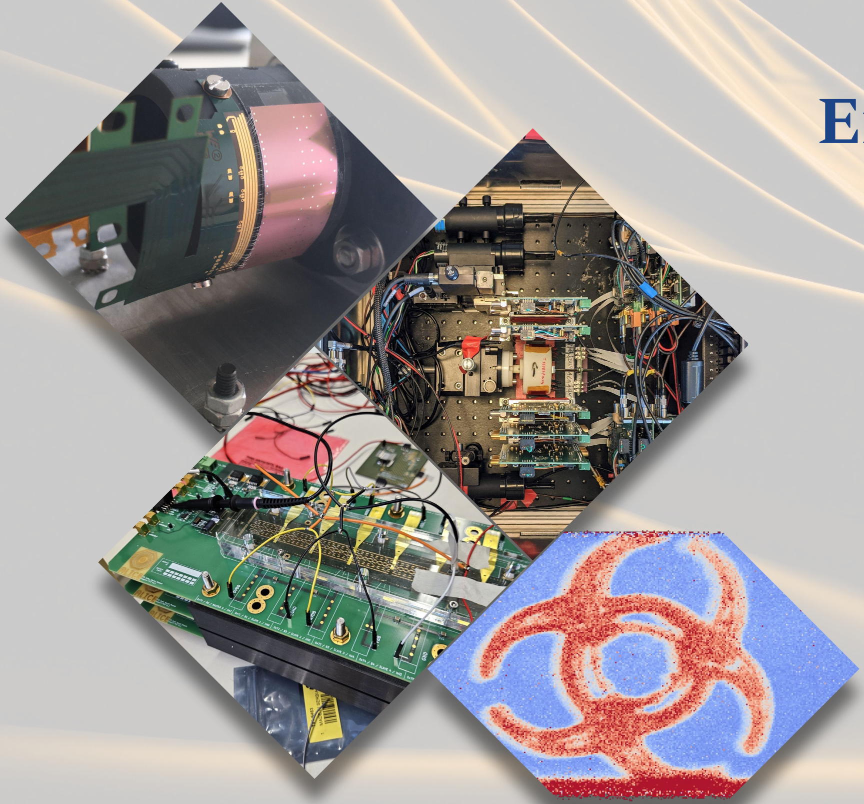


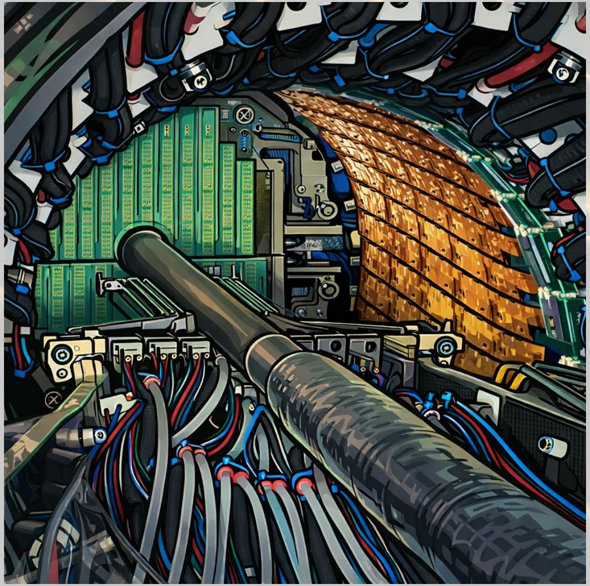
Experience with pixel sensors in the ALICE group at GSI

Bogdan-Mihail Blidaru
for the ALICE GSI group

Pixel Platform initiative @ GSI
23.03.2026

Pixels in ALICE

From ITS2 (currently operating)



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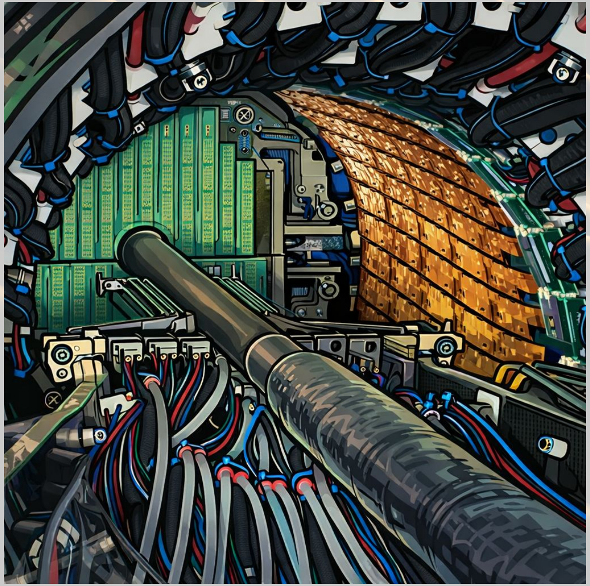
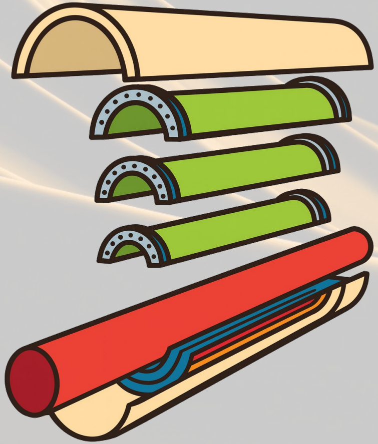


To ITS3 (LS3 upgrade)



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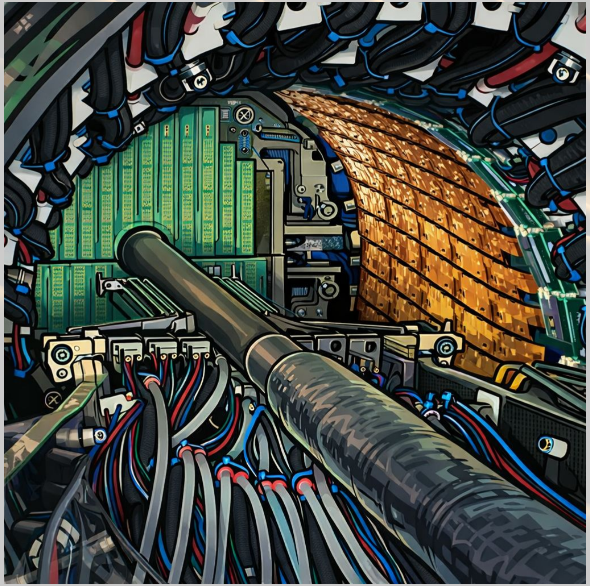

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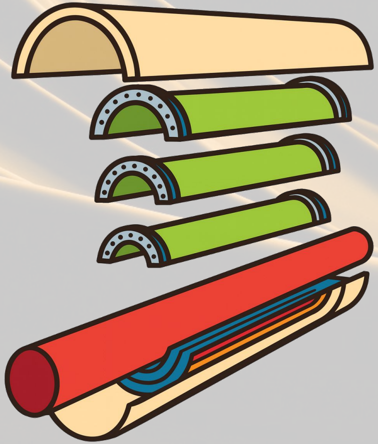
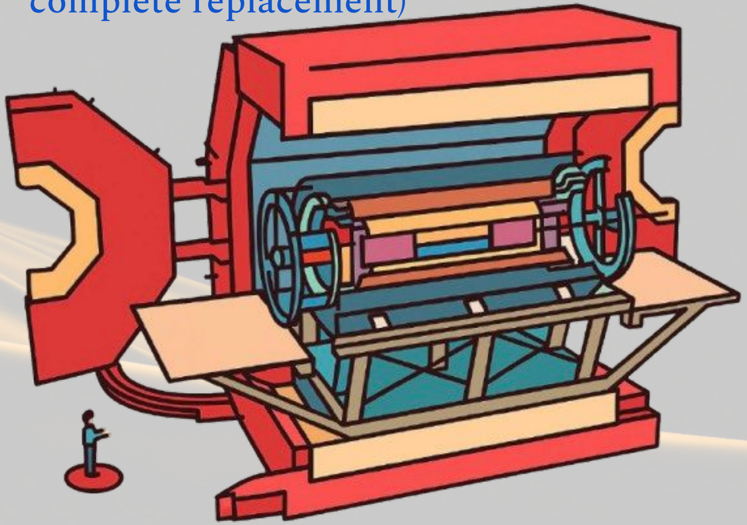


And finally to ALICE 3 (LS4 upgrade, complete replacement)



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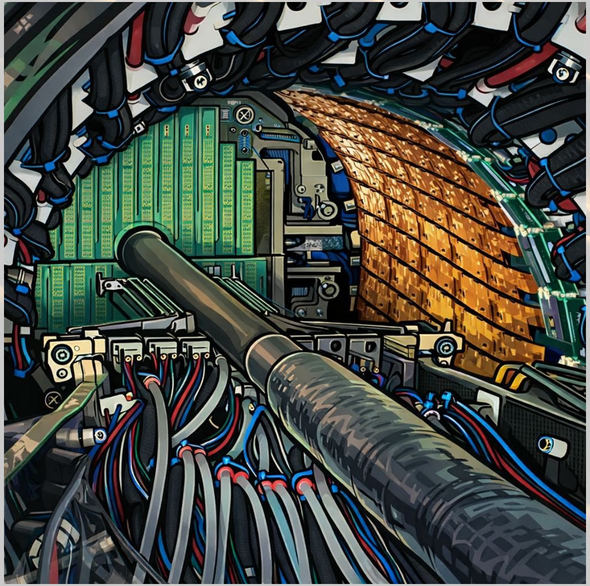

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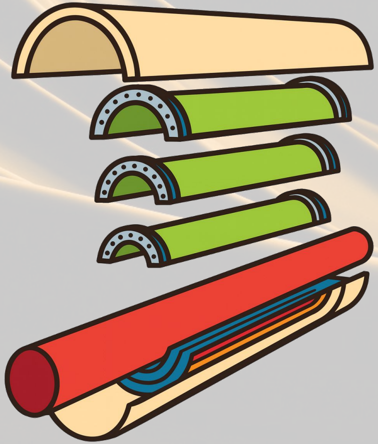

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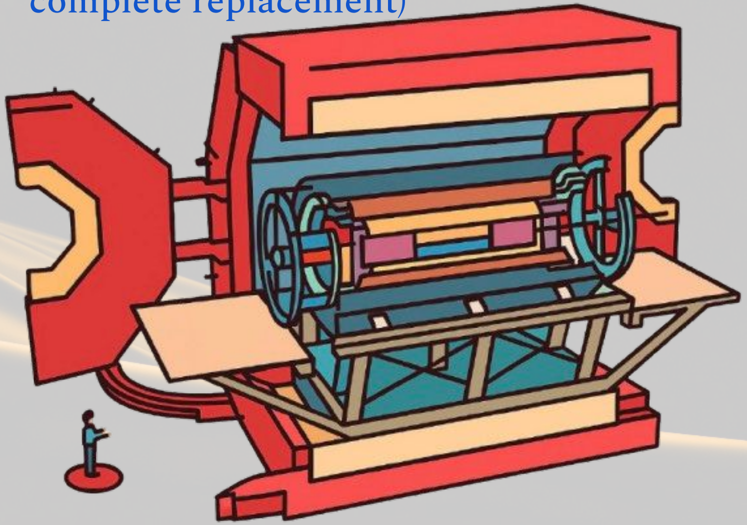

- ➠ Work in our GSI hardware group is framed within ALICE ITS3 and ALICE 3 upgrades
- ➠ Started the "pixel business" in 2019 → local know-how in the group
- ➠ The ASICs and associated hardware (both 180 nm and 65 nm)
  - → working together with the ALICE pixel groups at CERN (and associated groups)

Pixels in ALICE

From ITS2 (currently operating) ... pgrade,

The talk is about versatility of MAPS (in the context of ALICE technology) as seen from our local experience

The beautiful technology (& derived results): developed together with CERN colleagues & other ALICE groups

No performance of sensors will be discussed in detail.

We can happily provide further information (articles)

- W... ...LICE ITS3 and ALICE 3 upgrades
- S... ...usiness" in 2019 → local know-how in the group
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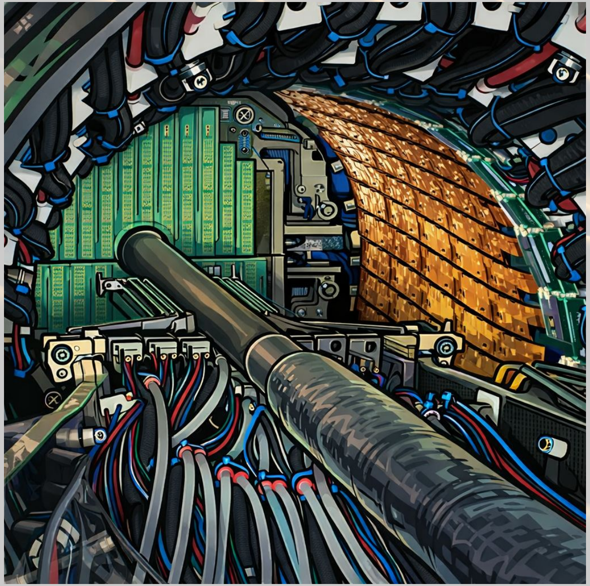
The technology and its use



Inner Tracking System 2

During LS2 and for Run 3: ALICE 2

➠ **thinner & lighter** vertexer (ITS2) with **MAPS**

➠ 7 concentric layers, stave-like structure, 10m^2 of silicon

➠ flagship sensor: ALPIDE (**180nm** **CMOS** TowerJazz)

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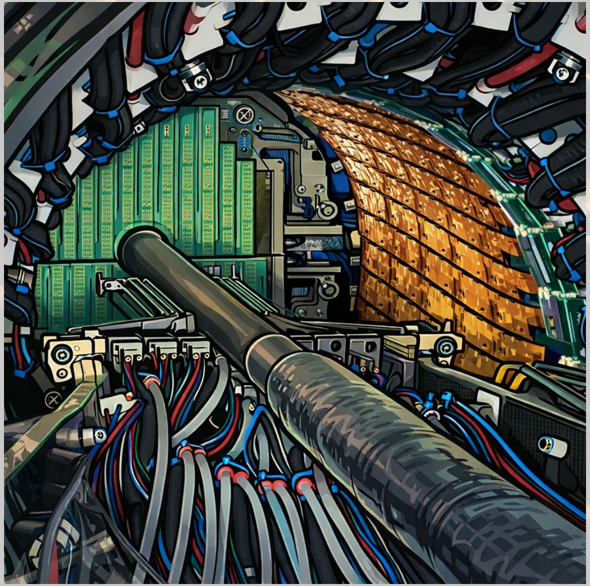

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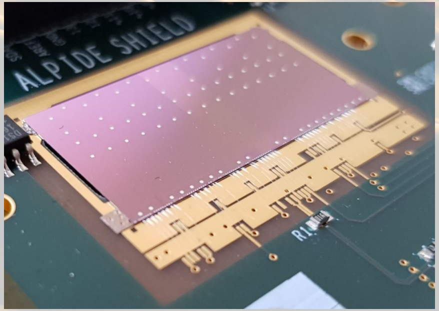
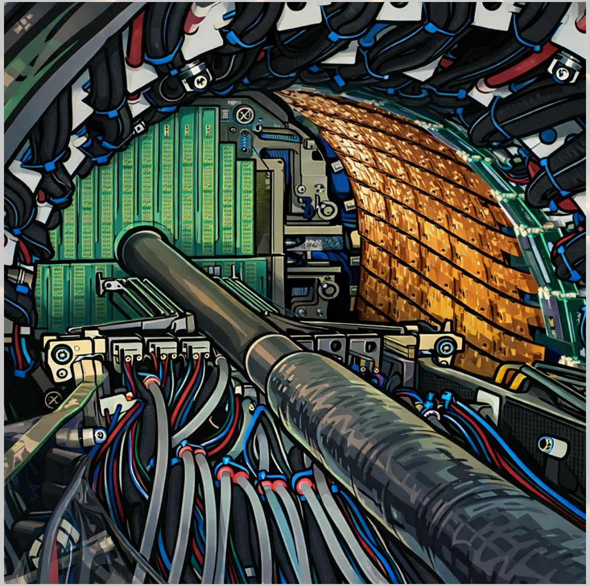


ALPIDE
➠ **high-resistivity** epitaxial layer (25 µm: active detection layer)
➠ small diode → low capacitance (~nF) → low noise
➠ reverse bias (few V) to increase depletion
→ process modification available

Key features
➠ In-pixel: amplification, discrimination, buffer
➠ In-matrix: zero-suppression (only hit pixels send information)
➠ Optimized for low power consumption (average <40 mW/cm^2) → integration time is below 10 µs

The technology and its use



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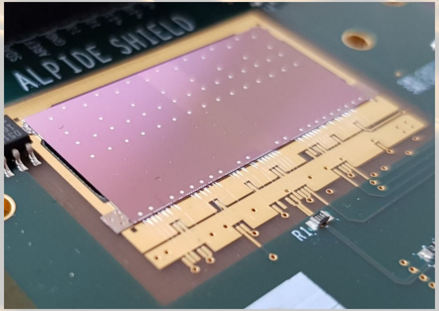

- 0.5 Mpx sensor (~29×27 μm^2)
- 50/100 μm thick (IB/OB)
- >99.9% efficient (detection)
- ≪ 10^{-6} fake hits / px / event
- ~5 μm position resolution

ALPIDE

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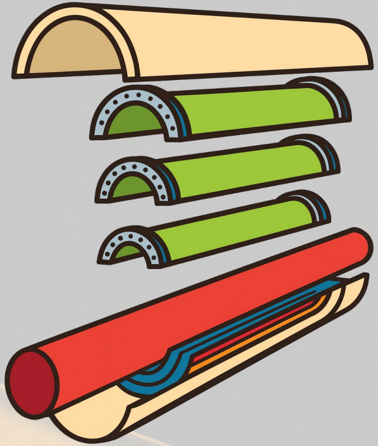
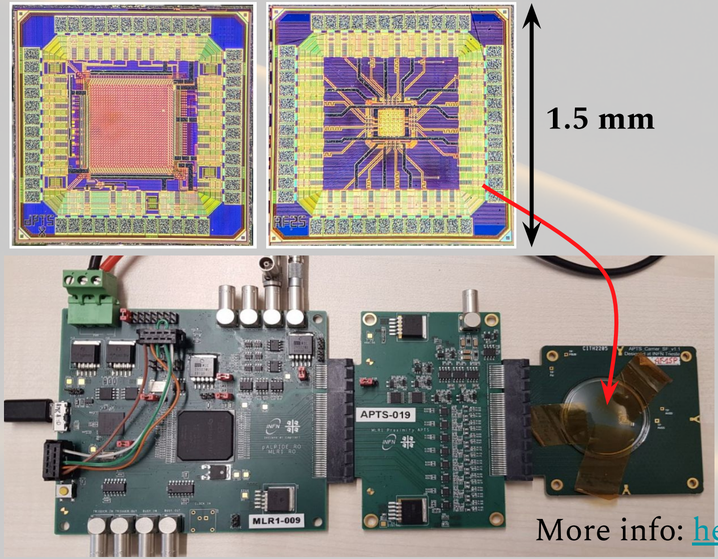
The technology and its use

Studies towards ITS3

➠ Sensor characterization, next-generation of chips

➠ **Analog and Digital pixel test structures** → new CMOS node (**65nm**)
→ both studied at GSI, incl. irradiated samples



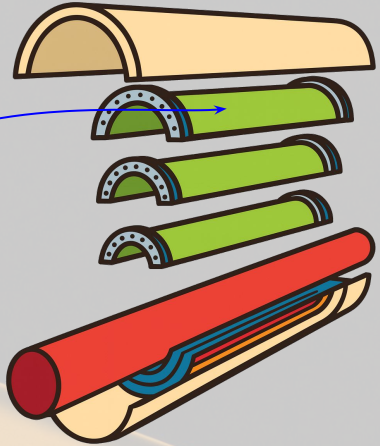


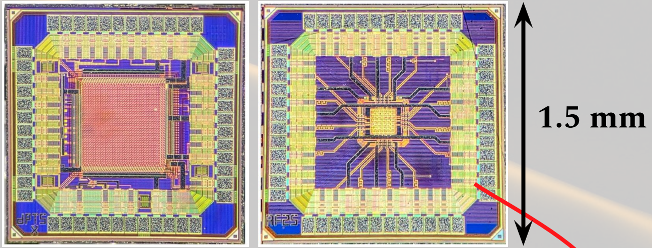
More info: here and here

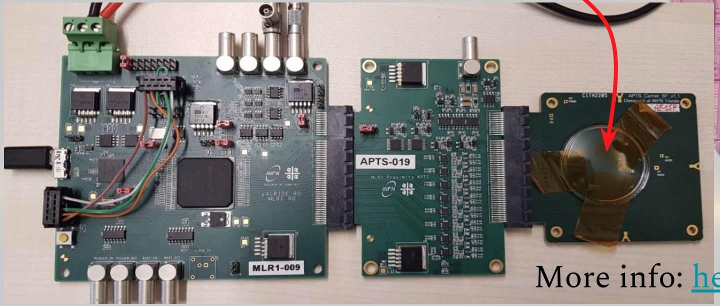
The technology and its use

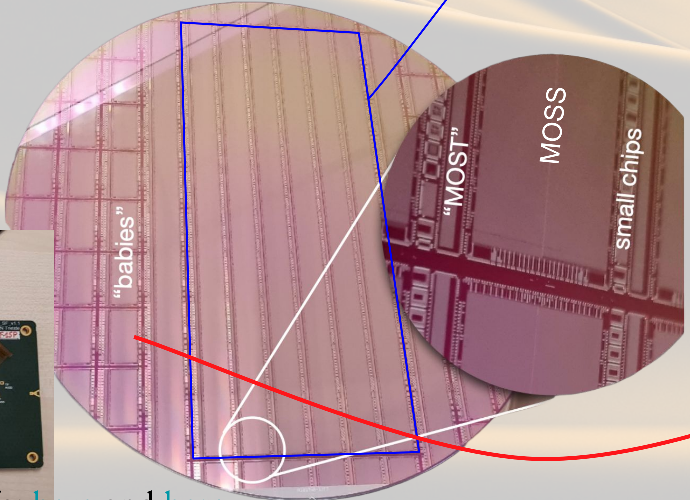
Studies towards ITS3
➠ Sensor characterization, next-generation of chips

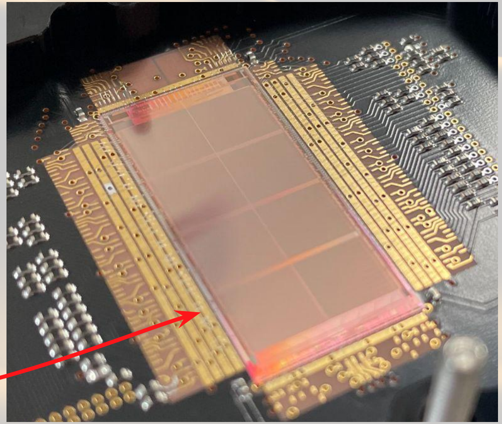
➠ **Analog and Digital pixel test structures** → new CMOS node (**65nm**)
→ both studied at GSI, incl. irradiated samples
➠ Going wafer-scale → first step: MOSS (and babyMOSS)
→ at GSI just the "*baby*" variant; the full MOSS system is too complex







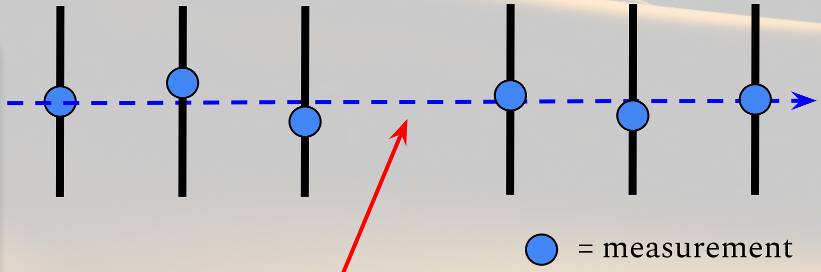




More info: here and here

Usage of ALPIDE sensors

- Flagship **ALPIDE** sensors routinely used in the lab
  → **well understood** behavior, reticle size (3×1.5 cm^2), DAQ setup distributed to many institutes and utilized for long
  → reference tracking detector for "***telescopes***" : needed e.g. for sensor characterization studies



DUT (Detector Under Test) can be placed in the middle → known: track intercept on the DUT

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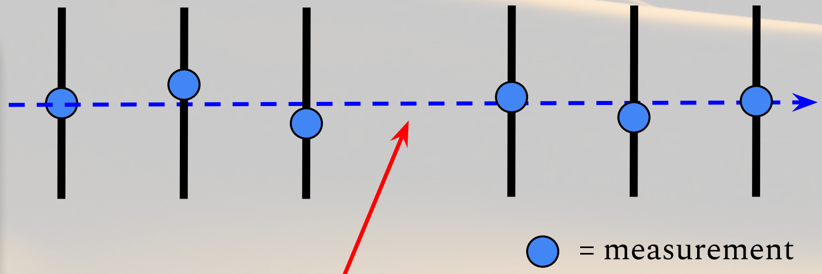
Applications where ALPIDE sensors are used / planned to be used:
Muon Forward Tracker, proton CT (medicine), HEPD@CSES-2 (satellite), sPHENIX, R^{3}B, SFRS tracker, AMBER, FoCal ...

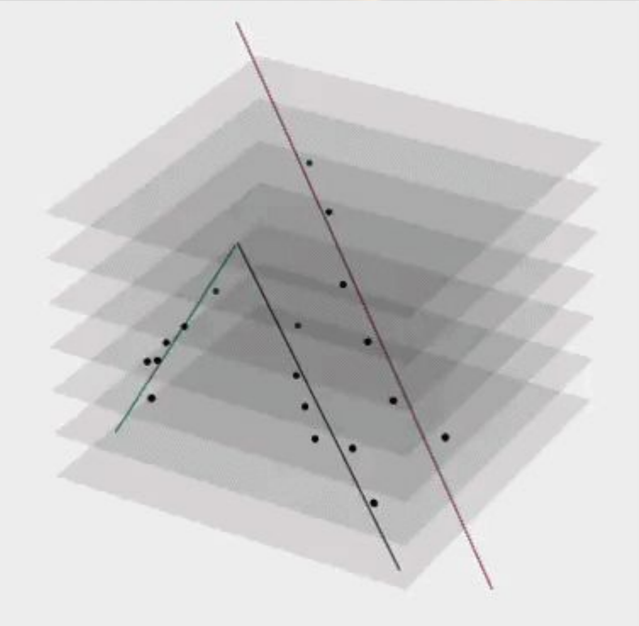
ALPIDE @ ALICE GSI group
➠ Operated in the laboratory and at testbeams → all needed equipment (& license) available
➠ Bonded at GSI (DL: C. Schmidt, C. Simmons, R. Vishinka)

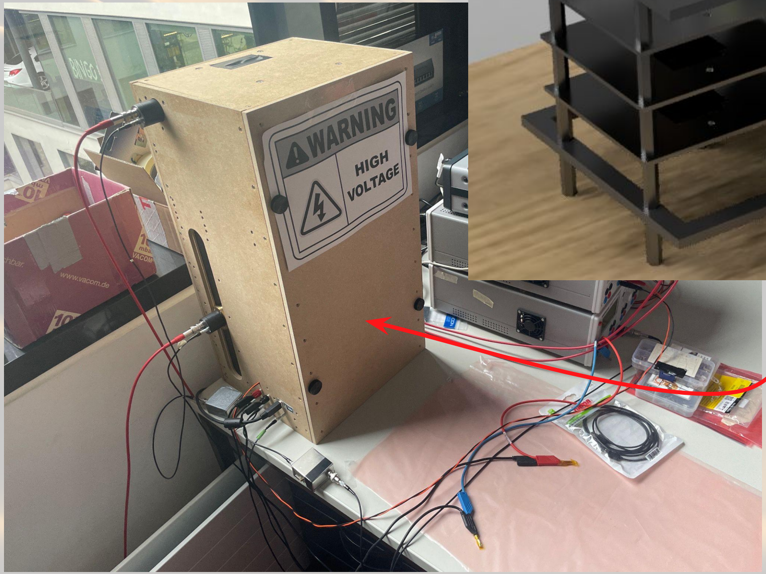


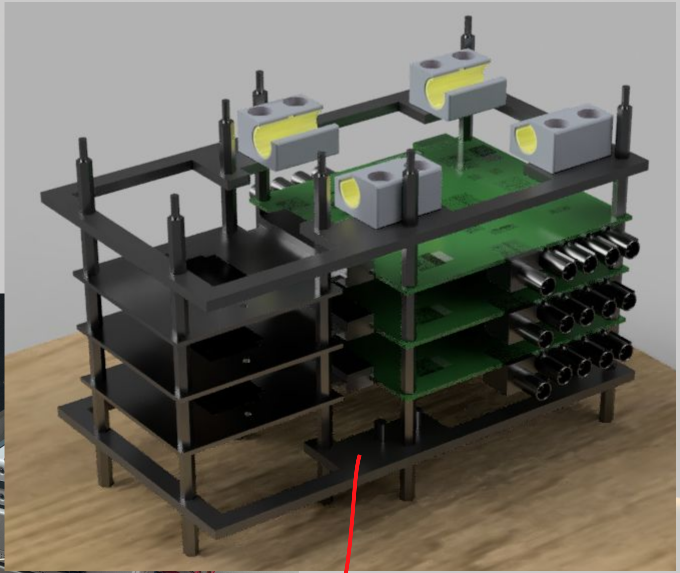
DUT (Detector Under Test) can be placed in the middle → known: track intercept on the DUT

Application: telescope for cosmics (educational)

- ➠ **ALPIDE** cosmics telescope
  - → good training resource for new students
  - → sensor operation, **tracking & alignment studies**
  - → all thesis in the group made use of ALPIDEs





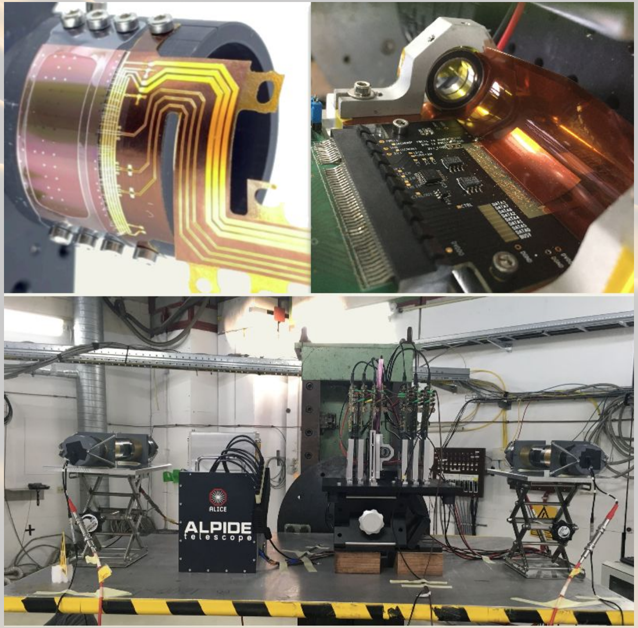


More info:
here, here,
here, here

Application: bent sensors

Bent ALPIDE sensors → ITS3 context
➠ **standalone**
→ electrical characterization, multiple radii
→ effects of bending on cluster size, detection efficiency position resolution, noise

Longitudinally bent | Laterally bent



More info: here and here (+new article soon)

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➠ barrel-configuration **µITS3** (complete tracking detectors: smallest ever?)
→ alignment & tracking

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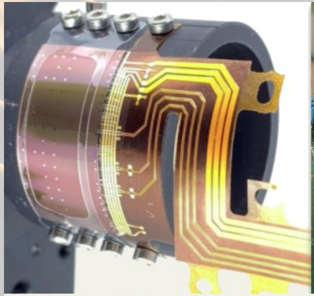

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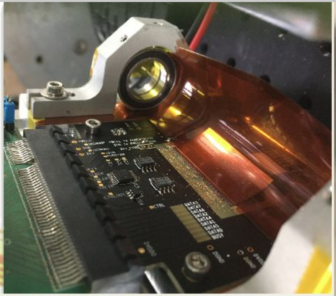
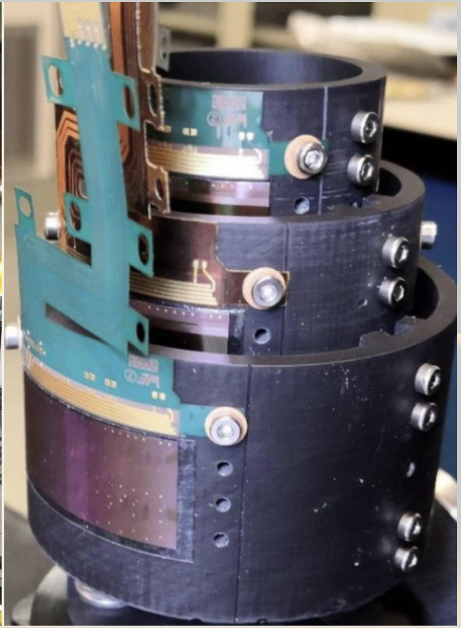


Multiple planes (e.g. ½ of the µITS3)



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➠ **standalone**
→ electrical characterization, multiple radii
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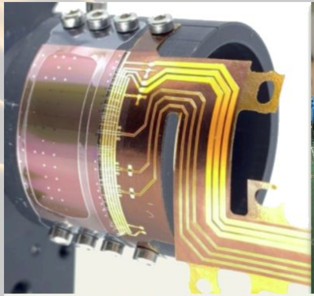
➠ barrel-configuration **μITS3** (complete tracking detectors: smallest ever?)
→ alignment & tracking
→ performance for physics measurements
→ pointing accuracy (impact parameter, DCA)
→ interaction vertex reconstruction

Longitudinally bent



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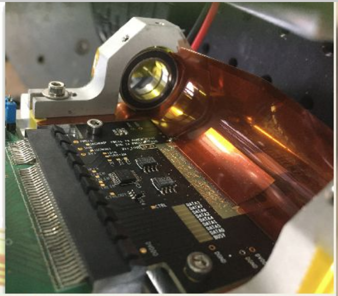

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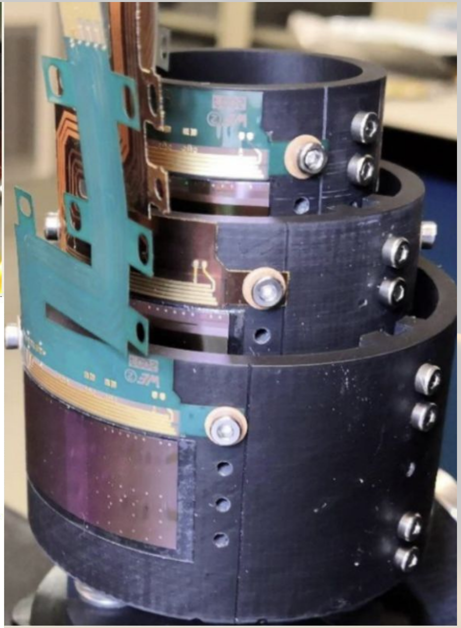
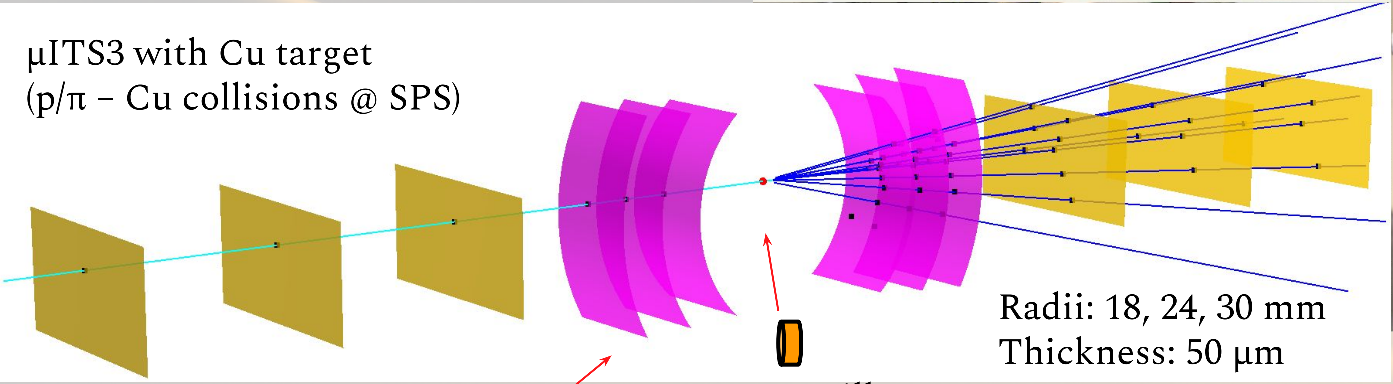




Cu pill

More info: here and here (+new article soon)

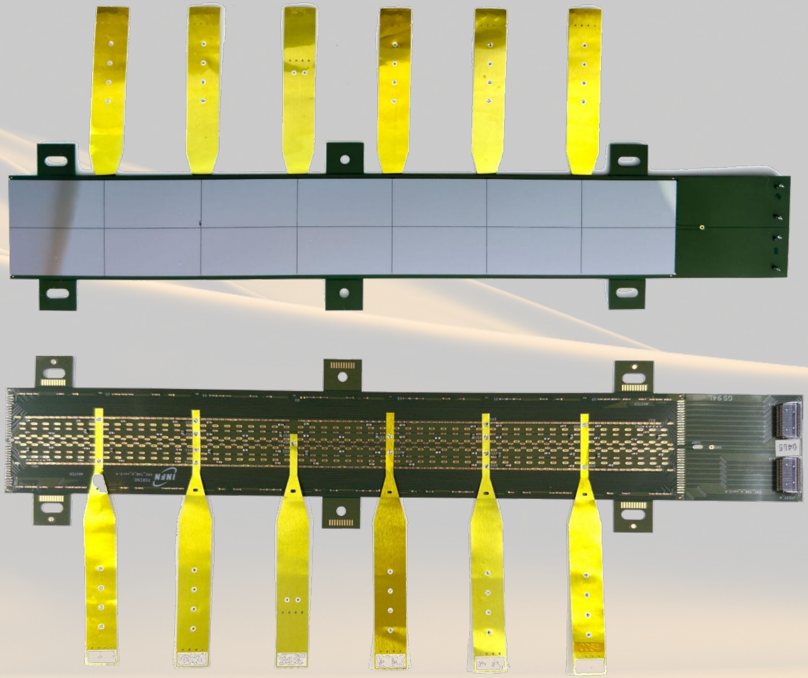
Application: large area sensors

➠ ITS2 **Outer Barrel Module** (OBM) for educational activities

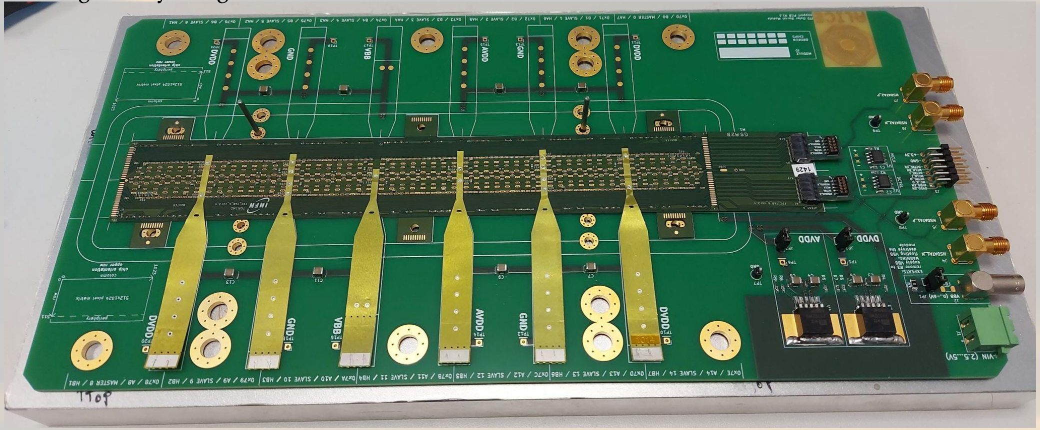
➠ Inherently: fragile objects (low material budget),
not meant to be used standalone (ITS2 readout system)

➠ Add mechanical and electrical interface & allow easy operation
→ marvellous tools for teaching and learning
(detector physics, electronics, (track/event) reconstruction)

Hybrid Integrated Circuit (HIC)
of ITS2 Outer Barrel



Designed by Magnus

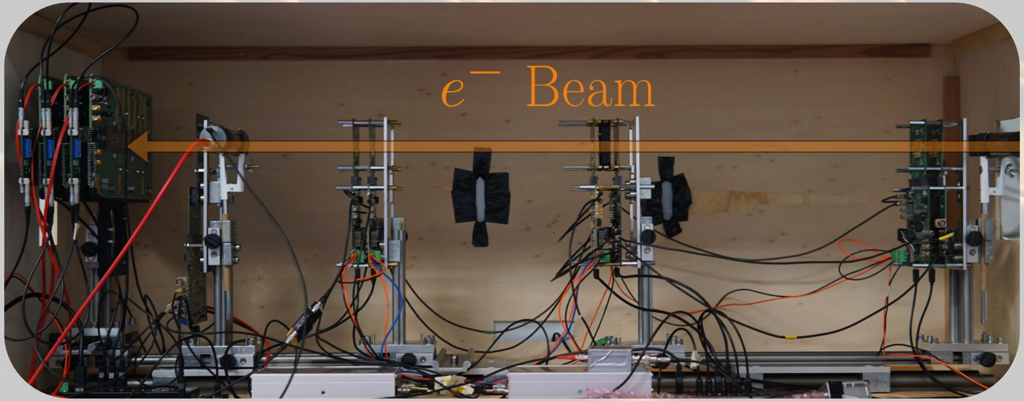


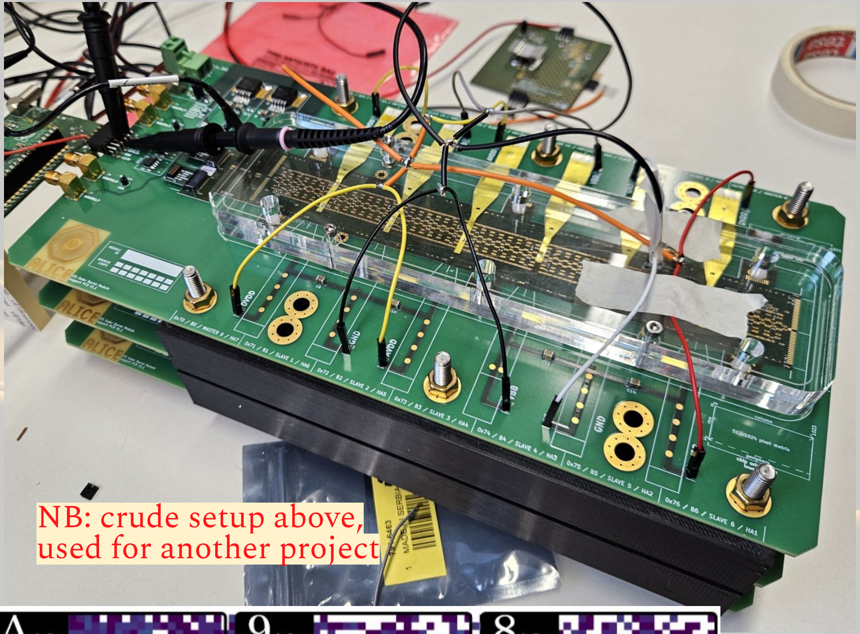
More info: here

Application: large area sensors

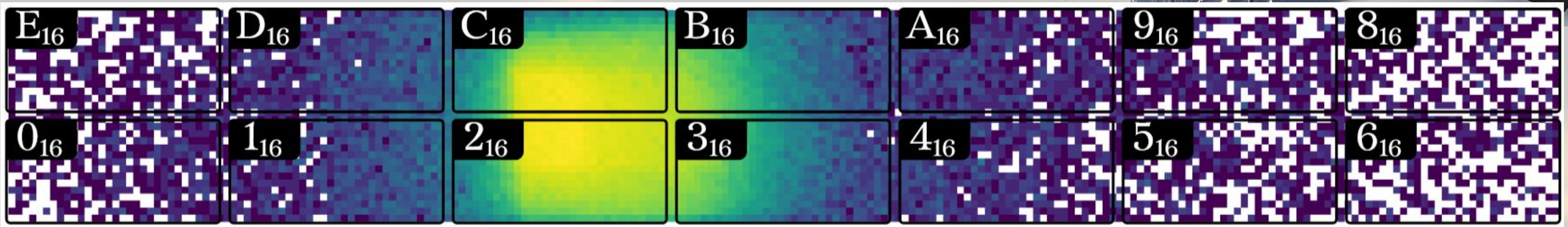
- **Large area tracking telescopes**
  → active area: ~57.7 cm^2, 7.3 MPx particle camera

Experiments in beam performed & validated





NB: crude setup above,
used for another project



More info: here

Application: reaction cross-section

Reaction cross-section of **d** (**p**) in an **Al** target

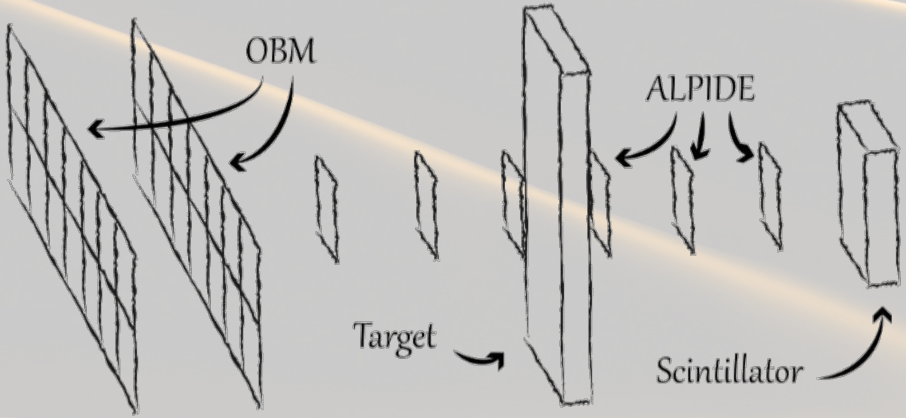
→ probability of inelastic interactions: measurement via attenuation method

→ simulation (corrections needed) + experiment

→ precise counting of incoming and outgoing particles

→ outgoing particles: large acceptance needed (low initial momentum) ➟ perfect for **OBM**

→ initially targeted COSY (d), then Marburg MIT (p)



Details here

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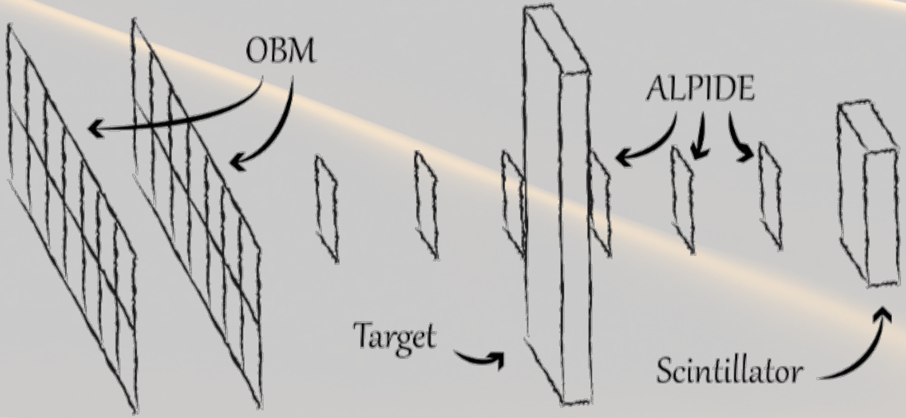
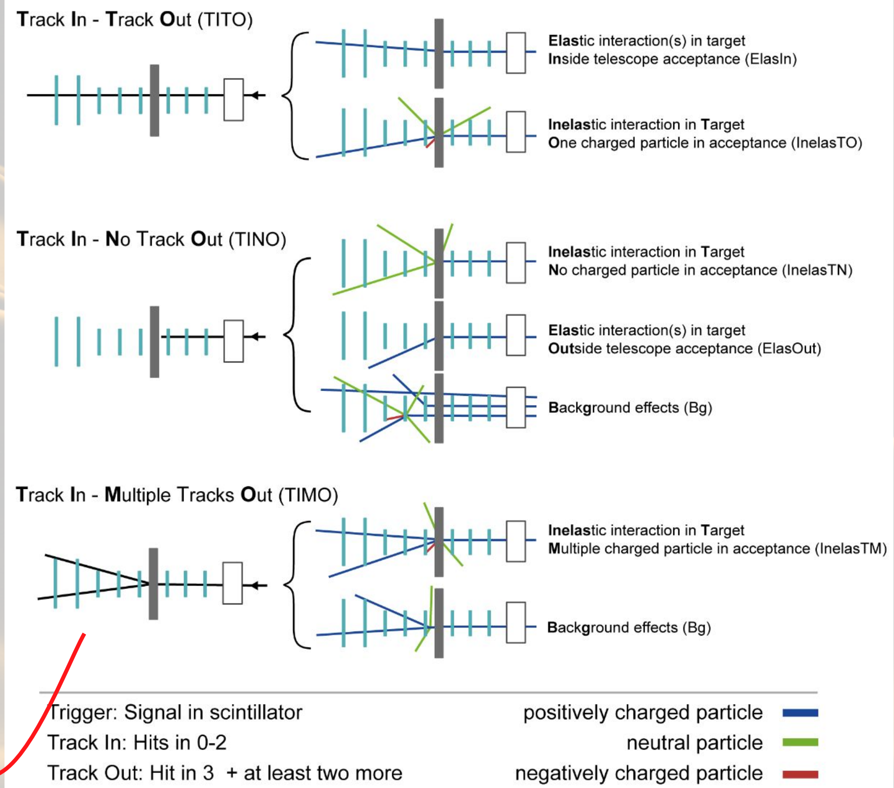


In essence a counting experiment



$$\sigma_R = \frac{M}{\rho\, t\, N_A} \cdot \frac{N_{reac}}{N_{in}}$$

Details here

Application: material budget imaging

Use tracking telescopes for measurements of **material budget of unknown samples**

➠ Place unknown target (x/X_0) in the middle of the setup

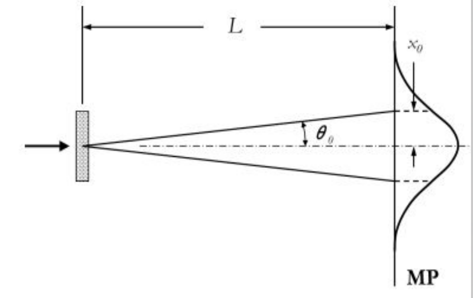
- resolve 2D (projection) structure (excellent tracking resolution ~2.5 µm resolution)
- Relate **scattering angle** to material budget (via the Highland formula)

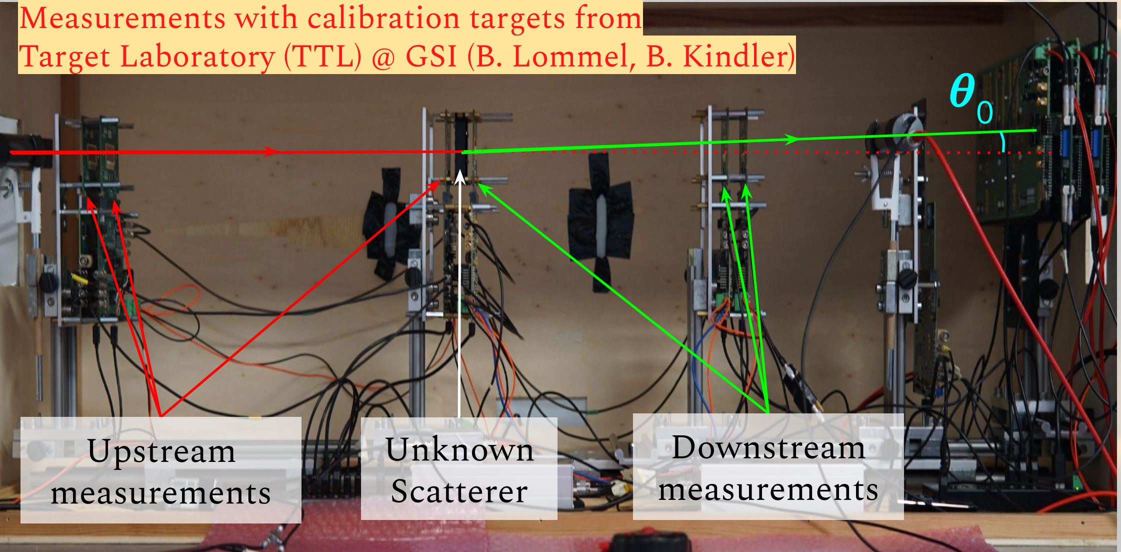
(more scattering = more material) ← tomography of sample

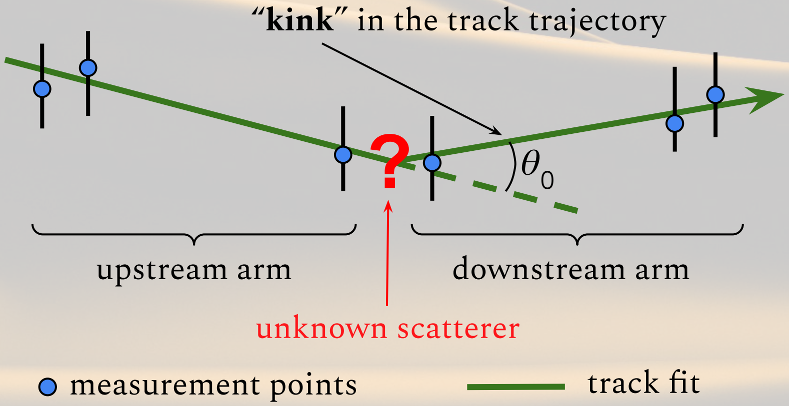
→ idea first introduced by Göttingen/DESY colleagues → further refined in our group

→ precision (separation power) reached now: few µm equivalent of Al (using known targets)

Many particles →
scattering distribution ➠ **width**







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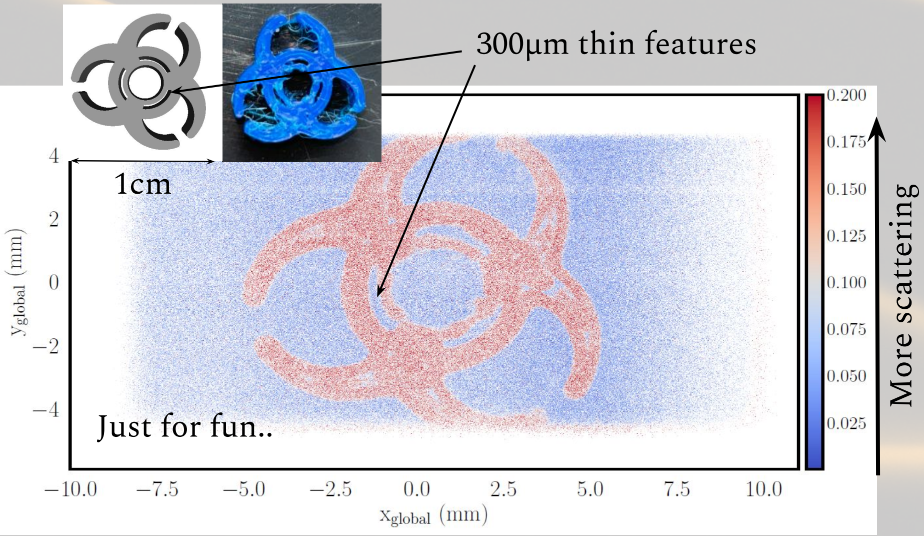

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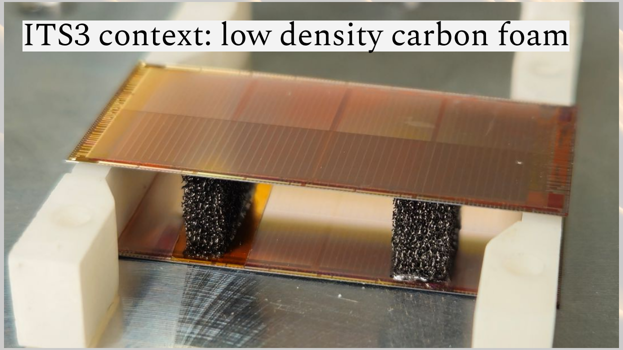

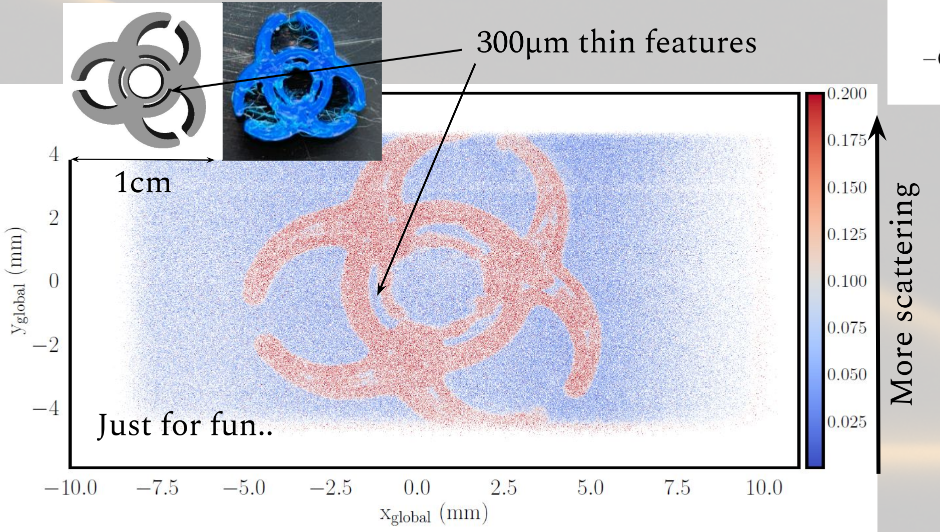

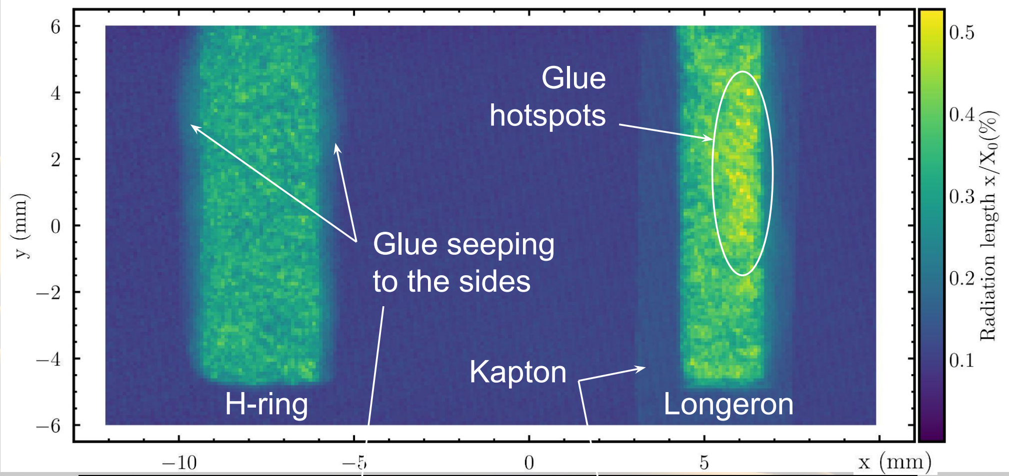

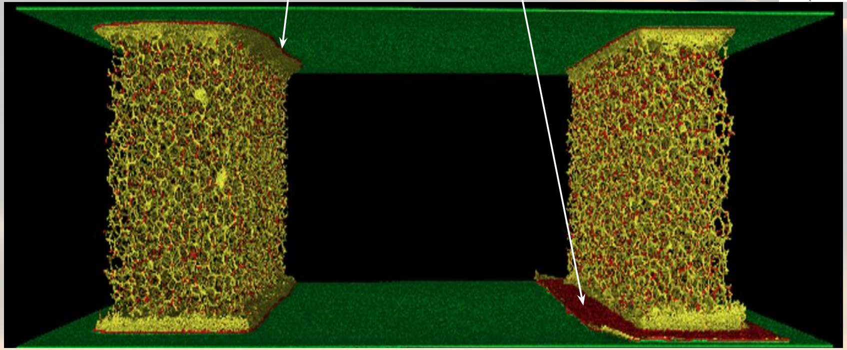

More details here, here and here

Application: particle identification

Can PID be performed with digital sensors (binary information: hit/no hit)?

→ dE/dx depends on □γ of particle

⇒ **PID based on energy loss**

→ cluster size/shape $= f$ (particle momentum, bias voltage, inclination of track, …)

→ **clusters** = **estimators of E_{loss}**

→ multi-layer telescope → correlated information from all sensors

→ shown previously for MIMOSA sensors

More info ELMA workshop

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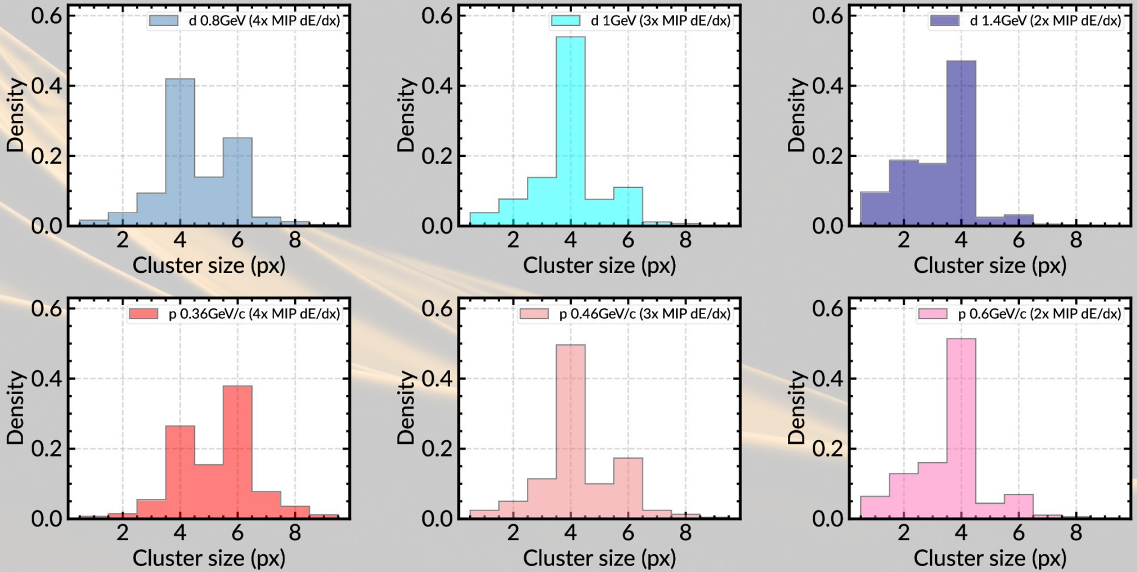
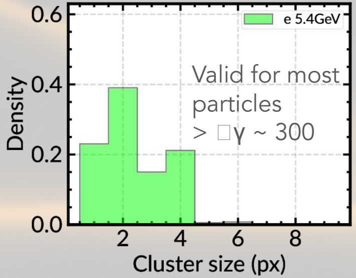
→ shown previously for MIMOSA sensors

More info ELMA workshop

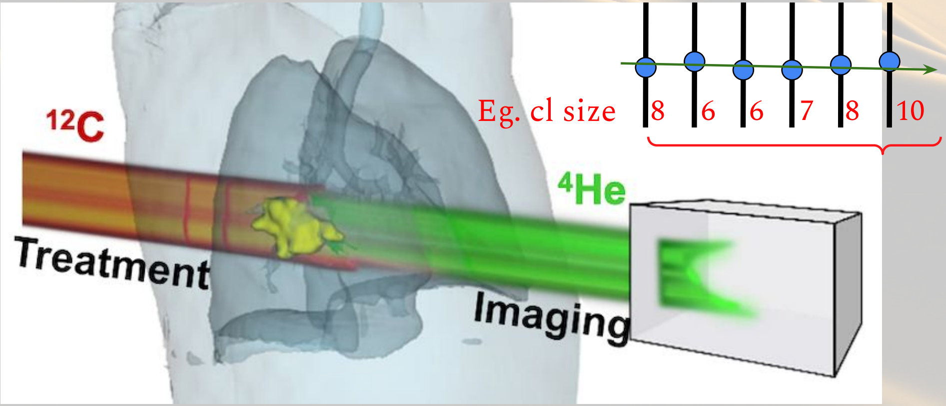




- Example of cluster sizes measured for beams of d, p and e (by our group)
- Further dimensions available for separation: cluster shape, sensor inclination, bias voltage..

Application: particle identification

Example usage for **C/He mixed beams at GSI** (Cave M)
→ separation C/He: studies for beam composition → medical application
→ one night of data taking (courtesy of group C. Graeff)
→ use **ALPIDE telescope for tracking** (+ ToF & ToT setup)



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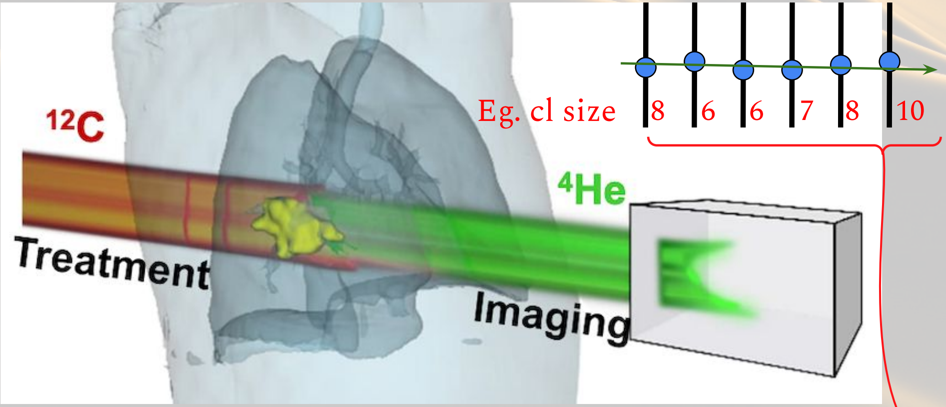
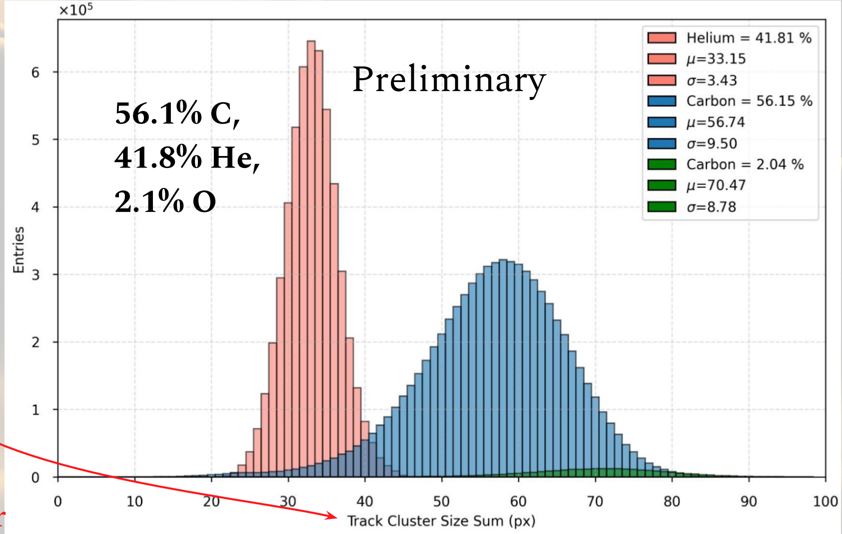


Σ
(better proxy)



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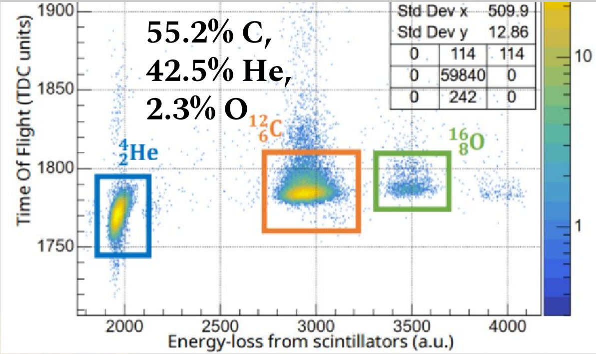

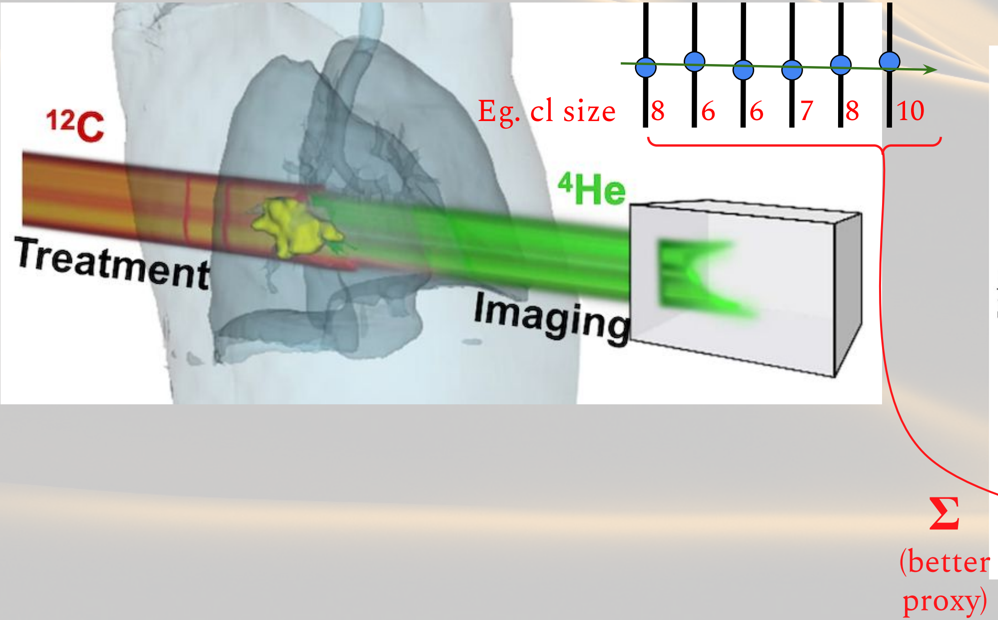

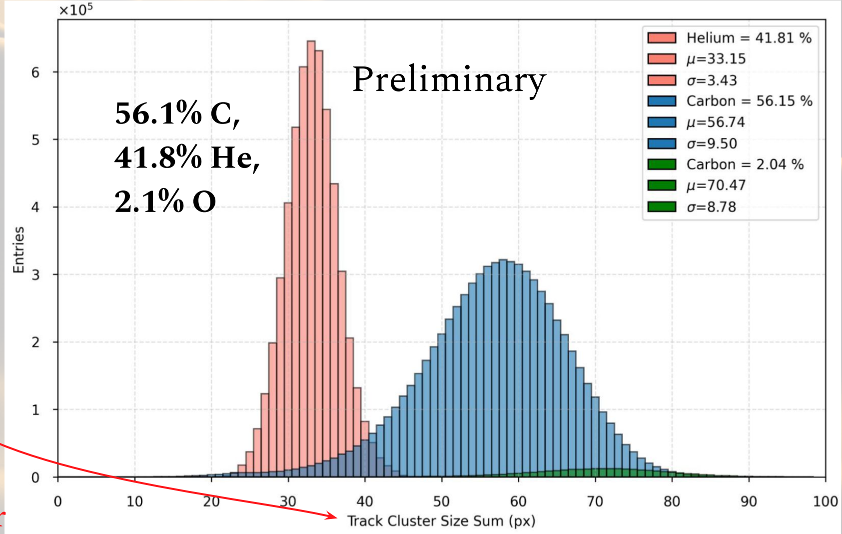

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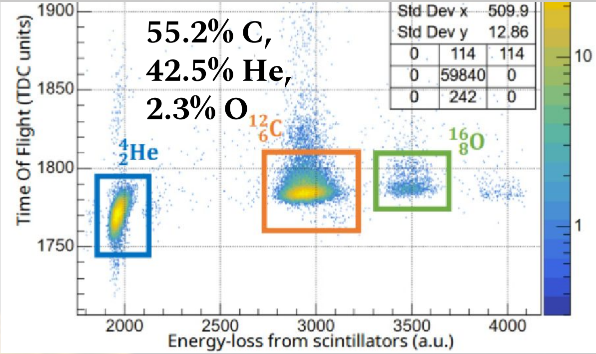

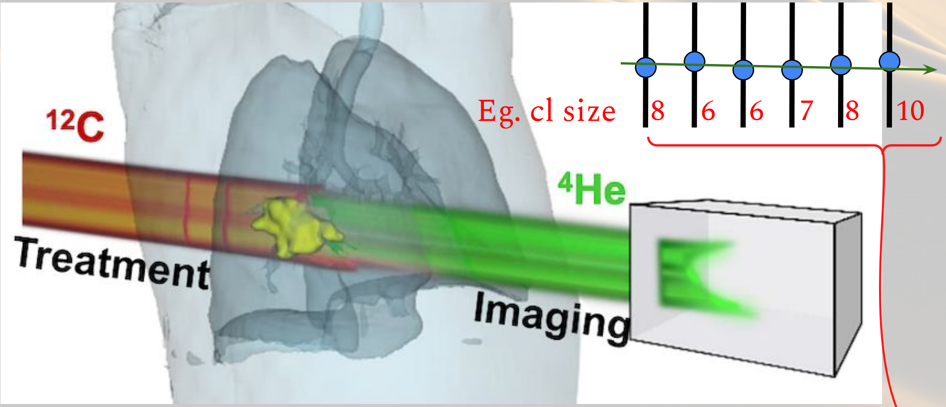

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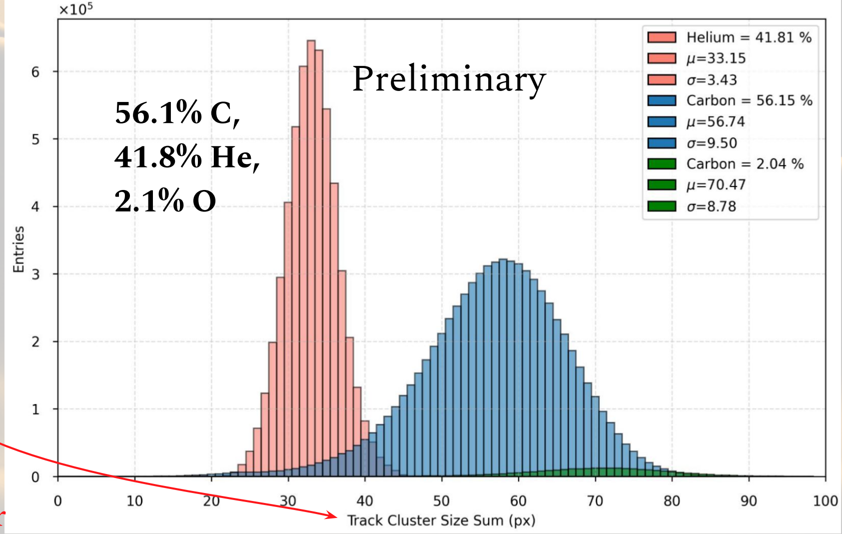


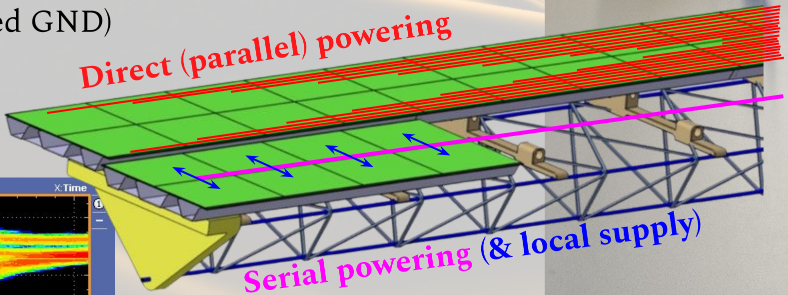
Also in ALICE: digital oversampling (Time Over Threshold)
NB: in ALICE MAPS not implemented in the chip (!)
→ See ref 1, ref 2 ITS2 color runs → ref3

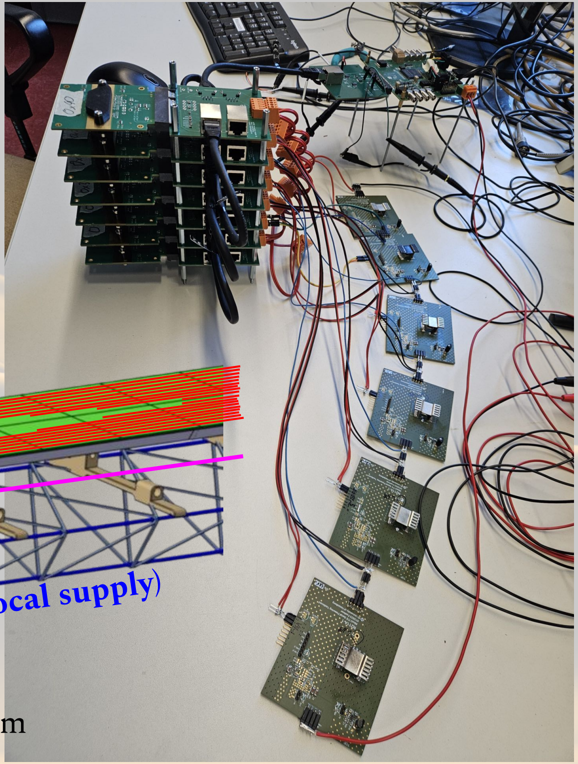
Application: efficient powering

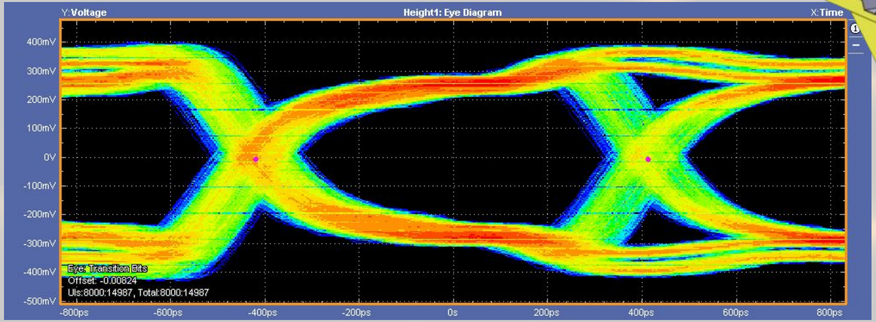
Recent: **attention shift** towards the realm of powering, readout and data transmission

➠ Classic staves → direct powering (chip to readout)
But large power inefficiencies (voltage drops) and many power cables
➠ ALICE 3 Outer Tracker: **serial powering** approach (following ATLAS & CMS)
→ Constant current fed in a chain of modules (1 cable)
→ Shunt regulators (**sLDO**) → generate local supply voltage & shunt excess current

Careful consideration:
→ data transmission (different local domains – raised GND)
→ high speed operation
→ failure modes







With help and expertise from
EEL group (M. Wiebusch)

Summary

CMOS MAPS: highly successful technology for HEP, combining strong commercial viability with excellent performance

➠ **Ideal** for applications requiring:
- → high spatial resolution (small pixels)
- → low material budget (thinnable & low power)
- → large-area coverage (scalable commercial fabrication processes)
- → non-planar geometries (thin silicon has paper-like flexibility)

ALICE **recognizes the potential of MAPS** for high-precision vertexing and tracking → It **drives** technology development:

➠ **ITS2**: 10 m^2 MAPS detector, fully commissioned and operational

➠ **ITS3**: replace innermost 3 layers for ITS2 → novelty in HEP: wafer-scale, bent, stitched sensors

➠ **ALICE 3**: 60 m^2 MAPS-based vertexer and tracker (incl. in-vacuum operation)

ALICE R&D pushes the CMOS nodes **far beyond** the strict ALICE needs → significant improvements in design in terms of integration density, power consumption, radiation hardness, and readout speeds over last years

MAPS can be **used in multiple domains and for many purposes**
- → local know-how based on ALICE technology & experience