Performance of the ATLAS ITK Pixel Detector Prototype

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ATLAS ITk Pixel Loaded Local Supports

- Detector integration from individual components to final detector one of the big challenges of the HL-LHC detector upgrades
- Smallest “feature-complete”, functional building block of the ITk Pixel detector: Loaded local supports (LLS)
  - contains: modules, on-detector services, light-weight support structure, cooling, ...
Loaded Local Support Demonstrator Program

- ITk Pixel project in the transition period to pre-production
- Dedicated LLS demonstrators essential for the validation of the design and the next steps in the project

**General Goals of the LLS Demonstrator Program**
- Validation of loading concept and procedures
  - Demonstration of meeting mechanical loading specifications (not covered in this talk)
  - Electrical performance evaluation of the detector after loading
- Development and test of large-scale system aspects

**System aspects that become important only at the integration level of LLSs**

- Mechanical detector support structure
- CO2 cooling
- Serial powering of multiple modules
- Connection through on-det. services
- Complex monitoring/interlock needs
- Large scale DCS
Implications of available hardware
• Lack of RD53B (ITkPix) readout chips at the time of module production
• Modules for demonstrators based on RD53A readout chip
• FE dimensions different from final chip
• Consequence:
  • No active bump bonds in the center of the module
  • Three different analog FE technologies
    (synchronous [dropped], linear [CMS], differential [ATLAS])

Limitations
• Data transmission
  → separate data transmission bench with ITkPix modules
• Exact thermal behavior on LLS
  → separate thermal mock-ups with heaters
• Exact serial powering properties
  → separate SP chain test stands with ITkPix modules
Loaded Local Support Demonstrator Program

<table>
<thead>
<tr>
<th>sub-system</th>
<th>LLS flavor</th>
<th>modules</th>
<th>SP chains</th>
<th>HV groups</th>
<th>electrical up links</th>
<th>electrical down links</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS</td>
<td>L0 stave</td>
<td>4 (8)</td>
<td>1 (2)</td>
<td>4 (8)</td>
<td>48 (96)</td>
<td>4 (8)</td>
</tr>
<tr>
<td>IS</td>
<td>L1 stave</td>
<td>6 (12)</td>
<td>1 (2)</td>
<td>2 (4)</td>
<td>12 (24)</td>
<td>6 (12)</td>
</tr>
<tr>
<td>IS</td>
<td>coupled ring</td>
<td>3+10 (26)</td>
<td>1+1 (4)</td>
<td>3+2 (10)</td>
<td>67 (134)</td>
<td>13 (26)</td>
</tr>
<tr>
<td>OE</td>
<td>L3 half-ring</td>
<td>11+11</td>
<td>1+1</td>
<td>2+2</td>
<td>44</td>
<td>22</td>
</tr>
<tr>
<td>OB</td>
<td>L2 longeron</td>
<td>6+12 (36)</td>
<td>1+1 (4)</td>
<td>2+2 (8)</td>
<td>36 (72)</td>
<td>18 (36)</td>
</tr>
<tr>
<td>OB</td>
<td>L3 half-ring</td>
<td>11 (22)</td>
<td>1 (2)</td>
<td>2 (4)</td>
<td>11 (22)</td>
<td>11 (22)</td>
</tr>
</tbody>
</table>

- All conceptually different flavors of LLSs have been built
- Mostly loading of only half of the LLSs for reasons of module availability
- Building of prototypes is significant achievement in the ITk Pixel project
- Electrical performance evaluation currently ongoing at different sites
  - Focus of this talk: first results of OB L2 longeron M6
Test Box
• Thermally insulated metal enclosure (→ Faraday cage)
• Dry air supply ($T_{\text{dewPoint}} \approx -60^\circ \text{C}$) and dew point monitoring
• Following the ITk grounding scheme
• Motor stage for source manipulation
ITk Pixel Outer Barrel System Test

Readout
- Density of electrical links allow up to 1MHz readout
- Service designed for data-merging of multiple FEs of a module (not yet available in RD53A)
- Maximum 2 up-links and 1 down-link per quad module
- 3m commercial twinax data cables
- Conversion of electrical to optical signal in optobox (GBCR – IpGBT – VTRx+)
- Realistic fiber plant (65m to rack area)
- Multi-module readout using phase-1 FELIX

> Very realistic readout setup and first time large scale validation of opto-system and data-transmission
Detector monitoring
- ATLAS ITk Pixel will have a monitoring chips (MOPS) inside the detector to monitor module properties (temperature, voltage drop) via independent readout path
  ➔ Successful validation of concept on system level
  ➔ Valuable tool for SP chain monitoring

Detector control system
- System size and complexity requires decent detector control system
- Design compliant with system for actual detector operation (WinCC) and scalability to large detector in mind
- Finite State Machine guaranties save detector operation at any moment
  ➔ Used and exercised extensively during LLS testing
Performance Tracking through Integration

- Thorough tracking of electrical detector performance essential for validation of loading procedures and detector concept
- Stage 1-3: measurement in single module test stand
- Stage 4: demonstrator system test

Performance measurements in between different integration steps:
- Digital response
- Analog response
- Threshold/noise scan
- Time-over-threshold response
- Cross-talk scan
- Disconnected bump-bond scan

Stage 1: after module production
Stage 2: after cell loading
Stage 3: after pigtail assembly
Stage 4: after final cell integration

Threshold vs. diff FE
Noise vs. diff FE
ToT vs. Mean ToT [BC]

Exceptionally well agreement keeping in mind the fundamentally different setups
Performance Tracking through Integration

**Stage 1:** after module production

**Stage 2:** after cell loading

**Stage 3:** after pigtail assembly

**Stage 4:** after final cell integration

- Example shows noise and threshold, but similar results for distributions of dead pixels, ToT, disconnected bump bonds
- Very stable performance of all tested chips through integration steps
- No sign for any performance degradation during loading
Serial Powering

- Serial powering is one of the novel key features of the HL-LHC tracker upgrades
- SLDO in RD53A known to be non-perfect affecting linearity and cold start-up
- Advantage of independent MOPS system: monitoring even when readout link no longer established
- Ohmic behaviour of SP chain from outside maintained also when single chips start to drop out

➔ **Beyond conceptual tests of monitoring/powering, dedicated SP chain tests have been successfully carried out with ITkPix modules**
Scans with Radioactive Source

- Ultimate tool to find disconnected bump bonds
- Aiming to spot large sensor delamination due to mechanical stress during loading
- Strong Sr source (beta radiator)
- No self-triggering of RD53A
- Random trigger readout

→ No systematic delamination of bump bonds due to loading procedure visible
Conclusions

- Completion of ITk Pixel Loaded Local Support prototypes important milestone in the project
- (Electrical) design validation currently ongoing
- Services, way of operation, readout, monitoring of demonstrators very complex and in many aspects close to final detector
- System Test is important contribution to preparations for detector operation
- First Outer Barrel RD53A Demonstrator (M6 longeron) fully tested
- No indication for any degradation or fundamental problem of the detector concept found on the system level
- Finalization of RD53A demonstrator program expected by the end of the year
BACKUP
DAQ/Readout Chain

- FELIX
- DAQ software computer
- commercial 1x MPO24 → 24xLC fanout for shuffling
- SR1 rack area
- fiber patch panel MPO24 → LC
- realistic 65m trunk fiber
- SR1 rad lab
- opto box
- custom ERF8-firefly adapter
- RD53A pigtail
- PP0
- commercial twinax cables (2-3m)
- "ItkPix-ready" PP0
- PP0
- commercial optical patch panel
- PP0
- "ItkPix-ready" PP0
- RD53A module
- insulated test box
- commercial 1x MPO24 → 24xLC fanout for shuffling
Cables, power supplies, off-detector chain

Wiener current source
ISEG HV supply
ISEG HV supply

DCS
PL512
opto box
MOPShub
MPOD MPV0860
IMC

SR1 rack area
SR1 rad lab

Positronics to SUBD adapter
Redel to SUBD adapter

CSB can easily be replaced with PP2 box

type-1 bundles to detector or dummy load (3.4Ohm)

2 channels
4 channels
4 channels

~65m
to 2nd CSB
~65m
to 2nd CSB

~5m
~0.5m

~5m
**DAQ/Readout Chain**

- **SR1 rack area**
  - FELIX
  - Fiber patch panel: MPO24 → LC
  - Commercial optical patch panel

- **SR1 rad lab**
  - Opto box
  - Custom ERF8-firefly adapter
  - Commercial twinax cables (2-3m)
  - Realistic 65m trunk fiber
  - RD53A pigtail

- **Commercial 1x MPO24 → 24xLC fanout for shuffling**

- **DAQ software computer**

- **PP0**

- **RD53A module**

- **Insulated test box**

- **“ItkPix-ready” PP0**

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