CMS Silicon Tracker Status and Plans

On behalf of the US Tracker Group

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Presentation at the US CMS DOE/NSF Status Review - Nov. 20, 2003 - FNAL, Batavia, IL

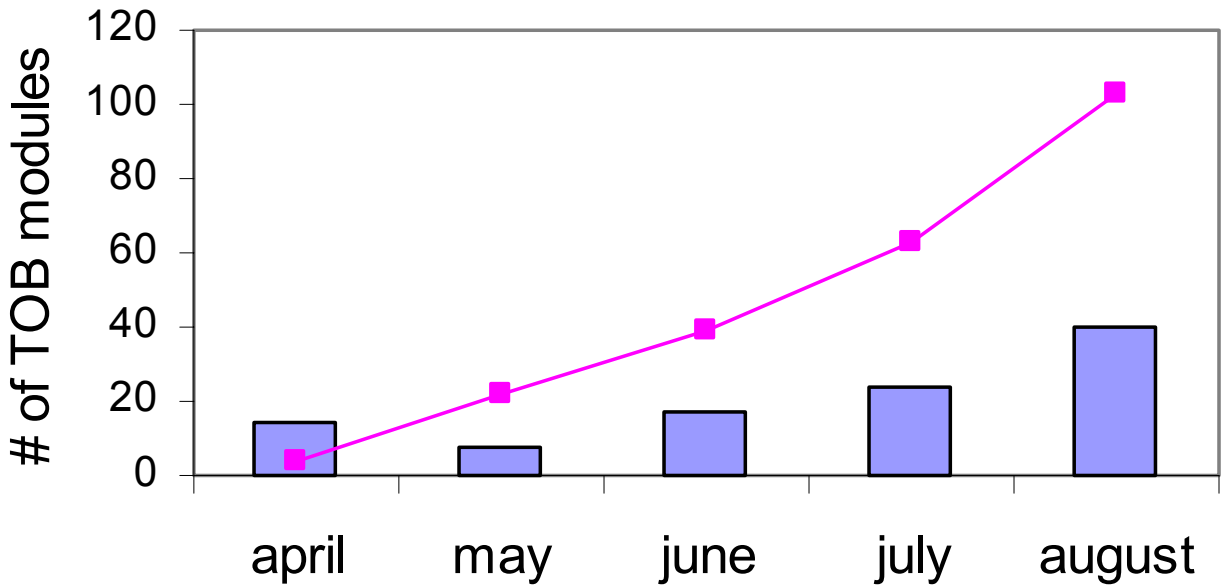
Overview

- Summer Pilot Production:
  - US tracker group found and helped to remedy a few residual issues
    - Transport damage (discussed at Lehman review in May)
    - Broken traces on hybrid cables
    - Common mode noise induced by leaky strips
- Component availability:
  - Significant flows began this summer but had to be stopped.
    - Hybrids halted in September, restarted October.
    - Sensor quality improving, deliveries well-underway, but some concerns remain
- US Production readiness
  - For Modules: Several innovations with productivity gains
    - UCSB now capable of $\geq$ 15 modules/day (require 9/day for TOB)
    - FNAL to be upgraded to match.
  - Rods: still on schedule to be ready for peak production in early 2004

Recent Changes and Additions

- Improving parts flow
  - US CMS will wirebond and thermal-cycle/pulse-test all Tracker Outer Barrel (TOB) and Tracker End Cap (TEC) hybrids (~11,000)
    - Relieves CERN bottleneck, improving hybrid flows
  - U. Rochester has been certified for ST sensor probing
    - Relieves potential bottlenecks in sensor deliveries to the US
- US group to be involved in Tracker End Cap (TEC) production:
  - Help to maintain quality and schedule of entire tracker project
    - Refined electronic test stands, developed uniform testing procedures, established cross-calibrations
    - Asked to review fabrication centers: consult and assist
  - To prepare for fabrication up to 2000 TEC modules
    - Backup Tracker End Cap production centers, provide expertise and critical review of overall TEC designs and procedures.

Spring/Summer Pilot Production



- 103 TOB modules produced in US
  - 14 April, 8 May, 17 June, 24 July, 40 August
  - Have produced only a handful since August due to various problems
- FNAL and UCSB have produced roughly equal numbers
  - Very high quality.
    - All are within mechanical specifications.
    - Production induced fault rate well under 1% and falling!

CMN Problem

- ~20%* modules have common mode noise (one chip)
  - Built with very early ST sensors
- Correlated w/increased bias current w.r.t. QTC probing
  - UCSB study ruled out hypothesis of mishandling in US
- High noise1-4 channels ⇒ source of CMN for chip
  - No obvious associated damage in visual inspection
- Problem generally appears at the first module test
  - 1 module at FNAL developed problem during module long-term thermal cycle testing

*The sampling of sensors was slightly biased toward high-fault rate sensors.
Almost all from old batches of type 2 sensors. Actual rate is around 10% for early sensors.

IV Test Results

Probed Current @ UCSB (400 V) – QTC Measurement (400 V)

Sensors	> 2 μA	> 5 μA	>10 μA	>20 μA	>100 μA	< -2 μA	<-5 μA	<-10 μA
OB2 ('00-01)	15%	9%	8%	5%	1%	8%	3%	1%
OB1 ('00-01)	6%	3%	3%	3%	3%	3%	0%	0%
OB2 ('02)	3%	3%	0%	0%	0%	2%	2%	0%

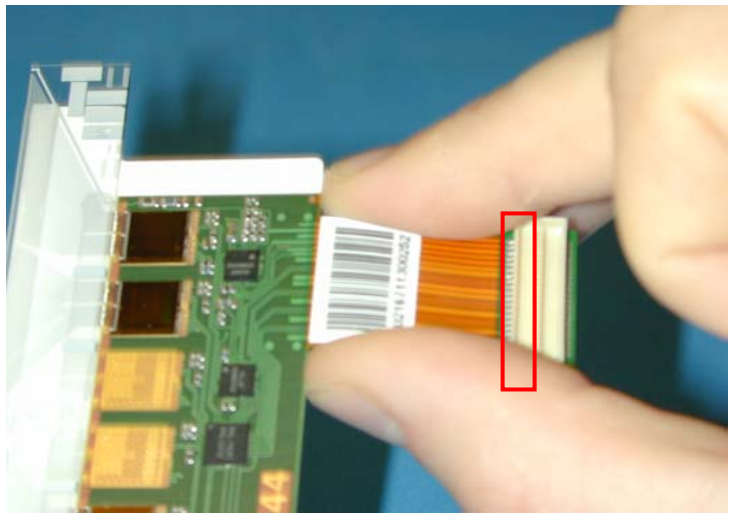
- An increase greater than 5 μA can cause CMN
- *Much better results with newer OB2 sensors (2002)*
  - Factor of ~4 decrease in the rate of higher (and lower) current measurement at UCSB relative to old OB2 sensors
- *A batch of 2003 sensors are now en route*

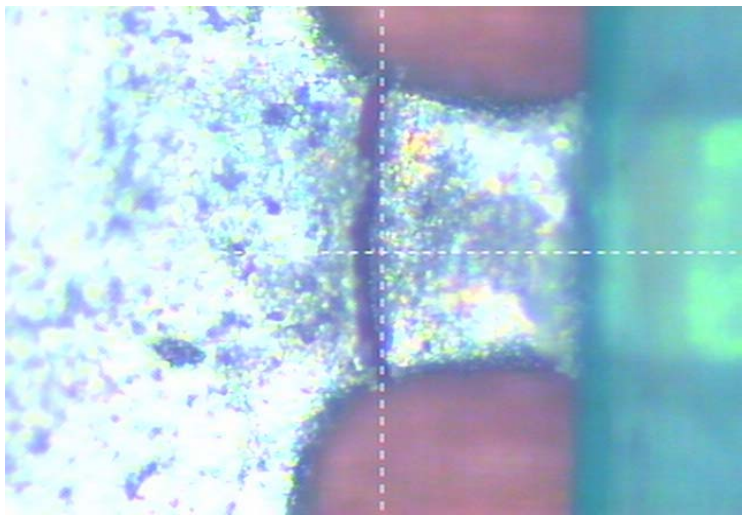
CMN problem and ST sensors

- UCSB Study
  - IV curves did not change after module fabrication
  - 4 of 5 modules with a ***high*** current sensor had CMN problems
  - 19 of 20 modules with a ***low*** current sensors had no problems
- The Situation
  - Probing centers selecting ST sensors with low total current
    - 75% of all delivered sensors pass a cut of 1.5 μA
      - All selected sensors expected to make good modules ***but***
        - » Delivery inadequate for schedule
        - » IV measurements alone saturate QA capacity
  - Steering Committee actively pursuing all options
      - Working with ST to improve quality to increase yield and increase production
      - Investigating other vendors

Hybrid Problem

- Cable brittle at connector solder pads
  - Differential data output lines break
- Reported by US on Sept. 4
  - Production was halted that week.
  - Protective stiffener designed and studied by US and vendor
  - Production re-started Oct. 20
- Current schedule looks good
  - 100 TIB hybrids delivered early Nov.
  - 500 hybrids per week as of late Nov.
- 4000 hybrids were in production when problem was discovered
  - 1000 throwaways and 3000 retrofits
- Barring new problems, sensors will replace hybrids as the limiting factor by January.

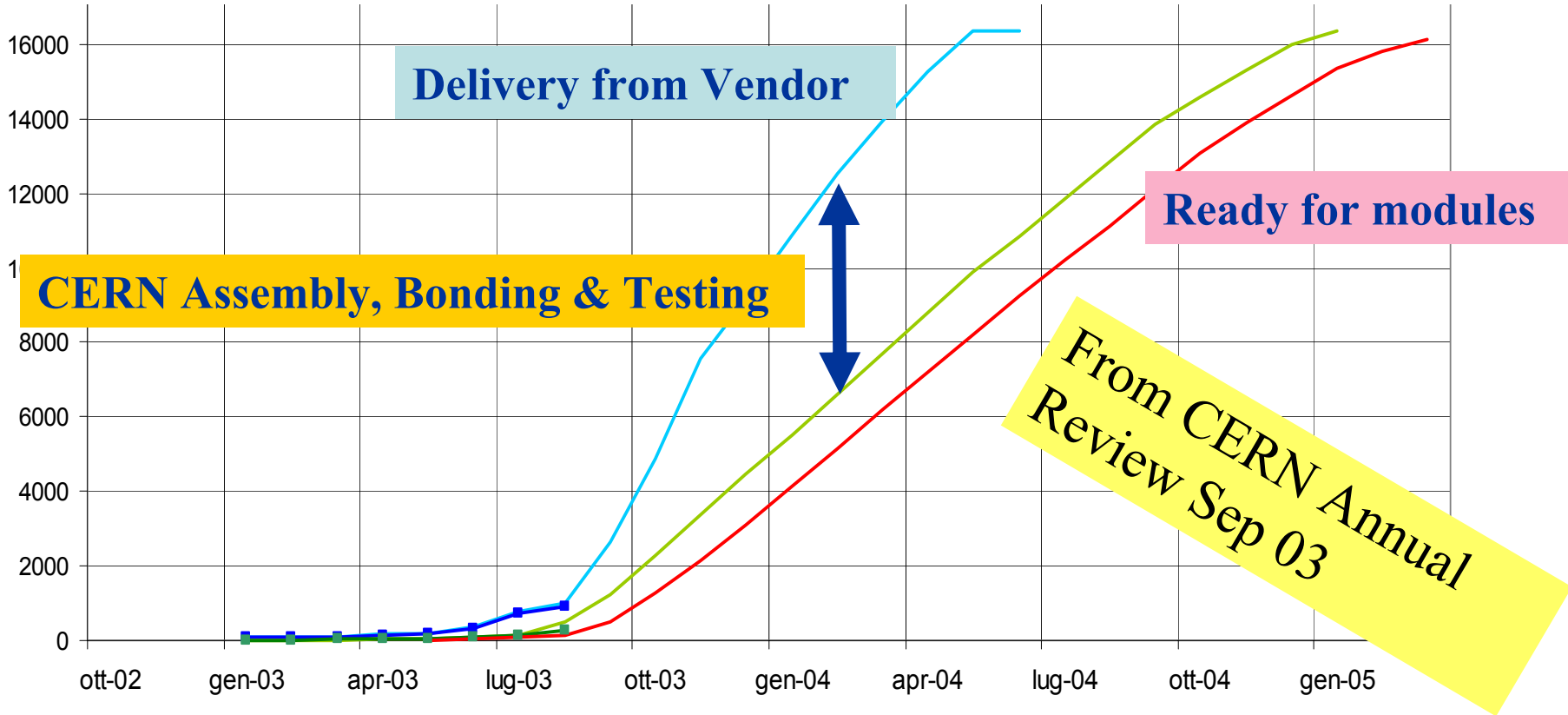




Overview of Production Lines

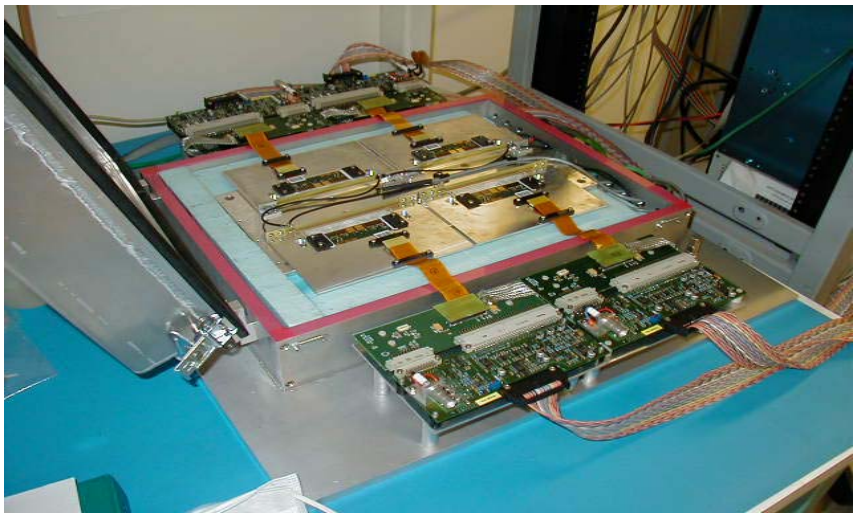
- Improvements, Readiness, Current Capacity
  - Hybrid Thermal Cycler/pulser
    - 1st stand completed, validated and online at UCSB
    - 2nd started, to be online at FNAL by early February
  - Gantry:
    - Stereo and 6 chip module production has been started
    - Problem with the gantry robot has been isolated and fixed
    - Can now do plate surveys off the gantry
  - Wirebonding
    - Full automation in effect
  - Module Testing
    - 90% of all necessary equipment installed and online
  - Full capacity LT test in Wien Cold Box
  - Rod Assembly, Test, LT test on schedule
- Near term Planning
  - A ***Sustained*** high throughput production run
  - Adding production capacity and manpower

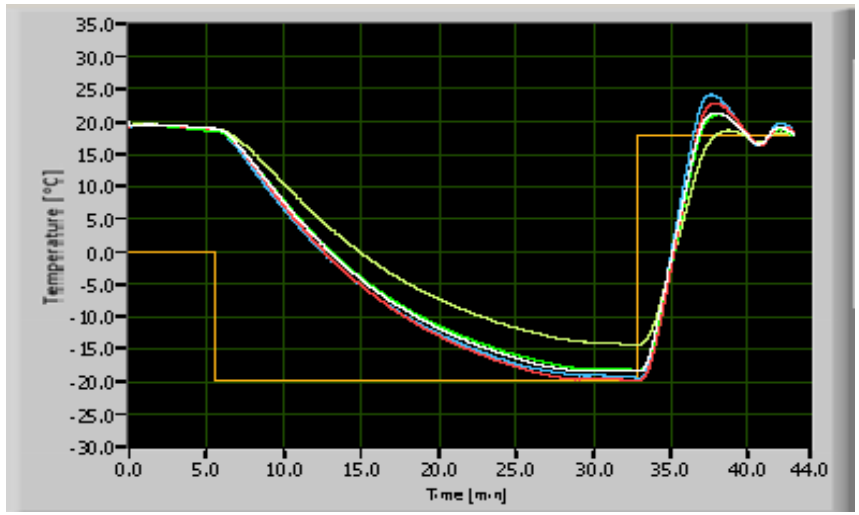
Front End hybrids delivery



Accelerate hybrid delivery with US help: CERN - FNAL - UCSB = 40% - 30% - 30%

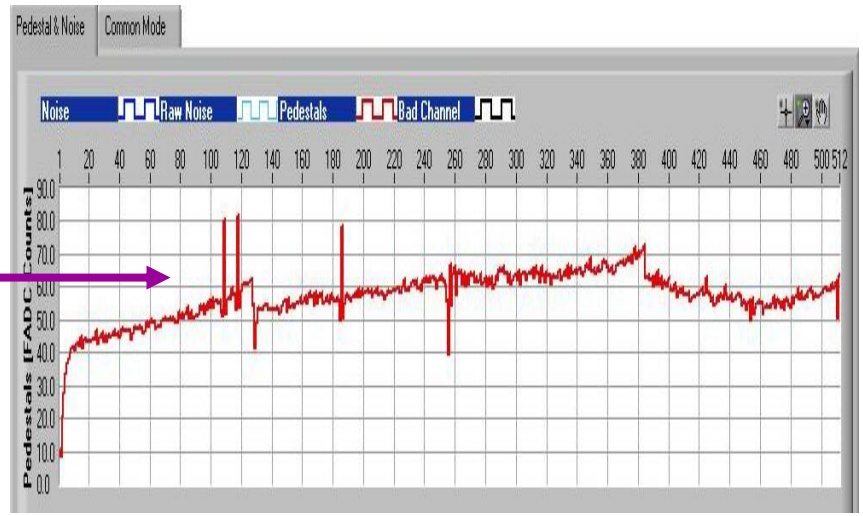
Hybrid Thermal Cycler & Pulser





- Now fully commissioned
  - Substantial effort!

  Many thanks to CERN group
- 40 minutes to cycle 4 hybrids
  - Finds shorts/opens
- Capacity ≥ 28/d per stand
  - UCSB stand already online
  - FNAL stand will be online by Feb.

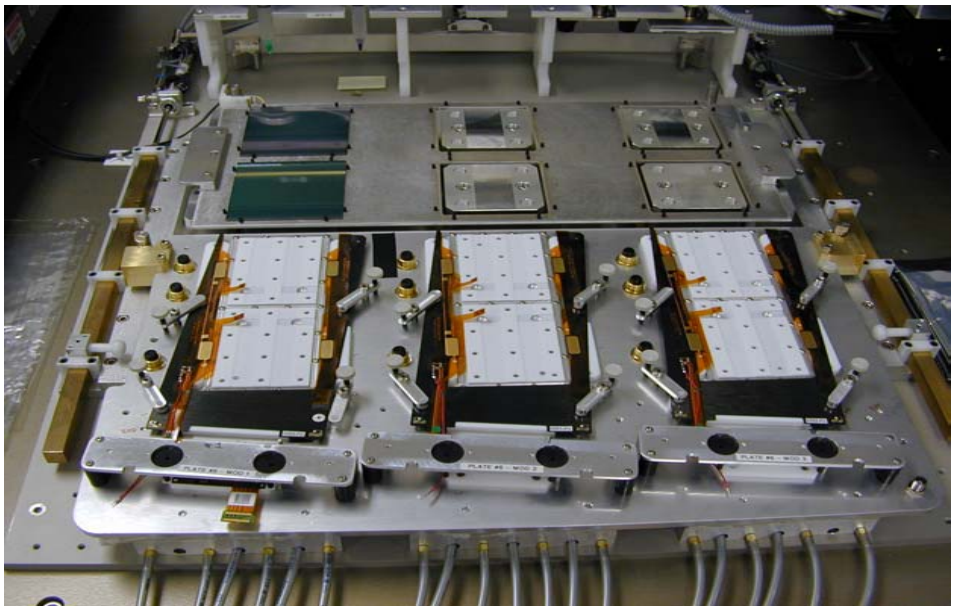


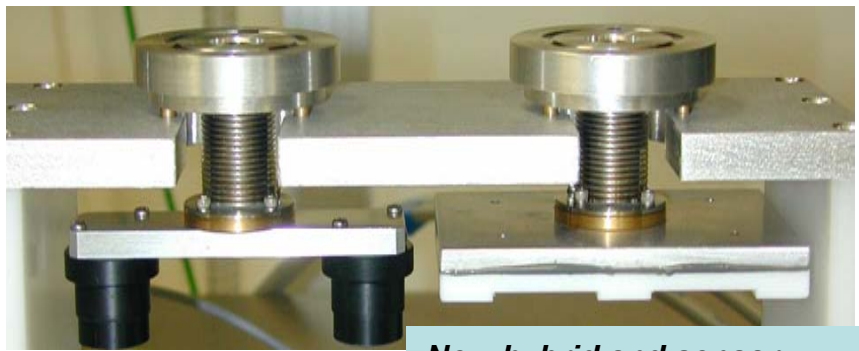
Assembly Plates & Tools

- *Plates work "right out of the box"*
  - *4 fully commissioned R-phi plates*
  - *1 prototype R-phi assembly plate (could be used if needed)*
  - *1 fully commissioned Stereo plate*

    3 μm alignment for 1st 3 modules!
- *New pickup tools*
  - *More reliable and accurate*

New Hybrid bridge





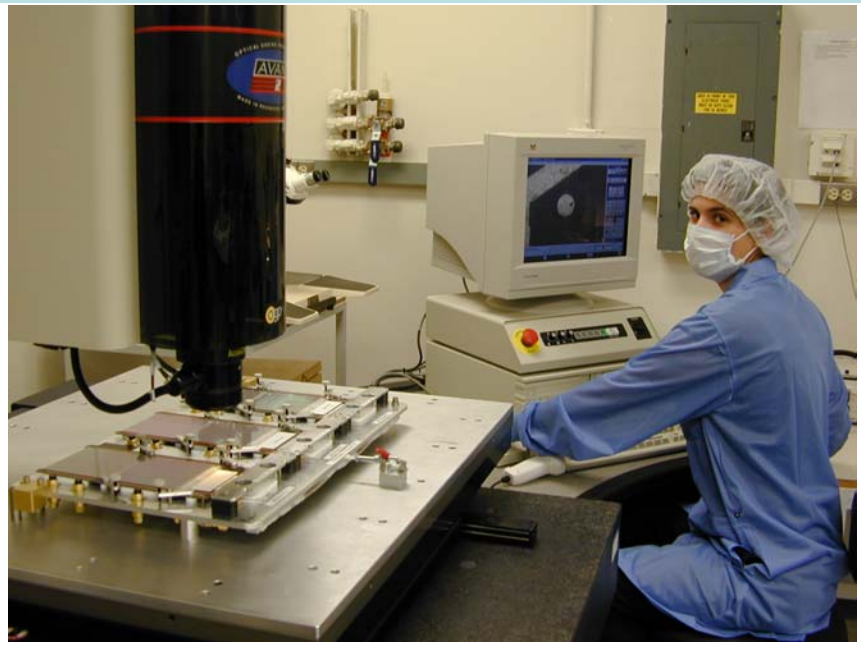
New hybrid and sensor pickup tools

Other Enhancements

- Gantry 3rd position problem fixed
  - Limited work area usage to 67%
- Surveying/DB
  - Recently automated full plate survey on OGP
    - Much faster than the gantry!
    - Macros compare the survey results to nominal values
      - Each position on each plate treated individually.
  - Allows module production on gantry all day.

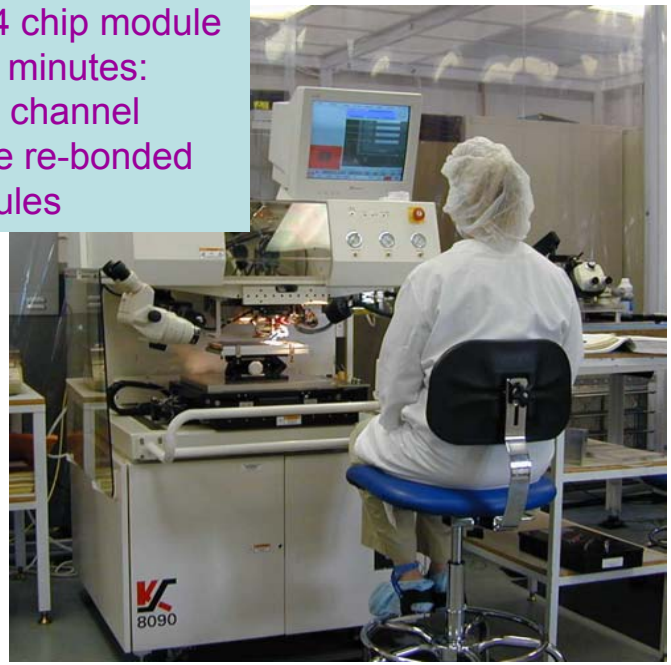
Commercial high precision (< 1 μm) automated measuring machines (OGP) with pattern recognition at FNAL and UCSB

- Provides *independent* survey of modules



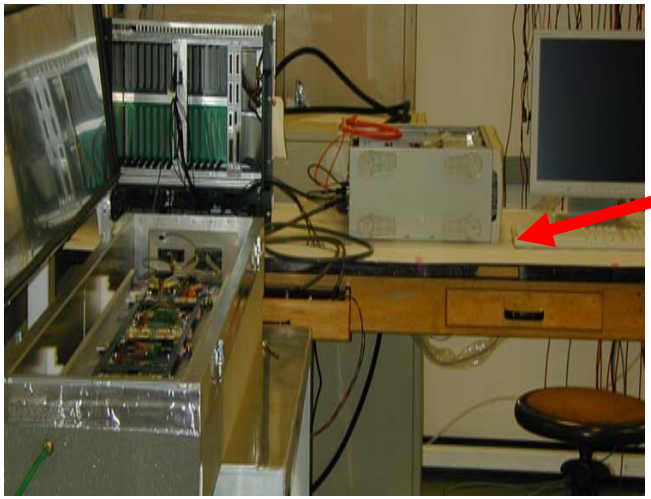
Wirebonding

UCSB TOB 4 chip module **bond time** 5 minutes: Average of 1 channel needing to be re-bonded every 7 modules

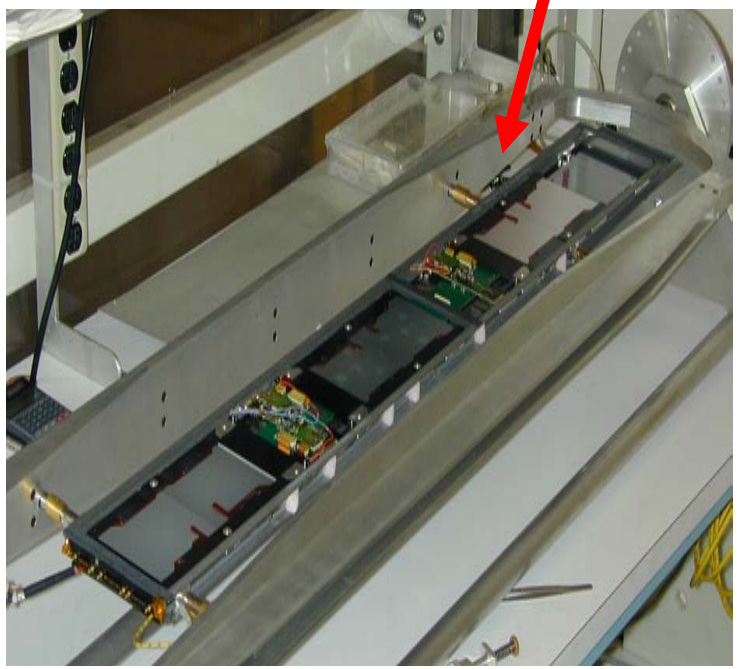


- K&S automatic wirebonders
  - Currently 4 machines: 3 at FNAL and 1 at UCSB
    - FNAL: will likely need 1-2 for other projects much of the time
  - Need backup at UCSB
    - Plan to buy a used K&S 8060
      - smaller work area but otherwise identical
      - more common (available and cheaper).

Long Term and Rod Testing

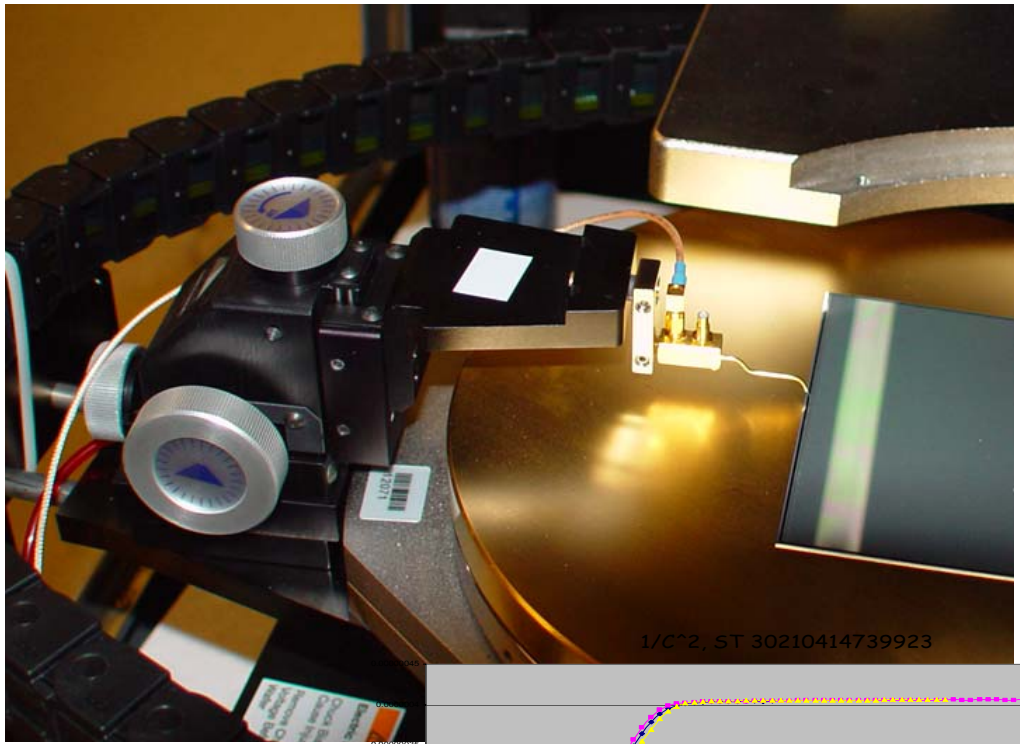


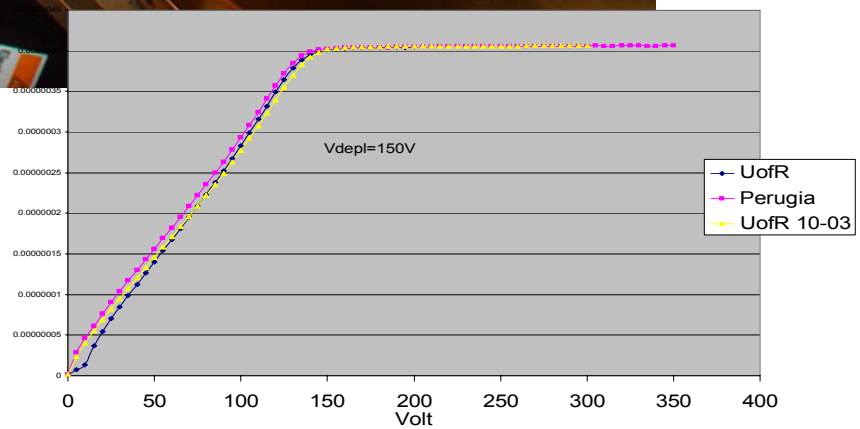
- Complete set of electronics ready to test single rods
  - Test box provides dry, dark, and electrically isolated environment
  - Uses Rod LT chiller for cooling
- First rod in US fully assembled
  - Took approximately 2 hours!
- Noise under control!



- Multi-rod Long Term test stands
  - 1st Freezer moved from Rochester to Fermilab this past October.
  - 2nd to be delivered to UCSB in December.
- Module Long Term test stand (Wien Boxes)
  - All functionalities demonstrated
    - Cold box fully instrumented
      - 10 module capacity
    - Conducted backplane pulse tests
  - LT test ALL modules with full readout of temperatures and currents

Probing at Rochester (see talk by S. Korjenvski)





- ✓ **Hardware** is in place and operational.
- ✓ **Software** is working as well, - test results are consistent with other testing centers
- ✓ Qualified

Capacity and Plans

- Current capacity
  - UCSB **current** capacity ≥ 15 modules per day
    - Over 12 requires shortening LT test to 12 hours
    - With expected improvements we can extend this
      - Requires 2nd wirebonder for backup
  - FNAL current capacity 8 modules per day
    - Limited by Wien box but MUX received
      - Should reach 12 per day soon
    - Will modify several setups and procedures to match UCSB
- Goals:
  - 15 per site in a normal work day
  - 21 per site in a slightly extended day

- *Near term: to produce ~100 modules in 1 week when hybrids arrive.*

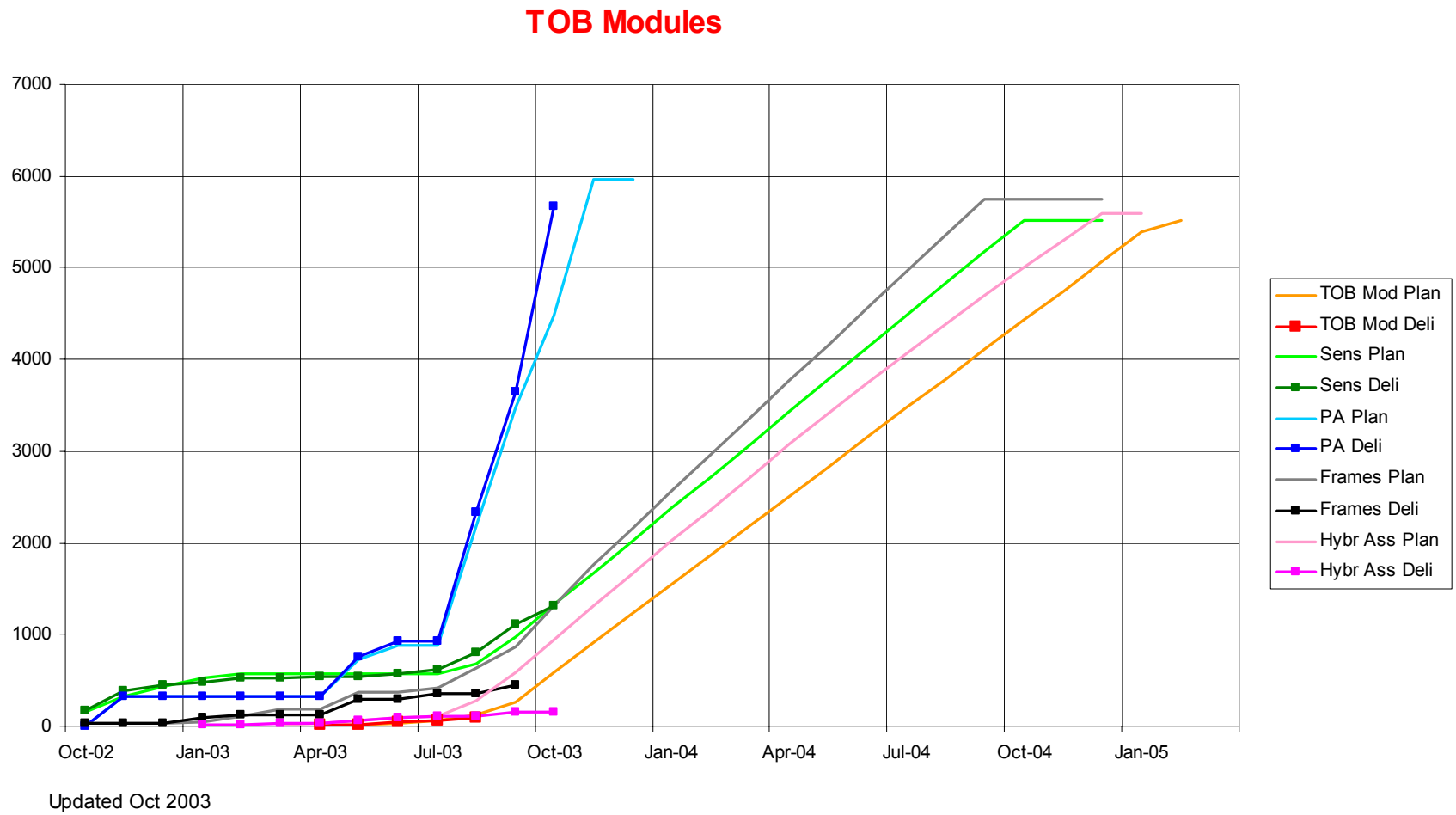
Contingencies

- Enhanced Capacity
  - 30 modules/day $\Rightarrow$ 6375 per year (with 15% downtime)
  - 42 modules/day $\Rightarrow$ 8925 per year (with 15% downtime)

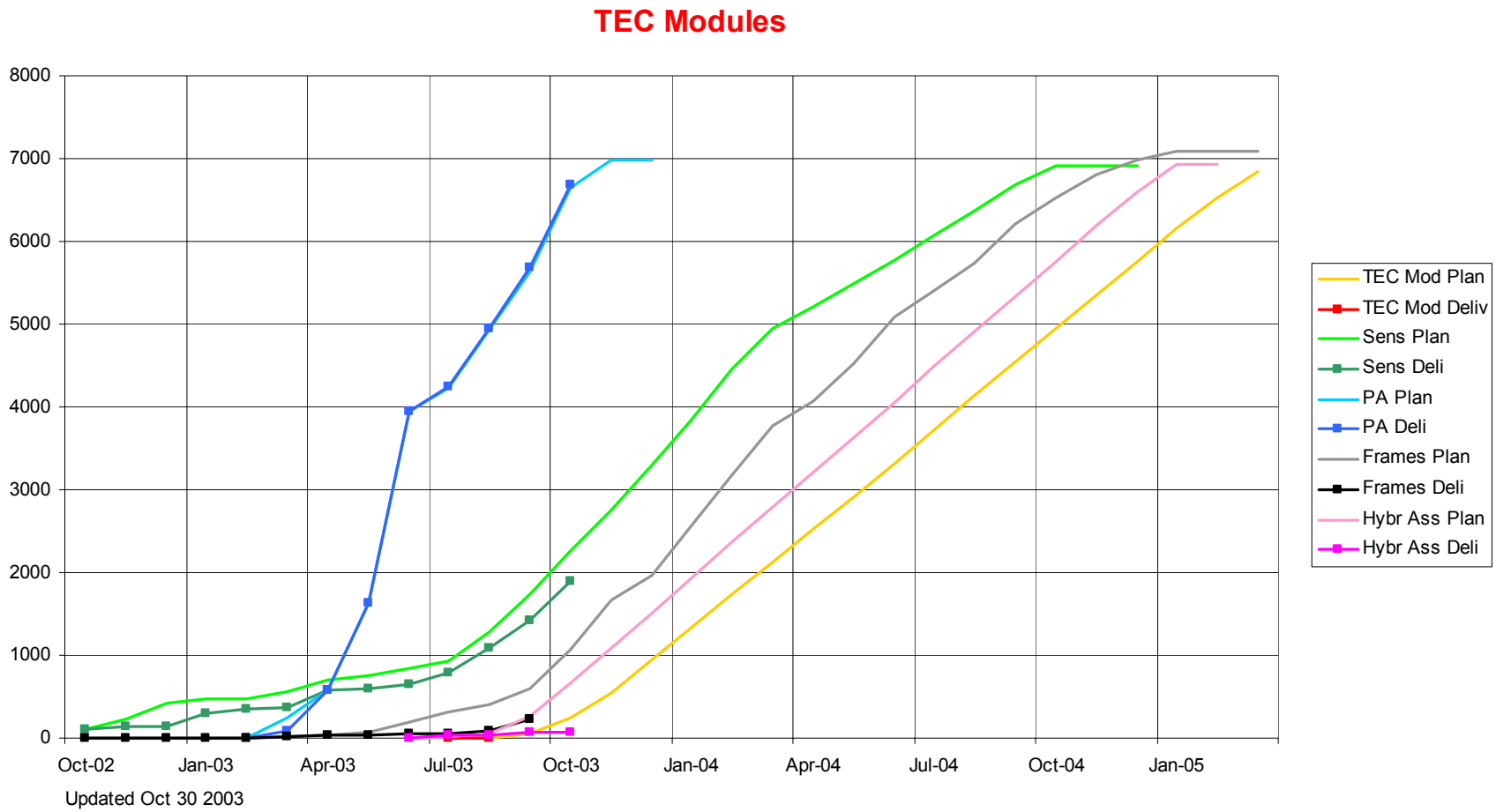
TOB total is 5500

- Several potential benefits
  - Contingency for a compressed TOB production schedule.
  - Backup for TEC production lines.

TOB Module Schedule



TEC Module Schedule



Additional Costs

- 465k$ + 250k$ contingency
  - Additional hybrid bonding and testing at FNAL
  - Enhancements to allow faster TOB production + some TEC Production.

	Cost (k$)	Contingency (k$)
Hybrids equipment	20	10
Hybrids Labor	130	40
Wirebonding Upgrades	90	40
Gantry Upgrades	50	25
Module Labor	110	110
Transport & Travel	65	35
Total	**465**	**260**

Schedule and Outlook

- Schedule
  - CERN schedule shows most modules complete by end of 2004
    - CERN management is committed to this

      To leave as much time as possible for commissioning
    - Nevertheless, this is an aggressive schedule

  - Completion by end of US CMS FY05 is not yet at risk:
    - 20 months from January 2004.
    - Components must be available in this period!
    - US capacity adequate for much shorter production period.

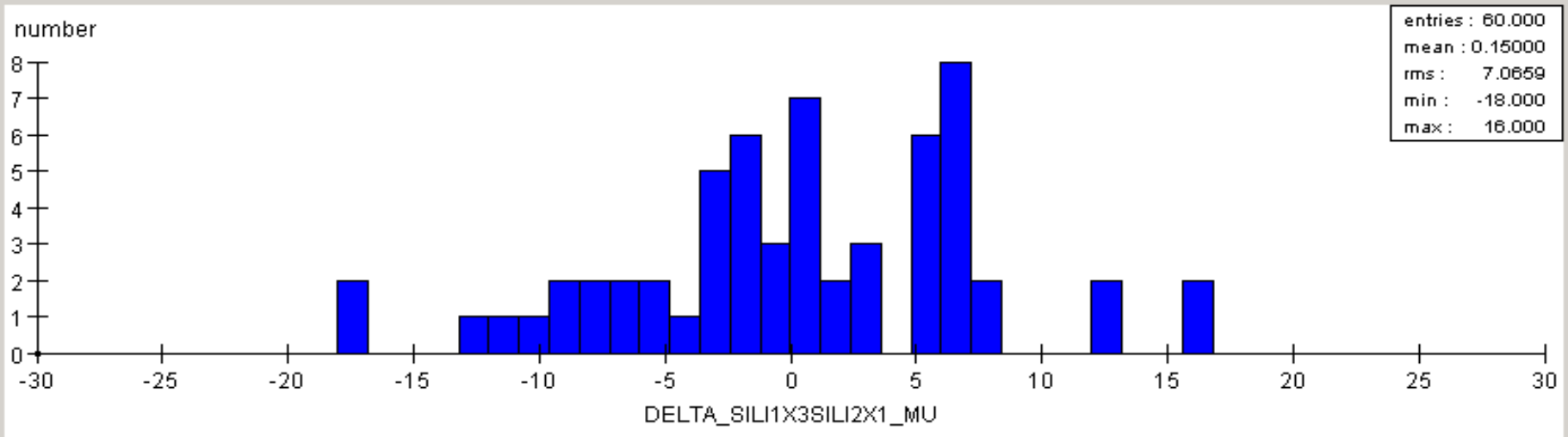
Conclusions

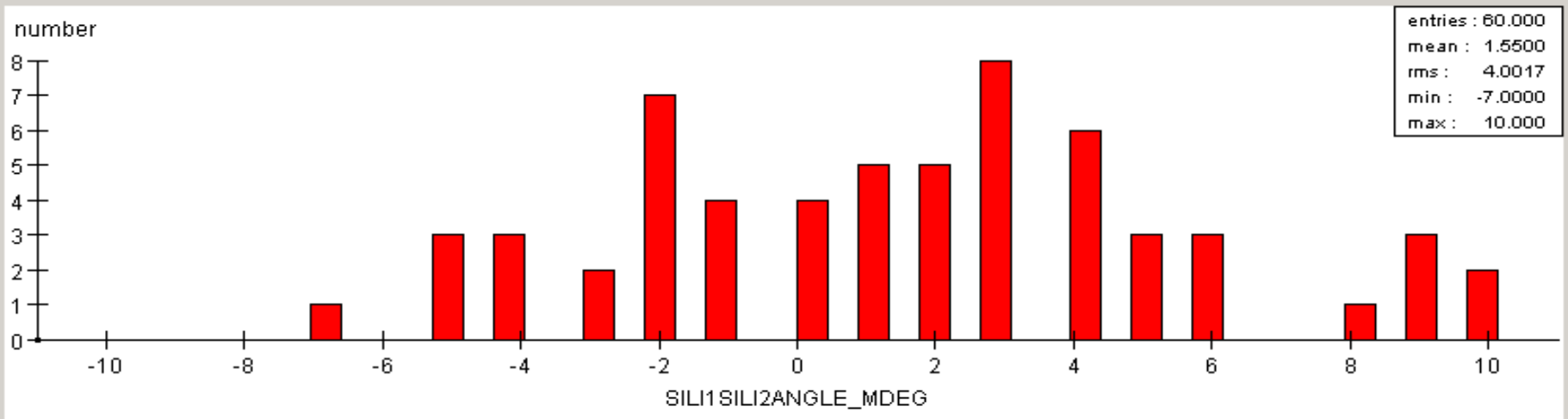
- Many productivity improvements
  - Gantry 3rd position problem fixed
  - Automated surveys on OGP
  - Automated wirebonding programs
- Many Significant Achievements
  - First rod assembled and tested – good results
  - First stereo modules
  - Wien box fully instrumented with backplane pulsing
  - 4-hybrid test stand fully functional
  - First LT Rod stand delivered to FNAL
  - Rochester qualified for sensor probing
- We'll increase capacity and production at low cost
  - Schedule contingency
  - Assist the overall tracker project

Additional Information

- Gantry Data – Sensor alignments
- Sources of faulty channels
- Common Mode Subtracted Noise
- UCSB Gantry Hardware Improvements
- *Gantry 3RD Position Problem*
- Modules Produced with Final Hybrids
- Vacuum Rod Assembly Tools

Gantry Data – Sensor alignments

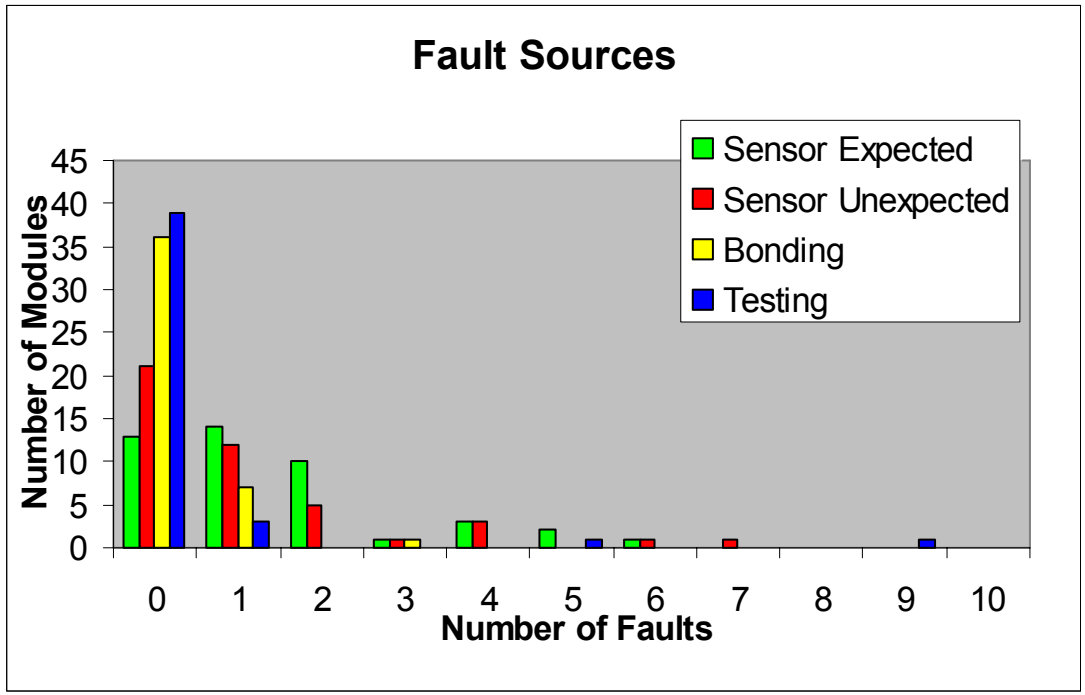




UCSB results shown, FNAL results are equivalently good

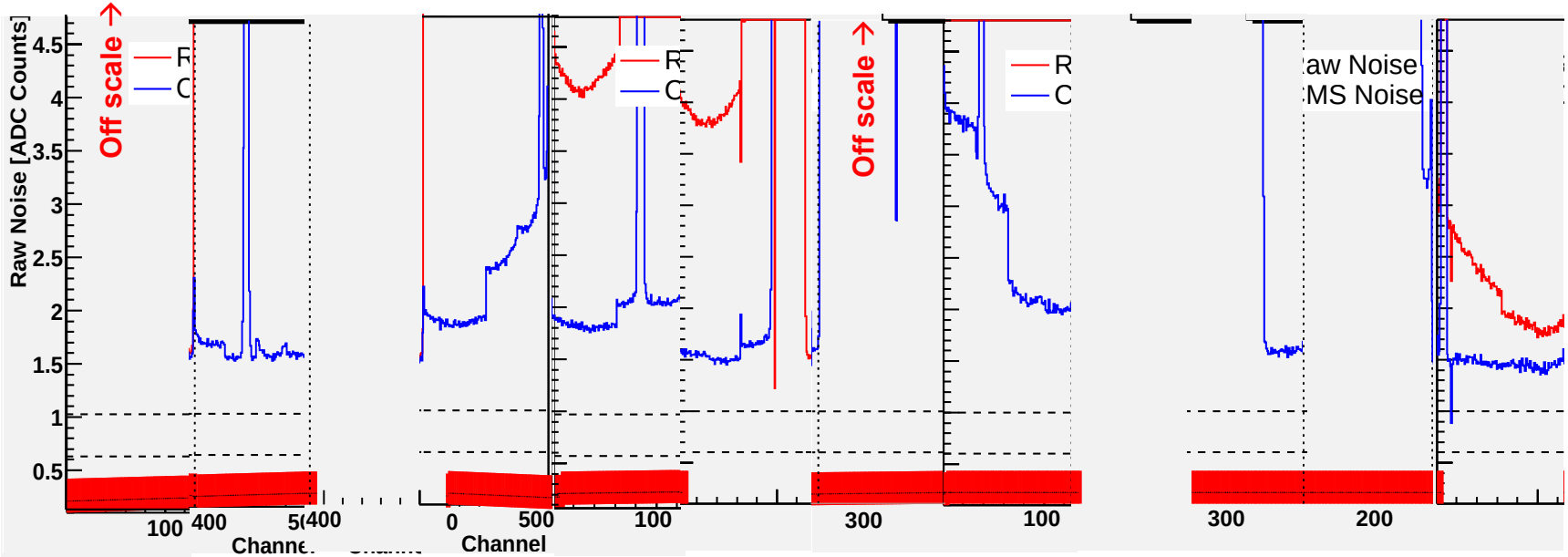
Faulty Channel Sources

- Fault Sources (excluding cable breaks and CMN)
  - Hybrid-0.011%
  - Sensor (in DB)-0.33%
  - Sensor (not in DB)-0.26%
    - Either high noise and/or visible sensor damage
  - Bonding-0.037%
    - Mostly due to early pitch-adaptors (RMT).
    - No problems seen with production pitch-adaptors (PLANAR).
  - Testing-0.074%
    - Mostly due to an early problem which has been alleviated
- Total faults – 0.712%



Common Mode Subtracted Noise

25 ADC **6.5 ADC**



Module #: 869 881 1010 1011 1013 1014 1015 1016 1030 1031 1038 1042

Chips with CMN in UCSB modules

Common mode subtracted noise in blue

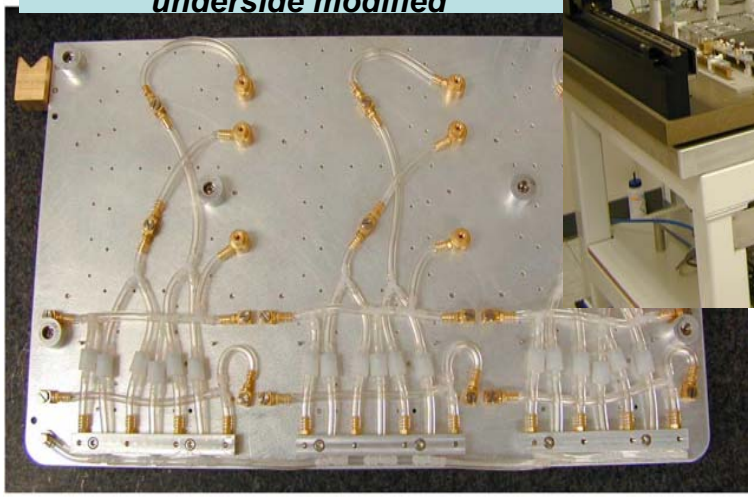
For majority of modules with problems, the CM subtraction is imperfect.
7 of 12 have >2.0 ADC noise
3 of 12 have more than twice the usual noise

US Gantry Hardware Improvements

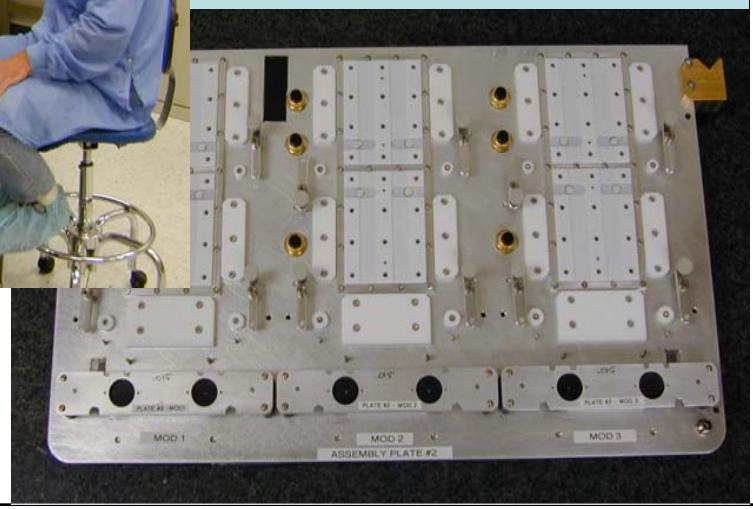
1. U motor mounting bracket replaced: Z and U axes orthogonal to base plate

2. New Support pads

3. Assembly plate underside modified

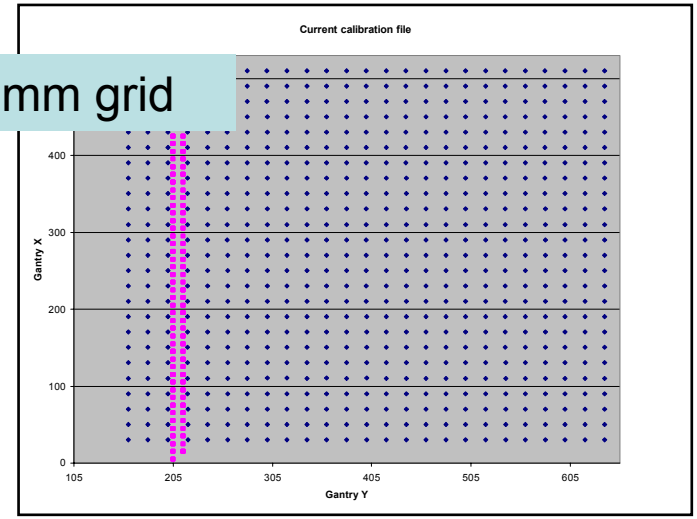


4. New Teflon topside

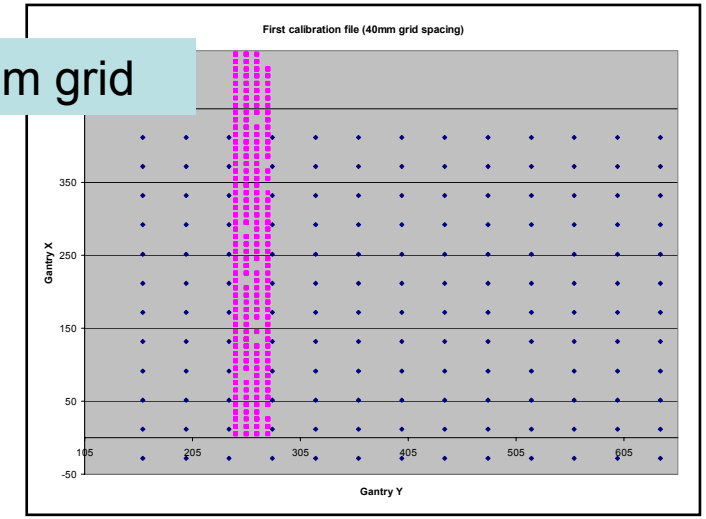


Gantry 3RD Position Problem

10 mm grid



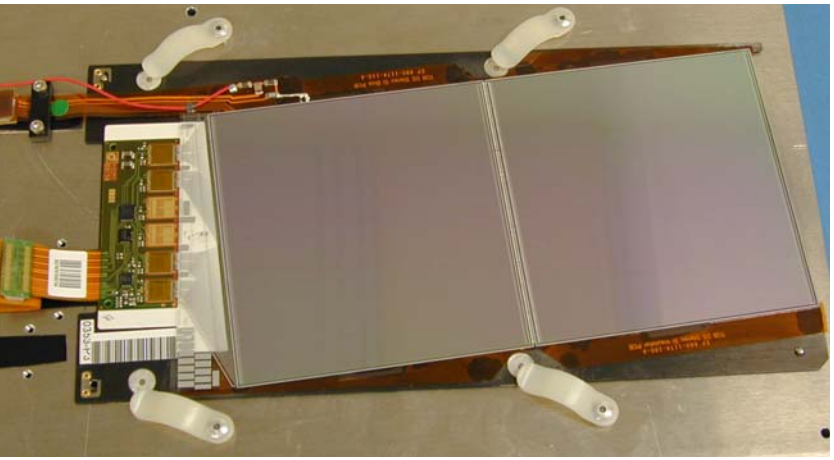
40 mm grid

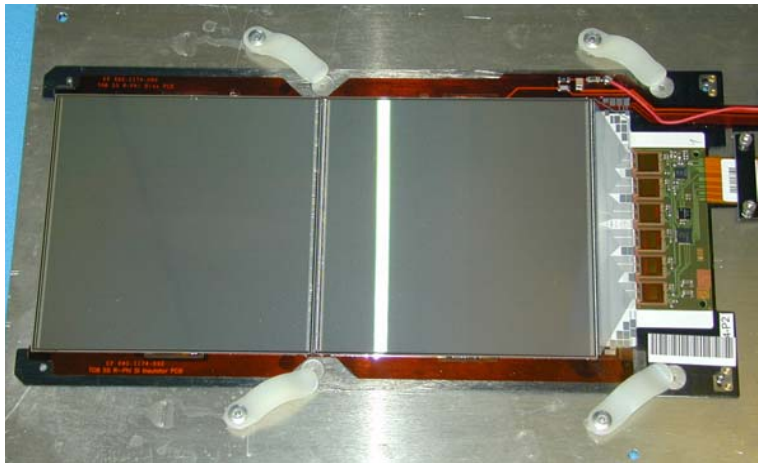


- Problems at all gantry centers in a specific region of gantry work area.
- Reduced CMS production capacity by 25-33% !!

- Russell Taylor (UCSB) pinpointed the problem and came up with a fix
  - Studies showed a ***strip in the gantry Y axis between the 3rd and 4th rows of the calibration file*** where counting errors occurred ***independent of calibration grid size*** (indicating a software or memory problem)
- We reported the problem to the OEM and they were able to update their software to remove the problem.

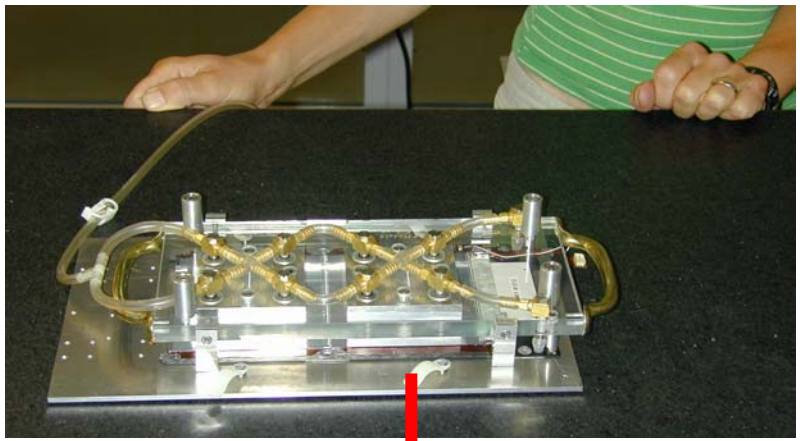
Modules Produced with Final Hybrids

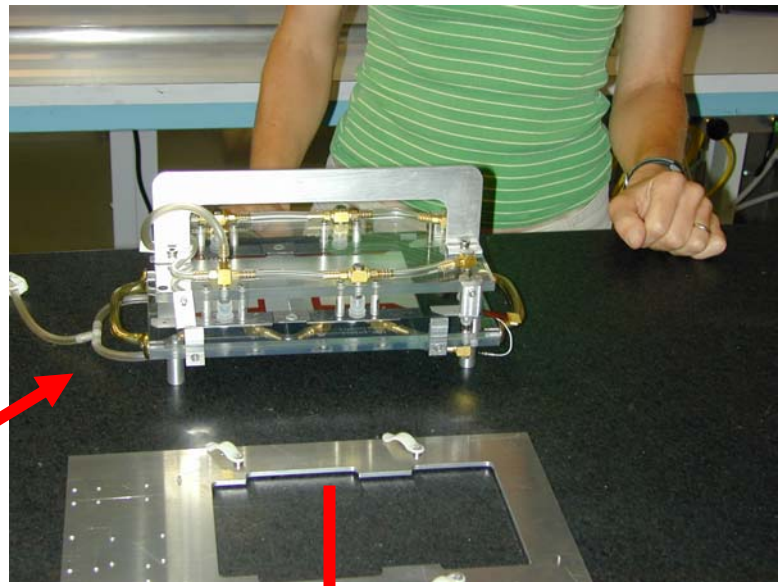


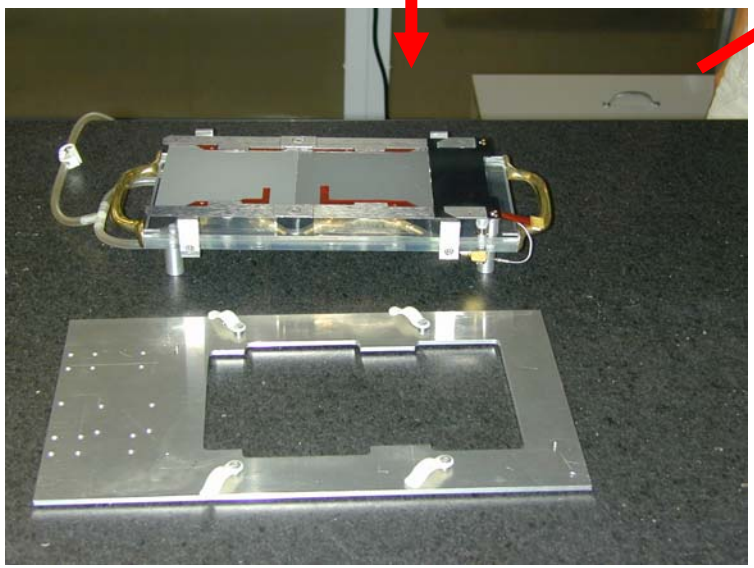


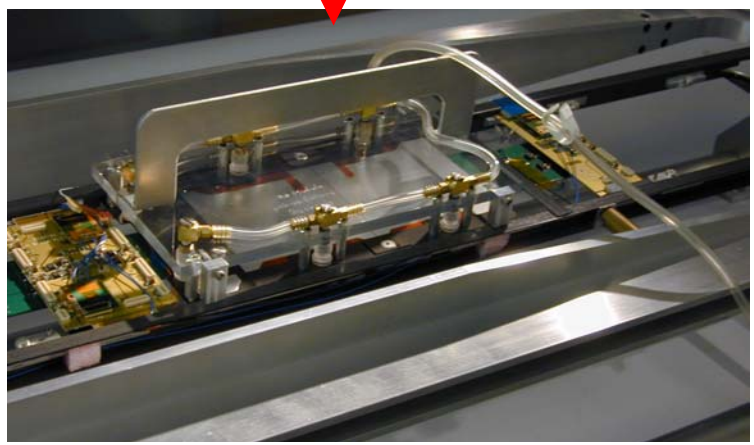
- First Stereo TOB module made!
  - 3 TOB stereo module produced in total
  - All well within specs mechanically and all Grade A
    - Kapton circuit was missing a trace for bias. We made it by hand with Ag Epoxy.
    - One chip has dead pipeline column
      - Found to be dead prior to module production
- 2 TOB 6-chip R-Φ module produced (first module of this kind produced!!)
  - Both Grade A
- 1 TOB 4-chip R-Φ module with final hybrid built
  - Grade B due to known sensor faults

Vacuum Rod Assembly Tools



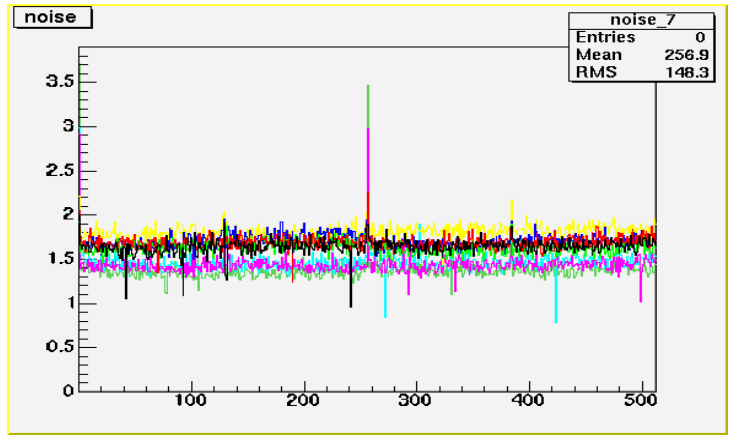


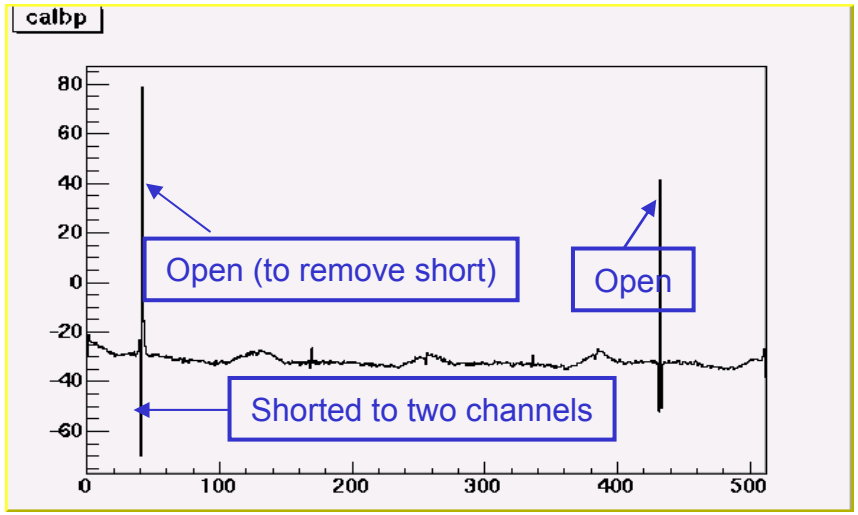




Wien Module LT Test

- All functionalities demonstrated
  - Cold box fully instrumented
    - 10 module capacity
  - Conducted first backplane pulse tests
- LT test ALL modules with full readout of temperatures and currents





Module 1025 Backplane test