BTTB Beam Telescopes & Test Beams

Material measurement of an ATLAS ITk pixel module via multiple scattering at the CERN PS T9 beamline

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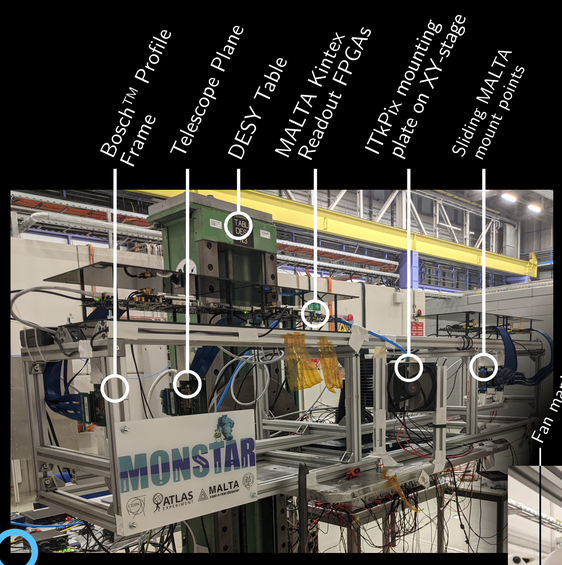
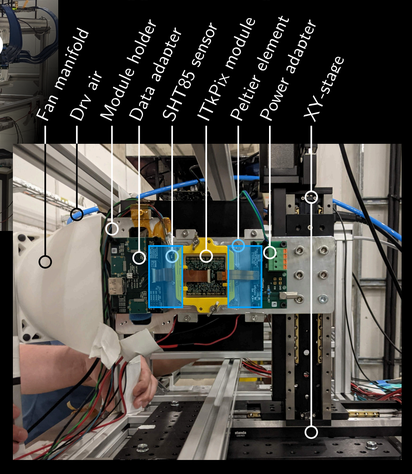
ATLAS PUBLIC PLOTS ITK-2023-002



- 2 m-long four-plane MALTA telescope
- Central *xy*-stage for a single DUT
- Adjustable telescope plane spacing
- Trigger coincidence from all four planes via MALTA trigger logic unit



The MONSTAR Telescope

- Custom holder and cooling for the ITkPix module
- Optical data readout via FELIX
- Events synchronised by trigger counting

Motivation - material

- Detector material budget has a large impact on physics performance for future HL-LHC detectors
- Material best **minimised during the design phase**
- **Accurate material models** are vital for Monte-Carlo simulations used in analyses
- These are usually **only validated post-commissioning** using calibration data
- Inspired by previous testbeam multiple scattering measurements at DESY, Göttingen, ETH Zurich

Multiple scattering

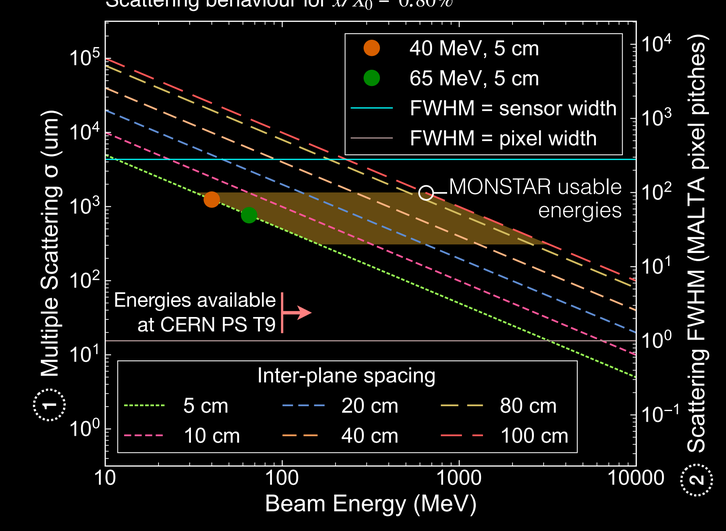
RMS of angle distribution

$$\theta_{\text{plane}}^{\text{rms}} = \frac{13.6\,\text{MeV}}{\beta c p} z \sqrt{x/X_0}\left(1 + 0.038 \ln(x/X_0)\right)$$ [2]

Fractional radiation length

Beam momentum × speed

- Dominates at **low momentum**
- Direct relation between scattering observables and x/X_0
- Leptonic beams preferable to reduce nuclear scattering

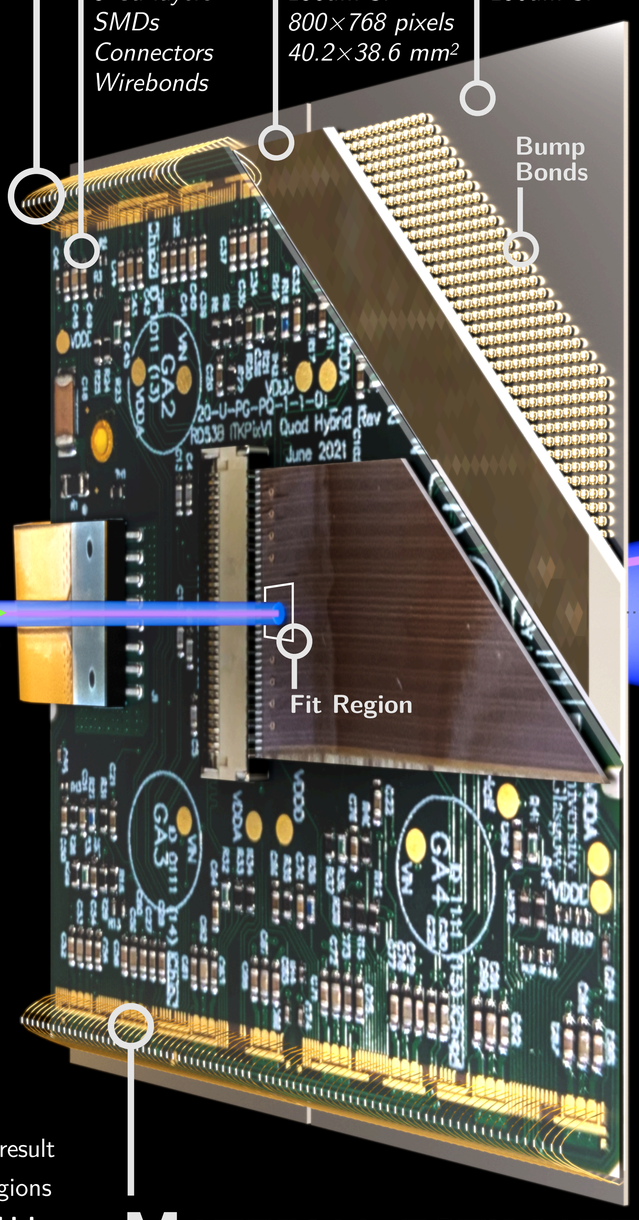


ITkPix Quad Module

Flex PCB v2.4: *3 Cu layers, SMDs, Connectors, Wirebonds*

Sensor: *150um Si, 800×768 pixels, 40.2×38.6 mm²*

4× ITkPix v1.1: *150um Si*



CERN PS T9

1.2 GeV/700 MeV e⁺
5% momentum band
~6k e⁺/spill
3 spills/40 s supercycle
Beam spot >1 cm²

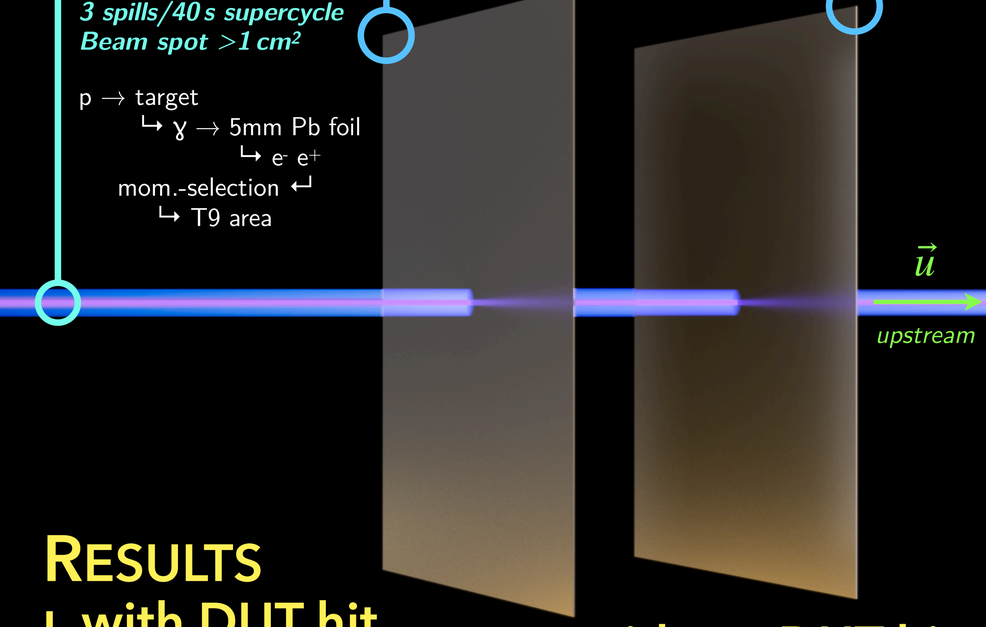
p → target
↳ γ → 5mm Pb foil
↳ e⁻ e⁺
mom.-selection
↳ T9 area

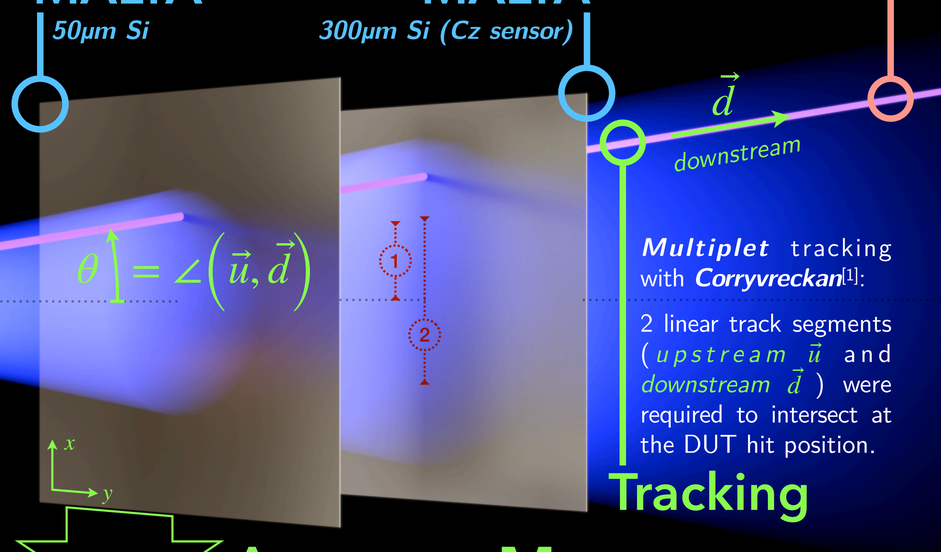
MALTA

300µm Si (Cz sensor)
Monolithic (DMAPS)
512×512 pixels
18.6×18.6 mm²

MALTA

50µm Si



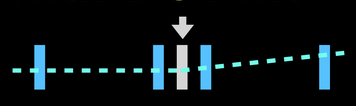


Multiplet tracking with **Corryvreckan**[1]:

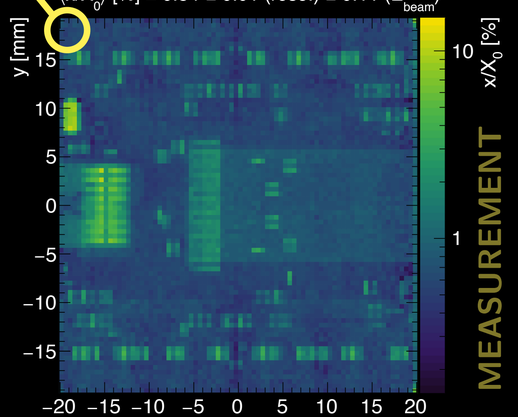
2 linear track segments (*upstream* $\vec{u}$ and *downstream* $\vec{d}$) were required to intersect at the DUT hit position.

Tracking

Results with DUT hit

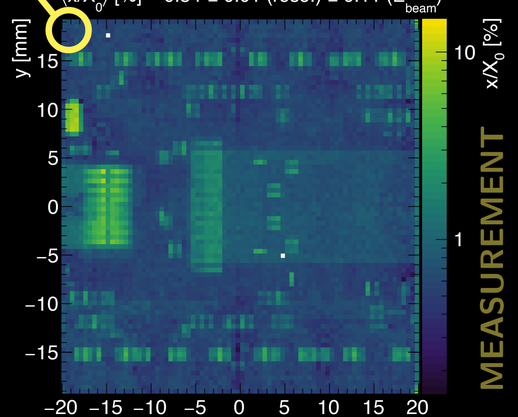


- **Sub-mm resolution, 14% relative uncertainty**
- ~2-3% stat. unc. in each region
- Connectors & HV filter capacitor are largest localised contributors
- Main limitations on precision were beam momentum band and rate

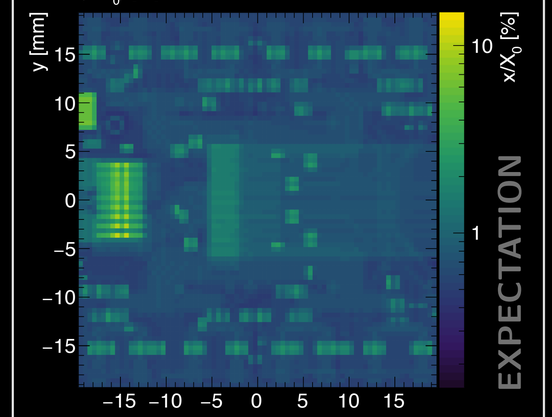


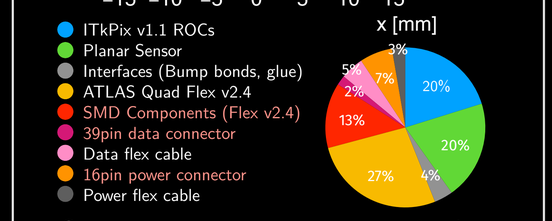
without DUT hit

- Alternative analysis
- Equivalent performance to main result
- Reduced fit stability in some regions
- Indicates this methodology **should be suitable also for static subjects** such as **detector mechanics**



Material estimate from specifications

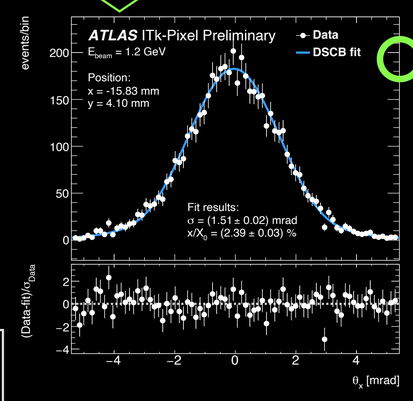




- Some components very **uncertain** due to lack of data or missing reference X_0
- Difficult to estimate uncertainty on this

Analysis Methodology

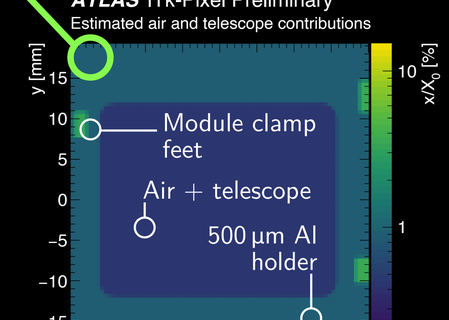
Angle distributions



- Angles projected onto *xz*- and *yz*-planes
- Separated into 0.5×0.5 mm² regions on DUT
- Fit to double-sided Crystal Ball functions to account for non-gaussian tails

Subtractions and calibration

- Scattering from mechanics estimated
  - metrology of the aluminium holder
  - dissection of the clamp
- Air + telescope calibration value from measurement of MALTA 50 µm DUT
- These contributions were subtracted to obtain the final result



- Imaged in 1×1 cm² regions
- Acceptance estimated per-track from fraction of all possible tracks with the same upstream vector and opening angle that miss a downstream plane

Telescope acceptance > 98%

Outlook and future measurement

- Paper in progress - working on simple scattering-only simulations, comparison of datasets from different telescope configurations
- Follow-up measurement in collaboration with the ETH Zurich CMS group in Oct. at PSI PiM1 to measure modules and support structures

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[1] *D. Dannheim, et. al. JINST 16 (2021) P03008.*
[2] *R.L. Workman et al. (Particle Data Group), PTEP 2022, 083C01*

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MALTA #not-a-real-detector

University of Oxford