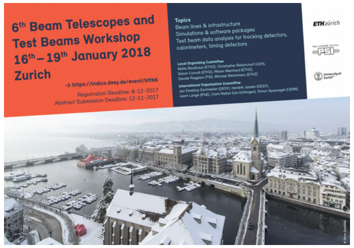
Radiation length measurements for the ATLAS ITk Strip Detector.

Jan-Hendrik Arling, Claire David, Michaela Queitsch-Maitland

6th Beam Telescopes and Test Beams Workshop



17th January 2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

ATLAS EXPERIMENT

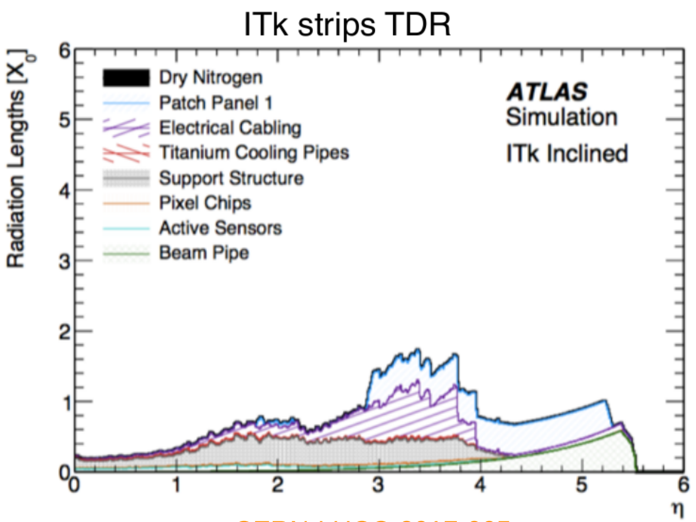
DESY TEST BEAM.

DESY

X0 Measurements: Introduction.

Why Radiation Length Measurements?

- Design goal for tracking detectors:
  - **Minimize material budget** (x/X0), e.g. from sensors, support structures and services.



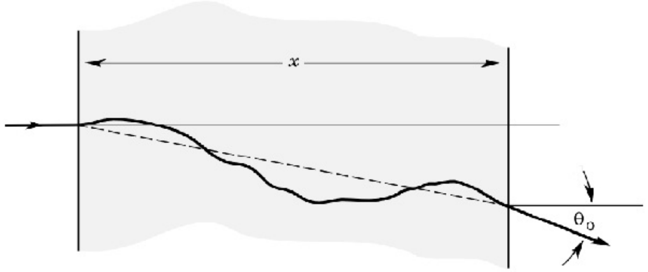
CERN-LHCC-2017-005

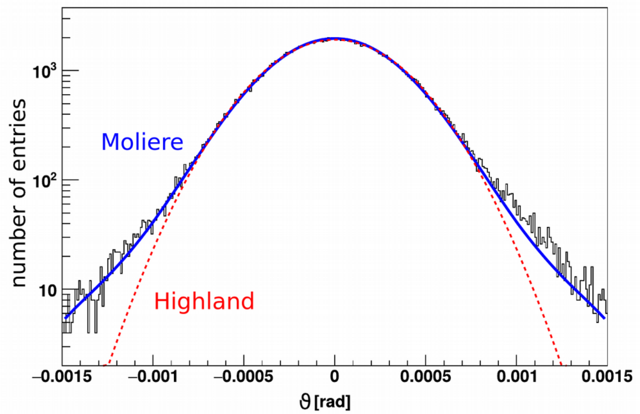
- Detector simulations are based on calculations of the radiation length with material properties.
  - Can one improve radiation length estimates for unknown materials/complex structures with **direct measurements**?
- First results also presented last year by L. Poley:

  "Radiation length measurements with the DURANTA beam telescope" BTTB5-Poley

Multiple Scattering & Material Budget.

- High-energy particles undergo **multiple Coulomb scattering** when traversing any material
  - Particle is **deflected** depending on material budget (x/X0)





- **Scattering angle** distribution with Gaussian-like center and tails for larger angles

https://doi.org/10.1016/j.nima.2016.06.086

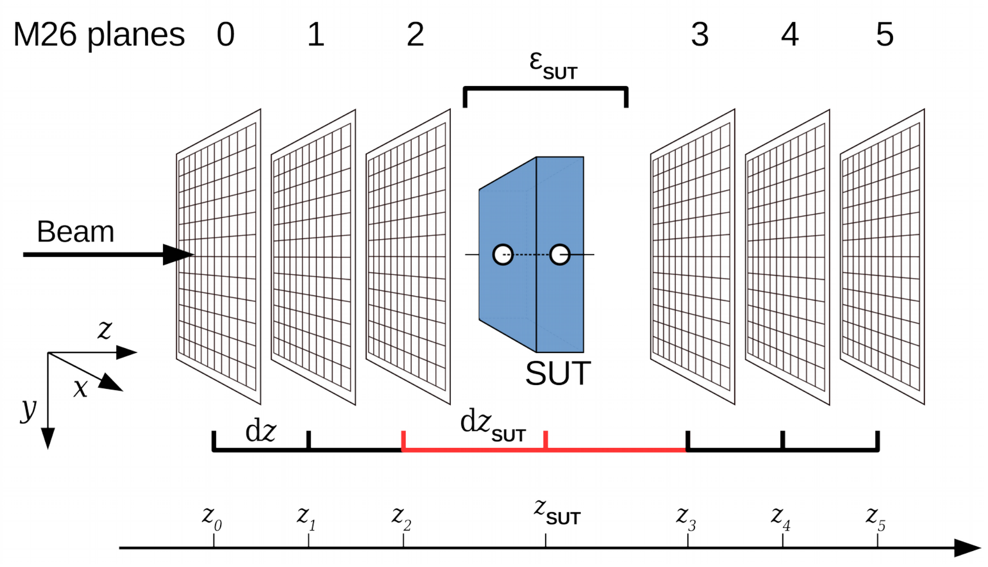
- Prediction of the width by the **Highland formula**:

$$\theta_{x,y} = \frac{13.6\,\mathrm{MeV}}{\beta c p}\sqrt{\frac{x}{X_0}}\left(1 + 0.038\ln\left(\frac{x}{X_0}\right)\right)$$

  - Relation of amount of scattering (θ) of particle beam in material to material's radiation length (X0) and thickness (x) and the beam momentum (p)

Material Budget Imaging.

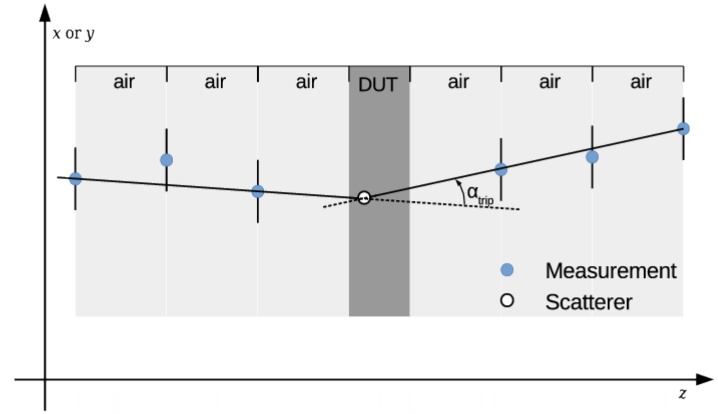
- **Goal**: Position-resolved measurement of material budget by measuring the scattering angle.
  - Use excellent resolution of **EUDET-type beam telescope** consisting of six Mimosa26 sensor planes.
- Measurement work flow:
  - Insert **material as SUT** (Scatterer Under Test) in between the telescope arms.
  - Illuminate sample with a **charged particle beam**.
  - Measure **hits** in the telescope sensor planes.
  - Reconstruct the **particle trajectories**.
  - Calculate the **kink angle distribution**.



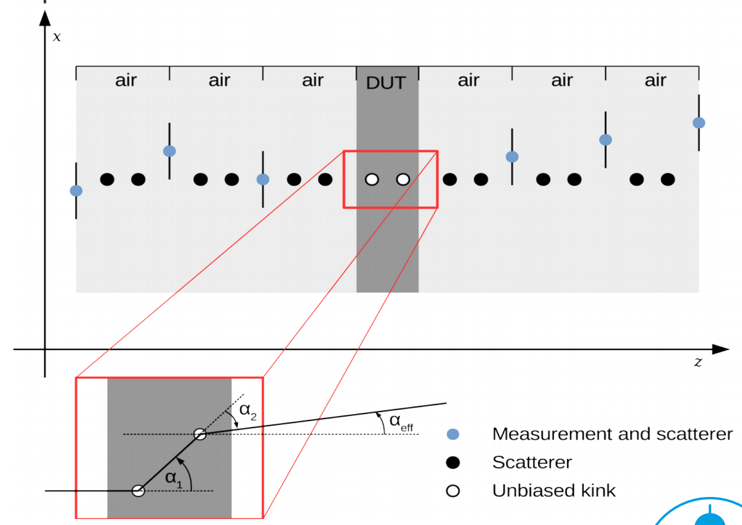
https://doi.org/10.1140/epjti/s40485-016-0033-2

Material Budget Imaging.

- Track reconstruction using **EUTelescope** with General Broken Lines (**GBL**) for track fitting.
- **Track matching** with triplet method:
  - Matching hits in up/downstream telescope planes form **triplets**
  - Matching upstream and downstream triplets form **track candidates**
  - Kink angle at the sample is difference of up- and downstream slopes



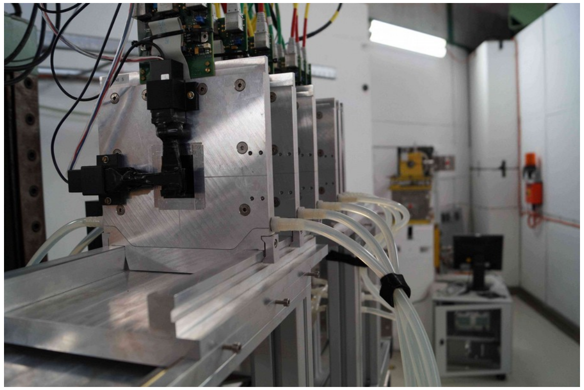
- **Track fitting** with GBL:
  - Optimize particle trajectory
  - Allows for scattering inside material volumes
  - Kink angle at the sample is defined as **local, unbiased parameter** in track model

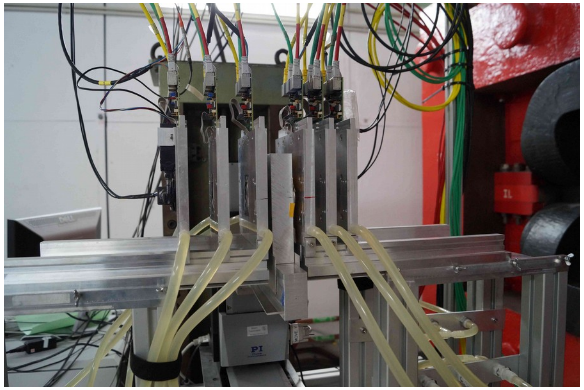


X0 Measurements: Results.

DESYII Testbeam: February 2017.

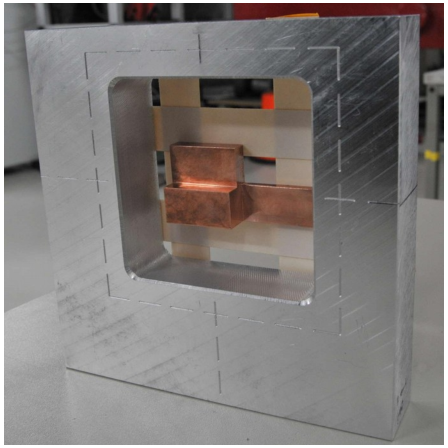
- Testbeam in February 2017 at **DESY** with the EUDET-type telescopes **DATURA** (TB21) and **DURANTA** (TB22).
- Measurements at **different beam energies** (1-5 GeV).
  - Nominal beam energy 2.4 GeV (high rate/energy)
- Telescope setup is compromise between **spatial** and **angular resolution**.
- Collected millions of events (**high statistics**) for different samples :
  - Homogeneous samples with known X0 for **calibration**
  - Complex structures or samples with **unknown X0**

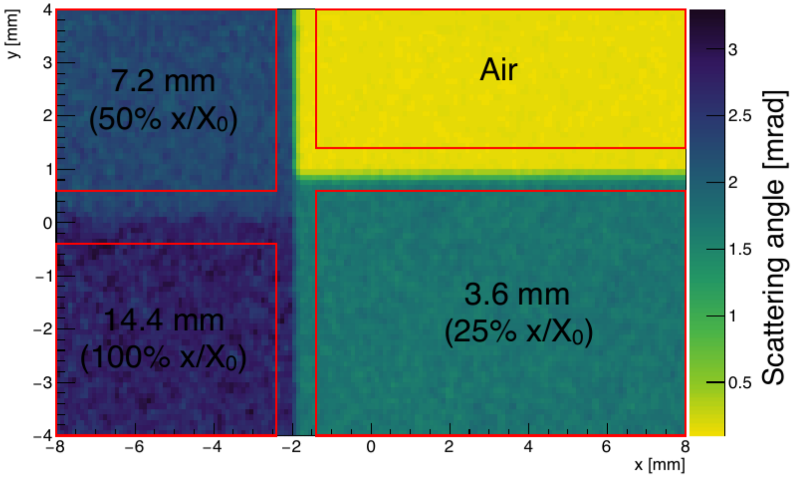




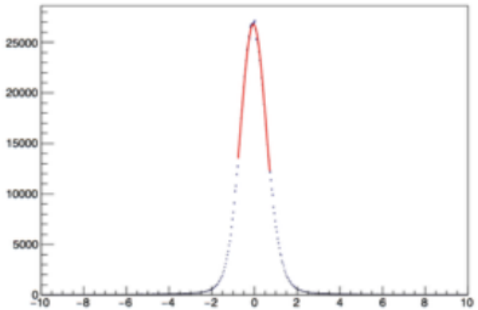
Calibration.

- Calibration targets:
  - **aluminium** sheet (3mm)
  - **copper** targets with different thicknesses (3-100% x/X0)

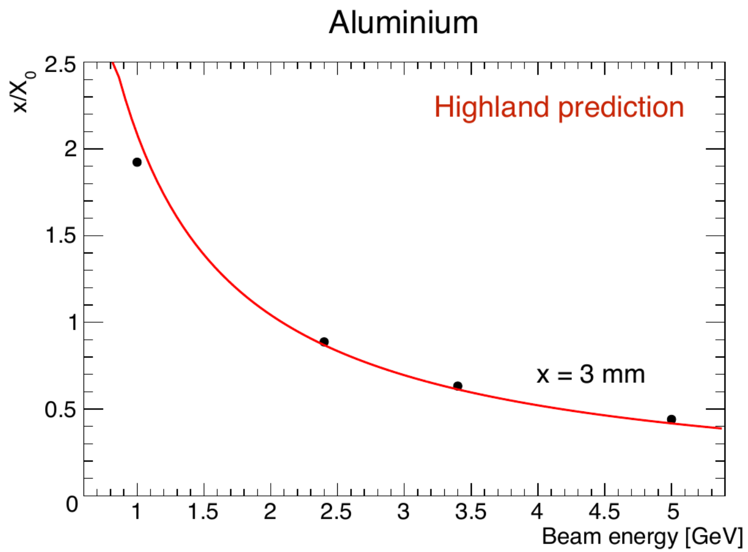


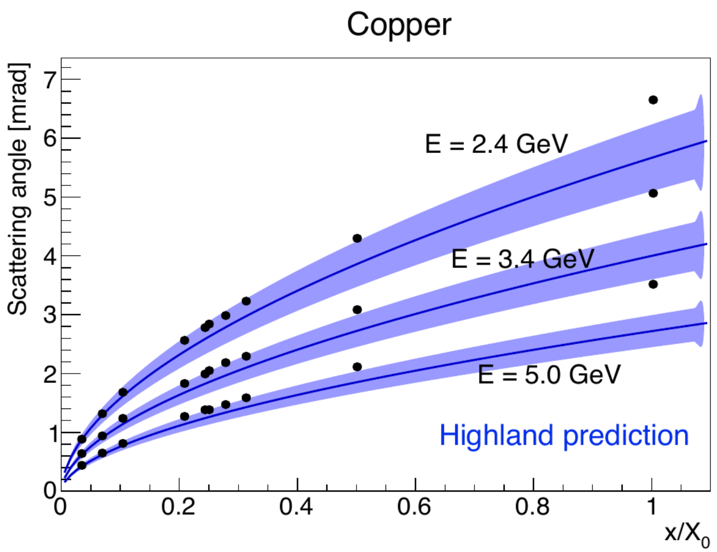


- Fit of kink angle distribution with **Gaussian fit to core** of distribution (±1.5σ)
- Scattering angle with **no SUT** ("air") measurement subtracted from measurements



Calibration.





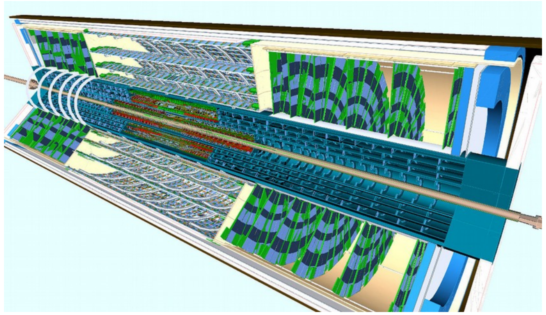
X_0 = 8.5 ± 0.3 cm (PDG 8.897 cm)

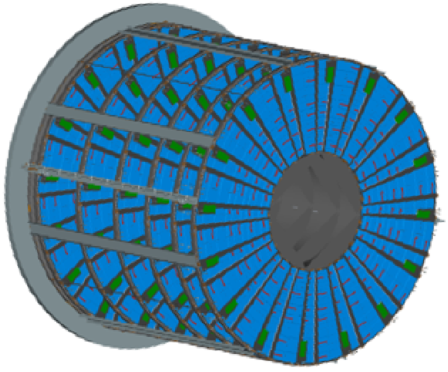
X_0 = 1.4 ± 0.1 cm (PDG 1.436 cm)

- Excellent agreement of measurements with **Highland prediction** within its expected accuracy (PDG ~10%)
- Worse agreement for two regions:
  - Low beam energy (1 GeV) : larger **beam momentum spread**
  - High material budget (x/X0>20%) : **Bremsstrahlung losses** in thick targets

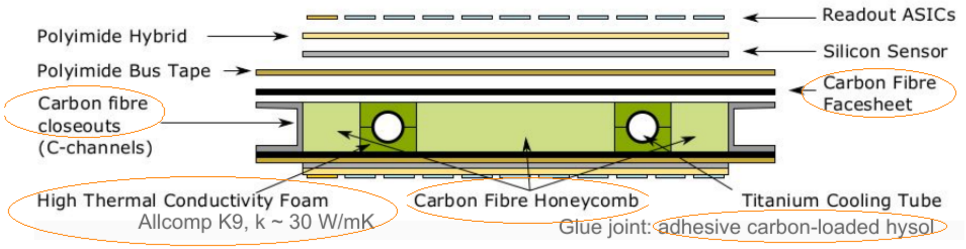
ATLAS ITk strip detector.

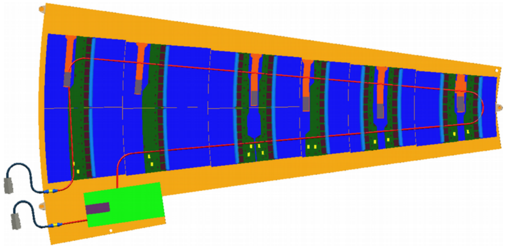
- Replacement of the current ATLAS Inner Detector with the **Inner Tracker (ITk)** for the phase-II upgrade
  - **full-silicon tracker** for the high-luminosity LHC (**HL-LHC**) phase
  - use of **pixel** and **strip** silicon sensors in the **barrel** and the two forward regions, called **end-caps**



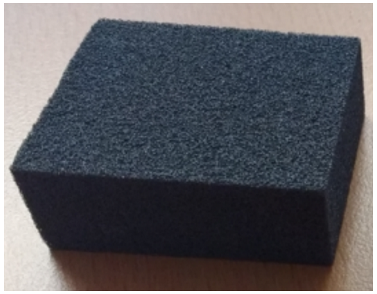


- **Strip end-cap** consists of disk assembled out of wedge-shaped petals
  - **Silicon micro-strip sensor** modules are glued on carbon fiber-based support structures, called **petal cores**

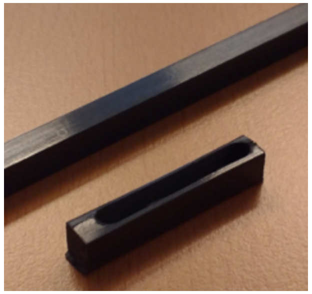




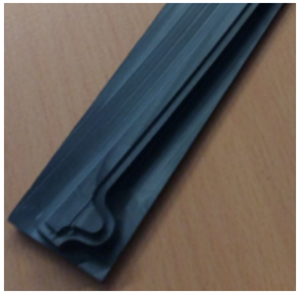
ITk strip petals: homogeneous materials.



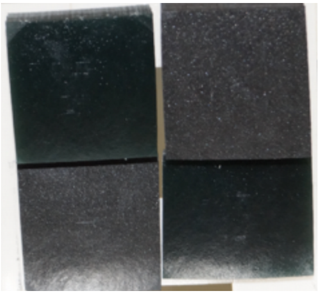
Allcomp CF foam



Pultruded CF



Torlon

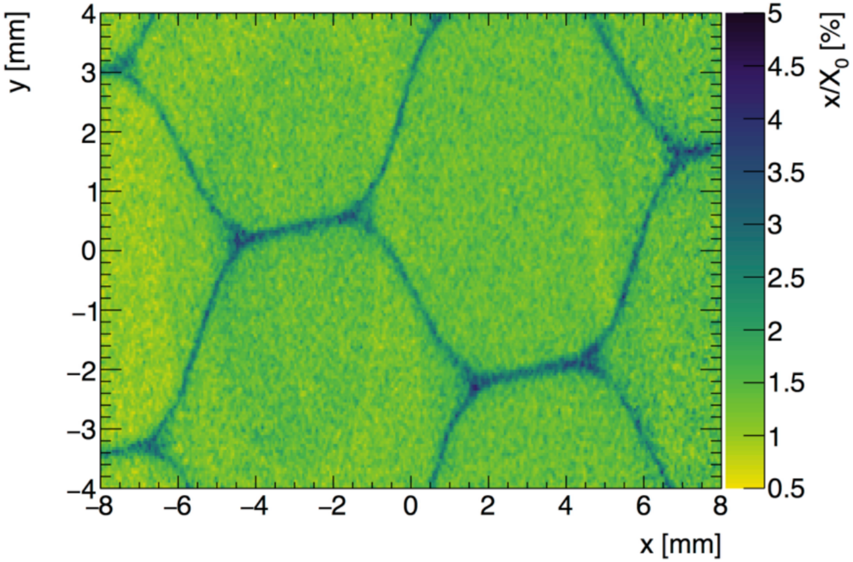


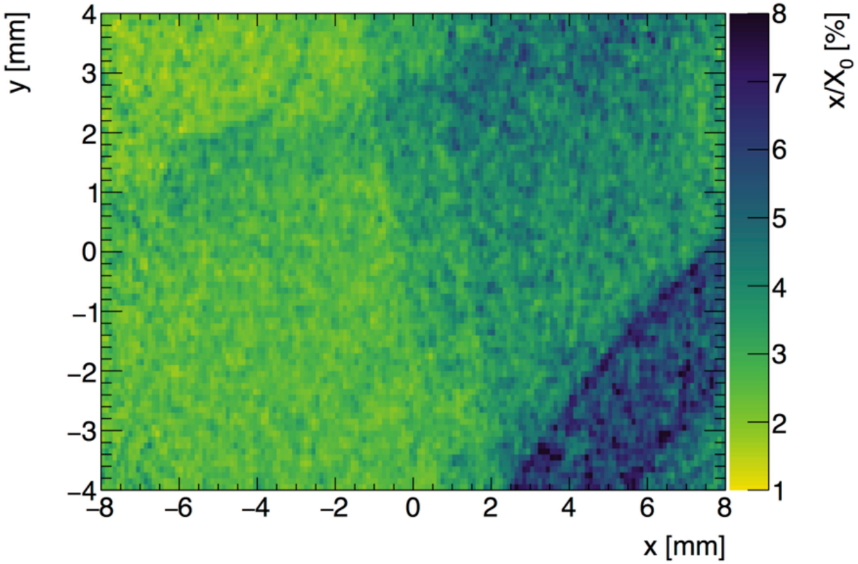
Hysol glue

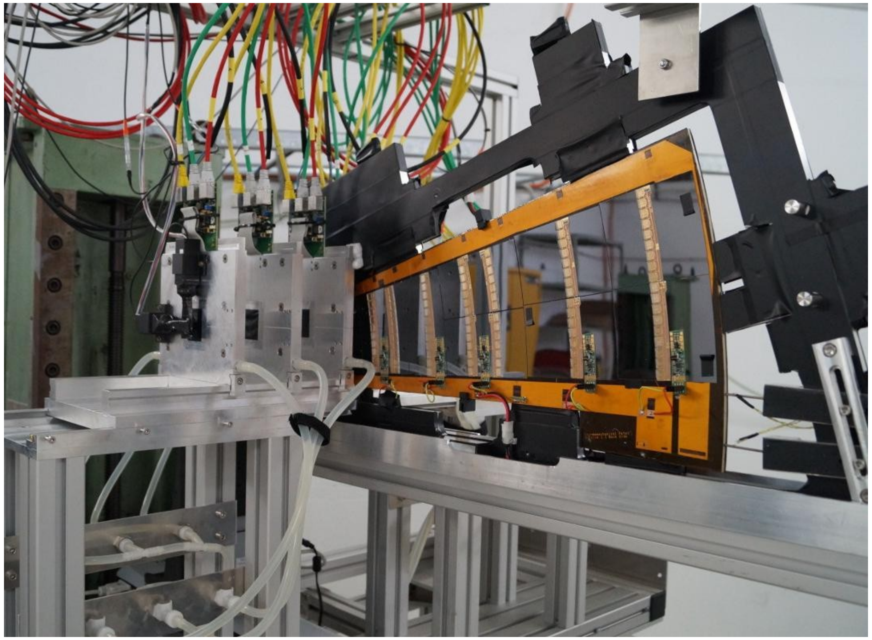
Material	Measured X_0 *	Simulation/PDG X_0
Hysol	32.0 ± 1.3 cm	30 cm
Hysol (carbon-loaded)	31.7 ± 1.3 cm	30 cm
Torlon	21.6 ± 0.4 cm	~32 cm (PEEK)
Pultruded carbon fibre	24.6 ± 0.6 cm	~29 cm
Allcomp foam	155 ± 5 cm	142 - 186 cm

* Uncertainty on target thickness not included

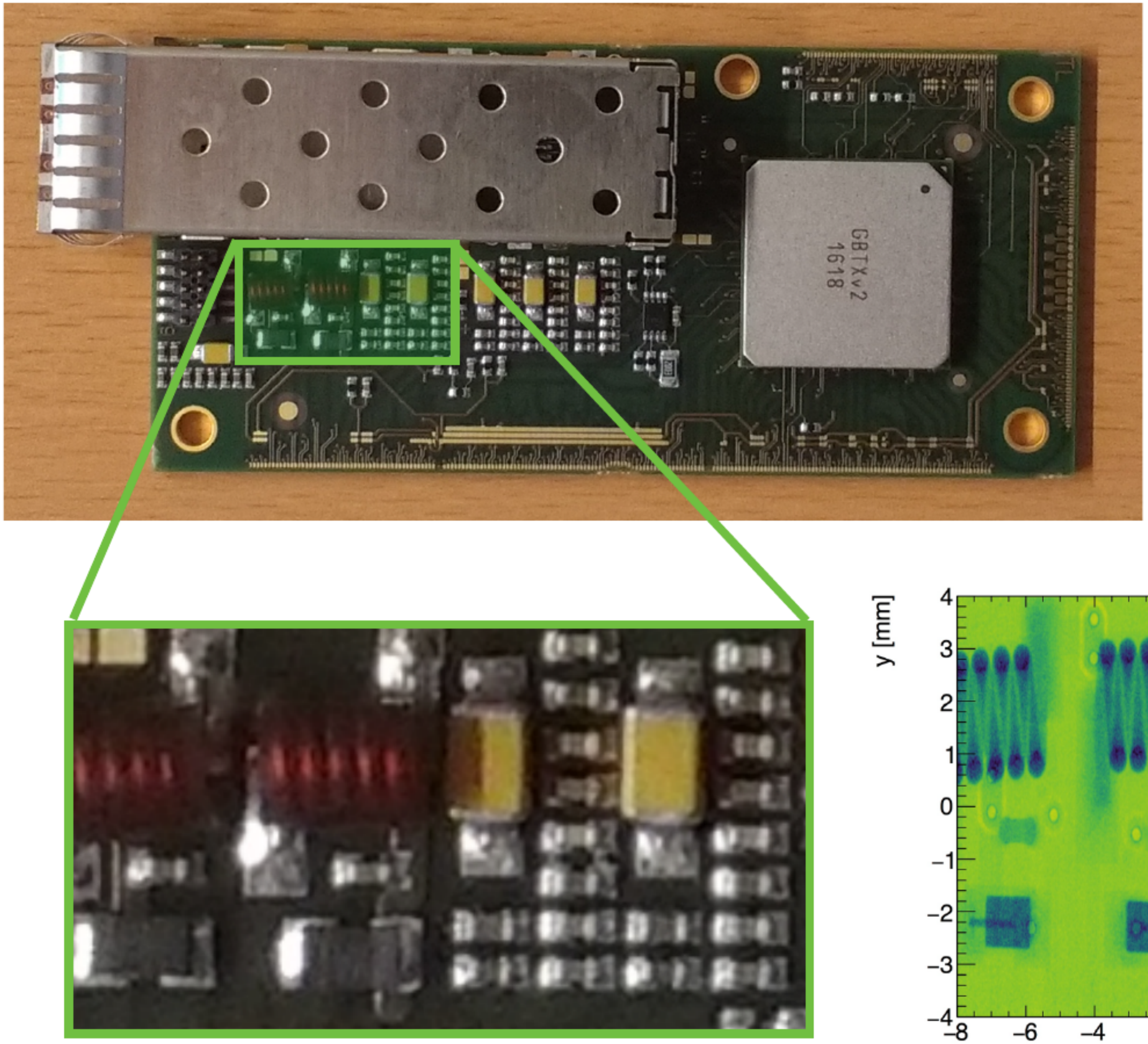
ITk prototype petal: complex structure.

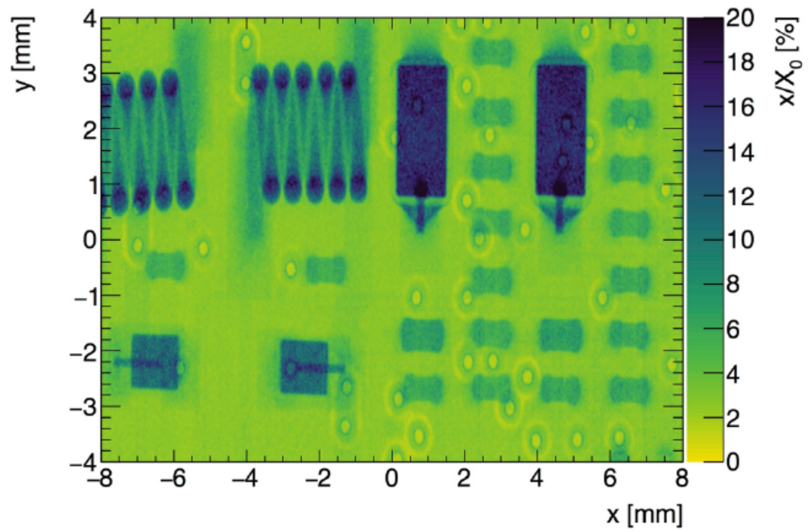






ITk End-of-Petal Card: complex structure.

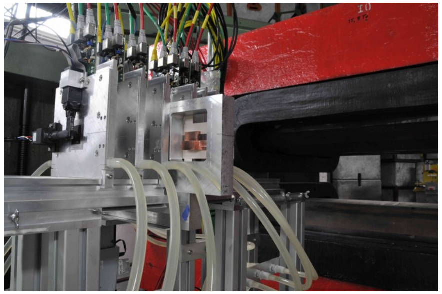
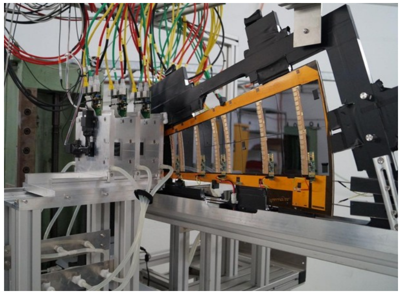
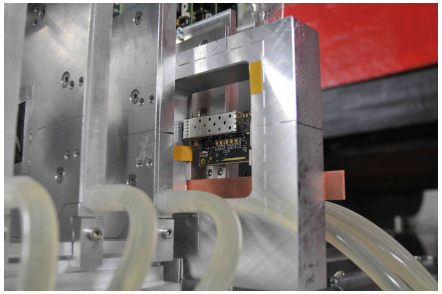




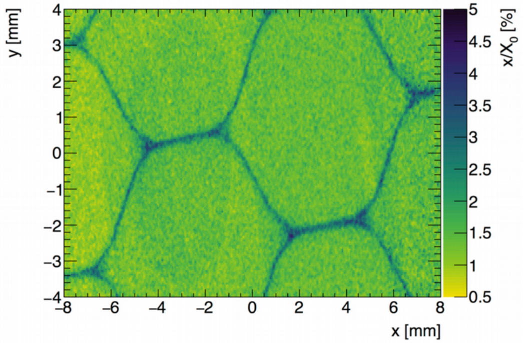
X0 Measurements: Outlook.

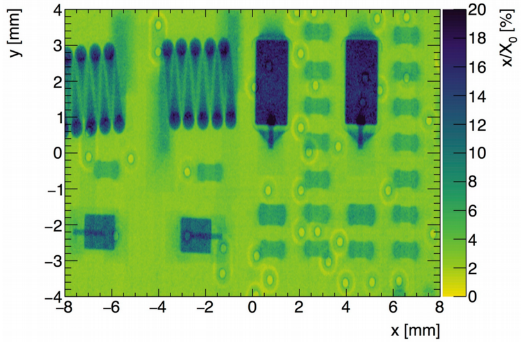
Summary.

- Successful **measurements of material budget** (x/X0) for different materials, either homogeneous or complex.

- Using **excellent performance** of EUDET-type beam telescopes and particle beams at DESY testbeam facility.
- **Good agreement** with theoretical prediction by Highland formula.
- Excellent spatial resolution to **resolve smallest structures** (e.g. honeycomb, electrical vias).





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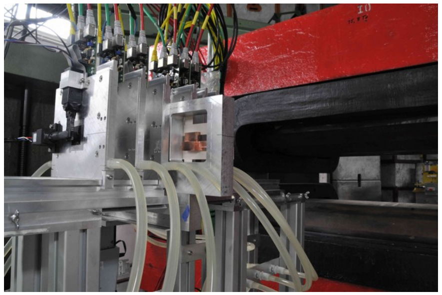
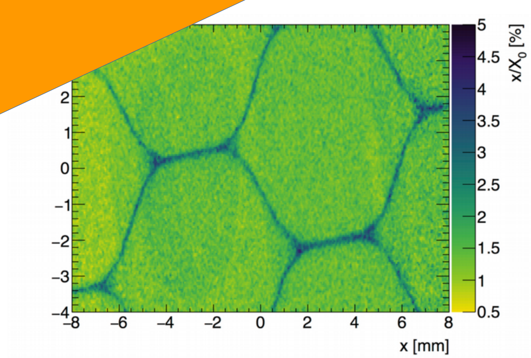
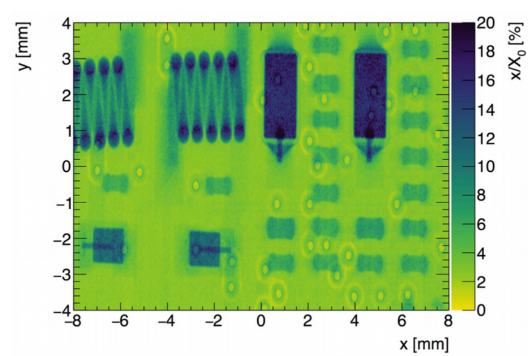


- Using excellent performan … copes and particle beams at DESY testb…
- Good agree… …on by Highland formula.
- E… …esolve smallest structures (e.g. honeycomb, e…

Hands-On: Scattering Images using EUTelescope

(by Michaela)

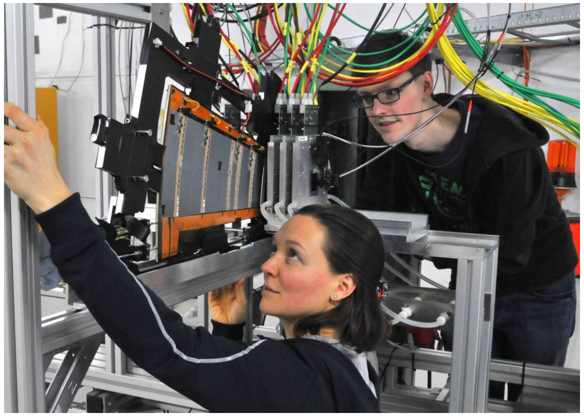




Outlook.

- **Positive response** on radiation length measurements in HEP community.
- Goal is to develop material budget imaging (MBI) as a **tool for testbeam users** at DESY.
  - Advise in setting up and taking X0 data with telescopes.
  - Provide software for analyzing and retrieving the material budget.
- People working on it:

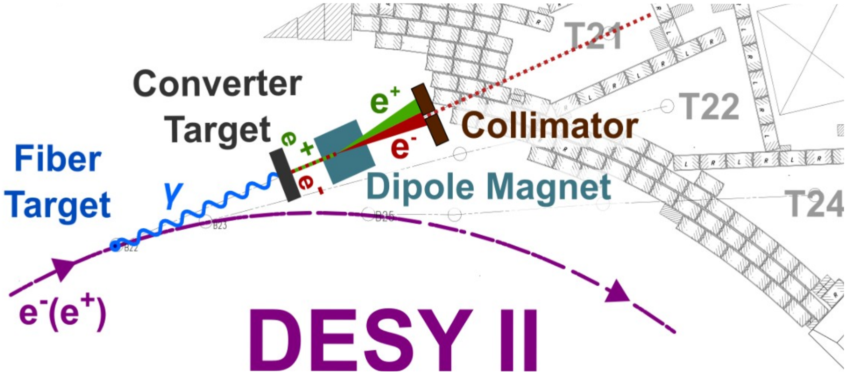
  H. Jansen, P. Schuetze, J, Dreyling-Eschweiler, U. Stolzenberg,
  B. Schwenker, L. Poley, M. Queitsch-Maitland, C. David, J.-H. Arling

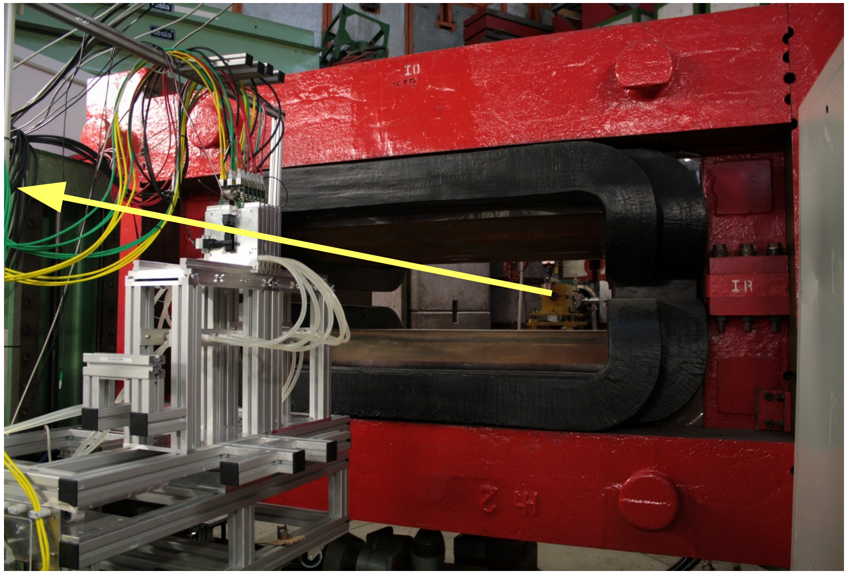


Bonus slides.

DESYII Test Beam Facility.

- Creation of positron or electron beams by conversion of bremsstrahlung photons.
- Energy tunable between 1 and 6 GeV.
- Particle rate up to 50kHz depending on the particle energy.
- Three test beam lines available, two equipped with EUDET-type beam telescopes.

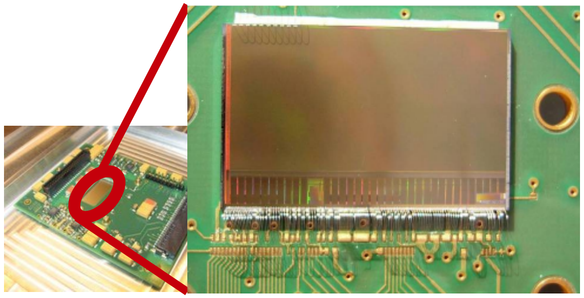




EUDET-type Beam Telescopes.

“Performance of the EUDET-type beam telescopes”, https://doi.org/10.1140/epjti/s40485-016-0033-2

- Six sensor planes: Mimosa 26.
  - Pixel pitch: 18.4 µm x 18.4 µm
  - Active area: 10.6 mm x 21.2 mm
  - Intrinsic sensor resolution: > 3.24 µm
  - Thickness: 50 µm sensor + 50 µm capton foil



- Coincidence trigger by two upstream and two downstream PMTs.

- TDAQ system & infrastructure available.
- Good track resolution (σ > 1.86 µm) due to …
  - Good intrinsic sensor resolution
  - Low material budget to reduce multiple scattering