Search for LFV and LNV decays at LHCb

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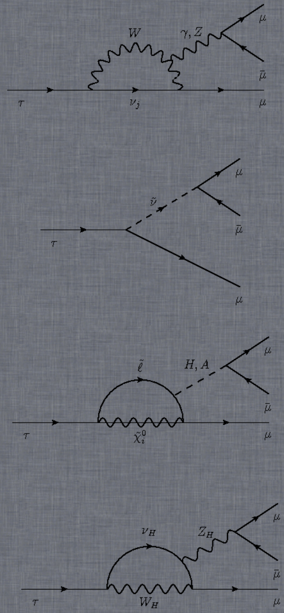


Overview

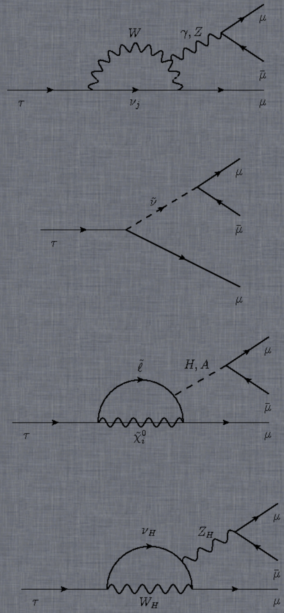
Majorana neutrinos

τ physics @ LHCb

τ decays

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

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



LHCb in quest for Majorana neutrinos

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)

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τ physics @ LHCb

① LHCb optimised for B decays.

- Relatively low background.
- Efficient trigger.
- Analysis can be made using hard cuts(the case of previous slide analysis).

② τ decays at LHCb.

- Many τ killed by trigger.
- Smaller cross section for production.
- Need complicated analysis strategy.

Studied τ decays

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

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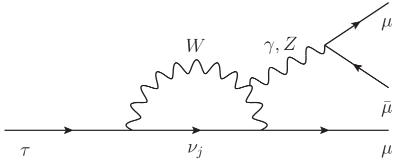
Status of $\tau^- \to \mu^-\mu^-\mu^+$

1) In SM small $\mathcal{B}(\tau^- \to \mu^-\mu^-\mu^+) \sim 10^{-50}$, due to neutrino oscillations.
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: $e^+e^- \to \tau^+\tau^-$
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: $D_s \to \tau \nu_\tau$ (78%)
4. No tag possible.

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Where do we get our τ.

Tablica: Relative contributions to $\sigma(pp \to \tau X)$.

Decay chain	Gauss no DPC (%)	Calc (%)	$w_{MC \to calc}$
$D_s \to \tau$	72.3 ± 0.1	77.9 ± 4.7	
$D_s \to \tau$	62.6 ± 0.2	67.8 ± 4.8	1.08 ± 0.08
$B_x \to D_s \to \tau$	9.56 ± 0.07	10.1 ± 2.1	1.1 ± 0.2
$D^- \to \tau$	2.08 ± 0.03	4.6 ± 4.4	
$D^- \to \tau$	1.90 ± 0.02	4.4 ± 4.2	2.3 ± 2.2
$B_x \to D^- \to \tau$	0.18 ± 0.01	0.3 ± 0.3	1.5 ± 1.5
$B_x \to \tau$	25.5 ± 0.1	17.5 ± 3.3	0.7 ± 0.1

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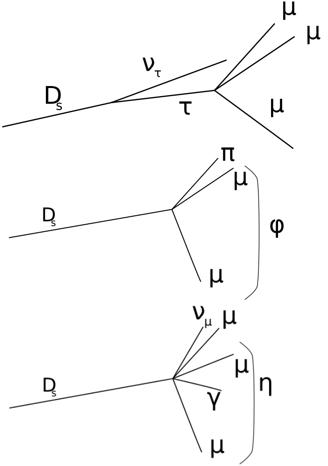
Strategy

- 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

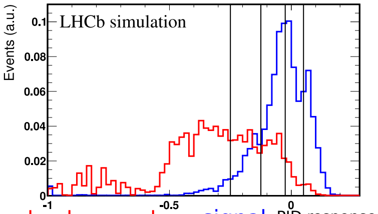
- hits in muon chambers
- energy in calorimeters
    - compatible with MIP
- RICH response

3 body decay likelihood

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

Calibration

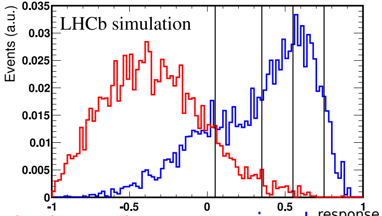
$J/\psi \to \mu^+\mu^-$



background signal

Calibration

$D_s \to \phi\pi$



background signal

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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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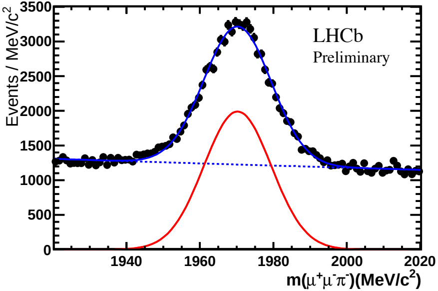

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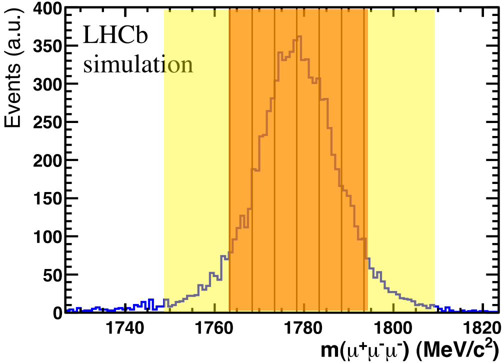
Invariant mass

- 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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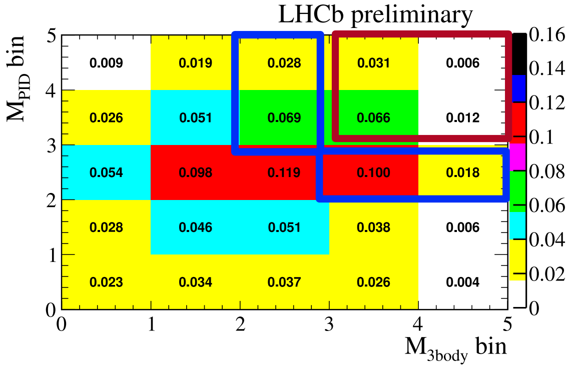
Signal likelihoods

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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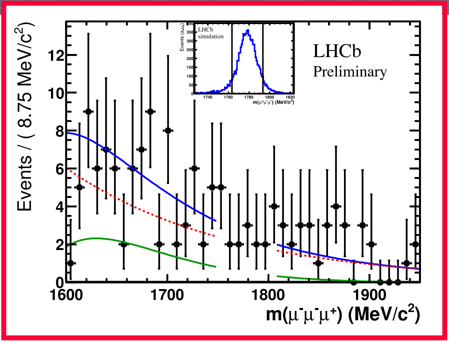
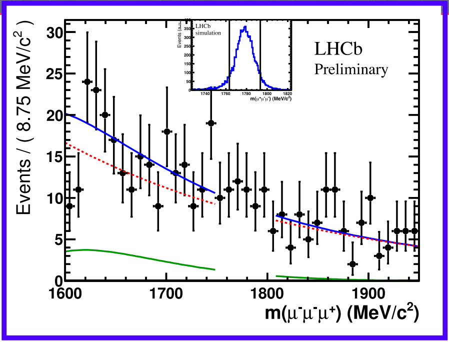
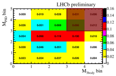
Observed events





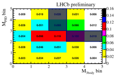
11 % of the signal

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} 7.8×10^{-8}	8.2×10^{-8} 9.9×10^{-8}	90% 95%

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

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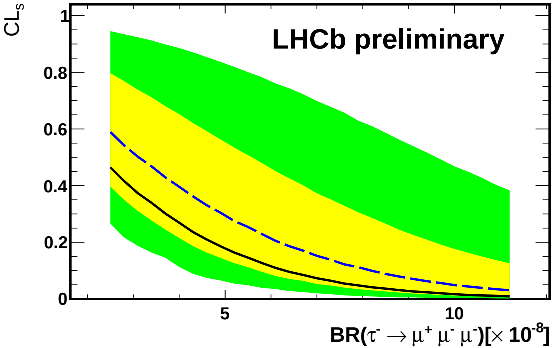

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LNV & BNV in τ^- sector

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

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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: $\tau^- \to \overline{\mathrm{p}}\mu^-\mu^+$, $\tau^- \to \mathrm{p}\mu^-\mu^-$.

(5) Analysis adopted from $\tau^- \to \mu^-\mu^-\mu^+$

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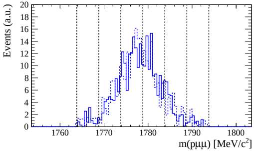
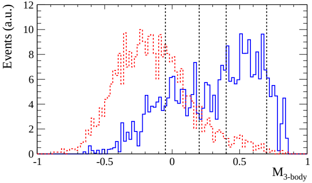
Differences

Mass distribution

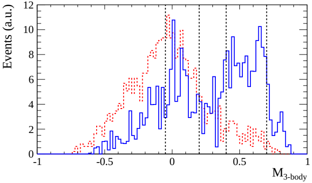


- Use the same $\mathcal{M}_{3body}$ BDT as for $\tau^- \to \mu^-\mu^-\mu^+$
- Insead of PID BDT use hard PID cut optimised on MC and Data.
- Worse normalization factor, due to hard PID cuts.
- Only combinatorical background expected.

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



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



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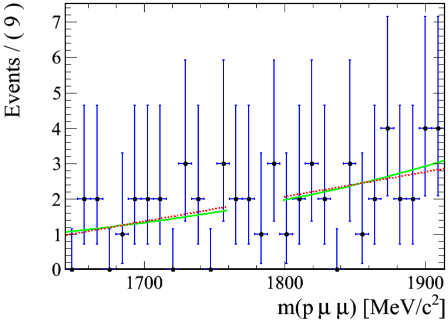
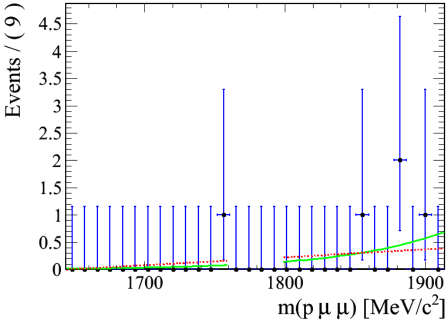
Background Fits

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



3-body BDT $(0.4, 0.7)$



3-body BDT $(0.7, 1.0)$

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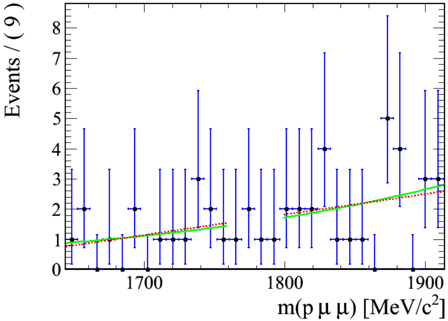
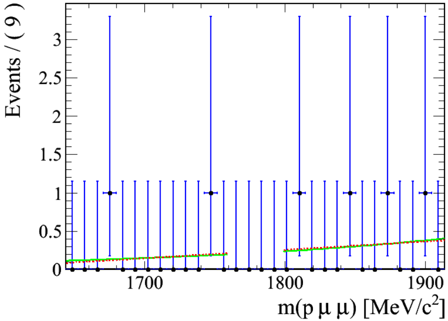
Background Fits

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



3-body BDT $(0.4, 0.7)$



3-body BDT $(0.7, 1.0)$

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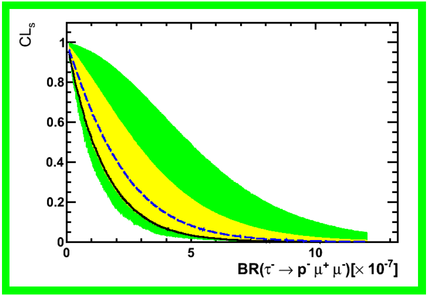
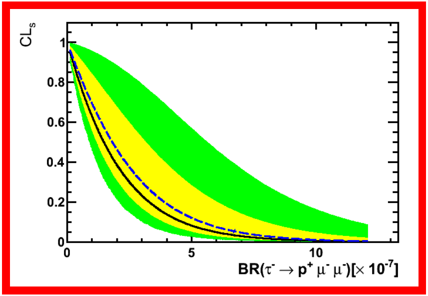
Limits on $\tau^- \to \bar{p}\mu^-\mu^+$ and $\tau^- \to p\mu^-\mu^-$





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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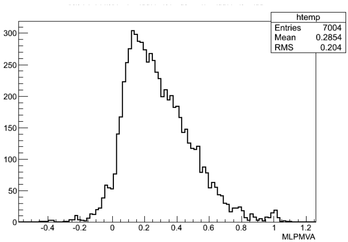
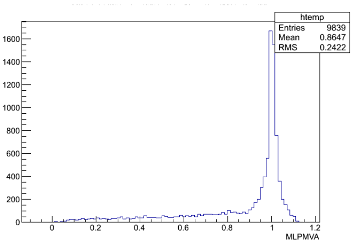
Going towards the paper

Possible improvements(work ongoing):

1. Cut background: $D_s \to \eta(\mu\mu\gamma)\mu\nu$ in Dalitz space.





2. Improve binning optimisation using inner sidebands.
3. Use bigger MC samples to reduce the systematics.

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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 $\mathcal{B}(\tau \to \mathrm{p}\mu\mu)$.
5. Paper expected at the end of 2012.

Thank you for your attention.

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Backup Slides

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