

Silicon Instrumentation, Research Development and Production

Vlad Berlea

DESY Zeuthen, 07.10.2025

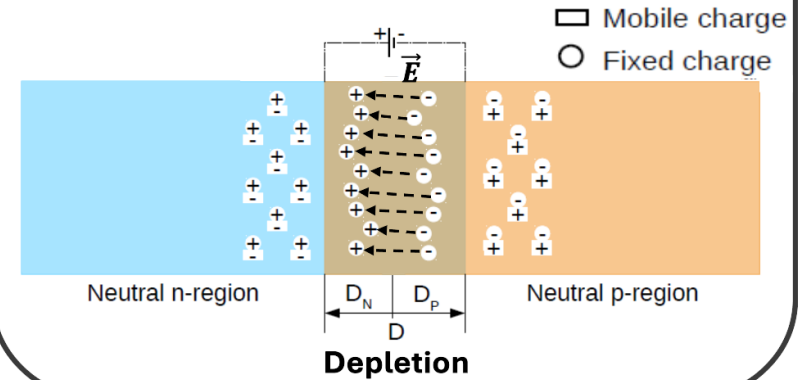
Silicon for particle detection

Silicon

- Abundant material (27.7% of Earth) → relatively cheap
- Ordered crystal → easy to grow + pure
- Rigid → self supporting
- Grows its own dielectric (SiO₂) → easy to passivate
- Semiconductor → charge collection
- Small band gap → large signal / noise

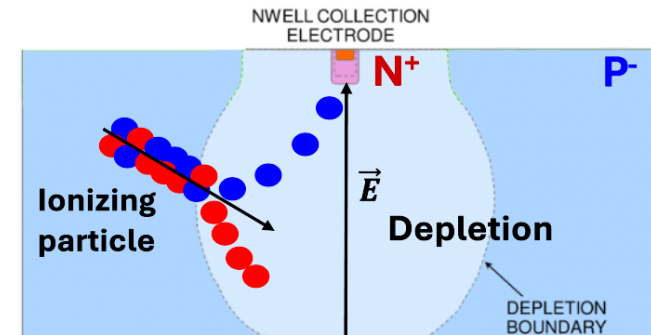
The p-n junction

- N-type = $+$ fixed; $-$ mobile
- P-type = $-$ fixed; $+$ mobile
- Depletion region → $\vec{E}$

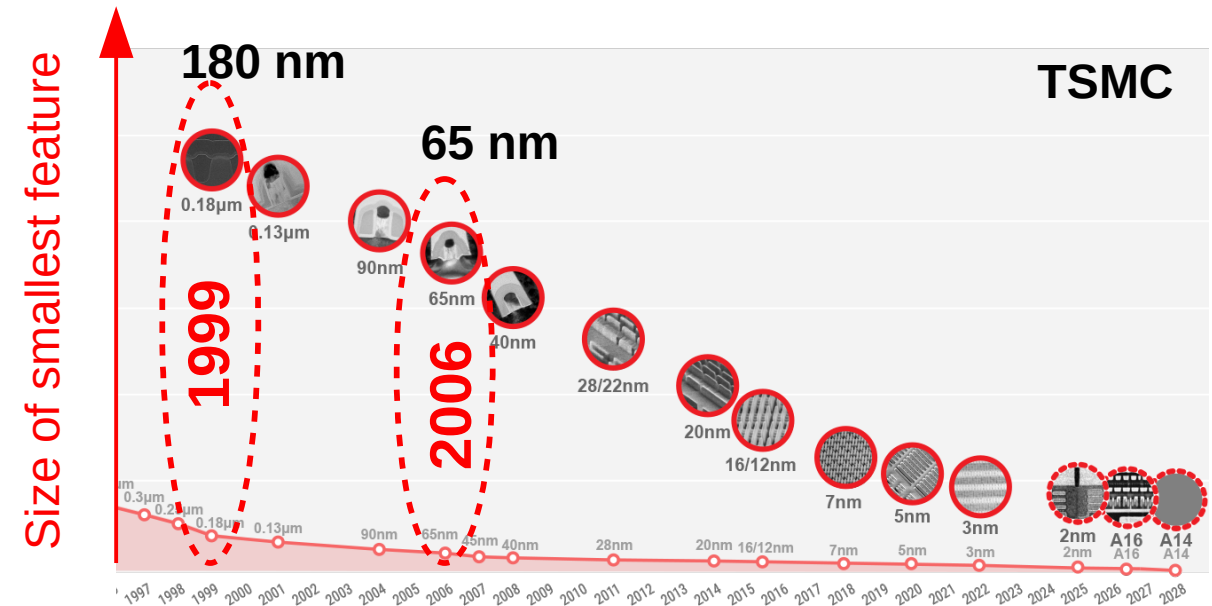
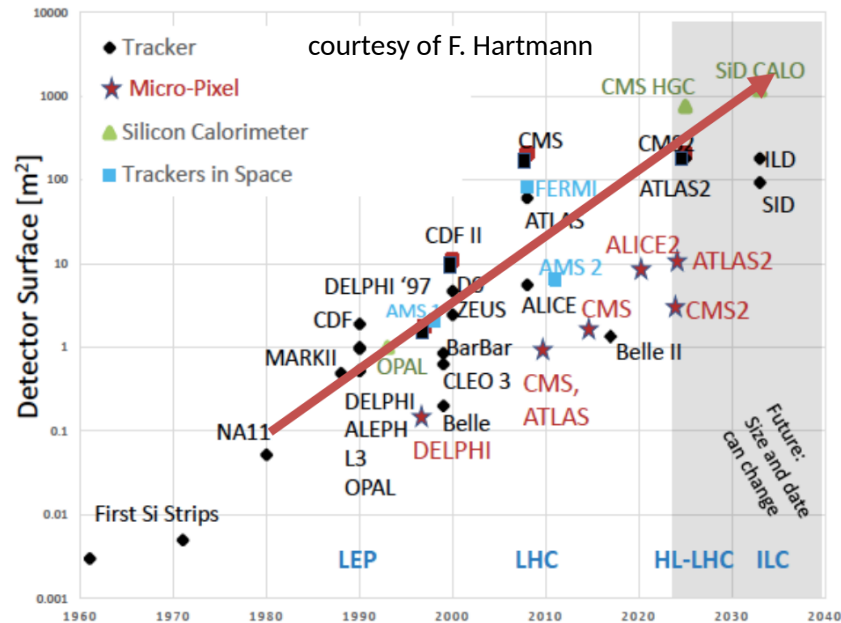


The photodiode

- $N_n \gg N_p \rightarrow$ asymmetric
- Ionizing particle → $e^- + h^+$
- $\vec{E} \rightarrow$ charge collection



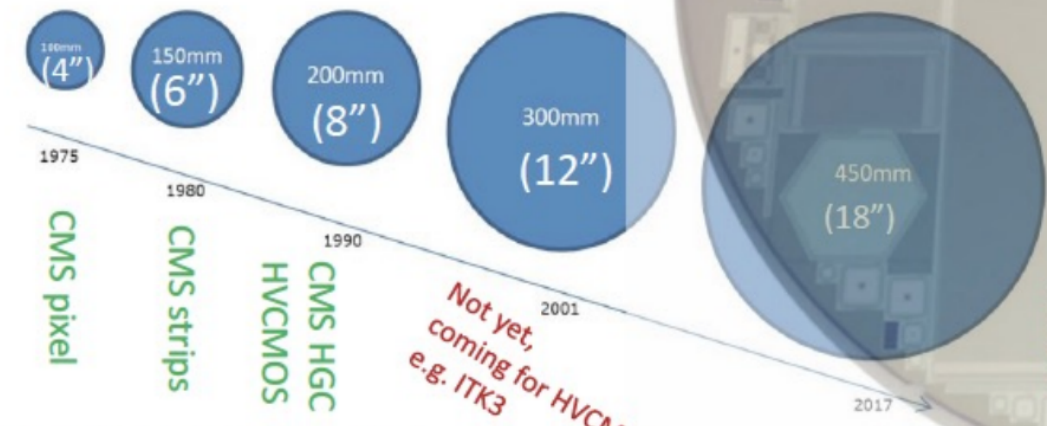
Silicon sensors. A chip industry success story.



Status of the imaging Si process

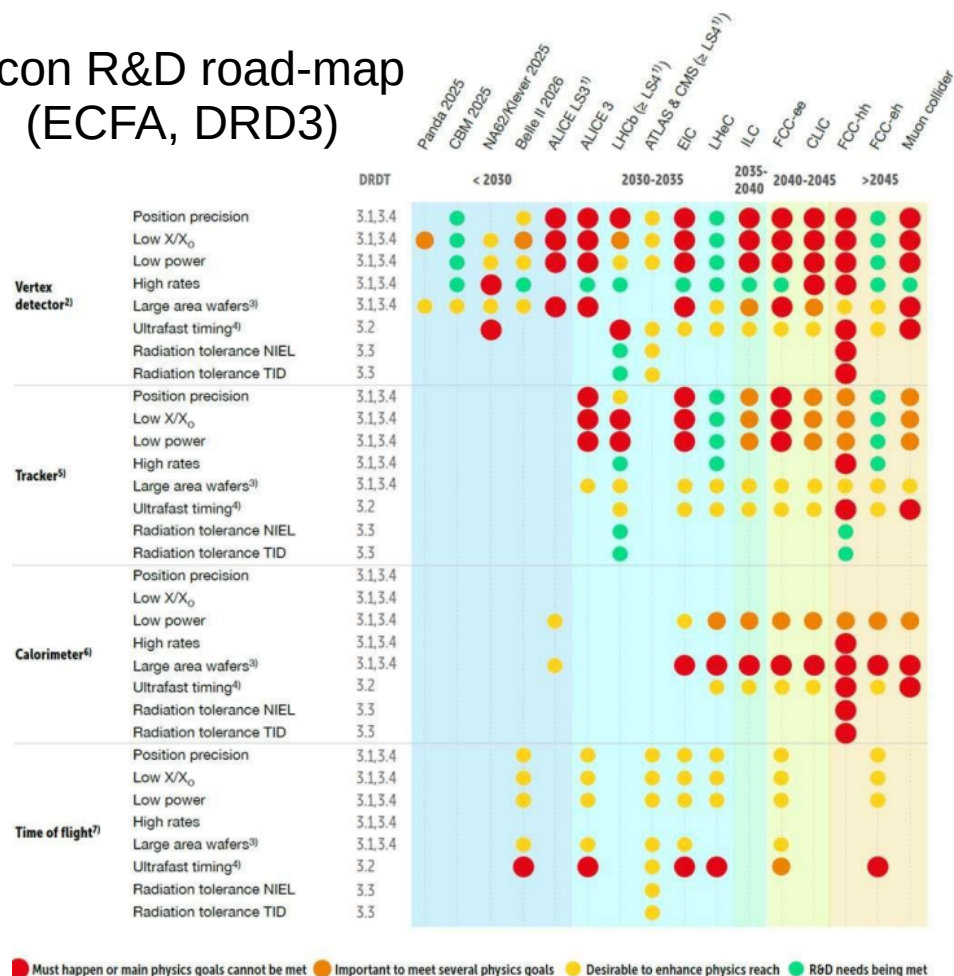
- Ever increasing detector size
- Continuous **miniaturization** → smarter, smaller chips
- Larger wafers → **large area** sensors (stitching)
- **180 nm** proven technology (MALTA, ALICE, BELLE2)
- **65 nm** current state of the art (CERN, DESY designs)

Wafer Areas in Chip industries:



The future of Silicon instrumentation

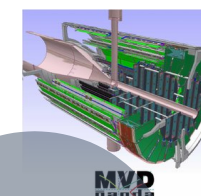
Silicon R&D road-map (ECFA, DRD3)



**More logic, less material, on larger,
more resilient detectors!**

R&D common themes

- Good position and time resolution
- Low material budget and power dissipation
- High rates
- Radiation tolerant



**Novel calorimetry
techniques**



Quantum

Nuclear

**Radiation hard
sensors**



Courtesy of G. Kramberger

R&D for
future
particle
physics

Fusion

Space

Medical
Imaging



**ULTRASAT
ASTROGAM2**

**KRANOS
FLASH @ PITZ**

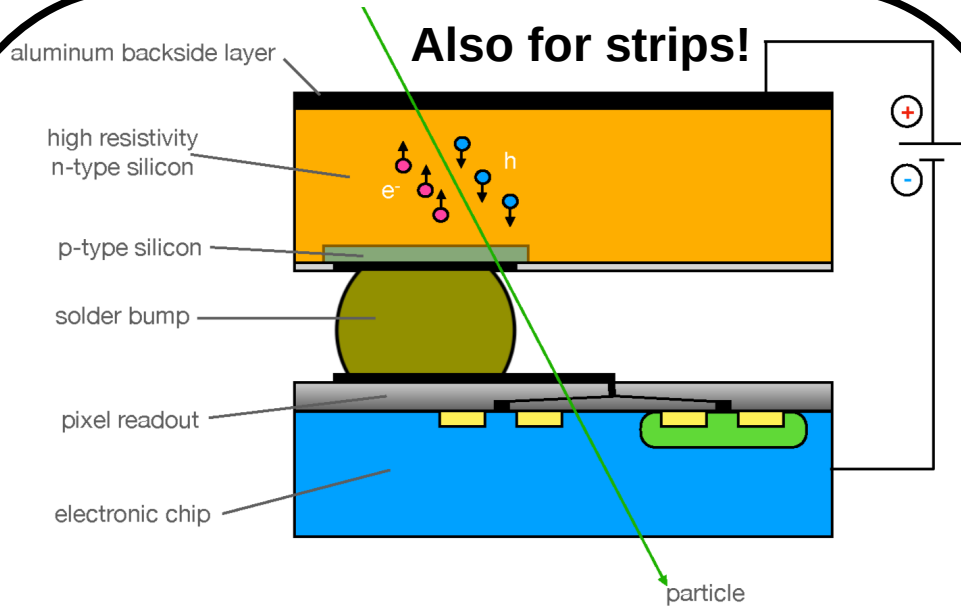


Radiotherapy

Silicon pixel detectors

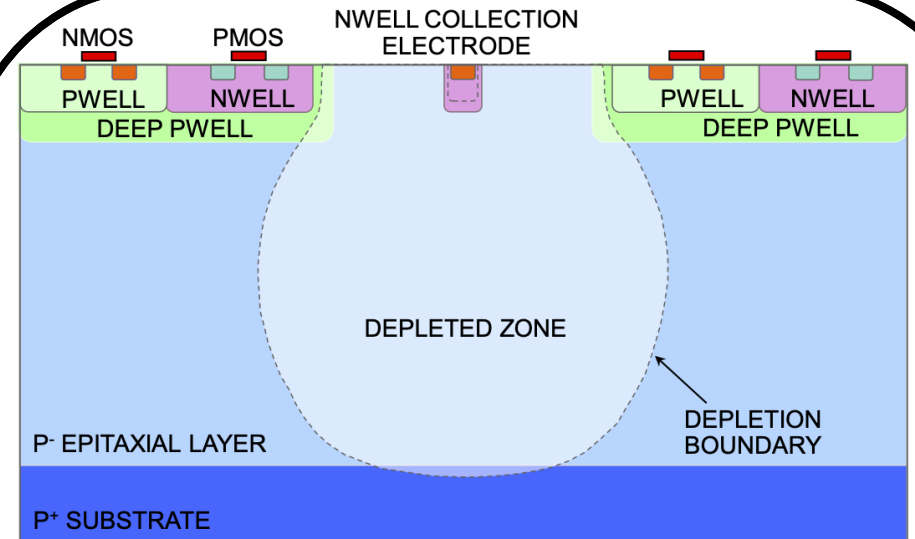
Hybrid Pixel Sensor

Also for strips!



- Sensing chip + Read out chip (ROC)
- Large material budget
- Larger pixel pitches ($\sim 50 \mu\text{m}$)
- Complex signal processing in the ASIC

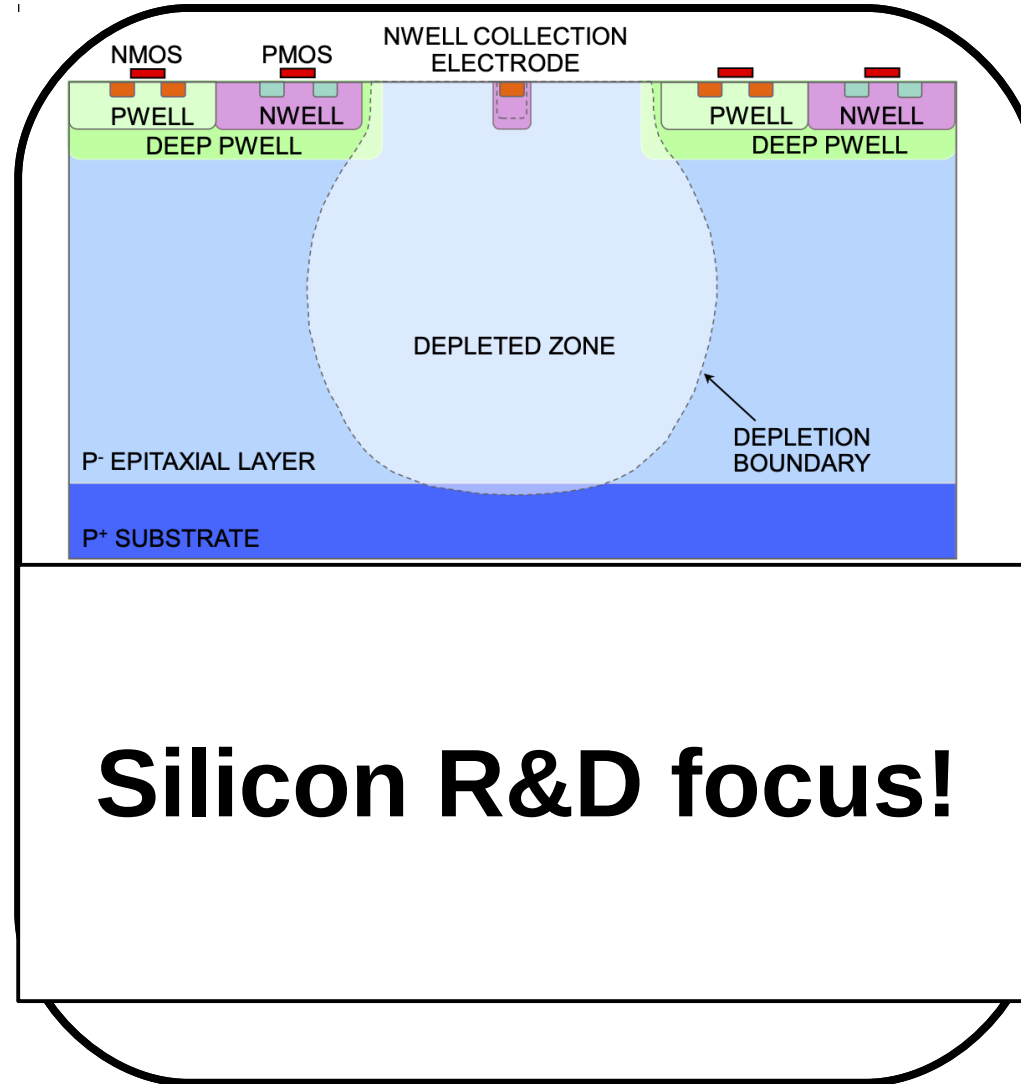
Monolithic Active Pixel Sensor



- One chip = Sensor + ROC
- Low material budget
- Up to $<4 \mu\text{m}$ pixel pitch
- Challenges in implementing in-pixel logic

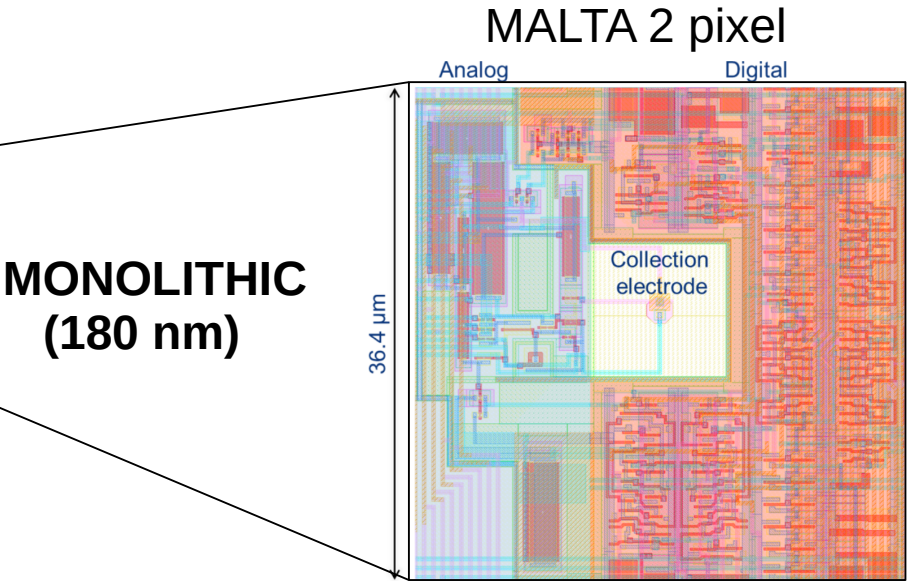
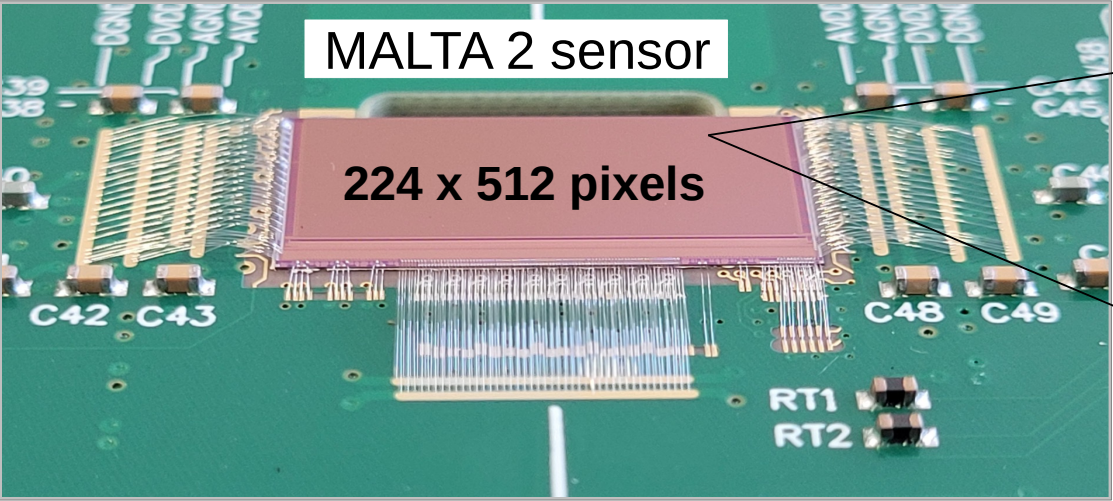
Silicon pixel detectors

Monolithic Active Pixel Sensor



MALTA. Tracker optimization for radiation hardness

Vlad Berlea, Lucian Fasselt, Steven Worm



Excellent time resolution

Excellent position resolution

Low threshold << MIP signal

Radiation hard

PAPER • OPEN ACCESS

Timing performance of radiation hard MALTA monolithic pixel sensors

G. Gustavino, P. Allport, I. Asensi, D.V. Berlea, D. Bortoletto, C. Buttar, F. Dachs, V. Dao, H. Denizli, D. Dobrijevic

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Journal of Instrumentation, Volume 18, March 2023

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DOI: 10.1088/1748-0221/18/03/C03011

Article PDF

Authors References

Article information

Abstract

The MALTA family of Depleted Monolithic Active Pixel Sensor (DMAPS) produced in Tower 180 nm CMOS technology targets radiation hard applications for the HL-LHC and beyond. Several process modifications and front-end improvements have resulted in radiation hardness up to 2×10^{15} 1 MeV n_{eq}/cm^2 and time resolution below 2 ns, with uniform charge collection efficiency across the pixel of size $36.4 \times 36.4 \mu m^2$ with a $3 \mu m^2$ electrode size. The MALTA2 demonstrator produced in 2021 on high-resistivity epitaxial silicon and on Czochralski substrates implements a new cascaded front-end that reduces the RTS noise and has a higher gain. This contribution shows results from MALTA2 on timing resolution at the nanosecond level from the CERN SPS test-beam campaign of 2021.

G. Gustavino et al., JINST C03011

Performance of the MALTA telescope

Milou van Rijnbach^{1,2,3}, Giuliano Gustavino¹, Phil Allport⁴, Ignacio Asensi Tortajada⁵, Dumitru Vlad Berlea⁶, Daniela Bortoletto⁶, Craig Buttar⁶, Edoardo Charbon⁷, Florian Dachs⁸, Valerio Dao⁹, Dominik Dobrijevic¹⁰, Leyre Flores Sanz de Acedo¹¹, Andrea Gabrielli¹², Martin Gatz¹³, Laura Gonella¹⁴, Vicente Gonzalez¹⁵, Stefan Guidon¹⁶, Matt LeBlond¹⁷, Heinz Pernegger¹⁸, Francesco Piro¹⁹, Petra Riedler²⁰, Heidi Sandaker²¹, Abhishek Sharma²², Carlos Solano Sanchez²³, Walter Snoeys²⁴, Tomislav Suligoi²⁵, Marcos Vazquez Nunez²⁶, Julian Weick^{1,2,3}, Steven Worm¹ and Abdelhak M. Zoubir²⁷

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Abstract

MALTA is part of the Depleted Monolithic Active Pixel sensors designed in Tower 180 nm CMOS imaging technology. A custom telescope with six MALTA planes has been developed for test beam campaigns at SPS, CERN, with the ability to host several devices under test. The telescope system has a dedicated custom readout, online monitoring integrated into DAQ with real-time map, time distribution and event hit multiplicity. It hosts a dedicated fully configurable trigger system enabling to trigger on coincidence between telescope planes and timing reference from a scintillator. The excellent time resolution performance allows for fast track reconstruction, due to the possibility to retain a low hit multiplicity per event which reduces the combinatorics. This paper reviews the architecture of the system and its performance during the 2021 and 2022 test beam campaign at the SPS North Area.

M van Rijnbach et al, 83;581

Radiation Hardness of MALTA2, a Monolithic Active Pixel Sensor for Tracking Applications

Publisher: IEEE

3 Citations

655 Full Text Views

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Abstract

MALTA2 is a depleted monolithic active pixel sensor (DMAPS) developed in the Tower Semiconductor 180-nm CMOS process. Monolithic CMOS sensors offer advantages over current hybrid imaging sensors in terms of both increase performance due to lower material budget and ease of integration and construction costs due to the integration of active sensor into one ASIC. Current research and development efforts are aimed toward radiation hard designs. Most in total ionizing dose (TID) and 1×10^{15} 1 MeV n_{eq}/cm^2 in nonionizing energy loss (NIEL). The design sensors was specifically chosen to achieve radiation hardness up to these requirements and satisfy current and future constraints. The current MALTA2 pixel architecture uses small electrodes which provide less noise, higher signal to better power-to-performance ratio. To counteract the loss of efficiency in pixel corners, modifications to the Tower been implemented. The MALTA2 sensors have been tested during the 2021 and 2022 SPS CERN Test Beam in the telescope. The telescope ran for the whole duration of the beam time and took data to characterize the novel MALTA and the performance of irradiated samples in terms of efficiency and cluster size. These campaigns show that MALTA2 is an interesting prospect for HL-LHC and beyond collider experiments, providing both very good tracking capabilities and hardness in harsh radiation environments.

V. Berlea et al., IEEE TNS 2023.3313721

Home > The European Physical Journal C > Article

Radiation hardness of MALTA2 monolithic CMOS imaging sensors on Czochralski substrates

Regular Article - Experimental Physics | Open access | Published: 10 March 2024

Volume 84, article number 251, (2024) | Cite this article

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Milou van Rijnbach^{1,2,3}, Dumitru Vlad Berlea⁴, Valerio Dao⁵, Martin Gatz⁶, Phil Allport⁷, Ignacio Asensi Tortajada⁸, Prafulla Behara⁹, Daniela Bortoletto¹⁰, Craig Buttar¹¹, Florian Dachs¹², Ganapati Dash¹³, Dominik Dobrijevic¹⁴, Lucian Fasselt¹⁵, Leyre Flores Sanz de Acedo¹⁶, Andrea Gabrielli¹⁷, Laura Gonella¹⁸, Vicente Gonzalez¹⁹, Stefano Guidon²⁰, Giuliano Gustavino²¹, Praneet Jans²², Long Li²³, Heinz Pernegger²⁴, Francesco Piro²⁵, Petra Riedler²⁶, Heidi Sandaker²⁷, Abdelhak M. Zoubir²⁸

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8 Citations

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Abstract

MALTA2 is the latest full-scale prototype of the Active Pixel Sensors (DMAPS) produced in Tower imaging technology. In order to comply with the (HEP) experiments, various process modifications have been implemented to achieve low power consumption, reduce random telegraph signal (RTS) noise, and optimise the charge collection geometry. Compared to its predecessors, MALTA2 targets the use of a high-resistivity, thick Czochralski (Cz) substrates in order to

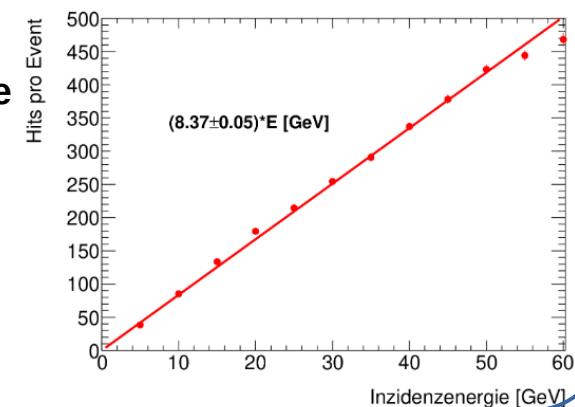
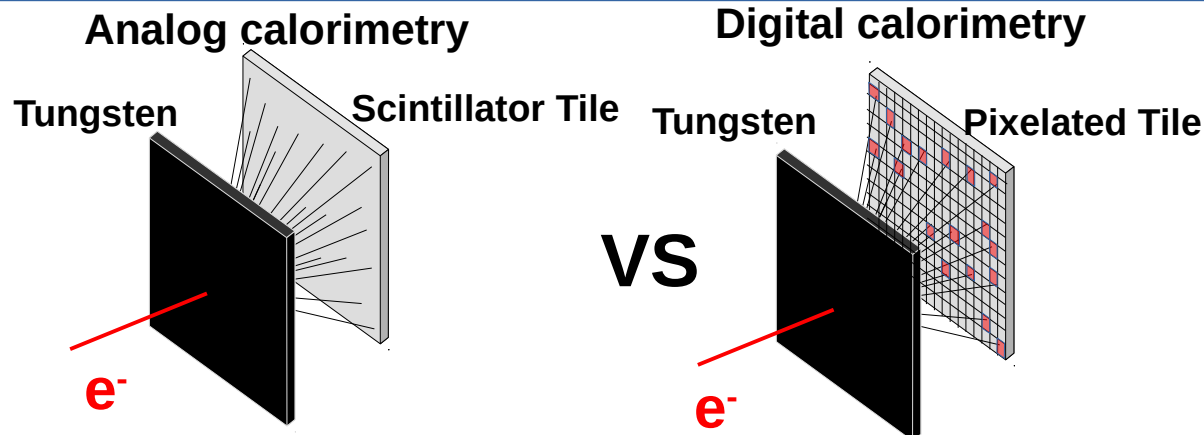
M. van Rijnbach et al., 2308.13231

DECAL. Fast simulation development for digital calorimetry

Vlad Berlea, Lucian Fasselt, Cigdem Issever, Steven Worm

Digital calorimetry

- No en. deposition fluctuation
- Better energy resolution
- Implementation with Silicon

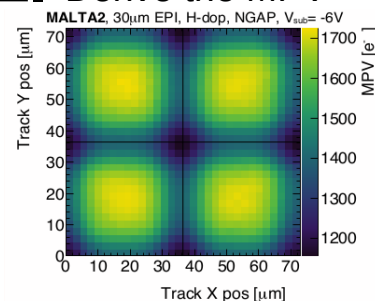


Fast Simulation

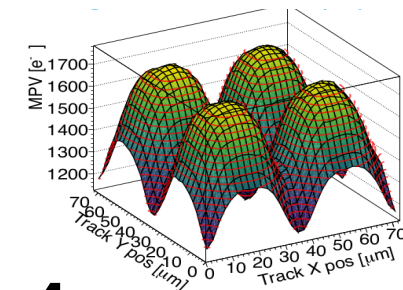
- Parametrized charge collection
- Based on SPS test beam data
- Computationally quick
- Optimization of digital circuitry

For more, see Lucian's poster!

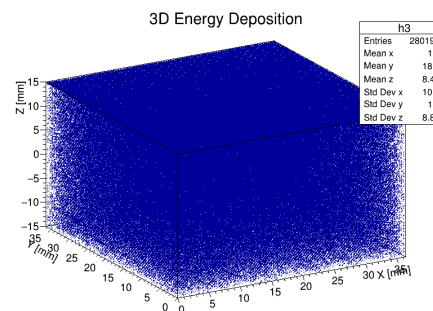
1. Derive the MPV



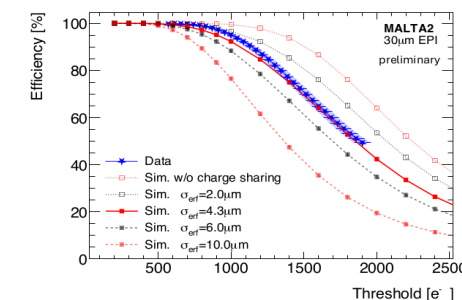
2. Derive analytical data parametrisation



3. GEANT4 Si energy deposition



4. Validation against data



General detector R&D

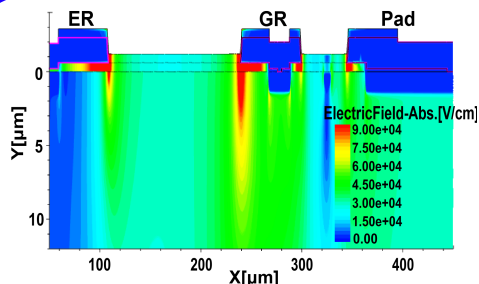
Ben Brüers, Peilin Li, Christian Scharf

Problems

- Silicon sensors used in HEP experiments require a **high electric field**
- Susceptible to **electrical breakdown** in the **edge region**
- Strong dependence on **surface conditions**

Approaches:

Device Simulation



TCAD simulation

IV/CV:

- Sensor geometry
- Current generation mechanism

Monte Carlo Simulation



Allpix squared simulation

Fast transport simulation

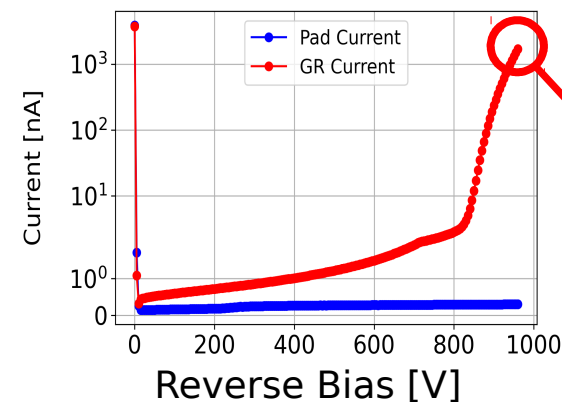
Fixed fields

Laser illumination

(Top-TCT):

→ Surface electric field

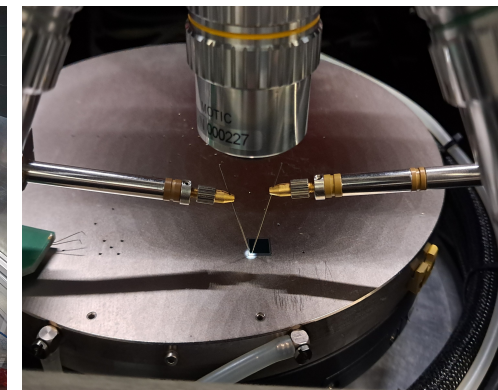
Guard ring (GR) breakdown
RH=36% T=25°C



Measurement



TCT

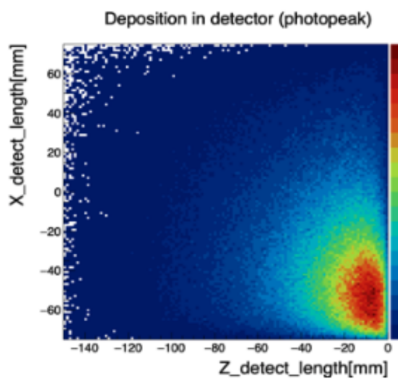
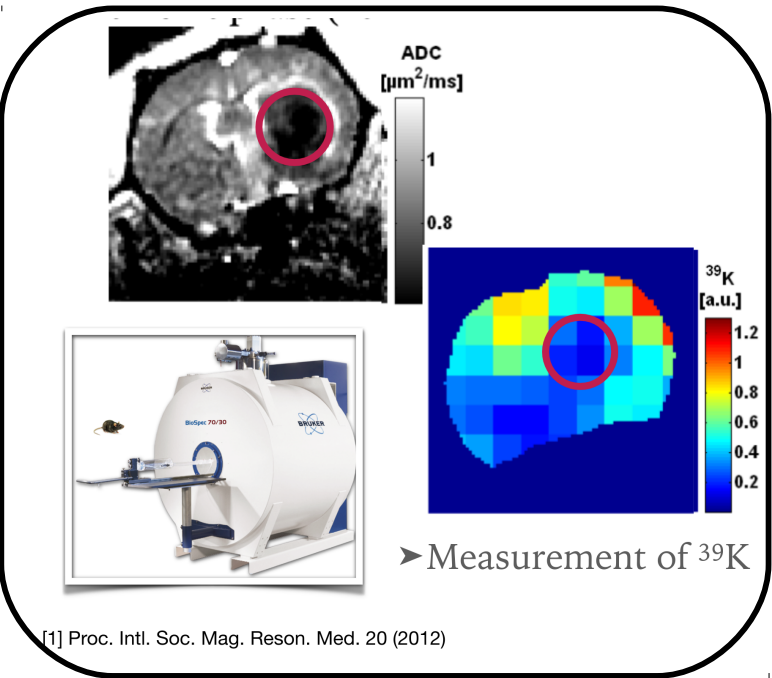


IV/CV

KRANOS. Stroke imaging using Silicon PhotoMultipliers

Vlad Berlea, Priscilla Pani, Claudia Seitz

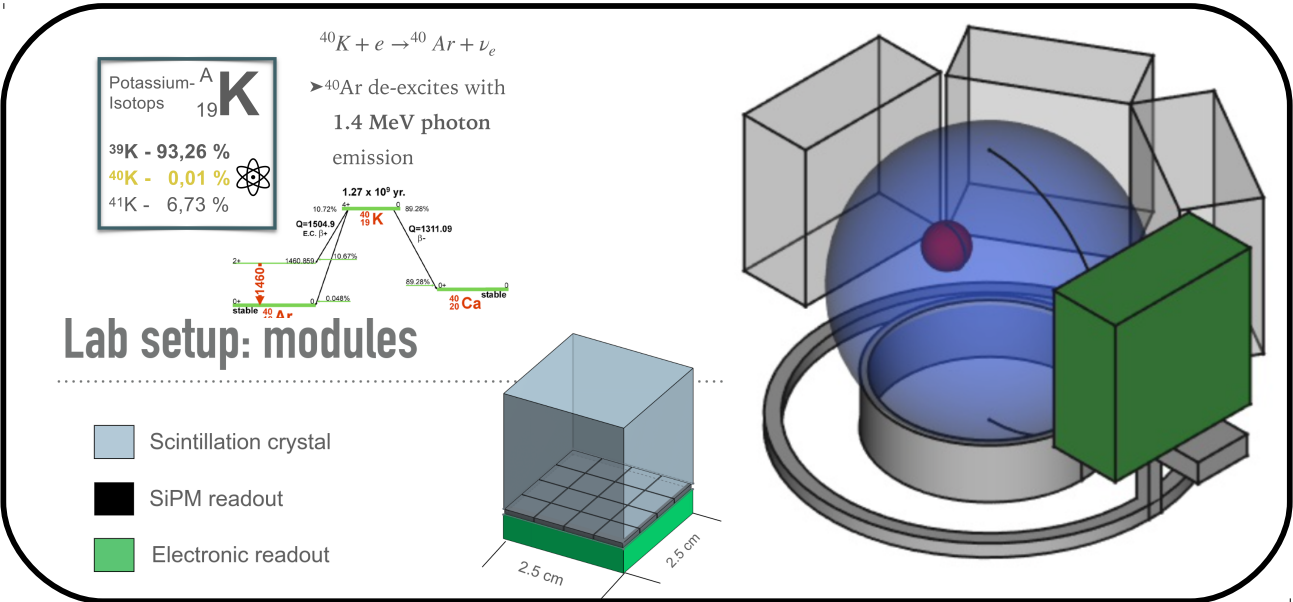
Currently: K-39 rat MRI



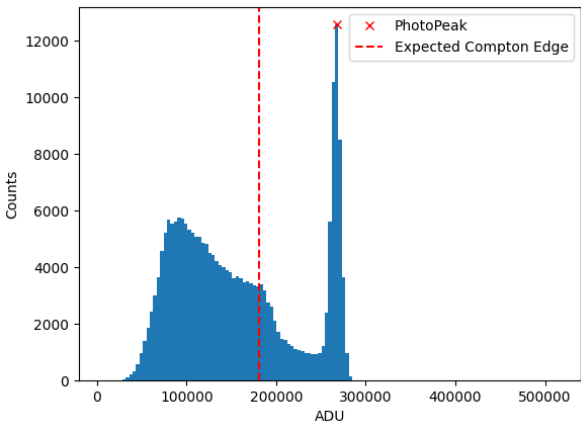
OpenGate simulation

Optimizing crystal material and depth for direct absorption via Photoeffect

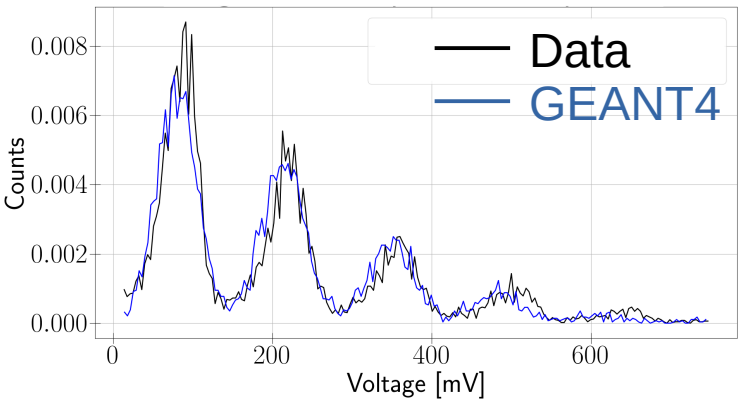
KRANOS: Gamma decay of K-40



Cs-137 spectrum (CeBr3)



Single Photon spectrum

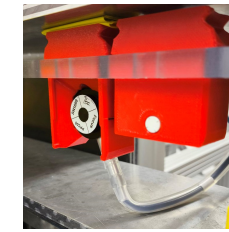
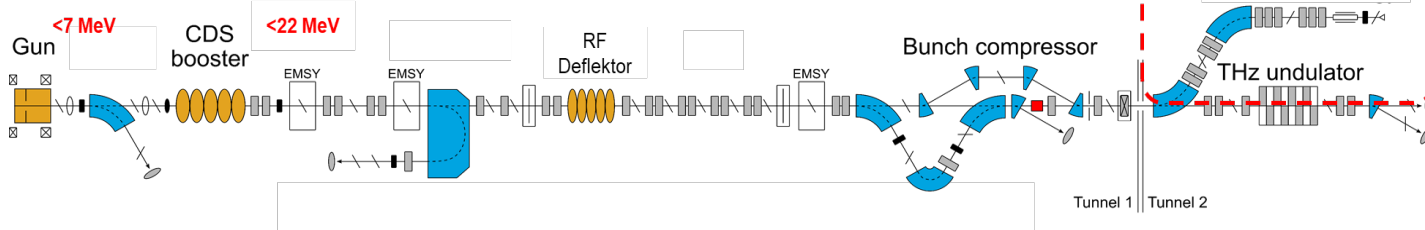


Medical applications $\hat{=}$ Cancer therapy

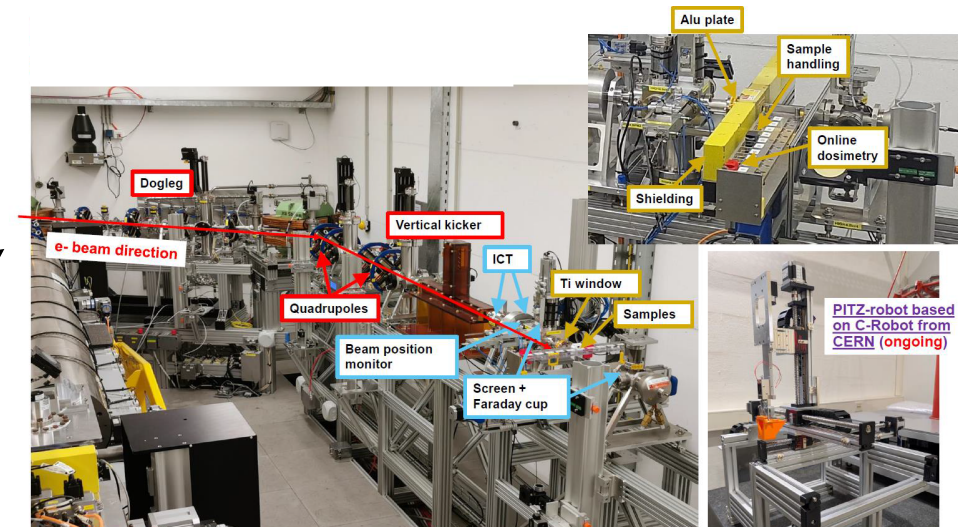
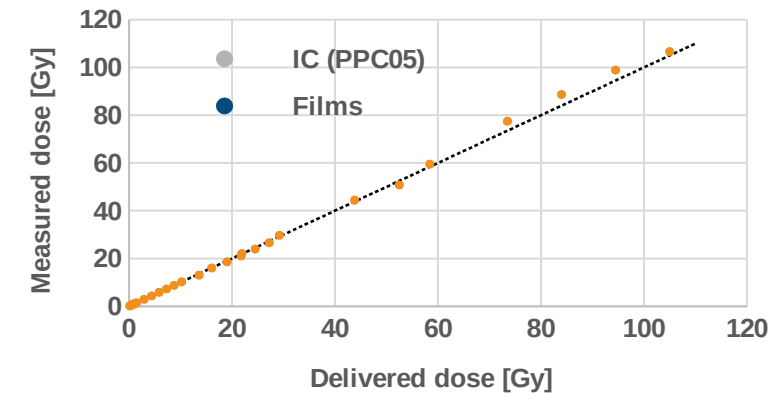
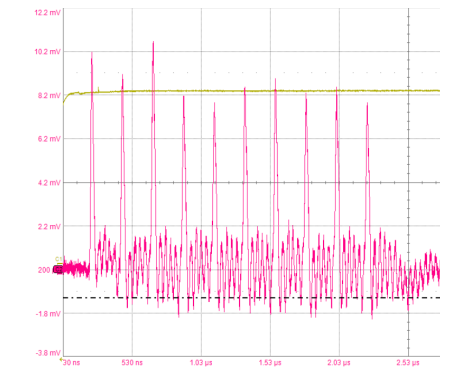
Irradiation with ultra-high dose rates spares normal tissue

- The PITZ accelerator in Zeuthen provides wide parameter range
Adjustable parameters:
Number of bunches per RF pulse, number of pulse trains, bunch charge, bunch repetition rate/timing and beam size
- Established detectors show saturation effects
(**comparison:** ATLAS ITk lifetime dose can be delivered within **a few minutes** at PITZ)
 - Online detectors**
 - Silicon detector (Timepix):* saturation (charge multiplication)
 - Ionization chamber:* saturation (ion recombination effects)
 - SiC detector:* linear response, resolution of single bunches possible BUT reduced radiation hardness
 - Diamond detector:* linear response, resolution of single bunches possible
 - $\hat{=}$ ideal detector for ultra-high dose rates
 - Passive detectors**
 - Gafchromic films:* show super-linearity
 - TLDs/OSLDs:* no dose-rate dependence
- Reliable Dosimetry is crucial for biological experiments and to optimize irradiation parameters

PITZ electron accelerator at DESY Zeuthen

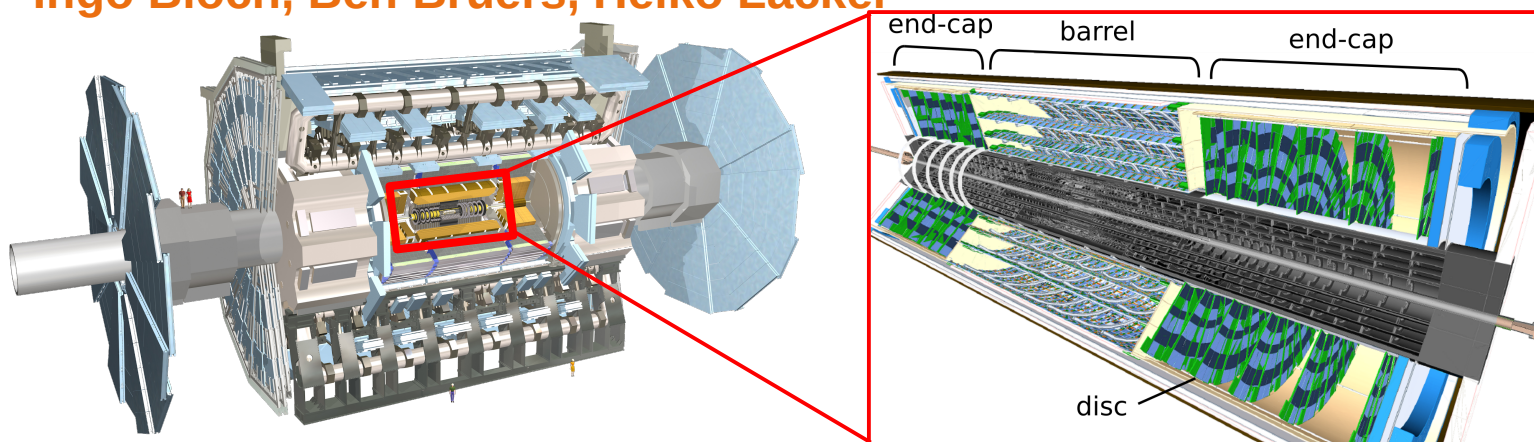


Ionization chamber and diamond detector at the end of the beamline (top)
Diamond signal on the oscilloscope (right)

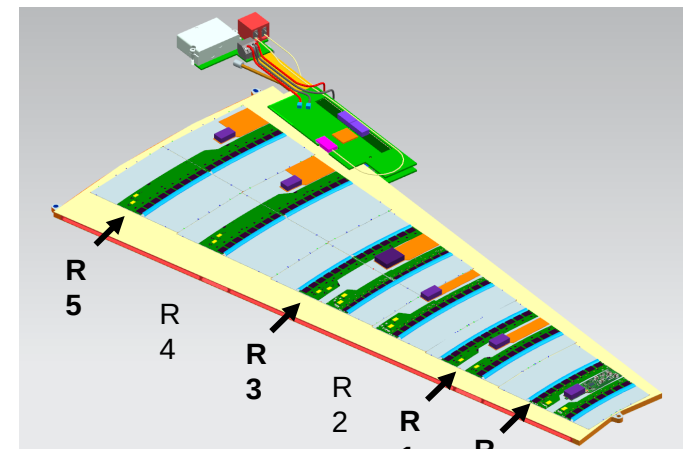


ATLAS HL-LHC Itk upgrade

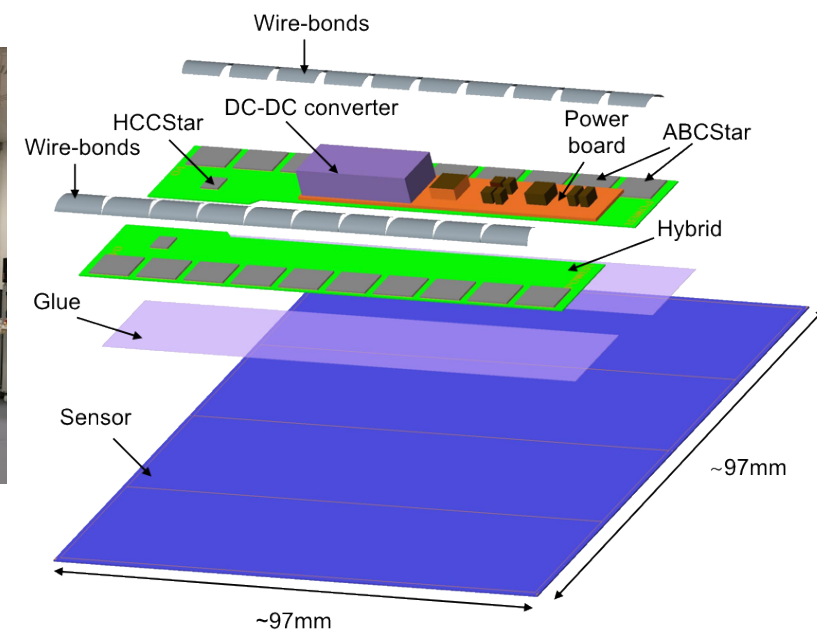
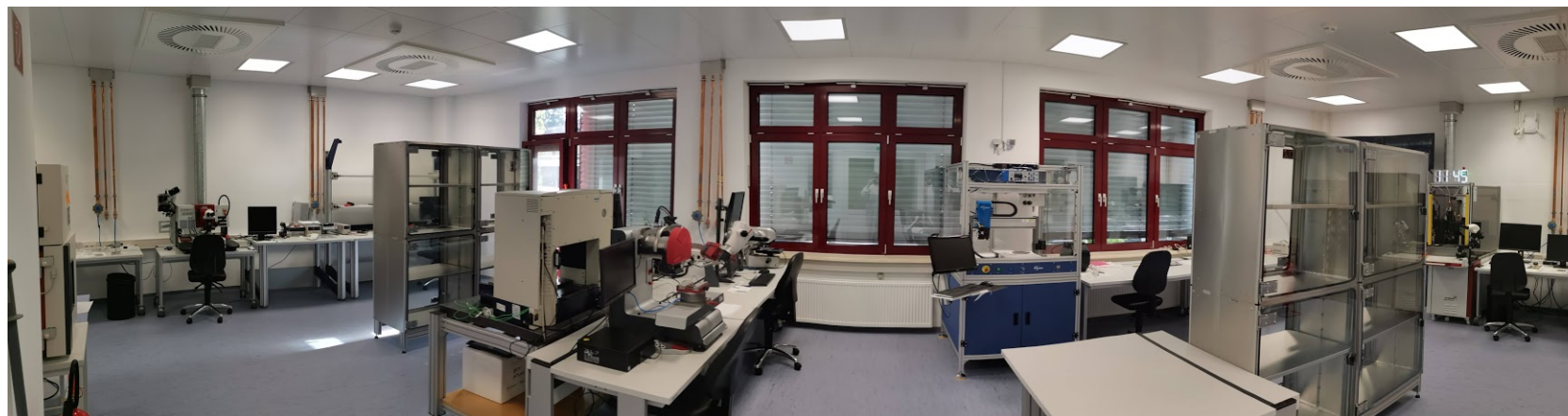
Ingo Bloch, Ben Brüers, Heiko Lacker



Silicon strip detector (1500 DESY + 500 HU)



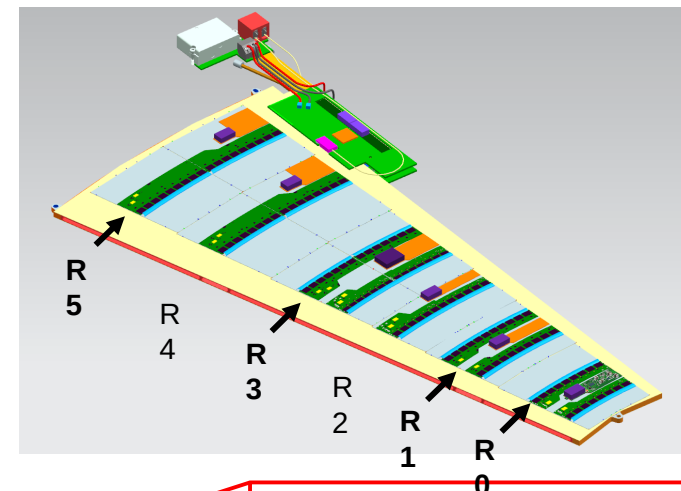
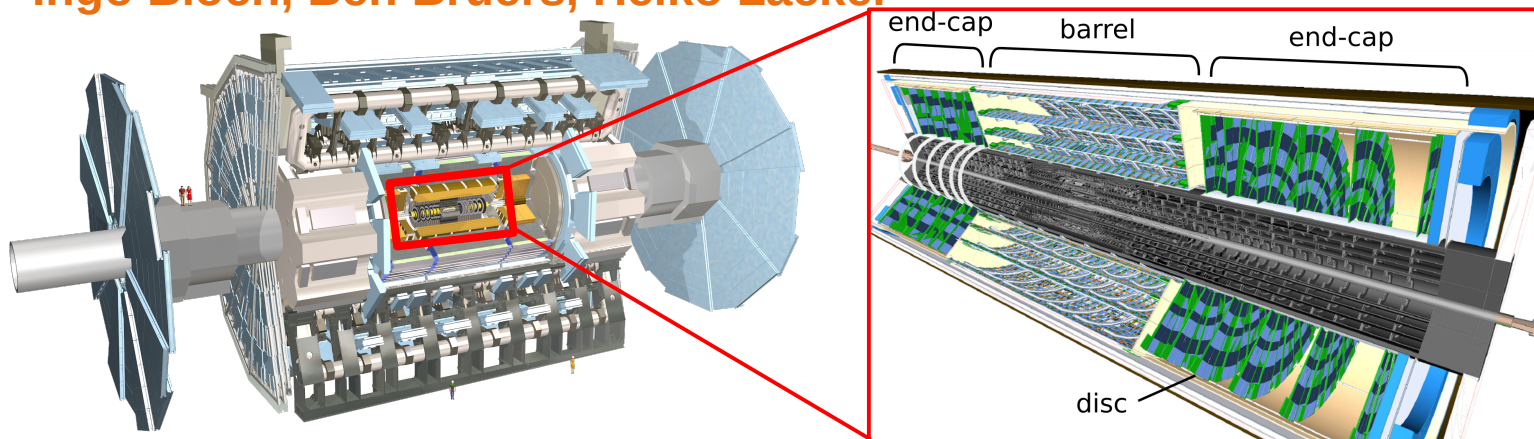
Zeuthen ATLAS upgrade production lab (ISO-6)



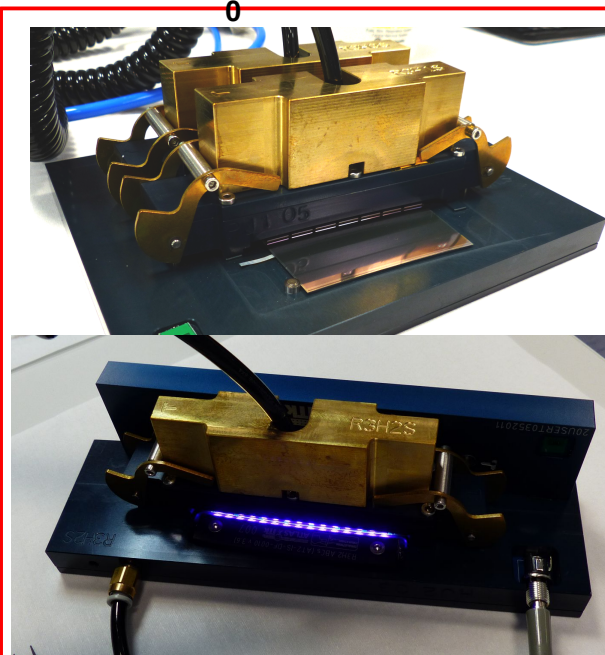
ATLAS HL-LHC Itk upgrade

Ingo Bloch, Ben Brüers, Heiko Lacker

End-cap modules (1500 DESY + 500 HU)



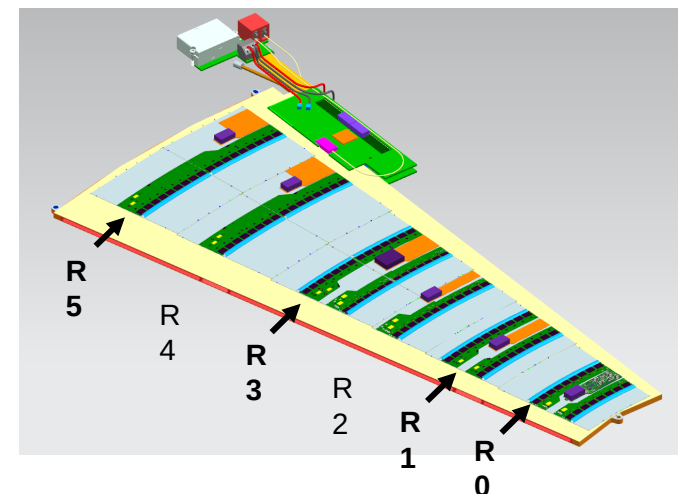
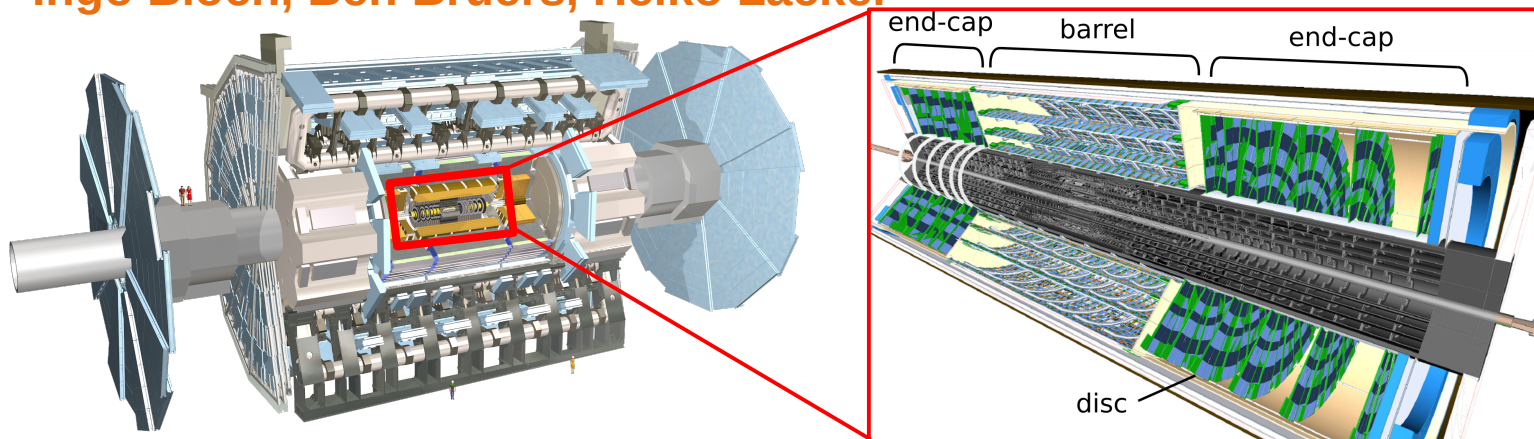
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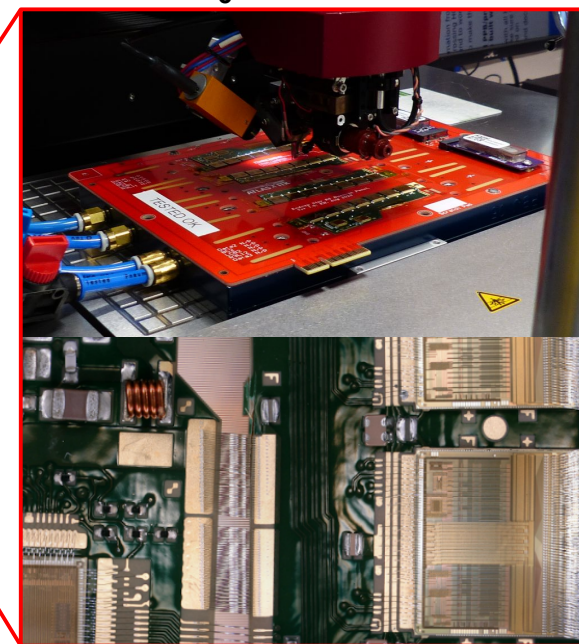
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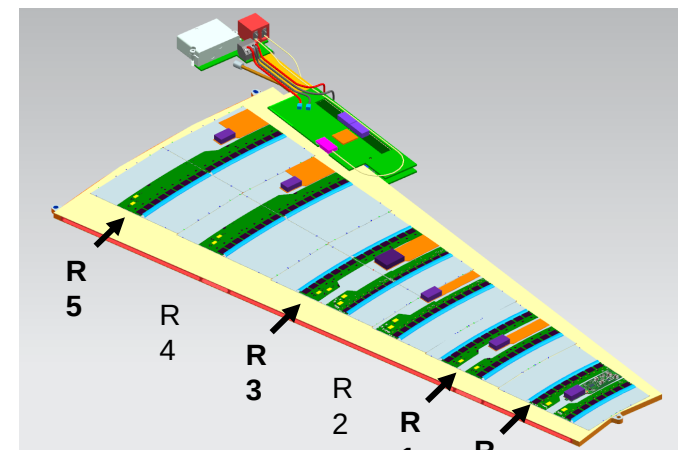
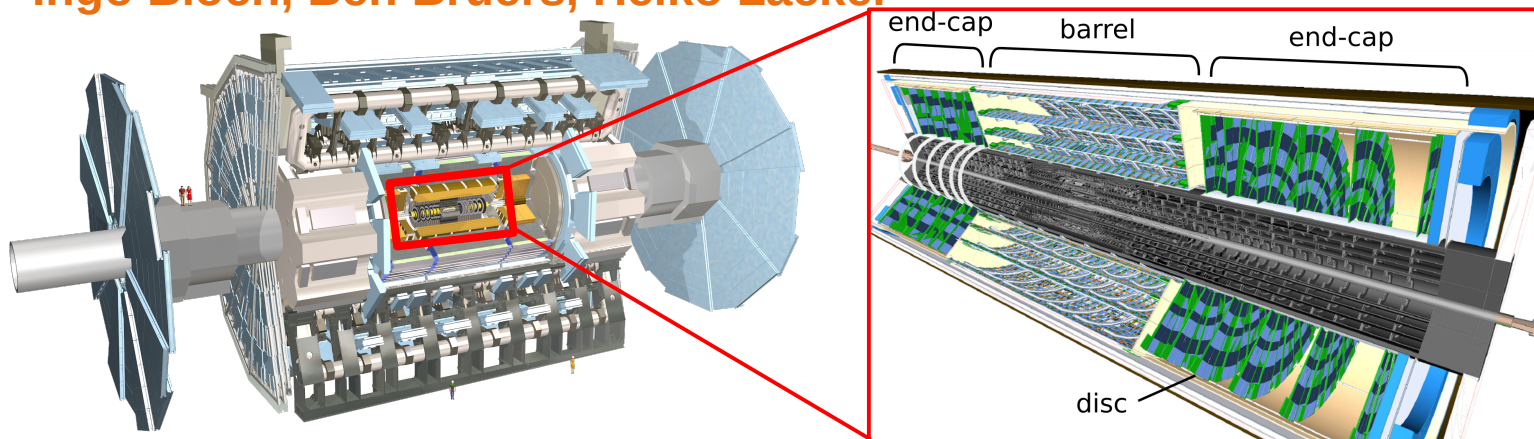
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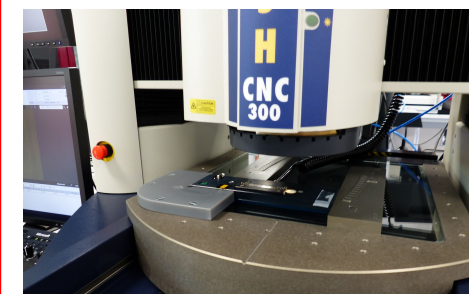
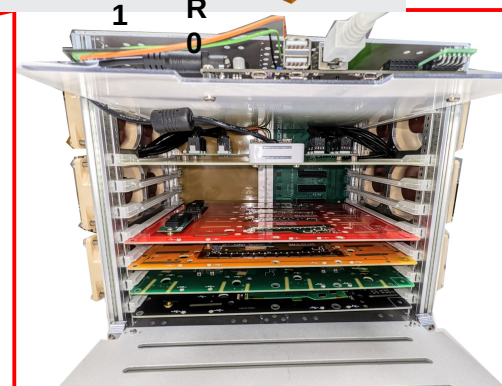
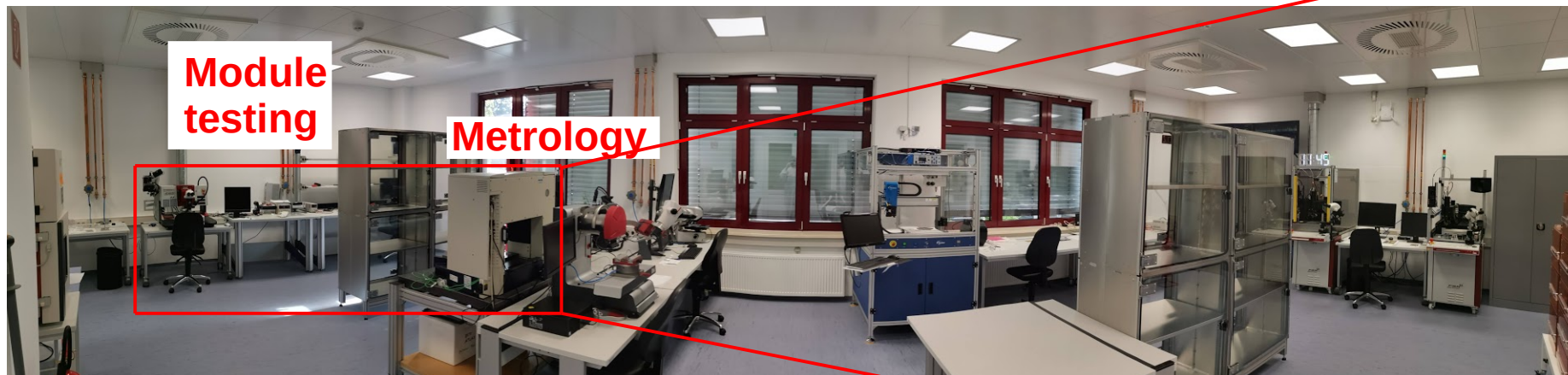
ATLAS HL-LHC Itk upgrade

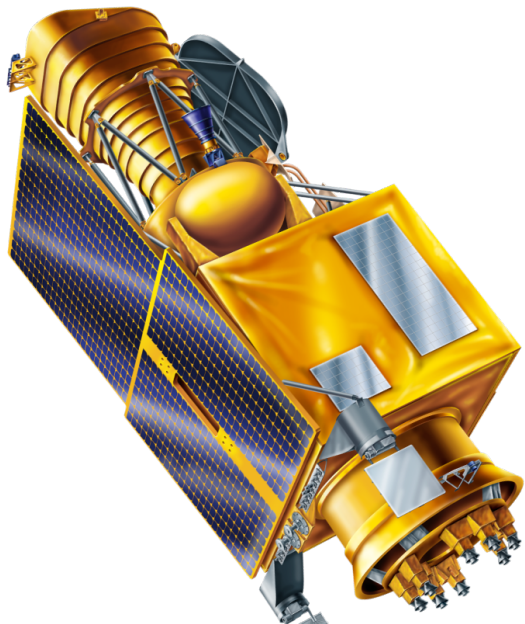
Ingo Bloch, Ben Brüers, Heiko Lacker

End-cap modules (1500 DESY + 500 HU)

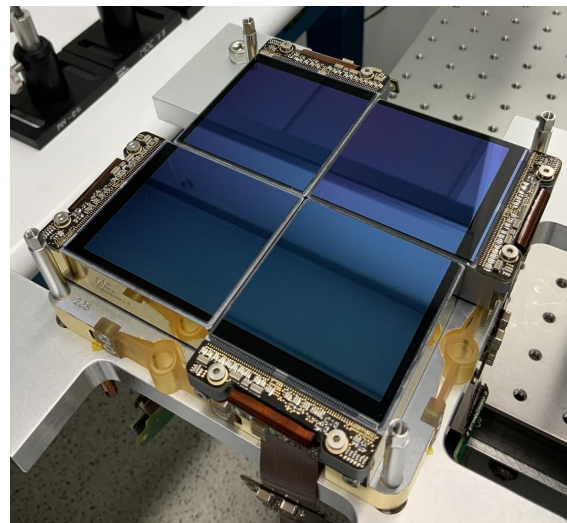


Zeuthen ATLAS upgrade production lab (ISO-6)

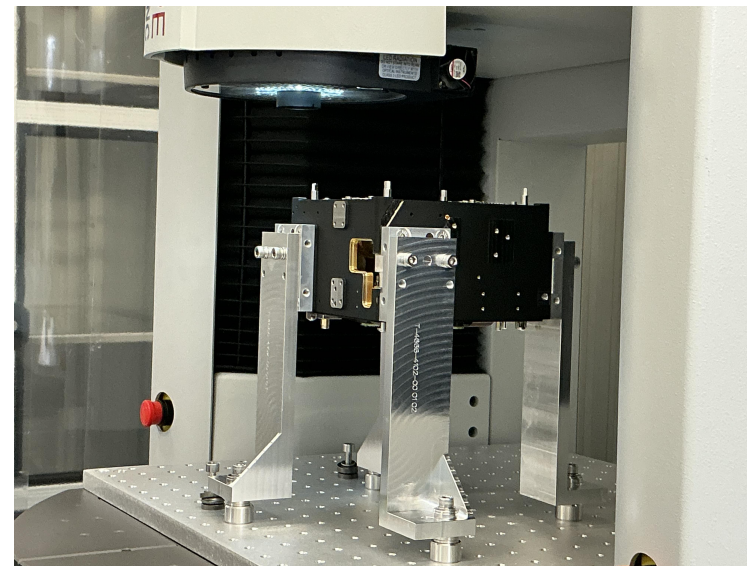




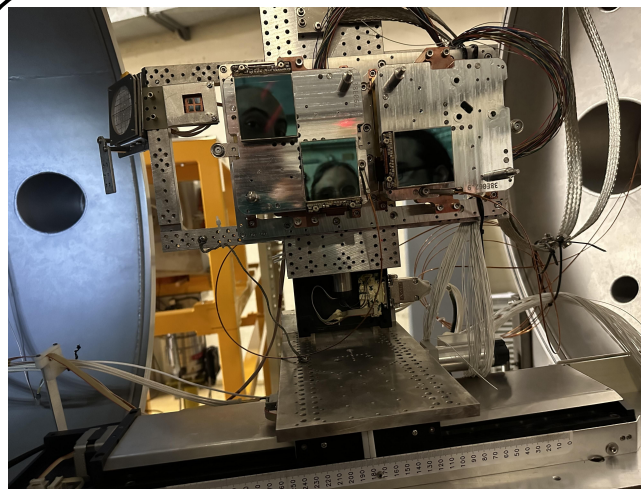
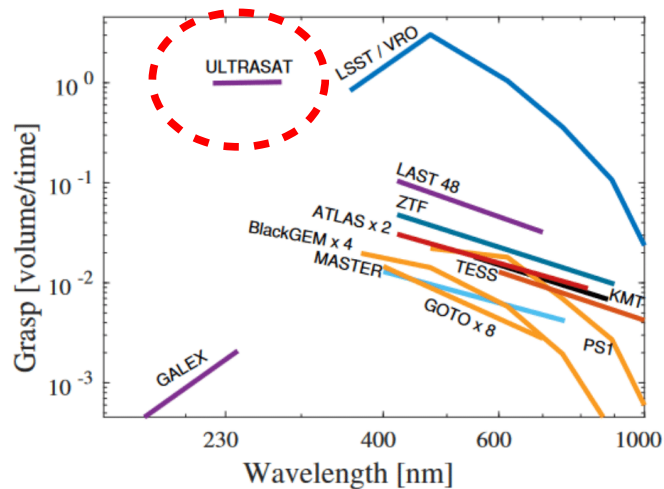
ULTRASAT Camera



Metrology @ DESY Zeuthen



Radiation testing. Single Event Effect @ SIRAD Italy



Conclusions and outlook

Research status at DESY and HU

- Very diverse research program (accelerator, HEP collider R&D and production, medical, space telescope)
- Significant overlap and collaboration (simulation work, equipment and facilities)

What to look for in the near future

- Move towards full silicon particle detectors (vertex, tracking, calorimetry) + ever increasing on-chip intelligence
- Very interesting advancements in medical imaging and dosimetry enabling new therapy procedures
- Ever expanding multimessenger astronomy: indirect DM searches, transient galactic events (e.g. SNe)

Thank you

Contact

Deutsches Elektronen-
Synchrotron DESY

www.desy.de

Name Surname

Department

E-mail

Phone