The SuperB Project

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1 Introduction

Motivated by the enormous impact shown by the $B$ Factories on Flavour Physics and in several
other areas, an Italian led, INFN hosted, collaboration of scientists from Canada, Italy, Israel,
France, Norway, Spain, Poland, Russia, UK and USA have worked together to design and propose
a high luminosity asymmetric $B$-Factory project. This project, called Super$B$, exploits a novel
collision scheme based on very small beam dimensions and betatron function at the interaction
point, on large crossing and Piwinsky angle and on the “crab waist” scheme 1). This approach
allows to reach a luminosity of $10^{36}\text{ cm}^{-2}\text{s}^{-1}$ and at the same time overcome the difficulties of
early super $e^+e^-$ collider designs, most notably very high beam currents and very short bunch
lengths. The wall-plug power and the beam-related background rates in the detector are therefore
kept within affordable levels. A conceptual design report of such a project had been published in
2007 2). Much more advanced progress reports have been published in 2010 discussing important
advances in the physics motivations 3), detector 4) and accelerator designs 5).

The LNF group is involved in the design of the Super$B$ Drift Chamber with important
responsibilities. In particular, a member of the group is co-convening the general Super$B$ DCH
group, which includes other Italian (Lecce University and INFN, RM3 University and INFN),
as well as several Canadian Institutions. Another member of the LNF group is co-convening the
FastSim and the Detector Geometry working groups (see secs. 3 and 4).

The baseline of the Super$B$ tracking detector is the $BABAR$ drift chamber, which was already
optimized to perform measurements of $B$-physics events, and has been working quite well for the
entire $BABAR$ lifetime. In particular, the Super$B$ Drift Chamber will operate with a Helium-based
gas mixture to minimize the multiple scattering contribution to the momentum resolution. The
main differences, with respect to $BABAR$, relevant to the Super$B$ tracking system are:

- reduced center-of-mass boost ($\beta\gamma = 0.24$ compared to 0.56 in $BABAR$);
- demise, in the machine design, of the support tube holding the final focus quads (as it was
  in PEP-II);
- higher occupancy due to electron-pair backgrounds from two-photon processes and radiative
  Bhabha events scattered in the tracking devices by bending/focussing elements of the machine
  optics; minimization of this occupancy requires thick Tungsten shields which could somewhat
  limit the Drift Chamber inner radius;
- possible presence in the backward region of an electromagnetic calorimeter.

The four items mentioned before require a device possibly lighter in terms of radiation lengths
with respect to $BABAR$, faster and with lighter endplates too. The lower boost envisaged for the
Super$B$ points also toward a detector in which the minimization of multiple scattering effects is
requested.
Various R&D programs are underway towards the definition of an optimal drift chamber for SuperB. A possibility being considered to improve the performances of the gas tracker is the use of the cluster counting method, which in principle holds the promise of a better resolution both in the spatial and in the energy loss measurements. The ability to count the individual ionization clusters and measure their drift times strongly depends on the average time separation between them, which is, in general, relatively large in He-based gas mixtures thanks to their low primary yield and slow drift velocity. Other requirements for efficient cluster counting include good signal-to-noise ratio but no or limited gas-gain saturation, high preamplifier bandwidth, and digitization of the signal with a sampling speed of the order of 1Gs/sec. Finally, it is necessary to extract online the relevant signal features (i.e. the cluster times), because the DAQ system of the experiment would hardly be able to manage the enormous amount of data from the digitized waveforms of the about 10000 drift chamber channels.

During 2011 the LNF group undertook an R&D program to study the feasibility of counting and measuring the drift times of the single ionization clusters. A full-length drift chamber prototype was designed, built and commissioned at LNF to study cluster counting in a realistic environment, including signal distortion and attenuation along 2.5 meter long wires. The prototype, which is also meant to serve as a test bench for the final Front-End electronics and for the Drift Chamber trigger, is composed by 28 square cells with 1.4 cm side, arranged in eight layers and – as in the final SuperB drift chamber – with a field-to-sense wire ratio of 3:1. The eight layers have either 3 or 4 cells each, and are staggered by half a cell side to help reduce the left-right ambiguity. Tracks with angle $|\vartheta| \leq 20^\circ$ cross all the eight layers of the chamber. Four preamplifier boards are used to extract the cell signals. Each board serves seven channels, each with a transimpedence preamplifier (rise time of about 2.4ns), at a nominal gain of 8mV/fC and a noise of 2200 e rms. Each boards also has a test input, both unipolar and differential outputs (50Ω–110Ω); the latter are used for a test implementation of the Drift Chamber first level trigger.

![Sample waveform from a cell of the full-length drift chamber prototype.](image1)

![Sample waveform from another cell of the full-length drift chamber prototype.](image2)

The data collected with this prototype are fed into a switch capacitor array digitizer\(^1\), which samples the wire signals at 1 GS/sec with and input BW $\geq$ 500 MHz. The challenge of detecting the ionization clusters in signals with a wide dynamic range and non-zero noise levels is apparent from the two sample waveforms recorded in the cosmic-ray setup shown in Figg. 1 and 2. Hits associated to cosmic ray tracks reconstructed in the drift chamber prototype are used to compare

\(^1\)CAEN V1742: [http://www.caen.it/csite/CaenProfList.jsp?parent=13&Type=W0Categ](http://www.caen.it/csite/CaenProfList.jsp?parent=13&Type=W0Categ)
Figure 3: dE/dx distribution (70% truncation fraction) from 10 samples of a single cell belonging to a track reconstructed in the prototype.

Figure 4: Average number of clusters from 10 samples of a single cell belonging to a track reconstructed in the prototype.

the performances of the traditional truncated mean algorithm and of the cluster counting method. Preliminary results when 10 samples from a single prototype cell are used to form a 70% truncated mean or to count the average number of clusters are shown in Fig. 3 and Fig. 4 respectively. In the experimental conditions of our test, cluster counting yields a 40-50% better relative resolution than the truncated mean method. Additional R&D efforts are ongoing to extend this encouraging result to different momentum regions, and study how the $K-\pi$ resolving power in the range of interest of SuperB ($|p| \leq 5 \text{ GeV}/c$) improves with the cluster counting technique.

3 Development of Simulation Tools for Detector Design and Physics Studies

The design of the SuperB detector and the study of the physics reach of the experiment require specific simulation tools. Depending on the nature of the study, a detailed simulation (Geant4) or a fast simulation are needed. The use of the latter is mandatory at the present stage to perform those studies that require the generation and complete reconstruction of the physics event. A member of our group is coordinating the Physics Tools group, whose main goal is the development and maintenance of the simulation and analysis tools needed to perform the physics and detector studies. The core of the SuperB physics tools is the fast Monte Carlo (FastSim), which includes a simplified and flexible detector element description, a full modeling of particles interaction with the detector, the parameterization of the detector response and the event reconstruction. It also allows to plug in the machine background simulated with Geant4.

4 The Detector Geometry Working Group

A member of our group has chaired the Detector Geometry Working Group (DGWG), setup at the end of 2008 to study the physics tradeoffs of the open detector options, such as a) a forward PID detector compared to a longer drift chamber (DCH), b) a backward EM calorimeter vs. no backward EM calorimeter, c) the internal geometry of the Silicon Vertex Tracker (SVT), d) the SVT-DCH transition radius and e) the distribution and amount of absorber in the muon system. The DGWG has completed its mission in 2011, with recommendations on the items it had to address. Two committees were then established to review the forward/backward regions of the SuperB detectors and recommend the final geometry for the TDR to the technical board. The DGWG studies were used as input by the committees to draw their conclusions. A member of our
group took part in the forward task force committee.

5 Sensitivity Studies at the Charm Threshold

SuperB is designed to operate at center-of-mass (CM) energies ranging from 3.77 GeV (the charm threshold) up to 11 GeV, thus extending the physics reach of the experiment. In particular, the machine could run at the $D\bar{D}$ threshold ($\psi(3770)$ resonance) with an estimated luminosity of $10^{35} \text{cm}^{-2}\text{s}^{-1}$, thus collecting 1 ab$^{-1}$ in one of data taking: a dataset two orders of magnitude larger than the one planned at BES-III, and more than three orders of magnitude larger than the one collected by CLEO-c. Such a large data sample would allow to perform unique measurements in the charm sector by exploiting the $D\bar{D}$ coherence. In addition, unlike CLEO-c and BES-III, time-dependent measurements at the charm threshold could be possible at SuperB if the CM boost is large enough. This possibility provides new handles to search for $CP$ violation in charm decays. Our group is performing sensitivity studies of time-dependent $CP$ violation measurements in $D$ decays at the $D\bar{D}$ threshold as a function of the CM boost to understand what the optimal boost range would be.

6 List of Conference Talks in Year 2011

1. M. Rama, Sensitivity studies for mixing and CP violation at SuperB, Workshop on charm physics at threshold, Beijing, China.

References


