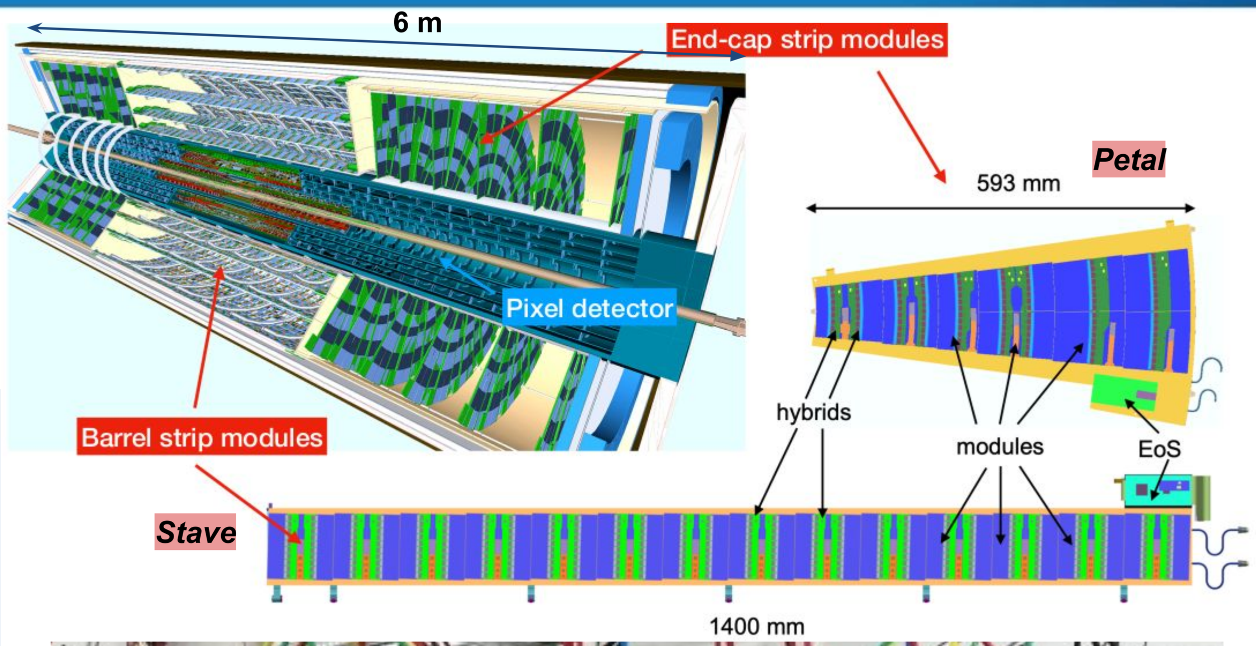
# TESTBEAM STUDIES OF IRRADIATED MODULES FOR THE ATLAS ITk STRIP UPGRADE

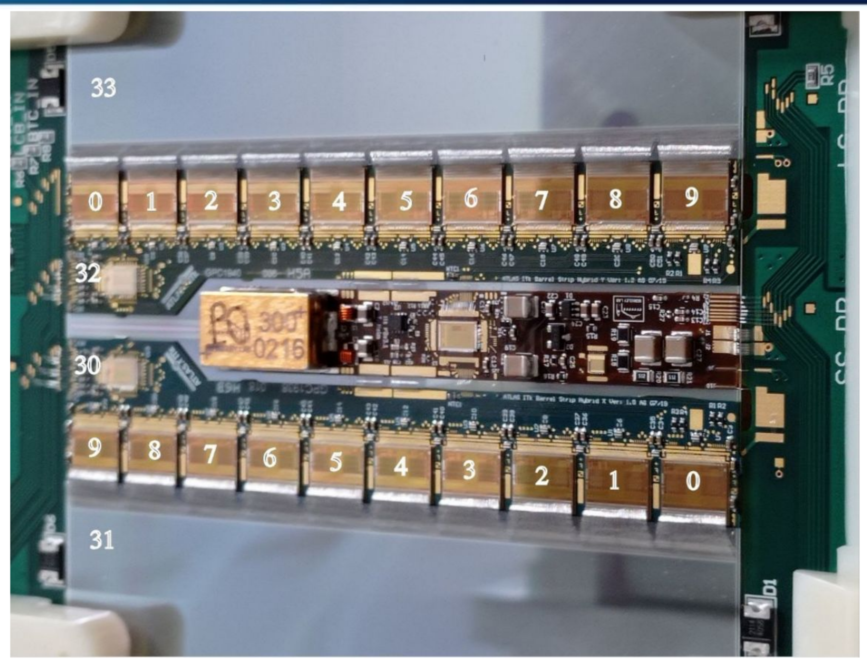
To cope with the occupancy and radiation doses expected at the High-Luminosity LHC, ATLAS will replace its Inner Detector with an all-silicon Inner Tracker (ITk), containing pixel and strip subsystems. The strip subsystem will be built from modules, consisting of one n+-in-p silicon sensor, one or two PCB hybrids with front-end electronics and one powerboard PCB for low / high voltage and monitoring electronics. The sensors in the central *barrel* region have a rectangular geometry, while the forward *end-cap* region uses a radial geometry with built-in stereo angle.

To validate the expected performance of the ITk strip detector, testbeam campaigns have been performed over several years at the DESY-II testbeam facility - with promising results!

**The ATLAS ITk system:**

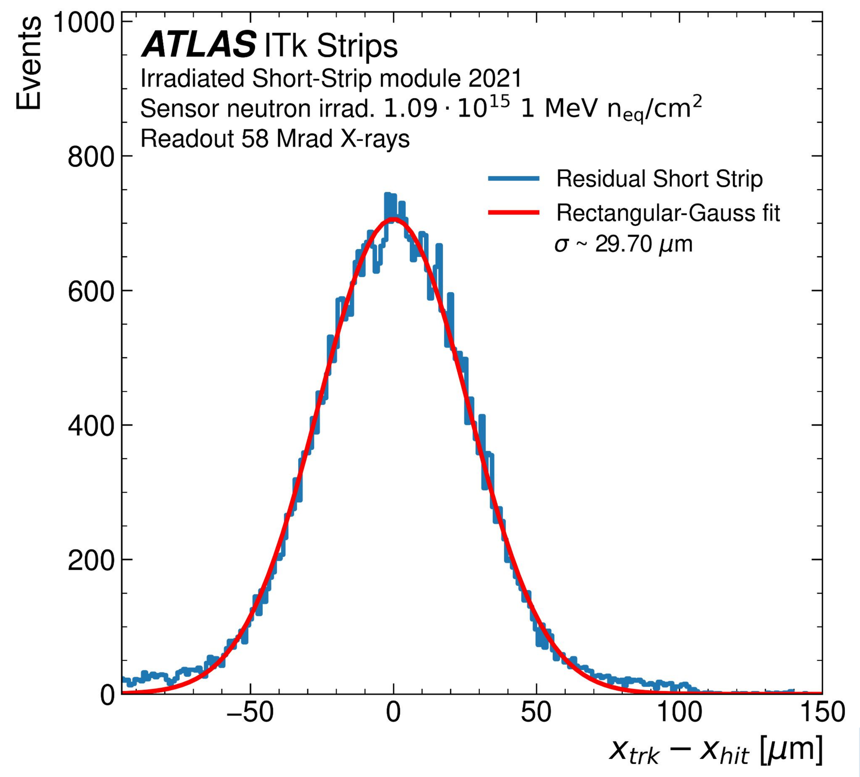
- 1400M channels of si pixel detectors over 12.7 m².
- 59.9M channels of si strip detectors over 165 m²



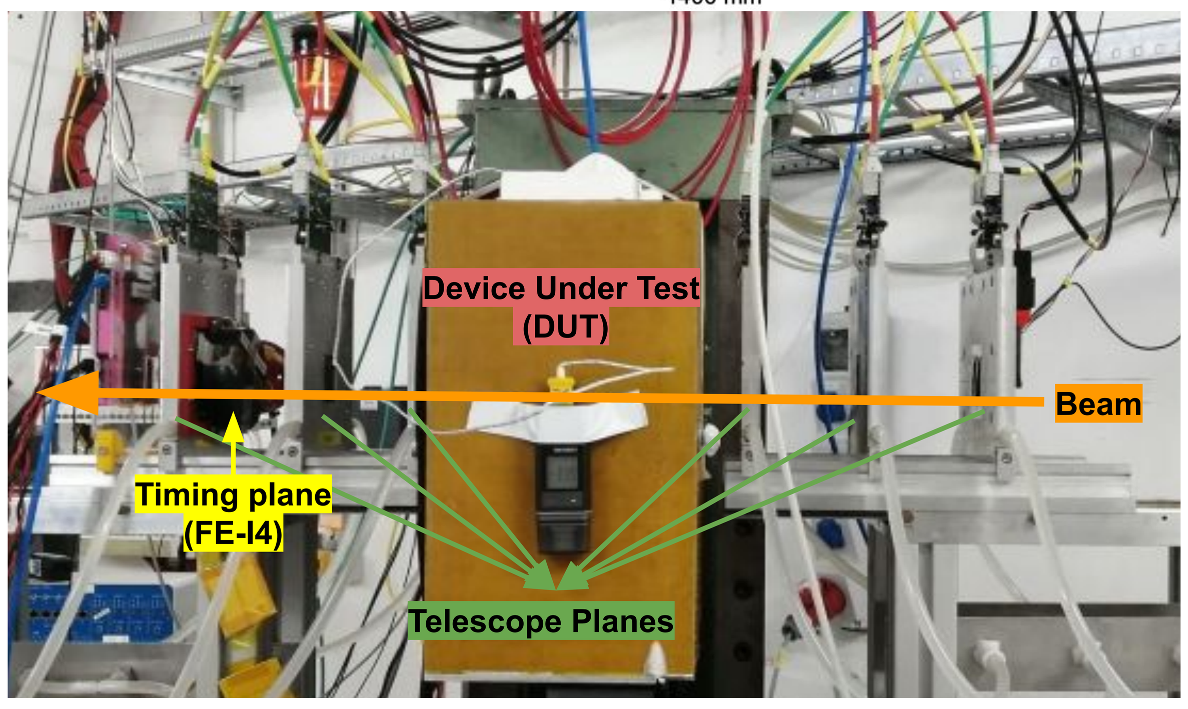
Short Strip (ss) *barrel* module, measured in June & September 2021.

Below is the measured residual distribution for charge threshold 1.0 fC - reconstructed in Corryvreckan.




## ITk Strip Detector

- The central *barrel* sector with four layers of *staves,* holding 10976 rectangular *modules*, having a strip length of 24 mm in the inner two layers (*Short Strip SS)* and 48 mm in the outer two layers (*Long Strip LS)*.
  Both module types have a strip pitch of 75.5 μm, and a stereo angle of 26 mrad implemented through the module position on the *stave.*
- Two *end-cap* sectors, each with six disks composed of *petals*, holding a total of 6912 trapezodial-shaped *modules* of six different geometric flavours (*R0-R5).* The latter 3 are split-module designs with two sensors - see R5 module below. The strips are arranged in a radial fan pattern all pointing towards the same origin, which is offset from beamspot with a built-in stereo angle of 20 mrad.
  The strip length and angular pitch vary across module types, from 15-60 mm in length and 86-194 μrad in pitch.




## Purpose of Testbeams

Demonstrating ATLAS ITk strip module performance in close-to-real conditions through testing with beams of different particle types.

In 2021-2022, focus of testbeam campaigns on assessing the end-of-life performance for both *barrel* and *end-cap* type modules.

Requires irradiating final production versions of sensors and front-end electronics to maximum expected fluence times 1.5 safety factor.

Measurements were performed of the charge collection, detection efficiency, noise occupancy and tracking performance in various sensor regions.

## Testbeam Setup

The DESY II synchrotron at DESY Hamburg (DE) delivers a tunable 1-6 GeV electron beam [2].

The EUDET-type telescope used for reference tracking consists of:

- Six *Mimosa26* silicon pixel planes, active area of 1x2 cm², spatial resolution ~ 5 μm and 115 μs time resolution.
- A *FE-I4 timing plane*, operating with the same 25 ns integration time as the DUT.

The *Device Under Test (DUT)* is placed in the center of the telescope in a -40 C cooling box.

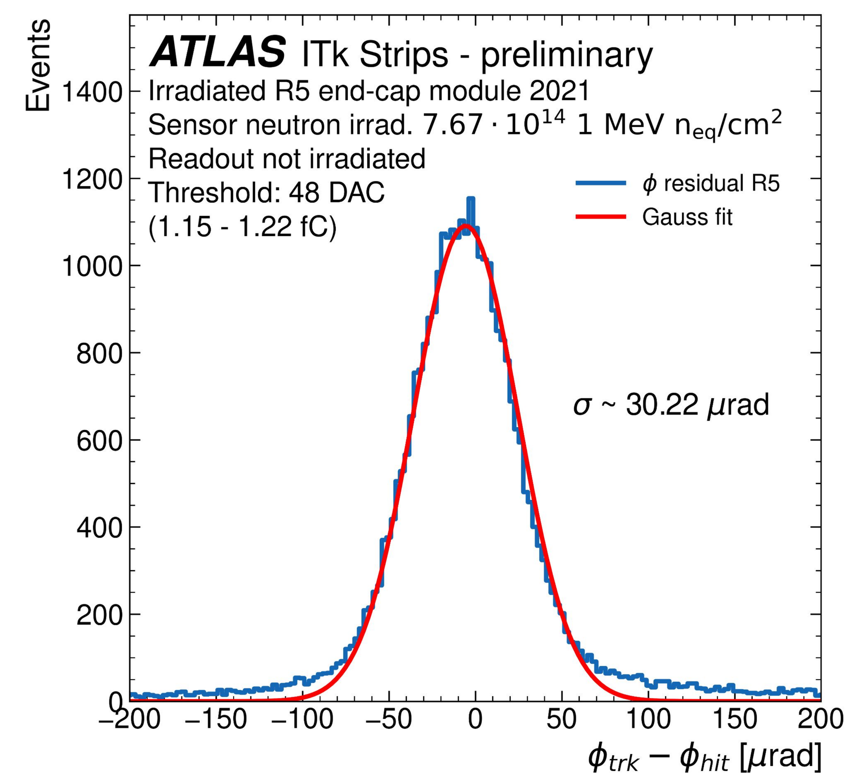
Track reconstruction via General Broken Lines algorithm, within the EUTelescope [3] and/or Corryvreckan [4] framework.


The first *end-cap* split-module (R5 type) was tested in December 2021.
Sensors were irradiated with neutrons at JSI Ljubljana, to $7.67 \cdot 10^{14}$ 1-MeV $n_{eq}/cm^2$.
Front-end electronics were not irradiated.

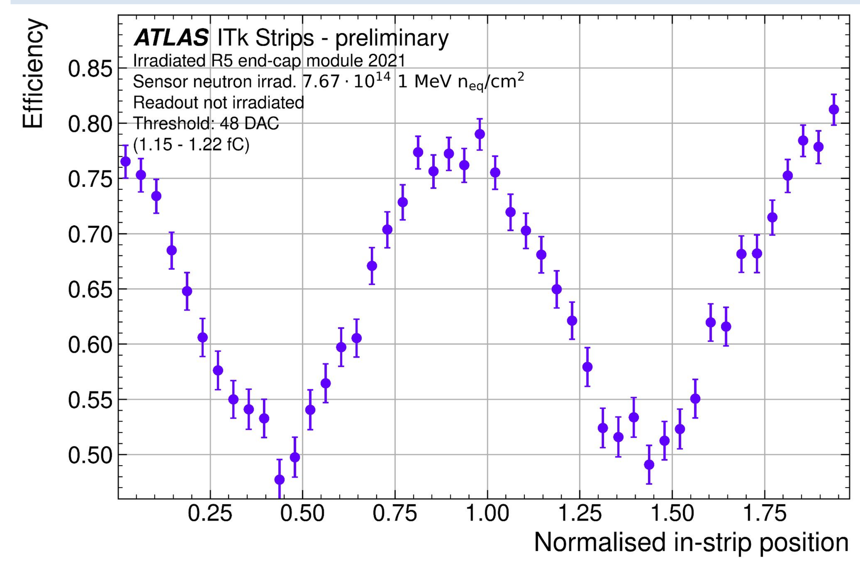
## Corryvreckan

We are moving towards Corryvreckan as our main data reconstruction framework.

Recently, significant efforts spent on fully integrating the polar geometry for radial strip modules.
The effort is nearing completion, with reconstruction running significantly quicker, both in setup and computing time, compared to the EUTelescope software.




Angular resolution for the R5 module displayed above.
Detection efficiency dependence on the normalised in-strip position shown below - showcasing the impact of charge sharing and sub-pitch reconstruction accuracy.




## The Hunt For An Operational Window

The charge threshold setting is constrained by design criteria, ensuring sufficient lifetime tracking performance of the ITk modules:

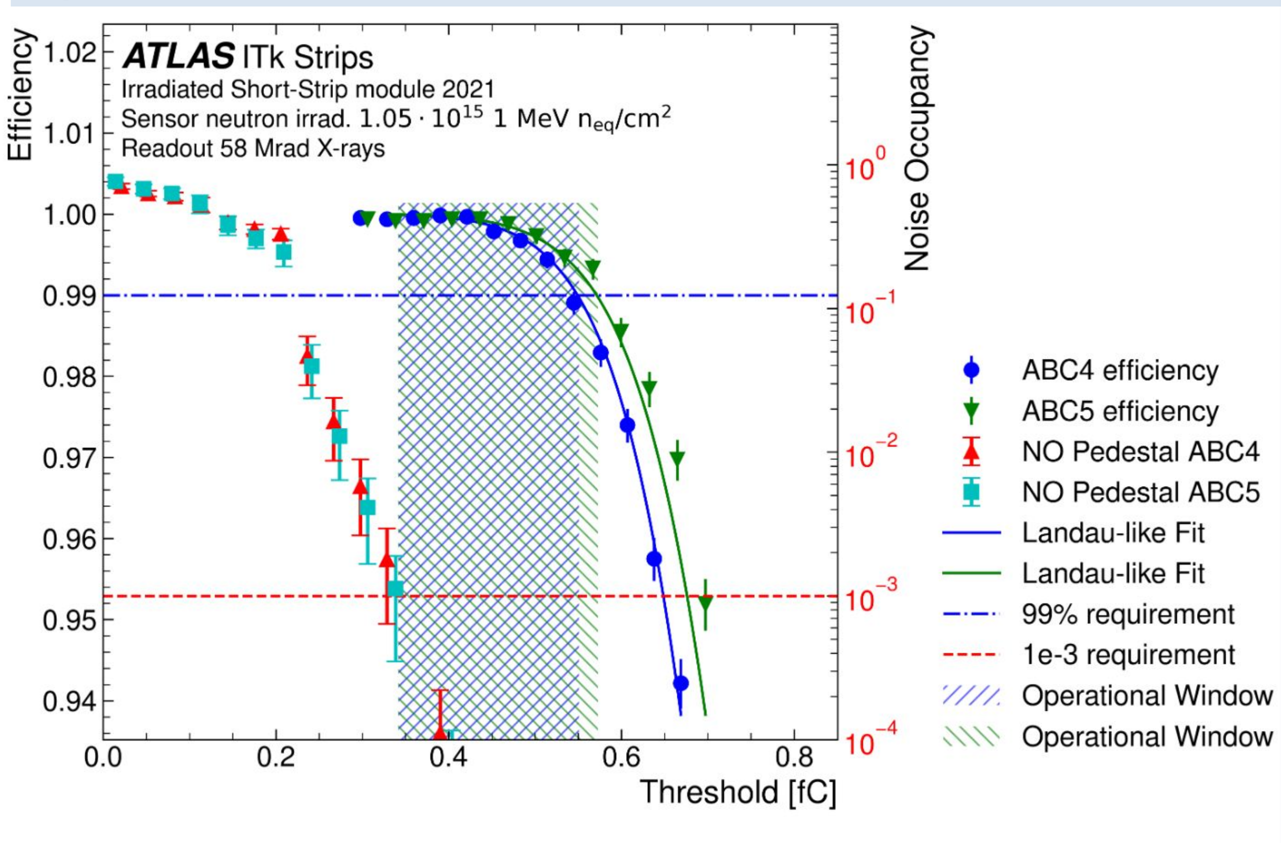
1. Detection efficiency > 99 %
2. Noise occupancy < 0.1 %

These criteria place opposing constraints on the charge threshold of the front-end ATLAS Binary Chip (ABC) ASICs. The chip operates as a binary hit/no-hit integrator, with a tunable charge threshold - To limit bandwidth.

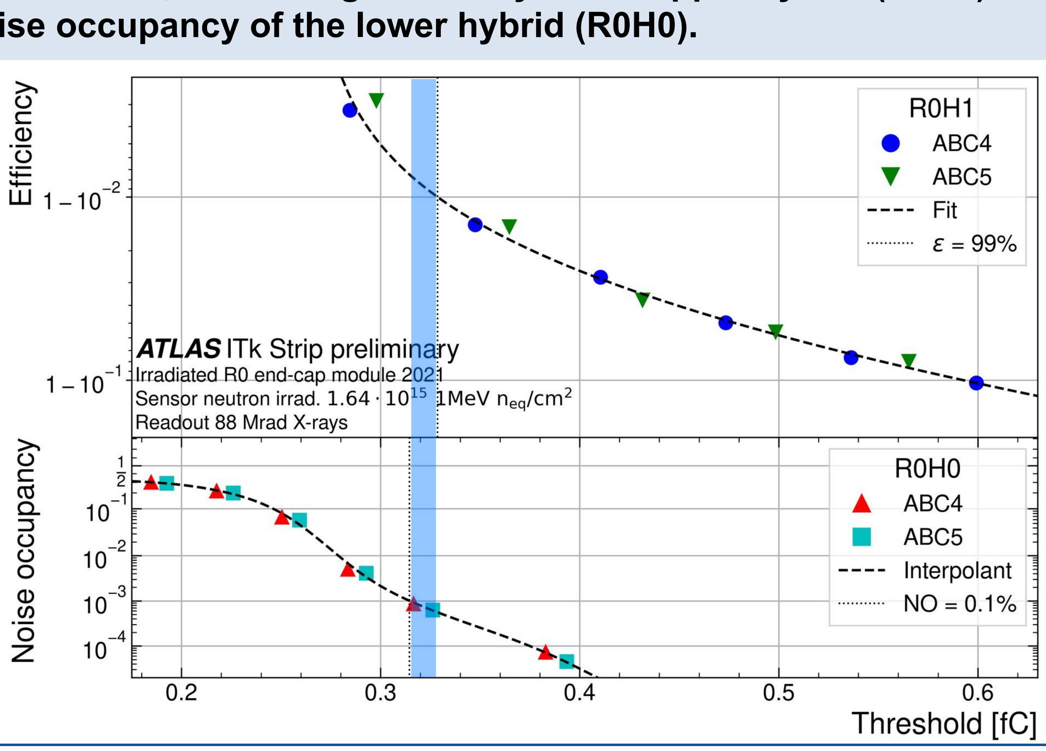
A high threshold results in a low noise occupancy, but also reduces the detection efficiency - tracks may be missed e.g. due to low charge deposition or significant charge sharing across multiple strips.

Demonstrating the existence of an *operational window* - a range of charge thresholds over which both criteria are satisfied, is therefore a primary goal of our testbeam campaigns.

Good operational window of a SS module, threshold range 0.33-0.55 fC, is shown below. Signal over noise (S/N) ratio was 16.9, above the min. required value of 10.
Receiving the highest dose, The SS and R0 modules have the lowest expected S/N ratio.




For the *end-cap* modules, demonstrating sufficient end-of-life performance is an ongoing investigation.
Best results obtained so far, see below, is a 0.09 fC operational window for a R0 module, combining efficiency of the upper hybrid (R0H1) with the noise occupancy of the lower hybrid (R0H0).




## Calculating Detection Efficiency

Reconstruction of the testbeam data is done in a four step process:

1. Resynchronising DUT and telescope data streams.
2. Masking of noisy channels.
3. Alignment of the beam telescope and construction of tracks.
4. Alignment of DUT and search for associable hits to the telescope track fit - which is based on a simple distance-to-nearest-cluster cut.

The efficiency is then calculated as

$$\epsilon = \frac{\mathrm{N}^{\mathrm{DUT+FEI4}}_{\mathrm{tracks}}}{\mathrm{N}^{\mathrm{FEI4}}_{\mathrm{tracks}}}$$


**References and Acknowledgements**

[1] The ATLAS Collaboration. Technical Design Report for the ATLAS Inner Tracker Strip Detector. 2017. CERN-LHCC-2017-005, ATLAS-TDR-025.

[2] R. Diener et al., Nucl. Instrum. Methods Phys. Res. A 922, 265 (2019). https://doi.org/10.1016/j.nima.2018.11.133

[3] T. Bisanz *et al* 2020 *JINST* 15 P09020

[4] D. Dannheim et al., Corryvreckan: A 4D Track Reconstruction and Analysis Software for Test Beam Data (November 2020) 2021 JINST 16 P03008, arXiv:2011.12730



*"The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)".*



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