

# Searches for New Physics at LHCb

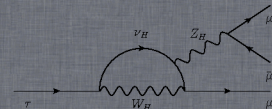
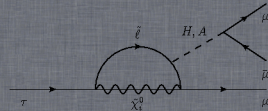
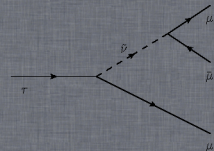
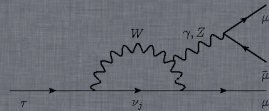
Marcin Chrzęszcz

University of Zurich,  
Institute of Nuclear Physics Krakow,  
on behalf of LHCb collaboration

21<sup>th</sup> May 2014



University of  
Zurich <sup>UZH</sup>



# LHCb detector

## Lepton Flavour Violation

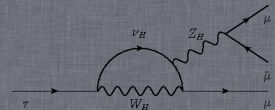
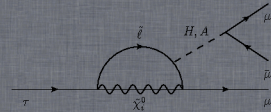
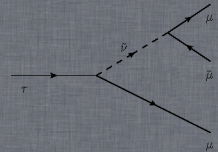
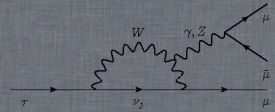
### B decays

$$B^- \rightarrow h^+ l^- l^-$$

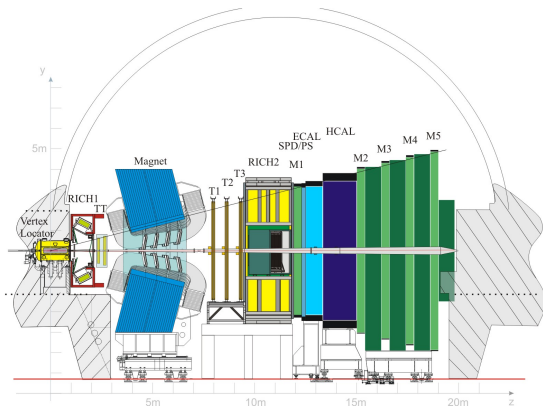
$$B_{(s)} \rightarrow l_1^+ l_2^-$$

### $\tau$ decays

$$\tau^- \rightarrow \mu^- \mu^- \mu^+$$



# LHCb detector



① LHCb is a forward spectrometer:

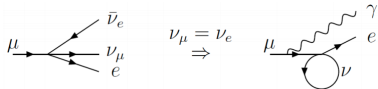
- Excellent vertex resolution.
- Efficient trigger.
- High acceptance for  $\tau$  and B.
- Great Particle ID

# Lepton Flavour/Number Violation

## Lepton Flavour Violation(LFV):

After  $\mu^-$  was discovered it was natural to think of it as an excited  $e^-$ .

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



## I.I.Rabi:

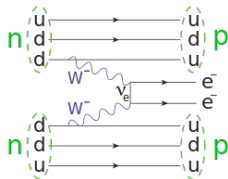
"Who ordered that?"



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

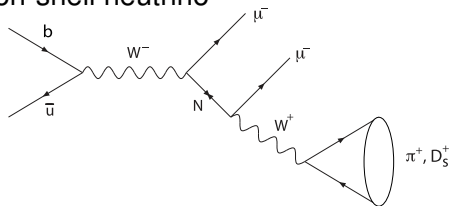
## Lepton Number Violation (LNV)

- Even with LFV, lepton number can be a conserved quantity.
- Many NP models predict its violation (Majorana neutrinos)
- Searched in so called Neutrinoless double  $\beta$  decays.



# LNV in bottom decays

on-shell neutrino



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

virtual neutrino

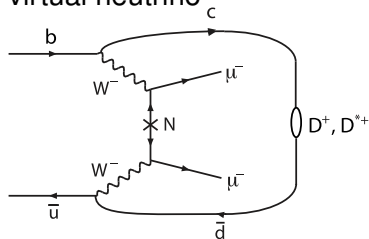
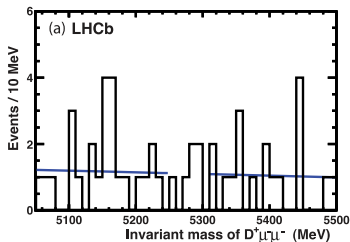


Diagram without mass restriction  
Cabbibo favoured for  $B \rightarrow D$   
Analogous to double  $\beta$  decay.

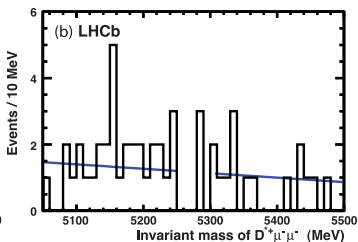
# Virtual Majorana neutrinos

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



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

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



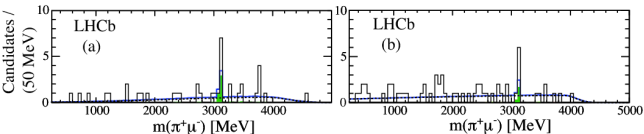
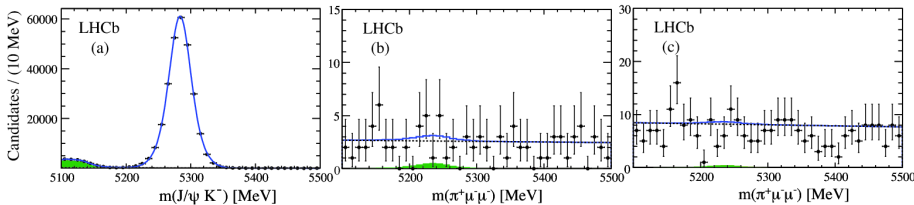
$\mathcal{B}(B^- \rightarrow D^{*+} \mu^- \mu^-) < 2.4 \times 10^{-6}$   
@ 95% CL

Phys. Rev.D85 (2012)  
112004

M.Chrząszcz 2014

# On-shell Majorana neutrinos

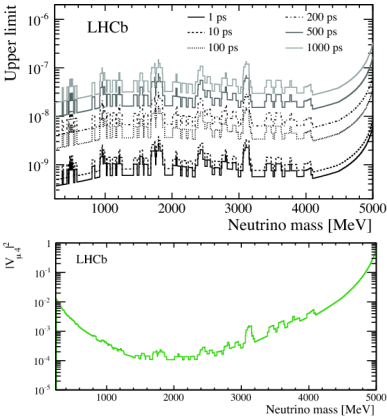
- $B^- \rightarrow \pi^+ \mu^- \mu^-$  searched with full data set  $3fb^{-1}$ .
- Cut based analysis.
- Normalization channel  $B^+ \rightarrow J/\psi(\mu\mu)K^+$ .
- Searches performed for two scenarios:
  - Short life-time neutrinos:  $\tau_4 < 1ps$
  - Long life-time neutrinos:  $\tau_4 \in (1, 1000)ps$



Phys. Rev. Lett.  
112, 131802

M.Chrzęszcz 2014

# On-shell Majorana neutrinos














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

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



# Summary on LNV in B decays

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

<sup>a</sup>BaBar, Phys. Rev. D **85**, 071103 (2012)

<sup>b</sup>CLEO, Phys. Rev. D **65**, 111102 (2002)

<sup>c</sup>Belle, Phys. Rev. D **84**, 071106(R), (2011)

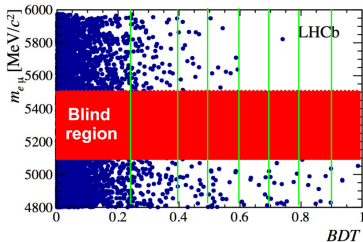
<sup>d</sup>LHCb, Phys. Rev. Lett. 108 101601 (2012)

<sup>e</sup>LHCb, Phys. Rev. Lett. (112) 131802 (2014)

$$B_{(s)} \rightarrow e^- \mu^+$$

- A separate physics interest is LFV B decays.
- Predicted by various NP models: lepto-quarks, SUSY, GUT.
- Analysis based on  $1 \text{ fb}^{-1}$  2011 data.
- Analogous to our  $B_s^0 \rightarrow \mu\mu$  analysis (PRL 111 (2013) 101804)

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



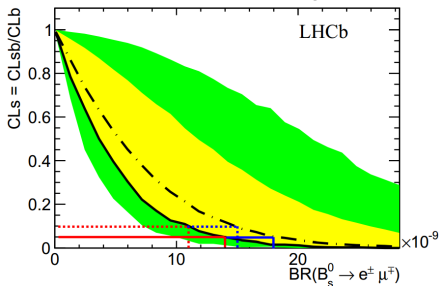
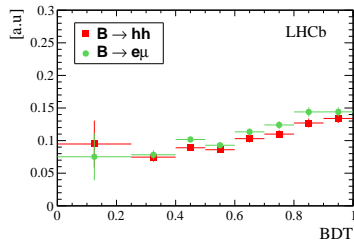
Phys. Rev. Lett.  
111, 141801 (2013)

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<sup>1</sup>A.L.Read, The CLs technique,  
Journal of Physics G (2012)

$$B_{(s)} \rightarrow e^- \mu^+$$

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

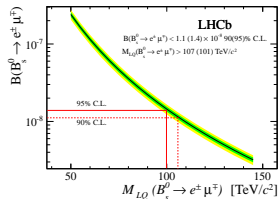
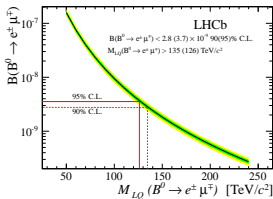


### Upper limits

	$Br(B \rightarrow e\mu)$ @ 90(95)%CL	$Br(B_s \rightarrow e\mu)$ at 90(95)%CL
Expected	$3.8(4.8) \times 10^{-9}$	$1.5(2.0) \times 10^{-8}$
Observed	$1.5(1.8) \times 10^{-9}$	$1.1(1.4) \times 10^{-8}$

# $B_{(s)} \rightarrow \ell_1^+ \ell_2^-$ Implications

- LHCb limits two times better than previous ones from CDF<sup>2</sup>.
- CDF implications to lepto-quarks mass<sup>3</sup>.
  - $m_{LQ}(B_s^0 \rightarrow e\mu) > 47.8(44.9) \text{ TeV}$  90(95%) @CL.
  - $m_{LQ}(B^0 \rightarrow e\mu) > 59.3(56.3) \text{ TeV}$  90(95%) @CL.



## LHCb limits:

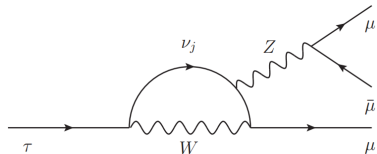
- $m_{LQ}(B_s^0 \rightarrow e\mu) > 107(101) \text{ TeV}$  90(95%) @CL.
- $m_{LQ}(B^0 \rightarrow e\mu) > 135(126) \text{ TeV}$  90(95%) @CL.

<sup>2</sup>Phys. Rev. Lett. 102 (2009) 201801

<sup>3</sup>Theoretical formula Phys. Rev. D 50 (1994) 6843

$$\tau \rightarrow \mu\mu\mu$$

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



Experiment	90% CL limit
BaBar <sup>4</sup>	$3.3 \times 10^{-8}$
Belle <sup>5</sup>	$2.1 \times 10^{-8}$

- ⑤ Can a hadron collider change the picture?

<sup>4</sup>Phys.Rev.D81:111101(R),2010

<sup>5</sup>Phys.Lett.B687:139-143,2010

# Analysis approach

## $B$ factories

- ① Clean signal:  $e^+e^- \rightarrow \tau^+\tau^-$
- ②  $1.2 \times 10^9$   $\tau$  pairs
- ③ Calculate the thrust axis
- ④ Tag the other  $\tau$
- ⑤ Small cross section  $0.919nb$

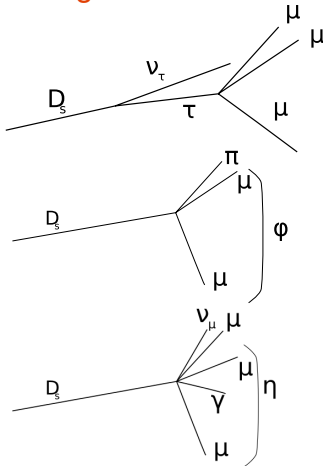
## LHCb, (7TeV, 2011 data)

- ① Inclusive  $\tau$  cross section:  
 $79.5 \pm 8.3 \mu b$ .
- ②  $8 \times 10^{10}$   $\tau$  produced.
- ③ Dominant contribution:  
 $D_s \rightarrow \tau \nu_\tau$  (78%)
- ④ No partial tag possible.

# 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  $D_s \rightarrow \phi(\mu\mu)\pi$
- CLs method to extract the result

## Signal & Calibration & Background channel



# Signal likelihoods

## particle identification

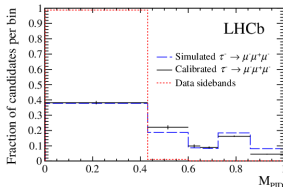
- hits in muon chambers
- energy in calorimeters
  - compatible with MIP
- RICH response

## 3 body decay likelihood

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

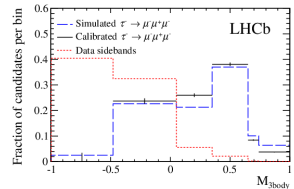
## Calibration

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



## Calibration

$$D_s \rightarrow \phi \pi$$



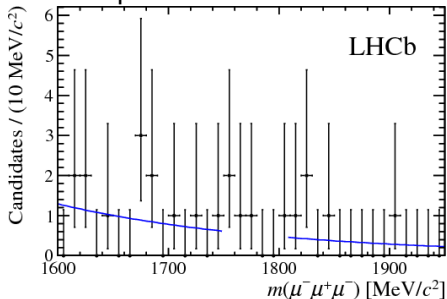
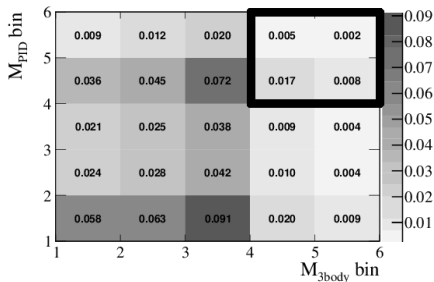


# Signal likelihoods

## 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.



# Extracted upper limit

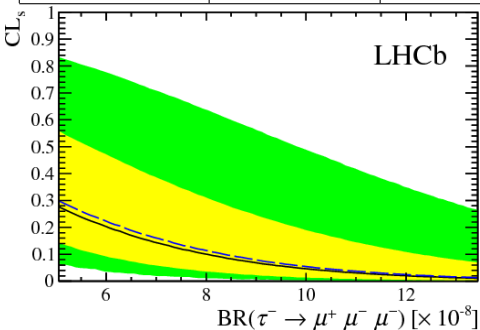


1 fb<sup>-1</sup>

PLB 724

(2013) 36-45

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



# Summary

- Analyses of LFV and LNV processes are going very well in LHCb
- We already have a number of best limits in our hands.
- Stay tuned, more new results coming up soon.