

A Journey through ITk Pixel Module Quality Control and Lessons from Preproduction

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BERKELEY LAB

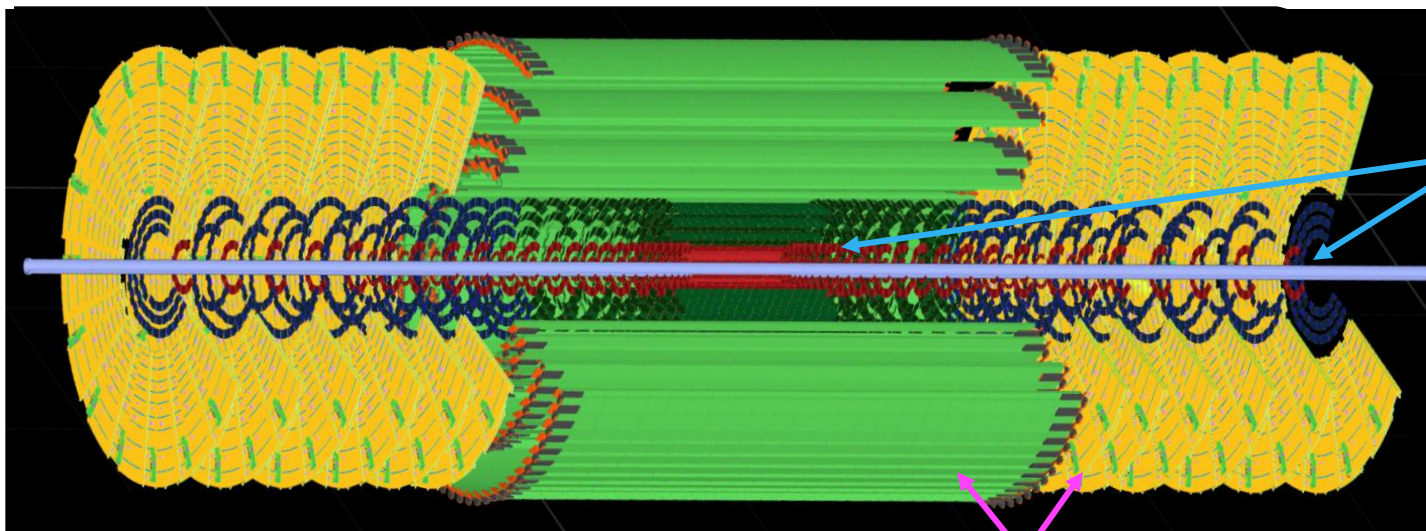
Bringing Science Solutions to the World



The HL-LHC is turning on in 2030. It will provide a challenging environment for charged particle tracking

- Much higher particle density and radiation damage compared to Run-3 conditions
- Increased trigger rate (100 kHz \rightarrow 1 MHz)

A **new, all-silicon tracking detector (ITk)** will replace the current ATLAS inner tracker:



ITk pixel detector

(this talk)

ITk strip detector

(A. Petersen's talk)

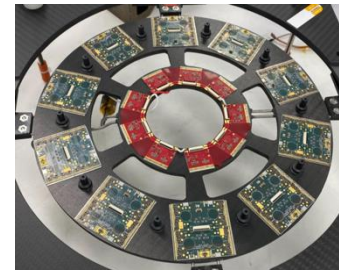
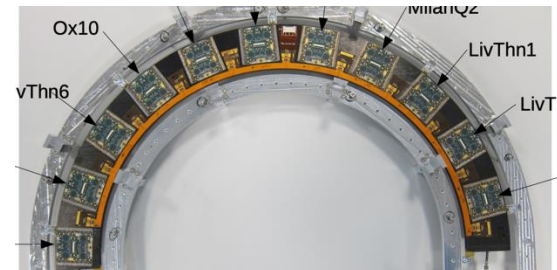
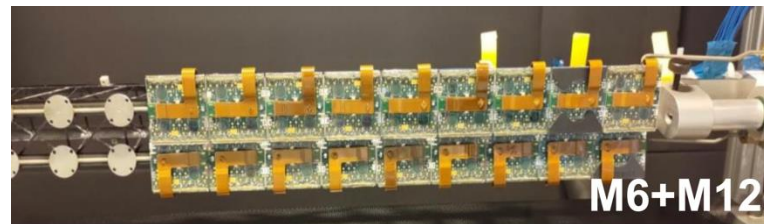
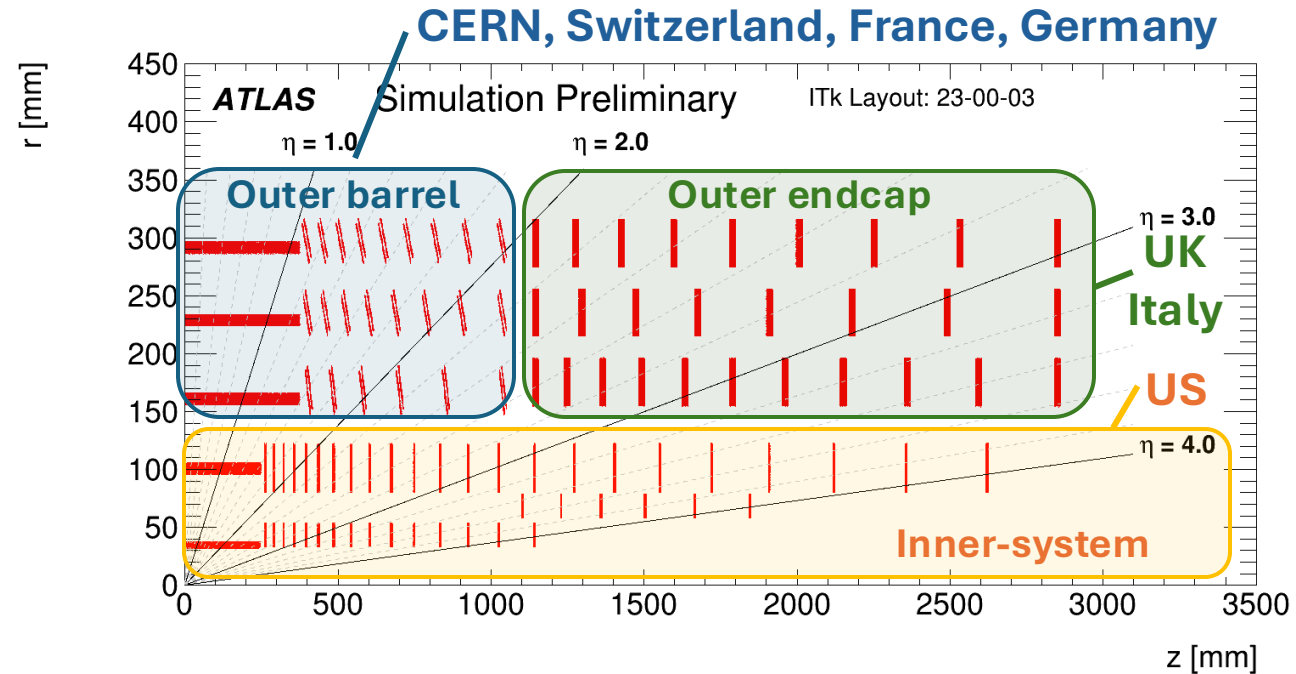
itk-viewer.web.cern.ch

The ITk pixel detector is a **bigger** and **better** version of the current silicon detector in ATLAS

Pixel detector	Current	ITk
Number of modules	1744	9164 → 5x
Active area [m^2]	1.6	13 → 8x
Channels	92M	5083M → 55x

New technology:

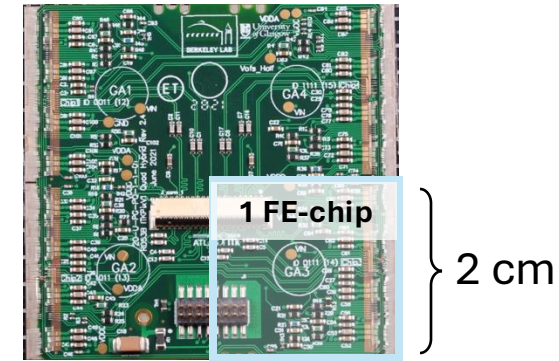
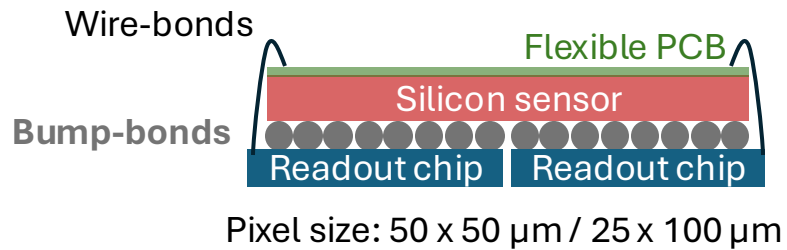
- Thinner silicon sensors with smaller pixels
- More radiation-hard FE-chips with higher readout bandwidth
- Novel serial powering scheme
- ...



Basic building block: ITk pixel modules

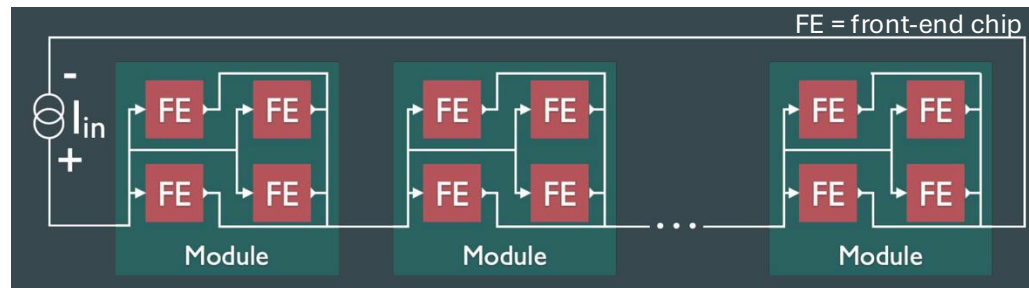
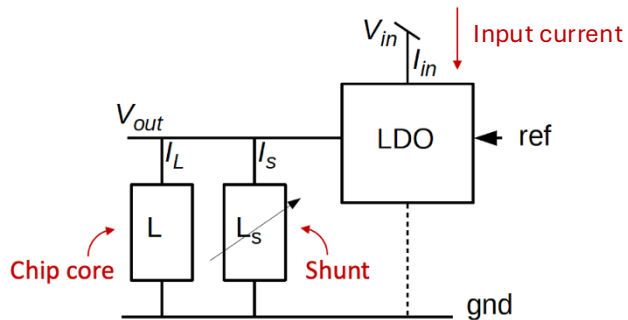
The ITk pixel detector will consist of $\sim 9,000$ pixel modules (but we need to build $\sim 12,000$)

Pixel module:



Highlight: **serial powering** \rightarrow fewer cables!

- Modules connected in series with constant input current (serial powering chain)
- FE-chips connected in parallel (equipped with shunt regulators (SLDO))

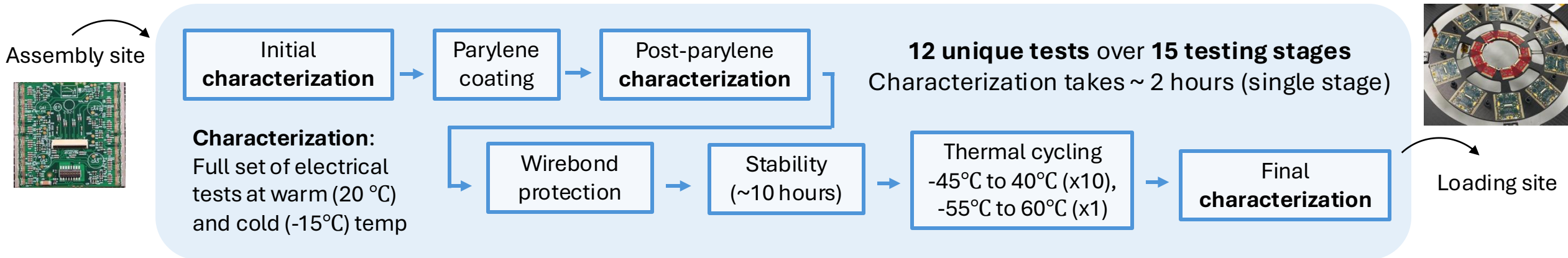


The journey

Quality control (QC): tests performed on **all 12,000 modules** to understand...

Will this module will work and deliver desired performance in the ITk for the entirety of the HL-LHC?

Journey of a module through QC:



Challenge #1

The ITk is big (many modules to build & test)

Challenge #2

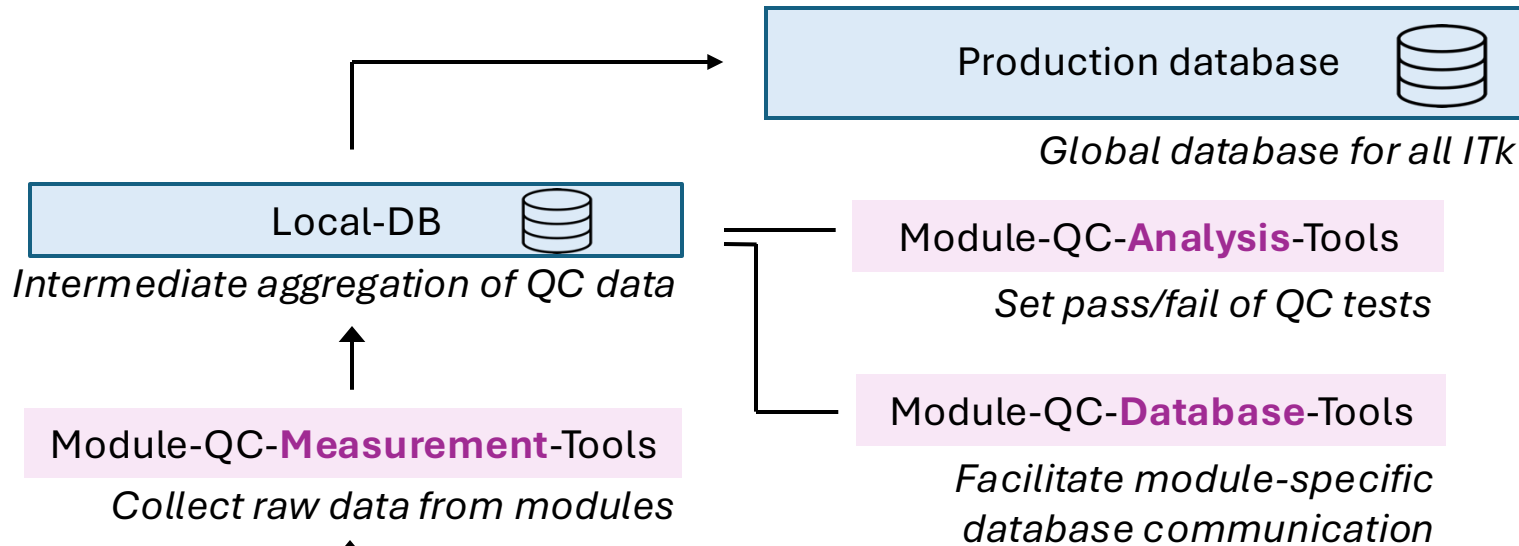
Highly distributed production model – 14 assembly sites and 23 testing sites

Ensuring **consistency** across testing stages and **uniformity** across testing sites is a major challenge of QC

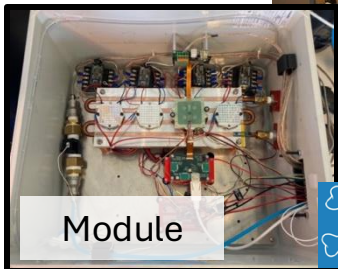
The tools

We developed a set of software tools (module-QC-tools) for the collection and analysis of QC data

- Set of python packages with minimal requirements to allow flexibility and usage at all testing sites



Lab setup



Module



Power supplies,
multimeter, DCS / DAQ

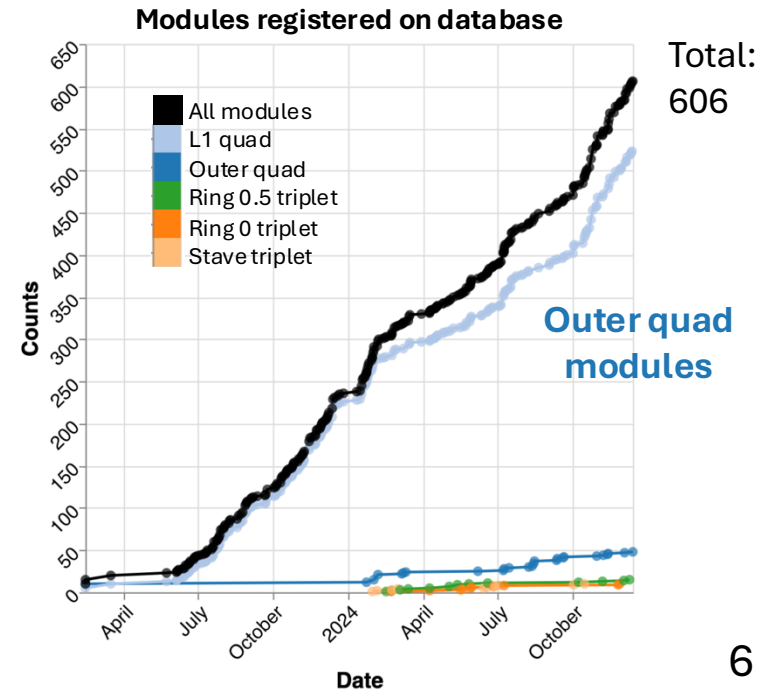
Testimonials:

“10/10, thanks.” - anonymous user

“QC-tools changed my life” – imaginary user

“That’s stupid, don’t put testimonials in your talk.” – developer

Module-QC-**statistical**-tools
Global analysis of QC data



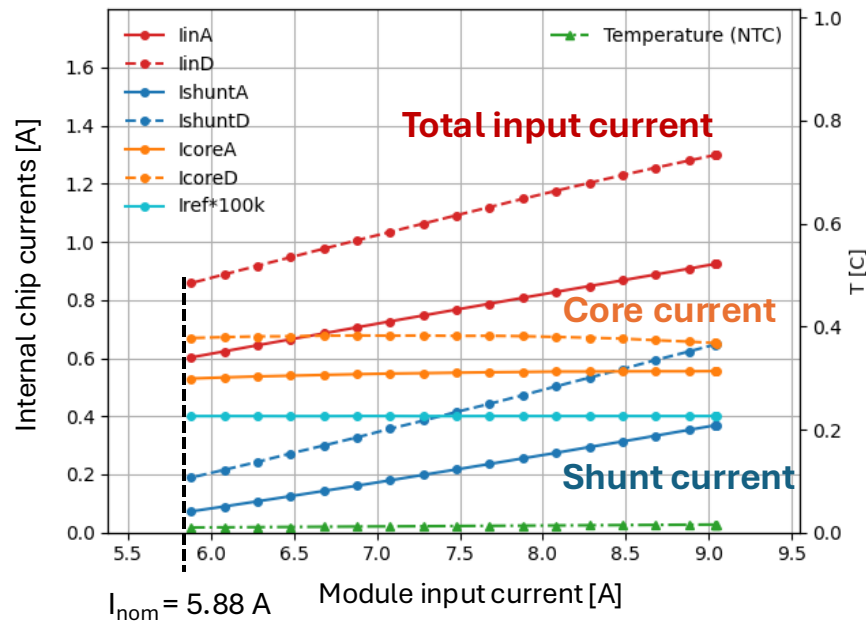
The results

We are at the end of *preproduction* → assembling and testing 10% of total modules

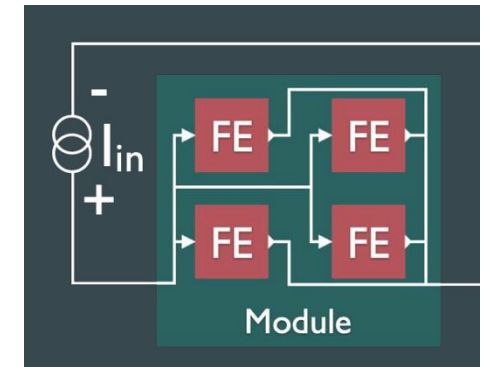
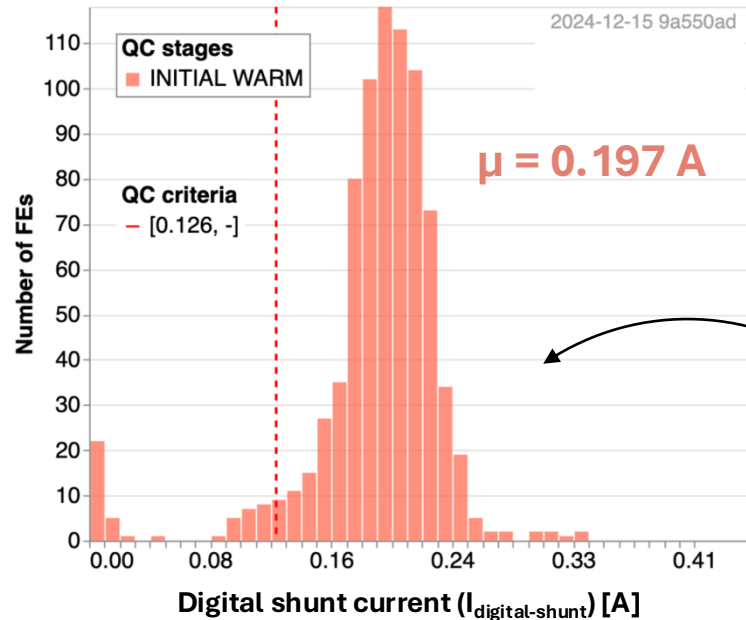
Are we building modules with production-level quality?

Example QC test of the module powering (SLDO) - expected to be the module yield driver:

Data from one FE-chip:



Data from all FE-chips:



Lower limit on digital shunt current ensures adequate current overhead during operation

✓ QC tests indicate that the SLDO powering is working as expected

✓ Passed the Production Readiness Review in Nov. 2024 – **ready to start module production!**

Lessons from ITk pixel module pre-production (non-exhaustive):

1. The QC **dataflow is working**

- Developing common tools was worth it – facilitate easier understanding of data

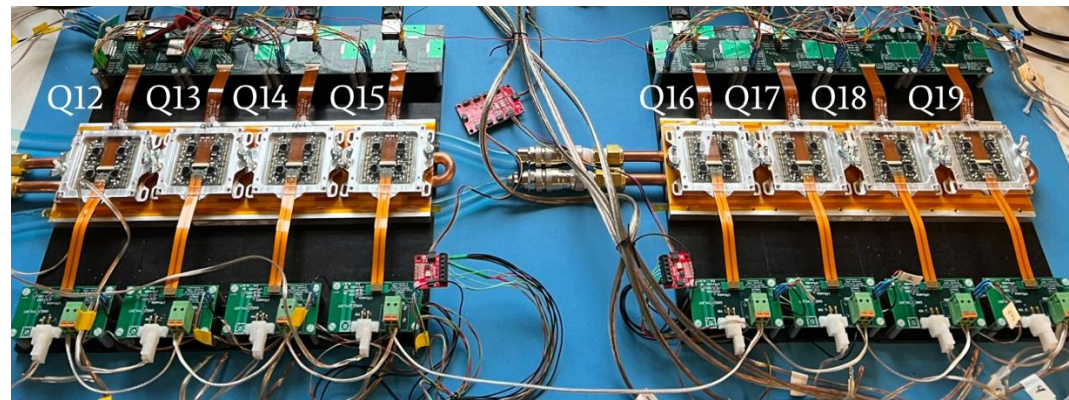
2. Need to **speed up QC**

- Systematically reviewing each test/stage to slim QC procedure without compromising detector quality

3. Need to pay close attention to **yield drivers** – especially for the test of serial powering

- Prioritizing **system tests** of serial powering chains

We are looking forward to start to module production in 2025!



Serial powering chain at LBNL