Validation of background contributions in tau pair analysis at Belle II

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Abstract

In this work the validation of the background contributions observed in the reconstruction of tau leptons at Belle II is performed. The disagreement between data collected by the Belle II experiment and MC simulation is determined in sidebands regions, where $q\bar{q}$ is the dominating process. After the direct comparison in the number of events between data and MC in the $M_{\text{tag}} > 1.8$ GeV/c^2 region, a correction factor for the number of $q\bar{q}$ events in the simulation of 0.501 ± 0.007 is determined.

Contents

1 Introduction

The tau lepton is the only one heavy enough to decay into hadrons, with more than 200 channels [2]. Therefore it provides an environment for the study of the hadronization of quarks and searches of physics beyond the Standard Model.
Belle II has a rich program in tau physics [1]. During the reconstruction there are background contributions from other physical processes generated in the e^+e^- collisions. In this work we validate such background contributions at Belle II. In particular, we will focus on the contribution of $q\bar{q}$ events, which is one of the largest observed currently.

1.1 The Belle II experiment

SuperKEKB collides electrons with positrons, where positrons circulate in the Low Energy Ring (LER) of the accelerator at the energy of 4 GeV and electrons travel the opposite direction in the High Enegy Ring (HER) at 7 GeV. When two bunches collide, the centre of mass moves in the direction of the electron beam.
Belle II is a detector located in the interaction point of SuperKEKB. The main function of Belle II is to collect data from the collisions. Figure 1 shows the Belle II experiment and its sub-detectors. The Pixel Detector (PXD) and Silicon Vertex Detector (SVD) are in charge of the reconstruction of decay vertices. The Central Drift Chamber (CDC), which identified charged particles traveling inside the magnetic field. The Time Of Propagation counters (TOP) and Aerogel Ring-Imaging Cherenkov detector counters (ARICH), which identify the nature of the tracks. Crystals of the Electromagnetic Calorimeter (ECL) detect electromagnetically interactive particles and measure their energy. K_L and muon detector (KLM) surrounds the whole system and detect muons and kaons.

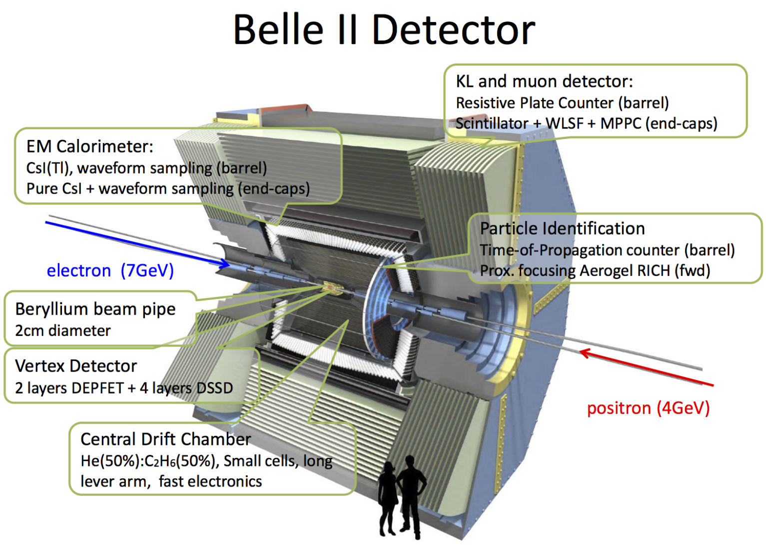

Figure 1: The Belle 2 detector and its sub-components

1.2 Background contributions in tau pair reconstructions

When a pair of tau leptons is reconstructed, contributions from $q\bar{q}$, two photon and Bhabha scattering represent sources of contamination.

1.2.1 $q\bar{q}$ production

$q\bar{q}$ is the direct production of a pair of quarks directly from the collision. Pairs of $u\bar{u}$, $d\bar{d}$, $s\bar{s}$ or $c\bar{c}$ can be produced, which later hadronize.

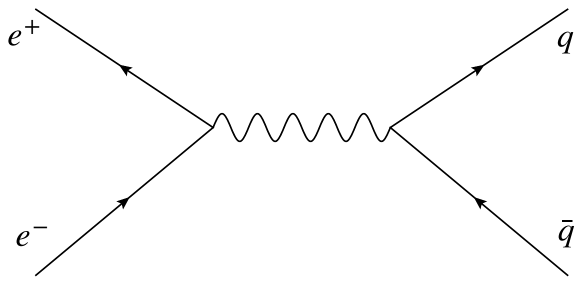

Figure 2: Feynman diagram of $q\bar{q}$ events produced from the electron-positron collision.

1.2.2 Two-photon events

In Two-Photon process the electron and the positron generate a pair of photons, following by the production of two leptons. The leptons interact and produce either a pair of leptons or quarks which later hadronize, as shown in Figure 3.

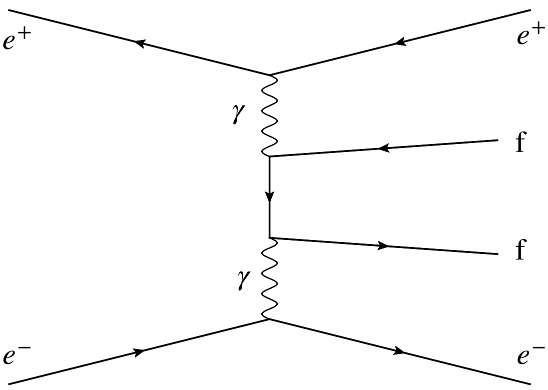

Figure 3: Feynman diagram of a two photon process.

1.2.3 Bhabha scattering

Bhabha is a direct scattering of electrons and positrons. Any of these particles can produce a photon which interacts with the material of the detector, and then it produces another pair of electron-positron. Figure 4 shows the Feynman diagram of the Bhabha scattering.

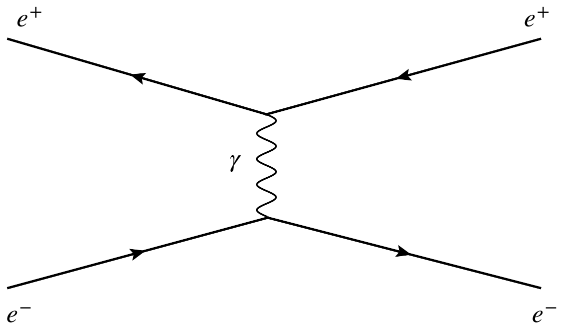

Figure 4: Feynman diagram of a Bhabha scattering process.

1.3 Validation of $q\bar{q}$ events in MC

Any tau analysis at Belle II require to account properly the contamination of non-tau sources. In this work our goal is the validation of the $q\bar{q}$ simulation when a tau pair selection is applied.

2 Data sets

2.1 Experimental Data

In this study we use data collected from March to December 2019, reprocessed during the proc12_chunk1 campaign. It corresponds to 8.76 fb^{-1}. Only events firing the low multiplicity lml triggers are used [3].

2.2 Monte Carlo samples

Simulated events during the MC14ri_a campaign are used to both determine the number of $q\bar{q}$ events produced in the simulation and estimate the background contributions. The data sets used for this study are listed on Table 1.

Event type	$L_{\rm int}$ (fb^{-}1)
$\tau\tau$	100
$u\bar{u}$	100
$d\bar{d}$	100
$s\bar{s}$	100
$c\bar{c}$	100
$\mu\mu$	100
$eeee$	100
$ee\mu\mu$	100
$eeq\bar{q}$	100
Bhabha	10

Table 1: MC14 data sets used in this work. The samples $u\bar{u}$, $d\bar{d}$, $s\bar{s}$ and $c\bar{c}$ are merged as $q\bar{q}$. $ee\mu\mu$, $eeee$ and $eeq\bar{q}$ are also merged as Two-photon.

3 Selection Criteria

The selection criteria applied aim to reconstruct a topology with 1 track in one side of the event, and three tracks in the other side, usually known as 1x3 prong topology.

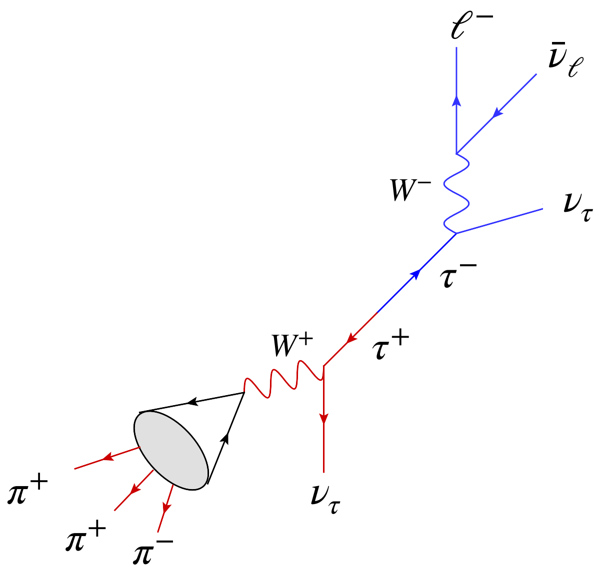

Figure 5: Tau pair decay with a 1x3 prong topology.

We select tracks satisfy the following criteria

- dr < 1cm
- -3.0cm $< dz <$ 3.0cm

The events are divided in two sides with a plane perpendicular to the thrust direction. One of the sides with 3 tracks and the other one keeping the remaining track. To remove electrons, tracks on the 3-prong side must have

- $0 < E_{cluster}/P < 0.8$

As we want remove two-photon events we apply the further selection cuts

- 2.5GeV <Visible Energy Of Event CMS < 10.2GeV
- $0.9 < thrust < 0.99$

Additionally, we include a cut to maximize contribution of $q\bar{q}$ events reducing as much as possible the number of tau pairs

- M-3prong > 1.8GeV/c^2

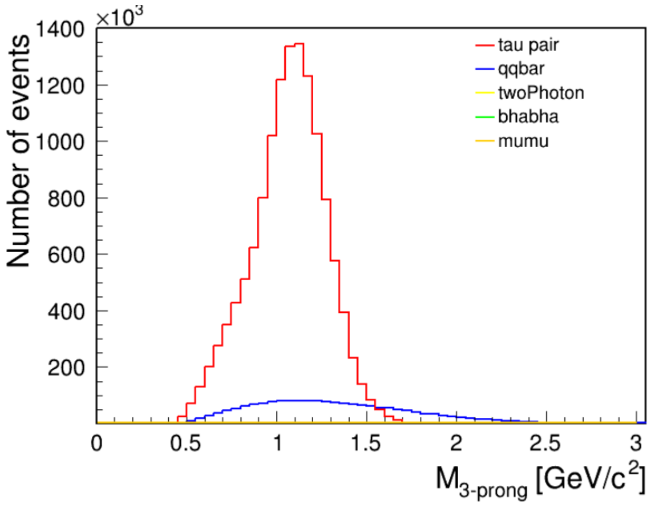

Figure 6: Invariant mass distribution of the 3prong side. A cut to select events above 1.8 GeV/c^2 has been applied.

Table 2 shows the number of events after applying the selection criteria described above. Figure 7 shows the distribution of the different event types in MC. As desired, $q\bar{q}$ is the largest contribution.

4 Data vs Monte Carlo comparison

We will compare the number of events in data vs MC simulation for obtain a correction factor:

$$f_{qq} = \frac{N^{data} - N^{MC}_{non-qq}}{N^{MC}_{qq}} \tag{1}$$

event type	number of events at 100 fb^{-1}	number of events at 8.76 fb^{-1}
qqbar	124778 ± 353	10931 ± 31
tau pair	4511 ± 67	395 ± 6
twoPhoton	522 ± 23	46 ± 2
bhabha	41 ± 6	4 ± 1
$B\bar{B}$	58 ± 8	5 ± 1
mumu	147 ± 12	13 ± 1

Table 2: Number of events for 100fb^{-1} from MC14 after applying the selection criteria described above. In the last column is presented the number of events for 8.76 fb^{-1}, which corresponds to the proc12_chunk1 luminosity.

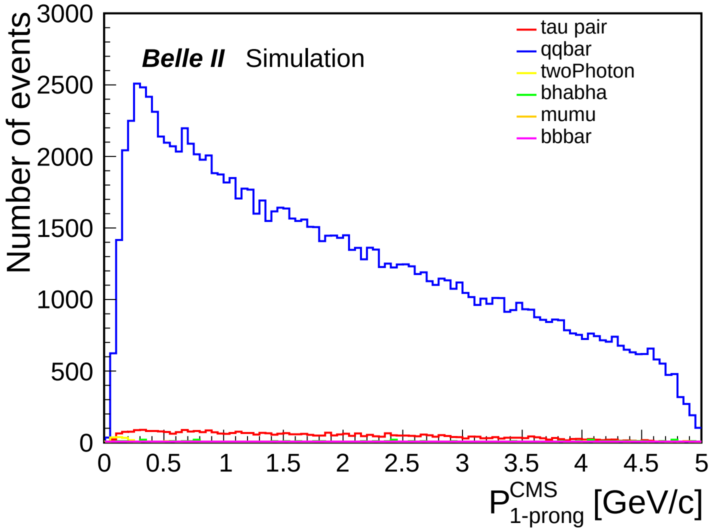

Figure 7: Momentum in the centre of mass system of the 1-prong track for simulated events from MC14. Events are required to fire at least one lml trigger.

The number of events in MC is taken from table 2, and the number of events of data is obtained from the plot shown in figure 9. Then the correction factor is

$$f_{qq} = \frac{5935 \pm 77 - 457 \pm 6}{10931 \pm 31} = 0.501 \pm 0.007 \tag{2}$$

5 Validation of the correction factor

After the computation of the correction factor, we pick up an independent data set for validation selecting events with the same selection criteria described in Section 3, but this time without the cut in the invariant mass. Figure 10 shows the distribution of the thrust of events after the selection criteria is applied. For the validation, we select events only with the thrust in the range of 0.7 to 0.8.

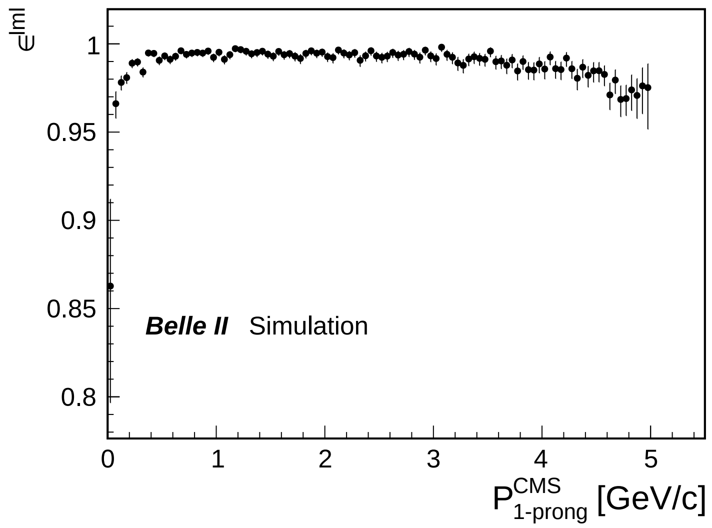

Figure 8: Absolute efficiency of lml triggers used for this study.

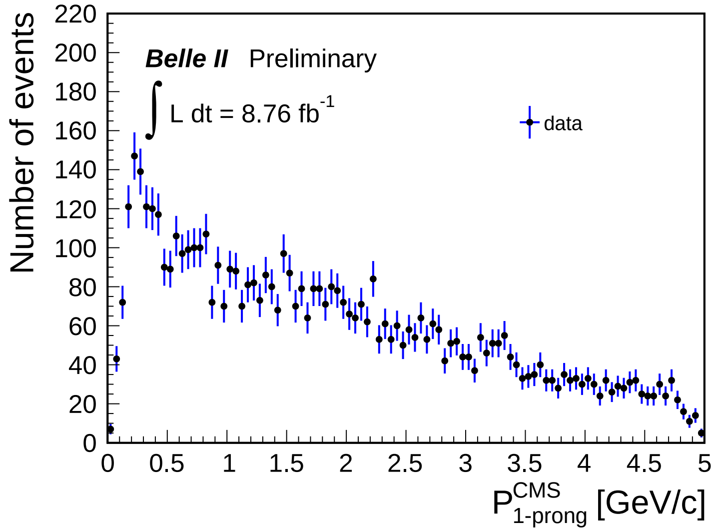

Figure 9: Momentum in the centre of mass system of the 1-prong track from events of proc12_chunk1.

A large contribution of two photon events has been observed in data. Figure 11 shows the distribution of missing invariant mass vs missing polar angle in data and MC events. A large excess of events is observed in the region of high missing invariant mass when data is compared to the simulation. To remove such events that contains two photon events not included to the simulation, we apply a cut requiring only events with a missing invariant mass lower than 10 GeV/c^2.
Figure 12 shows the distribution of the momentum for the 1-prong track for both data and MC, after applying the correction factor obtained in the previous section. An ac-

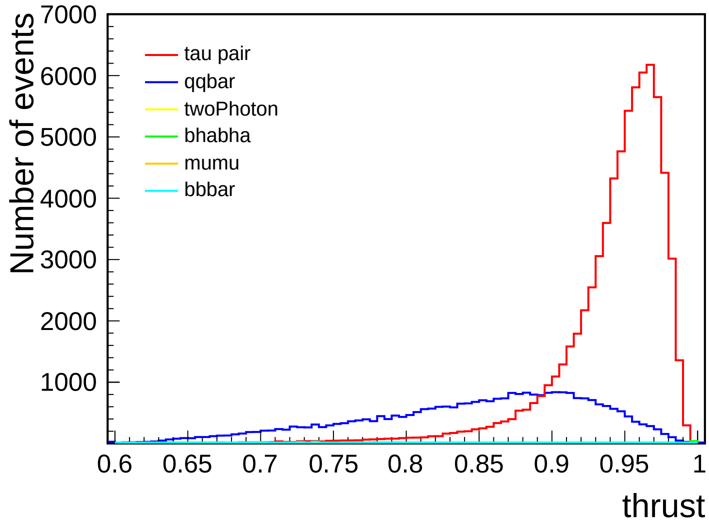

Figure 10: Figure shows the distribution of thrust events after selection. An independent data set is obtained selected events of thrust between 0.7 and 0.8.

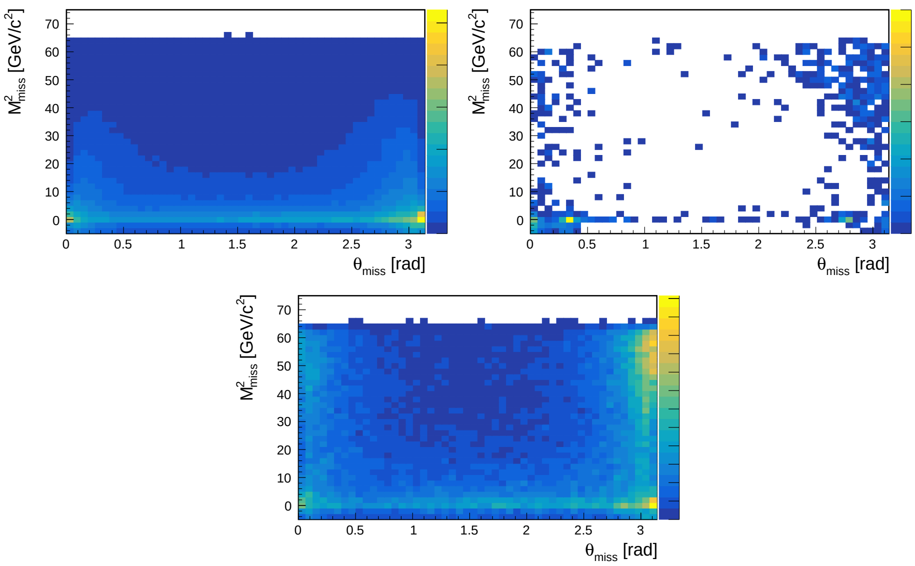

Figure 11: Distribution of missing invariant mass vs missing polar angle for $q\bar{q}$ (left) and two photon events (right) from MC. Distribution for events from proc12_chunk1 data are shown at the bottom.

ceptable agreement is observed in the region above 0.5 GeV/c, while the low momentum region presents an access of events in data which respect to the simulation.

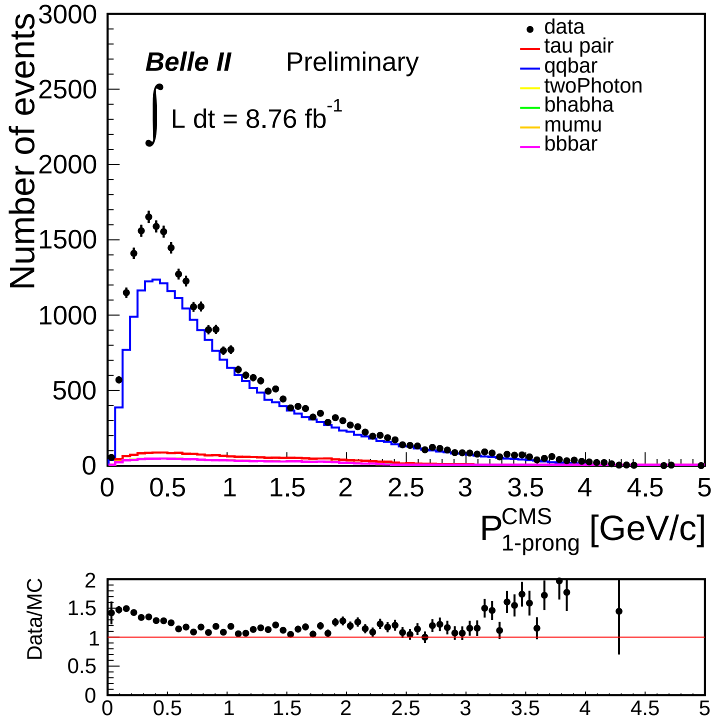

Figure 12: Distribution of thrust events after selection. An independent data set is obtained selected events of thrust between 0.7 and 0.8.

6 Conclusions

This is the first attempt in the comparison of data vs MC for background contributions observed during a tau pair analysis. It has been shown that the number of $q\bar{q}$ events is overestimated in the simulation with respect to the data collected by Belle II. Comparing the number of events in a region dominated by the $q\bar{q}$ contribution, a correction factor of 0.501 ± 0.007 has been obtained.
The validation of the correction factor in an independent set of events proves that, after the correction, a better agreement in the distribution of the momentum in data with respect to the simulation is obtained. In the low momentum region, between 0 to 0.5 GeV, there is a still a disagreement most likely caused by a high background from the beam, or two photon events that are not included in the simulation. Further studies are required.

References

[1] E. Kou *et al.* [Belle-II], PTEP **2019** (2019) no.12, 123C01 [erratum: PTEP **2020** (2020) no.2, 029201] doi:10.1093/ptep/ptz106 [arXiv:1808.10567 [hep-ex]].

[2] P. A. Zyla *et al.* [Particle Data Group], PTEP **2020** (2020) no.8, 083C01 doi:10.1093/ptep/ptaa104

[3] The Belle II Collaboration, BELLE2-NOTE-PL-2020-015