Rare decays @ LHCb

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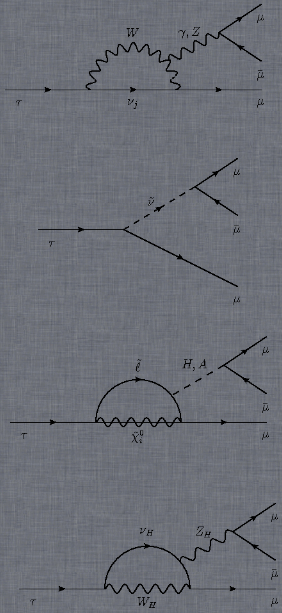
Institute of Nuclear Physics,
Polish Academy of Science,
on behalf of LHCb collaboration

7^{th} January 2013



Overwiew of LHCbs rare decays

Lepton Number Violation

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

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

τ decays

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

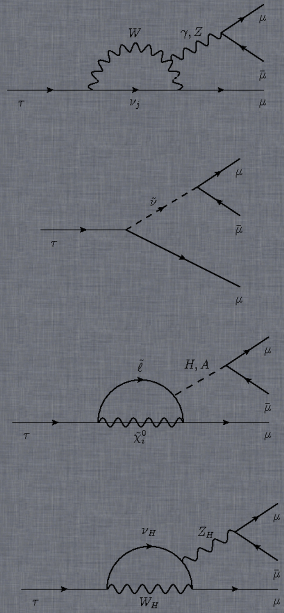
$\tau^- \to \overline{p} \mu^- \mu^+$, $\tau^- \to p \mu^- \mu^-$

Higgs Penguins

$K^0_S \to \mu\mu$

$D^0 \to \mu\mu$

$B^0_s \to \mu\mu$, $B^0 \to \mu\mu$



Rare decays LHCb

1. Lepton Flavour Lepton/Baryon Number Violating B, τ decays.
2. Precision tests of Higgs penguins.
   - Purely leptonic B, D, K decays.
3. Radiative decays.
   - CP asymmetry in $\mathrm{B}^0 \to \mathrm{K}^*\gamma$
4. New Vector or Axial couplings in EW Penguins
   - Angular analysis and CP asymmetry in $b \to s\mu\mu$ transitions.
   - Isospin asymmetry in $b \to s\mu\mu$ transitions.
   - First observation of $b \to d\mu\mu$ transition.

Discussed decays

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

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

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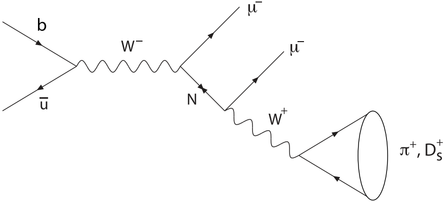
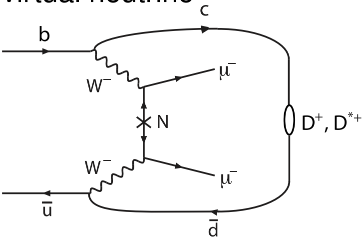
$B^- \to h^+ \mu^- \mu^-$

on-shell neutrino



- resonant production in accessible mass range
- rates depend on Majorana neutrino–lepton coupling $|V_{\mu 4}|$ (e.g. arXiv:0901.3589)
- $m_4 = m_{\ell^-,\pi^+}$

virtual neutrino



Special for B decays

Diagram without mass restriction
Cabbibo favoured for $B \to D$
Analogous to double β decay.

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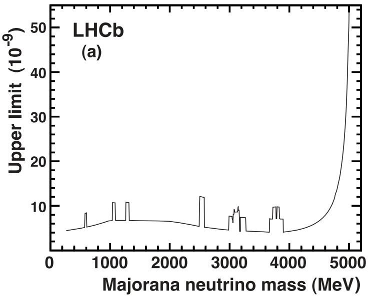
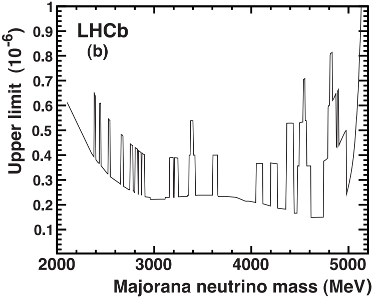
mass spectrum

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

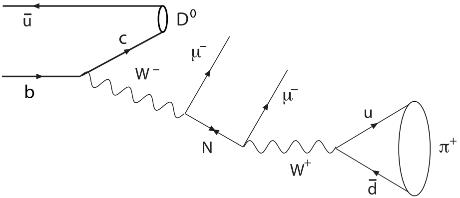
$B^- \to \pi^+\mu^-\mu^-$ $\qquad$ $B^- \to D_s{}^+\mu^-\mu^-$





Phys. Rev.D85 (2012) 112004 , $0.5 fb^{-1}$

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



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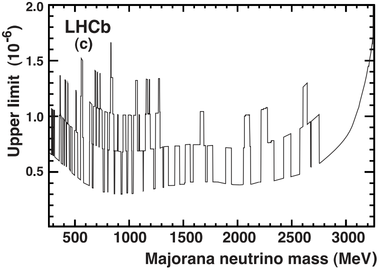
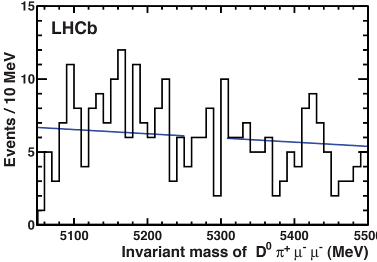
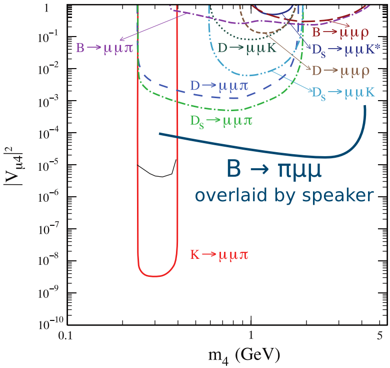
$B^- \to D^0\pi^+\mu^-\mu^-$







$\mathcal{B}(B^- \to D^0\pi^+\mu^-\mu^-) < 1.5\times10^{-6}$ @95 % CL [a]

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

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τ decays

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

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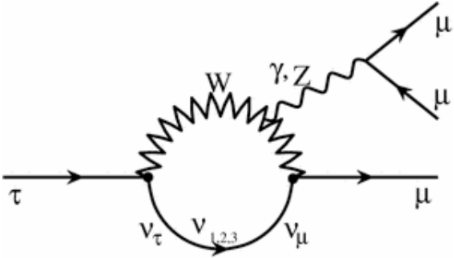
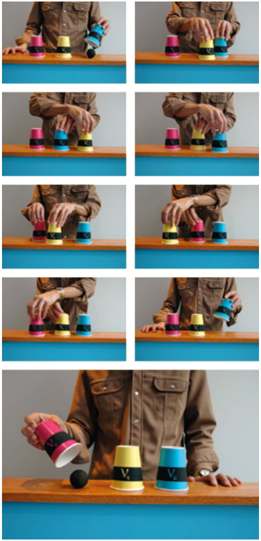
LFV in τ^- sector

$$\tau \to \mu\mu\mu$$





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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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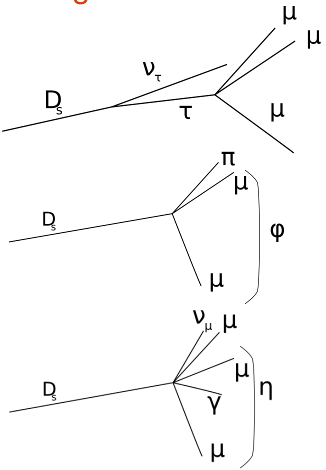
Strategy

- 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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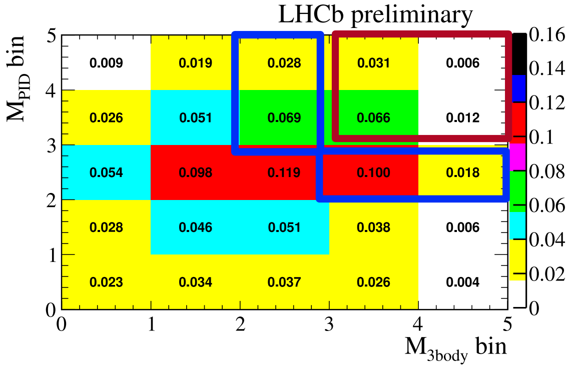
Signal likelihoods

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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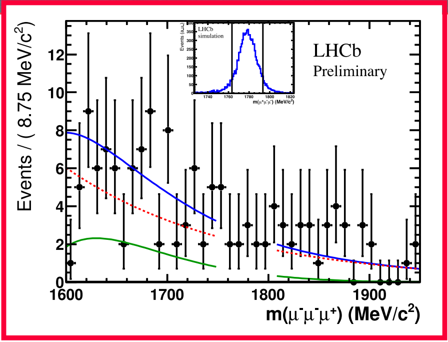
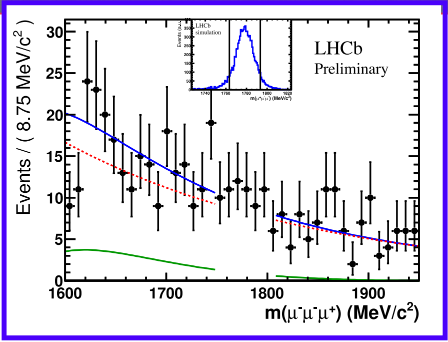
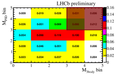
Observed events

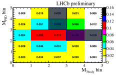




11 % of the signal
0.03 % of the background



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}

LHCb−CONF−2012−015

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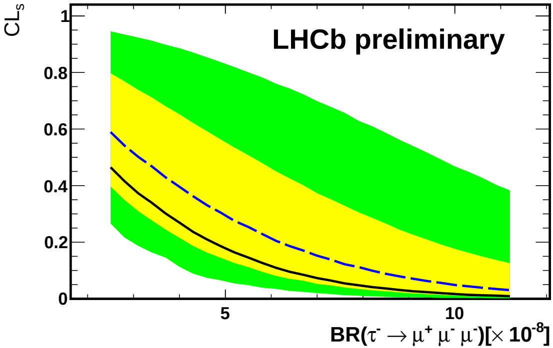
Extracted upper limit

1 fb^{-1}

LHCb-CONF-2012-015

	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%



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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 $\tau^- \to \Lambda h^-$, previously 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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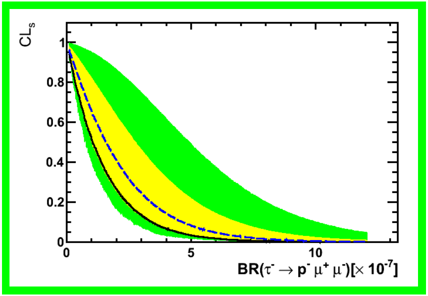
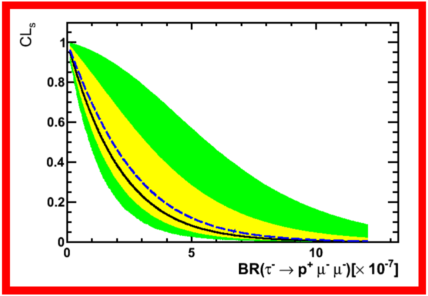
Limits on $\tau^- \to \bar{p}\mu^-\mu^+$ and $\tau^- \to p\mu^-\mu^-$





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}

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

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First time measured!!

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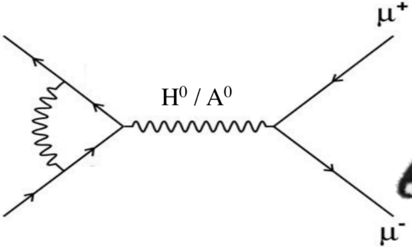
Purely leptonic decay

K_s, D^0,
B_0, B_s



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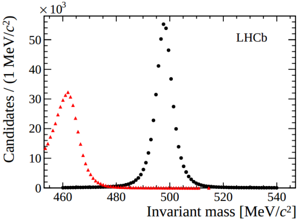
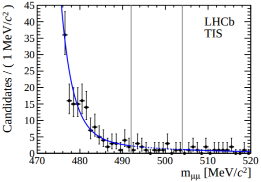
$K^0_S \to \mu\mu$

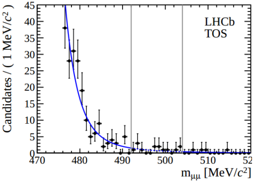
- $\mathcal{B}(K^0_S \to \mu\mu)_{SM} = (5.0 \pm 1.5) \times 10^{-12}$
- Good mass resolution enables to separate $K^0_S \to \pi\pi$ MisID peak.
- Previous limit $\mathcal{B} < 3.2 \times 10^{-7}$, PLB44 (1973) 217.
- BDT used, trained and callibrated on data.
- Background estimated from upper side bands.
- Normalization $K^0_S \to \pi\pi$.
- New LIMIT: $\mathcal{B} < 9 \times 10^{-9}$

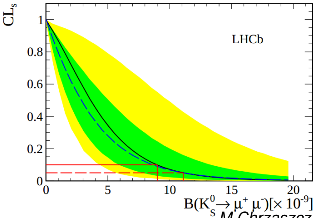
1 fb^{-1}

arXiv :1209.4029









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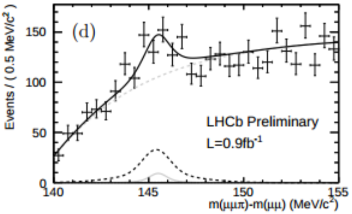
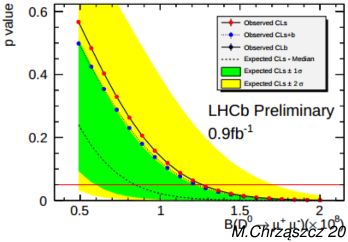
$D^0 \to \mu\mu$

$0.9\ fb^{-1}$

LHCb−CONF −2012−005

- BDT used, Good separation between c and b decays.
- Background estimated from upper side bands.
- Normalization $D^0 \to \pi\pi$, CLs method for the limit.
- 2D fit to $m(D^0)$ and $m(D^{0*} - D^0)$
- Limit: 1.3×10^{-8} 90% CL.





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A 25 years journey

DEUTSCHES ELEKTRONEN - SYNCHROTRON **DESY**

DESY 87-111
September 1987

B MESON DECAYS INTO CHARMONIUM STATES

ABSTRACT. Using the ARGUS detector at the e^+e^- storage ring DORIS II, we have studied the colour–suppressed decays $B \to J/\psi\ X$ and $B \to \psi'\ X$. We find the inclusive branching ratios for these two channels to be $(1.07 \pm 0.16 \pm 0.19)\%$ and $(0.46 \pm 0.17 \pm 0.11)\%$ respectively. From a sample of reconstructed exclusive events the masses of the B^0 and B^+ mesons are determined to be $(5279.5 \pm 1.6 \pm 3.0)\ MeV/c^2$ and $(5278.5 \pm 1.8 \pm 3.0)\ MeV/c^2$ respectively. Branching ratios are determined from five events of the type $B^0 \to J/\psi\ K^{*0}$ and three of $B^+ \to J/\psi\ K^+$. In the same data sample a search for $B^0 \to e^+e^-$, $\mu^+\mu^-$ and $\mu^\pm e^\mp$ leads to upper limits for such decays.

Table 2 Upper limits for exclusive dilepton decays.

decay channel	upper limit with 90% CL
$B^0 \to e^+e^-$	$8.5 \cdot 10^{-5}$
$B^0 \to \mu^+\mu^-$	$5.0 \cdot 10^{-5}$
$B^0 \to e^\pm\mu^\mp$	$5.0 \cdot 10^{-5}$

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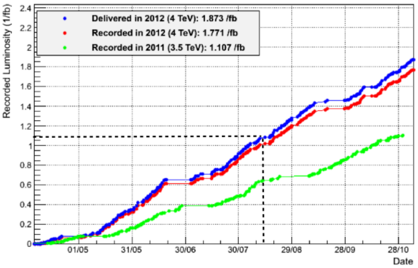
Datasets

1. Analyses done using 2011 and 2012 data.
   - 2011: 1.0fb^{-1} at *7 TeV*
   - 2012: 1.1fb^{-1} at *8 TeV*
2. Previous analyses done with 2011 data only.
3. Published PRL108(2012)231801
4. Results:
   - $\mathcal{B}(B_s^0 \to \mu\mu) < 4.9 \times 10^{-9}$
   - $\mathcal{B}(B^0 \to \mu\mu) < 1.0 \times 10^{-9}$
5. New analysis implements improvements.



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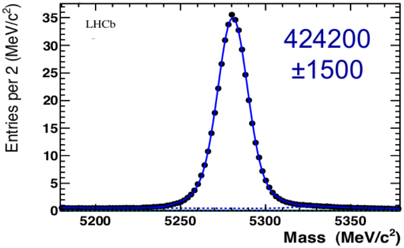
Analysis

1. Selection
   - Loose selection, for reducing data size.
   - Similar for control channels.
2. Normalization
   - Makes result more stable.
   - Channels: $B^+ \to J/\psi K^+$ and $B^+ \to hh$
3. Signal likelihoods
   - Same as for 2011 analysis.
4. Invariant mass resolutions:
   - $\sigma(\mathrm{B^0_s} \to \mu\mu) = 25.04 \pm 0.4$
   - $\sigma(\mathrm{B^0} \to \mu\mu) = 24.63 \pm 0.38$
   - comparable to 2011.



- Callibration channel & yield.
- Main bck $bb \to \mu\mu\gamma$
- Number of expected bck extrapolated from sidebands.
- Improved description of peaking background.

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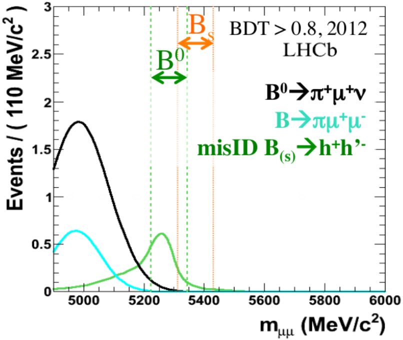
Peaking background

1. Improvement of combinatorial background interpolation by inclusion of exclusive decays in the fit.
   - Only $B_s^0 \to hh$ in the mass window (same as 2011).
   - Mass shapes different from exponential
     - $B^0 \to \pi\mu\nu$
     - $B^+ \to \pi^+\mu\mu$, $B^0 \to \pi^0\mu\mu$
   - Negligible contribution to signal window.
2. Exclusive backgrounds parameters used in fit as priors.
   - Mass shape from MC
   - Normalized to $B^+ \to J/\psi K^+$



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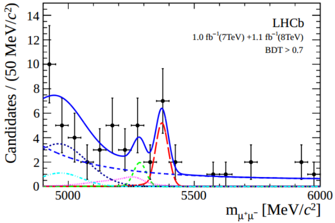
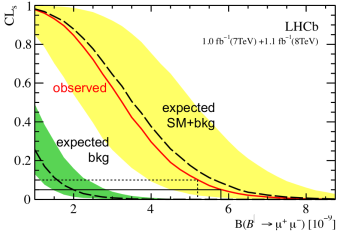
Results

2.1 fb^{-1}

arXiv :1211.2674

- RESULT:
  $\mathcal{B}(\mathrm{B}_s^0 \to \mu\mu) = 3.2^{+1.5}_{-1.2} \times 10^{-9}$
  $\mathcal{B}(\mathrm{B}^0 \to \mu\mu) < 9.4 \times 10^{-10}$
  SM predictions:
  $\mathcal{B}(\mathrm{B}_s^0 \to \mu\mu) = 3.54 \pm 0.3 \times 10^{-9}$
  Buras, Isidori: arXiv:1208.0934
  $\mathcal{B}(\mathrm{B}^0 \to \mu\mu) = 0.1 \pm 0.01 \times 10^{-9}$
  Buras, Isidori: arXiv:1012.1447
- 3.5σ significance.
- Double sided limit 95% CL.
  $1.1 \times 10^{-9} < \mathcal{B}(\mathrm{B}_s^0 \to \mu\mu) < 6.4 \times 10^{-9}$
- FIRST EVIDENCE OF SIGNAL





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Summary

1. First Evidence of $B_s^0 \to \mu\mu$, after 25 years of searches.
2. World's best limits for $B^0 \to \mu\mu$, $D^0 \to \mu\mu$, $K_S^0 \to \mu\mu$
3. Strongest constraints on Majorana neutrino coupling.
4. First searches for LFV in hadron colliders.
5. First search for $\mathcal{B}(\tau \to p\mu\mu)$.
6. Stay tuned for new results!

Thank you for your attention.

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

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Backup Slides

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Summary on LNV in B decays

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)
[e] LHCb, Phys. Rev. Lett. 108 101601 (2012)

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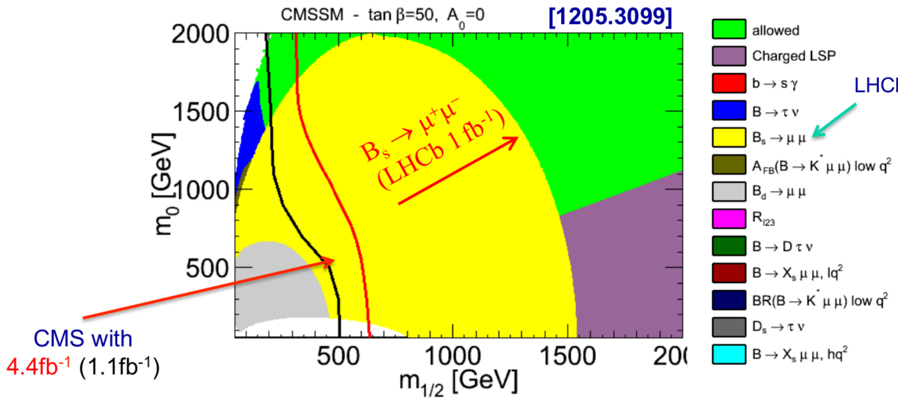

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