The electromagnetic calorimeter of the SuperB Experiment

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Abstract.
SuperB will run on a very high luminosity asymmetric $e^+e^−$ flavour factory. Being a natural partner of hadron colliders, it will provide unique information about the details of the physics discoveries in the coming decade. The SuperB detector is based on the BABAR apparatus, with those modifications required to operate at a luminosity of $10^{36} \text{cm}^{-2}\text{s}^{-1}$ or above. In this presentation a summary of the R&D work performed on the new electromagnetic calorimeter will be shown.

1. Introduction
SuperB [1] is a project aiming to study with great precision CP violating and rare processes of heavy quarks (c and b) and leptons ($\tau$). It will be based on an asymmetric electron (4.2 GeV) positron (6.7 GeV) machine designed to provide a luminosity of $10^{36} \text{cm}^{-2}\text{s}^{-1}$. The SuperB detector concept is based on the BABAR apparatus [2], shown in Fig. 1, with those modifications required to operate at a higher luminosity and with a reduced center-of-mass boost.

The current BABAR detector consists of a tracking system with a five layer double-sided silicon strip vertex tracker (SVT) and a 40 layer drift chamber (DCH) inside a 1.5T magnetic field, a Cherenkov detector with fused silica bar radiators (DIRC), an electromagnetic calorimeter (EMC) consisting of 6580 CsI(Tl) crystals and an instrumented flux-return (IFR) for $K_L^0$ detection and $\mu$ identification. Further improvements are needed to cope with higher beam-beam and other beam-related backgrounds, as well as to improve detector hermeticity and performance. The rates of the main sources of background are reported in Table 1 together with the expected rates of interesting events.

Several R&D are required to implement the needed upgrades on the various subdetectors.

2. The Electromagnetic Calorimeter
The SuperB Electromagnetic Calorimeter (EMC) provides energy and direction measurement of photons and electrons and is an important component in the identification of electrons versus other charged particles. The system contains three components, shown in Fig. 1:

- the barrel calorimeter, reused from BABAR, that will cover 85% of the total solid angle;
- the forward endcap calorimeter, replacing the BABAR forward endcap, that will cover 5.6% of the total solid angle;

1 On behalf of the SuperB-EMC group
Figure 1. The SuperB Detector.

Table 1. Parameters of the main background and signal processes expected.

| Process                  | Cross Section (m barn) | Events per bunch crossing | Rate (kHz) |
|--------------------------|------------------------|---------------------------|------------|
| Radiative Bhabha         | 340                    | 850                       | 300 10^6   |
| e^+e^- production        | 7.3                    | 18                        | 7 10^6     |
| e^+e^- production seen by L0 | 0.3                   | 1                         | 0.3 10^6   |
| Elastic Bhabha           | 10^-4                  | 2.5 10^-4                 | 100        |
| Y(4S)                    | 10^-6                  | 2.5 10^-6                 | 1          |

- the backward endcap calorimeter, a new device improving the backward solid angle coverage (3.1 % of total solid angle covered).

The total solid angle covered for a massless particle in the center-of-mass is 94.1% of 4π.

2.1. The Barrel Calorimeter

The barrel calorimeter for SuperB is the existing BABAR CsI(Tl) crystal calorimeter. Estimated rates and radiation levels indicate that this system will continue to survive and function in the SuperB environment. There are 48 rings of crystals in polar angle, with 120 crystals in each azimuthal ring, for a total of 5,760 crystals. The crystal length ranges from 16 X_0 to 17.5 X_0. They are read out by two redundant PIN diodes connected to a multi-range amplifier. In
Figure 2. The BABAR energy resolution on photons.

BABAR this detector was able to provide a very good energy resolution described as:

\[ \frac{\sigma_E}{E} = \frac{2.3\%}{\sqrt{E(\text{GeV})}} \oplus 1.35\% \]

and shown in Fig. 2. This behaviour can be taken as a reference for the performance required to the SuperB calorimeter: a resolution of the order of 4% in the 100 MeV region.

2.2. The Forward Endcap Calorimeter

The background level in the whole calorimeter system will be quite higher than in BABAR. The worst increase is expected in the forward endcap part (FWD). According to the last simulations, a rate of more than 2 MHz photons with an energy of few MeV, produced in radiative Bhabha processes, is expected per crystal in the FWD. These will produce a continuous and fluctuating level below the relevant signals (Fig. 3) spoiling their energy measurement. In order to cope

Figure 3. Behaviour of the light emitted by a FWD crystal due the radiative Bhabha photons.

with this background a fast enough crystal is needed to replace the CsI(Tl) ones that have a light yield decay time of more than 1 µs.
2.2.1. The LYSO prototype  The baseline solution is given by the LYSO(Ce). It is a high density crystal ($\rho = 7.4$ g/cm$^3$), very fast (40 ns of decay time) and very bright (1 p.e. per keV released) [3], really promising for applications in high energy physics. In order to test the properties of this material a matrix of 25 crystals, each readout by one APD, was assembled and tested with electron beam at CERN-T10 with particles of energy between 1 GeV and 3 GeV and at the Frascati-BTF [4] in the 100 MeV - 500 MeV range. Among other measurements, in both cases the energy resolution was evaluated. The spectrum of the response of the detector to a beam of 500 MeV electrons is shown in Fig. 4. The distribution was fitted with a “Crystal-Ball” function able to describe the asymmetry due the non-perfect energy containment. A resolution of 2.4% was found. Fig. 5 shows the behavior of the relative resolution obtained at CERN-T10 and at the BTF as a function of the electron energy. From this plot it appears evident that a constant effect, very likely due to an energy spread of the beam, was present at CERN downgrading the response of the detector. The BTF results were fitted with a curve described as:

$$\sigma_E = \frac{1.6}{\sqrt{E(\text{GeV})}} \oplus \frac{0.5}{E(\text{GeV})}$$

![Figure 4. The response spectrum of the prototype for 500 MeV electrons.](image)

![Figure 5. The relative resolution of the prototype as measured at CERN-T10 (1 GeV < E < 2 GeV) and at the BTF (below 1 GeV).](image)
It is anyway important to outline that, for lower values, the energy spread of the beam becomes important also at the BTF. The tests performed have shown that LYSO is a very good solution to equip the SuperB FWD calorimeter.

2.2.2. The BGO alternative

LYSO is a quite expensive material and some possible alternatives are taken into account. One of these is represented by the BGO, the same material used, for example, in the L3 experiment [5]. BGO is as dense as the LYSO, less brighter and its light output has a decay constant of about 300 ns [3]. From measurements with a 18 cm long crystal, readout with a PMT, a resolution of 10% was evaluated for the 660 keV photons of a $^{137}$Cs source (Fig. 6). From random trigger runs the pedestal width was evaluated to be 10 times smaller than the energy resolution and thus completely negligible. This means at least 150 p.e./MeV and thus a 1.1% of statistical term is expected at 50 MeV.

![Figure 6. Response spectrum of a single BGO crystal to the 660 keV photons of a $^{137}$Cs source.](image)

Moreover, in order to reduce the effect of the background, the integration time of the pre-amplifier in the front-end electronics can be reduced. In this case, only a fraction $f$ of the total charge will be integrated. The effect of this reduction on the energy resolution and its behavior as a function of $f$ was studied. The results obtained are shown in black in Fig. 7. The relative energy resolution behavior as a function of $f$ was fitted with a curve described by the function:

$$\frac{\sigma_E}{E} = \frac{\sigma_0}{\sqrt{f}}$$

Since the pedestal contribution is negligible, no other terms are needed. The energy resolution is found to upgrade as the square root of the total charge and thus to be dominated by the number of collected photo-electrons. From the fit, $\sigma_0$ is determined to be (9.1 ± 0.1)%$ for $f = 1$ a resolution of 9.1% is expected, in agreement with what is found from the total charge measurements.

In particular, for an integration time of 100 ns a resolution of 12.7% was measured which allows to extrapolate a statistical contribution to the energy resolution at 50 MeV of about 1.5%.

2.2.3. Background effects

With the latest results on the expected background at SuperB, the effects of soft photons produced by the radiative Bhabha on the energy resolution were simulated. The total charge collected in 5x5 crystal matrices and its fluctuations for different integration times were evaluated. The results show that in the barrel, the use of an integration time of...
Figure 7. Behaviour of the resolution $\sigma_E/E$ as a function of the fraction $f$ for two different sets of measurements.

300 ns instead of 700 ns (as it was in BABAR) can reduce the baseline fluctuation from 2.4 MeV to 0.6 MeV in the central part and from 7.3 MeV to 2 MeV in the worst case. In the FWD, the use of LYSO crystal would result in a baseline fluctuation of 0.5 MeV in the external part and 2.5 MeV in the internal part. The BGO with an integration time of 100 ns would give 0.5 MeV and 1.5 MeV respectively.

3. Conclusion
A new forward endcap calorimeter is being developed for SuperB. LYSO has already shown to fulfill the requirements to equip that region with a resolution of 2.3% at 500 MeV. However, it represents a quite expensive solution.

A possible alternative are BGO crystals with an optimized readout electronics to reduce the background effect without spoiling the energy resolution.

References
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