Nuclear Instruments and Methods in Physics Research A 718 (2013) 107–109

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

A LYSO calorimeter for the SuperB factory

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ARTICLE INFO

Available online 29 November 2012

Keywords:
Calorimetry
LYSO
SuperB
Scintillation crystals

ABSTRACT

The SuperB project is an asymmetric e^+e^- accelerator of 10^{36} cm^{-2} s^{-1} design luminosity, capable of collecting a data sample of 50−75 ab^{-1} in five years running. The SuperB electromagnetic calorimeter (EMC) provides energy and direction measurement of photons and electrons, and is used for identification of electrons versus other charged particles. In particular we present its design, geometry study and related simulations, as well as R&D on LYSO crystals and developments on readout electronics. A matrix of 25 crystals has been tested at the Beam Test Facility of Frascati (BTF) in May 2011 at energies between 200 MeV and 500 MeV. Results from this test are presented.

1. Introduction

The SuperB project is an asymmetric e^+e^- accelerator of 10^{36} cm^{-2} s^{-1} luminosity [1], capable of collecting a data sample of 50−75 ab^{-1} in five years of running (two orders of magnitude higher than the previous B-factories). The SuperB detector [2] concept is based on the *BaBar* detector [3], with modifications required to operate at a luminosity of 10^{36} or more, and with a reduced center-of-mass boost. Further improvements are needed to cope with higher beam–beam and other beam-related backgrounds, as well as to improve detector hermeticity and performance. A number of *BaBar* components are reused: the flux-return steel, the superconducting coil, the barrel of the EMC and the fused silica bars of the DIRC while the other parts will be replaced with new detectors. The hermeticity of the SuperB detector, and, thus, its performance for certain physics channels will be improved by including a backwards “veto-quality” EMC detector comprising a lead-scintillator stack and a forward particle identification detector consisting of a fast Cherenkov light based time-of-flight system.

2. Electromagnetic calorimeter

The forward electromagnetic calorimeter (FwdEMC) designed for SuperB is a new device replacing the *BaBar* CsI(Tl) forward calorimeter. Because of the increased background levels, a faster and more radiation hard material is required in the forward region. One proposed solution assumes the full or partial replacement of CsI(Tl) crystals with LYSO (Lutetium Yttrium Orthosilicate, with Cerium doping) crystals [4]. The advantages of LYSO include a much shorter scintillation time constant (LYSO: 40 ns, CsI(Tl): 680 ns and 3.34 μs), a smaller Molière radius (LYSO: 2.1 cm, CsI: 3.6 cm), and a better tolerance to radiation. The Calorimeter is composed of 20 rings of crystals, arranged in four groups of five layers each. The crystals maintain an almost projective geometry of the barrel. Each group of five layers is arranged in modules of five crystals each. Each crystal is up to 2.5×2.5 cm^2 at the back end, with a projective taper to the front. The maximum transverse dimensions are dictated by the Molière

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http://dx.doi.org/10.1016/j.nima.2012.11.100

radius. The length of each crystal is approximately 20 cm, or $17.5X_0$.

The readout sensors for FwdEMC are Avalanche Photodiodes (APD). A new Very Front End (VFE) board has been designed and it incorporates a dual-gain amplifier (1 ×, 16 ×); the VFE output signals are shaped by a Gaussian shaper with a shaping time of 100 ns. Finally signals are digitalized by a 12-bit Analog-to-Digital Converter (ADC).

3. Beam test on LYSO calorimeter prototype

A test beam has been performed with a prototype LYSO matrix at the Beam Test Facility (BTF) [5] in Frascati in May 2011. The prototype matrix is composed of 25 LYSO crystals of pyramidal shape inserted in a support structure assembled by the RIBA company (Faenza, Italy). Each crystal is coupled to an APD and the same VFE boards and Gaussian shaper designed for the FwdEMC are used in the test. The processed signals are acquired by four 12bit sampling ADC (Caen V1720 250 MS/s sampling ADC [6]).

The setup for the beam test of the matrix at the BTF is shown in Fig. 1. The setup shows the end of the electron beam line, two planes of silicon strip detector (one measurements in x and one measurements in y) and the box containing the matrix with the crystals and the VFE boards.

The silicon strip detector is composed of two planes with orthogonal strip orientation with digital readout, each plane is composed of 384 silicon strip with a pitch of 228 μm, and it is used to measure the position of the incoming particles.

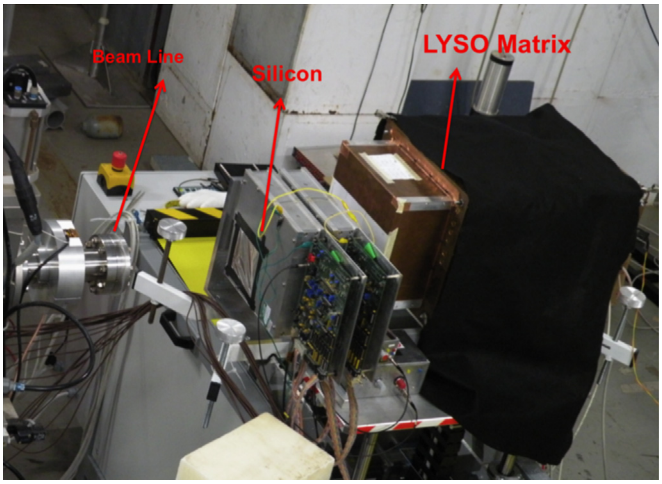

Fig. 1. Setup of the beam test at BTF.

Data are taken at five different electron energies: 486, 398, 297, 198 and 99 MeV, with the beam pointed to the center of the matrix.

The dimension and the energy spread of the beam depend on the electron energy, in fact due to the beam line layout both become larger at lower energies.

In order to select particles which hit the LYSO matrix face approximately at the same point, a selection on the electron position measured by the silicon detector is applied before the total energy deposited is evaluated. The selected area is about $6 \times 4\ \text{mm}^2$. The left plot in Fig. 2 shows the beam profile at 486 MeV, the black box represents the selected area at this energy. The right plot in the same figure shows the total energy distribution for the selected events at 198 MeV. Here the deposited energy of 1, 2 and 3 electrons are evident and each ones is fitted with a Crystal Ball function.

The beam energy spread is not known with precision so it is estimated directly from data. Events with more than one electron of the same energy are used in order to have more than one independent measurement at the same energy (i.e. 200 MeV could be measured with one e⁻ of 200 MeV or two e⁻ of 100 MeV). Considering the assumption that calorimeter prototype

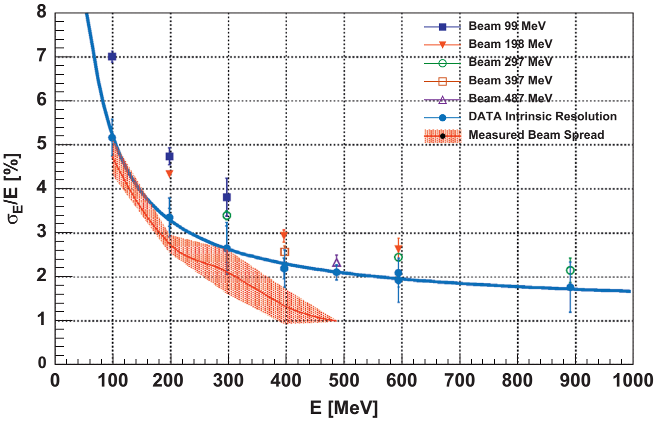

Fig. 3. LYSO EMC resolution at different energy. The colored points represent the measured value, the red shaded region is the estimation of the beam energy spread and the light blue point represents the intrinsic energy resolution of the prototype when beam spread is subtracted with superimposed the relative fit. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

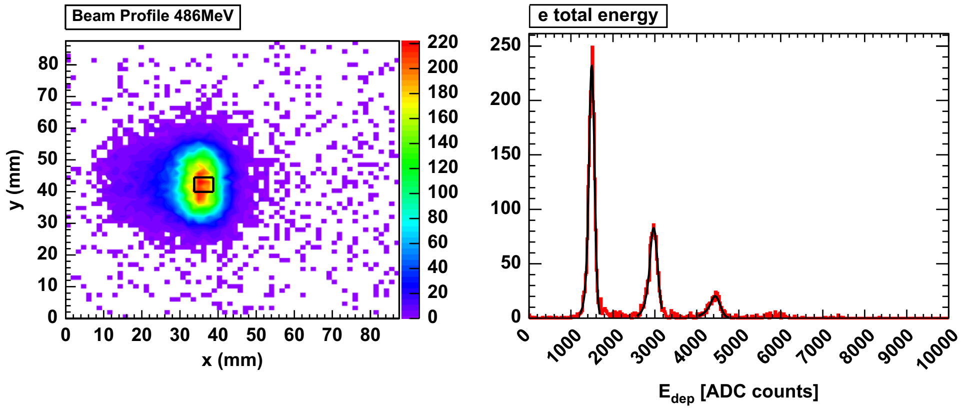

Fig. 2. (left) Beam profile at 486 MeV, the box represents the events selection; (right) total energy deposited on LYSO matrix distribution for the selected events at 198 MeV. The line represents the result of a fit with a Crystal Ball function.

resolution for two particles of energy E is the same as one particle of energy $2E$, we can estimate the beam energy spread at different beam line energy configuration and then subtract these values from the total resolution in order to extract the intrinsic LYSO EMC prototype resolution.

In Fig. 3 all the data points and the resulting beam spread and intrinsic LYSO EMC prototype resolution values are shown. The resulting resolution as a function of energy is

$$\frac{\sigma_E}{E} = \frac{(1.1 \pm 0.5)\%}{\sqrt{E(\mathrm{GeV})}} \oplus \frac{(0.37 \pm 0.15)\%}{E(\mathrm{GeV})} \oplus (1.2 \pm 0.7)\%. \tag{1}$$

This result is compliant to the SuperB requirements.

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