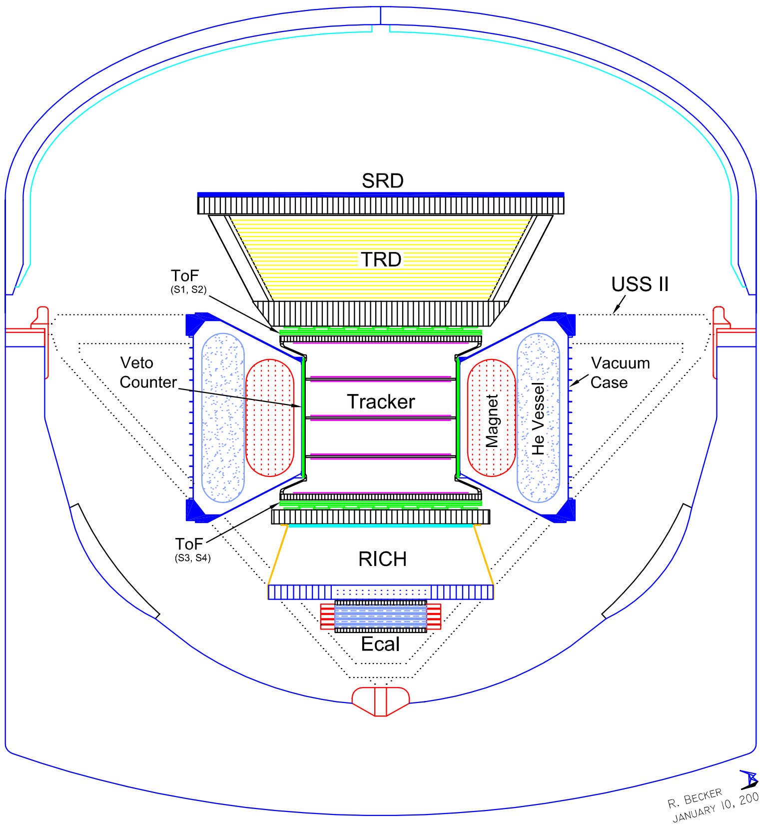
The AMS-02 Experiment

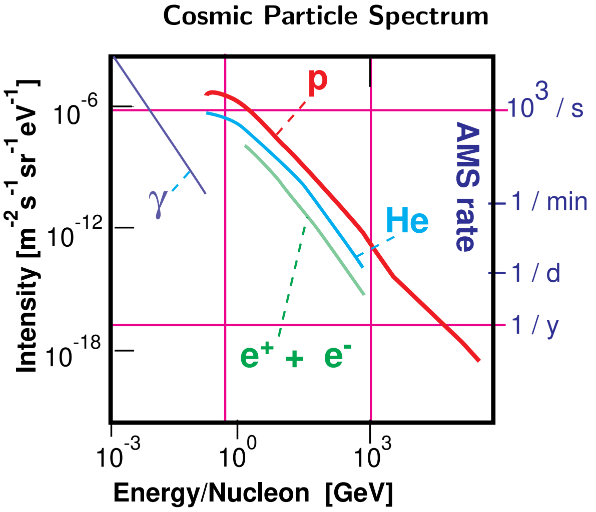


Catherine Leluc
Rencontres de Bossey
July 12th, 2002

AMS-02 on International Space Station

Design of the detector revised toward more ambitious goals:

- Long exposure time $\sim$ 3 years
- Increase of the energy domain by one order of magnitude
  · a superconducting magnet [1T, factor 6]
  · improved redundancy for the tracker with 8 layers of silicon (instead of 6 partially equipped) and better signal to noise ratio in silicon
- Isotopic separation improved by a RICH
- Separation of e^+ from p (or e^- from $\bar{p}$) from 10 to 300 GeV with a Transition Radiator Detector
- $e^\pm$ and γ detection up to 1 TeV via an Electromagnetic CALorimeter

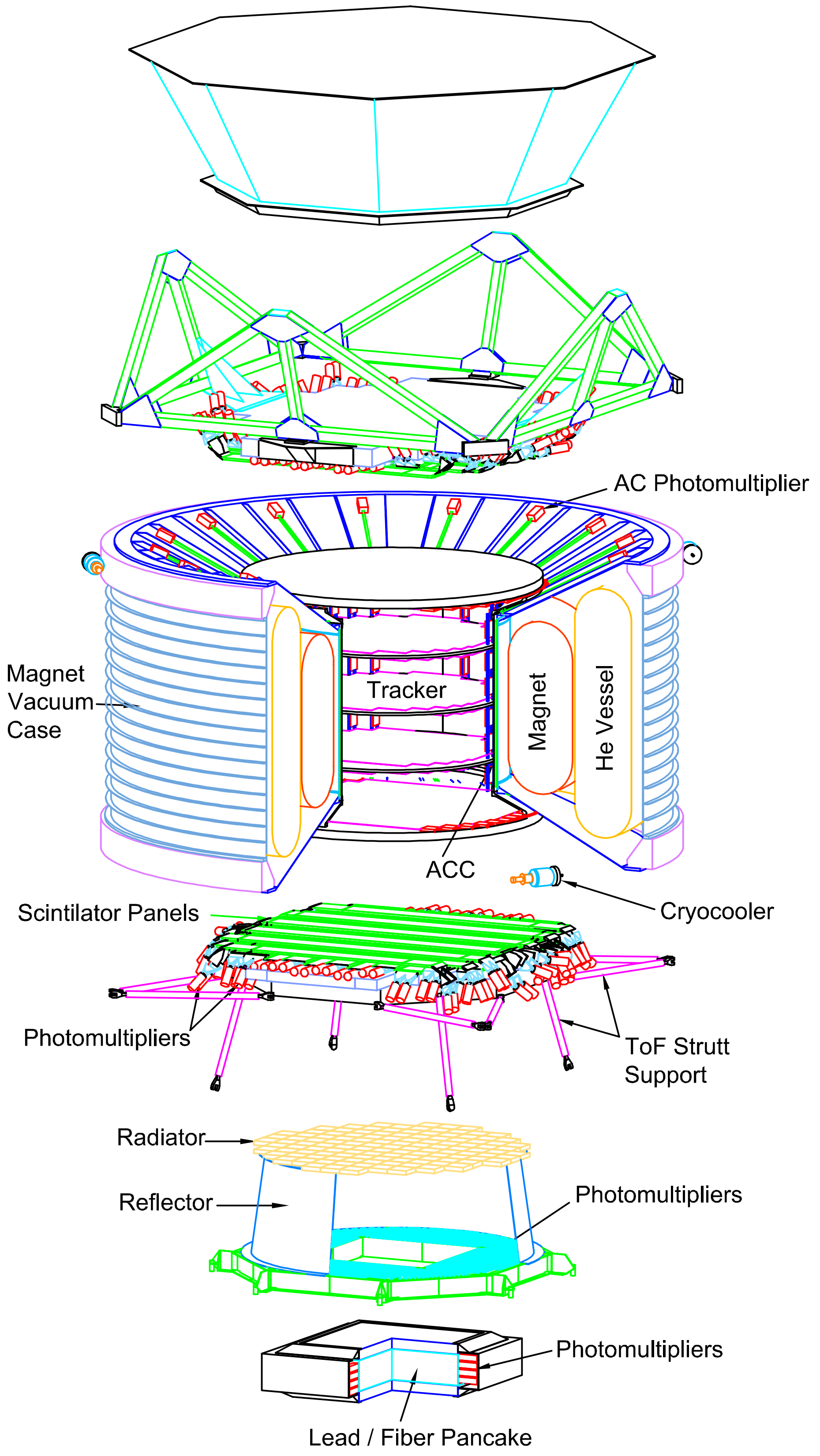


Experiments in space

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 to 14809 lb
- Datarate 1 Mbyte/s via 1 datalink
- Power consumption limited to 2kW
- Powersupply at 120V via 1 powercable
- Long exposure time $\sim$ 3 years

A TeV Detector in space



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)

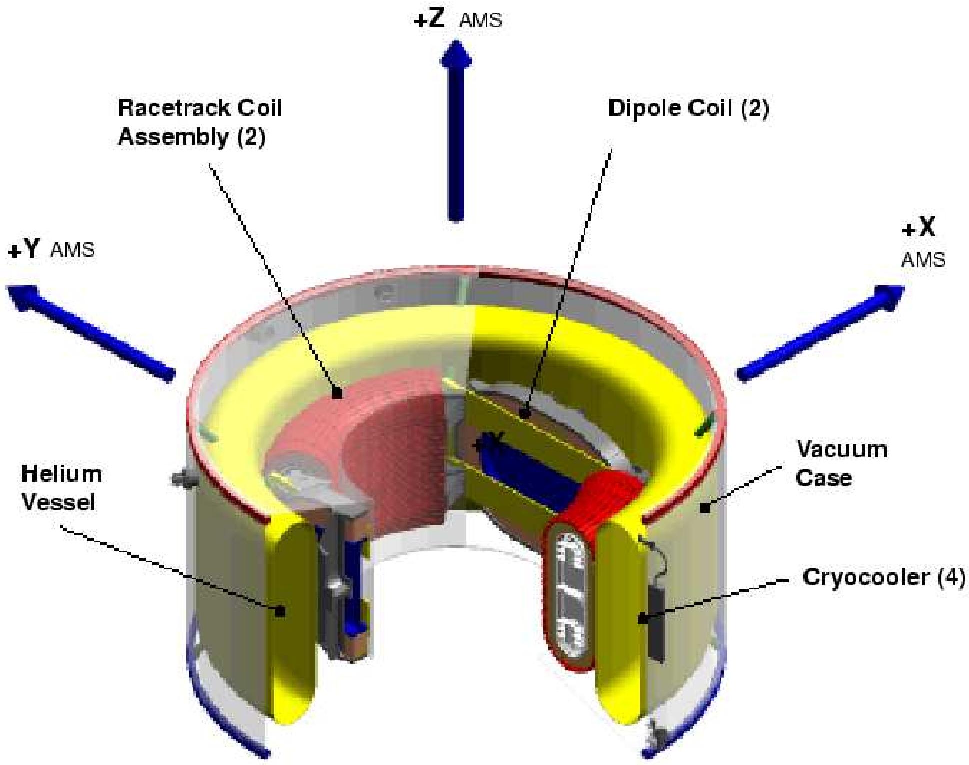
MG: Magnet
CC: Cryocooler

ToF: (s3,s4)
Time of Flight Detector

RICH:
Ring Image Cherenkov
Counter

EMC:
Electromagnetic
Calorimeter

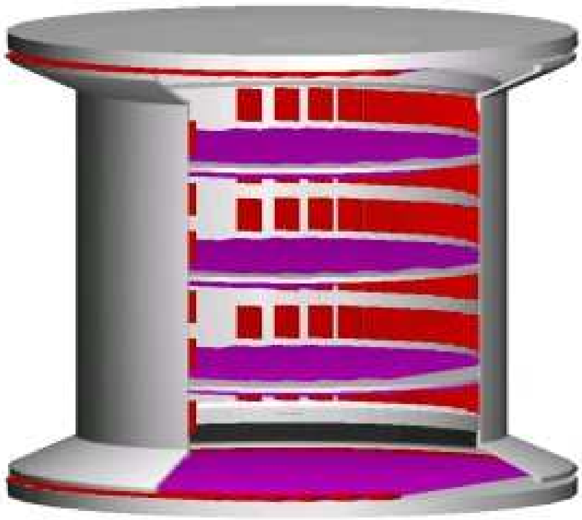
AMS-02: Superconducting Magnet

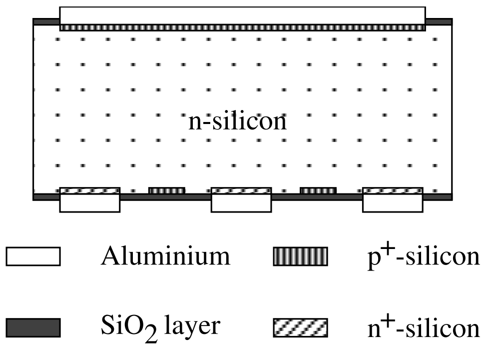


- 14 superconducting coils cooled by superfluid Helium at 1.8 K
- Reservoir for ∼3 years of operation without refill (2500l)
- Dipole field close to 1T, six times AMS-01
- Dimensions: same inner diameter as AMS-01 (1.1m), weight: 2100 Kg
- Extends measurement of rigidity by one order of magnitude

present status: 6 coils done and being tested

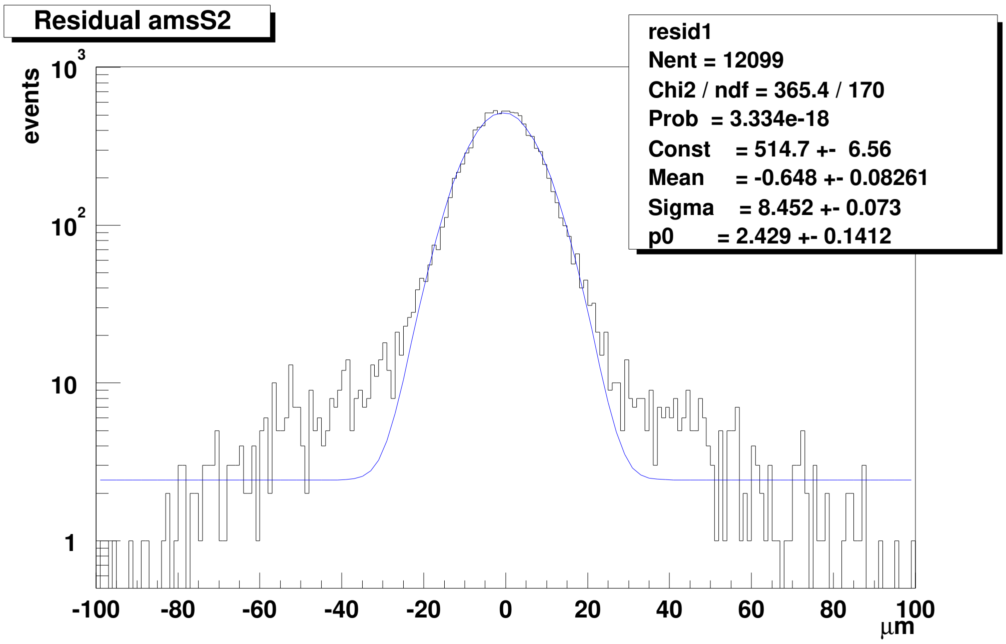
AMS-02: Tracking Detector

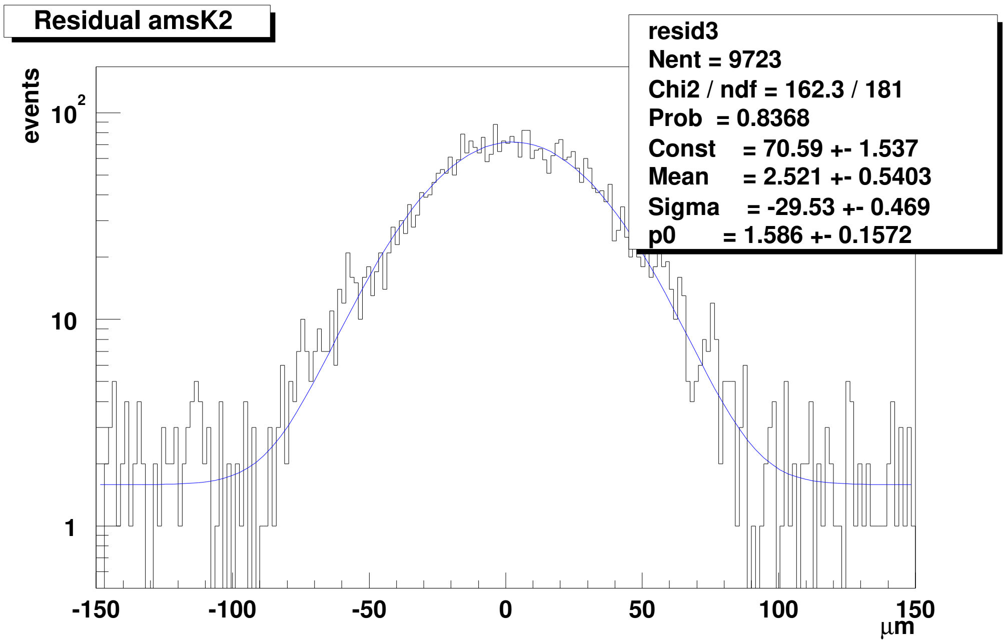




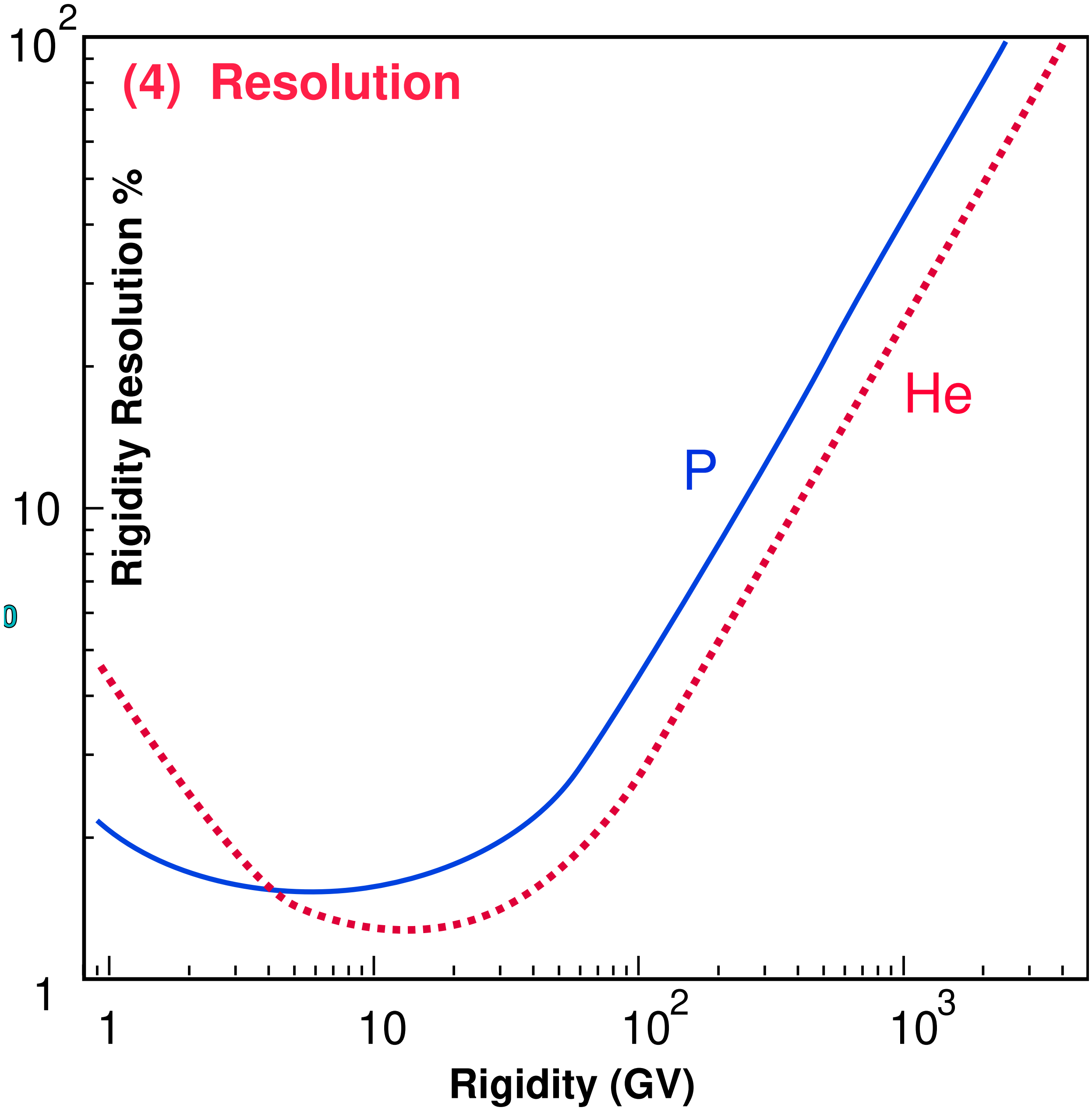
- Localisation of charged particle by double sided silicon sensors
- Eight layers of ~ 1m^2 on five planes, ultra-light support structure
- Total of ~2500 sensors in ~200 ladders
- Resolution ~10μm in bending direction, ~30μm orthogonal
- Measured rigidity $pc/|Z|e$ up to a few TV
- Measured specific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

AMS-02: AMS-02 tracker resolution



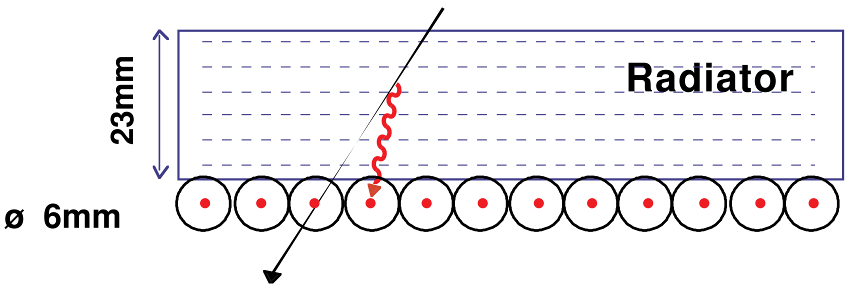


AMS-02: Spectrometer Rigidity Resolution



Safe rigidity measurement up to TV rigidities

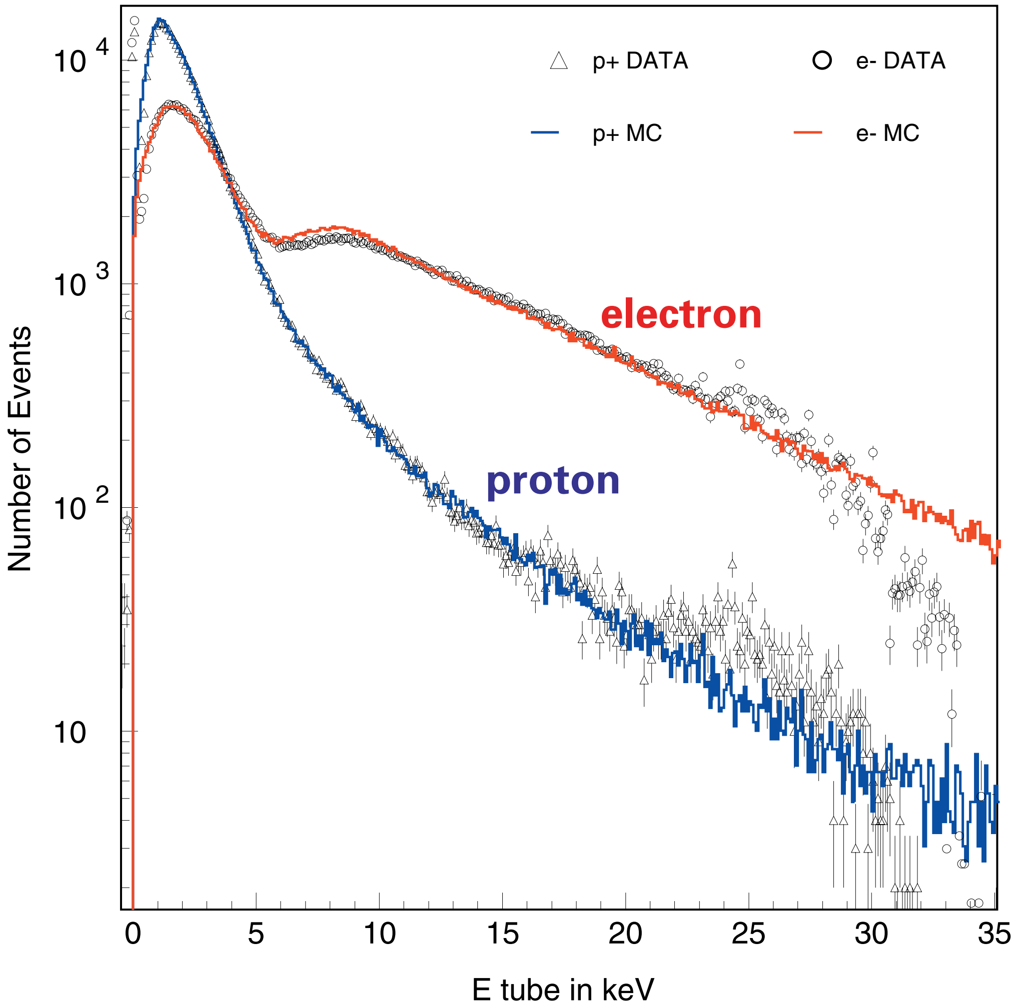
AMS-02: Transition Radiation Detector



- TR photons emitted by charged particle upon change in index of refraction, E_{γ}= few keV for electrons
- Emission probability small (10^{-2}) $\rightarrow$ fiber fleece
- TRD photons detected in straw tubes($\sim$ 5300) filled with Xe/CO_2
- 20 layers of straw tubes interleaved with fiber fleece (total thickness 60 cm)
- Separates hadrons from electrons up to 300 GeV
- Helps in tracker reconstruction pattern recognition, Measures also dE/dx
- Rejection requires careful control of gas gain (density,temperature $\Delta\, T \sim 1^o K$, HV, mixture, impurities)

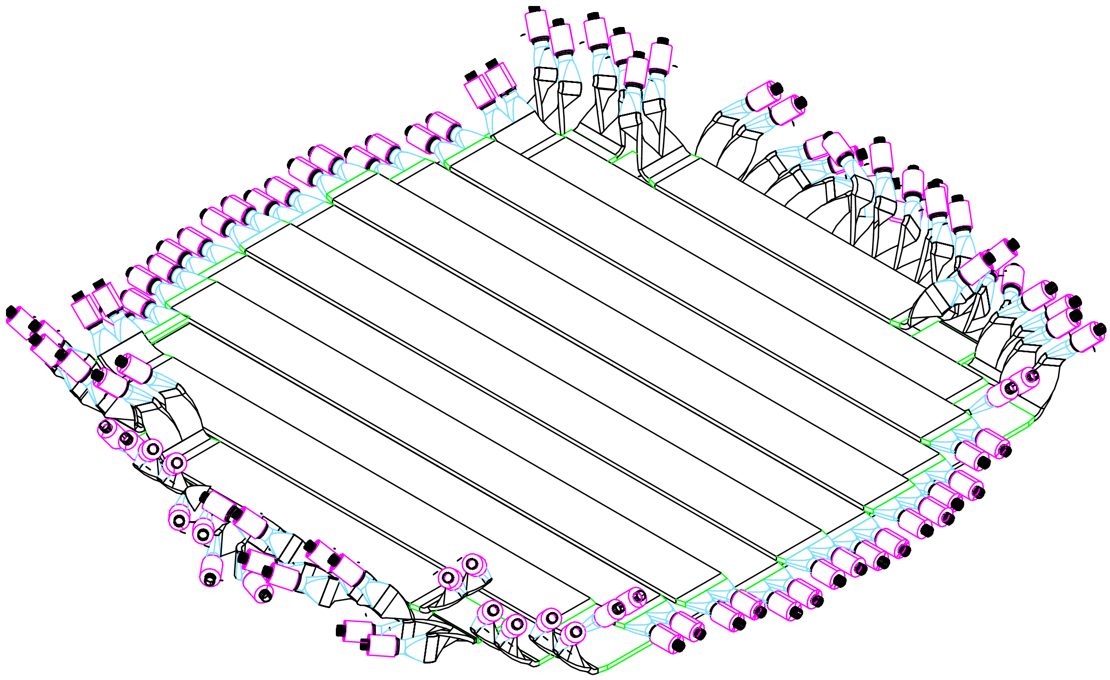
AMS-02: Transition Radiation Detector

TRD
Mass production and test results at CERN
5 - 250 Giga electron volt particles



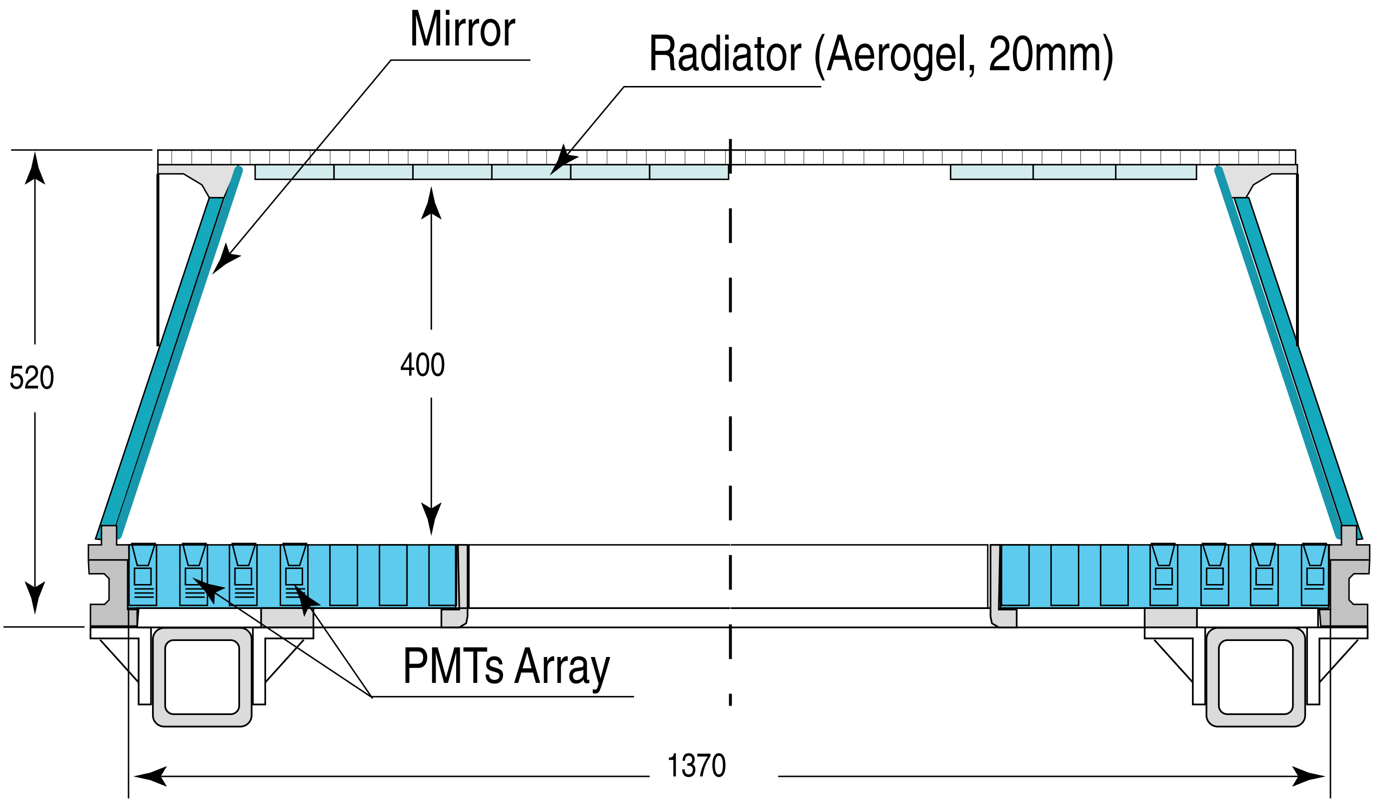
y01K513bSchael

AMS-02: Time-of-Flight Detector



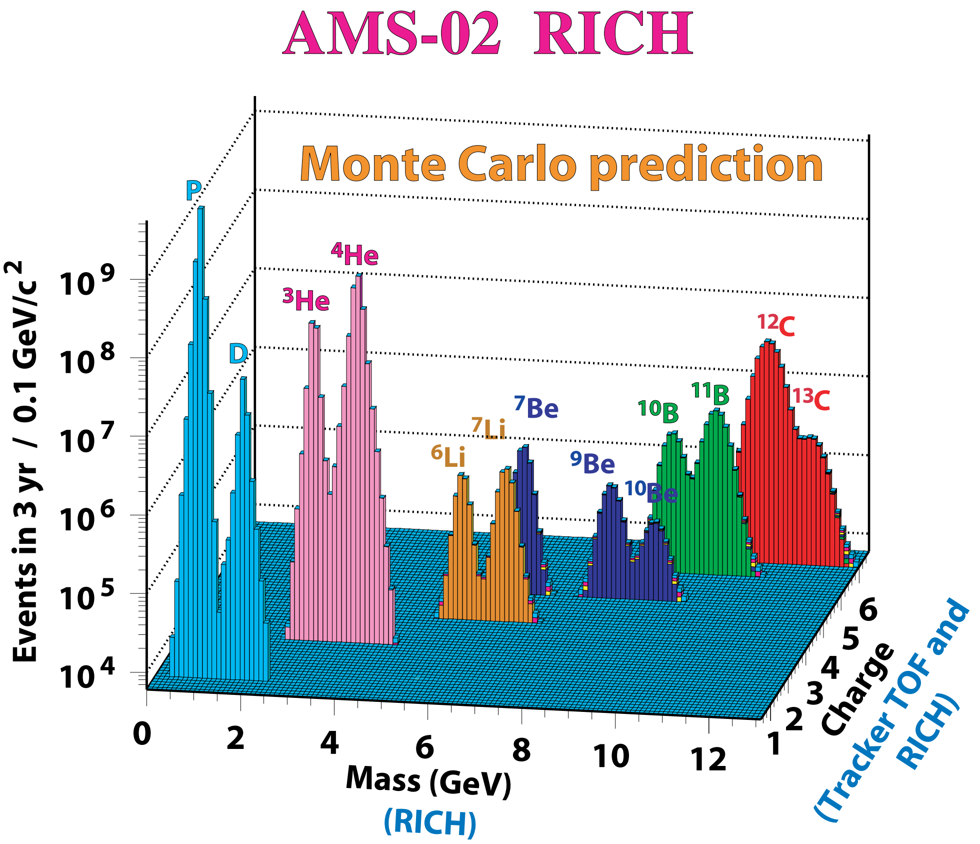
- 2×2 layers of crossed scintillators, 1.6 m^2/plane
- 64 plastic scintillator paddles, 1 or 2 PMT/end
- Photo-tubes aligned with $\vec{B}$ (stray field 3000 G)
- ToF measures transit time to 100 psec
- Measures time-of-flight, velocity β and direction
- Measures also dE/dx, $\Delta E/E$ ∼10% for MIPS → Z
- Fast coincidence between ToF planes provides “fast” trigger(≤5 kHZ)
- An upgraded version from AMS 01

AMS-02: Ring Imaging Cerenkov Detector

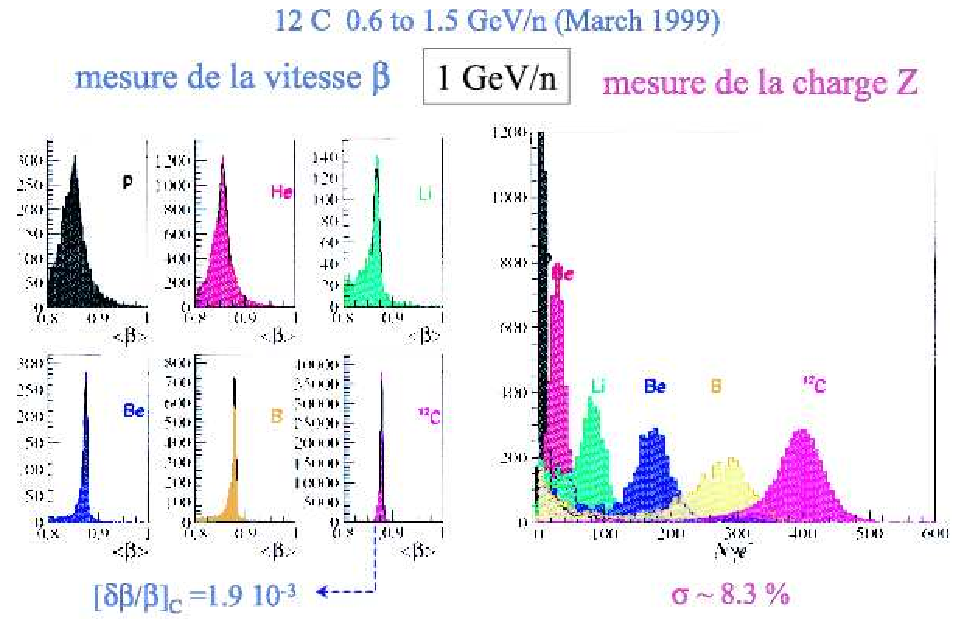


- Radiator: NaF (n=1.336) and Aerogel(n=1.035)
- Detection plane of 1056 16-pixel PMTs
- Cerenkov light emission for $v > c$ in radiator
- Emission angle measures velocity, $\delta\beta/\beta \simeq 2 \times 10^{-3}$
- Redundant detector for particle mass measurement
- Number of photo-electrons $\rightarrow$ Z, $\delta E/E \simeq 8$%

AMS-02: Ring Imaging Cerenkov Detector



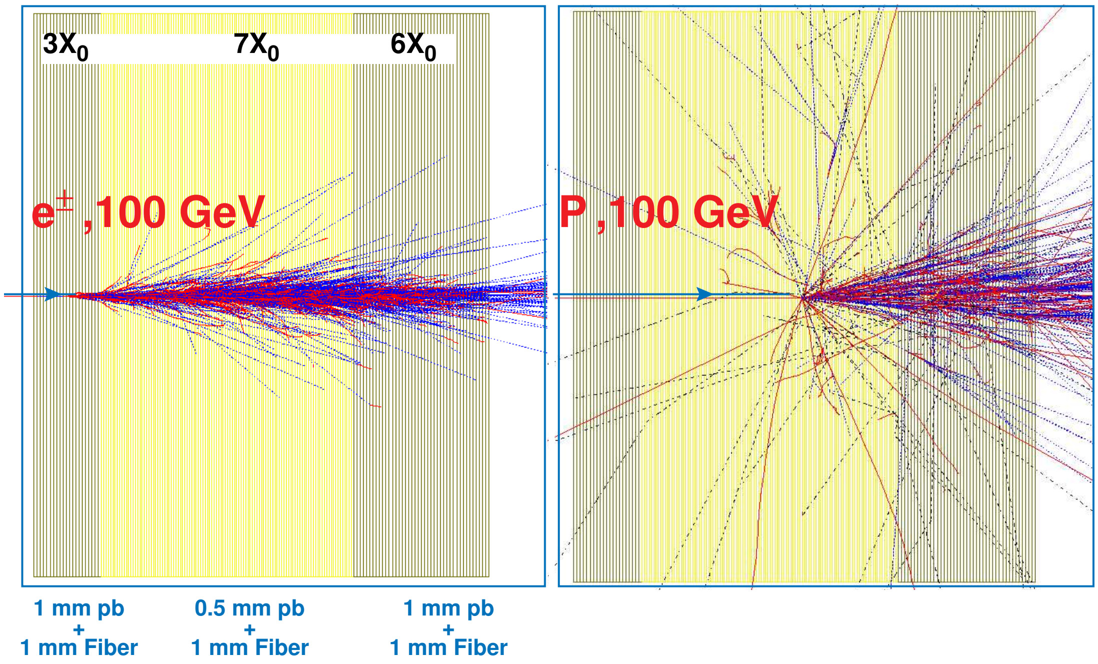
y01K370b Mana



Test results with an earlier version of RICH using

y2K075d Figure 200

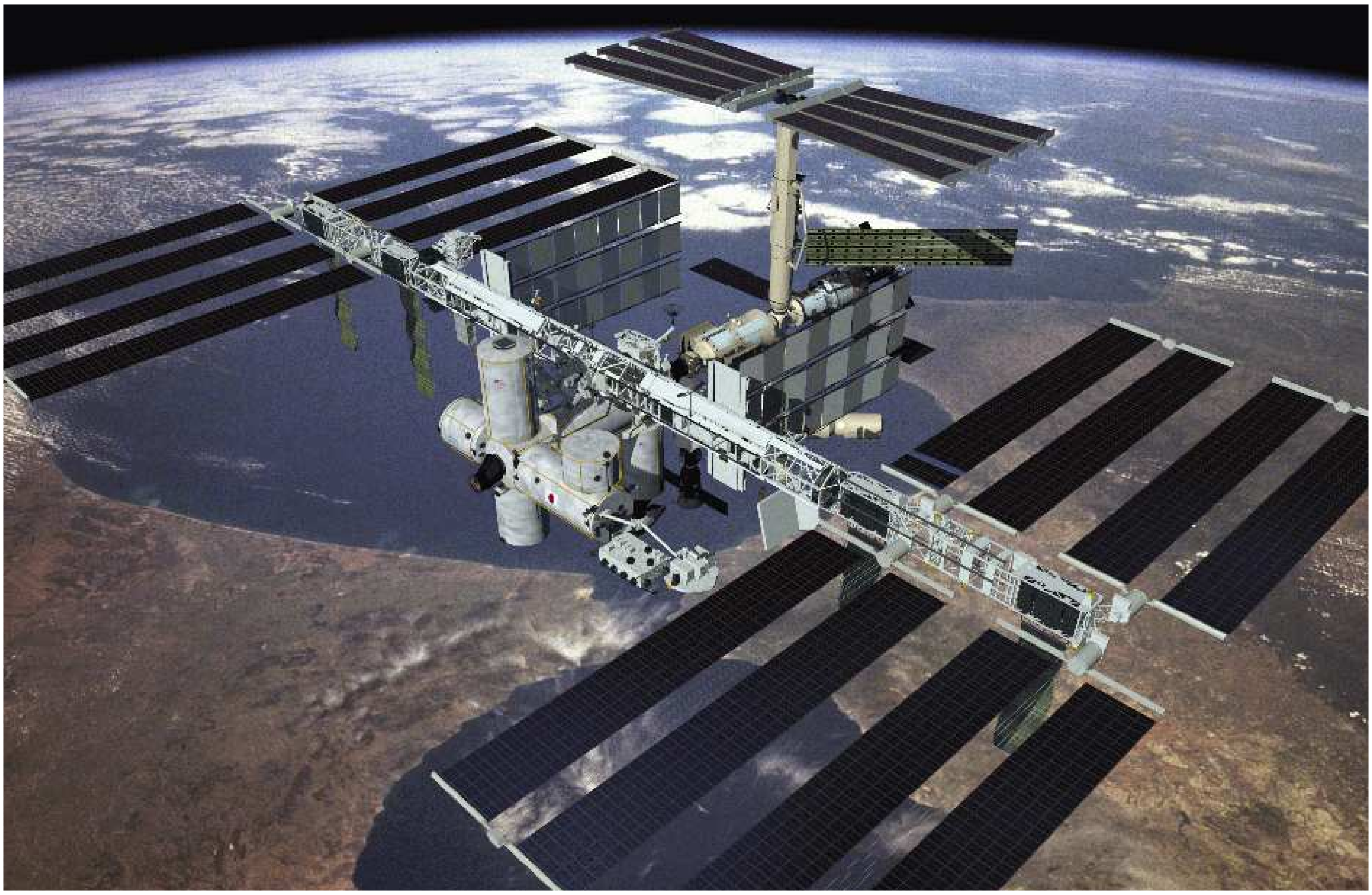
AMS-02: Electromagnetic Calorimeter



- 600 kg Lead scintillating fiber sandwich, 15X_o
- 3D sampling by crossed layers read out with 384 4-pixel PMTs
- Distinction between hadrons and e/γ by shower shape
- $\Sigma(dE/dX) \rightarrow$ particle energy
- Resolution $\delta E/E \simeq 12\%/\sqrt{E} + 1.5\%$ (E in GeV)
- Protons supressed by 10^{-4} from 10 to 300 GeV. Together with TRD, rejection of hadrons/electrons $> 10^6$
- Independent photon detector, angular resolution $\sim 1^\circ$

Presently ECAL prototype in test beam with final electronics

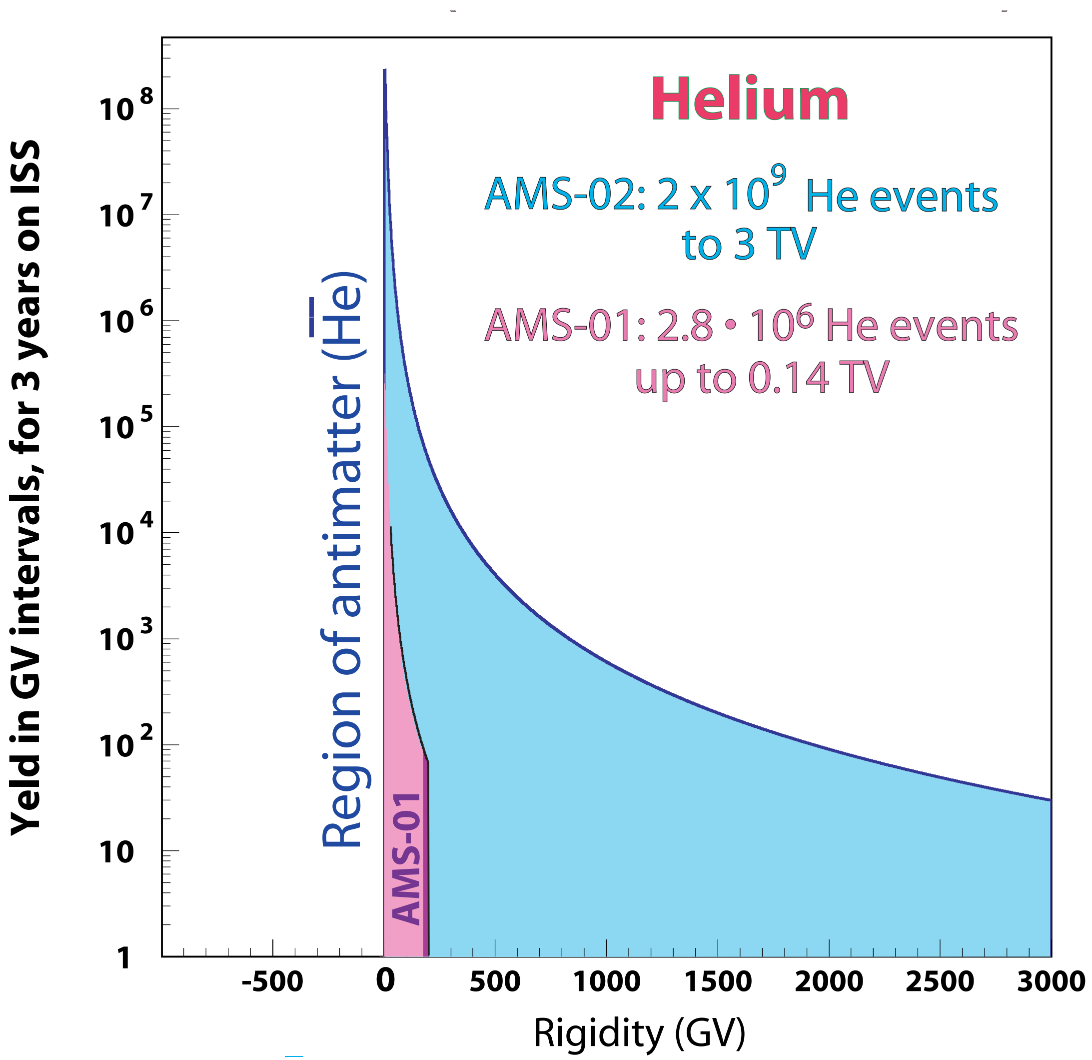
Physics with AMS-02 on ISS



Rich and diversified program:

- Search for antimatter extended in energy (TeV) and sensitivity
- Search for supersymmetric dark matter
- Origins and transport mechanisms of cosmic rays
- Working of natural accelerators (Pulsars, blazars, micro-quasars...) by observing energetic photons

AMS-02: Direct search for Antimatter



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

AMS-02: Direct search for Antimatter

If the universe contains regions of antimatter and matter, annihilation radiation at the boundaries should occur via,

$$\bar{N} + N \rightarrow \pi^o, \pi^\pm \rightarrow \gamma, e^\pm, \nu$$

$$e^+ + e^- \rightarrow \gamma + \gamma$$

No signal in the extragalactic diffuse γ background has been observed
No distortion in the CMB have been observed up to about 10 Mpc

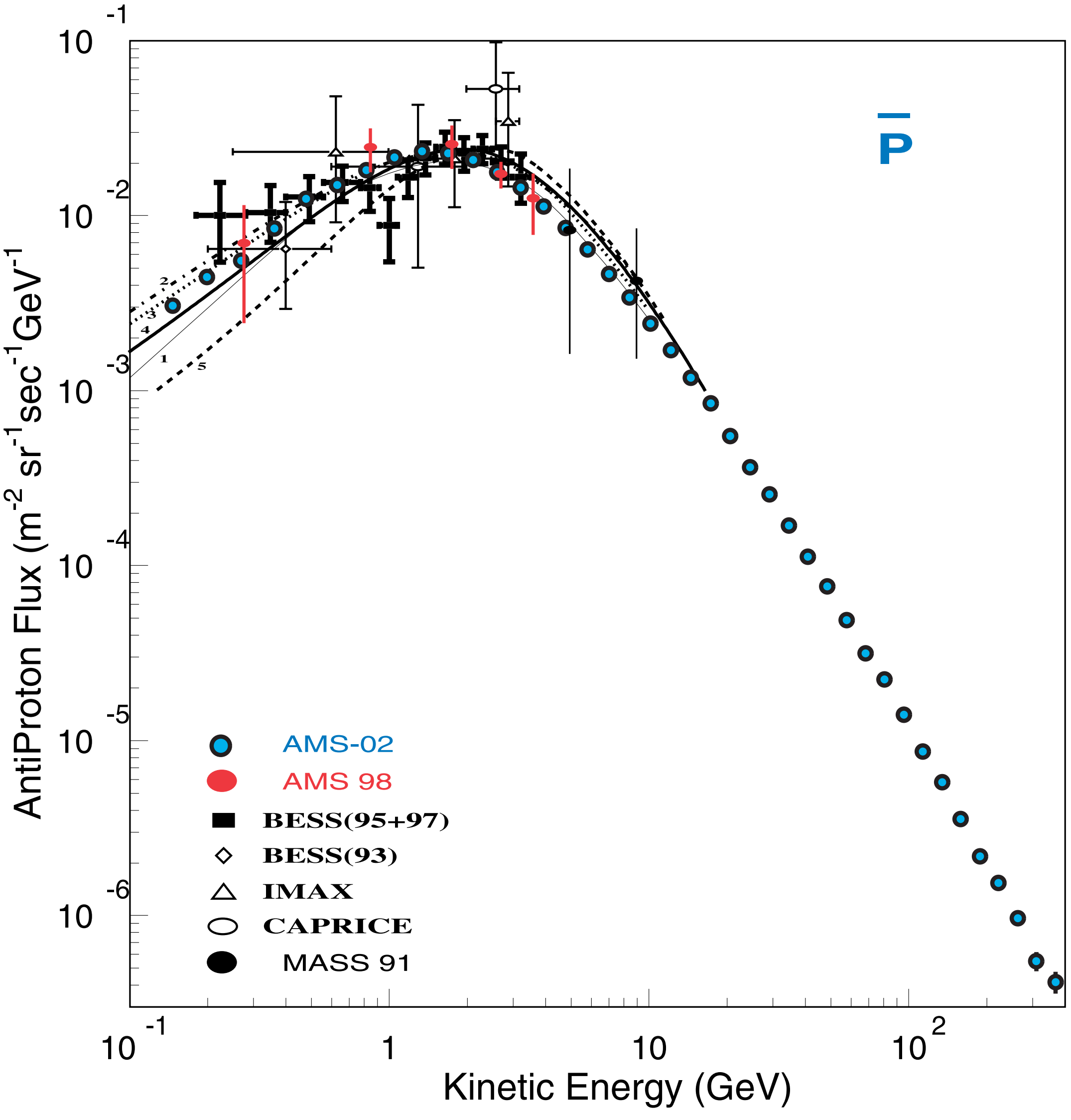
Big Bang Model predicts:$N_B/N_\gamma = N_{\bar{B}}/N_\gamma \sim 10^{-18}$

Observed values to-day:$N_B/N_\gamma \sim 10^{-9}, N_{\bar{B}}/N_B \leq 10^{-6}$

In 1967, Sakharov formulated 3 ingredients necessary for a non-symmetric baryogenesis:

- Baryon number violating interactions
- a non-equilibrium situation
- CP and C violation

AMS-02: Secondary anti-particle search



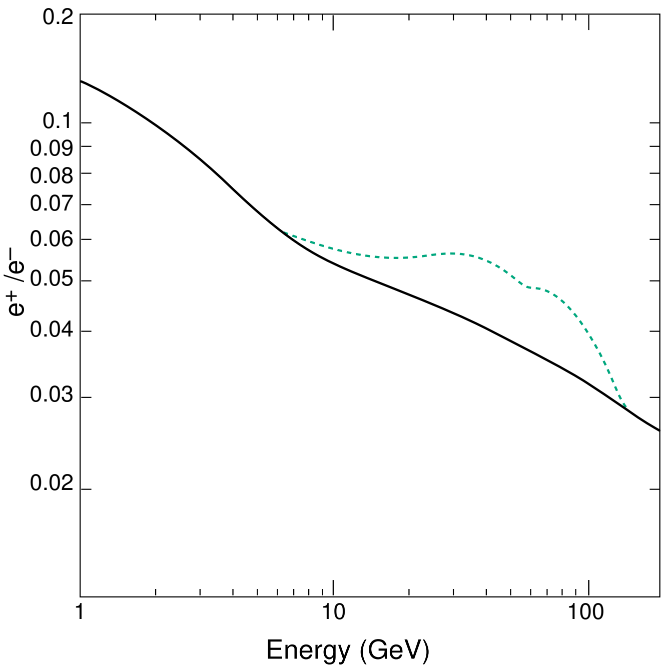
Antiprotons fully compatible with secondary production

AMS-02: Supersymmetric Dark Matter

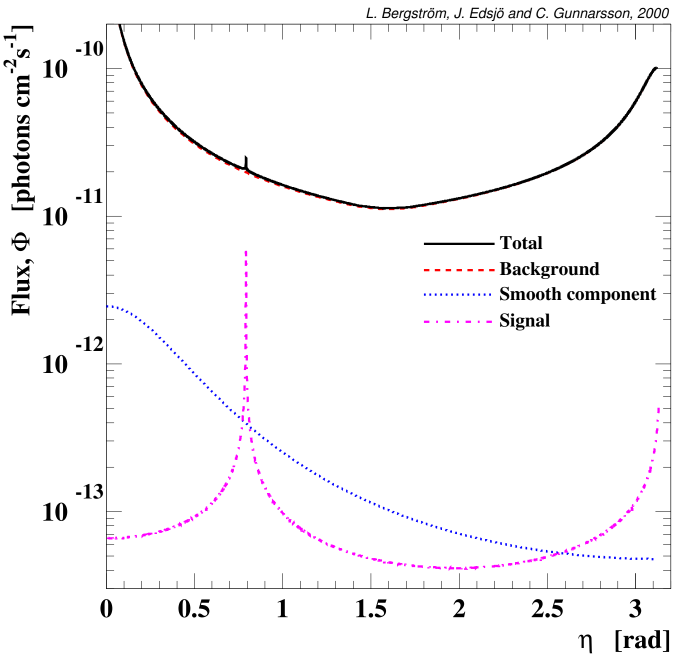
$\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow q\bar{q}$
antiprotons

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



AMS-02: Dark Matter

Most of the baryonic matter is non-luminous

- For visible luminous (baryonic) matter:
  $\rho_{lum} \sim 2 \cdot 10^{-29} kg \cdot m^{-3}$
  $\Omega_{lum} \sim 0.003 h_o^{-2}$
- total density of baryons inferred from baryogenesis model:
  $\rho_{baryon} = (3 \pm 1.5) \cdot 10^{-28} kg \cdot m^{-3}$
  $\Omega_{baryon} \sim (0.01 - 0.03) h_o^{-2}$

Most of the matter is non-baryonic

- total matter density inferred from galactic rotation curves
  $\rho_m \geq 5 \cdot 10^{-27} kg \cdot m^{-3}$
  $\Omega_m \geq 0.3$

What is the nature of dark matter?

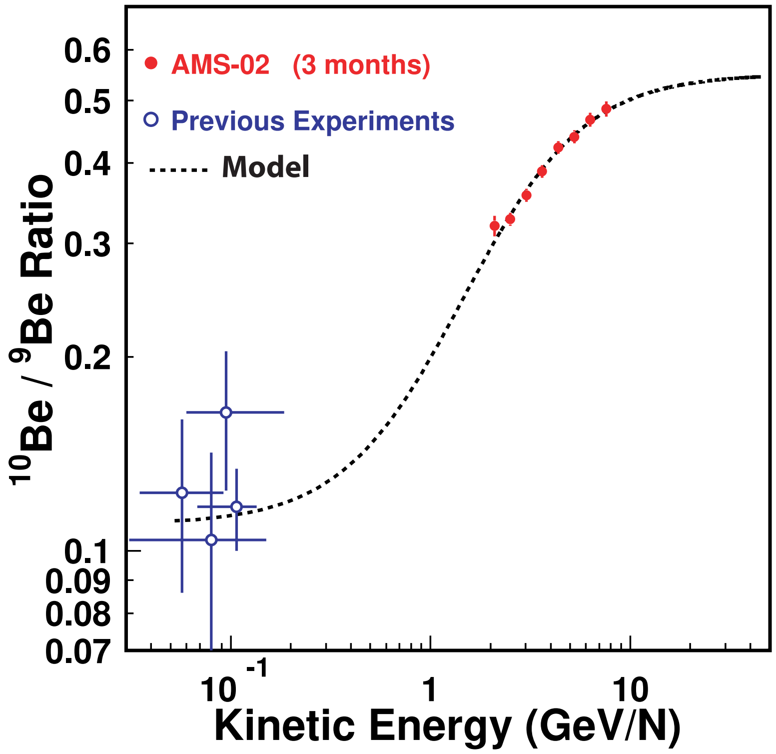
- baryonic dark matter : MACHOs (0.01-0.1 $M_\odot$).
- Non-baryonic dark matter :

Neutrinos
Axions
WIMPs: $\tilde{\chi}_1^0$

Origins and Transports of Cosmic Rays

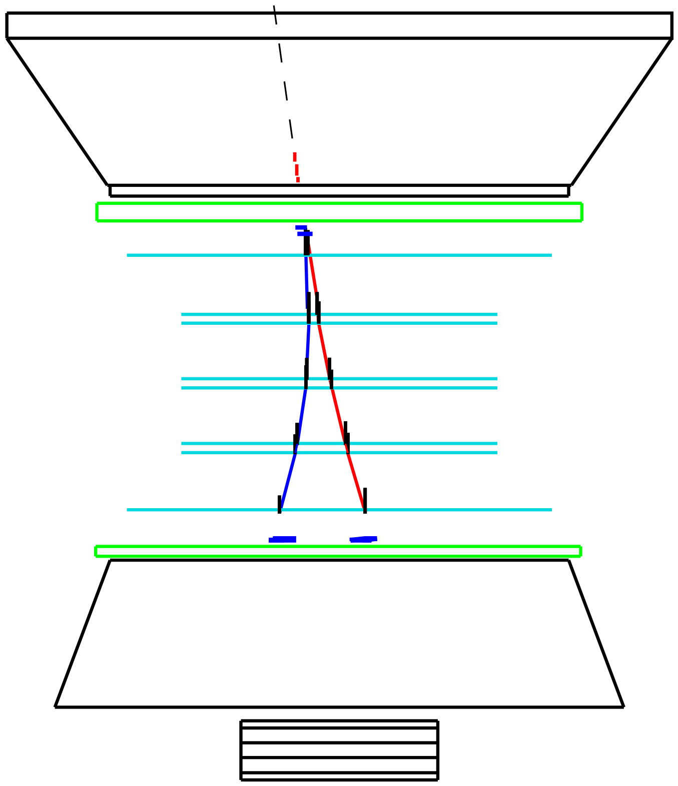
Element composition of CR well measured and similar to solar values with some remarkable exceptions: Li,Be,B

- 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 α colliding with C,N,O nuclei in the supernova explosion
- Propagation from source to Earth: Radioactive isotopes ^{10}Be (1.6 10^{6} yrs)



- high accurate determination of cosmic ray confiment in the galaxy
- mean density of interstellar material traversed

AMS-02: Photon Detection



- AMS-02 sees photons:
  - by conversion, 2 GeV $< E_\gamma <$ 400 GeV
  - by calorimetry, 8 GeV $< E_\gamma <$ 1 TeV
- Angular resolution: $\simeq 0.2$mrad (tracker) $\rightarrow 1^\circ$ (calor.)
- Energy resolution: $\simeq 15\%$ (tracker) $\rightarrow$
  $\simeq 12\%/\sqrt{E} \oplus 1.5\%$ (calor.)

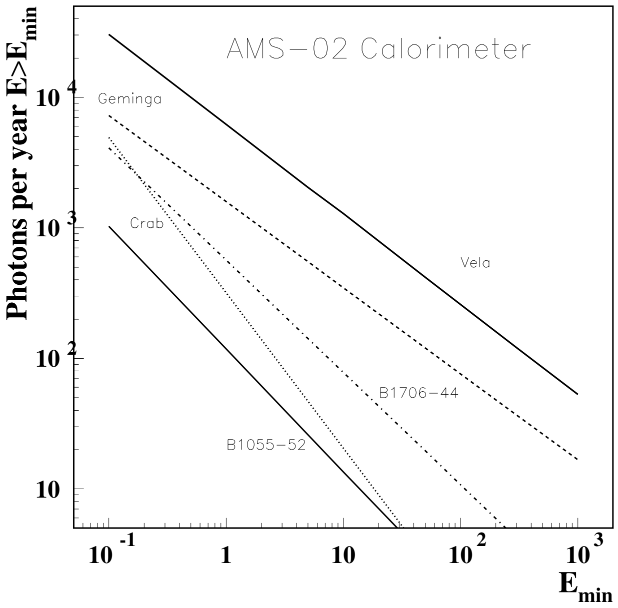
Need Star Tracker for accurate orientation

Diffuse Photons and Point Sources

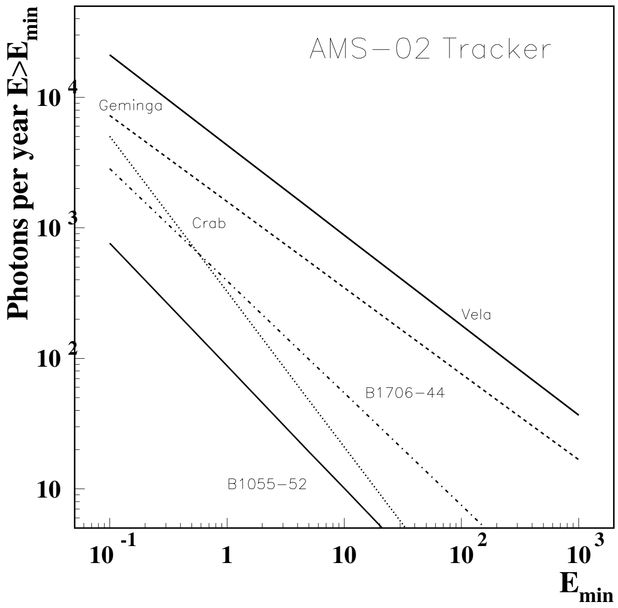
Signal estimate from known Galactic sources

LAPP-AMS, 2001

Calorimeter:



Tracker:



- Estimate based on accurate orbit and attitude model
- Rough estimate of reconstruction efficiency
- Sufficient rate for regular observation
- Long observation period
- Enlarged energy interval if no cut-off
- Complementary to satellite and ground based experiments

Extragalactic photon sources: AGN

- Black hole in the center, accretion disk
- Jets fuelled by accretion or rotation energy
- Acceleration of hadrons and/or leptons by shock wave
- High energy photon generation by synchrotron radiation and/or "inverse" Compton scattering
- When jet points toward Earth: blazar

Conclusions

- Astroparticle physics promises interesting insight into questions of cosmology, astrophysics and particle physics.
- Progress can come from synergy between different observational methods, using detectors on Earth, on balloons, in space.
- Progress can come from synergy between different messenger particles, cosmic rays, photons and neutrinos.

- 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.
- A rich and diversified physics program will result from the three year of data taking.