Search for LFV decays at LHCb

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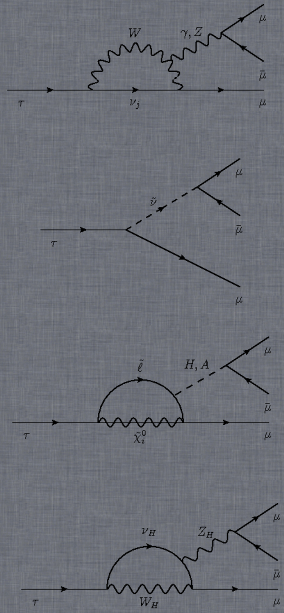
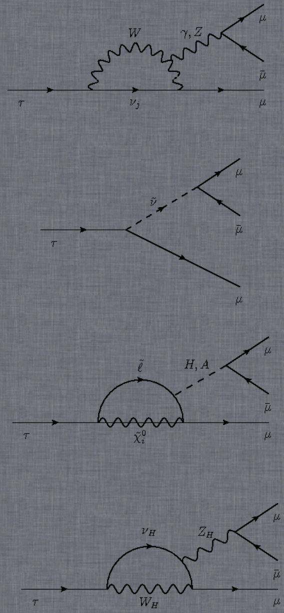


τ decays

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

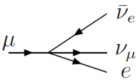
Model dependence



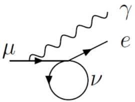
LFV hunting, "Who ordered that?"I. Rabi

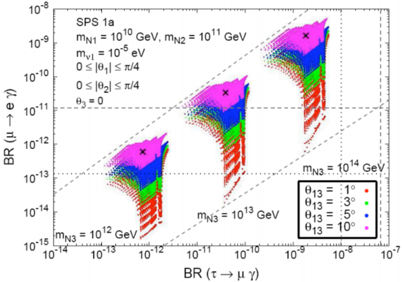
The history of LFV dates back to the discovery of muon:

- After discovery of μ it was natural to think about it as an excited electron.
- Unless you have an other neutrino.



$\nu_\mu = \nu_e$
$\Rightarrow$





- Analogy to GIM mechanism.

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τ decays

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

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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 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 ± 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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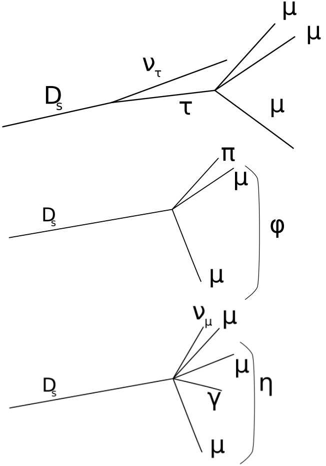
Strategy

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

Signal & Calibration & Background channel



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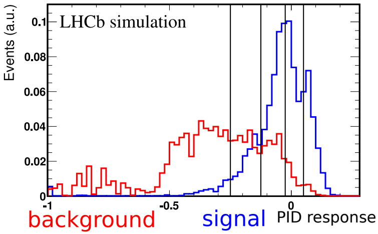
Signal likelihoods

particle identification

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

Calibration

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

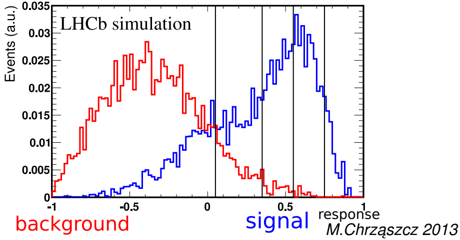


3 body decay likelihood

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

Calibration

$D_s \rightarrow \phi\pi$



Signal likelihoods

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3 body decay likelihood

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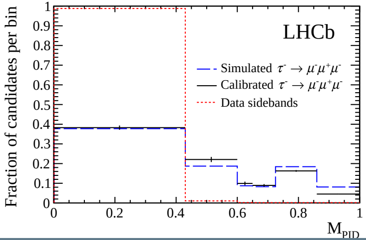
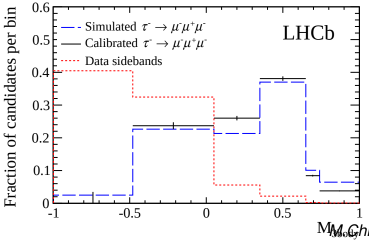


Calibration

$D_s \to \phi\pi$

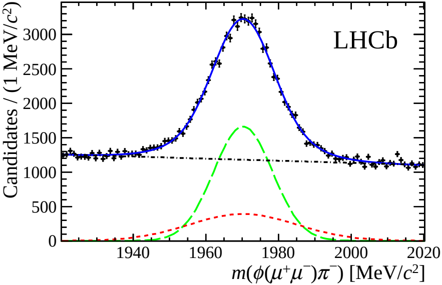


Normalization channel $D_s^+ \to \phi(\mu^+\mu^-)\pi^+$

Produced τ leptons

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

arxiv:1304.4518



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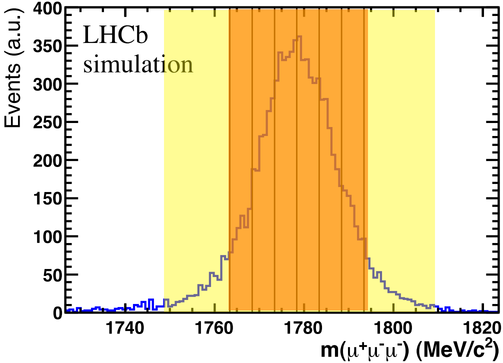
Invariant mass

- 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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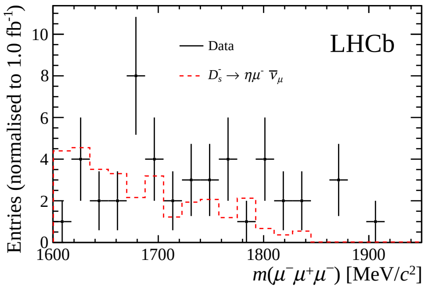
$D_s \to \eta(\mu\mu\gamma)\mu\nu$ background

- One of the main source of irreducible background for3μ is $D_s \to \eta(\mu\mu\gamma)\mu\nu$
- We simulated sample corresponding to $5fb^{-1}$ to get the corresponding pdfs.



- $\frac{1}{3}$ of events in the sensitive bins are coming from this decay.
- Pdfs looked to much like combinatorial background.
- We decided to cut this background away by using di-muon cut $M(\mu\mu) > 480MeV$.

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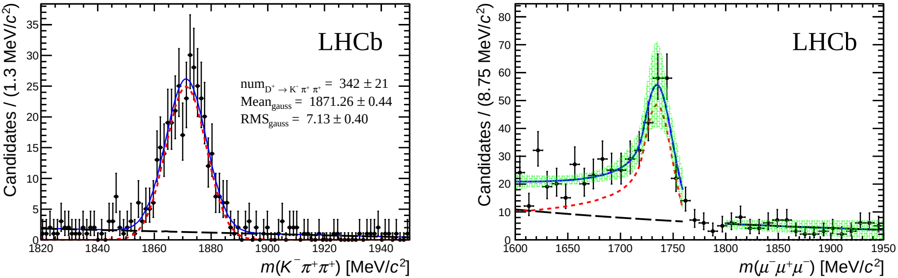
$D \to K\pi\pi$ background

- In the lowest PID bin we saw $D \to K\pi\pi$ with 3 miss-ID.
- Bins that suffer from this background are not taken into account in limit calculations.
- Negligible impact on the limit.



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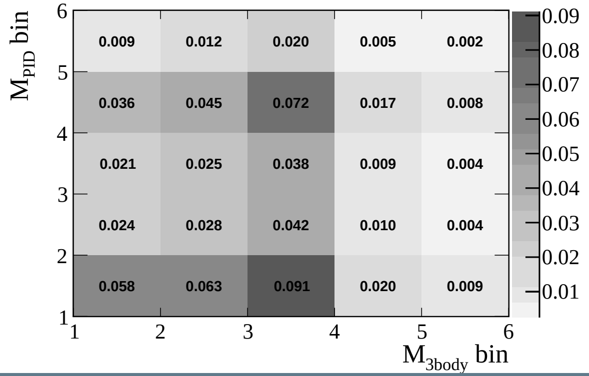
Signal likelihoods

combined signal distribution

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

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



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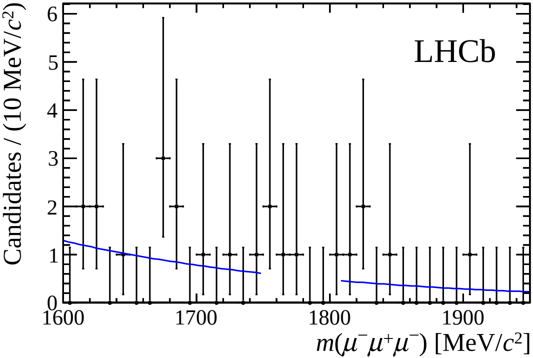
Observed events



- Analysis performed blinded.
- No evidence of signal seen after unbinding.
- Used Cls method for limit extraction.

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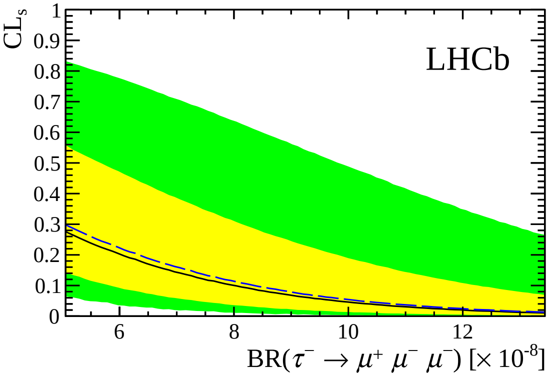
Extracted upper limit

1 fb^{-1}

arxiv: 1304.4518

	observed	expected	CL
$\mathcal{B}(\tau \to \mu\mu\mu)$	8.0×10^{-8}	8.3×10^{-8}	90%
	8.0×10^{-8}	10.2×10^{-8}	95%



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

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

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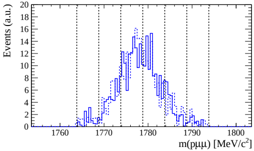
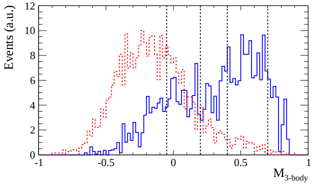
Differences

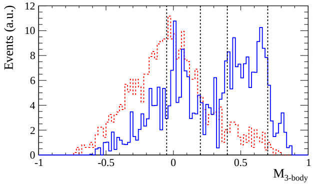
Mass distribution



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



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



- 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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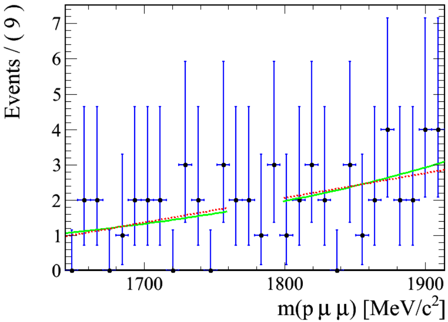
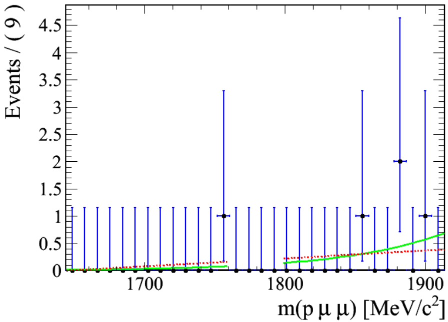
Background Fits

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



3-body BDT $(0.4, 0.7)$



3-body BDT $(0.7, 1.0)$

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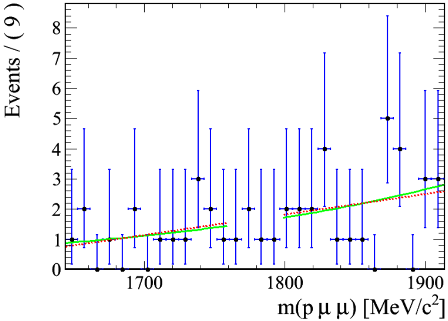
Background Fits

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



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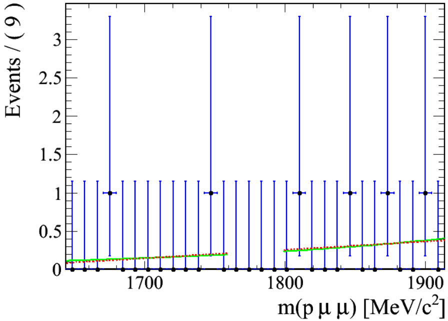

3-body BDT $(0.7, 1.0)$

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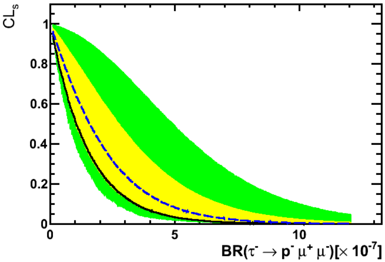
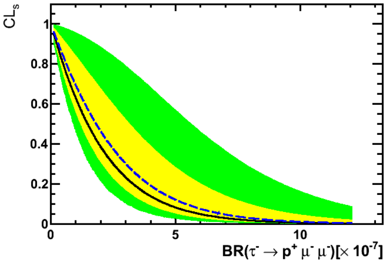
Limits on $\tau^- \to \bar{p}\mu^-\mu^+$ and $\tau^- \to p\mu^-\mu^-$





CL	Observed	Expected
90%	3.3×10^{-7} 4.4×10^{-7}	4.6×10^{-7} 5.4×10^{-7}
95%	4.3×10^{-7} 5.9×10^{-7}	5.9×10^{-7} 6.9×10^{-7}

First time measured!!

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Plans for future

- Almost all LFV models are based on flat phase space simulation.

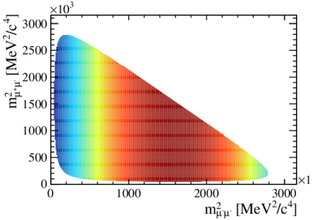
Minimal Lepton Flavour Violation Model[1]

- In effective-field-theory we introduce new operators that at electro-weak scale are compatible with $SU(2)_L \times U(1)$.
- Left handed lepton doublets add right handed lepton singlets follow the group symmetry: $G_{LF} = SU(3)_L \times SU(3)_E$.
- LFV arises from breaking this group.
- We focus on three operators that have dominant contribution to NP:
  1. Purely left handed iterations: $(\overline{L}\gamma_\mu L)(\overline{L}\gamma^\mu L)$
  2. Mix term: $(\overline{R}\gamma_\mu R)(\overline{L}\gamma^\mu L)$
  3. Radiative operator: $g'(\overline{L}H\sigma_{\mu\nu}R)B^{\mu\nu}$

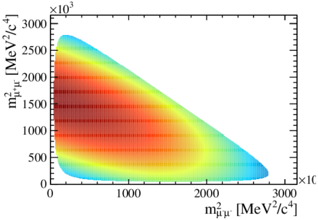
[1] arXiv:0707.0988

Dalitz plot for different scenarios

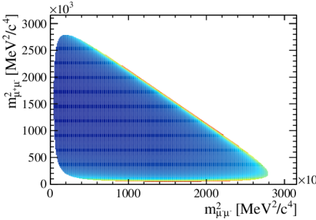
$(\overline{L}\gamma_\mu L)(\overline{L}\gamma^\mu L)$



$(\overline{R}\gamma_\mu R)(\overline{L}\gamma^\mu L)$



$g'(\overline{L}H\sigma_{\mu\nu}R)B^{\mu\nu}$



Summary

(1) 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) Very interesting studies about model dependence ongoing.

Thank you for your attention.

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Backup Slides

Backup Slides