US Module Production Status

US CMS Silicon Tracker Group

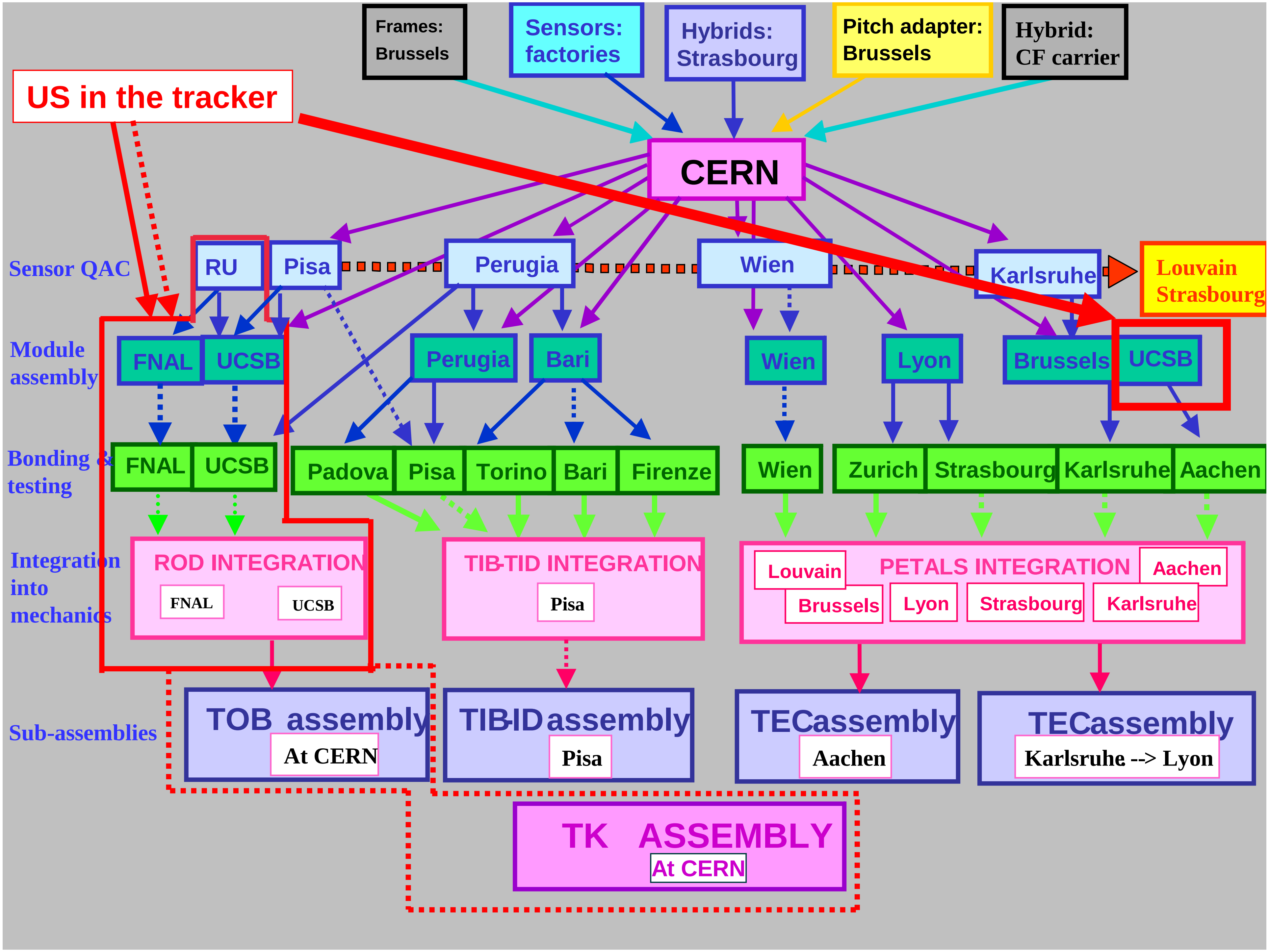
CERN Tracker Week

April 2004

US Group

- Fermilab (FNAL)
  - M. Demarteau, A. Ronzhin, K. Sogut, L. Spiegel, S. Tkaczyk

  + technicians
- *Kansas State University (KSU) – will now mainly work on Pixels*
  - *T.Bolton, W.Kahl, R.Sidwell, N.Stanton*
- University of California, Riverside (UCR)
  - Gail Hanson, Gabriella Pasztor, Patrick Gartung
- University of California, Santa Barbara (UCSB)
  - A. Affolder, S. Burke, C.Campagnari, D. Hale, J.Incandela, S. Kyre, J. Lamb, R. Taylor, D. White + techs.
- University of Illinois, Chicago (UIC)
  - E. Shabalina, C. Gerber, T. Ten
- University of Kansas (KU)
  - P. Baringer, A. Bean, D. Coppage, L. Christofek
- University of Rochester (UR)
  - R.Demina, R. Eusebi, E. Halkiadakis, A. Hocker, S.Korjenevski, P. Tipton
- Mexico:3 institutes led by Cinvestav Cuidad de Mexico
- Brown is also planning to join



US in the tracker
Frames: Brussels
Sensors: factories
Hybrids: Strasbourg
Pitch adapter: Brussels
Hybrid: CF carrier
CERN
Sensor QAC
RU
Pisa
Perugia
Wien
Karlsruhe
Louvain Strasbourg
Module assembly
FNAL
UCSB
Perugia
Bari
Wien
Lyon
Brussels
UCSB
Bonding & testing
FNAL
UCSB
Padova
Pisa
Torino
Bari
Firenze
Wien
Zurich
Strasbourg
Karlsruhe
Aachen
Integration into mechanics
ROD INTEGRATION
FNAL
UCSB
TIB-TID INTEGRATION
Pisa
PETALS INTEGRATION
Louvain
Aachen
Brussels
Lyon
Strasbourg
Karlsruhe
Sub-assemblies
TOB assembly
At CERN
TIB-ID assembly
Pisa
TEC assembly
Aachen
TEC assembly
Karlsruhe --> Lyon
TK ASSEMBLY
At CERN

Adapting to Delays

- In parallel with our work to help resolve component problems
  - US underwent a major upgrade of production lines to achieve significantly higher production capacity to recover lost schedule time.
    - New and better methods
    - More and better tooling and hardware
    - Better software and Quality Control
  - Both FNAL and UCSB production lines have demonstrated stable, high quality module production at high rates
- Our production capacity is large:
  - CDF Run 2 silicon detector = 750k channels:
    - We can produce this many channels in 10 weeks without an extended work week
      - With an extended work week we could do this in 6 weeks
      - It took CDF 1 year with extended working weeks

Productivity Enhancements

- Gantry (robotic) module assembly
  - Redesigned: more robust, flexible, easily maintained
- Surveying and QA
  - Automated use of independent system (OGP)
    - More efficient, accurate and an independent check of gantry
- Module Wirebonding
  - Automated wirebonding w/ pattern rec.
    - Faster and more reliable bonding
    - Negligible damage or rework
- Taken together:
  - Major increase in US capacity
  - Higher quality

FNAL Responsibilities

TOB Module Summary Table

Type	Layers	Quantity	APV/mod.	Pitch phi	Pitch stereo	Microbonds
SS6	TOB5,6	1,800	6	122	-	2,764,800
SS4	TOB3,4	1,450	4	183	-	1,484,800
DS - rphi	TOB1,2	1,150	4	183	-	1,177,600
DS - stereo	TOB1,2	1,150	4	183	183	1,177,600
		5,550				**6,604,800**

- 50% TOB modules: assembled, wire-bonded, and tested.
  - The workload split with UCSB will be adjusted as needed.
- 50% of the 688 TOB rods: assembled, tested, and thermal cycled.

- FNAL also responsible for bonding and thermal cycling
  - Half of the TOB hybrids
  - All of the 636 TEC R2 hybrids
  - Some fraction of the 2,658 R5 and R6 hybrids.

FNAL Personnel

- FNAL physicists (including Guests)
  - Marcel Demarteau, Anatoly Ronzhin, Kenan Sogut, Leonard Spiegel, Slawomir Tkaczyk
- University physicists who are currently spending a substantial fraction of their time at SiDet
  - Don Coppage, Ricardo Eusebi, Bill Kahl, Elizaveta Shabalina, Timour Ten
- Full time personnel
  - 4 FNAL technicians
  - 2 Rochester technicians (1 Gantry operator, 1 wire bonder)
- Other support personnel
  - 1 SiDet Engineering Physicist (Gantry)
  - 2 Designer/drafters
  - 8 SiDet technicians including micro-bonding techs., an optical inspection station operator, and tech. shop personnel.

Personnel Responsibilities

- Areas of responsibility
  - Don Coppage — DB, sensor studies/ARC testing
  - Marcel Demarteau — Hybrid bonding and testing
  - Ricardo Eusebi — Multi-rod thermal controls, interlocks
  - Bill Kahl — Gantry
  - Anatoly Ronzhin — Support for testing systems, repairs
  - Elizaveta Shabalina — Module testing
  - Slawomir Tkaczyk — Rod assembly and testing
- Technician support cont.
  - We will need another 3-4 full time techs. for full production
  - Given the ramp-down of the CDF and D0 silicon efforts and the U.S. CMS HCAL effort, we don't see a problem in locating and training additional technicians on a short time scale.

Production Sequence

• Hybrid bonding	Lab D bonding room
• Hybrid thermal cycling	Lab D clean room
• Module assembly	Lab D clean room
• Module bonding	Lab D bonding room
• ARC testing	Lab D clean room
• Long-Term testing	→ Lab C clean room
• ARC LED test	→ Lab C clean room
• ‘Encapsulation’	Lab A (→ Lab C ?)
• Rod assembly	Lab C clean room
• Single rod test	Lab C clean room
• Multi-rod burn-in	Lab C clean room
• Rod crating and shipment to CERN	

These are the normal steps for TOB module production. Module problem cases are handled separately and TEC hybrids will be shipped to Europe after successfully passing step 2.

FNAL Hybrid Testing

•

Hybrid thermal cycler in the Lab D clean room

•FNAL system

- For TOB, TEC R2, R5, and R6

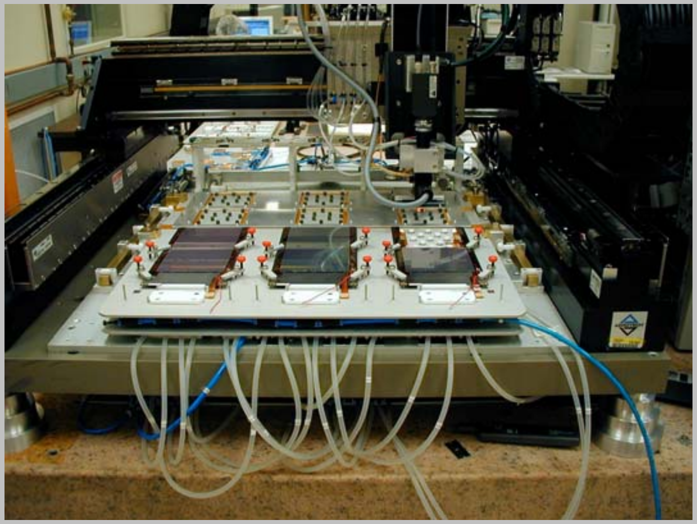
•To keep pace with TOB module production we will need to test at least <u>15 TOB hybrids</u> per work day.

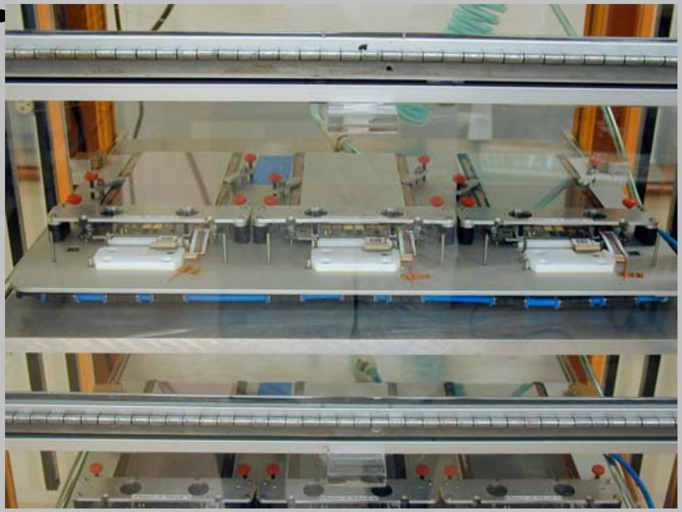
•TEC hybrids will be handled as a separate production line

- Up to an <u>additional 12 hybrids</u> per work day.

• System should easily handle the combined TOB and TEC hybrid testing load.

Gantry Assembly

• 

• 

- •15 modules/day requires 5 assembly plates (see above).
- •We now have 5 Rphi plates and 3 stereo plates on hand.
  - Some commissioning work still needs to be done for the stereo plates.
- •The curing station is capable of holding up to 6 plates.
- •Module assembly takes about 70 minutes per plate
  - 15 minutes spent at the start of each day to get the final survey numbers from the previous day's build.
  - We are working on off-loading the after_cure measurements to an optical inspection machine (OGP Avant 600) as is done by UCSB.

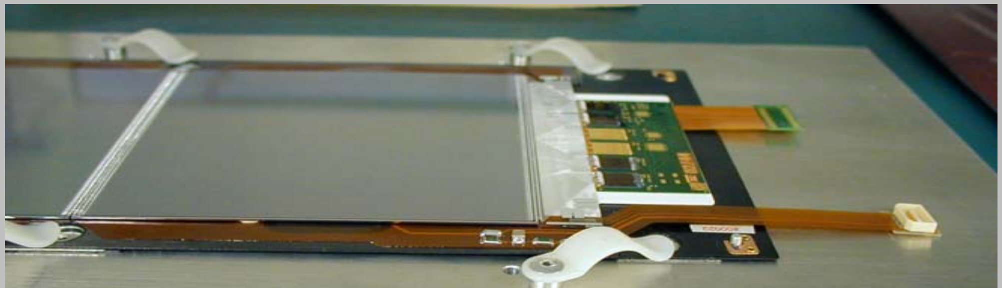
FNAL Wire Bonding

Purchased K&S 8090 for the project

- Have access to 2 more 8090's.

Experienced bonding group

- 10 minutes per TOB module
  - Does not include paperwork and DB entries.
- Separate production line for bonding TOB and TEC hybrids
  - Latter are shipped to TEC assembly centers in Europe



Bonded TOB module

FNAL ARC Testing

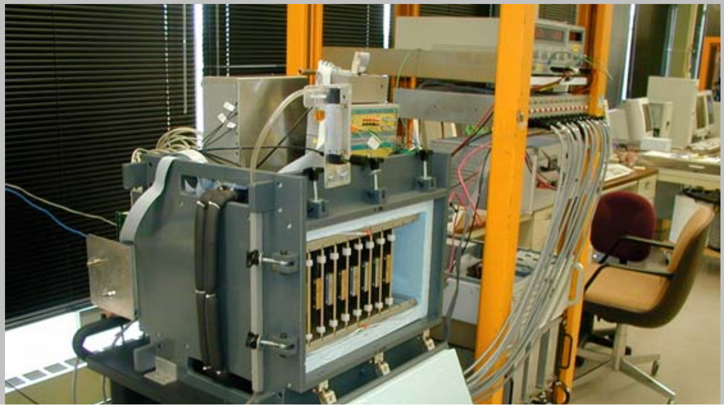
•

- 4 fully operational ARC test stands
  - 2 in Lab D (Module production)
  - 1 in the Lab C (Rod Assembly)
  - 1 will be used for repairs.
- ARC testing - 30 minutes/module
  - Includes LED illumination of strips.
- System is user friendly
  - Techs. will do most testing.

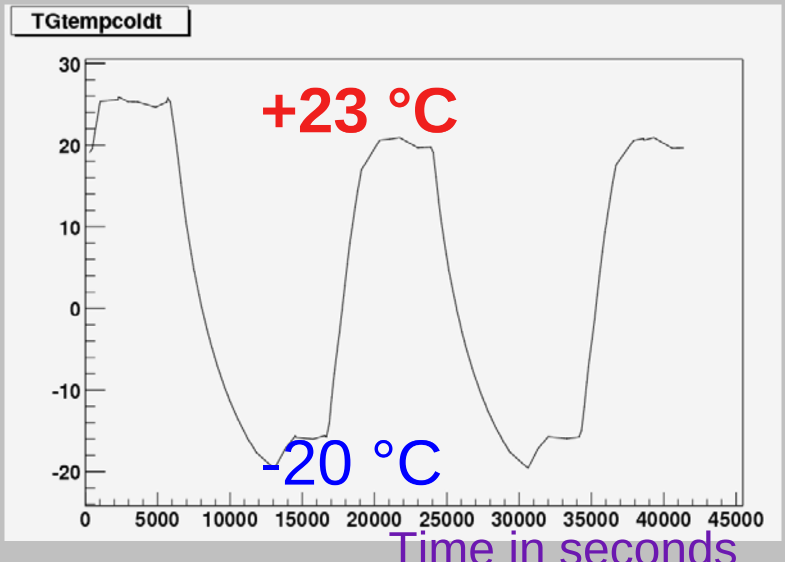
FNAL Long-Term (LT) Testing

- The testing cycle ~ 12 hours
  - In order to maintain 15 module per day rate of production
  - Includes readout at

    +23 °C, -20 °C, +20 °C, -20 °C, and +20 °C.
  - LT results tend to agree with ARC results
    - Module grades are based on ARC testing
- System ran reliably throughout the high-rate exercise.

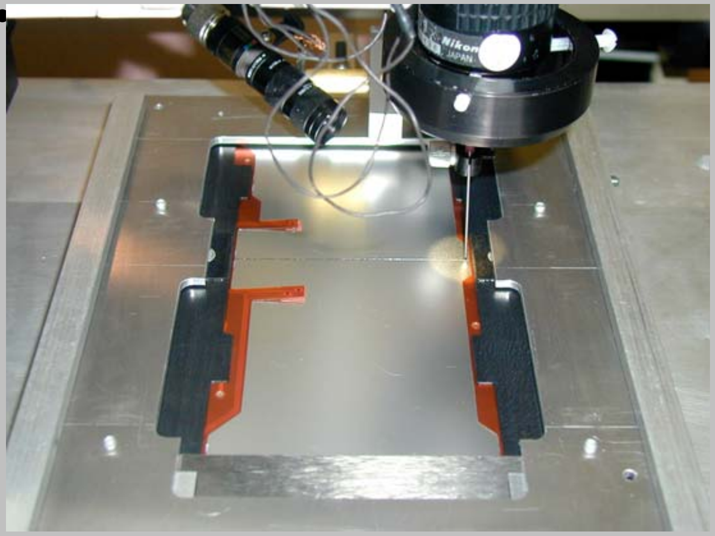


LT system in AB Bridge. Will be moved to the Lab C clean room.



FNAL Module Reinforcement

- Our ‘reinforcement’ is done by a semi-automated dispensing machine.
  - Takes a few minutes per module.



FNAL Rod Assembly

- We have obtained the services of Bert Gonzalez
  - Lead technician for the CDF SVX project
  - Now developing assembly procedure with tooling from CERN and UCSB.
  - See no trouble maintaining rod assembly rate that will be required

One of two rod assembly fixtures

Single rod test box

FNAL Multi-rod Testing

The multi-rod burn-in thermal controls and interlocks are working well ahead of schedule at both production sites.

Chest freezer holds up to 8 rods.

Rods are cycled over 72 hours

- 15 modules/day ⇒ 12.5 (SS) rods/week
- 2 1/3 cycles/week ⇒ 5-6 rods/cycle

As with the ARC and LT systems we expect that much of the loading, initializing, and monitoring will be carried out by technicians.

The single rod and multi-rod readout systems still need to be commissioned at FNAL, but these are very similar to the LT system (CMS DAQ components).

FNAL High Rate Exercise

•FNAL recently built 102 modules over an 8 day period, reaching the standard rate of 15 modules per day on the 4th day.

Production and testing went very smoothly.

•Preliminary preparations

- Probing 500 OB2 sensors, determining grades based on QTC and local IV curves, extracting information from the DB, pairing sensors, staging sensors and hybrids, DB registration and assembly, preparing lists for assembly, bonding, and testing.
- **Many of these steps will (hopefully) be unnecessary in normal production.**

•Gantry

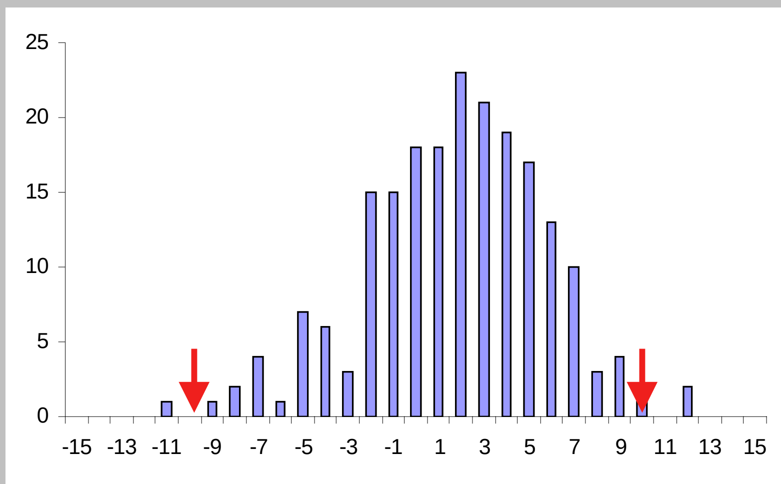
- 5th plate typically completed by 2:30PM. Benefited from 6:00AM after_cure measurement start. Only minor problems
  - .

FNAL Production Summary

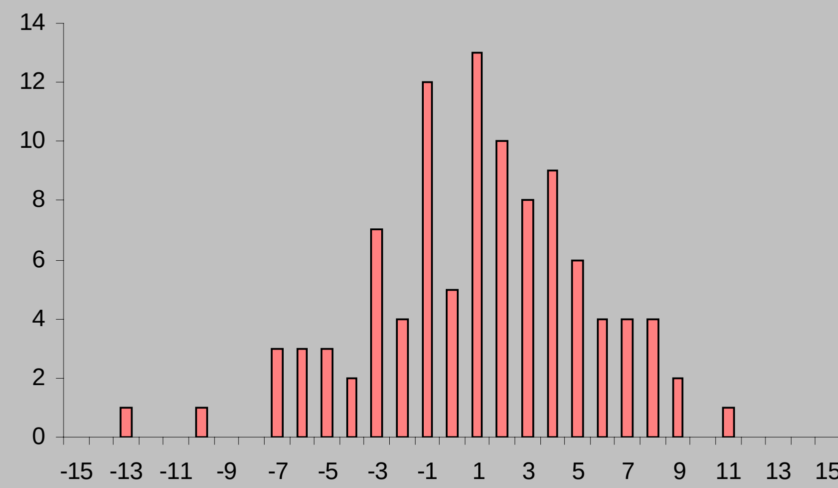
- Wire bonding
  - 15 modules bonded, inspected, and bad channels pulled *typically by 11 am*. Included test pulls for **one** module per day.
    - 2 additional hours for paperwork and database
  - Issue toward end with PA bond pad quality?!
- ARC testing
  - Two ARC stands were able to keep up with testing.

    Non-passing modules deferred until end of exercise.
    - An extra 20 minutes was spent on each module on a “raw noise” test, which was deemed unnecessary near the end.
- LT testing
  - System ran flawlessly following last minute change to CCU resistors.
  - Some questions arose regarding some data at low temperature.
- Sylgard 186 application for module reinforcement
  - Easily kept up with production.

Gantry Placement



Sili1/Sili2placement angles (mdeg)



Sili2-Sili1placement angles (mdeg)

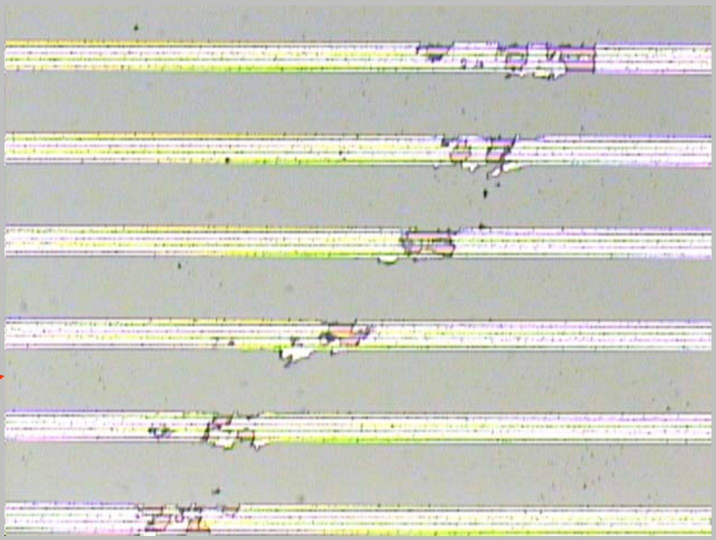
Only a few percent outside specifications

- Second order corrections will be done (See UCSB below)

Survey data were uploaded to the central db database daily.

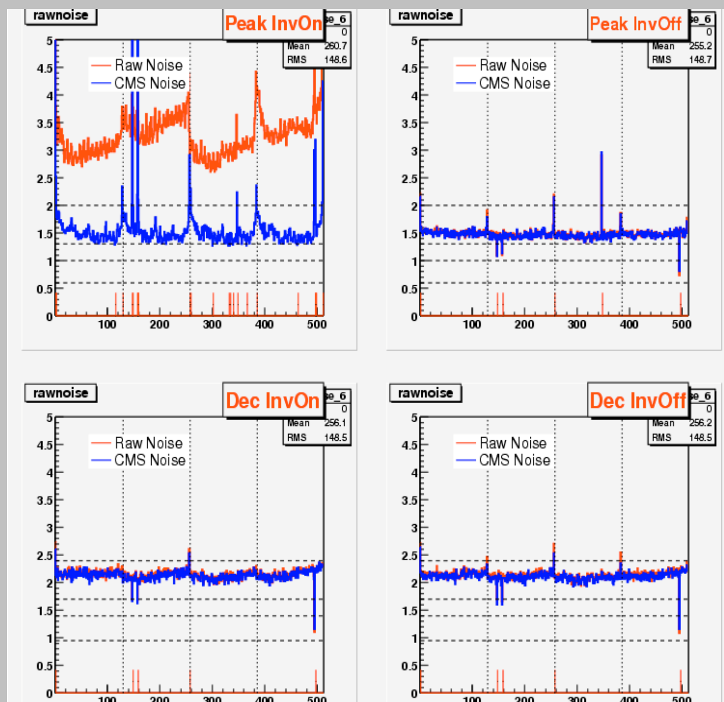
ARC Testing Results

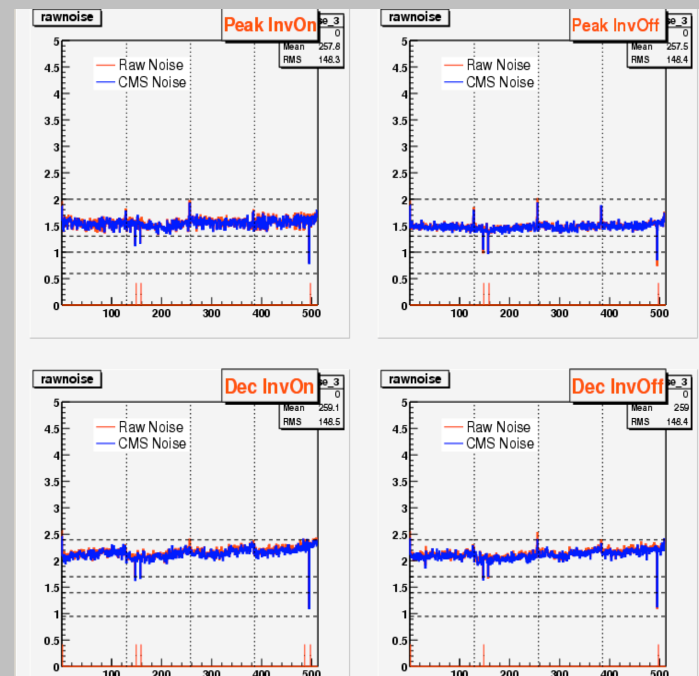
- 102 modules were tested on ARC test stands ⇒
  - Grade A – 78
  - Grade B – 10
    - A small number of the A/B grades are the result of repair actions.
  - For the remaining 14 failing modules
    - 5 have mask defects leading to too many noisy channels.
    - 1 exhibits Common Mode Noise in one of the APV's, which we attribute to micro-discharges in the silicon.
    - 6 have APV problems
      - Under study now
    - 2 have HV problems



ST Processing Defect (5% rate)

FNAL LT Testing





Some modules showed high noise at –20 °C in the PeakInvOn mode.
Traced to cases with 8 or more modules in the Vienna box.
Re-testing, with fewer than 8 modules, showed that the noise is an artifact of the testing arrangement.

In general there is good agreement between the ARC and LT test results and we do not see (real) problems at low temperature.

FNAL Summary

- FNAL can sustain a rate of 15 modules per work day
  - Have refined our techniques, procedures, and equipment.
- Quality of the modules is high.
  - Problems should drop with new hybrids, new ST, & HPK sensors
- The number of full-time technicians will need to increase
  - Not a problem. Many good ones available.
- Need practice with rod testing and burn-in
  - Awaiting equipment and software

UCSB Module Assembly Personnel

- Wirer Bonding Technicians: Julie Stoner
  Kirsten Affolder
- Gantry Technicians: Andrea Allen
  David Staszak
- Post-doc: Russel Taylor
- Engineers: David Hale
  Susanne Kyre
  Dean White

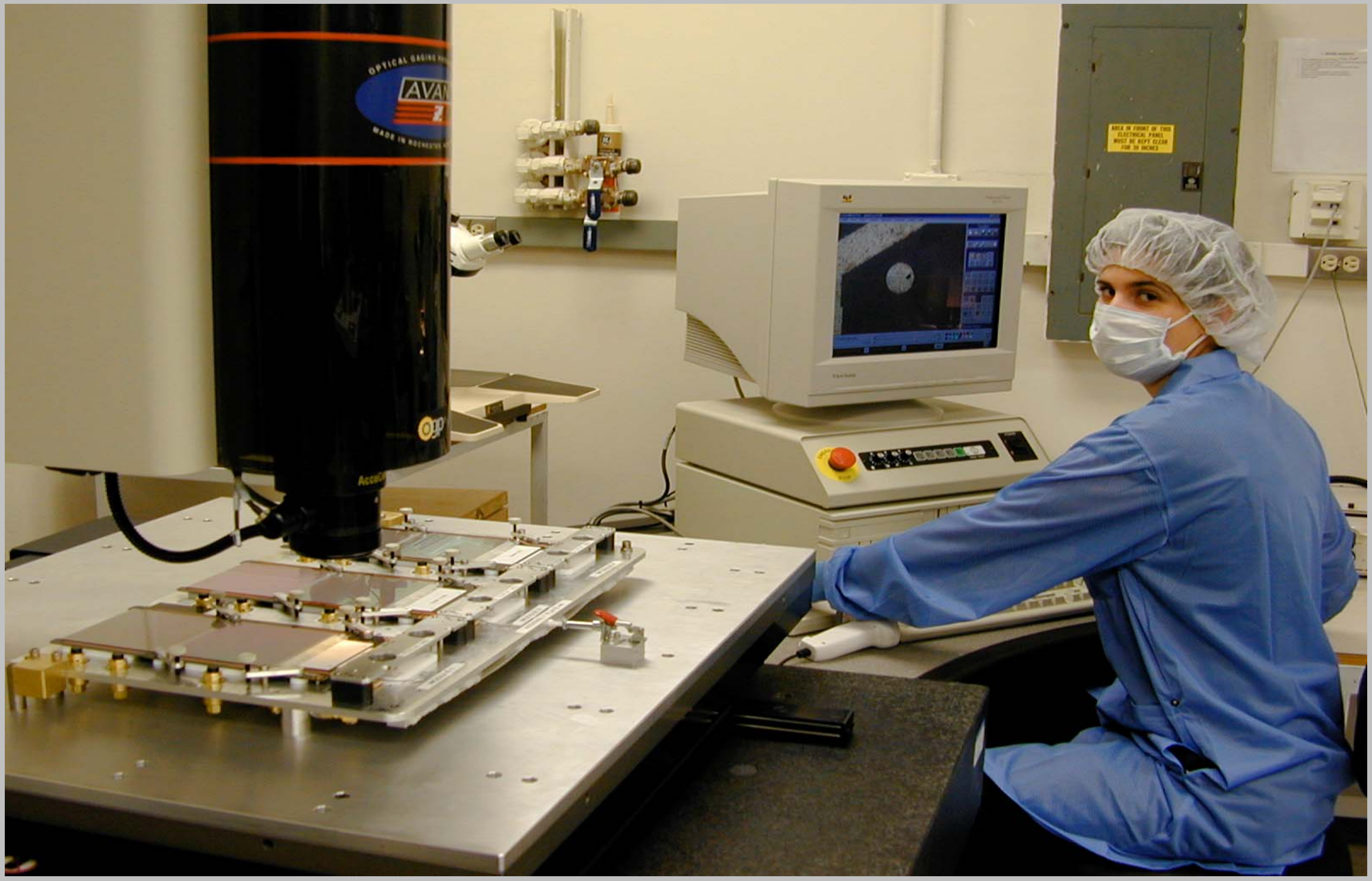
➢ These are the key people in module assembly. They also are involved to greater and lesser degrees in other areas of module production.

UCSB Module Curing

- 6 plates capacity cabinet.
- An additional plate can be cured on the gantry.

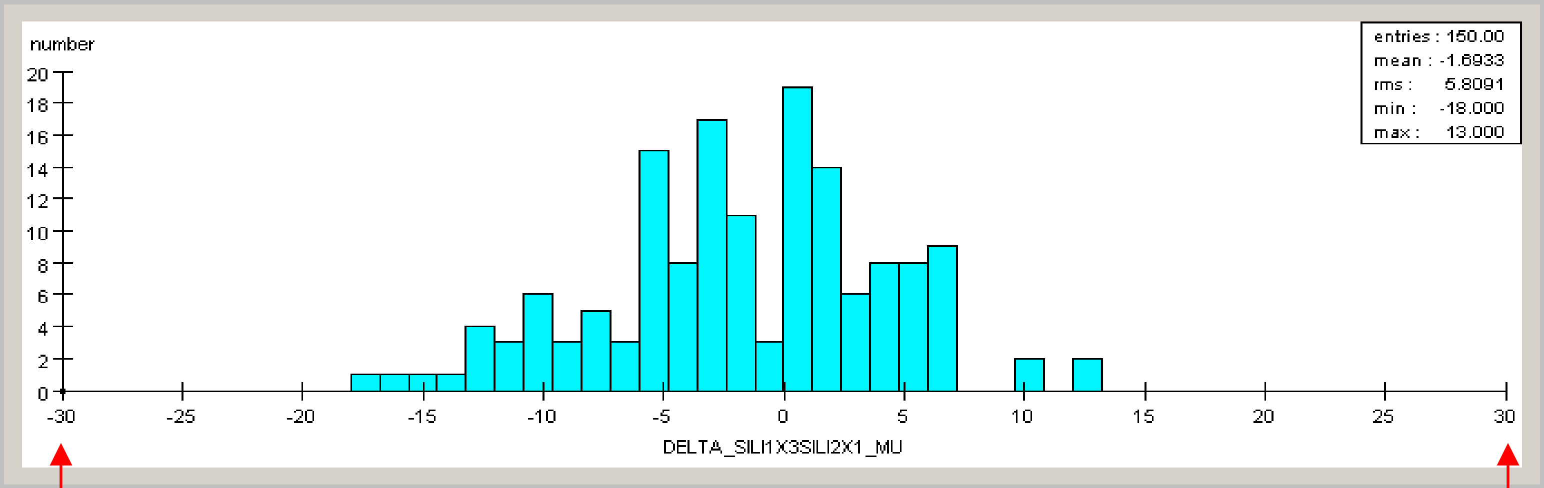
UCSB OGP Survey

- Final after-cure survey is done on an OGP (Optical Gauging Products) machine located next to the curing cabinet.
  - < 10 minutes per plate, allowing more module assembly time on gantry



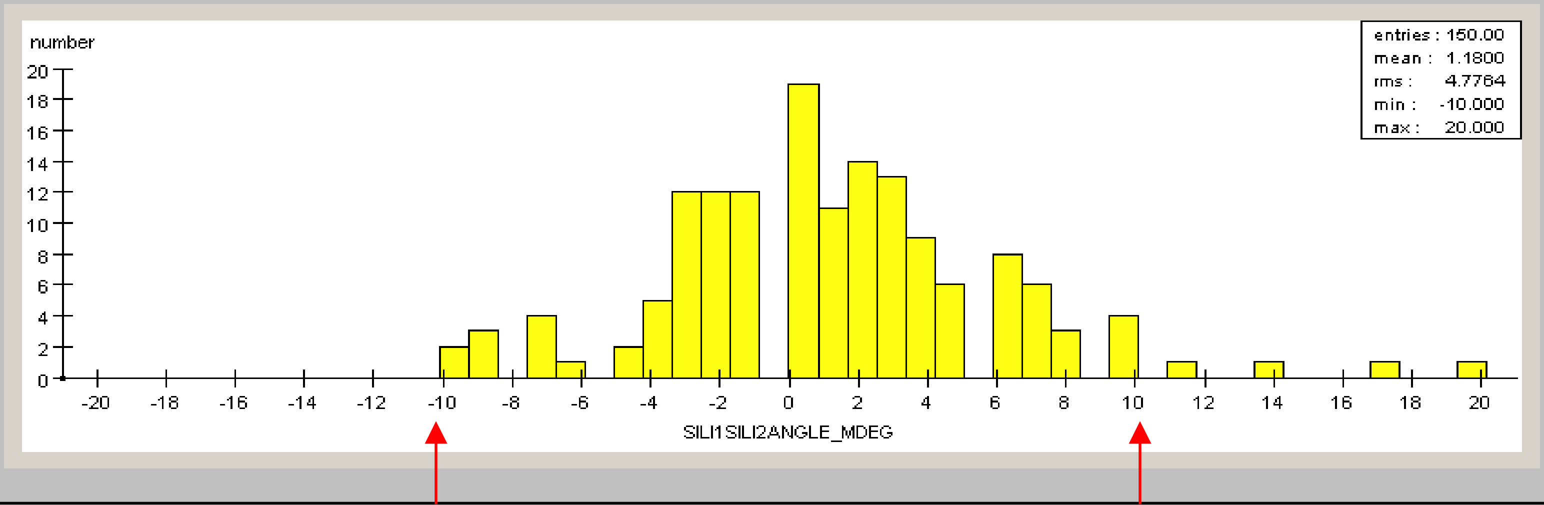
UCSB 150 Module Production Run

Delta Sili1X3 Sili2X1



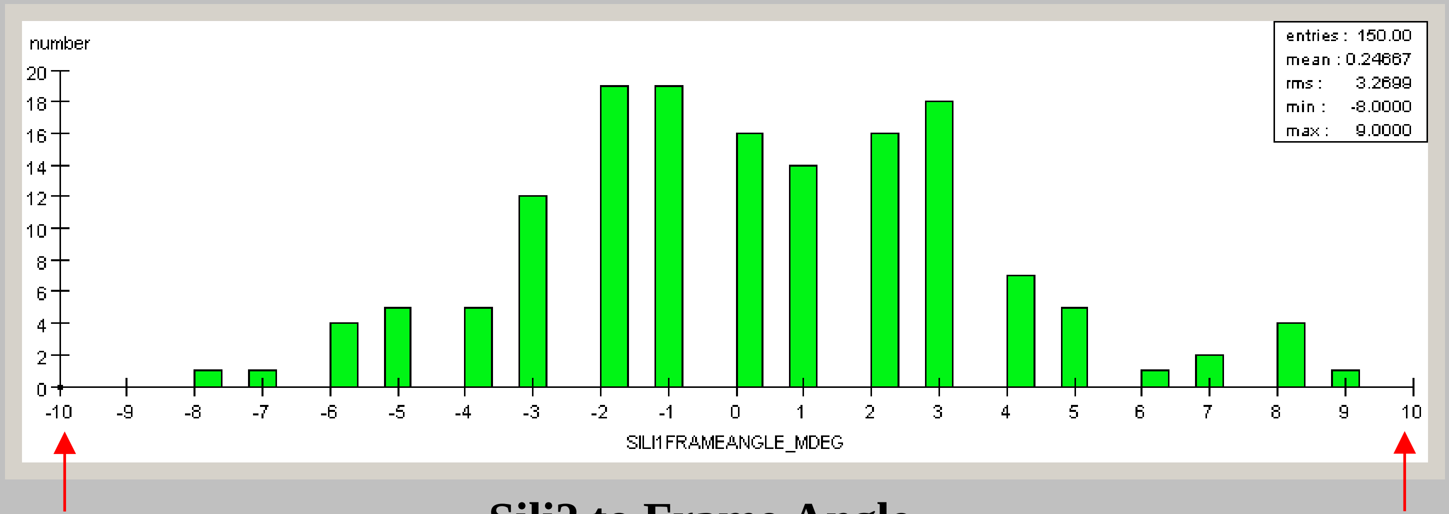
Red arrows show cuts

Sili1 Sili2 Angle

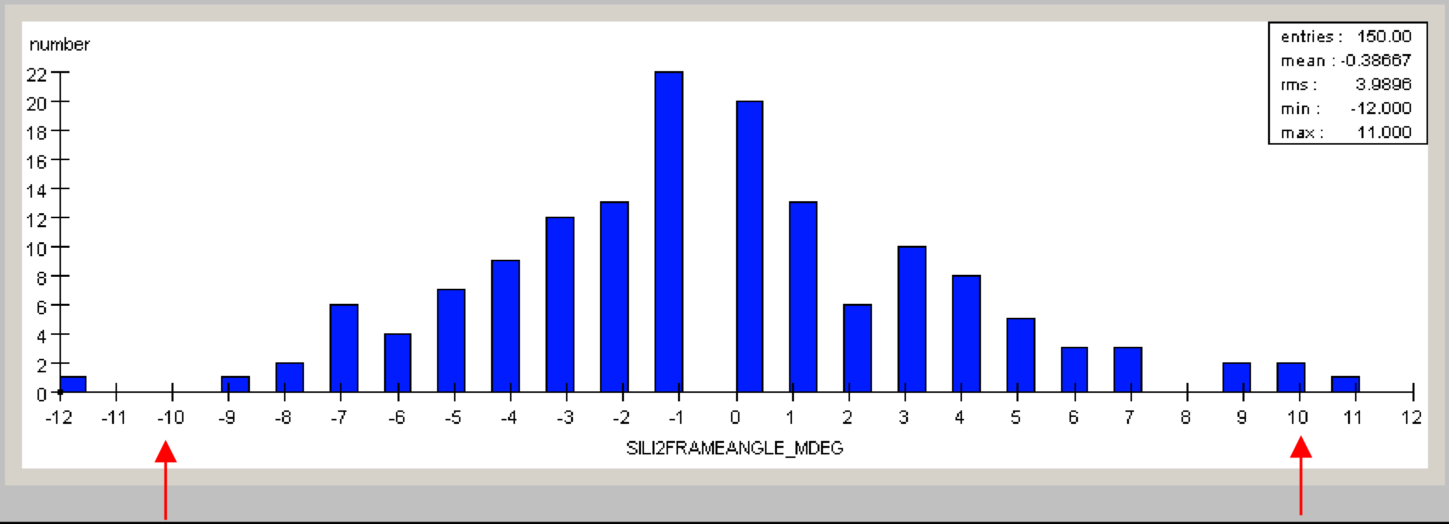


UCSB 150 Module Production Run

Sili1 to Frame Angle

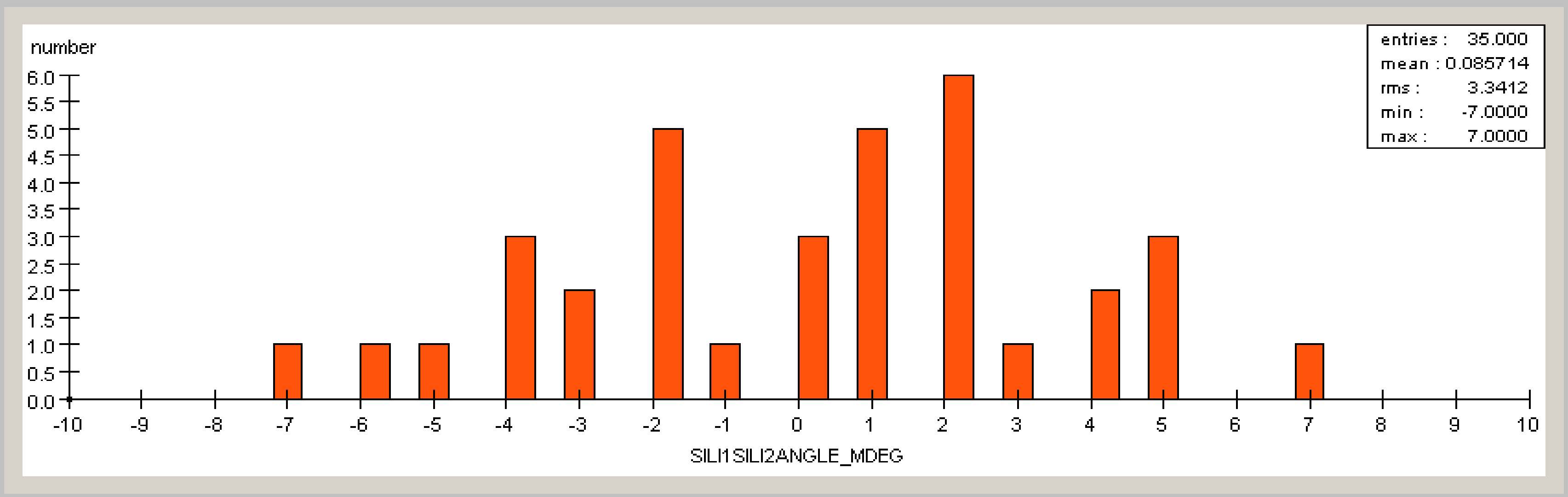


Sili2 to Frame Angle



UCSB Module Data (April ‘04)

- Of the 284 modules that have been assembled at UCSB so far,
  - 10 have be flagged as out of specification for sensor placement.
    - 2 were the first 2 modules built and there was a CTE problem during curing at elevated temperatures. We then changed to room temperature Ag epoxy.
    - 6 of the 8 others were flagged for sensor to sensor angle.
- For the last 35 modules built we incorporated new X,Y and for the 1st time U (rotational) corrections using data from our 150 module run
  - This has improved overall placement accuracy
    - No longer expect any modules outside specs



UCSB Production Capacity

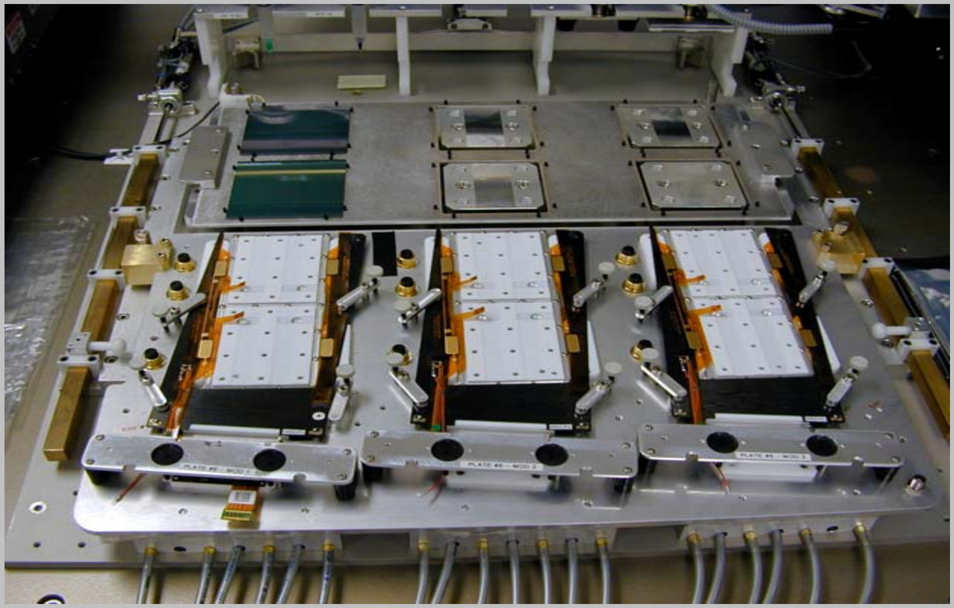
- Overall production went smoothly
  - (15 modules/day for 10 days in a row).
- After-cure surveying of 15 modules and production of 15 new modules (5 plates) could be accomplished by 3:00 (starting at 8:00) if no problems were encountered. Even when problems were encountered we finished by 5:00.
  - This seems to be about max production for 2 technicians per 8 hour day if parts reception and preparation are also included.
  - A rate of 7 plates/day can be maintained by
    - Going to a 10 hour work day (and/or)
    - Adding a support technician

UCSB: Assembly Plates Inventory

5 fully commissioned R-phi assembly plates

1 fully commissioned Stereo assembly plate

1 fully commissioned TEC R6 assembly plate



UCSB: Additional Assembly Plates

- 12 plates are at various stages of construction:
  - 4 more TEC R6 plates – parts completed
    - Will allow large rate R6 production if parts available
  - 2 TEC R5N (R-phi) plates – parts completed
  - 2 TEC R5S (stereo) plates – parts completed
    - R5 module production to start this month!
  - 2 more TOB R-phi plates – most parts completed
    - Allows possibility of 7 plates per day
  - 2 more TOB stereo plates – most parts completed

- Switching between assembly plate types is easy, so modules can be built from whatever parts are available.
- Note TEC modules will be built at UCSB only

UCSB Wirebonding Equipment

Equipment:

- K&S 8090 wirebonder
- K&S 8060 wirebonder
- Dage 3000 pulltester
- Stereo microscope
- Precision measuring microscope

UCSB Wirebonding Capacity

- Full Automation and Pattern Recognition:
  - Full automation has reduced bonding time by 50%
  - Wirebond programs for all module and hybrid types now use pattern recognition. Bonding time further reduced by about 2-3 minutes
  - Pure bonding times
    - module < 5min
    - hybrid < 4min
  - Additional time (set up, database entry, pull testing):
    - 11min for a module,
    - 8min for a hybrid
- Actual bonding times during 150 module production run:
  - 6.0 hours for 15 modules (one technician on K&S 8090)
  - 8.0 hours for 28 hybrids (one technician on K&S 8060)
- Total processing time can be reduced with a support technician

UCSB Wirebond Quality

- Extensive pull testing was done to determine a set of standard bonding parameters for each bonding surface
  - Hybrids:
    - We pull test 10 bonds on a test area on each PA
    - Average pull strength: 10.0 g, std. Deviation: 0.6g
  - Modules:
    - First 20 parts of each type, pull test every 50th bond
    - PA to Sensor bonds:
      - Average pull strength: 9.9g, std. Deviation: 0.7g
    - Sensor to Sensor bonds:
      - Average pull strength: 8.2g, std. Deviation: 0.8g

UCSB Wirebonding Faults

- 284 modules bonded so far
  - Bad channels introduced during bonding: 0.006%
- 550 hybrids bonded so far
  - Bad channels introduced during bonding: 0.041%
    - Majority of these were bond lift-offs associated with poor aluminum deposited on the PA’s for one batch.
  - Overall bonding quality has been excellent.

Hybrid Test Results

- 505 hybrids bonded and tested so far
  - 30 TEC R6
  - 2 TEC R5 phi
  - 5 TOB Stereo
  - 159 TOB 6 chip
  - 309 TOB 4 chip phi
- Bad channels (opens) introduced during bonding: 0.022%
  - Majority of these were bonds lifting off AL strip of PA
  - Overall bonding quality has been excellent.
- Total failure rate of 3.4%
  - 4 (0.8%) Broken Hybrids
    - 2 broken ceramics
    - 1 smashed set of wirebonds during repairs
    - 1 smashed wirebonds on arrival
  - 7 (1.4%) Fail @-20C (PLL Failure)
    - Should be usable. Still need software to force initialization in cold.
  - 6 (1.2%) have more than 4 AL pad lift offs
    - Bond parameters found to lower rate of problem, but may be PA batch dependent

UCSB Hybrid Database Usage

- Bonding
  - Standard bonding database interface used
  - Number of missing bonds and pull strengths (if applicable) entered
- Testing
  - Test automatically generates and uploads xml file
  - Pedestal, noise, bad channel list (opens, shorts noisy), and environmental variables inserted into database
  - Data used to determine expected faults in module testing

Results from module testing

- Status of test equipment and manpower
- Testing capacity
- Recent test results
  - common mode noise
  - other failures
- Conclusions and outlook

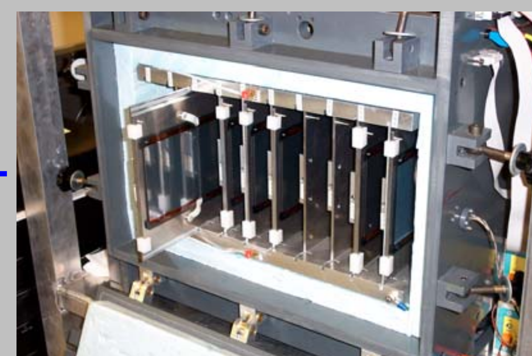
Module Testing Cycle

Expected production rate – 15 modules per day per site

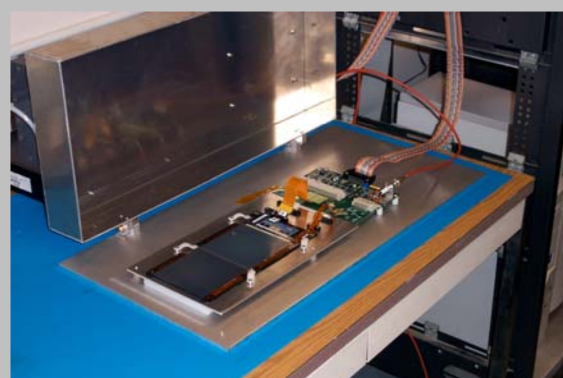
Gantry makes modules (15)

Wire bond (15)

Module quick test (15)



Thermal cycle modules (15): 2 loads, 8 hours each



Pinhole tests (15)

Storage/Mount on Rods

Test equipment and capacity

Fermilab

- Clean Room lab D
  - Adjacent to production area
  - Hybrid characterization and thermal cycling
  - Single module quick test
    - 2 ARC test stations
- Clean Room lab C
  - Single module quick test
    - 2 ARC test stations
  - Module burn-in station

UCSB

- Clean Room
  - Adjacent to production area
  - Hybrid characterization and thermal cycling
  - Single module quick test
    - 3 ARC test stations
  - Module burn-in station

Total testing capacity per site:

- Hybrid $\geq$28/day (4 hybrids per load $\times$ 7 hours)
- Module Test ~48/day (0.5 h/module $\times$ 8h $\times$ 3stands)
- LT Test ~20/day (10 modules per load $\times$ $\frac{1}{2}$ day thermal cycles)

Manpower

Fermilab
- professors – 2
- postdocs - 2
- graduate students – 1
- exchange visitor - 1
- engineer - 1
- technicians – 3
- Trained to run ARC:
  - 1 postdoc
  - 2 technicians
  - 1 engineer
- Trained to run LT:
  - 1 grad student
  - 1 exchange visitor
  - 1 technician

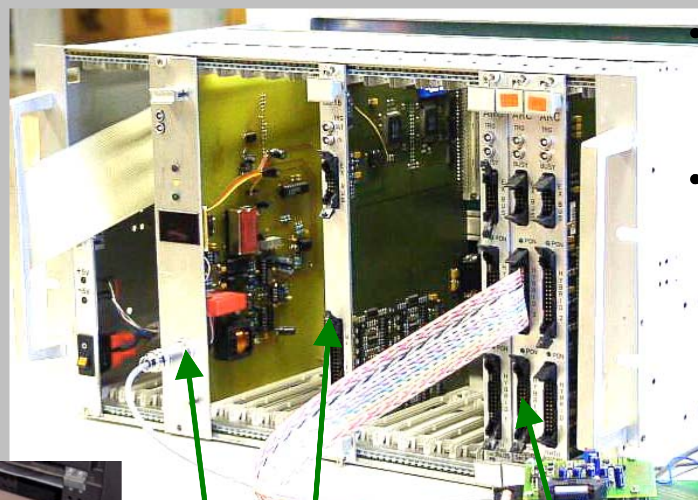
UCSB
- professors – 2
- postdocs - 3
- graduate students - 2
- electrical engineers - 1
- mechanical engineers – 2
- undergraduate students – 4
- Trained to run ARC:
  - 1 postdoc
  - 1 grad student
  - 3 undergrad students
- Trained to run LT:
  - 1 postdoc
  - 1 undergrad student

ARCS Based Test Stands

ARCS - APV Readout Controller Software

Purpose - Fast testing of hybrids and modules

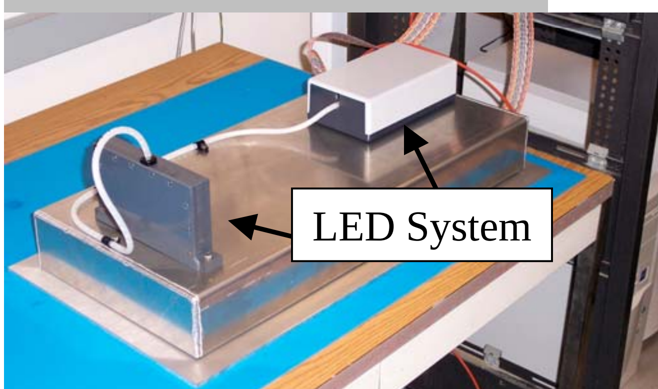
ARC FE
And adaptor card



DEPP

ARC Controllers

LED Controller



- Hybrid testing
  - Thermal cycle/pulsing
- Module testing
  - LED systems
    - Pinhole/Open Tests
  - DEPP HV supply
    - Automated IV curves
  - 3 Module test stands at UCSB
    - 2 TOB
    - 1 TEC
  - 4 Module test stands at Fermilab

Module Testing with ARCS

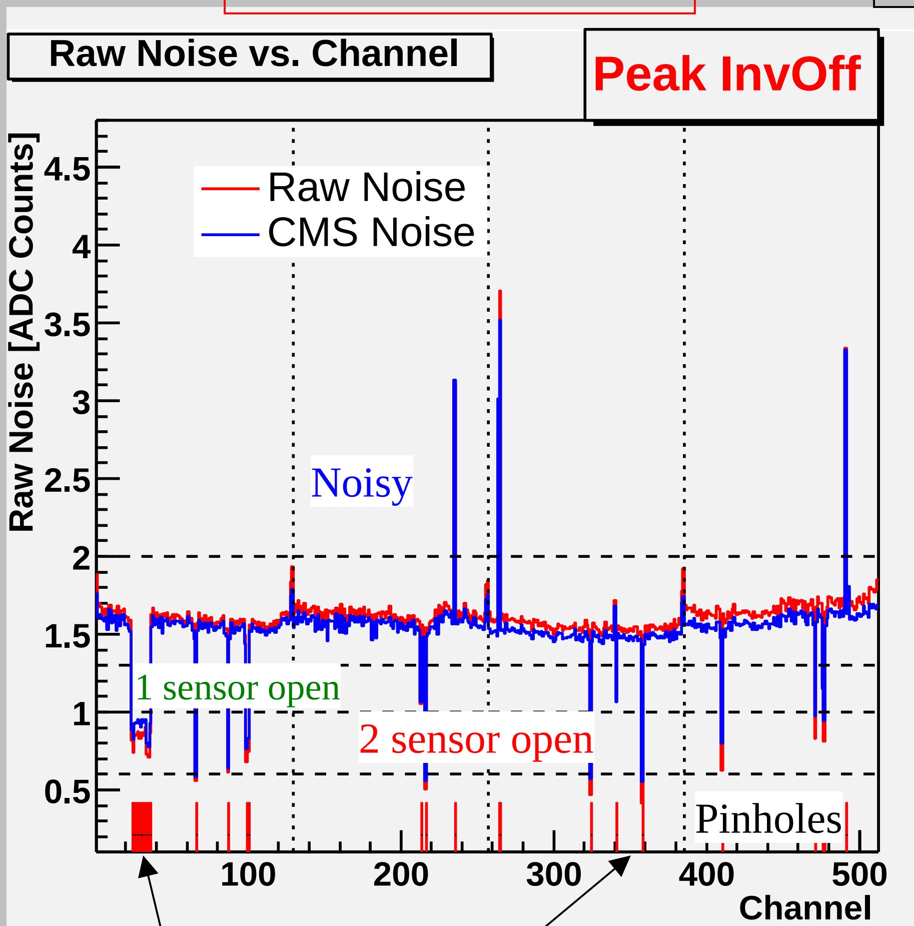
- Module testing has matured greatly
  - A standard set of tests was defined
  - Fault finding algorithms are now tuned to maximize fault finding and fault type identification, while minimizing false bad channel flagging
- Testing procedures are now almost automated
  - Work to automate testing → fault finding → module grading → database entry underway

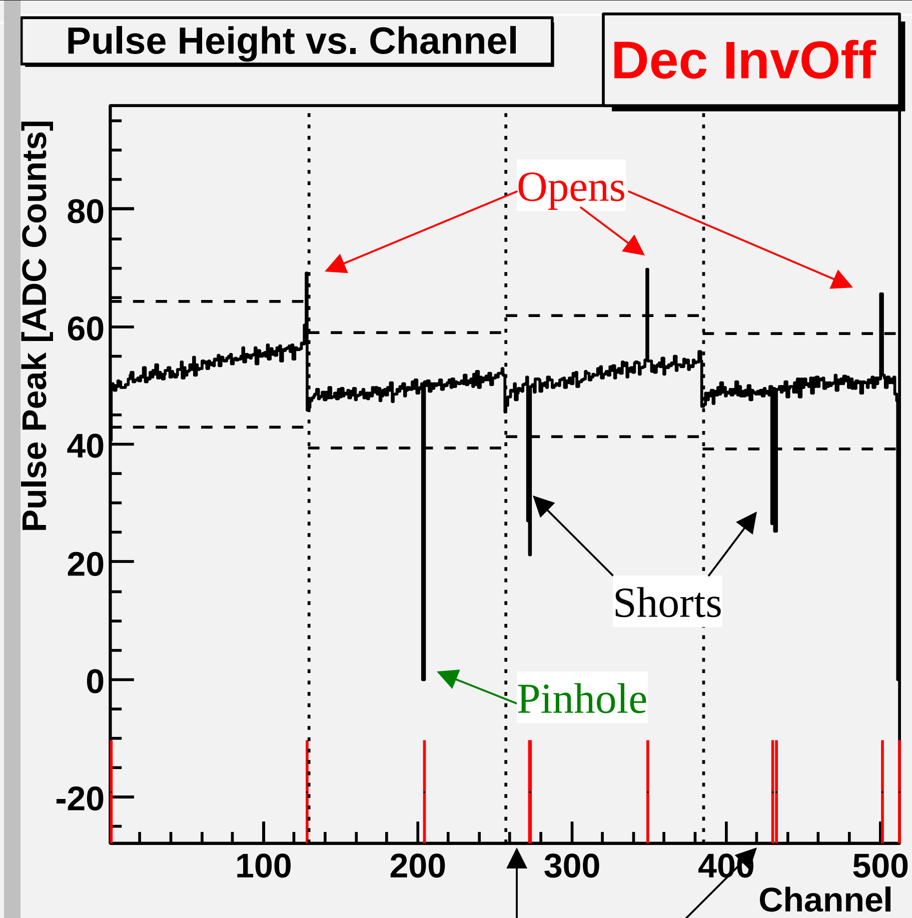
- Noise performance and shielding standardization has allowed for the same fault finding algorithms to work on the TIB, TEC & TOB modules
  - Minimize the effects of external noise sources
  - All test stands are cross calibrated to identify the same faults
- Faults identified:
  - sensor-sensor opens;
  - sensor-PA opens;
  - mid-sensor opens;
  - pinholes;
  - noisy channels.

Fault Finding Using ARCS

Noise Measurement

Pulse Height Measurement (with Calibration Pulse)



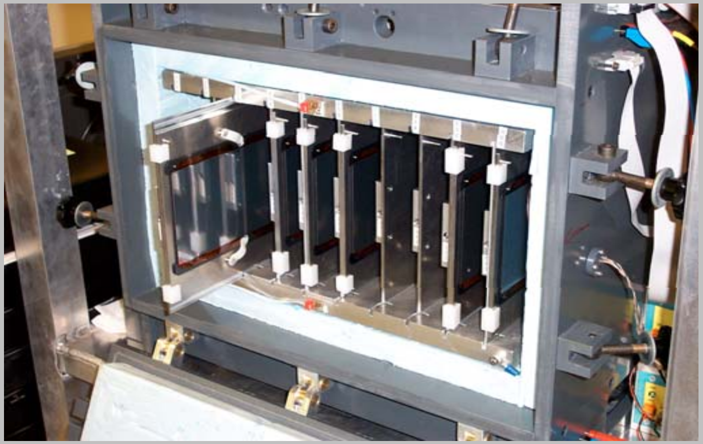


Bad Channel Flags

Bad Channel Flags

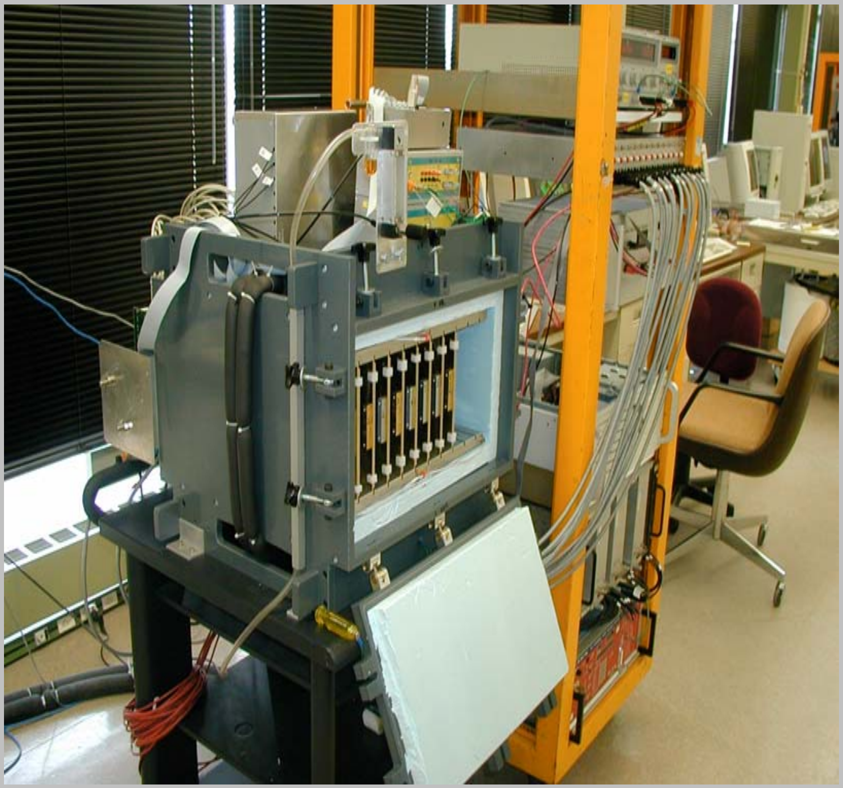
DAQ Based Test Stands

DAQ system – a PC based prototype of the real CMS tracker readout chain
Purpose – fast and long-term testing of modules and rods with thermal cycling



Module Burn-in (Vienna box) at UCSB

- Same structure of root output as on ARCS
- Similar analysis macro is applied to LT data for fault finding



LT system with brass insertion plates (one of two sets) at Fermilab

Recent Hi-Rate Production

- Goals
  - To establish new production capacity (15 modules/day)
    - Determine if testing capabilities sufficient
  - Build as many modules as possible using new ST sensors as agreed upon in December
    - Use sensor grading scheme to find out if subclass of perfect sensors exists (A, A+, A++ = A+ with no vacuum effect)
- Complete set of module tests made
  - ARCS quick test
  - Module thermal cycle (Vienna Box)
    - 1 thermal cycle for each module (~7–10 hours)
  - LED test
- Built: USCB – 200 (150+26TEC+24 TOB 6chip), Fermilab – 102
  - Easily met testing capacity needs
  - Extremely low rate of introduced failures seen
  - CMN modules occurred at approximately same rates as previous builds using re-probed sensors
    - Did not appear to depend on production period or sensor grading

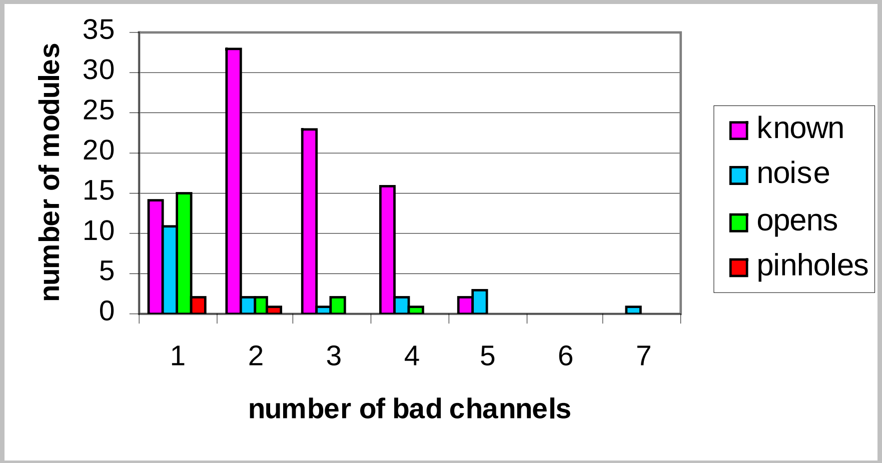
UCSB Module Grading

- 200 modules tested
- Failure rates/sources (excluding CMN modules)
  - 0.50% Bad channels on average
    - 0.29% Known bad sensor channels
    - 0.16% Unmarked bad sensor channels
    - 0.041% open hybrid-APV bonds
    - 0.006% module bonding
    - 0.001% testing errors
  - 0.048% bad channels introduced during assembly/bonding/testing
    - Vast majority of introduced failures were due to faulty pitch adaptors
- 166 modules have undergone 8-12 hours in Vienna box with a single thermal cycle

- Module Grades
  - 166 Grade A
  - 16 Grade B
  - 14 Grade A/F
    - *13 CMN modules*
      - **1 AFTER THERMAL CYCLE**
        - Had 10 ADC noise previous to test
    - 1 module fails to operate at -20 C
      - Tested in 3 different Vienna box slots
  - 4 Grade C/F
    - *2 CMN modules*
    - 12 mid-sensor opens in aluminum strips
    - 19 mid-sensor opens in aluminum

FNAL Module Grading

- 102 modules tested
- Module Grades
  - 78 Grade A
  - 10 Grade B
  - 1 Grade A/F
    - *CMN module*
  - 10 Grade C/F
    - *5 new type failures*
    - 5 modules with mid-sensor opens in aluminum strips affecting from 10 to 30 strips
  - 3 Grade F
    - 2 chips are missing in readout
    - Very high bias current
    - No HV



- Failure rates/sources for grade A and B modules:
  - 3.5 Bad channels on average per module (0.7%)
    - 2.5 Known bad sensor channels (0.5%)
    - 0.5 Unmarked bad sensor channels (0.1%)
    - 0.5 open hybrid-APV bonds (0.1%)
    - 4 pinholes
      - 1 real, 3 bad APV channels

Thermal Cycling Results

<u>UCSB</u>: 166 modules thermal cycled

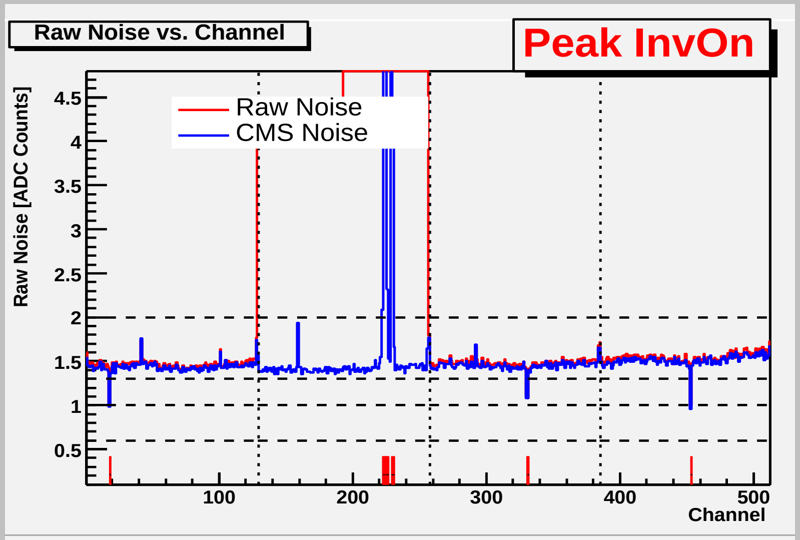
- One module does not function at -20 C
  - Tested in 3 different cold box slots
  - Hybrid bonded and thermal-cycled at UCSB without seeing this effect
- One module developed CMN
  - Prior to thermal cycling, the channel had 10 ADC noise
  - Now consistently has CMN
- One module develops open in HV circuit at -20 C
- One module has a single APV channel burn-out
- Multiple noisy channels (2-5 ADC) appeared and disappeared after cycling

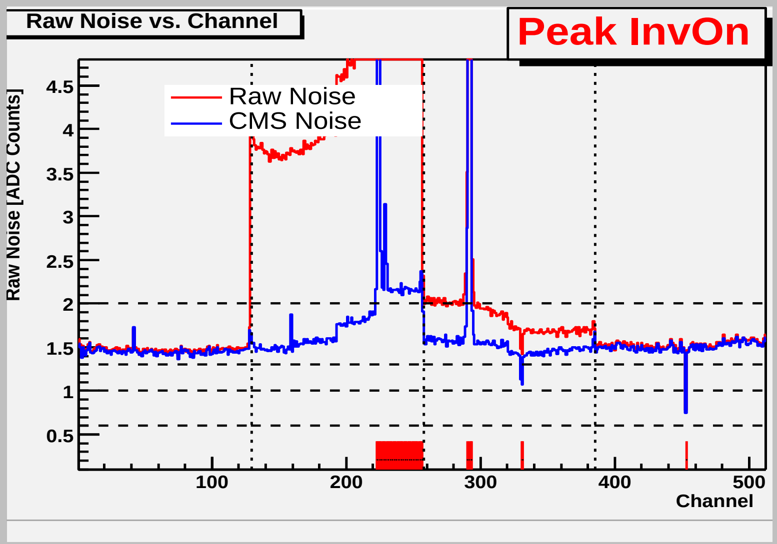
<u>Fermilab</u>: 92 modules thermal cycled

- 26 showed very high noise in one of the four testing modes (PeakInOn) at -20 C
- This effect is seen only when more than 7 modules at once are tested
- Retested in groups of 5: no problem is seen
- The effect is LT system related – work on fixing (UCR)

• no new CMN or pinholes observed after thermal cycling

Common Mode Noise (CMN) problem





CMN effect features:

- A group of very noisy (>20 ADC counts) strips
- Dependence on the applied bias voltage
- "turn-on" voltage above which all channels of the chip show high noise
- effect can reveal itself after thermal cycling
- often accompanied by other degradation effects (pinhole development, more CMN)
- often correlated with high module bias current

Example: second chip now has a high noise channel which causes common mode noise
Channel previously only had a slightly higher noise (0.3 ADC)

CMN modules and sensor grading

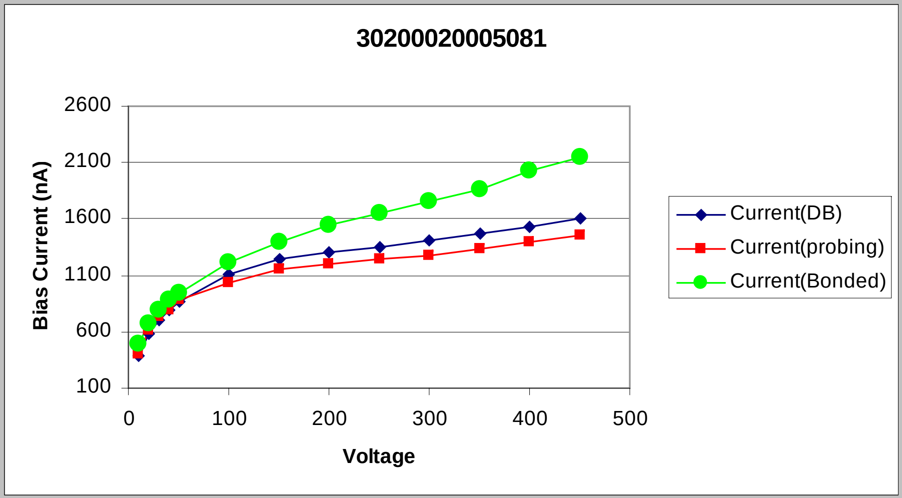
Sensor Grade	Pre-Production			Production I			Production II		
	NUMBER	CMN	%	NUMBER	CMN	%	NUMBER	CMN	%
GRADE A+	36	2	5.6%	12 (10)	0 (0)	0.0% (0.0%)	3	0	0.0%
GRADE A	53	3	5.6%	16 (11)	1 (0)	6.3% (0.0%)	19	1	5.3%
GRADE B	32	5	15.6%	1 (6)	0 (3)	0.0% (50.0%)	2	0	0.0%

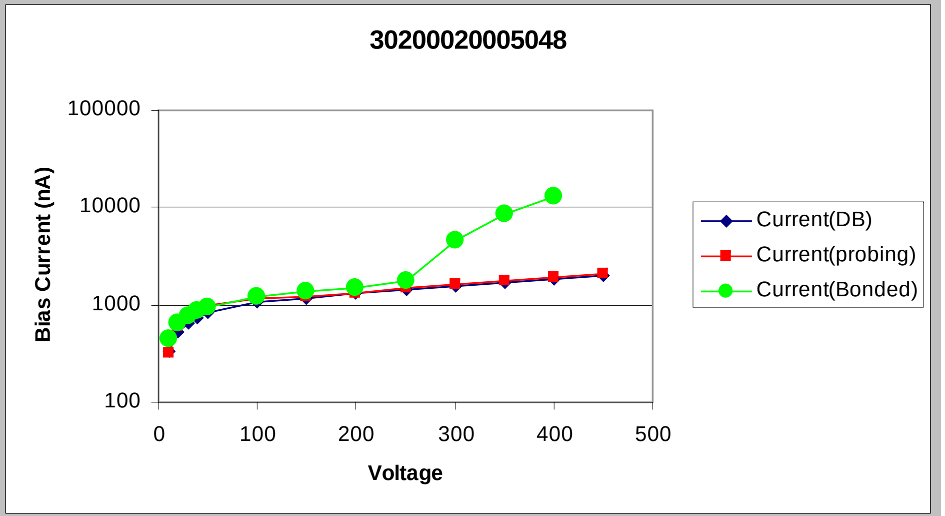
TOB – black, TEC – red

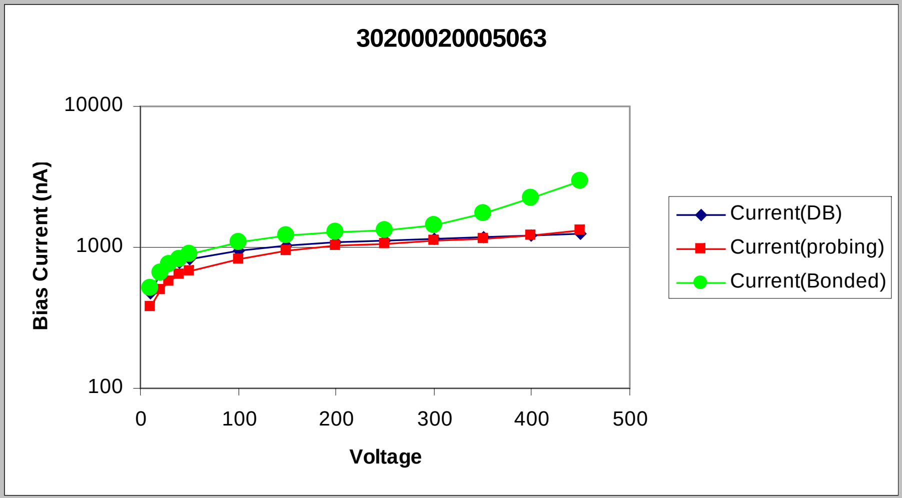
- Sensors graded using Vienna rules
  - All sensors were re-probed prior to assembly
  - Worst sensor grading out of two measurements used
- Sub-divided into three time periods
  - Prior to Week 12, 2003 (Pre-production)
  - Week 13, 2003-Week 37, 2003 (Production I)
    - All Handling Procedures Finalized
  - Week 38,2003-present (Production II)
    - Final Processing (Qualification Batch)

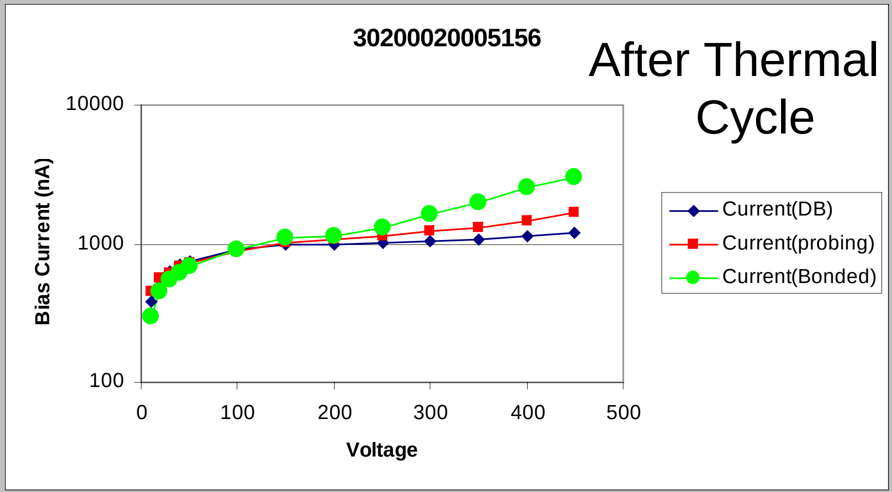
- 15 Common mode modules found (7.5% of production)
  - Same rate as seen previously with re-probed sensors
  - 1 after thermal cycling
- No significant difference between A+ and A sensors, production run, or TOB vs. TEC
  - CMN rate in grade B modules may be higher than grade A+/A
- Similar re-probing effort at FNAL

New CMN Module IV Curves

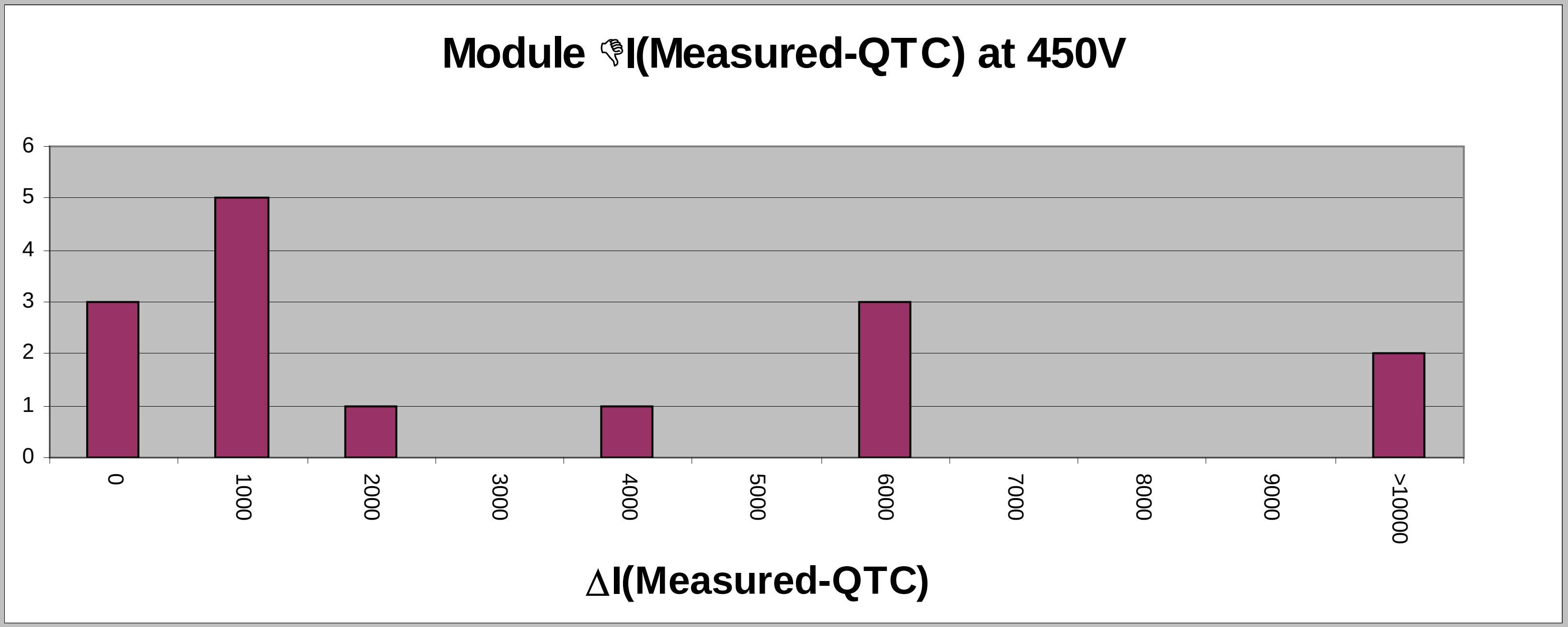






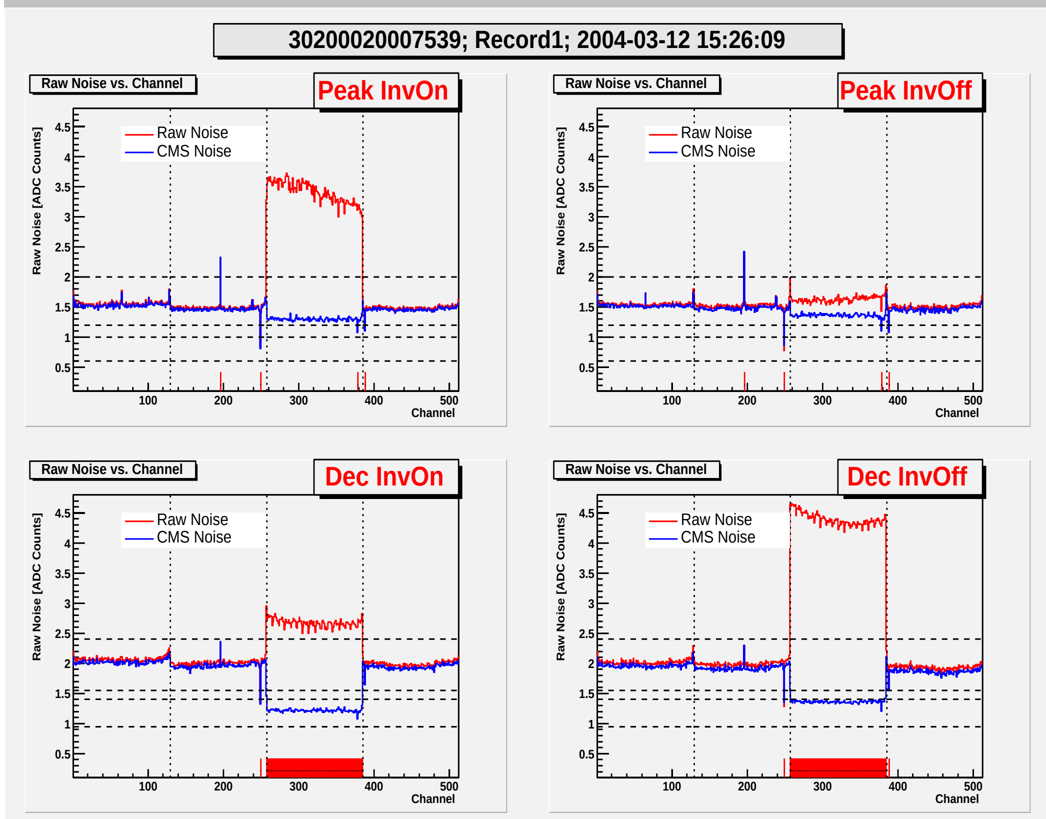


CMN Module Bias Current



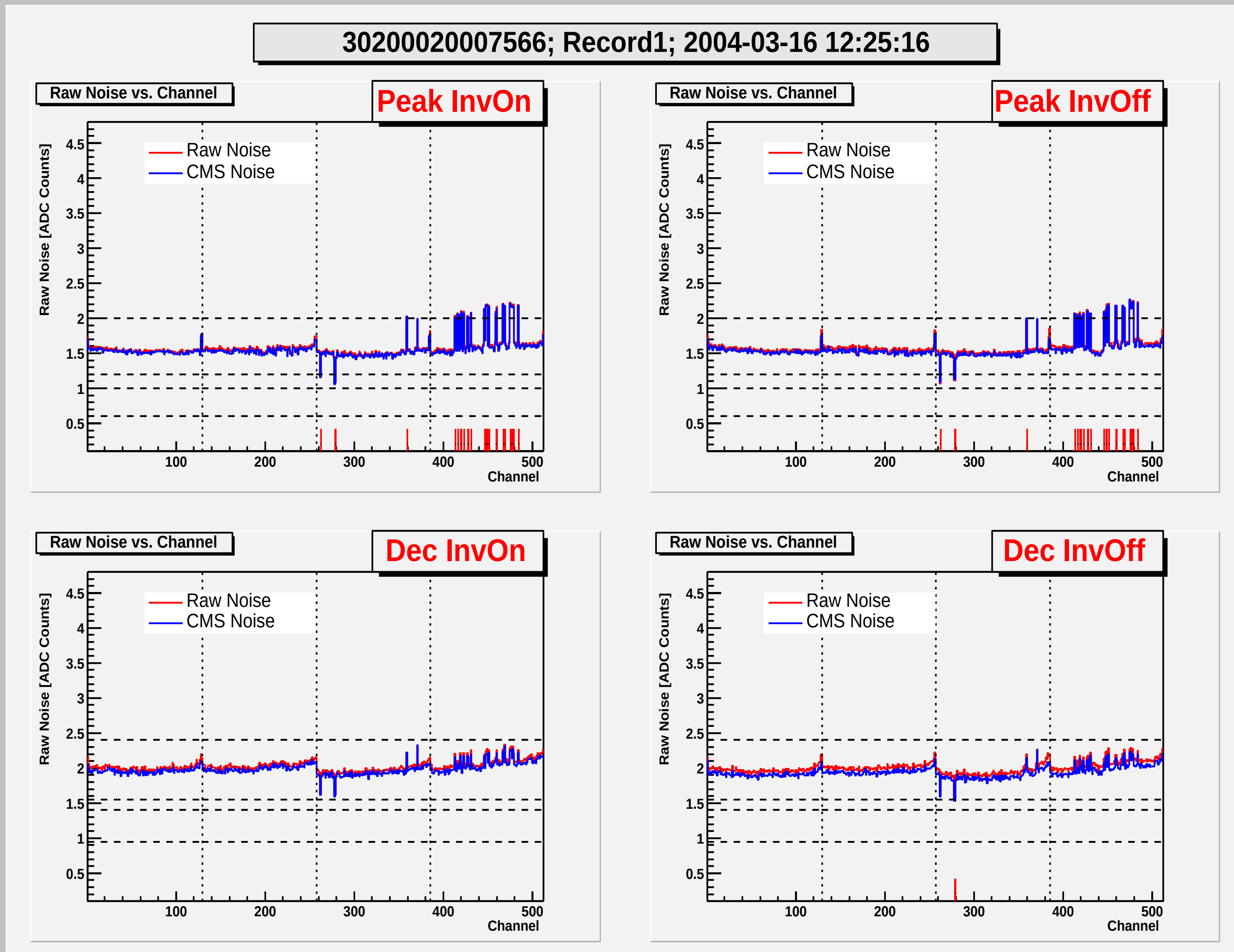
A large fraction (10/15) of CMN noise modules built with re-probed good sensors show a less than 5 μA current increase relative to the sensor QTC expectations!

New failure mode observed



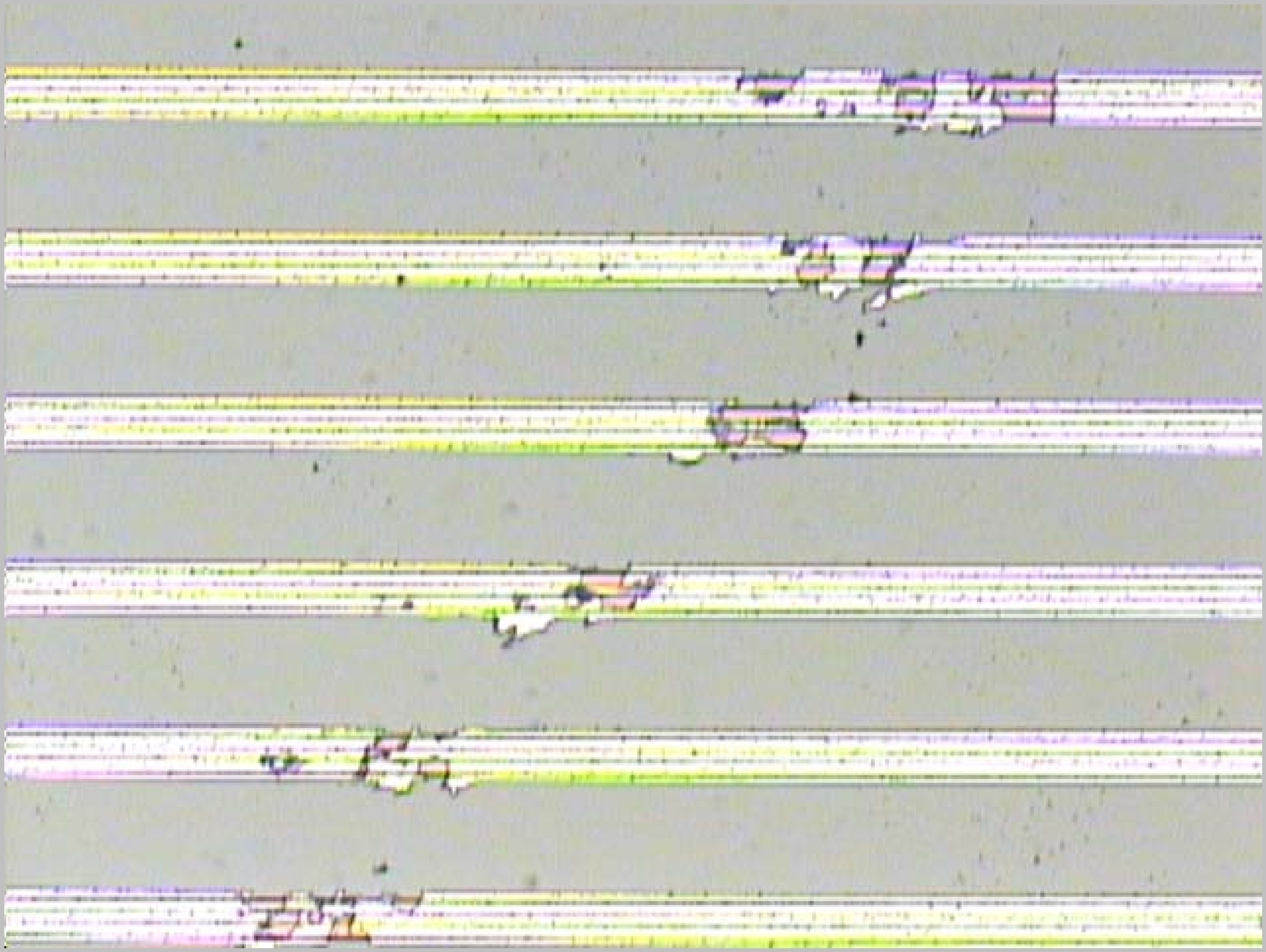
- The effect is seen as increased CMN but:
  - No strips with high noise on the chip with CMN
  - No dependence on applied voltage
  - Low response to calibration pulse (1/2 of the normal PH)
  - Pedestal "drifts" with time: goes up to 220 –230 ADC then goes down to 0 and stays there
  - Power cycling sets it to nonzero
- 5 cases are observed in FNAL
- Under study –
  - recently found to be related to a bad via in hybrid (April 19 /04)

Grade C module example



Sensor defects

Module 7566

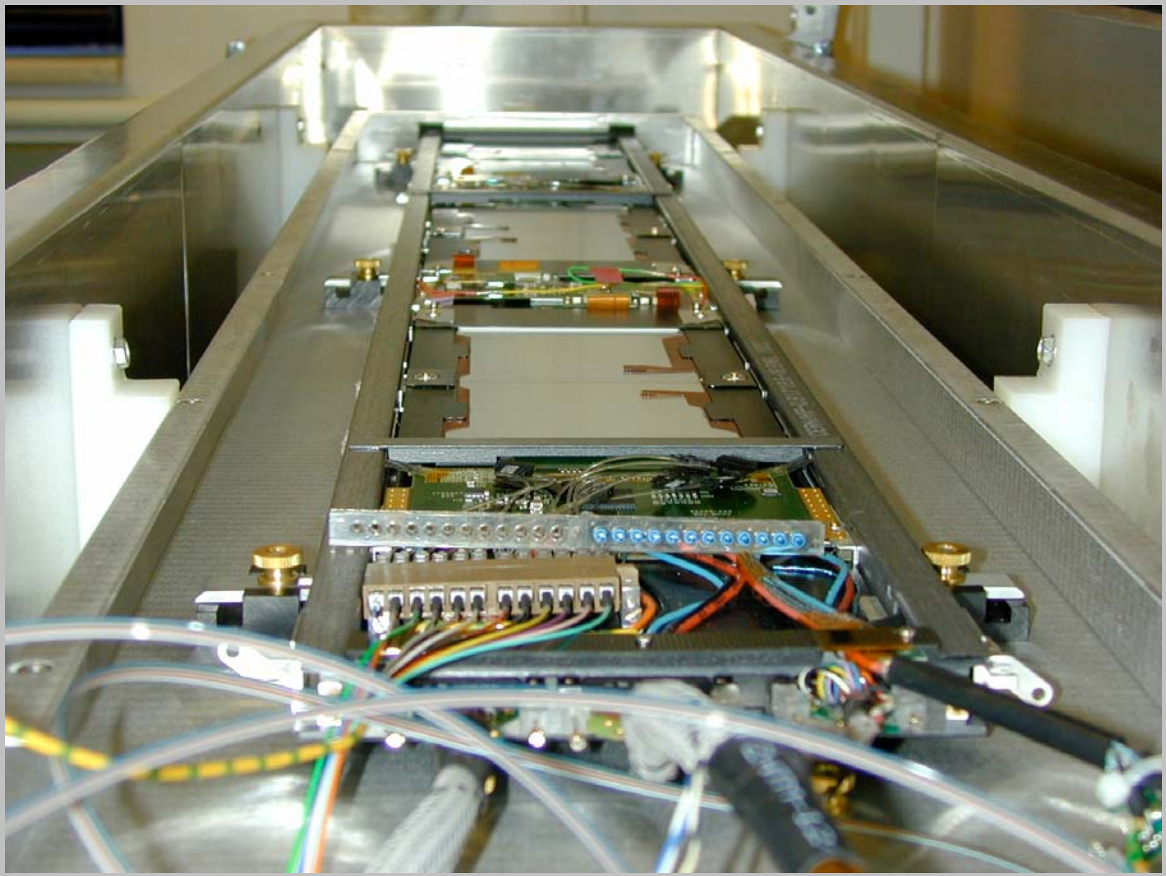


5(2) modules built at FNAL(UCSB) have sensor defects associated with marginally high noise channels like this one

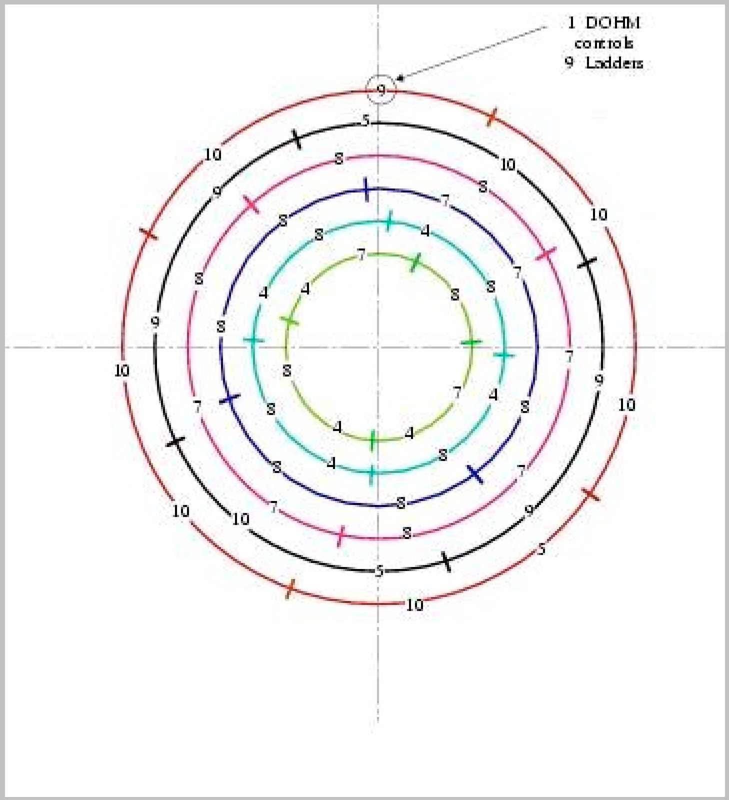
Module Test Conclusions

- Testing infrastructure is ready for the large scale module production
- Testing facilities have trained personal and with sufficient experience
- 302 modules were produced and fully tested in US in 2004
- Ability to test at production rate of 15/day demonstrated for ~2 week period

Rod Production

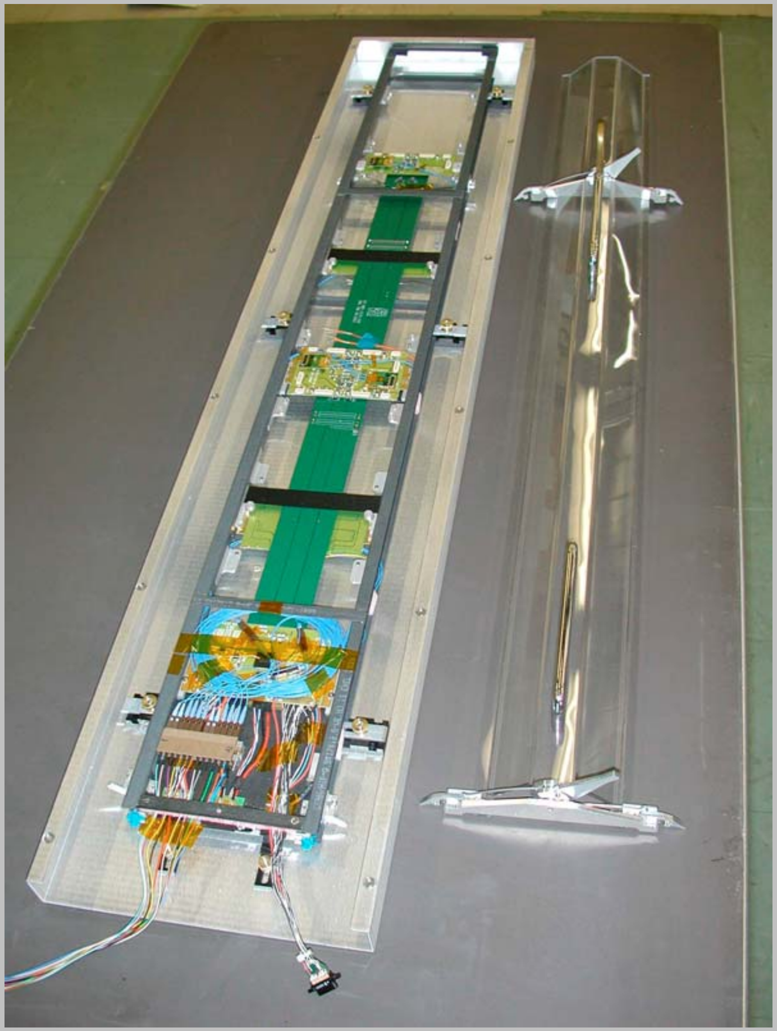


What is a rod?



- Barrel is grouped into 96 control rings, each containing 5-10 rods.
- Rods use token-ring protocol to communicate with data acquisition electronics.
- Redundancy architecture allows control ring to operate even in case multiple non-consecutive failure.

Rod as it Arrives in US



•Major components are Command and Control Unit (CCU), and Analog Opto-hybrids (AOH).

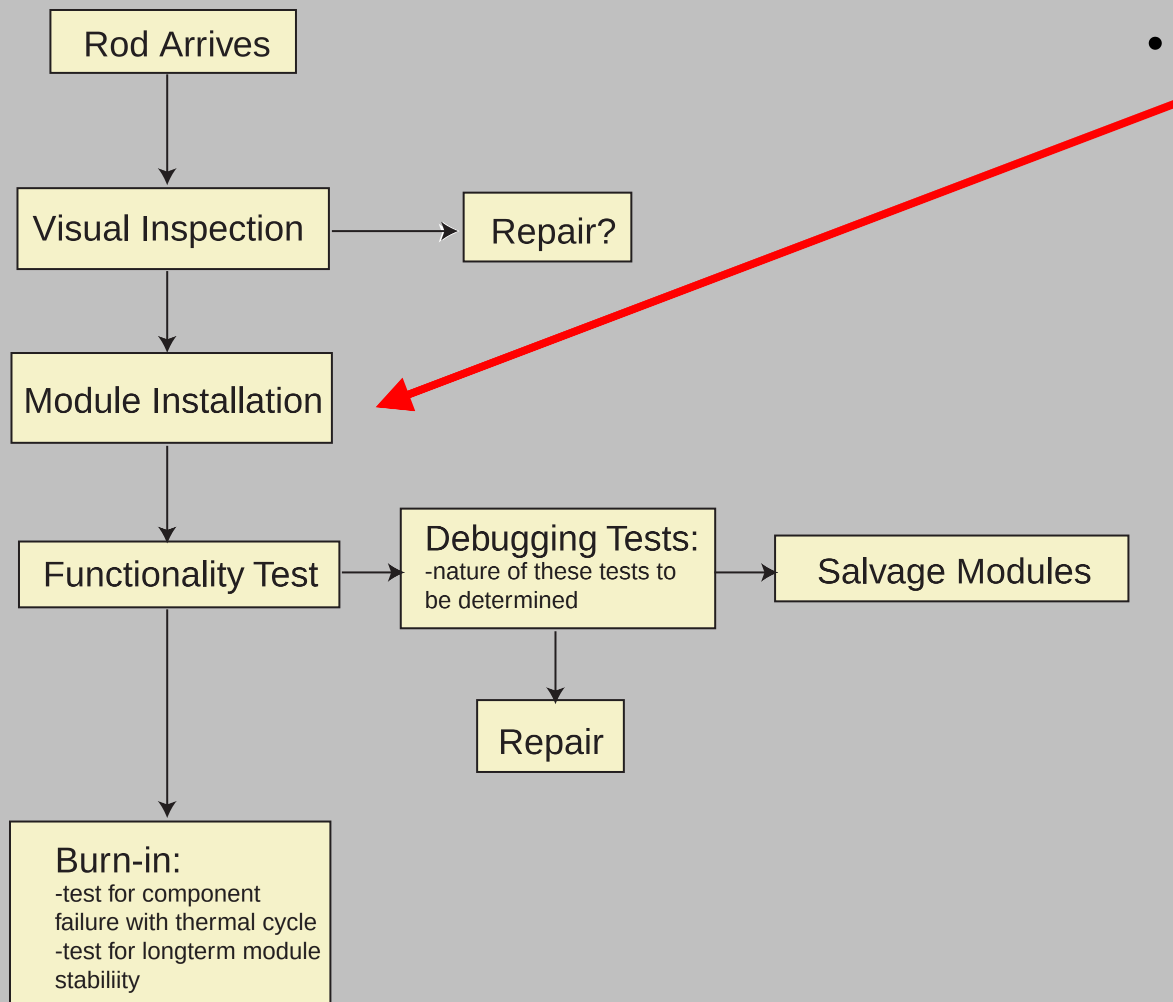
• CCU handles communication between rods, and between rod and readout electronics.

•AOH converts module’s electrical output to optical signal.

• Both of these components, as well as electrical connectivity of the whole, are tested at CERN prior to shipping.

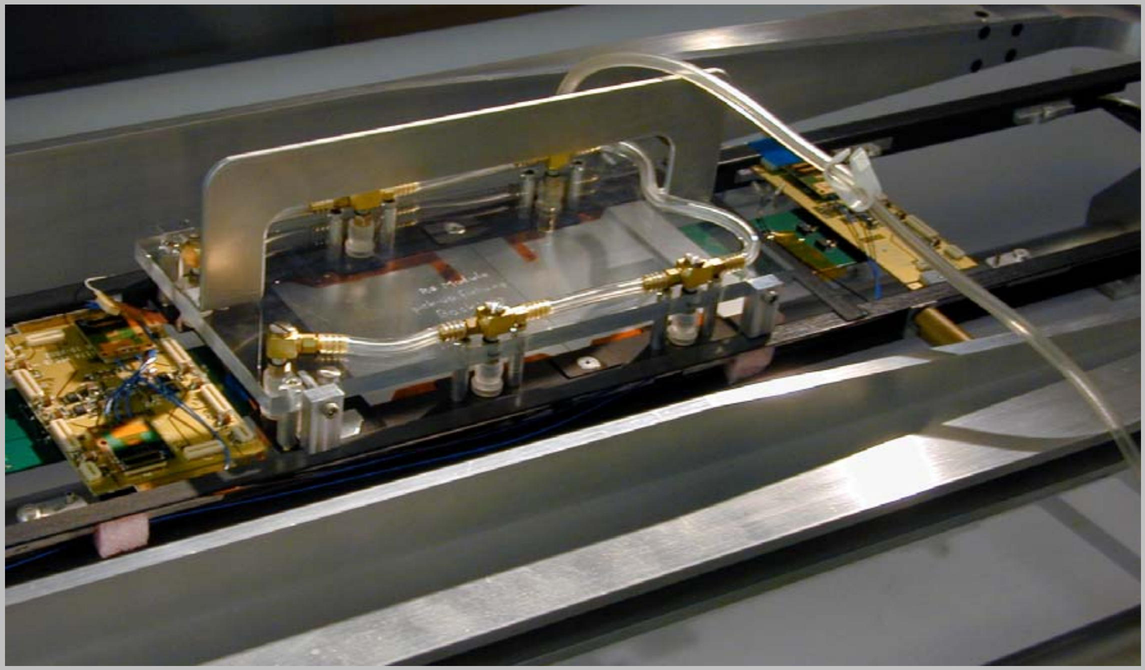
• Carbon-fiber frame produced in Helsinki, and assembly of CCU’s AOH’s and support electronics at CERN.

Rod Testing Flow Chart



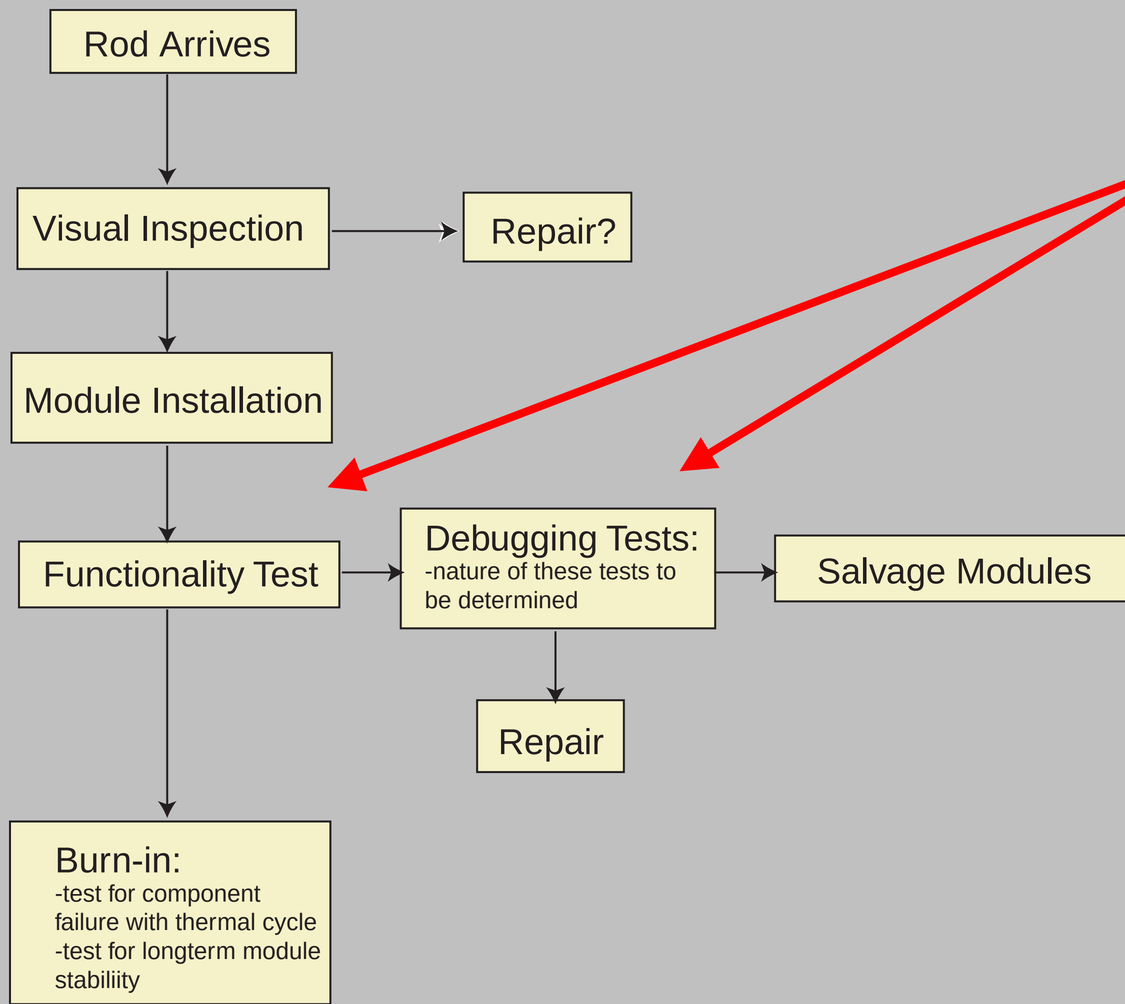
- Very conservative module installation ("assembly") time estimate is 2 hours for single-sided rod, 3 hours for double-sided rod. The planned assembly of 2 rods/day won't be stressful.

Rod Assembly



- Module placed on bare rod using handling tools developed at UCSB
  - Six rods assembled at UCSB.
  - One “dummy” rod assembled and disassembled multiple times at FNAL.

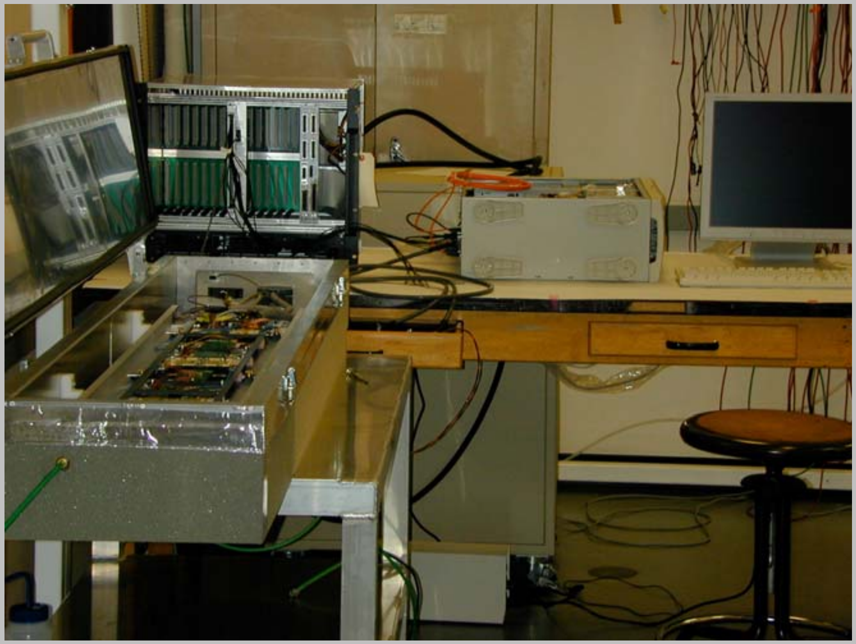
Rod Testing Flow Chart



•Components most likely to fail modules, optohybrids, and connectors.

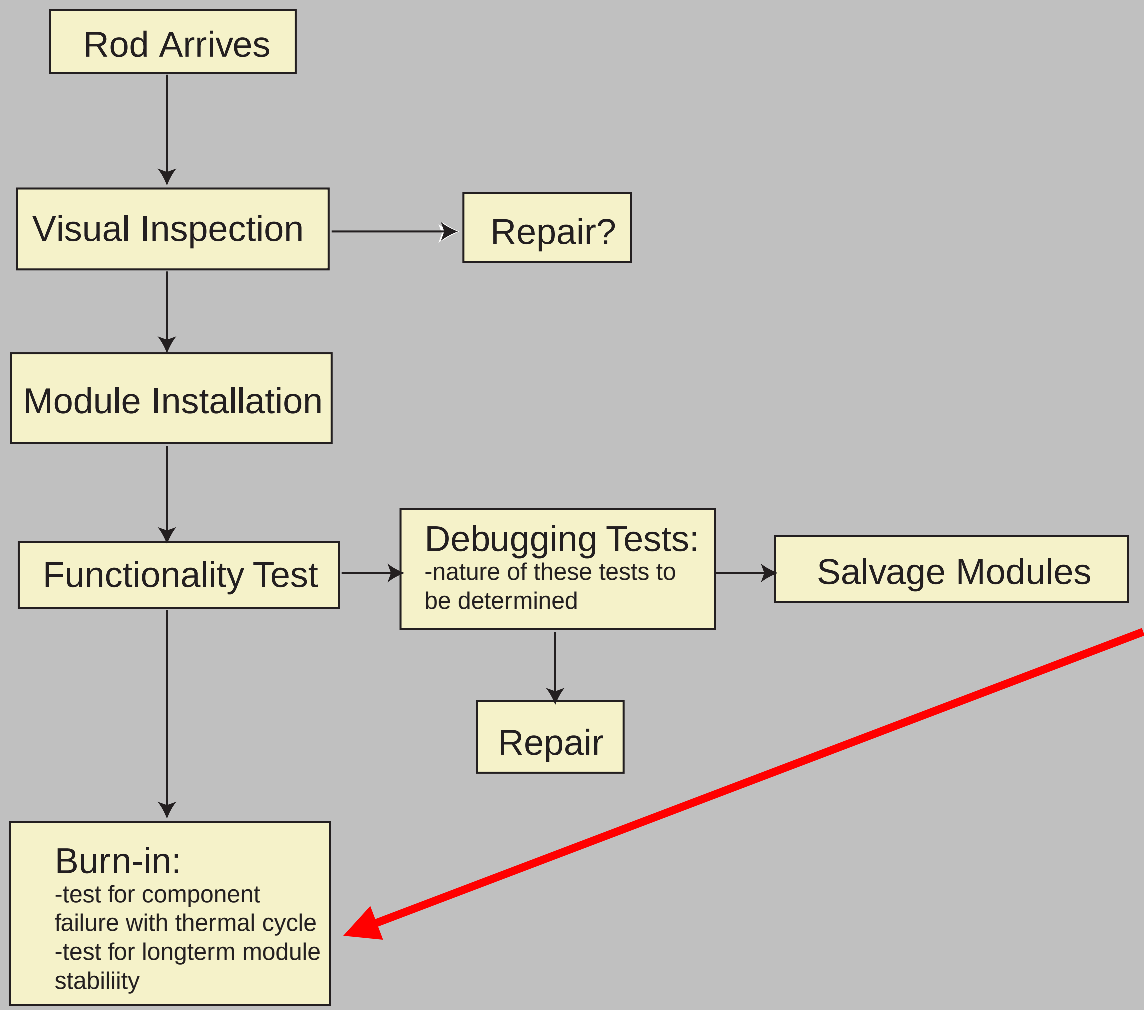
- Modules are built and extensively tested before installation on rods.
- An apparatus to independently test optohybrids is on order, and we have spare optohybrids on hand if needed.
- We're gaining experience in connector failure by the extensive handling of rods in the ramp-up phase.

Single Rod Test Stand



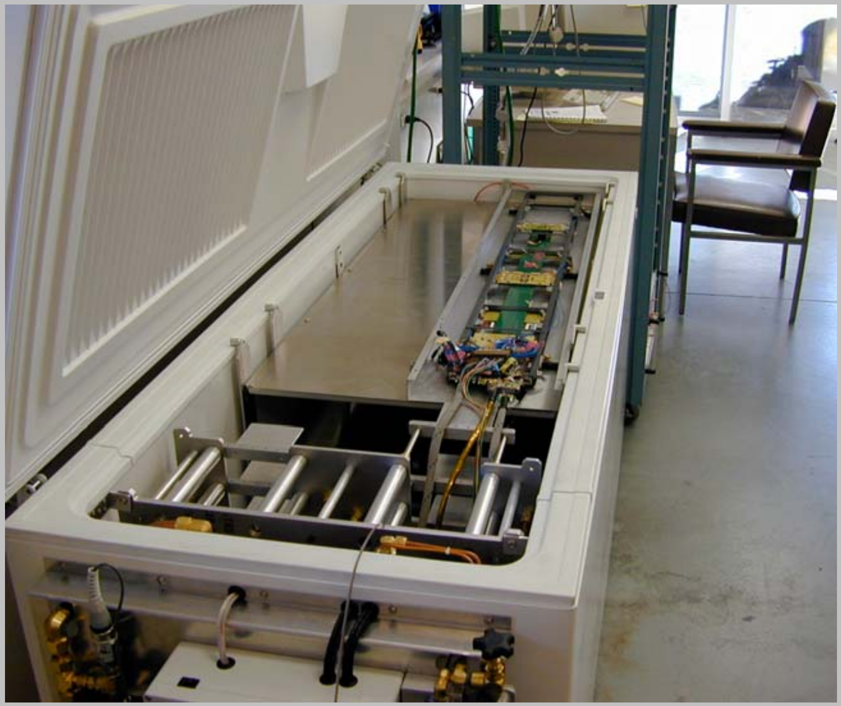
- Used for functionality test after assembly.
- Test box provides dry, dark, and electrical isolated environment
- Also used for cold-test of individual rods (not part of regular production).
- Connects to rod burn-in for cooling.
- Status:
  - complete at UCSB, except that we are planning to purchase a second, smaller chiller so it can be run completely independently of burn-in box.
  - Nearing completion at FNAL.

Rod Testing Flow Chart



- Rod burn-in very important.
- Only cold-test of entire rod substructure.
- First time every rod component is subjected to cold, long-term test.

US Multi-Rod LT Stands



• Status: UCSB stand is fully equipped. FNAL burn-in box is complete, but lacks rod power supplies from CERN. Rod readout software not complete, but it is possible to run burn-in especially at reduced pace during ramp-up.

• Up to 8 rods run for 3 days of thermal cycling: room temp to –20C and back.

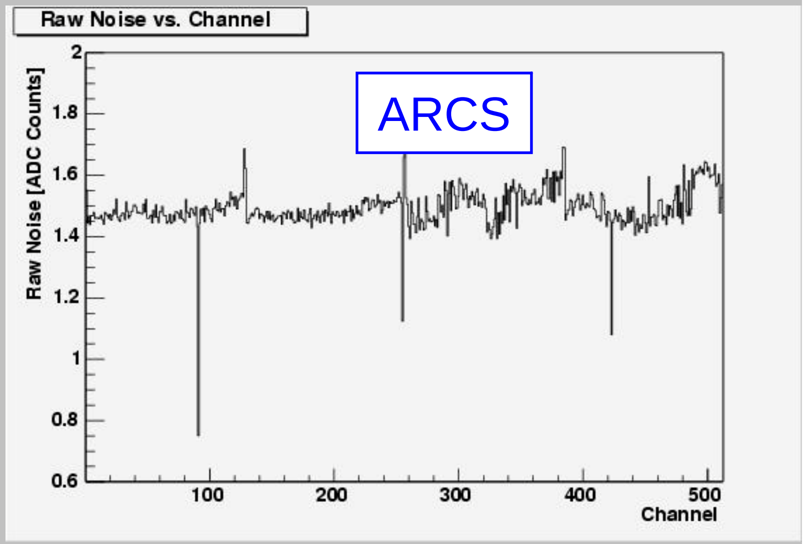
  • Burn-in hardware and interlock software developed and assembled by University of Rochester

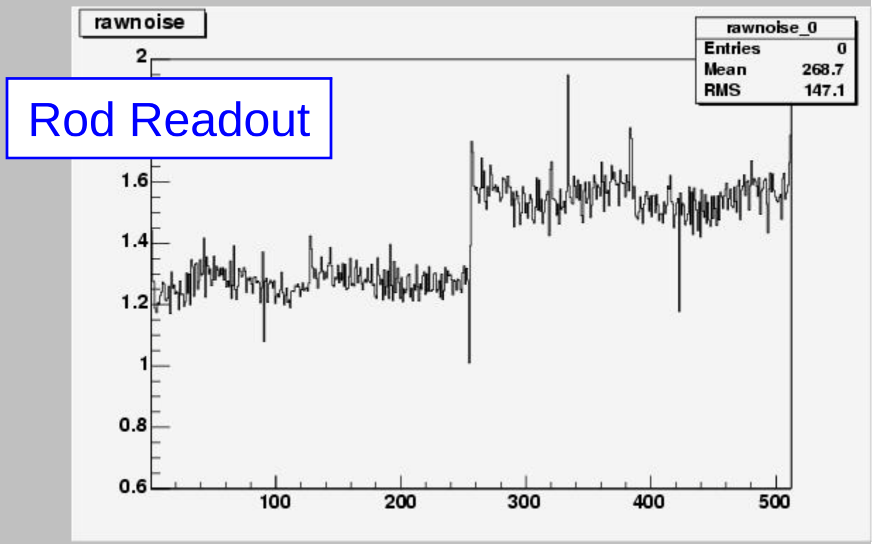
• Rods controlled and read-out with software already written for module test. Adaptation of the software to this larger task is ongoing.

• Data will be adapted so that initial module test (ARCS) criteria can be applied and module quality re-verified.

Rod Testing Results

- Faults clearly seen.
- More statistics needed in order to know how best to test rod.
- Difference in noise height between two halves of module is due to uneven laser gain. This is one of the issues being resolved in readout software.





Rods Summary

- Single rod test stand fully equipped at UCSB. Nearing completion at FNAL.
- Six complete rods assembled at UCSB, including one double-sided and one single-sided six-chip. Two more to be assembled in the near future.
- FNAL has experience assembling “dummy” rod.
- Rod burn-in hardware complete at UCSB. Complete at FNAL except for rod power supplies.
- Rod thermal-cycled to –20C.

Rods: Further Work

- First FNAL assembly of production rods. Waiting on shipment of rods from CERN, expected in May.
- Completion of rod readout software so that burn-in is as automated as possible.
- Commissioning of burn-in stand with full capacity.
- Implementation of adapting ARCS testing criteria to long-term Rod testing data.

Rod LT Introduction

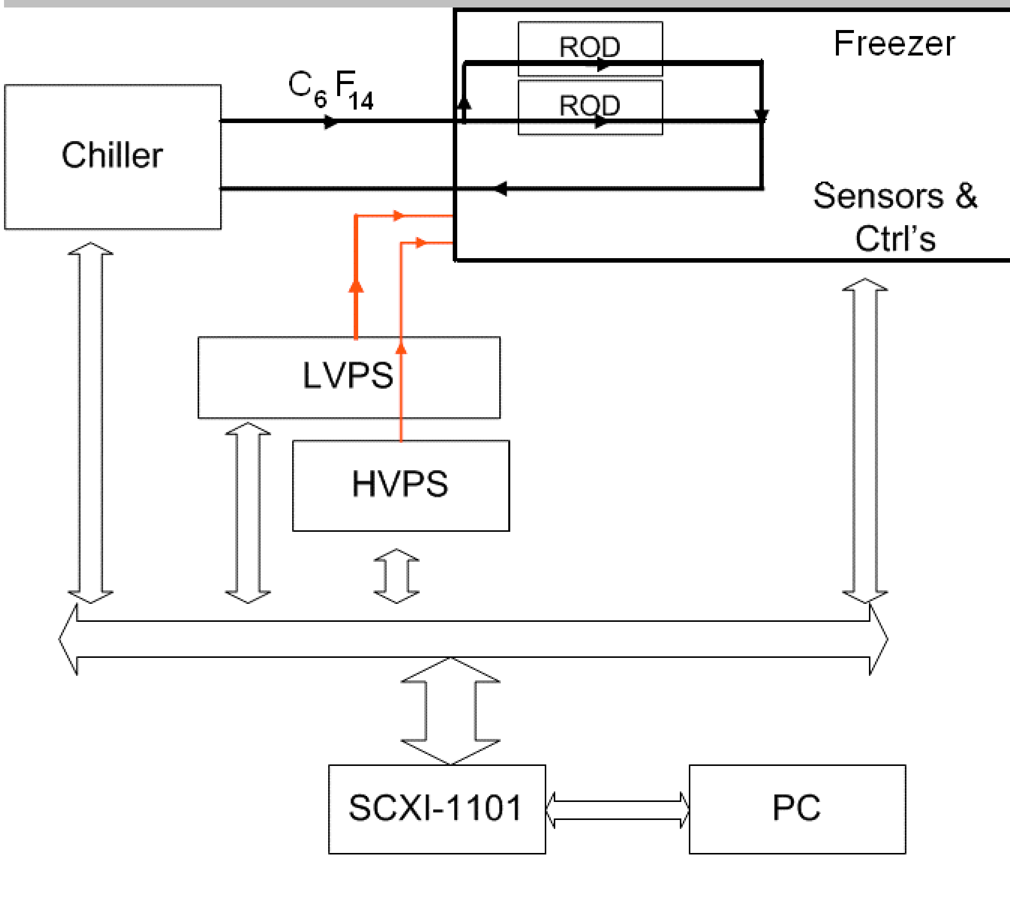
This Facility must provide:

- multi-day burn-in
- thermal-cycle capability between room temp and -20C
- At each of two production sites, FNAL and UCSB
- for up to 8 rods at a time per site
- While keeping rods safe and happy (dry, cool, dark, powered, biased)
- Ease of operation – by technicians

Rod LT: Needs

- Rod Container
- C_6F_{14} Chiller and pump
- Flow and temperature control hardware and software +interface to Lt DAQ
- Flow, pressure, temperature, and relative humidity monitoring and Interlocks
- Dry air and vacuum
- Cables and power supplies
- Rod readout using multi-rod Lt software (Not discussed here)

Rod LT: System Diagram



PC through SCXI Chassis controls and monitors:

- Chiller and chiller temp
- Enables for the power supply
- c_6f_{14} flow valves and flow sensors
- RH monitors
- Temperature
- Pressure
- Talks to Lt software through TCPIP

LT: Rod Container

- Modified commercial chest freezer provides light-tight insolated environment
- 4 removable shelves, each contain 2 rods
- Rods contained within their Aluminum transport boxes for protection and ease of insertion
- Dry air flow into each transport box

Rod LT: C_6F_{14} Chiller

- Commercial chiller placed outside cleanrooms
- 350W at -25C cooling capacity
- 15LPM maximum flow rate
- Controlled through RS232 port with PC.
- Brings rod to -17C in 2 hours with help from freezer

Rod LT: Multi-Rod Flow Control

•4 computer-controlled valves:

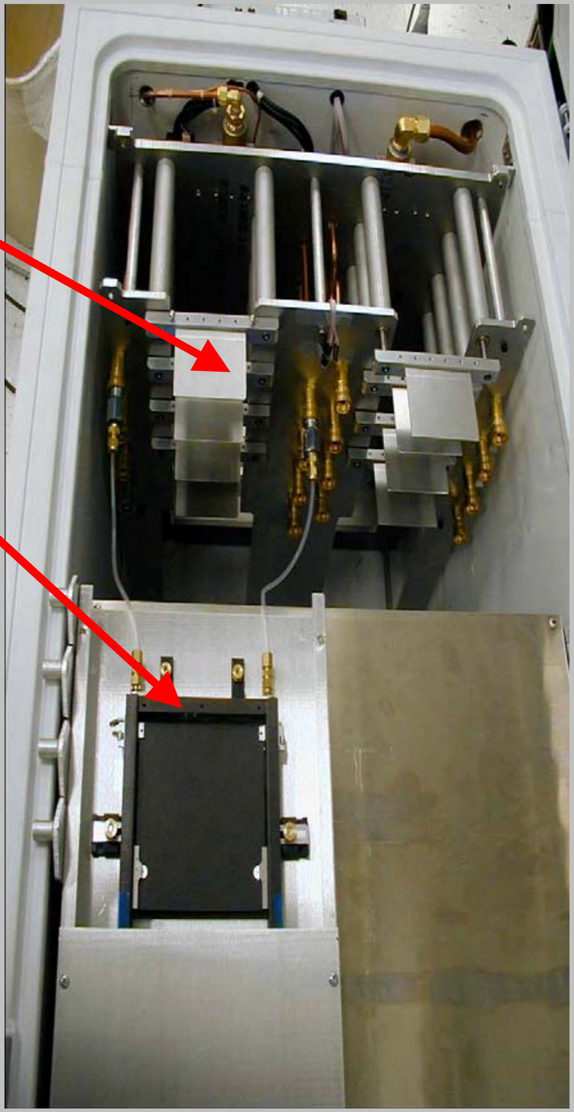
- 1 valve to control the C6F14 flow
- 1 valve to allow air in the input manifold
- 2 valves allow air/vacuum in the output manifold

Rod LT: C_6F_{14} flow control

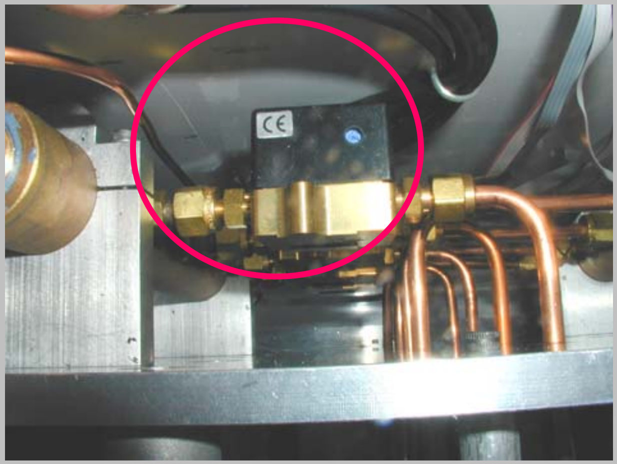
Input and output manifolds allow constant pressure differential across variable number of rods

Rod LT: Within the rod container

- Quick disconnects make installation easier
- Removable partial lid on transport box allows access without rod removal
- Automated test of rate-of-pressure drop after overpressure for leak detection at beginning
- Automated purge of C6F14 at end

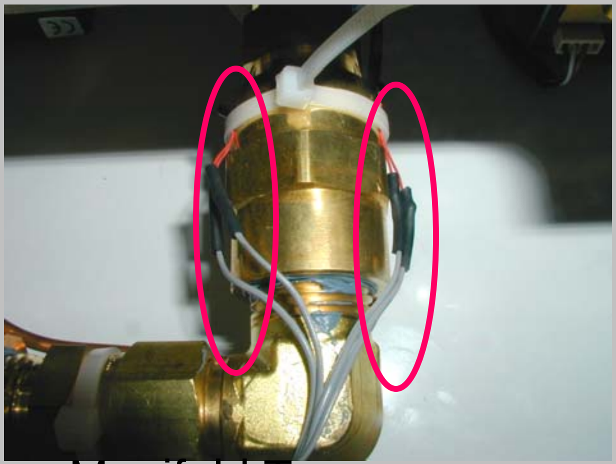


Rod LT: Sensors in the Container

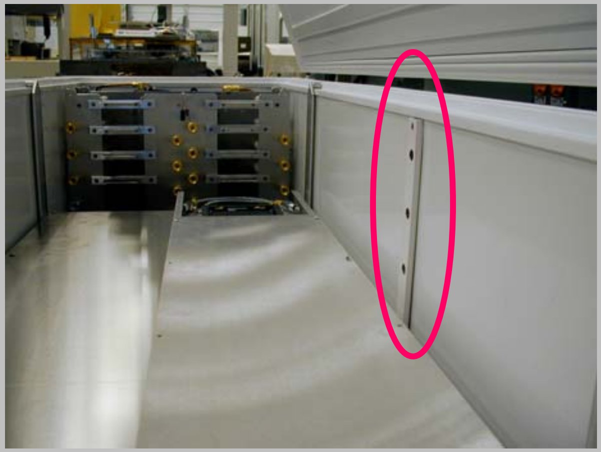


Flow meters

Container RH & T

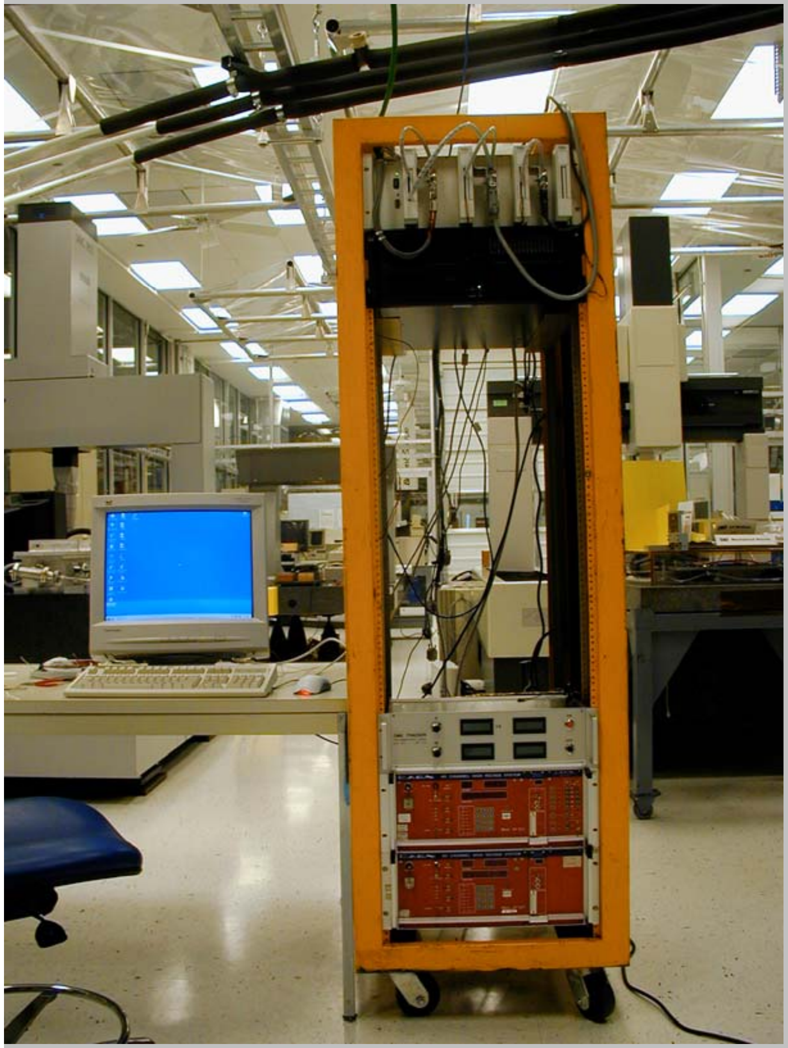


Manifold Temp.



Proximity detectors

Rod LT: Electronics Rack Contents:



- SCXI-1101 chassis
  (National Instruments)
- Interlock & Ctrl PC.
- Has space for 9 LV PS's (8 Rod's+ 1 Control loop (CCUs))
- 2 HV CAEN PS's (40 channels each)
- 2 separated electrical lines. (allows Duccio supplies to be reset via the computer)
  - Line1: 8 LV PS (computer controled)
  - Line2: SCXI,PC, HVPS and control LVPS

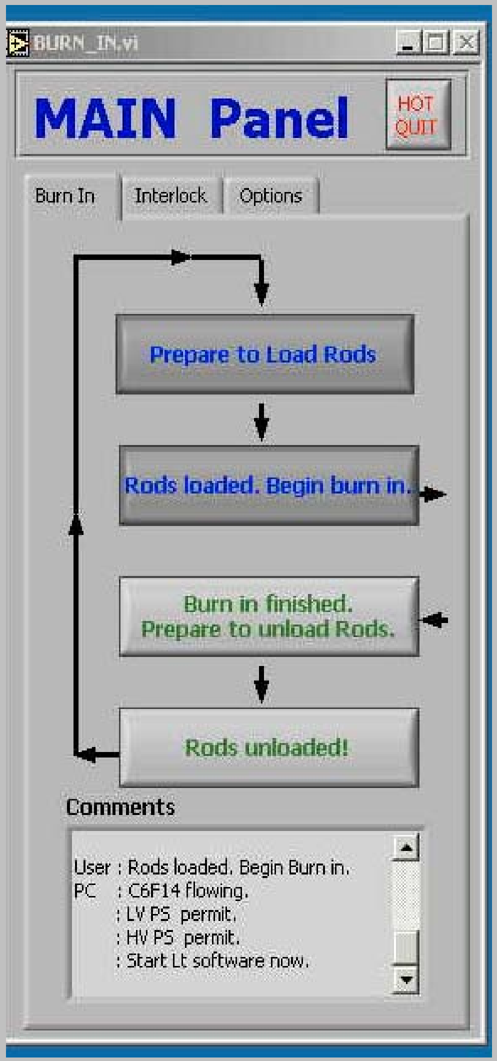
Rod LT: System Labview Software

PC guides the user through the rod burn-in cycle

- Button “Prepare to Load Rods.”
  - When selected system self-checks counts rods,etc, then returns

  Ready Rods Loaded.
- Rods are then leak-checked and system enables
- Button ”Prepare to burn in” when selected and completed
  - ⇒ Interlock software enables PS
  - ⇒ User can start Lt software
  - ⇒ Lt software chooses rod temperature, labview responds
- “Burn-in finished”.Button.

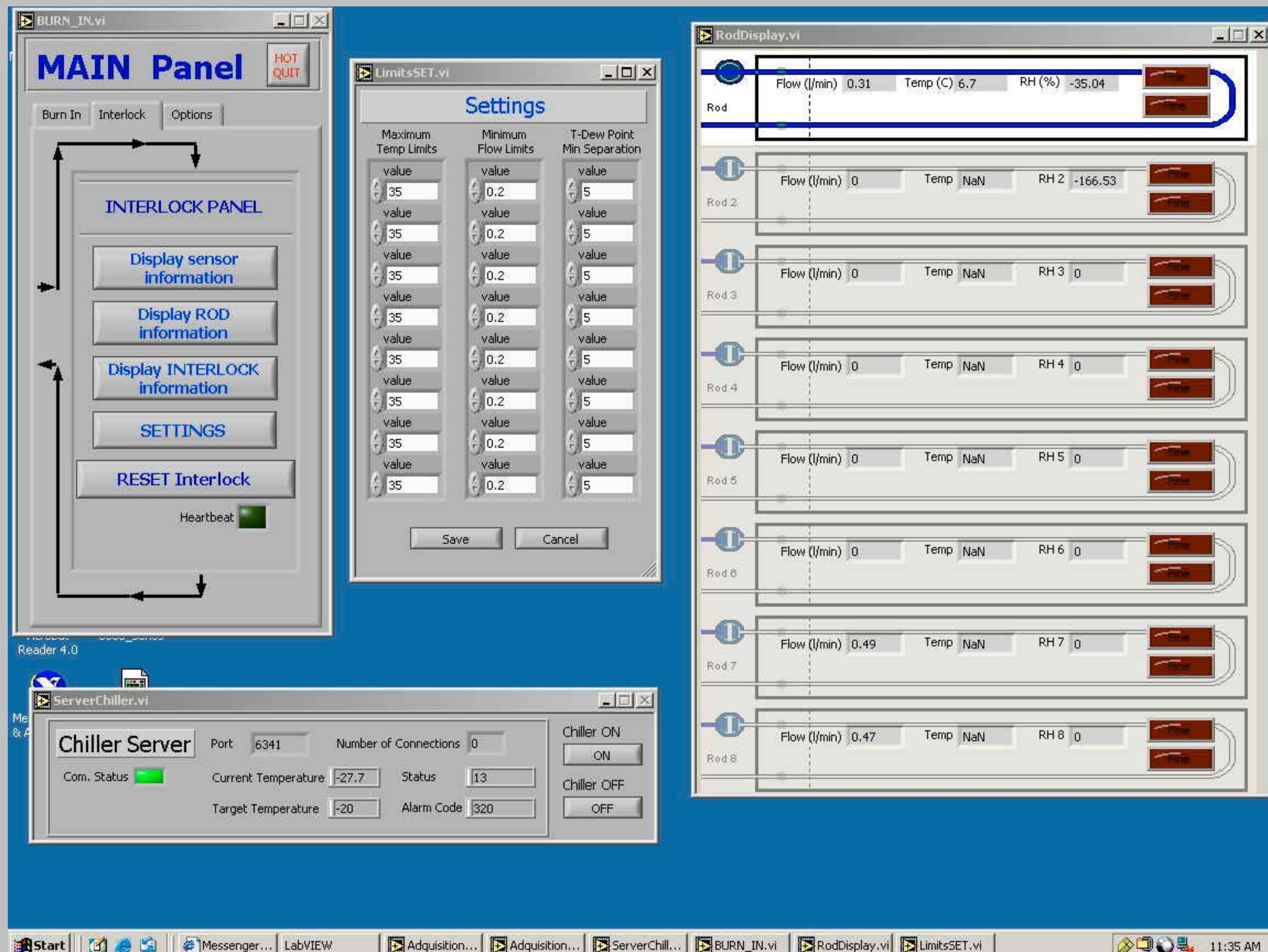
  ⇒ Drains rods, turns off interlocks
- Rods are then ready to be removed



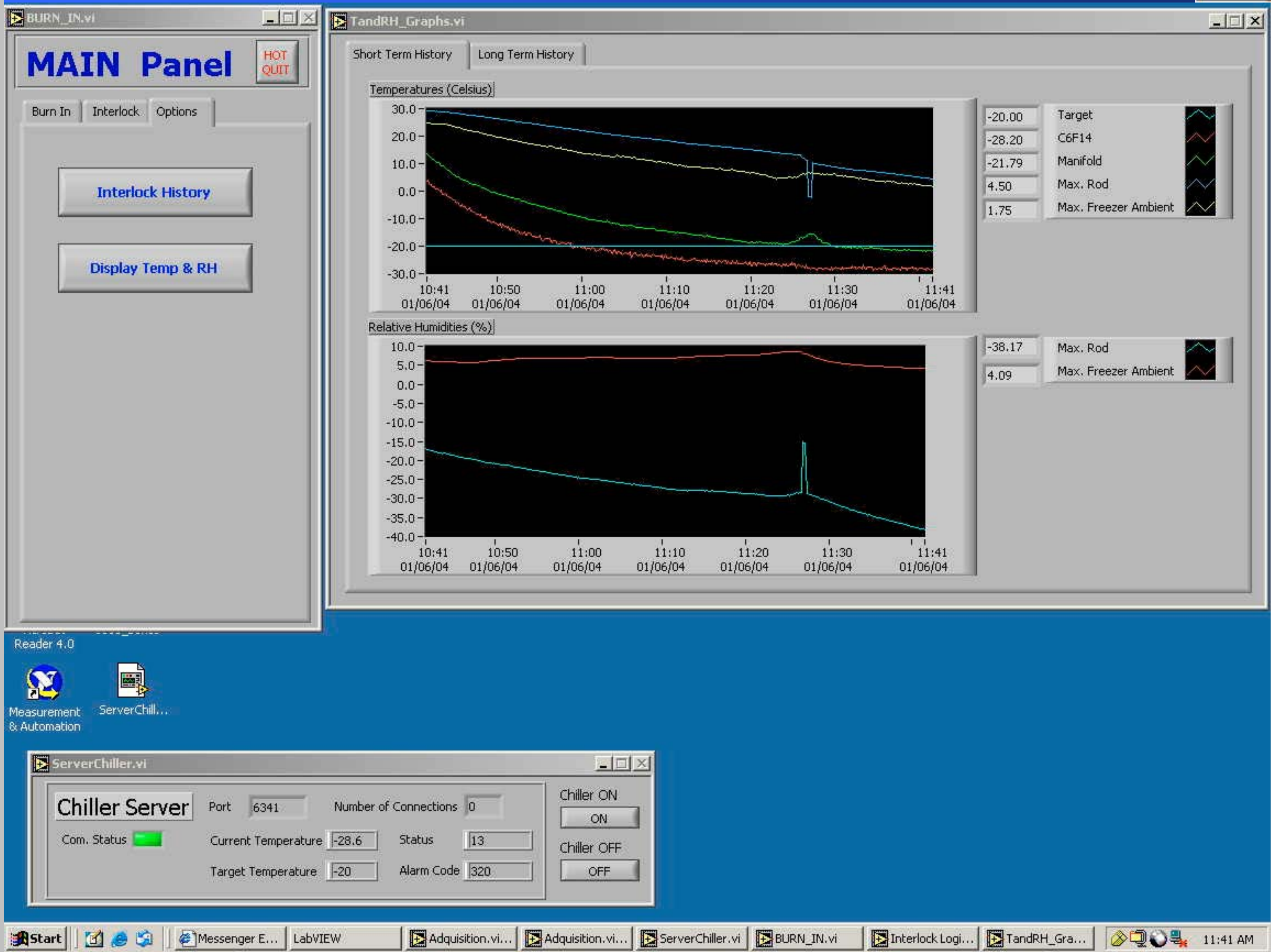
Multi-Rod LT Stand : Interlock Logic

- Power interlock
  Kill LV+HV
  - T_{ROD} and RH->Dewpoint
  - Flow (each Rod and total)
  - Chiller status
  - Rod container dewpoint
- Cooling interlock
  Stop coolant supply
  - Dew point of rods or manifolds
  - Freezer open (not yet implemented)

Rod LT: Display showing Status of Interlocks, Rods and chiller



Rod LT: Sample cool-down



Rod LT: Conclusions

To be Done

- The drain and setup of rods was performed with 1 rod and 7 bypass hoses (dummy rods). Need to test with 8 rods
- The software needs some fine tuning (timing for draining time, leak check, etc)
- We await full complement of cables and power supplies

Conclusions:

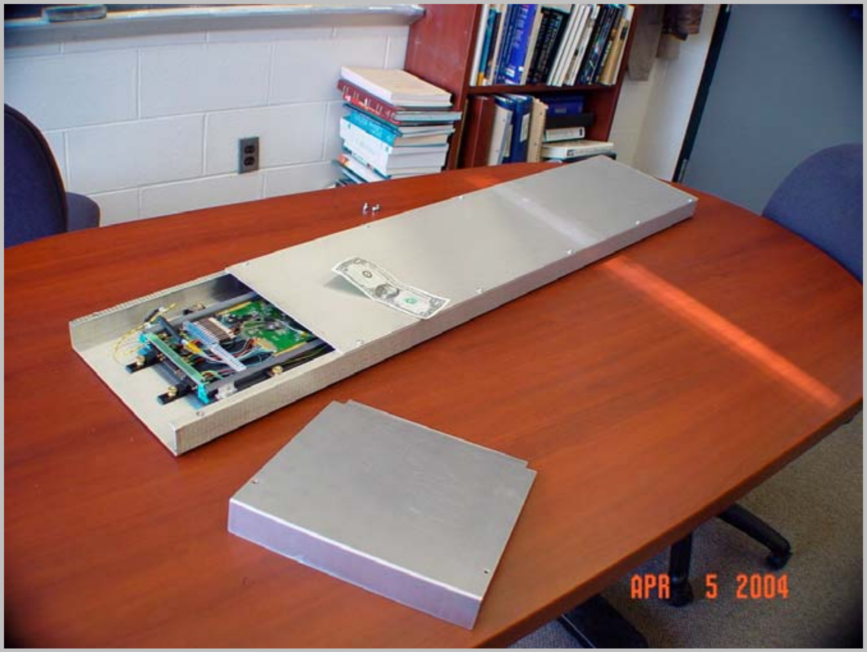
- The hardware and software are essentially completed.
- The commissioning of the burn-in stands is proceeding well, in advance or production ramp-up
- We need experience

Rod Transportation

- Each rod is shipped at least 3 times; Helsinki to CERN as a rod frame, and round-trip, CERN to Chicago or UCSB
- Have a packaging solution- rod boxes within a commercial crate with custom foam

Transport: Rod boxes

- sheet aluminum, very rigid with lid
- Rod clamped at 6 locations, butted at the end
- Two-piece lid allows for operation while still in box
- 210 fabricated



40 Rod Transportation Crate

- 6 inches of made-to-fit closed-cell antistatic polyurethane foam on inside top and bottom of crate, 2.5 on the sides

- Exterior toroidal cushions as feet of crate

Rod Transport: Some History

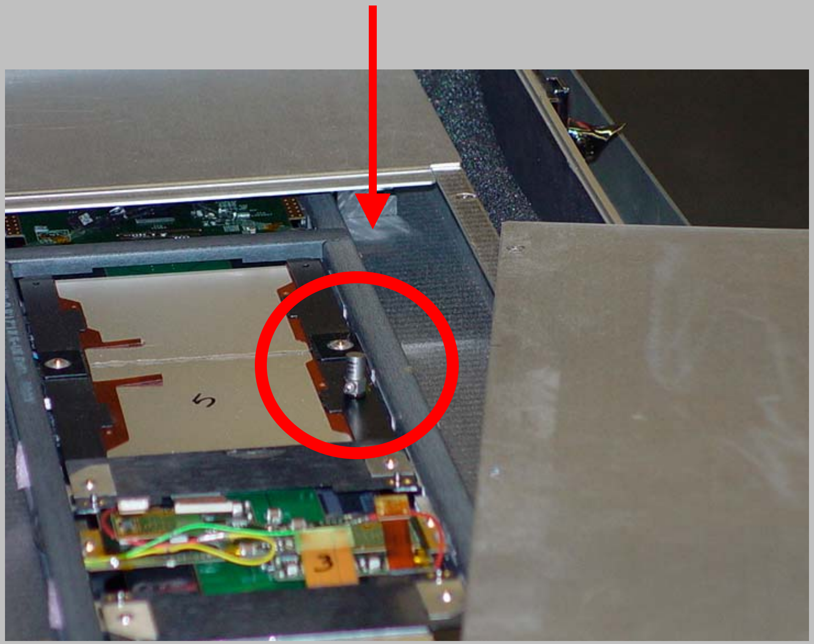
- We have had ~5 crates cross the Atlantic (or Baltic) without incident, some containing rods
- One empty shipment badly mishandled in FedEx International Hub in Memphis, Dec 20
  - (busiest day of year)
- Shock of about 80Gs to the crate, mostly vertical, but a significant horizontal component
- Several experts say this was a very rare event

Rod Transport: History(2)

- In order to:
  - Investigate the incident
  - Investigate adequacy of packaging
  - Investigate fragility of a rod
- We contracted with Rochester Inst. of Technology (RIT) Packaging Science Research Lab

Drop and Vibration Tests at RIT

- Performed vibration table and drop tests with case and rod instrumented with P.E. accelerometers



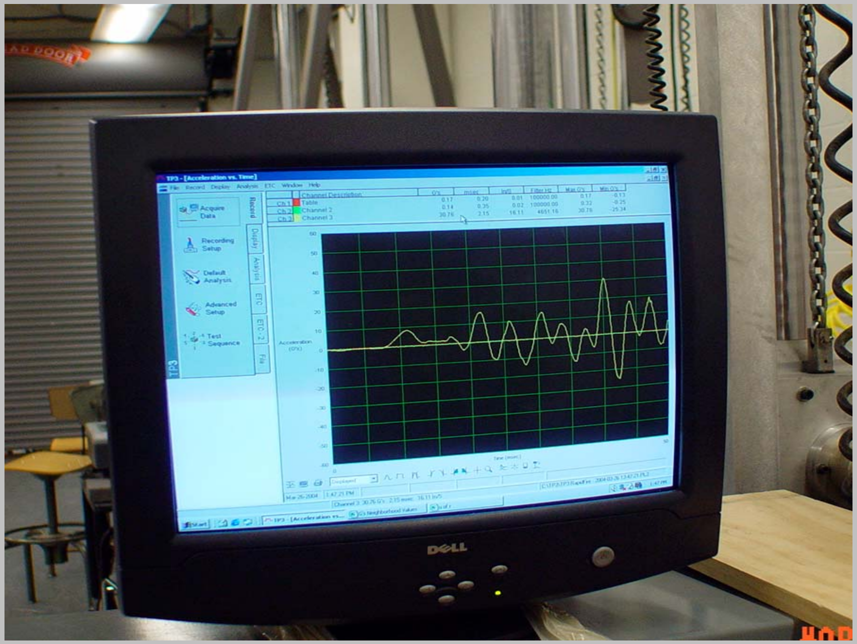
- Used pine boards to simulate load from missing rods

Packaging Test Results

- FedEx shock => top crate fell off a two-crate stack
- Our packaging scheme is absorbing most of the energy from typical shocks, as per design
- Vibration table showed no substantial resonances
- Should switch to softer doughnuts – already arrived and used in the tests

Results(2)

- Rod vibrates between clamps when shocked:
- Amp~30microns,
  period~2ms
  acc_max~<30Gs
- Large maximum acceleration is likely not a concern – stored energy is minimal

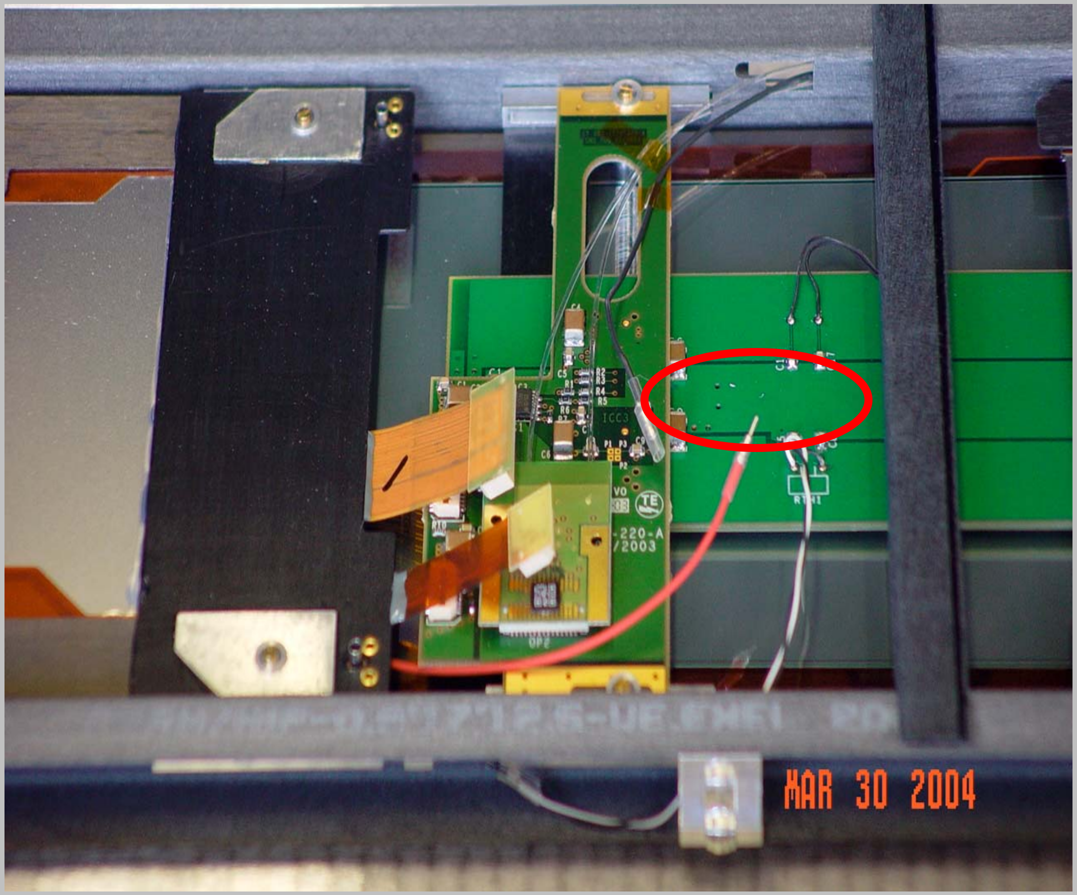


Results(3)

- Drop tests of single-rod 'rifle cases' show that they MUST be packaged within another padded container
- Suggest bubble-wrap rifle case then place within cardboard box

Results(4)

- Upon visual inspection, rod looks fine except for disconnected removable electrical connection from module to rod



Transportation Conclusions

- Packaging appears adequate for standard mishandling, perhaps even exceptionally bad handling
- Next logical step up in protection is ~ an order-of-magnitude more complicated and expensive
    - We don't believe it is necessary