Belle II

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1 Introduction

The Belle II experiment follows the path defined by the Belle and BaBar experiments, both of which started about 20 years ago at the B-factories KEKB (Tsukuba, Japan) and PEP-II (SLAC, USA) respectively. Until now all measurements made at B-factories are in agreement with the Standard Model; nowadays, however, there is compelling evidence for New Physics beyond the Standard Model from various sources (e.g. neutrino mixing, baryonic asymmetry in the universe). For this reason Japan has decided to upgrade the existing KEKB accelerator to deliver a 40 times higher instantaneous luminosity which will allow, in 5 years of data taking, to record a data sample 50 times larger than that recorded, jointly, by BaBar and Belle.

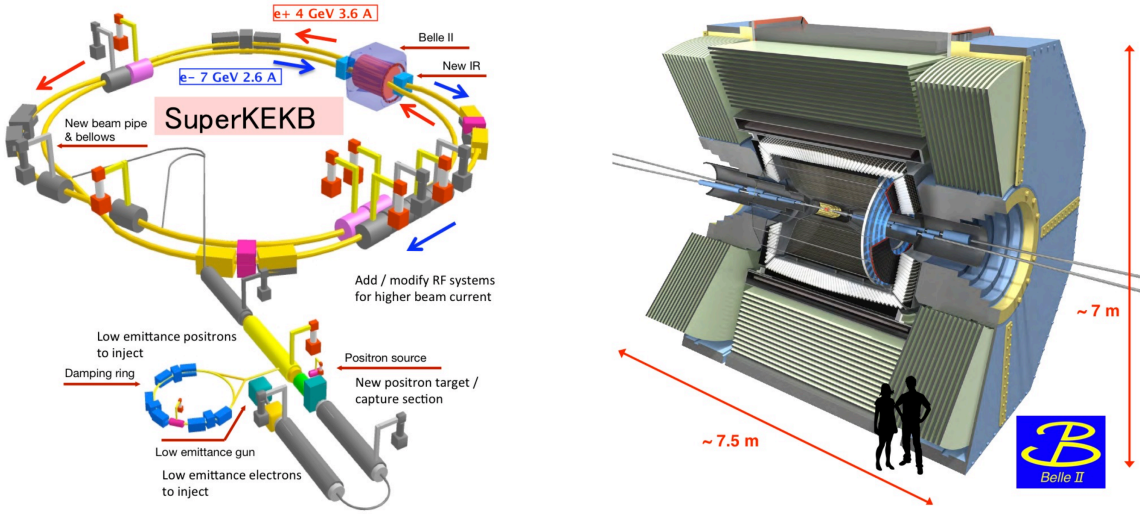

Figure 1: Overview of the SuperKEKB B-factory (left) and Belle II detector (right). In color the new or updated parts of SuperKEKB with respect to KEKB.

The LNF group joined the Belle II collaboration in July 2013, together with eight other INFN Institutions, for a total of about 50 physicists. The new machine, called SuperKEKB, has been completed. The design luminosity is $8 \times 10^{35} \mathrm{cm}^{-2} s^{-1}$ with a projected integrated luminosity of 50 ab^{-1} in 5 years running. Because of the increased level of background, the Belle II detector

has to cope with higher occupancy and radiation damage than the Belle detector. To be able to operate at the conditions of the SuperKEKB collider, the components of the Belle detector are either upgraded or replaced by new ones. A new vertex detector (VXD) and a a new drift chamber (CDC) with smaller cell size have been built and the particle identification system now 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 K_L and muon detector (KLM) only the outer barrel layers of glass RPCs are re-used, the remaining have been substituted with scintillation counters.

Commissioning (Phase 1) of the main ring (without final focus quadrupoles) has been successfully carried out between February and June 2016; instead of Belle II, a commissioning detector, BEAST II (Beam Exorcism for A STable experiment II), was used, in order to measure actual beam induced background rates at the Interaction Point (IP). The roll in of the Belle II detector without vertex detector, which has been replaced by a modified version of the BEAST II detector, has taken place in Early 2017 followed by a global cosmic run. The second phase of commissioning (Phase 2) and first physics runs has started in March 2018; during Summer-Fall 2018 shutdown the vertex detector has been installed and Phase 3 data-taking, with full Belle II detector, is scheduled to start by March 2019.

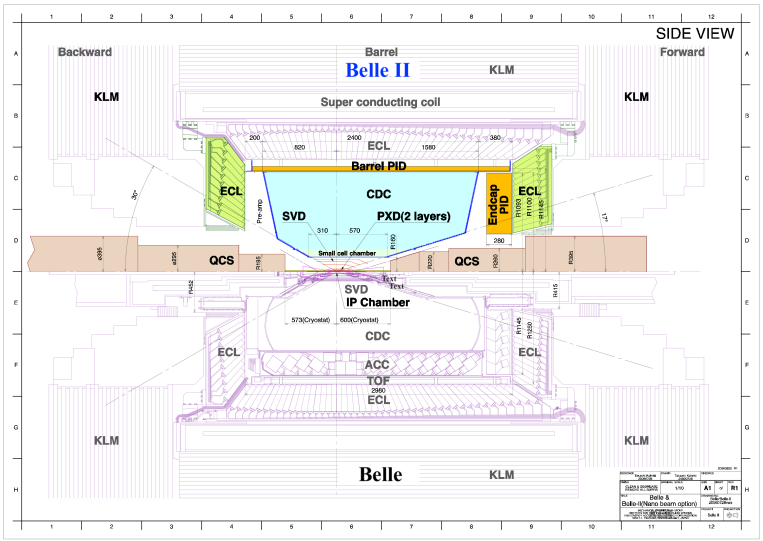

Figure 2: Comparison among the Belle (bottom) and Belle II (top) detectors. In color the upgraded parts.

The group participates to various Belle II programs related to software, physics analysis, R&D for future upgrades as well as detector construction and commissioning. Hereafter is a short description of the group's main activities during 2018.

2 Software & Analysis

The Frascati group is involved in the development of part of the the Belle II software system, called basf2 (Belle Analysis Framework 2). Currently the group is carrying on various tasks related to the development, revision and validation of the evaluation of physics performance code.

The group's main physics analysis work is the measurement of the time-dependent CP violation asymmetry in $B \to J/\psi K_L$ decays. $B \to J/\psi K^0$ is the "golden channel" for the measurement of the CKM angle β/ϕ_2 and, in fact, the first observation of CP-violation in the $B^0\bar{B}^0$ system was made in these channels. The main difficulty of this benchmark channel is the reconstruction of the K_L momentum, as only its direction can be measured. For this reason we have developed and implemented in the Belle II framework appropriate algorithms to reconstruct the K_L momentum magnitude based on kinematical constraints.

Our MC-based analysis for $B \to J/\psi K_L$ was the first analysis involving K_L's in the Belle II collaboration, the first analysis made on the equivalent of the full expected data sample (50 ab^{-1}), as well as the first one performed on our recently launched grid computing network. The analysis is now in an advanced state and a detailed background study is ongoing.

As a byproduct of our analysis work, in which we had to correct and update the official Belle II CP violating modes branching fractions and decay models of the EvtGen MC generator, we took the responsibility for their maintenance and we are now acting as liaison between the Belle II TDCPV physics group and the MC developers.

To evaluate the actual K_L reconstruction performance of Belle II, we are studying the benchmark channel $e^+e^- \to \phi\gamma$, $\phi \to K_L K_S$ [1]. This study has also led us to the first observation of the decay $e^+e^- \to \phi\gamma$, $\phi \to K^+K^-$($Fig.\,3$) [2].

Finally, we have also observed the decay $e^+e^- \to J/\psi\gamma$ with 250 pb^{-1} of early Belle II data and of $J/\psi \to \mu^+\mu^-$ with 370 pb^{-1} of data (Fig. 4) [3], which are among the first Belle II results approved to be shown at 2018 Summer conferences.

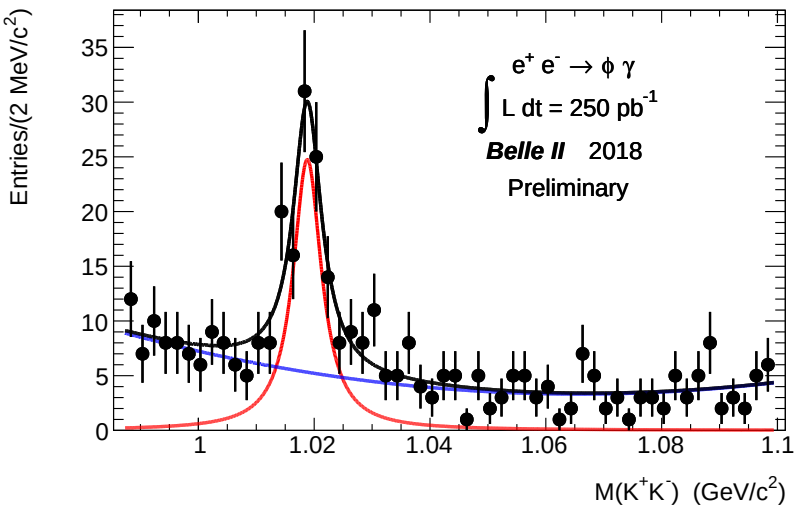

Figure 3: Invariant mass of the K^+K^- pair for reconstructed $e^+e^- \to \phi\gamma$ events.

Based on our experience in K_L reconstruction, we are responsible for the development of the official K_L ID for physics analyses.

3 R&D on Pure CsI

In 2018 the LNF group completed the analysis and documentation of the R&D program launched in the past years to propose a solution for a possible upgrade of the forward endcap of the Belle

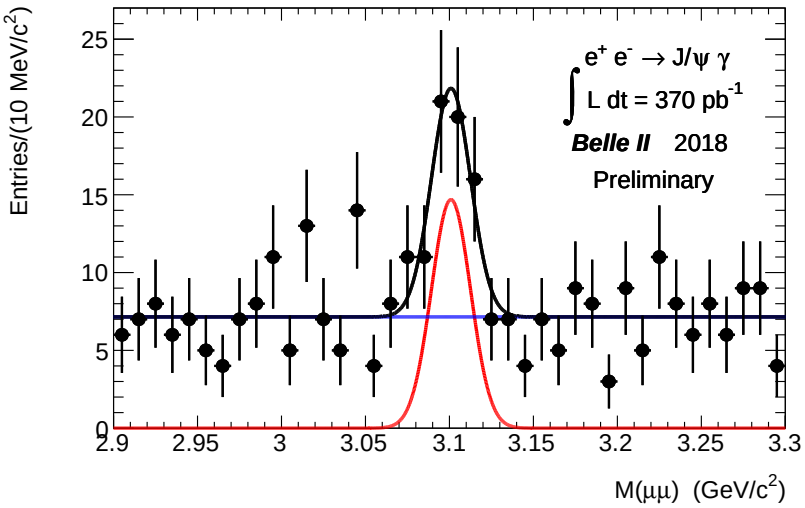

Figure 4: Invariant mass of the $\mu^+\mu^-$ pair for reconstructed $e^+e^- \to J/\psi\gamma$ events.

II Thallium-doped CsI crystal calorimeter. Such an upgrade could be necessary to cope with the increased levels of background due to the extremely high luminosity foreseen in Belle II.

The R&D was mainly focused initially on the replacement of CsI(Tl) crystals with pure CsI crystals, to be readout with high-gain avalanche photodiodes (APDs). A thorough comparison of several upgrade options is presented in the internal document [4]. In this document an original upgrade solution is also presented: the CsI(Tl) crystals of the present calorimeter are retained, and the present readout photodetectors (pin diodes) are complemented with two APDs. This scheme is appealing because good detector performance are obtained, without replacing the crystals. The upgrade would then be much less expensive and invasive, and one could in principle consider to extend it not only to the endcap but to the whole calorimeter.

4 K_L and Muon Detector

After the completion of the K_L and muon (KLM) front end electronics construction, test and installation last year, in 2018 the Frascati group took the responsibility of the maintenance of the installed system.

During the installation performed by the group at the end of 2017, a problem was found with some of the VME crates housing the front end cards: their power supplies were barely sufficient to power all the thirteen new boards, causing failures in the programming of the boards' FPGAs and the consequent loss of the entire KLM RPC sector connected to that crate ($1/16^{th}$ of the whole barrel). The decision was thus made by the KLM group to replace all of the 16 aging VME crates with new ones. The procurement process started in Summer 2018, with delivery expected by Spring 2019.

In the meantime, in order to be able to operate the full detector during Phase 2 and Phase 3, we operated on the old crates' power supplies to raise their current limits; with this temporary fix, by the end of 2018 all the RPC front end electronics were perfectly working.

The Frascati group also actively participated in the KLM detector Phase 2 data taking operations between March and July, and to the analysis of the KLM performance, described elsewhere in this report.

Another important contribution of the Frascati group has been the implementation of remote indirect programming capability in the front end electronics firmware of the VME controllers, called Data Concentrators (DC), interfacing with the front end boards in the crates.

Data concentrators store the firmware for the KLM RPC boards in their internal memory. At power on, the DCs upload the boards firmware from their internal flash memory to all the KLM RPC boards present in the same crate. To allow updating of the front end electronics firmware remotely, the DC firmware was modified to allow the use of JTAG programming via the slow control chain of the data acquisition system (FTSW boards), which eliminates the need to gain physical access to the DCs, thus greatly improving the development and debugging cycle of the front end electronics firmware.

5 Appointments and Responsibilities

Individual responsibilities of the group members in 2018 are listed below
- G. Finocchiaro: Belle II National Representative in CSN1 and Italian member of the Belle II Financial Board.
- R. de Sangro: coordinator of barrel KLM electronics construction and Belle II Shift Manager.
- B. Oberhof: responsible for K_L reconstruction at analysis level and modeling of CP-violating B decays.
- I. Peruzzi: Chair of the Belle II Speakers Committee.

6 Contributions at International Conferences

- R. de Sangro, "Belle II Status and Prospects", 56^{th} International Winter Meeting on Nuclear Physics, 22-26 January 2018, Bormio, Italy.
- B. Oberhof, "Precise measurements of CP violation in B decays at Belle II", plenary talk, HQL 2018, 27 May-June 1 2018, Yamagata Terrsa, Yamagata, Japan.
- B. Oberhof, "Belle II prospects for the mixing and CPV in B decays", CKM 2018, 17-21 September 2018, Heidelberg, Germany.

References

1. R. de Sangro, G. Finocchiaro, M. Piccolo, B. Oberhof, *"Study of K_L reconstruction at Belle II using the ISR reaction $e^+e^- \to \phi\gamma$"* BELLE2-NOTE-TE-2018-007, June 2018.
2. 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.
3. R. de Sangro, G. Finocchiaro, M. Piccolo, B. Oberhof, *"Observation of the $J\psi$ meson produced in $e^+e^- \to J\psi\gamma$ events in early Belle II data"* BELLE2-NOTE-PH-2018-021, June 2018.
4. R. de Sangro, G. Finocchiaro, M. Piccolo, B. Oberhof, *"Comparison of cosmic-ray data results for different forward ECL upgrade options"*, BELLE2-NOTE-TE-2017-015, July 2018.