Calibration of a 6-channel Front-End card

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The 6-channel Front-End (FE) cards for CMS hadron calorimeters are tested at FNAL (14th floor) before being assembled to Readout Module (RM). The 6-channel card is composed of 6 QIE chips. The QIE is the acronym for the functions of the ASIC, Q (charge) I (integration) and E (encode). A large dynamic range is accomplished through a multi-range technique. The input current is simultaneously integrated on all ranges, and comparators are used to select the lowest range that is not at full scale. The selected voltage representing the integrated charge is then put through an on-chip FADC. The outputs are a 5 bit mantissa representing the voltage and a two-bit code indicating the range. The QIE for CMS hadron calorimeter is described in detail elsewhere [1].

The goal of the test is not only to select good quality cards but to have the QIE response to the injected charge. The QIE response can be used for further calibration purposes. In this section, we describe procedures of quality controls of the 6-channel FE cards and the QIE responses for calibration Data-Base (DB).

1.1 Test Setup

The readout electronics for the QIE test shares the setup used for real data acquisition. The only difference is the source of input charge. Instead of HPD/PMT outputs, we use a charge injector as an input source.

We have divided FE cards into three types, HB/HE, HO, and HF. The HB, HE, and HO cards use HPD outputs as inputs and the only difference between HB/HE and HO cards is in different resisters. Since the difference is not shown up in the charge injector tests, the HB/HE and HO cards are considered as the same type of card. The HF cards have the same QIEs, but use an inverting input because the PMT output is a negative pulse. Therefore the HF cards omit one stage of amplifier, which has about 2.6× less gain per count.

The specifications of the charge injectors are,

- QIE test setup basic frequency : 40,079,900 Hz (± 0.01%)
- DAC LSB voltage = $20V/2^{18} = 76.294\ \mu V$ (± 0.01%)

- HPD (HB/HE/HO) QIE Injector board:
  - Ch. A injection resistor is 21,005 Ω (± 0.1%)
  - Ch. B injection resistor is 1,000,000 Ω (± 0.1%)
- PMT (HF) QIE Injector board:
  - Ch. A injection resistor is 7,660 Ω (± 0.1%)
  - Ch. B injection resistor is 68,100 Ω (± 0.1%)

All injected charges are relative (it's not ZERO when DAC A/DAC B=0x20000). Therefore the change in the injected charge with respect to the initial setting of 0 is relevant and the change is as follows.

- HPD (HB/HE/HO) QIE Injector board:
  - Charge A = 76.294 μV/40,078,900 Hz/21,005 Ω = 0.09063 fC per DAC A count.
  - Charge B = 76.294 μV/40,078,900 Hz/1,000,000 Ω = 0.0019036 fC per DAC B count.
- PMT (HF) QIE Injector board:
  - Charge A = 76.294 μV/40,078,900 Hz/7,660 Ω = 0.2485 fC per DAC A count.
  - Charge B = 76.294 μV/40,078,900 Hz/21,005 Ω = 0.02795 fC per DAC B count.

The input charges are carefully determined to scan through entire bins. The total 300 points are used for entire 4 ranges in the normal mode. Study shows that having 2-3 points per bin is enough to get the slope with accuracy better than 1%. We also checked that the individual point deviation is less than 1/2 of the bin size. The total of 100 points are used for the calibration mode. For the calibration mode, we also monitor pedestal variations by having QIE response to a certain input charge in each step (another 100 points in each change). The cards are tested using "Charge A" in the injector board for the normal mode and "Charge B" for the calibration mode.

The output data are stored in the directory, "*/data/qiec*", on cmshcal2.fnal.gov and run conditions are also recorded in the directory, "*/home/qiec/qiec/data*", as following file names.

- For HB/HE cards
  - *RunDescription.txt*
  - *ReTestRunDescription.txt*
  - *Final_Retest_RunDescription.txt*
- For HO cards
  - *HO_QIE_Run_Description.txt*
- For HF cards
  - *HF_QIE_Run_Description.txt*

1.2 Quality controls

The test is performed in the histogram mode so its output is stored as histograms. The histogram outputs are carefully analyzed to assure that only good quality cards are assembled to Readout Module (RM). The quality checks are done in both the normal and calibration modes.

1.2.1 Normal Mode

There are 4 ranges (0-3) and 5 different gains (1, 2, 3, 4, and 5 for 15, 7, 4, 3, and 3 bins, respectively) in each range. The gain factor is 1, 5, 25, and 125 for range 0, 1, 2, and 3, respectively. Therefore, the QIE gain varies from 1 fC/bin in the range 0 to the 625 fC/bin in the range 3, which compasses input charge from -1 fC to 10297 fC. The on-chip FADC in the normal mode is piece-wise linear.

The calibrations are done for each channel, range, capacitor. Therefore, a total number of calibration factors for a card is $6 \times 4 \times 4 = 96$. A QIE response in each bin is linearized based on the QIE specifications [1] and the mean value of linearized responses in a given injected charge is then taken as the QIE response. Only data points between bin=2 and bin=29 are considered for a global linear fit to exclude possible saturated data points.

Following values are defined for quality checks in the normal mode.

- Slope = Measured response (fC)/input charge (fC)
- Residual Rate = [(Measured-Expected) response from global fit]/input charge
- Residual in bin = Measured ADC bin-Expected ADC bin from global fit
- Missing bin = no signal bin

The slope distribution for HB/HE cards are shown in Figure 1 and a cut of $0.83 < slope < 1.03$ is imposed for all 4 ranges. The slope for HF cards is shown in Figure 2. The slope is about 1/3 of that of HB/HE cards and is required to be $0.331 < slope < 0.390$.

In addition to the slope requirement, following quality cuts are also imposed in the normal mode.

- Maximum of Residual Rate
  - < 0.002 in range 0.
  - < 0.002 in range 1.
  - < 0.003 in range 2.
  - < 0.006 in range 3.
- Maximum of Residual in bin
  - < 1.0 in range 0
  - < 1.0 in range 1

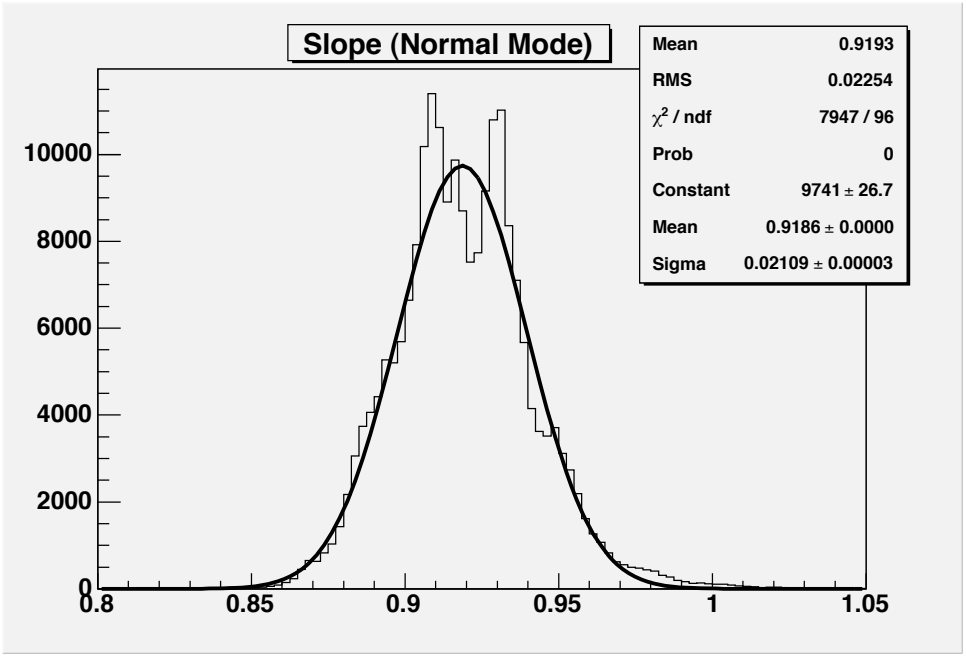

Figure 1: Slope distribution of HB/HE type cards in the normal mode.

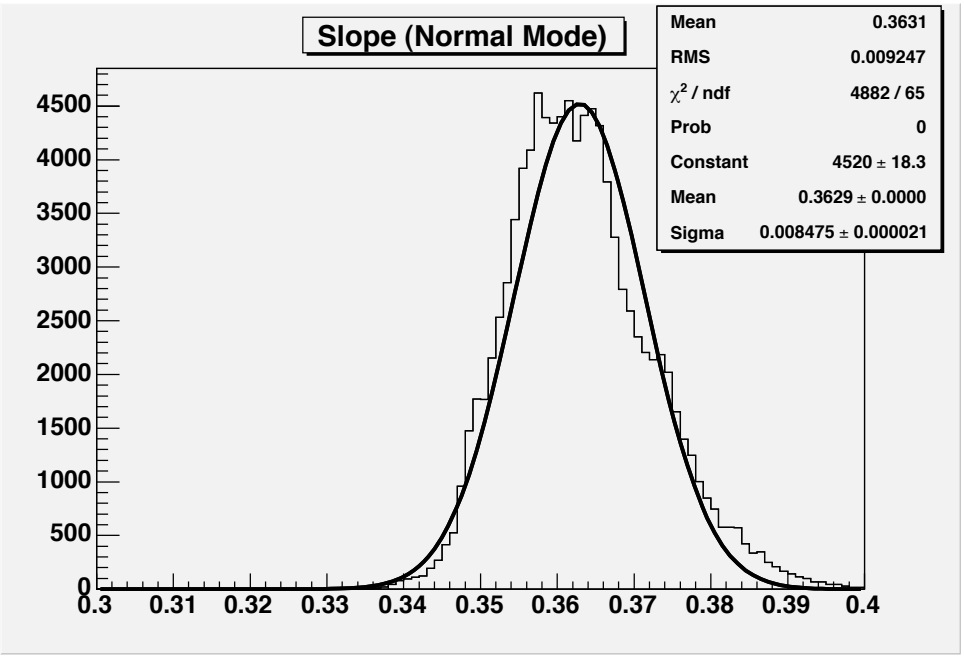

Figure 2: Slope distribution of HF type cards in the normal mode.

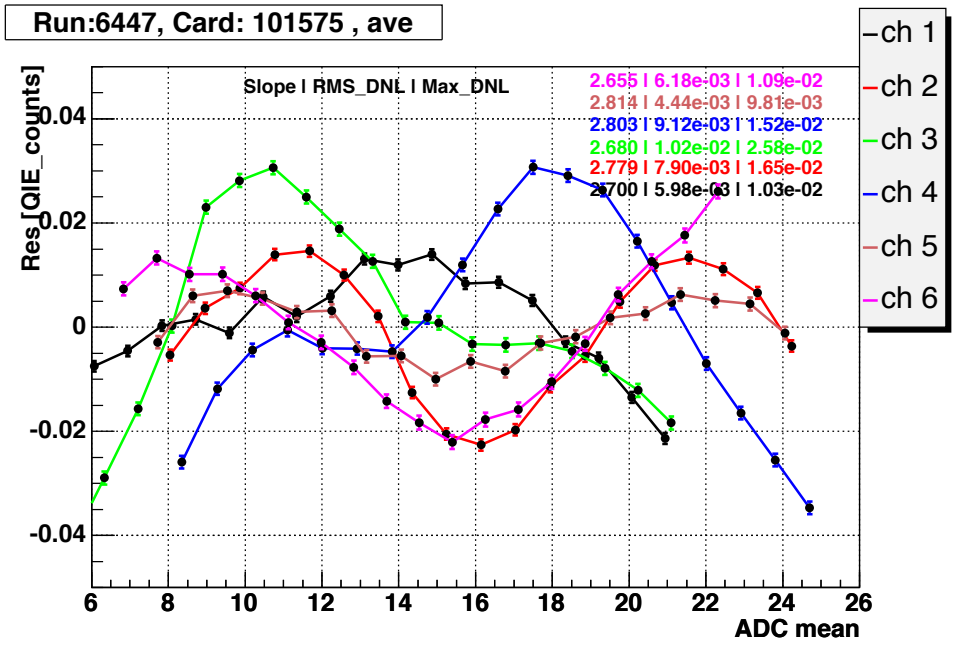

Figure 3: Residual distributions of 6-channel QIE card in the calibration mode.

  - < 1.0 in range 2
  - < 1.0 in range 3

- No missing bin in any range.

The missing bin is checked by looking at bin occupancies of histograms in the entire ranges and is required not to be present. Only cards that pass above requirements are processed to have calibration constants in the normal mode.

1.2.2 Calibration Mode

Only range 0 is active in the calibration mode and it is linear over the entire range. Its gain is 1/3 fC per bin and corresponding input charges for entire range are -2.333 fC to 10 fC.

A mean value of histogram for an injected charge is taken as the QIE response and the average of 4 capacitor outputs are used for calibration. The RMS of histogram is about 2.9 ADC counts. Therefore data points (histogram mean) between bin=4 and bin=28 are used for a global linear fit to exclude any saturated data point in the fit. The residual distributions of QIE responses to the global linear fit are illustrated in Figure 3. Because the maximum variation in the source calibration is expected to be less than 0.5 count, it is important to understand the residual. Based on our stability checks, the residuals to the linear fit in the QIE responses are reproducible. Therefore, the non-linearized (or measured) QIE response to each low bin edge is calculated and provided for better source calibration.

We define following values for quality checks in the calibration mode.

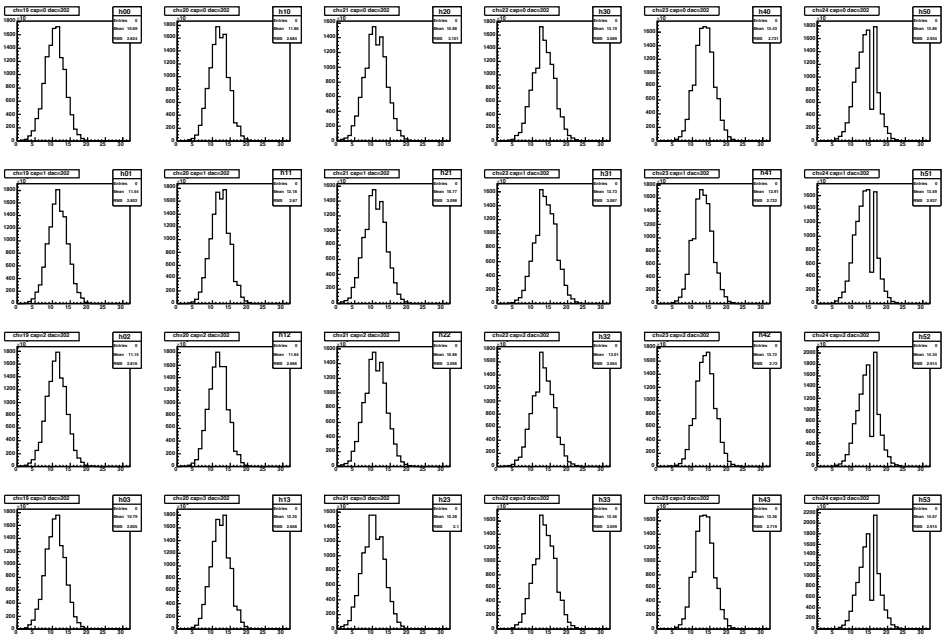

Figure 4: Pedestal distributions of a HF card in the calibration mode. The column represents 4 cap-id and the row shows 6 channels. The channel 6 has a small bin around bin=15.

- Slope = measured charge (fC)/input charge (fC)
- Integrated Non-Linearity (INL) = Measured-Expected from global fit
- Differential Non-Linearity (DNL) = [INL(i)-INL(i-1)]/[ADC(i)-ADC(i-1)]
- Small bin = Entries in bin (i) $< 0.6 \times$ Entries in adjacent bins (i-1) and (i+1)

We have observed several QIEs with at least a small bin as seen in Figure 4. The $4(cap-id) \times 6(channel)$ plots of pedestal distributions show a small bin=15 in channel 6. This might be due to a non-evenly divided resistor.

Figure 5 shows the slope distribution for HB/HE cards. We require the slope in calibration mode to be $2.55 < slope < 3.0$. The slope for HF cards is shown in Figure 6 and is required to be $1.01 < slope < 1.15$.

The other quality cuts are,

- RMS of DNL < 0.04
- Maximum of DNL < 0.1
- RMS of INL < 0.06
- Maximum of INL < 0.12

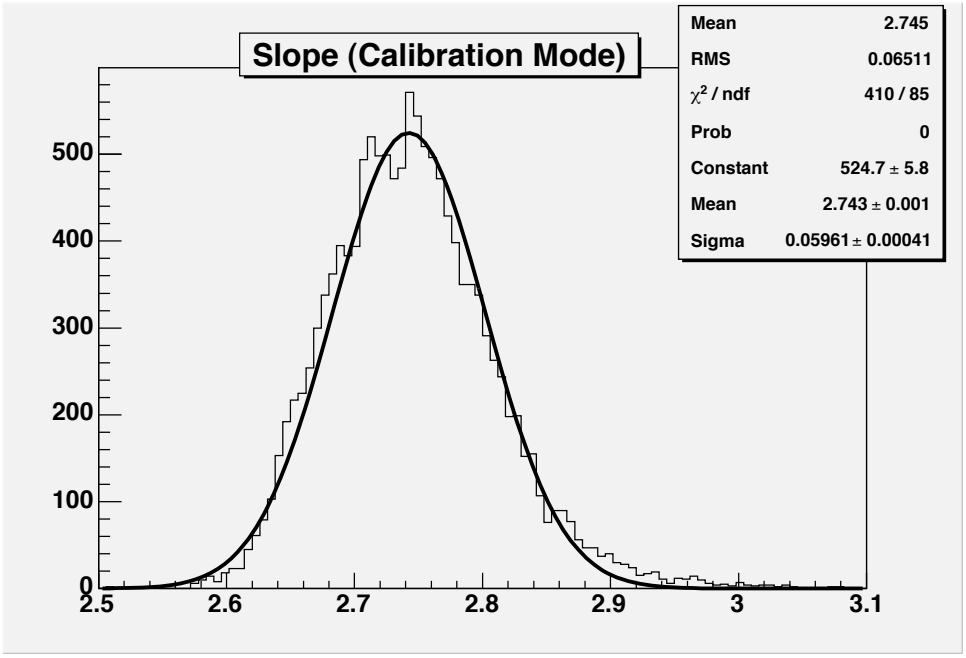

Figure 5: Slope distribution of HB/HE type cards in the calibration mode.

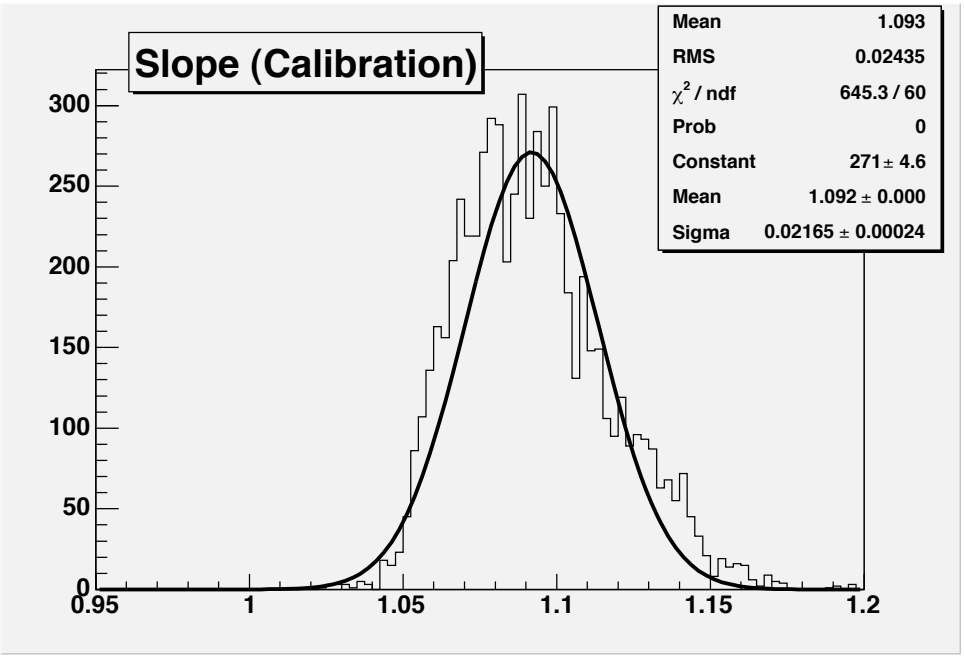

Figure 6: Slope distribution of HF type cards in the calibration mode.

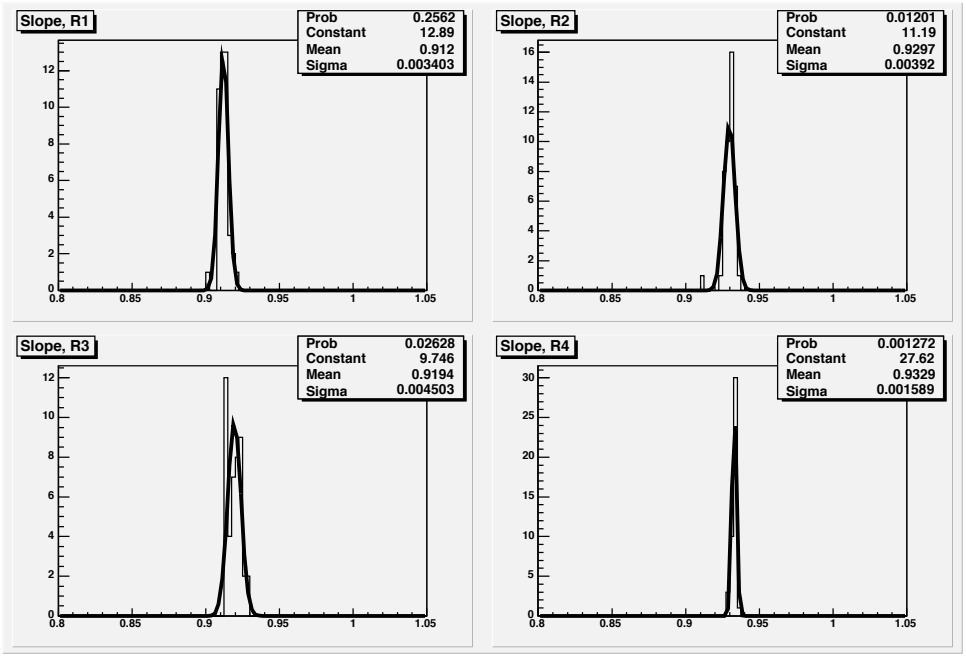

Figure 7: Slope distribution of card=100001, Ch=1, CapId=1 for 4 different ranges. The σ is $\sim$ 0.3-0.4 % to slope mean.

- No small bin

The only cards which pass quality requirements in both normal and calibration modes are passed to assemble into RM. There was an exception for some cards that failed in the calibration mode (called as "*ugly card*") but passed all requirements in the normal mode were assembled to the calibration module. The measured QIE responses in the calibration mode are also processed for calibration constants.

1.3 Stability of Charge Injection Test

We have selected 5 HB/HE type cards (barcode=100001, 100003, 10005, 10007, and 100009) to ensure that the test setup is properly running. In addition, we use data to check stability of the charge injection setup by analyzing the QIE responses over a long time. All 5 calibration cards were kept in a box safely and were tested each time before we processed to test other cards. Based on 46 good tests, we have analyzed the card=100001 to see the variation of QIE response, especially for a single range and a capacitor.

Figure 7 shows the slope distribution of a card=100001, ch=1, and CapId=1 for 4 different ranges. As seen in the plots, the σ is $\sim$ 0.3-0.4 % of the mean value and this is compared to the 2.2% in Figure 1.

The slope profile of the card=100001 and Ch=1 in terms of ranges and CapId is shown in the Figure 8. The response separation for different range and capacitor is clearly seen and this suggests that a separate calibration for each range and capacitor will improve calorimeter energy resolution.

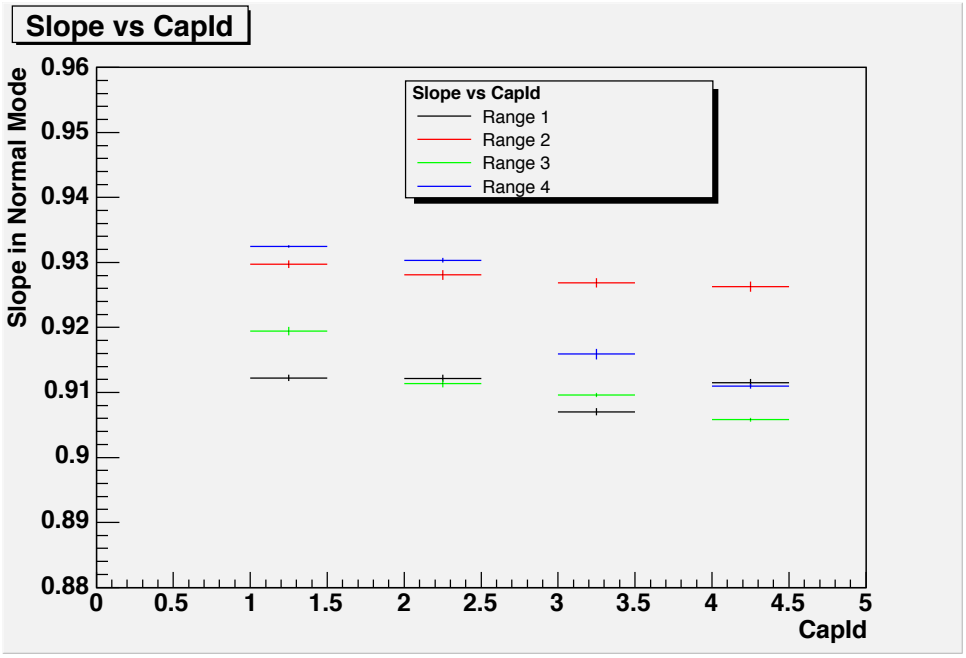

Figure 8: Slope profile of card=100001, Ch=1 for 4 different ranges and 4 capacitors.

1.4 Calibration constants

Output data are formated on a line by line basis and each line shows a self contained for interpretation. The outputs in each line reflect the mode ($Calibration/Normal$), card identification (barcode), channel, and QIE responses.

For the normal mode, we store slopes and offsets from linearized responses for each channel, cap-id, and range. Linearized response for each ADC bin is calculated by interpolating adjacent data points and is also provided for cross checks. In the calibration mode, the measured (non-linearized) responses for all 32 bins as well as the slope and offset from global linear fit are stored. Data points that were not measured (mostly in bin <5 or bin>25) are taken from linearized fit.

The corresponding QIE response to a bin in both normal and calibration modes is interpolated to the low edge of ADC bin based on two adjacent measured points.

The outputs are stored in the following directories,

- Calibration Mode
  - $/home/qiec/Prod\_scripts/DB\_HBHE(HO,HF)\_Calib$
- Normal Mode
  - $/home/qiec/Prod\_scripts/DB\_HBHE(HO,HF)\_Normal$

and data formats are as followings.

- Calibration mode

  - *Calibration run# barcode channel offset slope charge0 charge1...charge31*

- Normal mode
  - *Normal run# barcode channel cap-id range offset slope charge0 charge1...charge31*

References

[1] Specification for CMS QIE ASIC, 2/5/01,
http : *//www* − *ppd.fnal.gov/tshaw.myweb/CMS/QIE/qie_spec*1.*pdf*