Americium calibration of electron yield in BTEM crystals

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We have measured the electron yield (i.e. the number of electrons in the Si photodiodes per MeV deposited energy) in several Crismatec and Amcrys H 310mm crystals using the custom Hamamatsu dual-PIN diode by illuminating the PIN with ^{241}Am. For a subset of these crystals, we also compared with the calibration derived from charge injected into the test input of lab preamps. **The typical yield in BTEM crystals (after 10 months under pressure) is ~4000 e/MeV** when measured by ^{241}Am.

We studied a total of 30 crystal ends: 18 from the BTEM, 10 from five spare 310mm crystals that the logbook suggested had at least one good diode bond, and two from a spare Amcrys H bar still in its factory Tyvek wrap with no diodes attached. We attached diodes to this last bar with optical grease. To make the comparison of BTEM and spare crystals valid, we used the BTEM wrapping method on the spare crystals, namely two layers of 10-mil Tetratek and one layer of adhesive aluminized Mylar. We mounted the spare crystals in the GSI test box and read out both PINs on both ends with eV5093 preamps. The CAEN amps were set to shape time 3, which apparently is 6 μs peaking time.

In the BTEM, we illuminated the large PINs of adjacent pairs of logs with ^{241}Am, enabled triggers on only those log ends, and set the DLEX4 discriminator as close to pedestal as we could. By limiting the trigger to the two log ends under study, we were able to see both the 60 keV line and pedestals simultaneously in all cases with good efficiency, as well as occasionally a portion of the complex of lines below ~20 keV. In the test box, we illuminated the large and small PINs of a single crystal at a time and triggered on the OR of the PINs. Again, this gave us contemporaneous measurements of pedestal, 60 keV, and sub-20 keV complex (this last was visible because of the lower noise in the test box eV preamps). Figure 1 shows the ^{241}Am spectrum in a large and small PIN in the text box.

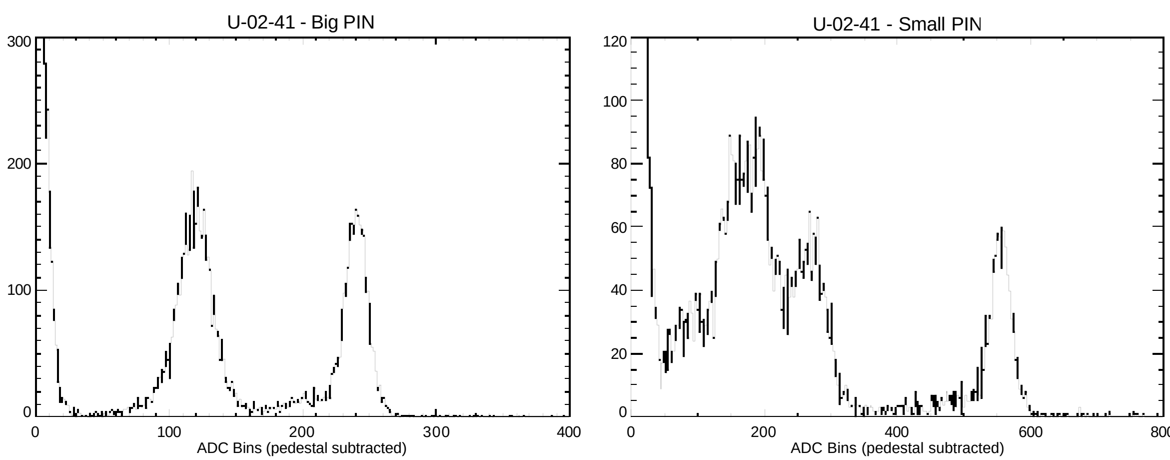

Figure 1: Am spectrum in large and small PIN photodiodes in test box. Pedestals have been subtracted. Preamp is eV 5093 in both cases. Small PIN shaping-amp gain is double that of large PIN.

We collected muon data in the BTEM calorimeter, logging data with the CalGSE. We measured pedestals and fit muon peaks derived by selecting muons that struck near the center of each crystal being studied, passing through the top and bottom faces of the crystal. Muons were required to give a large signal in the two crystals above and two crystals below the center of the crystal being studied, and they were required to miss the crystals on either side of the crystal being studied. We fit the muon peak with a simple analytic model approximating a Landau distribution. The mode of the muon distribution should be approximately the most-probable energy loss. We assumed that the typical muon angle of incidence was 20 deg and that the muon energy was minimum-ionizing (1.25 MeV/g in CsI). This gave a typical muon energy deposition of 13 MeV.

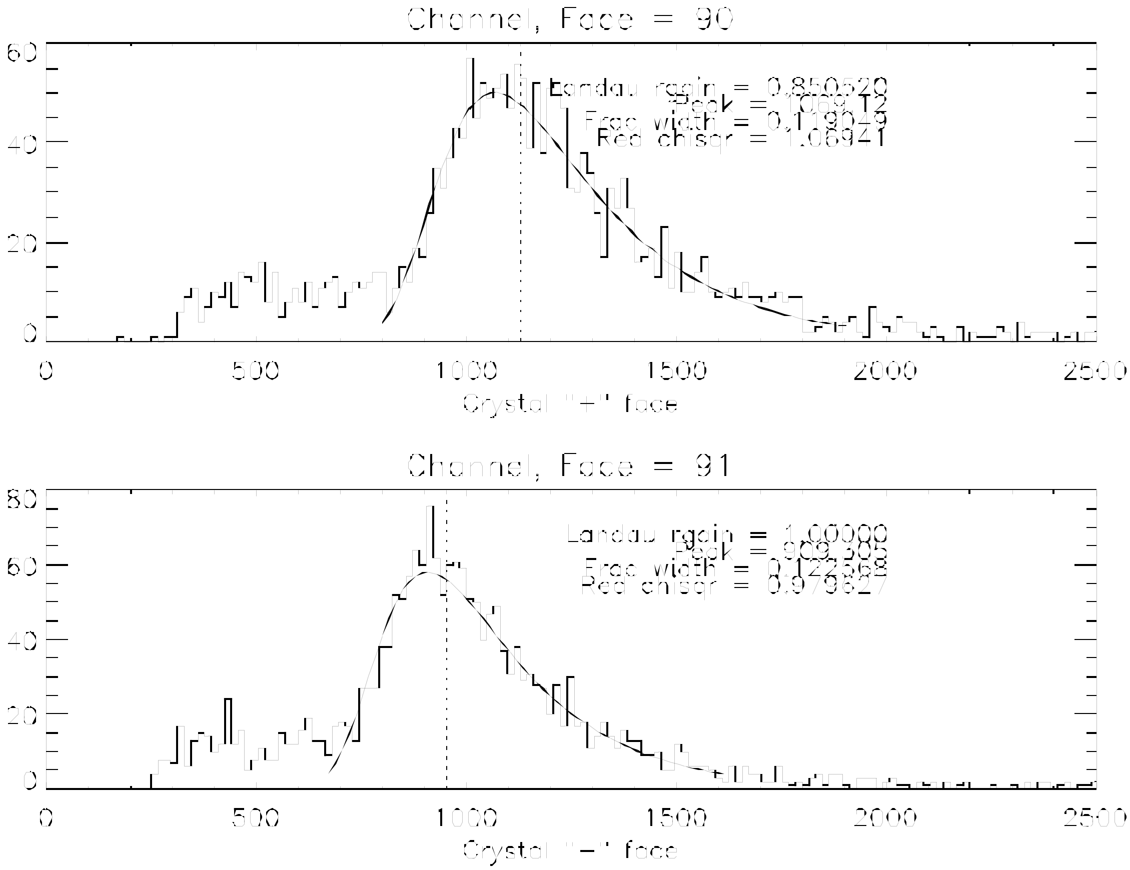

Figure 2: Muon spectra from large PINs on Amcrys crystal U-02-41 in test box. Crystal shown was on edge of array in test box, so only half of the side-escaping muons could be rejected.

We followed a similar procedure for muons in the spare logs in the GSI test box, but we used the 370mm GSI logs to define the geometry.

The BTEM electronics are significantly non-linear near pedestal, so we used the quadratic-quadratic model of the charge-injection calibration of 15 August to correct for this non-linearity. Muon data were also taken on 15 August, but the Americium data were collected on 30-31 August. The electron yields using the non-linearity corrections are generally 5–10% lower than the yields we calculate ignoring the non-linearity. I'll guess without proof that the residual uncertainty in the corrections is ~5%.

We calculated the electron yields from the following expression. We took the line energy to be 60 keV and the energy to liberate an electron-hole pair to be 3.6 eV. The electron yield Y is given by

$$Y = \frac{Q_{Am} / S_{Am}}{\Delta E_m / S_m}$$

where Q_{Am} = 60 keV / 3.6 eV/e = 16700 e is the charge created in the PIN, S_{Am} is the ^{241}Am peak, DE_m = 13 MeV is the typical muon energy deposit, and S_m is the muon peak. In the test box, S_{Am} and S_m are pedestal-subtracted ADC bins, but in the BTEM, they are corrected by the quadratic-quadratic model.

The electron yield for the 30 log ends in the BTEM and spare crystals is shown in Figure 3 and Table 1. **The typical yield is ~4000 e/MeV**, somewhat higher than the ~3100 e/MeV we measured with test charge-injection in a sample of crystals prior to stacking (JEG memo, NRL SEM1999-01). There is no obvious systematic difference between Crismatec and Amcrys H crystals. We also note that several log ends had substantially lower-than-average yield: These crystals (i.e. those from BTEM) all showed evidence of degraded optical bond in muon calibrations following the SLAC 99 beam test.

Yields for the four small PINs we tested are also listed in Table 1. They average ~1400 e/MeV. As expected, the yield scales by the area of the diodes.

Note that because of the extremely fast rise time of Si, *the ^{241}Am calibration may not be a more correct absolute calibration than the test charge-injection method*; however it is a simple test to perform under identical circumstances in NRL and France.

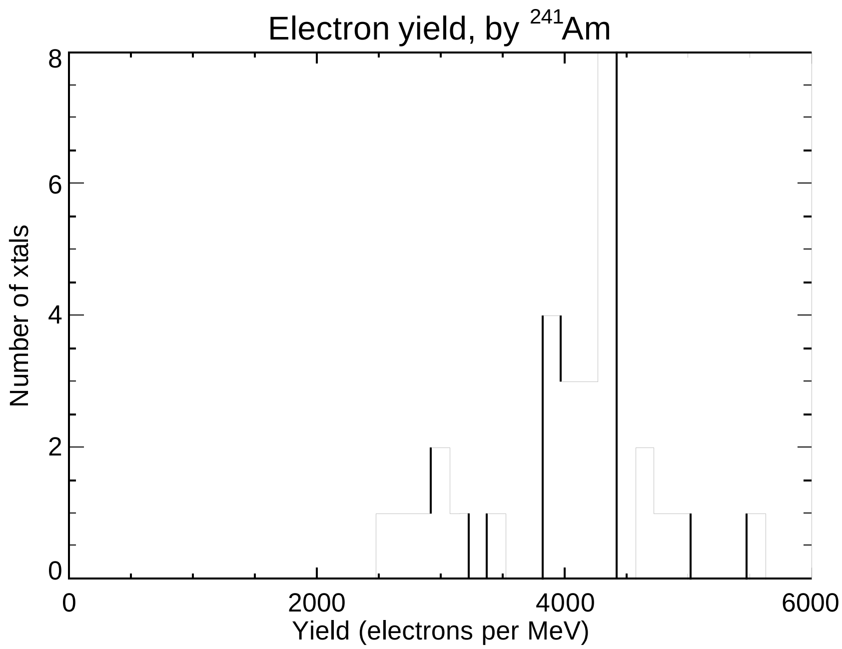

Figure 3: Electron yields (e per MeV deposited) in BTEM and spare crystals as estimated by Am calibration.

We calibrated preamp + shaper + ADC channels in the test box by injecting a known charge at three levels at the preamp test input (1 pF). We used 2, 4.2, and 8.0 mV tail pulses from a BNC 9010 pulser (2 μs rise, 10 μs width, 1000 μs decay times injected give an output pulse that has a similar shape to the muon pulse). Changing the rise time of the pulse to 0.2 μs changes the output by ~10% or less; thus our answer should be relatively independent of our choice of shape for the injected pulse. The following IDL code is an example of how we calculated the electron yield.

```
ped = [90,88,95,92]                  ; pedestal
pul = [698,678,820,772]              ; = 4.2 mV pulser peak
voltage = replicate(0.0042,n_elements(pul))
chg = voltage * 1e-12/1.6e-19        ; charge at preamp test input
e_per_chan = chg / (pul-ped)         ; electrons per ADC bin
dE = replicate(1.25*2.3*4.51 / cos(20/!radeg),4)  ; mu energy dep
muon = [881.7,1070.8,899.5,908.4]    ; ped-subtracted muon peak
Mev_per_chan = dE / muon             ; MeV per ADC bin
yield = e_per_chan / Mev_per_chan
print,yield
;  2758.79      3452.69      2360.28      2541.38
```

In Table 1 we find that the electron yield in the small PIN is ~¼ of that in the large PIN (as we expect), and that the mean yield in the large PIN (~2800 e/MeV) is similar to the ~3100 e/MeV we found in a sample of bars prior to stacking. But we also note that the yield determined by pulser is ~60% of the yield determined by ^{241}Am. In comparisons of previous NRL pulser calibrations to current French Am calibrations of CsI test cells, we should therefore scale the NRL pulser results upward by a factor of 1/0.6 = 1.6. The detailed origin of this discrepancy in calibrations is not obvious to us, but perhaps it does lie in the extremely short rise time of the Am signal in the Si PIN.

Appendix 1: Summary of Electron Yields

Table 1: Electron yields (e per MeV deposited) in BTEM and spare 310 mm crystals in large and small PIN diode. Crystals are sorted by layer in BTEM, followed by spare crystals in test box. We calibrated the small PIN and did pulser calibrations only on the spare crystals.

Crystal ID	Layer	Column	Face	PIN	Yield (by ^{241}Am) [e/MeV]	Yield (by pulser) [e/MeV]
C-03-32	2	4	+X	Big	4370	n/a
C-03-33	2	5	+X	Big	3220	n/a
C-03-34	2	6	+X	Big	4660	n/a
C-03-35	2	7	+X	Big	4490	n/a
C-03-20	3	3	–Y	Big	3980	n/a
C-03-21	3	4	–Y	Big	3980	n/a
C-03-22	3	5	–Y	Big	4370	n/a
C-03-23	3	6	–Y	Big	4090	n/a
U-02-12	4	2	+X	Big	3580	n/a
U-02-13	4	3	+X	Big	2680	n/a
U-02-15	4	4	+X	Big	3910	n/a
U-02-17	4	5	+X	Big	3060	n/a
U-02-20	4	6	+X	Big	3020	n/a
U-02-22	4	7	+X	Big	3950	n/a
U-01-04	5	4	–Y	Big	2740	n/a
U-02-01	5	5	–Y	Big	4160	n/a
U-02-02	5	6	–Y	Big	4870	n/a
U-02-03	5	7	–Y	Big	4400	n/a
C-02-04	-	-	Ukr label	Big	4410	n/a
C-02-04	-	-	NRL label	Big	4690	n/a
U-02-18	-	-	Ukr label	Big	4140	n/a
U-02-18	-	-	NRL label	Big	4300	n/a
U-02-41	-	-	Ukr label	Big	5580	3450
U-02-41	-	-	NRL label	Big	4480	2540
U-02-41	-	-	Ukr label	Small	1400	n/a
U-02-41	-	-	NRL label	Small	1240	680
U-02-42	-	-	Ukr label	Big	4280	n/a
U-02-42	-	-	NRL label	Big	4260	n/a
U-02-43	-	-	Ukr label	Big	2930	n/a
U-02-43	-	-	NRL label	Big	4950	n/a
U-02-46	-	-	NRL label	Big[1]	4490	2760
U-02-46	-	-	Ukr label	Big[1]	4360	2360
U-02-46	-	-	NRL label	Small[1]	1160	n/a

[1] Diode attached with optical grease, and crystal wrapped in Tyvek. Wrap reduces light yield by ~20%.

U-02-46	-	-	Ukr label	Small[1]	1120	690