Belle II

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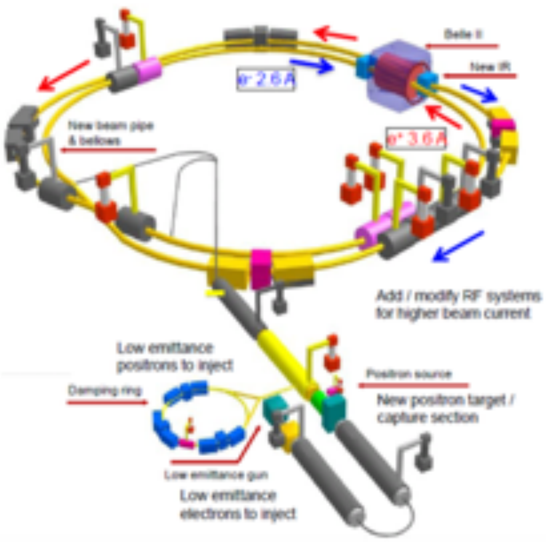
Introduction

The Belle II Collaboration follows the path defined by the Belle and BaBar experiments at the B-factories KEKB (KEK, Japan) and PEP-II (SLAC, USA). The most important heritage of these two experiments is the discovery of the CP-violation in the neutral B meson system and the proof of the Cabibbo-Kobayashi-Maskawa quark-mixing mechanism. All the measurements made at B-factories were found to be in agreement with the Standard Model, however there is now 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, in 5 years of data taking at its design luminosity of 8×10^{35} cm^{-2} s^{-1}, a data sample 50 times larger than that jointly recorded 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 more than 50 physicists.

The new machine, called SuperKEKB, has now been completed and commissioning has started. Because of the increased level of background associated with the higher luminosity, the Belle II detector has to cope with higher occupancy and radiation damage than the Belle detector. To be able to operate at the SuperKEKB collider, several 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 present CsI(Tl) crystals EM calorimeter (ECL) has been equipped with new readout electronics. 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. All the new, or upgraded, Belle II sub-detectors are in advanced stage of preparation, and the data acquisition has been almost fully integrated. The present

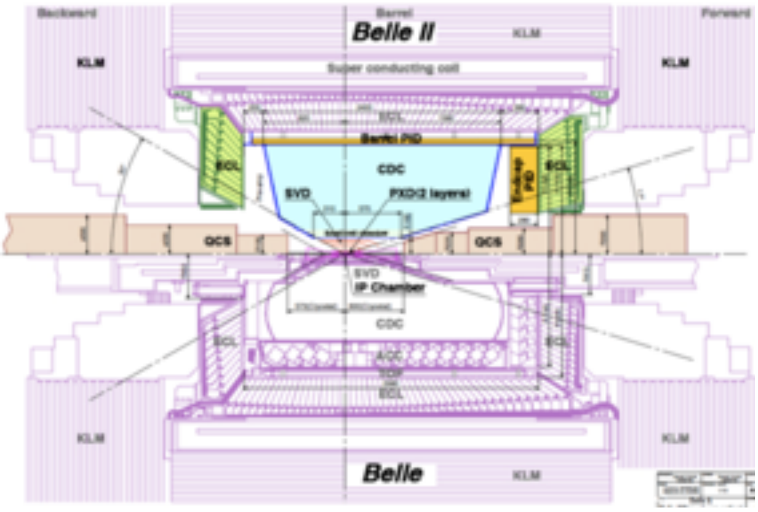


Fig. 2: comparison among the Belle (bottom) and Belle II (top) detectors. In color the updated parts.

schedule calls for first Physics in 2017. The Frascati group is participating to the R&D program related to the upgrade of the EM calorimeter in the forward end cap. There are serious concerns that the Thallium-doped CsI crystals used in the present calorimeter may suffer from radiation damage and high pile-up levels in the higher background environment of SuperKEKB, especially at small polar angles. For this reason, studies are ongoing for a possible upgrade of at least part of the crystals in the forward region, which may be replaced with pure CsI crystals. Non doped CsI has indeed better radiation hardness, and much faster light decay time (~30 ns), compared to that of CsI(Tl) (~1.2 μs). The light yield of pure CsI, however, is much lower and the emission peak of the fast components is at ~310 nm wavelengths, where photon sensor have diminished quantum efficiency. The PIN photodiodes reading the present CsI(Tl) crystals would therefore have to be replaced by photo detectors best matching these characteristics, that is having larger gain and higher efficiency in the near-UV region. The Frascati group also plays an active role in the revision of the software for the EM calorimeter, which is necessary because the expected data rate and size of Belle II is much higher than Belle, and of the same order, or even higher, than the one of an LHC experiment.

R&D on pure CsI

Following our previous work on the APD read-out for pure CsI, and the study of radiation hardness of both CsI(Tl) and pure CsI done in 2014, which showed that CsI(Tl) is relatively radiation resistant, we have studied the effect of the increased beam-background rate of SuperKEKB on the performance of the present ECL. The pile-up of low energy beam-background is expected to be an important source of noise limiting the low energy resolution of the ECL; the cumulation of these background hits modifies the baseline and peak of the signal hits, changing the value of the measured amplitude. The fluctuation on this change adds in quadrature to the electronics noise and the other fluctuations on the energy measurement and are particularly important at low energies (~50-100 MeV). We have studied the effect of pile-up on the resolution of the forward calorimeter using signals obtained both from cosmic rays and a toy-MC simulation. For the cosmic data the (baseline) we have used some spare Belle CsI(Tl) crystals equipped with PIN diodes and standard Belle pre-amplifiers, while pure CsI crystals have been equipped with Hamamatsu LAAPDs and commercial CREMAT CR-110 preamplifiers. The Belle CsI(Tl) crystals used for this run had previously been irradiated with 250 Gy, which corresponds approximately to a 25% loss in light

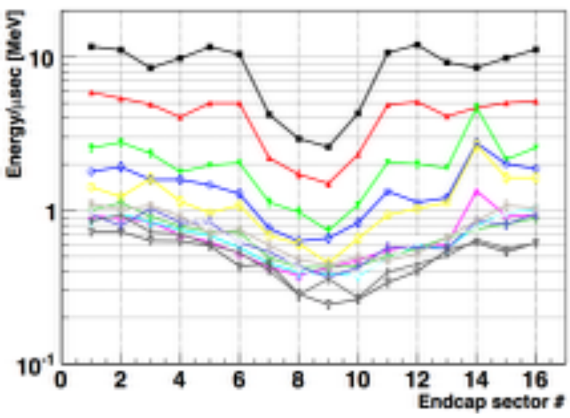


Fig. 3: expected beam-background in the 13 rings of the forward endcap of the EM calorimeter, in terms of energy/time, from innermost (top) to the outermost (bottom) ring as a function of the azimuthal angle.

yield. Background hits are simulated using cosmic ray waveforms, buffered from previous events. The expected background rate and energy distribution is obtained from the official Belle II beam-background MC simulation. The amplitude of the buffered event is rescaled to obtain the expected amplitude for a background hit. For the MC based approach we simulate the pile-up of signals coming from background photons inside a pure CsI crystal with an analytical function whose parameters are obtained from a fit to cosmic ray data. We exploit the long time constant of the CREMAT CR-110 preamplifier we used to read out the LAAPDs, which preserves the features of the slower components of scintillation light in pure CsI crystals. Due to large uncertainties which affect the current background simulation we applied safety factors up to a factor of 3 on the nominal expected rate; given the background levels currently predicted in crystals within the forward ECL acceptance, we do not see clear improvement in energy resolution for an upgrade with a pure CsI crystals with APD read-out; with this configuration pure CsI performs better than CsI(Tl) up to 500MeV photon energy only when a x3 safety factor is applied to the expected background level and only on the innermost rings used for cluster seeding.

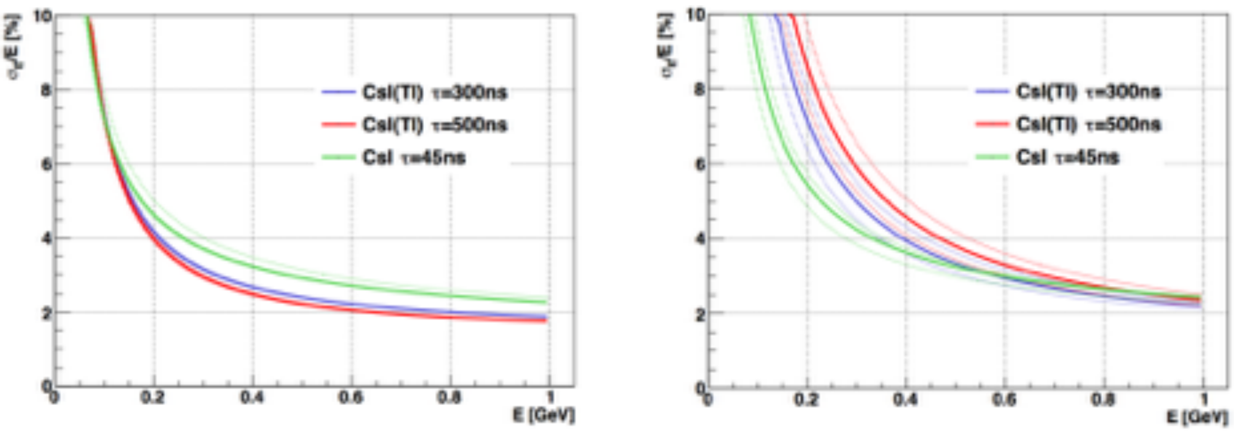


Fig. 4: energy resolution for pure CsI and CsI(Tl) for different shaping time constant for the nominal Belle II background rate (left) and applying a 3x safety factor (right).

Software development

In order to cope with higher expected background conditions, not only sub−detector upgrades but also upgrades of the data acquisition and offline computing systems are foreseen. Both systems use a common software framework with ROOT as persistency layer, allowing the efficient use of modern multicore machines. The Belle II software system, *basf2* i.e. *Belle Analysis Framework 2,* uses C++ object oriented software. The framework consists of functional objects called modules involving event generation, Monte Carlo (MC) simulation, track and cluster reconstruction, particle identification and physics analysis. *Basf2* uses dynamic module loading, with the steering of the framework done via python, and has capabilities of parallel processing. Our group is currently involved in many tasks related to development, revision and validation of the calorimeter related code and evaluation of physics performance. In particular, we performed various studies on the effect of the material budget of the inner detectors to have a realistic estimates of (in)efficiencies, which are particularly important in the endcaps, as well as a map of interaction vertexes which will be useful to improve reconstruction capabilities as well as tracking performance. A new version of the ECL Digitizer module, used in Monte Carlo to reproduce the signal shaping from the new calorimeter hardware configuration, has recently been developed to reproduce the behaviour of pure CsI crystals, and the group is testing it within Belle II reconstruction framework. We have also 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. The correct matching of the MC information to the data-like reconstructed quantities, identifying signal and background processes, represents a key ingredient for reconstruction optimization and is also one of the tasks assigned to the LNF group.

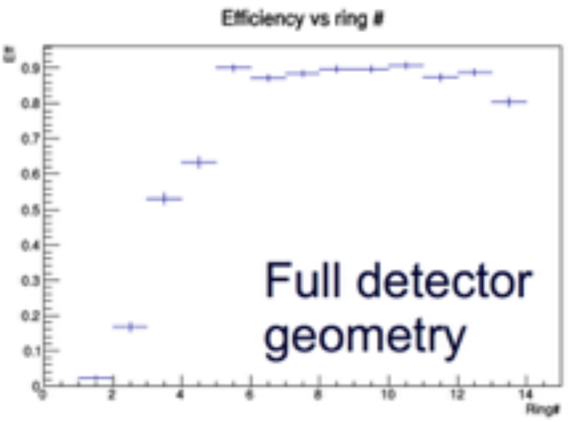


Fig. 5: photon detection efficiency as a function of the ring number of the forward endcap of the EM calorimeter. The shielding effect due to the inner tracking detectors can clearly be seen on the innermost rings.

Other tasks recently assigned to the LNF group include the identification of neutral K mesons using calorimeter information only and the analysis of benchmark physics channels to understand the expected performance of new hardware configurations, and to take the final decision on the upgrade of the forward calorimeter.