Response of the AMS-02 tracker silicon sensors to high energy heavy ions

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Abstract

This document describes a proposal to measure the response of the AMS-02 tracker silicon sensors with ^{12}C and ^{58}Ni primary and fragmented beams at FRS together with the already aproved GLAST test (S240) in November 2003 (14th to 23rd). ^{12}C will be used during day time, when not used for therapy, and ^{58}Ni will be used during nights together with GLAST (S240). A total of 22 shifts is requested.

1. Introduction

The abundance of matter and the apparent absence of antimatter nuclei (anti-helium, anti-carbon etc.) in the universe is one of the great puzzles in particle physics and cosmology. Theories which predict either the existence of antimatter in segregated domains or the total absence of antimatter require speculative new physics ingredients and lack experimental data to be confronted with. The overwhelming majority of the mass in the universe is invisible in the form of dark matter of unknown origin. Moreover, a novel form of energy, called dark energy, appears to be accelerating the universe expansion. The more one thus learns about the physics of the universe, the less one appears to understand in terms of the Standard Models of particle physics and cosmology.

The direct observation of comic rays by balloon and satellite experiments is traditionally limited less by energy than by rate. Since the primary rate falls by almost three orders of magnitude for every decade in energy, simultaneous direct measurements of composition and spectrum of cosmic rays have so far not been possible beyond a few tens of GeV. The AMS project aims at improving this situation by providing a large area, high resolution spectrometer to be exposed to cosmic rays over a long observation period on the International Space Station (ISS) in a near Earth orbit. Its main physics goals are:

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

$$\begin{aligned}\tilde{\chi}^0\tilde{\chi}^0 &\rightarrow \bar{\mathrm{p}} + \cdots \\ &\rightarrow \mathrm{e}^+ + \cdots \\ &\rightarrow \gamma + \cdots\end{aligned}$$

- **Antimatter:** The strong evidence supporting the Big Bang origin of the Universe requires matter and antimatter to be equally abundant at the very hot beginning. The absence of sharp annihilation photon peaks excludes the presence of large quantities of antimatter within our cluster of galaxies. Theories which predict either the existence of antimatter in segregated domains or the total absence of antimatter at the present time are highly speculative. The resolution of this important problem requires further data: from the current generation of particle colliders and the B factories at SLAC and KEK to improve our current understanding of CP-violation; from Tevatron and LHC to provide clues on the correct extension of the Standard Model; from proton decay experiments in Japan and Italy to improve our understanding of baryon stability; and from AMS to improve the observational basis of the matter-antimatter balance in the Universe.

- **Cosmic Rays:** AMS-02 will collect of the order of 10^9 nuclei of D, He, Li, Be, B and C. An accurate determination of isotope abundances over a wide range of energies provides crucial information regarding the propagation of cosmic rays in the galaxy.

- **High Energy Photons:** AMS-02 will constantly monitor the gamma ray sky, with rather good acceptance and resolution, both using conversion in the tracker and the electromagnetic calorimeter. Measurements of high energy gamma ray emission from galactic sources like pulsars and extragalactic sources like active galactic nuclei will complement the observations in other frequency bands to gain a better understanding of astrophysical particle acceleration mechanisms.

A precursor flight on NASA Space Shuttle mission STS-91 took place in June 1998. A simplified but performant version of the final detector[1] took data during 10 days resulting in about 100 million triggers. These data already allowed a broad spectrum of physics analysis both concerning cosmic rays and the Earth radiation belts. Based on experience gathered during the first mission, a more ambitious detector, AMS-02, is being built.

This detector, AMS-02, is based on a spectrometer with a superconducting magnet, its main components are shown in Figure 1. In addition to providing an extended rigidity range for charged particles, it also implements more performant particle identification, additional redundancy for the measurement of charge and velocity and no trigger bias against heavy elements.

The new superconducting magnet is cooled by evaporating liquid helium and has a reservoir for about three years of operation without refill. Its dipolar field, normal to the aperture of the magnet, is based on a magic ring configuration of race track coils around a pair of Helmholtz coils. It amounts to 0.8T close to the center, six times the field strength of the AMS-01 permanent magnet.

[1] J. Alcaraz *et al.* [AMS Collaboration], Phys. Rep. **366**, 331 (2002).

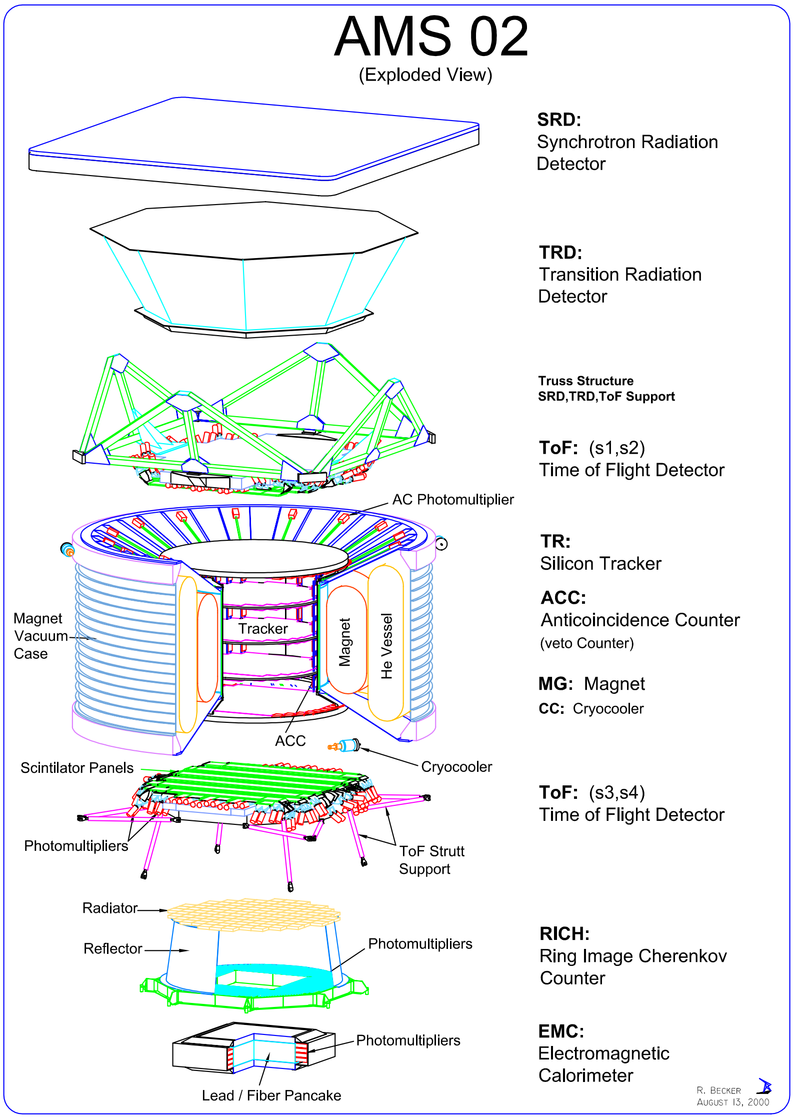

Figura 1: Exploded view of the AMS-02 detector layout identifying its major components.

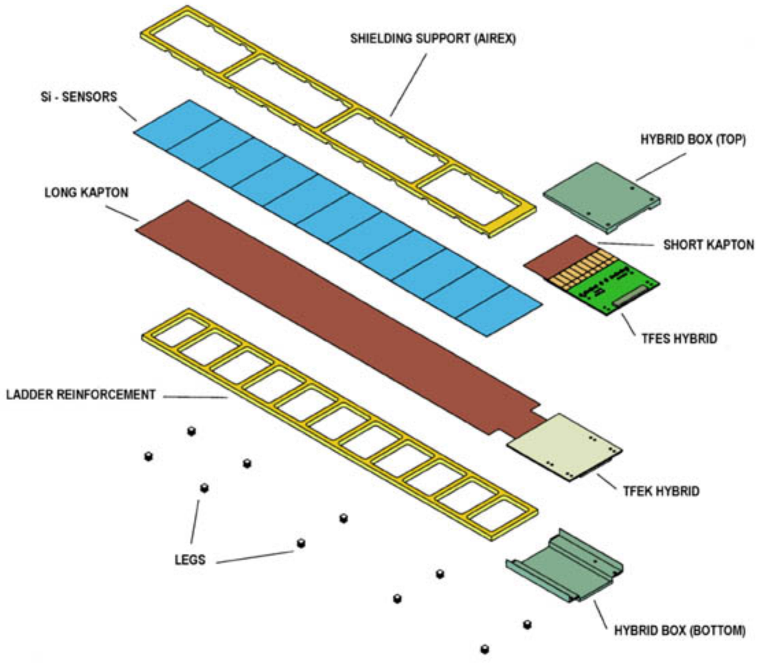

Figura 2: Exploded view of a ladder structure.

Trajectories of charged particles are determined by double sided silicon sensors, arranged in eight layers of about one m^2 each on five planes of an ultra-light support structure. Close to 2500 sensors provide a tracking resolution of $\sim$10μm in the bending direction, $\sim$30μm orthogonal to it. Together with the magnet, the spectrometer thus measures rigidity up to a few TV.

The measurement of specific energy loss, $dE/dx \propto |Z^2|$, in the silicon serves to identify nuclei. The tracker also measures the direction and energy of photons, converted in the material above the first tracker layer, with excellent directional resolution and good energy resolution.

2. AMS-02 tracker

The eight tracker planes of the AMS-02 detector will be equiped with close to 2500 silicon sensors arranged in 192 detectors called “ladders”. Figure 2 shows an overview of the components that form an AMS-02 silicon ladder. Each of them is composed of 7 to 15 silicon sensors and is the state of the art in silicon sensors manfacturing. The mechanical structure, made by a sandwich of foam and carbon fiber, provides mechanical strengh to support accelerations up to 9g needed for the take-off and landing of the shuttle.

Silicon sensors are double sided with a pitch of 27.5 μm and 14 μm width in p-side and 104 μm and 40 μm width on n-side. The readout pitch is 110 μm (1 out of 4) in p-side and 208 μm (1 out of 2) in n-side. Metalizations are 14 μm and 36 μm on p and n side. Big improvements have made in the quality of the silicon with respect to AMS-01 sensors.

Each ladder is readout by two front-end circuits (hybrids), one reading p-side (640 channels) and the other the n-side (384 channels) and both are connected through the very same

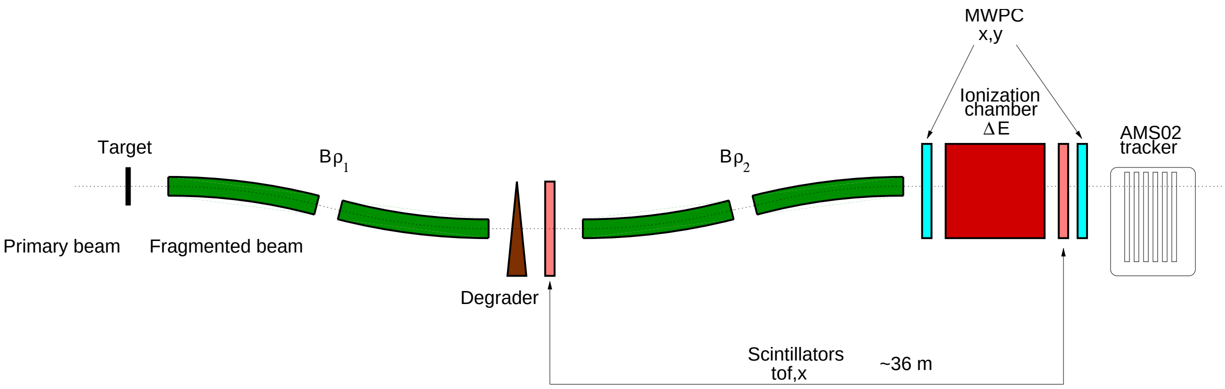

Figura 3: Proposed experimental setup

electronic chain to the readout board called TDR2.

3. Purpose of the test

The main purpose of the test is to study the capability of the AMS02 tracker to identify heavy ions as well as the spatial resolution achieved with different ion species. Special interest will be given to study spatial resolution for high energy deposition tracks (Z>8 in our case) where saturated channels will be present.

Ion tagging will be done using only associated hits in several planes to a track with the so called truncated mean method.

This test will also validate the whole electronic chain as well as the compression algorithms needed to reduce by a factor 1000 the amount of data. It is foreseen to take data in the so called mixed mode (raw+reduced data) in order to compare and test the quality of the various algorithms proposed.

4. Experimental setup

A proposal of the experimental setup is sketched in figure 3. Six AMS-02 ladders, housed in a box will be tested. The equipment asked to GSI to identify the ions is:

- Two standard FRS scintillation detectors at focal planes F2 and F4 respectively; the latter one will also be used for triggering purposes.
- Two standard MWPC at F4.
- A segmented ionization chamber (MUSIC3) that measures ΔE to identify ions.

An xy drive equiped with stepping motors is also needed to move the detector in and out the beam as well as to irradiate different parts of the sensors. A mechanical interface between the box described before and this table will be provided by the University of Geneva.

5. Measurement program

The response of the AMS-02 detector to a large variety of relativistic ions will be tested with a mixed fragment beam from the FRS in the same way as it is done in the already approved GLAST experiment (S240), where fragments from ^{58}Ni at 1.7 A GeV are utilized. In fact, we propose to test our detector simultaneously with S240 for one night shift with a setting where a mixed fragment beam with A/Z=2 impinges on GLAST. In addition, we require one night shift as main user where we select pure He, C, and O fragment beams by using at degrader at FRS-focal plane F2. These data at 1.7 A GeV can then be compared to similar data at 800 A MeV to be discussed below.

In addition, we intend to work during the daytime periods of S240 in the breaks of the therapy operation utilizing both primary the ^{12}C beam and fragments from ^{12}C at the maximum energy possible (800 A MeV). The total number of daytime shifts available during the S240 period is 24 shifts, where we expect to have access to the ^{12}C beam for about 40 % of the time. Out of those, we intend to use 20 shifts in the following way:

- Signal-to-noise ratios as a function of shaping time (4 shifts, primary $^{1}2$C beam).
- Response of the detector to diffenet ions (8 shifts, mixed fragment beam with A/Z=2, no degrader).
- Response of the detector to selected mono-isotopic fragment beams of He, Li, Be, and B (8 shifts, single fragments, with degrader).

In summary a total of 20 shifts is requested during daytime, in parallel with therapy, and 1+1 shifts during nighttime, one when GLAST will go to A/Z=2 run and one as main users with selected ions (low Z and maximum energy). No extra beam time is required.

The analysis of the test beam will be part of a PhD thesis at University of Geneva and/or University of Perugia, and will be included in a publucation describing the AMS-02 tracker performance.