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SVD Radiation and Environmental Monitoring: General Requirements

L.Bosisio, L.Lanceri, L.Vitale

INFN and University of Trieste, Trieste, Italy

Abstract

This is a summary of the monitoring requirements of the *Belle II* Silicon Vertex Detector (SVD), for radiation, temperature and humidity. Radiation monitoring and humidity interlocks are in common with the two layers of the Pixel Detector (PXD), that together with the SVD forms the *Belle II* Vertex Detector (VXD). Options for the implementation of the monitoring system are briefly discussed. Details of the hardware implementation and of the construction schedules are discussed in separate notes for the radiation, temperature, humidity and interlock subsystems.

Contents

I. INTRODUCTION

This document specifies the environmental monitoring requirements of the *Belle II* Silicon Vertex Detector (SVD), that consists of four layers of double-sided micro-strip silicon detectors. Radiation monitoring and humidity interlocks are in common with the two layers of the Pixel Detector (PXD), that together with the SVD forms the *Belle II* Vertex Detector (VXD). Hardware implementation options are briefly outlined; details are described in separate notes.

Section II outlines the requirements of a beam abort system, to protect VXD from the exposure to excessive radiation doses from beam losses. Continuous sampling and recording of radiation dose rates are also needed: by SuperKEKB for beam tuning, and by *Belle II* for data quality monitoring, for detector safety controls, and to keep track of the total integrated dose accumulated by the VXD detectors.

The power dissipated by the detector front-end electronics will be removed by a CO_2 -based cooling system, and a flux of dry gas across the VXD volume will prevent humidity condensation. Sections III and IV include the requirements for the temperature and humidity monitoring and the corresponding interlocks (Section V A) for the VXD power supplies.

Section VI lists the coordinators, who cross-checked and approved the requirements collected in the present document.

II. RADIATION MONITORING

Radiation doses are measured in units of *gray* (Gy), corresponding to the absorption of one *joule* of energy, in the form of ionizing radiation, per *kilogram* of matter. Some of the radiation doses and dose rates in the following will be expressed in multiples of the commonly used but deprecated *rad* units, where 1 rad= 0.01 Gy= 0.01 J/kg.

In some cases, the displacement damage due to non-ionizing energy losses is quoted. These effects can be quantified using the non-ionizing energy loss (NIEL). The NIEL is energy lost to non-ionizing events per unit length, MeV/cm or MeV/(cm^2/g).

A. Radiation Environment

The design luminosity of SuperKEKB, 40 times higher than that of KEKB, will be achieved by higher beam currents and smaller beams size at the interaction point. As a consequence, higher beam-induced backgrounds and radiation doses are expected. The main background sources will be Touscheck scattering, radiative Bhabha scattering, electron-positron pair production in photon-photon scattering, and off-momentum particles from beam-gas interactions. Synchrotron-radiation induced backgrounds are expected to be smaller and will be kept under control by appropriate shielding.

These backgrounds are strongly dependent on the beam optics and were not yet quantified in the Belle II Technical Design Report (TDR) [1]; simulations are presently in progress [2]. Similar estimates for the Silicon Vertex Detector in the SuperB TDR [3] gave total integrated doses (TID) ranging from 3.3 to 0.01 Mrad/year, depending on the detector layer, and 1 MeV neutron equivalent fluence, according to NIEL (non-ionizing energy loss), of 5.2×10^{12} to 1.8×10^{11} n/cm^2 per year.

Assuming for the PXD a particle flux of about 10 MHz/cm^2, the absorbed dose would be 2.6 Mrad in one year (10^7 s) [1]. If most particles are low-energy electrons just above the 6 MeV cutoff, taking into account their smaller damage factor with respect to neutrons, the expected NIEL damage (integrated over the experiment lifetime) is of the order of 10^{13}n/cm^2 (1 MeV neutron equivalent) [1].

More recent estimates [4] for the PXD total integrated doses range from about 15 to about 18 kGy/year (1.5 to 1.8 Mrad/year) per year of operation at full design luminosity. The corresponding expected fluence in the PXD after 10 years of operation is 2×10^{13}n(equiv.)/cm^2.

Moving away from the beams, radiation doses will decrease but still be rather large, particularly in the horizontal plane. The Belle SVD2 radiation monitors, based on RadFETs, measured a total dose of 55 krad for layers 2 and 3, whose positions correspond approximately to the innermost layers of the Belle2 SVD. One can therefore estimate for these layers a dose of about 90 krad per ab^{-1}, or approximately 4.5 Mrad for the projected lifetime of Belle II (total integrated luminosity: 50 ab^{-1}).

B. PXD and SVD Radiation Hardness

Pending more information on the expected background levels across the two PXD layers, the PXD components were required [1] to survive a total integrated dose of at least 10 Mrad, assuming an exposure of about $1 \div 2$ Mrad/year.

The radiation hardness of the different components in the PXD was tested to be as follows [4]:

- DCDB (Drain Current Digitizer): irradiated with X-rays up to 20 Mrad.
- DHP (Data Handling Processor): irradiated with X-rays up to 100 Mrad. Also tested to be SEU (Single Event Upset) tolerant in a proton irradiation.
- SwitcherB: irradiated with X-rays up to 36 Mrad.
- DEPFET: DEPFET matrices were irradiated with 10 MeV electrons up to 15 kGy (1.5 Mrad) and 1×10^{14} n(equiv.)/cm^2. In addition, DEPFET-like structures were irradiated up to the full expected dose (20 Mrad) and 5×10^{14} n(equiv.)/cm^2.

For the SVD inner layers the extrapolated integrated dose is 4.5 Mrad over the experiment lifetime. Adding a safety margin of about a factor two, radiation tolerance up to about 10 Mrad is also required for the SVD DSSD sensors and front-end AP25 chips. The AP25 chips, developed for the CMS experiment at LHC, were tested to be radiation-tolerant up to well above 30 Mrad.

C. Performance Requirements

The primary goal of the Belle II radiation monitoring system is to detect beam conditions that are potentially damaging for the PXD+SVD sensors and front-end electronics. These could either be a sudden large increase in backgrounds and the corresponding received instantaneous radiation dose, or a lesser increase, that however brings to an unacceptable integrated dose over some longer time period. The corresponding actions should be an immediate trigger signal to the SuperKEKB beam-abort system in the first case (*"fast" abort trigger*), and a warning signal followed after some time by a beam-abort trigger signal in the second case (*"slow" abort trigger*). Both situations are shown in Figure 1.

Appropriate radiation thresholds for these actions will be set based on operational experience, however minimum requirements can be specified based on previous experience from Belle and BaBar [7], on the present status of the SuperKEKB project, and on the available simulations.

The *"fast" abort trigger* system, protecting against radiation bursts, should be able to measure instantaneous dose-rates up to about 50 krad/s with a precision of 50 mrad/s, on the time scale set by the beam revolution period of about 10 μs. Typically, the trigger signal should be generated whenever a total dose of about $2 \div 3$ rad is integrated above a dose rate threshold of about 1 rad/s. The above precision requirement ensures that the uncertainty on the measurement of the radiation levels is small with respect to the radiation levels at which beams should be aborted. Two separate trigger signals should be provided to allow separate aborts for the two circulating beams (Low Energy and High Energy), in cases where the beam losses are clearly correlated with only one beam. Abort trigger signals should be

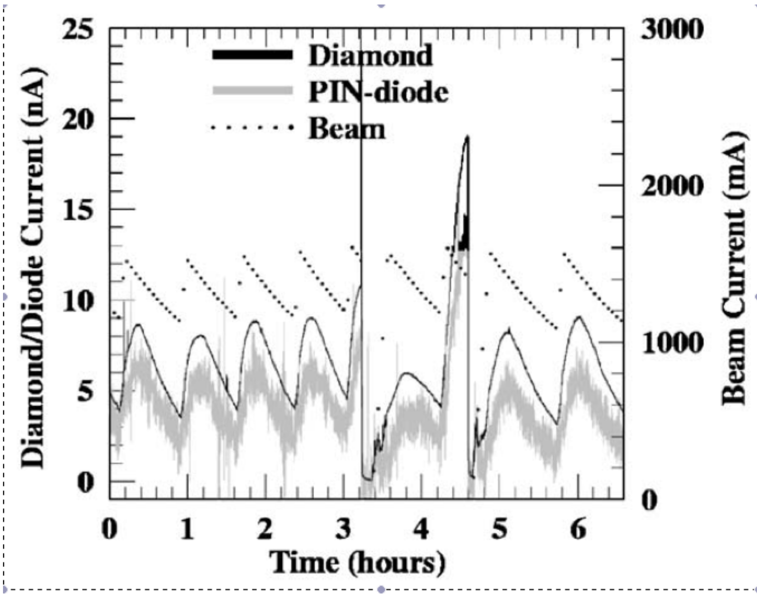


FIG. 1: Comparison of a pCVD diamond-sensor signal (black curve) and a silicon PIN-diode monitoring radiation in the BaBar SVT. Radiation levels in the SVT roughly track the electron beam current. The beam current gradually decreases between successive fills of the storage ring. The diamond sensor current is comparable to that of the silicon PIN-diode. At two points the beam is aborted. The first abort is due to an acute spike in the dose rate; the second abort is due to a smaller but longer lived increase in the dose rate. Both increases in radiation are seen in the diamond sensor and the silicon diode sensor [8].

provided in TTL standard to the Electrica/Optical (E/O) Conversion Box (Figure 4) for SuperKEKB-related signals, located in the Electronics Hut F2, B-7 rack (Figure 9), and reach the SuperKEKB beam abort [13] control system (Figure 2), through the path shown in Figure 3, generating an abort within about 20 μs of the detected event.

When a Beam Abort is generatad from any source, the signal to the Abort Kicker is also sent back to the Abort Module, to Abort Loggers and to Belle2 for confirmation and as a timing reference. This signal will be transmitted to the Electronics Hut by single-mode or multi-mode optical cable, and should be converted there to electrical, in the standard appropriate to the VXD monitoring and beam abort electronics.

The *"slow" abort trigger*, protecting against long-term radiation damage, should be able to measure instantaneous rates with an accuracy of about 5 mrad/s, allowing a 10% accuracy at a dose rate threshold of 50 mrad/s.

A secondary but important goal is to provide continuous monitoring and recording of radiation doses at sensitive spots in the PXD+SVD detector volume, and to deliver the information to the SuperKEKB accelerator operators, to the Belle II experiment shifters, and to the Belle II environmental conditions database. The instantaneous measurement uncertainty should not exceed about 1 mrad/s. The effective sampling rate should be at least 1 kHz; this may be accomplished averaging the output of faster digitizing circuits, to reduce random fluctuations. With appropriate buffering, two different output streams should be envisaged: a "slow" one for continuous monitoring, typically at the 1 Hz level, and a "fast" one, to dump on request more detailed information on the history around

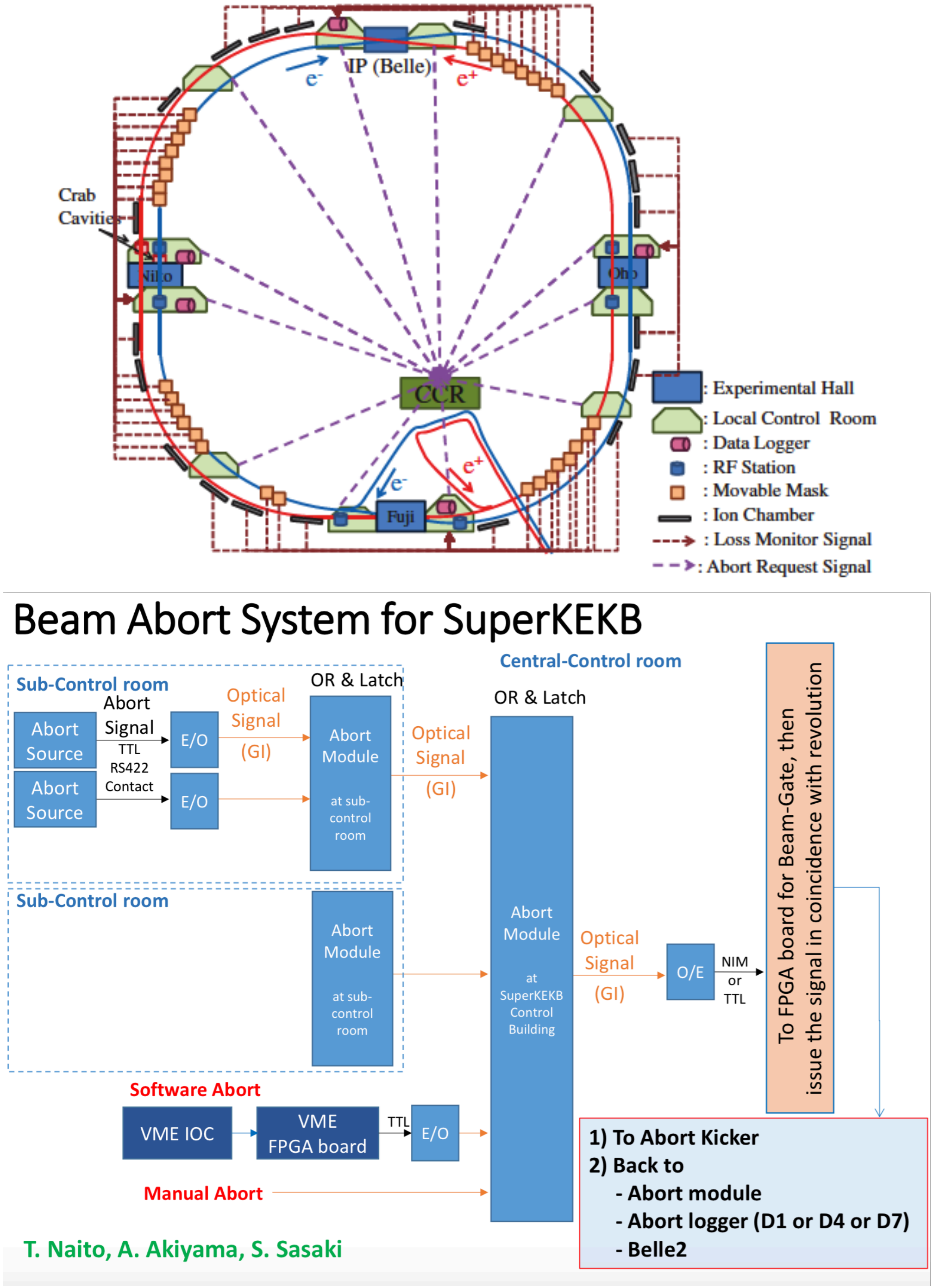
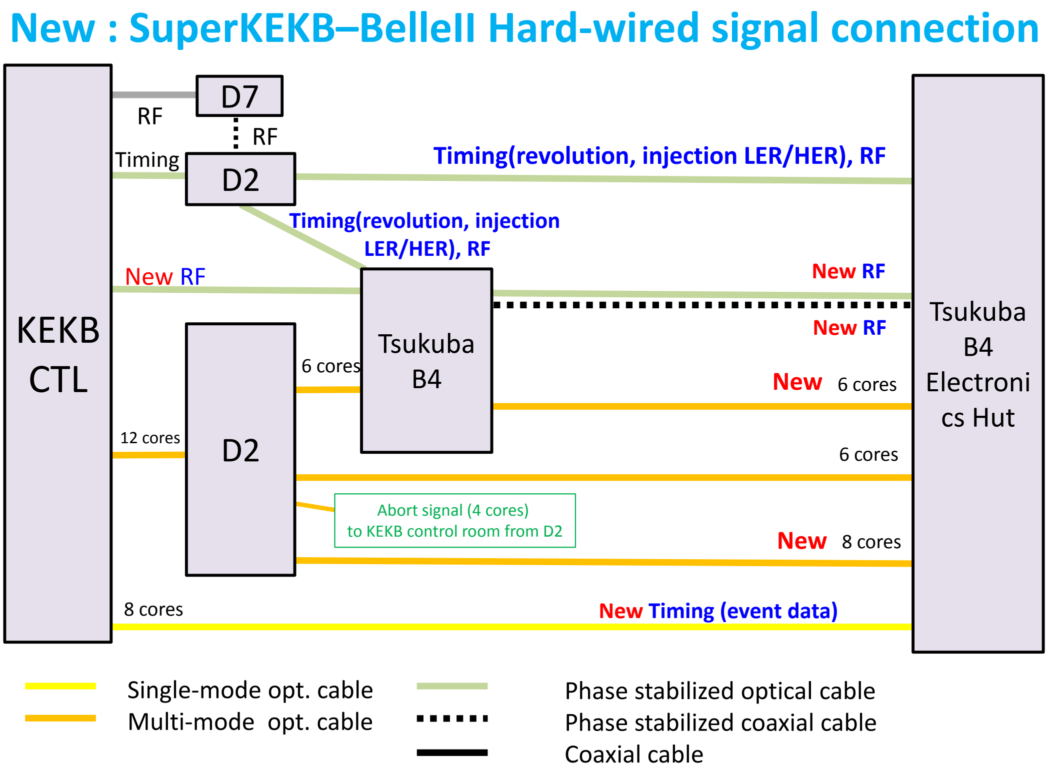


FIG. 2: The SuperKEKB beam abort system is an upgrade of the KEKB system [14]. More than 120 abort sources of different types can deliver their signals to Local Control Rooms and from there to the Central Control Room, to produce the Abort signal to the kicker magnet. Interlock modules provide an OR of the abort signals and latch them. Data from beam loss monitors are stored in Data Loggers and can be retrieved after a beam abort for post mortem analysis. When a Beam Abort is generatad from any source, the signal to the Abort Kicker is also sent back to the Abort Module, to Abort Loggers and to Belle2 for confirmation and as a timing reference.



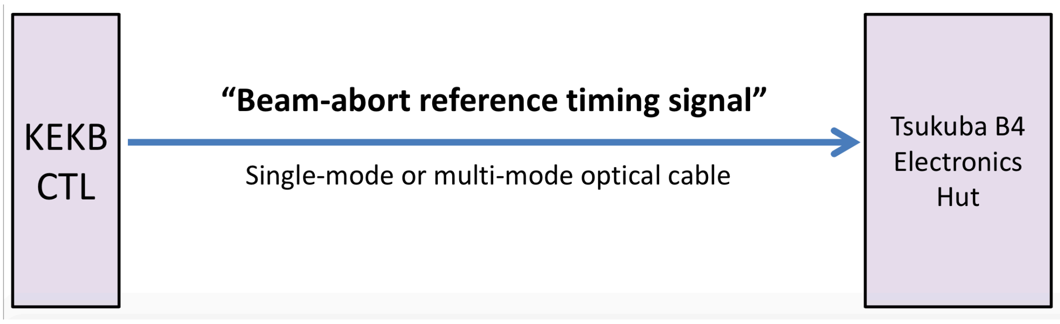


FIG. 3: Interconnections for signal transmission between the Belle Interaction Region (electronics hut) and the SuperKEKB beam abort control room [6].

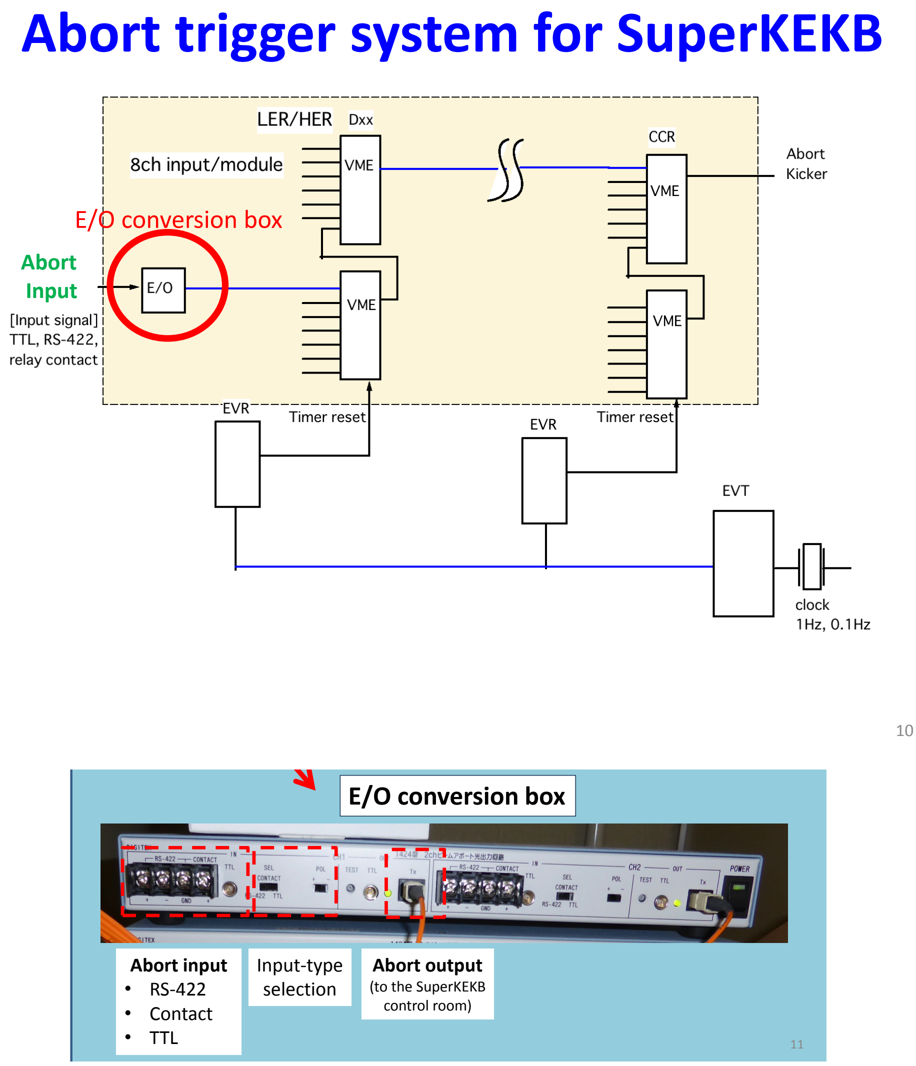


FIG. 4: Belle II beam abort triggers will be sent to the Electrical/Optical (E/O) Conversion Box in Electronics Hut F2 [6].

specific events, in particular beam aborts generated by any Belle II or SuperKEKB beam loss monitors. The depth of these buffers should match that of the equivalent SuperKEKB beam abort system, namely 600 ms with 10 μs sampling.

The experience from previous experiments suggests that four radiation sensors in the horizontal plane of the collider beams should be most effective for the beam-abort trigger, while several other sensors will be necessary to sample the dependence of the radiation dose on the azimuthal angle close to the PXD and SVD respectively. Simulations of the expected dose depositions are in progress to validate the location choice in two respects: sensitivity to machine-related beam losses and significant mapping of PXD and SVD radiation exposure.

A summary of the requirements on radiation monitoring and sensors is given in Table I.

The monitoring system, and in particular the beam abort trigger thresholds, should be implemented with the flexibility appropriate for different SuperKEKB operating modes, corresponding to different levels of radiation: *no beams*, *normal injection* and *machine*

TABLE I: Summary of the performance requirements of the radiation monitoring system.

Specification	Value
Number of radiation sensors	20
diamond sensor size	5 mm×5 mm×500μm
maximum coax. cable length from sensor to electronics	$3+40$ m
sensor current/dose rate conversion factor	$1 \div 10$ nA/(mrad/s)
sensor current measurement sensitivity	0.01nA
sensor current measurement range	$1 \div 10$mA
normal frequency of current sampling	100 kHz
depth of buffer memory for specific events (aborts etc)	600 ms
normal frequency of data recording on slow control DAQ	$1 \div 10$ Hz
response time of fastest (hardware) beam abort trigger	10μs
response time of slow (software) beam abort trigger	> 10 s
instantaneous dose rate sensitivity	1.0 mrad/s
integrated dose overall relative uncertainty	5%
for typical diamond sensors (fast aborts):	**Value**
current measurement, precision (time scale 1 ms)	10 nA
response time	up to 10 μs
current range	$0 \div 5$ mA
for typical diamond sensors (slow aborts):	**Value**
current measurement, precision (time scale 1 s)	< 1 nA
response time	$> 1 \div 100$ s
current range	$0 \div 15$ μA

tuning, *stable beams*, *continuous injection* during a fill, *machine development*. A typical machine operation sequence is shown in Figure 5.

- *No beams*: no circulating beams, no current is being injected in the rings. This situation can be exploited for calibrations and pedestal measurements.

- *Normal injection* for machine filling, and then *machine tuning* for collisions: radiation levels are considerably higher than during stable beams and more unpredictable. The PXD and SVD detectors high-voltage is off and detectors are not read out. The monitoring system operates with relaxed thresholds to allow higher radiation levels for a limited period (several minutes).

- *Stable beams*: colliding beams, delivering luminosity for a fully operational Belle II. Radiation levels are stable, and track beam currents. The monitoring system provides an accurate integration of radiation dose and guards against radiation accidents with appropriate thresholds, since the detector is powered and most vulnerable.

- *Continuos injection* during a fill: similar to stable beams; small amounts of particles are continuously injected to keep the beam currents constant. The monitoring system

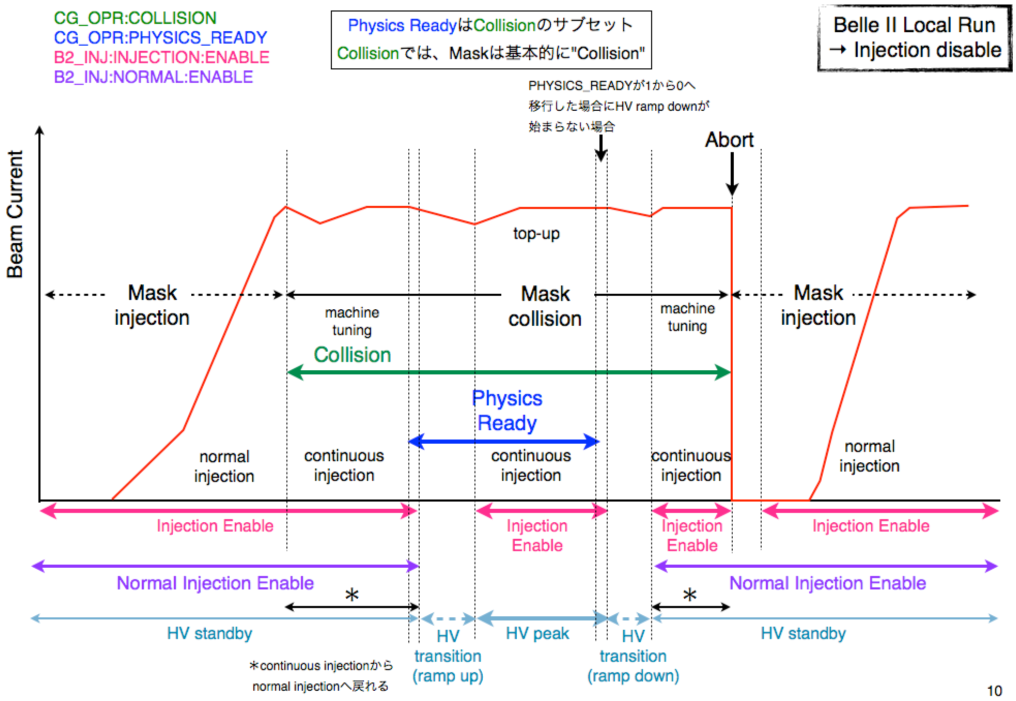


FIG. 5: Typical sequence of SuperKEKB conditions [6], as described in the text.

operates with the same threshold values as with stable beams.

- *Machine development*: the PXD and DVD detectors are usually off during this time. Radiation levels are unpredictable, but usually low if the beam currents are lower than in normal operation. The radiation monitoring system must be operational, to measure the integrated dose and to still protect the detector with the relaxed threshold values of injection.

It should be noted that, as shown in Figure 5, the *Belle II* permission is required for *normal injection* and *machine tuning* (both Injection Enable and Normal Injection Enable signals from *Belle II* to SuperKEKB).

After completing *normal injection* and going to *colliding beams* mode, SuperKEKB issues the Collision signal, and then the Physics Ready signal, once the machine tuning is completed. *Continuos injection* is allowed when *Belle II* has completed the HV ramping-up and issues the Injection Enable signal again.

D. Sensors, Mechanics, Cabling

In silicon PiN-diode sensors the leakage currents increase with the integrated dose, exceeding the μA level after the accumulation of a substantial exposure; the nA-level current originated by the instantaneous dose rate must be measured subtracting this large pedestal, and correcting for temperature and for exposure hysteresis effects, with increasing systematic errors. Radiation-hard diamond sensors were tested as beam loss monitors by Belle and

BaBar [8], and extensively used by CDF at FermiLab [9] and more recently by CMS [10] and ATLAS [11] at LHC in a high radiation environment.

Diamond sensors are single- or poly-crystals, grown with the vapour deposition technology: sCVD and pCVD respectively. pCVD sensors are less expensive; they have a lower charge collection efficiency with respect to sCVD sensors and require a higher operating voltage. Both sCVD and pCVDs have been used as beam loss monitors. For a rather small number of sensors, sCVDs may be the optimal choice for Belle II.

The typical response of a pCVD sensor, 10 mm$\times$10 mm$\times$500μm, reaching a charge collection distance (CCD) of about 200μm with a bias voltage of 500 V, is approximately 1 nA of current for every 70μGy/s (7 mrad/s) of radiation [8]. Smaller (5 mm$\times$5 mm$\times$500μm) sCVD sensors will receive a dose smaller by a factor 4 in the same conditions; the higher collection efficiency of sCVD will partially compensate the reduced amount of initial charge, and have a similar current/dose ratio. Assuming the above conversion factor from dose-rate sensitivity to sensor-current sensitivity as typical, the precision requirements for the monitoring and beam abort system would then be approximately:

- acute (fast) aborts: precision of 10 nA at a time scale of 1 ms. Response times up to 100 μs. Current range $0 \div 5$ mA.
- dose rate (slow) aborts: precision of better than 1 nA at a time scale of 1 s or higher. Current range $0 \div 15$ μA.

The space available for radiation sensors, cables and front-end electronics is extremely tight. Figure 6 shows planned locations for two sets of 4 sensors each, close to the beam pipe and the PXD, and two sets of 6 (or 8) sensors each, to be mounted on the support rings of the SVD inner layers. Figure 7 shows the *Belle II* coordinates system and the Forward/Backward, Inside/Outside definitions.

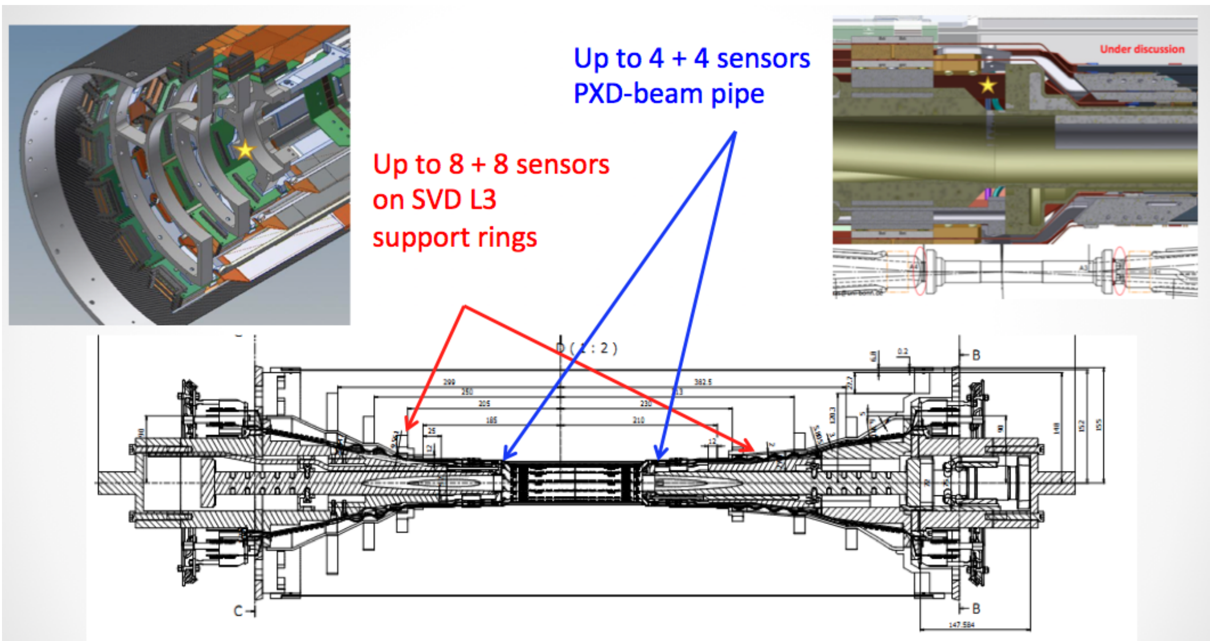


FIG. 6: Planned locations of radiation sensors for PXD and SVD.

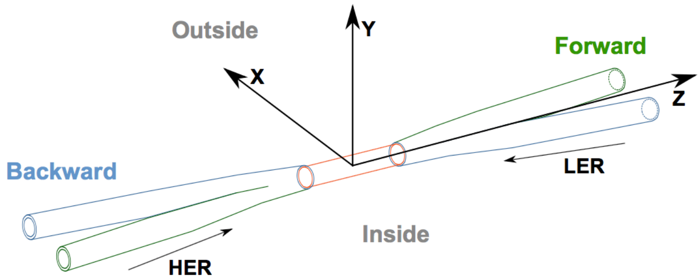


FIG. 7: Belle II coordinate system.

Based on previous experience [9], 80 m long triaxial cables can be used for the direct connection of the diamond sensors to the voltage bias supply and current-measuring circuits, without intermediate signal pre-amplification. A similar performance was obtained in tests with pairs of good-quality coaxial cables. In *Belle II*, connection points for long cables should be provided at interconnection boxes (”docks”) located at a distance of about 3 m from the sensors, as shown in Figure 8.

The cables from sensors to docks can be pairs of more flexible and less space-demanding thin coaxial cables. As far as cabling paths are concerned, assuming a total of $2\times(4{+}6) = 20$ sensors, each connected to two coaxial cables, 20 thin coaxial cables (3 mm diameter) in each of the forward and backward regions, with a filling factor of approximately $\pi/4 = 0.8$, will occupy a total cross-section of about 180 mm^2 in each region.

For the following path from docks to electronics, 20 pairs of good quality coaxial cables (5.5 mm diameter) will occupy a total cross-section of about 605 mm^2 in each of the forward and backward regions. From the point of view of accessibility during data taking, and proximity to the panels with connections to SuperKEKB signals, the assigned location for electronics is in Electronics Hut F2, Racks F-4, F-5. (Figure 9) at the detector side (cables not longer than about $30 \div 40$ m, depending on the detailed paths, to be measured). The cables should be halogen-free and radiation-hard, and grounding should be as specified in ref. [5].

E. Electronics, Interfaces, Slow Control

A collaboration with the Electronics Division of the Elettra Synchrotron light source was started, to modify and customize the design of the existing AH501B current digitiser [15], specifically realised for X-ray beam position monitoring by diamond sensors at Elettra. The functionality required is similar to that of the Fermilab Beam Loss Monitor (BLM) system [9] and the LHC [12] and ATLAS [11] BLM systems. This will mainly require the inclusion of FPGAs and additional memory for the digital filtering and beam abort trigger.

To meet the *Belle II* requirements for both the *dose-rate measurements* and the *beam-abort triggers*, specified in the previous section, the diamond sensors currents will be sampled and digitized at a frequency of at least 100 kHz, corresponding to the SuperKEKB beams revolution period of about 10μs (more accurately, the SuperKEKB RF frequency, 509 MHz, divided by 5120). The current digitisation range should be selectable at initialisation, between $0 - 50\mu$A and $0 - 2$ mA.

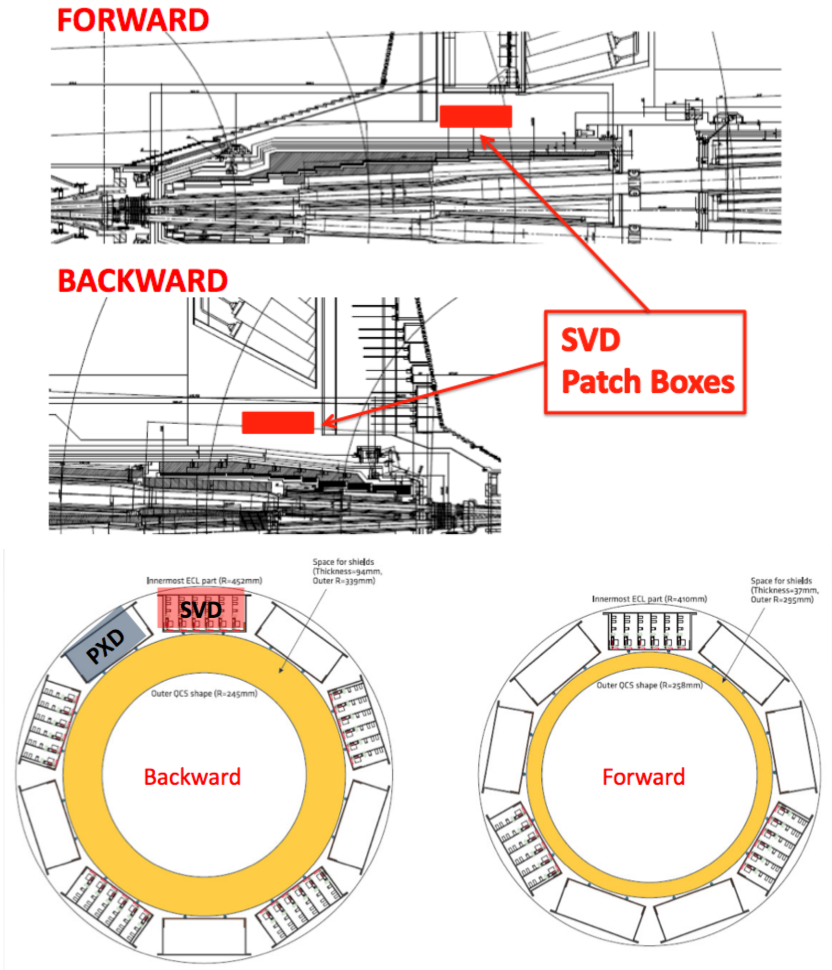


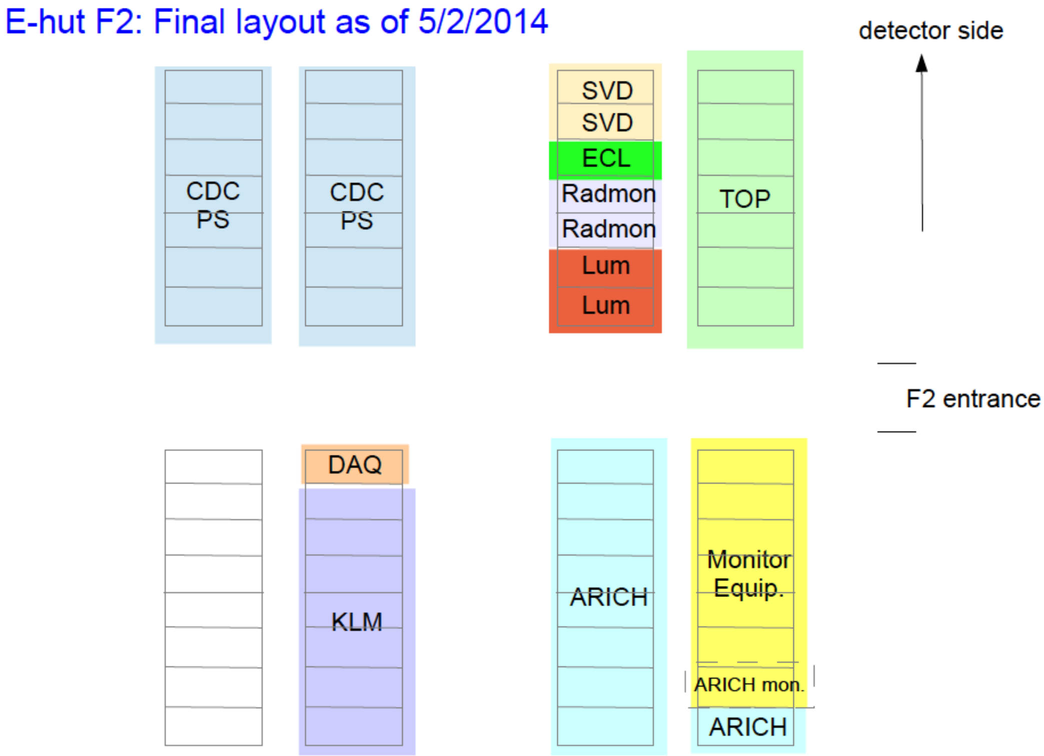
FIG. 8: Location of cable interconnection boxes (”docks”), at about 3 m from the radiation sensors)

Several levels of running averages (also called ”sliding sums” or ”running sums”) will be computed over programmable numbers of cycles, and updated every 10μs, providing an effective digital filter, smoothing out random fluctuations and 60 Hz noise. The corresponding data will be buffered in memories of appropriate depth, as specified above. As a reference, the Fermilab system allows four levels of running sums for each sensor, with the corresponding four revolving buffers to store the data averaged over four different time intervals.

The dose-rate monitoring will be accomplished by EPICS, reading out the averaged currents through an Ethernet interface at a rate not exceeding $1 \div 10$ Hz. This information will be made available to both Belle II and SuperKEKB through EPICS and the network.

For the beam abort, the different levels of running averages will be compared with programmable pre-loaded thresholds, selectable according to the SuperKEKB conditions (no beams, normal injection and machine tuning, stable beams and continuous injection, machine development): at least four different beam conditions. A dedicated status register will keep the current SuperKEKB status, set via EPICS. Hardwired signals (Collisions and Physics Ready) will be used to switch between relaxed and tight thresholds, correspond-

FIG. 9: Location of the radiation monitoring electronics (Radmon) in Electronics Hut F2. Numbering of the four Rack Raws: from the entrance E-, F-, G-, H-. Numbering of Racks in each Raw: right to left, with view from the entrance: right-hand side : -1, -2, ..., -7; left-hand side : -8, -9, ..., -15



ing to normal injection/machine tuning and stable beams/continuous injection respectively. The signals above thresholds from individual sensors, if allowed by programmable masks, will be combined in a programmable majority logic, whose output will be the two requested Beam Abort signals, for the low energy and the high energy ring separately.

For diagnostic purposes, the revolving buffers (at least 600 ms deep) containing the detailed information of currents sampled every 10μs, will be frozen whenever the Beam Abort Reference Timing Signal will be received from SuperKEKB; the read-out of the revolving buffers by EPICS, through the Ethernet interface, will follow.

An overall diagram of the diamond sensor electronics system and a block diagram of a module with voltage bias, monitoring and beam abort for four sensors, presently in the design and first prototyping stage, are shown in Figure 10. A detailed description of the system will be given in a separate Note.

III. TEMPERATURE MONITORING

After summarising the expected environmental conditions, a list of performance requirements are given for temperature monitoring and interlocks. Options for sensors, mechanics and cabling, and for electronics, interfaces and slow control are finally discussed.

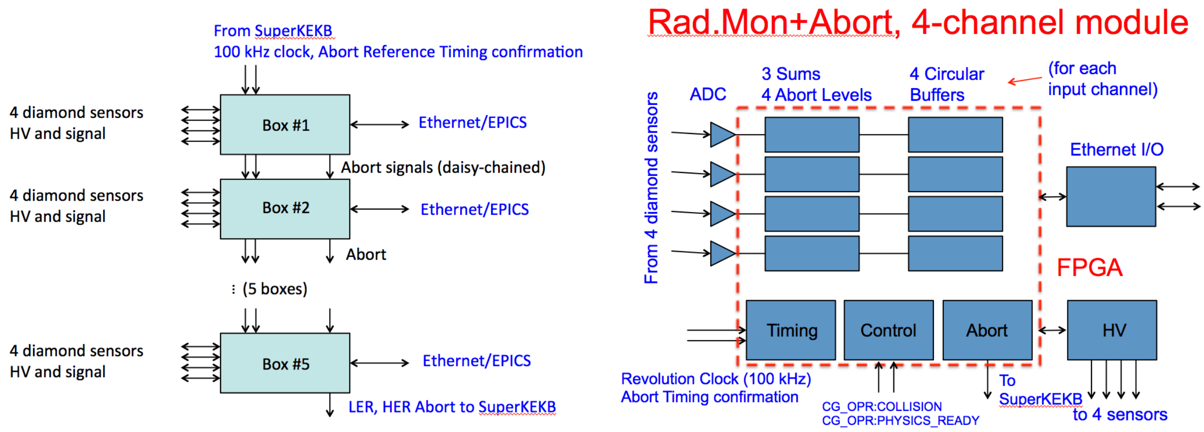


FIG. 10: Diamond-sensors electronics: overall block diagram and a diagram representing the functionality of one module, with detector bias, digitisation, readout and beam abort trigger logics for four diamond sensors.

A. Environmental Conditions

The power dissipation by the PXD DEPFETs and their front-end electronics will amount to about 18 W per module, 360 W in total for the 20 PXD modules. The APV25 front-end chips of the SVD will consume in total about 700 W in full operation.

The dissipated power will be removed by a cooling system based on heat exchange with a dual-phase CO_2 fluid at a temperature of -20° C circulating in thin pipes with good thermal contact with the heat dissipation sources, the front-end readout chips.

The whole volume of the PXD/SVD will be kept at low humidity, to prevent water vapour condensation, with a dew point lower than -30° C, by a flux of dry Nitrogen. The input and output temperature of the cooling CO_2 must be kept under control, as well as the temperature of SVD ladders, with distributed measurements close to the front-end chips.

B. Performance Requirements

A detailed analysis of the thermal behaviour of the cooling system and of the VXD system (sensors, front-end electronics, mechanical supports) is underway at the DESY VXD thermal mock-up, to identify (a) the possible failure modes, (b) the warning signals to be provided by the temperature and humidity monitoring system, and (c) the power-down actions required by the interlock systems.

For SVD, temperature sensors are required to monitor both the temperatures of the cooling pipes and the temperatures of ladders close to the heat sources, the front-end readout ICs.

For the first task (monitoring and interlocking the cooling system), one should measure the temperatures of the support rings, that contain the channels distributing the cooling fluid, and sample the temperature of the cooling pipes at their inlets and outlets. This requires 12 sensors on the outer surface of the rings (one sensor on each of the six half-rings) and 16 sensors on the cooling pipes (one for each inlet or outlet). Doubling the number of sensors for redundancy at each measurement spot brings the total number to 56 sensors. Standard radiation-hard NTC (Negative Temperature Coefficient) thermistors can be used [20]. The temperatures measured through the electrical resistance of normal NTC thermistors, will be available for readout at low frequency by the slow control EPICS software; the readout electronics will also be able to directly generate trigger signals to the interlock system, based on comparators and hard-wired thresholds, independent of the data acquisition system.

A second set of sensors is required to measure the temperatures of the SVD ladders, close to the front-end ICs. The hybrids hosting the readout ICs and the connectors were not designed to host also electrical temperature sensors and their signal lines. A different approach has to be used, similar to the one adopted by the PXD group [18]. At least for layers from 4 to 6, optical fibres can be inserted in channels prepared in the Airex foam, with several Bragg sensors along the ladder, in two positions per DSSD sensor, roughly corresponding to the presence of the front-end ICs on the "origami" hybrids. The readout in this case is via laser pulses of variable wavelength, generated by commercial "interrogator units". For cross-calibration purposes, a subset of the FOS (Fibre Optical Sensor) fibres should have an additional sensor located outside the Airex foam channel, to be thermally coupled with an NTC thermistor. Assuming at least 8 such cross-reference points, the total required number of NTC thermistors becomes $56 + 8 = 64$.

The operating range of the temperature monitoring system should cover the conceivable range in different conditions: from −20°C (cooling fluid) to about 25°C (room temperature); uncooled front-end electronics may exceed 40°C. The interlock threshold is required to be adjustable between −15°C and 30°C. To be able to measure the time constant in significant temperature variations over time intervals of a few seconds, the temperature should be measured with a sensitivity of about 0.1°C at a frequency of about 1 Hz. The latency for providing a power-down signal to the interlock logics should be of the order of 0.1 s, smaller than the typical time required to ramp down the power supplies. For a reliable safety interlock, the overall absolute accuracy and stability of the monitoring system should be at the 1°C level.

C. Sensors, Mechanics, Cabling

The temperature monitoring performance requirements and the lack of built-in sensors on the "origami" hybrids, close to the power dissipation sources (the SVD front-end ICs), suggest the dual approach discussed above: NTC thermistors to monitor the temperature of the cooling system (support rings and cooling pipes inlets and outlets), and Bragg sensors in optical fibers (FBG, Fibre Bragg Grating sensors), inserted in the ladders of SVD layers 4, 5, and 6, to measure the temperature of ladders, close to the ICs.

NTC thermistors have good precision and require only two wires per sensor, since their resistance (typically 100 kOhm) can be chosen to be much higher than that of connecting cables [20]. FOS require rather sophisticated read-out systems, that however are commercially available for industrial applications [21]. Both NTC cables and FOS fibres need to have interconnection points at the DOCKs, as all other SVD detectors and sensors, at about 3 m distance from the sensors. Longer cables and fibres (about 30 m long? to be checked!) will connect the DOCK boxes to the electronics, located in the F2 Electronics Hut.

Due to mechanical constraints, only layers 4, 5 and 6 can be equipped with FOS monitoring. The SVD layer, ladder, sensor numbering scheme is defined in Belle II Note 10 [17].

Figure 11 recalls the SVD layer, ladder and DSSD sensor numbering scheme. Figure 12 shows a preliminary organisation of the FBG read-out system.

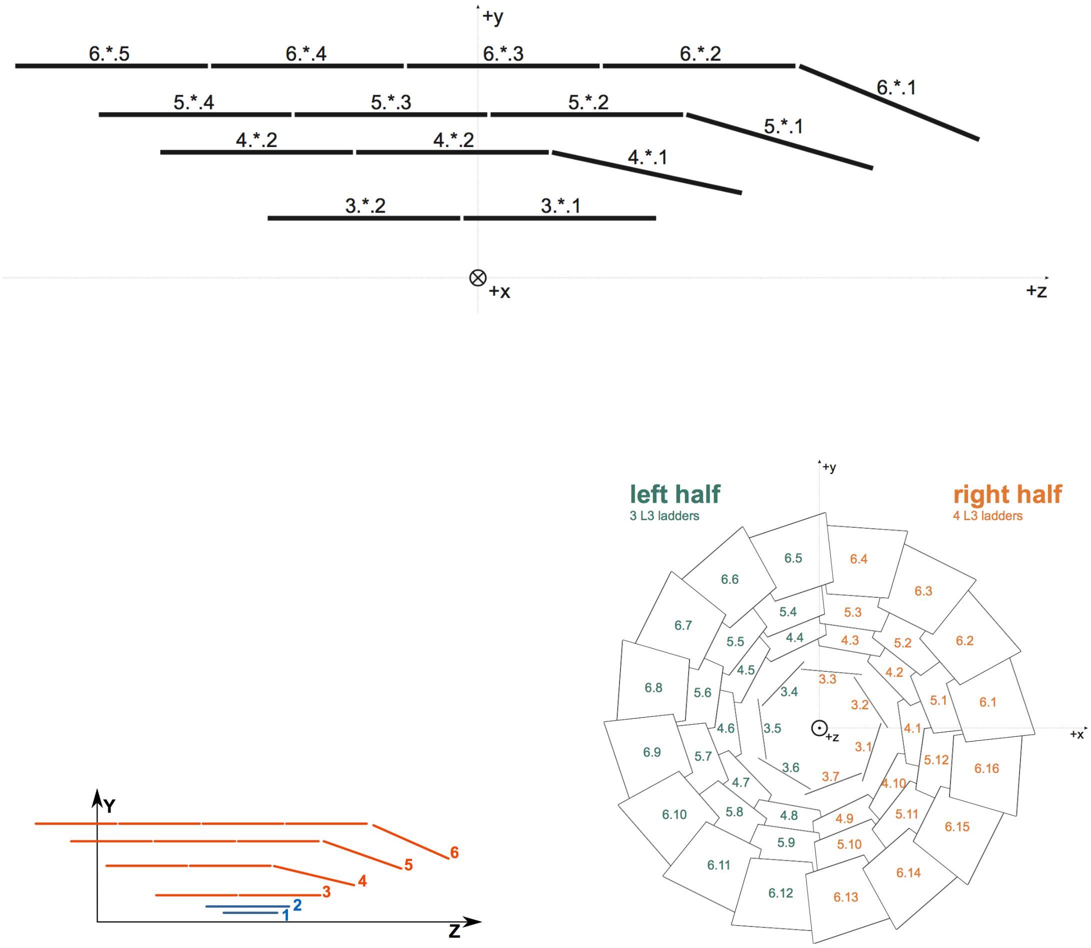


FIG. 11: SVD layers, ladders and DSSD sensors: numbering scheme.

The digitising electronics will be located, as shown in Figure 9, in E-Hut F2, Racks F-4, F-5 together with Radiation Monitor, or Racks E-11, E-12 (as a reserve for expansions, to be defined!). Grounding and cabling will follow the guidelines specified in ref. [5]. The locations reserved for temperature sensors are listed in Tables II and III.

D. Electronics, Interfaces, Slow Control

The readout of FOS FBG sensors will be performed by the sm225 Optical Sensing Interrogator from Micron Optics [21]. It is built upon the Micron Optics x25 optical interrogator core, featuring a high power, low noise swept wavelength laser, realized with Micron Optics patented Fiber Fabry-Perot Tunable Filter technology. The x25 interrogator core employs

TABLE II: List of NTC temperature sensors, mounted on end rings, on cooling pipes, and on a subset of FOS fibres. Sensors will be mounted in pairs, for redundancy and cross-checks. End-Ring NTCs numbering scheme: a.b.c.d, where a $= 3, 5, 6$; b $= 1, 2$ (1 = right half, intersecting $+x$ axis; 2 = left half at $-x$); c $= 1, 2$ (1 = forward; 2 = backward); d $= 1, 2$ (1 = first NTC; 2 = second NTC). Cooling-Pipe (Origami) NTCs numbering scheme: a.b.c,.d where a $= 9, 10, 11, 12$ (CO_2 circuit number; b $= 1, 2$ (1 = right half; 2 = left half); c $= 1, 2$ (1 = inlet; 2 = outlet); d $= 1, 2$ (1 = first NTC; 2 = second NTC).

NTC sensor pair IDs	CO_2 Circuit	End Ring	Half	Side
3.1.1.1, 3.1.1.2	8	3	right	forward
3.2.1.1, 3.2.1.2	7	3	left	forward
5.1.1.1, 5.1.1.2	8	5	right	forward
5.2.1.1, 5.2.1.2	7	5	left	forward
6.1.1.1, 6.1.1.2	8	6	right	forward
6.2.1.1, 6.2.1.2	7	6	left	forward
3.1.2.1, 3.1.2.2	6	3	right	backward
3.2.2.1, 3.2.2.2	5	3	left	backward
5.1.2.1, 5.1.2.2	6	5	right	backward
5.2.2.1, 5.2.2.2	5	5	left	backward
6.1.2.1, 6.1.2.2	6	6	right	backward
6.2.2.1, 6.2.2.2	5	6	left	backward
NTC sensor pair IDs	CO_2 Circuit	Origami Layer	Half	Side
9.2.1.1, 9.2.1.2	9	4, 5	left	backward inlet
9.2.2.1, 9.2.2.2	9	4, 5	left	backward outlet
10.1.1.1, 10.1.1.2	10	4, 5	right	backward inlet
10.1.2.1, 10.1.2.2	10	4, 5	right	backward outlet
11.2.1.1, 11.2.1.2	11	6	left	backward inlet
11.2.2.1, 11.2.2.2	11	6	left	backward outlet
12.1.1.1, 12.1.1.2	12	6	right	backward inlet
12.1.2.1, 12.1.2.2	11	6	right	backward outlet
$1 \div 8$	FOS $1 \div 8$			(to be chosen)

full spectral scanning and data acquisition, providing measurements with high absolute accuracy, flexible software post-processing, and high dynamic range performance. For calibrations and debugging Micron Optics ENLIGHT Sensing Analysis Software provides a single suite of tools for data acquisition, computation, and analysis of optical sensor networks [21]. A custom Micron Optics protocol via Ethernet is available: readout customisation to EPICS was already successfully implemented by the PXD group [19].

The readout of NTC sensors will be performed by a custom-designed system, based on the Embedded Local Monitor Board (ELMB), designed at CERN [23] and used in large numbers for the readout of many environmental monitoring channels in LHC experiments (see for example [22], [24]). Each ELMB hosts a CANbus-connected processor and an ADC

TABLE III: List of FBG FOS temperature sensors, inserted in ladders of SVD layers 4, 5, 6. The ladder numbering scheme is defined in Belle II Note 10 and recalled in Figure 11; the FOS readout scheme is shown in Figure 12. FBG sensors are numbered: a.b.c., where a $= 4, 5, 6$ (layer number); b =ladder number; c =Bragg sensor number. Some fibres will have an additional sensor for cross-calibration with NTCs. The Bragg sensor numbering c starts from the end of the fibre (from the right in Figure 12).

FBG IDs	Positions
4.b.c	Layer 4, ladders $b = 1 \div 10$, Bragg sensors $c = 1 \div 3(4)$
5.b.c	Layer 5, ladders $b = 1 \div 12$, Bragg sensors $c = 1 \div 5(6)$
6.b.c	Layer 6, ladders $b = 1 \div 16$, Bragg sensors $c = 1 \div 7(8)$

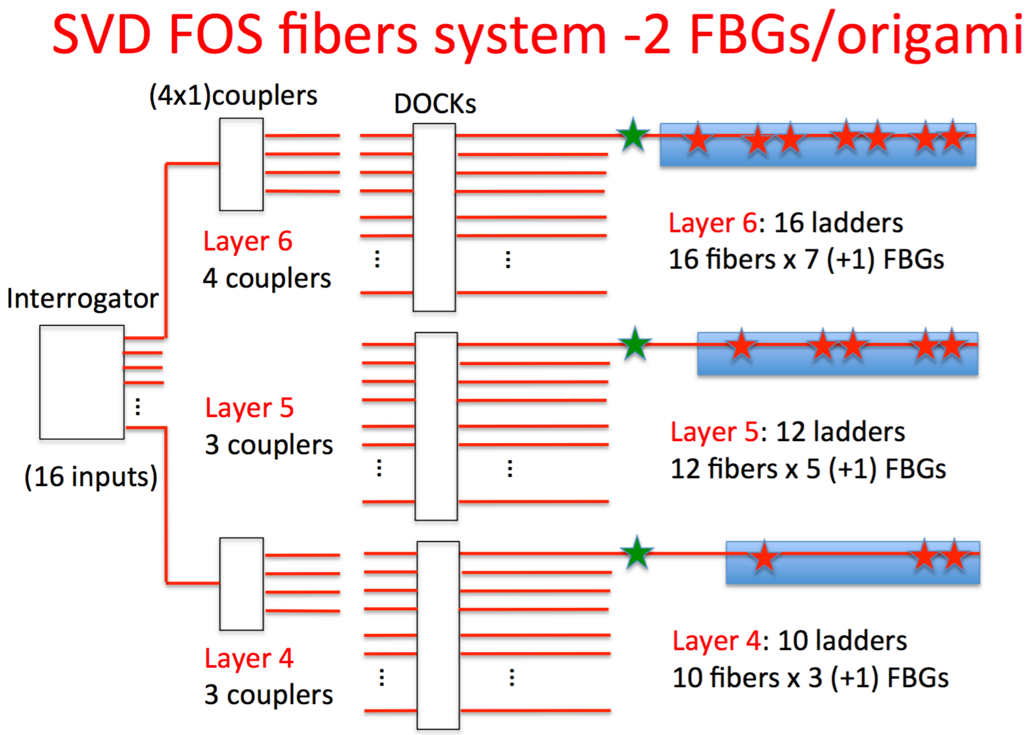


FIG. 12: Organisation of the FBG sensors readout (preliminary).

multiplexed to 64 input channels; half of them will be connected to reference resistors; 32 input channels will measure the voltage drop across NTC thermistors. A specially designed motherboard will provide the current sources and also hardwired comparators with trimmer-adjustable thresholds, OR-ed in groups of 8, to provide 4 fast interlock signals per group of 32 NTCs. Two motherboards with two ELMBs will be sufficient for the 64 NTCs specified in Section III B. A third ELMB is included in the design of the NTC readout box (see Figure 13) to provide 32 additional spare channels. A complete prototype of the system was already successfully tested, with readout (via CANbus interface) software based on OPC

Server and LabView. EPICS readout development is underway.

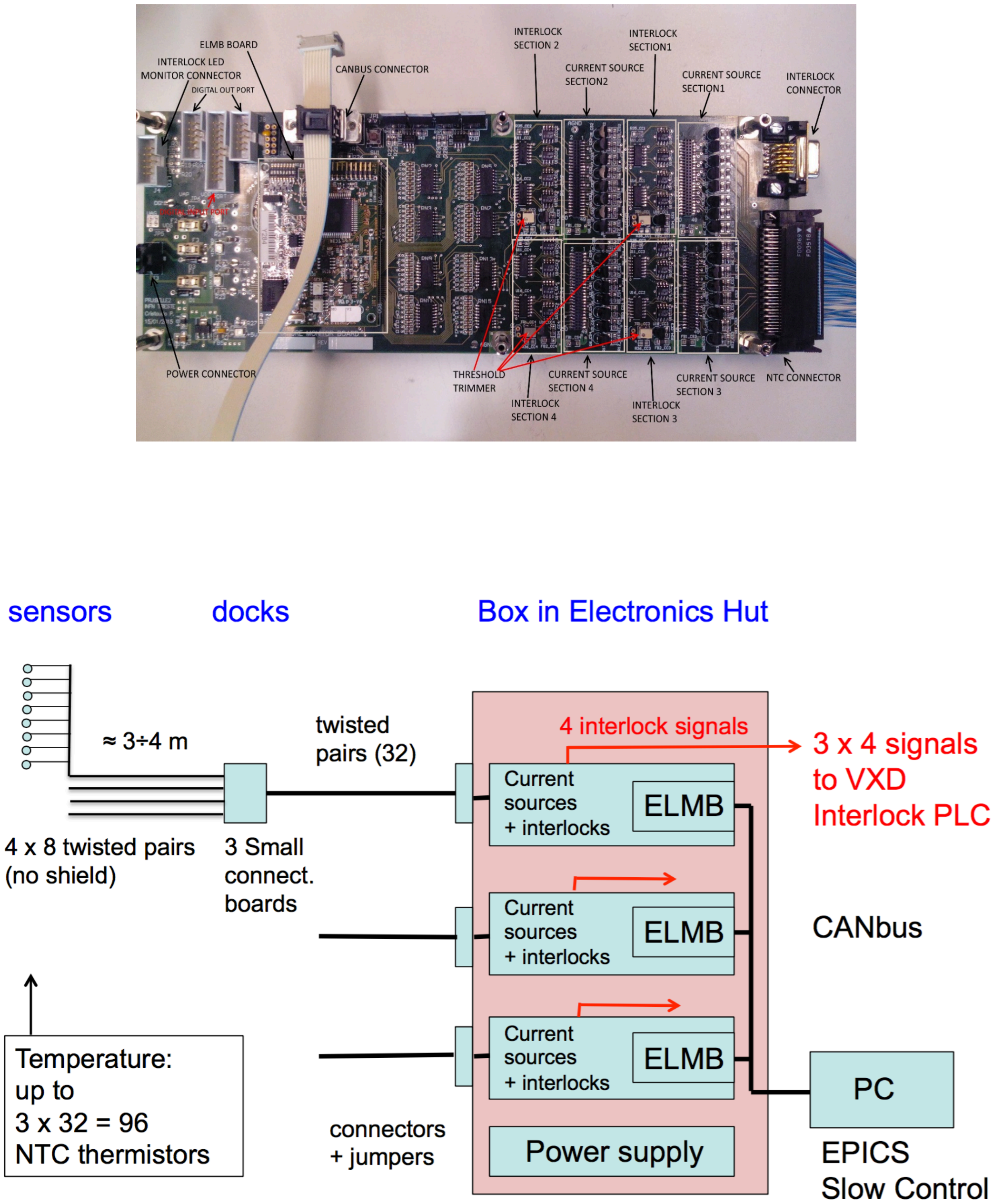


FIG. 13: ELMB prototype motherboard, and block diagram of the NTC readout system, based on three ELMB boards.

IV. HUMIDITY MONITORING

A. Performance Requirements

As described in Section III A, the power of about 1060 W, dissipated by the VXD front-end electronics, will be removed by a cooling system based on heat exchange with a dual-phase CO_2 fluid at a temperature of $-20°$ C, circulating in thin pipes.

To prevent water vapour condensation on the surface of the cooling pipes, a flux of dry Nitrogen will keep a dew point lower than about $-30°$ C. The dry volume shown in Figure 14, however, cannot be completely gas-tight, due to the complex arrangement of outgoing cables and services. It is therefore necessary to monitor the humidity, and interlock the VXD power supplies should the dew point exceed about $-30°$ C. The accuracy in dew point determination should be about $\pm 1°$ C.

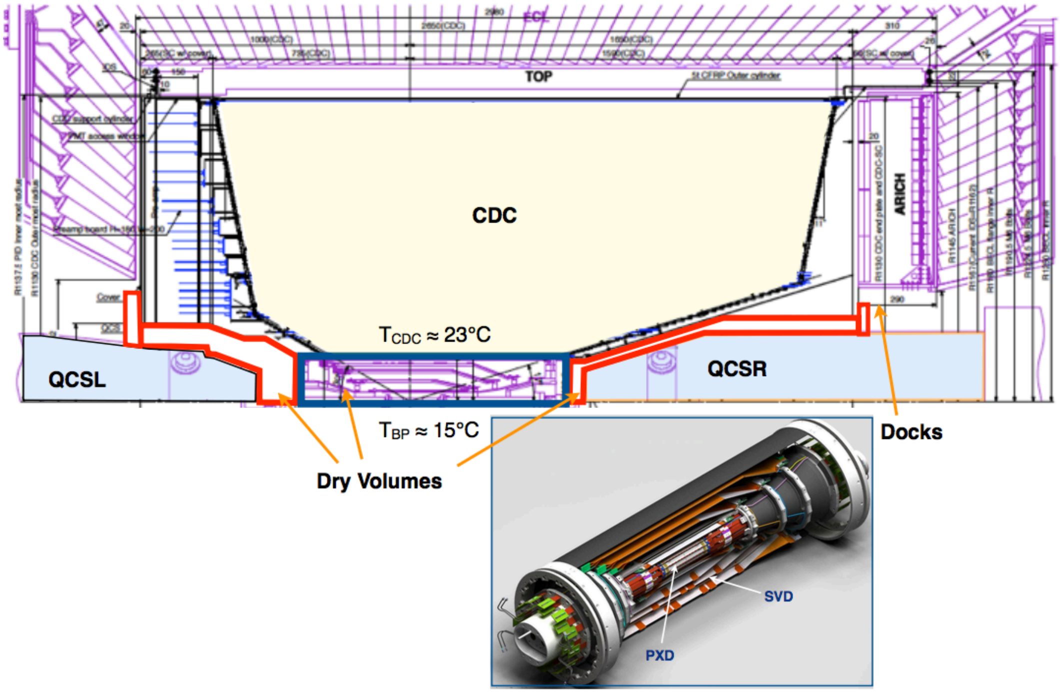


FIG. 14: PXD and SVD dry volumes.

B. Sensors, Mechanics, Piping

The PXD environmental monitoring design already includes some humidity-sensitive FOS Fibre Bragg Grating sensors, that however are not well suited for a fast, hardwired interlock. Most commercially available miniature humidity sensors have a limited sensitivity range and are not sufficiently radiation hard.

The use of sensitive, but bulky dew point sensors, requires sampling the gas circulating in the VXD volume by "sniffing pipes", that should carry the gas outside the detector, into a dew point measurement system, sketched in Figure 15. This approach was adopted by the CMS experiment for their tracker upgrade.

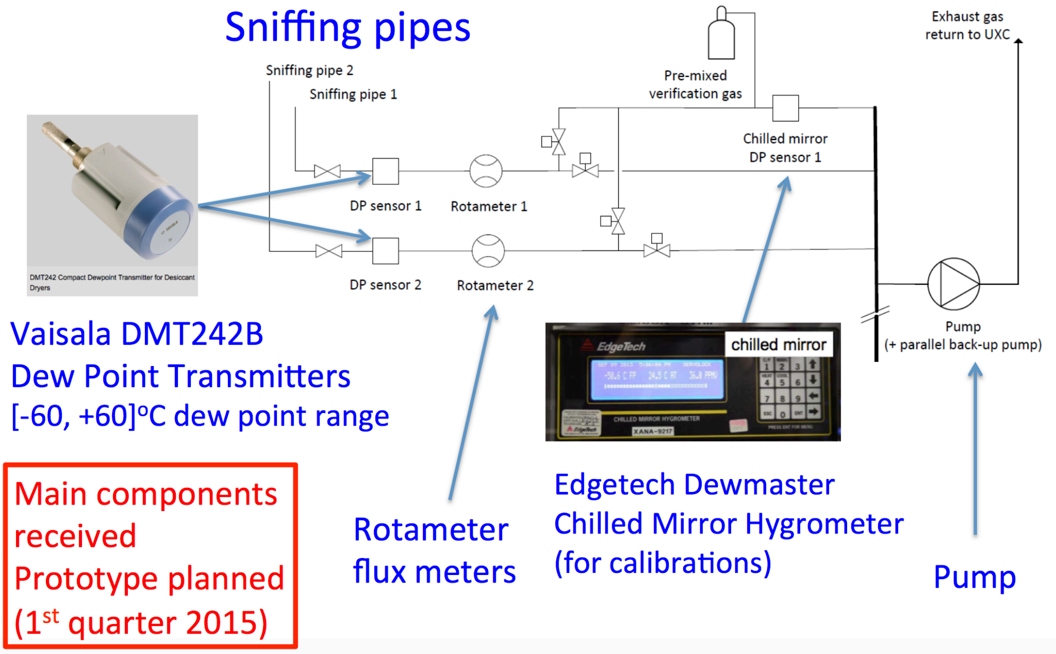


FIG. 15: Dew point measurement with sniffing pipes.

For the *Belle II* VXD, up to 6 pipes will bring the sampled gas to Vaisala Dew Point Transmitters [25]. The pump will be doubled for back-up; its possible failure will be taken into account in the interlock system. A precise and accurate Chilled Mirror Hygrometer [26] will be used to periodically check the response of the Vaisala sensors.

In order to obtain a response time of less than ... s to dangerous humidity changes, the flux of gas sampled by Vaisala should be at least ... l/min [25].

Additional, non radiation-hard miniature humidity sensors might be installed and used to complement the available information during the commissioning phase.

C. Electronics, Interfaces, Slow Control

The system sketched above will be mainly used to interlock the VXD power supplies; the digitisation and readout tasks should therefore be carried out through the interlock system, as described below.

V. INTERLOCKS

A. Interlocking PXD and SVD

A fast but orderly shutdown of PXD and SVD power supplies should occur on a number of critical conditions, triggered by hardwired signals, independent of the Slow Control network and software.

A preliminary, non-exhaustive list of such conditions includes temperature over safety thresholds by NTC thermistors, dew point above threshold from Vaisala sensors, a Beam Abort generated anywhere along the SuperKEKB rings, etc.

The interlock system should be both reliable and flexible, to accommodate different digital and analog input signals, and evolving interlock conditions. An optimal solution, adopted by several experiments, is based on industry-standard Programmable Logic Controllers (PLCs), that are reliable, programmable and easily expandable with both digital and analog input/output modules. For the VXD, the Slow Control software group requires EPICS compatibility, leading to the choice of a Schneider PLC: the present developments are based on a Schneider M340 PLC kit, that will be the basis for the hardware implementation of the VXD Interlock system.

B. SuperKEKB Injection Inhibit

As explained in Section II C and Figure 5, two hardwired signals will be used by *Belle II* to allow or deny permission to inject beams. Both Injection Enable and Normal Injection Enable should be present, to allow SuperKEKB to perform the initial "normal injection" of beams. Permission will be denied (both signals absent) during ramp-up or ramp-down of power supplies by *Belle II*, and possibly in other critical conditions, to be defined. During stable colliding beams, top-up "continuous injection" will be allowed by issuing only the Injection Enable signal.

The PXD and SVD power supplies, and possibly other VXD conditions, will contribute to the generation of both Injection Enable and Normal Injection Enable. Both the exact conditions and their hardware implementation need still to be specified.

VI. SCHEDULE, SIGN-OFF AND VERSION HISTORY

The general schedule constraints are given below; more detailed construction and installation schedules are updated regularly in the Twiki documentation.

- *Radiation Monitoring and Beam Abort*: a prototype system including four sCVD sensors and their readout and beam abort trigger electronics should be installed and ready for tests at the beginning of BEAST, phase 1, and operational throughout BEAST phase 1 and 2; the full system of 20 sensors and their final readout and beam abort electronics should be ready for installation at KEK when the VXD assembly will start.

- *NTC and FOS temperature monitoring*: prototypes should be provided for tests on the DESY mock-up in 2015 and for the environmental monitoring of the SVD ladders in BEAST phase 2. The full system should be ready and available for installation at KEK when the VXD assembly will start.

- *Dew point interlock*: prototypes should be provided for tests on the DESY mock-up in 2015 and for the environmental monitoring of the SVD ladders in BEAST phase 2. The full system should be ready and available at KEK when the cooling of the VXD will start.

TABLE IV: Sign-off: list and status.

Name	Function	Sign-off date
Christoph SCHWANDA	SVD Leader	TBD
Takeo HIGUCHI	SVD Deputy	TBD
Francesco FORTI	SVD QCG	TBD
Florian BUCHSTEINER	SVD Mechanics	TBD
Szymon BACHER	SVD Slow Controls	TBD
Christian KIESLING	PXD Leader	TBD
Carsten NIEBUHR	VXD Thermal Mock-Up Coordinator	TBD
Carlos MARINAS	PXD Monitoring	TBD
Hiroyuki NAKAYAMA	Belle II Monitoring and Interlocks Coordinator	TBD
Suji TANAKA	Belle II Mechanics Integration Coordinator	TBD
Masako IWASAKI	SuperKEKB - B2 Interface Coordinator	TBD
Ryosuke ITOH	Electronics Hut Coordinator	TBD

TABLE V: List of note versions and contents updates.

Version number	Contents update	Date
1.0	Initial version	May 4, 2015
2.0	NTC numbering convention (cooling pipes)	May 7, 2015

The monitoring and interlock requirements listed in this note were cross-checked and approved by the coordinators and experts listed in Table IV. A list of Note versions and modifications is given in Table V. The present version of the Note is 2.0.

[1] Belle II Technical Design Report, KEK Report 2010-1, October 2010.

[2] Belle II background simulations: recent reports at the 16th B2GM, Beam Backgrounds session, KEK, 15 November 2013:
http://kds.kek.jp/sessionDisplay.py?sessionId=39&confId=13911#20131115

[3] SuperB Technical Design Report, INFN-13-01-PI, LAL 13-01, SLAC-R-1003.

[4] Carlos Marinas, private communication.

[5] Cabling and grounding standards.

[6] M.Iwasaki, Network/Hard-wired signals between Belle II and SuperKEKB, Belle II Slow Controls Meeting, 17/06/2014.

[7] M.Bruinsma et al., SVT Radiation Protection: Upgrade Requirements and Scenarios, BaBar Analysis Document n.339, Version 09, September 15, 2003.

[8] A.J.Edwards et al., Radiation monitoring with CVD diamonds in BaBar, Nucl. Instr. Meth. A 552 (2005) 176-182.

[9] P.Dong et al., The CDF diamond group, Hardware Description of the Beam Condition Monitor Based on Diamond Sensors, CDF Note 8872, June 20, 2007.

[10] L.Hernadez-Fernando et al., Development of a CVD diamond Beam Condition Monitor for CMS at the LHC, Nucl. Istr. Meth. A 552 (2005) 183-188.

[11] A.Gorisek, Commissioning and first operational experience of the ATLAS beam conditions and loss monitors based on pCVD diamond sensors, Nucl.Instr. Meth. A617 (2010) 444-448.

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[14] Prog. Theor. Exp. Phys. 2013 , 03A007

[15] http://ilo.elettra.trieste.it/index.php?page=default&id=35&lang=en

[16] CAEN family of digitizers: http://www.caen.it/csite/Function.jsp?parent=11&idfun=1

[17] A.Moll et al., The vertex detector numbering scheme, Belle II Note 10.

[18] D.Moya et al. (IFCA, CSIC-UC and INTA): Update on FOS monitor, presentation at the PXD-SVD Workshop, DESY, October 21, 2013.

[19] V.Esperante, D.Platero (IFIC Valencia): Environmental Monitoring, presentation at the PXD-SVD Workshop, DESY, October 21, 2013.

[20] D.Kirkby, P.Burchat, Temperature Monitoring and Interlocks for the BaBar SVT Front-End Electronics, BaBar Note 323.

[21] http://www.micronoptics.com/

[22] K.Lantzsch et al., The ATLAS Detector Control System, CHEP 2012, Journal of Physics: Conference Series 396 (2012) 012028. http://www2.uni-wuppertal.de/FB8/groups/Teilchenphysik/atlas/dcs/ http://marpix1.in2p3.fr/Pixel/DCS/

[23] B.Hallgren et al., The Embedded Local Monitor Board (ELMB) in the LHC Front-end I/O Control System (CERN Note); technical documentation available at: http://elmb.web.cern.ch/ELMB/elmb128.html

[24] P. Adzic et al., The Detector Control System for the Electromagnetic Calorimeter of the CMS Experiment at the LHC, Proceedings of the International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS) 2005, Geneva, Switzerland.

[25] Vaisala Dew Point Transmitter DMT242B data sheet.

[26] Edgetech Dewmaster Chilled Mirror Hygrometer data sheet.