Module Quality Control & Assurance

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Outline

- **Mechanical Quality Control & Assurance**
  - Gantry calibration & qualification
  - Module quality

- **Wire Bonding Qualification & Testing**
  - Qualification of pitch adaptors
  - Wire bond pull tests

- **Electrical Qualification & Testing**
  - Test stand types & part flow
  - Test stand qualification & cross-calibration
  - Module test & grading
Module Quality Control & Assurance

Tracker Annual Review 2003, A. Affolder, UCSB

Module Quality Control & Assurance
General QC&A Philosophy

- How can process quality and uniformity be guaranteed in such a distributed system?
  - 7 module assembly centers
  - 13 module bonding and testing centers
  - 9 sub-detector assembly and testing centers

- Require that equipment, software, and procedures used are as identical as possible
  - Cross-calibrations are performed between sites in which standard candles (glass plates, hybrids, modules, etc.) are exchanged

- Require a high level of traceability of component/module flow and of testing results at all stages (Database)
  - Global quality of production can be monitored
  - Quick feed-back to production center, improving process quality and uniformity
Gantry centers

- Identical gantry systems assemble modules from components
  - Bari and Perugia => TIB/TID Modules
  - Brussels, Lyon and Wien => TEC Modules
  - FNAL and UCSB => TOB Modules
- Identical software used at all seven gantry cites
All centers have qualified gantries through measurement of standard glass plates and production of multiple dummy modules

The precision obtained is within our requirements
Module Mechanical Precision

- Before/after glue curing, fiducials of sensors, hybrid, and carbon fiber frame are measured
  - Requirements on relative positions and angles between the sensors, the hybrid and the frame are made
  - $\Delta x$ and relative angle between sensors and between the frame and the sensors are most critical
- All modules (but 1) have passed these requirements
- On some modules, the measurements are repeated on an independent precision measuring machine
  - All measurements are consistent in these cross checks.
Bonding Centers

- All centers are equipped with good bonding machines (mainly Delvotec and K&S) and are fully operational
  - Bari, Catania, Firenze, Padova, Pisa, Torino → TIB/TID Modules
  - Aachen, Hamburg, Karlsruhe, Strasbourg, Wien, Zurich → TEC Modules
  - FNAL, UCSB → TOB Modules
- Most of the centers have prior experience from other experiments
- Pitch adaptors and other test structures have been distributed between centers for bond quality testing
Bonding Qualification

• Each bonding center has been sent multiple bonding test pieces
• Wire bonds have their pull strengths, shapes, and break location studied at the center and at CERN
• All bonding centers have passed qualification with pull strengths greater than 9 grams

<table>
<thead>
<tr>
<th>ID#</th>
<th>Centre</th>
<th>CERN bond</th>
<th>Self test§</th>
<th>CERN test</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Torino</td>
<td>10.7 ± 0.6</td>
<td>12.5 ± 1.5</td>
<td>13.9 ± 0.9</td>
<td>Slight under deformation</td>
</tr>
<tr>
<td>2</td>
<td>Bari</td>
<td>11.6 ± 0.4</td>
<td>8.5 ± 1.0</td>
<td>10.7 ± 0.6</td>
<td>good</td>
</tr>
<tr>
<td>3</td>
<td>Catania</td>
<td>10.2 ± 0.4</td>
<td>7.1 ± 0.8</td>
<td>7.1 ± 0.4</td>
<td>Slight over deformation</td>
</tr>
<tr>
<td>4</td>
<td>Florence</td>
<td>11.1 ± 0.4</td>
<td>8.4 ± 0.9</td>
<td>8.3 ± 0.9</td>
<td>good</td>
</tr>
<tr>
<td>5</td>
<td>Karlsruhe</td>
<td>11.4 ± 0.4</td>
<td>10.7 ± 0.5</td>
<td>~10 ± 0.5</td>
<td>Very low loop:400µm</td>
</tr>
<tr>
<td>6</td>
<td>Strasbourg</td>
<td>11.6 ± 0.5</td>
<td>10.6 ± 0.5</td>
<td>11.2 ± 0.6</td>
<td>good, low loop:600µm</td>
</tr>
<tr>
<td>7</td>
<td>Vienna</td>
<td>10.3 ± 0.5</td>
<td>7.3 ± 1.7</td>
<td>10.0 ± 1.8</td>
<td>Lift-offs, large spread</td>
</tr>
<tr>
<td>8</td>
<td>Aachen</td>
<td>9.2 ± 0.4</td>
<td>11.0 ± 1.7</td>
<td>8.4 ± 2.0</td>
<td>Lift-offs, large spread</td>
</tr>
<tr>
<td>9</td>
<td>Padova 1</td>
<td>8.7 ± 0.4</td>
<td>10.3 ± 1.5</td>
<td>12.1 ± 1.5</td>
<td>On Hughes, large spread</td>
</tr>
<tr>
<td>10</td>
<td>Padova 2</td>
<td>8.7 ± 0.4</td>
<td>8.5 ± 1.2</td>
<td>9.8 ± 1.6</td>
<td>K&amp;S, lift-offs, spread</td>
</tr>
<tr>
<td>11</td>
<td>Pisa 1</td>
<td>11.4 ± 0.5</td>
<td>6.5 ND</td>
<td>11.8 ± 0.7</td>
<td>Do destructive test</td>
</tr>
<tr>
<td>12</td>
<td>Pisa 2</td>
<td>9.1 ± 0.4</td>
<td>?</td>
<td></td>
<td>Test new K&amp;S</td>
</tr>
<tr>
<td>13</td>
<td>Zurich 1</td>
<td>9.9 ± 0.4</td>
<td>9.9 ± 1.1?</td>
<td>8.5 ± 0.8</td>
<td>Very high loop</td>
</tr>
<tr>
<td>14</td>
<td>Zurich 2</td>
<td>8.9 ± 0.4</td>
<td>10.3 ± ?</td>
<td>14.6 ± 0.9</td>
<td>Amazing!</td>
</tr>
<tr>
<td>15</td>
<td>FNAL 1</td>
<td>9.0 ± 0.4</td>
<td>10.6 ± 1.1</td>
<td>10.4 ± 1.1</td>
<td>Good but some lift-offs</td>
</tr>
<tr>
<td>16</td>
<td>UCSB</td>
<td>-</td>
<td>9.6 ± 0.3</td>
<td>9.9 ± 0.4</td>
<td>good</td>
</tr>
<tr>
<td>17</td>
<td>FNAL 2</td>
<td>10.3 ± 1.0</td>
<td>10.8 ± 0.9</td>
<td>10.7 ± 1.9</td>
<td>1 bad bond in CERN test, some lift-offs</td>
</tr>
</tbody>
</table>

§= corrected value based on CERN measured height and length in purple = some areas of improvement to work on
Bonding QC&A During Production

- Pull strengths, bond deformation, and lift-off measurements are made on the test pad of pitch adaptor.
- Every 50th wire bond will be destructively pull tested and replaced on first ~20 module of each type at each test center.
- Bond heads are regularly inspected and replaced when necessary.
- A large number (>100) of hybrids and modules have been thermal cycled between –20 and 20 C with no wire bond breakage seen.
Hybrid & Module Electrical Testing

- Hybrids and modules are tested during the various stages of module production
  - Ensure that the performed operations do not introduce any or very few defects
    - Currently require <2% faulty channels per module
  - CERN, Louvain, Strasbourg, UCSB -> Hybrid Tests
  - Bari/Catania, Firenze, Padova, Perugia, Pisa, Torino -> TIB/TID Modules
  - Aachen, Brussels/Antwerper, Karlsruhe, Lyon, Louvain,
  - Strasbourg, Wien, Zurich -> TEC Modules
  - FNAL, UCSB -> TOB Modules

- A big effort of standardization in the hardware and software setups has been accomplished.
  - Only ARCS and DAQ-based testing stand are foreseen to be used
  - Both systems use the same data analysis and fault finding algorithms
    - Data file and database outputs of the two systems are being standardized
ARCS Based Test Stands

ARCS - **APV Readout Controller Software**
Purpose - Fast testing of hybrids and modules

- **Hybrid testing**
  - 28 test stands

- **Module testing**
  - LED systems
    - Pinhole/Open Tests
  - DEPP HV supply
    - Automated IV curves
  - Pre-bonding Test
    - 19 test stands
  - Post-bonding Test
    - 15 test stands
**DAQ Based Test Stands**

**DAQ system** - a PC based prototype of the real CMS tracker readout chain

**Purpose** - fast and burn-in testing of modules and sub-structures

- **Single Module Test Stand** (20 test stands)
- **Module Burn-in (Wien box)** (7 test stands)
- **Substructure Assembly** (10 test stands) and **Burn-in** (9 test stands)
Electronic Testing Cycle

- Quick test hybrid
- Gantry makes modules
- Quick test unbonded module
- Thermal cycle module
- Bonded module test
- Wirebond
- TEC/TOB
- Final pinhole test
- Assemble petals/rods
- Petal/rod burn-in
Hybrid Quick Tests

• Hybrids are tested prior to module assembly and bonding
  → Ensure no damage has occurred during process
  → Hybrids have had extensive QC & A prior to module assembly
    – See F. Hartmann’s talk

• The hybrid quick tests use the same systems (ARCS),
  algorithms, and fault finding requirements as the hybrid
  QC & A
Module Tests

• Module testing has matured greatly recently with the production of >50 modules of a given type.
  → Minimum set of tests defined
  → Fault finding algorithms are now tuned to maximize fault finding and fault type identification while minimizing false bad channel flagging

• Noise performance and shielding standardization has allowed for the same fault finding algorithms to work on the TIB, TEC & TOB
  → Minimize the effects of external noise sources
  → Results can be combined for the same module type measured at different sites in order to further refine testing

• Testing procedures are now almost automated
  → Work to automate testing → fault finding → module grading → database entry underway
Fault Finding Using ARCS (1)

### Noise Measurement

- **Raw Noise vs. Channel**
  - Red: Raw Noise
  - Blue: CMS Noise

- **Peak InvOff**
  - Noisy

- **Raw Noise vs. Channel**
  - 1 sensor open
  - 2 sensor open
  - Pinholes

- **Pulse Height vs. Channel**
  - Opens
  - Shorts
  - Pinhole

- **Dec InvOff**
  - Bad Channel Flags

- **Pulse Height Measurement (Using Calibration Pulse)**
  - Bad Channel Flags
Fault Finding Using ARCS (2)

Average Subtracted Peak Time (Calibration Pulse)

- Peak InvOn
- Peak InvOff

Pinhole Test (Using LED System)

- Calibration Injection Response
- Difference between max and min pulse heights vs. channel

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Fault Finding Using ARCS (3)

- Test failures are correlated in order to diagnose fault type
  - Open (1 or 2 sensor)
  - Short
  - Pinhole/Saturated Channel
  - Mid-sensor opens
  - Noisy Channels
- Faults are found >95% with correct fault type identified ~90% of the time
  - Less than .1% of good channel flagged as faulty
  - As more modules are built, fault finding criteria will be re-tuned to improve performance
- Database output of module testing is being finalized
  - Similar tuning of fault finding underway for DAQ-based systems
Test Stand Cross-calibration

- All ARCS systems have had first iteration of cross-calibrations
- Modules are circulated between testing centers
  - Multiple examples of common problems are added to each module
    - Shorts (neighbors & next-to-neighbors)
    - Opens (sensor-sensor & PA-sensor)
    - Pinholes
- With new qualification standards, results nearly identical
  - Final iteration of cross-calibrations are currently underway
  - DAQ cross-calibration is forthcoming
Wien cold box

- Wien cold box cycles modules from –20 C to 20 C while reading out up to 10 modules
  - DAQ Based System
  - Modules cycled 1-3 days with ~4 cycles per day.
  - TIB will cycle all modules
  - TEC/TOB will cycle all modules until sub-structure burn-in available
• Lyon Database
  → Complete description of all parts and assembly
  → Traces all movements of the parts between centres & keeps inventories
  → Includes all test results performed at any centre
  → Allows extract data for
    – Controlling the production
    – Tracing the anomalies
    – Later calibration or slow control purposes

For example, I-V curve of a TOB module at various stages of production
Conclusions

• Module assembly is underway
  → Assembled modules are very uniform and all meet specifications
  → Wire bond strengths and shapes have been excellent
  → Module electrical testing is semi-automatically finding the vast majority of faults with a very small false fault finding rate

• With the uniformity of results, the database allows for the tracking of global module quality
  → Any systematic problems can be quickly identified and addressed at the production centers