BELLE2-NOTE-PL-2022-XXX

Approved plots: 2021c energy scan information

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This document describes a plot made to demonstrate the change of beam energy during the energy scan in Run 2021c taken Nov. 10-29. Starting from $E_{\rm CM} \approx 10.579$ GeV, the energy scan consisted of four steps: 10.657 GeV, 10.706 GeV, 10.751 GeV, and 10.810 GeV.

In order to monitor the change of the beam energy, the invariant mass of muon pairs was measured in the online system data quality monitoring (DQM) plots. Muons were selected requiring $p_T > 2$ GeV/c , $|d_0| < 2$ cm, and $|z_0| < 4$ cm, and combinations satisfying $9 < M(\mu^+\mu^-) < 12$ MeV/c^2 were retained. The invariant mass was stored in the DQM ROOT plots for each run. The data here were combined in groups according to the center-of-mass energy.

Figure 2 shows the resulting dimuon invariant mass at each point. Because the online database conditions do not include proper calibration and particle identification, here we report $\Delta E_{\rm CM}$, defined as the change in dimuon invariant mass compared to the starting point from Exp. 20 at the $\Upsilon(4S)$ resonance. This is to account for large biases (between 10 to 20 MeV/c^2) arising from miscalibration, electron contamination, and radiative effects (*i.e.* $\ell\ell(\gamma)$) seen when comparing the absolute reconstructed $M(\mu\mu)$ value to the nominal expectation from the beam energy. Note that this bias is not unusual or unexpected, as seen in prior BaBar [1] and Belle [2] analyses, and uncalibrated Belle II data [3]. The individual peaks in Fig. 2 represent the various energy steps, with the areas under the curves individually normalized to 1 over the entire $9 < M(\mu^+\mu^-) < 12$ GeV/c^2 range.

The online conditions database was modified partway through the energy scan to update the magnetic field map. This resulted in a $(+10 \pm 1)$ MeV/c^2 shift in $M(\mu\mu)$ reported by the online DQM system for a small part of the data at 10.751 GeV and nearly all of the data collected at 10.810 GeV. For Fig. 2, these 10.751 GeV data have been excluded and the 10.810 GeV data corrected by -10 MeV/c^2 in order to provide a consistent $\Delta E_{\rm CM}$ comparison across all energy points.

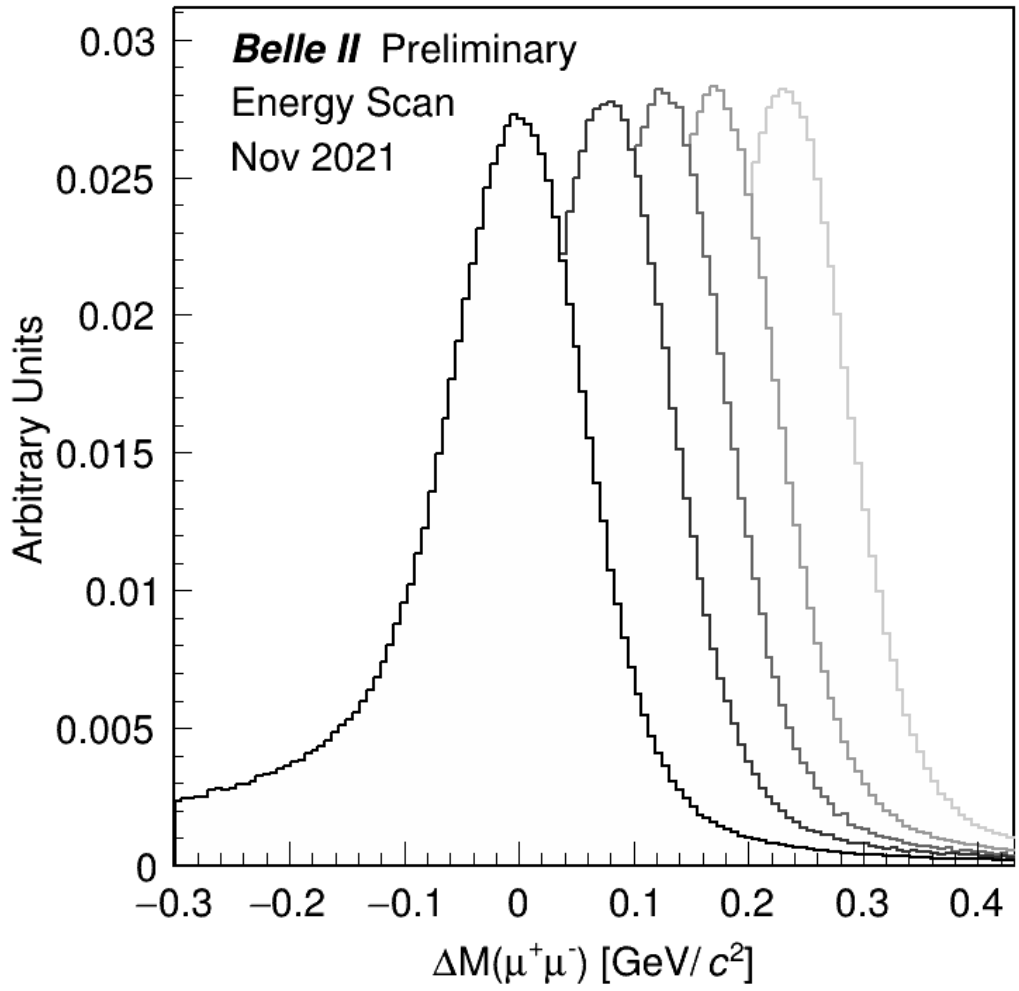

FIG. 1: Plot of $\Delta M(\mu\mu)$, the difference of the dimuon invariant mass distribution with respect to the value observed during collisions at the nominal $\Upsilon(4S)$ resonance (black). The various peaks indicate the increasing collision energies achieved during the November 2021 operations: 10.657 GeV, 10.706 GeV, 10.751 GeV, and 10.810 GeV (shown as gradually lighter in color), to study unusual features observed in Belle data [2]. This is the first time this energy region has been directly probed by e^+e^- collisions in more than a decade.

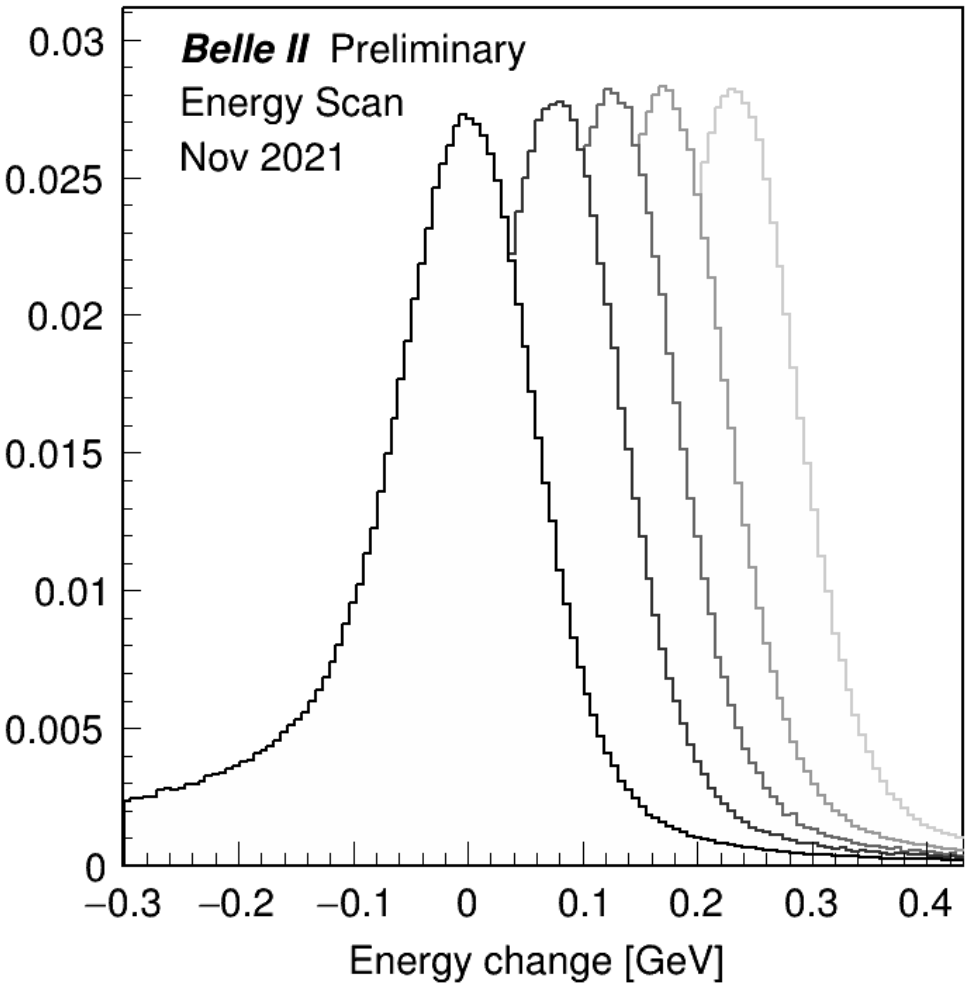

FIG. 2: Distribution showing the changes of collision energy from the (black) nominal $\Upsilon(4S)$ resonance. The collision energy scan was achieved during the November 2021 operations to study unusual features observed in Belle data [2]. The collision energy is visualized using the invariant mass of oppositely charge muon pairs, which are produced frequently and with low background in e^+e^- collisions The various peaks indicate the increasing collision energies: 10.657 GeV, 10.706 GeV, 10.751 GeV, and 10.810 GeV (shown as gradually lighter in color). This is the first time this energy region has been directly probed by e^+e^- collisions in more than a decade.

[1] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. Lett. **102**, 012001 (2009).
[2] R. Mizuk *et al.* (Belle Collaboration), J. High Energy Phys. **10**, 220 (2019).
[3] B. Fulsom, BELLE2-NOTE-PL-2021-001 (2021).