# Overview of $K_S \rightarrow 4l$ studies

EMTF session LHCb Starterkit

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# Main goals

- Study the $K_s \rightarrow \pi^+\pi^-e^+e^-$ decay and search for $K_S \rightarrow$ 4l decays.
- New physics: Possible dark matter signals in this type of decays https://arxiv.org/abs/2012.02142.
- Major improvement for $K_s$ studies in Run 3: Removal of L0
- Development of trigger lines for $K_s \rightarrow$ 4l decays.

# HLT2 lines

- Most work so far was done for:

1. $K_s \rightarrow 2(\mu^+\mu^-)$
2. $K_s \rightarrow 2(e^+e^-)$

- Normalization channel:

1. $K_s \rightarrow \pi^+\pi^-e^+e^-$

- Understand reconstruction and selection of low pT electrons.
- BR measured by NA48: BR = $4.79 \pm 0.15 \cdot 10^{-5}$

- Other channels:

1. $K_s \rightarrow \pi^+\pi^- \mu^+\mu^-$
2. $K_s \rightarrow \mu^+\mu^- e^+e^-$

# $K_s \rightarrow 2(\mu^+\mu^-)$

- Muon candidates were required initially to have long tracks.
- No cuts done for transverse momentum.
- Values chosen to ensure they come from the same vertex.

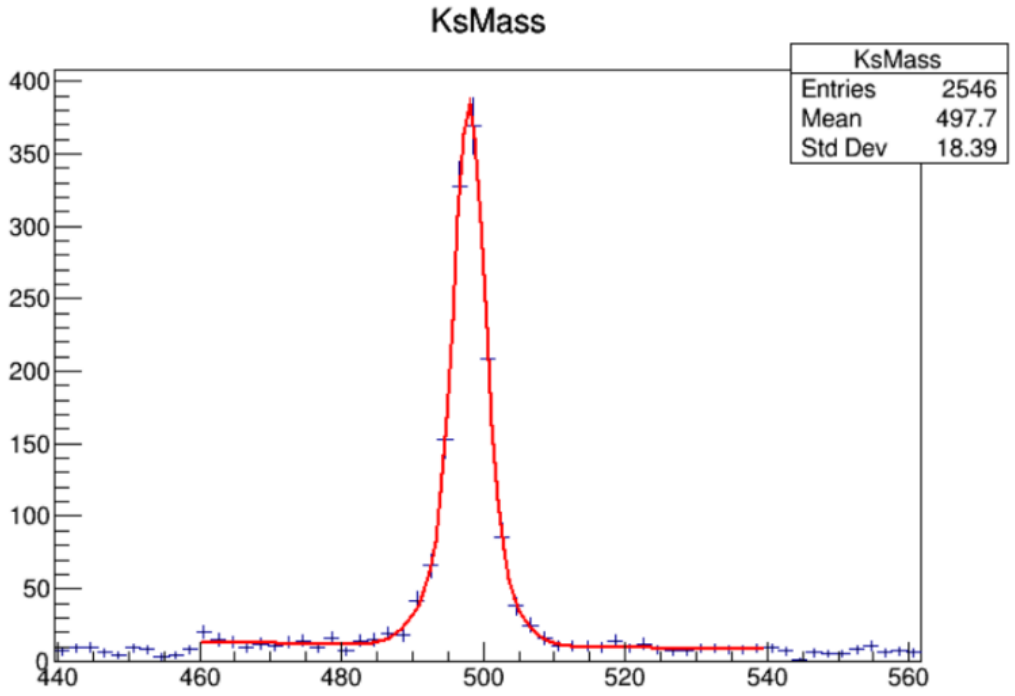
Requirements applied on muon candidates with long tracks.

| Variable | Units | Requirement |
|---|---|---|
| Track Ghost Prob | | $< 0.4$ |
| $\mu$ IP | mm | $> 0.2$ |

Requirements applied on 4-body combination of muon candidates.

| Variable | Units | Requirement |
|---|---|---|
| $\mu^+\mu^-\mu^+\mu^-$ max DOCA | mm | $< 1.0$ |
| $K_s^0$ Vertex $\chi^2/ndof$ | | $< 25.0$ |
| $K_s^0$ BPVDLS | | $> 2.0$ |
| $K_s^0$ invariant mass | MeV/$c^2$ | $\in [297.614, 697.614]$ |

# $K_s \rightarrow 2(\mu^+\mu^-)$




- $K_s$ invariant mass for MC simulations. Plot made by JJ Bermudez

- The line efficiency was checked for Monte Carlo simulations using HLTEfficiencyChecker tool:

- All events:

1. $\varepsilon = 4.4 \cdot 10^{-4}$
2. TOS $\varepsilon = 2.2 \cdot 10^{-4}$

- Can reconstruct children:

1. $\varepsilon = 0.081 \pm 0.013$
2. TOS $\varepsilon = 0.074 \pm 0.012$

# $K_s \rightarrow 2(e^+e^-)$

- Long tracks electrons with bremsstrahlung corrections.
- A minimum transverse momentum cut of 100 MeV.
- Values chosen to ensure they come from the same vertex.

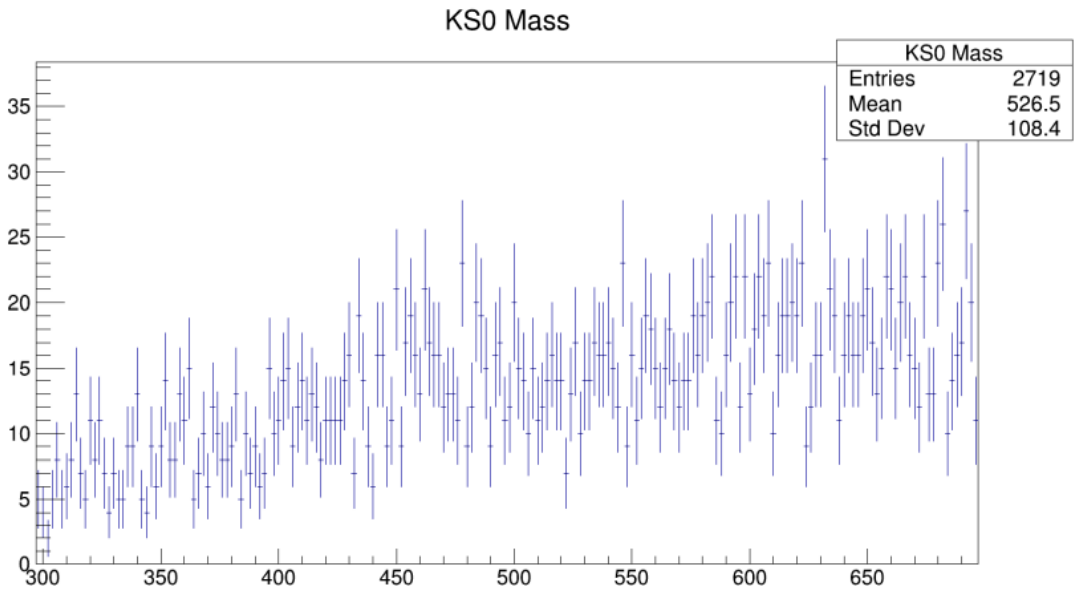
| Variable | Cut |
|---|---|
| Min pT | $> 100$MeV |
| Max Track Ghost Prob | $< 0.5$ |
| Min PIDe | $> 1.0$ |
| Min IP | $> 0.2$mm |

Variable requirements applied to the electron/positron selection

| Variable | Cut |
|---|---|
| Max DOCA | $< 1.0$mm |
| $K_s^0$ Vertex $\chi^2$ per dof | $< 25.0$ |
| $K_s^0$ BPVDLS | $> 2.0$ |
| $K_s^0$ invariant mass | $\pm 200$ MeV |

Cuts used for the 4-body combiner of electrons/positrons

# $K_s \rightarrow 2(e^+e^-)$




- $K_s$ invariant mass for MC simulations. Plot made by S. Quevedo
- Low pT electron difficult to reconstruct.

- All events:

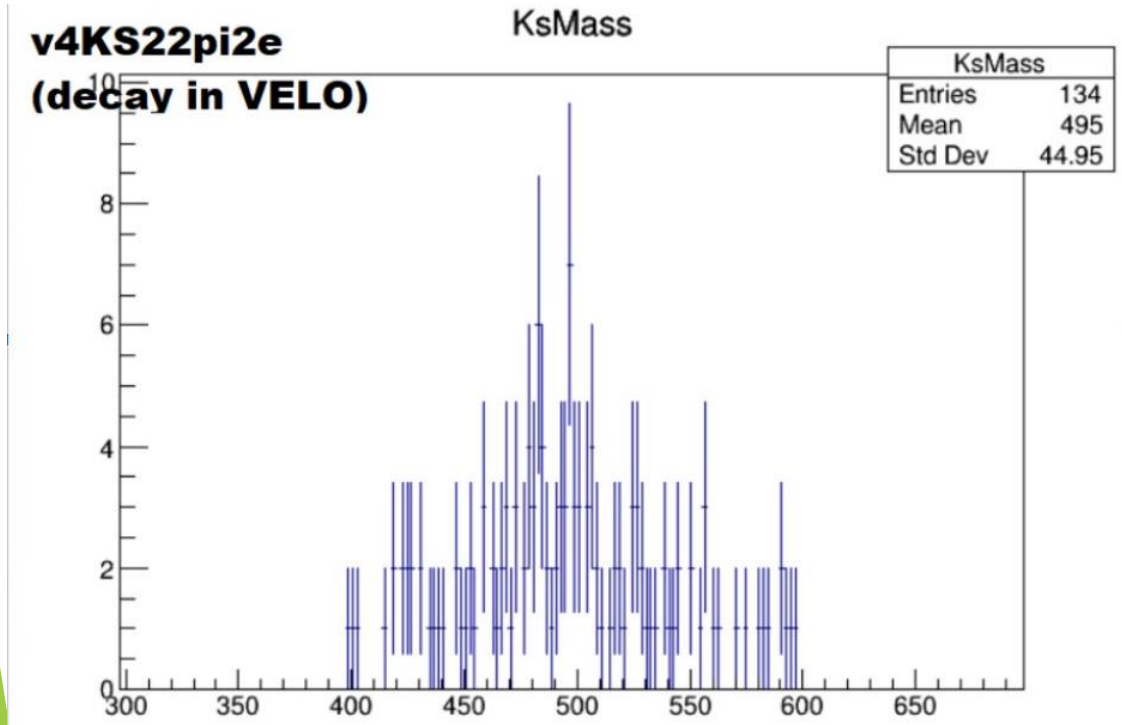
$\varepsilon = 1.91 \cdot 10^{-2}$

- Can reconstruct children:

$\varepsilon = 3.92 \cdot 10^{-2}$

- Ongoing work with truth matching information.

# $K_s \rightarrow \pi^+\pi^-e^+e^-$




- **Preliminary** $K_s$ invariant mass for MC simulations. Plot made by JJ Bermudez

- All events:

1. $\varepsilon = 7.5 \cdot 10^{-4}$
2. TOS $\varepsilon = 4.2 \cdot 10^{-4}$

- Can reconstruct children:

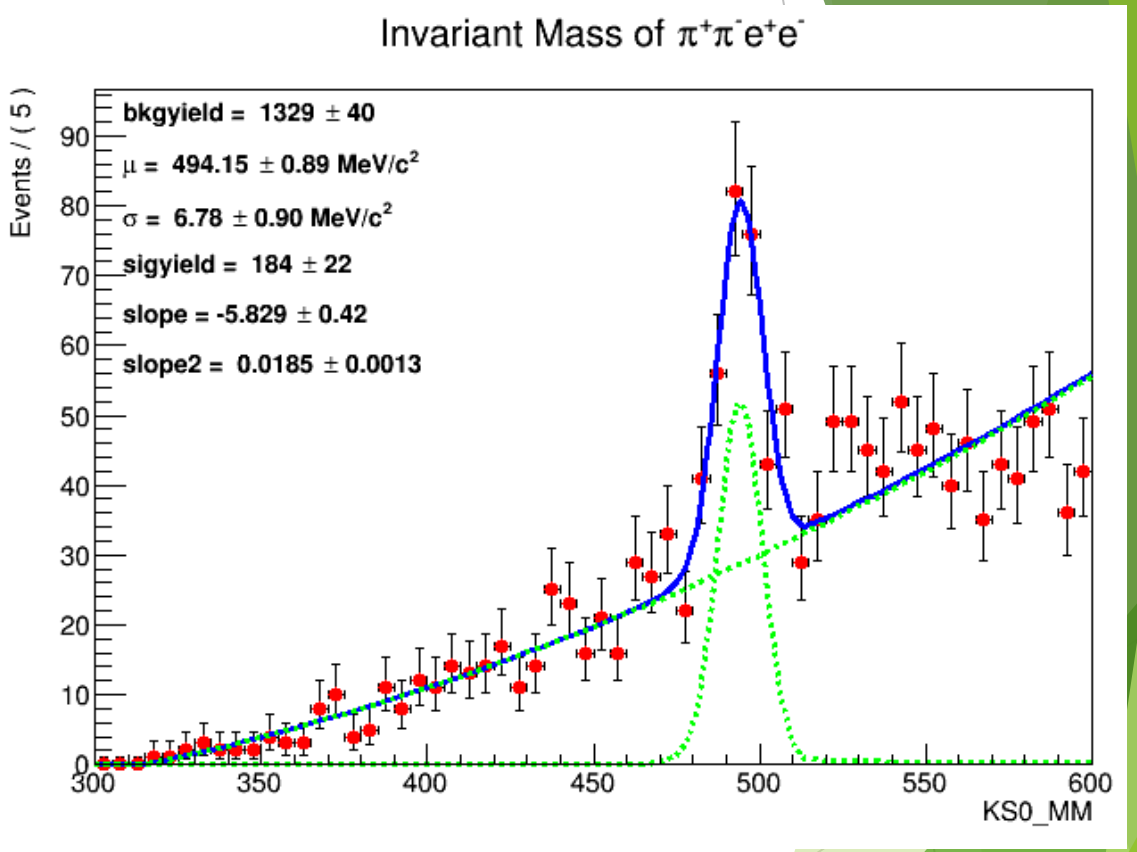
1. $\varepsilon = 0.040 \pm 0.007$
2. TOS $\varepsilon = 0.037 \pm 0.007$

# $K_s \rightarrow \pi^+\pi^-e^+e^-$ Run 2 studies

- $K_s$ peak can be seen in the invariant mass plot.

- Discrepancy between number of expected events and observed:

$$\mathbf{N_{obs}^{sig}} = \mathbf{184 \pm 22}$$
$$\mathbf{N_{exp}^{sig}} = \mathbf{1200 \pm 300}$$




- $K_s$ invariant mass. Plot made by P.Gironella

# Next steps

- Add truth matching to the $K_s \rightarrow 2(e^+e^-)$ line.
- Check the efficiency of the current HLT1 lines.
- Compute the total efficiency of the trigger line and calculate the sensitivity we could achieve for the 100 $pb^{-1}$ challenge.
- Have a better understanding and control of the normalization channel.
- Add downstream tracks.