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Lifetime Measurement of the Xi_C^+ Using Belle II Monte Carlo

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LIFETIME MEASUREMENT OF THE Ξ_c^+ USING BELLE II MONTE CARLO

by
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DEDICATION

This thesis is dedicated to everyone who guided and encouraged me throughout the year. Thank you.

ACKNOWLEDGEMENTS

Thank you to Dr. Bennett, who has been a fantastic professor, advisor, and friend over the past four years of our work together. Thank you to my parents for the support and late-night motivational phone calls when things looked grim. Thank you to my girlfriend for being my biggest cheerleader throughout this whole process, and thank you to all of the life-long friends I have made within the physics department.

ABSTRACT

This analysis uses simulated data from the Belle II experiment to measure the lifetime of the Ξ_c^+ baryon. Three different decay modes are investigated to explore the feasibility and accuracy of such measurements at Belle II. The Ξ_c^+ lifetime is measured using one of these modes after reducing backgrounds from sources other than the decay of interest. The final result is $\tau = 464 \pm 15$ fs, which is consistent with the expected result of 442 fs within uncertainty. This result shows that Belle II can make competitive measurements of particle properties and decays.

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LIST OF PLOTS

LIST OF ABBREVIATIONS

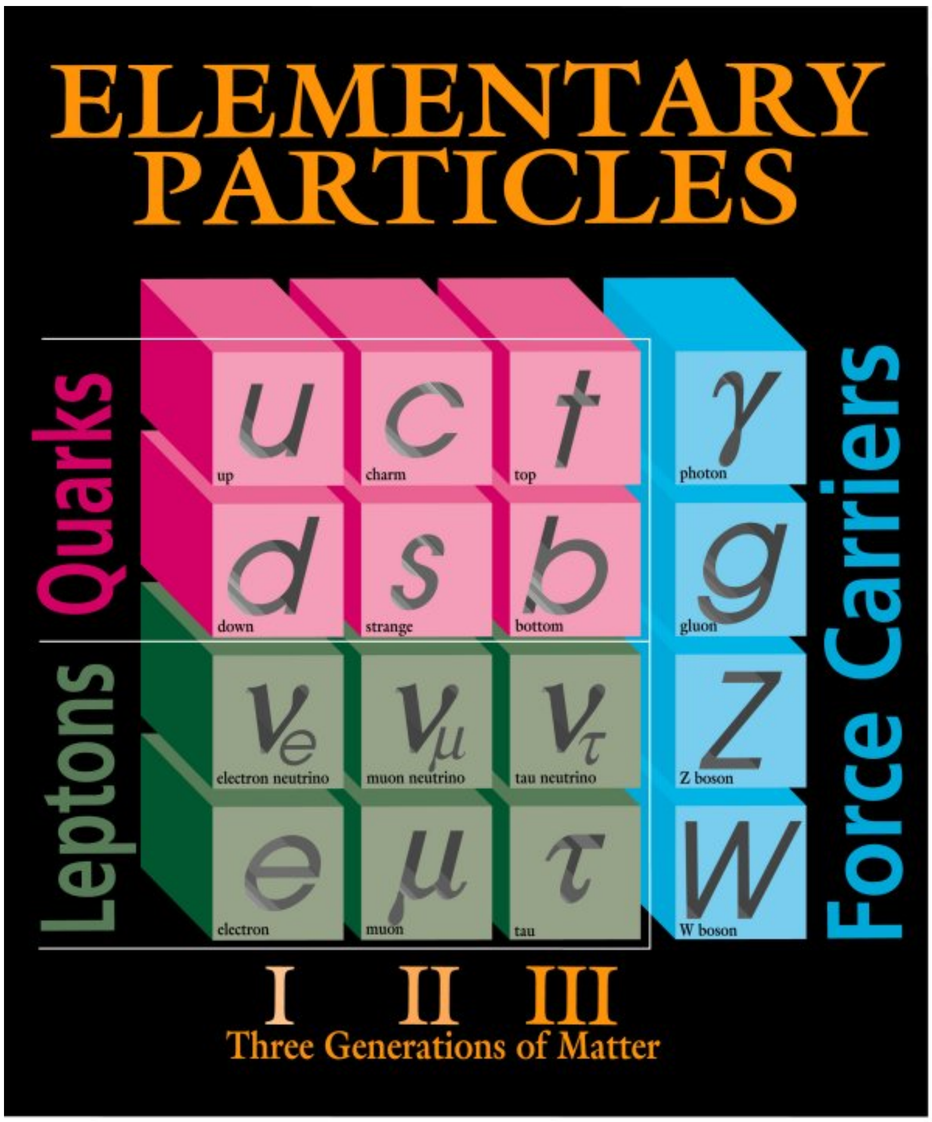
QCD	Quantum Chromodynamics
HQE	Heavy Quark Expansion
CDC	Central Drift Chamber
VXD	Vertex Detector
PXD	Silicone Pixel Detector
SVD	Silicone Vertex Detector
HEP	High Energy Physics
MC	Monte Carlo (simulated data)
Basf2	Belle II Analysis Software Framework
NP	New Physics
HQE	Heavy Quark Expansion

INTRODUCTION

Particle physics is well explained by the Standard Model [1], which describes the properties of fundamental particles; that is, the particles that are not made of other particles. For example, a hydrogen atom is made of a proton and an electron, and a proton is made of two up quarks and a down quark. However, an electron or quark does not consist of smaller particles, so they are considered fundamental.

All matter in the universe is made up of quarks and leptons that interact via the exchange of gauge bosons, which mediate the four fundamental forces. Quarks, leptons, and gauge bosons are part of the Standard Model of particle physics, which is illustrated in Figure 1 and describes particle interactions and decays with the exception of the gravitational force. For example, the interaction between quarks and gluons is described by Quantum Chromodynamics (QCD), a subset of the Standard Model, which Belle II serves an important role in strengthening.

Figure 1: Standard Model of Elementary Particles



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Quarks come in six types or “flavors”. The up, charm, and top quarks have an electric charge of +2/3 that of an electron and the down, strange, and bottom quarks having an electric charge of -1/3 that of an electron. Quarks and leptons are separated into “generations”, with the first generation being the state of least energy. Consequently, most matter is made of up quarks, down quarks, and electrons, as these are the lowest energy states. The flavor of second and third generation quarks is often described with intrinsic quantum numbers. For example, the strange quark has a property called “strangeness” such that strange quarks have strangeness -1 and the other five quarks have strangeness 0. This is important to describe particle decays, since quark flavor is conserved in strong interactions, but not in weak interactions.

While quarks are necessary to describe experimental results, they are not observed in isolation, but are bound together in states called hadrons. Hadrons are further divided into two categories: mesons, which consist of a quark antiquark pair (such as a pion), and baryons, which consist of three quarks (such as a proton). The subject of this analysis, the Ξ_c^+, is a baryon consisting of an up quark, a strange quark, and a charm quark.

Note that the strange and charm quarks are part of the second and third generations, respectively, and thus will decay to lower energy states as quickly as possible. This means that the Ξ_c^+ is a highly unstable particle which will rapidly decay into various “final state” particles, which are often made of quarks from the first generation of matter.

The lifetime of a particle is a parameter which describes the probability for the particle to decay per unit time. That is, the lifetime τ is the average time that the particle exists before decaying into various daughter particles. It is important to accurately measure such a parameter, as it is used as input to calculations of particle decays. In particular, lifetime measurements can be used to test models like Heavy Quark Expansion (HQE) that attempt to calculate decay rates for new particle and interactions beyond the Standard Model [2-8]. Higher order terms in the expansion model are needed to accurately describe particle lifetimes. With increased confidence in higher order terms, theorists can provide more accurate predictions for new physics.

This work describes a measurement of the lifetime of the charmed “cascade” baryon (Ξ_c^+) using simulated data from the Belle II experiment. The purpose of using simulations in the early stages of the experiment is not only to test the analytical procedure and tools, since the results should match expectations, but also to assess the capabilities of the newly constructed detector. If results from the analysis reasonably match expectations, then it strengthens the confidence with which Belle II can make competitive measurements with real data. The analysis presented here can be applied to real data from the experiment in the future, when there is a sufficient amount of data.

CHAPTER I: BELLE II

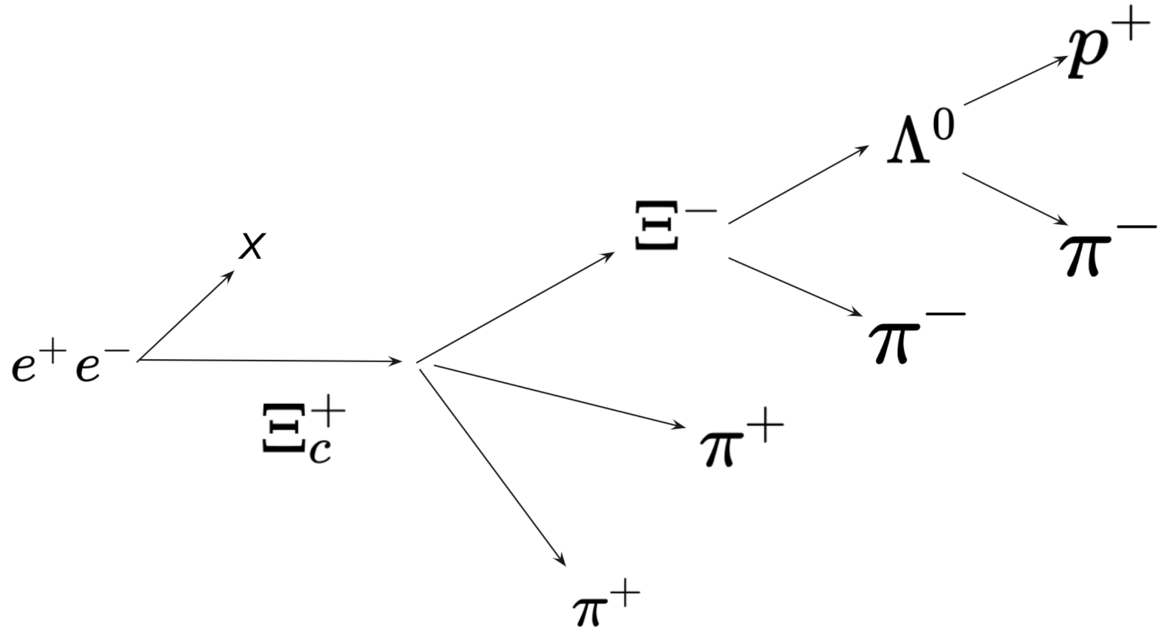
Belle II is a high energy physics experiment based at the SuperKEKB electron-positron collider in Tsukuba, Japan [9-10]. SuperKEKB collides beams of electrons and positrons (anti-matter partners of electrons) at very near the speed of light. The Belle II detector is constructed around the collision point and Belle II physicists use the data extracted from the detector to study particle and their interactions. The primary goal of the experiment is to search for new physics (physics beyond the Standard Model), such as new sources of CP violation, which is necessary to explain the matter-antimatter asymmetry in the universe. However, the hermetic nature of the detector and relatively clean environment allow for other studies, such as dark matter, lepton flavor violation, and many other topics.

The electron and positron beams collide in the interaction region (IR), and the high-energy collision produces various particles from the higher generations of matter. These particles typically decay quickly into particles from the first generation. The properties of those “daughter” particles must be used to infer information about the particles produced at the IR. To achieve this, various subsystems are put in place to measure as much as possible about the “final state” particles that leave the IR. Similarly, the detector subsystems do not measure properties of the particles directly; rather, the properties, such as momentum and mass, are inferred from their interactions in the detector. For example, charged particles deposit energy in a gas chamber, leaving a track that can be used to determine the particle trajectory and momentum. Particles deposit energy in the calorimeter, which can be used to determine the energy of the particle itself. In addition to this measured information, principles like conservation of momentum may be used to further constrain direct measurements. For example, when a particle decays, the momentum of its daughter particles must be equal to the momentum of the mother particle. Each such decay happens at what is called a particle vertex, as seen in Figure 2.

Particles that have a reasonably long lifetime travel away from the IR and through the vertex detector (VXD), which actually consists of two sub-detectors, the pixel detector (PXD) and the silicon vertex detector (SVD). Together, these two sub-detectors measure, to incredible precision, the trajectory of particle tracks. These measurements are crucial in determining where each vertex in a given decay occurs, as well as which tracks come from which vertices.

After passing through the VXD, the tracks travel through the central drift chamber (CDC), which is the primary tracking device for the Belle II detector. The CDC is filled with a gas mixture of 50% helium and 50% ethane. When a particle travels through the CDC, it ionizes the gas along its path, freeing electrons that drift toward wires held at a high potential. The amount and time at which these electrons hit the sense wire is used to

Figure 2: $\Xi_c^+ -> \Xi^-\pi^+\pi^+$ Decay Diagram



measure the trajectory and identification (mass) of the particle that crossed the drift chamber. A uniform magnetic field, created by a solenoid, causes the tracks to curve within the tracking system. The CDC can be used to measure this curvature and calculate the momentum of the track, which feels a magnetic force given by $F = qvBsin\theta$, where q is the charge, v is the velocity, B is the magnitude of the magnetic field, and θ is the angle between the magnetic field vector and the velocity vector. Since the track follows a circular (actually helical) path, this force is a centripetal force. With a little algebra, $F = qvBsin\theta = mv^2/r \implies p = mv = qrBsin\theta$, where r is the radius of the circle formed by the track's curvature. Therefore, from the measured quantities, one can determine the particle momentum.

With the information obtained by the VXD and CDC, as well as efficient particle identification from the Time of Propagation Counter (TOP) and information from the Electromagnetic Calorimeter (ECL), such as the total energy and cluster counting, physicists at Belle II can determine the properties of various particle decays. This reconstruction is primarily done using the Belle II Analysis Software Framework (basf2) and is the focus of the next chapter.

CHAPTER II: RECONSTRUCTION

The lifetimes of particles produced at the IP are often on the order of picoseconds, which is 10^{-12} seconds. With such a short lifetime, by the time any particles travel very far into the detector, they have already decayed into final state particles, such as pions and kaons. Thus, in order to proceed with the analysis, we must reconstruct the events of the entire decay from the information carried by these final state particles. For this analysis, reconstruction code uses generic Monte Carlo (simulated events) from the detector as input. Since the properties of the particles in the simulation are known, basf2 can be used to identify whether the reconstruction was performed properly and whether tracks originated from a Ξ_c^+. Then the particle information can be used to attempt to restrict or "cut" the data to isolate events of interest and remove background events from other types of particle decays.

Since the Ξ_c^+ decays into a variety of different particles, this analysis focused on three modes, $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$, $\Xi_c^+ \to \Sigma^+ K^- \pi^+$, and $\Xi_c^+ \to \Xi^0 \pi^- \pi^+ \pi^+$. These decays were chosen because the Ξ_c^+ decays into at least two final state particles that can be used to precisely measure the decay vertex, which is necessary to measure the lifetime of the Ξ_c^+. The reconstruction process for each decay is similar and each is outlined in the following subsections.

A. $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$ Reconstruction

To isolate signal events, we require that the distance of closest approach to the IR be less than 0.5 centimeters in the direction transverse to the electron beam and less than 2.0 centimeters in the longitudinal direction. Any final state particles that do not get this close to the IR could not have originated from a Ξ_c^+, given its relatively short lifetime, so this cut eliminates those background tracks from our analysis. Furthermore, these tracks must be within CDC acceptance and have at least 20 hits in the CDC to ensure a precise measurement of the particle momentum.

Furthermore, loose cuts are applied to the masses of the particles to reduce the likelihood that tracks can be improperly combined and therefore emulate the signal decay. The invariant mass of the Ξ_c^+ must be between 2.3 and 2.7 $\mathrm{GeV/c^2}$ and the invariant mass of the Ξ^- must be between 1.2 and 1.4 $\mathrm{GeV/c^2}$. The Ξ^- is also unstable and will decay into $\Lambda^0\pi^-$, so we require the invariant mass of the Λ^0 to be between 1.105 and 1.13 $\mathrm{GeV/c^2}$. Finally, to reduce backgrounds from decays of B mesons, the center of mass momentum of the Ξ_c^+ is required to be at least 2.5 GeV/c.

The next step in the reconstruction process is to apply a vertex fit, which varies the track parameters within their uncertainty to find the most likely position at which two tracks intersect. The vertex position is important because tracks that actually originate from a different point will skew the results of the analysis. Thus, using a vertex tree fit, which is a piece of software that constrains tracks to vertices following the entire decay chain, is applied to the Ξ_c^+ and a confidence level probability for the fit of 0.001 is required. This is a very loose restriction that essentially requires the vertex fit to be successful but is not so tight as to skew the sample. In other words, the low confidence level is solely to remove events with failed vertex fits. Altogether, this set of restrictions is sufficient to isolate the tracks from $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$ events with minimal backgrounds. This same process is followed (with slightly different cuts) for the other two decay modes, as described in the following subsections.

B. $\Xi_c^+ \to \Sigma^+ K^- \pi^+$ Reconstruction

The decay mode in which a Σ^+ is produced is much more difficult to investigate since it decays to a proton and a π^0, which will then decay into two photons. Photons are plentiful in the detector due to backgrounds produced by the beams, and thus it becomes extremely difficult to isolate photons that come from the π^0 of interest. Consequently, additional cuts must be applied. Photons in the detector are sorted into three different cluster regions based on their kinematics, due to the detector design. We require the energy of photons in cluster region 1, the endcap in the forward region relative to the electron beam, to be greater than 0.080 GeV, the photons in cluster region 2, the barrel region of the detector, to be greater than 0.030 GeV, and the photons in cluster region 3, the backward endcap, to be greater than 0.060 GeV.

The same track cuts from the previous decay mode are applied. That is, we require that the distance of closest approach to the IR be less than 0.5 centimeters in the direction transverse to the electron beam and less than 2.0 centimeters in the longitudinal direction, the tracks must be within CDC acceptance, and tracks must have at least 20 hits in the CDC. We also require the tracks to have at least one hit in the PXD and SVD respectively to improve the precision with which the Ξ_c^+ decay vertex is measured.

The invariant mass of the Ξ_c^+ must be between 2.3 and 2.7 GeV/c^2, with a center of mass momentum of at least 2.5 GeV/c, and the invariant mass of the Σ^+ must be between 1.0 and 1.3 GeV/c^2. We also require that the invariant mass of the neutral pion coming from the Σ^+ to be between 0.120 and 0.145 GeV/c^2. Similar to the previous mode, after reconstructing the $\pi^0, \Sigma^+,$ and Ξ_c^+ using a modular analysis, a vertex tree fit is applied and a minimum confidence level of 0.001 is required.

C. $\Xi_c^+ \rightarrow \Xi^0\pi^-\pi^+\pi^+$

In this mode, the Ξ^0 will decay via the process $\Xi^0 \rightarrow [\Lambda^0 \rightarrow p^+\pi^-]\pi^0$, meaning that we again have the difficulty of a neutral pion in our final state. We apply the same charged-track cuts as for the previous mode. Tracks must have a distance of closest approach to the IP of less than 2.0 centimeters in the direction longitudinal to the electron beam and less than 0.5 centimeters in the transverse direction, have at least one hit in the PXD and SVD, at least 20 hits in the CDC, and be within CDC acceptance.

Next, we require the invariant mass of the Ξ_c^+ to be between 2.3 and 2.7 GeV/c^2, with a center of mass momentum of at least 2.5 GeV/c, the invariant mass of the Ξ^0 to be between 1.1 and 1.5 GeV/c^2, and the invariant mass of the Λ^0 to be between 1.105 and 1.13 GeV/c^2. Afterwards, the decay is reconstructed in the same manner as the previous two modes. Finally, a vertex tree fit is applied and a minimum confidence level of 0.001 is required.

CHAPTER III: SELECTION CRITERIA

After the reconstruction step, we can construct variables that describe the decay of interest to analyze the data. However, reconstruction can never be perfect. There will naturally be physics events other than our particular decay of interest that mimic the signal decay and may skew the results of a measurement. We call such events background, and a large part of this analysis involved investigating additional cuts that may be useful to reduce backgrounds while keeping as much signal as possible. Otherwise, attempting to do a lifetime fit on a sample with more background than signal would produce very strange results.

A simple way to attack the problem of backgrounds is to analyze the plot of the invariant mass of the Ξ_c^+. Plotting this for each mode without applying additional cuts leads to an entirely invisible signal, completely covered by background, as shown in Figure 3. Then, as additional selection criteria are applied, the background gradually decreases, until eventually there is a clean signal peak. These additional cuts will vary depending on the different decay modes.

A. $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$ Selection Criteria

As shown in Figure 3, the invariant mass plot for this mode is initially completely covered with background and the signal is only a very small part of the full sample. The background is classified into different types: uubar, ddbar, and so on as shown. This nomenclature refers to background from processes originating from quark anti-quark pairs, such as $u\bar{u}$ and $d\bar{d}$, that are produced in the initial interaction between the electron and positron beams, as shown in Figure 4. Similarly, “charged” and “mixed” backgrounds refer to events that come from charged or neutral B mesons (the neutral B meson and anti-meson mix with each other).

Figure 3: $\Xi_c^+ -> \Xi^-\pi^+\pi^+$ Initial Plot of Ξ_c^+ Invariant Mass

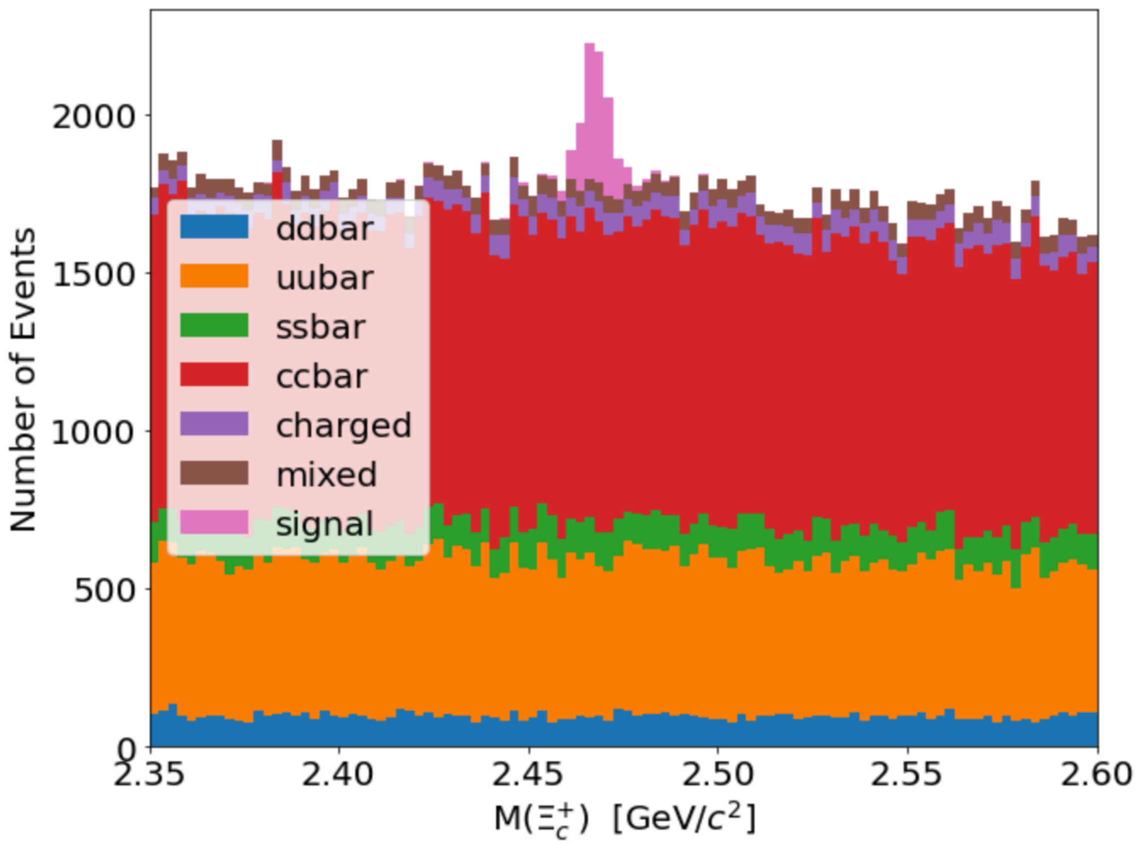
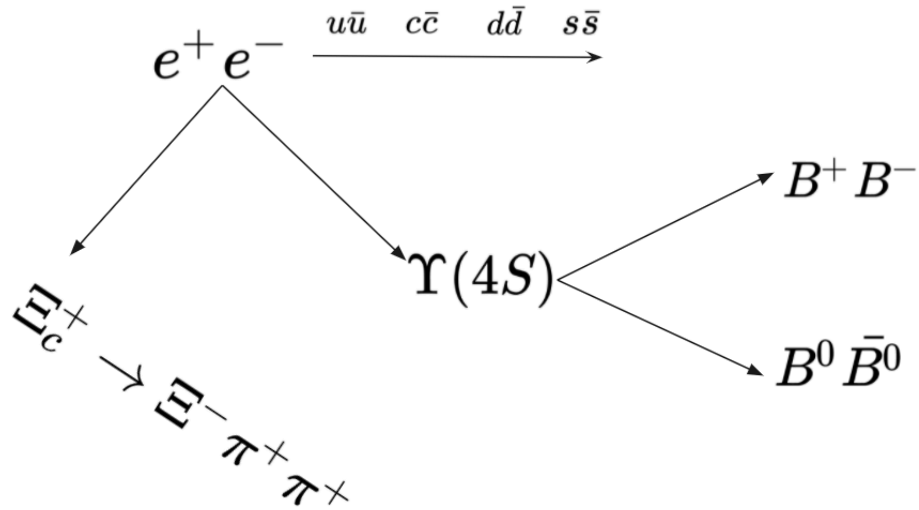


Figure 4: e^+e^- Collision Diagram



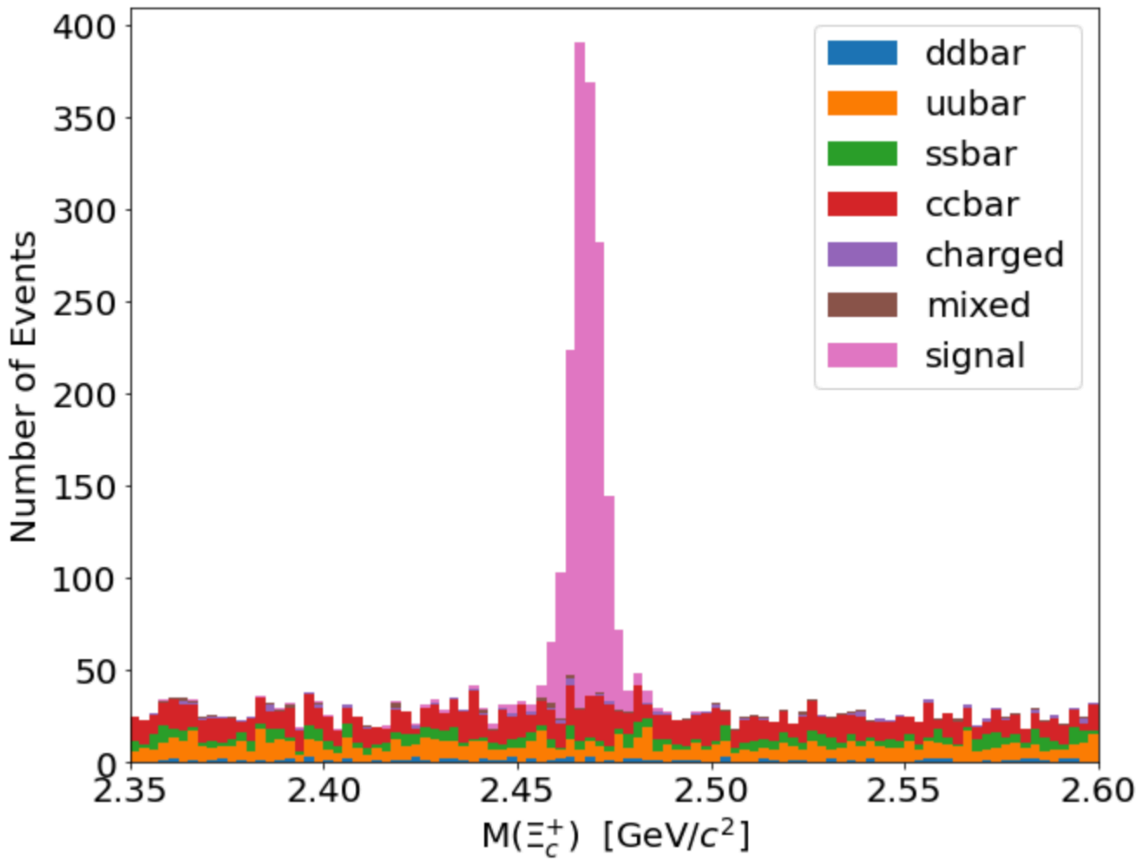
An important cut in this decay mode is the proton identification (ID). At Belle II, as aforementioned, all that is detected of particles are tracks made of ionized gas rather than particles themselves. Particle identification refers to the ability of the detector to identify what particles are causing these tracks. For example, it is important to distinguish whether the track from a positively charged particle comes from a proton or a pion. The proton ID is a likelihood value from 0 to 1, based on measured values of variables characteristic of protons. This is particularly important in this decay due to the presence of both protons and pions.

We require the proton ID for the track identified as a proton, coming from the Λ^0, to be greater than 0.82, to ensure the proton is not a particle of another type that is misidentified as a proton. This may seem like an arbitrary value, especially since we want the probability for protons to be identified as protons to be 100%, but cutting any tighter on this value will cause a loss in signal. The value used in this restriction was obtained through optimization, where many values were tested and their impacts on signal-to-background ratio were analyzed. Selection criteria are a balancing act in which the analyst methodically tests the impact of different values until a sufficient reduction in background is achieved while maintaining the desired amount of signal.

Additionally, we require the significance of the flight distance, which is the distance travelled divided by the uncertainty on the vertex position, for the Ξ^- to be greater than 10. Since we know that the Ξ^- has a significant lifetime, it will travel relatively far before it decays. It is important to note that cutting on this value for the Ξ_c^+ would skew the lifetime measurement, since the significance of the flight distance is closely related to the particle lifetime. We are not measuring the lifetime of the Ξ^-, so such a cut will not cause any problems. Additionally, we tighten the mass constraint on the Ξ^- to be between 1.310 and 1.332 GeV/c^2, since the initial cuts were fairly loose.

After these additional selection criteria, the background in the Ξ_c^+ mass plot is shown in Figure 5. As can be seen by comparing Figures 3 and 5, the resulting distribution is relatively clean, with only a small, flat background as desired. As will be discussed below, this mode required far fewer additional cuts than the other two modes, which include a π^0 in the decay of interest.

Figure 5: $\Xi_c^+ -> \Xi^-\pi^+\pi^+$ *Finalized Plot of* Ξ_c^+ *Invariant Mass*



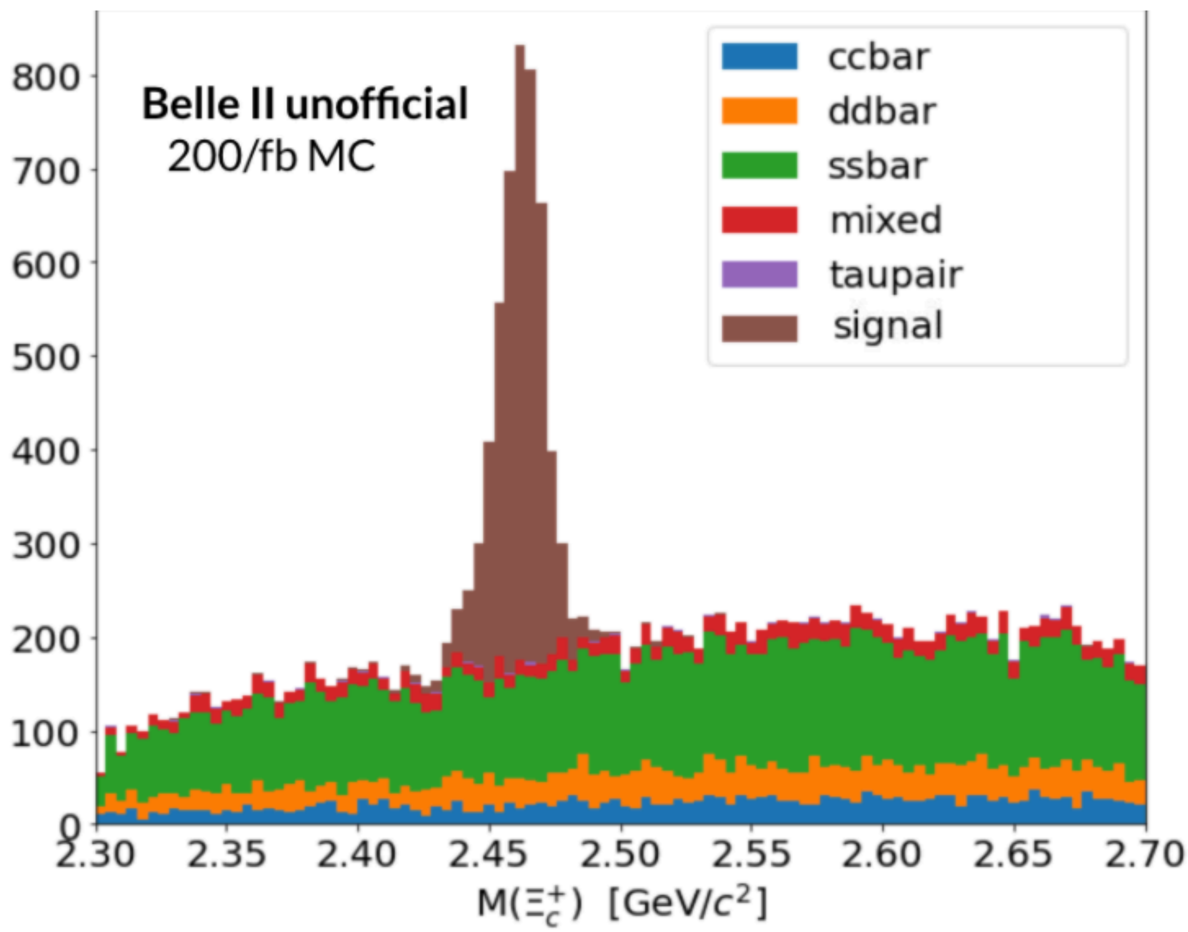
B. $\Xi_c^+ \to \Sigma^+ K^- \pi^+$

This mode's initial invariant mass plot is the same as for the previous mode, a sea of background that must be reduced. This mode will require more criteria to clean up due to the presence of the neutral pion. Similar to the proton ID for the previous mode, we require the kaon ID to be greater than 0.8 so as to avoid misidentifying another negative particle as a kaon. We also require the proton ID of the proton from the Σ^+ to be greater than 0.8. Moreover, the flight distance for the Σ^+ must be greater than 1, since it also has a significant lifetime and thus a significant flight distance.

Lastly, it is important to consider the photons produced from the neutral pion. The Belle II electromagnetic calorimeter (ECL), which is used to measure the energy of photons, is arranged in a grid structure around the IR, with rectangular crystals facing the IR. When a particle or photon encounters the ECL, it will deposit energy not just in the first crystal it encounters, but in several neighboring crystals as well. The photons produced from the neutral pion will deposit most of its energy within the central crystal and its eight nearest neighbors, which together create a 3x3 grid. However, hadrons like protons and pions will deposit energy over a wider region. Therefore, we can isolate photon clusters by requiring that the energy in the 21 crystals made up by a 5x5 grid without the four corner crystals be close to the value deposited within the inner 3x3 grid. The variable describing this ratio, clusterE9E21 is required to be greater than 0.96.

These cuts result in a cleaner distribution, but it is still not clean enough to proceed with the lifetime analysis. It is evident how much more difficult the neutral pion makes cleaning the background, as many more cuts were applied, but the distribution (Figure 6) requires further background reduction. This mode is still a work in progress, as applying efficient selection criteria is not straightforward. In Figure 6, backgrounds from B mesons are not included, since they are negligible.

Figure 6: $\Xi_c^+ -> \Sigma^+ K^- \pi^+$ Finalized Plot of Ξ_c^+ Invariant Mass



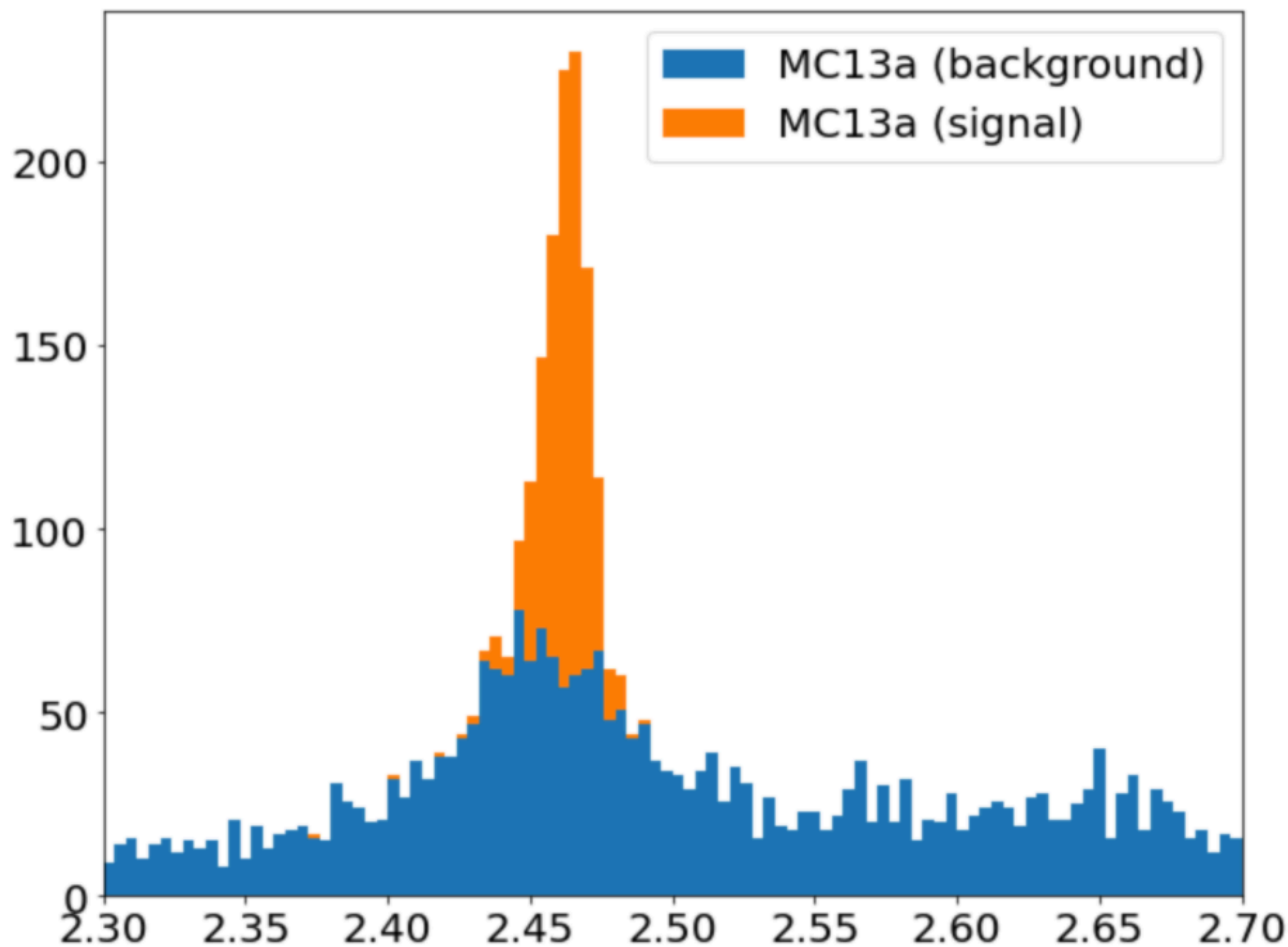
C. $\Xi_c^+ \rightarrow \Xi^0\pi^-\pi^+\pi^+$

Selection criteria for this mode are very similar to that for the previous mode, as both states include a neutral pion in the final state. The proton coming from the Λ^0 must have a proton ID greater than 0.9. Cuts on the flight distance were applied to both intermediate particles, with the flight distance of the Ξ^0 required to be less than 5, and flight distance of the Λ^0 to be between 0.1 and 20, since these particles are relatively short-lived. Moreover, the ClusterE9E21 must be greater than 0.875. The resulting plot is shown in Figure 7, where only the signal and background are identified, not the backgrounds from particular sources.

This mode is the least developed due to the time consuming nature of the lifetime fitting process and cleaning the previous mode. Results of the selection criteria are promising, but it is tricky to clean up background that peaks in the signal region without cutting out too much signal. Reasons for this background peak are being investigated.

After investigating each mode, only $\Xi_c^+ \rightarrow \Xi^-\pi^+\pi^+$ is ready to go through the lifetime fit, which is the focus of the next section. The other two modes will be included as well, once their respective backgrounds are further reduced.

Figure 7: $\Xi_c^+ -> \Xi^0\pi^-\pi^+\pi^+$ Finalized Plot of Ξ_c^+ Invariant Mass



CHAPTER IV: LIFETIME FIT

The Ξ_c^+ lifetime is determined using the $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$ mode by using an unbinned maximum likelihood fit, a statistical process of imposing a likelihood function to the (unbinned) data to estimate its parameters, to the decay time t and the decay time uncertainty σ_t for events falling within the signal range. The signal range is defined as the invariant mass of the Ξ_c^+ being between 2.460 and 2.475 GeV/c^2, a much tighter constraint than what was applied at reconstruction. Such a tight restrictions is permissible since the decay time is symmetric around the Ξ_c^+ mass. As long as the window is properly defined, the lifetime will not be affected by the narrowness of the window. We use an unbinned fit because binning the data could lead to a loss in precision.

The background contribution in the lifetime fit can be accounted by fitting events from the Ξ_c^+ sideband regions, defined as the invariant mass being between 2.4375 and 2.4450 GeV/c^2 (left sideband), or being between 2.4900 and 2.4975 GeV/c^2 (right sideband).

The likelihood fit is, essentially, imposing a probability density function (pdf) onto the values of t and σ_t. In this case, the pdf is defined as the convolution of an exponential distribution with a resolution function that depends on σ_τ,

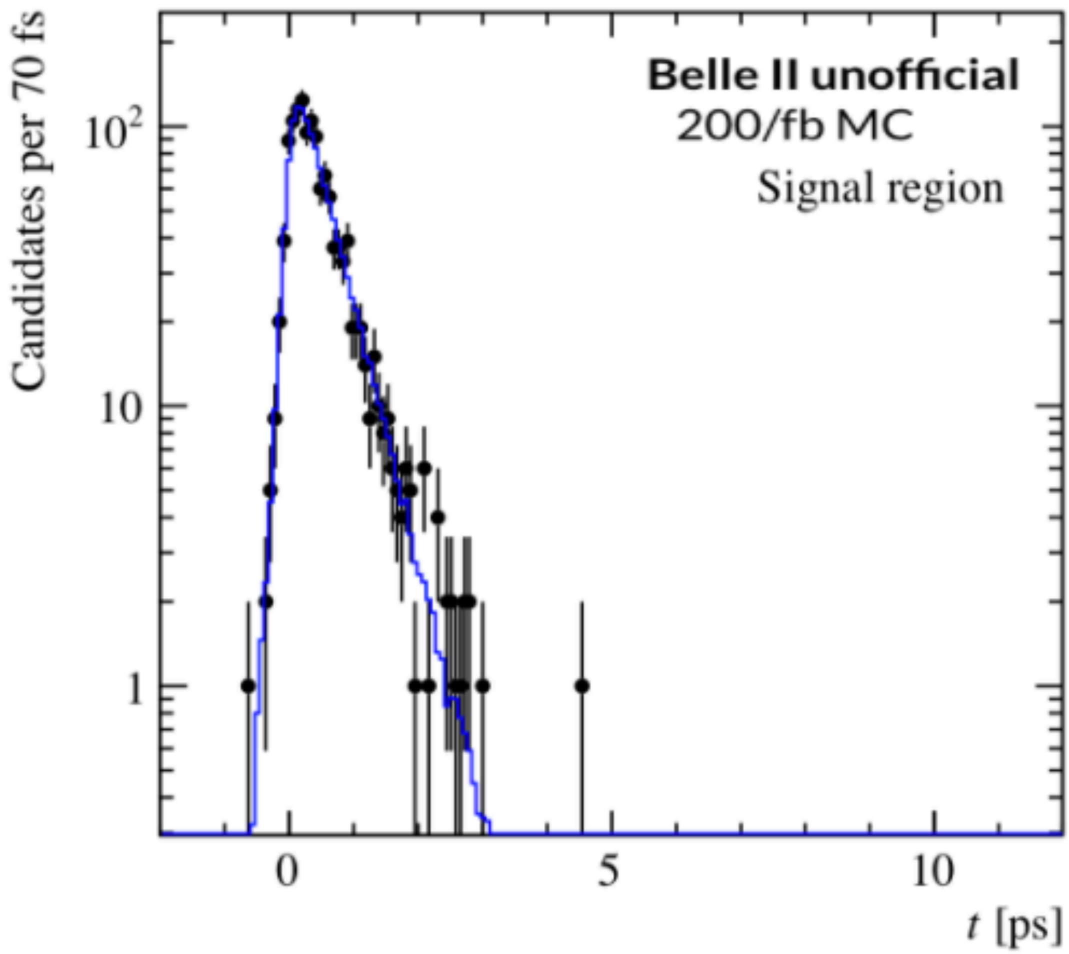
$$pdf(t, \sigma_t | \tau, f, b, s_1, s_2) = pdf(t | \sigma_t, \tau, f, b, s_1, s_2) pdf(\sigma_t) \ \alpha [e^{t/\tau} \times R(t | \sigma_t, f, b, s_1, s_2)] pdf(\sigma_t),$$

where s_1 and s_2 are scale parameters applied to the Gaussian width of the resolution function described below, f is the fraction of events falling within the narrow Gaussian in the resolution function, and b is a mean parameter to account for a possible bias in the decay time. The resolution function is parameterized as a double Gaussian distribution, $R(t\,|\,\sigma_t, f, b, s_1, s_2) = fG(t\,|\,b, s_1, \sigma_t) + (1-f)G(t\,|\,b, s_2, \sigma_t)$, where the scale parameters are multiplied to the per-candidate σ_t to account for a possibly incorrect estimation of the per-candidate decay-time uncertainty. The σ_t distribution is given by a fixed template from the sample for the $\Xi_c^+ -> \Xi^-\pi^+\pi^+$ mode, as shown in Figure 8.

The lifetime can be extracted by observing the slope of the fit, which decays according to $e^{-t/\tau}$. Therefore, since this is a logarithmic plot, simply taking the slope will yield $-t/\tau$, where τ is the lifetime. However, the imperfect resolution of the detector skews the lineshape, so the full distribution must be used, rather than the trailing edge.

The result of lifetime fit to a sample of simulated data equivalent to 200/fb gives a value of $\tau = 464 \ \pm 15\ fs$, which is consistent with the expected result of $\tau = 442\ fs$ within 1.5 standard deviations. It is also consistent with the recent measurement by the LHCb collaboration of 456.8 ± 3.5 ± 2.9 ± 3.1 fs [11], though with worse statistical precision. With additional data, the Belle II measurement will become more competitive.

Figure 8: Lifetime Fit Results



CHAPTER V: SYSTEMATIC UNCERTAINTIES

A difficult part of any particle physics analysis is accounting for the myriad of systematic uncertainties. In contrast to many other fields, nearly every source of uncertainty on a measurement can be accounted in particle physics. The next step in the analysis procedure is to understand and quantify sources of systematic uncertainty for the lifetime measurement of the Ξ_c^+. Recent studies of other particle lifetimes at Belle II, specifically the Λ_c^+, give a good estimate for what must be measured for this study.

One of the most challenging sources of systematic uncertainty is Ω_c^0 contamination. This analysis assumes that the Ξ_c^+ originates directly from the IR, so the distance between the Ξ_c^+ and the first decay vertex is the flight distance. The flight distance is crucial in determining the lifetime, so skewed flight distances will produce skewed lifetime results. However, the Ξ_c^+ may itself be a decay product from the decay $\Omega_c^0 \rightarrow \Xi_c^+\pi^-$. In this case, the Ω_c^0 originates at the IR and the Ξ_c^+ originates some distance away from the IR, meaning the Ξ_c^+ flight distance is shorter than what is measured in this analysis. In other words, Ω_c^0 decays (and other decays with Ξ_c^+ as a byproduct) are contaminating the lifetime results. This must be accounted for with a systematic uncertainty and/or a correction.

Another source of systematic uncertainty relates to the resolution function in the lifetime fitting code, which is assumed to be Gaussian distributed. Since this assumption is not perfect, a systematic uncertainty must be applied to account for potential discrepancies caused by this imperfect description of the detector resolution.

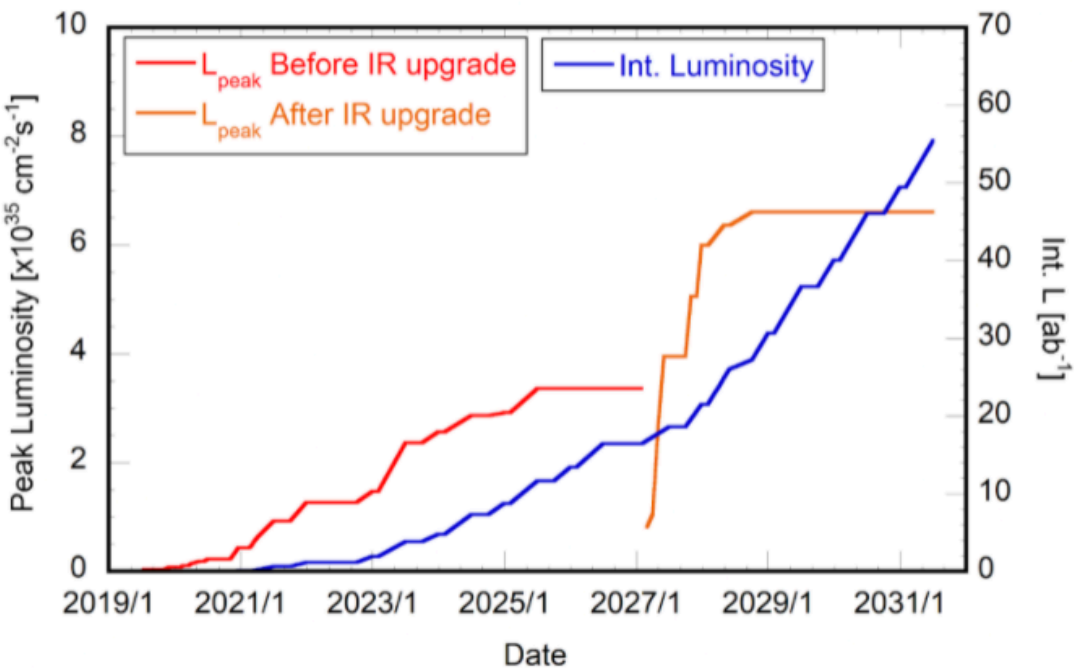
Other sources of systematic uncertainties include, but may not be limited to, systematic bias due to differences between the background fraction in the signal and sideband regions, imperfect detector alignment, and uncertainty in a momentum correction factor to account for imperfections in the tracking algorithms. These uncertainties must be well understood before the measurement on data can be attempted.

CONCLUSION

The Ξ_c^+ lifetime is measured with Belle II simulations to be $\tau = 464 \pm 15\ fs$, which is consistent with the expected result of $\tau = 442\ fs$ within 1.5 standard deviations. Only one decay mode was incorporated into the lifetime fit, so after investigating additional selection criteria the other two modes may be incorporated to increased the amount of data in the fit and reduce the statistical uncertainty. Moreover, Belle II is continuing to take data, so the sample size will increase and further reduce the statistical uncertainty.

The projected luminosity for Belle II (the amount of data collected) is expected to more than double in the coming months, as shown in Figure 9. Hence, only a little more work over the next few months will enable a lifetime measurement for the Ξ_c^+ that is competitive with other high energy physics experiments. The analysis presented here proves that given more data, Belle II can make precise measurements of charmed baryon lifetimes.

Figure 9: Belle II Projected Luminosity



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