Studies of Short-Lived Kaon Decays at LHCb

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Table of Contents

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)
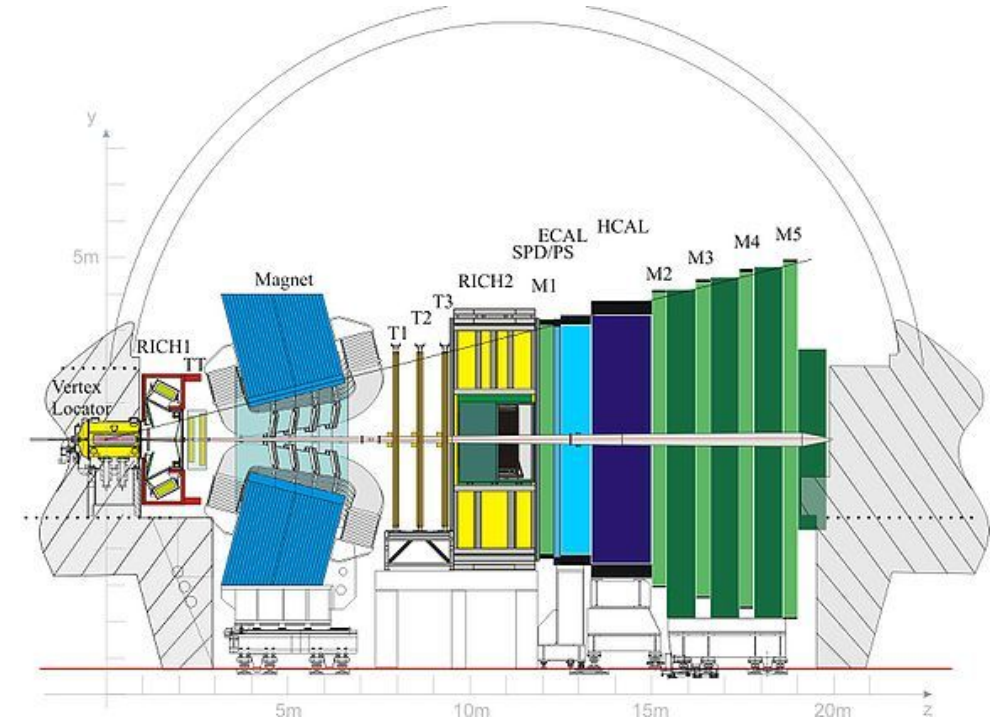
Some Definitions

- **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.
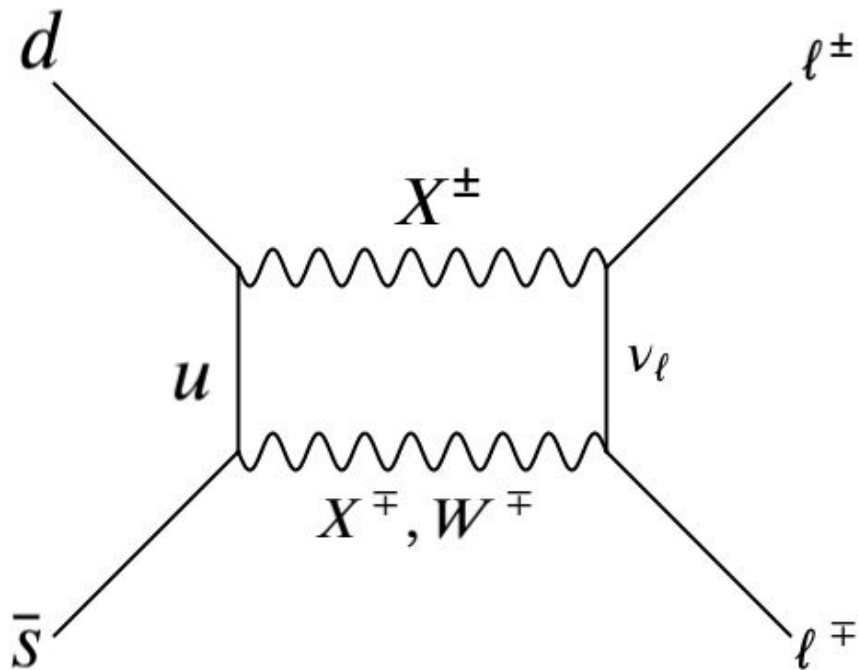
- LHCb has undergone an upgrade, so it is now possible to study processes with low-pt electrons.
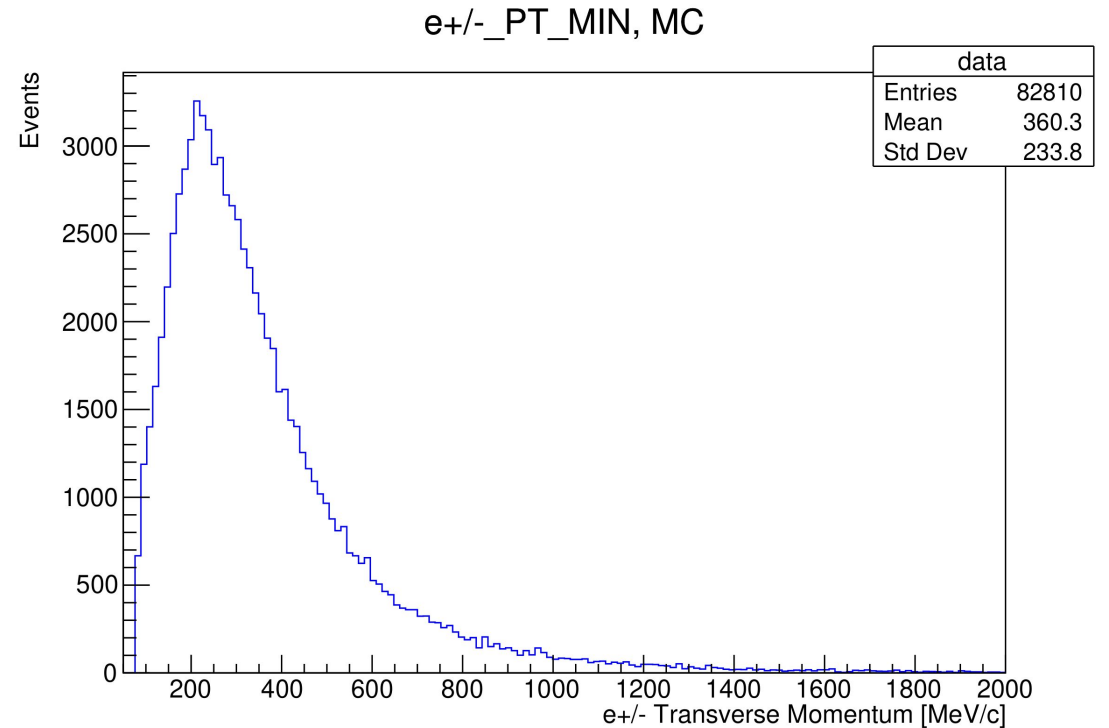
Making Some Histograms - The Basics (1/2)

- 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

```
21
22    #---------------------------------------------------------------
23            #Full disclosure, this is test code written by a moron. As per Murphy's law, what can go wrong will go wrong#
24
25    def electrons_for_Ks():
26        pvs = make_pvs()
27        cut = F.require_all(
              F.P > 3 * GeV,
29            F.PT > 0.3 * MeV,
30            F.CHI2DOF <  16, #9,
31            F.MINIP(pvs) > 0.5 * mm, #1.0 * mm,
32            F.MINIPCHI2(pvs) > 25., #36.,
33            F.PID_E > -3,
34            F.SIZE(pvs) > 0,
35        )
36        return ParticleFilter(make_long_electrons_with_brem(), F.FILTER(cut))
37
38
39    def K_short_for_e(electrons, pvs): #Changed the name to see what happens
40        combination_code = F.require_all(
41            in_range(400 * MeV, F.MASS, 600 * MeV),  # mass of the combination
42            F.MAXDOCACHI2CUT(25.),
43            F.MAXDOCACUT(0.2 * mm),
44            F.SIZE(pvs) > 0,
45        )
46        vertex_code = F.require_all(
              F.BPVLTIME(pvs) > 0.0045 * ns,
48            F.BPVVDZ(pvs) > 0. * mm,
49            F.MAXDOCACHI2CUT(25.),
50            F.MAXDOCACUT(0.2 * mm),
51            F.CHI2DOF < 25.,
52            F.MINIP(pvs) / F.BPVVDZ(pvs) < 1. / 60,
53            F.MINIP(pvs) < 0.4 * mm,
54            F.BPVVDRHO(pvs) > 3. * mm,
55            F.BPVDIRA(pvs) > 0.999,
56            F.SIZE(pvs) > 0,
57        )
```
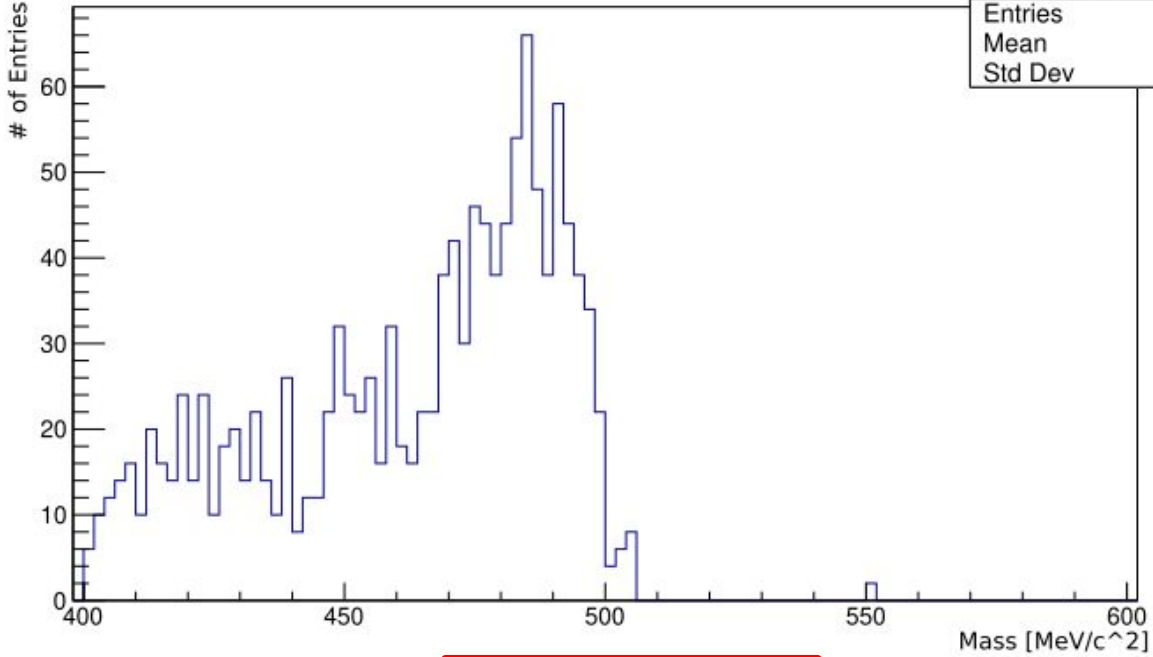
Making Some Histograms - The Basics (2/2)

Feed the simulation files through the written test line, then you've managed to generate some results!

Input files → A Histogram

Making Some Histograms - Verifying the Results

Histogram without MCTruth

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

Ks_M	
Entries	608
Mean	463
Std Dev	27.31

count

Mass [MeV/c^2]

Histogram with MCTruth

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

Ks_M	
Entries	545
Mean	465.6
Std Dev	26.15

count

Mass [MeV/c^2]
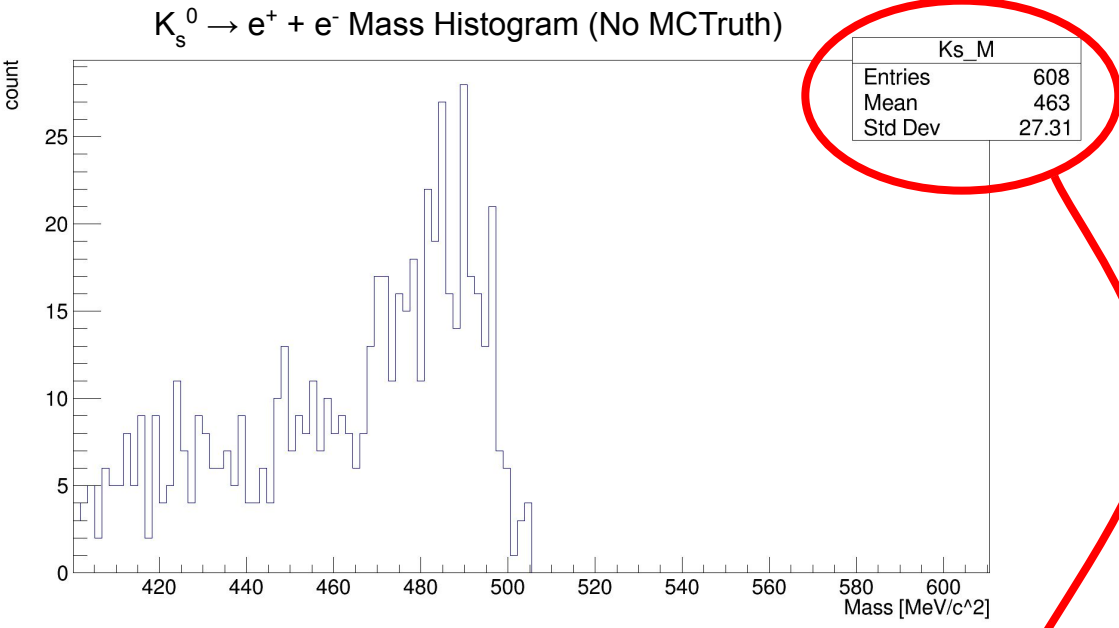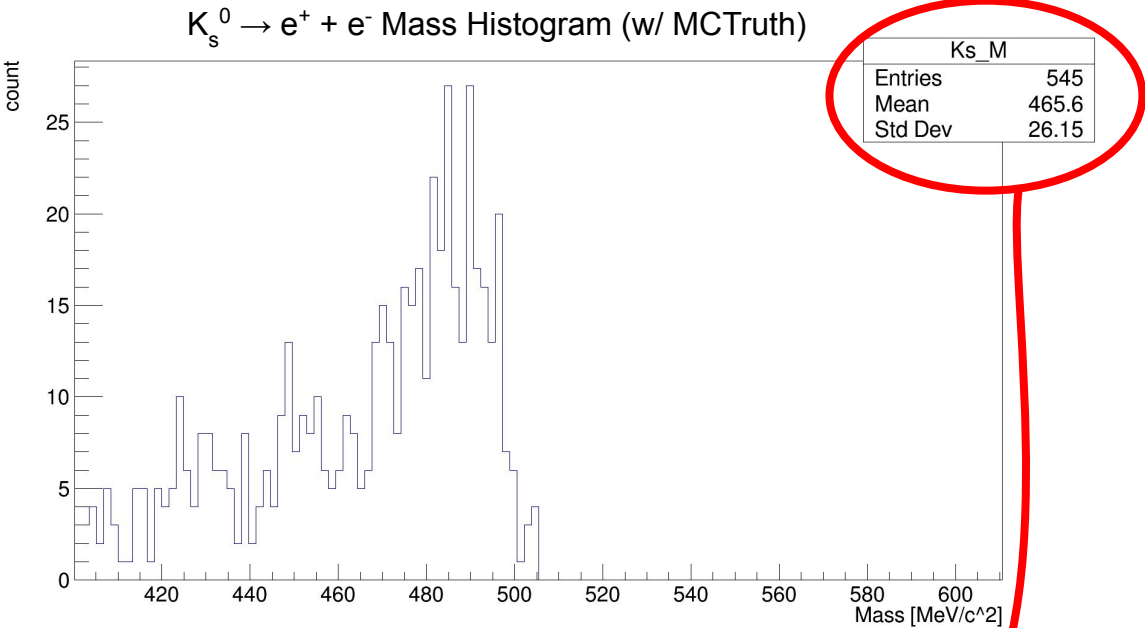
Notice the difference?

Final Results-
Effect of Bremsstrahlung on Ks mass histogram
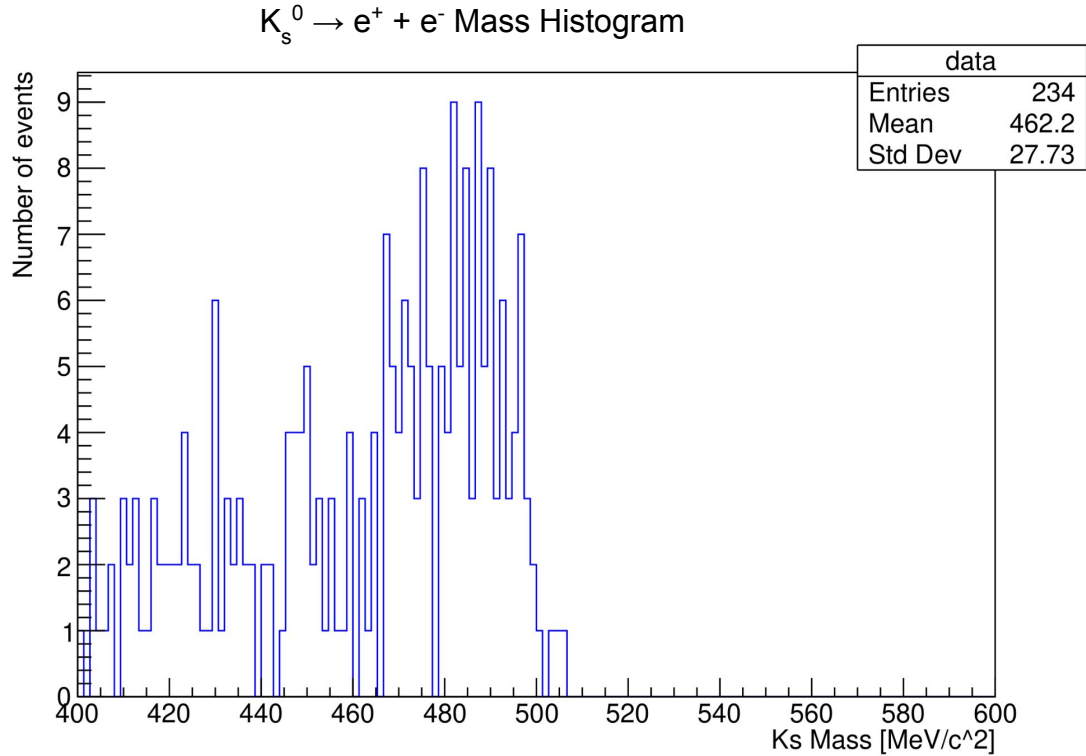
Histogram that has been corrected for the
Bremsstrahlung effect
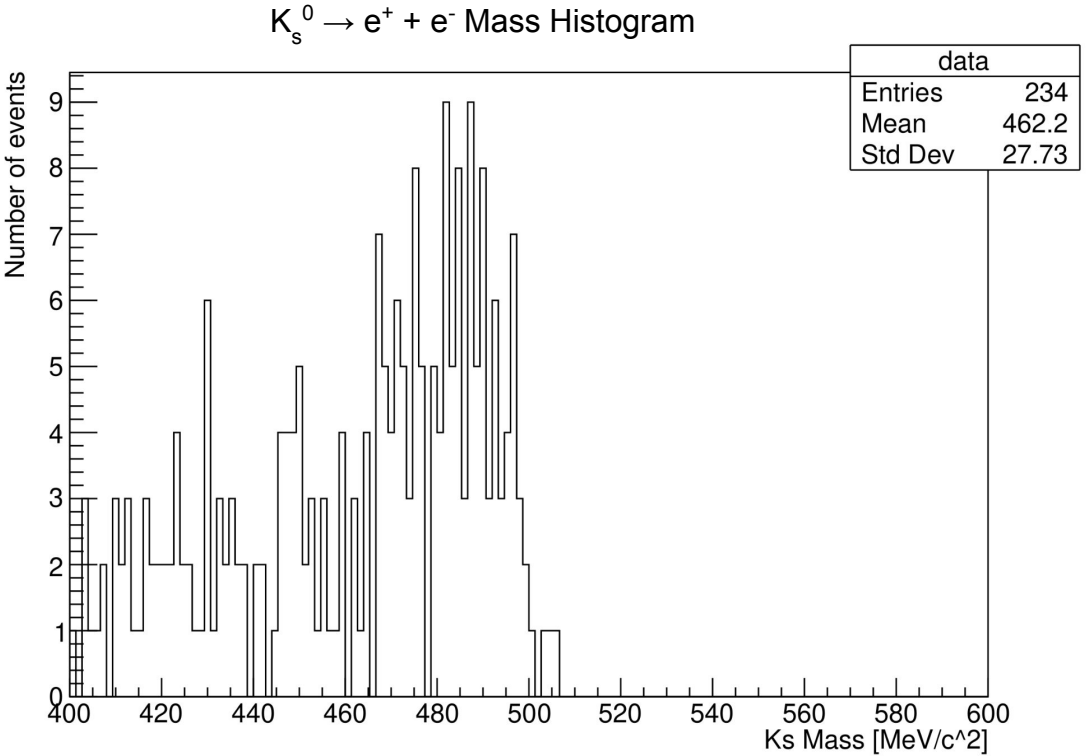
Histogram that has not been corrected for the
Bremsstrahlung effect

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.**
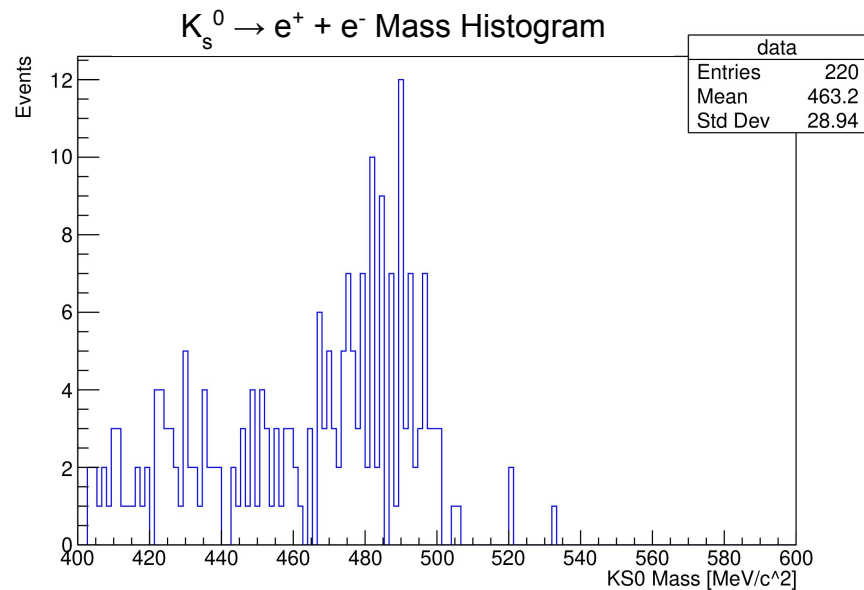
- reduction in events: **~18%**

- New rate output: **~551 HZ**
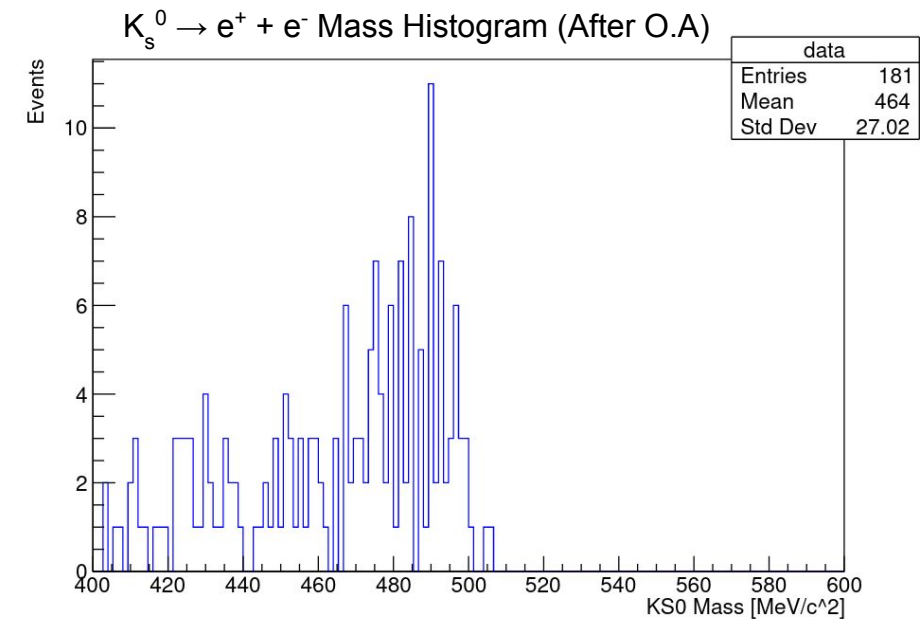
What I Have Learned

- **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**
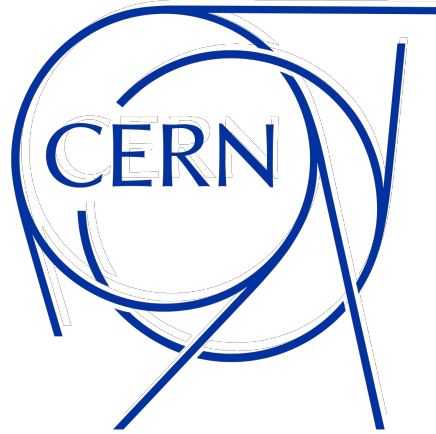 - More work is needed

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**
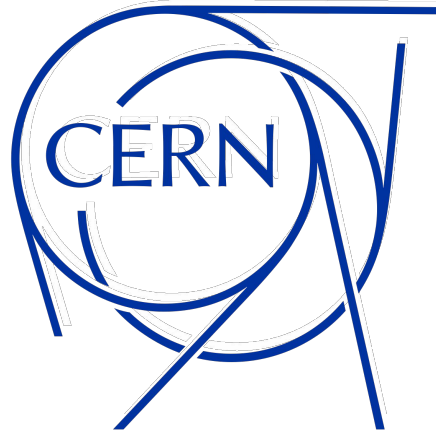 - Rate has been brought down to 551 Hz. That's progress, but it's still too high.

Thank you for a great summer. It was quite the journey

**Any Questions?**

Backup Slides

Table of cuts

| 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_BPVDIRA_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.

Histograms of Variables used (1/3)
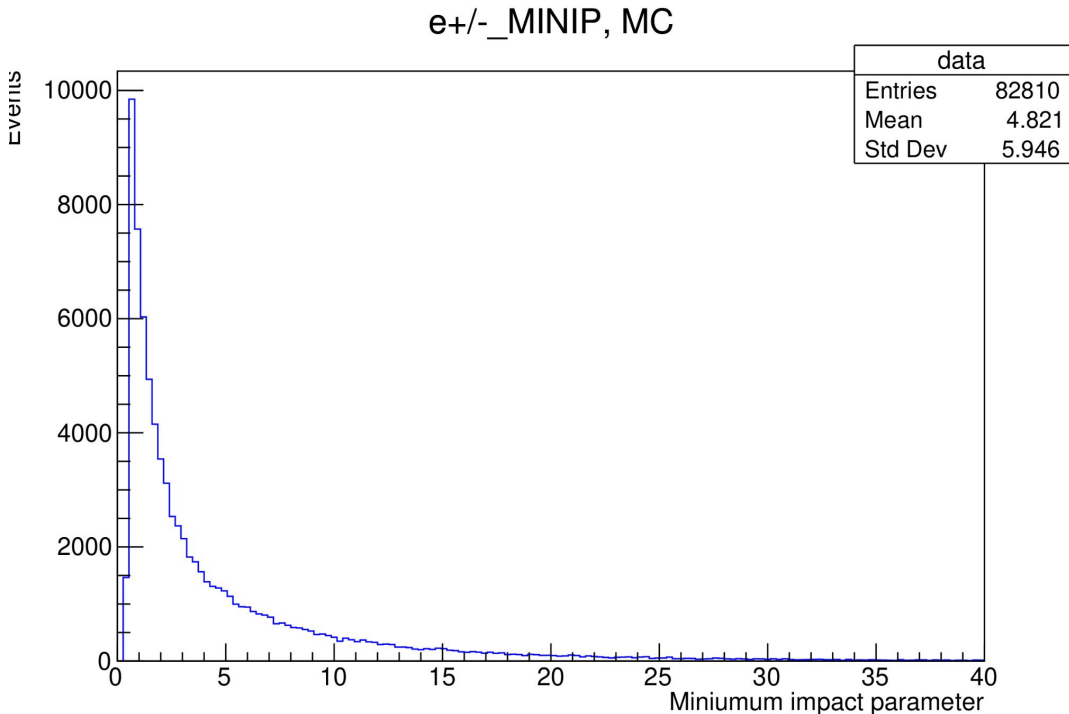
- **Electron transverse momentum**
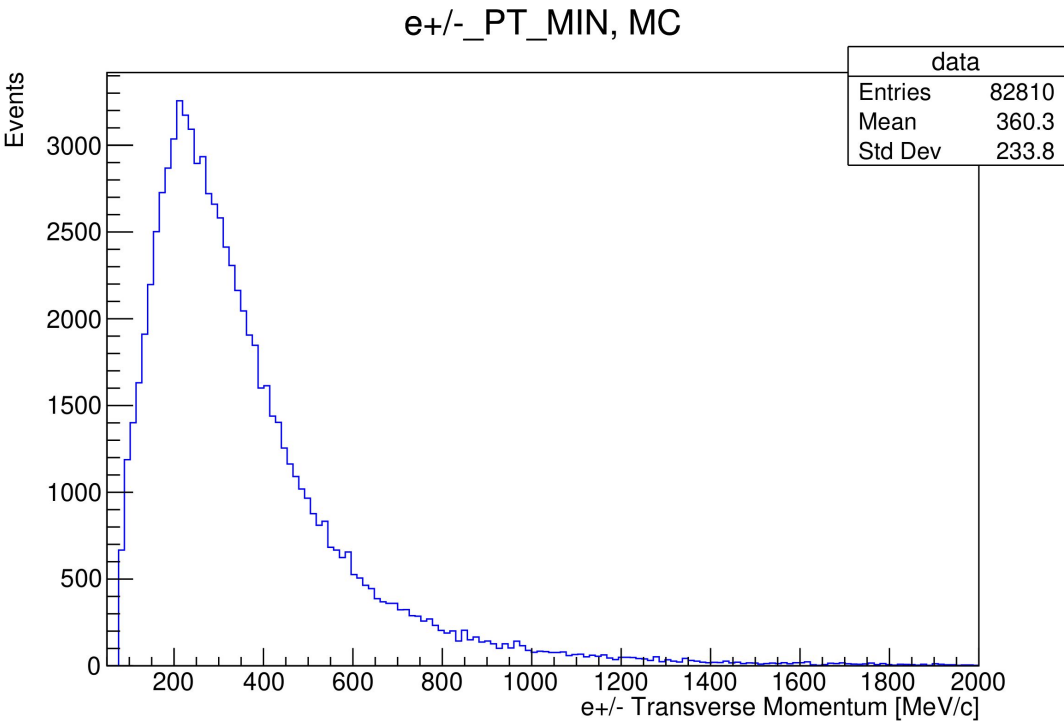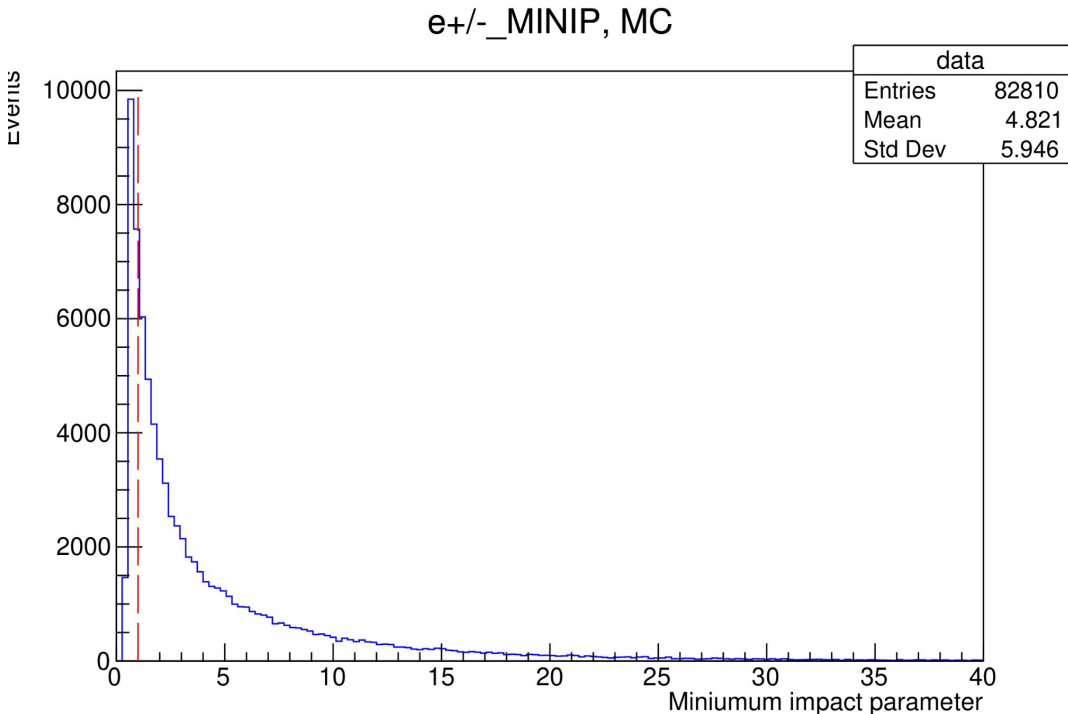

(No cut)
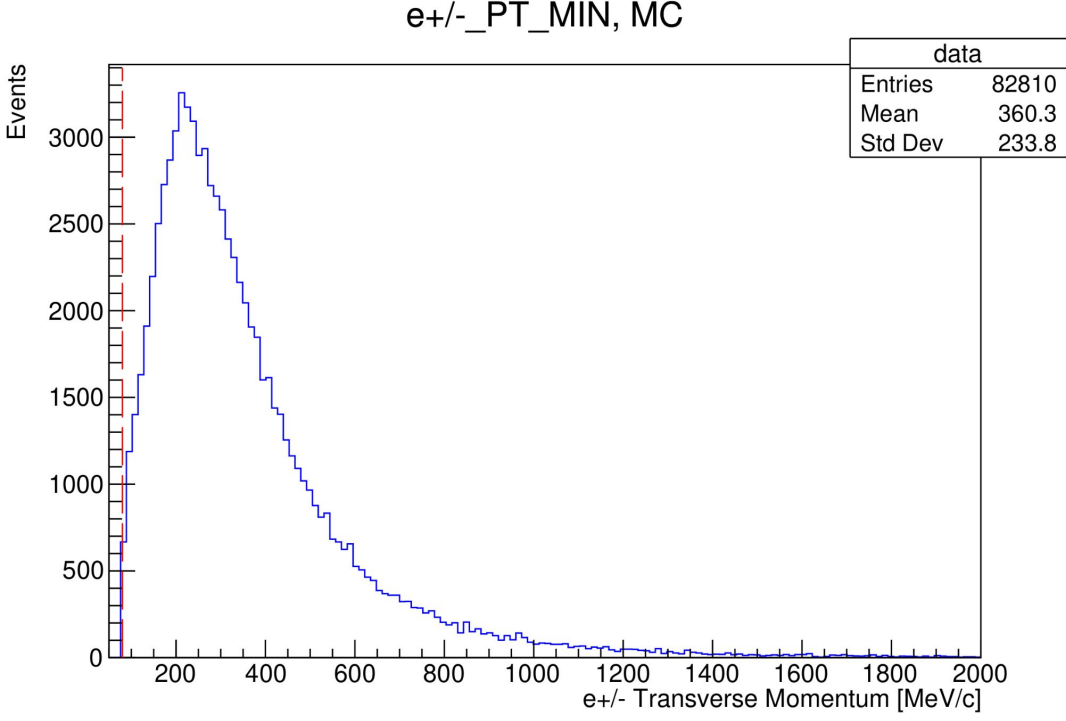
(Default cut)

Histograms of Variables used (2/3)

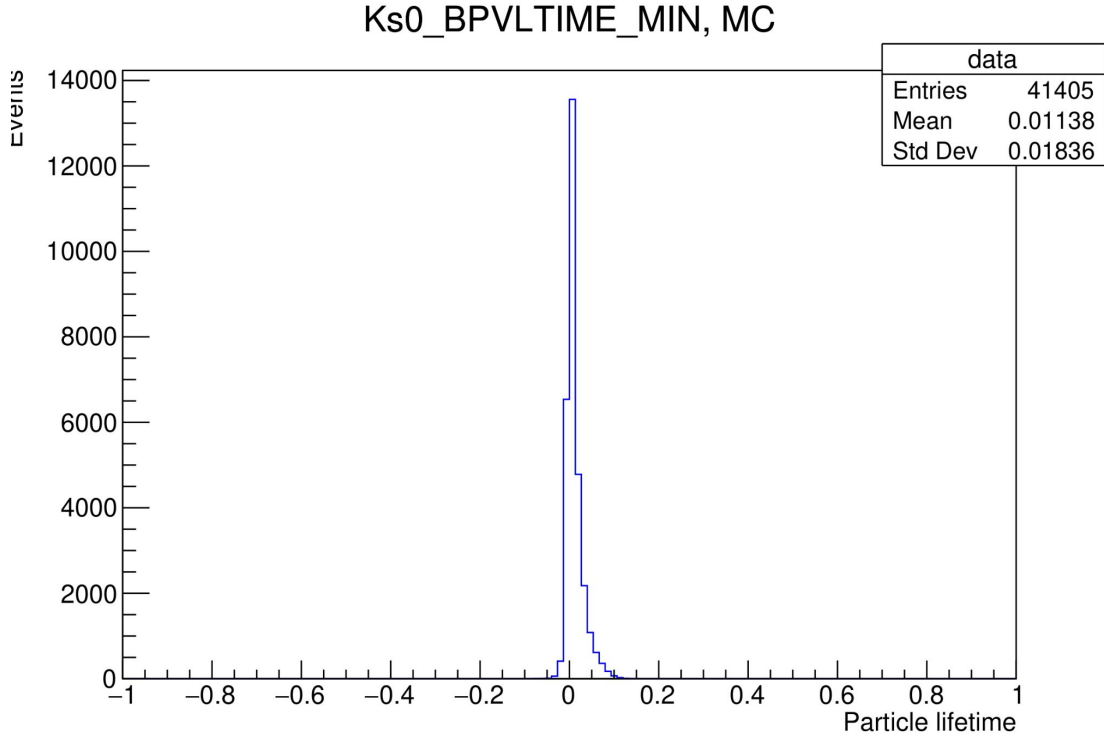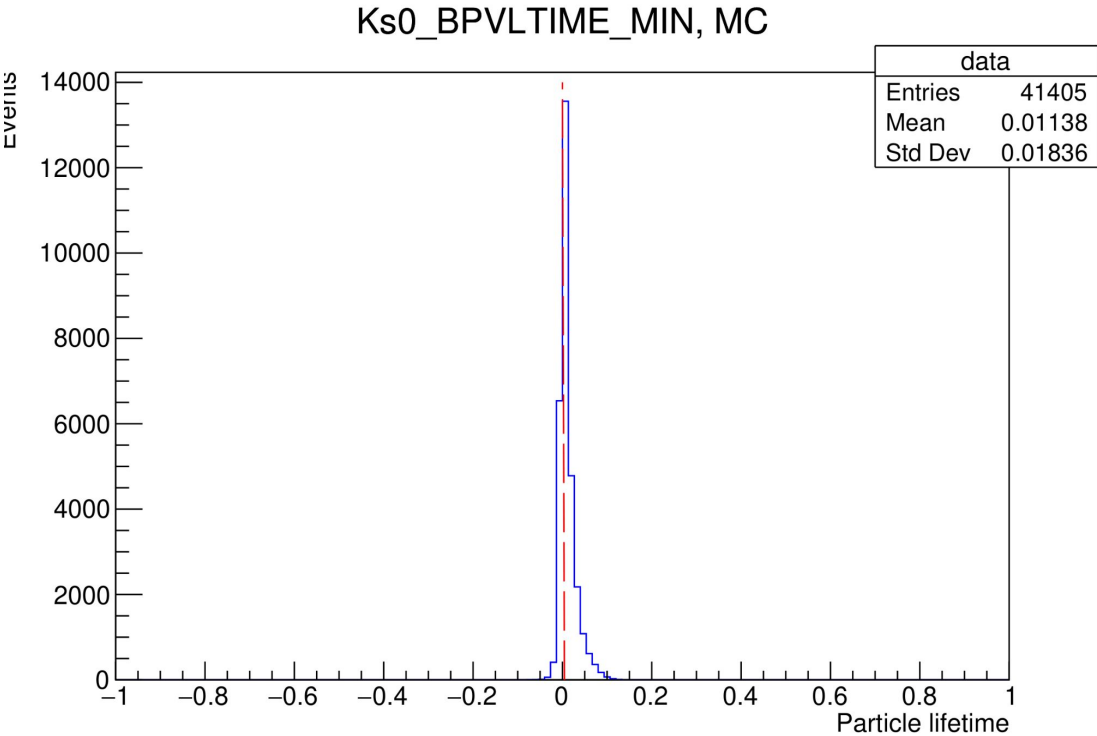- **Electron minimum impact parameter**

(No cut)

(Default cut)

Histograms of Variables used (3/3)

- **K-short minimum lifetime**

Ks0_BPVLTIME_MIN, MC

data	
Entries	41405
Mean	0.01138
Std Dev	0.01836

(No cut)

Ks0_BPVLTIME_MIN, MC

data	
Entries	41405
Mean	0.01138
Std Dev	0.01836

(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