AMS-02 experiment on the International Space Station

IF UJ, 18 May 2004

Mariusz Sapinski

Outlook

- Remarks about Cosmic Rays:
  nature, properties,
  history and techniques of measurements
- AMS 01 – a prototype
- AMS 02 - detector
- AMS 02 – physics goals
- Prospects

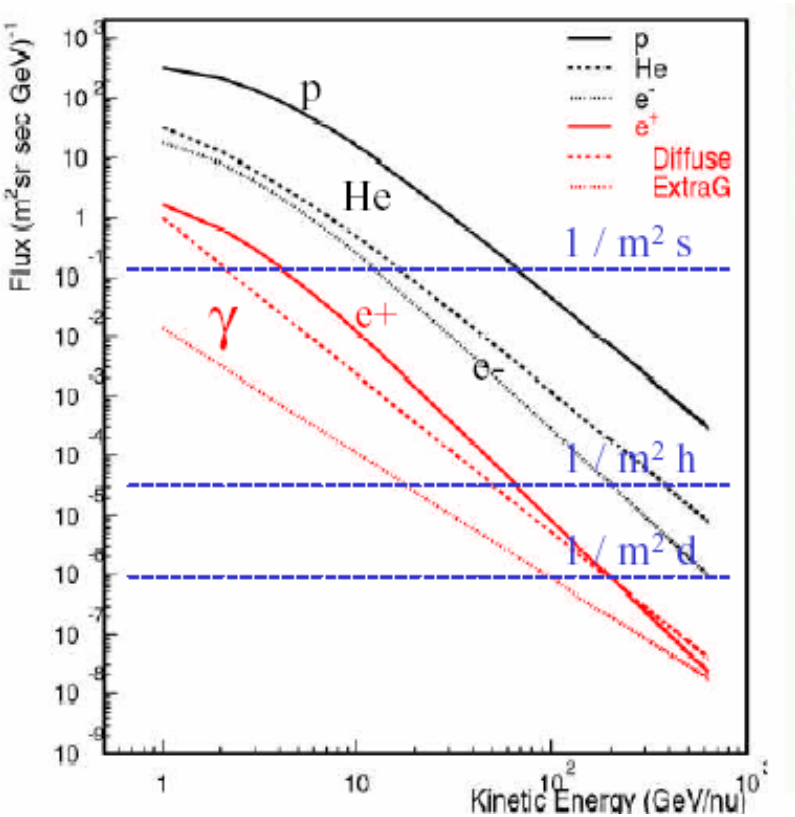
AMS – Alpha Magnetic Spectrometer or

- Anti-Matter in Space

Cosmic Rays

- Protons Dominant Component
- He 5% of P flux at 10 GeV
- p^- ~ 10^{-3} % of P Flux
- anti- D -very small amount, heavier anti-nuclei unobserved
- Power Spectra: Supernova Shock Acceleration n≈2.7

  (few theories we belive in)
- Propagation →Magnetic Fields



„knee" – 10^6 GeV

Astroparticle studies are embedded in Cosmic Ray Physics

CR measurements

- Discovery – 1900-1912: Elster,Geitel,Wilson,Hess...
- Measurements on the Earth's surface
  – variety of techniques:

  Cerenkov imaging and not imaging telescopes, fluorescence detectors ....

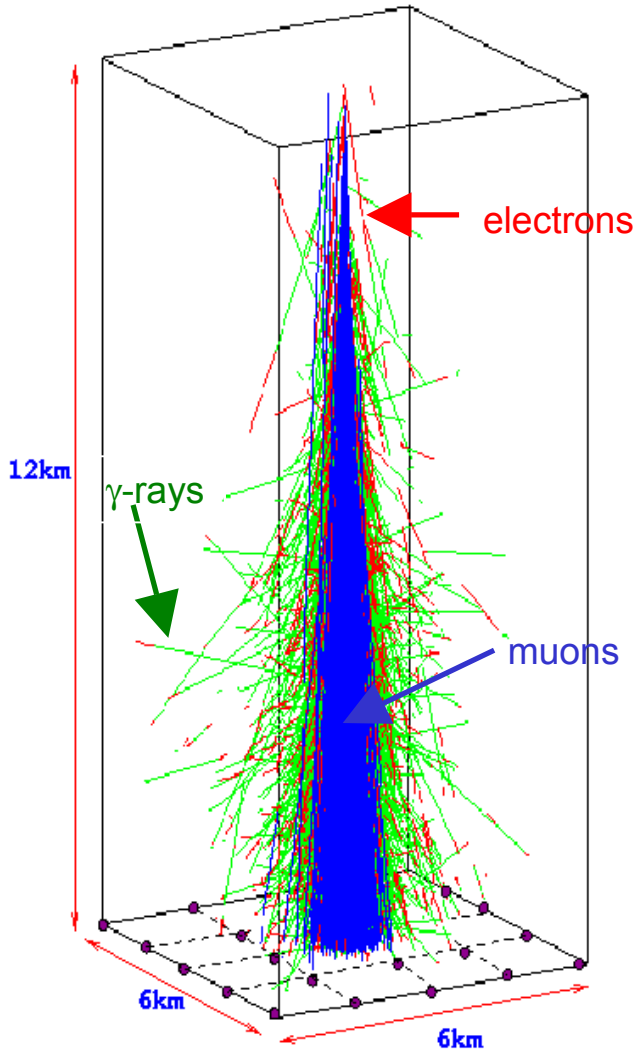
- Balloon – born instruments

  calorimeters, trackers, antennas, emulsions

- Space – born experiments

Atmospheric cascades

- Atmosphere as an active volume
- Detectors of muons or Cerenkov radiation or fluorescence emission
- New idea: measure of GHz radio pulses
- Atmosphere models... (CORSIKA)

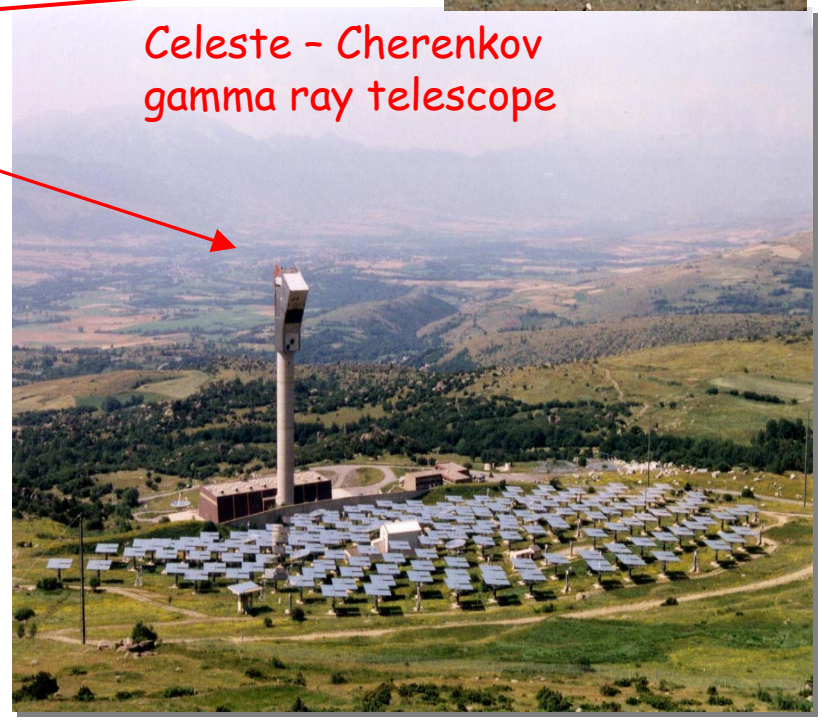


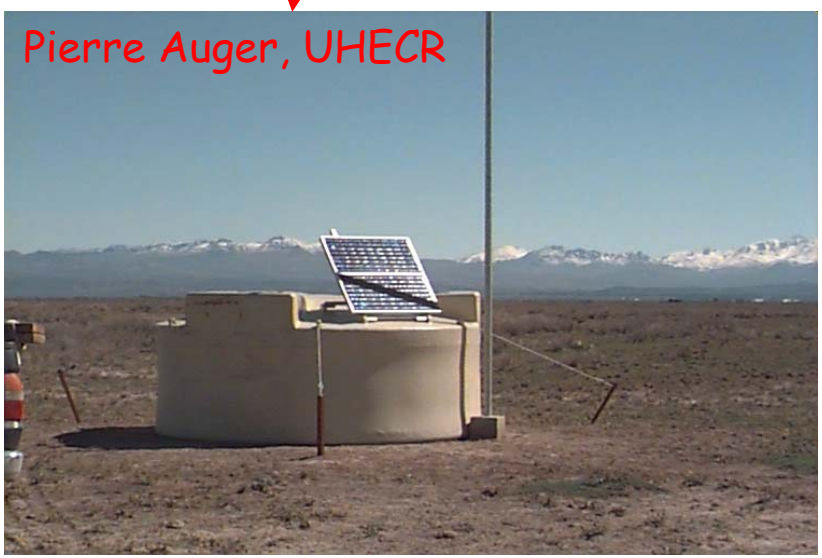
Ground-experiments

- Measurements on the Earth's surface
  - variety of techniques:
  - energies above 50 GeV

gamma

charged CR





Other experiments: Fly`s Eye, AGASA, KASCADE, MILAGRO, HESS...

Balloon-born instruments

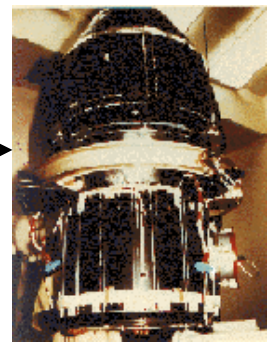
- Altitude 20-40 km - only a few cm of atmosphere!
- Duration – few days

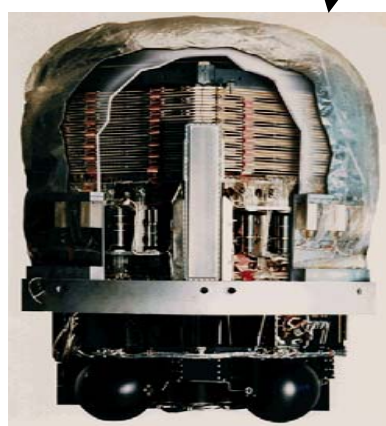
- JACEE – Japanese-American Collaborative Emulsion Experiment
- BESS – Balloon-borne Experiment with a Superconducting Spectrometer
- CAPRICE – The Cosmic Anti Particle Ring Imaging Cerenkov
- HEAT – High Energy Antimatter Telescope
- IMAX – Isotope Matter Anitmatter eXperiment
- MASS2 – Matter Antimatter Spectrometer

... and others!

Satellite experiments

- 1968 Oso III (USA) – first gammas, 50 MeV, from GC
- Vela military satellites, 1969-1972 – for gammas
  – GRB discovery
- SAS 2, 1972 observation of Crab, Vela, GC
- Cos-B,1975-82 – catalogue of 25 sources (incl. extragalactic 3C275)
- EGRET (on CGRO) 1991-2000
- Charged CR: NINA-1 (1998-99) and NINA-2 (2000-2001) ;
  for both energies 10 MeV-2 GeV, altitude 300-450 km

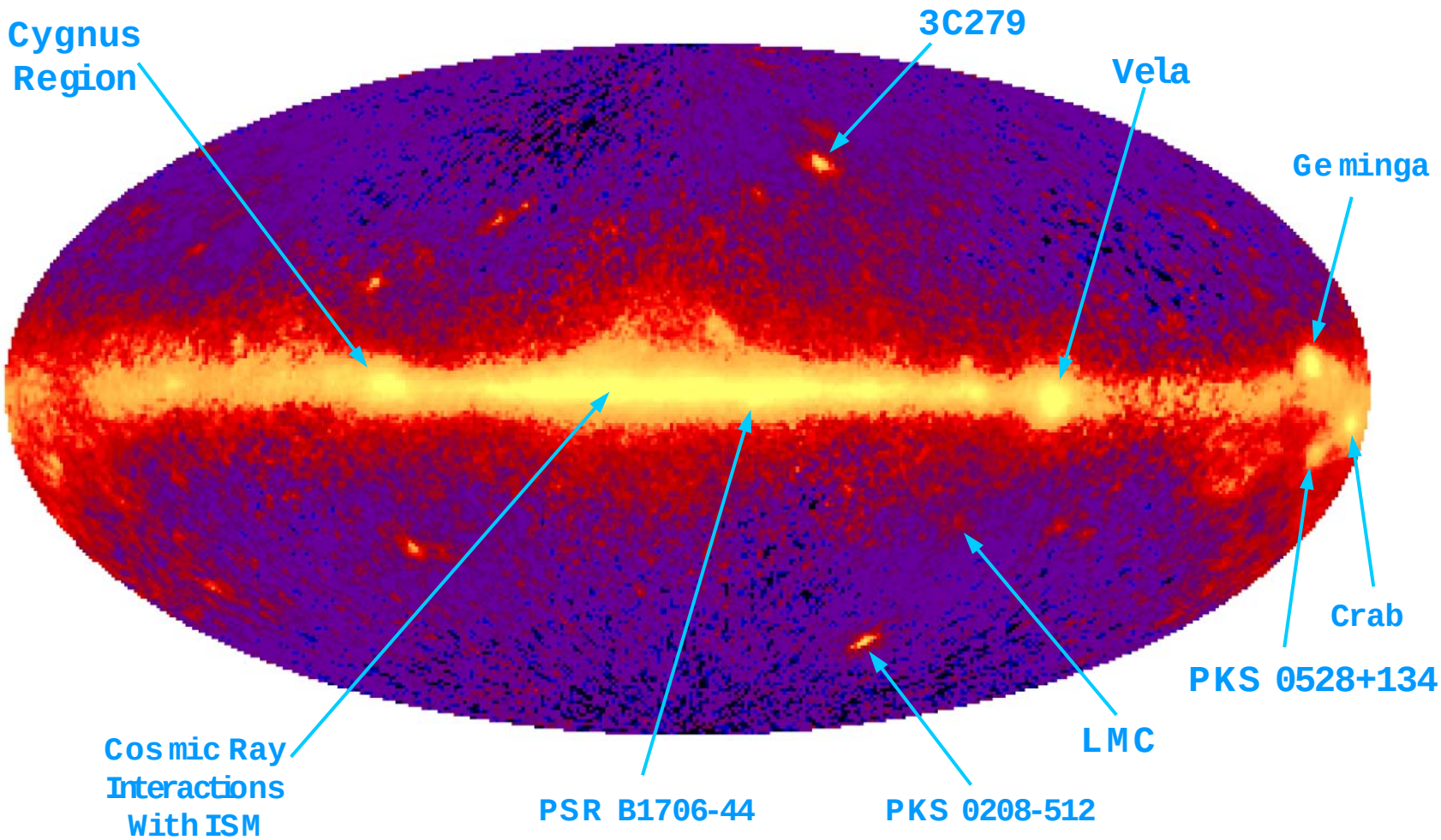




altitude about 300 km min! (what happends between 40-300km?)

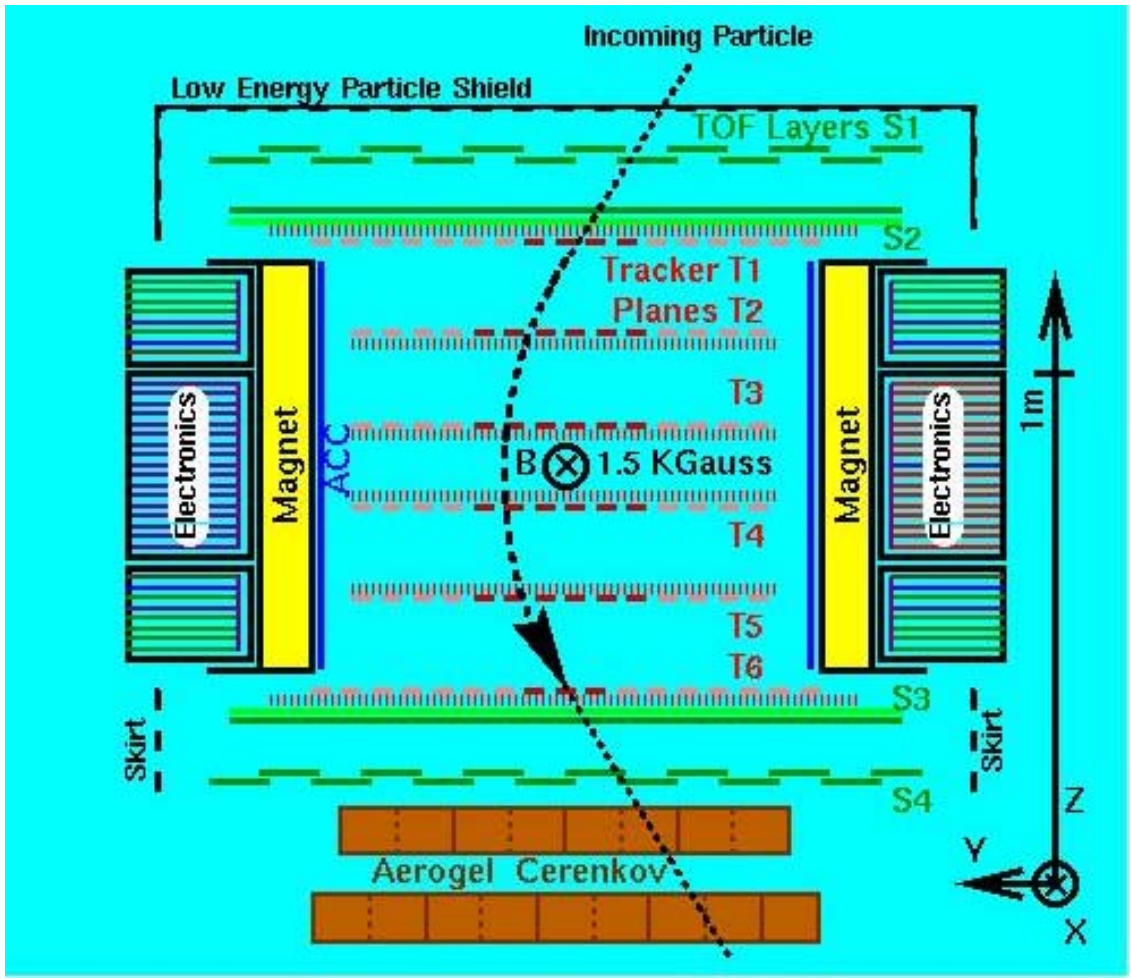
remark: project EUSO (OWL)

The Sky in Gamma > 100 MeV (EGRET)



AMS 01

- Launched on Space Shuttle Discovery in July 1998
- 10-day flight
- Detector mass 4200 kg
- Detector power consumption 700 W

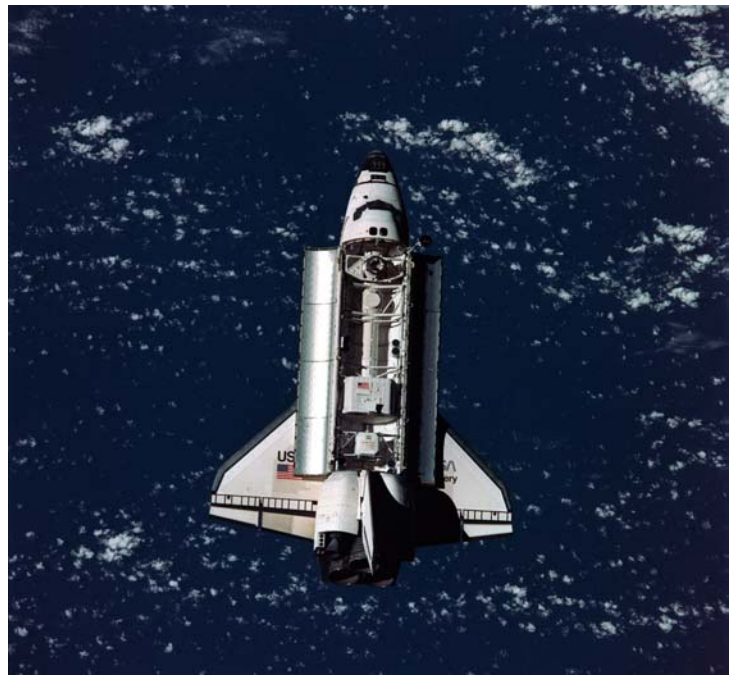


AMS 01

- Very interesting results, eg.:

A new radiation belt has been found at the altitude 300-400 km, contains e, p and ^{3}He: average lifetime about a few seconds

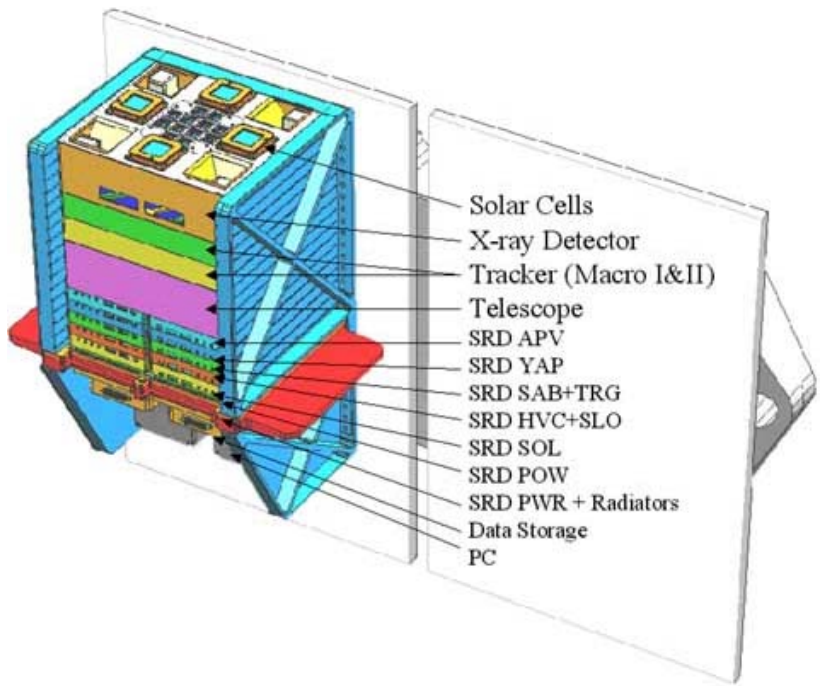
The best present limit on the anti-helium in CR



Phys. Lett. B461, 387-396; Phys. Lett. B472, 215-226; Phys. Lett. B484, 10-22; Phys. Lett. B490, 27-35 ..... And other publications!

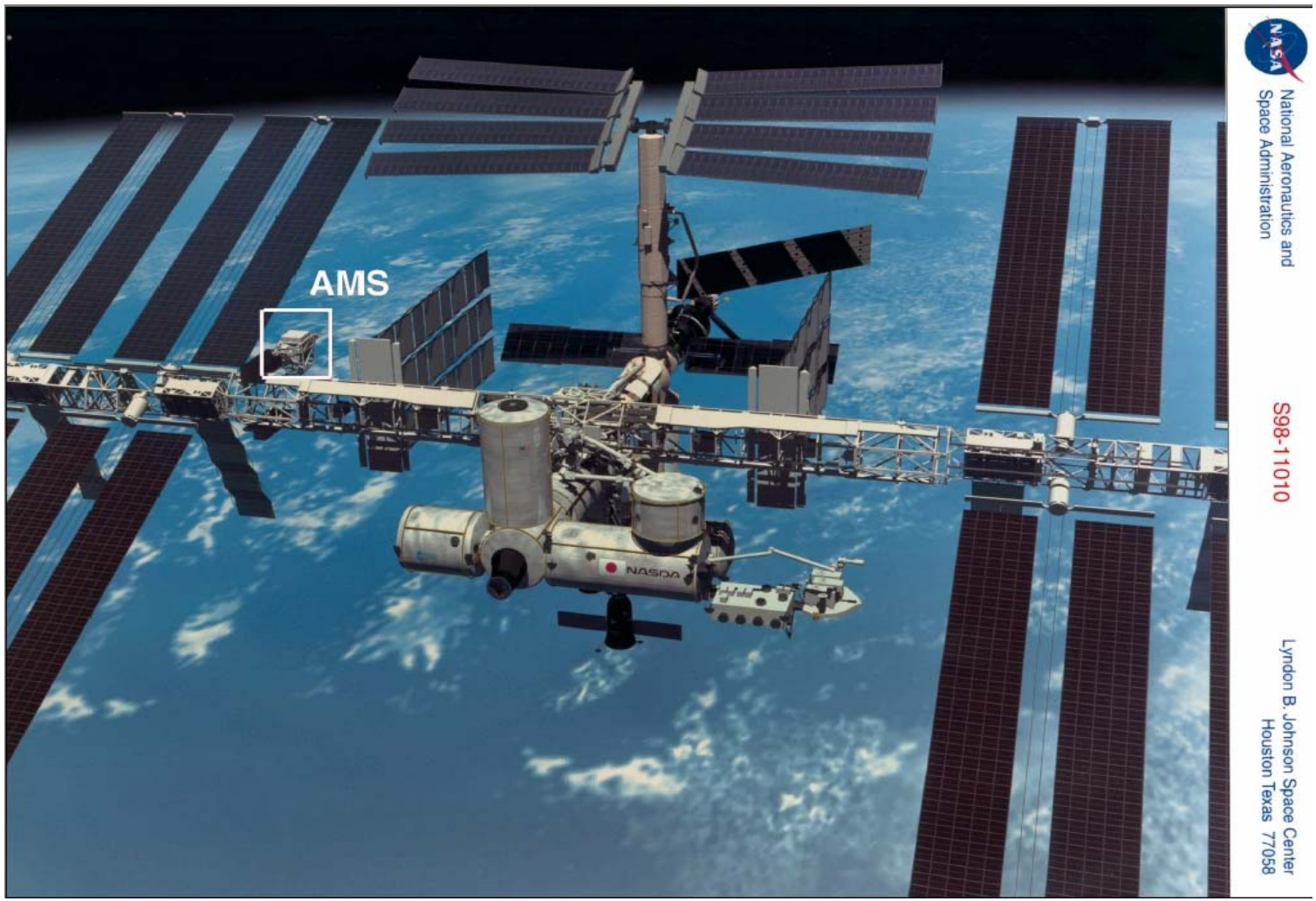
SRD detector

- Tested on STS Endeavour in December 2001
- Array ($2x3m^2$) of yttrium aluminium perovskite (YAP) crystals $25x25x2\ mm^3$ each
- SRD would be placed on top of the AMS
- It would measure synchrotron radiation of multi-TeV electrons and positrons in geomagnetic field (time resolution is crucial)
- It works well, but it is too late to include it in AMS-02 project



AMS-02 on ISS

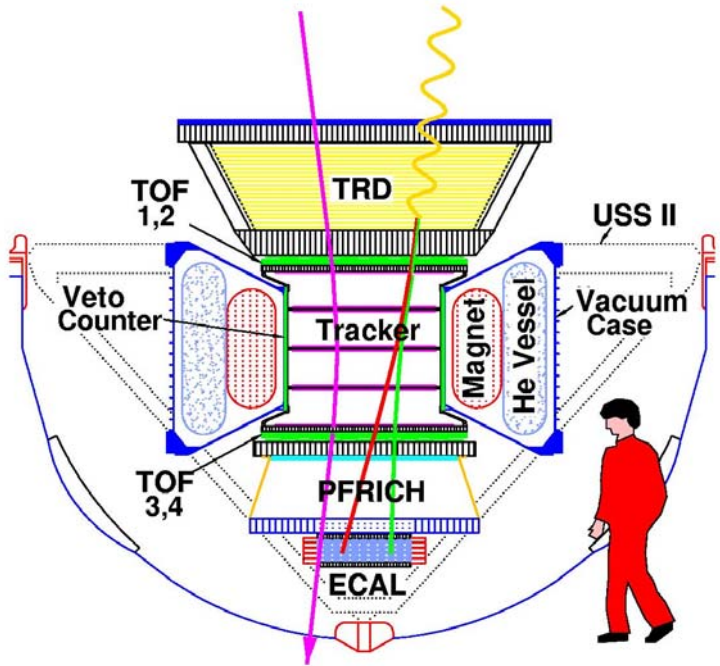
HEP – NASA experiment




ALPHA
Magnetic
Spectrometer
Size: 109 m x 80 m
Mass: 420 t.

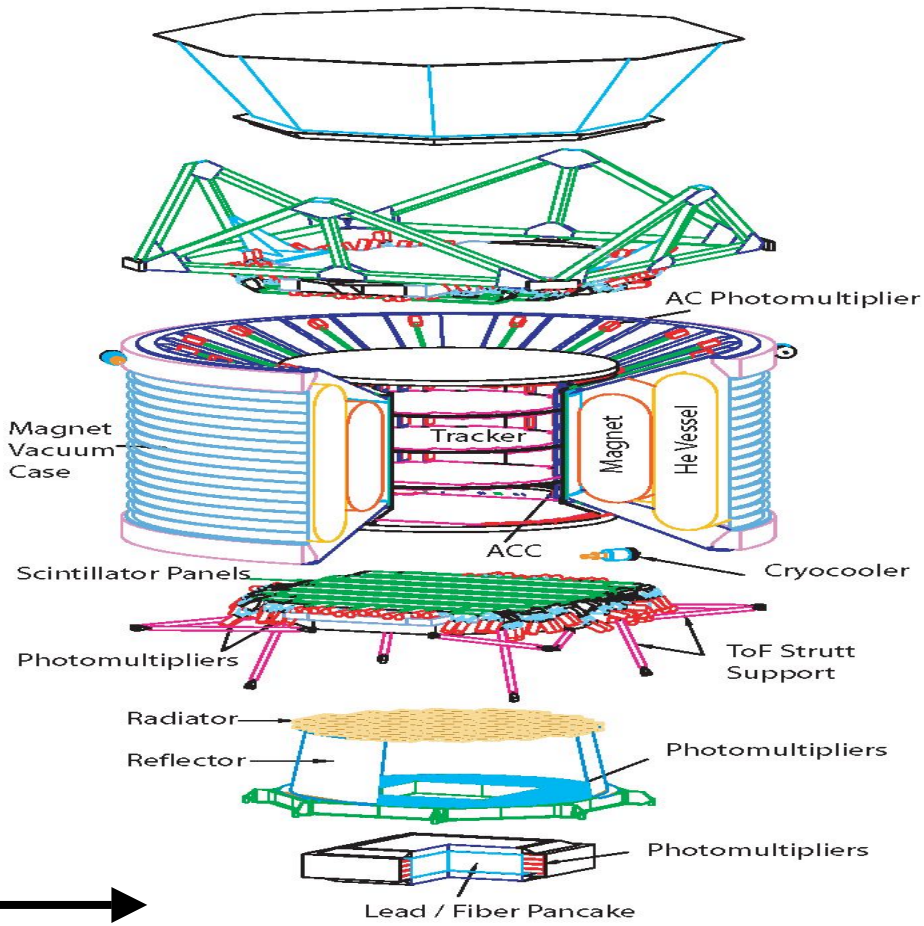
General AMS-02 design considerations

- High Statistics require Good Discrimination
- Space requirements:
  - Thermal Environment (day/night: $\Delta T \sim 100^{o}C$)
  - Vibration (6.8 G RMS) and G-Forces (17G)
  - Weight (6700 kg) and Power (2000 W)
  - Vacuum: $< 10^{-10}$ Torr
  - Reliable for 3 years – Redundancy
  - Radiation: Ionizing Flux ~ 1000 cm^{-2}s^{-1}
  - Orbital Debris and Micrometeorites
  - Small dipole moment



Detector

AMS-02



3 meters

2.5 meters

- Foam + drift tubes (Xe/CO_2)
- e/h rejection ~ 10^3-10^2 up to 300 GeV

TRD
Transition Radiation Detector
Germany

TOF: (s1, s2)
Time Of Flight Detector
Italy

TRACKER
Silicon Tracker
Germany, Holland, Italy, Switzerland (6 m^2)

ACC
Anticoincidence Counter
Germany

MAGNET
U.K. superconducting (0.85 $T \cdot m^2$)

TOF: (s3, s4)
Time Of Flight Detector
Italy

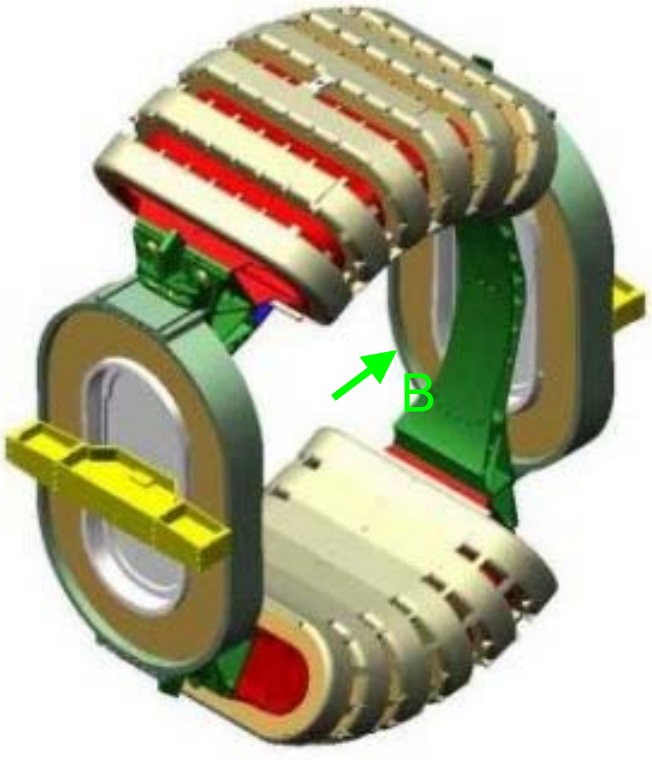
RICH
Ring Image Cherenkov Counter
Italy, Portugal, Spain
France

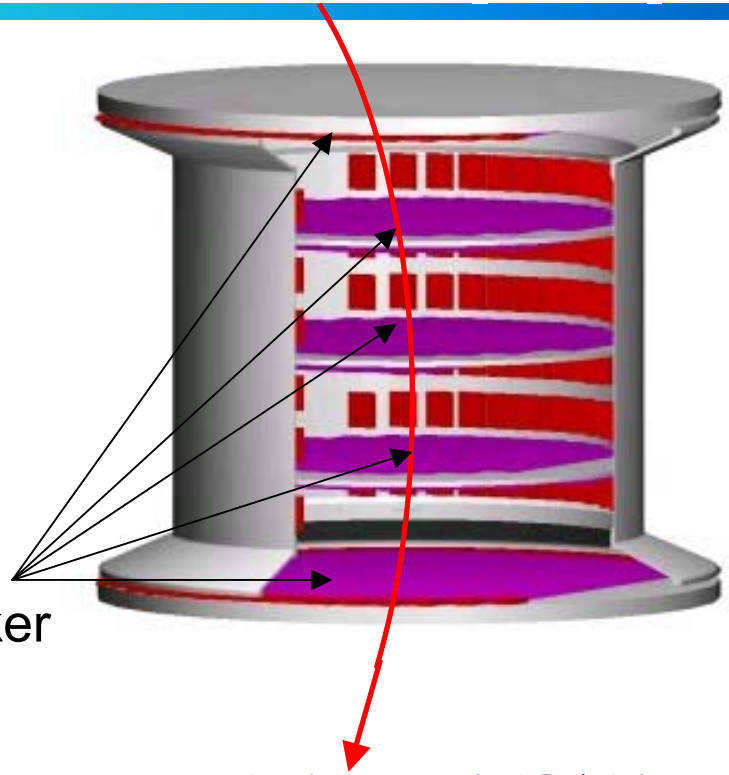
EMC
Electromagnetic Calorimeter
China, France, Italy

y2K269b Becker R.

Acceptance 0.5 m^2 sr

Eg. tracker

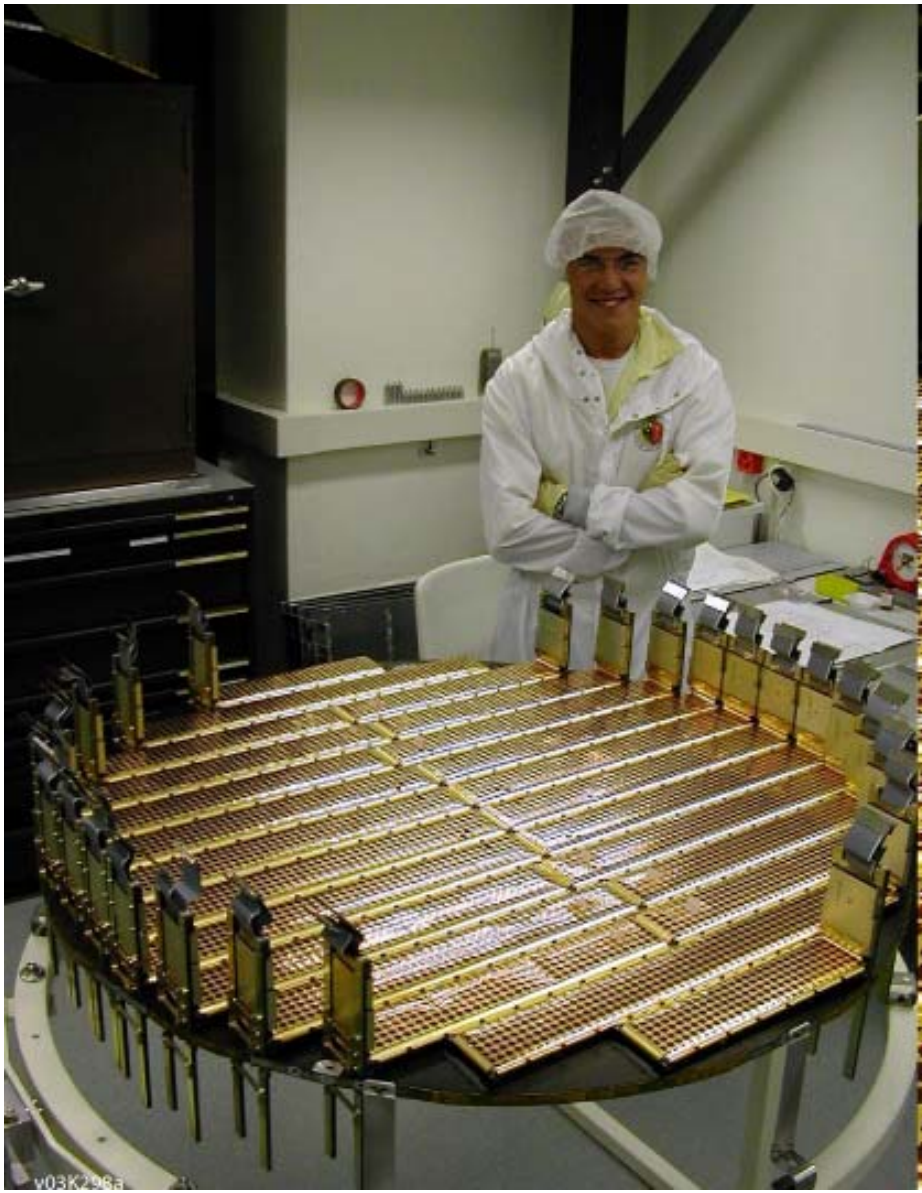


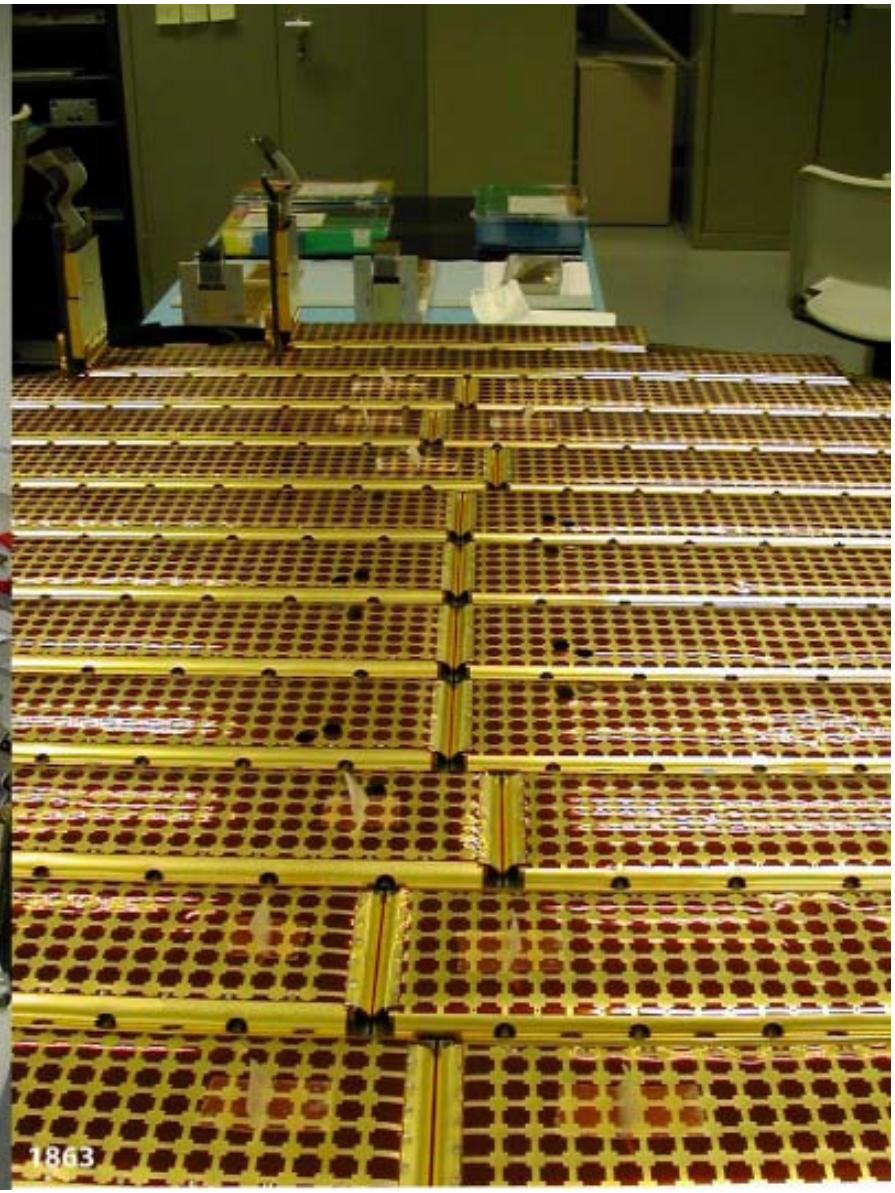


- State of the Art
- Cryogenic → 3000 Liters Superfluid He
- B = 0.8 T

- Signed Charge (*dE/dx*)
- 8 Planes, ~6m^2
- Rigidity (*dR/R* ≈ 2% for 1 GeV Protons) with Magnet
- Pitch (Bending): 27.5 microns
- Pitch (Non-Bending): 104microns

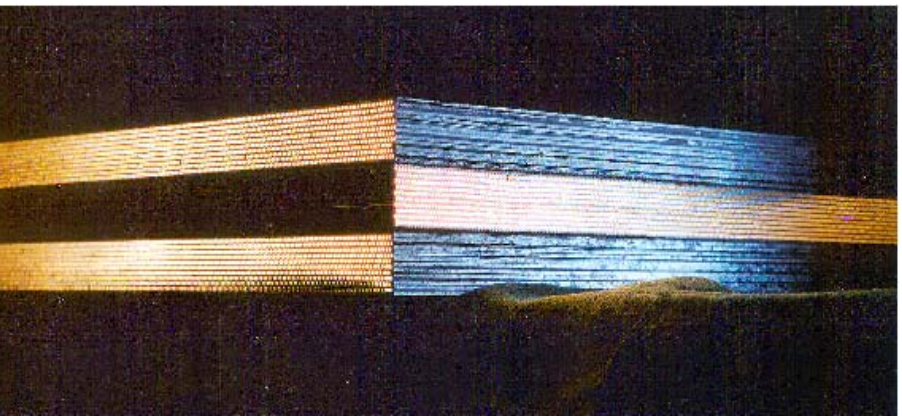
Eg. tracker (II)



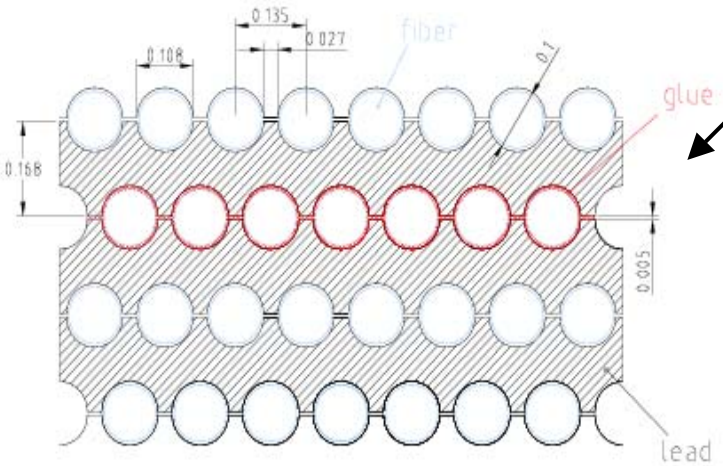


Eg. ECAL

The ECAL is a 3D sampling calorimeter made of Pb/scintillating fibers (Spacal Type).

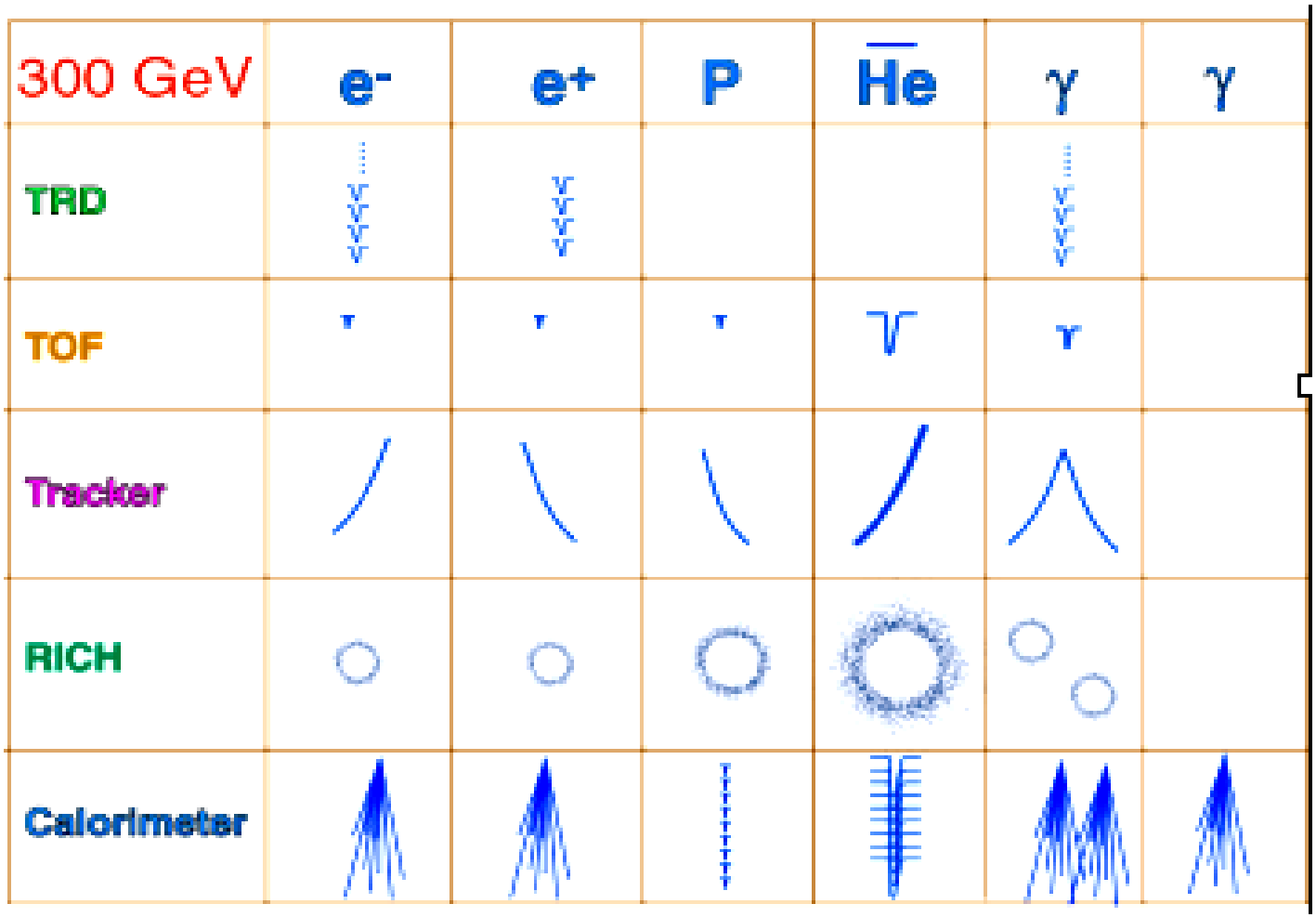


ECAL structure : only 3 superlayers shown



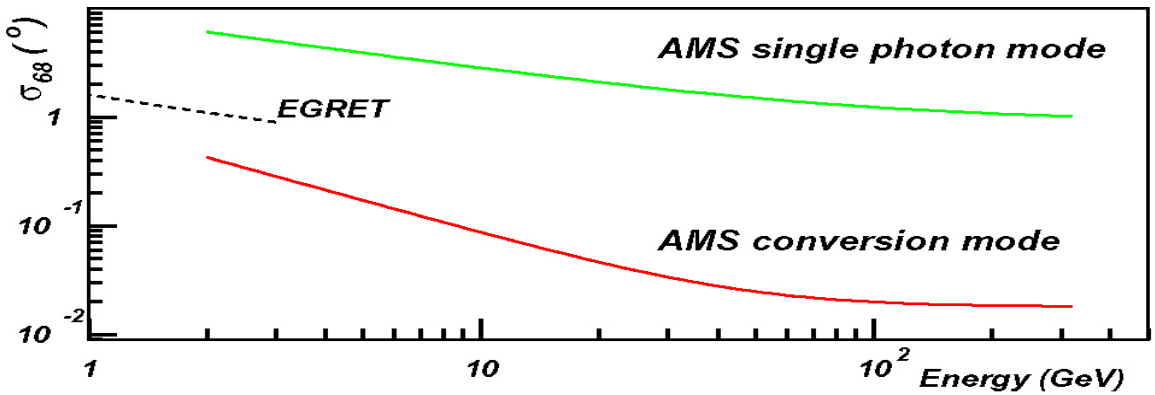
- 9 superlayers alternatively oriented along X or Y axis
- 1 SuperLayer:
  11 grooved Pb foils (1mm thick) interleaved with 10 layers of scintillator fibers (∅=1mm) glued by an epoxy resin
- Active detector
  - 9 superlayers alternatively in Y & X direction
  - 16 radiation lengths (X_0)

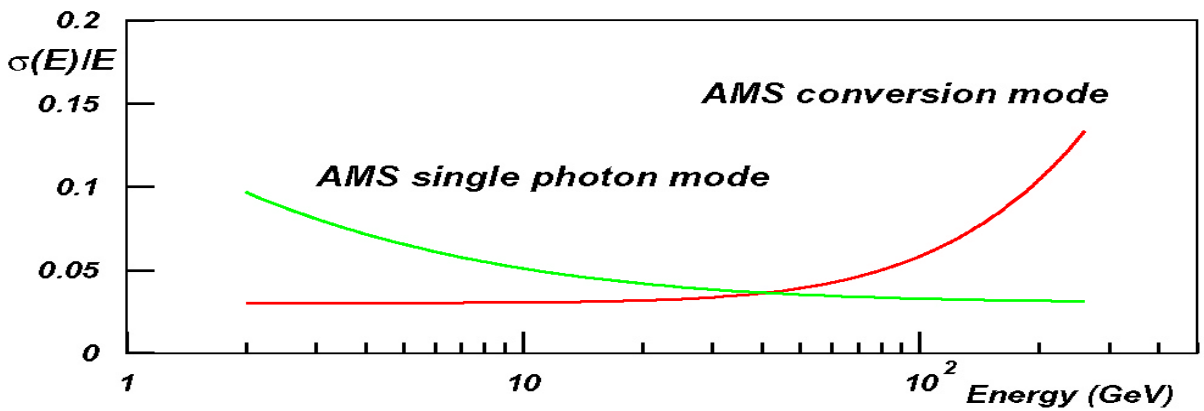
AMS-02 Completeness



Performances

Angular and Energy resolution for γs





Overall proton/γ suppression factor > 10^5

AMS collaboration

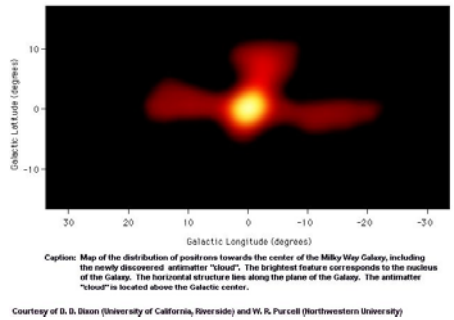
~ 200 scientists + dozens of contractors

U. of Aarhus (DK); Academia Sinica (Taiwan); U. of Bucharest (RO); Chinese Academy of Sciences, Inst. of High Energy Physics IHEP (Beijing); Chinese Academy of Sciences, Inst. of Electrical Engineering IEE (Beijing); Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas CIEMAT (Madrid, ES); Chung Shan Inst. of Science and Technology CSIST (Taiwan); EHWA Women's University (Seoul, KR) ETH Zurich (CH); Florida A&M U. (Tallahassee, FL); U. of Geneva (CH); Helsinki U. of Technology (FI); INFN Bologna & U. Bologna (IT); INFN Milano (IT); INFN Perugia, (IT); & U. Perugia (IT); INFN Pisa & U. Pisa (IT); INFN Roma & U. Roma (IT); INFN Siena & U Siena (IT); Inst. Superior Technico (Lisbon, PT); Inst. di Ricerca sulle Onde Elettromagnetiche IROE (Florence, IT); Inst. des Sciences Nucleaires de Grenoble ISN (FR); Inst. for Theoretical and Experimental Physics ITEP (Moscow, RU), Jiao Tong U. (Shanghai); Johns Hopkins U. (Baltimore, US); U. of Karlsruhe (DE); Kurchatov Institute (Moscow, RU); Kyungpook National University CHEP (Taegu, KR); Laboratoire d'Annecy-le-Vieux de Physique des Particules LAPP (FR); Laboratório de Instrumentaço e Física Experimental de Partículas LIP (Lisbon, PT); U. Maryland (College Park, US); Max Planck Inst. (Garching, DE) ; Massachusetts Inst. of Technology MIT (Cambridge, US); U. Montpellier (FR); Moscow State University (RU), Nat'l Aerospace Laboratory NRL (Amsterdam, NL); U. Nacional Autonoma de Mexico (MX); Nat'l Space Program Office (Taiwan); Nat'l Central University NCU (Taiwan); Nat'l Inst. for Nuclear Physics and High Energy Physics NIKHEF (Amsterdam, NL) I. Physikalisches Inst., RWTH Aachen (DE); III. Physikalisches Inst., RWTH Aachen (DE); Southeast U. (Nanjing); U. of Turku (FI); Yale U. (New Haven, US); Lockheed Martin, USA; Space Cryomagnetics LTD, UK; Arde, Inc., USA; CAEN Aerospace, IT; Carlo Gavazzi Space SpA, IT; ISATECH Engineering GmbH, DE; OHB GmbH, DE; Linde; NASA; ESA

Detector constructed in Europe, Taiwan and China in collaboration

Anti-matter search

- The **Primordial Antimatter** content of the Universe is unknown, and if there is any at all …
- Cobe limit : wide antimatter regions excluded up to 20 Mpc
- Sakharov's 3 Principles of Baryogenesis :
  1. Baryon Number Violation
  2. C and CP Violation
  3. Deviation from Thermal Equilibrium



Caption: Map of the distribution of positrons towards the center of the Milky Way Galaxy, including the newly discovered antimatter "cloud". The brightest feature corresponds to the nucleus of the Galaxy. The horizontal structure lies along the plane of the Galaxy. The antimatter "cloud" is located above the Galactic center.

Courtesy of D. D. Dixon (University of California, Riverside) and W. R. Purcell (Northwestern University)

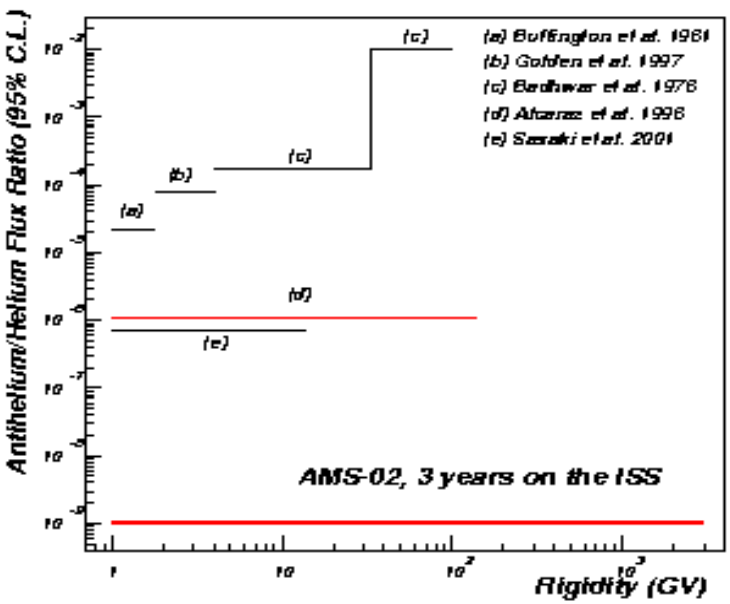
- Single anti-He Cosmic Rays nucleus → Strong Evidence for Large Anti-matter Domains in the Universe
- Single anti-C CR nucleus → Antimatter Bubbles (Stars, … ?)

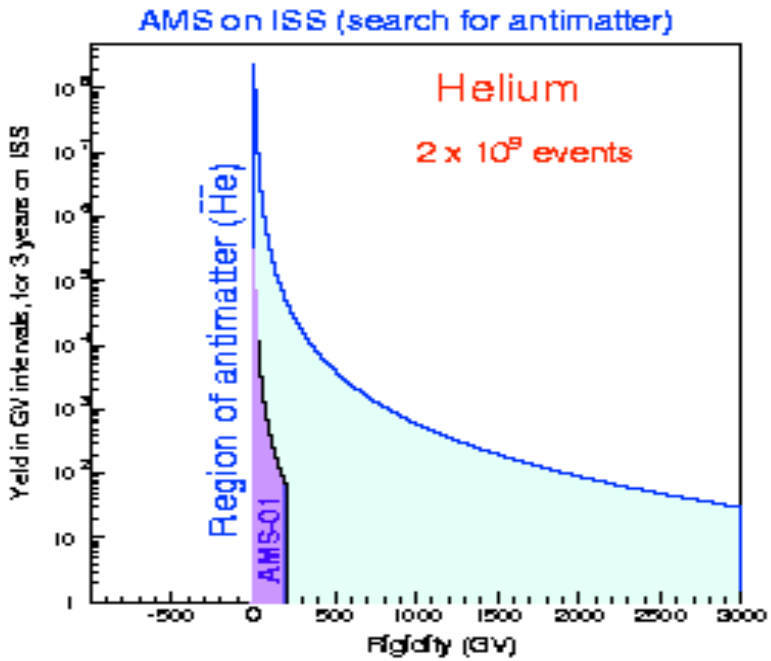
We need :

- very large statistics of primary CRs
- very good particle identification, including charge sign reconstruction

Anti-matter search – expected results

- No single anti-He detected by AMS-01
- AMS-02 will improve sensitivity by 10^3





Indirect Dark Matter Search

- Universe Matter budget – 90 % is Dark & non baryonic
- Structure formation – Dark Matter is Cold (CDM)
- SUSY provides an excellent WIMP candidate – neutralino : χ^0_1

$$\chi^0_1\chi^0_1 \rightarrow qq^- \ , \ W^+W^-, \ H^+H^-, \ \ldots$$
$$\rightarrow p- \ , \text{anti-D} \ , \ \gamma \ , \ e^+, \ +X$$

- Completeness of AMS-02:
  - p^- : Excess at Energy of a 10-1000 GeV
  - D^- : Excess Below 1 GeV
  - e^+ : Structure in Spectra above few GeV
  - γ : Energy Spectra differ from "power laws", or γ line detection $\chi^0_1\chi^0_1 \rightarrow \gamma\gamma, \ Z\gamma$

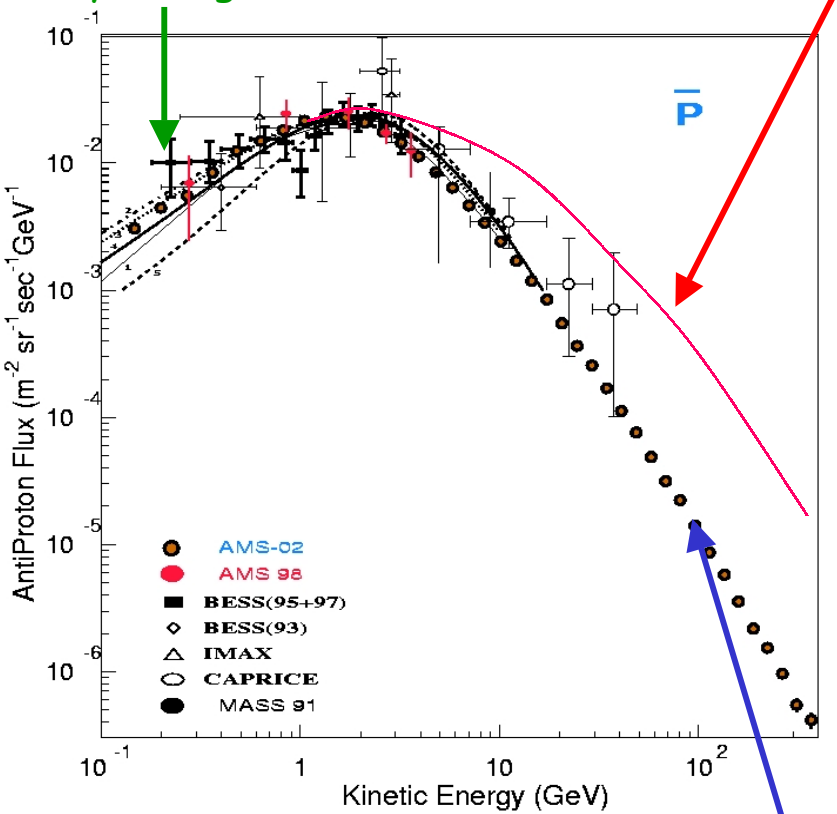
(W. de Boer et al. hep-ph/0309029)

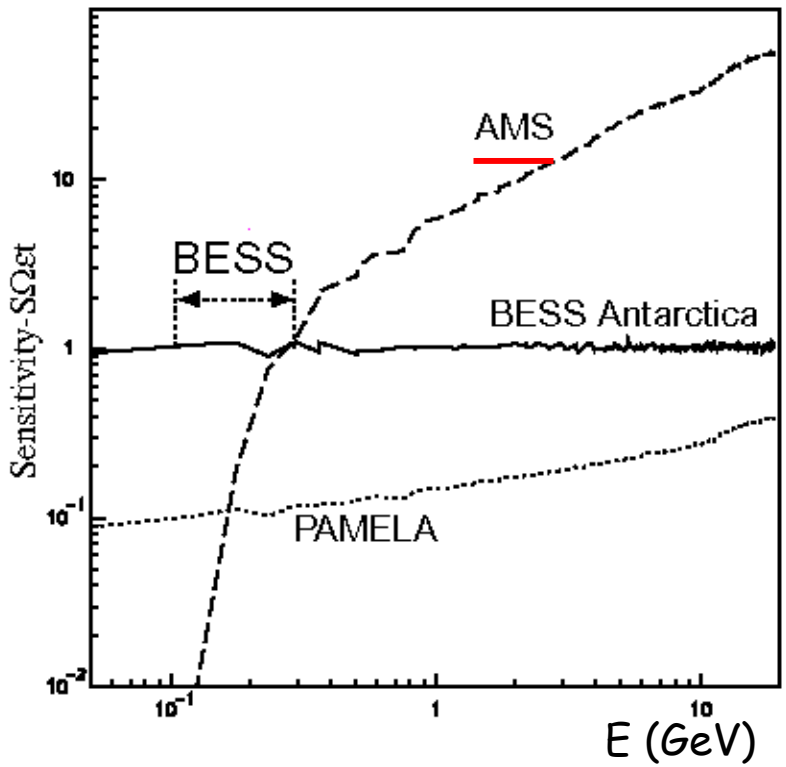
Anti-protons

In case of a SUSY contribution at high energy, this could be measured

Ullio (1999) , $m\chi \sim 900$ GeV

Tertiary background





Full 3 yr (MC) AMS sensitivity without considering any DM signature.

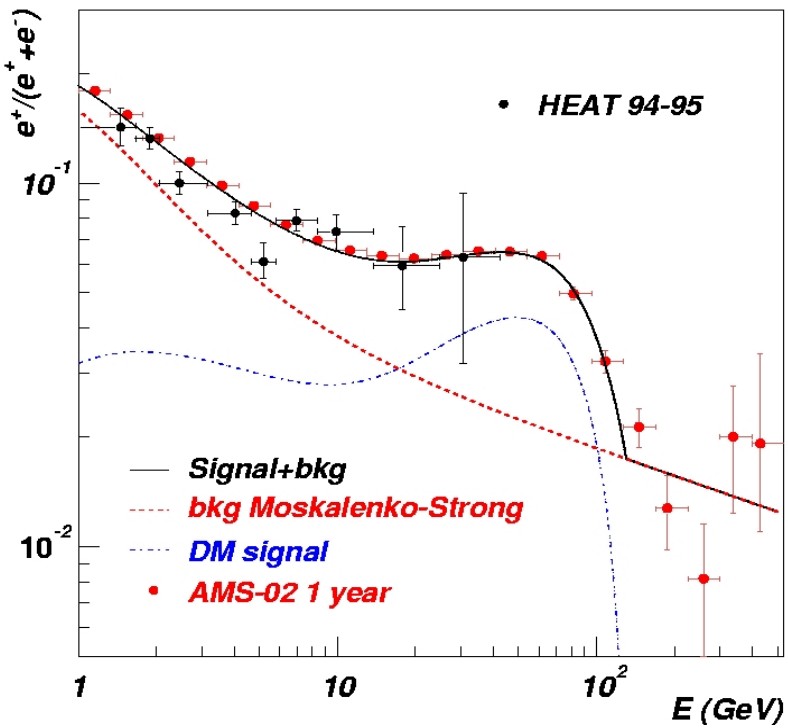
Cosmic-Ray Positrons

Heat Data : a bump in energy at 7 GeV, no standard astrophysical interpretation of e+/e- energy distribution

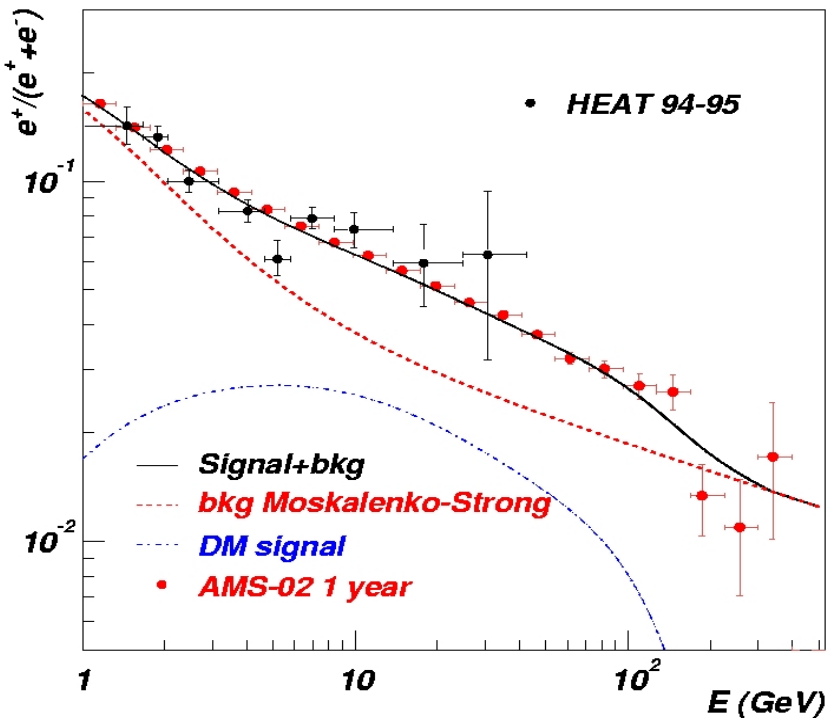
⟶ Precise data extended to higher energies will be provided by AMS

MSSM simulation for AMS-02 need high "boost factors"

m_χ = 336 GeV



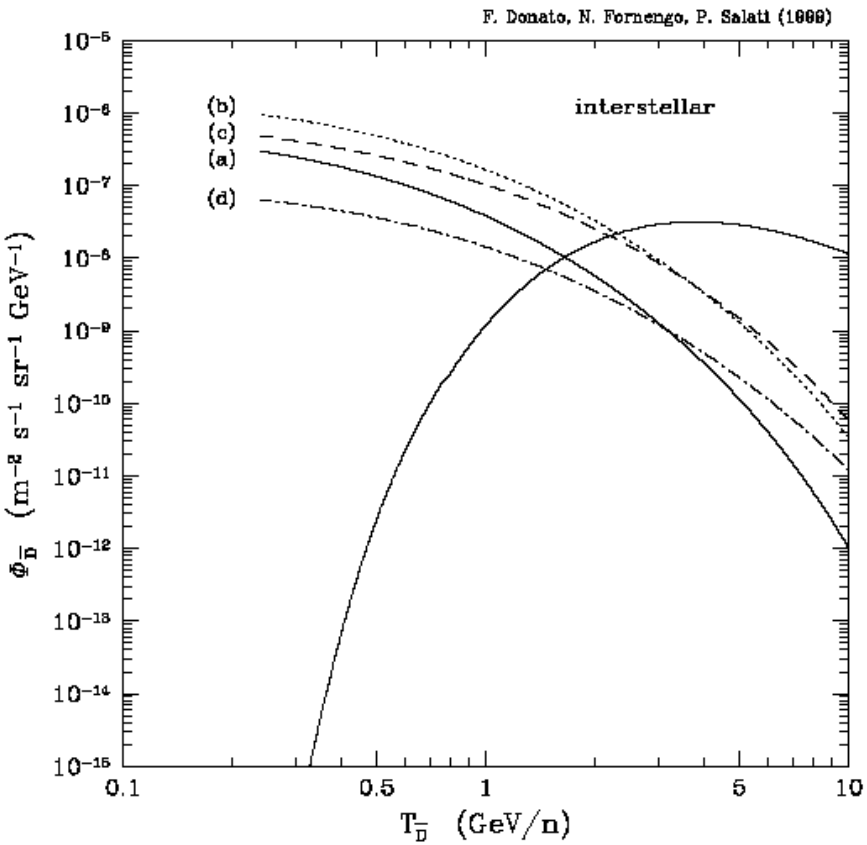
m_χ = 130.3 GeV



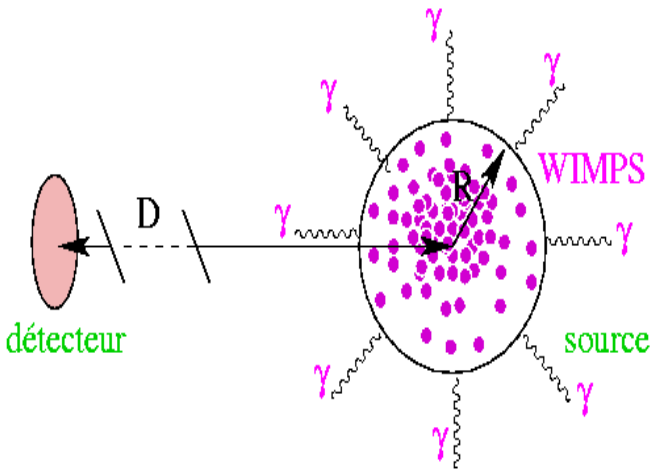
Anti-Deuterons

MSSM : Donato, Fornengo, Salati, 1999

Promising for long exposures large acceptance in space



Dark Matter - γ ray case



Detection rate (source) :

$$\Phi\gamma \sim \frac{N\gamma \langle\sigma v\rangle}{m^2_\chi} \int\int \rho^2(r)\, dl(\theta)\, d\Omega$$

LoS

SUSY — Astrophysics

- diffuse D M : galactic as ν , e+ , p-, D-, Direct Detection
  extragalactic
- source D M : - Galactic Centre (G. C.)
  - Nearby Spiral Galaxies : e. g. M31
  - Dwarf Spheroidals : e. g. DRACO
  - Globular Clusters : ϖ - centauris, Palomar13

→ Enhancement factors from cuspy halos, clumpiness or/and SBH

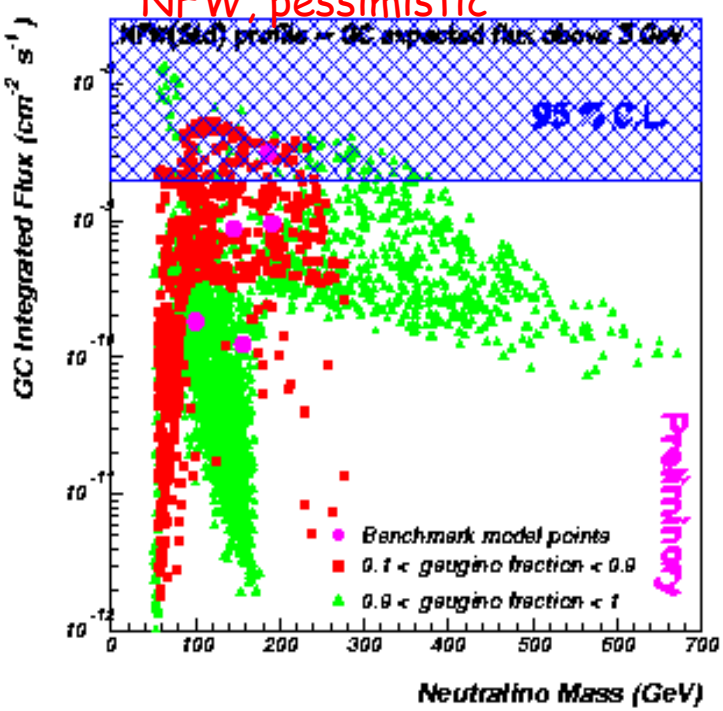
γ-rays from Galactic Centre

mSUGRA simulations for large m_0

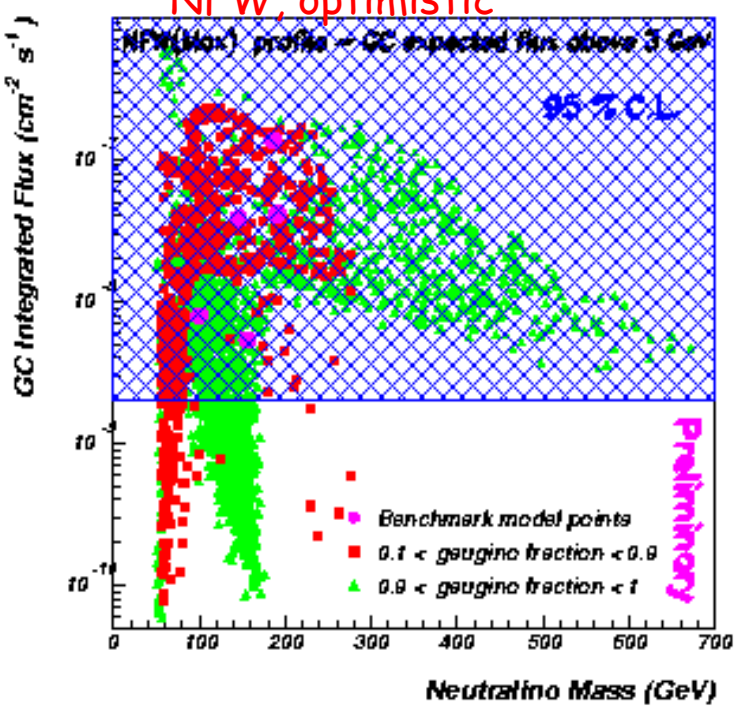
G. C. Navarro-Frenk-White profile with various parameters

"wild scan", flux above 3 GeV

NFW, pessimistic

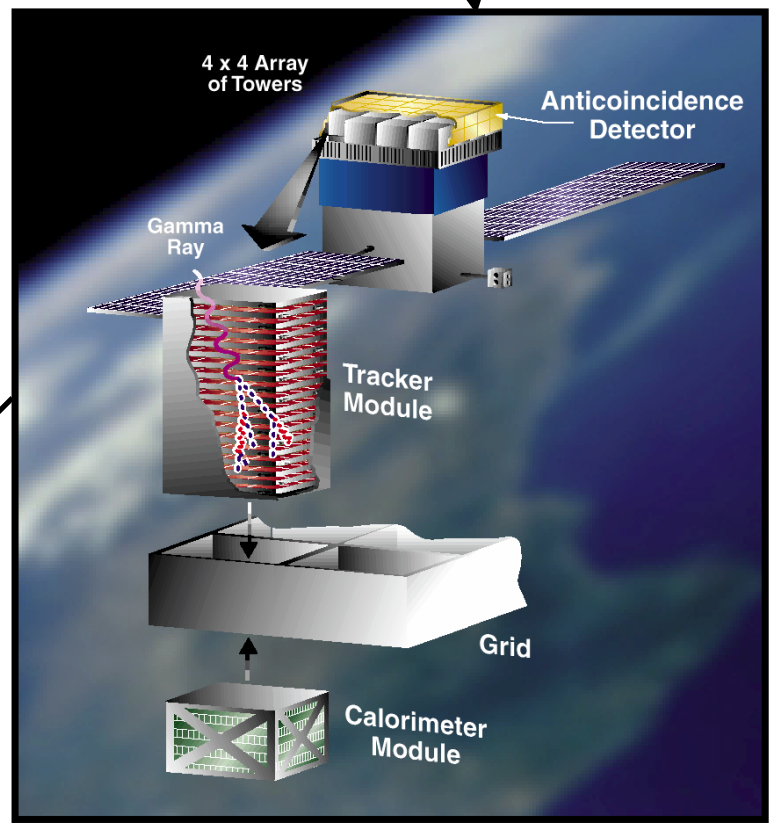


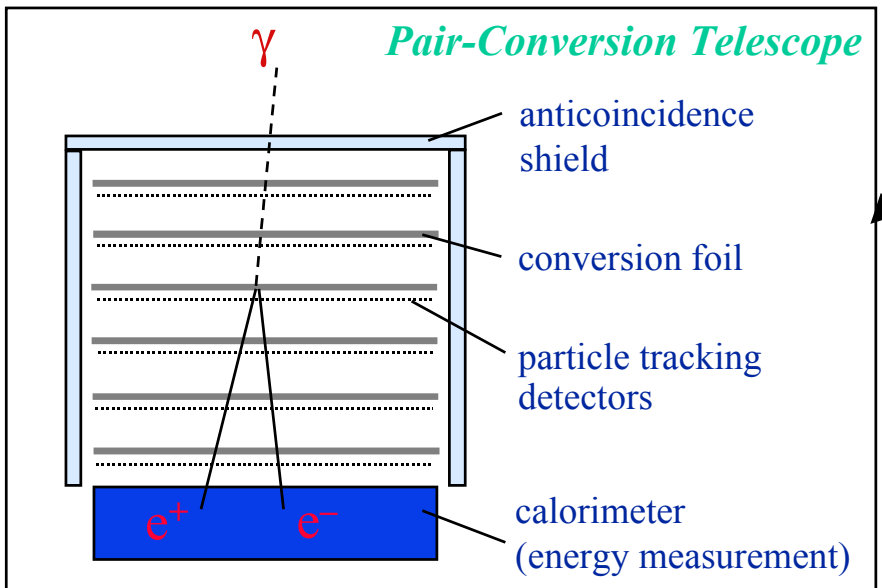
NFW, optimistic



Other experiments

- GLAST – launch in 2006 – high energy gamma telescope
- INTEGRAL
  (X-ray, interesting results concerning GC)
- PAMELA – successor of NINAs
- More distanced future:
  ACCESS (AMS-03)





PAMELA

TRD

• Threshold device. Signal from $e^{\pm}$, no signal from p, π

• 9 planes of Xe/Co_2 filled straws (4mm diameter). Interspersed with carbon fibre radiators ⇒ crude tracking.

• Aim: 10^2 separation e -vs- p (above 1GeV/c). NB: 10^6 with calorimeter.

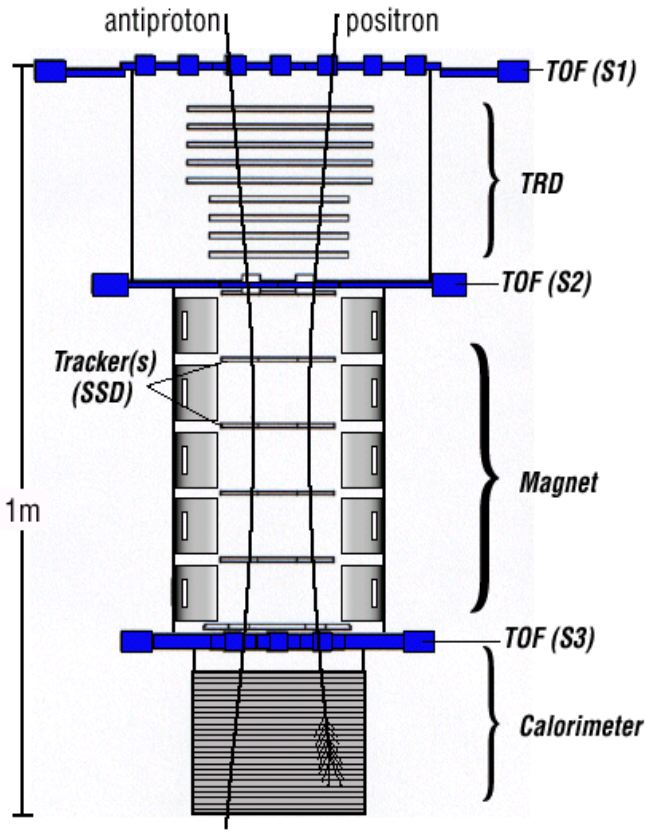
Si Tracker + magnet

• Measures rigidity

• 5 Nd-B-Fe magnet segments (0.4T)

• 6 planes of 300μm thick Si detectors

• ~3μm resolution in bending view demonstrated, ie: MDR = 740GV/c



Antiproton and positron tracks are shown with exaggerated curvature.

[Acceptance ~21 cm^2sr]

Anticoincidence system

• Defines acceptance for tracker

• Plastic scintillator + PMT

• Binary read-out

Time-of-flight

• Gives L1 trigger / detects albedos / particle identification (up to 1GeV/c) / dE/dx

• Plastic scintillator + PMT

• Timing resolution = 70ps

Si-W Calorimeter

• Measures energies of $e^{\pm}$. $\Delta E/E = 15\% / E^{1/2}$.

• Si-X / W / Si-Y structure.

• 22 Si / 21 W ⇒ $16X_0$ / $0.9\lambda_0$

• Imaging: EM - vs- hadronic discrimination. Reconstruct long. and transverse shower profile.

Summary

- **AMS-02 will provide data from**
  October 2006 and at least 3 years on
- **The completeness of AMS-02 detector**
  will allow to measure simultaneously the
  Astroparticle Signals and Cosmic Backgrounds
- **AMS-02 will probe**

– Dark Matter content in various channels (p-, D-,e+, γ)
– Baryon Asymmetry
– Cosmic Rays and γ-Astrophysics (not covered here)
– Exotics, strangelets, PBHs,

and unexpected …

- There is lot of experimental activity in CR physics !