AMS-02: Particle Physics in Space

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AMS-02

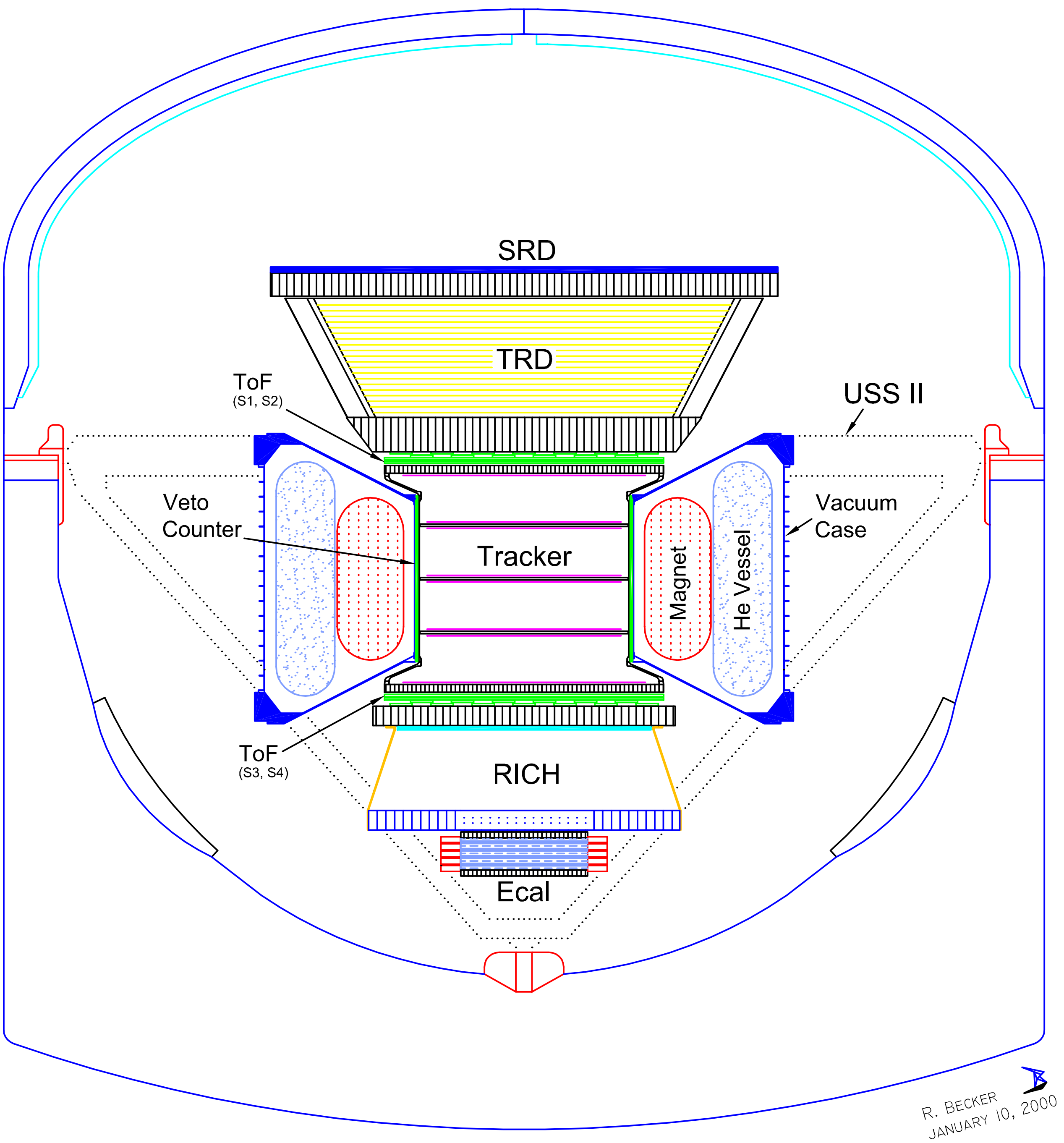
AMS is a particle physics experiment

... but ...

- Is going to be placed on ISS
  - Launch in September 2003
- Spatial environment
  - Radiation
  - $\Delta T \rightarrow$ -200^o +200^o C
- Mechanical hardness
  - 10g accelerations
  - meteorites
- Maximum weight $\sim$2 T
- Maximum power consumption $\sim$2 KW

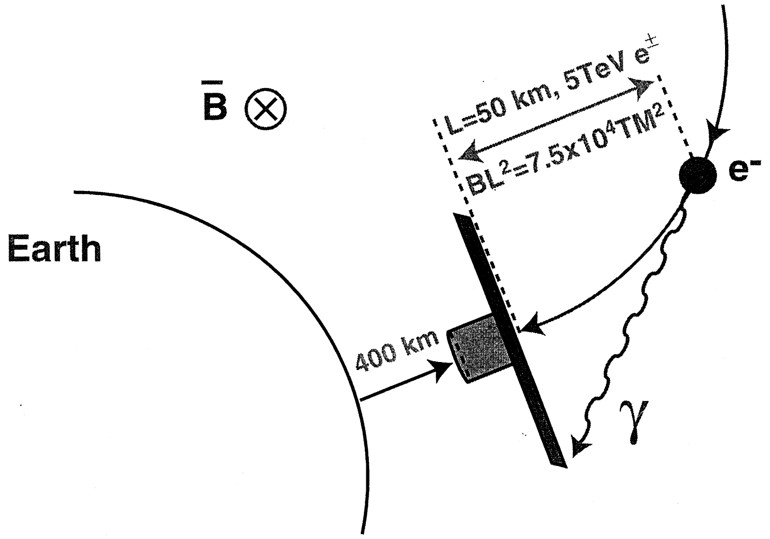
AMS 02

In Cargo Bay



Synchrotron Radiation Detector (SRD)

Measurement of Synchrotron X-rays from high energy electrons and positrons bend in the Earth Magnetic Field (2.5Kev-100KeV)

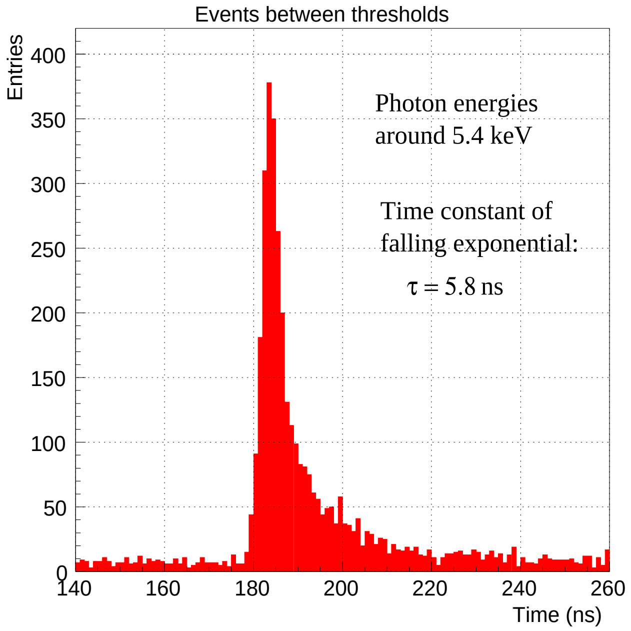


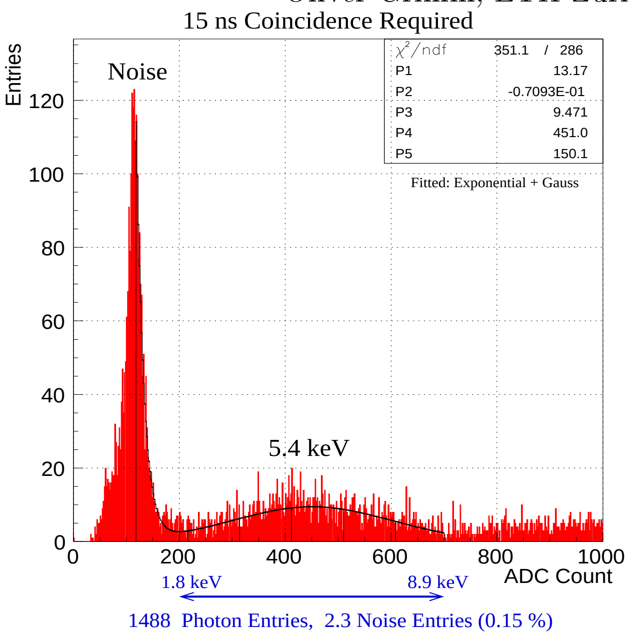
H.Hofer, M. Pohl Nucl. Instr. Meth. A416 (1998) 59

- Energy and Time correlation ($\sim$ 10 ns) in a plane of scintillating crystals
- Fast trigger ($<$ 25 ns) provided by ToF and EM-Calorimeter when a large energy loss is detected
- 2400 Crystal/PMT elements $100 \times 25 \times 1.0\ mm^3$
- Crystals made of YAP Cerium doped Yttrium Aluminium ($YAlO_3$)
- 4800 readout channels (two gain ranges)

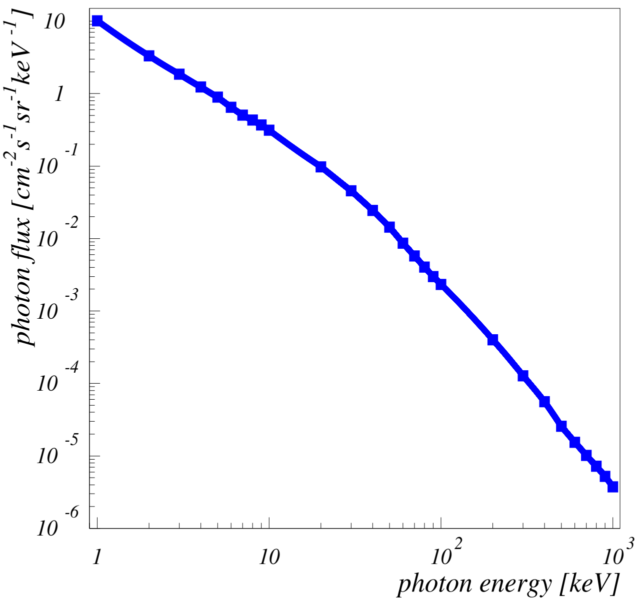
Time resolution expected for low-energy photons

Oliver Grimm, ETH Zurich



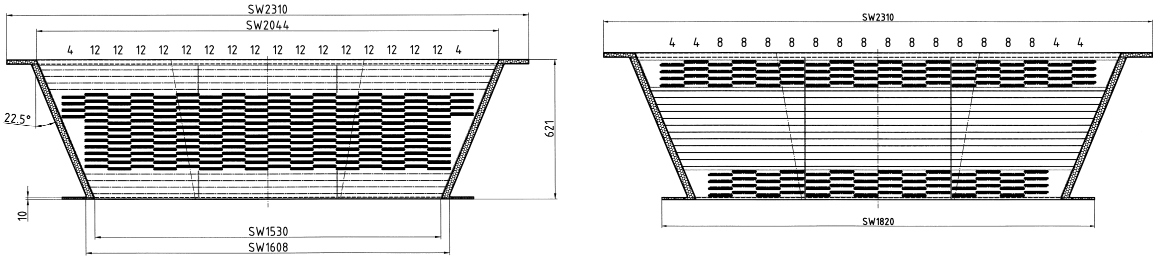


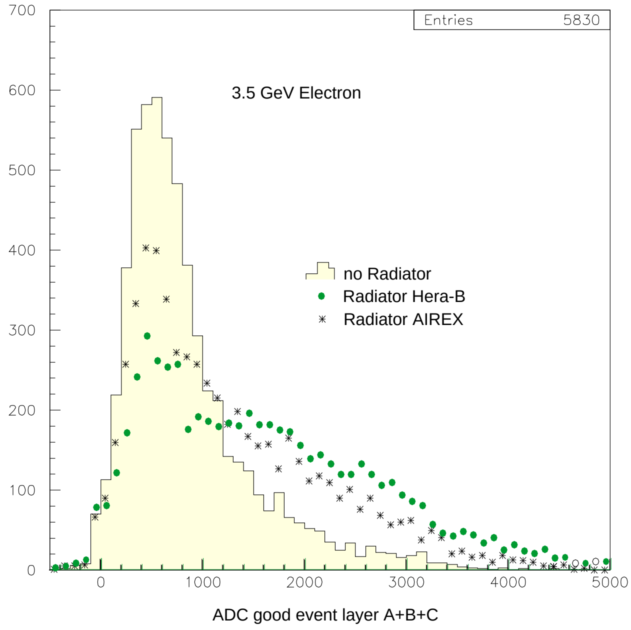
Michael Kraeber, ETH Zurich



Transition Radiation Detector (TRD)

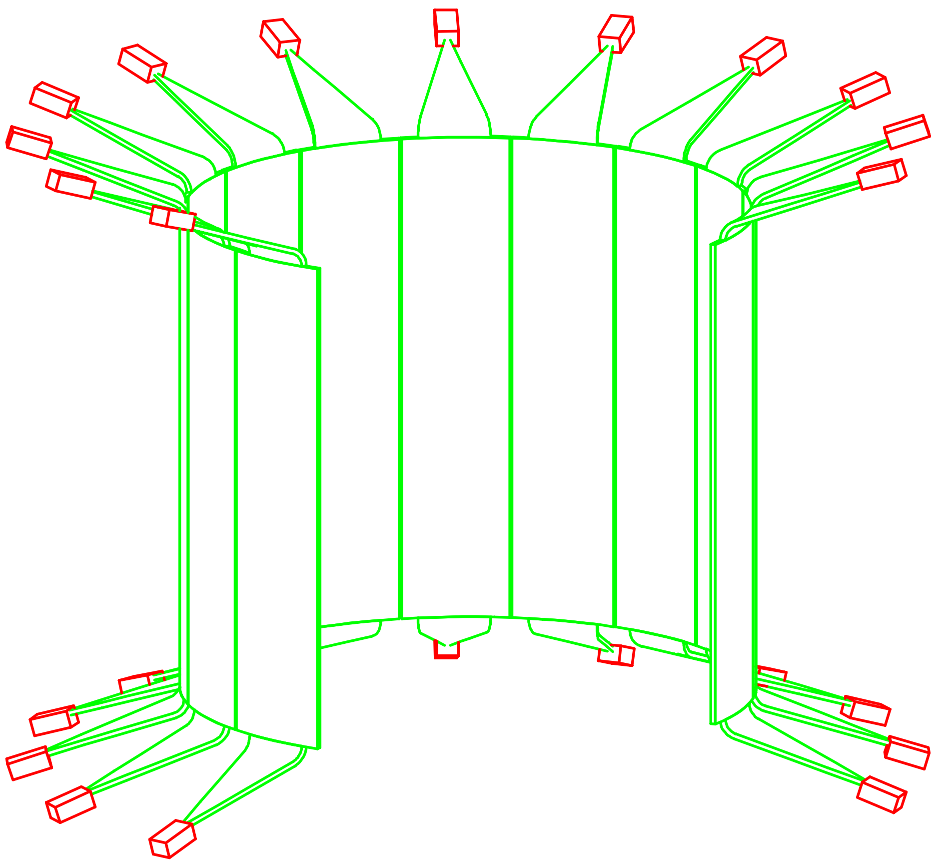
- 20 layers of radiators+proportional tubes
  - 12 in bending plane (y)
  - 8 in non-bending plane (x)
- Proton rejection $\sim 10^{-3}$





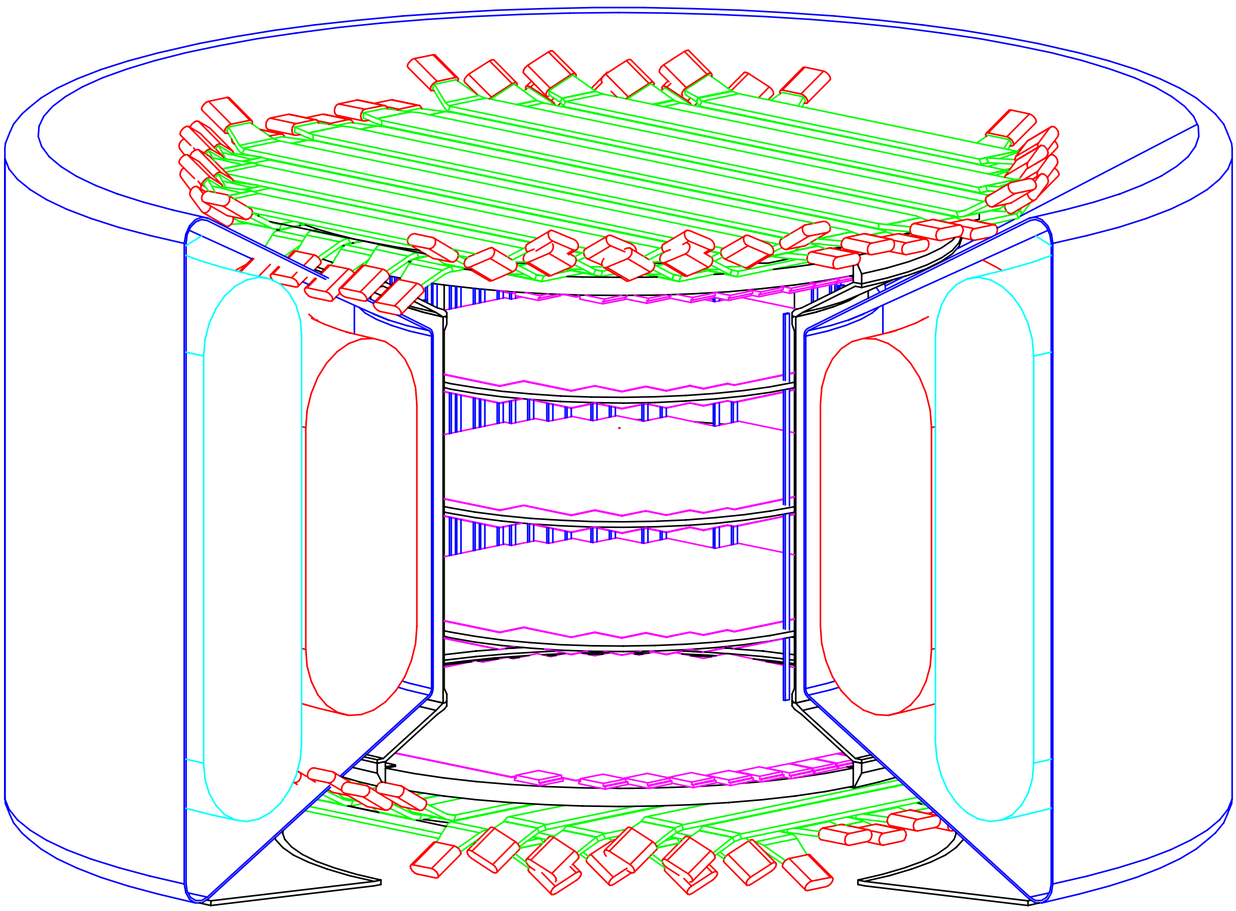
Anticoincidence counters (AC)

- 16 counters surronding the inner wall of magnet
- Signals on anticounters indicate that a particle entered or exited through magnet walls
- Used for event rejection



Time of Flight (TOF)

- Four layers of scintillators:
  - S1(x),S2(y) above tracker
  - S3(x),S4(y) below tracker
  - Each layer consist of 14 scintillators viewed by three PMs on each side.
- It will provide:
  - First level trigger
  - Time of flight measurement ($\sigma_{tof} \sim 100ps$)
  - Particle direction (up/down)
  - dE/dx measurement.

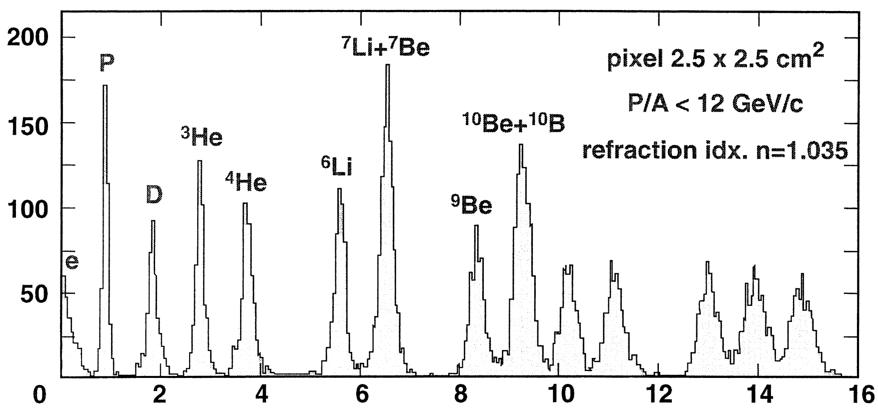


Tracker

- 8 layers of double sided silicon detectors distributed on 5 planes
  - 2 Outer planes located at top and at bottom of the magnet
  - 3 Inner planes inside magnet. Each inner planes is composed of two silicon layers
- 192 ladders (7-15 sensors each)
- Spatial resolution
  - 10 μm in bending plane
  - 30 μm in non-bending plane
- Each layer will give separate measurement on dE/dx
- 196.608 readout channels

Ring Imaging CHerenkov (RICH)

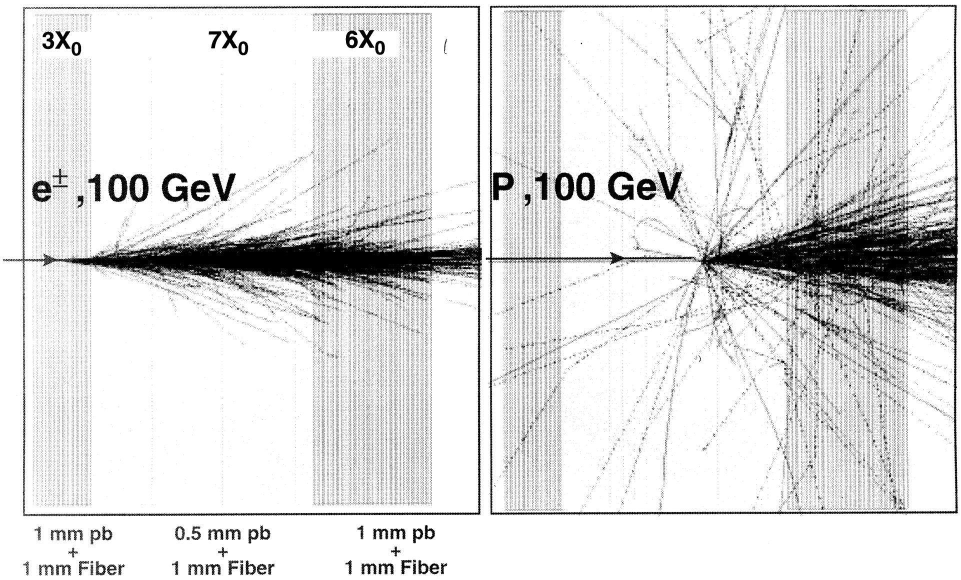
- Aerogel radiator ($n \sim 1.1$)
- $\Delta\beta/\beta$ measurement of the order of 10^{-4}
  - Cosmic ray identification up to 13 GeV/c per nucleon for $A < 25$



- Photon yield measure particle charge up to maximum rigidity and $Z \sim 26$

Electromagnetic Calorimeter (ECAL)

- 3D sampling calorimeter



- Pancake configuration. 80 layers of lead+fibers.
- Energy range from 0.5 GeV up to 1 TeV

$$\frac{\sigma_E}{E} = \left(\frac{9}{\sqrt{E}} \oplus 1.5\right)\%$$

- Total radiation length: 15.5 X_0
- Proton rejection $\sim 10^{-4}$

AMS-01 vs AMS-02

	AMS-01	AMS-02
Acceptance	$0.16\ m^2\ sr$	$0.6\ m^2\ sr$
Data taking time	10 days	3 years
Bending power	$0.14\ Tm^2$	$\sim 1\ Tm^2$
Tracker planes	6	8
e/p rejection	-	$< 10^{-5}$
$\Delta\beta/\beta$	2%	0.1%

Cosmic Rays

Primordial

Particles created just after Big-Bang.

$$\gamma,\ p,\ e,\ D,\ {}^4He,\ {}^3He,\ {}^7Li$$

Primary

Particles accelerated at astrophysical sources.

$$e,\ p,\ He,\ C,\ O,\ Fe$$

Secondary

Particles produced by the interaction of primaries with interstellar gas.

$$e,\ p,\ Li,\ Be,\ B$$

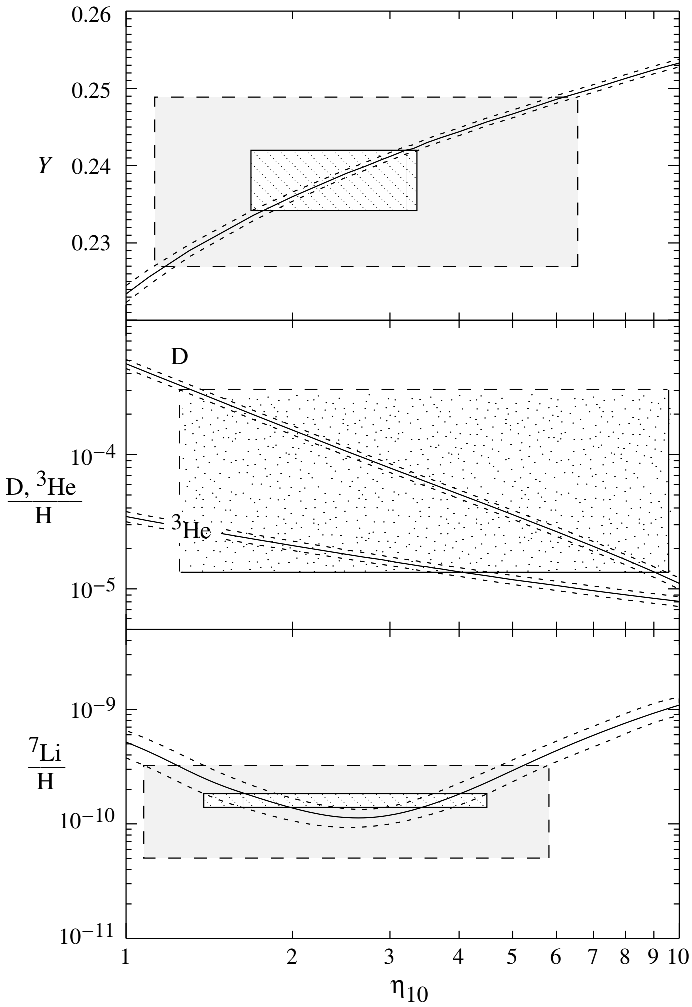
Propagation is described by the Leaky Box model

$$J_i\left(\frac{1}{\Lambda_e}+\frac{1}{\Lambda_{nuc}}+\frac{1}{\Lambda_{dec}}\right)+\Delta E_i = Q_i+\Sigma_k\left(\frac{J_k}{\Lambda_{ki}}\right)$$

Primordial nucleosynthesis

Relative abundance of light isotopes from primordial nucleosynthesis plotted as a function of the fraction of remaining baryons over photons

$$\eta_{10} = \frac{n_B}{n_\gamma} \times 10^{10}$$



Search of Antimatter

There is NO experimental evidence of antimatter in the Universe

- Our neighborhood ($\sim 20Mpc$) consists exclusively of matter
- No radiation from matter-antimatter annihilation observed.
  - COBE results shows extremely uniform Cosmic Background radiation
  - Uniformity relevant up to $\sim 10Mpc$

There are two possibilities

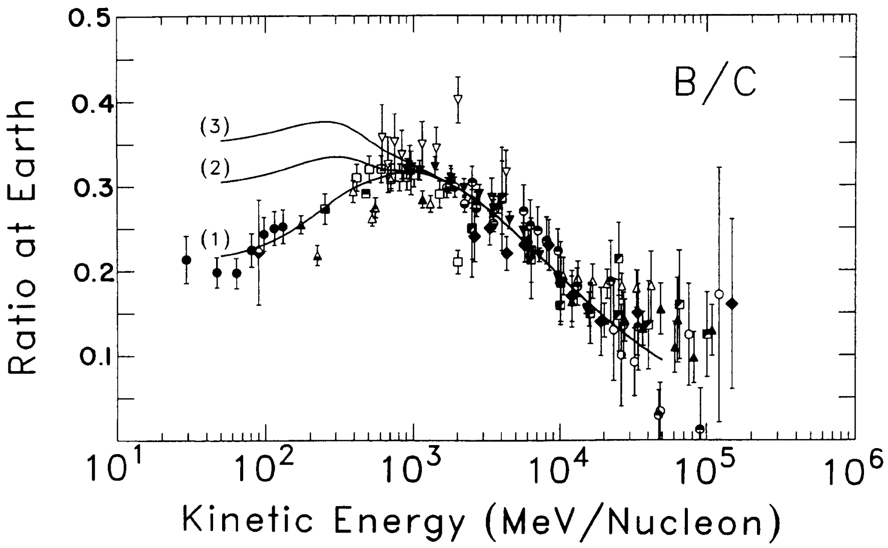
A) Antimatter has disappeared

B) It exists on isolated domains since Big-Bang

AMS will search directly for antimatter in cosmic rays

Cosmic Rays Composition

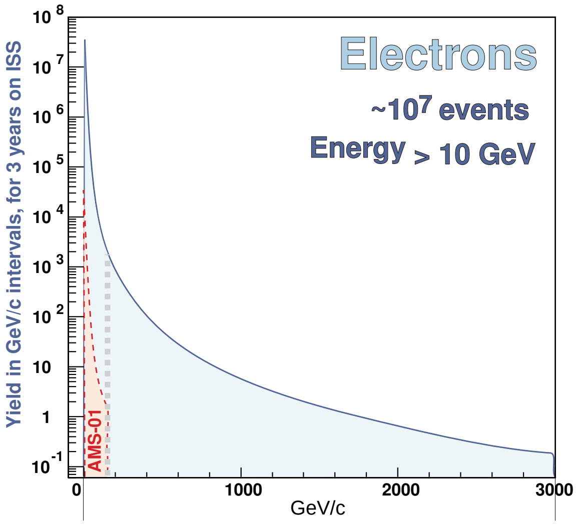
- Relative abundances provide a better understanding of origin, propagation and confinement of cosmic rays

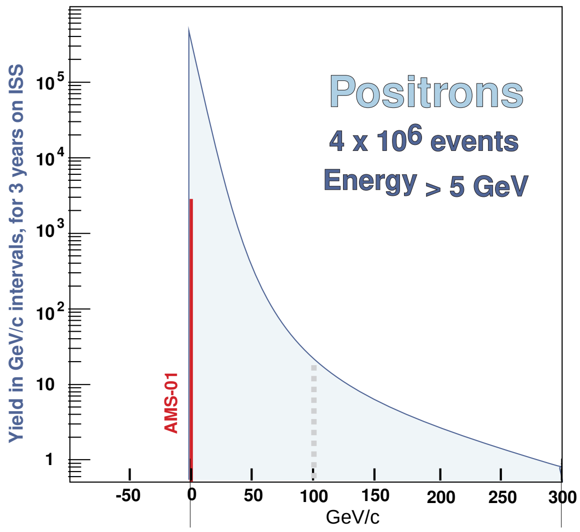


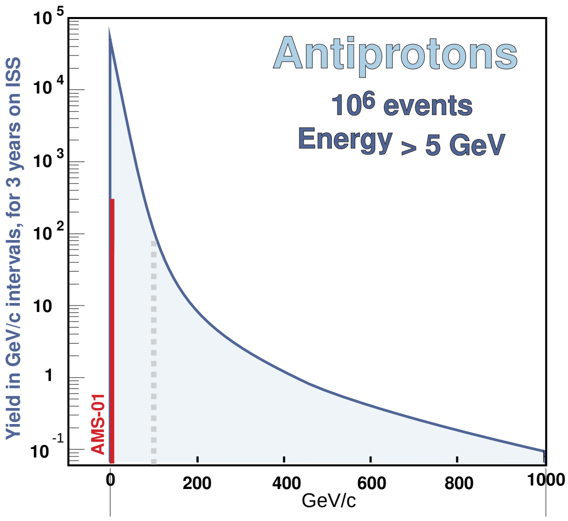
- B/C. AMS-02 will have better statistics than present data up to 100 GV

- D/p. AMS-02 will reduce the uncertainity by a factor $\sim$ 100. Measurement of D possible up to 4 GV
- $^3He/^4He$. AMS will reduce the uncertainity by a factor $\sim$ 200. Mesurement ^3He possible up to 5 GV
- $^{10}Be/^9Be$. ^{10}Be ($\tau = 1.6 \times 10^6\ yr$) decays to ^9Be stable isotope. It provide information of average density of the medium and confinement time in the galaxy. AMS-02 will increase enormously the ^{10}Be statistics.

Data yields


Electrons
~10^7 events
Energy > 10 GeV
Yield in GeV/c intervals, for 3 years on ISS
AMS-01
GeV/c


Positrons
4 x 10^6 events
Energy > 5 GeV
Yield in GeV/c intervals, for 3 years on ISS
AMS-01
GeV/c


Antiprotons
10^6 events
Energy > 5 GeV
Yield in GeV/c intervals, for 3 years on ISS
AMS-01
GeV/c

Baryogenesis

Theoretical conditions were formulated by Sakharov:

A.D. Sakharov, JETP Lett. 5(1) (1967)

- Baryonic charge (B) is not conserved
  Up to now not observed experimentally

Super-Kamiokande results on nucleon decay

Mode	Efficiency	Background	Candidates	Limit(90% CL)
$p \to e^+\pi^0$	44%	0.2	0	3.3×10^{33} yr
$p \to \mu^+\pi^0$	35%	0.1	0	2.7×10^{33} yr
$n \to n\pi^0$	25%	44.8	44	4.0×10^{32} yr
$p \to nK^+$	51%	1.1	0	7.3×10^{32} yr
$p \to e^+K^0$	11%	1.5	1	6.1×10^{32} yr
$p \to \mu^+K^0$	14%	2.9	0	1.0×10^{33} yr
$n \to nK^0$	14%	22.4	23	1.8×10^{32} yr

- C symmetry is not exact
  Assured by weak interactions

- CP is not an exact symmetry
  Confirmed recently @ CERN (Feb 2000 NA48)

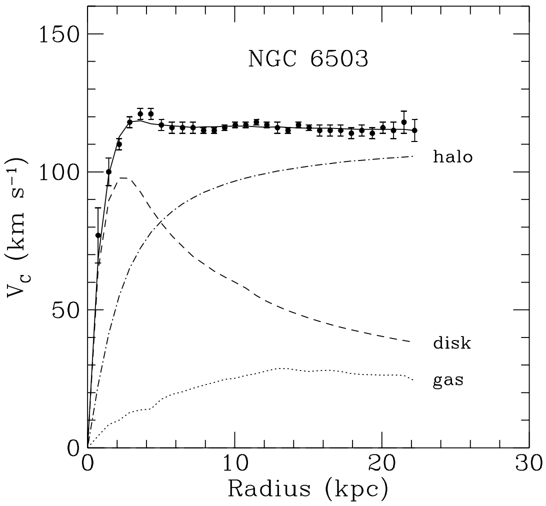
$$\mathrm{R}e(\epsilon'/\epsilon) = (19.3 \pm 2.4) \times 10^{-4}$$

- Baryogenesis only occur in thermally unstable Universe

Search of Dark Matter

- Several evidences of dark matter
  - Rotational velocities of galaxies

K.G. Begeman et al, Mon. Not. R. Astr. Soc 249 (1991) 523



if all mass is visible

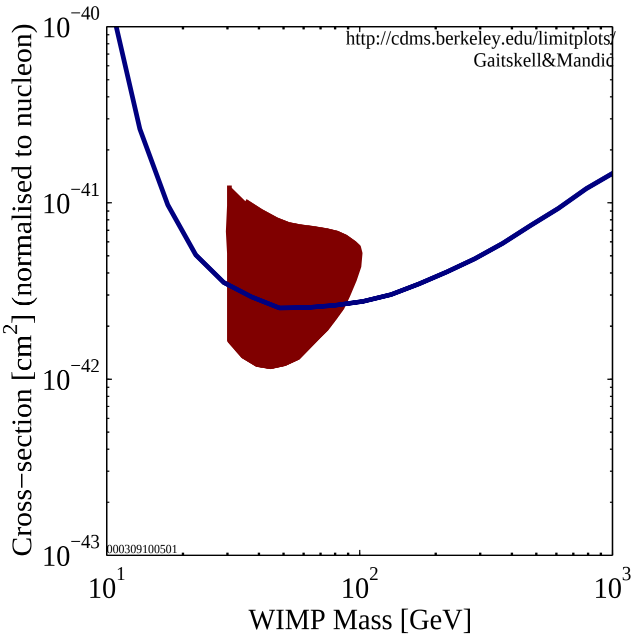
$$v_r \sim 1/\sqrt{r}$$

if $v_r \rightarrow$const:

$$\rho(r) \sim 1/r^2$$
$$M(r) \sim r$$

- Candidates to dark matter are:
  - MACHO (Massive AstrophysiCal Halo Objetcs). Direct search on Milky Way found $(13-17)/11.6 \times 10^6$ such objects that will not explain all dark matter.

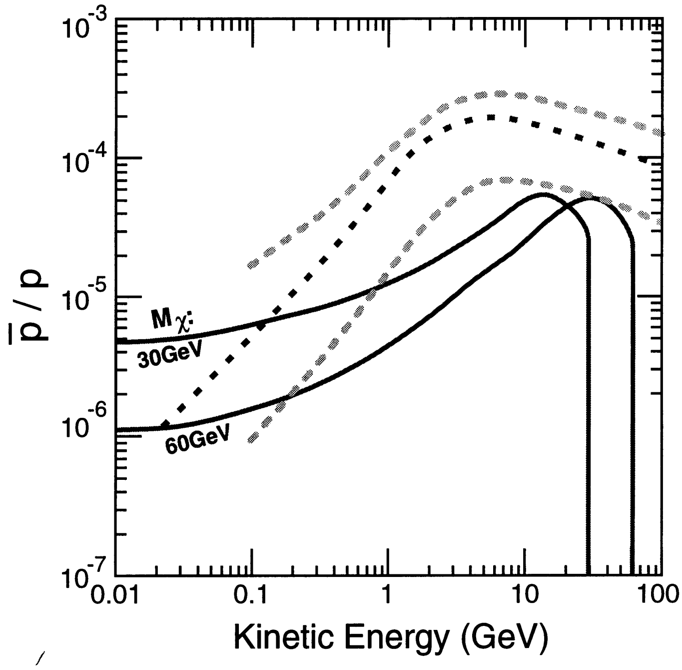
    MACHO coll. astro-ph/0001272
  - WIMP (Weak Interacting Massive Particles). Best candidate is LSP (neutralino - χ). Direct searches not compatible between them.



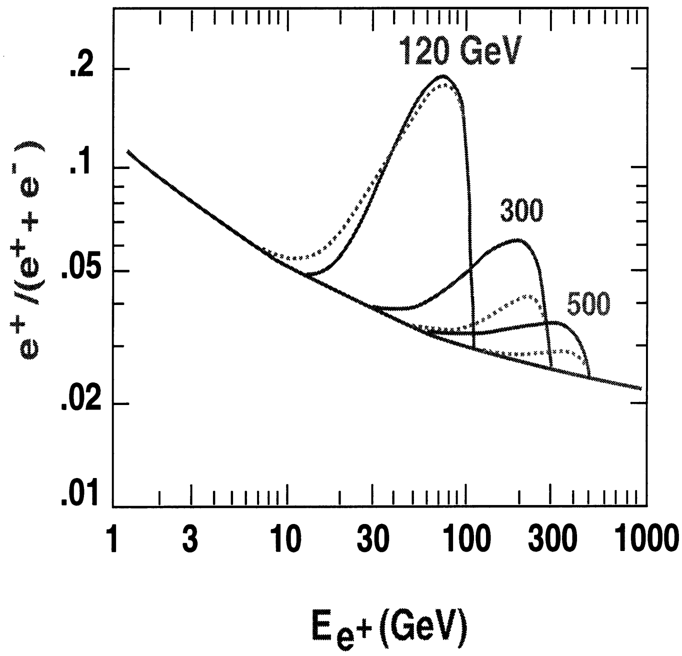
DAMA coll. ROM2F/2000/01 and INFN/AE-00/01
CDMS coll. astro-ph/0002471

AMS can contribute in this search studing signatures from WIMP annihilations on the galactic halo

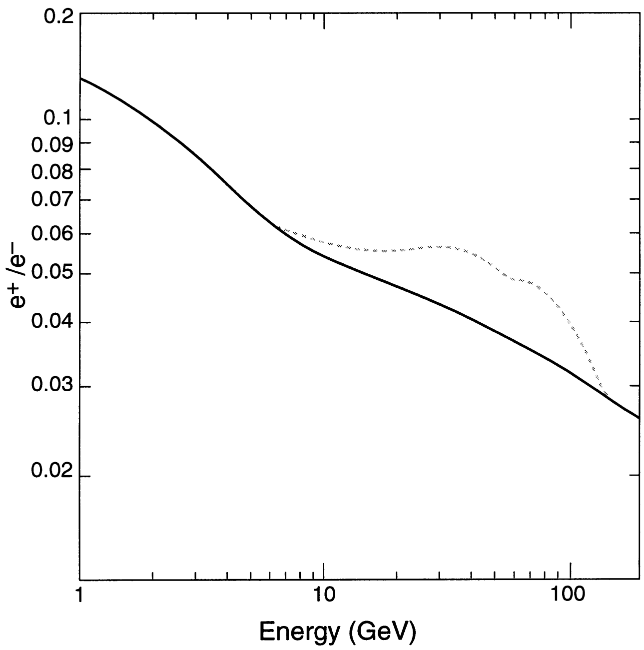
- $\chi\chi \rightarrow gg$. Fragmentation of gluons gives antiprotons



- $\chi\chi \rightarrow W^+W^-, ZZ$ in case χ is a pure higgsino



- $\chi\chi \rightarrow f\bar{f}$



- $\chi\chi \rightarrow \gamma\gamma, Z\gamma$ Monochromatic lines
- $\chi\chi \rightarrow W^+W^-, ZZ$ Continuum spectra. More abundant that monochromatic lines.

γ Physics

- Astrophysical sources of γ rays:
  - point sources: blazars and GRB
  - diffuse sources: γ ray background, γ from WIMP annihilation.
- Knowledge of γ-ray increased last decade due to EGRET
  - EGRET 30 MeV - 30 GeV
  - Ground experiments threshold $\sim$200 GeV
  - Next satellite generation
    * AGILE (2002) 30 MeV - 50 GeV
    * GLAST (2005) 20 MeV - 300 GeV
- AMS can cover both gaps in time and in energy. Discovery 120-170 new blazars and search of monoenergetic gammas from WIMP annihilations.

Conclusions

- Very sensitive magnetic spectrometer will be placed on ISS.
- Cosmics rays composition will be measured with orders of magnitude better than before and up to TeV region
- γ physics will be covered efficiently
- AMS-02 will open new sensitivity window in the search for antimatter and supersymetric dark matter in the galactic halo