Performance of the ATLAS ITK Pixel Detector Prototype

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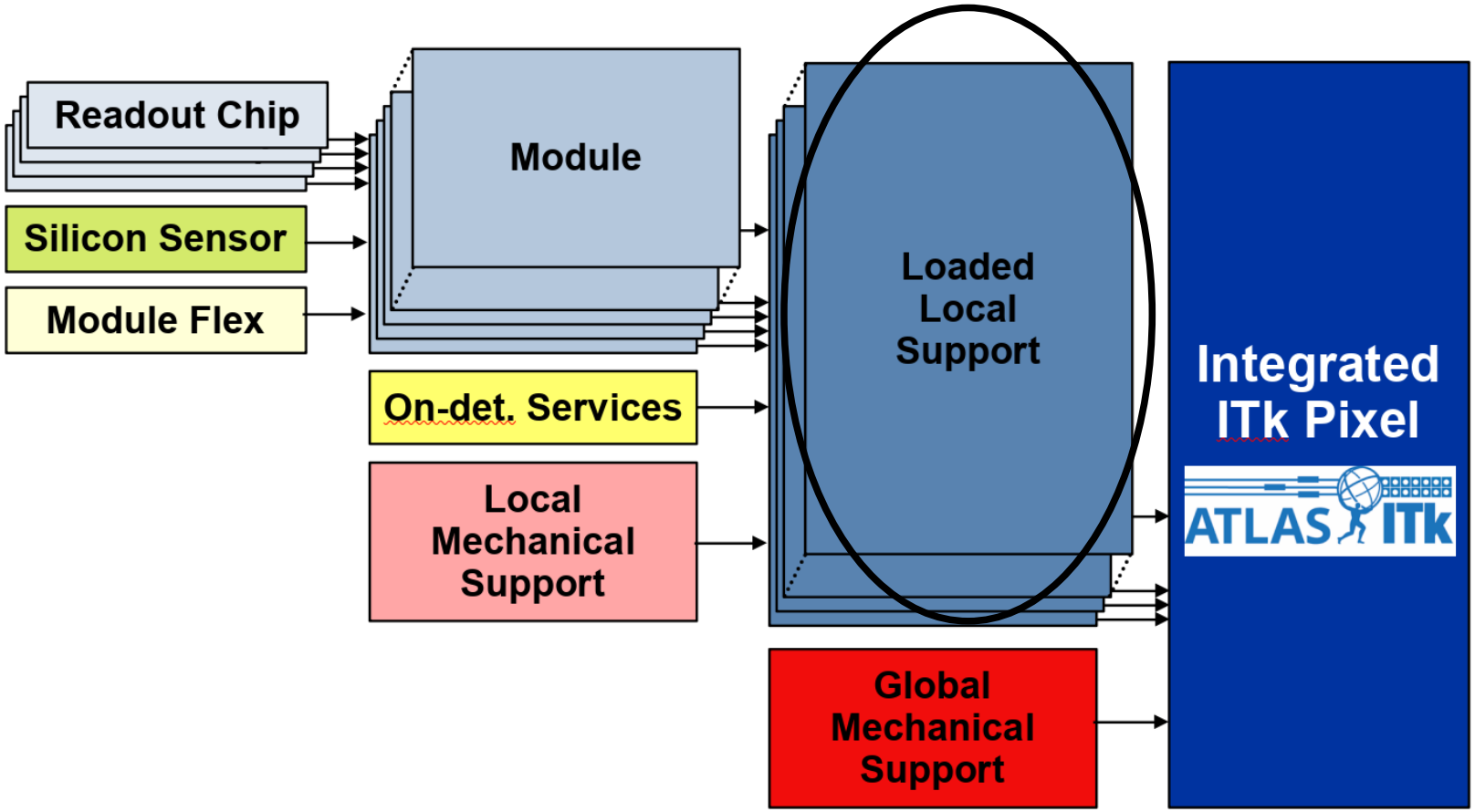
ATLAS ITk Pixel Loaded Local Supports

- 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, ...



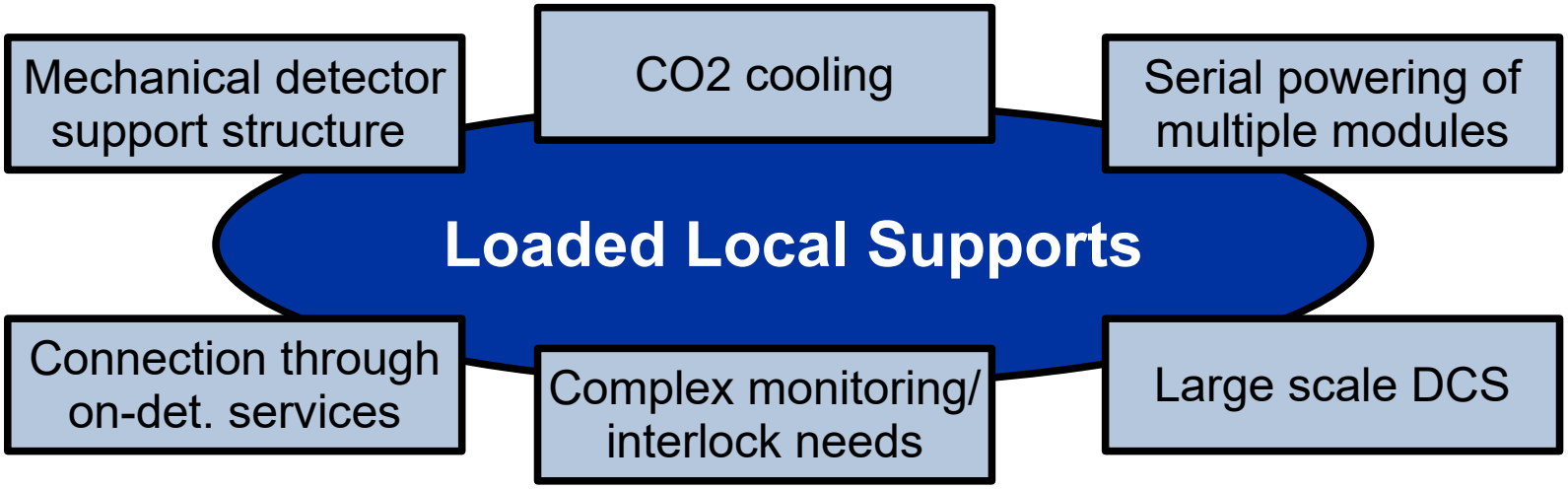
Loaded Local Support Demonstrator Program

- 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



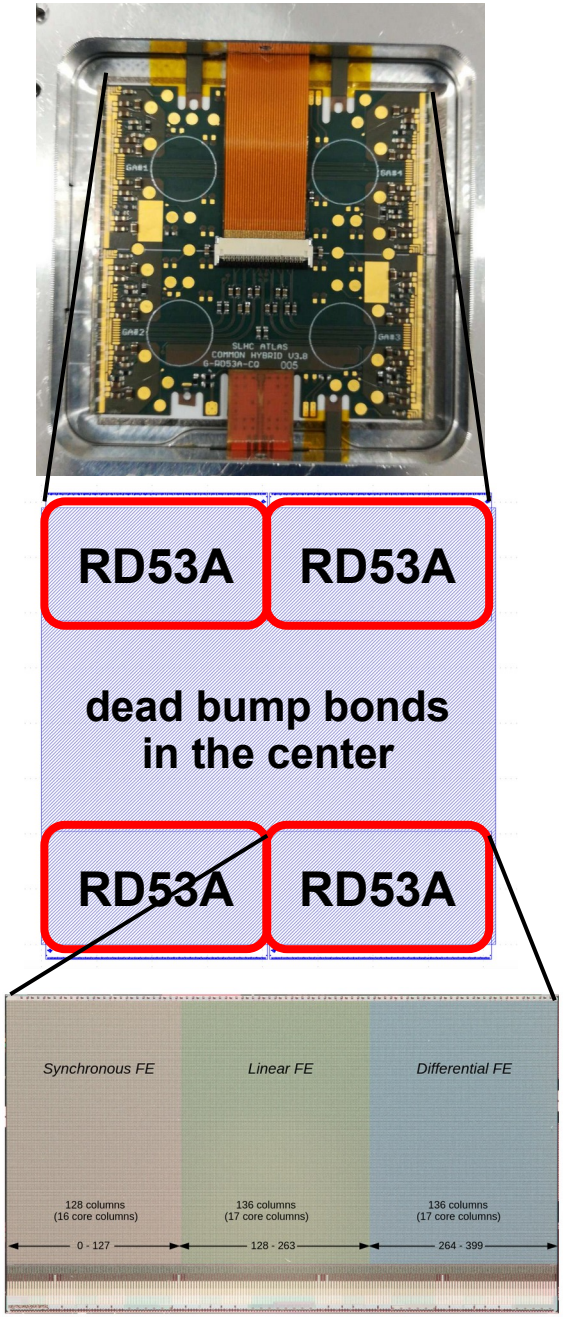
Loaded Local Support Demonstrator Program

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

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

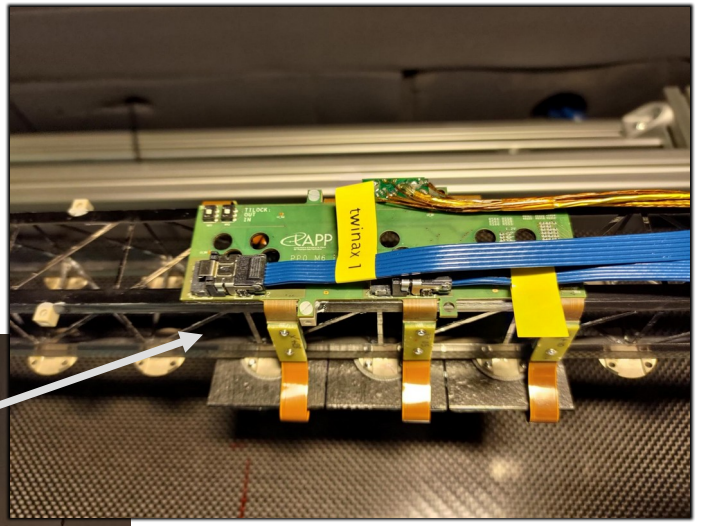
- All conceptually different flavors of LLSs have been built
- Mostly loading of only half of the LLSs for reasons of module availability
- Building of prototypes is significant achievement in the ITk Pixel project
- Electrical performance evaluation currently ongoing at different sites

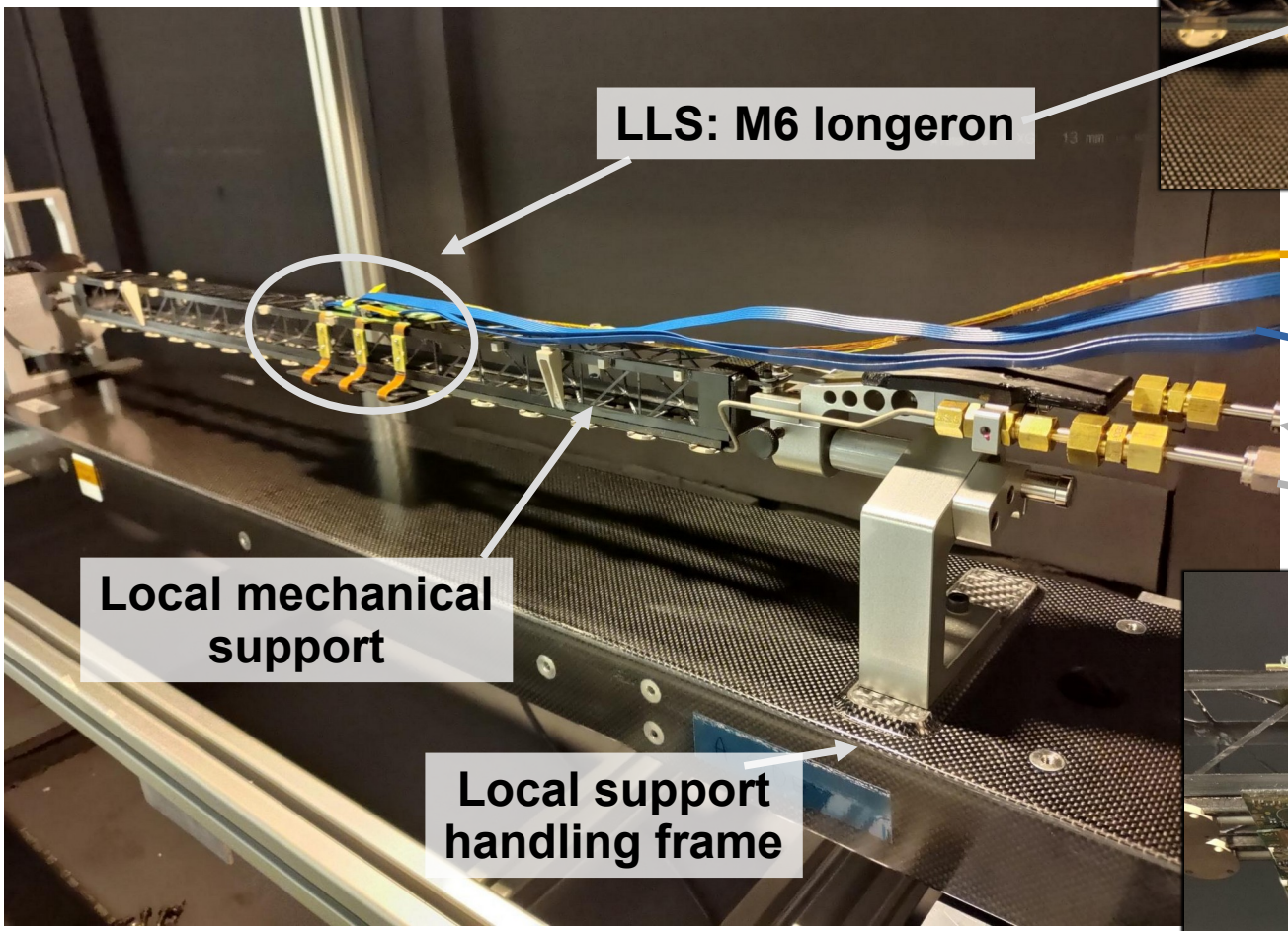
→ Focus of this talk: first results of OB L2 longeron M6

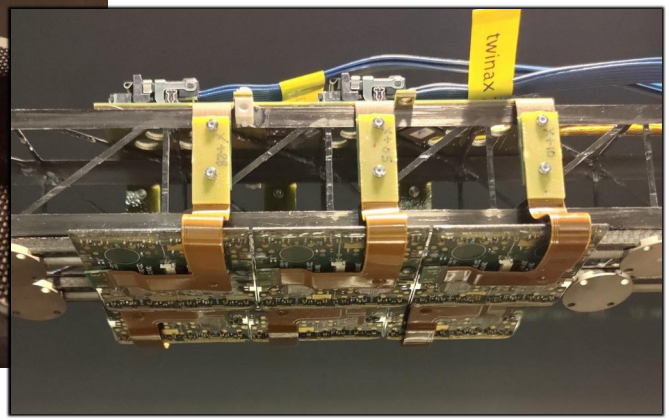
ITk Pixel Outer Barrel System Test

Test Box

- Thermally insulated metal enclosure (→ Faraday cage)
- Dry air supply ($T_{dewPoint}$ ≈ -60° C) and dew point monitoring
- Following the ITk grounding scheme
- Motor stage for source manipulation



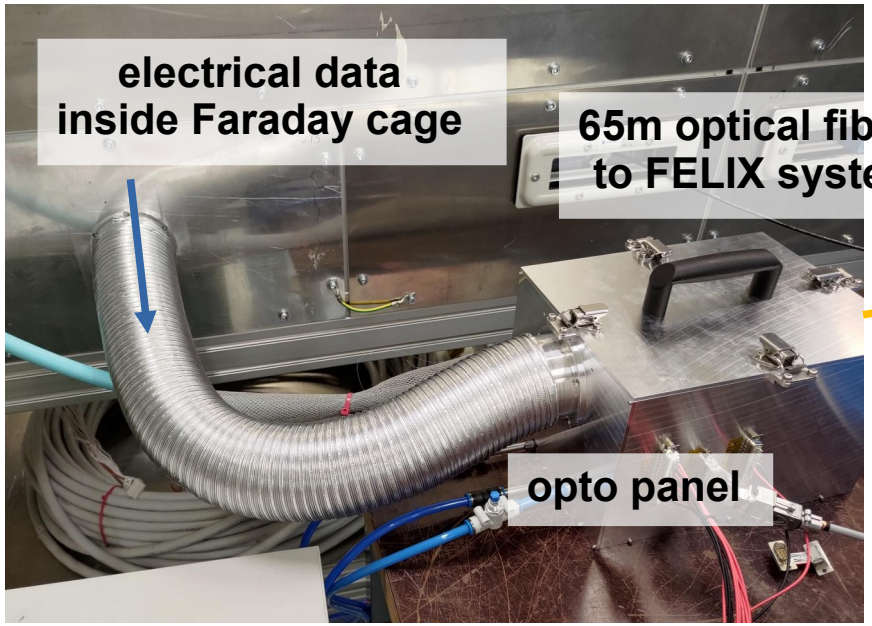


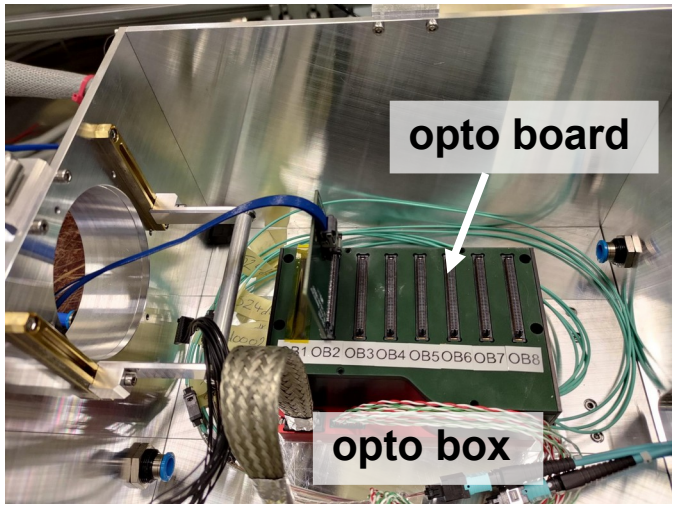


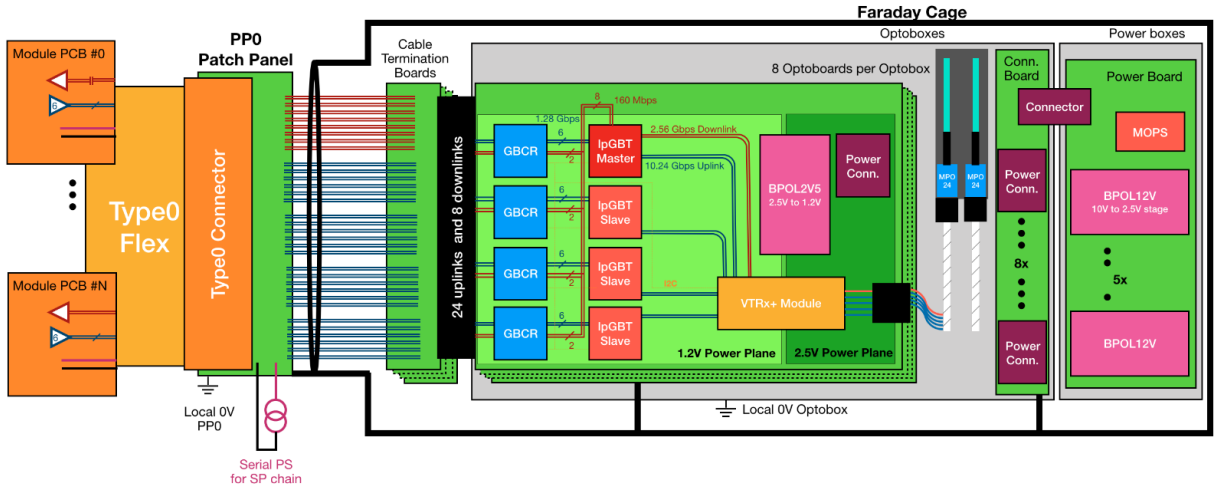
ITk Pixel Outer Barrel System Test

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 – lpGBT – VTRx+)
- Realistic fiber plant (65m to rack area)
- Multi-module readout using phase-1 FELIX

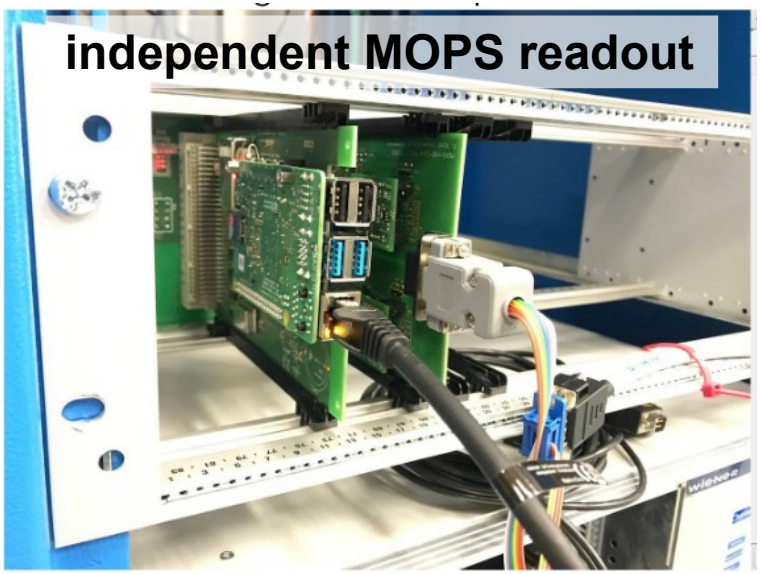






➔ **Very realistic readout setup and first time large scale validation of opto-system and data-transmission**

ITk Pixel Outer Barrel System Test

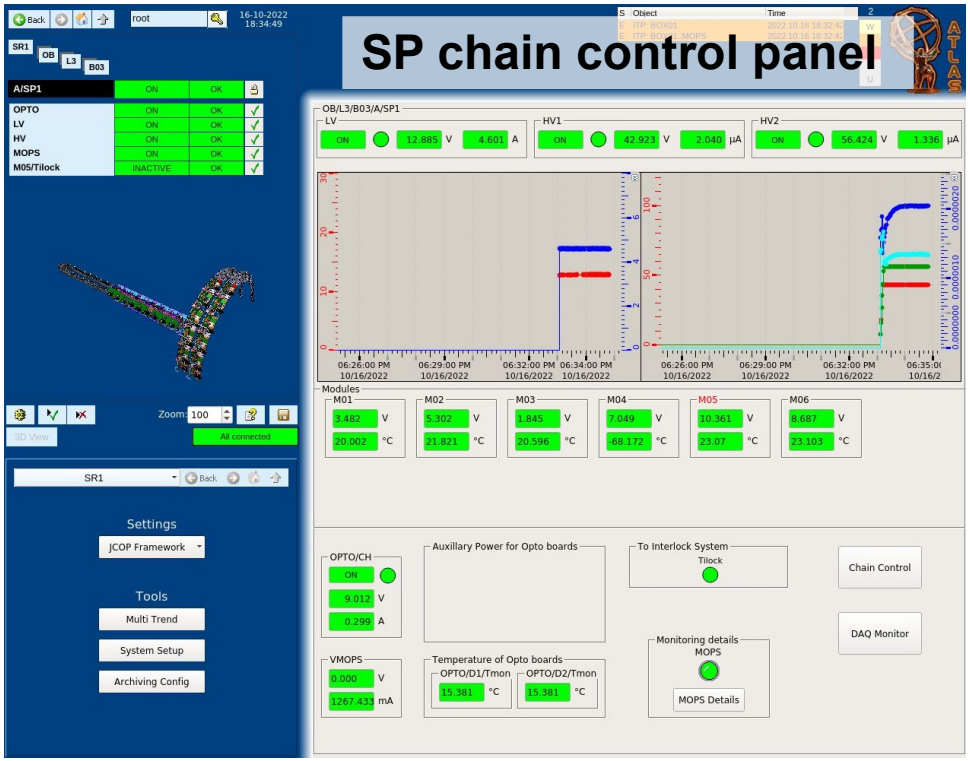


Detector monitoring

- 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**

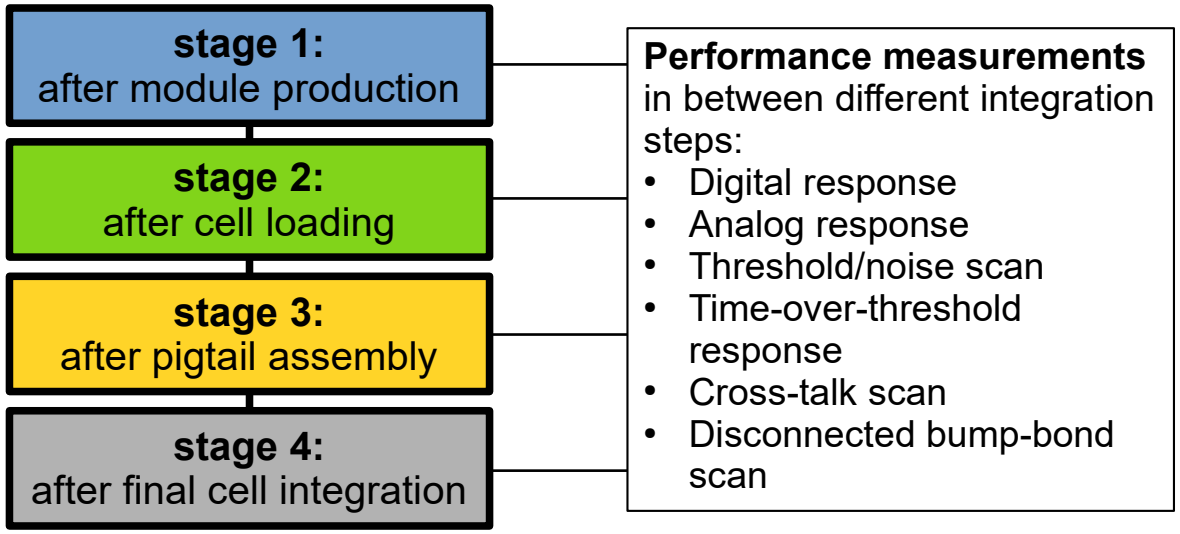
Detector control system

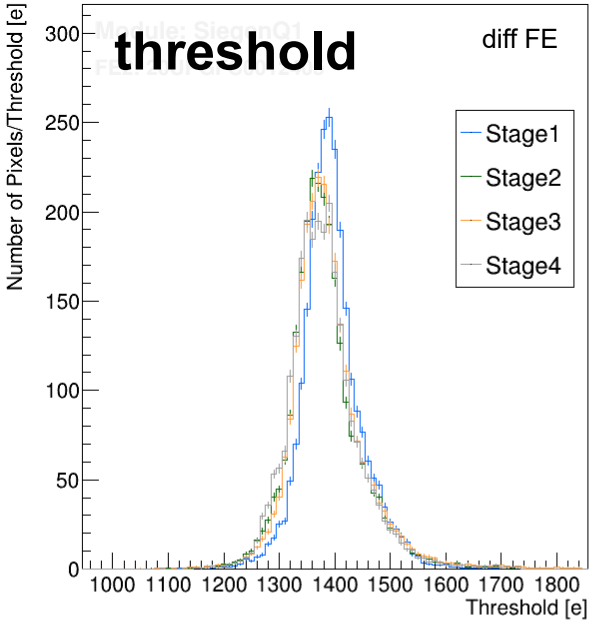
- System size and complexity requires decent detector control system
- Design compliant with system for actual detector operation (WinCC) and scalability to large detector in mind
- Finite State Machine guaranties save detector operation at any moment
- ➔ **Used and exercised extensively during LLS testing**

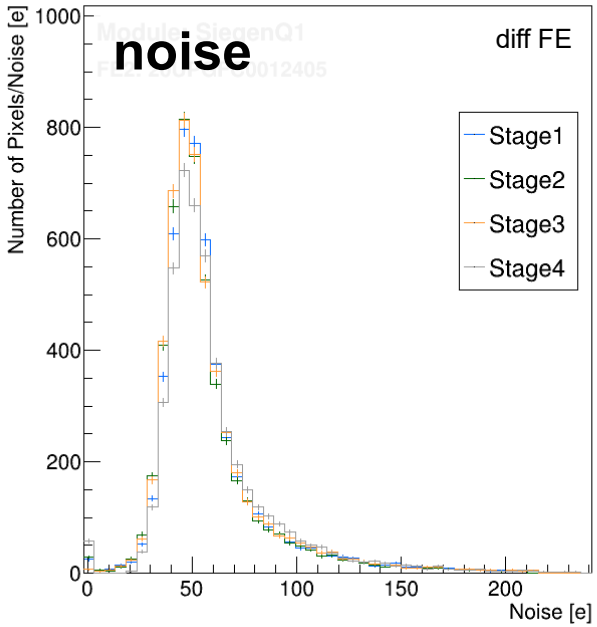


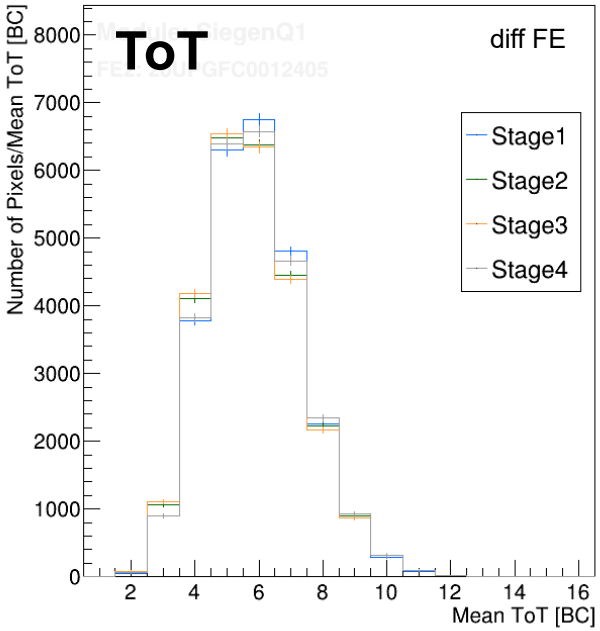
Performance Tracking through Integration

- 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









➔ **Exceptionally well agreement keeping in mind the fundamentally different setups**

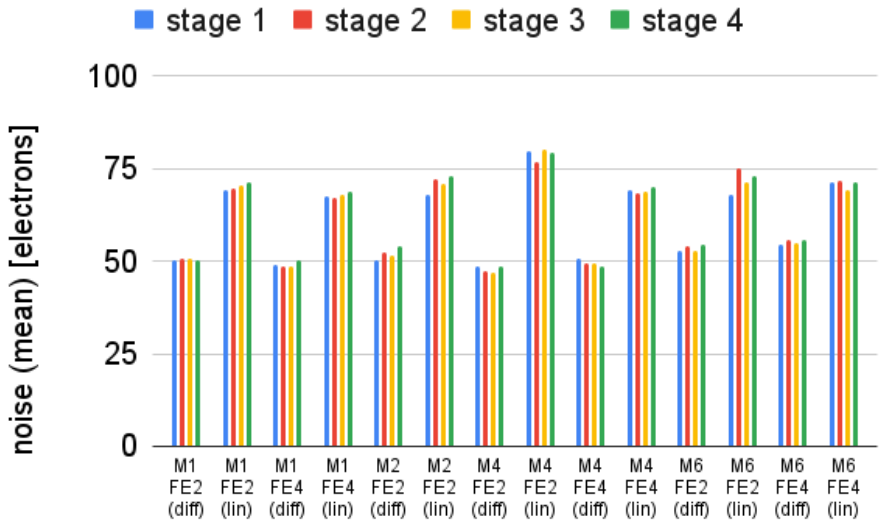
Performance Tracking through Integration

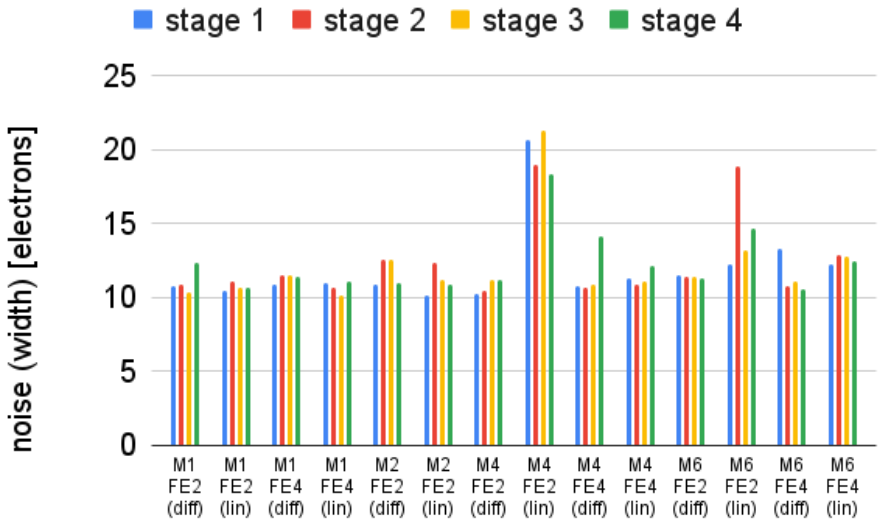
stage 1: after module production

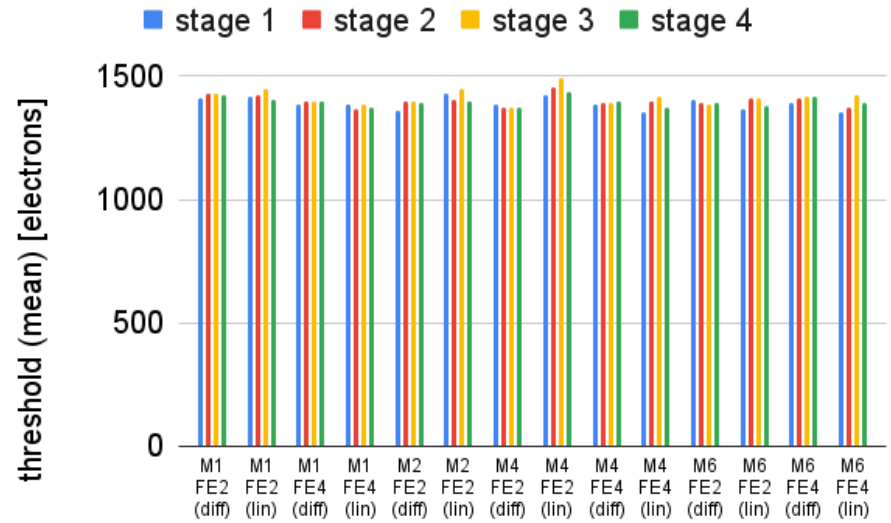
stage 2: after cell loading

stage 3: after pigtail assembly

stage 4: after final cell integration





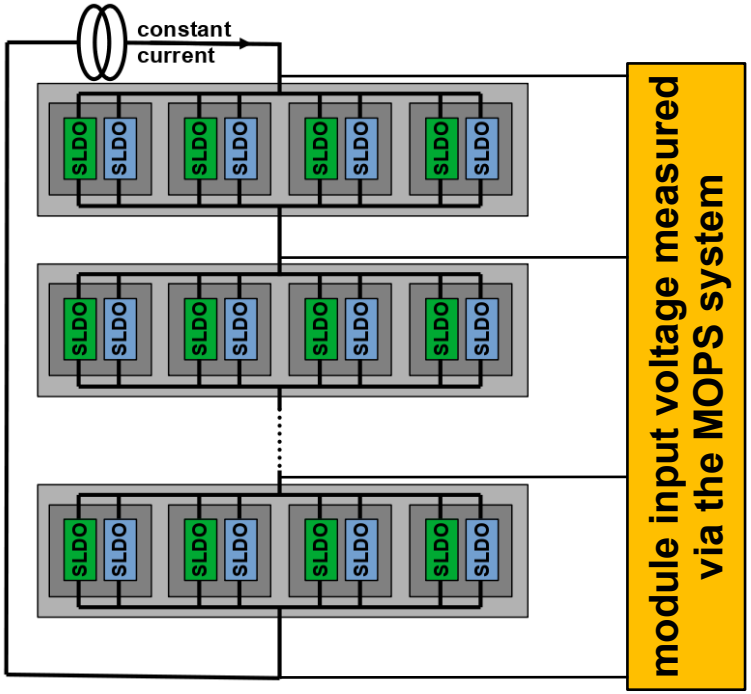


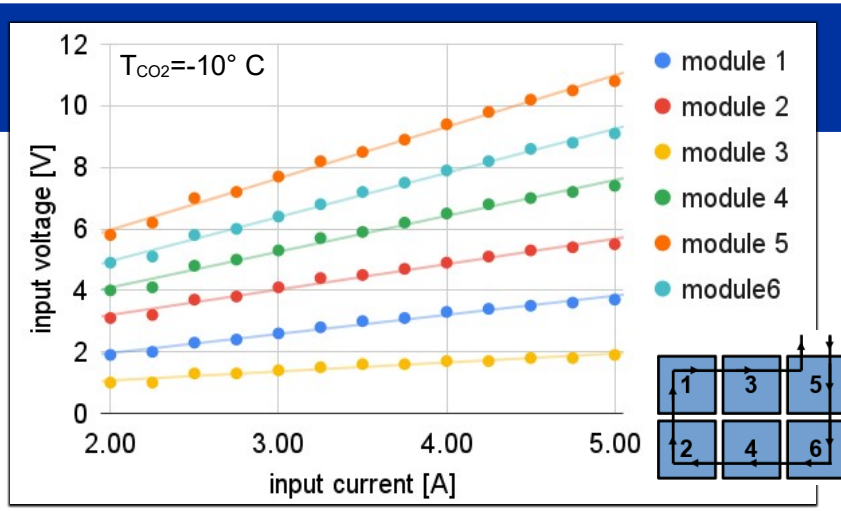
- Example shows noise and threshold, but similar results for distributions of dead pixels, ToT, disconnected bump bonds
- Very stable performance of all tested chips through integration steps
- → **No sign for any performance degradation during loading**

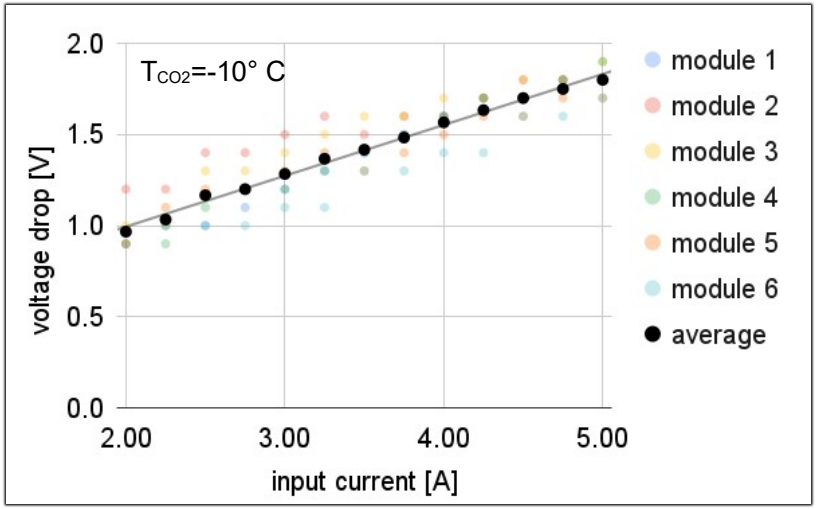
Serial Powering

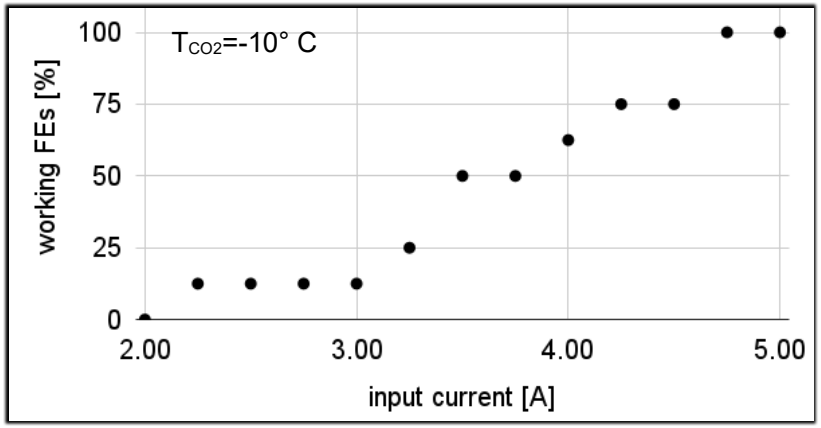
- Serial powering is one of the novel key features of the HL-LHC tracker upgrades
- SLDO in RD53A known to be non-perfect affecting linearity and cold start-up
- Advantage of independet MOPS system: monitoring even when readout link no longer established
- Ohmic behaviour of SP chain from outside maintained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



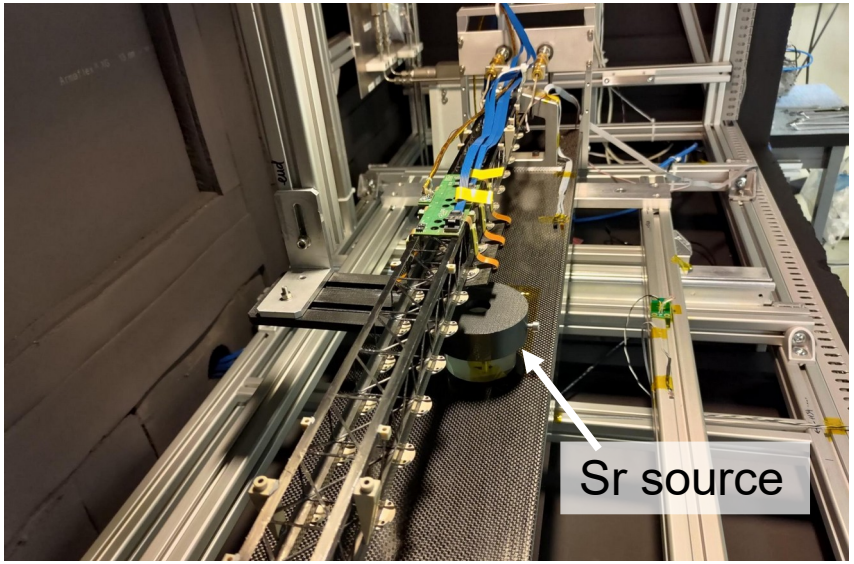


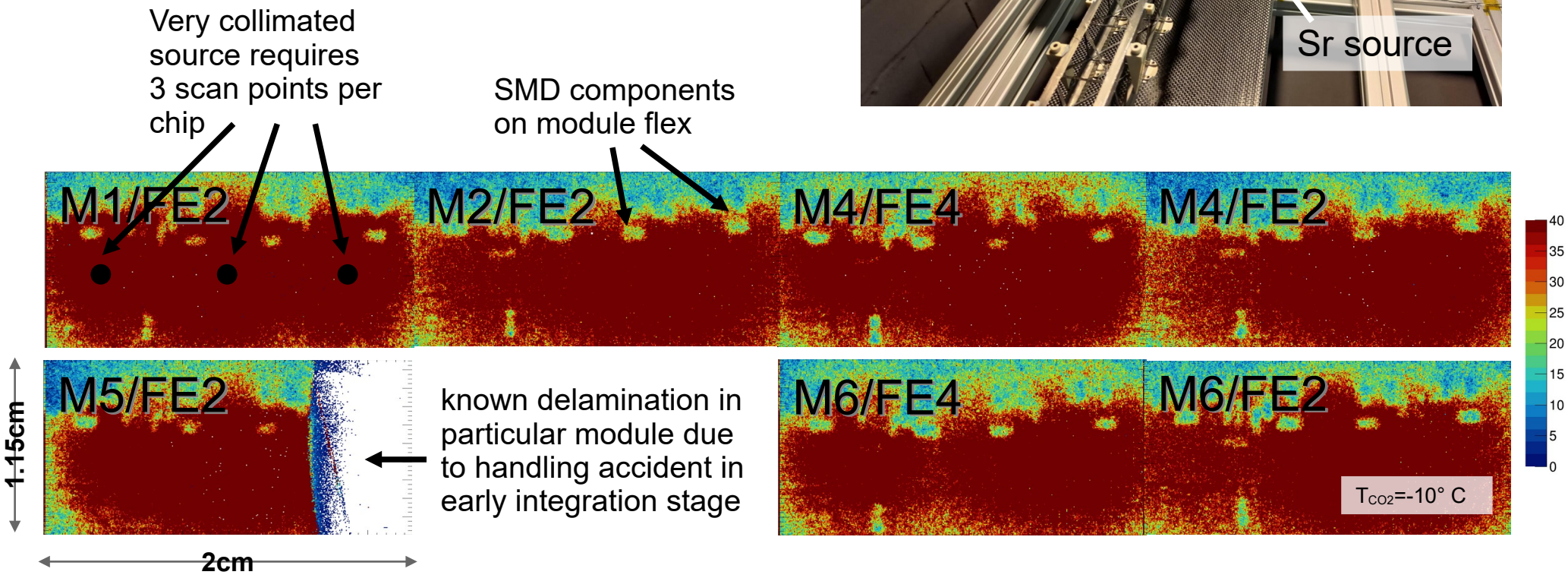




Scans with Radioactive Source

- 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





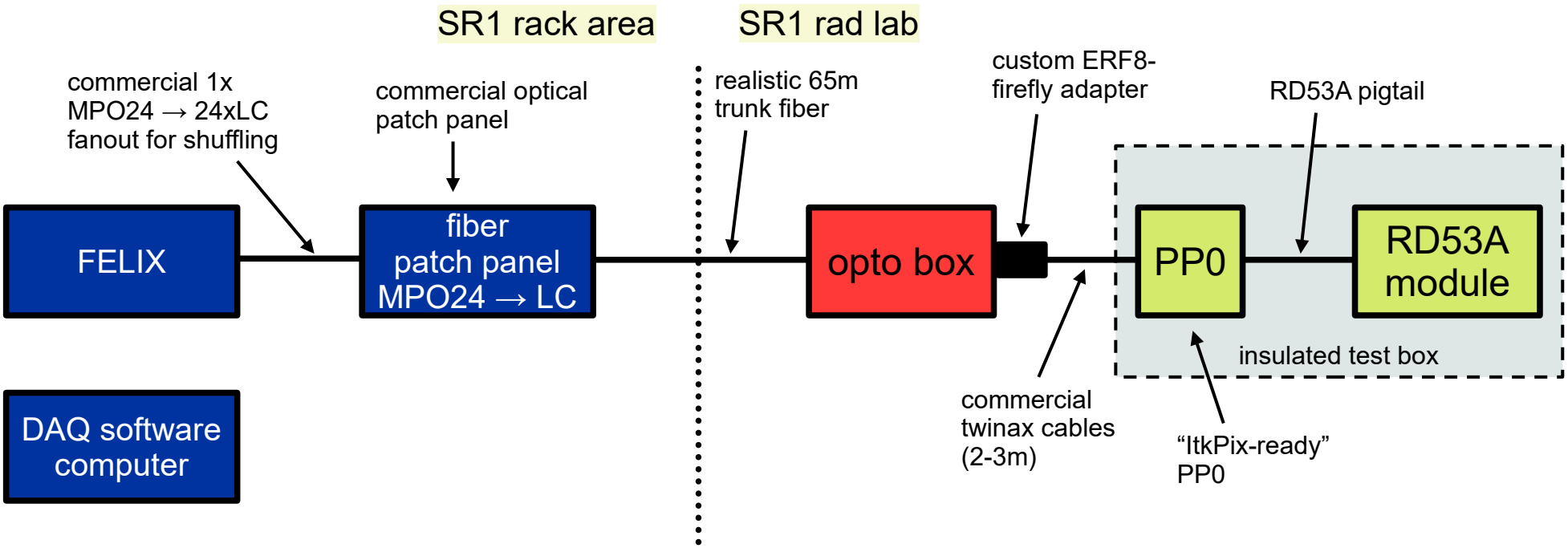
→ **No systematic delamination of bump bonds due to loading procedure visible**

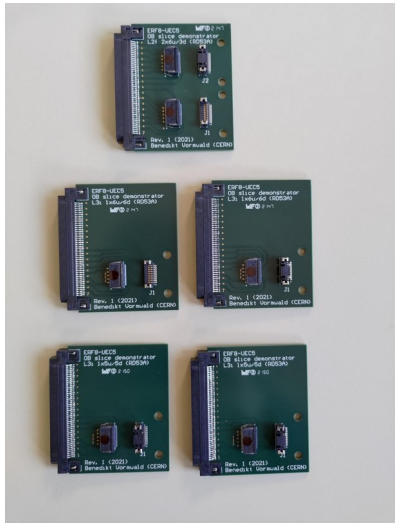
Conclusions

- 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

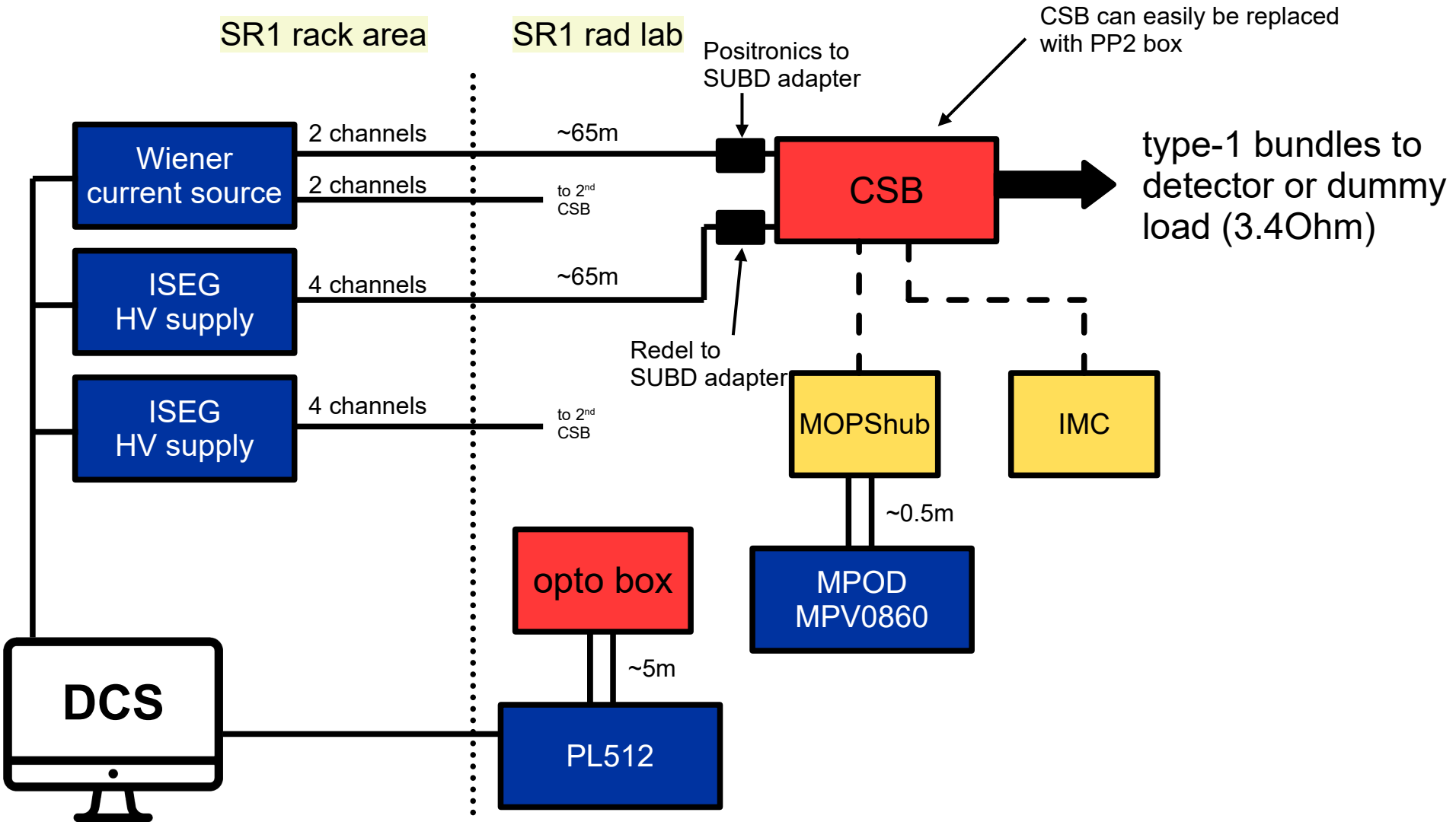
BACKUP

DAQ/Readout Chain





Cables, power supplies, off-detector chain



DAQ/Readout Chain