Search for LFV and LNV decays at LHCb

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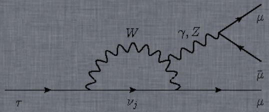
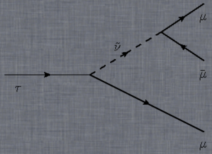
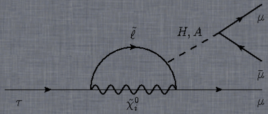
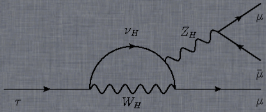








Lepton Number Violation

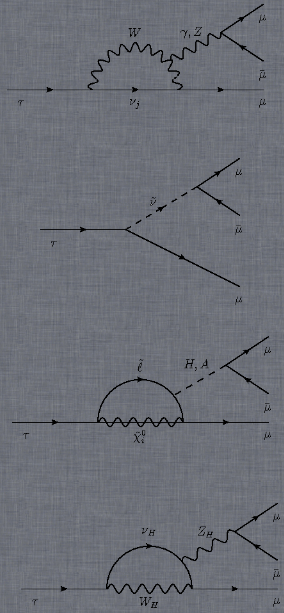
$B^- \to h^+ \ell^- \ell^-$

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

Lepton Flavour Violation

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

$\tau^- \to \bar{p} \mu^- \mu^+$



LNV in bottom decays

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

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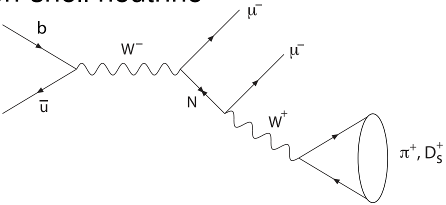
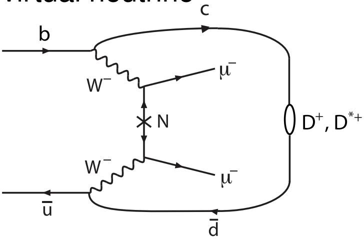
LNV in bottom decays

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 $\mathrm{B} \to \mathrm{D}$

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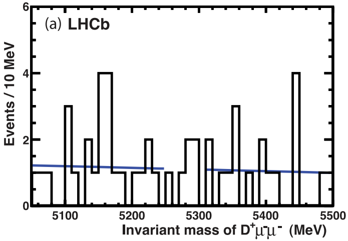
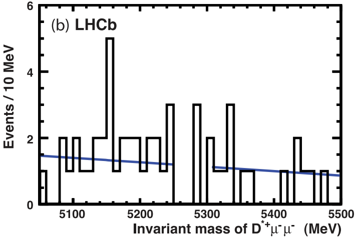
virtual Majorana neutrinos

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



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



$\mathcal{B}(B^- \to D^+ \mu^- \mu^-) < 6.9 \times 10^{-7}$
@ 95 % CL

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

0.41 fb^{-1}
arXiv:1201.5600

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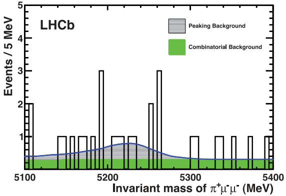
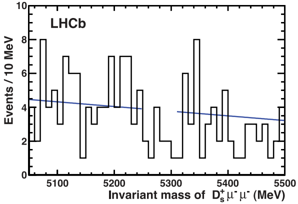
on-shell Majorana neutrinos

- mis-identification rates from data with mass shape from simulation

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



$B^- \to D_s{}^+\mu^-\mu^-$



assuming B^- phase space decay:

$\mathcal{B}(B^- \to \pi^+\mu^-\mu^-) < 1.3 \times 10^{-8}$
@ 95 % CL

$\mathcal{B}(B^- \to D_s\mu^-\mu^-) < 5.8 \times 10^{-7}$
@ 95 % CL

$0.41\ \mathrm{fb}^{-1}$

arXiv:1201.5600

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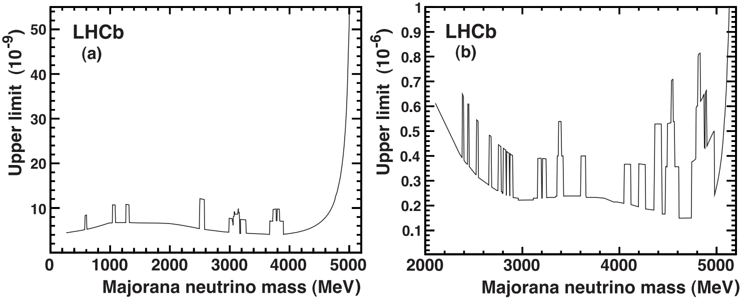
implications on Majorana mass

mass spectrum

Determine limit as function of $h^+\mu^-$ mass

$B^- \to \pi^+\mu^-\mu^-$ $\quad$ $B^- \to D_s^+\mu^-\mu^-$



0.41 fb^{-1}

arXiv:1201.5600

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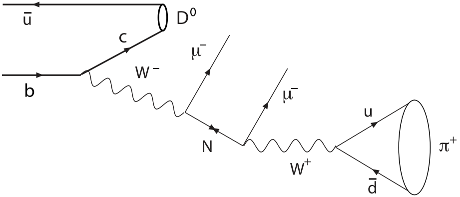
$B^- \to D^0 \pi^+ \mu^- \mu^-$



- Four body B decay complementary to three body decay (`arXiv:1108.6009`)
- $m_4 = m(\pi^+\mu^-)$

+ enhanced by W couplings
- smaller mass range accessible (260 MeV $< m_4 <$ 3.3 GeV)

- first performed at LHCb

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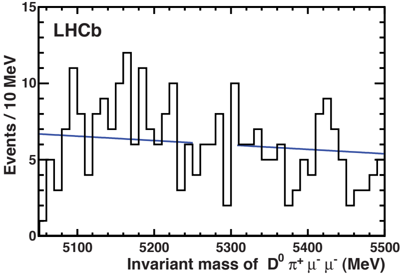
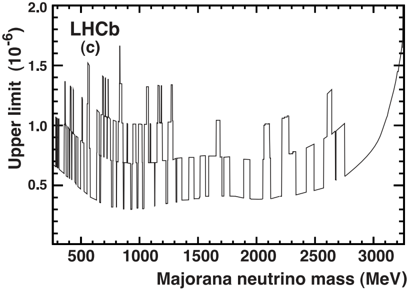
$B^- \to D^0\pi^+\mu^-\mu^-$





$\mathcal{B}(B^- \to D^0\pi^+\mu^-\mu^-) < 1.5 \times 10^{-6}$ @95 % CL [a]

Less restrictive than $B^- \to \pi^+\mu^-\mu^-$ on $|V_{\mu 4}|^2$

[a] LHCb, CERN-PH-EP-2012-006, arXiv:1201.5600

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Lepton Flavour Violation

① $\tau^- \to \mu^-\mu^-\mu^+$
② $\tau^- \to \overline{\mathrm{p}}\mu^-\mu^+$

LFV in τ^- sector

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

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LFV in τ^- sector

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 aproach

$\mathcal{B}$ factories

1. Clean signal: $\mathrm{e}^+\mathrm{e}^- \to \tau^+\tau^-$
2. Claculate the trust axis
3. Semi tag the other tag

LHCb

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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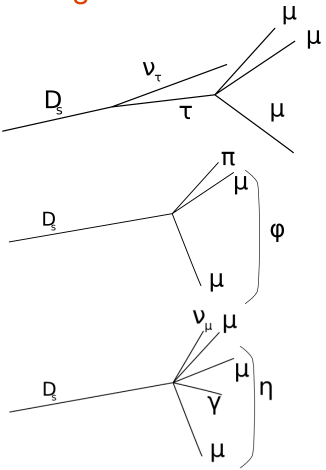
Strategy

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

Signal & Calibration & Background channel



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signal likelihoods

particle identification

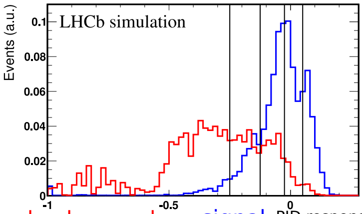
- hits in muon chambers
- energy in calorimeters
  - compatible with MIP
- RICH response

3 body decay likelihood

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

Calibration

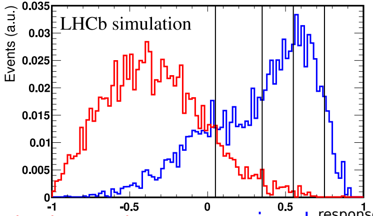
$J/\psi \to \mu^+\mu^-$



background signal PID response

Calibration

$D_s \to \phi\pi$



background signal response

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Normalisation channel $D_s^+ \to \phi(\mu^+\mu^-)\pi^+$

Produced τ leptons

$$\mathcal{B}(\tau \to \mu\mu\mu) = \frac{\sigma(pp \to D_s \to \tau)}{\sigma(pp \to \tau)} \frac{\mathcal{B}(D_s \to \phi(\mu\mu)\pi)}{\mathcal{B}(D_s \to \tau\nu_\tau)} \frac{\varepsilon_{norm}}{\varepsilon_{sig}} \frac{N_{\tau\to\mu\mu\mu}}{N_{D_s\to\phi(\mu\mu)\pi}}$$

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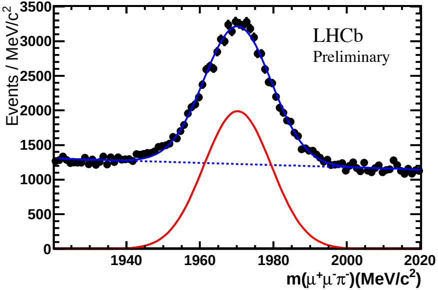

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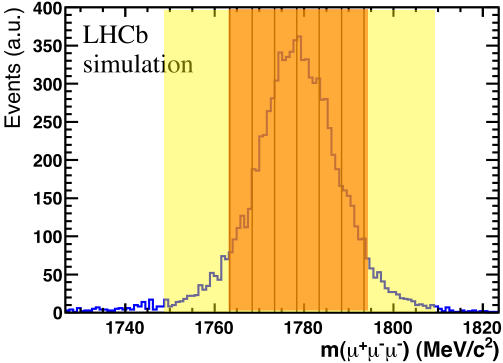
Invariant mass

- background estimation in sidebands
- different signal likelihood inside signal region

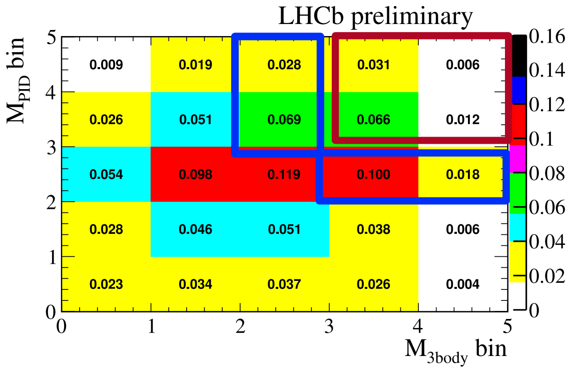


- mass resolution and mass scale calibrated on data

Signal likelihoods

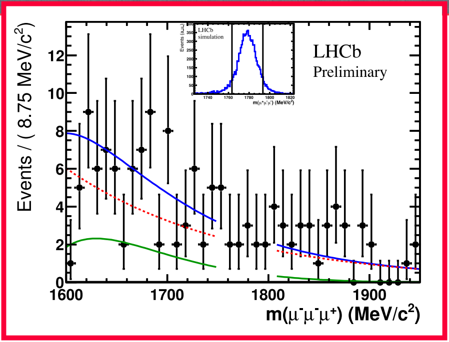
combined signal distribution

- events distributed over 25 likelihood bins
- background estimate from mass sidebands

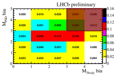


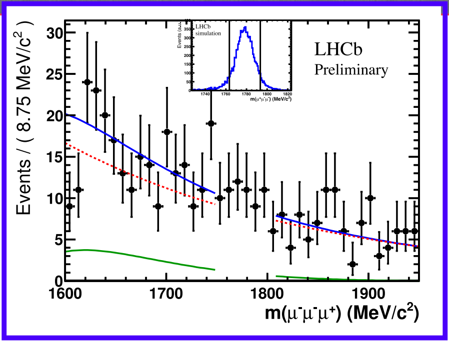
- 11 % signal efficiency
- 21 % signal efficiency
- for illustration: high likelihood range shown

Observed events

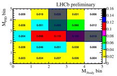


11 % of the signal
0.03 % of the background





21 % of the signal
0.14 % of the background



red dashed combinatorial background

green $D_s^+ \to \eta(\mu^-\mu^+\gamma)\mu^+\nu_\mu$

blue combined background

1 fb^{-1}

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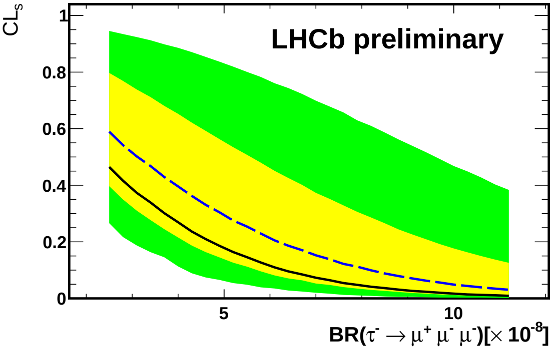
Extracted limit

	observed	expected
$\mathcal{B}(\tau \to \mu\mu\mu) <$	6.3×10^{-8} 7.8×10^{-8}	8.2×10^{-8} 9.9×10^{-8}



$1\ fb^{-1}$

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LFV in τ^- sector

$\tau^- \to \bar{\mathrm{p}}\mu^-\mu^+$

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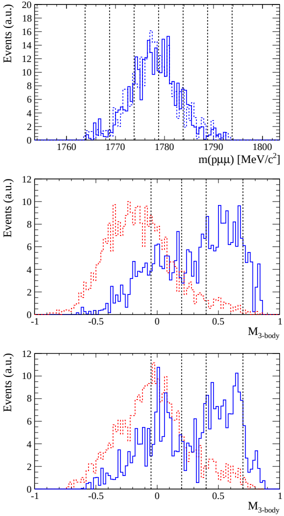
LFV in τ^- sector

1. Search for baryon number violation processes so far unsuccessful, but must have occurred in the early universe
2. Decay fall into $|B - L| = 0$ category, which is predicted by many NP models.
3. Similar decays $\tau^- \to \tilde{\ell}$, previous studied in $\mathcal{B}$ factories.
4. Two possible decay and new physics modes: $\tau^- \to \overline{\mathrm{p}}\mu^-\mu^+$, $\tau^- \to \mathrm{p}\mu^-\mu^+$.
5. Analysis adopted from $\tau^- \to \mu^-\mu^-\mu^+$

Differences

- Use the same $\mathcal{M}_{3body}$ BDT as for $\tau^- \to \mu^-\mu^-\mu^+$
- Insead of PID BDT use hard PID cut optimised on MC and Data.
- Worse normalization factor, due to hard PID cuts.
- Only combinatorical background expected.



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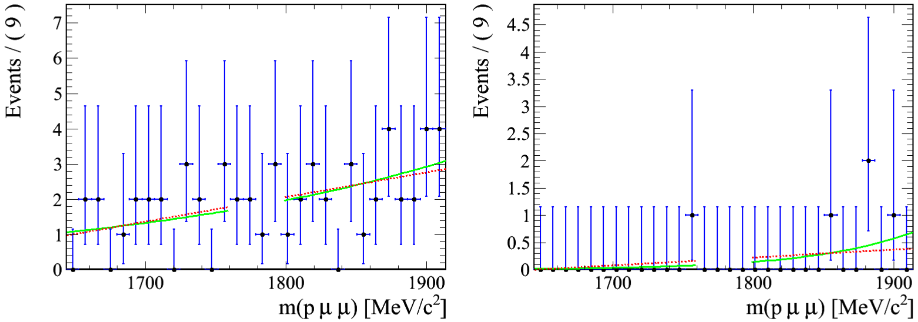
Backorund Fits

$$\tau^- \to \overline{p}\mu^-\mu^-$$



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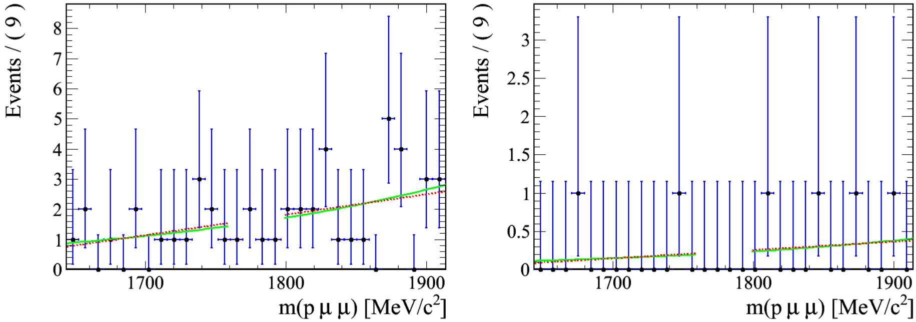
Backorund Fits

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



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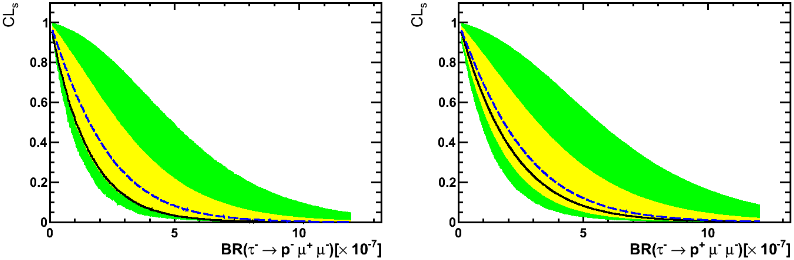
Limits on $\tau^- \to \bar{p}\mu^-\mu^+$ and $\tau^- \to p\mu^-\mu^-$



CLs	Observed		expected	
90%	4.7×10^{-7}	5.4×10^{-7}	4.7×10^{-7}	5.4×10^{-7}
95%	5.9×10^{-7}	6.9×10^{-7}	4.5×10^{-7}	6.0×10^{-7}

First time measured!!

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Summary

1. LNV, LFV and BNV still hides before us.
2. First measurements on τ physics on hadron coliders.
3. LHCb caughting up $\mathcal{B}$ factories.
4. $\mathcal{B}(\tau \to \mathrm{p}\mu\mu)$ first time measured.

Thank you for your attention.

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