Contents

1. Belle II and SuperKEKB (SKB) accelerator

This first chapter aims to present a brief introduction of the Belle II physics program, focusing on those measurements wich could particularly benefit from the upgrade the whole detector and in particular of the VerteX Detector (VXD), discussed in this work. A short description of the SuperKEKB accelerator's operation, the Belle II detector's structure and to conclude some highlights on te actual state of measurements are also presented.

1.1 Physics program of the B-factories

Belle II is a B-factory dedicated to improve precision measurements of the Standard Model's parameters (SM) and to looking for the physics Beyond the Standard Model (BSM). In particular the experiment investigates the Charge-Parity Violation (CPV) in the B mesons system and it also searches for New Physics (NP) evidences in the decays of B and D mesons, in τ leptons and in the dark matter sector (DM), above all, hunting for dark photons.

1.1.1 Opened questions in SM

The SM is a physics theory that describe three of the fundamental forces [interactions] involving elementary particles, which are strong, weak and electromagnetic interaction (with the exclusion of the gravitational one). It classifies all known particles up to now in 4 main groups: quark, leptons, bosons and Higgs (figure 1.1 on the following page).

Despite its undeniable success achieved over the years in predicting with high precision new particles and mechanisms unknown until that moment, there are many aspects of the Nature on which it is unable to give answers. Some of them are listed in the following.

- Three generations of quark and leptons are known, but it is not obvious wheter they should be the only ones and the reasons behind their mass hierarchy.

- Higgs mechanism is able to explain the cause of elementary particles' masses through spontaneous electro-weak symmetry breaking, but it doesn't justify those of neutrinos.

Figure 1.1: Particle classification in the Standard Model.

- The SM also predicts other Higgs-like bosons, potentially vector bosons, whose existance would be justified in some SUper-SYmmetry (SUSY) theories or in others of New Physics.
- Another opened question is the matter-antimatter asymmetry in the Universe. Even though CP violation is necessary to explain the current state of the universe, the observed quantity is several orders of magnitude less than needed to explain the matter domination over antimatter, which allowed the evolution of the universe as we know it today.
- The elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, which complex phase is at the foundation of CP Violation (CPV) in the quark flavor sector, are diagonal and it might suggest the existance of a new symmetry, that is unbroken at high energy (greater than the order of TeV).

All these topics encourage the research of new particles and processes that could give reasonable answers.
At the energy frontier, experiments like the Large Hadron Collider (LHC) in Geneve are looking for new particles created from the proton-proton collision with a center mass energy up to 14 TeV.
At luminosity frontier instead, the trace of new particles and mechanisms is searched in precision measurements of suppressed reactions in flavour physics or in the deviations from SM. The discrepancies indeed, could be interpreted as a clue of new physics beyond SM. The last is the Belle II approach.

1.1.2 Belle II Physics channels

The field of reaserch at SuperKEKB is very extended and in the following we will go through the main physics goals of the experiment, underlining how the measurements could be enhanced by the upgrade of the vertex detector.

FLAVOR PHYSICS

CP-violating phases in quark sector:

- as we mentioned above, the amount of CP violation in the SM is not enough to explain the difference observed between baryon-antibaryon matter. New clues of CPV could be found studying the discrepancy between B^0 and $\bar{B}_0$ decay rates, so measuring the time-dependent CP violation in penguin transition of b $\rightarrow$ s and b $\rightarrow$ d quarks (such as B $\rightarrow \phi K^0$ and B $\rightarrow \eta' K^0$). In fact this violation is expected to be very small in the SM, so any significant observation of CPV can be interpreted as a signal beyond the SM.
- Also the CP violation in charm mixing, negligible in the SM, could draw attention to new phenomena in the up-type quark sector.
- Another aspect that need to be understood is the large amount of CP violation in the time-integrated rates of charmless hadronic B decays, such as B $\rightarrow K\pi$ and B $\rightarrow K\pi\pi$, observed by other B factories and LHCb.

Conclusive measurements of time-dependent CP violation require a combination of data size and high precision measurement of Δz (discussed further in on the next page), the distance between the tag and signal in B meson decay vertices. In this respect, the upgrade of VXD could improve a lot the flavor tagging efficiency losses, due mainly to the beam-induced backgrounds, among the others.

Multiple Higgs bosons: Another fundamental channel is the measurement of the Branching Ratio (BR) of B $\rightarrow \tau\nu$, which is particularly sensitive to the charged Higgs boson (in addition to a neutral SM-like Higgs) that in general couples more strongly to heavier particles. But also the BR of the decay B $\rightarrow D^{(*)}\tau\nu$, where BaBar, Belle and LHCb had already reported some anomalies. Moreover extended Higgs mechanism could introduce extra sources of CP violation. We could notice that semi-tauonic decay measurements, rely on efficient and pure tag side B full reconstruction, and so also on the performance of VXD.

Flavor Changing Neutral Current (FCNC):

- For this purpose, measurements of time-dependent CP violation in B $\rightarrow K^{*0}(\rightarrow K_S^0\, \pi^0)\gamma$, triple product CP violation asymmetries in B $\rightarrow$ VV decays, and semileptonic decays B $\rightarrow$ V$l\nu$, V$= D^*$, ρ are the main approaches.
- It is also important to measure b $\rightarrow$ s$\nu\bar{\nu}$ transitions (such as B $\rightarrow K^{(*)}\nu\bar{\nu}$) which belong to a class of decays with large missing energy and to improve FCNC measurements of b $\rightarrow$ d, b $\rightarrow$ s, and c $\rightarrow$ u transitions.

Most analyses with missing energy in the final state utilise hadronic or semileptonic B full reconstruction techniques and the performance of these methods is most dependent on low momentum track finding and so on the capabilities of the vertex detector as well.

Sources of Lepton Flavor Violation (LFV): LFV in charged lepton decay (at rates of 10^{-8}) is a key prediction in many neutrinos mass generation mechanisms and other models of physics BSM. Belle II has an unrivalled sensitivity to τ decays, because of their production in a clean e^+e^- collision background and the large dataset. The experiment analyzes τ leptons to search for LF and CP violation and to measure its the electric dipole moment and (g-2) value.

NON FLAVOR PHISICS

Dark Sector: Belle II has a unique sensitivity to dark matter via missing energy decays. Although most research for NP are indirect, there are different model that predict the existance of new particles at the MeV to GeV scale, that couple to the SM via new gauge asymmetries. They also predict a vast range of hidden particles, including dark matter candidates and new gauge bosons.

In these last two areas, τ and dark sectors physics, the aim is to probe forbidden and ultra-rare transition in low-multiplicity final states with as large dataset as possible. This mostly relies on trigger efficiency and strategies, that could take advantage from the upgrade. Many of these processes can only be addressed by Belle II, so it is essential to increase the perfomance of the detector.

Binding Hadrons: As time goes on, a large numbers of states not predicted by conventional mesons interpretation are discovered in other B factories and hadron colliders, changing our understanding of QCD in the low-energy regime. For this reason, study of quarkonia is a fundamental purpose for Belle II. In fact new particles can be produced near resonance, achievable by adjusting the machine energy, or by intial state radiation, which effectively provides a continuum of center of mass energies.

CKM matrix: Belle II is also dealing with the measurements of CKM observable, the matrix elements and their phases, with unprecedented precision.

1.1.3 B meson decay vertices

The main task of VXD is the reconstruction of the production and decay vertices of the particles originated from the collisions and it is crucial to perform time-dependent measurements, core of the Belle II physics program.

The center of mass energy of Belle II experiment has its peak at the $\Upsilon(4S)$ resonance, such as $\sqrt{s} = 10.58$ GeV, which decays almost instantaneously into two B mesons ($B^0\ \bar{B}^0$) in nearly 96% of all cases. The choice of the asymmetric configuration of the beams, relies precisely in the requirement to boost the mesons in order to measure their life-time, exploiting the information on the distance between their decay vertices. In fact in a beam symmetric situation, they would have been produced at rest, decaying roughly at the same point or in any case at undetectable distances. The investigation of CP Violating processes instead, requires to measure the decay time difference of the two B mesons, and its uncertainty is dominated by that of decay vertex measurement (order of hundreds microns).

SuperKEKB collides an electrons beam of 7 GeV with a positrons beam of 4 GeV, chosen in order to have the center mass energy equal to 10.58 GeV. Indeed it must be valid:

$$s = (p^{\mu}_{e^-} + p^{\mu}_{e^+})^2 = m^2_{\Upsilon(4S)}, \;\; with\, m_{e+/-} \ll E_{e+/-} \Rightarrow 4E_{e^-}E_{e^+} = m^2_{\Upsilon(4S)} \quad (1.1)$$

So it's possible to compute the Lorentz boost of the mass center:

$$\vec{P}_{\Upsilon(4S)} = \vec{p}_{e^-} + \vec{p}_{e^+} = (\beta\gamma)_{\Upsilon(4S)} m_{\Upsilon(4S)} \approx 3GeV \;\Rightarrow\; (\beta\gamma)_{\Upsilon(4S)} = \frac{4GeV}{10.58GeV} \approx 0.28 \quad (1.2)$$

which is the same boost acquired by mesons, because they are produced almost at rest ($m_{\Upsilon(4S)}$ - $m_{2B_0} \approx$ 19 MeV). Moreover knowing that $\tau_B \simeq$1.5 $\times$ 10^{-12} s ans so cτ_B $\simeq$ 450 μm, we can compute the average flight distance travelled before decaying:

$$l = (\beta\gamma)_{\Upsilon(4S)} c\tau_B \approx 126\mu m \quad (1.3)$$

This value must be within the vertex detector sensitivity in order to distinguish the vertex decay and as consequence a precision measurements of lifetimes, mixing parameters and CP violation. The six-layer VXD could determine the position of the vertices with a precision better than 100 μm, allowing to reconstruct secondary vertices, i.e. the decay position of the particles coming from B decays, and also the tau and D mesons vertices. [In the topology of the B meson decay vertices, lie the combined great efforts employed to be able to build a fast, high-granularity and radiation hardness detector]

Let's take a closer look at the event kinematics (e.g. on this page). The two B mesons are produced in an entangled quantum state, so from the decay products of the first it's possible to assign its flavor (for example B^0, identifyed as B^0_{tag}) and as consequence that of the second, which will be the opposite ($\bar{B}^0$, called $\bar{B}^0_{phys}$).

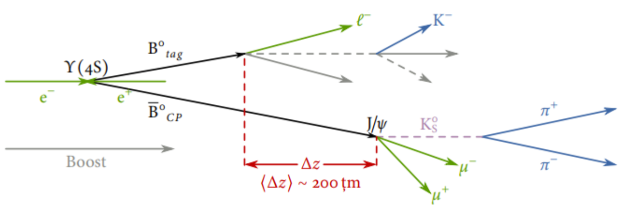


Figure 1.2: Example of the kinematics of the golden channel of Belle II experiment.

After this reconstruction, both B decay vertex positions z_1 and z_2 are evaluated, in order to compute their difference:

$$\Delta z = z_1 - z_2 = (\beta\gamma)_{\Upsilon(4S)} c\Delta t \tag{1.4}$$

where Δt is the proper time decay difference. Therefore this topology allows to transform a temporal information in a spatial one that we are able to measure. Without the boosted center of mass none of it could be possible, and this is a main feature of an asymmetric B-factory.

1.2 SuperKEKB accelerator

Belle II sensitivity in the precision measurements that we sift throug in the previous section, is feasible expecially thanks to the extraordinary performance of the SuperKEKB accelerator which host the (almost) hermetic detector. This complex facility is the result of efforts and efficient collaboration between the researches of KEK laboratory and all the international working groups that partecipate to the experiment.

1.2.1 The facility

SuperKEKB is an asymmetric e^+e^- collider with a circumference of 3 km and a center of mass energy peak equal to $\sqrt{s} = 10.58$ GeV, which corresponds to the mass of the $\Upsilon(4S)$ resonance. Compared to its predecessor KEKB (which started its operation in 1998 and concluded in 2010), the current accelerator has allowed to obtain the highest luminosity ever achieved, equal to 4.7×10^{-34} $cm^{-2}s^{-1}$ in July 2022, using a new scheme to accelerate and collide the beams, the so called *nano-beam scheme*(section 1.2.2 on page 10). Moreover a new upgrade of the machine, still under study, will also include other interventions expecially to cope with higher background levels, in view of further increase in luminosity.

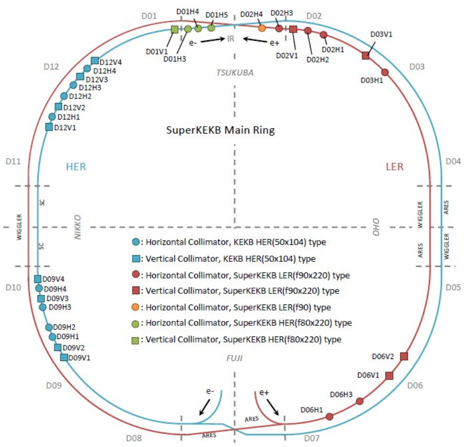


Figure 1.3: SuperKEKB accelerator in 2021. The letters V and H denote respectively vertical and horizontal collimators. Each ring is divided in 12 sections, from the first called D01 to the last D12.

We will briefly see the main features and parameters of the accelerator.

Luminosity

Luminosity is one of the key parameters of an accelerator and it represents the interaction rate per unit of cross section between colliding particles. Reversing this equation is possible to obtain N, namely the number of the physical events produced in the interaction with a given luminosity:

$$L = \frac{1}{\sigma}\frac{dN}{dt} \qquad \Rightarrow \qquad N = \int_0^T L\sigma dt \tag{1.5}$$

where T is the duration of the experiment, σ the cross section of the physical process of interest. Specifically luminosity is strictly dependent from both machine parameters and the main characteristics of the beam. With respect to this, it can be expressed as:

$$L = ... \tag{1.6}$$

where ......

As we have already seen, SuperKEKB holds the actual world record in luminosity (with β_y^*= 1.0 mm) and in the near future the target will be to reach 6.3×10^{-35} $cm^{-2}s^{-1}$ (by 2030?), by increasing current beams and reducing their section in the Interaction Point (IP), through the reduction of the betatron function to $\beta_y^* = 0.3$ mm.

For these reasons, the supervision of the beams background becomes crucial: right now it has been estimated that the background should remain accettable up to a luminosity value equal to 2.8×10^{-35} $cm^{-2}s^{-1}$ with β_y^*= 0.6 mm. So the possibility(hope) to achieve higher luminosity is closely (strictly) related to an upgrade plan of both the detector and the accelerator.

Beam energy

Energy beams is mostly decided by the physics program interesting for the experiment. Currently SuperKEKB collides an electron beam with energy of 7 GeV (High Energy Ring, HER) , with a positron beam of 4 GeV (Low Energy Ring, LER), reaching a center of mass energy peaked to Υ(4S) resonance.
The choice of colliding asymmetric beam (like its predecessor KEKB, which got collide electrons beam of 8 GeV with a positrons beam of 3.5 GeV) is necessary to identify and measure the decay vertices of particles created in the collisions, as we have seen in section 1.1.3 on page 6.
Indeed this mechanism allows to boost the decay products, improving the vertices reconstruction and increasing the sensitivity of the physics measurement, too. In particular this makes possbile time-dependet measurements, expecially in CP violation.

In figure 1.4 on the next page the flexibility of the energy of both LER and HER beams is showed, which provides a continuum of the center mass energy. The possible range covers energies which goes from the Υ(1S) (9.46 GeV) resonance to the Υ(6S) (11.24 GeV).

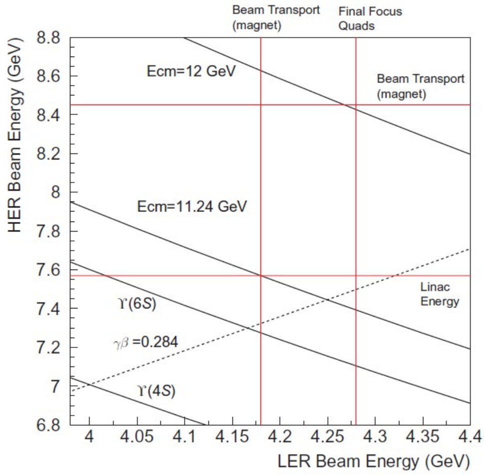


Figure 1.4: Beam energies to reach center of mass energy equal to $\Upsilon(4S)$, $\Upsilon(6S)$, 11.24 GeV and 12 GeV. Horizontal axis represents the energy of LER and the vertical one the energy of HER.

1.2.2 "Nano-beam" scheme

[?]

As mentioned in the previous section, another decisive factor to define the luminosity is the *beta function* β in the Interaction Point (IP). To be able to increase luminosity, it's necessary to decrease the value of β depending also but not only, on the variation of the other machine parameters in the difinition (on the preceding page). The mechanism used in SuperKEKB is called *nano-beam scheme*, and it allowed to obtain luminosity 40 times greater than that of KEKB, managing to (succeding) decrease of 1/20 the β function in the IP.

This new scheme, designed by P. Raimondi, dictates that the beams have to collide at large angle, equal to 83 mrad in SuperKEKB (keeping beams divided through quadruople magnets), in order to reduce the *hourglass effect*, which succeed when the bunches in the beam are much longer.

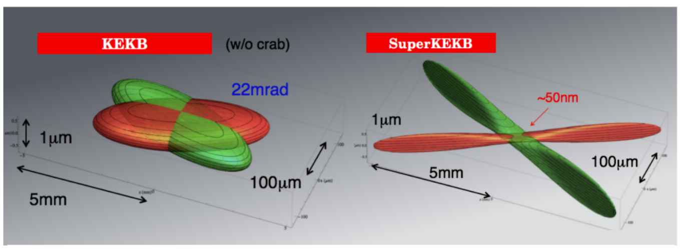


Figure 1.5: Comparison between the beams scheme used in KEKB and SuperKEKB.

Using a crossing angle large enough, has other positive implications on the operation of the accelerator:

- allows the placement of a new focusing system in the IP with a superconducting quadrupole magnet;
- allows to have two distinct line which host HER and LER beams;
- diminishes the *fringe fields* effect in the IP, wihch are the residuals of the magnets (magnetic fields) in the proximity (nearby).

1.3 Belle II detector

Belle II detector is a general-purpose spectrometers, which consists of a series of nested subdetectors that surrounds the IP of the two beams, placed around the berillium beam pipe of 10 mm of radius. Here we will go trough a briefly description of the several subdetectors.

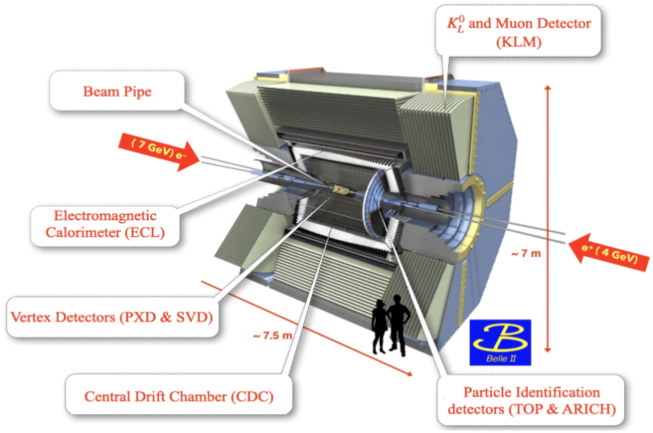


Figure 1.6: Belle II detector.

1.3.1 Vertex Detector (VXD)

The **VerteX Detector (VXD)** is composed by two devices, the silicon Pixel Detector (PXD) and the Silicon Vertex Detector (SVD), for a total of six layers around the beam pipe.
The inner two layers of PXD (L12) consist of pixelated sensors based on the depleted field effect transistor (DEPFET) techonology, realised with very thin (< 100 μm) sensors, allowing to minimise multiple scattering, thus improving the tracking resolution for low-momentum particles. They are at a radius of 14 mm and 22 mm, respectively.
The remaining four layers of SVD (L3456) instead, are equipped with double-sided silicon strip (DSSD) sensors (at 39 mm, 80 mm, 104 mm and 135 mm respectively). Since a lower background rate is expected with respect to PXD, DSSD allow to achieve similar performance with a much smaller number of readout channels. These layers are mainly used for tracking/vertexing and also for particle identification (dE/dx).

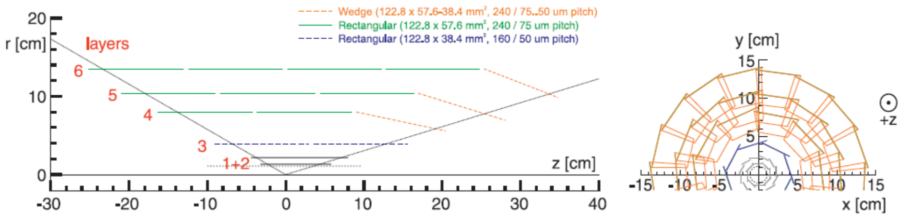
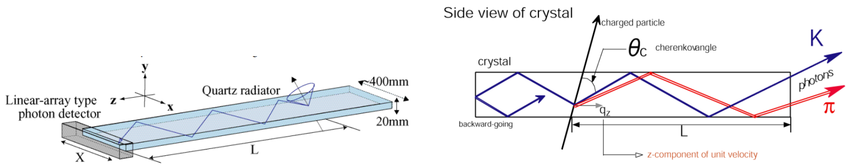


Figure 1.7: A schematic view of the Belle II vertex detector with a Be beam pipe and the six layers of PXD and SVD.



(a) A schematic view of the TOP radiator. (b) A side view of the TOP radiator.

Figure 1.8: TOP detector.

1.3.2 Central Drift Chamber (CDC)

It is the central tracking device, with a large-volume drift chamber and small drift cells. The chamber gas is composed of a He$-$C$_2$H$_6$ 50:50 mixture with an average drift velocity of 3.3 μs^{-1} and a maximum drift time of about 350 ns for a 17 mm cell size. The CDC contains 14336 wires arranged in 56 layers either in *axial* (so aligned with the solenoidal magnetic field) or *stereo* (skewed with respect to the axial wires) orientation. In fact by combining information from both the axial and the stereo layers it is possible to reconstruct a full three-dimensional helix charged tracks and measures their momenta. It also provides information for particle identification by measuring ionization energy loss, which is particularly useful for low-momentum particles that cannot reach the outer particle identification subdetectors.

1.3.3 Particle identification system (TOP e ARICH)

TOP (Time Of Propagation) is a special kind of Cherenkov detector used for particle identification in the barrel region. It employs the two-dimensional information of a Cherenkov ring image, such as the time of arrival and impact position of Cherenkov photons at the photodetector at one end of a 2.6 m quartz bar. It is composed by 16 detector modules, each one consisted in a 45 x 2 cm quartz bar (Cherenkov radiator) with a small expansion volume (about 10 cm long) at the sensor end of the bar. In order to achieve a single-photon time resolution of about 100 ps (required for a good PID), 16-channel microchannel plate photomultiplier tubes (MCP-PMT), specially developed for this purpose, are employed.

ARICH (Aerogel Ring Imaging CHerenkov) is used to identify charged

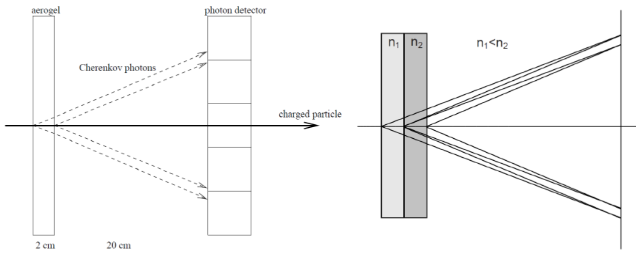


Figure 1.9: ARICH detector.

particle and it is placed in the forward endcap region. It is a proximity focusing Cherenkov ring imagine detector which adopts aerogel as Cherenkov radiator. In particular this detector employs a novel method to increase the number of detected Cherenkov photons: two 2 cm-thock layers of aerogel with different refractive indices (n_1 = 1.045 upstream, n_2= 1.055 downstream) that increase the yield without degrading the Cherenkov angle resolution. A hybrid avalanche photon detector (HAPD) are exploited as single-photon-sensitive high-granularity sensor. Here photo-electrons are accelerated over a potential difference of about 8 KV and are detected in avalanches pyotodiodes (APD).

The main task of these detector is to improve the K/π separation until 3.5 and 4 GeV/c of momentum, respectively.

1.3.4 Electromagnetic calorimeter (ECL)

The **ECL** is a highly segmented array of tallium-doped caesium iodide CsI(Tl) crystals assembled in a 3 m long barrel section with a radius of 1.25m, and two endcaps discs located at 2 m (forward) and 1 m (backward). All of them are instrumented with a total of 8736 crystal, covering about 90 % of the solid angle in center-of-mass system. This detector is used to detect gamma rays and to identify electrons in order to separate the latter from hadrons, expecially pions.

1.3.5 K_L muon detector (KLM)

It consists of an alternating sandwich of 4.7 cm-thick iron plates and active detector elements located outside the volume of the superconducting solenoid that provides a 1.5 T magnetic field. The iron plates serve as the magnetic flux return joke for the solenoid. They also provide 3.9 interaction lenghts or more of material, beyond the 0.8 interaction lenghts of the calorimeter, in which K_L^0 mesons can shower hadronically. The active detector elements have been chosen in order to cope with the reduction of the detector efficiency under the SuperKEKB background rates: resistive plate chambers (RPCs) for the outermost active layers, and scintillator strip, with wavelenght-shifting fibers, readout by silicon photomultipliers (SiPMs) in the two innermost layers of the barrel region and for the endcaps regions.

1.3.6 Trigger system

The trigger system of Belle II has a non-trivial role to identify events of interest during data-taking at SuperKEKB, where high background rate are expected. This system is composed of two levels: a hardware-based low-level trigger (L1) and a software-based high-level trigger (HLT), implemented in the data acquisition (DAQ) system.

- **L1**: has a latency of 5 μs and a maximum trigger output rate of 30 kHz, limited by the read-in rate of the DAQ.
- **HLT**: is a key component of the DAQ, used to fully reconstruct events that passed the L1 trigger selection. It has to reduce online event rates to 10 kHz for offline storage and it must identify track regions of interest for PXD readout in order to reduce data flux. It fully recreates events with offline reconstruction algorithms, using all detectors infromation except for the PXD.

1.4 Current state and perspectives of data taking

As we already said, Belle II has reach the world record luminosity with $L_{MAX} = 0.47 \times 10^{-35}\ cm^{-2}s^{-1}$ in June 2022. In further perspectives, the target is to achieve a new record with $L = 6 \times 10^{-35}\ cm^{-2}s^{-1}$ and to increase the integrated luminosity from 428 fb^{-1} (actual value, starting in 2019) to 50 fb^{-1}, in order to increase the statistics and also the hope to give an insight in some the opened questions of SM.

In order to accomplish the fixed(estabilished) goals mentioned above, an upgrade not only of the vertex detector but of the whole experiment is necessary, among several reasons, to cope with a more complex circumstances due to the increased luminosity, which undermine its proper functioning.

Therefore a three-phase program is envisaged (considered):

- **short term**: year 2022. Long Shutdown 1 (LS1) is planned for approximately 15 months starting in July 2022, to install a complete pixel detector (PXD). Was it done?
- **short term**: approximately year 2026-27. Long Shutdown 2 (LS2) will probably be needed for the upgrade of the Interaction Region (IR) to reach a new luminosity target $L_{peak} = 6.5 \times 10^{-35}\ cm^{-2}s^{-1}$. A new Vertex Detector might be required to accommodate the new IR design, and other sub-detector upgrades are possible.
- **long term**: years $>$ 2032. Studies have started to explore upgrades beyond the currently planned program, such as beam polarization and ultra-high luminosity, such as L_{peak} in excess of $1 \times 10^{-36}\ cm^{-2}s^{-1}$. While the beam polarization has a concrete proposal, for ultra-high luminosity studies have just started.

At time of writing we are in the period of a long shut-down (LS1), last since June 2022 and the restart of data taking is planned at the beginning of 2024.

2. Belle II Upgrade

This second chapter wants to adress some of the main reasons in favor of the upgrade of Belle II. We will give an overview of the primary background sources in the experiment to understand how to mitigate them to be able to achieve a better performance of the whole detector, even increasing the luminosity. Eventually we will also introduce some of the proposes made for the vertex detector, which is the focus of this thesis.

2.1 Background sources and limitations in Belle II

SuperKEKB is already the world's highest-luminosity collider and it aims to reach a new luminosity peak and to increase the statistics in the future, to become more sensitive to rare process and precise measurements of Belle II physics program. But to be able to do this without loosing the good functionality of the entire detector, it's necessary to understand how to mitigate the beam backgrounds where possible and how to cope with the consequent challenges.

Several simulations and measurements of beam background are still being done in order to guess possible future machine scenarios, under new luminosity conditions. This is necessary to study the vulnerability of the subdetectors (and more generally of the machine) and so to design the countermeasures to adopt against the deterioration of performance and material.

2.1.1 Beam-induced background sources

Making clear that even the interaction of the beams is a source of noise for the measurements, in the following are listed some of the *beam-induced* and *luminosity-dependent* background sources.

Touschek effect : It is an intra-bunches scattering process, where the Coulomb scattering of two particles in the same beam bunch causes a variation of their energies, increasing the value of one of them and lowering that of the other from the nominal value. This interaction among the bunch particles is the first beam background source at SuperKEKB.

Beam-gas scattering : this represents the collision of beam particles with residual gas molecules in the beam pipe. It's the second beam background source and it can occur via two processes: Coulomb interactions, which changes the direction of the beam particles, and bremsstrahlung scattering, which instead decreases their energy.

Because of these two processes, the scattered particle fall out the stable orbit and hit the beam pipe while they move around the ring. This causes electromagnetic showers that could reach the detector if their origin (loss position) is close to it.

Radiative Bhabha scattering and two-photon processes : There are several undesirable collision processes at IP, which have very high cross sections but only little interest for the physics studied in the experiment. Two of them are **Bhabha scattering** ($e^+e^- \rightarrow e^+e^-\lambda$) and **Two-photon processes** ($e^+e^- \rightarrow e^+e^-e^+e^-$). In the first effect the emitted photon interacts with the iron magnets and produces a very large amounts of neutrons via the photo-nuclear resonance mechanism. [Such neutrons are the main background source for the outermost Belle II detector, the K_L and muon detector (KLM).] The electrons-positrons pairs of the latter instead, can spiral around the solenoid field lines and leave multiple hits in the inner Belle II detectors.

These processes increase the Belle II occupancy and radiation dose, and they are reffered as *Luminosity background* because their strenght is proportional to the luminosity. The future upgrade intends to deal with this problem in order to keep occupancy low.

Synchrotron Radiation (SR) : X-rays emitted from the beam when electrons and positrons pass through the strong magnetic field near the IP. The HER beam is the main source of this type of background, because SR power is proportional to the square of beam energy and magnetic field. SR can potentially damage the inner layers of the vertex detector due to an higher radiation dose. As a matter of fact, many current studies aim to enhance radiation hardness detector.

There are also other background sources beyond those mentioned aboce and during the last decade a well-structured set of countermeasures have been developed trying to ease each one of them.

2.1.2 Current background status and future implications (predictions)

Several monitoring devices are located all along the accelerator to keep under control radiation doses on both detector and delicate regions of the ring, to intervene as soon as possible in case too high levels are reached. Indeed large doses of radiation could cause accidental damages on the detector, decreasing its performance.

Event though, the current level is of no concern in terms of occupancy for the innermost layers of the vertex detector, in the case of a larger amount, SR may cause inhomogenities in PXD module irradiation, which would make it more difficult to compensate by adjusting the operation voltages of the affected modules.

Until now it can be said that SuperKEKB and Belle II are operating stably. Beam-induced backgorund rates are well below the limits of the detector and do not prevent from increasing further tha current and hence the luminosity.

Despite that, there are several other difficulties that can limit beam currents and so the possibility to move the luminosity frontier at towards higher levels, allowing Belle II reaserchers to study rare physics processes.

2.2 Purposes of the upgrade

3. Conclusions

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