The HELIX Project: Calibration of Aerogel for Cherenkov Counter

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High Energy Light Isotope eXperiment

► What is it?
A balloon-borne detector designed to measure the chemical and isotopic abundances of light cosmic ray nuclei.

► When and Where?
Two stage experiment
Stage 1: 14 day flight (depend on He consumption) from NASA’s McMurdo Station facility in Antarctica during the 2020/21 austral summer.
Stage 2: 28 day flight
The collaboration

- McGill University
  - David Hanna, Emma Ellingwood, Thomas Rosin
- University of Chicago
  - Scott Wakely, Dietrich Müller, Nahee Park, Ian Wisher
- Indiana University
  - James Musser, Mark Gebhard, Brandon Kunkler, Mark Lang, Gerard Visser
- Pennsylvania State University
  - Stephane Coutu, Isaac Mognet
- Northern Kentucky University
  - Scott Nutter
- University of Michigan
  - Michael Schubnell, Gregory Tarle, Andrew Tomasch, Noah Green
- Ohio State University
  - Jim Beatty
We wish to explain the recent results from AMS-02 (Alpha Magnetic Spectrometer).

The positron fraction excess can’t be explained by current cosmic ray propagation model.

Positron fraction = $\frac{e^+}{e^+ + e^-}$

Hypothesis:
- Positron production by nearby pulsars
- Annihilation or decay of dark matter
Properties of $^{10}\text{Be}$:

- Made in spallation reactions with interstellar medium
- Unstable element with half life of 1.5Myr ("clock isotope").

A $^{10}\text{Be}/^{9}\text{Be}$ measurement gives an estimate of how long the cosmic ray have been travelling. This helps discriminate between many propagation models.

AMS-02 can’t make this measurement

Goal: Measuring $^{10}\text{Be}/^{9}\text{Be}$ between 0.1 to 3 GeV/n for Stage 1 up to 10 GeV/n for Stage 2

\[ \text{Cosmic ray} + ^{14}_7\text{N} \xrightarrow{\text{ISM}} ^{10}_4\text{Be} + ^4_2\text{He} + e^+ + \nu_e + \text{spallation byproduct} \]
HELI X Payload

- Experimental Method
  1. Measure **charge** to get Beryllium
  2. Measure **rigidity** (momentum)
  3. Measure $\beta$ (**velocity**)
  4. Particle ID using mass spectrometry

- Magnet
  - 1T superconducting magnet

- Drift Chamber Tracker
  - Multiwire drift chamber with 72 sense layers
  - Spatial resolution $\sim 65 \mu m$ for $Z>3$
  - Measure **rigidity**

- Time-of-Flight (TOF) and Charge System
  - 1.5cm thickness scintillator, readout by SIPMs, 2.3m separation
  - Timing resolution <50 psec for $Z>3$
  - Measure **charge** (identify Be element)
  - Measure **velocity** up to 1GeV/n

HELI X stage1 detector configuration
HELIX Payload

Ring Imaging Cherenkov Detector (RICH)

- Particles with $v > c/n$ generates Cherenkov Photons emitted at an angle:
  \[ \cos(\theta_c) = \frac{1}{n\beta} \]
- $\theta_c$ can be measured to get $\beta$
- 70 cm x 70 cm aerogel radiator $n \sim 1.15$
- 1.3 $m^2$ readout plane covered by SiPMs arrays
- Measure **velocity**
Mass Spectrometry

\[ \frac{\Delta m}{m}^2 = \left( \frac{\Delta R}{R} \right)^2 + \left( \gamma^2 \frac{\Delta \beta}{\beta} \right)^2 \]
Aerogel Calibration

- Radiator: Aerogel with refractive index 1.15
- Aerogel Properties:
  - refractive index is intermediate between gases (near 1.00) and conventional materials (water 1.33, glass 1.5) and can be tuned during production.
  - optimize the geometry of the detector
  - perform proximity focusing
- $n$ needs to be calibrated to a precision of $\frac{\Delta n}{n} = 7 \times 10^{-4}$ to get accurate $\beta$ measurements.
- The refractive index and the thickness have to be measured on a fine grid to calibrate the apparatus.
- Produced in Japan by Makoto Tabata from Chiba University
- 92 aerogel tiles to calibrate
Calibration of Aerogel: Beam Calibration

- Idea:
  Scan the aerogel tile with an relativistic electron beam to find n.
- Beam test at NRC: 35MeV electron linac in Ottawa
Calibration of Aerogel: Beam Calibration

- Use a circle of 16 one-dimensional CCDs to measure the Cherenkov ring
- Nominal radius is 200 mm
- We chose the Toshiba TCD1304AP:
  - 3648 pixels
  - 8 µm x 200 µm each
  - electronic shutter
  - high sensitivity low noise
- Control signals from STMicroelectronics / NUCLEO-F401RE
- Readout into Acqiris DC270 FADC digitizers (8-bit 1 GS/s)
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Calibration of Aerogel: Gradient Index

- based on Fermat’s principle of least action
- gradient in the refractive index can deflect a laser beam traversing the tile
- needs a knowledge of tile thickness
- limited by surface roughness and Rayleigh scattering
Laser
Aerogel
Screen
Camera

Thomas Rosin - McGill University
Calibration of Aerogel: Gradient Index

- Scan tile in x and y
- Measure deflection in x and y direction for each scan point
- Compute index map using minimization algorithm
- Correct using thickness map made with CMM (coordinate measuring machine)
Index of refraction map of Aerogel
Questions?