Module and ladder characterization and burn-in tests of the STS for the CBM experiment

FAIRNESS 2024

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for the CBM Collaboration

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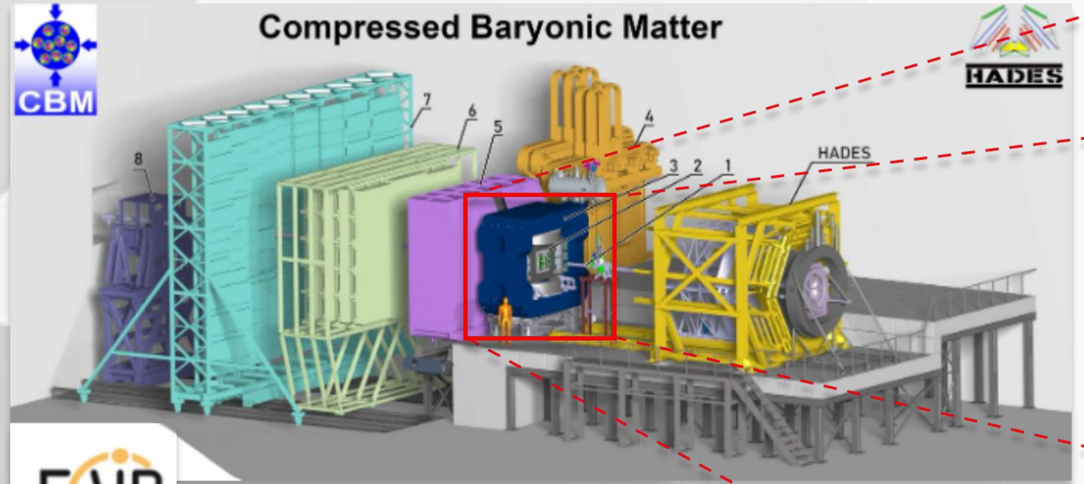
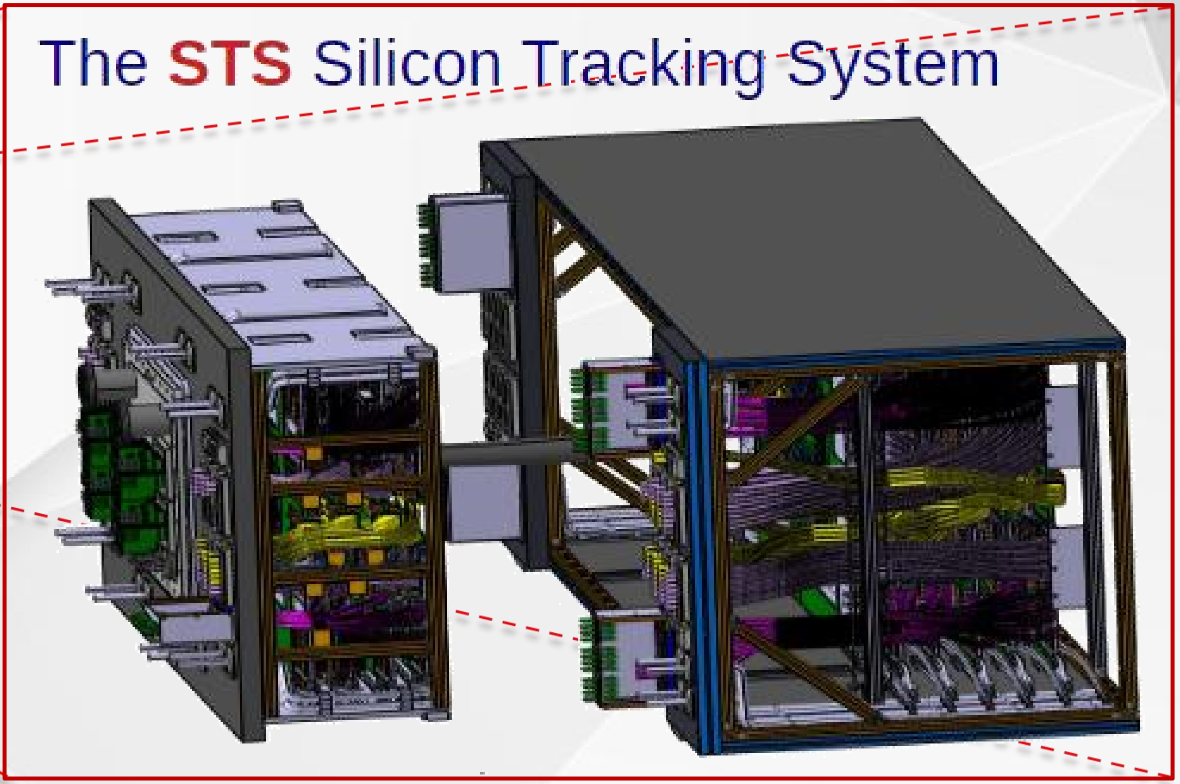
September 26th , 2024

The CBM experiment - STS

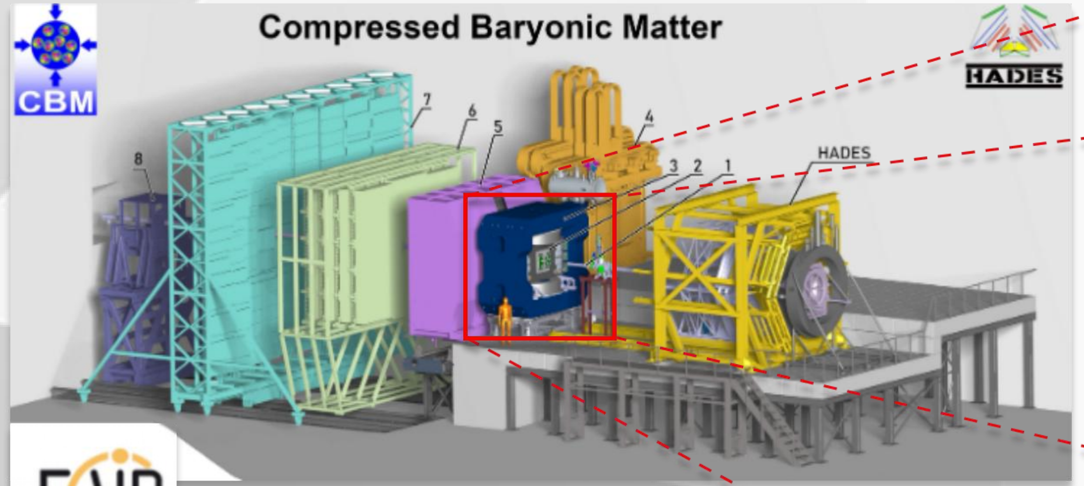




The **CBM** experiment intends to explore the QCD phase diagram in the region of high baryon densities using high-energy nucleus-nucleus collisions.

- The measurements will be performed at beam-target interaction rates up to 10 MHz.
- Maintaining material budget within 2 – 8% X_0.
- High granularity, spatial, and timing precision.

The CBM experiment - STS



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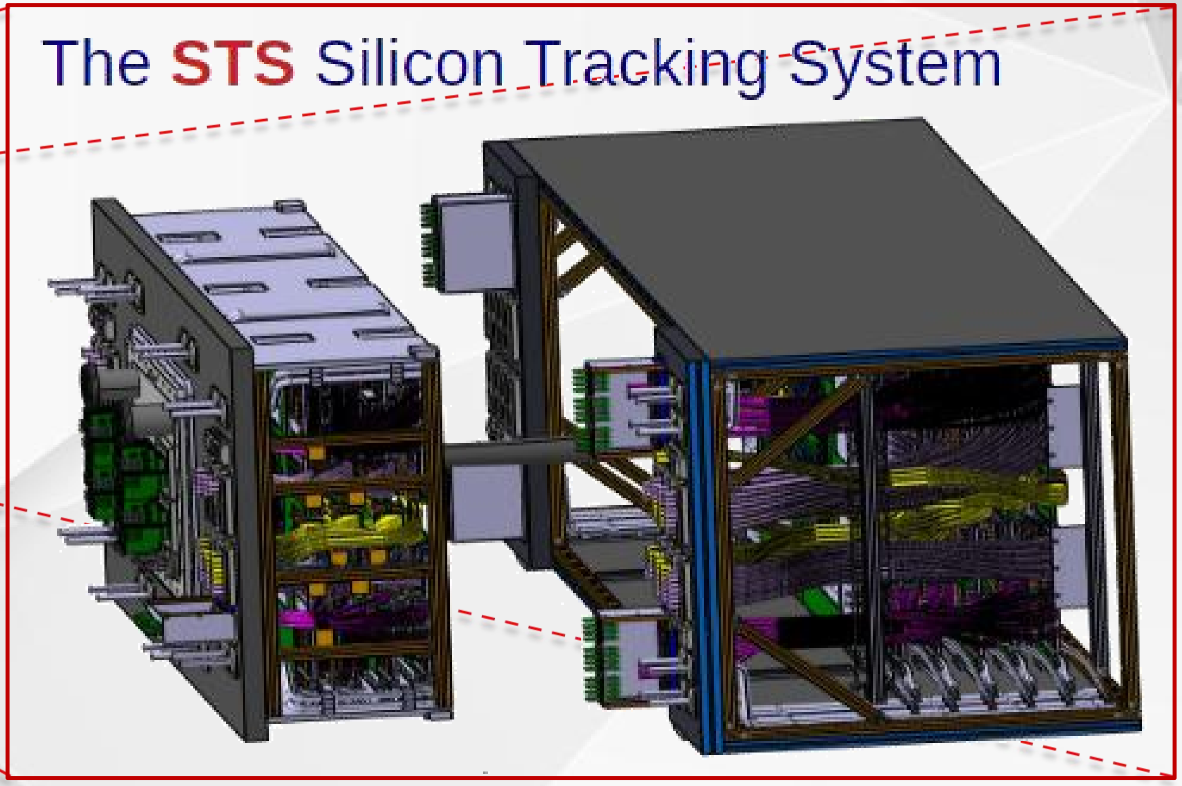


- The measurements will be performed at beam-target interaction rates up to 10 MHz.
- Maintaining material budget within 2 – 8% X_0.
- High granularity, spatial, and timing precision.

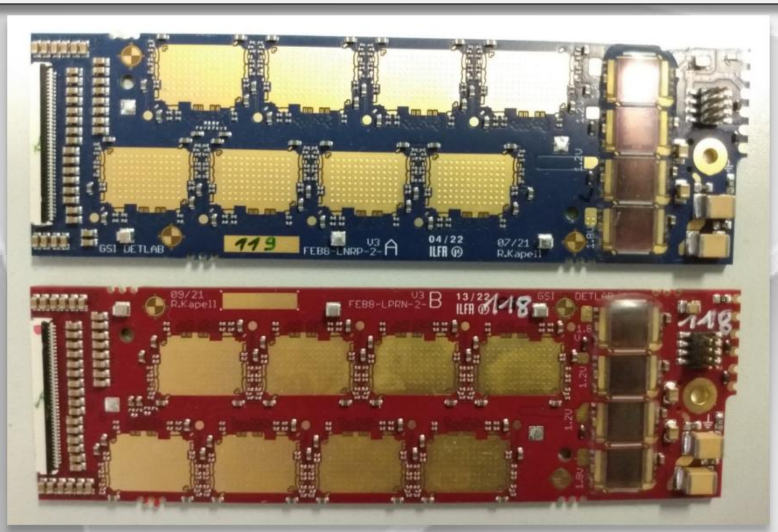
- A novel integration approach was employed where the read-out electronics are placed outside of the sensitive volume.

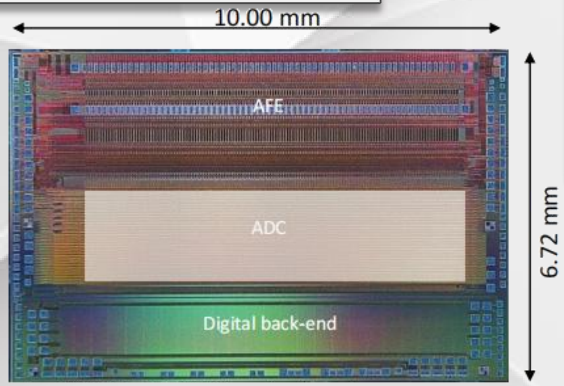
CBM - STS module

STS detector consists of **876** DSDM micro-strip modules.

Each double-sided silicon strip sensor is connected via a stack of low-mass microcables to two Front-End Boards (FEBs).

Each FEB has eight custom-designed STS-XYTER ASIC (SMX).

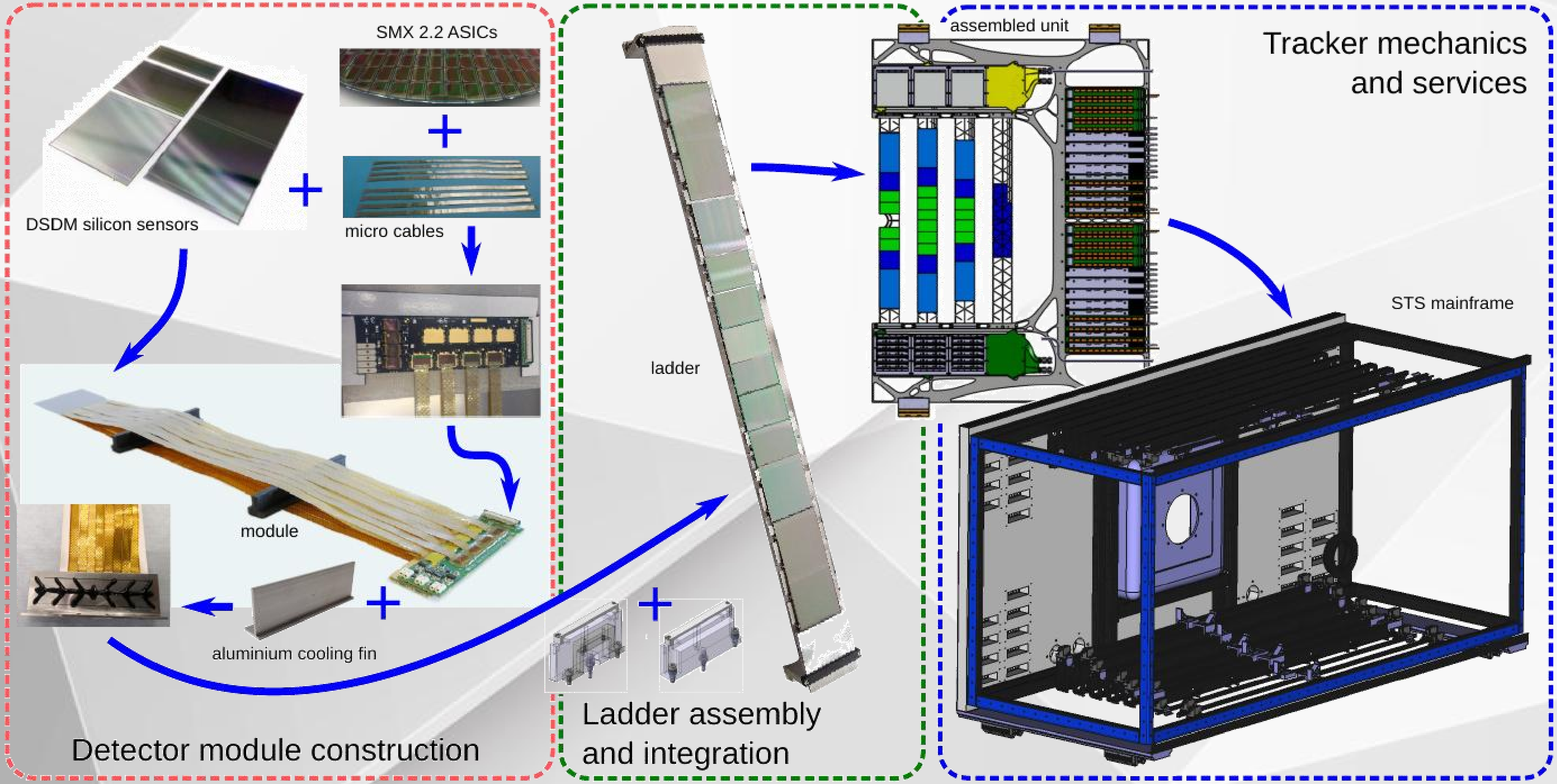




The STS-XYTERv2 ASIC under the microscope.

After module assembly, a 2.7 mm thick aluminum cooling shelf is glued (STYCAST) between FEBs. Necessary step to ensure proper cooling of the FEB (Average power dissipation per FEB ~11 W).

STS assembling sequence and structure



- **40** C Frames in STS
- Each C Frame contains between two and four ladders
- Each Ladder carries up to 10 modules
- In total STS will be built with **106** ladders and **876** modules

Module and ladder characterization

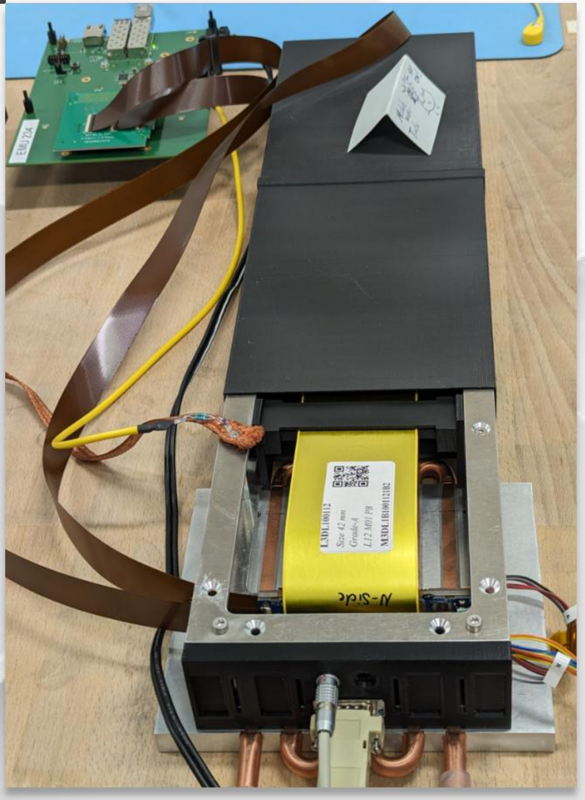
Module Assembly

STS has started the module series production

Produced: **264 (30% of total)**
Tested: **181 (20.6% of total)**
Assembled in Ladder: **26**

Module and ladder characterization

Module Assembly
↓
Reverse bias voltage scan
↓
Electrical and functional test



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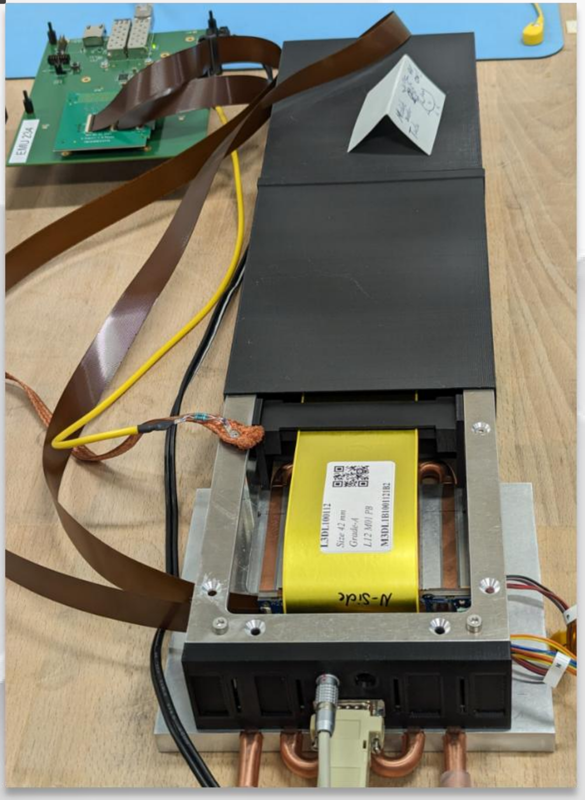
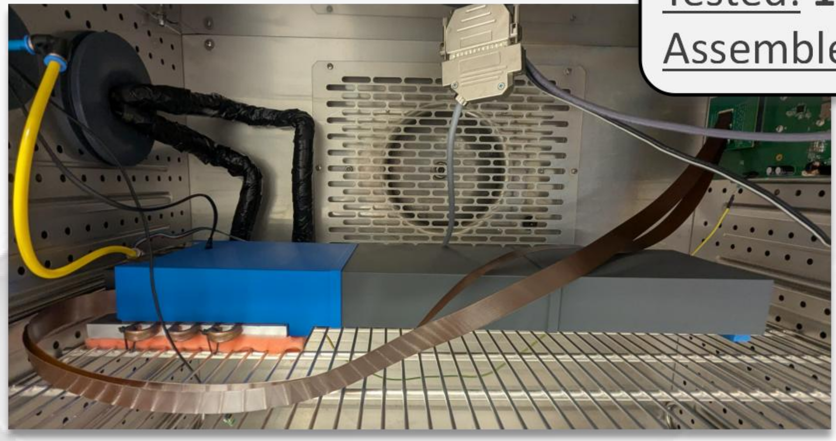
Thermal Test (Burn-in)





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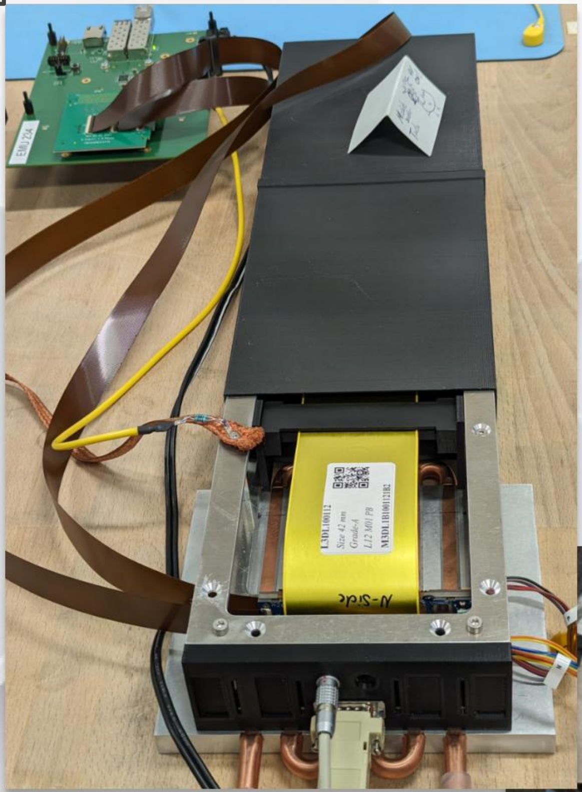
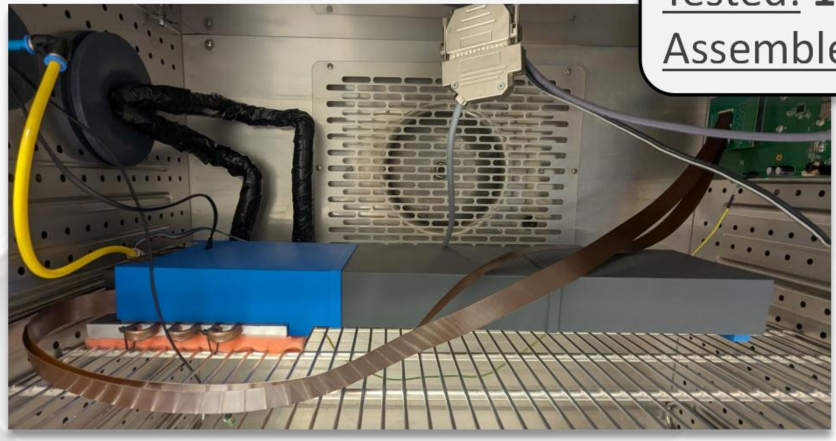
Ladder Testing





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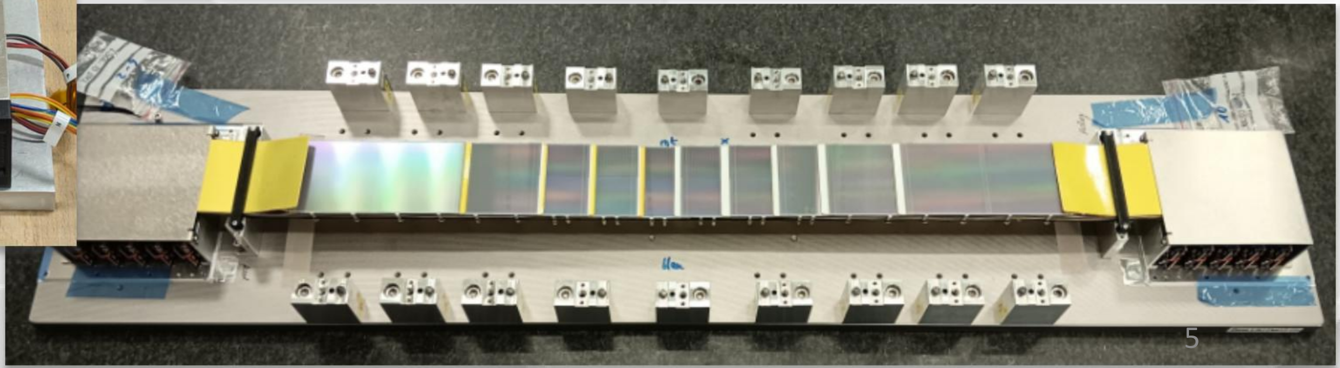
Quality Assurance grade ready for Ladder Assembly



Module and ladder characterization

- Module Assembly
- Reverse bias voltage scan
- Electrical and functional test
- Thermal Test (Burn-in)
- Ladder Assembly
- Ladder Testing

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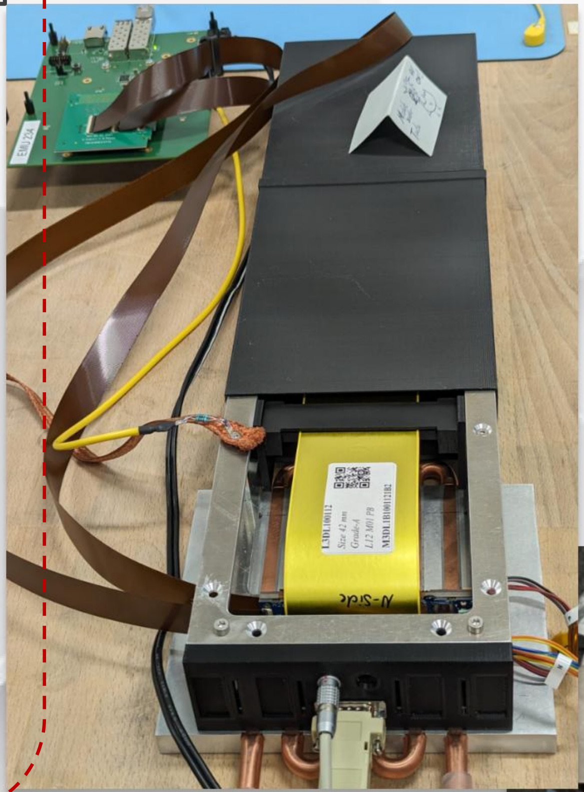

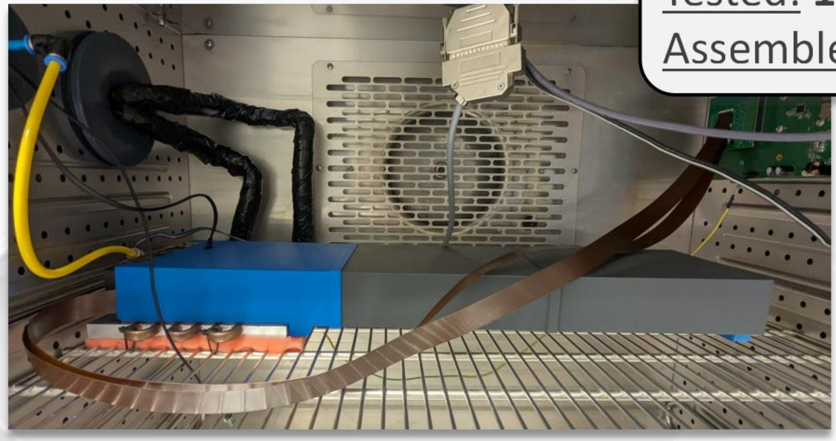

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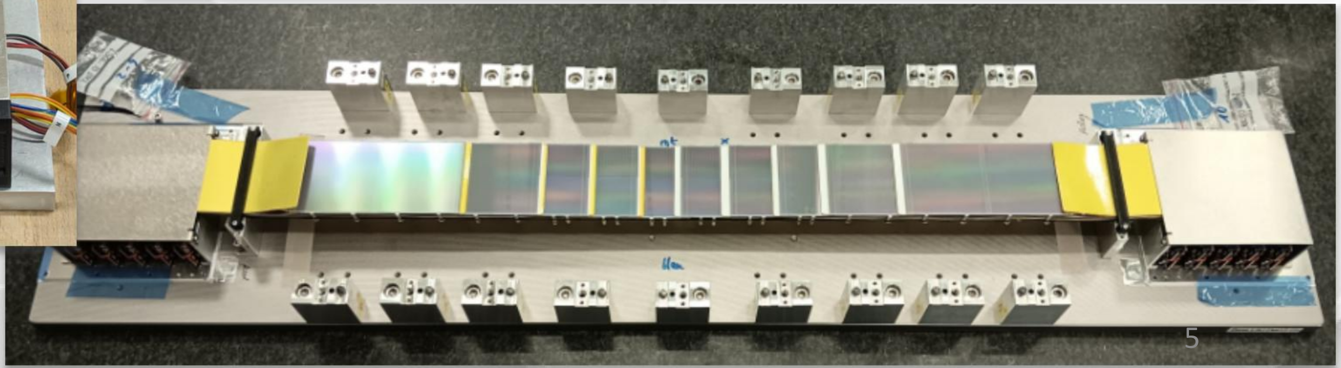
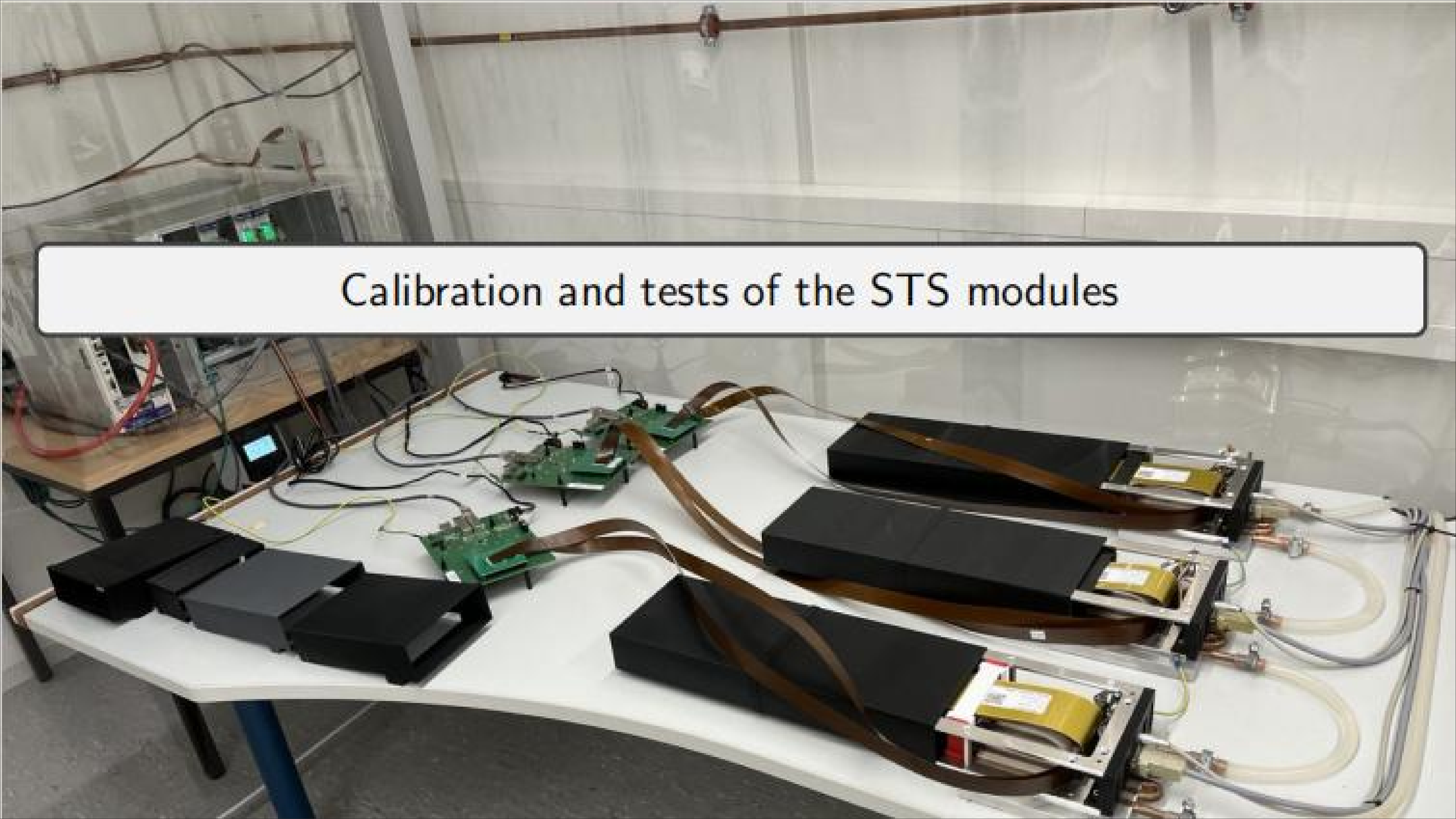


Calibration and tests of the STS modules



How do we test the modules?

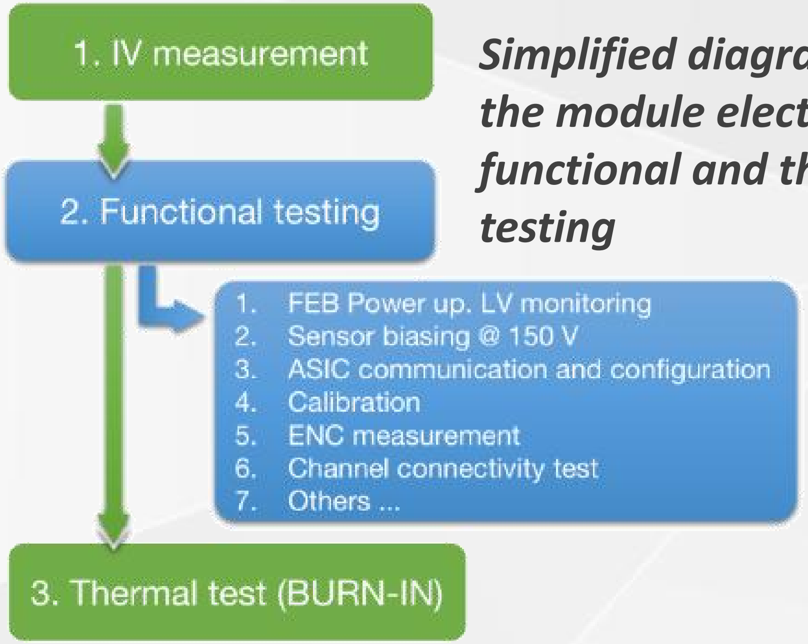
Module Testing & Burn-in

First step:

- Placing the module in a carrier

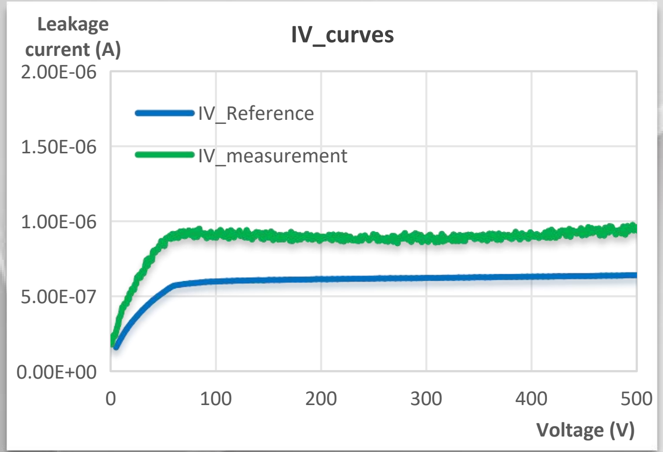
Main objectives of Module Testing:

- Evaluate modules functional operation
  - Sensor current-voltage characteristic (IV)
  - Calibrate the Front-End Electronics (FEE)
  - Estimate noise level
- Evaluate the thermal performance of the full assembly object at the final operational temperatures

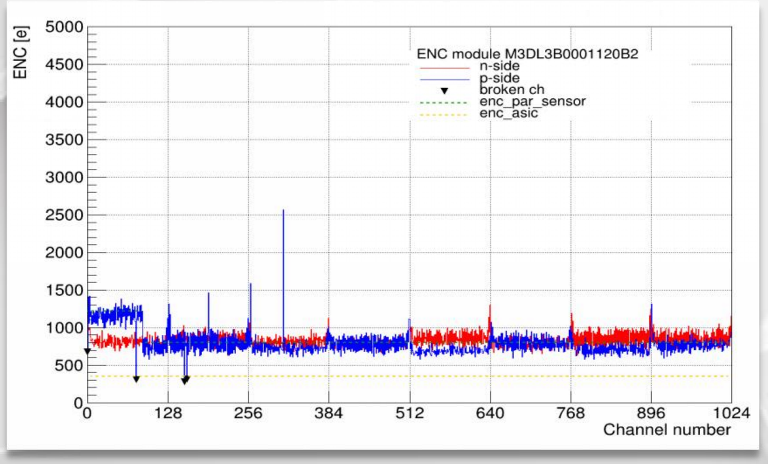


Simplified diagram of the module electrical, functional and thermal testing

Reverse bias voltage scan

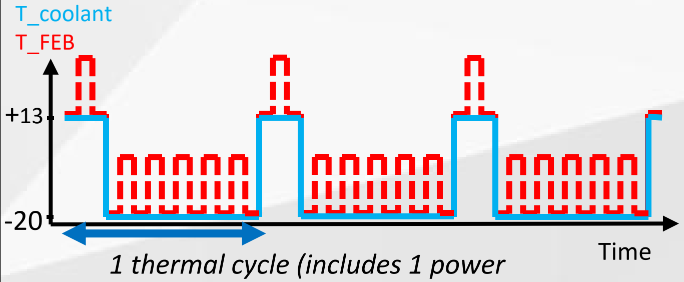


Electrical & Functional Tests



Burn-in

STS operation temperature: $-20°C$

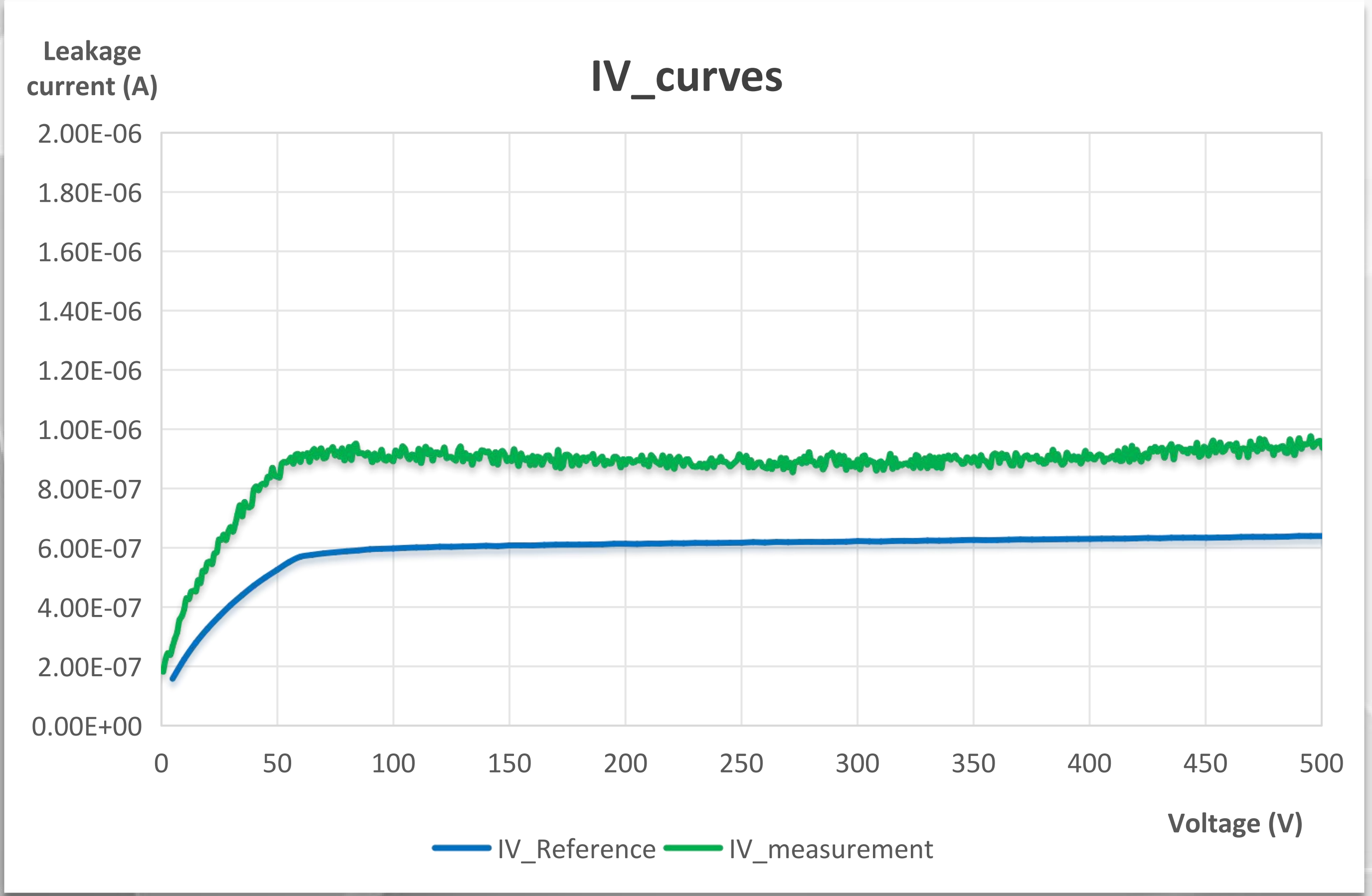


1 thermal cycle (includes 1 power cycles at max. temp. and 5 power cycles at min. temp.)

Voltage scan

Module Testing

Reverese bias voltage scan



One IV setup:

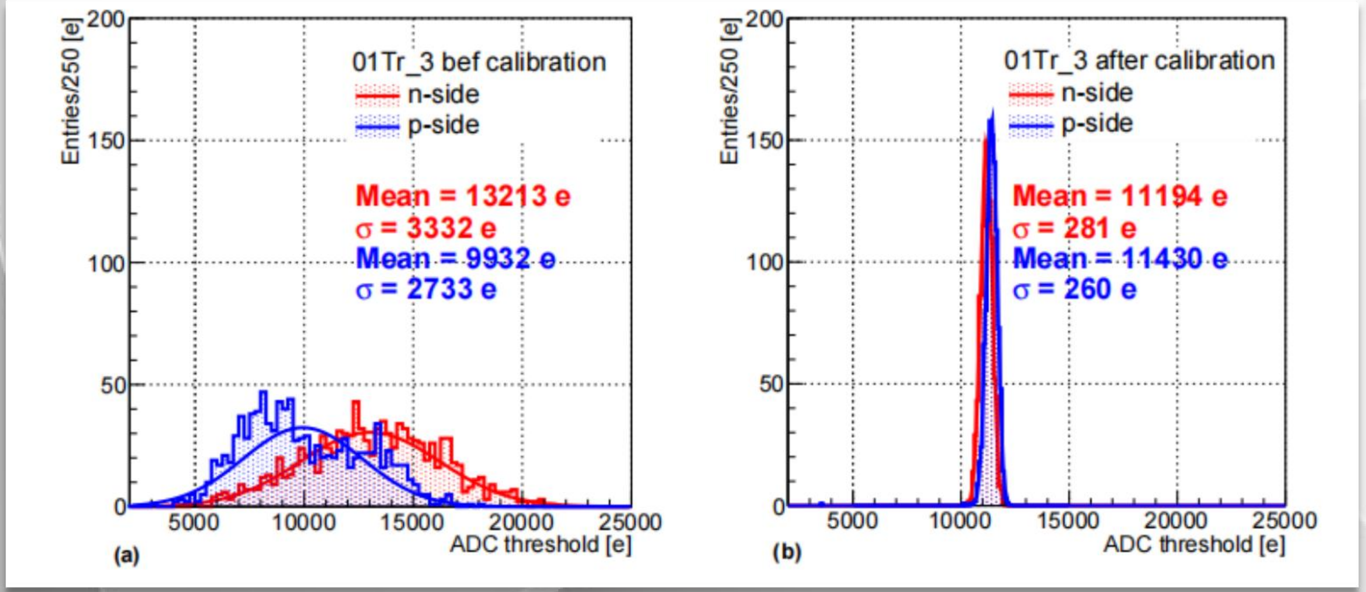
- ➢ a module / every 25 min
- ➢ It allows to compare the measurements with the results of the Electrical Inspection.
- ➢ A sensor is assigned to a given position in the detector according to the particle flux that it will receive in operation so that the best grades will go to the region of higher exposure to particle, and the sensor is biased depending on the assigned grade.
- ➢ Edge cleaning and thermal treatment for modules identified with an early breakdown. Possibility to recover modules with IV issues due to high humidity.

Functional performance

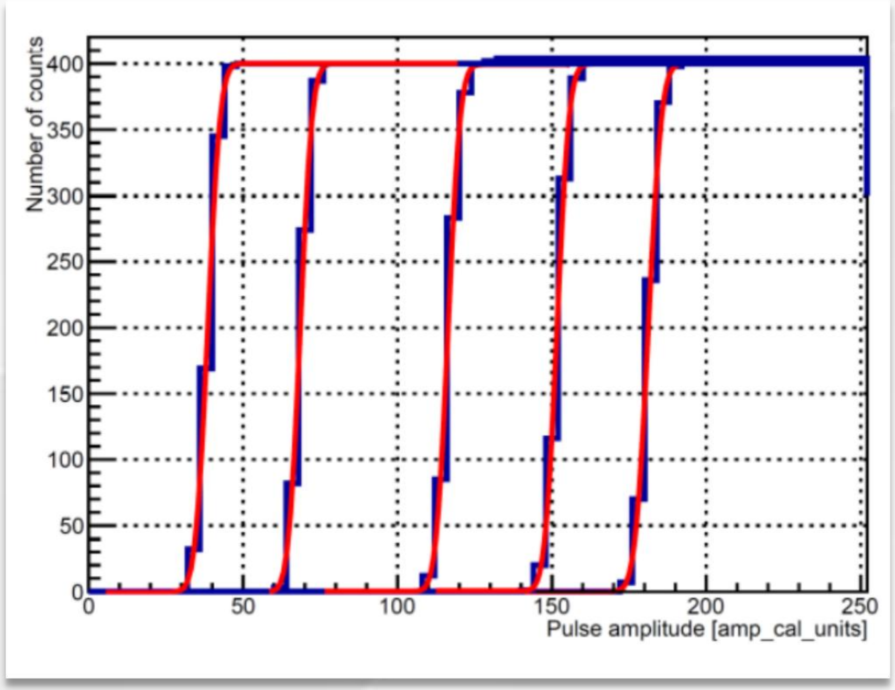
Module Testing

Functional Tests

- Three modular testing setups:
  - The possibility to study a module with issues while continuing with regular series testing



Comparison of the ADC threshold distribution before (a) and after (b) charge calibration.



- The response function of each discriminators in a channel are fitted with erfc.
  - mean represents the effective discriminator threshold
  - σ represents the ENC value in units of the internal pulse generator

Functional performance

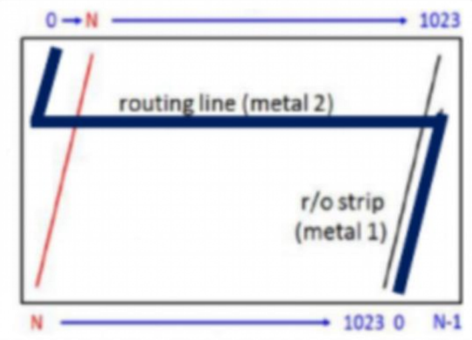
Module Testing

Functional Tests

- Check ASICs functionalities:
  - downlinks, uplinks
  - ASIC potentials VDDM, temperature
- Module ADC calibration
- ENC performance
- Identification of broken channels

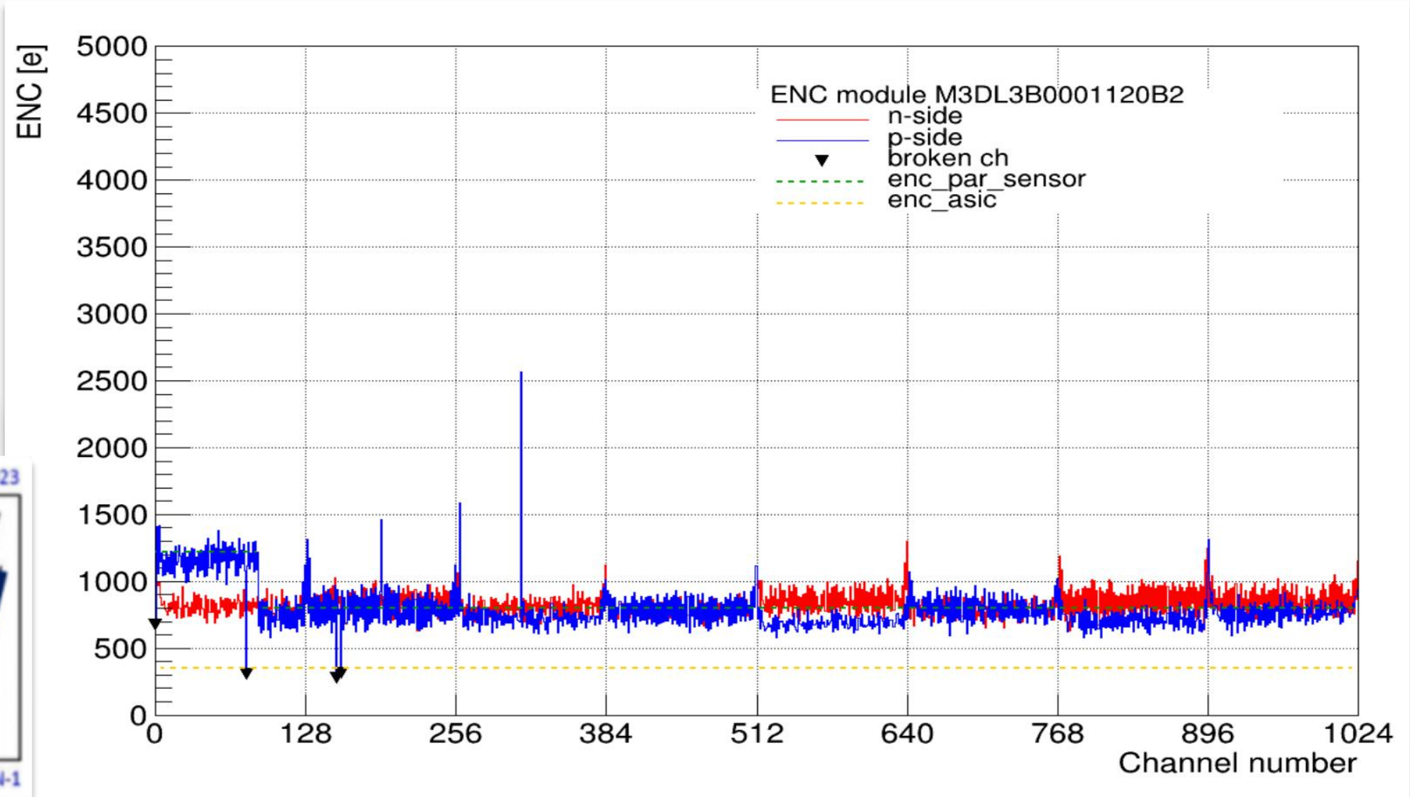
Z-strip: 17 pF extra from the double metal routing

Panasenko, I., Ph.D. diss., Univ. of Tübingen, 2022.



$$ENC = \Big[\underbrace{L_{\text{sensor}} \cdot 1.02\ \frac{\text{pF}}{\text{cm}}}_{\text{sensor}} + \underbrace{L_{\text{cable}} \cdot 0.38\ \frac{\text{pF}}{\text{cm}}}_{\text{microcable}}\Big] \cdot 25\ \frac{\text{e}}{\text{pF}} + \underbrace{350\ e}_{\text{ASIC}}$$

Rodríguez, A., Nucl. Instrum. Meth. A 1058 (2024)



Equivalent Noise Charge (ENC) derived from an S-curves scan in every channel, where the discriminator response is evaluated in a pulse amplitude scan

Thermal stress test

Burn-in

Burn-in Test

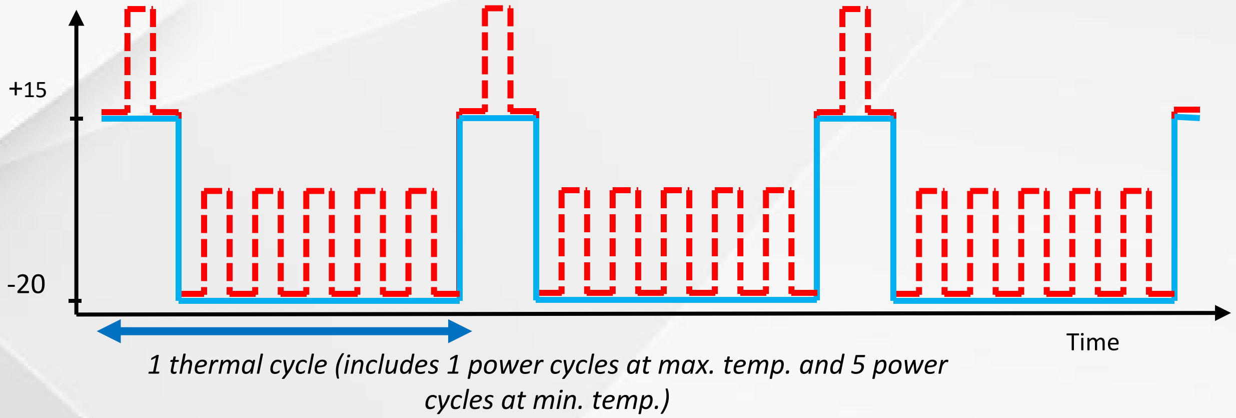
Test parameters:
The **temperature** ranges:
[-20,15] in LAUDA chiller, and [-15, 20] in BINDER climatic chamber

Thermal cycles: 3 thermal cycles

Power-ups at low temp: 5 per thermal cycle

Power-ups at high temp: 1 per thermal cycle

Two burn-in setups:
- two module / 6.5h



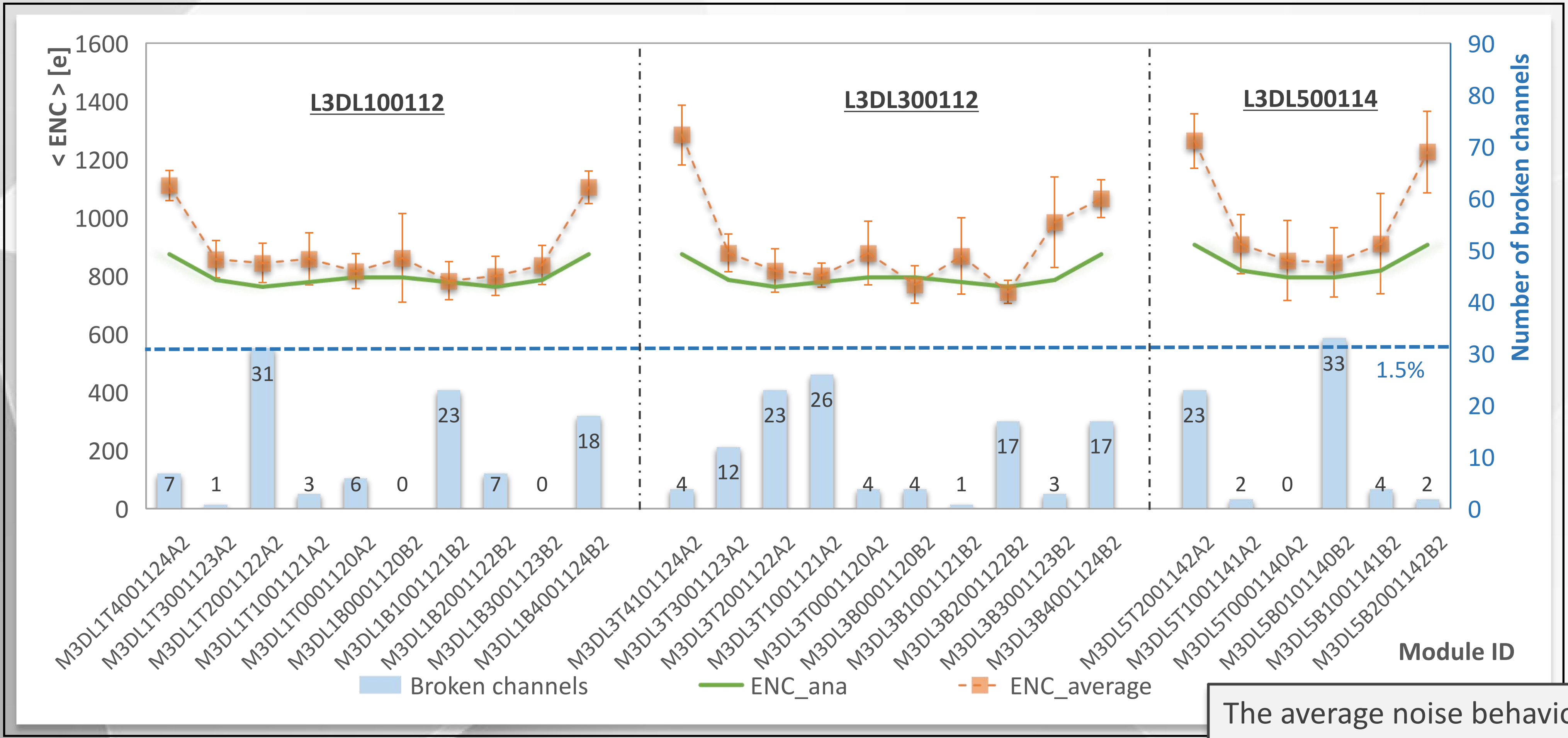
STS operation temperature: $-20°C$

Continuous nitrogen gas flows inside the module enclosure

QA for series module production

Module characterization

Module Testing results for the first three assembled ladders



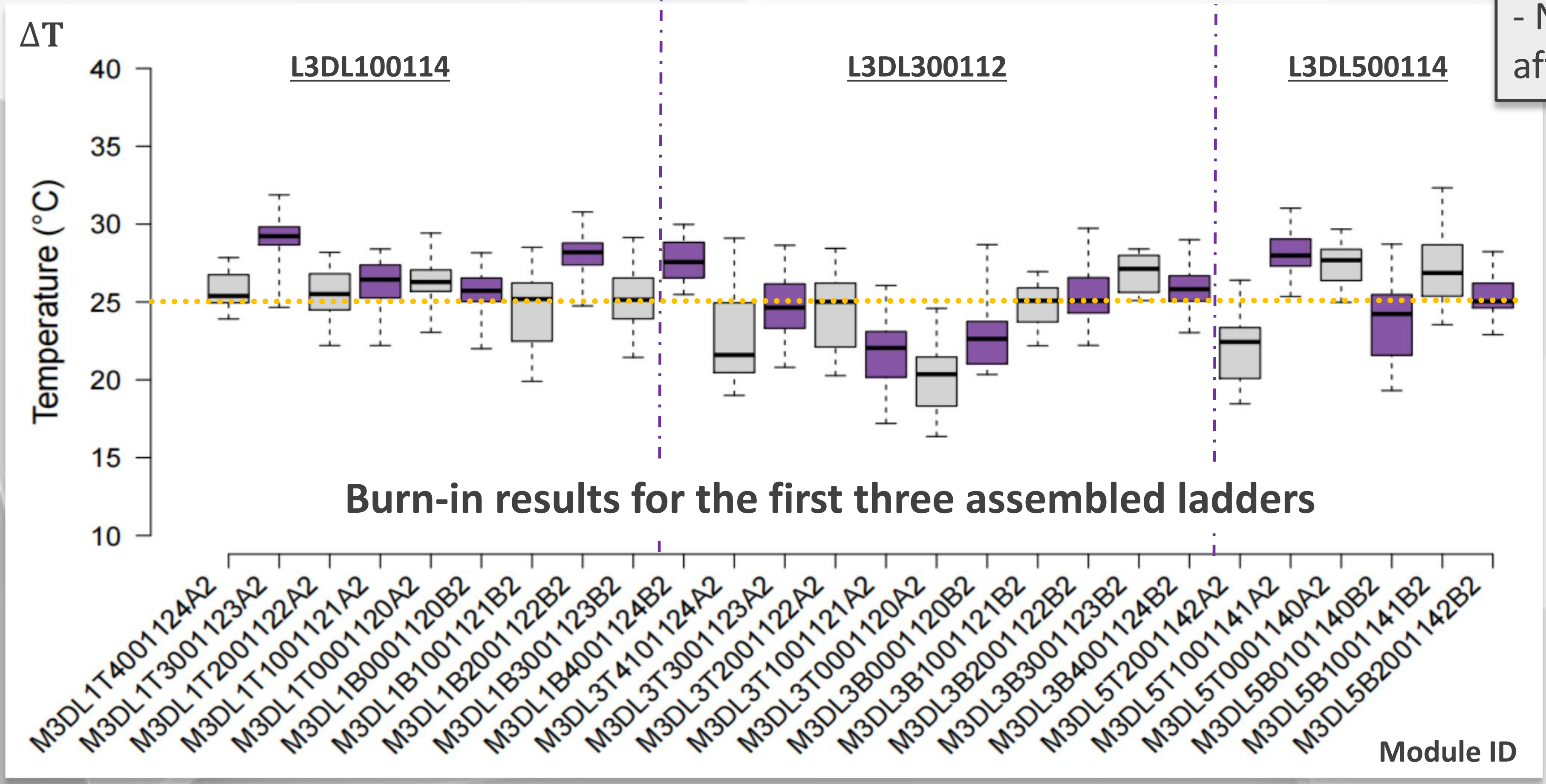
The average noise behavior is consistent with the sensor size, and the number of broken channels for each module is in agreement with our acceptance criterion.

Thermal stress test

Module Burn-in results

Overall results: 150 / 150 modules **OK**
16 ASICs per module ≈ 2400 functional ASICs

What data do we collect?
- Power consumption
- Temperature
- Operation potentials in FEE
- Number of broken channels after thermal stress test

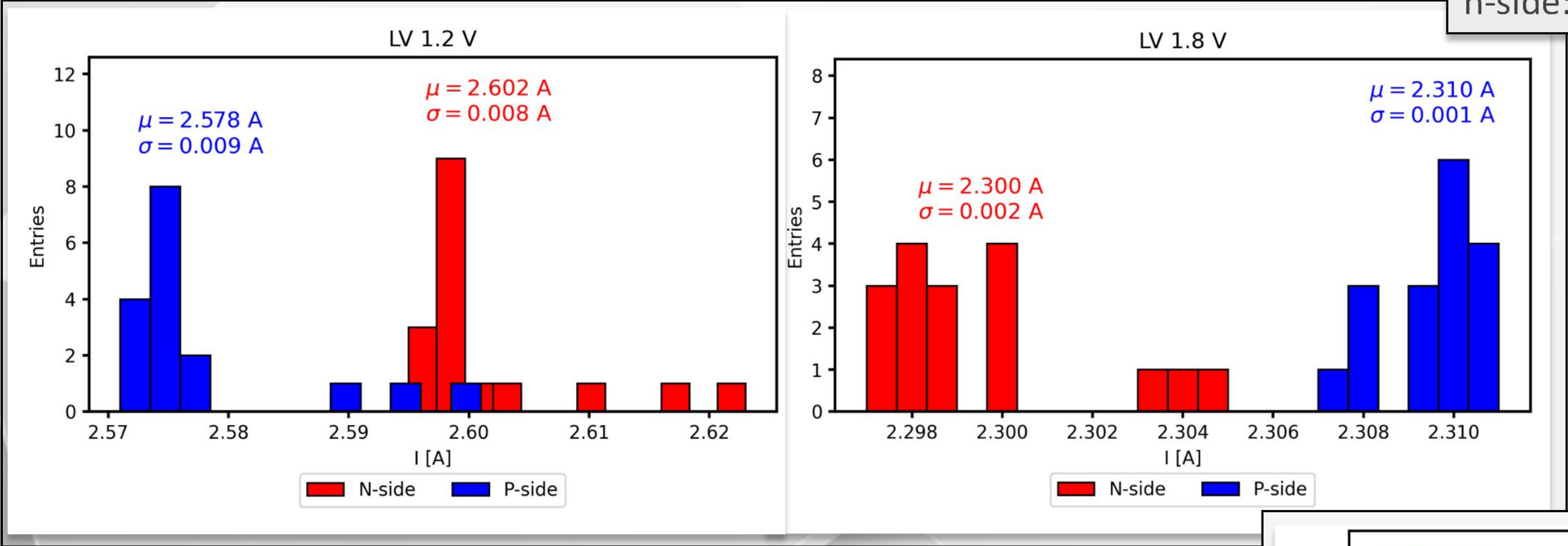


Burn-in results for the first three assembled ladders

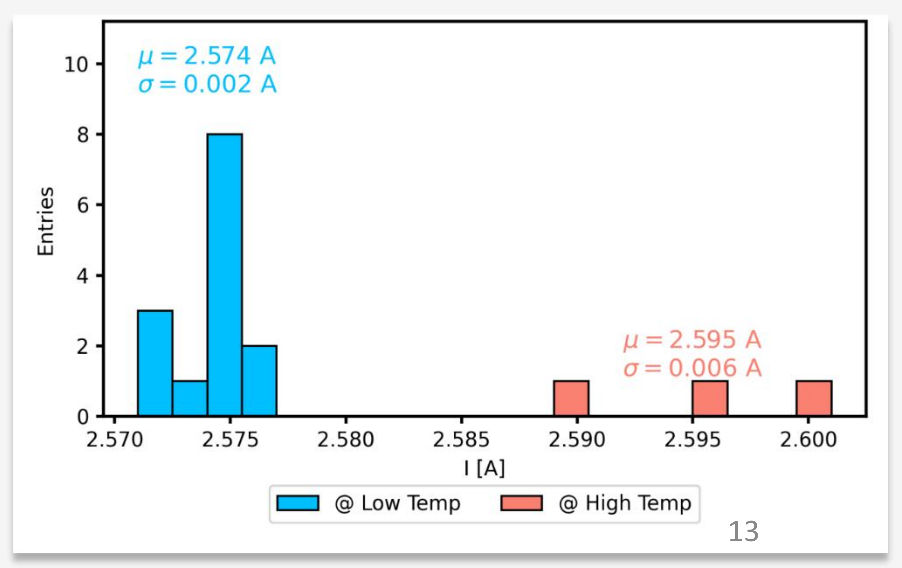
Thermal stress test

Power consumption during Burn-in test

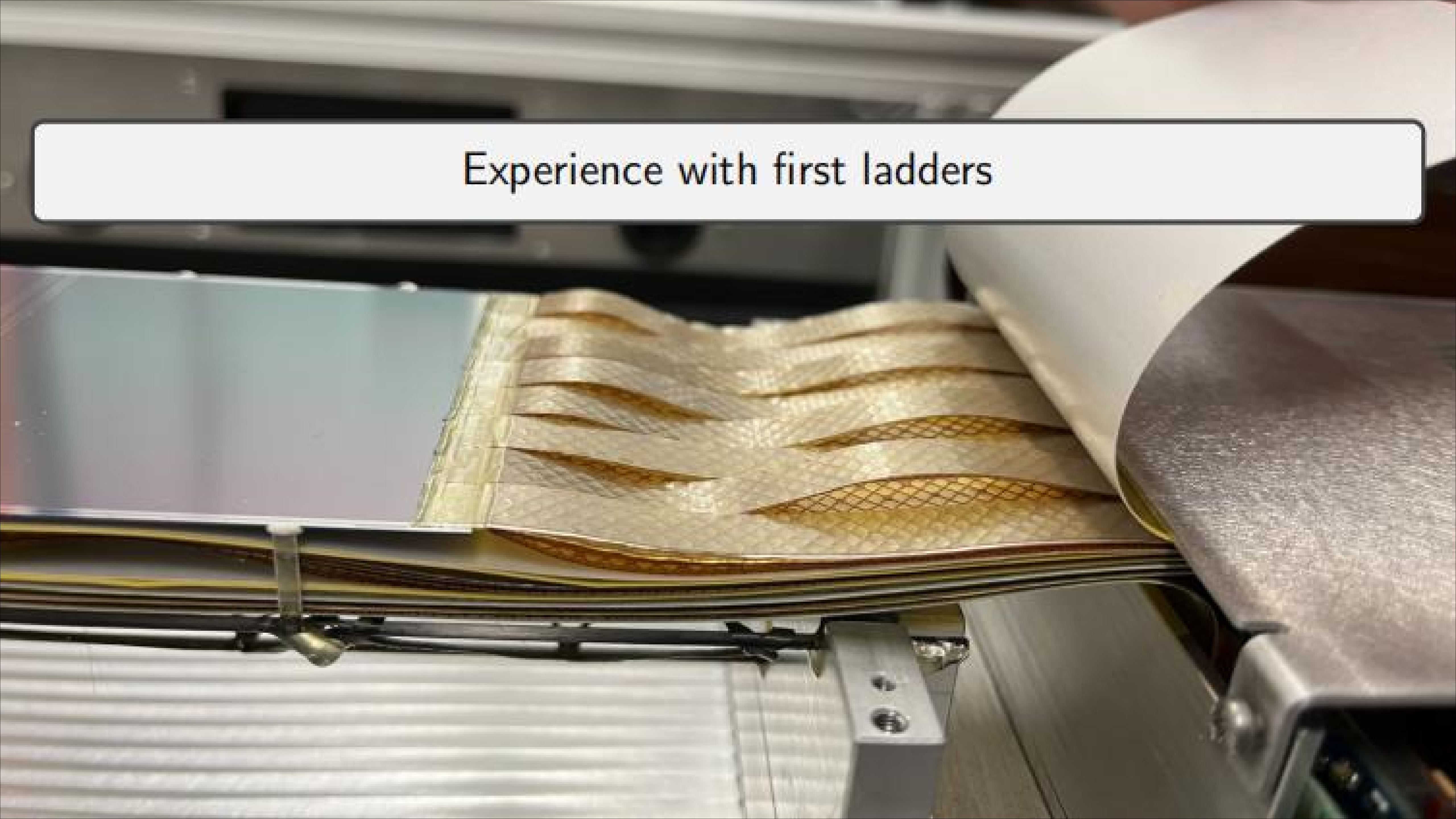
FEB power dissipation
n-side: 10.9 W   p-side: 10.9 W



FINDINGS:
- Differences in current consumption between p and n-side for each power line are below 50 mA.
- Current consumption at room temperature and operating temperature (-20 C) is quite similar.

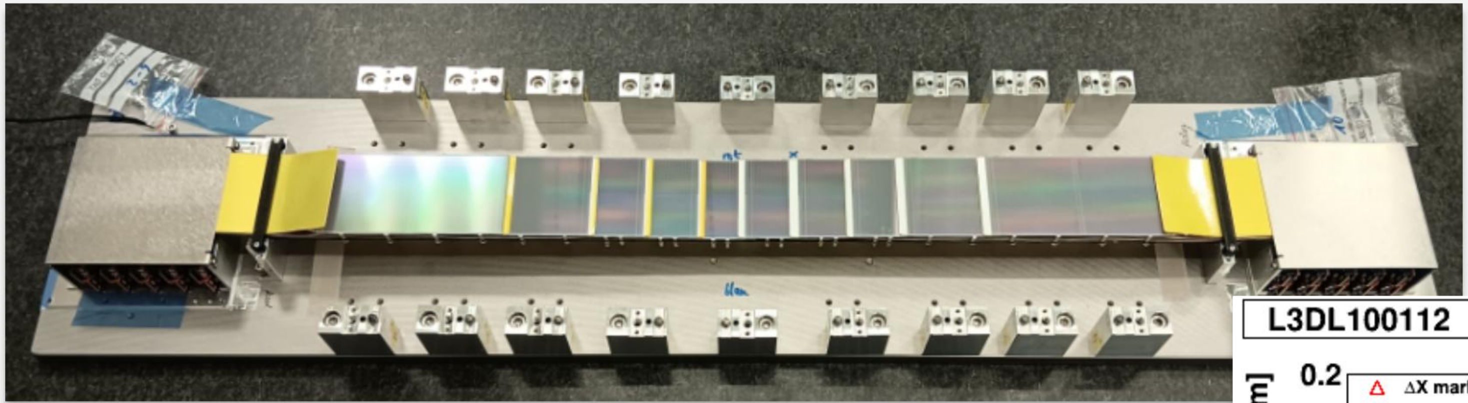


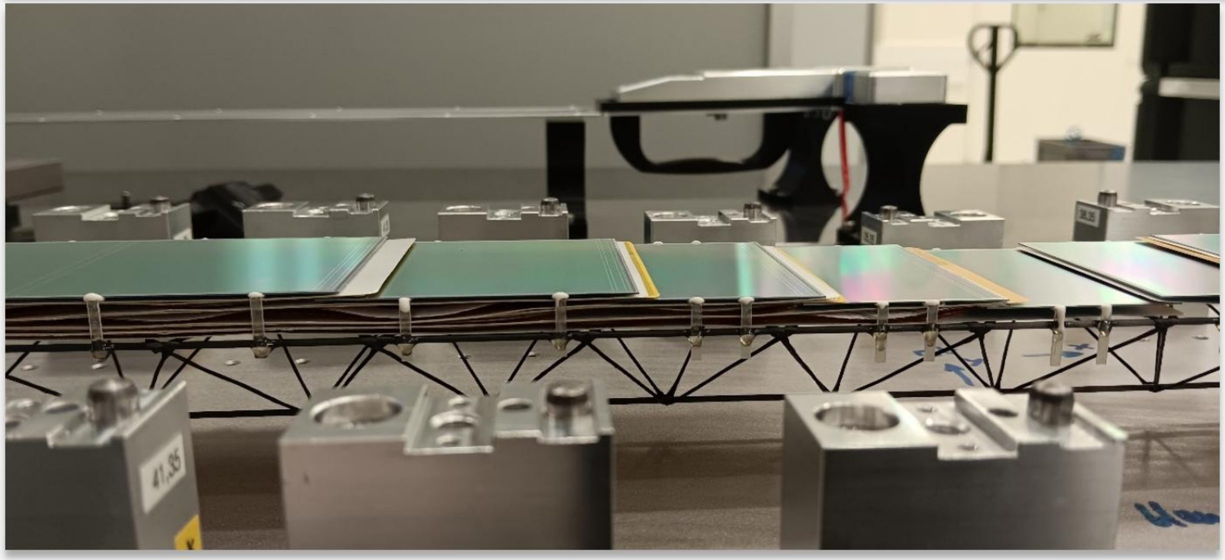
Experience with first ladders

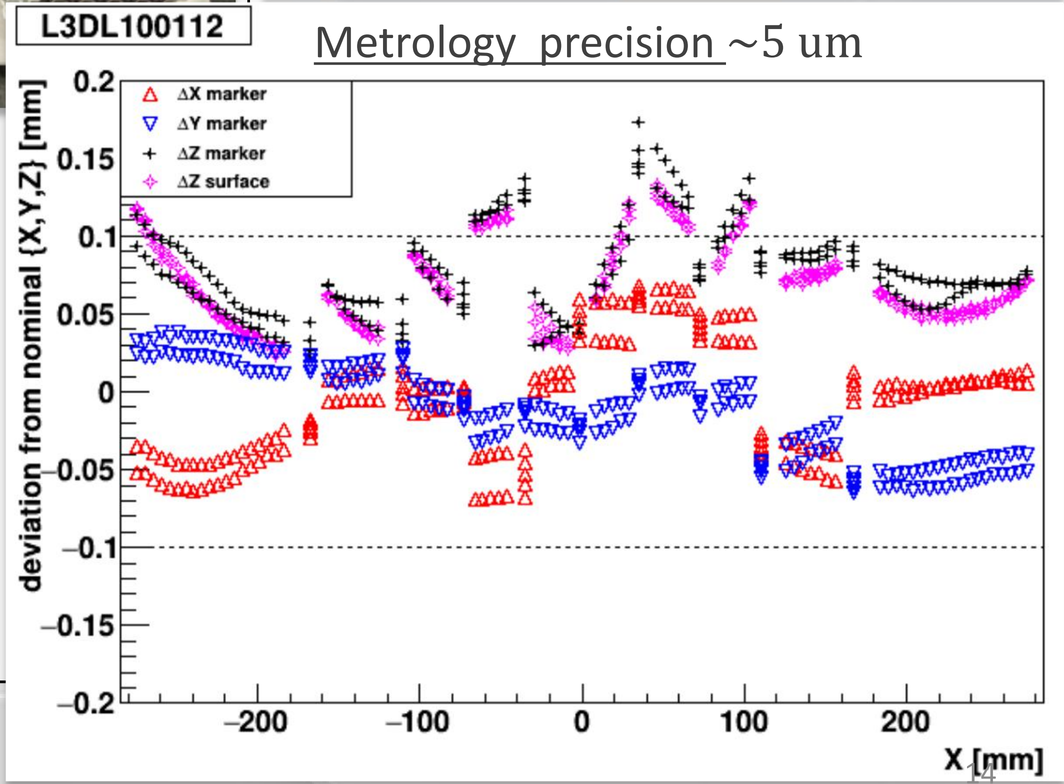


Ladder assembly

Ladder Assembly:







Ladder characterization

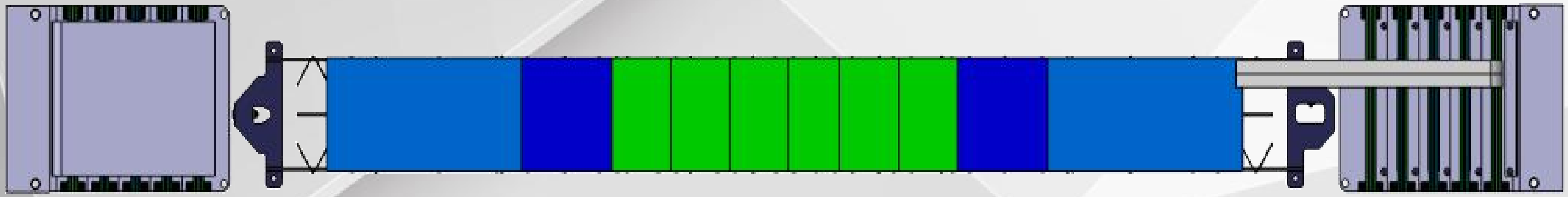
The construction and setting up of a Ladder test box:

Features of the Ladder test box:

- Modular design: can test all types of STS ladders
- Light tight, EMI protection
- Integrate LV, HV, data readout and cooling interfaces.

The test and characterization of the ladder started with the first of series fully assembled ladder: L3DL300112 (Ladder type 12, holding 10 modules with different form factors):

- - 6 modules built from 4.2 $\times$ 6.2 cm^2 sensors (Electrical grade B, i.e., EOL biasing up to 350 V)
- - 2 modules built from 4.2 $\times$ 6.2 cm^2 sensors (Electrical grade C, i.e., EOL biasing up to 250 V)
- - 2 modules built from 12.4 $\times$ 6.2 cm^2 sensors (Electrical grade C, i.e., EOL biasing up to 250 V)



CAD drawing of a Ladder 12 type.

Ladder characterization

Testing sequence and ststaus

Ladder in Test box

☑ IV measurement (max 500 V)

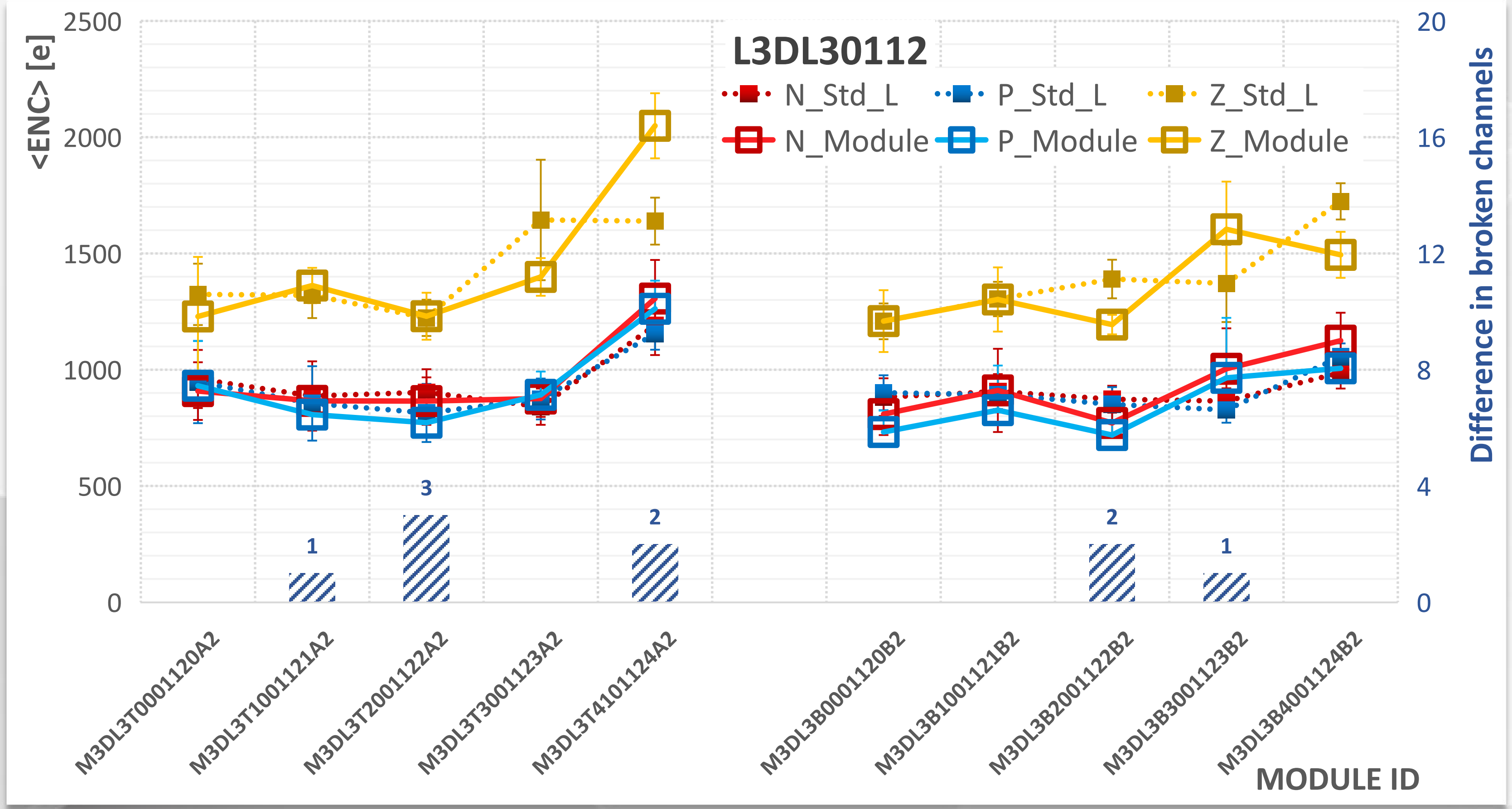
☑ LV Power up. Monitor LV currents

☑ Establish connection w/ ASICs

☑ Check ASICs configuration

☑ ENC measurements

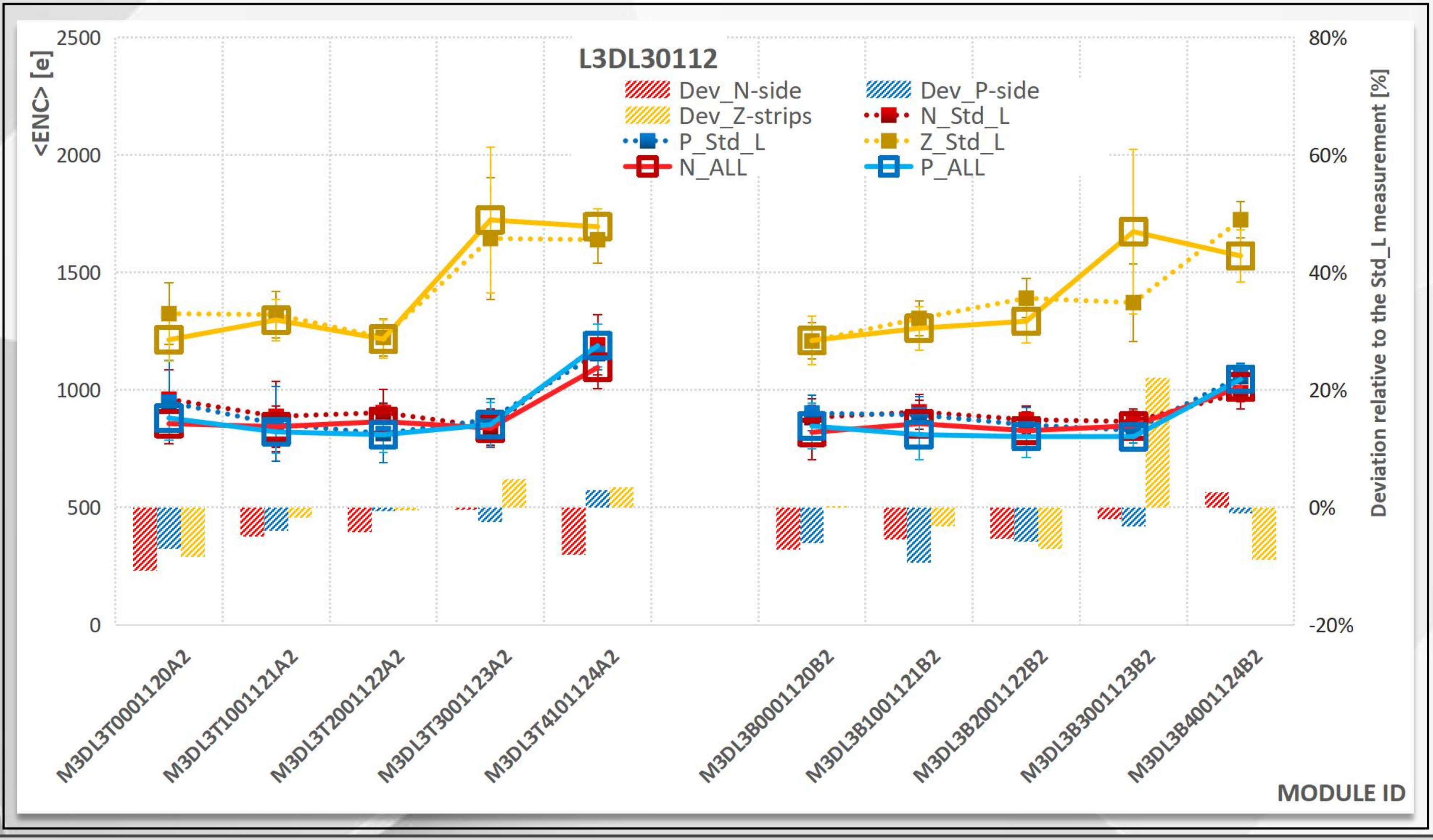
☑ Data readout from $^{90}Sr/Y$



- Direct comparison of ENC measurements between each individual module in the ladder with its previous tests at "Module testing".
- The number of broken channels suffered a very small deterioration during the assembly procedure.

Ladder characterization

ENC characterization for each module in the ladder



The large percentual deviation in the Z-strips of module B3 appeared after reworking the position of the microcables.

- Comparison of the module's ENC measured mounted onto the ladder in two different stages:
  - **Std_L** refers to the standalone biasing and operation of 1 module
  - **ALL** refers to the simultaneous biasing and configuration of all modules

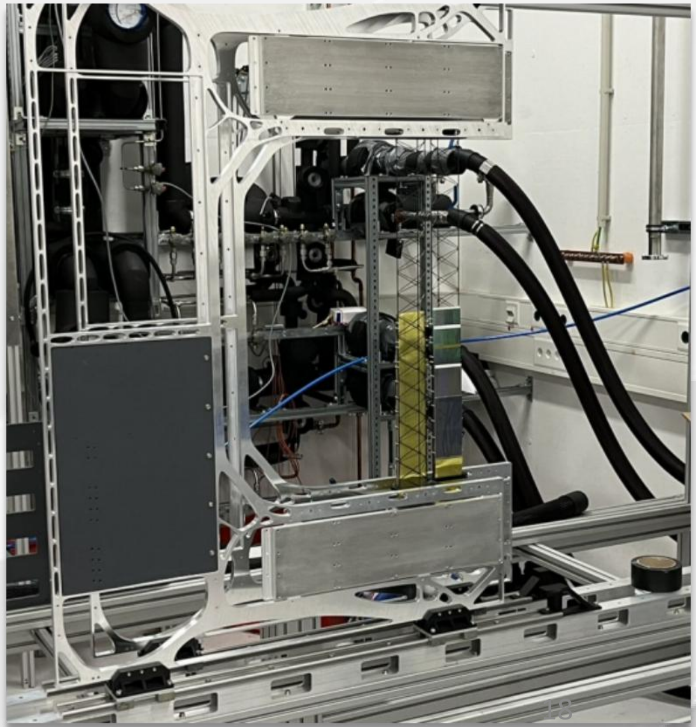
Module and ladder characterization and burn-in tests

CONCLUSIONS

- The test and characterization of fully assembled modules is fundamental to ensure reliable performance, improve their operation, and correctly interpret the collected data in the final detector.
- The burn-in test identifies potential weaknesses and evaluates the robustness of the electronics and functionality of the whole module under realistic operational conditions.
- The ladder test ensure that the module proper functionality and performance are preserved.

What are the next steps in the assembly?:

- Each ladder will be placed in the corresponding C Frame
- It will be integrated with the final components: Cooling interfaces, Readout boards, Power boards, LV, HV and data cables.
- C frames will be tested to ensure proper operation.
- Each C Frame will be mounted in the mainframe, and further tests are foreseen.
- Transported to the CBM cave, where it will be finally operated.



THANKS