Search for LFV and LNV decays at LHCb

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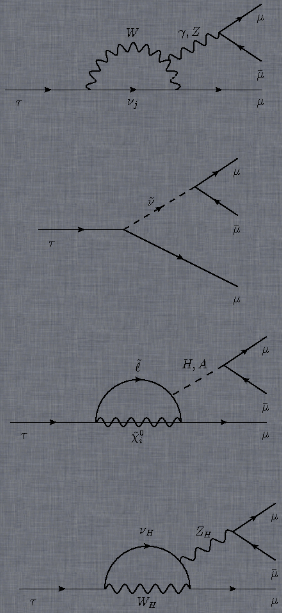
29^{th} September 2012



B decays

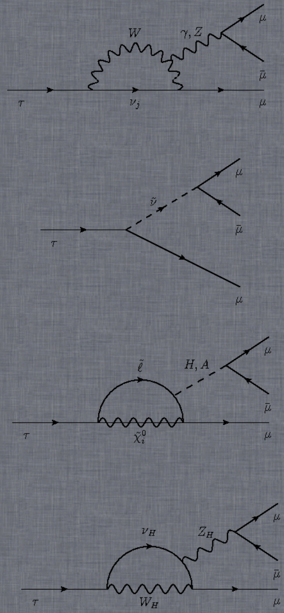
$B^- \to h^+ \ell^- \ell^-$

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

τ decays

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

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



Overview of B and τ decays at LHCb

1. LHCb optimised for B decays.
   - Relatively low background.
   - Efficient trigger.
   - Analysis can be made using hard cuts(the case of LNF decays).
2. τ decays at LHCb.
   - Many τ killed by trigger.
   - Smaller cross section for production.
   - Need complicated analysis strategy.

LNV in bottom decays

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

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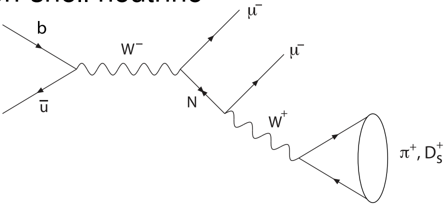
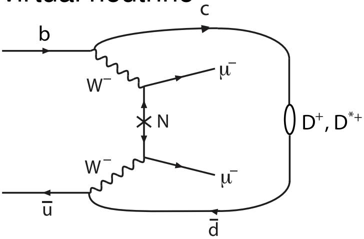
LNV in bottom decays

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 $\mathrm{B} \to \mathrm{D}$
Analogous to double β decay.

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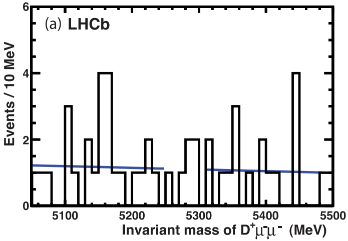
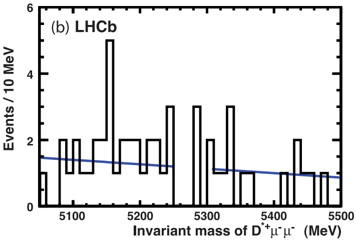
Virtual Majorana neutrinos

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



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



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

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

Phys. Rev.D85 (2012) 112004

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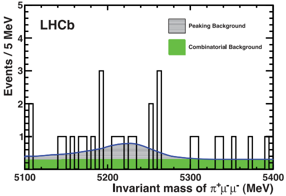
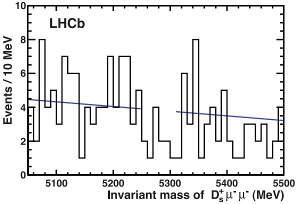
On-shell Majorana neutrinos

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

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



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



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

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

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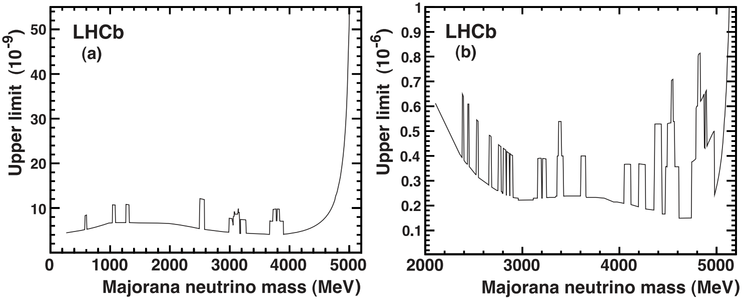
Implications on Majorana mass

mass spectrum

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

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



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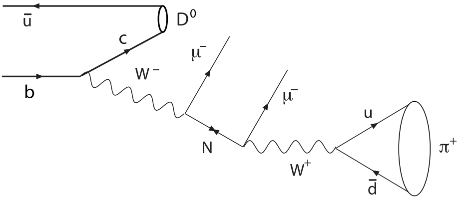
$B^- \to D^0\pi^+\mu^-\mu^-$



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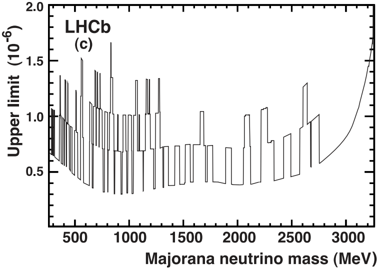
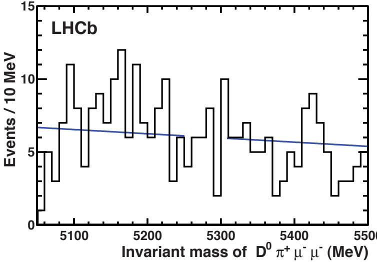
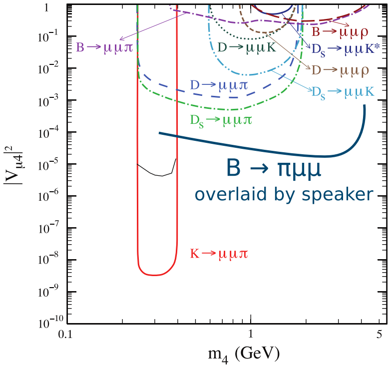
$B^- \to D^0 \pi^+ \mu^- \mu^-$







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

[a] LHCb, CERN-PH-EP-2012-006, arXiv:1

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Summary on LNV in B decays

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

(1) $\tau^- \to \mu^-\mu^-\mu^+$
(2) $\tau^- \to \bar{\mathrm{p}}\mu^-\mu^+$

LFV in τ^- sector

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

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

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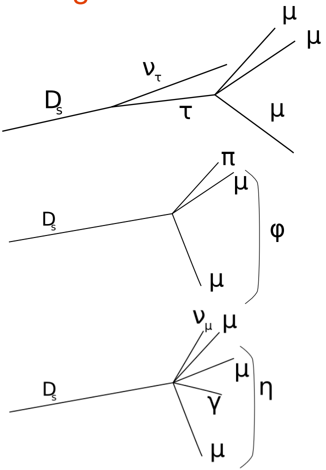
Strategy

- 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 $\mathrm{D_s} \to \phi(\mu\mu)\pi$
- CLs method to extract the result

Signal & Calibration & Background channel



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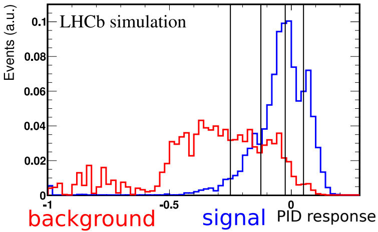
Signal likelihoods

particle identification

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

Calibration

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

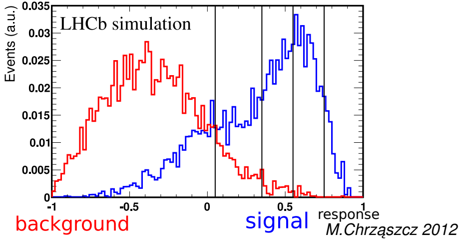


3 body decay likelihood

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

Calibration

$D_s \rightarrow \phi\pi$



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

Produced τ leptons

$$\mathcal{B}(\tau \to \mu\mu\mu) = \underbrace{\frac{\sigma(pp \to D_s \to \tau)}{\sigma(pp \to \tau)}}_{77.9\%} \frac{\mathcal{B}(D_s \to \phi(\mu\mu)\pi)}{\mathcal{B}(D_s \to \tau\nu_\tau)} \frac{\varepsilon_{norm}}{\varepsilon_{sig}} \frac{N_{\tau\to\mu\mu\mu}}{N_{D_s\to\phi(\mu\mu)\pi}}$$

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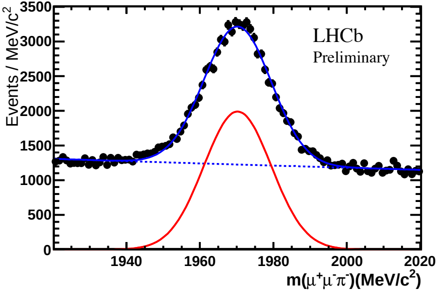

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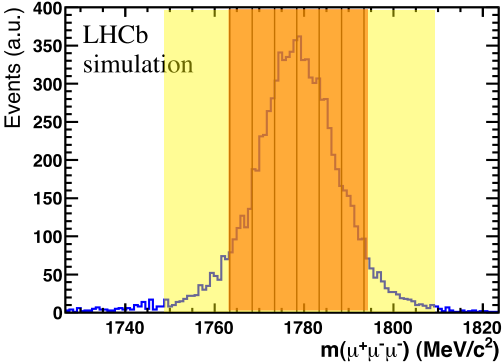
Invariant mass

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



- Mass resolution and mass scale calibrated on data
- Blinded window
- Mass window
- Mass resolution: 9.16*MeV*

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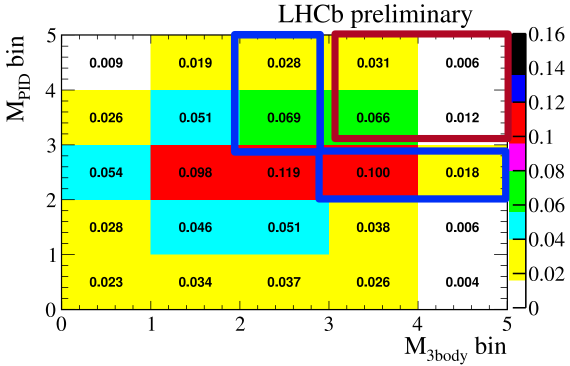
Signal likelihoods

combined signal distribution

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

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



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

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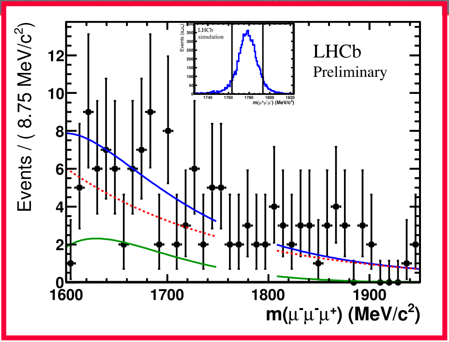
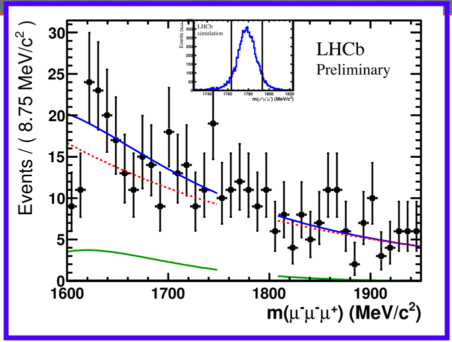
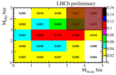
Observed events

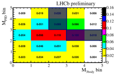




11 % of the signal
0.03 % of the background



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 upper limit

	observed	expected	CL
$\mathcal{B}(\tau \to \mu\mu\mu)$	6.3×10^{-8}	8.2×10^{-8}	90%
	7.8×10^{-8}	9.9×10^{-8}	95%

1 fb^{-1}

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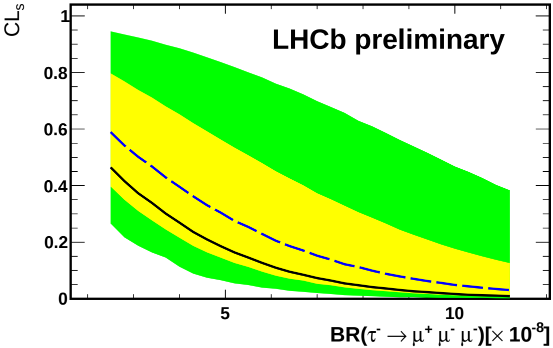

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LNV & BNV in τ^- sector

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

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LNV & BNV 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 $\tau^- \to \Lambda \ell^-$, previous studied in $\mathcal{B}$ factories.
4. Two possible decay and new physics modes: $\tau^- \to \bar{\mathrm{p}}\mu^-\mu^+$, $\tau^- \to \mathrm{p}\mu^-\mu^-$.
5. Analysis adopted from $\tau^- \to \mu^-\mu^-\mu^+$

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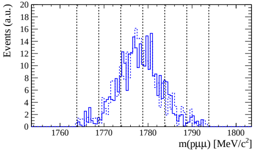
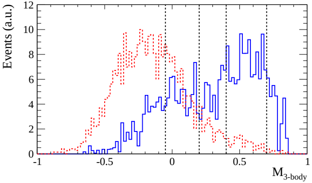
Differences

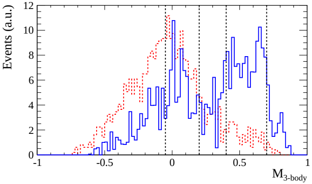
Mass distribution



3-body BDT distribution for $\tau^- \to \overline{\mathrm{p}}\mu^-\mu^+$



3-body BDT distributiion for $\tau^- \to \mathrm{p}\mu^-\mu^-$



- 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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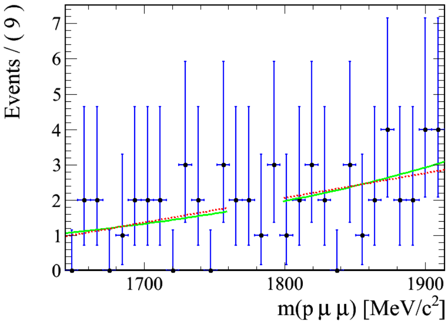
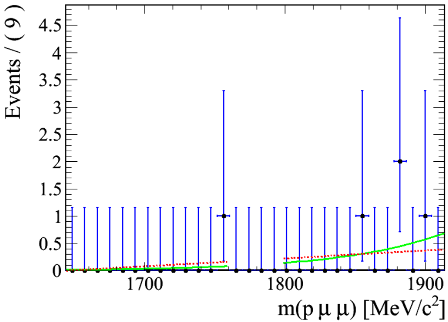
Background Fits

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



3-body BDT $(0.4, 0.7)$



3-body BDT $(0.7, 1.0)$

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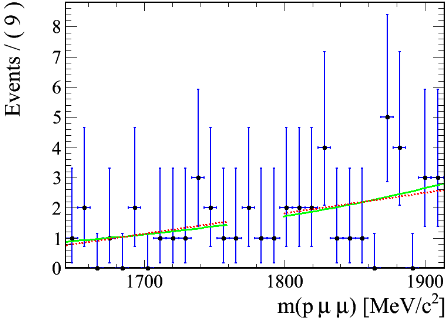
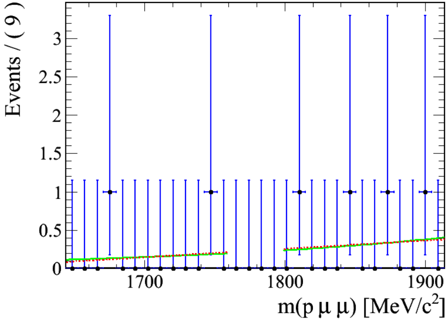
Background Fits

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



3-body BDT $(0.4, 0.7)$



3-body BDT $(0.7, 1.0)$

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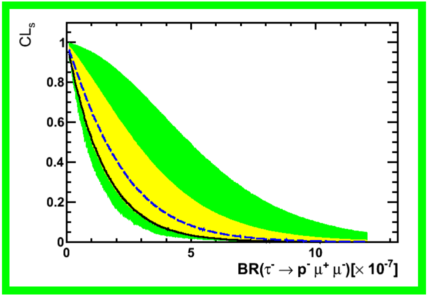
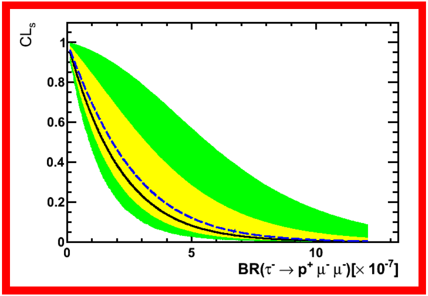
Limits on $\tau^- \to \bar{p}\mu^-\mu^+$ and $\tau^- \to p\mu^-\mu^-$





CL	Observed	Expected
90%	3.4×10^{-7} 4.6×10^{-7}	4.7×10^{-7} 5.4×10^{-7}
95%	4.5×10^{-7} 6.0×10^{-7}	5.9×10^{-7} 6.9×10^{-7}

First time measured!!

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Summary

1. LNV, LFV and BNV still hidden from us.
2. First upper limits for τ LFV and LNV in hadron colliders.
3. LHCb catching up $\mathcal{B}$ factories.
4. First search for $\mathcal{B}(\tau \to \mathrm{p}\mu\mu)$.

Thank you for your attention.

Work partially funded by the Polish Ministry of Science and Higher Education under the "Diamond Grant"

Backup Slides

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