$e^+e^- \rightarrow \tau^+\tau^-$ production and the $\tau \rightarrow 3\pi\nu$ Branching Ratio measurement at Belle II

Gayane Ghevondyan

Yerevan State University

September 5th, 2019

Supervisors
Petar Kevin Rados
Armine Rostomyan

Abstract

The report describes the reconstruction of tau-pair production from Phase III collision data at Belle II. After events selection and trigger correction, the branching ratio of $\tau \rightarrow 3\pi\nu$ has been determined to be $(10.19 \pm 0.01)\%$, in reasonable agreement with the PDG value.

Contents

1. Introduction

Tau leptons have a electric charge,a spin of 1/2 and a mass of 1776.86 MeV/c^2 (compared to 105.66 MeV/c^2 for muons and 0.511 MeV/c^2 for electrons) .

The τ lepton has a lifetime of $2.9{\times}10^{-13}$s, due to their short lifetime, tau leptons will decay before reaching the active regions of the Belle II detector and so are reconstructed via their decay products. Tau leptons mainly decay into charged pions, muons or electrons in association with neutrinos.

This report presents preliminary results on the reconstruction of tau-pair production $e+e- \rightarrow \tau+\tau-$ and the τ → 3πν branching ratio measurement.

2. Event Selection

2.1 Dataset

The analysis are performed using release-03-02-02 and "proc9" data from Experiment 8 (with integrated luminosity: 1982.3±0.6 pb^{-1}) .

The official Phase 3 MC12 productions were used with the background condition "BG×1" fro the event selection and background suppression studies. Details of MC12 are sescribed at https://confluence.desy.de/display/BI/Data+Production+MC12

Sample	$\int Ldt$	/belle/MC/release-03-01-00/DB00000547/MC12b/
taupair	80 fb^{-1}	prod00007809/s00/e1003/4S/r00000/taupair/mdst/sub00
uubar	80 fb^{-1}	prod00007801/s00/e1003/4S/r00000/uubar/mdst/sub00
ddbar	80 fb^{-1}	prod00007803/s00/e1003/4S/r00000/ddbar/mdst/sub00
ssbar	80 fb^{-1}	prod00007805/s00/e1003/4S/r00000/ssbar/mdst/sub00
ccbar	80 fb^{-1}	prod00007807/s00/e1003/4S/r00000/ccbar/mdst/sub00
ee	0.167 fb^{-1}	prod00007464/s00/e1003/4S/r00000/3900520000/mdst/sub00
eeee	5.30 fb^{-1}	prod00007464/s00/e1003/4S/r00000/3900520000/mdst/sub00
eemumu	5.29 fb^{-1}	prod00007465/s00/e1003/4S/r00000/3900420000/mdst/sub00
mumu	47.9 fb^{-1}	prod00007466/s00/e1003/4S/r00000/3500420000/mdst/sub00
pipi	1139.4 fb^{-1}	prod00007469/s00/e1003/4S/r00000/3700001000/mdst/sub00

Table 1: Phsae III MC12 samples used in the analysis

2.2 Candidate event selection

In the $e+e- \rightarrow \tau+\tau-$ centre-of-mass system (CMS), both τ leptons are boosted and their decay products are well separated in two opposite hemisphere defined by the plane perpendicular to the thrust axis n_{thrust} is defined such that the value V_{thrust}

$$V_{thrust} = \sum_i \frac{|\vec{p}_i^{\,cm} \cdot \hat{n}_{thrust}|}{\sum \vec{p}_i^{\,cm}}$$

is maximized. Here $\vec{p}_i^{cm}$ is the CMS momentum of each charged particle and photon. A pion mass hypothesis is used for all charged tracks. Given the vector $\hat{n}_{thrust}$ that splits the event into two hemispheres, the signal hemisphere is expected to contain the products of 3-prong deacy, while the tag side is expected to contain one charged particle being $\pi\pm$ and a number of additional photons and π^0s.

The candidate events are selected by requiring only four charged tracks in the event with zero net charge. Each track should satisfy the following requirements:

- |dz| < 5 cm
- |dr| < 2 cm

The signal side and the track is required to satisfy the condition, E/P > 0.8, where E is the energy deposit in the ECL and P is the momentum of the particle in laboratory system.
In addition, we have the following selection for photons:

- E> 200MeV

2.3 Background suppression

There are other processes than tau-pair production that would satisfying to the selection criteria discused anbove. The list of background processes that would contaminate the tau-pair production sample are listed in Table 2

Processes	Cross section$[nb]$	Name of the production
$e^+e^- \to u\bar{u}$	1.61	'uubar'
$e^+e^- \to d\bar{d}$	0.4	'ddbar'
$e^+e^- \to s\bar{s}$	0.38	'ssbar'
$e^+e^- \to c\bar{c}$	1.3	'ccbar'
$e^+e^- \to e^+e^-\gamma$	300 ± 3	'ee'
$e^+e^- \to \mu^+\mu^-\gamma$	1.148	'mumu'
$e^+e^- \to e^+e^-e^+e^-$	39.7 ± 0.1	'eeee'
$e^+e^- \to e^+e^-\mu^+\mu^-$	18.9 ± 0.1	'eemumu'
$e^+e^- \to \pi^+\pi^-\gamma$	0.167	'pipi'

Table 2: Possible background processes with the corresponding cross section

For $e+e-$ annihilation data, the magnitude of the thrust vector varies between 0.5 (for spherical events) and 1 (for events with all tracks aligned with the thrust axis). The distribution of the thrust value (see left panel of Figure3) of tau-pair production indicates that the τ lepton decay particles deviate relatively mild from the primary trajectory.
The total CMS visible energy of the event can be used to reduce the background contaminations further through a threshold cut (see right panel of Figure3). The visible energy distribution clearly shows that there are undetected neutrinos in the signal events which shift the distribution towards smaller values. This is in contrast to some of the background processes where the visible energy peaks near the collision energy $\sqrt{s}$.

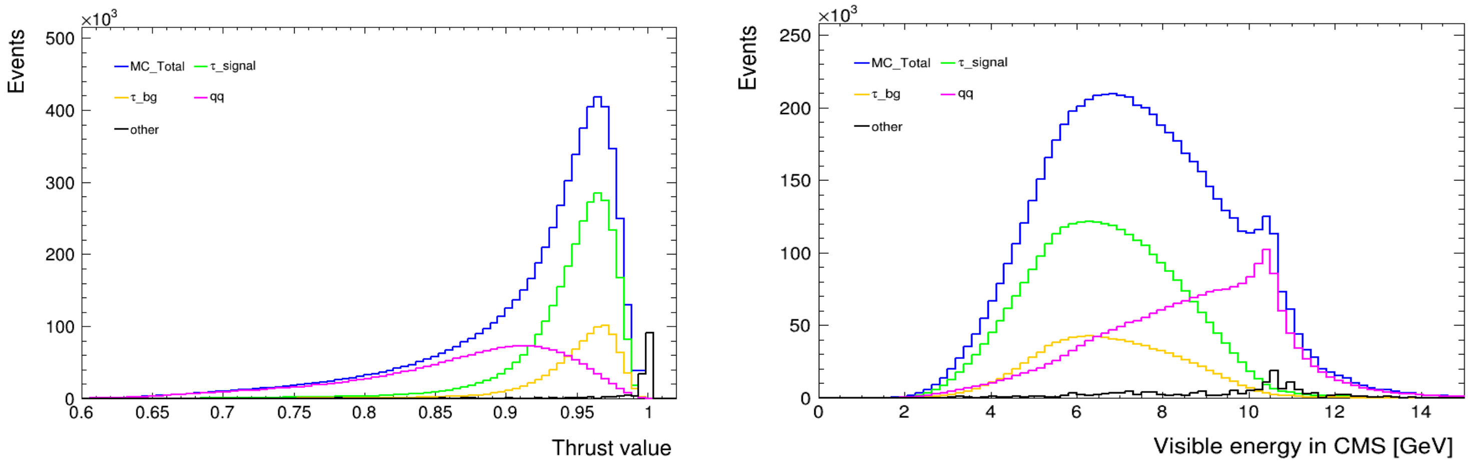

Figure 3: The distribution of the thrust value (left) and visible energy in CMS (right).

All events are required to have no photons and have less than $3\pi^0$s on the tag side. Regarding the signal side, all 3-prong track events are required to have no photon and no π^0s. All these cuts are summarized in Table3.

variable	requirement imposed
track(1,2,3)_3prong_EoverP	> 0
track_1prong_EoverP	> 0
VisibleEnergyOfEventCMS	< 9.8
nPhotons_3(1)prong	= 0
nPi0s_3prong	= 0
nPi0s_1prong	< 3
Thrust	> 0.9,< 0.99
track(1,2,3)_3prong_muonID	< 0.2
Track(1,2,3)_3prong_electronID	< 0.2

Table 3: Summar of requirement for tau-pair production

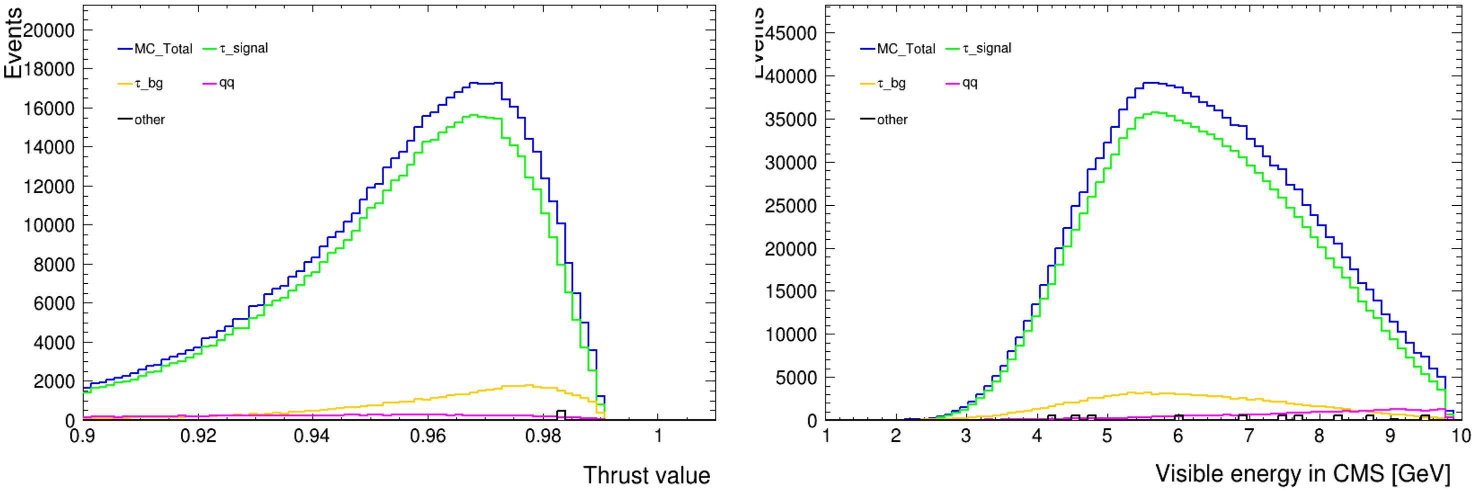

Figure 4: The distribution of the thrust value and visible energy in CMS after all cuts

3.Invariant mass distribution of 3-prong side

The invariant mass of the three tracks on the signal side without any selection is shown in Figure5:

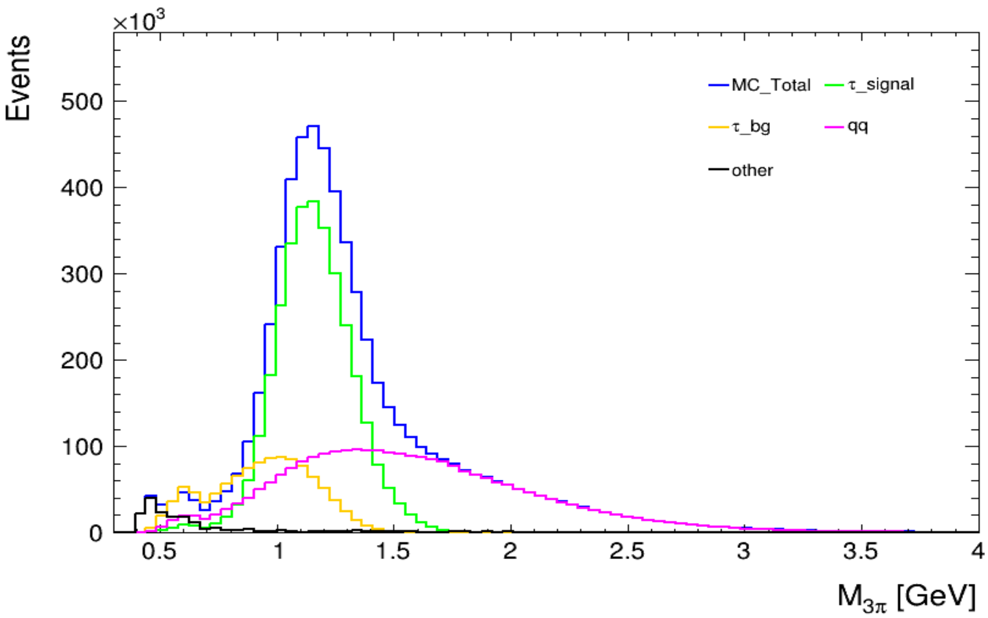

Figure 5: The distribution of the M-3prong without any selection

$M_{3\pi\pm}$ distribution after the inclusive 3-prong decay selections is shown in Figure 6:

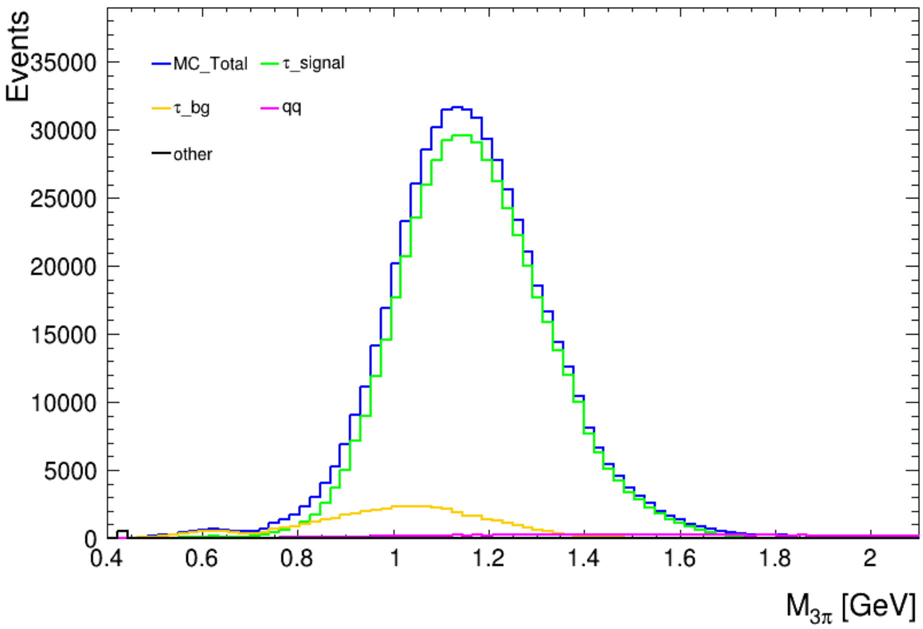

Figure 6: The distribution of the M-3prong after all selections

4.Trigger

After all of selections it is important to check how well our MC models the observed dara. The CDC trigger (bit 0) is fired for events in data, which has been shown to have higher efficiency than the ECL trigger(bit 27) for events entering this analysis. This trigger requires the CDC energy to be above 1 Gev, and vetos events if they are also fire the Bhabha trigger. After the above mentioned trigger requirement for data, it's important to require trigger efficiency for MC. Although the trigger information is not available in the MC12 samples, we can calculate the efficiency from data and reweight the MC accordingly.

We use an ECL trigger as a reference trigger for probing the CDC trigger efficiency. The particular reference trigger considered is bit 27. It requires at least three two-dimensional tracks. We define the trigger efficiency as:

$$\varepsilon_{CDC}^{trig} = \frac{fire\ trigger\ bit\ 27\ and\ bit0}{fire\ trigger\ bit27}$$

The measured CDC trigger efficiency in data for thrust, visible energy are shown in Figure7:

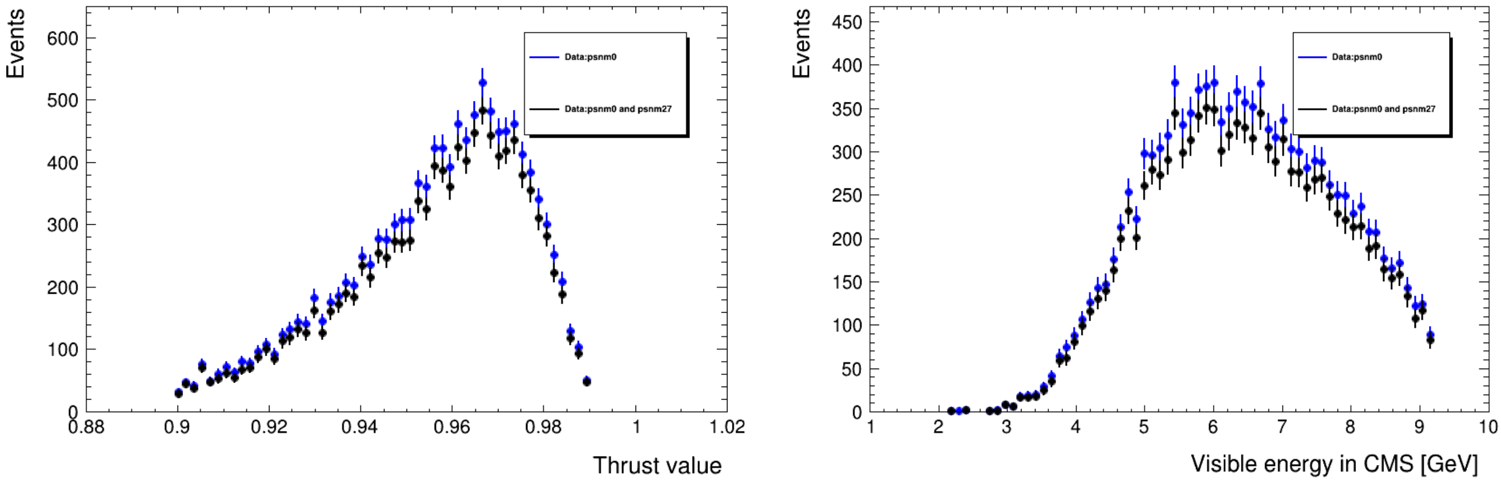

Figure 7

5. Results

5.1 Data-MC comparison

The distributions of thrust, visible energy after pre-selection are shown in Figure8 as contrast. After reweighting MC by the measured trigger efficiency in data, the resulting thrust, visible energy distributions are shown in Figure9. As can be seen form Figure9, the discrepancy disappeares and there is a good agreement between data and MC after trigger correction.

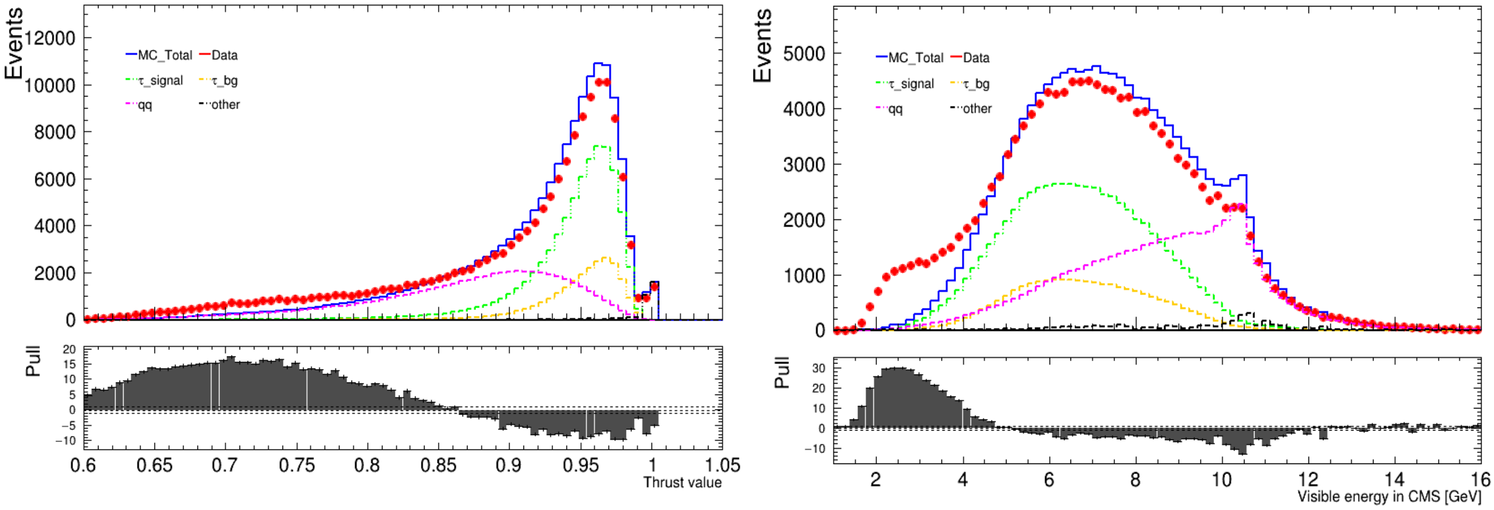

Figure 8: The thrust and visible energy distributions after the pre-selections. The bottom panel shows the ratio of the data and total MC prediction.

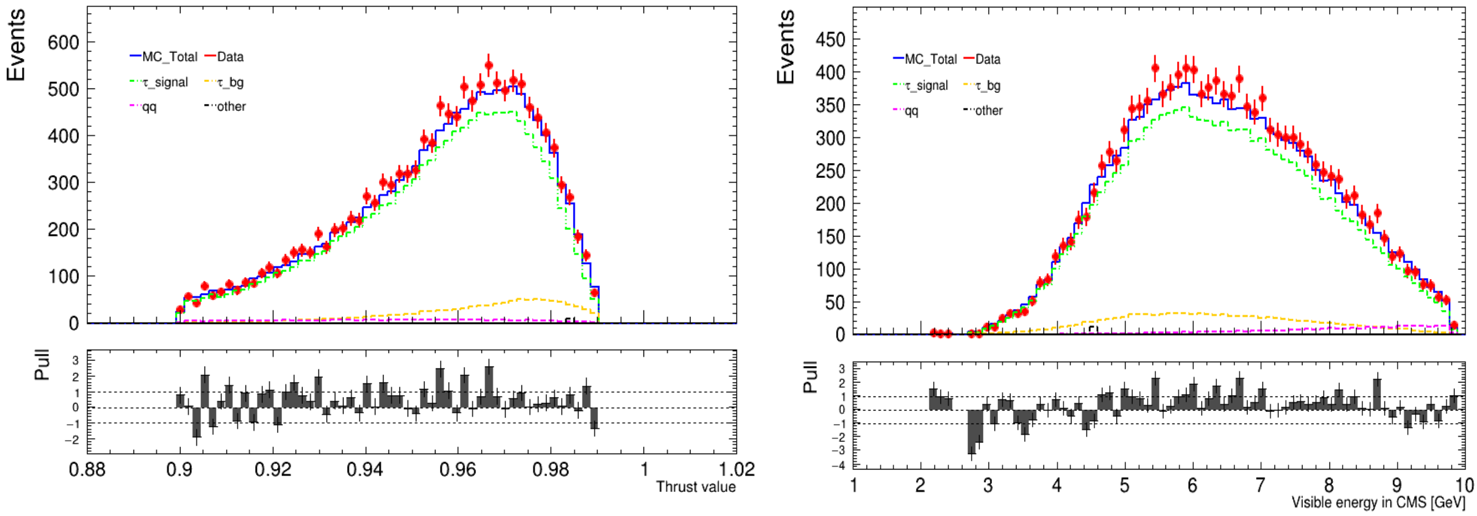

Figure 9: The thrust and visible energy distributions after all cuts have been applied. Events in data are required to fire CDC trigger

5.2. BR measurement

To measure the $\tau \rightarrow 3\pi\nu$ branching ratio, we used 1-prong branching ratio. It is (83.73 ± 0.06)%.
The branching ratio is given by:

$$BR = \frac{N_{data}^{sig}}{\sigma * L * BR_{tag} * \varepsilon_{trig} * \varepsilon_{sig}}$$

Where N_{data}^{sig} is the number of signal events in data after selection, σ is the cross section $e+e- \rightarrow \tau+\tau-$, L is luminosity of experiment 8, ε_{trig} is the CDC trigger efficiency, ε_{sig} is the signal efficiency.
In this report, the signal efficiency is taken from Monte Carlo simulation, here is the equation:

$$\varepsilon = \frac{N_{MC}^{sig}}{BR_{tag} * BR_{\tau \rightarrow 3\pi\nu} * N_{gen}}$$

where N_{MC}^{sig} is the number of signal events in MC after selection, BR_{tag} is the branching ratio of tag side, N_{gen} is the number of generated signal events in MC.

variable	value	Comments
N_{MC}^{sig}	521585	
N_{gen}	12.06×10^6	
BR_{tag}	83.73%	source: PDG
BR_{sig}	9.8%	source: PDG
σ	0.919nb	
ε_{trig}	4.3	

6. Conclusion

The aim of this project is to understand the detector performance and analysis tools, and finally get the measured Branching ratio value.
The preliminary result on $\tau \rightarrow 3\pi\nu$ branching ratio measurement obtained from Phase III data is in reasonable agreement with the PDG value. The measurement reported in this work is BR($\tau \rightarrow 3\pi\nu$) = (10.19 ± 0.01)%. Systematic uncertainties were not considered.