Very rare decay searches at LHCb

Implications of LHCb measurements and future prospects

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Outline

- Introduction
- LHCb very rare decays current searches
  - $B_{d,s} \rightarrow \mu^+\mu^-$
  - $B_{d,s} \rightarrow \mu^+\mu^-\mu^+\mu^-$
  - Searches for Majorana neutrinos in B^- decays
  - $\tau^\pm \rightarrow \mu^+\mu^-\mu^\pm$
  - $K_s \rightarrow \mu^+\mu^-$
- Prospects for other channels
- Conclusions

Introduction

Introduction

- General concept of **very rare decays** in LHCb:
  - Access NP through new virtual particles entering in the loop: **indirect search of NP**, accessing higher energy scales!
  - Very relevant test of SM predictions, for extremely small BR.

- Searches are experimentally similar:
  - **Control channels** used to avoid dependence on simulation.
  - **Geometrical properties** combined in MVA to classify the events.
  - **Use of normalization channels** (with similar geometry/trigger) to convert observed number of events in BR, without use of absolute luminosity.
  - **Blind** analyses (signal region not looked at until the analyses are frozen)
  - Produce results which **constraint the phase space of NP!**

LHCb very rare decays current searches

→ $B_{d,s} \to \mu^+\mu^-$

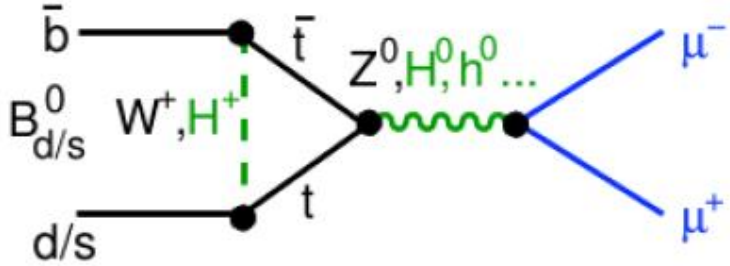
$B_{d,s} \to \mu^+\mu^-$ - Introduction

- $B_{d,s} \to \mu^+\mu^-$ decays are very supressed in the SM:
  - **$BR(B_s \to \mu\mu) = (3.2 \pm 0.2) \times 10^{-9}$**
  - **$BR(B_d \to \mu\mu) = (0.10 \pm 0.01) \times 10^{-9}$**

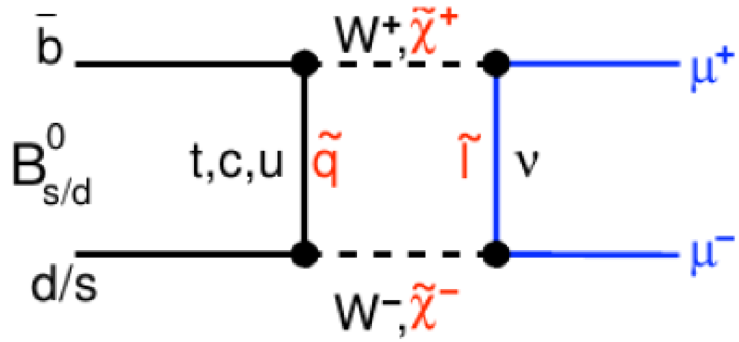
A. J. Buras, M. V. Carlucci, S. Gori, and G. Isidori, JHEP 1010, 2010
A. J. Buras, Phys. Polon. B41, 2010

- They turn out to be, however, very sensitive to scalar and pseudo-scalar operators, so sensitive to NP.

SM, NP

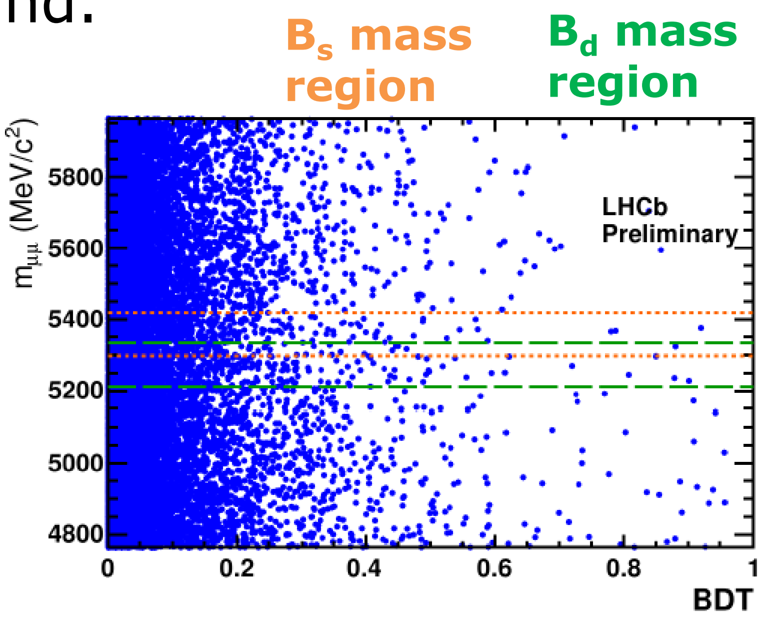


SM, NP



$B_{d,s} \to \mu^+\mu^-$ - Analysis overview

- Selection: apply some cuts on all μμ candidates to remove most of the background.
- Classify each event using two variables (bins in a 2D parameter space):
  - **Geometrical properties** (combined in Boosted Decision Tree)
  - **Invariant Mass**



- Treat each bin as an independent experiment. Results combined using **CL_s method** (Modified Frequentist Approach) see T. Junk NIM A434, 435,1999
- Use of control channels to calibrate and normalize (normalization to $B^+ \to J/\psi K^+$, $B_d \to K\pi$ and $B_s \to J/\psi\Phi$, give compatible results)

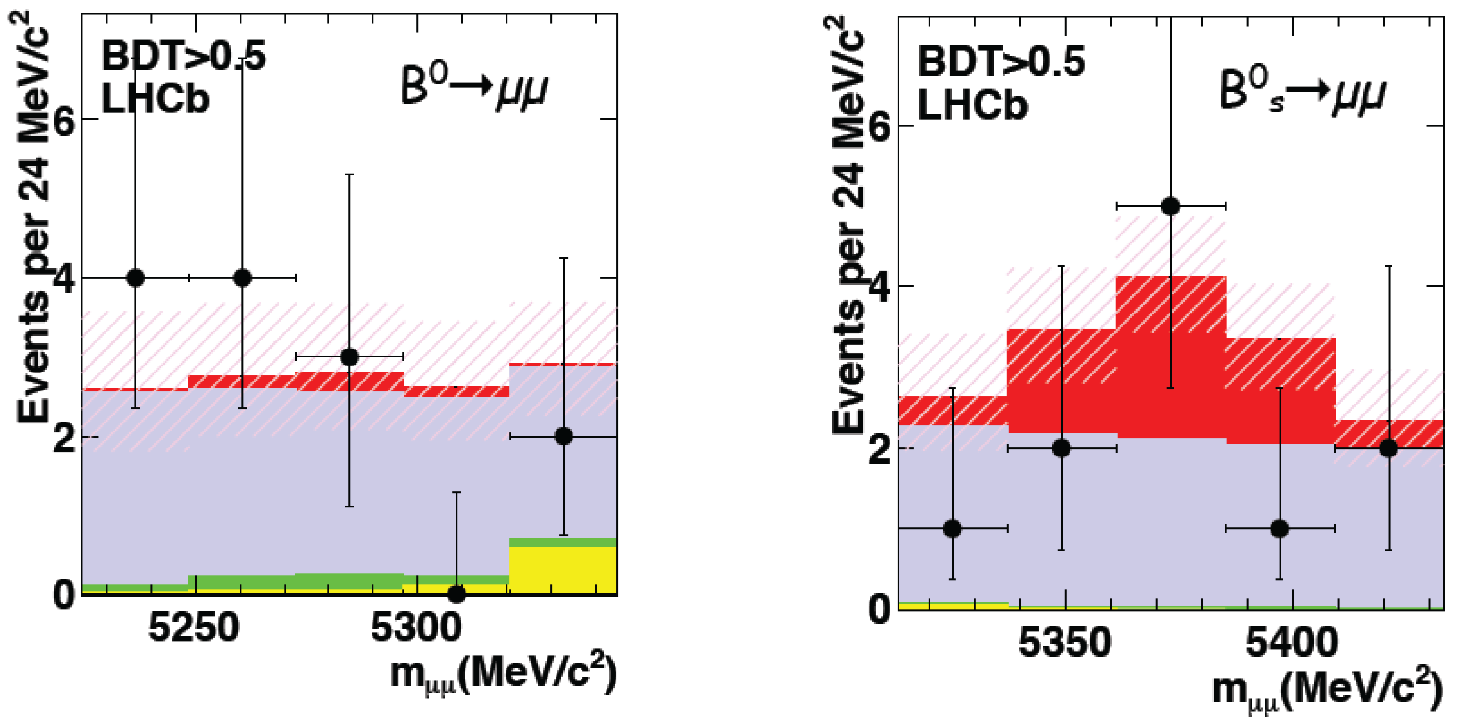
$B_{d,s} \to \mu^+\mu^-$ - Mass projections

- Results in **1 fb^{-1}** consistent with SM

Data

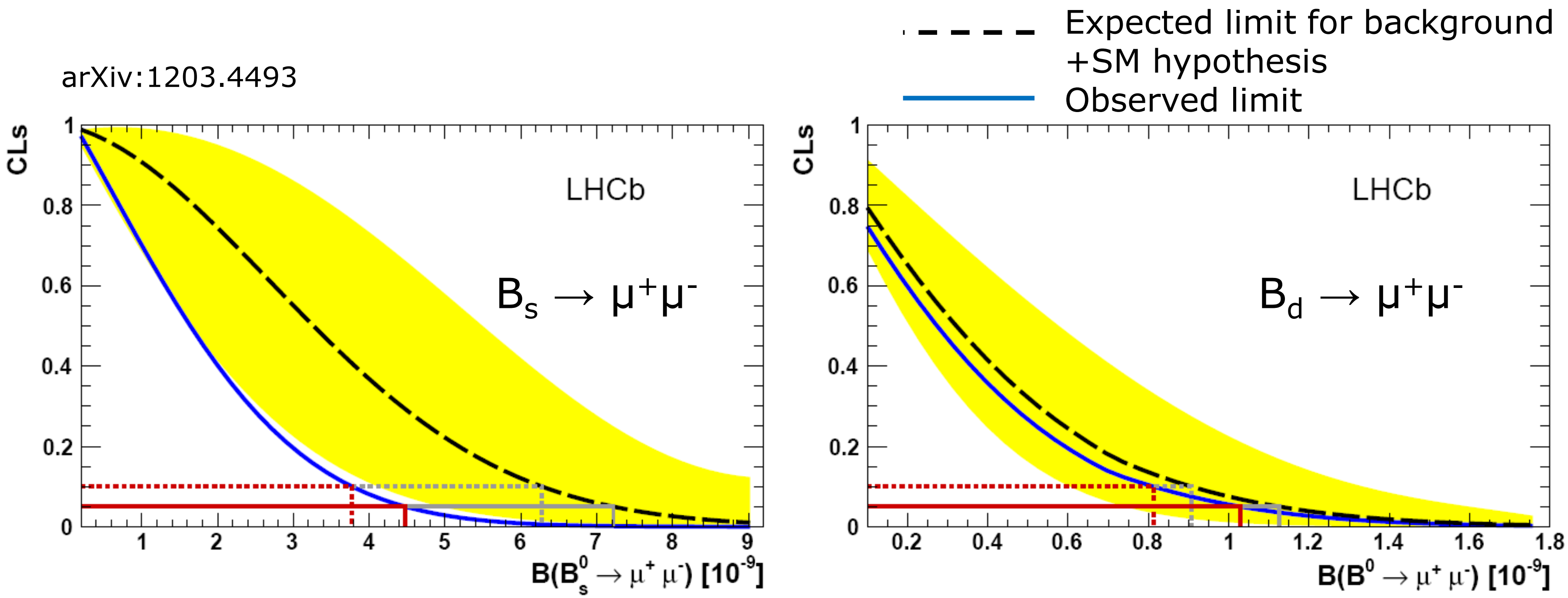
Error in sum of all expected background contributions (hatched area) → SM signal, Combinatorial bkg., $B_{d,s} \to h^+h^-$ misID, Crossfeed between channels

Results in most sensitive region of BDT



$B_{d,s} \rightarrow \mu^+\mu^-$ - Results

arXiv:1203.4493



- Limits **1 fb^{-1}** @ 95% CL (WB)
  - BR($B_s \rightarrow \mu^+\mu^-$) < 4.5 x 10^{-9}
  - BR($B_d \rightarrow \mu^+\mu^-$) < 8.1 x 10^{-10}
- BR($B_s \rightarrow \mu^+\mu^-$) estimate:
  - BR($B_s \rightarrow \mu^+\mu^-$)=($0.8^{+1.8}_{-1.3}$) x 10^{-9}

→ NP could still be there, supressing $B_s \rightarrow \mu^+\mu^-$

→ With the 2012 data, we could be able to find a 3σ evidence if BR($B_s \rightarrow \mu^+\mu^-$) is SM

For the theory implications of the result, see talks by G. Isidori and N. Mahmoudi

LHCb very rare decays current searches

→ $B_{d,s} \rightarrow \mu^+\mu^-\mu^+\mu^-$

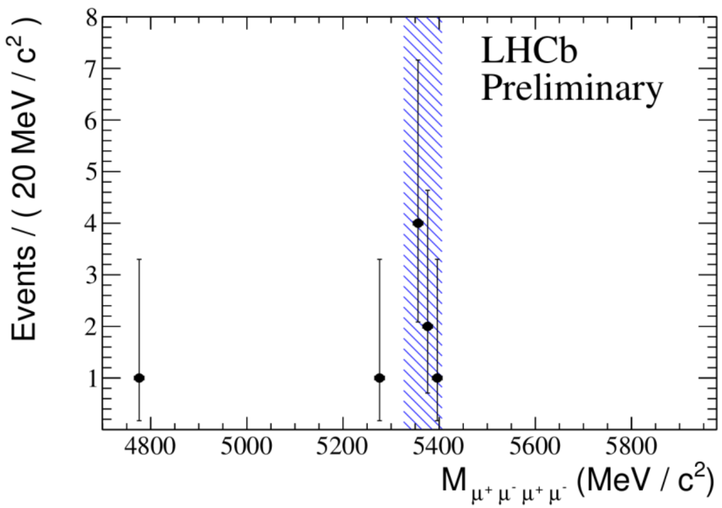
$B_{d,s} \to \mu^+\mu^-\mu^+\mu^-$ - Overview

- SM process: $B_{d,s} \to \mu^+\mu^-\gamma^*$ with $\gamma^* \to \mu^+\mu^-$
  - Non-resonant BR predicted to be 10^{-10} - 10^{-11}

D. Melikhov and N. Nikitin, Phys. Rev. D 70, 114028, (2004)
D. Melikhov, N. Nikitin, and K. Toms, Phys. At. Nucl. 68, 1842 (2005)

- Decay sensitive to NP:
  - eg sGoldstinos ($B_s \to S(\mu^+\mu^-)P(\mu^+\mu^-)$)

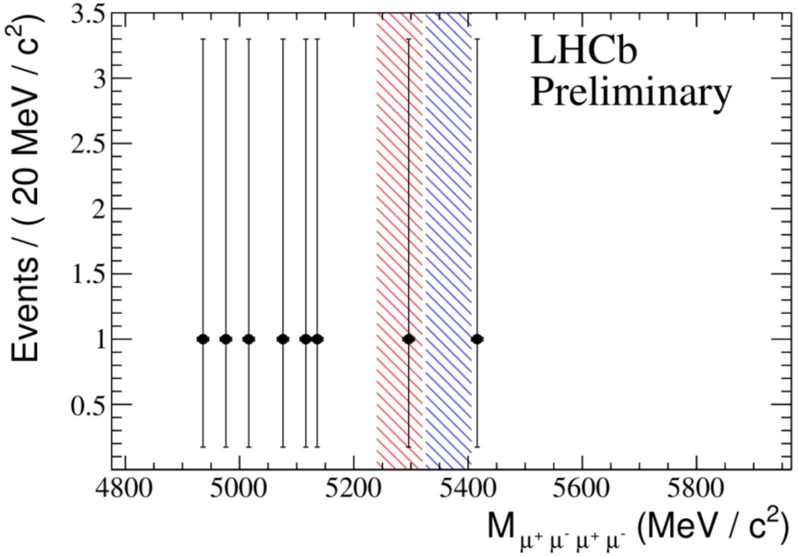
- Resonant decay mode $B_s \to J/\psi(\mu^+\mu^-)\Phi(\mu^+\mu^-)$ with expected BR at the level of $(2.3\pm0.9) \times 10^{-8}$. Observed yield consistent with expectation.



- Cut based analysis, normalization to $B_d \to J/\psi K^*$. Non-resonant peaking backgrounds kept under control

$B_{d,s} \to \mu^+\mu^-\mu^+\mu^-$ - Results

- Number of observed events in 1 fb^{-1} consistent with background expectation



- Set a limit on signal events using the CL_s method (as in $B_s \to \mu^+\mu^-$)

- Limits @ 95% CL (first world limits on these decays)

LHCb preliminary, 1 fb^{-1}

  - $BR(B_s \to \mu^+\mu^-\mu^+\mu^-) < 1.3 \times 10^{-8}$
  - $BR(B_d \to \mu^+\mu^-\mu^+\mu^-) < 5.4 \times 10^{-9}$

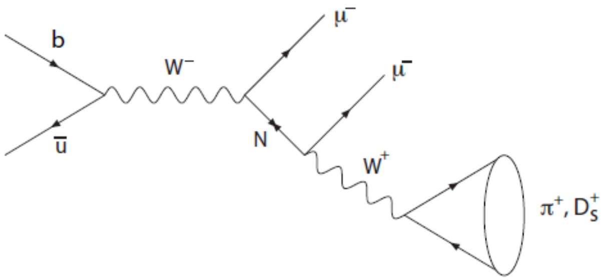
LHCb-CONF-2012-010

LHCb very rare decays current searches

→ **Searches for Majorana neutrinos in B^- decays**

Searches for Majorana neutrinos in B^- decays

- $B^- \to D^+\mu^-\mu^-$ and $B^- \to D^{*+}\mu^-\mu^-$ can arise from the presence of virtual Majorana neutrinos of any mass. Other states containing π^+, D^+_s , or $D^0\pi^+$ can be mediated by an on-shell Majorana neutrino

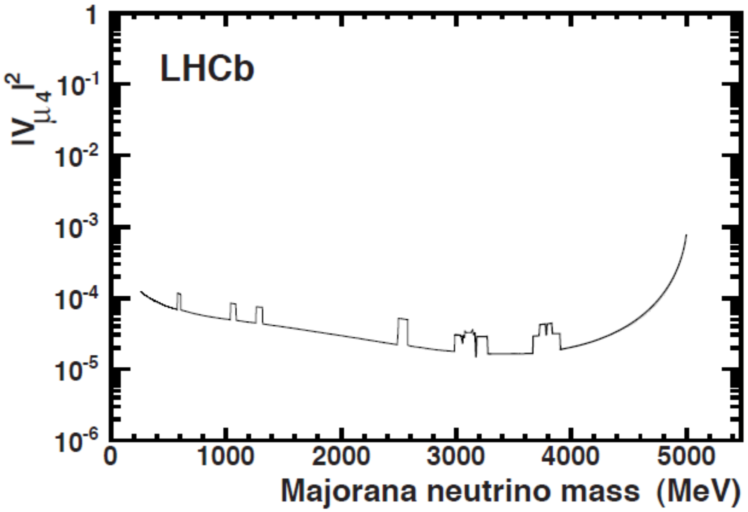


e.g. Majorana neutrino mediated $B^- \to \pi^+(D_s^+)\mu^-\mu^-$

- No signal found in the searched channels in 0.41 fb^{-1}

LHCb-PAPER-2011-038

- $B^- \to \pi^+\mu^-\mu^-$ has been used to establish neutrino mass dependent upper limits on the coupling $|V_{\mu 4}|$ of a heavy Majorana neutrino to a muon and a virtual W.

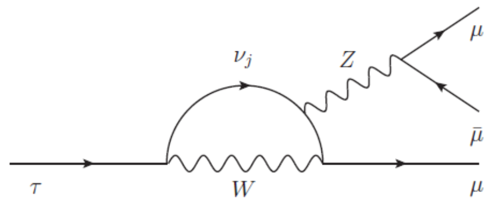


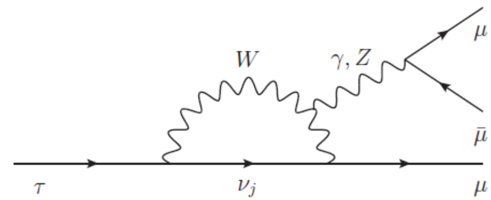
LHCb very rare decays current searches

→ $\tau^{\pm} \rightarrow \mu^{+}\mu^{-}\mu^{\pm}$

$\tau^{\pm} \to \mu^{+}\mu^{-}\mu^{\pm}$
Theory interest

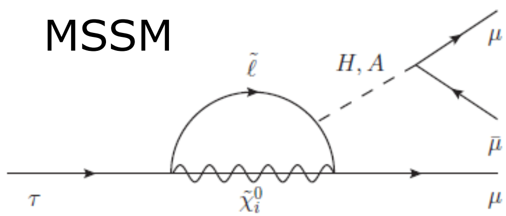
- Decay extremely supressed in SM BR ~ 10^{-40}



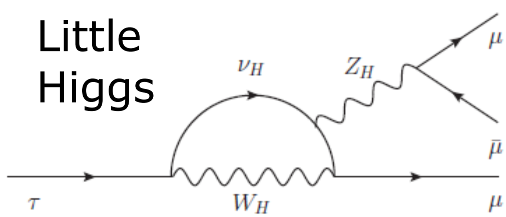


- But very enhanced by several NP models

MSSM



Little Higgs



Model, processes	$\mathcal{B}(\tau^- \to \mu^+\mu^-\mu^-)$
Unparticles	$10^{-3} - 10^{-11}$
Neutral SUSY Higgs	$< 10^{-7}$
Littlest Higgs with T-Parity	$< 10^{-8}$
Non universal gauge interaction	$< 10^{-8}$
mSUGRA + seesaw	$< 10^{-9}$
SUSY + seesaw (Higgs mediated)	$< 10^{-10}$
SUSY SO(10) + seesaw	$< 10^{-10}$
SM + heavy Majorana neutrino	$< 10^{-10}$
SM + neutrino oscillations	$< 10^{-40}$

see talk by S. Davidson

$\tau^\pm \to \mu^+\mu^-\mu^\pm$ Experimental status

- Current limits (@ 90% CL)
  - BaBar $BR(\tau^\pm \to \mu^+\mu^-\mu^\pm) < 3.3 \times 10^{-8}$
  - Belle $BR(\tau^\pm \to \mu^+\mu^-\mu^\pm) < 2.1 \times 10^{-8}$

* Extrapolating from these results, a future super B factory (SuperB or SuperKEKB) is expected to reach a sensitivity of

$$BR(\tau^\pm \to \mu^+\mu^-\mu^\pm) \sim 10^{-9} - 10^{-10} \text{ with } 75\ ab^{-1}$$

B. Meadows et al., arXiv:1109.5028

$\tau^{\pm} \rightarrow \mu^{+}\mu^{-}\mu^{\pm}$
Analysis strategy

- Initial loose selection
- Discriminate signal from background in bins of 3 distributions:
  - Likelihoods from geometrical variables
  - Likelihoods from muon PID variables
  - 3μ invariant mass
- Calibrate the 3 likelihoods on data
- Background estimation from mass sidebands
  - Specific backgrounds also considered
- Relative normalization with $D_s \rightarrow \phi(\mu\mu)\pi$
- Blind analysis

⟶ Competitive sensitivity can be reached very soon

LHCb very rare decays current searches

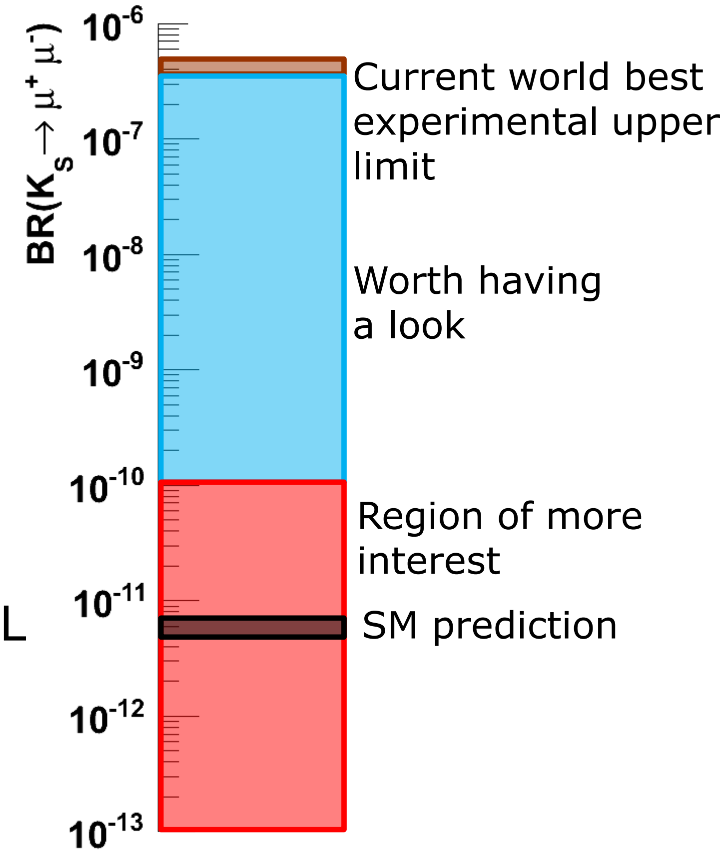
→ $K_s \rightarrow \mu^+\mu^-$

$K_s \rightarrow \mu^+\mu^-$ - Introduction

- FCNC, with SM BR predicted,
  - $BR(K_s \rightarrow \mu^+\mu^-) \sim 5 \times 10^{-12}$ (±30%)

    G. Ecker, A. Pich, Nuclear Physics B 366 (1991)
    G. Isidori, R. Unterdorfer, JHEP 0401 (2004)

  - Probe CP violating phase in $s \rightarrow dl^+l^-$ amplitude
  - Interesting region for NP: BR below $10^{-10,-11}$

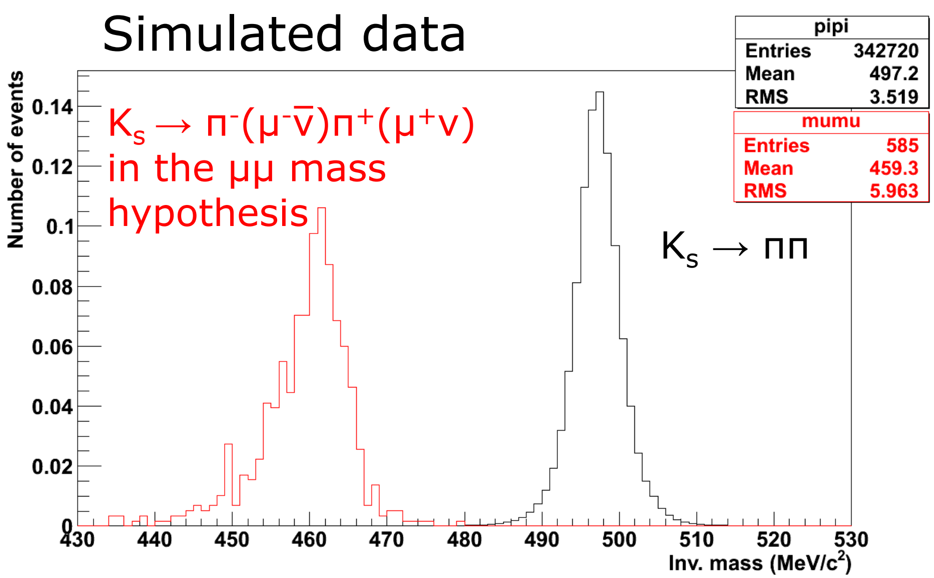


- Experimental status: current limit from 1973!
  - $BR(K_s \rightarrow \mu^+\mu^-) < 3.2 \times 10^{-7}$ @ 90% CL

    S. Gjesdal, J. Steinberger et al, Physics Letters B, 44 (1973)

$K_s \to \mu^+\mu^-$ - Analysis strategy

- Use $\mathbf{K_s^0 \to \pi^+\pi^-}$ to calibrate and normalize.
  - Use same geometrical selection for both channels
- Build geometrical BDT and classify events in 2D space.
- Assess possible backgrounds:
  - Combinatorial, extrapolate from sidebands
  - $K_s^0 \to \pi^-(\mu^-\bar{\nu})\pi^+(\mu^+\nu)$
  - Physical: $K_s \to \pi^+\mu^-\nu$, $K_L \to \mu^-\mu^+$



- Combine results using CL_s method

  ⟶ With 1 fb^{-1}, expected upper limit in the range 10^{-8} - 10^{-9}

Prospects for other channels

Prospects for other channels

- $B_{d,s} \to \mu^+\mu^-\gamma$
  - Sensitivity to NP not clear to us, regardless of its SM BR.
  - The mode is accesible experimentally, but more challenging than $B_s \to \mu^+\mu^-$

See next talk by A. Petrov

- $B_{d,s} \to J/\psi\gamma$
  - Similar situation to $B_{d,s} \to \mu^+\mu^-\gamma$. LHCb could measure the BR, depending on its actual value

- $B_{d,s} \to e\mu$
  - Studies of this decay ongoing, world best limit should be in reach with 1 fb^{-1}

- $B_{d,s} \to \tau\tau$
  - Also preliminary work done. Experimentally not easy, because of difficult reconstruction of τ

Conclusions

Conclusions

- **Very rare decays** are a very relevant indirect search for NP.
  - These decays are a strong point of LHCb! Several searches performed, with the advantage of being similar from an experimental point of view.

- New results presented in $B_{d,s} \to \mu^+\mu^-$, $B_{d,s} \to \mu^+\mu^-\mu^+\mu^-$ and Majorana neutrinos search. Very important constraint to NP phase space, in particular from $B_{d,s} \to \mu^+\mu^-$, where a world best upper limit on the BR has been set!

- New results soon:
  - $\tau^\pm \to \mu^+\mu^-\mu^\pm$
  - $K_s \to \mu^+\mu^-$

And more to come…