The AMS-02 Experiment on ISS

Search for Antimatter, Dark Matter, and High Energy Gamma Rays Observation

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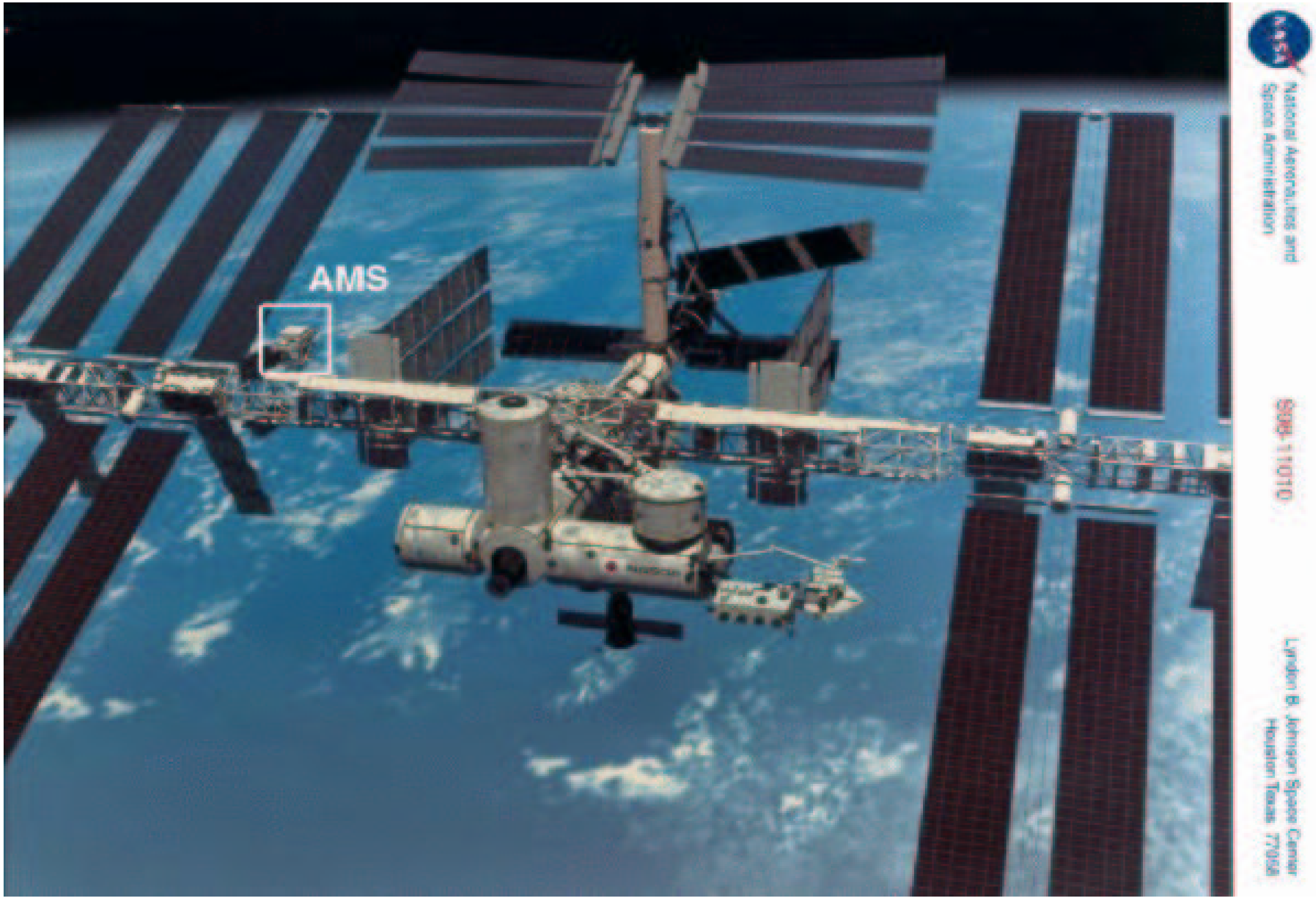
Outline:

- ISS and AMS-02
- Physics Goals
- The detector
- AMS-02 expected performances
- Conclusions

ISS and AMS-02



What is AMS ?

*A*lpha *M*agnetic *S*pectrometer

A large acceptance magnetic spectrometer on the ISS

Orbital parameters of ISS:

- → *Orbital period* $\sim 92min$
- → *Mean altitude* $\sim 382km$
- → *Inclination* $\sim 51.6^o$

Main physics topics:

- → *antimatter*
- → *dark matter*
- → *origin and transport of cosmic rays*
- → *Study of γ-rays from galactic and extragalactic sources*

Antimatter

- The Big Bang Theory requires *matter* and *antimatter* to be equally abundant at the very hot beginning.

- Antimatter within our cluster of galaxies is excluded by the absence of sharp annihilation photon peaks.

- Theories on the existence of antimatter in segregated domains or the total absence of antimatter are still highly speculative:
  - Single anti-He Cosmic Rays nucleus → Antimatter Domains
  - Single anti-C Cosmic Rays nucleus → Antimatter Stars

- To solve this problem further data are needed:
  - better understanding of CP-violation via B-factories (SLAC, KEK)
  - correct extension of the Standard Model (Tevatron, LHC)
  - improvement observation of the matter-antimatter balance in the Universe (AMS-02)

Dark Matter

- More than 90 % of the Universe is made of Dark Matter
- Theory suggests that Supersymmetric particles like the $\tilde{\chi}^0$ could be an important contributor to this dominant component.
- Annihilation of these particles in the galactic halo might produce a visible contribution to the anti-particle and photon spectra via:

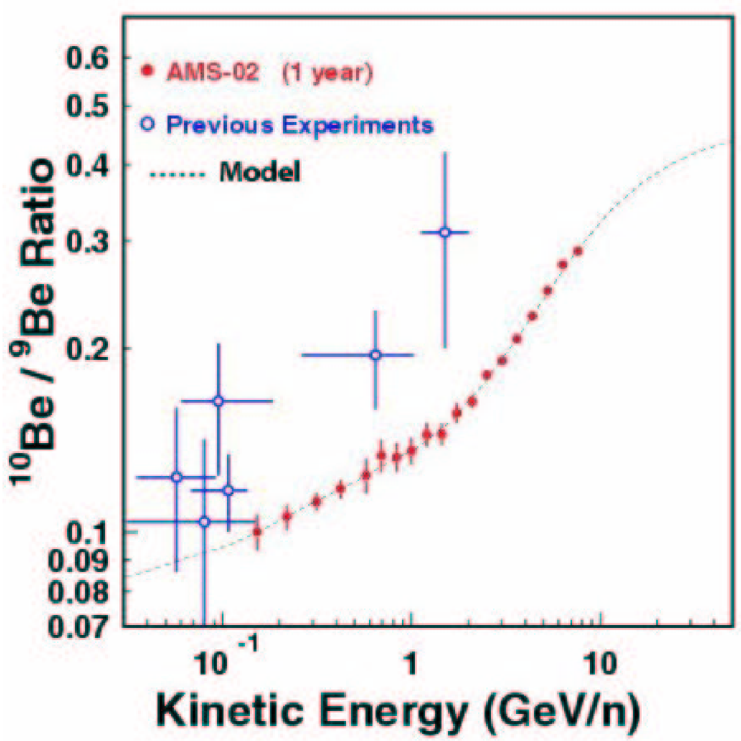
$$\begin{array}{ccccccc} \tilde{\chi}^0\,\tilde{\chi}^0 & \rightarrow & q\bar{q} & \rightarrow & \bar{p} & + & \mathrm{X} \\ & \rightarrow & W^+W^-, ZZ & \rightarrow & e^+ & + & \mathrm{X} \\ & \rightarrow & W^+W^-, ZZ & \rightarrow & \gamma & + & \mathrm{X} \end{array}$$

- AMS-02 is conceived to measure:

- $\bar{p}$ spectrum ($\sim$ 1GV$< R <$ 200 GV, $R = pc/Ze$)
- e^+ structure in spectra above few GeV

Cosmic Rays

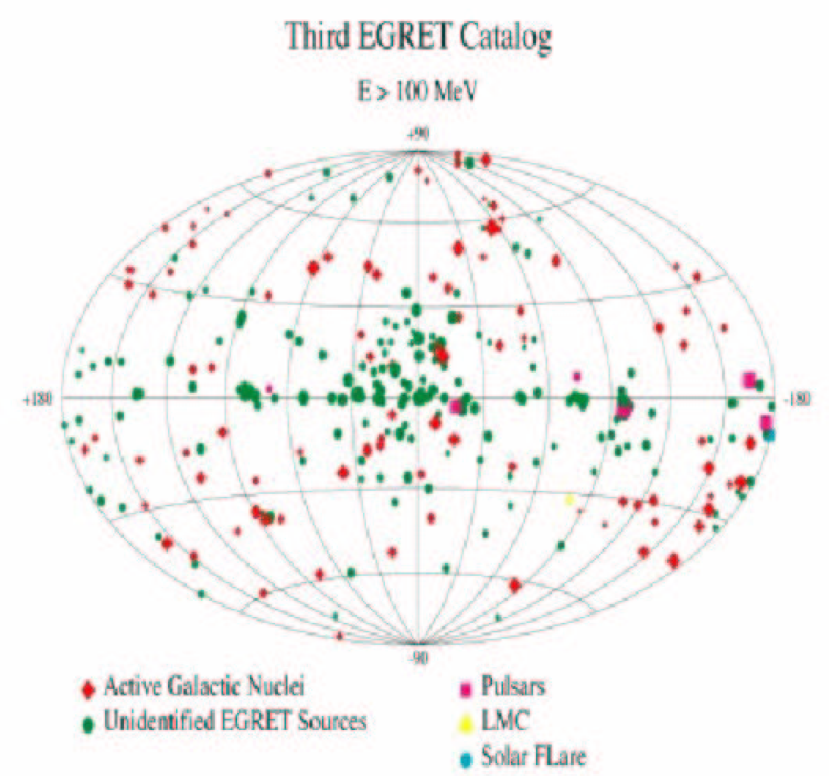
- An accurate determination of isotope abundances over a wide range of energies provides information on the propagation of Cosmic Rays in the galaxy.



- $^{10}Be/^{9}Be$ ratio ($^{10}Be \rightarrow 1.6 \cdot 10\ yrs$) gives information on:
  - Cosmic Rays confinement time in the galaxy
  - Mean density of interstellar material traversed

- AMS-02 will collect of the order of 10^9 of:
  - Proton: dominant component
  - He: 5 % of p flux at 10 GeV
  - D, Li, Be, B and C
  - Anti-proton: $\sim 10^{-3}$ % of p flux

High Energy Gamma Rays

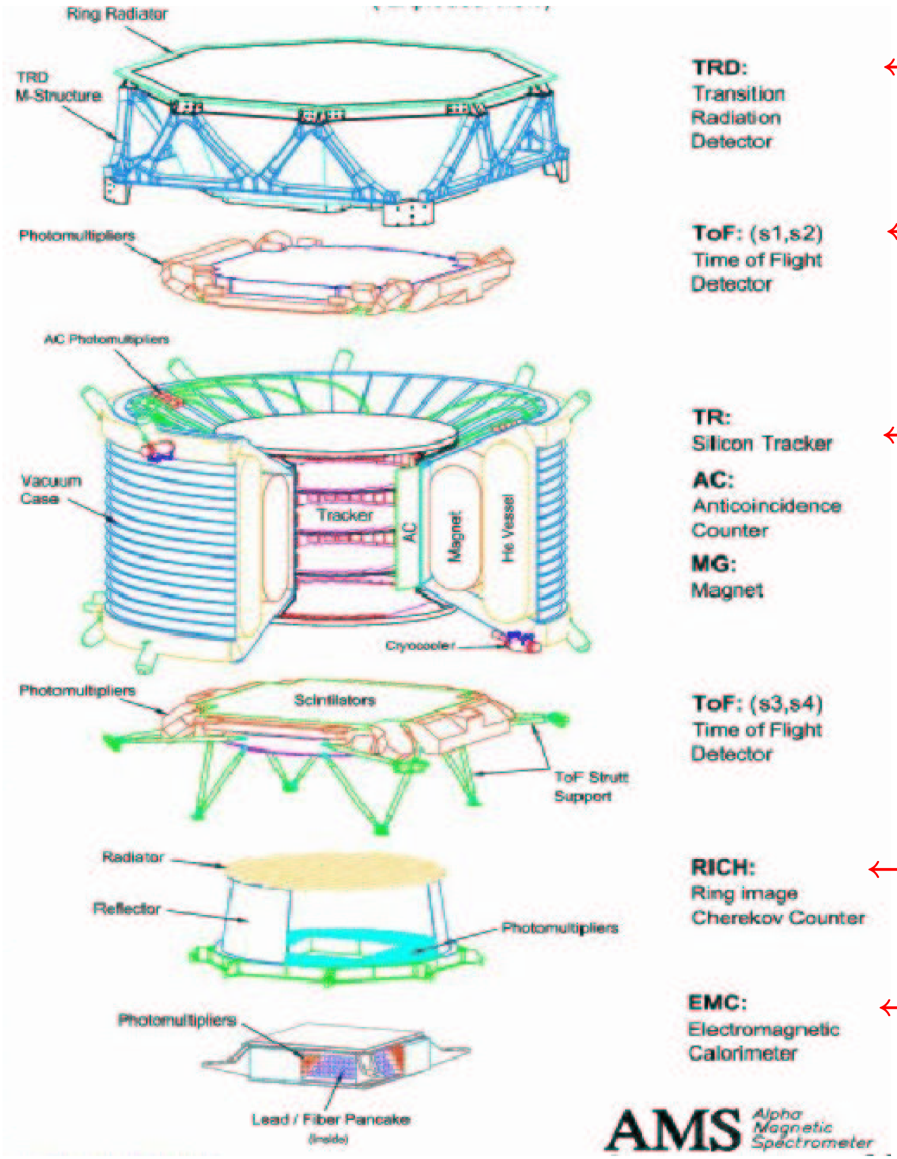


- AMS-02 will constantly monitor the gamma ray sky. Measurements from galactic and extragalactic sources (Pulsars and AGN) will complement the observations in other frequency bands to gain a better understanding of astrophysical particle acceleration mechanisms.

$\sim$ 280 pointlike γ-ray sources detected by EGRET (variable sources, transients)

- $\sim$ 70 Active Galactic Nuclei (AGNs)
- $\sim$ 7 Pulsars
- $\sim$ 200 sources not identified by an astronomical object

AMS-02 detector



←TRD Allows hadrons/electrons separation, measures dE/dx

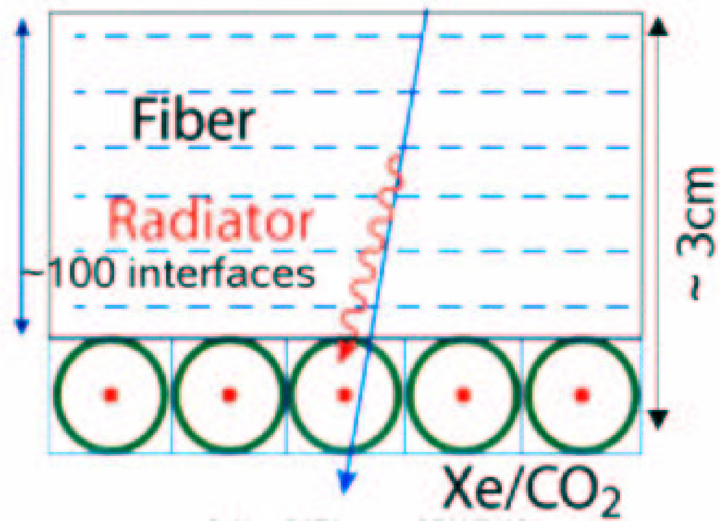
←TOF Measures time of flight, velocity β, direction and dE/dx

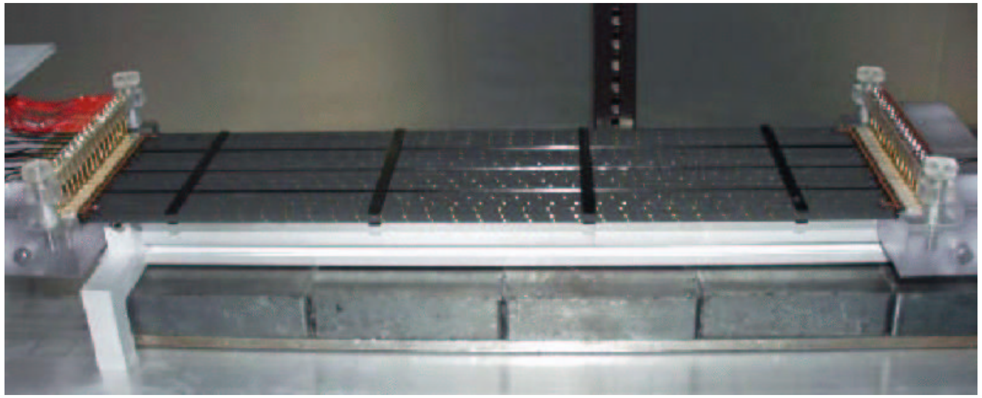
←TRK Localisation of charged particles, Rigidity ($R = pc/Ze$) with Magnet, specific energy loss ($dE/dx \sim |Z^2|$), direction and energy of converted photons)

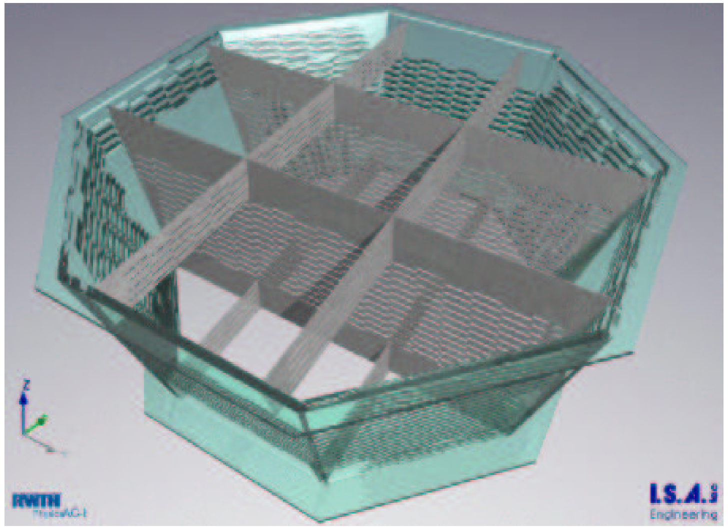
←RICH Velocity β, energy loss dE/dx and mass measurements

←EMC Lepton/Photon measurements, Lepton/Hadron separation

AMS-02 Transition Radiation Detector







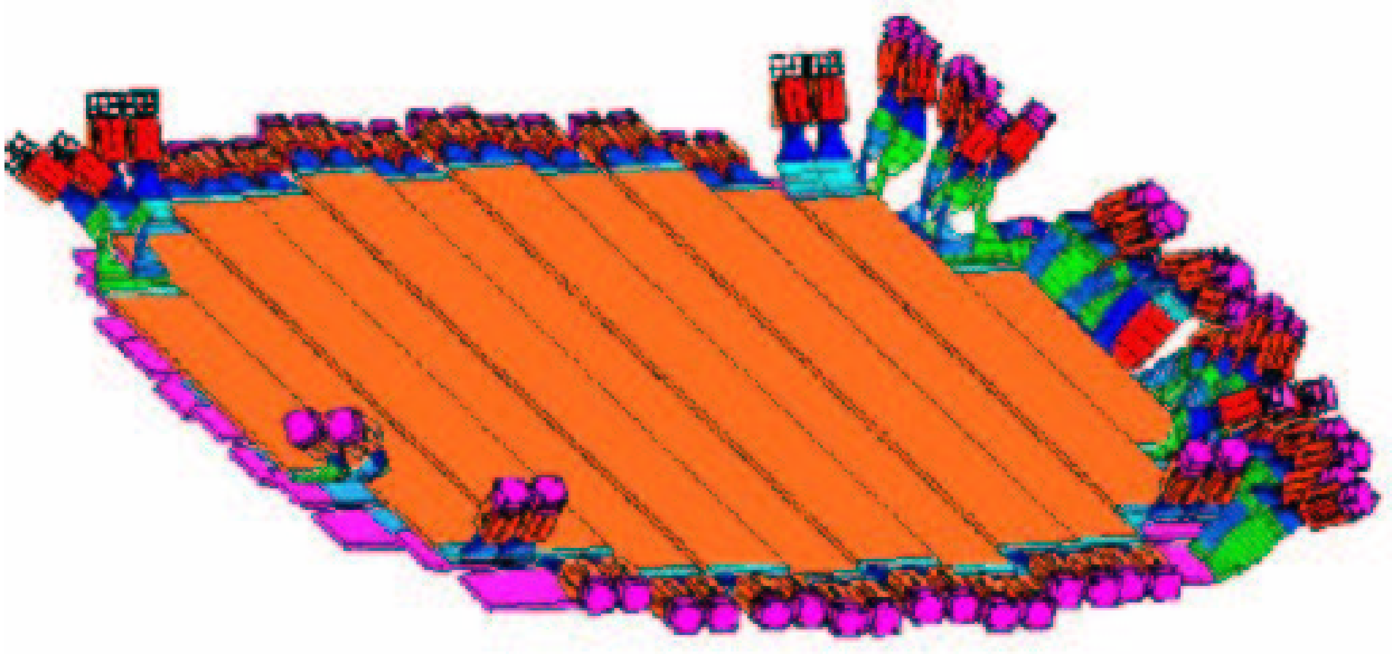
20 layers of TRD
5248 straw tubes

h/e rejection of $10^2 - 10^3$
(in the range $3 - 300$ GeV)

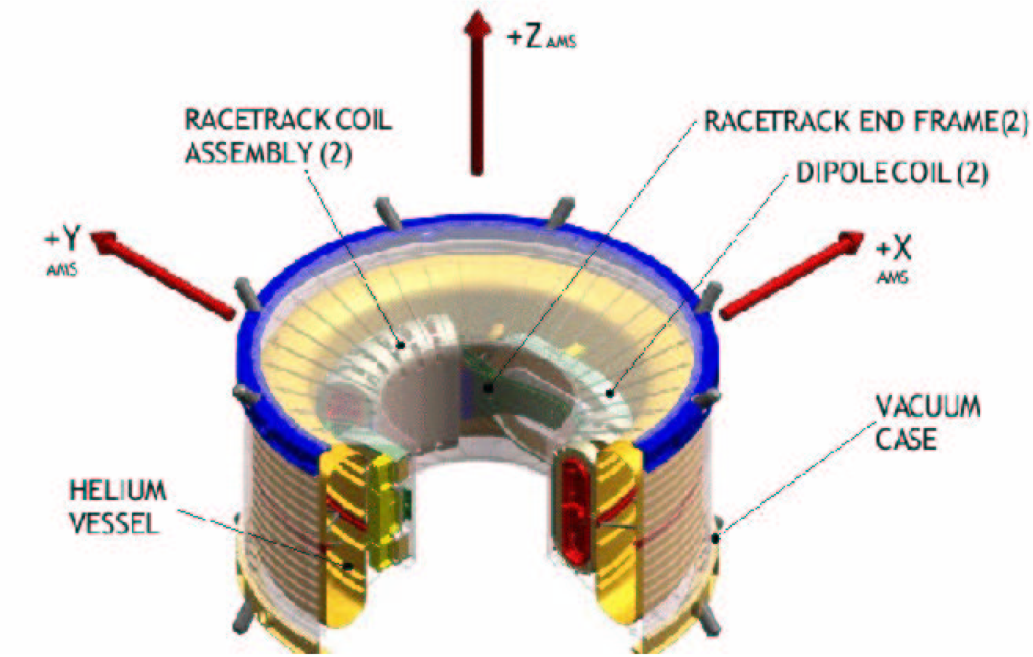
AMS-02 Time of Flight System

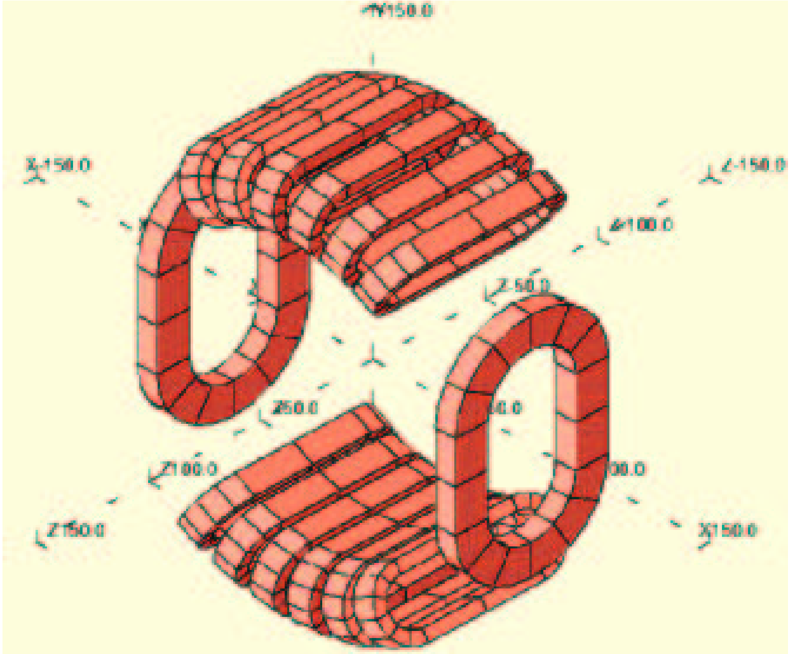
4 planes + total of 34 scintillator paddles
(seen by 2 PMTs on each side)

Time resolution: $\Delta\tau \sim 140\ ps$



AMS-02 Superconducting Magnet

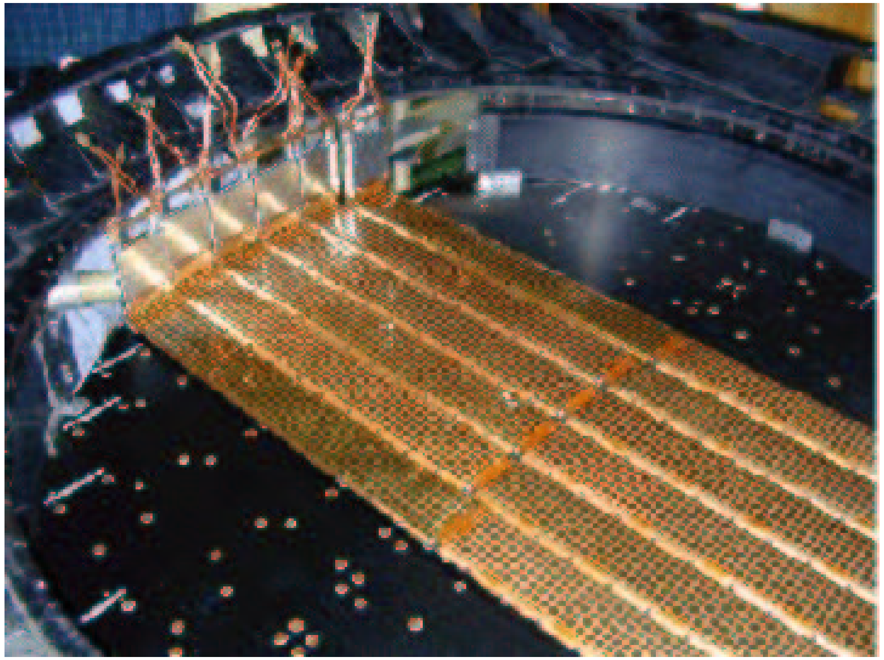


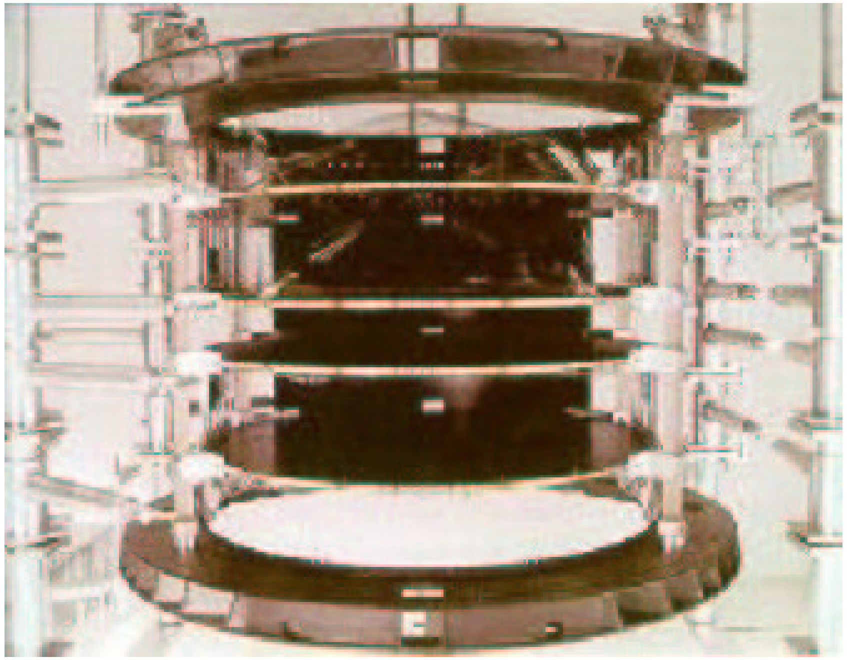


12 racetrack coils + 2 dipole coils
2500 liters of superfluid helium

Bending power: $BL^2 = 0.86 Tm^2$

AMS-02 Silicon Tracker

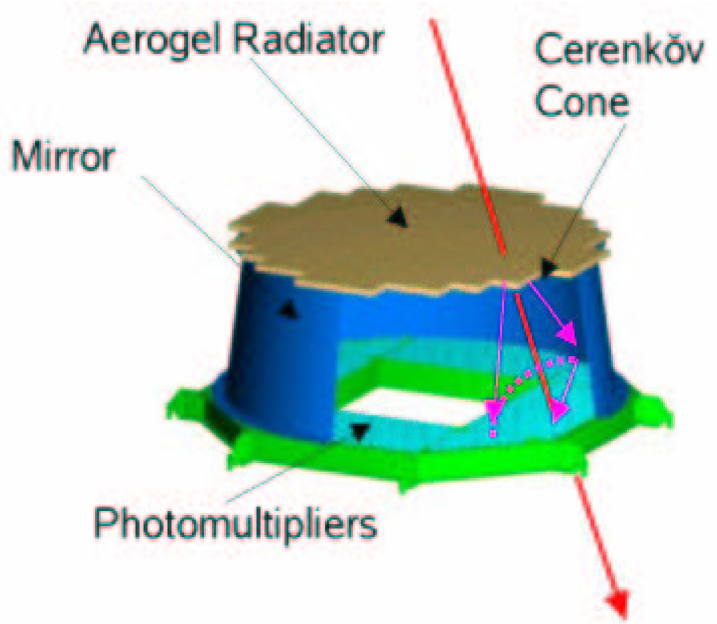




8 layers of double sided silicon sensors
$6.5m^2 \rightarrow 192$ **Ladders** $\rightarrow 196k$ **channels**

$\sigma(p)/p = 1.5$ **% @** 10 **GeV**
max detec. rigidity ~ 2.5 **TV**

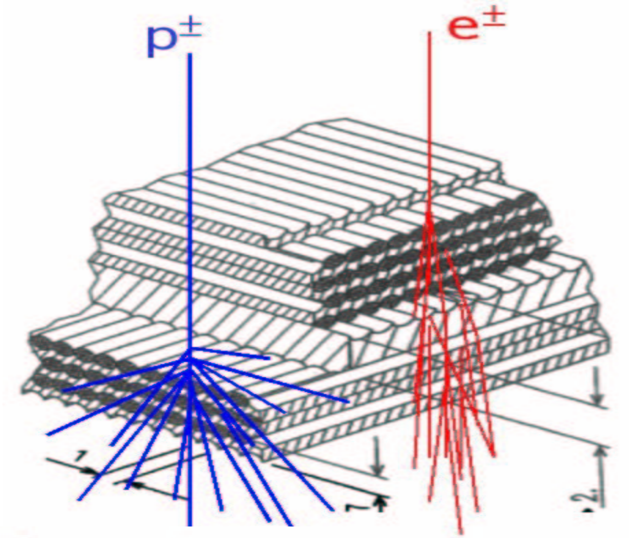
AMS-02 Ring Imaging Cerenkov Counter

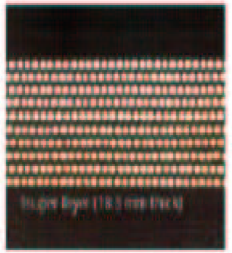


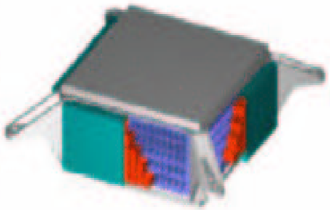
3 cm silica aerogel ($n = 1.05$) +
NaF ($n = 1.33$) radiator
(680 multianode PMTs)

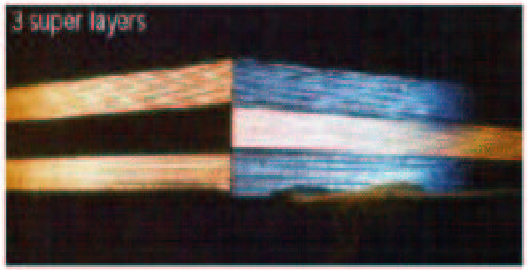
$\sigma(\beta)/\beta = 0.1$ % @ $\beta = 1$ (protons)

AMS-02 Electromagnetic Calorimeter









9 super layers of Sci-Fi/Lead (15 X_0)

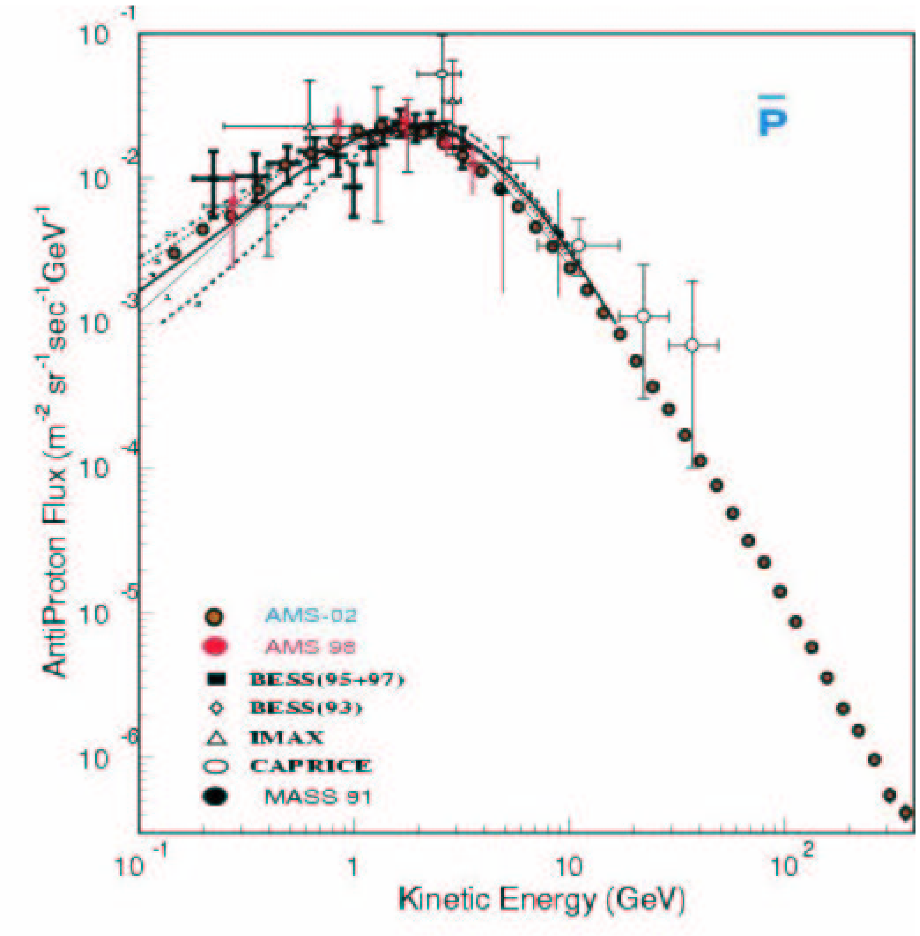
(324 multianode PMTs)

$\sigma(E)/E = 3$ **% @ 100 GeV**

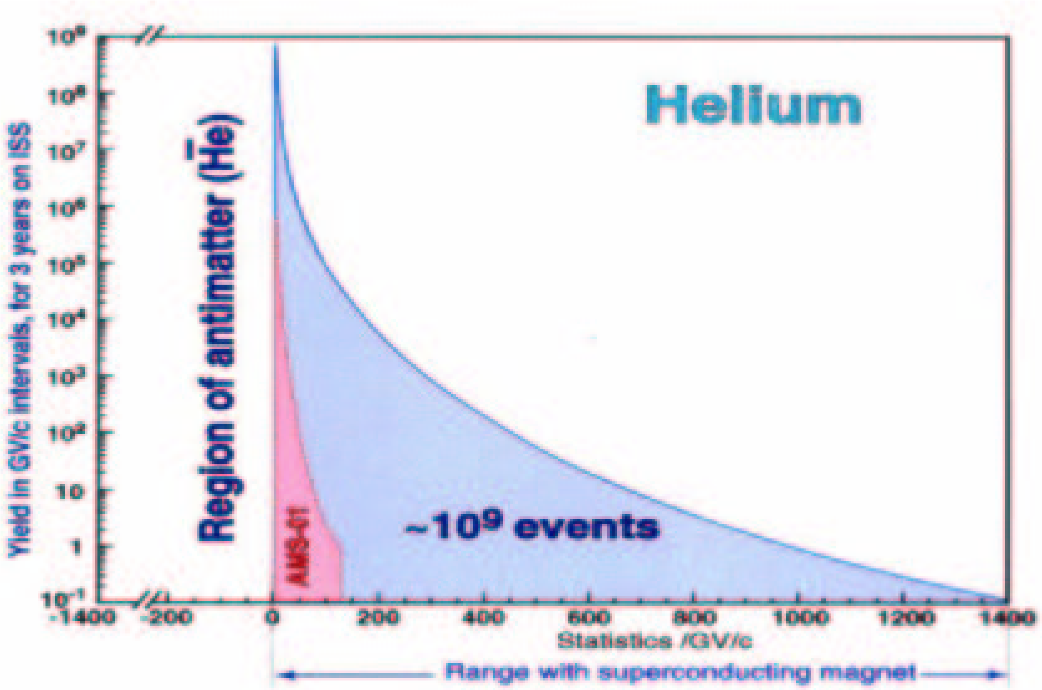
(p/e rejection of 10^3)

Search for Antimatter

Anti-Proton Flux

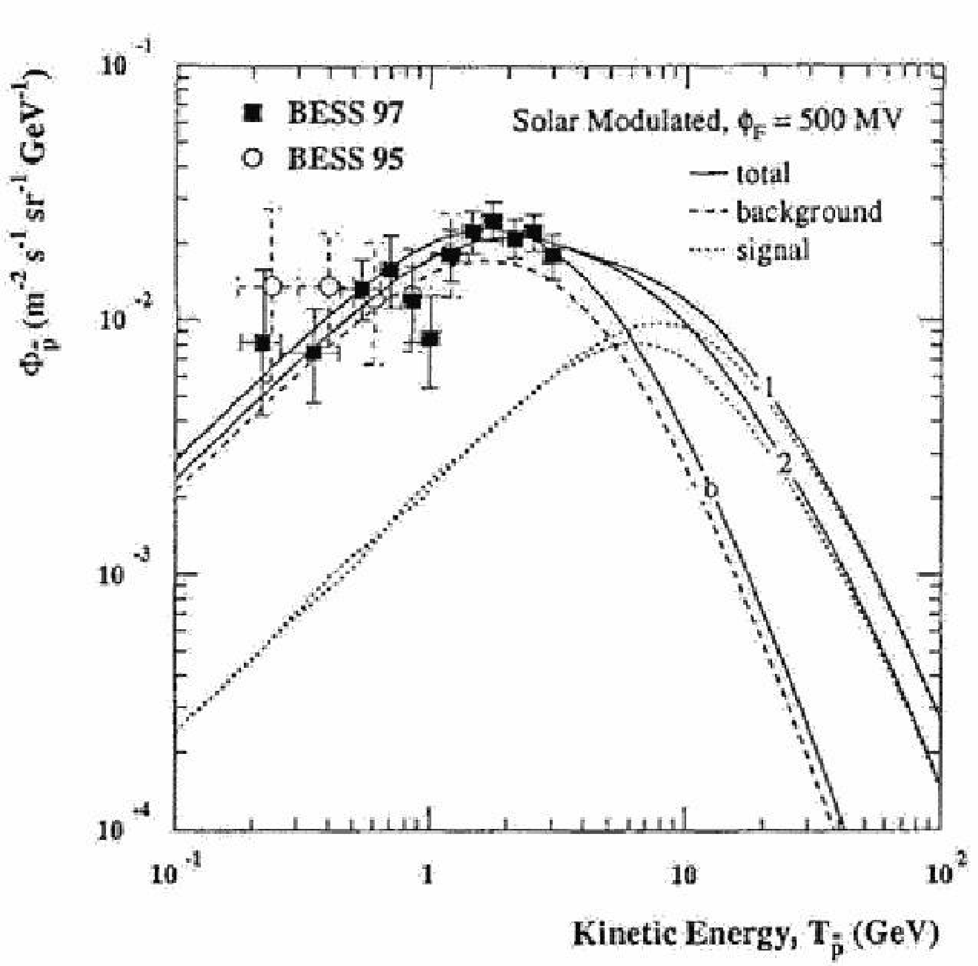


Anti-helium Capabilities

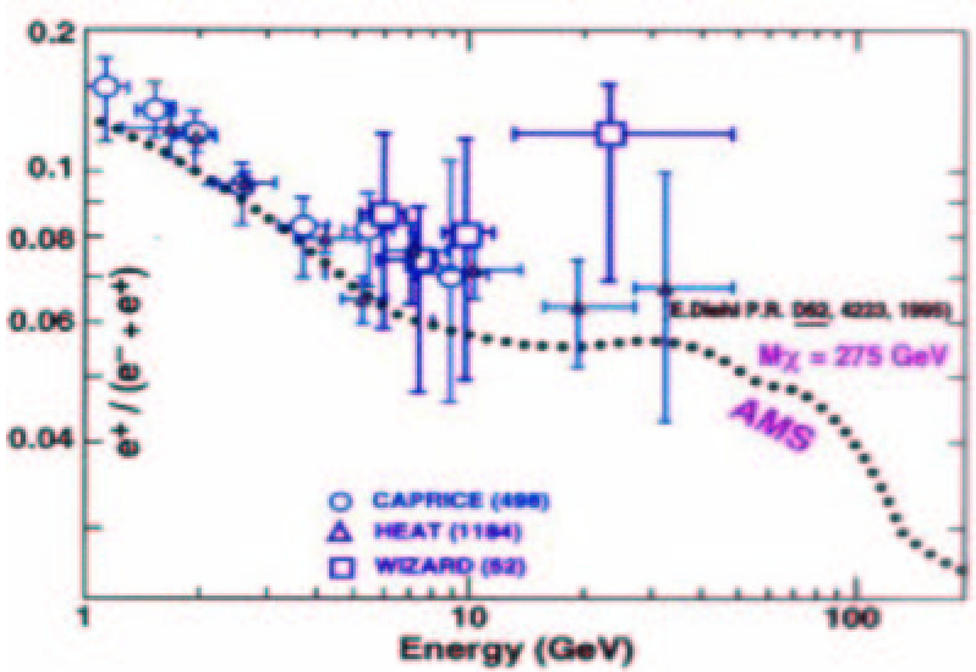


Search for Dark Matter

Anti-proton Spectrum

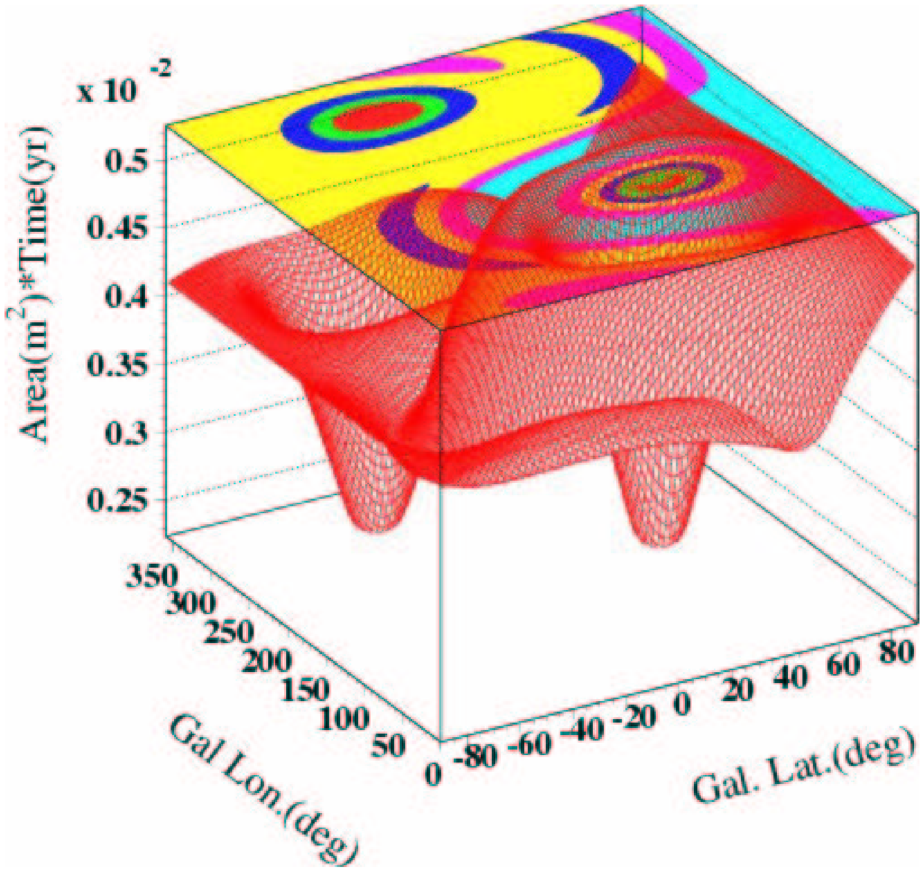


Positron Spectrum

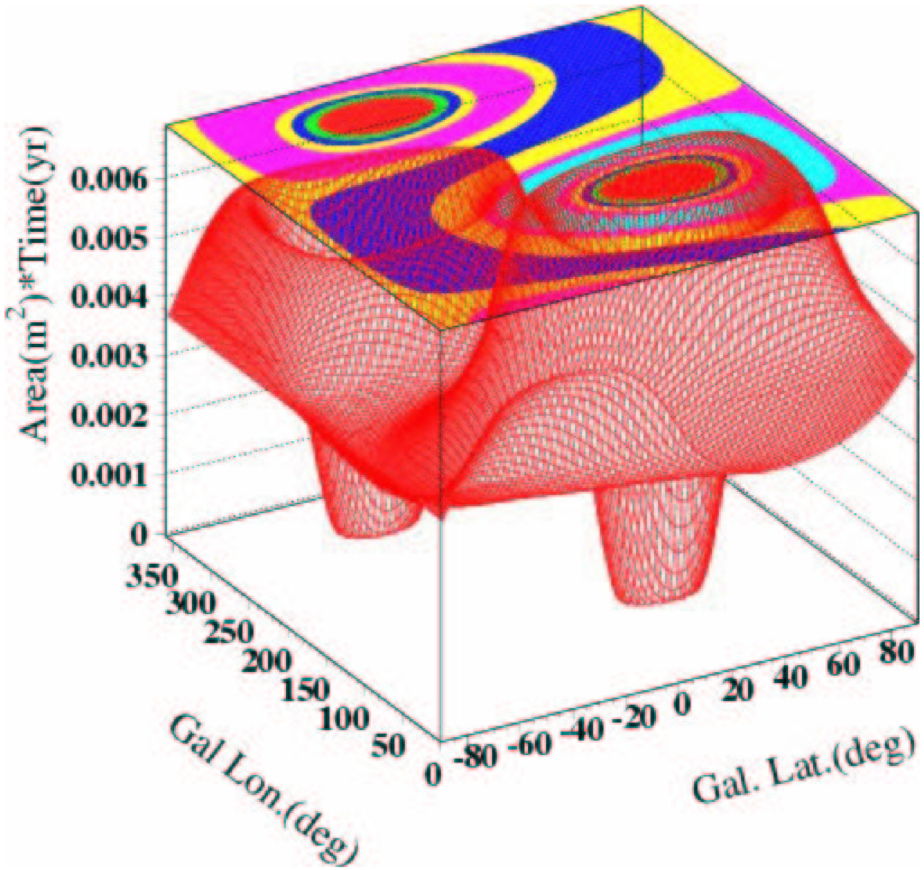


High Energy Gamma Rays Exposure

Tracker



Calorimeter



Conclusions

- AMS-02 is approved by NASA to operate on the ISS for 3 years.
- AMS-02 will be ready to fly in October 2005.
- AMS-02 large acceptance and long exposure time outside the Earth's atmosphere, will allow an unprecedented sensitive search of Antimatter, Dark Matter and studies of Cosmic Rays.
- Interesting Galactic and Extragalactic Gamma Rays Source measurements can be made.

More on the detector

General AMS-02 Design Features

- Thermal Enviromnment (day/night: $\Delta T \sim 100^o C$)
- Vibration (6.8 $G\ rms$) and G-Forces (17 G)
- Weight ($\sim 7\ tons$) and Power ($\sim 2\ kW$)
- Vacuum: $< 10^{-8}\ Pa$
- Realiable for 3 years
- Radiation: Ionizing flux $\sim 1000\ cm^{-2}s^{-1}$
- Orbital Debris and Micrometeorites

General TRD Design Features

- Allows e^+/p^+ and e^-/p^- separation beyond 2 GeV.
- Dark Matter Search.
- 20 Layers of Aluminazed Kapton Strawtubes with Polypropelene Radiator Fiber Filler.
- 6000 Tubes, 20000 Gas Connections.
- $E_{ph} \rightarrow \gamma$, $\Theta_{ph} \rightarrow 1/\gamma$, $N \sim \alpha = 1/137$.

General T-o-f Design Features

- Time of flight $\longrightarrow$ velocity.
- Charge determination (dE/dx).
- 20 Trigger and Up/Down Separation.
- Scintillator Paddles with Phototubes at both ends.
- 240 Phototubes (120 Channels).
- 120 ps Time Resolution.
- 4 Planes (2 upper, 2 lower) $\longrightarrow$ 8 m^2 Total Area.

General Magnet Design Features

- Cryogenic $\longrightarrow$ 3000 liters superfluid He.
- $B = 0.8\ T$.
- Determines Rigidity ($R = pc/Ze$ (GV)) with Tracker.
- Very low fringe Field and Dipole Moment.

General Silicon Tracker Design Features

- Rigidity ($R = pc/Ze$ (GV), $dR/R \sim 2\%$ for 1 GeV protons) with Magnet.
- Signed Charge (dE/dx).
- 8 Planes $\longrightarrow \sim 6\ m^2$ equipped by double-sided silicon ladders.
- Pitch: Bending $\rightarrow 27.5\ \mu m$, Non-Bending $\rightarrow 104\ \mu m$.

General RICH Design Features

- Accurate Velocity measurements via Opening Angle of Cerenkov cone $\rightarrow$ Isotopic separation.
- $d\beta/\beta \sim 0.1\%$.
- Cosmic Ray propagation.
- Additional particle identification capability.

More on Gamma Rays Astrophysics

How are γ-rays produced ?

F **Need powerful ENGINES!**

$\rightarrow$ *astronomical objects supplying energy*

- Star explosions
- Rotational energy
- Accretion energy
- Magnetic energy

F **Need efficient ACCELERATION!**

$\rightarrow$ *charged particles*

- Electromagnetic
- Shock waves

Need "right" ENVIRONMENTS!

$\rightarrow$ *γs production*

- Synchrotron radiation
- Inverse Compton
- π^0-production

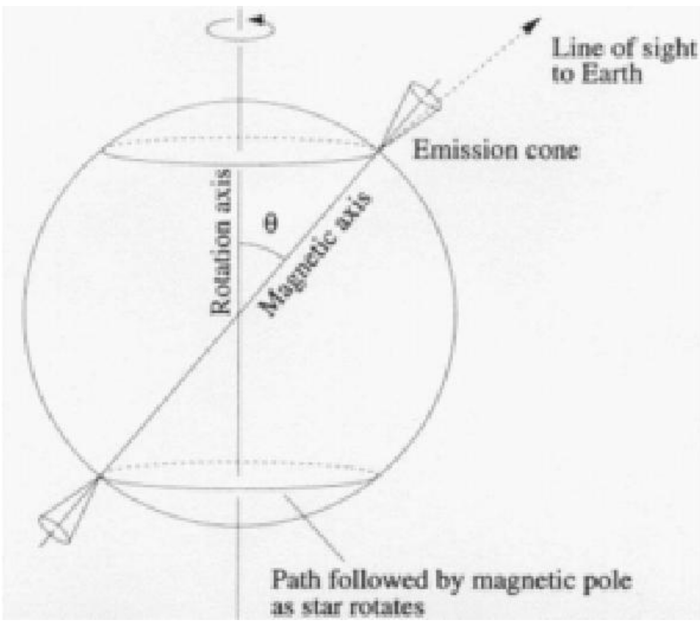
How are γ-rays produced ?

Galactic sources:

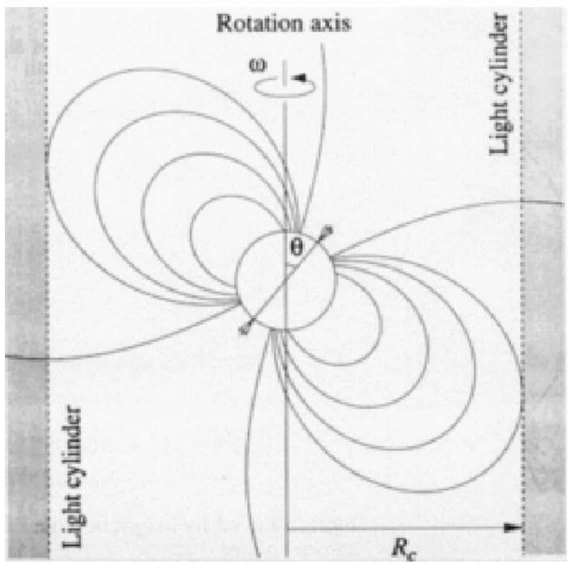
Pulsars

Rotating neutron stars from supernovae remnants, for which the axis of rotation is misaligned with the magnetic axis.

- Fields at the surface liberate e^-, e^+, p which are then accelerated by the magnetosphere.



Carroll & Ostlie 1996



How are γ-rays produced ?

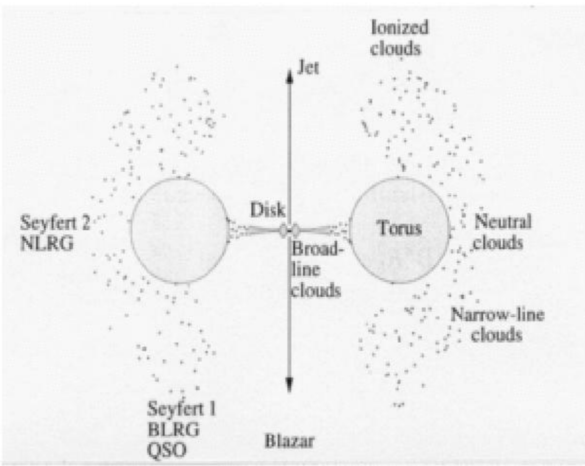
Extragalactic sources:

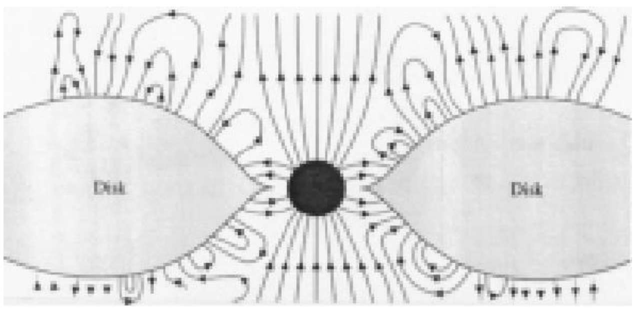
AGNs

Very massive rotating black hole surrounded by its accretion disk and by a giant torus of gas and dust.

- Jets of particles are ejected along the rotation axis and confined by the magnetic fields generated from the accretion disk.
- Particle acceleration can occurs by shock waves.

Urry & Padovani 1995





- When the jet points towards Earth the object is called ***blazar***.

3 fundamental needs of γ-ray astrophysics

Imaging & **Field of Obs.**

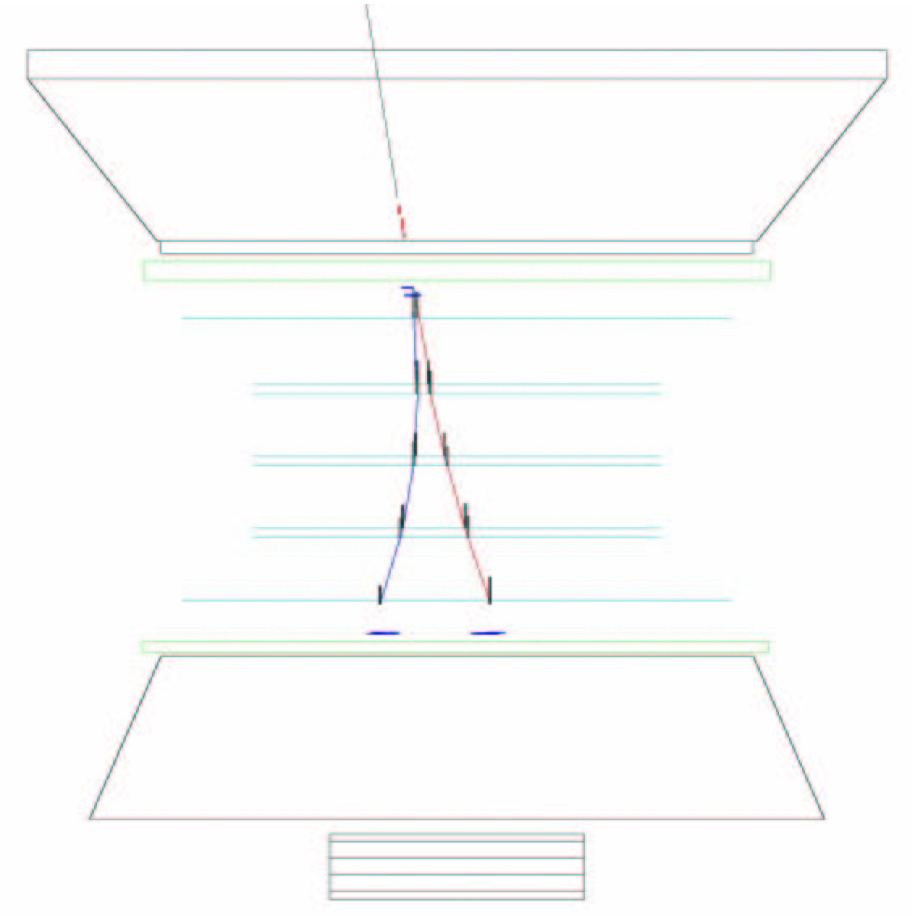
$(\theta \sim 0.017 \rightarrow 0.17^o)$ $(\Omega \sim \pi)$

Absolute Timing $(1 \rightarrow 10 \mu s)$

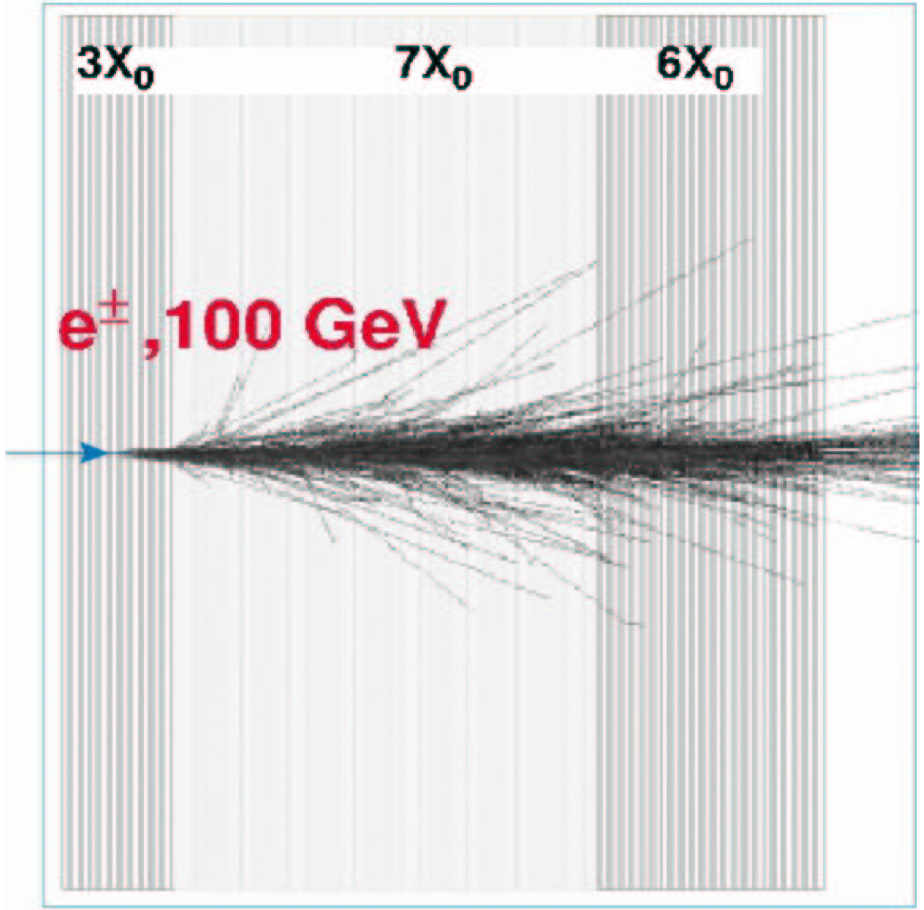
Absolute Orient.: ***Star Tracker***

More on Gamma Rays detection with AMS-02

Conversion Mode

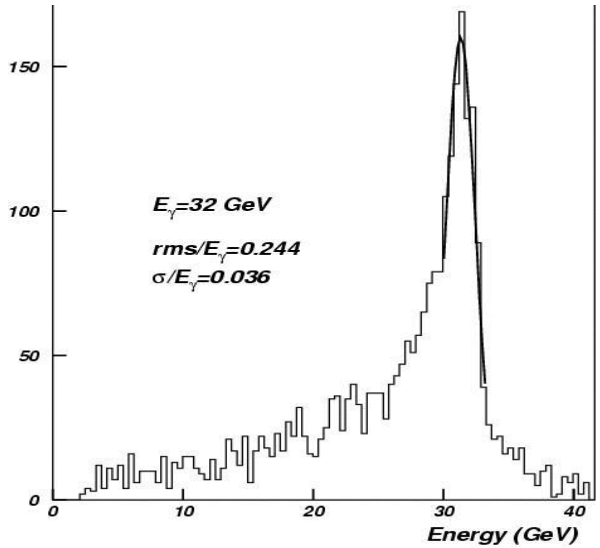


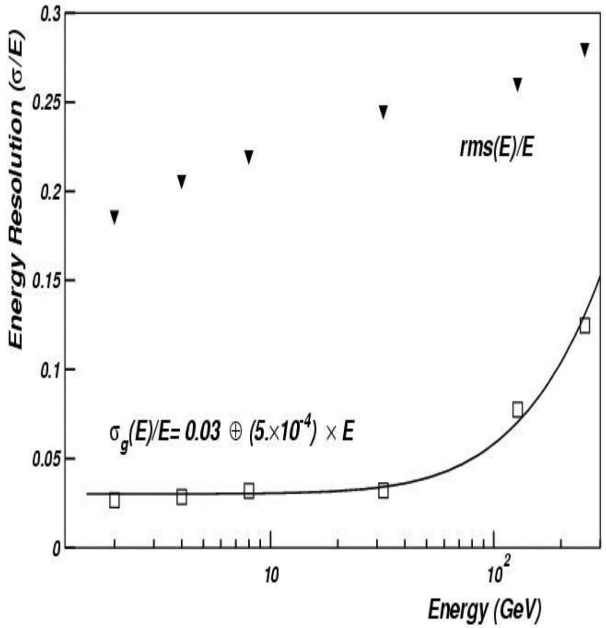
Calorimetric Mode

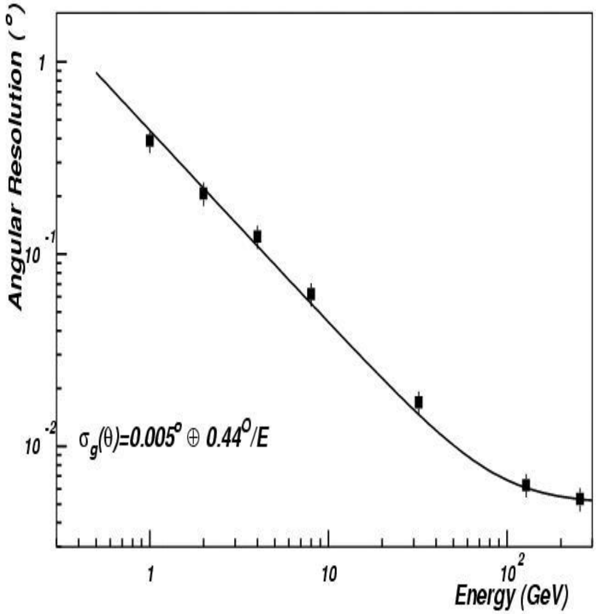


Tracker performances

Energy range	$1 - 100$ **GeV**
E resolution	3 **%** **@** 10 **GeV**
Θ resolution	0.04^o **@** 10 **GeV**

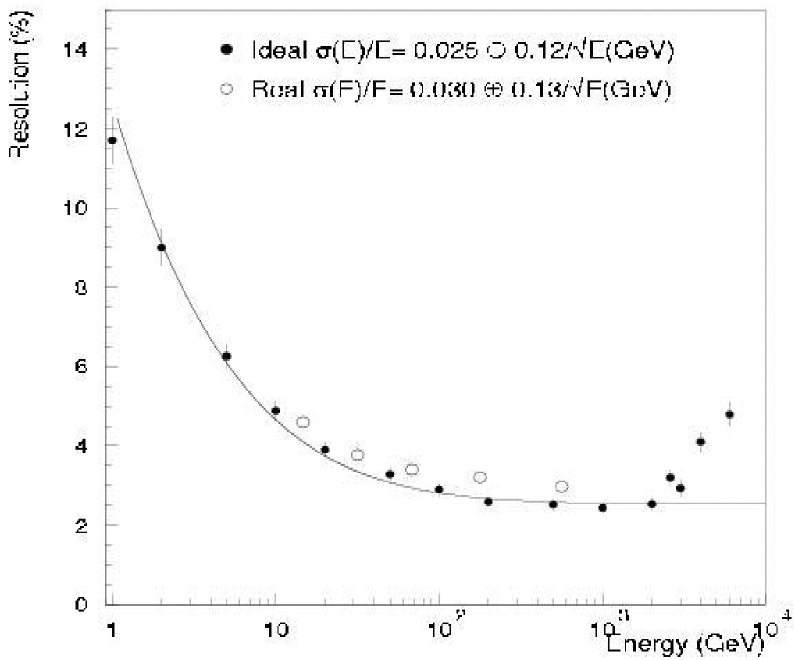


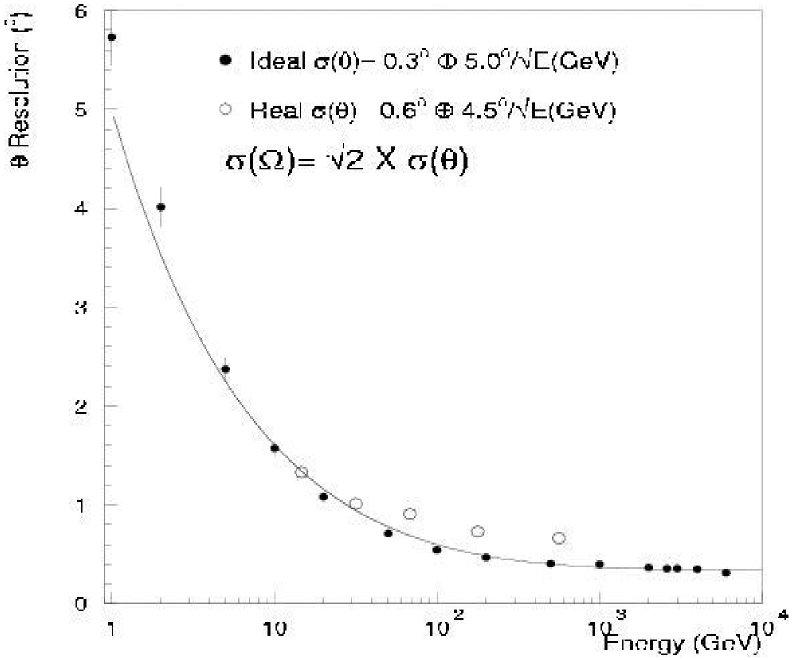




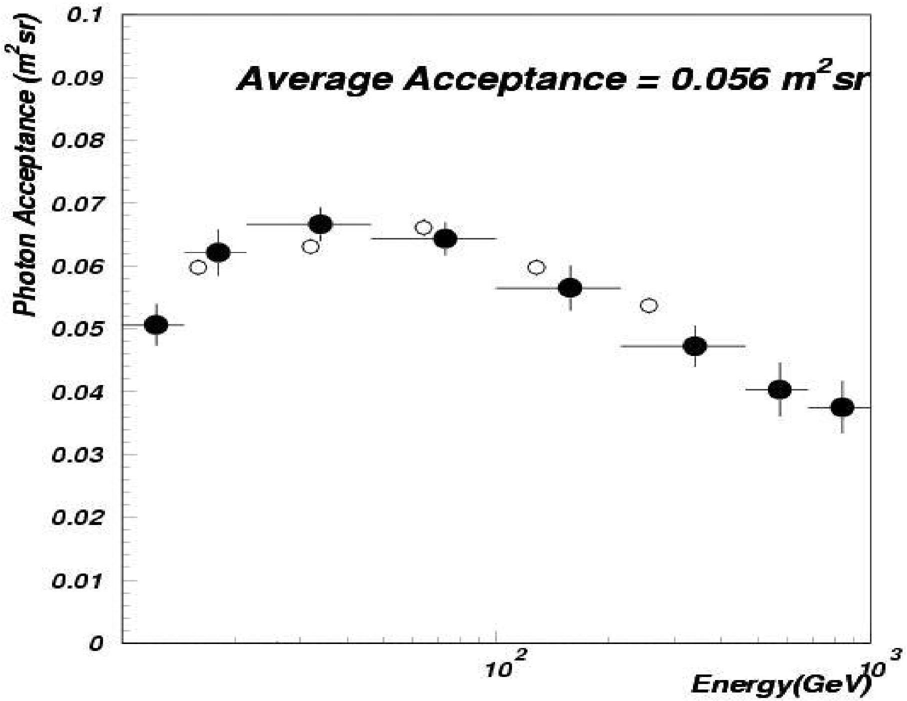
Calorimeter performances

Energy range	10 – 1000 **GeV**
E resolution	3 % @ 100 **GeV**
Θ resolution	0.5^o @ 100 **GeV**

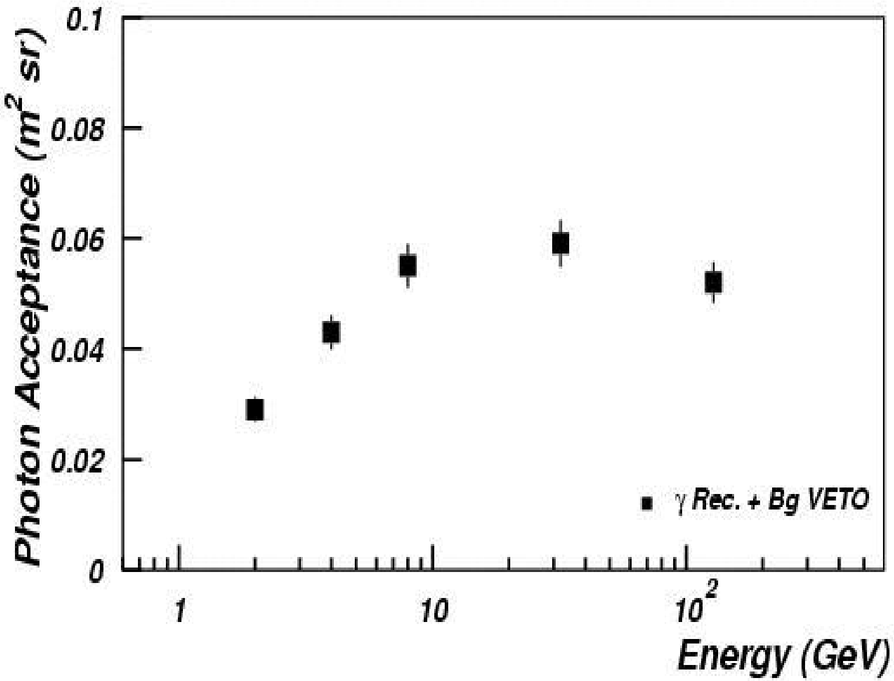




Calorimeter

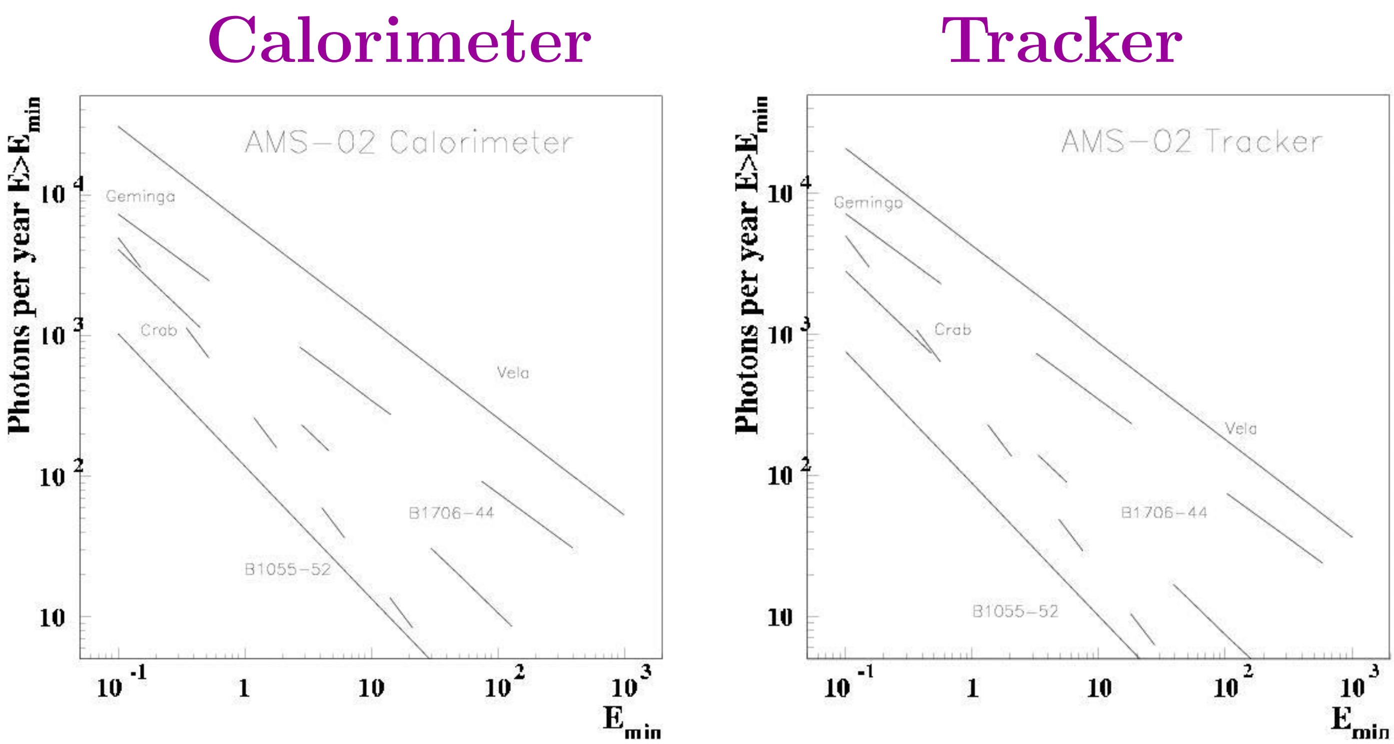


Tracker



Almost the same acceptance @ 10 GeV $\rightarrow 0.06 m^2 sr$

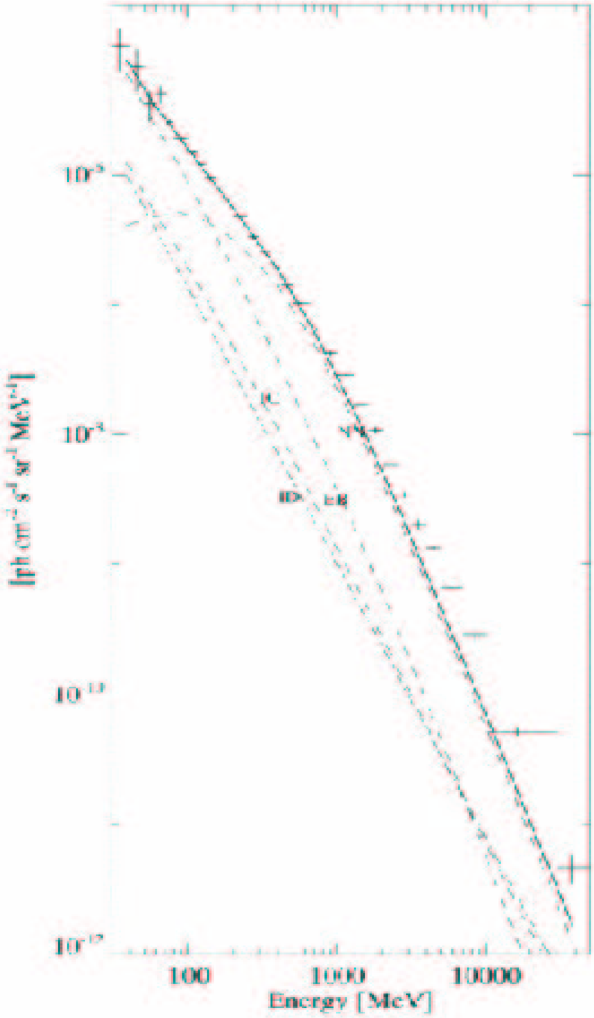
Signal estimate from Galactic sources



- Estimate based on accurate orbit and attitude model.
- Rough estimate of reconstruction efficiency.
- Sufficient rate for regular observation.
- Long observation period.
- Enlarged energy interval.
- Complementary to satellite and ground based experiments.

Diffuse Galactic Background

Hunter et al., 1997



ID: isotropic diffuse

IC: inverse Compton

EB: electron bremsstrahlung

NN: nucleon-nucleon

- Origin and emission spectra
- Attenuation and spectrum deformation
- Background for point sources

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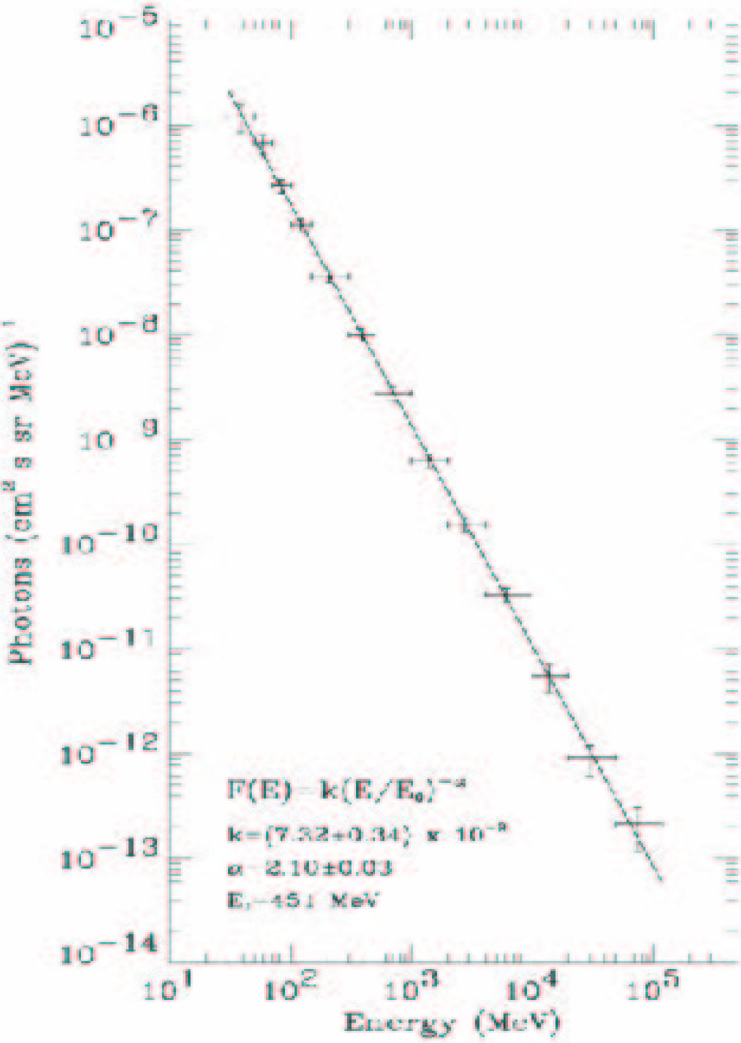
Diffuse Extragactic Background

Sreekumar et al., 1998



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Magnetic Field