EPJ Web of Conferences **66**, 11038 (2014)
DOI: 10.1051/epjconf/20146611038

Design and construction of the structure of the DEMONSTRATOR of the CALIFA detector for R^{3}B-FAIR using carbon-fiber composites

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Abstract. In this paper we describe the DEMONSTRATOR structures and active units (PETALs) developed for the detector CALIFA of the experiment R^{3}B - FAIR. The design is based in the CALIFA BARREL mechanical solutions, but adapted to the characteristics of the PETALs, namely in what concerns the load distribution during setup and service. The R&D program defined the materials and procedures for both producing the pieces of carbon fiber (CF) composites as well as the mounting of the bundles to make an alveolar structure. The procedures also include a quality control program to ensure the dimensional properties of the CF assemblies. We are also developing the use of tomographic imaging analysis for this quality program, that will be of mayor interest in the construction of the future CALIFA CF-structure.

1 Introduction

The next generation experimental setup for studies of *Reactions with Relativistic Radioactive Beams* (R^{3}B) [1] is one of the 8 experiments of the Nuclear Structure, Astrophysics and Reactions (NUSTAR) collaboration, of the international facility FAIR (Facility for Anti-proton and Ion Research)[2]. R^{3}B includes more than 50 different institutes from all over the world. One of the main activities of the members these years are the R&D programs to define the future setup of the experiment.

The detector CALIFA (CALorimeter for the In Flight detection of gamma-rays and light charged pArticles) surrounds the R^{3}B reaction target and will be used in a wide spectrum of experiments. CALIFA [3] consists of two sections, a cylindrical *Barrel* and a *Forward EndCap*. The Technical Design Report (TDR) of the BARREL was already approved. The construction will start with the DEMONSTRATOR (DMTR), a system corresponding to about 20% of the active volume of the CALIFA BARREL, using the same elements for both the active parts and the mechanical solutions. The program to start the construction of the DMTR is already launched in 2013. The schedule includes six PETALs to be ready for tests in-beam in 2014. Such system will be operative for doing benchmark experiments before the construction of CALIFA starts.

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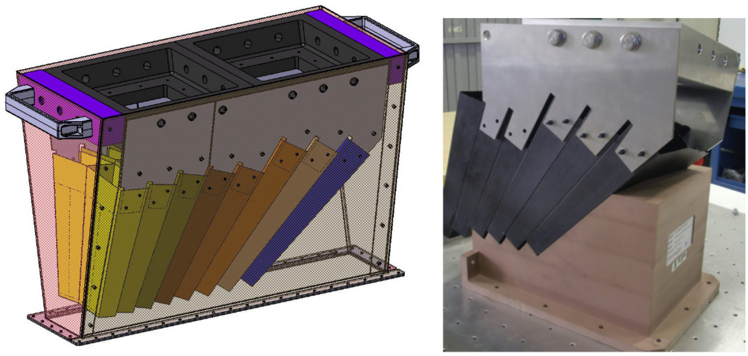

Figure 1. Left panel: Design of a PETAL assembly. A bundle of 2x8 pieces made of CF composite conform the CF-structure, hold at the upper-inner part of the walls by a piece with flaps; and along the outer sides with panel-like pieces (semi-transparent in the drawings). Two modular pieces hold the CF-structure at the top. A foil closes the system at the bottom, clamped by a frame. Right panel: Construction of a PETAL. A CF bundle is hold over a mockup to test the assembly of the structure. We can see the pieces with flaps that are attached to the upper part of the CF-structure.

2 PETAL units.

The functional units for the DMTR are called PETALs. The PETALs are built using the same construction procedures, materials and elements as for CALIFA [4]. Carbon fibre (CF) reinforced composites are used to make an alveolar structure. Each of the pieces of this structure, pocket-like, holds four crystals. The PETAL unit corresponds to a section of the most forward 8 rings of the CALIFA Barrel, and two CF pieces width (SINGLE configuration), holding 64 crystals. A TWIN configuration, with double width and 128 crystals, is also possible. The PETALs are autonomous and functional units. They are made of structures adequate to hold and position correctly the crystals, as well as to support the total weight (about 60 Kg for a single-PETAL). They must be gas- and light-tight. The self-supporting PETAL must be safely handled both hanging in the DMTR structure as well as during the integration phases in the lab (crystal positioning and locking, calibration, etc.).

The alveolar CF-structure of CALIFA is designed to be supported by a cover structure [4], with an intermediate structure based in pieces with flaps that hold the CF structure by the upper part of the pocket walls. Such design was developed considering that the CF-structure was closed, therefore the weight and loads are shared and distributed properly in the whole assembly. This is not the case of the isolated PETALs, since the CF-structure is now just a bundle of 2x8 CF pieces. We have to use a modified design, robust enough as to support the loads with no paired CF-structure on the sides.

We have developed a structure which is additionally a box-envelope, necessary to isolate the unit. In the figure 1 we show a view of the assembly, and a picture of a setup of one CF-bundle. The CF-structure is hold at the upper-inner part of the walls by the same piece with flaps as for CALIFA; and along the outer sides with panel-like pieces (semi-transparent in the drawings) which make an envelope of the PETAL. The overall dimensions of the PETAL are about 59 cm (length) x 27 cm (width) x 37 cm (height). The same cover modules of CALIFA are used in the top of the PETALs. A PET foil closes the unit at the bottom, adding a minimum of mass between the target and the active crystals, while isolating the system. With this design, the weight and load distribution on the CF-structure is achieved similarly as for CALIFA while the PETAL is hold in the DMTR structure. We use a dedicated support (kind of mockup) in the bottom of the CF-structure to preserve its integrity,

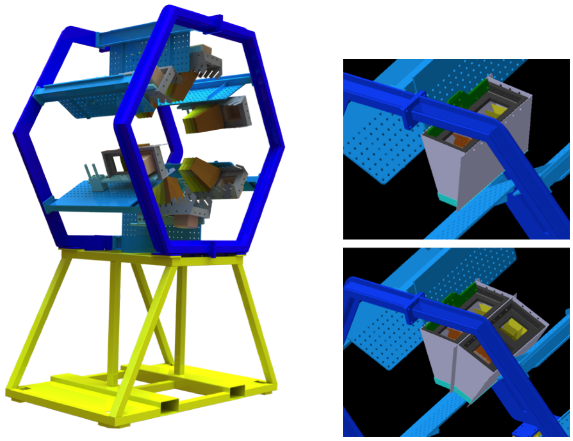

Figure 2. View of the DMTR structure. Each arm holds a panel with a matrix of holes to allow the positioning of the PETALS by using arm-like pieces, that hold firmly the assembly by the upper part. The structure can hold up to six PETALS single or twin, in a row, or even hold a second row. Different numbers of PETALS can be configured into different angle geometries around the beam axis. Right panels: the SINGLE and TWIN configurations of the PETALs.

during the operations of mounting / dismounting / locking the crystals. The PETALs have inlets for gas. A flow of some litres per hour of dry air or nitrogen keeps the humidity low enough as to guaranty the integrity of the crystals of CsI(Tl), with a tiny over pressure inside.

3 DEMONSTRATOR structure

The DMTR is an open structure gantry-like to be placed around the target (hence the PETAL name). The hexagonal gantry can be split if necessary to be set around a beam line. Each arm holds a panel able to support and position the PETALs, see figure 2. The PETALs are positioned in the discrete matrix of holes. A fine tuning of the angle and position is possible with custom pieces that serve as arm to attach the PETAL to the structure. Such arm clamps the cover modular pieces in a similar way as they are in the CALIFA structure. Both single- and twin- PETALs can be accommodated in the DMTR structure, up to 6 blocks, totalizing between 6x64 and 6x128 crystals. The structure could even accommodate a second line of PETALS, doubling its capacity. The nominal position of the CALIFA BARREL as well as other orientations and configurations are possible, including a forward-like configuration with small angles around the axis.

4 CF-structure: Advanced metrology and quality control program

To design the CF-structure we developed a program to study both the calculations (based in finite elements models FEM) and the prototyping. It is well know that the analysis of composite materials has a limited reliability, which limits the validity of the results in order to evaluate the design options. The only accepted results are after the actual test of the pieces. We have developed mechanical calculations with FEM using the dedicated analysis modules of ANSYS-ACP [5], developed for composites. The models were parameterised if necessary after tests done to validate the designs. The analysis results guided the design, material choice, etc., see figure 3.

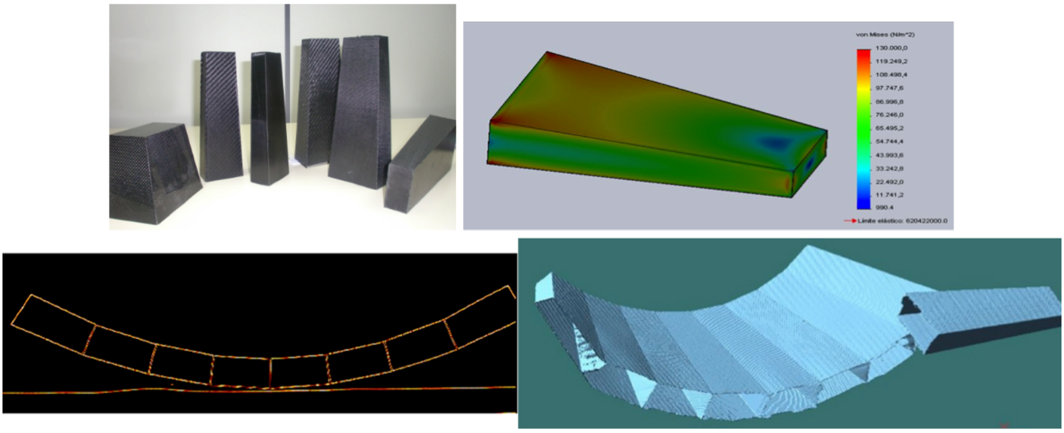

Figure 3. Upper-left panel: A collection of CF pieces produced for the project with different sizes, fabrics, procedures, etc. Upper-right panel: Analysis based in a finite elements models for composites. Lower-left panel: the tomographic 3D images can be analyzed visualizing cuts in any plane to study every detail of the actual structure. Lower-right panel: The 3D images are converted into engineering CAD information to quantitatively compare with the designs.

Additionally we did an R&D program to define the materials and procedures to build the pieces as well as the alveolar structure. We use pre-preg fabrics cured under a temperature-pressure cycle to obtain the optimum mechanical properties. The pieces are handcrafted one-by-one, with male-female moulds to obtain the demanded geometrical accuracy and reproducibility, with thickness homogeneity within 15%. During our program we built pieces of different CF fabrics, layers, sizes, as well as different assembly geometries: bundles and rings, see figure 3. We finally obtained composite pieces of less than 20 grams to hold a bundle of 4 CsI(Tl) crystals of about 2.6 Kg, that is a ratio of less than 0.7% for the structural material.

The CF pieces are glued together in bundles to conform the CF-structure. We developed the tooling and technical procedures to guaranty the assembly tolerances and reproducibility of the whole process. The metrology is the key to control the production quality and guaranty the results. We use conventional tactile coordinate measurement techniques, which is a tough task for these non-rigid materials. The individual pieces are checked in thickness and geometry after production. The geometry is measured after the gluing of the bundles. We additionally developed a methodology to use **tomographic imaging** to produce actual 3D-images of the structures, to directly compare with the CAD design. This method gives unique and key information on the **internal** parts of the CF assemblies, as well as information about the geometrical quality of the glueing in any edge and corner of the structure, whatever its location. This procedure is a powerful tool that will show its relevance in the construction of complex structures as it will be that of the whole CALIFA CF-structure.

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[4] E. Casarejos et al., *The mechanical design of the BARREL section of the detector CALIFA* ..., in this proceedings.

[5] ANSYS is a trademark for ANSYS software, http://www.ansys.com