The Design and Status of the HELIX Ring Imaging Cherenkov Detector and Hodoscope Systems

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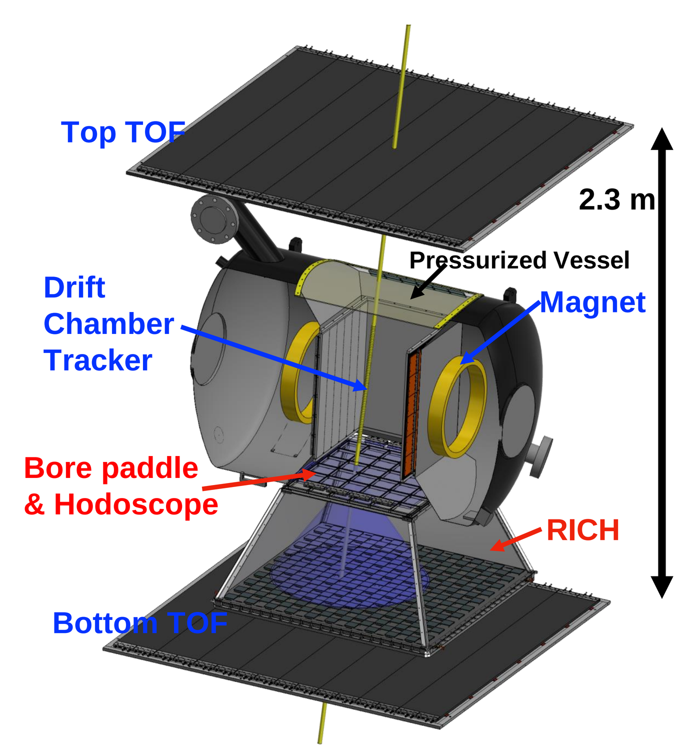
ABSTRACT

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 ^{10}Be from 0.2 GeV/n to beyond 3 GeV/n, will provide an essential insight into the propagation processes of the cosmic rays. HELIX features a Ring Imaging Cherenkov (RICH) detector designed to measure the velocity and charge of nuclei with energies greater than ~1 GeV/n. The RICH detector consists of a radiator volume of high-transparency high-index aerogel tiles imaged by a ~1 m^2 focal plane instrumented by 200 8×8 arrays of silicon photomultipliers (SiPMs). A scintillating fiber hodoscope readout with SiPM arrays is installed directly above the RICH radiator plane to improve the accuracy of track reconstruction in the non-bending plane of the instrument's magnet spectrometer system. We present the design and current status of the HELIX RICH and hodoscope systems.

HELIX experiment

HELIX measures the chemical and isotopic abundances of light cosmic-ray nuclei from protons to neon (Z=1-10) especially Be isotopes from 0.2 GeV/n to beyond 3 GeV/n. Because ^{9}Be is stable and ^{10}Be decays with a life time of 1.4 Myr comparable to the containment time within the Galaxy, measurements of the ^{10}Be/^{9}Be ratio can provide an important key for understanding the propagation of cosmic rays.

The HELIX instrument consists of:
- 1 T superconducting magnet
- Drift-chamber tracker: rigidity by and trajectory measurements
- Time-of-Flight: charge at all energies and velocities of particles with E ≲ 1 GeV/n
- RICH: velocities of particles with E ≳ 1 GeV/n and charge at all energies
- Hodoscope: particle track in non-bending plane near at the RICH location



▲ HELIX instrument

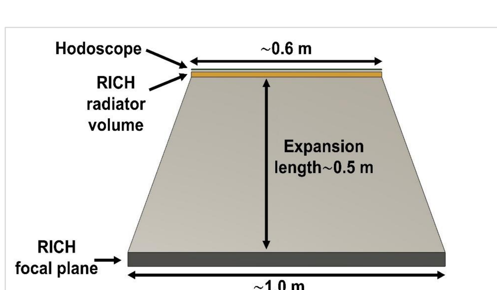
HELIX RICH and Hodoscope

- The **RICH** is designed to provide a velocity measurement with a Lorentz-weighted velocity resolution, $\gamma^2 d\beta/\beta$, of <2% for particles with energies above 1 GeV/n.
- The **RICH** is a proximity-focused RICH designed to measure the velocity (β) of particles radiating Cherenkov light in a medium (with a refractive index, n) by reconstructing rings of photons detected on a focal plane. From the impact parameter of the photon hits from the particle trajectory, the Cherenkov angle (θ) can be determined, leading to the particle velocity through the well-known formula

$$\beta = \frac{1}{n\cos\theta}$$

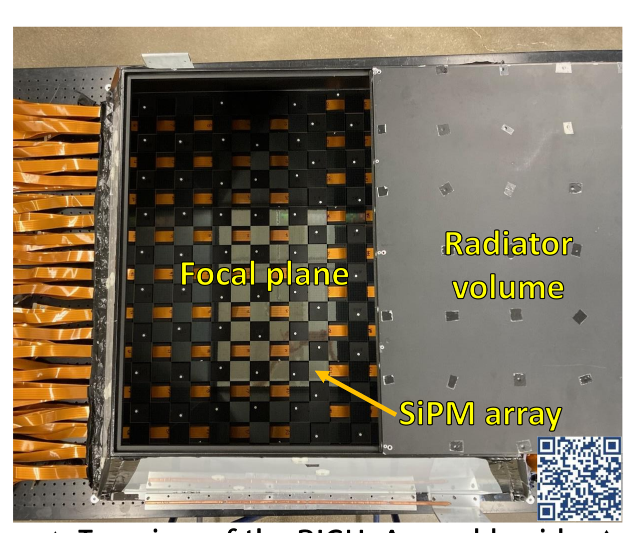
- A **scintillating fiber hodoscope** has been introduced directly above the radiators in order to improve the RICH performance by reducing uncertainties in the trajectories of particles entering the radiators.

HELIX Ring Imaging CHerenkov Detector



▲ A drawing of the RICH

▲ Aerogel tile [2]



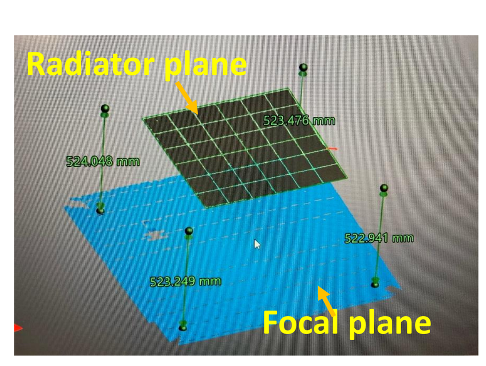
▲ Top view of the RICH. Assembly video↑

The RICH consists of a radiator volume and focal plane with an expansion length of ~50 cm. The radiator volume is made of 36 high transparency and high index aerogels with the refractive index of ~1.15 ± 0.1% [1]. The focal plane comprises 200 8×8 silicon multiplier (SiPM) arrays designed for HELIX by Hamamatsu.

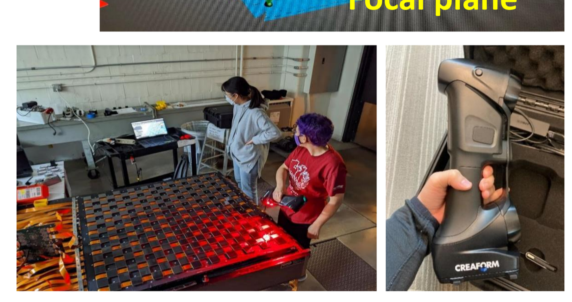
Mechanical measurements

It is crucial to know the accurate expansion length and position of the SiPMs on the focal plane to calculate the emission angle of Cherenkov light used to measure particle velocities. The RICH is 3D scanned using a Handyscan 307 (CREAFORM).

- ➡ The expansion length is measured to be 516.6 ± 0.7 mm.
- ➡ The top surfaces of the SiPMs form a uniform plane with a precision of 0.1 mm.
- ➡ SiPM 2D positions on the focal plane are consistent with the design with a residual of -0.1 ± 0.2 mm.



A 3D model of the RICH created by 3D scanning ▲

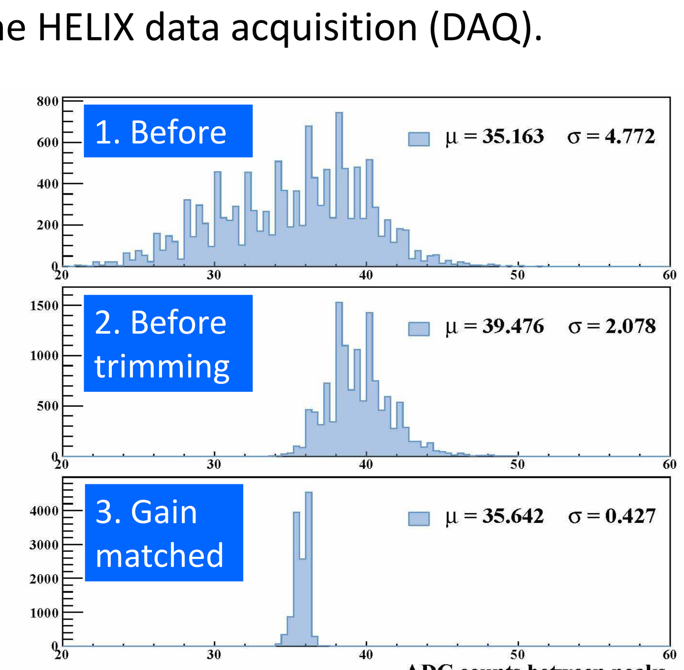


Scanning of the SiPMs on the focal plane ◀ the 3D scanner ▶

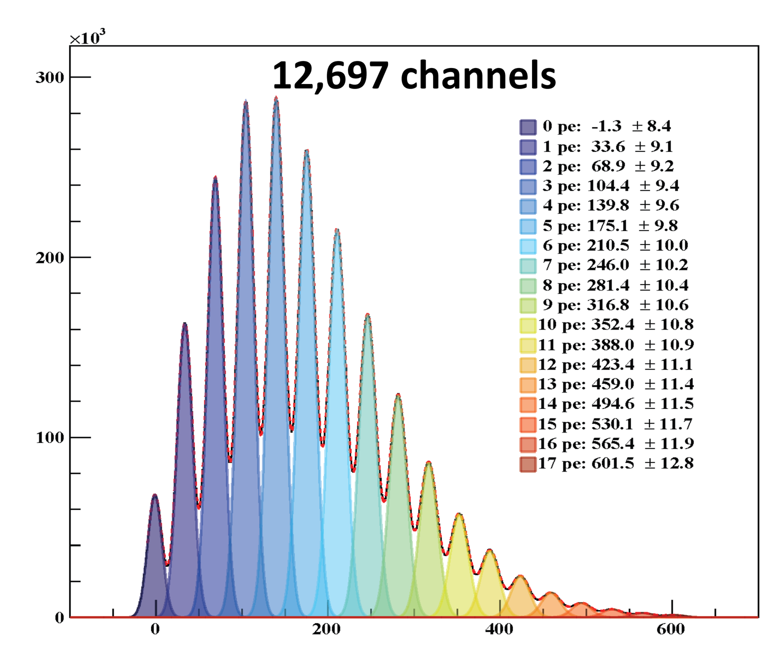
Gain matching

Gain matching of the SiPMs ensures that every SiPM channel produces the same amount of charge in response to a single photoelectron (PE).

- The SiPM outputs are read by CITIROC ASICs[3] on the RICH front-ends. A SiPM bias is determined by a bias common for all SiPM channels and trim voltage for individual channels by $V = V_{com} + V_{trim}$.
- The desired SiPM gains are determined by optimizing the bias for individual pixels as the focal plane is illuminated using a pulsed laser. The laser pulse is synced with an external trigger fed to the HELIX data acquisition (DAQ).

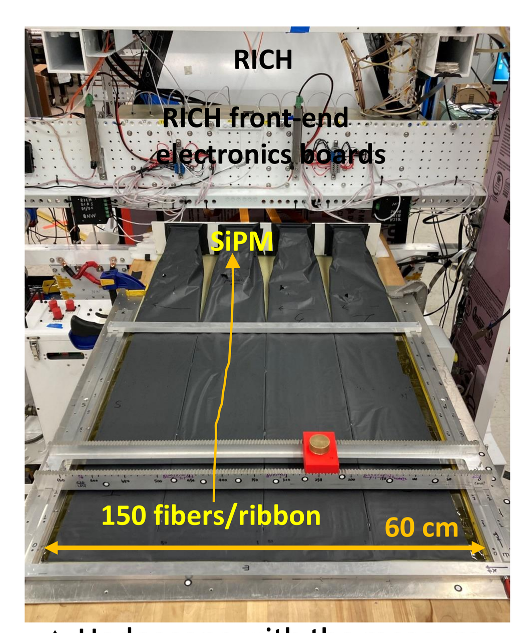


- At step 2, a common voltage is chosen that would satisfy all channels in the SiPM if a trim voltage within the linear range were applied.
- At step 3, at the selected common bias, the trim voltage is determined for fine-tuning



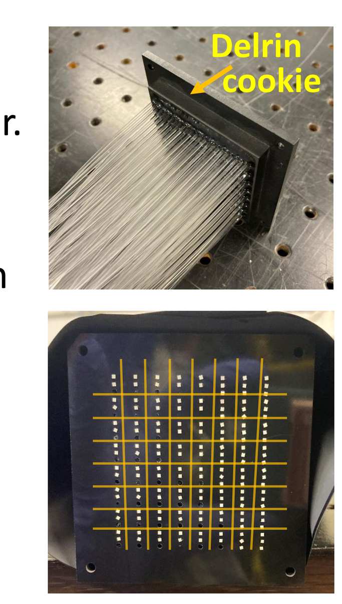
99.2% of a total of 12,800 SiPM channels on the focal plane show remarkable agreement with clear peak separations, with a uniform spacing of ~36 ADC for this case.

HELIX Hodoscope



▲ Hodoscope with the measurement system to get a fiber map

The scintillating fiber hodoscope consists of four 150-fiber ribbons arranged in a single layer. Each ribbon is made of BCF12 plastic scintillating fibers from Saint-Gobain Crystals with a 1 mm^2 square cross section and a length of 1 m. The active area is 60 cm × 60 cm covering the full radiator area. The fibers of the ribbon are woven into a Delrin cookie with a position-multiplexed pattern (150→64) to mate with a sensor which is the same SiPM used for the RICH. The outputs of the SiPMs are then read by the RICH front-end board.



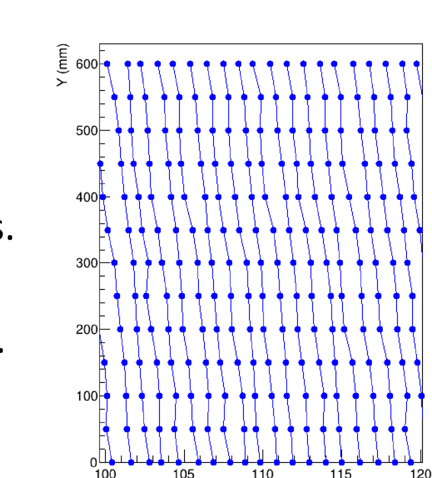
▲ Delrin cookie with fibers and its back side with a multiplexed fiber pattern

Fiber map and spatial resolution

Because the flexible fiber ribbons are not completely colinear, a table is generated to map 2D fiber positions to channel IDs by scanning the fibers using a ^{90}Sr radioactive source.

- The fiber fired by the source is found based on the level of signal rates.
- The measurement system for the mapping locates the source at the desired position with a precision of 1 mm along the non-bending plane.

- ➡ A fiber map is produced to provide the location of all 600 fibers.
- ➡ A tentative spatial resolution of 0.33 mm is obtained.
- ⇨ With the achieved spatial resolution, the hodoscope can improve uncertainties of particle trajectories at the radiators in the non-bending plane by a factor of >10 compared to that of Monte-Carlo simulation without the hodoscope.



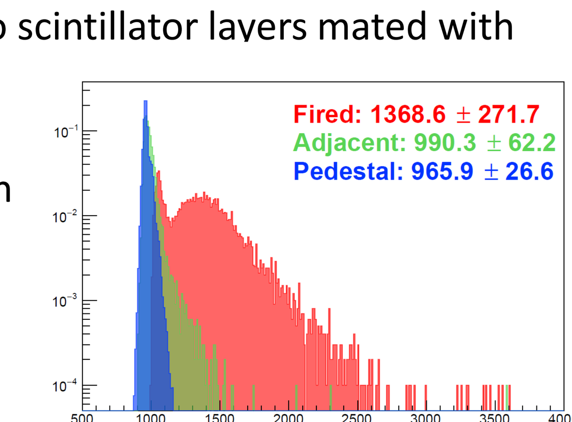
▲ A part of the fiber map obtained by scanning with a radioactive source.

Cosmic-ray muon signals from the hodoscope

Charge signals from ground-level cosmic-ray muons hits are taken with the hodoscope on the bench but read out by the flight RICH electronics.

- External triggers produced by a telescope composed of two scintillator layers mated with photomultipliers are used to trigger the HELIX DAQ system and force readout of the hodoscope outputs
- "Fired" is a signal of a fiber with the largest signal is chosen in an event, and "Adjacent" is an averaged signal of two adjacent fibers of the fired one.

- ➡ Muon hits on the hodoscope have been detected!
- ➡ The signal ratio between the fired and adjacent fibers is (preliminary) ~8%, which may be explained by corner-clipping tracks, as well as crosstalk in the fiber and electronics.



▲ Charge signal distributions of cosmic-ray muons from the stand-alone hodoscope test

Plan

- The RICH calibration at different temperatures is currently in progress.
- Once the hodoscope is installed, performance verification of the full instrument will follow in the 3rd quarter of this year.
- A first HELIX long-duration balloon flight is scheduled for late spring 2024 from Kiruna, Sweden.

[1] S. O'Brien at al., ICRC (2021); [2] M. Tabata et al., ICRC (2019); [3] J. Fleury et al, Journal of Instrumentation 9 (01) (2014) C01049–C01049

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