Lepton Number Violation (Experiment)

15th September 2011

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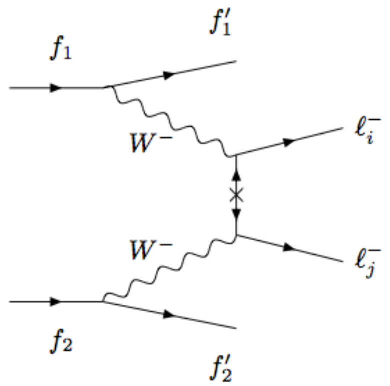
LHCb

Introduction

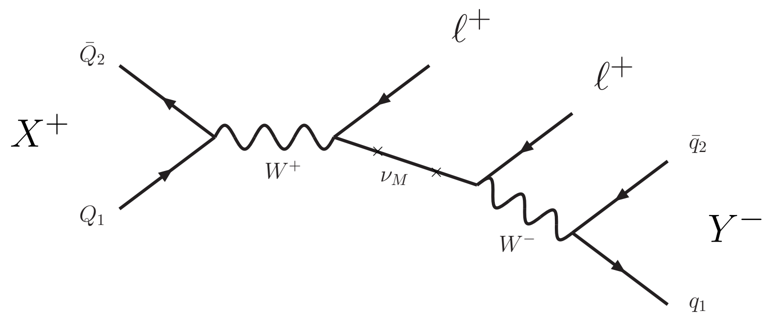
- Lepton number violating processes can occur in a number of NP models

  e.g. 4^{th} generation(1), left-right symmetric models(2), SO(10) SUSY GUT(3), other GUTs(4), models with exotic Higgs(5), Extra Dimensions(6)…

- Involve Majorana mass terms – classic way of searching for Majorana ν, $0\nu\beta\beta$ decay (Prof. Biller, next talk)



- An alternative, processes such as $M_1^+ \to M_2^- l_1^+ l_2^+$



(1) arXiv:hep-ph/1106.0343
(2) J. C. Pati and A. Salam, Phys. Rev. D10, 275 (1974)
(3) arXiv:hep-ph/9501298
(4) arXiv:hep-ph/0504276
(5) A. Zee, Phys. Lett. B93, 389 (1980)
(6) arXiv:hep-ph/981144

$M_1^+ \to M_2^- l_1^+ l_2^+$ as a probe of LNV

- Processes $M_1^+ \to M_2^- l_1^+ l_2^+$
  - as for $0\nu\beta\beta$ decay, absent in SM, $\Delta L=2$, lepton number violating processes
  - get resonant production in presence of Majorana ν with mass in kinematically accessible range
  - Rates depend on Majorana Neutrino-lepton coupling V_{l4}

    see e.g. [Pascoli *et al.*, arXiv:0901.3589v2]

$$M_1^+(q_1) \to \ell^+(p_1)\ \ell^+(p_2)\ M_2^-(q_2).$$

Pseudoscalar case

$$\begin{aligned} i\mathcal{M}^P &= 2G_F^2 V_{M_1}^{CKM} V_{M_2}^{CKM} f_{M_1} f_{M_2} V_{\ell_1 4} V_{\ell_2 4}\, m_4 \\ &\times \left[\frac{\overline{u_{\ell_1}}\, \not{q}_1\, \not{q}_2 P_R v_{\ell_2}}{(q_1-p_1)^2 - m_4{}^2 + i\Gamma_{N_4} m_4}\right] + (p_1 \leftrightarrow p_2), \end{aligned}$$

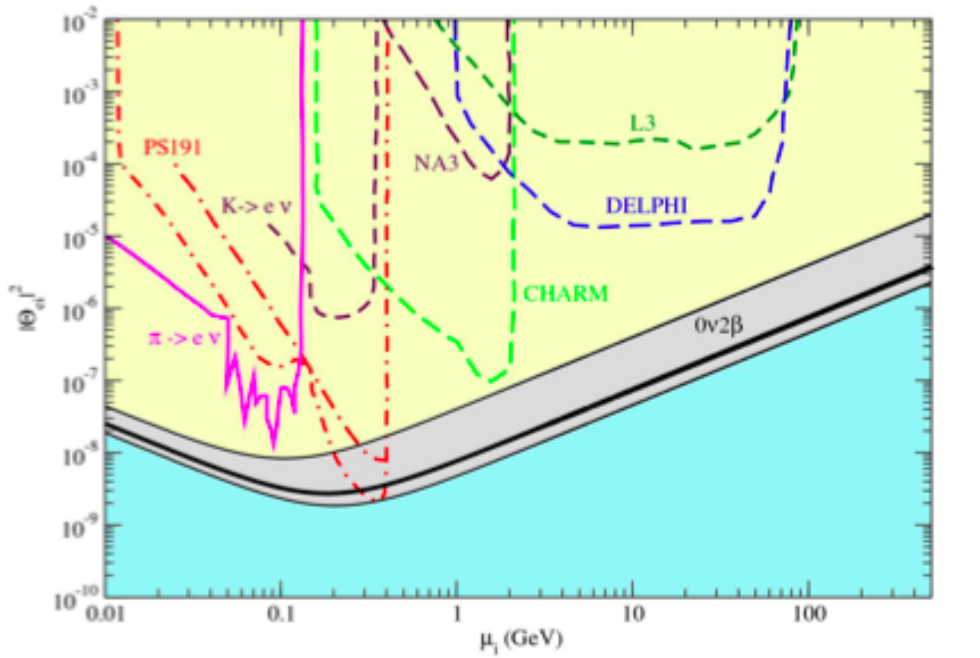
Vector case

$$\begin{aligned} i\mathcal{M}^V &= 2G_F^2 V_{M_1}^{CKM} V_{M_2}^{CKM} f_{M_1} f_{M_2} V_{\ell_1 4} V_{\ell_2 4}\, m_4\, m_{M_2} \\ &\times \left[\frac{\overline{u_{\ell_1}}\, \not{q}_1\, \not{\epsilon}^\lambda(q_2) P_R v_{\ell_2}}{(q_1-p_1)^2 - m_4{}^2 + i\Gamma_{N_4} m_4}\right] + (p_1 \leftrightarrow p_2), \end{aligned}$$

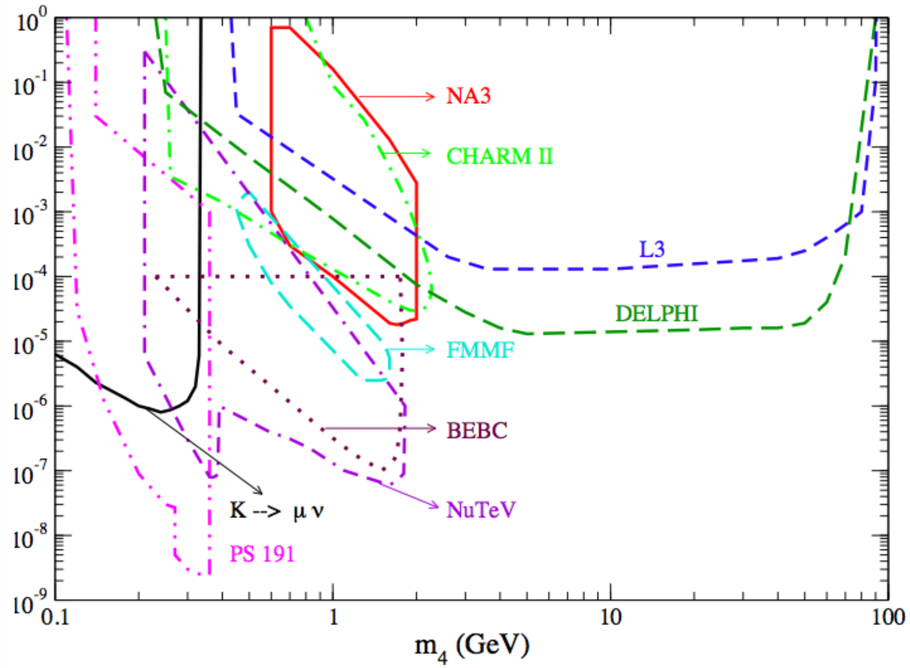
- Decays $B \to Dll\pi$ also recently studied [N. Quintero *et al.*, arXiv:1108.6009v1]

Experimental Status

- Strong constraints from π, K decays, less so from D and B decays



From, Mitra *et al.*, arXiv:1108.0004 $\mu = m_N$

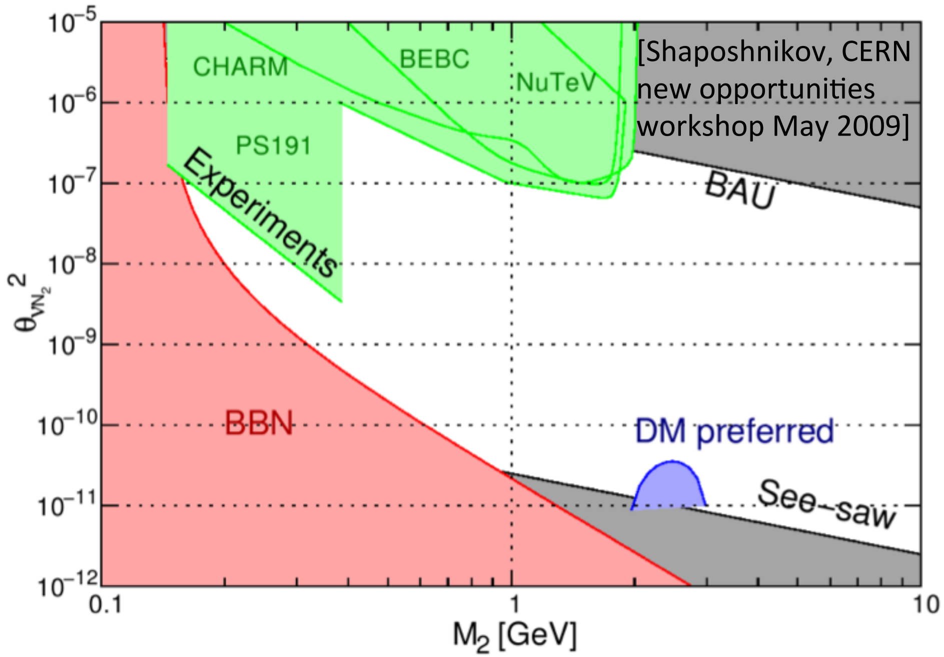


From, Pascoli *et al.*, arXiv:0901.3589v2

- In region where D,B decays can have resonant enhancement, $|V_{e4}|^2$ probed at 10^{-7} level, $|V_{\mu4}|^2$ probed at $10^{-7} \rightarrow 10^{-4}$ level
- However, region accessible to B, D processes may still be of interest…

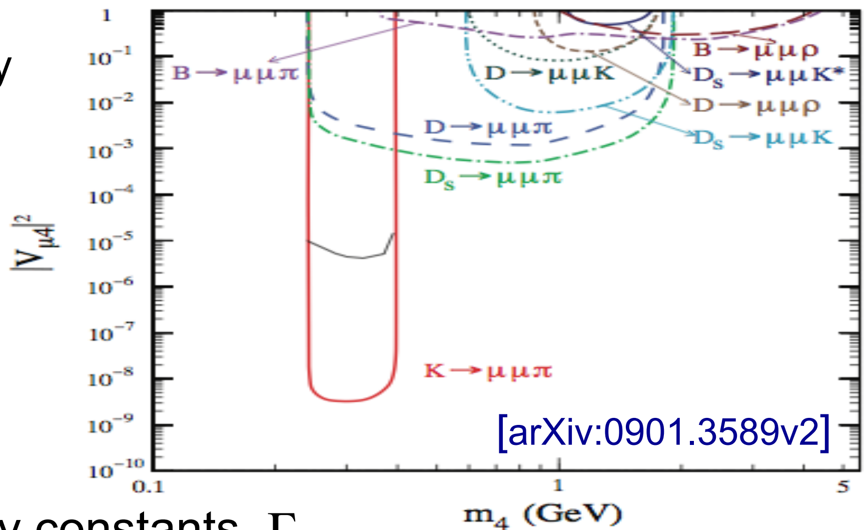
The nuMSM

- The nuMSM [Shaposhnikov *et al.*, Phys.Lett.B631:151-156,2005]
  - "minimal" addition to SM which is consistent with cosmological observations (BAU, BBN, seesaw)
  - Adds three sterile Majorana neutrinos
    - Lightest is dark matter candidate ~10 keV
    - Heavier two involved in generating baryon asymmetry → masses O(0.1-10) GeV
  - Doesn't solve fine-tuning or hierarchy problem



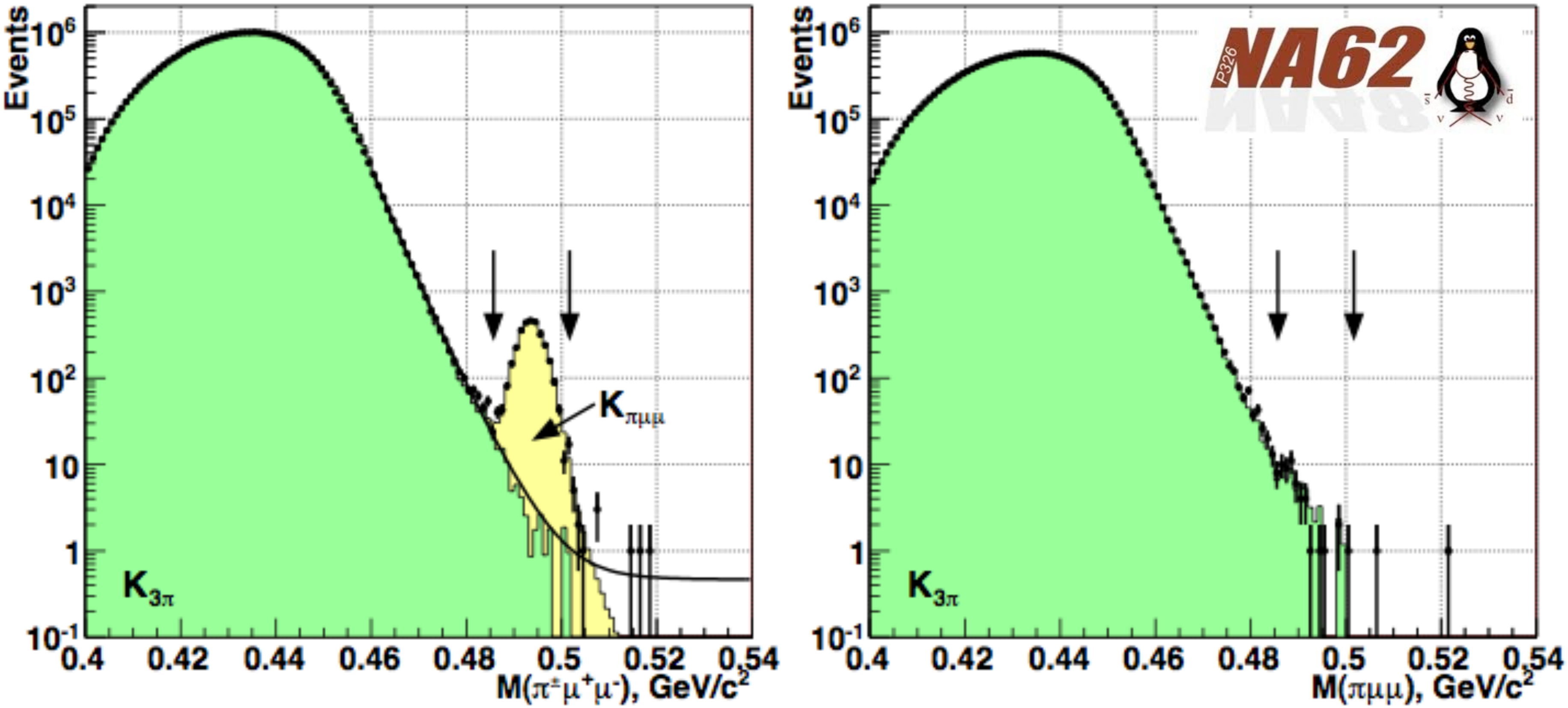
$$\mathrm{Br}(K) \sim |V^{CKM}_{M_1} V^{CKM}_{M_2}|^2 \ |V_{\ell_1 4} V_{\ell_2 4}|,$$
$$\mathrm{Br}(D,\ B) \sim 10^{-4} \ \ |V^{CKM}_{M_1} V^{CKM}_{M_2}|^2 \ |V_{\ell_1 4} V_{\ell_2 4}|,$$
$$\mathrm{Br}(D_s) \sim 10^{-5} \ |V^{CKM}_{M_1} V^{CKM}_{M_2}|^2 \ |V_{\ell_1 4} V_{\ell_2 4}|.$$

assumptions RE: m_4, decay constants, Γ_4



Branching Ratio Limits

- In K decays limits from NA62 experiment now at 10^{-9} level

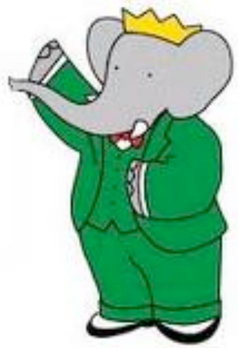


$\longrightarrow$ BR($K^{\pm} \rightarrow \pi^{\mp}\mu^{\pm}\mu^{\pm}$) < 1.1×10^{-9} at 90% CL

Branching Ratio Limits

- In D decays limits from BaBar at 10^{-6} level ($384 fb^{-1}$) [arXiv:1107.4465v1]

Decay mode	Yield (events)	Eff. (%)	BR UL 90% CL (10^{-4})	BF UL 90% CL (10^{-6})
$D^+ \to \pi^- e^+ e^+$	$4.7 \pm 4.7 \pm 0.5$	3.16	6.8	1.9
$D^+ \to \pi^- \mu^+ \mu^+$	$-3.1 \pm 1.2 \pm 0.5$	0.70	7.5	2.0
$D^+ \to \pi^- \mu^+ e^+$	$-5.1 \pm 4.2 \pm 2.0$	1.72	7.4	2.0
$D_s^+ \to \pi^- e^+ e^+$	$-5.7 \pm 14. \pm 3.4$	6.84	1.8	4.1
$D_s^+ \to \pi^- \mu^+ \mu^+$	$0.6 \pm 5.1 \pm 2.7$	1.05	6.2	14
$D_s^+ \to \pi^- \mu^+ e^+$	$-0.2 \pm 7.9 \pm 0.6$	2.23	3.6	8.4
$D^+ \to K^- e^+ e^+$	$-2.8 \pm 2.4 \pm 0.2$	2.67	3.1	0.9
$D^+ \to K^- \mu^+ \mu^+$	$7.2 \pm 5.4 \pm 1.6$	0.80	37	10
$D^+ \to K^- \mu^+ e^+$	$-11.6 \pm 4.0 \pm 3.1$	1.52	6.8	1.9
$D_s^+ \to K^- e^+ e^+$	$2.3 \pm 7.9 \pm 3.3$	4.10	2.1	5.2
$D_s^+ \to K^- \mu^+ \mu^+$	$-2.3 \pm 5.0 \pm 2.8$	0.98	5.3	13
$D_s^+ \to K^- \mu^+ e^+$	$-14.0 \pm 8.4 \pm 2.0$	2.26	2.4	6.1
$\Lambda_c^+ \to \bar{p} e^+ e^+$	$-1.5 \pm 4.2 \pm 1.5$	5.14	0.4	2.7
$\Lambda_c^+ \to \bar{p} \mu^+ \mu^+$	$-0.0 \pm 2.1 \pm 0.6$	0.94	1.4	9.4
$\Lambda_c^+ \to \bar{p} \mu^+ e^+$	$10.1 \pm 5.8 \pm 3.5$	2.50	2.3	16



Branching Ratio Limits

- Limits from CLEO (BaBar) with 9.6 (230)×10^6 BB decays

CLEO PRD 65, 111102(R) (2002)

Decay mode	Significance of Signal	Upper Limit (10^{-6})
$B \to K e^{\pm}\mu^{\mp}$	0.0σ	1.6
$K^{*} e^{\pm}\mu^{\mp}$	2.0σ	6.2
$\pi e^{\pm}\mu^{\mp}$	0.0σ	1.6
$\rho e^{\pm}\mu^{\mp}$	0.6σ	3.2
$B^{+} \to K^{-} e^{+} e^{+}$	0.0σ	1.0
$K^{*-} e^{+} e^{+}$	0.0σ	2.8
$\pi^{-} e^{+} e^{+}$	0.0σ	1.6
$\rho^{-} e^{+} e^{+}$	1.1σ	2.6
$B^{+} \to K^{-} e^{+}\mu^{+}$	0.0σ	2.0
$K^{*-} e^{+}\mu^{+}$	0.0σ	4.4
$\pi^{-} e^{+}\mu^{+}$	0.0σ	1.3
$\rho^{-} e^{+}\mu^{+}$	0.3σ	3.3
$B^{+} \to K^{-}\mu^{+}\mu^{+}$	0.0σ	1.8
$K^{*-}\mu^{+}\mu^{+}$	0.5σ	8.3
$\pi^{-}\mu^{+}\mu^{+}$	0.0σ	1.4
$\rho^{-}\mu^{+}\mu^{+}$	1.0σ	5.0

5.1×10^{-7}
3.8×10^{-8}
9.2×10^{-8}

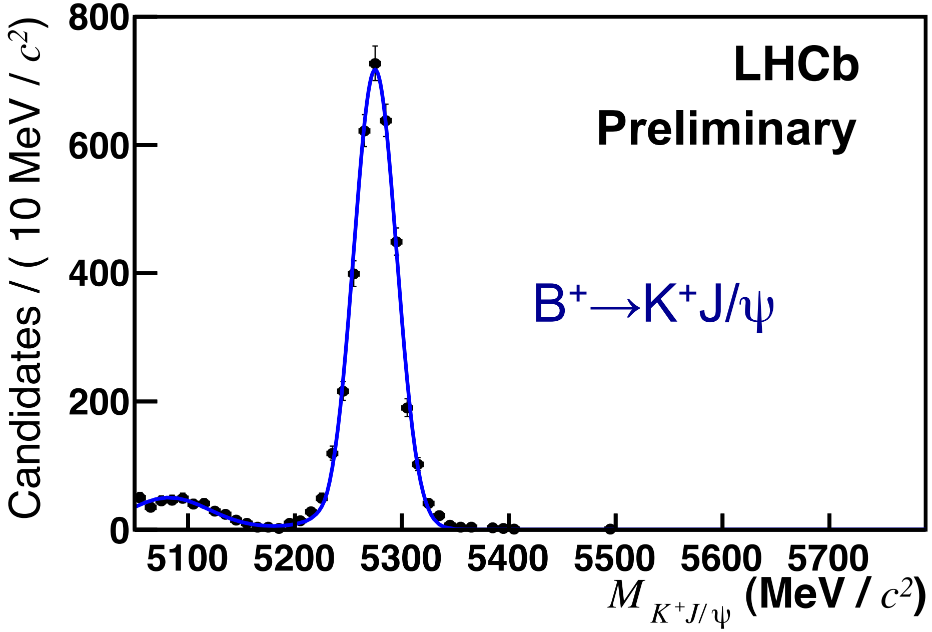
PRD 73, 092001 (2006)

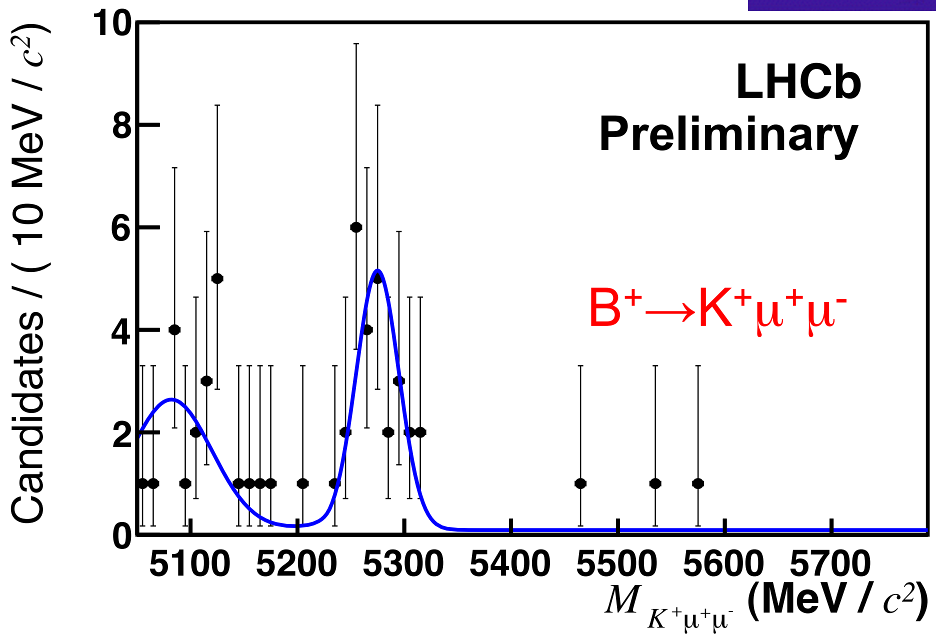
PRL 99, 051801 (2007)

Even the first LHC data should allow extension of these searches …

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

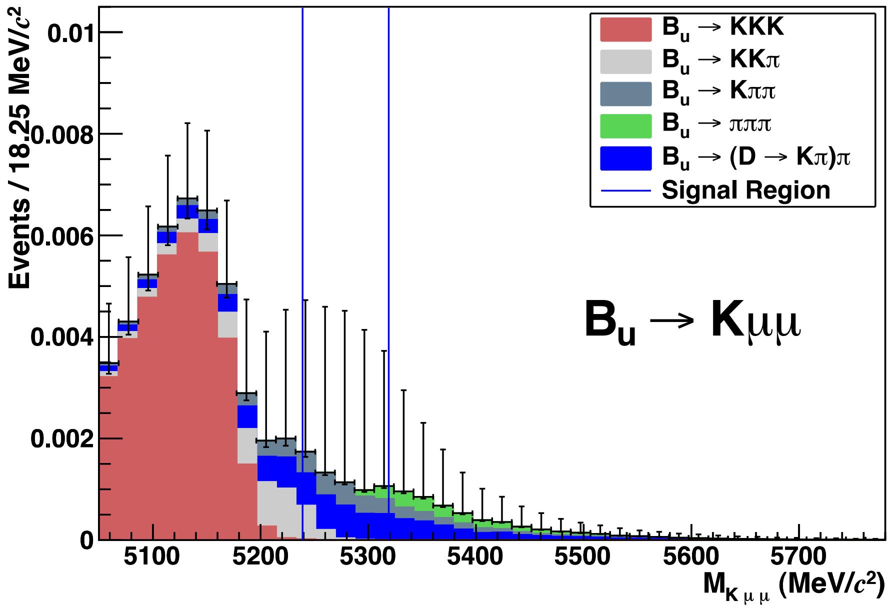
- Analysis performed with 36pb^{-1} of LHCb data taken during 2010
- Select $B^+ \to h^- \mu^+ \mu^+$ candidates and use $B^+ \to K^+ J/\psi$ as a normalisation mode
  - Develop selection criteria using $B^+ \to K^+ J/\psi$ as a proxy for the signal mode, events in $B^+ \to K^+ \mu^+ \mu^-$ upper mass sideband as proxy for bkgrd
  - Check sensitivity by searching for the $B^+ \to K^+ \mu^+ \mu^-$ rare decay signal

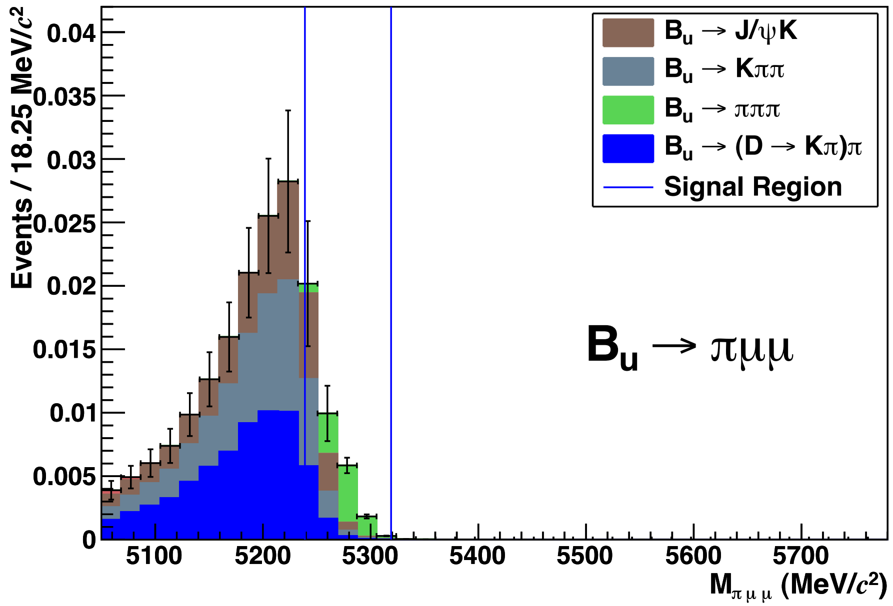




Peaking Backgrounds

- Peaking backgrounds from B decays to hadronic final states, final states with a J/ψ and semileptonic final states are considered
  - Mass shapes from simulation
  - Mis-id rates derived from control channels which provide unambiguous and pure source of particles of known type e.g. $D^* \rightarrow D^0(K\pi)\pi$





$B^+ \to h^- \mu^+ \mu^+$ Results with $36 pb^{-1}$

- Observed signal / background
  - <0.3 (0.1) bkgrd evts expected in $\pi\mu\mu$ ($K\mu\mu$)
  - No events observed in signal or mass sideband regions

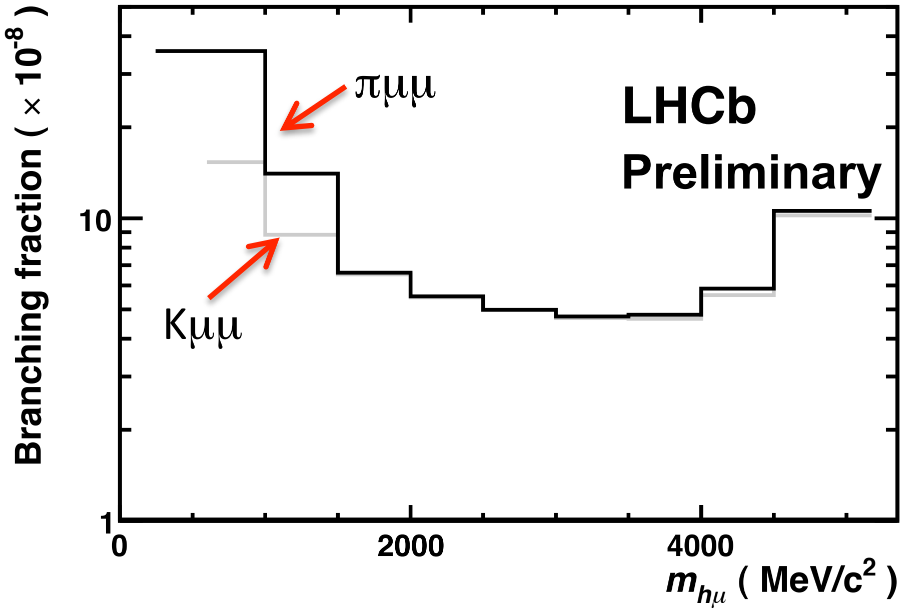
- Observed limit @ 90% CL

  $BR(B^+ \to K^- \mu^+ \mu^+) < 4.3 \times 10^{-8}$

  $BR(B^+ \to \pi^- \mu^+ \mu^+) < 4.5 \times 10^{-8}$

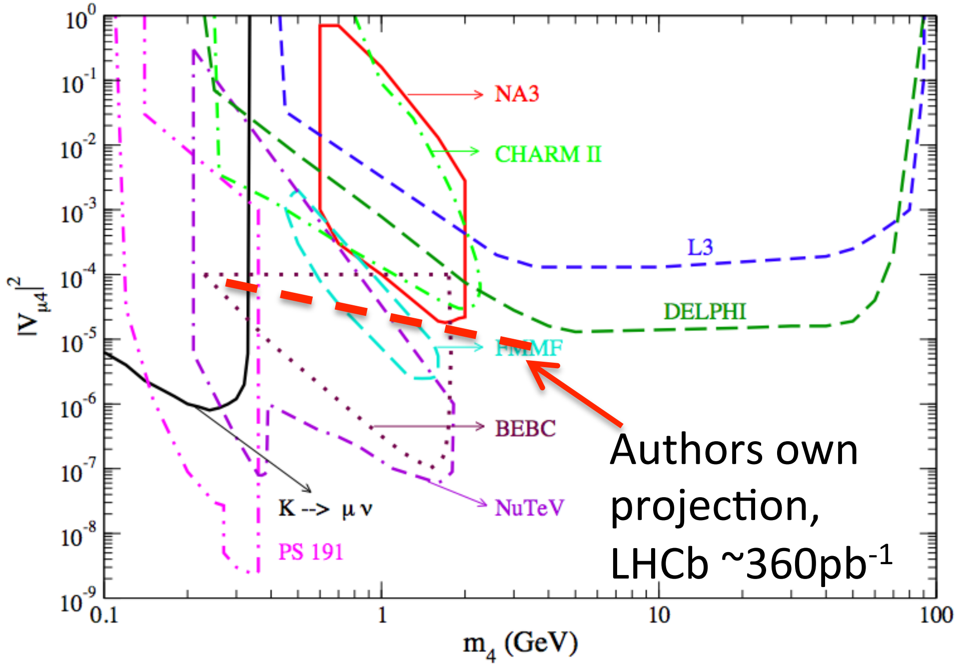
- Factor 40(30) improvement cf previous best limit (CLEO)

- Variation of efficiency with Majorana neutrino mass, $m_{h\mu}$ →



Future Results

- Present analysis with 36pb^{-1} of data, 10× this already being analysed, expect ~1000pb^{-1} collected by winter conferences
- Given background expectation already fraction of an event, with 10× more data limit should improve like $1/\sqrt{L}$
- Expect analysis will be extended to other channels e.g.
  $B^+ \to D^-\mu^+\mu^+$, $B^+ \to D^0\mu^+\mu^+\pi^+$,
  $B^+ \to D_s^-\mu^+\mu^+$, $B^+ \to D^{*-}\mu^+\mu^+$



- D decays also under study, expect factor 100 improvement of present limits → probe BFs down to O(10^{-8})

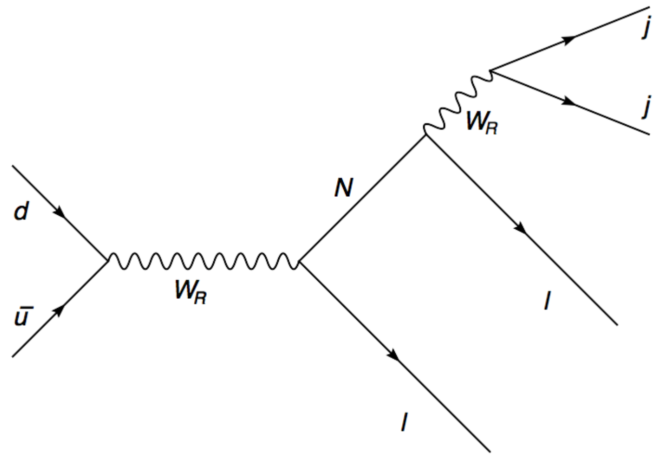
Searches at Central Detectors

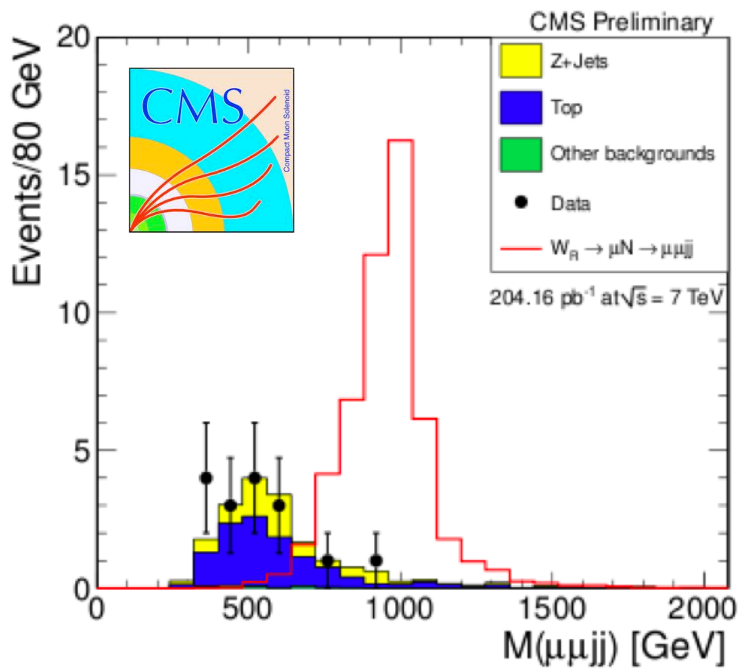
- L-R symmetric model: restores parity at higher energies by introducing new heavy charged bosons

- Central detectors at LHC searching for lepton number violating processes mediated by right-handed W-boson, W_R

- Search for two jets and two same-sign leptons

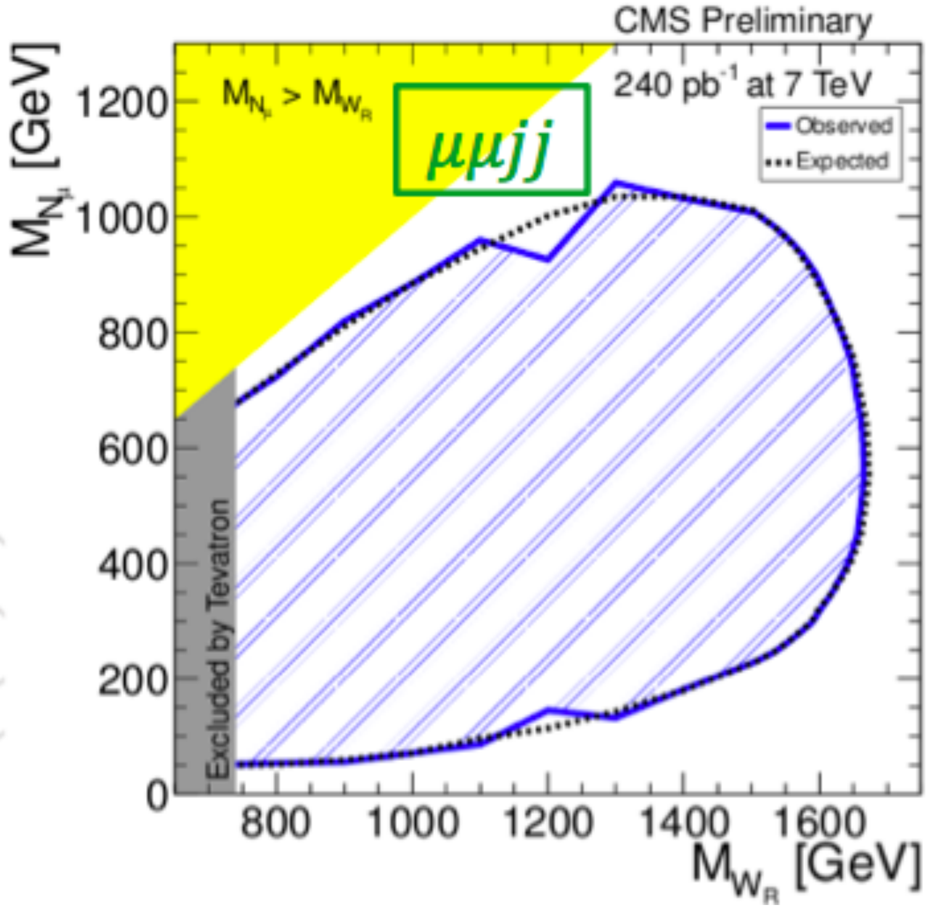
- CMS analysis of 204pb^{-1}, no excess cf bkgrd expectation [PAS EXO-11-002]





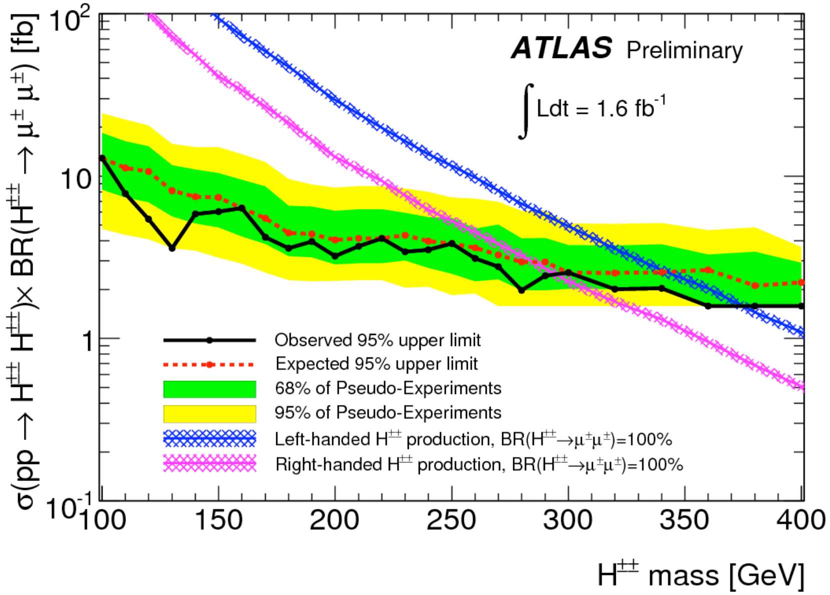
Searches at Central Detectors

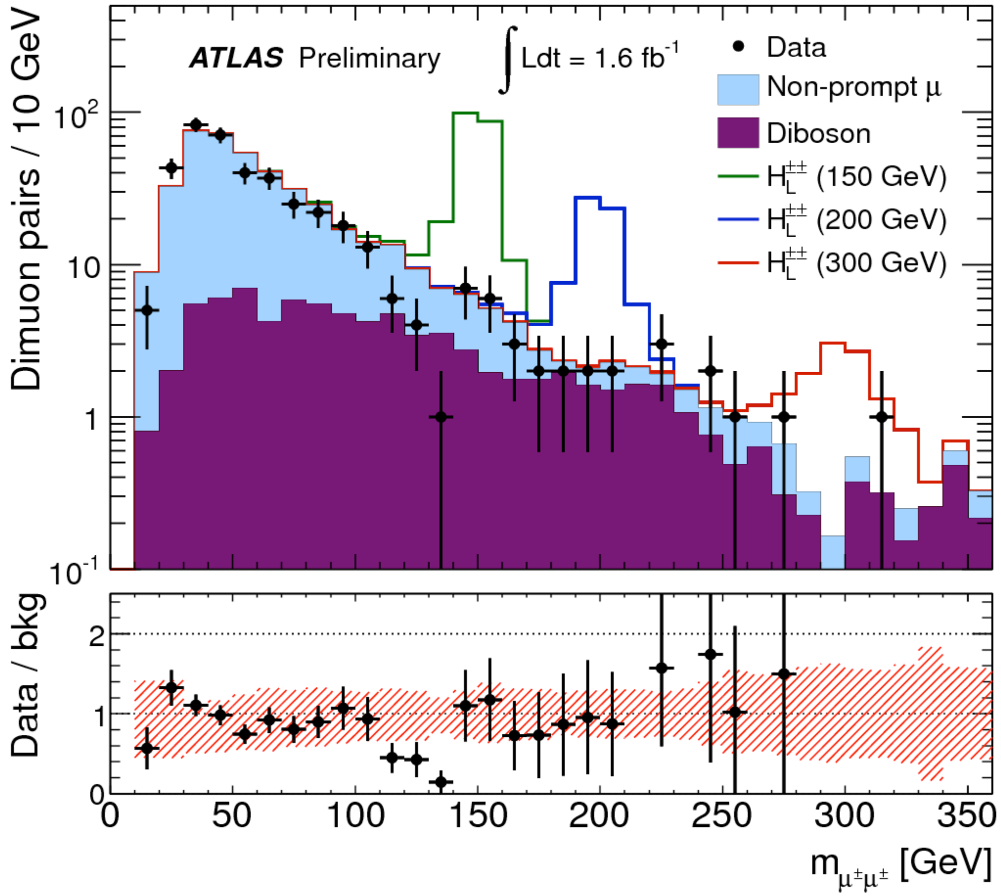
- Assuming SM-like couplings and no interference with other bosons, lower bound on m_{WR} at 1.7 TeV (for m_{Nl}~500GeV)



Searches at Central Detectors

- Another LNV signature: doubly charged Higgs, Δ^{++} decaying leptonically
- Search performed at ATLAS with 1.6 fb^{-1} [ATLAS-CONF-2011-127]
- No evidence for signal,





The Future

- Both direct and indirect searches at LHC will clearly improve with more data

- Super-B factories should be able to look at B-meson decay modes already mentioned as well as those involving $e^+\mu^+$ or e^+e^+
  - Assuming $50ab^{-1}$, $1/\sqrt{L}$ gives factor ~15 improvement: few $10^{-8} \rightarrow 10^{-9}$

- Some questions for the theory community :
  - No attempt yet to look at Λ_B decays (also B violating) – also of interest?
  - Is there any reason to pursue the neutral modes e.g. $B^0 \rightarrow D^-\pi^-\mu^+\mu^+$, or $K^-\pi^-\mu^+\mu^+$, or $\pi^-\pi^-\mu^+\mu^+$ e.g. http://arxiv.org/abs/1108.6009 ?
  - Is τ^+l^+ of interest? (again presumably easier at Super-B factories but should also be possible at LHCb)

Conclusions

- LNV decays interesting probes of a number of models
- Existing searches constrain e.g. $(m_4, V_{\mu 4})$ plane for "low" m_4
- LHCb starting to extend these searches
- Central detectors placing increasingly stringent limits on heavy right-handed W bosons and other particles that can mediate LNV decays