for various crystal wrappings and sleeve linings

We measured the absolute light yield, i.e. the number of electrons collected in the 1-cm^2 PIN per MeV deposited in the crystal, for various wraps and sleeve linings. For all but one measurement, we used Bogaert's Crismatec crystal.

We illuminated the crystals with ^{228}Th gamma rays collimated to roughly the center 3 cm of the crystal. In all cases, we read out both ends with PINs. The data acquisition system logged data in list mode, which permitted us to study the log ends individually or as a coherent sum. All results reported here are for the coherent sum, which gives greater signal to noise and simplifies peak finding. We measured the location of the 2.61 MeV photopeak or shoulder in the sum of the PINs by eye. We estimate that the uncertainty in locating the peak was a few percent or less.

Wrap or lining	Data file	2.6 MeV peak	Yield (e/MeV)
3M loosely wrapped	th3mw1.dat	435	5300
Tetratek + adhesive aluminized Mylar	thtt1.dat	380	4630
3M cold	Th3mco2.dat	345	4200
3M hot	Th3mhot2.dat	320	3900
Tyvek	thtyvek1.dat	290	3530
3M loosely wrapped, after light tapering	Th3msw2.dat	420	5120

Table 2: Light yields for the Crismatec crystal with various wraps or sleeve linings. The location of the 2.6 MeV peak is the average of the two ends, and it includes the –90 bin pedestal. The yield is derived by scaling the peak location by (31.8 e/bin / 2.61 MeV). Unlike all other runs in this table, the 3M hot cell run used Sylgard optical pads rather than solely grease, and therefore the light yield may not be strictly comparable to the other runs. In the same cell, the Amcrys H crystal gave 4700 e/MeV, but we did not run that crystal in any of the other configurations. See text.

In Figure 1, the pedestal of –90 bins has been subtracted from each spectrum, i.e. each spectrum is shifted 90 bins to the right from its raw value. Apart from the Tyvek run, each spectrum clearly shows the 2.61 MeV photopeak and the first and second escape peaks. Each histogram contains 500k events, but the higher discriminator thresholds in the tapered run (data file th3msw2.dat) and the cold cell run (data file th3mco2.dat) result in more counts in the photopeak and escape peaks.

The worst-performing material was the Tyvek + aluminum foil wrap supplied by Amcrys H. It showed about 25% less light (3530 e/MeV) than the Tetratek + adhesive aluminized Mylar wrap we used for the BTEM99 calorimeter crystals – precisely the value we'd observed in comparisons of the wraps in Summer 1999, prior to our assembly of the BTEM99 crystal modules.

The 3M hot cell gave approximately 10% more light (3900 e/MeV) than the Tyvek. The hot cell did not show the specular reflection characteristic of the bare 3M material, and scattered light observed down the length of the cell seemed to be less intense than down the cold cell. The weave of the composite material was clearly visible, formed into the surface of the 3M material. We also note that – alone among the tests listed here – this run used Sylgard elastomeric pads for optical coupling. We have not yet studied the effect on the total light yield of the presence of the ~0.25 mm pads, and we cannot judge whether the 3900 e/MeV measured here is thereby artificially reduced. However, we note that the response from the ends is equal, which indicates that the optical bond quality is equal on the two ends, and therefore likely good on both ends.

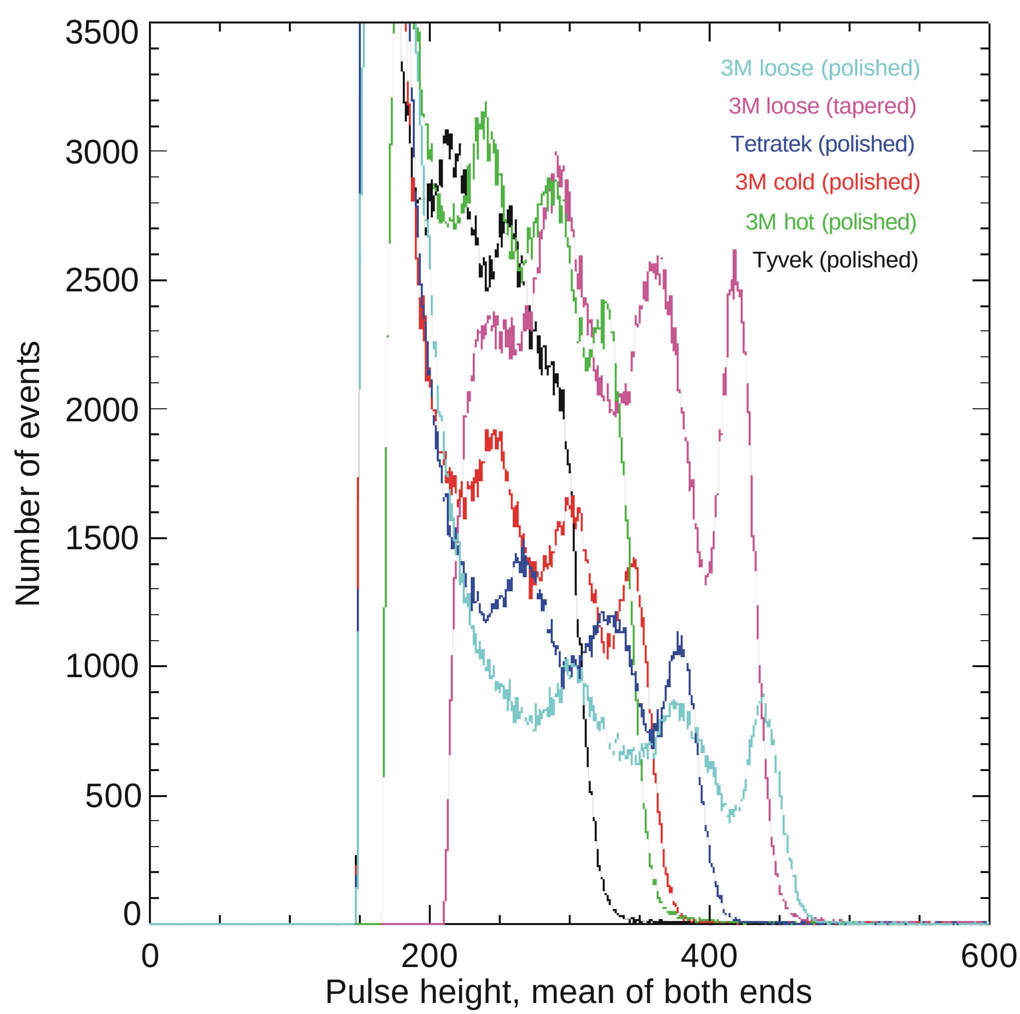


Figure 1: Spectra of ^{228}Th in the Crismatec crystal for various wraps or sleeve linings. The 2.61 MeV photopeak and first and second escape peaks are visible. Entries in the legend are ordered by increasing photopeak, from bottom to top.

The 3M cold cell gave ~10% more light (4200 e/MeV) than the 3M hot cell, which perhaps is consistent with its apparent greater brightness in scattered light. We note also that the spray adhesive used to attach the 3M material to the composite cell wall moved the reflective surface into closer contact with the crystal sides than in the 3M hot cell.

The Tetratek + adhesive aluminized Mylar wrapping performed 10% better still, giving 4630 e/MeV, which is fairly consistent with the value we typically observed (~4000 e/MeV) in the $310 \times 30 \times 23$ mm Crismatec and Amcrys H crystals of the BTEM99 calorimeter in the same wrapping after 10 months under pressure ("Americium calibration of electron yields in BTEM crystals", NRL SEM 2000-01, by Grove and Sandora, 14 Sep 2000). We note that the Tetratek wrap we applied for these tests differed from that applied to the BTEM crystals in that it did not cover the end faces, which instead we left bare to be covered with Tyvek windows around the PINs, and that the whiteness of the end face is important in determining the total light yield.

The best-performing wrap was the 3M birefringent material loosely wrapped around the crystal, yielding ~25% more light (5300 e/MeV) than the Tetratek wrap. It is not clear why this loose wrapping was decidedly superior to the 3M cold cell. Indeed we applied this wrap quite loosely, without creasing the material at the edges of the crystal. The material was free to separate from the long crystal surfaces by up to a few millimeters.

We conclude that the 3M birefringent material gives excellent light yield, but that it suffers some degradation during its application to the composite cell. It certainly merits further study, either as a crystal wrap or a sleeve liner.

We made a single measurement of the light yield from the Amcrys H crystal U-02-49 in the 3M hot cell (run th3mhoa1.dat). See Table 3. The measured light yield was 4700 e/MeV, which is substantially higher than that observed with the Crismatec crystal in the same cell (3900 e/MeV). It is not clear why the Amcrys crystal gave significantly more light. It may be that this crystal is intrinsically brighter than the Crismatec crystal. This run used optical grease rather than the Sylgard pads that the Crismatec run used, but it also differed from the other runs with grease in that an additional spacer between the diode and the diode mounting fixture pressed the diode into closer contact with the crystal face.

Wrap or lining	Data file	2.6 MeV peak	Yield (e/MeV)
3M hot	Th3mhoa1.dat	385	4700

Table 3: Light yield from the Amcrys H crystal in the sole configuration we ran. The location of the 2.6 MeV peak is the average of the two ends, and it includes the –90 bin pedestal. The yield is derived by scaling the peak location by (31.8 e/bin / 2.61 MeV).

It was not possible to insert the Amcrys crystal in the 3M cold cell because of the thickness of the adhesive used to hold the 3M material in place.

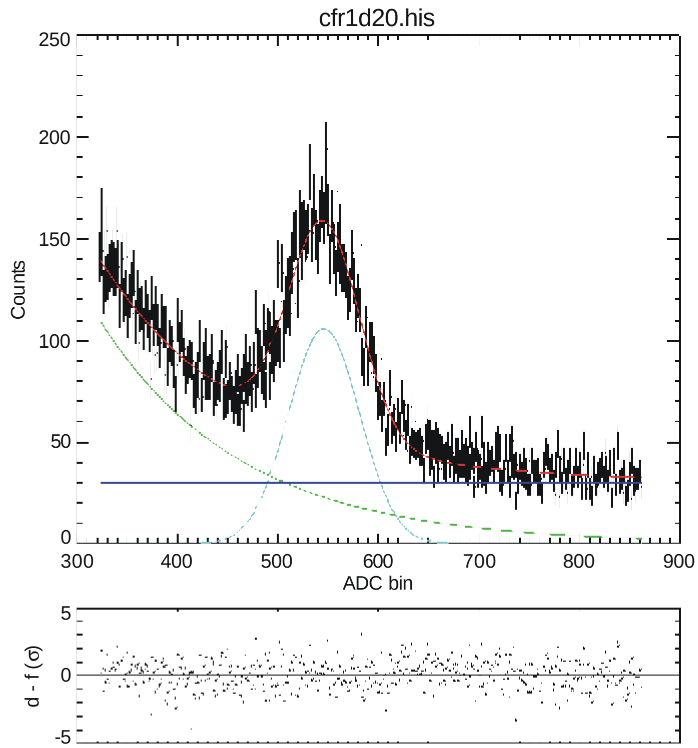
Insertion and removal of crystals from composite cells

Prior to shipment to NRL, the Crismatec crystal had been inserted at Polytechnique using Mylar sleeves to protect the crystal faces during the insertion procedure. During travel to NRL the crystal was kept in the cell. After the first measurement, we removed the crystal, inspected its surfaces, and found slight damage to a few square cm of once side of the crystal near its end. The damage likely occurred during the removal process.

Indeed we had some difficulty inserting the Crismatec crystal into the composite cells. We twice inserted and removed crystal from the 3M or silver cell using the rubber-band corner spacers, and both times scratched the long surfaces of the crystal. We then decided to use ½ mil Mylar sleeves to protect the crystal during insertion, and we pulled the sleeves out after the crystal was fully inserted. We have no clear evidence for further damage to crystals or cell lining when the sleeves were used.

Light tapering

In a previous memo, Grove had demonstrated that tapering the light along the length of a crystal does not substantially change the mean light yield ("Effect of Light Tapering on Light Yield", NRL SEM 2000-02, by J. Eric Grove, 20 Oct 2000). Because of the typical lag of several weeks between untapered and tapered light yield measurements used in that memo, it was possible – although Grove asserted unlikely – that gain drifts in the crystal testing station could have masked a change in the light yield. We repeated the untapered and tapered light yield measurements here with Bogaert's Crismatec crystal, and we confirmed that the mean yield was unchanged by tapering.

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 2      83.7358      1.7715                              BOUND  FWHM
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   Exponential Function
 1     109.6250      1.9082                              BOUND  Amplitude
 2     142.2932      7.7667                              FREE   E-folding Length
 3     323.0000                                          FIXED  Normalizing Chan
   Constant Function
 1      30.0223      0.9741                              SIGN+  Constant
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Figure 2: Sample fit of 511 keV line from ^{22}Na in Crystal Testing Station.

We measured the relative light yield as a function of position along the length of the crystal in the Crystal Testing Station. We scanned a ^{22}Na source along the crystal, accumulating for 300 sec at each of 12 locations (or 500 sec at each of 4 locations). We fit the 511 keV line with a gaussian + exponential + constant model, using the standard IDL analysis package we developed for the BTEM crystals (fit_pm2.pro). Figure 2 shows a sample fit to the spectrum from a single PMT. The top panel shows the count spectrum and its statistical uncertainties along with the best-fit model (red curve), which is comprised of a gaussian (cyan), an exponential (green), and a constant (dark blue). The middle panel shows the deviation from the best fit, bin by bin, in units of rms. The bottom panel shows the reduced chi-squared, the best-fit model parameters, and their uncertainties (68%).

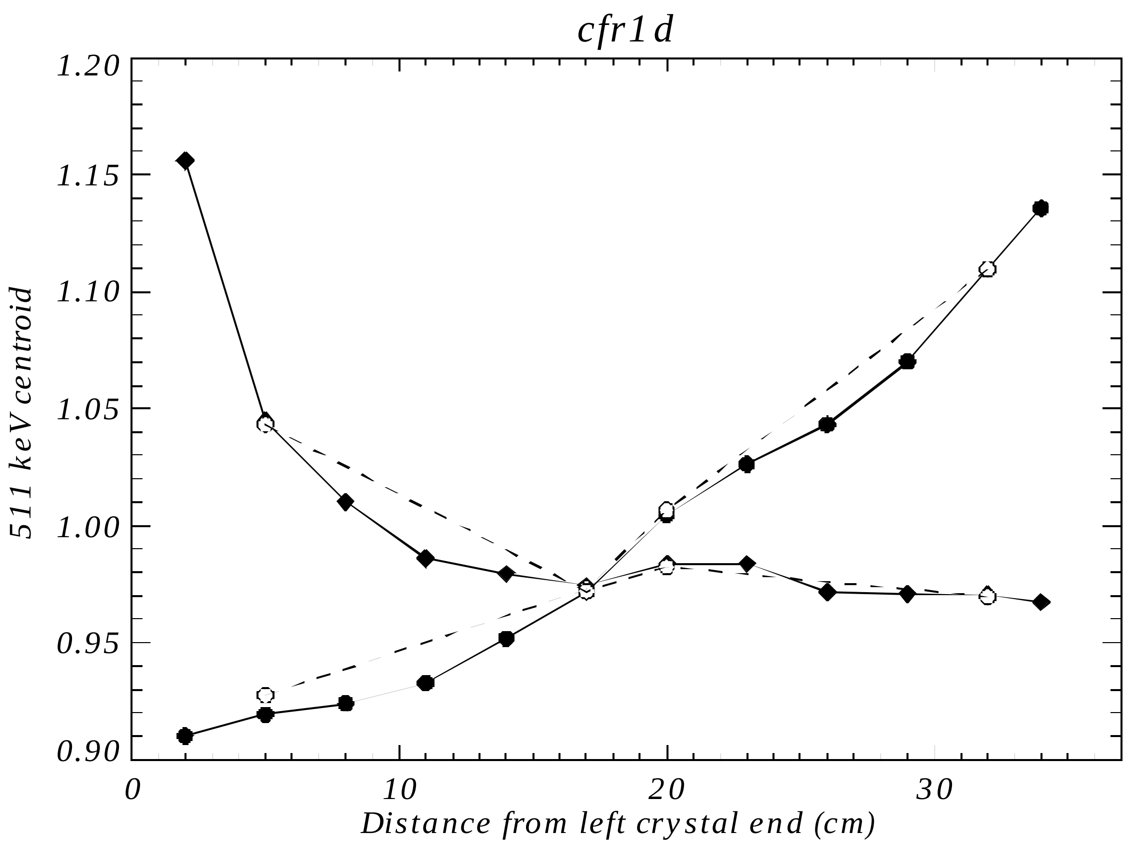

Figure 3: Relative light yield along the polished Crismatec crystal. Filled diamonds are light yield measured by left-hand PMT. Filled circles are light yield measured by right-hand PMT. Open circles connected by dotted lines are from a previous measurement at fewer positions but higher statistics.

First we measured the light yield as a function of position in the Crismatec crystal with all polished surfaces. The crystal was wrapped in Tyvek and aluminum foil. Figure 3 shows the results of two scans of this crystal. The filled diamonds and filled circles are the relative light yield measured by the left-hand and right-hand (respectively) PMTs (data file cfr1d.his). Each curve is normalized to the mean value of the light yield for that PMT. The open circles connected by dotted lines are from a previous measurement at fewer positions but with longer integration times (data file cfr1c.his). The excellent agreement between open and filled points demonstrates the reproducibility of the measurement technique.

We note that the left-hand PMT shows a sharp drop in response in the first ~6 cm, but then a reasonably constant response beyond. In contrast, the right-hand PMT shows a small but constant tapering along its entire length. After these tests, we removed the crystal from its Tyvek wrap and found small smudges on the crystal surface, and linear marks likely coming from its removal from the carbon cell, near its end. Whether or how these smudges and imperfections could cause the response shown in Figure 3 is not clear. We are forced to conclude that crystals must be handled carefully at all times to prevent any damage to the surfaces, and that even crystals that are ostensibly polished on all surfaces for uniform light collection indeed can and do have position-dependent light collection and must be mapped. This last conclusion is not new: we at NRL had observed typically ~5% gradients from end to end in the 310 mm BTEM crystals from Amcrys that were polished for uniform response.

Some of the 310 mm BTEM crystals showed some asymmetry in light tapering, but none were as severe as this Crismatec crystal. Inspection of the light-tapering maps in NRL's GLAST lab notebooks #4 and #5 shows that a number of the crystals had reasonably linear tapering viewed from one end, but from the opposite end, linear tapering that flattened out near the PMT face. This deviation from linearity has the same form as we observed in the Crismatec crystal, i.e. a rise in light collection near the PMT face.

Phlips then sanded the two 370 × 23 mm surfaces with 400-grit paper and 100% ethanol, using the same technique he applied to the Amcrys H crystals for the BTEM calorimeter. The goal was to achieve nearly linear tapering of roughly a factor of two from end to end.

We measured the light yield as a function of position in the Crismatec crystal after the sanding. The crystal was loosely wrapped in the 3M birefringent polymer material. Figure 4 shows the light attenuation created by the sanding. The filled diamonds and filled circles are the relative light yield measured by the left-hand and right-hand (respectively) PMTs (data file cfr3ms.his). Each curve is normalized to the mean value of the light yield for that PMT. We find that indeed we have achieved nearly linear tapering of the desired magnitude, and that the asymmetry in the light collection is gone, perhaps because the surface flaws that created the asymmetry were removed by sanding.

We also returned the crystal in its loose 3M material wrap to Polytechnique's crystal mount with diode readout and collected a ^{228}Th spectrum. The photopeak appeared in bin 410 (including the –90 bin pedestal), which corresponds to 5100 e/MeV. Comparison with the light yield from the polished crystal in the loose 3M wrap (Table 2, 5300 e/MeV) shows that after tapering the mean light yield declined by ~3%, which is close to the measurement error and likely results from small differences in the quality of the optical contact with the diodes. Thus,

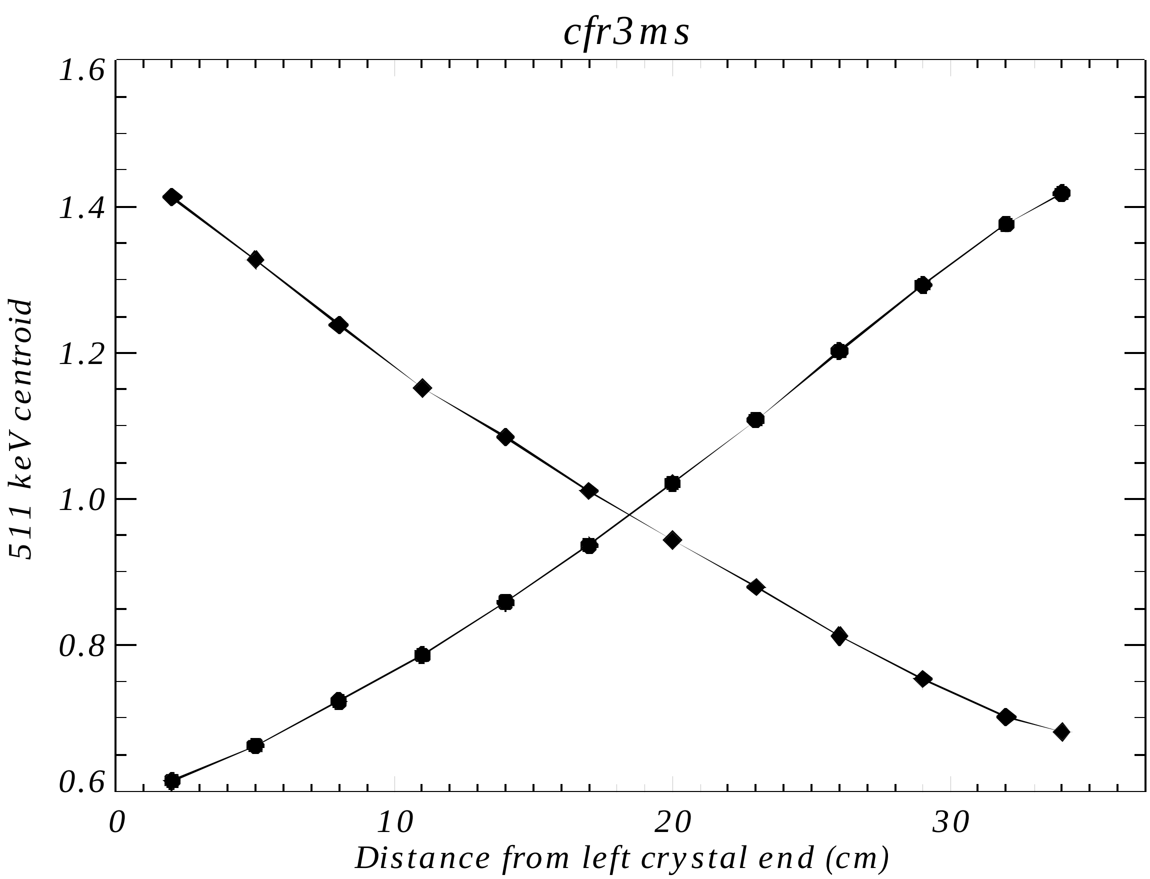

Figure 4: Relative light yield along Crismatec crystal after sanding. Curves are normalized to mean response for each end. Note that taper is smooth.

Conclusions

The electronics for light yield measurements must be calibrated using a well-known external capacitance or a quantized physical process (as is the case for the ^{241}Am method). This eliminates a potential source of large systematic errors.

Both NRL and Polytechnique obtain similar results for the light yield provided these calibration methods are used.

The 3M birefringent material gives excellent light yield, but it suffers some degradation during its application to the composite cell. It certainly merits further study, either as a crystal wrap or a sleeve liner. The Tetratek + adhesive aluminized Mylar wrap gives superior light yield to the 3M material when the latter is applied to the composite cells.

Even crystals that ostensibly have polished surfaces can show variations in light yield along their length and must be mapped. NRL had measured typically 5% gradients in response in the Amcrys 310 mm crystals for the BTEM calorimeter. The effect might even be greater for well-polished crystals with minor damage to their surfaces: The Crismatec crystal used here had suffered some minor scratches on its long surfaces, likely from repeated insertion into the composite cells. All crystals must be mapped.

Tapering the crystals can smooth the position response and simplify the mapping and modeling of the position dependence of light yield.

We confirm that, as reported in NRL SEM 2000-02, tapering the light yield by sanding the crystal surfaces does not change the mean light yield.

NRL and Polytechnique share a concern about crystal optical damage during insertion and removal from optical cells. The procedure warrants further study, and/or the crystal sizes and tolerances need to be reviewed.