The HELIX Drift Chamber Tracker Design and Implementation

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Abstract HELIX (High Energy Light Isotope eXperiment) is a balloon-borne experiment designed to measure the chemical and isotopic abundances of light cosmic-ray nuclei. Detailed measurements by HELIX, especially of 10Be from 0.2 GeV/n to beyond 3 GeV/n, will provide an essential insight into the propagation processes of the cosmic rays. HELIX measures the rigidity of cosmic rays by tracking their deflection in a 1 Tesla magnetic field. This high-resolution gas tracking system, the Drift Chamber Tracker (DCT), utilizes hundreds of thin sensing wires to provide both bending and non-bending view measurements. The DCT sense wires collect cosmic-ray-induced ionization through a strong electric drift field of 1 kV/cm. Precise monitoring and control of the gas composition and drift field are accomplished with a suite of housekeeping instruments. We present the design and implementation of the DCT and its readout electronics and highlight cosmic-ray muon analysis developments with straight-through tracks.

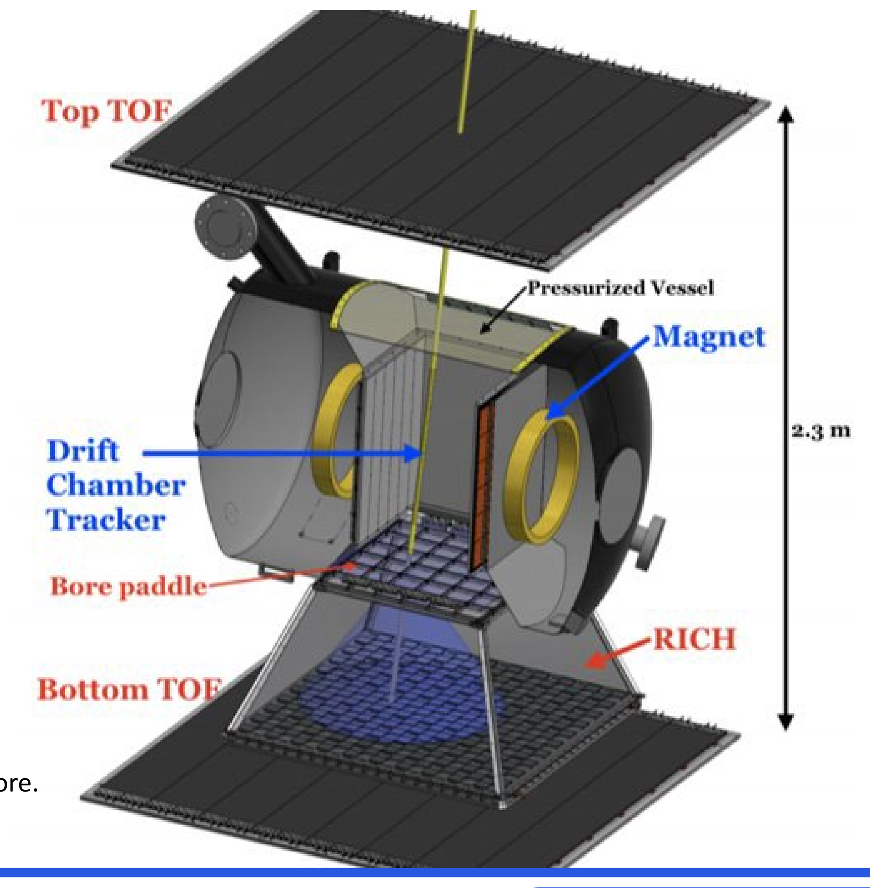
HELIX: High Energy Light Isotope eXperiment

The HELIX experiment is designed to provide key isotope data to improve our understanding of galactic cosmic-ray (GCR) propagation. Beryllium isotope GCR measurements test these models using the long-lived isotope Be-10, decaying with a half-life of 1.4 Myr. HELIX will resolve Be-10 from its stable partners in the energy range of 0.2 GeV/n to beyond 3 GeV/n.

HELIX is a magnet spectrometer that measures the **rigidity**, **charge**, and **velocity** of GCRs. The superconducting magnet provides 1 Tesla of magnetic field, deflecting charged cosmic-ray nuclei at high energies. The **rigidity** is measured by tracking this deflection with a high-precision tracking system, **the Drift Chamber Tracker (DCT).**

- The Time-of-Flight system measures the **charge** and **velocity.**
- The Ring Imaging-Cherenkov Detector (RICH) measures **velocity** at high energies.
- The DCT measures the **rigidity.**
  - **Maximum Detectable Rigidity: 800GV**
- Mass is calculated for GCRs:

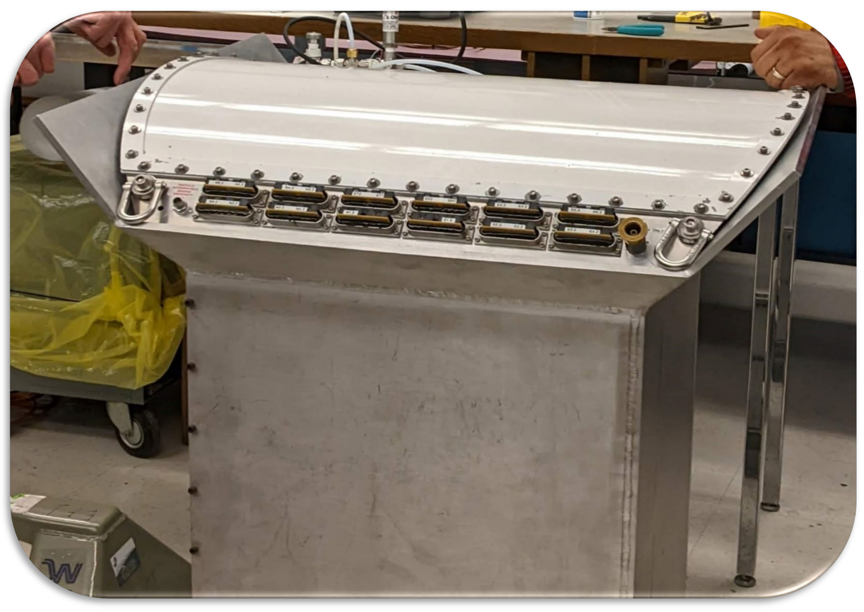
$$m = \frac{R(Ze)}{\gamma\beta}$$



A drawing of the HELIX systems with DCT inside of the magnet bore. The gold line shows a cosmic ray crossing the entire payload.

DCT Overview

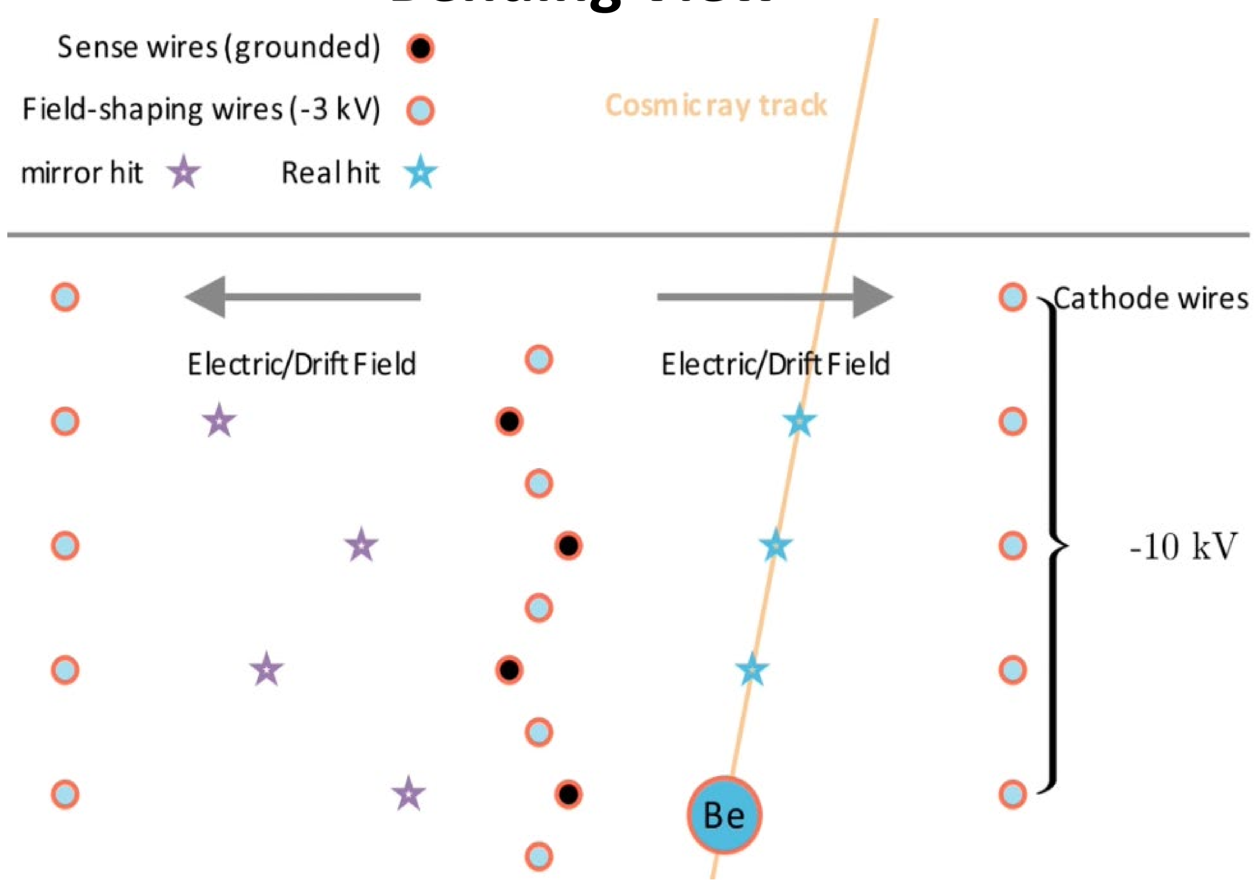
- The DCT measures the ionization trail of GCRs with a goal of **70 µm resolution** in an active area of 45 cm by 45 cm by 58 cm, size constrained by the magnet bore region.
- Gas-filled chamber for generating the ionization from Coulomb interactions. We use CO_2 and Argon at 90:10 held at 1 atm by placing the DCT inside a custom-built vessel.
- Ions drift at roughly constant speed called the **drift velocity** from a strong Electric Field (~1kV/cm) in the dense gas.
- Current is measured at grounded **sense wires,** and then amplified and filtered for readout with high-speed electronics.
  - 80 Mega samples per second
  - 12-bit resolution
- Both the bending view (see below) and the non-bending view tracks are measured.



The DCT inside its pressurized vessel.

The DCT laying on its side with its top open.

Bending View



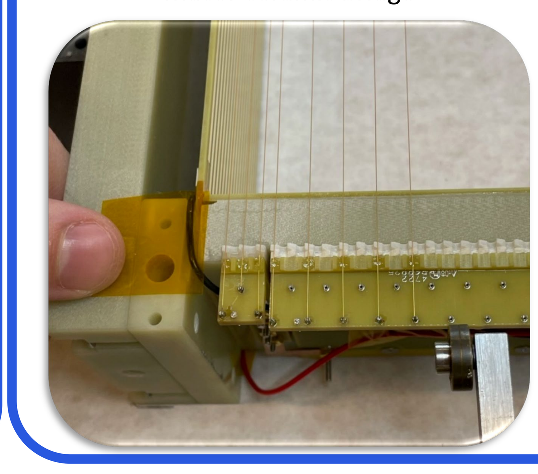
- Schematic view of sense wires and drift field wires along with field-shaping wires interspersed. 4 drift cells are shown.
- Cosmic-ray hit positions are fundamentally time measurements with ambiguity on which side.
- Staggering of alternating sense wires resolves the left/right ambiguity in reconstructing the track.

Wires and Data Acquisition

Wires: There are 3 drift cells per layer and 72 layers, for a total of 216 in the tracker. Each drift cell includes one sense wire and drift field wires on either side to generate the strong Electric field. Wires span the width of the tracker (45 cm) and are positioned with 50 µm precision.

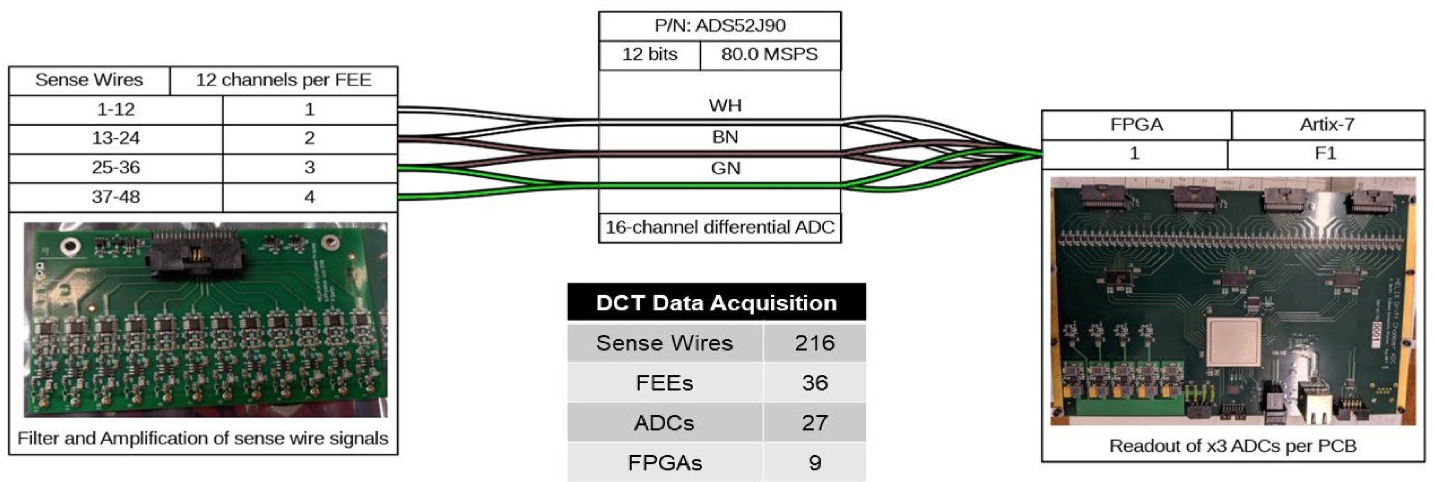
Close-up of the wires to illustrate positioning and size

Wires	Diameter (µm)	Material	Pitch (mm)	Total
Sense	20	Moleculoy	8	216
Drift	200	Gold-plated Aluminum	4	288



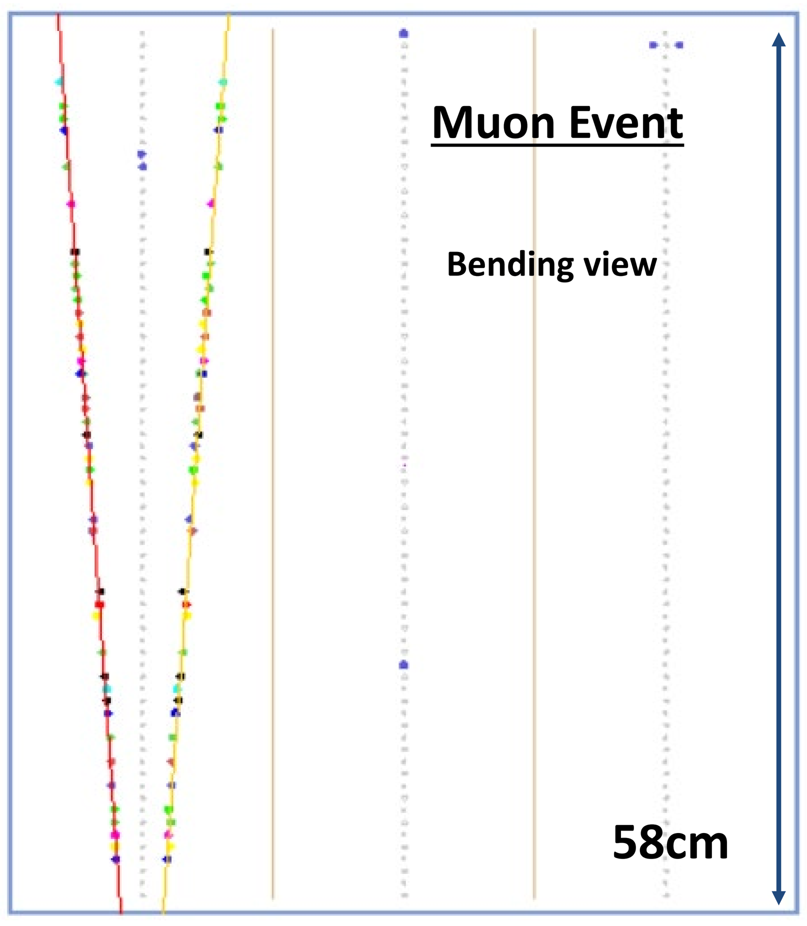
Close-up of the field-shaping wires on Macor ceramic bridge

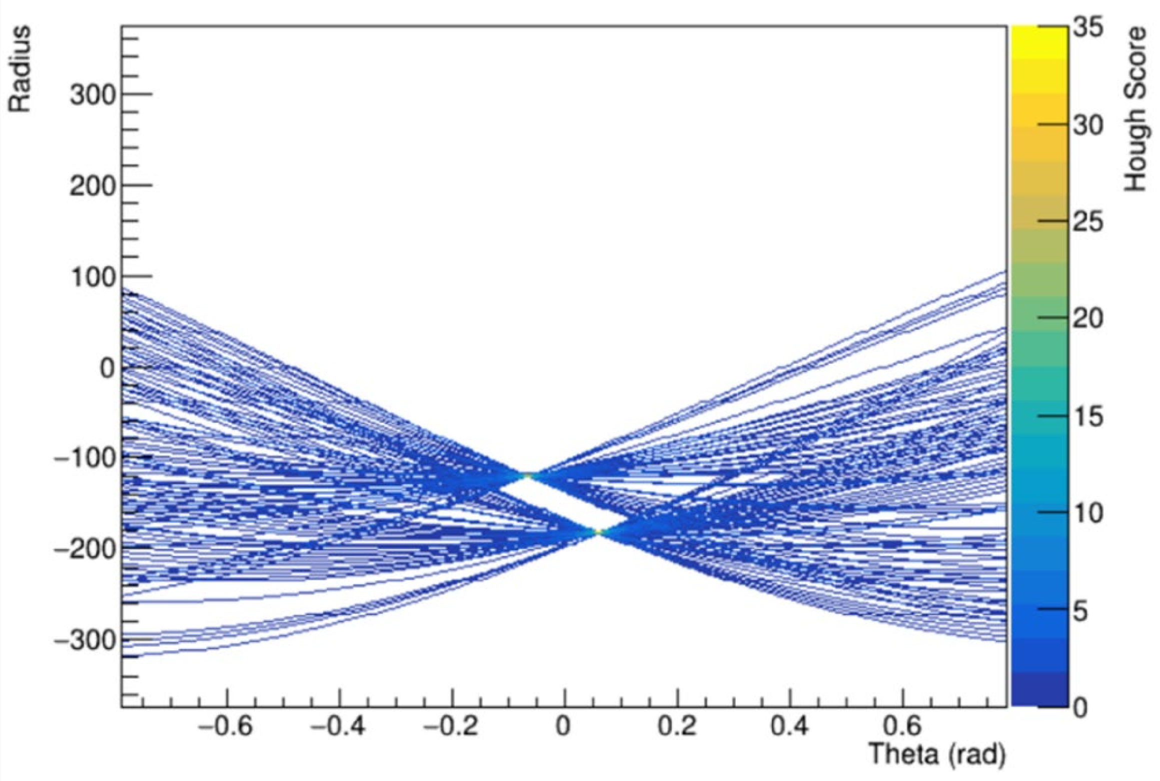
DCT electronics include Front-End Electronics and ADC boards



- Sense-wire signals are measured at both ends with the same electronics for non-bending view measurement.
- The Front-End Electronics (FEE) consist of two stages:
  - 0^{th} stage uses wire-termination PCBs
  - 1^{st} stage consists of filtering and amplification of signal
- Differential signals for each sense wire are read out from 16-channel ADCs at 80 MSPS.
- ADCs interface with Artix-7 field-programmable gate arrays for control and forwarding of the data

Cosmic-Ray Muon Tracks



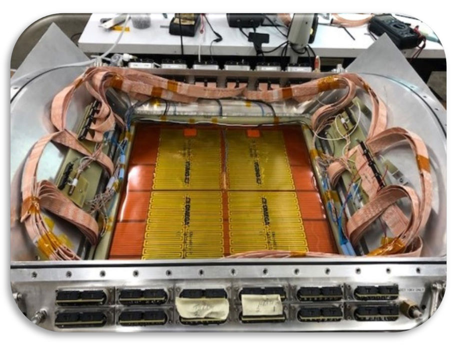


- The bending view display for an example muon event is shown above. Each sense wire is shown as a gray dot and the golden vertical lines are shown for the drift-field wires.
  - The magnet is off, this is a straight through muon track.
- Two hit positions are shown per sense-wire hit using the drift velocity to convert the time measurements.
- On the right is a Hough Transform of the cosmic-ray muon event at left, and the lines are the inverse Hough Transform when considering all hits.

- Hough Transform for each hit position
  - $(x, y) \rightarrow r = x\cos\theta + y\sin\theta$
  - Radius and angle describe the line that the most hits vote for in the transform.
- There are multiple regions in the Hough space, but a maximum exists for more hits voting for those Hough parameters (θ, r) which describe the red track in the display.
  - Second best line is the yellow track, showing the Hough Transform resolving the ambiguity.

Housekeeping System

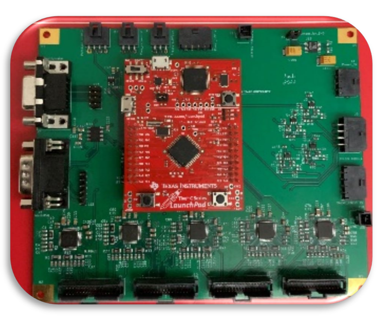
- Sense-wire time measurements are converted to distances using the drift velocity **(b~6 mm/µs)** $\quad \mathbf{b \rightarrow d = b \times t}$
  - The gas density and electric field strength contribute to the drift velocity resolution which impacts the tracking resolution.
- Gas is regulated by 3 controllers to tune the flow rate and mix the gas.
- Temperature is monitored to better than 0.5 °C with thermistors and the uniformity is maintained with heaters on the outer faces of the DCT.
- Electric field is generated from a pair of identical high-voltage supplies that are controlled and monitored by the housekeeping system.
  - Tunes the 10 kV high voltage with better than 0.1% precision on the drift field.
- This housekeeping suite has a central PCB utilizing a microcontroller to interface with all components and meet the DCT tracking requirements.



DCT heaters on the top of the DCT. The DCT installed inside the vessel.

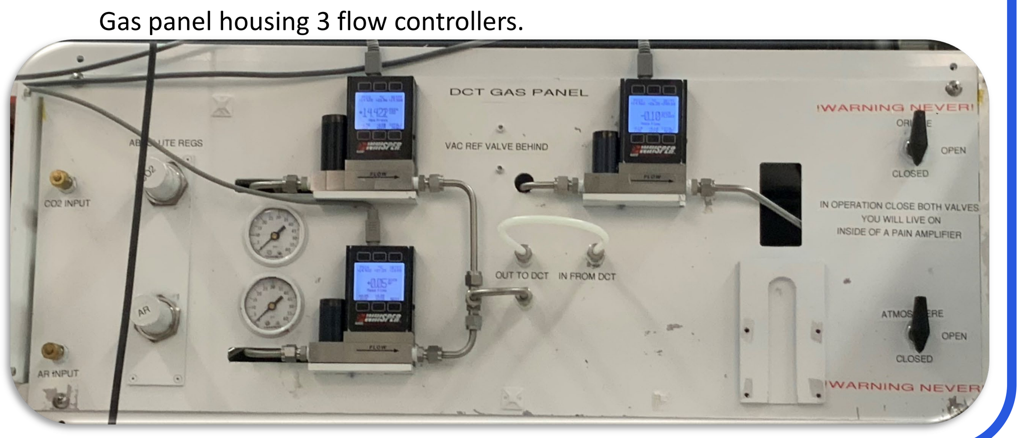
DCT Housekeeping System

Parameter	Device	Quantity
Gas Flow rate	Flow controller, Alicat MCW Series	3
Temperature	Thermistors	23
Chamber Pressure	Transducer, Gems 2200 Series	3
Heat/power	Polyimide heaters, 2 Watts	20
Drift-field voltage	HV Supply, Spellman UM8-40	2



Housekeeping PCB.

Gas panel housing 3 flow controllers.



Conclusions

- Next steps are calibrating the time-to-distance function and analysis of curved tracks.
- The DCT is on track to meet the 70 µm tracking resolution for Z>3 cosmic rays.
- The HELIX team is expecting a first flight from Kiruna, Sweden in spring 2024.

Acknowledgements

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