Progress report of the CALIFA/R^{3}B calorimeter*

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CALIFA, the CALorimeter for In Flight detection of γ rays and light charged pArticles, surrounds the R^{3}B reaction target and is one of the key detectors of the R^{3}B experiment [1]. The CALIFA design is optimised for the requirements given by the ambitious physics program proposed for the R^{3}B facility and combines very stringent calorimetric and spectrometric properties.

The Technical Design Report [2] of the Barrel section, with a polar angular coverage of 43.2-140.3^o, was approved in January 2013 by FAIR, following the recommendation of the Expert Committee Experiments (ECE) [1]. The technical solution adopted for this section, needed to reach the required spectrometric properties, defines a very segmented device with 1952 CsI(Tl) crystals that are readout by Large Area Avalanche Photodiodes (LAAPDs). The crystals are orientated within a compact geometry, with an internal radius of 30 cm, to optimise the calorimetric properties.
The Forward EndCap section (polar angular coverage 7-43.2^o) is in the R&D phase.

The main activities of the CALIFA Working group over 2013 have concentrated around three lines of work: a) determination of the final technical specifications and the purchase of "Barrel" detector components, b) development of innovative solutions to fulfil the requirements of the "Forward EndCap" and c) realisation of in-beam tests of different small size prototypes.

The performance of single elements of the CALIFA Barrel have been carefully evaluated. Light collection and output signal proportionality over the crystal length are central when long scintillator crystals are used for spectroscopic purposes. These properties can be adjusted by surface treatment, in the CALIFA case by surface lapping. Considering the large number of crystals involved in CALIFA it is also important to investigate if an optimum strategy for surface treatment can be found that could simplify industrial production. For this reason models of the different crystal geometries have been introduced in GEANT4 and testing procedures for the surface lapping have been simulated for a large number of different cases by tracing optical photons through the crystals. This work continues in parallel with laboratory tests on individual crystals, already at this stage clear trends can be identidied between the size and position of lapped areas and the linearity of the response.

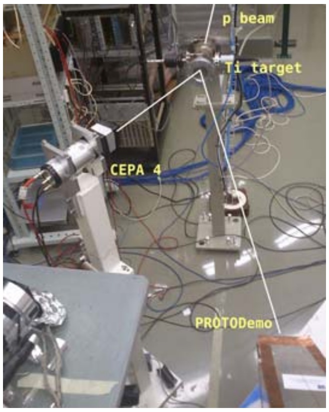

Figure 1: Prototypes detectors surrounding a 50μm Ti target at IFJ PAN, where irradiation with protons 70 - 230 MeV was possible with a beam energy spread better than 1%.

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[1] decision adopted in the ECE first meeting in November 2012

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Beam tests were undertaken at the IFJ PAN Kraków cyclotron. This accelerator, designed for medical treatment, provides mono-energetic proton beams over an energy range of 70-230 MeV with a beam energy spread better than 1%. A range of smaller size prototypes, corresponding to different sections of the CALIFA detector, were tested using scattered protons on a 50μm thick Ti target, the setup is shown in Fig. 1.

- A scattered proton beam with energies ranging from 70 to 230 MeV was used to irradiate a 4x8 array (ProtoDemo) of 180 mm long CsI(Tl) crystals with a truncated pyramidal shape corresponding to a crystal geometry used in the Barrel section. The dimensions of the exit face are well matched to the Hamamatsu S12102 double LAAPDs. The signals from the APDs were fed into MPRB-16 preamplifiers. The amplified signals are distributed to FEBEX3 boards, which contain two 8-channel fast-sampling ADCs and one FPGA [3]. To fit the output range of the preamplifier exactly to the input range of the FEBEX boards, a new add-on board was developed for the FEBEX module (FAB for FEBEX Addon Board). It adjusts the baseline of the input signals and implements a Nyquist filter to avoid aliasing effects due to the 50 MHz sampling of the ADCs. The baseline correction is active and the correction is directly controlled by the FPGA. The first FAB prototypes have been implemented and tested during this beam time, validating the principle of the method. In a second revision currently under test, the noise figure and dynamic range of the boards have been further improved.

  In addition to detector response to protons over the full energy range, the prototype was used in various configurations to probe inactive matter effects, which may be extrapolated from using the R3BRoot dedicated simulation framework. The response to protons was complemented by a gamma calibration reaching up to 6.13 MeV. A direct scaling of the gamma - proton linear fits reveals a surprisingly uniform relation, where a common factor of 10.24 (close to the MPRB-16 preamplifier high - low gain factor of 10) applied to the gamma calibration matched well to calibrate over the proton energy range. The importance of extending the gamma calibration energy is evident on examination of the residuals, as seen in Fig. 2.

  The high linearity of the CsI(Tl)+LAAPD combination looks promising to allow simple gamma calibration scaling to be used as a method to calibrate CALIFA at the R^3B proton energies.

  A new algorithm for particle identification, adapted to real-time use in logic electronics, has been developed from the observation and concepts reported in [4]. The algorithm showed a clear separation between γ rays and protons. Several papers published in 2013 detail the R&D campaign and report progress in areas such as advancement in event reconstruction algorithms and characterization of a range of CALIFA prototype detectors at a number of international facilities [5, 6, 7]. They are complemented by R3BRoot simulations which allow to extrapolate to the full calorimetric performance of CALIFA.

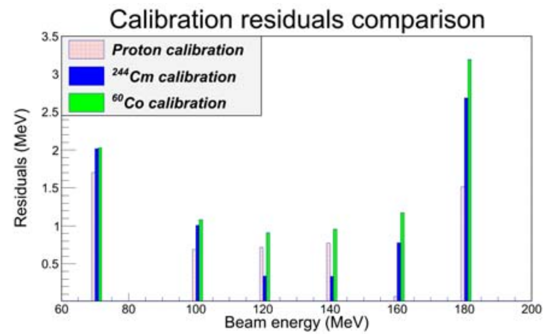

Figure 2: Mean proton energy residuals for a sample of five 180 mm CsI:Tl crystals after scaling a ^{137}Cs, ^{60}Co gamma calibration with, and without, the inclusion of the 6.13 MeV photopeak (^{244}Cm+^{13}C).

- We also tested a new prototype of the Forward End-Cap: CEPA4. This is an array of 4 individual scintillator detectors, each of them consisting of 4 cm of $LaBr_3$(Ce) crystals optically coupled to 6 cm of $LaCl_3$(Ce) in phoswich configuration (see Fig. 3).

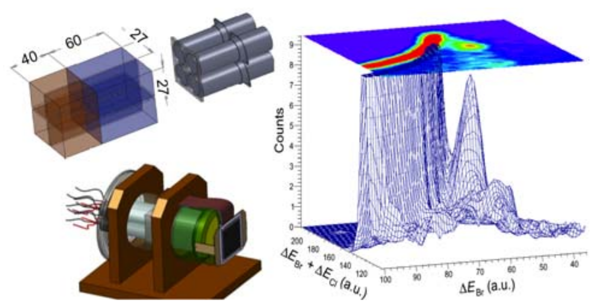

Figure 3: Left: schematic view of CEPA4 with its crystals, casing and photomultiplier tubes. During the experiment it was coupled to a DSSSD allowing the study of proton response at different positions. Right: proton spectrum at 220 MeV. The horizontal axis represent, respectively, the total energy deposited in the phoswich ($LaBr_3$+$LaCl_3$) and the partial energy deposited in the first part of it (the $LaBr_3$). At the top there is a 2-dimensional projection of the plot. The peak corresponding to 220 MeV protons is clearly separated from the rest.

The response of CEPA4 to high-energy protons was measured with the available proton beams. The maximum energy was just enough to test the punch-through of protons in a 10 cm phoswich, which happens at 200 MeV. Fig. 3 right shows a 220 MeV proton spectrum. In this plot the XY-plane represents the energy deposited in the $LaBr_3$(Ce) versus the total energy deposited in the phoswich, and the Z-axis represents the number of events. The method used to disentangle the energy deposited in each of the two crystals is explained in Ref. [8]. In the plot one can clearly see the peak corresponding to the 220 MeV protons that have passed through the two crystals leaving part of their energy in each of them. This is the first time the initial energy of the protons have been reconstructed from the partial deposition of their energy in two different crystals.

- The $LaBr_3$-$LaCl_3$ phoswich concept functions well over the IFJ PAN proton energy range, though simulations highlight potential energy resolution concerns when employed at the R^3B operational energies. Additionally, the encapsulation required due to the material's high hygroscopy introduces inactive matter, which does not aid optimisation of calorimetric performance. Therefore, alternative solutions are also investigated. In particular, the concept of a CsI(Tl)-LYSO phoswich was studied as it contains cheaper material which is less hygroscopic and may reduce the amount of dead material required. It would not require new readout electronics as the time constants (600 ns and 3200 ns for CsI(Tl) and 40 ns for LYSO) allow for a clear signal separation, however the internal radioactivity of LYSO is a subject of concern as when scaled to EndCap proportions the background radiation would be non-negligible. The tested prototype was composed of two crystals of $1 \times 1 \times 1\text{cm}^3$ from each material coupled with optical glue. The electronic pulse allowed a good qualitative identification of the signals from the energy deposited in both crystals. A modified version of the algorithm mentioned above allowed the reconstruction of the energy deposited as shown in Fig. 4. The illustrated example shows a good energy reconstruction for the tested energies, validating this concept for a phoswich. The counts outside the branches are related to the different particle types and arises from surface effects of the small prototype crystals.

The development of CALIFA is now entering a very intense period. The purchase and construction of 20% of the Barrel has started. The full implementation and commissioning of the CALIFA Demonstrator is expected in 2014-2015. In parallel, the submission of the Technical Design Report corresponding to the Forward section is foreseen by the end of 2014. According to our schedule, the complete CALIFA could be installed and operational in the R3B cave by the end of 2016.

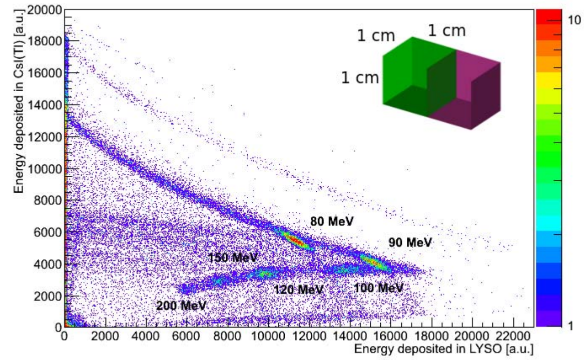

Figure 4: Reconstructed energy deposited in CsI(Tl) as a function of the reconstructed energy deposited in LYSO for protons at various energies. Protons punching through the 1 cm CsI layer show an increasing signal in LYSO while the CsI amplitude is dropping. Protons with energies larger than ∼95 MeV are not stopped any more and appear in the lower branch of the figure.

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