1 Executive Summary

1.1 Proposed Tests

We propose that all groups use the following three tests to flag bad channels:

- Pinhole Test: Identifies pinholes and noisy channels; is insensitive to grounding scheme and local noise sources. (See section 4.4 for details.)
- Gain Scan: Identifies pinholes, PA-sensor and sensor-sensor opens, and shorts; is insensitive to grounding scheme and local noise sources. (See section 4.5 for details.)
- Noise Measurements: Identifies pinholes, PA-sensor and sensor-sensor opens, and shorts and in insensitive to local noise sources when properly grounded and held in proper fixturing. (See section 4.1 for details.)

The channel failure's in these three test can be correlated to definitely identify the fault type. To do this, various failure levels have to be defined and assigned in each test. By requiring confirmation of failures in multiple tests, we avoid incorrect bad channel flagging due to statistical fluctuation in one test.

A root macro which analyzes the root output of the ARCS 6.0 software is under development and can currently identify both open types, pinholes, and noisy channel.The macro, described more thoroughly in section 5 is downloadable from hep.ucsb.edu/cms/arcs_macro.html.

1.2 Proper setup for noise measurements

To use the noise measurement to its full potential, proper grounding and fixturing is needed. This entails the following:

- The testing fixture has to have a complete metal shield
- The module holding plate has to held by non-conductive material with at least 3 mm distance from the metal shield.
- The metal shield has to be connected to ground with a very thick wire or ground braid. The wire should connect to the ground at the hybrid-to-utri adapter (the closest point to the hybrid not on the module).

- No other ground connections should be made. Floating LV and HV power supplies are preferable, but have not been shown to be absolutely necessary

The fixturing and grounding are done properly if and only if the common mode noise taken in peak mode, inverter off is less than 0.5 ADC. The fixturing, used by UCSB and FNAL, which achieve this grounding is described in section 2. Diagrams and pictures of the clam shell are available at hep.ucsb.edu/cms/clamshell.html.

1.3 Pedestal and pulse height measurements

The pedestal test and pulse height measurement should not be used in bad channel flagging. The pedestal test does not much sensitivity to bad channels. The pulse height measurement is sensitive to grounding scheme and does not find most opens; we propose it is made optional.

Study for Cross Calibration Procedures of the CMS Silicon Strip Detectors

Tony Affolder, Claudio Campagnari, Joe Incandela, Steve Levy
University of California-Santa Barbara

Patrick Gartung
University of California-Riverside

Elizaveta Chabalina
University of Illinois-Chicago

Alice Bean, Leonard Christofek
University of Kansas

Lenny Spiegel, Slawek Tkaczyk
Fermilab (FNAL)

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2 Introduction, Test Setup and Grounding Schemes

The following study is designed to define the set of tests for cross calibration of CMS silicon strip detectors. The study uses the first production TOB module produced at UCSB. The test setup consisted of floating LV and HV supplies, an ARCS controller, a new ARC FE, an ARC LED system, a hybrid-to-utri version D adapter card, and UCSB module clam shell (with a dry air supply).The module clam shell, shown in figure 1 acts as a Faraday cage and a dark box. The module is positioned by two plastic guide pins and two plastic bars, which separate the module carrier plate from the clam shell by 1 cm. The clam shell is designed so that the grounding of the module carrier plate can be easily changed by the user. All tests were performed at a relative humidity less than 20%.

Figure 1: UCSB module clam shell.

Four grounding schemes have been investigated. Grounding scheme 0 has both the clam shell and the module holding plate floating. Grounding scheme 1 has the clam shell grounded and the module carrier plate floating. The grounding line is a high gauge wire which is soldered to the ground side of a tantalum capacitor on the hybrid-to-utri adapter board; the other end of the wire is screwed onto the clam shell (see figure 2), connecting the ground as close as possible to the hybrid. Grounding scheme 2 has module carrier plate grounded with the same wire with the clam shell floating. Grounding scheme 3 has both the module carrier plate and the clam shell connected to ground with separate wires soldered to the same tantalum capacitor.

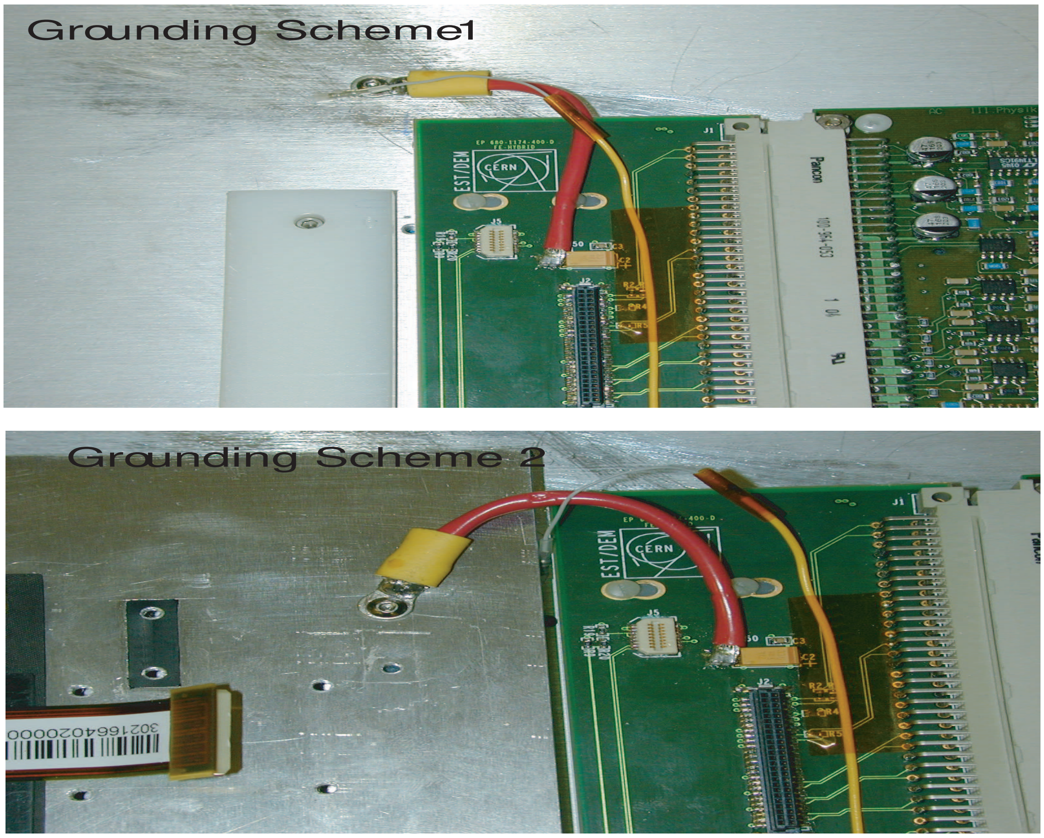


Figure 2: Top: Grounding Scheme 1. Bottom: Grounding Scheme 2

In addition, the effects of environmental noise was studied using the largest controlled source of broadcast noise we had available, the CMS gantry system. Each test was performed twice: first with the gantry not operating and then again with the gantry operating continuously.

2.1 Bad channels in TOB module 876

Thorough testing along with an extensive visual inspection found the following number of flawed/bad channels:

- Channels 1, 2, and 511 have opens between the pitch adapter (PA) and the first sensor.
- Channels 266 and 295 have opens between the two sensors.
- Channels 278 and 279 have high noise, believed to be caused by a visual defect in the strips. The noise is highly correlated with the module's bias current, strengthening the agreement that they are leaky strips. Unfortunately, this makes the channel's noise fairly variable.
- Channel 500 has a bonded pinhole, which was seen in sensor probing.
- Channel 92 and 93 has a bad CAC in sensor probing.
- Channel 176 has a high I_{strip} in sensor probing.

3 Tests Studied

The following module tests were performed in all modes available (peak off, peak on, deconvolution off, deconvolution on) using ARCS 6.0β (where all other settings assume their ARC default value):

- Pedestal/noise test.
- Two-MIP calibration charge injection.
- Multi-point gain.

In addition, the pinhole test (increasing LED illumination) was taken in peak off mode

3.1 Quality control criteria in *Procedures for Module Testing* [1]

We summarize the quality control cuts proposed in [1] for convenience:

1. $|P_i - \langle P \rangle| < 0.2\langle P \rangle$
2. $|N_i - \langle N \rangle| < 0.2\langle N \rangle$
3. $|C_i - \langle C \rangle| < 0.2\langle C \rangle$

where P_i (N_i, C_i) indicates the pedestal (common mode subtracted noise, calibration response) of the i-th channel and $\langle P \rangle$ ($\langle N \rangle$, $\langle C \rangle$) is the mean pedestal (common mode subtracted noise, calibration response) of the chip corresponding to the i-th channel. The calibration response is measured at its maximum value. Backplane pulsing, proposed in [1], is not available in ARCS 6.0β .

The modules are determined to be *Grade A* if it has less than 1% bad channels with a bias current of less than $40\mu A$, *Grade B* if it has less than 2% bad channels with a bias current less than $40\mu A$, and *Bad* otherwise. We note that since these hybrids hold 4 chips with 128 channels each, this means that a module with 11 channels which fail the tests listed above will be marked as *Bad*.

4 Study Results

4.1 Noise measurements

The test that we found most sensitive to grounding scheme/noise environment is the noise measurement. Figures 3 and 4 show the noise in the grounding scheme 1, the default scheme for testing at UCSB. With this grounding (where the clam shell is grounded and the module holding plate is floating), the clam shell acts as an ideal Faraday cage, removing any broadcast (radiation) effects. As shown in figure 3, no common mode noise is seen in any of the four modes of operation with the gantry off (the gantry will be used as a source of noise in this study). The known open channels have a characteristic noise which decreases with decreasing load capacitance, as one would naively expect. The known pinhole acts saturated with noise lower than that of a disconnected channel, again matching expectations. Figure 4 shows that the grounding scheme with the clam shell is effective at removing broadcast effects, yielding the same noise performance as when the gantry is not operating.

The noise characteristics of a PA-sensor open, a sensor-senor open, and a pinhole are the same on 8 modules tested at UCSB and 3 modules tested at FNAL, using the module clam shell and this grounding scheme. These noise ranges have been included in our analysis macro of the ARCS 6.0β root file to locate opens and pinholes, and are shown in the noise figures as dotted lines. Using the noise to locate the position of opens will be useful when visual

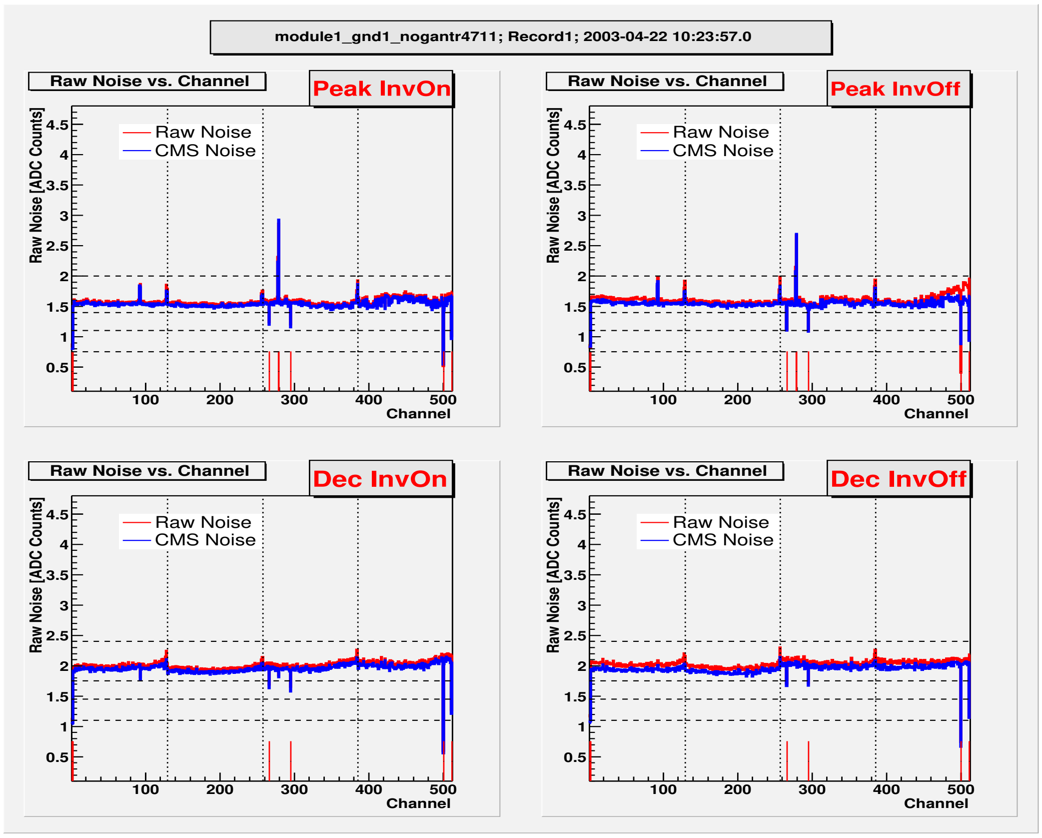


Figure 3: Noise measured using grounding scheme 1 (module holder floating, clam shell grounded) with the gantry not operating

inspection and/or led systems are not available, such as rod/petal burn-in or during operation. The high noise cut was chosen to be at a semi-arbitrary value above the noise at chip edges. The preliminary values of these values are:

Peak mode:

- $N_i < 0.75$ (pinhole)
- $0.75 < N_i < 1.10$ (PA-sensor open)
- $1.1 < N_i < 1.4$ (sensor-sensor open)
- $N_i < 2.0$ (high noise channel)

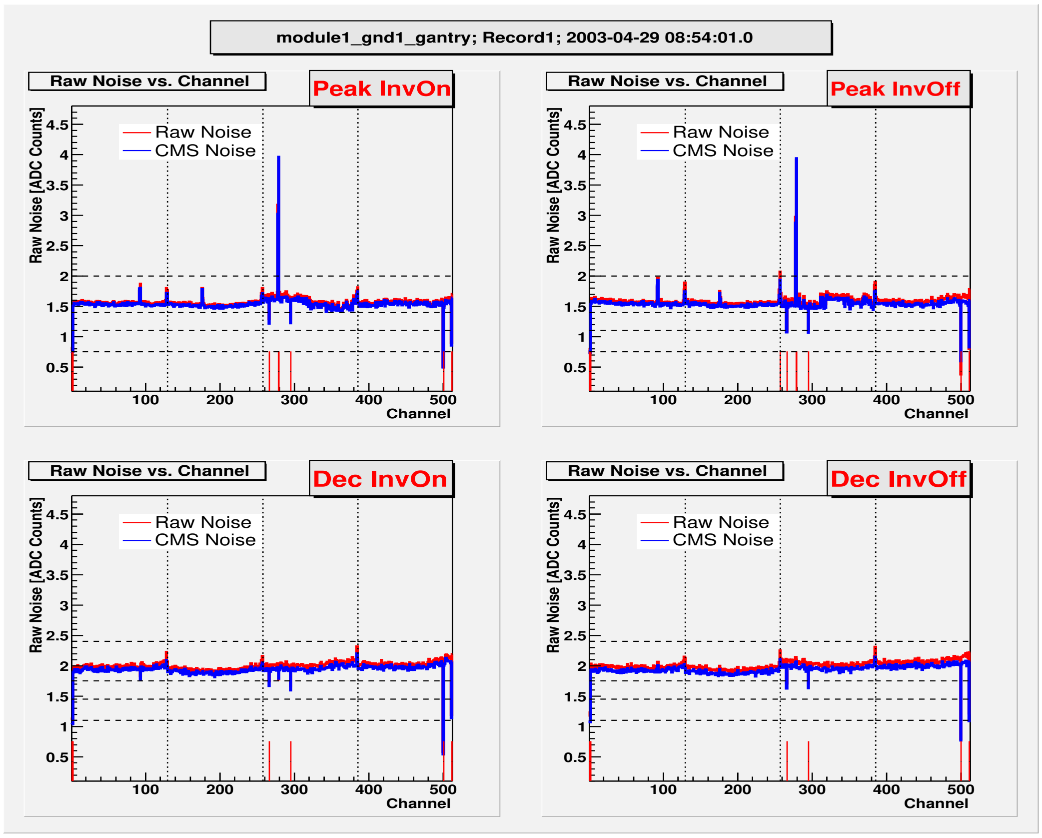


Figure 4: Noise measured using grounding scheme 1 (module holder floating, clam shell grounded) with the gantry operating

Deconvolution mode:

- $N_i < 1.1$ (pinhole)
- $1.1 < N_i < 1.4$ (PA-sensor open)
- $1.4 < N_i < 1.75$ (sensor-sensor open)
- $N_i < 2.4$ (high noise channel)

The noise performance in grounding scheme 3 (where both the module carrier plate and the clam shell are grounded) is the same as in grounding

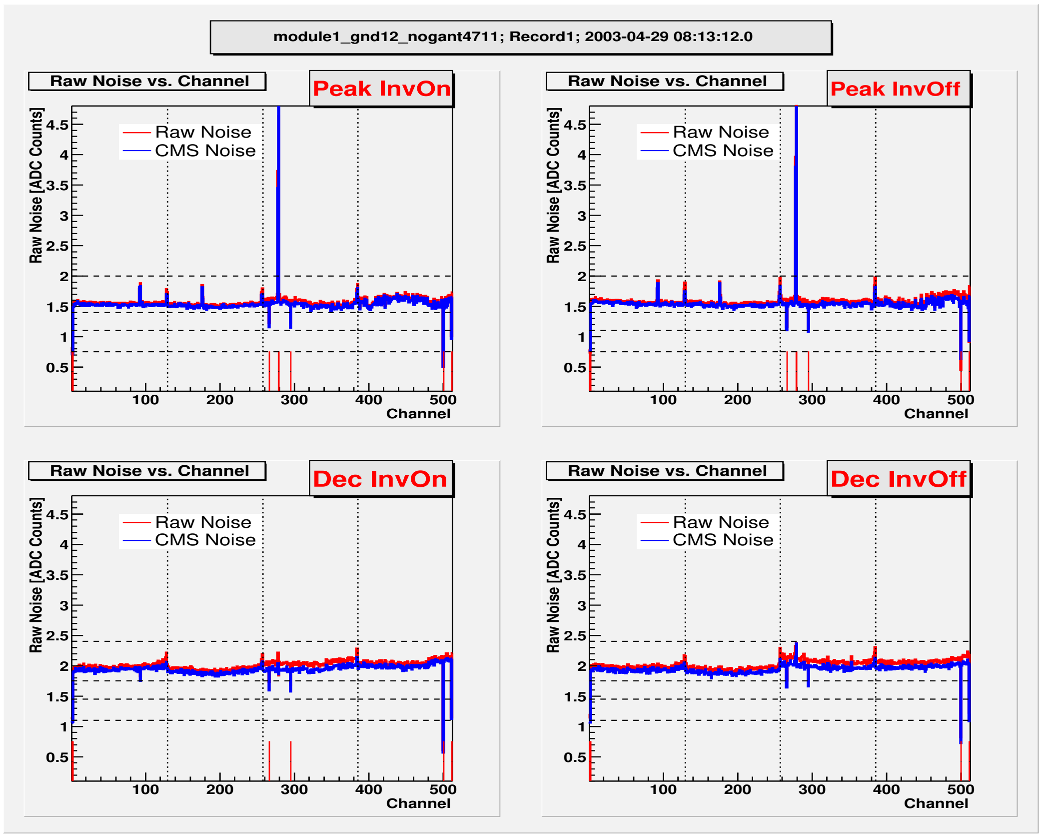


Figure 5: Noise measured using grounding scheme 3 (module holder and clam shell grounded) with the gantry not operating.

scheme 1, as shown in figures 5 and 6. We chose grounding scheme 1 as the default only because it is closer to the ideal Faraday cage test configuration.

Figures 7 and 8 show the noise with neither the module holding plate nor the clam shell grounded (grounding scheme 0). The common mode noise with peak inverter off is very large (3-4 ADC) without the gantry in operation and is about 0.5 ADC counts larger with the gantry in operation. The common mode subtracted noise for pinholes varies greatly between the inverter off and on modes. In peak inverter off, the pinhole (channel 500) has a very large noise (4 ADC); in peak inverter on, the pinhole's noise (0.8) is lower than a regular channel. The noise of all open channels is higher than good channels, but the exact noise level though is dependent on the environmental

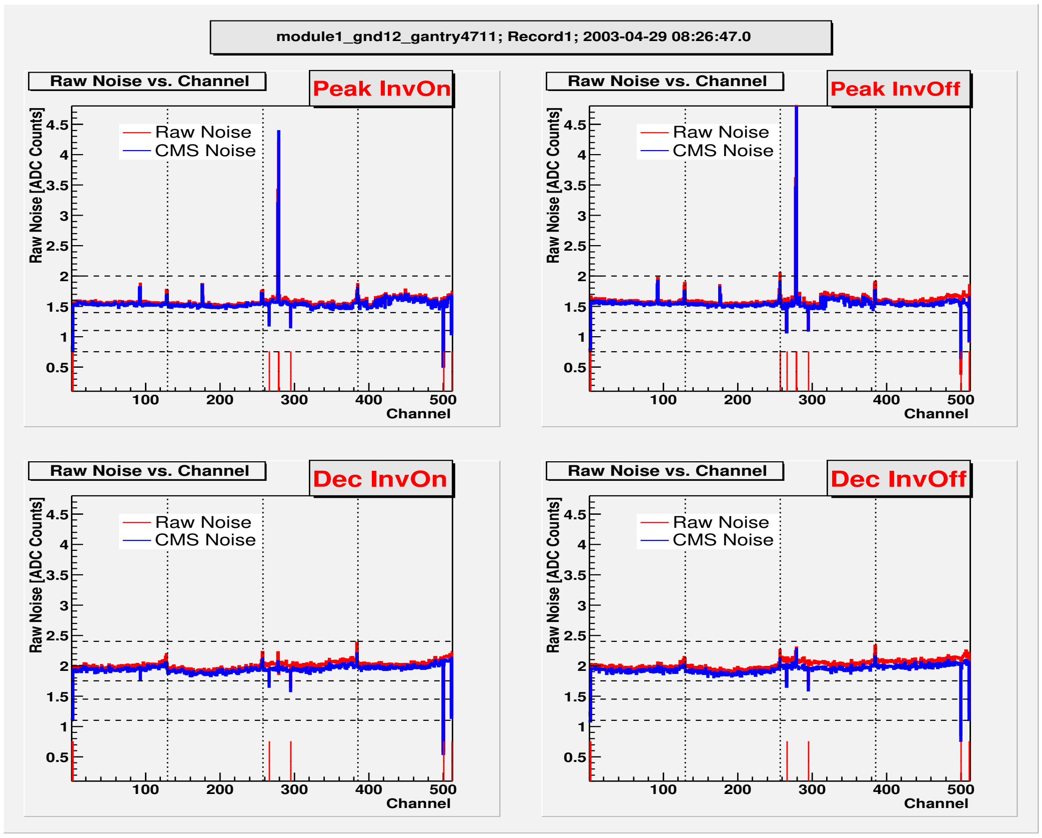


Figure 6: Noise measured using grounding scheme 3 (module holder and clam shell grounded) with the gantry operating.

conditions during testing. The sensor-sensor opens when the gantry is not operational is 3 ADC in peak mode, but increases to > 4.8 ADC when the gantry is operational. The variation of the noise level with environmental conditions does not allow for the identification of the open's location using the noise.

The noise measurements using grounding scheme 2 (where the module holding plate is grounded and the clam shell is floating) shows the real danger of testing when the common mode noise is not minimized. Figure 9 shows the noise performance with the gantry off. The sensor-sensor opens and the pinhole have the same noise as in the grounding scheme 1 in peak mode. On the other hand, the PA-sensor opens are at the same level as good channels.

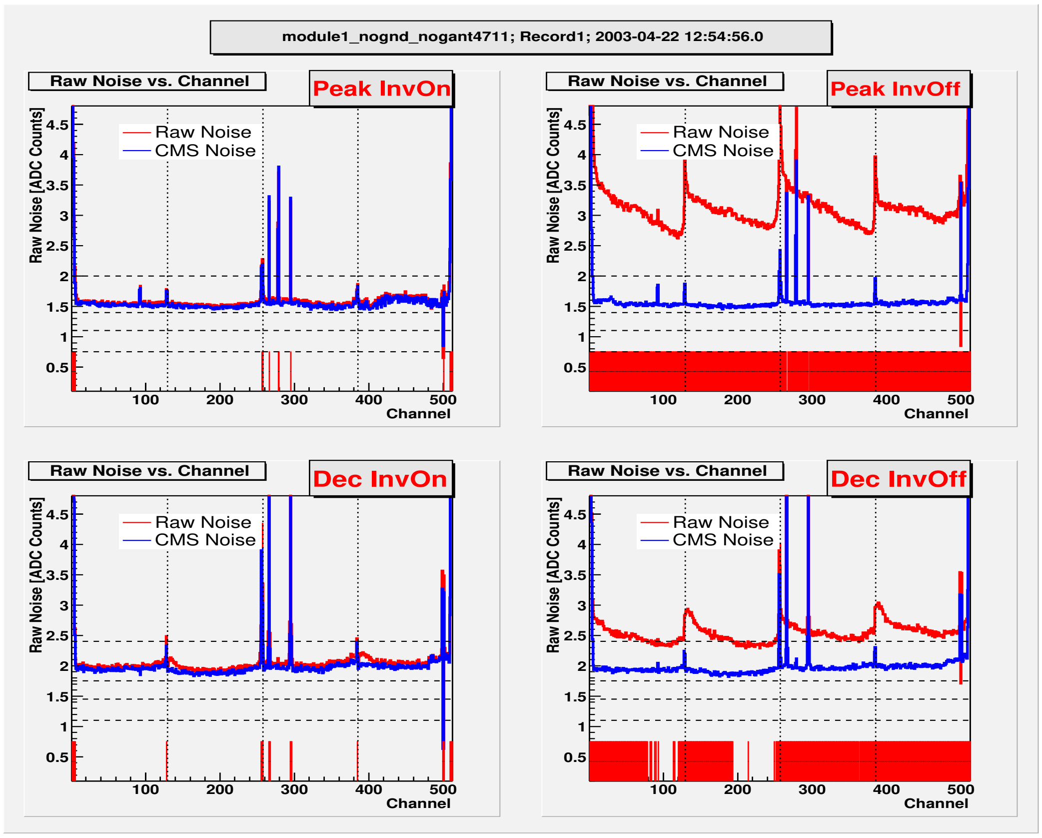


Figure 7: Noise measured using grounding scheme 0 (module holder and clam shell floating) with the gantry not operating.

In deconvolution mode, the pinholes also have the same noise characteristics as in grounding scheme 1. The noise in channel with sensor-sensor opens, on the other hand, cannot be distinguished from regular channels, and PA-sensor open now have a very high noise (4 ADC).

The situation is confused even more when environmental noise sources are present (shown in figure 10). With the gantry on in peak mode, the noise of sensor-sensor opens is now higher than average; in contrast to the situation without the gantry operating as a noise source, where the noise was lower than average. This indicates that there is a level of noise induced from environmental effects that can cause the noise of open channels to be lower than, equal to, or higher than an average channel. The pinhole's common

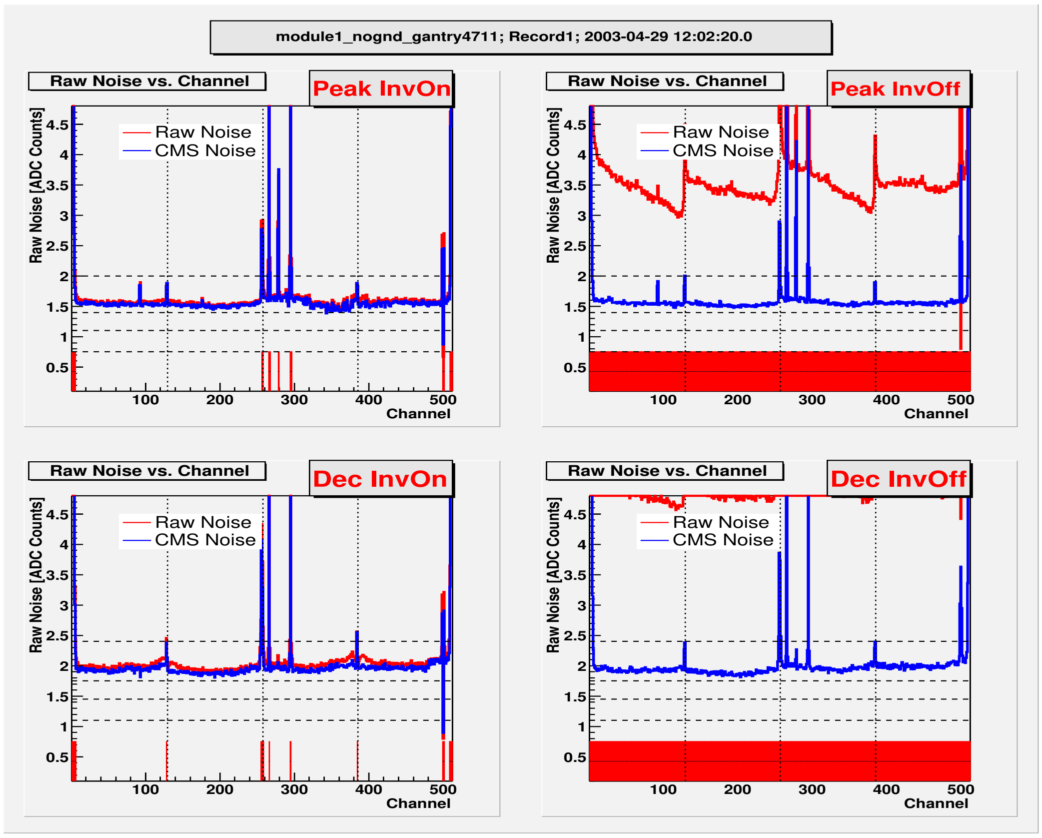


Figure 8: Noise measured using grounding scheme 0 (module holder and clam shell floating) with the gantry operating.

mode subtracted noise also increase with gantry operation. With a larger noise source, it is conceivable that pinhole could have the same noise as a good channel. Thus, extremely low common mode noise along with good shielding will be extremely important to get uniform testing over the 1-2 year long production run.

4.2 Pedestal measurements

The pedestal is not affected greatly by grounding or environmental effects. Figures 11 and 12 show the pedestal measured in the quietest and nosiest environments respectively. The pedestal levels for good channels are the

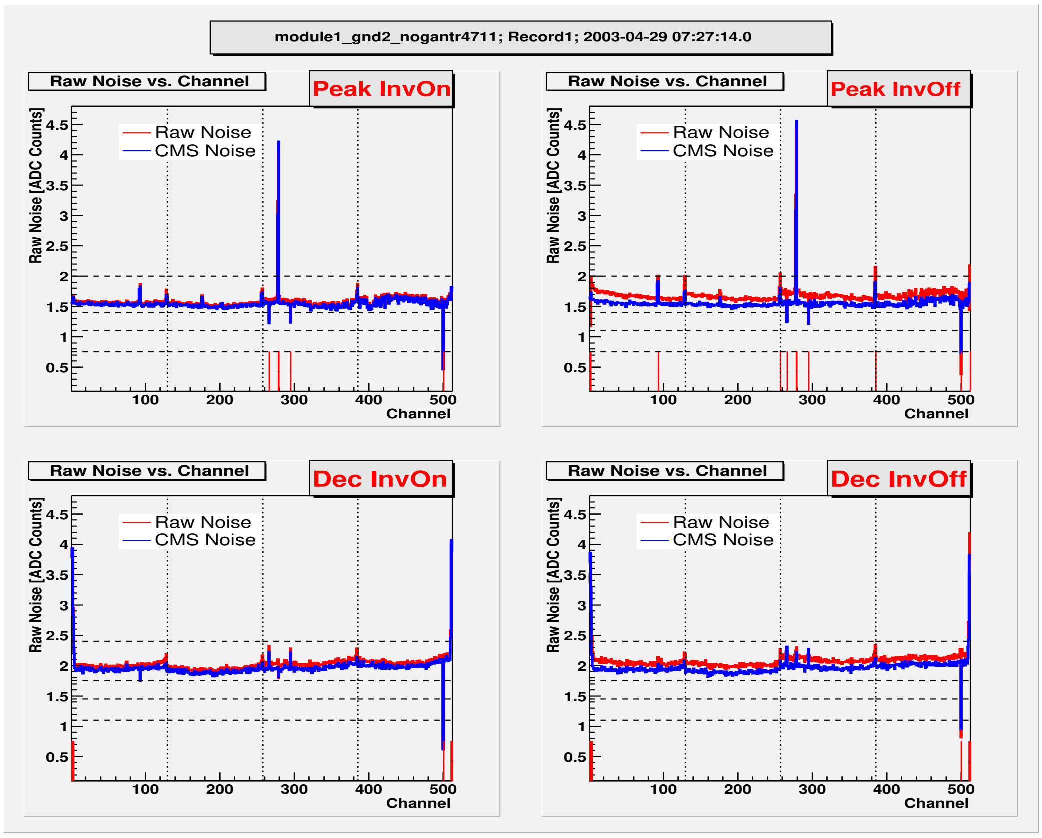


Figure 9: Noise measured using grounding scheme 2 (module holder grounded, clam shell floating) with the gantry not operating.

same in the two cases. In a quiet environment, the pedestals of good and flawed channels are the same; in the noisy environment, the pedestal for the flawed channels are different, but are not reliably differentiated from good channels. The pedestal requirements are designed to find channels with a limited dynamic range; it is not clear whether the pedestal measurements can measure this effect.

4.3 Pulse shape

The pulse shape measurement is intended as a single point (2 MIP) gain measurement, which searches for opens, shorts, and pinholes. In [1], a channel has

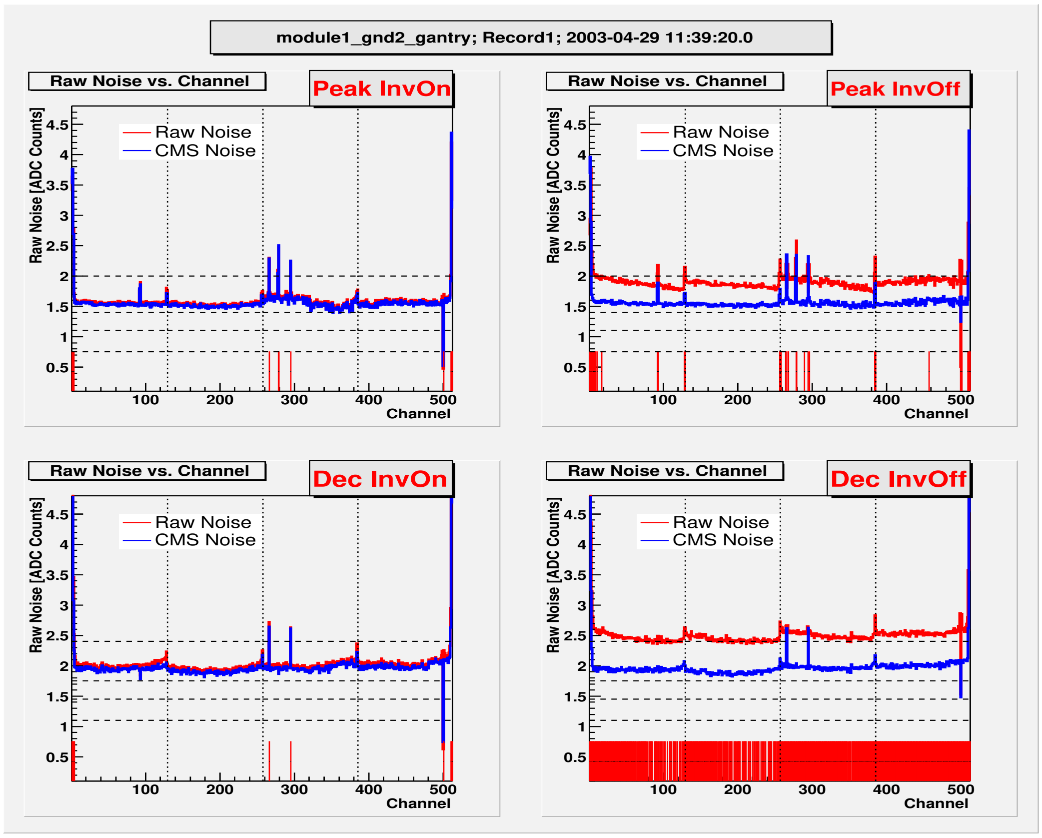


Figure 10: Noise measured using grounding scheme 2 (module holder grounded, clam shell floating) with the gantry operating.

to be within ±20% of the chip's average response to pass the requirements; the ±20% requirement is determined by the uniformity of the calibration injection. The capacitor in the calibration circuit varies at the ±10% level, and pickup from the trigger sequence causes additional non-uniformity of the pedestal at the ±10% level. For the figures, a tighter ±12% requirement is used, in the hopes of being more sensitive to faulty.

Figures 13–15 give representative examples of this test's results with the different grounding schemes and with local noise sources. The pulse shape test is fairly insensitive to the external noise sources as shown by the first two figures. This insensitivity holds true for all grounding schemes. In all tests performed, pinholes acts as expected: the channel has no calibration injec-

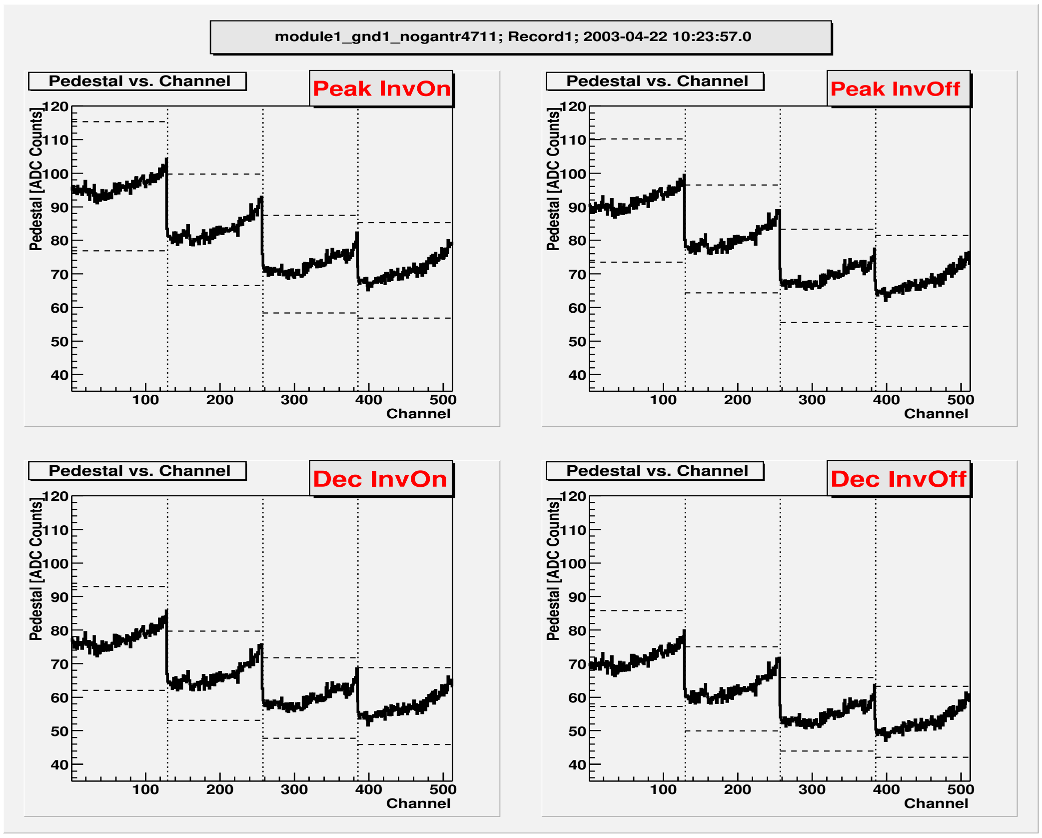


Figure 11: Pedestal measured using grounding scheme 1 (module holder floating, clam shell grounded) with the gantry not operating.

tion response. The sensitivity to opens is much less uniform. In grounding scheme 1 (which has the least amount of noise), only 1 of the 5 open channel fail the test in peak mode, even with the tighter requirements. The requirements cannot be tightened further without greatly increasing the likelihood of incorrectly marking a good channel as bad, especially at the chip edges. In deconvolution mode, all 5 opens would be marked as bad with the tighter requirements; otherwise, only PA-sensor opens would be marked as bad. Thus, as long as all modules are tested in both modes, all opens should be marked as bad by this test. Obviously, one would prefer that opens would fail in both modes, allowing for correlations between tests that would dramatically reduce the rate of marking good channels as bad.

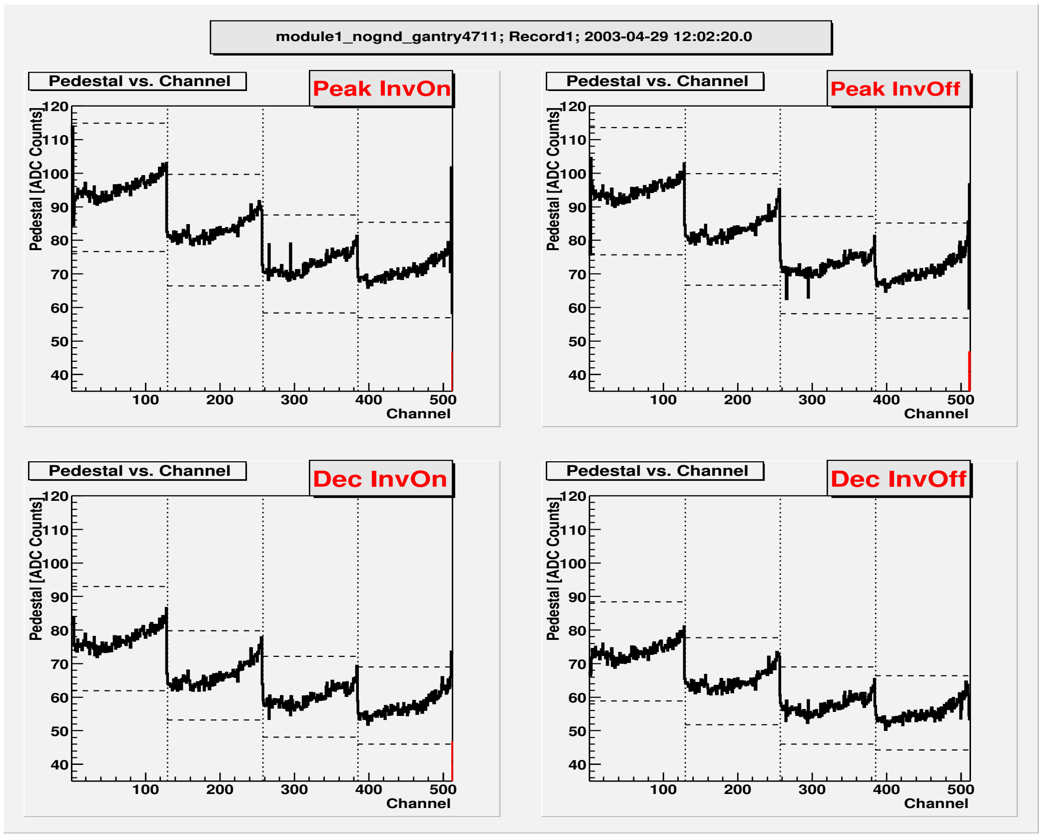


Figure 12: Pedestal measured using grounding scheme 0 (module holder floating, clam shell floating) with the gantry operating.

Figure 15 demonstrates the pulse height's sensitivity to grounding. Taken using ground scheme 2, the PA-sensor opens show no response to calibration injection in peak mode, and much larger response in deconvolution mode. The sensor-sensor opens, on the other hand, are even more difficult to see using this test. The ability of this test to find opens is very dependent on the grounding scheme and the mode the test is run in.

4.4 Pinhole test (continuous light)

The pinhole test using the LED array with continuous illumination is a powerful tool for finding pinholes. As the amount of light increases, the bias

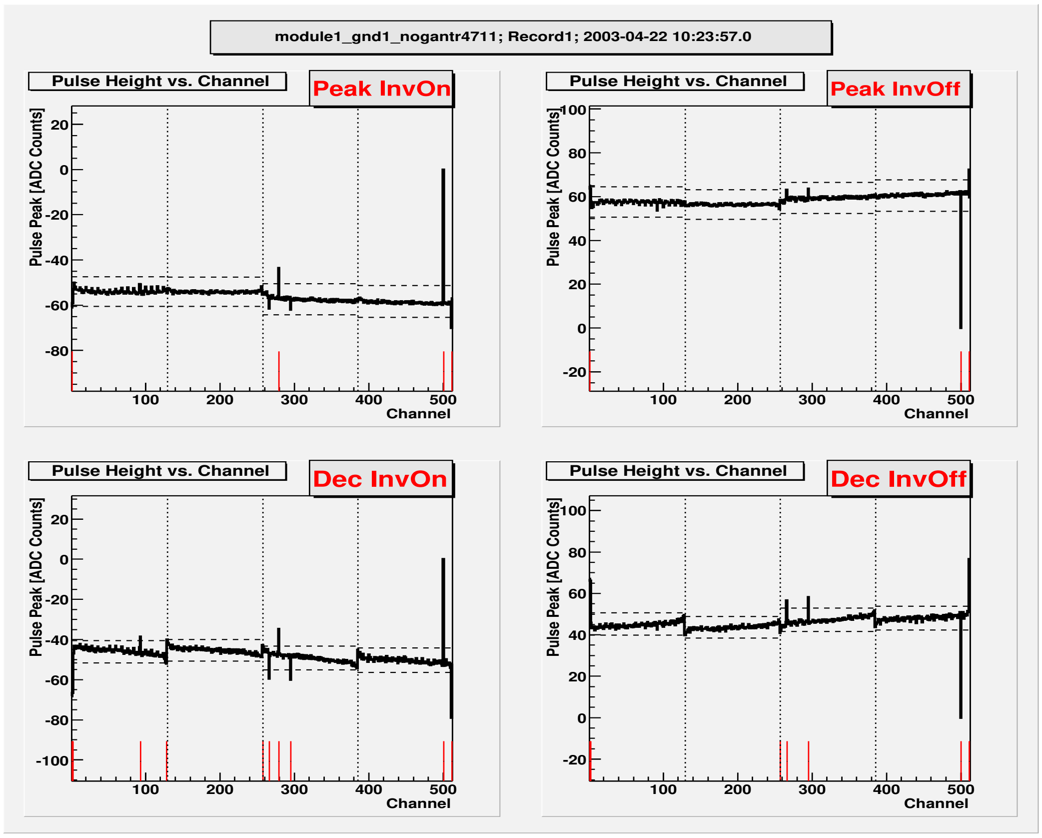


Figure 13: Pulse height measured using grounding scheme 1 (module holder floating, clam shell grounded) with the gantry not operating.

current increases. At some point, the voltage-drop in the bias return circuit causes the voltage at the bias ring and the APV preamplifier input (virtual ground) to match, unsaturating the pre-amp and allowing the channel to respond to calibration injection. The test result is displayed as the maximum difference in the calibration response of each channel while scanning the LED intensity.

We have found this test to be insensitive to the grounding choice and noise environment. We also found that problems other than pinholes can be found with this test. Noisy channels with high I_{strip} have a higher difference in pulse heights due to noise effects. Thus, in our analysis macro, we set two levels of failure of this test. There are:

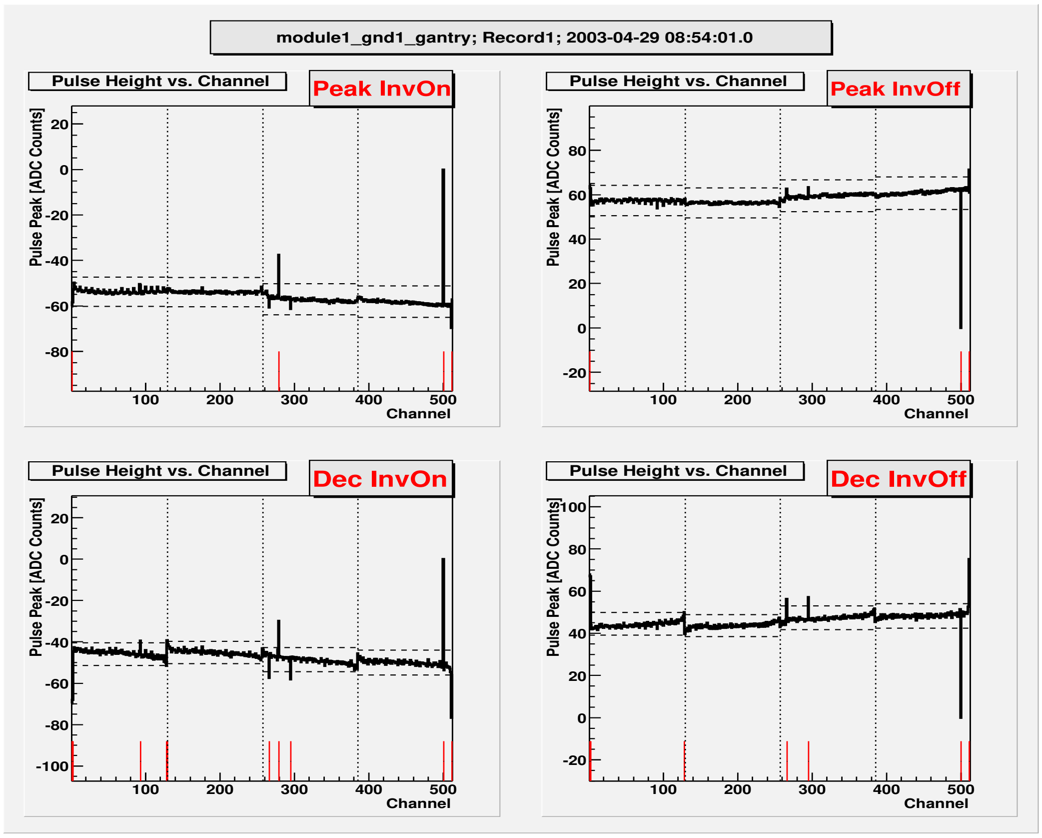


Figure 14: Pulse height measured using grounding scheme 1 (module holder floating, clam shell grounded) with the gantry operating.

- $|PH_i - \langle PH \rangle| > 4.5\langle PH \rangle$ (pinhole)
- $0.8\langle PH \rangle < |PH_i - \langle PH \rangle| < 4.5\langle PH \rangle$ (noisy)

Since a good channel's response is close to 0, an absolute requirement may be better suited for this test; we will try to determine the best technique once more modules are produced.

4.5 Gain test

The last test studied is a multi-point gain measurement recently added by the Aachen group for the ARCS system. The test returns the slope, offset,

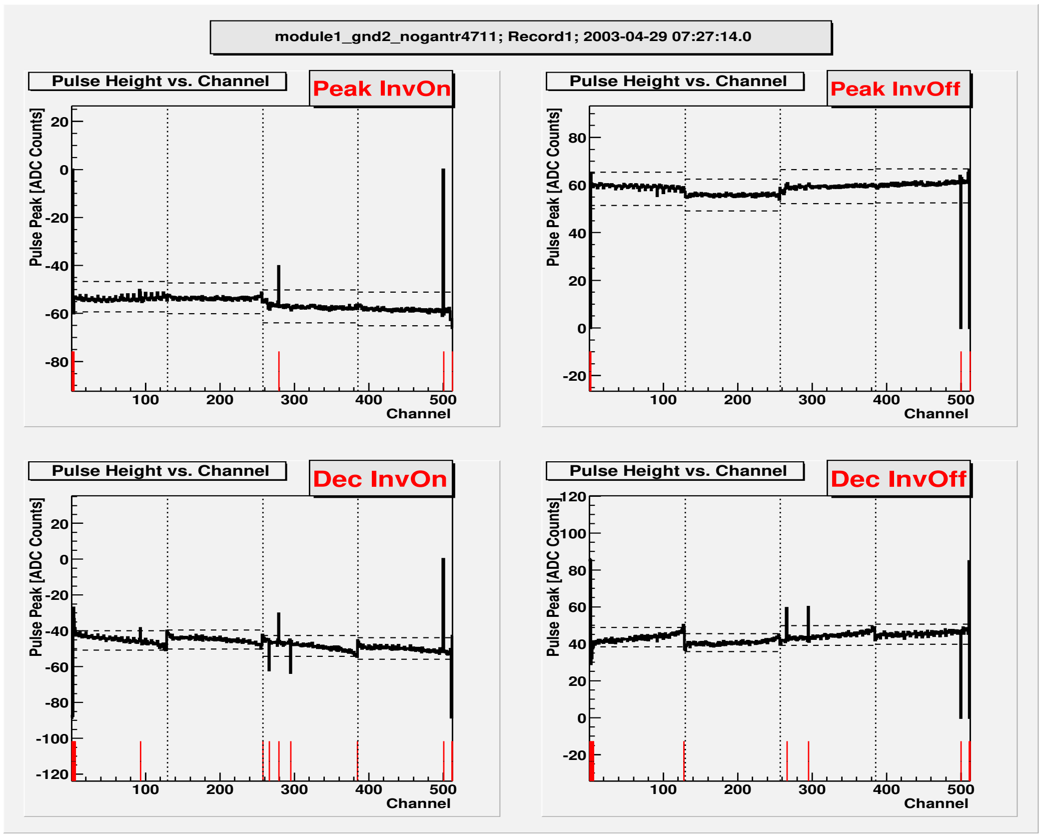


Figure 15: Pulse height measured using grounding scheme 2 (module holder grounded, clam shell floating) with the gantry not operating.

and χ^2 of the line fit for each channel's calibration response versus the ICAL setting. The test was designed to reduce sensitivity to pickup, grounding, and noise. The test proved to be completely insensitive to grounding and noise environment, and has found every known open, short, and pinhole so far. As this test is new, we include the gain slope measurement for every grounding scheme and gantry operational status combination studied (figures 17–24). The results of all tests look identical.

For the analysis macro, four levels of failure of this test are used:

Peak mode:

- $|G_i - \langle G \rangle| < 0.3\langle G \rangle$ (pinhole)

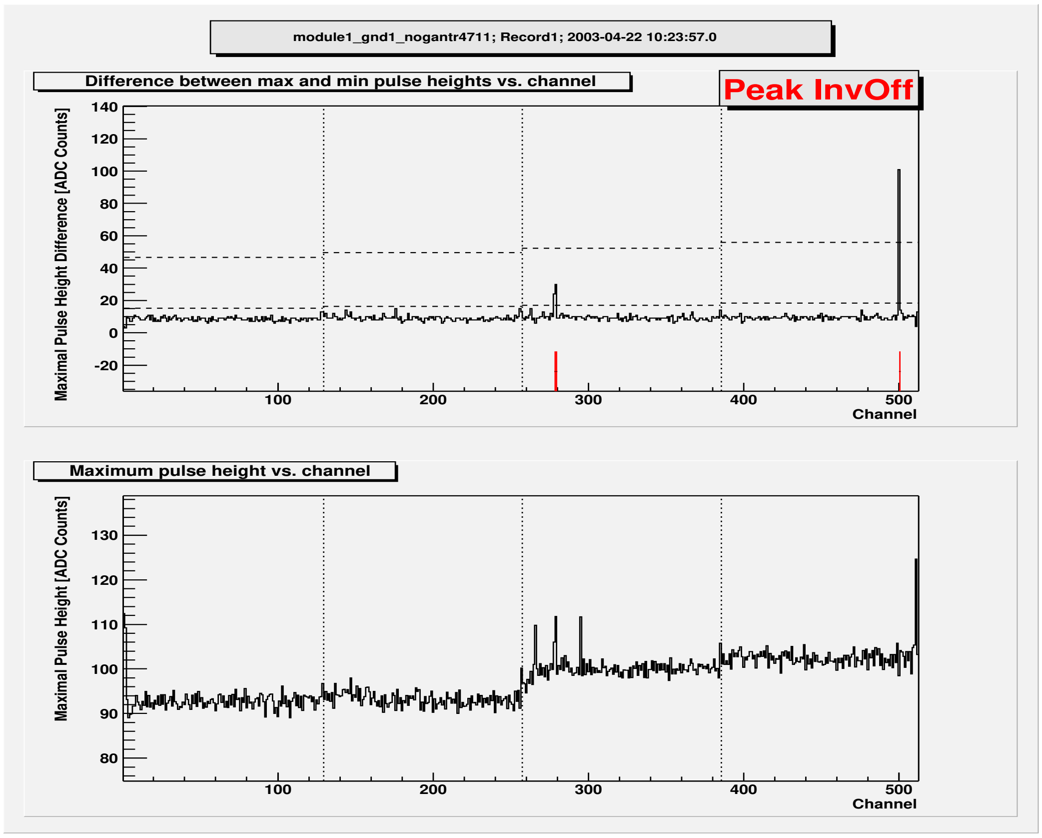


Figure 16: Pinhole test results using grounding scheme 1 (module holder grounded, clam shell floating) with the gantry not operating

- $0.3\langle G\rangle < |G_i - \langle G\rangle| < 0.88\langle g\rangle$ (noisy)
- $1.12\langle G\rangle < |G_i - \langle G\rangle| < 1.18\langle G\rangle$ (PA-sensor opens)
- $|G_i - \langle G\rangle| > 1.18\langle G\rangle$ (Sensor-sensor opens)

Deconvolution mode:

- $|G_i - \langle G\rangle| < 0.3\langle G\rangle$ (pinhole)
- $0.3\langle G\rangle < |G_i - \langle G\rangle| < 0.88\langle G\rangle$ (noisy)
- $1.12\langle G\rangle < |G_i - \langle G\rangle| < 1.4\langle G\rangle$ (PA-sensor)

- $|G_i - \langle G \rangle| > 1.4\langle G \rangle$ (Sensor-sensor)

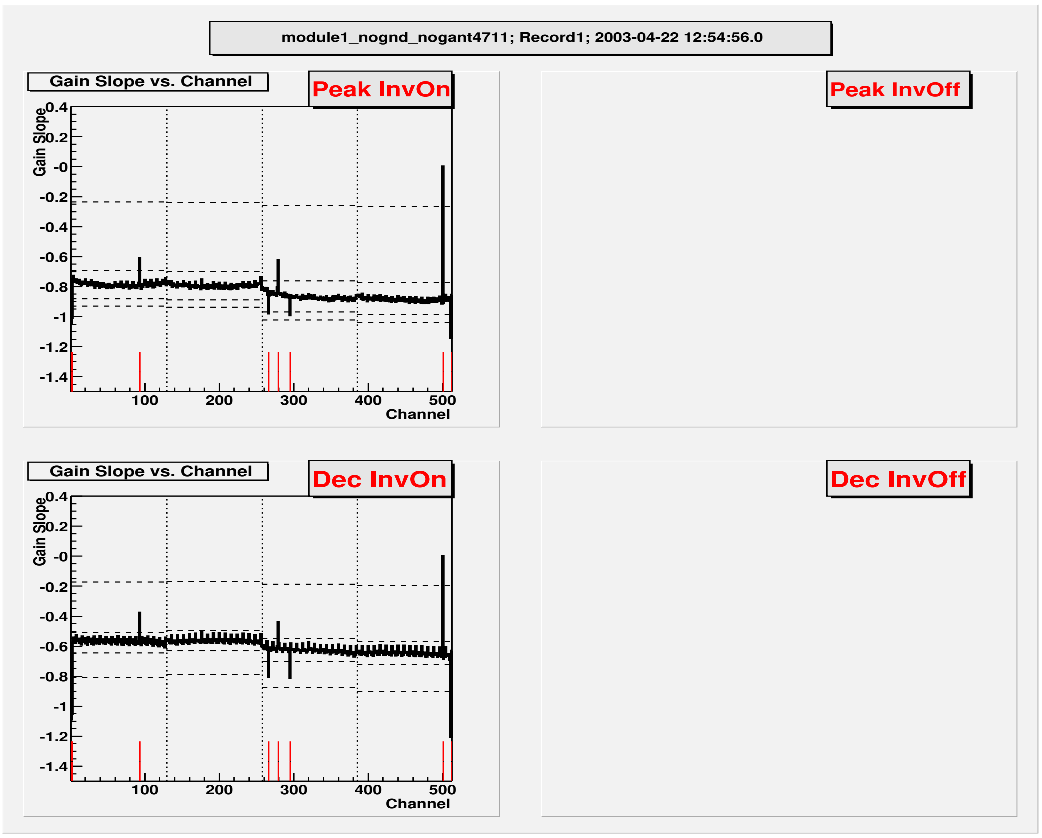


Figure 17: Gain measured using grounding scheme 0 (module holder and clam shell floating) with the gantry not operating.

5 Analysis Macro Status

A macro which analyzes the data from the ARCS 6.0β is under development. Instructions and current macro and configuration files can be found at hep.ucsb.edu/cms/arcs_macro.html

The macro currently works as follows. First, the macro inputs an user-defined configuration file. The configuration file contains the file name and

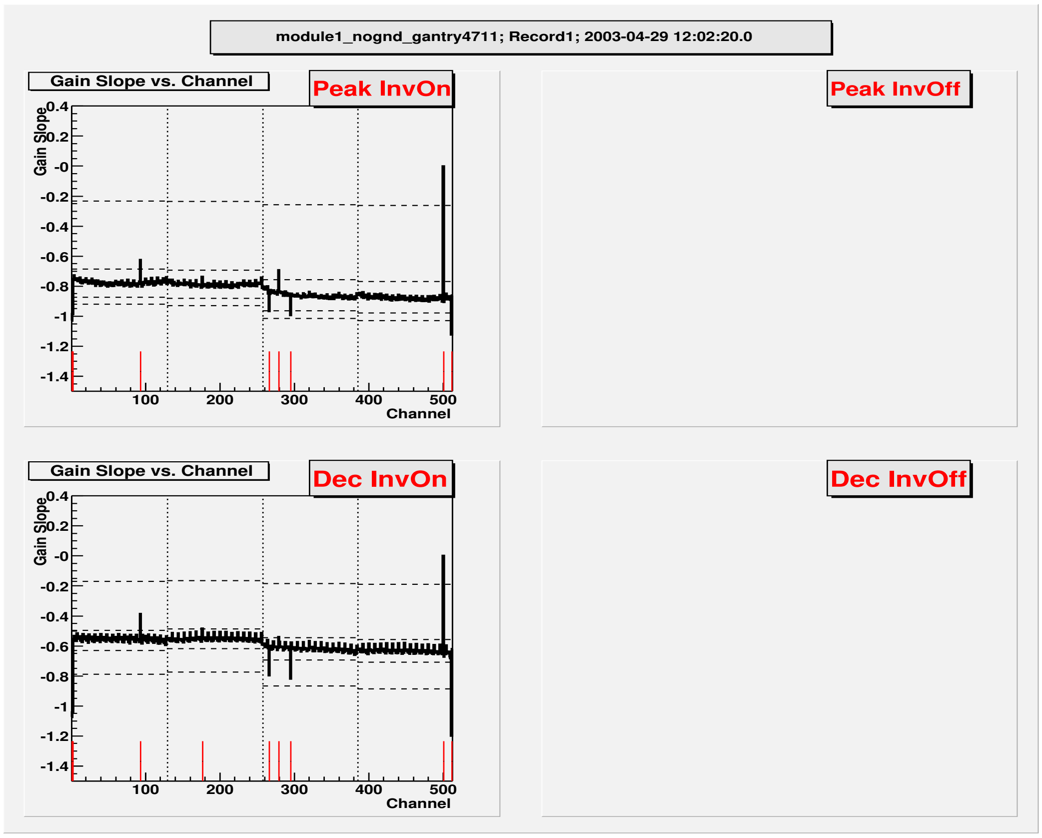


Figure 18: Gain measured using grounding scheme 0 (module holder and clam shell floating) with the gantry operating.

directory of the root file, the output directory for the eps files, and a set of test requirements. Next, the macro analyzes the root file generating the eps output with selection criteria and bad channels marked on the figure. Next, the macro outputs a summary file for the peak on and deconvolution on tests. These summary file shows the test results for each channel. Failed tests are marked by a letter, which described how the test fails. Passed tests or untaken tests are shown as a dot (.). The test results for the noise, pinhole, and gain tests are then compared. If they give a consistent pass or failure analysis, the strip is marked with the failure flag or the passed flag. Failures that are not consistent with a known failure pattern, the channel summary is marked with a question mark (?). This indicates that the user should

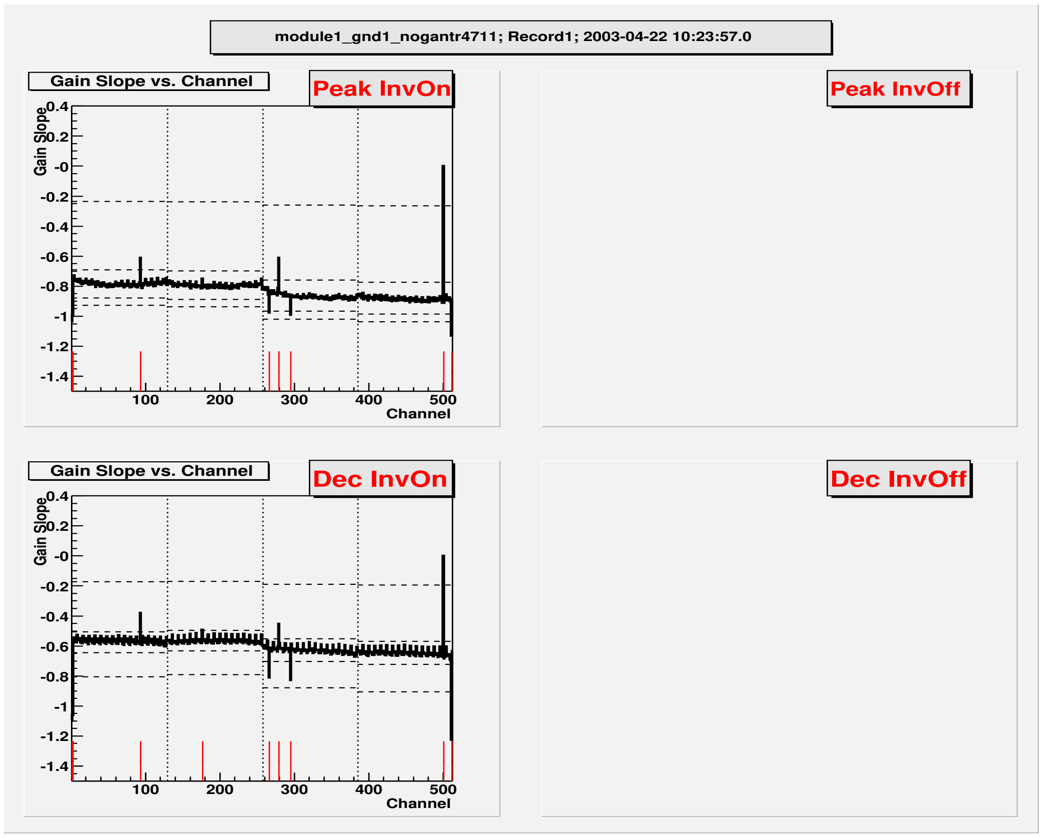


Figure 19: Gain measured using grounding scheme 1 (module holder floating and clam shell grounded) with the gantry not operating.

study the module and its test results for the given channel more carefully. Currently only opens (both sensor-sensor and PA-sensor) and pinholes can be diagnosed. As we get more experience with shorts (only one has been seen so far), short finding will also be added. As new types of problems are diagnosed, they will also be added to the macro. A sample output of the macro is shown in figure 25.

A few improvements are in the works. A summary of the bad channels is being developed. The summary will list all channels that fail any of the gain, noise, or pinhole test and suggest any repairs/inspections that are needed. We also hope to include the ability of the macro to read in previous test results of the components (sensors, hybrids), so known problem channels can

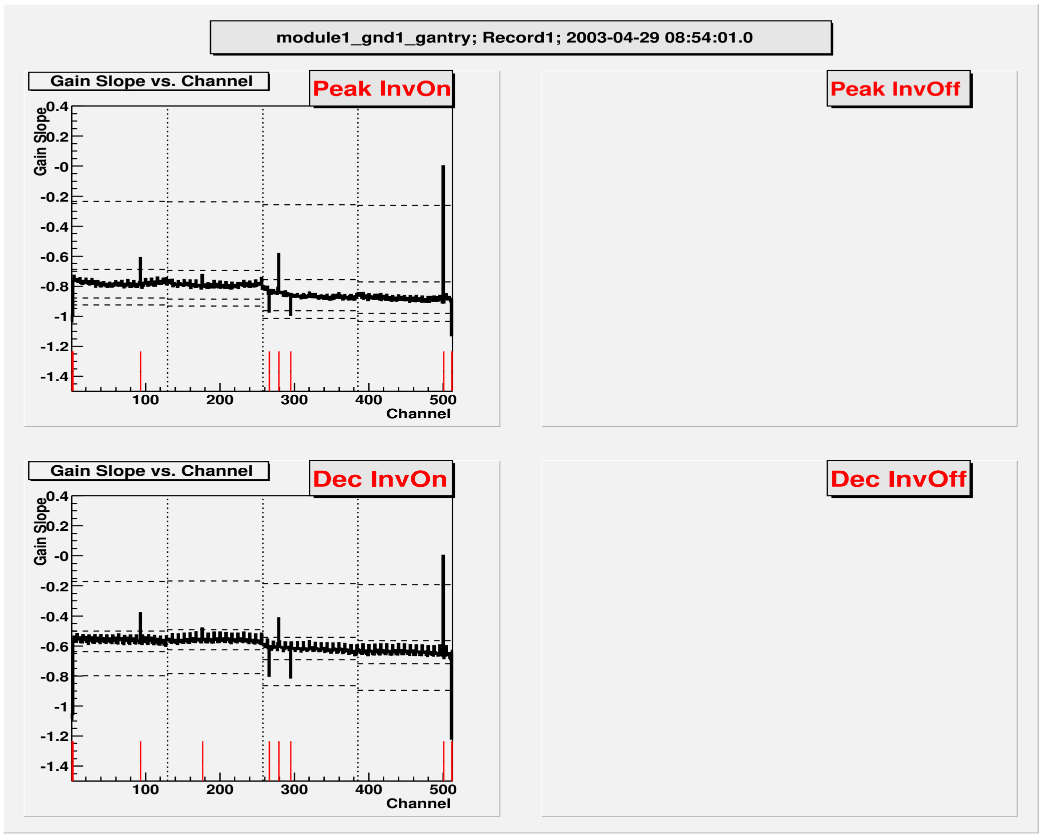


Figure 20: Gain measured using grounding scheme 1 (module holder floating and clam shell grounded) with the gantry operating.

be marked with the previously known diagnosis.

6 Draft of Cross-calibration Procedures

The following cross-calibration procedures assume that the tests will be performed on a ARCS stand using ARCS software 6.0β or later. The tests need to be performed with the module in a dry environment ($< 20\% relativehumidity$). In addition, the module should be tested in an environment with minimal common mode noise. The default macro fault finding settings will not work if the common mode noise is greater than ≈ 0.5 ADC; in this case, the user

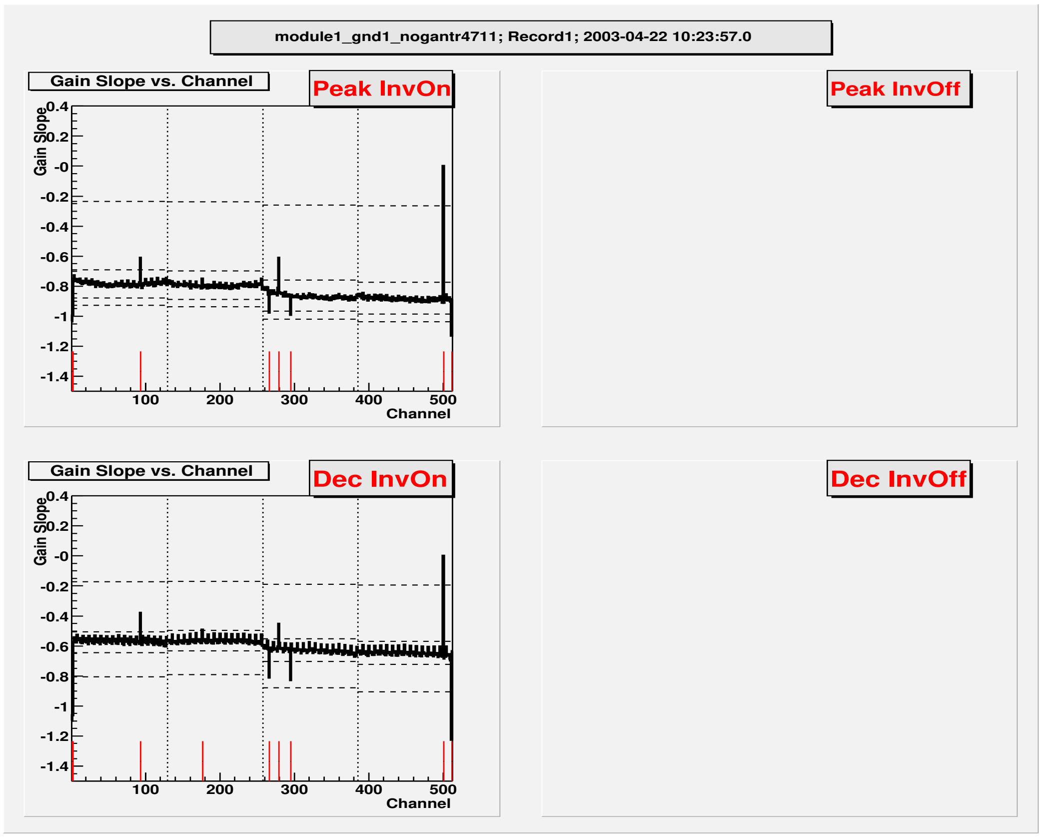


Figure 21: Gain measured using grounding scheme 2 (module holder grounded and clam shell floating) with the gantry not operating.

will have to modify the cut values to work on his/her system. The set of known problems and IV curves from the module's originating site should be included. Data on the bad channels found in probing and the expected IV curve from sensor probing (the sum of the two sensors' IV curves) should also be provided.

The tests should be taken at two voltage values: the bias voltage and the maximum testing voltage. These voltages should be clearly indicated for the module. The following tests should be performed at both 250 and 550 V, using two separate root output files which include the voltage the test is taken at:

- An IV curve with the voltage taken every 10 V. The current at the

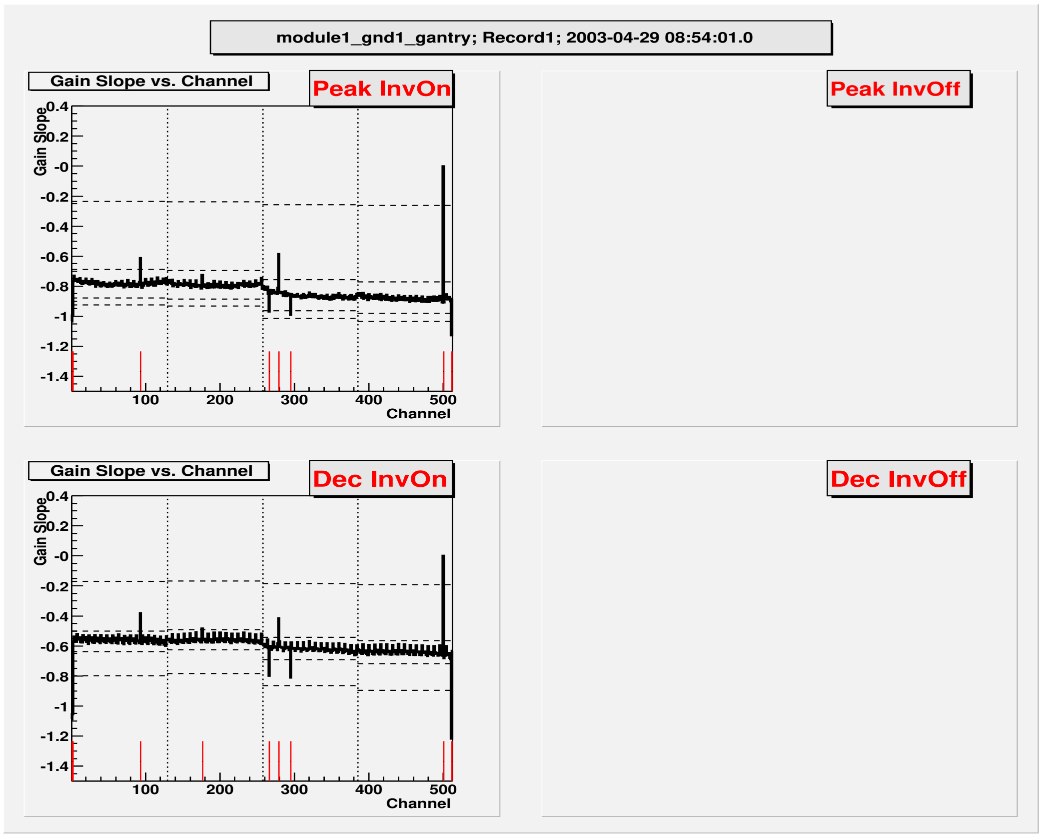


Figure 22: Gain measured using grounding scheme 2 (module holder grounded and clam shell floating) with the gantry operating.

final voltage should be taken when reached and again after 1 minutes at bias.

- Pedestal/noise runs should be taken in all four modes with 5000 events per run.
- Pulse shape runs should also be taken in all four modes.
- A pipeline scan should be performed in peak on and deconvolution mode with 200 events per cell. This will take some time, but these data may indicate problems that other tests miss.

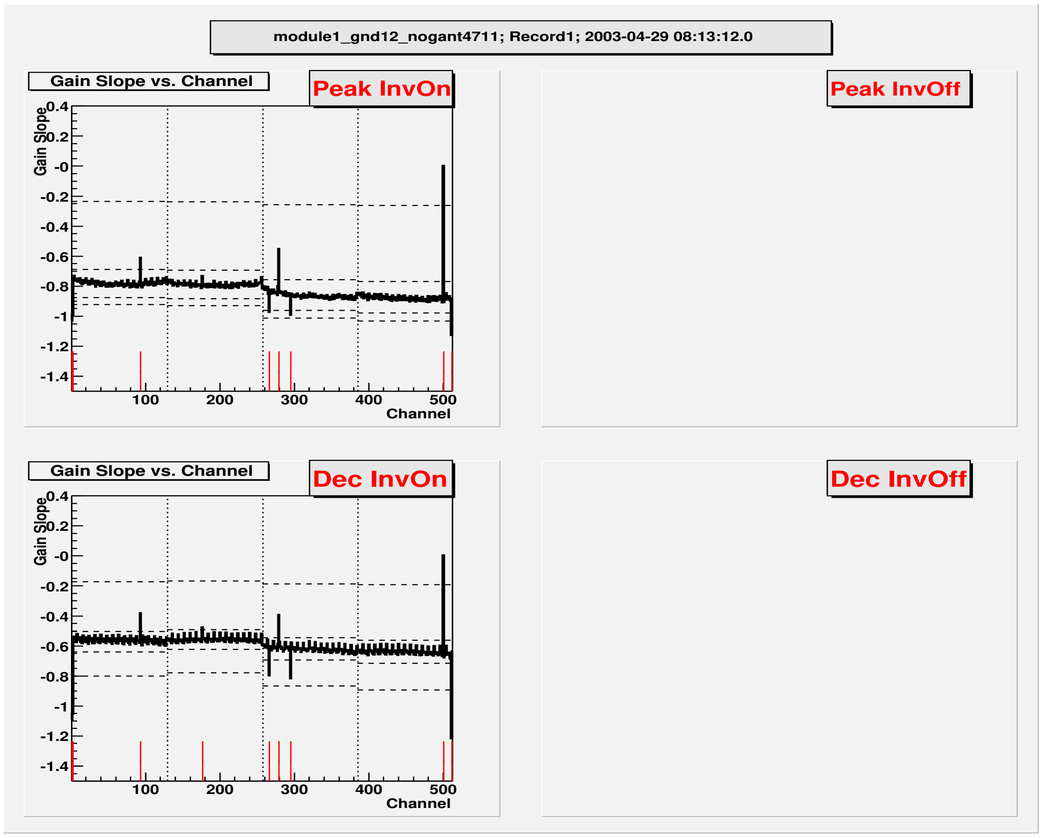


Figure 23: Gain measured using grounding scheme 3 (module holder and clam shell grounded) with the gantry not operating.

- The gain should be measured in all 4 modes. The number of points measured should be set to 21 (the maximum for ICAL between 0 and 100). If using "all tests" page of the ARCS interface to run the tests, return to the gain scan page after all tests complete, so that the peak on gain scan will begin. (Bug which will be removed in a future ARCS release)
- The pinhole test should be run with the maximum intensity setting (3).

After finishing the tests, run the available macro, and see if the marked channels are consistent with the set of known problem. Make sure that all the eps plots have been made correctly. Make a tar file containing both

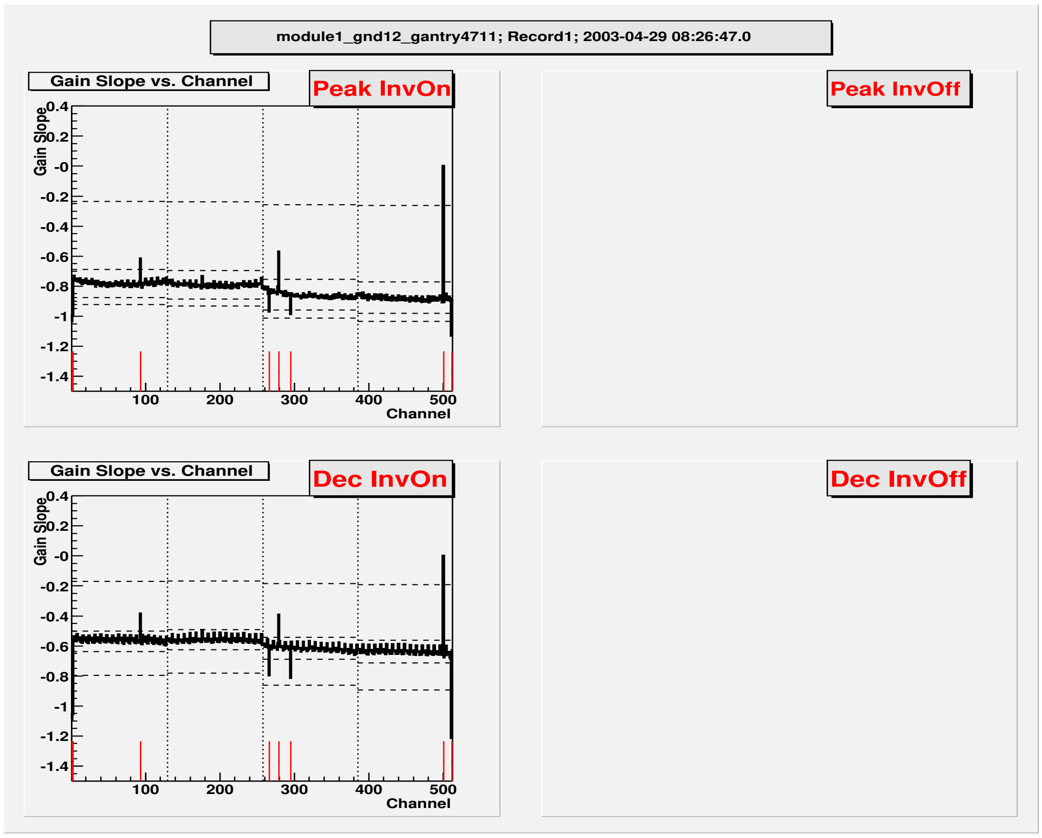
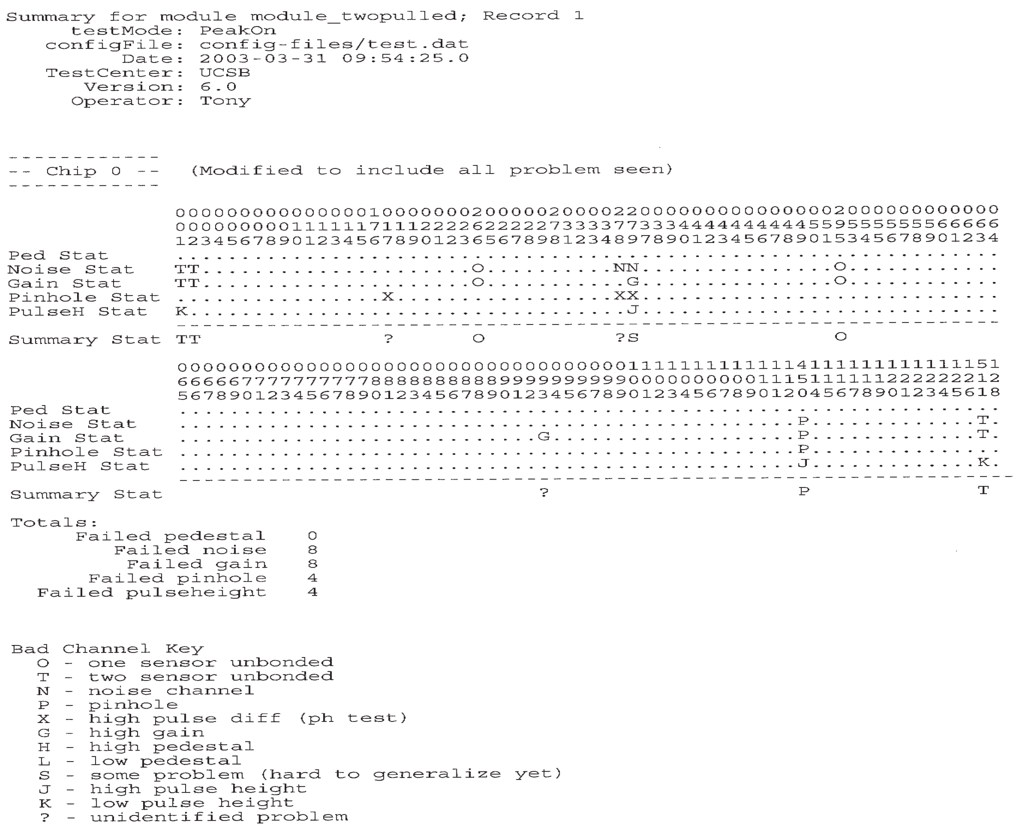


Figure 24: Gain measured using grounding scheme 3 (module holder and clam shell grounded) with the gantry operating.

summary files, the configuration file used, all eps plots, and the IV curves, and send to the person/group correlating the results from these tests.

7 Acknowledgments

This study would not be possible without the responsiveness and hard work of the Aachen group, both in supplying extremely solid testing hardware and software.



```
Summary for module module_twopulled; Record 1
     testMode: PeakOn
   configFile: config-files/test.dat
         Date: 2003-03-31 09:54:25.0
   TestCenter: UCSB
      Version: 6.0
     Operator: Tony


------------
-- Chip 0 --   (Modified to include all problem seen)
------------

             0000000000000001000000020000020000220000000000000000200000000000
             0000000001111117111222262222273333773334444444444559555555566666
             1234567890123456789012365678981234897890123456789015345678901234
Ped Stat     ................................................................
Noise Stat   TT.....................O..........NN...............O............
Gain Stat    TT.....................O...........G...............O............
Pinhole Stat ................X.................XX............................
PulseH Stat  K..................................J............................
             ----------------------------------------------------------------
Summary Stat TT              ?      O          ?S               O

             0000000000000000000000000000000000011111111111114111111111111151
             6666677777777778888888888999999999900000000001115111111222222212
             5678901234567890123456789012345678901234567890120456789012345618
Ped Stat     ................................................................
Noise Stat   ................................................P.............T.
Gain Stat    ............................G...................P.............T.
Pinhole Stat ................................................P...............
PulseH Stat  ................................................J.............K.
             -----------------------------------------------------------------
Summary Stat                             ?                   P             T

Totals:
     Failed pedestal   0
        Failed noise   8
         Failed gain   8
      Failed pinhole   4
  Failed pulseheight   4


Bad Channel Key
  O - one sensor unbonded
  T - two sensor unbonded
  N - noise channel
  P - pinhole
  X - high pulse diff (ph test)
  G - high gain
  H - high pedestal
  L - low pedestal
  S - some problem (hard to generalize yet)
  J - high pulse height
  K - low pulse height
  ? - unidentified problem
```

Figure 25: Example of output from macro.

References

[1] L. Demaria, M. Meschini, F. Hartman, G. Dirkes, *Procedures for Module Test (Draft 2)*