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The AMS-02 TRD
A detector designed for space

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ABSTRACT

For the AMS-02 experiment which will be installed on the International Space Station ISS during 2004 for a data taking period of 3 years a large TRD detector is under construction at RWTH Aachen. The gas system will be built at MIT. The TRD consists of 20 layers of straw modules and radiator (LRP 375 BK) with a total of 328 modules (16 straws each). The housing consists of a conically shaped octagon structure made out of CFC-Al-honeycomb material and is closed by a lower and upper honeycomb plate. The gas is a 80:20 Xe:CO2 mixture. The signals are readout by VA chips.
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1 Introduction

The AMS-02 experiment will measure the cosmic ray particle spectra on the International Space Station ISS for a period of three years. AMS-02 addresses two of the greatest puzzles in modern astrophysics: The possible disappearance of cosmological antimatter and the pervasive presence of dark matter. The ob-

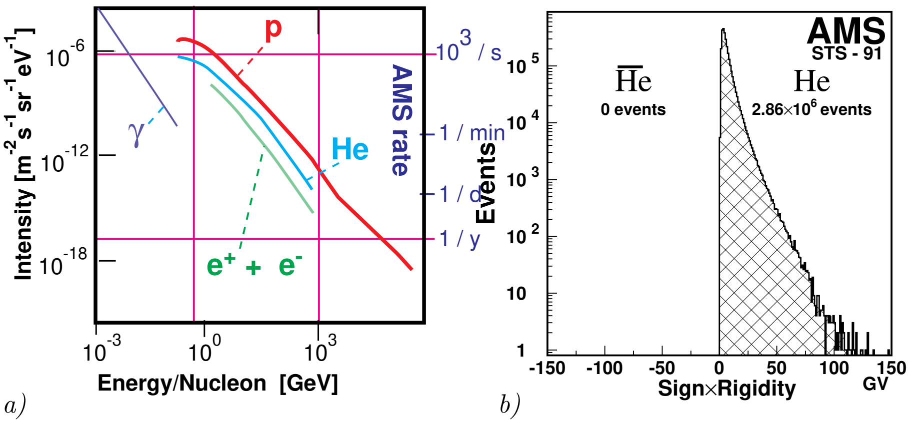


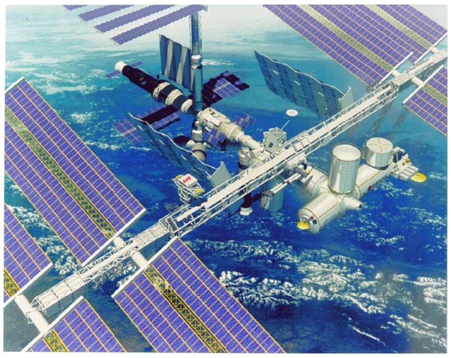
Figure 1: *a) Expected cosmic particle spectrum and particle rate for AMS-02. b) He spectrum measured with AMS-01* [2]*.*

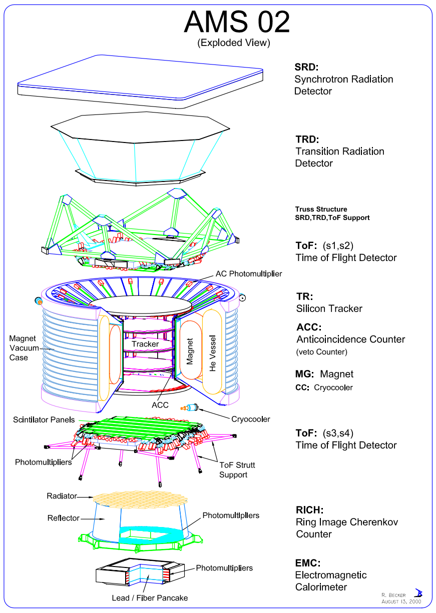
servation of a matter antimatter asymmetry at the 10^{-9} level in the universe cannot be explained by the CP-asymmetry in the K- and B-meson system. An only locally broken matter antimatter symmetry would imply regions of the universe consisting of matter and others of antimatter. The observation of anti-nuclei would be the proof of the existence of antimatter domains. Up to now the best experimental limits for the antimatter search are derived from the succesful 10 days precursor flight (STS91) of AMS-01 [1] with the Space Shuttle Discovery in 1998. A total of 100 million charged particles were recorded during this flight. Detailed simulations [2] of the earth magnetic field and of the transport and interaction of charged particles inside the earth atmosphere have lead to an excellent understanding of the obtained spectra. The non-observation of any anti-He-nuclei (Fig.1b) in a sample of $3 \cdot 10^6$ He-nuclei in the full rigidity range up to 140 GeV can be translated into an upper limit for anti-matter: $N_{\overline{He}}/N_{He} < 1.1 \cdot 10^{-6}$(@ 95% CL) The AMS-02 experiment is designed to look

for primary anti-helium and anti-carbon in cosmic rays.
In astronomy, there is overwhelming evidence that more than 90% of the mass in the universe is some non-luminous "dark matter", of as yet unknown origin. There are strong indications that the bulk of this dark matter is non-baryonic, i.e. it consists of weakly-interacting massive particles (WIMP'S). The lightest supersymmetric particle, the neutralino χ, is one of the most promising WIMP candidates. The AMS-02 experiment will allow indirect searches of dark matter by high statistics precision measurements of e^+, $\overline{p}$, anti-deuteron and γ spectra as annihilation and decay products of neutralinos. The expected composition of cosmic radiation is shown in Fig.1a). It is dominated by protons. To measure positron spectra with high accuracy (momentum resolution of 15% at 300 GeV/c) a very good proton-positron separation is required. The proton rejection has to reach a level of 10^6 up to particle energies of 300 GeV. In AMS-02 this will be achieved by a combination of an electromagnetic calorimeter, proton rejection 10^4 , and a transition radiation detector (TRD) which should reach a proton rejection of 10^2.

2 The AMS-02 Detector

The design of the detector (Fig.2b) is optimised for precision particle spectroscopy in space based on the experience gained from the precursor flight of AMS-01 in 1998. The total weight of AMS-02 is limited to 13500 lbs and the total power consumption is 2 kW.
The superconducting magnet generates a magnetic field of 0.9 T. Inside this cylindrical volume of 0.6 m^3 a double sided silicon strip detector measures the trajectories of charged particles in 8 planes with a high accuracy of 8 μm per point in the two coordinates perpendicular to the track. The silicon tracker determines the particle momenta with an accuracy of $\sigma(p)/p = 4.5 \cdot 10^{-4} p/GeV$ and measures the particles charge up to the TeV scale. The geometric acceptance is 0.6 m^2sr. An optical laser alignment-system monitores the mechanical stability of the silicon tracker. Above and below the tracker system a time of flight (ToF) hodoscope is placed consisting of 2 crossed scintillator panels which are read out by photomultipliers. The time a particle needs to traverse the tracker is measured with an accuracy of 125 ps. The signal is also used to trigger the read out of the AMS-02 detector. An anticoincidence scintillation counter (ACC) covers the inner surface of the magnet to reject the background





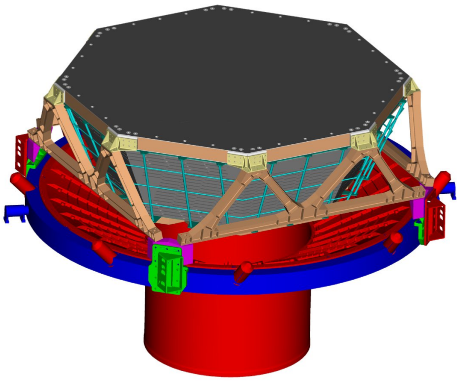
a) *b)*

Figure 2: *a) Computer generated views of the AMS-02 experiment on ISS. b) Exploded view of AMS-02.*

caused by particles passing through the experiment from the sides. On top of the silicon tracker a conical octagon structure is placed which houses a 20 layer transition radiation detector (TRD) for particle identification. The task of the TRD is to ensure in combination with the lead/fibre electromagnetic calorimeter (Fig.2b) a proton rejection of 10^6 up to particle energies of 300 GeV. The particle identification capabilities of AMS-02 are completed by a ring image cherenkov counter below the silicon tracker.
The design and construction of the novel TRD detector will be discussed in more detail in the following.

3 The AMS02 Transition Radiation Detector

Transition Radiation Detectors (TRD) have been flown [3] and are currently under construction for large accelerator [4, 5] and space based experiments [6].



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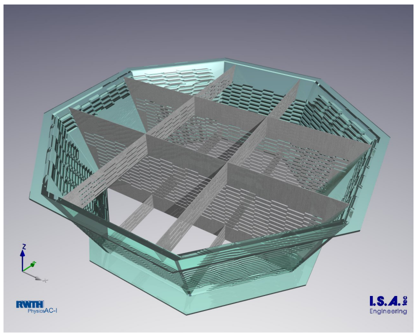
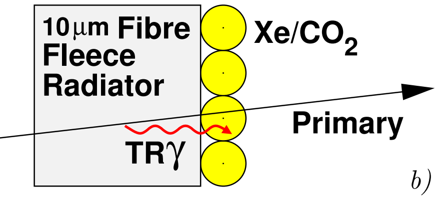


b)

Figure 3: *Computer generated view of a) the TRD on top of the magnet vacuum case and of b) the TRD support structure.*

The challenge is to operate such a large gas detector safe and reliable in space for 3 years. Figure 3a) shows the AMS-02 TRD on top of the magnet vacuum case. The TR photons generated in a 20 mm thick fleece are detected in straw tubes, filled with a Xe/CO2 (80%/20%) gas mixture (Fig.4a). The TRD



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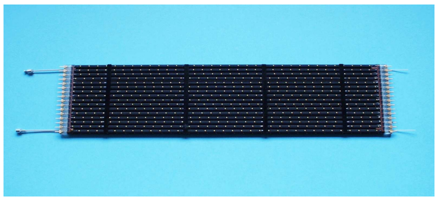


b)

Figure 4: *a) The principal of the AMS-02 TR-detector, b) TRD straw module.*

consists of 20 layers of straw/fleece modules mounted in a conical octagon structure (Fig.3b). The top and the bottom 4 layers of straws are oriented parallel to the AMS x-axis while the middle 12 layers are orthogonal, parallel to the y-axis. The length of the 328 straw modules varies from bottom to top layer from 0.8 m to 2.0 m. Each straw module consists of 16 straws (Fig.4b). The straws have an inner diameter of 6 mm, the wall material is a multilayer aluminum-kapton foil with a total thickness of 72 μm. A gold plated 30 μm thick tungsten wire, fixed in a polycarbonate endpiece, is used as sense wire. The crimping technique used for the connection between the tungsten wire and a CuTe-end piece has been developed in Aachen [7]. The straw modules are mechanically stabilized by longitudinal and vertical carbon fiber stiffeners. With a mechanical wire displacement of $\leq 100\ \mu$m a gasgain variation of less then 2% is achieved.

For the operation of the TRD in space the gas tightness of the straw modules

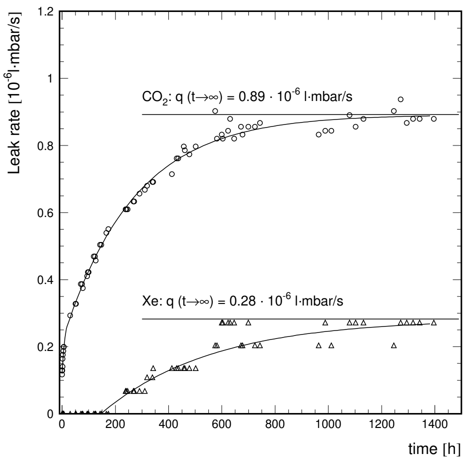


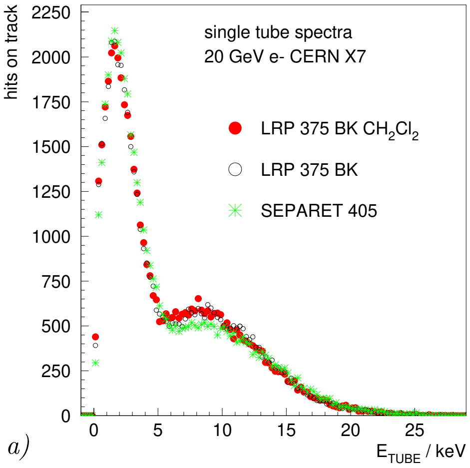
Figure 5: *Gas leak rate as measured with a mass spectrometer for Xe/CO2 (80%/20%) with three 1.3 m long straws connected in series.*

is important. The measured leak rate for one straw of $0.3 \cdot 10^{-6}$ l mbar/s/m is dominated by diffusion through the straw walls (Fig.5). Assuming pure diffusion leaks this would correspond to a loss of 50 l Xe and 170 l CO2 gas equivalent to a total leak rate of 10^{-5} mbar/s for the data taking period off 1000 days on the ISS. It is foreseen to carry 50 kg of gas storage to the ISS, corresponding to 8100 l Xe and 2000 l CO2 at 1 atm, resulting in a safety factor of nearly 50. The excess amount of storage gas can also be used for refreshing the circulating gas. The circulating gas system serves 41 loops at 1 l/h, each loop with 8 straw modules in series.

As radiator material the polyethylene/polypropylene fleece LRP 375 BK[1] [4] is used in the AMS-02 TRD. The fiber thickness is 10 μm and the fiber sheets have a density of 0.06 g/cm^3. Each straw module will be covered by 20 mm of this

[1]manufacturer: Freudenberg Vliesstoffe KG, Germany

fleece material. All materials used in the detector must be space qualified. The deposition rate on nearby attached payloads on the ISS is 10^{-14} g/s/cm^2. A measurement of the outgassing rates with respect to the NASA-ASTM E 1595 report has shown that this limit was reached after cleaning the fleece material with CH_2Cl_2 (soxhlet extraction method, Fig.6b). Results from a prototype test [9)] have shown that this cleaning does not affect the transition radiation performance (Fig.6a).



a)

b)

Figure 6: *a) Single straw spectrum with LRP 375 BK fleece material in front of the straw modules in comparison to a spectrum with LRP 375 BK cleaned with CH_2Cl_2. b) Soxhlett extraction setups at the Organic Chemistry Institute of RWTH Aachen.*

The conically shaped octagon structure is made out of a carbon fiber and aluminium honeycomb sandwich material and is closed by a lower and upper honeycomb plate. The structure is machined with a precision of 100 μm. The TRD is supported by the upper plate and by an aluminium M-structure which is attached to the USS-02 (Fig.3a). On the outside of the octagon a grid structure (carbon fiber tubes) is attached to support the services like gas tubes, HV cables and signal cables.

The DAQ system of the TRD is divided into two parts (Fig.7). The front end electronic which is mounted on the octagon walls of the TRD, and the first level of data acquisition which is hosted in two identical crates next to the TRD. The digitization of the signals from the 5248 straw tubes is done in the front

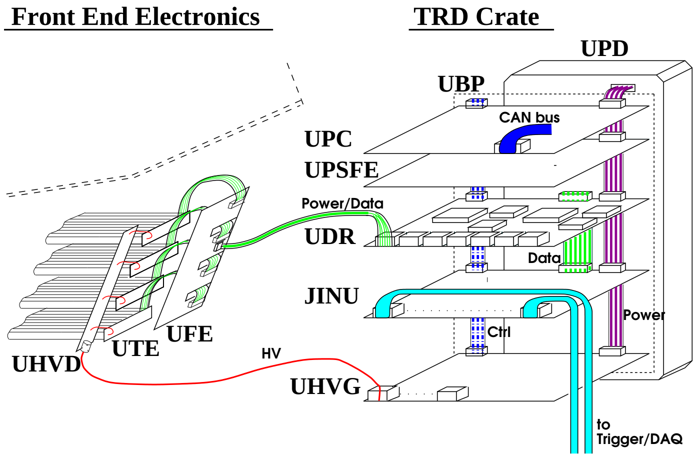


Figure 7: *Schematic view of the TRD electronics.*

end electronics which consists of three parts, the UTE-, UFE-, and UHVD-board. Each straw module is equipped on one end with a printed circuit board called UTE which distributes the high voltage to the 16 wires and to decouple the high voltage from the wire signals. One UHVD board and a coaxial cable are used to feed the high voltage from the high voltage unit UHVG to the 4 straw modules of one group which is connected to one readout board UFE, performing amplification, shaping and digitalisation of the wire-signals. The crate hosts the power supplies, the boards which collect and compress the data and the control of the TRD DAQ system. The front end electronics produce approx. 25 W which will be cooled off by radiation via a ring radiator on top of the TRD.

After the successful production of 60 TRD modules for the test beam measurements in summer 2000 [9] the following procedures for quality insurance and quality control have been established. In a first step the individual straws are cut to length and glued together with the longitudinal and transversal stiffeners on a precision jig. Then the polycarbonate endpieces are glued to the straw modules. The second step is the wiring, tensioning and crimping [7]. A signal feedthrough measurement is applied to all wires to find and replace broken wires. The wire tension is (1 ± 0.1) N and is controlled for each wire using an eigenfrequency measurement [8]. The noise level of each wire is measured by counting the discharges over a time period of 100 s. For this a high voltage is applied to the straw module which is placed in an Ar/CO_2-atmosphere. Finally all wires are checked again with a signal feedthrough test. The third step is the high-voltage board mounting and the final potting of the straw module end-pieces. The produced straw modules undergo the following operational tests:

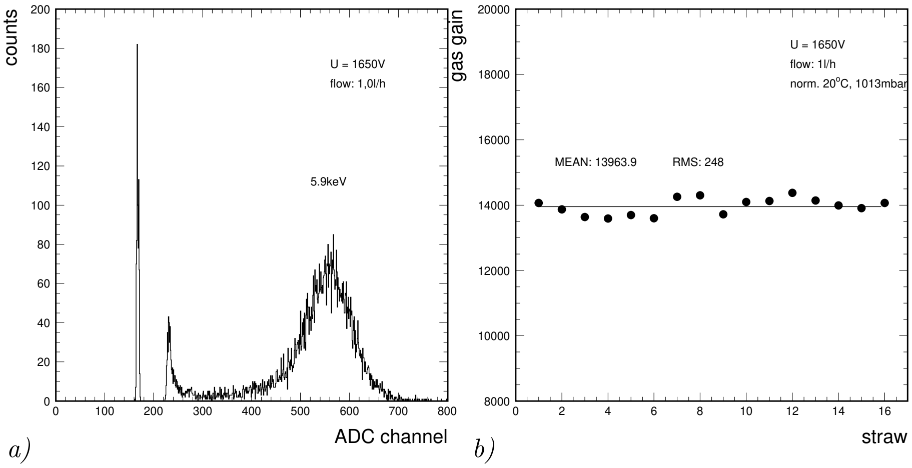
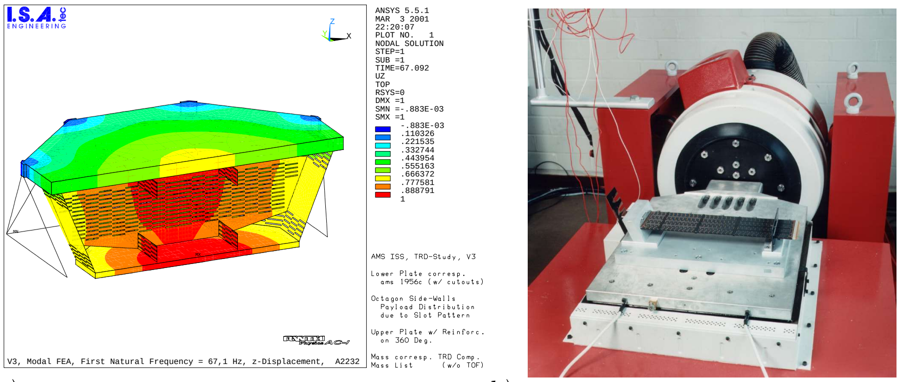


Figure 8: *The gasgain measurement using signals of converted 5.9 keV photons of an* Fe^{55}*-source.*

Overpressure burst test: In space the straw modules operate at a gas-pressure of 1.25 bar. Therefore the gas tightness of each straw module is checked up to an overpressure of 2.5 bar (safety factor of 2).
Pressure drop test: The leak rate of each straw module is measured by a pressure drop test at 2 bar in a vacuum vessel with a limit of $5 \cdot 10^{-5}$ mbar/s.
Dark currents: The operational high-voltage range of (1400-1650) V corresponds to a straw gas gain in the range of $(2-14) \cdot 10^3$ in a Xe/CO2 (80%/20%) gas mixture. The straws should operate without any significant (< 1 nA) dark current over this high-voltage range.
Gasgain measurement (Fig.8): A calibration of each straw is done by a measurement of the gasgain as a function of the high voltage on a precision granite block. The straw-signals are caused by converted 5.9 keV photons of an Fe^{55}-source.
Long term test: 8 straw modules (equivalent to a TRD gasgroup) are mounted in a vacuum vessel to study the long term behaviour of the straw modules. The

Xe/CO2 gas mixture is flushed through the 8 chambers in series at the nominal flow of 1.0 l/h in a closed circulating gas system. The gasgain is measured again using the signals of converted 5.9 keV photons of an Fe^{55}-source.



a) *b)*

Figure 9: *a) TRD modal analysis, b) vibration test stand loaded with a TRD straw module at the RWTH Aachen.*

A coupled load analysis of the entire TRD structure based on the "structural Verification Plan" (JSC-28792, Rev. A) has been carried out by means of a detailed Finite Element Calculation (F.E.C.). As the result of the modal analysis (Fig.9a) the first natural eigenfrequency turns out to be 67.1 Hz, well above the required 50 Hz.

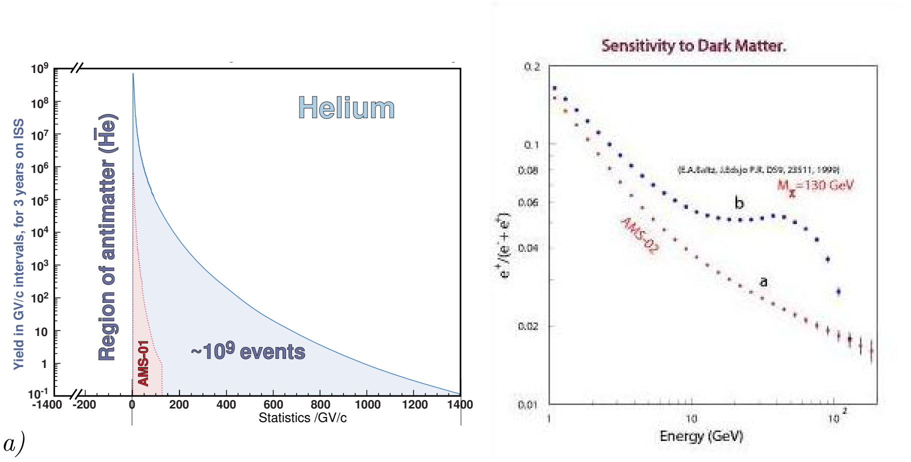
Various experimental tests are foreseen or already partly carried out (Fig.9b) to verify material properties and analytical calculations. Four 1.4 m long straw modules, the octagon panel, the CFC Honeycomb plates, the M-structure, the brackets and the qualification boards of the various electronics components will undergo a vibration test (a 0.5 g sine sweep will be followed by a 6.8 grms random test followed again by a 0.5 g sine sweep), acoustic tests with a sound pressure level of 115 db, 8 cycle thermo vacuum tests between -20°C and +40°C and an EMI test will be carried out.

All materials will be space qualified according to LMSO on the basis of manufacturing lists. Various special materials have been tested or will undergo outgassing tests by LMSO with proper qualification.

4 Conclusions

The AMS-01 experiment demonstrated that it is possible to operate a modern particle physics detector in space collecting 100 millions of charged particles in the momentum range from 0.1 GeV to 100 GeV resulting in a detailed knowledge of the composition of particle fluxes in the near earth space. During the 3 years data taking period on the ISS, AMS-02 will collect a factor of 1000 more particles in an extended momentum range up to the TeV range. Special goals are the search for nuclear antimatter and dark matter.

The AMS-02 TRD fulfilles the space qualification requirements like eigenfrequencies, material stresses, outgassing, gastightness, weight and power. The assembly of AMS-02 will be finished end of 2003 to be ready for a launch with the Space Shuttle in 2004.



a)

Figure 10: *a) The expected Helium spectrum as measured with AMS-02 after 3 years on the ISS compared to the AMS-01 measurement. b) The expected relative positron rate as measured with AMS-02 on the ISS after 3 years. a) Without neutralino annihilation in the galactic halo. b) With neutralinos of 130 GeV mass as the dominant source of dark matter annihilating in the galactic halo.*

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