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 KEKB (Tsukuba, Japan) and PEP-II (Stanford, USA) B-factories, respectively. Most of the measurements done at B-factories are in agreement with the Standard Model although there are hints of possible deviations that require further study. Moreover, nowadays, there is compelling evidence for New Physics beyond the Standard Model from other 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.

The LNF group joined the Belle II collaboration in July 2013, together with eight other INFN Institutions, for a total in 2016 of about 60 physicists.

The new machine, called SuperKEKB, has now been completed and commissioning has started. Because of the higher level of background expected when SuperKEKB will operate at its design peak luminosity of 8×10^{35}cm$^{-2}s^{-1}$, the new detector must cope with higher occupancy and radiation damage than the Belle detector.

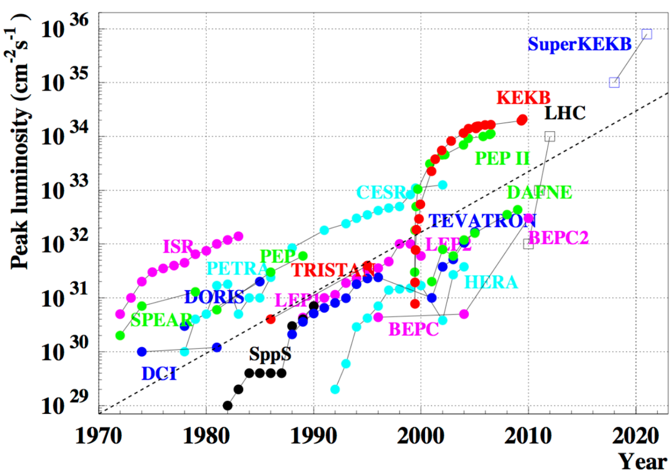

Figure 1: The SuperKEKB peak-luminosity compared to existing and past colliders.

To be able to operate in these extreme conditions, most components of the Belle detector are either being 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 thallium doped CsI crystals of the electromagnetic calorimeter (ECL) have been equipped with enhanced readout electronics, while studies are being carried on for the endcaps upgrade. In the K_L and muon detector (KLM) only the outer barrel layers of glass RPCs will be re-used, the remaining have been substituted with scintillation counters. All the new, or upgraded, Belle II sub-detectors are in advanced stage of preparation, and the data acquisition has been integrated. Commis-

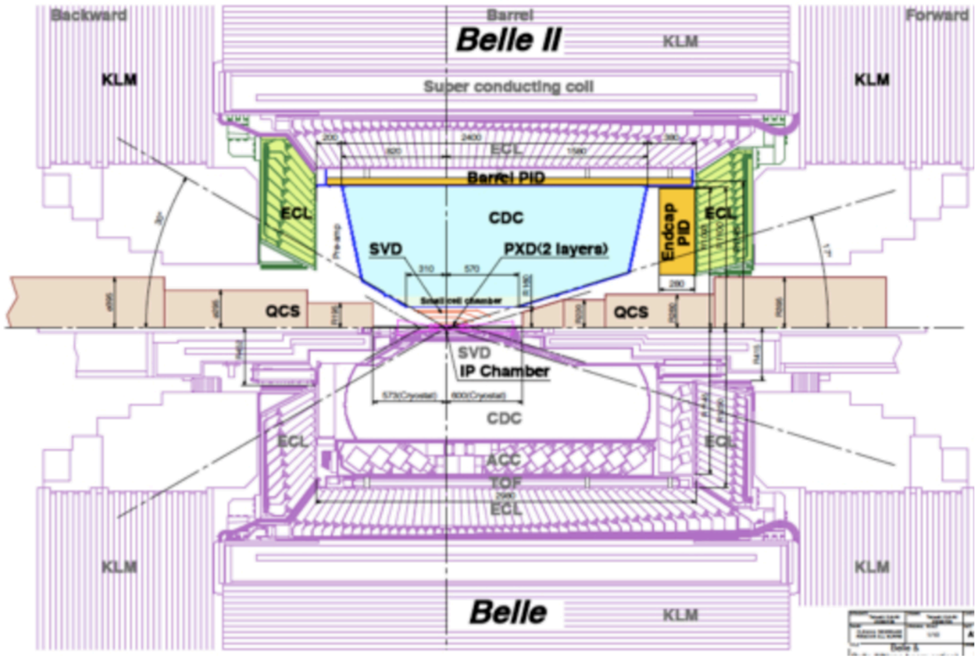

Figure 2: Comparison among the Belle (bottom) and Belle II (top) detectors. In color the updated parts.

sioning (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. The roll in of the Belle II detector will take place in April 2017, and the vertex detector will be replaced by a modi?ed version of BEAST II. After a global cosmic run the second phase of commissioning (Phase 2) and first physics runs will start in early 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 is involved in various Belle II activities 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 contributions during 2016.

2 R&D on Pure CsI

A possible upgrade of the existing system is the replacement of the relatively slow Thallium-doped crystals with faster and radiation hard pure CsI ones. We studied two main aspects: the radiation hardness of the existing CsI(Tl) crystal calorimeter, and the effect of pile-up due to the expected higher background levels at the SuperKEKB accelerator.

In 2016 we performed a complete characterization of three CsI(Tl) crystals and one pure CsI crystal using cosmic rays, measuring number of primary photoelectron, equivalent noise energy (ENE) and energy resolution.

Moreover, we performed a thourough comparative study of the effect of pile-up from low-energy photons on the response of pure CsI and CsI(Tl) crystals in cosmics using a data-driven and a Toy MC background simulations, and a high-intensity ^{60}Co radioactive source, to reproduce the high background conditions expected during the Belle II data taking.

In Figure 3 the Equivalent Noise Energy (ENE) for the CsI(Tl) crystal is shown as a function of the front-end electronics shaping time. We observe that for CsI(Tl) the ENE in

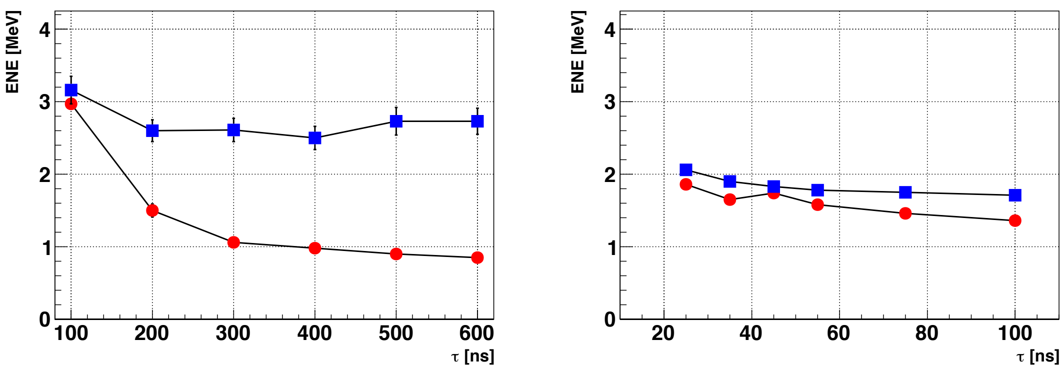

Figure 3: ENE for a CsI(Tl) crystal (left) and a pure CsI crystal (right), as a function of the front-end electronics shaping time shaping time. Red circles: data without the ^{60}Co source; blue squares: data with the ^{60}Co source.

the presence of background is rather pronounced. On the contrary, the effect is minimal for pure CsI. This is due to the much faster light emission time of the latter. On the other hand, the much lower light yield of pure CsI crystals leads to a worsening of the stochastic fluctuations observed in our measurements. This unfortunately offsets almost completely the better performances of pure CsI in terms of ENE.

3 BEAST

The commissioning of SuperKEKB is staged in three phases. During Phase 1 from February to June of 2016, the beams were accumulated in the main rings, with currents as high as 1 Ampere. The goal of phase 1, along with basic tuning of the optics and vacuum scrubbing, was the study of beam backgrounds. The ECL group participated in the BEAST II phase 1 experiment with a detector system made of six boxes, each containing a pure CsI, a LYSO and also a CsI(Tl) crystal, all readout with photo-multipliers. The experiment was run for about five months in 2016, when the crystal detectors ran smoothly and collected data recording the rates and the energy of low energy hits produced by the beams circulating in the SuperKEKB rings. Several measurements were performed with the BEAST crystal detectors to validate the

Monte Carlo simulation, and to characterize the beam backgrounds. As an example, Figure 4

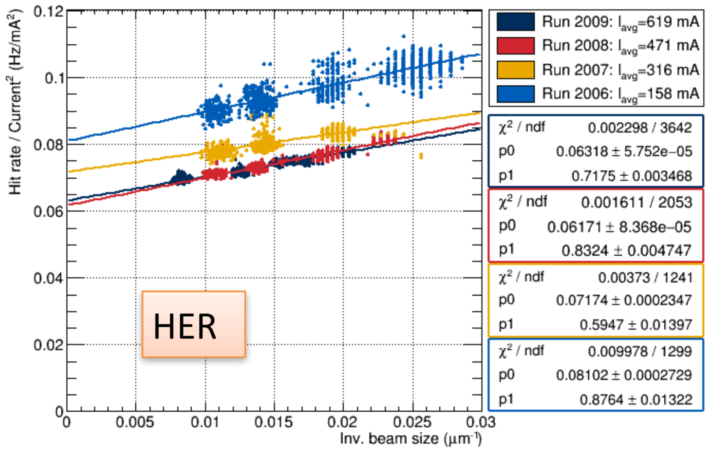

Figure 4: Background rates measured in CsI crystals vs. inverse beam size.

shows background rates in the CsI crystals as a function of the inverse beam size of the High Energy Ring (HER). A clear linear behavior is observed, which allows to separate Touscheck-related from beam gas-related backgrounds. The different colors refer to runs in which the beam currents and optics settings were changed, thus affecting the beam gas contribution to backgrounds. Another issue studied with the crystal detectors in BEAST is the time structure of the injection background, which is a crucial element to selectively veto the electromagnetic calorimeter DAQ during the injection of a given bunch. We show in Figure 5 a plot of the

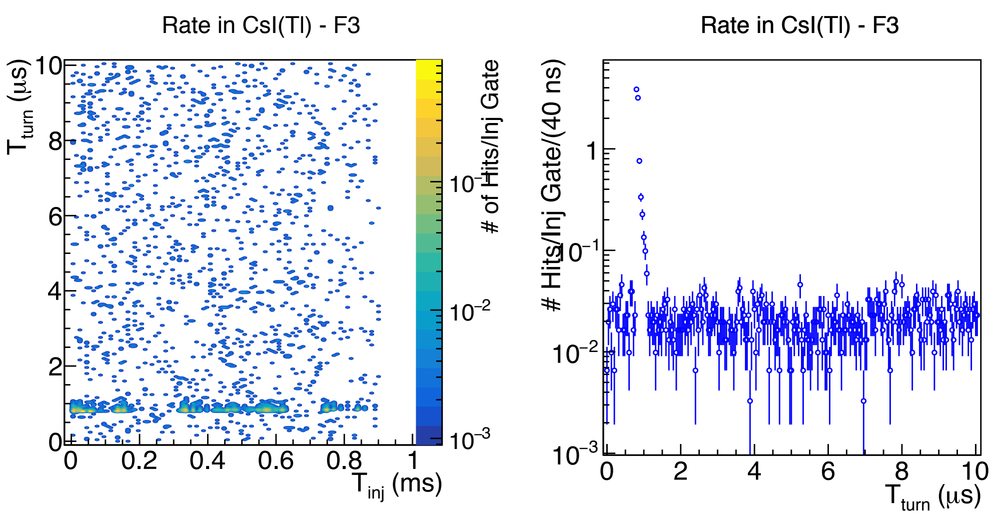

Figure 5: Background rates timing structure.

time within one revolution (vertical axis) versus the time after injection (horizontal axis) of the background rates. Clearly, the background is highly correlated with the time of passage of the injected bunch through the interaction region. This scatter plot shows that the hits time cluster around that of the injected bunch in an interval of about 100ns around the time of the injected bunch, and that the rates remain high for several tens of turns after the injection ($\mathcal{O}(1\,\mathrm{ms})$). This study allows the determination of a timing scheme for the acquisition veto that is highly efficient in cutting the background, while keeping the total dead time within a reasonable few percent.

4 Software & Analysis

Since the beginning, our group has been involved in the development of software for the Belle II software system, focusing in particular on the reconstruction performance of the ECL. Currently we are involved in projects for the development, revision and validation of the calorimeter-related code, including physics performance.

One of the responsibilities of the LNF group is the identification and reconstruction of neutral (long-lived) K mesons 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 separate non-hadronic contributions in shower overlap, and started to develop dedicated clustering algorithms in order to improve K_L reconstruction performance. Following the recent involvement of our group in the commissioning of the KLM, the next step will be the merging of the information from the ECL and the KLM to provide a new "combined-cluster" object to further improve physics performance.

In view of the first run with the full Belle II detector scheduled for mid-2018 we have recently started to study the time dependent CP violation in $B \to J/\psi K_L$ using the full Belle II simulation (Figure 6). $B \to J/\psi K_L$ 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, in fact, the first observation of CP-violation in the $B^0\overline{B}^0$ 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. Besides this more recent activities, we have performed simulations for the upgrade of the forward endcap of the ECL with pure CsI crystals with benchmark physics channels, to understand the expected performance of the new hardware configuration, and to finalize the R&D on the upgrade of the forward calorimeter carried out at Frascati. We also maintain previously developed code for the official validation of ECL related quantities which is run centrally on daily basis and

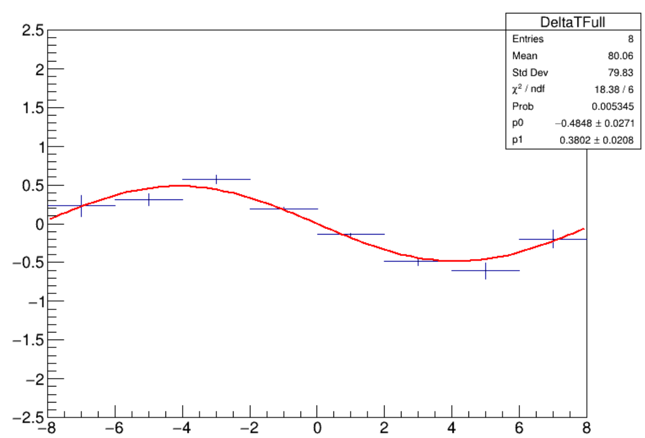

Figure 6: Preliminary result for the asymmetry $(N_{B^0} - N_{\bar{B}^0})/(N_{B^0} + N_{\bar{B}0})$, where $N_{B^0} = N(B^0 \to K_L J/\psi)(\Delta t)$ and $N_{B^0} = N(\bar{B}^0 \to K_L J/\psi)(\Delta t)$, as functions of Δt.

used by software shifters to monitor the performance of the development version of the code.

5 K_L and Muon Detector

In 2016 the Belle II group presented to CSN1 the case of joining the KLM detector effort with the construction, test, installation, and maintenance of the readout electronics for the RPC system in the barrel KLong and Muon detector (previously an outstanding missing piece of the Belle II detector upgrade). After thorough discussion, CSN1 approved and funded this activity, which is carried out by the LNF in collaboration with the RM3 INFN section. The responsible person for this activity is a member of the Frascati group.

A small pre-production of three readout boards was done, and the boards were tested successfully both in the Frascati laboratory and on a test bench in Indiana University. Later the boards were also integrated in the Belle II RPC system at KEK, showing good behaviouor. A bid for the construction of all the 250 boards was then started.

6 Appointments and Responsibilities

We resume hereby individual responsibilities of our group members:
- R. de Sangro is coordinator of barrel KLM electronics construction and National Representative of the BEAST II crystal subsystem, as well as editor of the related NIM paper.
- G. Finocchiaro is the Belle II National Representative in CSN1, and Italian member of the Belle II financial board.
- I. Peruzzi is the chair of the Belle II Speakers Committee.

7 Contributions at International Conferences

- G. Finocchiaro,"Belle II Status and Prospect", 11th Franco-Italian Meeting on B Physics, LPNHE, Paris, 11-13 April 2016.
- B. Oberhof, "Status and perspectives of τ g-2 measurements", MIAPP Workshop "Flavour Physics with High-Luminosity Experiment" & Belle2 Theory Integration Platform, MIAPP, Munich, 24 October-18 November 2016.

8 Publications

- E. Manoni *et al.*, *The upgrade of the Belle II forward calorimeter*, Nucl. Instrum. Meth. A**845**, (2017).
- A. Aloisio *et al.*, *A pure CsI calorimeter for the Belle II experiment at SuperKEKB*, Nucl. Instrum. Meth. A**824**, (2016).
- S. Fiore *et al.*, *APD readout for Belle II endcap calorimeter upgrade with undoped Cesium Iodide crystals*, IEEE Xplore, 10.1109/NSSMIC.2014.7431163.