Belle II

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1) Introduction

The Belle II experiment is running at the B meson factory SuperKEKB (Tsukuba, Japan), which collides electrons and positrons at the center-of-mass energy of the Υ(4S) resonance. Belle II follows the path defined by Belle and BaBar, both of which started about 20 years ago at the B-factories KEKB (Tsukuba, Japan) and PEP-II (SLAC, USA) respectively. The aim of Belle II is to collect 50 ab^{-1} of data, about 50 times than that recorded, jointly, by BaBar and Belle.
This second generation B-factory will allow to complement the exploration of New Physics beyond the Standard Model currently being carried out at the energy frontier by the experiments at the Large Hadron Collider (LHC). The LHC experiments provide a direct probe of the TeV mass scale; Belle II will use high-precision measurements of rare decays and CP-violation to search for New Physics at even higher mass scales, through the effects of new particles in higher order processes.
SuperKEKB is the first collider to employ the nano-beam scheme and to achieve a β^*_y focusing parameter of 1 mm; this was possible with major upgrades to KEKB, including a new low-energy ring beam pipe, a new and complex system of superconducting final-focusing magnets, a positron damping ring, and a new advanced injection system. A significant improvement was the introduction of crab-waist technology, which stabilizes beam-beam blow-up using carefully tuned sextupole magnets located symmetrically on either side of the interaction point (IP). This scheme was first proposed by Pantaleo Raimondi at the LNF and successfully tested at DAΦNE,

The Belle II detector is the result of a major upgrade of the Belle detector: the superconducting magnet and the iron return yoke have been kept, while the sub detectors have been replaced, or significantly improved.

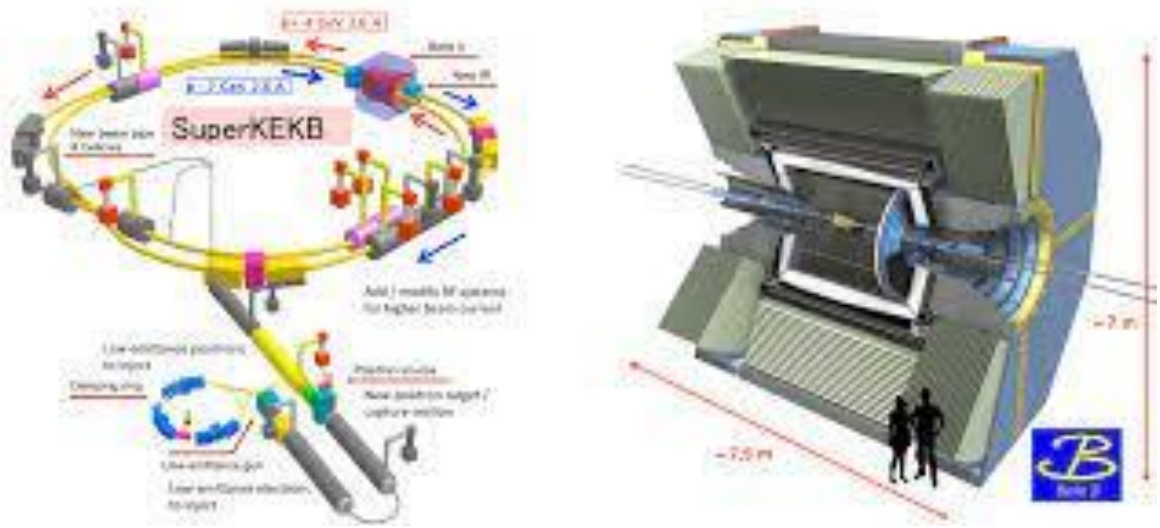

Figure 1: Overview of the SuperKEKB B-factory (left) and Belle II detector (right). In color the new or updated parts of SuperKEKB with respect to KEKB

Because of the increased level of event and background rates, the Belle II detector has to cope with higher occupancy and radiation damage than the Belle detector. To be able to operate at the expected conditions, the tracking subsystem has been replaced: a new vertex detector (VXD) and a new drift chamber (CDC) with smaller cell size have been built. The particle identification system includes a new Time Of Propagation (TOP) detector. The barrel CsI crystals, thallium doped, EM calorimeter (ECL) have been provided with new readout. In the

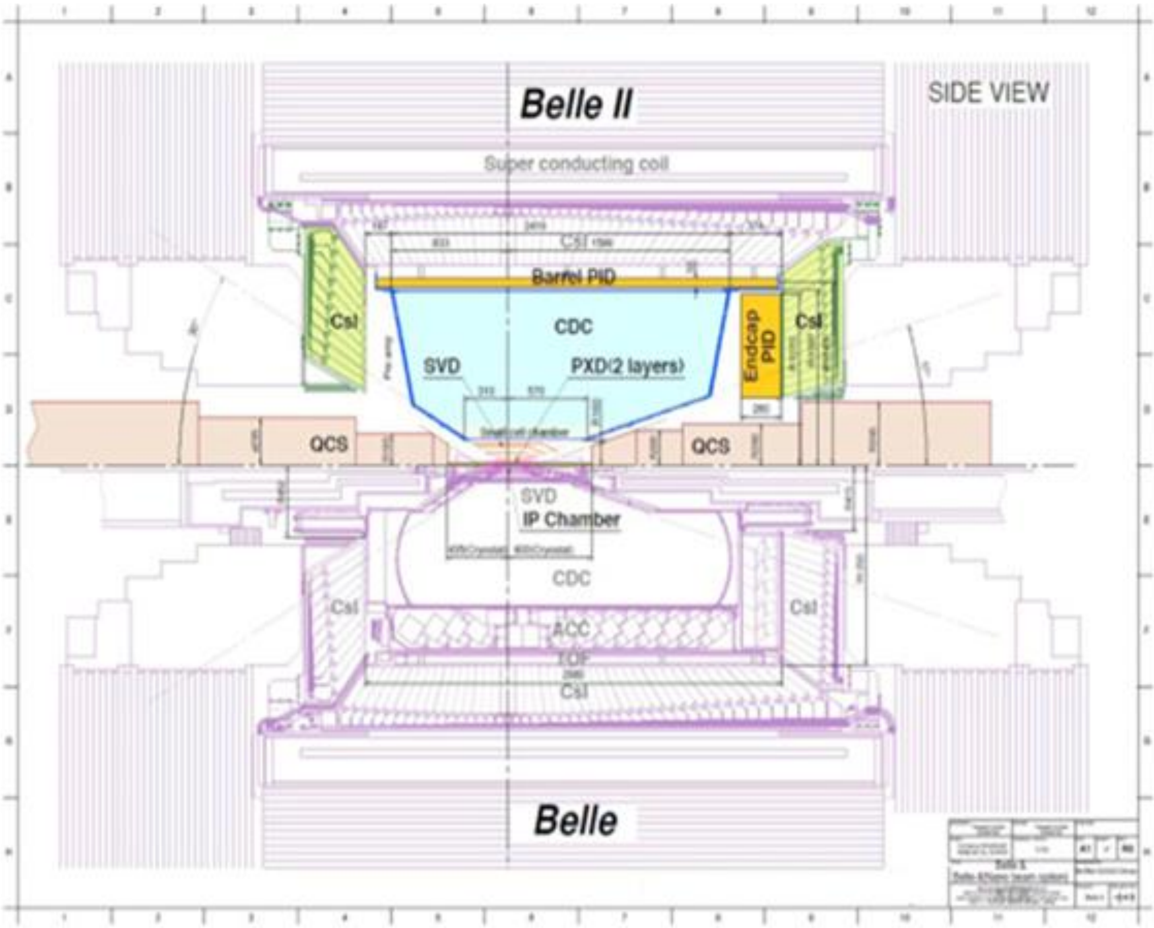

Figure 2: Comparison among the Belle (bottom) and Belle II (top) detectors. In color the upgraded parts.

KL and muon detector (KLM) only the outer barrel layers of glass RPCs are re-used, the remaining have been substituted with scintillation counters.

The dataset collected by Belle II will allow, in the next few years, a wide range of precision measurements in the B meson, charm, and τ sector, along with an unprecedented accuracy in the determination of the CKM (Cabibbo-Kobayashi-Maskawa) matrix elements, specifically |Vub | and |Vcb | and the angles of the Unitarity triangle.. Babar and Belle have proved that a B-factory provides the opportunity to study a wide range of additional topics, as exotic quarkonia or dark matter and axion searches.
First collisions were recorded in Spring 2018, data taking with the full Belle II detector and significant luminosity started one year later.

2) Belle II run in 2020

In 2020 the Covid-10 pandemic made impossible for collaboration members, which are present in 26 countries, spread in 4 continents, to participate in person to the data taking and detector maintenance activities. In spite of such difficult situation, the running of the machine and the data recording continued following the program, with a small Japanese team, about forty people working in situ, and a wide effort of the remaining collaboration using remote connections.

Control room shifts, and shifts by experts checking the various sub detectors, were all covered remotely; all operation and run meetings were conducted online, as well as physics meeting, committees meetings, and general collaboration meetings.

A new record for the highest luminosity at a particle collider has been set by SuperKEKB: on June 15, when electron–positron collisions reached an instantaneous luminosity of 2.22×10^{34} cm^{-2} s^{-1} surpassing the LHC's record of 2.14×10^{34} cm^{-2}s^{-1} set with proton–proton collisions in 2018. Just a few days later, SuperKEKB pushed the luminosity record to 2.4×10^{34} cm^{-2}s^{-1}.

Due to the need to improve the accelerator performance, runs were split, roughly half dedicated to machine physics, and the rest to Belle II data taking; by the end of the year, the collected luminosity was about 90 fb^{-1} (≈20% of BABAR total).

The collected data were used for studies covering the full range of heavy quark physics and dark matter searches, resulting in the publication of several papers and many conference presentations; not only were many results rediscovered, but additional new information emerged, as new more stringent limits on invisible decays or the Z' or a large exclusion zone for axion-like particles. As an example of how the analysis tools are already working well, B^0

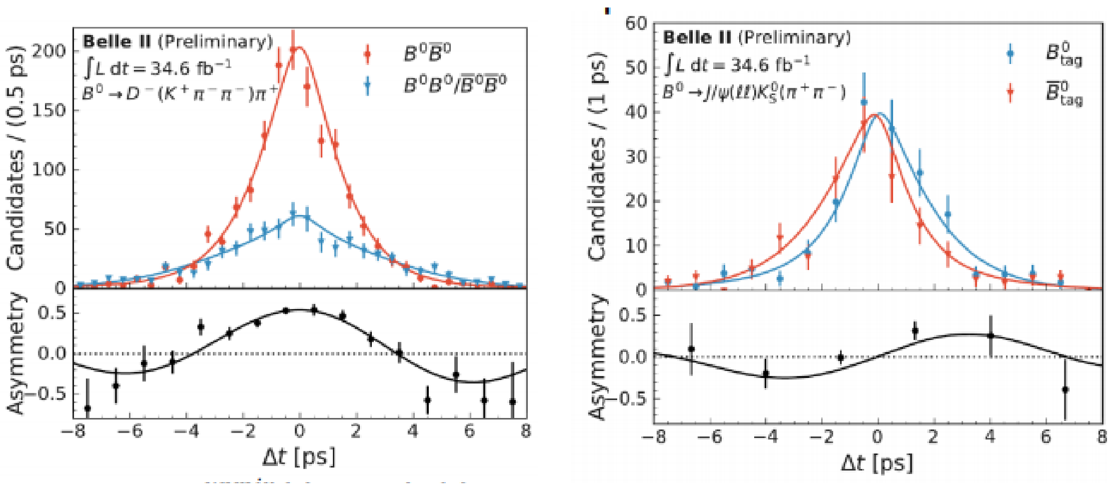

Fig3: Left $B^0\overline{B^0}$ mixing, right CP violation in the channel $B^0 \to J/\psi\ \ K_S$ using 34.5 fb^{-1} of data

mixing and CP violation are clearly visible using only one about one third of the data now available, as shown in Fig 3.

3) Activity of the Frascati group

The Frascati group joined Belle II in 2013, and has since participated to various programs related to software, physics analysis, R&D for future upgrades, as well as detector construction and commissioning. Members of our group held, or are holding, institutional responsibilities. Following is a short summary of the 2020 activities.

In hardware the group is involved in the KLM sub detector; no in situ activity was possible during 2020, so the group has participated remotely to run control shifts and data quality monitoring. The detector has performed well

In software development, the group has produced the tools for the KL identification; Giuseppe Finocchiaro is responsible for the study of the systematics, and acts as liaison to the group that studies neutral particle identification. The physics channel we are working on is $B^0 \rightarrow J/\psi\ K_L$, very important for the CP violation studies: an important test of the Standard Model is that the asymmetry in this channel should have the same value, but opposite sign, of the one measured in the high precision mode$B^0 \rightarrow J/\psi\ K_S$.

Our MC-based analysis for $B^0 \rightarrow J/\psi\ K_l^0$ was the first analysis involving K_l^0's performed in the Belle II Collaboration. In 2020, we have refined this analysis, and prepared a note to be used in conference presentations. To identify the K_l^0s, we make use of the energy depositions they leave in the KLM. This technique does not allow a usable measurement of the particle energy, but only of its direction.

We calculate the momentum of the K_l^0 candidate from its direction and the reconstructed momentum, as obtained by energy conservation in the event, and using the B^0 mass constraint.The procedure correctly reconstructs the generated K_l^0 momentum, with a typical resolution of about 15MeV/c, albeit with some non-gaussian tails, as shown in Figure 4.

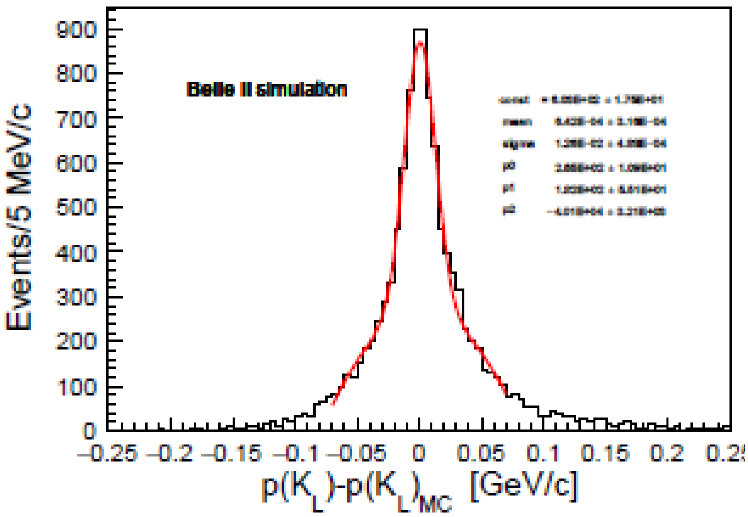

Fig. 4. Difference between calculated K_l^0 momentum and true K_l^0 for truth-matched events in signal MC.

Once signal candidates have been selected, we can calculate the difference between the B^0 candidate energy and the beam energy in the CM frame, which for genuine $B^0 \to J/\psi\, K_l^0$ events is expected to be close to zero.
In a small number of cases (about 2 %) there are two $B^0 \to J/\psi K_l^0$ candidates after the K_l^0 selection; in these cases, we choose the K_l^0 with the best identification, defined with the parameter *Klongid*.

The distribution of this parameter, at the base of our analysis, is shown in Figure 5. for all reconstructed K_l^0 candidates and for those truth-matched to a true K_l^0, respectively. We use the requirement *klongID* > 0.25.

We model the signal ΔE distribution with a Crystal Ball (CB) PDF. The signal PDF coefficients are determined by an unbinned ML fit to the ΔE distribution in a high-statistics MC sample of $B^0 \to J/\psi K_l^0$ events; the fits are performed in the range -20 < ΔE < 80 MeV.

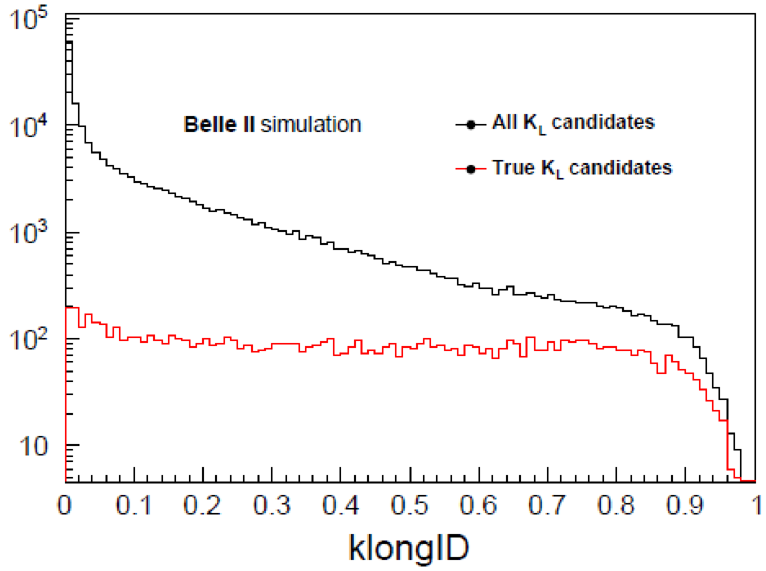

FIG. 5. KlongID distribution of all K_l^0 candidates (black curve) and truth-matched candidates (red curve) in the generic MC.

We performed an accurate study of the background, which is mainly due, roughly by the same amount, to $B^0\bar{B}^0$ and B^+B^- events, We classify the background in three categories: a) events with a wrong combination of a real J/ψ and a real K_l^0 b) events with a fake J/ψ ; c) events with a true J/ψ and a fake K_l^0. The latter is found to be the dominant background source. In order to rely on MC simulations as little as possible, we estimate the fake J/ψ and the fake K_l^0 directly from data. Wrongly reconstructed J/ψ candidates can be estimated using the reconstructed J/ψ mass sidebands, while fake K_l^0 mesons are estimated using an "anti-selection" of neutral clusters, with the requirements Nlayers = 1, klongID < 0:05.

We determine the number of signal and background $B^0 \to J/\psi K_l^0$ events with an unbinned ML fit to our 62:8fb^{-1} dataset in the ΔE interval [-20, +80] MeV, as shown in Figure 6. The background shape parameters determined in the background control sample are fixed in the fit, as well as the peaking background fraction estimated in the fit on simulated background events. The signal shape parameters are used as starting values in the fit, but to minimize the

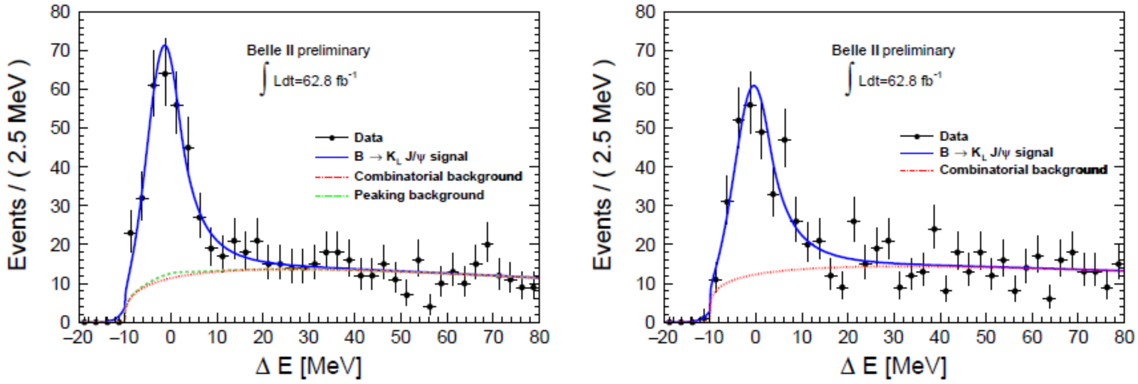

Fig. 6 ΔE distribution of $B^0 \to J/\psi K_l^0$ candidate events for $J/\psi \to \mu^+\mu^-$ final states (left) and $J/\psi \to e^+e^-$ final states (right)

dependence on Monte Carlo the sigma and mean of the CB are left free.

Finally, to extract the number of signal and background events, we also float the relative normalization of the signal and background distributions. The results for the two sets of J/ψ decay modes we have studied are: Nsig($\mu^+\mu^-$) = 267 ± 21, Nsig(e^+e^-) = 226 ± 20.
Systematic effects have not yet been studied in detail; a conservative estimate of this uncertainty is obtained by varying in the final fit the fraction of peaking background by two times (95%CI) its statistical error. This procedure yields Npeaking ($\mu^+\mu^-$) = 28, Npeaking (e^+e^-) = 31.

4) Institutional responsibilities

In the Belle II organization chart, Riccardo de Sangro is the operation shift manager, and as such is responsible for the shift assignment in all categories: run control, detector experts, etc; Ida Peruzzi is the chair of the Speakers Committee, responsible for assigning talks at International conferences and workshop and reviewing the drafts, for quality assurance. Giuseppe Finocchiaro is the KLM responsible for K_l^0 reconstruction and liason to the neutral particle reconstruction group.

5) BELLE II Notes

1. R. de Sangro, G. Finocchiaro, M. Piccolo, B. Oberhof, "Reconstruction of $B^0 \to J/\psi K_l^0$ in early Belle II data" , BELLE2-NOTE-PH-2020-011, April 2020.

2. R. de Sangro, G. Finocchiaro, M. Piccolo, B. Oberhof, "Study of KL reconstruction at Belle II using the ISR reaction $e^+e \to \phi\gamma$" ,BELLE2-NOTE-TE-2018-007, June 2018.

3. R. de Sangro, G. Finocchiaro, M. Piccolo, B. Oberhof, "Observation of the ϕ meson produced in $e^+e \to \phi\gamma$ events in early Belle II data", BELLE2-NOTE-PH-2018-012, June 2018.

4. R. de Sangro, G. Finocchiaro, M. Piccolo, B. Oberhof, “Observation of the J/ψ meson produced in $e^+e \rightarrow J/\psi\ \gamma$ events in early Belle II data" BELLE2-NOTE-PH-2018-021, June 2018.

5. R. de Sangro, G. Finocchiaro, M. Piccolo, B. Oberhof, ”Comparison of cosmic-ray data results for dfferent forward ECL upgrade options", BELLE2-NOTE-TE-2017-015, July 2018.