Characterization of pixel modules for the Phase-II upgrade of the ATLAS detector

18th Gentner Day, 28th October 2020

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Federal Ministry of Education and Research

This work has been sponsored by the Wolfgang Gentner Programme of the German Federal Ministry of Education and Research

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- Characterization of RD53A pixel modules using X-Ray Fluorescence
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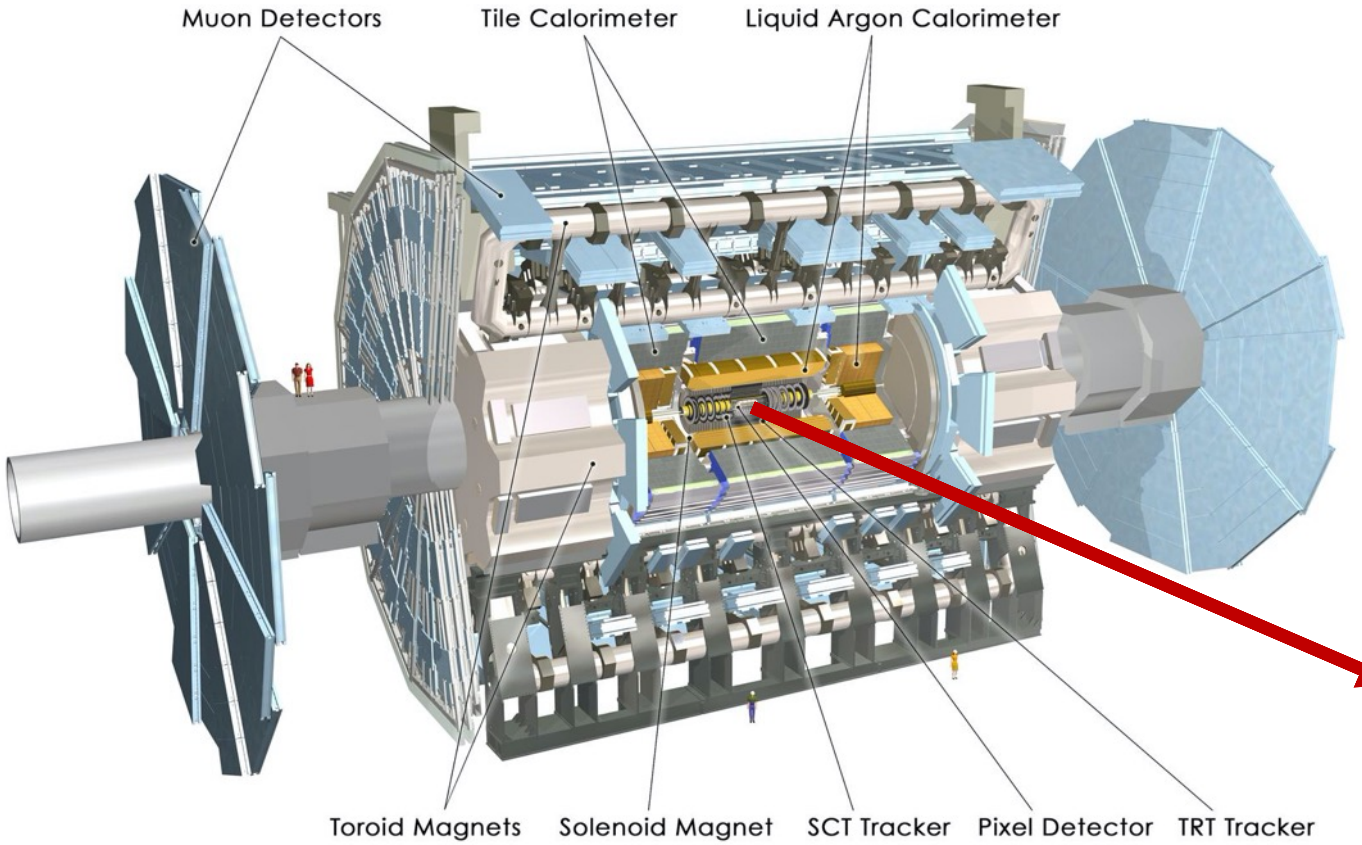
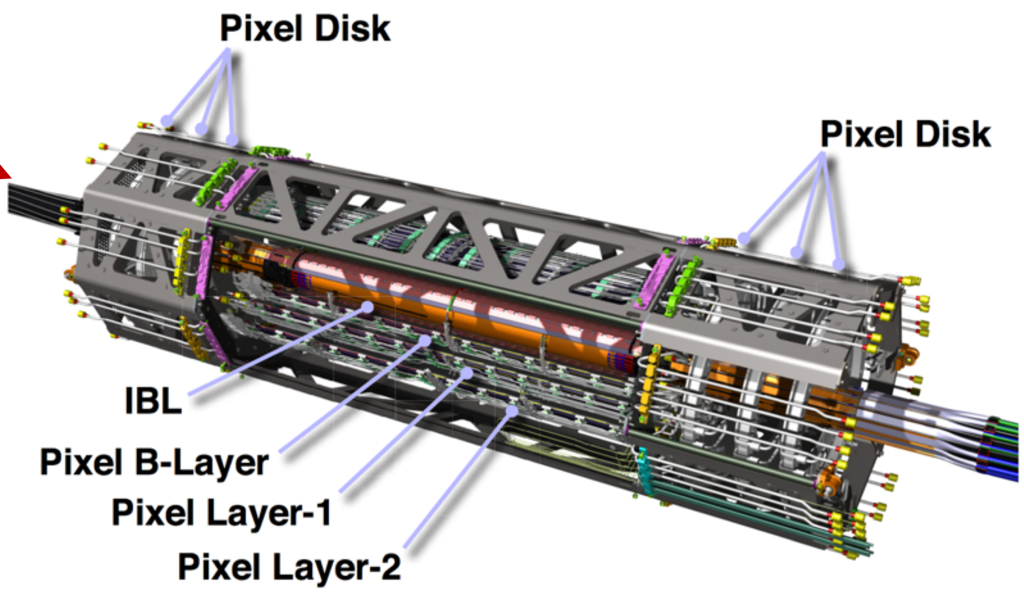
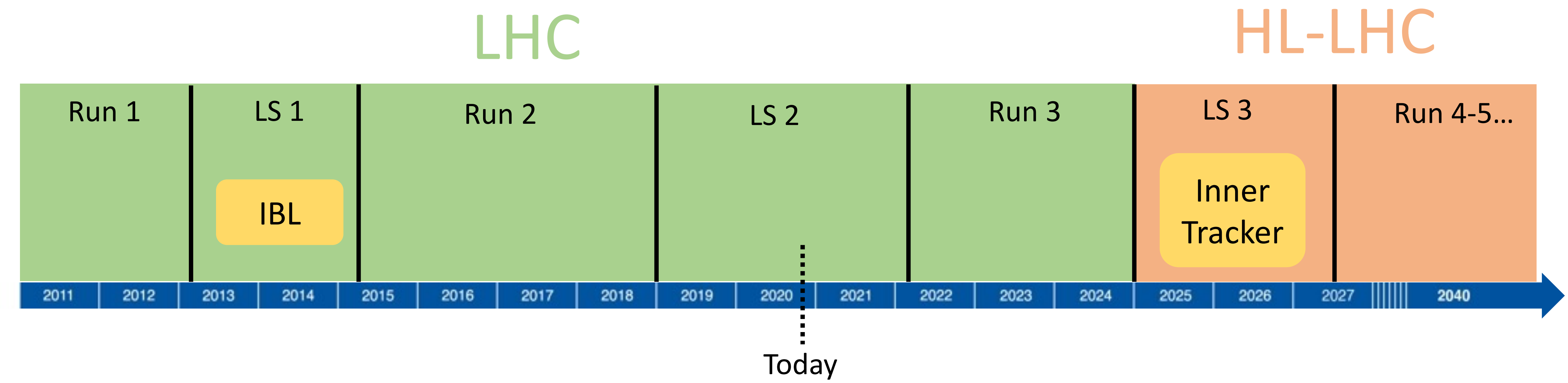
ATLAS Pixel Detector

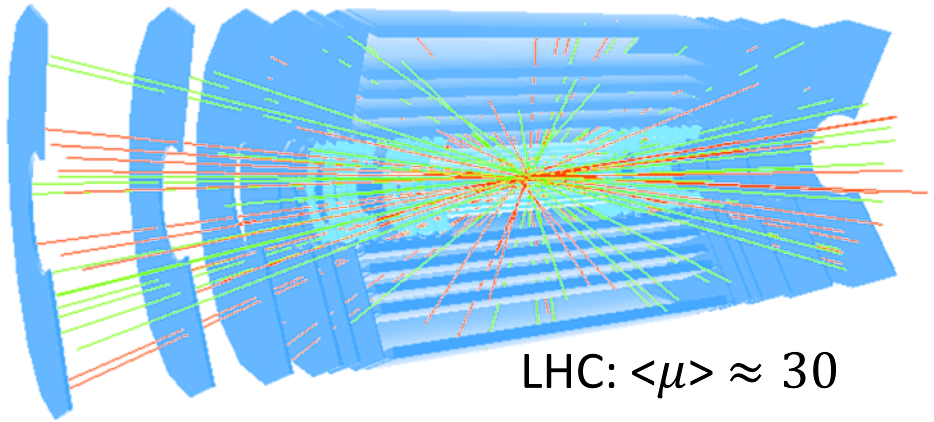


ATLAS EXPERIMENT

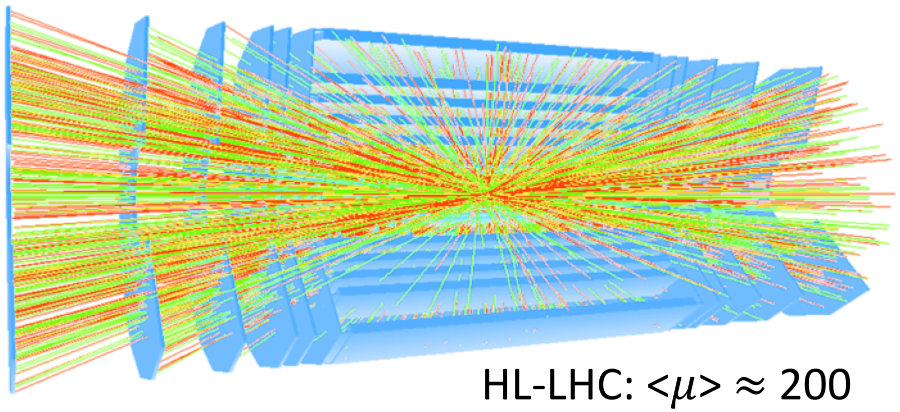


ATLAS Pixel Detector





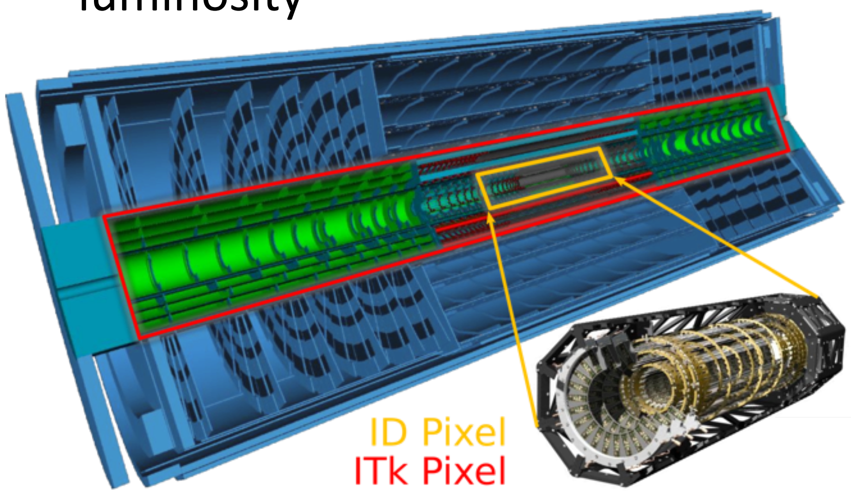
LHC: $<\mu> \approx 30$



HL-LHC: $<\mu> \approx 200$

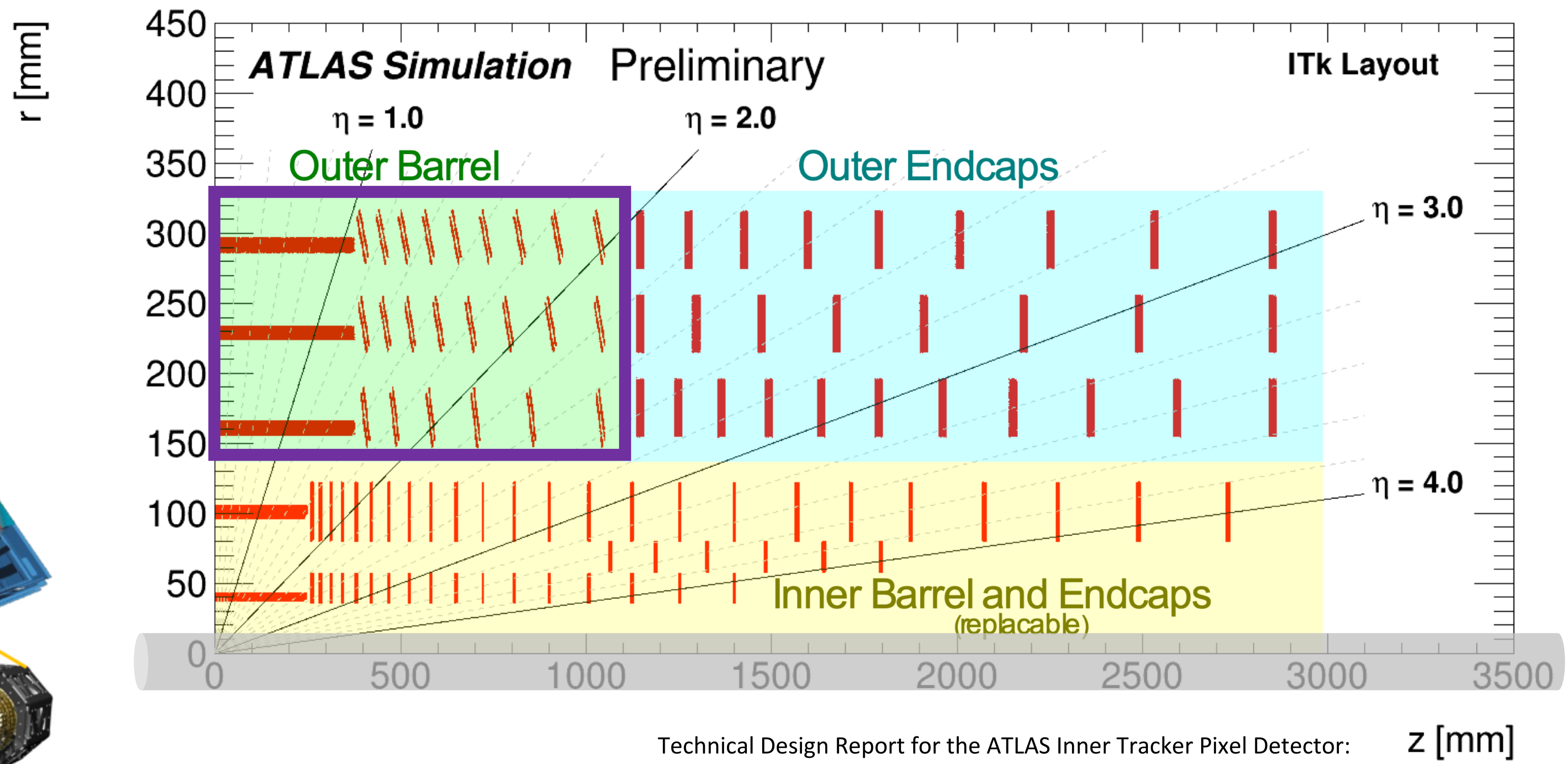
HL-LHC (Phase-II) Upgrade

- Current tracking detector (ID) will be replaced by an all silicon tracker, the Inner Tracker (ITk)
- ITk consists of a pixel and a strip subdetector
- Requires novel silicon modules, powering and data transmission schemes to cope with the challenges of the increased luminosity



Most Important challenges for pixel detector:

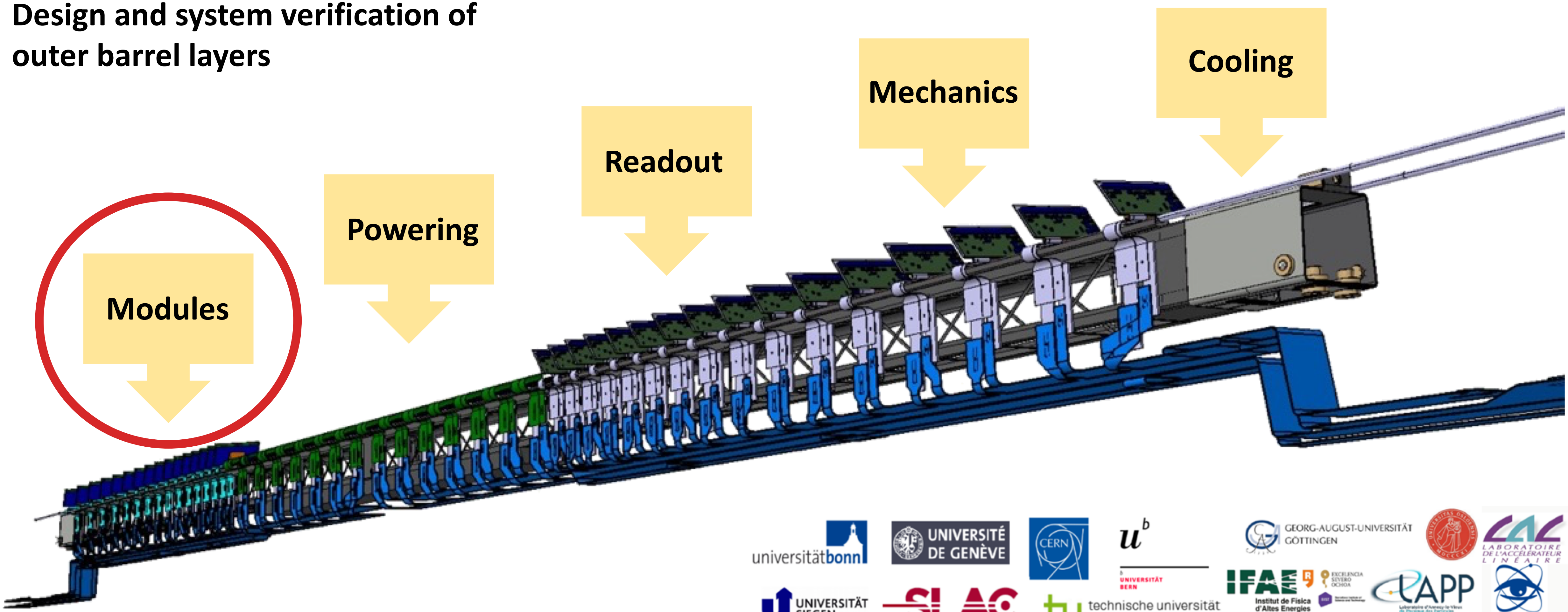
- low occupancy and high data rates
- radiation hardness



Technical Design Report for the ATLAS Inner Tracker Pixel Detector: https://cds.cern.ch/record/2285585/files/ATLAS-TDR-030.pdf

Outer Barrel Demonstrator

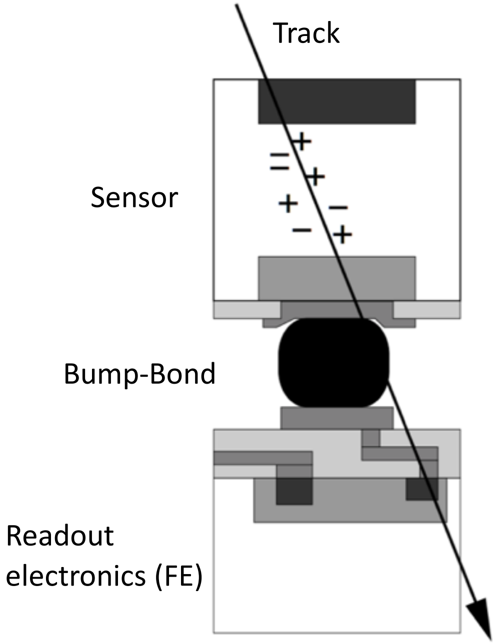
Design and system verification of outer barrel layers



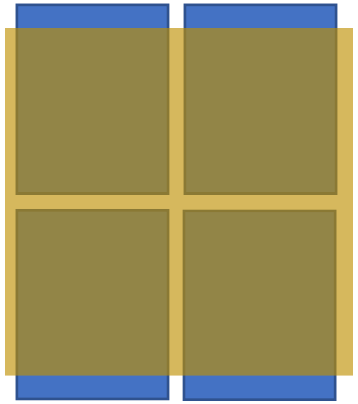
In total 46 pixel modules needed

“Bare” Module

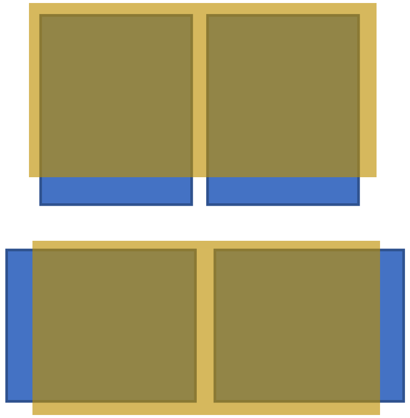
- Planar pixel modules with FE-I4b chips (Hybrid)
- Technology used for IBL
- 336 x 80 pixel, 50 x 250 μm^2
- Each pixel of sensor is connected with one channel of FE via Bump-Bond (flip chiping)



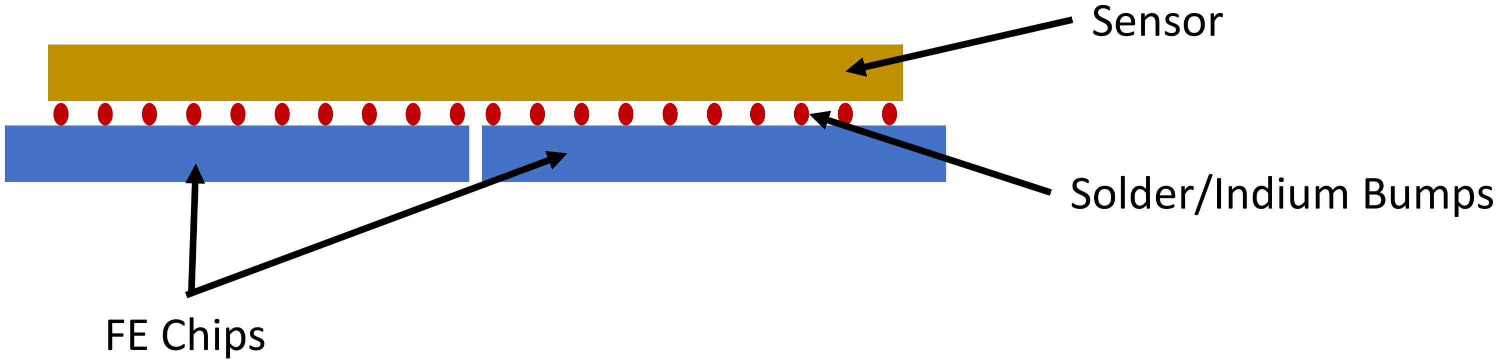
Pixel Detectors for Charged Particles, N. Wermes, arXiv:0811.4577



Quad Chip Module

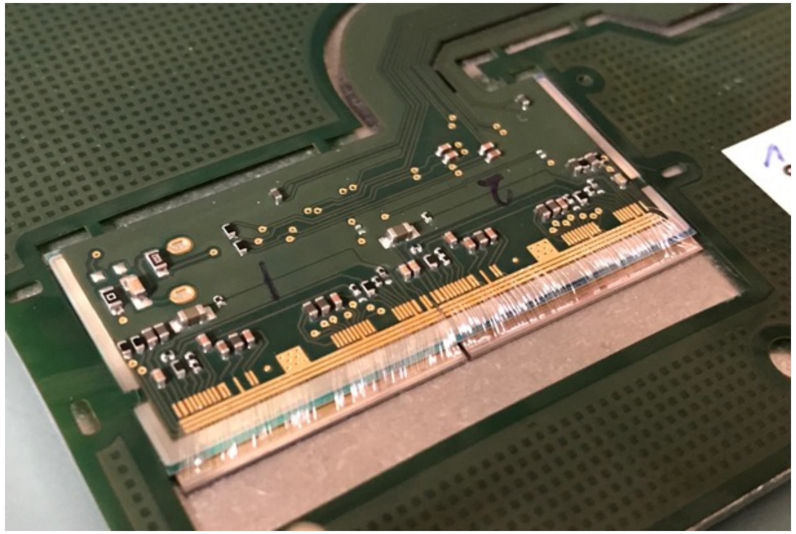


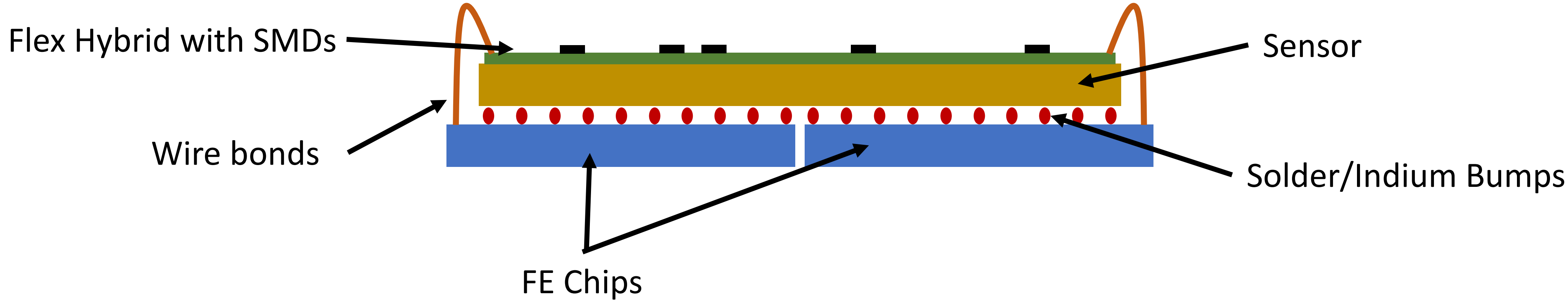
Dual Chip Module



"Dressed" Module

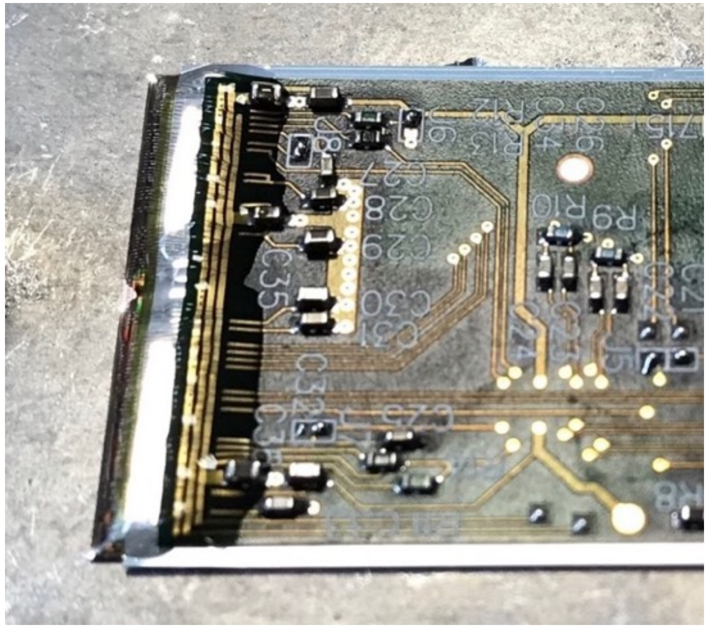
- Attaching flip chipped bare module to module flex
- Using UHU Endfest 300 epoxy for physical attachment of the components
- Wirebonding for electrical connection between flex and FEs pads

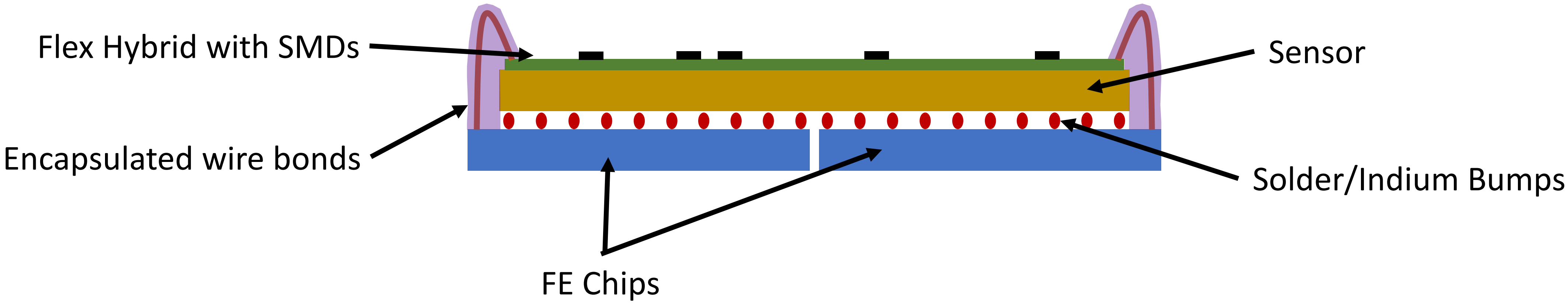




"Potted" Module

- Encapsulation of fragile wirebonds
- Manual and automatic procedure used
- Using Sylgard 186 Silicone Elastomer
- Study ongoing for alternative (combination of parylene and mechanical protection)

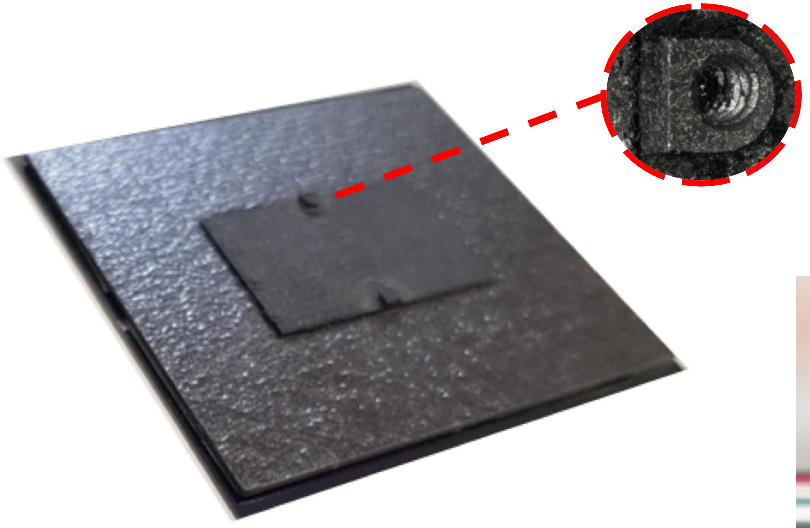


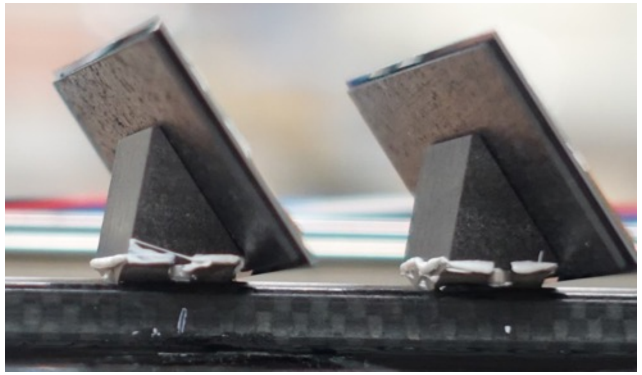


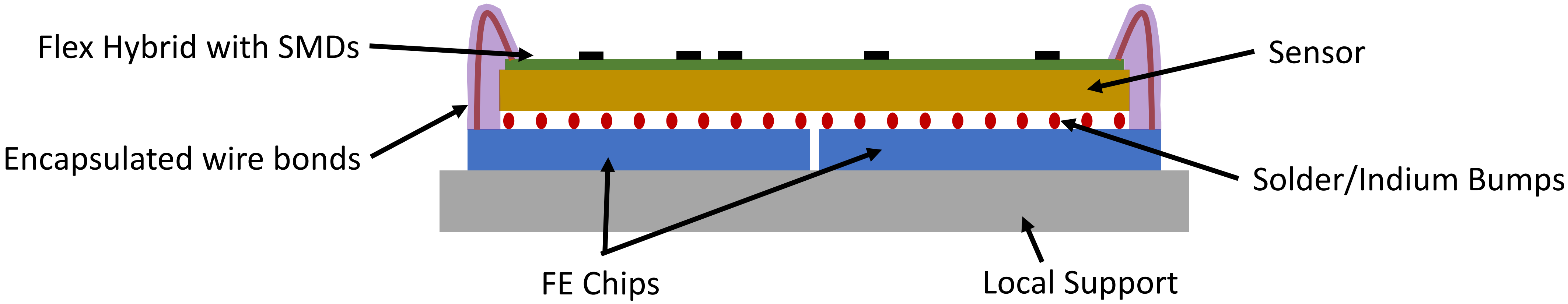
Module Production Steps

“On Cell” Module

- Light graphene interface to connect module with carbon support
- Used for mounting and cooling
- Good thermal contact
- Flat and inclined cells

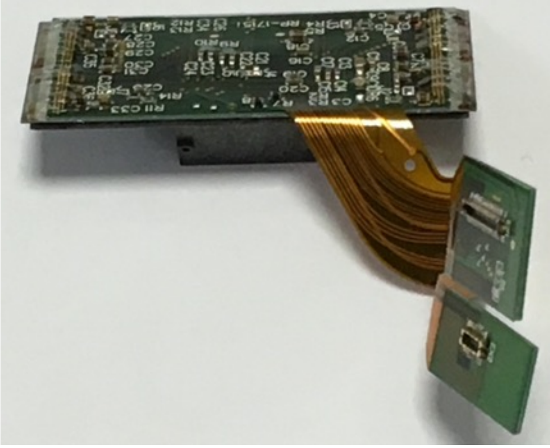




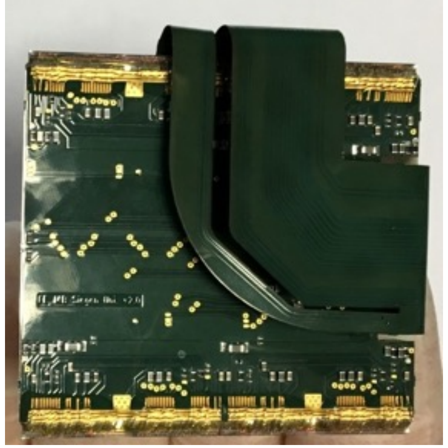


Module Production Steps

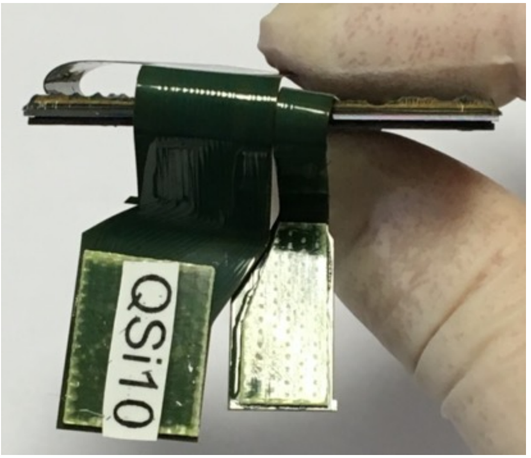
"Bent" Module



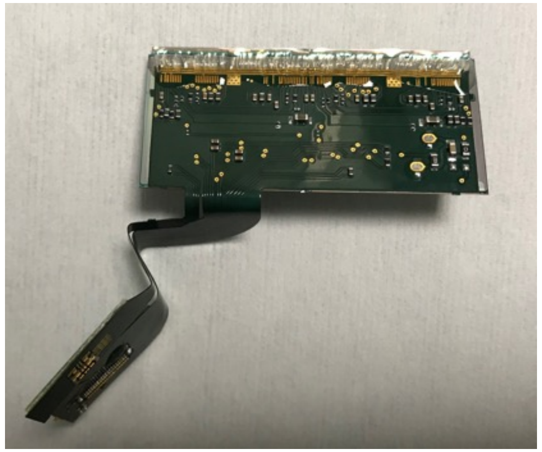
A-side Dual



Quad

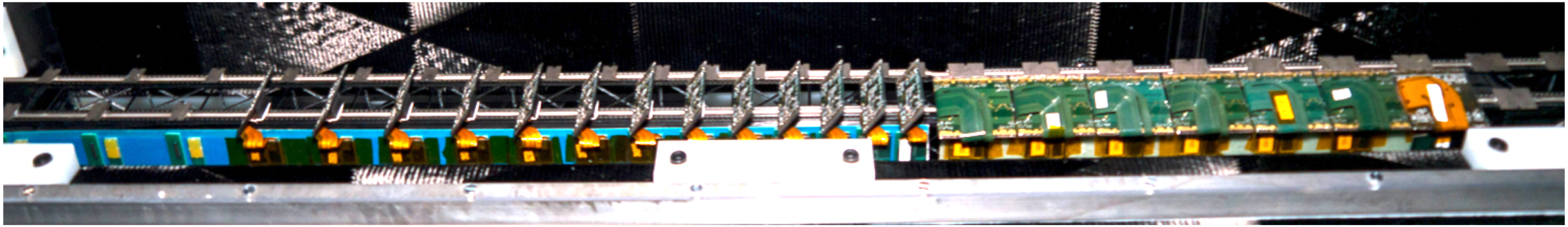


Quad (side view)



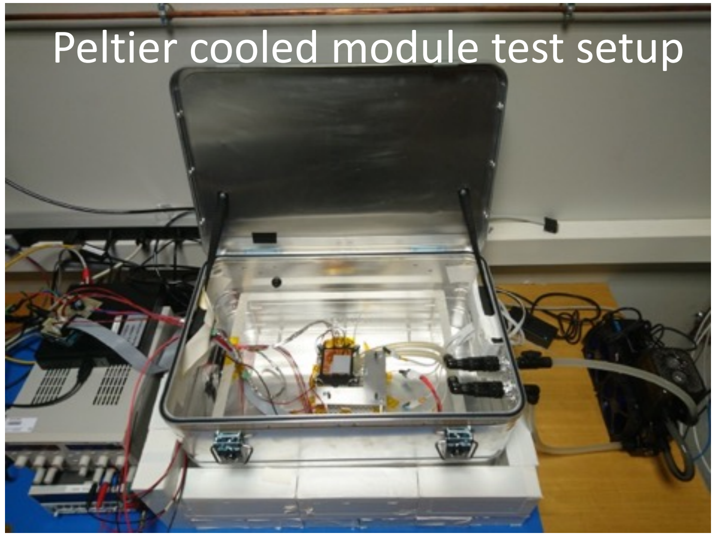
C-side Dual

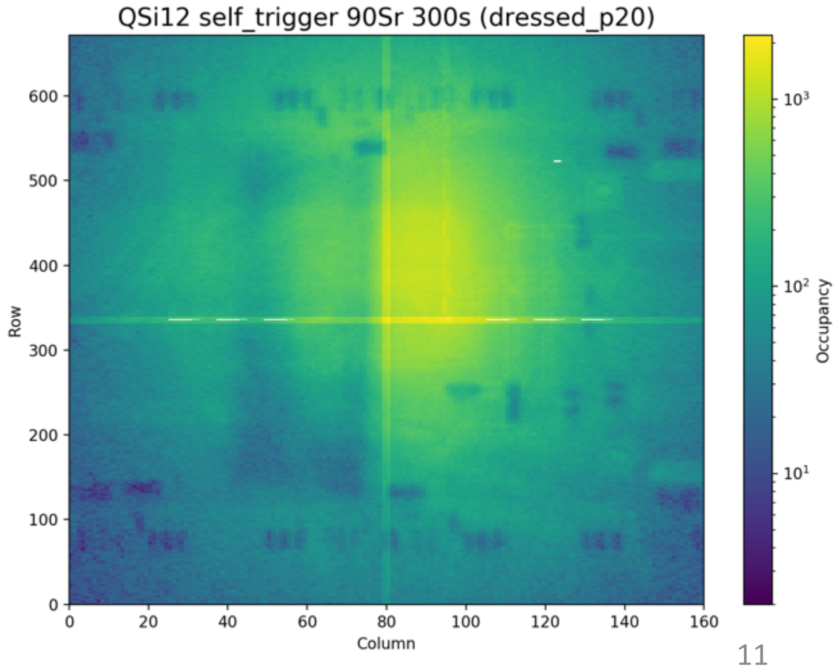
"Integrated" Module



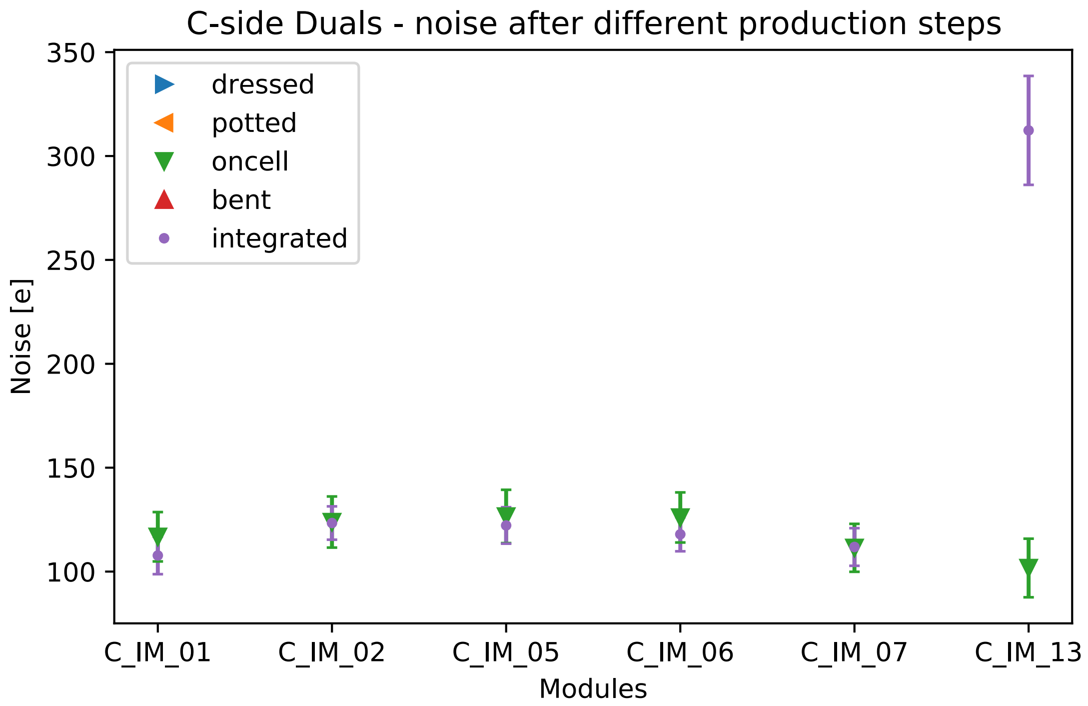
Module Testing

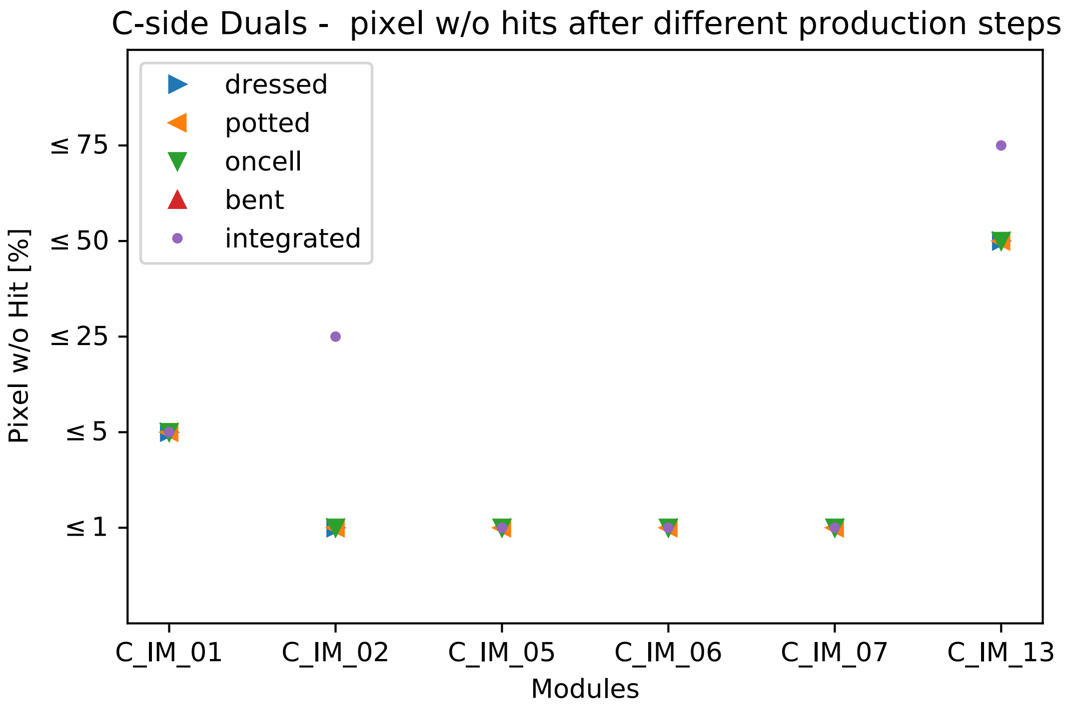
1. **Visual inspection**
2. **IV curve**
3. **Tuning**
4. **Scans:**
   - Digital Scan, Analog Scan, Threshold Scan, Stuck Pixel Scan, Noise Occupancy Tuning, Hot Pixel Tuning
   - Source Scan with ^{90}Sr source





- ○ Modules are operated in a controlled environment :
  - Dry air
  - Cooling
- ○ Modules powered in constant current mode



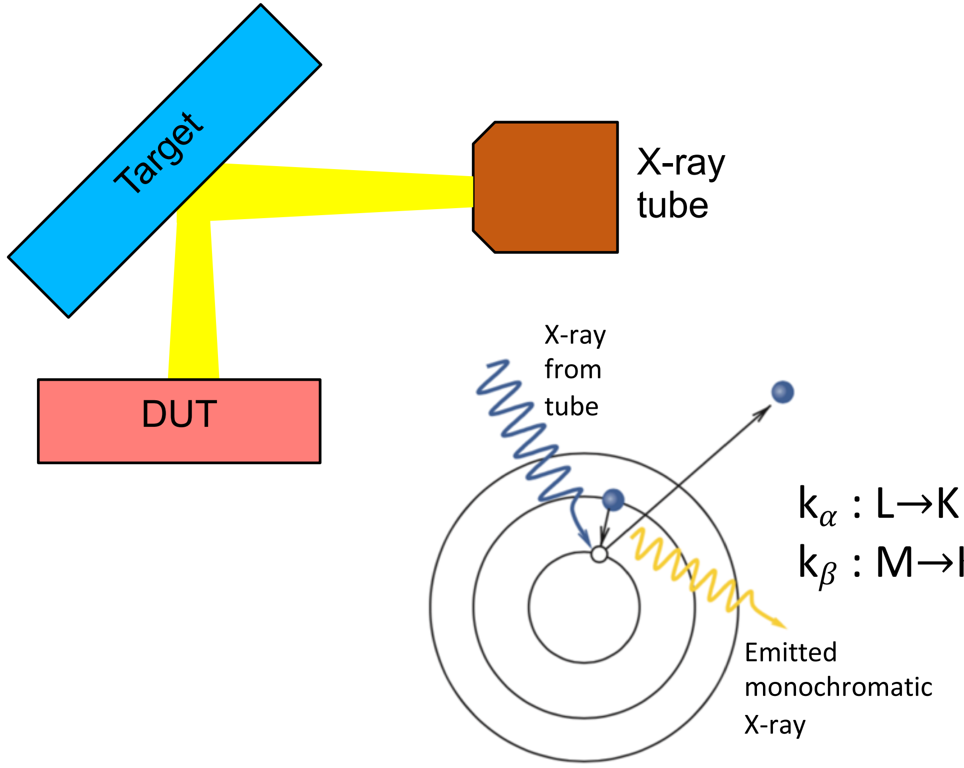


- Systematic study showing good results
- In total 40 Quads and 48 Duals were produced and tested

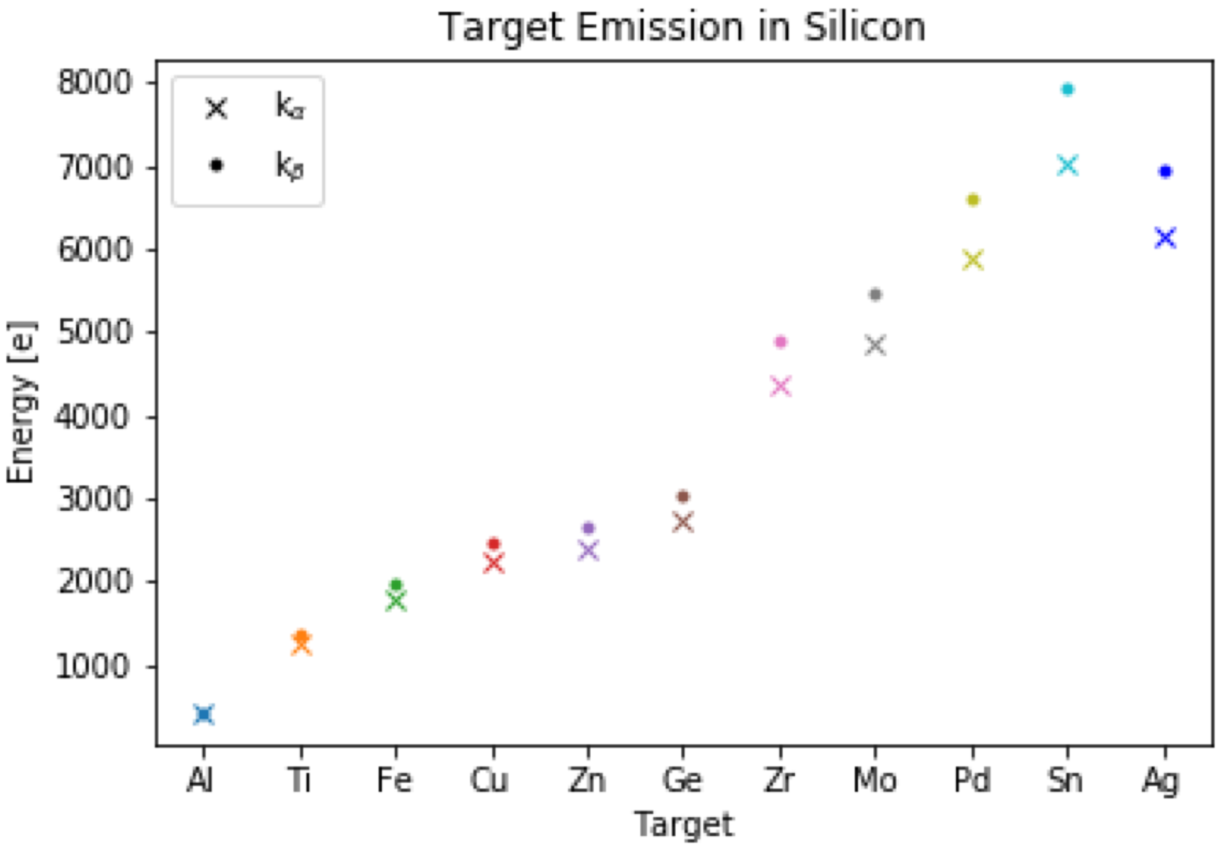
Characterization of RD53A pixel modules using X-Ray Fluorescence

X-Ray Fluorescence Method

- Method to calibrate and study the linearity of response of new pixel modules in the lab
- Allows measurement of charge spectra and energy resolution



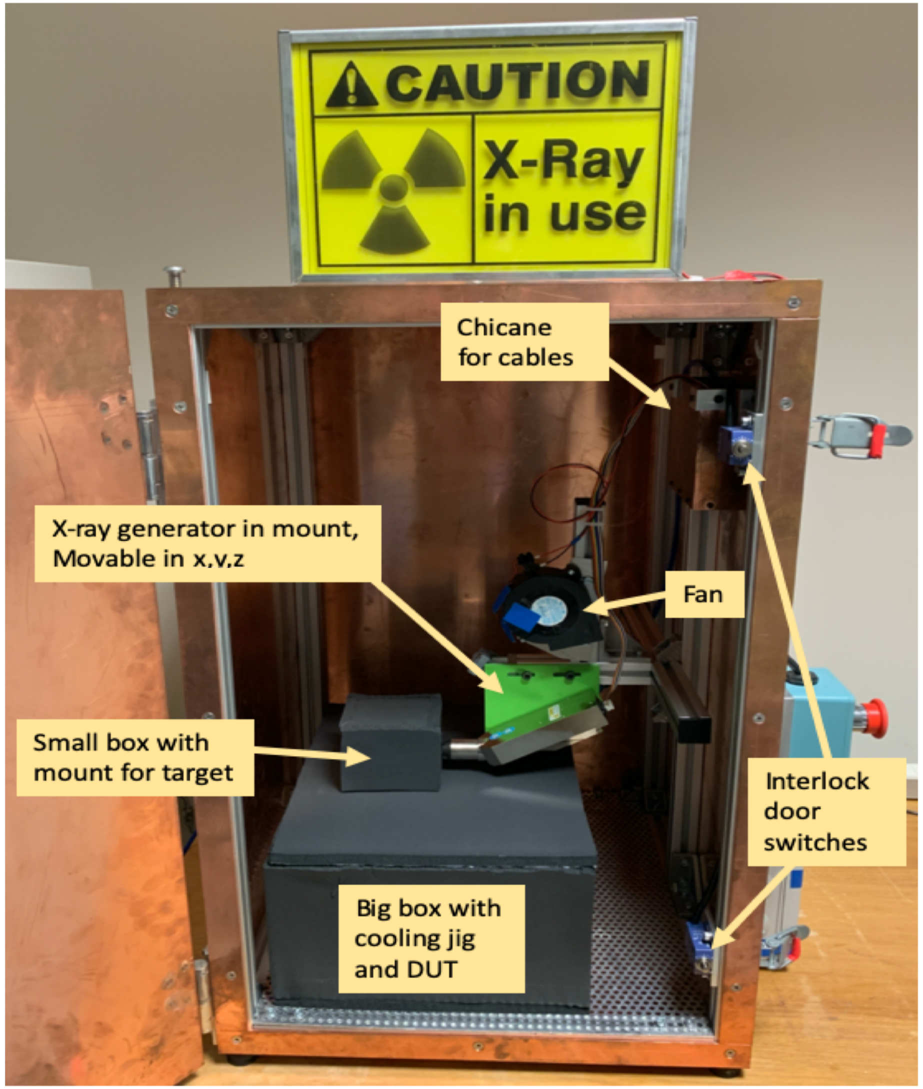
k_α : L→K
k_β : M→K

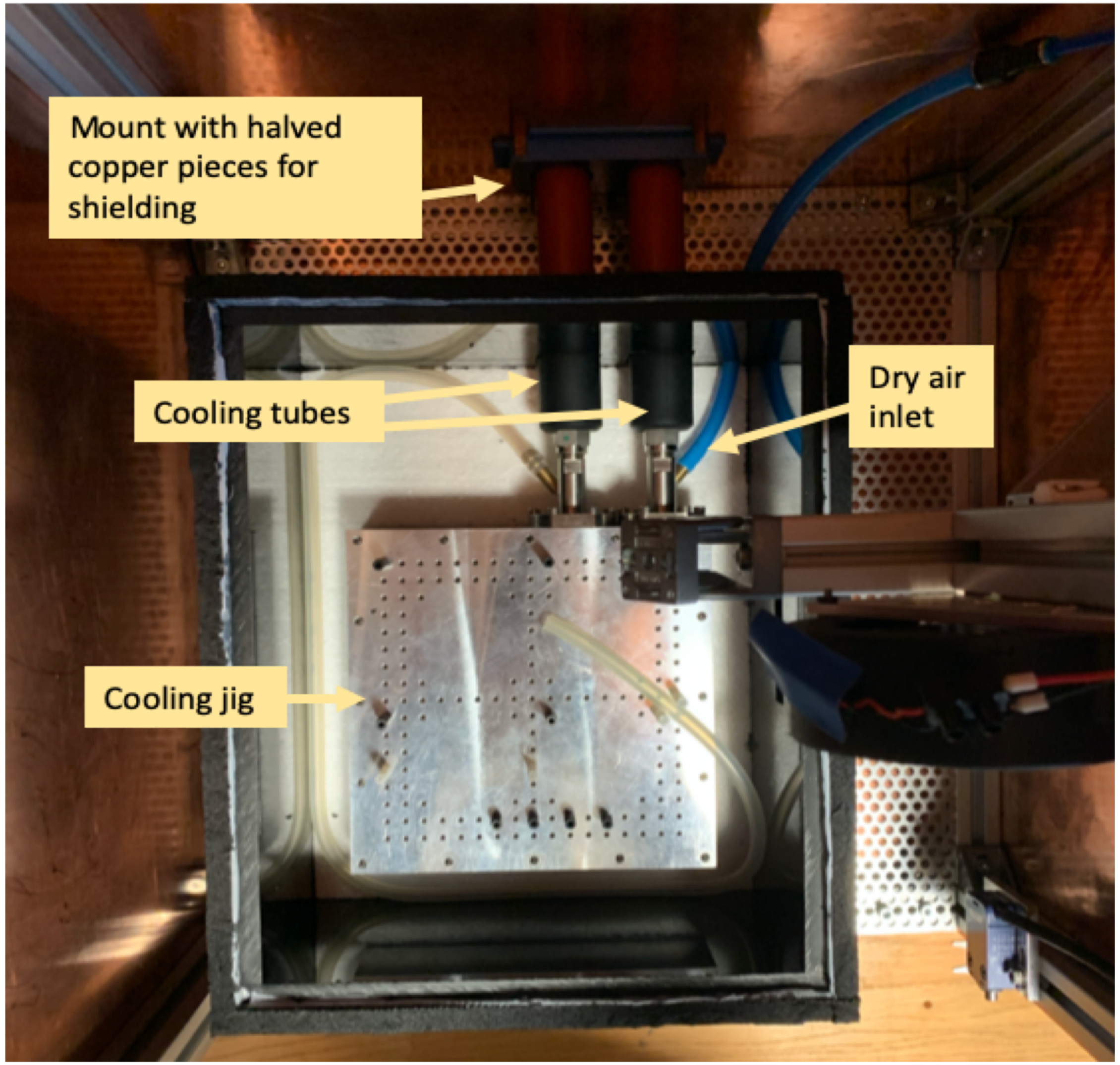


X-Ray Data Booklet, A. Thompson et al, October 2009

- **Targets:** Aluminum (Al), Titanium (Ti), Iron (Fe), Copper (Cu), Zinc (Zn), Germanium (Ge), Zirconium (Zr), Molybdenum (Mo), Palladium (Pd) and Tin (Sn)
- Amptek Mini-X2 X-ray tube (50kV, 200 μA, 4W, Ag)

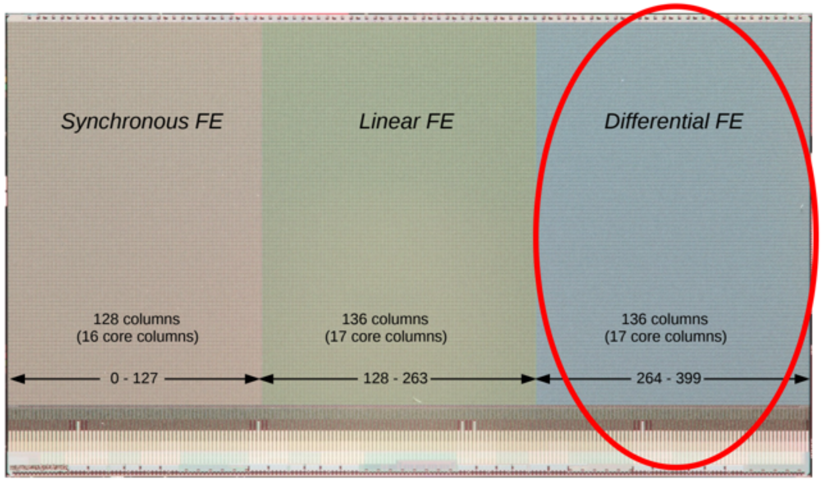
X-Ray Fluorescence Setup



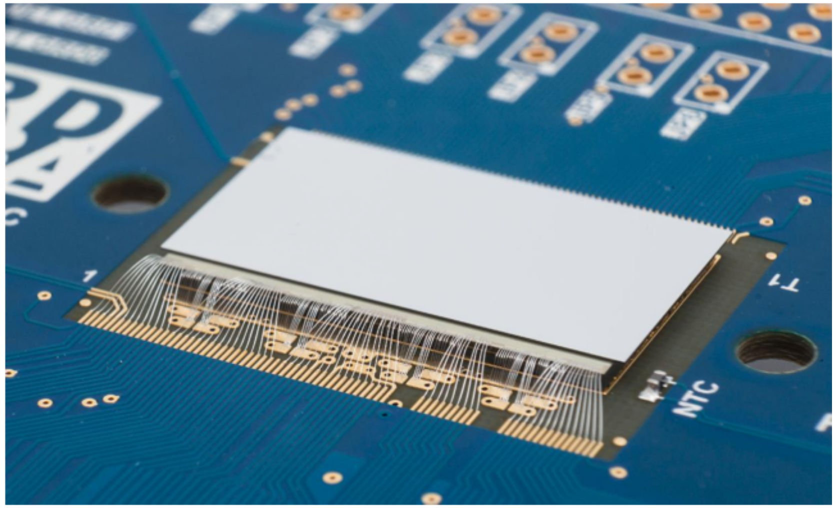


RD53A Module

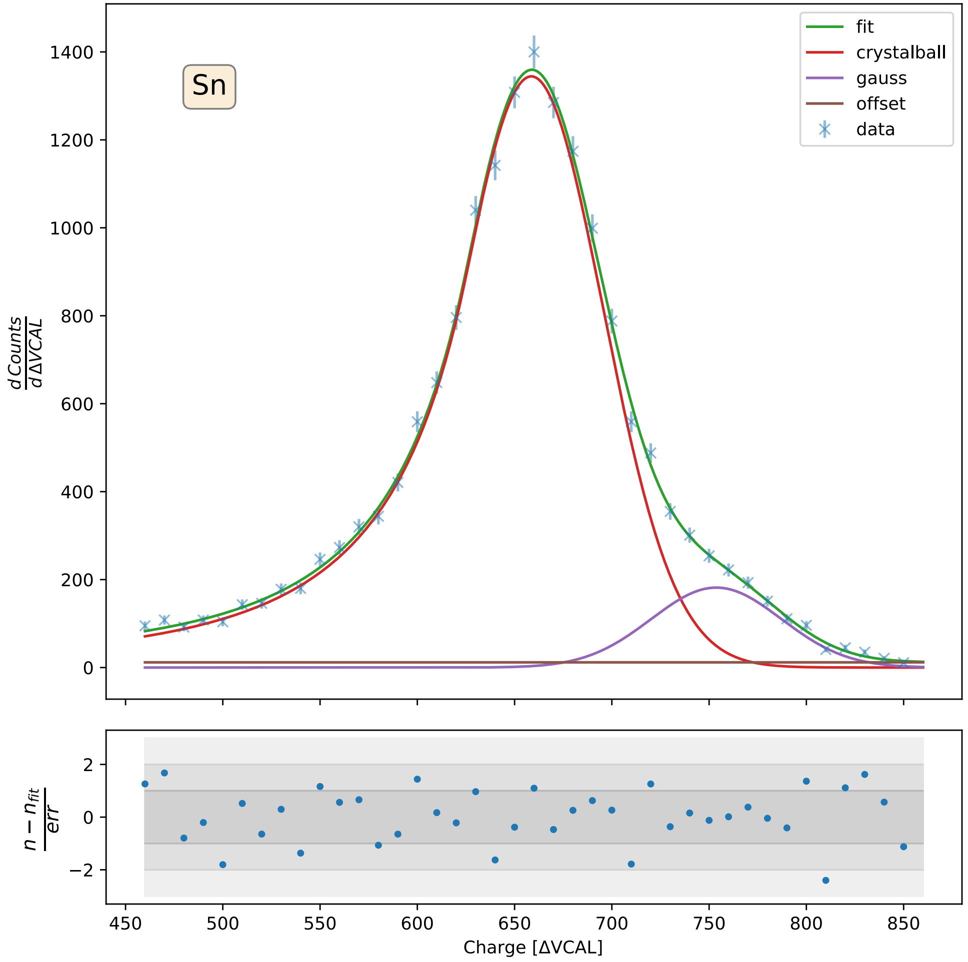
- Future readout chip for ATLAS and CMS pixel detectors
- Developed by RD53 collaboration
- RD53A (half size chip): 400 x 192 pixel, 50 x 50 μm^2
- FE separated in 3 parts with different analog flavors
- ATLAS has chosen Differential FE

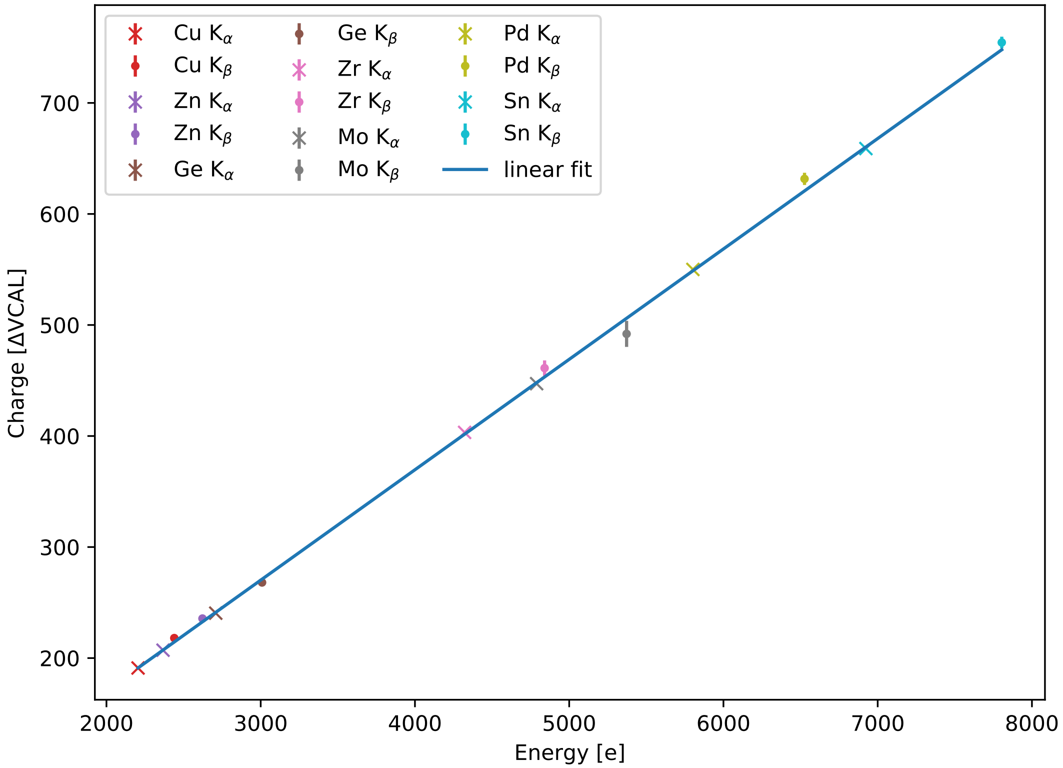


Technical Data:
- High hit rate: 3GHz/cm² (FE-I4:400 MHz/cm²)
- High trigger rate: 1 MHz with 12.8 µs latency
- Data rate up to 5.12 Gbit/s per chip
- Low threshold ~600e
- 500 Mrad radiation tolerance
- Low power: ~4µA/pixel (analog/digital)



Tuning: 1000e Threshold, 10ToT@8ke





fit = crystalball(k_α) + gauss(k_β) + offset

- ΔV_{CAL} is internal energy unit of RD53A chip
- Energy [e] = 10.06 e/ΔV_{CAL} * Charge [ΔV_{CAL}] + 282.84 e

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Summary and Outlook

Summary:

- Systematic investigation of new pixel modules for the upgrade of the pixel detector of the ATLAS experiment
- Assembly and testing of many modules through production flow
- Collected experience and lessons learnt in distributed production flow and resulted in optimization of all production steps
- Large variations in noise and number of pixel w/o hit due to the production steps have not been observed
-
- For further investigation of new pixel modules built and commissioned X-ray Fluorescence setup which can be operated at temperatures low as -35 °C
- Energy calibration conducted for unirradiated RD53A pixel module

Outlook:

- Energy calibration of irradiated RD53A pixel modules and new pixel modules using X-Ray Fluorescence

Backup

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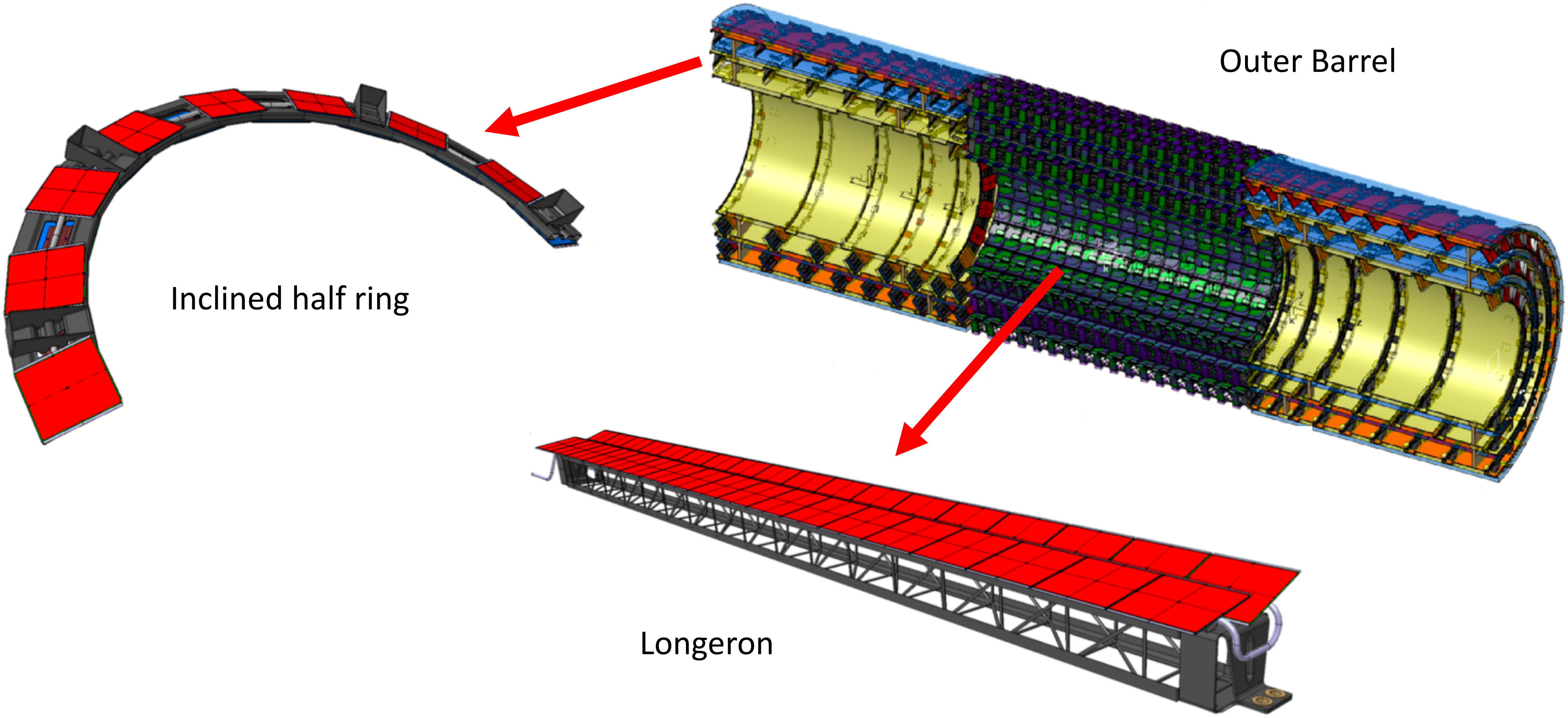
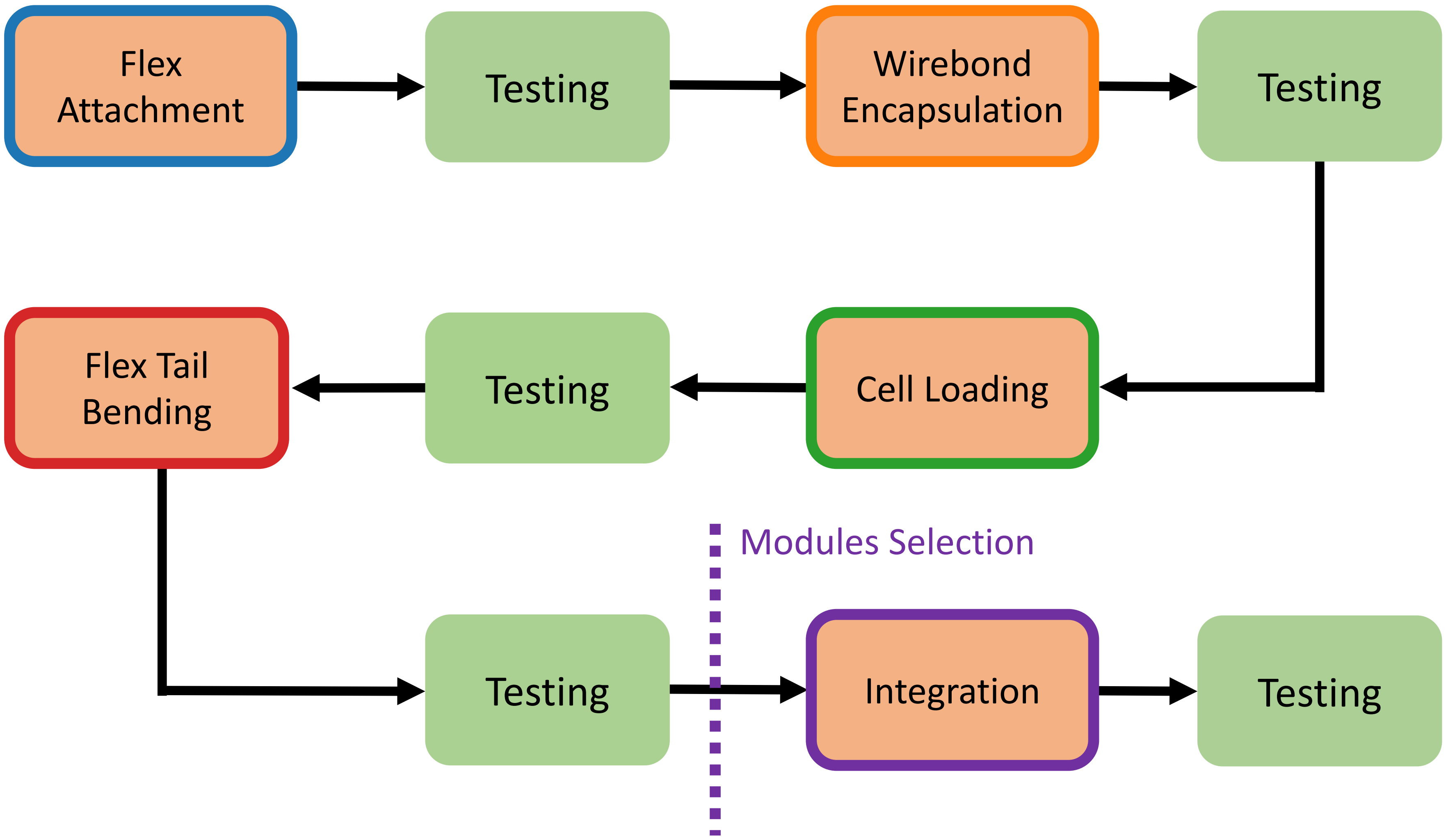
Outer Barrel System



Path of the Modules



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Noise after different production steps

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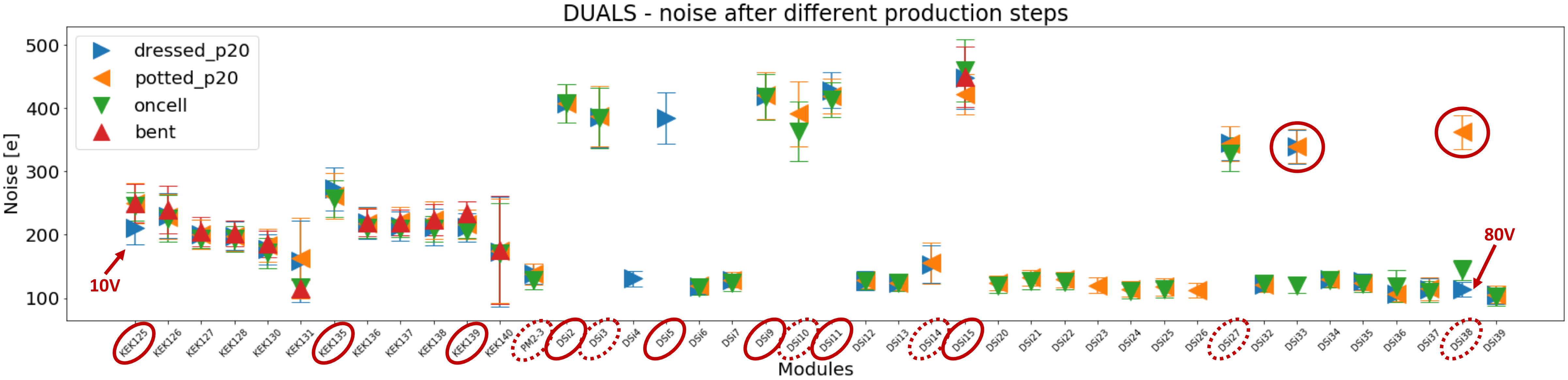
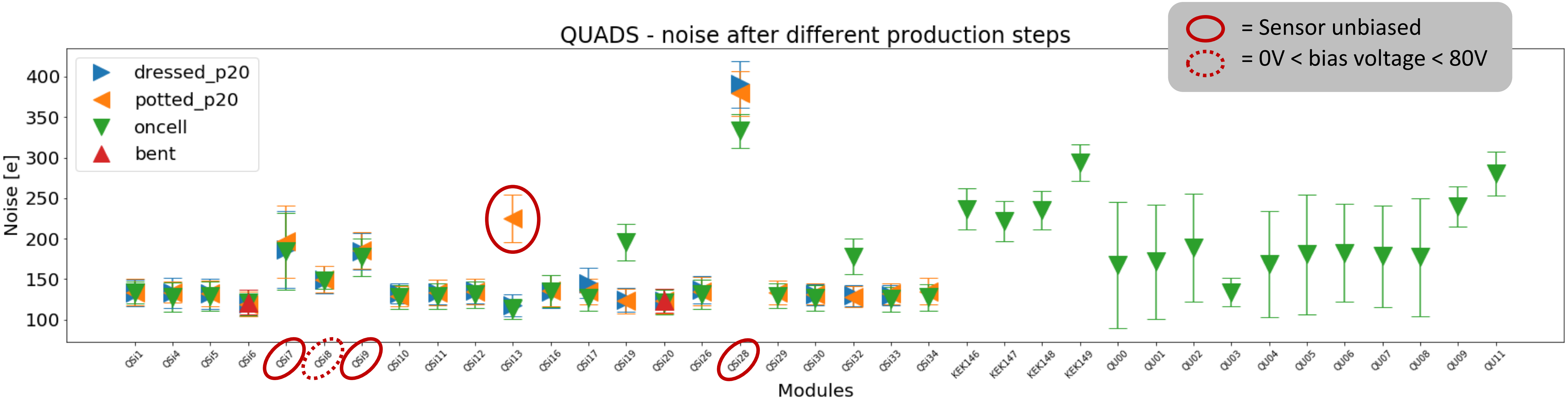
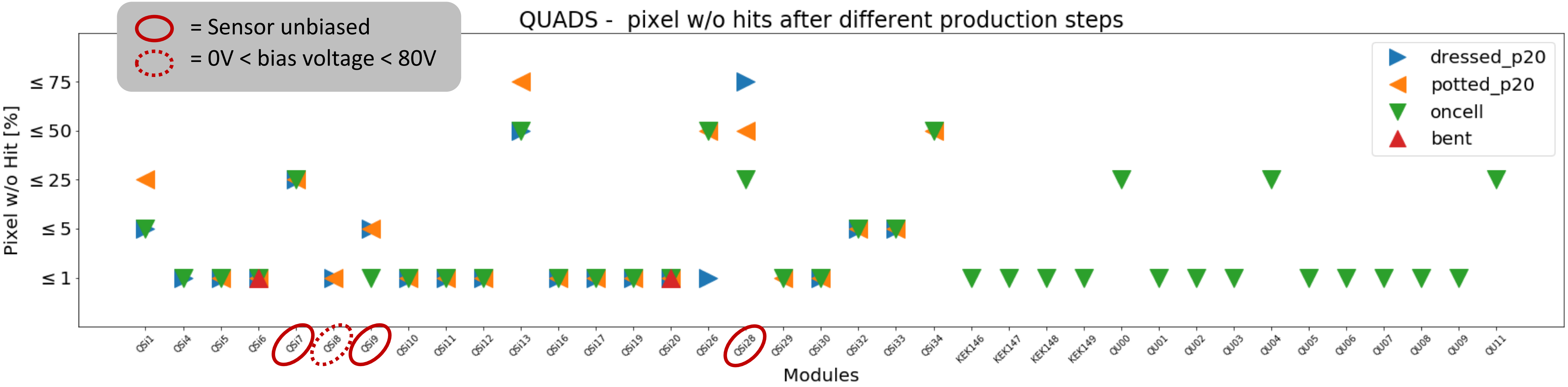
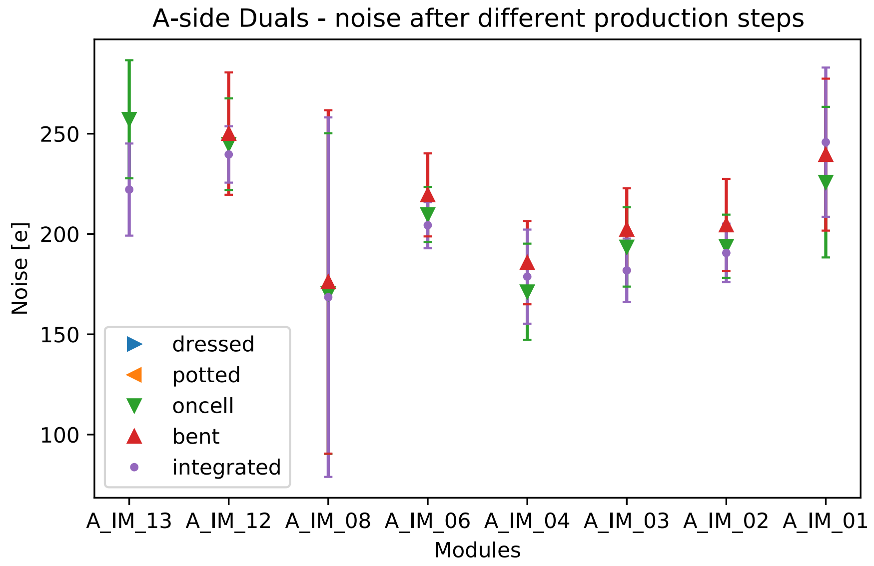


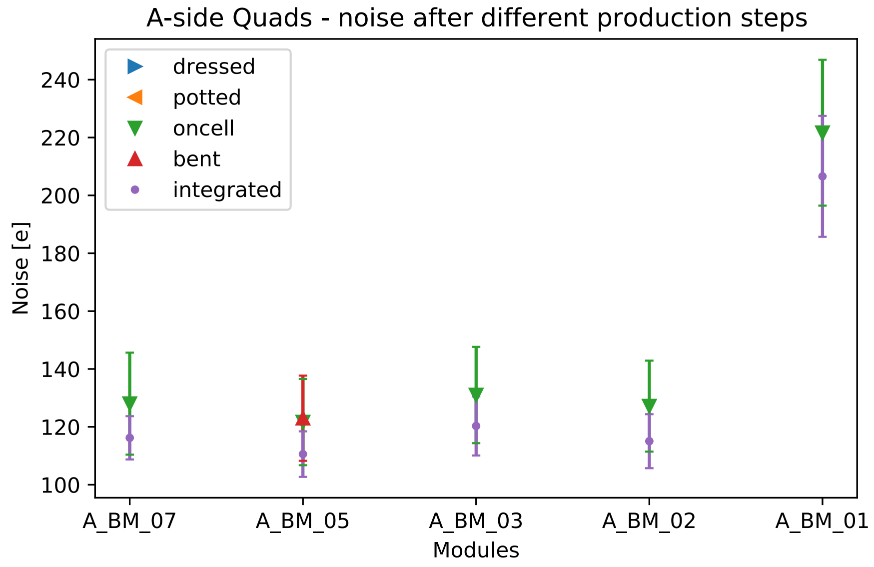


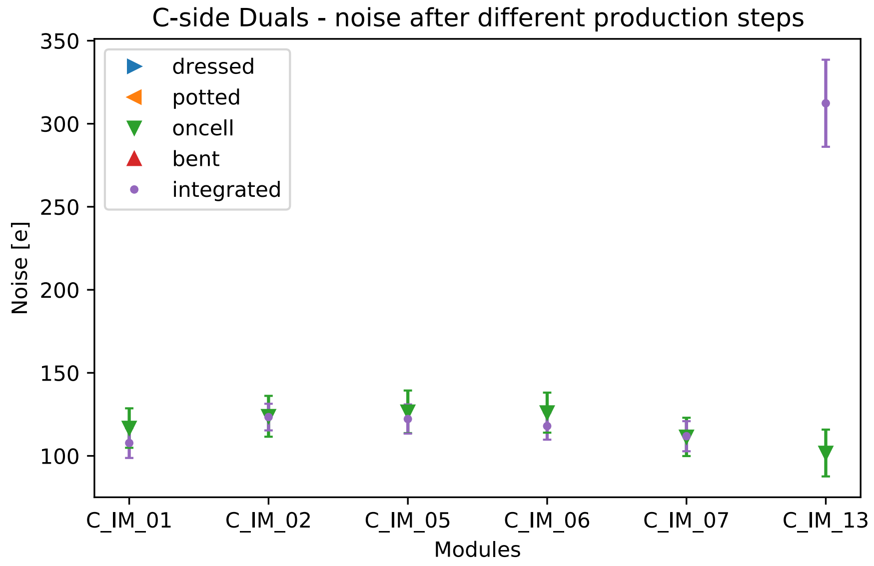
Pixel w/o hits after different production steps

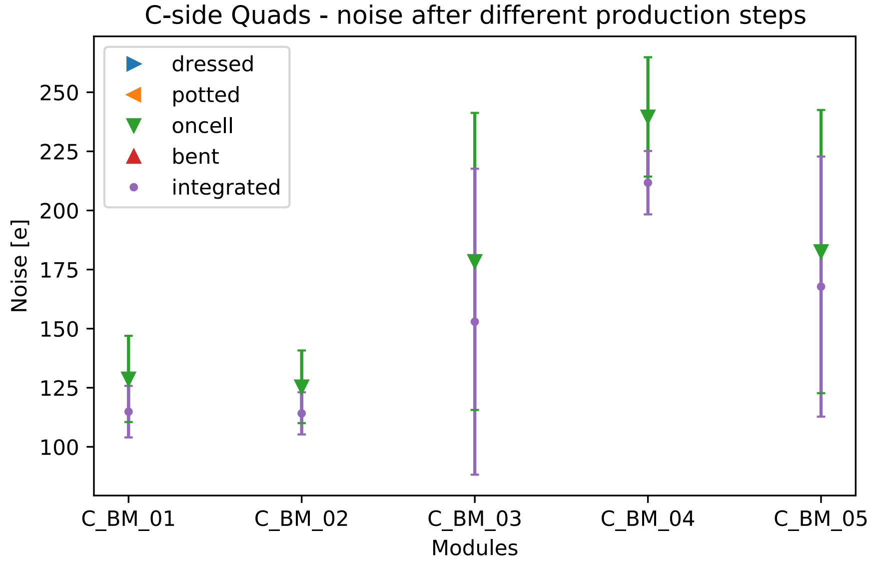


Noise after different production steps









Pixel w/o hits after different production steps