Studies of Short-Lived Kaon Decays at LHCb

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Overview of Experiment

- **Name:** The Large Hadron Collider Beauty (LHCb) Experiment.
- **Main focus:** Matter-Antimatter Asymmetry & the beauty quark.
- **Unique aspect:** The LHCb only focuses on forward-moving particles (Unlike, say, ATLAS and CMS)

What I worked on: Analysing the decays of the short-lived kaons via programs written within Python (Experimental/Analytical Physics)
Some Definitions

- **High-Level Trigger (HLT)**: A software application to help decide what events are interesting
  - HLT1: Conducts partial-reconstruction of events
  - HLT2: Conducts complete reconstruction of events
    - Work was done entirely within HLT2
- **Reconstruction**: The process of generating a set of tracks that model the path a particle takes through a detector.
- **Rate**: How many events are created within a given time period (i.e., events/second)
- **Cut**: A maximum and/or minimum placed on a certain variable
  - Completely up to the programmer to decide this value
  - Ex: electron pt > 80 MeV
Motivations

- Decay of $K_s^0 \rightarrow e^+ + e^-$ can serve as a probe into beyond standard-model Physics.
- LHCb has undergone an upgrade, so it is now possible to study processes with low-pt electrons.
Making Some Histograms - The Basics (1/2)

- Code being shown: The test line that was written for $K_s^0 \rightarrow e^+ + e^-$

- First function defines the cuts that will be applied to the electrons

- Second function defines the cuts that will be applied to the K-short candidates

*Important note: This code was used for learning purposes*
Making Some Histograms - The Basics (2/2)

Feed the simulation files through the written test line, then you’ve managed to generate some results!
Making Some Histograms - Verifying the Results

Histogram without MCTruth

$K_s^0 \rightarrow e^+ + e^-$ Mass Histogram (No MCTruth)

<table>
<thead>
<tr>
<th>Ks_M</th>
<th>Entries</th>
<th>Mean</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>608</td>
<td>463</td>
<td>27.31</td>
</tr>
</tbody>
</table>

Histogram with MCTruth

$K_s^0 \rightarrow e^+ + e^-$ Mass Histogram (w/ MCTruth)

<table>
<thead>
<tr>
<th>Ks_M</th>
<th>Entries</th>
<th>Mean</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>545</td>
<td>405.6</td>
<td>26.15</td>
</tr>
</tbody>
</table>

Notice the difference?
Final Results-
Effect of Bremsstrahlung on $K_s^0$ mass histogram

$K_s^0 \rightarrow e^+ + e^-$ Mass Histogram

Histogram that has been corrected for the Bremsstrahlung effect

**data**
Entries: 234  
Mean: 462.2  
Std Dev: 27.73

$K_s^0 \rightarrow e^+ + e^-$ Mass Histogram

Histogram that has not been corrected for the Bremsstrahlung effect

**data**
Entries: 234  
Mean: 462.2  
Std Dev: 27.73

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Final Results - Offline Analysis

- Main purpose was to optimize cuts used in generation of $K_s^0 \rightarrow e^+ + e^-$ mass histogram.
  - Maximum rate of a line: 100 Hz
  - Rate output of $K_s^0 \rightarrow e^+ + e^-$ line: 880 Hz
- To minimize the rate, offline analysis is required.

- reduction in events: ~18%
- New rate output: ~551 Hz
What I Have Learned

- I have learned...
  - How research within the LHCb collaboration is conducted.
  - How to write an HLT2 line as well as run tests on that line to learn more about the reconstructed events.
  - More about Python and the various ways it can be used for data analysis.
  - How to work in Linux.
  - How to work with ROOT (to a degree).

- Quick Acknowledgement: I never would have gotten this far without my supervisor, Dr. Sergio Arguedas Cuendis. He helped me at every step along the way, and I cannot thank him enough for being there to answer my questions (even the stupid ones).
## Conclusion

### What’s been done:

- A peak has been found in the $K_s^0 \rightarrow e^+ + e^-$ mass histogram
  - (As far as I know) this measurement has never been made before within the LHCb

- The results within the mass histogram have been proven to be signal events
  - Proven via Monte Carlo Truth

- Bremsstrahlung has been proven to have no effect on the mass histogram
  - More work is needed

### What still needs to be done:

- Verification is needed for the Bremsstrahlung result.

- The rate of $K_s^0 \rightarrow e^+ + e^-$ needs to be lowered even further
  - Rate has been brought down to 551 Hz. That’s progress, but it’s still too high.
Thank you for a great summer. It was quite the journey.
Any Questions?
Backup Slides
### Table of cuts

<table>
<thead>
<tr>
<th>Variables</th>
<th>Default cuts</th>
<th>Tight cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>e+/-_P_MIN</td>
<td>3.e3 MeV (3 GeV)</td>
<td>3.e3 MeV (3 GeV)</td>
</tr>
<tr>
<td>e+/-_PT_MIN</td>
<td>80 Mev</td>
<td>115 MeV</td>
</tr>
<tr>
<td>e+/-_PID_E_MIN</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>e+/-_CHI2DOF_MAX</td>
<td>9</td>
<td>2.5</td>
</tr>
<tr>
<td>e+/-_MINIP</td>
<td>1 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>e+/-_MINIPCHI2</td>
<td>36</td>
<td>256.</td>
</tr>
<tr>
<td>Ks_BPVVDZ_MIN</td>
<td>0 mm</td>
<td>0 mm</td>
</tr>
<tr>
<td>Ks_BPVVDRHO_MIN</td>
<td>3 mm</td>
<td>3.7 mm</td>
</tr>
<tr>
<td>Ks_BPVDIRA_MIN</td>
<td>0.999</td>
<td>0.996</td>
</tr>
<tr>
<td>Ks_BPVLTIME_MIN</td>
<td>0.0045 ns</td>
<td>0.0045 ns</td>
</tr>
<tr>
<td>Ks_MAX_IPBPVVVDZ_RATIO</td>
<td>1 / 60</td>
<td>1 / 60</td>
</tr>
<tr>
<td>Ks_MAXIP</td>
<td>0.4 mm</td>
<td>0.3 mm</td>
</tr>
<tr>
<td>Ks_MAXDOCACUT</td>
<td>0.2 mm</td>
<td>0.2 mm</td>
</tr>
<tr>
<td>Ks_MAXDOCACHI2CUT</td>
<td>25.</td>
<td>25.</td>
</tr>
</tbody>
</table>
Histograms of Variables used (1/3)

- Electron transverse momentum

![Graph showing electron transverse momentum distribution with (No cut) and (Default cut) labels.](image-url)
Histograms of Variables used (2/3)

- Electron minimum impact parameter

Graphs showing the distribution of electron minimum impact parameter for MC data with (No cut) and (Default cut) cuts applied.
Histories of Variables used (3/3)

- **K-short minimum lifetime**

  

  ![Histograms](attachment:image.png)

  \[\text{Ks0\_BPV Lifetime}_\text{MIN, MC}\]

  - Data
    - Entries: 41405
    - Mean: 0.01138
    - Std Dev: 0.01836

  \[\text{No cut}\]

  \[\text{Default cut}\]
HLT1 Line for $K_s^0 \rightarrow e^+ + e^-$

- Merge request for decay line
- lhcb/Allen!1134

- Intended for strange decays such as $K_s^0 \rightarrow e^+ + e^-$.  
  - Work is still being done on this line
LHCb dataflow

LHC BUNCH CROSSING (40 MHz)

5 TB/s 30 MHz non-empty pp

FULL DETECTOR READOUT

5 TB/s

PARTIAL DETECTOR RECONSTRUCTION & SELECTIONS (GPU HLT1)

0.5-1.5 MHz

70-200 GB/s

REAL-TIME ALIGNMENT & CALIBRATION

FULL DETECTOR RECONSTRUCTION & SELECTIONS (CPU HLT2)

10 GB/s

FULL CALIB EVENTS

1.6 GB/s

68% TURBO EVENTS

2.5 GB/s

26% FULL EVENTS

5.9 GB/s

OFFLINE PROCESSING

ANALYSIS PRODUCTIONS & USER ANALYSIS

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