PROCEEDINGS OF SCIENCE

# B-Lab : Open Data Analysis Program using Belle data

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B-Lab is an open data analysis program to give members of the public a taste of particle physics by presenting tools to search real experimental data for particle decays. This program started as an outreach program for Belle experiment, targeting high school students. It utilizes an adapted data sample of 1.3fb$^{-1}$ of the real experimental $e^+e^-$ collisions accumulated at KEK by the Belle detector. The overview of B-Lab and the activity is presented. We also introduce BellePlus, a 4-day summer program for high school students held annually at KEK, where B-Lab is used as one of the studies.

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## 1. B-Lab

B-Lab [1] is an outreach program for Belle experiment [2], started in 2004. The main target of the program is high school students, but anyone who made a registration can participate in the program. In the B-Lab program, we provide 1.3fb$^{-1}$ of the real experimental data taken by the Belle experiment, examples of analysis codes, and textbooks. B-Lab is a first trial of the open data program in the field of high energy physics.

The data contains the information of particles detected at Belle, namely $\pi^{\pm}$, $\pi^0$, $K^{\pm}$, $K^0_S$, $p$, $\bar{p}$, $e^{\pm}$, $\mu^{\pm}$ and $\gamma$. Here, although $\pi^0$ and $K^0_S$ are not directly detected in the Belle detector, these particles are treated as final state particle after reconstruction with Belle standard software through $\pi^0 \to \gamma\gamma$ and $K^0_S \to \pi^+\pi^-$. The data is provided in ROOT format, in the combination of 4-momentum, charge ($\pm 1$ or 0) and particle identification ($\pi$, $K$, $p$, $e$, $\mu$, $\gamma$).

The analysis is done using ROOT with C++ source codes. A few simple example codes to reconstruct a particle from two body decays are prepared. Figure 1a is the histogram from an example code to reconstruct $K^0_S \to \pi^+\pi^-$. The peak from $K^0_S$ is seen around 0.5 GeV, but it is not so clean because no vertex information is available in B-Lab.

The textbook describes how to run these example codes on ROOT, after the introduction of the elementary particle physics and reconstruction of particles. There are a few exercises to reconstruct $\phi$ or $J/\psi$ particles, where participants are requested to modify the example source codes. The modification is easy: they need to replace the particles used in the reconstruction and modify the range of the histogram. The last two excercises are the reconstructions of $B^+ \to J/\psi(\to e^+e^-, \mu^+\mu^-)K^+$ and $D^{*+} \to D^0(K^-\pi^+)\pi+$, which require major modification of the source codes.

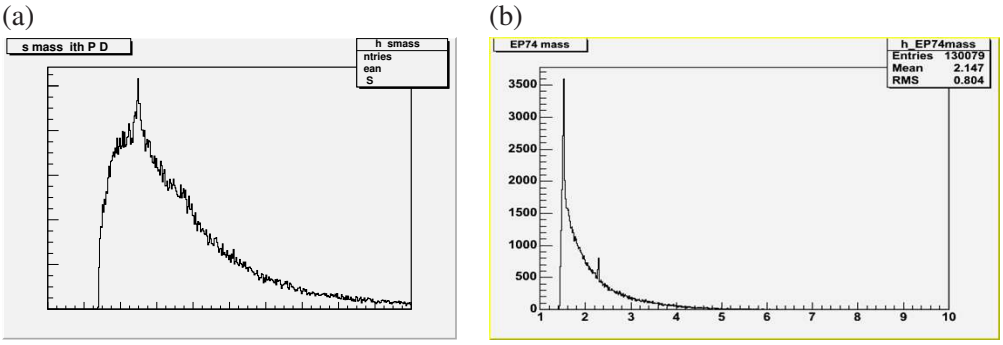


**Figure 1:** (a) Invariant mass distribution obtained from the example code to reconstruct $K^0_S \to \pi^+\pi-$. (b) Invariant mass distribution reported by a group of Japanese high school students, where $\Lambda_c^+ \to pK^-\pi^+$ was "discovered". The unit of the holizontal axis is GeV for both the histograms.

The target of B-Lab is to search for "unknown" particle in the data. One can reconstruct the particles like $\eta$, $\Lambda$, $K^*$, $D$ from two body decays. The reconstruction of three body decays is relatively difficult. $D^+ \to K^-\pi^+\pi^+$, as well as $B^+ \to J/\psi K^+$, $D^{*+} \to D^0\pi^+$ in the excercises, is possible to reconstruct. In addition, several more new particles and processes are "discovered" by participants, which was rather unexpected for us. A group of Japanese high school students successfully reconstructed $D_s \to K^-K^0_S$, $\Lambda_c^+ \to pK^-\pi^+$ (Fig. 1b) and $\Lambda_c^- \to \bar{p}K^0_S$. This achievement was reported in a Japanese newspaper. Other students and participants independently reported

a mass peak at 10.58 GeV in various final states, which corresponds to the processes such as $e^+e^- \to \mu^+\mu^-\mu^+\mu^-$.

In principle, all the necessary information to learn B-Lab is available in the web, but we also deliver a lecture of B-Lab upon request from high schools. We have this kind of lecture several times per year, and typically around 10 high school students attend in each lecture.

Figure 2 shows the number of participants to the B-Lab program. Approximately 1400 people have participated in this program.

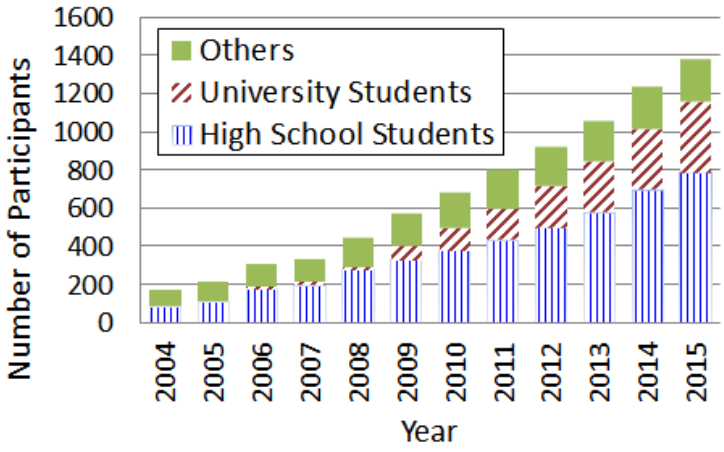


**Figure 2:** Number of participants to B-Lab.

Looking at the students who attended a lecture of B-Lab, there seem no difficulty in searching a particle from two body decays. They enjoy looking for a peak, even if they do not understand how the reconstruction is done. On the other hand, it looks difficult to many of high school students to do some more complicated thing, such as reconstruction of $B^+ \to J/\psi(\to e^+e^-, \mu^+\mu^-)K^+$. This is not only because the analysis code becomes complicated, but also because it requires knowledge of the particle physics. Therefore, we believe the B-Lab program is very useful for students to have an experience of the analysis for short term, while it needs some improvement if we want to make use of it as a long term study more generally.

## 2. Belle Plus

Belle Plus is a science camp for high school students held at KEK. This program is organized by approximately 10 physicists, including the B-Lab team, several more Belle members, and a few theorists. Belle Plus started in 2006 and has been held annualy except 2010.

The camp is funded by KEK and Nara University of Education, based on an MoU between the two institutes on outreach activity. Several graduate students in Belle collaboration help to teach the high school students. In addition, graduate students from Nara University of Education, who major in pedagogy, also help the management of the camp.

In each camp, around 20 students from high schools all over in Japan stay 4 days at KEK (Fig. 3a). The program consists of lectures on Particle Physics, visiting tour of KEKB accelerator

and Belle detector, experimental or theoretical studies, and presentation. We generally prepare 4 studies, and students choose one study during the camp forming a group of 5 or 6 students. The purpose of this workshop style program is to give a real experience of researchers to students, and we try to make the studies similar to the real research activity. For example, one of the studies is the measurement of the cosmic rays, and when Belle was in operation till 2010, we offer a study to observe a cosmic ray using Belle detector. It was a good experience for students to operate such a big experimental facility. B-Lab is also one of the studies. Belle Plus also has a theory course, in which students learn basic rules of Feynman diagram and calculate the processes that can be observed at Belle (Fig. 3b).

(a) (b)

**Figure 3:** (a) Group photo of high school students together with supervising researchers and graduate students at Belle Plus (b) Students in theory course at Belle Plus.

## 3. Summary

We provide B-Lab program to general public including high school students, as an outreach program of Belle experiment. This is a first open data program in high energy physics. Approximately 1400 people have participated in this program. We plan to use this program as an outreach program for Belle II [3], possibly with improvement to enable complicated reconstruction more easily. We also hold a science camp called Belle Plus, as an outreach program for Belle.

## References

[1] `http://belle.kek.jp/b-lab/b-lab-english/`.

[2] A. Abashian *et al.* [Belle Collaboration], Nucl. Instr. and Meth. **A479** (2002) 117; J. Brodzicka *et al.* [Belle Collaboration], PTEP **2012**, 04D001 (2012).

[3] T. Abe *et al.* [Belle-II Collaboration], arXiv:1011.0352 [physics.ins-det].