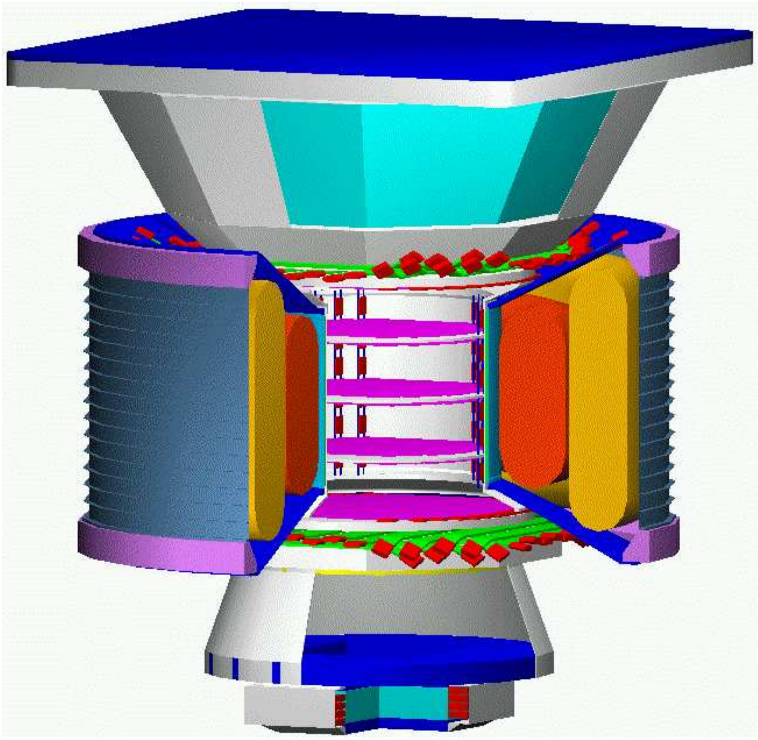
# AMS
# a particle spectrometer in space

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**LEAP03**

**March 3-7, 2003**

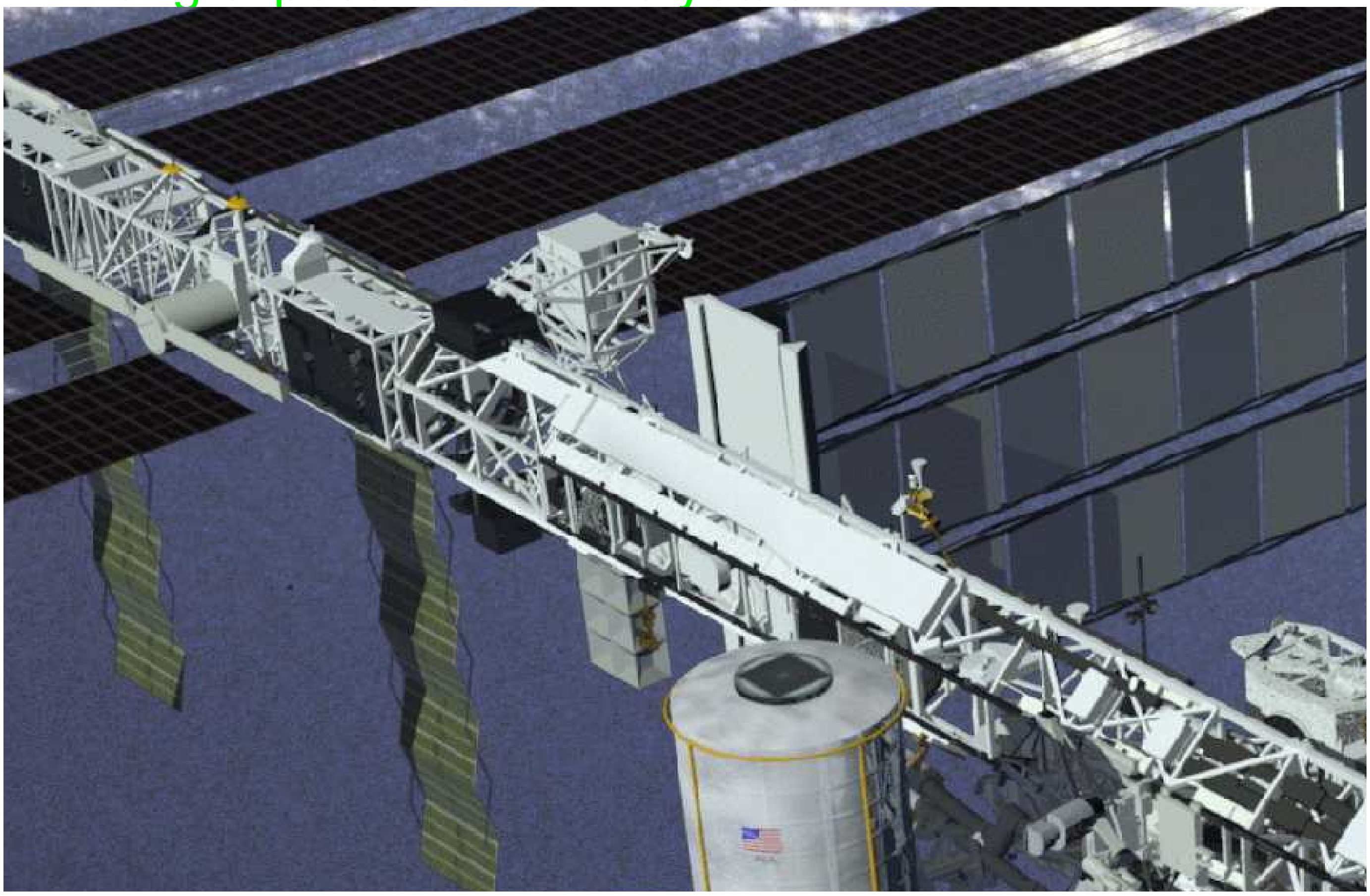
# Outline

- AMS-01 on the space shuttle (June 1998):
  - Prototype detector AMS-01
  - Selected results
  - Will not cover:
    leptons, deuterons, atmospheric secondaries, geomagnetics
- AMS-02 on ISS:
  - Upgraded detector AMS-02
  - Search for cosmic antimatter and dark matter
  - Composition and energy spectrum of primary cosmic rays
  - Detection of high energy photons sources
- Conclusions

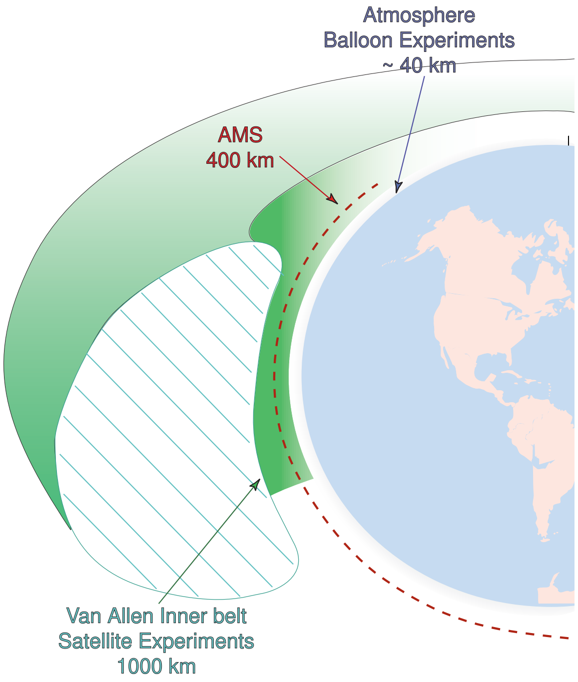
# Experiments in space

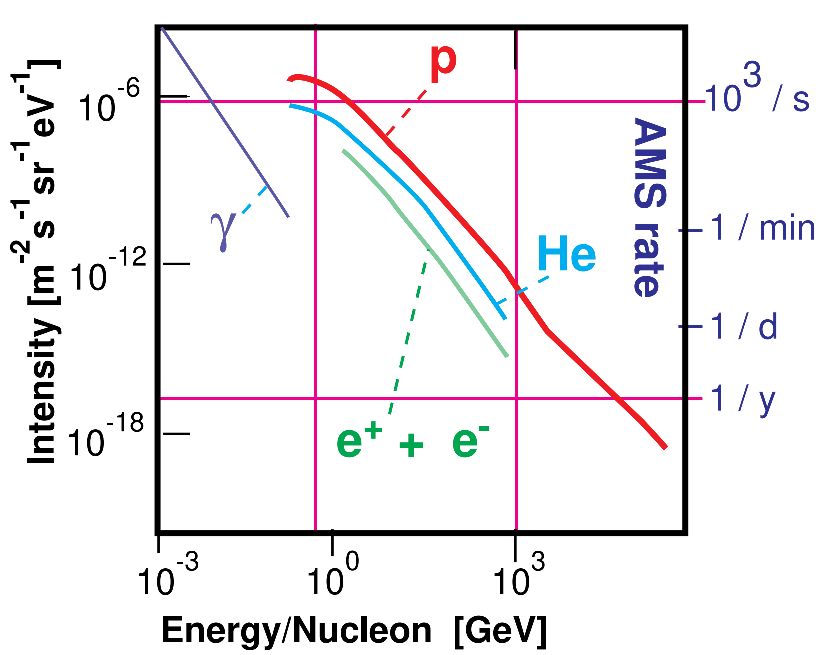
New environment for HEP experiments

- Operation in vacuum
- Acceleration during start and landing up to 9g
- Temperature variations -180$^o$ to +50$^o$C
- Weight limited (14809 lb for AMS-02)
- Datarate 1 Mbyte/s via 1 datalink
- Power consumption limited to 2kW
- Powersupply at 120V via 1 powercable
- Long exposure time $\sim$ 3 years



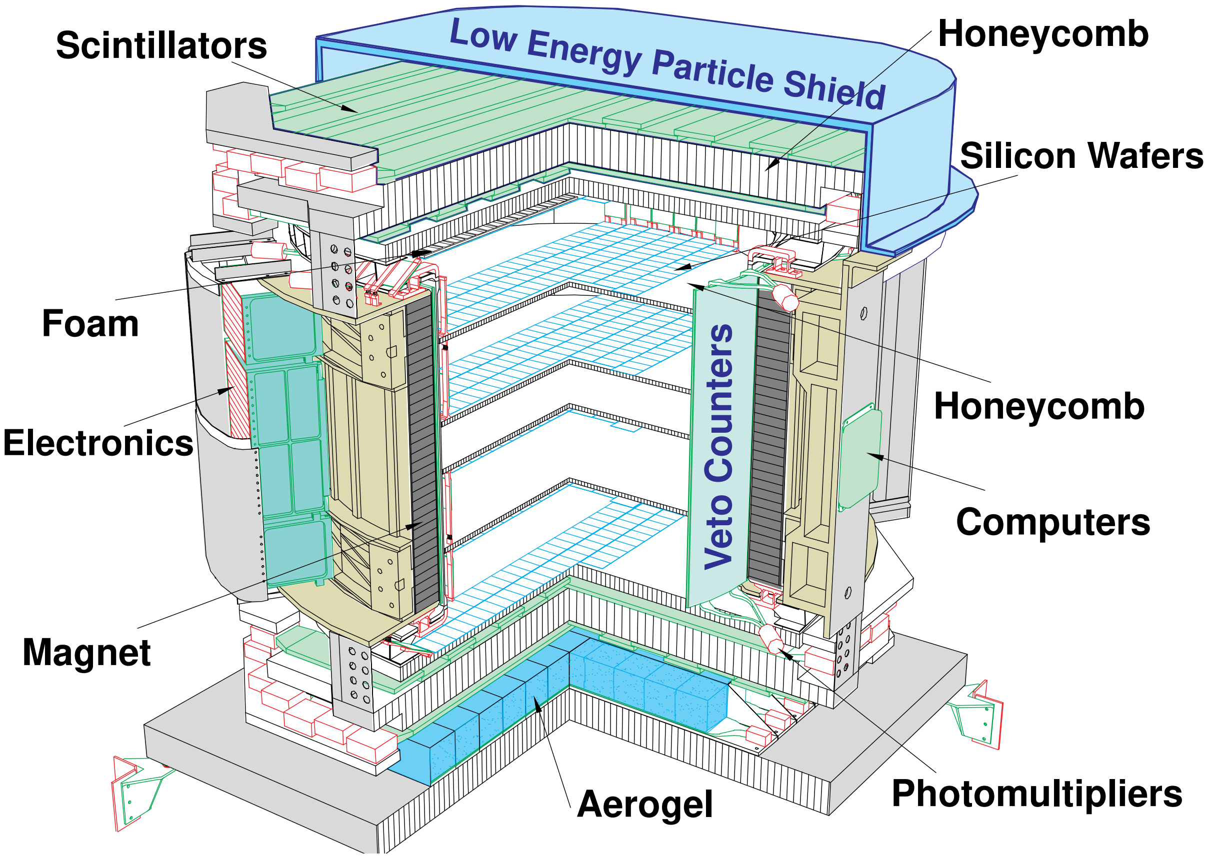
# Cosmic Rays: Direct Observation



# Prototype Detector AMS-01

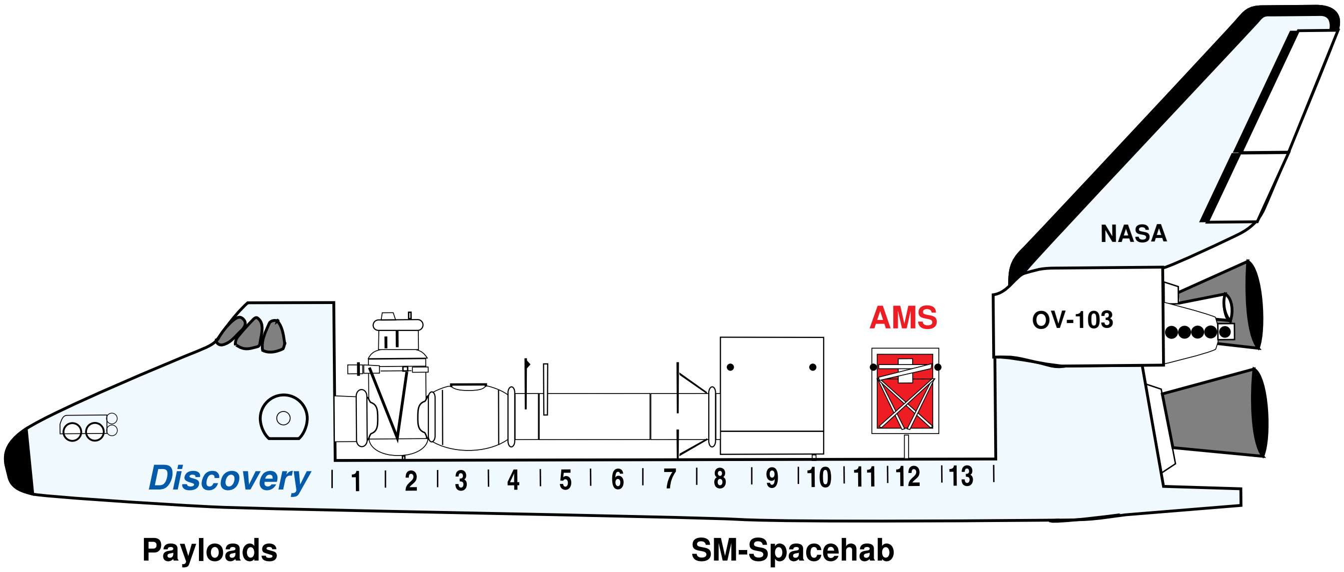
AMS-01 1998




- Permanent Magnet ($BL^2 = 0.14Tm^2$)
- 6 ultra light honeycomb planes
- 6 layers of doubled sided silicon wafers (2.1$m^2$)
- 4 layers plastic scintillators $\rightarrow$ Main Trigger + TOF
- Veto counters
- Aerogel threshold cerenkov

Measures $dE/dx$, $Z$, $R = \frac{pc}{|Z|e}$, $\beta$

# AMS-01 Pilot Exp't: STS91, June 2-12, 1998

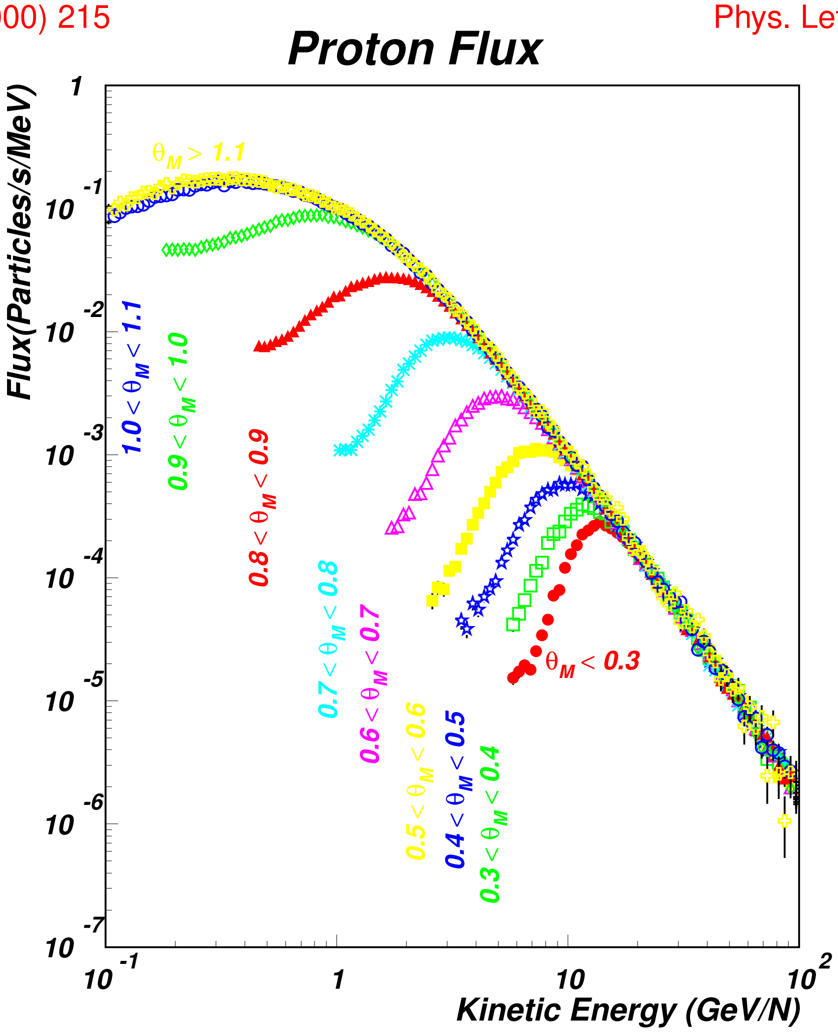



- Principle goal: resupply MIR and crew exchange
- Qualification and test mission for AMS-01
- 90 hours of dedicated data taking
- Variable attitudes and altitudes (320-390 km)
- Latitudes $\pm 51.7^{\circ}$, all longitudes
- Detector functioned without faults
- $10^8$ events registered
- Results on e$^{\pm}$, p and $\bar{p}$, D, He and $\overline{\mathrm{He}}$, heavy ions and anti-heavy ions.
- Six publications (`http://ams.cern.ch/AMS/Publications`)

# AMS-01: Primary Proton Spectrum

Phys. Lett. B472 (2000) 215

Phys. Lett. B490 (2000) 27

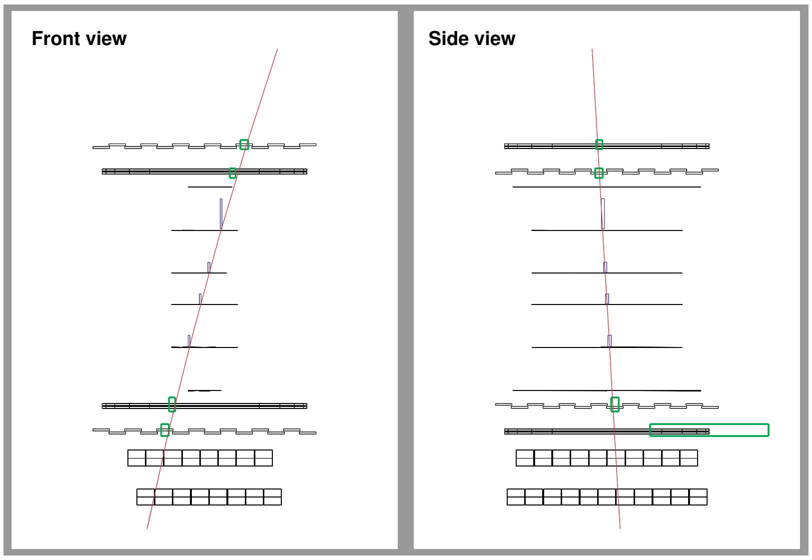



Cutoff: depending on the magnetic latitude, a charged particle must have a minimal rigidity in order to overcome the Earth's magnetic field

# AMS-01: Cosmic Antiprotons

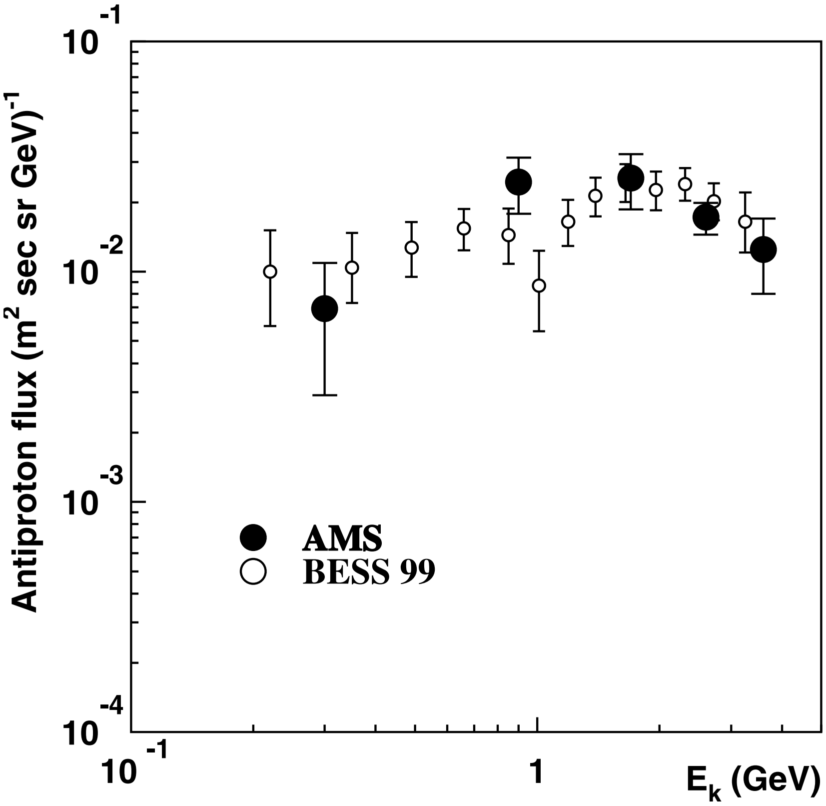
**Alpha Magnetic Spectrometer Event Display**

**ANTI PROTON CANDIDATES**



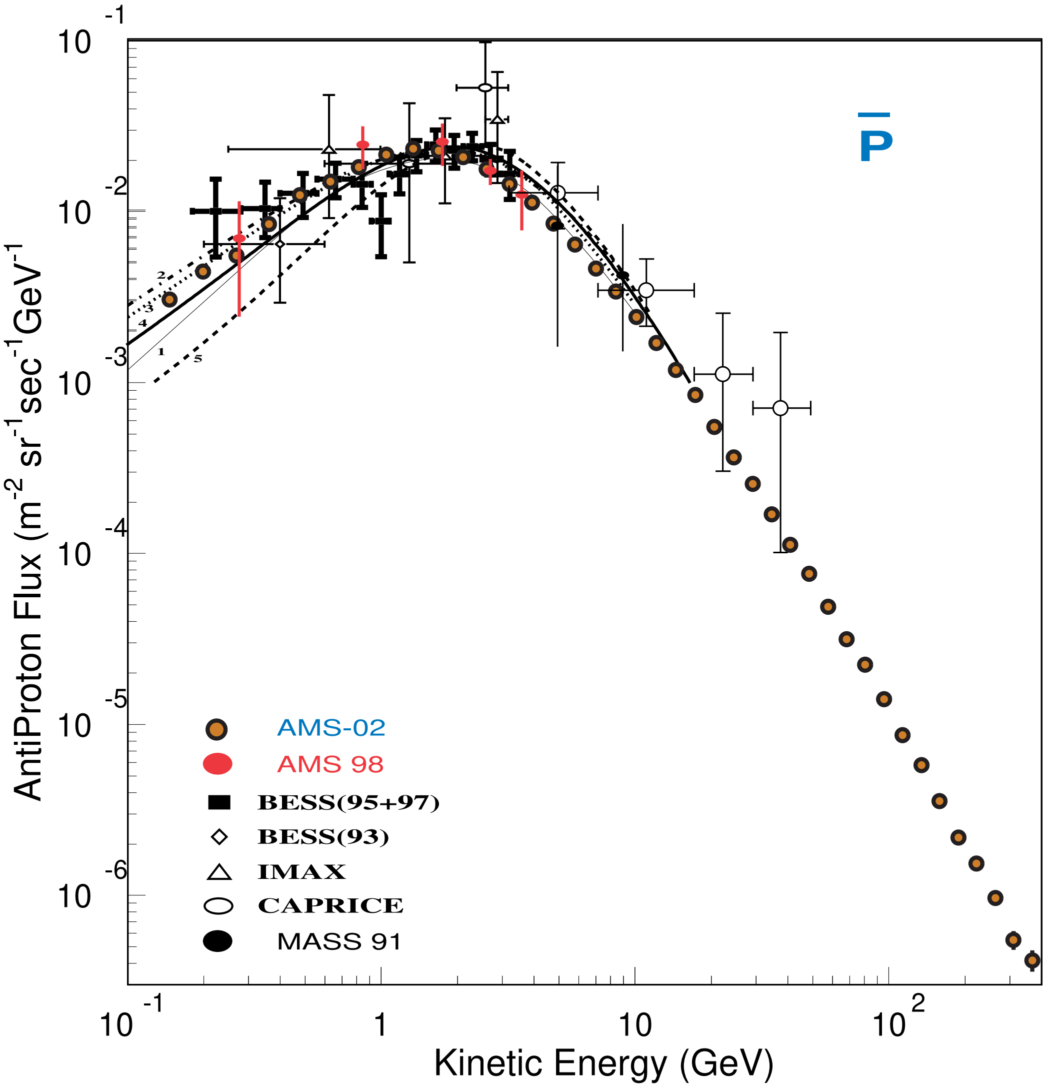

**On-line display of antiproton events:**

**$m = 1.0 \pm 0.15$ GeV/$c^2$, $p = -0.7 \pm 0.12$ GeV/c, charge = 1.0**




Fully compatible with secondary production.

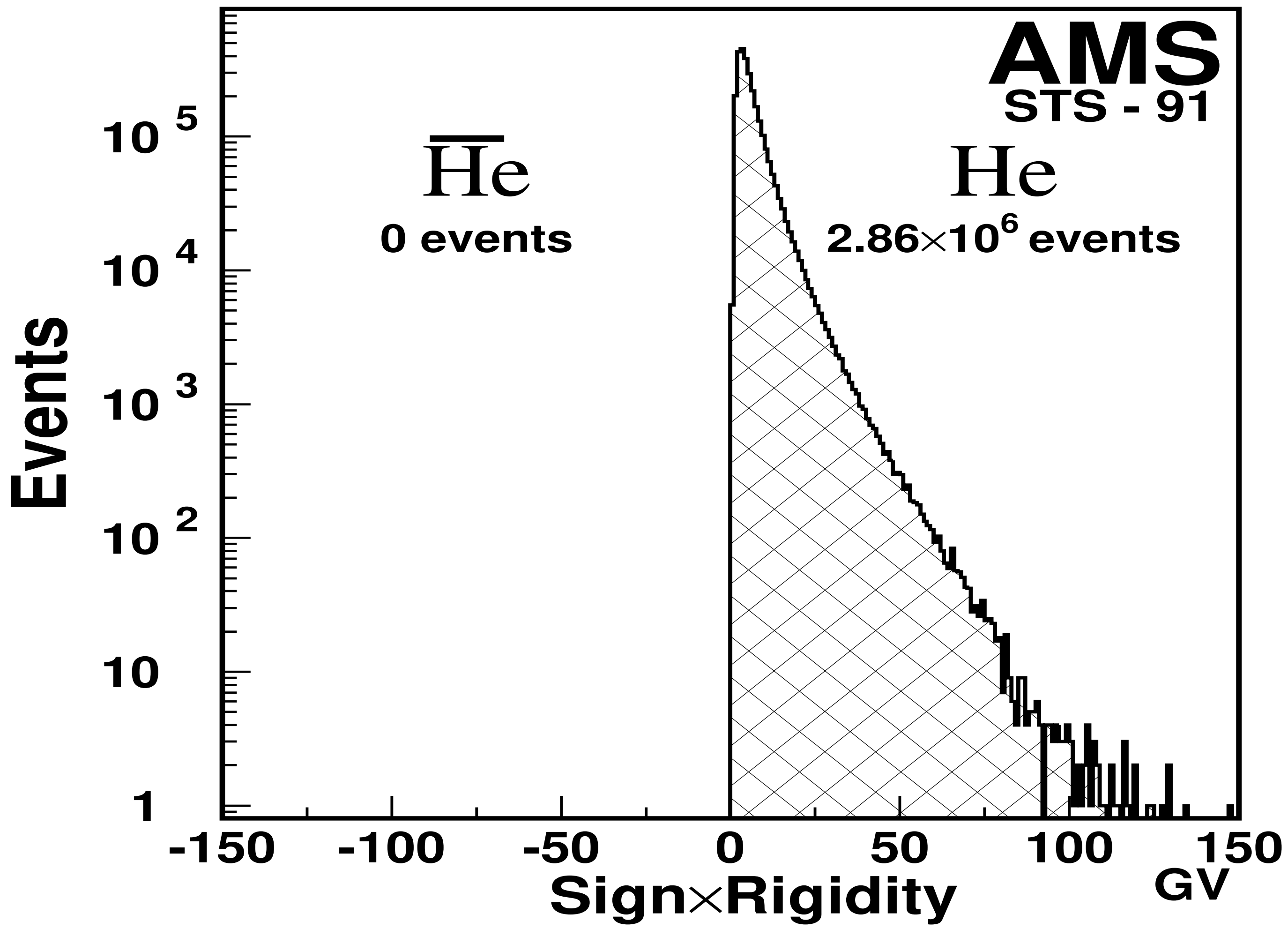
# AMS-01: Cosmic Antiprotons




- Low energy flux fully compatible with secondary production.
- High energy flux sensitive to supersymmetric Dark Matter

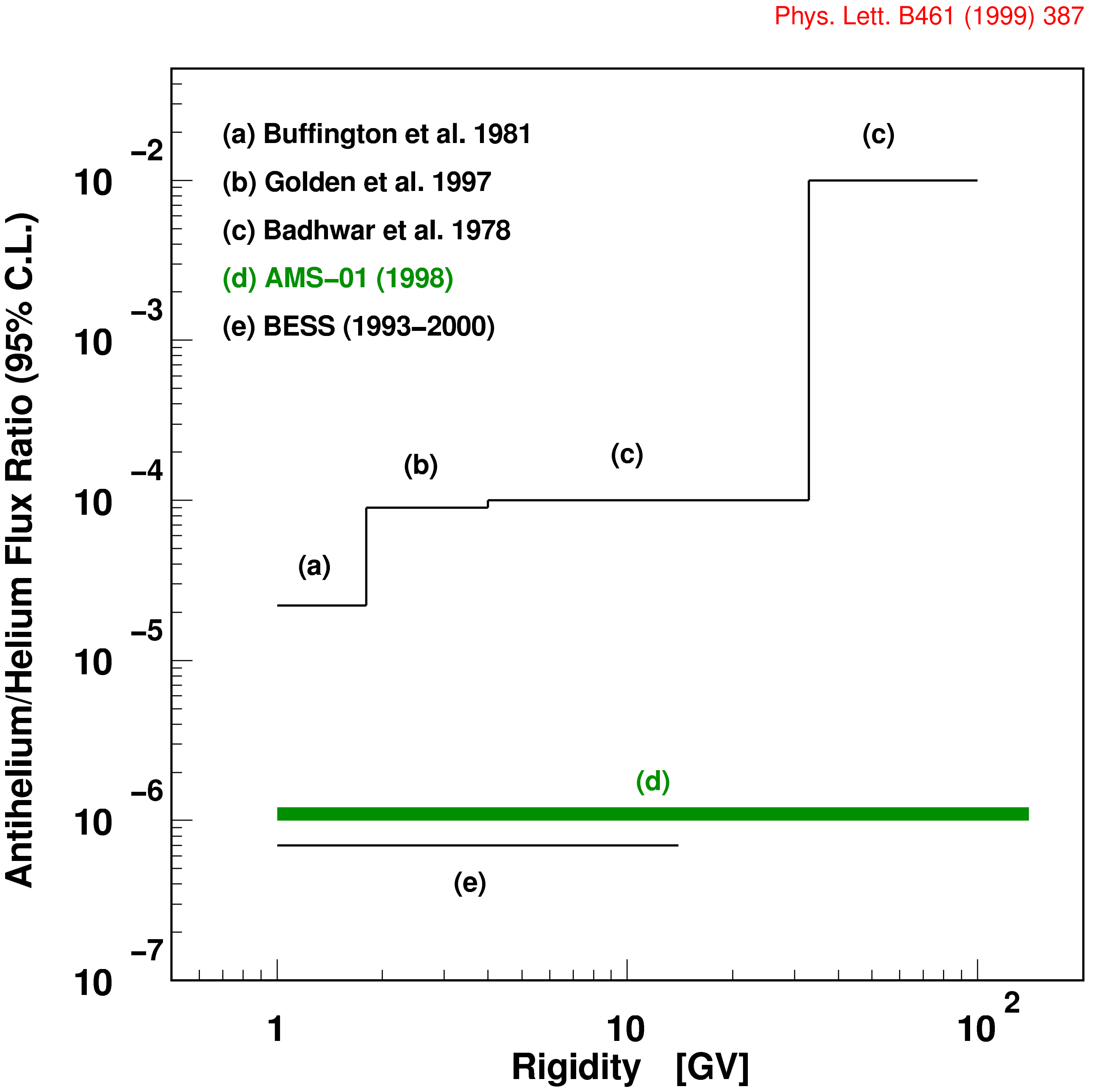
# AMS-01: Search for Anti-Helium

Phys. Lett. B461 (1999) 387



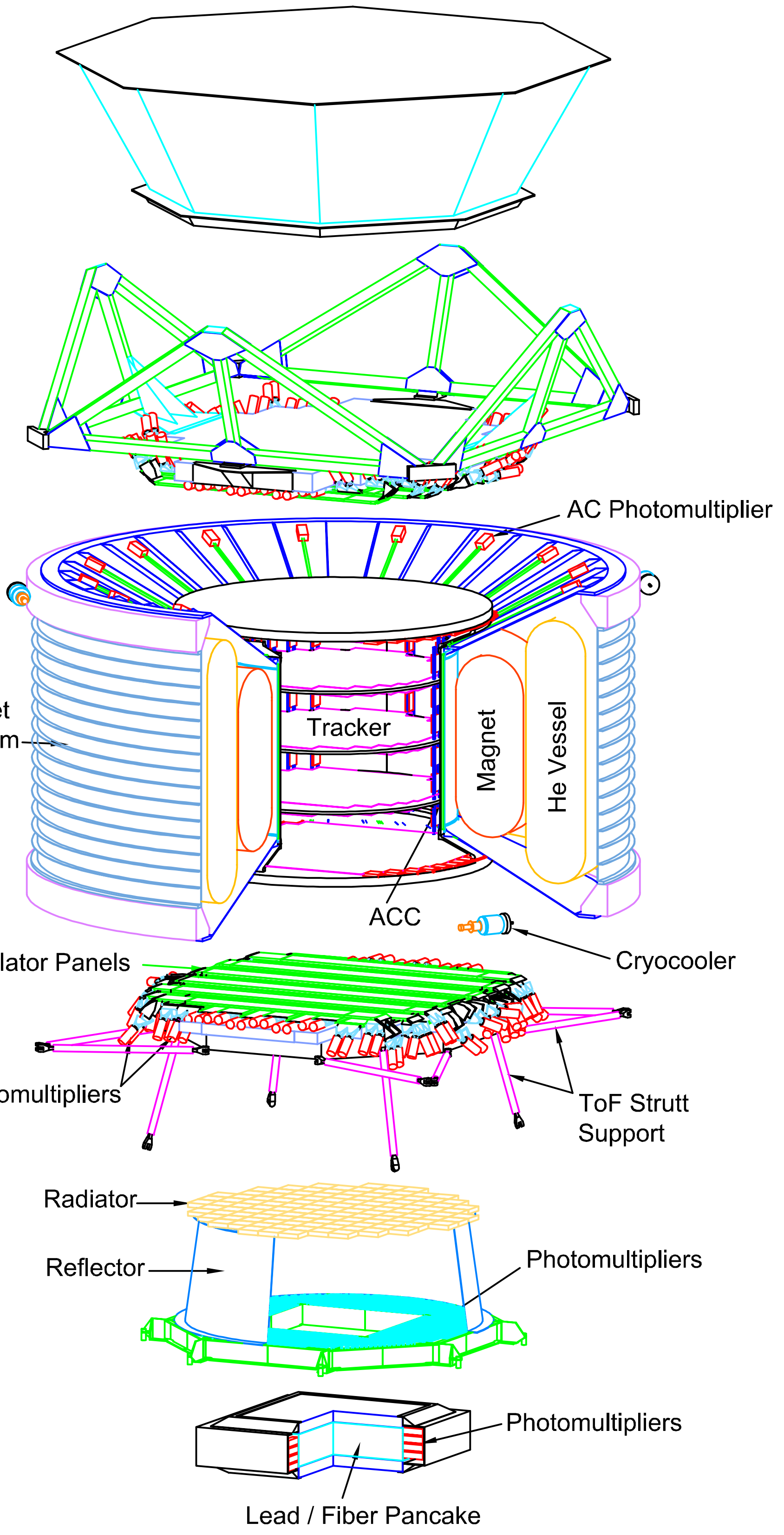

- No acceptable candidate with $Z = -2$
- Hypothesis: same spectra for $\overline{\mathrm{He}}$ and He
- AMS-01 98, $R < 100$GV : $\overline{\mathrm{He}}$/He $< 1.1 \times 10^{-6}$ (95% CL)

# AMS-01: Search for Anti-Helium




Conservative limit: minimum of acceptance applied to whole rigidity interval

# AMS-02 on International Space Station




**TRD:**
Transition Radiation Detector

**Truss Structure**
**SRD,TRD,ToF Support**

**ToF:** (s1,s2)
Time of Flight Detector

**TR:**
Silicon Tracker

**ACC:**
Anticoincidence Counter
(veto Counter)

**MG:** Magnet

**CC:** Cryocooler

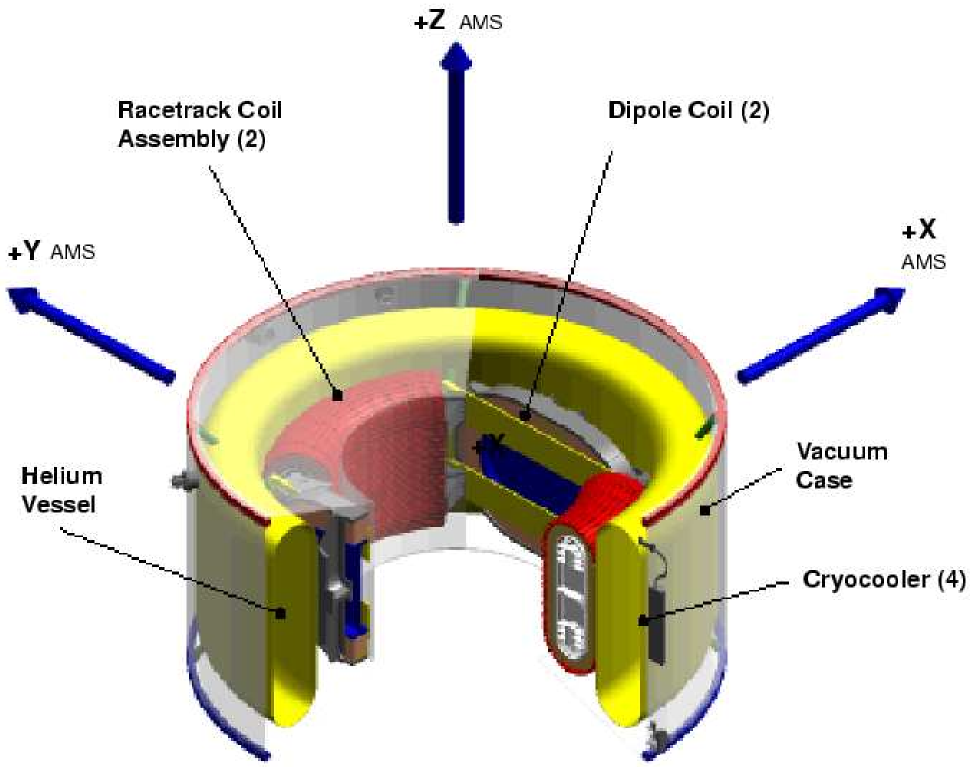
**ToF:** (s3,s4)
Time of Flight Detector

**RICH:**
Ring Image Cherenkov Counter

**EMC:**
Electromagnetic Calorimeter

R. Becker
August 13, 2000

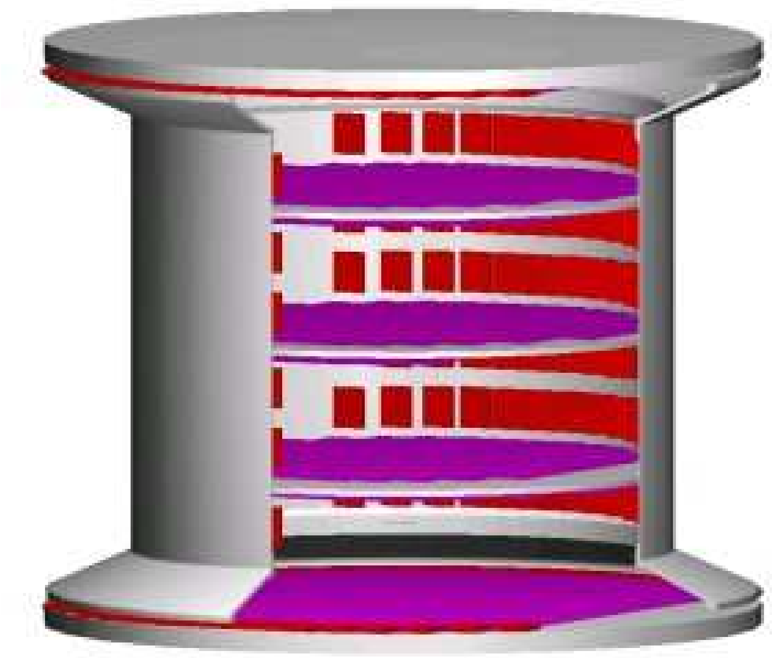
# AMS-02: Superconducting Magnet

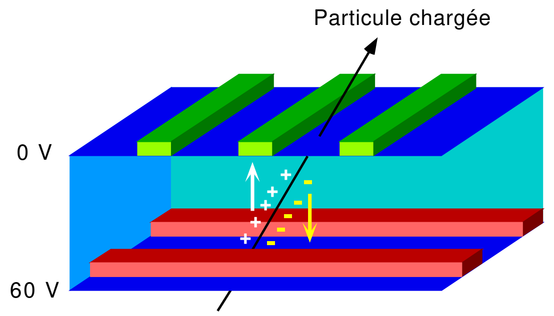



- 14 superconducting coils cooled by superfluid Helium at 1.8 K
- Reservoir for ∼3 years of operation without refill (2500l)
- Dipole field close to 1T, six times AMS-01
- Dimensions: same inner diameter as AMS-01 (1.1m), weight: 2360 Kg

Measurement of rigidity extended up to few TV

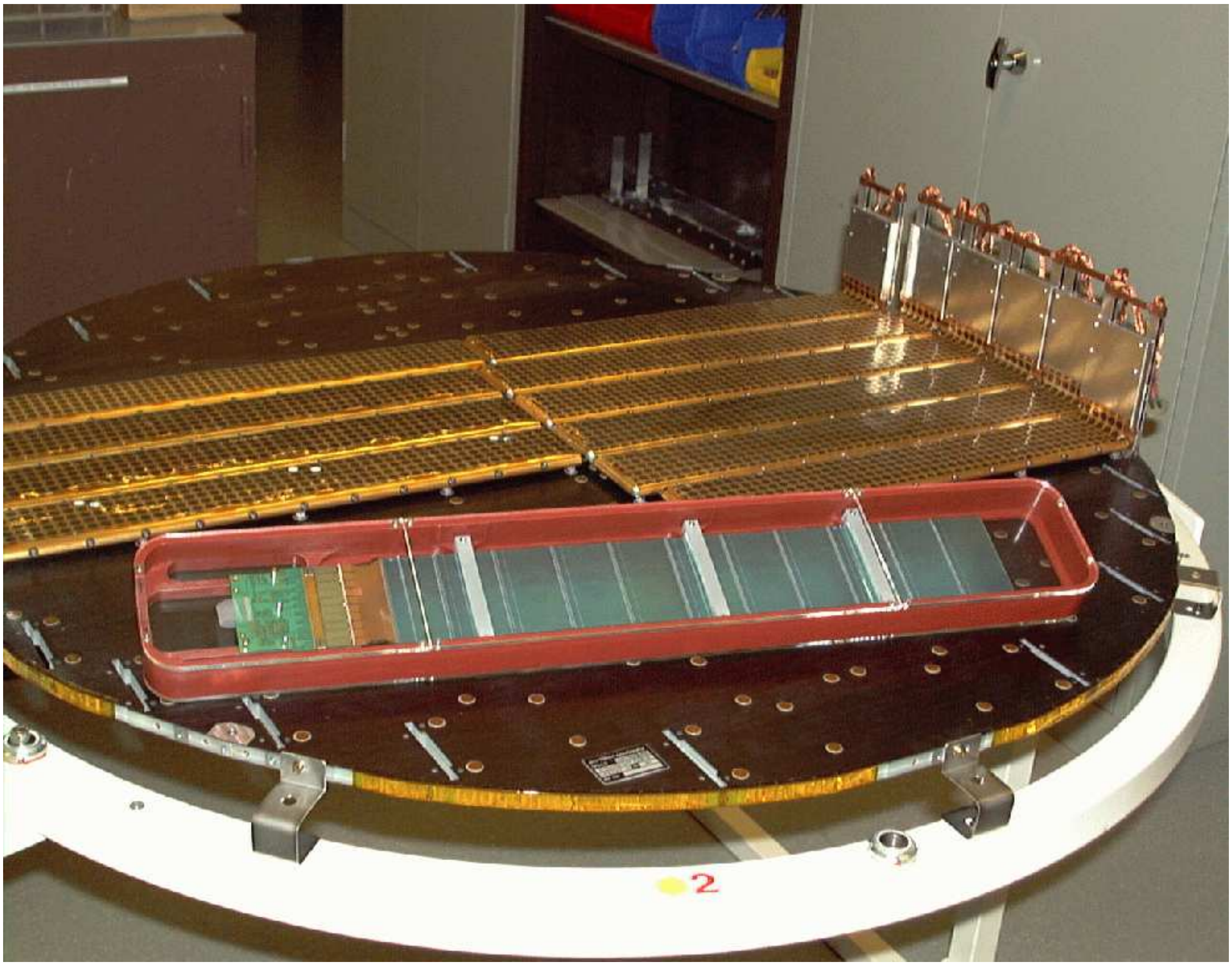
# AMS-02: Tracking Detector



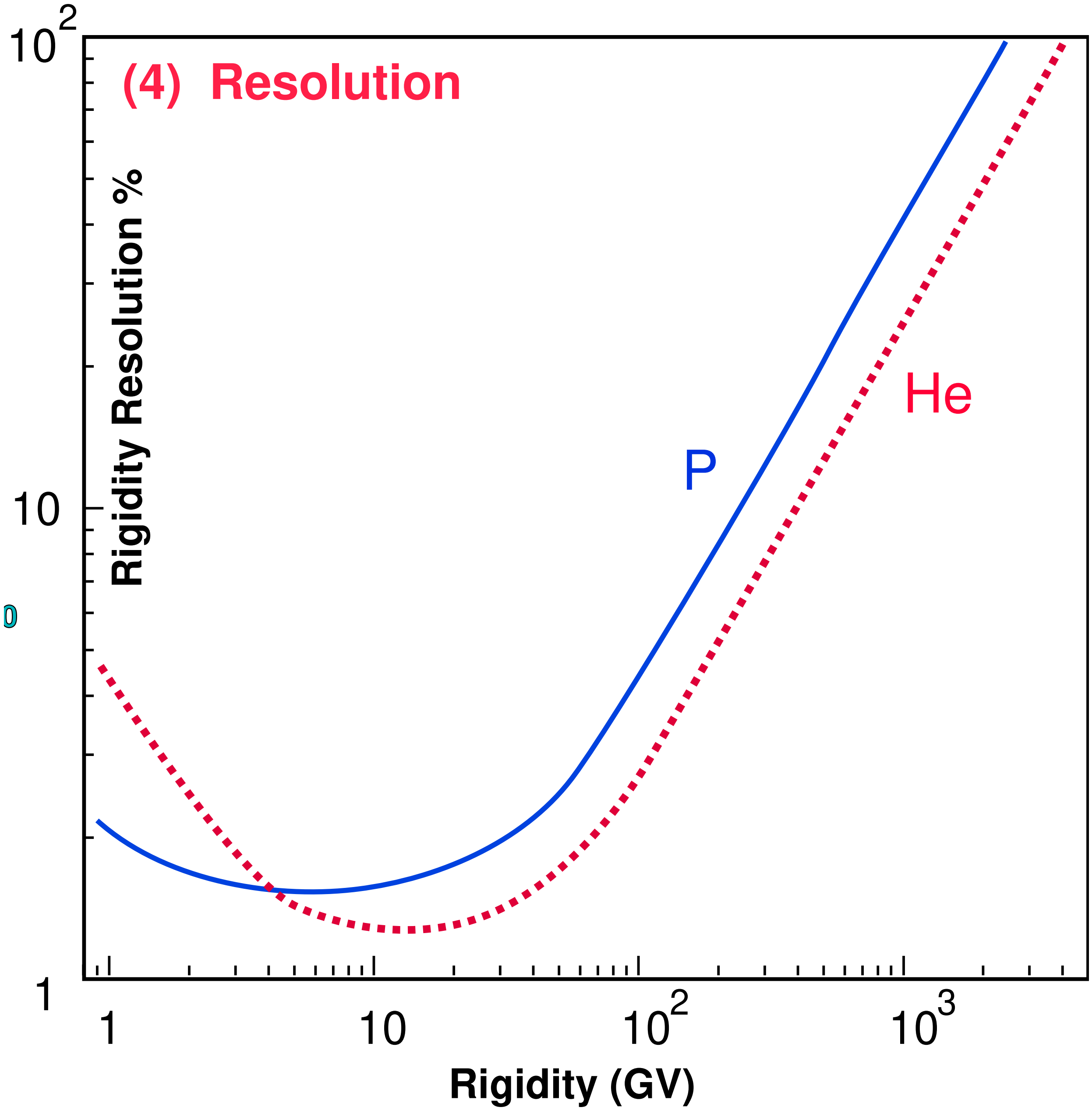



- Localisation of charged particle by double sided silicon sensors
- Eight layers of $\sim 1$m$^2$ on five planes, ultra-light support structure
- Total of ∼2500 sensors in ∼200 ladders
- Resolution ∼10$\mu$m in bending direction, ∼30$\mu$m orthogonal
- Measured rigidity $R = \frac{pc}{|Z|e}$ up to a few tens of TV
- Measured specific energy loss $dE/dx \sim |Z^2|$ for identification of elements
- Measures direction and energy of converted photons

# AMS Tracker Plane during Metrology

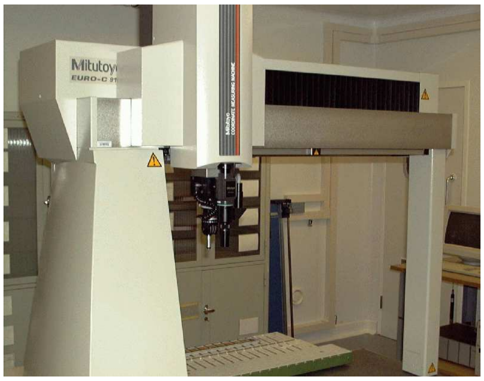


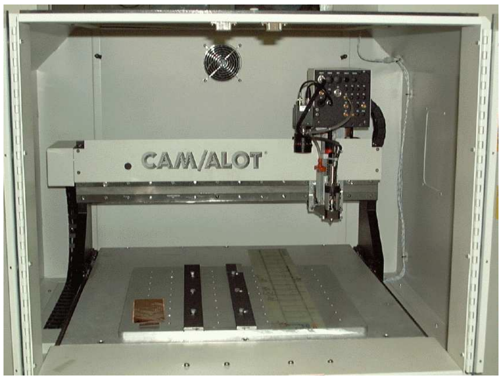
# AMS-02: Spectrometer Rigidity Resolution




Rigidity measurement up to TV rigidities

# Infrastructure

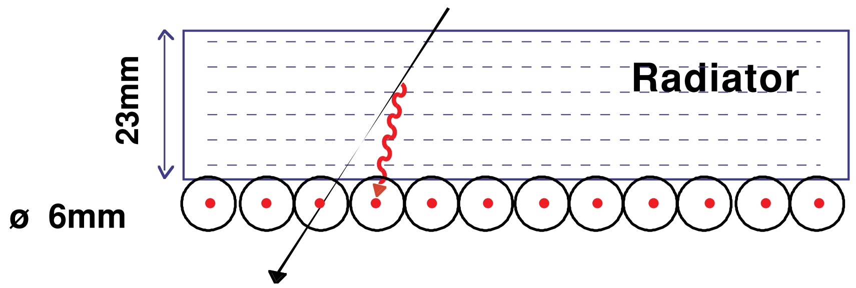




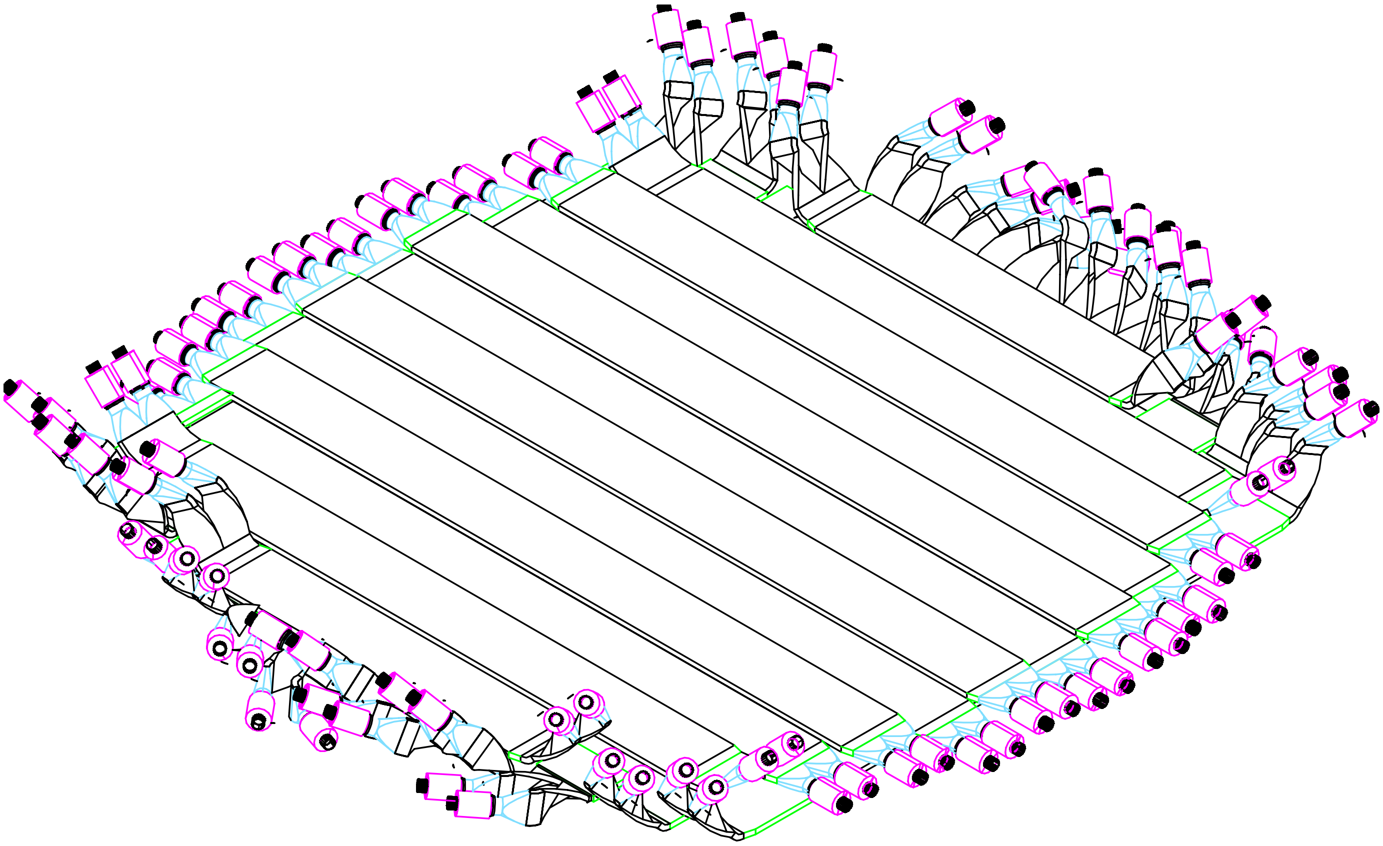
From left to right: Mitutoyo metrology machine, Camalot glue dispenser and Delvotec wire bonder.

# AMS-02: Transition Radiation Detector




- Transition radiation emitted by charged particle upon change in index of refraction, $E_\gamma$= few keV for $e^-$
- Emission probability small $(10^{-2}) \rightarrow$ multilayer radiator
- TRD photons detected in proportional straw tubes ($\sim 5300$) filled with $Xe/CO_2$
- 20 layers of straw tubes interleaved with fiber fleece (total thickness 60 cm)
- Helps in tracker reconstruction pattern recognition
- Measures also $dE/dx$
- Separate hadrons from electrons up to 300 GeV

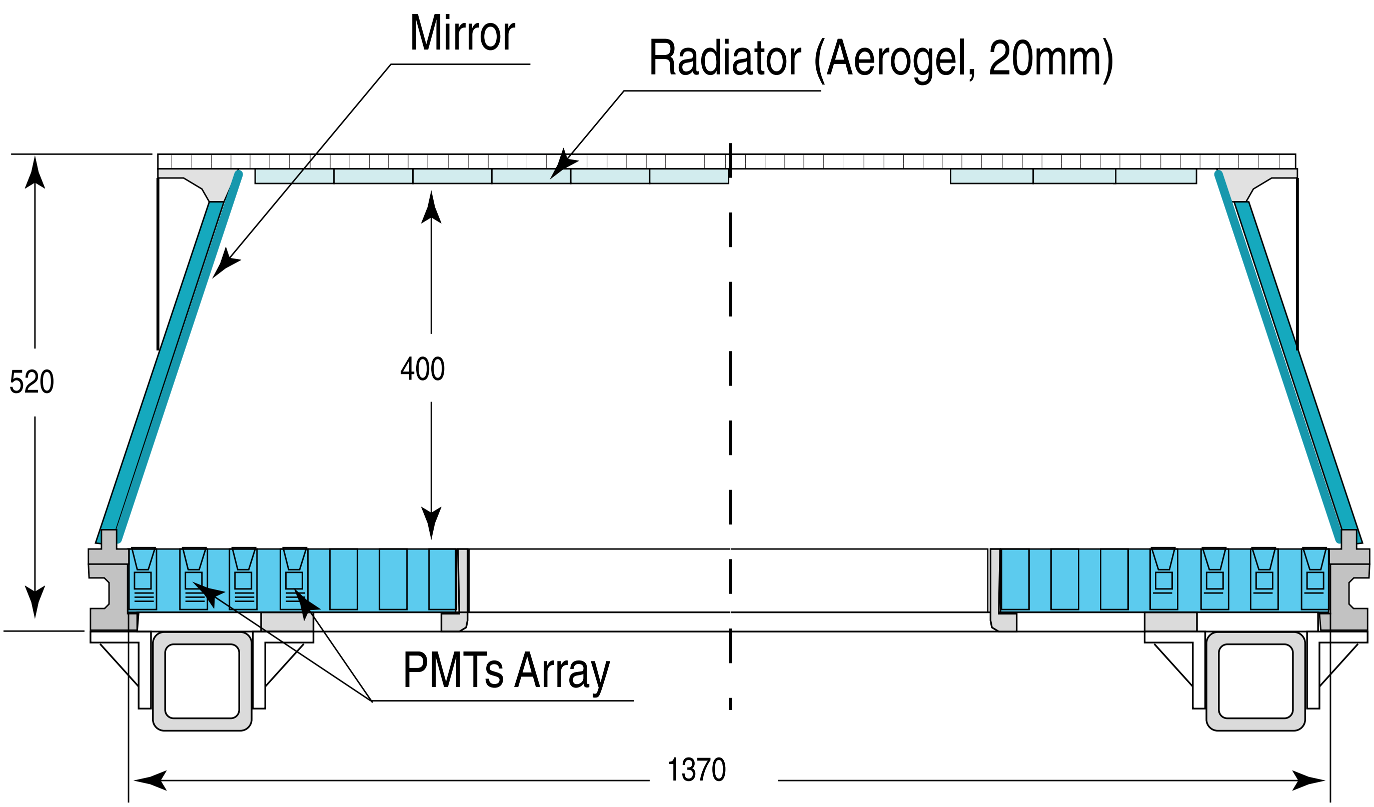
# AMS-02: Time-of-Flight Detector



- 2×2 layers of 34 crossed scintillators, 1.6 $m^2$/plane
- Photo-tubes aligned with $\vec{B}$
- Measures time-of-flight (resolution $\sim 140psec$), velocity $\beta$ and direction
- Measures also $dE/dx$, $\Delta E/E$ ~10% for MIPS →Z

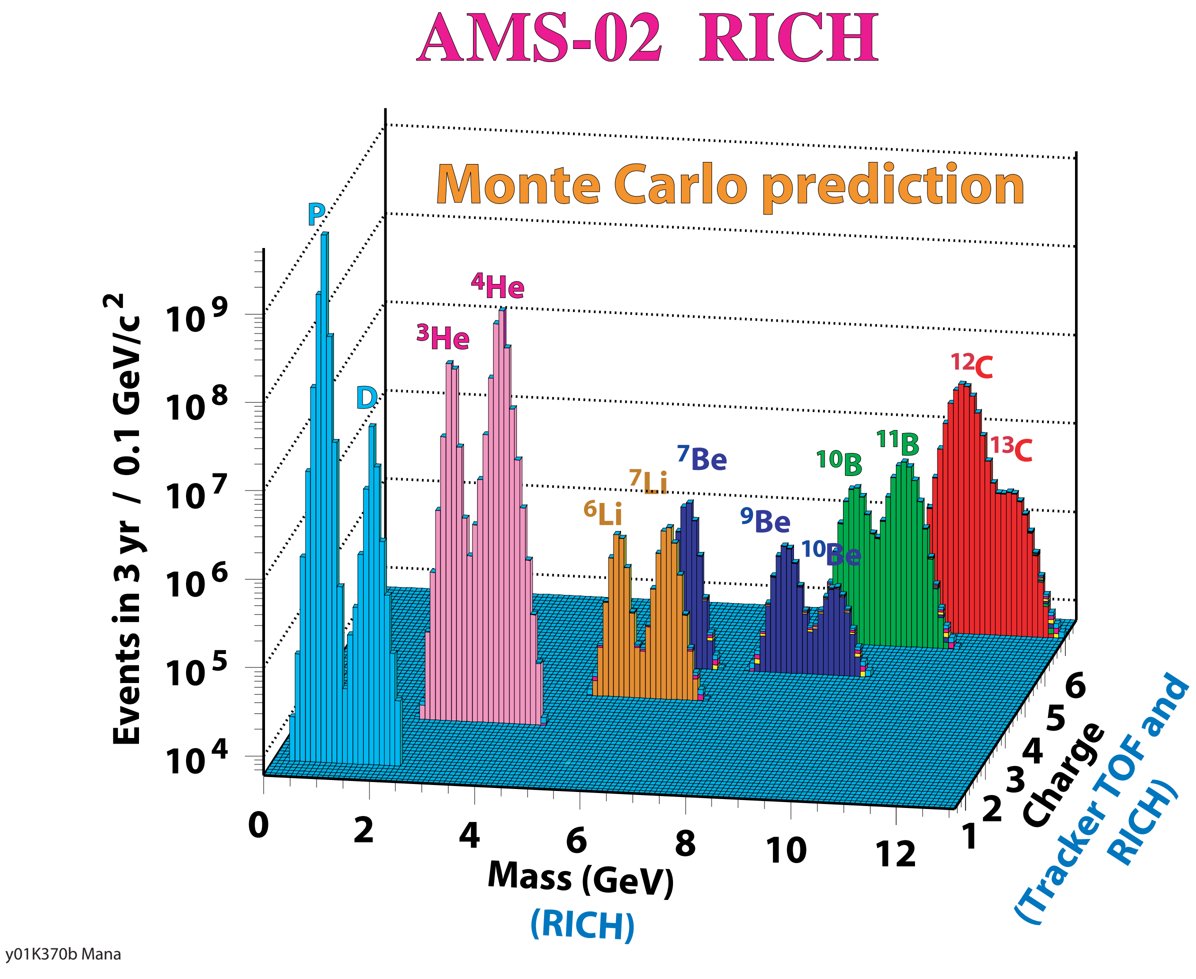
Principle trigger detector for charged particles

# AMS-02: Ring Imaging Cerenkov Detector

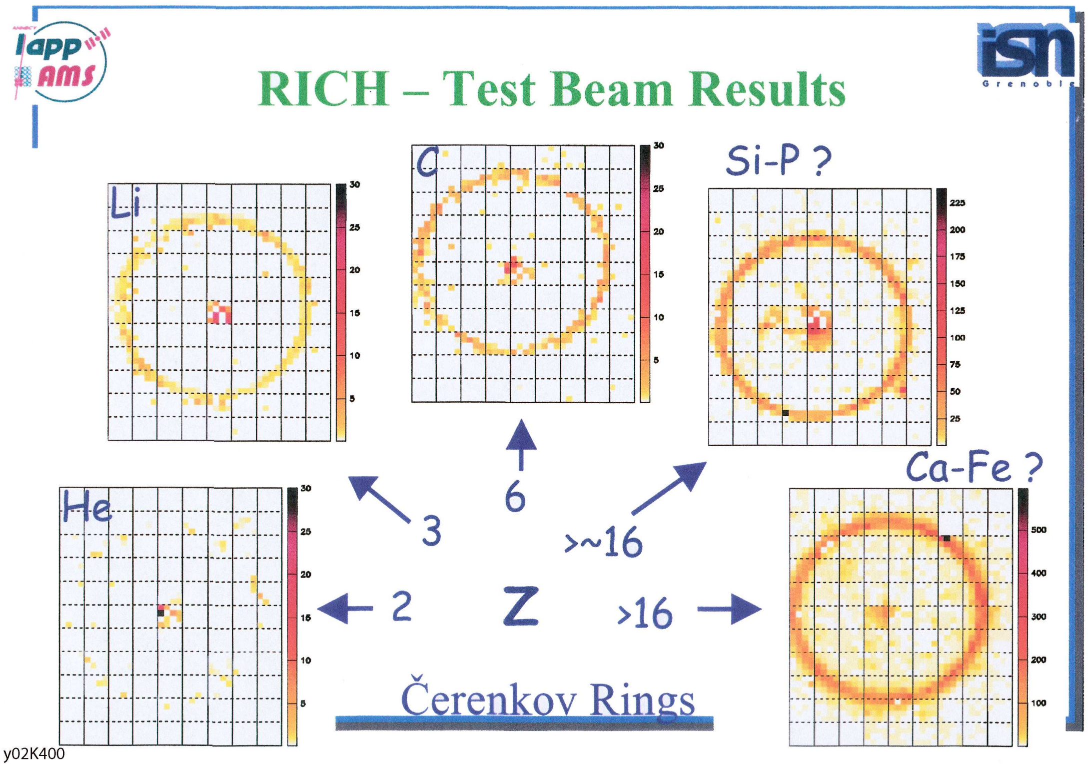



- Cerenkov light emission for $v > c$ in radiator
- Radiator: NaF (n=1.336) and Aerogel (n=1.035)
- Photon detection on a circle
- Emission angle measures velocity, $\delta\beta/\beta \simeq 10^{-3}$
- Redundant detector for particle mass measurement
- Number of photo-electrons measures $dE/dx$, $\delta E/E \simeq 8$%, independent measurement of Z up to Fe

# AMS-02: Ring Imaging Cerenkov Detector

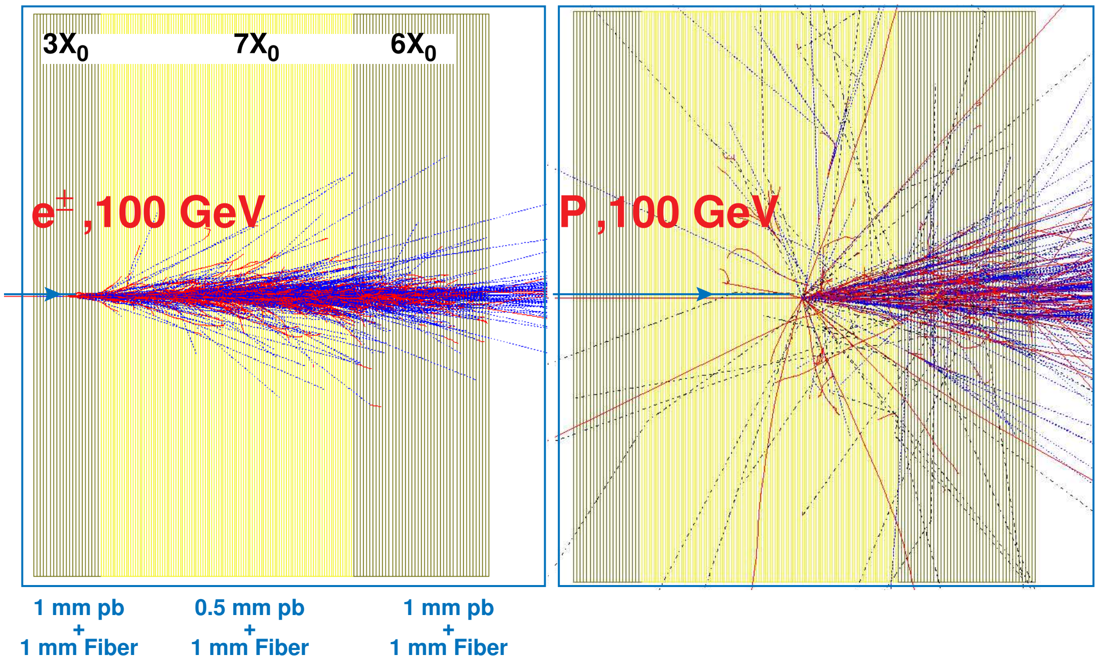


# AMS-02: Ring Imaging Cerenkov Detector



y02K400

# AMS-02: Electromagnetic Calorimeter



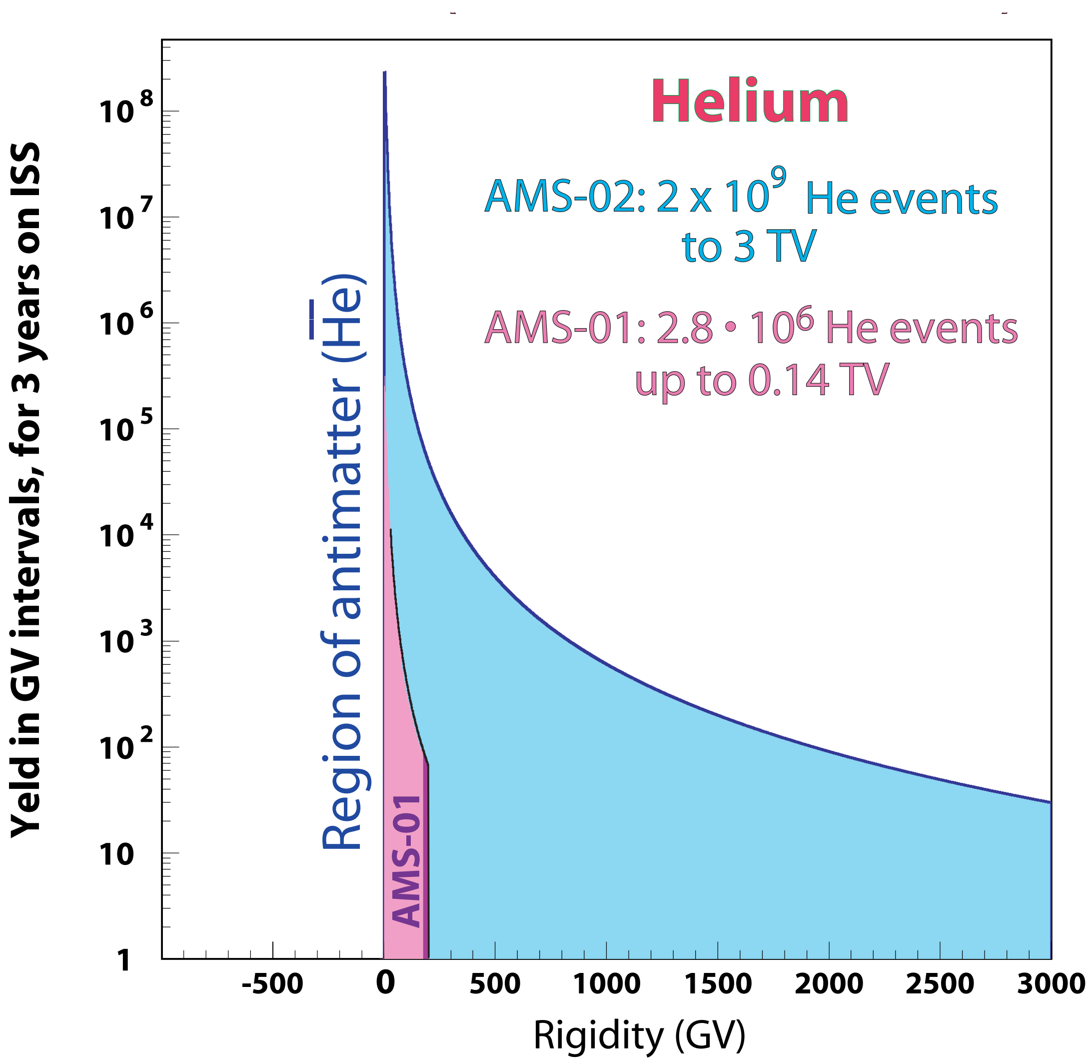

- 640 kg Lead scintillating fiber sandwich, 18$X_o$
- 3D sampling by crossed layers, read out with 384 4-pixel PMTs
- Resolution $\delta E/E \simeq (12 \pm 0.4)\%/\sqrt{E} \oplus (2.8 \pm 0.1)\%$ ($E$ in GeV)
- Distinction between hadrons and e/$\gamma$ by shower shape
- Protons supressed by $10^{-4}$ from 10 to 300 GeV. Together with TRD, rejection of hadrons/electrons $\geq 10^6$
- Independent photon detector, angular resolution $\sim 1^\circ$

# Physics with AMS-02 on ISS

Rich and diversified program:

- Search for antimatter extended in energy and sensitivity
- Search for supersymmetric dark matter
- Origins and transport mechanisms of cosmic rays
- Pulsars, blazars, micro-quasars and other sources of energetic photons

# AMS-02: Search for Antimatter

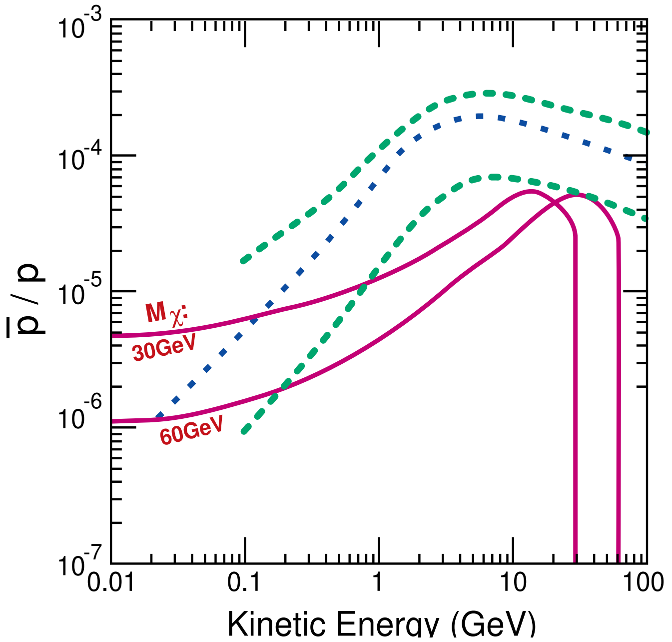



- Discovery of $\bar{He}$ $\rightarrow$ Cosmological antimatter
- Discovery of $\bar{C}$ $\rightarrow$ Antimatter stars
- Presently, no antinucleus with $Z \geq 2$ found
- Will discover tiny amounts of antimatter if it exists and can reach Earth
- Otherwise limit improved by three orders of magnitude

# AMS-02: Supersymmetric Dark Matter

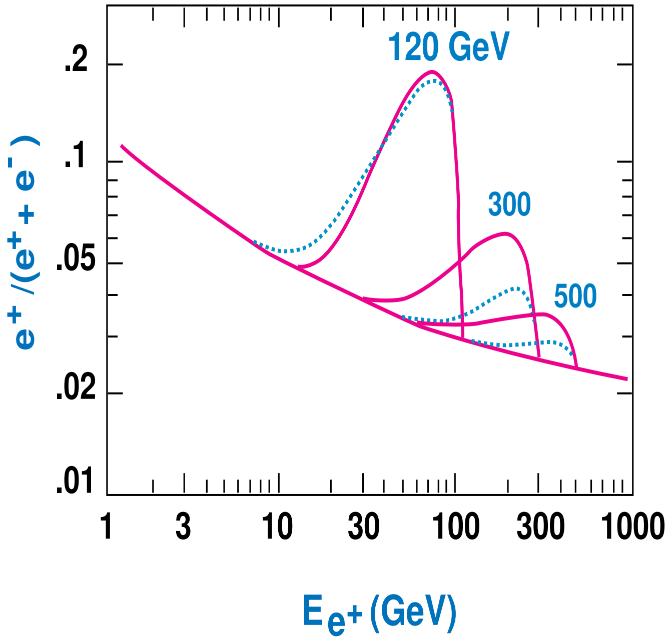
$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow q\bar{q}$

antiprotons



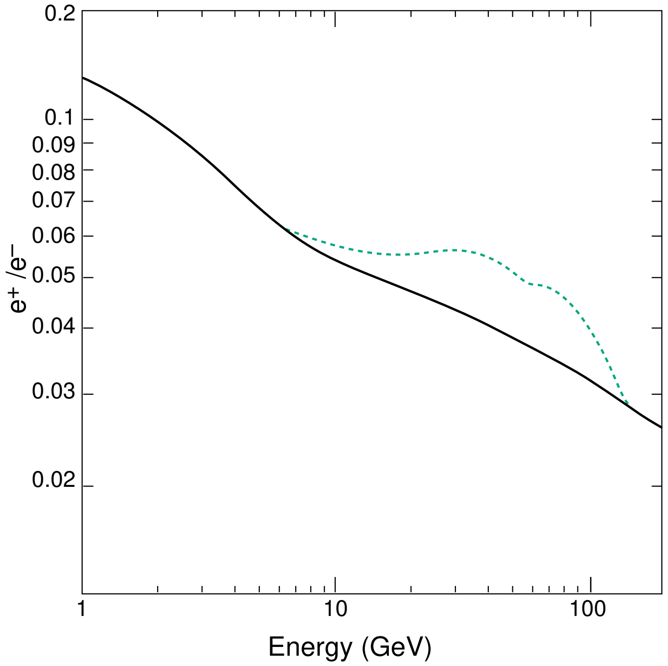

$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow W^+W^-, ZZ$

positrons



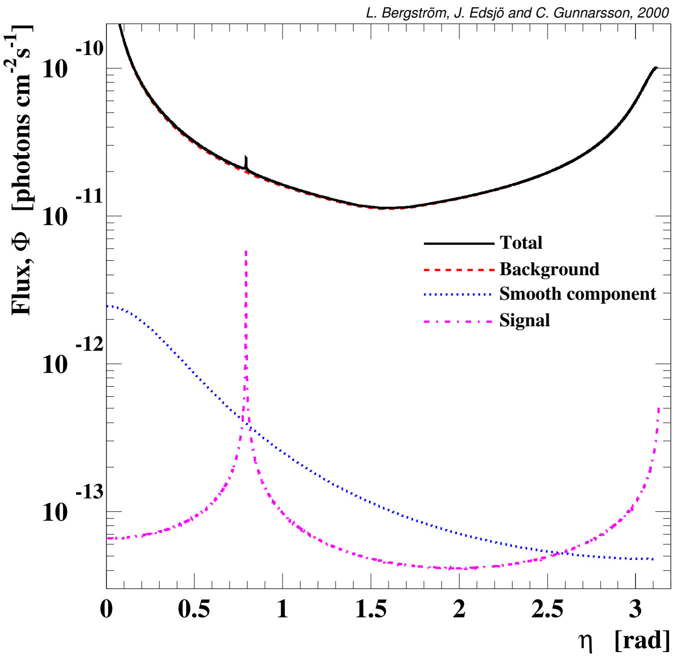

$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \tau^+\tau^-, b\bar{b}, t\bar{t}$

positrons




$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \gamma\gamma, Z\gamma, W^+W^-, ZZ$

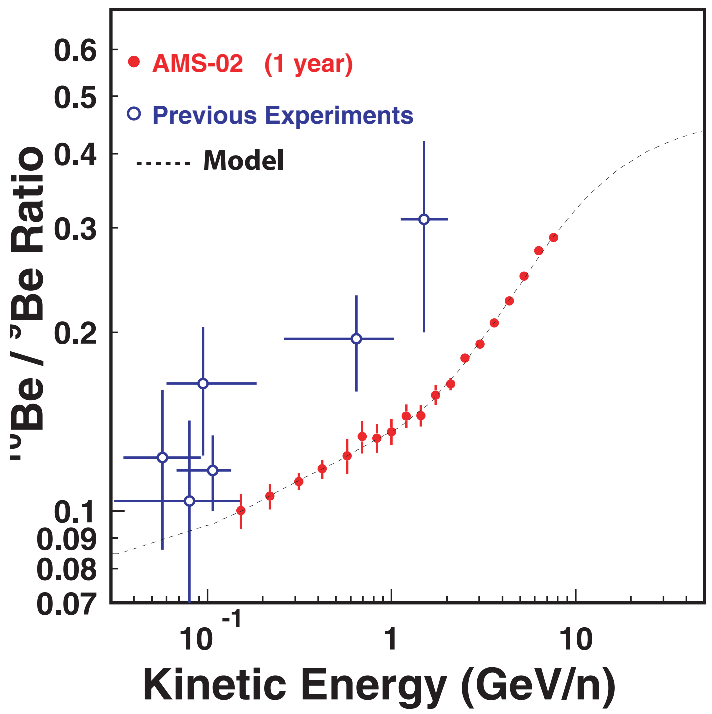
photons



# Origins and Transport of Cosmic Rays

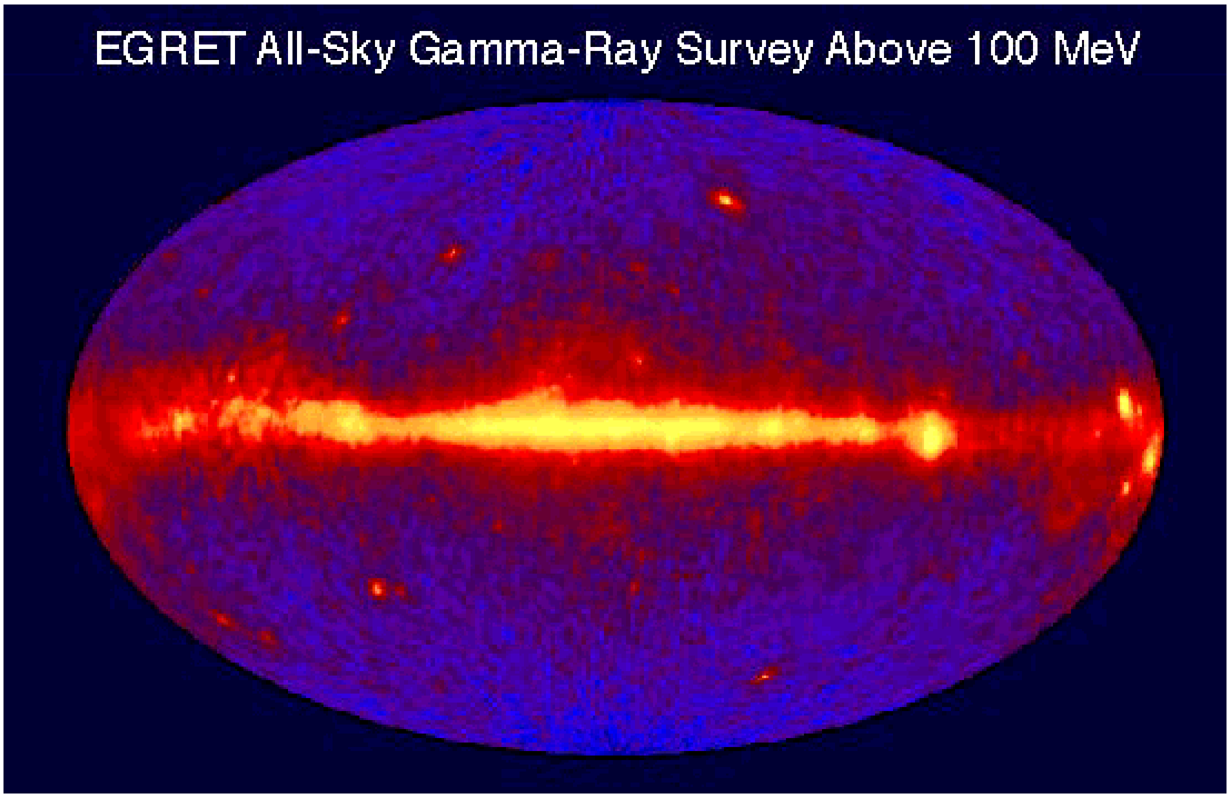
Element composition of CR well measured and similar to solar values with some remarkable exceptions: Li,Be,B

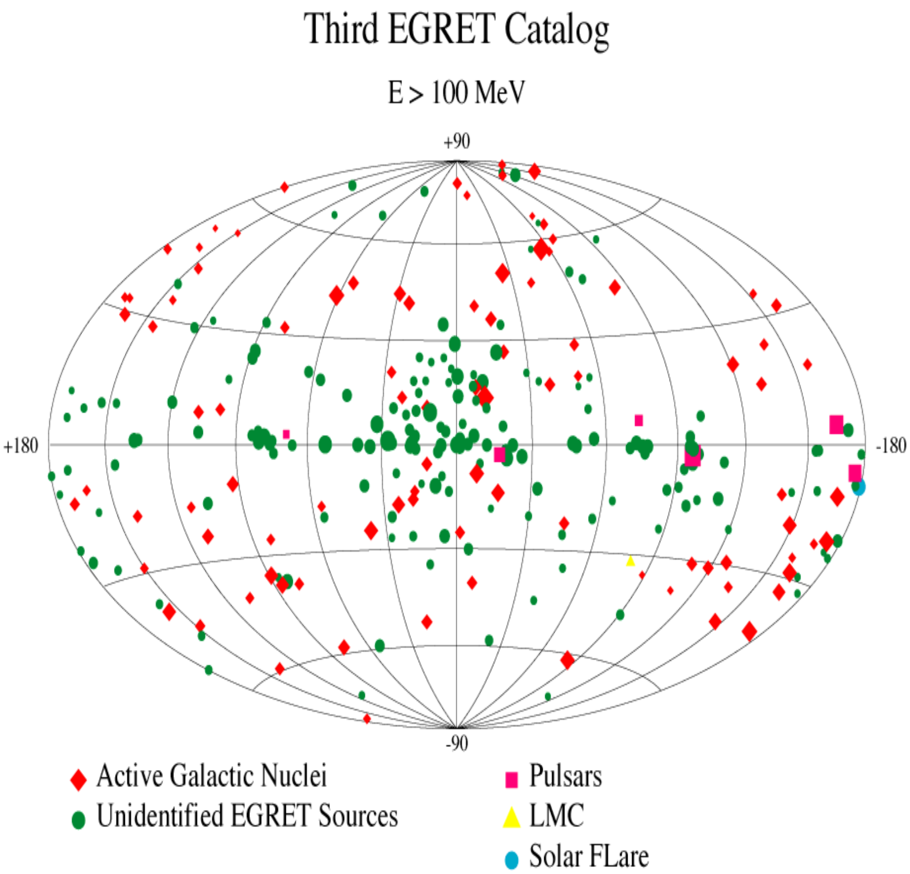
- Li(except $^7$Li), Be and B not produced in the primordial nucleosynthesis, nor made in stars
- Li, Be and B are produced by spallation reactions involving $p$ and $\alpha$ colliding with C,N,O nuclei in the supernova explosion
- Propagation from source to Earth: Radioactive isotopes $^{10}$Be (1.6 $10^6$ yrs)




- cosmic ray confinement time in the galaxy
- mean density of interstellar material traversed

# Diffuse Photons and Point Sources

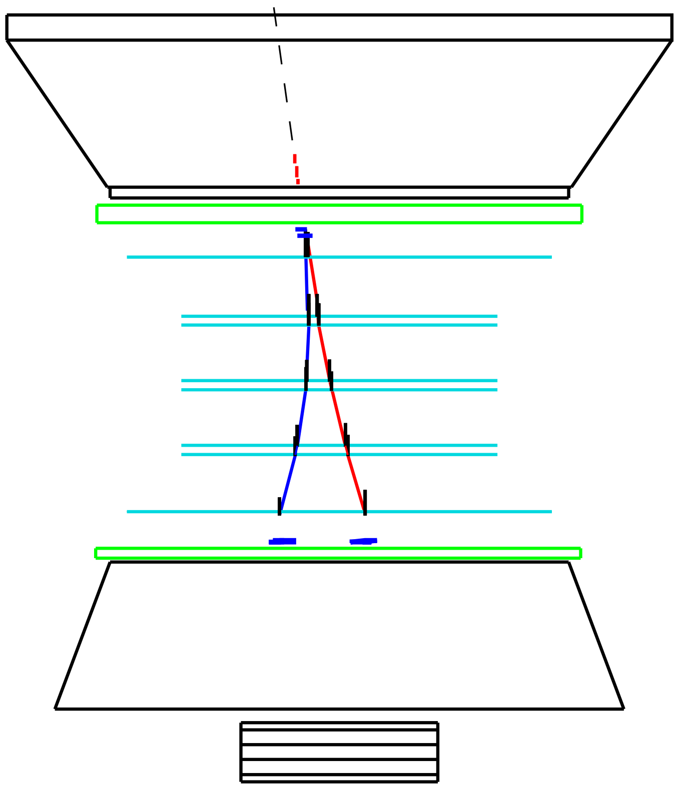


# AMS-02: Gamma Astrophysics

AMS-02 sees photons:

- by conversion
- by calorimetry



2 complementary methods:

- Energy range: few $GeV < E_\gamma <$ hundreds of GeV
- Angular resolution: $0.03^o$(tracker) $\rightarrow$ $1^o$ (calor.)
- Energy resolution: few %

Need Star Tracker for accurate orientation

# Conclusions

- AMS-02 will contribute to the observation of cosmic rays and photons in space, complementary both in time scale and energy range to other projects.
- A sophisticated and complete detector will be available over a long observation period.
- The construction and commissioning of the detector are a first class technological challenge.
- The detector will be ready for launch in October 2005, and ISS is likely to provide the required services by that time.
- A rich and diversified physics program will result from the three year of data taking.