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A compact Time-Of-Flight detector for space applications: The LIDAL system

A. Rizzo [a,b,*], L. Narici [a,b], R. Messi [a,b], P. Cipollone [b], C. De Donato [b], L. Di Fino [a], M. Iannilli [a,b], C. La Tessa [d,c], C. Manea [c], G. Masciantonio [b], M.C. Morone [a,b], G. Nobili [b], D. Pecchi [a,b], P. Picozza [a,b], E. Reali [a,b], M. Rovituso [c], F. Tommasino [d,c], G. Vitali [a,b]

[a] University of Rome "Tor Vergata", Physics Department, via della Ricerca Scientifica 1, 00100 Rome, Italy
[b] INFN Sezione Roma Tor Vergata, via della Ricerca Scientifica 1, 00100 Rome, Italy
[c] Trento Institute for Fundamental Physics and Application - TIFPA INFN -Via Sommarive 14, 38123 Povo (Trento), Italy
[d] University of Trento, Physics Department, via Sommarive 14, 38123 Povo (Trento), Italy

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ABSTRACT

LIDAL (Light Ion Detector for ALTEA system) is a compact detector designed to upgrade ALTEA (Anomalous Long Term Effects on Astronauts) silicon detector apparatus, in order to study in detail the low-Z part of ions spectrum inside the International Space Station (ISS) and to enhance the Particle Identification (PID) capability of the system.

The new detector is designed to trigger ALTEA and to perform Time-Of-Flight measurements. It is based on plastic scintillators for fast timing applications read by Photo-Multiplier-Tubes (PMTs). A custom Front End Electronics (FEE) has been designed to reach time resolutions less than 100 ps (σ) for protons.

A LIDAL prototype has been developed at the University of Rome Tor Vergata to test the timing performance of the scintillators, the PMTs and of the custom FEE using the proton beam line at the TIFPA (Trento Institute for Fundamentals Physics Applications) center in Trento, Italy. The results of these tests are reported and discussed. They have also been used for a preliminary evaluation of the Particle Identification (PID) capability of the final LIDAL-ALTEA detector system in response to the ions spectra expected on-board the ISS.

1. Introduction

Very fast plastic scintillator detectors represent nowadays a well established technology to be used for Time-Of-Flight (TOF) measurements, allowing to design compact devices suitable for space applications.

The LIDAL detector (Light Ion Detector for ALTEA) exploits this technology for radiation monitoring in human space habitats. It extends the sensitivity of the ALTEA apparatus (Anomalous Long Term Effects on Astronauts) to the low-Z ions since it allows to lower the trigger energy thresholds and to enhance the PID capability thanks to TOF measurements. The detector is based on fast plastic scintillators read by Photo-Multiplier-Tubes (PMTs); a custom fast Front-End-Electronics (FEE) allows LIDAL to reach time resolutions (σ) below 100 ps for proton energies expected onboard the International Space Station (ISS).

ALTEA apparatus has already been hosted onboard the International Space Station (ISS) (2006–2012) in missions aiming at the study of the ISS radiation environment [1–3]. The integration between the two detectors is shown in Fig. 1, where three ALTEA silicon telescopes (hereafter SDUs, Silicon Detector Units) are placed between the two LIDAL Detector Units (hereafter LDU). The possibility to have an efficient PID by matching the velocity β measured by LIDAL with the deposited energy measured by ALTEA for each event, will allow for the first time to measure in real time the ratio Z^2/β^2, a fundamental parameter related to the radiation risk for astronauts [4].

A first LIDAL prototype with two fast scintillator bars has been designed and constructed at the University of Rome Tor Vergata (URTV), featuring a custom fast FEE, based on the NINO chip (a fast discriminator and shaper [5]). The FEE output is processed by a CAEN V1290 Time to Digital Converter (TDC) module, including the CERN HpTDC chip, used in high resolution mode (32bit/channel). This chip will be used in the Data Acquisition (DAQ) electronics designed for the final LIDAL-ALTEA apparatus. Tests of the prototype have been performed at the Trento Institute for Fundamentals Physics Applications (TIFPA) proton beam line in Trento (Italy) to demonstrate that a time resolution better

* Corresponding author at: University of Rome "Tor Vergata", Physics Department, via della Ricerca Scientifica 1, 00100 Rome, Italy.
E-mail address: alessandro.rizzo@roma2.infn.it (A. Rizzo).

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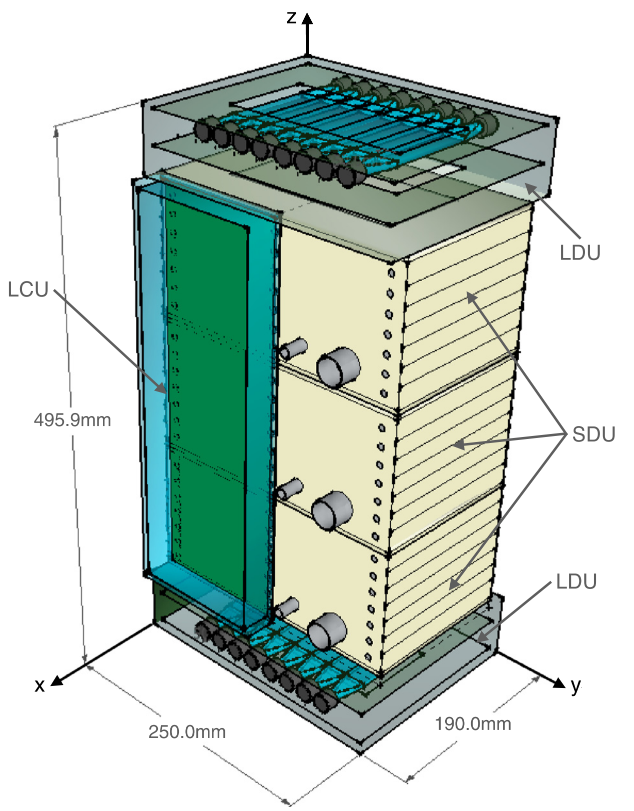

Fig. 1. Sketch of the LIDAL-ALTEA system in the final configuration designed to fly onboard the ISS (namely Flight Model or FM). The LIDAL detector will consist of three modules: two LDUs, each made of eight scintillators, and one LCU (LIDAL Collector Unit), for data acquisition. In between the two LDU modules three ALTEA SDUs are placed . Each ALTEA SDU is a particle telescope with six stripped silicon planes (380 μm thick, 8×16 cm^2 active area) stacked in a tower configuration, able to measure the energy loss and to reconstruct the track of a particle passing through. The Energy loss measured by ALTEA SDUs and the velocity measured by LIDAL will allow an efficient PID for a reliable risk assessment in real time.

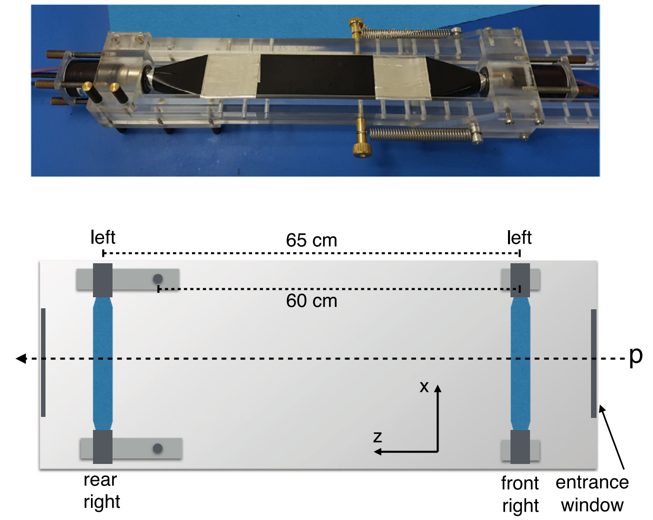

Fig. 2. *top*: A LIDAL scintillation unit, consisting in a scintillator bar coupled with two PMMA light guides and two PMTs, is shown. The traction springs of the plastic holder assure a constant and homogeneous pressure for the optical contacts between the different surfaces, obtained by a thin layer of optical grease. *bottom*: Two LIDAL scintillation units are placed at a distance d which can be set at 60 or 65 cm inside the aluminum box. Hereafter the first scintillator facing the beam is the *front scintillator*, the other is the *rear scintillator*.

than 100 ps may be achieved by LIDAL for protons. The experimental apparatus, the results and the future perspectives are discussed in the following sections.

2. LIDAL prototype

The LIDAL prototype has been designed and constructed to test the characteristics of the detector and the related electronics using a particle beam, so its geometry is quite different from the final LIDAL-ALTEA system. For this reason some mechanical solutions used for this prototype will not be implemented in the final design of the apparatus to fly onboard the ISS.

The prototype has been developed using plastic scintillators EJ-230 (Eljen Technologies) for fast timing application [6] and HAMAMATSU Photo Multiplier Tubes (PMTs) RS9880-U210. The PMTs have a Quantum Efficiency (QE) of 40% in the wavelength spectrum emitted by the scintillator (between 375 and 400 nm), a nominal rise time of 570 ps and compact dimensions [7]. The plastic scintillator EJ-230 is characterized by a rise time of 500 ps and a light output of 9700 photons for 1 MeV deposited electron energy [6]. These characteristics assure the fast timing response required to perform the TOF measurements together with a light output sufficient to provide a good trigger signal. The final scintillator dimensions ($90 \times 25 \times 8$ mm^3) have been chosen to maximize the timing resolution, according to FLUKA simulation results [8,9]. Both extremities of the scintillator bars are coupled to PMMA light guides, specifically designed to maximize the light collected to the PMTs. The optical contacts with light guides and PMTs are realized using high quality optical grease (BC630). A scintillation unit, formed by a scintillator bar, two PMMA light guides and two PMTs, is assembled using a plastic holder shown at the top of Fig. 2 . Two traction springs at both sides of the plastic holder assure a constant and homogeneous pressure among the optical contact surfaces. To maximize the light collected at the extremities, scintillator bars and light guides are wrapped in mylar foil, while multiple layers of black tape assure that the detector is light-tightened. Two scintillation units have been placed inside an aluminum box at a distance that can be set at 60 or 65 cm (see Fig. 2, bottom). The entrance window of the box is closed by a double wrap of black tape to light-tight the system.

The PMT signal is discriminated and shaped by the NINO chip in the FEE and then sent to the CAEN V1290 module. The module is based on the CERN HpTDC chip, which is used in high resolution mode (32bit/channel) to achieve the best timing resolution performance. A second and independent data acquisition chain has been set up to evaluate the deposited energy in the scintillator bars: the split PMTs signals are sent to a low-threshold discriminator (CAEN 417) followed by a CAEN V792 QDC module. Ad-hoc electronic boards, which integrate the HpTDC and NINO chips, are currently being designed for the final LIDAL-ALTEA apparatus.

3. Test at TIFPA proton beam line

The detector prototype has been tested at the TIFPA proton beam line (Trento, Italy) to study the timing performance of the system including its custom FEE. Protons are delivered at the facility by a superconducting cyclotron with an energy which can be set at values ranging from 90 to 228 MeV, with a rate up to 10^9 particles per second. The beam spot presents a round shape at the isocenter, with a diameter of about 15 mm. Several proton beam energies have been used in the tests at rates below 10 kHz. The low rate condition is achieved by putting in *dark current* mode the proton source inside the cyclotron. The high voltage of the source is set below the threshold used for the standard operations, resulting in low proton fluxes accelerated by the cyclotron. The monitoring devices along the beam line are not efficient at this