DEVELOPMENT OF A DETECTOR (ALFA) TO MEASURE THE ABSOLUTE LHC LUMINOSITY AT ATLAS

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The ATLAS collaboration plans to determine the absolute luminosity of the CERN LHC at Interaction Point 1 by measuring the trajectory of protons elastically scattered at very small angles (μrad). A scintillating fibre tracker system called ALFA (Absolute Luminosity For ATLAS) is proposed for this measurement. Detector modules will be placed above and below the LHC beam axis in roman pot units at a distance of 240 m on each side of the ATLAS interaction point. They allow the detectors to approach the beam axis to millimeter distance. Overlap detectors also based on the scintillating fibre technology, will measure the precise relative position of the two detector modules. Results obtained during beam tests at DESY and at CERN validate the detectors design and demonstrate the achievable resolution. We also report about radiation hardness studies of the scintillating fibres to estimate the lifetime of the ALFA system at different operating conditions of the LHC.

1. Introduction

The ATLAS experiment will determine the absolute luminosity of the CERN LHC at Interaction Point 1 (IP1) to a precision $\Delta L/L \sim 3\%$ by measuring the trajectories of elastically scattered protons at very small angles in the limit of the Coulomb Nuclear interference region[1]. A tracker system called ALFA (Absolute Luminosity For ATLAS) is proposed for this measurement. It is based on scintillating fibres and will be located in Roman Pots above and below the LHC beam axis at a distance of 240 m on each side of IP1. The first ALFA detector prototypes were tested at DESY in 2005[2], demonstrating that the main requirements of the fibre tracker can be achieved with the current design. A further test beam was carried out at CERN in 2006[3], with the main objectives of testing the first prototype of the dedicated Front-End (FE) electronics[4] and the alignment method using overlap detectors[5] (ODs). During the summer of 2007, plastic scintillating fibres have been irradiated in a proton beam at CERN and characterized[6].

2. Requirements on the detector

In order to approach the beam at mm distance the tracker should not have any sizeable inactive region (< 100 μm). The spatial resolution should be significantly smaller than the size of the beam spot at the detector; a resolution of 30 μm or better is required. The vertical distance between the upper and lower tracker must be known with a precision of about 10 μm. The detectors have to be insensitive to RF emitted by the LHC beam and to possible magnetic stray fields from nearby magnets. They need to operate in a secondary vacuum inside the roman pots and need to stand an accumulated dose of 100 Gy/yr.

3. The ALFA system

A tracking detector based on plastic scintillating fibres fulfills the requirements in a simple and cost effective way. As shown in Figure 1 it will be inserted in a roman pot together with an OD that is also a scintillating fibre tracker that reconstructs only the vertical coordinate for the precise relative alignment of the top and bottom pot. Trigger scintillators[a] define the active areas of the tracker and the ODs. The baseline fibres[b] of the ALFA tracker and the overlap detector are coated with an Al film to avoid cross talk. They are routed inside the roman pot to fibre connectors and coupled to MAPMTs[c]. The fibre connectors are inside the vacuum flange that closes the roman pot and the MAPMTs are inside

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[a] 3 mm thick Bicron BC-404

[b] Kuraray SCSF-78, S-type, 0.5 × 0.5 mm^2 square section

[c] Multi-Anode PhotoMultiplier Tube R7600 from Hamamatsu

a mu-metal shield. The very compact FE electronics is mounted directly on the back of the MAPMT.

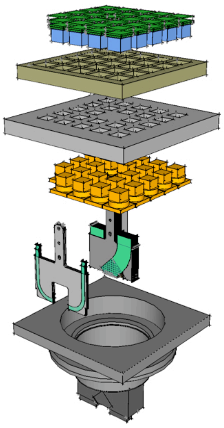

Figure 1. Exploded view of one detector unit of the ALFA system. From bottom to top we see the roman pot, the overlap detector and the tracker, the fibre connectors, the vacuum flange, the mu-metal shield and the MAPMTs with the PMFs. Not shown on the drawing are the trigger scintillator tiles.

The tracker consists of 10 ceramic plates (170 µm thick) supporting 2 layers of 64 fibres arranged in UV geometry under an angle of ±45° relative to the vertical axis. The planes are staggered by multiples of $(500\mu\text{m}/10) \times \sqrt{2} = 70.7$ µm to obtain an effective fibre pitch of 50 µm and a theoretical spatial resolution of $\sigma_{x,y} = (500\mu\text{m}/10)/\sqrt{12} = 14.4$ µm. Recently an alternative design has been proposed where titanium plates are used instead of ceramics. A prototype of a tracker based on this new design is under construction.

Each Roman Pot unit (upper and lower pots) will house in special extrusions two ODs (one in each pot) to determine the precise relative position of the upper and lower pot. They consist of 3 planes vertically staggered by multiples of $(500\mu\text{m}/3) = 166.7$ µm. Horizontal fibres define an active area of 6×15 mm^2. The ODs will be precisely positioned relative to the tracker.

Due to space limitations a very compact system design[4] is adopted where a large part of the binary FE electronics is mounted directly at the back of the MAPMTs. The so-called PMF (PhotoMultiplier Front-end) is a stack of three PCBs. The first board from the MAPMT is a custom voltage divider, the second board routes the signals to the third board which contains the MAROC[7] chip (Multi-Anode Readout Chip) and an FPGA called ALFA-R[8] (ALFA Readout) on the other side. The MAROC chip contains variable gain preamplifiers to correct for the MAPMT non-uniformity and transmits binary information to the ALFA-R which stores it in a pipeline until it receives an ATLAS Level 1 Accept trigger signal via the TTC (Timing, Trigger & Control) system. The data is then sent to the Roman Pot mother board which formats it and sends it to the common ATLAS readout system[9] through a Gigabit Optical Link.

4. Beam tests of prototype ALFA detectors

The results obtained during the beam tests confirmed the detector's design. The baseline fibre gave an average light yield of approximately 4 photoelectrons for an efficiency of 95% leading to a tracking efficiency of the detector superior to 99%. The spatial resolution of the tracker was of 36 μm during the first test beam with 6 GeV electrons. During the second test beam a spatial resolution of 23 μm was found with 230 GeV protons in agreement with the 30 μm required. No significant dead space at the edge of the detector was identified.

In addition to the ALFA prototype trackers two prototype ODs were built and tested. One OD consisted of 2 staggered layers with 30 fibres each. The ODs, as well as the alignment method, were tested for the first time in the CERN test beam achieving a vertical relative alignment with a precision better than 15 μm.

5. Characterization of irradiated scintillating fibres

Scintillating fibres of various types[d] were irradiated with 24 GeV/c protons with fluences ranging from 6.78×10^{11} p·cm^{-2} to 8.40×10^{15} p·cm^{-2} in the IRRAD1 facility[10] in the T7 beam line of the CERN PS accelerator. A specially designed tooling allowed simultaneous irradiation of fibres along the beam axis and fibres perpendicular to the beam. The irradiation campaign lasted 1 month and 7 batches of fibres were irradiated to doses ranging from about 100 Gy to more than 2 MGy. The light yield of fibres was measured by exciting them with a Sr-90 source. The fibre under test was coupled to a silicon photomultiplier[e]. An Al-coated reference fibre coupled to a photomultiplier tube[f] served as trigger. From the spectra obtained we determined the average number of photoelectrons for each fibre and calculated the detection efficiency which is plotted in Figure 2 as a function of the accumulated dose. The analysis[6] is ongoing and preliminary results show that the ALFA baseline fibre's efficiency starts decreasing for doses greater than 3 kGy. This confirms the full suitability of the scintillating fibre technology for luminosity measurements and indicates its potential for

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[d] Kuraray SCSF-78 with and without Al-coated, Kuraray 3HF, Bicron BCF-12; all fibres have a square section of 0.5×0.5 mm^2.

[e] Hamamatsu MPPC (Multi Pixel Photon Counter) S10362-11-100U

[f] Hamamatsu R647-01

physics runs up to a luminosity of 10^{31} $cm^{-2}s^{-1}$ assuming that proton-proton interactions dominate over background of the beam halo[6].

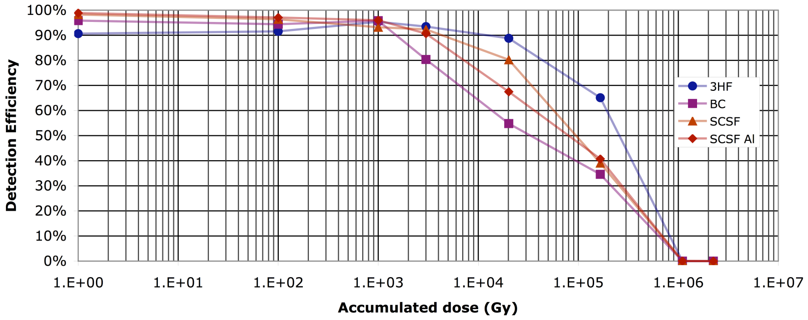

Figure 2. Detection efficiency of single fibres as a function of the dose (preliminary results).

6. Conclusions

Two beam test experiments have allowed us to validate the design of the ALFA tracker and to confirm that it meets the requirements for a precise measurement of the absolute luminosity at Interaction Point 1 where the ATLAS detector is located. The alignment method of the roman pots with overlap detectors has proven to provide the required precision. The next step is to build a full-size detector of 10 planes with 2 layers of 64 fibres each that will be integrated in a Roman Pot unit together with the overlap detectors and the trigger counters. The aim is to obtain a full system including also the front-end electronics to evaluate its performance and address integration issues such mounting and alignment precision.

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