Zach Bernens
DVCS3 Experiment
August 26th, 2016

BCM Calibration and Charge Analysis for E12-06-114 Winter 2016 Data

BCM detectors based on resonant cavity technologies are used to measure the current of the electron beam. The charge of the electron beam can be calculated by integrating the current with respect to time. In knowing the charge we then can determine the number of electrons approaching the target, which is an integral part in understanding the probability of the reaction occurring once the beam impacts the target. In order to interpret BCM measurement of the current we first need to calibrate the devices for both the fast and slow scalers. The scalers provide a count reading where the fast and slow scalers take readings every 200 events (~1s) and 10 seconds respectively. The fast and slow scaler's calibration results are in agreement with each other as expected. The calibration using the slow scaler was completed by Bishnu Karki while this paper focuses on the fast scaler calibration. We used the calibrated device to measure the absolute charge. The majority of the BCMs measured charges are with in ± 0.05% of D3 BCM charge measurement.

Introduction

Beam Current Monitor (BCM) is a device that makes a non-invasive current measurement of the electron beam. The BCM is broken down into two main components the parametric current transformer (PCT or Unser) and the upstream and downstream resonant cavities. Figure 1 shows a diagram of the BCM device. As the beam travels through the beam pipe it induces a magnetic field within the resonant cavity of the BCM device. A magnetic field probe is located within the cavity and produces a signal that is proportional the current of the beam. The output signals generated from the cavities are a relative measurement but can be calibrated against the Unser which is equipped with an absolute calibration system.

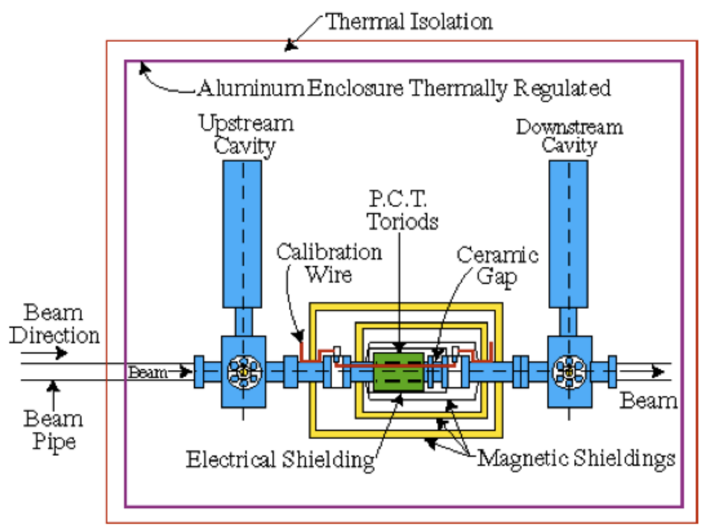

Figure 1: Diagram of a Beam Current Monitor (BCM) *[3]

Calibration Method

The BCM cavities are used to measure current instead of the Unser, because of the cavities high stability during runtime condition and the ability to remove the unstable offset of the Unser. Therefore, we use the Unser current to calibrate the resonant cavities for each BCM device, resulting in measurements with the accuracy of the Unser and the stability of the cavities. In calibrating the BCM device we need to first calibrate the Unser. The Unser calibration is performed by injecting a known current into a calibration wire (see figure 1). Then the rate of the Unser output signal is plotted against the known current. The slope of this linear relationship is the gain. T. Gautam has completed this analysis and his results are in table 1.

Date	Run Number	Gain (10^{-6}) μA/Hz	Random Error (10^{-6}) μA/Hz
01/29/2016	21590	2754	6.1
03/02/2016	12323	2753	6.1
04/12/2016	22324	2753	6.1

Table 1: Unser gain values from Unser calibration [2]

Once we determine the Unser gain we use the relationship below to determine the Unser current.

$$I = fp_1 \quad [1]$$

I = Unser Current (μA)
f = Unser frequency at non-zero current (Hz)
p_1 = gain from the Unser calibration

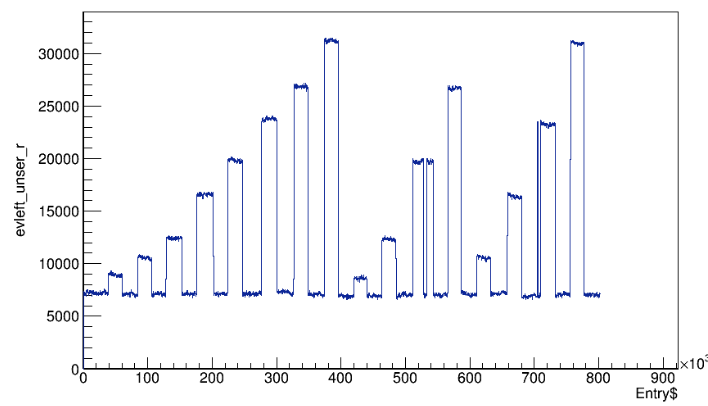

Figure 2: The on and off periods of current for the BCM calibration run 13447. The rate of the on periods drive the calibration of the cavities in the BCMs

The BCM calibration runs were completed on February 16th (12514), March 4th (12916), April 10th (13220), and April 21st (13447). Figure 2 shows a typical BCM calibration run where the current is stepped up in succession but is also broken down into periods where the current on or off for the Unser monitor only. The pedestal of the off periods is averaged and removed from the on periods. This procedure is repeated for each on–off period. The removal of the pedestal allows the BCM to be calibrated without the instability of Unser offset. The signal rate for the Unser and cavities for each on period during the calibration run is plotted against the Unser current. The slope of the plotted linear relationship is equal to the calibrated gain and the y-intercept is equal to the offset. Some cavities have range of non-linearity as can be seen in appendix A for the following cavities. The U1 & D1 cavities show a linear relationship once the current increases past 7μA, where D10, Unew, and Dnew saturate at 25 μA, 45μA, and 45μA respectively. The BCM are calibrated using both slow and fast scaler. The slow scaler takes a data reading every 10s where the fast scaler makes reading every 200 events (~1s). The calibration using the slow scaler

	Gain (μA/Hz)	Offset (μA)
All Runs		
U1	351.17 +/- 0.72	0.75 +/- 0.06
D1	319.28 +/- 0.65	0.41 +/- 0.06
D3	93.09 +/- 0.18	0.30 +/- 0.05
D10	32.14 +/- 0.18	0.19 +/- 0.06
Runs (12514 & 12916)		
Unew	199.25 +/- 0.76	0.20 +/- 0.06
Dnew	172.15 +/- 0.66	0.19 +/- 0.06
Runs (13220)		
Unew	295.64 +/- 1.66	0.20 +/- 0.12
Dnew	249.95 +/- 1.41	0.10 +/- 0.12
Runs (13447)		
Unew	50.05 +/- 0.29	0.05 +/- 0.12
Dnew	42.94 +/- 0.25	0.04 +/- 0.12

Figure 3: Calibration results for the all 4 calibration runs individually and consolidated. Gain in order of 10^{-6}. Unew and Dnew are consolidated for runs 12514 and 12916

was completed Bishnu Karki while this paper focuses on the fast scaler calibration. The calibration using the fast scaler follows the same procedure but should provide better measurement because of the increase frequency of fast scaler. Once the analysis of all 4 calibration runs was completed, we consolidated all calibration data in one analysis in order to improve accuracy. The consolidated gains and the offset values for each BCM resonant cavity are shown in figure 3. For calibration runs 13220 and 13447 the Dnew and Unew cavity gain and offset varied significantly from runs 12514 and 12916 resulting in these cavities being consolidated independently for remaining cavities. The calibration results from the slow and fast scaler are in agreement with each other as expected. Figure 4 shows the gains and offsets of the fast and slow scalers within each scalers uncertainty. In addition each runs calibration results are in agreement with the consolidated calibration, except for Unew and Dnew where the consolidated calibration were only determined for the first two calibration runs.

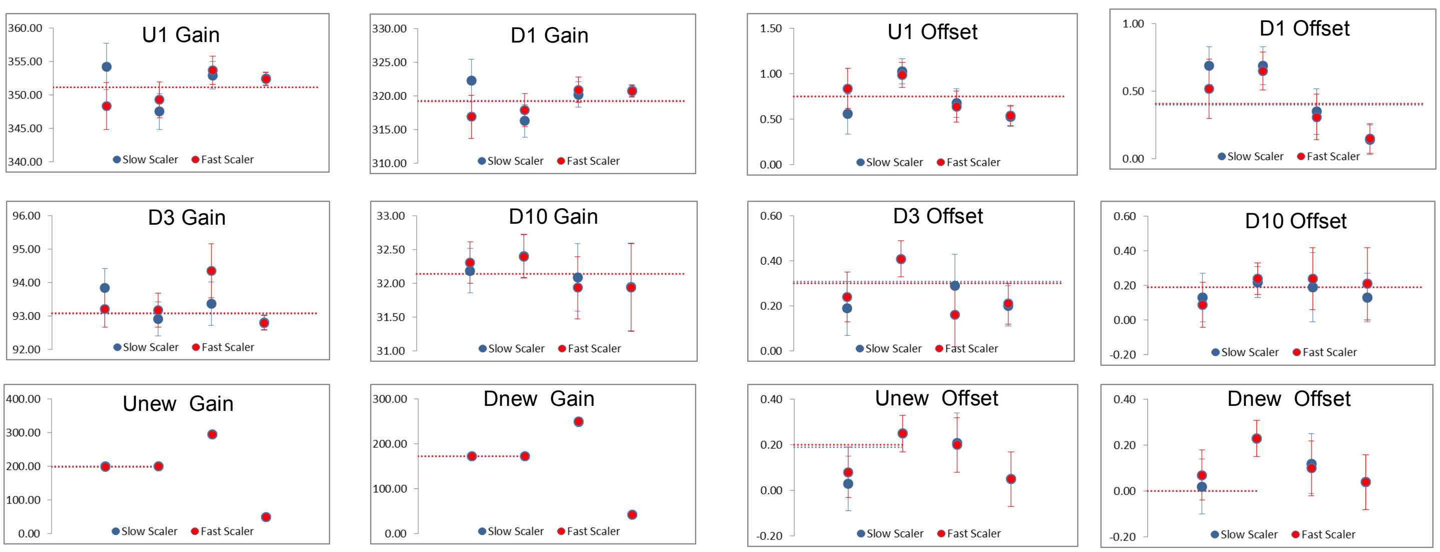

Figure 4: The gain and offset from the fast scaler fall within the uncertainty of the both scaler's calibration results. The consolidated calibrations are represented by the dotted line. All gain are stable expect Unew and Dnew, where large variations are observed in the last two calibration runs compared to the first two.

Charge Analysis

In calibrating the cavities of the BCM we are able to use equation [2] to determine the instantaneous current, where f is the frequency of BCM current.

$$I = fp_1 + p_0 \qquad [2]$$

Then by integrating the current with respect to time we calculated the charge in each cavity.

$$Q = Np_1 + p_0 t \qquad [3]$$

Q = charge in the cavity (μC)
N = scaler reading at the end of the run

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p_1 = calibrated gain (μA/Hz)
p_0 = calibrated offset (μA)
t = duration of the run time [s]

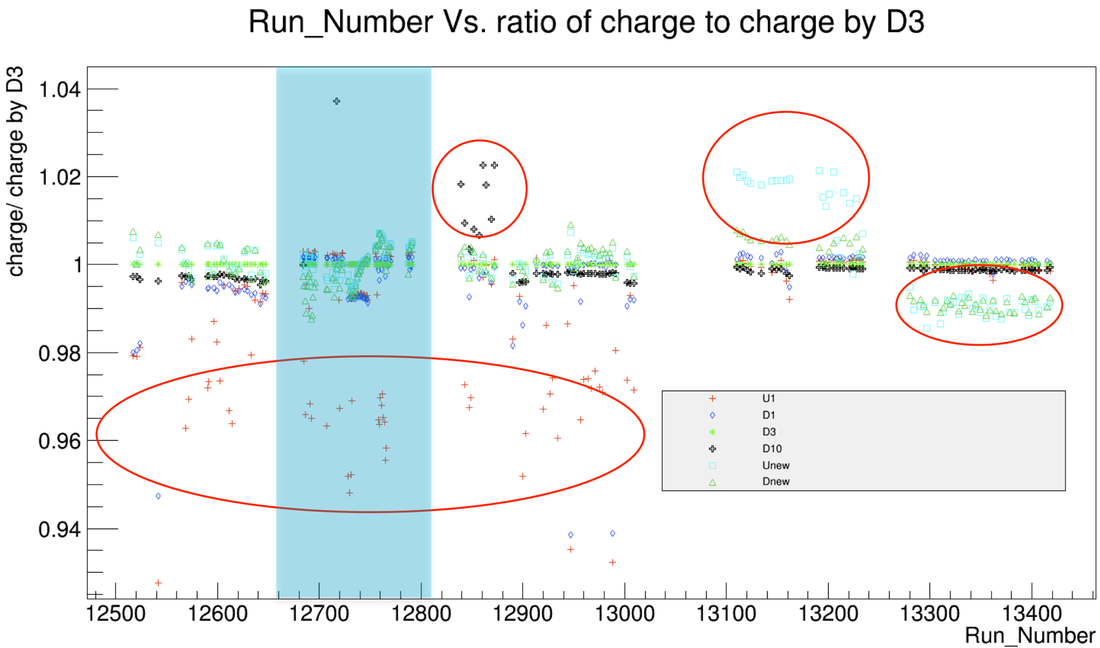

Figure 5: Charge measured compared against D3 charge. Binomial distribution for U1 cavity, D10 slight charge increase between run 12839 and 12980, Dnew and Unew charge difference in later runs. Optic runs all in the blue box.

Figure 5 compares the charge of all cavities against the D3 cavity for 30% of the production runs and all of the optic runs. The production runs chosen evenly spanned all production runs used in the slow scaler charge analysis. The red circles on the graph above highlight the major discrepancy between the cavities. There is a binomial distribution of charge for U1 cavity on the earlier runs, a slight increase in charge in the D10 cavity directly following the HRS optic runs and another slight variation in the Dnew and Unew cavities on the later runs. These abnormalities still require some further investigation to completely understand the cause of their divergence. The results for the fast scaler are similar to the slow scaler results obtained by Bishnu Karki. Figure 7 compares the ratio of the D3 charge of the fast scaler and slow scaler. The ratio is distributed around 1 except for a slight increase which is circled in red. This increase is directly related the length of the runs. When the runtime is short a larger difference between the total count of the fast and slow scaler is more frequent. When the time

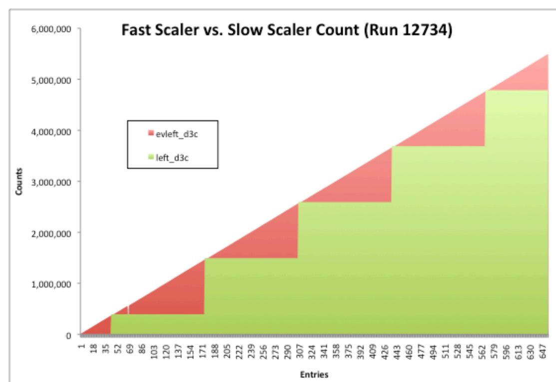

Figure 6: The fast and slow scaler counts for a specific run. The ratio between the yellow and red shade approaches one while number of entries increase

of the run increases the additional counts accumulated between readings is significantly smaller than the total count. This is observed in figure 6 where the ratio of the counts between the fast and slow scaler is larger in earlier entries.

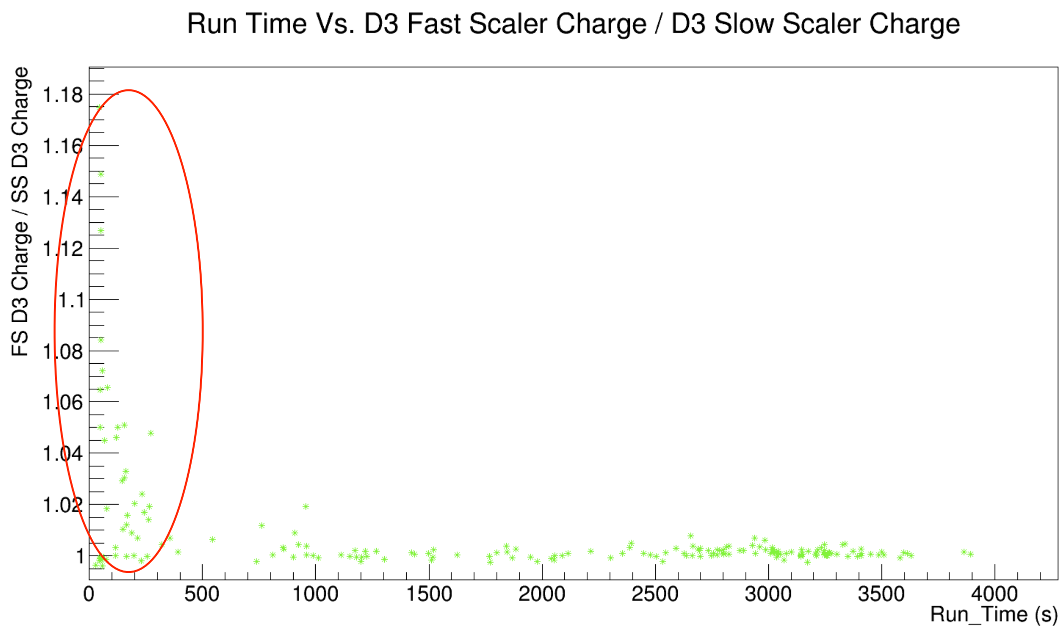

Figure 7: D3 charge for fast scaler divided by the D3 charge of the slow scaler. The area circled in red shows the impact of run length on the charge ratio between the two scalers.

Caveat

Figure 8 is an example of the fast scaler making a measurement error for two entries in run 13375. This error appears for random entries. This type error was observed in 15 out of 41 runs. The error either increases drastically, decreases drastically, or goes to zero. The random reading does not have an impact of the final signal count. A fix was put in place to remove the errors from the analysis. Dr. Paul King has resolved the issue and put in place fix to prevent future reading errors.[1]

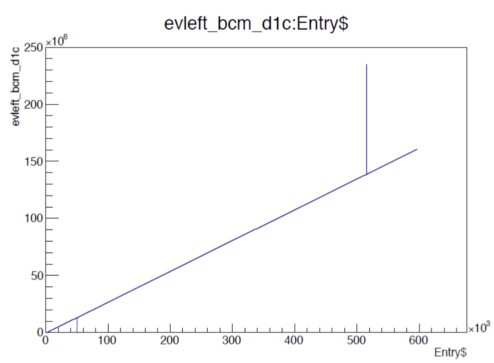

Figure 8: Error in count measurement with the fast scaler for the D1 cavity. There two errors in this example. One were the count goes to zero and where the count increases drastically. [Run # 13775]

Conclusion

[1] See Dr. Paul King' DVCS elog entry for fast scaler reading error: https://hallaweb.jlab.org/dvcslog/12+GeV/369

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In conclusion the vast majority of charges measured in each cavity are in agreement with the charge measured in the D3 cavity within 0.5%. The fast scaler and slow scaler results are in agreement with each other when runtime is closer to the production run length of 1 hour. However, resolution of the fast scaler is greater when the run time is shorter. Some of the abnormalities observed by some of the detectors still have uncertainty in their causes.

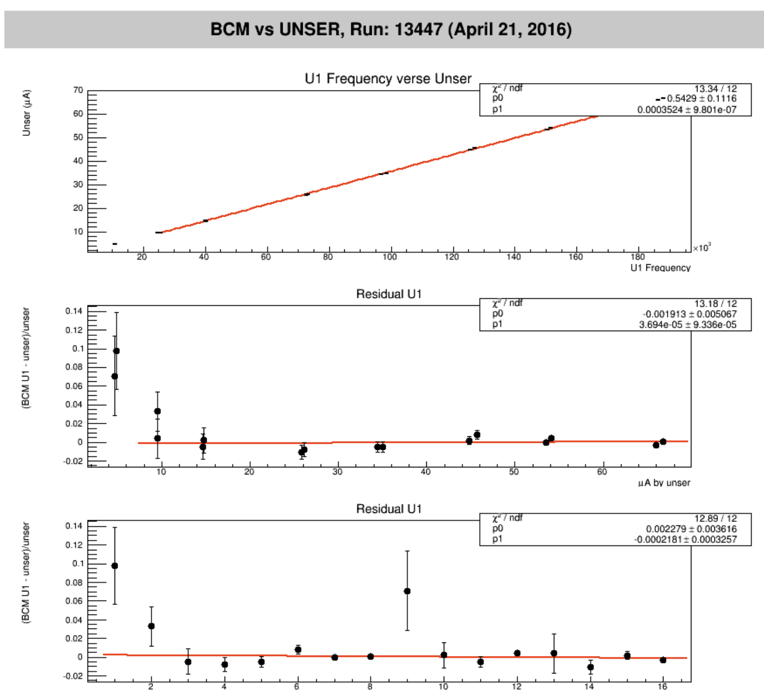
References

[1] Karki, Bishnu & Roche, Julie; "BCM's Calibration and Charge Normalization for Spring 2016", Ohio University, Athens, Ohio, June 6, 2016

[2] Laveissiere, Geraud; "Hall A Current Monitor (Operational Manual)", Jefferson Lab, Newport News, Virginia, November 25, 1997

[3] Denard, J.C.; Laveissiere, Geraud; & Saha, A.; "High Accuracy Beam Current Monitor System for CEBAF's Experimental Hall A", Proceedings of the 2001 Particle Accelerator Conference, Chicago

Appendix A: BCM Calibration Results for Run 13447



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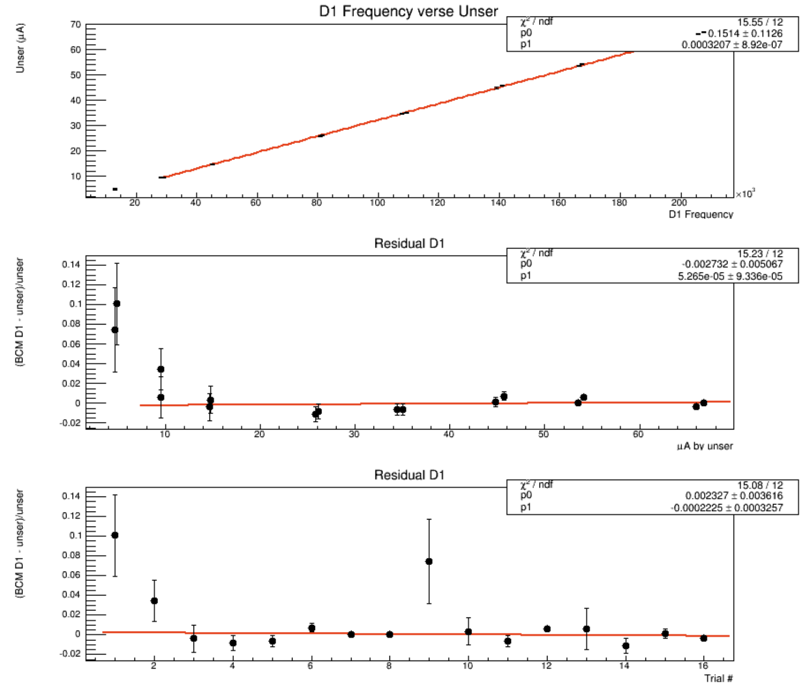
BCM vs UNSER, Run: 13447 (April 21, 2016)



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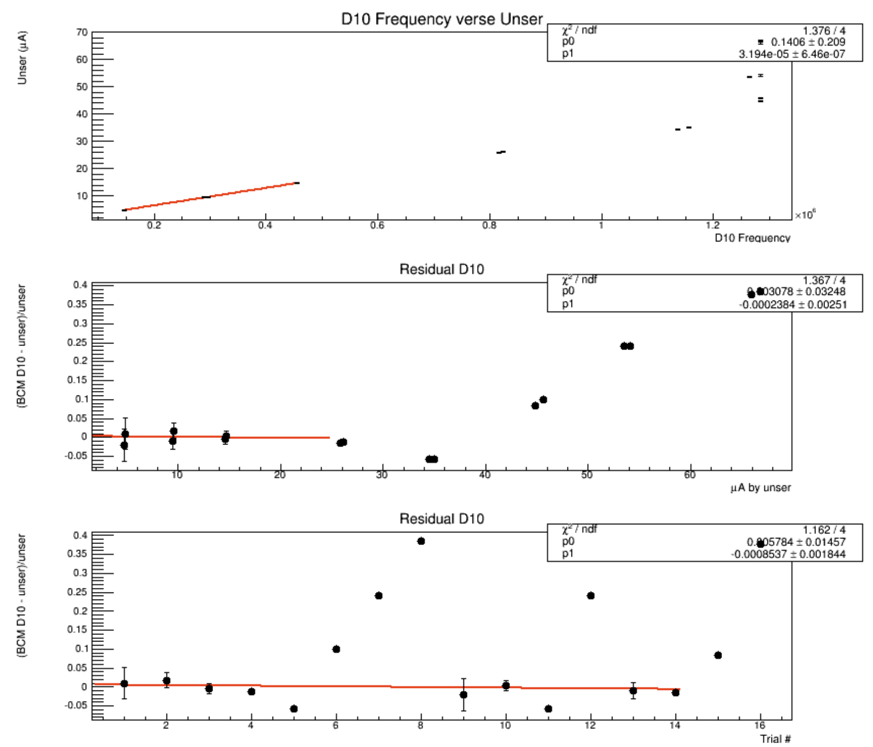

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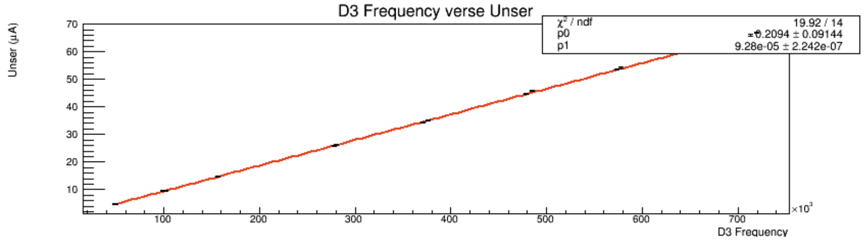
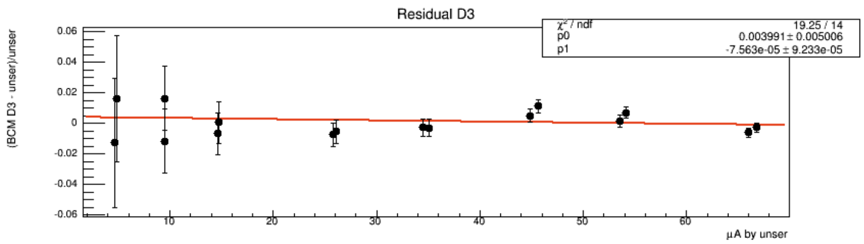
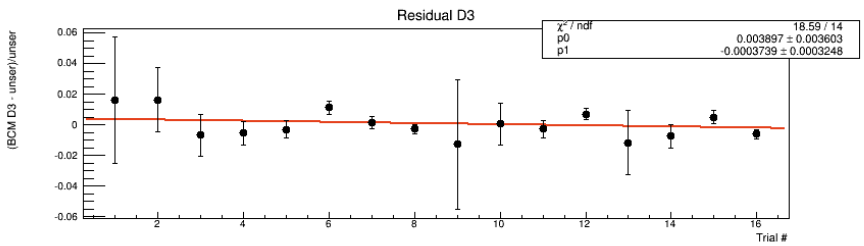
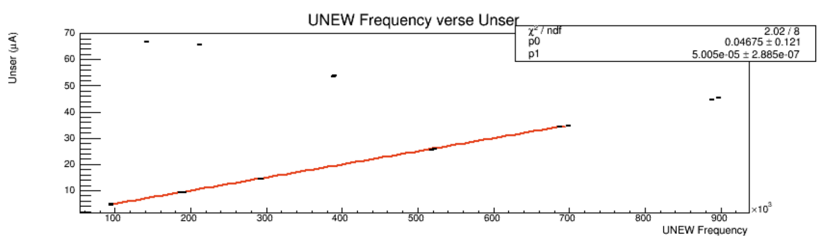
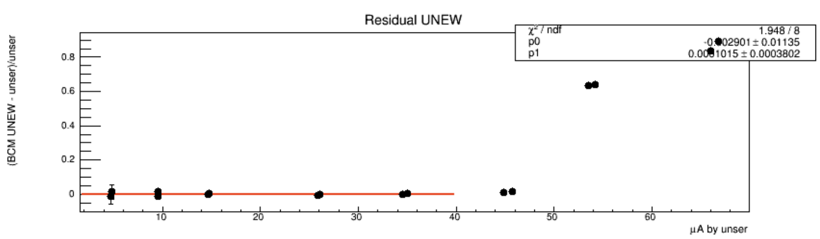


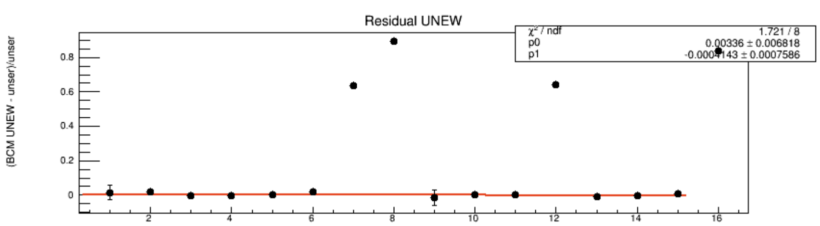




BCM vs UNSER, Run: 13447 (April 21, 2016)







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