$K_S \rightarrow \mu\mu$

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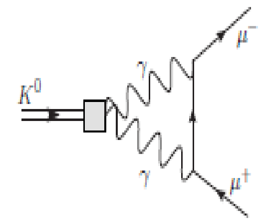
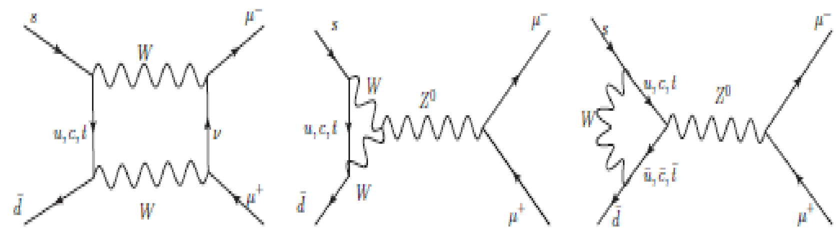
Overview

- Introduction to Ks →μμ
- LHCb experiment
    - Detector acceptance for Ks
    - Trigger efficiency
- Ks →μμ analysis strategy
- K_L →μμ in LHCb (bkgd for Ks)
- Expected sensitivity and impact of known improvements w.r.t past result
- Downstream Ks
- Conclusions

→ the long-distance (LD) contributions:

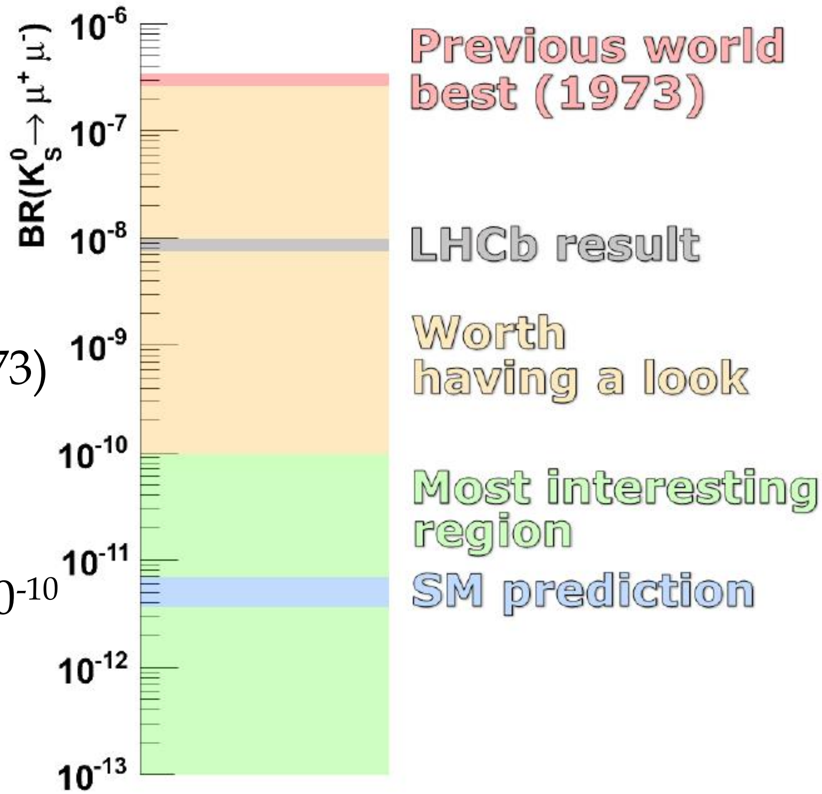


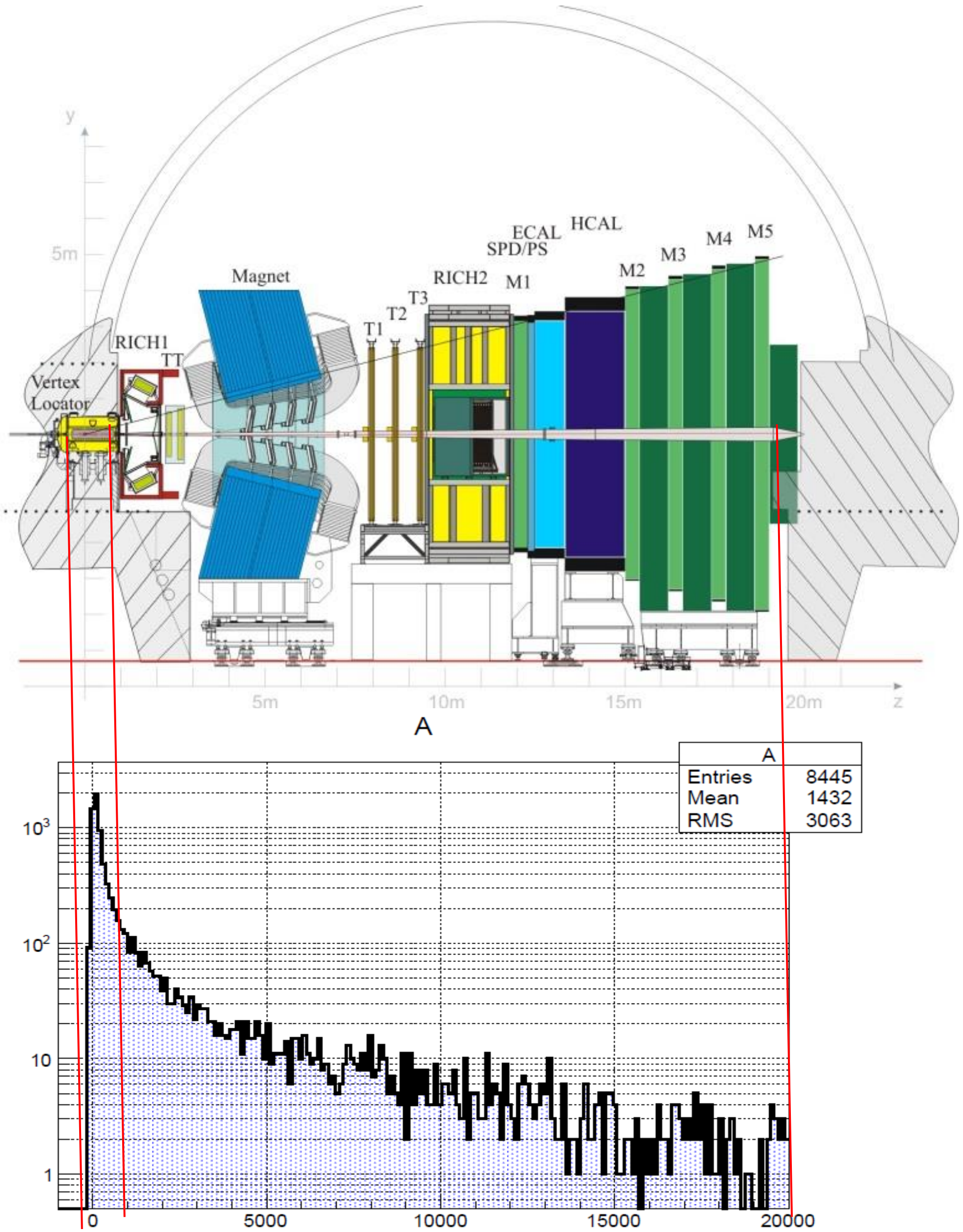
→ the short-distance (SD) contributions:



Overview

- BR(Ks → μμ) in SM is expected to be (5.0□0.2) x 10^{-12}
- Pre-LHCb world best upper limit BR(Ks → μμ) < 3.1 10^{-7} (PS@CERN, 1973)
- 5 orders of magnitude to search for NP
- Although most interesting region is <10^{-10}
- LHCb set an upper limit BR(Ks → μμ) < 9x10-9@90%CL with 1fb-1 of data (1/3 of what is currently on tape)

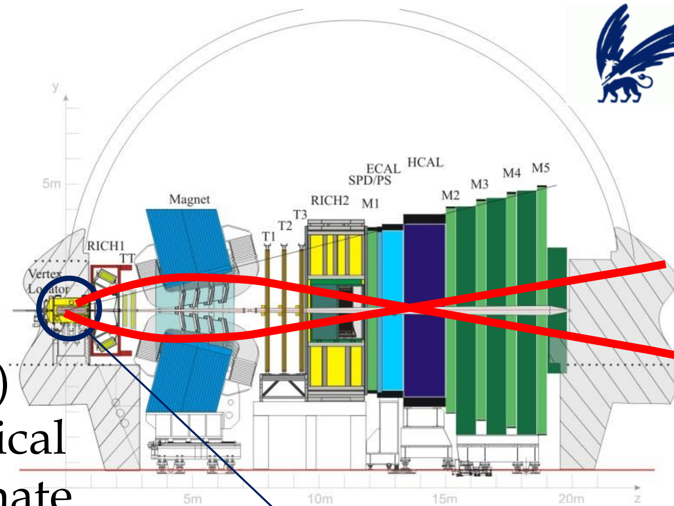




LHCb is not desgined for Ks
Yet a significant fraction of them decay in the acceptance and can be reconstructed

Bottleneck is the trigger. Only ~**1% of the well-reconstructed Ks→μμ** decays would fire the trigger we used for our first analysis.
This can be compared to ~ 90% for Bs→μμ .
We have already improved our trigger efficiency to 3% for our next update.
But you see there is still a big big for improvements at the trigger level (Connor's talk)

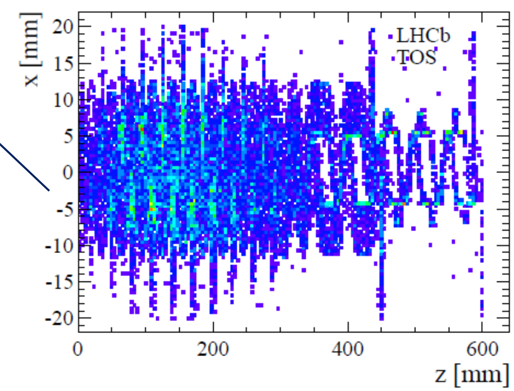
Ks→μμ analysis strategy

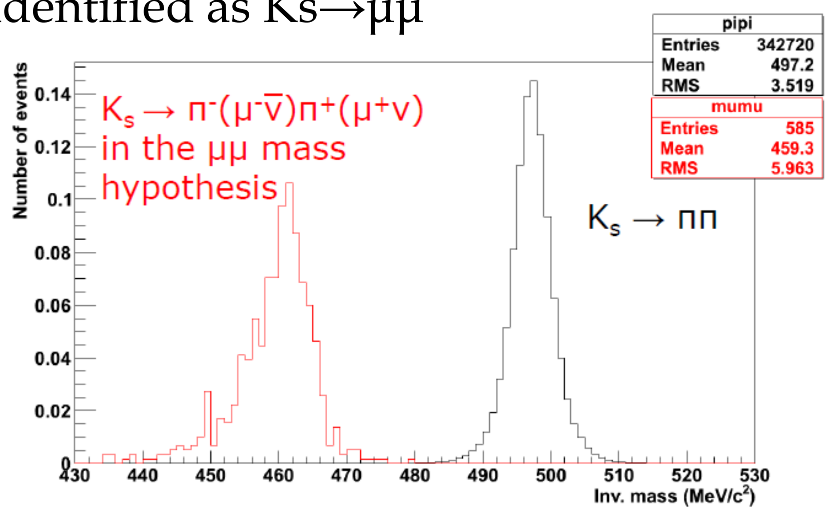


- Reconstruct di-muon pairs

- Build a Boosted Decision Tree (**BDT**) combining geometrical and kinematical information of the event to discriminate against combinatorial background and material interactions

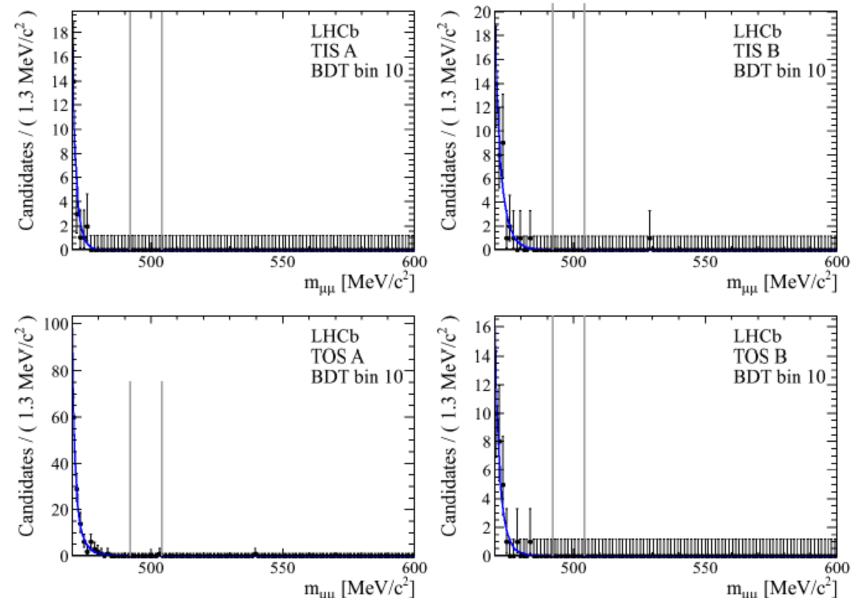
- **Invariant mass resolution** is very important here, to discriminate against Ks→ππ identified as Ks→μμ

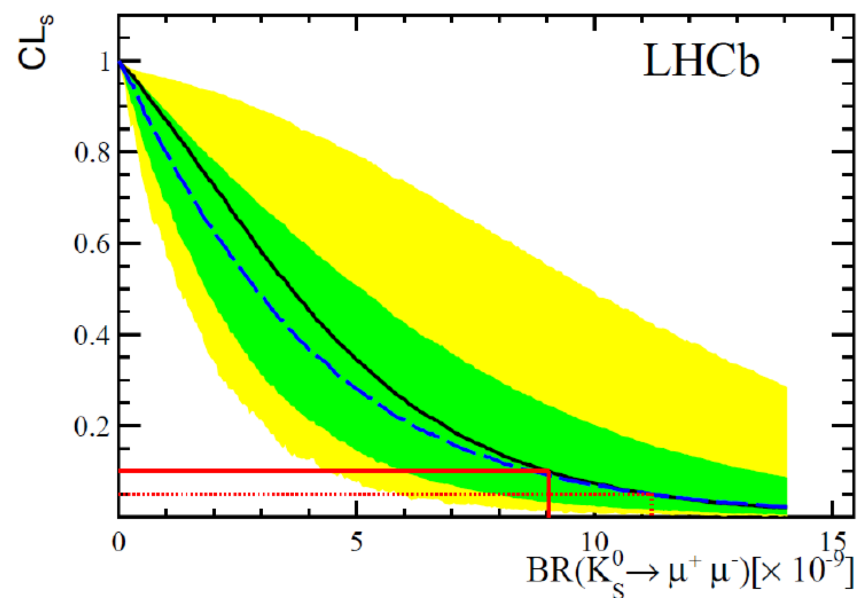




Ks→μμ analysis strategy

- Make several bins (with different sensitivity each) in such BDT
- In each bin, search for Ks→μμ in a mass window around the K0 mass
- Combine all the BDT bins (and all the trigger categories) into a single CLs limit
- Use data-driven techniques to obtain the necessary efficiencies with minimal dependency on detector simulation





Lifetime acceptance and $K_L \to \mu\mu$ background

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

$\epsilon(t) \sim e^{-\beta t}$ With $\beta \gtrsim 5 \mathrm{x} \Gamma_s$ ($>> \Gamma_L$).

This makes the two lifetime distributions to look similar

But the overall efficiency ratio is of course different

$$\frac{\epsilon_{K^0_L \to \mu^+\mu^-}}{\epsilon_{K^0_S \to \mu^+\mu^-}} = \frac{\dfrac{\int_0^\infty Acc(t) e^{-\Gamma_L t} dt}{\int_0^\infty e^{-\Gamma_L t} dt}}{\dfrac{\int_0^\infty Acc(t) e^{-\Gamma_s t} dt}{\int_0^\infty e^{-\Gamma_s t} dt}} = O(10^{-3})$$

And makes $K_L \to \mu\mu$ to become a negligible background for the current level of precision
But can be relevant when we approach the 10^{-11} level

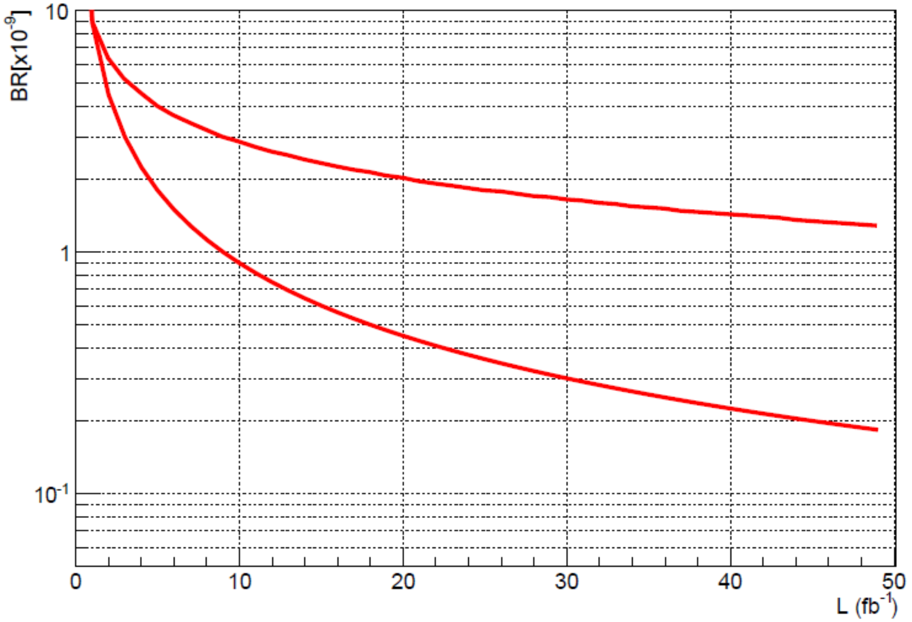
Expected sensitivity

Without further improvements (direct extrapolation from last paper):

BR upper limit at 90% CLs

Lines reflect uncertainty in background prediction

Naïve extrapolation suggests we can go below 10^{-9} with the LHCb upgrade



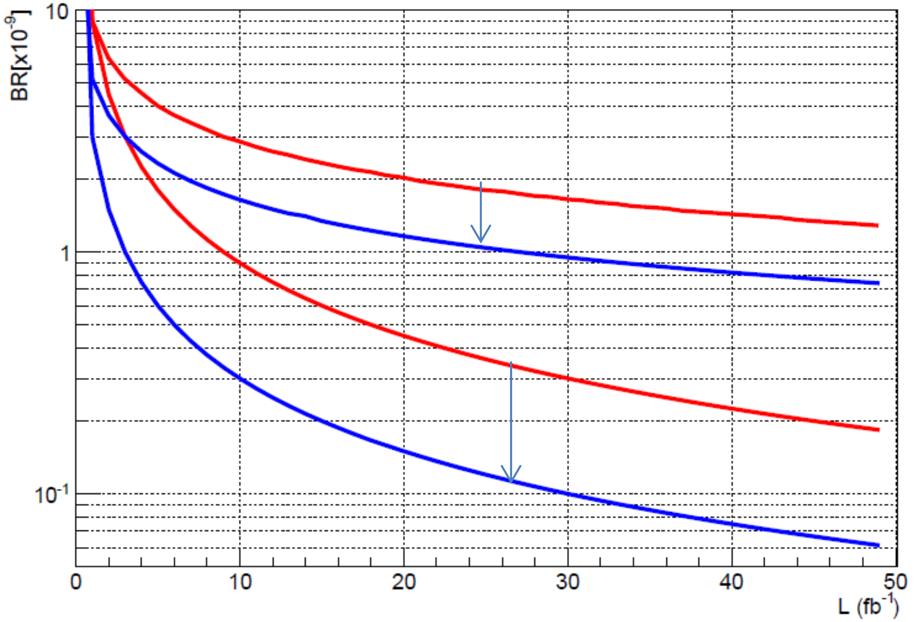
Expected sensitivity

Without **known** improvements (**factor x3 in trigger efficiency**):

BR upper limit at 90% CLs

Lines reflect uncertainty in background prediction

Naïve extrapolation suggests we can go **even below 10^{-10}** with the LHCb upgrade



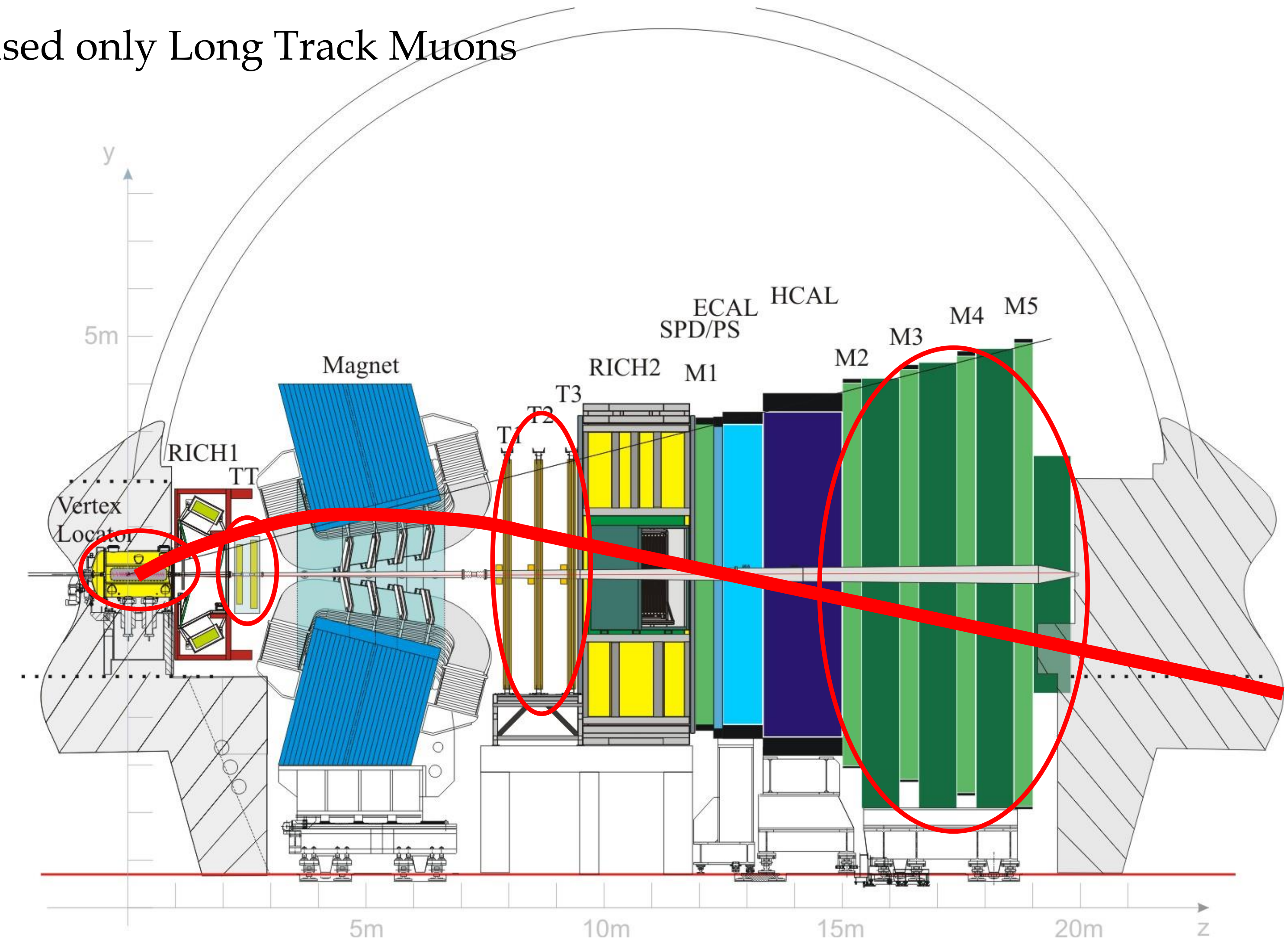
And there is ongoing work to further gain sensitivity

Still quite some room for improvements in the trigger (see Connor's talk)

Increased statistics by using different reconstruction (this talk)

Gaining statistics

Last analysis used only Long Track Muons



Gaining statistics

Last analysis used only Long Track Muons

We can gain significant statistics by using “Downstrean Muons”

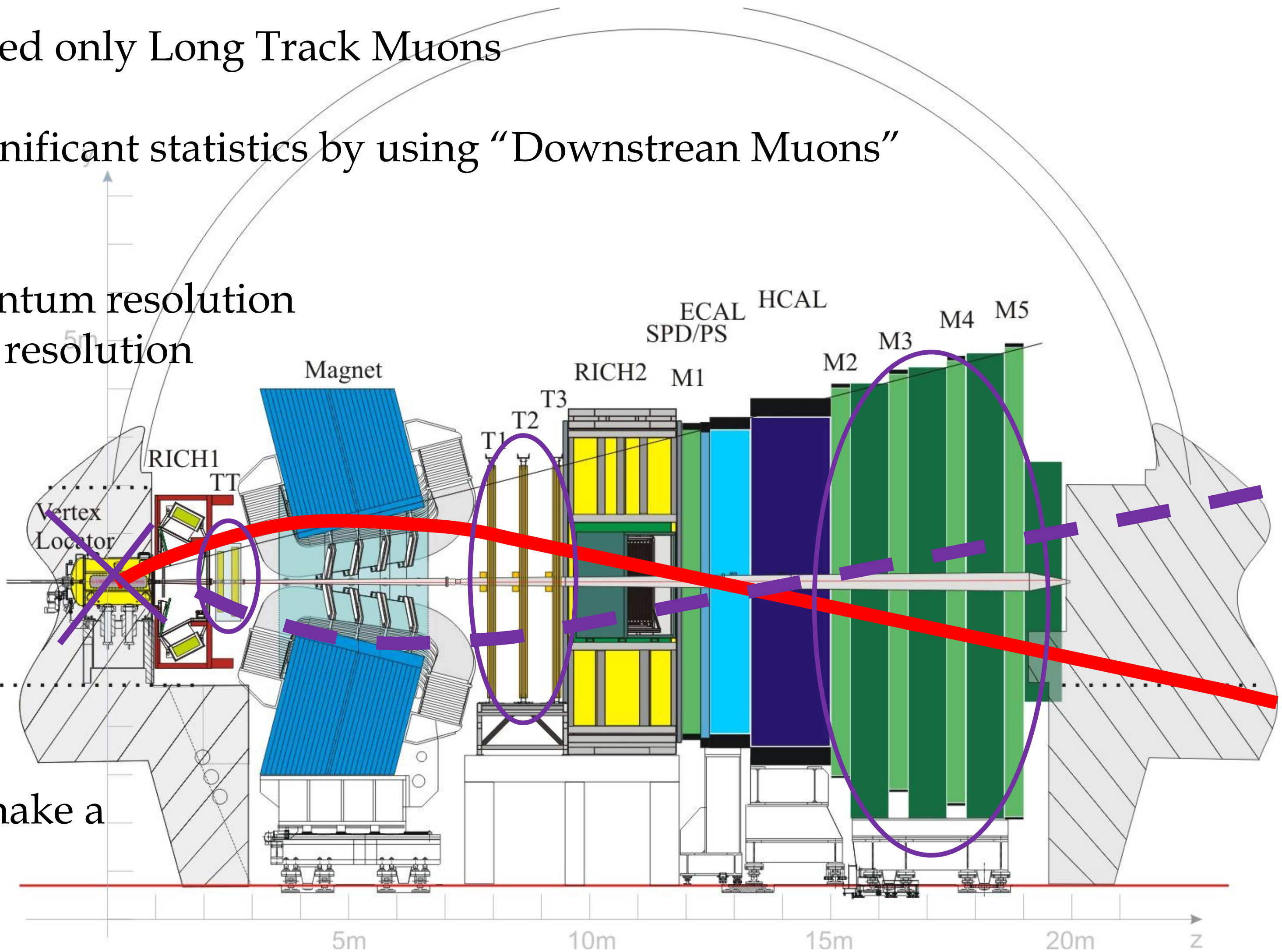
But

Worse momentum resolution

Worse vertex resolution

i.e we can get a new sample, but of lower quality

(and requires to make a trigger for it)

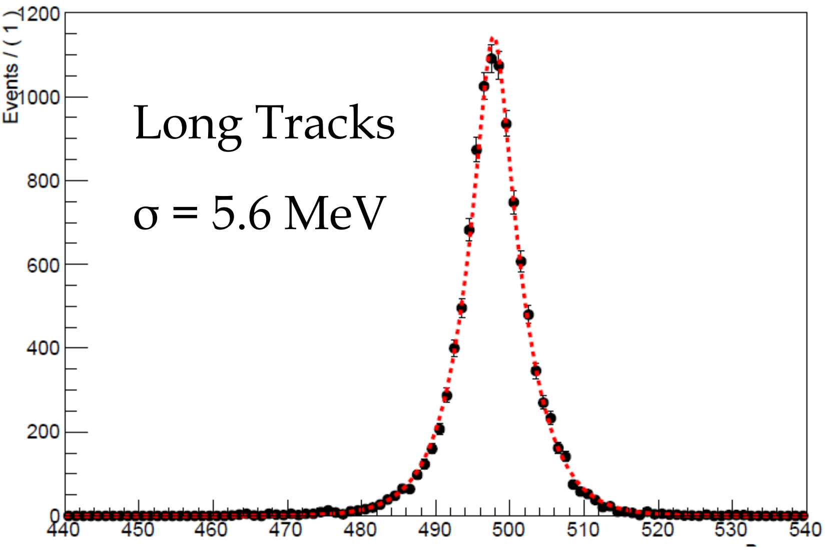


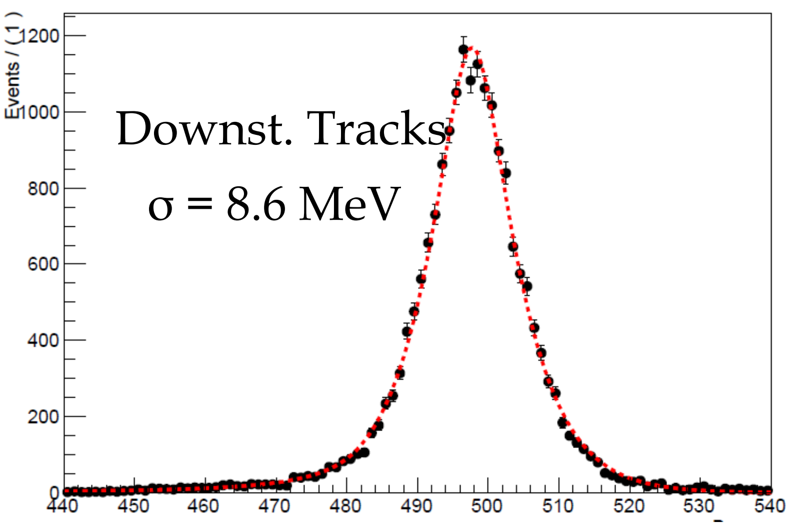
Size of the sample

According to simulation study we would expect **a ~176% increase of statistics** at reconstruction and muon identification level by using Downstream decays

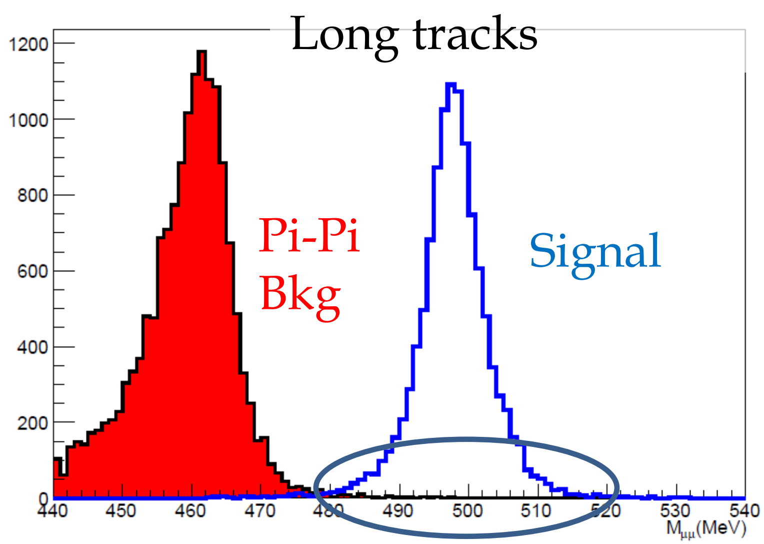
But still:

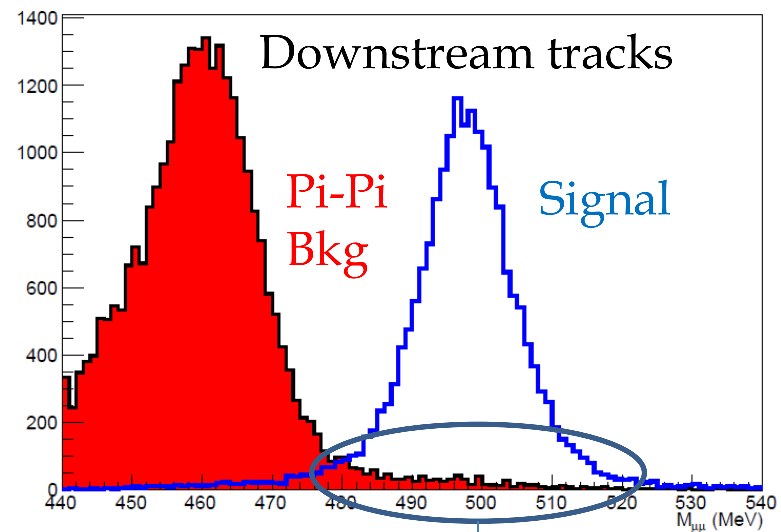
- Need to figure out how to trigger them
- Need to figure out suitable selection algorithms
- The quality of the reconstruction is worse





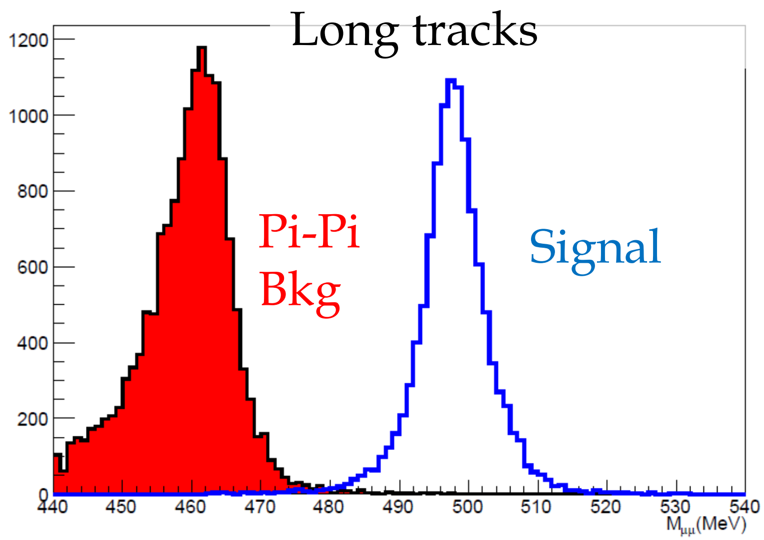
How do the Downstream events look like?

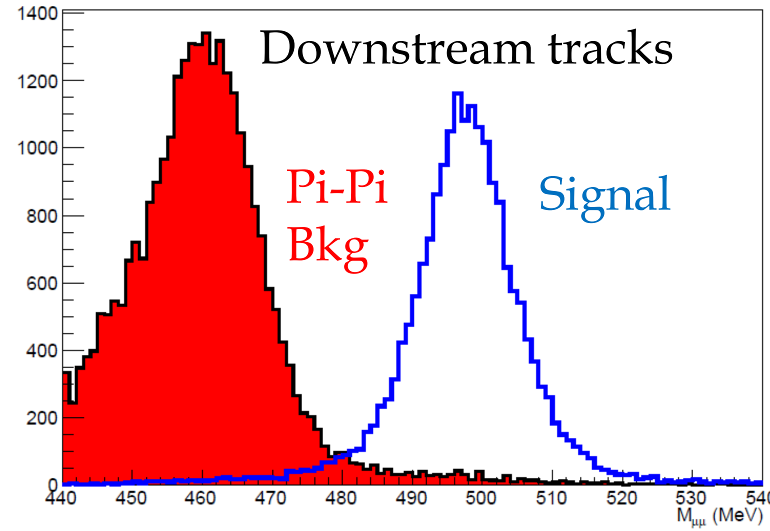


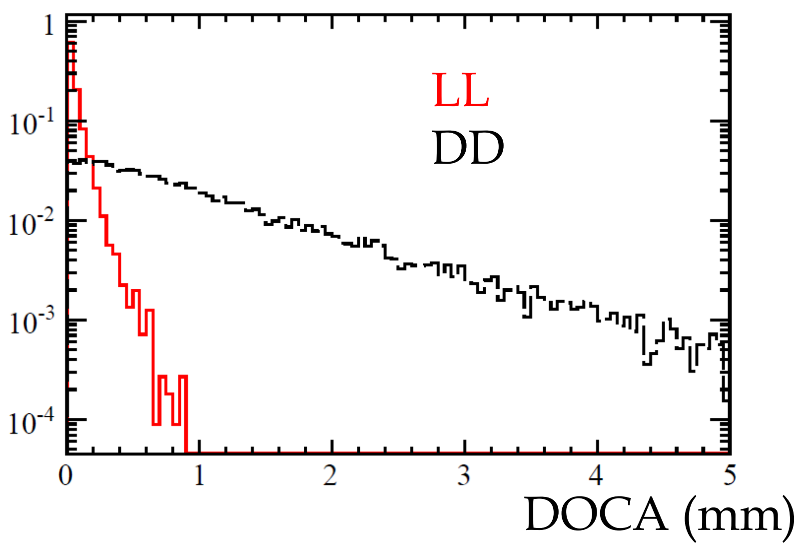


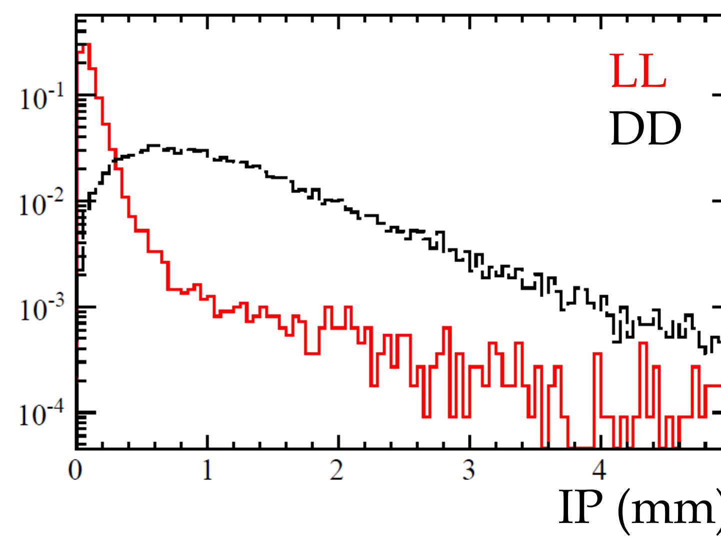
Signal over misid background is worse by a factor ~~10 (Accurate number would depend on selection/trigger/etc…)

How do the Downstream events look like?









Potential of the DD sample

If (optimistically) we assume that:

- We manage to get a similar trigger efficiency for DD

- Similar discrimination against combinatorial, or at least stay as subdominant w.r.t Ks→ππ misid

- KL background will be slightly larger, but still small (10^{-11} level). See Andrea's talk

- K0 regeneration still unimportant

Then we could (again, a bit optimistically) aim to a ~(15)% gain of effective luminosity by using Downstream Ks

Conclusions

- LHCb trigger wasn't originally designed for Ks
- Large improvements are possible
- We could reach BR's in the 10^{-11} level or below with the upgrade
- Using downstream tracks we may gain a bit, but not an order-of-magnitude factor

Backup

Lifetime acceptance and K_L / Ks lifetime differences

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

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

The decay distributions will look like:

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

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

	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

Lifetime acceptance and K_L / Ks lifetime differences

This also changes the overall efficiency

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

	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