Rare Components in Cosmic Rays with AMS-02

TAUP Sendai Sep.07

Andreas Sabellek
IEKP - Universität Karlsruhe (TH)

for the AMS Collaboration
The AMS Project: History and Future

1998

10 days Precursor Flight on board the Space Shuttle Discovery

2008 again ready for launch

AMS-01

Alpha Magnetic Spectrometer

AMS-02

3 years on the International Space Station ISS with 1000-times higher statistics measurement

Spectra of primary and secondary p,e and He

Superconducting magnet and new subdetectors for better particle identification: Precise antimatter and heavy nuclei fluxes measurement

Outline

• AMS-02 Experiment on board the ISS

• Science with AMS-02 and Achievement Potential
  – “Standard Cosmology”: Cosmic Ray Spectra and Composition
  – Gamma ray astrophysics
  – Indirect Dark Matter Search
  – Direct Search for Antimatter (a heavy Anti-nucleus)
  – Search or Exotic Matter: Strangelets, …

• Flight Status and Summary

AMS-02 will record about $2 \times 10^{10}$ physics events from cosmic rays in 3 years and identify its rare components with excellent particle identification.
The AMS-02 Detector

Dimensions: 7 tons and 3x3x3.5 m³
Acceptance: 0.5 m²sr
Lifetime (cryomagnet): min 3 years

Redundant measurement in different subdetectors to gain precision
Flight Subdetector Hardware

**Superconducting Magnet:**
Field 0.86 Tesla; 5.2 MJ stored
NbTi/Copper conductor I~460A;
Cooled to 1.8K by 2500l
Superfluid Helium

**8 Plane Silicon Tracker:**
200,000 channels on 6.6m² strips
Resolution $\sigma=30\mu m$ and 10$\mu m$ in bending direction
- Rigidity measurement up to few TeV
- Particle identification by $dE/dx \sim Z^2$
- Measurement of gammas in conversion mode

**Anticoincidence counters:**
16 cylindrical shell paddels of plastic scintillator for veto
Flight Subdetector Hardware

Transition Radiation Detector:
- 20 layers, 5248 strawtubes with Xe/CO₂ Gas @ 1 bar
- Fleece radiator for electron/proton separation:
  - e/h rejection > 100
  - dE/dx measurement

Time of Flight:
- 2x2 scintillator planes as primary trigger
- Resolution t<130ps
  - Velocity measurement dβ/β~3%
  - dE/dx measurement
Flight Subdetector Hardware

Ring Image Cherenkov Detector:
NaF (n=1.336) and Aerogel (n=1.035) radiator
PMT’s array of spatial pixel size 8.5x8.5 mm
• β measurement up to 20GeV/n
• Charge measurement up to Z=26 (N_γ~Z^2)

Electromagnetic Calorimeter:
18 planes (640kg) of Pb with scintillator fiber
inserts; thickness 16X_0 / .5λ_h
e/p separation ~1000 to 1Tev

dE/E=0.023+0.10/√E[GeV]

Space qualified electronics running with 650 micropocessors to read out
300000 channels, GPS, Startracker Camera and heat control systems.
Photon Detection with AMS-02

**Single photon mode**
- $\gamma \rightarrow \text{EM Shower}$

**Conversion mode**
- $\gamma \rightarrow e^+ / e^-$-pair

**Energy resolution (100 GeV) $\sim 3\%$**

**Angular resolution (100 GeV) $\sim 0.02^\circ$**
Chemical Composition Measurement

Test results from accelerator 158 GeV/n

Cosmic spectra with 1% accuracy from Helium to Cobalt

$dE/dx \sim Z^2$

Abundance of cosmic nuclei

$N_\gamma \sim Z^2$

Univ. of Karlsruhe

Cosmic spectra with 1% accuracy from Helium to Cobalt

11/09/2007 TAUP 07, Sendai Andreas Sabellek p.9
Precision Study of Cosmic Rays – Radioactive Isotopes

- AMS-02 will collect $10^5$ $^{10}$Be isotopes in 3 years
- Half-life of $^{10}$Be in the order of confinement time
- Information about
  - Confinement time
  - Galactic halo size

- ... and collect $10^5$ C and $10^4$ B to measure the ratio of Carbon to its spallation secondary Boron up to 1TeV/n
- Information about
  - Amount of matter traversed
  - Diffusion (to understand propagation and to fix free parameters of models)
Isotope Identification

- AMS-02 can distinguish $^4$He and $^3$He
- There is room for discoveries in different channels
  - Unexpected result from AMS-01: He isotopes are completely separated
- AMS-02 is also a long duration cosmic radiation monitor (e.g. solar modulation)
Diffuse Gamma Rays and Sky Survey

- Two complementary modes for Gamma detection
- Main source: cosmic ray interaction with gas (Pion decay, Bremsstrahlung, Inverse Compton)
- Information about
  - Interstellar matter
  - Accelerating processes and origin of cosmic rays in ‘standard’ astrophysics
Probe the Unknown

- Dark Energy ~73%
- Matter ~27%
  - ~4.4% Barions (~0.5% Stars)
  - 23% Cold Dark Matter

- Leading idea is some kind of not-yet-seen stable particle (WIMP candidate: Neutralino as lightest SUSY-particle in R-conserving model)

- Direct search on Earth ongoing (if the Earth not in a void, results expected)
- Indirect searches are based on $\chi + \chi \rightarrow bb$ quark pair production in annihilation, its decay then is well known from accelerator experiments

From CMB + SN1a + structure formation

\[ \approx 37 \text{ gammas} \]
AMS-02 will at the same time measure $p^-$ and $e^+$ spectra, which may contain an antimatter excess from annihilating dark matter particles.
Dark Matter Fit in different Sky Directions

3 components gamma spectrum: galactic background + extragalactic bg + DM annihilation fitted simultaneously with same WIMP mass in all directions.

EGRET Data

W. de Boer et al.

Univ. of Karlsruhe

inner Galaxy

outer disc

outer Galaxy

low latitude

intermediate lat.

galactic poles
Dark Matter Ring Interpretation

Fit in 180 directions implies substructure in the galactic distribution. Observed rotation curve of our galaxy then can be very well explained with obtained dark matter profile.

- Inner ring (coincidences with H$_2$ ring)
- Outer ring (coincidences with orbit of dwarf galaxy, which looses mass by tidal forces)


→ Promising hint for annihilation of 60 GeV WIMP from Gamma rays: Verification of EGRET data necessary!
→ Theory could allow to predict mass spectrum of SUSY from annihilation, which could be checked with accelerators.
Fluxes of Positrons and Antiprotons dependent on propagation models, but Dark Matter Annihilation with same Halo and WIMP parameters from Gamma Rays could (as input) be used to tune cosmic models, e.g. introduce unisotropic diffusion.
Antideuterons in standard astrophysics are produced with high energies, whereas antideuterons from Neutralino annihilation can be found below 1 GeV. This is more promising than antiprotons since easier extraction of SUSY signal (orders of magn.!!).

A large acceptance spectrometer like AMS-02 is required to measure the extremely low fluxes.
Kaluza-Klein Bosons as Dark Matter Candidates

Low Scale Quantum Gravity (extra-dimensional) predicts Bosons with mass, allowing direct annihilation into $e^+/e^-$ pairs (dominant channel $\sim 20\%$).

$\rightarrow$ steep spectra from BB collisions are different from neutralino annihilation

Excess from possible Boson mass of 300 GeV can be seen by AMS-02

Search for the existence of Antimatter in the Universe

The primordial antimatter content of the Universe is unknown.

- Up to today existence of antimatter domains in the universe is not excluded (predicted by Big Bang)

- No antimatter annihilation signal from within our cluster

- No antimatter particle found by AMS-02 means there is no Antimatter in the Universe

- A single anti-C: there are antimatter stars!

\[ \text{He/He (CL 95\%)} \]

\[ \text{AMS-01} \]

\[ \text{AMS-02} \]

(a) Buffington et al 1981
(b) Golden et al. 1997
(c) Badhwar et al. 1978
(d) Sasaki et al. 2001

1/10^3 \quad 1/10^5 \quad 1/10^6

Rigidity (GV)
Example for Exotic Matter in the Universe: Strangelets

Signature of a Strangelet event simply is anomalous $Z/A$

$Z \sim 0.3A^{2/3}$
$Z/A < 0.12$

One anomalous event was reported by AMS-01 (background probability $<10^{-3}$), compatible with a Strangelet.

Stable strange quark matter was first proposed by E. Witten, Phys. Rev. D, 272-285 (1984)

Could there be another new type of matter?
AMS-02 Flight Status

• Final Detector Integration at CERN, Geneva cleanroom in progress

• ... and completed for detector test at ESTEC, NL space simulating chamber in Summer 2008

• AMS-02 is strongly supported by NASA and on schedule for delivery to KSC, Florida in December 2008

ISS construction continued ‘06

CERN Cleanroom

Kennedy-Space-Center
Summary

• AMS-02 perfectly complements current big experiments in exploring new physics and is a general purpose instrument.

• It will take high statistics and long duration cosmic ray data on board ISS and is ready for launch early 2009.

• It will provide simultaneous measurements to
  – tune parameters of current cosmic models
  – allow combined dark matter search on matter/antimatter ratios and Gamma ray spectra

• AMS-02 will strongly extend limits on direct searches for heavy Antimatter as well as exotics in the Universe.

Thank you!
Backups
# Current Experiments

<table>
<thead>
<tr>
<th></th>
<th>BESS-Polar</th>
<th>PAMELA</th>
<th>AMS-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance (m²sr)</td>
<td>0.3</td>
<td>0.002</td>
<td>0.5</td>
</tr>
<tr>
<td>MDR (GV)</td>
<td>150</td>
<td>740</td>
<td>2500</td>
</tr>
<tr>
<td>Flight duration (days)</td>
<td>10+20</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Flight Altitude (km)</td>
<td>36</td>
<td>690</td>
<td>350</td>
</tr>
<tr>
<td>Residual air (g/cm²)</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Weight (tons)</td>
<td>1.5</td>
<td>0.38</td>
<td>~7</td>
</tr>
<tr>
<td>Power consumption (W)</td>
<td>600</td>
<td>345</td>
<td>2000</td>
</tr>
<tr>
<td>Magnetic field (Tesla)</td>
<td>0.8-1</td>
<td>0.4</td>
<td>0.87</td>
</tr>
<tr>
<td>Flight latitude (deg.)</td>
<td>80</td>
<td>±70</td>
<td>±52</td>
</tr>
<tr>
<td>Energy region (GeV)</td>
<td>&gt; 0.1</td>
<td>&gt; 0.1</td>
<td>~ &gt; 0.5</td>
</tr>
<tr>
<td>Flight vehicle</td>
<td>Balloon</td>
<td>Satellite</td>
<td>ISS</td>
</tr>
<tr>
<td># of events for:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>protons (range in GeV/n)</td>
<td>3 × 10⁹ (0.2-200)</td>
<td>3 × 10⁸ (0.08-700)</td>
<td>2 × 10¹⁰ (0.5-2500)</td>
</tr>
<tr>
<td>antiprotons</td>
<td>3 × 10⁴ (0.2-4)</td>
<td>3 × 10⁴ (0.08-190)</td>
<td>3 × 10⁶ (0.08-700)</td>
</tr>
<tr>
<td>e⁻</td>
<td>-</td>
<td>-</td>
<td>6 × 10⁶ (0.05-2000)</td>
</tr>
<tr>
<td>e⁺</td>
<td>-</td>
<td>-</td>
<td>6 × 10⁵ (0.05-270)</td>
</tr>
<tr>
<td>Anti-He/He</td>
<td>3 × 10⁻⁸</td>
<td>7 × 10⁻⁸</td>
<td>3 × 10⁷ (1.400)</td>
</tr>
<tr>
<td>Anti-D/D</td>
<td>10⁻⁵</td>
<td>-</td>
<td>3 × 10⁻⁷</td>
</tr>
</tbody>
</table>