Evaluating the impact of PID on Λ_c signal extraction with the ALICE 3 detector

Umberto Follo

Summer student report

September 2021

Contents

1 Introduction

ALICE is one of the main experiments at CERN and its goal is to analyse the physics of strongly interacting matter at the highest energy densities reached in the laboratory. In such conditions, a phase of matter - the quark-gluon plasma - is predicted to be formed. Studying this primordial state, in which quarks and gluons are deconfined i.e. they are freed from their strong interaction over long distances, will allow us to understand better how matter is organized and how the confinement and asymptotic freedom work. For this purpose hadrons, electrons, muons and photons generated in heavy nuclei collisions (es Pb) and proton-proton collisions are studied. In these hadronic collisions, when hard parton scattering processes occur with large momentum transfer, heavy quarks (charm and beauty) are produced . They traverse the medium while interacting with its constituents, thus experiencing its full evolution. Therefore, heavy quarks are ideal probes to investigate the properties of the QGP.
The aim of this report is the study of the reconstruction performances of ALICE3 detectors (implemented in the O^2 software) for the Λ_c particle. In particular, the significance and the signal to background ratio with and without particle identification.

ALICE3 In 2021 the ALICE experiment is completing a significant upgrade of its detectors but there are already studies for the next layout that will be used after Run 5: ALICE3 [1].
In order to study the best condition of the detectors for the future upgrade, ALICE3 collaboration uses a simulation software called O^2. With this tool different geometries and detectors can be simulated. The performances are evaluated in different ways: for example, the differences between a heavy particle generated from a MC simulation and the same particle reconstructed in a specific experiment setup can be studied .
Differently from ALICE, in ALICE3 the time projection chamber detector (TPC) will be replaced with a multi layer silicon tracker, and a time of flight system based on silicon detectors (TOF). Also a aereogel RICH detector will be added. They will be useful for particles identification (PID) [2].

The O^2 software Due to the new running condition after LS2 upgrade, the experiment will work with an interaction rate above 50 kHz. Therefore, the trigger techniques are rather inefficient because of the extremely small signal-to-background ratio. Thus, in order to fulfill the main physics purpose of the ALICE3, which is the study of heavy flavour hadrons, low-momentum quarkonia and low mass di-leptons, a new software must be developed: O^2 [3].

To minimise the cost and requirements of the computing system for data processing and storage, the ALICE3 Computing Model for Runs 3 and 4 is designed for a maximal reduction of the data volume read out from the detector as early as possible during the data-flow. The zero-suppressed data of all collisions will be shipped to the O^2 facility at the anticipated interaction rate above 50 kHz for Pb–Pb collisions or 200 kHz for pp and p–Pb collisions (same).

The O^2 software framework implements a distributed, parallel and multi-staged data processing model. It is designed from the beginning to combine all the computing functionalities needed in a HEP experiment: detector read-out, event building, data recording, detector calibration, data reconstruction, physics simulation and analysis. It can be tailored to different configurations by the adaptation or addition of detector specific algorithms and to specific computing systems [4].

Λ_C particle The Λ_C^+ is a baryon with a *charm* quark inside (udc). Some of the most important parameters are listed in the table below [5]:

Mass	$2.286 GeV$
Mean life	$202.4 \cdot 10^{-15} s$
Charge	Positive
Parity	Positive

Two main decays are studied: $\Lambda_c^+ \to p\,K^-\pi^+$ (and conjugal candidate) and $\Lambda_c^+ \to p\,K_s^0$ (and its charge conjugate). In this report, the first channel only will be analysed (BR 6.28%). The Λ_c^+ and its charge conjugate are relevant for the analysis of the presence of a stable bound diquark state in the QGP state, as the latter can enhance the production of this baryon.

2 Λ_c analysis

Data and Monte Carlo samples In order to estimate the impact of the particle identification on the significance of the Λ_c, two different MC sample were used for the decay channel: a $C\bar{C}$ enhanced production and a minimum bias production. The former was used to evaluate efficiencies, the latter to study the background.
First of all, the signal range generated from the Λ_c should be found. In order to do this, the $C\bar{C}$ sample was used.

2.1 Topological cuts

After the particles track and vertex reconstruction, different cuts were applied to select the Λ_c signal. Only reconstructed tracks with transverse momentum higher than 0.3 GeV/c and pseudorapidity lower than 1.44 were accepted. Then, only 3-prong decay were considered. In addition, the distance of closest approach (DCA) was tuned as a function of the transverse momentum.
All these cuts are justified by the comparison between signals matched in MC enriched $C\bar{C}$ production and background in MB production [Figure 1, 2].
Other topological parameters can be set in order to maximize the signal:

- Cosine of the pointing angle (CPA) [Figure 3]
- Decay length [Figure 4]

2.2 PID

Thanks to the RICH and TOF detectors it was possible to identify particles applying a 3σ cut. Different analyses with different cuts were performed. The combination of the two detectors leads to $K\,\pi$ separation up to 10 GeV/c and to $p\,K$ separation up to 16 GeV/c.
After PID selection the invariant mass spectrum for MC production with enhanced $C\bar{C}$ collisions allowed the determination of signal mass range [Figure 5].

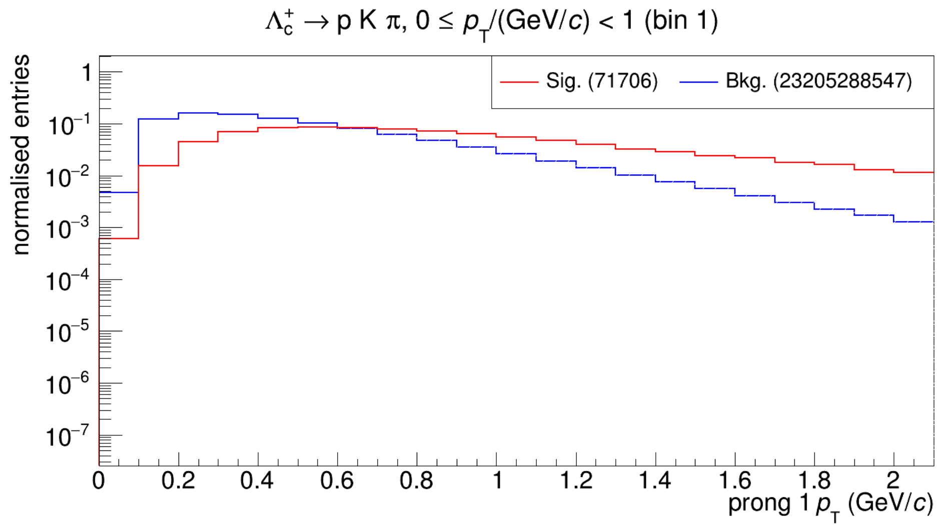

Figure 1: Transverse momentum distribution of the reconstructed Λ_c parents. Signal from matched particles in $C\bar{C}$ enriched production. Background from minimum bias MC production.

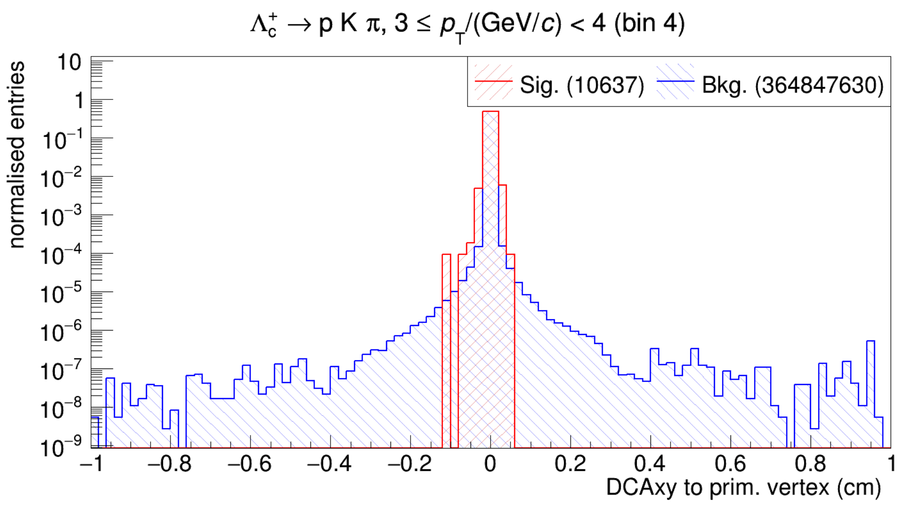

Figure 2: Reconstructed DCA distribution for Λ_c parents with transvers momentum between 3 and 4 GeV/c . Signal from matched particles in $C\bar{C}$ enriched production. Background from minimum bias MC production.

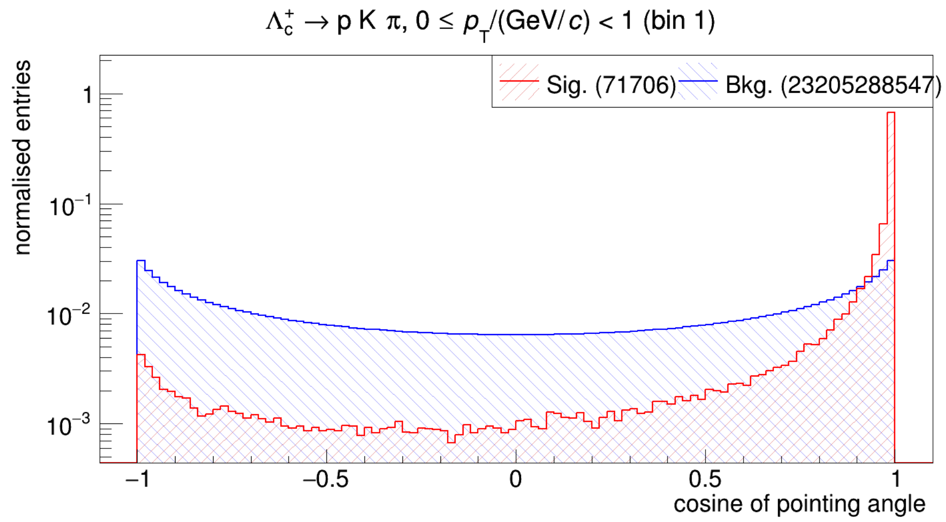

Figure 3: Reconstructed Λ_c parents CPA. Signal from matched particles in $C\bar{C}$ enriched production. Background from minimum bias MC production.

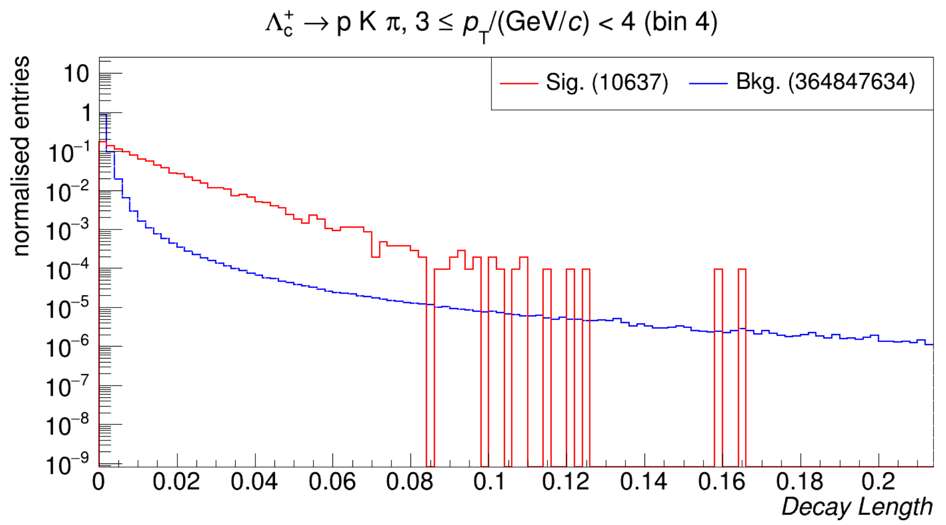

Figure 4: Reconstructed Λ_c decay length distribution for transverse momentum range $[3, 4]$ GeV/c. Signal from matched particles in $C\bar{C}$ enriched production. Background from minimum bias MC production.

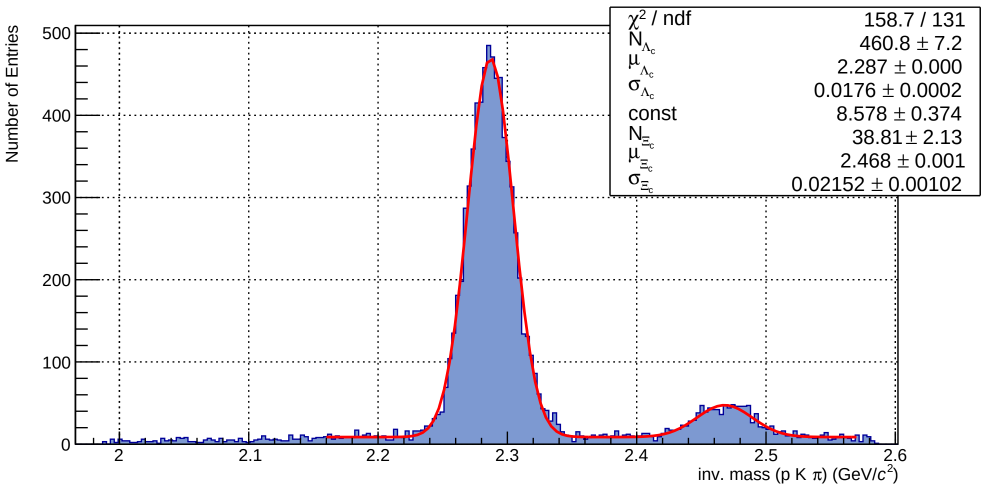

Figure 5: Invariant mass fit, transverse momentum range $[0, 36] GeV/c$. First peak: Λ_c signal. Second peak: Ξ_c (same decay, higher mass). $C\bar{C}$ enriched production. PID selection.

2.3 Estimated background

Using the minimum bias production the background could be estimated.

The invariant mass spectrum from MB production was fitted with polynomial functions outside the signal range found in MC enriched $C\bar{C}$ production $[\mu_{\Lambda_c} - 3\sigma, \mu_{\Lambda_c} + 3\sigma]$.

Invariant mass spectrum is divided in range of reconstructed Λ_c transverse momentum [Figure 6].

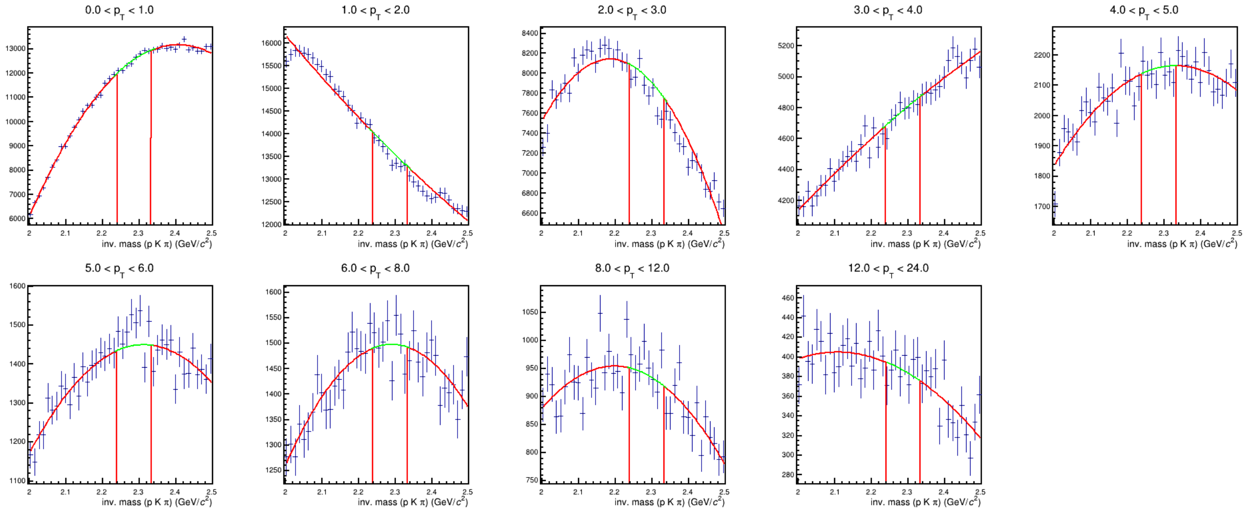

Figure 6: Background fit in different transverse momentum range of λ_c. No PID, $CPA > 80$. Red: sideband fit. Green: fit extrapolation in signal area

2.4 Efficiency

The efficiency could be estimated for different cuts and, as it is shown in the figure 7, better efficiencies could be achieved without RICH and TOF selection. However, the gain in performances without particle identification was not particularly significant.

2.5 Significance

The significance is defined as:

$$Sign = \frac{S}{\sqrt{S+B}}\sqrt{N_{ev}}$$

where signal (S) and background (B) are normalized to the number of total events (collisions). The background was extracted from the fit function of minimum bias production with an integration in signal region $[\mu_{\Lambda_c} - 3\sigma, \mu_{\Lambda_c} + 3\sigma]$ and the signal was evaluated using the yield between Λ_c and pp cross sections, this ratio was found using *Pythia8* [6]. N_{ev} is the expected number of event for LHC upgrade: $N_{ev} = L\sigma_{pp}$.

Figure 8 highlights how the signal grows by two orders of magnitude using PID.

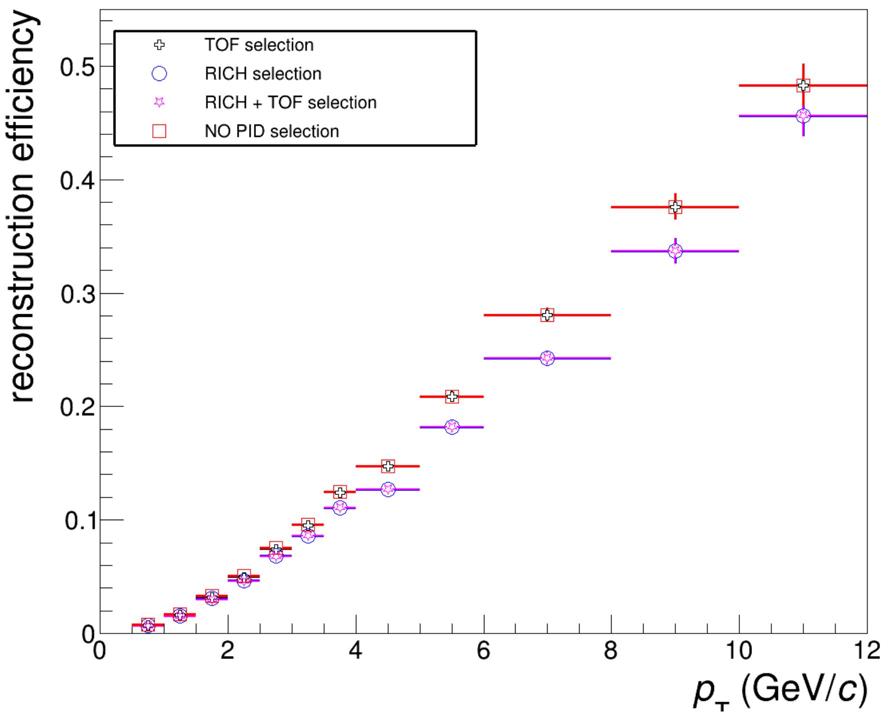

Figure 7: Reconstruction efficiency for different cuts. Red: only topological cuts. Violet: topological cuts with PID (RICH+TOF). Blue: topological cuts with RICH selection. Black: topological cuts with TOF selection. 3σ discrimination for RICH and TOF selection. $CPA > 0.98$.

2.6 Signal to background ratio

Thanks to PID, a high level of signal to background ratio was achieved [Figure 9]. The signal and background values were the same used for the significance.

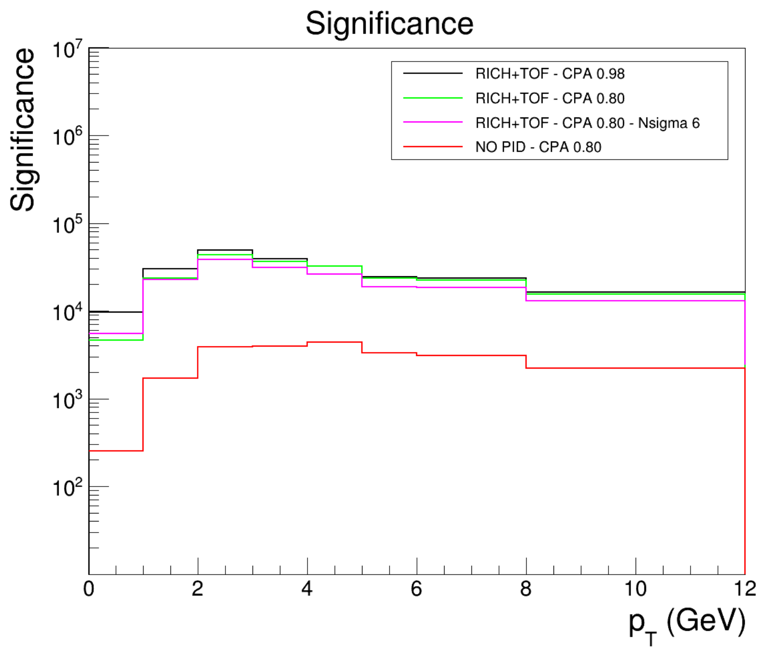

Figure 8: Significance for different selection processes. Red: only topological cuts ($CPA > 0.8$). Violet: topological cuts ($CPA > 0.8$) with PID, 6σ discrimination. Green: topological cuts ($CPA > 0.8$) with PID, 3σ discrimination. Black: topological cuts ($CPA > 0.98$) with PID, 3σ discrimination.

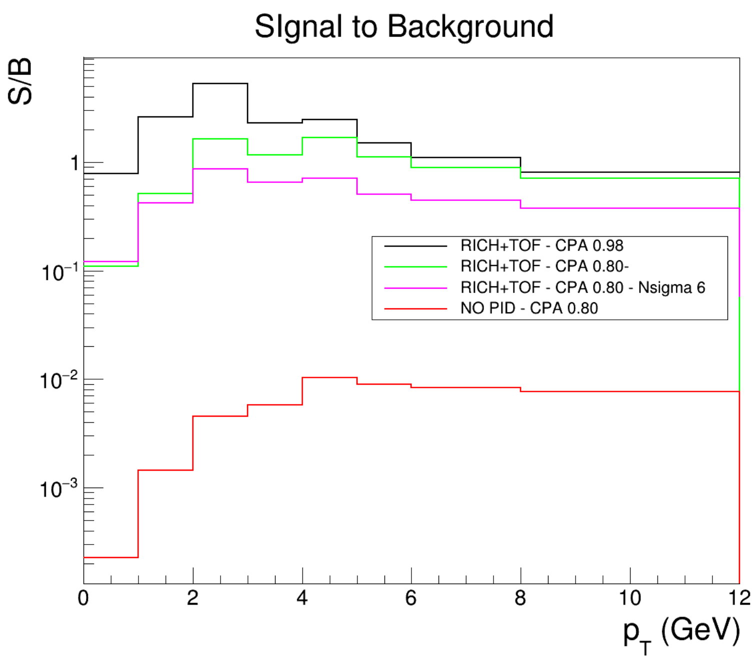

Figure 9: Signal to background ratio. Different cuts applied. Red: only topological cuts ($CPA > 0.8$). Violet: topological cuts ($CPA > 0.8$) with PID, 6σ discrimination. Green: topological cuts ($CPA > 0.8$) with PID, 3σ discrimination. Black: topological cuts ($CPA > 0.98$) with PID, 3σ discrimination.

3 Conclusion

The objective of this work was the performances investigation of ALICE3 for Λ_c. From this analysis, it can be inferred that the Particle Identification with TOF and RICH can be exploit to enhance the significance and the signal to background ratio without losing efficiency. In fact, efficiency decreases by a maximum of 10% at high transverse momentum while significance increases by an order of magnitude. The signal-to-noise ratio also grows by more than two orders of magnitude.

Acknowledgments

Although the whole project was carried out online due to Coronavirus, with the help of my supervisors Marianna and Nicolò, I managed to improve my physics knowledge and coding skills. Thanks to their advice, I was able to carry out the analysis just reported.
Working on an experiment at CERN, despite being online, has been truly incredible.

References

[1] Alice Collaboration. *ALICE 3*. URL: `https://alice-collaboration.web.cern.ch/node/34993`. (accessed: 09.09.2021).

[2] Nicolò Jacazio. *Fast simulation: tracking and particle identification*. Alice3 workshop. June 2021.

[3] AliceO2Group. *The O^2 software framework*. URL: `https://aliceo2group.github.io`. (accessed: 09.09.2021).

[4] P. Buncic, M. Krzewicki, and P. Vande Vyvre. "Technical Design Report for the Upgrade of the Online-Offline Computing System". In: (Apr. 2015).

[5] P.A. Zyla et al. "Review of Particle Physics". In: *PTEP* 2020.8 (2020), p. 083C01. DOI: `10.1093/ptep/ptaa104`.

[6] PYTHIA Collaboration. *PYTHIA 8*. URL: `https://pythia.org`. (accessed: 09.09.2021).