Search for New Physics with rare leptonic decays of $B_{(s)}$ and D mesons

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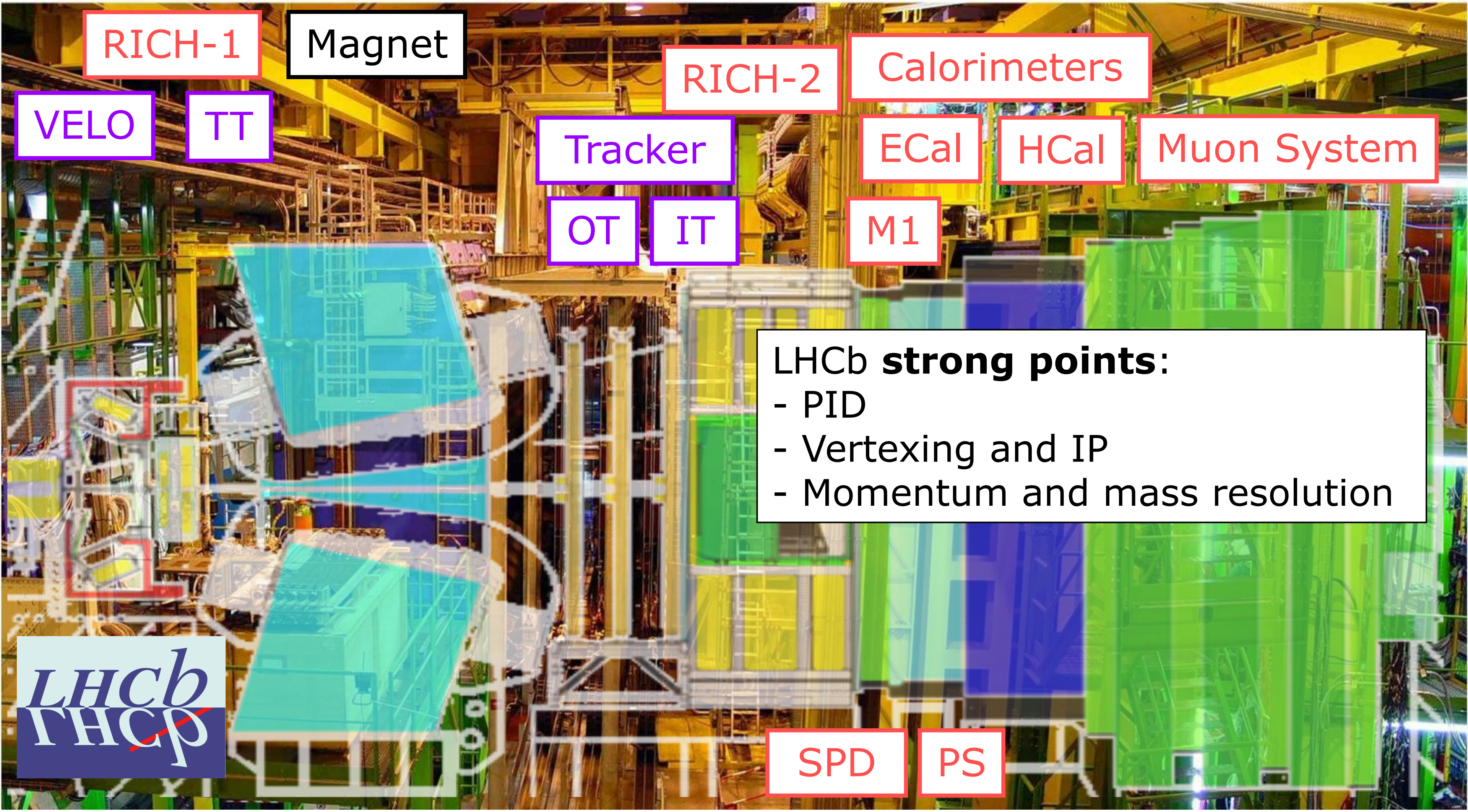
LHCb

Outline

- Introduction
- LHCb rare leptonic decays results
  - $B_{d,s} \rightarrow \mu^+\mu^-$
  - $B_{d,s} \rightarrow \mu^+\mu^-\mu^+\mu^-$
  - Searches for Majorana neutrinos in $B^{\pm}$ decays
  - $D^0 \rightarrow \mu^+\mu^-$
- Conclusions

Introduction

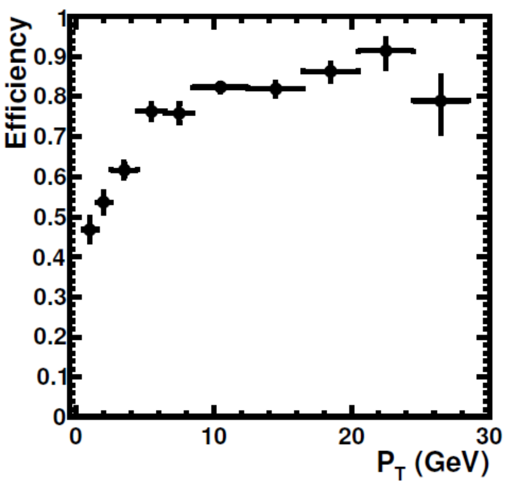
LHCb overview



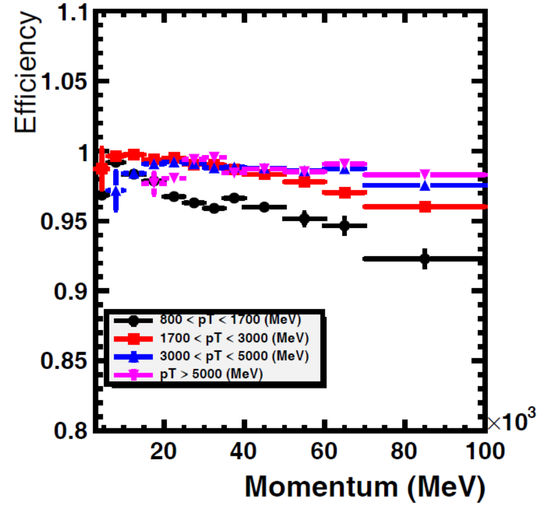
LHCb **strong points**:
- PID
- Vertexing and IP
- Momentum and mass resolution

LHCb overview

Experiment **well tuned for muons**!



Trigger efficiency vs p_T
Total efficiency on offline selected $B_s \to \mu^+\mu^-$, ~91%!



MuonID efficiency vs p/p_T
Total efficiency on $B_s \to \mu^+\mu^-$, ~92%!

Introduction

- General concept of **rare leptonic leptonic 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.
  - **Use of normalization channels** (with similar geometry/trigger) to convert observed number of events in BR, reduces systematic errors!
  - **Geometrical properties** combined in MVA to classify the events.
  - Good **particle ID (muon)** and **low pion/kaon misID** needed!
  - **Blind** analyses (signal region not looked at until the analyses are frozen)

LHCb rare leptonic decays results

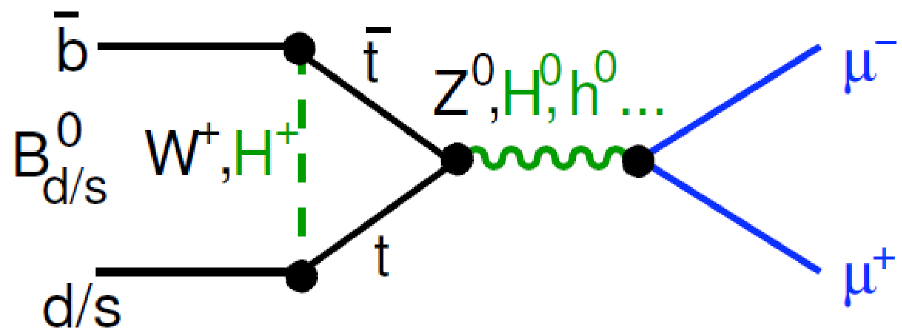
$B_{d,s} \rightarrow \mu^+\mu^-$ - Introduction

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

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

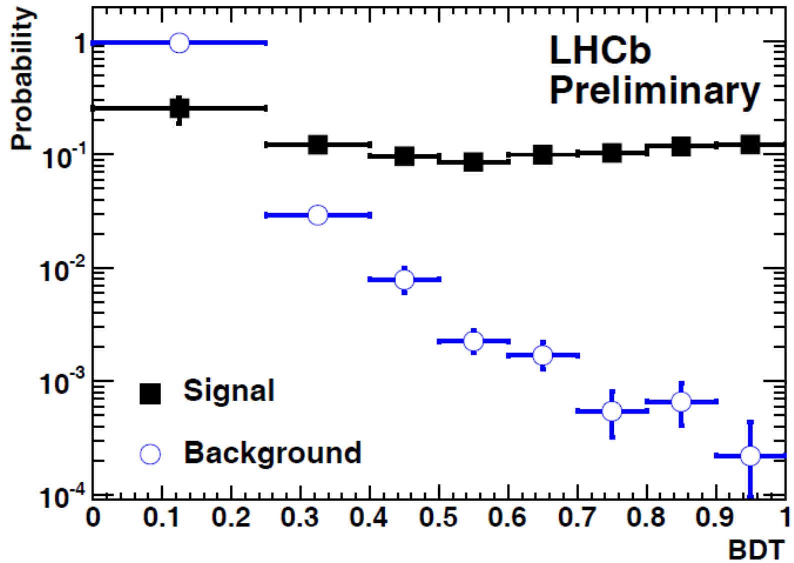
- They turn out to be, however, very sensitive to scalar and pseudo-scalar operators, so sensitive to NP.

SM, NP



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

- 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):
  - **Invariant Mass**
  - **Geometrical properties** (combined in Boosted Decision Tree)
    - **Separation** of the candidate and daughters **from the primary vertex**
    - **Isolation** of the candidate and daughters
    - $\mathbf{p_T}$ of the candidate and daughters
    - **Quality** of the **B vertex**



- BDT trained with MC, estimated with data:
  - Signal, B→hh trigger unbias
  - Background: $B_{d,s}$→μμ sidebands
- Signal uniformly distributed, background peaking at 0

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

- Treat each bin in 2D space (mass, BDT) 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: signal BDT with $B \to hh$, mass resolution with dimuon resonances (J/ψ, $\psi(2S)$, Υ), muonID and trigger efficiencies with $B^+ \to J/\psi K^+$, …
  - and normalize: $B^+ \to J/\psi K^+$, $B_d \to K\pi$ and $B_s \to J/\psi \Phi$, give compatible results)

$$\mathcal{B} = \mathcal{B}_{\rm norm} \times \frac{\epsilon_{\rm norm}}{\epsilon_{\rm sig}} \times \frac{f_{\rm norm}}{f_{d(s)}} \times \frac{N_{B^0_{(s)} \to \mu^+\mu^-}}{N_{\rm norm}}$$
$$= \alpha^{\rm norm}_{B^0_{(s)} \to \mu^+\mu^-} \times N_{B^0_{(s)} \to \mu^+\mu^-},$$

	$\alpha^{cal}_{B_d \to \mu^+\mu^-}$ $(\times 10^{-11})$	$\alpha^{cal}_{B_s \to \mu^+\mu^-}$ $(\times 10^{-10})$
$B^+ \to J/\psi K^+$	8.464 ± 0.433	3.170 ± 0.297
$B^0_s \to J/\psi \phi$	11.13 ± 3.124	4.169 ± 1.123
$B^0 \to K^+\pi^-$	7.709 ± 0.957	2.887 ± 0.424

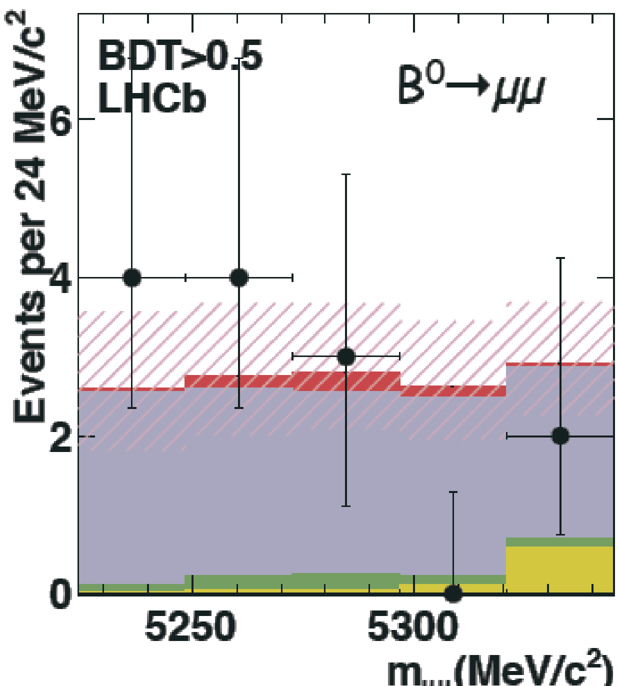
$B_{d,s} \rightarrow \mu^+\mu^-$ - Mass projections

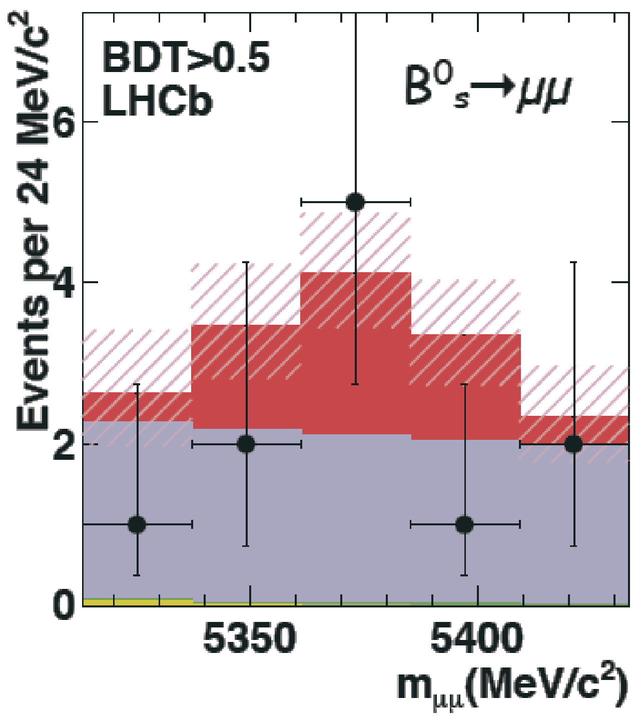
- Results in **1 fb^{-1}** consistent with SM

Data

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

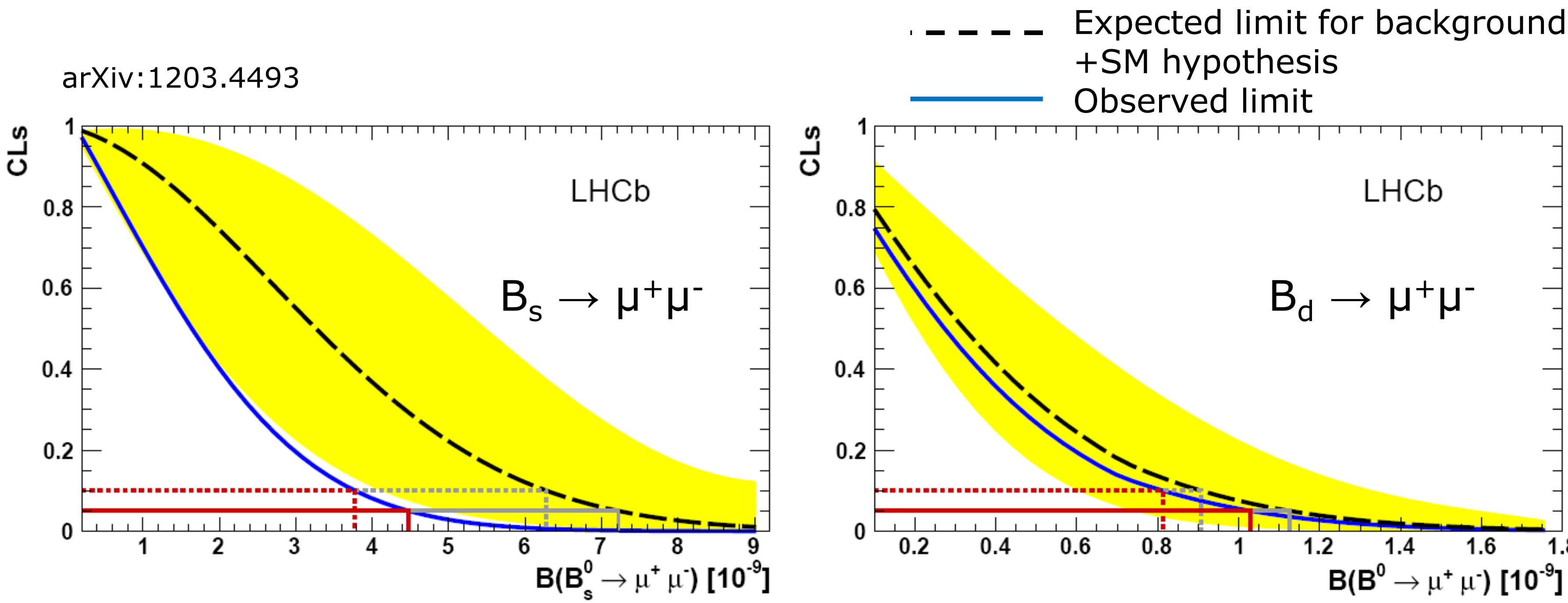
Results in most sensitive region of BDT





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

arXiv:1203.4493

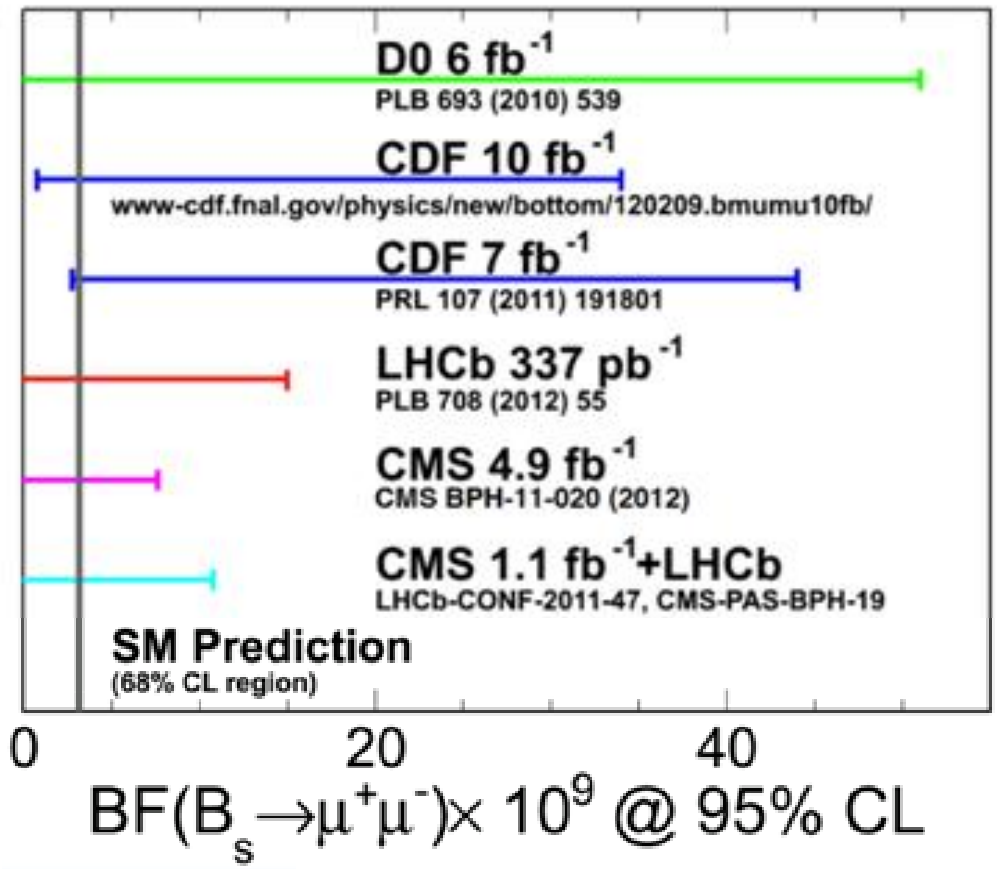


- Limits **1 fb^{-1}** @ 95% CL (WB)
  - BR($B_s \rightarrow \mu^+\mu^-$) < 4.5 x 10^{-9}
  - BR($B_d \rightarrow \mu^+\mu^-$) < 1.0 x 10^{-9}

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

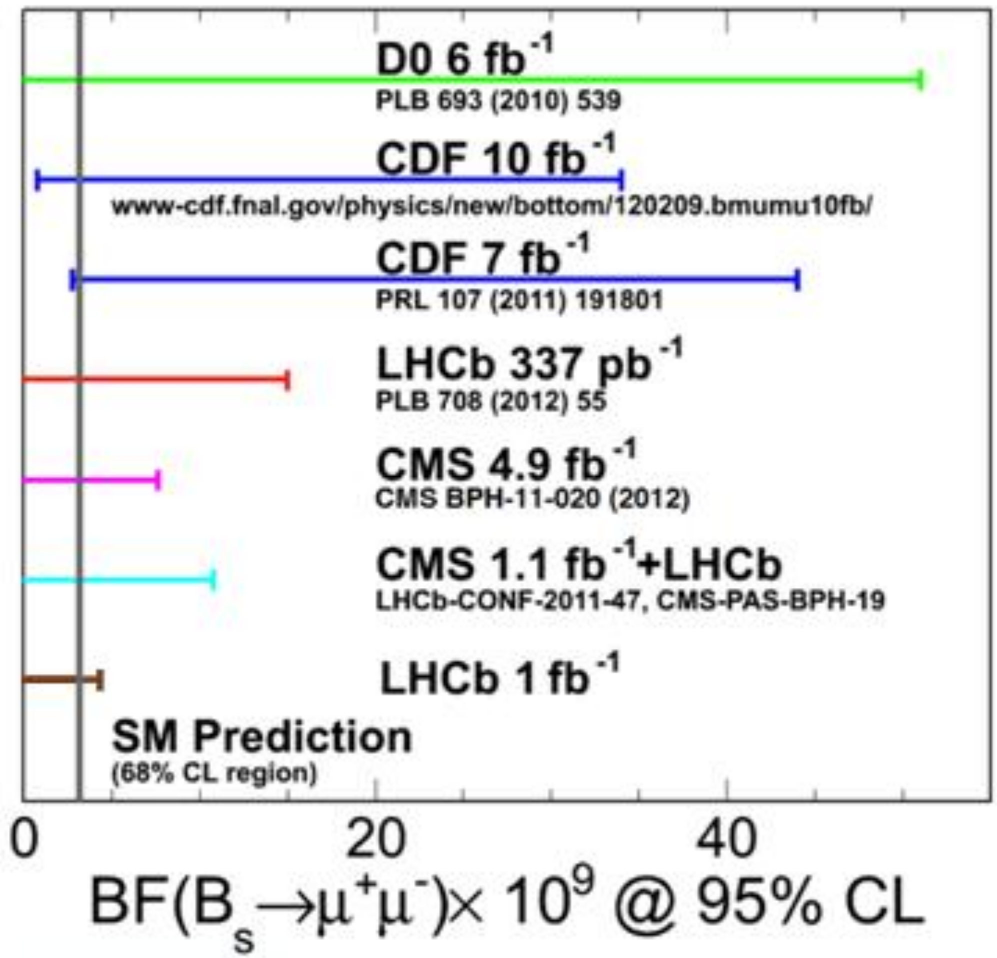
- BR($B_s \rightarrow \mu^+\mu^-$) estimate:
  - BR($B_s \rightarrow \mu^+\mu^-$)=($0.8^{+1.8}_{-1.3}$) x 10^{-9}

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



Adapted from
H. Miyake, La Thuile,
29 Feb 2012

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



Adapted from
H. Miyake, La Thuile,
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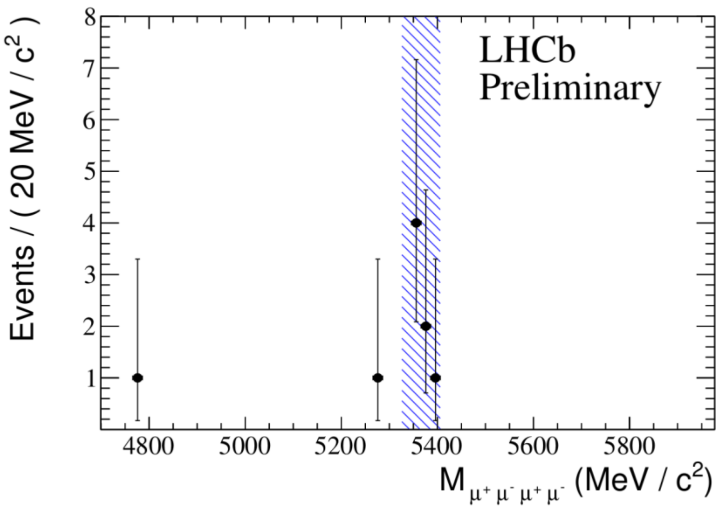
$B_{d,s} \rightarrow \mu^+\mu^-\mu^+\mu^-$ - Overview

- B to four muons decays are strongly suppressed in the SM.
  - Largest contribution from $B_s \rightarrow J/\psi(\mu^+\mu^-)\Phi(\mu^+\mu^-)$ with expected BR at the level of $(2.3\pm0.9) \times 10^{-8}$. Observed yield consistent with expectation.



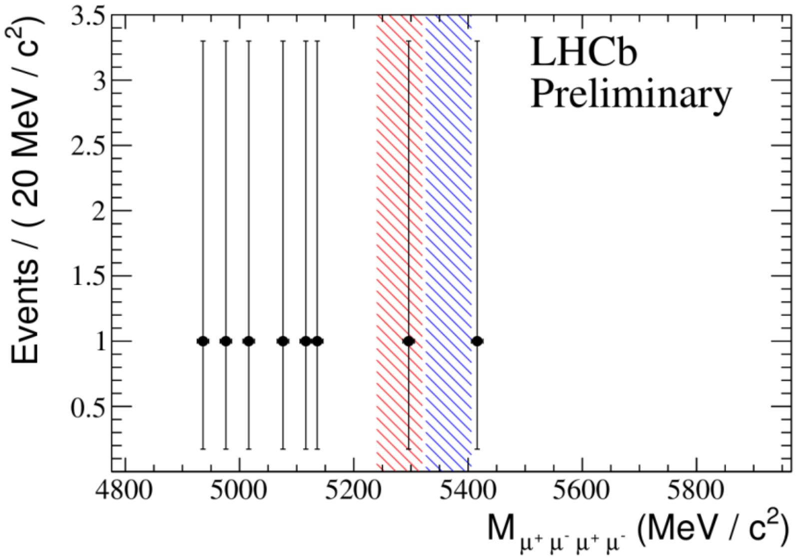
- **Non resonant process** also possible in SM: $B_{d,s} \rightarrow \mu^+\mu^-\gamma^*$ with $\gamma^* \rightarrow \mu^+\mu^-$
  - BR predicted to be 10^{-10} - 10^{-11}

D. Melikhov and N. Nikitin, Phys. Rev. D 70,
D. Melikhov, et al., Phys. At. Nucl. 68

  - Decay sensitive to NP, e.g., sGoldstinos ($B_s \rightarrow S(\mu^+\mu^-)P(\mu^+\mu^-)$)
- Cut based analysis:
  - Vetos in the J/ψ and Φ mass. PID. Separation between B vertex and primary vertices. Quality of B vertex.
  - Normalization to $B_d \rightarrow J/\psi K^*$

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

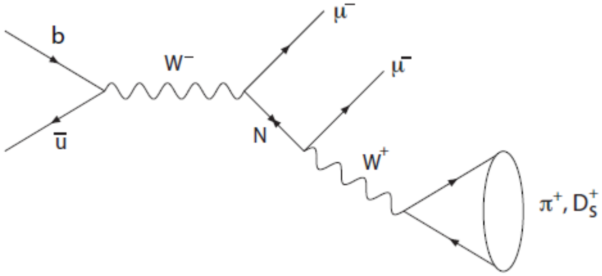
LHCb preliminary, 1 fb^{-1}

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

LHCb-CONF-2012-010

Searches for Majorana neutrinos in $B^\pm$ decays

- $B^- \rightarrow D^+\mu^-\mu^-$ and $B^+ \rightarrow D^{*+}\mu^-\mu^-$ 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

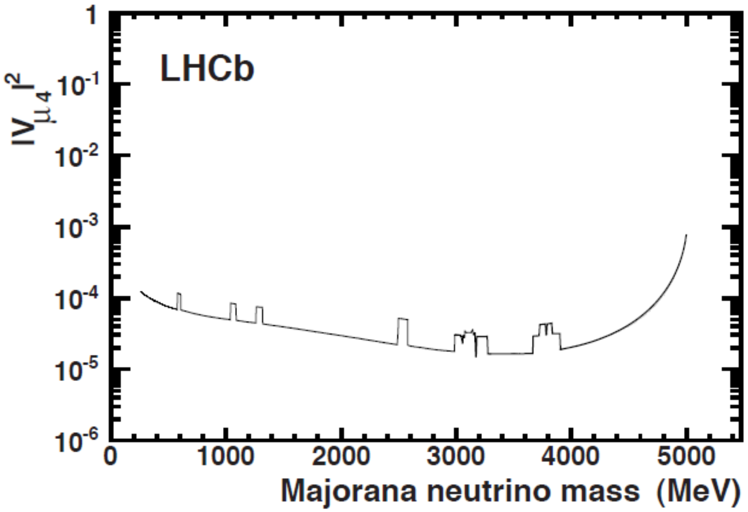


e.g. Majorana neutrino mediated $B^- \rightarrow \pi^+(D_s^+)\mu^-\mu^-$

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

arXiv:1201.5600

- $B^- \rightarrow \pi^+\mu^-\mu^-$ 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.



$D^0 \to \mu^+\mu^-$ - Introduction

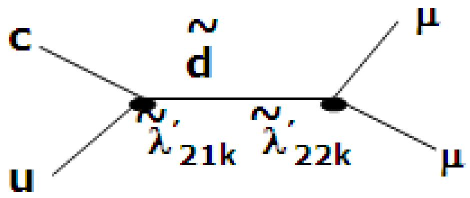
- In the SM, BF dominated by Long Distance contributions:

G. Burdman et al. arXiv:hep-ph/0112235

$$\mathcal{B}(D^0 \to \mu^+\mu^-) \simeq 2.7 \times 10^{-5} \mathcal{B}(D^0 \to \gamma\gamma)$$

$$\to \mathcal{B}(D^0 \to \mu^+\mu^-) \gtrsim 10^{-13}$$

- But enhancement likely in several NP models:
  - e.g. BR~10^{-9} with RPV-SUSY tree level transitions



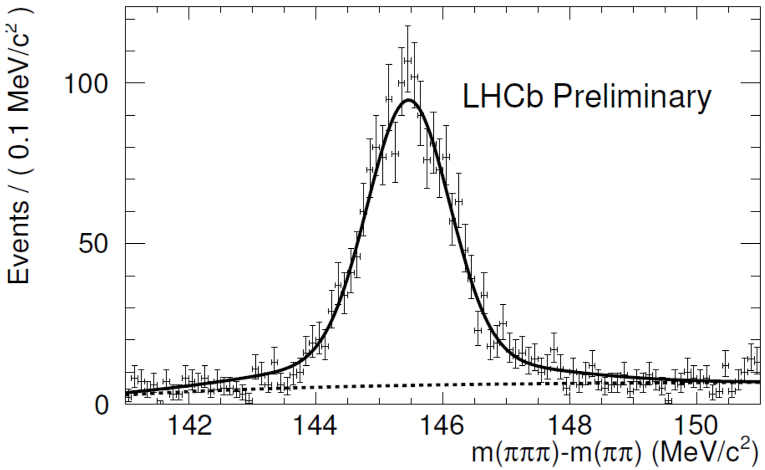
- Best experimental upper limit up to now by Belle, with 660 fb^{-1}, at 90% CL

$$\mathcal{B}\left(D^0 \to \mu^+\mu^-\right) < 1.4 \times 10^{-7}$$

Petric & al, arXiv:1003.2345

$D^0 \to \mu^+\mu^-$ - Analysis overview

- Normalization to $D^0 \to \pi^+\pi^-$
- Low π-μ misID rate(<1%)
  - Keep $D^0 \to \pi^+\pi^-$ double misID low although $B(\pi\pi)/B(\mu\mu)>10^5$
- Large X-sections: $\sigma(D^{*+})=(676 \pm 137)$ μb LHCb-CONF-2010-013
  - Can use D* and still have large yields

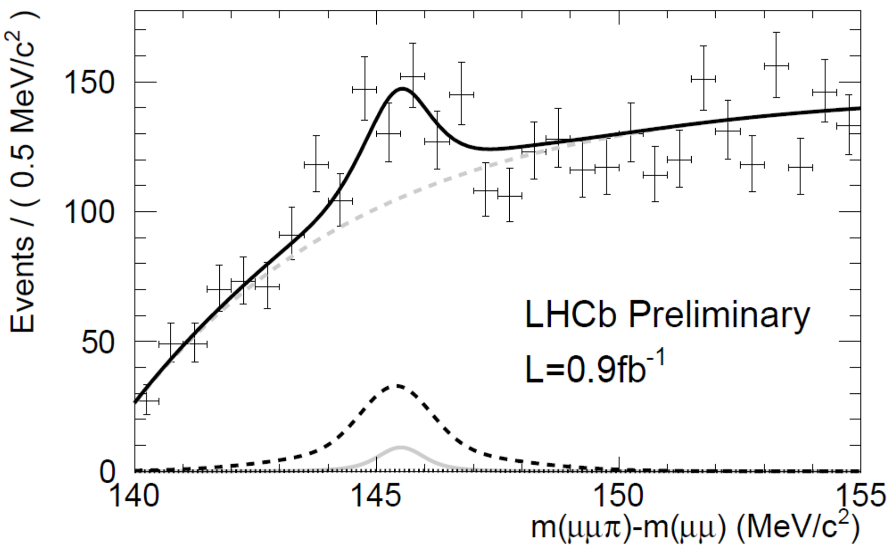


D^*- D^0 mass difference in $D^0 \to \pi^+\pi^-$ (used for normalization)

- Easy to have large control samples: D→Kπ for (efficiency and misID rate), J/Ψ(μμ) (trigger and muID efficiency).

$D^0 \to \mu^+\mu^-$ - Results

- Fit with 0.9 fb^{-1} done with different components
  - Comb. background: Reduced by Boosted Decay Tree (p_T + topology). – – –
  - Peaking backgrounds ($D^0 \to \pi^+\pi^-$) – – –
  - "μμ signal" ——— (compatible with 0)



- Observed number of events compatible with background:
  - Limit set using again CL_s method

LHCb preliminary, 0.9 fb^{-1}

$BR(D^0 \to \mu^+\mu^-) < 1.3 \times 10^{-8}$, at 95% CL

LHCb-CONF-2012-005

  - Factor 10 better than Belle
  - Expect 90% CL limit around 5×10^{-9} in the coming years.

Conclusions

Conclusions

- **Rare leptonic 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 $B_{d,s} \rightarrow \mu^+\mu^-$, $B_{d,s} \rightarrow \mu^+\mu^-\mu^+\mu^-$, Majorana neutrinos search and $D^0 \rightarrow \mu^+\mu^-$. Very important constraint to NP phase space, in particular from $B_{d,s} \rightarrow \mu^+\mu^-$. Chance to see a 3σ evidence in 2012 for a SM BR.

And more exciting results to come…!

Thank you!