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CALIFA, a Dedicated Calorimeter for the R^3B/FAIR

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The R^3B experiment (Reactions with Relativistic Radioactive Beams) at FAIR (Facility for Antiproton and Ion Research) is a versatile setup dedicated to the study of reactions induced by high-energy radioactive beams. It will provide kinematically complete measurements with high efficiency, acceptance and resolution, making possible a broad physics program with rare-isotopes. CALIFA (CALorimeter for In-Flight detection of gamma-rays and high energy charged pArticles), is a complex detector based on scintillation crystals, that will surround the target of the R^3B experiment. CALIFA will act as a total absorption gamma-calorimeter and spectrometer, as well as identifier of charged particles from target residues. This versatility is its most challenging requirement, demanding a huge dynamic range, to cover from low energy gamma-rays up to 300 MeV protons. This fact, along with the high-energy of the beams determine the conceptual design of the detector, presented in this paper, together with the technical solutions proposed for its construction.

I. INTRODUCTION

FAIR (Facility for Anti-proton and Ion Research) is an international facility presently under construction on the basis of the German laboratory of GSI (Darmstadt). FAIR, with around 10 participant countries and a large number of scientists ($\approx$ 3000), will be the largest nuclear physics facility in Europe in the next decade. It will provide very energetic (up to 15 GeV) and very intense primary beams ranging from p to U. One of the experimental possibilities of FAIR will be the production of intense secondary beams using the well known technique of in-flight projectile fragmentation/fission with the help of the powerful magnetic spectrometer (Super-FRS) designed for this purpose. These secondary beams could either be slowed down or sent (at relativistic energies) to different experimental areas.

R^3B (Reactions with Relativistic Radioactive Beams) [1] is a versatile and multi-purpose detection set-up that will be located at the High Energy Branch of the Super-FRS. The purpose of R^3B is the investigation of reactions induced by radioactive beams at relativistic energies. This experimental setup is

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suitable for a wide variety of scattering experiments, such as heavy-ion induced electromagnetic excitations, knockout and breakup-reactions, reactions of astrophysical interest, or light-ion (in)elastic and quasi-free scattering in inverse kinematics, and would enable a broad physics program with rare-isotope beams.

R^3B will be the first experiment to be operational at FAIR and will provide an important number of nuclear structure data, reaction rates of astrophysical interest and fragmentation and fission yields on a large number of nuclei far from beta-stability that would represent a significant improvement in our knowledge of nuclear data.

II. CALIFA

CALIFA, CALorimeter for the In Flight detection of γ rays and light charged pArticles, surrounds the reaction target and is one of the key detectors of R^3B, accordingly optimised for the exact requirements of the ambitious physics program proposed for the R^3B collaboration.

CALIFA is a versatile setup that will be used in a wide spectrum of experiments. In certain cases, a high gamma energy resolution (5% at 1 MeV) and multiplicity determination is requested to do spectroscopy. In others, the goal is to obtain a calorimetric response with high efficiency. Part of the complexity arises from the kinematics of the reactions, producing a large Lorentz boost and broadening, the correction of which should be accounted for by the detector. Charged particles of moderate energy, for instance protons up to 300 MeV, should be identified with an energy resolution superior to 1%.

In order to achieve these goals the detector is divided into two sections, a “Forward EndCap” covering polar angles between 7-43.2^o and a cylindrical “Barrel” section that ensures angular coverage up to 140.3^o. The Technical Design Report [2] of the latter section was approved by FAIR, following the recommendation of the Expert Committee Experiments (ECE). Figure 1 shows a schematic view of the detector.

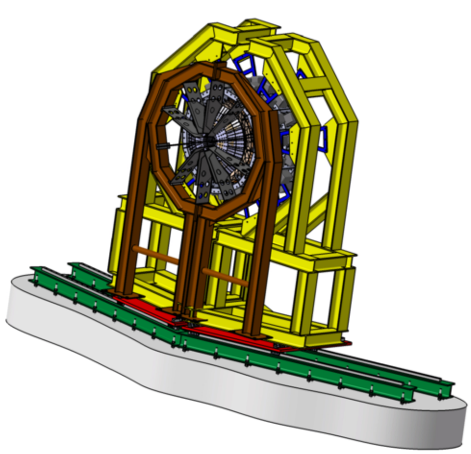

FIG. 1. Schematic view of the CALIFA detector.

A. CALIFA Barrel

The technical solution adopted for this section of the detector consists of 1952 CsI(Tl) crystals, wrapped with a layer of specular reflector VM2000 and readout by Large Area Avalanche Photodiodes (LAAPDs), orientated within a very compact geometry (internal radius 30 cm) that maximizes the calorimetric properties. On average only a few percent of the deposited energy is lost in the passive material made of very thin carbon fibre (two layers of 125 μm). This has demanded an in-depth investigation into the best crystal housing, support structures and general mechanical design [3].

The particular kinematics of particles emitted by relativistic moving sources imposes the large segmentation to minimize the effect of Doppler broadening on the final system energy resolution. To guarantee an approximately constant Doppler broadening contribution, never exceding the 5% limit at 1 MeV, the polar and azimuthal aperture of the CsI(Tl) crystals vary with angle. The radial length also varies to be within the range of the most energetic particles of interest.

The coupling of LAAPDs to CsI crystals was found to fulfil many of the R^3B programme’s most challenging demands. APDs have a Q.E. of 75-80% in the CsTl(I) emission spectrum, internal gain of 40-50 and linear light response in the CsI(Tl) emission spectrum. Their adequacy in meeting the energy resolution requirement has been proven with gamma sources [6] (4.42 % at 662 keV and 1 cm^3 CsI(Tl) crystal). Masks coupling two APD of 10x10 mm active area, have been developed by Hamamatsu for this project. They allow a larger light collection permiting a threshold reduction, increase the gamma energy resolution and reduce the effect of crystal non linearity. The final gamma energy resolution expected when coupled to CALIFA crystals is ΔE/E 6% at 1 MeV.

The readout of the photosensors is realized using Meseytec MPC-16B preamplifiers, which feature an “on-the-fly” temperature-gain correction, designed to compensate the impact of the APD sensitivity with temperature variations. The electronic chain is completed by the new digital FEBEX electronic support system. In addition to the compact, high performance design, this approach takes advantage of the different decay times for CsI scintillation for Pulse Shape Analysis, enabling particle identification. The FEBEX setup is highly flexible, allowing FPGA online processing to be easily reprogrammed to suit individual experimental requirements [4].

Detector performance (photosensor and electronics response over an extensive dynamic range) has been tested via irradiation of small size prototypes with beams with high energy protons (up to 180 MeV) and gamma-rays (15-20 MeV) [5–8]. These tests have also validated the calorimetric ability of CALIFA.

Detailed simulations of the response of the CALIFA Barrel have also been performed within the R3BROOT analysis framework, guiding progression through each stage of the development process. These simulations have been validated via comparison with experimental data for a number of small scale prototypes representing different calorimetric sections with the corresponding geometry. All the details related to these developments can be found in the CALIFA Barrel TDR [2].

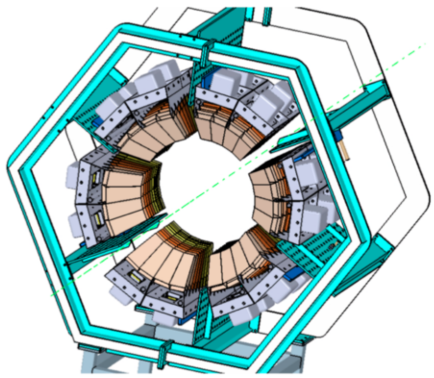

FIG. 2. Schematic view of the CALIFA Barrel Demonstrator.

1. *CALIFA Demonstrator*

However, the experimental verification of the calorimetric properties of CALIFA cannot be probed with small size prototypes. To overcome this difficulty and also to demonstrate the validity of the present design we have envisaged the construction of a large scale prototype corresponding to $\approx 20\%$ of the final detector. The CALIFA Demonstrator is currently under construction. It has a modular configuration of up to 12 petals. A petal is a structure comprising 16 carbon fiber alveoli glued on a honey comb structure. Each alveoli hosts four CsI(Tl) crystals and mimics the CALIFA Barrel geometries corresponding to the most forward rings. These detection units will ultimately be incorporated, after testing, into the final CALIFA. A dedicated mechanical structure which allows for modifying the final orientation of the petals would allow this Demonstrator to cover a polar range of 32.5°-65°, with 4 types of alveoli/crystals and 3 segments of 2 alveoli in the azimuthal direction and 10 alveoli in polar direction. In addition to detector characterisation, the Demonstrator is intended for use in a real experimental campaign. An artistic view of the CALIFA Demonstrator is given in Fig. 2.

B. CALIFA Forward Endcap

The Doppler effect above mentioned makes particularly challenging the design of the "Forward EndCap". The R&D towards a final solution for this section is presently ongoing. The solution retained for the "Barrel", which would fulfill the requirements of CALIFA, suffers from the incident charged particles undergoing a large number of inelastic reactions, which would significantly reduce the energy peak efficiency. This restriction can be overcome via use of a phoswich detector concept, which would determine the incident particle energy through the measurement of two individual energy losses. This approach reduces significantly the detector volume, thus the reaction losses. Several "phoswich" concepts are currently under investigation [9] with the evaluation of small size prototypes with high-energy protons that would guide the right technical choice for this part of the detector.

III. SUMMARY AND PERSPECTIVES

We have reported in this paper about the design and construction status of a detector exhibiting unprecedented characteristics concerning its double use as spectrometer and calorimeter for both gamma-rays and light charged particles. This detector will be a key component of the R^{3}B/FAIR experimental setup and would allow the study of nuclear reactions induced by relativistic radioactive beams, knowledge of the nuclear matter equation of state, reaction rates of astrophysical interest and fragmentation and fission yields on a large number of nuclei far from the beta-stability.

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