Stefano Zambito, CERN

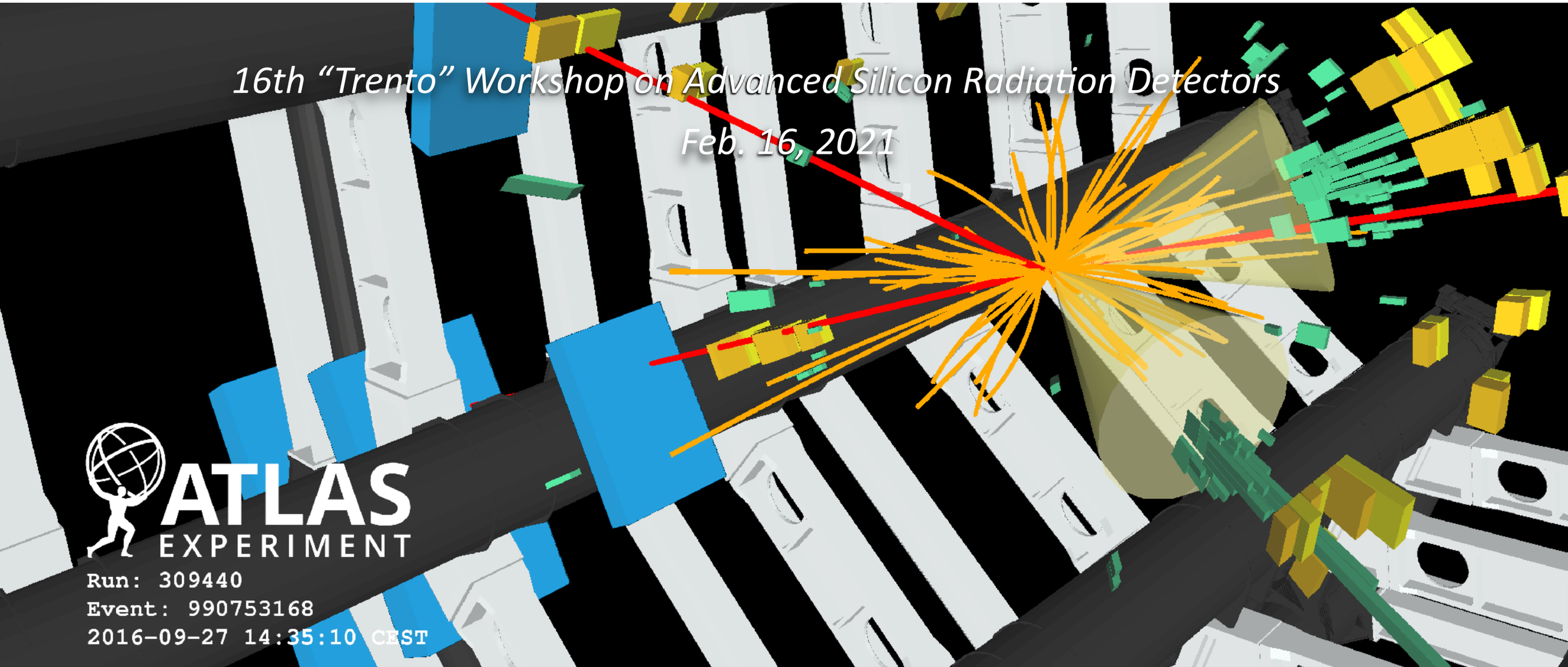
On behalf of the ATLAS-ITk Collaboration

ATLAS Inner Tracker Pixel Outer Barrel Demonstrator

System Tests with Serial Powering: Results

16th "Trento" Workshop on Advanced Silicon Radiation Detectors

Feb. 16, 2021

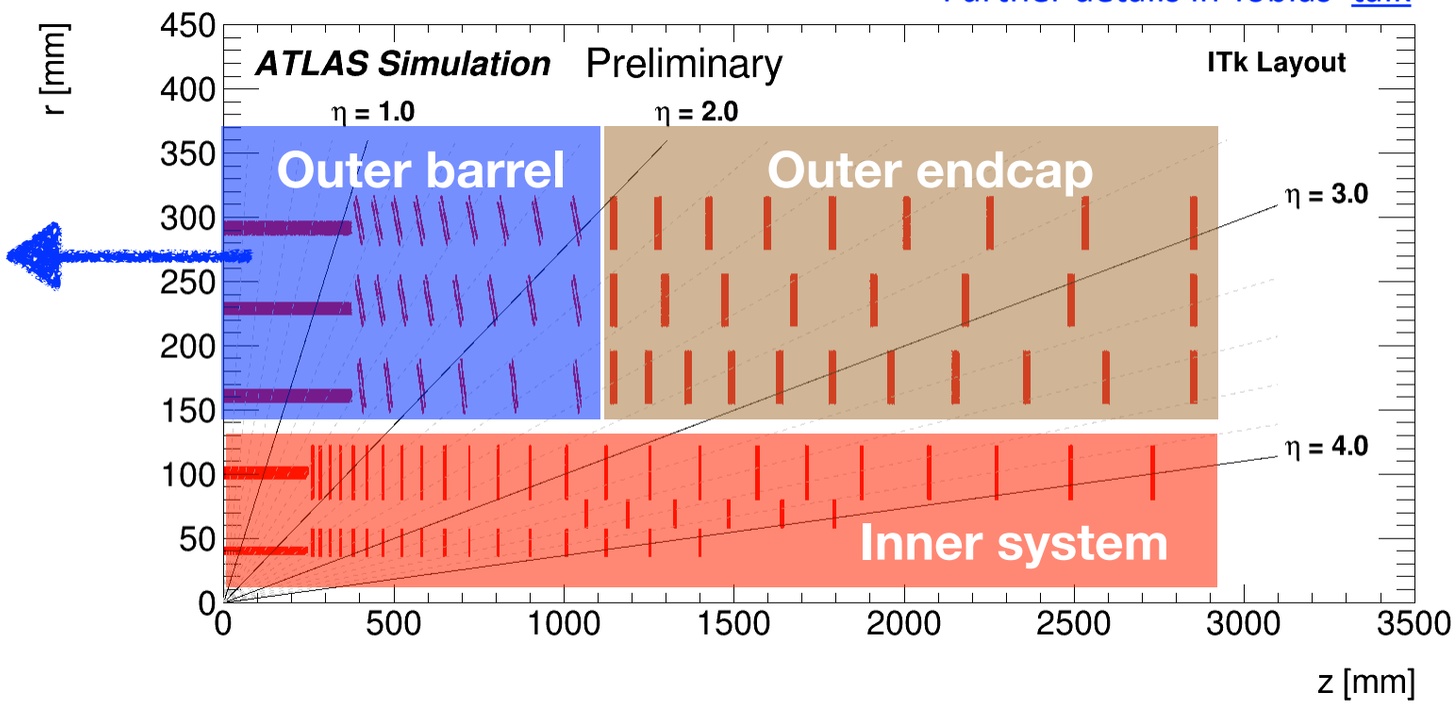


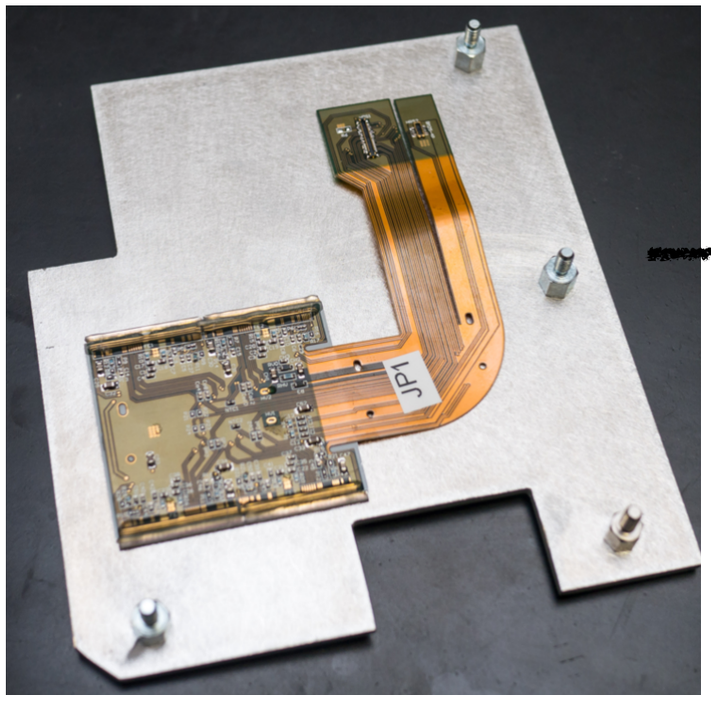
Outer Barrel Demonstrator: Introduction

In parallel to ITk Pixel sensors, crucial to study integration and system aspects

This talk focuses on outer barrel (OB): *demonstrator program* to validate key features of detector design

Further details in Tobias' talk





As RD53A chips weren't available yet, used sensors with *FE-I4 fronted chip* (= ATLAS IBL)

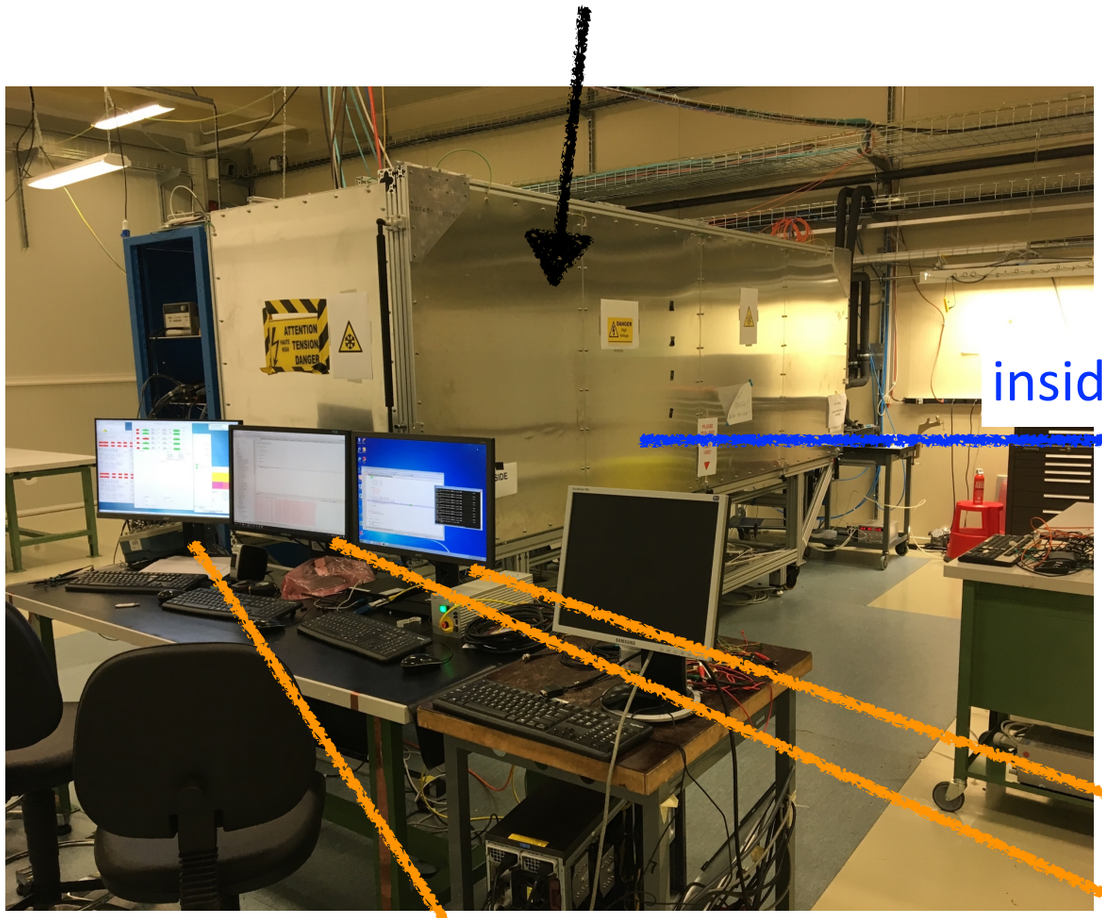
FE-I4 demonstrator: originally targeting 2017-2020 timeline with an ambitious program comprising *many* important tests

Outer Barrel Demonstrator: Box & Longeron

Study integration and system aspects: FE-I4 services, PSU, DCS, cables…

Infrastructure / services

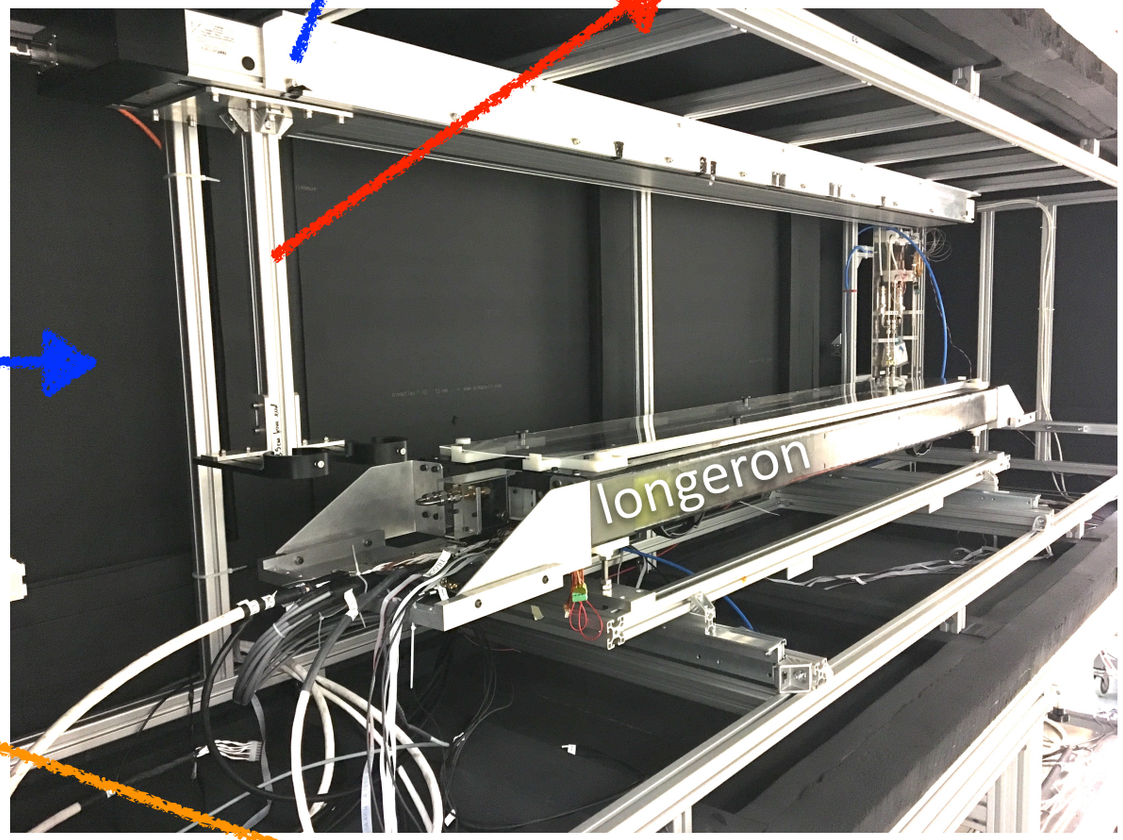
- Environment-controlled and monitored box



inside

motor stage for source scans

mobile arm holding sources



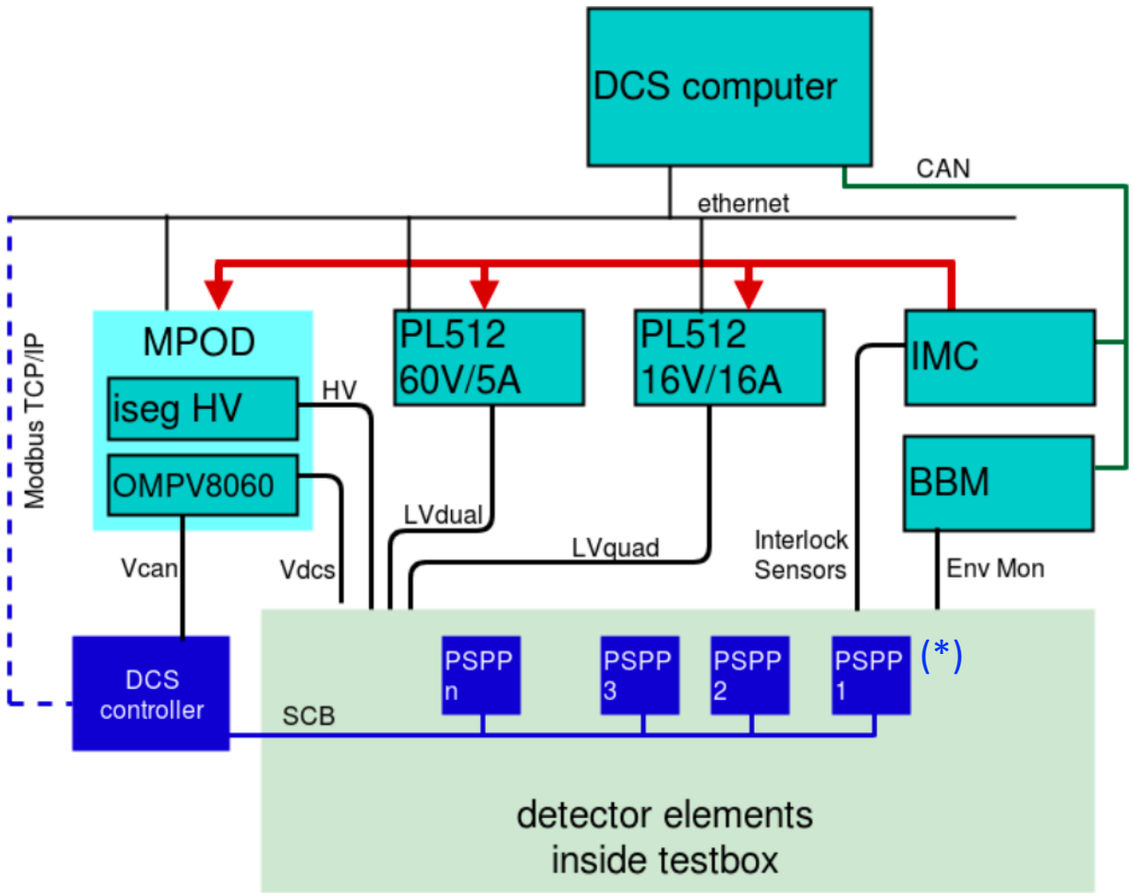
GUIs for detector control (DCS) and readout systems, CO_2 cooling, motor stage, etc…

Outer Barrel Demonstrator: Interlock & DCS

Study integration and system aspects: FE-I4 services, PSU, DCS, cables…

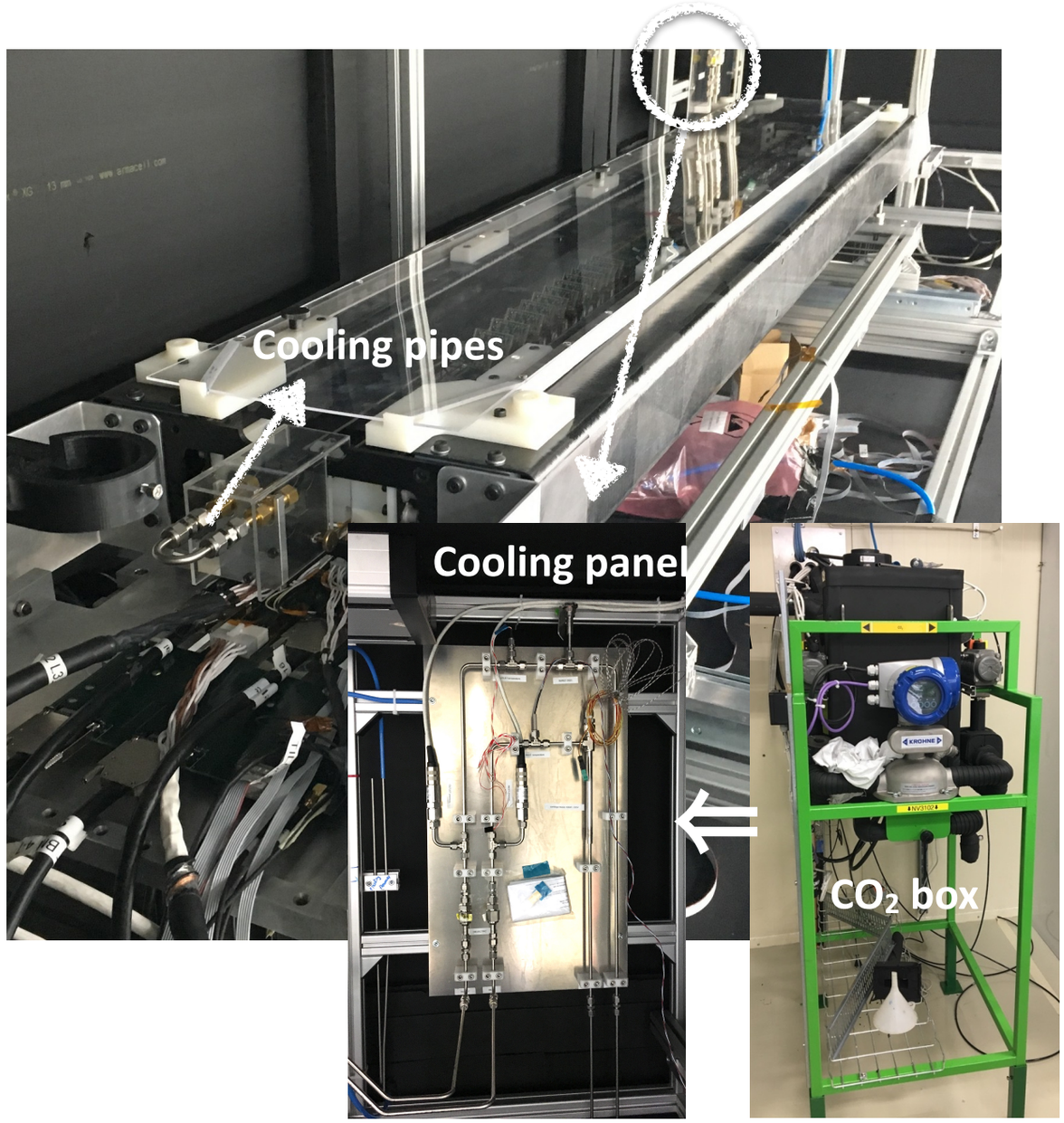
Infrastructure / services

- DCS and Interlock systems, connected to demonstrator via two ARTY FPGA controllers



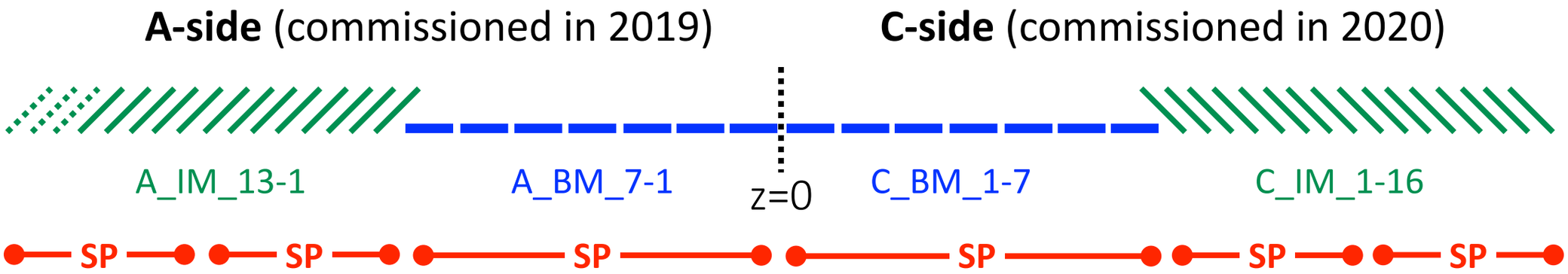
(*) Pixes Serial Powering Protection (PSPP) chip

Two-phase CO_2 cooling system



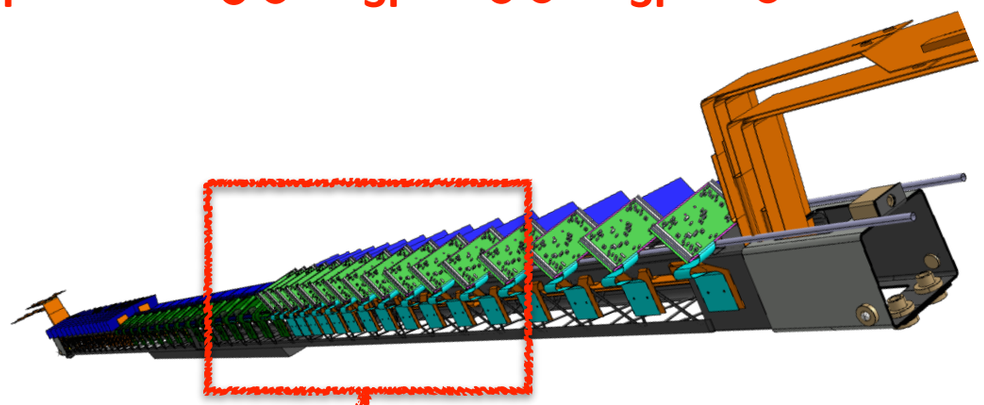
Outer Barrel Demonstrator: Modules

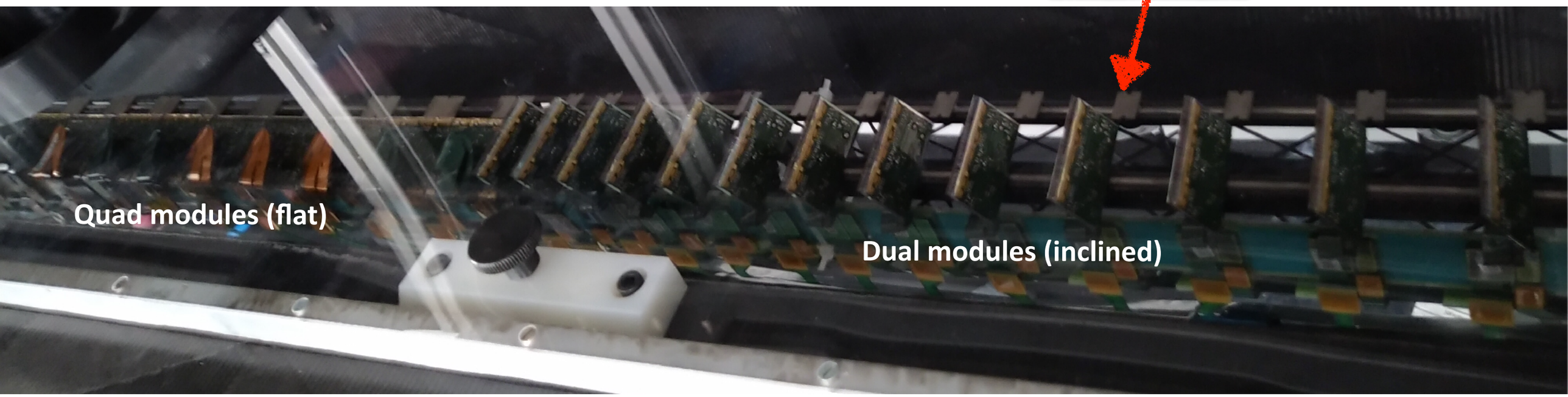
43 sensors = 114 FE-I4 frontends, 6 serial powering (SP) chains over 1.6m support



7(A)+7(C) flat quad (4 FEs / module) modules in the center

13(A)+16(C) inclined duals (2 FEs /module) toward high |z|





System Tests

Extensive program for FE-I4 demonstrator:

- ➙ Mechanical, thermal, powering and readout tests performed
- ➙ Exercised full production flow (with few components), including integration

System tests, *objectives*:

- ➙ Scrutinize many aspects of ITk “pixel system”: powering, cabling…
- ➙ Validate / amend / optimize the original design & production flows

Some highlights shown today:

- ➙ For 1st time operated 6 serial-powering (SP) chains on same local support
- ➙ Read out simultaneously and studied all modules via source scans
- ➙ Studied grounding and shielding under different failure scenarios

Noise Level, Before/After Integration

Module quality tested at each step of production flow (assembly → integration)

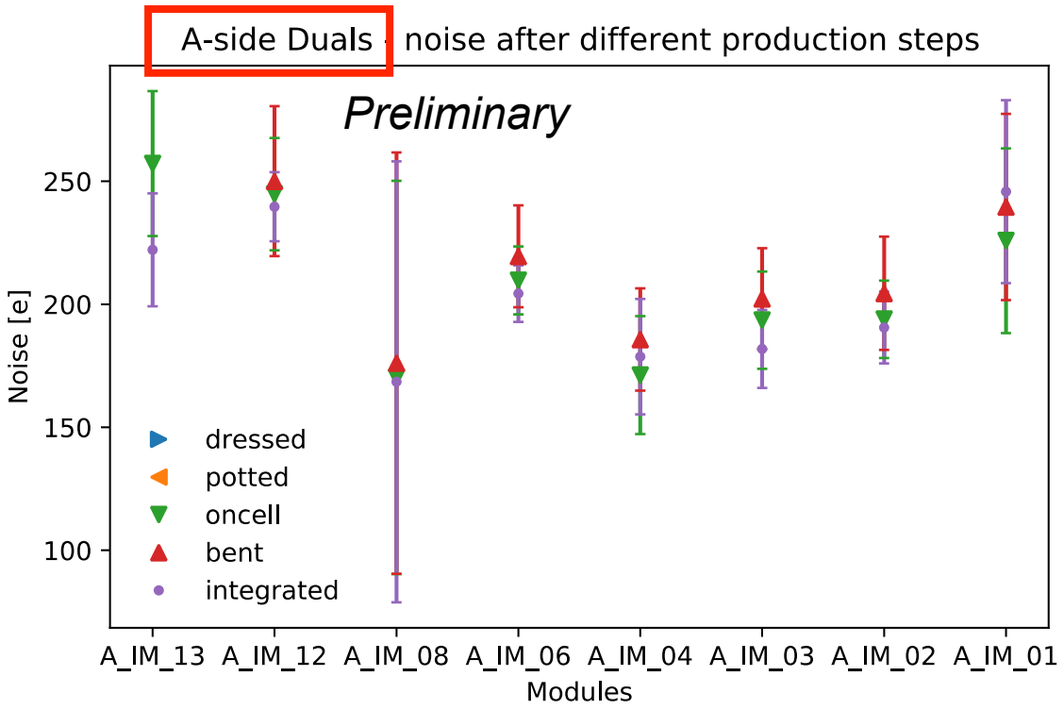
Dressed (▶) → bare module assembled with "pigtail" flex cables

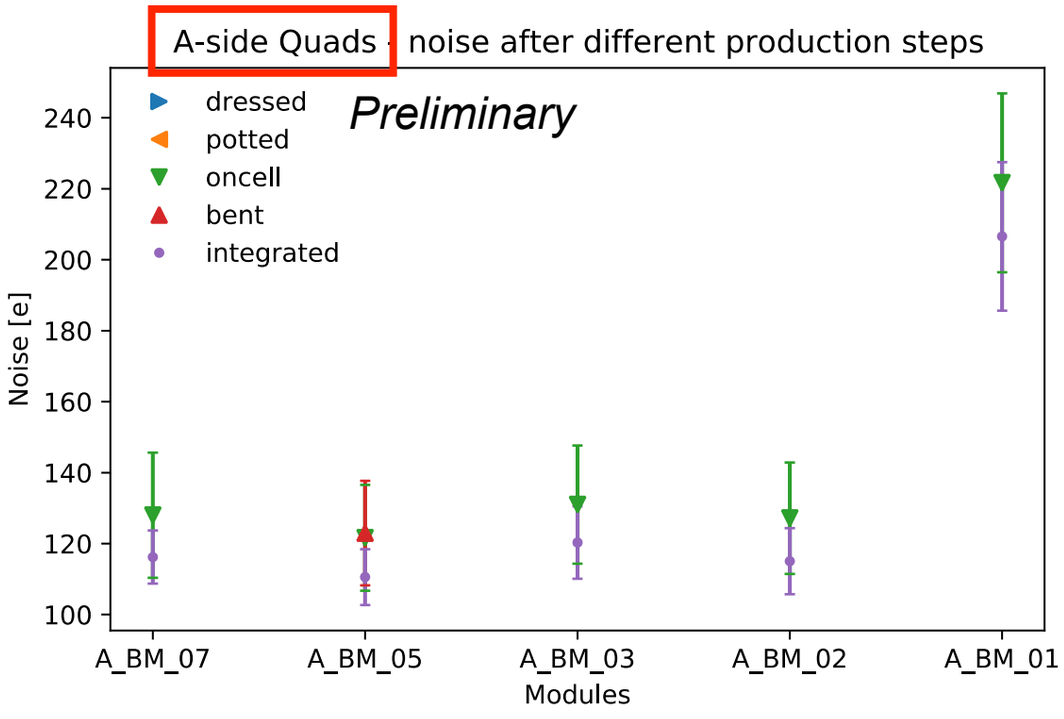
Potted (◀) → wire bonds encapsulation on dressed (i.e. with flexes) modules

On Cell (▼) → loaded on support structure needed for installation on longeron

Bent (▲) → flex cables of functional modules are bent, and modules re-tested

Thresholds at different prod. steps tuned to slightly different values; still, noise ≈compatible





Integrated Modules: Quality Evolution

After module QC

Stage 1 ➞ module loaded on support structure for installation on longeron

Stage 2 ➞ module fully integrated in longeron, and tested in system tests

All good ➞ "production-quality": holds HV, less than 1-2% disconnected bumps, …

OK ➞ can be used for tests, but not of production-quality (e.g. no HV)

	A-side Duals (13)		A-side Quads (7)		C-side Quads (7)		C-side Duals (16)	
	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
All good	8	7	7	6	7	5	13	11
Ok	4	3	-	-	-	-	3	-
Not all FEs	1	2	-	1	-	2	-	3
No communication	-	1	-	-	-	-	-	2

new issues with 1 module after integration

new issues with 1 module after integration ↓ *Single FEs*

new issues with 2 modules after integration ↓ *Single FEs*

new issues with 2 modules after integration

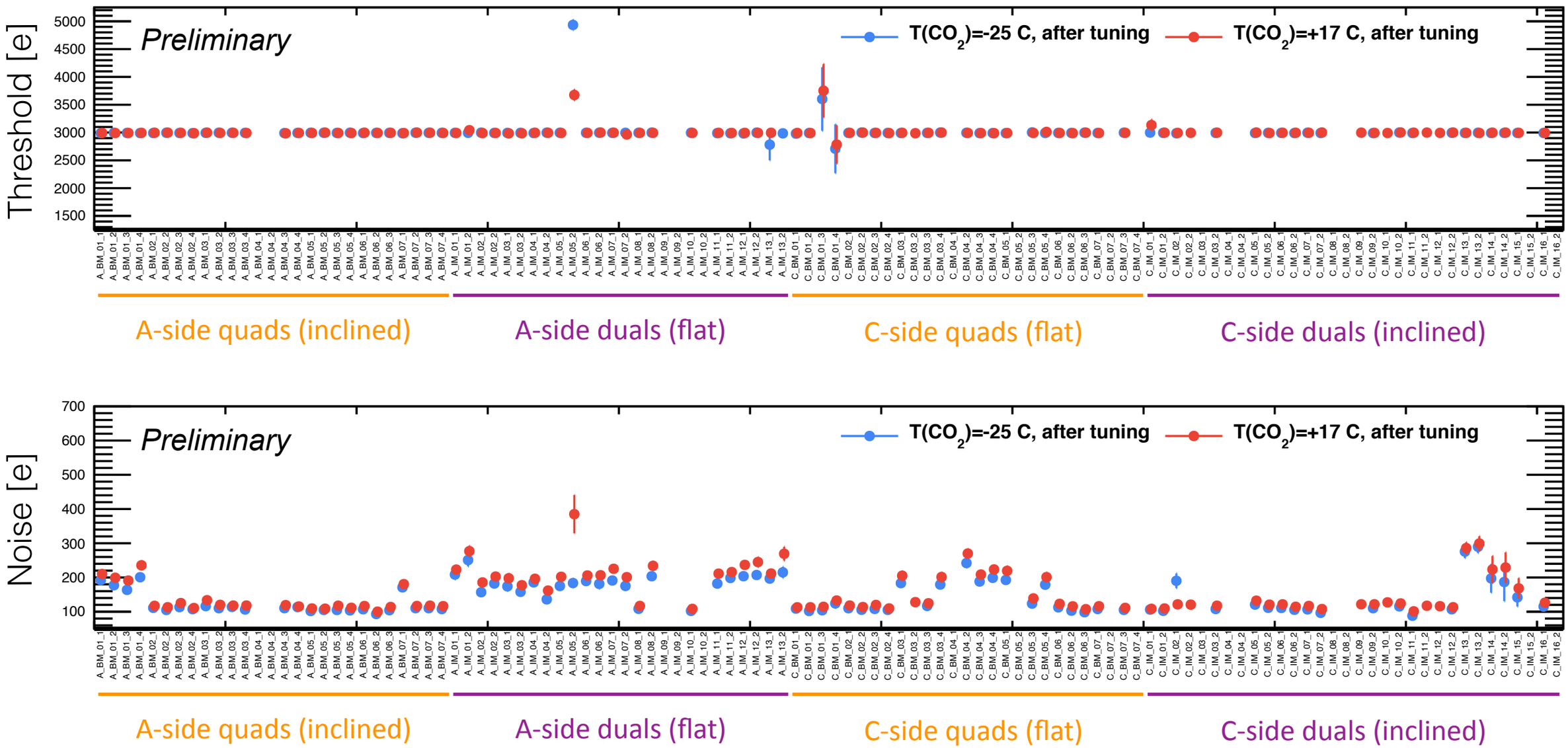
Scrutinized & understood: mostly communication issues, mostly related to cabling

Average Threshold & Noise After Module Tuning

For first time, simultaneous operation with 6 SP lines. Good performance overall

Only very few problematic / noisy front ends after tuning algorithm

Noise reduction at lower T(CO_2), as expected



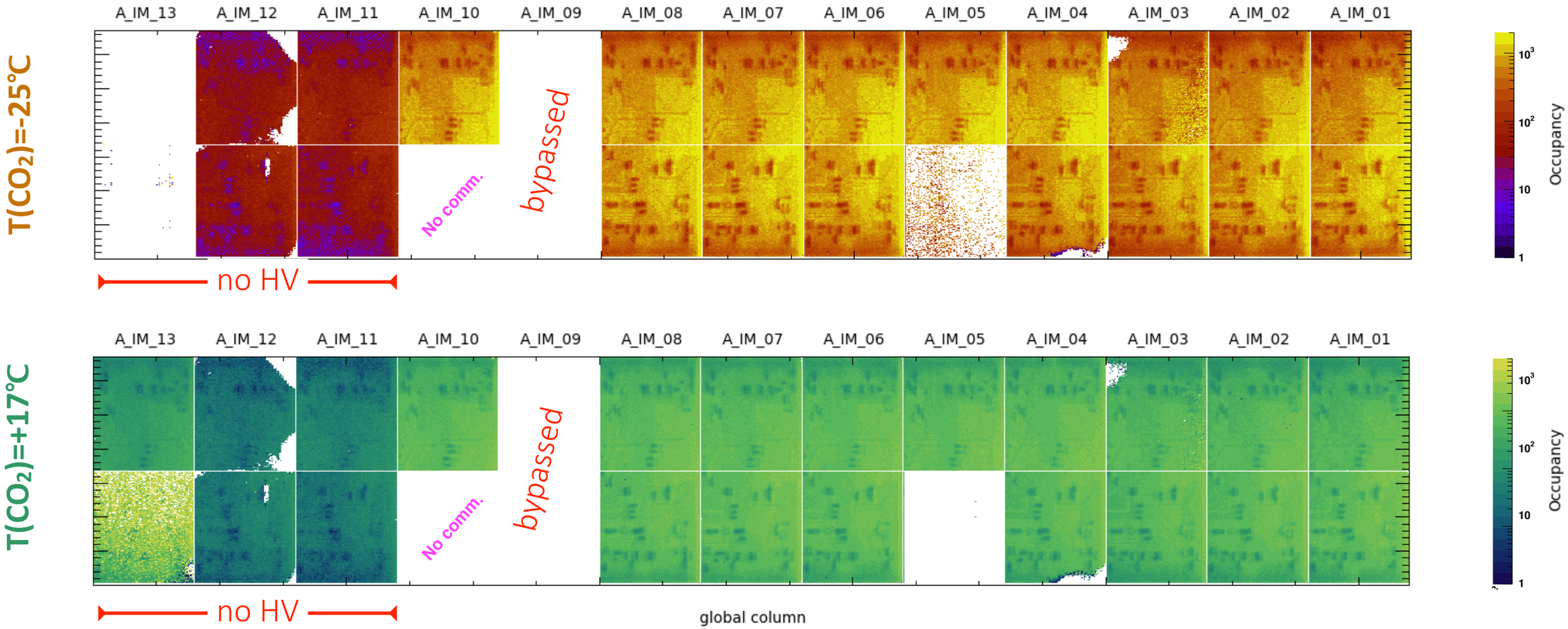
Source Scans, Example: A-Side Duals

Two Sr sources installed, scanning entire longeron for several hours

No communication
unable to readout FE

Working but excluded
working standalone, but excluded from readout

Bypassed
module bypassed in SP chain



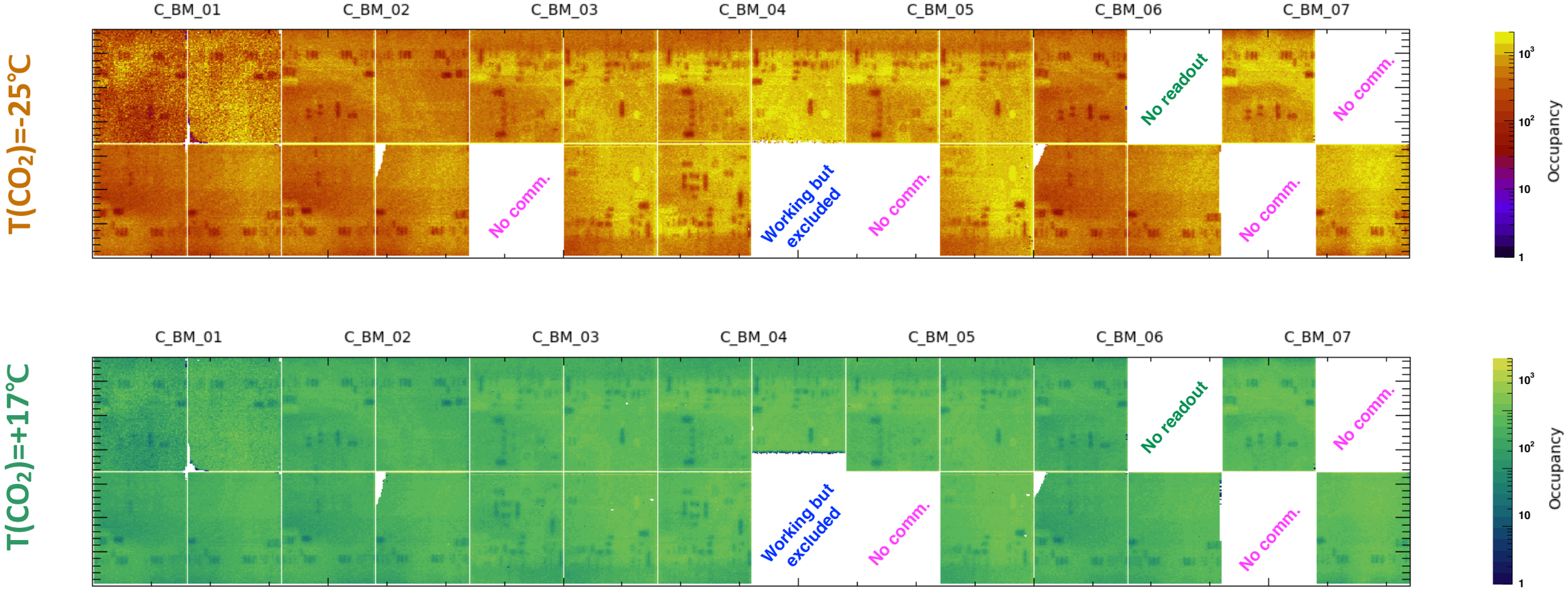
Source Scans, Example: C-Side Quads

Two Sr sources installed, scanning entire longeron for several hours

No communication
unable to readout FE

Working but excluded
working standalone, but excluded from readout

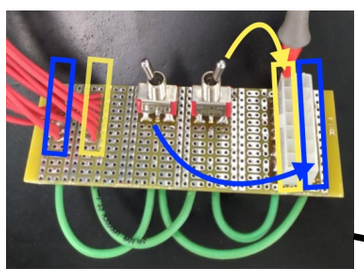
Bypassed
module bypassed in SP chain

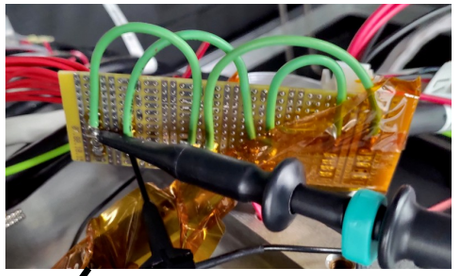


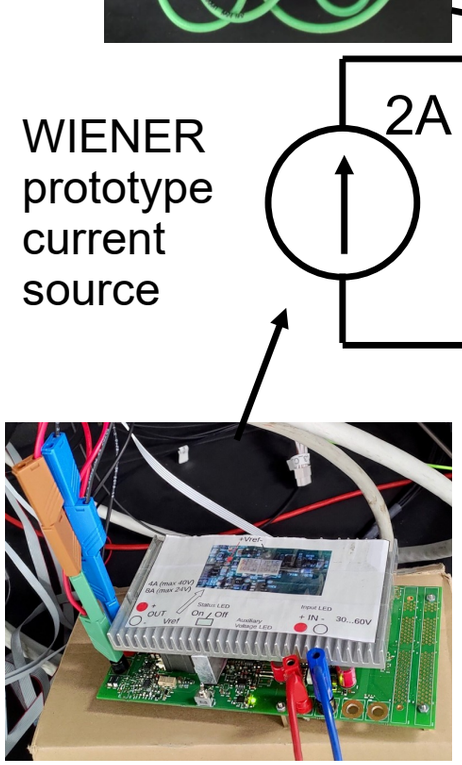
Grounding & Shielding Tests

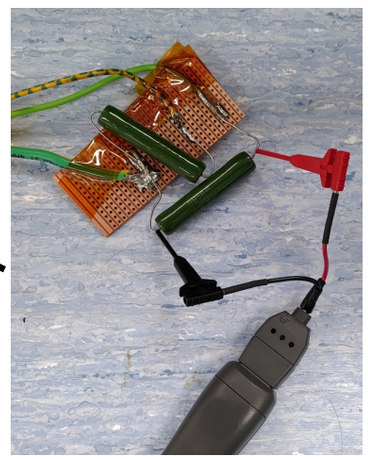
Test goal: *check different failure scenarios, measure current ground line may need to carry*

G&S principle for OB demonstrator: local supports and piping connected; services and modules disconnected from local supports, but connected to each other and using common LV and HV ground reference









Mimic foreseen detector's ground connection to reference potential

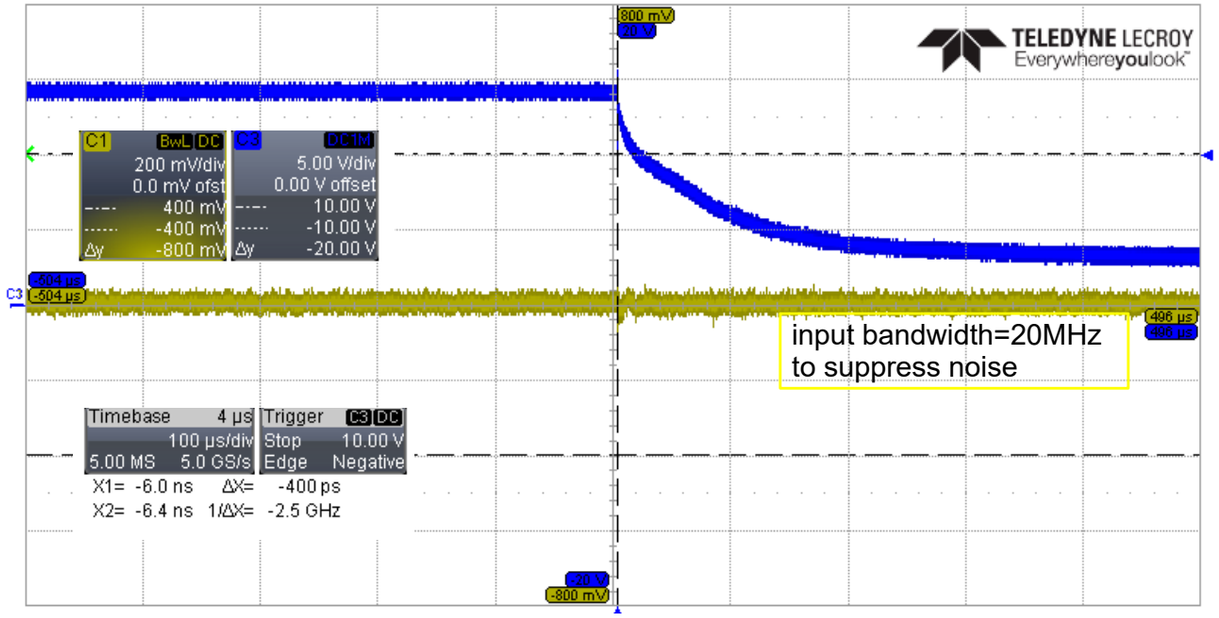
Grounding & Shielding Tests

Fundamental-level tests of not-obvious interplay between our SP and grounding systems

Removed all other ground connections: unplugged HV, standard LV, and data cables

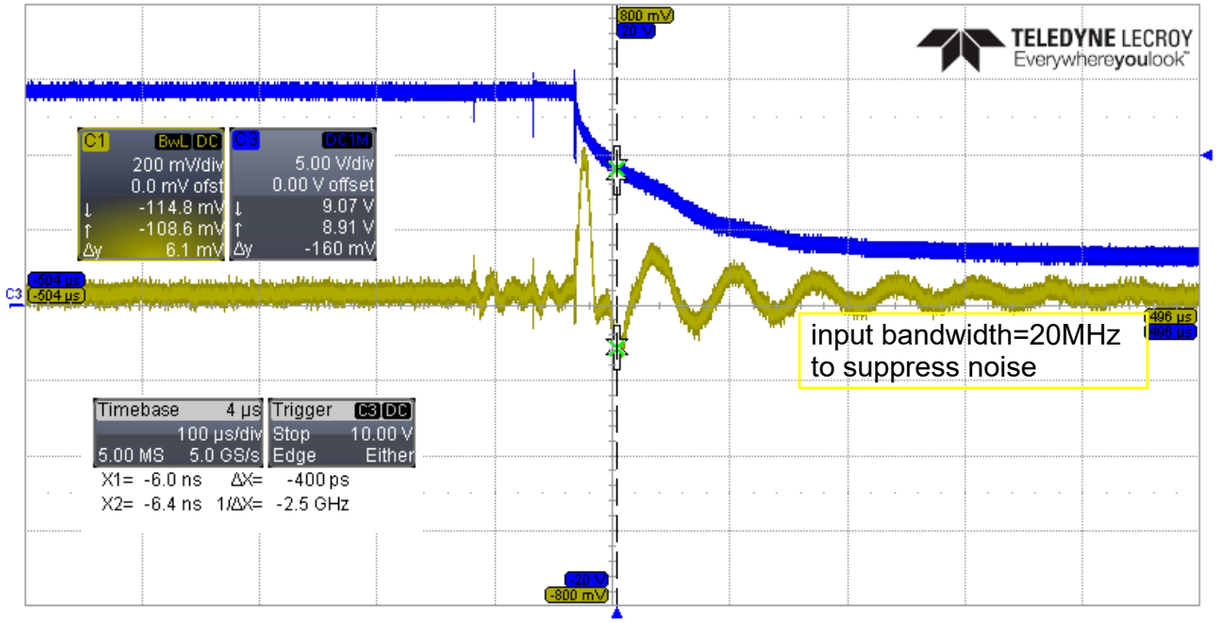
Switching on/off current source and cutting input line

no activity on ground line



Cutting return line: observe current on ground line (≈222 mA)

current spike:	U=400mV over R=1.8Ω → I=222mA
length of current peak:	t=20µs
oscillation frequency afterwards:	T=66µs → f=15kHz



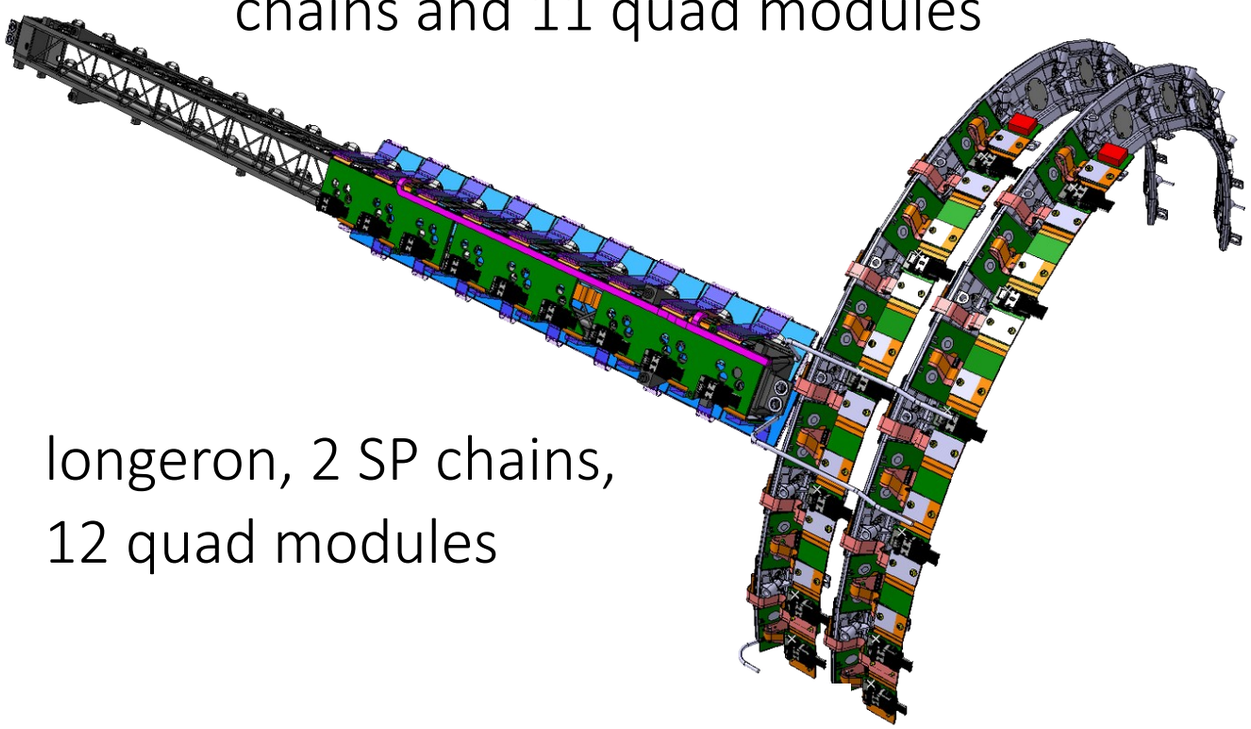
Measured current gives hint on needed dimensions of connection to reference potential

Next Generation Demonstrator With RD53A

Work on next generation demonstrator -with RD53A chips- already ongoing

Feb 2021	*Apr 2021*	*Aug 2021*	*Fall 2021*
old demonstrator to new location	decommissioning old demonstrator	commissioning new demonstrator	upgrade to full service chain

at least one half ring with 2 SP chains and 11 quad modules



longeron, 2 SP chains, 12 quad modules

RD53A: 150 µm FE, 150 µm sensor

All subsystems will be updated:

Getting much closer to actual detector design in all aspects: frontend chip, on-detector services, power supplies, cables, etc…

OB loading concept:

easily inserted/removed modules;

also preparing for **ItkPixVx** modules

Summary & Conclusions

- ✓ ATLAS ITk Pixel OB demonstrator: coordinated effort of many institutes
- ✓ Steady progress in spite of challenging working conditions due to COVID-19
- ✓ Extensive tests of full production / integration / commissioning chains
- ✓ Successfully operated six SP chains on single local support
- ✓ Tests with current demonstrator will continue till ≈April
- ✓ Work on next demonstrator with RD53A chip already ramped up: new round of system tests foreseen in the Fall

Spares

Noise Level, Before/After Integration

Module quality tested at each step of production flow (assembly → integration)

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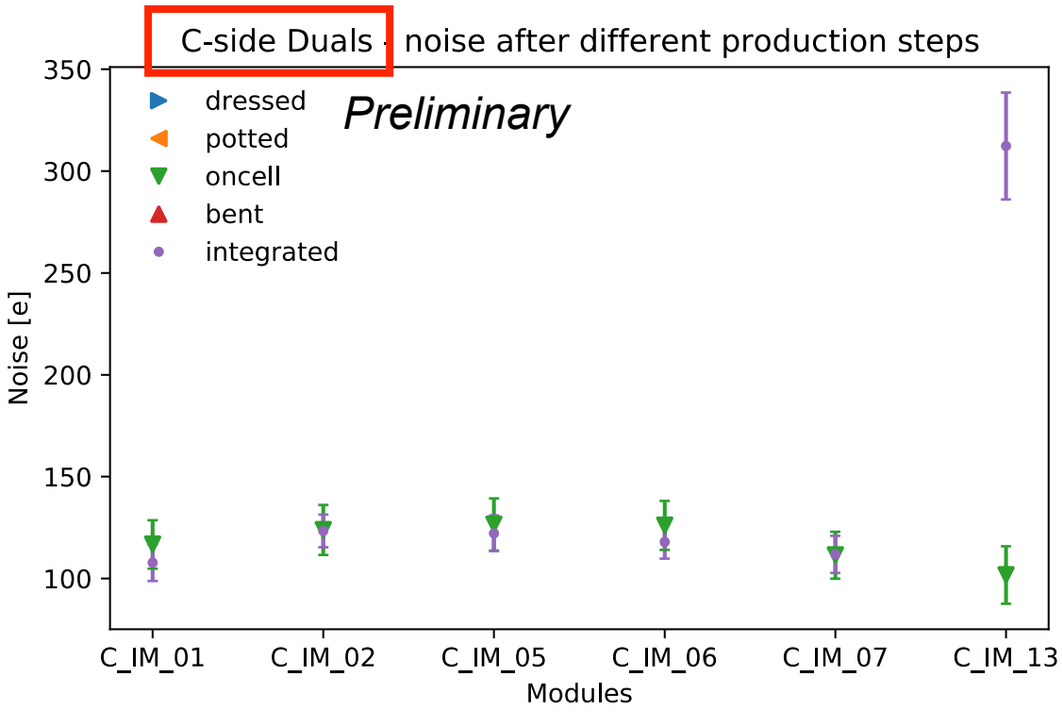
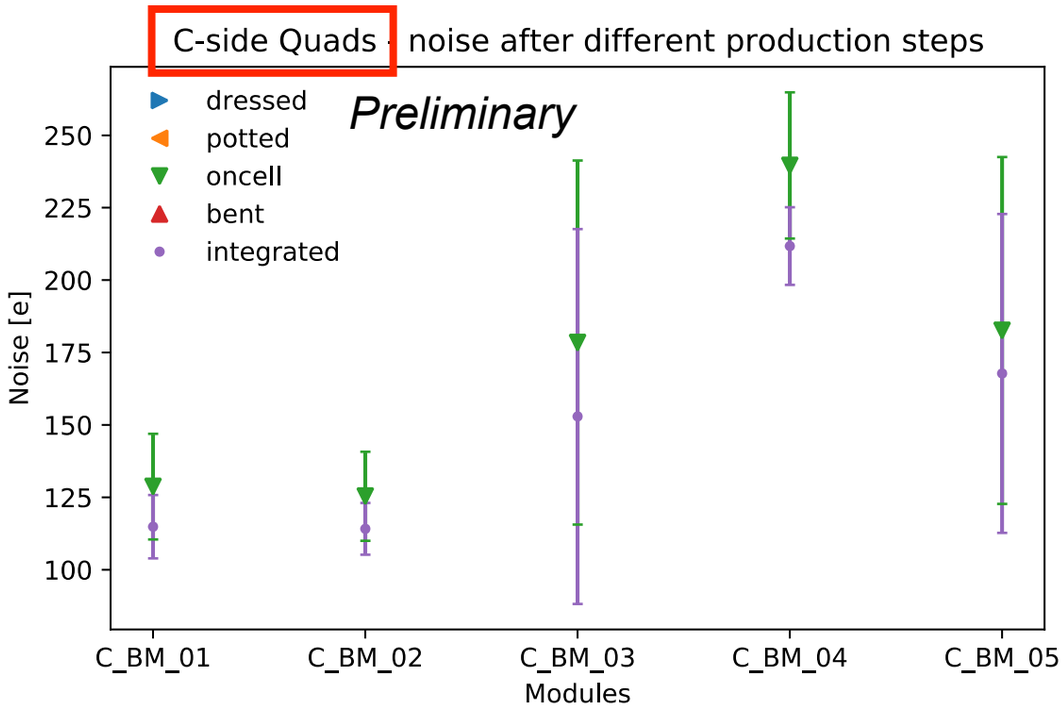
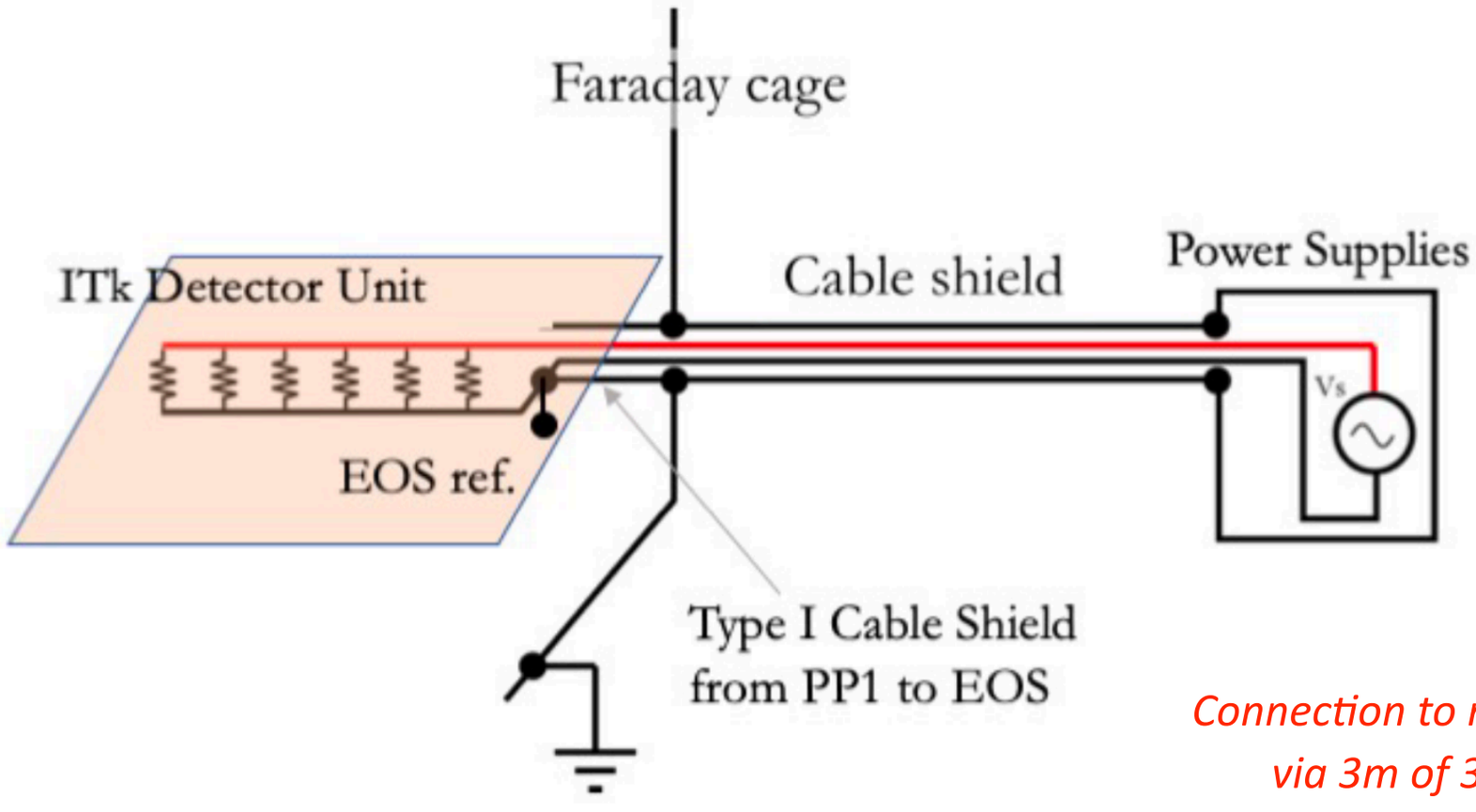




ITK Grounding & Shielding

G&S principle for FEi4 OB demonstrator: local supports and piping connected; services and modules disconnected from local supports, but connected to each other and using common LV and HV ground reference



Connection to reference potential via 3m of 32 gauge cable

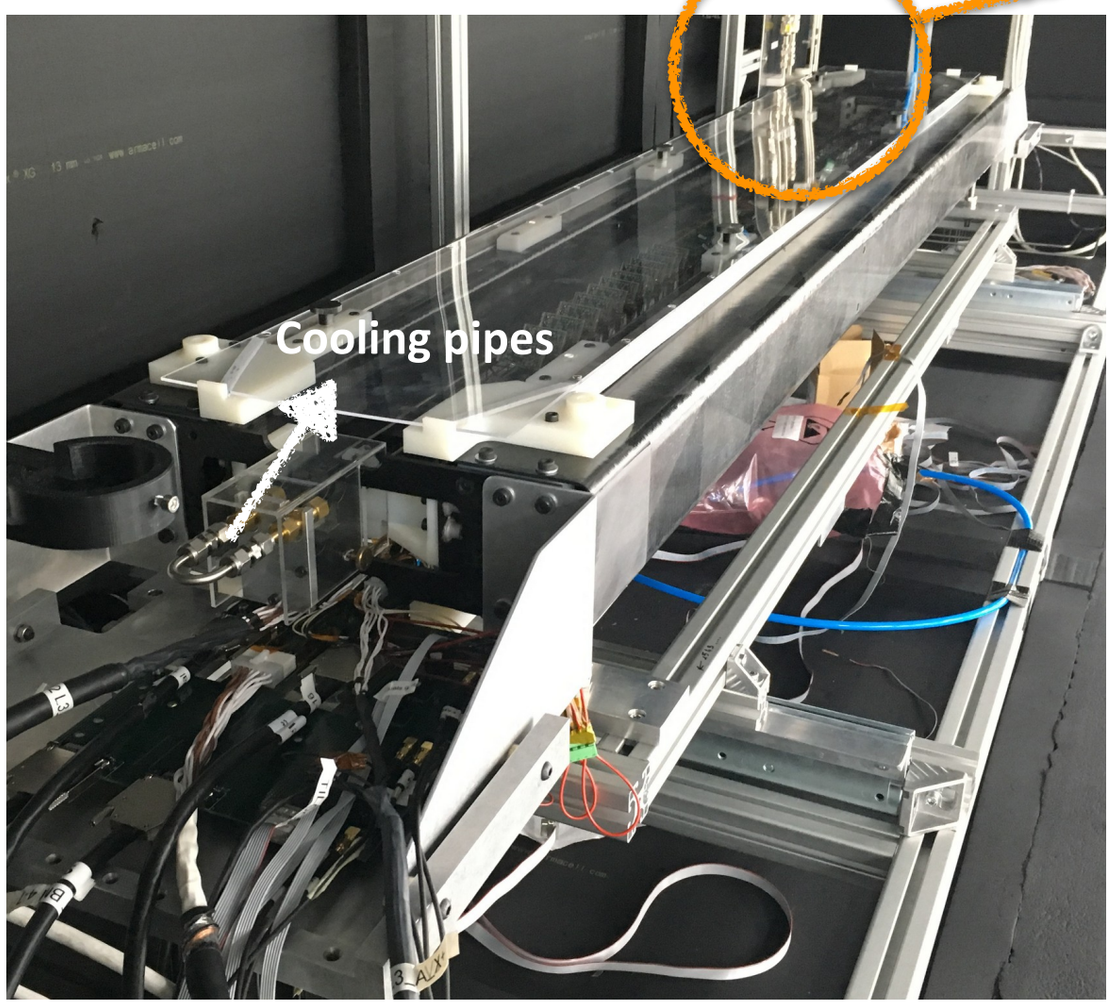
FIGURE 16. STRATEGY FOLLOWED TO REFERENCE THE END OF STAVE BACK TO THE FARADAY CAGE THROUGH THE CABLE SHIELDS

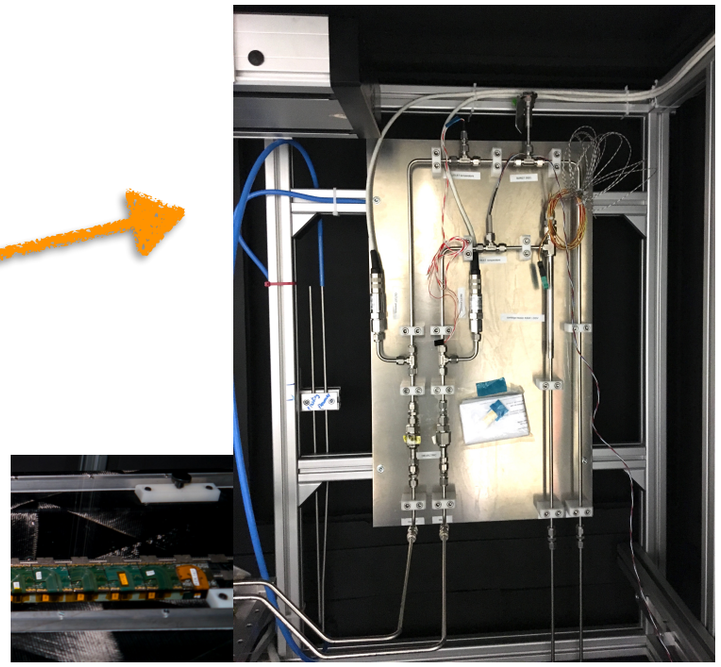
Outer Barrel Demonstrator: Cooling System

Study integration and system aspects: FEi4 services, PSU, DCS, cables…

Infrastructure / services

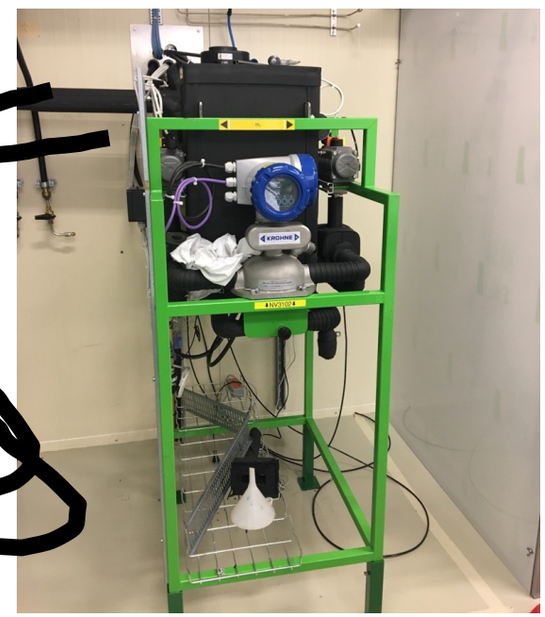
- Two-phase CO_2 cooling system



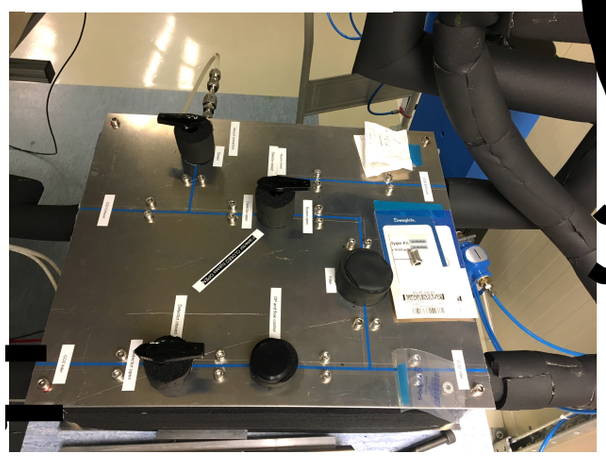


Internal patch panel

CO_2 local box



External patch panel

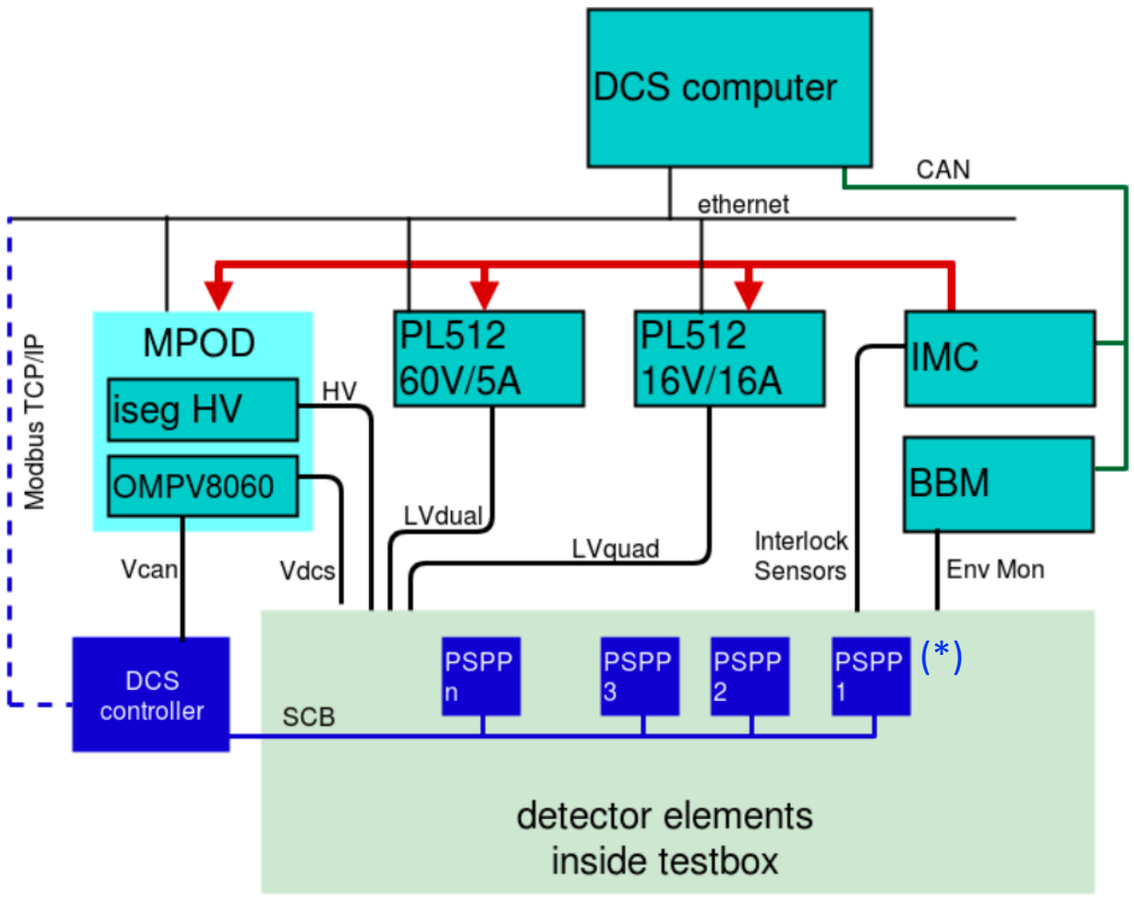


Outer Barrel Demonstrator: Interlock & DCS

Study integration and system aspects: FEi4 services, PSU, DCS, cables…

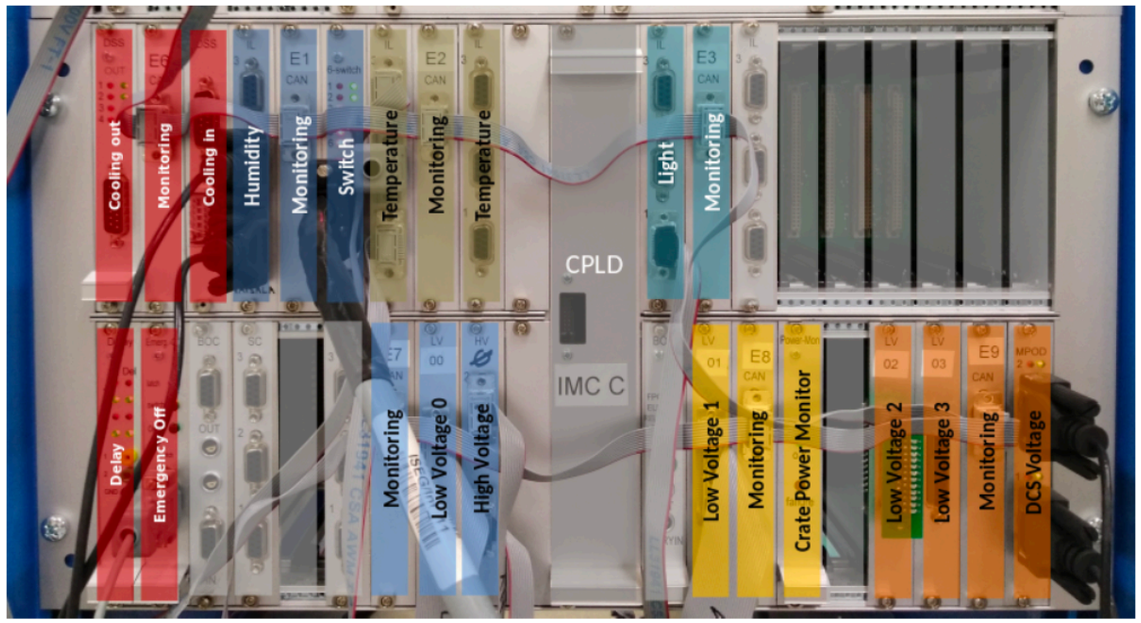
Infrastructure / services

- Interlock and DCS systems, connected to demonstrator via two ARTY FPGA controllers

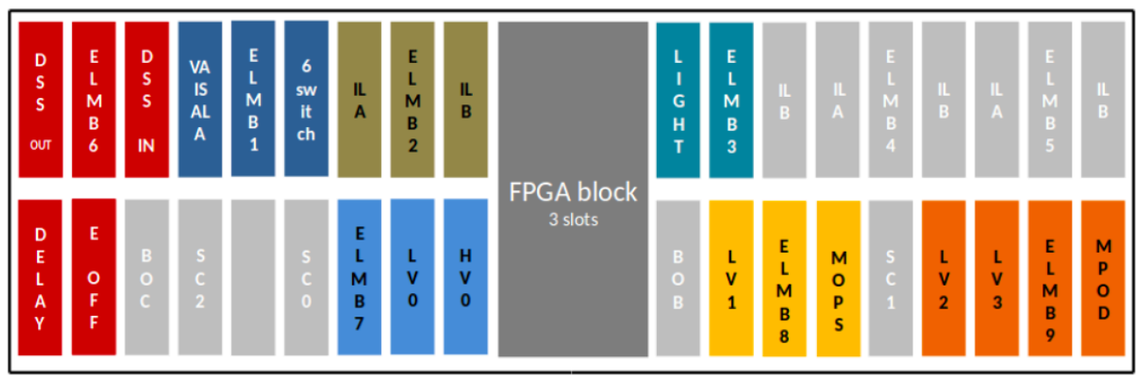


(*) Pixes Serial Powering Protection (PSPP) chip

Same interlock matrix (IMC) as ATLAS IBL: it monitors sensors and protects from possible system failures



The IMC is a modular crate which has different slots filled like in the graphic below.



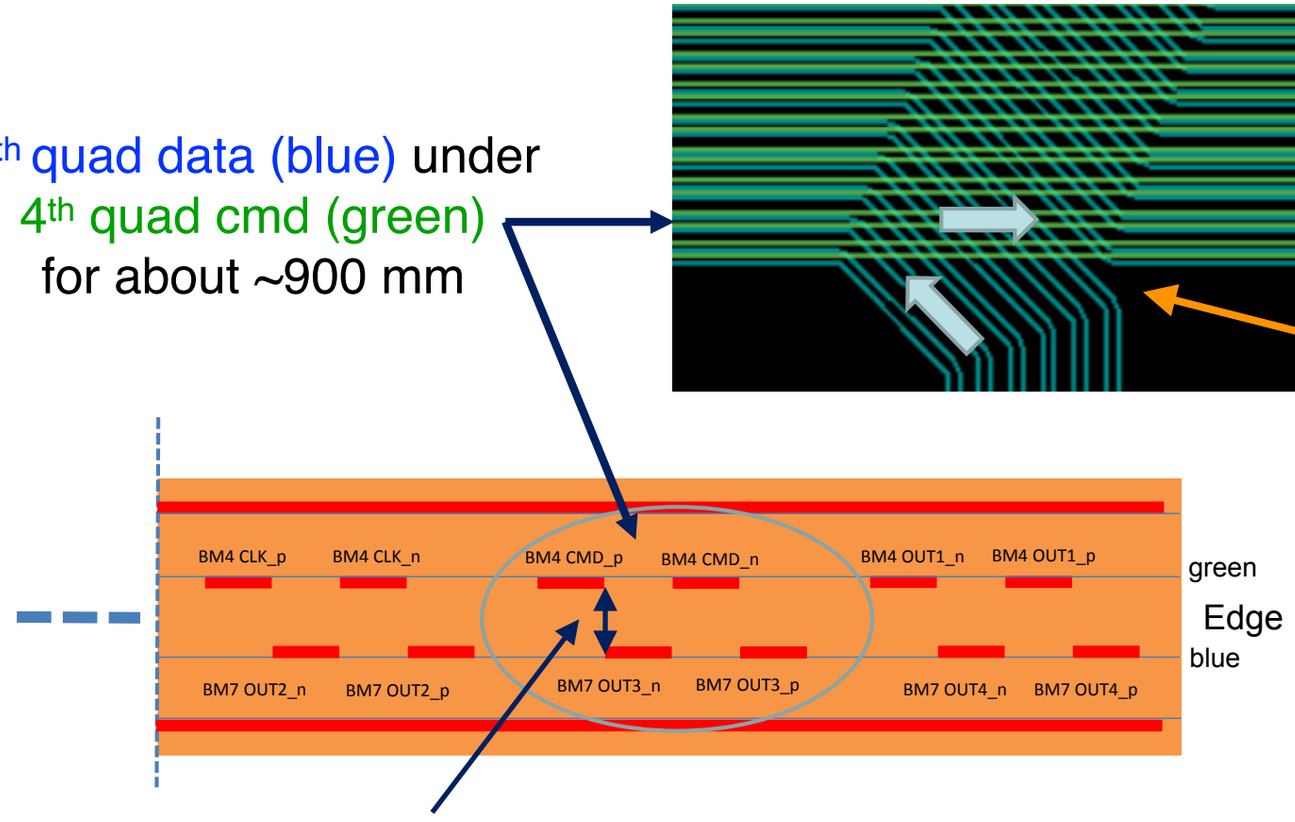
Lesson Learned

Observed cross-talk (e.g. 4th-7th quads) led to review of design of data flex cables

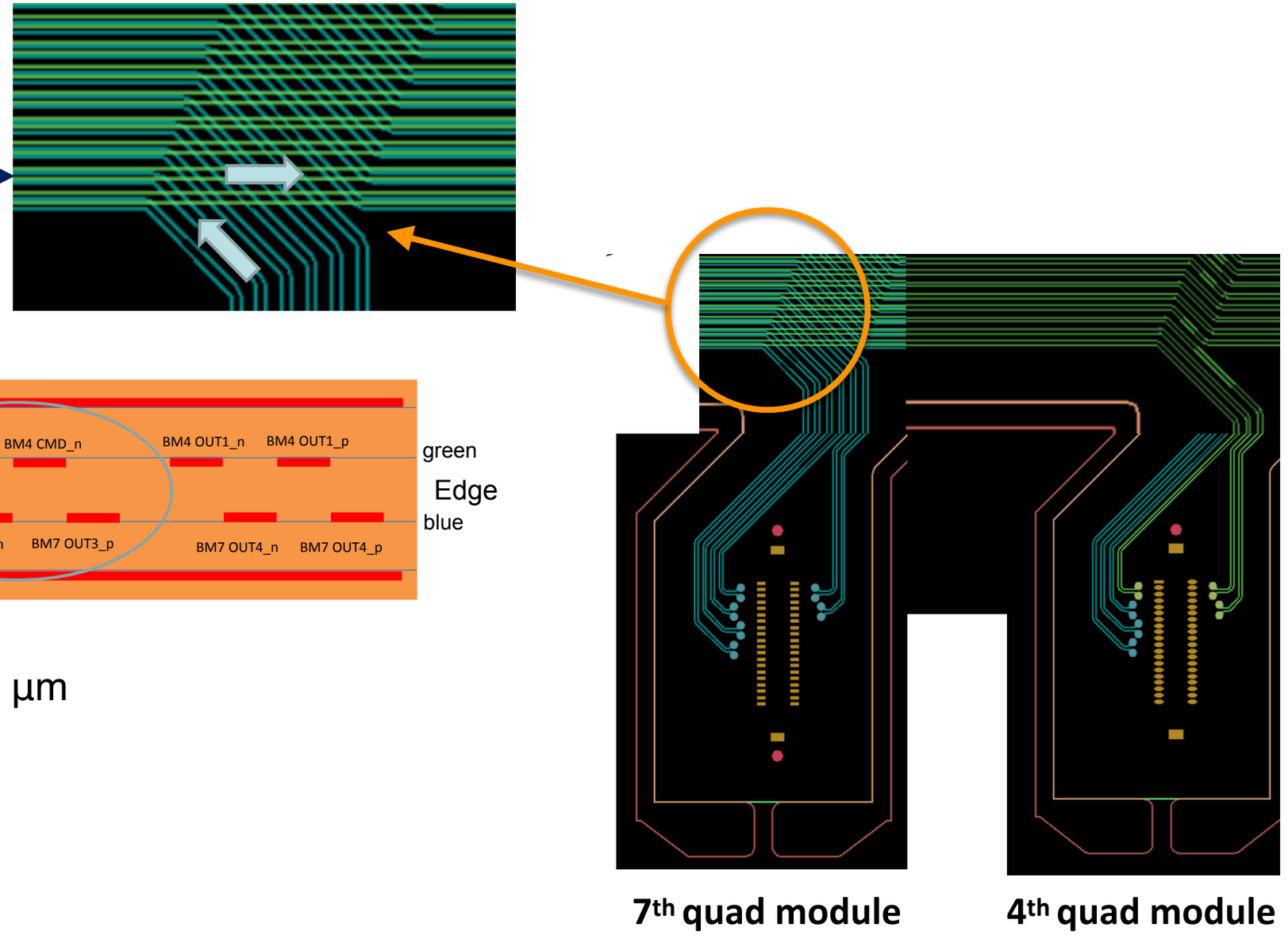
In demonstrator's setup, long PCB needed to rout out signal, but limited room

For ITk: reduced length (x10) and increased spacing will prevent similar issues

7th quad data (blue) under
4th quad cmd (green)
for about ~900 mm



Separated by only 200 µm



7th quad module **4th quad module**

Source Scans, A-Side Quads

Two Sr sources installed, scanning entire longeron for several hours

No communication
unable to readout FE

Working but excluded
working standalone, but excluded from readout

Bypassed
module bypassed in SP chain