VERVE

Vertexing in Extreme Radiation & Vacuum Environment

<u>Participating institutes</u>

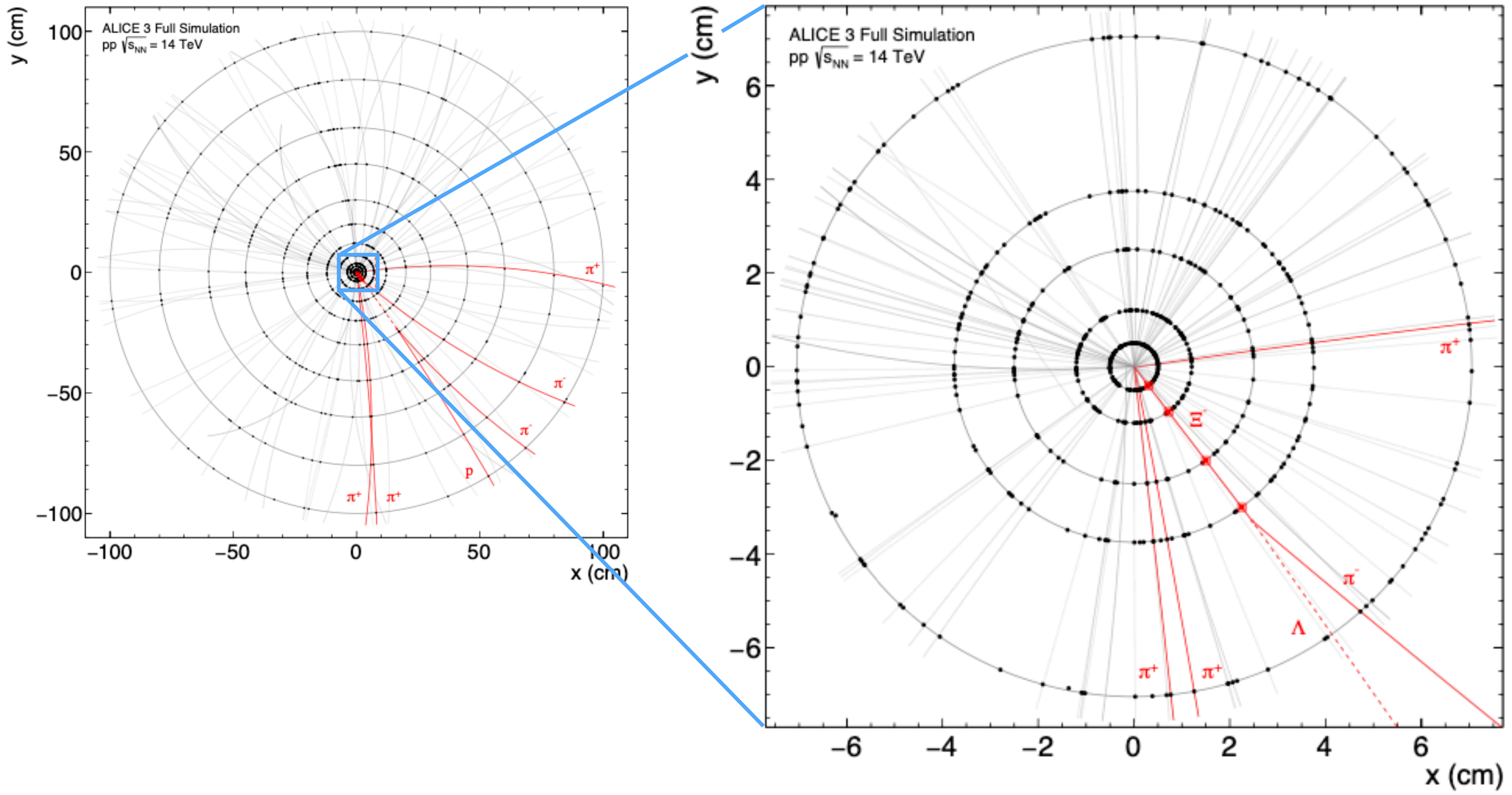
CERN and INFN (Bari, Cagliari, Catania, Frascati, Padova, Torino, Trieste)

<u>Project leaders</u>

Domenico Colella (University and INFN Bari, Italy)
Jochen Klein (CERN)

Introduction

What is needed to fully exploit potential of LHC?

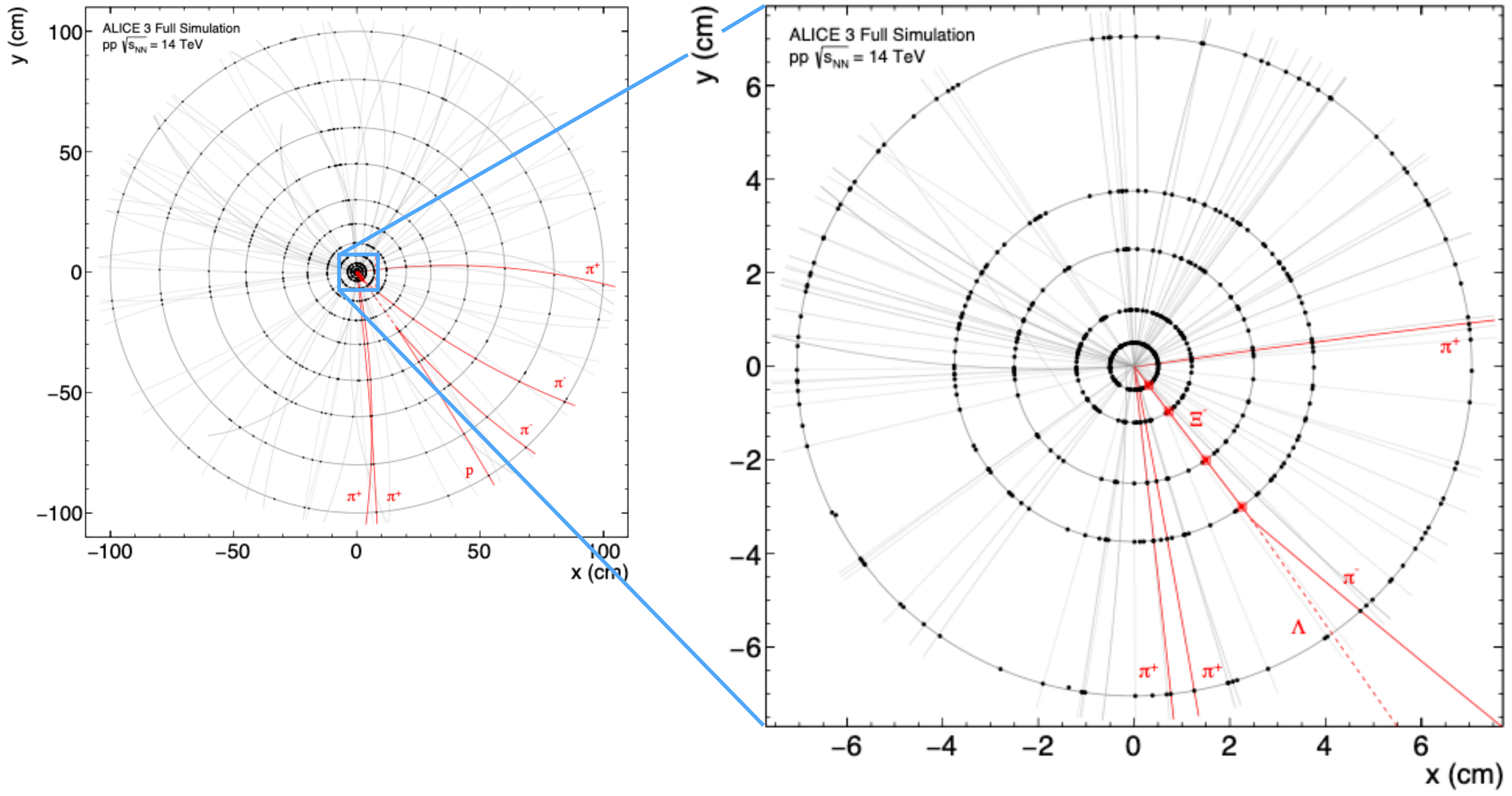


- LHC provides ideal and **unique environment to study hot QCD** matter and multi-charmed baryon production is a key tool
- Present devices are insufficient
  - Complex multi-stage decay chain in a track-dense environment
    → Small signal in large combinatorial background
  - Reconstruction of decay vertices is crucial

Introduction

What is needed to fully exploit potential of LHC?

- LHC provides ideal and **unique environment to study hot QCD** matter and multi-charmed baryon production is a key tool
- Present devices are insufficient
  - Complex multi-stage decay chain in a track-dense environment
    → Small signal in large combinatorial background
  - Reconstruction of decay vertices is crucial



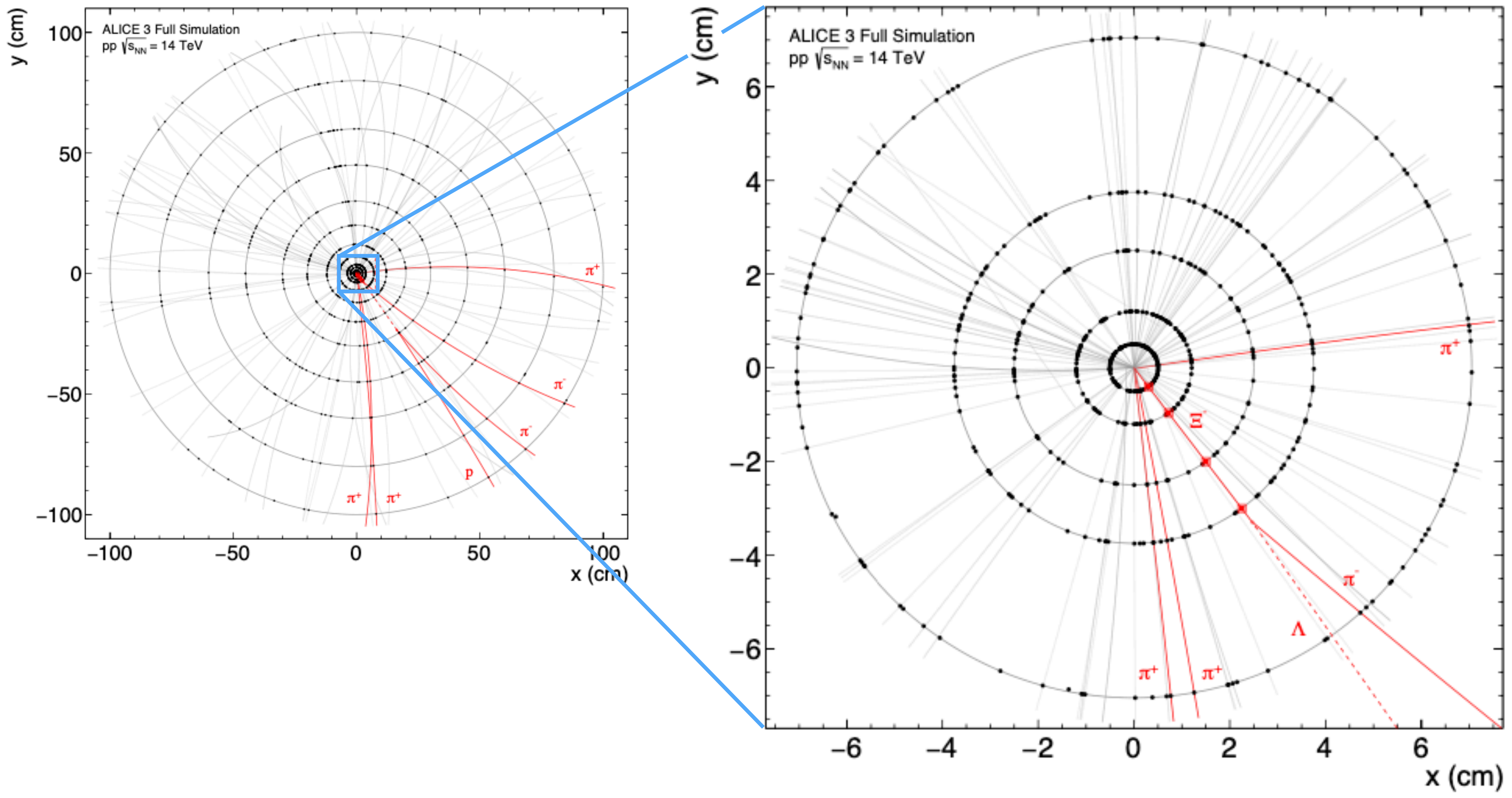
- Two required conditions to improve pointing resolution and allow such a measurement:
  - Reduce material budget
  - Reduce distance of first layer from interaction point

VERVE
Vertexing in Extreme Radiation & Vacuum Environment

Introduction

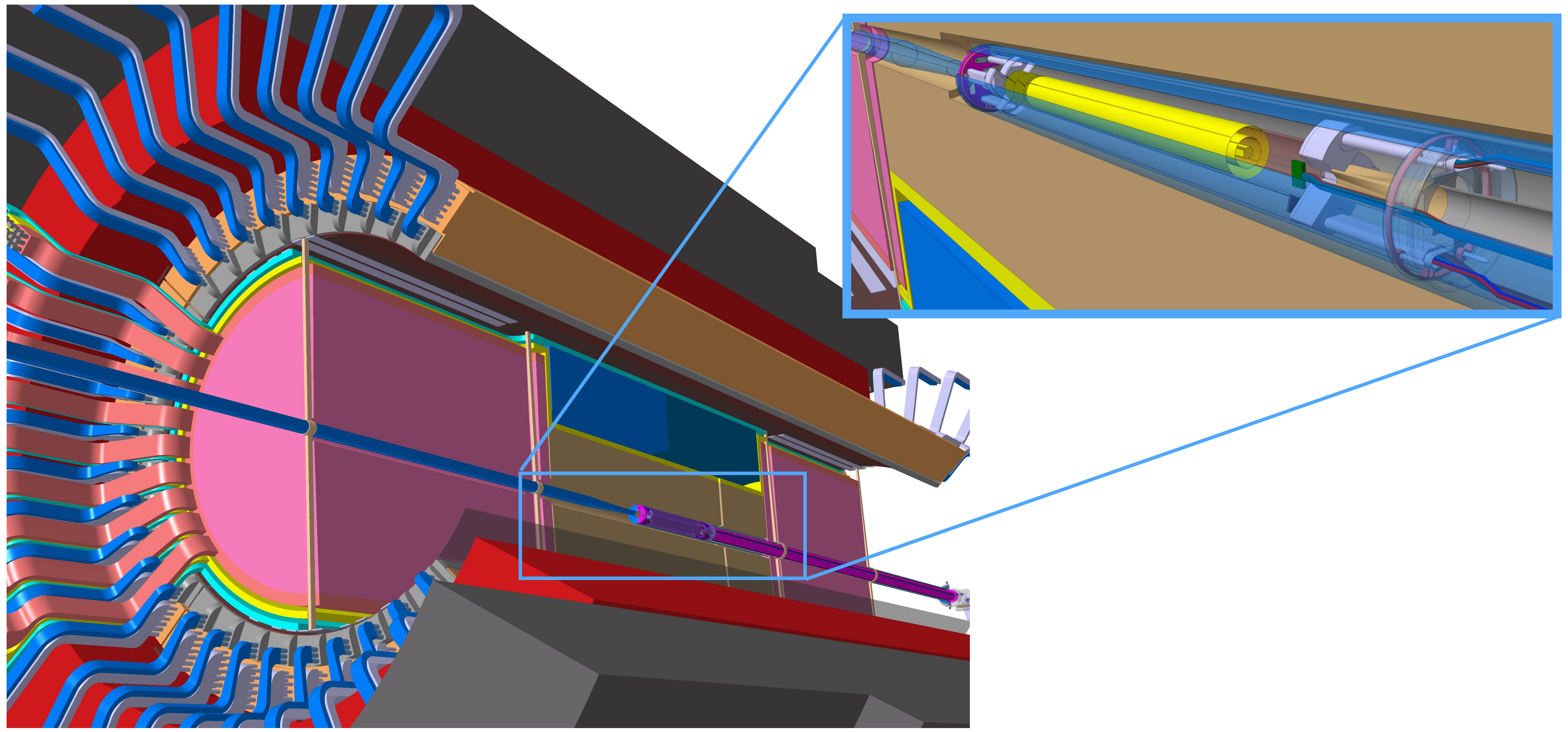
What is needed to fully exploit potential of LHC?

- LHC provides ideal and **unique environment to study hot QCD** matter and <u>multi-charmed baryon</u> production is a key tool
- Present devices are insufficient
  - Complex multi-stage decay chain in a track-dense environment
    → Small signal in large combinatorial background
  - Reconstruction of decay vertices is crucial



- Two required conditions to improve pointing resolution and allow such a measurement:
  - Reduce material budget
  - Reduce distance of first layer from interaction point

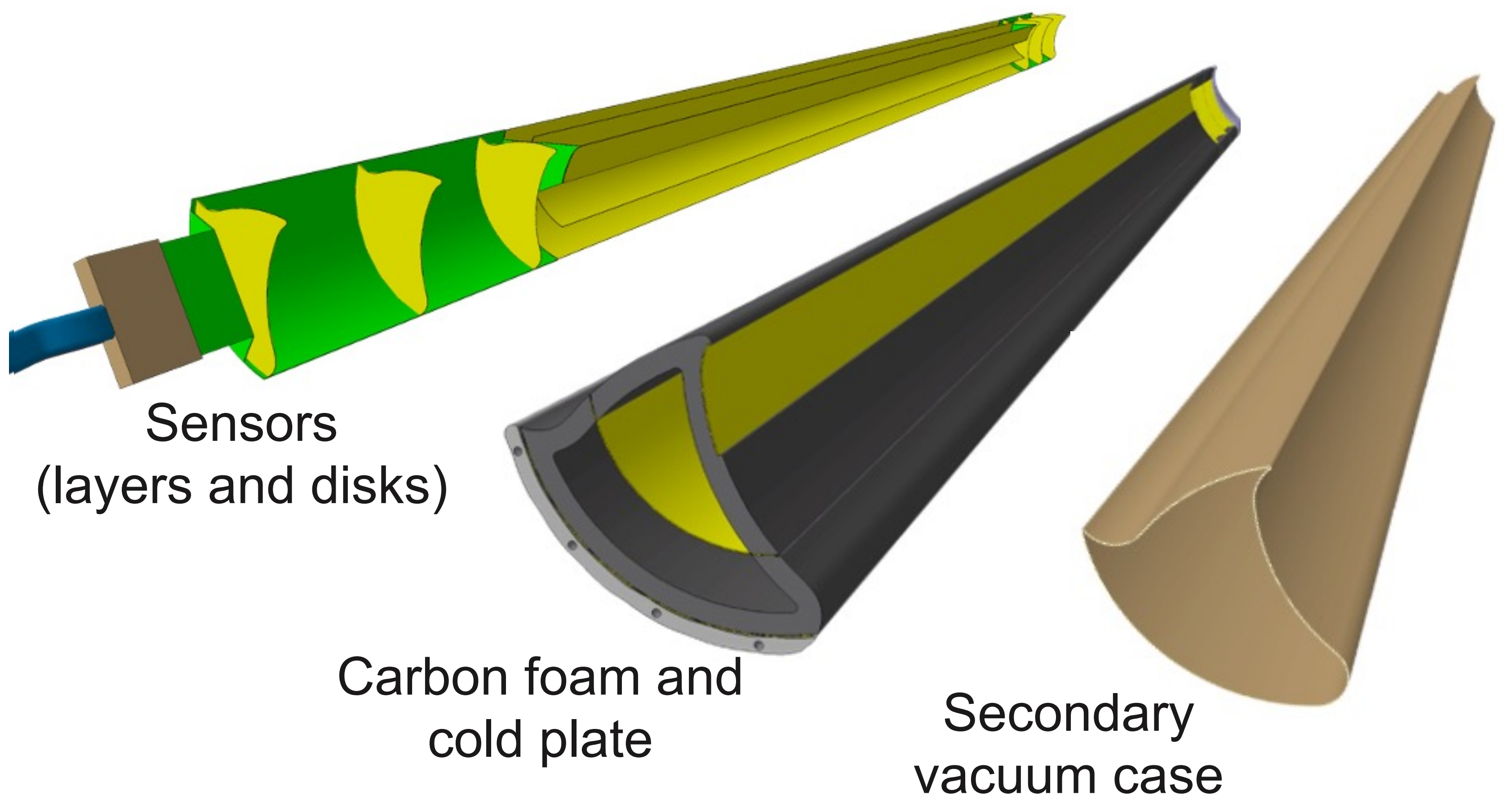
Move a light-weight vertex detector inside the beam-pipe



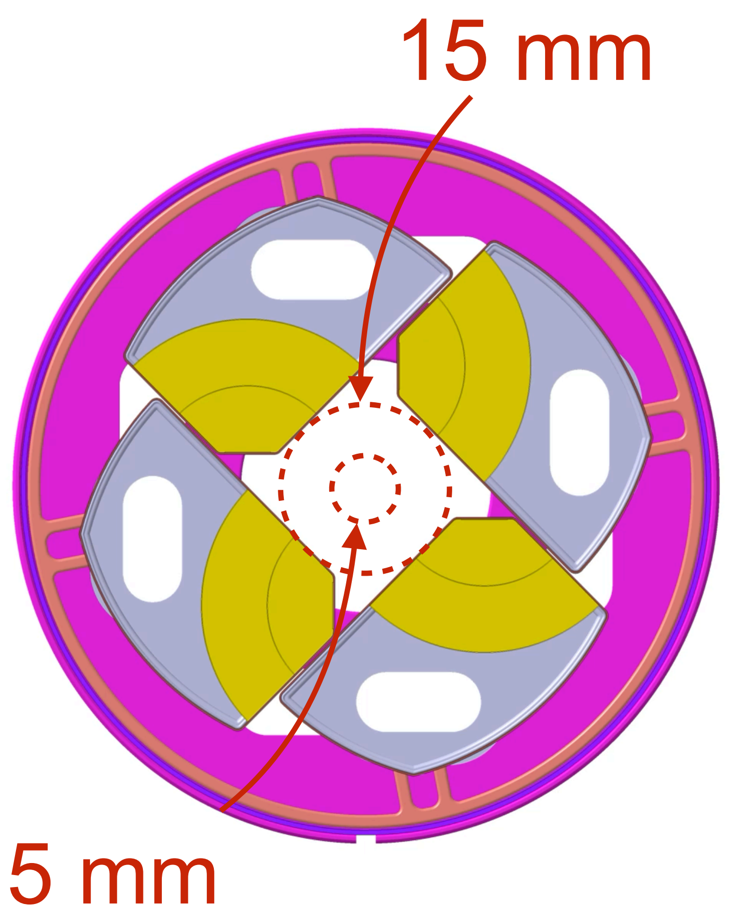
Introduction

- Technical requirements
  - Bent thin sensors supported by light material (e.g. carbon foam) [mastered within the ITS3 project]
  - Sensors and services integrated in vacuum
  - Movable components to reach minimum distance to primary vertex only during stable beams
  - Sensor performance under high radiation flux

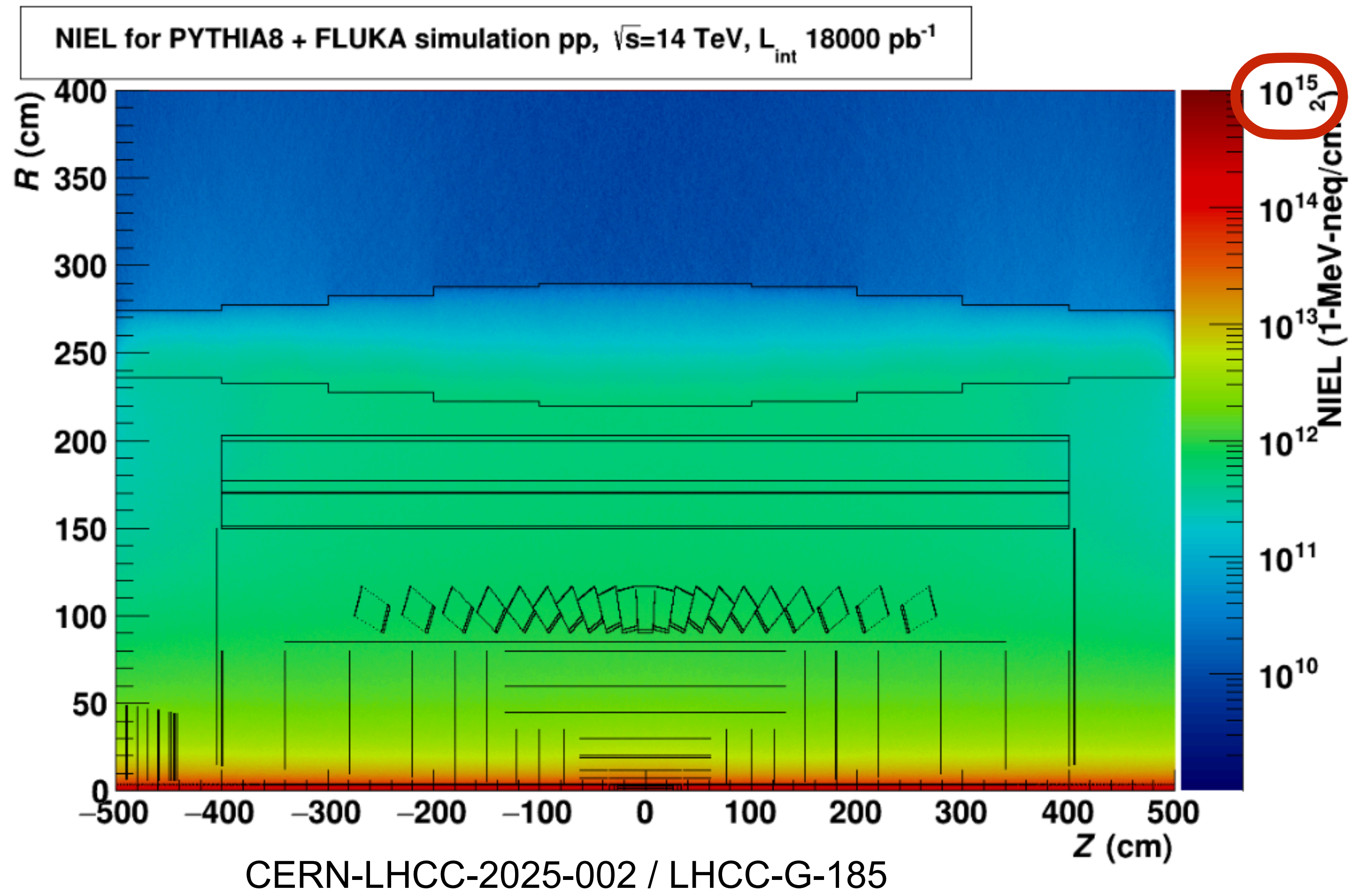
INTEGRATION IN VACUUM



PETALS OPENING/CLOSURE



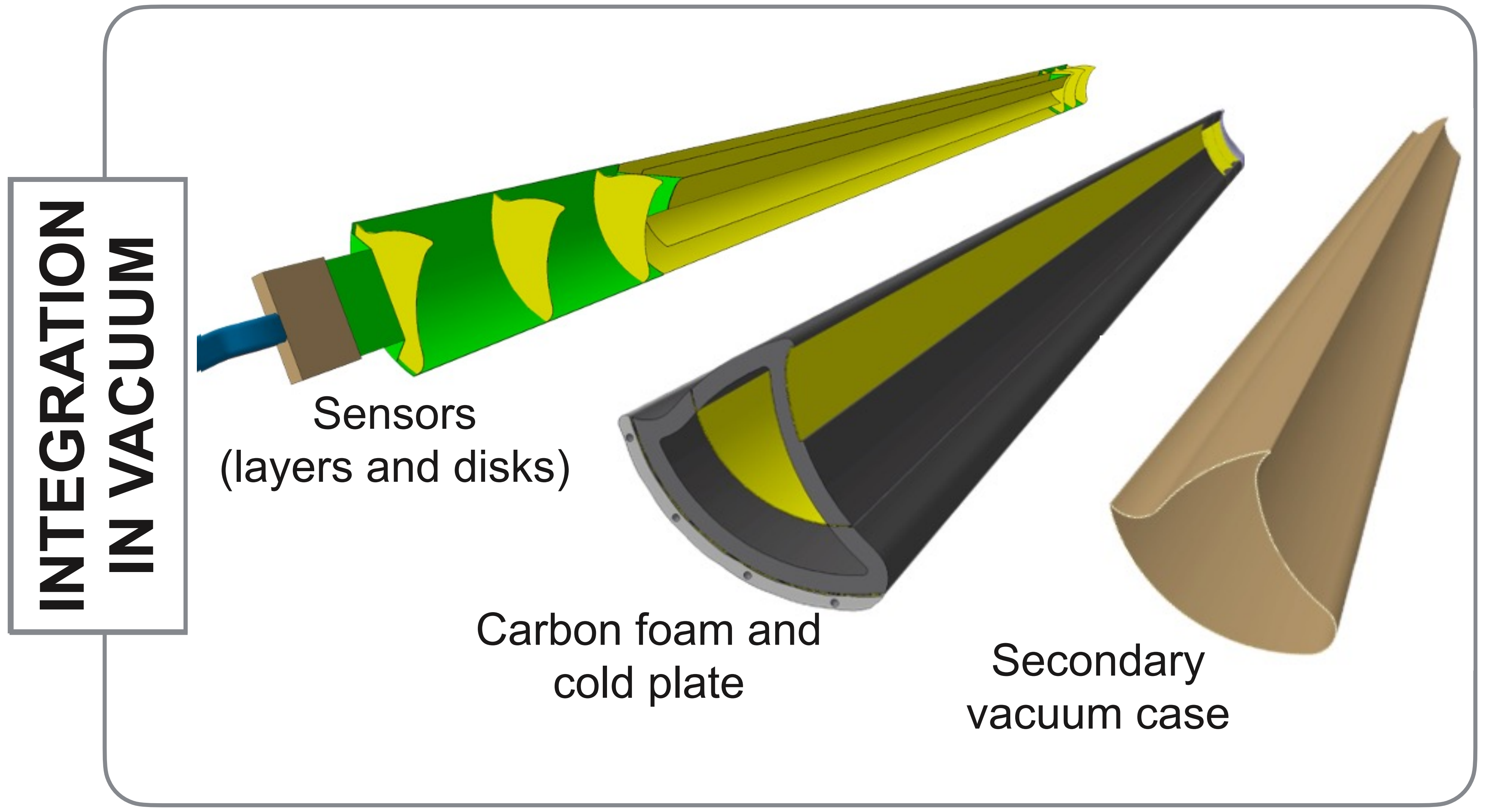
HIGH RADIATION LOAD

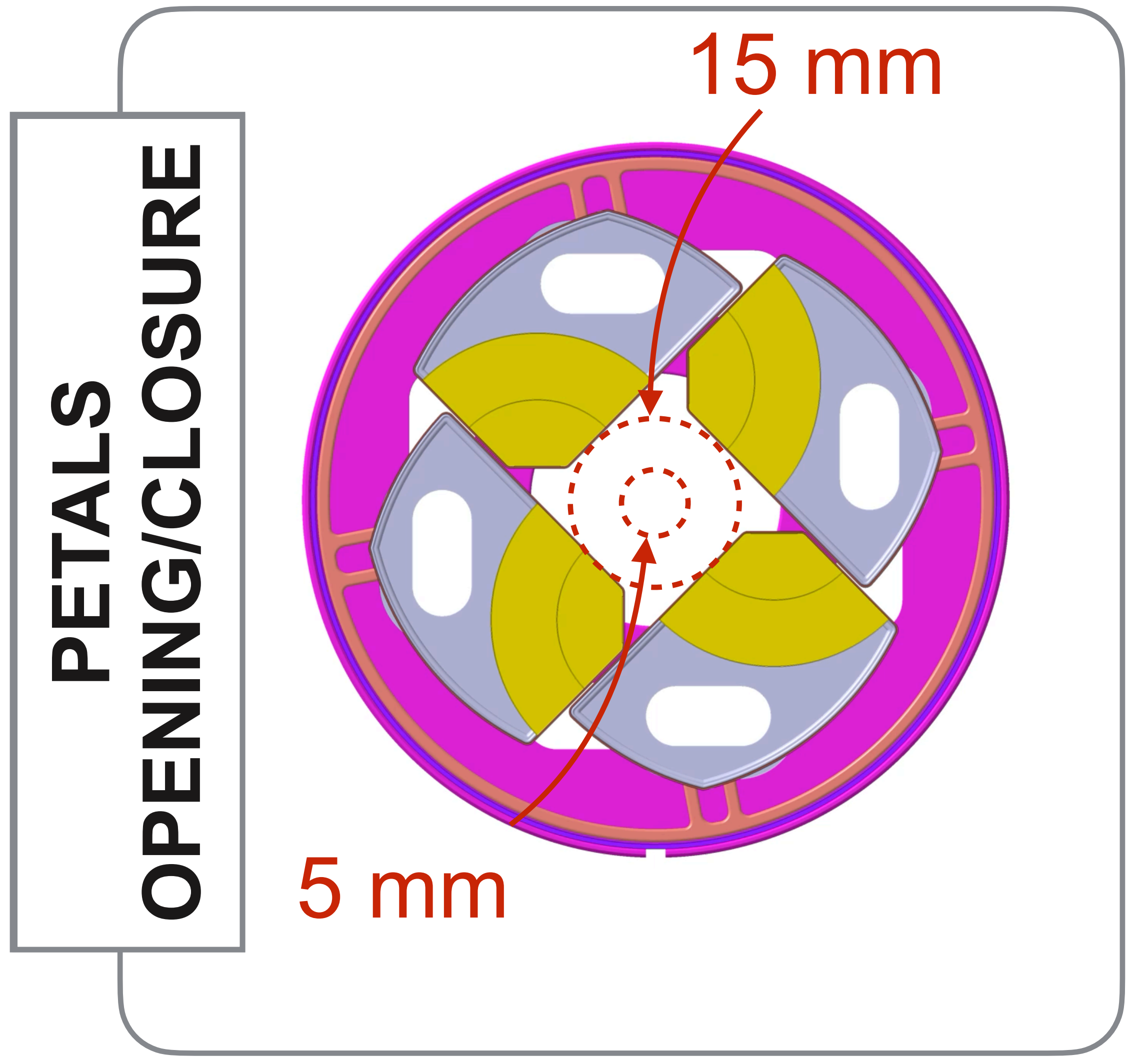


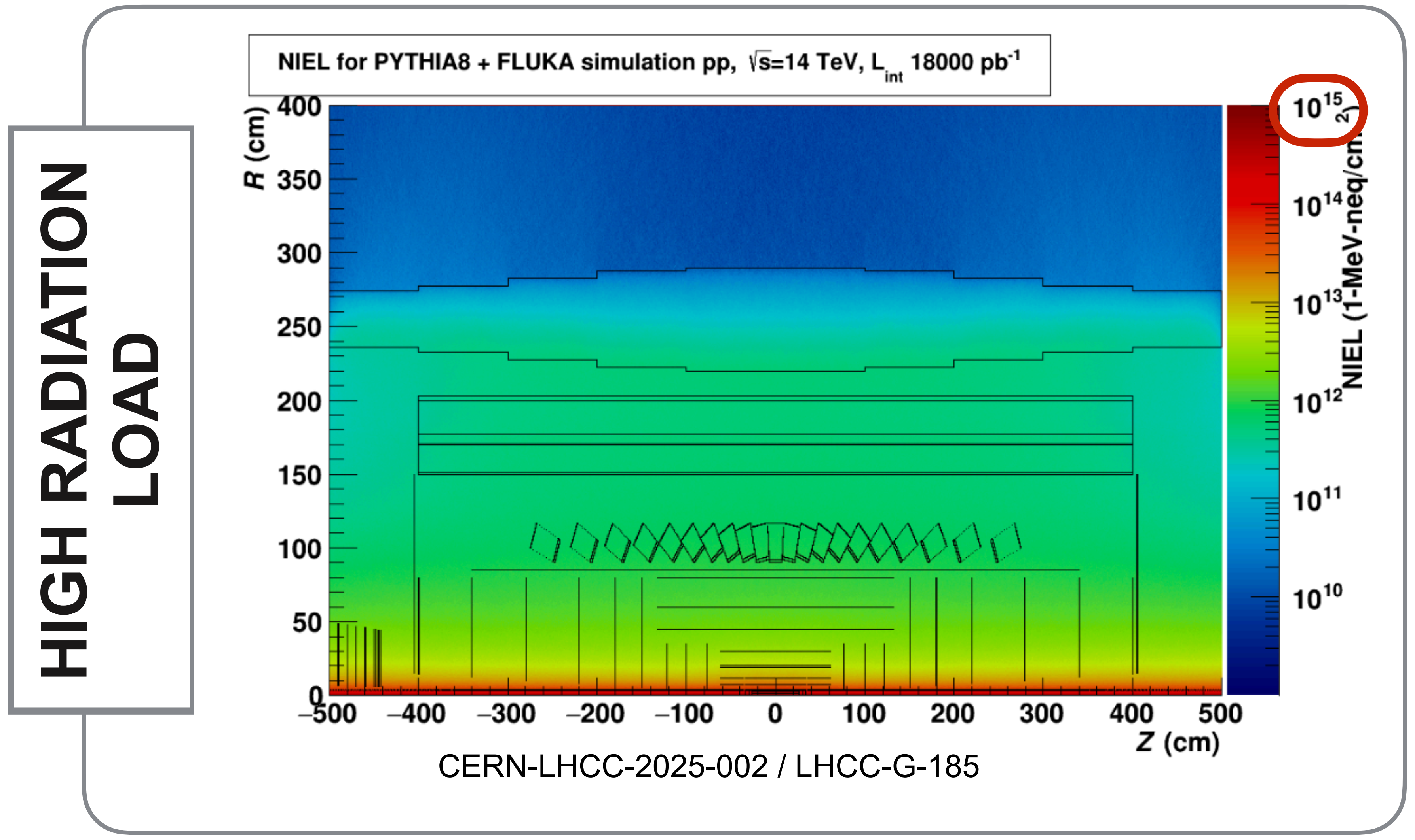
CERN-LHCC-2025-002 / LHCC-G-185

Introduction

- Technical requirements
  - Bent thin sensors supported by light material (e.g. carbon foam) [mastered within the ITS3 project]
  - Sensors and services integrated in vacuum
  - Movable components to reach minimum distance to primary vertex only during stable beams
  - Sensor performance under high radiation flux







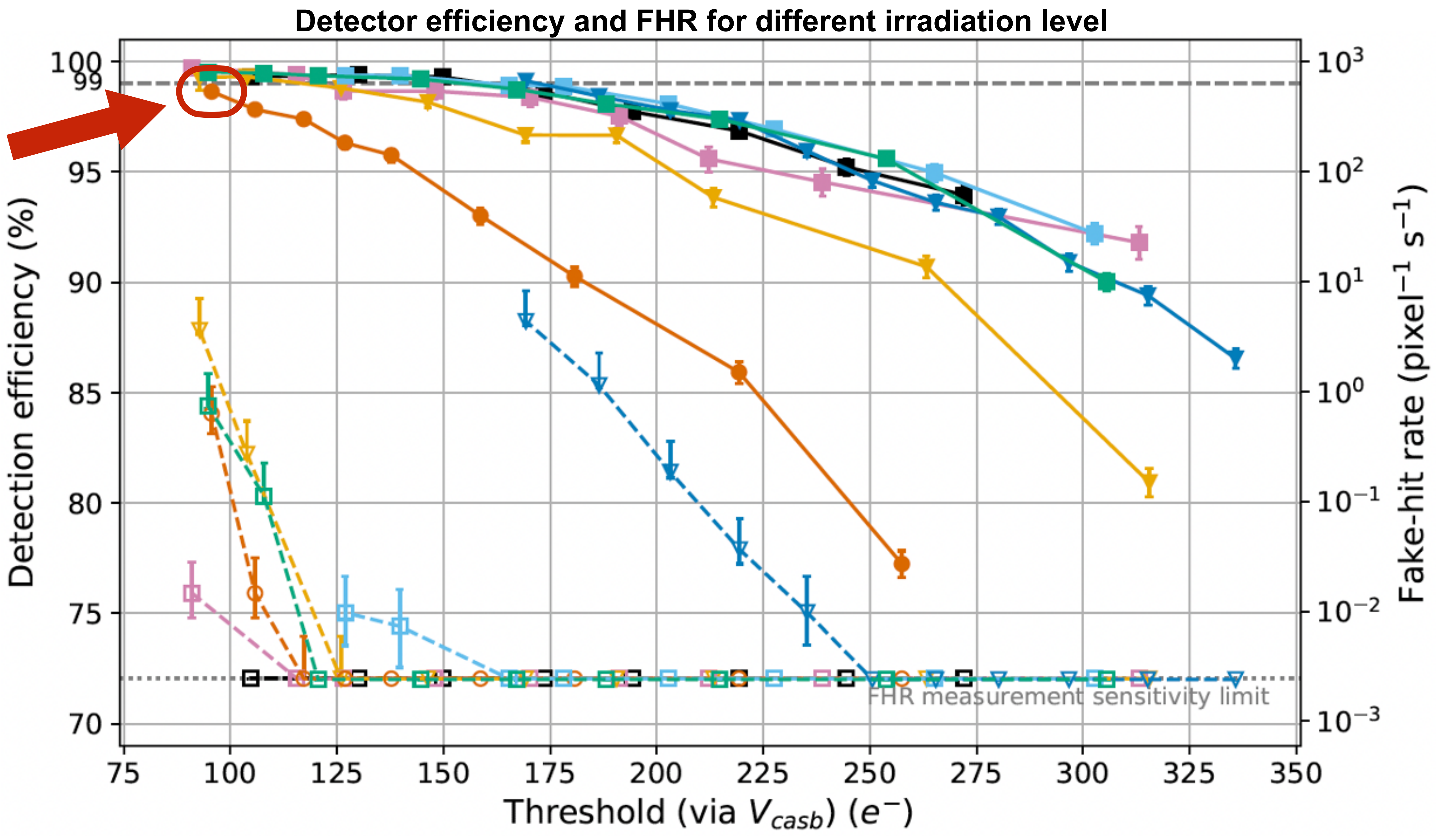
R&D for low-mass silicon sensors in vacuum

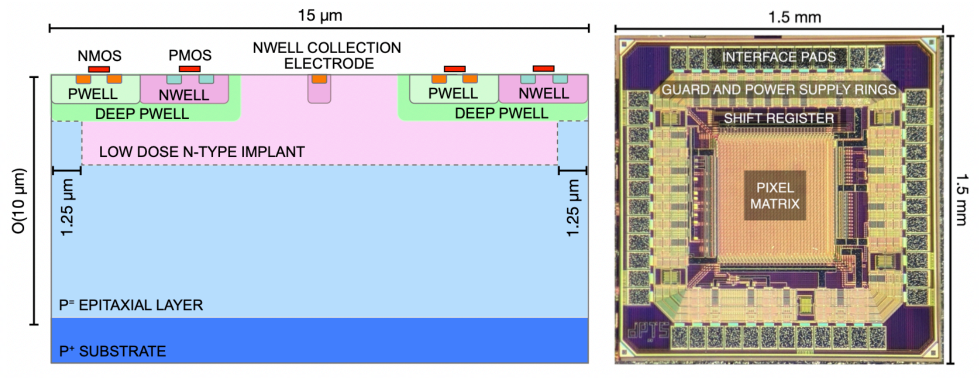
Research objectives
- Enhancing radiation tolerance of CMOS pixel sensors
- In-vacuum integration of sensors

Research objectives

Enhancing radiation tolerance of CMOS pixel sensors - In-vacuum integration of sensors

- So far demonstrated close to 99% efficiency after irradiation to 10^{15} 1 MeV n_{eq}/cm^2
  - ALICE ITS3 test chip (DPTS)
  - Operated at room temperature
  - Pixel pitch: 15 μm

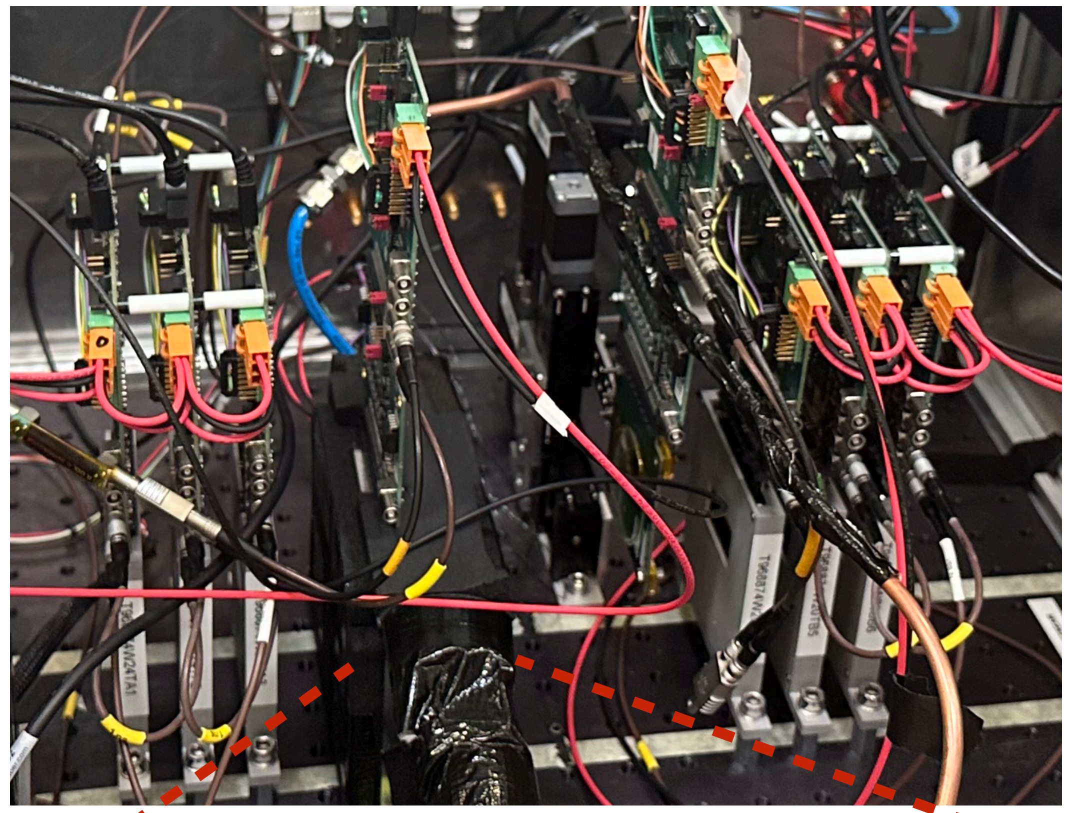




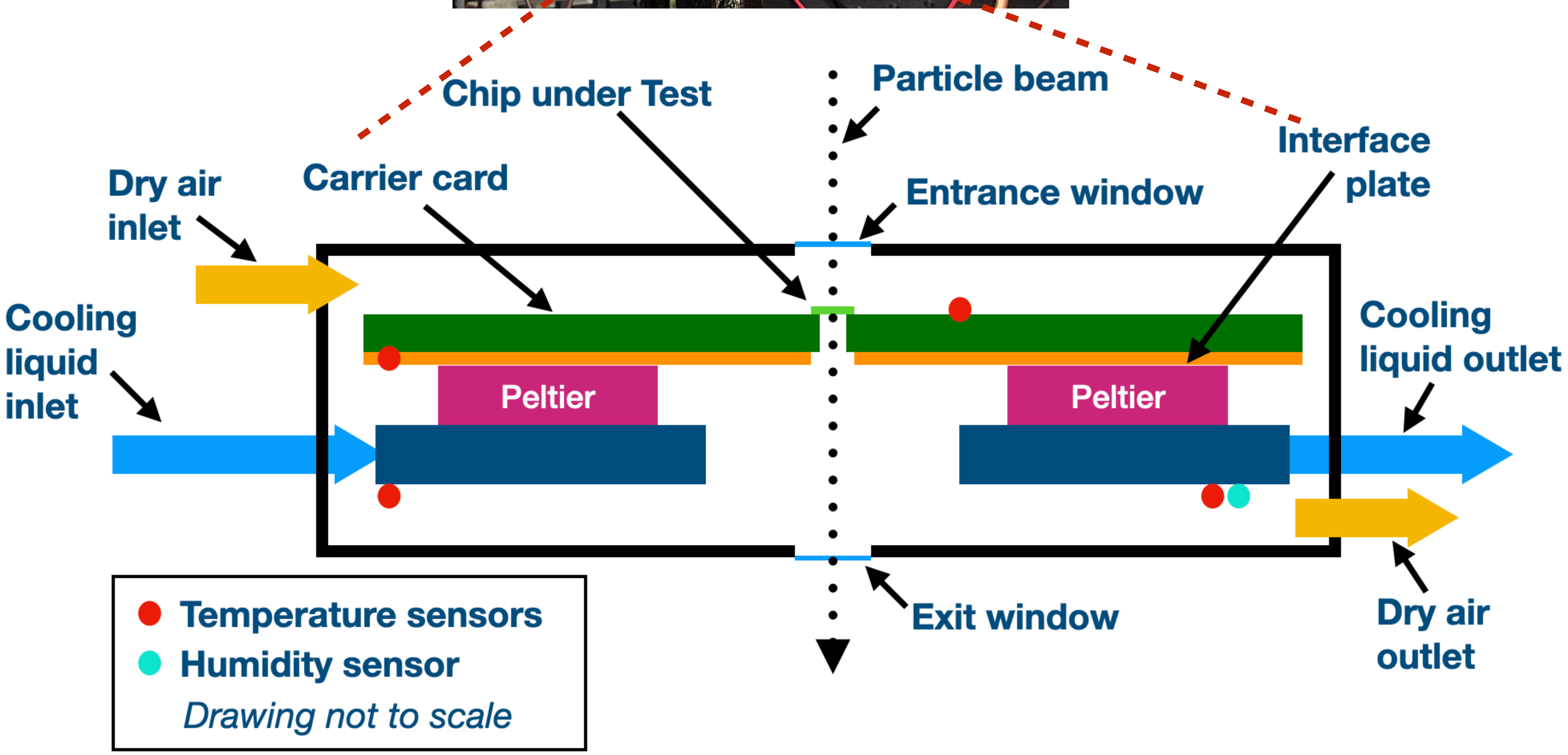
https://doi.org/10.1016/j.nima.2023.168589

ALICE-ITS3 MLR1 DPTS

- What's next?
  - Optimize pixel implant structures
    → variations of existing test chips being submitted
  - Study pitch dependence
    → variations at 10, 12 and 15 μm included in submission
  - Explore behavior at low temperatures
    → cryogenic setups



- **Cryogenic setup** key requirements
  - Thin entrance/exit window
  - Dry air circulation to avoid condensation
  - Temperature range: 15ºC to 25ºC
  - Monitoring of temperatures and humidity level
  - Based on Peltier elements and liquid cooling
  - Compact to allow use in beam telescopes



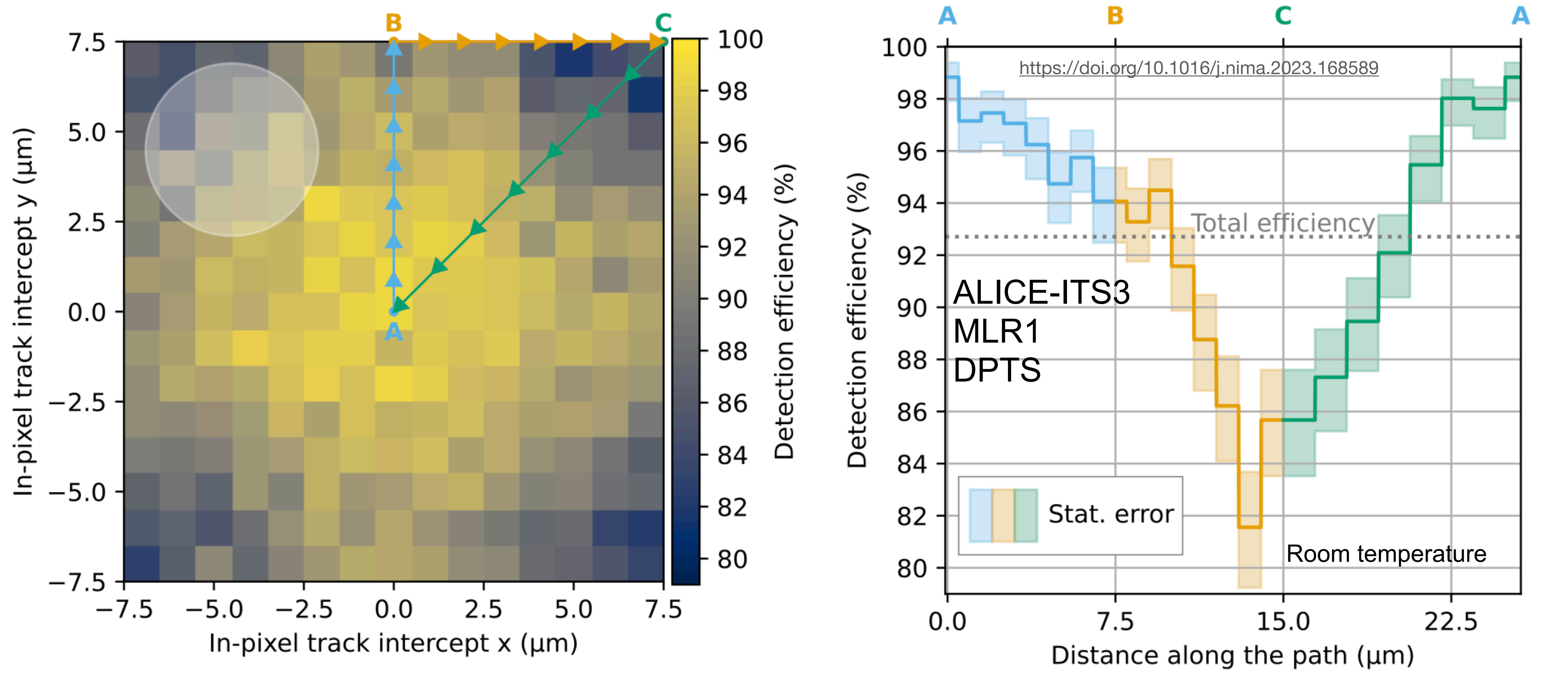
Research objectives

Enhancing radiation tolerance of CMOS pixel sensors - In-vacuum integration of sensors

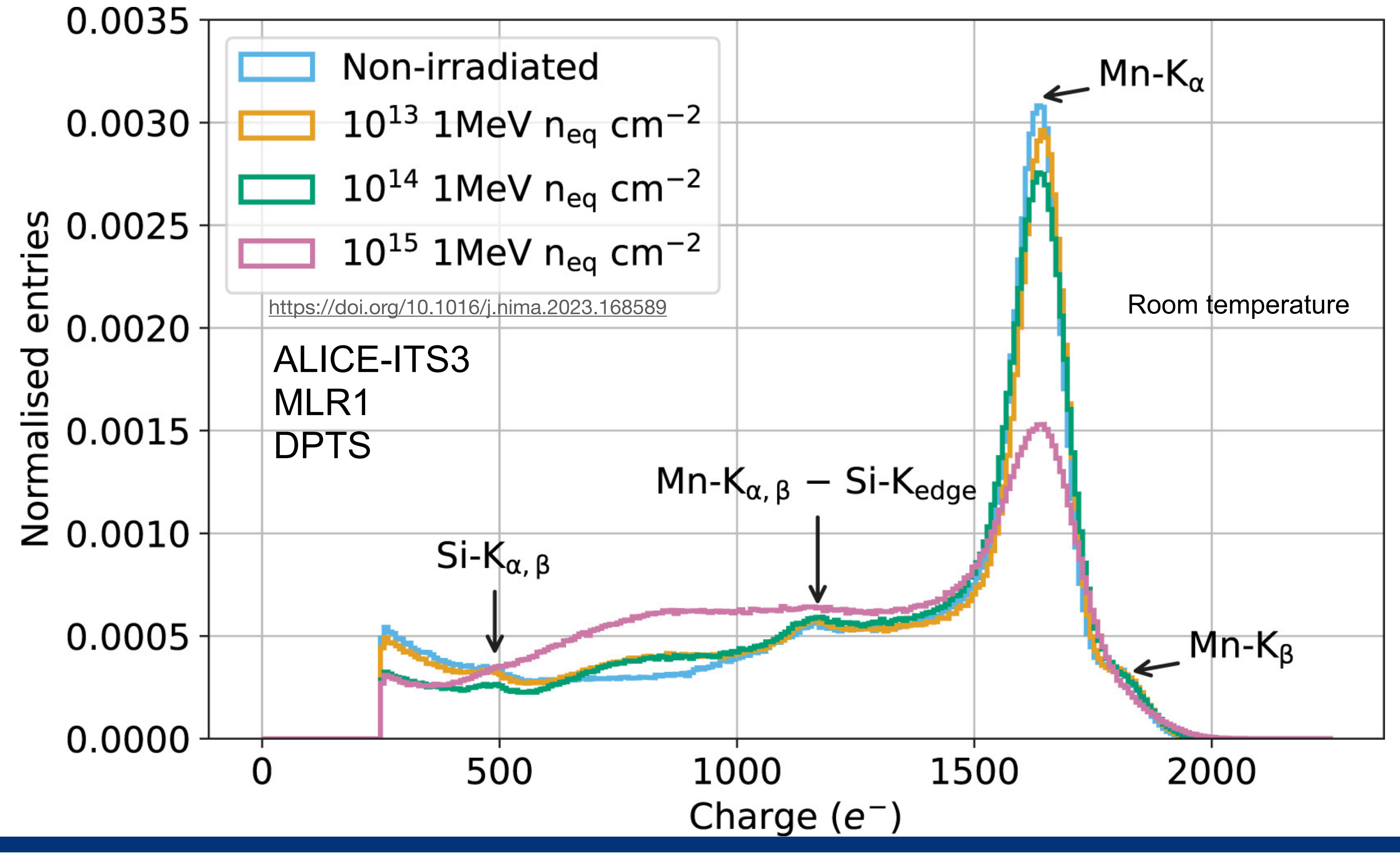
Vertexing in Extreme Radiation & Vacuum Environment

Studying **efficiency in detail**: in-pixel measurements

- Probing the charge collection and electric field of a pixel via in pixel efficiency measurements at test beam



- Systematic comparison of test beam and laboratory measurement results to simulations of the pixel implant structures carried out prior to the chip submission

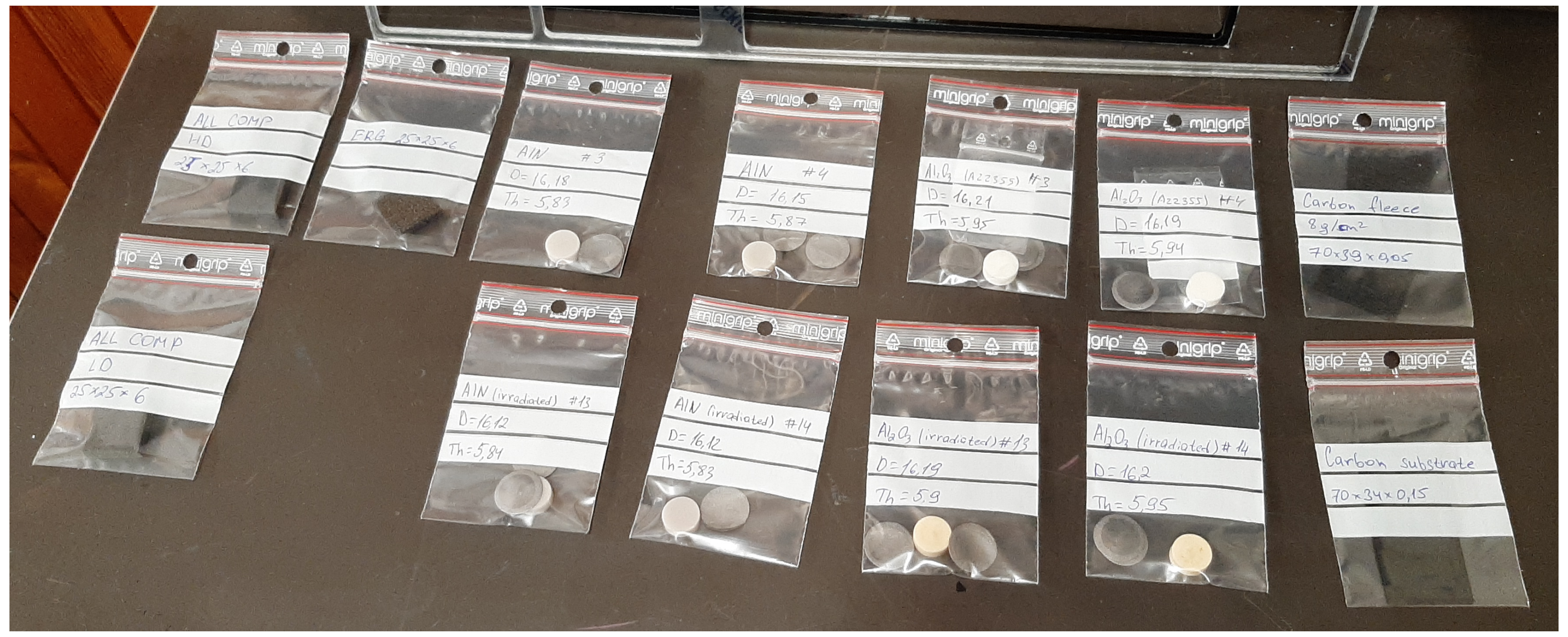


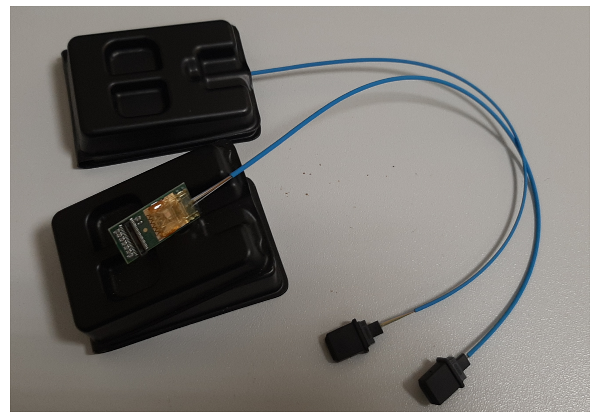
Research objectives

Enhancing radiation tolerance of CMOS pixel sensors - In-vacuum integration of sensors

VERVE
Vertexing in Extreme Radiation & Vacuum Environment

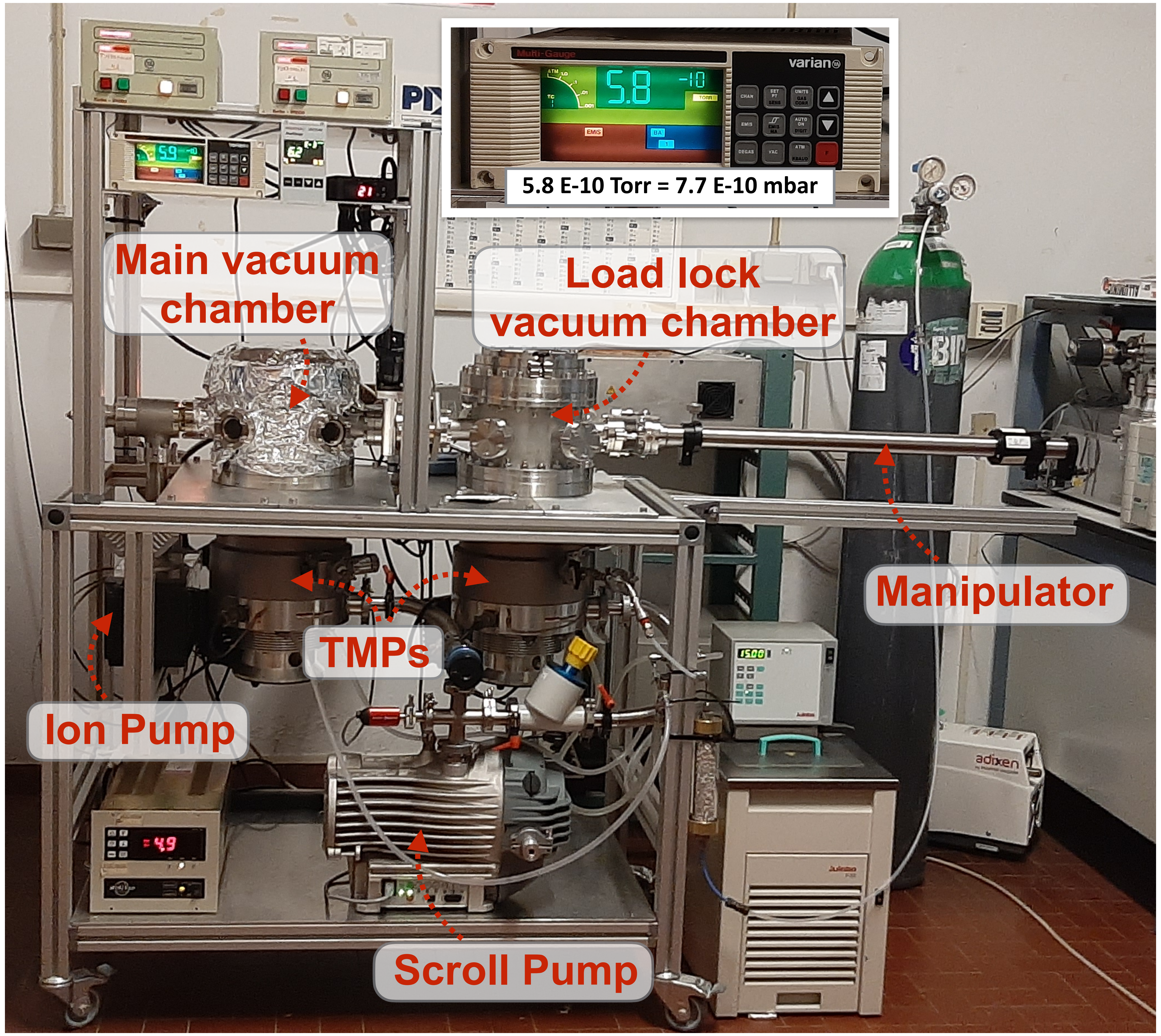
- UHV setup assembled in Bari
  - Characterization campaign ongoing on a large preliminary set of materials



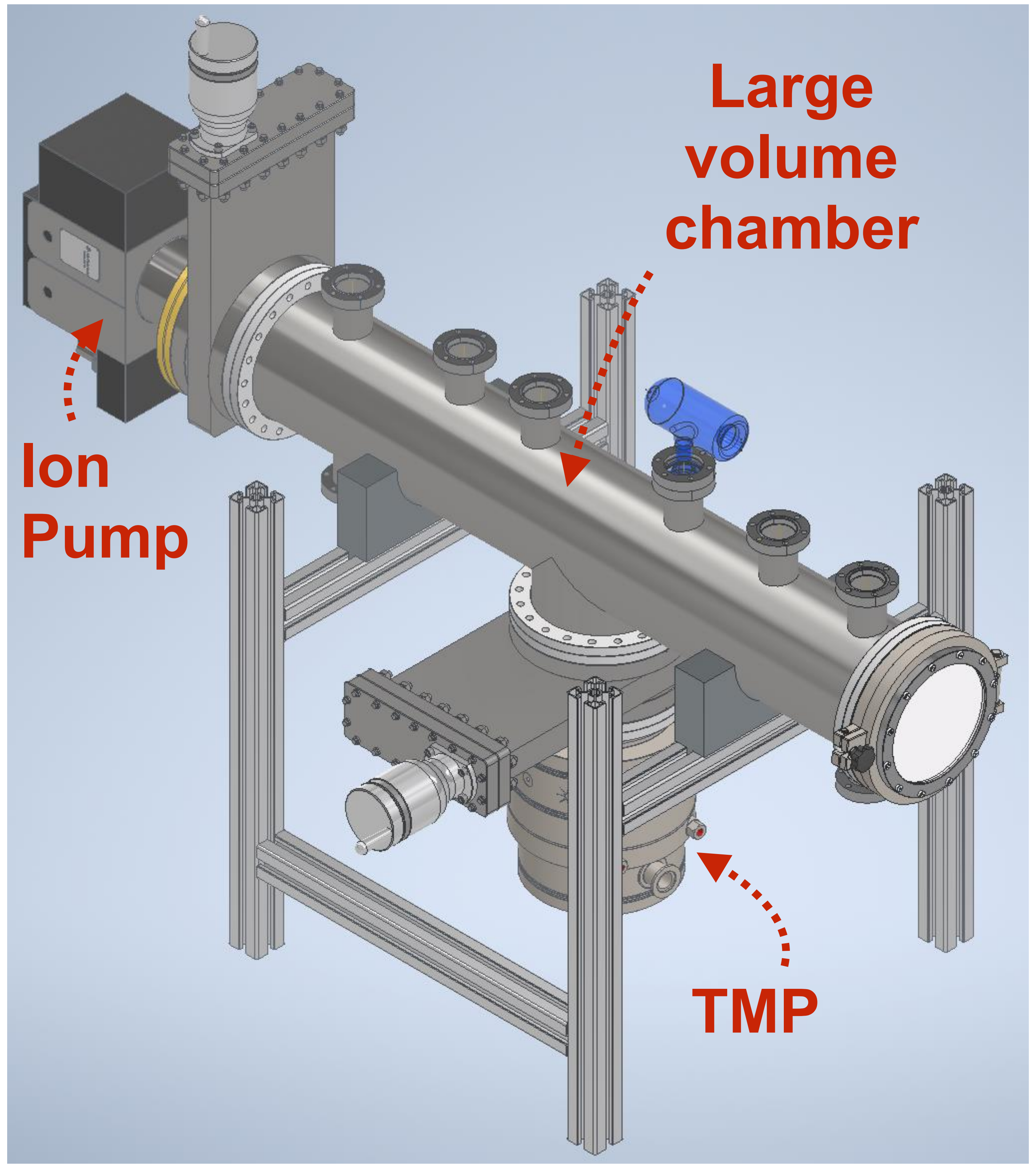


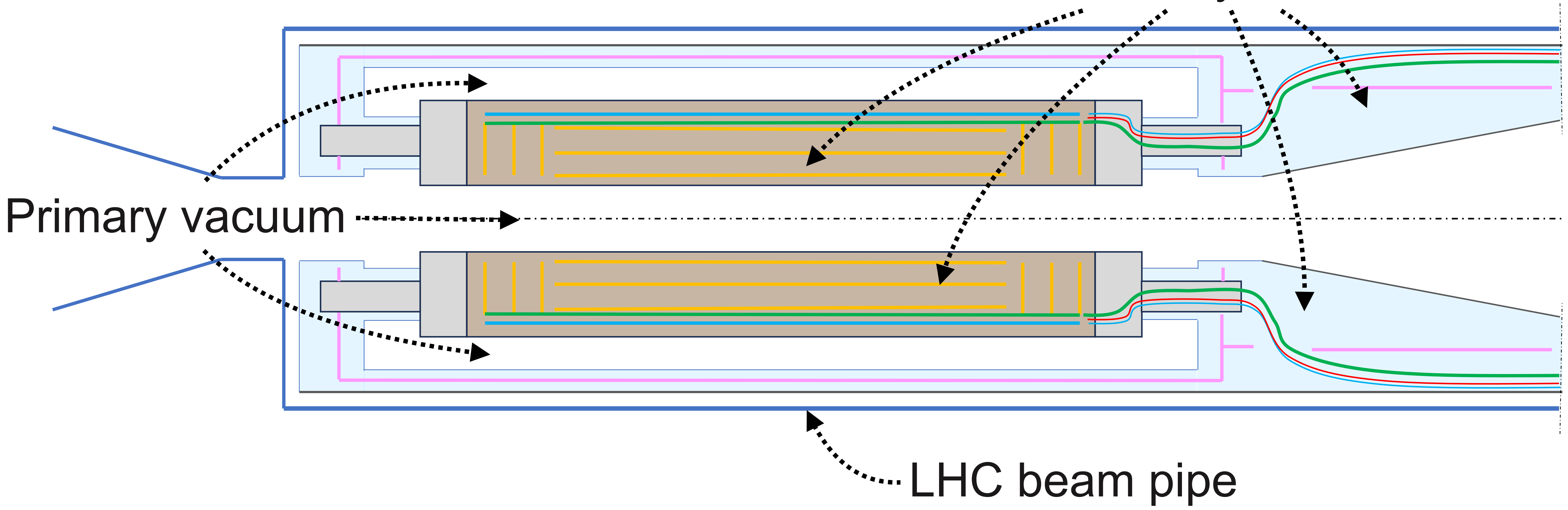
- carbon foam
- 3D printed aluminium nitride (AlN), alumina (Al_2O_3) and silumin (AlSi)

- optical fiber
- Si wafer
- standard flex circuit



- What's next?
  - Outgassing studies for a full IRIS prototype → New large volume setup
    - Outgassing studies from internal material (into secondary vacuum) and external wall (into primary vacuum)





IRIS early prototype

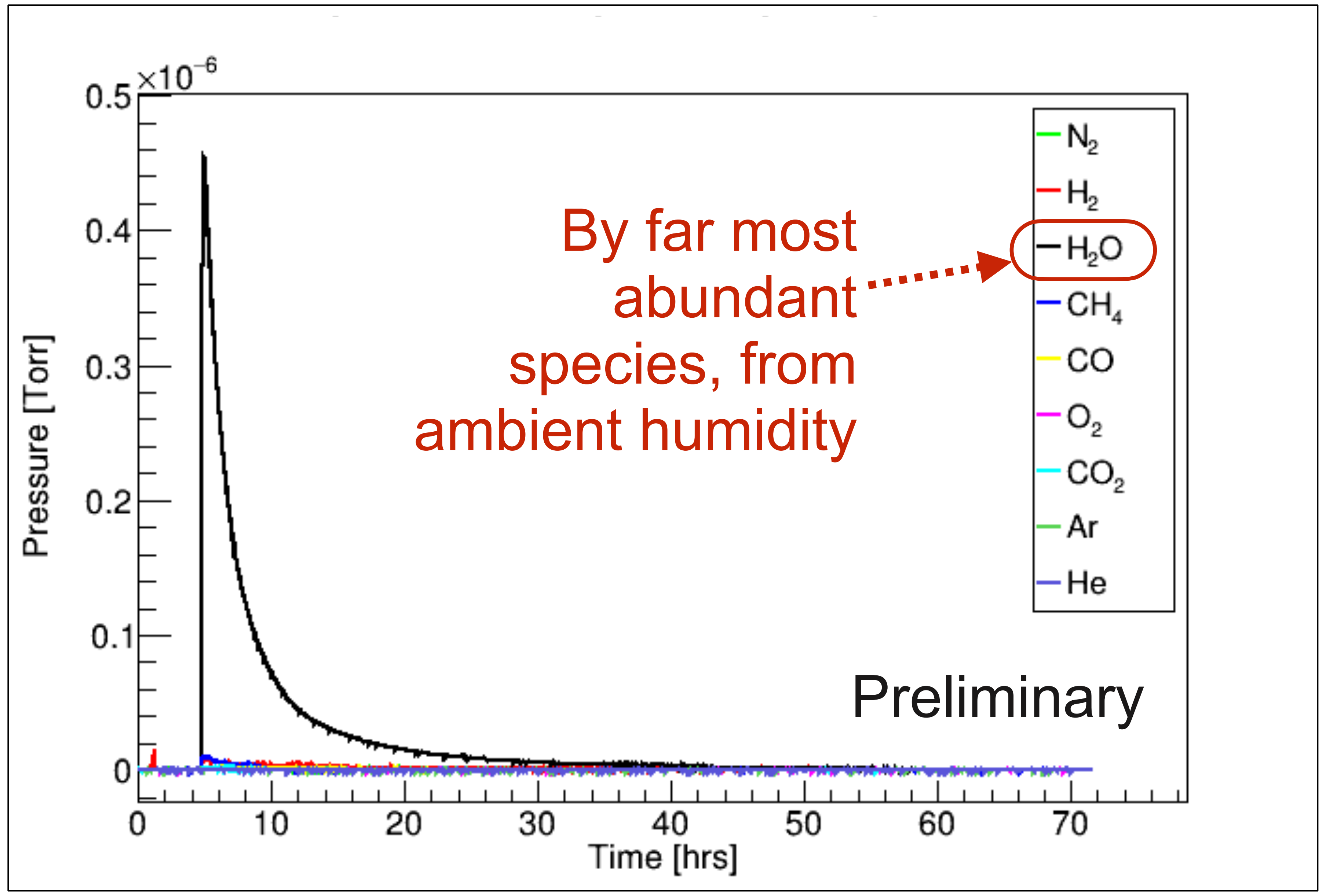
Research objectives

VERVE
Vertexing in Extreme Radiation & Vacuum Environment

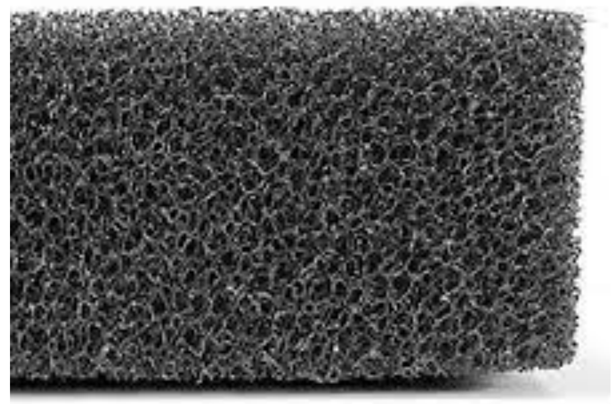
How to **identify and treat outgassing components** based on well established procedures:

Residual Gas Analysis (RGA)

Identify desorbed species from detector materials
→ Help understanding outgassing due to mechanical movements (e.g. IRIS opening/closure)

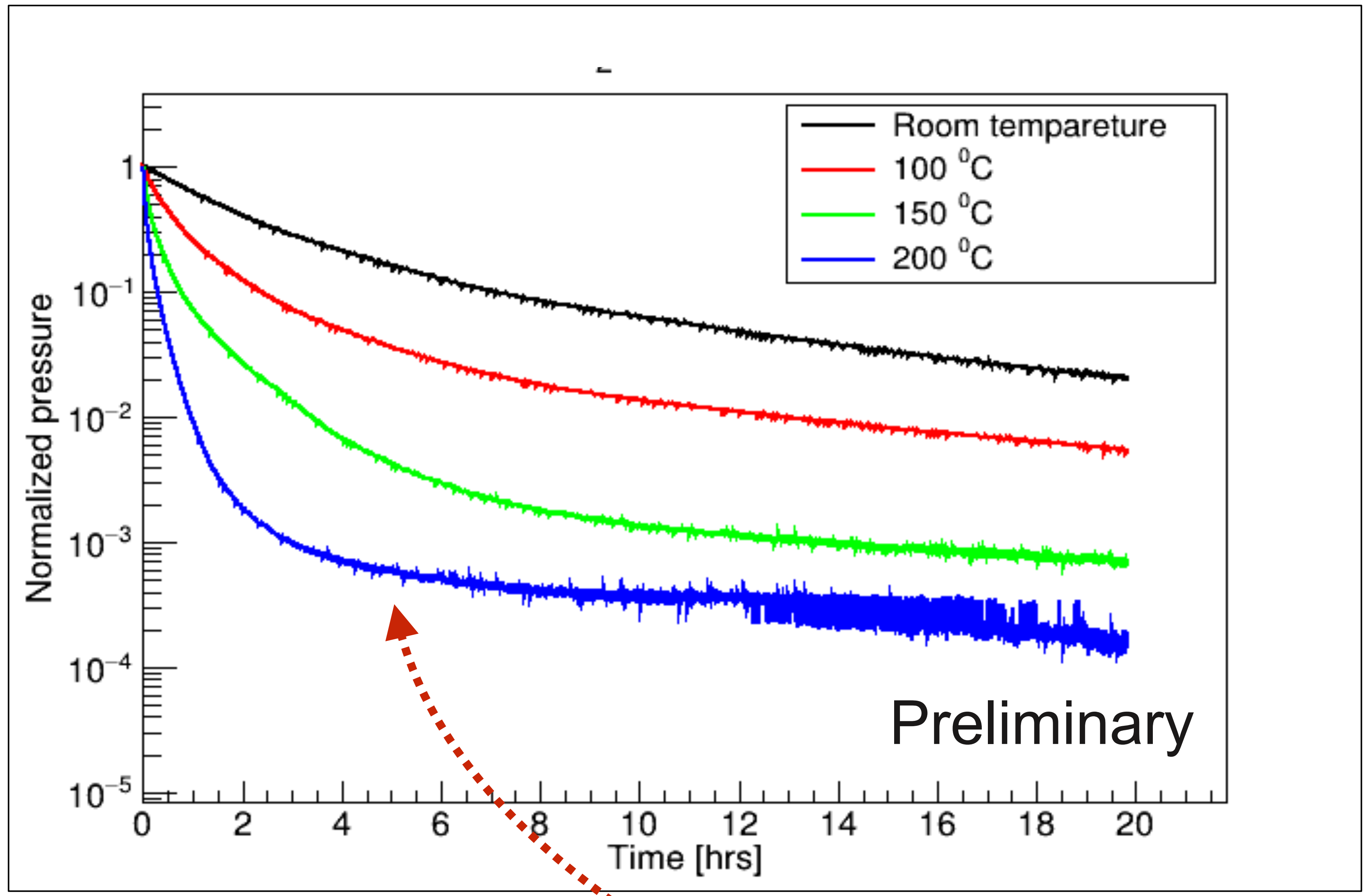


Carbon RVC foam



Thermal Desorption Spectroscopy (TDS)

Monitoring the species desorbing during heat treatment under vacuum → Help defining handling procedure during detector construction



Fast and more effective initial degassing when pre-temperature treated

Budget request

VERVE
Vertexing in Extreme Radiation & Vacuum Environment

Personnel	85 k€/year	2 or 3 PhD (different costs in Italy and at CERN)		
Travel support and workshops	10 k€/year	Start-up and wrap-up workshops		
Consumables/ Hardware	30 k€/year	Radiation studies	• Planning to prepare samples (thinning@dicing, carrier cards, wire bonding, irradiation)	8 k€
			• Procurement of new readout systems providing higher bandwidth and sampling rate	60 k€
			• Mechanics (raw material + work)	20 k€
		Vacuum studies	• Large volume vacuum chamber, flanges, gate valves and consumables	12 k€
			• Turbo and ion pumps	20 k€
Indirect cost	31 k€/year	25% of the direct costs		
TOTAL per year	156 k€/year			
TOTAL (4 year)	**624 k€**			

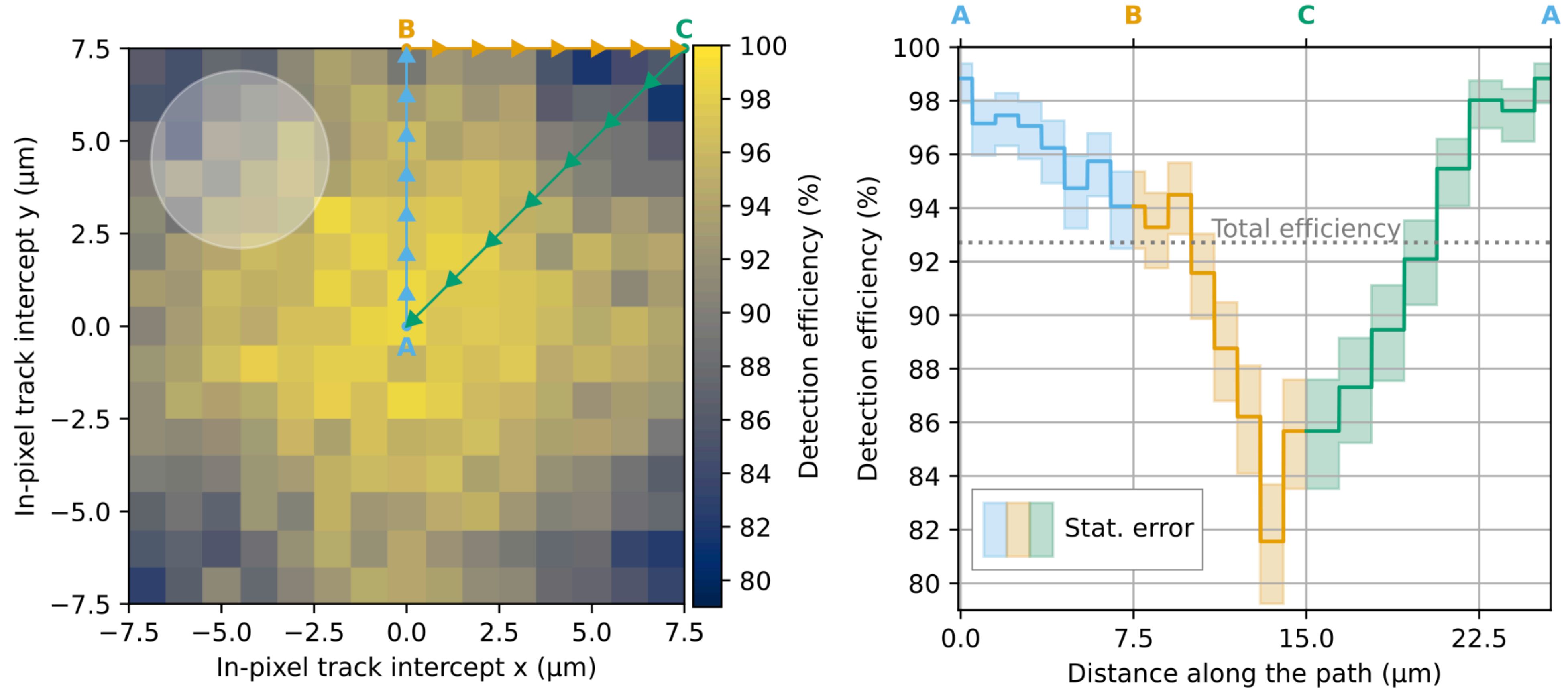
Backup

Research objectives

Enhancing radiation tolerance of CMOS pixel sensors

How to **study efficiency in detail**, based on prior experience with ITS2/3:

- Probing the electric field configuration and the charge collection of pixel via in pixel efficiency through test beam measurements
- Complementing with laboratory measurements with radioactive source (Fe-55, Sr-90)
- Comparison to simulations
    - -



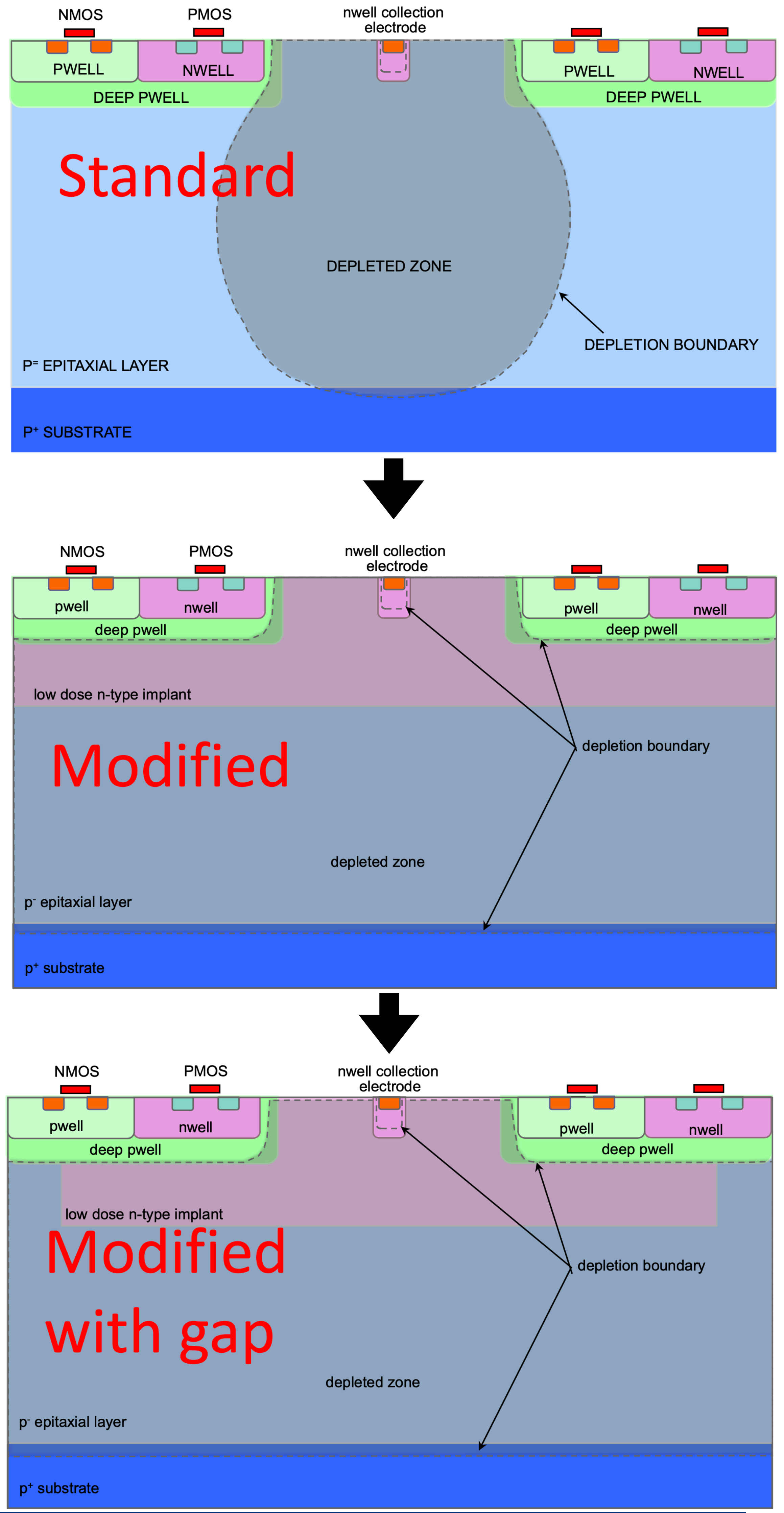
New slide: "Studying efficiency in detail"

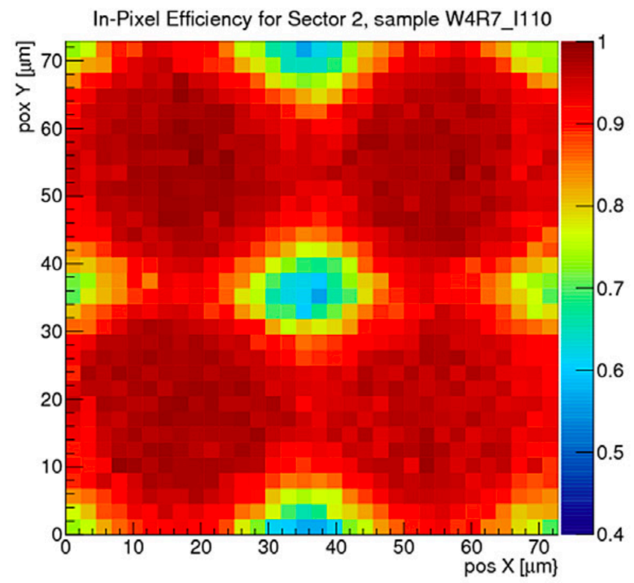
- In-pixel efficiency plot -> probing the field configuration and charge collection of the pixel
- Comparison to simulations:
    - Pixel implant structure variations have been simulated prior to submission
    - Laboratory measurements with radioactive sources (Fe-55, Sr-90) complementing the test beam measurements
      Also saying based on prior experience with ITS2/3

Research objectives

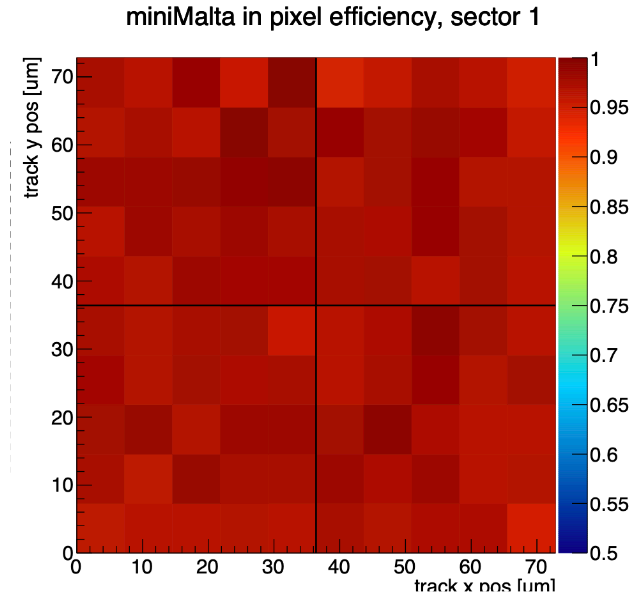
Enhancing radiation tolerance of CMOS pixel sensors

- It has been shown that changing the doping profile of the epitaxial layer, the radiation hardness of MAPS can be improved
  - **Standard process** → Operational up to 10^{13} 1 MeV n_{eq}/cm^2
  - **Modified process** → Operational up to 10^{14} 1 MeV n_{eq}/cm^2
    - additional deep blanket low doped implant over the full pixel area
  - **Modified with gap process** → Operational up to 10^{15} 1 MeV n_{eq}/cm^2
    - gap in the deep low dose n-implant





In pixel efficiency in a 2x2 matrix MALTA sensor



J. NIMA 871 (2017) 90–96
J. NIMA 958 (2020) 162404

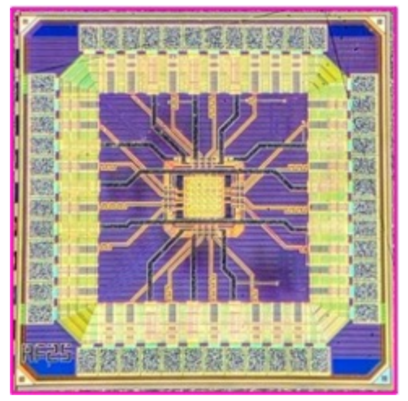
2019 JINST 14 C05013
2020 JINST 15 P0200

Research objectives

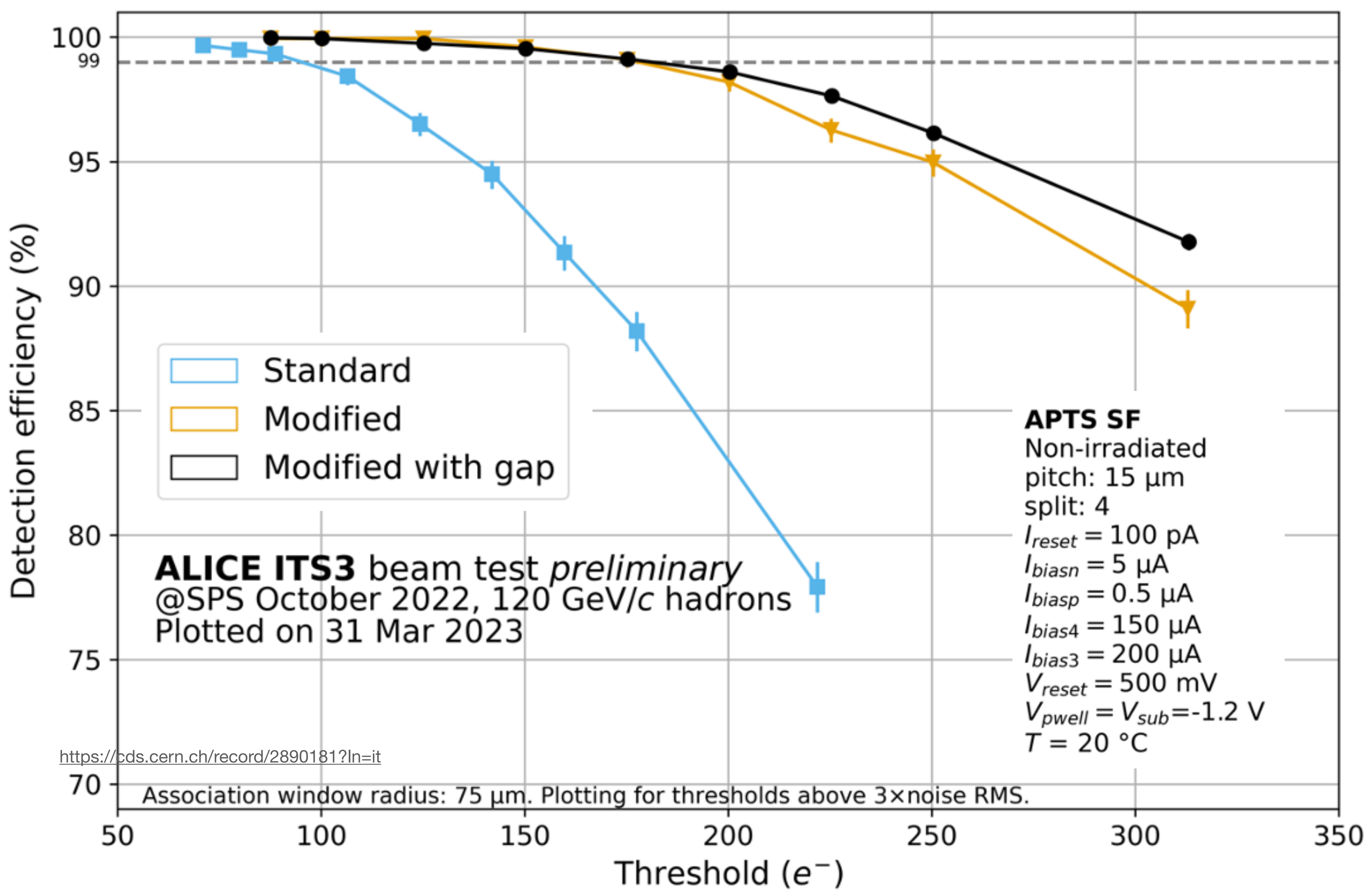
Enhancing radiation tolerance of CMOS pixel sensors

- It has been shown that changing the doping profile of the epitaxial layer, the radiation hardness of MAPS can be improved
  - **Standard process** → Operational up to 10^{13} 1 MeV n_{eq}/cm^2
  - **Modified process** → Operational up to 10^{14} 1 MeV n_{eq}/cm^2
    - additional deep blanket low doped implant over the full pixel area
  - **Modified with gap process** → Operational up to 10^{15} 1 MeV n_{eq}/cm^2
    - gap in the deep low dose n-implant

ALICE-ITS3
MLR1
APTS



Detector efficiency for different processes

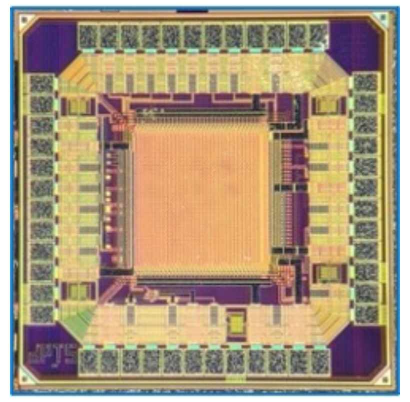


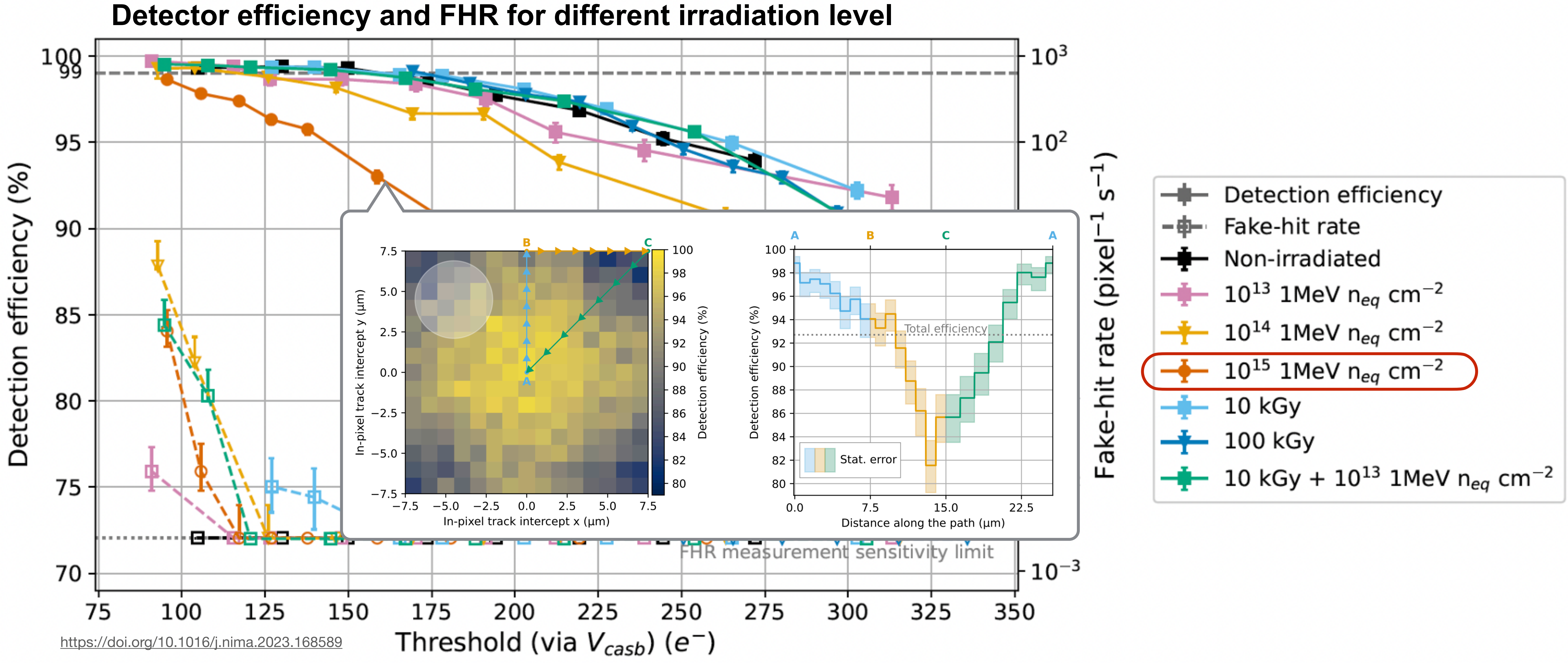
Research objectives

Enhancing radiation tolerance of CMOS pixel sensors

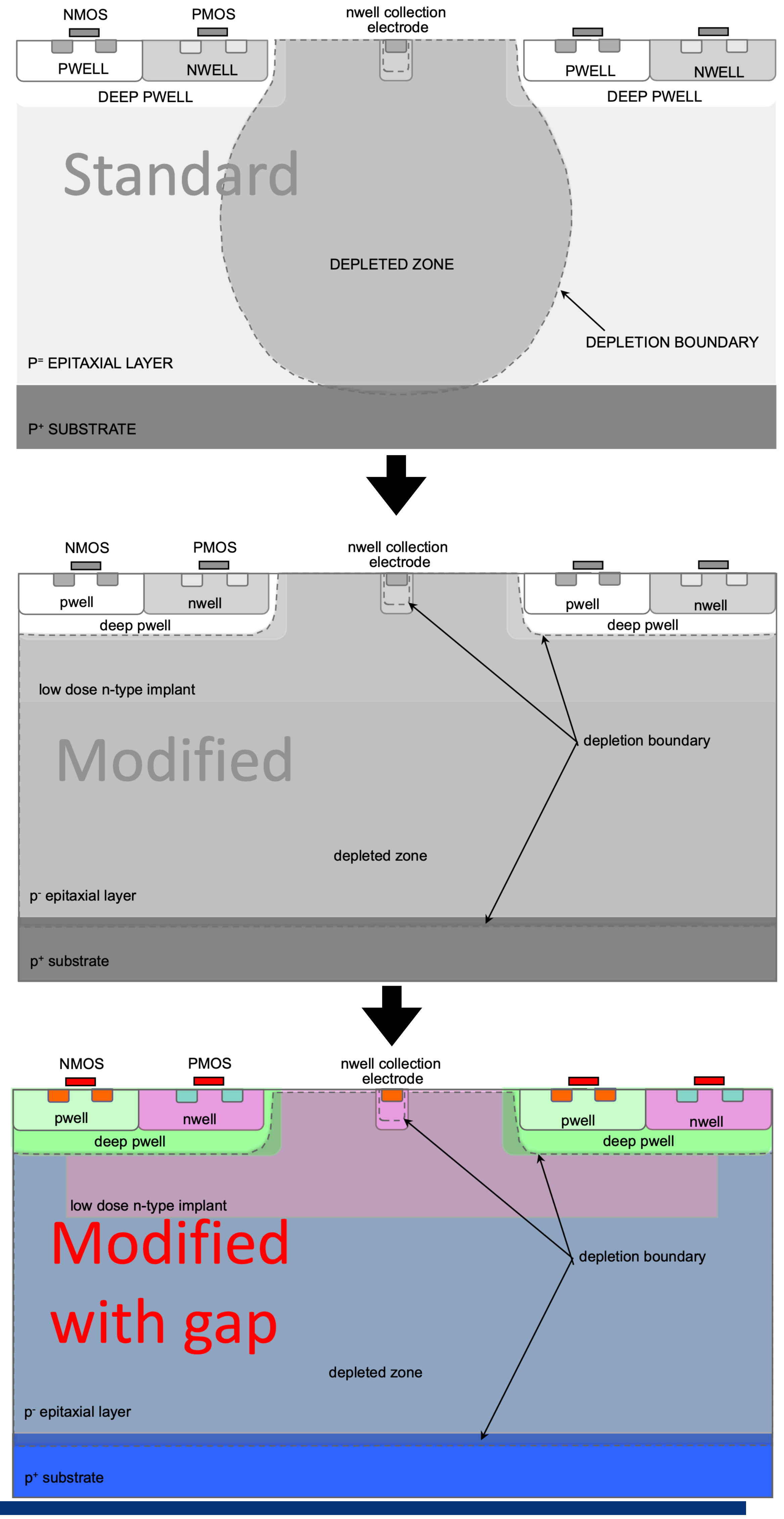
- It has been shown that changing the doping profile of the epitaxial layer, the radiation hardness of MAPS can be improved
  - **Standard process** → Operational up to 10^{13} 1 MeV n_{eq}/cm^2
  - **Modified process** → Operational up to 10^{14} 1 MeV n_{eq}/cm^2
    - additional deep blanket low doped implant over the full pixel area
  - **Modified with gap process** → Operational up to 10^{15} 1 MeV n_{eq}/cm^2
    - gap in the deep low dose n-implant

ALICE-ITS3
MLR1
DPTS





https://doi.org/10.1016/j.nima.2023.168589

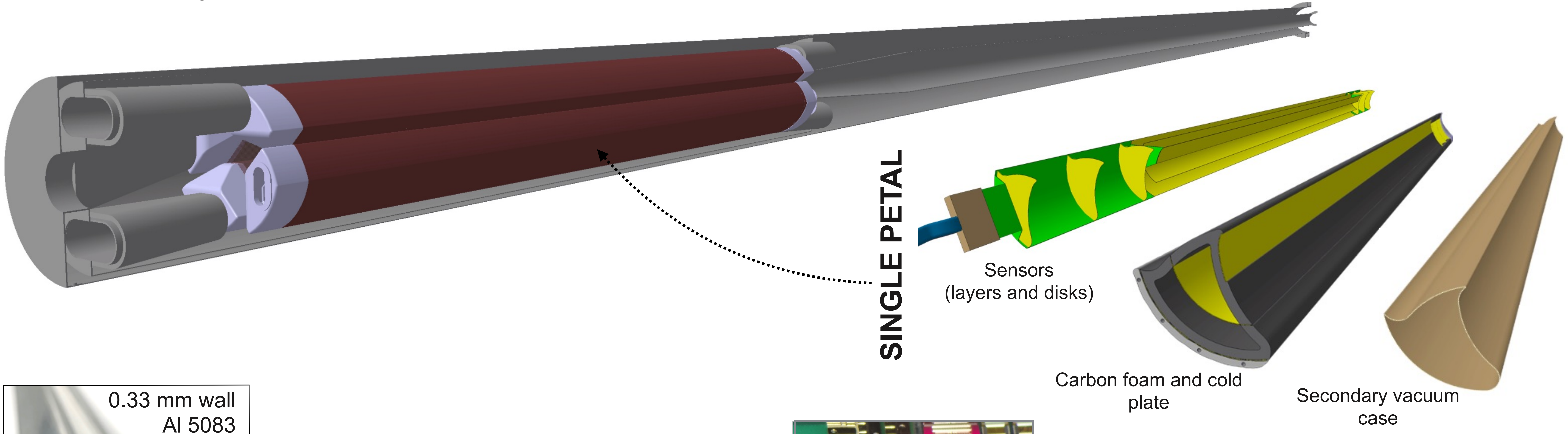


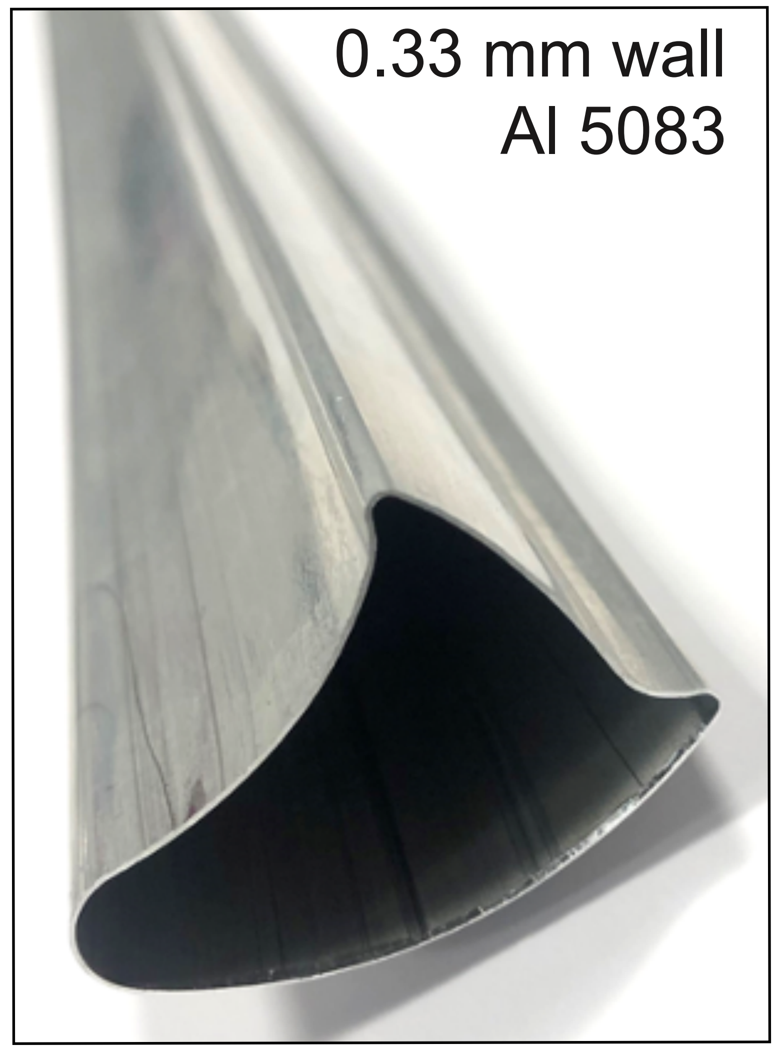
J. NIMA 871 (2017) 90–96
J. NIMA 958 (2020) 162404
2019 JINST 14 C05013
2020 JINST 15 P0200

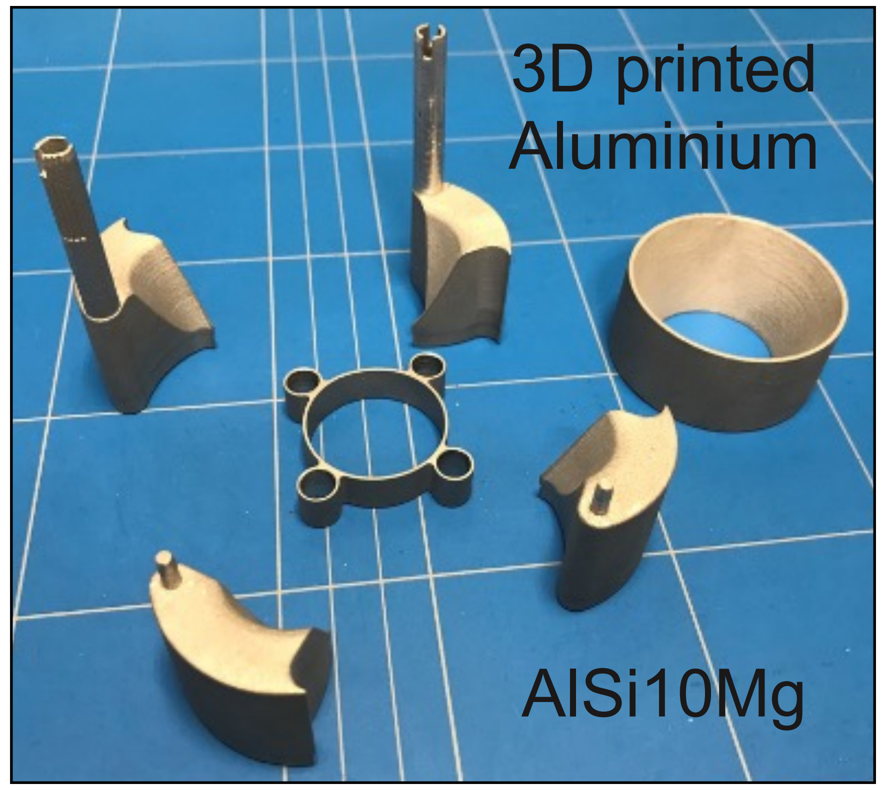
Research objectives

In-vacuum integration of pixel sensors

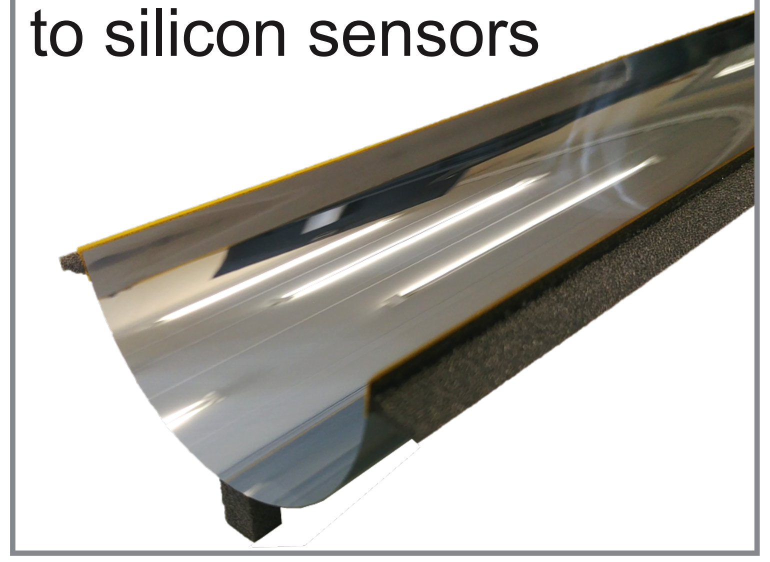
VERVE
Vertexing in Extreme Radiation & Vacuum Environment

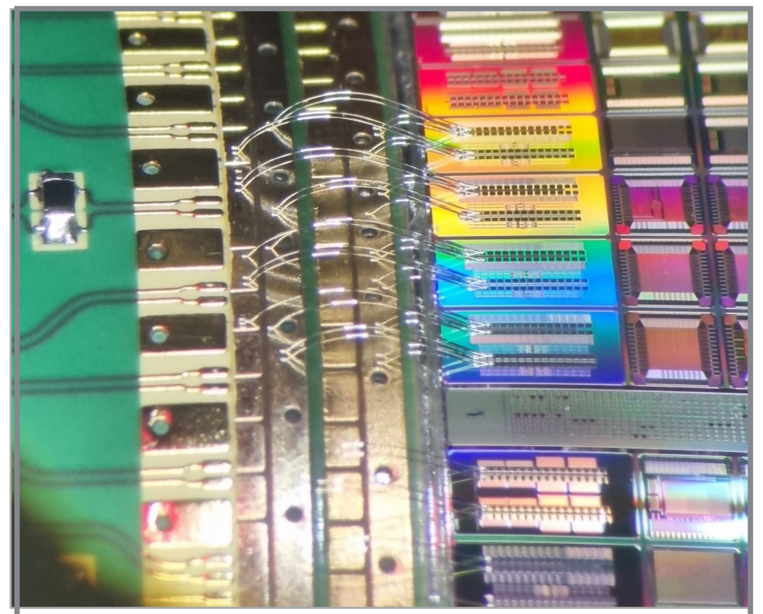






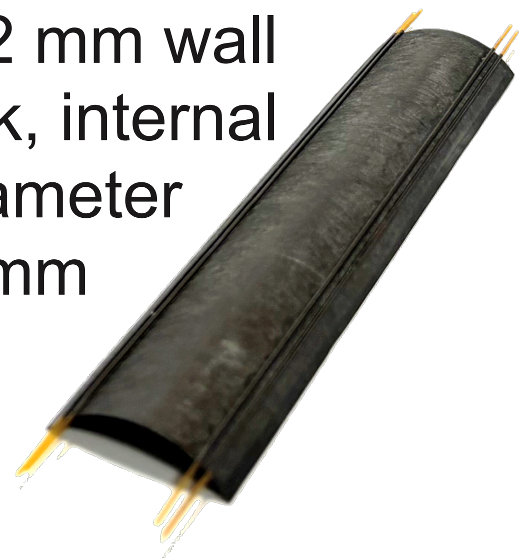
Carbon foam glued to silicon sensors





FPC (PW & Data) connected at the edge of the sensors by wire bonding

Carbon composite for cooling
0.2 mm wall tick, internal diameter 1 mm



3D printed ceramic for cooling
0.2 mm wall tick, internal diameter 0.4 mm