12th Workshop on τ Lepton Physics

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Lepton number violating τ decays

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Motivations

- Majorana ν's ⇔ Lepton Number Violation $\overline{\nu_R^c} M_M \nu_R + \overline{\nu_R} M_M^+ \nu_R^c$
- Searches for Lepton Number Violation (|ΔL|=2)
  - $(A, Z) \to (A, Z+2) e^- e^-$
  - $M_1^\pm \to M_2^\mp l^\pm l'^\pm, \quad (M = meson)$
  - $\tau^\pm \to l^\mp M_1^\pm M_2^\pm$
  - $\Sigma^- \to \Sigma^+ e^- e^-, \quad \Xi^- \to p \mu^- \mu^-$
  - $l^- \to l'^+ \quad conversion\ in\ nuclei$
  - $pp, p\bar{p} \to l^\pm l'^\pm X$

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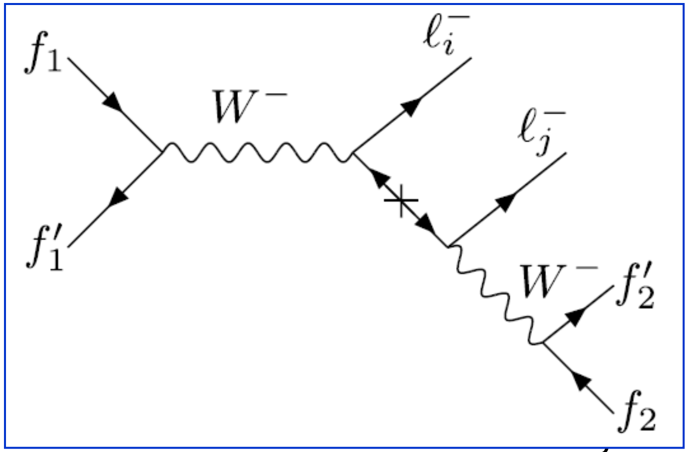
- Very light neutrinos → $\langle m_{ll'} \rangle = \Sigma_i U_{il} U_{l'i} m_i$,
- Very heavy neutrinos→ $\Sigma_k V_{lk} V_{l'k} / m_k$,
- Resonant neutrinos → $\Sigma_k V_{lk} V_{l'k} m_k / \Gamma_N$

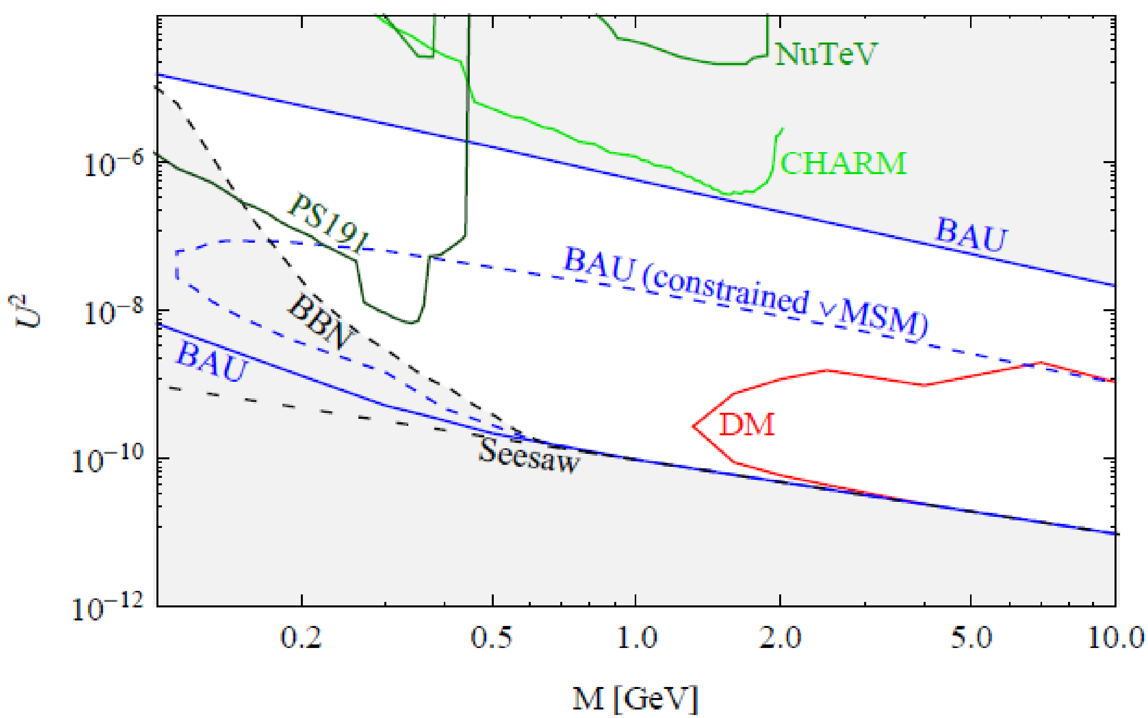


- Neutrino minimal Standard Model (νMSM)= SM + 3 RH sterile ν's (sterile ν's couple to matter only via mixing with active ν's)

$$\nu_l = \sum_{i=1}^{3} U_{li}\nu_i + \sum_{N=4}^{n+4} V_{lN}\nu_N$$

M. Shaposhnikov et al (around 20 papers in last 7 years); most recent 1208.4607 [hep-ph]

$$M = m_{N_{2,3}} \sim O(1GeV), \qquad BAU$$



νMSM may explain DM, BAUand ν oscillations, simultaneously

"Strong constraints, not achievable even at (super)flavor factories"!

New decay channels of interest at (super)flavor factories:

$$\tau^- \to \nu_\tau l^- l'^- M^+; \qquad l, l' = \mu, e$$

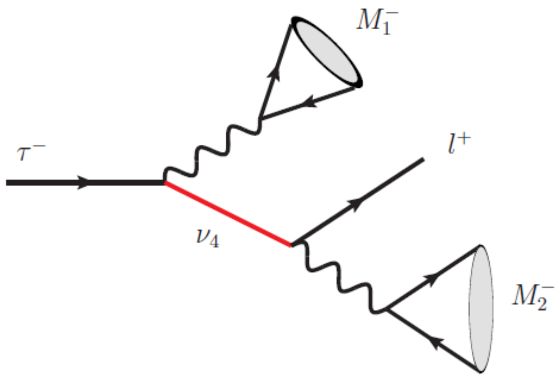
$$M = \pi, K, \rho, K^*$$

$$B^0 \to D^- l^+ l'^+ M^- \qquad l, l' = e, \mu, \tau$$

$$M = \pi, \rho, K, \cdots$$

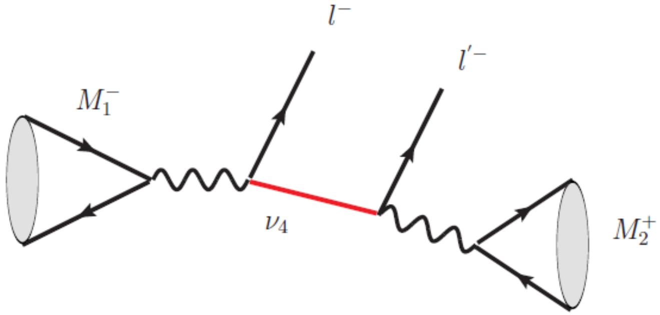
- **D. Delepine, GLC, NQuintero, PRD84, 096011 (2011);**
- **N. Quintero and GLC, PRD85, 076006 (2012)**

LNV in 3-body decays of mesons and τ's



Assumption: Only 1 heavy neutrino dominates

$$\sim G_F^2 V_{\tau 4} V_{l4} m_4 F_{RES} V_{M_1}^{CKM} V_{M_2}^{CKM} f_{M_1} f_{M_2}$$



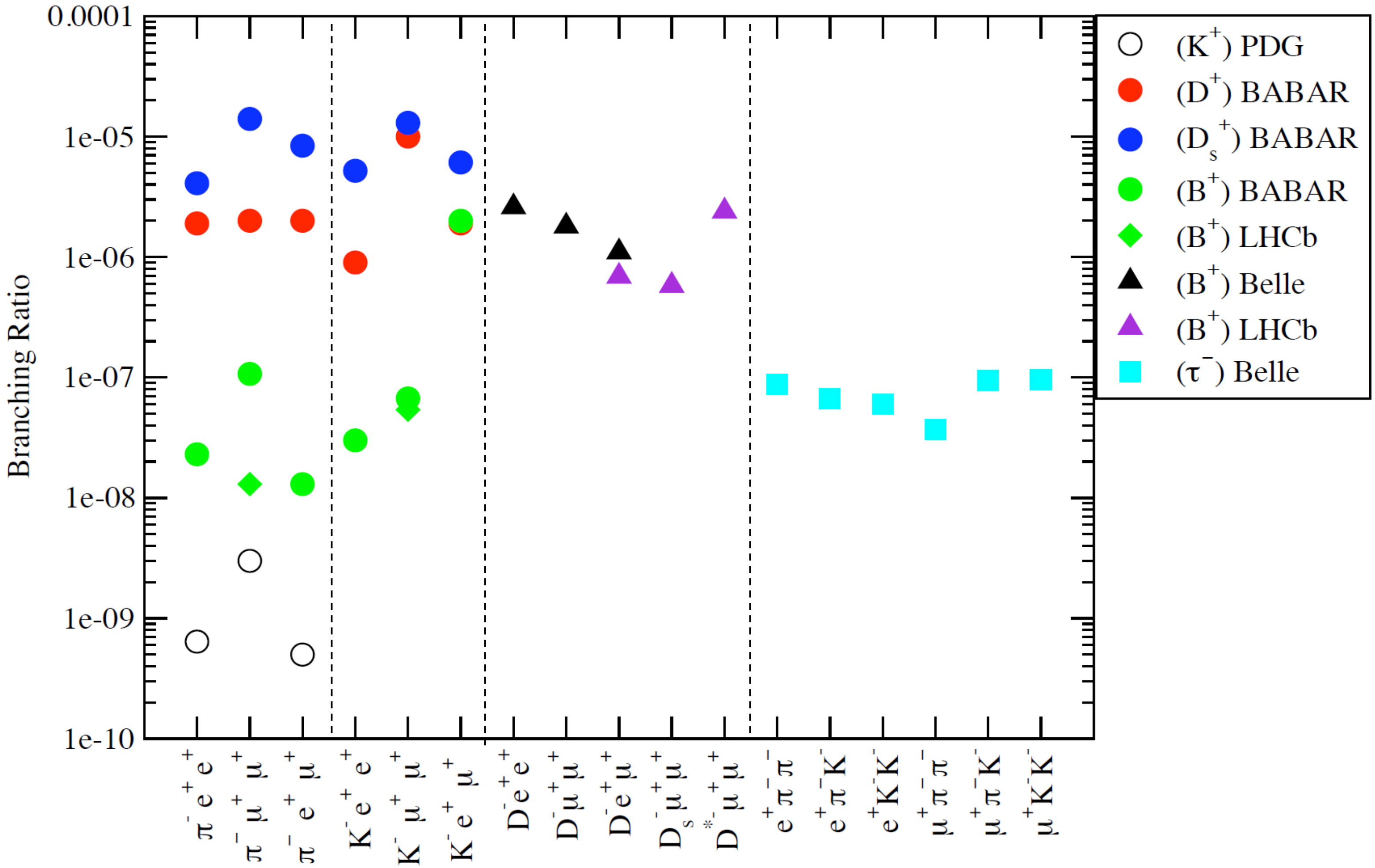
$$\sim G_F^2 V_{l4} V_{l'4} m_4 F_{RES} V_{M_1}^{CKM} V_{M_2}^{CKM} f_{M_1} f_{M_2}$$

$$F_{RES} \sim \left(q^2 - m_4^2 + i m_4 \Gamma_4\right)^{-1}$$

Resonance enhancement

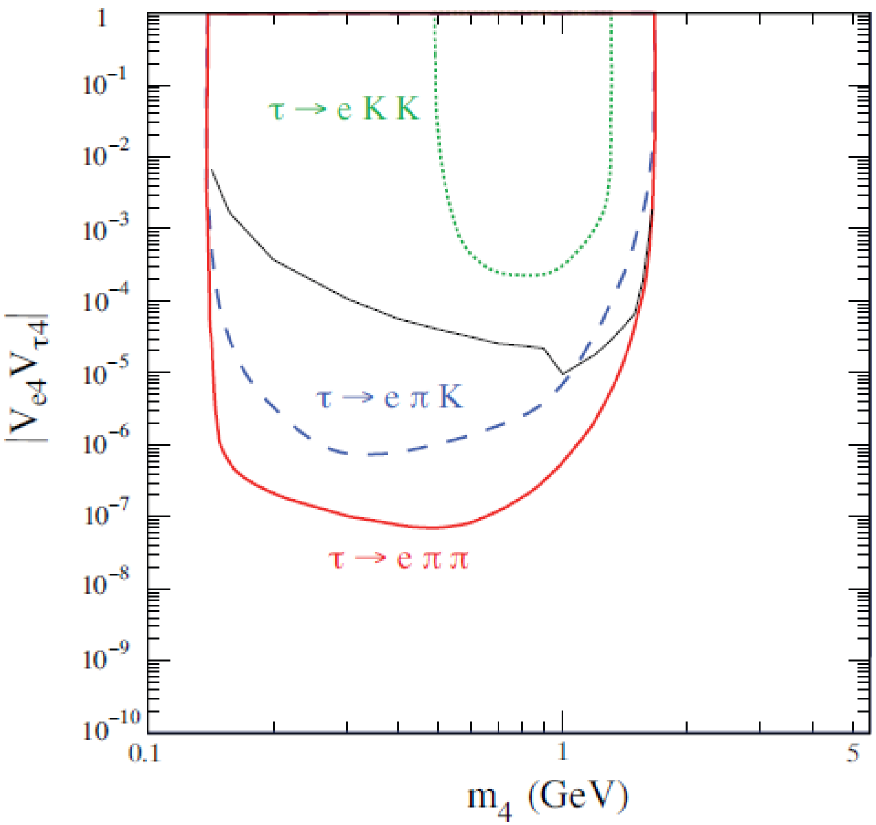
Atre, Han, Pascoli, & Zhang, JHEP 0905, 030 (2009)
Helo, Kovalenko, & Schmidt, NPB853, 80 (2011)
Zhang & Wang, EPJC 71, 1715 (2011)
Gribanov, Kovalenko & Schmidt, NPB607, 355 (2001).

UL's on charged meson and τ^- LNV 3-body decays

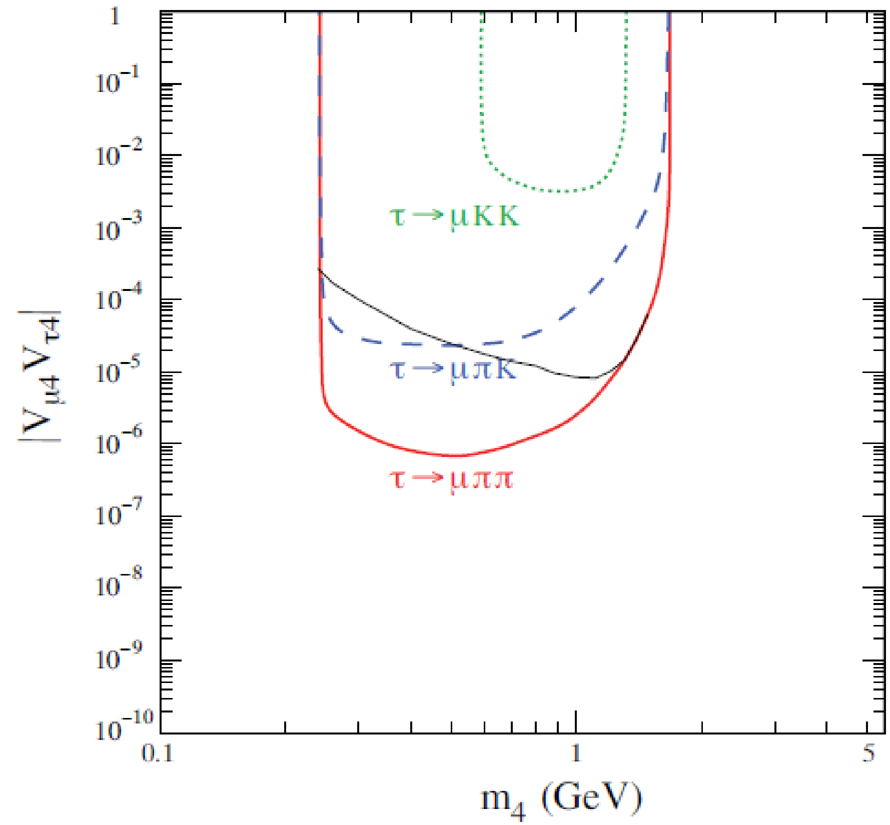


- J. P. Lees et al (BABAR Collab), PRD 84 (2011); PRD 85 (2012)
- R. Aaij et al (LHCb Collab), PRL 108 (2012); PRD 85 (2012)
- O. Seon et al (Belle Collab) PRD 84 (2011)
- Y. Miyazaki et al (Belle Collab) PLB 682 (2010)

$\tau^- \to e^+ M_1^- M_2^-$



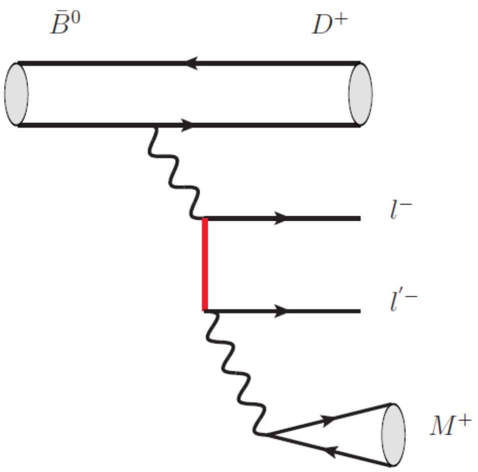
$\tau^- \to \mu^+ M_1^- M_2^-$



Atre, Han, Pascoli, & Zhang, JHEP **0905**, 030 (2009)
Helo, Kovalenko, & Schmidt, NPB**853**, 80 (2011).

Bounds on the product $V_{l4}V_{\tau 4}$ only

LNV 4-body decays of neutral B mesons



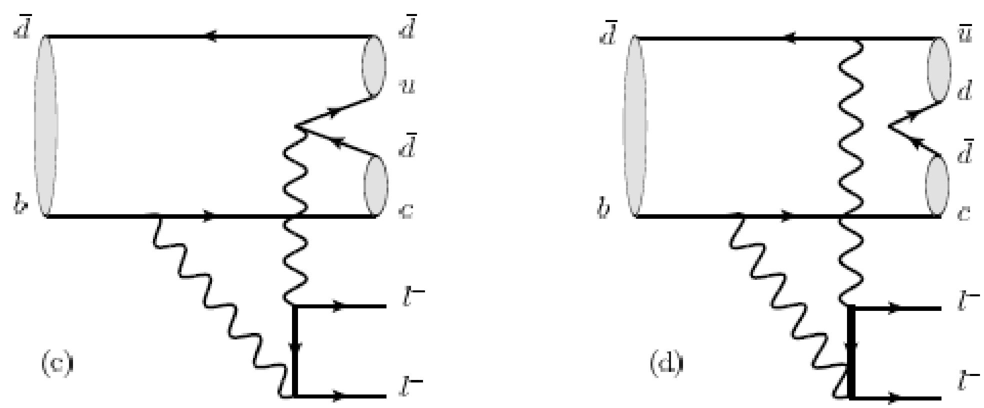
$$\sim G_F^2 V_{lN} V_{l'N} F_{RES} V_{cb}^{CKM} V_{ud}^{CKM} \, f_\pi F_+^{B\to D}(Q^2)$$

CKM allowed

Different dynamics

Delepine, GLC, Quintero, PRD84 (2011)

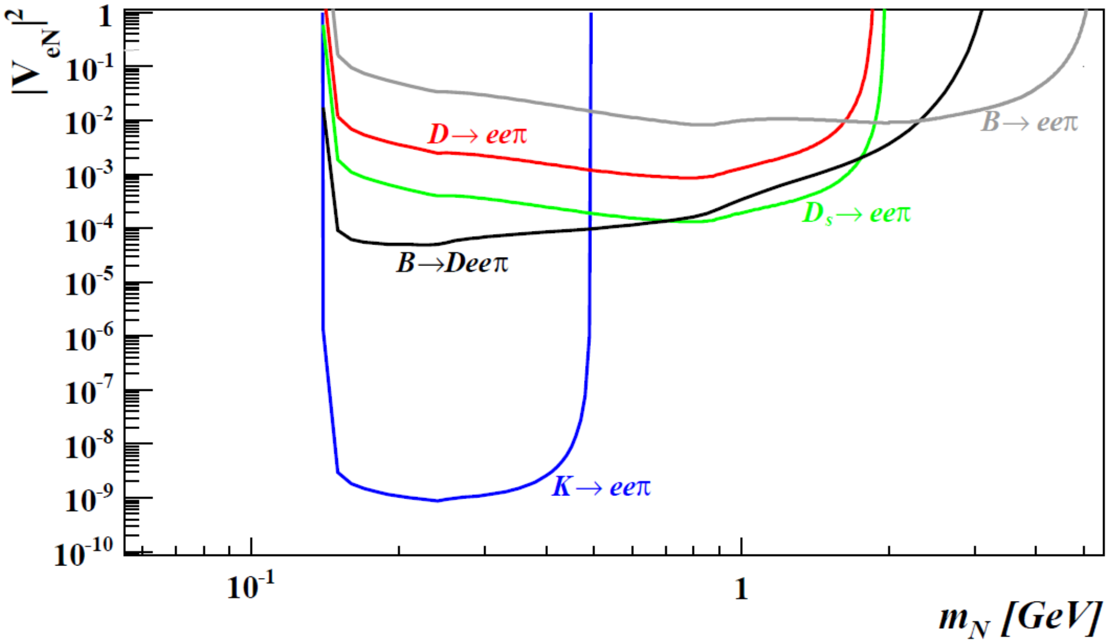
Disadvantage:
loop contributions

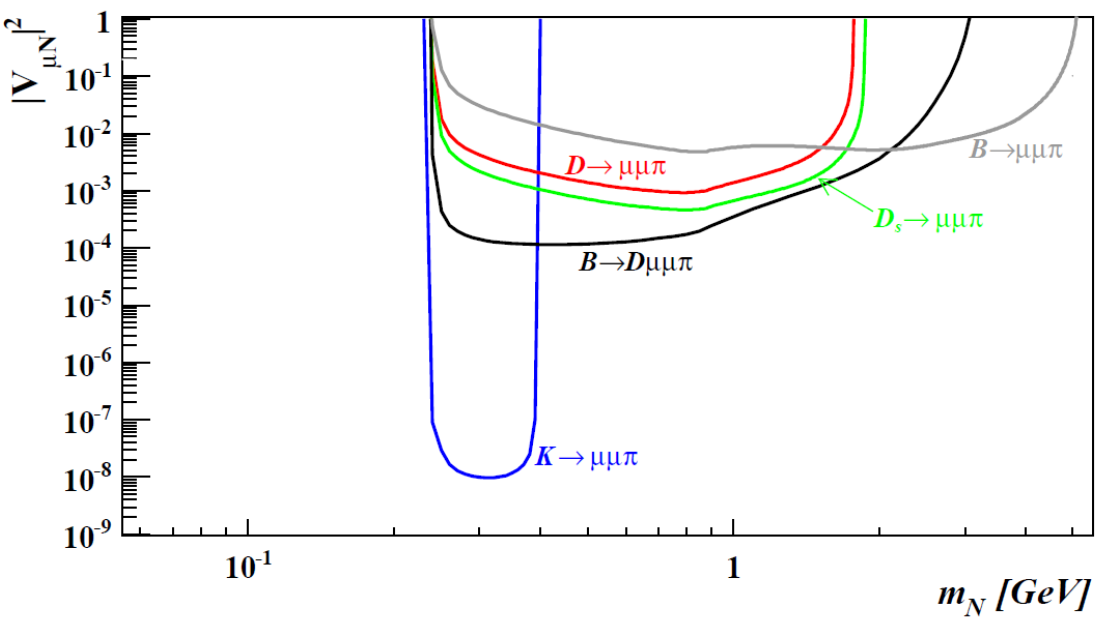


Current upper limits for 4-body decays

Channel	BR (UL)	Collaboration
$D^0 \to \pi^- \pi^- \mu^+ \mu^+$	2.9×10^{-5}	E791 (2001)
$D^0 \to \pi^- \pi^- e^+ e^+$	1.1×10^{-4}	E791 (2001)
$D^0 \to \pi^- \pi^- \mu^+ e^+$	7.9×10^{-5}	E791 (2001)
$D^0 \to K^- \pi^- \mu^+ \mu^+$	3.9×10^{-4}	E791 (2001)
$D^0 \to K^- \pi^- e^+ e^+$	2.1×10^{-4}	E791 (2001)
$D^0 \to K^- \pi^- \mu^+ e^+$	2.2×10^{-4}	E791 (2001)
$D^0 \to K^- K^- \mu^+ \mu^+$	9.4×10^{-5}	E791 (2001)
$D^0 \to K^- K^- e^+ e^+$	1.5×10^{-4}	E791 (2001)
$D^0 \to K^- K^- \mu^+ e^+$	5.7×10^{-5}	E791 (2001)
$B^- \to D^0 \pi^+ \mu^- \mu^-$	1.5×10^{-6}	LHCb (2012)

- **E. M. Aitala et al (E791 Collab), PRL86 (2001)**
- **R. Aaij et al (LHCb Collab), PRD 85 (2012)**





Assuming:

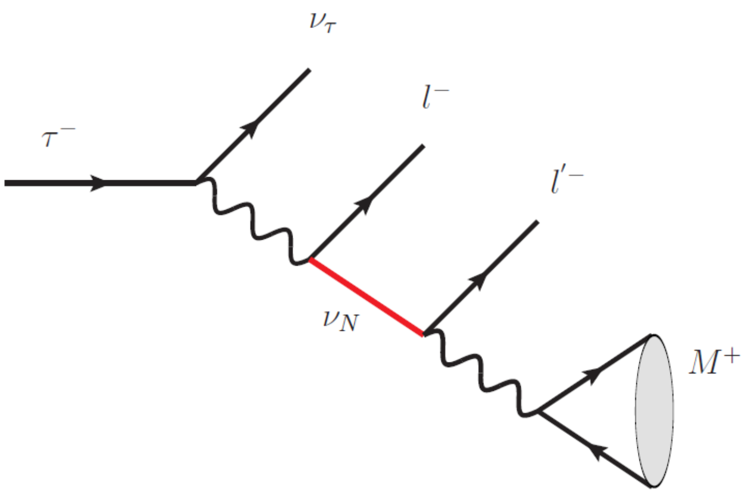
$BR(B^0 \to D^+ l^- l^- M^+) \leq 10^{-7}$

Form factors $B \to D$ from:

- Lattice Fermilab & MILC, arXiv: 1202.6364 ; BABAR, PRL 104 (2010)

Delepine, GLC, Quintero, PRD84 (2011)
Erratum to be submitted

LNV 4-body decays of τ's



$$\sim G_F^2 V_{lN} V_{l'N} m_N F_{RES} V_M^{CKM} f_M$$

ℓ, ℓ'=e, μ

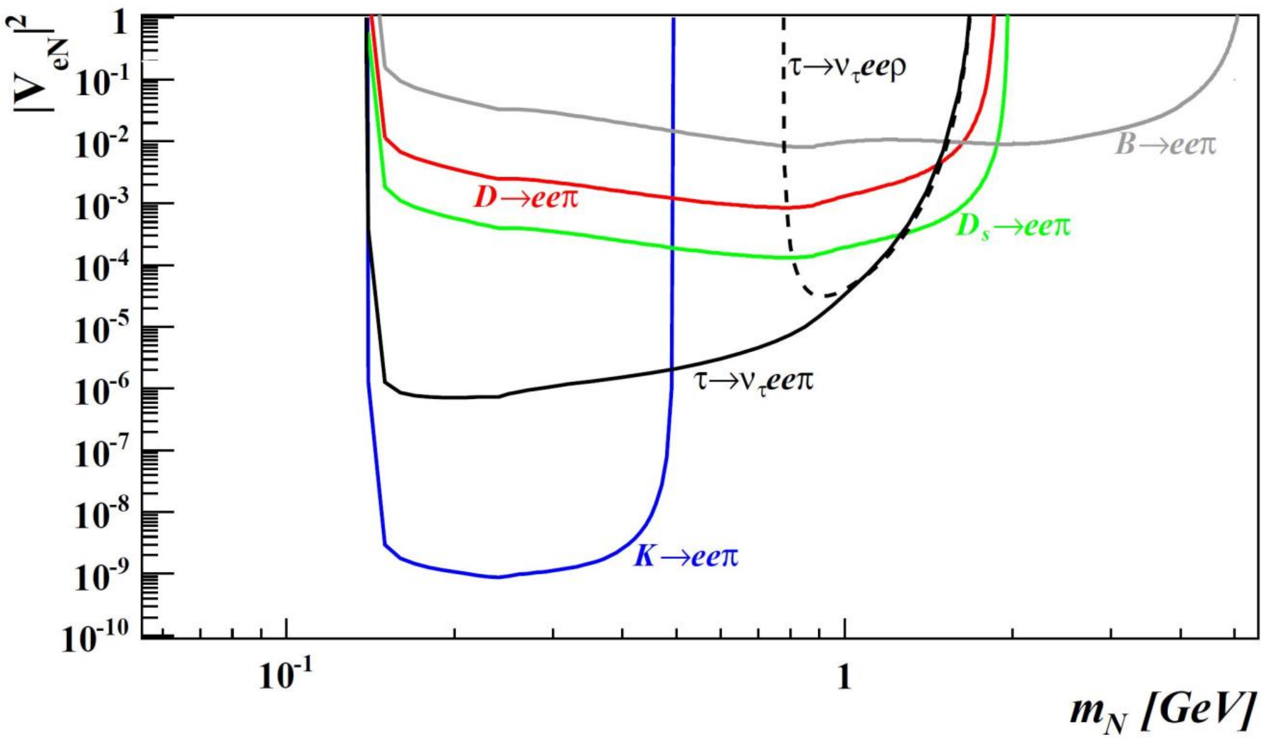
M=π, K, ρ, K*

Advantages:

- Access to $|V_{lN}|^2$ contrary to 3-body decays ($\sim V_{\tau 4} V_{l4}$)
- Leptonic couplings other than $V_{\tau N}$ compared to meson decays
- Absence of loop contributions

Quintero & GLC, PRD85, 076006 (2012)
Erratum to be submitted

Comparing bounds on $|V_{eN}|^2$

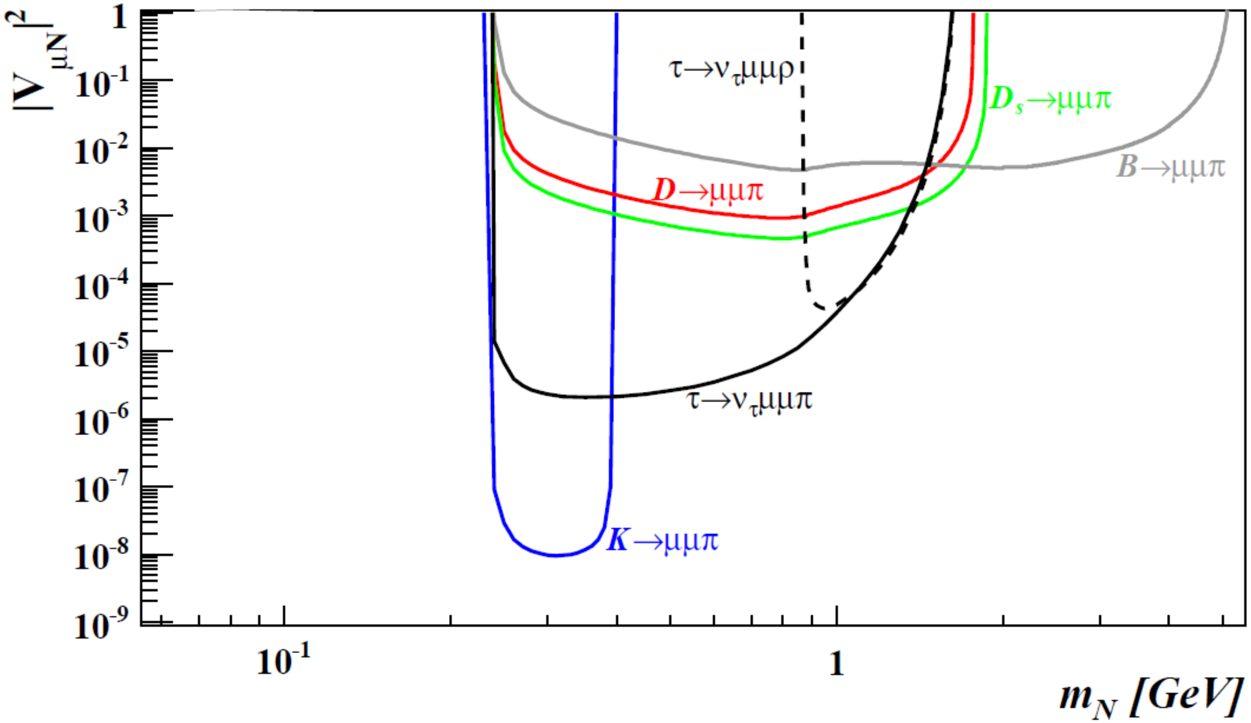


BR(e⁻ e⁻ M⁺) ≤ 10⁻⁸

In NWA

$$BR\left(\tau^- \to \nu_\tau l^- l'^- X^+\right) = \frac{\left|V_{lN} V_{l'N}\right|^2}{f_e(m_N)\left|V_{eN}\right|^2 + f_\mu(m_N)\left|V_{\mu N}\right|^2} \cdot G(m_N)$$

Comparing bounds on $|V_{\mu N}|^2$



assume:

$BR(\mu^- \mu^- M^+) \leq 10^{-8}$

$$BR(\mu^-\mu^-\pi^+) \leq \begin{cases} 1.4\times10^{-5} \\ 8.2\times10^{-5} \end{cases}$$

$$for \quad m_N = 0.4\,GeV$$

Our evaluation using $|V_{lN}|^2 \sim 10^{-3}$

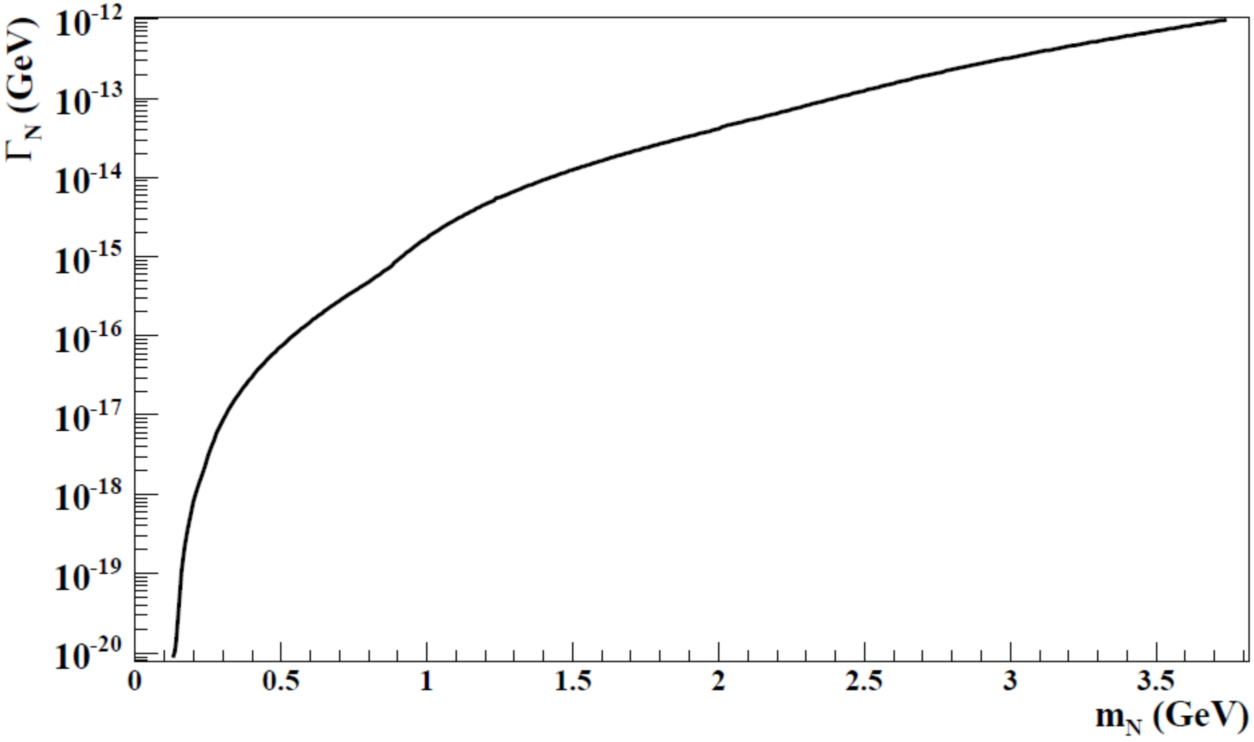
Estimate: C. Dib et al, PRD85 (2012)

Summary and Conclusions

- Effects of resonant Majorana neutrinos can be searched at (super)flavor factories in ($\Delta L=2$) τ, D, B decays
- Limits from 4-body decays can be competitive and complementary to searches in 3-body decays
- Strong limits on parameter space ($|V_{lN}|^2$ vs. m_N) can be derived from τ & B meson decays (may be, not competitive to astro and cosmological bounds)

Heavy neutrino decay width:

$$N \to l^{\pm}P^{\mp}, \nu P^{0}, l^{\pm}V^{\mp}, \nu V^{0}, l_1^{\pm}l_2^{\mp}\nu_{l2}, \nu_{l1}l_2^{+}l_2^{-}, \nu_{l1}\nu\bar{\nu}$$



Atre et al, JHEP (2009)

Leptonic mass terms in SM + n right-handed singlets after SSB:

$$-L = \overline{\nu_L} m_D N_R + \frac{1}{2}\left(\overline{N_R^c} M_R N_R + \overline{\nu_L} M_L \nu_L^c\right) + h.c.$$

$$M = \begin{pmatrix} M_L & M_D \\ M_D^T & M_R \end{pmatrix}$$ Diagonalized by $$T = \begin{pmatrix} U_{3\times 3} & V_{3\times n} \\ X_{n\times 3} & Y_{n\times n} \end{pmatrix}, \quad TT^+ = 1$$

$$\begin{pmatrix} \nu_{iL}^{ph} \\ N_{iR}^{ph} \end{pmatrix} = \begin{pmatrix} U_{ij}\nu_{jL} + V_{ik} N_{kR}^c \\ X_{ij}\nu_{jL}^c + Y_{ik} N_{kR} \end{pmatrix}, \quad V \approx X \approx M_D M_N^{-1}, \quad U^+ M_R + Y^+ M_D = 0$$

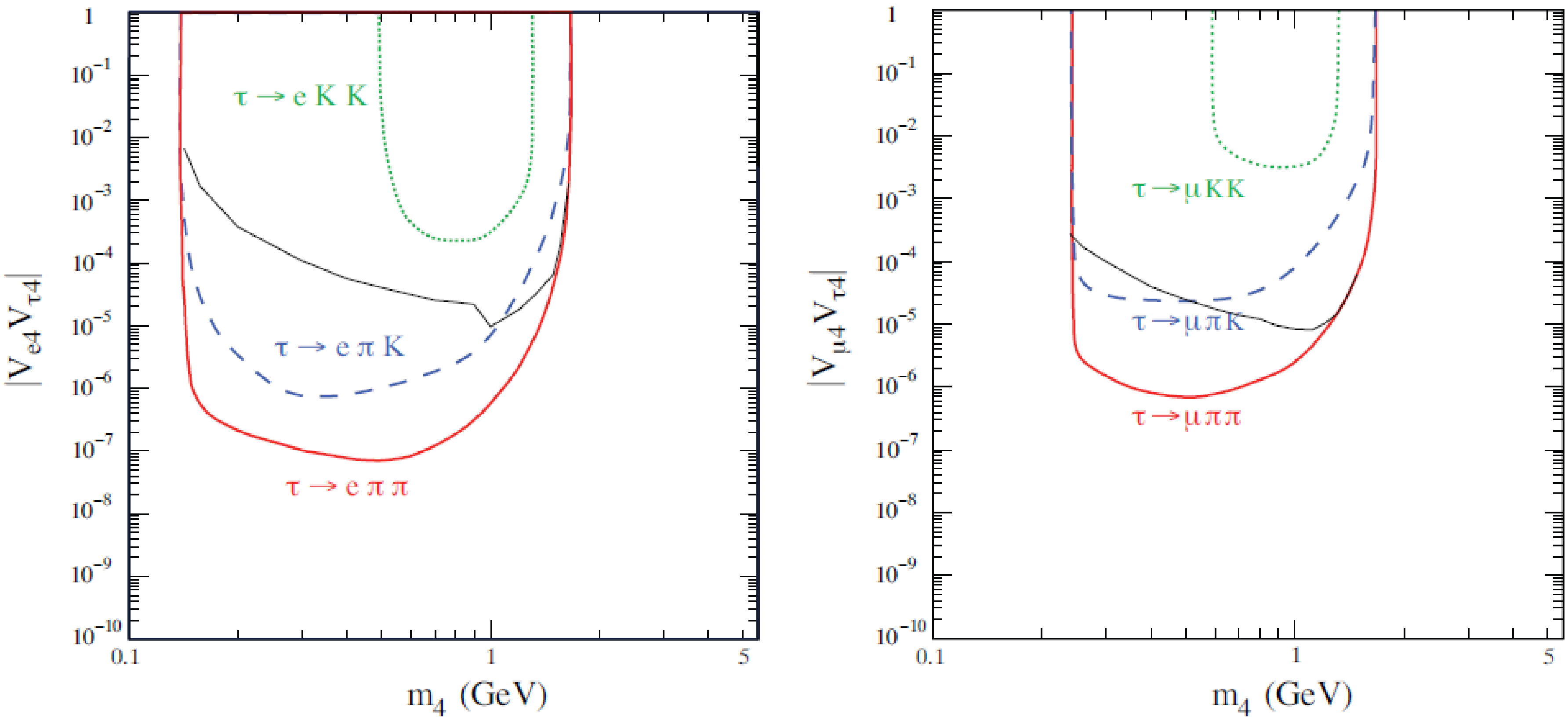
$$L_{cc} = -\frac{g}{\sqrt{2}} W_\mu^+ \sum_{l=e}^{\tau}\left(\sum_{m=1}^{3} U_{lm}^* \overline{\nu_m}\gamma^\mu P_L l + \sum_{m'=4}^{3+n} V_{lm'}^* \overline{N_{m'}^c}\gamma^\mu P_L l\right) + h.c.$$

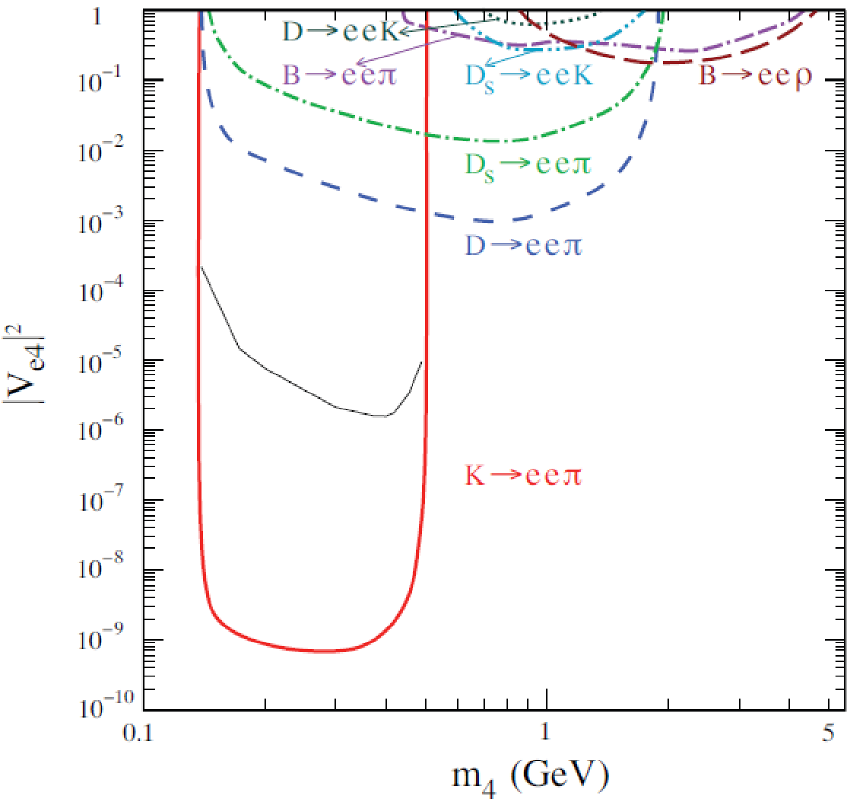
A. Atre et al, JHEP (2009); S.S. Bao et al, arXiv: 1208.5136

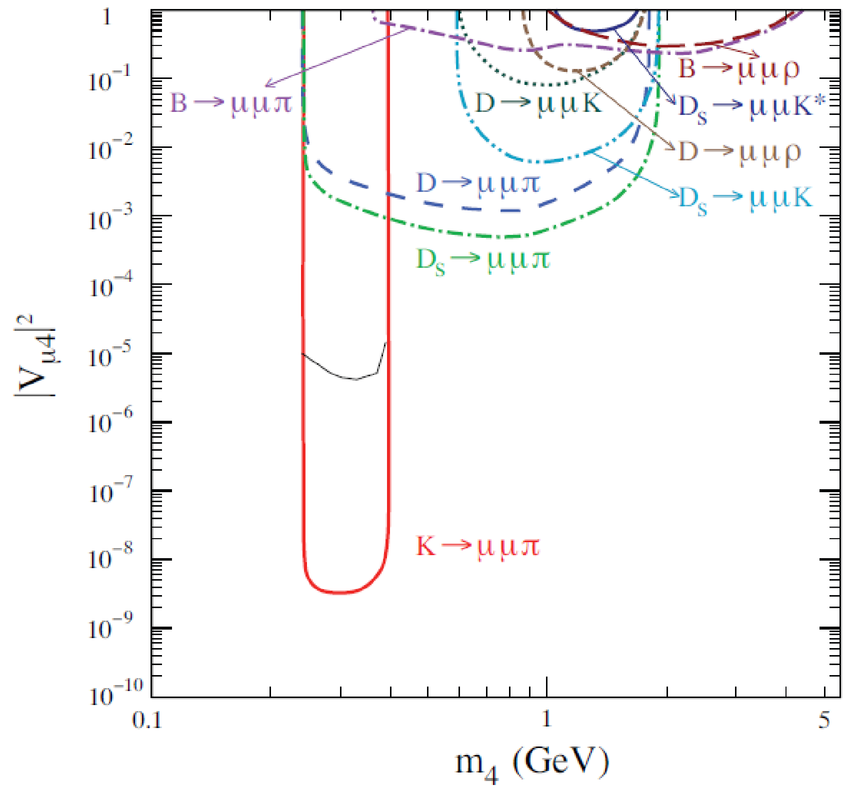
Decays occur within detector, L_{dec}: $P=1-\exp(-L_{dec}\,\Gamma_N)$

L_{dec}=10 mt, $\tau\rightarrow\pi ee$, $\pi\mu\mu$ (solid line)

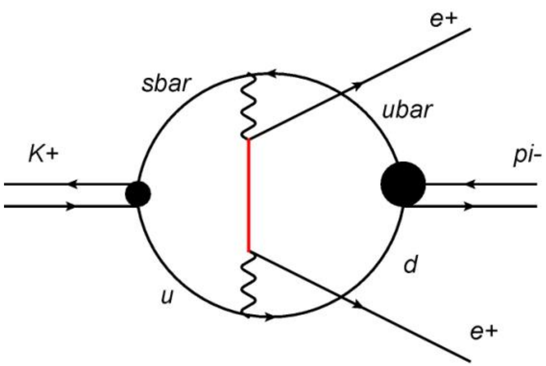
Atre et al, JHEP (2009)







-Atre, Han, Pascoli & Zhang, JHEP 0905, (2009);
-Helo, Kovalenko and Schmidt, NPB 853, (2011)



Important for charm and bottom

A. Ali,A.Borisov,M.Sidorova,2006

Upper limits from charged mesons

$K^+ \to \pi^- e^+ e^+$	6.4×10^{-10}			
$K^+ \to \pi^- \mu^+ \mu^+$	3.0×10^{-9}	PDG		
$K^+ \to \pi^- e^+ \mu^+$	5.0×10^{-10}			
$D^+ \to \pi^- e^+ e^+$	1.9×10^{-6}	$D_s^+ \to \pi^- e^+ e^+$	4.1×10^{-6}	
$D^+ \to \pi^- \mu^+ \mu^+$	2.0×10^{-6}	$D_s^+ \to \pi^- \mu^+ \mu^+$	14×10^{-6}	
$D^+ \to \pi^- e^+ \mu^+$	2.0×10^{-6}	$D_s^+ \to \pi^- e^+ \mu^+$	8.4×10^{-6}	BABAR1
$D^+ \to K^- e^+ e^+$	0.9×10^{-6}	$D_s^+ \to K^- e^+ e^+$	5.2×10^{-6}	
$D^+ \to K^- \mu^+ \mu^+$	10×10^{-6}	$D_s^+ \to K^- \mu^+ \mu^+$	13×10^{-6}	
$D^+ \to K^- e^+ \mu^+$	1.9×10^{-6}	$D_s^+ \to K^- e^+ \mu^+$	6.1×10^{-6}	
$B^+ \to \pi^- e^+ e^+$	2.3×10^{-8} BABAR2	$B^+ \to D^- e^+ e^+$	2.6×10^{-6} Belle	
$B^+ \to \pi^- \mu^+ \mu^+$	10.7×10^{-8} BABAR2	$B^+ \to D^- \mu^+ \mu^+$	1.8×10^{-6} Belle	
	1.3×10^{-8} LHCb		6.9×10^{-7} LHCb	
$B^+ \to \pi^- e^+ \mu^+$	1.3×10^{-6} BABAR2	$B^+ \to D^- e^+ \mu^+$	1.1×10^{-6} Belle	
$B^+ \to K^- e^+ e^+$	3.0×10^{-8} BABAR2	$B^+ \to D_s^- \mu^+ \mu^+$	5.8×10^{-7} LHCb	
$B^+ \to K^- \mu^+ \mu^+$	6.7×10^{-8} BABAR2	$B^+ \to D^{*-} \mu^+ \mu^+$	2.4×10^{-6} LHCb	
$B^+ \to K^- e^+ \mu^+$	2.0×10^{-6} BABAR2			

BABAR1: J. P. Lees et al, PRD 84, (2011)
BABAR2: J. P. Lees et al, PRD 85, (2012)
Belle: O. Seon et al, PRD 84 (2011)
LHCb: R. Aaij et al, PRL 108 (2012); PRD 85 (2012)

Current limits from tau leptons

Belle: PLB 682, 355 (2010), (90 % C.L.).

	$\mathcal{B}(\times 10^{-8})$
$\tau^- \to e^+\pi^-\pi^-$	8.8
$\tau^- \to e^+\pi^-K^-$	6.7
$\tau^- \to e^+K^-K^-$	6.0
$\tau^- \to \mu^+\pi^-\pi^-$	3.7
$\tau^- \to \mu^+\pi^-K^-$	9.4
$\tau^- \to \mu^+K^-K^-$	9.6