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Performance of AMS-02 Time of Flight

V. Bindi[a,b], D. Casadei[a,b], G. Castellini[a,c], F. Cindolo[a], A. Contin[a,b],
F. Costa[a,b], F. Giovacchini[a,b], G. Laurenti[a], G. Levi[a,b], A. Oliva[a,b], F. Palmonari[a,b],
L. Quadrani[a,b] and C. Sbarra[a]
(a) INFN Bologna, viale Berti Pichat 6/2, Bologna 40127, Italy
(b) Physics Department, Bologna University, via Irnerio 46, Bologna 40126, Italy
(c) IFAC-CNR Firenze, via Panciatichi 64, Firenze 50127, Italy
Presenter: F. Giovacchini (giovacchini@bo.infn.it), ita-giovacchini-F-abs1-he21-oral

AMS-02 Time of Flight (TOF) plastic scintillators prototypes were tested with ion beams at CERN SPS in 2002 and 2003. The response of the polyvinyltoluene counters to the energy lost by ions with $Z < 16$ was studied in order to find the best parametrization and the ion separation power of the TOF detector. The values for the parameters of the Birks-Chou formula were found to be consistent among the different counters. Good cosmic nuclei separation of the TOF system up to $Z = 16$ can be anticipated. The operation of TOF scintillator counters at 400 km from Earth will be characterized by a large hit rate and an estimated absorbed dose of about 0.5 krad/year. Gamma radiation tests were carried on all parts of a TOF counter prototype to study the aging effects on the detector performance. No visible radiation damage was found up to 15 krad.

1. Introduction

The Alpha Magnetic Spectrometer (AMS-02) [1] is a large acceptance particle spectrometer that will operate on the International Space Station (ISS) for at least three years to measure Cosmic Ray (CR) fluxes. The TOF system of AMS-02, completely developed and built at the INFN Laboratories of Bologna, consists of four planes of 8, 8, 10, 8 plastic scintillator counters each. Scintillators are 1 cm thick and the light is collected by two or three PhotoMultiplier Tubes (PMT) per side. In order to minimize the angle between the magnetic field and the PMT axis, a bended light guides variety was produced.

The TOF system is expected to: provide the fast trigger to the experiment with a negligible inefficiency; distinguish between upward and downward particles at the 10^{-9} level; measure the particle β (β=v/c) with $\sigma_\beta = 3\%$ for protons; estimate the value of the particle charge up to $Z \simeq 20$ [2]. Two beam tests were carried out to study the TOF system performance and a counter ageing test is in progress to search for radiation damage.

2. Beam tests

Prototypes of AMS-02 TOF polyvinyltoluene scintillator counters were tested at CERN in 2002 and 2003 with standard NIM and CAMAC electronics at the SPS ion beam facility. The primary line (20 A GeV/c Pb in 2002 and 158 A GeV/c In in 2003) was directed against a Be target producing secondary nuclei from proton to the incident ion itself with a small spread in β. Mass over charge selection was made possible by tuning the magnets of the T8 selection line. Runs with A/Z=1, 2, 9/4, 7/3 were used to get large statistic of all important CR species.

During the 2003 test [2], 4 TOF counters equipped with different light guides, were set along the ion beam together with AMS-02 RICH [3][4] and tracker prototypes: 3 over 4 scintillators were made of Eljen EJ-200, adopted for the AMS-02 TOF, whereas the last one was made of Bicron BC-408, used in AMS-01. The time of

Table 1. TOF counter mean charge resolution vs atomic number.

Ion	σ_Z	Ion	σ_Z	Ion	σ_Z	Ion	σ_Z
H	0.15	B	0.21	F	0.29	Al	0.34
He	0.14	C	0.24	Ne	0.37	Si	0.5
Li	0.17	N	0.29	Na	0.34	P	0.4
Be	0.23	O	0.31	Mg	0.34	S	0.4

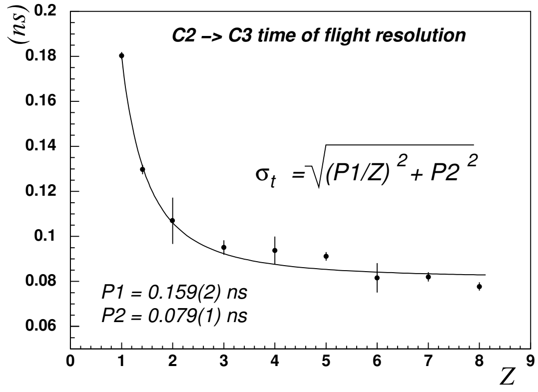

Figure 1. Time of flight resolution vs atomic number.

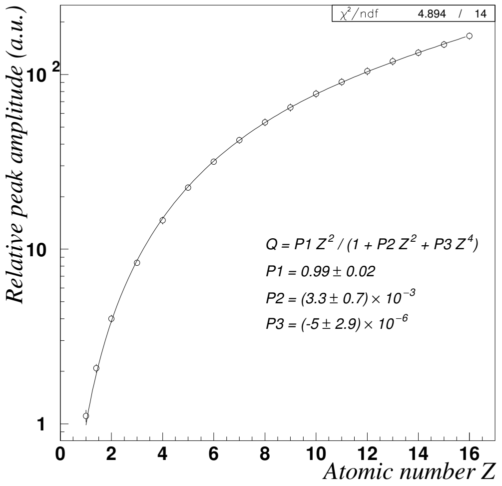

Figure 2. Fit of the measured average amplitude vs the atomic number.

flight between two different TOF counters was measured; the resolution obtained in the worst case for counters with curved and twisted light guides is shown in Fig.1 and it is 180 ps for protons and about 100 ps for light ions.

The charge of a particle crossing the scintillator can be measured by looking at its energy loss: for particles heavier than electrons the mean rate of energy loss is a function (the well known Bethe Bloch equation) of the medium and of the incident particle velocity and charge. Two charge measurements, which are not statistically independent, are carried on with the PMTs placed in both sides of a given counter. Hence, the best side of each counter is used to estimate the particle charge. The charge resolution reported in Table 1 for ions up to S is the average over the four counters. Custom electronics boards [5] are being developed fo AMS-02, which will extend the charge range up to $Z = 20$.

The scintillator response is not a simple linear function of the ionization energy density, but it is well modelled by the Birks-Chou law [6]:

$$\frac{d\mathcal{L}}{dx} = \frac{A(\frac{dE}{dx})}{1 + kB(\frac{dE}{dx}) + C(\frac{dE}{dx})^2} \tag{1}$$

where $\mathcal{L}$ is the scintillator luminescence, kB is proportional to the density of excited or damaged molecules, which act as quencher, C is a small correction parameter due to saturation. For particle crossing the same

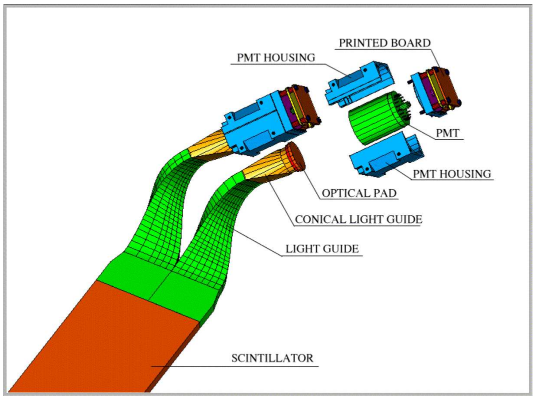

Figure 3. TOF counter: exploded view.

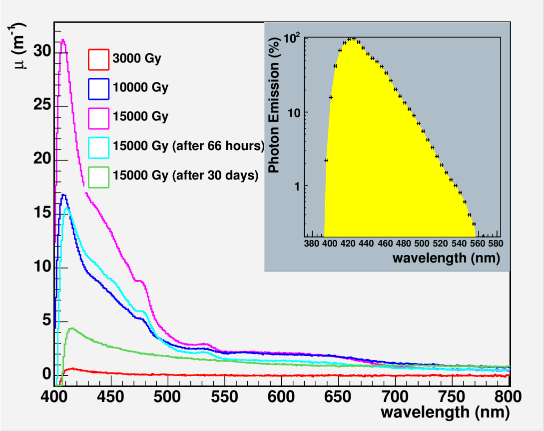

Figure 4. Induced absorption coefficient measured in the wavelenght range 400-800 nm for different absorbed doses. Also the recovery after 1.5 Mrad is shown. In the inset the EJ-200 emission spectrum is reported.

material and with the same β, the mean energy loss is a function only of their atomic number. The four fits of the luminous response vs Z give compatible results. Fig.2 shows the global fit obtained with the averaged amplitude peaks of the four detectors. The uncertainties associated to each point are of the order of 5%.

3. Radiation hardness

The TOF materials must be radiation hard enough to keep their characteristics stable for 10 years in space: the estimated absorbed dose is about 0.5 krad/year. It is known that the radiation induced darkening occurs in the majority of optical materials. Indeed organic materials are sensitive to radiation because of the generation of reactive intermediate free radicals, which take place when covalent bounds are excited or ionized by radiation. A set of studies about the radiation damage on each single part making up the TOF counter was performed using gamma sources.

One side of the TOF counter, including epoxy joints and light guides (see Fig.3), was irradiated at the GIF (Gamma Irradiation Facility - CERN) ^{137}Cs gamma source. At 60 cm from the source the dose rate was of the order of 11.5 rad/h (in water); 4.5±0.4 krad at the center and 3.1±0.3 krad at one side were achieved. No measurable changes were found in the attenuation length and in the number of photoelectrons, when compared to the measurements done before the irradiation and on the non-irradiated side.

In collaboration with the ISOF-CNR Institute of Bologna, several radiation damage tests were carried out on every TOF counter part: silicon optical pad, a plexyglass conical light guide and a small sample of scintillator ($42\times55\times10$ mm^3). Facilities employed: the Gamma Cell of ^{60}Co (ISOF-CNR) characterized by an activity of 4.27×10^{13} Bq (21 Feb '05) and a dose rate of 1.51±0.22 krad/min (in water); a Perkin-Elmer spectrometer (lambda 45 model) with 2 lamps (deuterium lamp for the UV region and a halogen one for $\lambda > 326$ nm) and a monochromator with 0.1 nm resolution. First, the optical pad was irradiated at several dose levels up to 15 krad, corresponding to three times the maximum absorbed dose expected in ten years. The optical transmission spectra of the pad in the range 190-1100 nm were measured before and after each irradiation by the spectrometer. The multiplication of the optical pad transmission spectrum with the scintillator emission spectrum (inset of Fig.4) does not show any appreciable variations of the integrated light output. A similar study was performed on the light guide. Even though the integrated transmittance spectrum in the scintillator emission region is stable within 5%, it is possible to recognize few small absorption structures.

The two most important types of radiation damage in plastic scintillators [7] are the production of new stable absorption centers that decreases the light transmission, and the deterioration of fluor and shifter molecules that reduces the light production. Both effects produce a loss of light output to the exit face. The concentration of colour centres is estimated from optical transmission measurements because it is proportional to the induced absorption coefficient μ defined as follows:

$$\mu = \frac{1}{d} \ln \left(\frac{T_0}{T} \right) \tag{2}$$

where T_0 and T are the transmission before and after irradiation and d is the sample length in meters. The scintillator sample was irradiated up to 400 krad observing negligible variation on the transmission spectrum. That dose corresponds to about hundred times the expected dose for the whole AMS mission. Above this threshold an absorbing peak at about 410 nm increases as is shown in Fig.4, where the radiation induced absorption coefficient μ is plotted as a function of the dose. The absorption in the lower wavelength region of the spectrum can be related to a deterioration of the wavelength-shifter molecules. In Fig.4 the measurements done some hours after the irradiation are also included to appreciate the recovery of the scintillator. A deeper investigation of recovery time of our scintillators is in progress.

4. Conclusions

TOF scintillator counters show a good charge resolution in particular up to Nitrogen and Oxygen nuclei. A first preliminary estimation of the Birks-Chou parameters kB and C for polyvinyltoluene EJ-200 scintillator can be anticipated: $kB = (1.2 \pm 0.5) \times 10^{-3}$g MeV^{-1} cm^{-2} and $C = (-6.4 \pm 6) \times 10^{-7}$g^2 MeV^{-2} cm^{-4}. The TOF system has a good radiation hardness and in particular neither optical pad nor light guide suffer radiation up to an absorbed dose of about 15 krad. The scintillator transmission spectrum is unchanged up to 400 krad.

5. Acknowledgements

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