Status of the **H**igh **E**nergy **L**ight **I**sotope e**X**periment

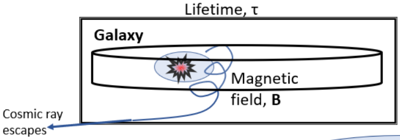
K. McBride, OSU

07/14/2020

Cosmic Ray Nuclei

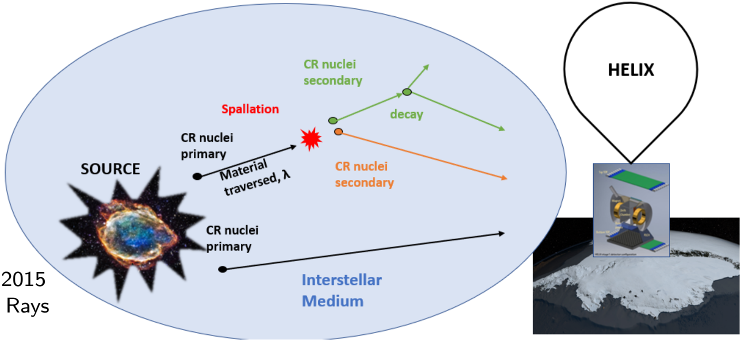
Protons, electrons, and nuclei with energies between **GeV** to 100 EeV.

*Focus on nuclei in this talk



It is hard to measure τ, where $\tau = \frac{\lambda\rho}{v}$

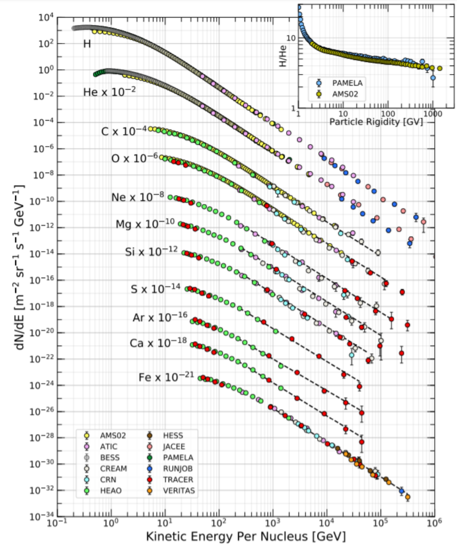
$\frac{\textit{secondaries}}{\textit{primaries}}$ constrain λ (grammage)



see Grenier et al. 2015
9 Lives of Cosmic Rays

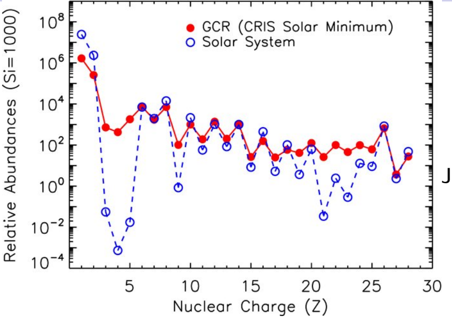
Cosmic Ray Nuclei Spectra

- Known about cosmic rays:
  - Primary element fluxes: mostly protons
  - Power law is the same.
  - Secondaries produced via spallation (next)
- Note, fluxes are scaled.
- Secondaries are measured precisely nowadays (higher E).
- Typical models of CR transport:
  - MW is a disc surrounded by halo
  - Disc is denser than halo
  - CR sources in disc (match fluxes)
  - Apply diffusion-convection → Diffusion Coeff., Halo Size, etc.



Beatty & Wakely, PDG 2019

Abundances and ratio measurements



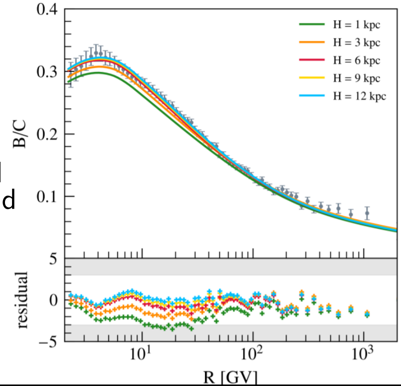
Research shows the overabundance of elements in CR spectra compared to stellar processes. Call these uncommon stellar elements “secondary” CR. Note the lighter elements (Li, Be, B).

J. S. George, et al 2009 ApJ 698, 2

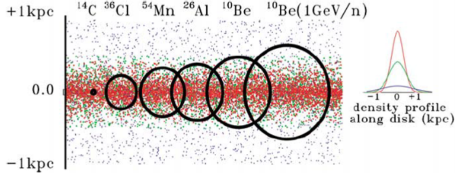
Use secondary-primary ratios like Boron-Carbon to constrain galactic model parameters. AMS-02 most recent data and various halo size predictions on right.
*Bigger halo → more Boron produced

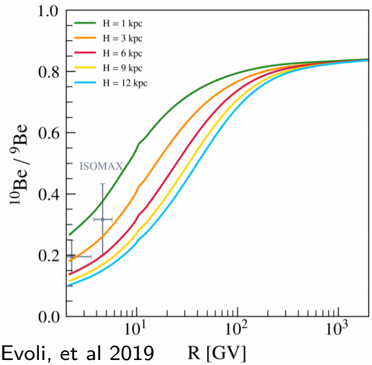
These galactic properties are used in other research like DM and pulsars.

Evoli, et al 2019 arxiv 1910.04113



Isotope measurements





Evoli, et al 2019

- Probing composition further, isotopes of both primaries and secondaries are useful
  - supernovae origin: Fe, Ni
  - propagation: N-14/15, He-3/4
- But radioactive isotope measurements are sought after
  - acceleration: Fe-60, 15 events in 17 years of data (low E) 2016, Binns et al.
  - transport: Be-10,$\tau \sim$ 15Myr (1978, Meyer & 2004, ISOMAX)
- Current CR experiments do not have mass resolution at high energies to identify isotopes.

Measuring mass

Mass identification using **rigidity**, **velocity**, and **charge**.

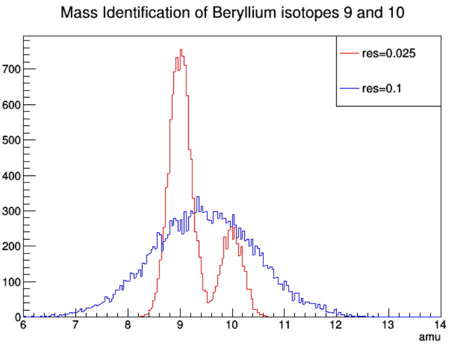
$$R \equiv \frac{p}{Ze} \rightarrow m = \frac{R(Ze)}{\gamma\beta}$$

Required resolution for 4σ separation is $\frac{\Delta m}{m} \sim 0.025$. High resolution necessary for determining the isotope ratios.

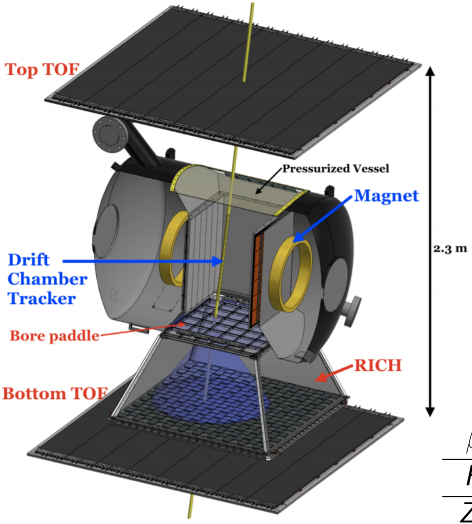
High energy mass measurement is difficult! To separate the two mass peaks, need high magnetic field and good velocity precision: Resolution:

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

Note: $R = B\rho$ from deflection of charge.



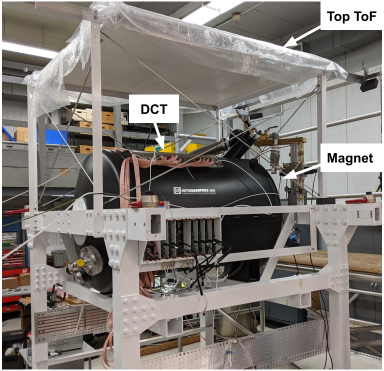
HELIX Superconducting Magnetic Spectrometer (HMS-02)



- Drift Chamber Tracker (DCT) with magnetic field → $\frac{p}{Ze} = R = B\rho$
- Magnet cooled to 4K with LHe and holds 277L. B ≈ 1T, I ≈ 100A
- Time-of-Flight (TOF) → Ze, β (E< 1GeV/n)
- Ring Imaging CHerenkov (RICH)
- Bore paddle for triggering
- HELIX is being built to have multiple flights.

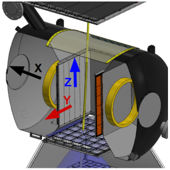
β	TOF and RICH
R	DCT + Magnet
Ze	TOF scintillator

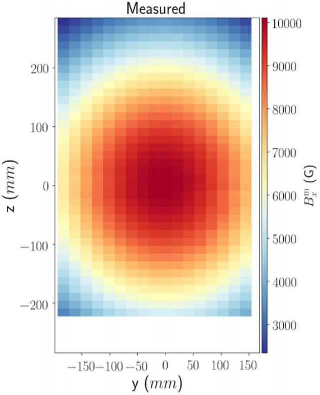
Magnet Challenges



The magnet has been used on previous experiments. Monitoring the pressure and LHe levels is crucial for multiple flights. Tested remote discharge of magnet in Feb.

(left) Picture of Magnet on gondola



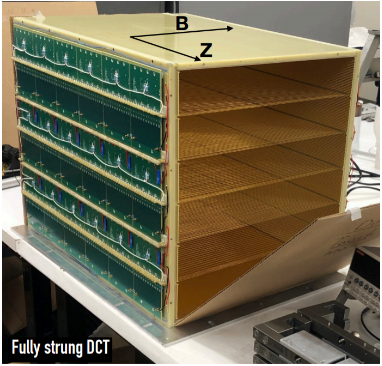


Fine magnetic field mapping completed (right). Slice in plane orthogonal to magnetic north. This is the bore of the magnet. CR enter above (+z), deflect in y in tracker (DCT). Metrology of magnet and DCT underway, $\sigma < 1$ mm.

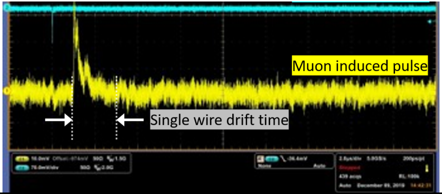
Green and Mbarek, 2018 HELIX pres.

Drift Chamber Tracker

- DCT consists of 2 types of wires
    - Sense: measure induced current
    - Potential: HV → $\vec{E} \perp$ to $\vec{B}$
- Current pulse is recorded on both sides of all 216 sense wires.
- Chamber is filled with Ar(10%)-CO_2(90%) gas for CR ionization.
- Amplification with fADC readout
- Position measurements to track particles:
    - Drift time → radial position away from wire
    - Timing between multiple wires → z-measurement.
    - Time on both ends of a wire → hit position along wire.



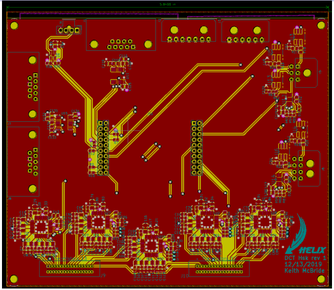
Fully strung DCT

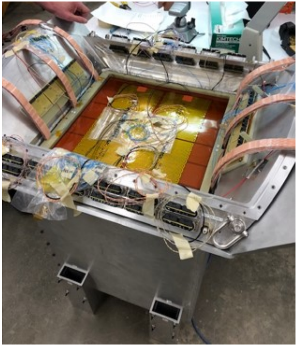


DCT-monitoring and status

The drift time is related to the impact parameter (r) via the drift velocity: $v = \frac{dr}{dt}$. The physical properties of the gas affect v, so DCT is put into a vessel and dressed with heater sheets. I built system (right) to control T and monitor P. COVID-delayed.

Blum, Rolandi, and Riegler, 2008
Particle Detection with Drift Chambers





DCT in vessel with sense wire cables (left).

Current DCT Status

-Nominal resolution on position: < 100 um.

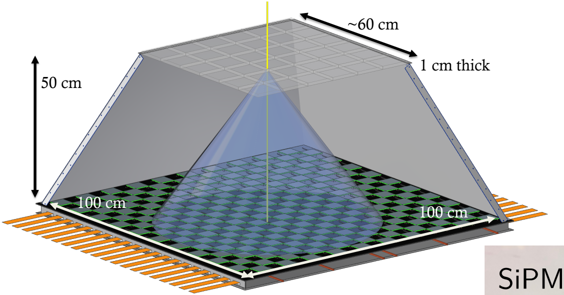
-Testing of 2*216 channels (9 ADC boards).

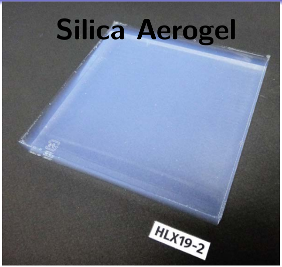
-HV, Temperature, Pressure, heater testing soon.

-Muon tracks coming soon.

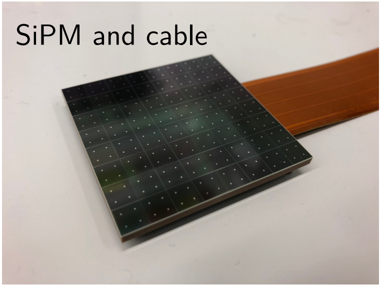
RICH or Ring Imaging CHerenkov Detector

Wisher et al. 2019 ICRC





Tabata et al. NIM A, 952 2020



Radiation from CR: $\cos\theta_C = \frac{1}{n\beta}$

Aerogel nominal: $n = 1.16$

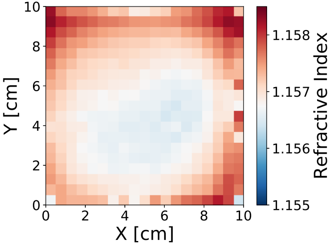
$\theta_C > 0 \rightarrow \beta > 0.87 \rightarrow E >$ 2 GeV/n

Challenge: achieve high precision...

RICH-Analysis

Top: Electron beam scan of tiles

Collaborators at McGill utilize CCD cameras and fine positioning to map tiles. Each 2D bin is a 25 mm^2 square. With good enough tracking, velocity can be precisely measured.



O'Brien et al. 2019
HELIX pres

Bottom: Scope traces & P.E. peaks

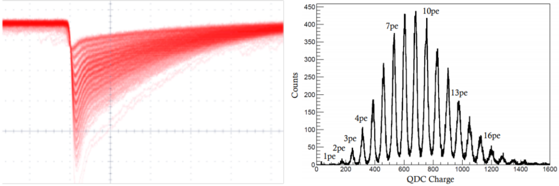
U. Chicago studies the SiPM arrays.
The resolution on counting photons (*P.E)
is needed to achieve high precision on imaging the cherenkov ring.

*P.E. is photo-electron

Many other tests complete.

Current Status: Full readout of 200 SiPM arrays using 25 RICH electronics boards.

SiPM studies



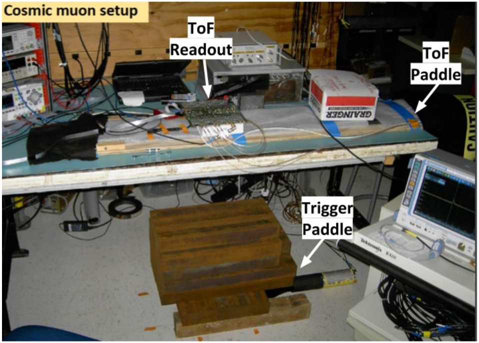
Wisher et al. 2019 ICRC

Time-of-Flight

ToF is made up of scintillator paddles (right) with 8 SiPMs on each end of each paddle. Each paddle tested with LED and muons optimal gains and end-to-end timing res. This gives hit position along paddle for analysis. Nominal resolution on end-to-end: $\sigma_t = 0.4$ ns.

Chen, 2020 HELIX pres.

Top ToF panel



There are 8 paddles in both top and bottom panel in the ToF system.

Big panels → 0.6 m^2 sr days

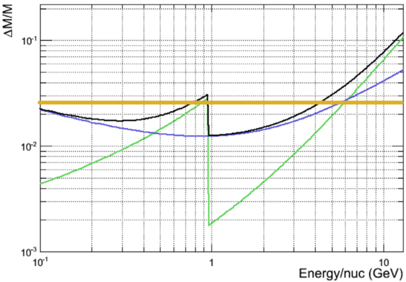
SiPM signal amplitudes are used to measure charge of CR, ongoing study and working on the full readout.

PSU work, 2020

HELIX Goals and integration

HELIX aims to make the following **1st** measurements:

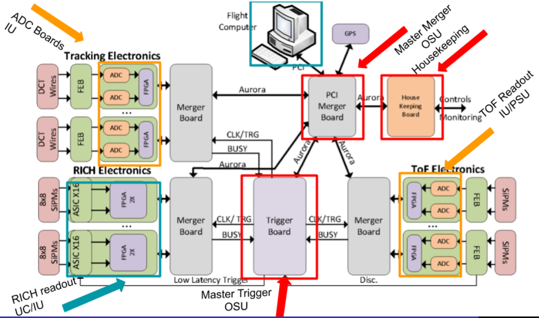
Measurement	Energy GeV/n
$*{}^{10}\mathrm{Be}/{}^{9}\mathrm{Be}$	> 2
${}^{22}\mathrm{Ne}/{}^{20}\mathrm{Ne}$	> 1
${}^{7}\mathrm{Li}/{}^{6}\mathrm{Li}$	> 1
${}^{10}\mathrm{B}/{}^{11}\mathrm{B}$	> 1



Yellow line is $\frac{\Delta m}{m} = 0.025$

Blue is $\frac{\delta R}{R}$, Green is $\gamma^2 \frac{\delta\beta}{\beta}$

Integration of DAQ - In Progress



ADC Boards IU

Master Merger OSU

Housekeeping

TOF Readout IU/PSU

RICH readout UC/IU

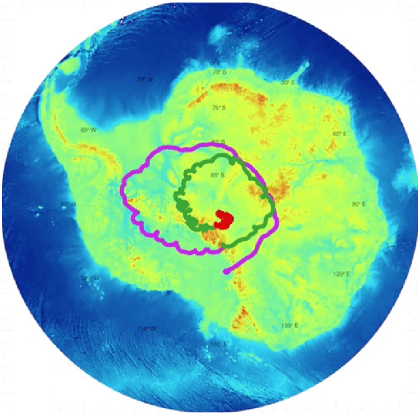
Master Trigger OSU

With two flights we expect to see thousands of Be events.

Flight

- Polar Vortex during Austral Summer
- Winds keep payload over continent.
- 30km altitude.
- Constant daylight improves altitude stability.

ANITA-4 Trajectory 2016



30 day flight with 2 orbits

HELIX Collaboration

- In summary, HELIX is a cosmic ray superconducting magnet spectrometer to fly over the Antarctic ice in Dec 2022(?). Integration of all subsystem detectors and DAQ hopefully completed by end of this year.
- Collaboration
- University of Chicago
- The Ohio State University
- Indiana University
- Penn State University
- Northern Kentucky University
- McGill University
- University of Michigan

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