Radial Strip Detectors for Cosmic Ray Studies

Allpix² + Corryvreckan Studies for the ITk Strips System Test | BTTB 11

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HELMHOLTZ

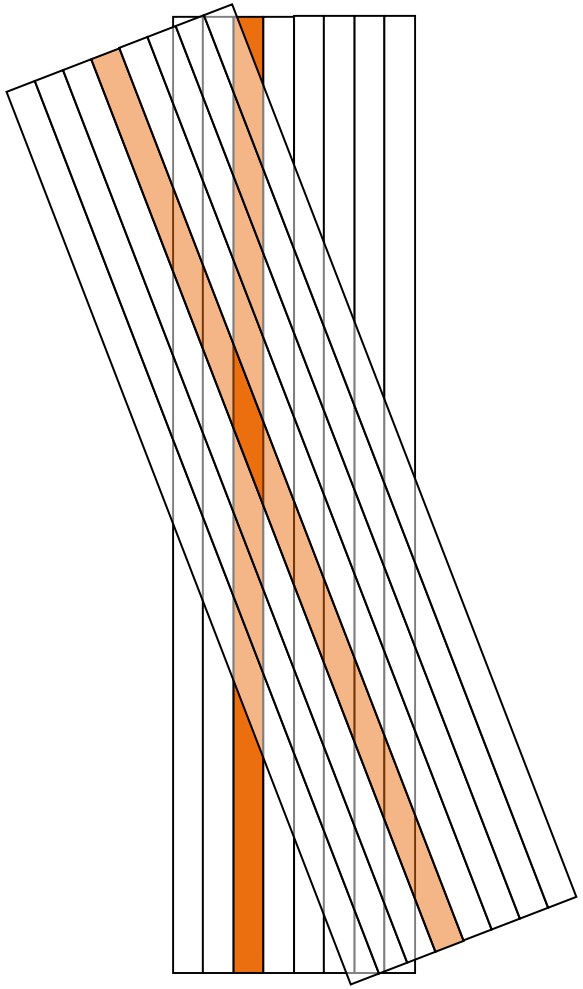
DESY.

ATLAS ITk Strips Modules

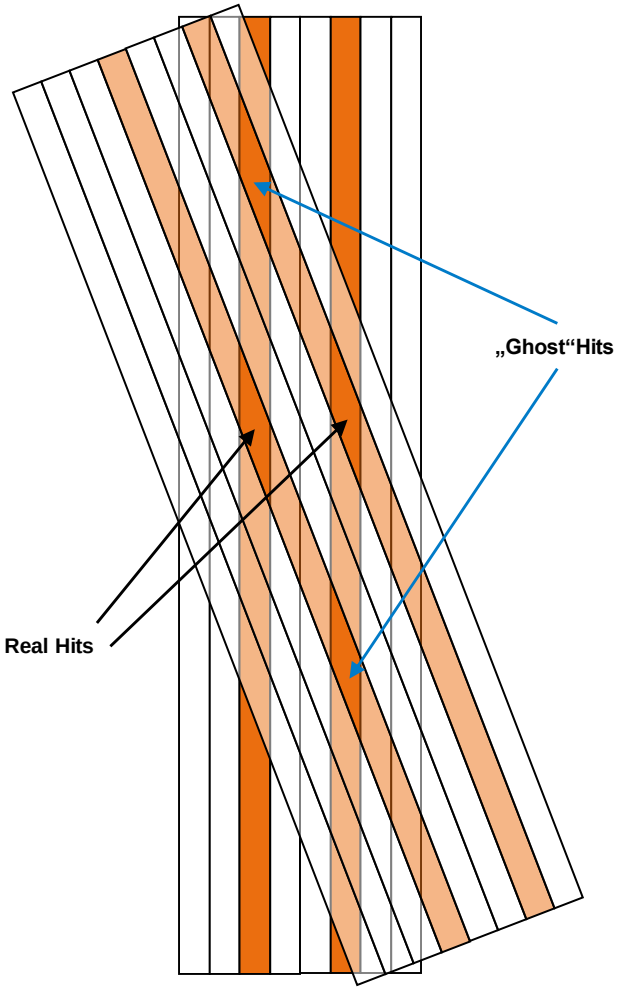
What are Strip Detectors?

Strips

- Strips are basically “very long pixels” (usually several cm)
- n x n Pixel Detector: n^2 readout channels
- Covering the same area with 2 strip detectors: 2n channels
- Stereo angle allows for reconstruction of 2D position, but leaves ambiguity in multi-hit events



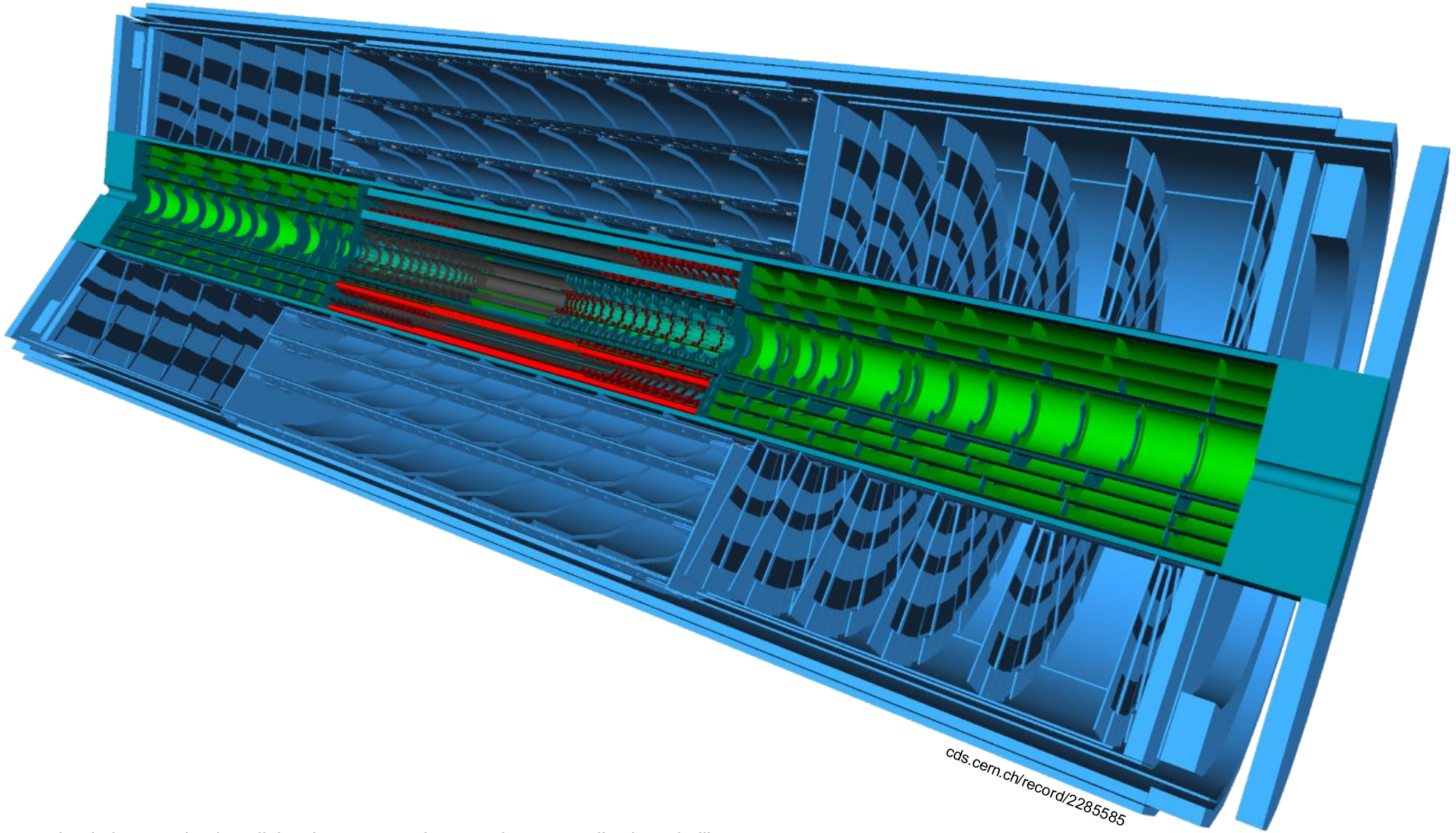
Single Hit with Stereo Angle



Multiple Hits with Stereo Angle

ATLAS ITk Strips Modules

The Detector Layout



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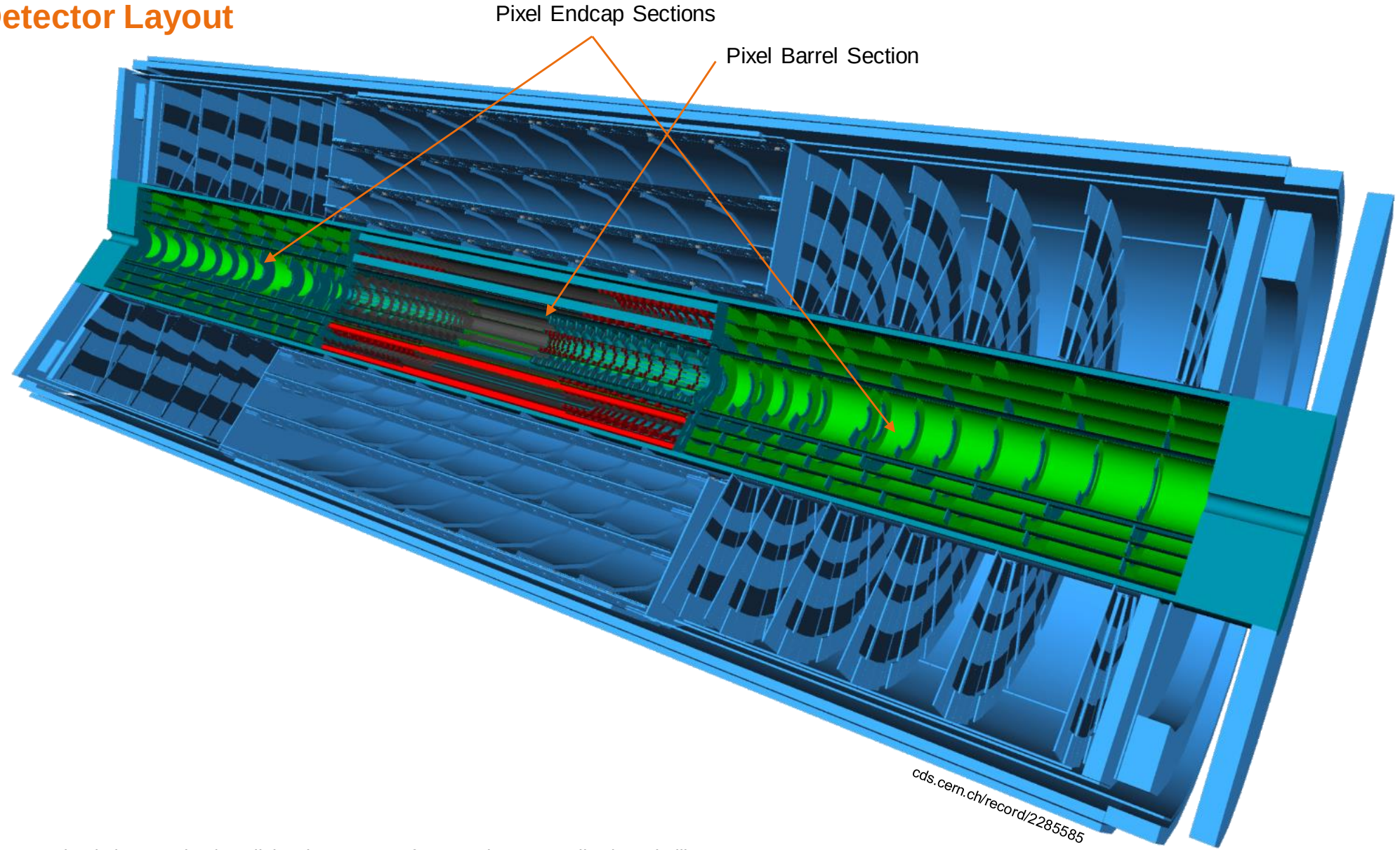

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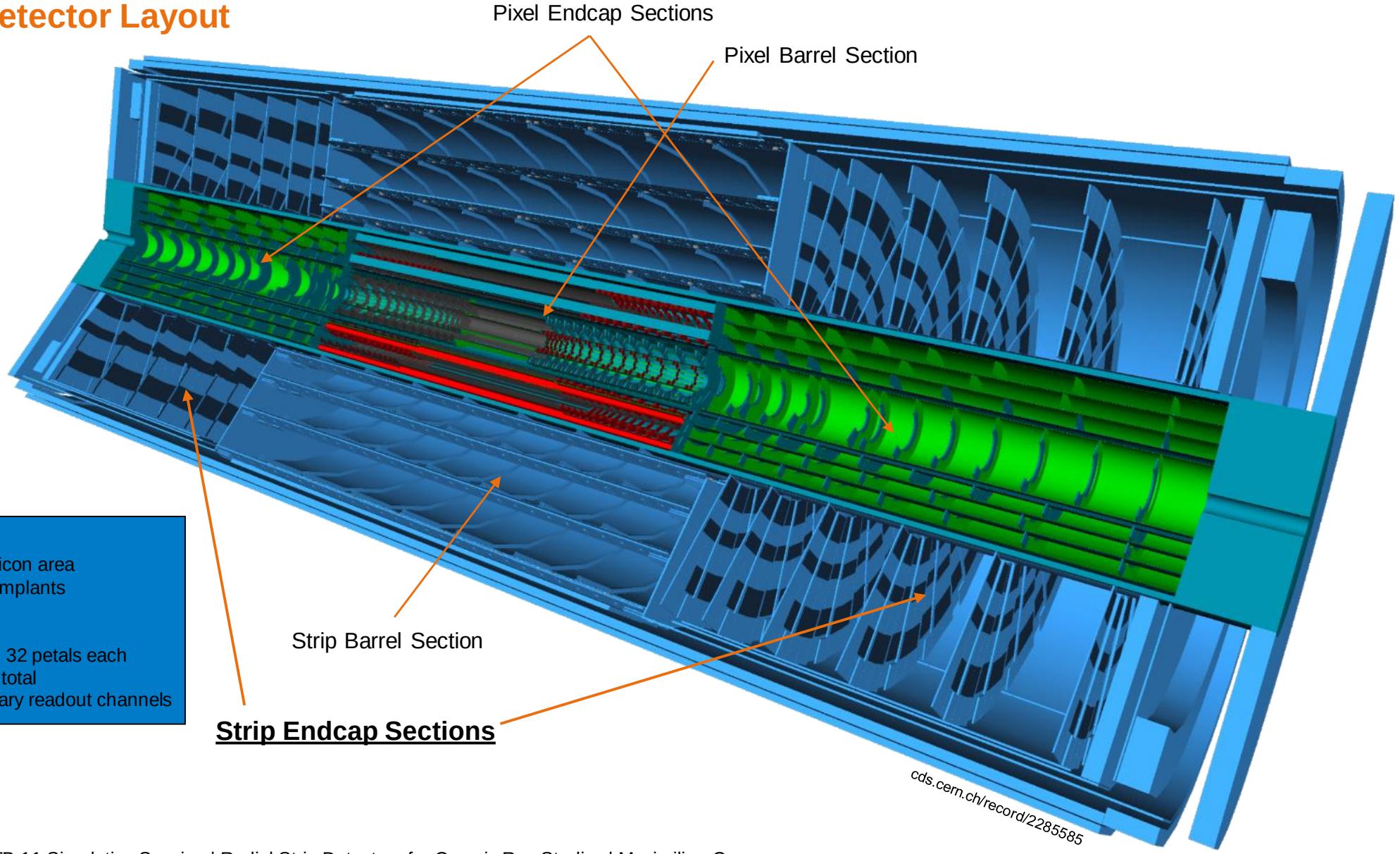


Itk Strips
~ 165 m² of slicon area
p-bulk with n implants

Endcaps
2x6 discs with 32 petals each
6912 sensors total
22060032 binary readout channels

ATLAS ITk Strips Modules

Building the Petal

The Rings

- Petal made up of six rings R0 – R5
- Module in rings R3 – R5 are split

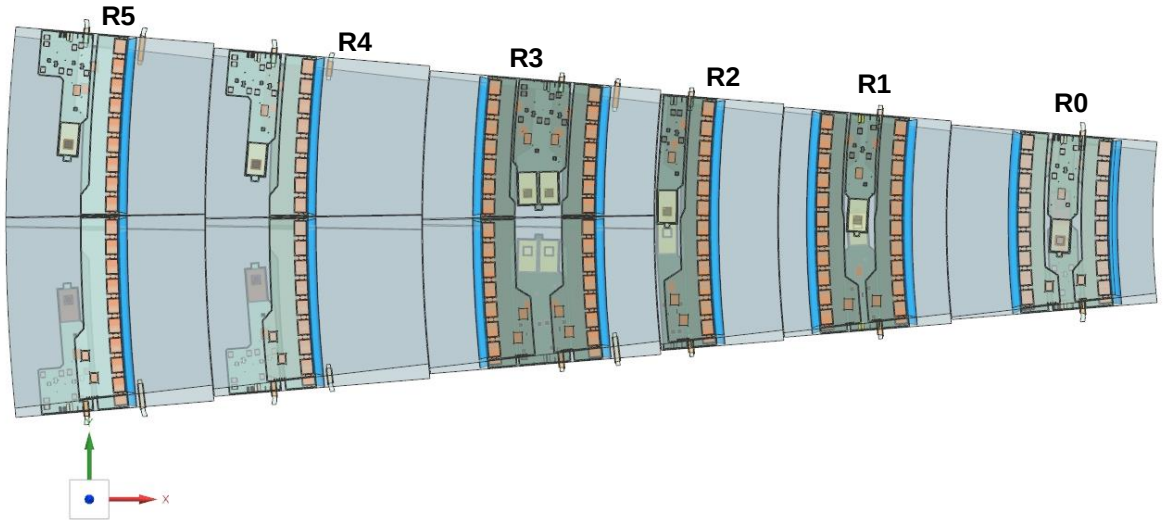
The Sides

- Each petal has a front and a back side
- Back side sensors are rotated 180°

For Simulations

- Complete module positions for a single petal available in an Allpix² example
  - In petal coordinates (relative to origin fiducial)

Available at
https://gitlab.cern.ch/allpix-squared/allpix-squared/-/tree/radial_det_fix_center/examples/atlas_itk_petal

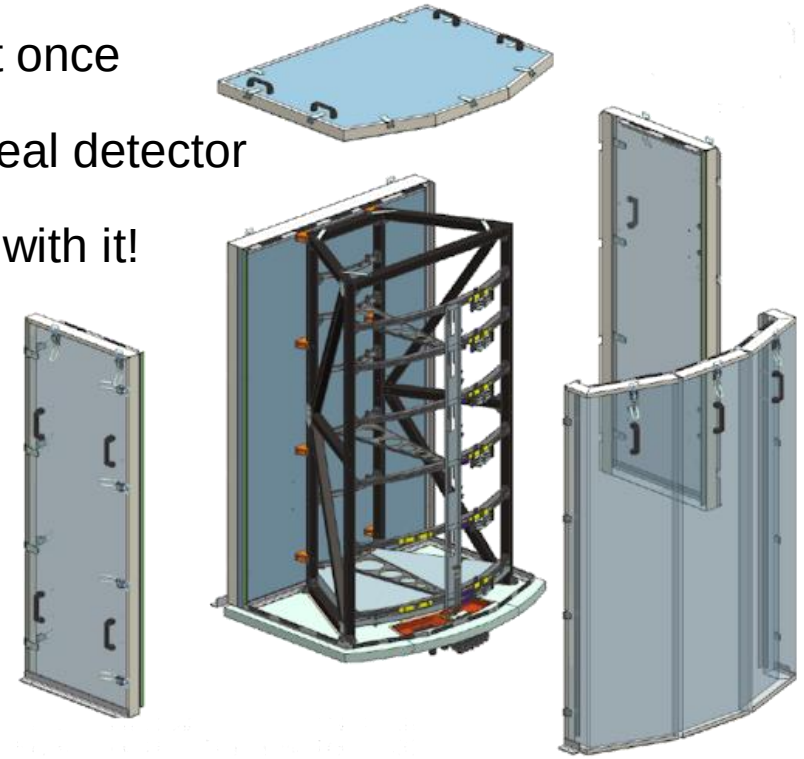


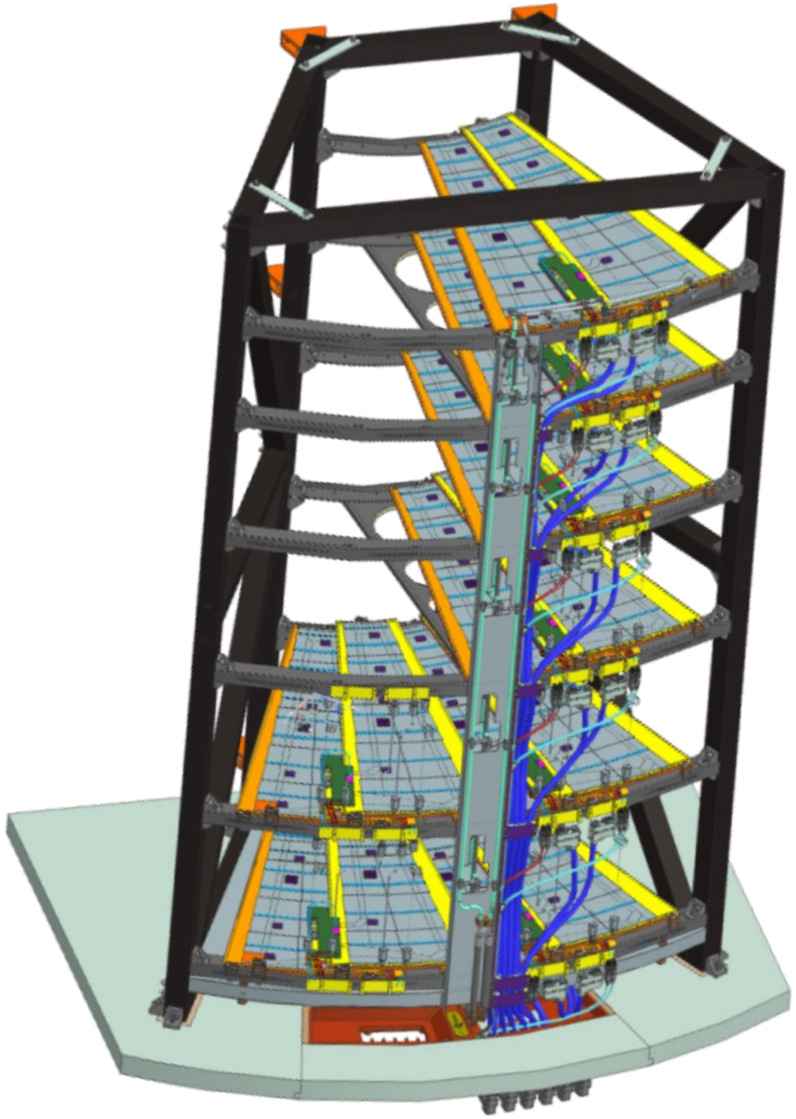
ATLAS ITk Strips Modules

Endcap System Test

System Tests at DESY

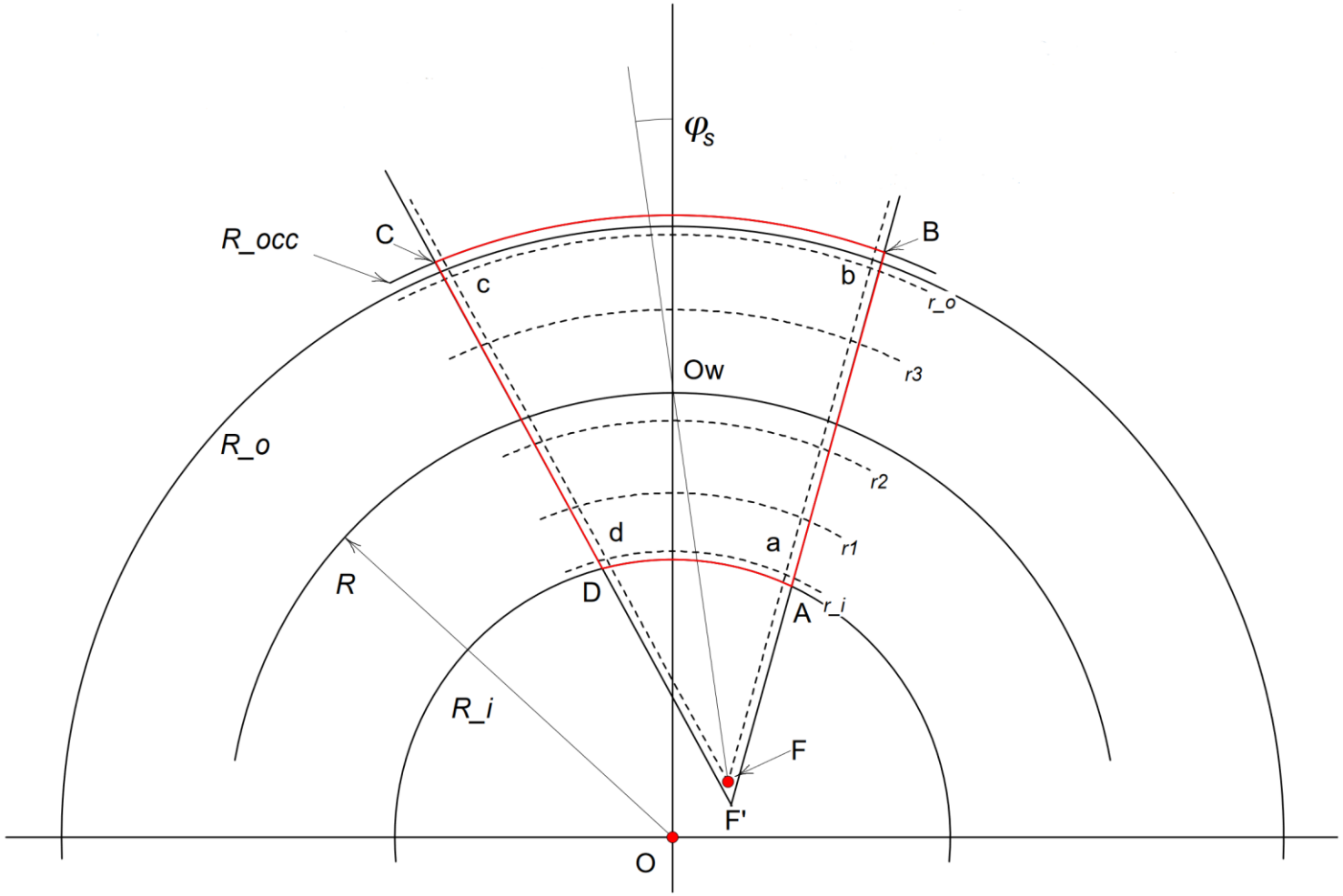
- 1/8 slice of the Endcap as a testing environment
- Can support up to 12 petals at once
- Services & DAQ close to the real detector
- Plan: Measure cosmic muons with it!





ATLAS ITk Strips Modules

The Stereo Annulus Geometry



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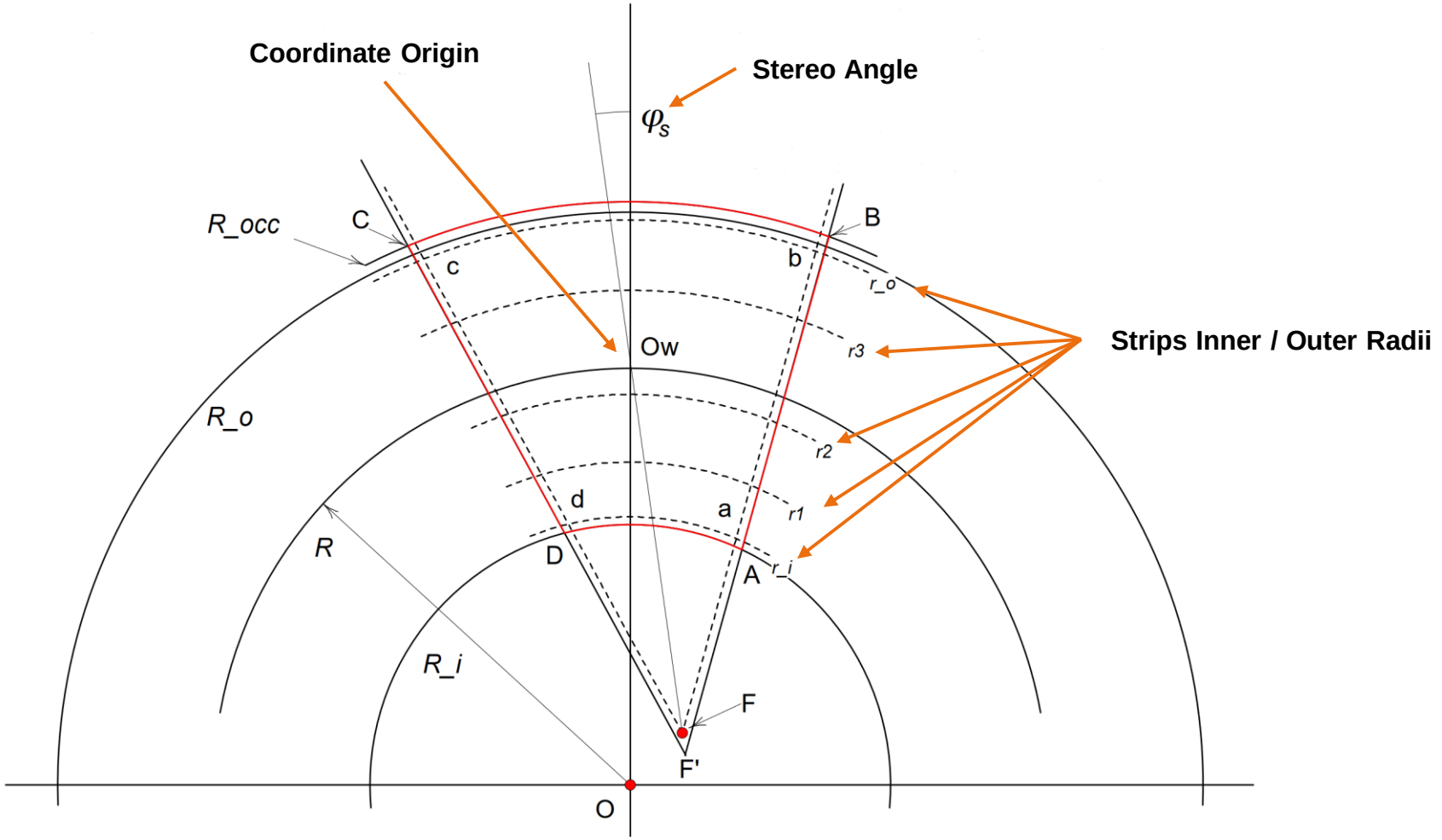


ATLAS ITk Strips Modules

The Stereo Annulus Geometry

Coordinate System

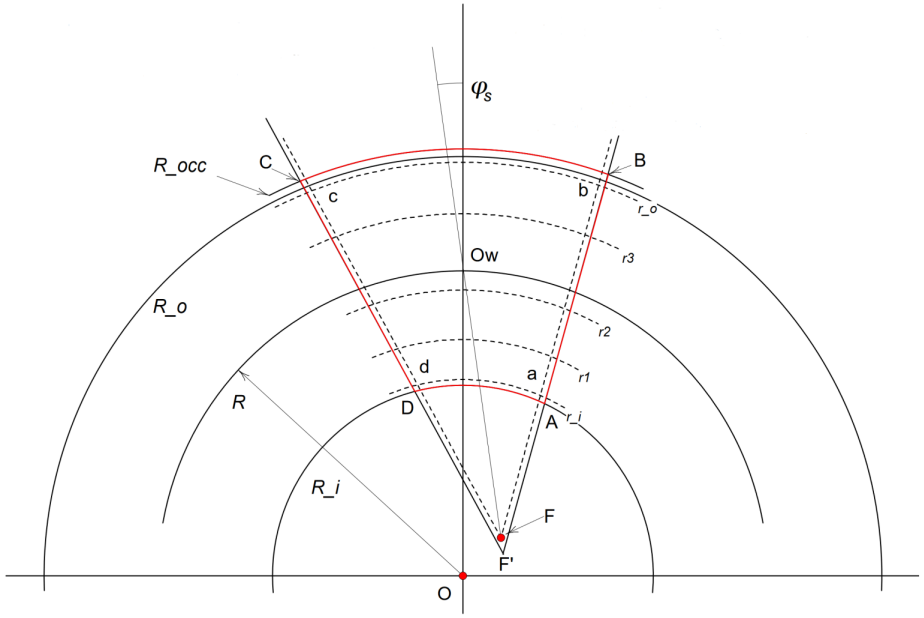
- R defined by distance to the beam axis
- Φ defined in relation to a shifted point F

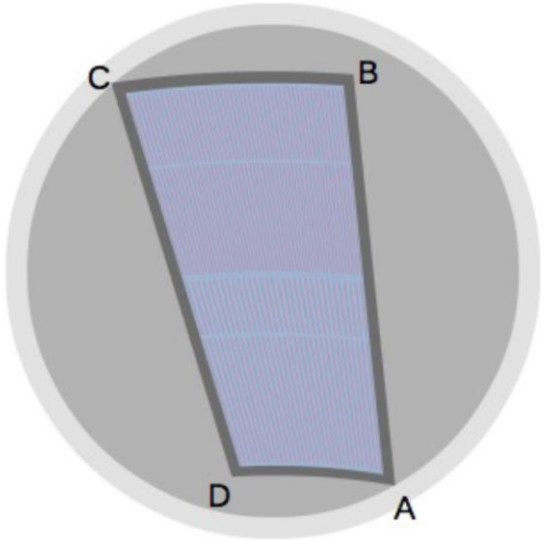
Outer Shape

- Intersection between two annulus sections
- The second annulus section is rotated by the stereo angle around the origin point
- Added additional distance around the active area

Strips

- All strips in a row start & end at the same radii
- Each row has the same angular pitch





Reconstruction in Corry

Clustering in Radial Coordinates

Radial Coordinates (on Sensor)

- Each row of strips is associated with an angular and radial pitch
- Resolutions in R / φ are calculated by assuming uniform distribution
- Radius and angle of the cluster centre are calculated using inverse-variance weighted averaging

Cluster Centre

	Radial Coordinate		Angular Coordinate
Weight	$\omega_{R,i} = \frac{12}{\mathrm{Pitch}_{R,i}^2}$		$\omega_{\varphi,i} = \frac{12}{\mathrm{Pitch}_{\varphi,i}^2}$
Centre	$R = \frac{\sum_{i=1}^{N} \omega_{R,i} \cdot R_i}{\sum_{i=1}^{N} \omega_{R,i}}$		$\varphi = \frac{\sum_{i=1}^{N} \omega_{\varphi,i} \cdot \varphi_i}{\sum_{i=1}^{N} \omega_{\varphi,i}}$
Resolution	$\sigma_R^2 = 1 / \sum_{i=1}^{N} \omega_{R,i}$		$\sigma_\varphi^2 = 1 / \sum_{i=1}^{N} \omega_{\varphi,i}$

Implemented in
https://gitlab.cern.ch/mcaspar/corryvreckan/-/blob/polar_detectors/src/modules/ClusteringSpatial/ClusteringSpatial.cpp

Reconstruction in Corry

Cluster Centre in Cartesian Coordinates

$$\alpha = \cos^{-1}\frac{L_F}{2 \cdot R_C}$$

Distance of focal point to the centre

Radius of the centre

Cartesian Coordinates

- Cluster centres are translated into cartesian coordinates for tracking in Corryvreckan
- Resolutions in local cartesian coordinates are found using gaussian error propagation
- Global resolution matrix is calculated by rotating the error ellipsis

$$\gamma = \sin^{-1}\left(\frac{L_F}{R} \cdot \sin(\alpha + \varphi + \varphi_{\text{Stereo}})\right)$$

Angular component of cluster centre

Radial component of cluster centre

Detector's intrinsic stereo angle

$$\varphi^* = 2 \cdot \alpha + \gamma + \varphi + \varphi_{\text{Stereo}} - \pi$$

$$\begin{pmatrix} X \\ Y \end{pmatrix} = R \cdot \begin{pmatrix} \sin\varphi^* \\ \cos\varphi^* \end{pmatrix}$$

Cartesian Position in local coordinates

Implemented in
https://gitlab.cern.ch/rprivara/corryvreckan/-/blob/polar_detectors/src/core/detector/PolarDetector.cpp

Reconstruction in Corry

Cluster Centre in Cartesian Coordinates

$$\begin{pmatrix} X \\ Y \end{pmatrix} = R \cdot \begin{pmatrix} \sin\varphi^* \\ \cos\varphi^* \end{pmatrix}$$ **Cartesian Position in local coordinates**

Cartesian Coordinates

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Gaussian Error Propagation

$$\sigma_X^2 = \sigma_R^2 \cdot \left.\frac{\partial X}{\partial R}\right|^2_{(R,\varphi)} + \sigma_\varphi^2 \cdot \left.\frac{\partial X}{\partial \varphi}\right|^2_{(R,\varphi)}$$

$$\sigma_Y^2 = \sigma_R^2 \cdot \left.\frac{\partial Y}{\partial R}\right|^2_{(R,\varphi)} + \sigma_\varphi^2 \cdot \left.\frac{\partial Y}{\partial \varphi}\right|^2_{(R,\varphi)}$$

Implemented in
https://gitlab.cern.ch/rprivara/corryvreckan/-/blob/polar_detectors/src/core/detector/PolarDetector.cpp

Simulation

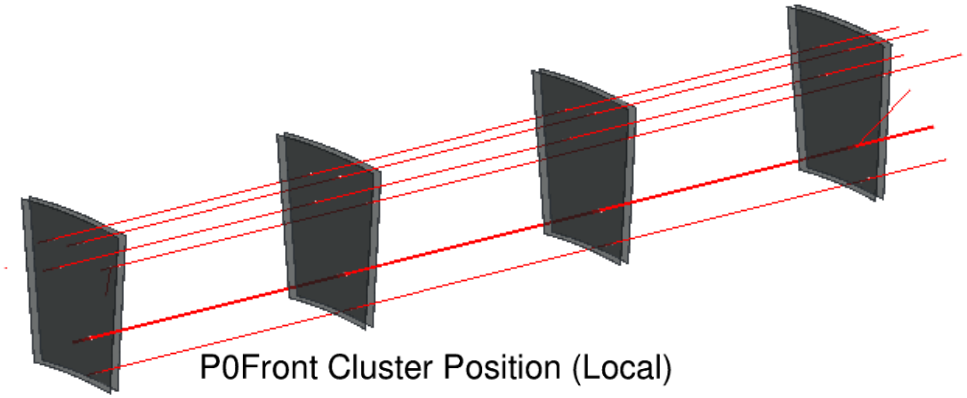
Tacking Telescope with Radial Sensors

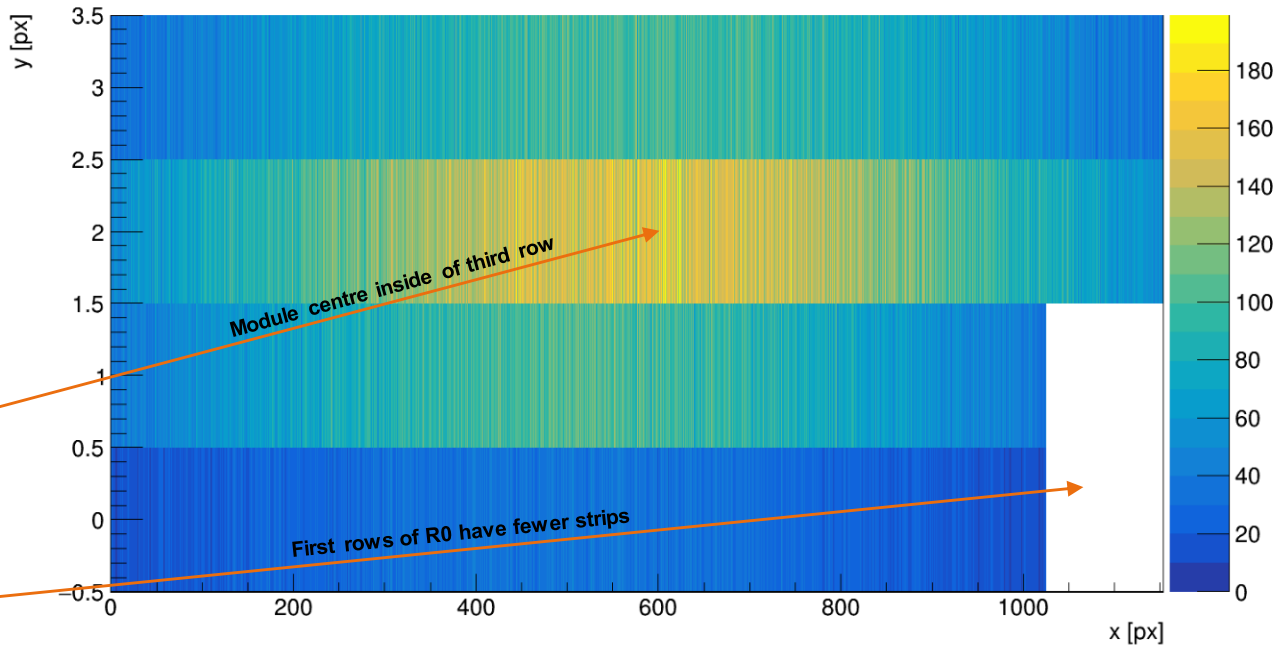
R0 Telescope Simulation Benchmark

- Geometry of the Radial Strip sensors newly implemented in Allpix² & Corry
- Telescope made up of R0 modules served as a first benchmark of our implementation

Results

- Good tracking performance with a Straight Line Track model





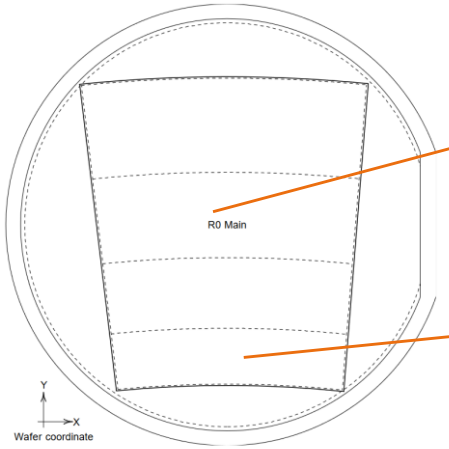


Fig.4 Endcap wafer layout: R0

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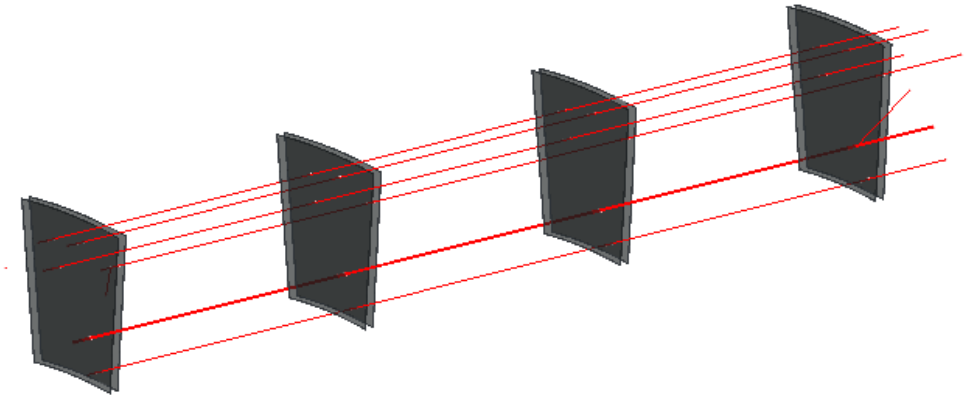
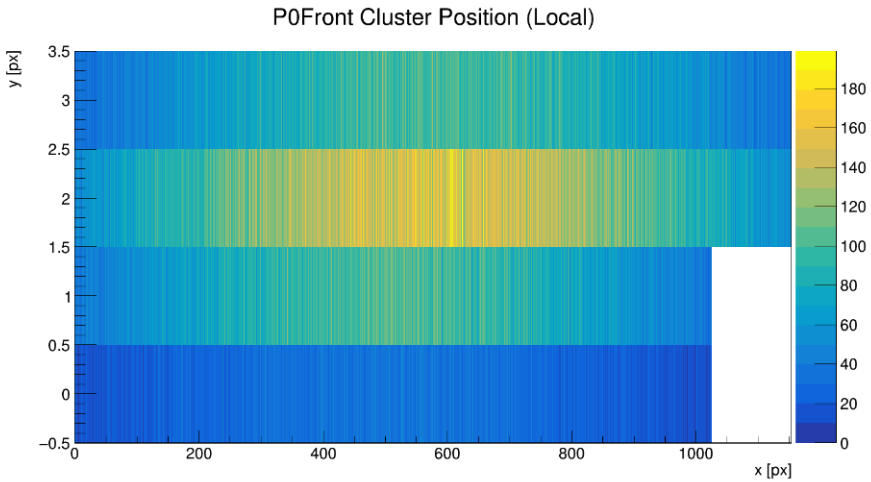
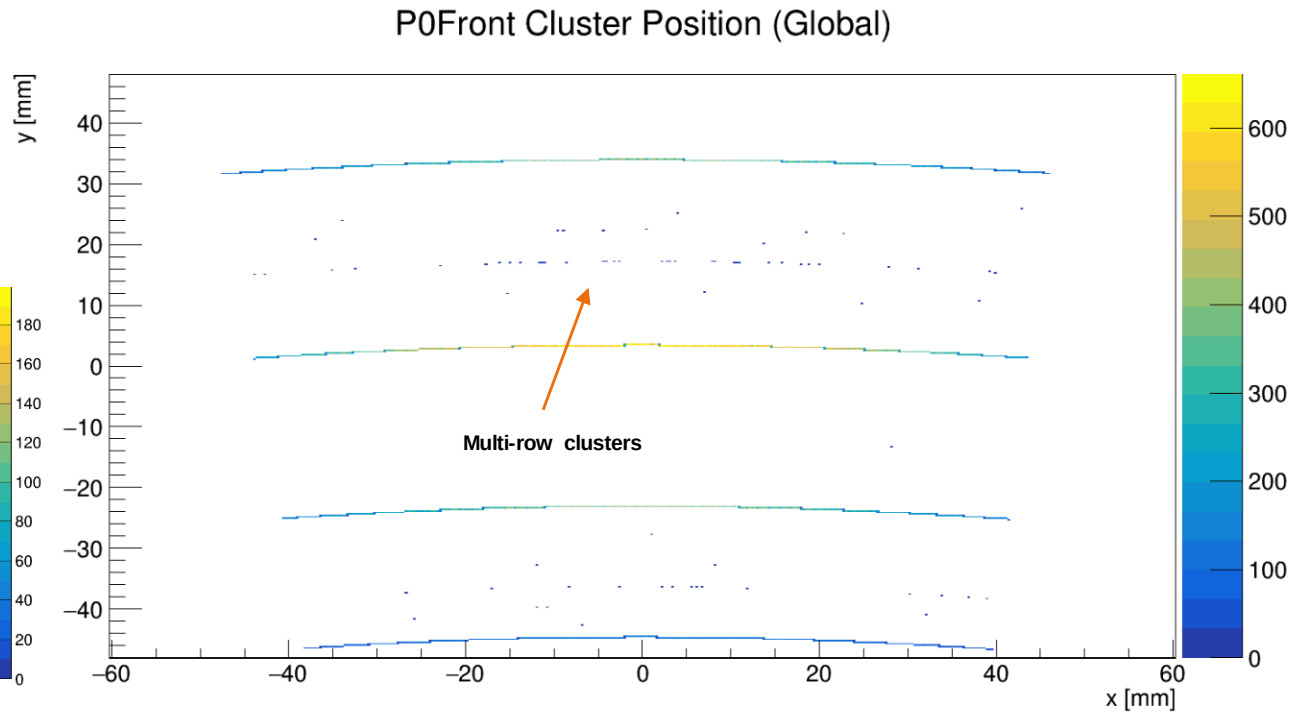


Results

- Good tracking performance with a Straight-Line Track model





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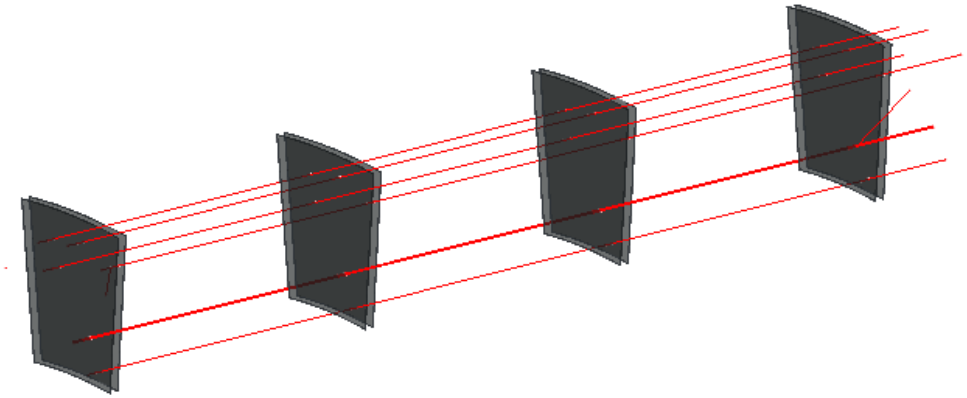

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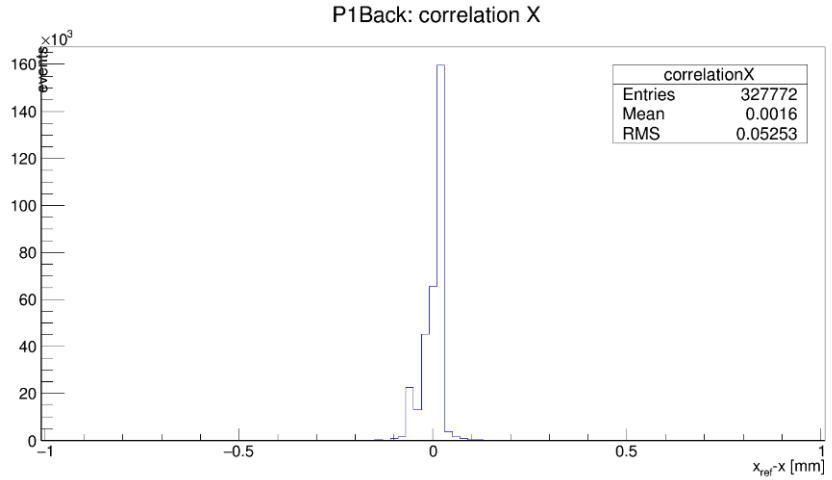

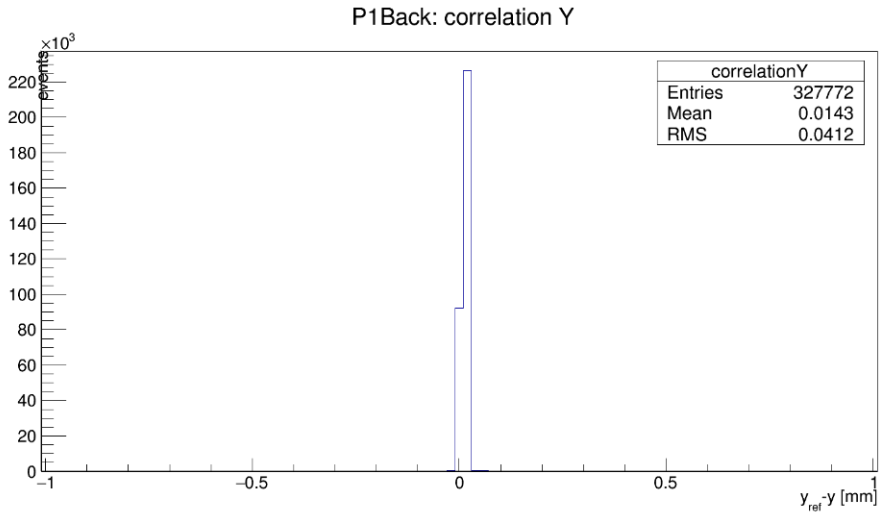

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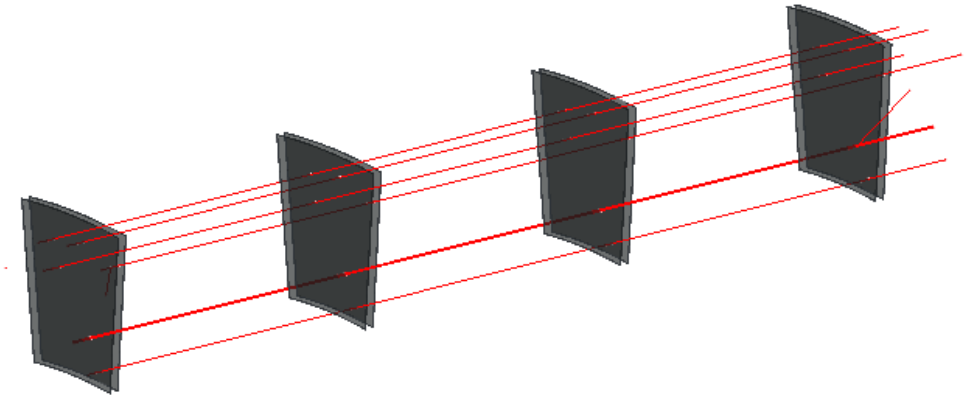

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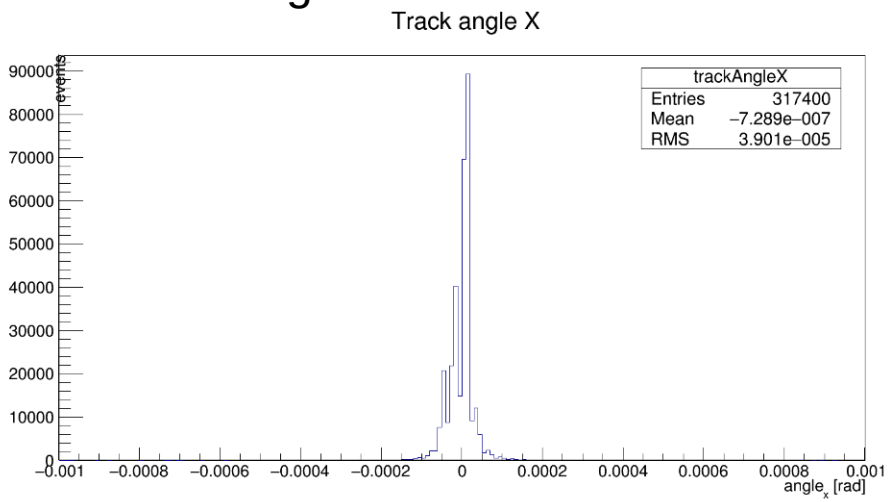
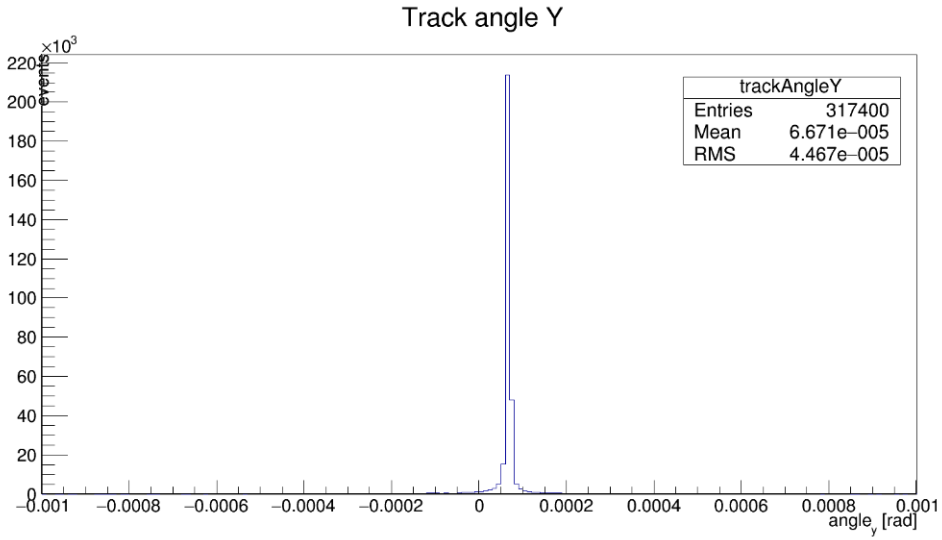




Simulation

Cosmic Rays in Allpix²

Cosmic-ray Shower Library (CRY)

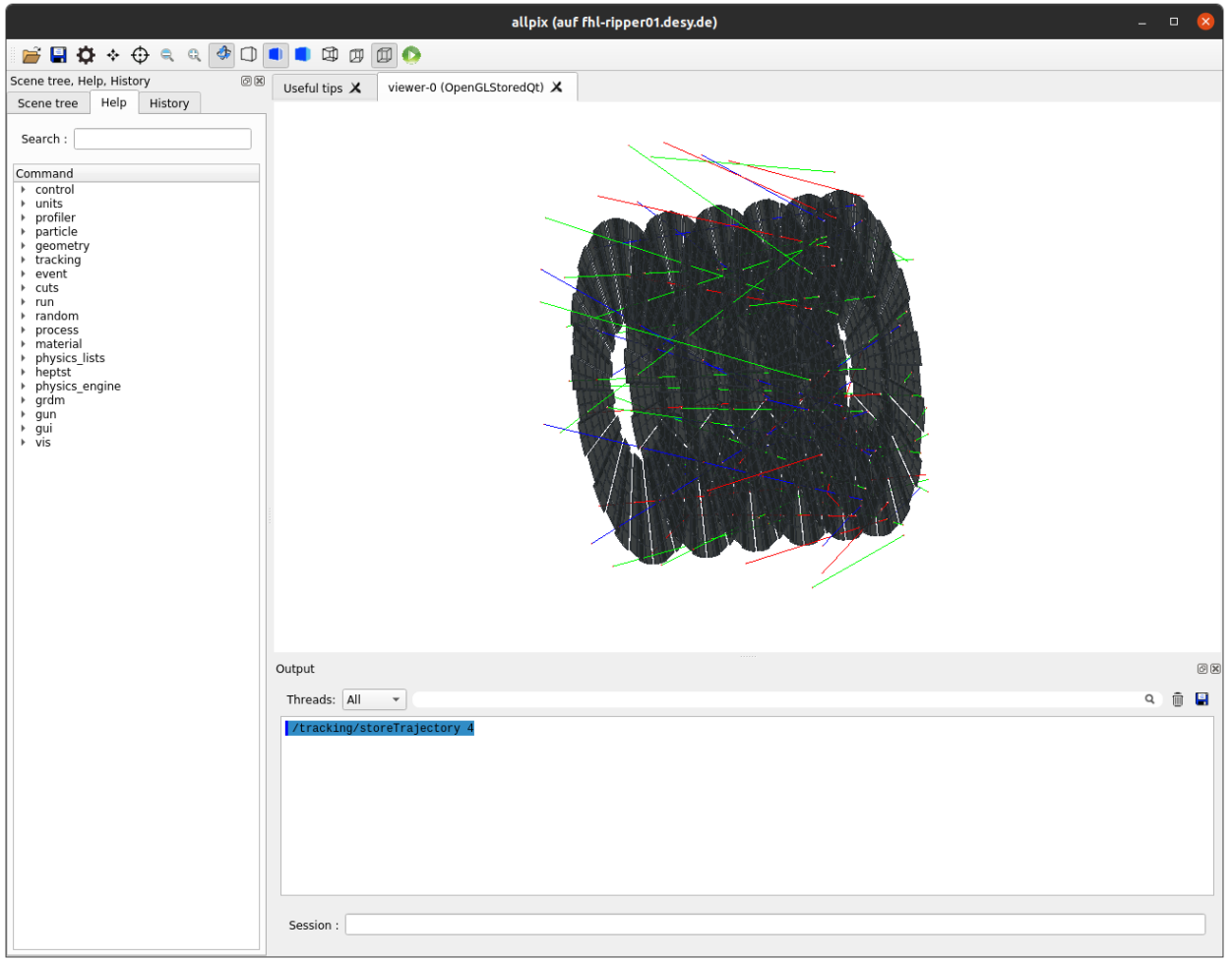
- Generates realistic cosmic ray distributions
- Particles are returned in a square plane surface

https://doi.org/10.1109/NSSMIC.2007.4437209

The DepositionCosmics Module

- Can be called within Allpix² to generate showers
- Allows for selection of CRY framework parameters
  - Altitude & Latitude
  - Solar Cycle
  - Particles Types
- Returns total simulated time for all events

https://gitlab.cern.ch/allpix-squared/allpix-squared/-/tree/master/src/modules/DepositionCosmics



Simulation

System Test Cosmics Setup (4 Petals)

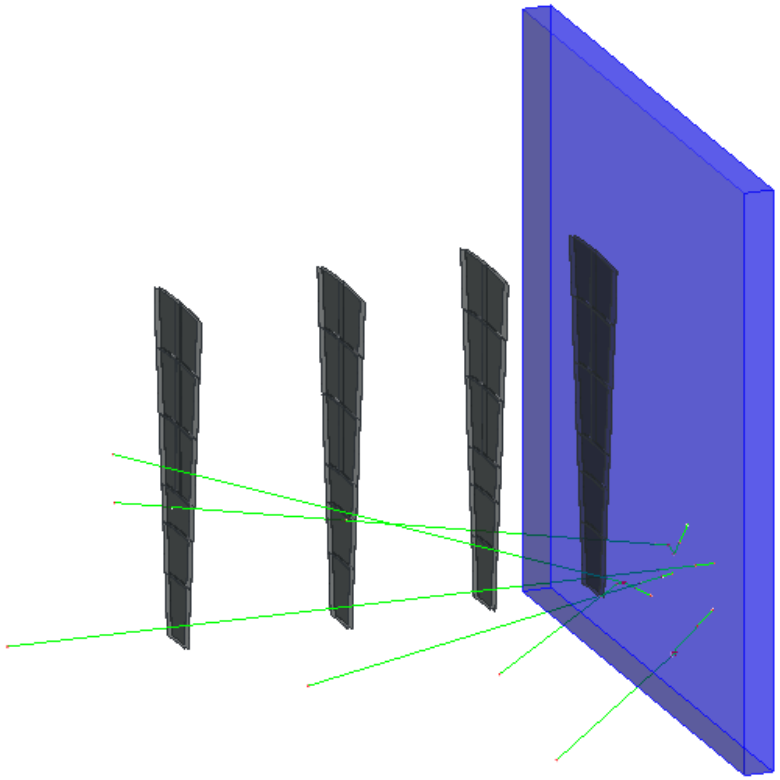
The Setup in Allpix²

- Cosmic muon run with 4 petals planned this year
- Usage of 10 cm concrete ceiling to mimic the laboratory building
- Cosmics generated on 1m x 1m square

The Analysis in Corryvreckan

- Clustering is done in radial coordinates before conversion into the cartesian system
- At least 7 hits per track
- Rejecting tracks where multiple clusters are in the same z plane

Allpix² Setup



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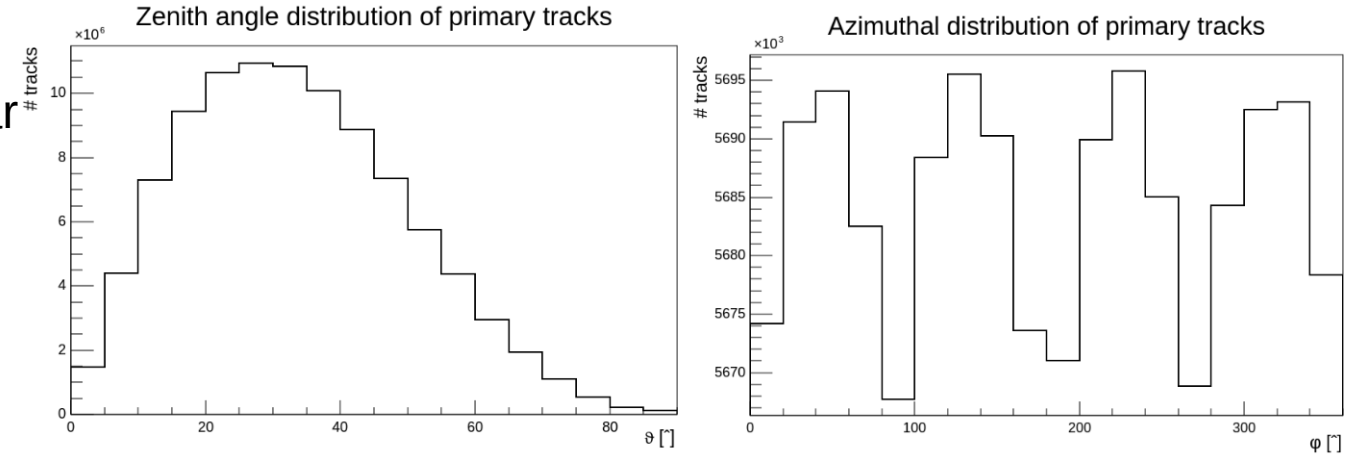
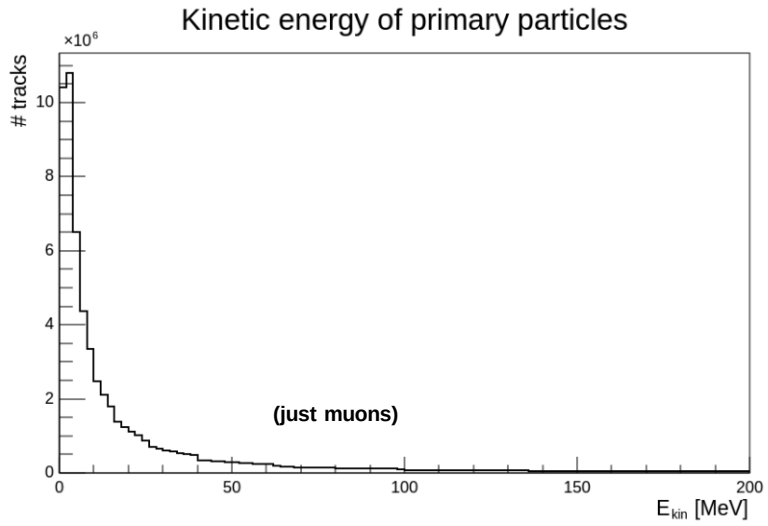
CRY Primary Particles





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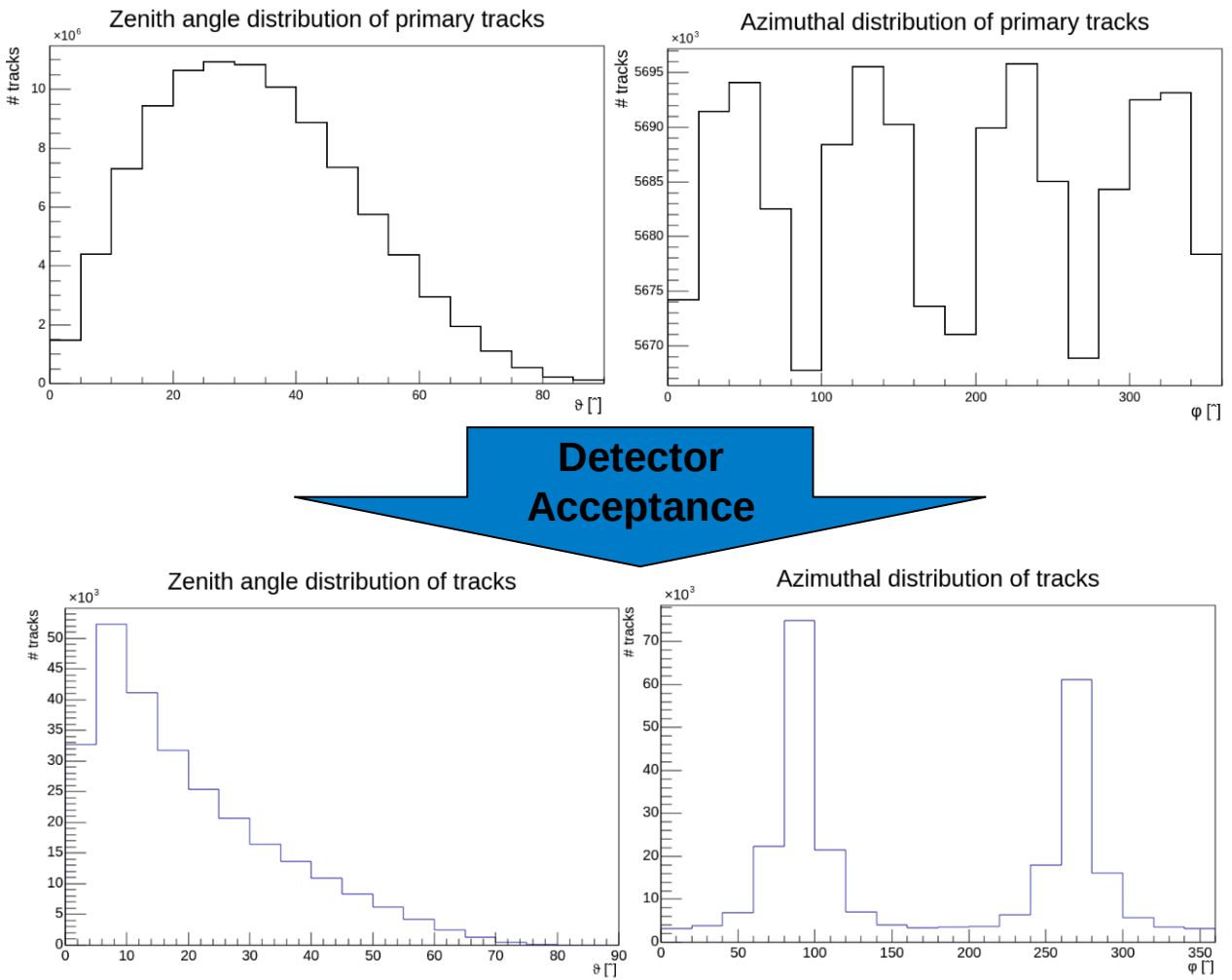

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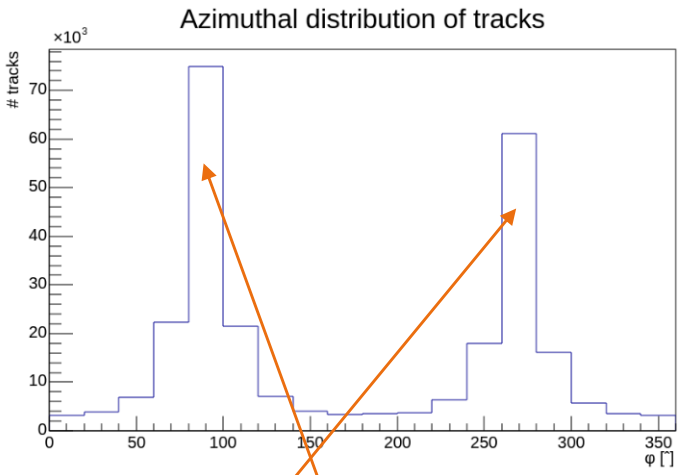

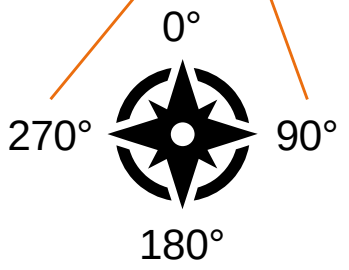

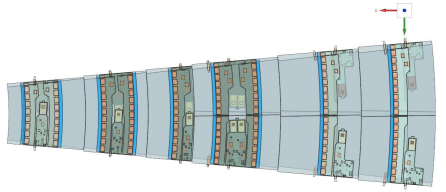

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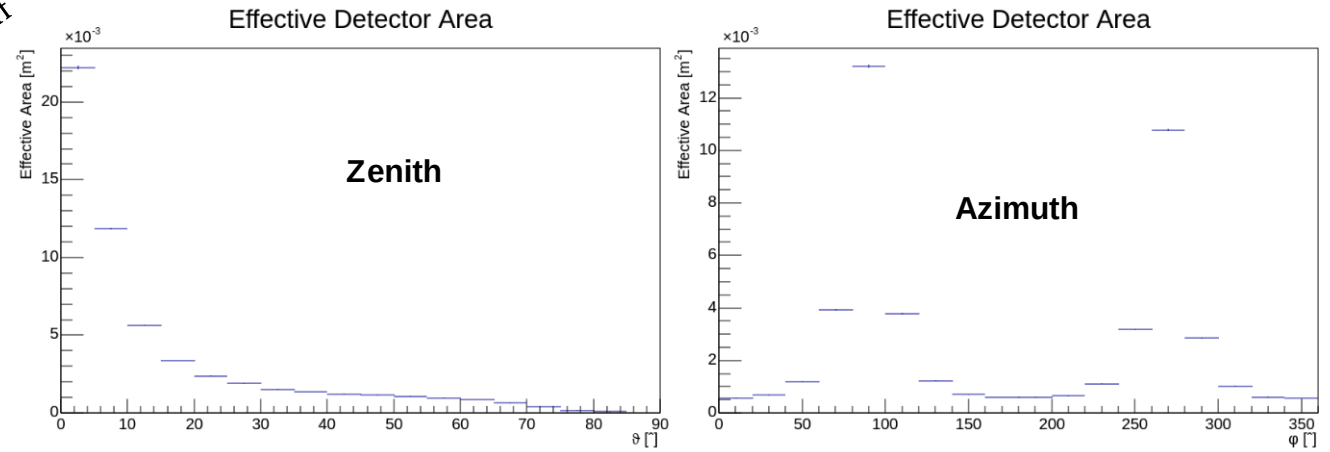
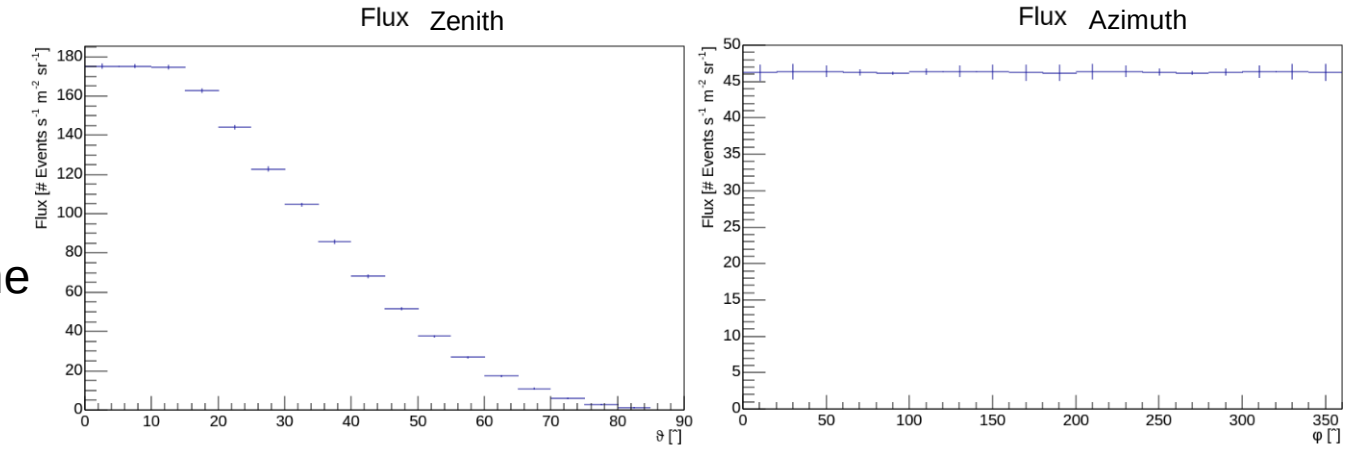
$$A_{\mathrm{Eff}} = A_0 \cdot \frac{N^{\mathrm{Reconstructed}}}{N^{\mathrm{MC}}} \quad (6.1)$$

https://inspirehep.net/literature/1755341

Flux Measurement





$$\Phi = \frac{N_{\mathrm{Tracks}}}{\delta t \cdot \delta\Omega \cdot A_{\mathrm{Eff}}}$$

Conclusion and Outlook

What now?

What we did

- Successfully tested & implemented:
  - Radial Strips geometry in Allpix²
  - Tracking for Radial Strips in Corryvreckan
- Performed muon flux simulation for System Test studies

What's left to do

- Test sensor alignment in Corryvreckan
- Study the tracking resolution of the System Test muon setup
- Test it all on real cosmics data ☺

Thank you

Contact

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Synchrotron DESY

www.desy.de

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ATLAS
maximilian.caspar@desy.de

Backup Slides

ATLAS ITk Strips Modules

The ITK Strips Endcap Modules

Sensor

- 320 µm p-bulk silicon, n-implant strips
- For Endcap: “Stereo Annulus”-shape

Readout Electronics

- Front-end electronics located on a PCB (“Hybrid”) glued to the sensor
- Strips are wire bonded to the front-end chips
- Sensor is glued to a capton PCB (“Bustape”) that also carries an End-of-Substructure card with optical links

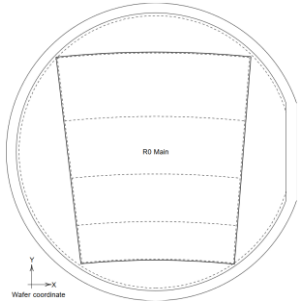

Fig.4 Endcap wafer layout: R0

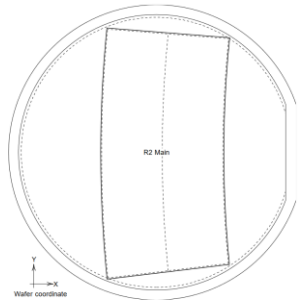

Fig.6 Endcap wafer layout: R2

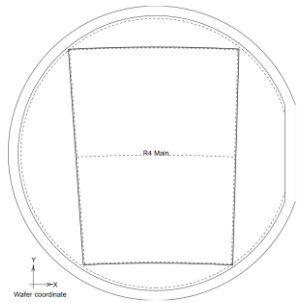

Fig.8 Endcap wafer layout: R4

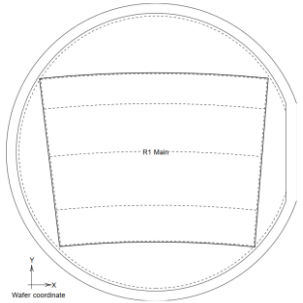

Fig.5 Endcap wafer layout: R1

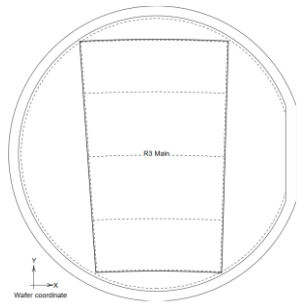

Fig.7 Endcap wafer layout: R3

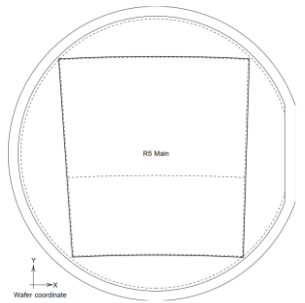

Fig.9 Endcap wafer layout: R5