

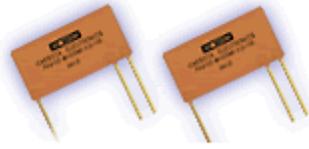
Power Supply Control Diagram

Technique

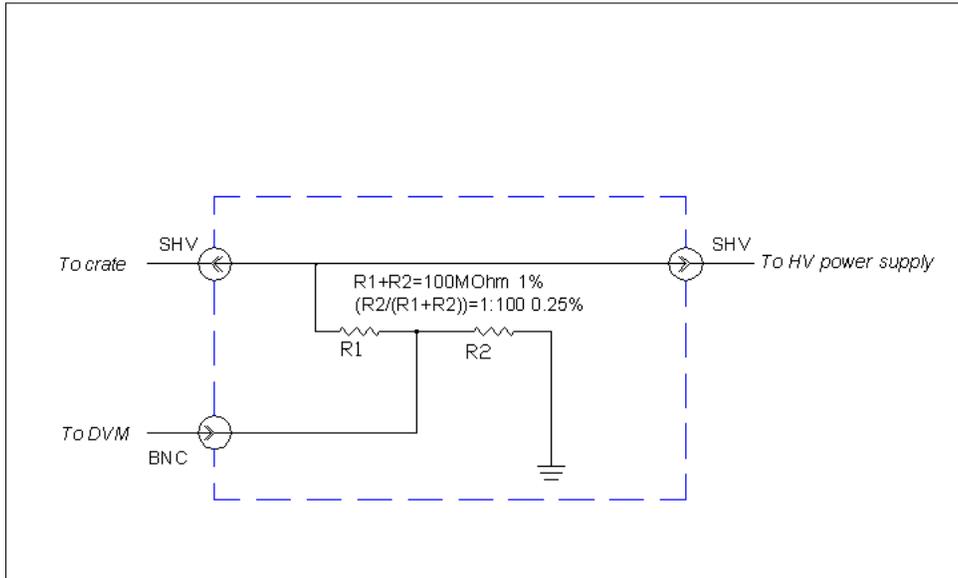
For these measurements type THV Precision High Voltage Divider Networks from CADDOCK ELECTRONICS - THV10-B-100M-1.0-25 were used. Type THV networks provide tight ratio temperature coefficients and tight ratio tolerances:

- Ratio Temperature Coefficients of 25 ppm/°C from -55°C to +125°C.
- Ratio Tolerances of ±1.0% at Rated Voltage.
- Voltage Ratings of 10 KVDC at +125°C.
- Voltage Division Ratio 100:1.

The previous value used to originally calibrate HV power supplies was 1000:1. However, a lower ratio of 100:1 was chosen in order to use a better dynamic range of the multimeter. So far only three of this devices were purchased

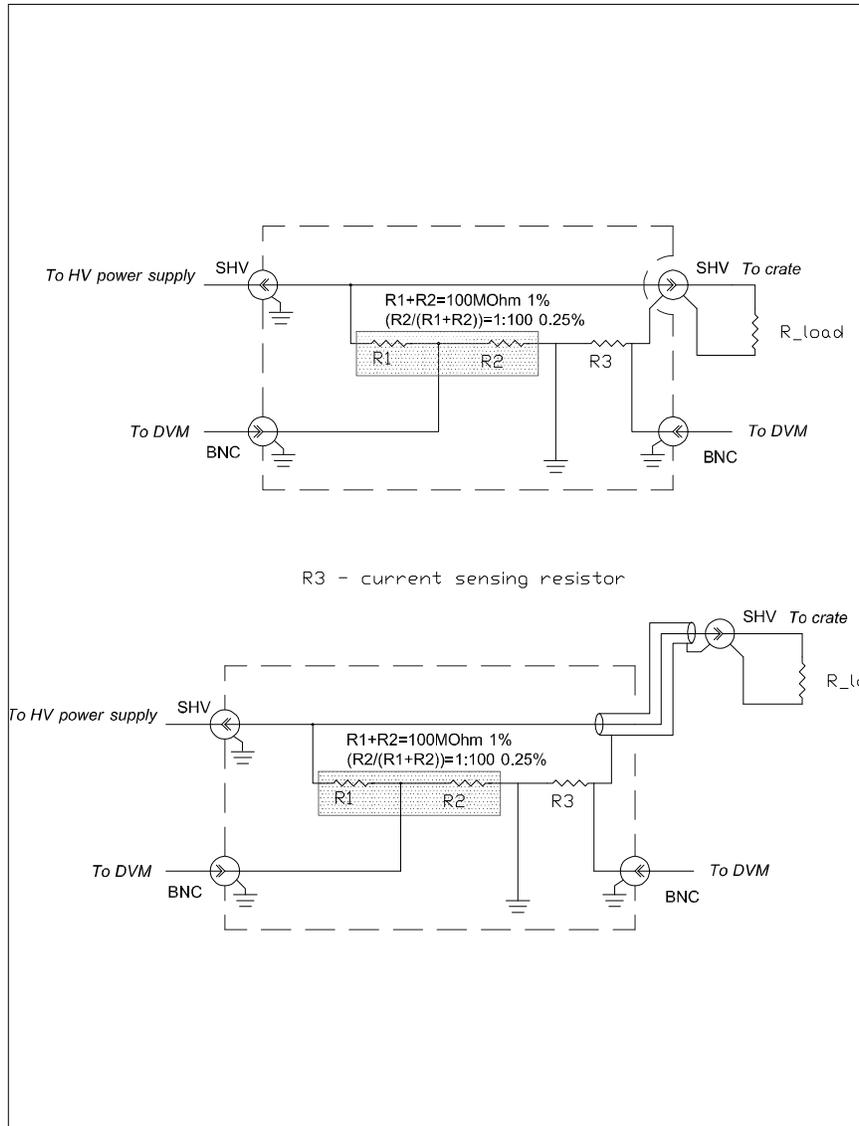


to make a high voltage divider box with the output for DVM as shown on the picture below.



Block-diagram of the high voltage divider box.

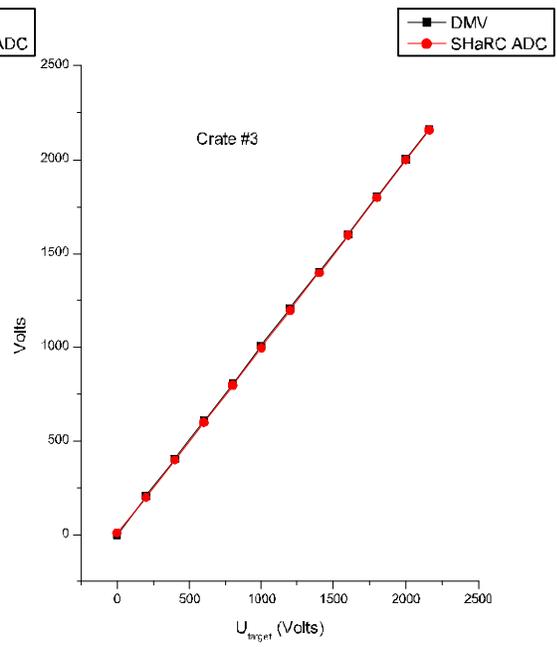
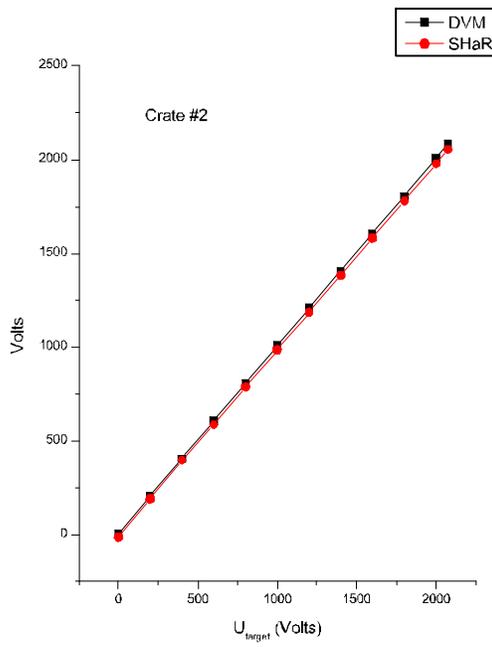
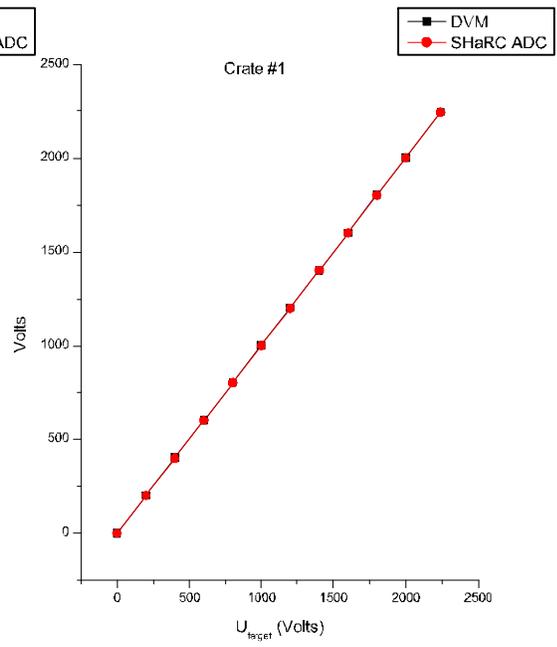
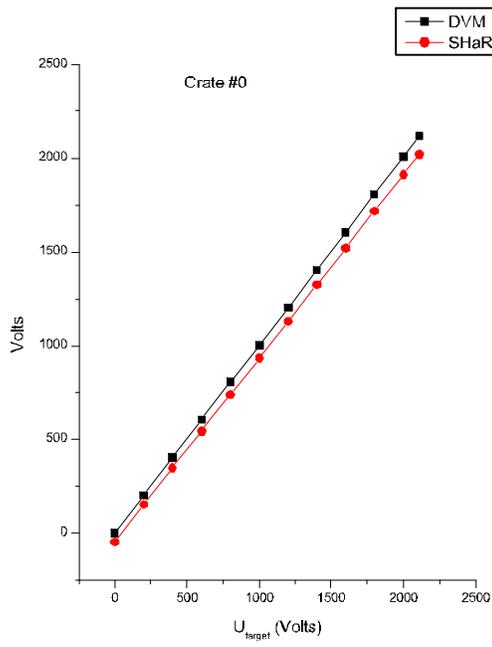
Future modification of this box must include a current sensor. In order to implement a current sensing resistor into the HV divider box, a grounding path for the SHV connector (to crate) has to be changed. It is quite a serious safety issue, which has to be addressed before making these changes. In the next diagram the top version shows the SHV connector to the crate used in the box. An alternative solution (bottom version) is to use an HV cable with a female SHV connector on the far end. In this case HV cable is permanently attached inside the box making ground connection safer.



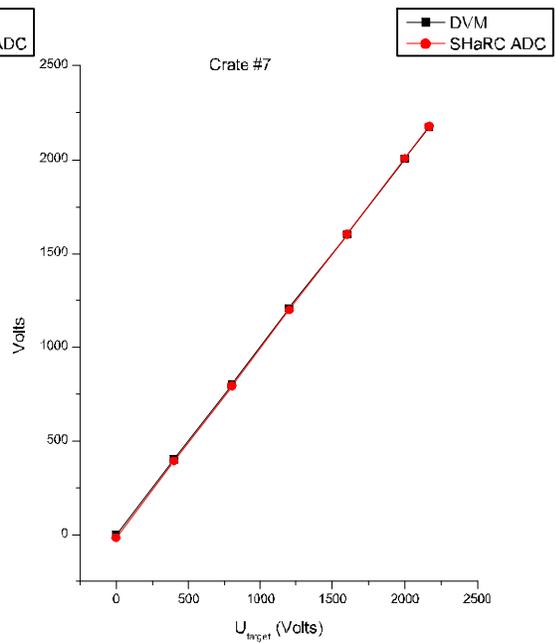
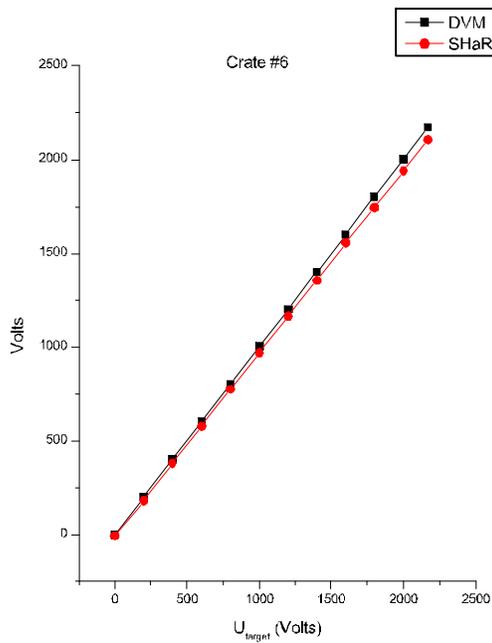
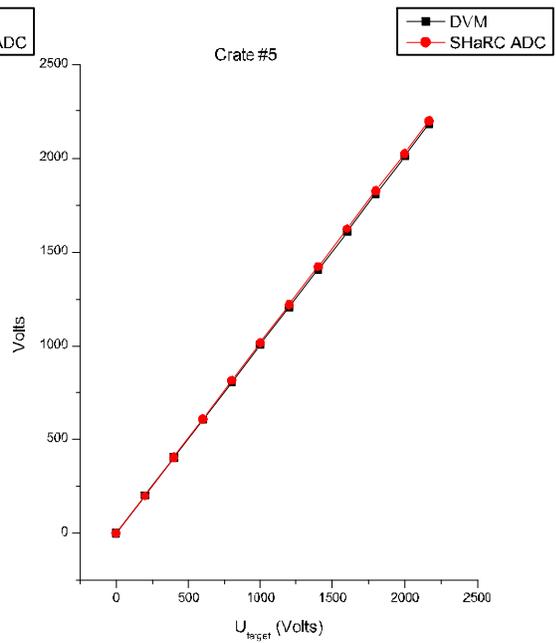
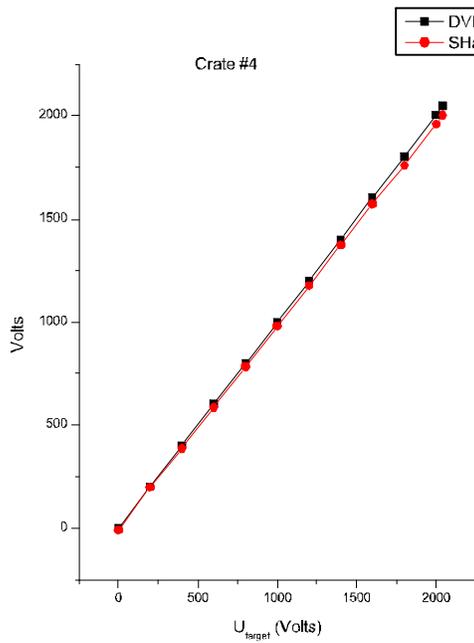
Possible implementation of current measurement.

Results of the measurements

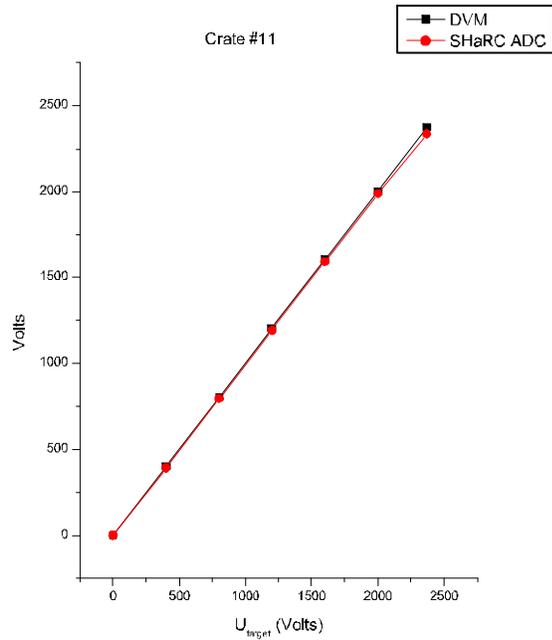
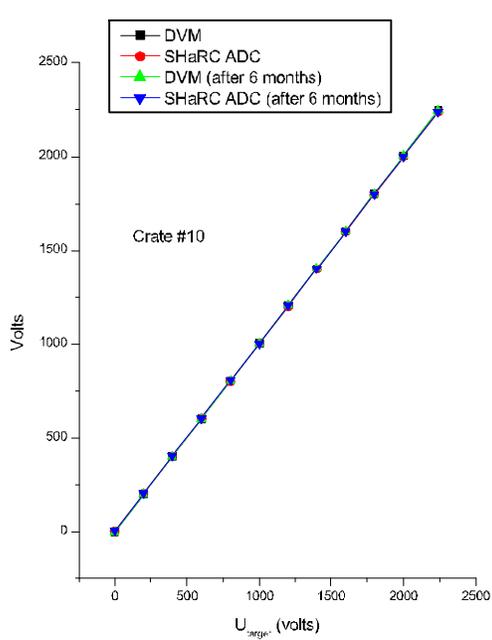
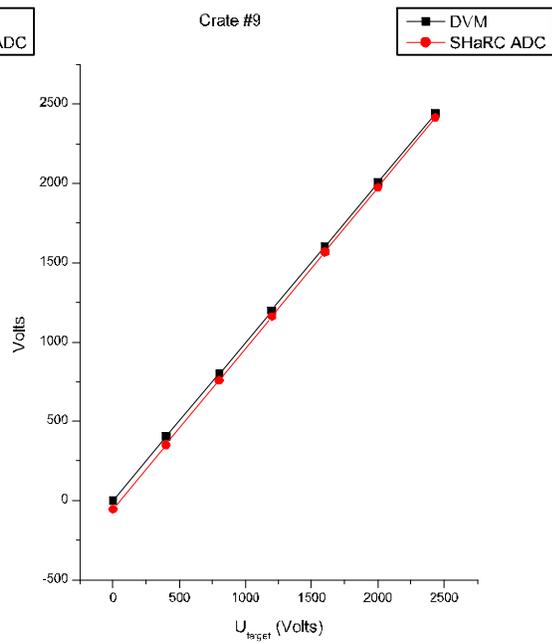
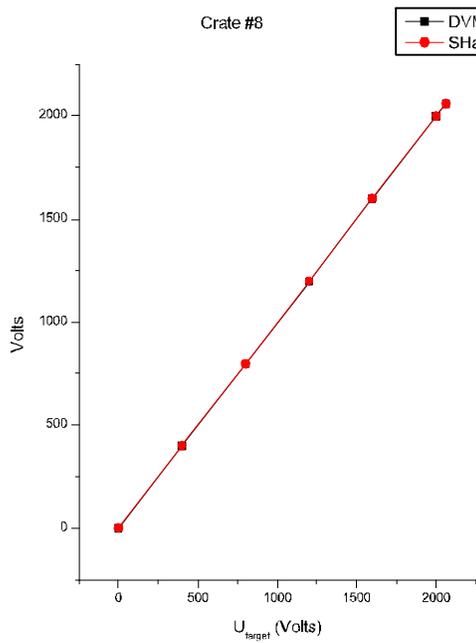
Data logging procedure and subsequent analysis are described in full detail in the Appendix using example for crate #0. Only final results are presented here. The following sets of graphs are combined in three sections containing 20 graphs each (19 power supplies for all 19 crates and one OWL power supply). In some cases additional sets of measurements have been performed. These additional studies are related to possible load dependency of the high voltage output. For this purpose several crates were tested with only one slot on-line. The first set of 20 graphs presents the comparison of the DVM and SHaRC measurements with target voltage. In every case the target voltage was ramped from zero to the final target value. At the beginning a 200 volt step for ramping was chosen. About half of the power supplies were tested using this step. This step value was later changed to 400 volts in order to make this calibration faster. One special case is presented for crate #10, where two full sets of measurements have been taken five months apart.



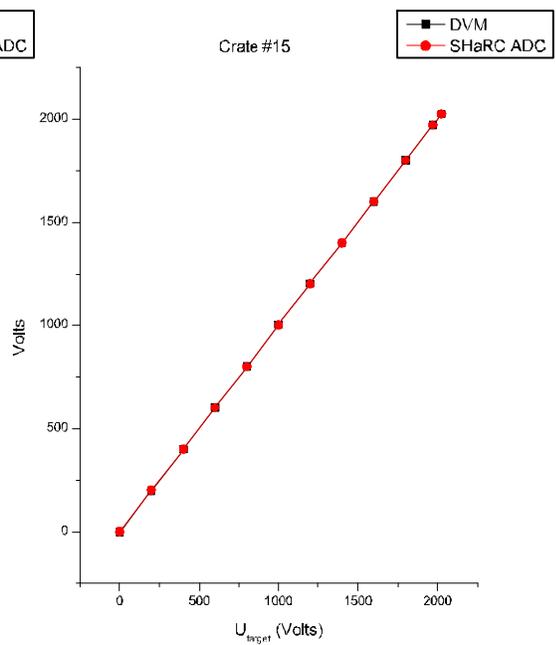
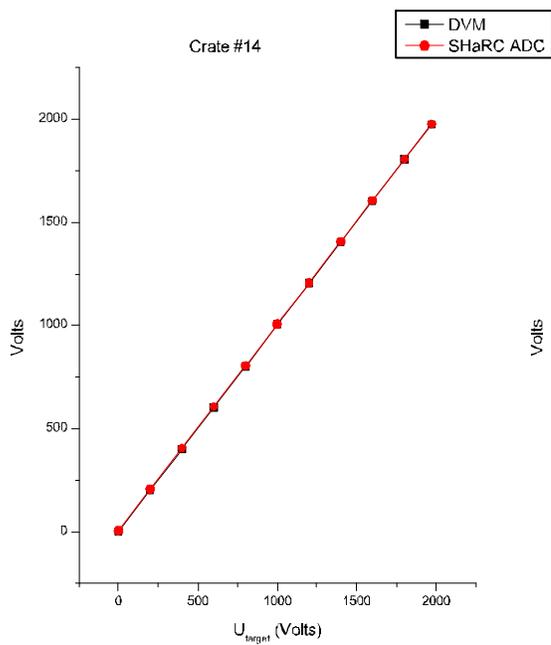
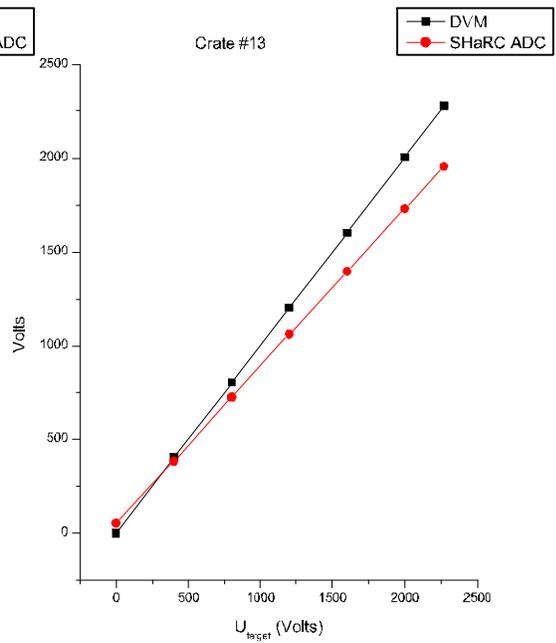
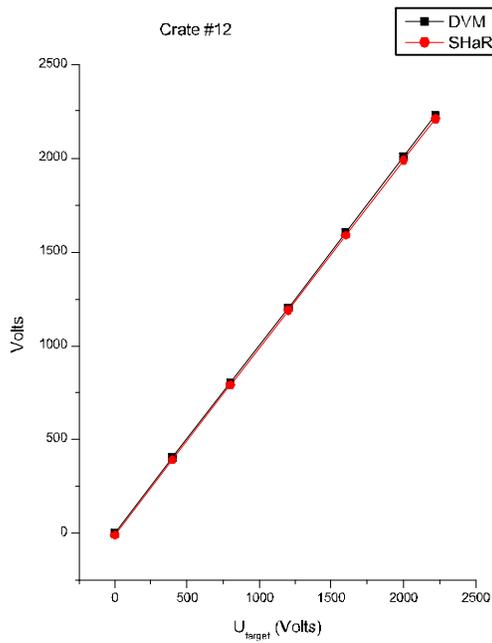
DVM and SHaRC ADC vs. target voltage (crates 0..3)



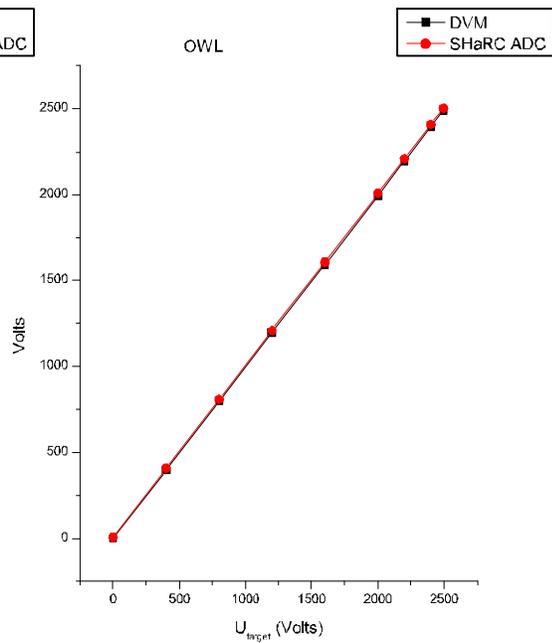
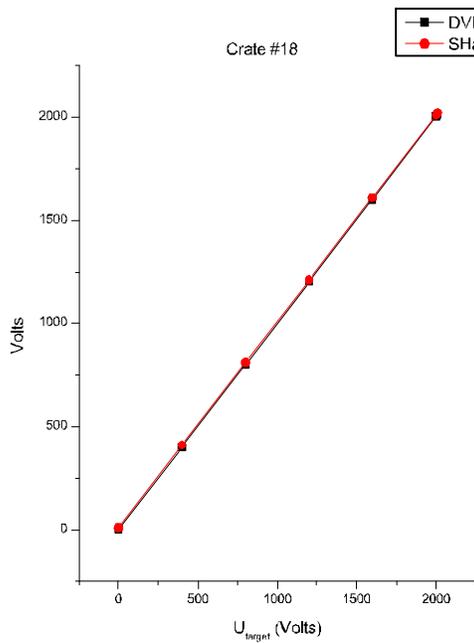
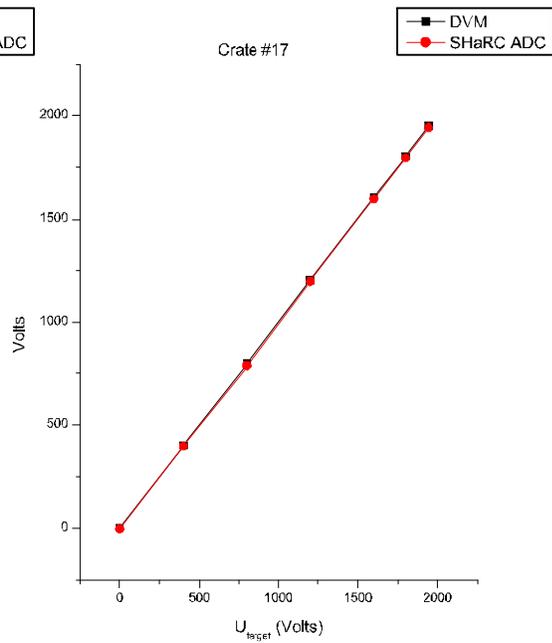
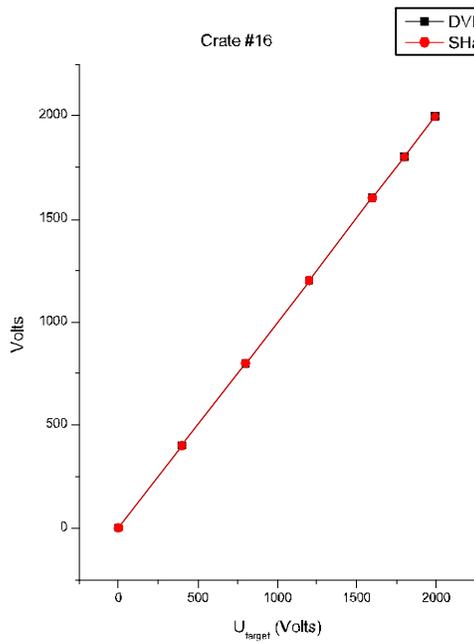
DVM and SHaRC ADC vs. target voltage (crates 4..7)



DVM and SHaRC ADC vs. target voltage (crates 8..11)

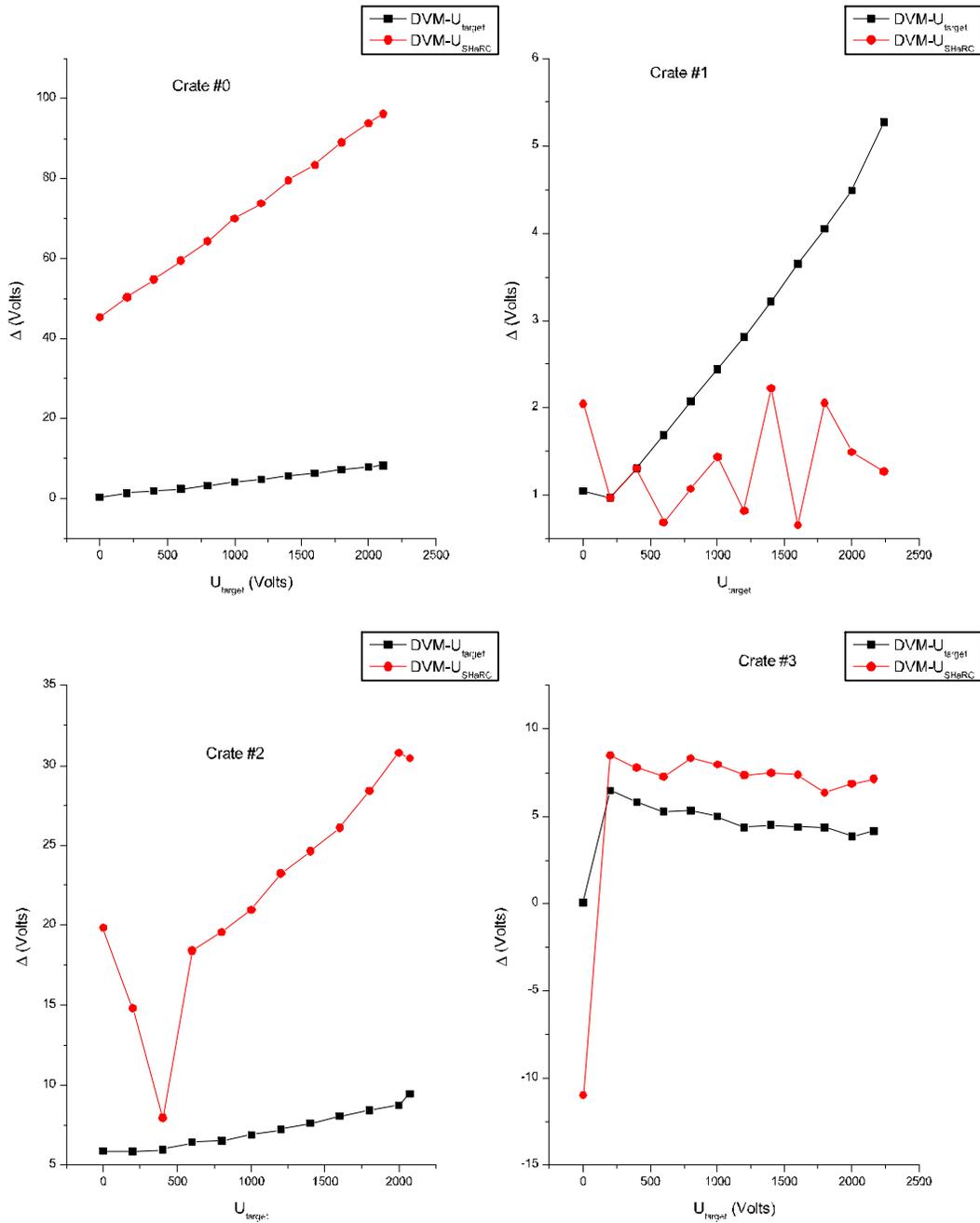


DVM and SHaRC ADC vs. target voltage (crates 12..15)

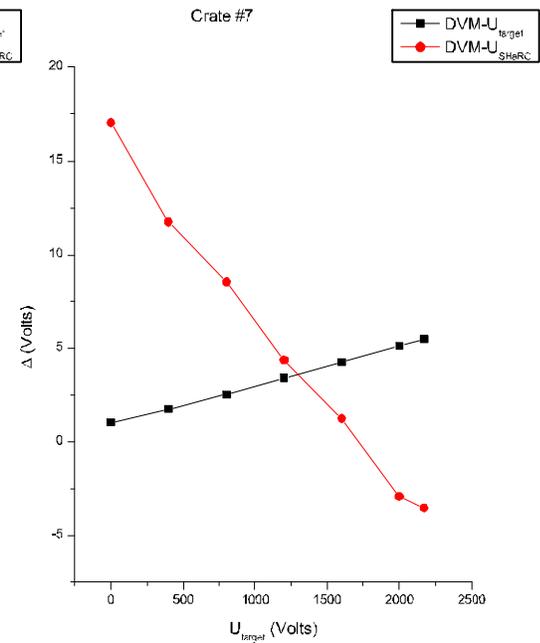
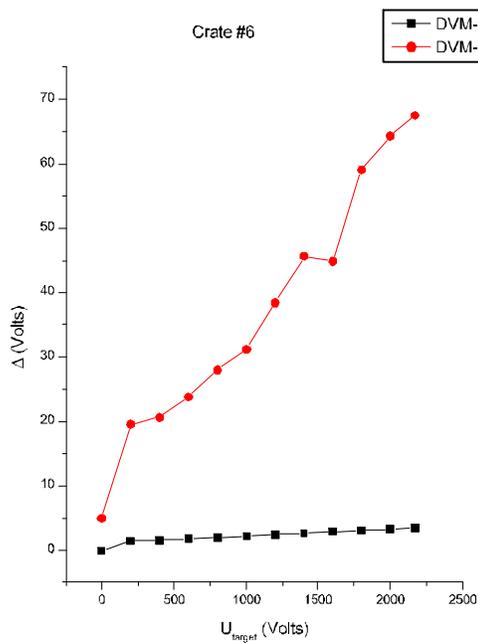
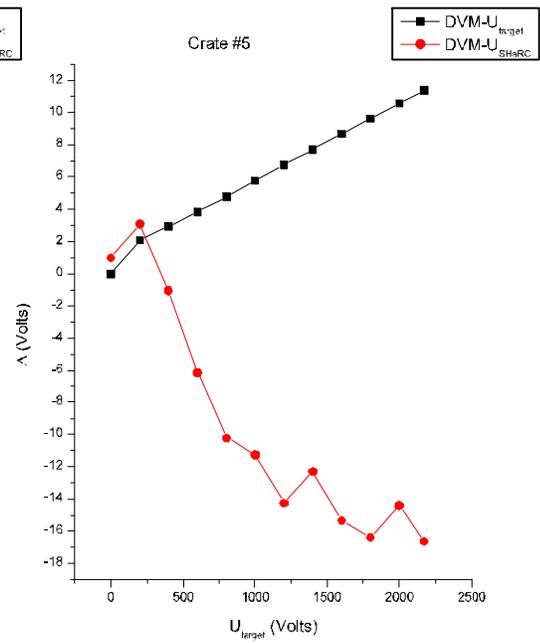
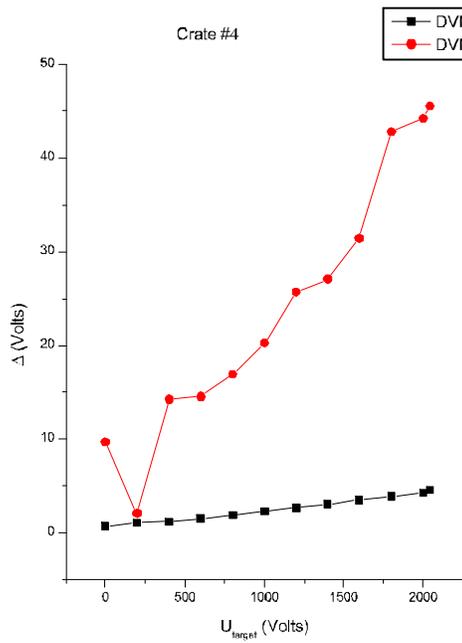


DVM and SHaRC ADC vs. target voltage (crates 16, 17, 18 and OWL)

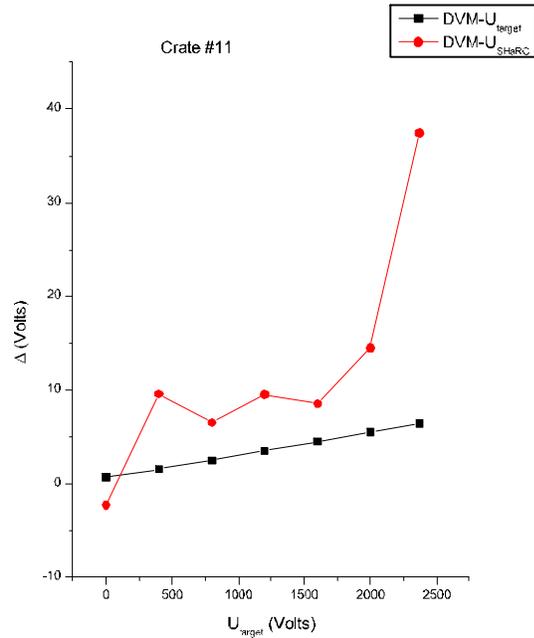
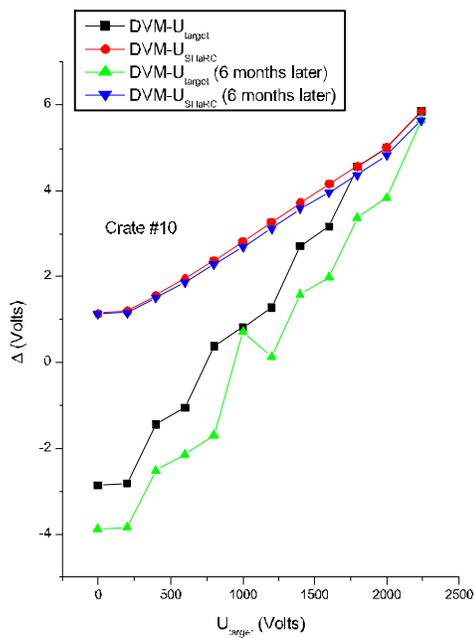
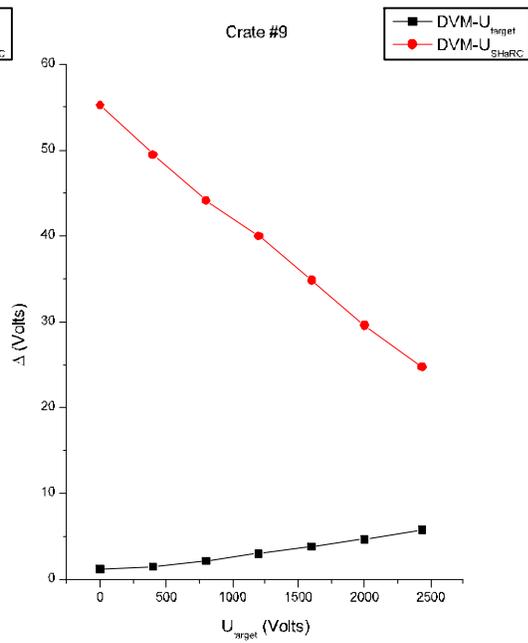
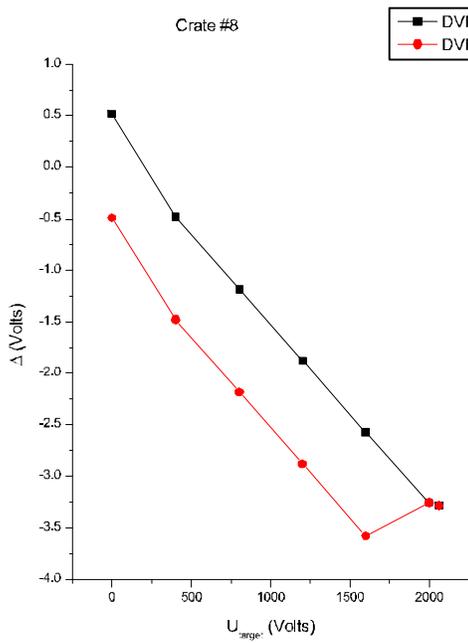
DVM and SHaRC ADC deviations from target voltage vs. target voltage are presented next.



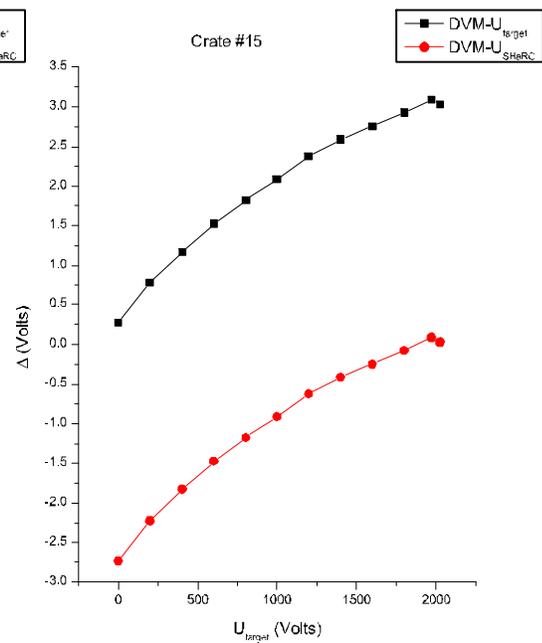
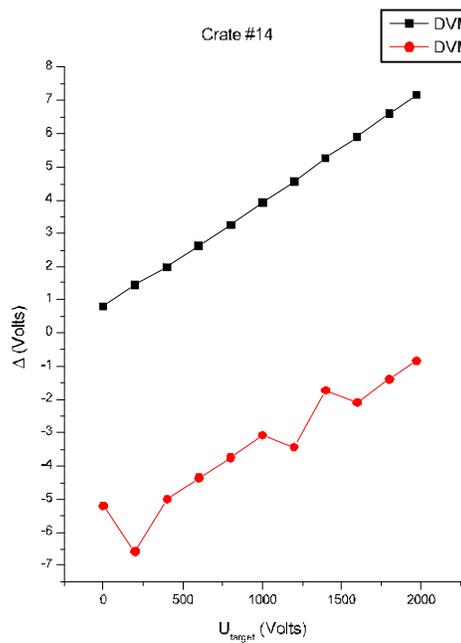
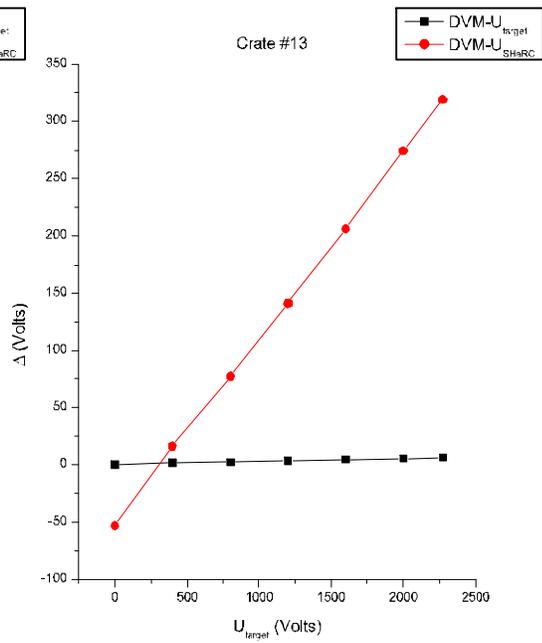
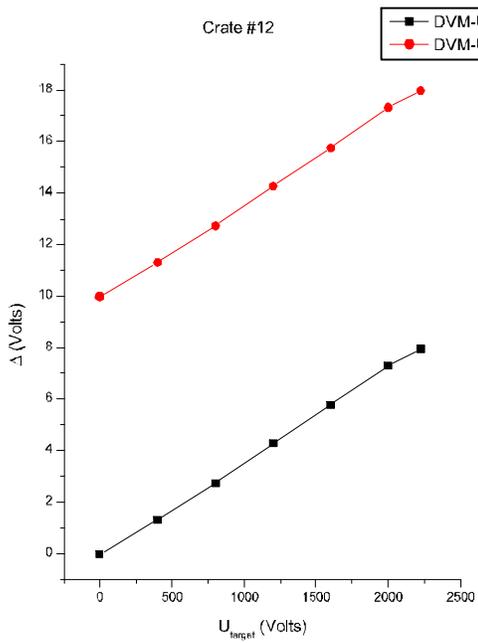
Difference in voltage readings (crates 0..3)



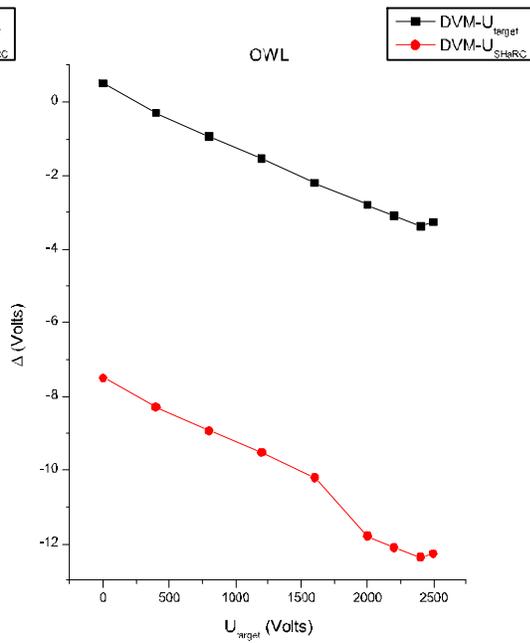
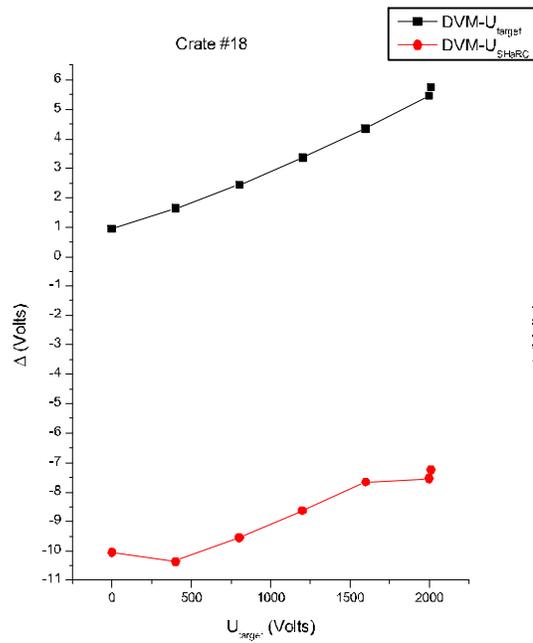
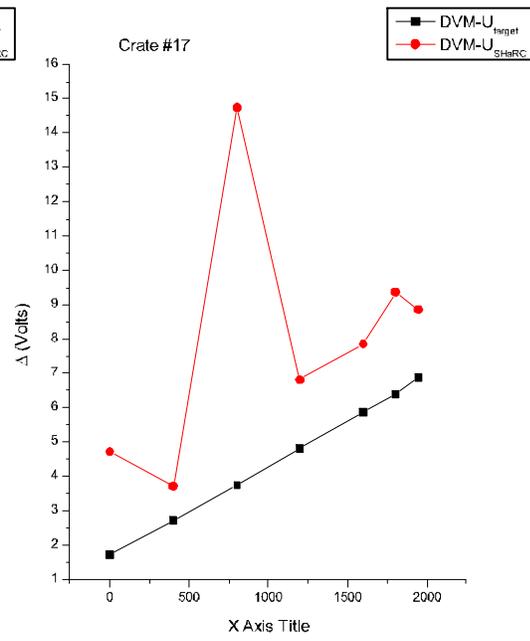
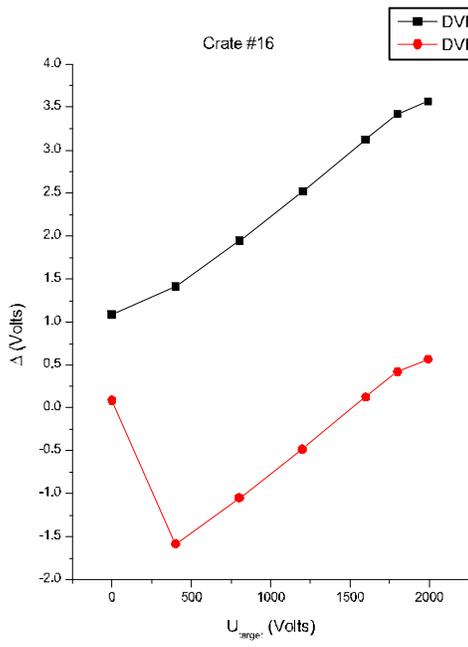
Difference in voltage readings (crates 4..7)



Difference in voltage readings (crates 8..11)

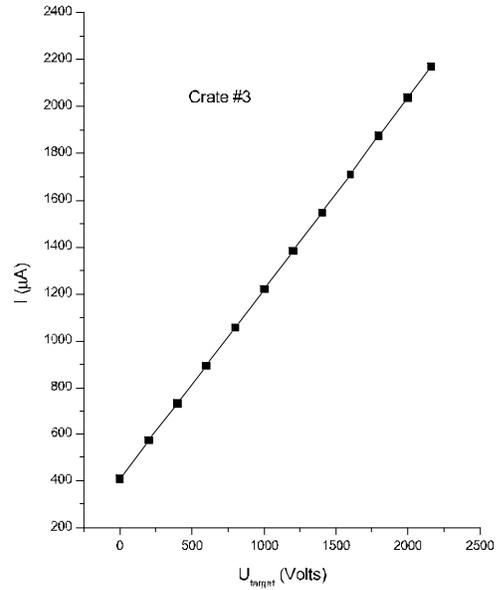
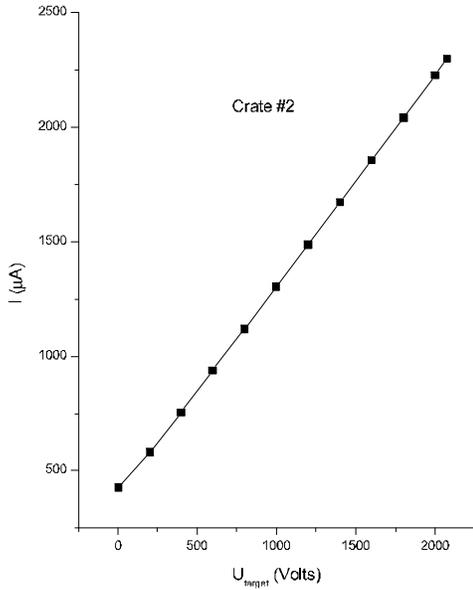
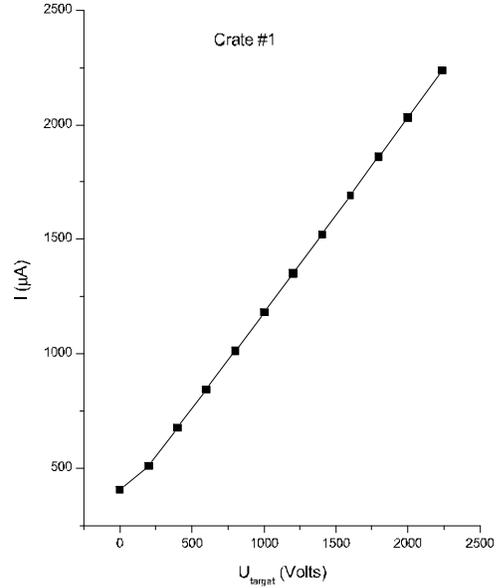
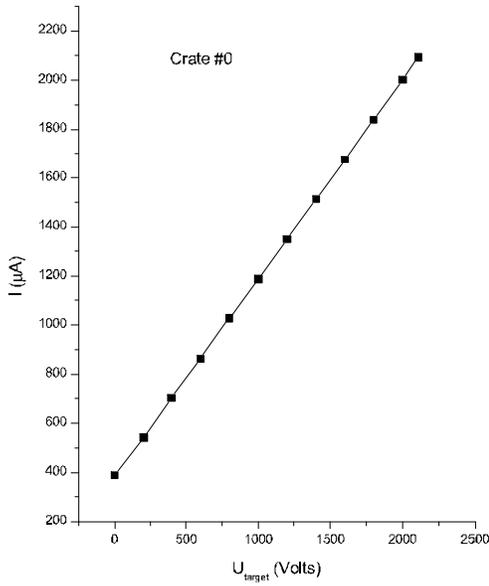


Difference in voltage readings (crates 12..15)

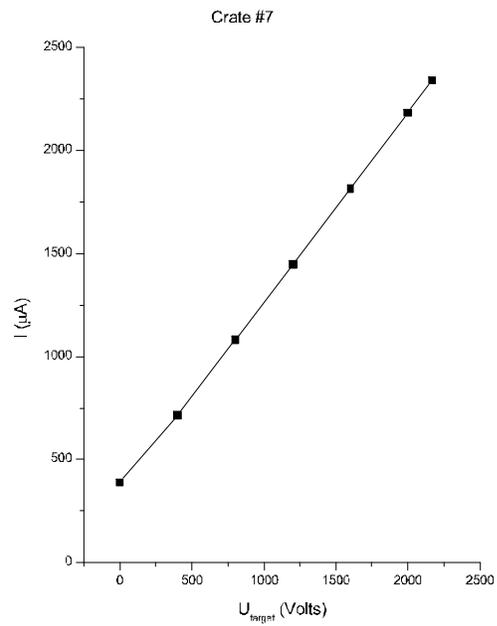
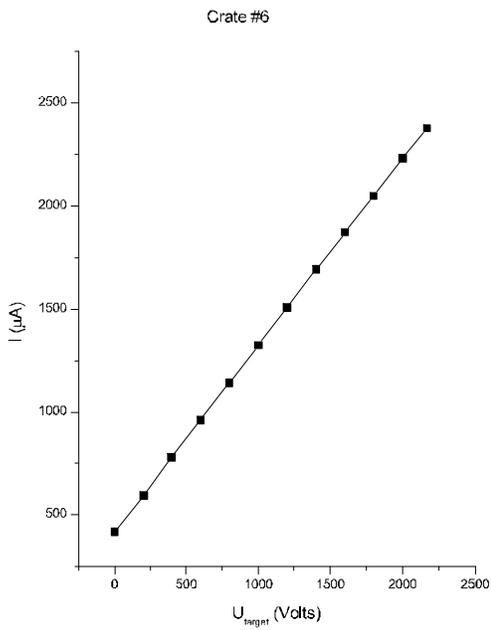
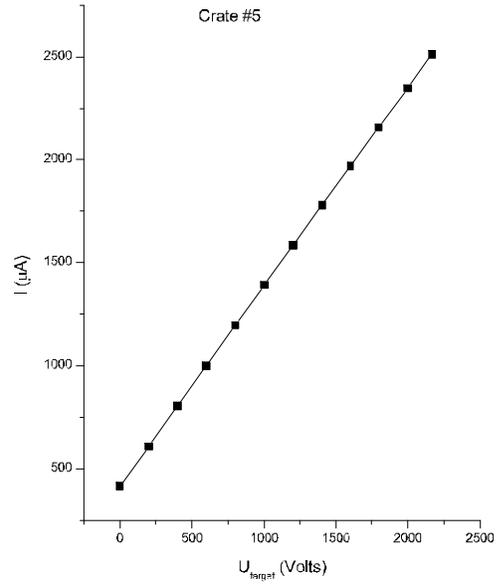
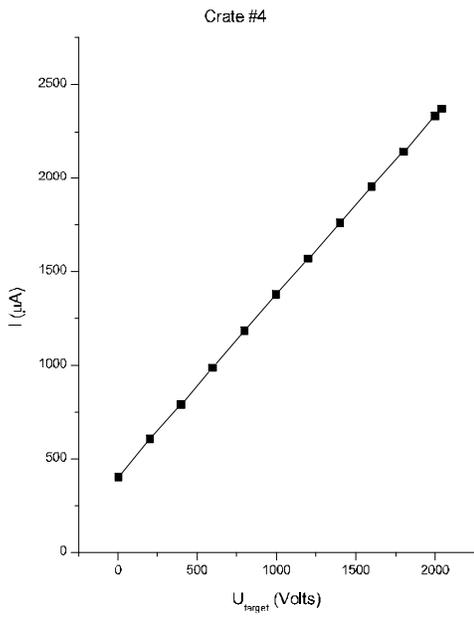


Difference in voltage readings (crates 16,17,18 and OWL)

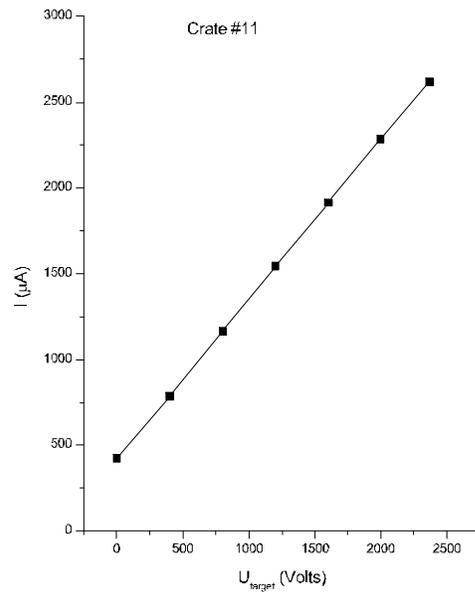
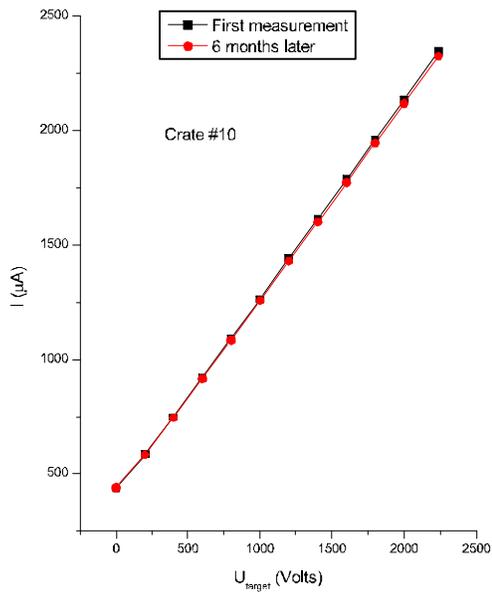
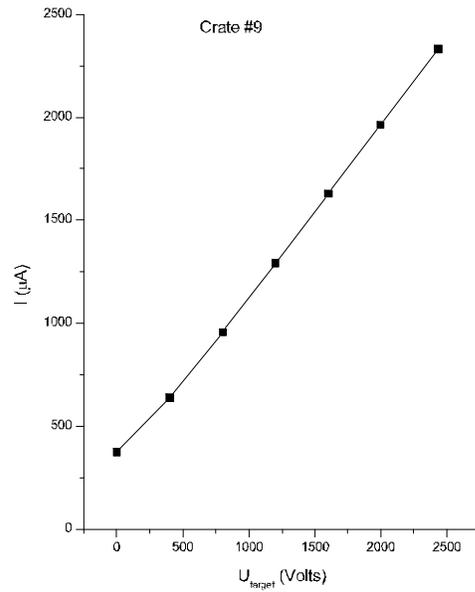
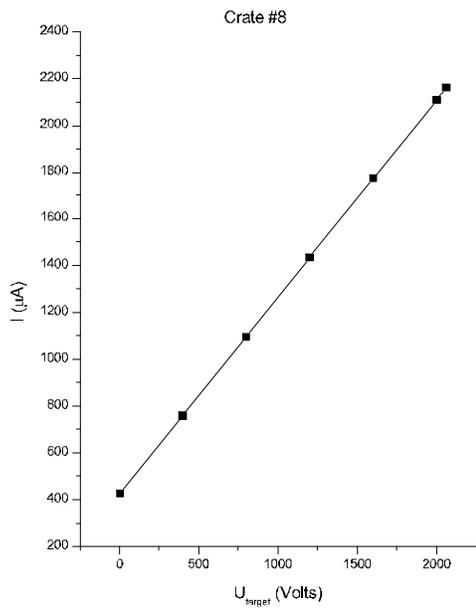
Current consumption has been recorded as reported by SHaRC during high voltage ramping. Discussion is still open whether or not independent measurements should be performed using the current sensor. The following are currents for every power supply vs. target voltage.



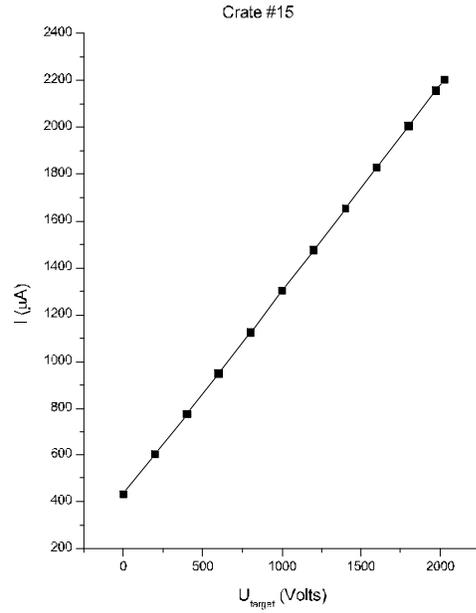
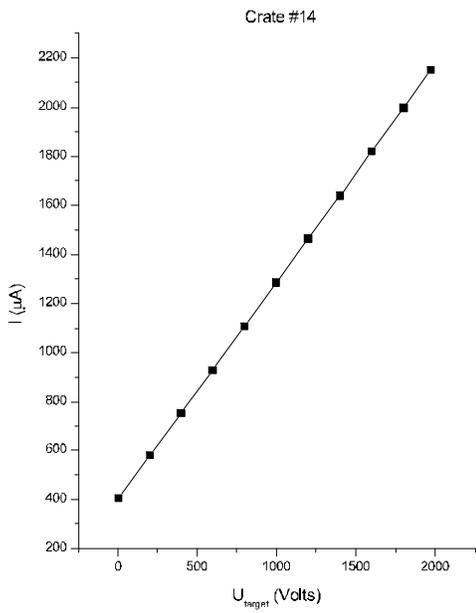
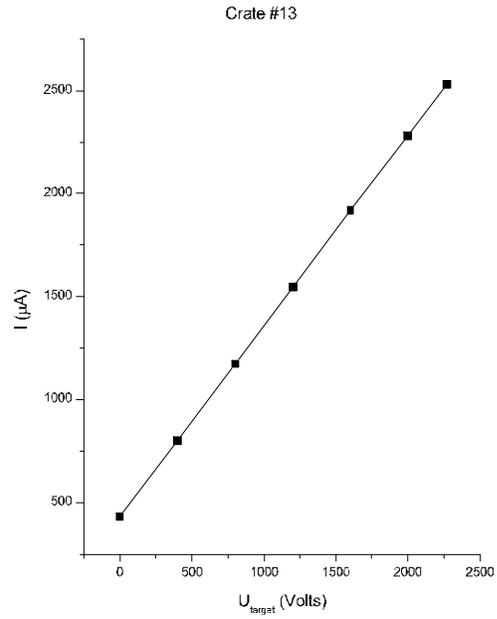
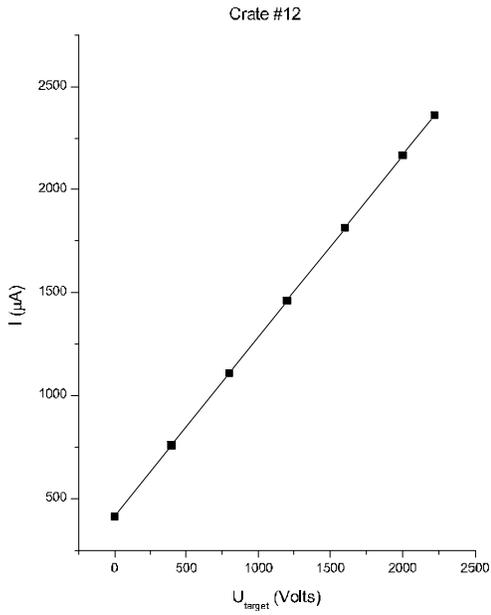
Current consumption (form SHaRC, crates 0..3)



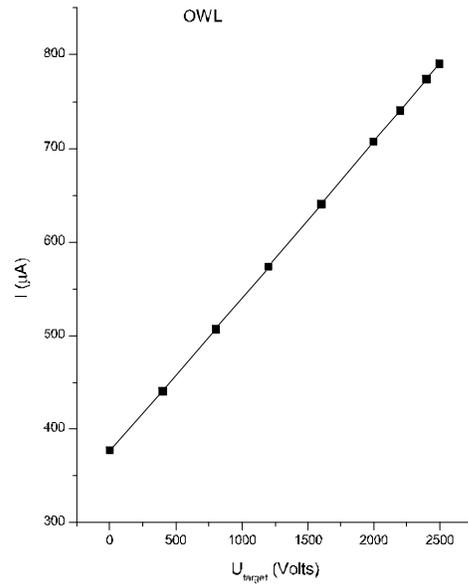
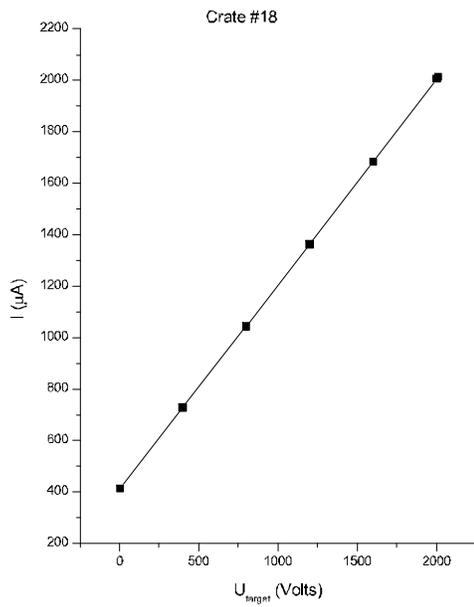
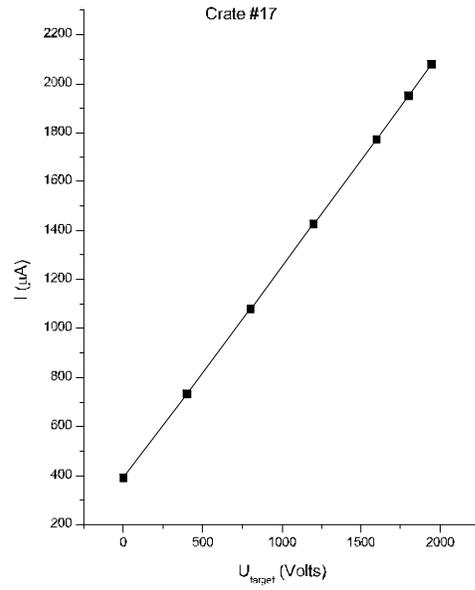
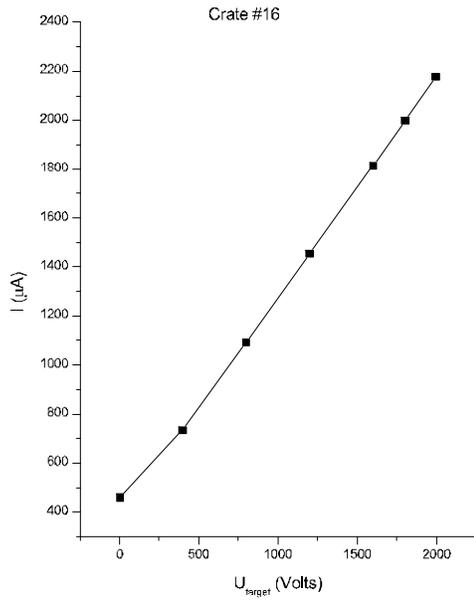
Current consumption (from SHaRC, crates 4..7)



Current consumption (from SHaRC, crates 8..11)



Current consumption (from SHaRC, crates 12..15)



Current consumption (from SHaRC, crates 16,17,18 and OWL)

Final measurements related to the target values are compiled in the following table.

Table 1.

Crate	Target Voltage (V)	SHaRC (V)	SHaRC (μ A)	DVM (V \pm V)	Date
0	2109	2022	2095	2118.459 \pm 0.130	2002-01-17
1	2240	2245	2239	2245.287 \pm 0.011	2002-01-17
2	2075	2053	2299	2084.464 \pm 0.011	2002-01-17
3	2160	2157	2171	2164.066 \pm 0.114	2002-01-17
4	2043	2005	2373	2047.550 \pm 0.017	2002-05-27
5	2169	2210	2515	2181.372 \pm 0.012	2002-03-06
6	2169	2123	2380	2173.509 \pm 0.023	2002-03-06
7	2169	2177	2343	2175.468 \pm 0.008	2002-06-11
8	2060	2059	2164	2056.708 \pm 0.010	2002-06-11
9	2435	2427	2335	2440.704 \pm 0.065	2002-06-12
10	2240	2240	2347	2245.897 \pm 0.027	2002-01-14
				2245.662 \pm 0.012	2002-06-11
11	2369	2364	2617	2376.431 \pm 0.011	2002-06-12
12	2219	2208	2364	2227.976 \pm 0.012	2002-06-11
13	2270	1959	2533	2276.446 \pm 0.010	2002-06-11
14	1969	1978	2150	1977.164 \pm 0.012	2002-02-27
15	2024	2029	2205	2027.853 \pm 0.074	2002-02-27
16	1994	1997	2177	1998.576 \pm 0.008	2002-06-12
17	1945	1937	2088	1951.874 \pm 0.014	2002-06-12
18	2010	2018	2015	2015.756 \pm 0.013	2002-06-12
OWL(19)	2495	2503	790	2491.742 \pm 0.010	2002-06-12

Here is a brief description of the data in the columns of the table :

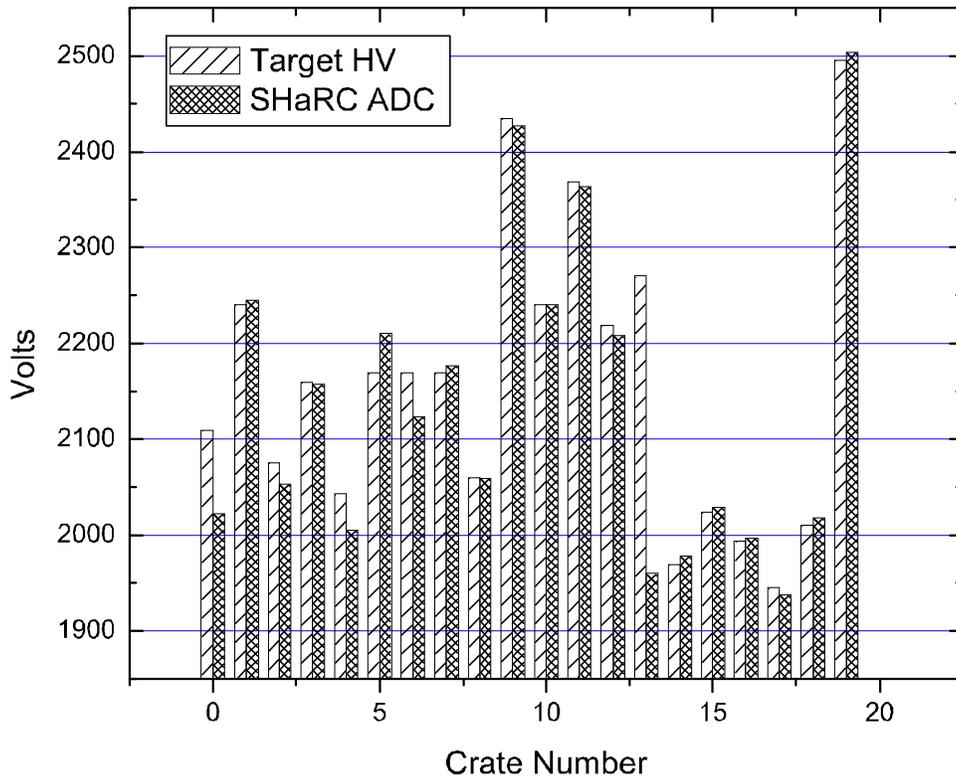
1. Power supply number 0..18 for every crate. Number 19 is assigned to OWL's HV power supply.
2. Target value of the high voltage set from SHaRC.
3. ADC high voltage values read by SHaRC from XL2.
4. Current consumption reported by SHaRC (read from XL2).
5. High voltage measured by the digital multimeter.
6. Date when the data were taken (*year-month-day*).

This table will be updated and DWG will be notified after every additional measurement.

As one can see from the comparison graph below the difference between target and SHaRC voltages (combined uncertainty of DAC and ADC of the XL2)

$$\Delta_{combined} = U_{target} - U_{ADC}$$

is quite alarming, reaching as far as ~300V for crate 13.



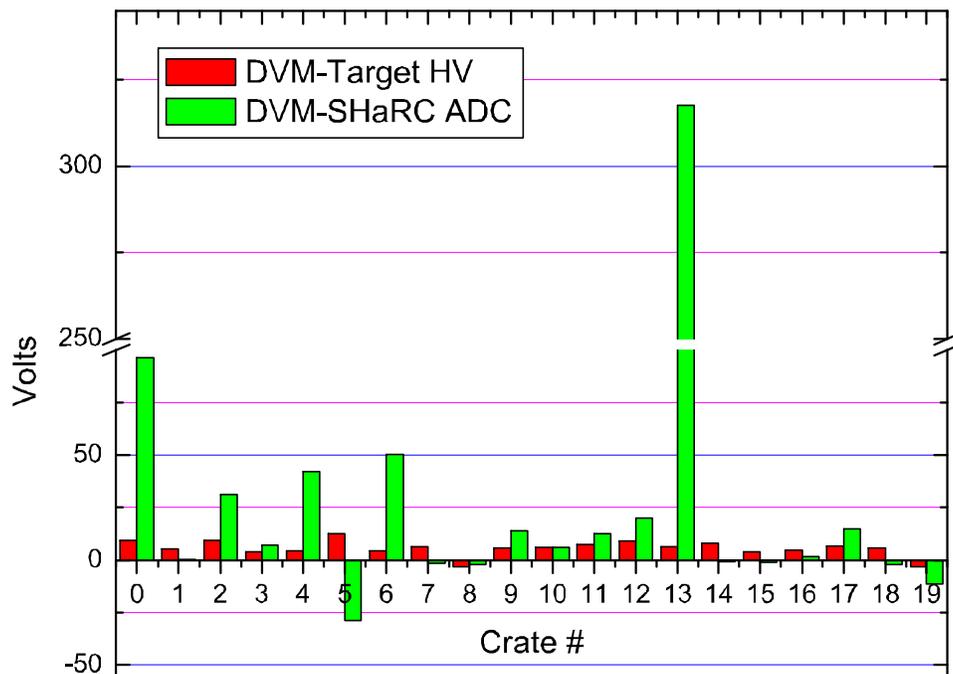
Therefore, it was important to understand where this difference is coming from - either from the DAC of the XL2, which sets the output voltage, or from the ADC of the XL2, which measures it. Based on the data from Table 1 difference between the DVM voltage and the target voltage :

$$\delta = U_{DVM} - U_{target}$$

and between the DVM and the SHaRC's ADC values:

$$\Delta = U_{DVM} - U_{ADC}$$

were calculated for every crate. These differences are compiled on the following graph.



Clearly, all of the real voltages are within a 25 volt gap from their target values although systematically higher. The possibility (and necessity) of making them precisely on the target value is still under investigation. Recently a successful attempt was made to change two constants in SHaRC in order to bring reported values as close as possible to the real ones.

In order to investigate the stability of the high voltage output with load changes two crates (0 and 1) were tested with only one slot on-line. Results of this investigation are to follow.

Short- and long-term stability

Inconsistency in the SHaRC's reading of the HV raises a question not only about accuracy of this reading, but about the stability of it as well. Analysis of the SHaRC ADC values based on data from the shift reports shows that these readings can reach as far as ~30 volts from their average values. For every crate an attempt was made to take long readings of the high voltage at its target set. Time was varying from a few minutes to several hours (up to two sequential shifts) for different crates. The analysis of this investigation will be added to this report shortly.

Appendix

Important Note

This document initially has been started as a "live" Mathcad worksheet. Therefore, it was unavoidably contained some specific for Mathcad functions. It may appear author's long use of this software tool over more than 10 years led him to somewhat delusional believe that it is one of the most simple way to perform data analysis. Simply because the Mathcad uses normal native mathematical interface. However, present version of the document has been simplified to remove unnecessary details of the analysis, which are in full preserved only in the Appendix. Comments have been added to the text in all appropriate cases to make absolutely clear how these functions are used. Although native mathematical notation should make it easy to read and hopefully understand, there is always a chance for "bugs". All comments will be greatly appreciated and can be submitted to: *starinsn@surf.sno.laurentian.ca*. As time permits, more information will be added to this document. New versions will be regularly posted immediately after such additions are done and, therefore, by all means it is a preliminary document.

Crate #0. High Voltage Study.

Control of the digital multimeter and data transfer are done by KEITHLEY's software via RS232 interface. Data are stored on the computer in ASCII file, which consist of the header, sample numbers, actual measurements and absolute time stamps for them. Several channels (up to 20) can be stored in the data file simultaneously. Here is an example of the raw data file taken for three channels:

```
"Date and Time: 06/11/2002 1:55:01 PM
Sample,channel 101,time(abs),channel 102,time(abs),channel 103,time(abs)
0,6.32093573,0,-0.0000130400158,0.609,-0.0000105299332,1.218
1,6.32093716,2.001,-0.0000123344789,2.61,-0.0000104349574,3.219
2,6.32093906,4.002,-0.0000126872474,4.611,-0.0000105570698,5.22
3,6.32094049,6.003,-0.0000129721757,6.612,-0.0000102857093,7.221
4,6.32093859,7.998,-0.0000126872474,8.607,-0.0000101907326,9.216
5,6.32094193,10,-0.0000127415196,10.609,-0.0000104485252,11.218..."
```

For further analysis, two lines of the header are manually removed. The rest can be treated as a matrix directly read by software. The MathCAD *READPRN* function reads an entire data file, determines the number of rows and columns, and creates a matrix out of the data. Each line in the data file becomes a row in the matrix. The number of elements in each row must be the same. Used as follows:

$$A := \text{READPRN}(\text{file})$$

The argument *file* is string variable corresponding to structured ASCII data filename or path. Total number of data points in the file is determined by using *rows* function:

$$N_{max} := \text{rows}(A)$$

This function returns the number of rows in array **A**. If **A** is a scalar, returns 0.

Crate	0
Target HV	2110
Date of measurement	2002-01-17

Crate #0 together with several other crates was undergoing special additional study. In this case two configurations were studied - fully loaded crate and single slot on-line only
Reading data files:

$$A := \text{READPRN}(\text{"HV_crate00_01.txt"})$$

- data taken when all slots were on (except slot #13 -digital problem);

$$B := \text{READPRN}(\text{"HV_crate00_slot00.txt"})$$

- data taken when only one slot was on-line (slot #0);

Extracting voltage data for both data sets:

$$N_{maxA} := \text{rows}(A)$$

$$N_{maxB} := \text{rows}(B)$$

$$i := 0..N_{maxA} - 1$$

$$j := 0..N_{maxB} - 1$$

$$U_a := 109.911 \cdot A^{(1)}$$

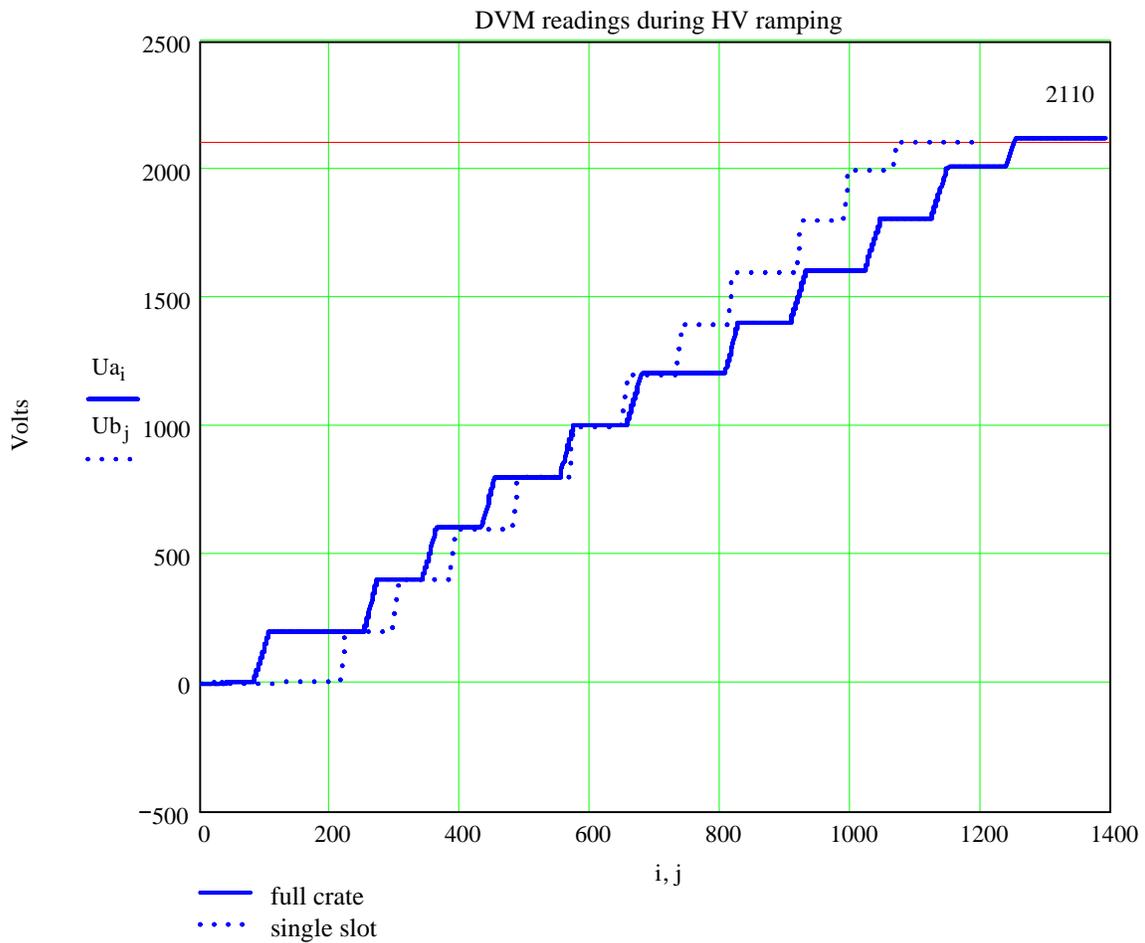
$$U_b := 109.911 \cdot B^{(1)}$$

There is something to say about coefficient 109.911 used in the data extracting procedure above. As it was mentioned in the technical description of the measuring procedure, 100 : 1 voltage divider was used. Normally 1000 : 1 division is used for measuring high voltage values applied to the PMT. With this ratio it is impossible to see fluctuations of the high voltage below 1 volt when using, for example, small hand held DVM with limited accuracy. Since KEITHLEY DVM has high dynamic range ($6\frac{1}{2}$ digits), it was interesting to see at which level high voltages for SNO detector are actually fluctuating. Therefore, smaller ratio for the divider was chosen. As one can see from the picture in the main text, high voltage divider consist of two parts: R1 and R2:

$$R1 = 99M\Omega \quad R2 = 1M\Omega$$

All measurements were done using 30 volts limit setup for the DVM. For this range the internal resistance of the DVM is well known to be $10M\Omega$. Therefore, real ratio is slightly higher and is 109.911.

High voltage was ramped with 200 volts step except the last one. For crate #0 two configurations were investigated: fully loaded crate and a single slot on-line. The ramping charts for both cases are presented:



Ramping chart

Simultaneous readings were taken from SHaRC (ADC_a for the full crate and ADC_b for a single slot). They are related to the flat regions on the ramping chart. For each reading a time stamp is given in order to compare relative data (T_{sa} for full crate and T_{sb} for one slot). Flat regions on the plot correspond to the following tabulated values of the target voltage:

$$k := 0..11$$

$$U_{target_k} := 200 \cdot k \quad (200 \text{ volts steps})$$

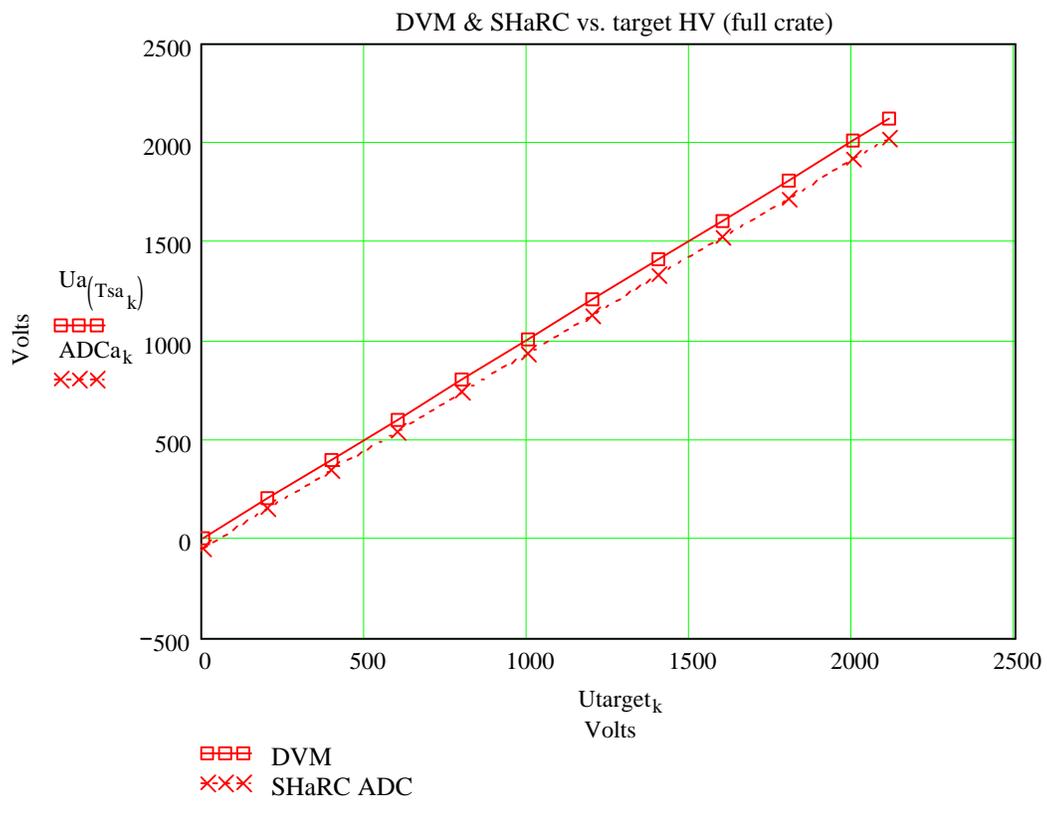
$$U_{target_{11}} := 2110 \quad (\text{final target value; last step was always less than } 200 \text{ volts})$$

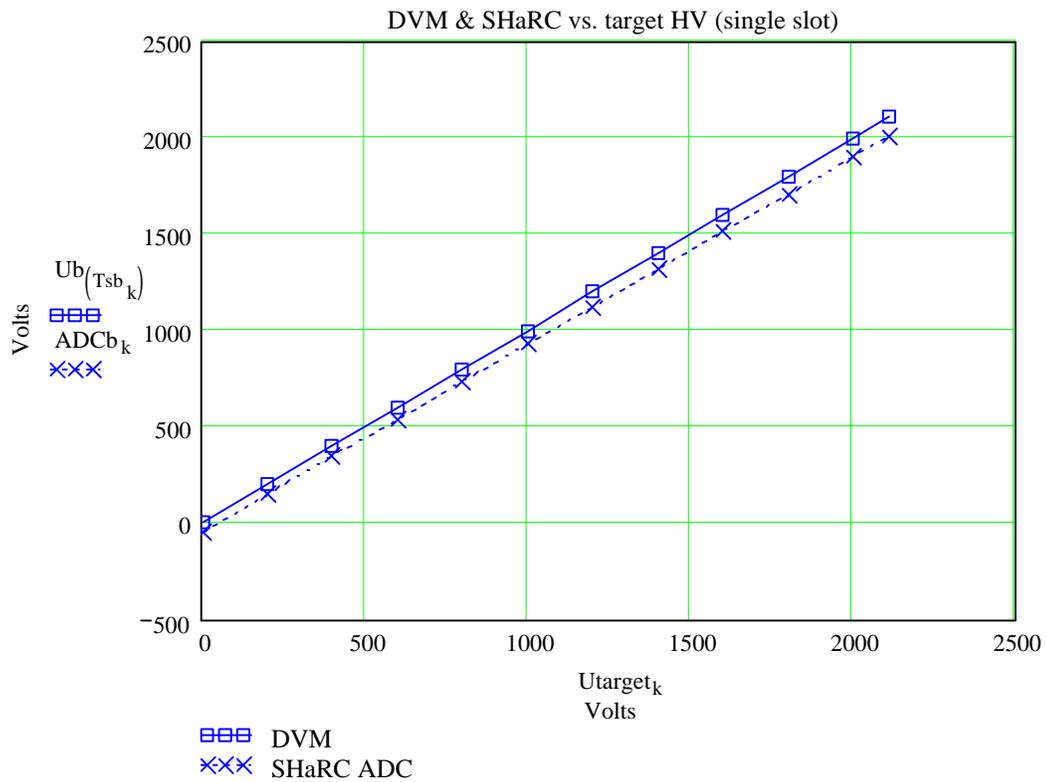
Time stamps T_{sa} and T_{sb} were arbitrarily chosen from two sets of data points $\{i\}$ and $\{j\}$ correspondingly in the middle of flat regions on the plot above:

$$T_{sa} := \begin{pmatrix} 60 \\ 200 \\ 310 \\ 400 \\ 500 \\ 600 \\ 750 \\ 870 \\ 980 \\ 1100 \\ 1200 \\ 1300 \end{pmatrix} \text{ - (for the full crate); } \quad T_{sb} := \begin{pmatrix} 150 \\ 260 \\ 350 \\ 440 \\ 530 \\ 620 \\ 700 \\ 780 \\ 880 \\ 960 \\ 1030 \\ 1100 \end{pmatrix} \text{ - (for a single slot);}$$

Corresponding to these time stamps SHaRC ADC readings were taken after each ramping step was finished (flat regions on the plot above):

$$ADC_a := \begin{pmatrix} -45 \\ 151 \\ 347 \\ 543 \\ 739 \\ 934 \\ 1131 \\ 1326 \\ 1523 \\ 1718 \\ 1914 \\ 2022 \end{pmatrix} \text{ - (for the full crate); } \quad ADC_b := \begin{pmatrix} -46 \\ 150 \\ 344 \\ 539 \\ 734 \\ 929 \\ 1124 \\ 1318 \\ 1513 \\ 1708 \\ 1903 \\ 2010 \end{pmatrix} \text{ - (for a single slot);}$$





Difference between measured and target voltages:

$$\delta a_k := U_{a(T_{sa_k})} - U_{target_k}$$

- for full crate;

$$\delta b_k := U_{b(T_{sb_k})} - U_{target_k}$$

- for single slot.

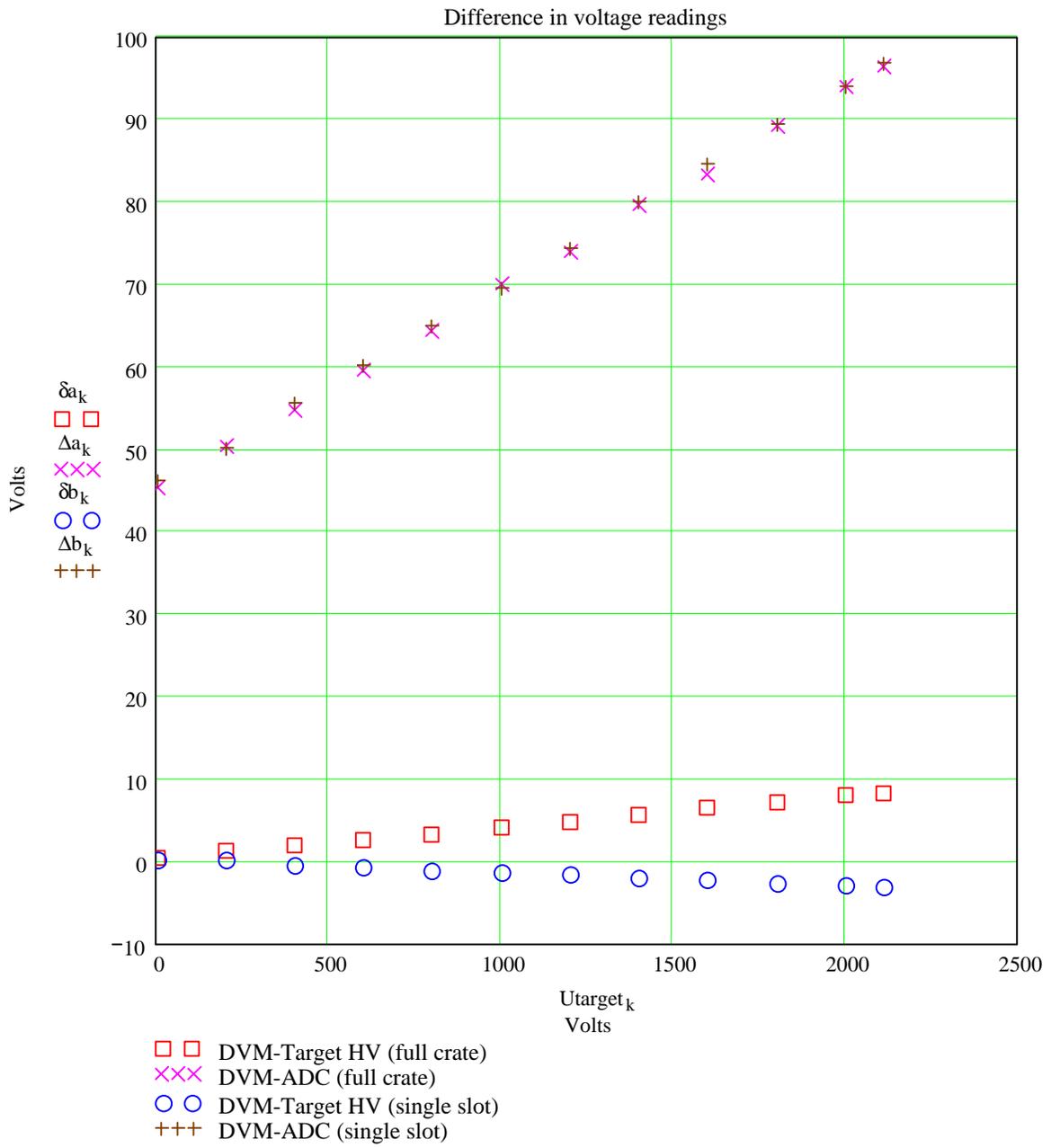
Difference between measured and reported voltages:

$$\Delta a_k := U_{a(T_{sa_k})} - ADCa_k$$

- for full crate;

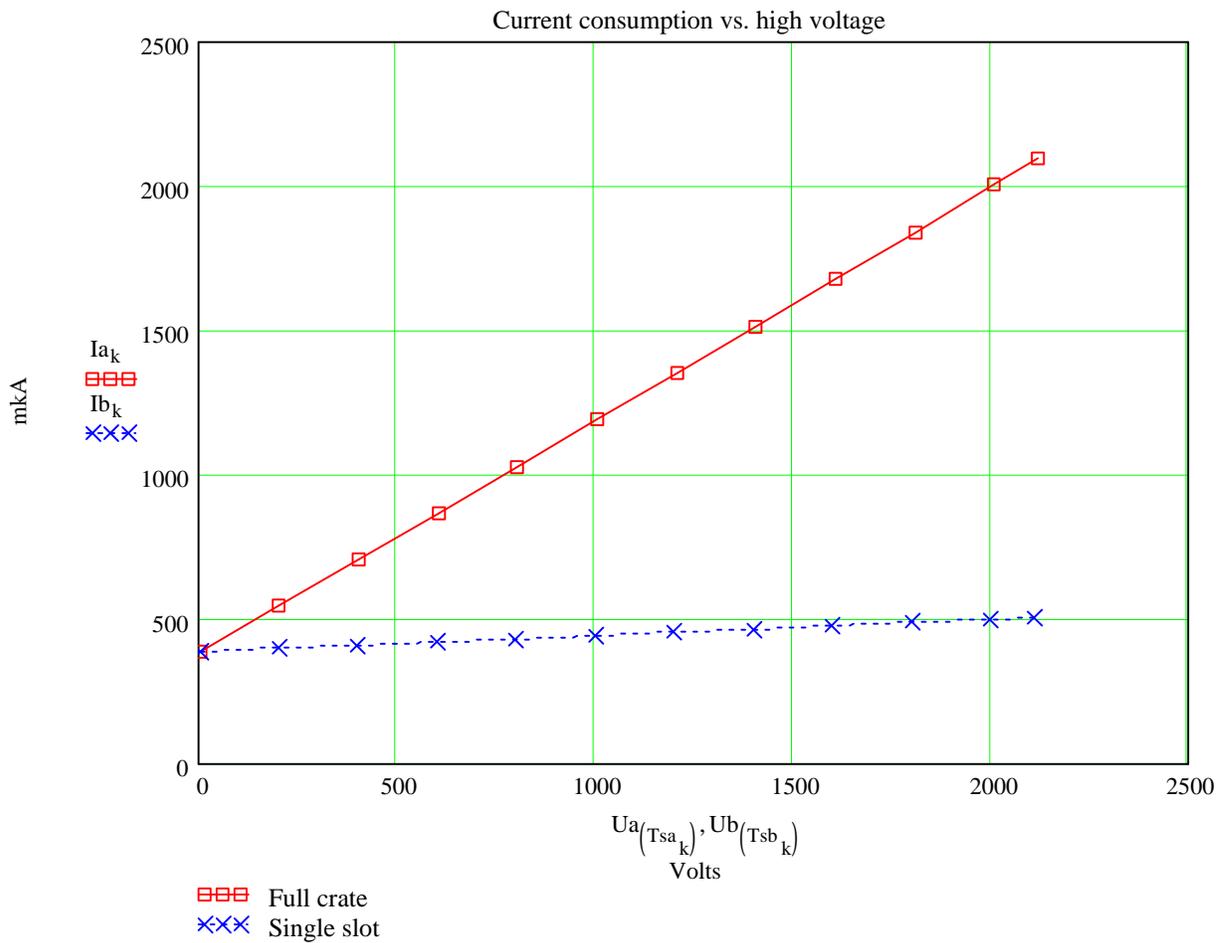
$$\Delta b_k := U_{b(T_{sb_k})} - ADCb_k$$

- for single slot.

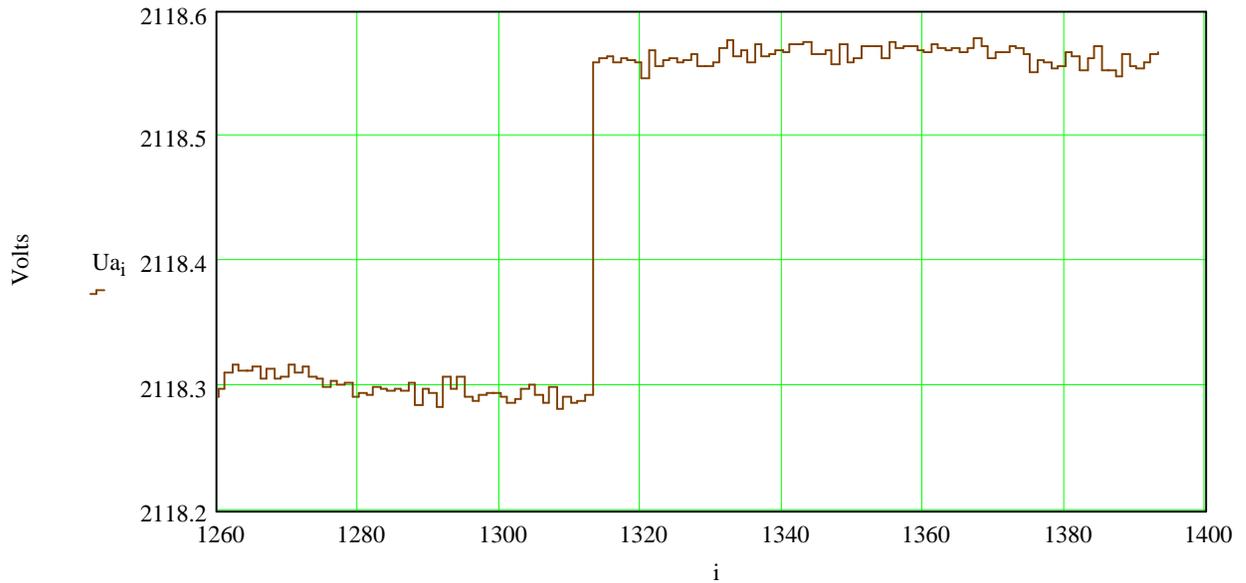


Current consumption reported by SHaRC during HV ramping:

$$I_a := \begin{pmatrix} 388 \\ 543 \\ 704 \\ 865 \\ 1027 \\ 1188 \\ 1350 \\ 1513 \\ 1676 \\ 1840 \\ 2004 \\ 2095 \end{pmatrix} \quad \text{- (for the full crate);} \quad I_b := \begin{pmatrix} 388 \\ 397 \\ 408 \\ 419 \\ 430 \\ 442 \\ 453 \\ 464 \\ 477 \\ 488 \\ 499 \\ 504 \end{pmatrix} \quad \text{- (for a single slot);}$$



Short-term stability after HV ramping:



For the last subset of data shown on the graph above the mean value and standard deviation is calculated. In order to extract this last set data points are reassigned into new set of voltages U_{last} :

$$N := N_{maxA} - 1260$$

$$k := 0..N$$

$$U_{last_k} := U_{a_{1260+k}}$$

for which mean and standard deviation values are calculated using Mathcad functions:

$$HV := \text{mean}(U_{last})$$

$$\delta HV := \text{stdev}(U_{last})$$

$$HV = 2118.459$$

$$\delta HV = 0.130$$