Feasibility of $K_S \to \pi^0 \mu^+ \mu^-$

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Rare'n'Strange Workshop on rare strange decays at LHCb

Introduction (I)

- $K_L \to \pi^0 \mu^+ \mu^-$ is one of the hot channels in rare kaon decays (BF could be sensitive to new physics!)
  - K_S equivalent decay very useful to constraint the CP violating amplitude that enters in this BF
  - Current experimental measurement from NA48:

$$BF(K_S \to \pi^0 \mu^+ \mu^-) = [2.9^{+1.5}_{-1.2} \pm 0.2] \times 10^{-9}$$

~50% error

- Purpose of this study: can LHCb measure this BF and improve current error?

Introduction (II)

- The LHC provides LHCb around 10^{13} K_S in our acceptance per fb^{-1} (we currently have 3 fb^{-1} on tape)
  - However reconstructing and triggering K_S is difficult for us, given the low p_T of the daughters
  - Dealing with π^0 it's even more challenging!

- Considered 3 options for reconstructing the signal:
  - $K_S \to \pi^0(e^+e^-)\mu^+\mu^-$, via $\pi^0 \to e^+e^-\gamma$ (BF~1%)
  - $K_S \to \pi^0(\gamma\gamma)\mu^+\mu^-$, via $\pi^0 \to \gamma\gamma$ (BF~99%)
  - $K_S \to \pi^0\mu^+\mu^-$ trying to reconstruct the K_S only with the muons

Some LHCb jargon

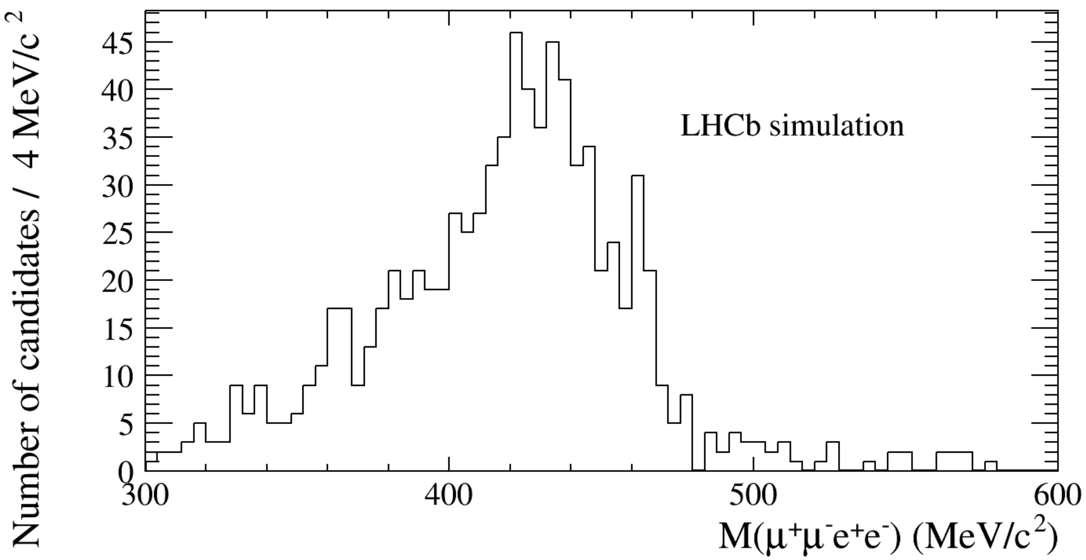
- $\pi^0 \to \gamma\gamma$ at LHCb
  - π^0 merged: both γ end up in the same calorimeter cluster
  - π^0 resolved: each γ ends up in a different calorimeter cluster
- TIS/TOS?
  - TIS (trigger independent of signal): events in which none of the K_S daughters were responsible for the trigger
    - TIS probability is ~independent of the daughters! (e.g. same prob. for $K_S \to \pi^0\mu^+\mu^-$ and $K_S \to \pi^+\pi^-$)
  - TOS (trigger on signal): events in which at least one of the K_S daughters was responsible for the trigger

$K_S \to \pi^0(e^+e^-)\mu^+\mu^-$

- Very low reconstruction efficiency, driven by low efficiency on electrons
  - Too soft to be reconstructed!

	Efficiency for particles in acceptance (%)
μ	21.0 ± 1.5
e	2.5 ± 0.5

Total reconstruction efficiency (%)
0.018 ± 0.001

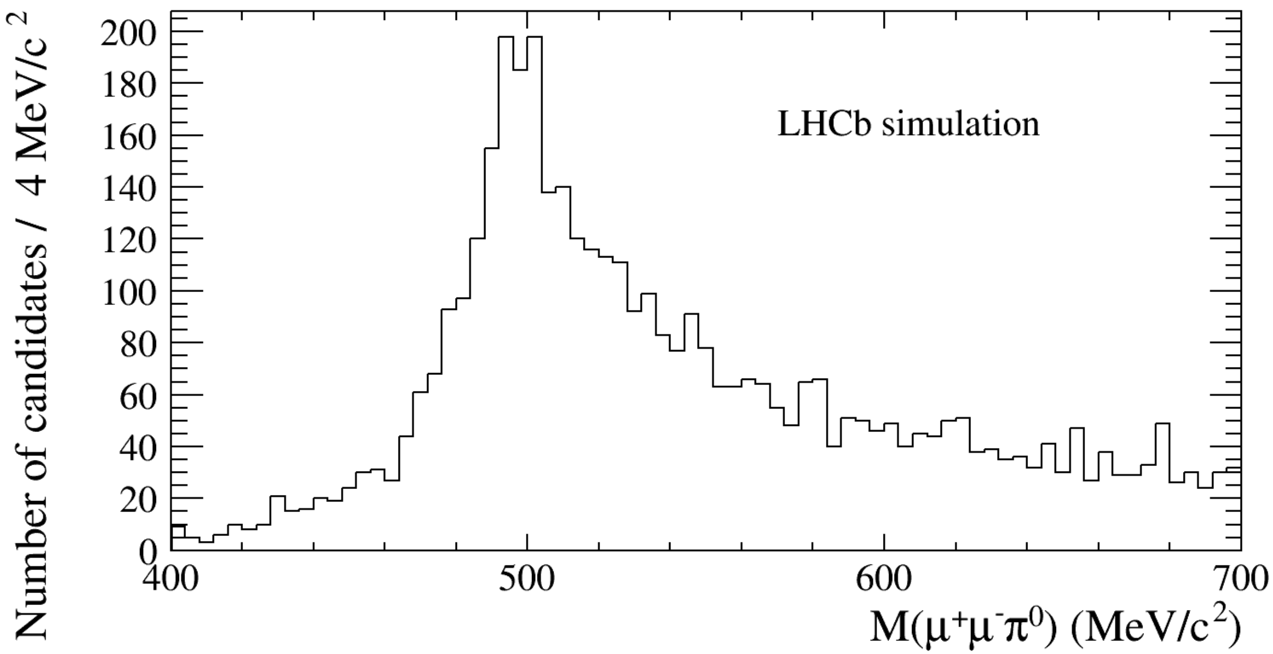


- Option not feasible! (also 1% from BF[$\pi^0 \to e^+e^-\gamma$])

$K_S \to \pi^0(\gamma\gamma)\mu^+\mu^-$

- Also low reconstruction efficiency, driven by low efficiency on π^0
  - Reconstructed candidates in the resolved category

	Total reconstruction efficiency (%)
π^0 resolved	0.140 ± 0.002
π^0 merged	0.004 ± 0.000



$K_S \to \pi^0(\gamma\gamma)\mu^+\mu^-$ normalisation

- Determining the expected yields → normalise with respect to a channel with well known BF
  - In this case, easiest normalisation to $K_S \to \pi^+\pi^-$!

$$N_{K_S^0\to\pi^0\mu^+\mu^-} = \frac{\epsilon^{\pi^0\mu^+\mu^-}}{\epsilon^{\pi^+\pi^-}} \times \frac{BF(K_S^0 \to \pi^0\mu^+\mu^-)}{BF(K_S^0 \to \pi^+\pi^-)} \times N_{K_S^0\to\pi^+\pi^-}$$

  - The $K_S \to \pi^+\pi^-$ efficiencies were obtained for the $K_S \to \mu^+\mu^-$ analysis (efficiencies from MC, $N[K_S \to \pi^+\pi^-]$ from data)
  - For the trigger efficiency, use TIS candidates, for which the efficiency is the same!
  - Focus only in resolved π^0

$K_S \to \pi^0(\gamma\gamma)\mu^+\mu^-$ yields (I)

- TIS yields

TIS yield / fb^{-1}
~0.4

- TOS yields (i.e. using all triggers)
  - TOS efficiency from MC (not fully accurate, but right order of magnitude)

TOS yield / fb^{-1}
~3

- Yields in tape
  - For current data in tape, trigger efficiency in 2011 expected lower than in 2012
  - So probably not enough statistics for now (around **~7** events in total, with too soft cuts)

$K_S \rightarrow \pi^0(\gamma\gamma)\mu^+\mu^-$ yields (II)

- Post LS1 yields:
  - Post LS1 we expect ~10 fb^{-1} (optimistic) + higher trigger efficiency (optimistic). So some chances to observe the decay?

- Upgrade yields
  - In the upgrade, ~50 fb^{-1} and higher trigger efficiency, so fairly good chances for a competitive measurement of the BF

- In any case, selection should be tighten, which will have some cost in efficiency! Also consider background (next slide)

$K_S \to \pi^0(\gamma\gamma)\mu^+\mu^-$ background (I)

- Combinatorial background should be ~similar to $K_S \to \mu^+\mu^-$, so reasonably low (requiring two very detached muons cleans a lot!)
- Consider also $K_S \to \pi^+\pi^-$ double misID (both pions misidentified as muons)+ π^0 from underlying event

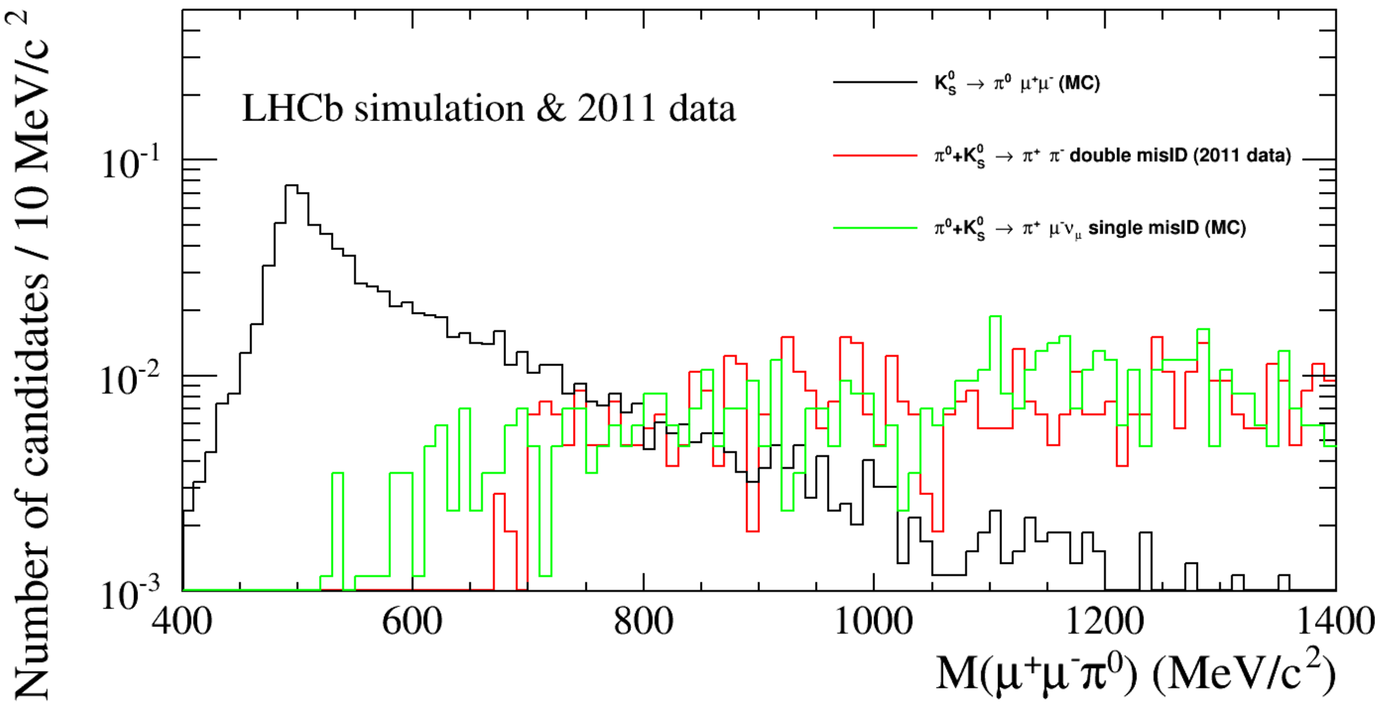
$$BF(K_S^0 \to \pi^+\pi^-) \times \epsilon(\pi \to \mu)^2 \sim 0.69 \times 0.01^2 \sim 7 \times 10^{-4}$$

  - Change of mass hypothesis ($\pi \to \mu$) moves peak to the left. Adding π^0 could move it back to the right!
- Similar situation with $K_S \to \pi^-\mu^+\nu_\mu$ (pion misidentified as muon)

$$BF(K_S^0 \to \pi^-\mu^+\nu_\mu) \times \epsilon(\pi \to \mu) \sim 4.7 \times 10^{-4} \times 0.01 \sim 5 \times 10^{-6}$$

$K_S \to \pi^0(\gamma\gamma)\mu^+\mu^-$ background (II)

- Use $K_S \to \pi^+\pi^-$ (data) and $K_S \to \pi^-\mu^+\nu_\mu$ (MC) and add π^0 from underlying event to fake this background
- Mass spectra of signal and backgrounds:
  - Histograms simply normalised to 1



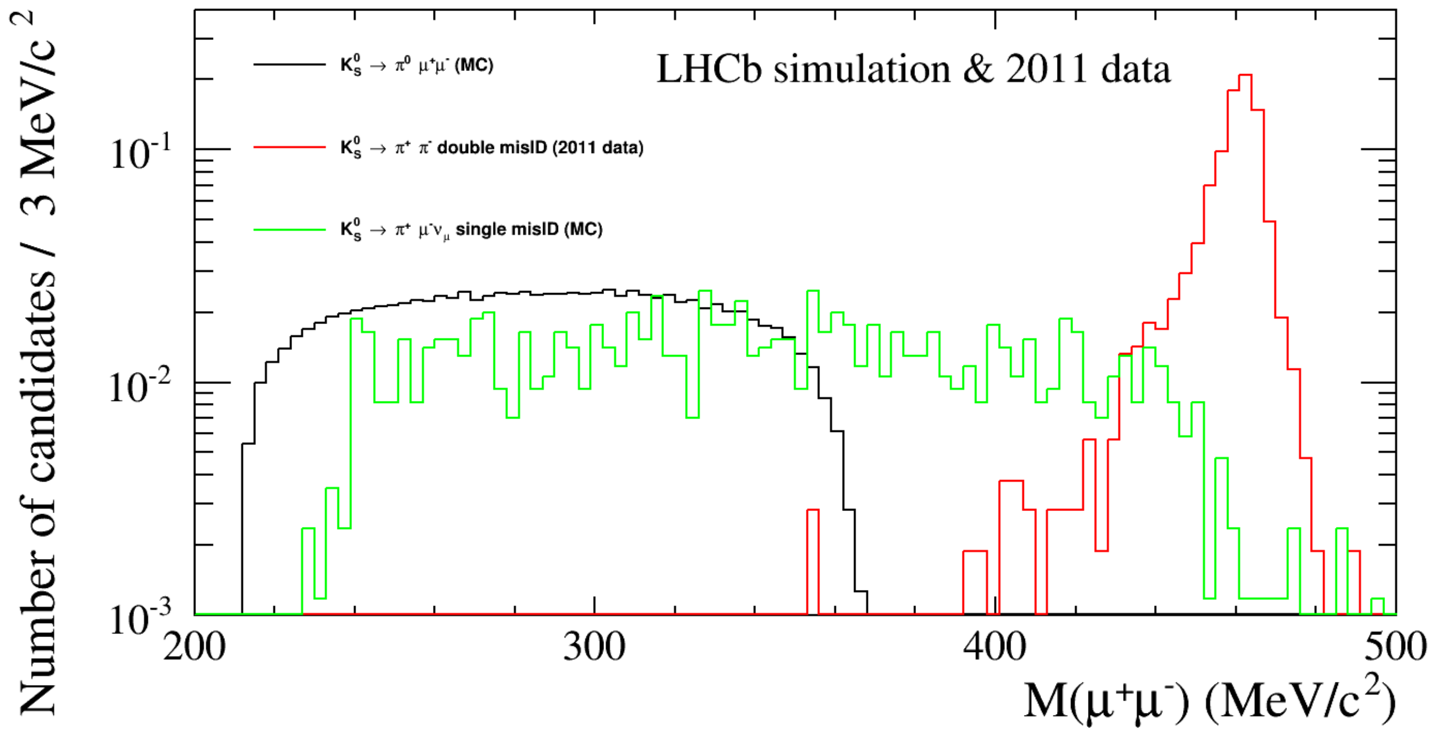
$K_S \to \pi^0 \mu^+ \mu^-$ (I)

- Final alternative, reconstruct signal using only muons, à la $K_S \to \mu^+ \mu^-$
  - Reconstruction efficiencies much larger!
  - However mass not peaking (because of missing π^0)

- Same non-combinatorial backgrounds to be considered
  - $K_S \to \pi^+ \pi^-$ double misID (both pions misidentified as muons)
  - $K_S \to \pi^- \mu^+ \nu_\mu$ single misID (pion misidentified as muon)

$K_S \rightarrow \pi^0 \mu^+ \mu^-$ (II)

- Mass spectra of signal and backgrounds:
  - Histograms simply normalised to 1



  - Signal region dominated by $K_S \rightarrow \pi^- \mu^+ \nu_\mu$

Conclusions

- Have tried to see different possibilities to reconstruct $K_S \rightarrow \pi^0 \mu^+ \mu^-$ at LHCb
  - Different decay modes to reconstruct π^0
  - Just ignoring π^0 and focusing on the muons only
- The mode with the standard LHCb π^0 reconstruction seems the best strategy!
- Analysis not feasible with our current dataset but should be in the future, particularly in the upgrade!