Performance and Design Validation of CMS Phase-2 Pixel Modules

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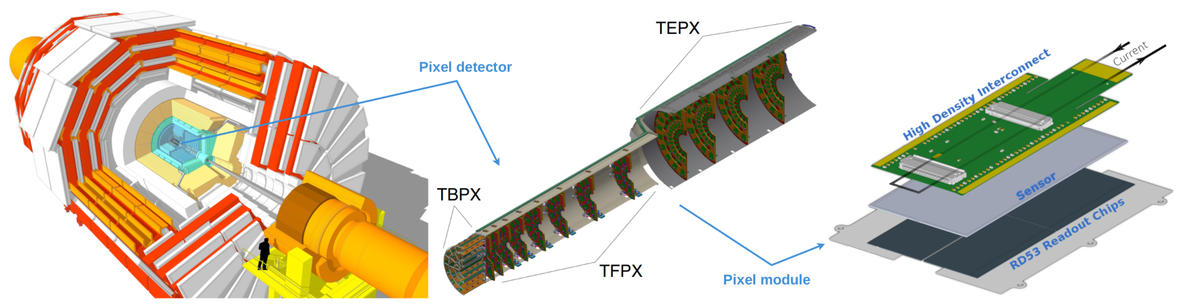
The High-Luminosity LHC and Phase-2 Upgrade

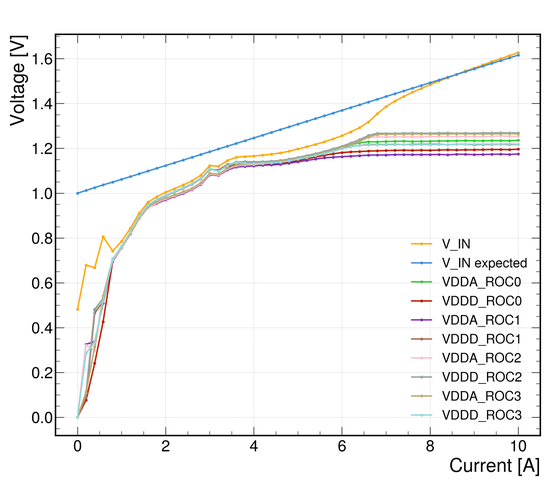
In view of the High Luminosity LHC (HL-LHC), the current CMS tracking detector will have to be replaced during Long Shutdown 3. In particular, to survive the higher radiation environment and to withstand an increased data rate, the CMS Inner Tracker (IT) will employ for the Phase-2 Upgrade

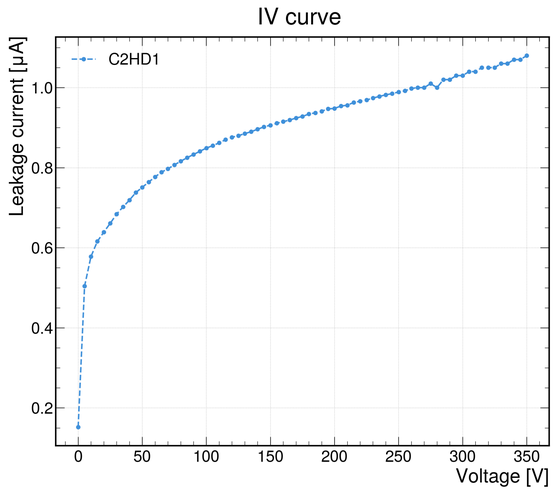
- a higher granularity with silicon sensors featuring a pixel size of 25x100 μm^2 bump-bonded to a readout chip in 65nm CMOS technology
- a serial powering scheme where the input current is shared by a chain of devices using a Shunt-LDO circuit



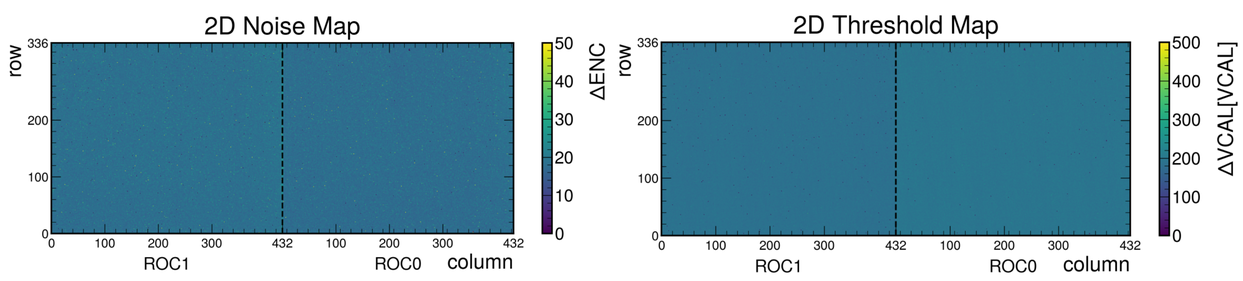
A new testing workflow

A procedure was developed to evaluate the performance of the Pixel module prototypes, establish the upgrade requirements, and qualify the modules against these standards.





- Powering test of the Shunt-LDO circuit of the readout chip (ROC)
- Sensor bias test, or sensor IV curve



- Generation of the mask for dead and noisy pixels
- Adjustment and equalization of noise and threshold pixel by pixel

Through the Quality Control procedure, various changes were implemented to optimize performance, starting with the first full-size prototype chip CROCv1, progressing through the "kick-off" modules, and leading to the final prototypes before production CROCv2.

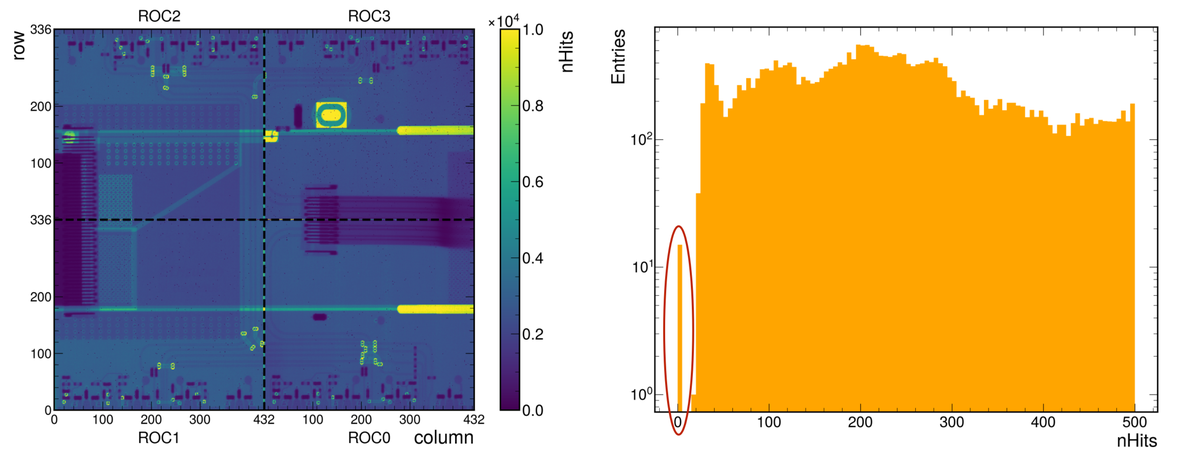
CROCv1	First full-size prototype chip
Kick-off	Prototype HDI design, final bump bonds technique, chip v1
CROCv2	Prototype HDI design, final bump bonds technique, chip v2

Quality Assurance

Innovative strategy for detecting faulty bump bond connections and evaluating their durability under harsh temperature conditions.

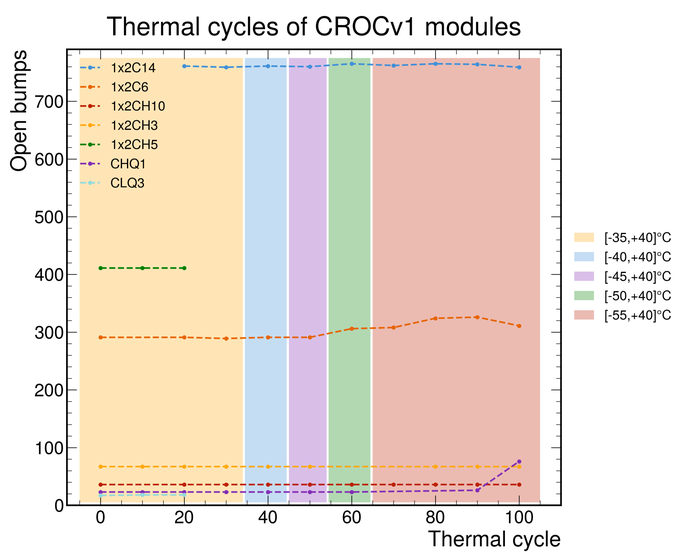
Bump bond connectivity tests

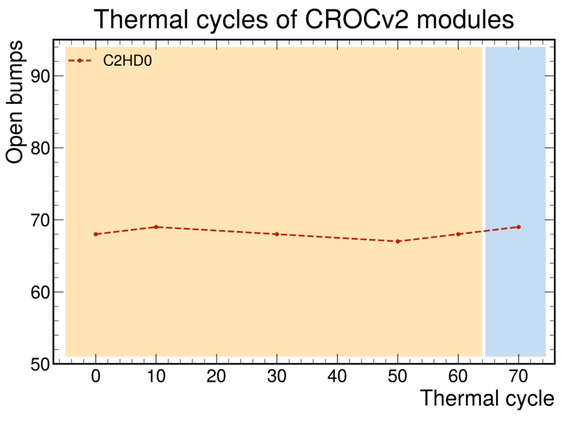
X-ray technique to identify problematic or open bump bonds. Quality requirement of less than 0.4%.

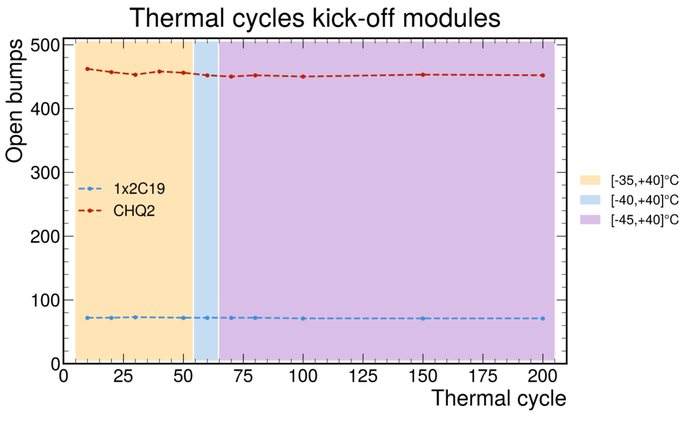


Thermal stress tests: *NEW*!

Technique applied for the first time to test the resistance of bump bonds under large temperature gradients. Despite the temperature ranges were extended over the standard limits, the increase of open bumps is negligible.

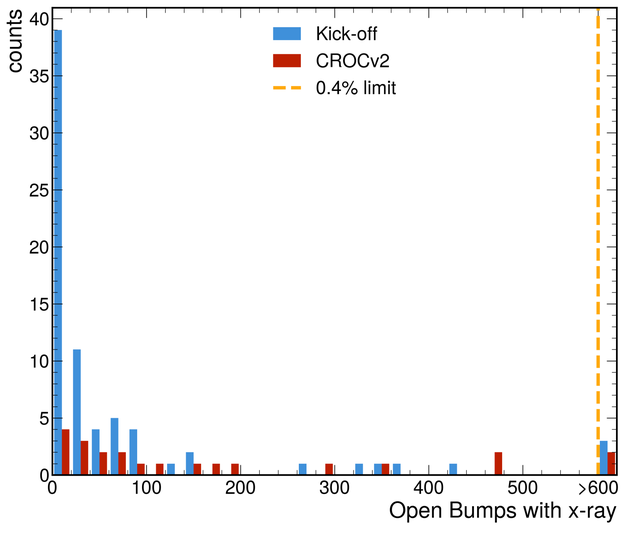






Summary before production

- Test-flow and open bumps detection techniques validated on several prototypes
- Good modules yield despite the stringent requirement of **0.4**% for the open bumps
- All module designs withstood the thermal stress tests, also with extended temperature ranges, and showed no new clusters of open bumps



Conclusions and Outlook

- The Quality Control strategy was newly developed and optimized first on prototype modules CROCv1.
- The requirements for the Quality Control of modules for the Phase-2 inner tracker upgrade were defined based on the initial prototype measurements

The pre-series prototype modules (CROCv2) were qualified against requirements, giving the "green light" for production.

- The full Quality Control procedure will be applied to production modules to monitor the performance before the installation

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