AMS-02 and the TOF detector: performance and physical perspectives

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The TOF system provides:
- the **fast trigger** to the whole AMS and the selector of the events through the LT, HT and SH;
- the measurement of the time of flight ($\Delta t$ – better than 180 ps), for the determination of the particle velocity ($\beta$), with a resolution of few %;
- the measurement of the absolute particle charge up to $Z = 15$;
- the **distinction** from upward and downward going particles at a level of $10^{-9}$ necessary to distinguish between matter and antimatter;
TOF consists of 4 plastic scintillator planes, 2 above and 2 below the magnet. The counters of adjacent planes are orthogonal. The number of counters per plane has been reduced to 8, 8, 10, 8 counters to reduce the weight (34 scintillators).

Each TOF counter is composed by:

- a plastic scintillator 1 cm thick and around 120 cm long (Eljen-Technology type: Ej-200),
- read at both ends by 2 independently powered photomultiplier tubes (fine-mesh Hamamatsu R5946 with max spectral response at 420 nm),
- connected with transparent light guides.
The AMS-02 TOF

Layer 2 - Particle TOF coords

On the ISS

206p
Performance - Charge

Charge Separation

Time Resolution
Performance - Time

Time Resolution: 160 ps/pad

TOF Time

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<tr>
<td>$\chi^2 / \text{ndf}$</td>
<td>330.8 / 110</td>
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<tr>
<td>Constant</td>
<td>$3202 \pm 10.8$</td>
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<tr>
<td>Mean</td>
<td>$0.005219 \pm 0.000895$</td>
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<tr>
<td>Sigma</td>
<td>$0.3196 \pm 0.0006$</td>
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TOF response to Z=1 particles in space - Velocity

\[ \beta \text{ Resolution: } >4.8\% \]
Go baby go!
And physics begins
AMS–02 and the Antiworld Island of Antimatter?

The CPT theorem assures that any particle species there exists the antiparticle with exactly the same mass and decay width and eventually opposite charges. This striking symmetry would naturally lead us to conclude that the Universe contains particles and antiparticles in equal number densities.

The observed Universe is drastically different.

- 100 MeV $\gamma$ flux excludes wide antimatter regions up to 100 Mpc
- Sakharov’s 3 Principles of Baryogenesis .....  
  ... but alternative models predict distant antimatter local domains
- A single anti–He CR nucleus represents a strong evidence for Antimatter Domains in our Universe
Expected number of detected cosmic ray particles above a given energy threshold in three years of data

<table>
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<th>&gt; 10 GeV/c</th>
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<td>P</td>
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<td>He</td>
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<td>2.1 × 10^8</td>
<td>7.3 × 10^6</td>
<td>1.7 × 10^5</td>
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</table>

Antihelium/Helium Flux
Expected Goal for Antinuclei Search

- Buffington et al. 1981
- Golden et al. 1997
- Badhwar et al. 1978
- Alcaraz et al. 1998
- Sasaki et al. 2001

Pamela

AMS-02 3 Years
AMS will measure of cosmic ray spectra for nuclei, for energies from 100 MeV to 2 TeV with 1% accuracy continuously over the solar cycle.

The isotopic composition of the CR is correlated with their propagation mechanisms.
Light nuclei ratios to fix the propagation parameters and improve the accuracy of GALPROP.
New Physics: Strangelets

There are six types of Quarks found in accelerators \((u, d, s, c, b, t)\).
All matter on Earth is made out of only two types \((u, d)\) of quarks.
“Strangelets” are new types of matter composed of three types of quarks \((u, d, s)\) which should exist in the cosmos.

**Carbon Nucleus**  
\(Z/A \sim 0.5\)

**Strangelet**  
\(Z/A \sim 0.1\)
$\Phi_{\text{strangelets}} = 5 \times 10^{-10} \text{(cm}^2\text{s sr)}^{-1}$
Dark Matter Program (TOF Group)
Indirect detection via annihilation/decay chain products: antiproton, positron, gamma, antideuteron

No Dark Matter Signal!

PAMELA results on the Cosmic-Ray Antiproton Flux
Are we seeing dark matter?

PAMELA requires: leptons but no antiprotons.

Fermi and Hess set the mass: $M_{DM} \simeq 2 - 3$ TeV
Primary CR Positron from Dark Matter
Mass and Decay Channel

For heavy hadrophilic high cross section WIMP

Antideuteron Flux and Uncertainties comparison
Propagation Model and dark Matter Halo

TOA $\bar{d}$-flux from $\chi \bar{\chi} \rightarrow b\bar{b}$

$M_{DM} = 10$ TeV, DM profile: Einasto, $\langle \sigma v \rangle = 7 \times 10^{-22}$ cm$^3$s$^{-1}$

$M_{DM} = 10$ TeV, propagation: med, $\langle \sigma v \rangle = 7 \times 10^{-22}$ cm$^3$s$^{-1}$

dashed: NFW
solid: isothermal
dotted: Einasto

$\Phi$ in (m$^2$ sr s GeV/n)$^{-1}$

$T$ in GeV/n
An example: Antideuteron flux from neutralino, KK Photon and right-handed neutrino LZP

Light LZP provides measurable fluxes for AMS-02

With e+ and low energy antideuteron we can probe

SUSY Wino, Little Higgs, KK Theory, PBH, Singlet Scalar, Minimal DM, Technicolor...
And also...
High Energy Hadrons

Total Flux High Energy

- PAMELA
- AMS-02 (projected 3 year data)

Antiproton High Energy Signal from KK particle
Antiproton & Antideuteron HE Search with AMS–02:

Dark Matter Parameters Space for a non-leptophilic candidate:

\[ M_{DM} \geq 2 \text{ TeV} \]
\[ \langle \sigma v \rangle \sim 10^{-26/22} \text{ cm}^3 \text{s}^{-1} \]

High Energy \( \bar{p}, \bar{d} \) Fluxes of \( 10^{-(5/6)} \text{[GeV m}^2 \text{s sr]}^{-1} \)

for Kinetic Energy of \( 70 \div 500 \text{ GeV/n} \)

A lot of new stuff! Stay tuned....