Belle II

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In collaboration with:
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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) as well as hints from Babar and Belle, for example in $B \to D^{(*)}\tau\nu$ decay rates. 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.

The LNF group joined the Belle II collaboration in July 2013, together with eight other INFN Institutions, for a total of about 60 physicists. The new machine, called SuperKEKB, has now been completed and commissioning has started. 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) is being built, a new drift chamber (CDC) with smaller cell size has been built, the particle identification system will include a new Time Of Propagation (TOP) detector. The barrel CsI crystals, thallium doped,

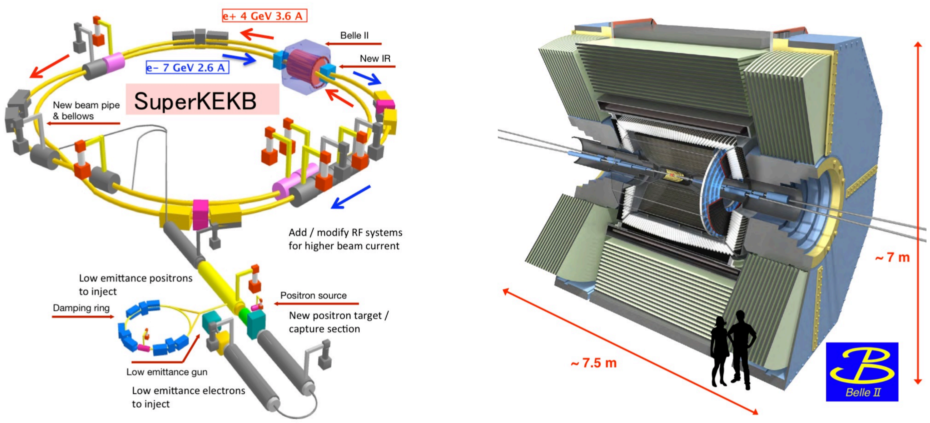

Figure 1: Overview of the SuperKEKB B-factory (left) and Belle II detector (right). In color the new or updated parts of SuperKEKB with respect to KEKB.

EM calorimeter (ECL) will be provided with new readout; studies are being carried on for the end caps upgrade. In the K_L and muon detector (KLM) only the outer barrel layers of glass RPCs will be re-used, the remaining will be 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 will be 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 will start by the end of March 2018 with the goal of reaching KEKB peak luminosity; during summer 2018 shutdown the vertex detector will be installed and Phase 3 data-taking, with full Belle II detector, is scheduled to start by the end of 2018.

Our 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 our group's main activities during 2017.

2 Software & Analysis

Since our group joined Belle II it has been involved in the development of software for the Belle II software system, called basf2 i.e. Belle Analysis Framework 2, focused, in particular, on the reconstruction performance of the ECL. Currently we are involved in various tasks related to development, revision and validation of the code and evaluation of physics performance. One of the tasks is the identification and reconstruction of neutral (long-lived) K mesons (K_L) using calorimetric information; we have performed various studies using Multi Variate Analysis (MVA) techniques in order to increase signal to background ratio as well as to improve K_L reconstruction performance. In Belle II, each energy deposit in the ECL is treated under different assumptions (γ, neutral hadron, etc..) and for each of this hypotheses a different clustering algorithm is used in order to optimize relevant quantities for each kind of particle, for every event all hypotheses are kept and it's then up to the analyst which hypothesis to choose based on the likelihoods and the analysis he performs. Based on our studies we implemented a new reconstruction algorithm for the K_L, which improves K_L ID as well as resolution on K_L flight direction up to a factor of 2. Motivated by the involvement of the LNF group in both ECL and the KLM (KL and Muon detector) sub-detector systems we decided, as first physics analysis task, to study the measurement of the time-dependent CP violation asymmetry in $B \to J/\Psi K_L$. $B \to J/\Psi K_L$ along with the CP-conjugate $B \to J/\Psi K_S$ is a "golden channel" for the measurement of the CKM angle β (ϕ_1) and,

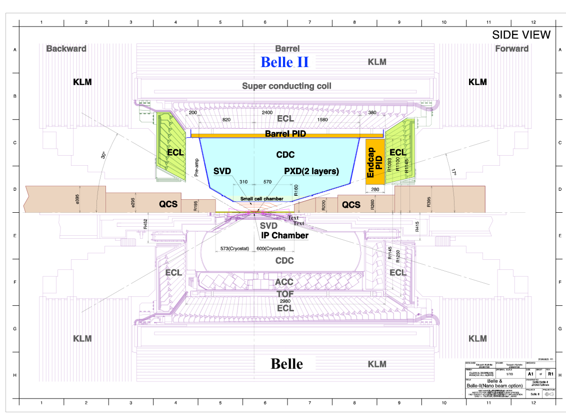

Figure 2: Comparison among the Belle (bottom) and Belle II (top) detectors. In color the updated parts.

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, and hence it will be an important test to understand actual detector performance for neutral kaons, especially in view of the first run with the full Belle II detector scheduled for mid-2018.

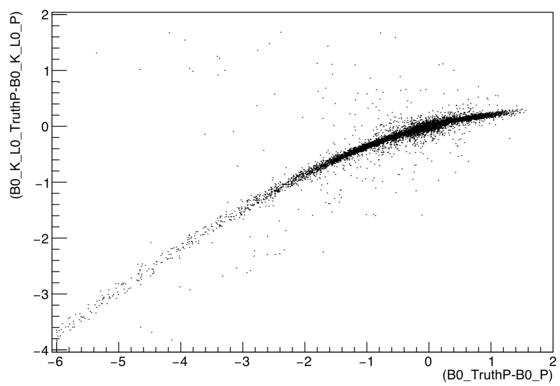

Figure 3: Correlation for the difference of true and reconstructed momentum between K_L (y-axis) and B (x-axis) momenta in $B \to \phi K_L$ decays.

Our MC-based analysis is actually the first analysis inside the Belle II collaboration involving K_Ls, as well as the first completely performed on our recently launched grid computing network. The analysis is now in an advanced state and a detailed background study is ongoing. Based on our analysis experience we also corrected and updated the official Belle II branching fractions and decay models of the EvtGen MC generator for the time dependent CP violation (TDCPV) modes and are currently responsible for their maintenance acting as liaison between the Belle II TDCPV physics group and the MC developers. Based on our experience in KL reconstruction we have been assigned to the definition and maintenance the K_L candidate lists which merge the information from the ECL and the KLM to provide a new "combined-cluster" object which improves physics performance and which are used as default lists by analysts. Being in charge of this new tasks we recently started also to study K_L reconstruction in $e^+e^- \to \phi\gamma$ where $\phi \to K_L, K_S$ or K^+K^- at the CM energy of the $\Upsilon(4S)$ in order to determine Belle II K_L reconstruction efficiency during Phase 2 data-taking. Besides the activities related to or focused on neutral hadron reconstruction and physics analysis we are also completing simulations for the upgrade option of the forward (FWD) end-cap of the ECL with pure

CsI crystals. In fact a completely new algorithm for photon clustering w.r.t. to Belle was recently introduced in Belle II in order to cope with the much higher expected background levels. The new clustering algorithm optimizes the number of crystals in the shower based on raw deposited energy and expected background level in each detector region in order to get the best possible resolution on photon energy. We have developed a fully equivalent reconstruction chain for a pure CsI FWD end-cap and are now fine-tuning the parameters of the algorithm to get the final comparison among CsI and CsI(Tl). This is crucial to compare performance of the new hardware configuration with state-of-the-art reconstruction software, and to conclude the R&D on the upgrade of the forward calorimeter previously carried out at Frascati. Besides we also maintain previously developed code for the official validation of ECL related quantities which is run centrally on daily basis and used by software shifters to monitor the performance of the development version of the code.

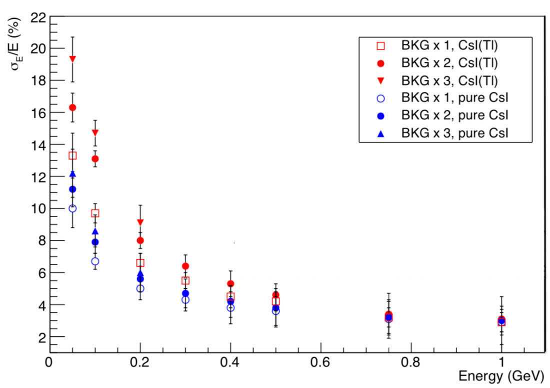

Figure 4: relative energy resolution of the ECL with baseline configuration and with pure CsI upgrade option in the FWD endcap for various beam-background levels.

3 R&D on Pure CsI

One of the Belle II activity in which our group was involved is the study of a possible upgrade of the EM calorimeter in the forward end cap. For the Thallium-doped CsI crystals used by Belle, the concern existed of radiation damage and of high pile-up levels, especially at small polar angles. For this reason, at least part of the crystals in the forward region might be replaced with pure CsI crystals. Non doped CsI has in fact improved radiation hardness and much faster light decay time (6/35 ns for the two main components, compared to 1.2 μs in CsI(Tl)). Pure CsI yields, however, much less light, and has the emission peak of the fast components at 310-420 nm wavelengths. An intensive R&D program was carried out to study a possible upgrade solution in the past years, which was completed in 2016. The experimental program was performed on single CsI(Tl) and pure CsI crystals, readout with UV-extended APDs on pin diodes.

In 2017 our group worked on documenting all this R&D work, which resulted in the publication of three internal Belle II technical notes. The most relevant results include a complete characterization of the CsI and CsI(Tl) crystals in terms of number of primary photoelectrons, correlated and uncorrelated components of the equivalent noise energy, relative energy resolution and stochastic fluctuations due to light fluctuations. We also devised a technique to measure the absolute APD gain in the actual operating conditions, and thus determined the excess noise factor. Finally, using a high-intensity ^{60}Co source operated in the "Laboratorio Sorgenti" at LNF, we studied the effect of pile-up due to low-energy particles, and set up simulations to extrapolate the results to different background levels.

4 K_L and Muon Detector

In 2016 the Belle II group presented to CSN1 the case for joining the K_{L} and muon (KLM) detector effort with the construction, test, installation and maintenance of the readout electronics for the RPC system in the barrel; this was an outstanding missing piece of the Belle II detector upgrade. After the CSN1 in spring 2016 approved and funded this activity, which is carried out by the LNF in collaboration with the RM3 INFN section, in fall 2016 a bid for the construction of all the 250 boards was started and then awarded to an outside firm by the end of the year.

In 2017 the boards production was started. After a pre-production in late January, the tests performed in Frascati revealed some problems which were discussed with the production company and addressed. After a second pre-preproduction was completed in April and passed the thorough Frascati acceptance tests, the full production was started in May and delivered to Frascati for the acceptance test; the last boards of the full production were delivered at the end of June.

In the meantime, the accepted boards were shipped to the KEK laboratory in Japan, where they were installed and commissioned on the Belle

II KLM detector. Three installation periods in June, July and October, led to the completion of the instrumentation of the full barrel RPC detectors in time for the start of the global cosmic ray tests in fall of 2017, respecting the foreseen delivery schedule.

5 Appointments and Responsibilities

The individual responsibilities of our group members are:
- R. de Sangro is INFN coordinator of barrel KLM italian group.
- G. Finocchiaro is the Belle II National Representative in CSN1 and Italian member of the Belle II financial board.
- B. Oberhof is responsible for K_L reconstruction at analysis level and modelling of CP-violating B decays.
- I. Peruzzi is the chair of the Belle II Speakers Committee.

6 Contributions at International Conferences

[1] R. de Sangro, "SuperKEKB and Belle II Status Report", FPCP 2017, Prague, Czech Republic, 5-9 June 2017, PoS FPCP **2017**, 2017, 037.

[2] G. Finocchiaro, "Status and prospects of the Belle II experiment", CIII Congresso della Societá Italiana di Fisica, Trento, Italy, 11-15 September 2017.

[3] G. Finocchiaro, "Belle-II Status", Beyond the LHCb Phase-1 Upgrade Workshop, Portoferraio, Italy, 28-31 May 2017.

7 Publications

[1] T. Bilka *et al.*, "The track finding algorithm of the Belle II vertex detectors", EPJ Web Conf. **150** (2017) 00007.

[2] C. Cecchi *et al.*, "The Belle Electromagnetic Calorimeter and its Upgrade to Belle II", JINST **12** (2017) no.07, C07032.

[3] E. Manoni *et al.*, "The upgrade of the Belle II forward calorimeter", Nucl. Instrum. Meth. A **845** (2017) 524.

[4] P. M. Lewis *et al.*, "First Measurements of Beam Backgrounds at SuperKEKB", arXiv:1802.01366 [physics.ins-det].

8 Technical Notes

[1] R. de Sangro *et al.*, Study of pileup effect on CsI(Tl) and pure CsI crystals performance, [BELLE2-NOTE-TE-2017-007].

[2] R. de Sangro *et al.*, Characterization of Large-Area APD, [BELLE2-NOTE-TE-2017-006].

[3] R. de Sangro *et al.*, Performance study of CsI(Tl) and pure CsI crystals with cosmic rays, [BELLE2-NOTE-TE-2017-005].