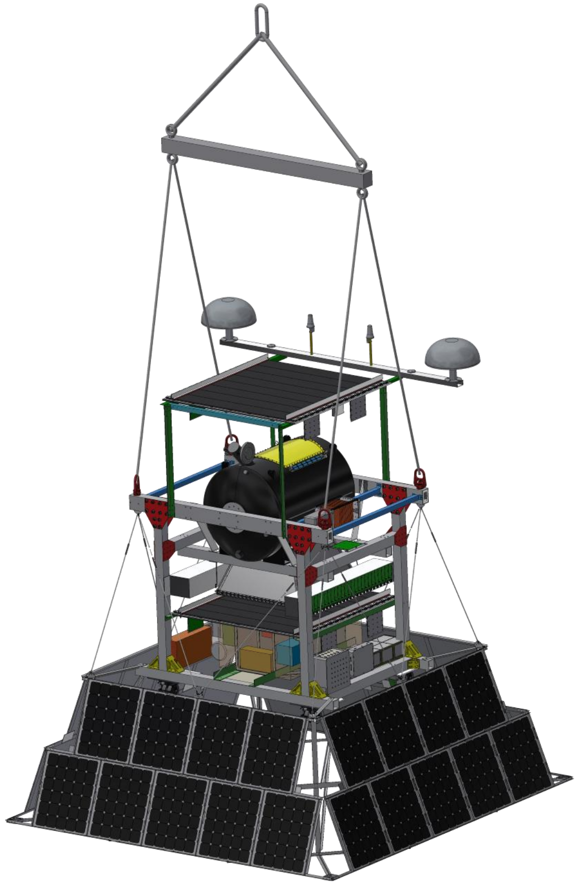
HELIX

The High Energy Light Isotope eXperiment

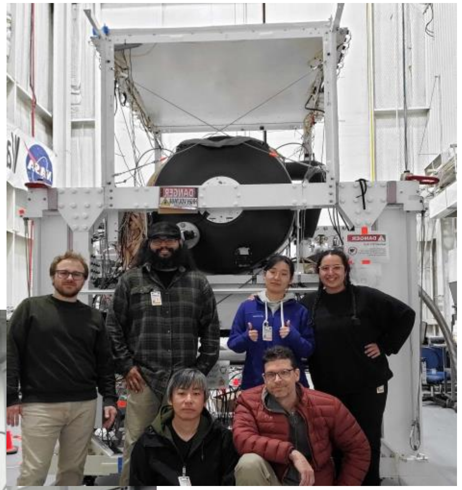


Melissa Baiocchi

Queen's University

HELIX Collaboration

A special thank you to the HELIX collaboration and my supervisor Dr. Nahee Park



University of Chicago
- Hyebin Jeon, Rostom Mbarek, Keith McBride, Dietrich Muller, Kenichi Sakai, Scott P. Wakely

Indiana University
- Brandon Kunkler, Michael Lang, James Musser, Gerard Visser

McGill University
- David Hanna, Stephane O'Brien

Northern Kentucky University
- Scott Nutter

Ohio State University
- Patrick Allison, James J. Beatty, Lucas Beaufore, Dennis Calderone

Pennsylvania State University
- Yu Chen, Stephane Coutu, Isaac Mognet, Monong Yu

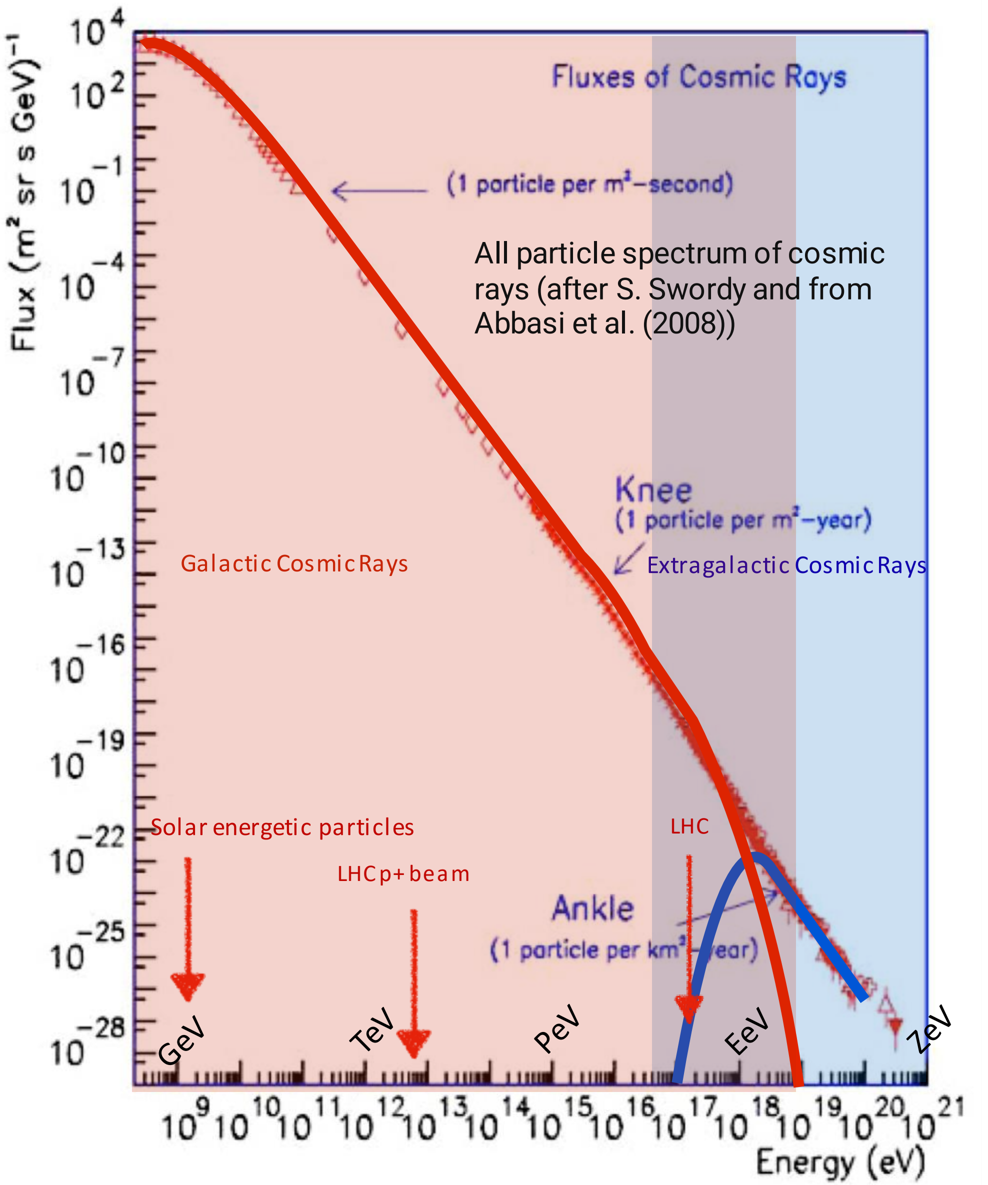
Queen's University
- Melissa Baiocchi, Avani Bhardwaj, Conor McGrath, Nahee Park

University of Michigan
- Noah Green, Gergory Tarle

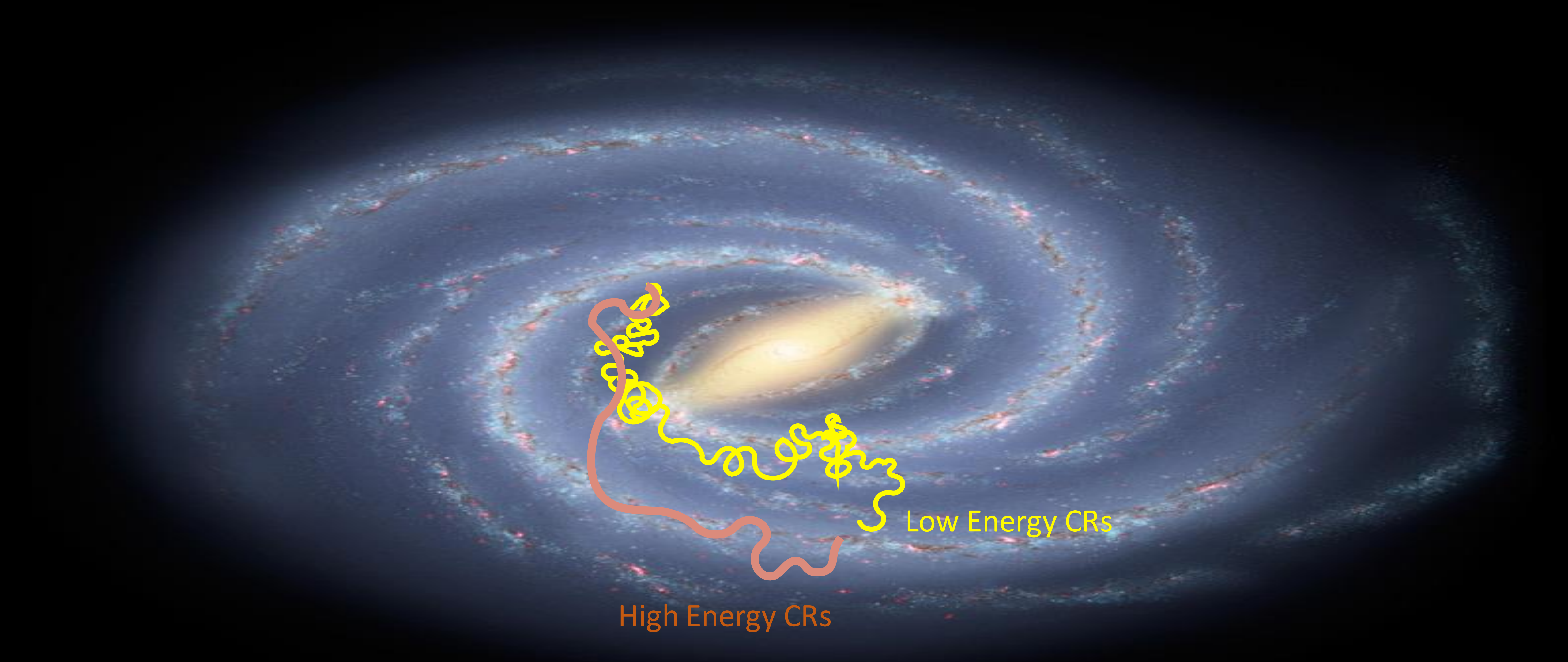
Cosmic Rays

- **High Energy Charged Particles, originating from outer space**
  - Mostly atomic nuclei: 85% Protons, 12% Helium, 2% Heavy Nuclei
  - 1% Leptons
  - Spectrum follows a smooth power law distribution over a wide range of energy

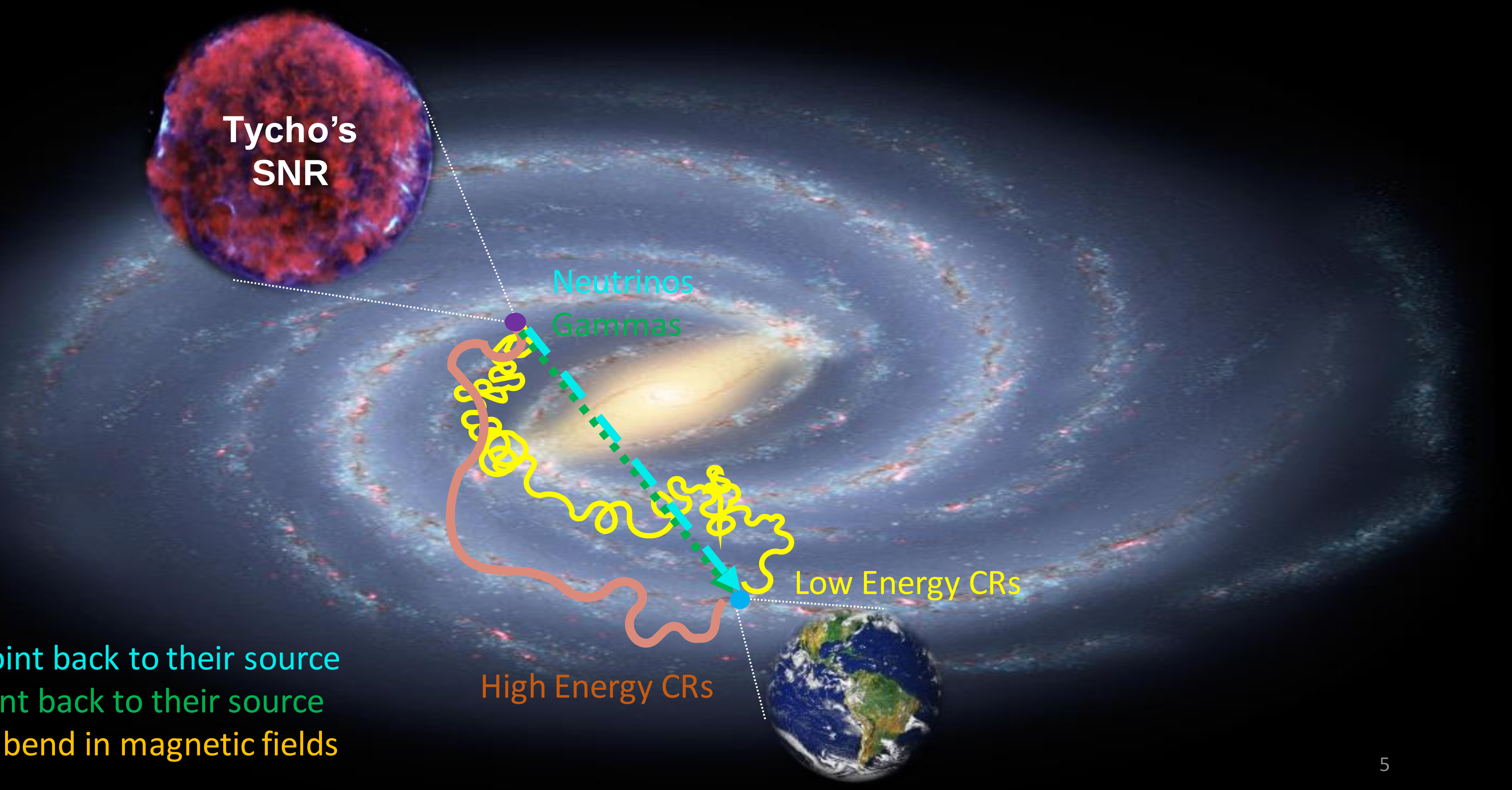
- **Several Unanswered Questions:**
  - Where do cosmic rays originate from?
  - Ho do they get their energies?
  - How do cosmic rays reach us?



Cosmic Rays Don't Point to Their Sources



Cosmic Rays Don't Point to Their Sources



Neutrinos point back to their source
Gammas point back to their source
Cosmic Rays bend in magnetic fields

Cosmic Ray Elemental Abundances

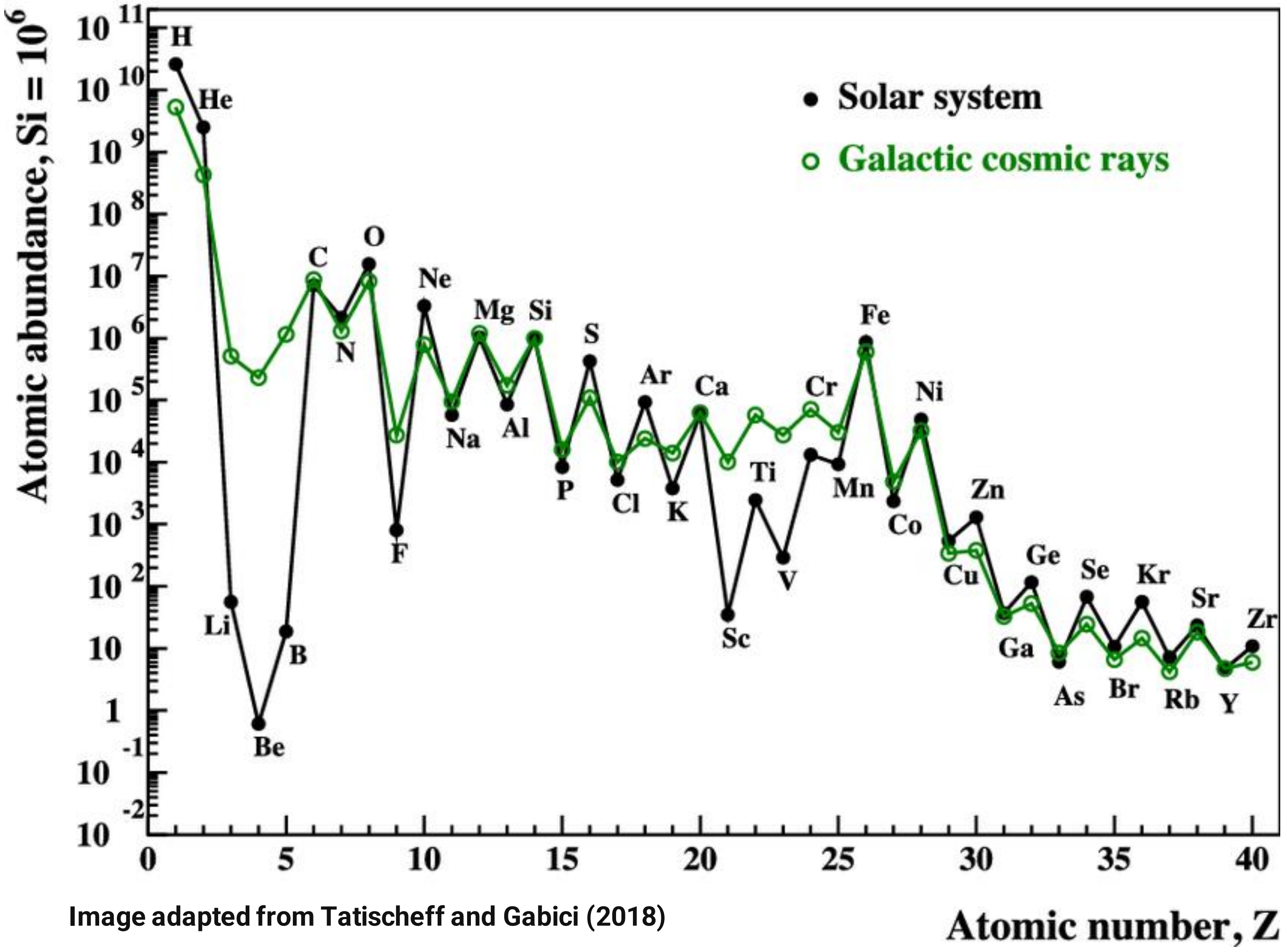


Image adapted from Tatischeff and Gabici (2018)

- Cosmic rays measured from protons up to Uranium
  - Every nuclide observed on earth exists in cosmic rays
- Some elements are more abundant in CRs than in the solar system
- Inelastic collisions of heavier nuclei with interstellar medium (ISM) could create lighter nuclei
- Collision results (interaction probabilities) can be estimated with accelerator data

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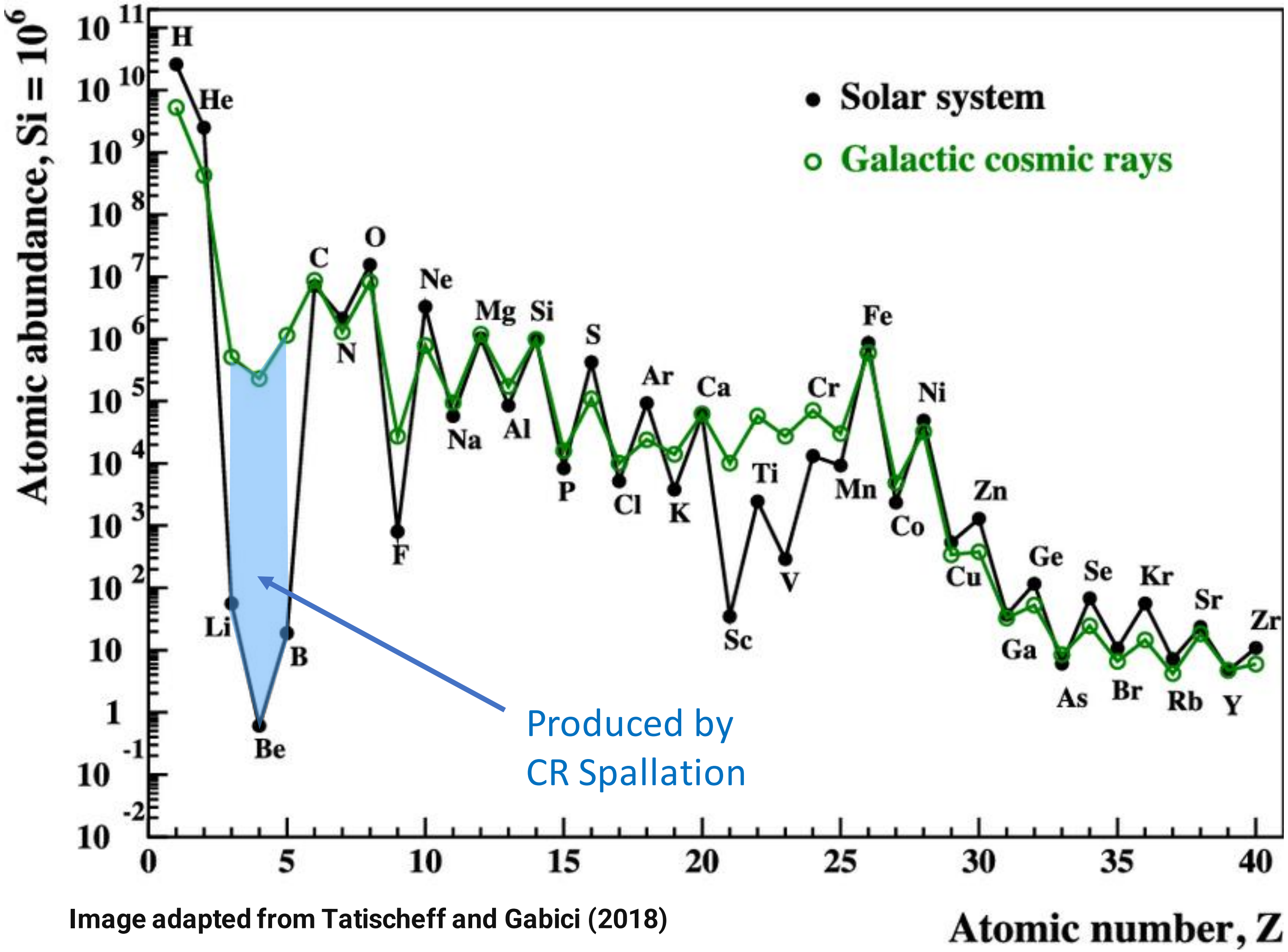

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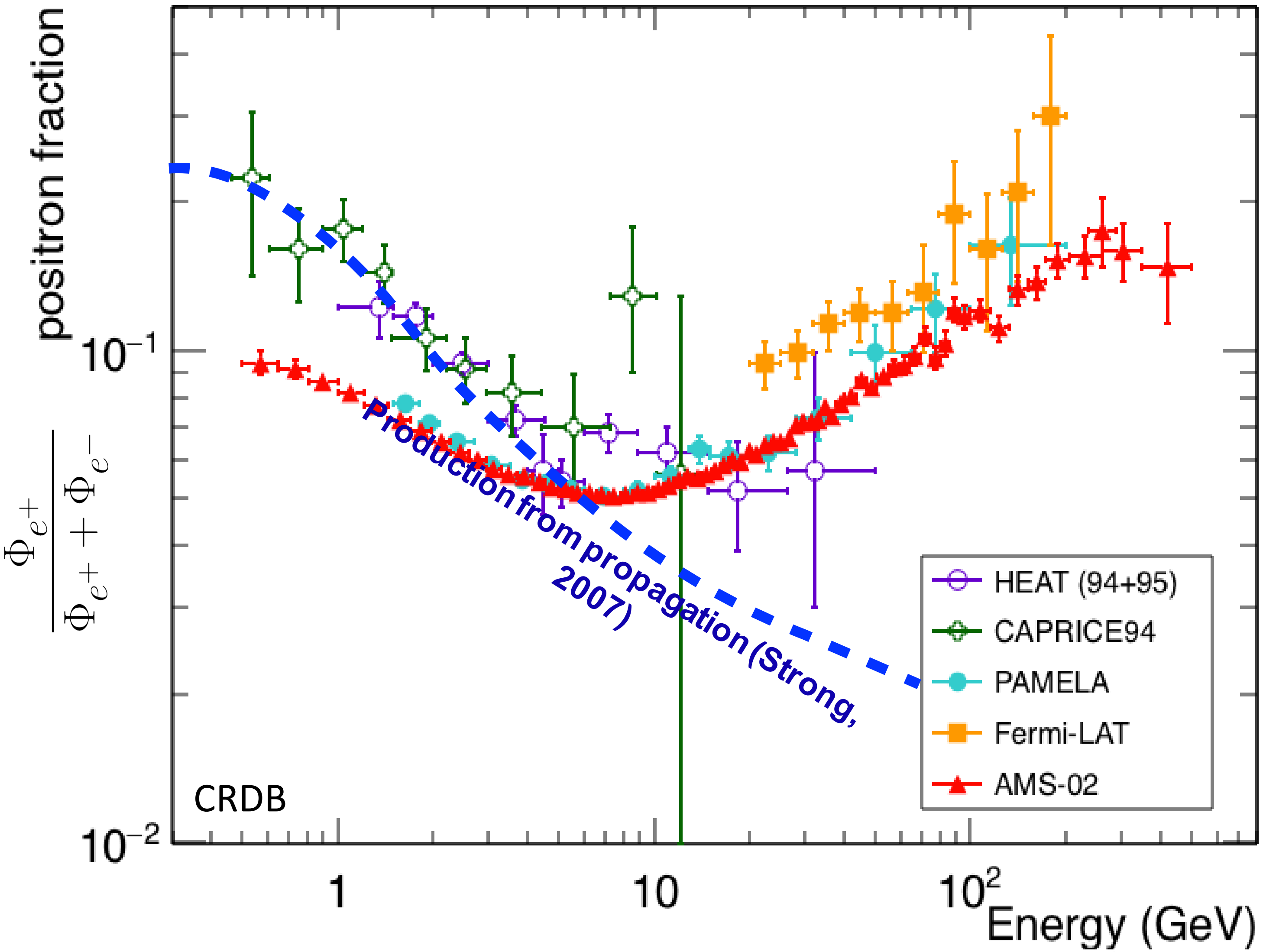
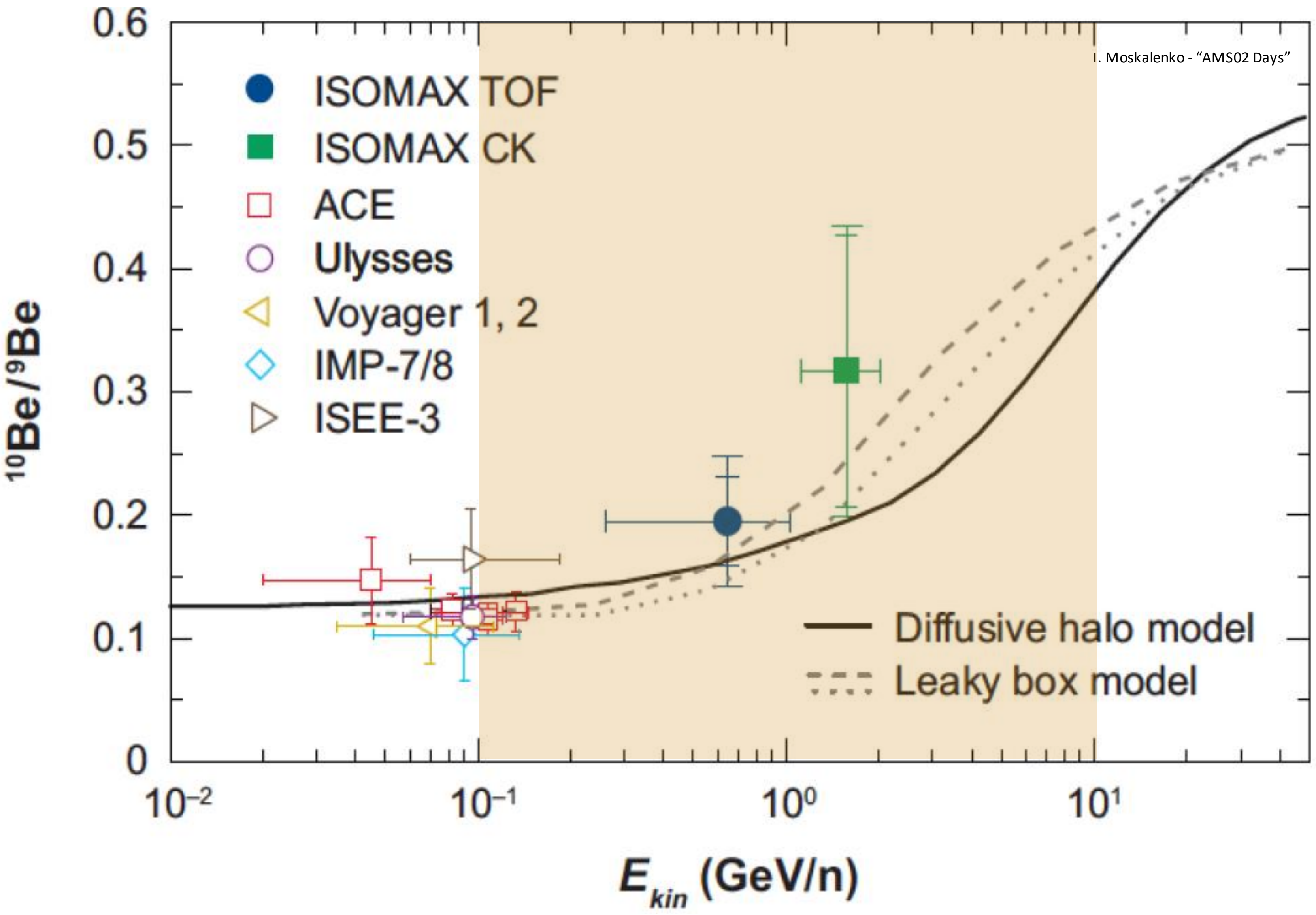
Rising Positron Fraction

- Positrons were expected to be produced as propagation events (their fraction decreasing with increasing energy), following the blue trendline
- Surprise! At higher energies, positron fraction rises
- Need to understand the propagation better!



Propagation Clock Isotopes

- ^{10}Be is an unstable isotope of half-life 1.39 x 10^6 years, ^{9}Be is stable
- Quantifying the $^{10}Be/^{9}Be$ ratio of cosmic rays would help determine average lifetime of cosmic rays in our galaxy and provide strong constraints for current propagation models
- This would make for a great experiment target...

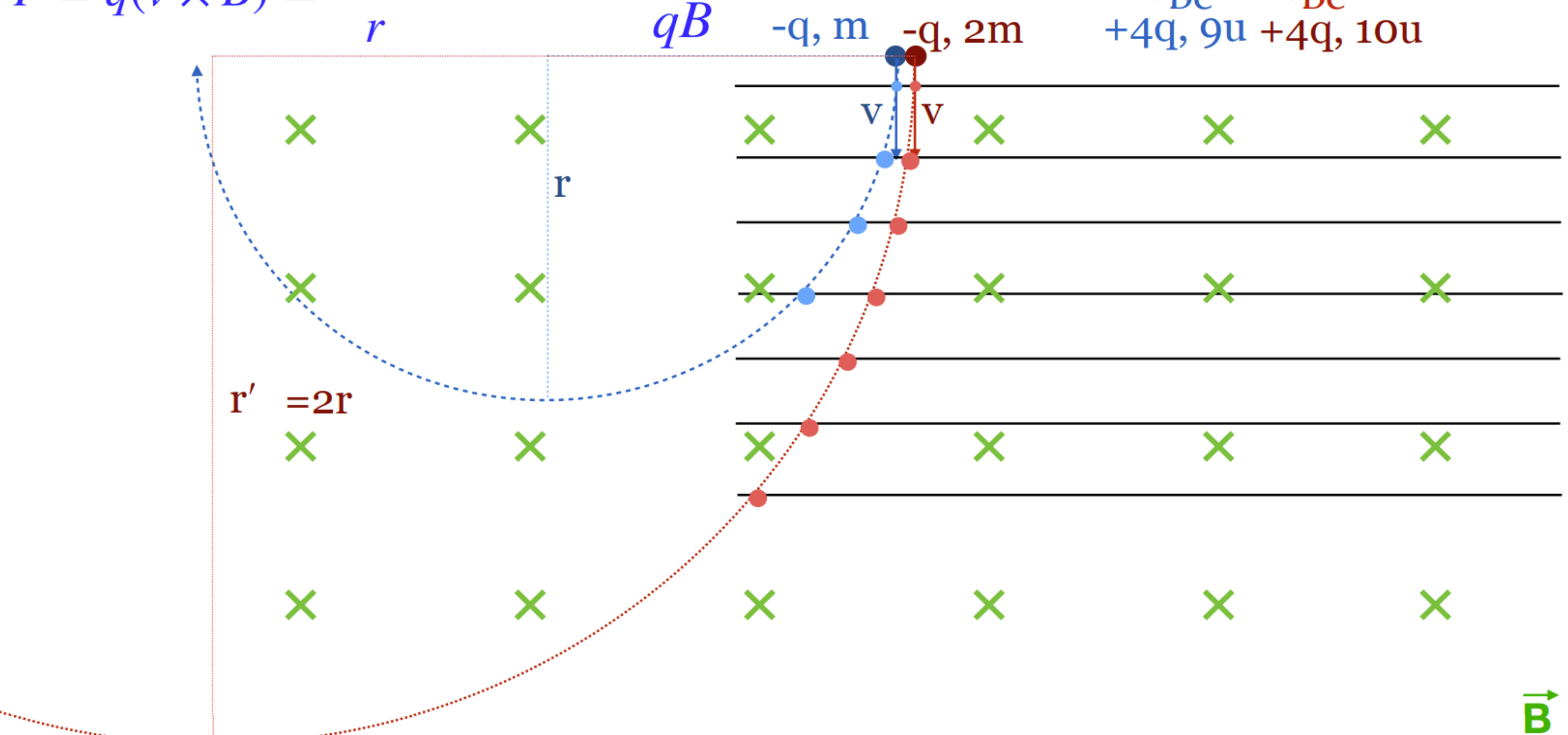


Measurement Challenges

- Need to measure charge, mass, and energy of incident particles
- ^{9}Be and ^{10}Be have a 10% mass difference

$$F = q(v \times B) = \frac{mv^2}{r} \quad \leftrightarrow \quad r = \frac{mv}{qB}$$

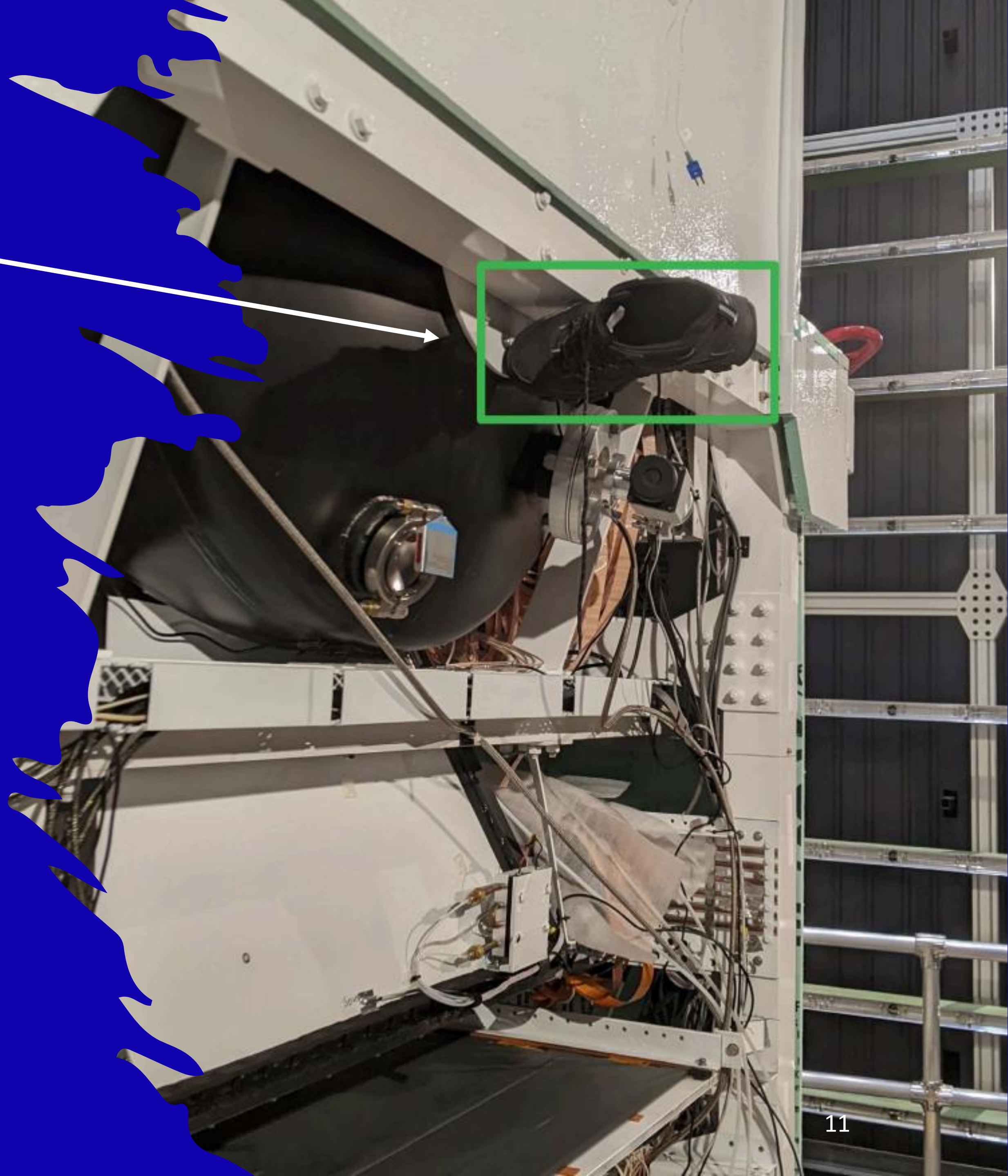
Magnet Spectrometer!



We need a very high resolution to measure this (better than 3%)

Our magnet is Super-conducting and generates a uniform 1 Tesla magnetic field within!

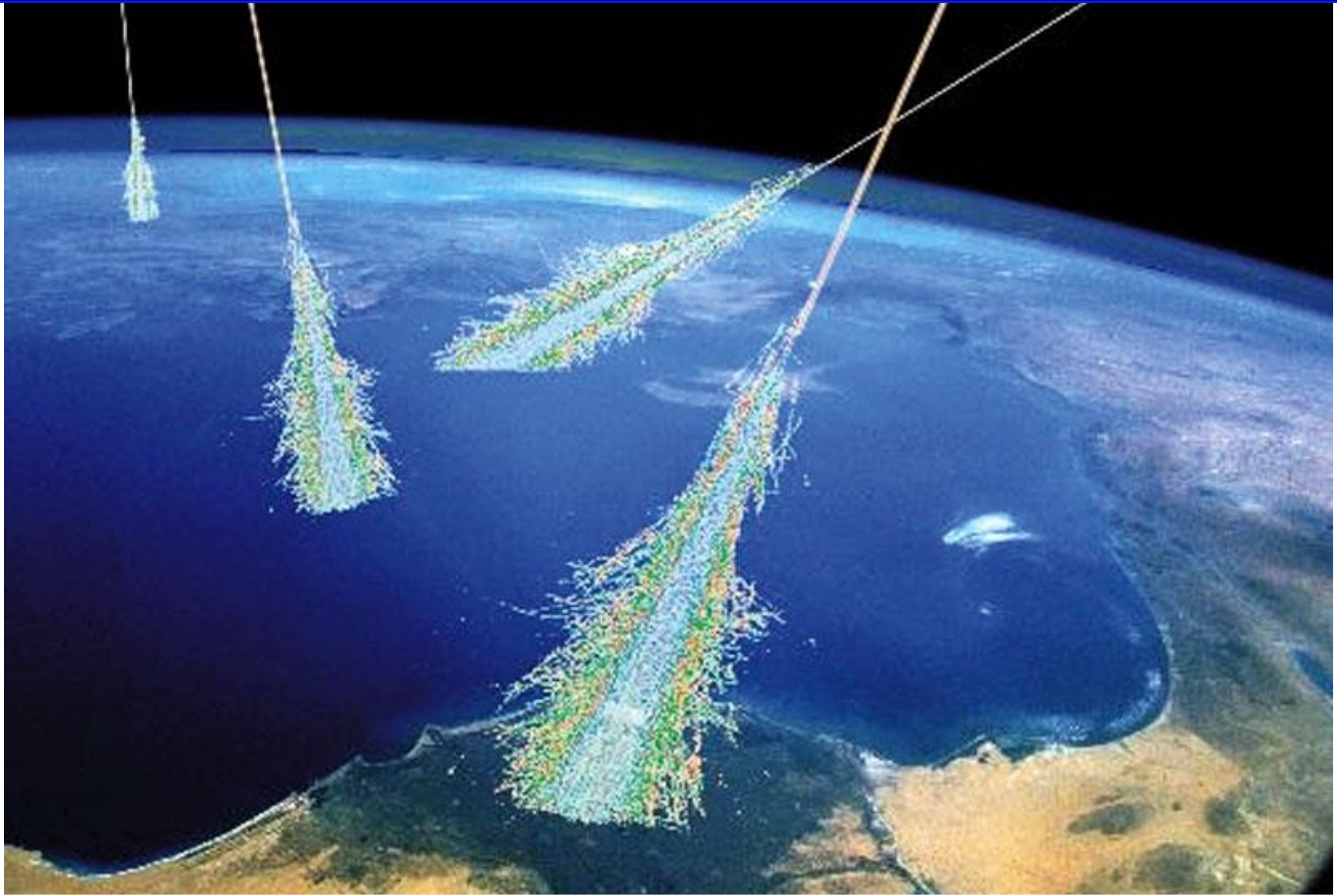
This is enough to lift a steel toe-boot



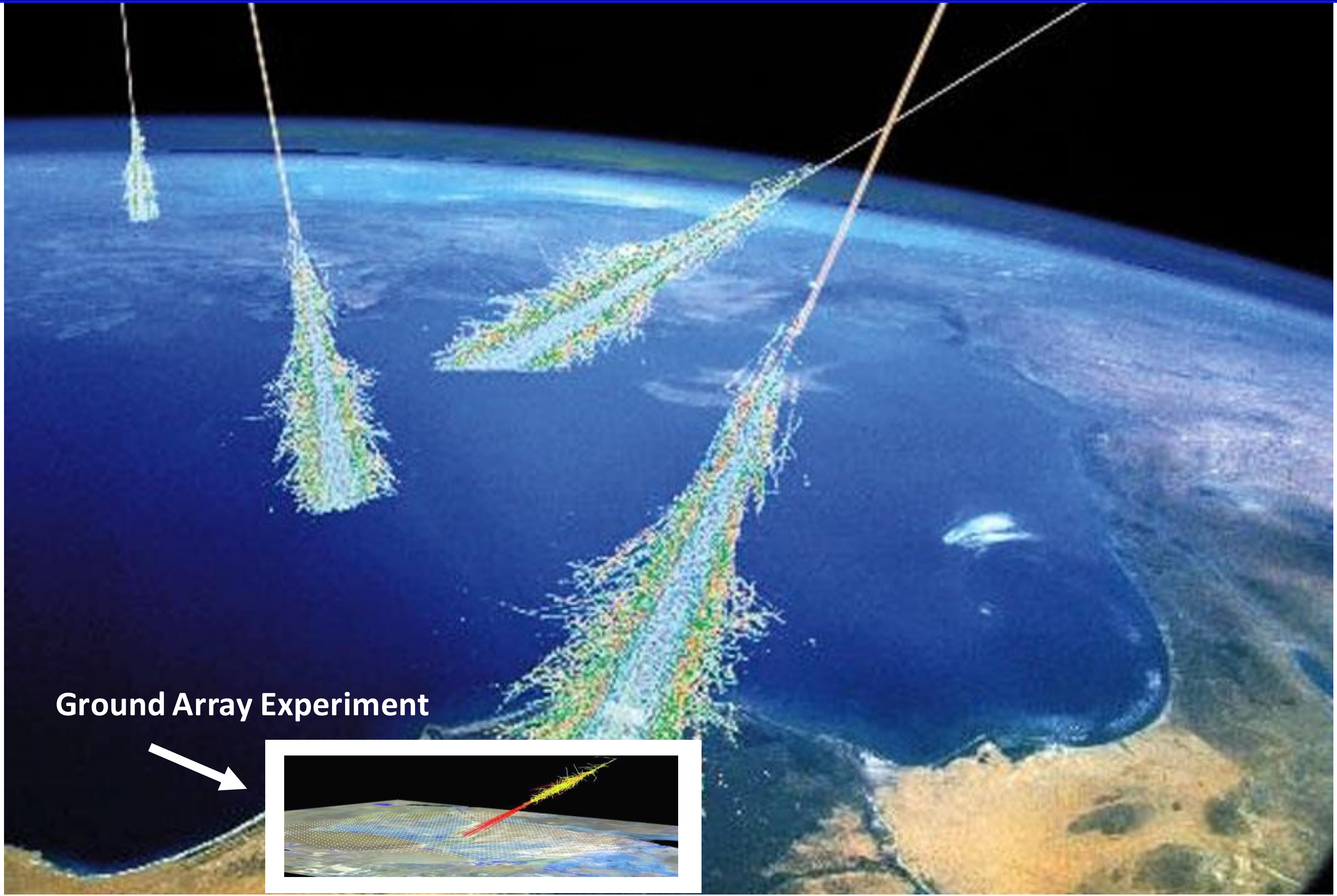
Fun Fact #1

If you have a pacemaker, you cannot come within 20 ft of HELIX when the magnet is on

Where will we put our detector?



Cosmic Ray Measurements



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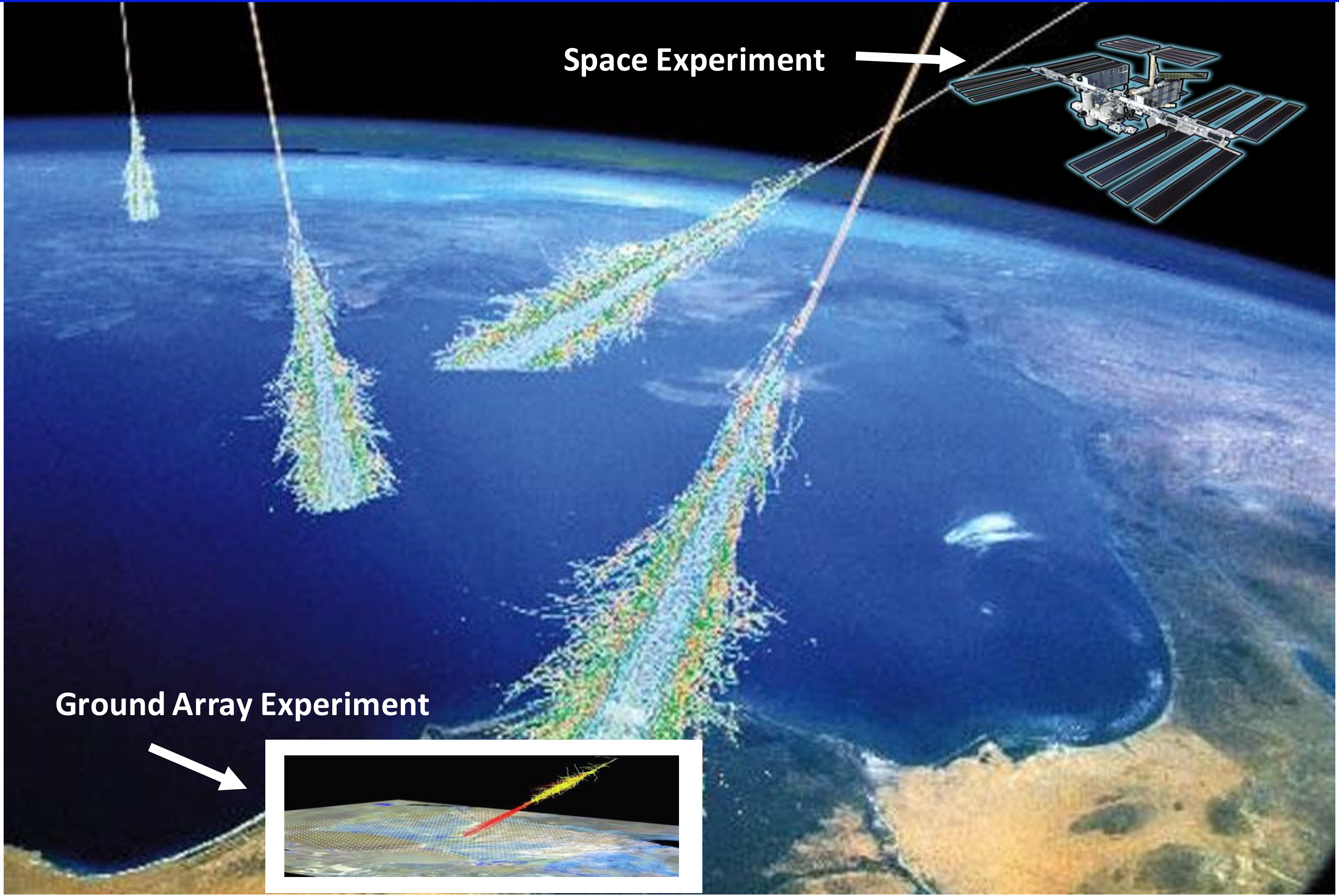

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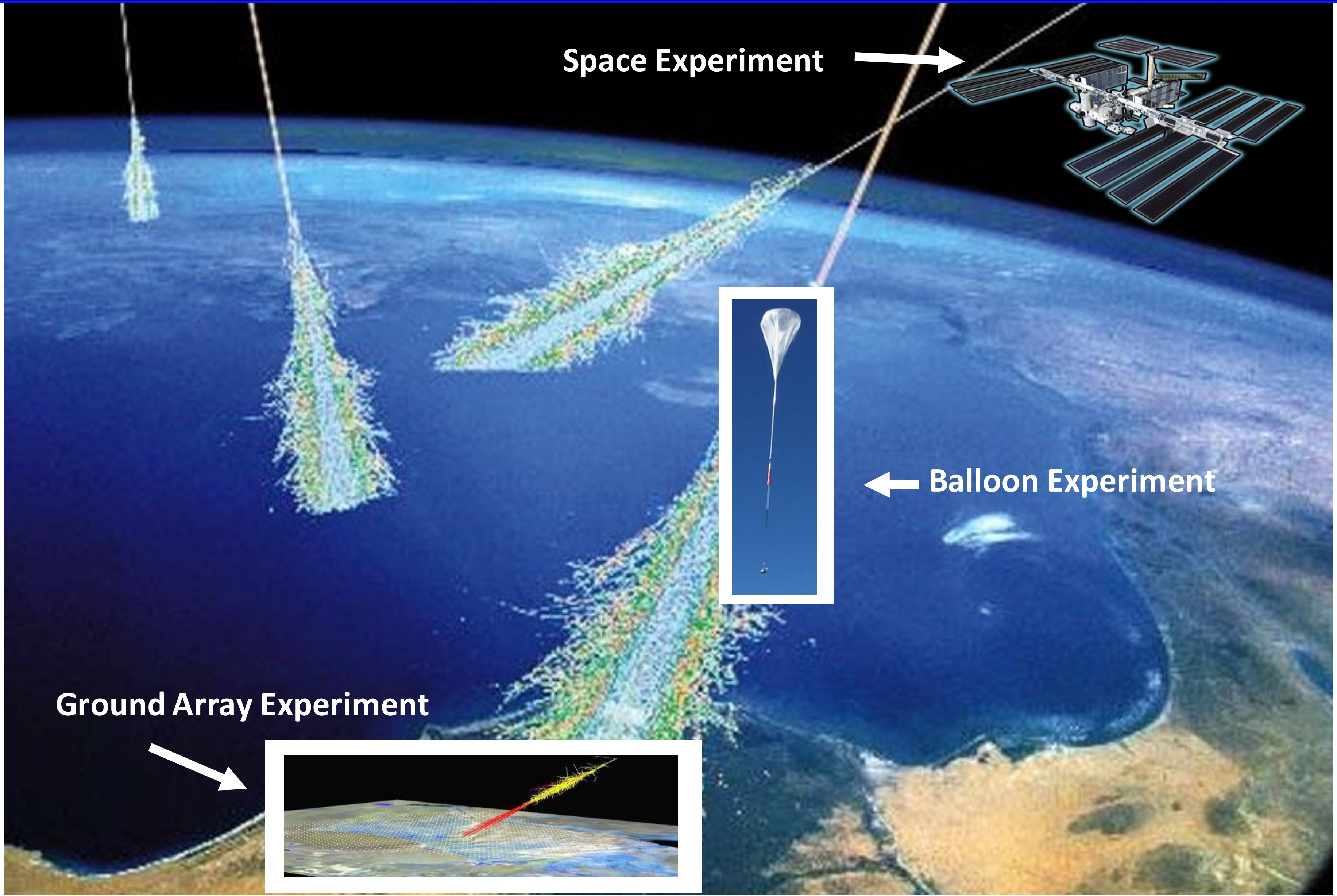
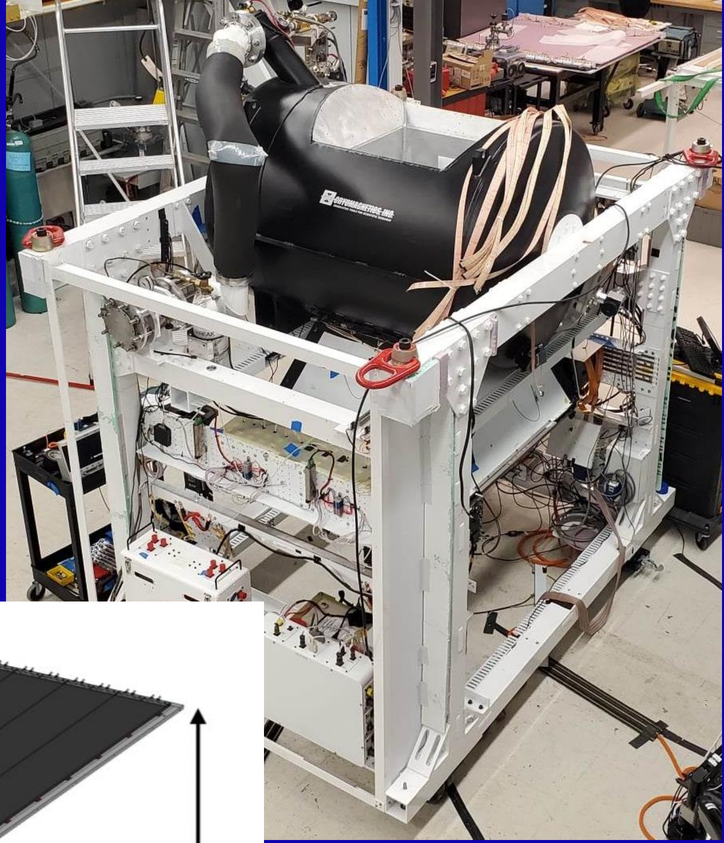
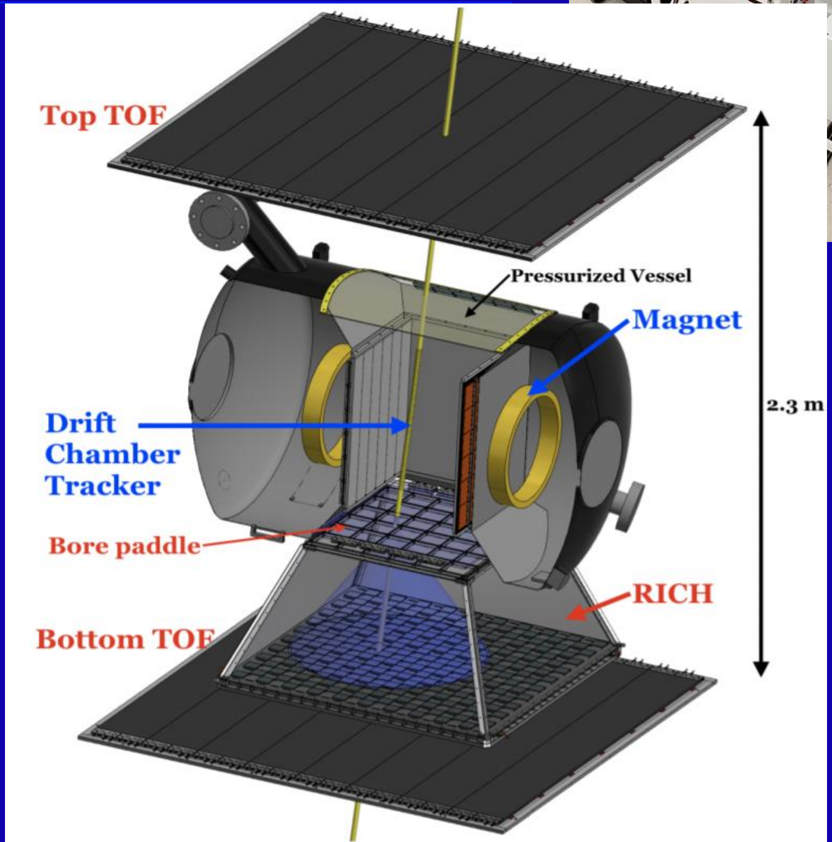


HELIX!

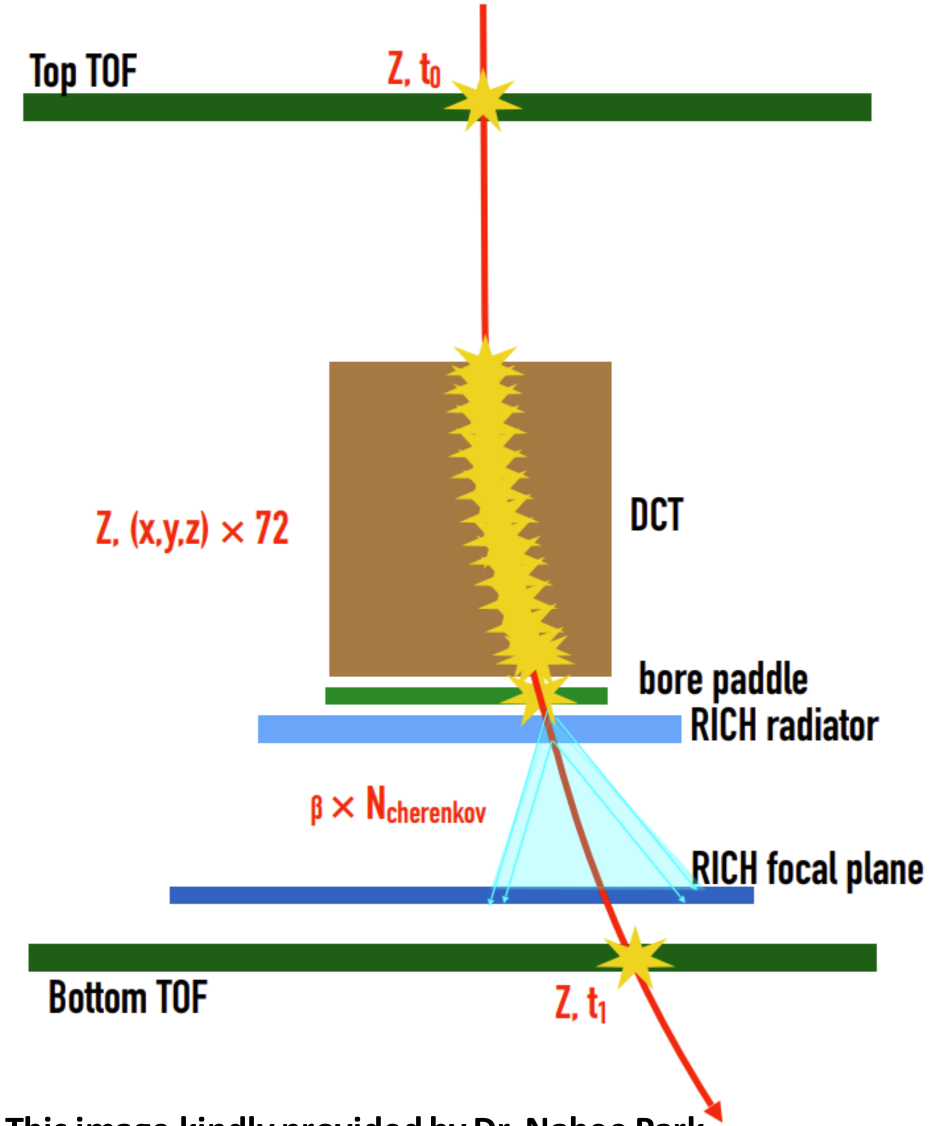
High Energy Light Isotope eXperiment

- A magnetic spectrometer to measure ^{9}Be and ^{10}Be masses and achieve mass resolution of 3%
- A payload designed for a long-duration balloon flight
- Energy range: 1-3 GeV/nucleon
  → Stage 1 (first flight)





HELIX Stage 1 Performance Goal



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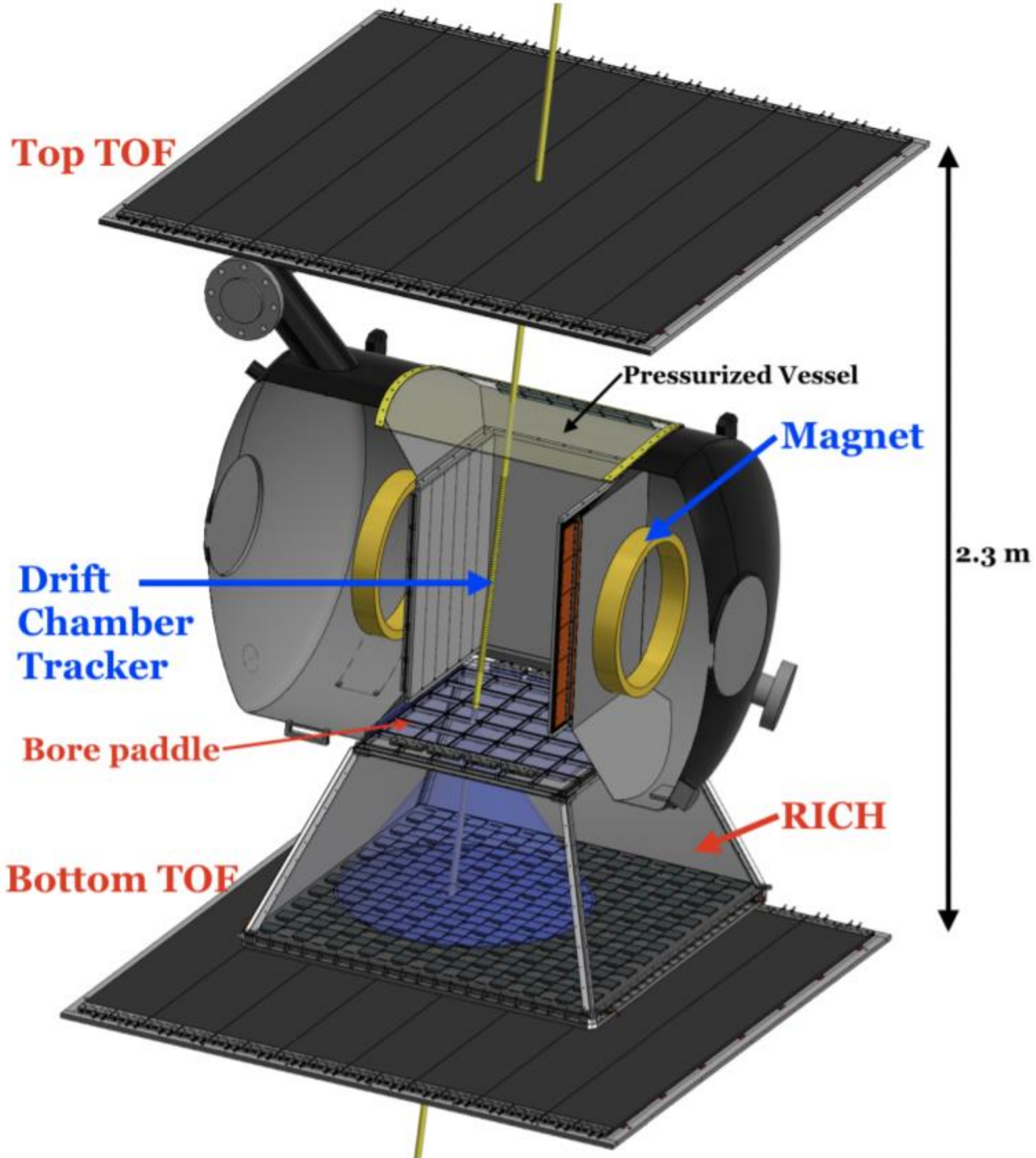

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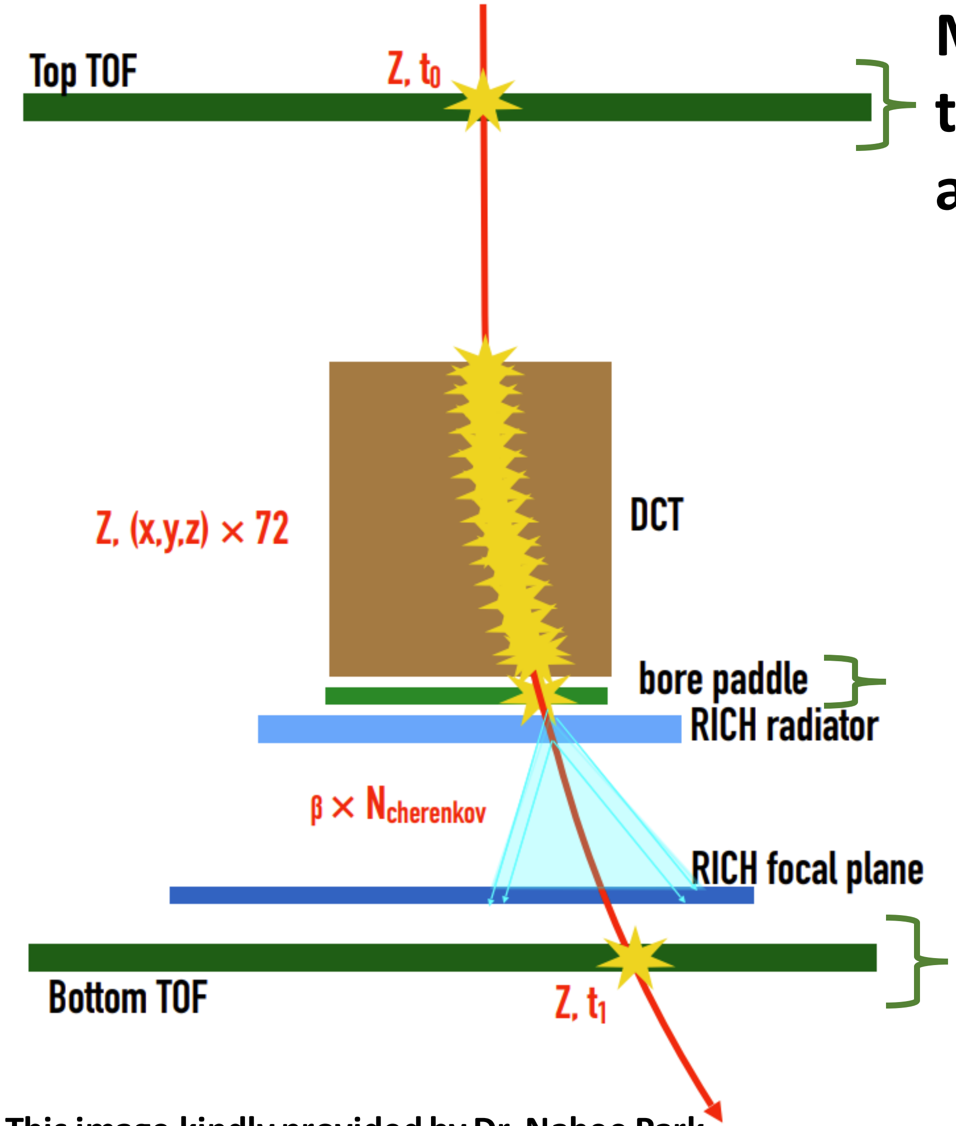
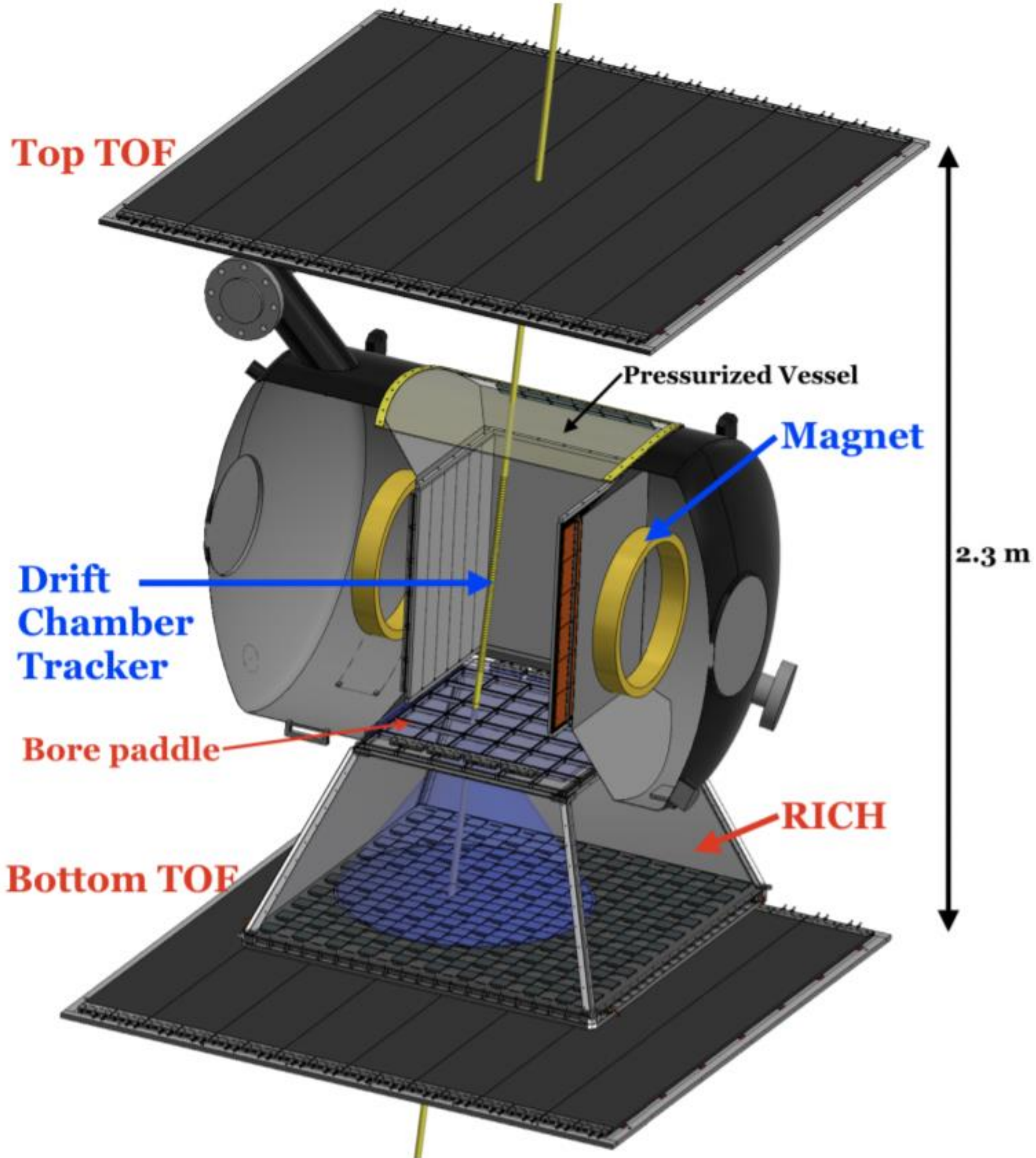


Measures particle timing (Velocity) and charge



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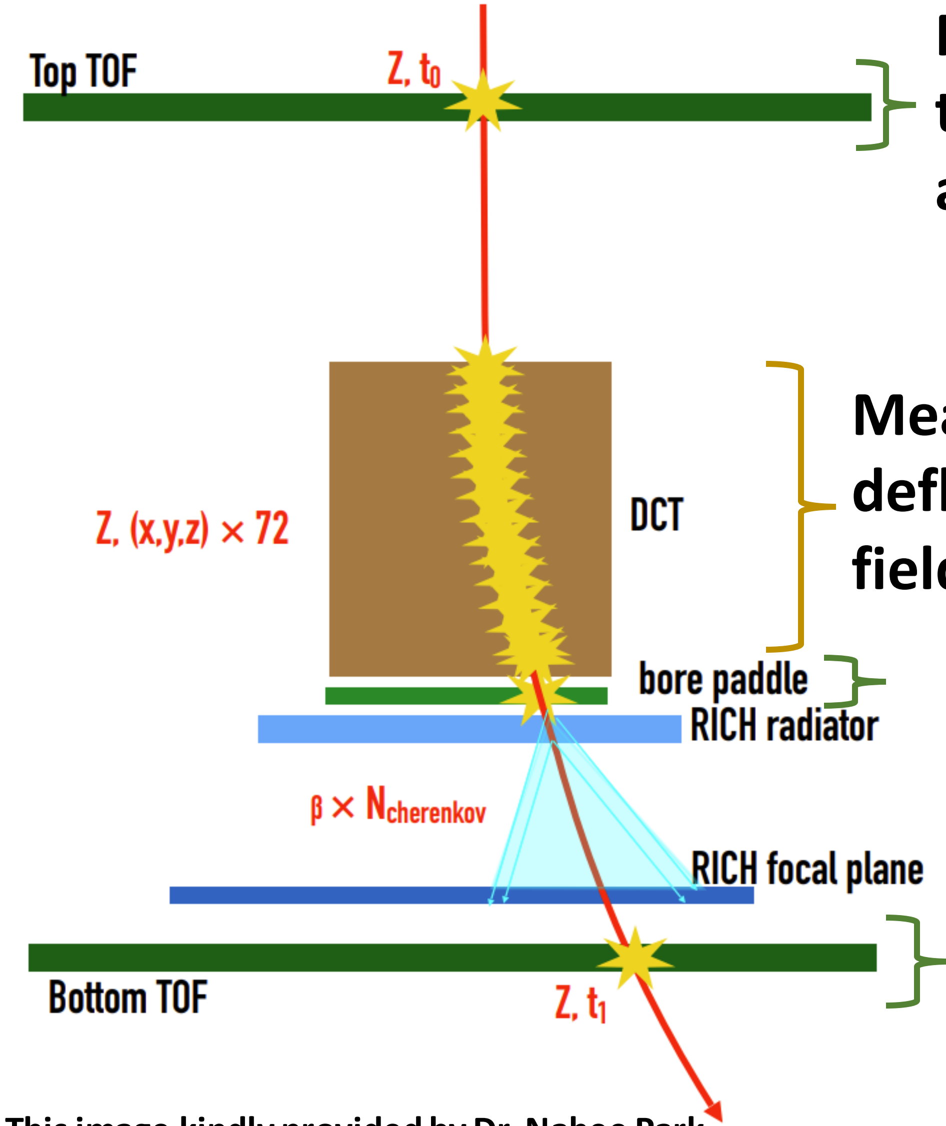
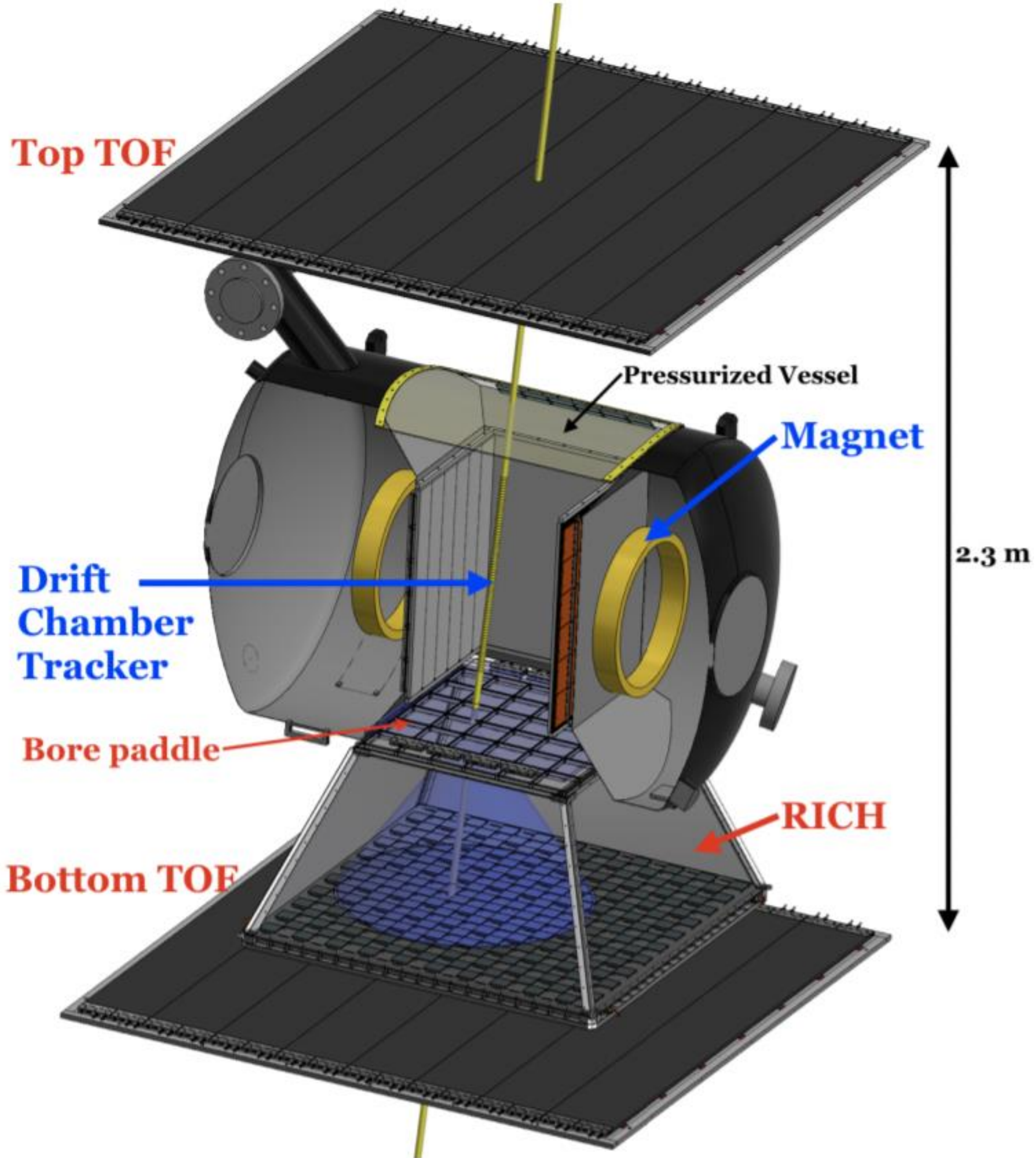


Measures particle timing (Velocity) and charge

Measures particle deflection in magnetic field (curvature)



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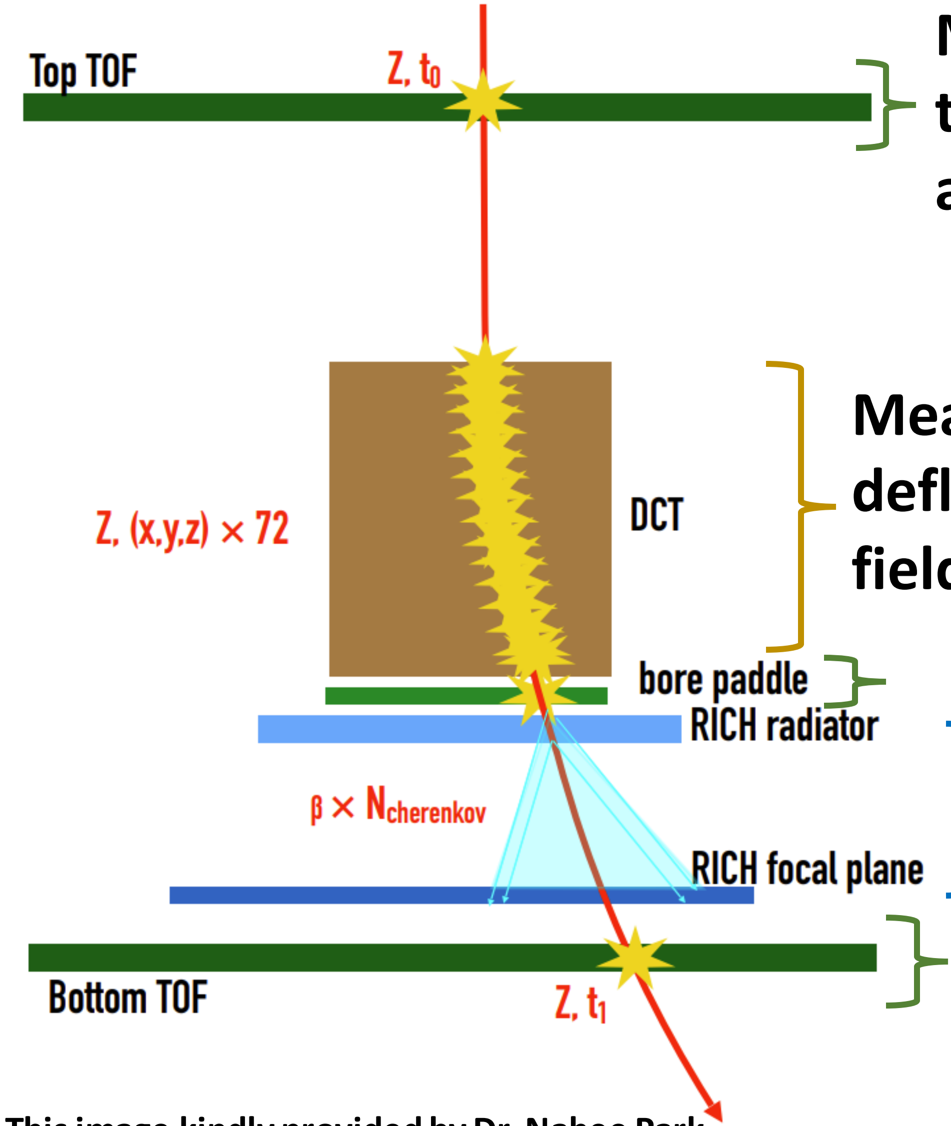
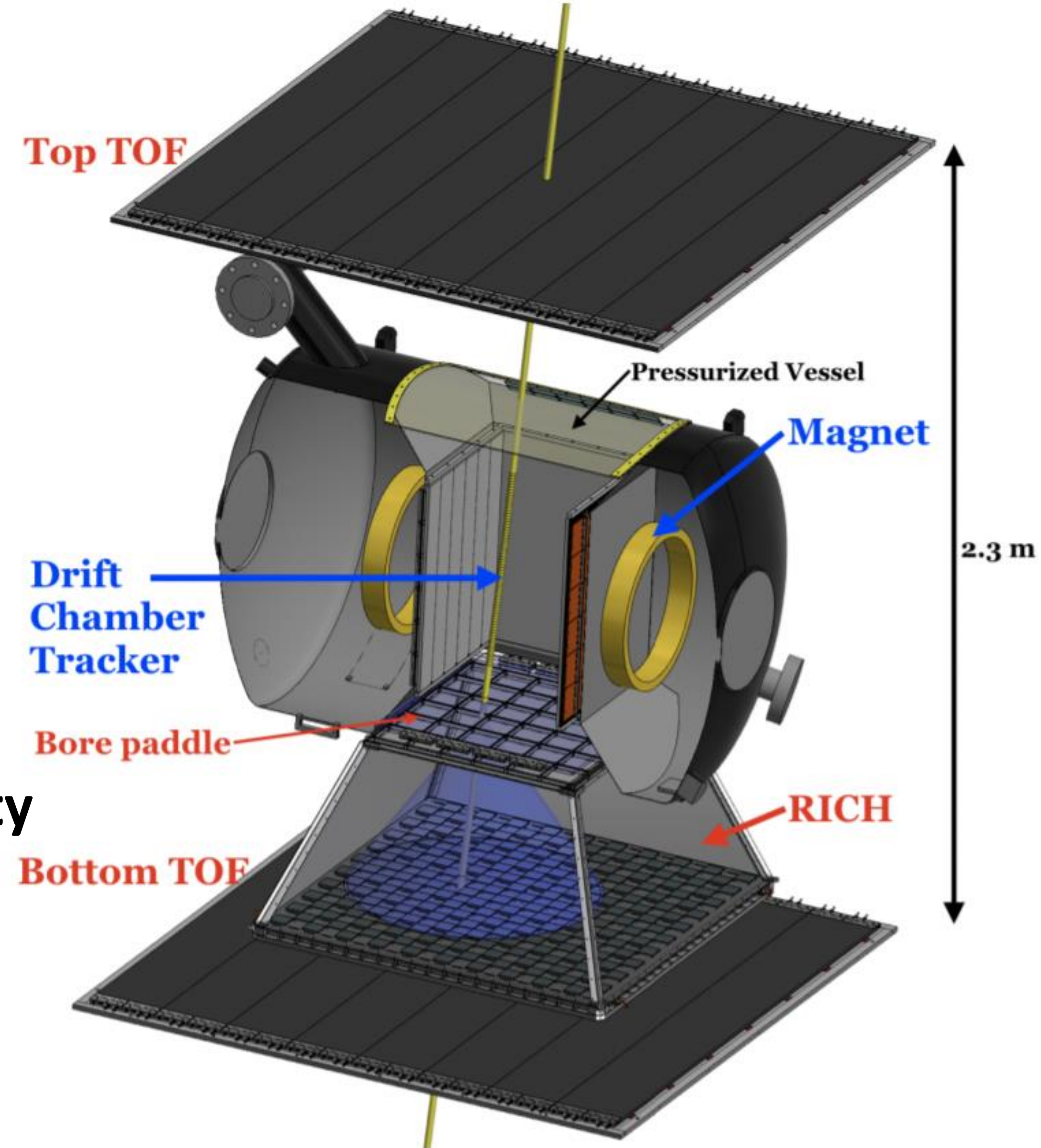


Measures particle timing (Velocity) and charge

Measures particle deflection in magnetic field (curvature)

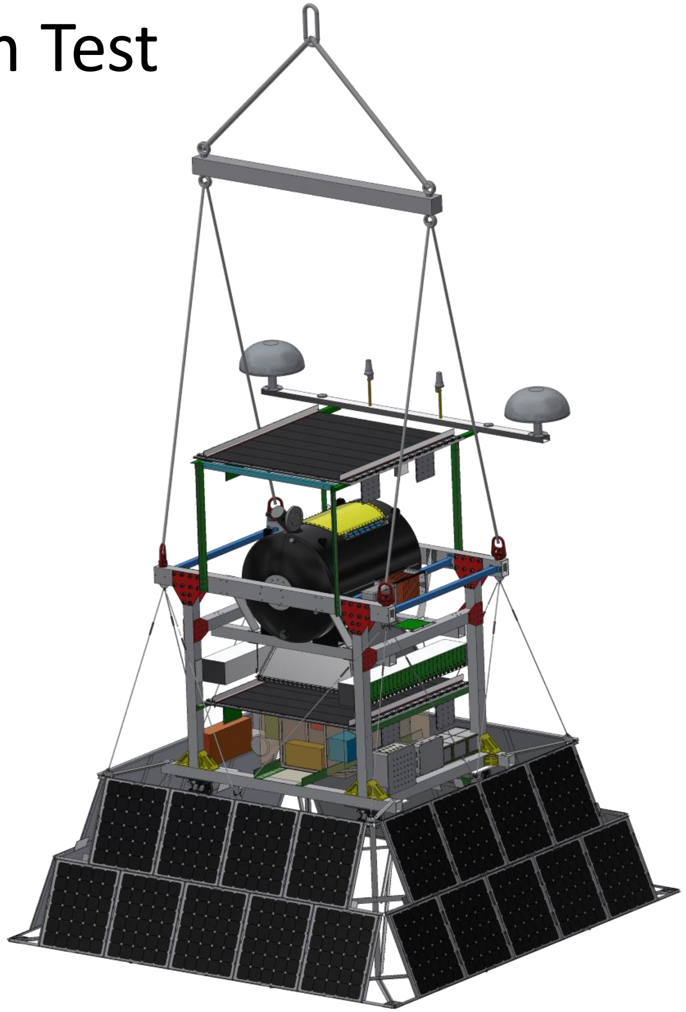
Accurate relativistic velocity measurement

This image kindly provided by Dr. Nahee Park



Validation Process

1. **Build Experiment**
2. Thermal Vacuum Test
3. Magnet Test
4. Integration Test
5. Shipping to Site
6. Launch!



Validation Process

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Validation Process

1. Build Experiment
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Fun Fact #2

Liquid Helium boil-off destroys apple products, but not Samsung products!

Validation Process

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Validation Process

1. Build Experiment
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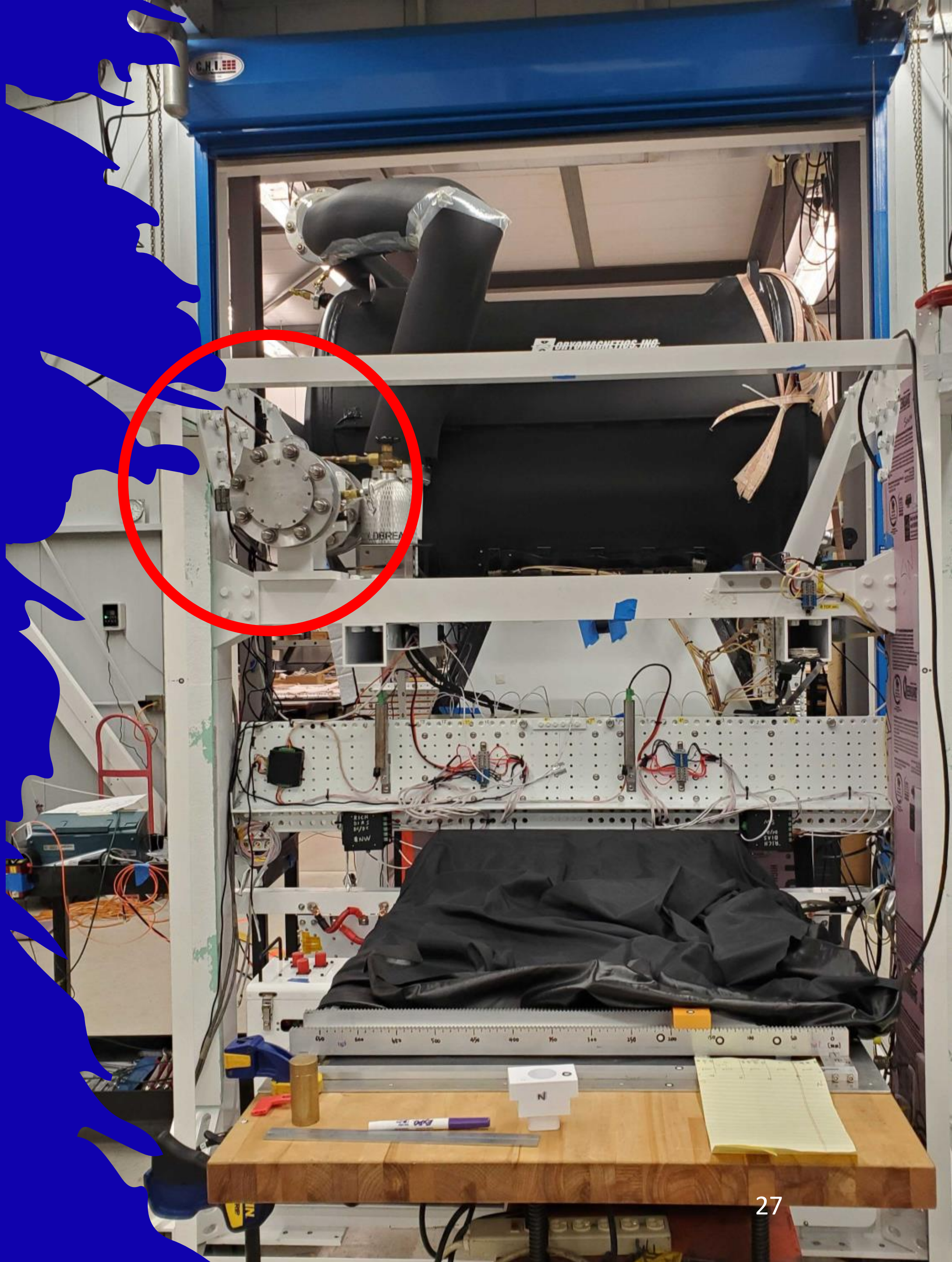
5. **Shipping to Site**
6. Launch!

Fun Fact #3

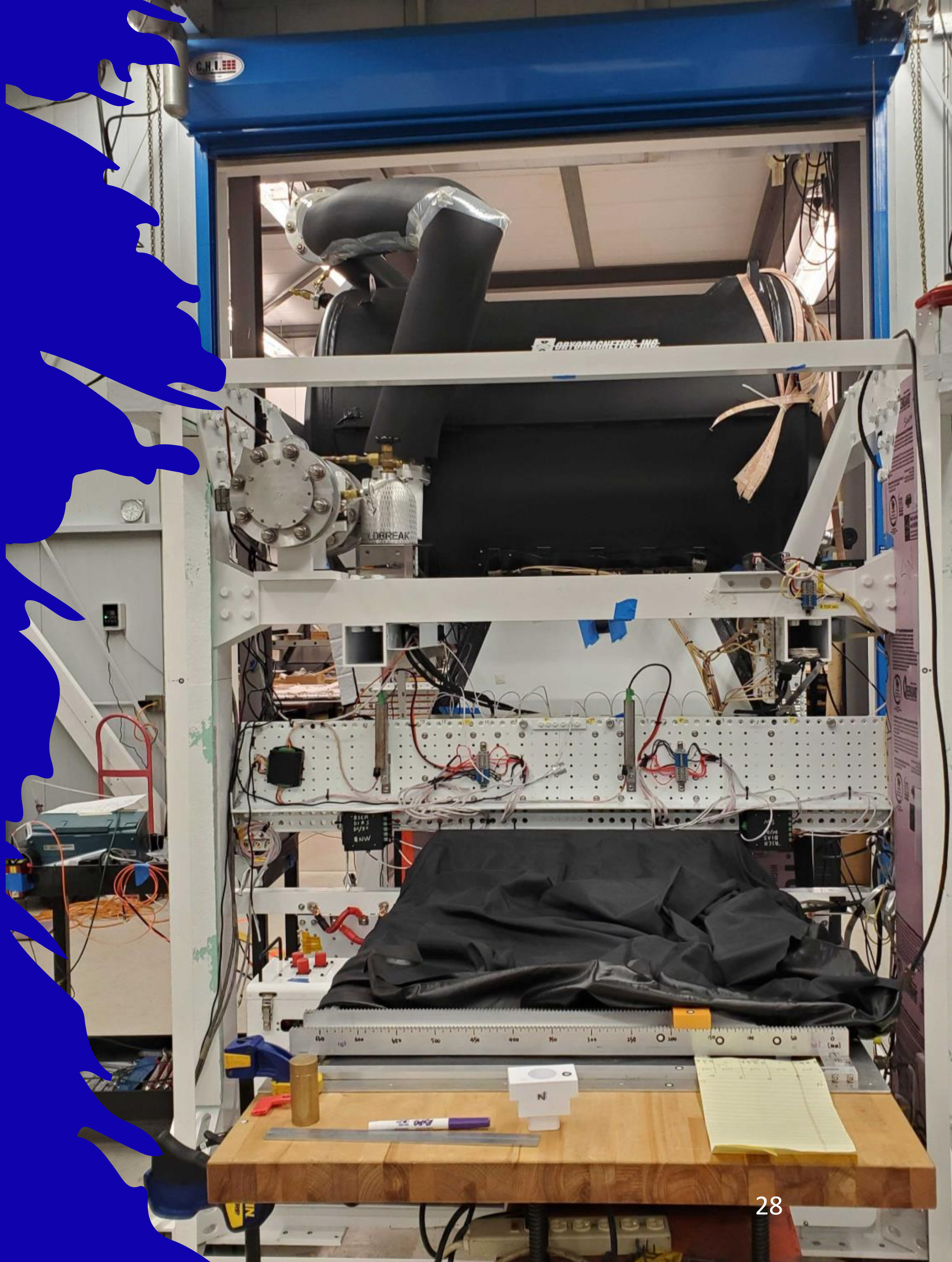
Every high pressure system needs some kind of relief valve. The HELIX one is nicknamed the "Prime Weapon" and you should not stand in front of it when the magnet is filled.



~~Fun~~ Fact #3.5

The magnet once exploded because of poor internal welding. The dewar did not endure the pressure it was designed for and almost killed :(

Phys/EngPhys Students, please take note!



Validation Process

1. Build Experiment
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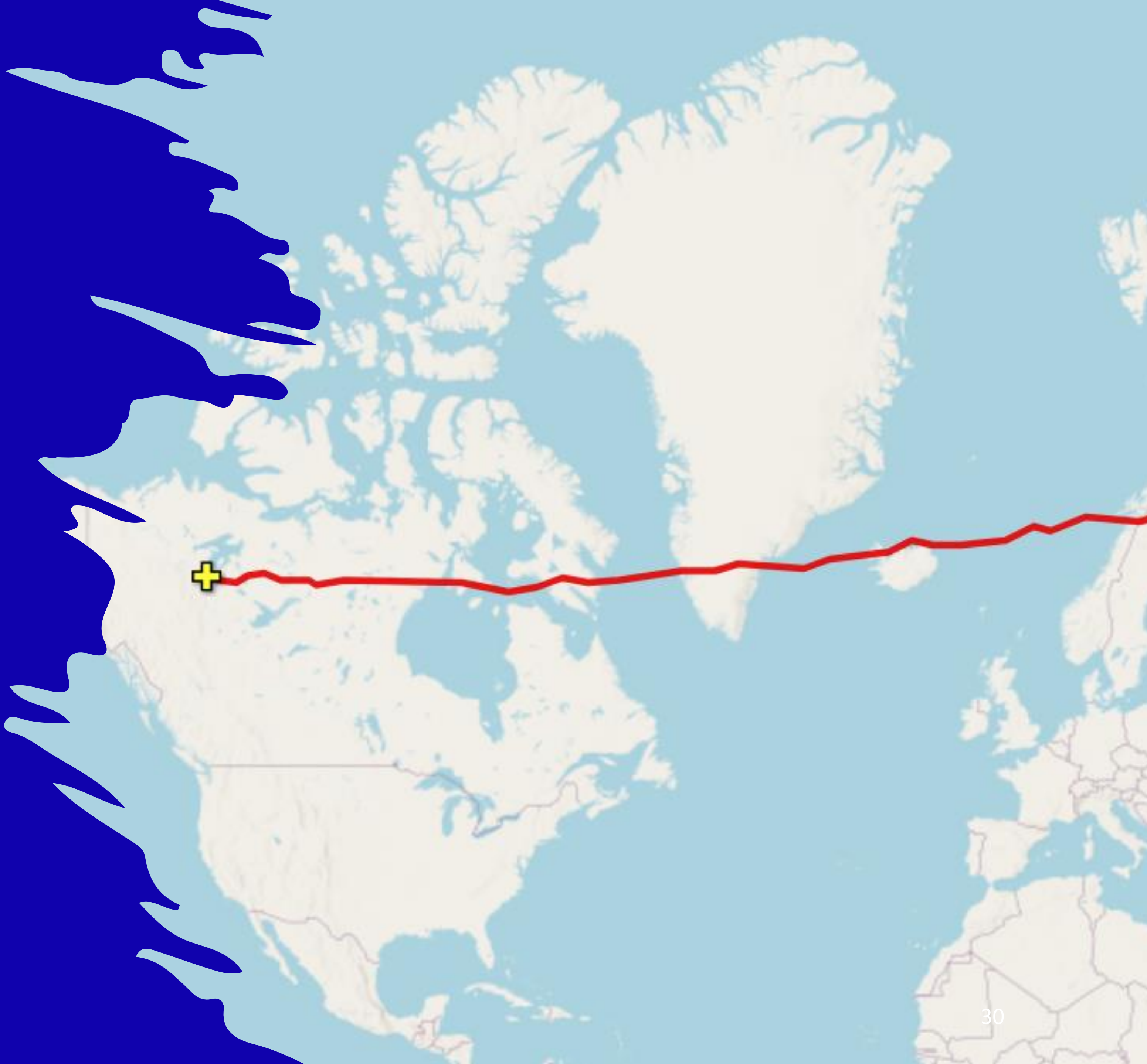
6. **Launch!**

Happening Soon!

Payload is currently in Kiruna, Sweden :)

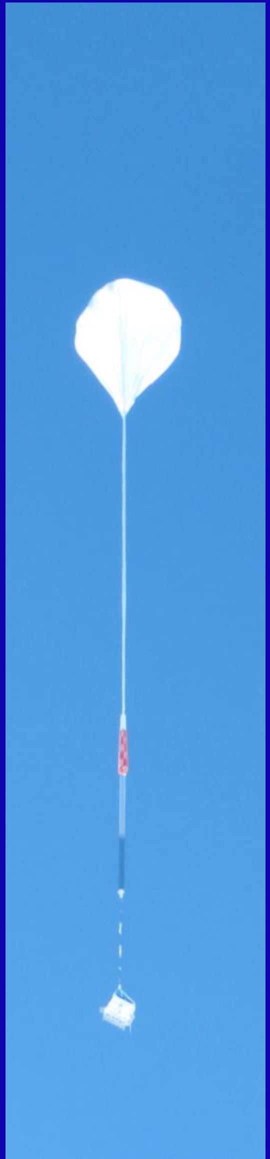
Fun Fact #4

When Launching from the North pole (specifically Kiruna, Sweden), you must be certain the polar vortex will take you over Canada and not Russia if you want to get full flight time and recover your payload

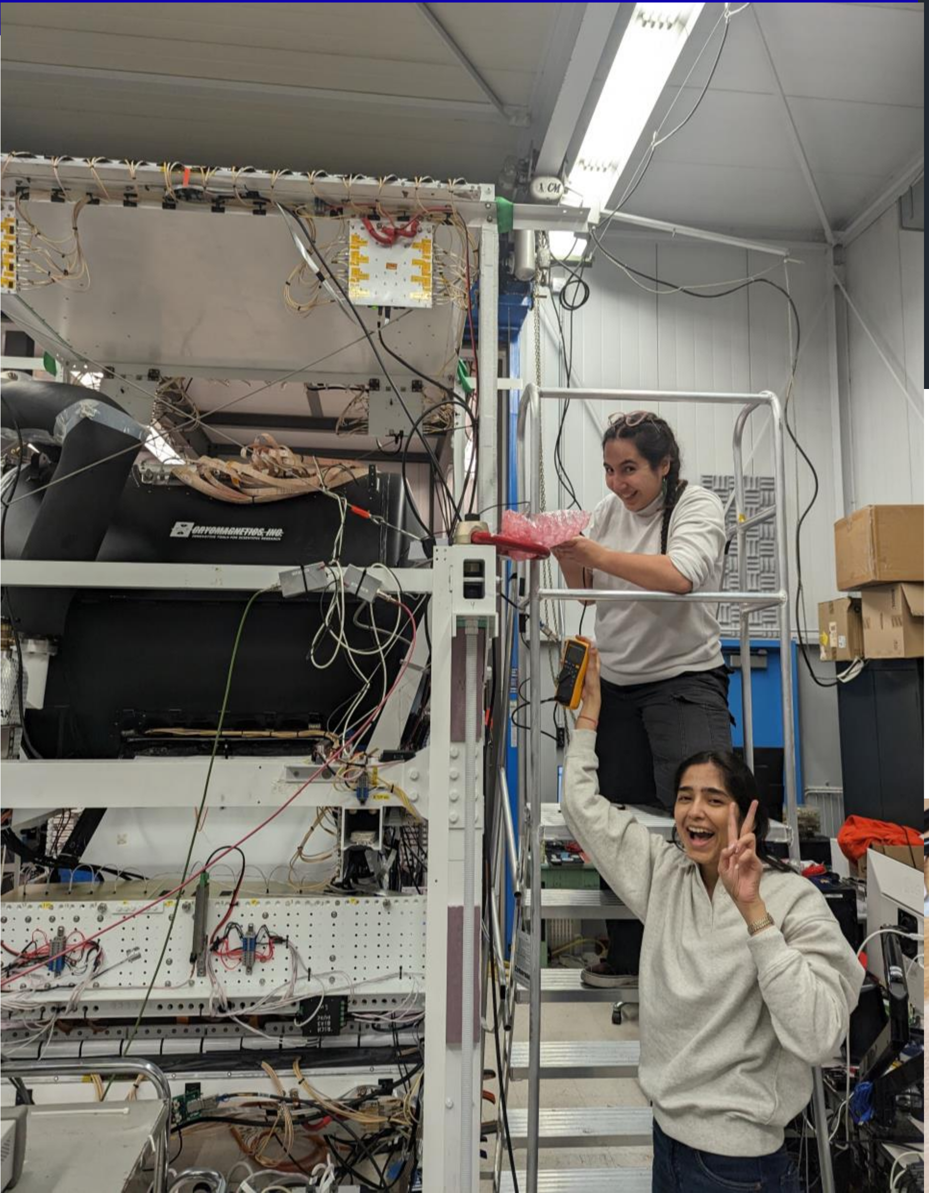


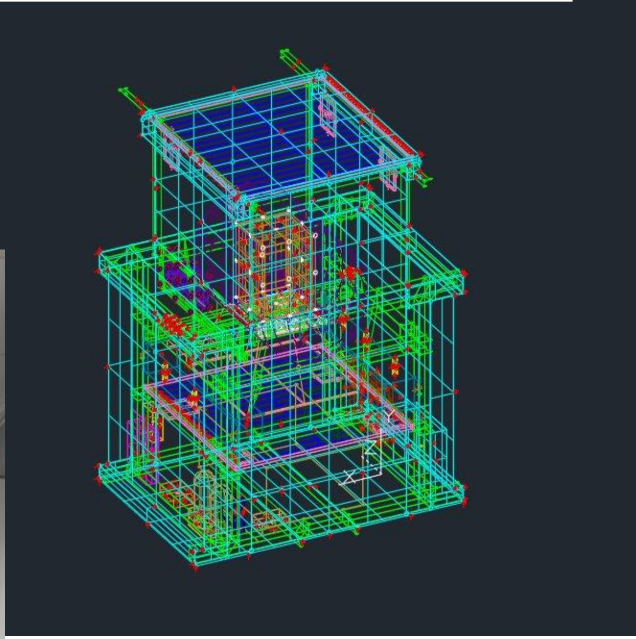
Challenges of Balloon Experiments

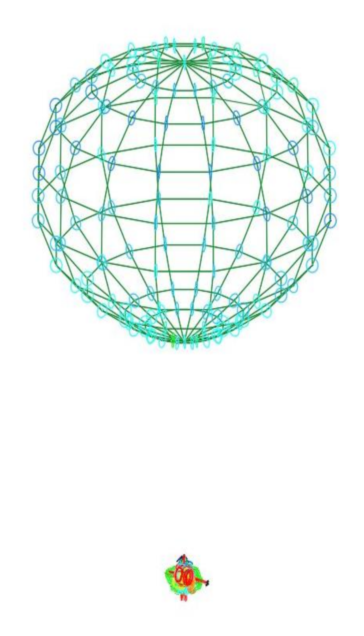
- Power: Solar Panels + Batteries
- Weight <2700 kg (To reach 40 km Alt.)
- Bandwidth for data transfer
- Thermal limitation: Only conductive and radiative cooling
- **You cannot repair or modify apparatus after launch!**



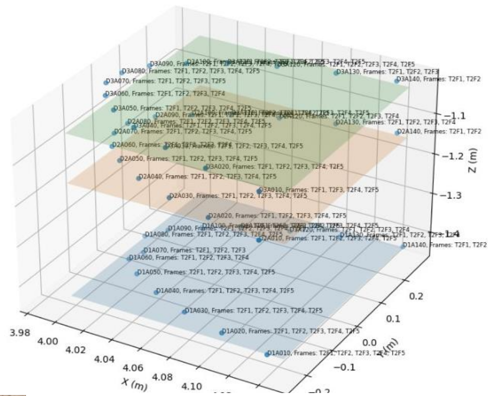
My Work

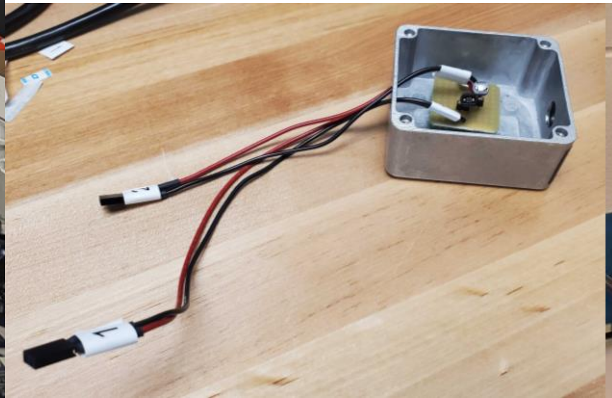


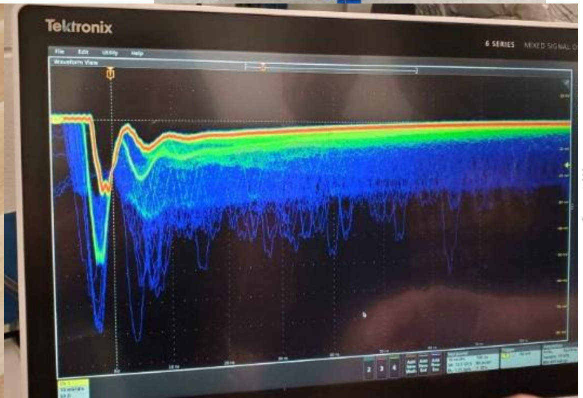


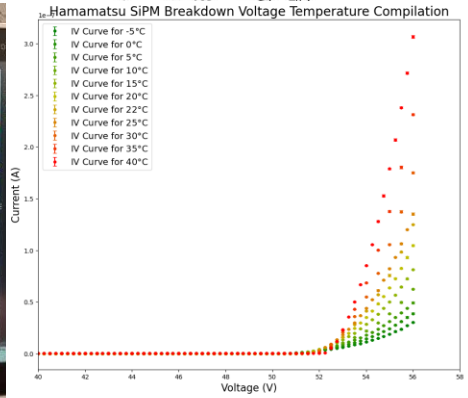


- Thermal Model
- Metrology
- SiPMs









Summary

- HELIX will provide key measurements of propagation clock isotopes that will be essential to understand new features of cosmic rays and discriminate between propagation models
- **The first stage of HELIX is scheduled to fly soon out of Kiruna, Sweden!**

HELIX

Thank You!

Up Next: Bonus Slides

Primary to Secondary Ratio

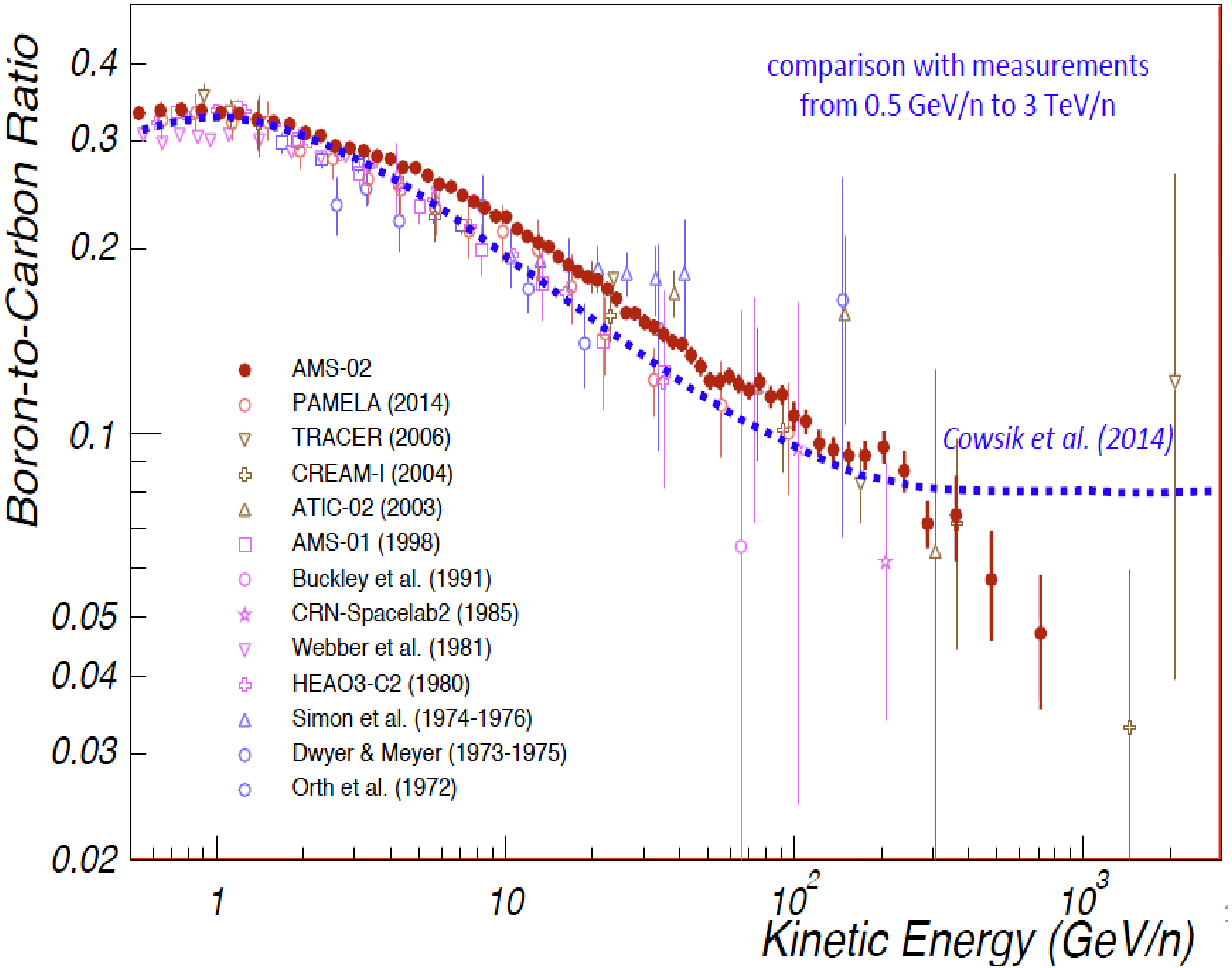
- Secondaries are generated by primary particle interactions
- Primary to secondary cosmic ray ratio of interest: Boron to Carbon

$$\frac{\Phi_{Boron}}{\Phi_{Carbon}}$$

Secondary

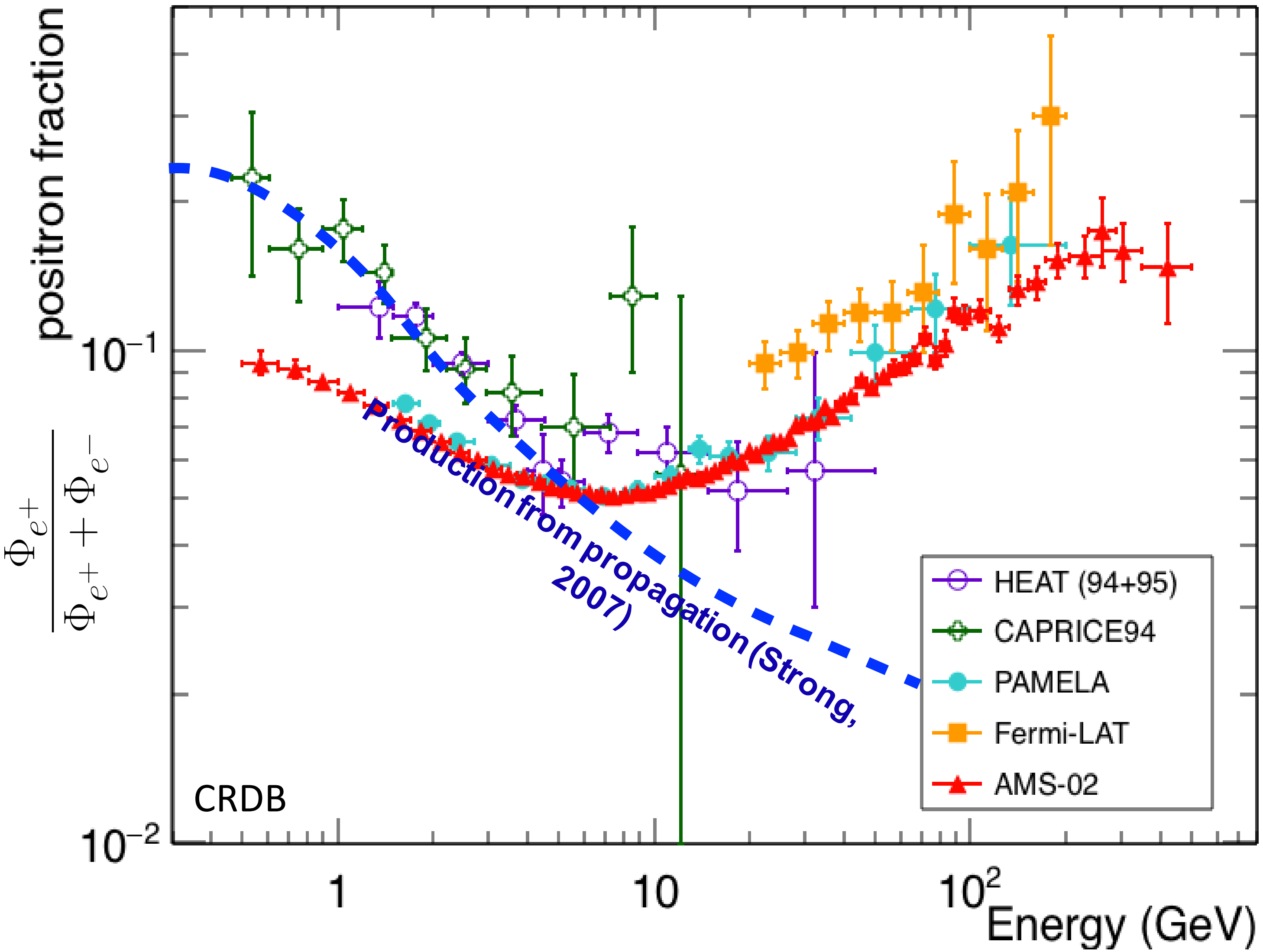
Primary

- Sensitive to amount of matter traversed to reach earth



Rising Positron Fraction

- Positrons were expected to be produced as propagation events (their fraction decreasing with increasing energy), following the blue trendline
- Surprise! At higher energies, positron fraction rises
- Need to understand the propagation better!



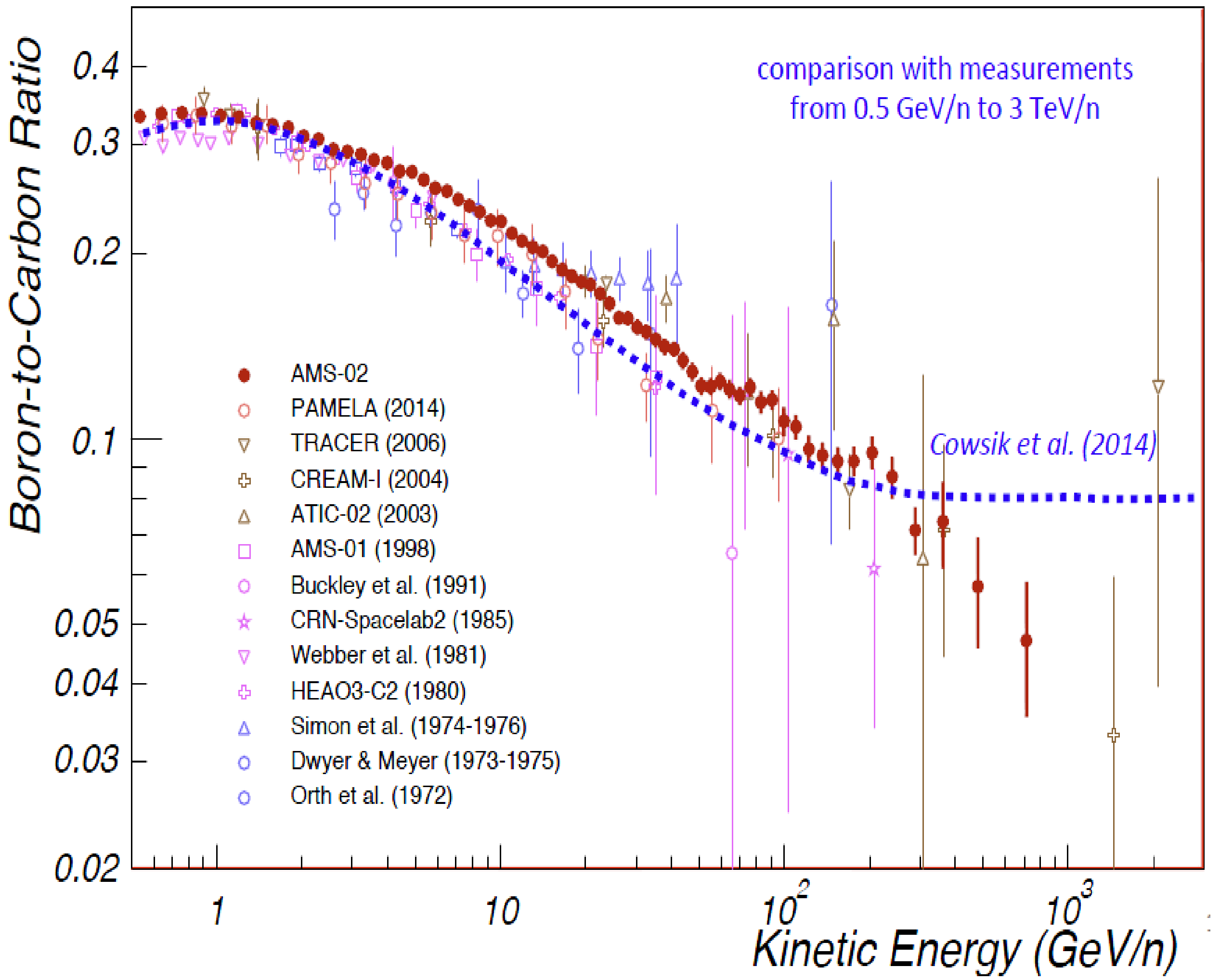
Primary to Secondary Ratio for Propagation Studies

$$\# \, of \; created \; sceondary \; particles =$$

$$(cross \; section) \times (\# \, of \; primary \; particles) \times$$

$$(amount \; of \; matter \; primaries \; traversed \; during \; lifetime)$$

- Degeneracy between matter traversed and lifetime :(
- (Cannot tell difference between cosmic rays travelling through a lot of matter in a short time, or, travelling for a long time through very little matter)

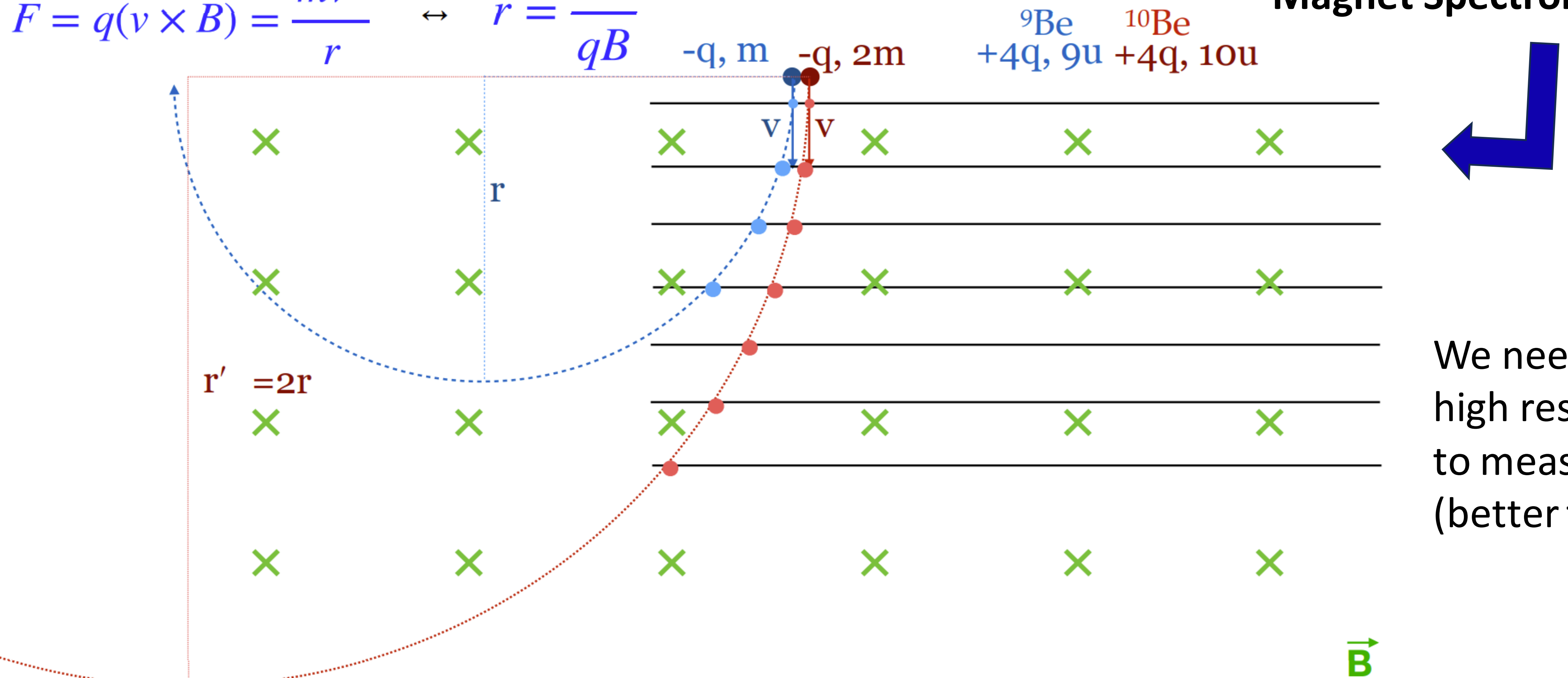


Measurement Challenges

- Need to measure charge, mass, and energy of incident particles
- ^{9}Be and ^{10}Be have a 10% mass difference

$$F = q(v \times B) = \frac{mv^2}{r} \quad \leftrightarrow \quad r = \frac{mv}{qB}$$

Magnet Spectrometer!



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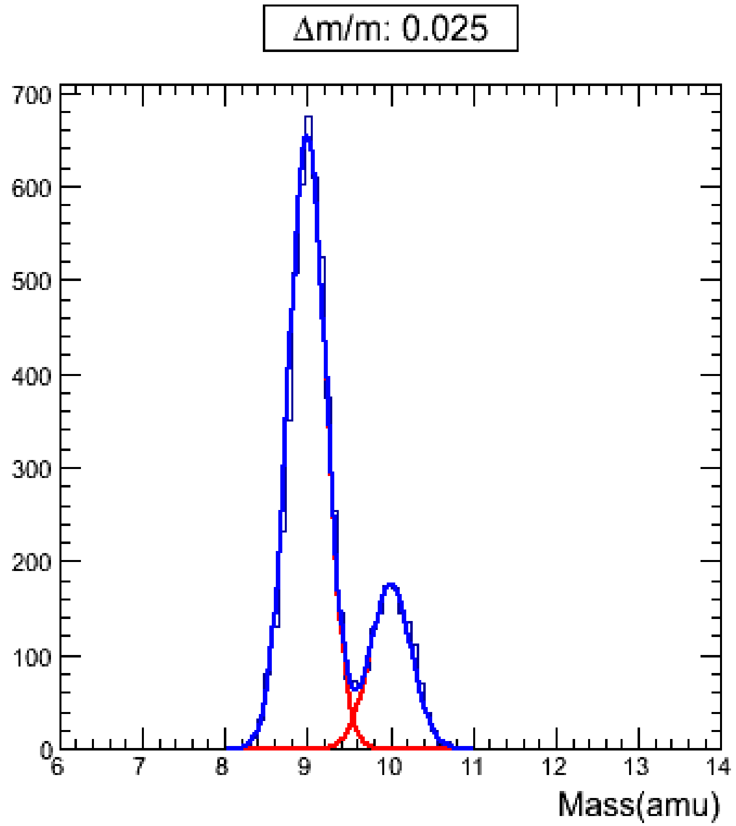
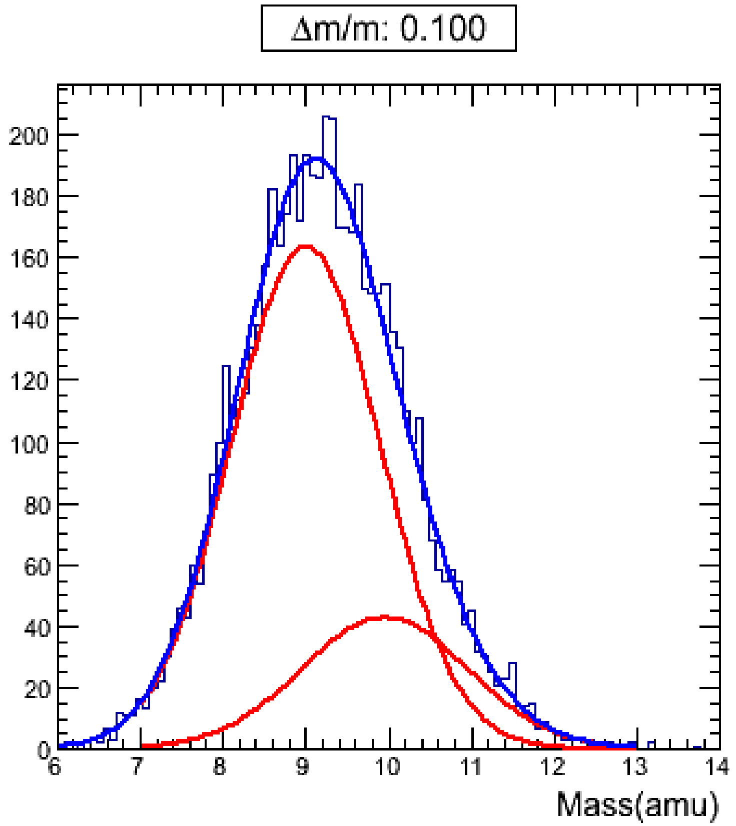
-q, m -q, 2m

^{9}Be +4q, 9u ^{10}Be +4q, 10u





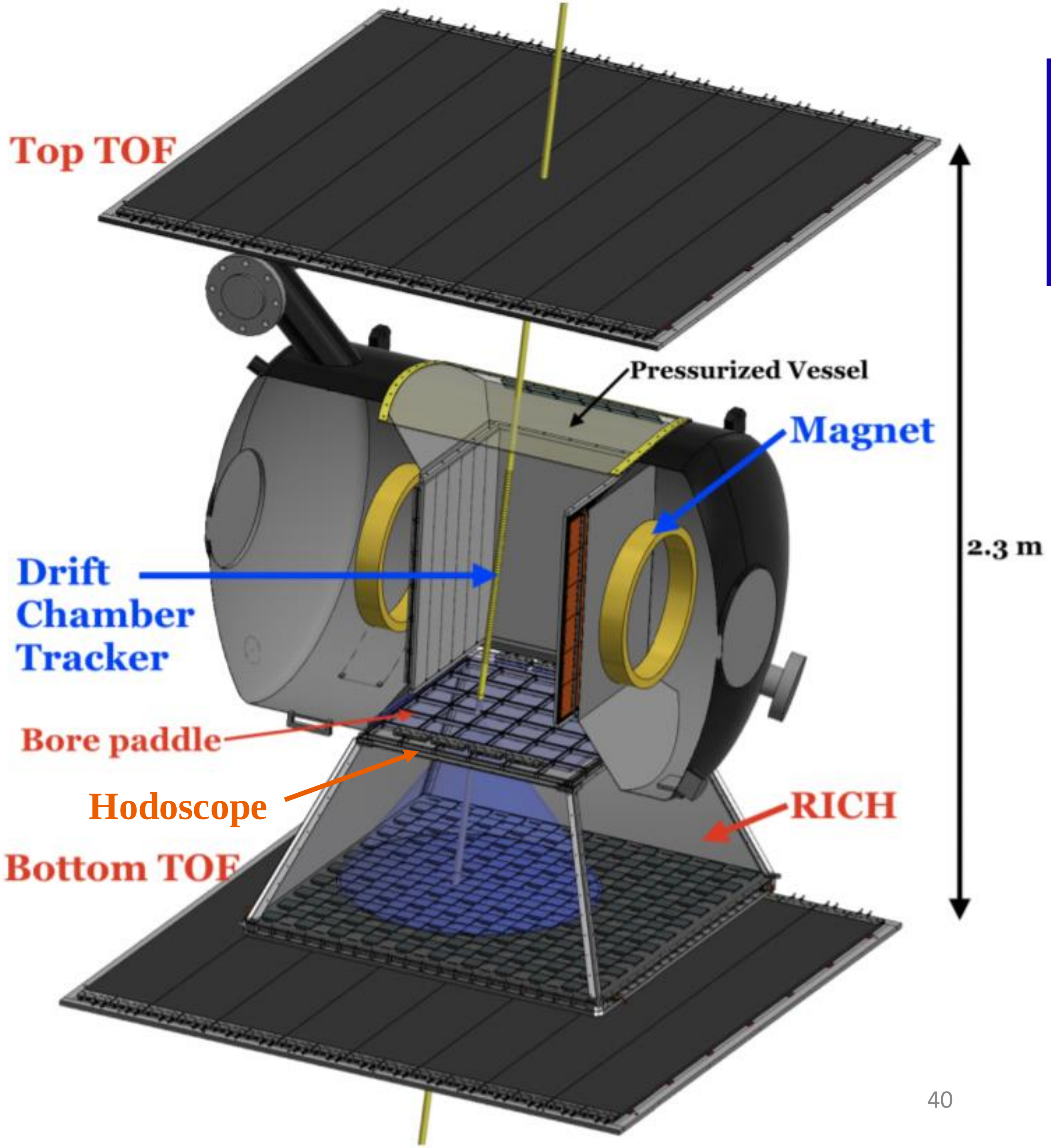
→ Both rigidity and velocity must be measured at a few percent level precision.

→ HELIX mass resolution:

Δm/m ~ 2.5%

HELIX Detectors

- **TOF:** Time of Flight
  - 3 scintillating paddles with resolution better than 50 ps when charge >3
- **DCT**: Drift Chamber Tracker
  - measures curvature path of deflected charged particles in magnetic field
- **RICH:** Ring Imaging Cherenkov
  - Provides accurate velocity measurement of relativistic charged particles with Cherenkov light
- **Hodoscope:**
  - Provides an additional position measurement for particles in 1-dimension (along x-axis)



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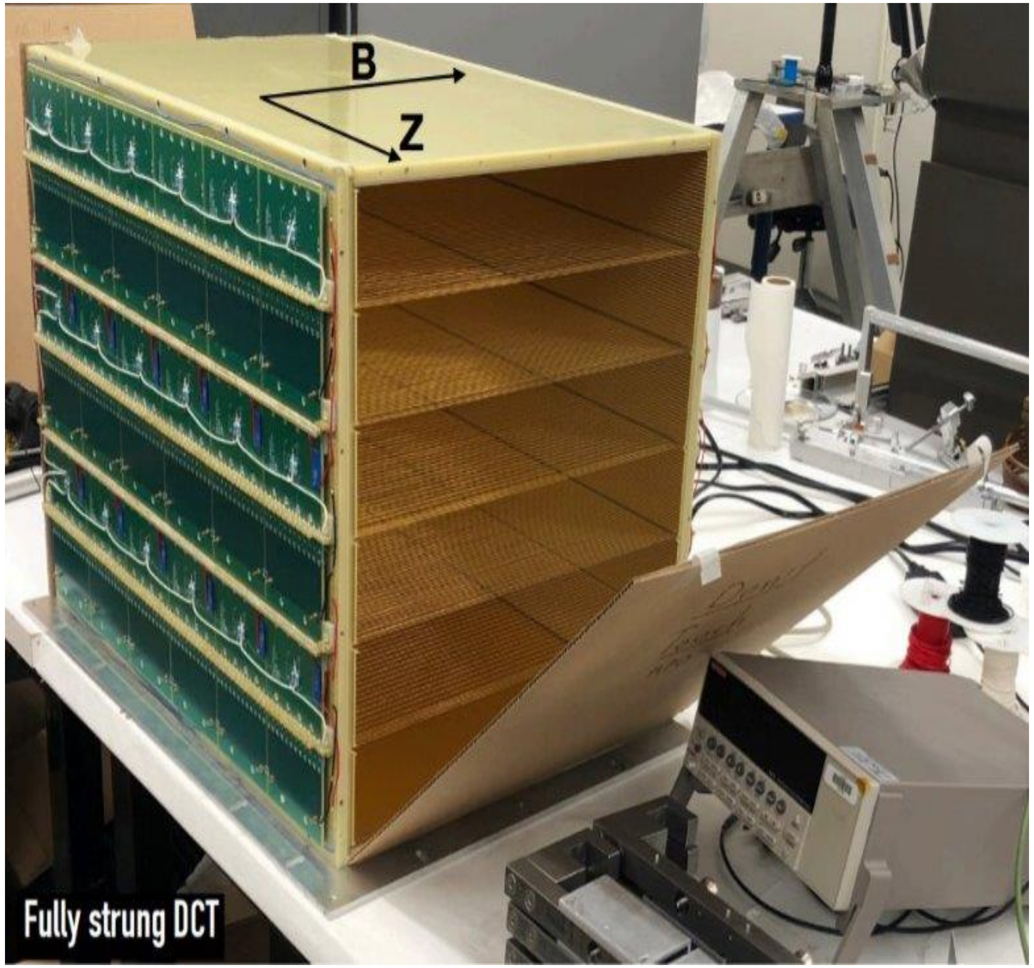

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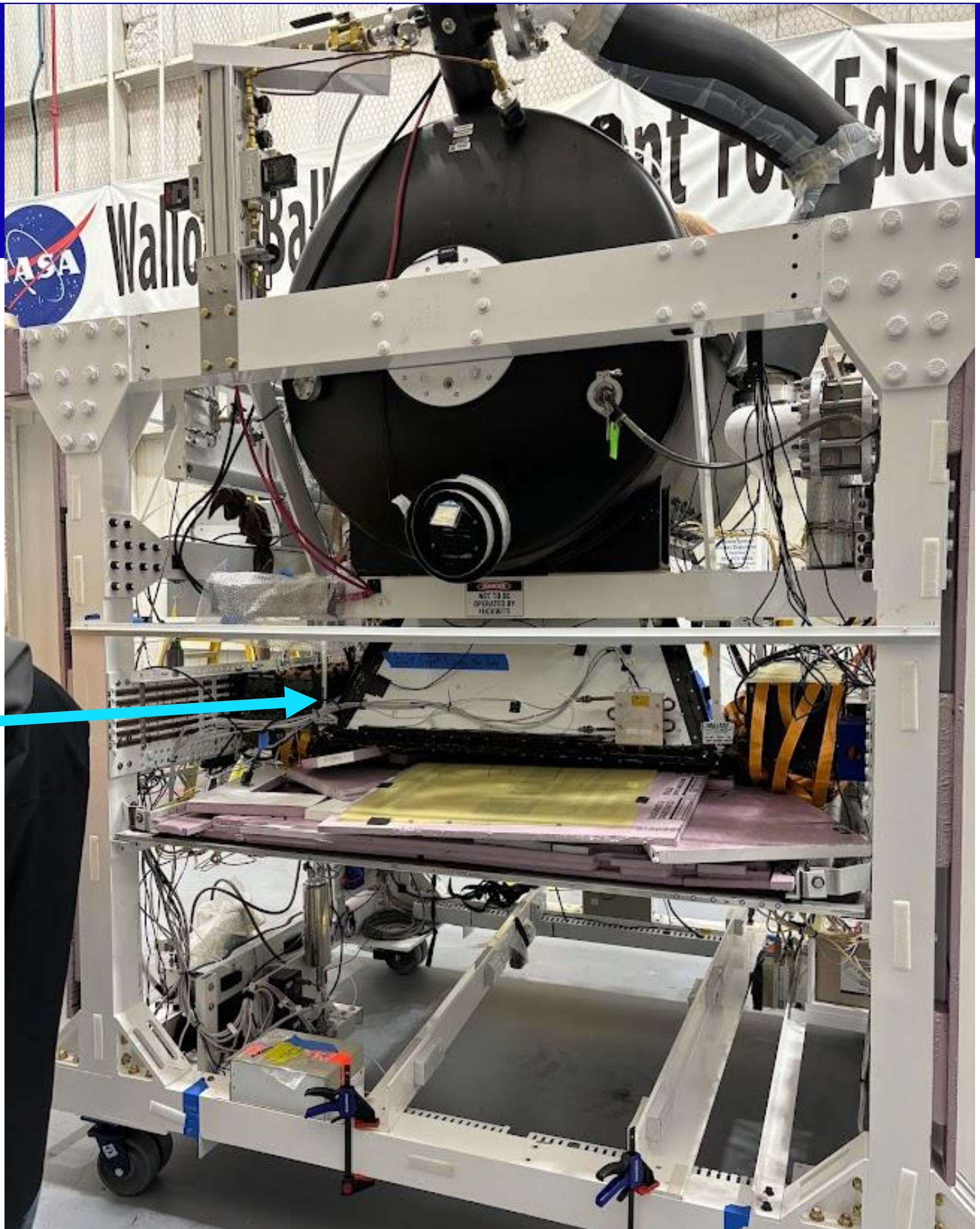

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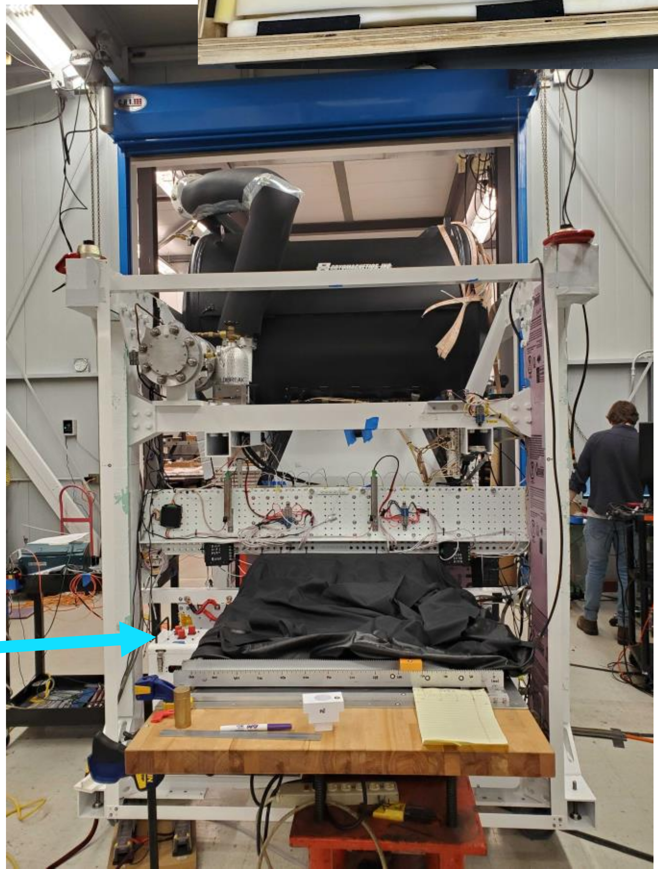

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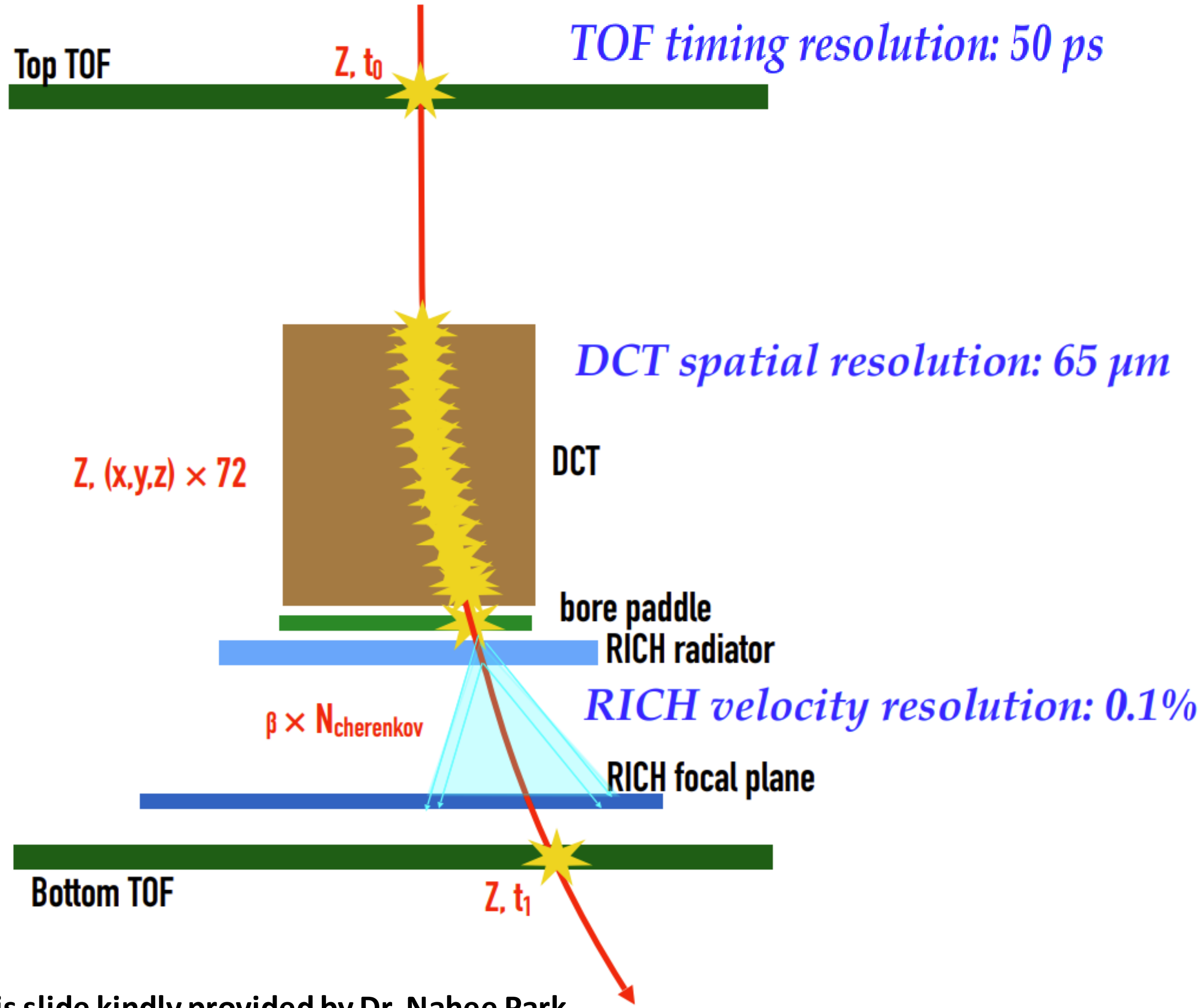
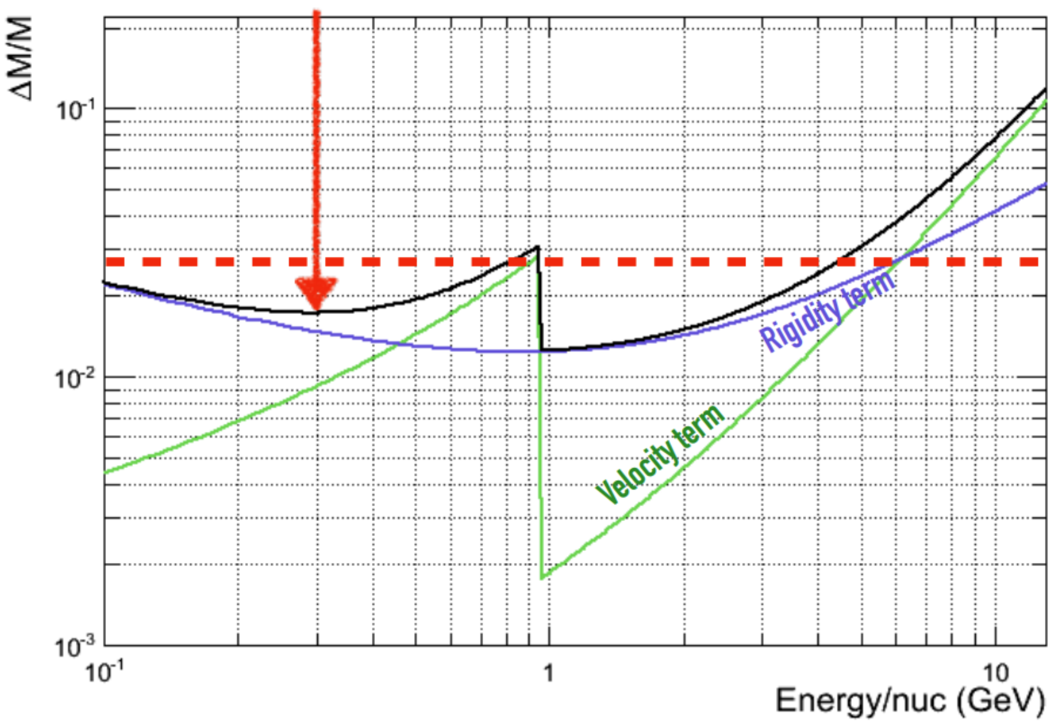


$$m = \frac{RZe}{\gamma\beta c}\,, \quad \left(\frac{\Delta m}{m}\right)^2 = \left(\frac{\Delta R}{R}\right)^2 + \gamma^4\left(\frac{\Delta\beta}{\beta}\right)^2$$



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