Searches for New Physics with LHCb

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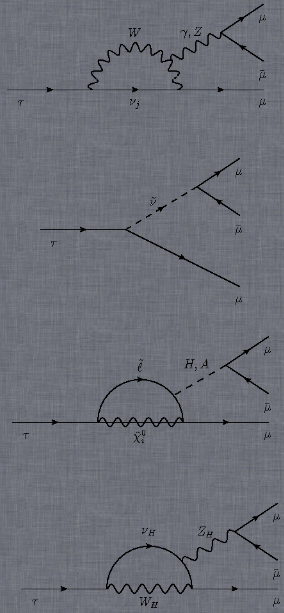
on behalf of LHCb collaboration

29th May 2014



LHCb detector

Lepton Flavour Violation

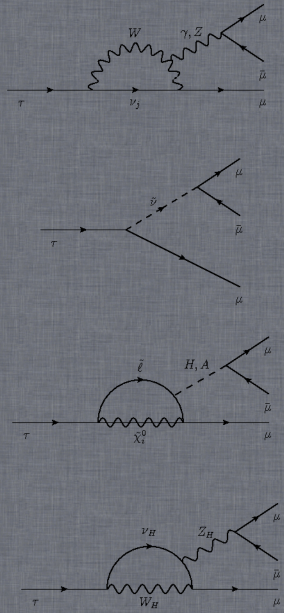
B decays

$\mathrm{B}^- \to h^+ \ell^- \ell^-$

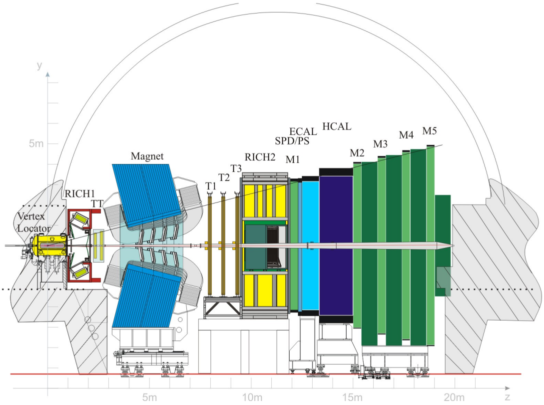
$\mathrm{B} \to \ell^+ \ell^-$

τ decays

$\tau^- \to \mu^- \mu^- \mu^+$



LHCb detector



1. LHCb is a forward spectrometer:
   - Excellent vertex resolution.
   - Efficient trigger.
   - High acceptance for τ and B.
   - Great Particle ID.

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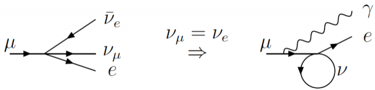
Lepton Flavour/Number Violation

Lepton Flavour Violation(LFV):

After μ^- was discovered it was logical to think of it as an excited e^-.

- Expected: $B(\mu \to e\gamma) \approx 10^{-4}$
- Unless another ν, in intermediate vector boson loop cancels.

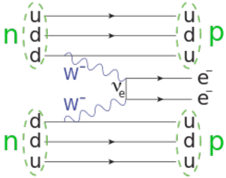


I.I.Rabi:
"Who ordered that?"

- Up to this day charged LFV is being searched for in various decay modes.
- LFV was already found in neutrino sector.

Lepton Number Violation (LNV)

- Even with LFV, lepton number is a conserved quantity.
- Many new thesis predict it violation(Majorana neutrinos)
- Searched in so called Neutrinoless double β decays.



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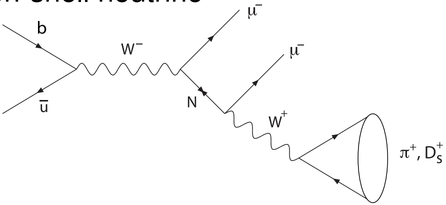
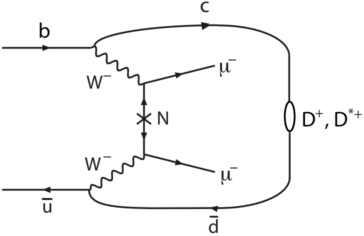
LNV in bottom decays

on-shell neutrino



virtual neutrino



- resonant production in accessible mass range
- rates depend on Majorana neutrino–lepton coupling $|V_{\mu 4}|$ (e.g. arXiv:0901.3589)
- $m_4 = m_{\ell^-,\pi^+}$

Special for B decays

Diagram without mass restriction
Cabbibo favoured for $\mathrm{B} \to \mathrm{D}$
Analogous to double β decay.

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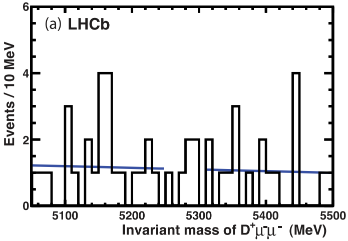
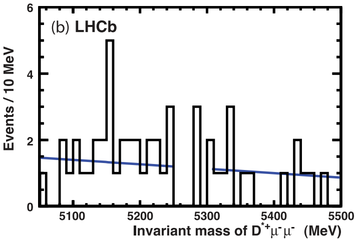
Virtual Majorana neutrinos

$B^- \to D^+ \mu^- \mu^-$



$B^- \to D^{*+} \mu^- \mu^-$



$\mathcal{B}(B^- \to D^+ \mu^- \mu^-) < 6.9 \times 10^{-7}$
@ 95 % CL
Based on 0.41 fb^{-1} 7 TeV data.

$\mathcal{B}(B^- \to D^{*+} \mu^- \mu^-) < 2.4 \times 10^{-6}$
@ 95 % CL

Phys. Rev.D85 (2012) 112004

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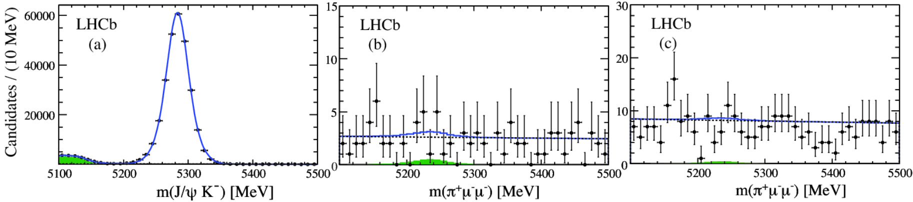
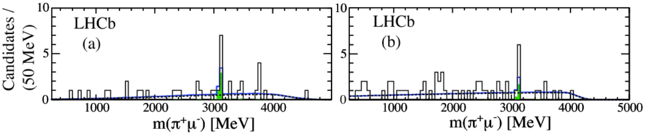
On-shell Majorana neutrinos

- Based on full data set $3fb^{1}$.
- Cut based analysis.
- Normalization channel $\mathrm{B}^+ \to \mathrm{J}/\psi(\mu\mu)\mathrm{K}^+$.
- Searched performed for two scenarios:
  - Short life-time neutrinos: $\tau_4 < 1ps$
  - Long life-time neutrinos: $\tau_4 \in (1, 1000)ps$





Phys. Rev. Lett. 112, 131802

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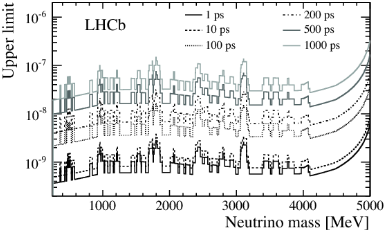
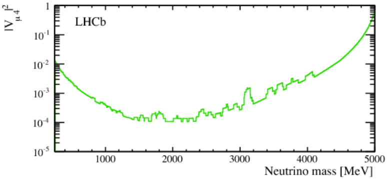
On-shell Majorana neutrinos





- In absence of signal UL. were set.
- $Br(\mathrm{B}^- \to \pi^+\mu^-\mu^-)$ in range 10^{-9}.
- Limits also set for the coupling $|V_{\mu 4}|^2$

$$Br(\mathrm{B}^- \to \pi^+\mu^-\mu^-) = \frac{G_f^4 f_B^2 f_\pi^2}{128\pi\hbar}\tau_B m_B^5 |V_{ub}V_{ud}|^2 |V_{\mu 4}|^4 (1 - \frac{m_4^2}{m_B^2})\frac{m_4}{\Gamma_{N_4}}$$

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Summary on LNV in B decays

channel	limit		
$\mathcal{B}(B^- \to \pi^+ e^- e^-)$	$< 2.3 \times 10^{-8}$	@90 % CL	[a]
$\mathcal{B}(B^- \to K^+ e^- e^-)$	$< 3.0 \times 10^{-8}$	@90 % CL	[a]
$\mathcal{B}(B^- \to K^{*+} e^- e^-)$	$< 2.8 \times 10^{-6}$	@90 % CL	[b]
$\mathcal{B}(B^- \to \rho^+ e^- e^-)$	$< 2.6 \times 10^{-6}$	@90 % CL	[b]
$\mathcal{B}(B^- \to D^+ e^- e^-)$	$< 2.6 \times 10^{-6}$	@90 % CL	[c]
$\mathcal{B}(B^- \to D^+ e^- \mu^-)$	$< 1.8 \times 10^{-6}$	@90 % CL	[c]
$\mathcal{B}(B^- \to \pi^+ \mu^- \mu^-)$	$< 1.3 \times 10^{-8}$	@95 % CL	[d]
$\mathcal{B}(B^- \to K^+ \mu^- \mu^-)$	$< 5.4 \times 10^{-7}$	@95 % CL	[e]
$\mathcal{B}(B^- \to D^+ \mu^- \mu^-)$	$< 6.9 \times 10^{-7}$	@95 % CL	[d]
$\mathcal{B}(B^- \to D^{*+} \mu^- \mu^-)$	$< 2.4 \times 10^{-6}$	@95 % CL	[d]
$\mathcal{B}(B^- \to {D_s}^+ \mu^- \mu^-)$	$< 5.8 \times 10^{-7}$	@95 % CL	[d]
$\mathcal{B}(B^- \to D^0 \pi^- \mu^- \mu^-)$	$< 1.5 \times 10^{-6}$	@95 % CL	[d]

[a] BaBar, Phys. Rev. D **85**, 071103 (2012)
[b] CLEO, Phys. Rev. D **65**, 111102 (2002)
[c] Belle, Phys. Rev. D **84**, 071106(R), (2011)
[d] LHCb, CERN-PH-EP-2012-006, `arXiv:1201.5600` (2012)
[e] LHCb, Phys. Rev. Lett. 108 101601 (2012)

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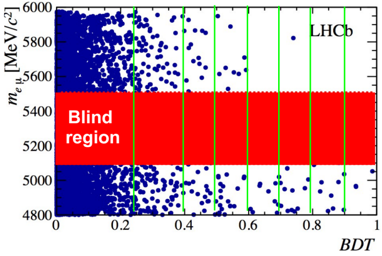
$\mathrm{B} \to \ell^+\ell^-$ 1

- A separate physics interest are LFV B decays.
- Predicted by various NP models: lepto-quarks, SUSY, GUT.
- Analysis based on $1 fb^{-1}$ 2011 data.
- Analogues to our $\mathrm{B}^0_s \to \mu\mu$ analysis(Phys. Rev. Lett. 110, 021801 (2013))



1. Loose reselection based on topology and PID.
2. Classifier trained on MC signal and $b\bar{b} \to \ell\ell X$
3. Calibration channel: $\mathrm{B}^0{}_{(s)} \to h^+ h'^-$
4. Normalization Channel: $\mathrm{B}^0 \to \mathrm{K}^+\pi^-$
5. CLs method for limit extraction.

Phys. Rev. Lett. 111, 141801 (2013)

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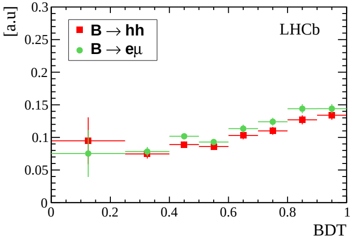
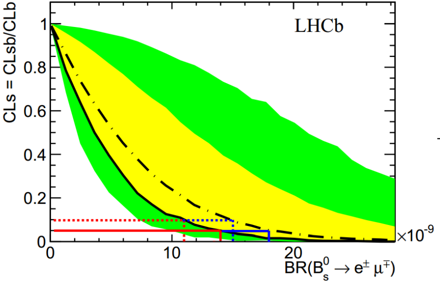
$B_{(s)} \to \ell^+\ell^-$ 2

- Correction to MC and DATA discrepancies.
- Excellent proxy: $B^0_{(s)} \to hh'$.
- Fit each BDT bin for $B^0_{(s)} \to hh'$ and extract number of events.
- Correct MC efficiency for each bin.
- Electron Bremsstrahlung corrected on $J/\psi \to ee$.





	$Br(B \to e\mu)$ @ 90(95)%CL	$Br(B_s \to e\mu)$ at 90(95)%CL
Expected	$4.0(5.0) \times 10^{-9}$	$1.5(2.0) \times 10^{-8}$
Observed	$2.8(3.7) \times 10^{-9}$	$1.1(1.4) \times 10^{-8}$

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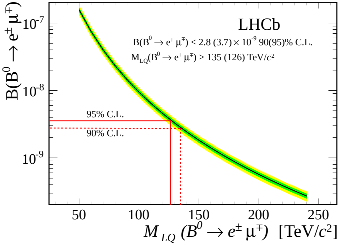
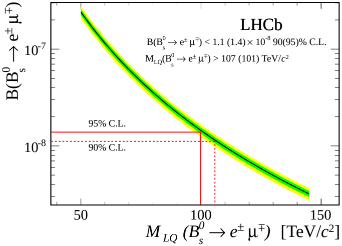
$\mathrm{B}_{(s)} \to \ell^+\ell^-$ Implications

- LHCb limits exceeds previous CDF by 20 times.
- CDF implications to lepto-quarks mass[1].
  - $m_{LQ}(\mathrm{B_s^0} \to \mathrm{e}\mu) > 47.8(44.9)\,TeV$ 90(95%) @CL.
  - $m_{LQ}(\mathrm{B^0} \to \mathrm{e}\mu) > 59.3(56.3)\,TeV$ 90(95%) @CL.





LHCb limits:

- $m_{LQ}(\mathrm{B_s^0} \to \mathrm{e}\mu) > 107(101)\,TeV$ 90(95%) @CL.
- $m_{LQ}(\mathrm{B^0} \to \mathrm{e}\mu) > 135(126)\,TeV$ 90(95%) @CL.

[1] Theoretical formula Phys. Rev. D 50 (1994) 6843

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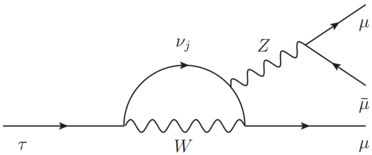
$\tau \to \mu\mu\mu$

1. In SM small $\mathcal{B}(\tau^- \to \mu^-\mu^-\mu^+) \sim 10^{-50}$
2. NP can enhance $\mathcal{B}$.
3. Nature still hides $\tau^- \to \mu^-\mu^-\mu^+$ from us.
4. Current limits:



Experiment	90% CL limit
BaBar	3.3×10^{-8}
Belle	2.1×10^{-8}

5. Can a hadron collider change the picture?

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Analysis approach

$\mathcal{B}$ factories

1. Clean signal: $\mathrm{e}^+\mathrm{e}^- \to \tau^+\tau^-$
2. Calculate the thrust axis
3. "Partial tag"the other τ
4. Small cross section 0.919*nb*

LHCb, (7*TeV*, 2011 data)

1. Inclusive τ cross section: 79.5 ± 8.3 µb.
2. $8 \times 10^{10} \tau$ produced.
3. Dominant contribution: $\mathrm{D_s} \to \tau\nu_\tau$ (78%)
4. No tag possible.

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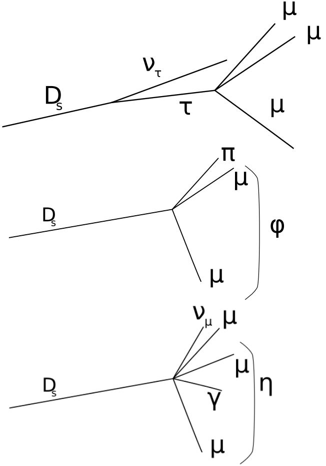
Strategy

- Loose cut based selection
- Classification in 3D space:
  - invariant mass
  - decay topology (multivariate)
  - particle identification (multivariate)
- Classifier trained on simulation
- Calibration with control channel
- Normalization with $D_s \to \phi(\mu\mu)\pi$
- CLs method to extract the result

Signal & Calibration & Background channel



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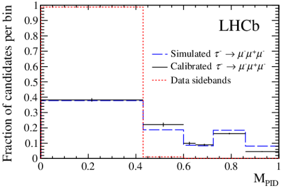
Signal likelihoods

particle identification

- hits in muon chambers
- energy in calorimeters
  - compatible with MIP
- RICH response

Calibration

$J/\psi \to \mu^+\mu^-$

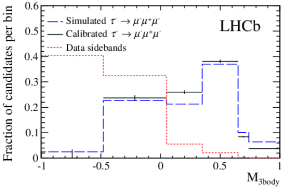


3 body decay likelihood

- vertex properties
  - vertex fit, pointing
- track quality
- isolation

Calibration

$D_s \to \phi\pi$



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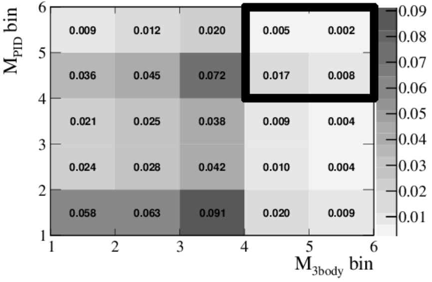
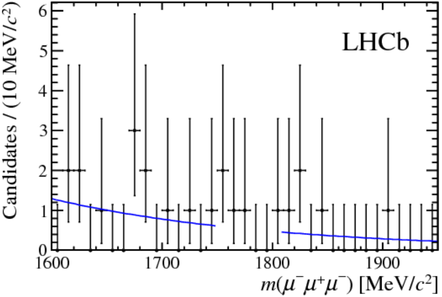
Signal likelihoods

combined signal distribution

- events distributed over 25 likelihood bins
- background estimate from mass side-bands

Signal efficiency in 3-BODY BDT vs PID BDT plane.





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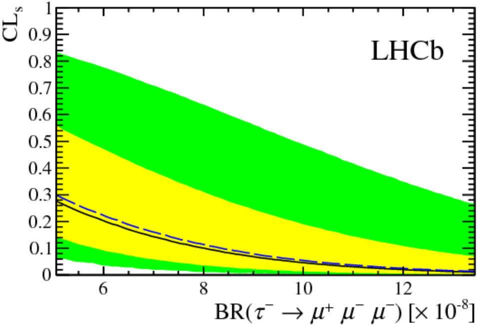
Extracted upper limit

1 fb^{-1}

PLB 724 (2013) 36-45

	observed	expected	CL
$\mathcal{B}(\tau \to \mu\mu\mu)$	8.0×10^{-8}	8.3×10^{-8}	90%
	9.8×10^{-8}	10.2×10^{-8}	95%



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Summary

- LFV and LNV processes are doing very well in LHCb.
- Lots of best limits already in our hands.
- Keep tune, lots of new results are coming very soon.