Optimization of the (anti-)hyper-nuclei reconstruction in ALICE

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1 Introduction

ALICE (A Large Ion Collider Experiment) is the heavy-ion experiment at LHC. Relativistic heavy-ion collisions offer unique ways to study the behaviour of nuclear matter. One of them is (anti-)hyper-nuclei. A Hypernucleus is a nucleus which conatains at least one hyperon (a baryon which contains at least one strange quark, but no charm, top or bottom quark) in addition to the nomal proton and neutron. The hypertriton is known as the lightest hypernucleus, and is a bound state of a proton, a neutron and a Λ. The lifetime of ${}^{3}_{\Lambda}H$ is close to the lifetime of the Λ Baryon, however it is still not precisely known and its precise value is still one of the main open questions in modern nuclear physics. The two main decay channels of the hypertriton are ${}^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$ and ${}^{3}_{\Lambda}H \rightarrow d + p + \pi^{-}$. In this study, the two body decay channel of the (anti-)hypertriton is analyzed. So far, ALICE has measured hypertriton only using the two decay products, and the tracking of the charged mother were neglected. The purpose of this study is to improve the reconstruction of the decay by taking into account the charged mother track.

2 The ALICE detector

For this analysis, the Inner Tracking System (ITS) and the Time Projection Chamber (TPC), which are located inside a 0.5 T solenoidal magnetic field, are mainly used. The ITS consists of six cylindarial layers of silicon detectors which surround the collision point. It covers the central pesudorapidity range of $|\eta| < 0.9$, and its radii is from 3.9 cm to 43 cm from the beam axis. The main purposes of the ITS are to reconstruct the primary vertex and the secondary vertex and to track and identify charged particles. The two innermost layers of ITS is the Silicon Pixel Detector (SPD). A Tracklet is defined as a track segment with one hit in each layer of SPD. The TPC is the main detector for tracking and particle identification through the specific energy loss in the TPC gas. It covers the same central pesudorapidity as the ITS.
ALICE is planning a major upgrade during the Long Shutdown 2 (LS2) from December 2018 to February 2020 toward the significant increase of the luminosity after LS2. The planned upgrades include the new detectors, the readout electronics and the online and offline system. The new ITS consists of seven concentric layers of pixel detectors. The ITS upgrade plan is mainly based on building a new silicon tracker. It improves the track position resolution at the primary vertex, the tracking efficeincy at low p_T and readout capabilities. The expected lead-lead collision rate in the LHC Run3 is 50 kHz. That does not allow the TPC to use the traditional gating grid technique for the blocking of ions. In order to record the information of all charged particles of all collisions, a continuos readout technique will be employed for the TPC. The analysis presented here is a pilot study for the reconstruction of charged hyper-nuclei with the upgrade detectors.

3 Analysis

For this analysis, the HIJING event generator with Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV injected (hyper)nuclei are used.

3.1 Kinematic variables

Rapidity y is used as a measure for relativistic velocity, and is defined as

$$y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z} \right) \tag{1}$$

where E is the energy of the particle and p_z is the component of the momentum along the beam axis. In high energy limit, a particle mass is sufficiently small compared to its momentum. Thus rapidity can be written by the polar angle θ as follows, and it is called pseudorapidity η.

$$\eta = -\ln \left[\tan \left(\frac{\theta}{2} \right) \right] \tag{2}$$

Transverse momentum p_T is the component of the momentum in the transverse plane (xy - plane), and is defined as

$$p_T = p \sin \theta \tag{3}$$

where p is the total momentum of the particle.

3.2 Particle identification

Particles are identified by the amount of energy loss per distance traveled (dE/dx) in the TPC. Figure 1 shows the dE/dx measured in TPC versus rigidity p/Z, where p is the track momentum and Z is the charge number. Figure 2 shows the probability for the particle to be ^3He or π^- expressed in standard deviation (σ) as a function of transverse momentum. ^3He are identified by using a 5σ cut. π^- are identified by using a 3σ cut. These values are listed in Table 1.

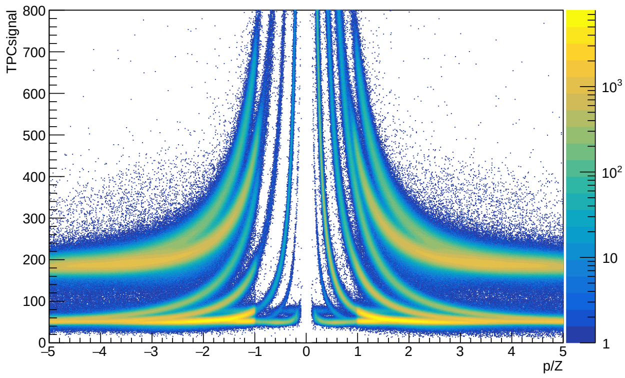

Figure 1: TPC signal vs p/Z.

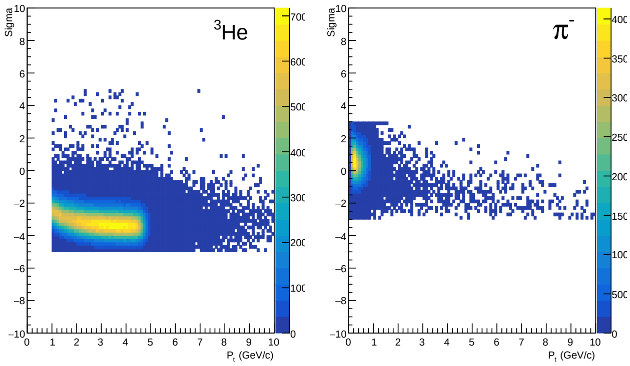

Figure 2: (left) The number of standard deviation identified as ^3He in TPC vs transverse momentum of ^3He. (right) The number of standard deviation identified as π^- in TPC vs transverse momentum of π^-.

To guarantee the selection of optimally tracked particles, the following cuts listed in Table 1 are also applied.

cut	value
^3He identification	5σ
π^- identification	3σ
The number of TPC clusters	> 80
^3He p_T	> 1GeV/c
$\lvert\eta\rvert$	< 0.8

Table 1: The values of cuts for the track selection.

3.3 Vertex selection

Once both daughter particles are identified, it is possible to identify the candidates for the hypertriton signal. Figure 3 shows the pictorial view of two body decay. The following cuts are applied to reduce the background, and are listed in Table 2.

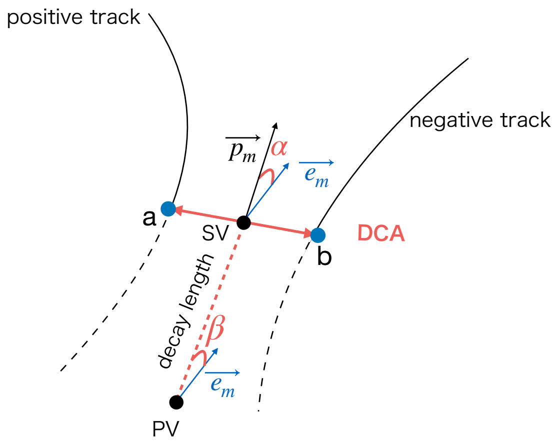

Figure 3: Pictorial view of two body decay.

The first cut is DCA cut. The two tracks identified as ^3He and π^- are looped over and propagated to distance closest approach (DCA). DCA is the distance between point a and b shown in Figure 3. The tracks of which values of DCA is lower than 1.0 cm are selected.

The second cut is the pointing angle cut. The pointing angle, which is shown as α in Figure 3, is the angle between the mother momentum vector $\overrightarrow{P_m}$ and the tracklet vector $\overrightarrow{e_m}$. The tracks of which $cos\alpha$ is greater than 0.999 are selected. Where the mother momentum vector is defined as

$$\overrightarrow{P_m} = \overrightarrow{p_1} + \overrightarrow{p_2} \tag{4}$$

The third cut is the $\sin\beta$ cut. The angle β is defined as the angle between the tracklet vector $\overrightarrow{e_m}$ and the decay length R. The tracks of which $\sin\beta$ is lower than 0.05 are selected. The $\sin\beta$ is calculated as follows. In the orthonormal vector space, if the line l goes through the primary vertex and has a direction vector (which is tracklet vector $\overrightarrow{e_m}$ in this case), the distance between the secondary vertex and the line l is

$$d(SV, l) = \frac{||\overrightarrow{R} \times \overrightarrow{e_m}||}{||\overrightarrow{e_m}||} \tag{5}$$

where $\overrightarrow{R}$ is the subtraction of the each coordinate of the primary vertex and the secondary vertex. The secondary vertex is defined as the average of the coordinates of ^3He and π^- shown as point a and b in Figure 3. Thus $\sin\beta$ is

$$\sin\beta = \frac{d(SV, l)}{||\overrightarrow{R}||} \tag{6}$$

The fourth cut is the decay length cut. The decay length R is the distance between the primary vertex and the secondary vertex, and is defined as

$$R = ||\overrightarrow{R}|| = \sqrt{(x_{PV} - x_{SV})^2 + (y_{PV} - y_{SV})^2 + (z_{PV} - z_{SV})^2} \tag{7}$$

where (x_{PV}, y_{PV}, z_{PV}) and (x_{SV}, y_{SV}, z_{SV}) are the coordinates of the primary vertex and the secondary vertex respectively. The tracks of which decay length is greater than 10.0 cm are selected.

On the left side of the Figure 4 to 7, the red line shows signal and the blue line shows (signal+background). On the right side of the Figure 4 to 7, the ratio of signal to (signal+background) is shown.

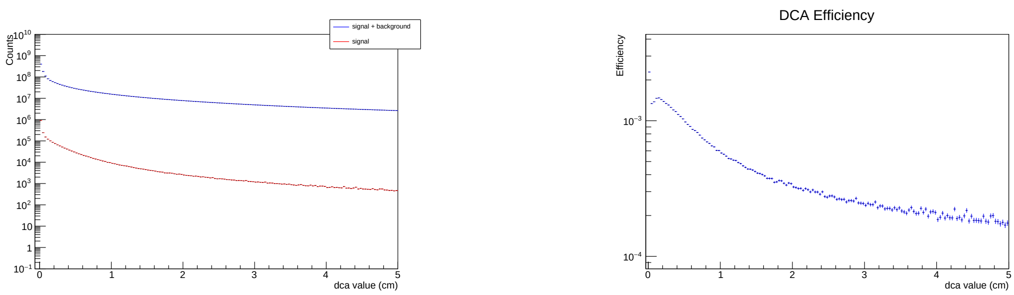

Figure 4: (left) DCA value. The red line shows signal. The blue line shows (signal+background). (right) The efficiency of DCA value.

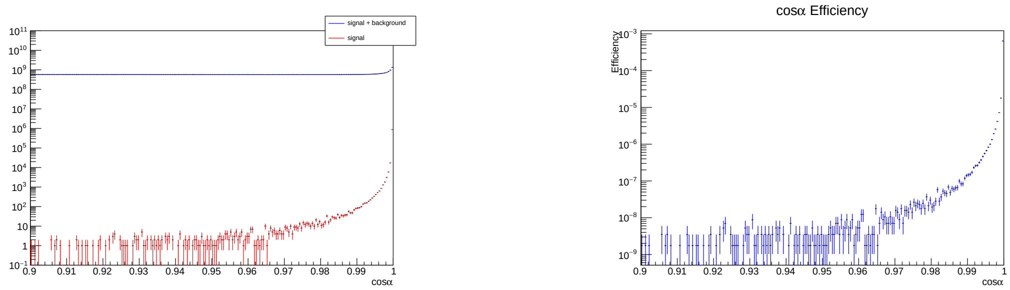

Figure 5: (left) $\cos\alpha$. The red line shows signal. The blue line shows (signal+background). (right) The efficiency of $\cos\alpha$.

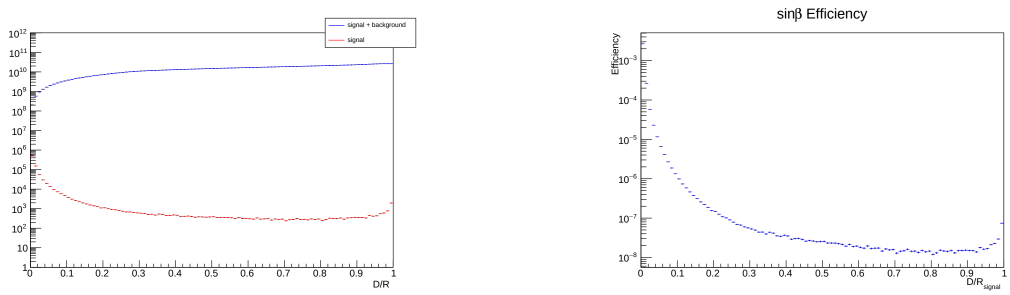

Figure 6: (left) $\sin\beta$. The red line shows signal. The blue line shows (signal+background). (right) The efficiency of $\sin\beta$.

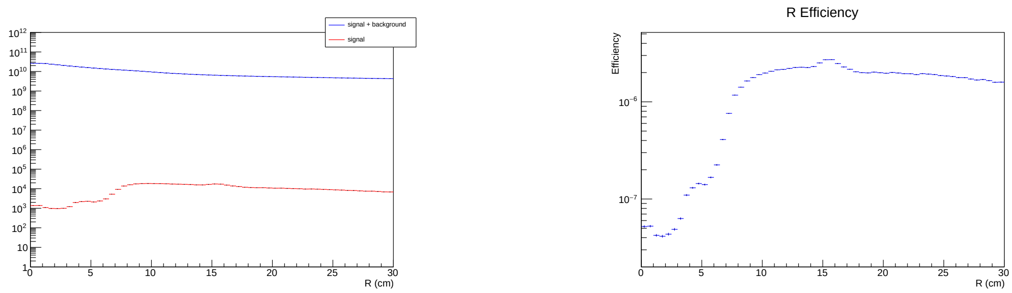

Figure 7: (left) Decay length. The red line shows signal. The blue line shows (signal+background). (right) The efficiency of Decay length.

cut	value
DCA	< 1.0 cm
$\cos\alpha$	> 0.999
$\sin\beta$	< 0.05
decay length	> 10 cm

Table 2: The values of cuts for the vertex selection.

3.4 Invariant mass

The invariant mass of ^3He and π^- is calculated by:

$$M = \sqrt{(E_1 + E_2)^2 + (\overrightarrow{p_1} + \overrightarrow{p_2})^2} \tag{8}$$

E_1 is defined as

$$E_1 = \sqrt{m_1^2 + |\overrightarrow{p_1}|^2} \tag{9}$$

where m_1 is the nominal value of the ^3He mass = 2.80923 GeV/c^2. The definition of E_2 is same as E_1, where m_2 is the nominal value of the π^- mass = 0.13957 GeV/c^2.

Figure 8 shows the invariant mass of ^3He and π^- after applying each vertex selection. DCA cut is the most effective cut, since it reduces the largest fraction of the background.

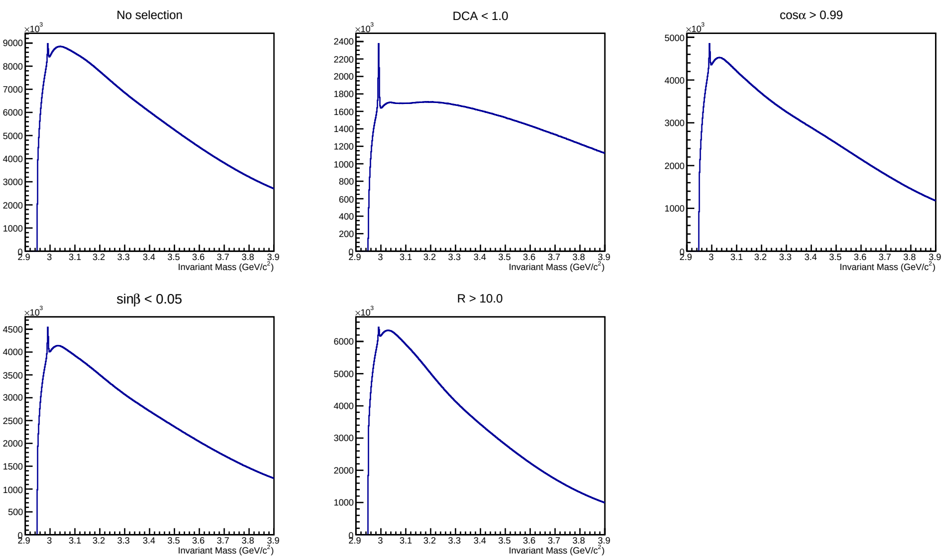

Figure 8: A comparison between invariant mass of ^3He and π^- when applying no selection and each of the selection cuts. (top left) no selection. (top middle) DCA cut. (top right) $cos\alpha$ cut. (bottom left) $sin\beta$ cut. (bottom middle) decay length cut.

Figure 9 shows the invariant mass of ^3He and π^- applied vertex selection in sequence.

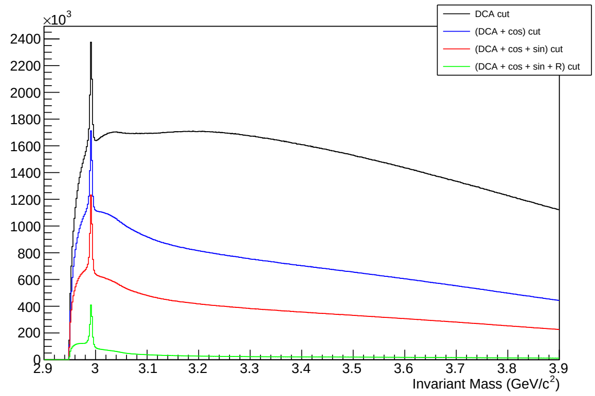

Figure 9: Invariant mass of ^3He and π^-. Black shows DCA cut, blue shows (DCA+cosα) cut, red shows (DCA+cosα+sinβ) cut, green shows (DCA+cosα+sinβ+R) cut.

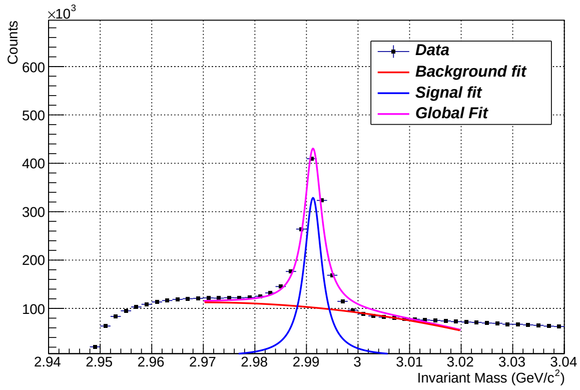

Figure 10: Invariant mass of ^3He and π^- applied all of the cuts listed in Table 2.

Figure 9 shows the invariant mass of ^3He and π^- applied all of the cuts listed in Table 1 fitted by Lorenzian Peak function and Quadratic background function. The mean invariant mass is 2.991 GeV/c^2. Nominal value is 2.991 GeV/c^2 as well.

3.5 Lifetime

The lifetime of $^3_\Lambda H$ is calculated by:

$$c\tau = \frac{R}{\beta\gamma} \tag{10}$$

Where τ is lifetime, R is the decay length calculated by eq.(7) and $\beta = \frac{P_m}{E_m}$. E_m is defined as

$$E_m = \sqrt{M^2 + |\overrightarrow{P_m}|^2} \tag{11}$$

where M is the nominal value of the $^3_\Lambda H$ mass = 2.991 GeV/c^2 and $\overrightarrow{P}_m$ is the same definition as eq.(4). To calculate $\overrightarrow{P}_m$, reconstructed momenta of daughters are used in reconstructed data, and generated momenta of daughters are used in generated data in reconstructed loop and generated data.

Figure 11 shows distribution of $c\tau$. The lifetime of $^3_\Lambda H$ calculated from the mean value of $c\tau$ is shown in Table 3. Generated data contains the full information about generated particles such as particle identification and momentum. Reconstructed data is simulated data which through the detector in simulation.

To evaluate the detector and software performance, it is useful to compare between generated data and reconstructed data. Generated data in reconstructed loop is used for evaluating the performance.

The ${}^{3}_{\Lambda}H$ lifetime of generated data is smaller than nominal. That was not expected and the reason needs to be investigated.

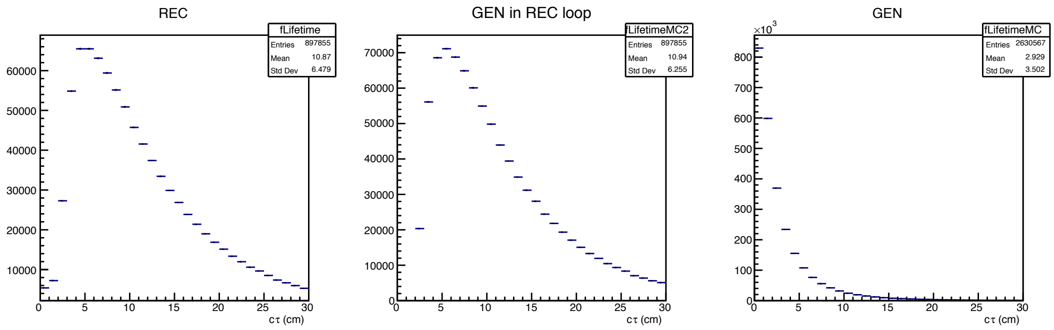

Figure 11: The distribution of $c\tau$. (left) Reconstructed data. (middle) Generated data in Reconstructed loop. (right) Generated data.

	nominal[2]	Reconstructed data	Generated data in Rec. loop	Generated data
τ (ps)	181^{+59}_{-39}(stat.)$\pm$33(syst.)	363	363	97.7

Table 3: The lifetime of ${}^{3}_{\Lambda}H$.

Figure 12 shows cτ as a function of P_m. The middle histogram in figure 12 shows there is no acceptance for low p_T. The ALICE upgrade is expected to improve the acceptance for low p_T. Figure 13 shows the resolution of cτ. The resolution is defined as

$$\text{Resolution} = c\tau_{\text{Gen2}} - c\tau_{\text{Rec}} \tag{12}$$

where cτ_{Gen2} means cτ of generate data in reconstructed loop. The value of standard deviation is 1.188 cm, and represents the resolution on the cτ.

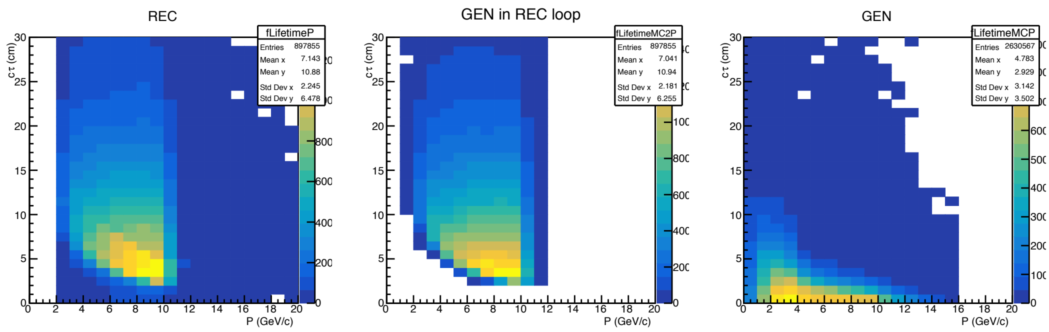

Figure 12: $c\tau$ vs P. (left) Reconstructed data. (middle) Generated data in Reconstructed loop. (right) Generated data.

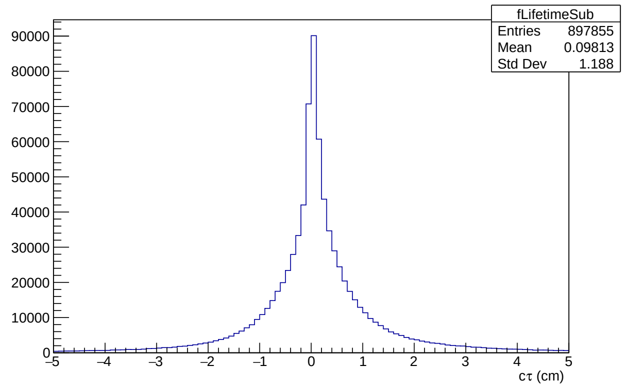

Figure 13: Resolution of $c\tau$.

4 Conclusion

Optimization of (anti-)hyper-nuclei reconstruction in the Monte Carlo data sample of Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV was presented in this report. So far, ALICE has measured hypertriton only using the two decay products, and the tracking of the charged mother were neglected. By contrast, by using the information of the tracking of the charged mother, the reconstruction of the decay was improved. This seems a promising approach for the analysis. The ${}^{3}_{\Lambda}H$ lifetime of generated data is different from nominal. The cause of that has not been clarified yet, therefore needs to be investigated. As further study, machine learning can be used to optimise the topological selection. The new ALICE detector will allow to further reduce the statistical uncertainties in LHC Runs 3 and 4.

References

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