

# Antimatter and Dark Matter search in space with AMS-02

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## 1 Introduction

AMS-02 is a space-borne magnetic spectrometer designed to measure with very high accuracy the composition of Cosmic Rays near Earth. With a large acceptance of  $5000 \text{ cm}^2$ , an intense magnetic field from a superconducting magnet (0.7 T) and a very efficient particle identification, AMS-02 will provide the highest precision in Cosmic Rays measurements up to the TeV region.

During a three-years mission on board of the International Space Station, AMS-02 will achieve a sensitivity to the existence of anti-Helium nuclei in the Cosmic Rays of one part in a billion, as well as provide important information on the origin and nature of the Dark Matter.

We review the status of the construction of the AMS-02 experiment and its remarkable discovery capabilities.

## 2 Cosmology with Cosmic Rays

Recent precision measurements of cosmological quantities, such as the Cosmic Microwave Background temperature and polarization [1, 2, 3] and the Supernova luminosity-to-distance relationship, together with Large Scale Structure and structure formation studies [4, 5], allowed to build a *standard cosmological model*, that describes a universe spatially flat, homogeneous and isotropic at large scales.

Our universe consists of ordinary matter and radiation only for a 4.5%: as shown in figure 1, a considerable fraction of the total matter (23%) is in the form of Cold Dark Matter. The largest fraction (73%) consists of Dark Energy, acting like a cosmological constant, whose origin is unknown [6]. The antimatter content of the universe appears to be only  $10^{-6}$  of the matter content [7].

The aim of AMS-02 is to perform precision studies of Cosmic Ray properties such as composition, production, acceleration and propagation mechanisms. Its large acceptance, energy resolution and particle identification capabilities allow AMS-02

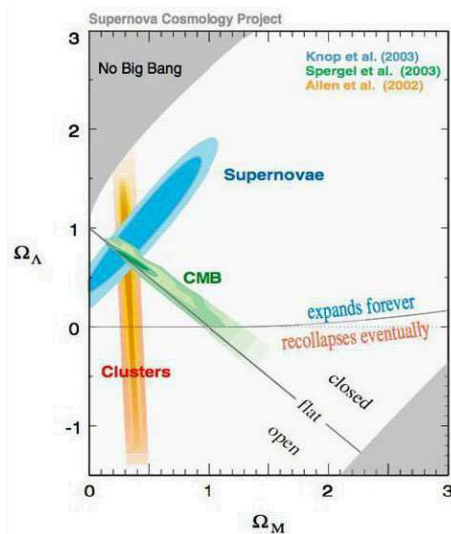


Figure 1: Independent measurements of several cosmological quantities all point in the direction of a universe composed mostly of Dark Matter and Dark Energy.

to search for primordial antimatter by direct detection of antinuclei, and for Dark Matter annihilation products independently in different charged and neutral particles spectra.

### 3 The AMS-02 detector

AMS-02 is designed as a single particle spectrometer with large acceptance, high momentum range and efficient particle identification for reliable operation in space, to provide high statistics spectra of charged particles with nuclei and isotope separation, as well as gamma-ray measurements. It will carry out a 3-years mission taking data above the atmosphere on the International Space Station.

AMS-02 is shown in figure 2. It consists of a fully equipped tracker inside a superconducting magnet (the first ever to operate in space) providing a  $0.8 \text{ T m}^2$  magnetic field. Rigidity is measured up to 3 TeV and nuclei and isotopes are separated up to 12 GeV/n for  $Z \leq 26$  or  $A \leq 25$  with a Ring Imaging aerogel/sodium-fluoride Cherenkov detector (Agl/NaF RICH), combined with Time of Flight (TOF) and  $dE/dX$  measurements. At 90% positron efficiency, a proton suppression by 3-4 orders of magnitude is achieved with a lead/scintillating fibre sandwich 3D sampling calorimeter (ECAL) based on shower shape information and the matching of shower energy with track momentum. Further proton suppression by 2-3 orders of magnitude up to 300 GeV/c is achieved with a 20 layer fibre fleece Xe/CO2 proportional wire straw tube Transition Radiation Detector (TRD). The overall  $10^6$  proton rejection

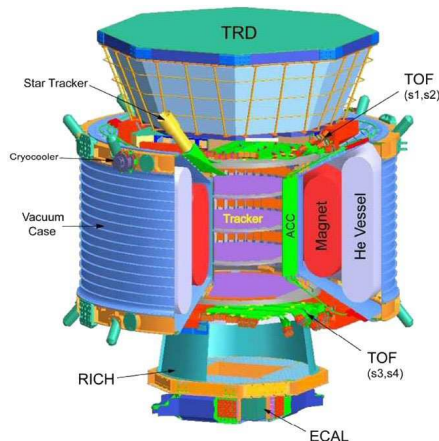


Figure 2: The AMS-02 detector.

factor is essential for Dark Matter search.

## 4 Indirect search for Dark Matter

A weakly interacting massive particle (WIMP) is the favoured Dark Matter candidate, and supersymmetric extensions of the standard model such as mSUGRA contain a *neutralino* which is stable when R-parity is conserved. AMS-02 is capable of detecting WIMPs indirectly by measuring decay products of neutralino annihilation processes, as an extra source for positrons, antiprotons, antideuterons and gammas on top of standard model predictions from galactic propagation models. With annihilation cross sections proportional to the square of the neutralino density, these measurements are also sensitive to Dark Matter density fluctuations.

Recent measurements of gamma-ray fluxes [8] and the positron fraction [9] have shown deviations from standard model expectations which are consistent with supersymmetric Dark Matter, but controversial within the available statistics and without standard model explanation for the positron excess [10, 11].

AMS-02 will measure the positron spectrum with substantially improved precision for background and signal, in the energy region where an excess has been claimed. Moreover, the simultaneous measurement in other independent channels will increase the sensitivity to Dark Matter detection. The spectra of positrons and antiprotons expected in the AMS-02 sensitivity region are shown in figure 3.

AMS-02 can also detect gamma rays up to 1 TeV either directly in the ECAL, or indirectly as an electron-positron pair after conversion in the material above the tracker, which amounts to 40% of a radiation length. The part of the parameter space from new physics that is within reach of AMS-02 gamma measurements in the case of

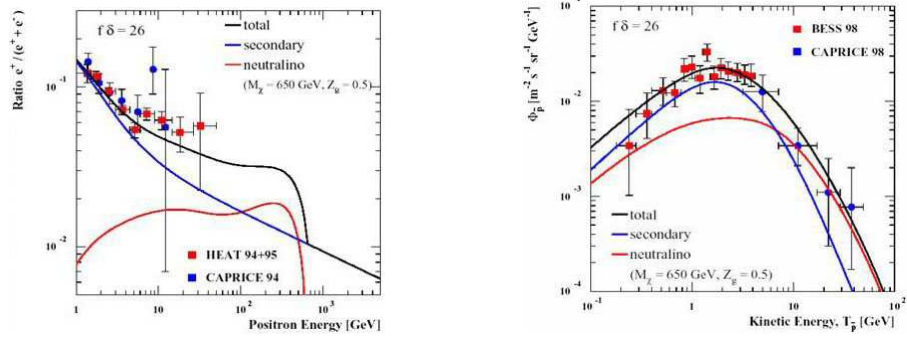


Figure 3: Left: positron flux; right: antiproton flux, in the energy region accessible to AMS-02. The red solid line shows the expected signal for a 650 GeV neutralino.

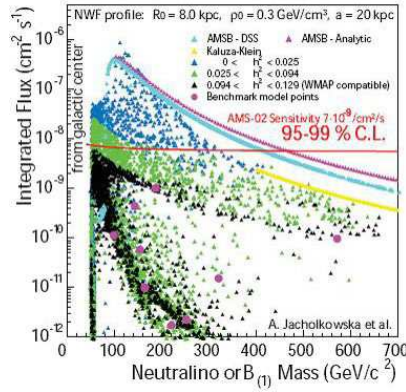


Figure 4: Part of the parameter space from new physics that is within reach of AMS-02 gamma flux measurements.

cuspy halo profile or extra enhancements, and even for a standard NFW dark matter halo [12], is shown in figure 4.

## 5 Direct search for antimatter

In the Big Bang theory matter and antimatter are created with equal abundances, and the disappearance of antimatter requires baryon number violation and another source of CP violation. Antiparticles are indeed produced in collisions between high energy particles, and are observed in the Cosmic Rays. For example,

$$\begin{aligned}\phi(e^+)/\phi(e^-) &\sim 10^{-1} \text{ at } 10 \text{ GeV} \\ \phi(p)/\phi(\bar{p}) &\sim 10^{-5} \text{ at } 10 \text{ GeV}.\end{aligned}$$

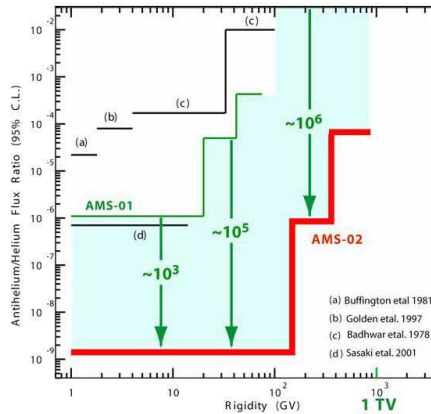


Figure 5: AMS-02 sensitivity to the anti-Helium flux.

However, an anti-Helium nucleus has very low probability of being produced in collisions:

$$\phi(\overline{He})/\phi(He) \sim 10^{-6} - 10^{-8}$$

Anti-Helium detection in the Cosmic Rays would be a clear indication of the existence of an antimatter area somewhere in the universe. AMS-02 will collect in three years  $2 \times 10^9$  nuclei with energies up to 2 TeV, with a sensitivity that reaches anti-Iron. The limit put by the precursor flight AMS-01 will be increased of a factor  $10^3$ , meaning that, if no antinucleus is observed, there is no antimatter to the edge of the observable universe (about 1000 Mpc). The limit on antimatter presence they can be set by AMS-02 is shown in figure 5.

## 6 Status and outlook

AMS-02 will provide a coherent dataset of unprecedented precision for charged Cosmic Rays and gamma rays up to the TeV region.

These data will confirm or disprove with high accuracy the excess in the HEAT positron data in the few GeV region. The multichannel analysis will allow combined fits to the parameters of standard model extensions to establish the nature of Dark Matter. Several models can be constrained and eventually ruled out.

AMS-02 will put a stringent limit on the presence of antimatter: if no antinucleus is observed, the hypothesis of baryon asymmetry will be strongly favoured as no antimatter areas are present in the observable universe.

In general, our knowledge of the Cosmic Rays physics will be improved. AMS-02 will perform an accurate study of composition (H, He, B/C,  $^9\text{Be}/^{10}\text{Be}$ ) and energy spectra, and put significant constraints on galactic propagation model parameters.

It is also worth mentioning the possibility for a search of new types of matter (e.g. strangelets).

The detector integration will be completed in 2008, on schedule to be ready for launch with the Space Shuttle in 2010.

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