Experimental Essential — Detectors

Cutting-edge R&D to Explore the Energy Frontier

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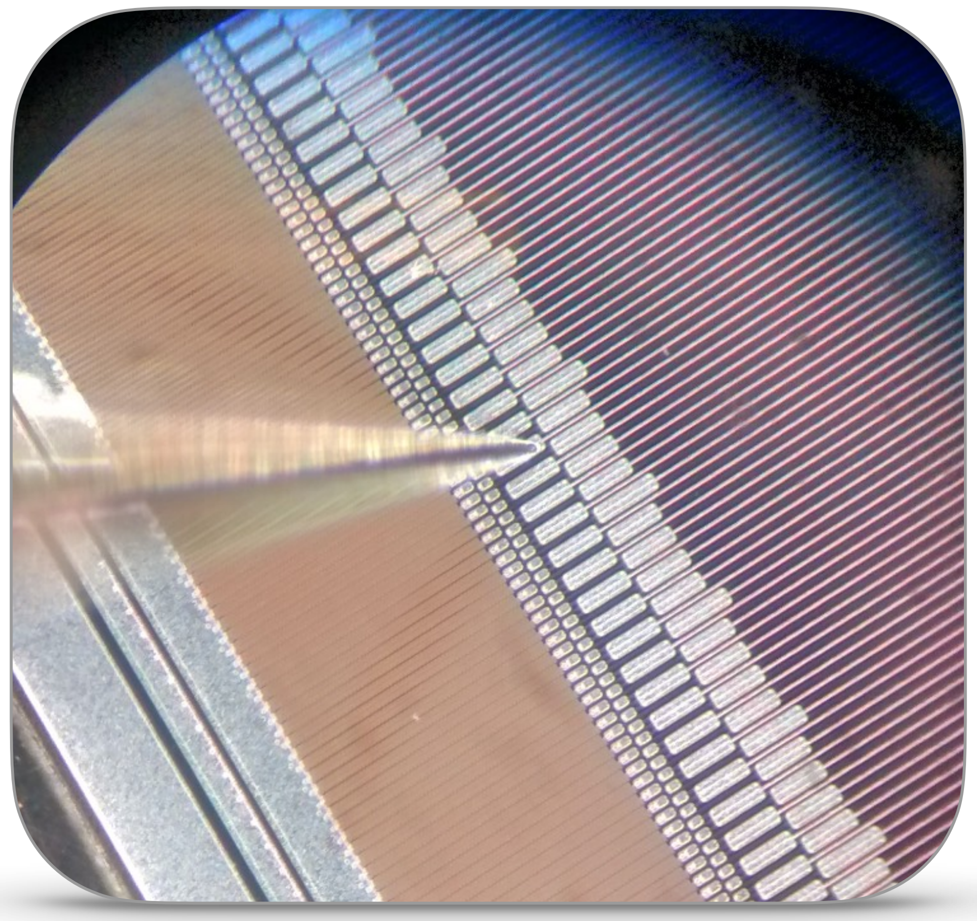
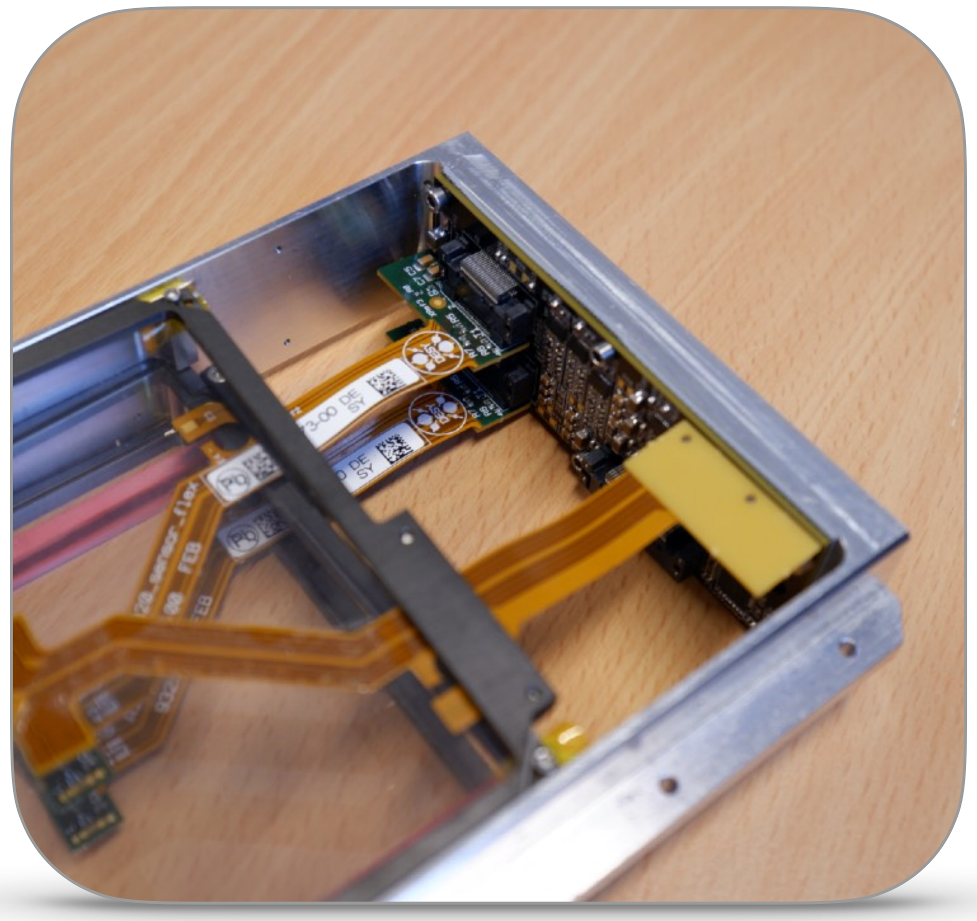
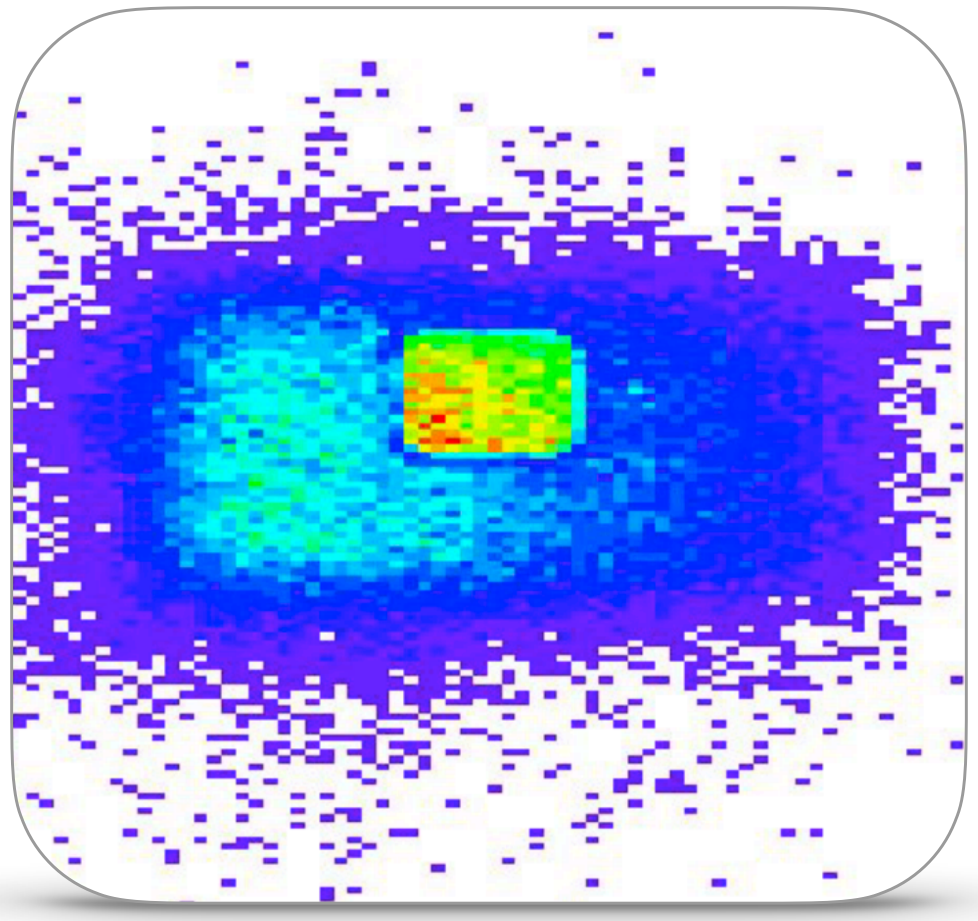
HEF Department Seminar
May 25th, 2021

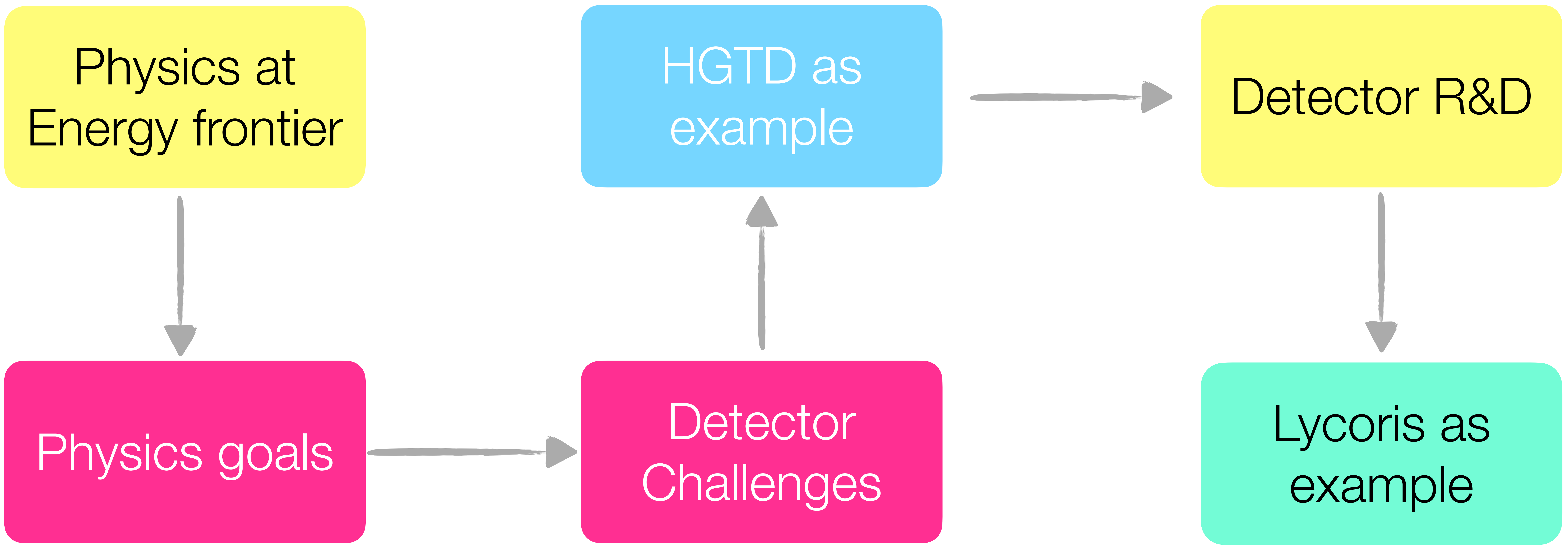






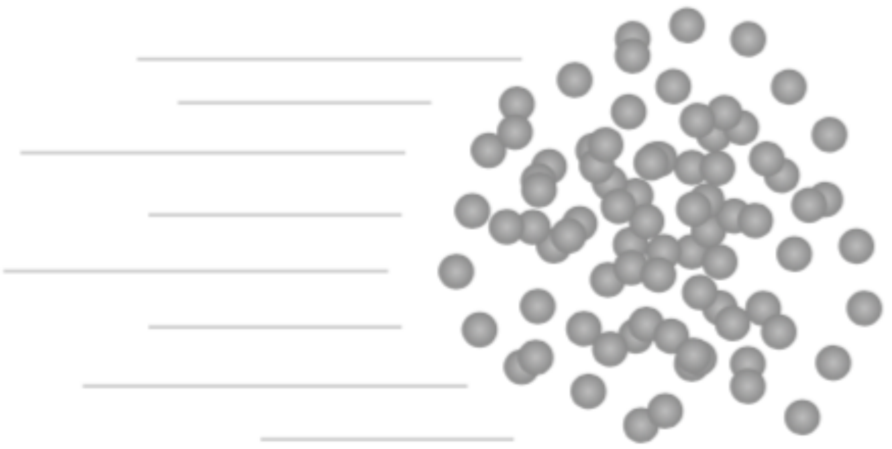
Radboud University

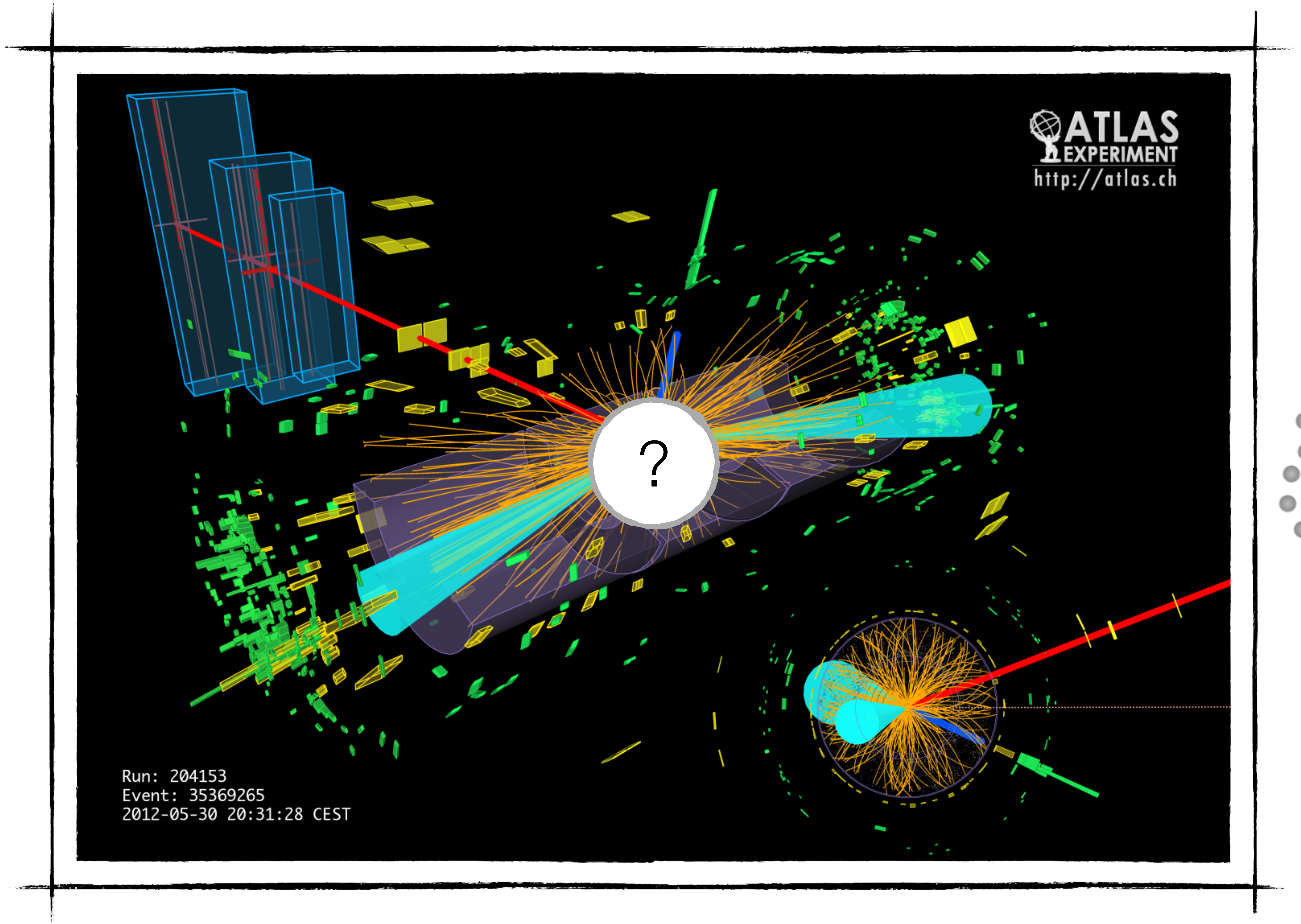
Roadmap for today



Explore at the High Energy Frontier

A bunch of
energetic protons





A bunch of
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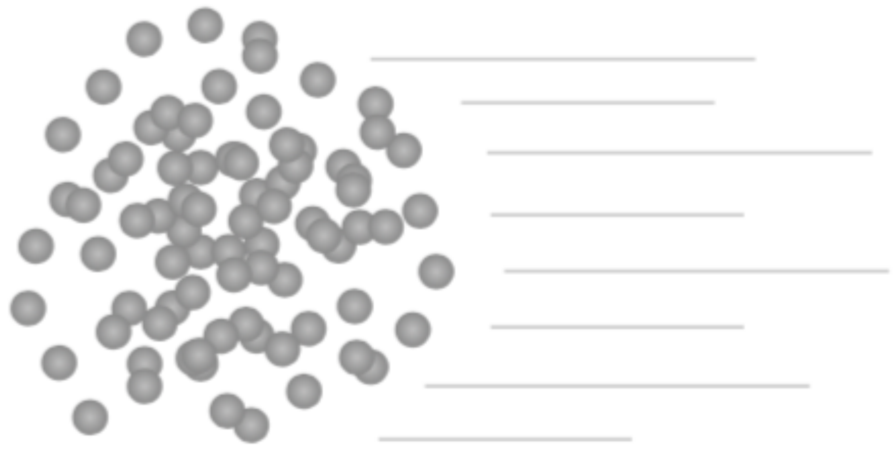
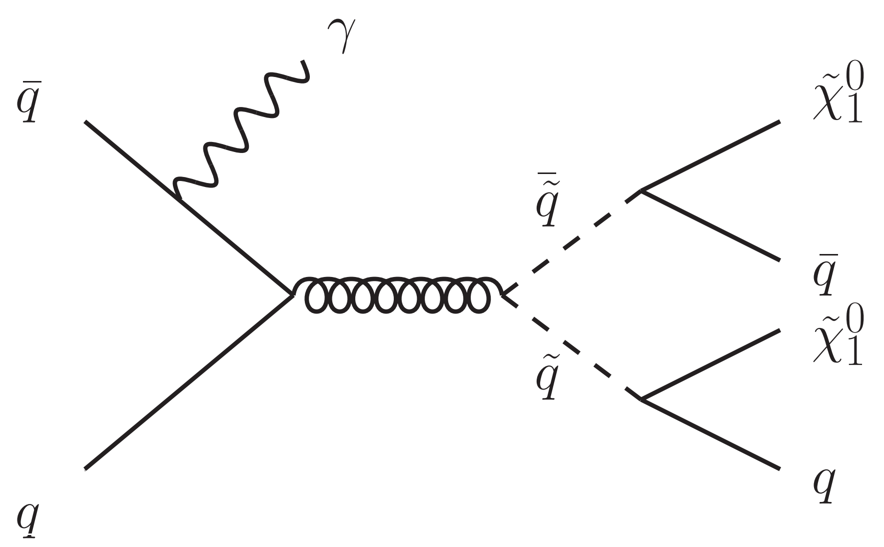
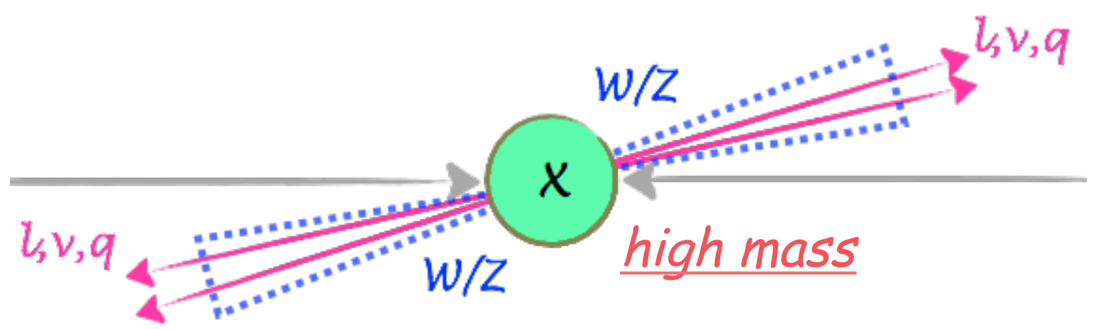


Various physics processes of interest may happen, producing unknown particles
what we can measure is their final **states/stable products.**

Physics Goals

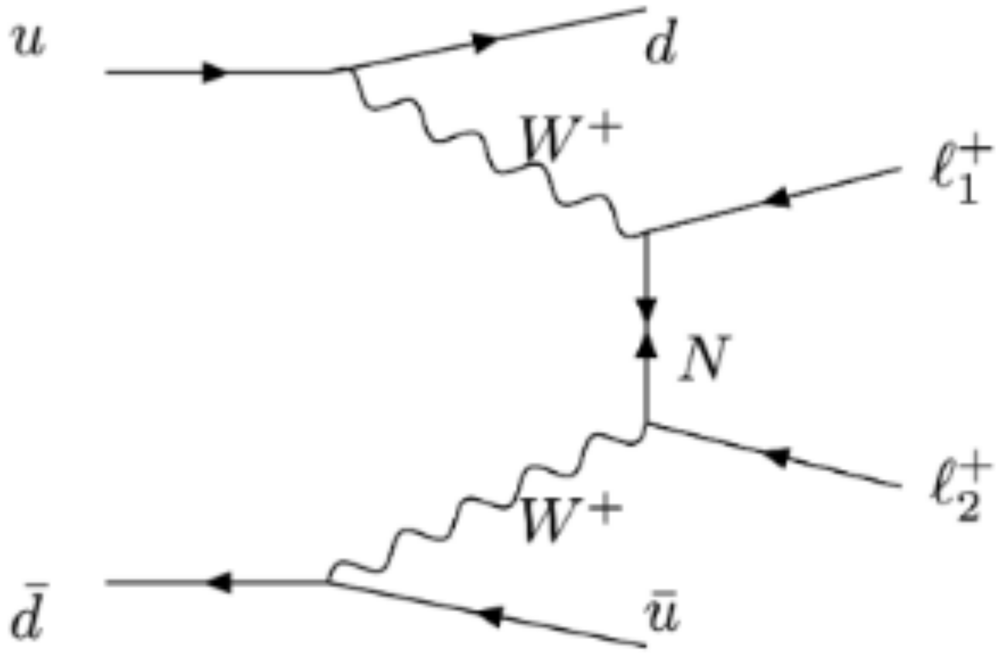
Examples given are either I have participated, or intend to participate





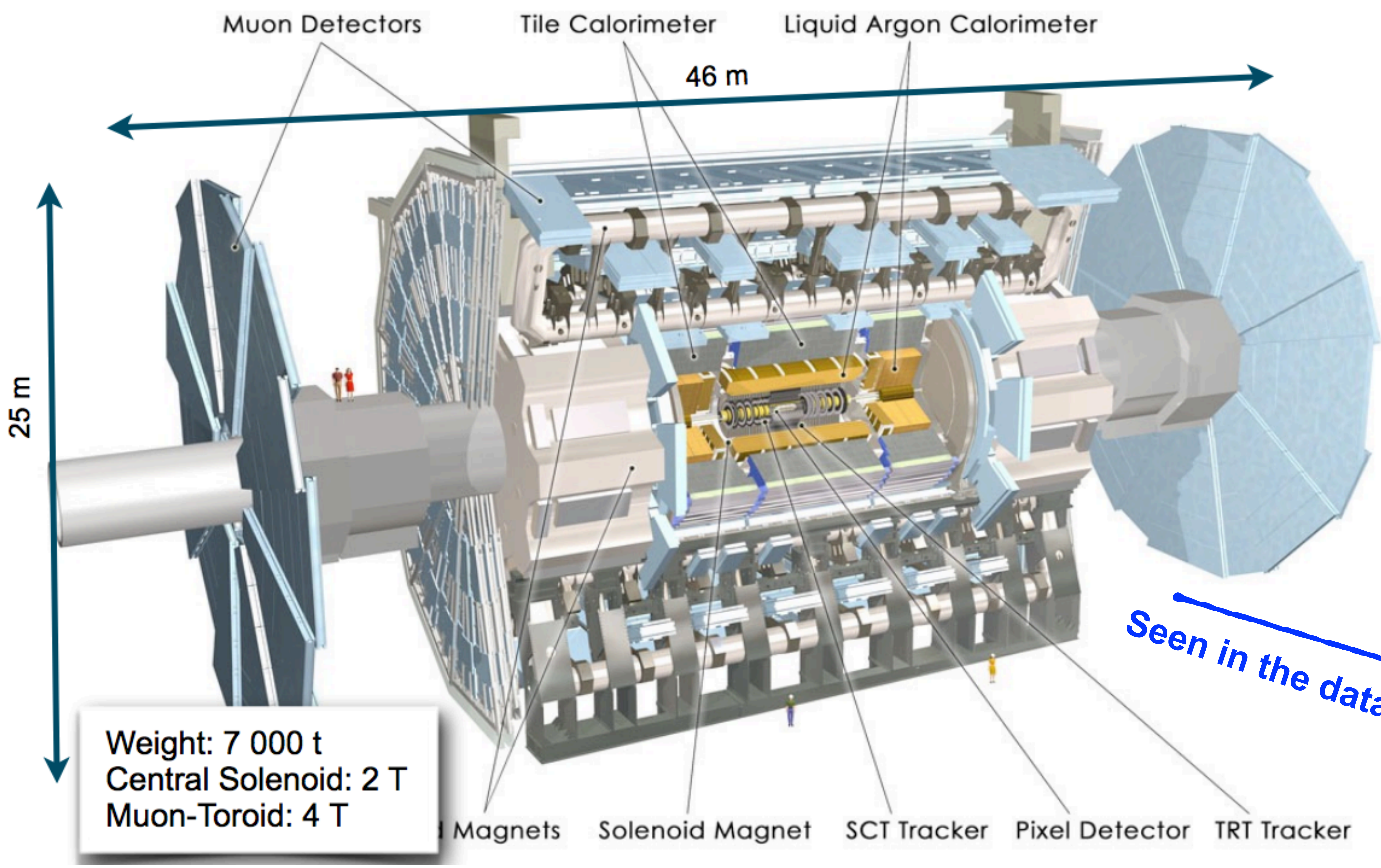
- BSM EFT models with different final states
  - Clean but not easy: MET+photon
  - Well defined object but difficult with background: high mass di-boson resonance

- The "missing" CP-violation in lepton sector
  - Mostly results are done by neutrino oscillation experiments
  - Can we do something on collider?
- Looking for BSM in searching for lepton flavour violation and lepton number violation



VBS heavy majorana neutrino

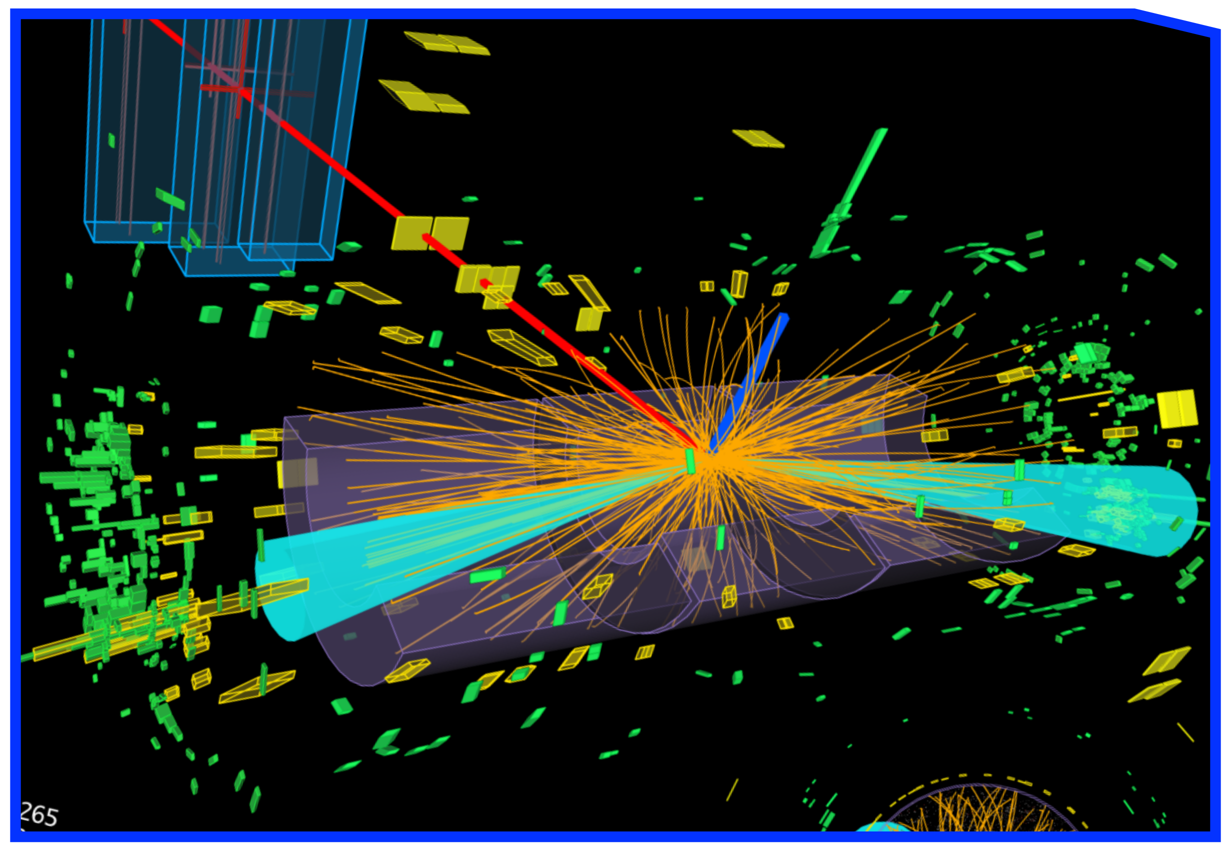
Detectors built to realise the task



Requirements raised by physics goals, for example:

- Able to identify the created particles from detector electronic response
- Able to find out which particles coming from which interaction vertex
- Able to measure the properties of the particles, e.g. charge, momentum, energy…

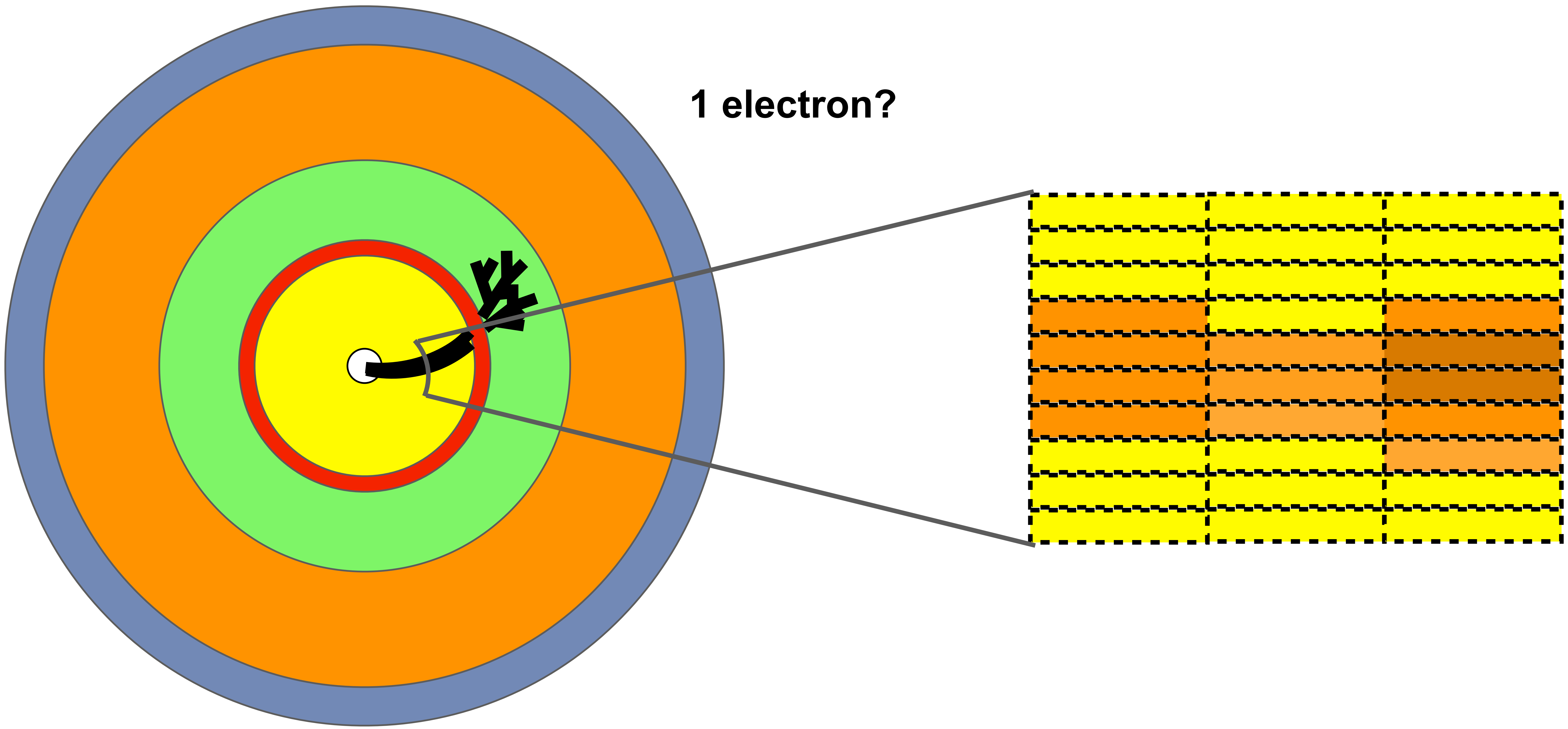
Seen in the data taken



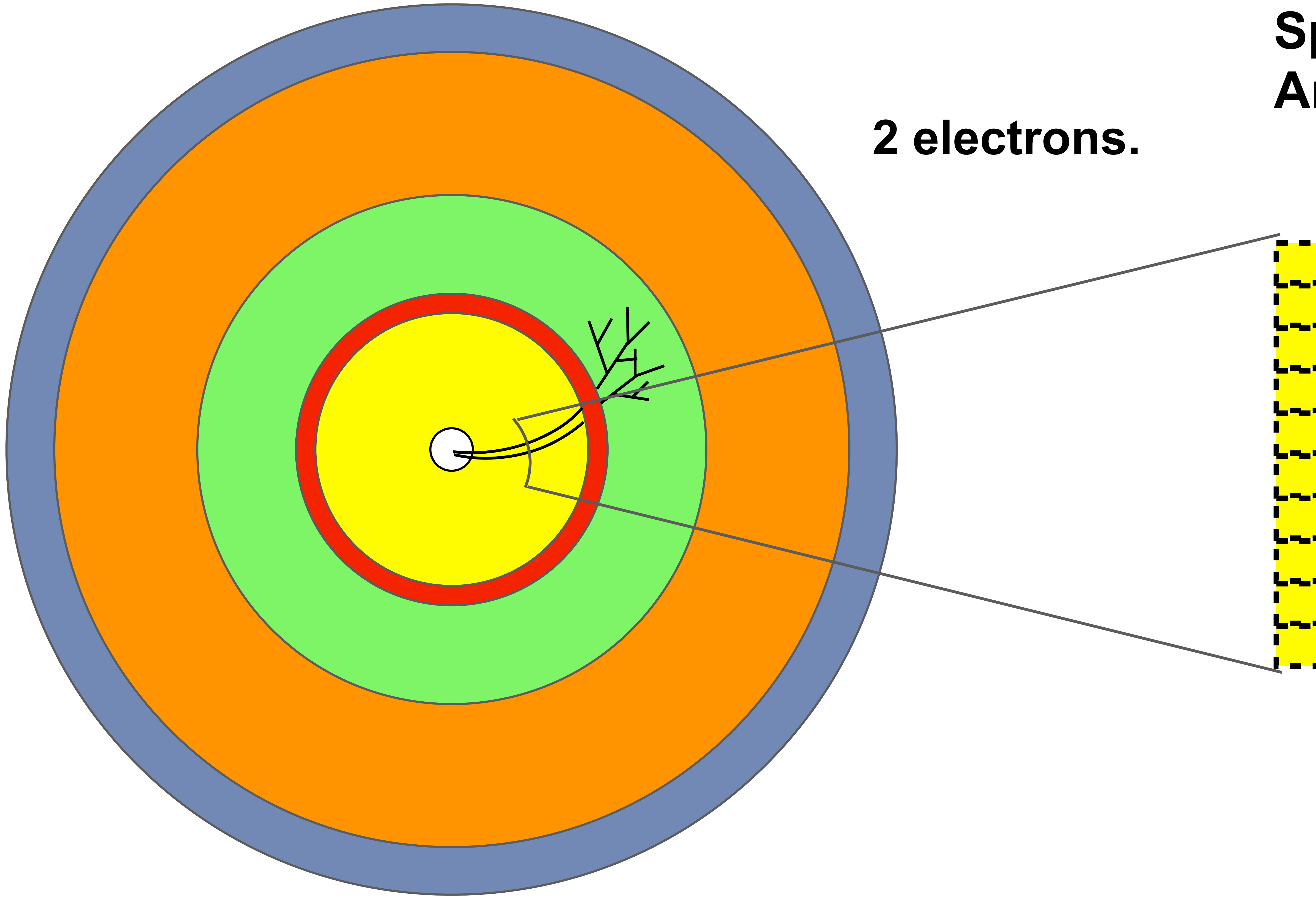
Detector Challenges

- Design requirement:
  - Faster, higher precision, higher granularity, radiation hard, less dead material, 4 pi coverage …
  - a realistic technology with a realistic budget
- Detector system
  - We are measuring few fC signal -> any perturbation can overwhelm your measurement
  - One basic element of a detector may work as expected, but what about a matrix of thousands of them?
- Data Acquisition, digitisation, and reconstruction
  - From electronic signal to meaningful physics object, in a high intensity environment -> challenging but lots of fun

3D spatial precision

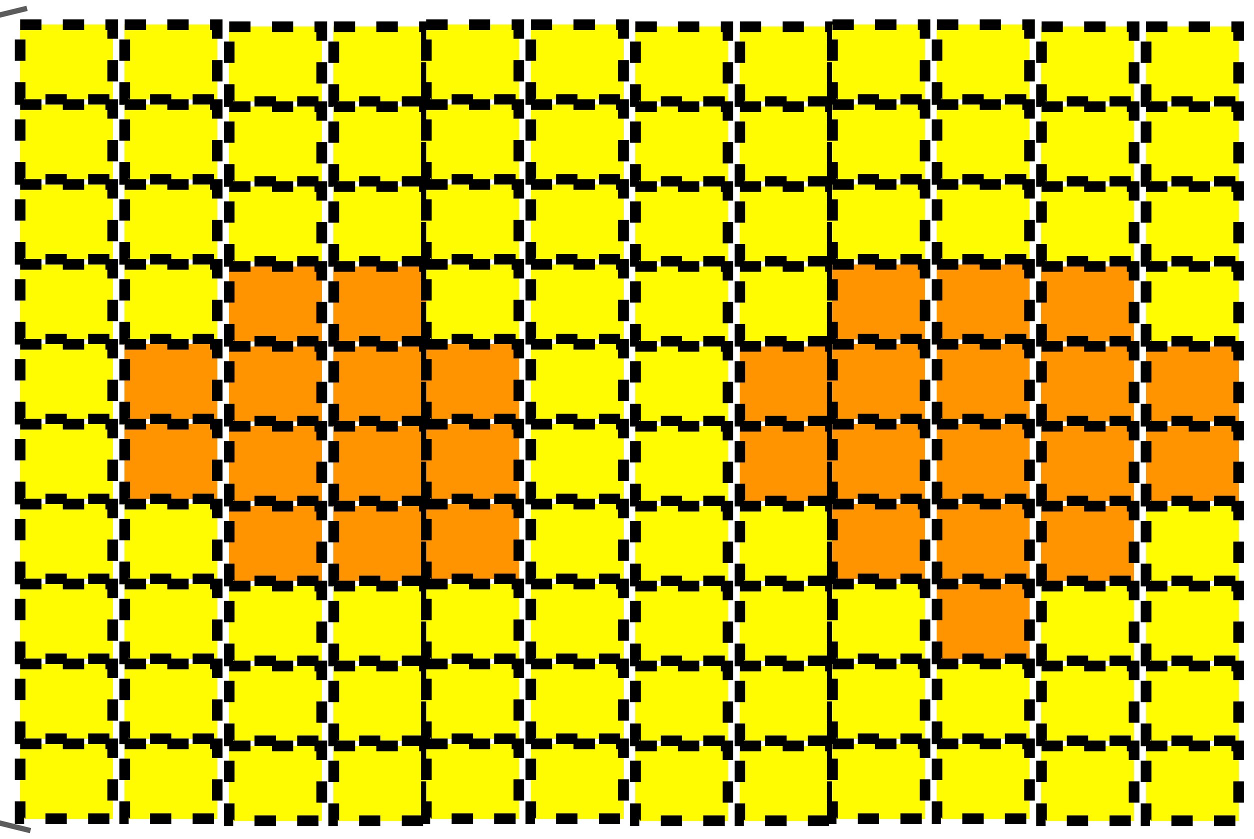


3D spatial precision



2 electrons.

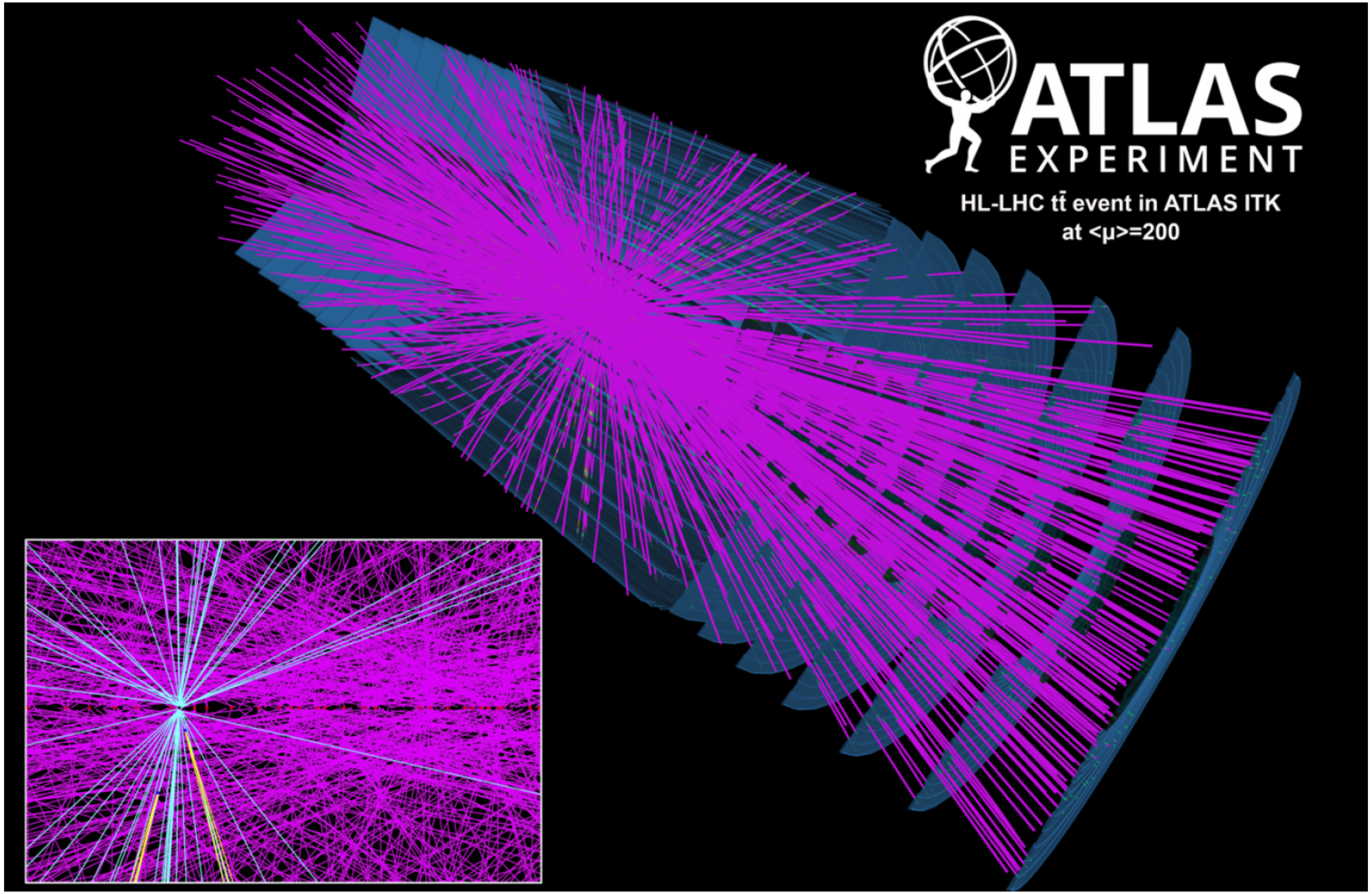
Spatial resolution :
An important figure of merit for detectors.



Q —> Are these 2 electrons come from the same interaction vertex?

R&D phase - Design

Example taken from ATLAS HL-LHC upgrade

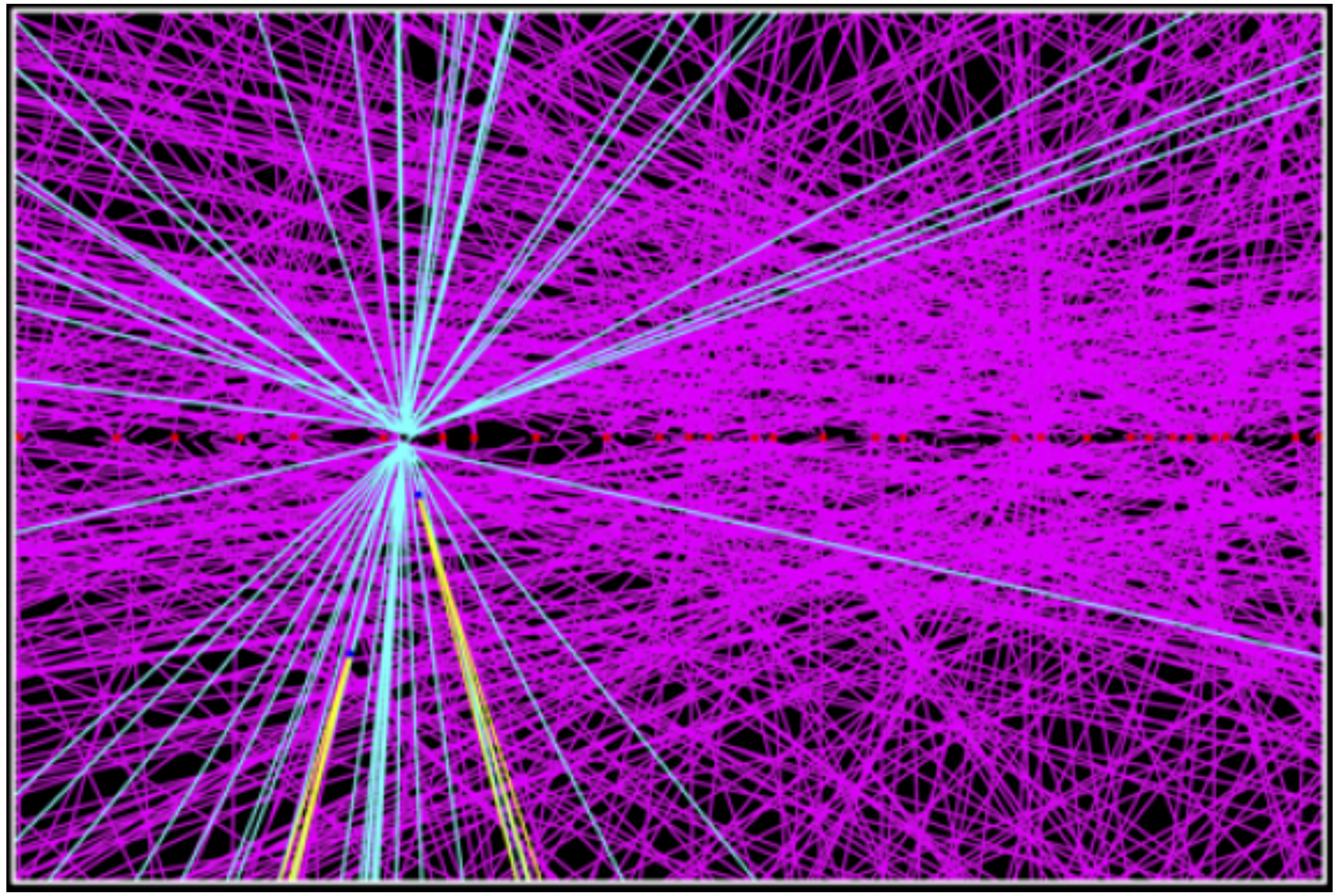


- Simulation to understand what to expect from the detector side, such as:
- 200 vertices happen in one bunch-crossing
- Only one vertex corresponds to the process of interest
- In real data, we will not know which tracks associate to which vertex, nor which vertex belongs to which process

-> Defines requirements

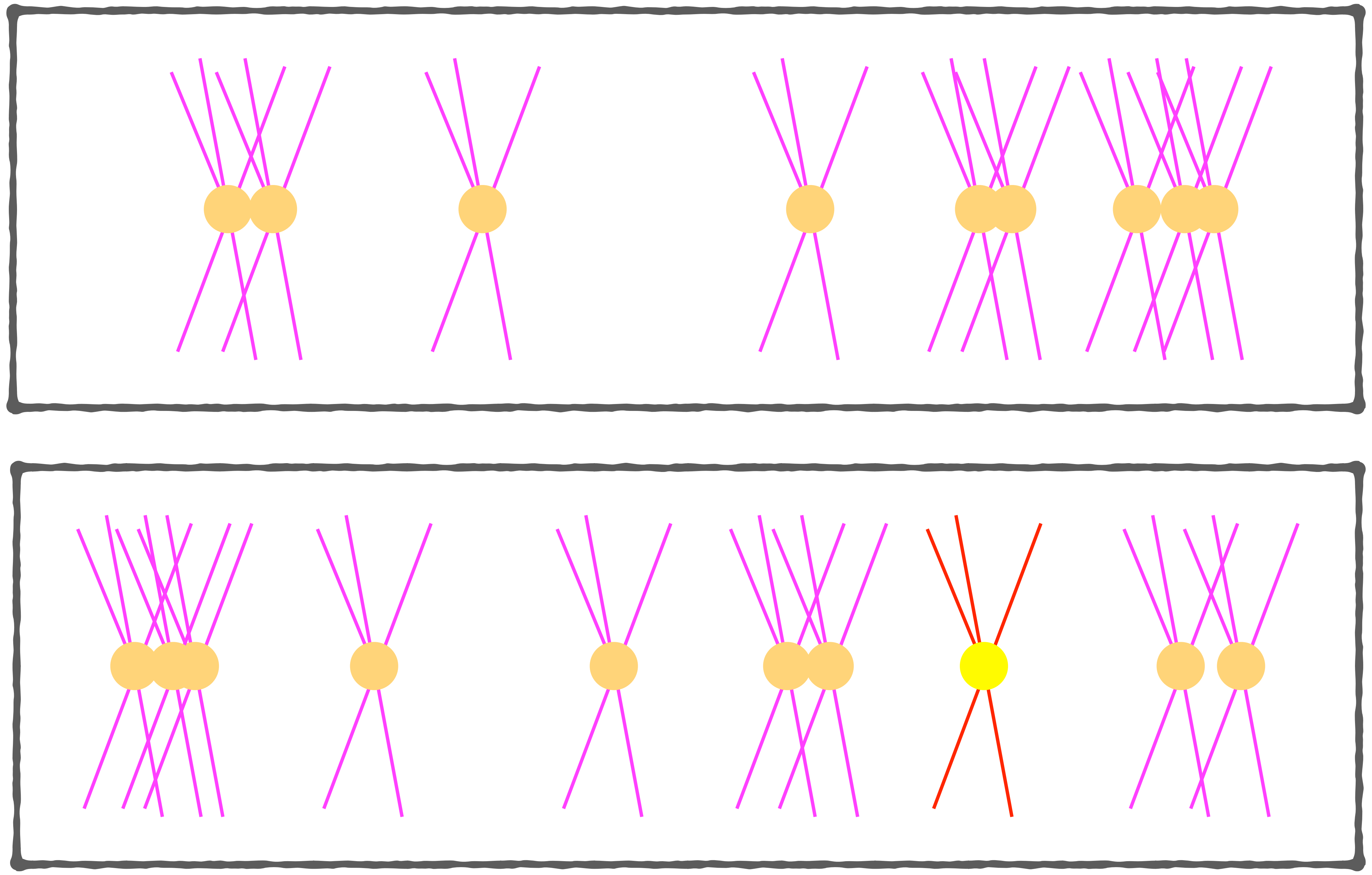
4D precision: to handle higher intensity

The piled up instrumentation responses start to be separable.



Separate frames

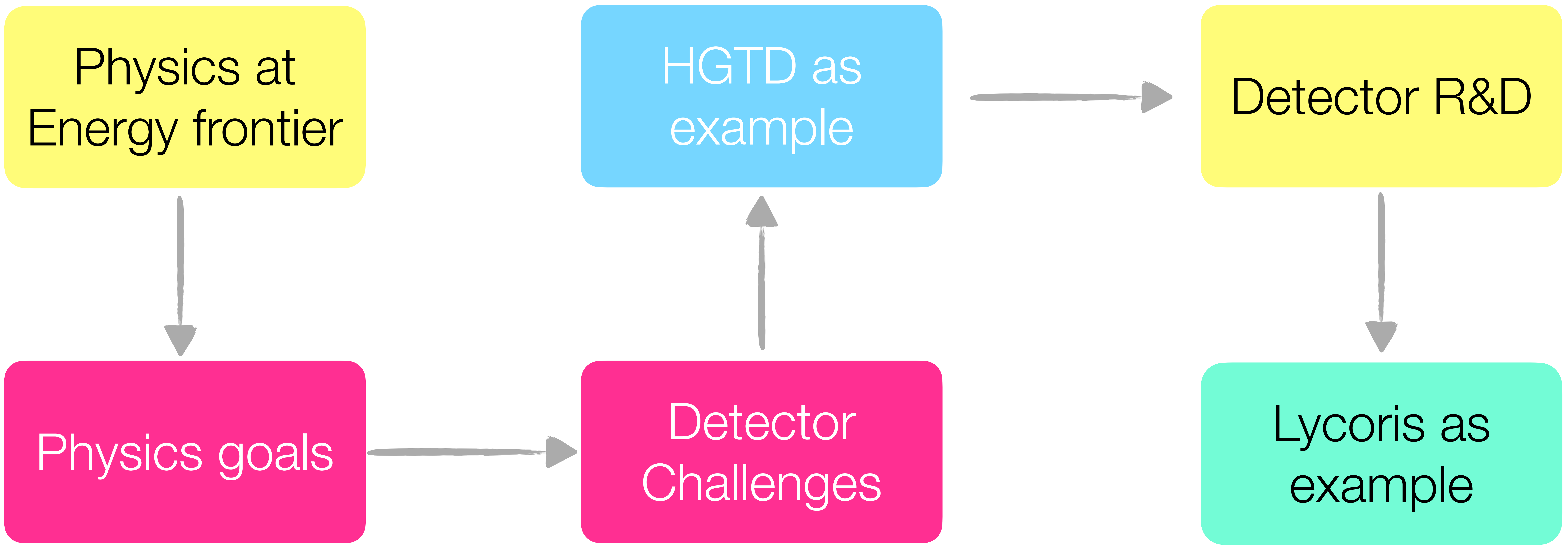
+ ps fast timing



...

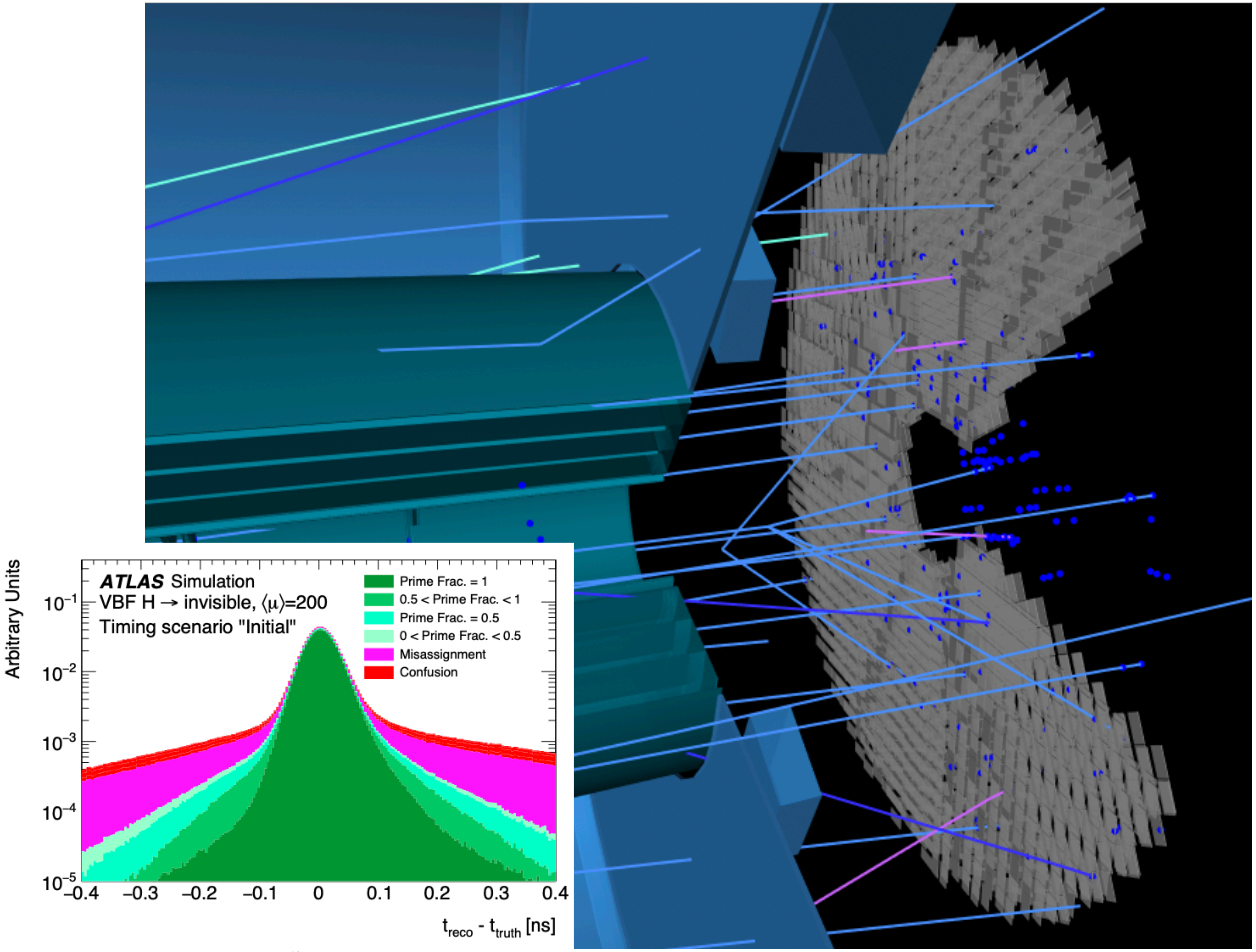
Based on these requirements, we can get a design —>

Roadmap for today



R&D Phase — Simulations

Example taken for ATLAS HGTD upgrade

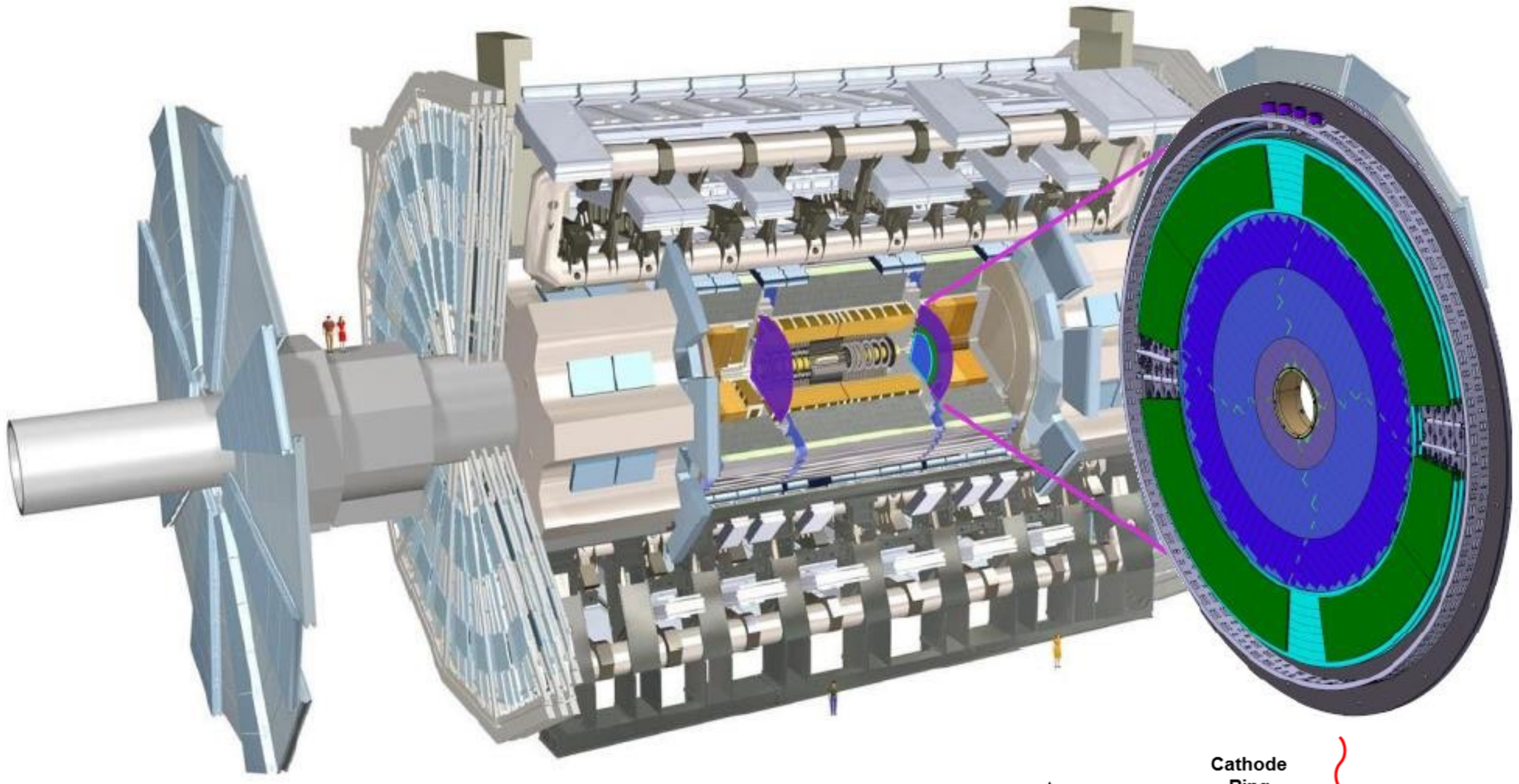


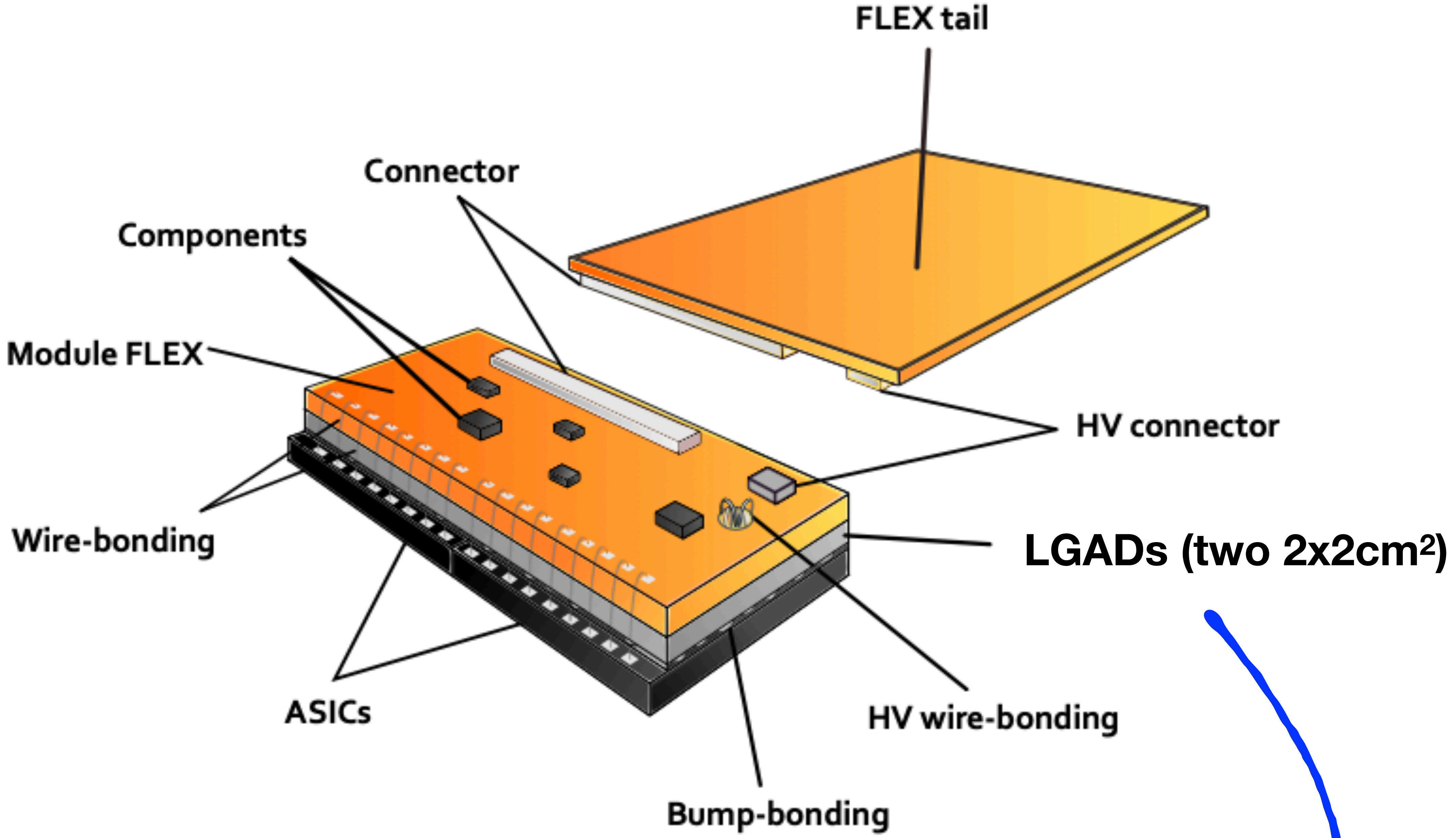
Based on physics goals, simulations give **design requirements** for later prototyping

- From machine run and sensor technology* it gives radiation tolerance (neq/cm2): 2.5x10^15 neq/cm2 -> means 1.5MGy (one adult chest x-ray is 0.7mGy)
- Physics event simulation gives requirements on timing resolution: 30ps - 50ps per track -> 35ps - 70ps per hit
- Based on intensity, defines the granularity requirement: 1.3x1.3 mm2

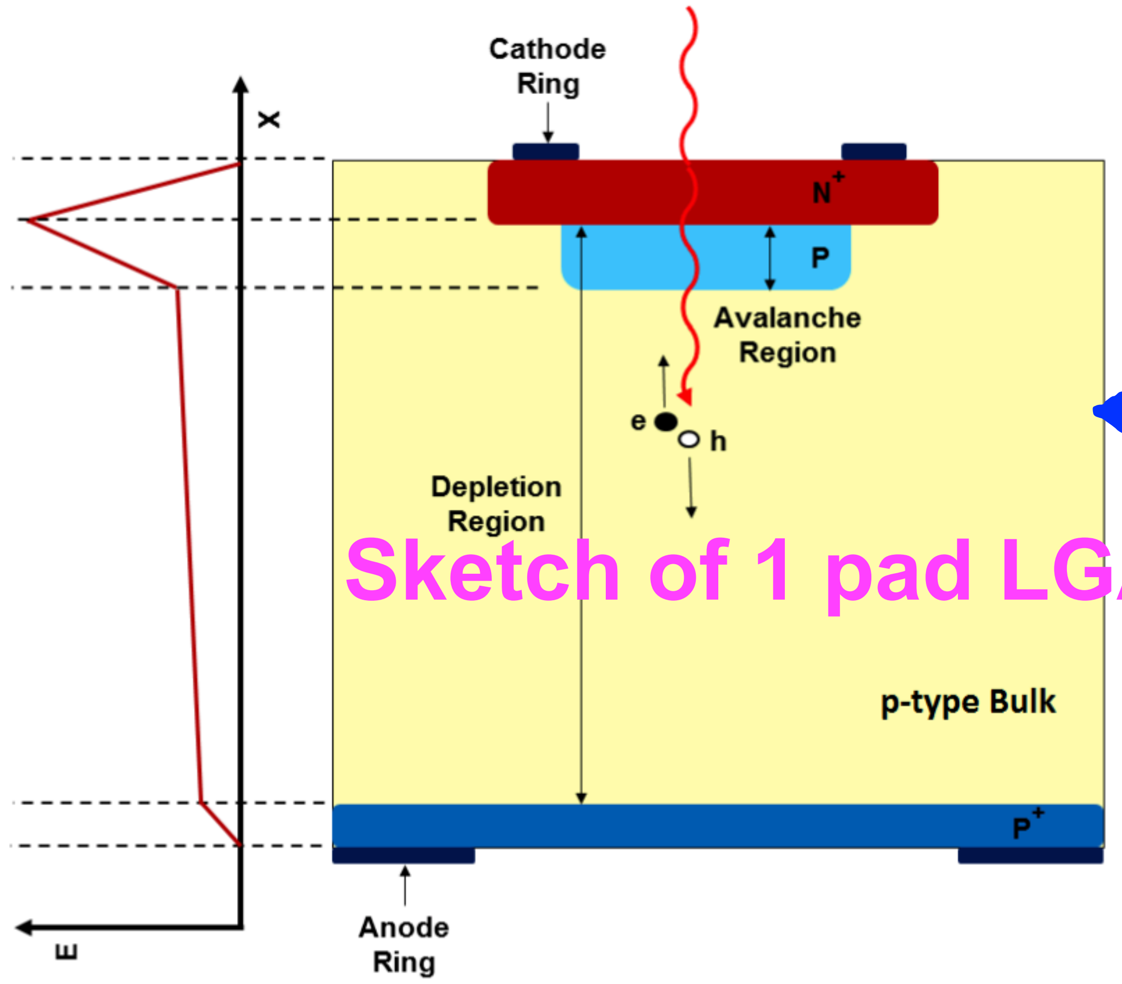
A Detector Design

Example taken for ATLAS HGTD upgrade

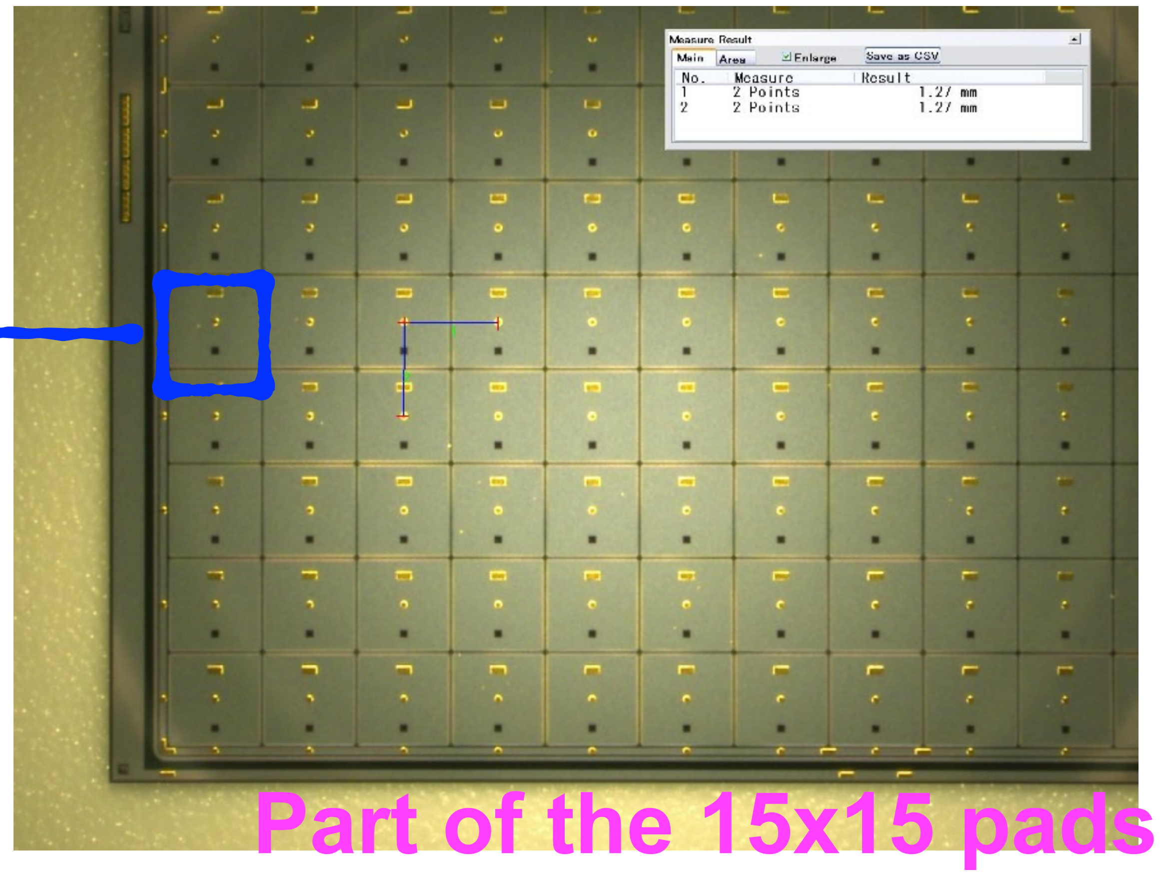




*not to scale



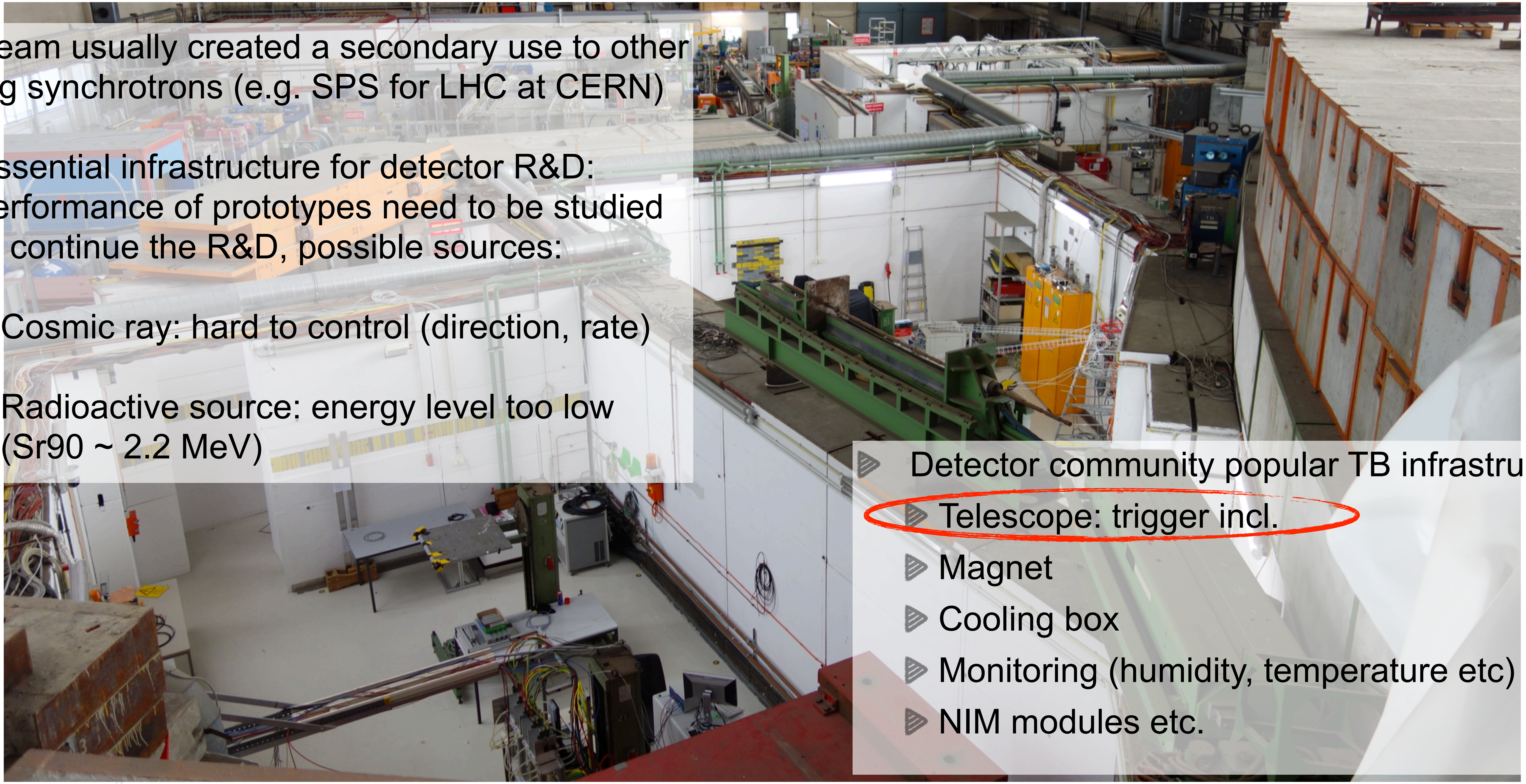
Sketch of 1 pad LGAD



Part of the 15x15 pads

Test Beam — Detector R&D infrastructure

Photo from DESY II TB facility



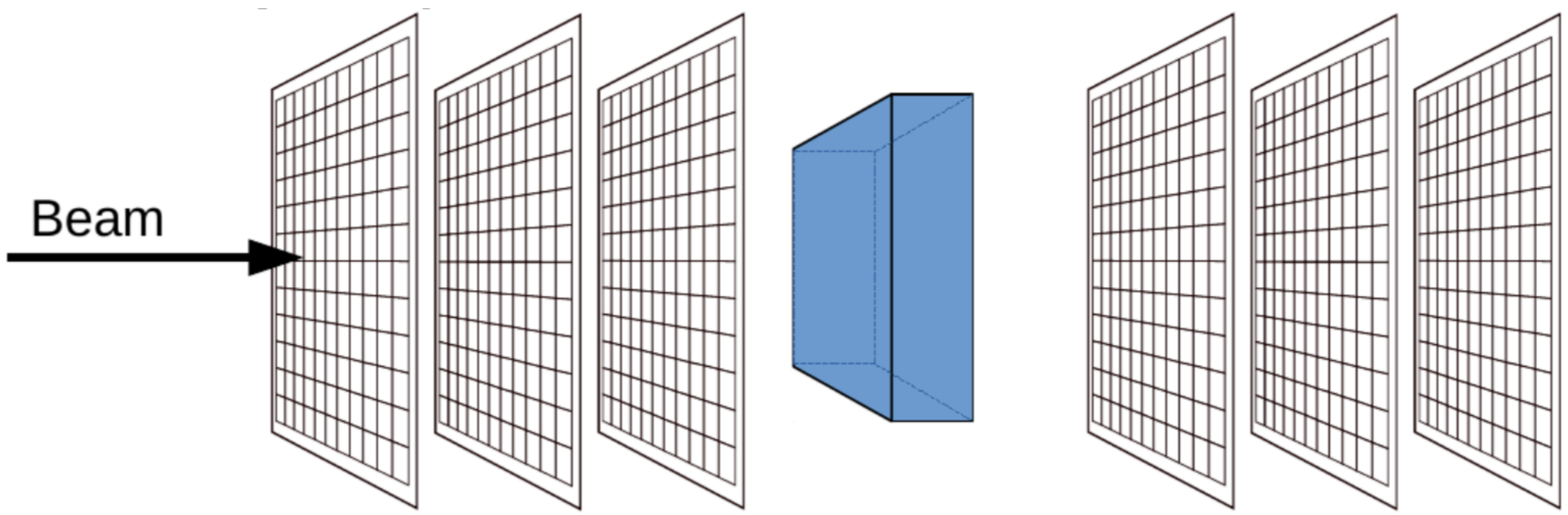
- Beam usually created a secondary use to other big synchrotrons (e.g. SPS for LHC at CERN)
- Essential infrastructure for detector R&D: performance of prototypes need to be studied to continue the R&D, possible sources:
  - Cosmic ray: hard to control (direction, rate)
  - Radioactive source: energy level too low (Sr90 ~ 2.2 MeV)

- Detector community popular TB infrastructure:
  - Telescope: trigger incl.
  - Magnet
  - Cooling box
  - Monitoring (humidity, temperature etc)
  - NIM modules etc.

Unique tool for detector R&D — telescope

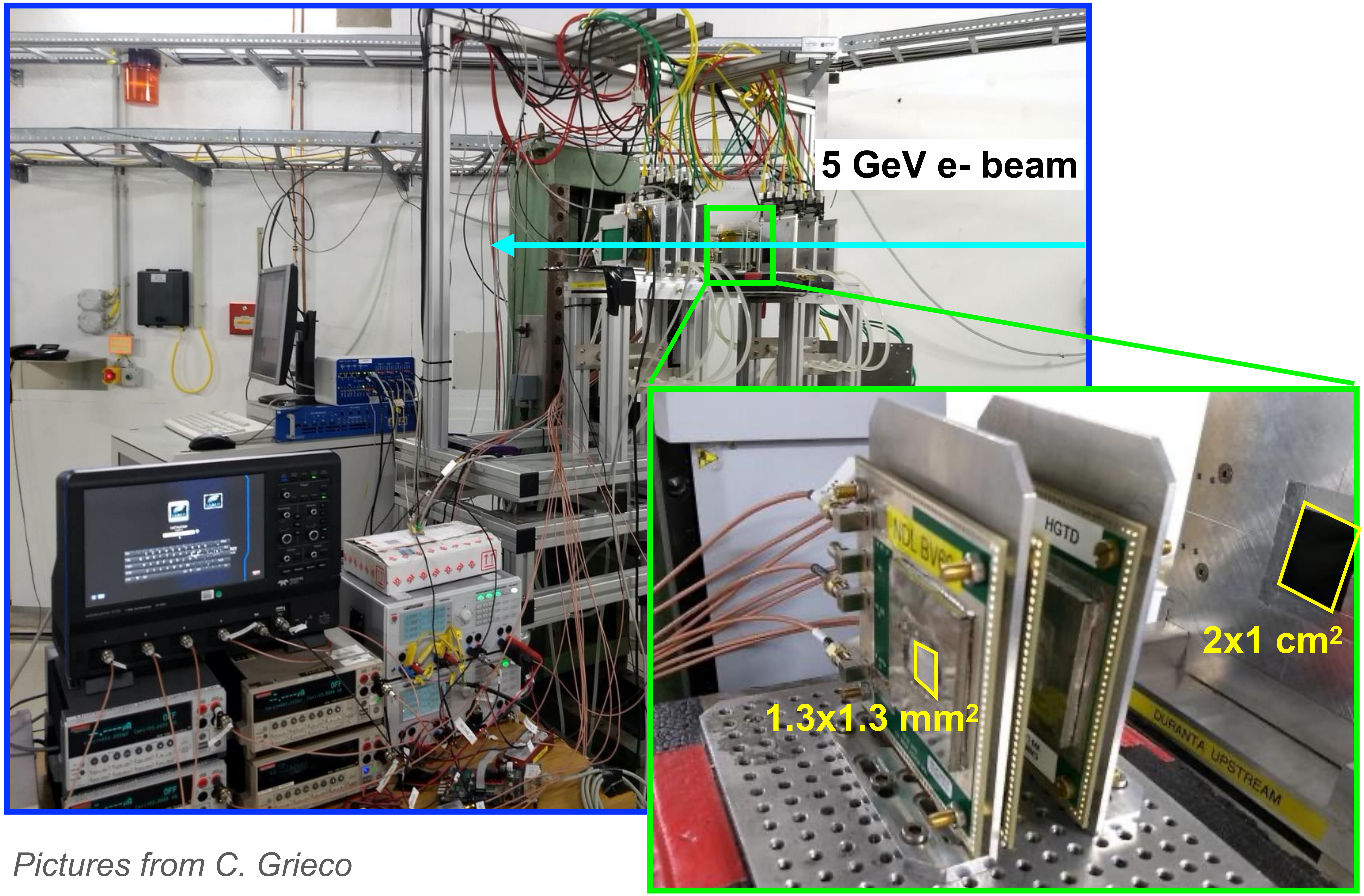
What is a beam telescope?

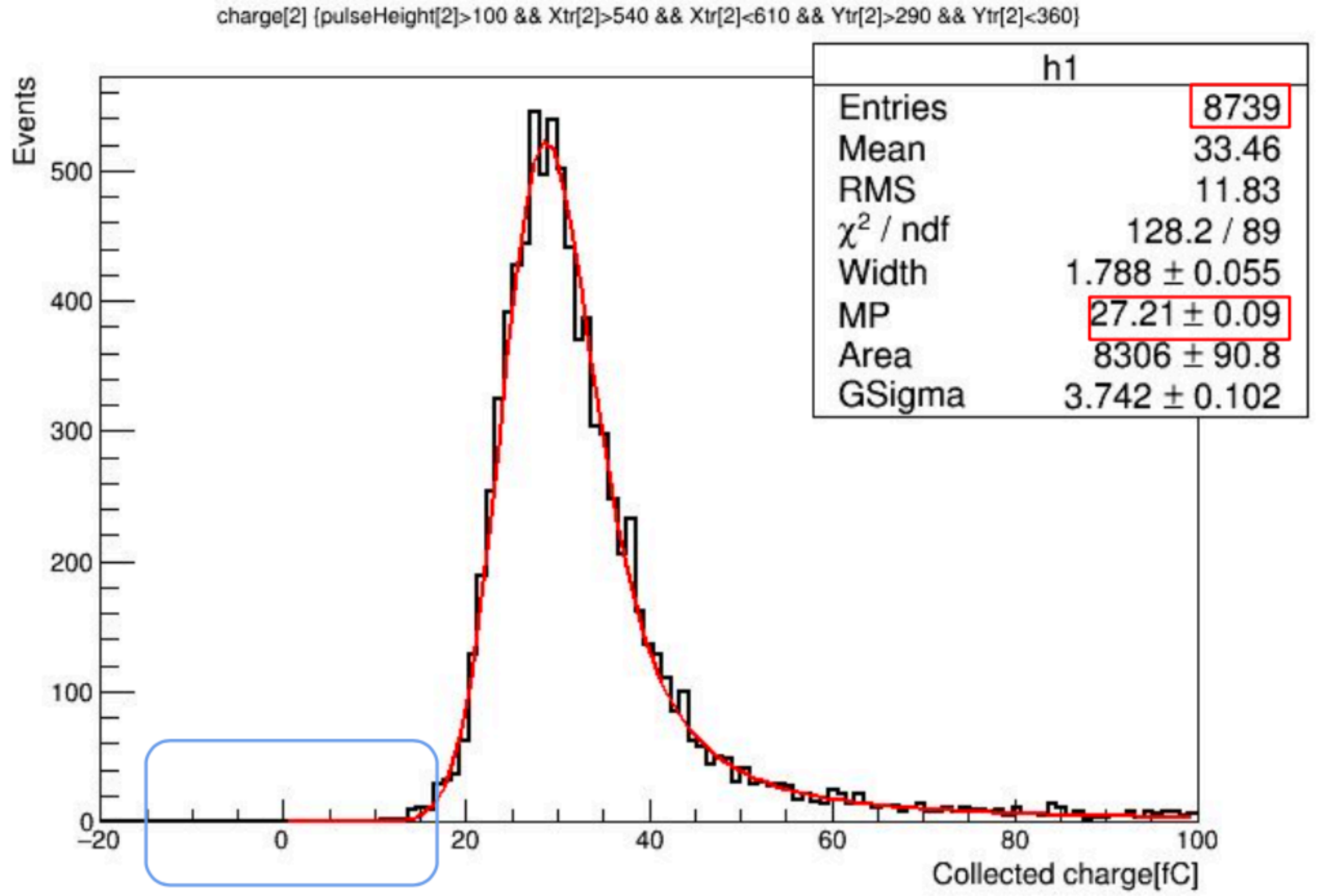
- it defines the exact track of a particle in a test beam for the Device Under Test (DUT), requiring it:
  - Good spatial resolution;
  - Less material budget;

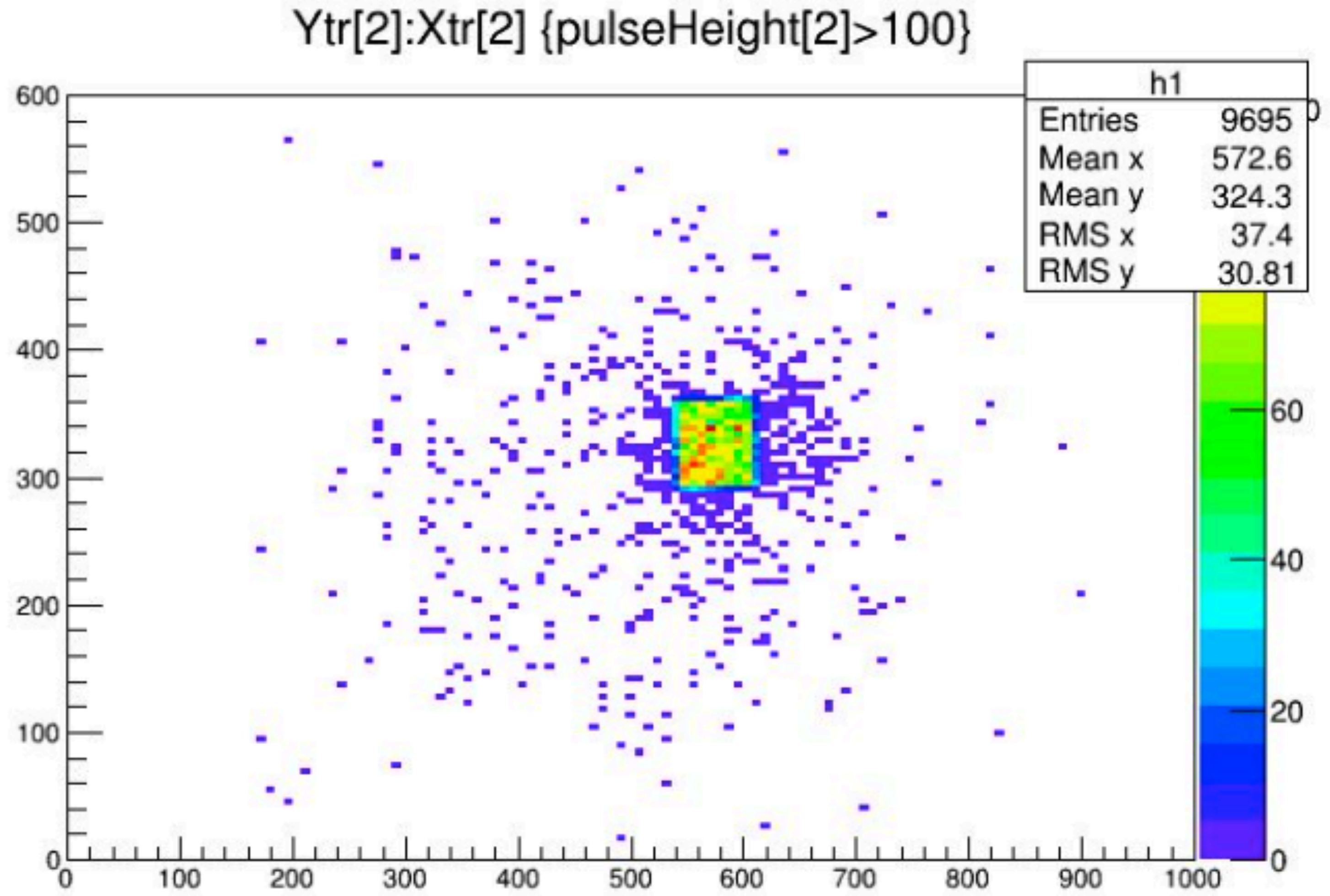


Prototypes at Test Beam - performance

Plots from B. van der Linden
Example taken for ATLAS HGTD upgrade



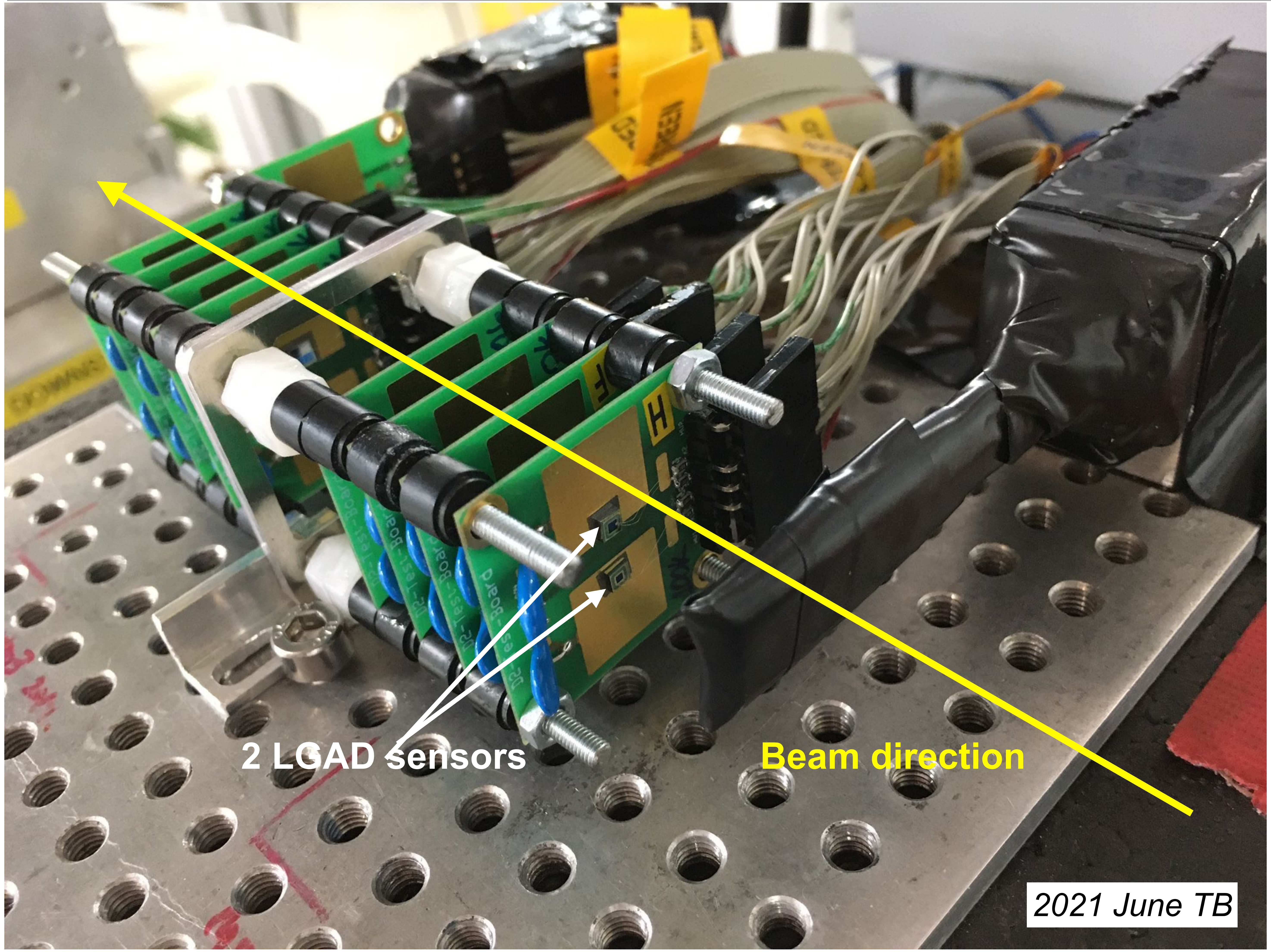


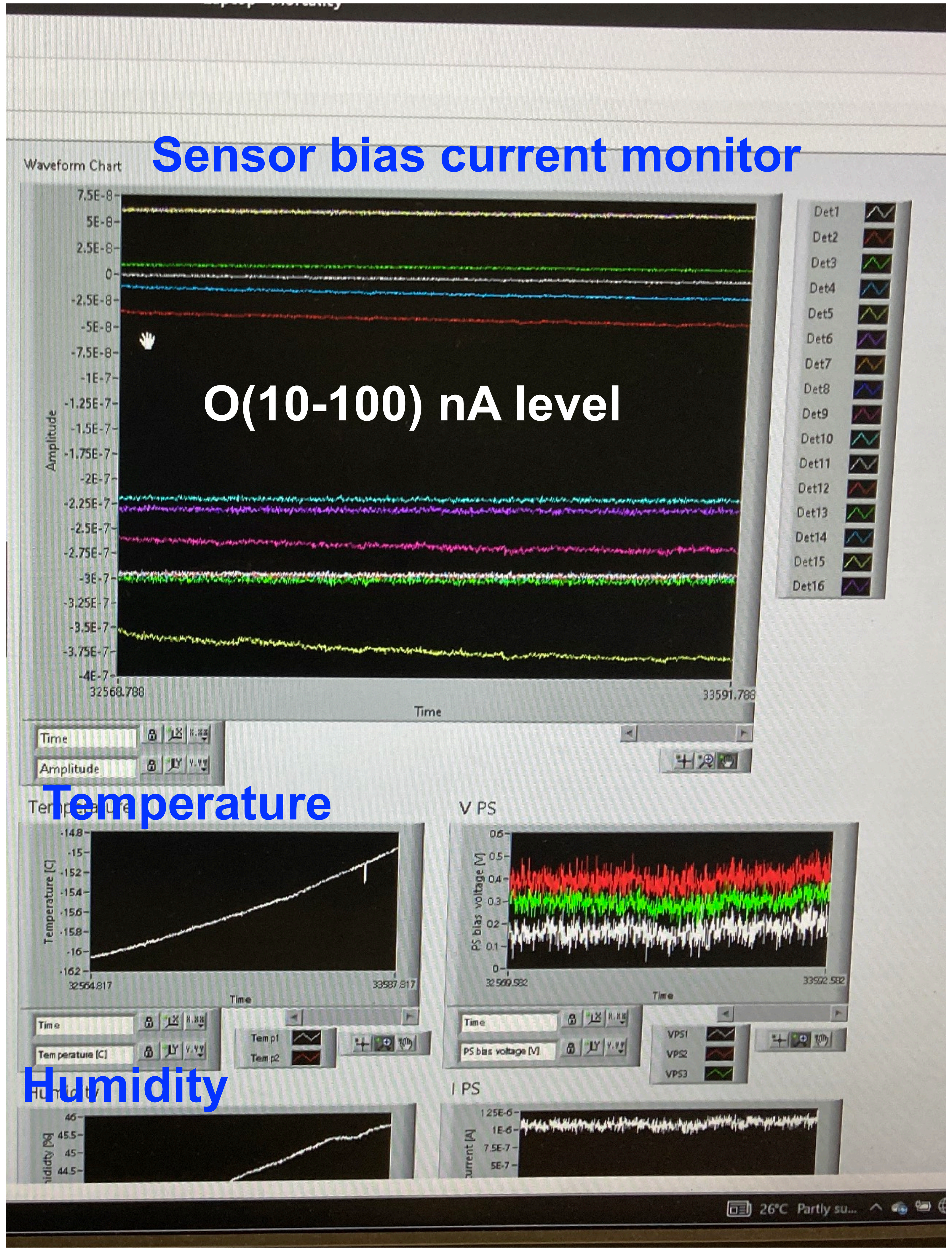


Pictures from C. Grieco

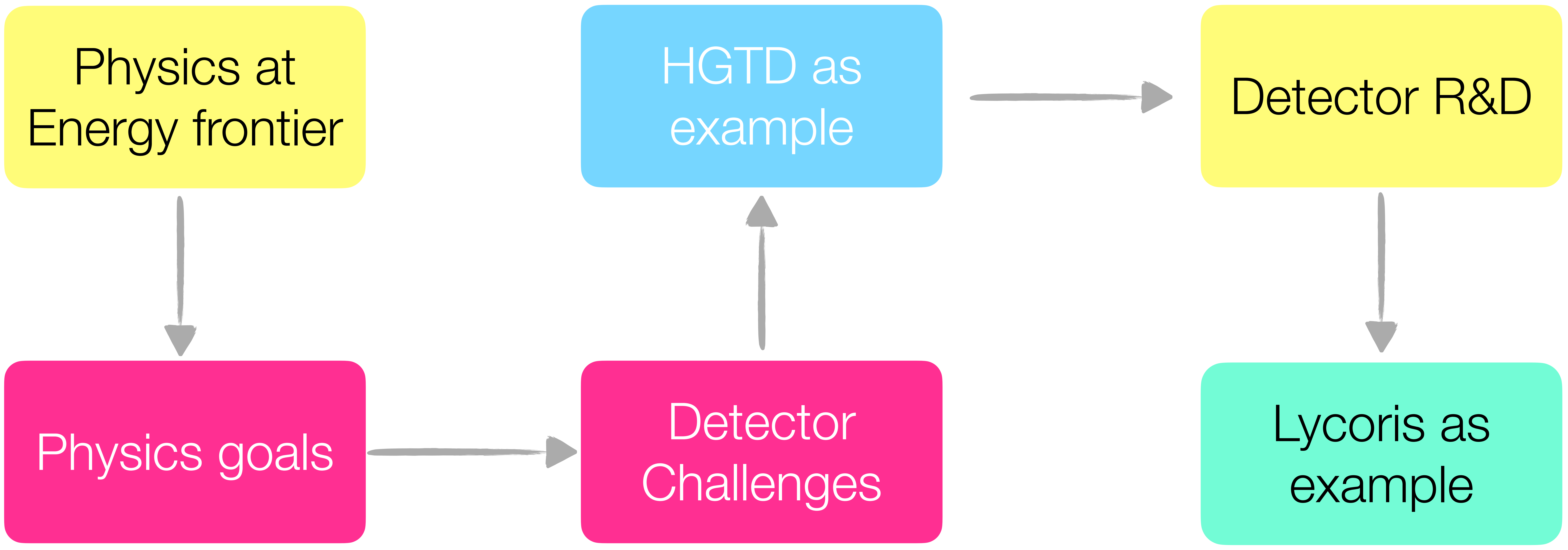
Prototypes at Test Beam - irradiation mortality

Example taken for ATLAS HGTD upgrade





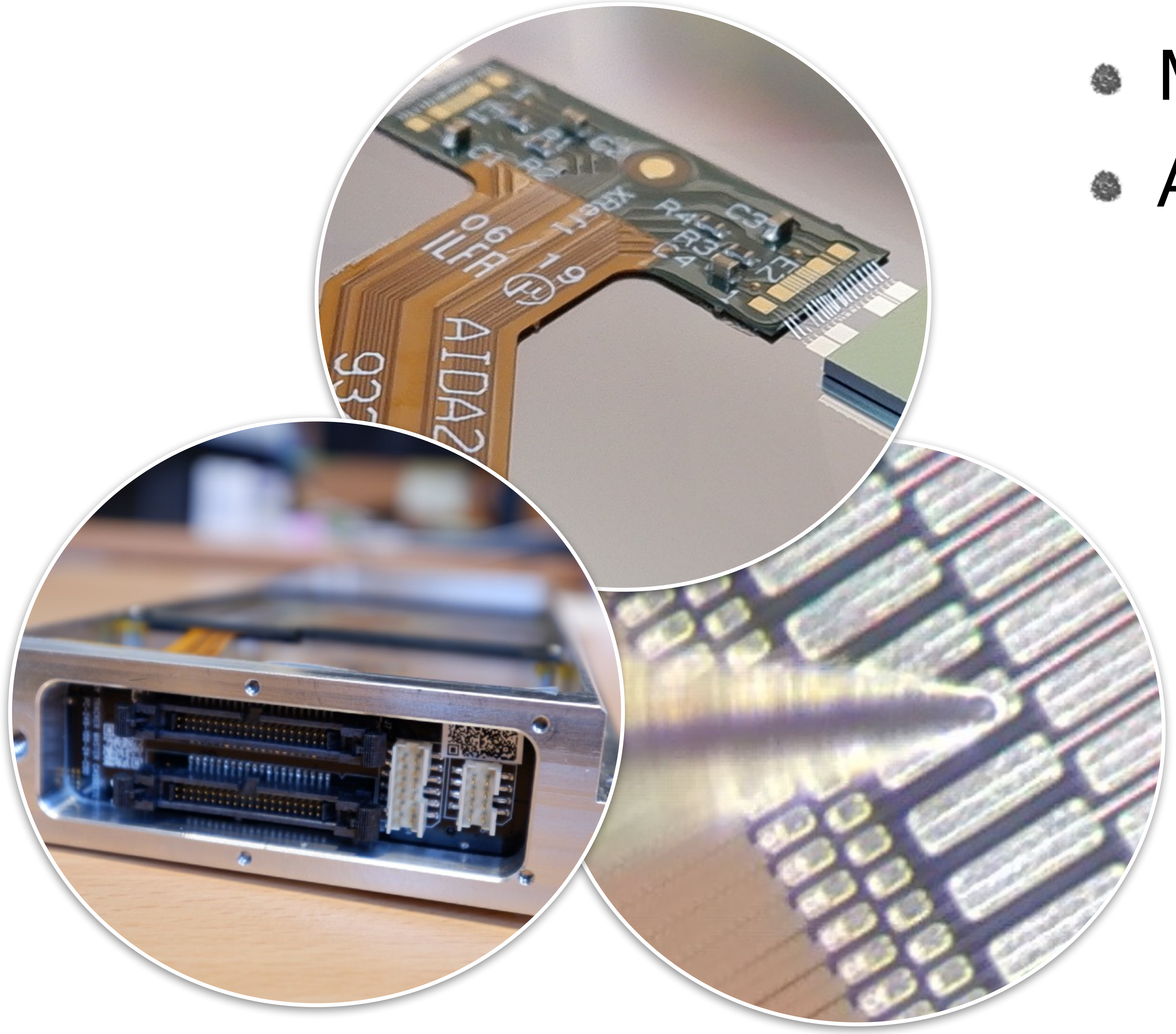
Roadmap for today



A generic life cycle of a detector project

R&D phase

- Iterative process of Design and Prototyping
  - Lab test
  - Test Beam
- Including various phases:
  - Conceptual Design
  - Technical Design
  - Specifications given
  - final prototyping towards production readiness



Construction

- Mass production
- Assembly and quality control

Integration, installation and commissioning

- Integrate with other sub-detectors
- Install at experimental carven
- Commissioning run

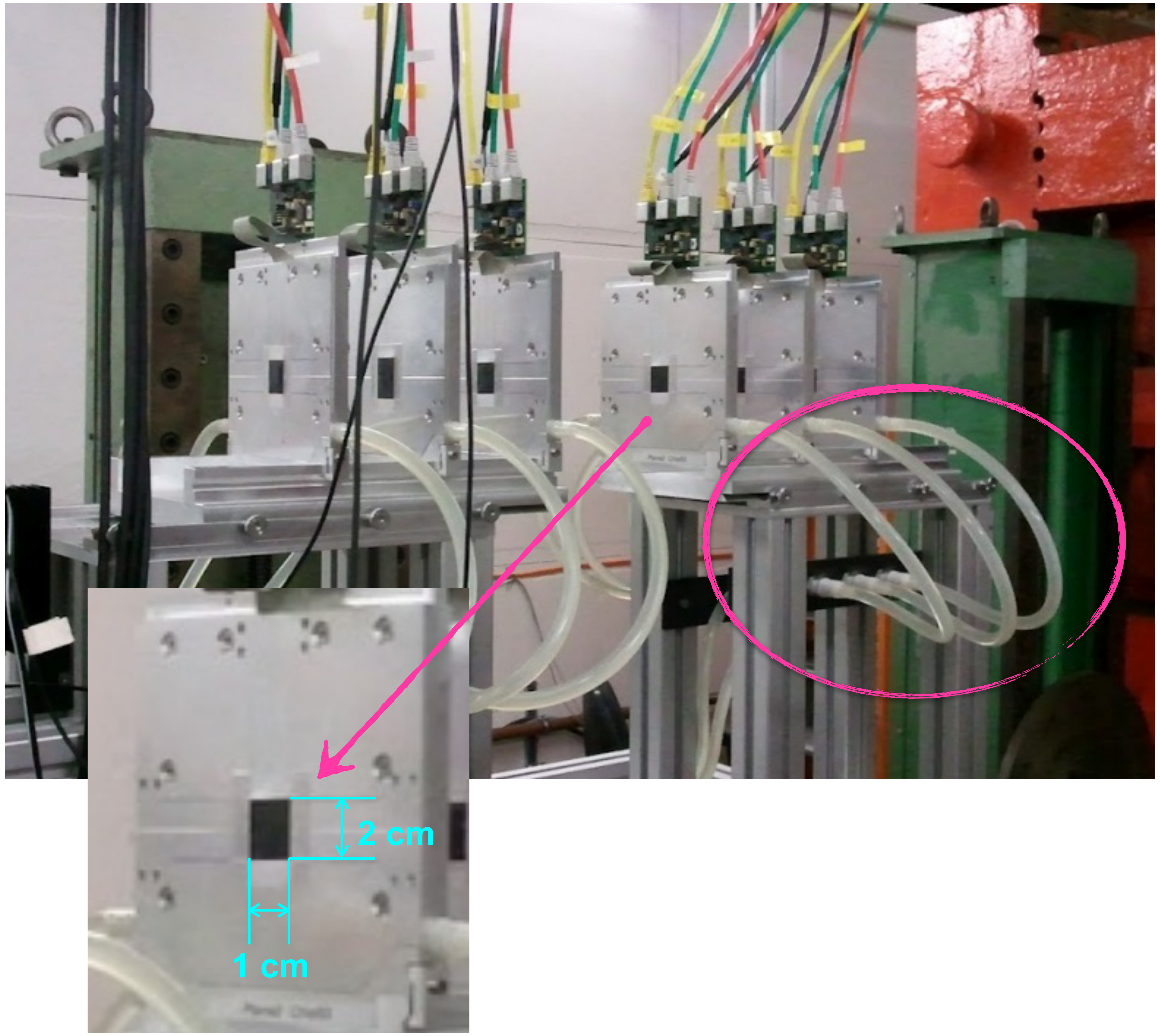
A

R&

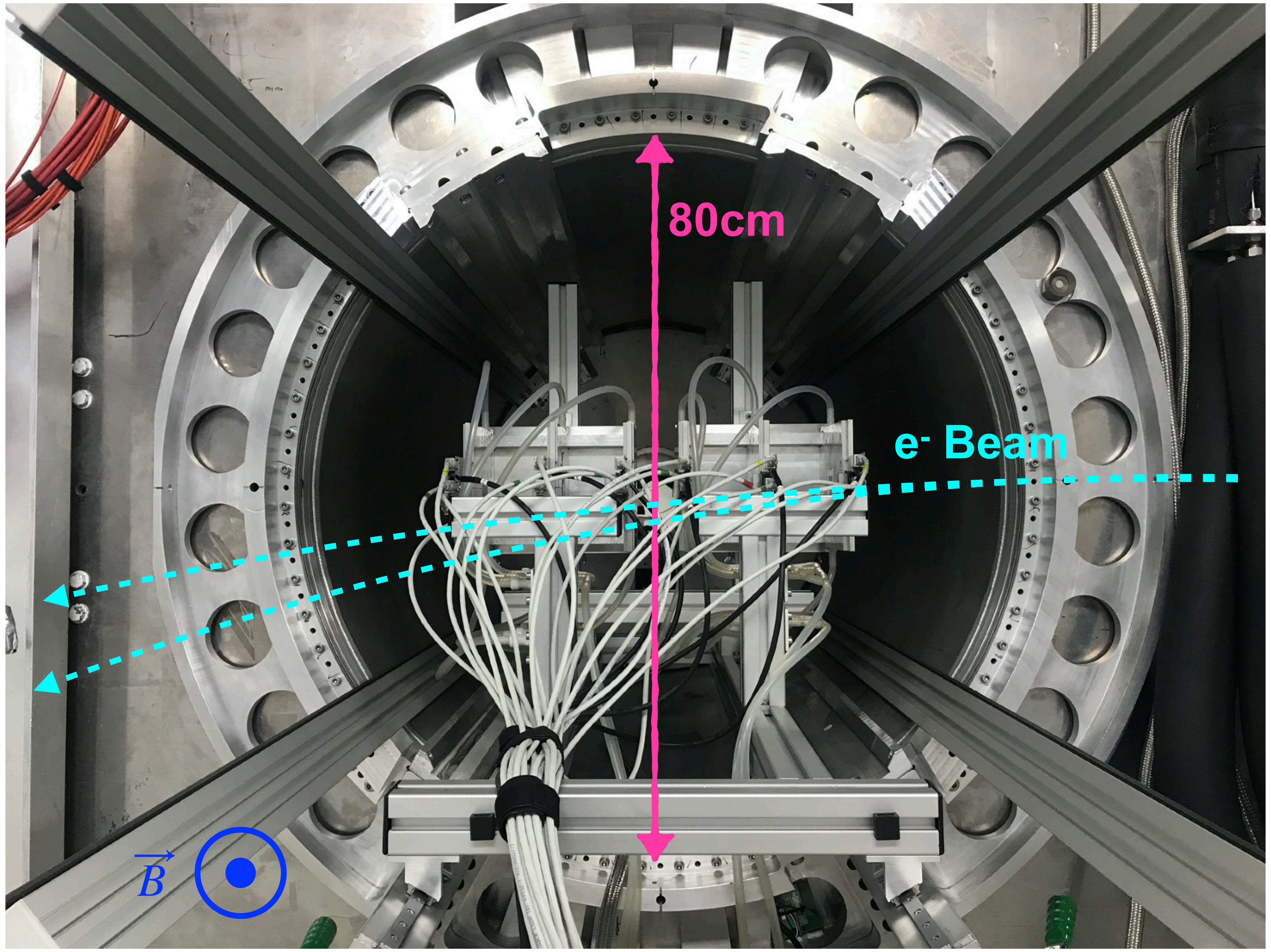
d

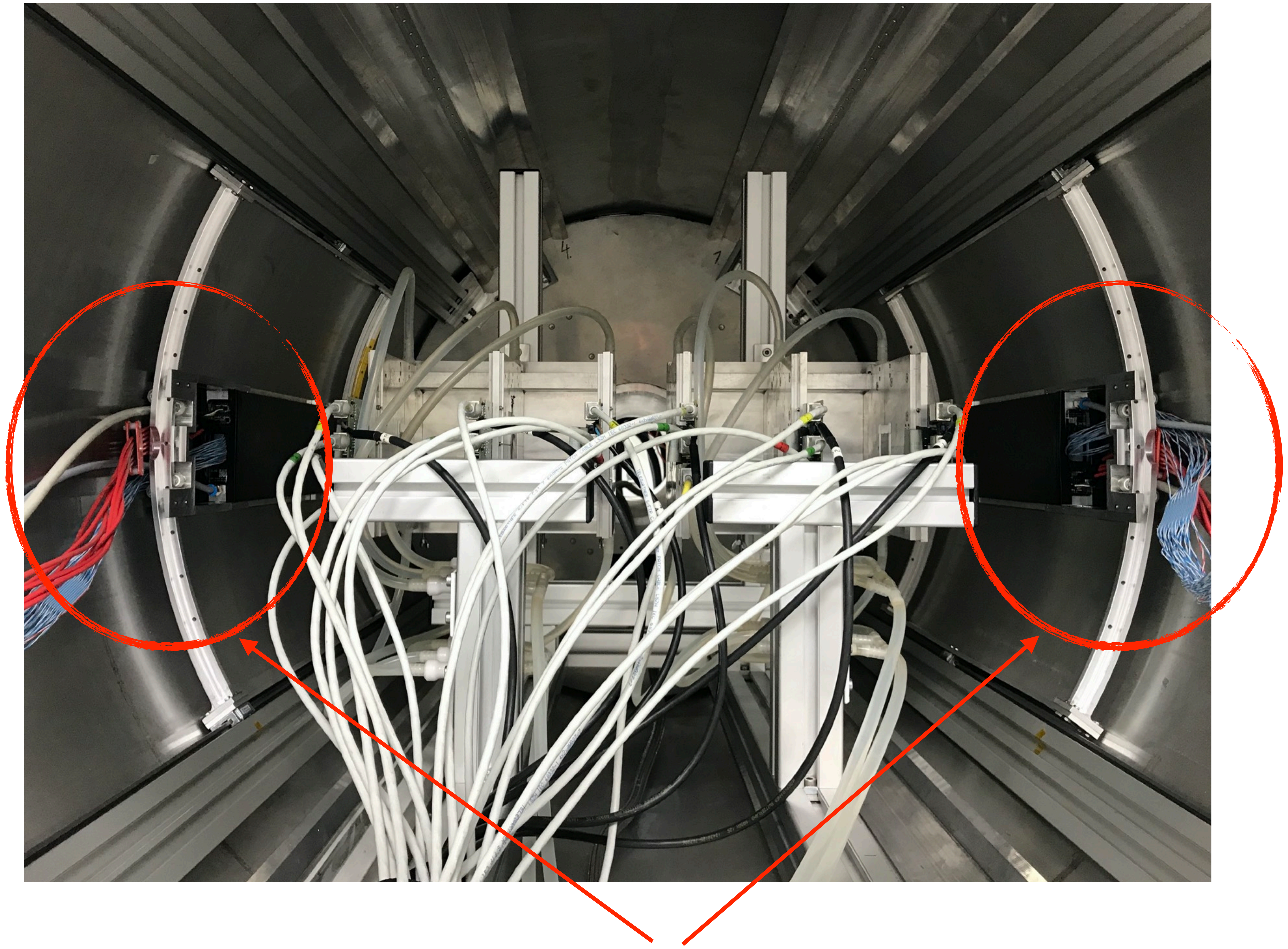
rven

An existing telescope — EUDET-type Telescopes



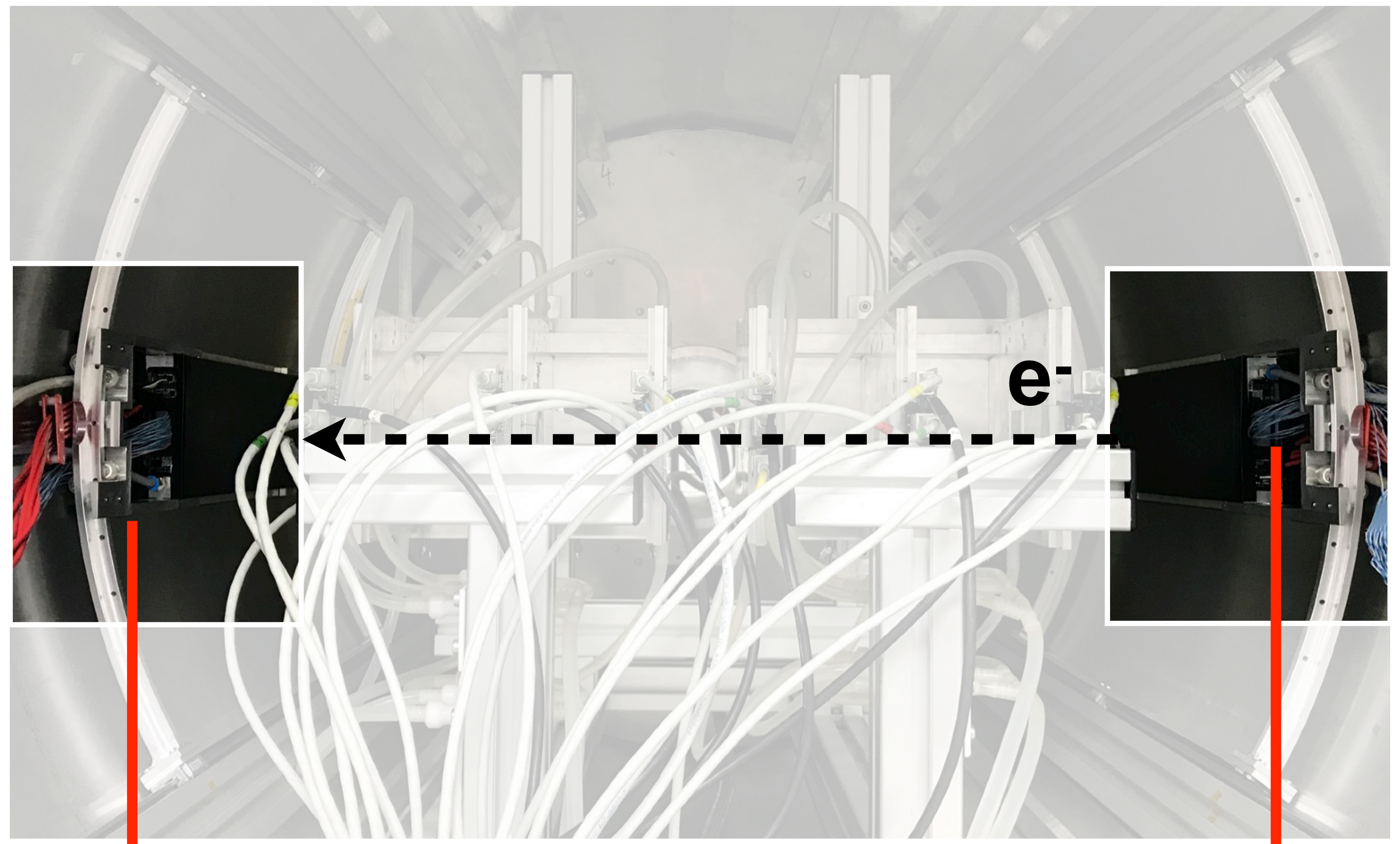
- 7 copies worldwide at 5 different test beam facilities
- Operated 10 years — a lot detector projects benefited from it
  - Good spatial resolution ~ 3-4 μm
  - Less material (=less perturbation of particle trajectory): 50 μm thick
- Disadvantage:
  - **Small** active area 2x1 cm2 — hard to cover a B-field bent curvature
  - **Slow readout** — always requires an extra timing plane for modern detector R&D + cannot handle high intensity beam (CERN usage limited)
  - **Large mechanic support** (aka **not compact**) — hard to fit in a solenoid with a large detector prototype to test



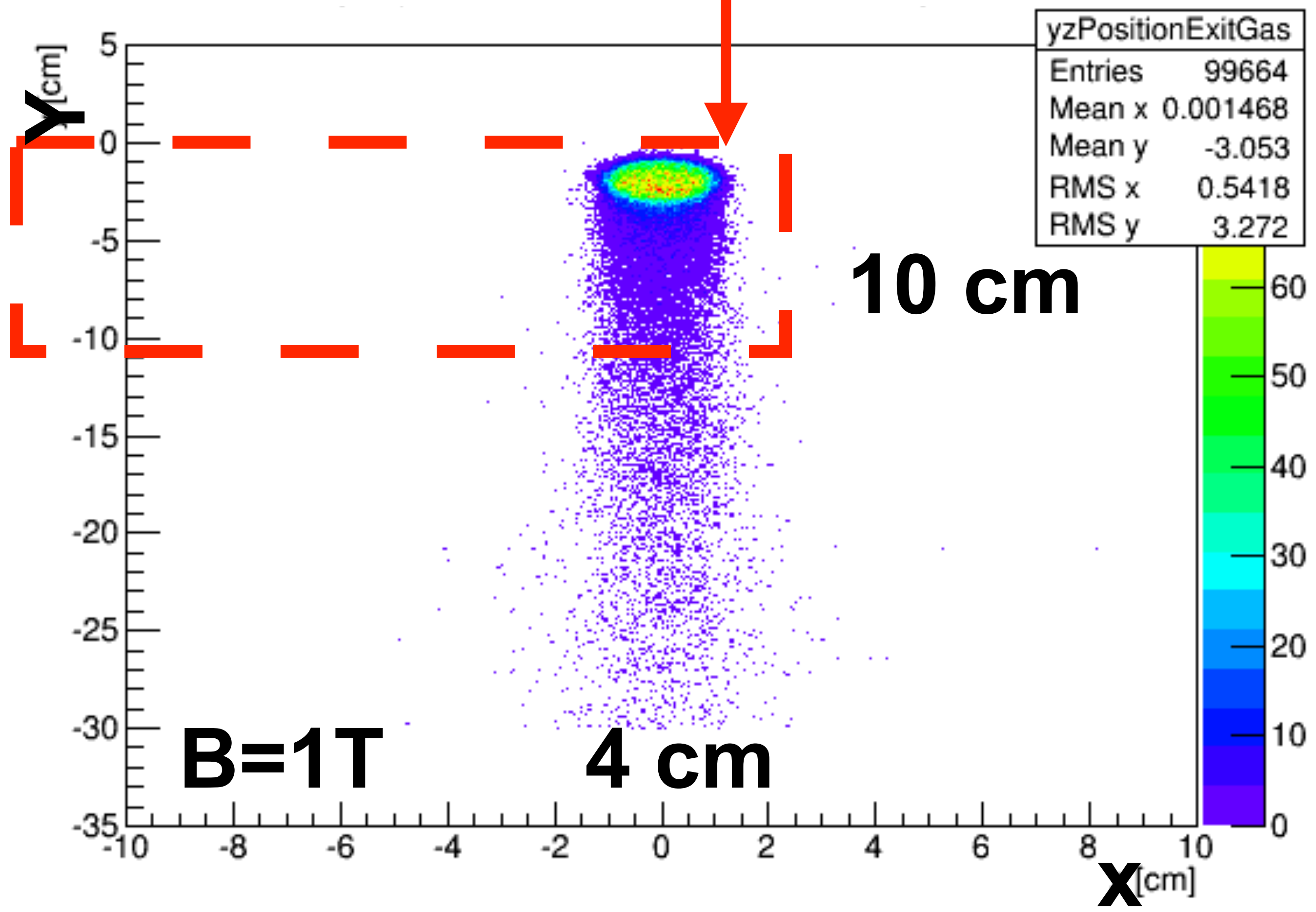


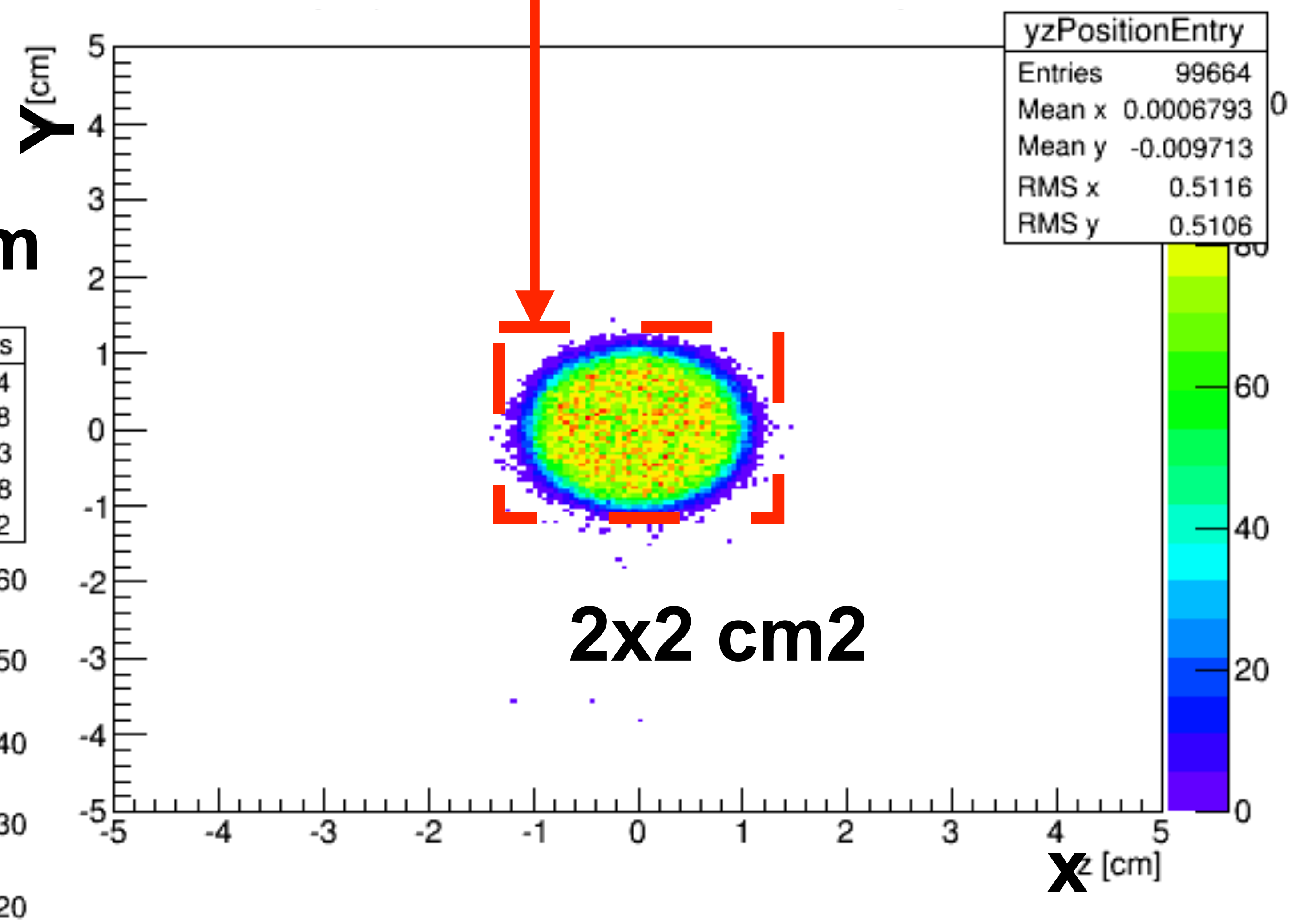
These are the Lycoris stations

R&D — Design and prototyping



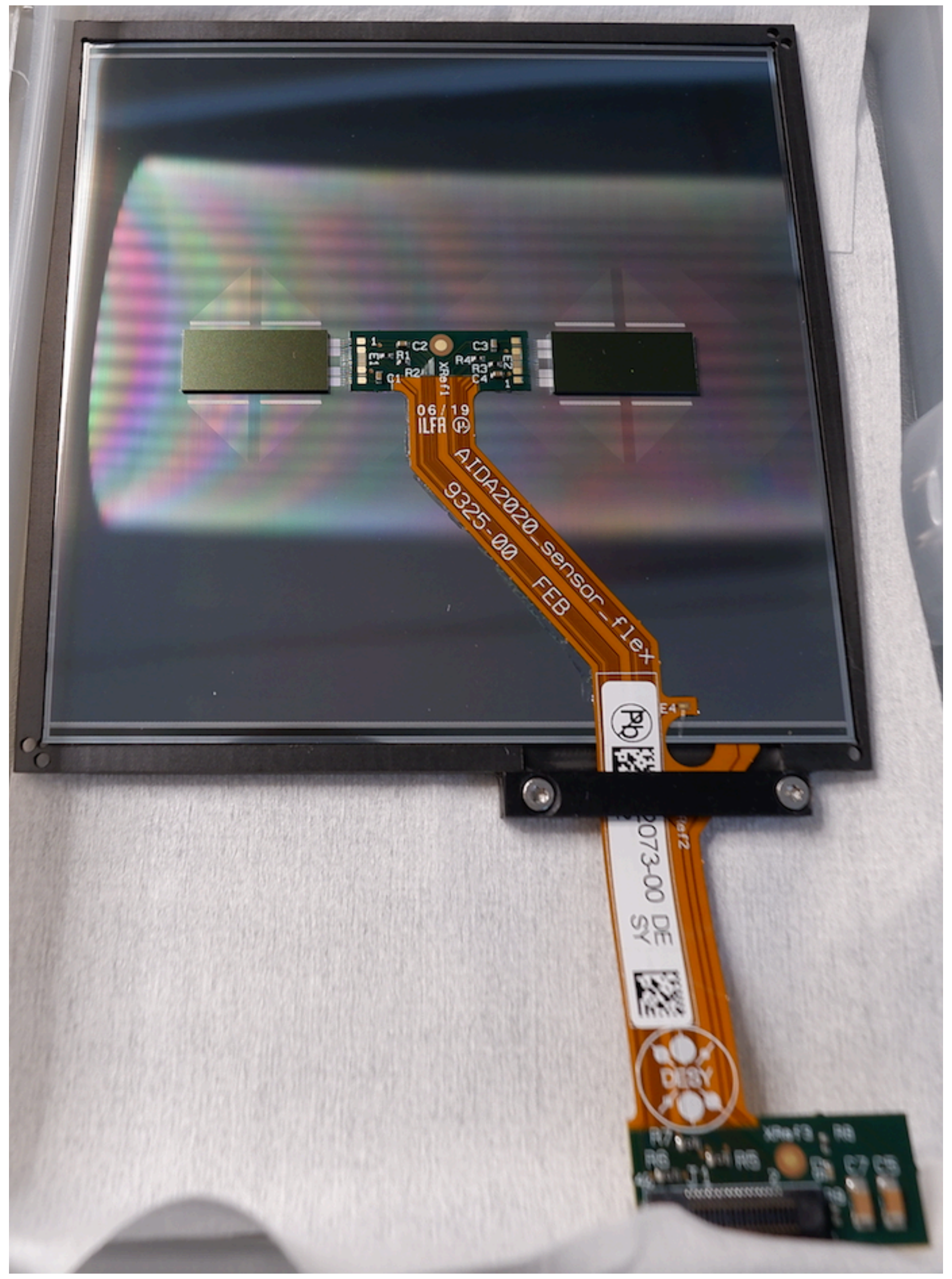
96% contained for 6GeV beam





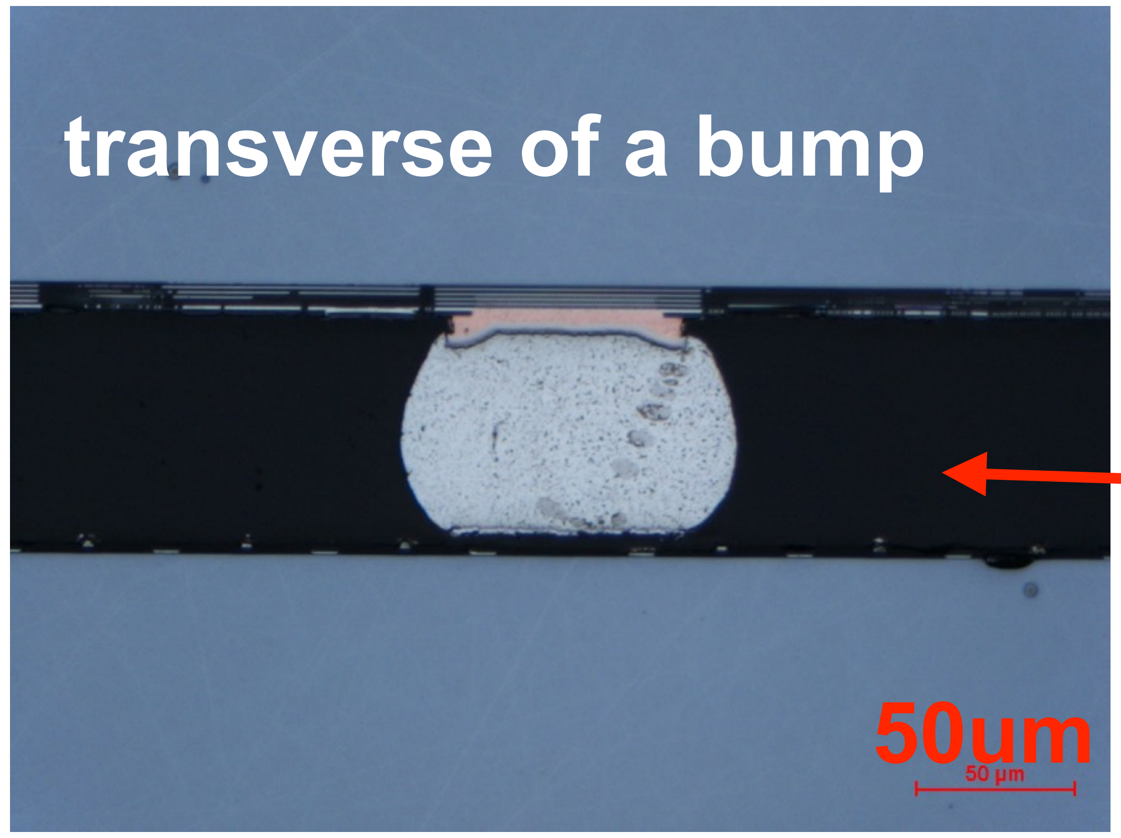
Resolution in bending plane	σ_y	$< 10\,\mu m$
Resolution orthogonal to the bending plane	σ_x	< 1 mm
Area coverage	A_{xy}	$10\times 10\,cm^2$
Thickness of single station	d	< 3.5 cm

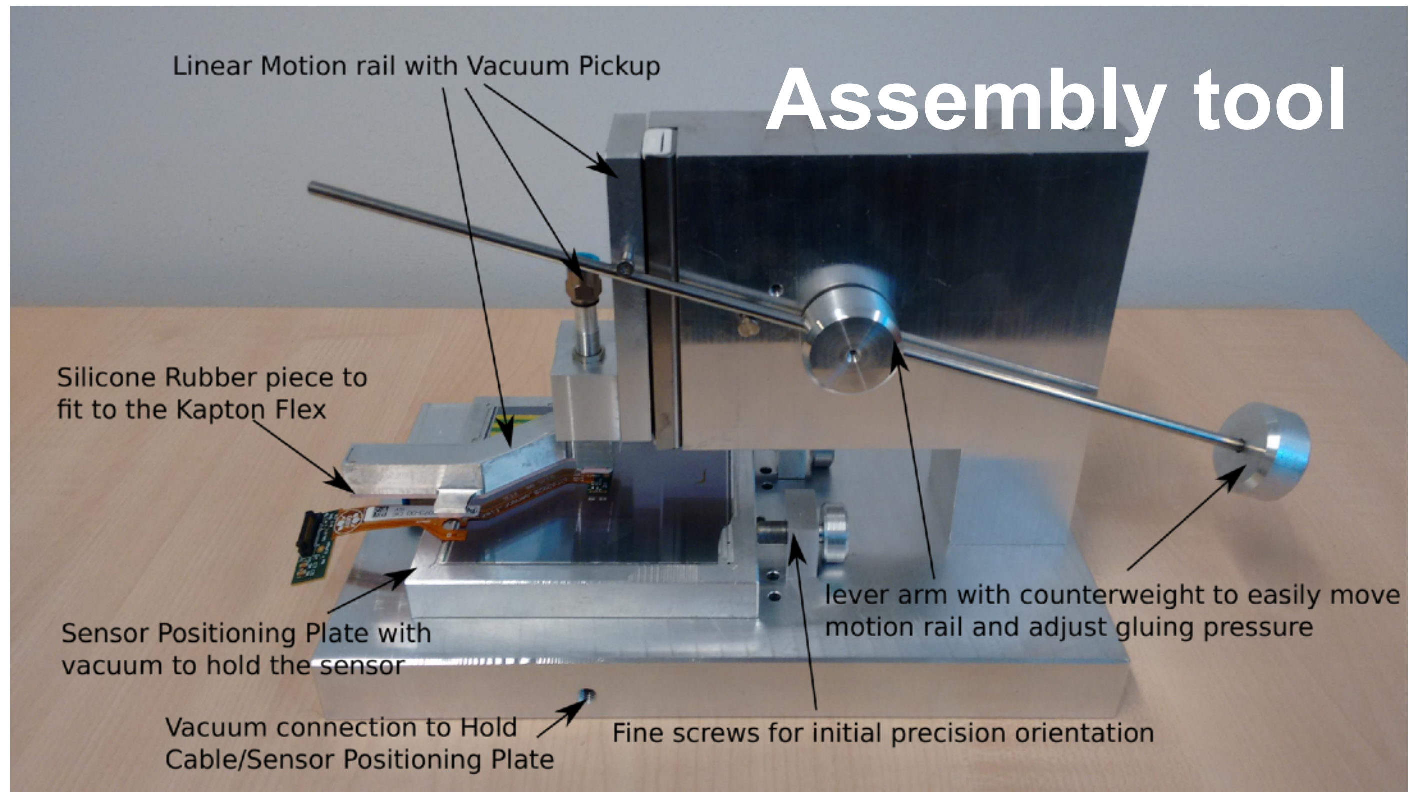
Table 1. The key requirements for developing the LYCORIS telescope.

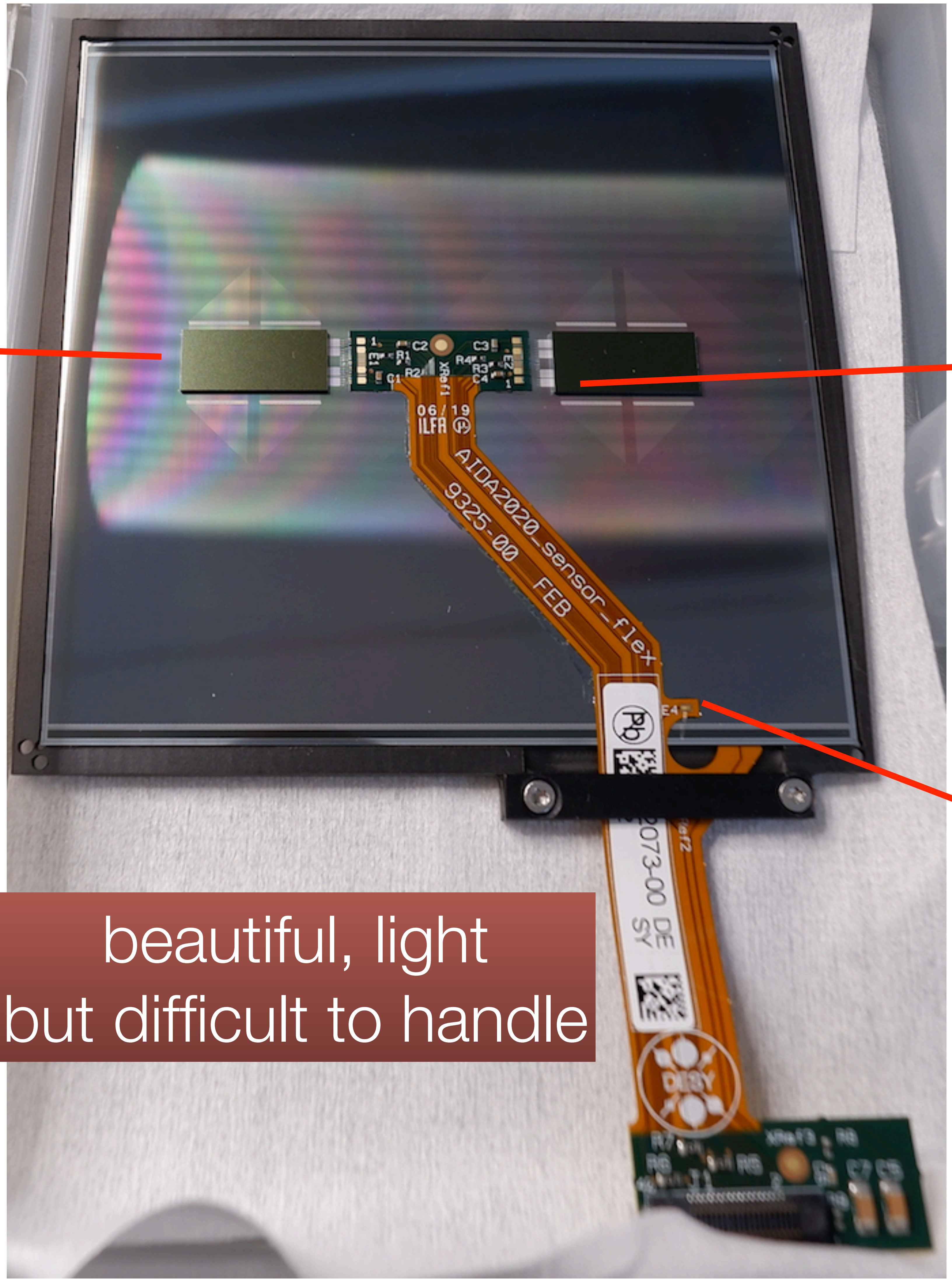


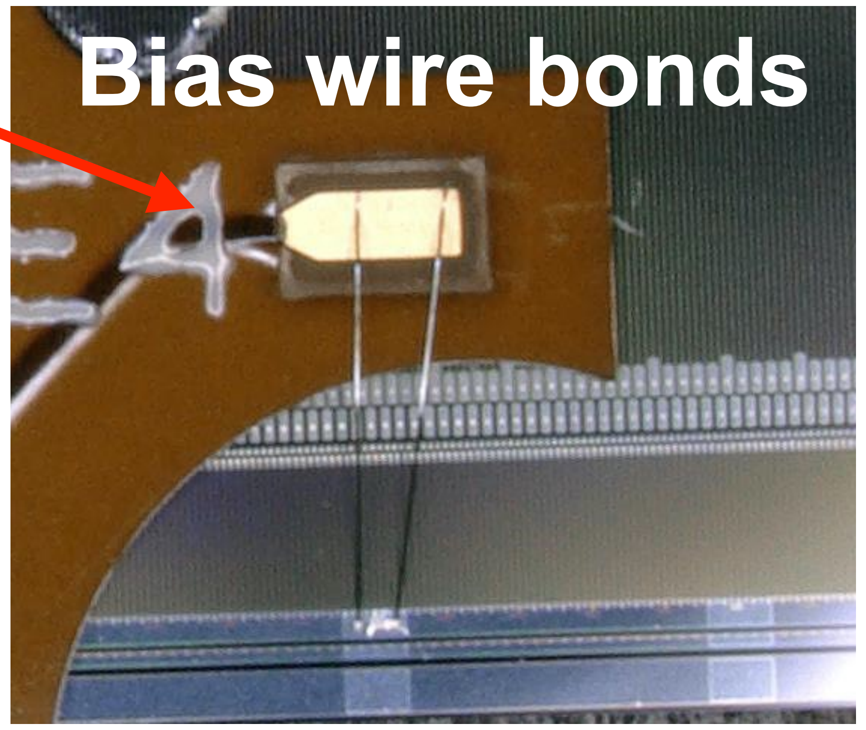
- 25um pitch
  - ➠ meets $\sigma_y < 10\ \mu m$
- Compact:
  - Readout chip can be power up and down during data taking
    - ➠ no dedicated cooling needed
  - Design without a hybrid PCB board

Assembly and production

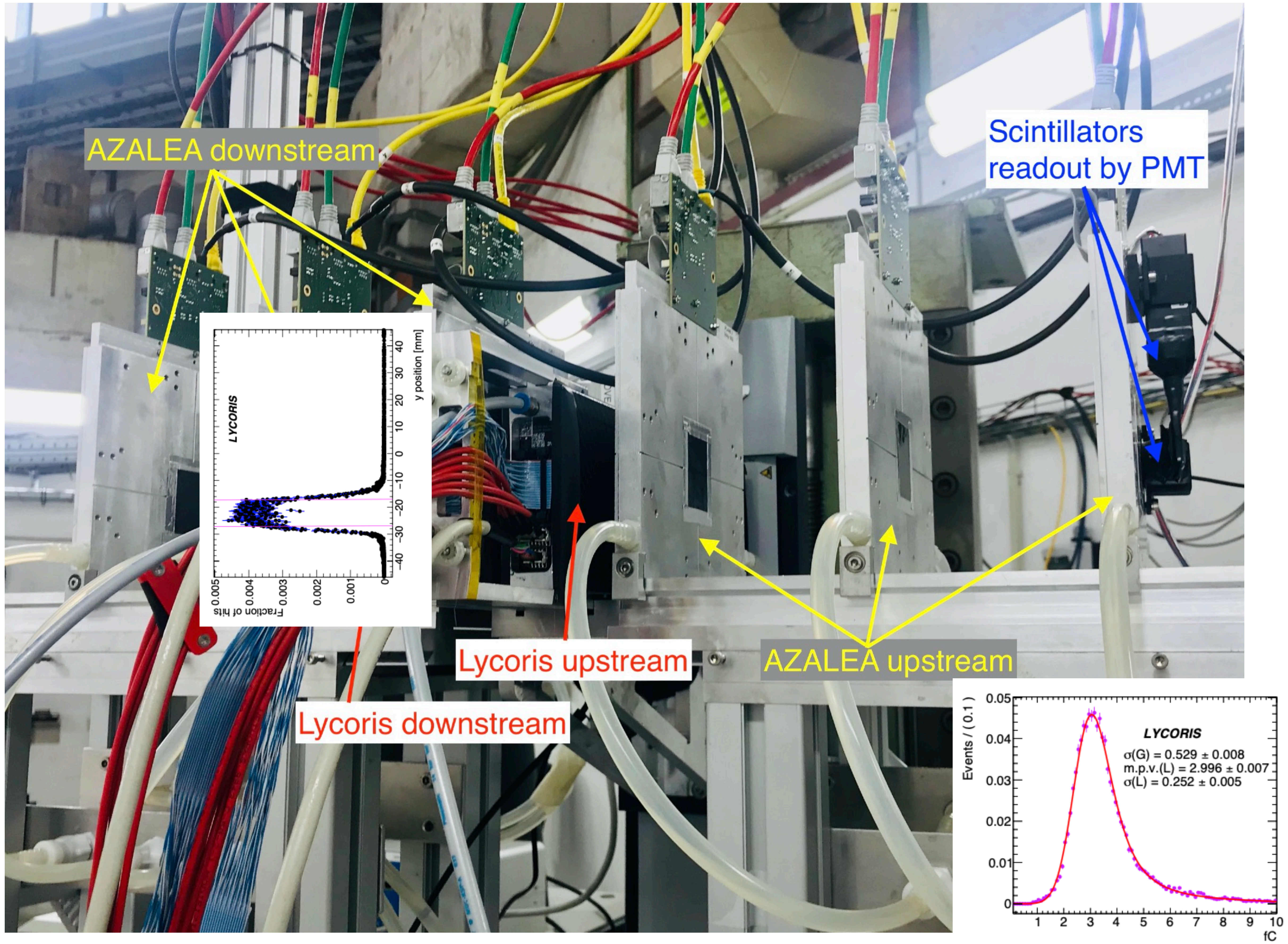


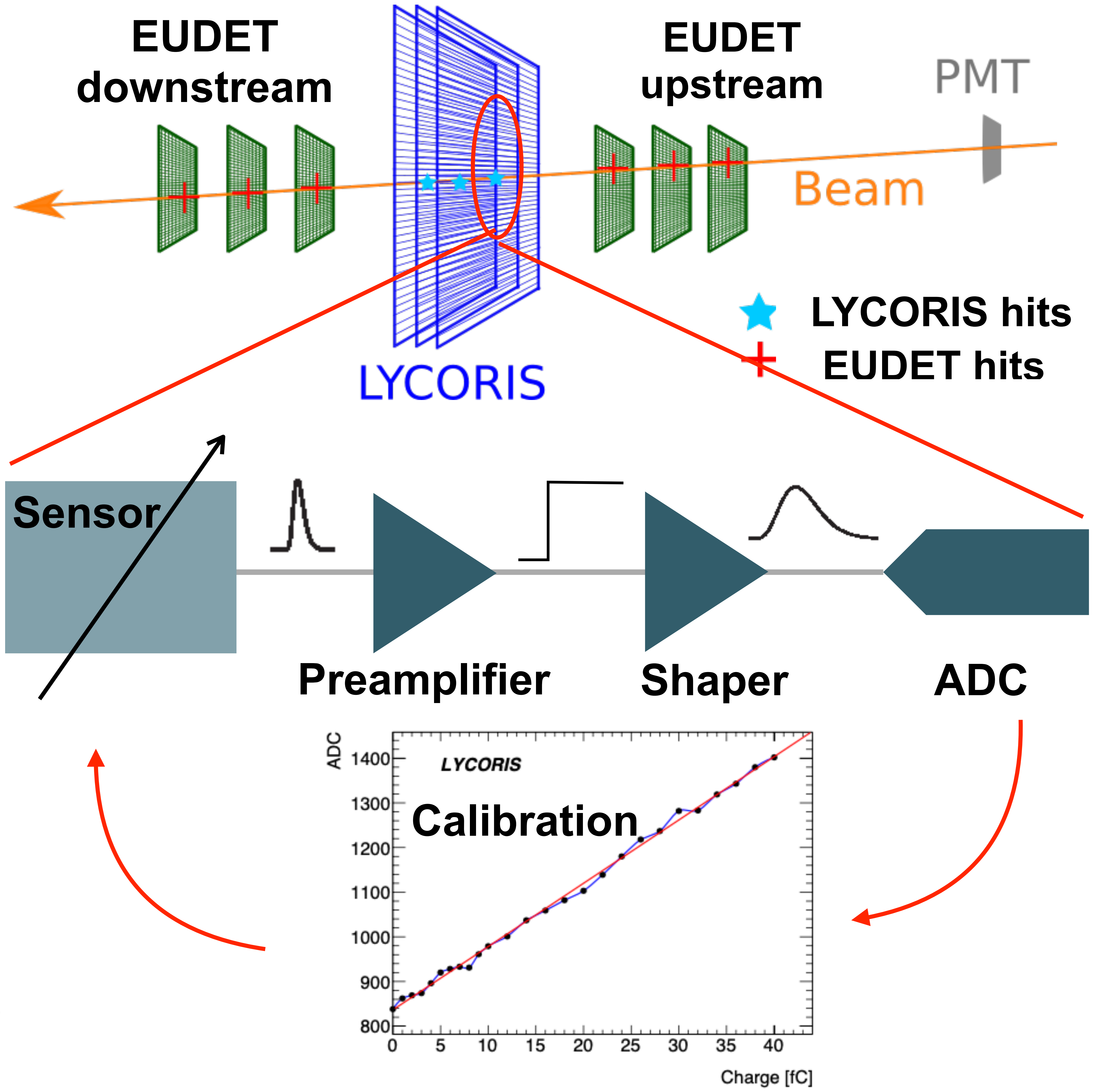






Commissioning



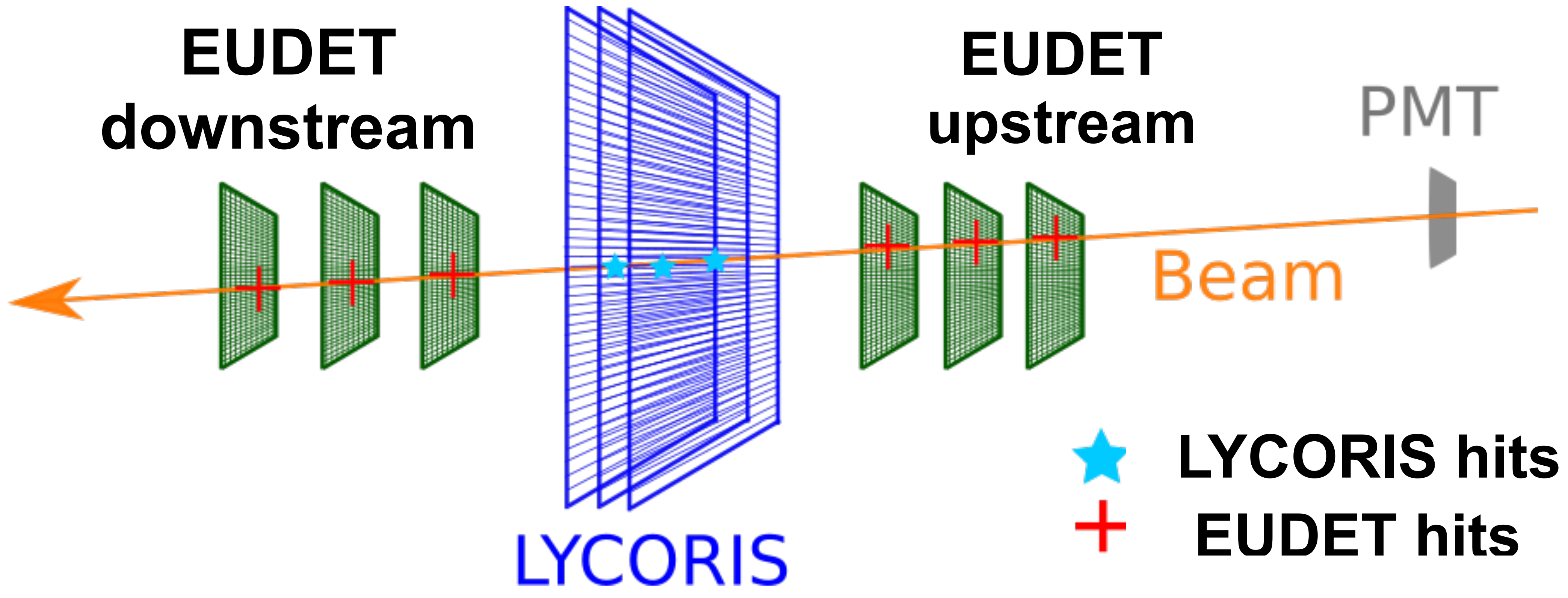


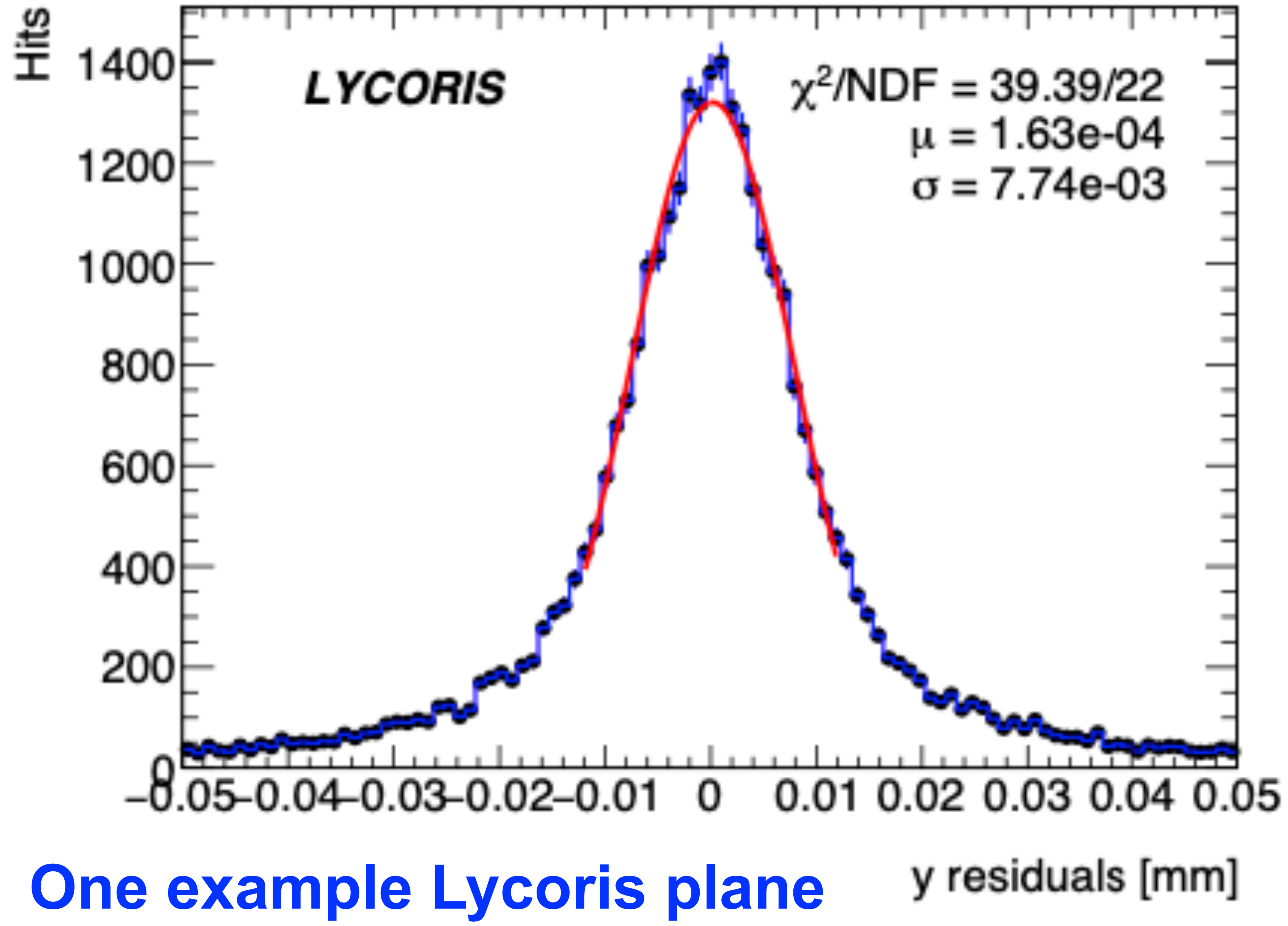
Performance

Paper accepted by JINST, preprint arXiv:2012.11495

Resolution in bending plane	σ_y	$< 10\,\mu m$	✔
Resolution orthogonal to the bending plane	σ_x	< 1 mm	✔
Area coverage	A_{xy}	$10\times 10\,cm^2$	✔
Thickness of single station	d	< 3.5 cm	✔

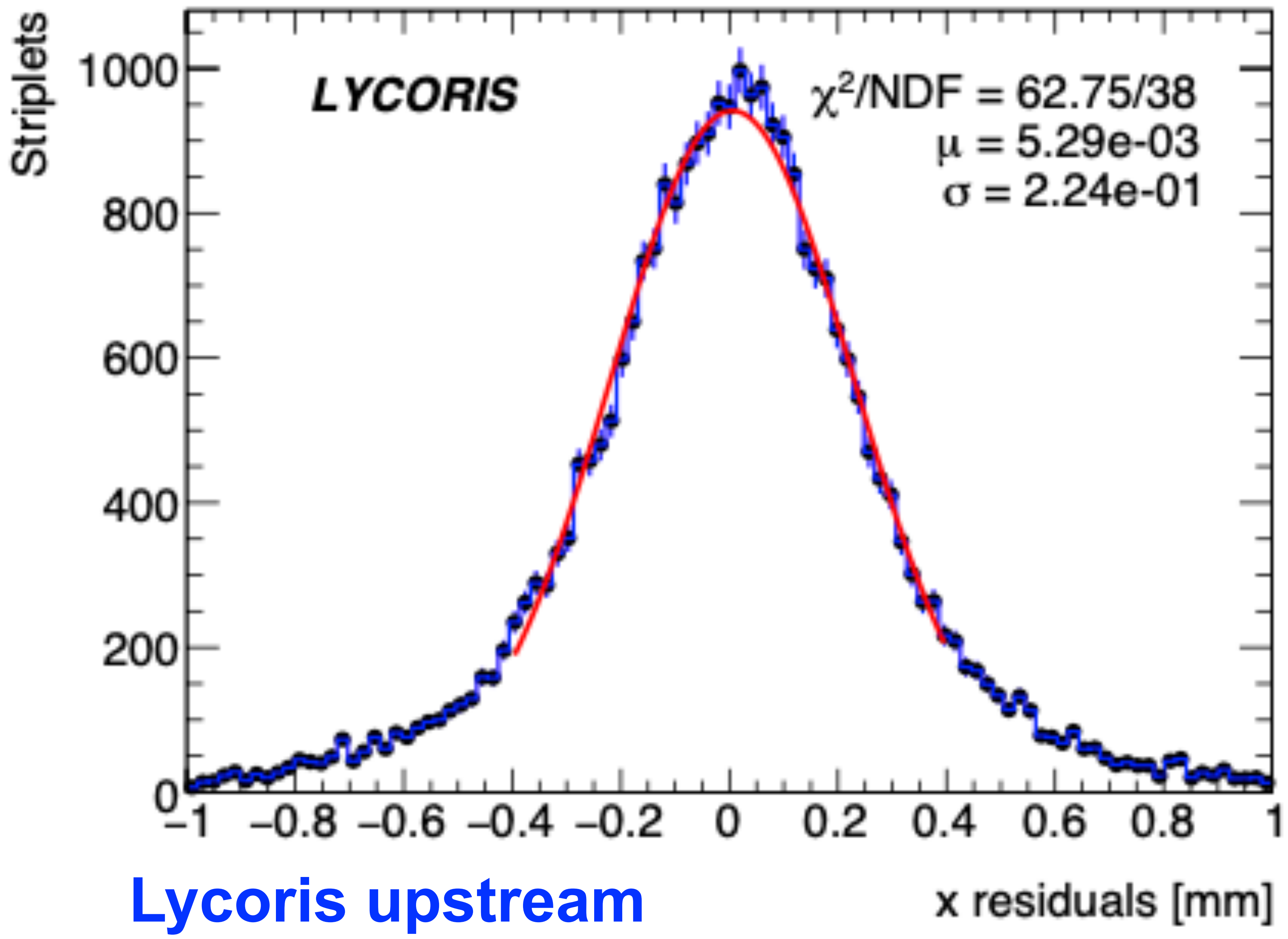
Table 1. The key requirements for developing the LYCORIS telescope.





One example Lycoris plane

Sensor ID	Efficiency	$\sigma_y \mu m$
upstream 0	95.0%	7.32 ± 0.07
upstream 1	97.0%	6.92 ± 0.06
upstream 2	96.2%	7.22 ± 0.07
downstream 0	96.7%	7.01 ± 0.08
downstream 1	96.6%	7.06 ± 0.06
downstream 2	96.7%	7.21 ± 0.07

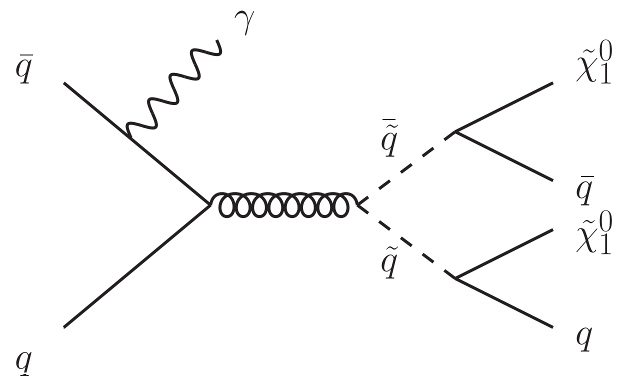


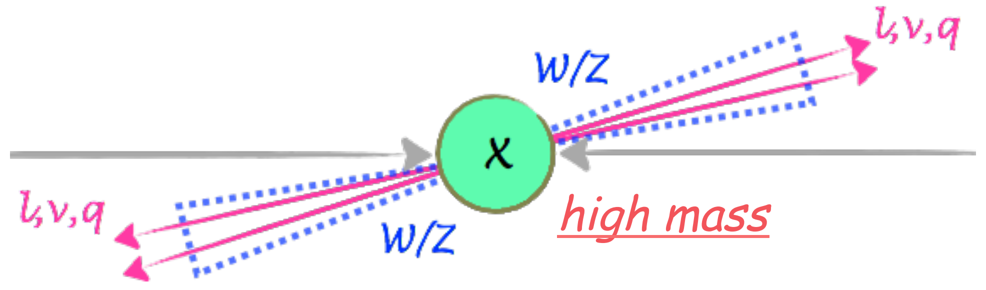
Lycoris upstream

Summary

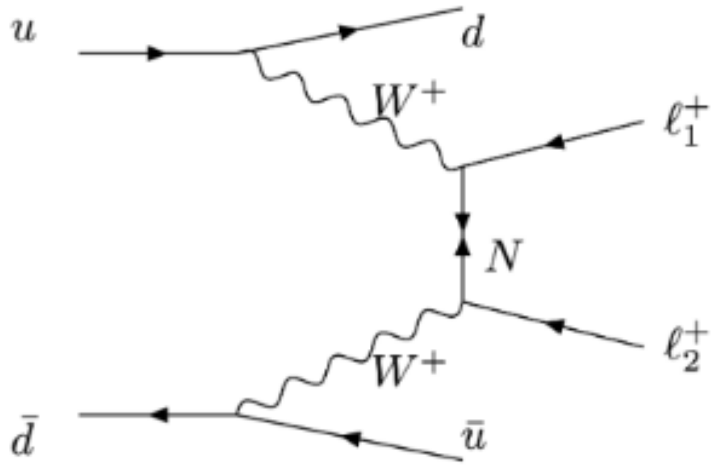
Physics Analyses

From 2012-2017





From 2021 -

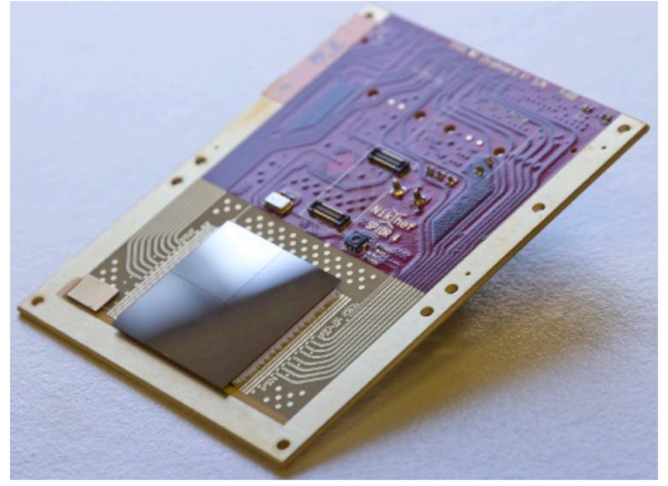


Lycoris
an AIDA2020 project

From 2017 - 2020

Timepix4
an AIDAInnova project

From 2021 - 2025
kick-off on 13 Apr 2021



HGTD
ATLAS HL-LHC upgrade

From 2021 -

FELIX
ATLAS TDAQ upgrade

From 2020 -