SuperKEKB Touschek, Beam-gas, and Radiative Bhabha Particle Fluxes at the Belle Calorimeter

Candidacy Report

Samuel de Jong
Department of Physics and Astronomy
University of Victoria

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Abstract

Simulations of radiative Bhabha, Touschek, and beam gas particle fluxes in the electromagnetic calorimeter of Belle II have been produced. In order to verify the accuracy of the thermal neutron flux predicted by these simulations, a He-3 thermal neutron detector will be installed in Belle II's commissioning detector, BEAST II. Shielding studies have also been carried out to mitigate the undesirable effect these fluxes will have on the performance of the calorimeter.

1 Introduction

The SuperKEKB accelerator will have a much higher luminosity than its predecessor. The detector, Belle II, will therefore be subject to much higher radiative Bhabha, beam gas, and Touschek particle fluxes than Belle, its predecessor. These particle fluxes can cause problems with the measurement of the actual physics Belle II is attempting to measure, so it is necessary to understand and attempt to reduce the effect these sources have on the detector. To understand the sources, simulations of radiative Bhabha, beam gas, and Touschek have been produced. To verfiy these simulations, a comissioning detector, known as BEAST II will be installed in the location where Belle II will be, prior to the physics run. Various detectors will be installed, including a set of He-3 thermal neutron detectors. To reduce the effect of these sources, shielding will be installed to block the particles before they can reach the detector.

In this report, I will describe SuperKEKB, the Belle II experiment, and BEAST II. I will also discuss the He-3 detectors, and the work that has been done on them. Next, I will mention the simulation studies that have been done to estimate the level of particle flux. Finally, I will mention what future work has yet to be done.

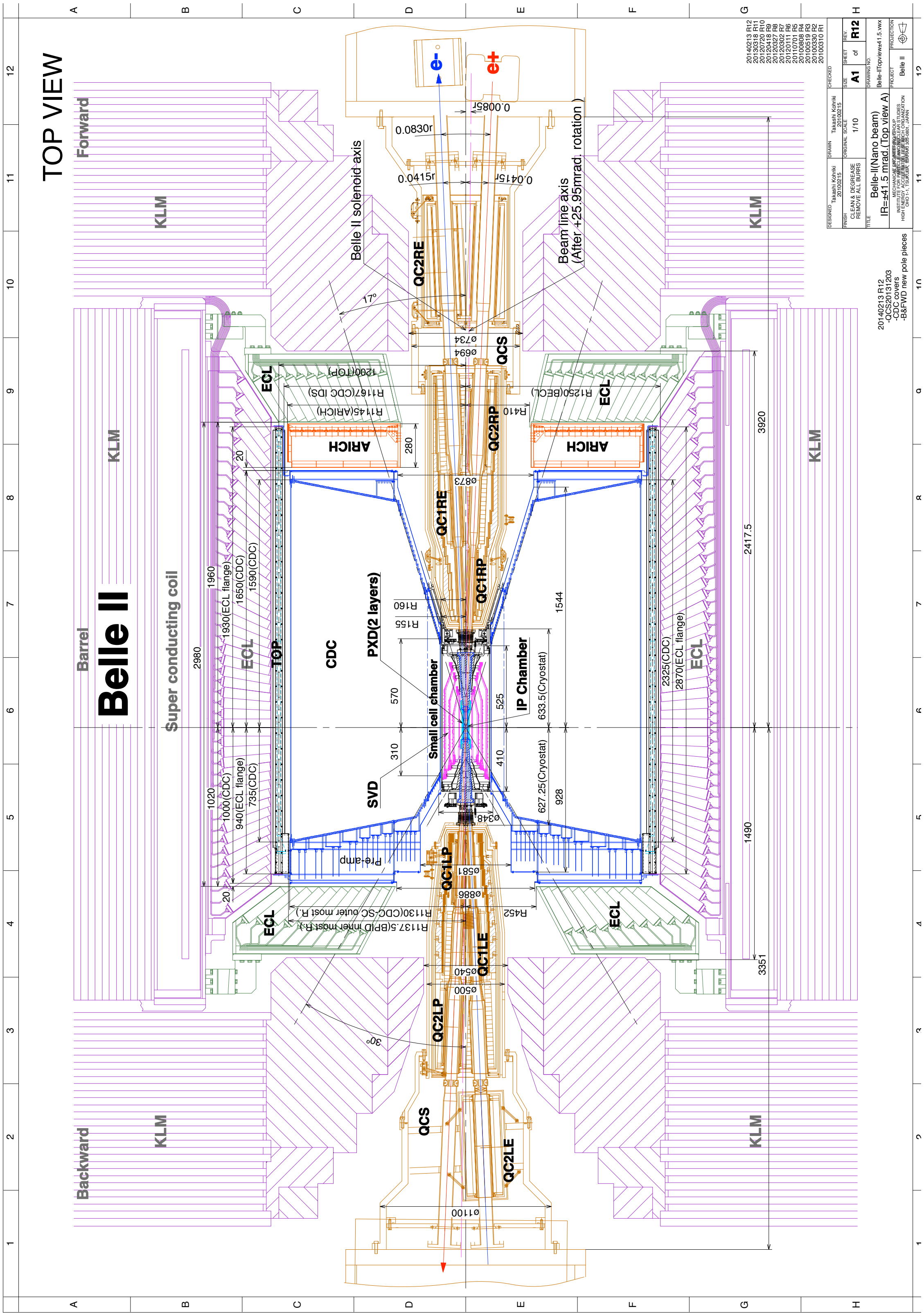


Figure 1: The Belle II detector

1.1 SuperKEKB and Belle II

SuperKEKB will be a Super B factory e^+e^- accelerator at the KEK lab in Tsukuba, Japan. Its electron ring (also called the high energy ring, or HER) will have a momentum of 7 GeV/c, and its positron ring (low energy ring, or LER) will have a momentum of 4 GeV/c. It will have a luminosity of $8 \times 10^{35} cm^{-2}s^{-1}$. Wrapped around the interaction point will be the Belle II detector.

The Belle II detector (see Fig 1) will be composed of several subdetectors. Starting from the interaction region, the first subdetectors are the pixel detector (PXD) and the silicon vertex detector (SVD), the purpose of which is to the decay vertex of various decay channels. The PXD and SVD will be surrounded by the central drift chamber (CDC), which provides tracking information as well as particle identity information using measurements of energy loss within the gas volume. The entire detector will be immersed in a 1.5T magnetic field, which allows momentum measurement via the radius of curvature of particle tracks. Next is the particle identification system, consisting of the time of propagation (TOP) counter and, in the forward end-cap, the aerogel ring-imaging Cerenkov detector (ARICH), both of which use Cerenkov light to identify particles. The penultimate subdetector is the electromagnetic calorimeter (ECL), used to measure the energy of photons and electrons. More info about the ECL can be found in 1.1.1. Finally, the K_L and muon detector, consisting of alternate layers of iron and active detector elements, will measure K_L and muons. [1].

1.1.1 Electromagnetic Calorimeter

The Electromagnetic Calorimeter (ECL) is composed of 8,736 crystals of thallium doped caesium iodide (CsI(Tl)). It is divided into three parts: the forward end-cap containing 1,152 crystals, the barrel containing 6,624 crystals, and the backward end-cap containing 960 crystals. The entire calorimeter is the same as was used in the Belle experiment, the predecessor to Belle II.

Attached to the end of each crystal is a diode, which measures the energy deposited in that crystal.

The goal of the calorimeter is to measure the energy of electrons and photons.

The ECL is sensitive to so called backgrounds produced by Touschek, radiative Bhabha, and beam gas interactions (see section 3). These backgrounds produce gamma photons and neutrons. Gamma photons can damage the electronics, as well as produce signals in the crystal volume, which distorts the signal produced by the physics events that we are interested in studying. Neutrons can also damage the electronics. To mitigate these background gammas and neutrons, a shield will be installed to stop the particles before they reach the ECL.

ThetaID A brief explanation of the parameter thetaID is necessary, since many of the plots presented here use it as an axis, instead of θ. ThetaID is a value assigned to each ring of crystals, starting from 0 for the first ring of crystals in the forward end-cap of the ECL, and ending at 68 for the last ring of crystals in the backward end-cap. A visual explanation of this can be found in Fig 2. ThetaID values from 0-12 are in the forward end-cap, from 13-58 are in the barrel, and 59-68 are in the backward end-cap.

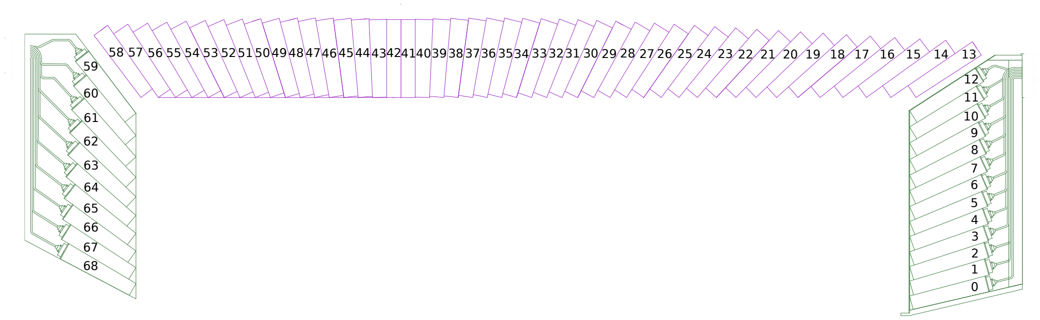


Figure 2: ThetaID values for ECL

1.1.2 Physics Motivation

Super B factories are a type of collider experiment that used electron-positron colliders with high luminosity to make precision measurement of particle interactions involving mesons containing b quarks. The center of mass energy of Belle II is just enough to produce B-anti-B meson pairs (B mesons contain a b and d quark), but the majority of collisions produce other particles. Measurement of CP-violation, in which matter and antimatter behave differently, will be made in Belle II. Due to the precision of the measurements that will be made at Belle II, small deviations from the Standard Model of paricle physics can be detected, which may be a sign of new physics. Rare and forbidden decays can also be measured, which is another sign of new physics. [6]

1.2 BEAST II

The commissioning detector for Belle II is known as the BEAST II (Beam Exorcism for A STable experiment). Data will be recorded during three distinct phases, each having a more complex set of subdetectors than the previous, culminating in the complete Belle II detector. Phase 1 will consist of a set of eight PIN diodes for measurement of ionizing radiation, eight BGO crystals for measurement of radiative BhaBha events, two microTPCs (time projection chambers) for measurement of fast neutrons, and two to four He-3 tubes, for measurement of slow neutrons. The He-3 tubes will be mounted next to the microTPCs. Fig 3 shows 8 possible locations for the TPCs and He-3 tubes. The actual locations have not been finalized yet.

In Phase 2, most of the Belle II detector will be in place, except for vertex detector (the PXD and SVD). During this phase, the He-3 tubes will be moved to the forward dock space, as seen in Fig 4.

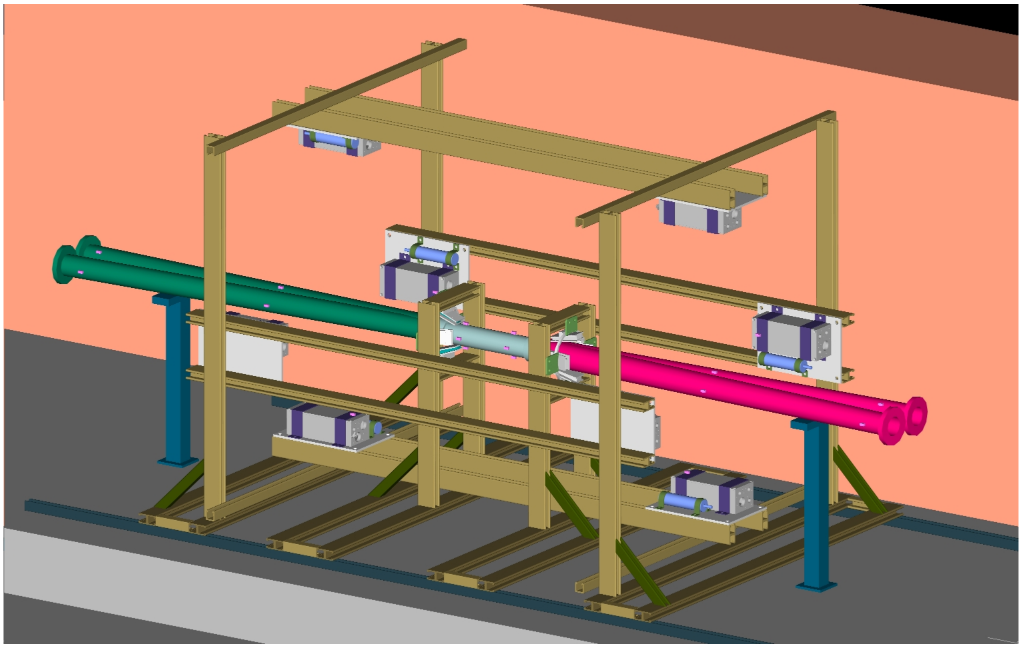


Figure 3: Phase 1 of BEAST

In Phase 3, the vertex detector will be installed, and full running of Belle II will begin. There is a plan to have one or more He-3 tubes left in place during full Belle II running.

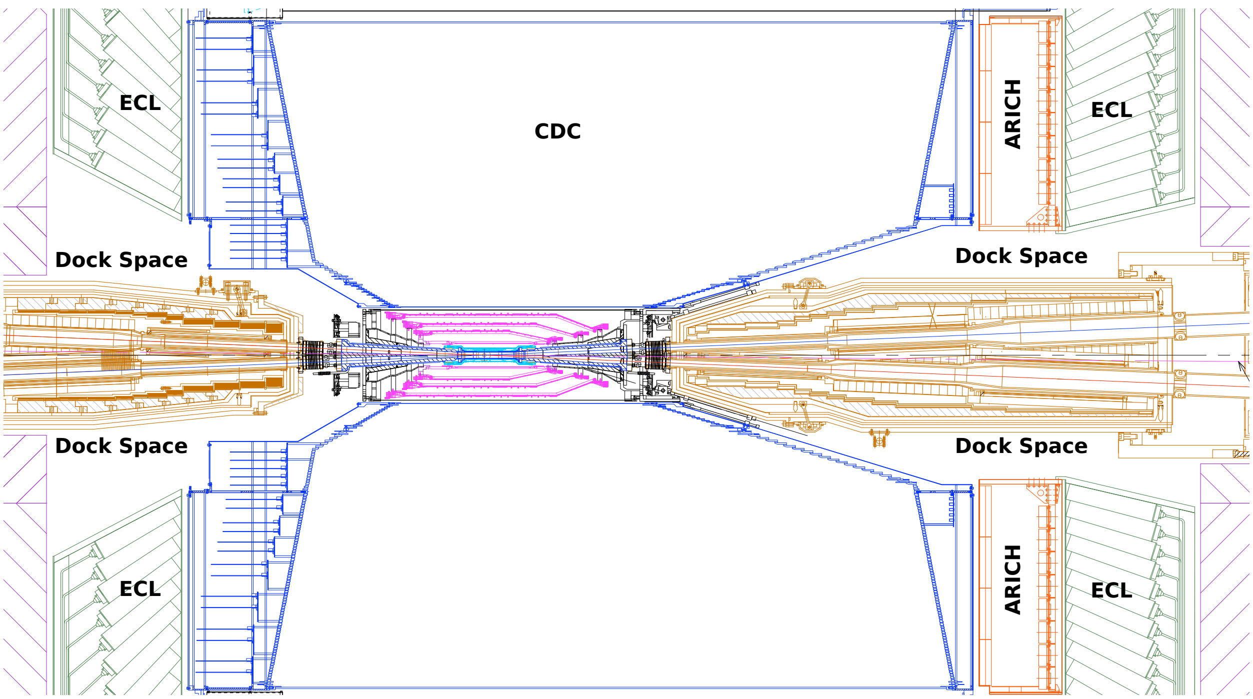


Figure 4: Locations of dock space

2 He-3 thermal neutron detectors

In order to verify that simulation studies of thermal neutron backgrounds are correct, it was decided that thermal neutron detectors would be installed into BEAST II. The maximum rate of neutrons on Belle II (based on simulation studies, see section 3) is expected to be $9kns{-}1cm^{-2}$, which corresponds to a rate of $\sim 700kHz$.

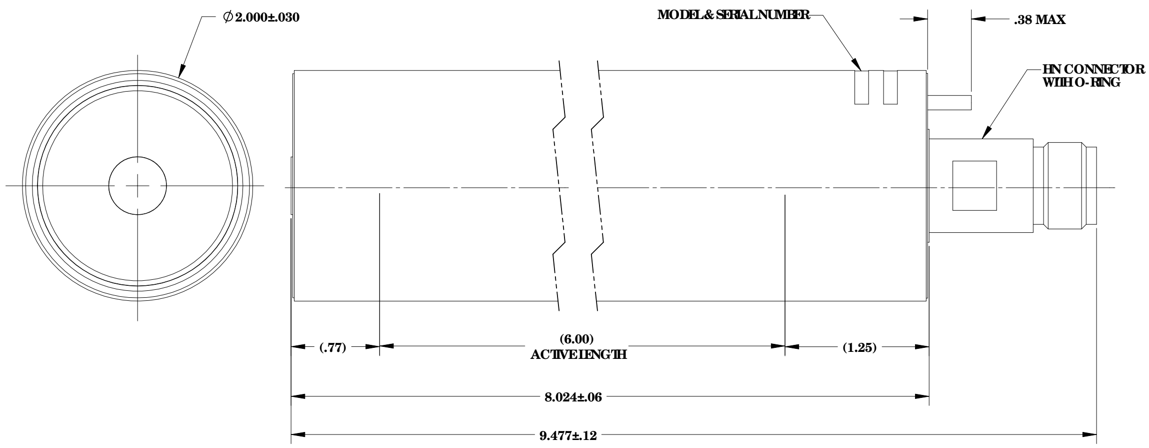


Figure 5: Schematic of He-3 tube

A pair of He-3 thermal neutron detectors were purchased from GE-Reuter Stokes. These detectors are stainless steel tubes 9.47" long and 2" in diameter filled with He-3 (see Fig 5). When a thermal neutron passes through the active area of the detector, it may be captured by a He-3 atom [5]:

$$ {}^3_2He +^1_0 n \rightarrow^3_1 H +^1_1 H + 760MeV \tag{1}$$

The cross section for this reaction decreases as the energy of the neutron increases as seen in Fig 6.

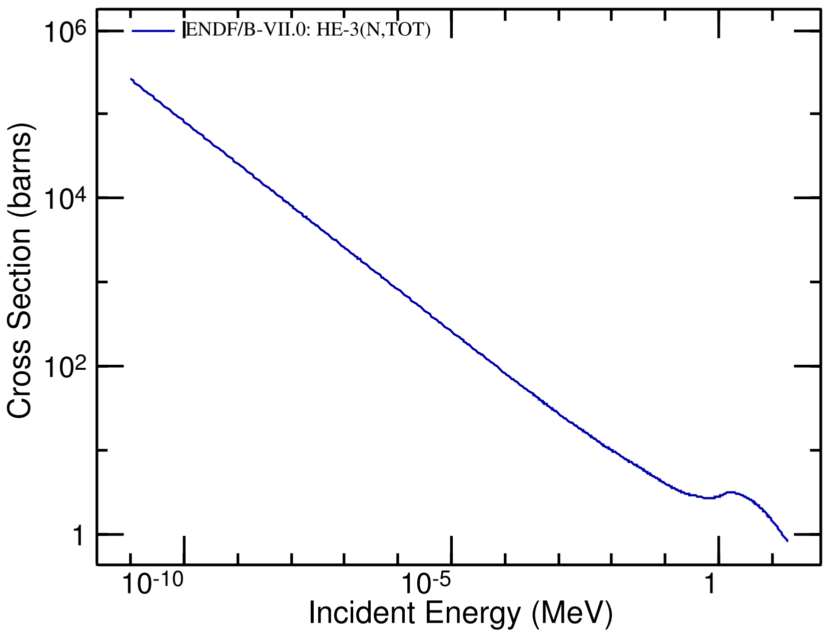


Figure 6: Neutron capture by He-3 as a function of neutron energy [4]

2.1 Magnetic field testing

In Phase II of BEAST II, most of the components of Belle II will be in place, and the magnetic field will be turned on. It was thus necessary to determine whether or not the He-3 tubes would be affected by the magnetic field, or if they would distort the field in an undesirable way. To test this, a single horseshoe magnet was placed with its poles pointing upward. A gaussmeter probe, supported by a lab stand, was placed between the poles. A He-3 tube, also supported by a lab stand, was placed in various locations near the probe, as seen in Fig 7.

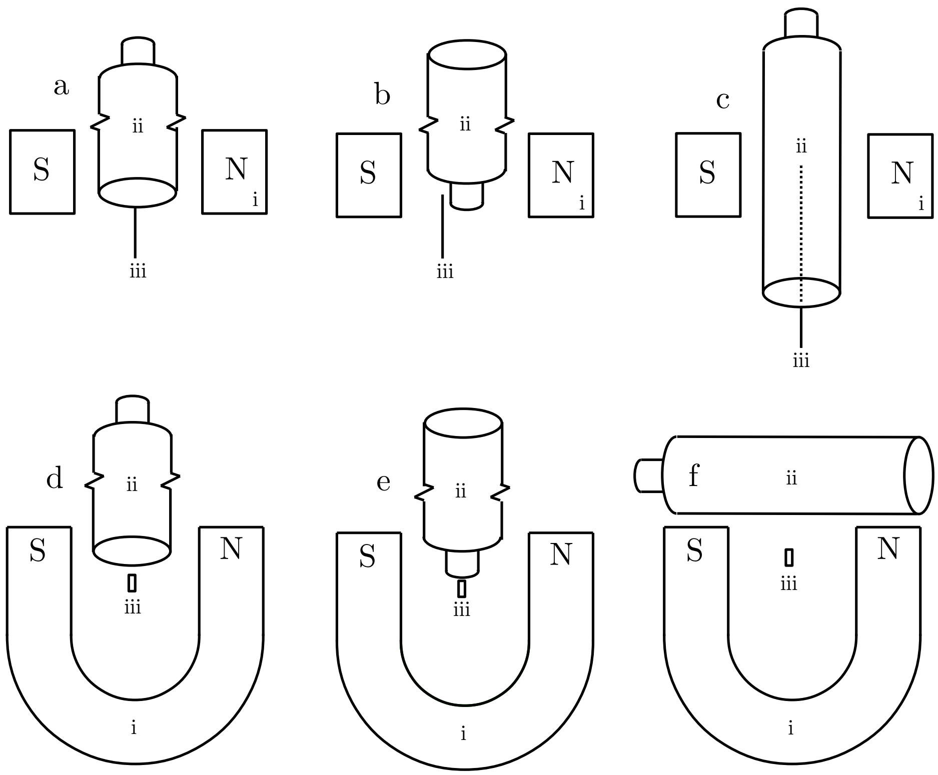


Figure 7: Schematic of neutron detector and gaussmeter probe placement (not to scale).

Results of the experiment can be found in Table 1. From the results of this test, we can conclude that the detector is non-magnetic.

Position	Field without He-3 tube present (kG)	Field with He-3 tube present (kG)
a	1.322	1.321
b	1.321	1.319
c	1.322	1.322
d	1.323	1.321
e	1.323	1.314
f	1.489	1.489

Table 1: Results of magnetic field test

2.2 Neutron Source

The University of Victoria has an 241-AmBe neutron source, which produces neutrons using the following reaction:

$$ {}^{241}_{95}Am \rightarrow^{237}_{93} Np +^{4}_{2} He + \gamma \tag{2a} $$

$$ {}^{9}_{4}Be +^{4}_{2} He \rightarrow^{12}_{6} C +^{1}_{0} n + \gamma \tag{2b} $$

With an activity of 2200n/mCi. The source is surrounded by a cube of graphite 1.83m to a side, which thermalizes the neutrons. This source provides a convenient location to test the neutron detectors.

The detectors will be plateaued using this source in order to find the working voltage. One of the devices has already been plateaued.

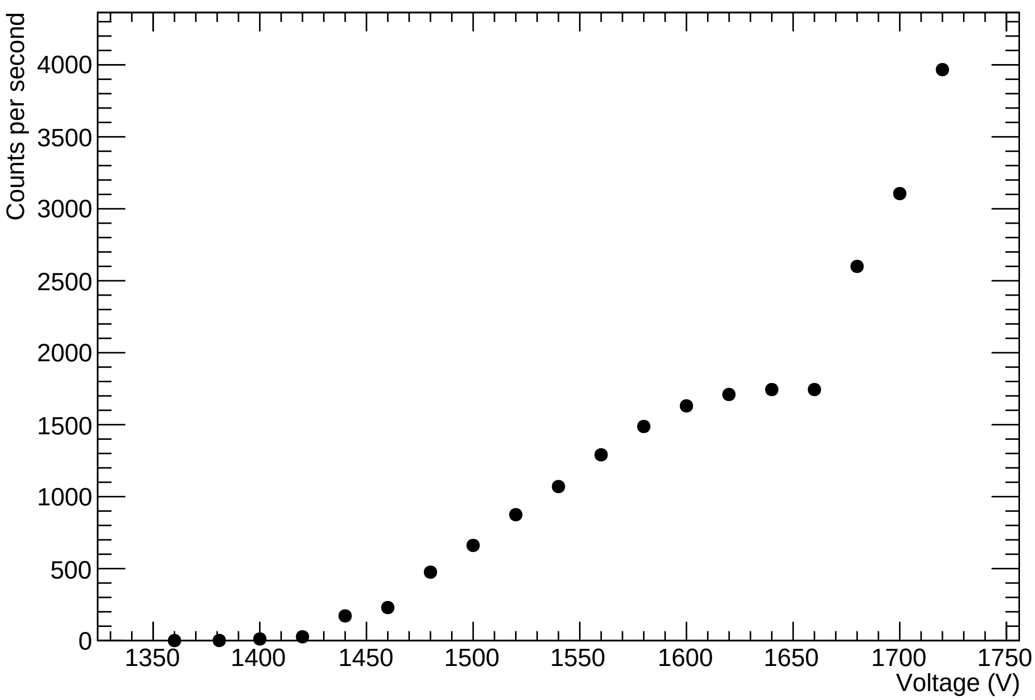


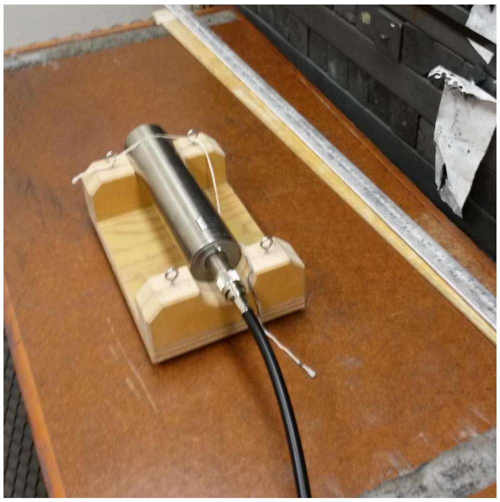
Figure 8: Plateau curve for He-3 tube

Another part of the testing was seeing what the effect of placing various materials between the detector and the neutron source. The materials used were borax, paraffin wax, and polyethylene. For these tests, the detector remained in one place, and the shielding materials were stacked around them. Photographs of the arrangement can be found in Fig 9. Table 2 summarized the change in rate measured by the detector for each material. Note that the coverage by each material is not equal.

Material	Density (g/cm^3)	Thickness (cm)	Count rate (Hz)
Nothing	-	-	6895.2
Borax	1.73	5.0	2254.5
Paraffin Wax	0.90	11.8	1768.9
Polyethylene	0.94	7.5	592.1
All	1.39*	24.3	194.0

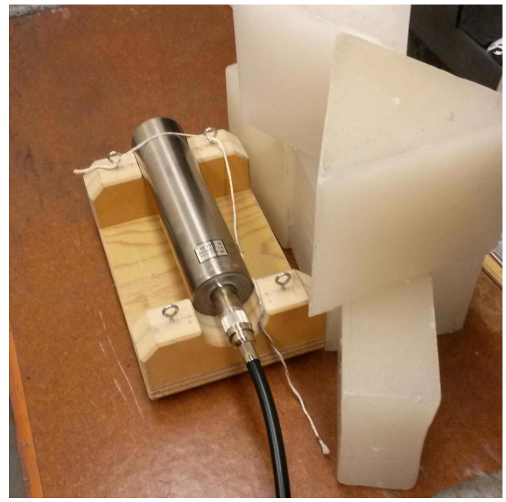
* Mean, Weighted by thickness

Table 2: Count rate for various shielding materials

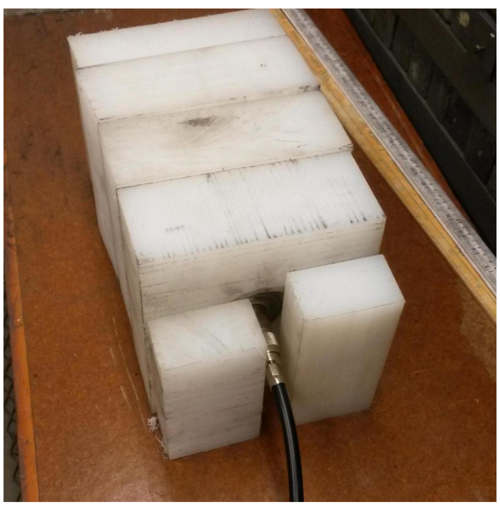


(a) Nothing

(b) Borax



(c) Paraffin Wax



(d) Polyethylene

(e) All

Figure 9: Arrangement of various shielding materials

The count rate as a function of distance from the neutron source was also measured. Rate measurements were taken at 5cm increments in the distance from the source, up to 1.5m. Rate vs. distance was plotted (see Fig 10) and fitted to a $1/r^2$ function:

$$C = \frac{A_0}{(r - r_0)^2} + C_0 \tag{3}$$

Where r_0 and C_0 are offsets due to the measurements not starting at the source and the background rate being non zero. The rate follows the expected $1/r^2$ behaviour.

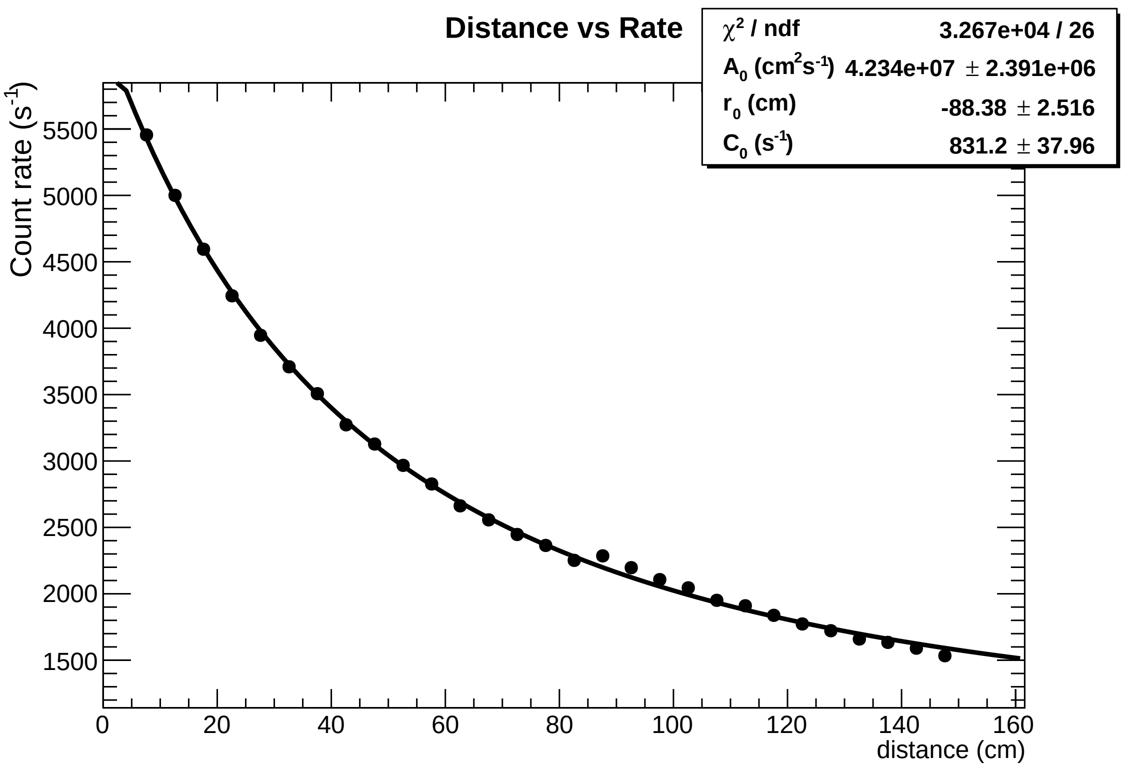


Figure 10: Neutron rate vs distance from source

2.3 Preamplifiers

A prototype preamp was designed and built by the electronic shop in the Physics and Astronomy department at UVic.

The final preamp design is currently being built. It will attach to the end of the He-3 tube directly, as seen in Fig 11. Thus, three cables will have to be routed to the tube: high voltage for the sense wire, low voltage to power the preamp, and the signal cable.

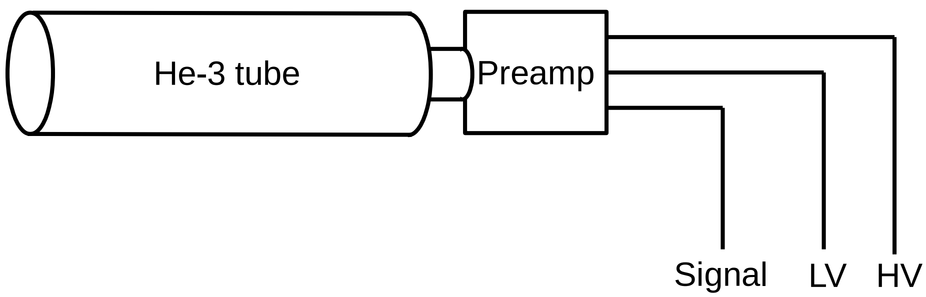


Figure 11: Preamp placement

2.4 Data Acquisition

The data acquisition is done using a CAEN VME digitzer and a CAEN VME-USB bridge. The signal pulses from the He-3 tubes are sent to the digitizer via the preamp. The digitizer calculated the pulse height of the signal, which is then sent to the a computer, along with a time stamp, via the VME-USB bridge.

On the software side, a DAQ program has been written that unifies the CAEN libraries with the Experimental Physics and Industrial Control System (EPICS), which is the interface that will be used to control BEAST II. The program will be used to initialize the digitizer, start and stop the acquisition of data, and send monitoring plots to the BEAST II control room. At this point, the software is at a preliminary stage, and work is still being done on it. A schematic of the data flow from the He-3 tube to the computer can be found in Fig 12.

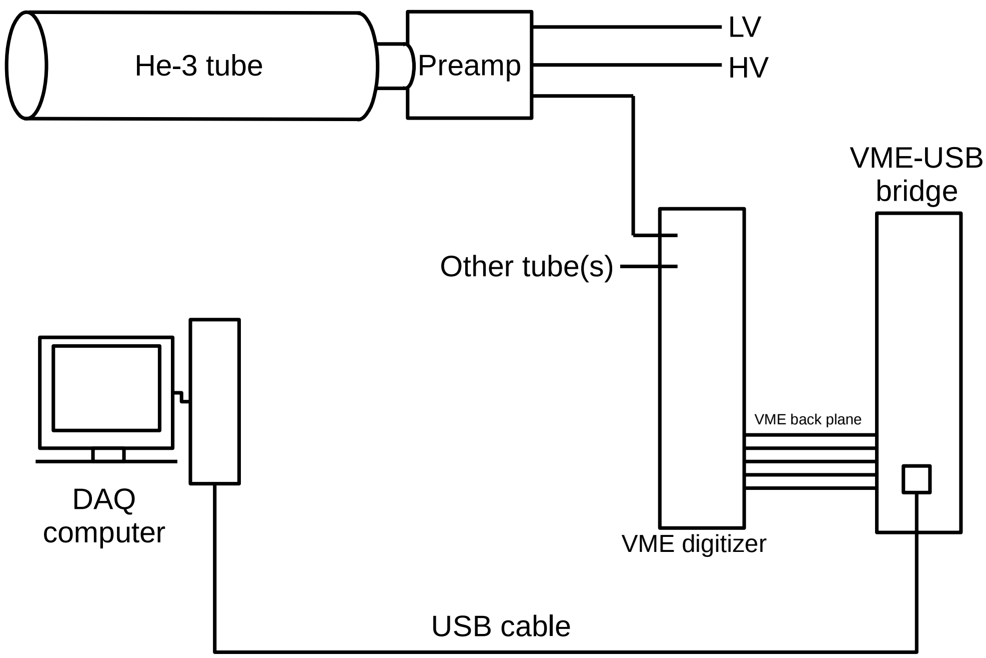


Figure 12: Data pipeline

2.5 Schedule

BEAST is scheduled to go online in the fall of 2015 (see Table 3). Construction will therefore occur in the spring.

<table>
<tr><td></td><td colspan="5">2014</td><td colspan="12">2015</td><td colspan="12">2016</td><td colspan="12">2017</td></tr>
<tr><td></td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td></tr>
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shutdown</td><td colspan="5">Phase I
NO QCS
No Solenoid</td><td colspan="9"></td><td colspan="4">Phase II
QCS
Solenoid
No VXD</td><td colspan="3"></td><td colspan="3">Summer
shutdown</td><td colspan="3">Phase III</td></tr>
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Belle II</td><td colspan="8"></td><td colspan="3"></td><td colspan="3"></td><td colspan="5"></td><td colspan="9">QCS Installation
Belle II roll-in (No VXD)</td><td colspan="4"></td><td colspan="3">VXD</td><td colspan="3"></td><td colspan="3"></td></tr>
</table>

Table 3: BEAST Schedule

3 Simulation Studies

There are 3 sources these fluxes: radiative Bhabha, Touschek, and beam gas:

Radiative Bhabha Radiative Bhabha (RBB) occurs when an electron and positron scatter off each other, with one or both particles emitting a photon. This photon can cause showers of electrons and photons in the detector. Additionally, the electron (or positron) can be steered into the detector, producing more showers. These showers lead to degredation in the performance of the detector.

Touschek Beam losses from the Touschek effect are driven by large angle Coulomb collisions within a bunch of electrons (or positrons), which lead to longitudinal momentum transfers. If these losses happen near the detector, the lost particles can be steered into the support structure or detector itself, producing showers which degrade performance. [3]

Beam Gas Interactions with the gas in the beam are another source of particle flux. These are called beam-gas interactions, and they occur when an electron (or positron) interacts with gas molecules remaining in the beampipe. There are several processes that can occur: elastic collisions, where the electrons are deflected by gas nuclei, or inelastic collisions, where energy is transferred to a residual gas molecule. As before, the stray electrons can produce showers in the detector. [2]

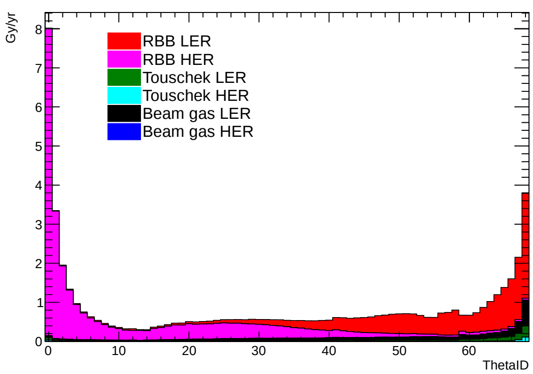
Simulations of each background source have been produced and are updated on a regular basis. Each subdetector group uses the same simulations to determine the effects on their subdetector. The results for the ECL from the most up to date simulation, the 9th background campaign, are presented in Fig 13. What follows is an explanation of what each parameter means.

Crystal Radiation Dose In Fig 13(a), the radiation dose in the ECL crystals is shown as a function of thetaID (for an explanation of thetaID, see Fig 2), in Gy/yr.

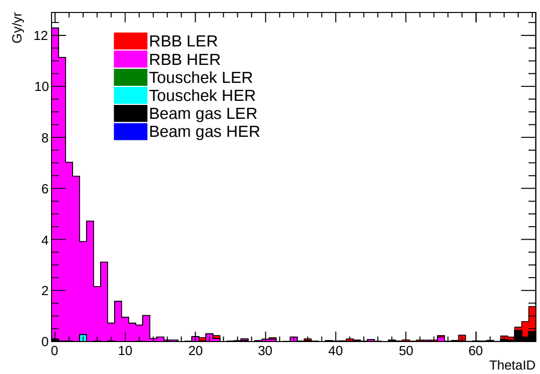
Diode Radiation Dose Similar to crystal radiation dose, the diode dose is seen in Fig 13(b).

Neutron Flux The flux of neutrons through the sensor diodes can be seen in Fig 13(c).

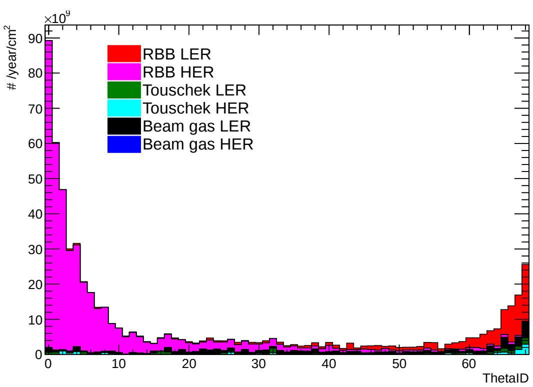
Pileup noise Pile up noise (see Fig 13(d)) is the energy that is measured in a crystal as a result of the RBB, Touschek, and beam gas particles, rather than from a signal.



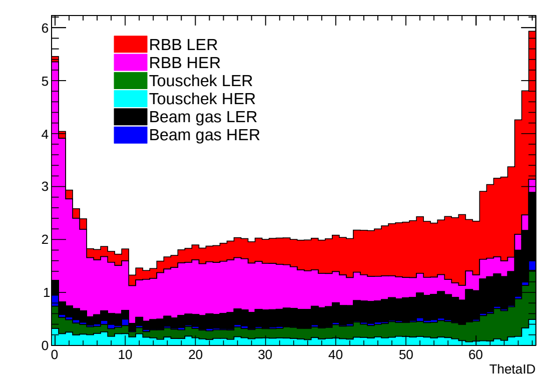
(a) Crystal Radiation Dose



(b) Diode Radiation Dose



(c) Neutron Flux in Diodes



(d) Pile Up Noise

Figure 13: Parameters with no shield

3.1 Shielding

In order to mitigate the effects of background, a shield will be installed below the ECL end-caps. The location of this shield can be seen in Fig 14.

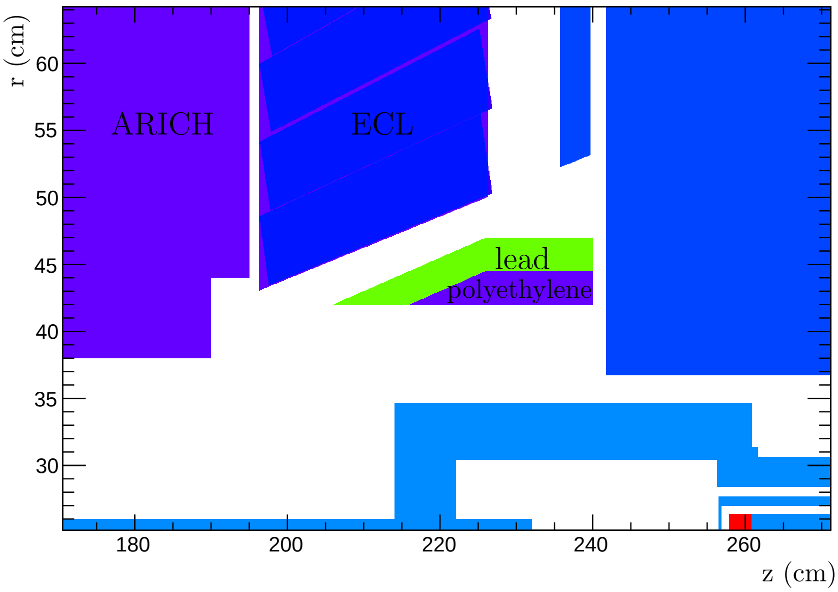


Figure 14: Position of forward shield

Fig 15 shows the values of the previously defined parameters if the shield is present, showing the reduction in radiation dose, neutron flux, and pile up noise.

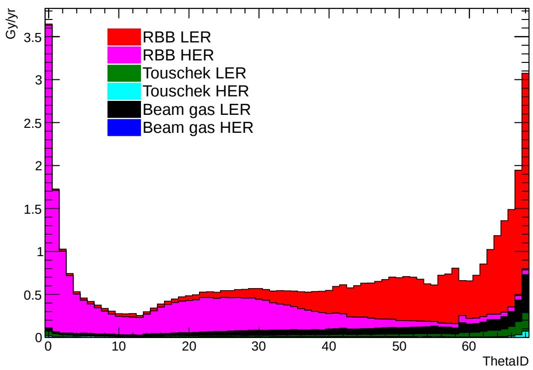
Work is currently being done to optimize the configuration of this shield.

4 Future Work

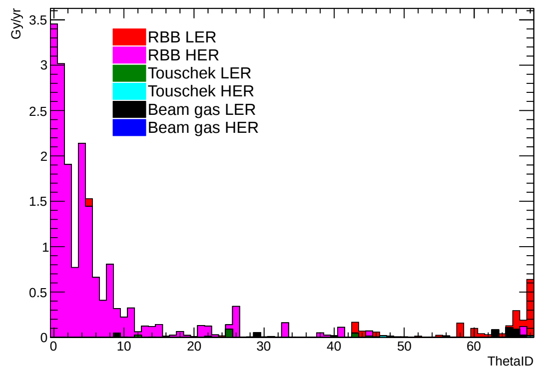
There is still work that needs to be done in both the He-3 tubes and the simulation studies.

4.1 He-3 tubes

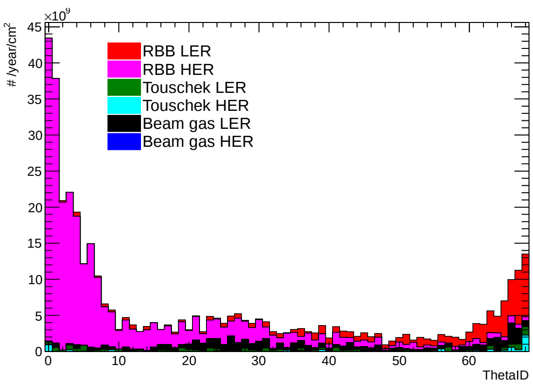
Before the He-3 tubes can be deployed in BEAST II, the preamps must be completed, and the DAQ software completed. To reach from BEAST II to the DAQ room, 37ft of cable is required. In our case, three cables will be required for each device: Signal, high voltage for the sense wire, and low voltage to power the preamp. Research must be done to determine which cables to purchase. Supplies to provide the high and low voltage must be purchased as well.



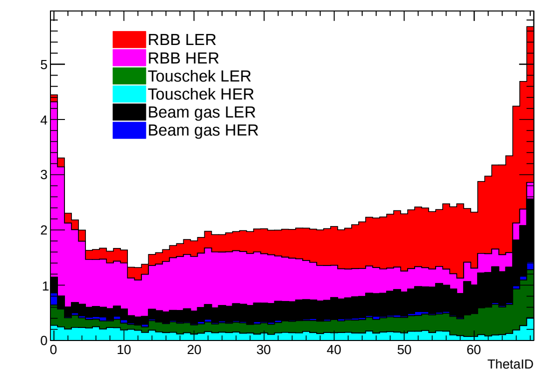
(a) Crystal Radiation Dose



(b) Diode Radiation Dose



(c) Neutron Flux in Diodes



(d) Pile Up Noise

Figure 15: Parameters with shield

The University of Victoria owns a calibrated neutron detector, which will be used to calibrate the He-3 tubes, using the Am-Be source previously mentioned.

4.2 Simulation Studies

It is important to simulate each Phase of BEAST II, so that we have an expected neutron flux to compare to what is measured when it goes online. This work has been begun for other BEAST subdetectors, but has not yet been done for the He-3 tubes.

Optimization of the shielding material for Belle II is currently ongoing. There are several configurations that are been tested, consisting of various combinations of lead and polyethylene.

5 Conclusion

SuperKEKB, Belle II and its commissioning detector, BEAST II, have been described, as well as the He-3 thermal neutron detector that will be installed, and the work that has been done to date to prepare the detectors for installation, and the work that as yet need to be done. Simulations of RBB, Touschek, and beam gas particle fluxes in the ECL have been done, and shielding configurations to mitigate these fluxes have been investigated.

All of this work is towards the goal of investigating, through comparison with data collected in Phase I of BEAST II, the accuracy of the simulation of RBB, Touschek, and beam gas particle fluxes in the Belle II detector.

References

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