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HLT2 Analysis of $K_s^0 \rightarrow e^+ + e^-$ via Run 3 Simulations

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Abstract The decay of the short-lived Kaon, or K-short, into a positron-electron pair will be analyzed using Monte Carlo Simulations with parameters from the 2024 LHCb-like detector and the suite of HLT2 programs provided by the Large Hadron Collider Beauty (LHCb) collaboration. Interest will be given to the $K_s^0 \rightarrow e^+ + e^-$ mass histogram, which has not been measured before within the LHCb. Moreover, the $K_s^0 \rightarrow e^+ + e^-$ decay could also prove to be a probe into beyond standard model physics. Some theory will be discussed to provide context to the completed work along with the process of generating a mass histogram of the decay of interest.

INTRODUCTION/THEORY

With regards to the Standard Model (SM) of particle physics, physicists are attempting to find possible probes that could allow them to peer beyond the matter-oriented model they have been working in for decades now. While the SM does offer an explanation to how most of our world works on the sub-atomic level, it does not offer an explanation on dark matter and dark energy, which make up most of the universe. (~27% dark matter, ~68% dark energy, and <5% matter). [1]

As a result, various decay processes have been chosen as probes into Beyond Standard Model Physics, or BSM. One such decay is $K_s^0 \rightarrow e^+ + e^-$, where a short-lived kaon, or K-short, decays into a positron-electron pair with a branching ratio of $Br(K_s^0 \rightarrow e^+ + e^-) < 4.2 \times 10^{-7}$ [2]. Feynman diagrams like the one shown in Figure 1 show one possible way in which K-short can decay into a positron and an electron.

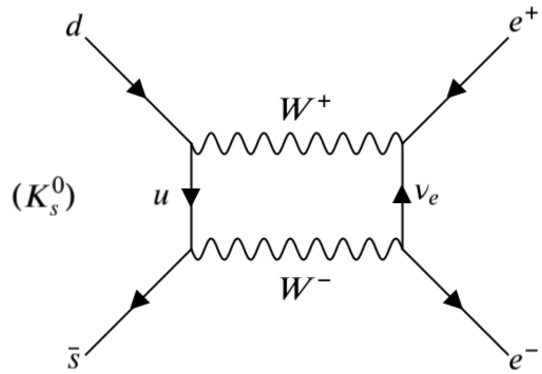

Figure 1: Feynman diagram depicting K_s^0 -->e^+ + e^-

K-short commonly decays into its daughter particles via the weak interaction. This interaction is unique in that it has been proven to violate CP symmetry in kaons. As such, scientists believe that the weak interaction is one such way they can probe into beyond standard model physics. Namely, it is theorized that the $K_s^0 \rightarrow e^+ + e^-$ decay can be mediated by some $X^\pm$ particle (Figure 2), which is a possible candidate for a dark photon.

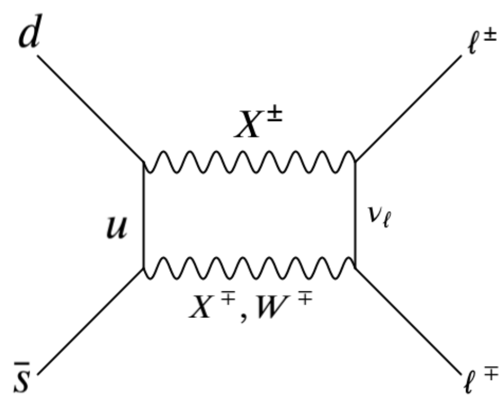

Figure 2: Feynman diagram depicting K_s^0 --> e^+ + e^- (w/ the presence of X+/-)

TESTS

At the European Council for Nuclear Research (CERN), high-energy particle decays are studied through the use of a collider known as the Large Hadron Collider (LHC). Two proton beams move throughout the collider in opposite directions and collide at four key points, where the four major detectors of the LHC are located.

One such detector, the Large Hadron Collider beauty experiment (LHCb), is focused on detecting the forward-moving particles that pass through it to study CP violations and rare decays of beauty, charm, and strange hadrons, among other topics. After a collision occurs and particles pass through the detector, the dataflow system within the LHCb is activated. Within this system, two software applications referred to as High-Level Triggers (HLTs), help decide what events are interesting and worth saving [3]. Since the LHCb needs to take 5 TB/s worth of data and reduce that value to 10 GB/s [4], this dataflow system needs to be able to reliably reduce a large amount of data to a more manageable size. Data from the LHCb's detectors first flows through HLT1, where the partial reconstruction and selection of events is carried out. The selected events then enter a buffer to allow real-time alignment to take place. After that, the events then enter HLT2, where the complete reconstruction and selection of events is carried out. Specifically, this research was conducted entirely within HLT2 since the complete reconstruction of events was required.

The main library/module most HLT2 programs are written in is called Moore, where the reconstruction and selection of events takes place. Monte Carlo simulations based on the 2024 LHCb-like detector, which models the conditions the LHCb will be under in 2024, was used as the dataset that was fed into the written HLT2 line. The trigger line first selects a candidate that is interesting, which is typically determined by the person who writes the code. In the case of this research, a positron-electron pair is selected as the daughter particles of K-short, and the tracks are reconstructed from there. Cuts are applied to the candidates so that only the desired candidates are left over. Combining algorithms then use these candidates to recreate K_s^0 parent particles, and the following cuts are applied to the combinations (See table 1).

Efficiency tests can be run through another library called MooreAnalysis. This test is used to see how efficient a certain HLT2 line at selecting a signal event within a given set of events. A rate test can also be run to see how many events are kept from a given HLT2 line.

The last set of tests are contained within another library called DaVinci, which is primarily used for offline processing at LHCb. The previous tests that have been mentioned are considered online processing since the simulated dataset is processed in real time and is subsequently stored in an output file, like a root or dst file. Tests in DaVinci involve taking already-processed results and continuing to analyze them. Programs written within DaVinci are primarily used to generate histograms of the many variables used to manipulate the Monte Carlo simulation. One such test within DaVinci is Monte Carlo Truth, which verifies that the selected events are from the signal rather than from some other source. Any event that passes this test is truth matched.

Variables	Default Cuts	Tight Cuts
e+/-_P_MIN	3.e3 MeV (3 GeV)	3.e3 MeV (3 GeV)
e+/-_PT_MIN	80 Mev	115 Mev
e+/-_PID_E_MIN	-3	-3
e+/-_CHI2DOF_MAX	9	2.5
e+/-_MINIP	1 mm	1 mm
e+/-_MINIPCHI2	36	256
Ks_BPVVDZ_MIN	0 mm	0 mm
Ks_BPVVDRHO_MIN	3 mm	3.7 mm
Ks_BPVVDIRA_MIN	0.999	0.996
Ks_BPVLTIME_MIN	0.0045 ns	0.0045 ns
Ks_MAX_IPBPVVDZ_RATIO	1 / 60	1 / 60
Ks_MAXIP	0.4 mm	0.3 mm
Ks_MAXDOCACUT	0.2 mm	0.2 mm
Ks_MAXDOCACHI2CUT	25.	25.

Table 1: Default and tight cuts used on the reconstruction combinations.

RESULTS

The first result was a mass histogram of $K_s^0 \rightarrow e^+ + e^-$ that was generated from a test line. (Figure 3).

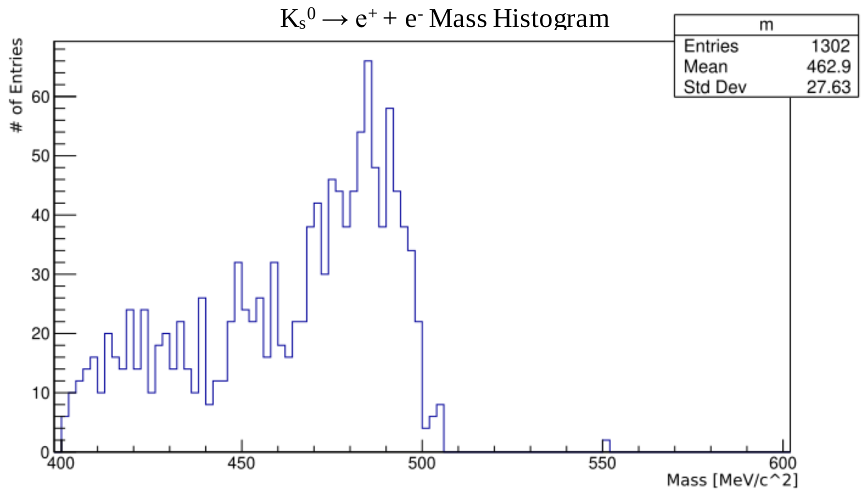

Figure 3: Mass histogram of K_s^0 --> e^+ + e^- decay

After the test line was proven to work, the main line used for data taking was used to generate new histograms. In addition, a test referred to as Monte Carlo Truth was used on the results generated by the main line to ensure the results were signal events and not fake events (Figures 4 and 5).

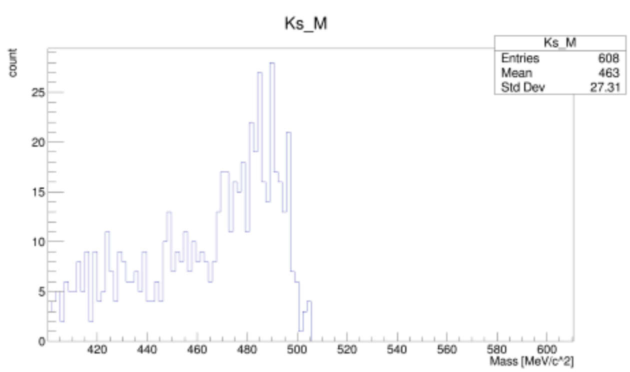

Figure 4: Mass histogram of K_s^0 --> e^+ + e^- before MCTruth was applied to the simulation.

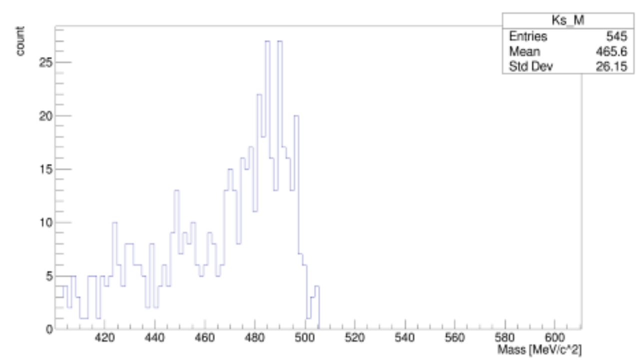

Figure 5: Mass histogram of K_s^0 --> e^+ + e^- after MCTruth was applied to the simulation.

Upon comparison of the two graphs, ~90% of events passed the Monte Carlo Truth test, which indicates the presented results are signal events. The next focus of this research was to investigate how the Bremsstrahlung effect changed our histogram. Since electrons undergo Bremsstrahlung when they interact with matter, special care must be given to the reconstruction process to ensure that the right number of photons are assigned to the right number of electrons. As such, two histograms were generated: one that was corrected for Bremsstrahlung and one that was not (Figures 6 and 7).

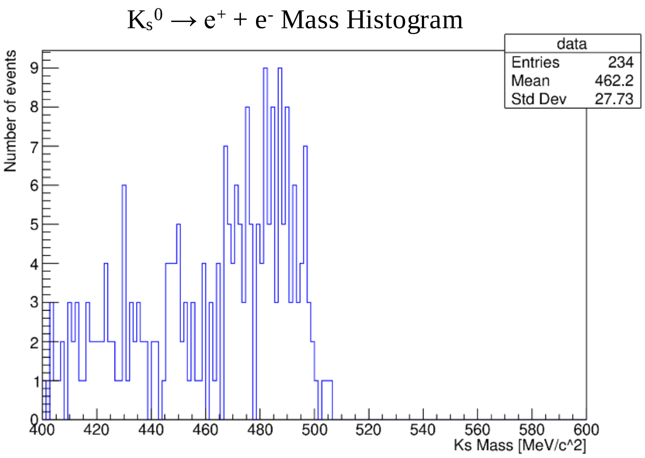

Figure 6: K_s^0 --> e^+ + e^- mass histogram that has been corrected for Bremsstrahlung.

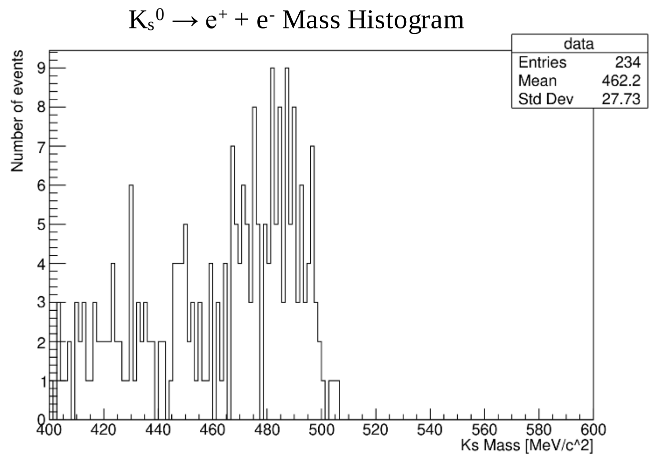

Figure 7: K_s^0 --> e^+ + e^- mass histogram that has not been corrected for Bremsstrahlung.

The main takeaway from these two plots is that bremsstrahlung corrections do not appear to have a big influence on the resulting mass peak. This result indicates that the peak will not be incorrectly shifted due to the presence or absence of bremsstrahlung, among other effects.

The next focus for this research was conducted in offline analysis. Minimal cuts were applied to the HLT2 line to ensure all possible tracks were available. This flexibility provided a fair deal of freedom in applying cuts to variables for both the electron/positron and the kaon to see how the signal was affected in the mass histogram. In addition, it was possible to optimize the signal-to-noise ratio to ensure the desired signal was not drowned out. The reason why offline analysis is so important is because it helps decrease the rate of the HLT2 line. While a high rate means a lot of events are being recorded, it also means a lot of events need to be saved somewhere. The maximum rate a line should have is around 100 Hz. The current rate the $K_s^0 \rightarrow e^+ + e^-$ decay line has is 880 Hz, which is problematic since it is not possible to store all the data from a high-rate line. As such, offline analysis helps lower that rate to make data storage more feasible.

After variables were fine-tuned and the new cuts were applied, two mass histograms were generated-one with default cuts and one with tighter cuts (Figures 7 and 8). The cuts of which are contained in Table 1.

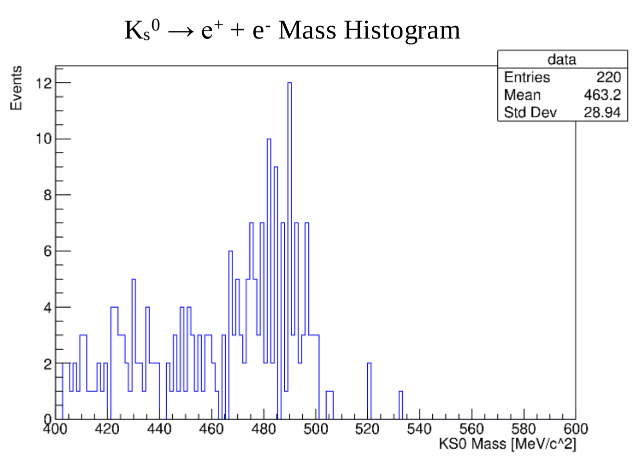

Figure 8: K_s^0 --> e^+ + e^- Mass histogram with default cuts

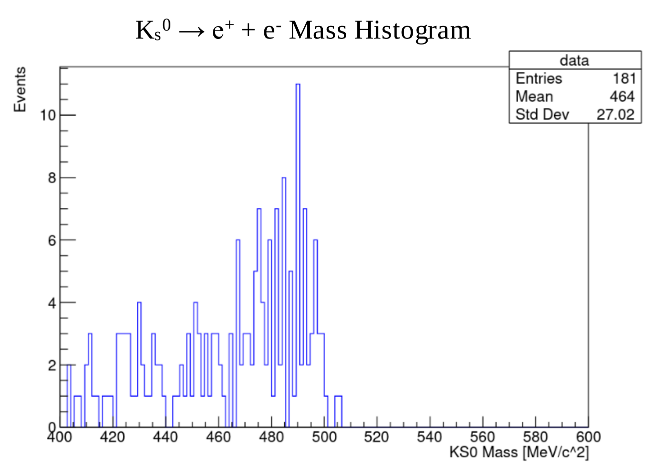

Figure 9: K_s^0 --> e^+ + e^- Mass histogram with tighter cuts

From the results above, the tighter cuts resulted in an 18% decrease in the event count. However, the line rate was brought down to 551 Hz. More work needs to be done to decrease the rate even further, but the results from figures 7 and 8 are a step in the right direction.

CONCLUSION

The major outcome of this research is that a peak does exist in the $K_s^0 \rightarrow e^+ + e^-$ mass histogram of the signal Monte Carlo simulations. More work needs to be done to validate these results, but this decay process has not been analyzed within LHCb up to this point. Since the simulations used during this work were based on the 2024 LHCb-like detector, which models the conditions the LHCb will be under in 2024, there is a possibility that such a decay could be detected and reconstructed within the LHCb. Other important outcomes of this research regarding personal progress include becoming more familiar with how research at the LHCb is conducted, how to write HLT2 lines that select signal events, how to verify results and how to connect theory to the code. While attempting to connect the two areas together is difficult at times, the research conducted this summer helped show a way in which physicists are attempting to learn more about how the universe works beyond the standard model.

REFERENCES

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