Cosmic Ray and Gamma Astrophysics with AMS-02 Experiment

Sonia Natale
University of Geneva
on behalf of the AMS Collaboration

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Outline:

✔ ISS and AMS-02
✔ Physics Goals
✔ The Detector
✔ AMS-02 Expected Performances
✔ Conclusions
The Alpha Magnetic Spectrometer (AMS)

A large acceptance and high precision magnetic spectrometer on the ISS

✓ Orbital parameters of ISS:
  - Orbital period ~ 92 min
  - Mean altitude ~ 382 km
  - Inclination ~ 51.6°

✓ Main Physics topics:
  - Origin and transport of cosmic rays (from 1GeV to 1TeV)
  - Antimatter (e⁺, p, N)
  - Dark matter (e⁺, p, γ, D)
  - Study of galactic and extragalactic γ-rays
Cosmic Rays

AMS-02 will collect in 3 years:
- \( p \): dominant component \( (2 \times 10^{10}) \)
- \( \text{He} \): 5\% of \( p \) flux @ 10GeV
- \( D, \text{Li, Be, B and C} \)
- Anti-proton: \( \sim 10^{-4} \) of \( p \) flux

Protons: a way to measure the solar activity.

Isotopes: information on the propagation of Cosmic Rays in the Galaxy.

\(^{10}\text{Be}/^{9}\text{Be} \) ratio \( (^{10}\text{Be} \rightarrow 1.6 \times 10^6 \) yrs):  
- Cosmic Rays confinement time in the Galaxy  
- Mean density of interstellar material traversed.
The Big Bang Theory requires matter and antimatter equally abundant.

Antimatter within our cluster of galaxies excluded: no photon annihilation signal.

- Single anti-He Cosmic Rays nucleus:  Antimatter Domains
- Single anti-C Cosmic Rays nucleus:  Antimatter Stars
Annihilation of neutralinos in the galactic halo might produce a visible contribution to the anti-particle and photon spectra:

\[ \tilde{\chi}^0 \tilde{\chi}^0 \rightarrow q\bar{q} \rightarrow \bar{p} + \ldots. \]
\[ \rightarrow W^+W^-, ZZ \rightarrow e^+ + \ldots. \]
\[ \rightarrow W^+W^-, ZZ \rightarrow \gamma + \ldots. \]

AMS-02 is conceived to measure:
- \( \bar{p} \) spectrum (\( \sim 1 \text{GV} < R < 200 \text{ GV}, R=\text{pc}/\text{Ze} \))
- \( e^+ \) structure in spectra above few GeV

See Corinne Goy's talk in Dark Energy IV Session
AMS-02 will constantly monitor the γ-ray sky to complement the observations in other wavelength bands.

~ 280 pointlike γ-ray sources detected by EGRET:
~ 70 Active Galactic Nuclei (AGNs)
~ 7 Pulsars
~ 200 sources not identified yet
AMS-02 Detector

**Transition radiation**: allows hadron/electron separation

**Time of Flight**: measures time of flight, velocity $\beta$, direction and $dE/dx$

**Magnet**: superconducting magnet ($B=0.8T$)

**Tracker**: charged particle localization, rigidity with magnet, specific energy loss ($dE/dx \sim |Z|^2$), direction and energy of converted photons

**Cerenkov**: velocity $\beta$, energy loss $dE/dx$ and mass measurements

**E.m. Calorimeter**: lepton/photon energy and lepton/hadron separation
AMS-02 Transition Radiation Detector

- 20 layers assembled in octagonal structure.
- 328 modules of fleece and straw tubes.

\[ h/e \text{ rejection of } 10^2 - 10^3 \]

(in the range 300 - 3 GeV)
AMS-02 Time of Flight System

2x2 planes + total of 34 scintillator paddles
(see by 2 (or 3) PMTs on each side)

Time resolution: $\Delta t \sim 180$ ps ($Z=1$), 100 ps ($Z>1$)

2002 Test beam @ Cern
AMS-02 Superconducting Magnet

- 12 racetrack coils + 2 dipoles coils
- 2500 liters of superfluid helium

*Bending power: $BL=0.86\text{Tm}^2$*

**AMS-02 is still the only experiment in space which will use a superconducting magnet**
AMS-02 Silicon Tracker

- 8 layers of double sided silicon sensors
- 6.6m² → 192 Ladders → 196k channels

\[ \sigma(p)/p = 1.5\% \text{ @ } 10\text{GeV} \]

MDR\(^(*)\) \sim 2.5TV

\(^(*)\text{ max detec. rigidity} \)

2002 Test beam @ Cern
AMS-02 Ring Imaging Cerenkov Counter

- Cerenkov Cone
- Photomultipliers
- Mirror

3 cm silica aerogel (n=1.05) + NaF (n=1.33) radiator

680 multianode PMTs

$\sigma(\beta)/\beta=0.1\% \text{ @ } \beta=1 \text{ (protons)}$

$\Delta Z \sim 0.2 \text{ up to Fe}$

$\left( \frac{\Delta \beta}{\beta} \right) = \left( \frac{A}{Z} \right) + B$

Aerogel.CIN105

$A = (0.975 \pm 0.005) \times 10^{-3}$

$B = (0.080 \pm 0.001) \times 10^{-3}$

Expansion height, 33.5 cm

2002 Test beam @ Cern
AMS-02 Electromagnetic Calorimeter

9 super layers of Sci-Fi/Lead (16X)
(324 multianode PMTs)

$\sigma(E)/E = 3\% \ @ \ 100\text{GeV}$

$p/e$ rejection of $10^3$

2002 test Beam @ Cern

Energy resolution

Angular resolution
Cosmic Ray Detection

- Helium
- Boron/carbon
- Deuterons
- Beryllium isotopes
Search for Antimatter

Anti-proton

Anti-Helium

Helium

AMS-02: $2 \times 10^9$ He events to 3 TV

AMS-01: $2.8 \times 10^6$ He events up to 0.14 TV
γ-Ray Detection with AMS-02

**Conversion Mode:**
e+e- pair in the TR

**Calorimetric Mode:**
e.m. shower in ECAL
Tracker and Ecal Performances

Acceptance

![Acceptance graph]

Effective Area

![Effective Area graph]

Energy Resolution

![Energy Resolution graph]

Angular resolution

![Angular resolution graph]
AMS-02 high energy Gamma Rays Exposure

One year AMS-02 Ecal Exposure

One year AMS-02 Tracker Exposure

One year AMS-02 Tracker+ Ecal Exposure

Tracker + Calorimeter give the whole sky coverage
Using a fast simulation tool with parametrization of AMS-02 ECAL and Tracker acceptances and resolutions

One example: estimates for $\gamma$-sources

<table>
<thead>
<tr>
<th>3EG Catalog</th>
<th>Other Name</th>
<th>$N_\gamma$ (Tracker)</th>
<th>$N_\gamma$ (ECAL)</th>
<th>$N_\gamma$ (total)</th>
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<tbody>
<tr>
<td>J0210-5055</td>
<td>0208-512</td>
<td>47.0</td>
<td>13.4</td>
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<tr>
<td>J0530+1323</td>
<td>0528+134</td>
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<td>J0534+2200</td>
<td>Crab</td>
<td>102.2</td>
<td>26.6</td>
<td>128.8</td>
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<td>J0834-4511*</td>
<td>Vela</td>
<td>491.4</td>
<td>203.8</td>
<td>695.2</td>
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<td>J1255-0549</td>
<td>3C279</td>
<td>138.6</td>
<td>35.8</td>
<td>138.6</td>
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<td>J1409-0745</td>
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<td>5.9</td>
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<tr>
<td>J1635+3813</td>
<td>1633+382</td>
<td>65.5</td>
<td>18.3</td>
<td>83.8</td>
</tr>
</tbody>
</table>
One example: estimates for $\gamma$-sources
Conclusions

- **AMS-02 is approved by NASA to operate on the ISS for 3 years at least.**

- **AMS-02 will be fully assembled end 2007.**

- **AMS-02 large acceptance and long exposure time outside the Earth's atmosphere, will allow an unprecedented sensitive search for Antimatter, Dark Matter and studies of Cosmic Rays.**

- **Interesting Galactic and Extragalactic Gamma Ray measurements can be made.**