BESS and Antimatter: Eyes Above the Skies

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Wind Crest Learners
Academy for Lifelong Learning

What other eyes do we have?

- Antimatter searches
- UltraHighEnergyCosmicRays (UHECR)
- GAMMA RAYS finish origin of cosmic rays
- X-rays
- ACE, stereo
- Parker probe

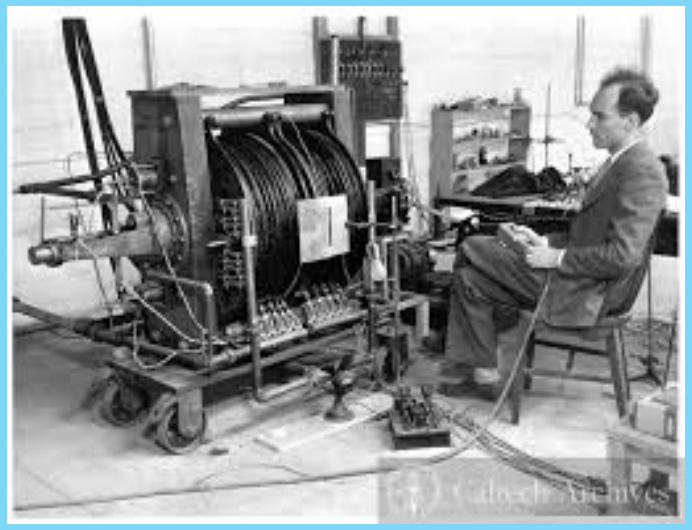
- Other
- Gravitational waves
- CALET

Today – our antimatter searches

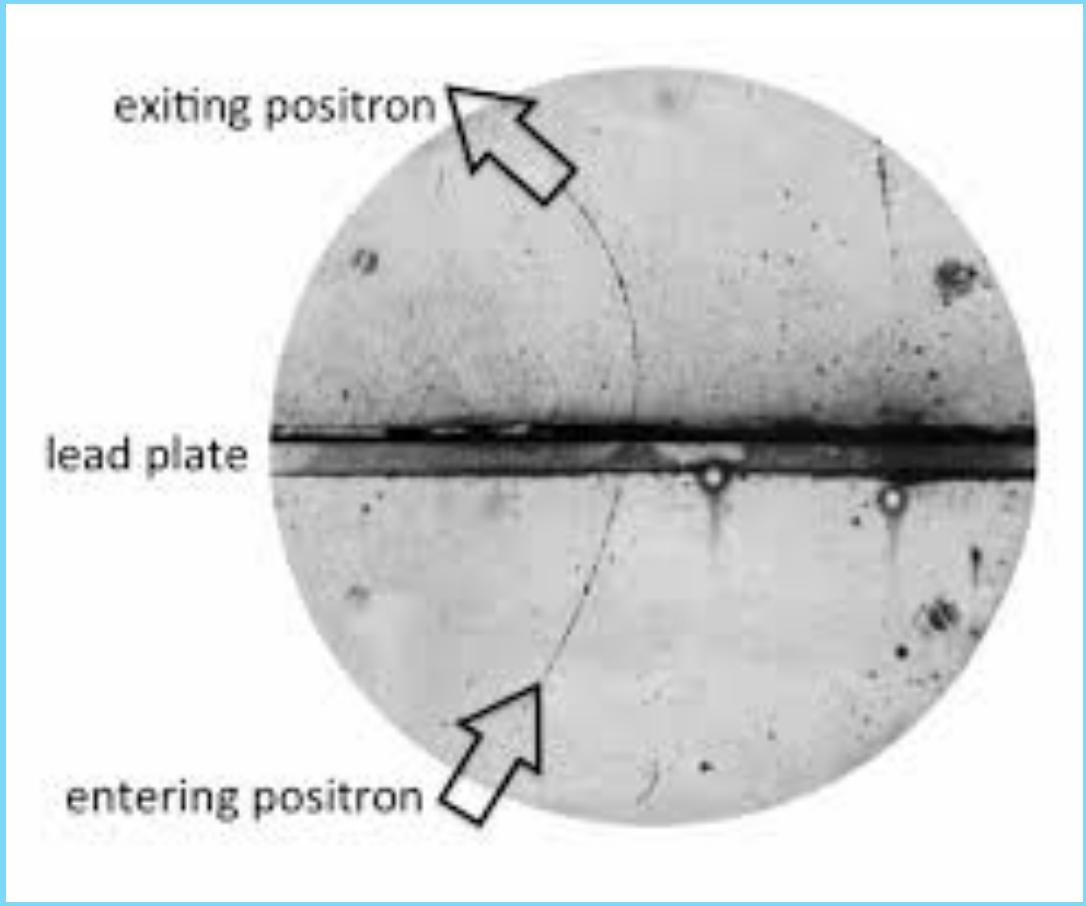
- We had applied to be part of a satellite program and designed a calorimeter experiment known as HECRE (High Energy Cosmic Ray Experiment) for a satellite called HEAO (High Energy Astrophysical Observatory).
  - The satellite also had experiments to study electrons and to look for antimatter.
  - The satellite was just under construction when budgetary problems arose and it had to be cancelled
  - We turned then to searching for antiparticles in the cosmic rays
    - Low probability of success, but very high payoff if we succeeded.

Carl Anderson
Dirac had predicted antimatter from symmetry arguments (Nobel Prize 1933)

Millikan commissioned his graduate student Carl Anderson to build a cloud chamber inside a magnetic field



Discovery of the positron, an antielectron (e^+)

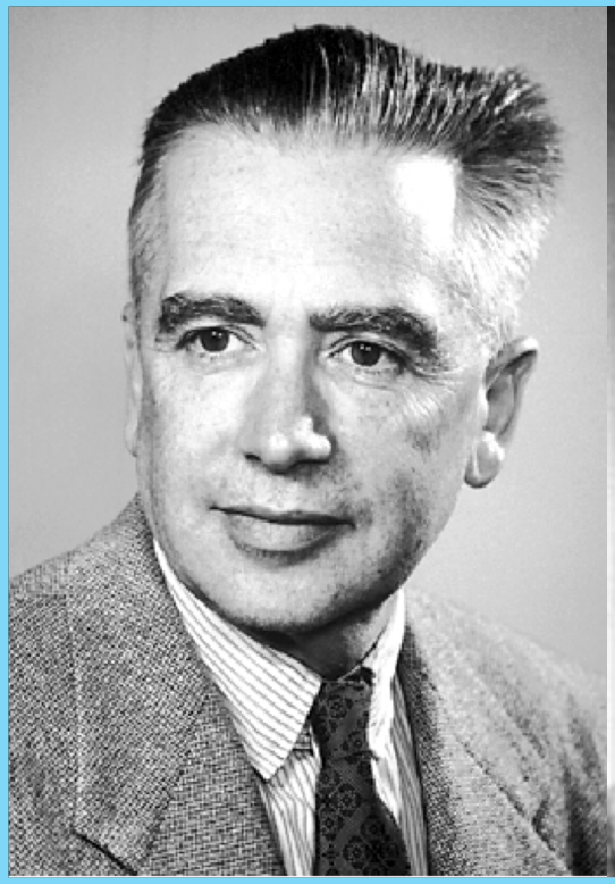


Cloud chamber on the ground in Pasadena, CA

Why not an e- from above?

Note how the curvature increases after the particle loses energy going through the plate.

Antiproton discovered



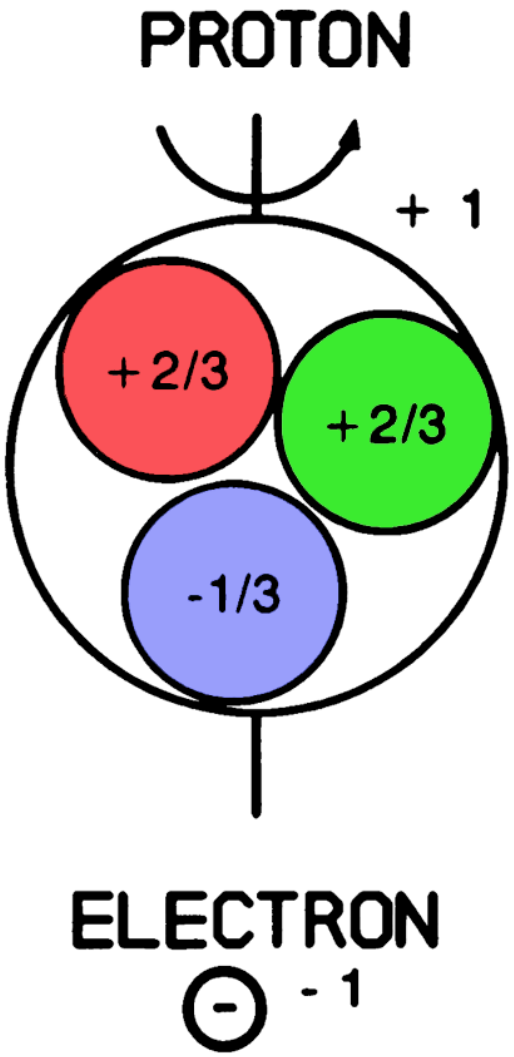
1955

Nobel Prize

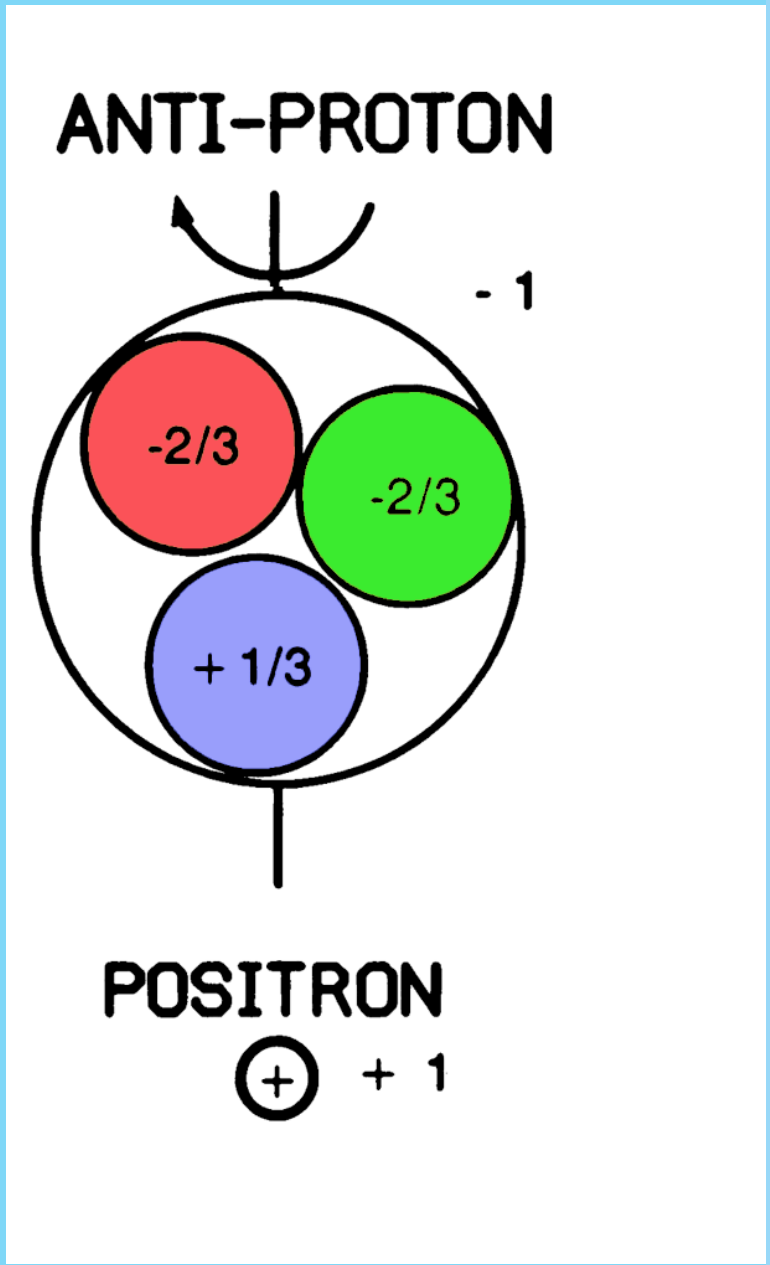
1959

Emilio Segrè and Owen Chamberlain

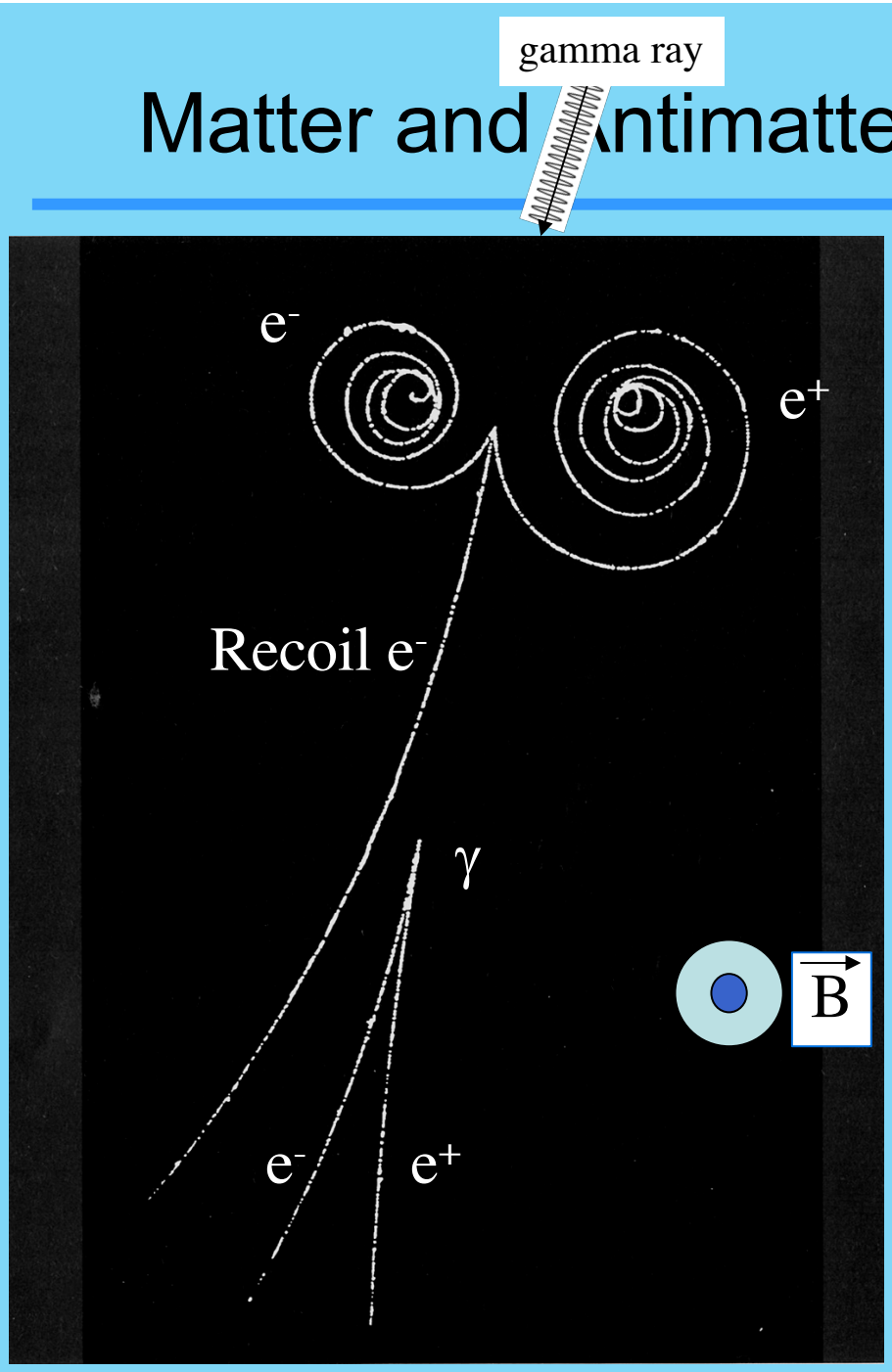
Matter



Antimatter



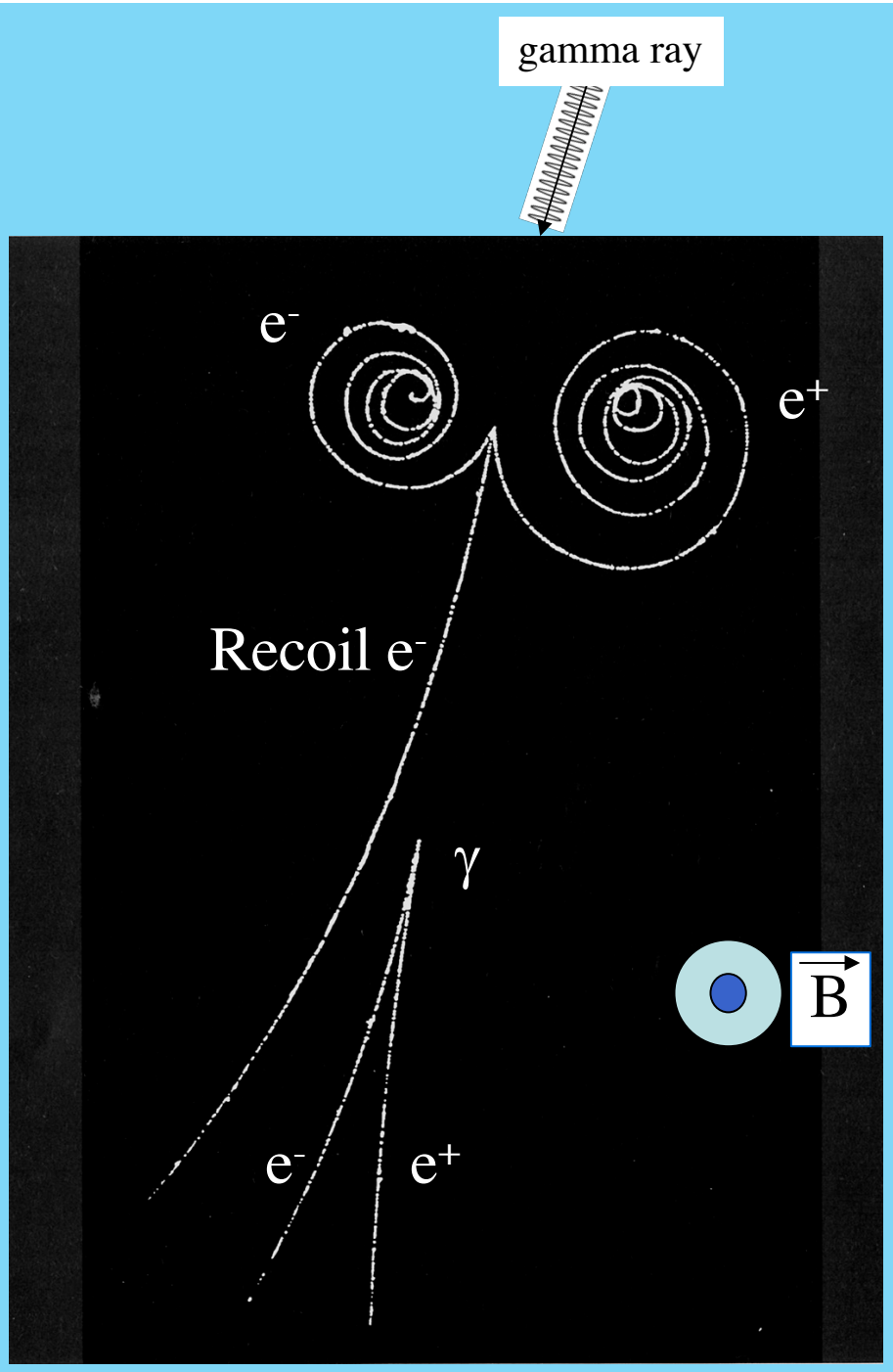
Matter and Antimatter in a Magnetic Field



Note that most of the energy is "carried off" by the γ-ray. It's actually a different γ-ray with slightly lower energy. The energy in the 1st pair is much less that in the lower pair.

- **Matter and antimatter are created in "matched" pairs from gamma-rays**
- Here, in a magnetic field that is out-of-the-page, the matter and anti-matter particles have opposite curvature

How can you tell?



Note that most of the energy is "carried on" by the γ-ray. It's actually a different γ-ray with slightly lower energy. The energy in the 1st pair is much less that in the lower pair.
How can you tell?

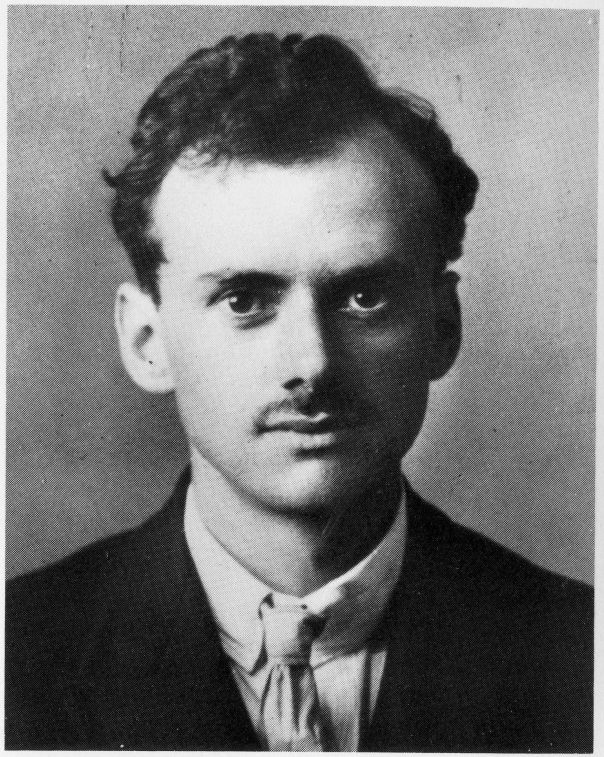
Higher energy particles are more "rigid". They aren't bent as easily by the magnetic field. We give this property the name "ridigity". It is equal to energy but depends on the A/Z ratio of the particle. A/Z=1 for e^- and p.

NASA contemplated building a Space Station

- Very ambitious plans
- NASA scientists enlisted to propose payloads to use the station
- We were loyal soldiers and we got on the bandwagon
- Developed plans for a superconducting magnet measurements of cosmic rays on the station
  - We called it Astromag
- Budget crisis hit, space station was greatly descoped in size
- Astromag never built
  - It did stimulate studies on balloons

P. A. M. Dirac
Nobel 1933

"We must regard it rather as an accident that the Earth (and presumably the whole solar system), contains a preponderance of negative electrons and positive protons, It is quite possible that for some of the stars it is the other way about."



UPI/BETTMANN NEWSPHOTOS

"We must regard it rather as an accident that the Earth (and presumably the whole solar system), contains a preponderance of negative electrons and positive protons. It is quite possible that for some of the stars it is the other way about."

-Paul Dirac, in his speech accepting the Nobel Prize in Physics, 1933

The search for antimatter

- Antiprotons should be present from the collisions of cosmic rays with interstellar gas and dust – the same process (the fog) that made the Li, B and B we discussed earlier. Predicted anti-p/p = 10^{-4}
- Antideuterons (deuterons, D, are hydrogen atoms with both a one proton and one neutron in the nucleus) should be present at around anti-D/p=10^{-8}
- Heavier anti-nuclei should have been formed in stars made of anti-matter.

- No known reason why such stars couldn't exist.
- Unlikely in our galaxy due to annihilation.

Fundamental problem in physics

- Why is the universe apparently all matter, why not anti-matter?

- We decided to see if we could find anti-matter in cosmic rays. The experiments would be Earth shaking if we found a heavy anti-nucleus such as anti-carbon or an anti-oxygen.
  - We knew there was a very low probability of finding it; if we did – Nobel Prize for sure.

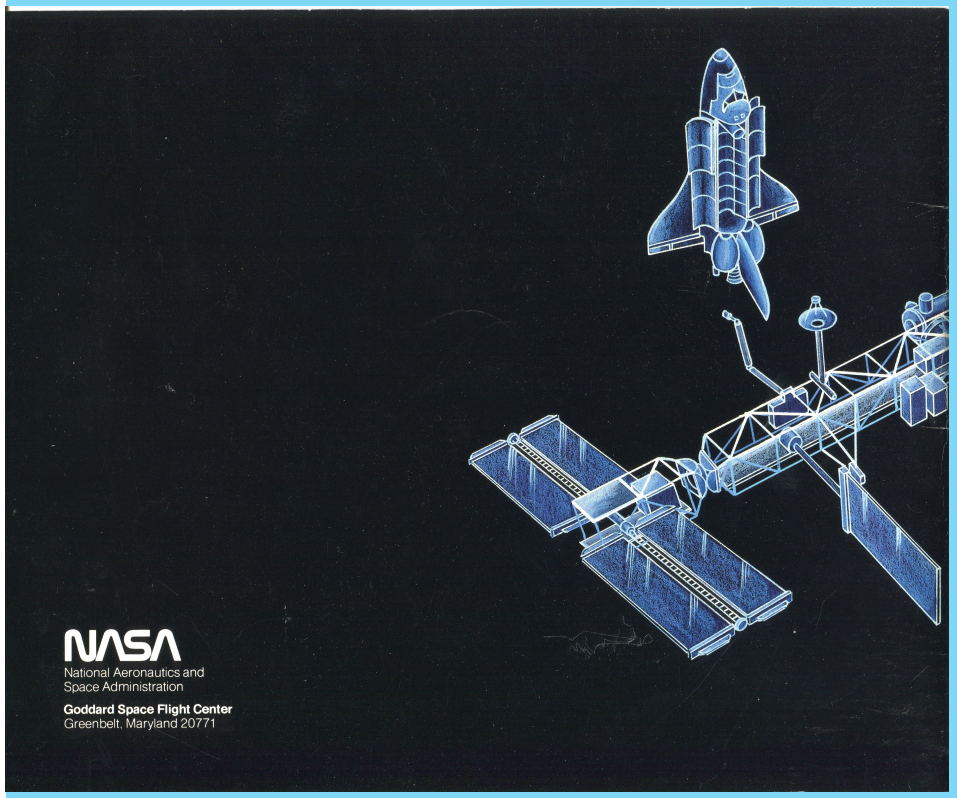
- Solid experiment to find antiprotons over the energy range from v ~ 0.2c to v ~ 0.8c.

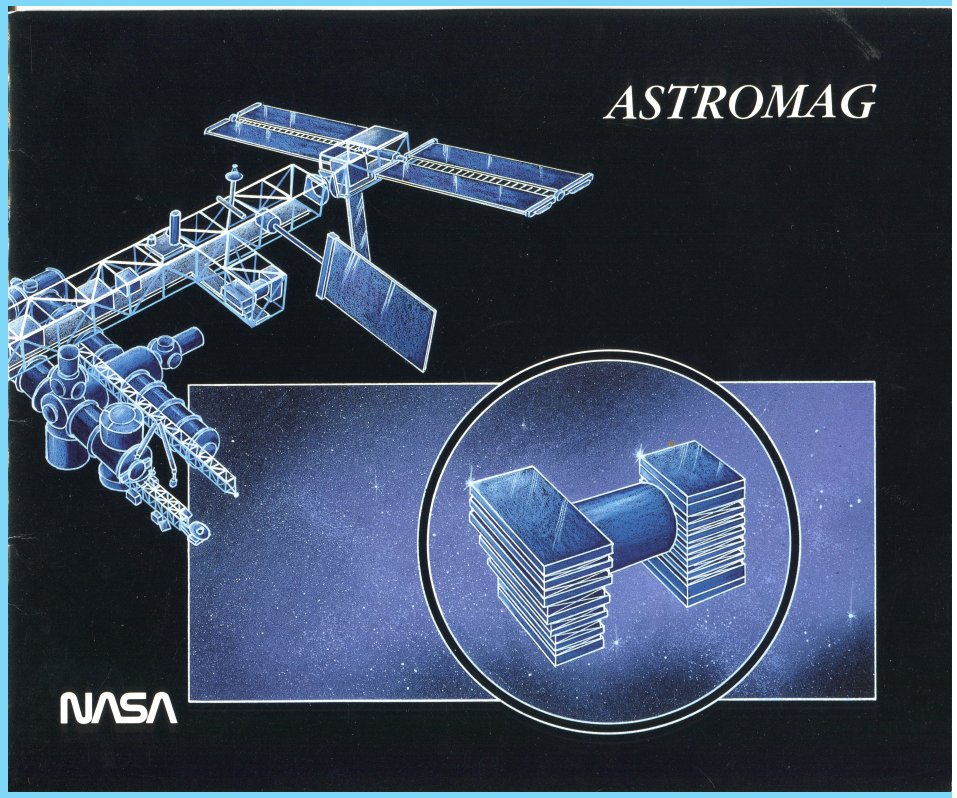
“Astromag”: Experiment Proposed for Space Station

Objectives

- Investigate the origin and evolution of matter in the galaxy by direct sampling of galactic material
- Examine cosmological models by searching for anti-matter and evidence of the nature of dark matter.
- Investigate the origin of extremely energetic particles and their effects on the dynamics and evolution of the galaxy.

Astromag Brochure





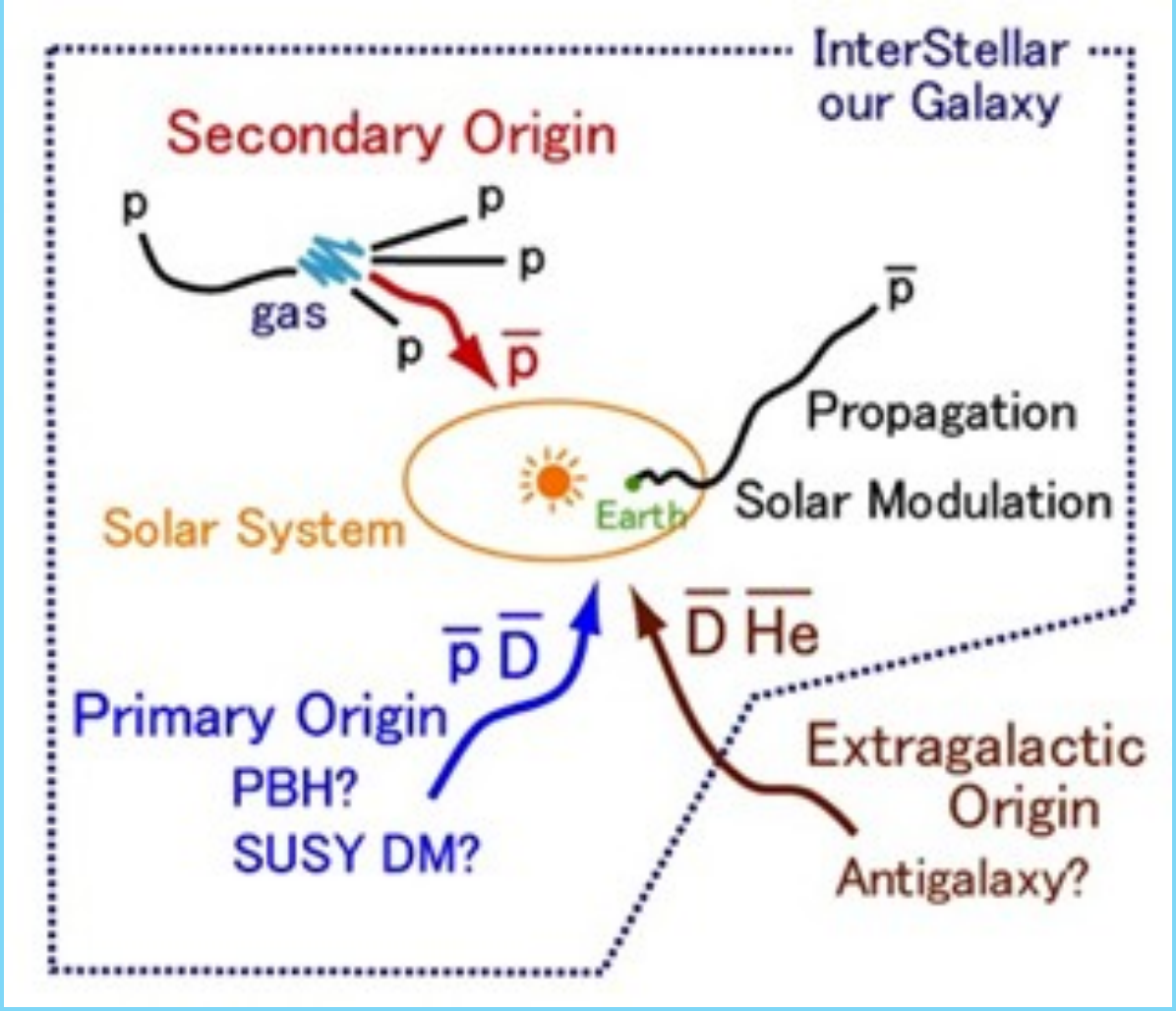
Budget cuts: Astromag went poof!

- Started collaboration with Japanese scientists using the magnet design they had proposed for Astromag
- I got involved with gamma-ray astronomy
- Best hope for solving “origin of cosmic rays”

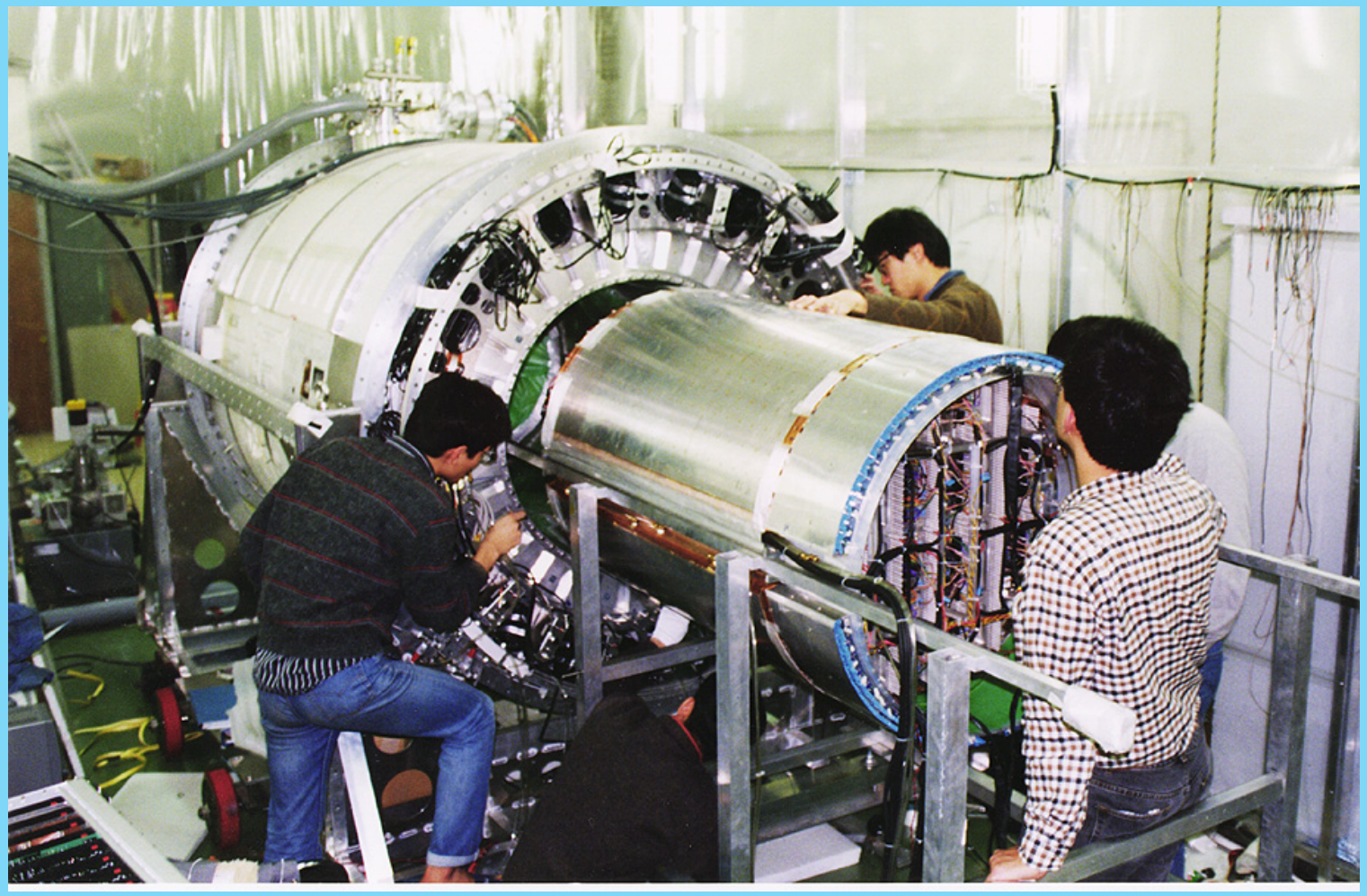
Japanese scientists

- Proposed we try to study using balloons instead of very expensive satellites.
  - Space Station access to space was proving illusory
- BESS: Balloon-Borne Superconducting Solenoid
  - USA – expertise with balloon-borne experiments and cosmic ray studies
  - Japanese – experts in design and construction of superconducting magnets
- Program was born
  - Flights in Northern Canada
  - BESS-polar in Antarctica
- Balloon payload could be recovered, improved and flown again

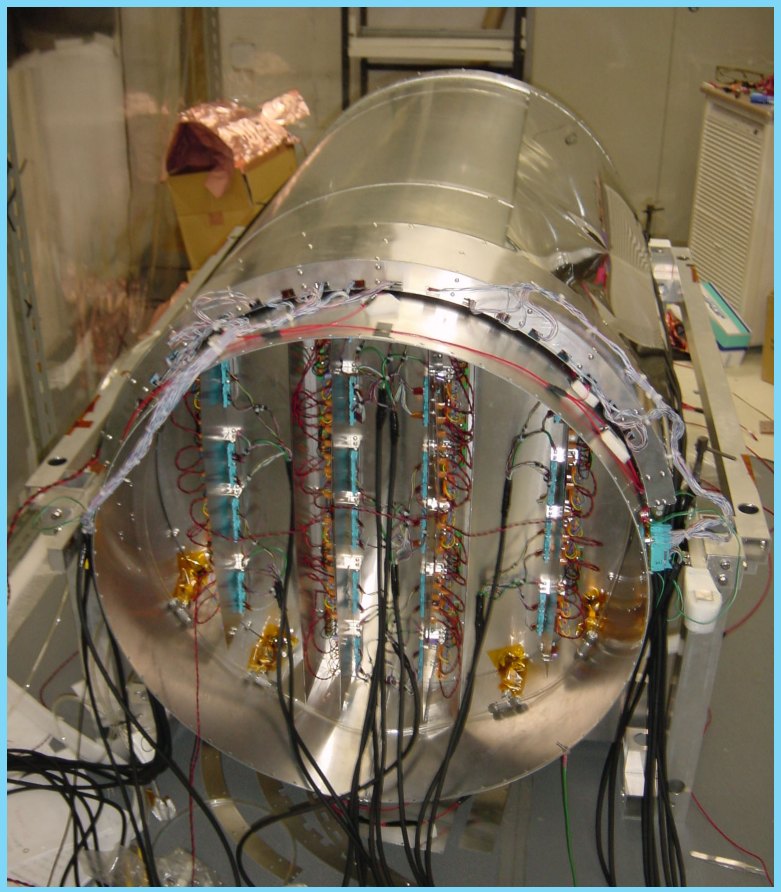
Schematic of BESS objectives



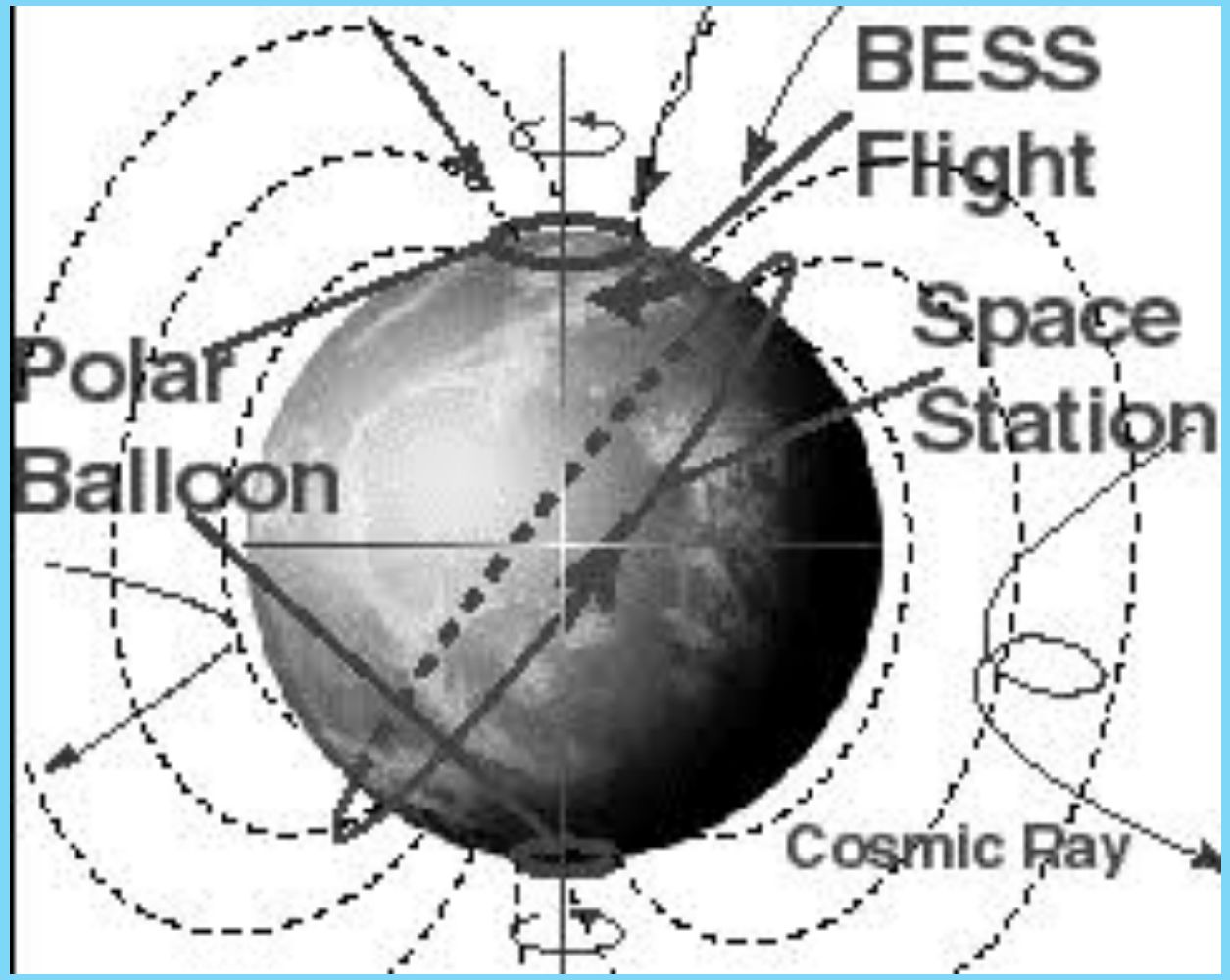
BESS Tracking detector being inserted into bore of magnet



BESS slides

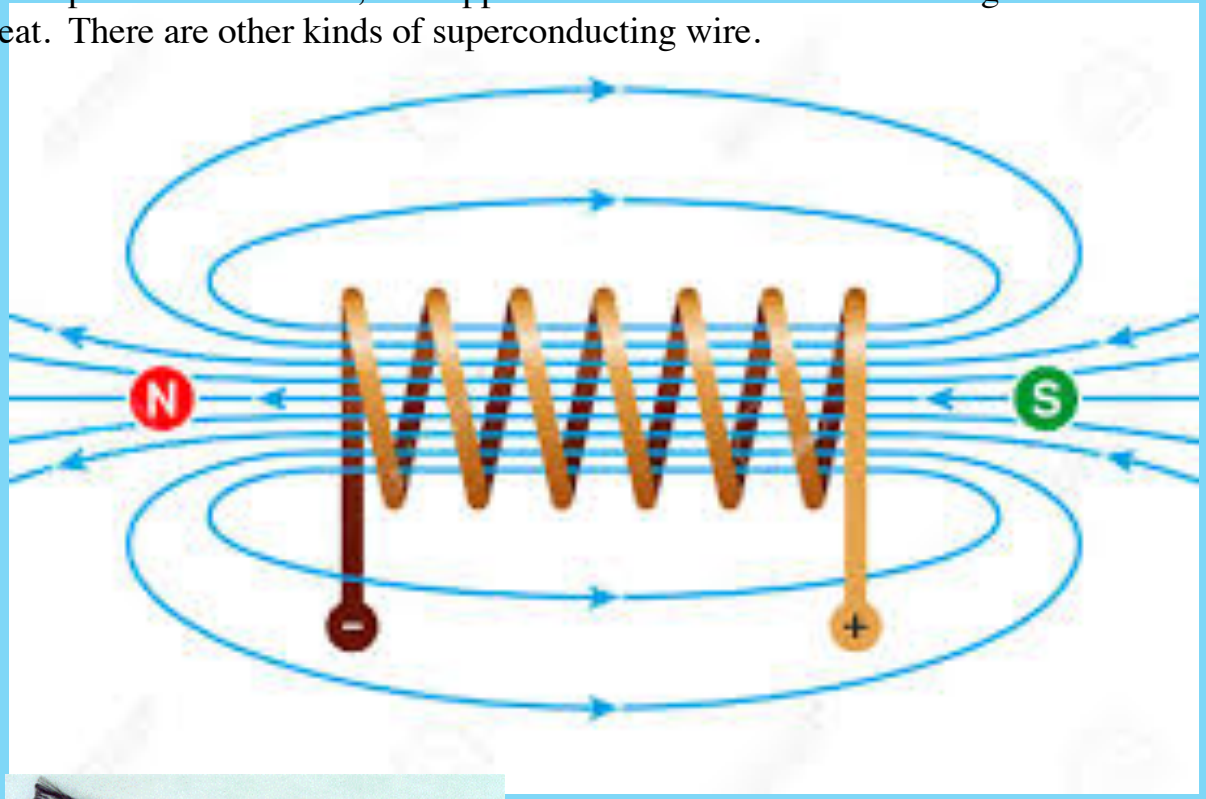


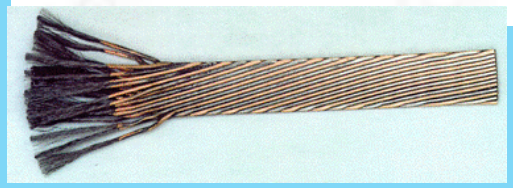
Energy of particles required study at polar latitudes.



Magnetic coil

Around each filament there is a 0.0005 mm layer of high-purity copper. This image is of a Rutherford cable. It is 1.510 cm across and 1.480 mm thick, tolerances are only a few micrometers. Copper coats each NdTi filament. It is an insulation material between the filaments in the superconductive state, when the temperature is below -263C = 10 Kelvin. When leaving the superconductive state, the copper acts as a conductor transferring the electric current and the heat. There are other kinds of superconducting wire.

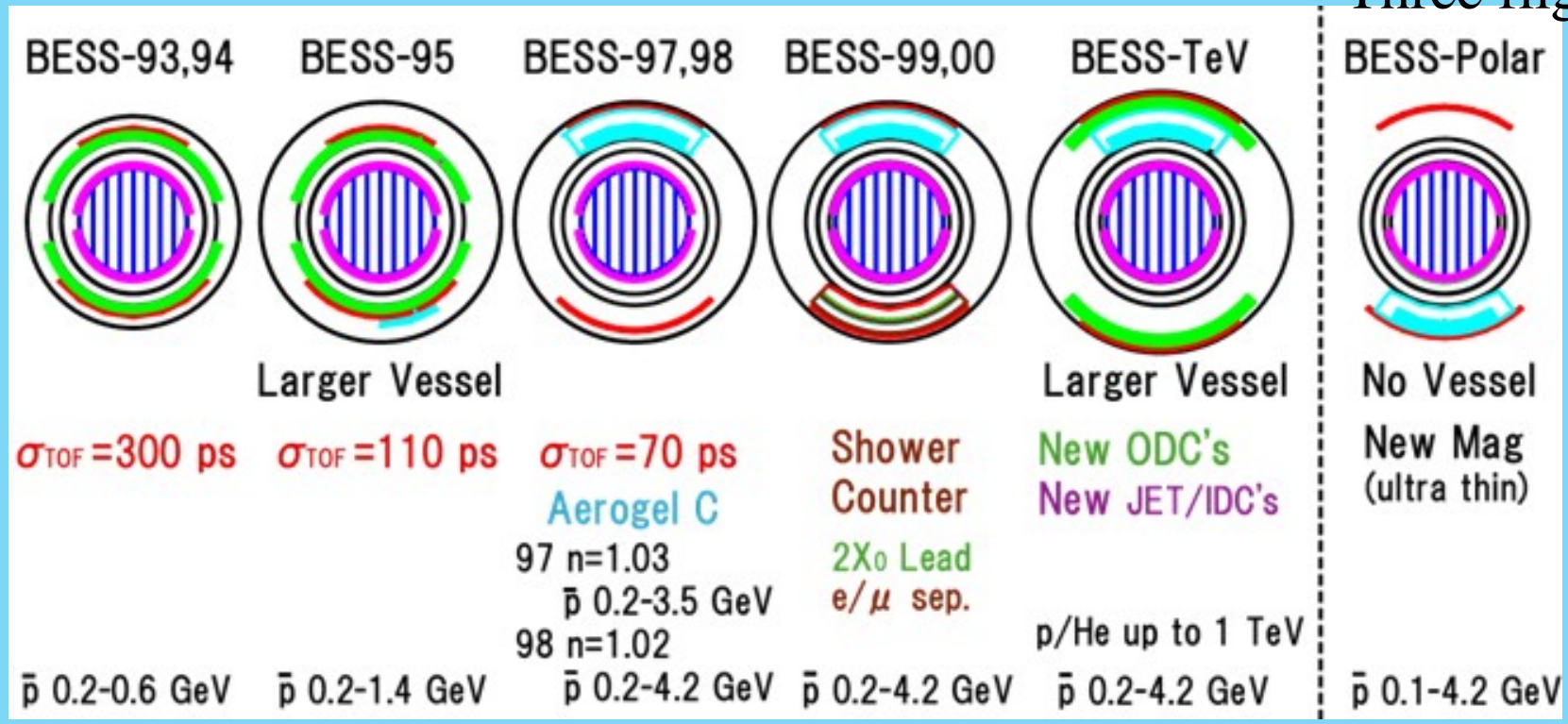




Niobium-Titanium (NbTi)

Evolution of BESS

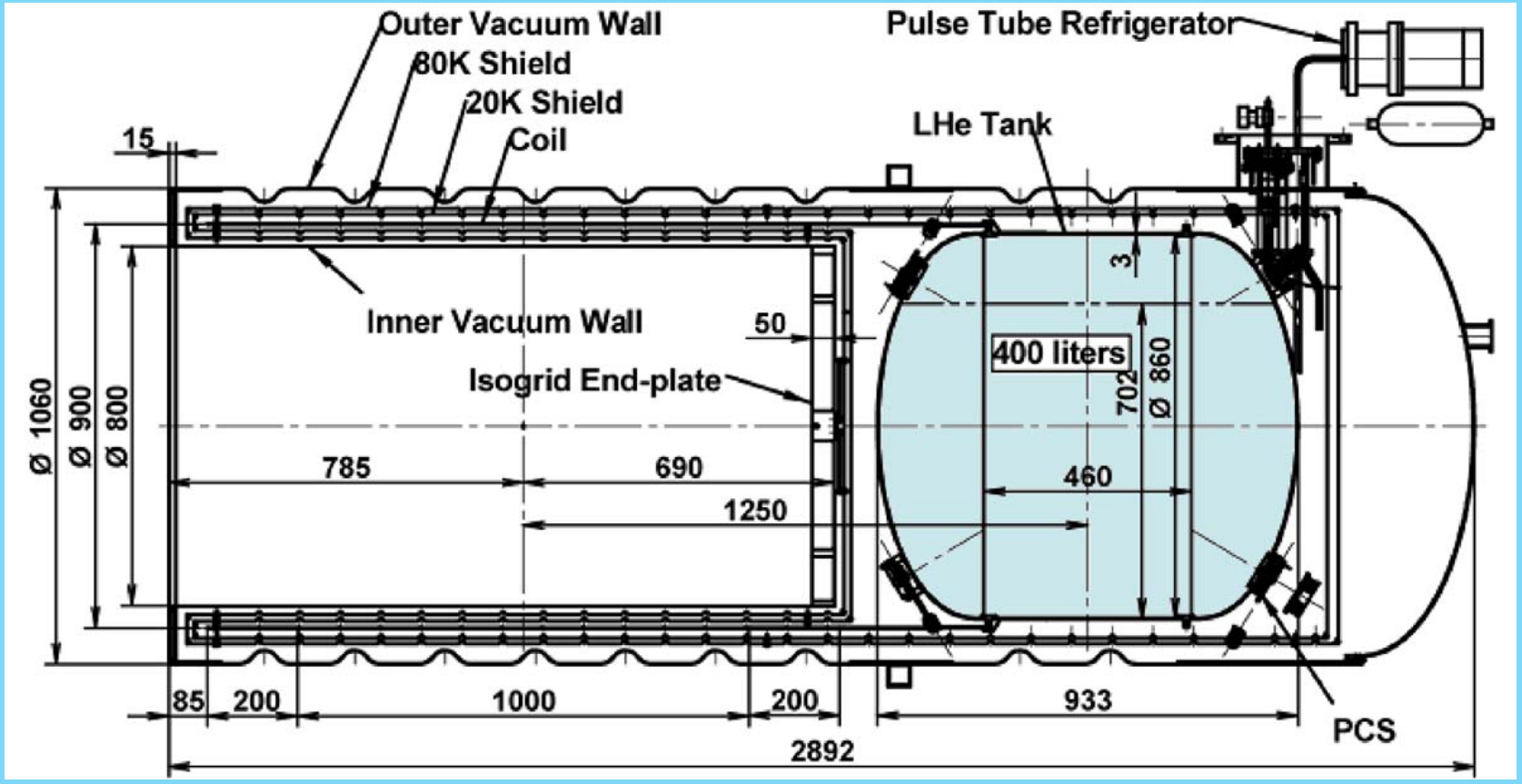
Three flights



Improving ancillary detectors

finally a new magnet

BESS superconducting coil and dewar

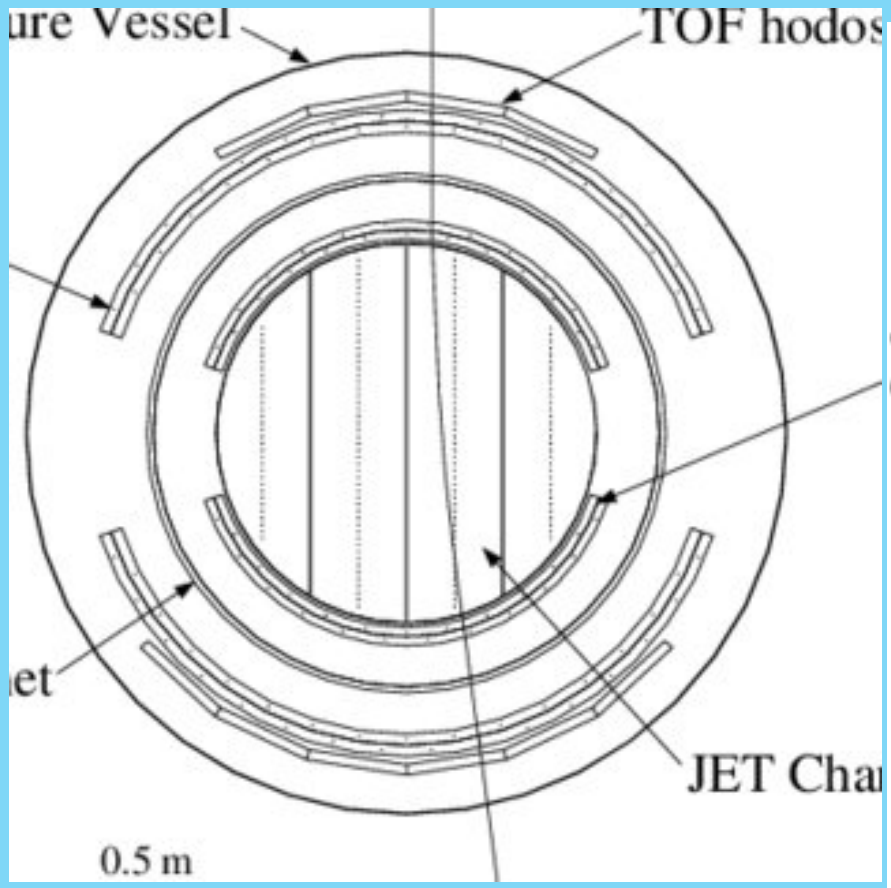


He at 4 Kelvin (-270 °C or -452.2 °F)

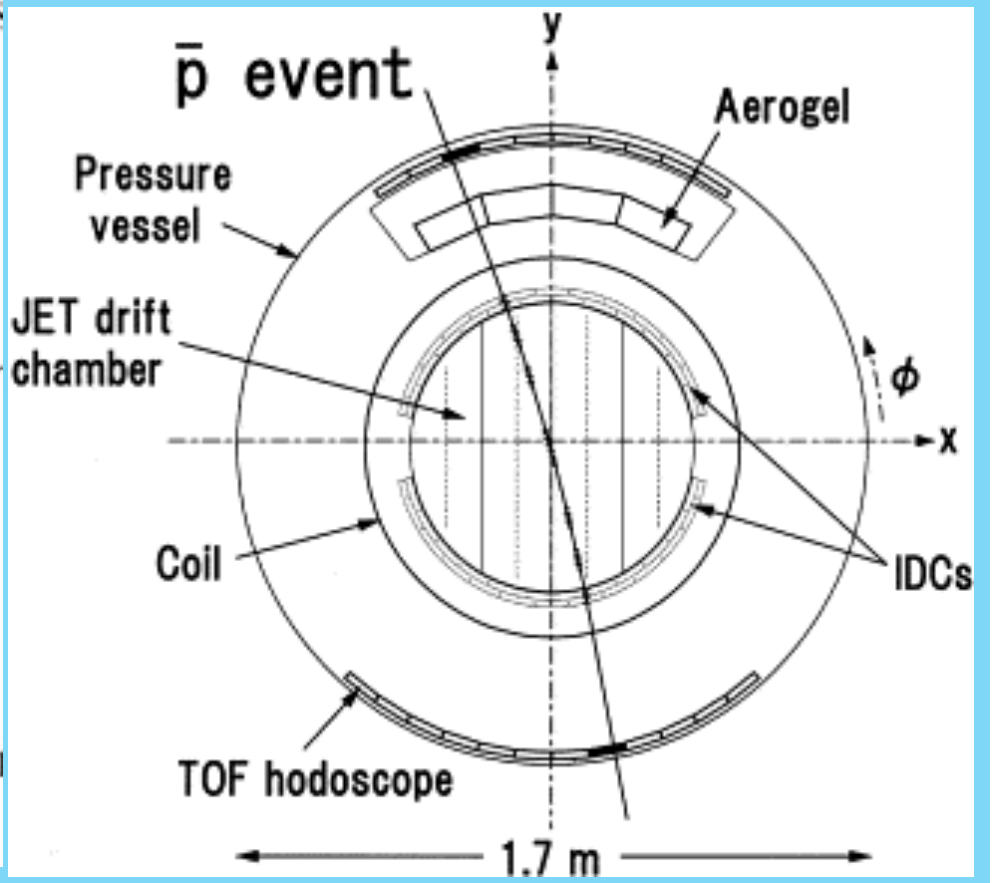
B = 0.8 Tesla

BESS schematic

p^+ (+ charge)



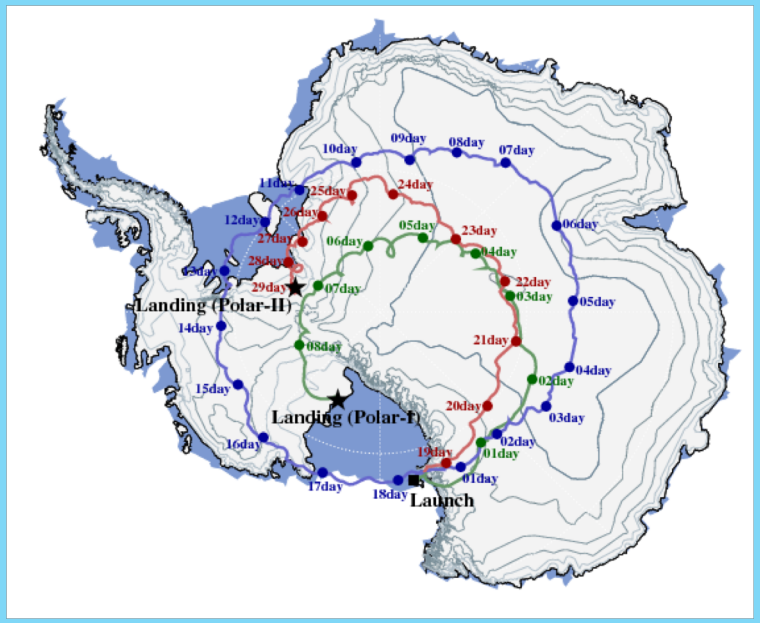
p^- (- charge)



BESS-polar launch in Antarctica

Pre-flight layout BESS-polar

Launch, Williams Field, McMurdo



Launch, Williams Field, McMurdo

Results from BESS

- No anti matter found. Upper limits place constraints on the existence of anti-matter in nearby extragalactic space outside the Milky Way galaxy.
  - These eyes looked and saw – nothing.
- We did see antiprotons in an amount consistent with all we knew about cosmic rays.
  - These eyes looked and saw exactly what was expected.
- We looked for anti-deuterium from the decay of primordial black holes predicted by Stephen Hawking.
  - These eyes looked and saw – nothing.
- Oh, well, no Nobel Prize. But we did give it our best shot.

So where are we now on anti-matter?

The end of an early BESS flight
Recovery was always an adventure

Grouping by subject

- So far I have more or less followed the track of my career. But that won't work for the remainder of the course.

- So I will simply go by topics from here on.

We will start with searches for anti-matter.