CMS Silicon Tracker Status and Plans

On behalf of the US Tracker Group

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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.
• 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 noise 1-4 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

<table>
<thead>
<tr>
<th>Probed Current @ UCSB (400 V) – QTC Measurement (400 V)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensors</strong></td>
</tr>
<tr>
<td>OB2 ('00-01)</td>
</tr>
<tr>
<td>OB1 ('00-01)</td>
</tr>
<tr>
<td>OB2 ('02)</td>
</tr>
</tbody>
</table>

- 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

CERN Assembly, Bonding & Testing

Delivery from Vendor

Ready for modules

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

From CERN Annual Review Sep 03
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
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 2\textsuperscript{nd} 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 ⇒ 6375 per year (with 15% downtime)
  - 42 modules/day ⇒ 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.
TEC Module Schedule

TEC Modules

Updated Oct 30 2003
Additional Costs

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

<table>
<thead>
<tr>
<th></th>
<th>Cost (k$)</th>
<th>Contingency (k$)</th>
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</thead>
<tbody>
<tr>
<td>Hybrids equipment</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Hybrids Labor</td>
<td>130</td>
<td>40</td>
</tr>
<tr>
<td>Wirebonding Upgrades</td>
<td>90</td>
<td>40</td>
</tr>
<tr>
<td>Gantry Upgrades</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Module Labor</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Transport &amp; Travel</td>
<td>65</td>
<td>35</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>465</strong></td>
<td><strong>260</strong></td>
</tr>
</tbody>
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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 3\textsuperscript{rd} 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

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

- 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