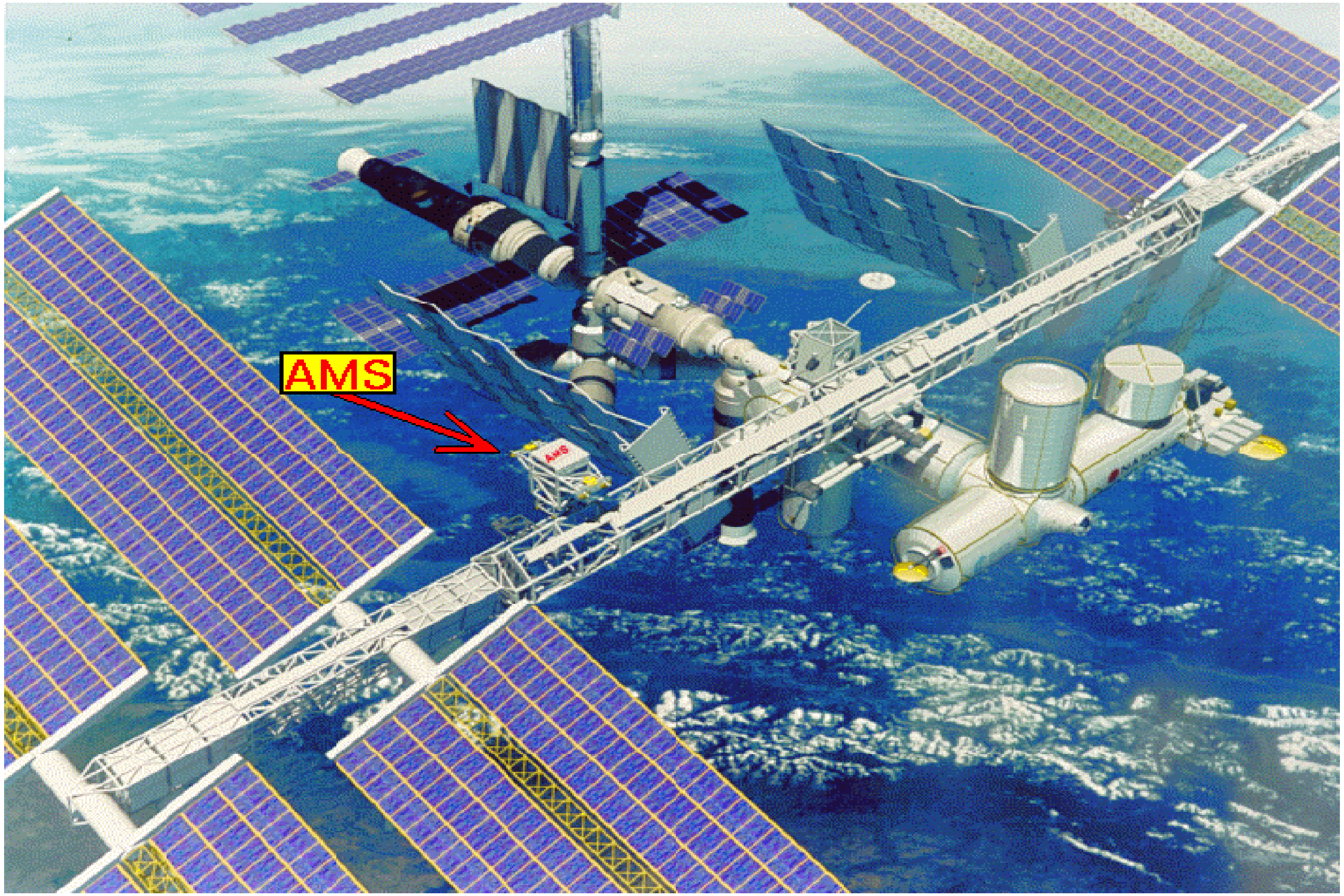
Dark Matter search with AMS-02

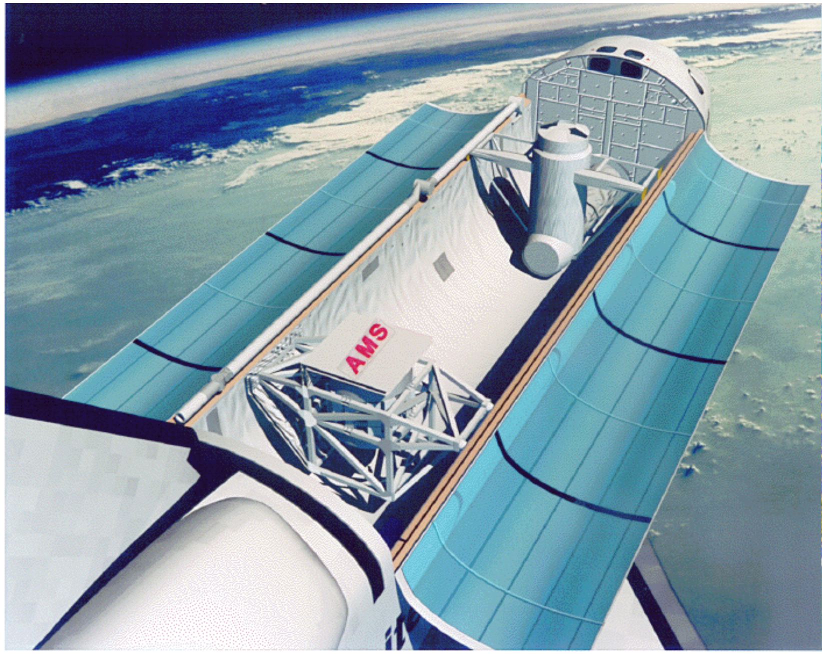


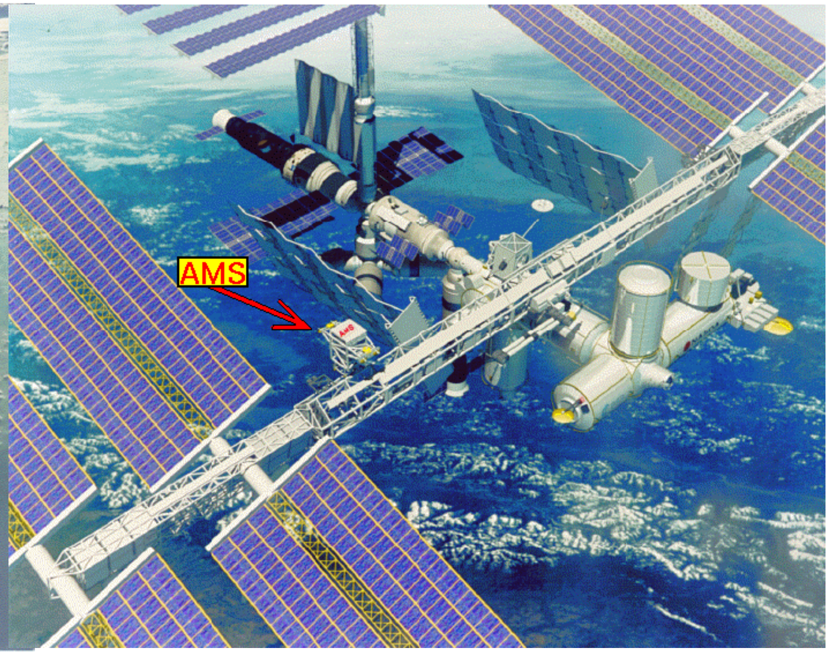
Overview

- What is AMS (01 and 02)
- Dark Matter: WIMPs and halo
- WIMPs annihilation
- Search channels:
  antiprotons positrons antideuterons gamma
- Other experiments: GAPS, Pamela, GLAST
- ^{6}Li mystery

AMS-01 and 02 Experiments

AMS-01





AMS-02

Launched on Space Shuttle Discovery in July 1998 (10-day flight)

AMS-02: Large acceptance cosmic-ray spectrometer to be located on the ISS for a period of at least three years (2008-...)

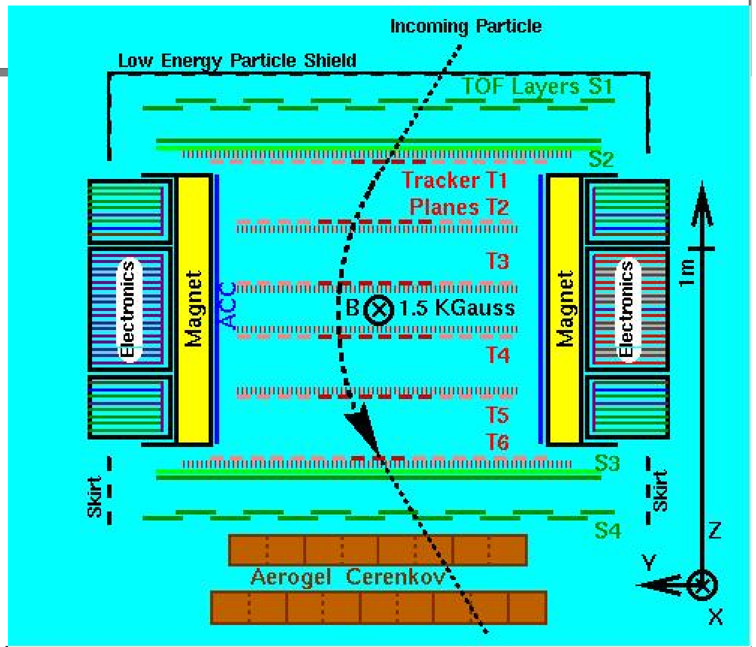
AMS-01

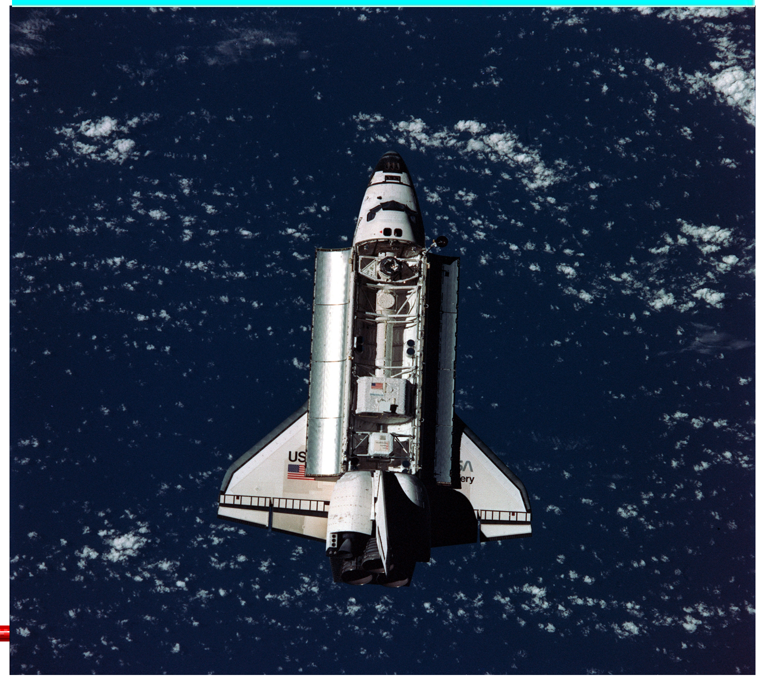
Very interesting physical results:

- Best present limit on antihelium
- One of the best measurement of proton/electron/positron fluxes
- New radiation belt (e,p,^{3}He, atmospheric origin, short-lived)

(Phys. Lett. B461, 387-396;

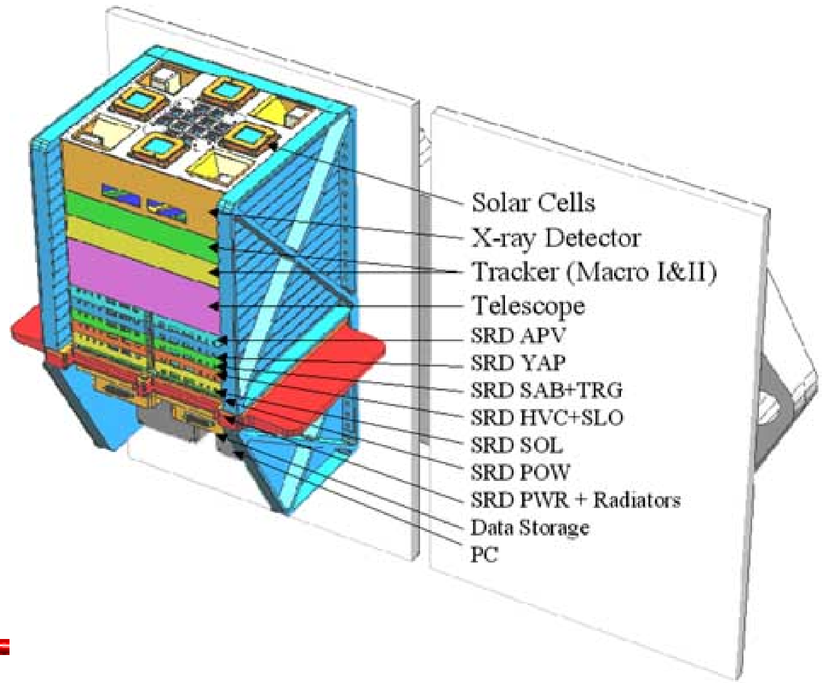
Phys. Lett. B472, 215-226 and other)



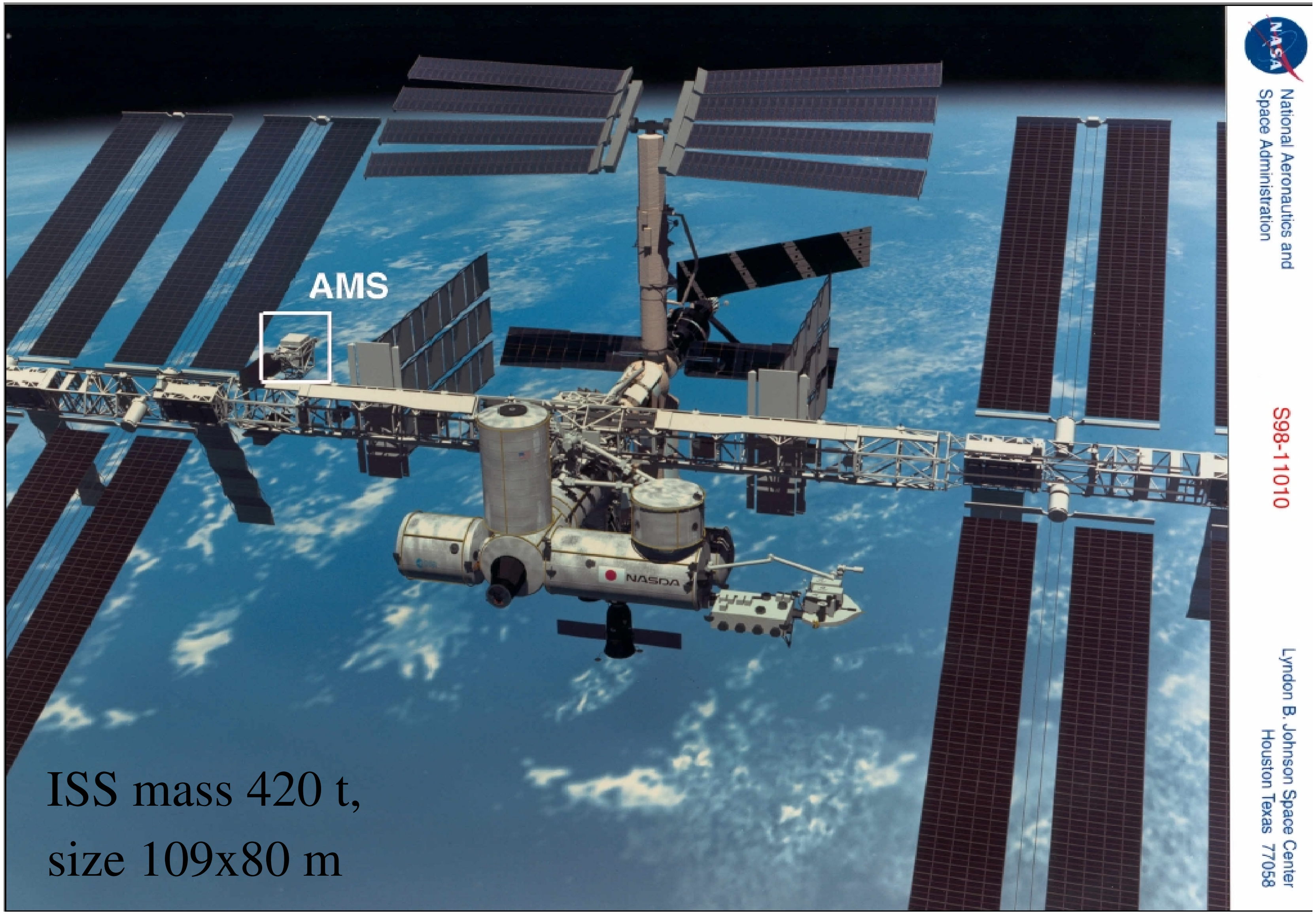


SRD detector

- Another 'side-effect' of AMS Collaboration works
- It would measure synchrotron radiation of multi-TeV electrons and positrons in geomagnetic field (time resolution is crucial)
- Tested on STS Endeavour in December 2001, but too late to include it in AMS-02
- Other project: superconducting magnet for Mars program



AMS-02 on ISS


AMS
NASDA
National Aeronautics and Space Administration
S98-11010
Lyndon B. Johnson Space Center Houston Texas 77058
ISS mass 420 t,
size 109x80 m

AMS-02 general considerations

- Goal: CR measurement with large statistics
- Space requirements:
  - Weight 6700 kg
  - Power consumption 2 kW
  - Vibration: 17 G RMS
  - Reliability (3 years) – redundancy
  - Thermal environment (ΔT = 100 C)
  - Radiation resistance
  - Orbital debris and micrometeorites
  - Small dipole moment (even smaller in case of free satellite)

AMS-02 Experiment

Transition Radiation Detector (TRD): *Foam + Straw Drift Tubes (Xe/CO_2)*

e/p separation, rejection power > 100 up to 300 GeV

Time of Flight (TOF): *scintillators, Δt =~160ps*

Main trigger, charge separation, β with few % precision

Superconducting Magnet : *$BL^2 = 0.85\ Tm^2$*

Tracker (8 layers) : *double sided silicon microstrip detector*

<2% resolution below 10 GV, rigidity up to 2-3 TV, charge separation

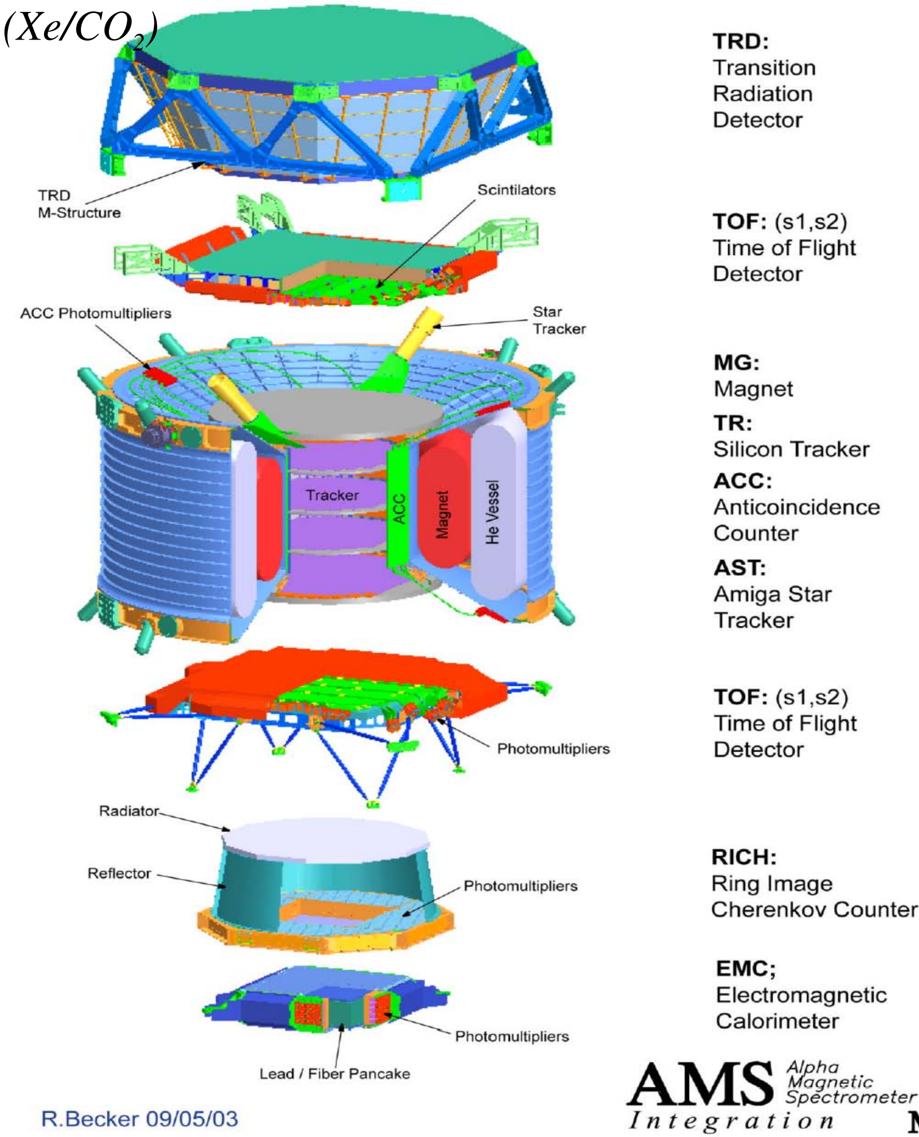
RICH : *Radiator (Aerogel, NaF)*

β measurement with 0.1% precision, charge separation, isotope separation (2% precision on mass below 10 GeV/n)

Electromagnetic Calorimeter (ECAL): *Lead+scint. Fibers*

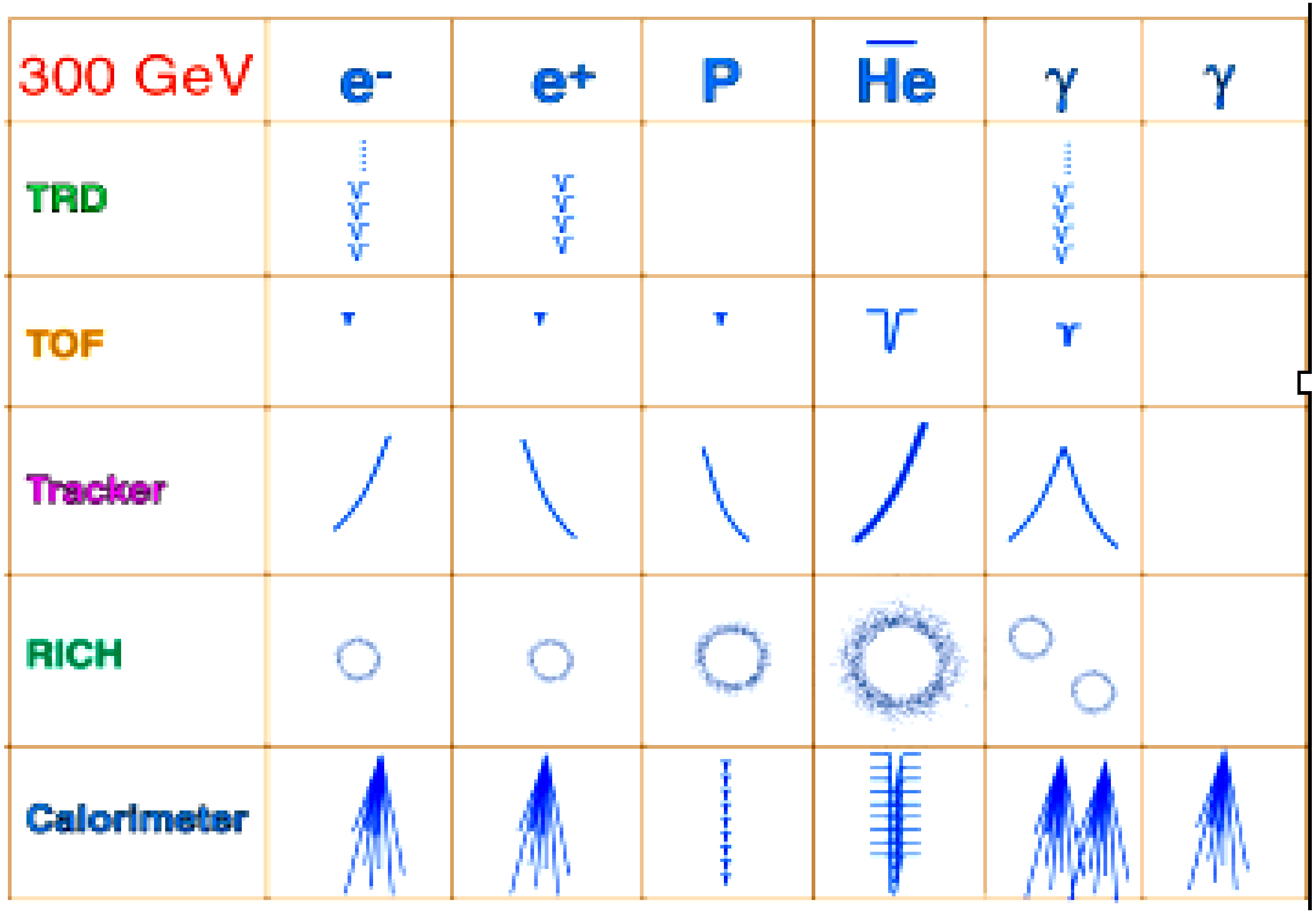
$e^{\pm}$,γ, detection, standalone trigger

<3% en. res. above 10 GeV, e/p separation >1000



AMS Alpha Magnetic Spectrometer Integration MIT

Strategies of measurements

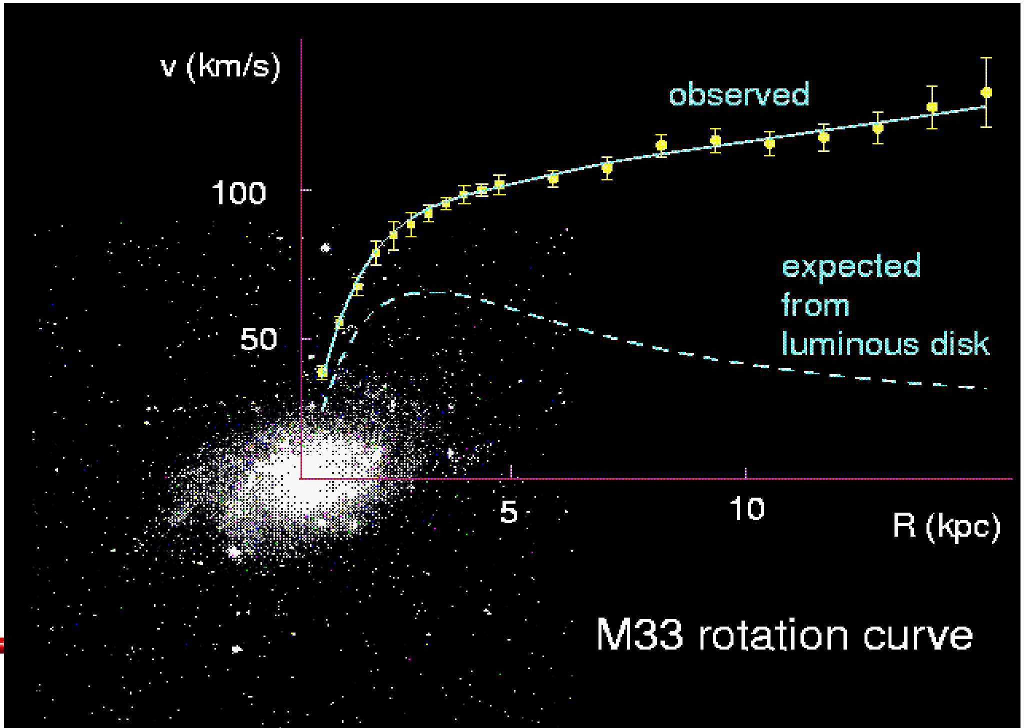


Dark Matter – short history

- Proposed by Zwicky (1933) to explain movements of galaxies in Coma cluster
- Babcock (1939) – flat rotation curve of M31
- Peebles and Ostriker (1973) – need of a massive halo to stabilise galaxies -

DM becomes a part of scientific paradigm

CMB fluctuations (WMAP), gravitational microlensing, large structure formation, BBN

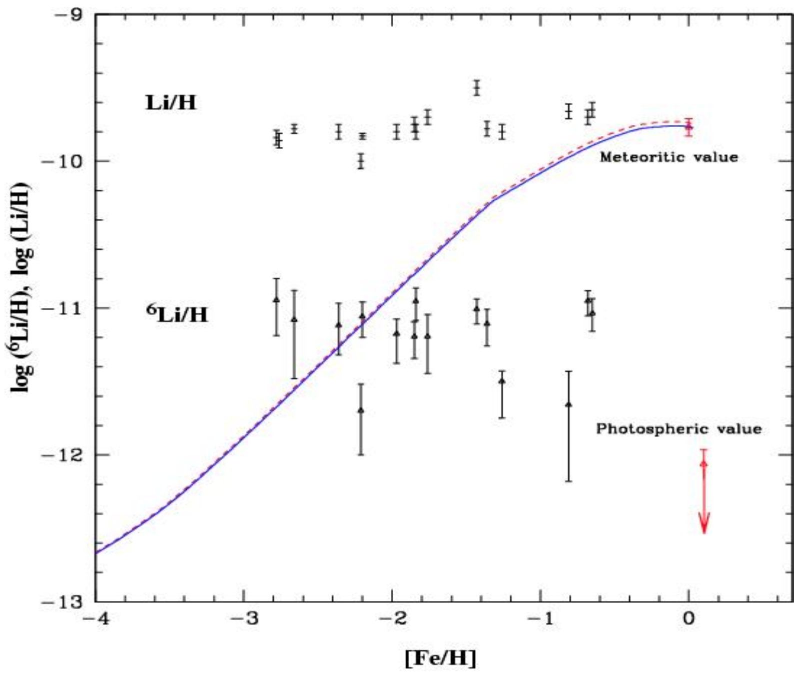


Dark Matter particles – expected properties

- Made of massive non-relativistic particles
- Weakly-interacting (it is dark – no electromagnetic interaction) – typical cross sections of the order of weak interactions (nuclear recoil, annihilation)
- Non-baryonic particles (production of such amount of baryons would affect nucleosynthesis)
- Big Bang nucleosynthesis not affected but WIMPs might synthesize ^{6}Li isotope after freez-out
- Candidates SUSY- LSP (neutralinos), Universal Extra Dimensions- LKP with m=1/R > 300 GeV ($B^{(1)}$ boson)

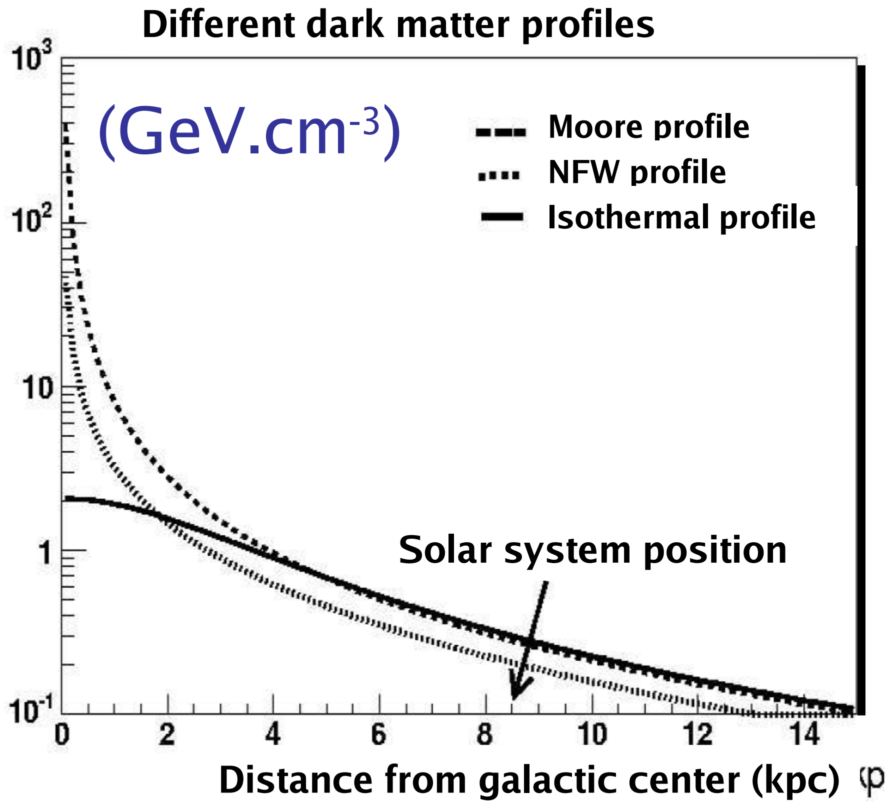
Dark Matter particles – ^{6}Li abundance

- ^{6}Li is poorly synthesized during BBN (1000 times less than observed)
- It is basically not produced nor destroyed in nuclear reactions in stars.
- There are low-metalicity stars containing too much ^{6}Li isotope – proposed solution: annihilation or decay of heavy particles just after Big Bang Nucleosynthesis (astro-ph/0402344 and astro-ph/0405583).

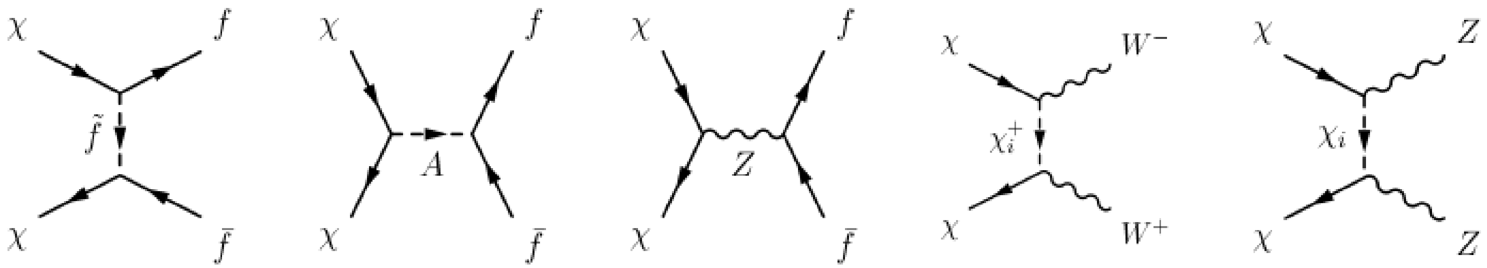


Dark Matter halos – expected properties

- NFW – profile existing in many N-body simulations
- Central cusp due to Black Hole
- Possible local clumps
- Local energy density 0.3 GeV/cm^3
- Total amount: 83% of matter component of the Universe (WMAP data – fit with concordance model)



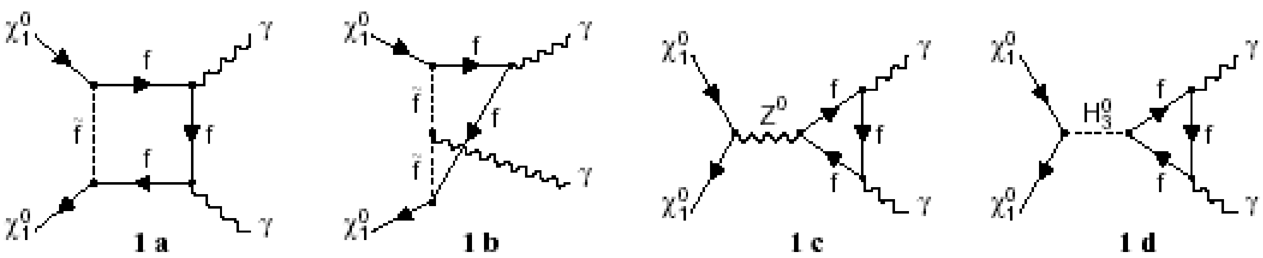
Dark Matter annihilation



$\chi^0_1\chi^0_1 \to q\,\bar{q}$, W^+W^-, ZZ, ... hadronization, decays ....

$\to \bar{p}$, $\bar{D}$, γ (continuum), e^+ (also neutrinos-> km3, IceCube)

Channels observable in AMS (or other CR detectors) plus suppressed but very characteristic:

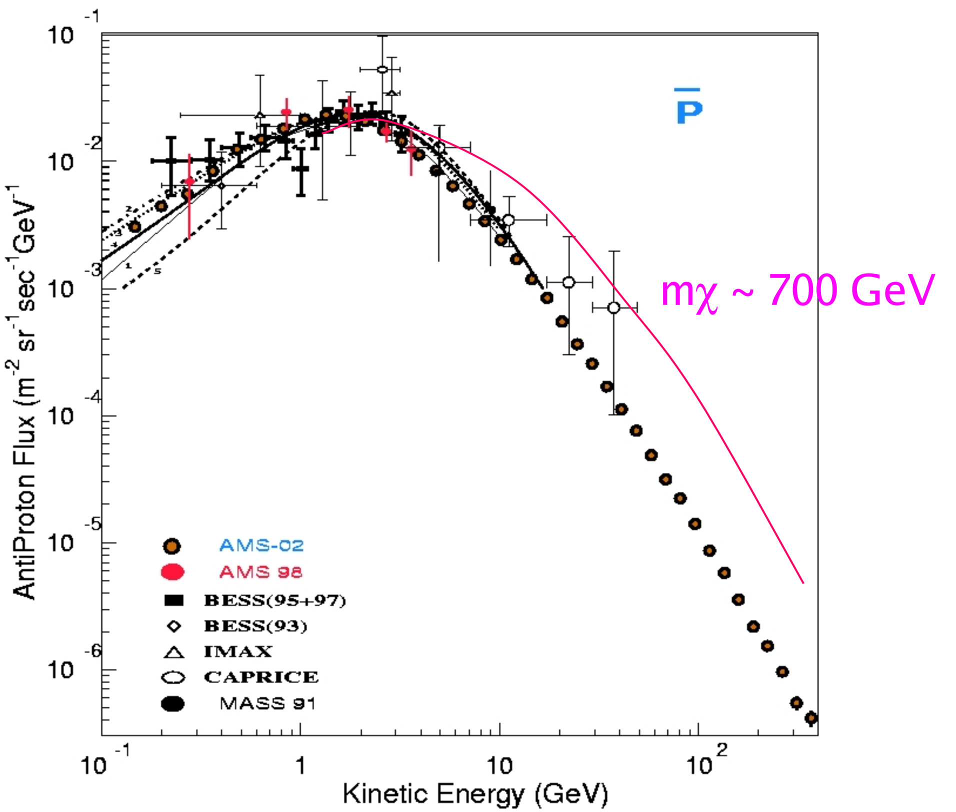


Antiproton channel

- First the focus was on low-energy (sub-GeV) antiprotons (expected to be background-free region) but now:

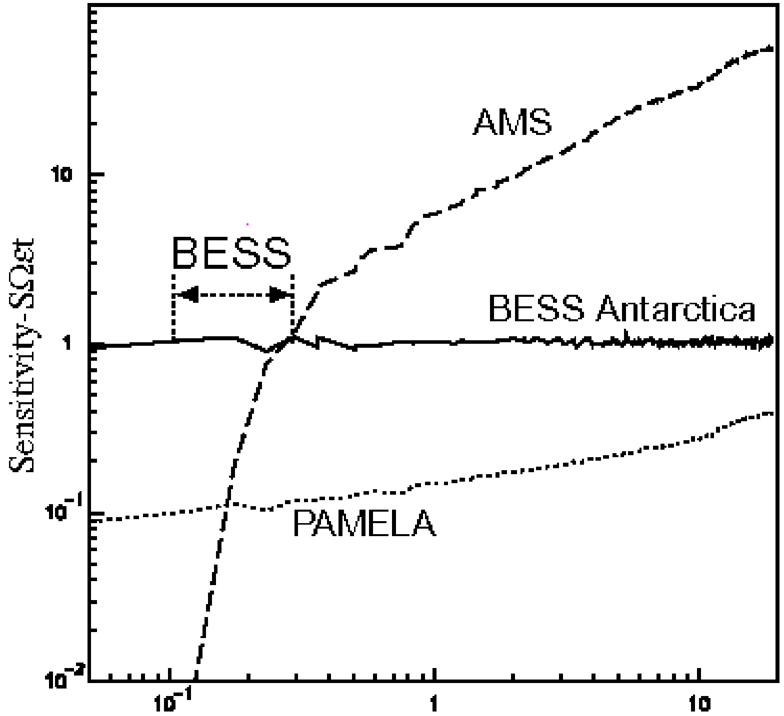
Rather heavy neutralino, signal as a distortion of spectrum at high energies (above a few GeV).

Unfortunately the shapes of DM and secondary spectra are not very different



ApJ 526:215-235, 1999

Antiproton channel – present status



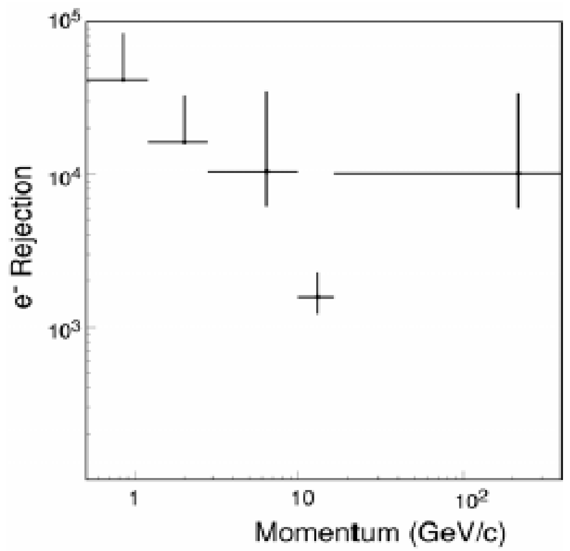
From low-energy part of the spectrum a constraint on DM can be drawn due to agreement between data and secondary antiproton calculation:

$$p, \alpha(CR) + H, He(ISM) \rightarrow \bar{p} + X$$

This will be further improved by AMS measurement of variables which control propagation of CR (B/C ratio).

Antiprotons in AMS-02

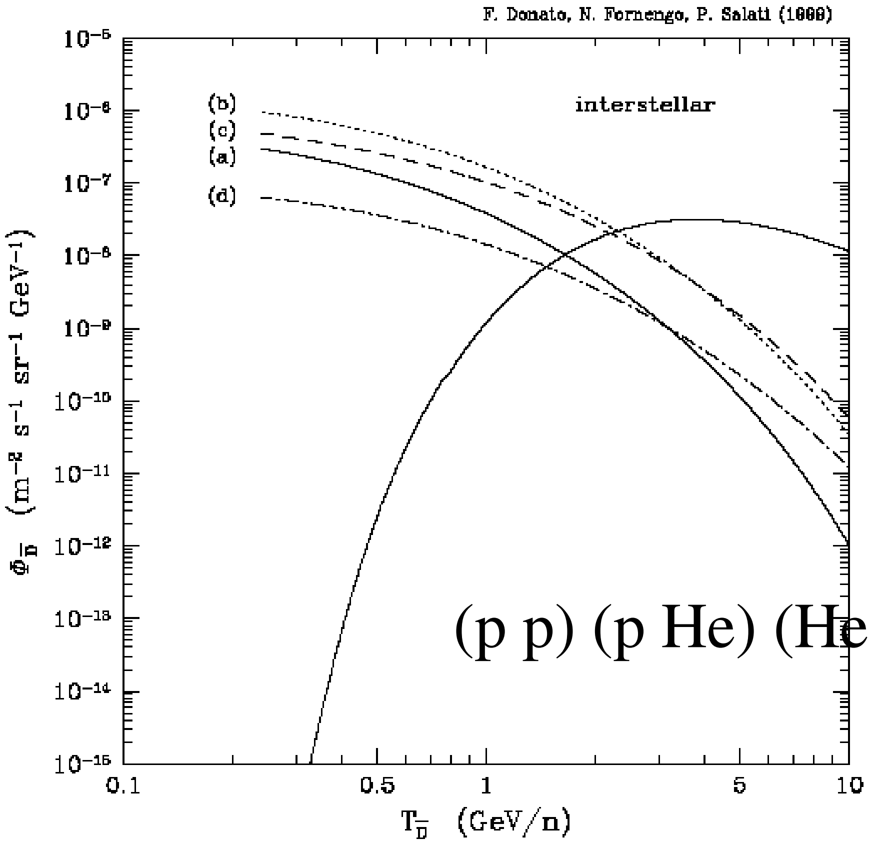
- Main backgrounds: protons and electrons
- proton rejection > 10^6 (tracker + TOF)
- electron rejection > 10^4 (TRD, ECAL, RICH)
- acceptance: 0.16 m^2sr (0.5-16 GeV)
- 0.033 m^2sr (16-300 GeV)



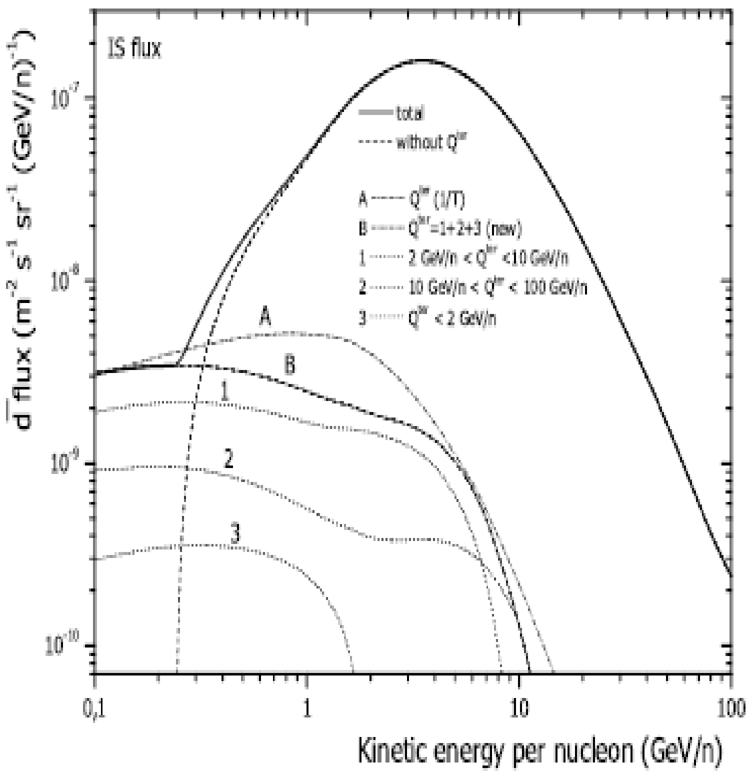
Antideuteron channel

- Spectra of DM signal and secondary background very different:

astro-ph/0503544



(p p) (p He) (He p)

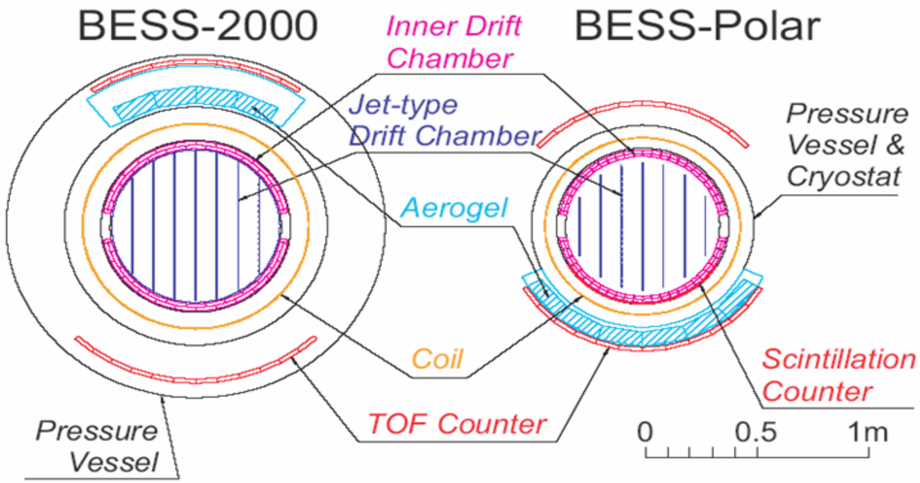


+ (antip p) (antip He)

See also astro-ph/0510722 review!

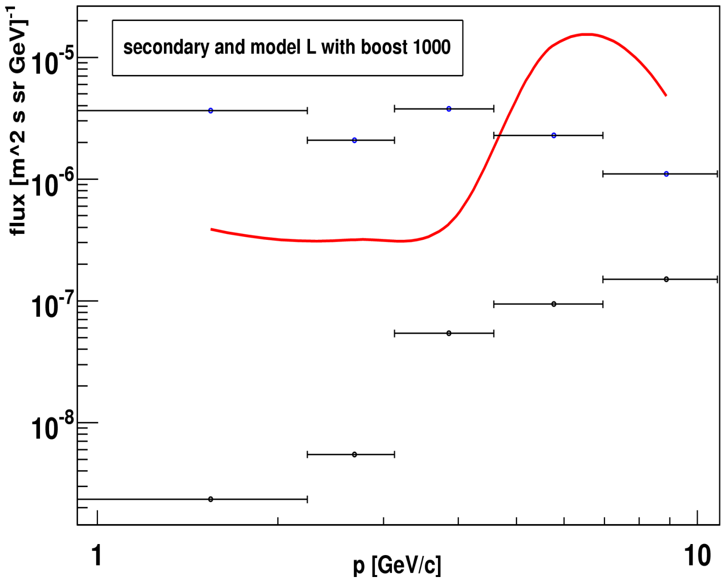
Antideuterons – present status

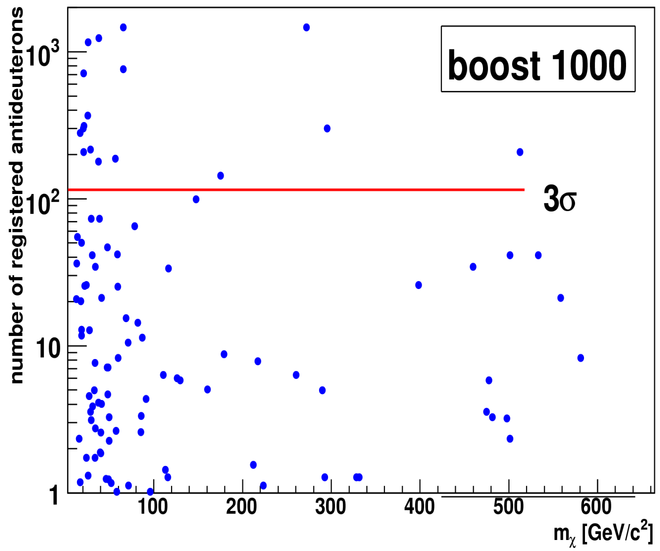
- BESS collaboration upper limit on low enegy antideuteron flux (astro-ph/0504361) : $\Phi < 1.9 \cdot 10^{-4}\, m^{-2}\, s^{-1}\, sr^{-1}\, (GeV/n)^{-1}$ (BESS energy range 0.17 – 1.15 GeV/n)
- From this no constraint on WIMPs (no model predicts so high fluxes), some constraint on primodial Black Holes



Antideuterons - AMS

- Antiprotons and electrons – main backgrounds
- For low energy – TOF used, for high – RICH
- Secondary antideuterons are behind AMS sensitivity
- DM flux could be visible if it is 10-100 times secondary





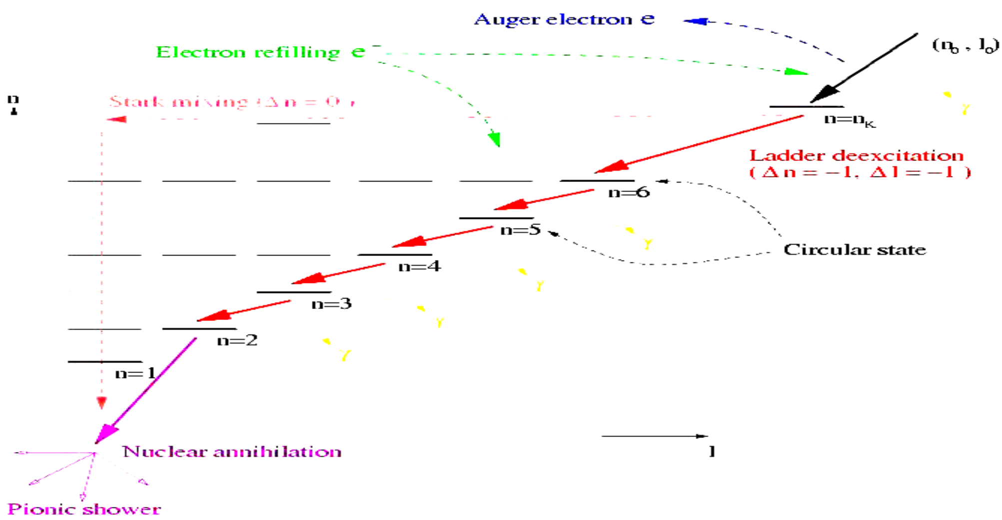
Antideuterons - GeneralAntiParticleSpectrometer

- Detection technique based on characteristic de-excitation signal from exotic atoms where electron is replaced by antideuteron nuclei plus annihilation hadronic cascade (Astrophys.J. 566,604 (2002) : astro-ph/0109463)

- Discrimination against protons 10^{12}

- Kinetic energy range 0.1-0.4 GeV/n

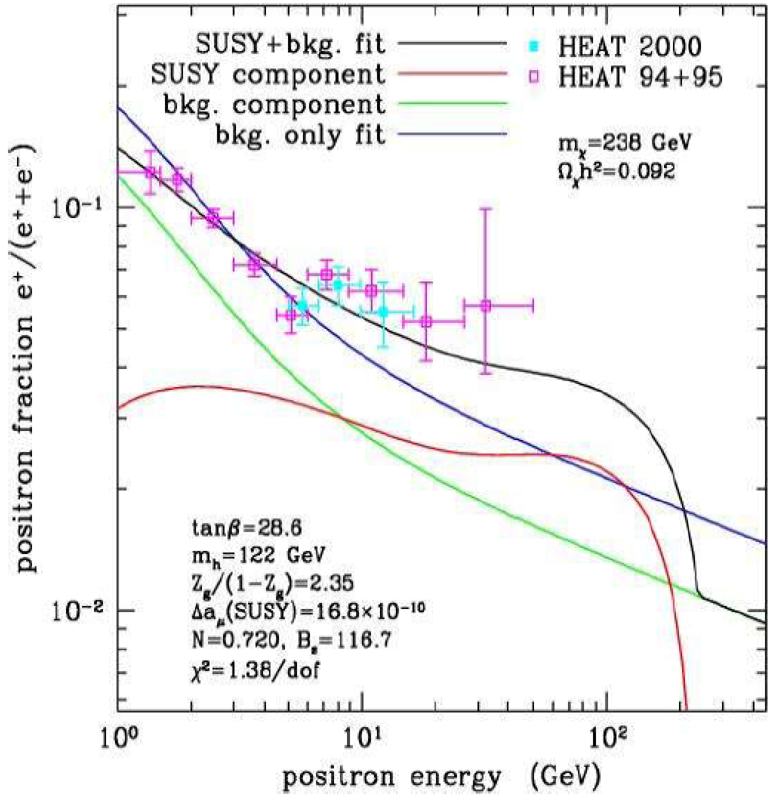
- Planned balloon flight (2009) and than satellite or a deep space probe avoid geomagnetic and solar effects)



- Deep space probe not good for galactic background and antideuteron production in WW final state (higher energies)

Position channel

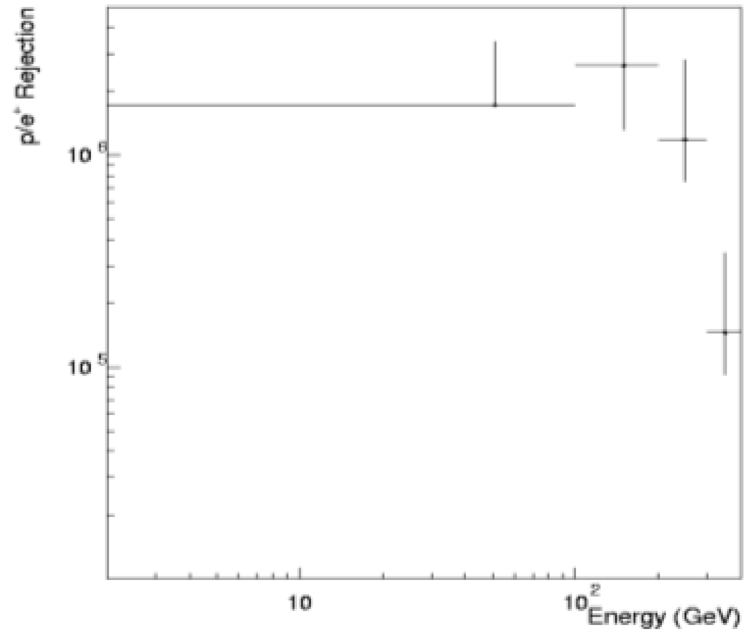
- Particularly interesting due to confirmed HEAT excess above 8 GeV
- Large boost factors are needed
- $e^+/(e^+ + e^-)$ - allows to neglect solar and geomagnetic effects
- High sensitivity to local properties of halo



E.A. Baltz et al., Phys.Rev.D65:063511,2002

Positrons in AMS-02

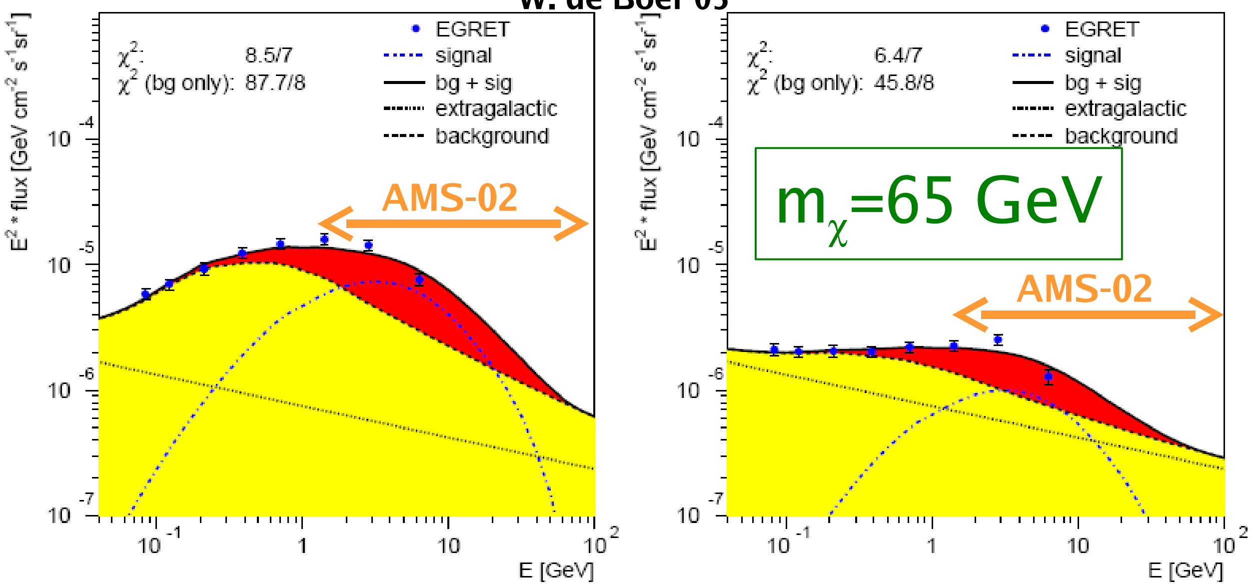
- TRD selection up to 300 GeV;
- ECAL e/p selection with shower shape
- Overall Proton rejection of ~10^5
- Acceptance ~$4.5 \cdot 10^{-2}$ $m^2 \cdot sr$



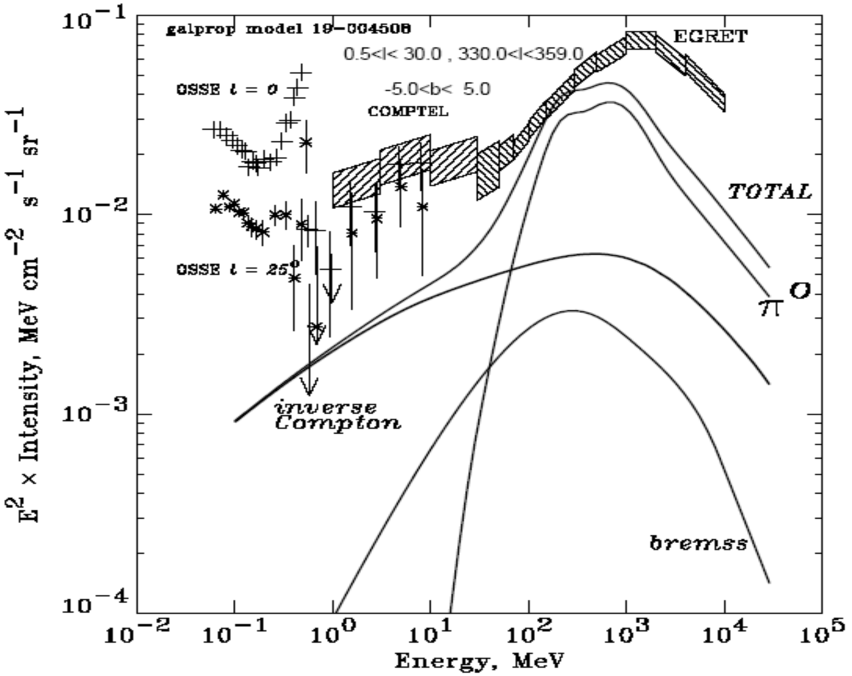
Gamma channel

- Gammas indicate sources – regions of higher DM density
- Possible line in spectrum (annihilation into 2 photons)
- Background difficult to estimate (especially towards Galactic Centre which is suppose to be the strongest source)
- Possible evidence in EGRET data?
- Other sources: M31, Draco, Palomar13

W. de Boer 05



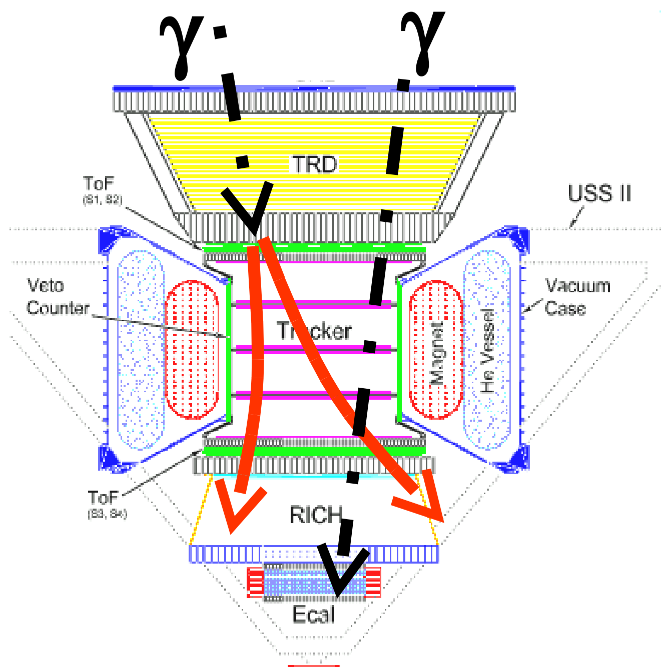
Gamma – present status

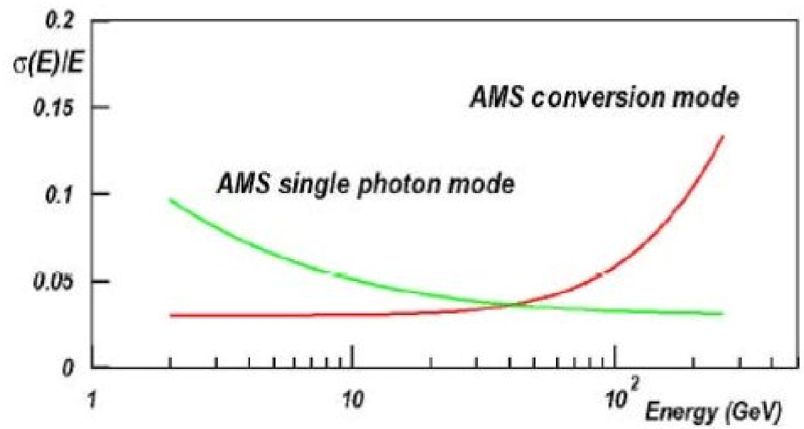


- Lot of measurements with a big hole in spectrum between 10 and 100 GeV
- Below 10 GeV – EGRET, above 100 GeV – ACTS etc.
- GLAST launch in 2007

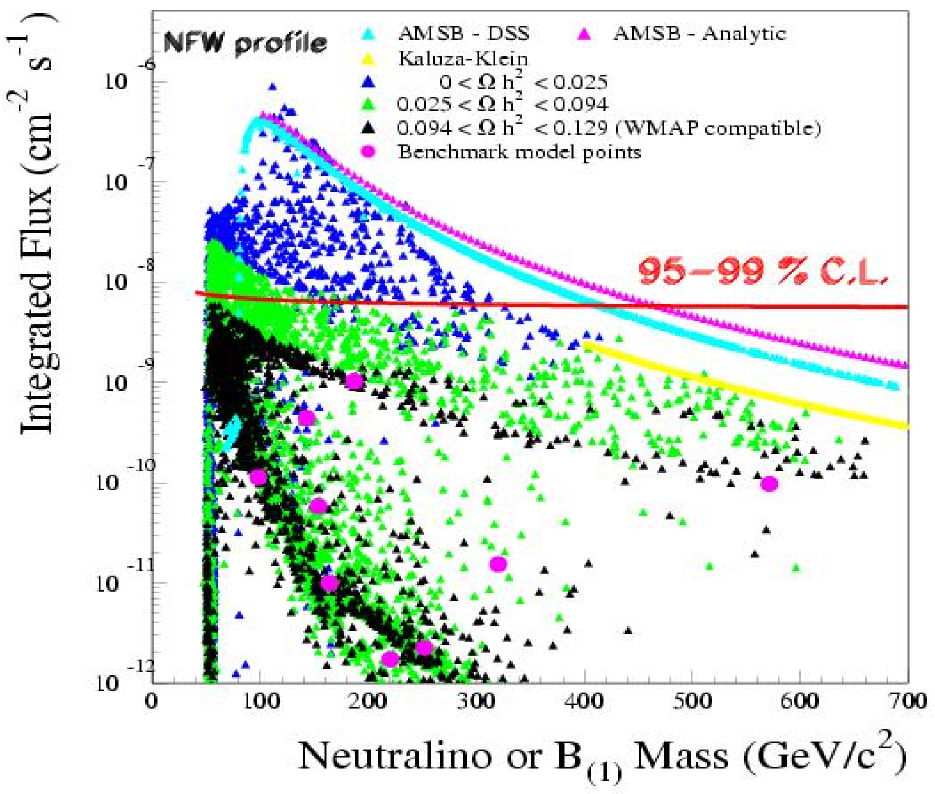
Gamma channel in AMS-02

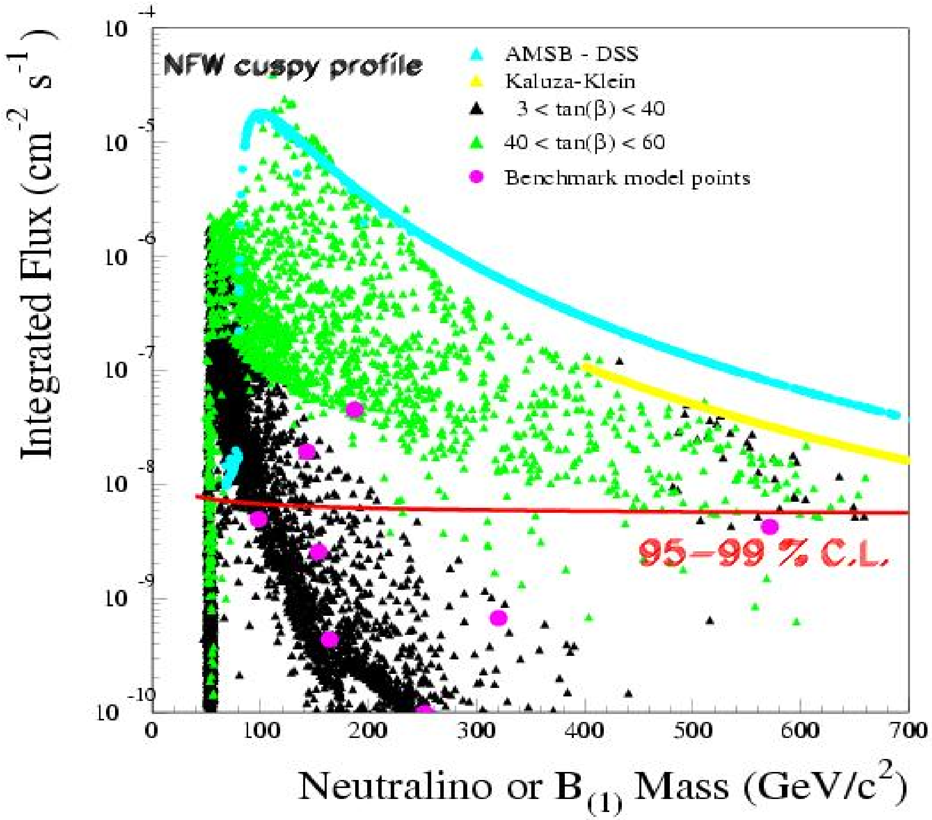
- Two detection modes: “tracker” and “ECAL”
- Compatible acceptances of about 0.05 m^2sr
- 400h/year of GC observation
  (AMS is not a telescope! Orbit constraint)
- Complementary features (angular resolutions)





Gamma channel in AMS-02



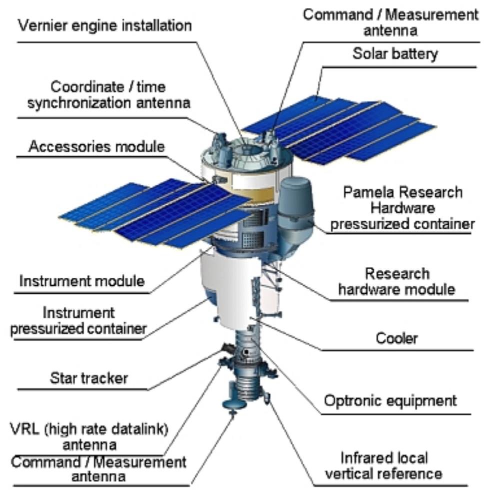


astro-ph/0508349

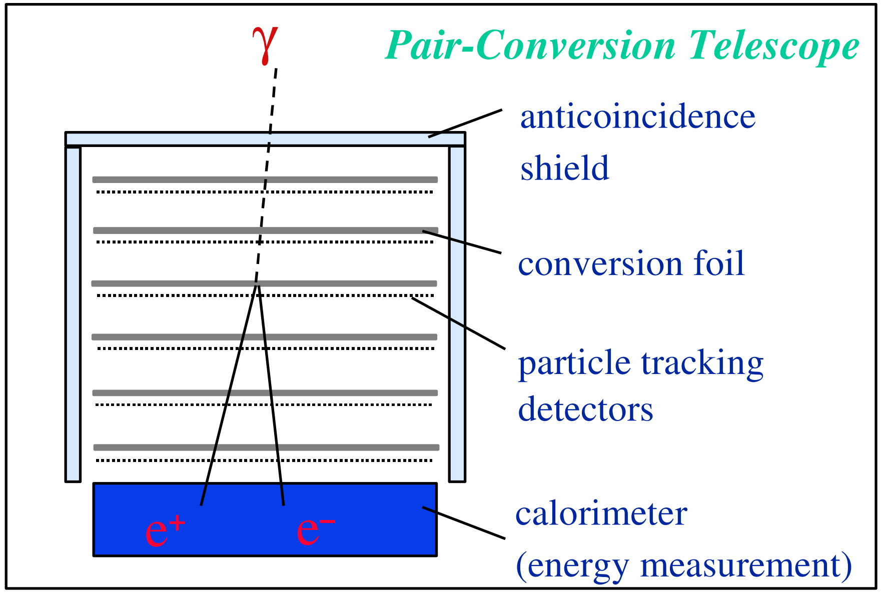
Assume cuspy profile in CG and treat it as a point source.

Pamela and GLAST

- PAMELA is small-AMS (21cm^2 acceptance) but it will fly probably in july this year
- They might be already sensible to some DM effects



- GLAST will fly next year
- Effective surface 0.8 m^2



Conclusions

- In optimistic scenarios AMS will be able to detect signals from Dark Matter.
- Search in 4 detection channels simultaneously.
- Due to precise measurements of DM fluxes will provide data which will allow to constraint CR propagation models and might be useful for other experiments (eg. GLAST).