High Energy Light Isotope eXperiment

Isotopic Composition of the Light Cosmic Rays with HELIX

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TeVPA 2022 - Kingston

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HELIX Collaboration

Queen's University

Chiba University

McGill University

Indiana University

The Ohio State University

The University of Chicago

Isotopes Offer Insights

Secondary-primary ratios are sensitive to the material pathlength

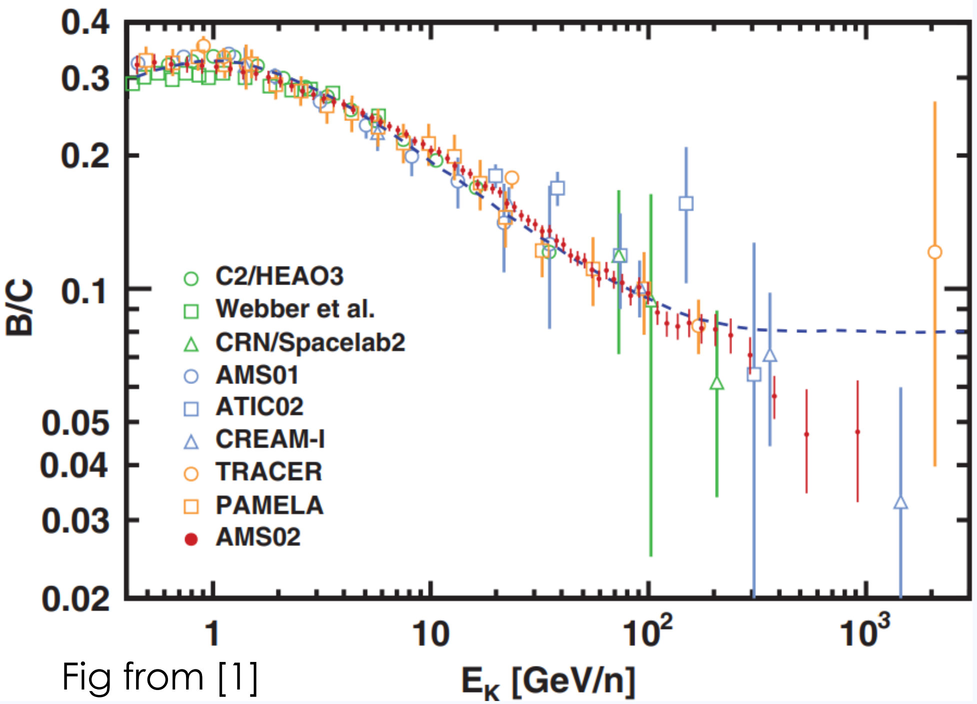

Fig from [1]

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Degeneracy of diffusion coeff and halo size in models like GALPROP

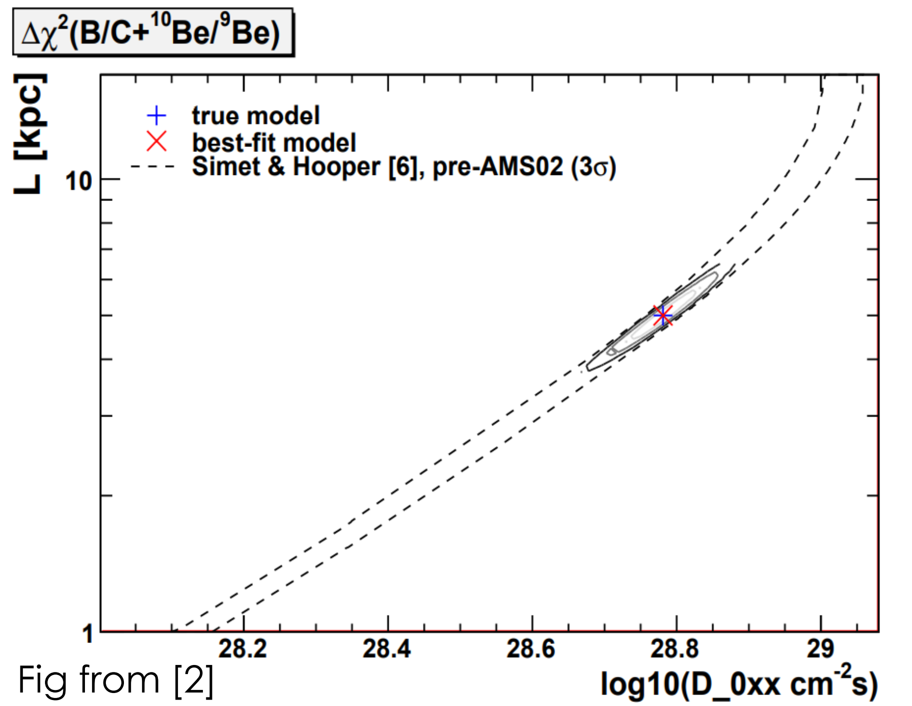


Fig from [2]

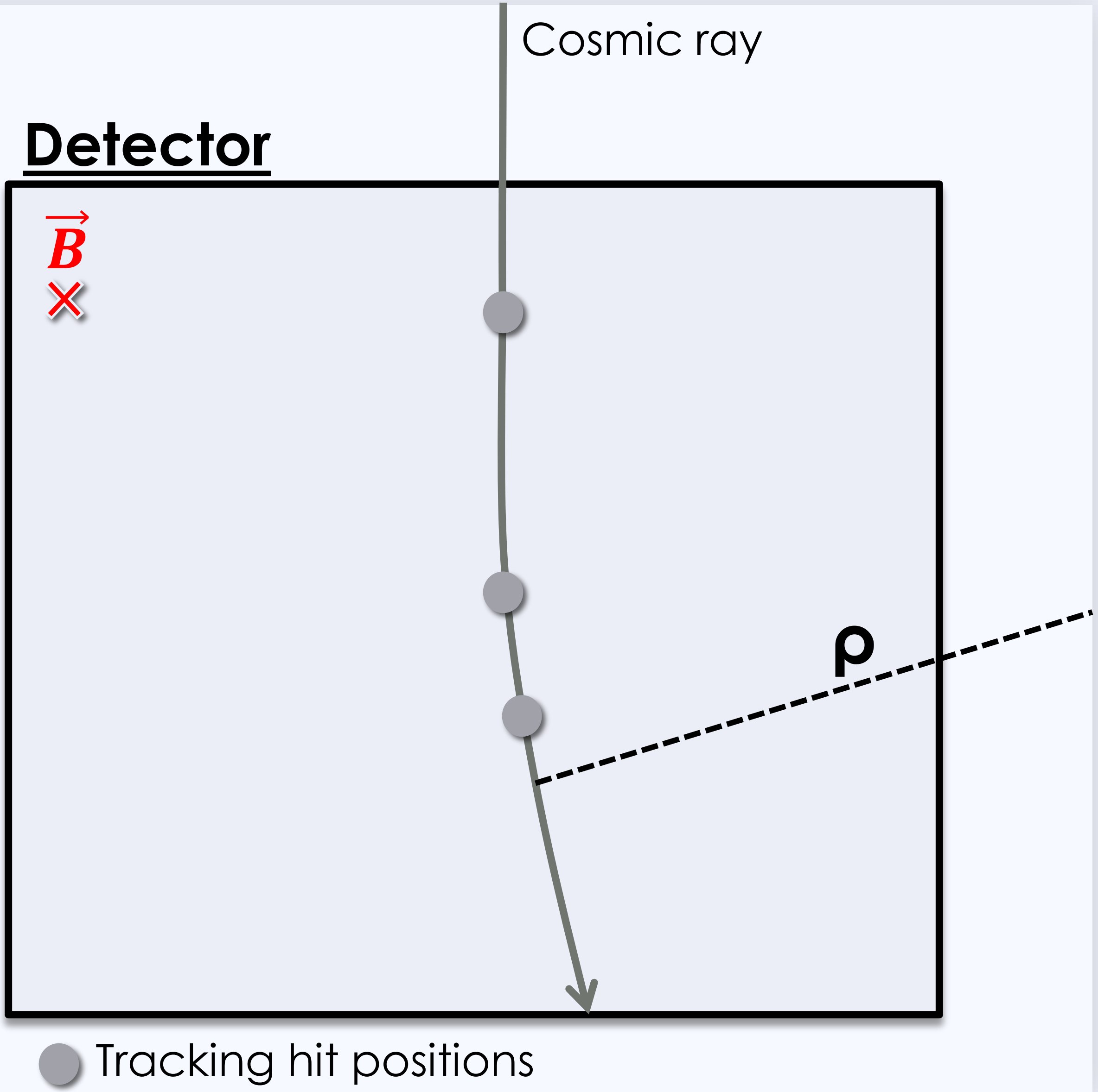
Need to measure unstable (clock) isotopes like **^{10}Be** at higher energies

Magnet Spectrometers

1. Measure rigidity in magnetic field
   - $R = \frac{p}{Ze} = \rho B$
2. Measure velocity, β, and charge, Ze, separately
3. Calculate the mass of particle
   - $m = R \frac{Ze}{\gamma\beta}$

* Requires high precision tracking and strong magnetic field for high precision mass measurements

HELIX is this capable experiment

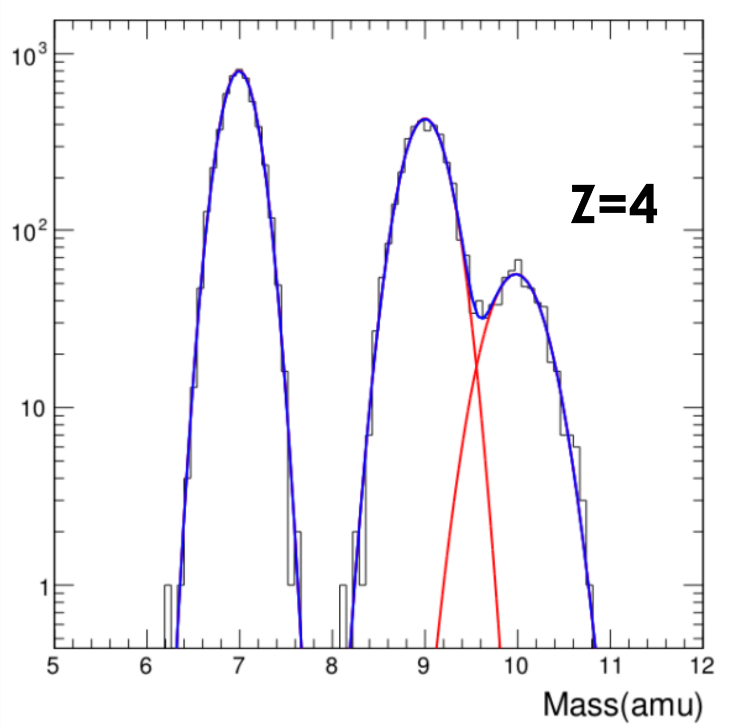


Mass Resolution with Magnet Spectrometers

$$\left(\frac{\delta m}{m}\right)^2 = \left(\frac{\delta R}{R}\right)^2 + \gamma^4\left(\frac{\delta \beta}{\beta}\right)^2$$

- Challenge in confidently separating the close peaks of ^{9}Be & ^{10}Be
- For beryllium isotopes, a good benchmark is **2.5%** mass resolution
- Resolve ^{10}Be, shown in histogram

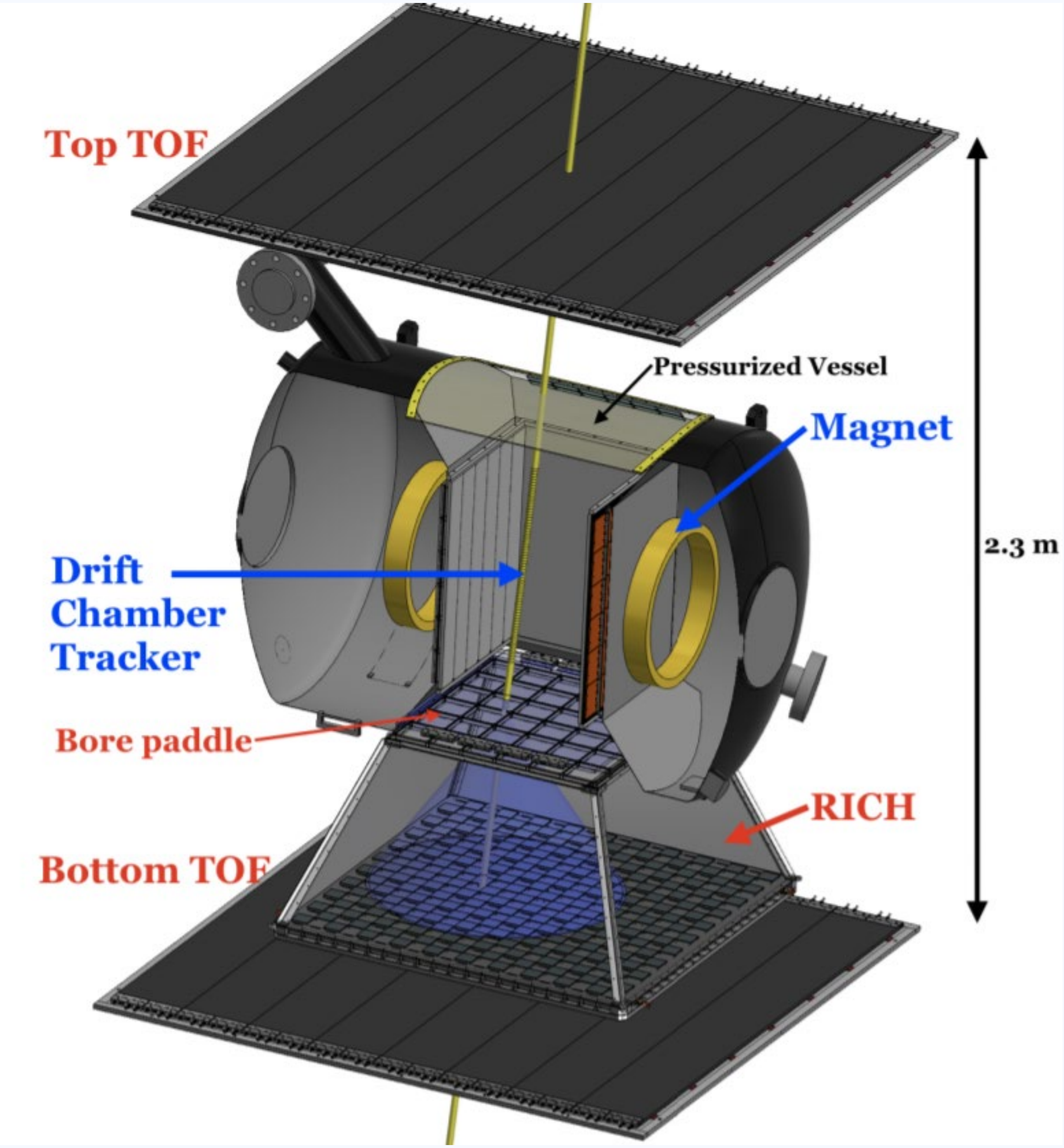
HELIX is designed to meet this resolution goal



[3] Park, N. ICRC 2021

Measuring Mass with HELIX

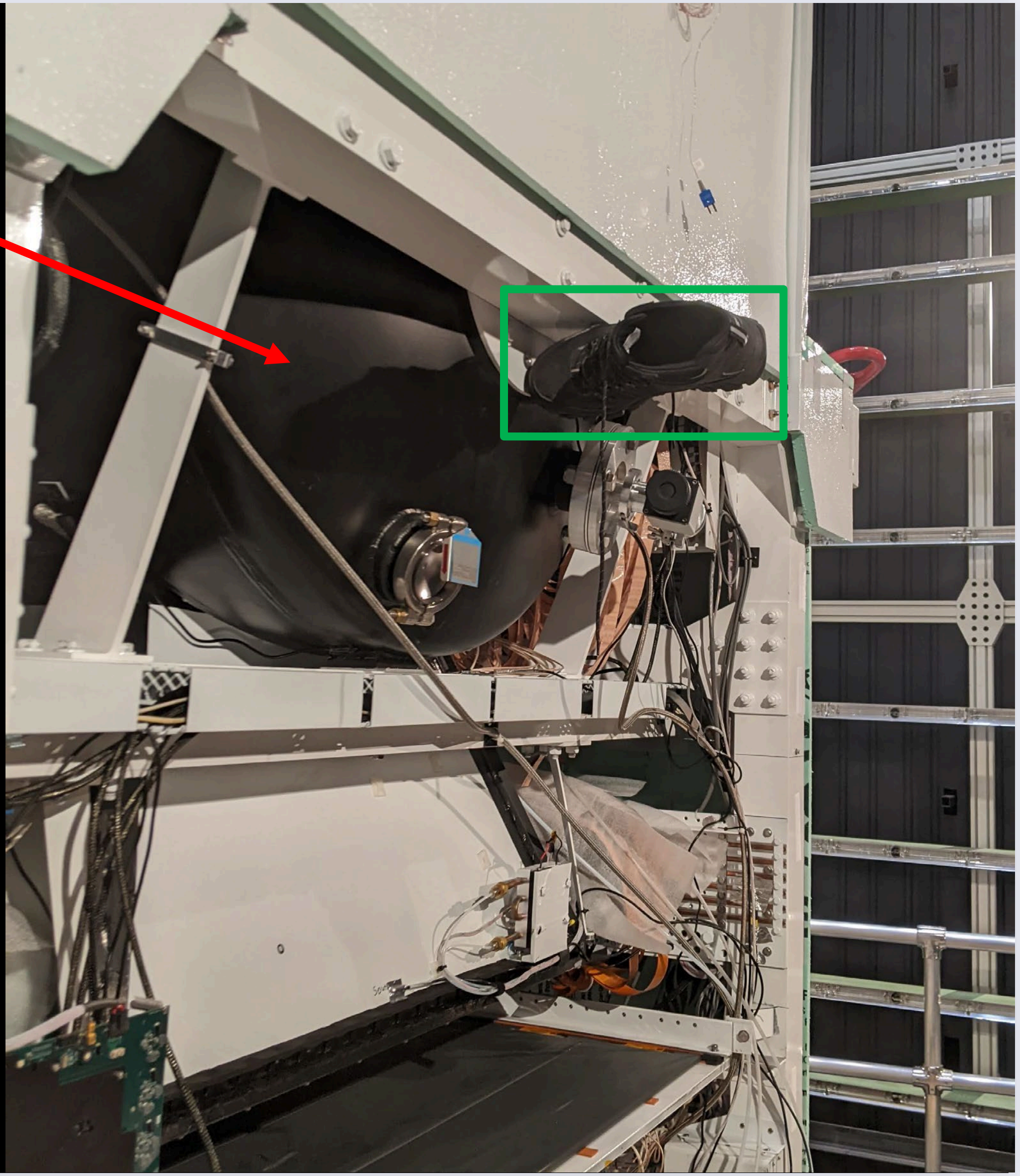
- Time-of-flight system to measure Ze and β
- Drift Chamber Tracker for R measurement
- Higher $\gamma\beta$ measurements with Ring Imaging Cherenkov (RICH)
- Staged approach – HELIX stage 1 shown



Thermal Vacuum Test, Jan 2022 at NASA Armstrong Test Facility

SUPERCONDUCTING MAGNET

- Good for levitating steel-toe boots and deflecting relativistic particles
  - Binary measurement of magnet ON/OFF
- Cryogen Operation, 4K
  - 1 Tesla field
- Flown previously on successful HEAT balloon experiments [4]
  - Proven flight heritage
- Up to 7 days of hold time

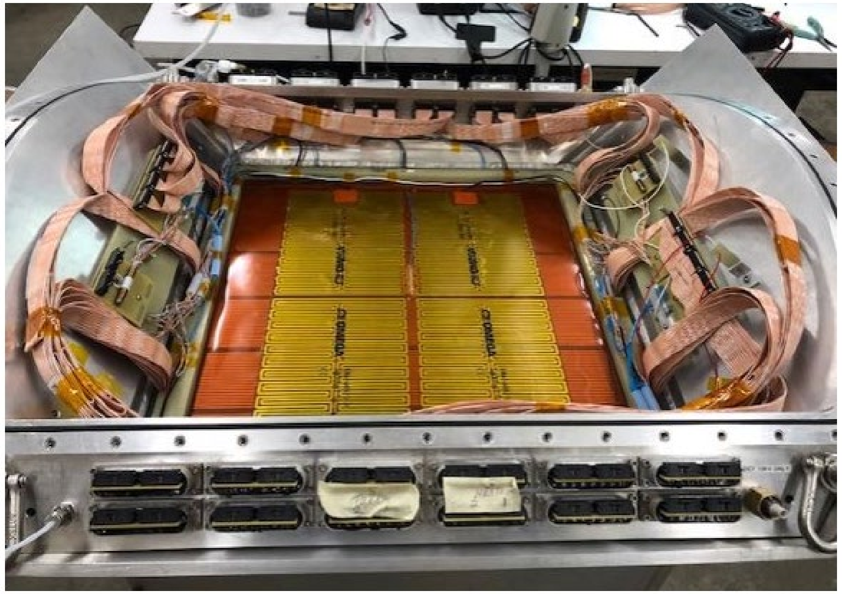


Measures the Rigidity, *R*

Drift Chamber Tracker

- Gas-filled (CO_2 + Ar) tracker
  - 1 atm during flight
  - Charged nuclei leaves ionization trail
- Detect ionization with sense wires
  - Strong electric drift field, 1.3 kV/cm
- Density and drift field contribute to resolution
  - Gas flow system with thermal and pressure monitoring, and mixing control.
  - High voltage control system with field-shaping wires near sense wires

Inside the DCT



DCT inside vessel

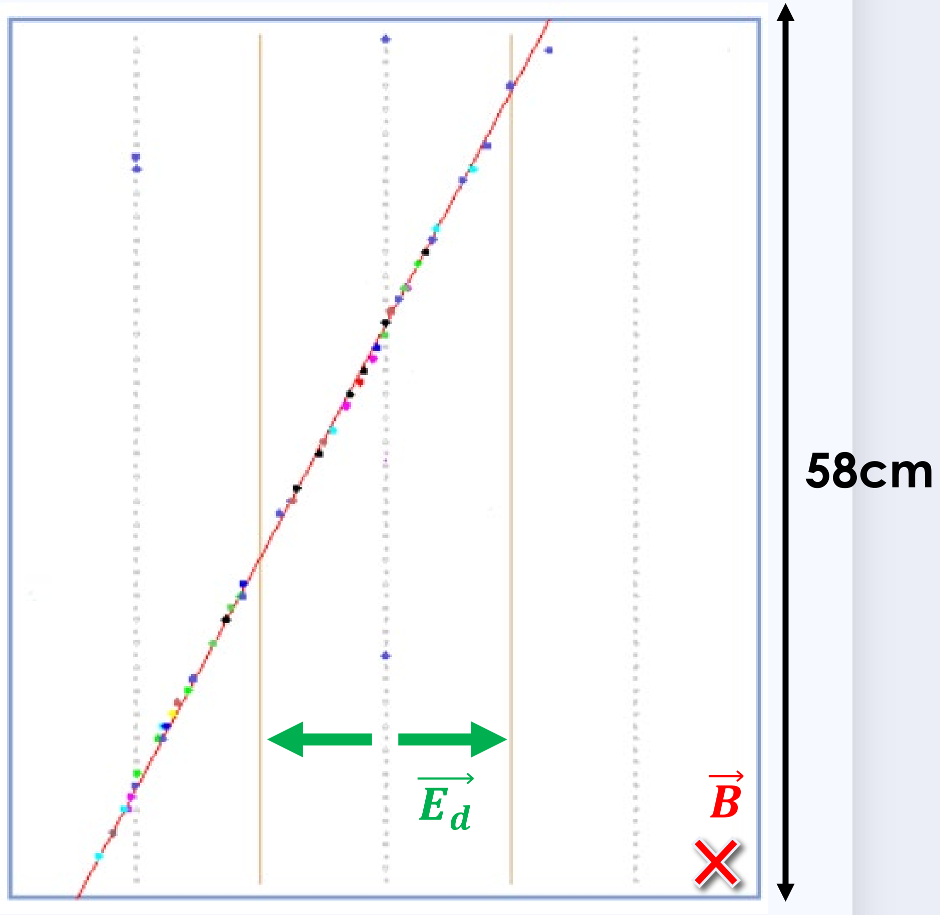
DCT Muon Tracks

- Bending plane – impact parameter from the induced current of drifting ions
  - 3 separate sense wire planes
  - 216 sense wires total
- Additional non-bending plane measurement along sense wire
  - Readout per end of sense wires

Aiming for better than 70μm resolution for $Z > 3$

Maximum Detectable Rigidity ~ 800GV

DCT Bending Plane Display

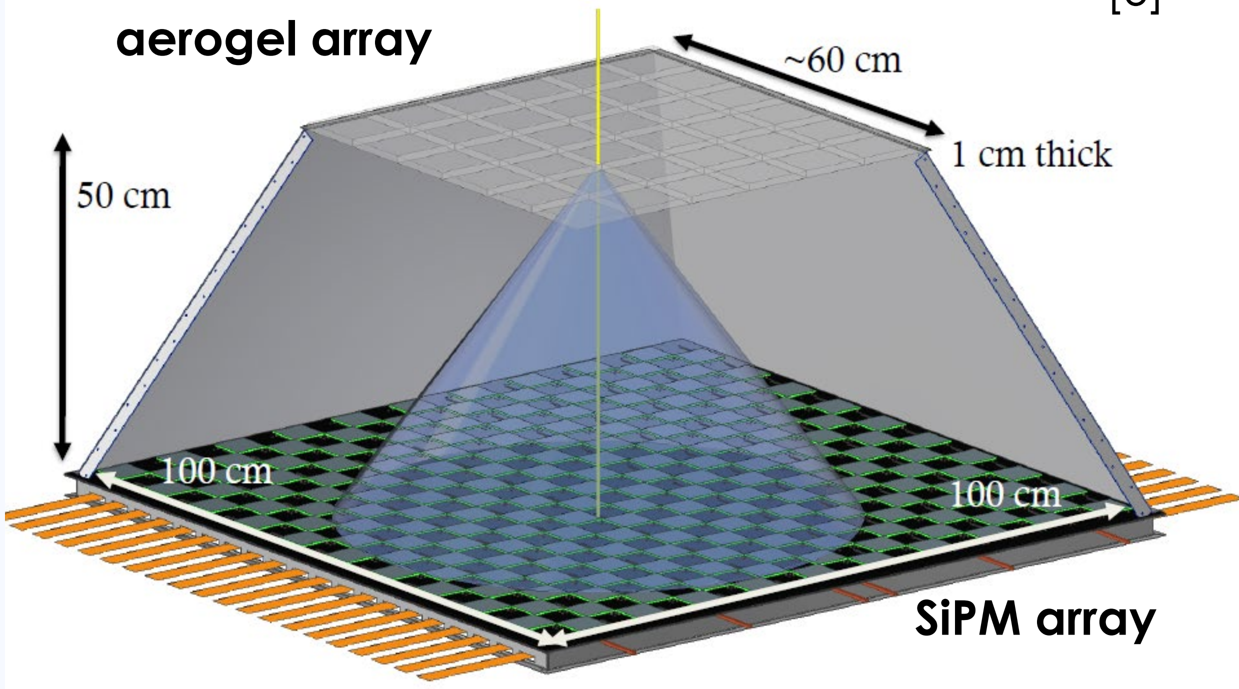


Example muon straight-through

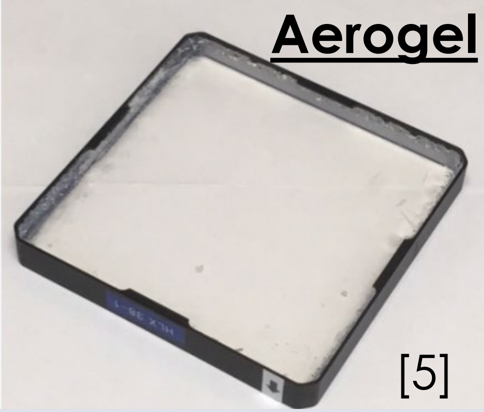
Measures the velocity, β

Ring-Imaging Cherenkov System (RICH)

- High $\gamma\beta$ GCRs radiate in aerogel medium
- Transparent with high index of refraction, $n \approx 1.15$ [5]
- Extensive testing of aerogel:
  - vacuum, thermal, beam line scanned, and shaken [6]
  - $\beta = \frac{1}{n \cos\theta_C}$



[6]



[5]

Measures the velocity, β

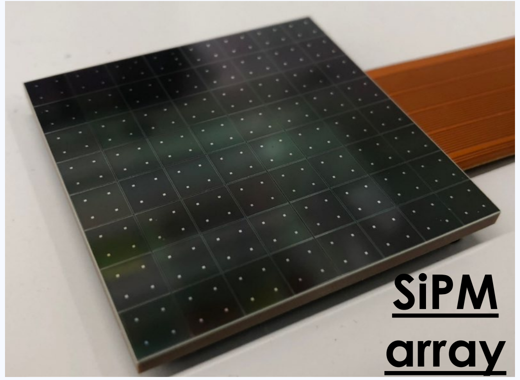
RICH Focal Plane

- Focal plane of Hamamatsu SiPMs
- 1 m^2 area – half-filled in Stage 1
  - 200 SiPM arrays – 12,800 SiPMs
  - Fully populated, 400 SiPM arrays in Stage 2

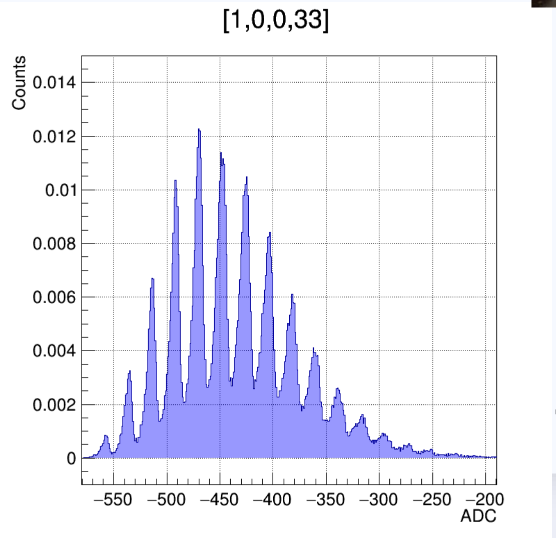
Aiming for β resolution of 0.1% ($Z > 3$)

Stage 1 populated Focal Plane

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



SiPM array



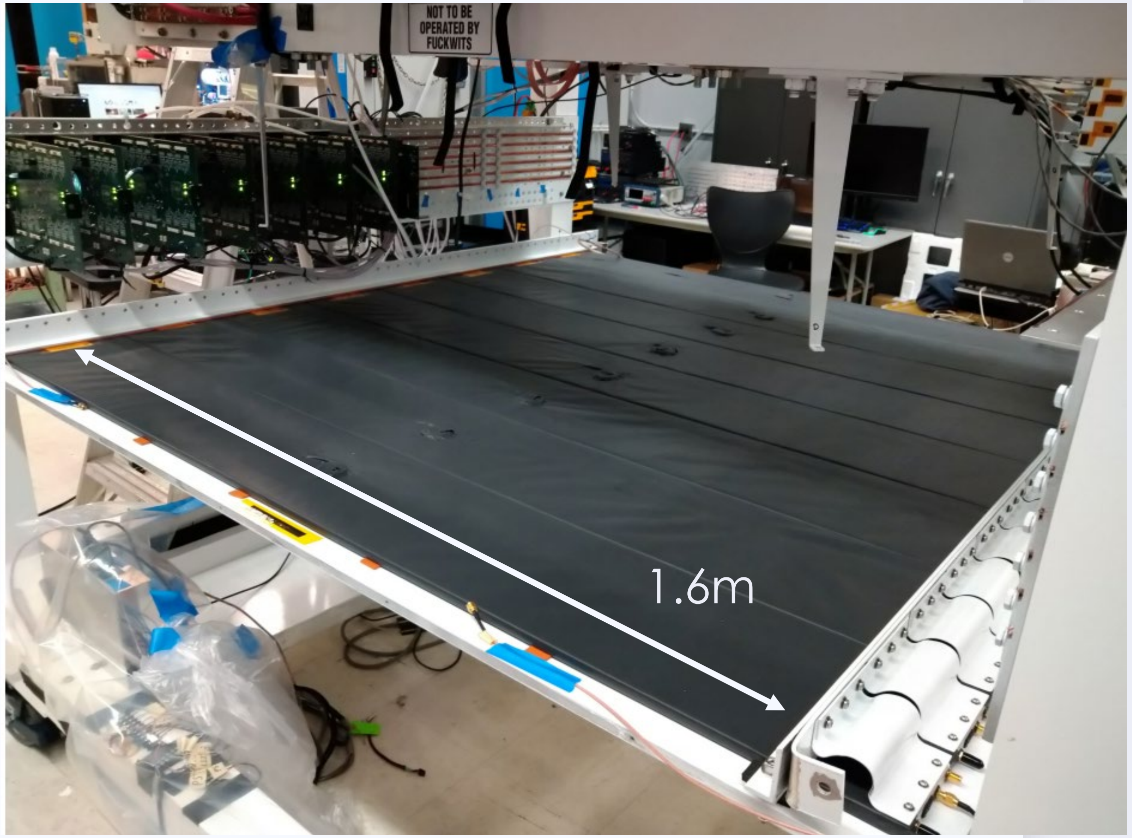
Flight system readout

Measures the velocity, β, and charge, Ze

Time-Of-Flight

- Made up of three planes of EJ200 scintillator:
  - Top and bottom have 8 paddles
  - Aperture defining scintillator paddle just under the DCT
- 2.3 m separation of top + bottom
  - High-precision β up to 1 GeV/n, turn-on of the RICH
- Total acceptance ~ 0.1 m^2 sr
- 8 SiPMs per end of paddle

Bottom TOF installed on payload



Measures the velocity, β, and charge, Ze

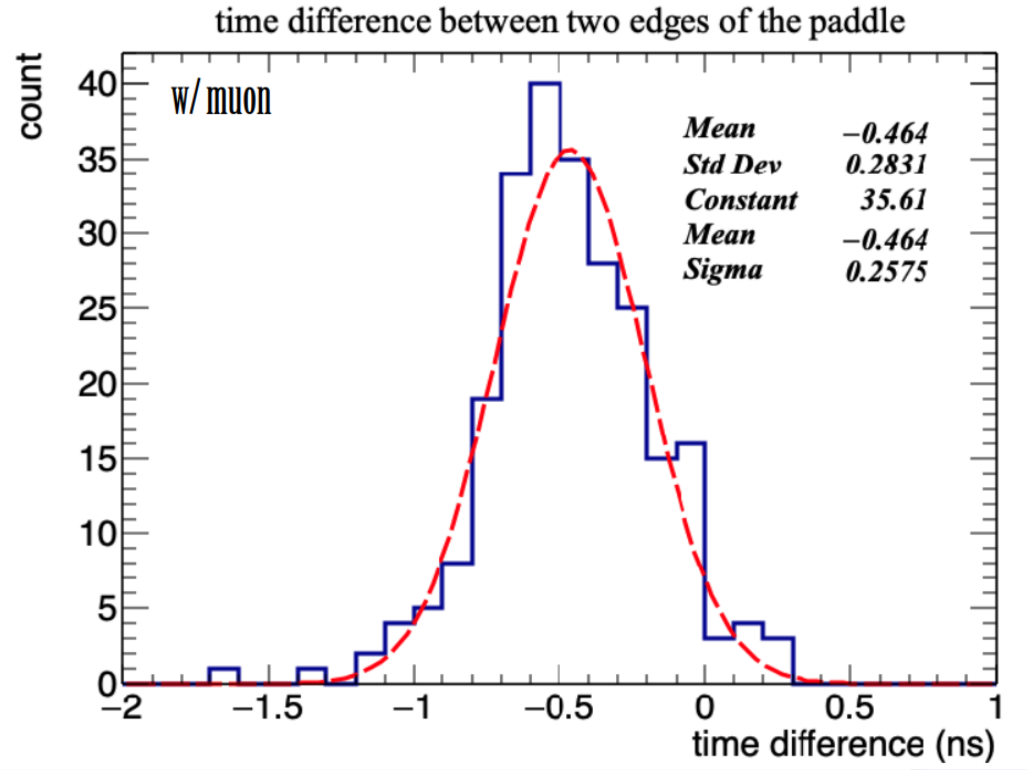
Time-Of-Flight Readout

- Measuring at both ends yields hit position along paddle
  - Complements the DCT bending plane
- Fast channel - timing between sections for β
  - TDC timing resolution is better than 25 ps

On track for timing resolution better than 50ps for $Z > 3$

- Slow channel – amplitude for Ze measurement

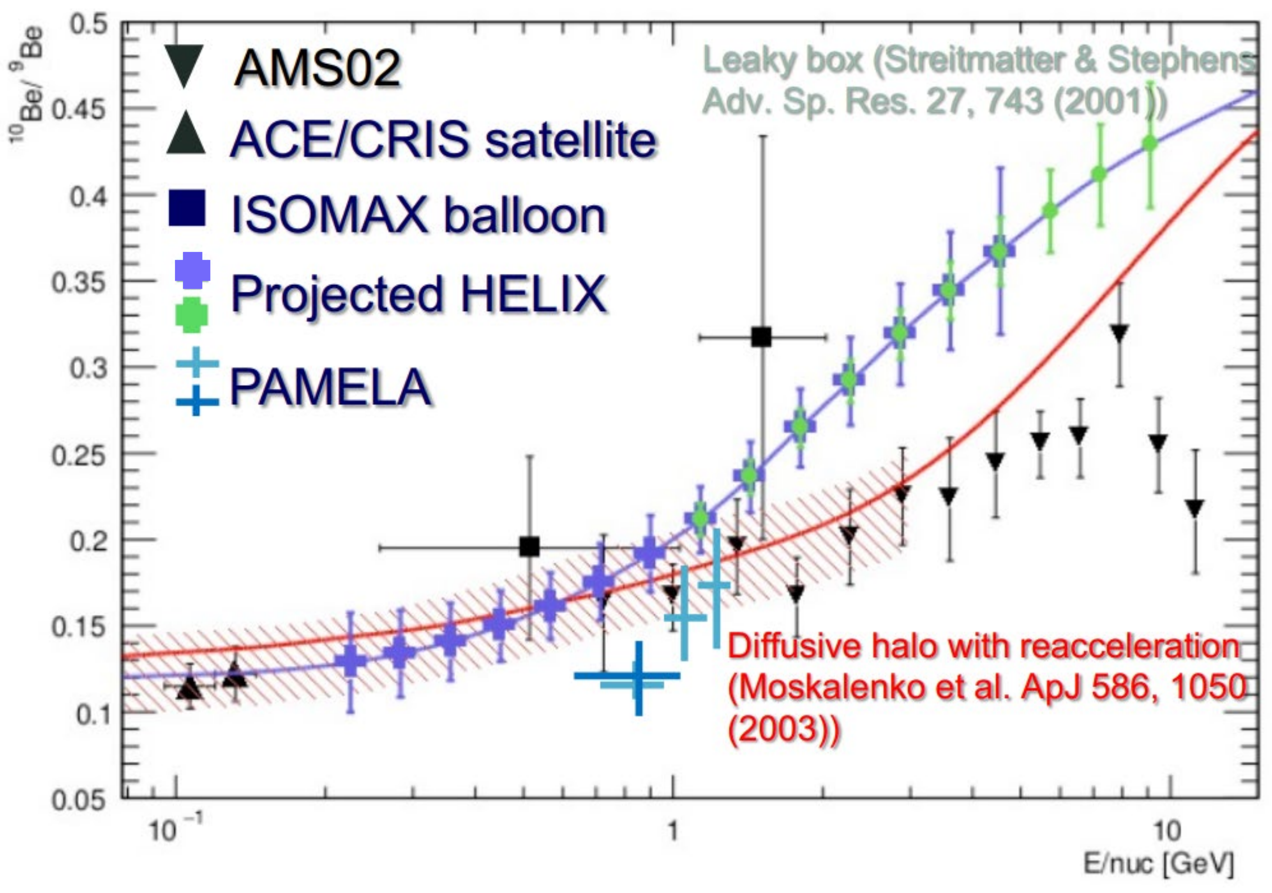
Aiming for β resolution of 0.1% and Ze resolution of 0.1e (Z<11)



[3] Park, N. ICRC 2021

EXPECTED HELIX PERFORMANCE

- Targeting 2.5% mass resolution
- HELIX will resolve Be isotopes:
  - Stage 1: Up to E ~ 4 GeV/n [blue]
  - Stage 2: Extends to 10 GeV/n [green]
- Chemical and isotopic composition of several light nuclei



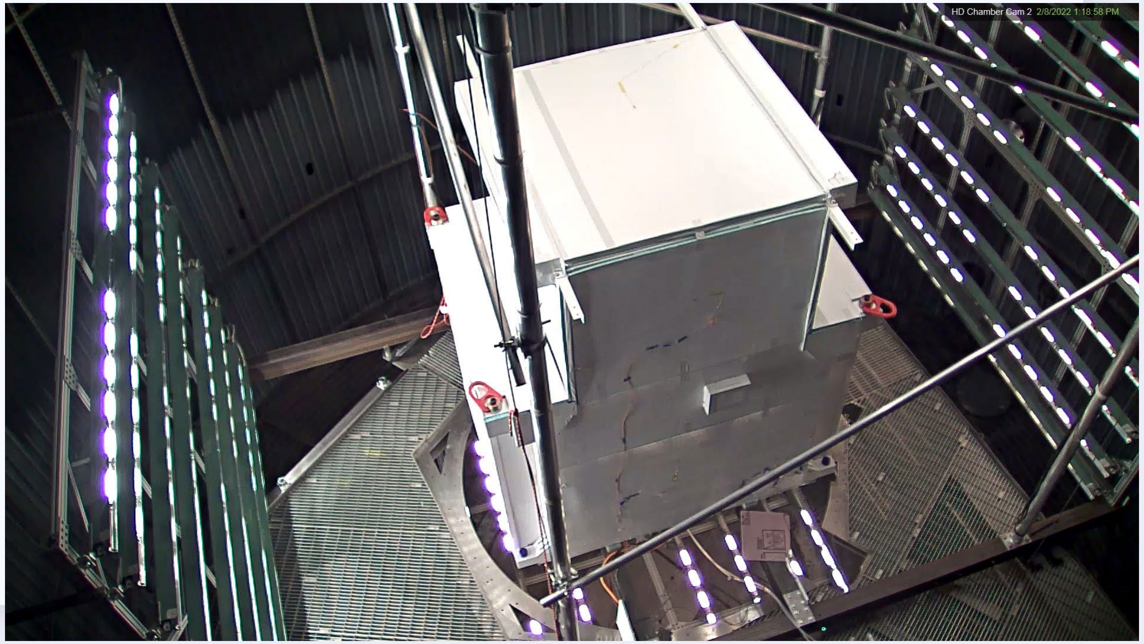
HELIX will significantly improve our understanding of GCR propagation

Conclusions

NASA Grant 80NSSC18K0232

- HELIX will resolve Beryllium isotopes in the first stage up to 4 GeV/n with mass resolution ≤ 3%
- Production of flight components complete
- Thermal vacuum test of payload successful
- Working for Long Duration Balloon flight opportunity

Isotope measurements significantly improve our understanding of GCR propagation



Citations

[1] M. Aguilar et al. (AMS Collaboration) Phys. Rev. Lett. 120, 021101 – Published 11 January 2018

[2] Miguel Pato et al JCAP06(2010)022

[3] Park ICRC 2021 Berlin https://pos.sissa.it/395/091

[4] Nutter, S, et al. Detection of Cosmic-Ray Antiprotons with the HEAT-Pbar Instrument. Aug. 2001.

[5] Tabata et al. NIM A, 952 2020

[6] O'Brien ICRC 2021 Berlin https://pos.sissa.it/395/090

[7] Wisher ICRC 2019 Madison https://pos.sissa.it/395/090

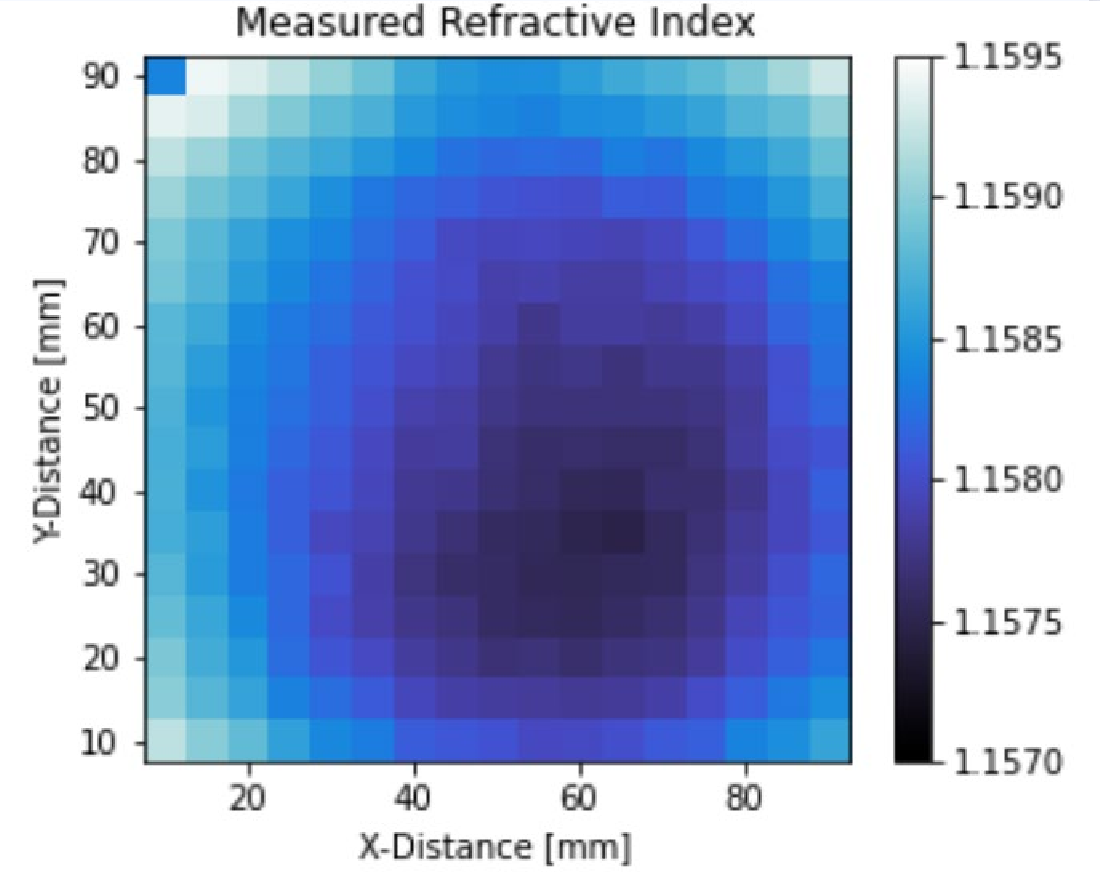
Extra Stuff

Other systematic Uncertainties

- New cross-section measurements at higher energies are needed
- Isotopes produced above the HELIX payload in atmosphere during flight, relevant for interpreting the data as GCR fluxes
- Isotope production during propagation in diffusion-halo models (or others) that include nuclear interaction networks, relevant for interpreting data in the context of the models
  - See the proceeding by Neeraj Amin for NA61/SHINE from ICRC 2021
  - And see the relevant paper by Maurin et. al. (2022) on the arxiv: arxiv:2203.00522

Aerogel measurements

- Beam line scanned
  - TRIUMF – electrons
  - Using CCD to image Cherenkov ring
- 36 aerogel tiles
- See O'Brien ICRC 2021 proceeding for more details

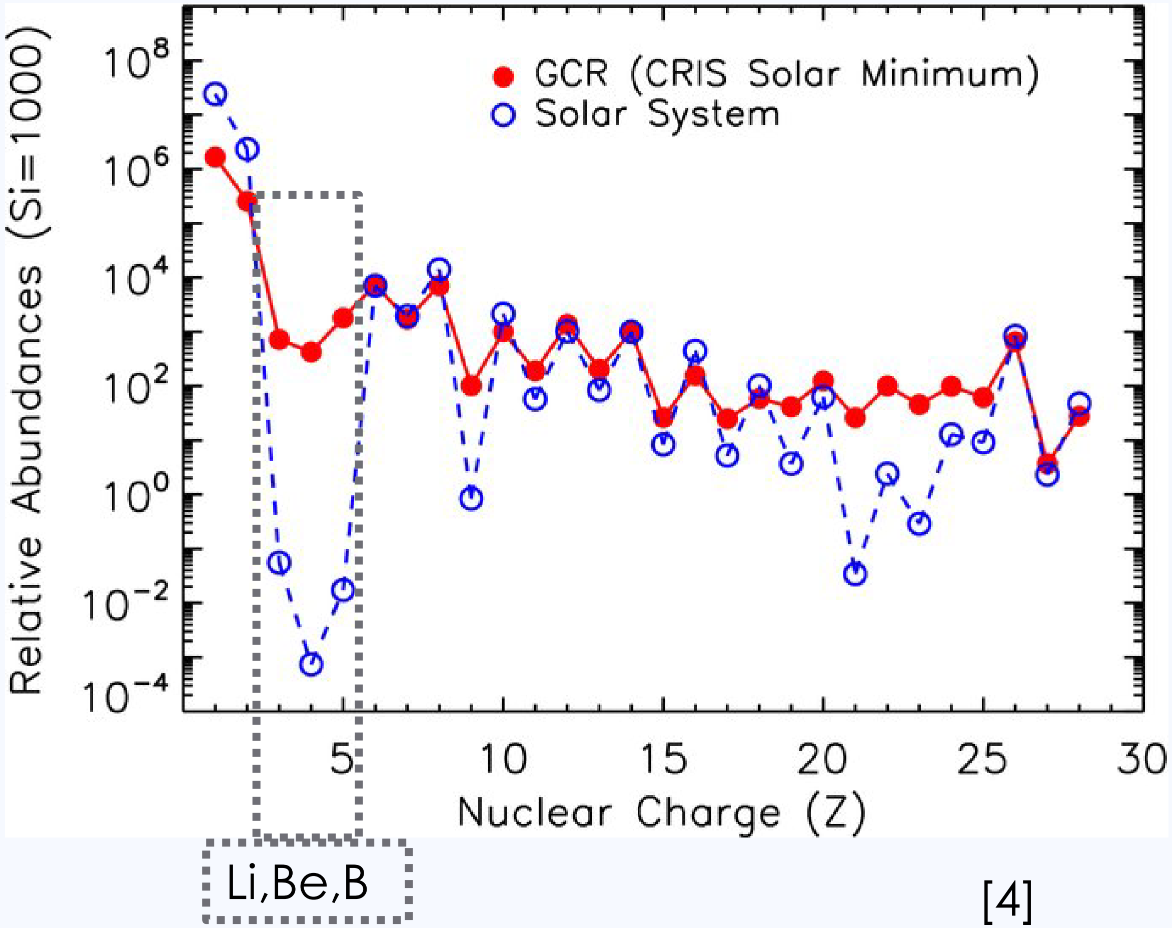


GCR Abundances

- Sources accelerate He, C, O, Si and Fe (primary cosmic rays)
- Overabundant in some elements
  - Li, Be, B and F
  - Sc, Mn, sub-iron
- Spallation (high energy collisions) of primaries produces lighter elements
- Wealth of precise data from AMS-02 on the GCR nuclei

  Nuclei => Charge

  Isotope => Mass



[4]