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29th International Cosmic Ray Conference Pune (2005) **3**, 381–384

AMS - A magnetic spectrometer on the International Space Station

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The Alpha magnetic Spectrometer (AMS) is a particle physics detector designed to measure charged cosmic rays spectra up to the TV region, with high energy photon detection capability up to few hundred GeV. With its large acceptance, long duration (at least 3 years) and state of the art particle identification techniques, AMS will provide the most sensitive search for the existence of anti-matter nuclei and for the origin of dark matter. The detector is being constructed with an eight layers Silicon Tracker inside a large superconducting magnet, providing a $\sim$0.8 Tm^2 bending power and an acceptance of $\sim$0.5m^2. A Transition Radiation detector and a 3D Electromagnetic Calorimeter allow for electron, positron and photon identification, while independent velocity measurements are performed by a Time of Flight scintillating system and a Ring Image Cerenkov detector. The overall construction is due to be completed by 2006.

1. Introduction

The Alpha Magnetic Spectrometer (AMS) is a high energy particle physics experiment in space to be installed on the International Space Station (ISS) in 2008 for at least three years of operation. It is a large acceptance (~ 0.5 m^2.sr) superconducting magnetic spectrometer able to investigate the composition of cosmic rays with high statistics up to the TV region [1] and provide the most sensitive search for the existence of anti matter nuclei and for the origin of dark matter [2]. It will also measure high energy photons up to few hundred GeV [3].

A 'scaled-down' version, AMS-01, was built and successfully flown on the shuttle Discovery (STS-91) for 10 days in June 1998 at a mean altitude of 370 km. The heart of the AMS-01 detector was a magnetic spectrometer, using a 0.15T permanent dipole magnet in magic ring configuration and a partially equipped six plane silicon tracking detector. The set-up was completed by a two double layer scintillator time-of-flight system, an Aerogel threshold Cherenkov counter and veto counters located on the magnet inner wall. The detector thus measured the charge Z, rigidity $R \equiv pc/|Z|e$, velocity β and specific energy loss dE/dx of particles traversing its aperture. The main goal of the 10 days STS-91 flight in June 1998 was docking to and resupplying the MIR station. For AMS, it was a mission to test the equipment under stringent conditions during the launch and in the space environment, and to familiarize the AMS team with operations in space. After MIR undocking, AMS had control of the shuttle orientation for ninety hours. Data were taken with variable attitudes, at altitudes between 320 and 390 km above sea level. The space shuttle's orbit covered latitudes between $\pm 51.7°$ and all longitudes. A total of 10^8 events were registered. Results have so far been obtained on rates and spectra of electrons and positrons protons antiprotons and deuterons helium the search for antihelium nucleias well as heavy anti-ions [4].

Due to the environmental conditions in space, AMS has to fulfill various special requirements concerning weight (limited to 7 tons), thermal vacuum, vibration, cosmic radiation, electromagnetic interference, power consumption (limited to 3kW) and data communication.

2. The AMS-02 detector

Following the experience gathered during the AMS-01 mission, a more ambitious detector with extended rigidity range from a few GV to the TV region was designed for installation on the ISS. 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 less trigger bias against heavy elements.

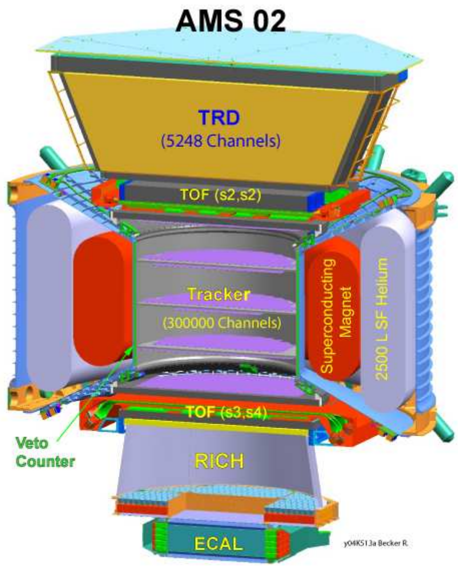

Figure 1. Full view of the AMS Spectrometer.

The superconducting magnet [5] consists of two helmholtz coils and two series of six smaller racetrack coils circumferentially distributed, cooled by superfluid helium at 1.8 K. This configuration was chosen for three reasons: to increase the overall dipole field, to reduce the stray field and to suppress the torque resulting from the interaction the magnetic moment of the magnet with the Earth magnetic field. The magnetic field reaches 0.8T close to the center, six times the field strength of the AMS-01 permanent magnet. It is thermally connected to a 2500 l vessel of liquid helium for about 3 years of operation without refill.

Trajectories of charged particles are localised by double sided silicon sensors [6], arranged in eight layers of about one squared meter each on five planes of an ultra-light support structure. Close to 2500 sensors provide a tracking resolution of $\sim 10\mu$m in the bending direction, $\sim 30\mu$m orthogonal to it. Together with the improved magnet (BL^2=0.9Tm^2), particle rigidity is measured with an accuracy better than 2% up to 20 GV and the maximal detectable rigidity is around 1 TV. The measurement of specific energy loss, $dE/dx \sim |Z^2|$, 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.

Separation between light and heavy particles is provided by the Transition Radiation Detector (TRD) [7] on top of the set-up, which measures the radiation emitted by particle upon changes in the index of refraction of the traversed medium. The detector features 20 layers of a fleece radiator and proportional straw tubes with a

Xe/CO_2 gas mixture for X-ray detection. Since the intensity of emitted transition radiation (TR) is proportional to the Lorentz factor γ, light particles such as positrons have a much higher probability of emitting TR than heavy particles such as protons. It will separate hadrons from electrons in the range 10 to 300 GeV. It will also help in the tracking of charged particles, identify photon conversion points and measure dE/dx.

As in AMS-01, two crossed double layers of scintillators placed at the magnet end-caps provide time-of-flight (TOF) [8] and thus measure particle velocity. Due to the higher magnetic stray field of the AMS-02 superconducting magnet, the phototubes have to be aligned more carefully with the local magnetic field. A timing resolution for protons of $\sim$ 180 ps is nevertheless expected and 100 ps for light ions. In addition to measuring the velocity of particles and their direction, the time-of-flight system provides a redundant measurement of dE/dx with about 10% resolution for minimum ionising particles. It is also the principal trigger detector for charged particles.

Below the spectrometer, a Ring Imaging Cerenkov detector (RICH) [9] provides further velocity and charge measurements. Light emitted in the combined Aerogel ($n = 1.05$) and sodium-fluoride ($n = 1.334$) radiators on the top is detected as a close to an elliptical pattern of photons by an array of position sensitive photo multipliers on the bottom, occasionally after reflection off a conical mirror. The emission angle measures velocity, with an expected resolution of $\delta\beta/\beta \simeq 10^{-3}$. The number of photo-electrons measures the charge with a resolution better than 20% for low Z ions, thus providing an independent measurement of the charge up to iron.

At the very bottom, an Electromagnetic Calorimeter (ECAL) [10] made of 640 kg of lead scintillating fiber sandwich completes the set-up. The calorimeter reconstructs the shower with three dimensional sampling using crossed layers. Its energy resolution is expected to be $\delta E/E \simeq 10.1\%/\sqrt{E(\mathrm{GeV})} \oplus 2.6\%$ for electromagnetic showers. It distinguishes hadronic from electromagnetic showers by their lateral and longitudinal shape, thus suppressing protons by a factor of 10^{-4} up to several hundred GeV. The calorimeter will also serve as an independent photon detector, with an angular resolution of about $\sim 1°$.

Particle identification on AMS-02 relies on a very precise determination of the magnetic rigidity, energy, velocity and electric charge. Velocity of low energy particles (up to $\sim$ 1.5 GeV) is measured by the TOF detector while for kinetic energy above the radiator thresholds (0.5 GeV/n for sodium fluoride and 2.1 GeV/n for aerogel) the RICH will provide very accurate measurements; a target resolution of 1% and $\sim$ 0.1% for single charged particles is expected, respectively for sodium fluoride and aerogel radiators. The absolute value of the electric charge is measured by the silicon tracker and TOF detectors through dE/dx samplings and by the RICH through Cherenkov signal integration. Ion identification at least up to iron is expected. The new detector thus features sophisticated particle identification devices that will allow to discriminate the small amount of antiprotons and other antinuclei against the large background of electrons, as well as positrons against the overwhelming background of protons, up to high energies. It will also have two ways of measuring high energy photons, by conversion in the tracker and in the electromagnetic calorimeter, which will allow systematic long term observations of the gamma ray sky.

3. Conclusions

AMS-02 is a complete and sophisticated detector which should be completed in 2006. Due to its large geometrical acceptance, large momentum range and dynamics, its particle identification capability and its long duration measurements, it will collect close to three orders of magnitude more statistics than in AMS-01 under much better instrumental conditions. It will contribute to the observation of cosmics rays and photons in space in an energy domain and time scale complementary to other projects. A rich and diversified physics program will result from its at least three years of data taking on the ISS.

4. Acknowledgements

The construction of AMS-02 is an undertaking of many individuals and organizations. The support of NASA and the U.S. Dept. of Energy has been vital in the inception, development and fabrication of the experiment. The interest and support of NASA, the Federal Agency for Atomic Energy, Russia, the Ministry of Science and Technology, China, and the European Space Agency is gratefully acknowledged. The dedication of Dr. Robin Staffin, Dr. A. Byon-Wagner and Dr. P.K.Williams of U.S. DOE, the support of the space agencies from Germany (DLR), Italy (ASI), France (CNES), Spain (CDTI) and China and the support of CSIST, Taiwan, have made the construction possible.

The support of GSI-Darmstadt, particularly of Dr. Reinhard Simon made it possible for us to test electronics components for radiation effects. The support of ESA, including Martin Zell, Jean Jamar and Wolfgang Supper, will enable the overall thermal vacuum test of ESTEC.

The support of INFN, Italy, IN2P3, Region Rhône-Alpes and Haute Savoie, France, CIEMAT and CICYT, Spain, LIP, Portugal, CHEP, Korea, the Chinese Academy of Sciences, the National Natural Science Foundation and the Ministry of Science and technology of China, Academia Sinica, Taiwan, the U.S. NSF, M.I.T., ETH-Zűrich, the University of Geneva, National Central University, National Space Program Office, National Chaio Tung University and National Cheng Kung University, Taiwan, Moscow State University, Southeast University, Nanjing, Shanghai Jiao Tong University, Sun Yat-sen University, Guangzhou, Shandong University, Jinan, RWTH-Aachen, the University of Turku and the University of Technology of Helsinki, is gratefully acknowledged.

We are grateful for the strong support and interest shown from the private sector, including Dr. E.Ettlinger, Linde, Dr. R.Herzog, ILK, Dresden, Mr. M.Molina, CGS, Milan, Mr. F.Petroni, CAEN, Viareggio, CRISA (Astrium), Madrid, Ing. A.Pontetti, G&A Engineering, Italy, Dr. E.A.Werner and Dr. J.Krieger, ISATEC, Aachen, and Dr. H.Bieri, Bieri Engineering, Switzerland.

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