AMS
A magnetic spectrometer on the International Space Station

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Outline

- Physics motivations

  Antimatter, Dark Matter, Astrophysics

- Detector requirements
- Overview of the AMS Spectrometer
- Physics prospects

  Antimatter, Dark Matter searches and Astrophysics

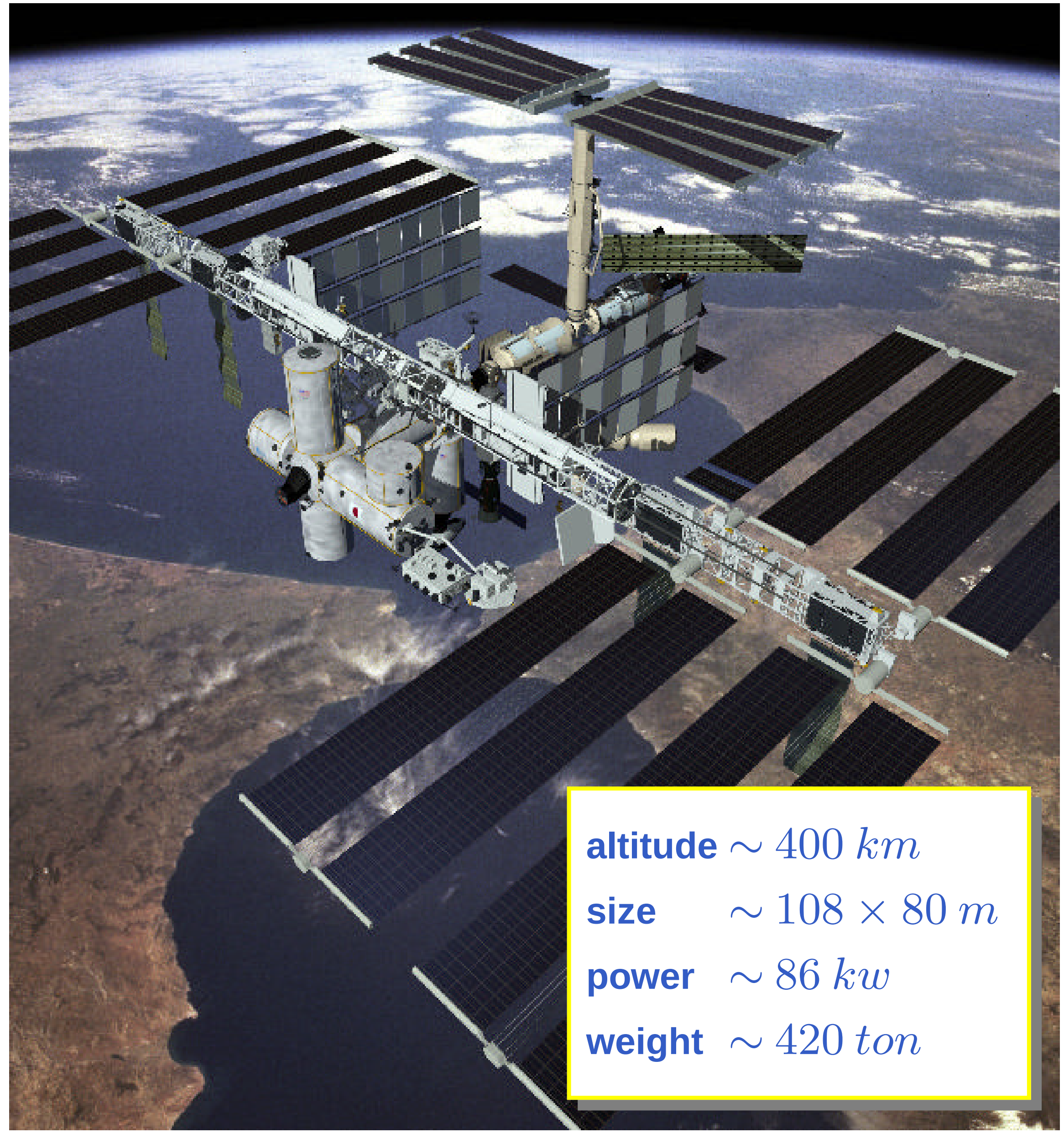
- Conclusions

AMS on the International Space Station

AMS is a precision magnetic spectrometer scheduled to be installed in the International Space Station (ISS) by 2006, for three years.

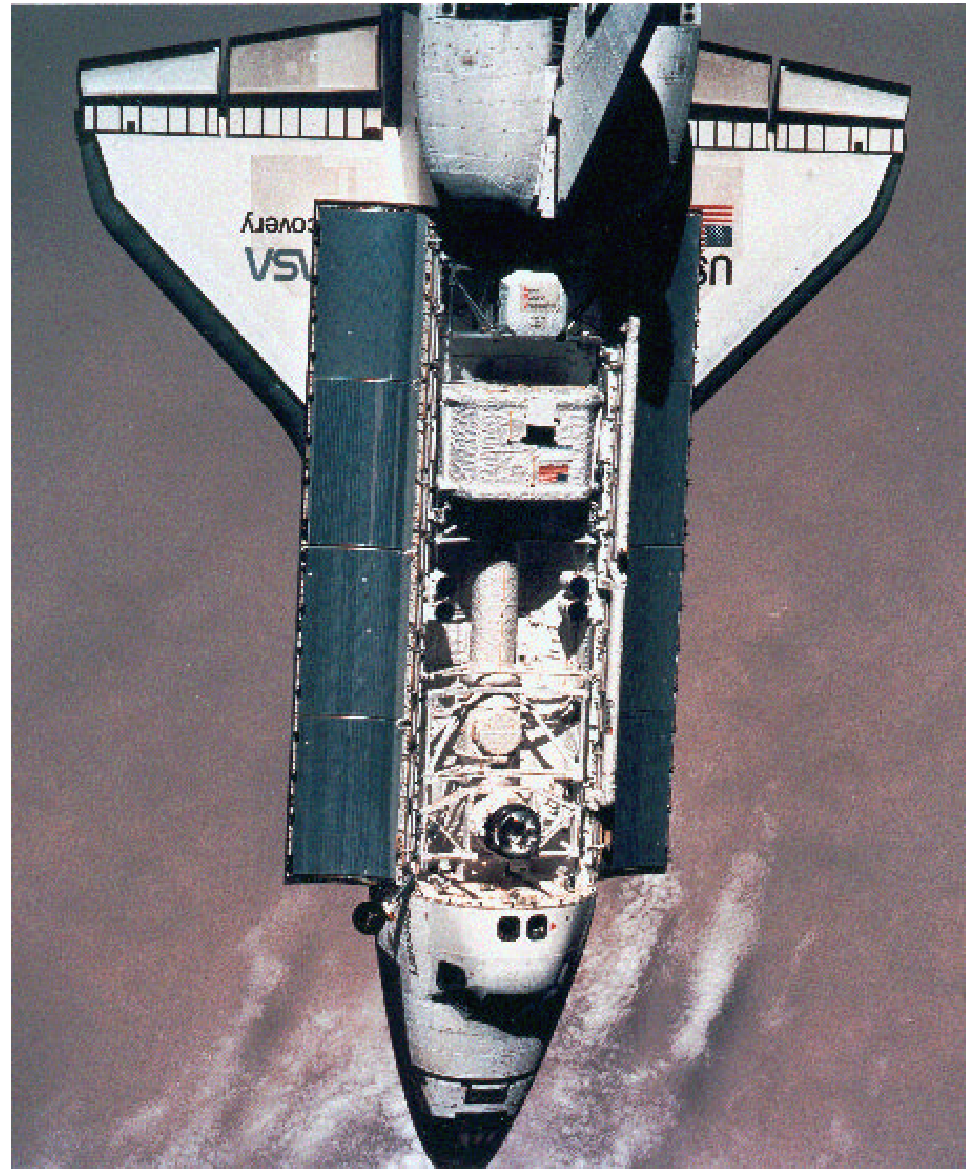
physics issues

- ▷ Search for Cosmic *Anti-matter*
- ▷ Search for *Dark Matter*
- ▷ Precision measurements on the relative abundance of different *nuclei* and *isotopes* of primary cosmic rays
- ▷ *gamma ray* astrophysics

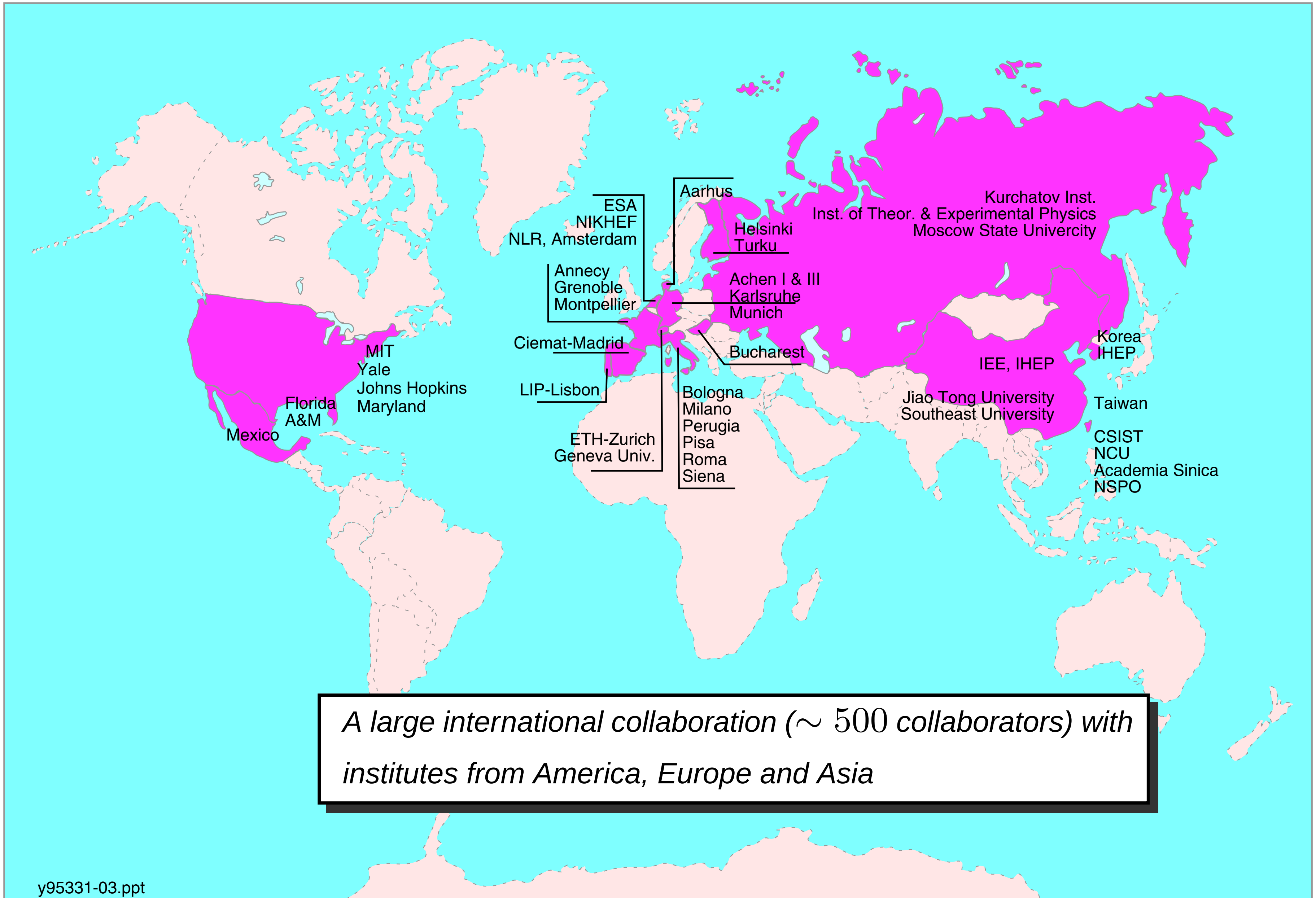


STS-91 shuttle experimental flight

- 2-11 June, 1998
  10 days flight on Shuttle Discovery
- about 100 hours of data taking
  100 million events
- very interesting physics results
  - measurement of primary fluxes
    p, He, $e^{\pm}$ ...
  - detection of secondary fluxes
    geomagnetic field effect
  - antimatter sensitivity extended
    $\overline{He}/He \sim 10^{-6}$



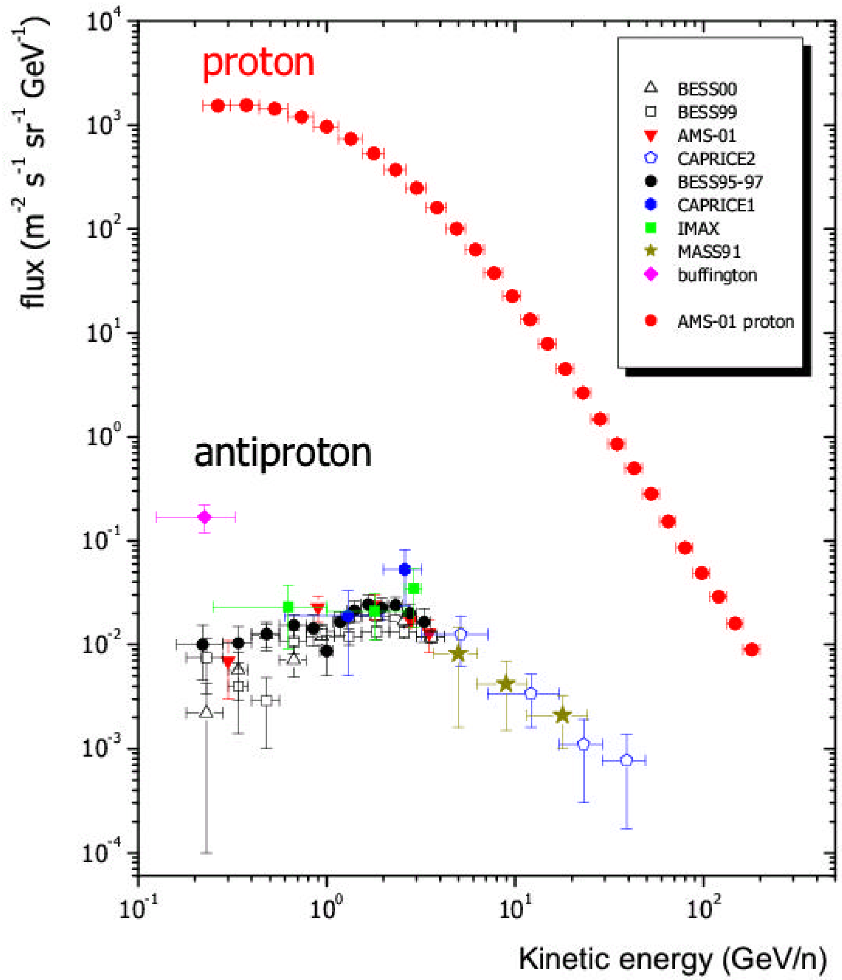
AMS Collaboration



A large international collaboration (~ 500 collaborators) with institutes from America, Europe and Asia

Antimatter Quest

- At the Big Bang equal amounts of matter and antimatter produced
- What is nowadays observed ?
  - **low antiparticle fluxes**
    essentially explained by secondary production
  - **baryon-photon ratio** $\frac{N_B}{N_\gamma} \sim 10^{-10}$
    BBN prediction : $\frac{N_B}{N_\gamma} \sim 10^{-19}$ *!*



Baryogenesis mechanism ? ? ?
CP Violation
Baryon number violation

$$\frac{\Phi_{\bar{p}}}{\Phi_p} \sim 10^{-4} - 10^{-5}$$

DarkMatter Quest

Evidence for the existence of a large quantity of non-baryonic darkmatter

- Rotation galactic curves indicate the presence of non-luminous galactic halos
- Universe matter content is $\sim 5\times$ larger than the baryonic matter BBN prediction
  $\Omega_m \sim 0.3 \quad (BBN: \;\; \Omega_b \sim 0.05)$

- Weakly Interacting Massive Particles (WIMP's)
- SUSY has a good candidate
  Lightest Supersimmetric Particle (LSP) - neutralino (χ)
  $\chi\chi \rightarrow f\bar{f},\; W^-W^+,\; ZZ,\; Z\gamma,\; \gamma\gamma$
- physics signatures
  anomalies on $e^+,\; \bar{p},\; \gamma, \bar{d}$ spectra

Astrophysics motivations

▷ *Secondary nuclei*

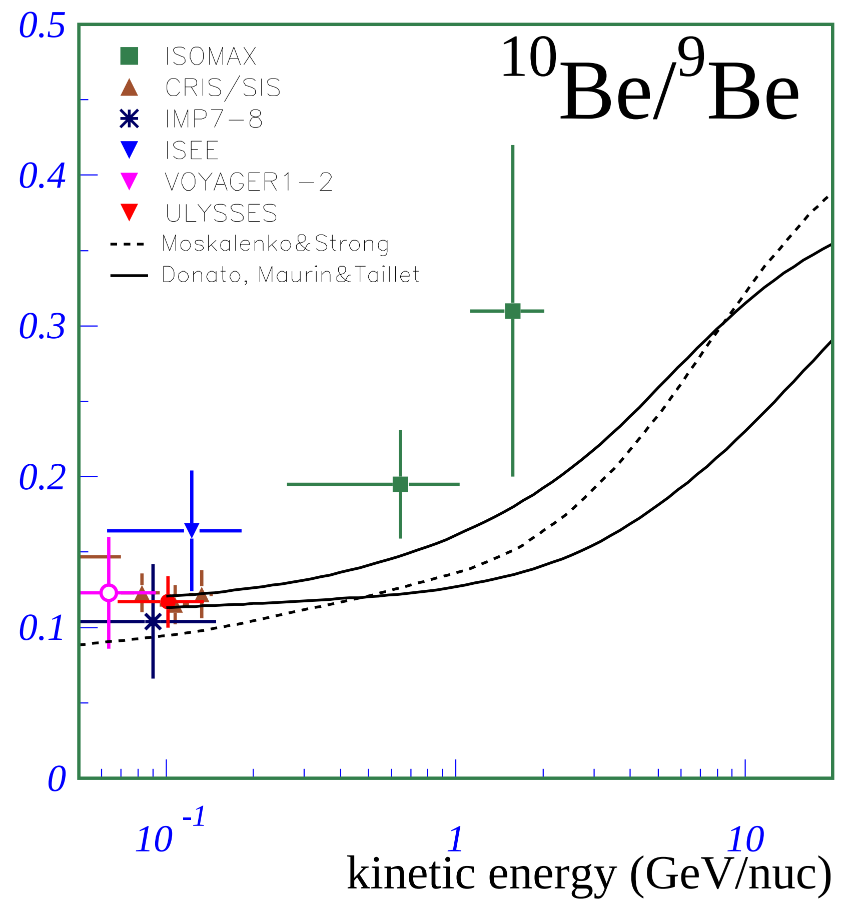
CNO spallation $\longrightarrow$ Li, Be, B

information about propagation of cosmic-rays in the galaxy

▷ *Cosmic Rays Clocks*

radioactive secondary nuclei produced ($^{10}Be_{T1/2} \sim 1.5 \times 10^6\ yrs$)

$^{10}Be/^9Be$ provides information about confinement of cosmic rays



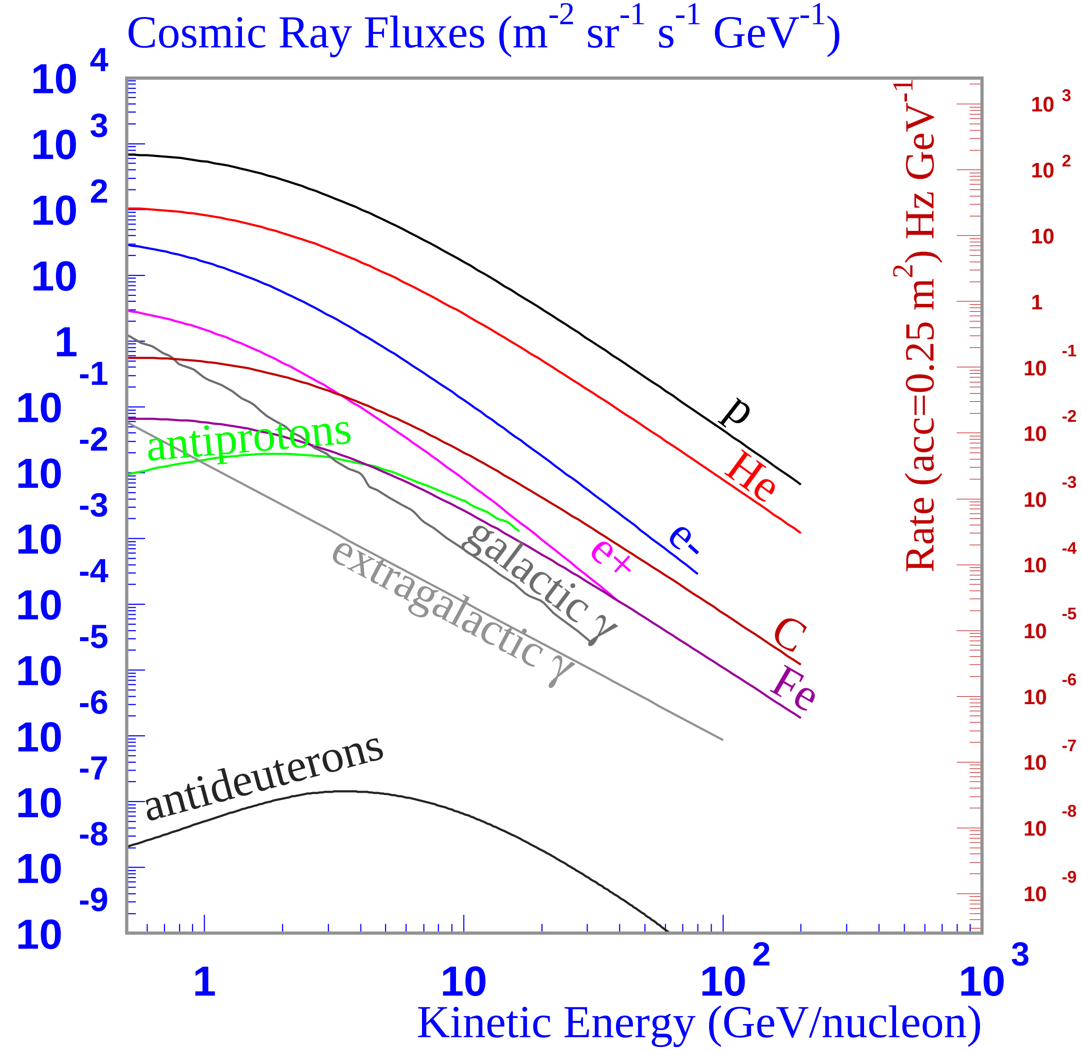
Improvement of current isotopic measurements needed !

- done at relatively low energies
- based on low event statistics

Cosmic Rays Fluxes

- Spectra modulated at low energy
  solar wind effect
- Event rates depend on the geo-magnetic lattitude
  geomagnetic cutoff effect
- AMS maximal rate expected
  $\sim 2\ KHz$

protons	~ 1
heliums	$\sim 10^{-1}$
electrons	$\sim 10^{-2}$
positrons	$\sim 10^{-3}$
carbon	$\sim 10^{-4}$
iron	$\sim 10^{-5}$



Detector Requirements

Antimatter

antinuclei production from matter collisions is strongly suppressed
$(p + ISM \rightarrow \bar{N} + \ldots)$

$\frac{\bar{N}}{\bar{p}} \propto \exp\left(-\frac{M_N - m_p}{80\ MeV}\right)$

detection of antinuclei would be a clear signal of existence of antimatter

DarkMatter

signals : $\bar{p}$, e^+, γ, $\bar{d}$

- e^+ and $\bar{p}$ produced in $p + ISM$ collisions
- physics background :
$p/e^+ \sim 10^3$
$e^-/\bar{p} \sim 10^2$

a good e,p separation is needed
$B/S \sim 1\% \Downarrow$
Rejection Factor $\sim 10^5$

Astrophysics

detection of a large range of nuclei (Z)

ability to identify different isotopes

detection of gamma rays

- charge identification
- rigidity measurement
- velocity measurement
- e.m energy measurement
- e/p separation
- albedo rejection
- strong system redundancy

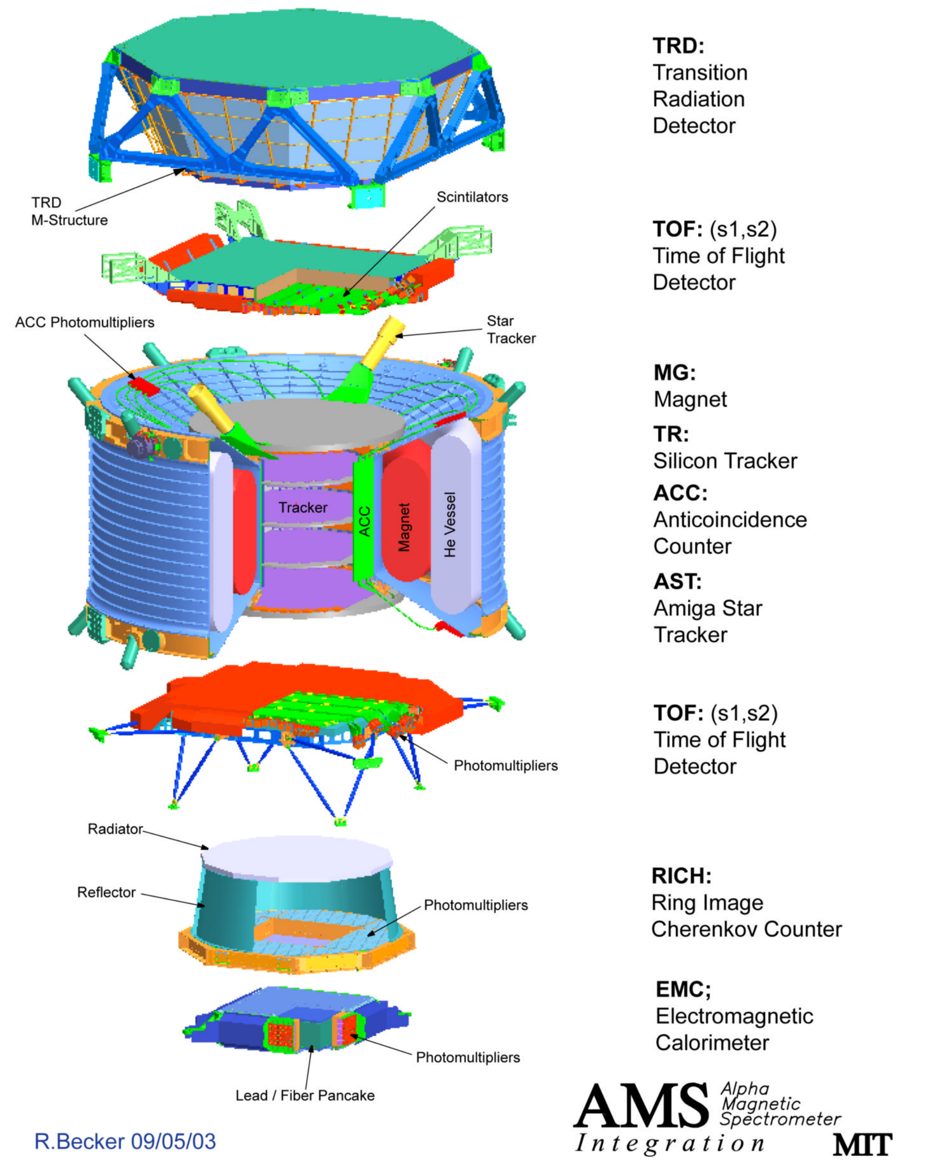
From AMS1 to AMS2

Improved capabilities

- ▷ larger acceptance
  $\sim 0.5\ m^2.sr$
- ▷ Superconducting magnet
  a magnetic field ~ 8 times larger
- ▷ larger silicon Tracker
  8 double-sided layers
  $\sim 6.5\ m^2$ silicon surface
- ▷ a momentum resolution improved by a factor ~ 10

New Detector systems

- ▷ New Cerenkov Detector (RICH)
- ▷ Electromagnetic Calorimeter (ECAL)
- ▷ Transition Radiation Detector (TRD)



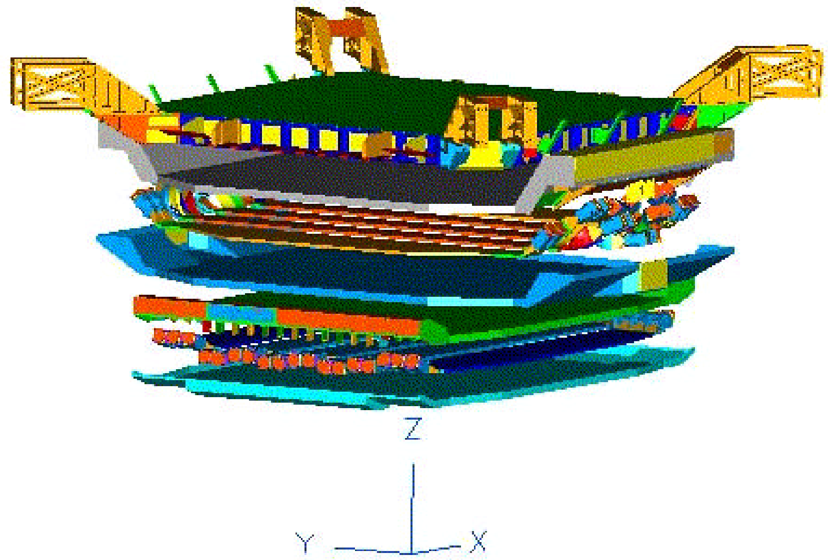
Time-of-Flight (TOF)

Construction

- ▷ 4 scintillator planes
- ▷ a total of 34 paddles large of 12 cm
- ▷ light guides twisted/bended to minimize magnetic field effects
- ▷ $2/3$ PMT's for light readout at both ends

It provides

- ▷ fast trigger (3×4) on $200\ nsec$
- ▷ velocity measurement
- ▷ absolute charge measurement
- ▷ upward/dowward particle separation (10^{-9})



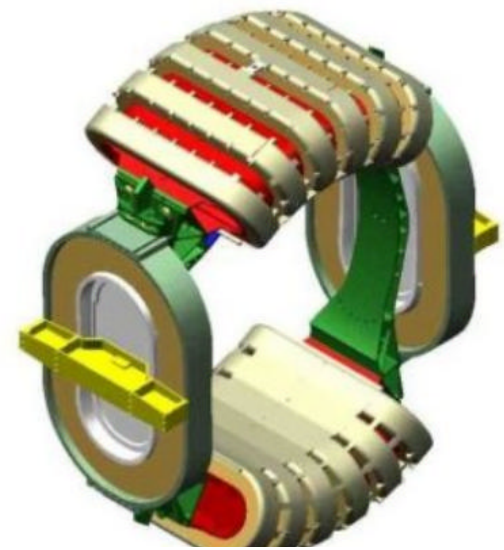
Superconducting Magnet

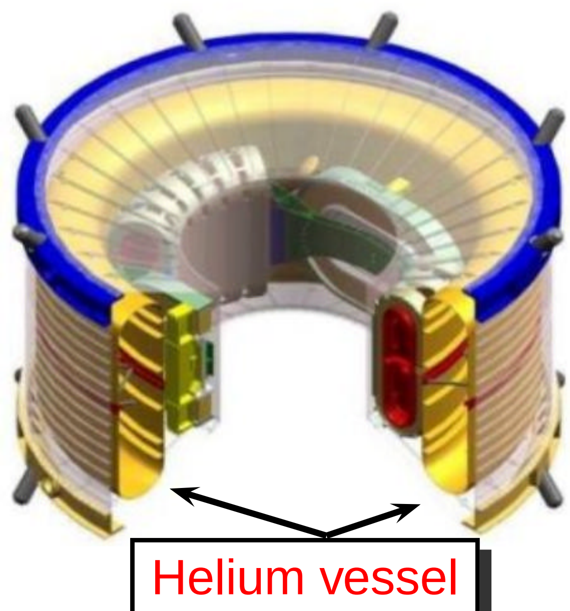
Construction

- ▷ 14 superconducting coils
- ▷ geometrical configuration to ensure a null magnetic dipole moment
- ▷ minimization of the stray field outside magnet
- ▷ indirect cooling system based on Superfluid Helium
  - ► cold mass : $2000\ kg$
  - ► helium vessel capacity : 2500 liters

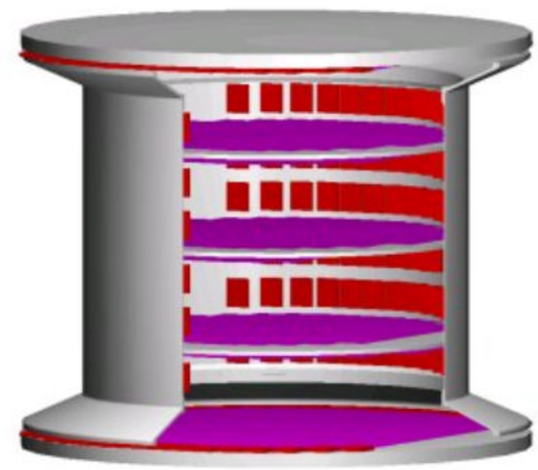
It provides

- ▷ an intense magnetic field : $\sim 0.9\ T$
- ▷ a large bending power : $\sim 0.8\ T.m^2$



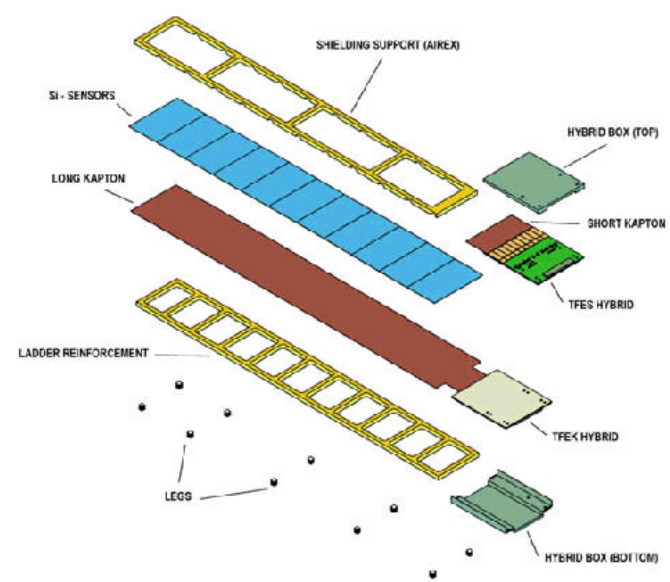


Silicon Tracker



Construction

- ▷ a total of 5 *planes* (3 inside the magnet and 2 outside)
- ▷ 8 *layers* of double-sided silicon microstrip sensors
- ▷ a total of ~ 2500 *sensors* arranged on 192 *ladders*
- ▷ $7-15$ sensors per ladder



It provides

- ▷ 8 independent position measurements of the particle track
- ▷ particle rigidity ($R \equiv \frac{pc}{Z}$) from track reconstruction
- ▷ electric charge (Z) from energy deposition (dE/dx)

Transition Radiation Detector (TRD)

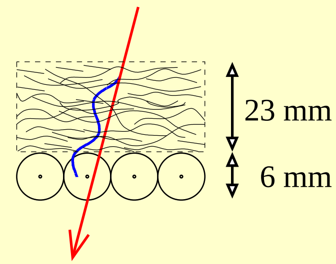
Construction

- ▷ *modules* (328) made of fleece radiator and straw tubes
  - 16 straw tubes per module
  - radiator thickness of $23\ mm$
  - straw tubes ($\Phi = 6\ mm$) filled with Xe/CO_2
- ▷ 20 *layers* assembled on a octogonal shape
  - 4 layers on upper/lower part along the bending plane
  - 12 layers on the middle transversally placed

It provides

- ▷ evaluation of the particle $\gamma \equiv \frac{E}{m}$ boost
- ▷ separation of particles with extreme mass differences

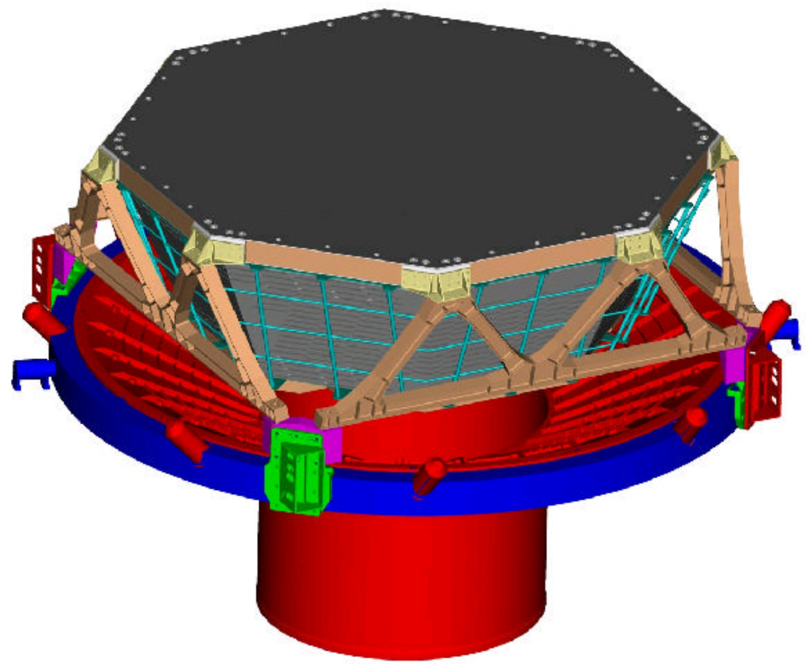
Principles



X-ray photons radiated when particle crosses radiator boundaries

- $E_\gamma \sim \gamma\,(eV)$
- $N_\gamma \sim \alpha\, N_{transitions}$ $\sim 100\ transitions$

detectable signal for $\gamma \gtrsim 1000$



(See Poster PA-24)

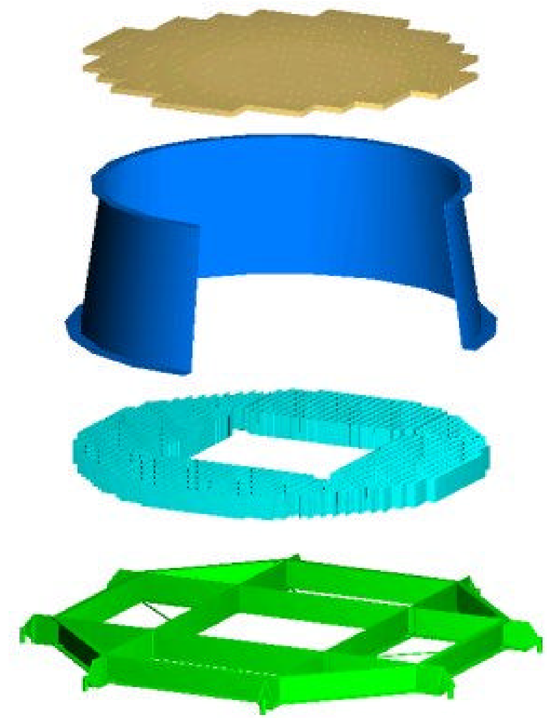
Ring Imaging Cerenkov Detector (RICH)

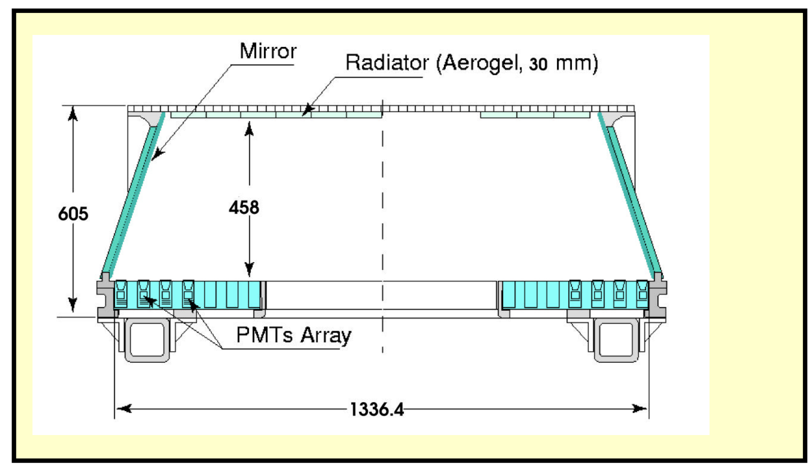
Construction

- ▷ proximity focusing Ring Imaging Detector
- ▷ dual solid radiator configuration
  low index aerogel ($n \sim 1.03$, $3\ cm$ thickness)
  sodium fluoride ($n \sim 1.33$, $0.5\ cm$ thickness)
- ▷ conical reflector
- ▷ photomultiplier matrix
  680 multipixelized (4×4) detectors
- ▷ spatial pixel granularity : $8.5 \times 8.5\ mm^2$

It provides

- ▷ accurate particle velocity measurement
  $\Delta\beta/\beta \sim 0.1\%$ for protons
- ▷ electric charge determination
  $\Delta Z \sim 20\%$
- ▷ albedo rejection
  directional sensitivity

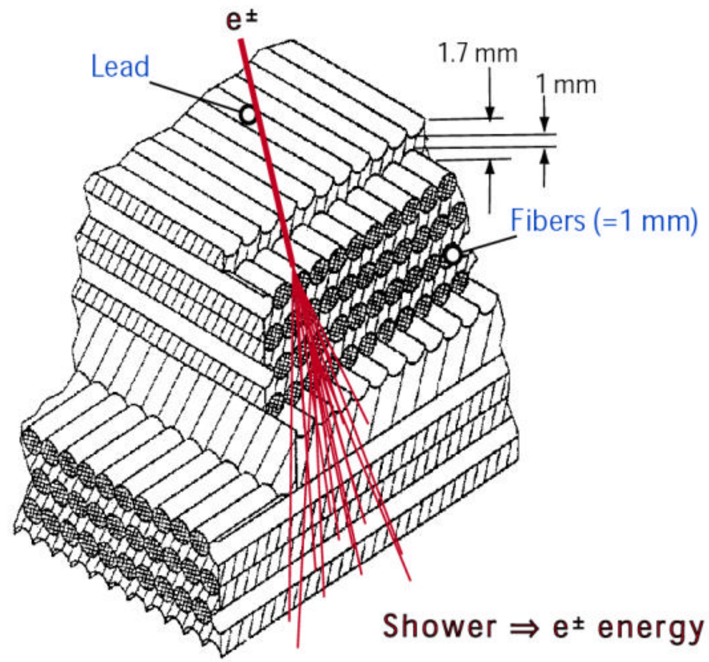




Electromagnetic Calorimeter (ECAL)

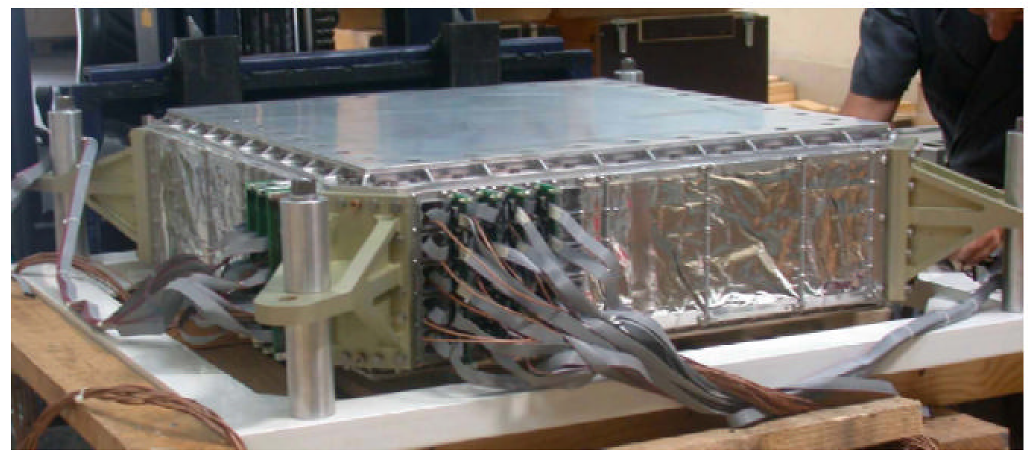
Construction

- ▷ sampling e.m. calorimeter
  $658 \times 658 \times 166\ mm^3$
- ▷ lead-scintillating fibers structure
- ▷ 9 superlayers piled up
  disposed along X and Y alternately
- ▷ $\sim 17 X_0$ radiation lengths
- ▷ cell granularity $\sim 0.5\ R_M$ (35 fibers)
  18 samplings of e.m. shower
- ▷ multi-pixel (2×2) photomultiplier's
  large dynamic range

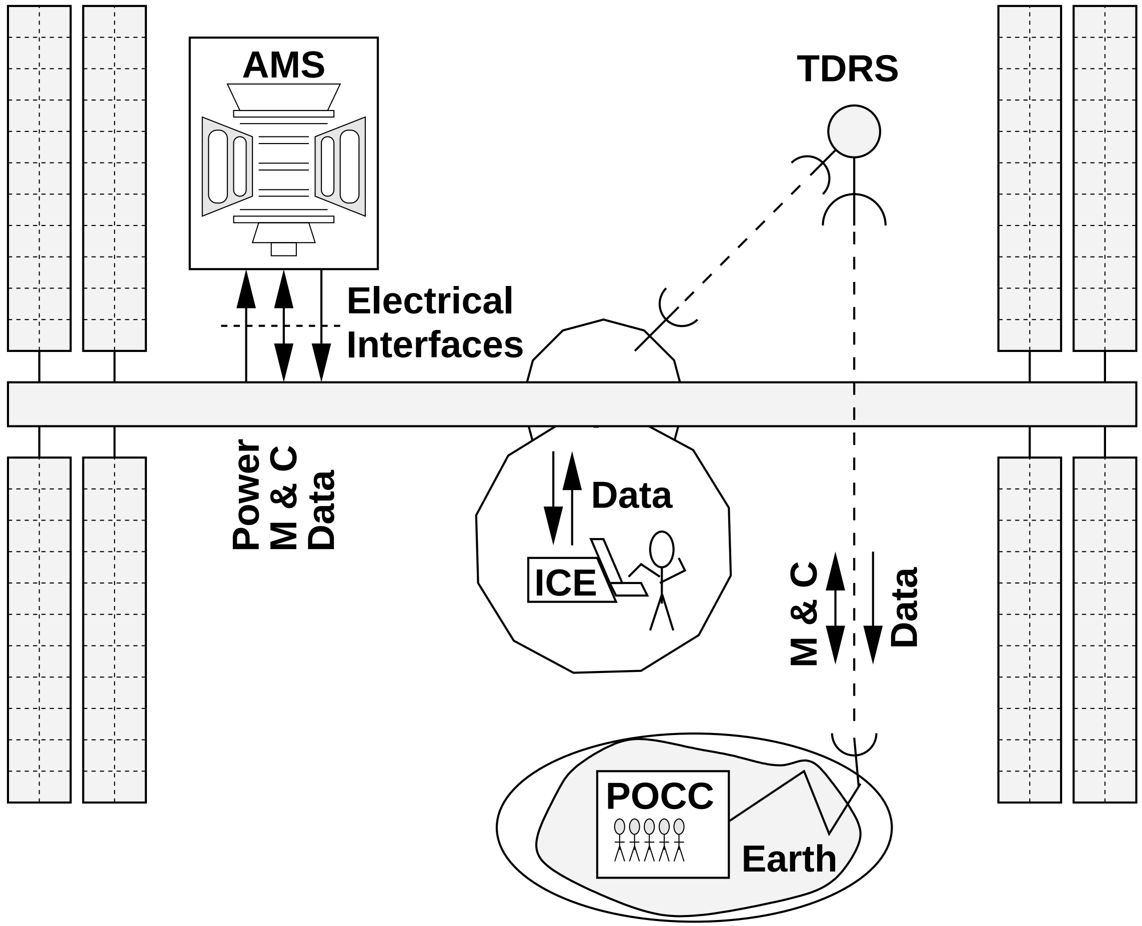


It provides

- ▷ $e^{\pm}, \gamma$ energy measurement
- ▷ particle direction
- ▷ trigger signal for photons tagging (dynode)



AMS Data Transfer to Earth



- *Data backup on ISS and transfered to earth :* $2\ Mbit/s$
- *Payload Operation Center and Scientific Operation Center at Cern*

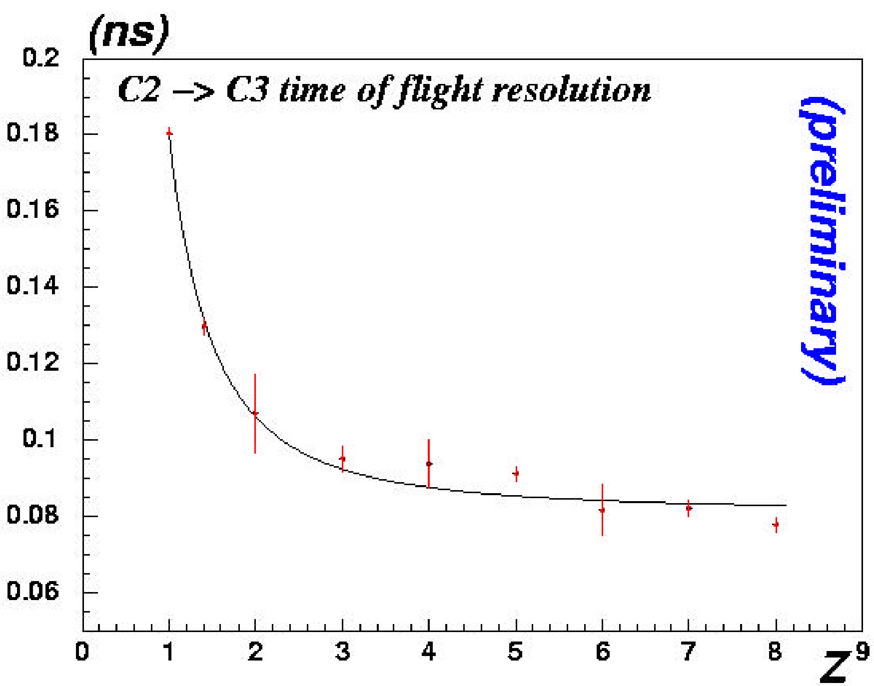
Velocity measurement (β)

TOF

- $\beta = \frac{\Delta L}{\Delta t}$

Test Beam with In ions fragment

$\sigma_t \sim 110\, psec \;\; (Z = 2)$

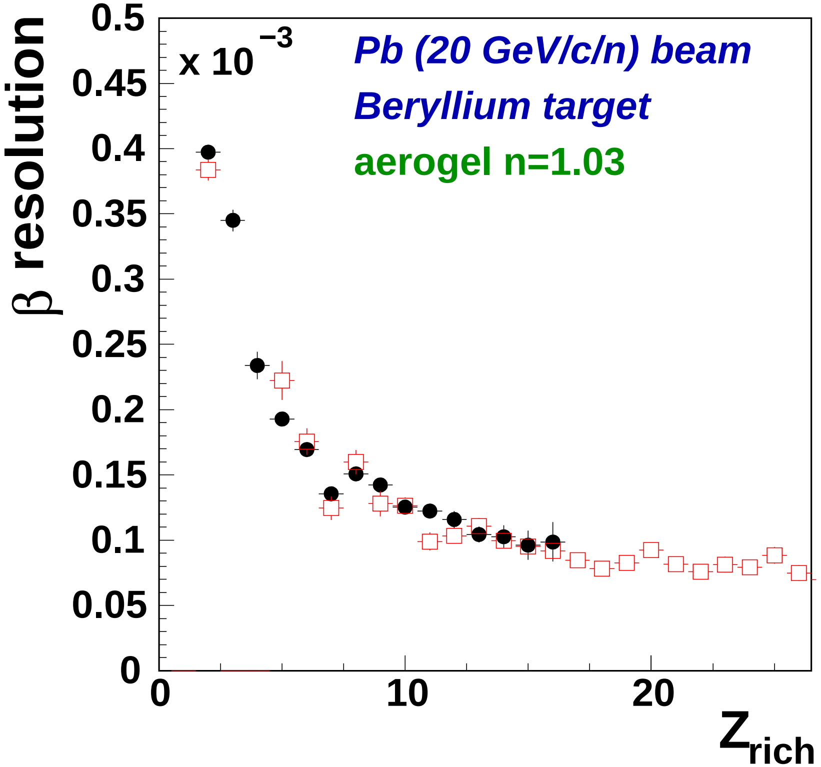


RICH

- $\beta = 1/cos\theta_c n$
- $\delta\beta/\beta \sim 0.1\% \;\; (z = 1)$

A prototype (96 PMT's) was tested

$\delta\beta/\beta \sim 0.07\% \;\; (z = 1)$



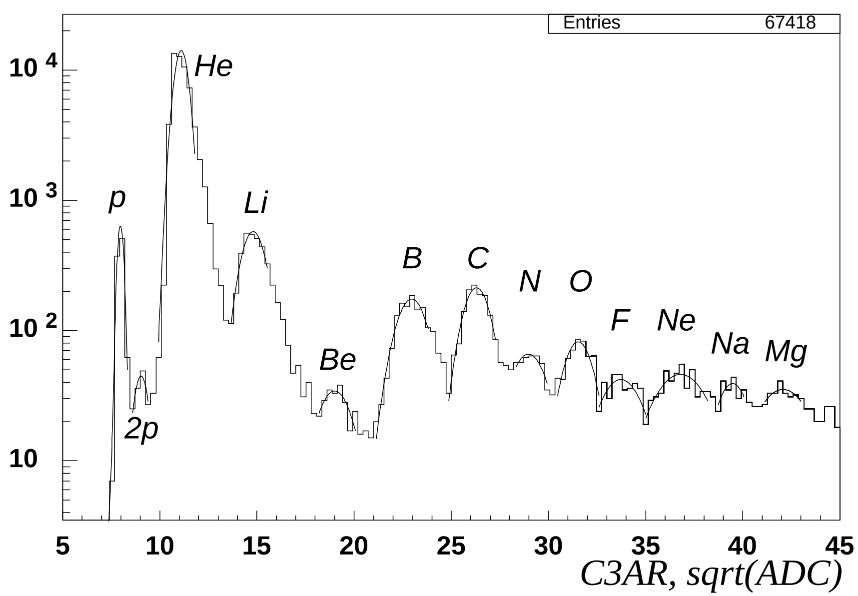
Charge measurement (Z)

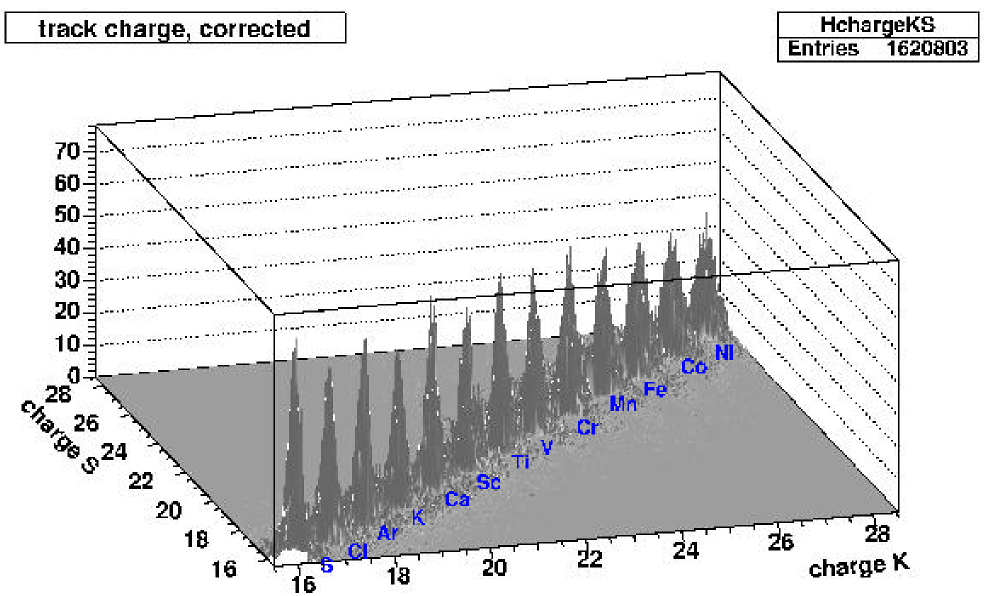
TOF

- $4\ dE/dx$ samplings
- Test beam data : In ions fragmented
- Charge separation on a scintil bar up to $Z \sim 12$

TRACKER

- $16\ dE/dx$ samplings
- Test beam data : Pb ions fragmented
- Charge separation for a 6-ladders setup up to $Z \sim 28$

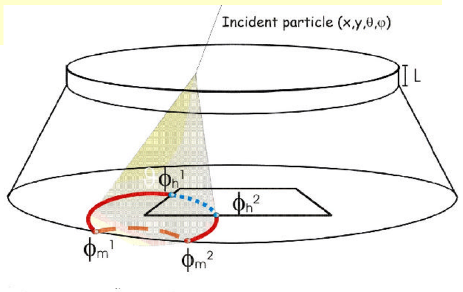


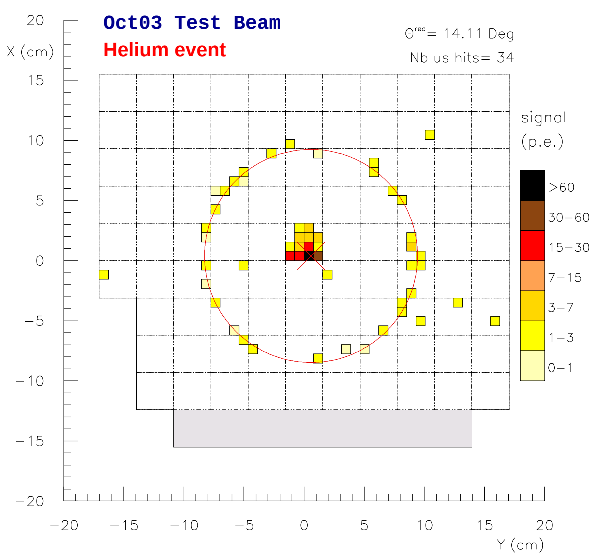


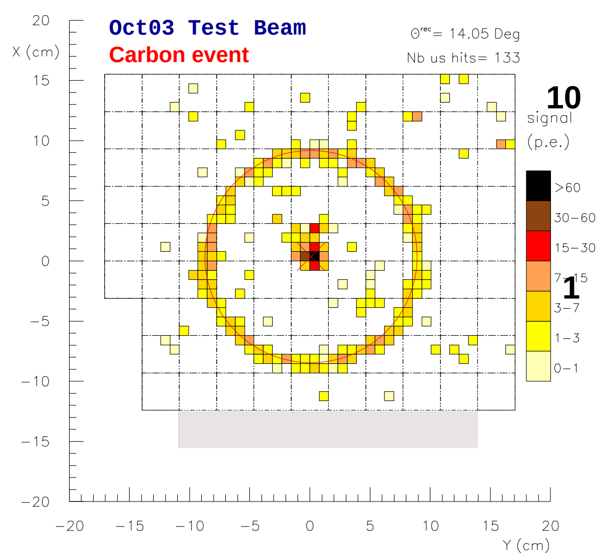
Charge measurement with the RICH

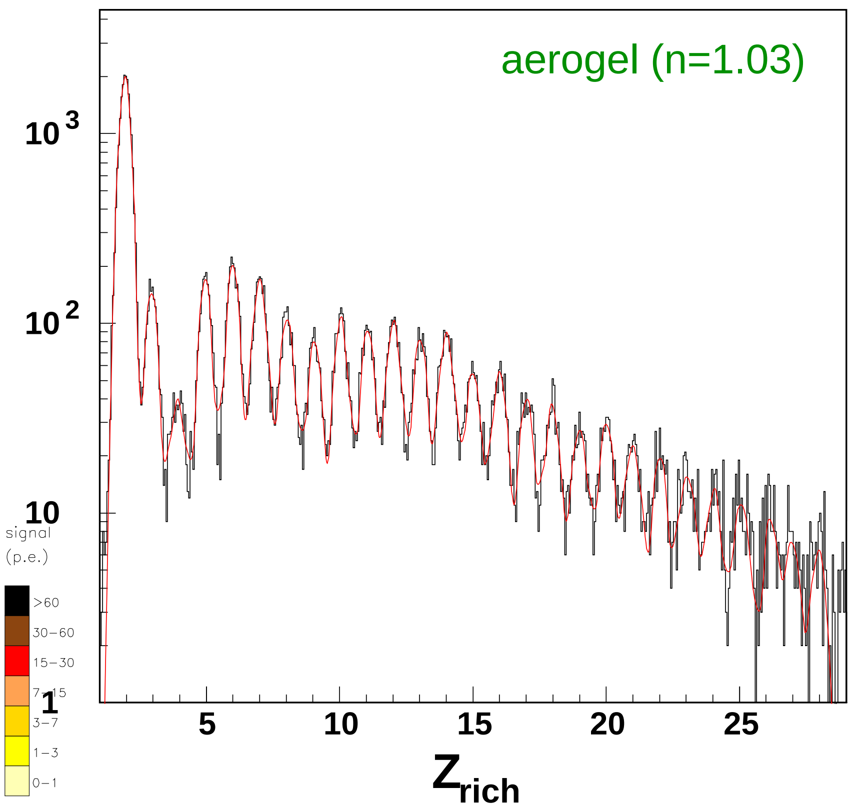
- ▷ $N_\gamma \propto Z^2 sin^2\theta_c \Delta L$
- ▷ *Count signal associated to reconstructed photon ring*
- ▷ *Correct for photon detection efficiency*

- ▷ *RICH Prototype test with data* $Pb\ (20\ GeV/c/n)$ fragmented ions
- ▷ *Charge separation up to* $Z \sim 30$



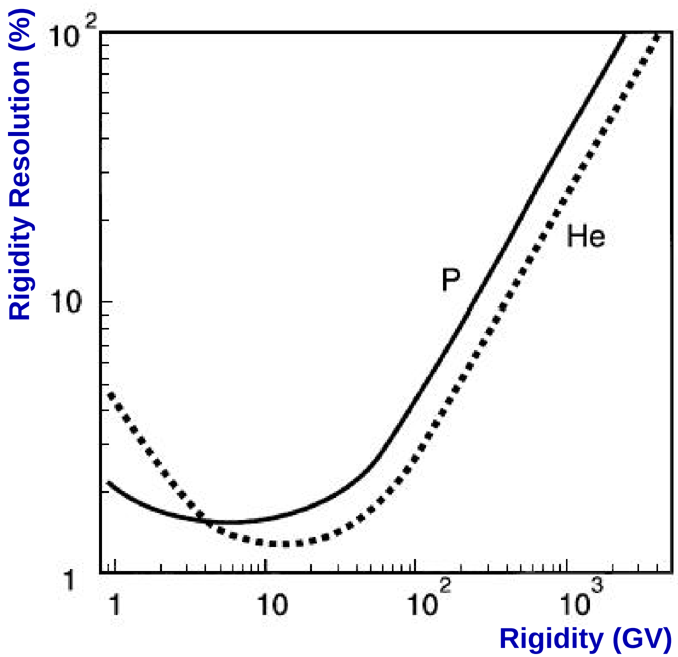






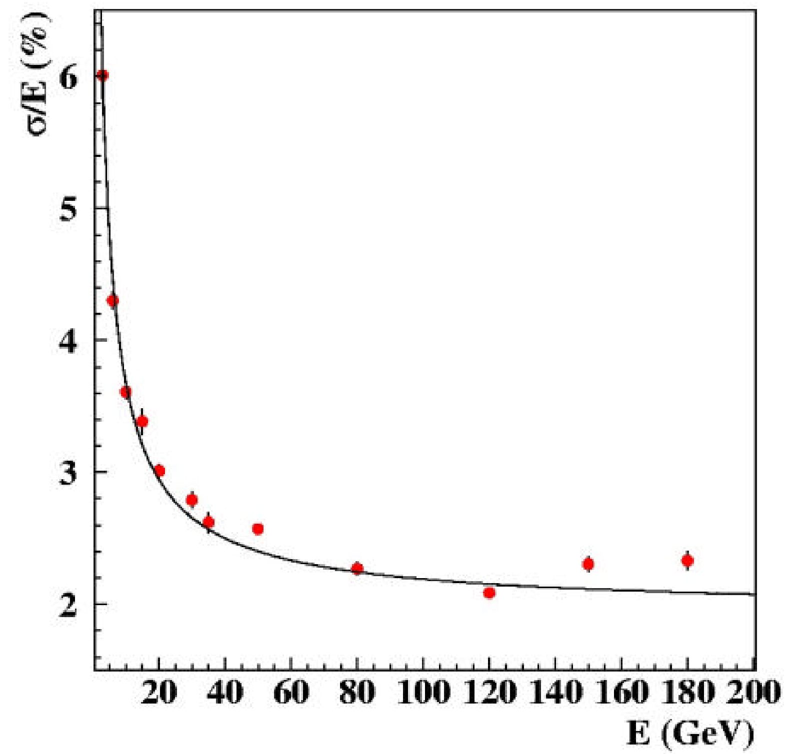
Energy and Rigidity measurements

- **Rigidity ($R = pc/Z$)**
  - ▷ 8 *hits measured*
  - ▷ *spatial resolution*
    $10\ \mu m$ on bending plane
    $30\ \mu m$ on non-bending plane
  - ▷ *expected resolution*
    MDR $\sim\ 3\ TV$



- **E.m. energy**
  - ▷ *energy resolution measured on test beam*

$$\frac{\Delta E}{E} \simeq \frac{10.6\ \%}{\sqrt{E}} \oplus 2.6\ \%$$



positron (e^+) detection

- *detection of positron signal*

  proton and electron background

  $\Phi_p/\Phi_{e+} \sim 10^3$

  $\Phi_{e-}/\Phi_{e+} \sim 10$

- e-p separation with TRD

  test beam data

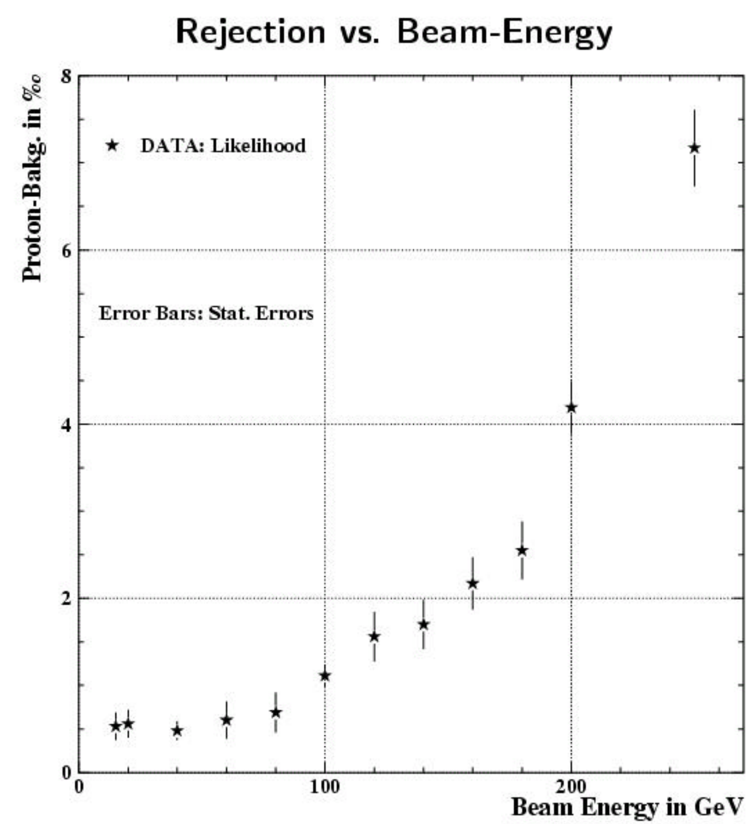
- proton rejection factor $\gtrsim 200$

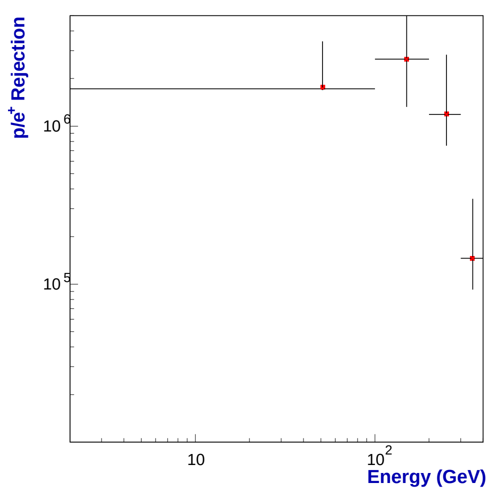
  $(p < 200\ Gev/c)$

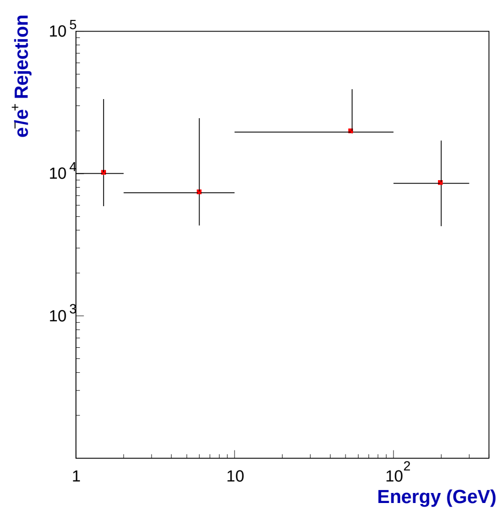
  $\sim 90\ \%$ electron selection ε

Different detectors can contribute

TRD, TRACKER, RICH, ECAL





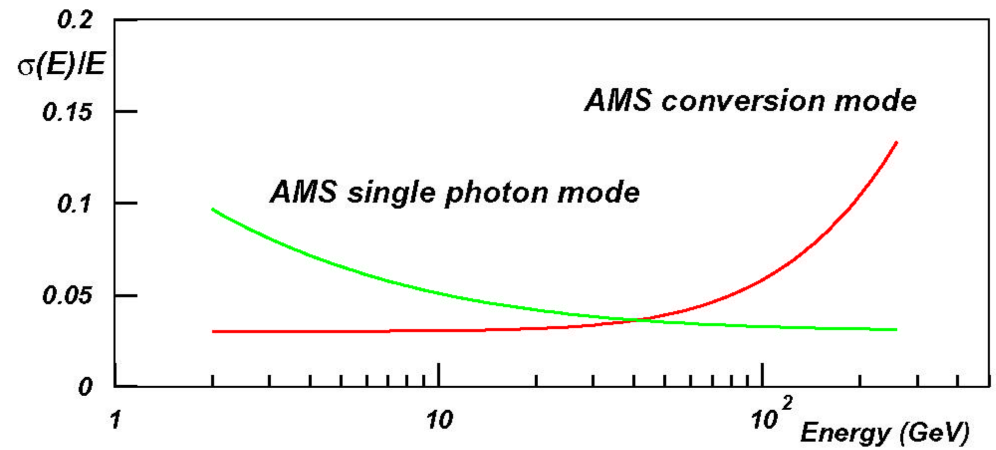


photon detection

Converted photon $\gamma \to e^- e^+$

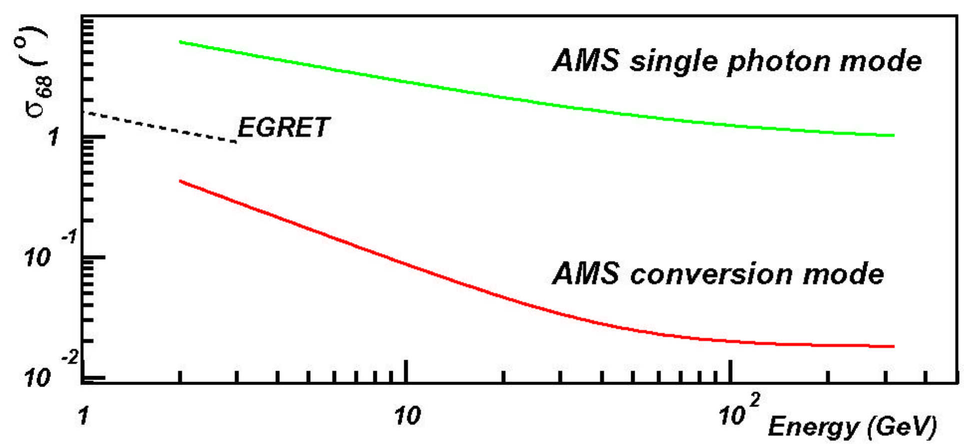
- some matter before the 1st TOF layer
  $\ell \sim 0.25\ X_0$
  conversion probability $\sim 20\ \%$
- γ energy and direction reconstructed from charged pair
- energy range limited by double track reconstruction ($E \sim 200\ GeV$)
- large angular view ($\theta_{max} \sim 42^\circ$)

mean acceptance $(10 - 250 GeV)$
$\sim 0.05\ m^2.sr$



Non-converted photon

- direction of reconstructed photon inside fiducial region ($\theta_{max} \sim 22^\circ$)
- large rejection power against protons and electrons ($\sim 10^6$)
- large energy range ($8\ GeV - 10^3\ GeV$)

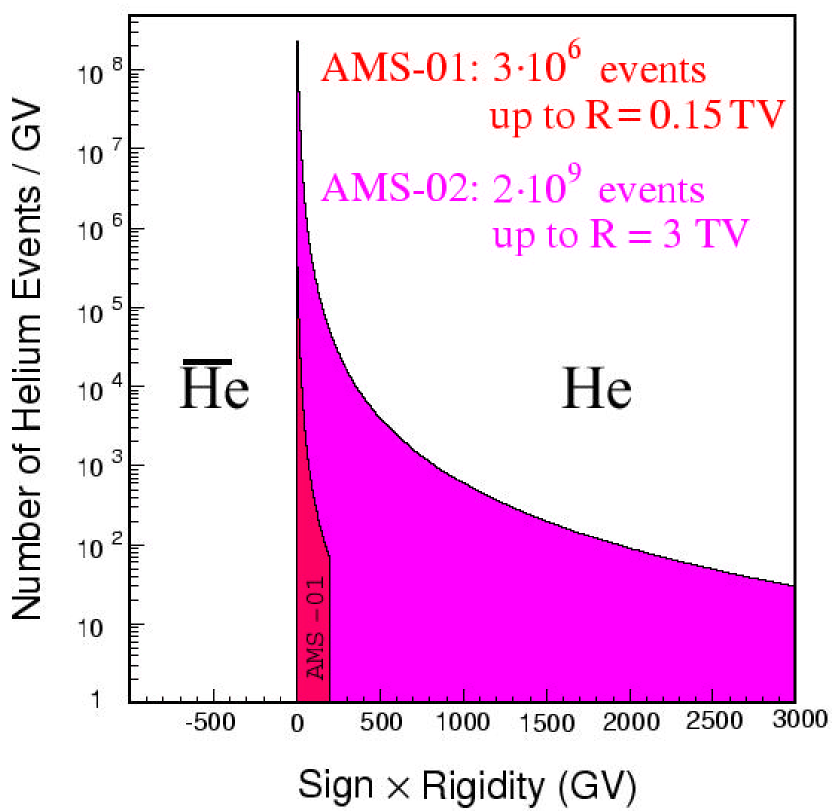


Physics Prospects with AMS2

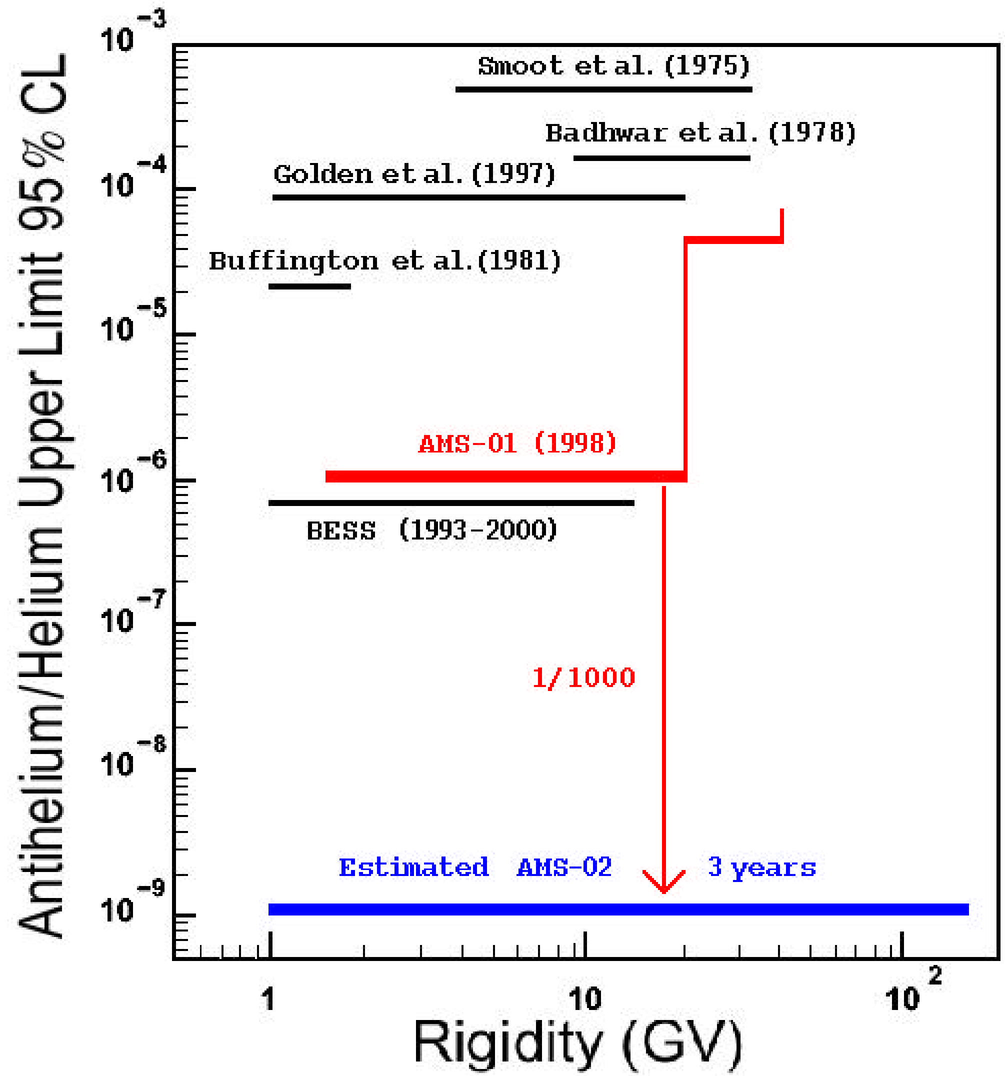
- **Antimatter Search**
- **Dark Matter Search**
- **Astrophysics Studies**

Antimatter Search with AMS2 - antihelium

- an expected efective statistics of more than 10^9 events
- a rigidity sensitivity improved ~ 8 times



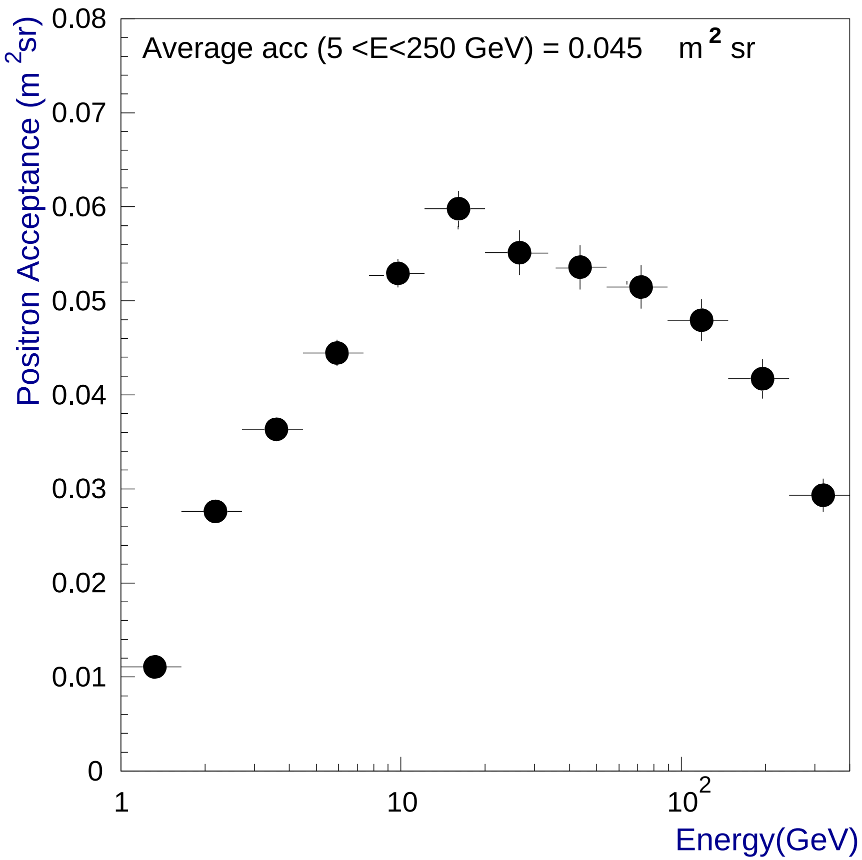
AMS expected limit with 3years data

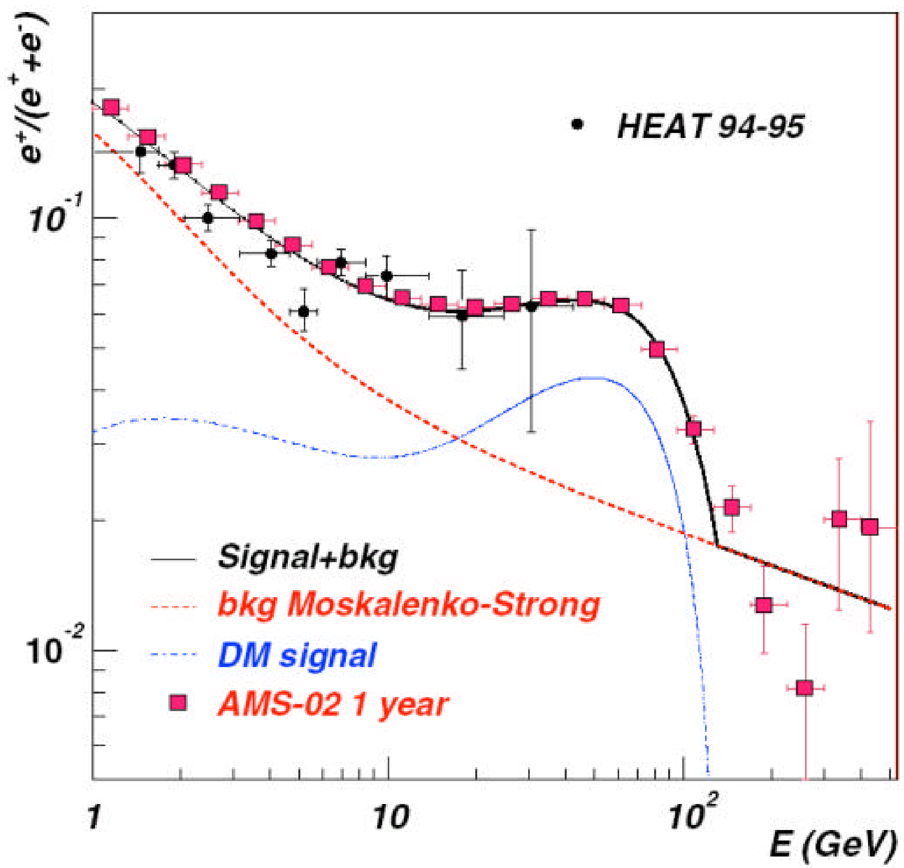


Darkmatter Search with AMS2 - positrons

- ▷ **energy range up to** $\sim 400 GeV$
- ▷ **geometrical acceptance** $\sim 0.04\ m^2.sr$

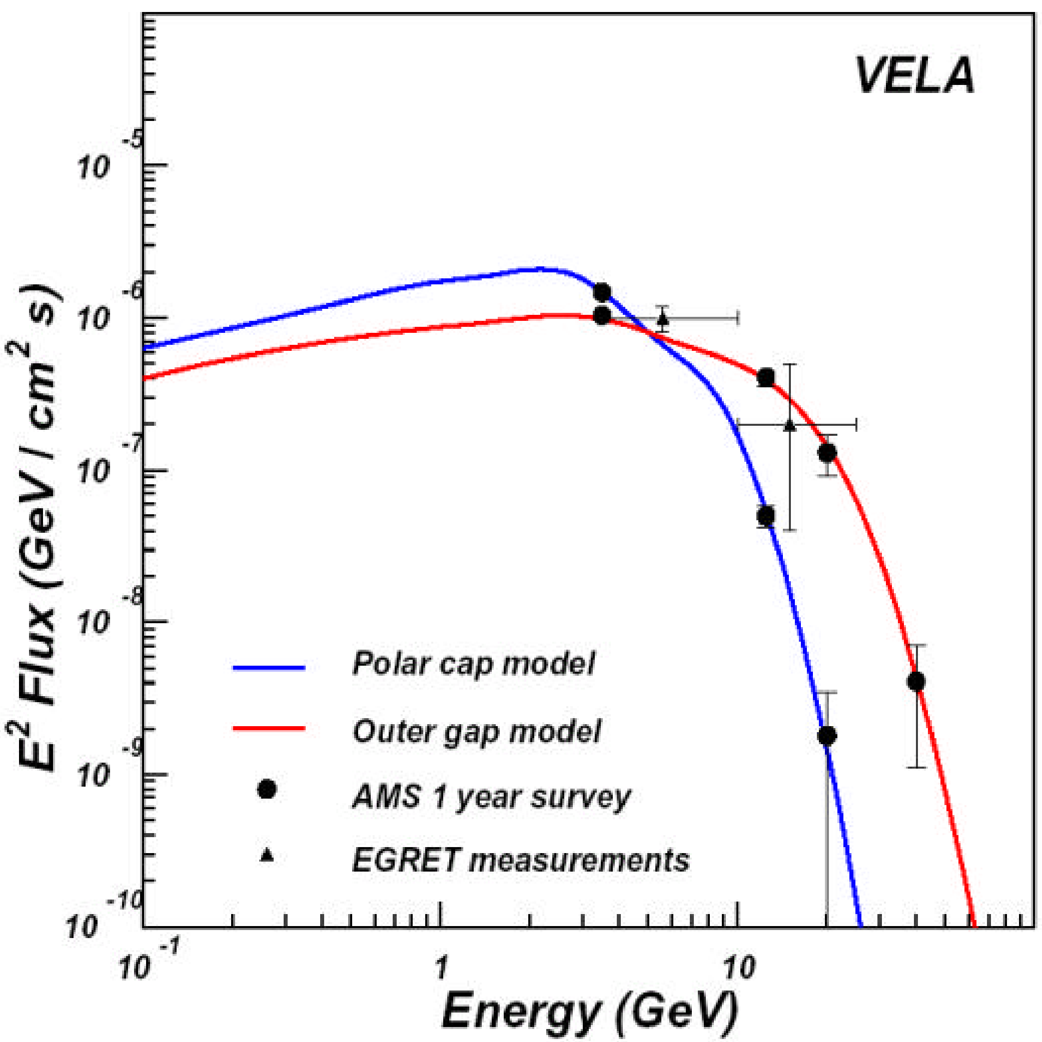
- ▷ **statistics : 1 year of data**
- ▷ **signal : neutralino** **(**$M = 336\ GeV/c^2$**) annihilation**





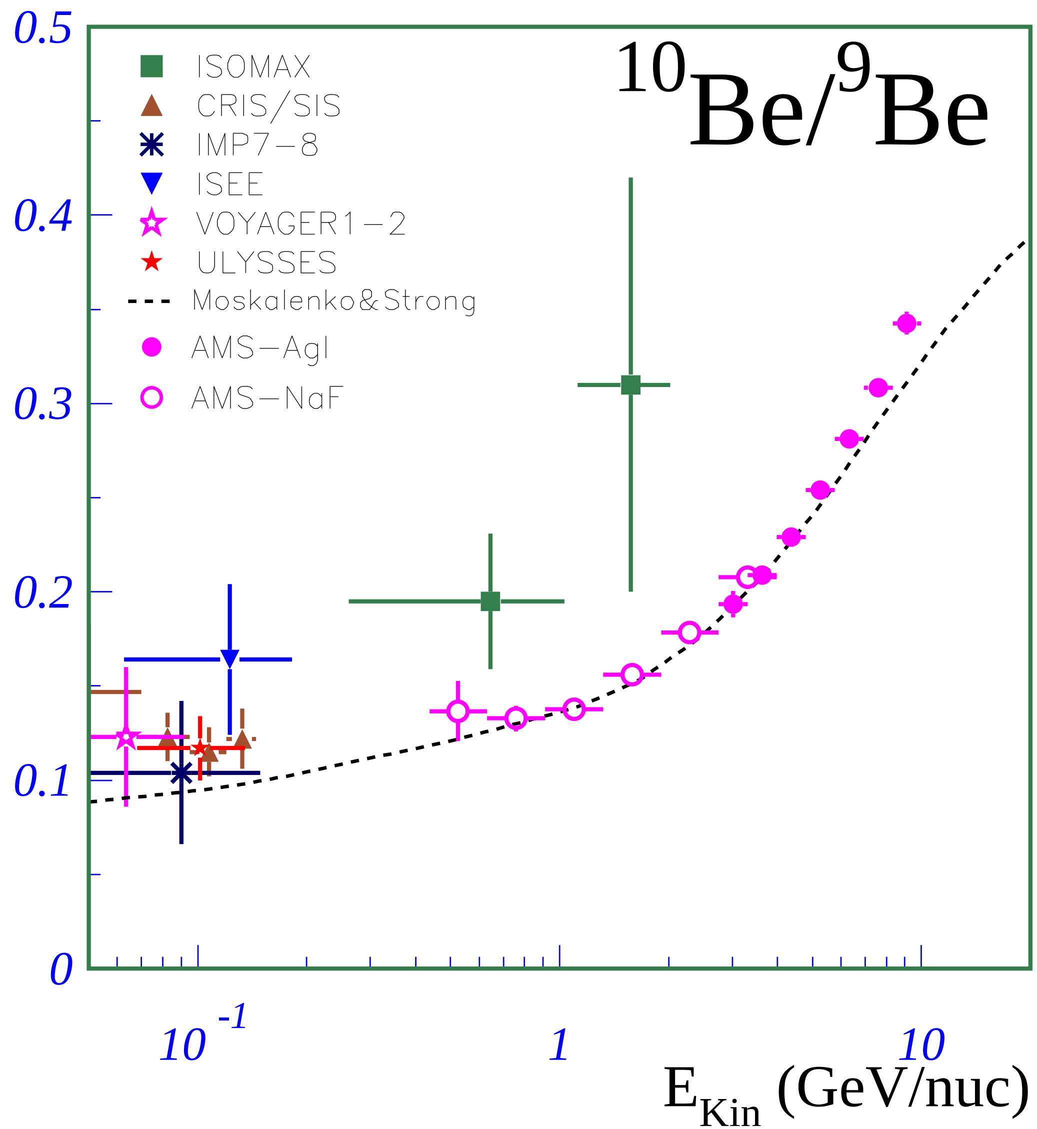
Astrophysics with AMS2 - gammas

- compare different γ-ray pulsar models
- energy spectrum sensitivity



Astrophysics with AMS2 - nuclei isotopes

1 **year of accumulated statistics simulated ($\sim 10^5$ events)**



Conclusions

- After a very successfull test flight aboard Space Shuttle Discovery on June 1998, the AMS detector capabilities were extended through the inclusion of new detector systems and a larger magnetic field
- The detector will be installed on the International Space Station on 2006 for three years
- The fundamental physics issues (antimatter, darkmatter) will be addressed
  - antimatter sensitivity of the order 10^{-9}
  - dark matter searches through different signatures ($e^+, \bar{p}, \gamma, \ ...$)
- Astrophysics measurements with unprecedent large statistics will be performed
  - charge identification up to Iron nuclei
  - isotopes separation up to $\sim 10GeV/n$

Mass separation