Possibilities with K^+ and K_L decays.

A Contu

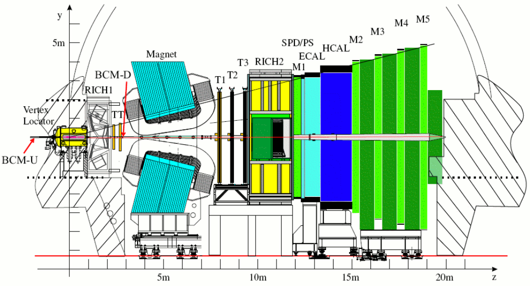
INFN Cagliari/CERN

Rare'n'strange Workshop - 6 Dec 2013

Outline

Possibilities at LHCb

Lenght of tracking system is $9\,\mathrm{m}$ along the beam axis (z direction)



Tracks in LHCb are tipically reconstructed as

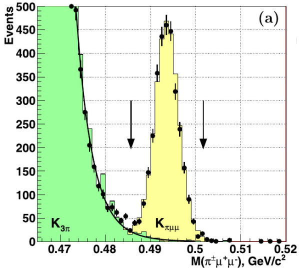
- **Long**: hits in VELO and T1,2,3 stations
- **Downstream**: hits in TT and T1,2,3 stations

Secondary vertices formed by Long (Downstream) tracks are reconstructed in the region $0 \lesssim z \lesssim 40\,\mathrm{cm}$ ($40 \lesssim z \lesssim 250\,\mathrm{cm}$)

A K^+ of $10\,\mathrm{GeV}/c$ momentum decays on average at $z \approx 70\,\mathrm{m}$, similarly for K_L...

K^+ decays

- Idea is to study $K^+ \to \pi^+\mu^+\mu^-$, $\mathcal{B}(K^+ \to \pi^+\mu^+\mu^-) = (9.4 \pm 0.6) \times 10^{-8}$
- Control channel is $K^+ \to \pi^+\pi^+\pi^-$, $\mathcal{B}(K^+ \to \pi^+\pi^+\pi^-) \approx 5\%$
- Latest measurements from NA48 [PLB 697 (2011) 107–115]



- $\sim$3K $K \to \pi\mu\mu$ events ($\sim 10^9$ $K \to 3\pi$)
- branching fraction measurement
- Study of form factor $W((M_{\mu\mu}/M_K)^2)$
- Limits on charge asymmetry and AFB at $\lesssim 10^{-2}$ 90% CL
- LFV search with same-sign muons

Strategy

Focus on $K^+ \to 3\pi$ to define a reconstruction and selection strategy

1. Maximise "reconstructible" region for K^+ decay vertex
2. Remove large combinatorial background from random pions which is not removed by a pointing requirement

Strategy

Focus on $K^+ \to 3\pi$ to define a reconstruction and selection strategy

1. Maximise "reconstructible" region for K^+ decay vertex
2. Remove large combinatorial background from random pions which is not removed by a pointing requirement

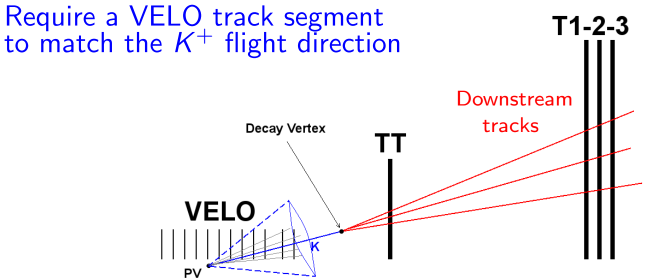
Use downstream candidates $\to$ Improves slightly 1 but not 2

Strategy

Focus on $K^+ \to 3\pi$ to define a reconstruction and selection strategy

1. Maximise "reconstructible" region for K^+ decay vertex
2. Remove large combinatorial background from random pions which is not removed by a pointing requirement

Use downstream candidates $\to$ Improves slightly 1 but not 2

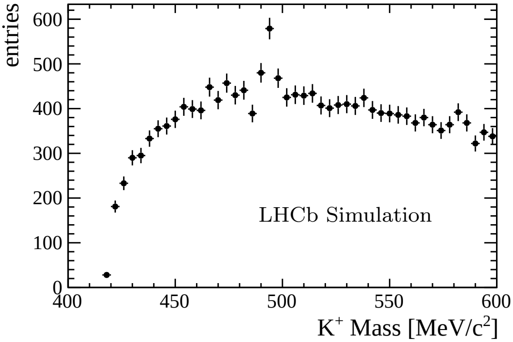


Test method on MC minimum bias

Search for K^+ decaying in RICH1 ($z \in [1, 2.3]\,\mathrm{m}$) by combining three downstream tracks with "typical" selection.

$K^+_{p_T} > 300\,\mathrm{MeV}/c$ + track and vertex quality cuts + pointing to the PV

No VELO segments are used so far

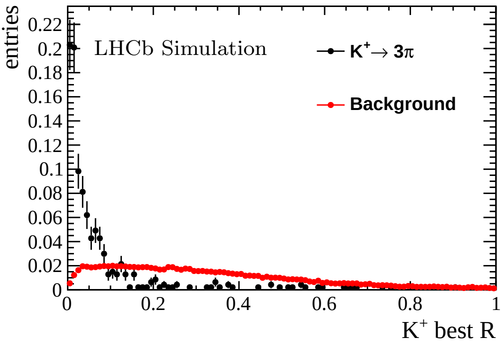


Test method on MC minimum bias

Search for K^+ decaying in RICH1 ($z \in [1, 2.3]\,\mathrm{m}$) by combining three downstream tracks with "typical" selection.

Use VELO segments within a cone around the K^+ flight direction, chose the closest one by comparing the slopes

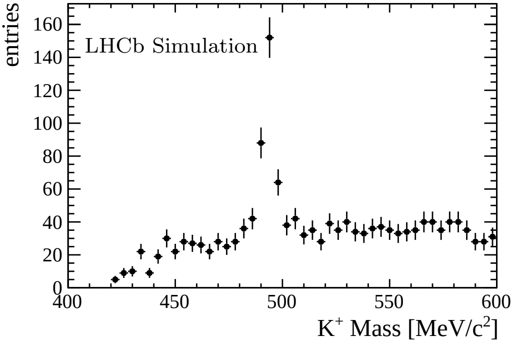
$$R = \sqrt{\left(1 - \frac{s^{Down}_{dx/dz}}{s^{Velo}_{dx/dz}}\right)^2 + \left(1 - \frac{s^{Down}_{dy/dz}}{s^{Velo}_{dy/dz}}\right)^2}$$



Test method on MC minimum bias

Search for K^+ decaying in RICH1 ($z \in [1, 2.3]\,\mathrm{m}$) by combining three downstream tracks with "typical" selection.

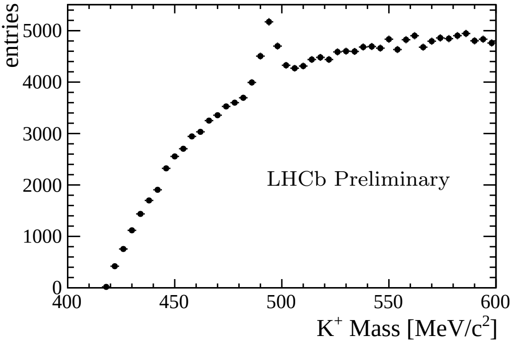
Requiring $R < 0.05$ (non-optimised)
Background is largely reduced with very little loss on signal (efficiency is around 70%)



Data

Repeat same exercise on data.
Events selected by B decays dedicated selections! ($\sim 1\,\mathrm{fb}^{-1}$)
No dedicated selection nor dedicated trigger line for $K^+ \to 3-$body exists yet.

No cut on R
Peak is visible but background is large, tightening the cuts starts cutting out signal as well

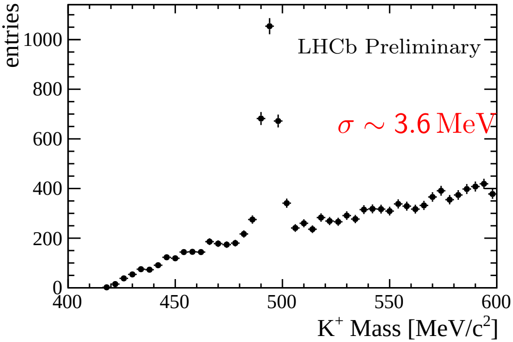


Data

Repeat same exercise on data.
Events selected by B decays dedicated selections! $(\sim 1\,\mathrm{fb}^{-1})$
No dedicated selection nor dedicated trigger line for $K^+ \to 3-$body exists yet.

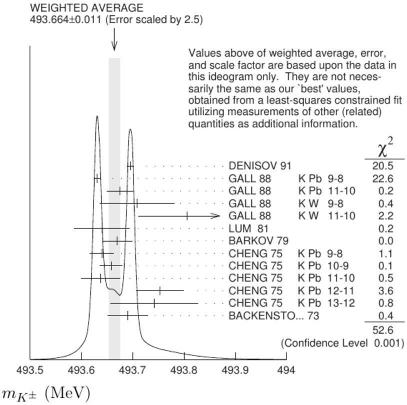
Using VELO information greatly reduces the background with very little loss in efficiency

Yield is $\sim 2K$ and can be marginally improved, purity easily improved with little signal loss by tightening cut on R



K^+ mass measurement

Serious disagreement between two most precise measurements (x-ray energies from Kaonic atoms)



Current measurement is $493.677 \pm 0.016\,\mathrm{MeV}$

$K^+ \to \pi^+\pi^-\pi^+$ would be ideal for a measurement at LHCb, Very rough estimate suggests that our systematic uncertainty could be of about $0.02\,\mathrm{MeV}$ but likely to improve with some effort.

Still a lot more signal is needed to push down the statistical uncertainty, a couple of 100K events should be enough, hard but not impossible with current dataset.

Prospects for K^+ decays

- Results from VELO track matching are encouraging and also applicable to other decays (e.g. $\Sigma \to p\mu\mu$)
- Statistics is our enemy, but
  - Running a dedicated selection on our current dataset will increase the statistics significantly (hopefully by a factor 10). We can check this in the next re-processing
  - A dedicated trigger line may produce a similar result but can only be available from Run2
- A competitive K^+ mass measurement, although not a world-best, could be interesting.

K_L^0 reconstruction (all credits to D Martinez Santos - NIKHEF)

Lifetime acceptance and KL / Ks lifetime differences

KL and KS are distinguishable only by the decaytime...
... and that is in theory. In practice, LHCb decaytime acceptance is not great for kaons

The decay distributions will look like:

$\epsilon(t) \sim e^{-\beta t}$

KS $\quad p(t) \sim e^{-(\beta+\Gamma_S)t} = e^{-\Gamma_{S,eff}t}$

KL $\quad p(t) \sim e^{-(\beta+\Gamma_L)t} = e^{-\Gamma_{L,eff}t}$

	Effective Γs	Effective ΔΓ/Γs
2 Body (Long Track)	~60 ns-1	~O(10%)
2 Body (Down Track)	~18 ns-1	O(50%)
4 Body (Long Track)	~150 ns-1	~0
4 Body (Down Track)	~28 ns-1	O(30%)

Warning: exact numbers depend significantly on selection and trigger requirements

K_L^0 reconstruction (all credits to D Martinez Santos - NIKHEF)

Lifetime acceptance and KL / Ks lifetime differences

This also changes the overall efficiency

$$\frac{\epsilon_{K_L^0\to\mu^+\mu^-}}{\epsilon_{K_S^0\to\mu^+\mu^-}} = \frac{\dfrac{\int_0^\infty Acc(t)e^{-\Gamma_L t}dt}{\int_0^\infty e^{-\Gamma_L t}dt}}{\dfrac{\int_0^\infty Acc(t)e^{-\Gamma_S t}dt}{\int_0^\infty e^{-\Gamma_S t}dt}}$$

	Efficiency ratio
2 Body (Long Track)	~1-2 per mil
2 Body (Down Track)	~5 per mil
4 Body (Long Track)	~1-2 per mil
4 Body (Down Track)	~2-3 per mil

Warning: exact numbers depend significantly on selection and trigger requirements

Conclusions

- K^+ decays can already be reconstructed by the current LHCb tracking system
- Statistics could be a limiting factor but there are ways to increase it (dedicated selection + trigger)
- Technique can also be appied to other analyses
- A measurement of the Kaon mass should be feasible. If not now, in LHCb Run2/Upgrade
- Typical efficiency to select a K_L decay in LHCb is 1000 times smaller than for a K_S going to the same mode. i.e, it has the same sensitivity for K_L BR's 1000 time larger
- The decay time of K_L's in LHCb looks similar to that of K_S decays because of acceptances. Some separation ($\mathcal{O}(30-50\%)$) seems possible but only by using downstream tracks