High Energy Light Isotope eXperiment

Isotopic Composition of the Light Cosmic Rays with HELIX

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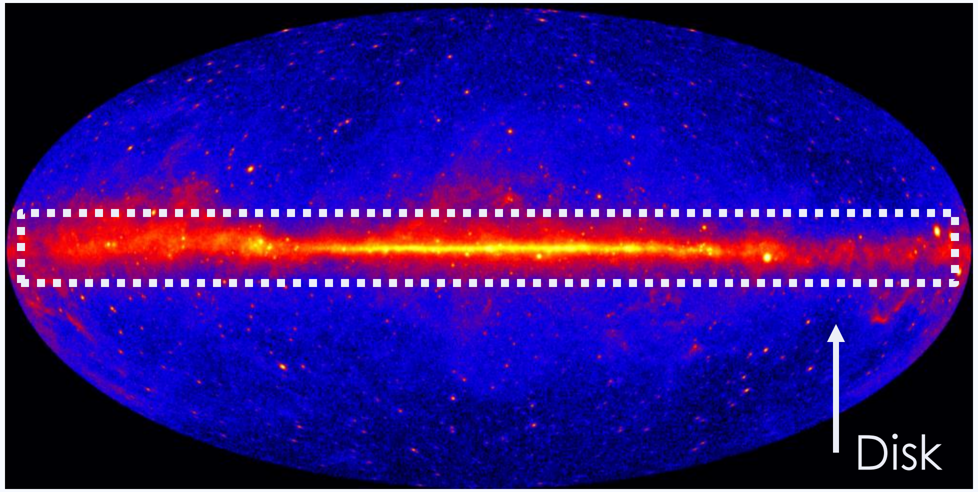
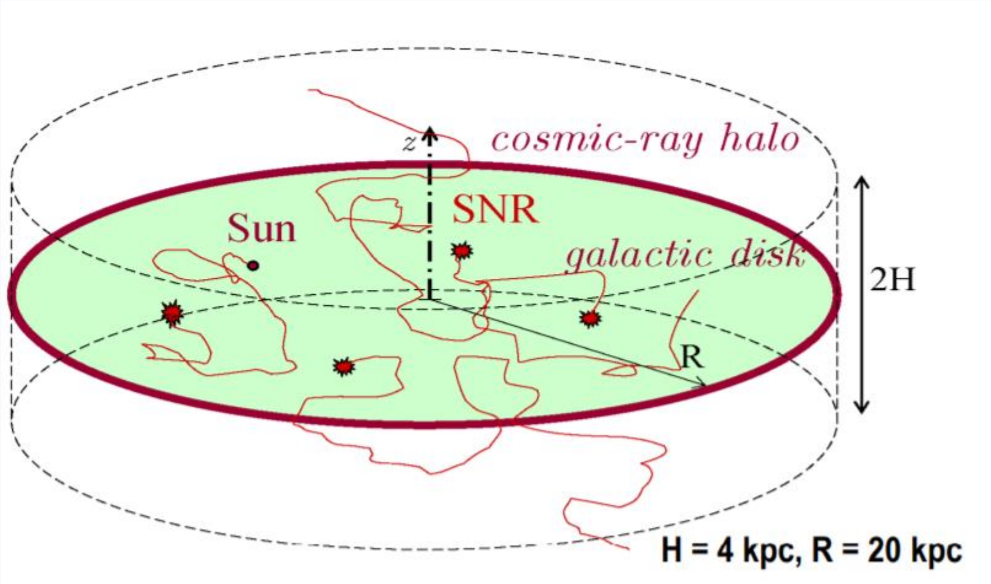
PIKIMO 2022 - Cincinnati

Background on Galactic Cosmic Ray Propagation

The Galaxy in gamma rays



[1] Fermi γ-rays >1 GeV



[2] Ptuskin slides 2013 Cargese

- Mostly protons, but many kinds of nuclei
- Cosmic rays produce gamma rays and other cosmic rays when colliding with gas, the Interstellar Medium

- Diffusion-halo model, with some parameters not so well understood

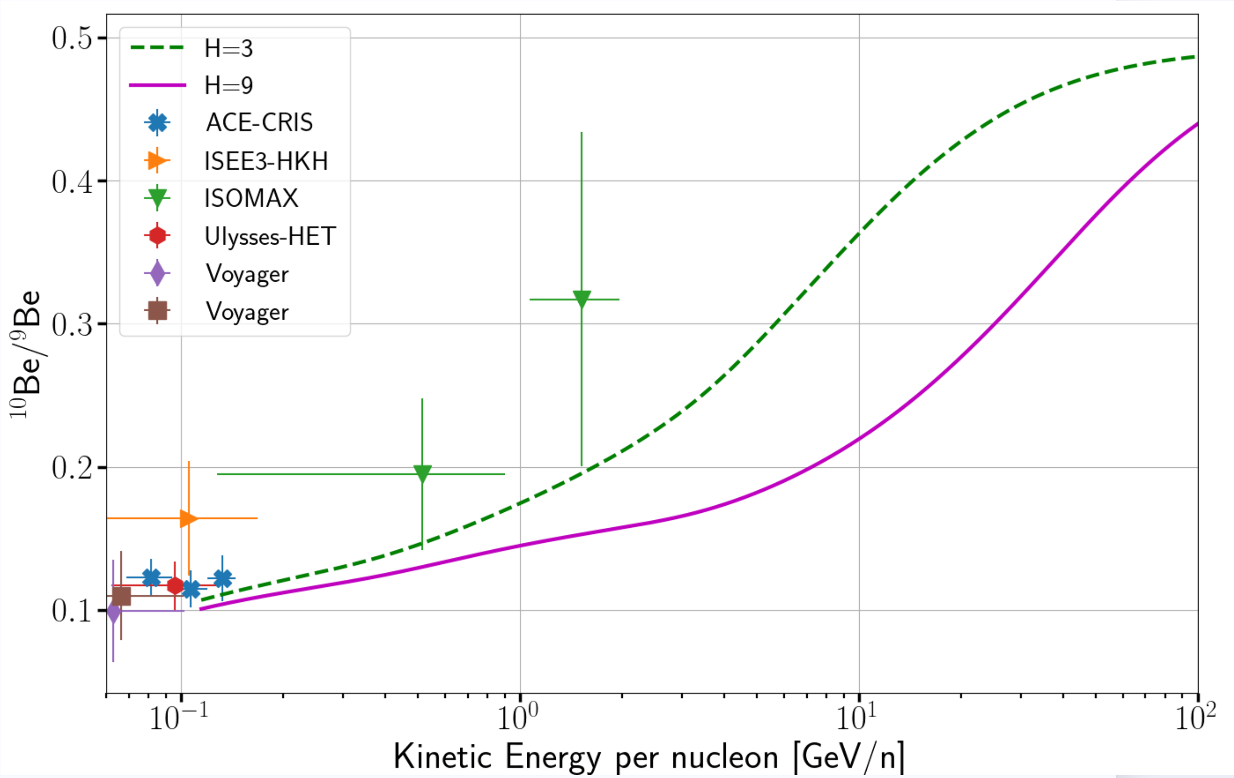
How far do cosmic rays extend into the halo?

Beryllium Isotopes in GCRs

- Beryllium nuclei are secondary
  - products of interactions during propagation
- ^{9}Be is stable, ^{10}Be is long-lived but unstable
- Ratio is sensitive to time of GCR propagation
  - Larger cosmic ray halo, H, longer timescale for diffusion into that halo
- Until recently, very few intermediately high energy measurements…

^{10}Be has half-life of 1.4 Myrs [3]

GALPROP sims with varying halo size [4]



HELIX is optimized for this kind of light nuclei measurement!

Data retrieved with [5]

Magnet Spectrometers

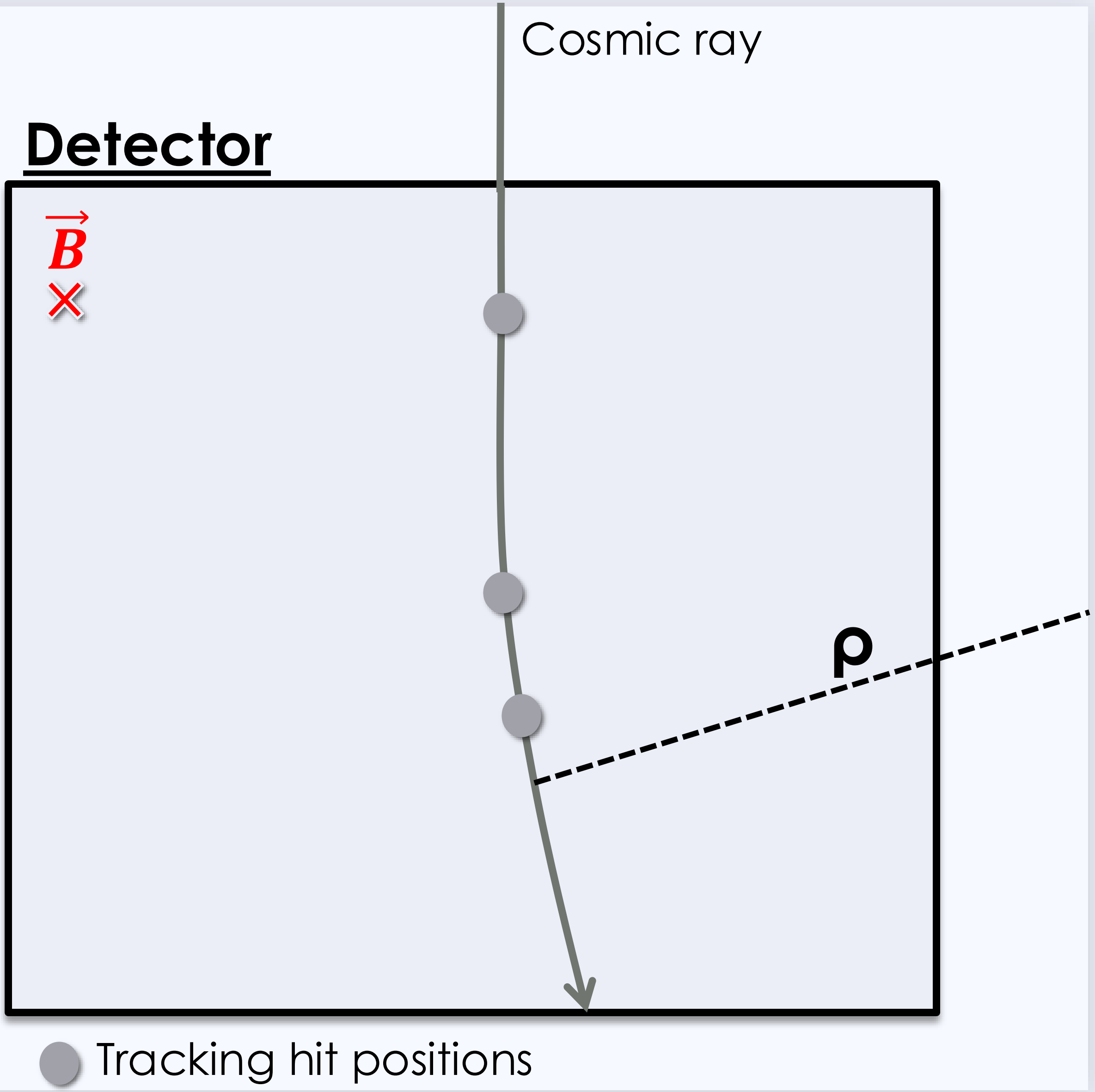
1. Measure rigidity in magnetic field
   - $R = \frac{p}{Ze} = \rho B$

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

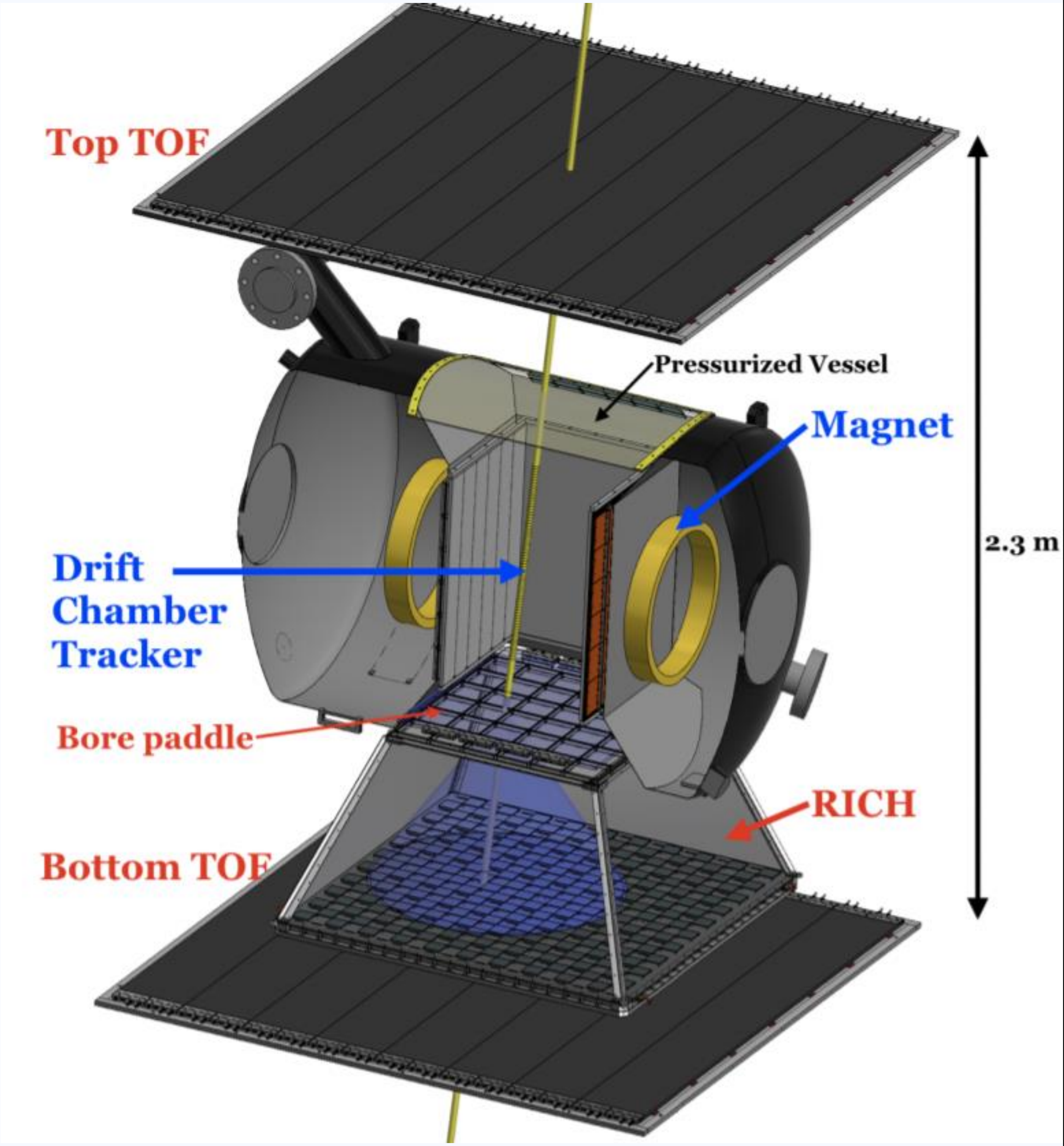
HELIX is this capable experiment



[6] Park, N. ICRC 2021

Measuring Mass with HELIX

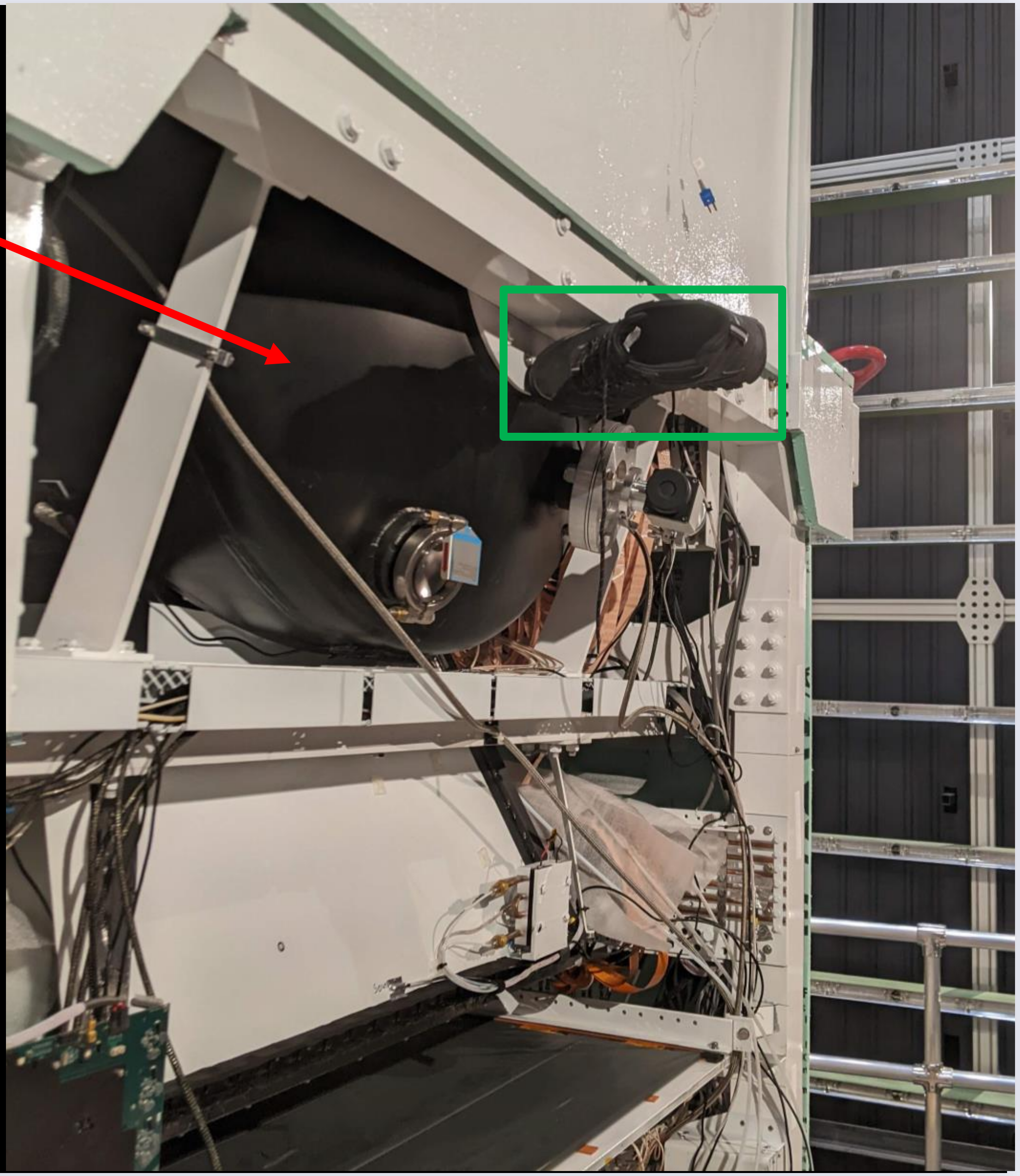
- Time-of-flight system to measure Ze and β
- Drift Chamber Tracker for R measurement
- Higher $\gamma\beta$ measurements with Ring Imaging Cherenkov (RICH)
- Staged approach – HELIX stage 1 shown



Thermal Vacuum Test, Jan 2022 at NASA Armstrong Test Facility

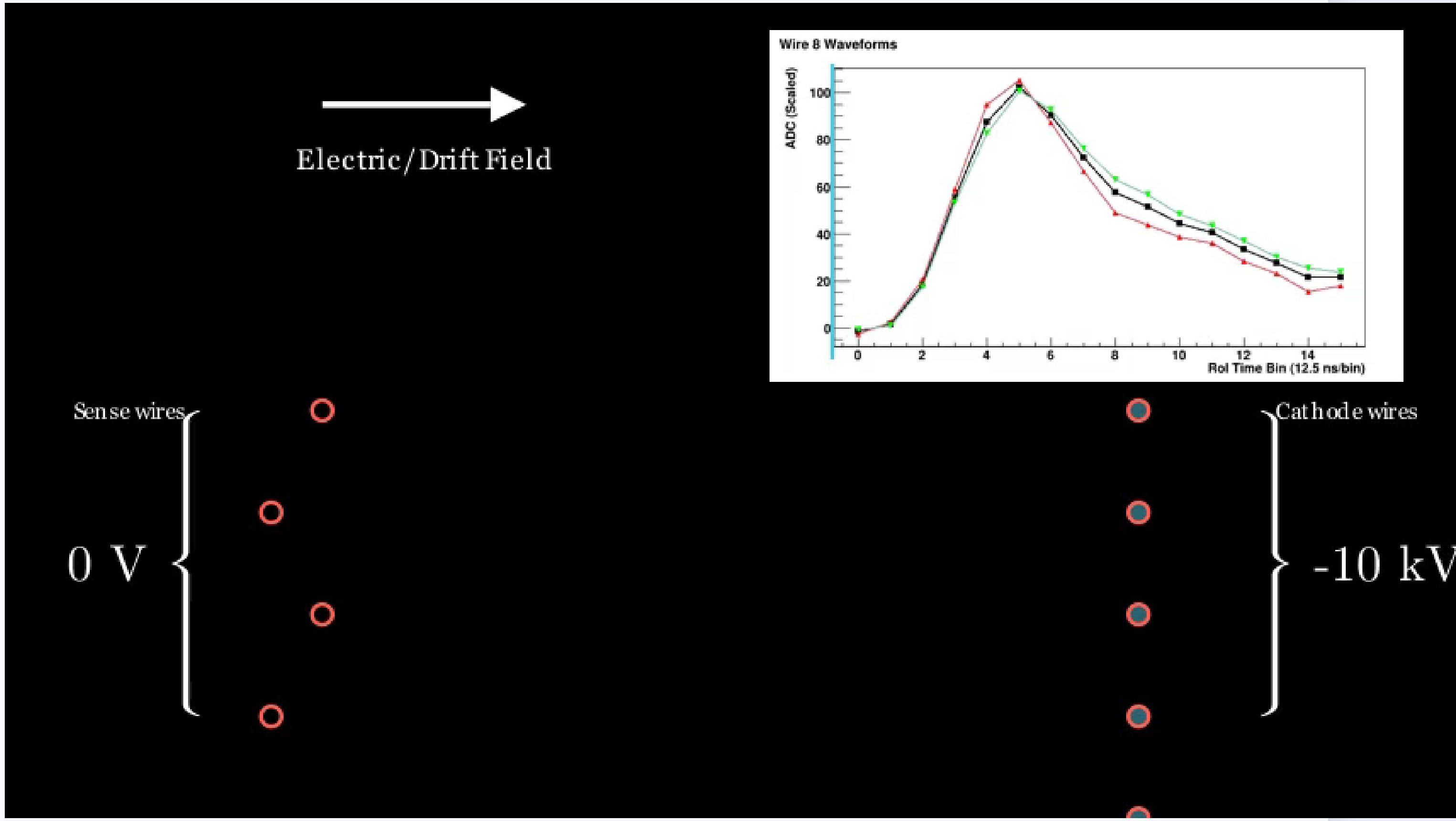
SUPERCONDUCTING MAGNET

- 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 [7]
  - Proven flight heritage
- Up to 7 days of hold time



Drift Chamber Tracker

- Gas-filled (CO_2 + Ar) tracker
  - Charged nuclei leaves ionization trail
- Detect ionization with wires
  - Strong electric drift field, 1.3 kV/cm
  - Induced current pulses map to distances
- Staggering of sense wires to resolve Left/Right ambiguity



Measures the Rigidity, R

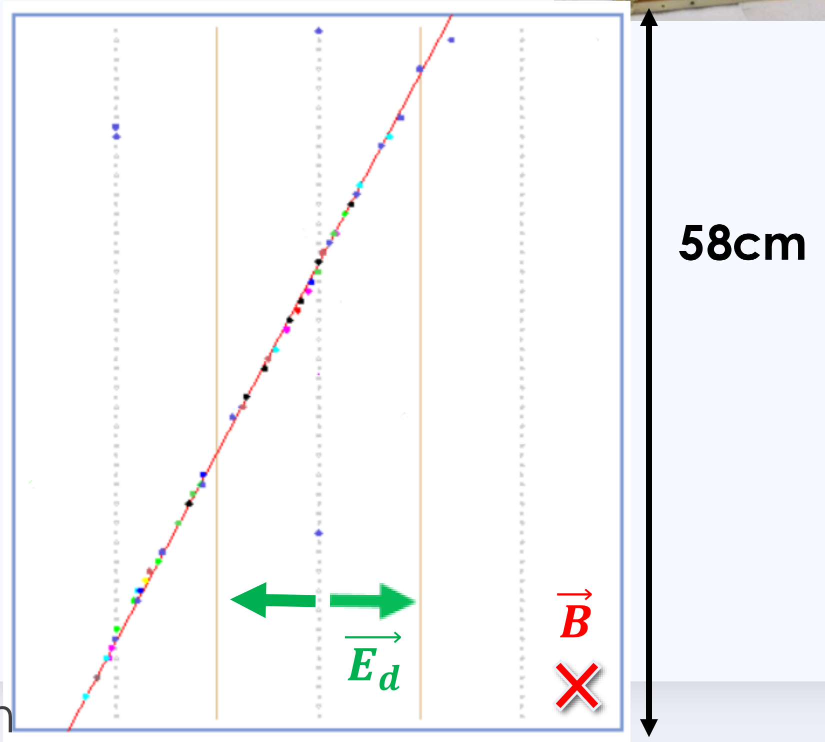
Inside the DCT

Drift Chamber Tracker

- Detect ionization with sense wires
  - 3 separate sense wire planes
  - 216 sense wires total
- Additional non-bending plane measurement along sense wire
  - Readout per end of sense wires
- Density and electric field contribute to resolution
  - High voltage control system

On track for better than 70μm resolution

DCT Bending Plane Display

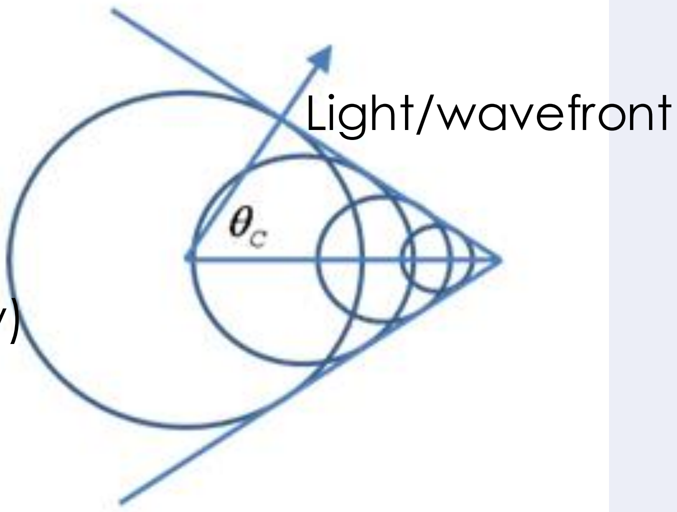


Example muon straight-through

Measures the velocity, $\boldsymbol{\beta}$

Ring-Imaging Cherenkov System

Charged particle (cosmic ray)

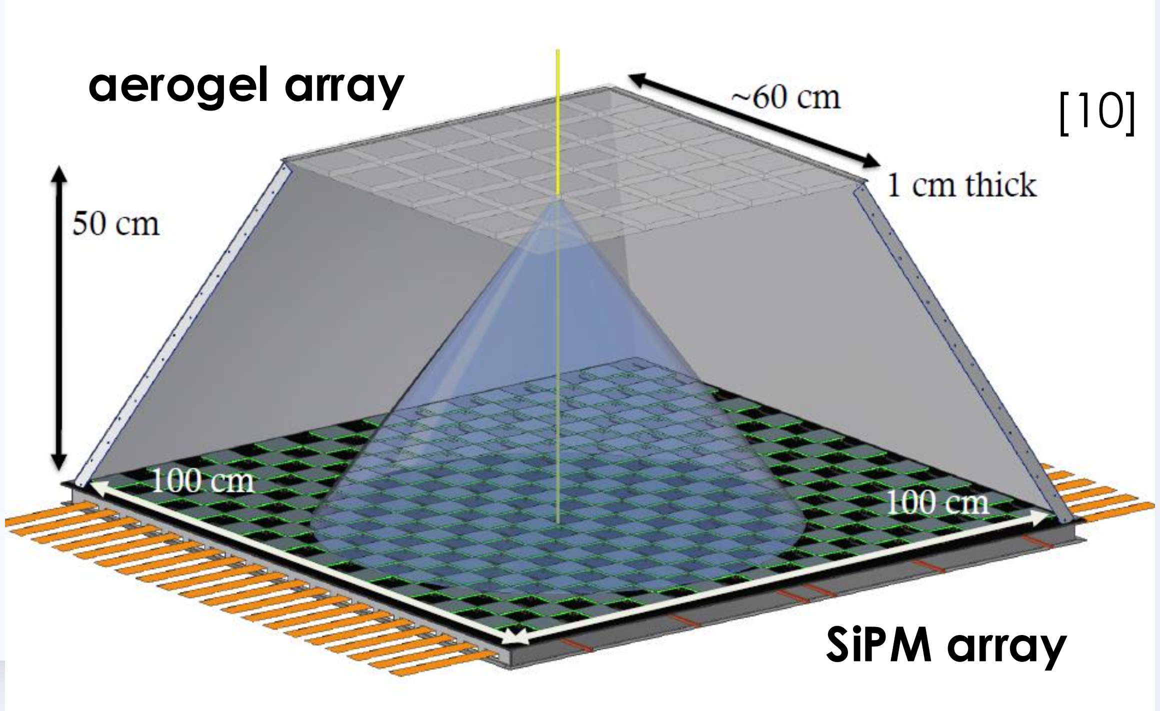


- Cherenkov light with opening angle θ_c

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

- High $\gamma\beta$ GCRs radiate in aerogel medium
- Transparent aerogel with high index of refraction, $n \approx 1.15$ [8]
- Extensive testing of aerogel:
  - vacuum, thermal, beam line scanned, and shaken [9]

Silicon PhotoMultiplier (SiPM)

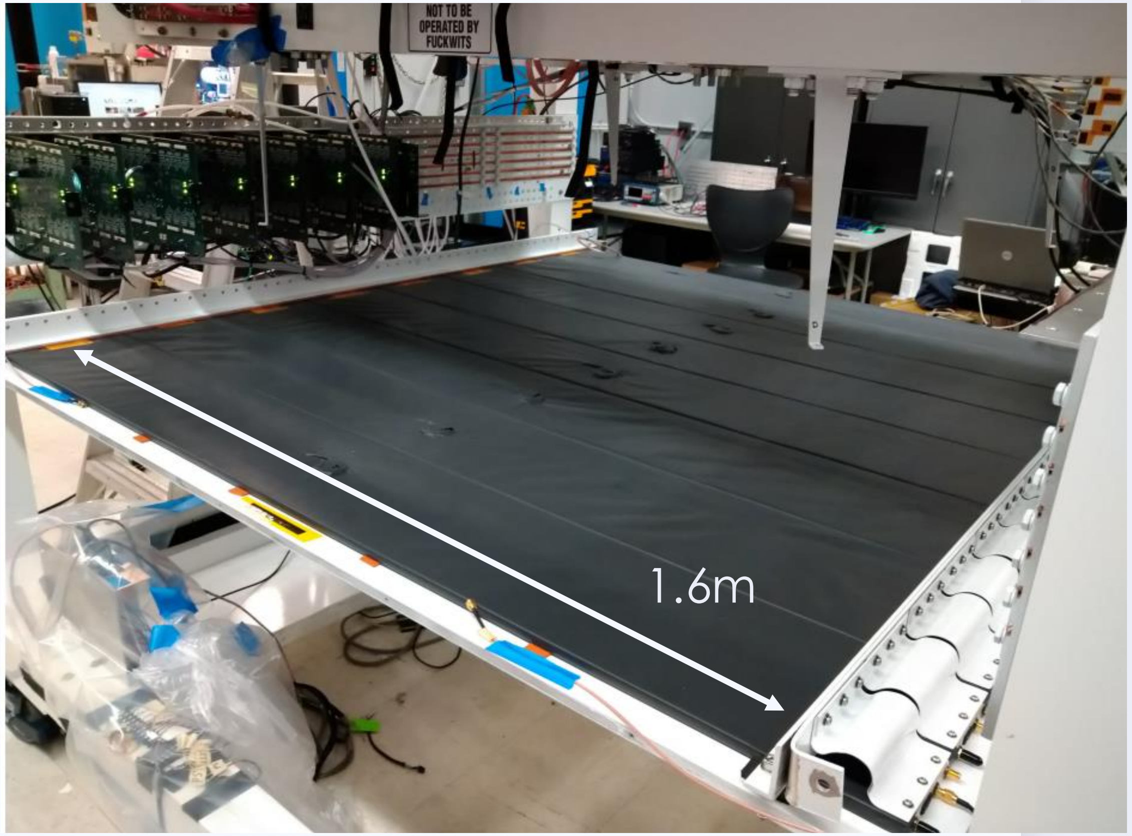


Measures the velocity, β, and charge, Ze

Time-Of-Flight

- Made up of three planes of scintillator:
  - Top and bottom planes
  - Aperture defining scintillator paddle just under the DCT
  - SiPMs per end of paddle to measure light
- 2.3 m separation of top + bottom
  - High-precision (timing) β up to 1 GeV/n, turn-on of the RICH
- Light amplitude → $\underline{Ze}$ measurement
- Total acceptance ~ 0.1 m^2 sr

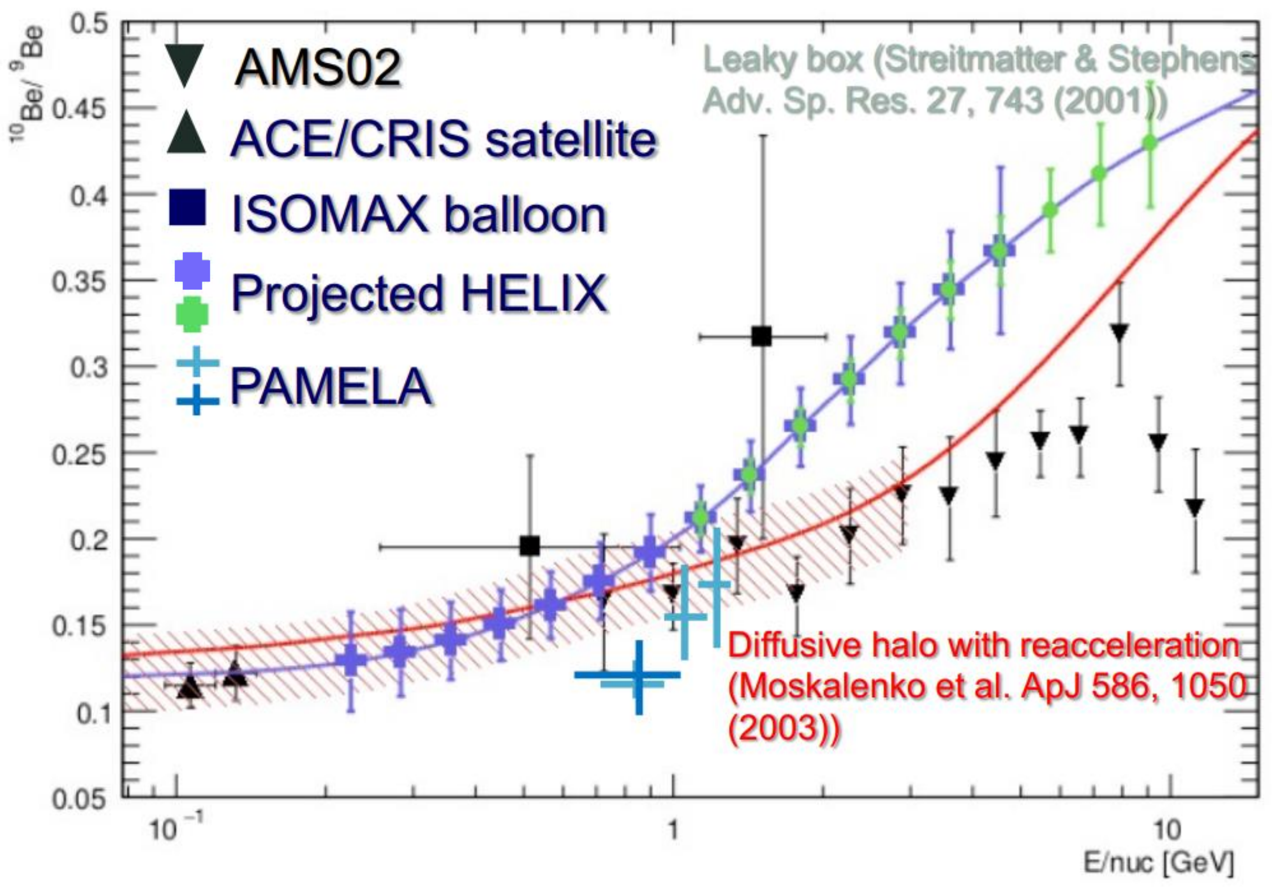
Bottom TOF installed on payload



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

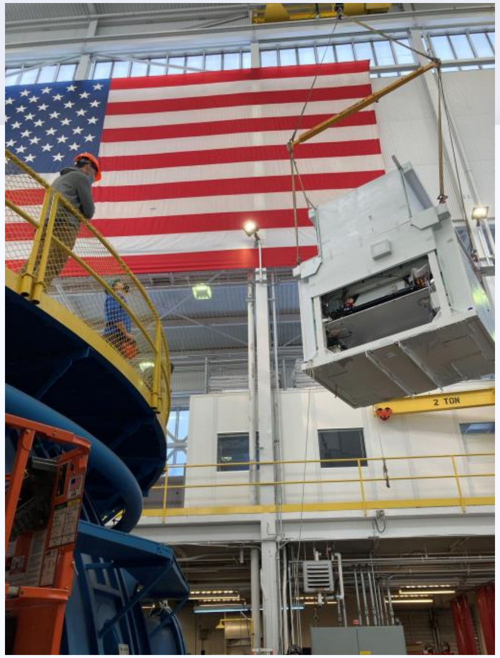
HELIX will significantly improve our understanding of GCR propagation



AMS data preliminary

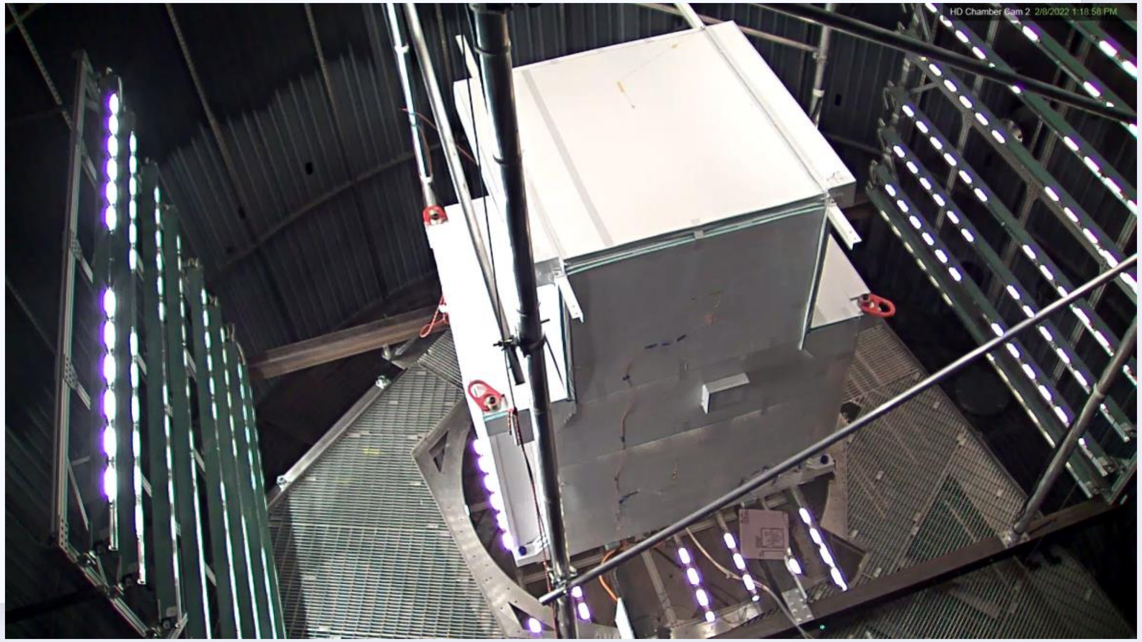
Conclusions

NASA Grant 80NSSC18K0232



- HELIX will resolve Beryllium isotopes in the first stage up to 4 GeV/n with mass resolution $\leq 3\%$
- 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



NKU NORTHERN KENTUCKY UNIVERSITY

HELIX Collaboration

UNIVERSITY OF MICHIGAN

Queen's UNIVERSITY

McGill UNIVERSITY

THE OHIO STATE UNIVERSITY

PennState

CHIBA UNIVERSITY

INDIANA UNIVERSITY

THE UNIVERSITY OF CHICAGO

Citations

[1] https://svs.gsfc.nasa.gov/11342

[2] http://www.issibern.ch/cargese2013/images/d/d6/PTUSKIN_Cargese2013.pdf

[3] Korschinek et. Al. (2010) NIM B Vol 268, 2: https://doi.org/10.1016/j.nimb.2009.09.020

[4] R. Trotta et al 2011 ApJ 729 106 https://doi.org/10.1088/0004-637x/729/2/106

[5] Maurin, D., Melot, F., and Taillet, R., \A database of charged cosmic rays,“ A&A, vol. 569, p. A32, 2014. [Online]. Available: https://doi.org/10.1051/0004-6361/201321344

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

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

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

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

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

Extra Stuff

Isotopes Offer Insights

Secondary-primary ratios are sensitive to the material pathlength

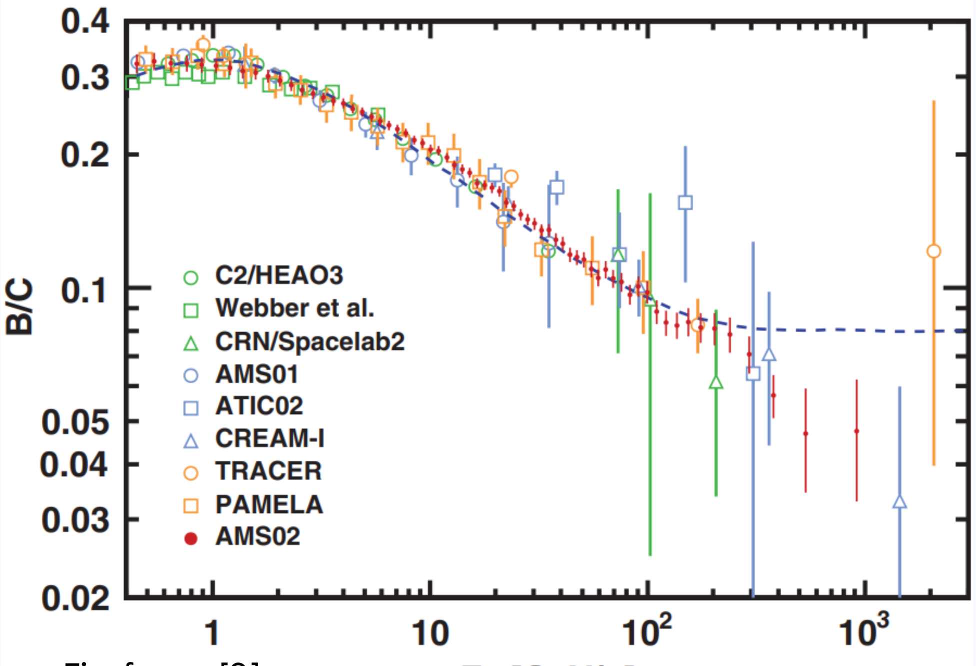


Fig from [3]

B and Be are secondary GCRs - byproducts of primaries (accelerated at sources)

Degeneracy of diffusion coeff and halo size in models like GALPROP

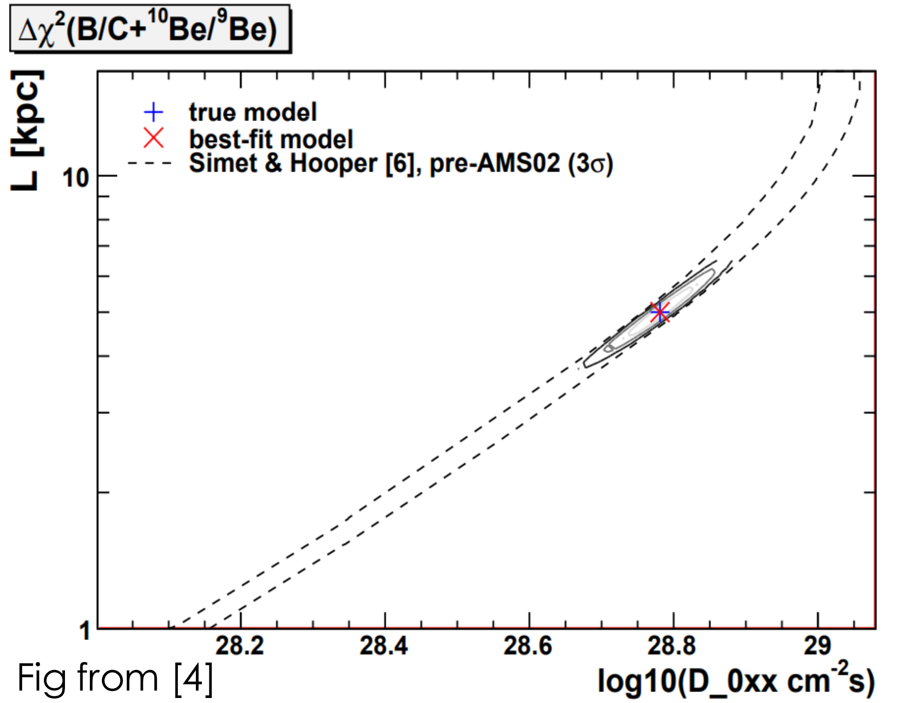


Fig from [4]

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

Other systematic Uncertainties

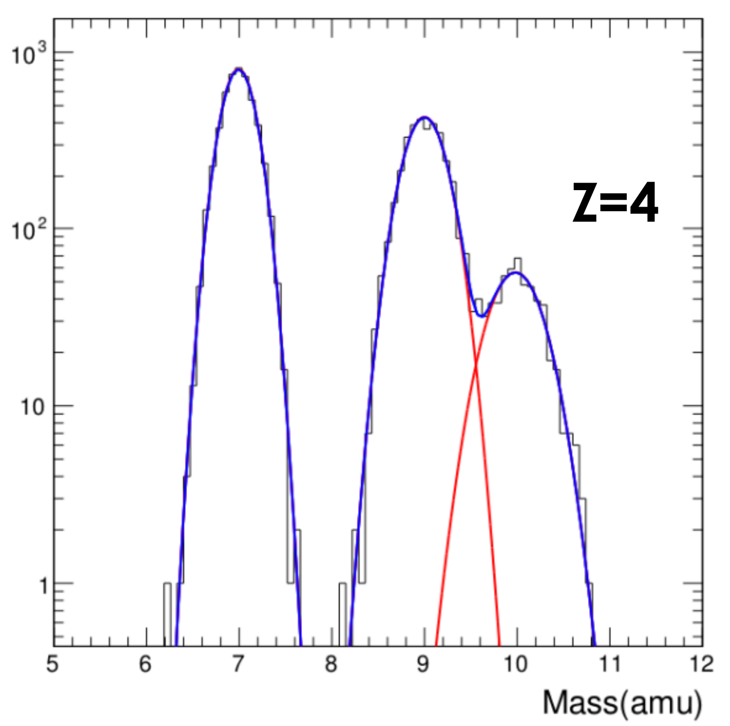
- New cross-section measurements at higher energies are needed
- Isotopes produced above the HELIX payload in atmosphere during flight, relevant for interpreting the data as GCR fluxes
- Isotope production during propagation in diffusion-halo models (or others) that include nuclear interaction networks, 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

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

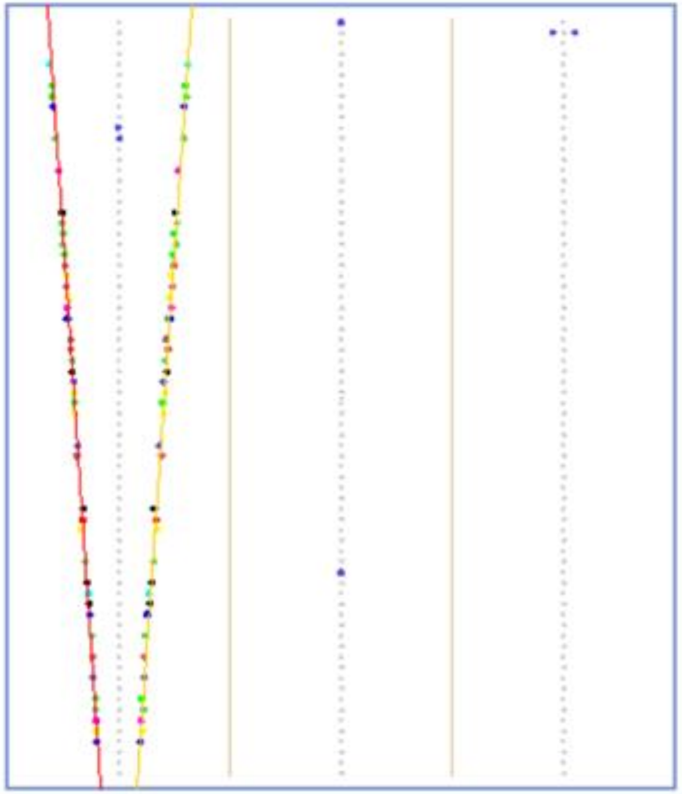
HELIX is designed to meet this resolution goal



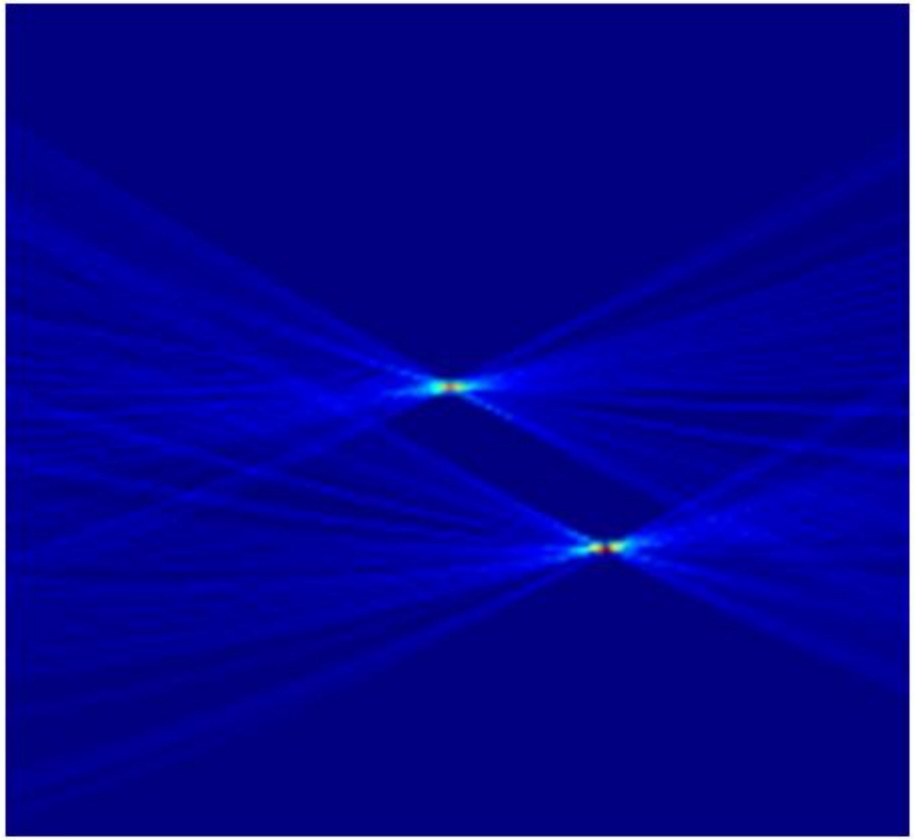
Tracker images

Drift Chamber Tracker

Tracker muon event



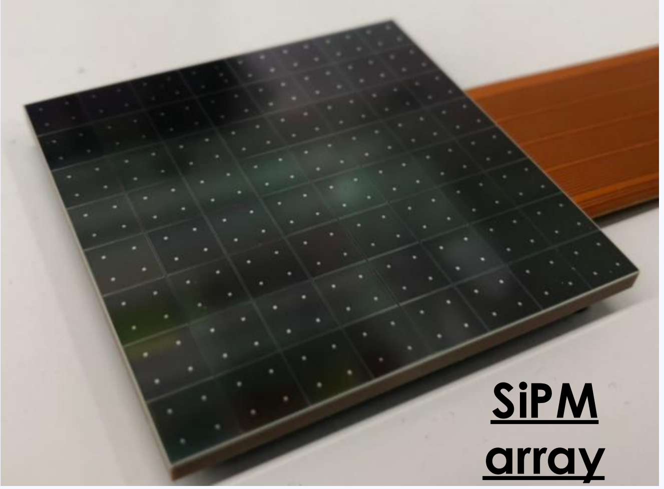
Hough Transform



Measures the velocity, β

RICH Focal Plane

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



SiPM array

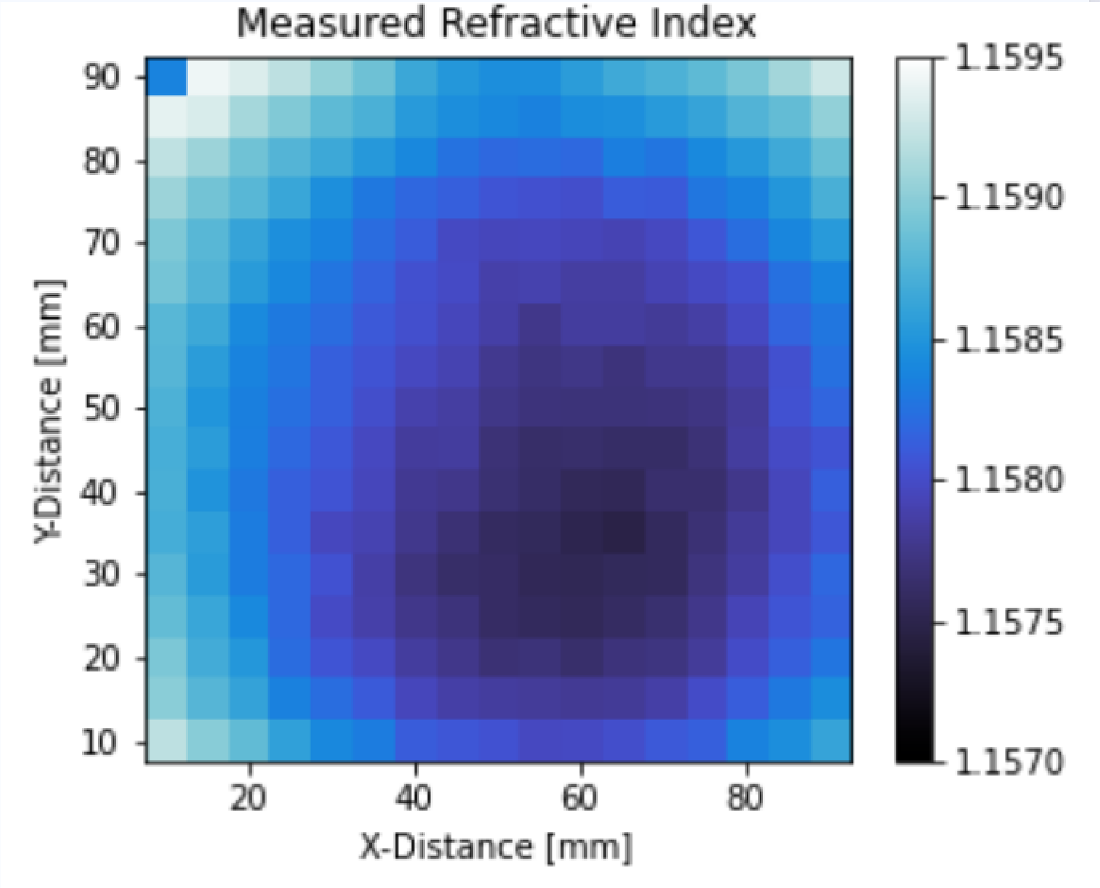
$$\beta = \frac{1}{n\cos\theta_C}$$

β resolution 0.1% (Z >= 4)

Stage 1 populated Focal Plane

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



Measures the velocity, β, and charge, Ze

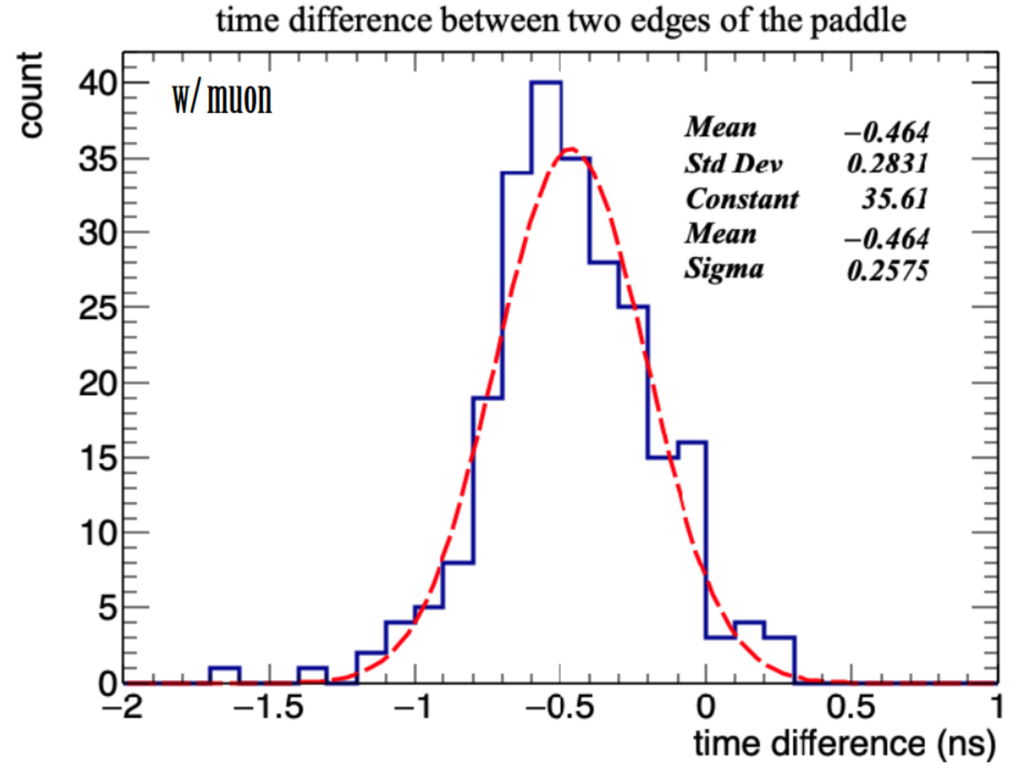
Time-Of-Flight Readout

- 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)



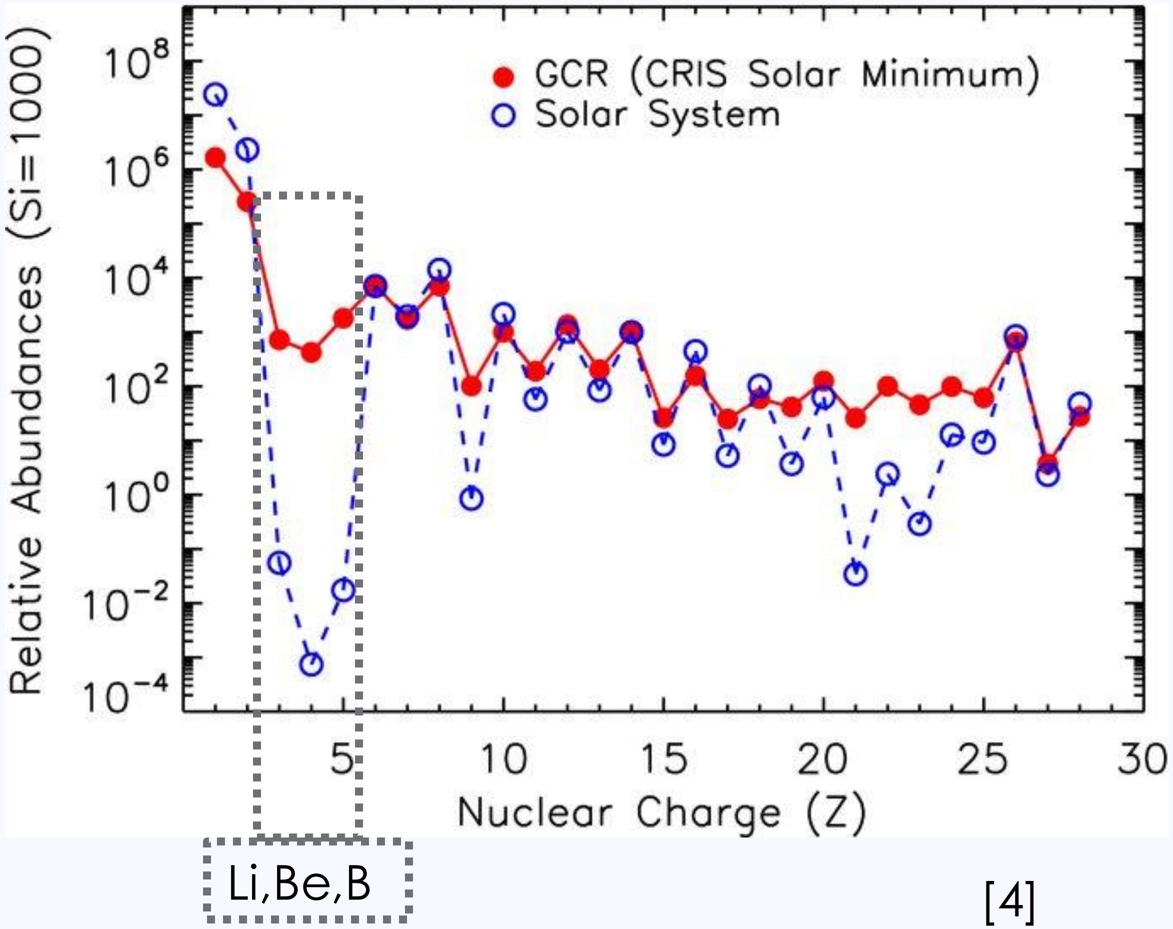
[3] Park, N. ICRC 2021

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]