$K_s \to$ electron modes

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Motivation

- After publication $K_s \to \mu\mu$ analysis (JHEP01(2013)090), theoretic interest in K_s decays in LHCb.
- Predictions on BR($K_s \to llll$) enhanced introducing a form factor in the effective lagrangian (arXiv:1309.5736v2).

Our purpose: study the feasibility of $K_s \to e^+e^-e^+e^-(\mu^+\mu^-)$ in LHCb.

- Taking into account new predictions (see D. Greynat talk), BR are up to:
  - $\to$ BR($K_s \to e^+e^-e^+e^-$) $\sim 10^{-10}$
  - $\to$ BR($K_s \to \mu^+\mu^-e^+e^-$) $\sim 10^{-11}$
- Challenge:
  - $\to$ Very low BR
  - $\to$ electrons are experimentally complicated (energy loss by Bremsstrahlung).

Study outline

The question we want to answer is:

Is it possible to observe these decays in LHCb?

We use MC generated events with LHCb reconstruction to answer the specific questions (Work in progress):

- How many signal events are expected?
  - $\rightarrow$ Define a selection.
  - $\rightarrow$ Compute selection efficiency.
  - $\rightarrow$ Compute expected sensitivity with current LHCb statistics.
- Could backgrounds hide the signal events?
  - $\rightarrow$ Are candidates from other decays passing our selection?
  - $\rightarrow$ Does our resolution allow us to distinguish signal from background candidates?

MC sample

MC events:

→ Generated using Pythia 8 configuration (8 TeV) and detector response implemented using Geant4.

→ Reconstructed with the LHCb reconstruction algorithms.

→ More than one candidate per event can be reconstructed.

→ Soft pre-selection.

Statistics by channel:

	MagUp	MagDown	Total
$K_s \to e^+e^-e^+e^-$	268500	263499	531999
$K_s \to \pi^+\pi^-e^+e^-$*	273499	253000	526499

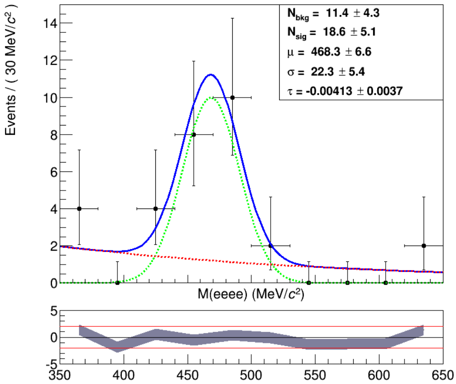
*Possible normalization channel and background.

No $K_s \to \mu^+\mu^-e^+e^-$ MC available at the moment.

$$K_s \to e^+e^-e^+e^-$$

MC matching selection

Using MC matching, select only real K_s and $e^+e^-e^+e^-$ particles.



Fit: $N_{sig} \cdot \text{gauss}(\mu, \sigma) + N_{bkg} \cdot \text{expo}(\tau)$

$\mu_{\text{MC truth}} = 468.3 \pm 6.6\ \text{MeV}/\text{c}^2$, $M_{K^0}^{\text{PDG}} = 497.6\ \text{MeV}/\text{c}^2$ energy loss!

$\sigma_{\text{MC truth}} = 22.3 \pm 5.4\ \text{MeV}/\text{c}^2$, $\sigma_{K_s \to \mu\mu} \approx 4\ \text{MeV}/\text{c}^2$

Towards an offline selection

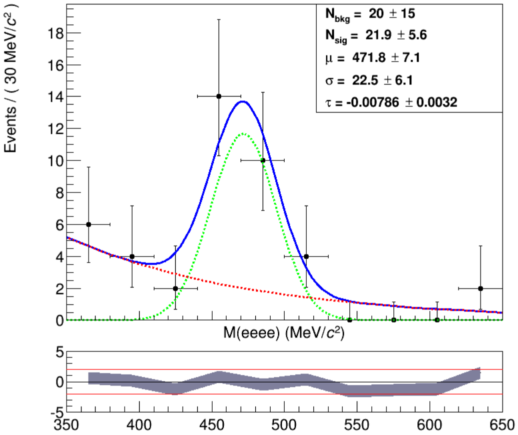
Let us define a selection without using MC truth information.

- To select K_s decays: daughters should NOT come from the *pp* vertex (PV) as the K_s flies ($\tau_{K_s} = 8.9 \cdot 10^{-11}$ s).
  $\rightarrow$ IP χ^2 with respect to PV > 10 (from $K_s \rightarrow \mu\mu$ analysis)

- To select electrons: need to distinguish them from π's.
  $\rightarrow$ $log(\mathcal{L}_e) - log(\mathcal{L}_\pi) > -2$

- To reject converted photons (see later):
  $\rightarrow$ $m_{ee} > 10$ MeV/c^2

Very soft selection due to the lack of statistics.



Fit: $N_{sig} \cdot \text{gauss}(\mu, \sigma) + N_{bkg} \cdot \text{expo}(\tau)$

$\mu = 471.8 \pm 7.1$ MeV/c^2, $M_{K^0}^{\text{PDG}} = 497.6$ MeV/c^2 energy loss!

$\sigma = 22.5 \pm 6.1$MeV/c^2, $\sigma_{K_s \to \mu\mu} \approx 4$ MeV/c^2

Background due to misidentification

$K_s \to e^+e^-\pi^+\pi^-$ with $\pi\pi$ reconstructed as ee.

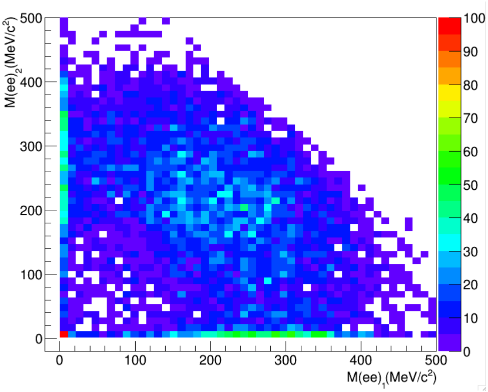
- $\rightarrow$ $\mathrm{BR}(K_s \to e^+e^-\pi^+\pi^-) = (4.79 \pm 0.15) \cdot 10^{-5}$
- $\rightarrow$ Could also be used as normalization channel.
- $\rightarrow$ Mass variation due to $\pi\pi \to ee$ misidentification: $\Delta M = -278.118\ \mathrm{MeV/c^2}$
- $\rightarrow$ Our resolution is $\sigma \sim 20\ \mathrm{MeV/c^2}$ $\rightarrow$ We can distinguish it easily!

Background due to converted photons

$K_s \to X\gamma$ with conversion $\gamma \to e^+e^-$.

- $\to$ $\text{BR}(K_s \to \gamma\gamma) = (2.63 \pm 0.17) \cdot 10^{-6}$
- $\to$ $\text{BR}(K_s \to \pi^+\pi^-\gamma) = (1.79 \pm 0.05) \cdot 10^{-3}$
- $\to$ $\text{BR}(K_s \to \pi^0\gamma\gamma) = (4.9 \pm 1.8) \cdot 10^{-8}$

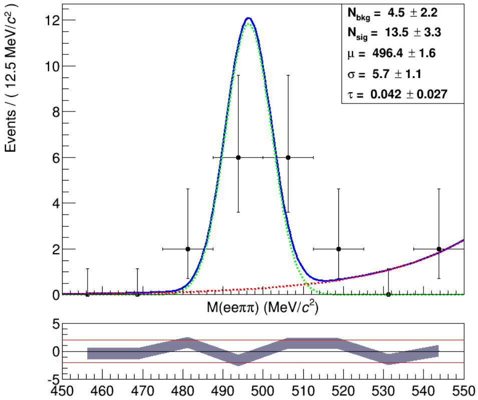
To reject them, select $m_{e^+e^-} > 10$ MeV/c^2.



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

Normalization channel and possible background

MC matching selection



Fit: $N_{sig} \cdot \text{gauss}(\mu, \sigma) + N_{bkg} \cdot \text{expo}(\tau)$

$\mu = 496.4 \pm 1.6$ MeV/c^2, no energy loss with only 2e.

$\sigma = 5.7 \pm 1.1$ MeV/c^2, much better resolution.

Towards an offline selection

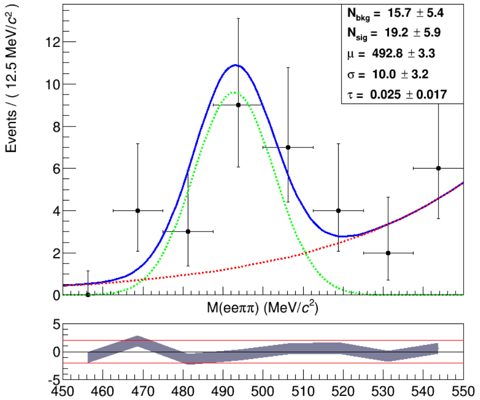
Define again a selection without using MC truth information.

- To select K_s decays:
  $\rightarrow$ IP χ^2 with respect to PV > 20 (from $K_s \rightarrow \mu\mu$ analysis)

- To select electrons:
  $\rightarrow$ $log(\mathcal{L}_e) - log(\mathcal{L}_\pi) > -2$
  No id. requirement on π's as are the most common.

- To avoid converted photons:
  $\rightarrow$ $m_{ee} > 10$ MeV/c^2

Towards an offline selection



Fit: $N_{sig} \cdot \text{gauss}(\mu, \sigma) + N_{bkg} \cdot \text{expo}(\tau)$

$\mu = 492.8 \pm 3.3$ MeV/c^2, very small energy loss with only 2e.

$\sigma = 10.0 \pm 3.2$ MeV/c^2, better resolution than $K_s \to e^+e^-e^+e^-$.

$K_s \to e^+e^-\pi^+\pi^-$ as background

Let us study $K_s \to e^+e^-\mu^+\mu^-$ and $K_s \to e^+e^-\pi^+\pi^-$ separation:

- $\to$ Mass variation due to $\mu\mu \to \pi\pi$ misidentification: $\Delta M = -67.8$ MeV/c^2
- $\to$ Our resolution for $K_s \to e^+e^-\pi^+\pi^-$ is $\sigma \sim 10$ MeV/c^2
- $\to$ Assume similar resolution for $K_s \to e^+e^-\mu^+\mu^-$

$\Rightarrow$ We can separate them but need to be careful with the tails!

Expected sensitivity

Normalization channel: $K_s \to e^+e^-\pi^+\pi^-$

Definition of single event sensitivity:

$$\alpha = \frac{\epsilon^{accep}_{norm}}{\epsilon^{accep}_{phys}} \cdot \frac{\epsilon^{reco|accep}_{norm}}{\epsilon^{reco|accep}_{phys}} \cdot \frac{\epsilon^{sel|reco}_{norm}}{\epsilon^{sel|reco}_{phys}} \cdot \frac{1}{(\epsilon^{PID})^2} \cdot \frac{\epsilon^{trig|sel}_{norm}}{\epsilon^{trig|sel}_{phys}} \cdot \frac{BR_{norm}}{N_{norm}}$$

- → ϵ^{accep} very similar for both channels.
- → Assume $\epsilon^{sel|reco}$ and $\epsilon^{trig|sel}$ are the same.
- → $\epsilon^{reco|accep}_{e} \approx 9\%$, $\epsilon^{reco|accep}_{\mu} \approx 20\%$ and $\epsilon^{reco|accep}_{\pi} \approx 6-9\%$.
- → $\epsilon^{PID}_{e} \approx 50\%$ and $\epsilon^{PID}_{\mu} \approx 90\%$ (from $B \to e\mu$ and $K_s \to \mu^+\mu^-$ analysis).
- → $BR(K_s \to e^+e^-\pi^+\pi^-) = 4.79 \cdot 10^{-5}$ from PDG.

Assuming $N_{K_s \to e^+e^-\pi^+\pi^-} \sim 50$ (very conservative!)

$$K_s \to e^+e^-e^+e^-: \ \alpha \sim 10^{-6}$$
$$K_s \to e^+e^-\mu^+\mu^-: \ \alpha \sim 10^{-7}$$

Conclusions

- $K_s \to l^+l^-l^+l^-$ decays are interesting to test the Standard Model.
- $K_s \to l^+l^-l^+l^-$ with electrons are experimentally challenging due to electron energy loss.
- $K_s \to e^+e^-e^+e^-$ very preliminary results:
  - $\to$ Mass peak shifted by ~ 30 MeV/c^2 due to energy loss in electron reconstruction.
  - $\to$ Mass resolution ~ 20 MeV/c^2. Factor 5 wider than muonic modes.
  - $\to$ Well separated from normalization channel $K_s \to e^+e^-\pi^+\pi^-$.
  - $\to$ Expected (preliminary) sensitivity: $\sim 10^{-6}$
- $K_s \to e^+e^-\mu\mu$ very preliminary results:
  - $\to$ Mass peak shifted by ~ 5 MeV/c^2 only.
  - $\to$ Mass resolution ~ 10 MeV/c^2.
  - $\to$ Separated from normalization channel $K_s \to e^+e^-\pi^+\pi^-$, but may have contamination from the tail.
  - $\to$ Expected (preliminary) sensitivity: $\sim 10^{-7}$

Future work

Many options to cross-check the preliminary results:

$\rightarrow$ Use Bremsstrahlung correction for electron momenta.

$\rightarrow$ Use information from electromagnetic calorimeter to identify electrons $\rightarrow$ may enhance reconstruction efficiency.

$\rightarrow$ Generate more MC statistics.

$\rightarrow$ Optimize the selection.

From theory: what BR range would be worth investigating? (take into account our expected sensitivity!)

Stay tuned!

THANK YOU FOR YOUR ATTENTION

BACK-UP

MC very soft pre-selection for event reconstruction

- StdNoPIDsParticles:
  - $\rightarrow$ $P_T > 250$ MeV/c^2
  - $\rightarrow$ IP χ^2 PV > 4
  - $\rightarrow$ Track $\chi^2 < 3$
- Other cuts to the combination:
  - $\rightarrow$ $\Delta M_{K_s} < 150$ MeV/c^2
  - $\rightarrow$ SV $\chi^2/ndf < 15$

PIDe efficiency

From $B \to e\mu$ analysis (LHCb-ANA-2012-079-v5), choosing the 1st bin (low P and P_T).

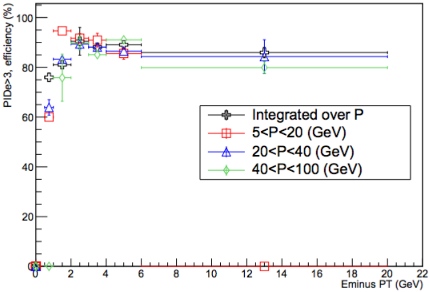


Figure 50: Efficiency of the requirement $\texttt{DLL}(e-\pi) > 3$ as a function of p_{T} of the probe track and for different p bins.

PIDμ efficiency

From $B \to \mu\mu$ analysis (LHCb-ANA-2011-101):

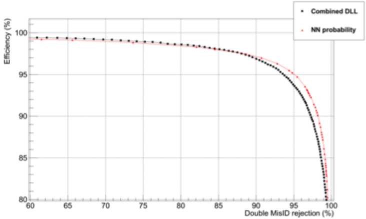


Figure 5: Efficiency vs. rejection of doubly misidentified $K_S^0 \to \pi^+\pi^-$. The curves are built with cuts in the $CDLL_{\mu-\pi}$ and in the NN_μ [20]. The efficiency (which appears squared) is determined using a data sample of trigger unbiased muons from $B^+ \to J/\psi K^+$, in the p, p_T range of $3-10$ GeV/c and $0.05-1.7$ GeV/c, which mainly corresponds to muons from the signal (see figure 6). The misID rejection, from data $K_S^0 \to \pi^+\pi^-$ doubly misidentified as $K_S^0 \to \mu^+\mu^-$ and also trigger unbiased. This double misID, as it will be seen, is the main component of the left sideband of $K_S^0 \to \mu^+\mu^-$. The $K_S^0 \to \pi^+\pi^-$ double misID sample has been previously cleaned using a geometrical MVA classifier. The cut finally selected for the analysis, $CDLL > -4$, yields an efficiency of $\sim 98\%$ for $K_S^0 \to \mu^+\mu^-$ for a rejection of 80% in double misID $K_S^0 \to \pi^+\pi^-$. The efficiency will be carefully obtained in section 7.2.

Expected $N_{K_s \to e^+e^-\pi^+\pi^-}$

$$N^{TIS}_{K_s \to e^+e^-\pi^+\pi^-} = N^{TIS}_{K_s \to \pi^+\pi^-, 1fb^{-1}} \cdot N_{fb^{-1}} \cdot \frac{BR(K_s \to e^+e^-\pi^+\pi^-)}{BR(K_s \to \pi^+\pi^-)} \cdot \frac{\epsilon_{K_s \to e^+e^-\pi^+\pi^-}}{\epsilon_{K_s \to \pi^+\pi^-}}$$

where:

- $\rightarrow$ $N^{TIS}_{K_s \to \pi^+\pi^-} \sim 10^8$ from $K_s \to \mu\mu$ analysis.
- $\rightarrow$ We have used $N_{fb^{-1}} = 3$.
- $\rightarrow$ $BR(K_s \to e^+e^-\pi^+\pi^-) = 4.79 \cdot 10^{-5}$ and $BR(K_s \to \pi^+\pi^-) = 6.9 \cdot 10^{-1}$, from PDG.
- $\rightarrow$ $\frac{\epsilon_{K_s \to e^+e^-\pi^+\pi^-}}{\epsilon_{K_s \to \pi^+\pi^-}} \sim \frac{\epsilon^2_{PIDe} \cdot \epsilon^2_{reco\ \pi} \cdot \epsilon^2_{reco\ e}}{\epsilon^2_{reco\ \pi}}$ is the ratio of efficiencies, computed with the values given in slide 16.