

Majorana neutrino search at LHCb experiment

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On behalf of LHCb Collaboration

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1 Dirac neutrino vs. Majorana neutrino

2 LHCb detector

3 New Physics

- Beyond the Standard Model

4 B and D decays

- $B^- \rightarrow \pi^+ \mu^- \mu^-$
- $B^- \rightarrow D^0 \pi^+ \mu^- \mu^-$
- $D_s^+ \rightarrow \pi^- \mu^+ \mu^+$

5 Future in B decays

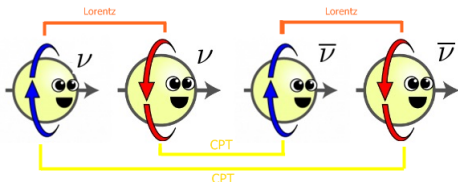
- $B^- \rightarrow \mu^- N (\rightarrow \pi^- e^+)$

6 Conclusions

DIRAC



$$\nu \neq \bar{\nu}$$



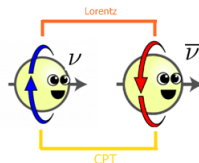
Standard Model of Elementary Particles

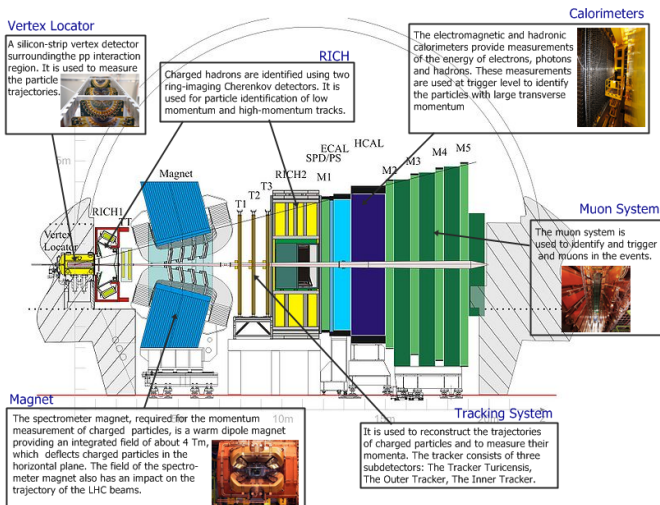
		three generations of matter (fermions)				
		I	II	III		
mass		~2.4 MeV/c ²	~1.275 GeV/c ²	~172.44 GeV/c ²	0	~125.09 GeV/c ²
charge		2/3	2/3	2/3	0	0
spin		1/2	1/2	1/2	1	0
	QUARKS	u up	c charm	t top	g gluon	H Higgs
		d down	s strange	b bottom	γ photon	
	LEPTONS	e electron	μ muon	τ tau	Z Z boson	
		ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
						SCALAR BOSONS
						GAUGE BOSONS

MAJORANA



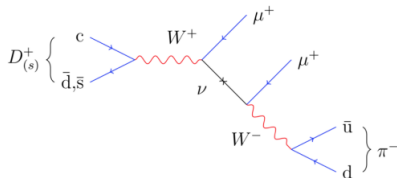
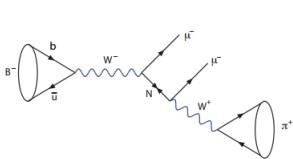
$$\nu = \bar{\nu}$$





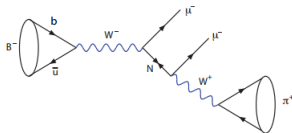
Motivation

- Lepton number and lepton flavour are conserved in the Standard Model, but can be violated in New Physics
- Neutrino oscillations imply that neutrinos are massive
- Existence of Majorana neutrinos \Rightarrow Lepton Flavour Violation or Lepton Number Violation \Rightarrow New Physics models
- Searches for lepton flavour and lepton number violating decays at LHCb are presented in various B and D decays



$$\begin{aligned}
 B^- &\rightarrow \pi^+ \mu^- \mu^- \\
 B^- &\rightarrow D^0 \pi^+ \mu^- \mu^- \\
 D_s^+ &\rightarrow \pi^- \mu^+ \mu^+
 \end{aligned}$$

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

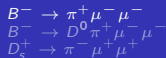


- Center-of-mass energy of 7 TeV for 2011 data and 8 TeV for 2012 data (Run1)
- 3 fb⁻¹ of data collected with LHCb
- Neutrinos with mass in range 250-5000 MeV and lifetimes 0-1000 ps
- Normalisation channel $B^- \rightarrow J/\psi K^-$

LHCb analysis Phys. Rev. Lett. 112, 131802 (2014)

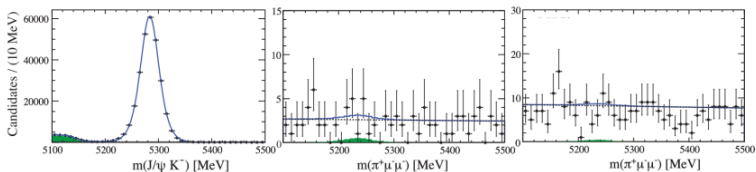
- Different selections for short-lived ($< 1ps$) and long-lived ($< 1ns$) neutrino.
- Selection efficiency varies as a function of the neutrino mass and lifetime.

Lepton Flavour Violation
 and
 Lepton Number Violation



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

No signal was found \Rightarrow Upper Limit

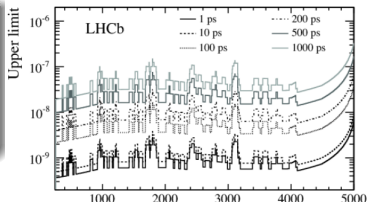


The upper limit on branching fraction for shorter than 1 ps lifetime neutrino

$$\mathcal{B}(B^- \rightarrow \pi^+ \mu^- \mu^-) < 4.0 \times 10^{-9} \text{ at } 95\% \text{ CL.}$$

LHCb analysis Phys. Rev. Lett. 112,131802

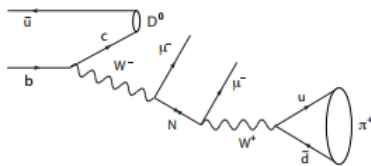
Anna Ossowska



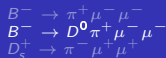
Majorana neutrino search at LHCb experiment

$$\begin{aligned}
 B^- &\rightarrow \pi^+ \mu^- \mu^- \\
 B^- &\rightarrow D^0 \pi^+ \mu^- \mu^- \\
 D_s^+ &\rightarrow \pi^- \mu^+ \mu^+
 \end{aligned}$$

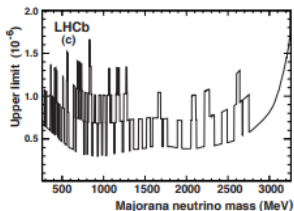
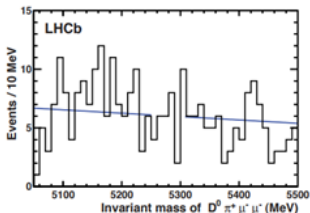
$$B^- \rightarrow D^0 \pi^+ \mu^- \mu^-$$



- semileptonic B^- decay
- D^0 in final state \Rightarrow smaller mass range than in the case of $\pi^+ \mu^- \mu^-$
- reconstruction of the $D^0 \rightarrow K^- \pi^+$ \Rightarrow limited sensitivity
- peaking backgrounds are essentially absent



$B^- \rightarrow D^0 \pi^+ \mu^- \mu^-$ - results



No signal was observed \Rightarrow Upper limit on branching fraction

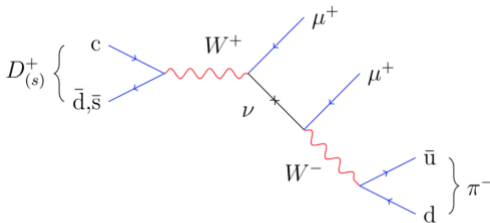
Upper Limit on branching fraction

$$\mathcal{B}(B^- \rightarrow D^0 \pi^+ \mu^- \mu^-) < 1.6 \times 10^{-6} \text{ at 95\% CL}$$

arXiv:1201.5600v3

$$\begin{aligned} B^- &\rightarrow \pi^+ \mu^- \mu^- \\ B^- &\rightarrow D^0 \pi^+ \mu^- \mu^- \\ D_s^+ &\rightarrow \pi^- \mu^+ \mu^+ \end{aligned}$$

$$D_s^+ \rightarrow \pi^- \mu^+ \mu^+$$



- Decay is forbidden in the SM (lepton number violating LNV)
- PID cuts + BDT = classification of signal and background
- 1 fb^{-1} data collected in 2011 at the center-of-mass energy 7 TeV
- Normalisation to $D^+ \rightarrow \phi(\mu^+ \mu^-) \pi^+$
- Candidates from the kinematically similar $D_s^+ \rightarrow \pi^+ \pi^+ \pi^-$ decay form an important peaking background.

$$\begin{aligned}
 B^- &\rightarrow \pi^+ \mu^- \mu^- \\
 B^- &\rightarrow D^0 \pi^+ \mu^- \mu^- \\
 D_s^+ &\rightarrow \pi^- \mu^+ \mu^+
 \end{aligned}$$

$D_s^+ \rightarrow \pi^- \mu^+ \mu^+$ results

Fit in bins of $m(\pi^- \mu^+)$ to improve statistical significance.

Bin description	$m(\mu^+ \mu^-)$ range [MeV/c ²]
ϕ	850 – 1250
bin 1	250 – 1140
bin 2	1140 – 1340
bin 3	1340 – 1550
bin 4	1540 – 2000

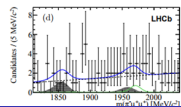
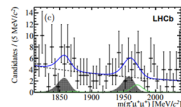
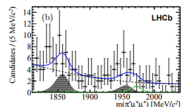
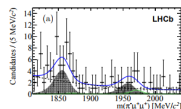
No signal was observed...

Upper limit on branching fraction:

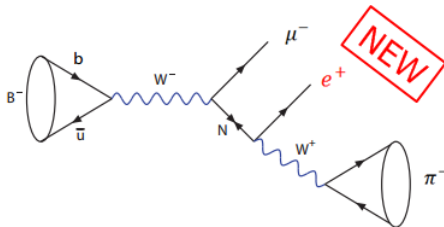
$$\mathcal{B}(D_s^+ \rightarrow \pi^- \mu^+ \mu^+) < 1.2 \times 10^{-7} \text{ at 90 \% CL}$$

Factor of 50 improvement with respect to previous limits!

arXiv:1304.6365v1



$$B^- \rightarrow \mu^- N(\rightarrow \pi^- e^+)$$



- 1.67 fb^{-1} of data from Run2 (2016)
- center-of-mass energy - 13 TeV
- mass range 150 - 4500 MeV
- lifetime 1 - 1000 ps

First MC samples and preselection algorithm ready

Lepton Flavour Violation
Total Lepton Number is
CONSERVED

Conclusions

- $B^- \rightarrow D^0 \pi^+ \mu^- \mu^-$, $B^- \rightarrow \pi^+ \mu^- \mu^-$, $D_s^+ \rightarrow \pi^- \mu^+ \mu^+$,
 $B^- \rightarrow \mu^- N (\rightarrow \pi^- e^+)$ - forbidden in the SM
- any observed signal would be a clear indication of physics beyond the SM
- the worlds best limits on $\mathcal{B}(B^- \rightarrow h^- \mu^+ \mu^+)$ and $\mathcal{B}(D_s^+ \rightarrow \pi^- \mu^+ \mu^+)$ decays from LHCb

Thank you for your attention