학사학위 논문

벨 II 소프트웨어 프레임워크에서의 1차 Λ^0 입자와 2차 Λ^0 입자의 시뮬레이션 기대수명 비교

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국문초록

Comparison of the Simulated Lifetime of Primary and Secondary Λ^0 Particles in Belle II Analysis Software Framework

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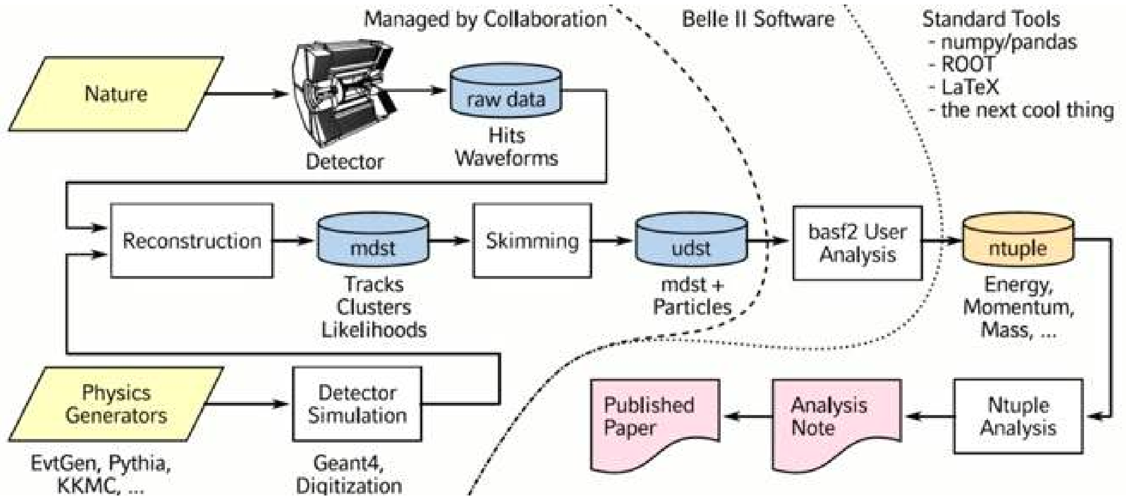
The problem of the simulated lifetime of secondary Λ^0 particles in the Belle II detector simulation has been reported by Hikari Hirata at Nagoya University. As stated in her report, the difference between the simulated lifetime of secondary Λ^0 particles and the one of primary Λ^0 particles is about 10 percent[1].

In the Belle II experiment simulation, the particles produced by event generators, such as the continuum generator or the ParticleGun, are taken as the input information for the Geant4 simulation; they are called the primary particles. Depending on the physics processes of the Geant4, primary particles produce their daughter particles; they are called the secondary particles[2].

In this undergraduate thesis, the issue is reproduced using the MC11 ccbar continuum sample, and the length of flight is plotted against the momentum. The result of the plots shows that the discrepancy is dominated in $p < 1 GeV$. In consequence, the ParticleGun is used to test secondary Λ^0 particles in the range $p < 1 GeV$. The results obtained from the ParticleGun show that the simulated lifetime of the secondary Λ^0 particles tends to decrease as the momentum of their mother particles increases.

제 1 장 서 론

1.1 Event Generators in Belle II Analysis Software Framework



<Figure 1>: Provided by Martin Ritter, DESY

The process of how a plethora of data is analyzed in High Energy Physics Experiment is well described in Figure 1. In the simulation part, event generators produce tons of primary particles whose information is taken as the input for the detector simulation[2]. The Geant4 is a simulation toolkit that plays a key role in the detector simulation. It constructs the geometry of the simulated Belle II detector[3],[4], calculates the physics processes along with the steps of particles as they pass through the detector, leaves hits in the detector, and so on[5].

The Belle II Analysis Software Framework, basf2, contains a lot of event generators[6]. In the following sections, the continuum generator and the ParticleGun are described.

1.1.1 Continuum Generator

In basf2, the continuum generator performs the hard process, the fragmentation, and the hadron decay. Each of the processes is generated using KKMC, PYTHIA, EvtGen respectively[6]. For example, Λ^0 particles, produced during the hadron decay by EvtGen, are classified as the primary particles. The information of primary particles is stored in the MCParticles block with the value of m_secondaryPhysicsProcess == 0. A variety of hadrons produced by the continuum generators are fed into the Geant4 simulation; their daughter particles, produced along with the physics processes of the Geant4, are classified as secondary particles. In particular, if G4DecayProcessType of the secondary particles is DECAY, the information of the secondary particles is stored in the MCParticles with the value of m_secondaryPhysicsProcess == 201[2].

1.1.2 ParticleGun

In basf2, the ParticleGun is an event generator based on the Geant4, in which users can choose what primary particles to be shot to the simulated Belle II detector with what momentum, theta, and phi, etc[7]. As in the continuum generator, the information of primary particles is stored in the MCParticles with the value of m_secondaryPhysicsProcess == 0; the secondary particles, produced with G4DecayProcessType of DECAY, are stored in the MCParticles with the value of m_secondaryPhysicsProcess == 201[2].

1.2 History of Λ^0 Particle and Its Lifetime

1.2.1 History of Λ^0 Particle

In 1947, the Λ^0 particle was first discovered, and its proper lifetime was measured to be in the order of $10^{-10}(s)$, which was much longer than expected. Physicists introduced the strangeness to explain this phenomenon; it was found that the Λ^0 particle has a long lifetime because it decays via a weak interaction that does not conserve the strangeness[8].

1.2.2 Proper Lifetime

To calculate the proper lifetime of the Λ^0 particles, the following equation has been used[9].

$$L = \gamma \upsilon \tau = \frac{pc}{m}\tau$$

L: length of flight (in lab), γ: Lorentz factor, υ: particle velocity, τ: proper lifetime, p,m : momentum and mass (in GeV)

제 2 장 본 론

2.1 Bug-Reported Results and Bug Reproduction

According to "An Issue in Particle Lifetime of MC9 Continuum Samples" reported by Hikari Hirata at Nagoya University, the simulated lifetime of the secondary Λ^0 particles produced during the Geant4 simulation shows a discrepancy of about 10%, compared to the one of the primary Λ^0 particles produced by the continuum generator[1].

2.1.1 Bug-Reported Results

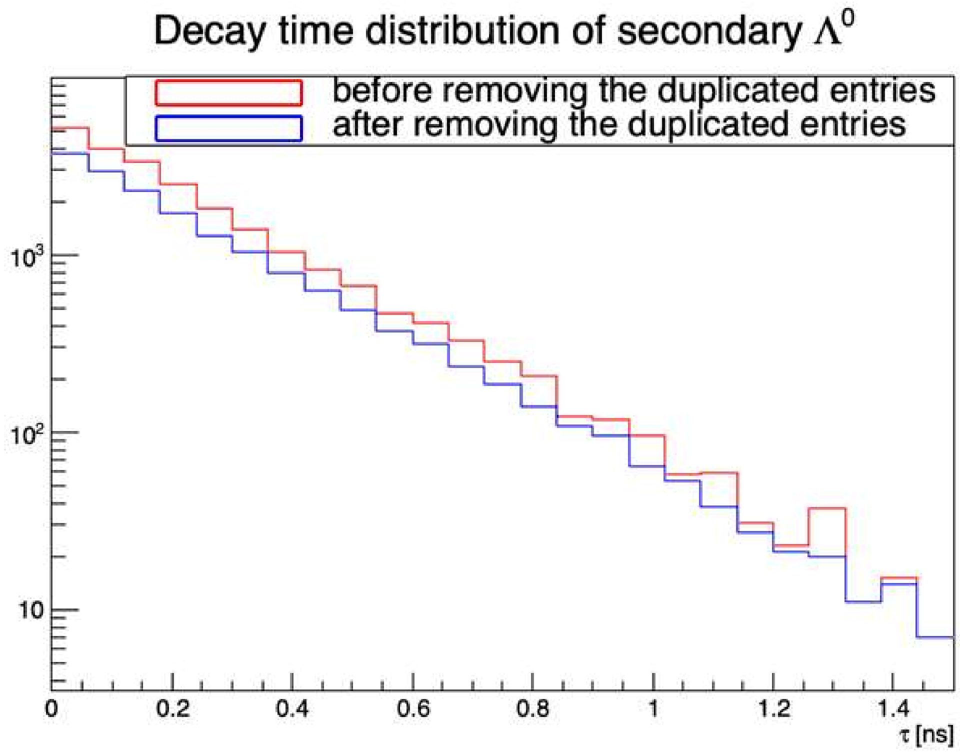
Primary/Secondary Λ^0 Particles	(Proper) Lifetime [ns]
m_secondaryPhysicsProcess == 0	0.2565 ± 0.0024
m_secondaryPhysicsProcess == 201	0.2364 ± 0.0028
Geant4 (default) value	0.2631

<Table 1>: Results from Hikari Hirata[1]

2.1.2 Bug Reproduction

It is necessary to reproduce the bug for the Belle II Software developers to be able to find reasons of the problem and test their patch files. In this undergraduate thesis, the MC11 ccbar continuum sample is used to reproduce the problem. Because DataStore used by basf2 is in the ROOT format[3], ROOT has been used to obtain the simulated lifetime of particles and plot all the histograms in the following sections[10].

As printing out the information of the secondary Λ^0 particles, there are duplicated entries. The comparison of the simulated lifetime of the secondary Λ^0 particles before and after removing the duplicated entries is shown in Figure 2 and Table 2.



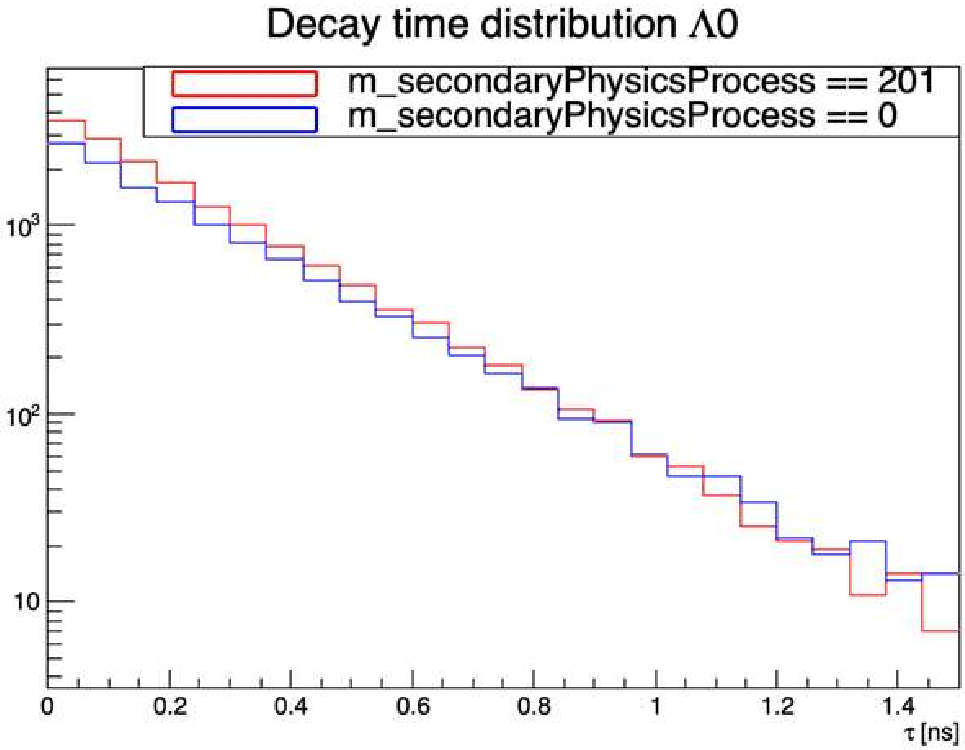
<Figure 2>: Decay time distribution of secondary Λ^0 particles before/after removing the duplicated entries

Secondary Λ^0 Particles	(Proper) Lifetime [ns]	# of Entries
with all entries	0.2301 ± 0.0016	23107
without duplicated entries	0.2364 ± 0.0019	16659
Geant4 (default) value	0.2631	

<Table 2>: The comparison of the simulated lifetime of secondary Λ^0 particles before/after removing the duplicated entries

The results above indicate that the problem is not due to the duplicated entries. In the followings, all entries of the same information are not double-counted.

As comparing the simulated lifetime of the secondary Λ^0 particles with the one of the primary Λ^0 particles, the same problem occurred.



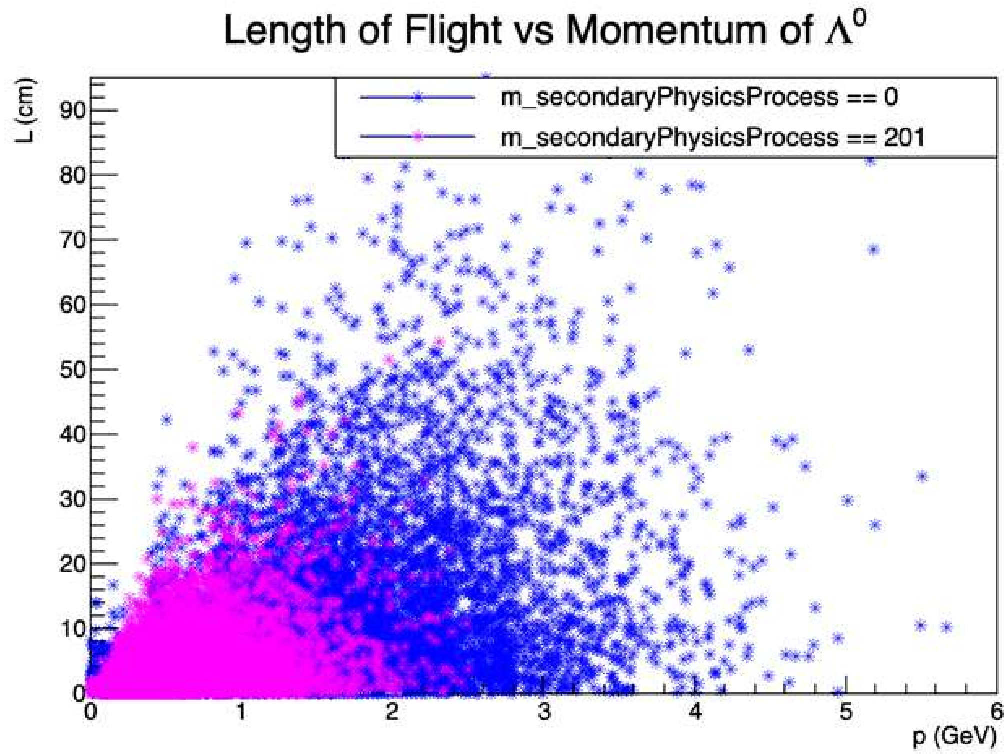
<Figure 3>: The decay time distribution of the primary/secondary Λ^0 particles

Primary/Secondary Λ^0	(Proper) Lifetime [ns]	# of Entries
m_secondaryPhysicsProcess == 0	0.2569 ± 0.0025	12784
m_secondaryPhysicsProcess == 201	0.2364 ± 0.0019	16659
Geant4 (default) value	0.2631	

<Table 3>: The Results from the Bug-Reproduction

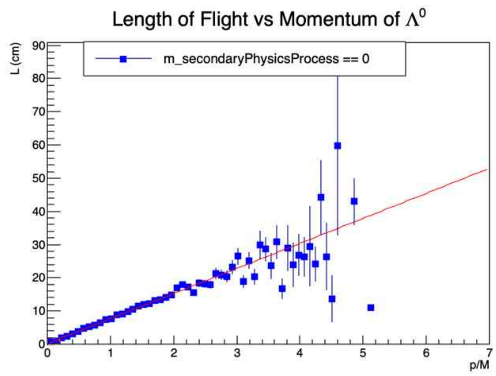
2.2 Length of Flight vs Momentum

In order to investigate reasons of the problem, it can be helpful to plot the length of flight against the momentum for the primary and secondary Λ^0 particles and visualize them. Figure 4 is the 2D scatter plot of Length of Flight vs Momentum for the primary and secondary Λ^0 particles.

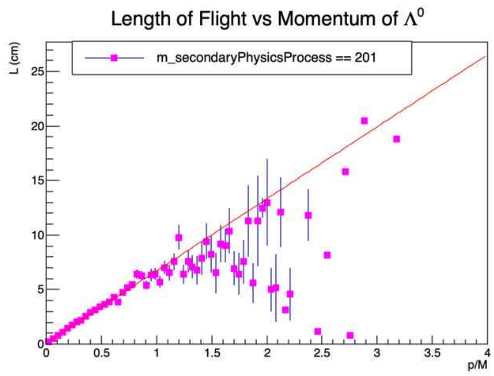


<Figure 4>: Scatter Plot of Length of Flight vs Momentum

Converting the 2D scatter plot to 1D plot by projecting them onto the X-axis, the simulated lifetime of Λ^0 particles can be obtained from the fitting parameter. Figure 5 and Figure 6 are the 1D plots of Length of Flight vs Momentum/Mass for the primary and secondary Λ^0 particles respectively.



<Figure 5>: Length of Flight vs Momentum/Mass for the primary Λ^0 particles

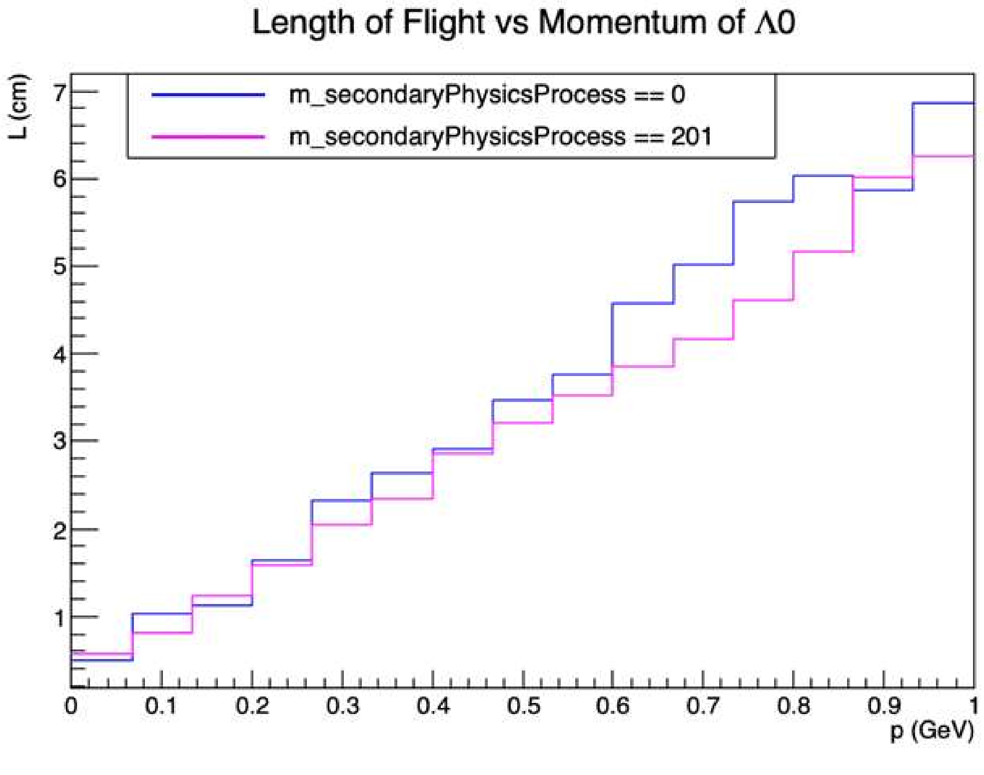


<Figure 6>: Length of Flight vs Momentum/Mass for the secondary Λ^0 particles

Primary/Secondary	(Proper) Lifetime [ns]	# of Entries
m_secondaryPhysicsProcess == 0	0.2515 ± 0.0025	21811
m_secondaryPhysicsProcess == 201	0.2202 ± 0.0025	16682
Geant4 (default) value	0.2631	

<Table 4>: The comparison of the simulated lifetimes obtained from the fitting parameter

Figure 5 and Figure 6 show that the simulated lifetime is dominated in the range $p < 1GeV$. Figure 7 clearly shows that the discrepancy between the simulated lifetimes of the primary and secondary Λ^0 particles occur in $p < 1GeV$.



<Figure 7>: Length of Flight vs Momentum

2.3 Results of the ParticleGun

2.3.1 Ξ^0 particles

In order to obtain secondary Λ^0 particles in the same momentum region as in Figure 7, the Ξ^0 particles in the range $0.05GeV < p < 1GeV$ with the uniform momentum distribution have been chosen for the primary particles. Table 5 shows that the secondary Λ^0 particles produced do not have a significant discrepancy in their simulated lifetime; however, the secondary Λ^0 particles produced from the Ξ^0 particles in higher momentum have a shorter lifetime as reported.

Momentum Region of Ξ^0 particles	(Proper) Lifetime [ns]	# of Entries
uniform, [0.05, 1]	0.2603 ± 0.0088	1490
normal, [1.72, 0.806]	0.2373 ± 0.0059	2490
Geant4 (default) value	0.2631	

<Table 5>: The simulated lifetime of secondary Λ^0 particles produced from the Ξ^0 particles in the ParticleGun

2.3.2 K^- particles

Table 6 shows that the same tendency occurs when the primary particles are set to be K^- particles.

Momentum Region of K^- particles	(Proper) Lifetime [ns]	# of Entries
uniform, [0.05, 1]	0.2631 ± 0.0048	3800
uniform, [1.5, 3.0]	0.2378 ± 0.0027	8980
Geant4 (default) value	0.2631	

<Table 6>: The simulated lifetime of secondary Λ^0 particles produced from the K^- particles in the ParticleGun

2.4 Mother Particles

Table 7 shows that the secondary Λ^0 particles come from various mother particles. Only some of them are listed.

Particles/PDG	Frequency	Particles/PDG	Frequency
π^0/111	>2500	D^+/411	>100
π^+/211	>2000	γ/22	>400
K^+/321	>600	K^-/-321	>700
K_L^0/130	>500	p/2212	>45
K_S^0/310	>400	n/2112	>25
D^0/421	>400	Ξ^0/3322	3

<Table 6>: The mother particles of the secondary Λ^0 particles in the MC11 ccbar continuum sample.

제 3 장 결 론

In this undergraduate thesis, the bug reported by Hikari Hirata at Nagoya University has been reproduced. Table 2 shows that the discrepancy of the simulated lifetime of secondary Λ^0 particles is not due to the duplicated entries. Figure 7 shows that the problem is dominated in the range $p < 1 GeV$. In terms of Table 5 and 6, the simulated lifetime of secondary Λ^0 tends to decrease as the momentum of their mother particles increases. This may be because the mother particles in the region of higher momentum would interact with the nuclei in detector material. If that is the case, the de-/excitation of nuclei would explain the shorter lifetime of secondary Λ^0 particles.

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