The Super$B$ 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 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 $10^{36}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ 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.

In the course of the years Super$B$ has evolved into a full-fledged project, with a Conceptual Design Report published in 2007 2), progress reports on the Physics potential 3), on the detector 4) and on the accelerator design 5) in 2009 3) and a formal collaboration structure set up in 2010 with hundreds of members from several countries. All aspects of the project, physics potential, accelerator design, detector design, successfully passed several international reviews setup by INFN. In 2010 Super$B$ was inserted in the Italian Research Ministry National Research Plan as Flagship Project, and a good fraction of the required funds were allocated, although not the full amount. The decision to build Super$B$ on the land of the University of Rome Tor Vergata led, in 2011, to the formation of the Cabibbo Laboratory consortium between INFN and TorVergata, with the explicit mission of constructing and managing a new research infrastructure for flavour physics. A ministerial cost and schedule review of the accelerator project was held in fall 2012. A combination of a more realistic cost estimates and the unavailability of funds due of the global economic crisis led to a formal cancelation of the project on Nov 27, 2012.

Despite the project cancelation, it was decided to document the huge work done by the Super$B$ collaboration and by the LNF group in particular to optimize the design of a detector capable of matching the challenges posed by the extreme project luminosity of the accelerator project in a Technical Design Report. This document (almost 500 pages long) is undergoing final review at the time of writing the present report.

2 Activities in the LNF Group

The LNF group has been involved in the design of the Super$B$ Drift Chamber with major 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 grup is convening the *Physics Tools* and the *Detector Geometry Working Groups* (see secs. 4).

3 The Super$B$ Drift Chamber

The Super$B$ Drift Chamber (DCH) is the main tracking detector of the Super$B$ experiment. Immersed in a 1.5 T solenoidal magnetic field, the DCH provides several position measurements along the track for a precise reconstruction of the particle momentum. It also measures the ionization energy loss used for particle identification. In fact, the DCH is the primary device in Super$B$ to measure velocities of particles having momenta below approximately $700\,\mathrm{MeV}/c$ and, at least in the initial phase of the experiment when no forward PID device is foreseen, it is the the only particle identification device for tracks with $\vartheta \leq 25°$.

Finally the drift chamber, together with the electromagnetic calorimeter, will provide the trigger of the experiment.

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*);
- 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 items mentioned above require a device possibly lighter in terms of radiation lengths with respect to *BABAR*, faster and with lighter endplates too. Super$B$'s lower boost also points toward a detector introducing minimal multiple scattering.

4 Development of Simulation Tools for Detector Design and Physics Studies

The design of the Super$B$ 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 has been mandatory at the to perform those studies that require the generation and complete reconstruction of the physics event. A member of our group has coordinated the *Physics Tools* group, whose main goal was the development and maintainance of the simulation and analysis tools needed to perform the physics and detector studies. The core of the Super$B$ 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. FastSim has been used to perform all physics studies and a large fraction of the detector optimization studies of Super$B$.

5 Optimization of the Drift Chamber Geometry

We have made extensive simulation studies to evaluate the impact on track reconstruction and ionization energy loss measurement of a number of design choices concerning both the external structure and the internal layout. These performance studies have been carried out using the Super$B$ fast simulation tool FastSim using signal samples with both high (*e.g.* $B \to \pi^+\pi^-$), and medium-low (*e.g.* $B^0 \to D^{*-}K^+$) momentum tracks (see previous section), and concerned: radius and thickness of the inner wall; drift chamber length and position and shape of the endcaps, both on the forward and on the backward directions; gas and wire material; layout of the stereo angles (stereo-only layers vs. axial+stereo) and the possible improvements due to cluster counting.

A side view of the drift chamber as resulting from the studies just sketched above and satisfying all the constraints from the other Super$B$ sub-detectors is shown in Fig. 1.

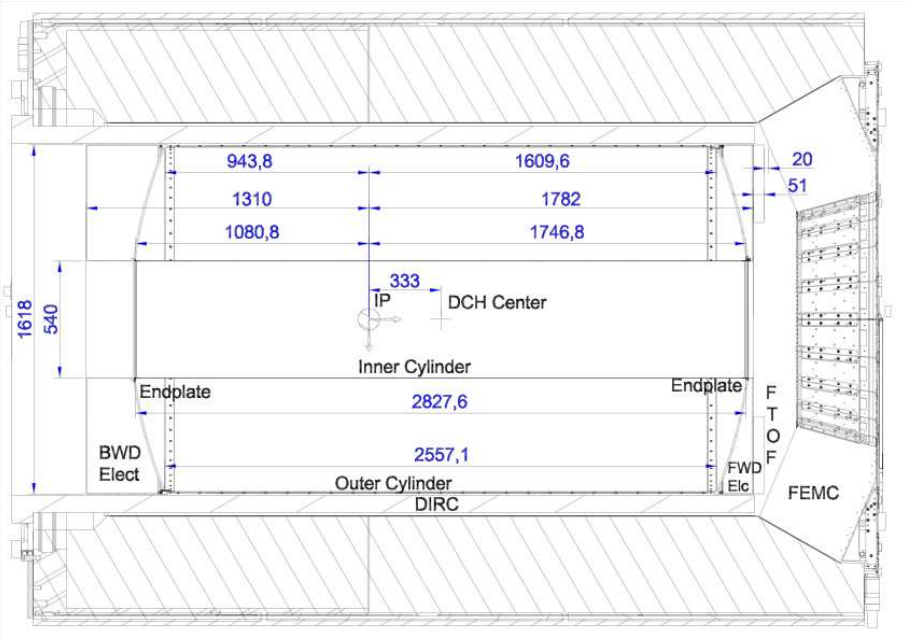

Figure 1: *Longitudinal section of the DCH with principal dimensions.*

6 R&D for the Super$B$ Drift Chamber

Various R&D programs have been carried out towards the definition of an optimal drift chamber for Super$B$. 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 conting 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 10 000 drift chamber channels.

During 2012 the LNF group continued the R&D program to study the feasibility of counting and measuring the drift times of the single ionization clusters. The full-length drift chamber prototype designed and built at LNF to study cluster counting in a realistic environment, including signal distortion and attenuation along 2.5 meter long wires was exposed to cosmic rays and beam test particles. The spatial resolution measured from tracks fitted through the eight layers of the detector operated in a 90%He-10%iC_4H_{10} gas mixture is shown in Figg. 2 and 3 as a function of the drift distance. This spatial resolution matches the requirements on the needed momentum resolution obtained with our simulation physics studies.

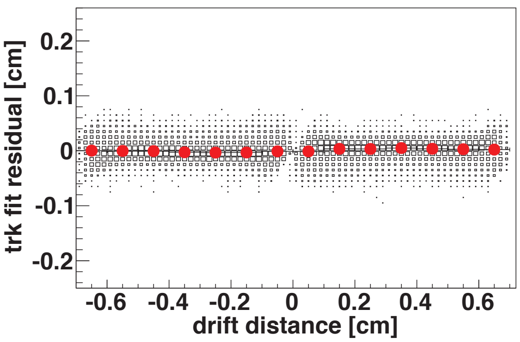

Figure 2: *Track fit residuals as a function of the drift distance from trcks fitted in the rectangular cells of the long prototype, operated in a 90%He-10%*iC_4H_{10} *gas mixture.*

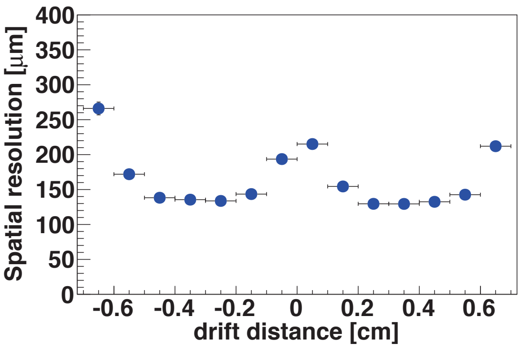

Figure 3: *Spatial resolution as a function of the drift distance from trcks fitted in the rectangular cells of the long prototype, operated in a 90%He-10%*iC_4H_{10} *gas mixture.*

In Fig. 4 we show the dE/dx resolution from a truncated mean technique as a function of the number of associated hits along the tracks. Scaling this figure to the number of samples in the real Super$B$ drift chamber (40 layers) would extrapolate to a relative dE/dx resolution of 6.7%, somewhat better than in the *BABAR* drift chamber. Studies comparing the particle identification capabilities of the detector with the standard dE/dx and the *cluster counting* are currently in progress.

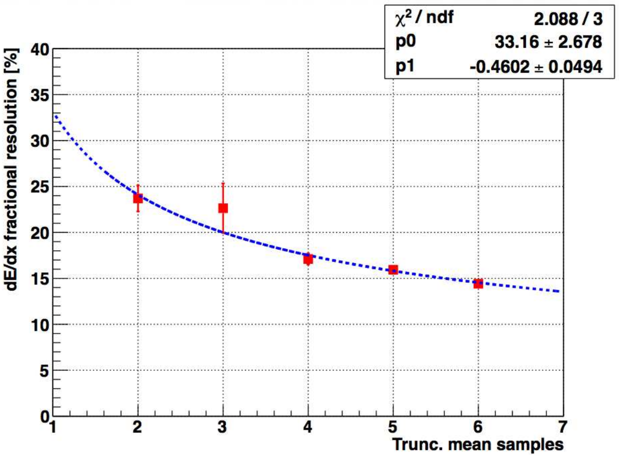

Figure 4: dE/dx *resolution as a function of the number of associated hits.*

7 Mechanical Design

The drift chamber mechanical structure must sustain the wire load with small deformations, while at the same time be as light as possible to minimize the degradation of the performances of the surrounding detectors. The structure is also required to ensure tightness for the gas filling the drift volume. We opted for a structure entirely in Carbon Fiber (CF) composite, with an approximately cylindrical geometry. Given the studies mentioned in Sec. 5 the active length of the chamber has been maximized. In particular the length in the backward direction is increased with respect to *BaBar* despite the 160 mm reserved in Super*B* for the possible backward EMC to be installed at a later stage; this is possible thanks to the new design of the drift chamber front-end electronics, which require substantially less space than *BaBar*.

Detailed studies of static deformations and buckling instabilities have been performed with the aid of Finite Element Analysis programs. These studies allowed to tune the mechanical design to minimize the deformation under the wire load and the material thickness at the same time, finally leading to the drawing shown in Fig.1. Examples of the calculated buckling shapes for the endplates, inner and outer cylinder are shown in Fig. 5.

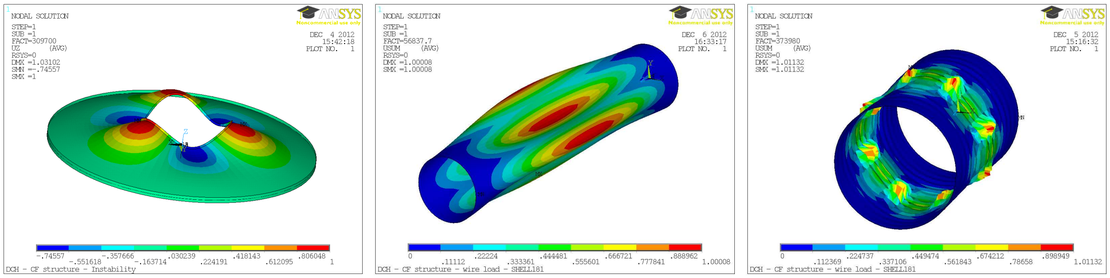

Figure 5: *Calculated first buckling shape of the endplates (left), inner cylinder (middle), outer cylinder (right).*

Details of how the the inner and outer flanges are connected to the endplates (all elements are in Carbon Fiber composite) are shoen in Fig.6.

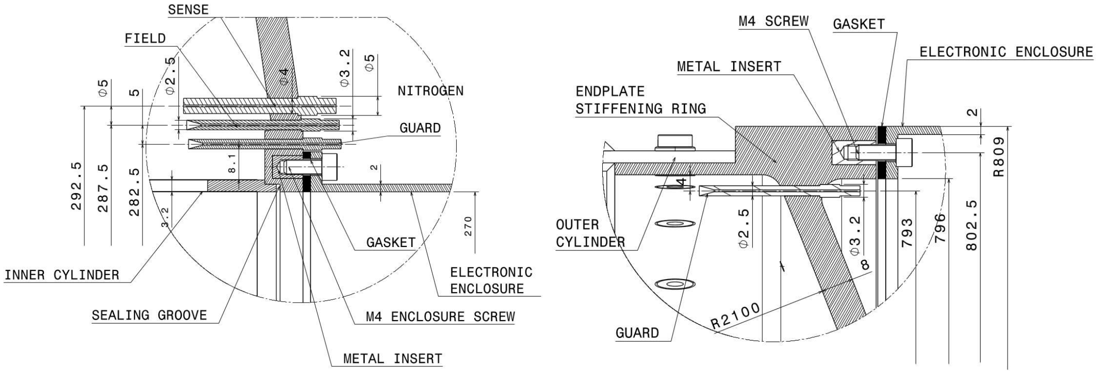

Figure 6: *Left: coupling of the DCH inner cylinder to the endplate; right: Detail of the outer flange of the DCH endplates.*

8 List of Presentations and Conference Talks in Year 2012

1. M. Rama, *Status of the SuperB project*, BEACH 2012, Wichita (KS), USA.
2. G. Finocchiaro, *SuperB Status and Prospects*, Belle2 Open Meeting, Bad Aibling, July 2012.

3. G. Finocchiaro, *Prospects at Future B Factories*, CKM 2012, Cincinnati (OH), USA.

References

1. *P. Raimondi*: Talk given at the 2^{nd} Super B-Factory Workshop, `http://www.lnf.infn.it/conference/superb06/talks/raimondi1.ppt`; *P. Raimondi, D. Shatilov, M. Zobov*: arXiv:physics/0702033v1 [physics.acc-ph].
2. *SuperB Conceptual Design Report*, `http://www.pi.infn.it/SuperB/CDR` arXiv:0709.0451v2 [hep-ex]
3. *B. O'Leary et al.: SuperB Progress Report - Physics*; arXiv:1008.1541v1 [hep-ex].
4. *E. Grauges et al.: SuperB Progress Report - Detector*; arXiv:1007.4241v1 [hep-ex].
5. *M. E. Biagini et al.: SuperB Progress Report - Accelerator*; arXiv:1009.6178 [physics.acc-ph].
6. *G. Finocchiaro: Prospects at Future B Factories*; arXiv:1212.6758 [hep-ex].