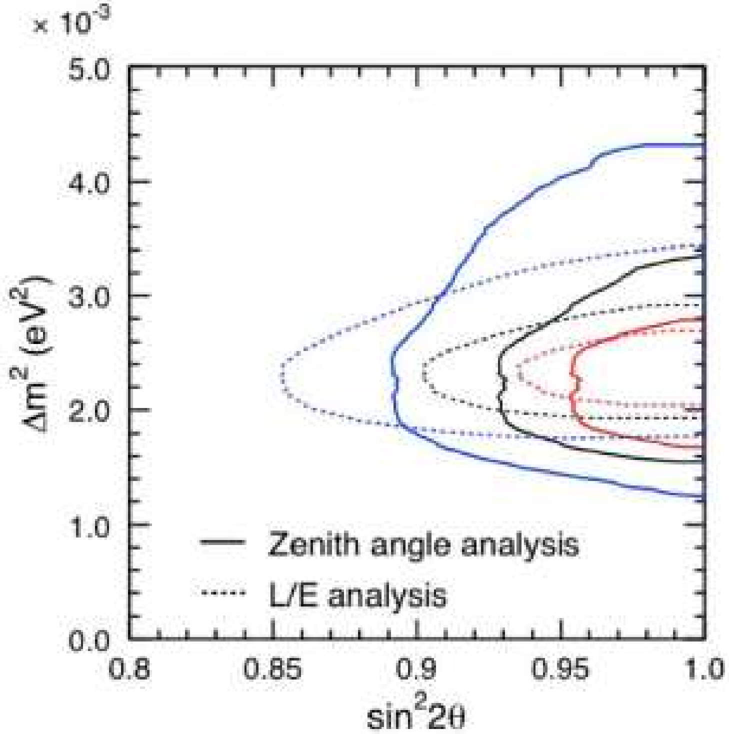
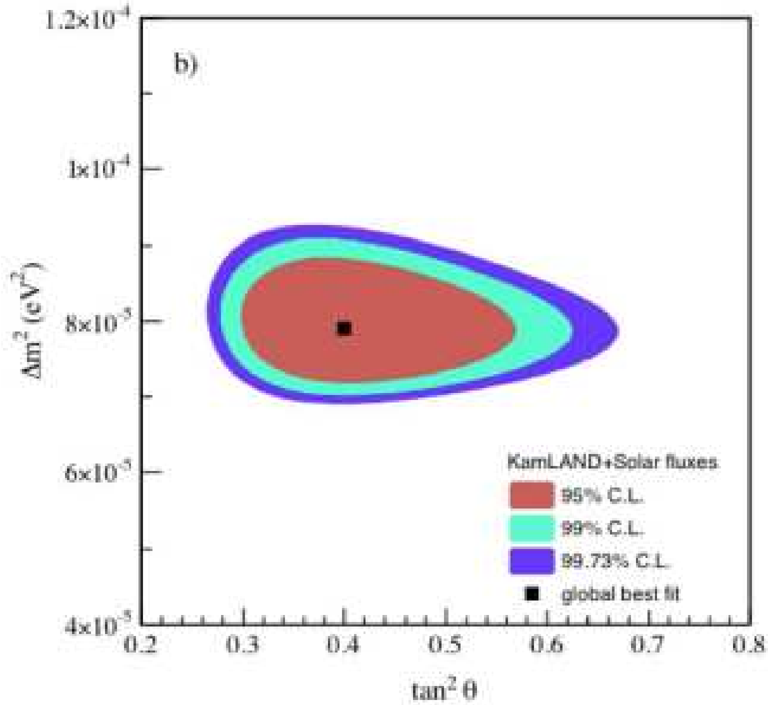
Search for Lepton-number Violating Processes

Pheno 2006

Anupama Atre

Neutrinos are massive





$$1.9 \times 10^{-3}\ \mathrm{eV}^2 < \Delta m^2_{atm} < 3.0 \times 10^{-3}\ \mathrm{eV}^2$$
$$7 \times 10^{-5}\ \mathrm{eV}^2 < \Delta m^2_{sol} < 9 \times 10^{-5}\ \mathrm{eV}^2.$$

We also know

- There are only three "active" light neutrinos
  N_ν = 2.984 $\pm$ 0.008, from Z pole at LEP-1.

- Direct lab bound: m_β < 2.2 eV
  from Tritium beta decay

- $\Sigma\, m\nu_i$ < 0.17 – 1 eV
  from WMAP, SDSS (Lyα spectra), SNIa.

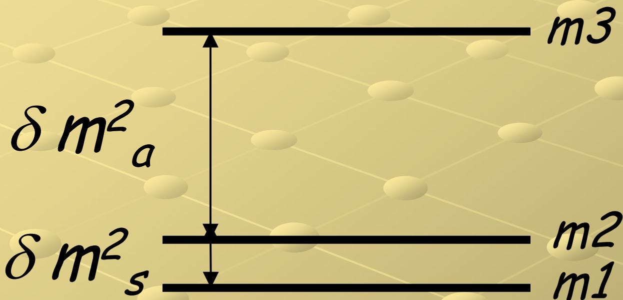
- The absence of neutrinoless double beta decay
  bound on Majorana mass $\langle m \rangle_{ee}$ < 1 eV

- *Absolute mass scale ?*

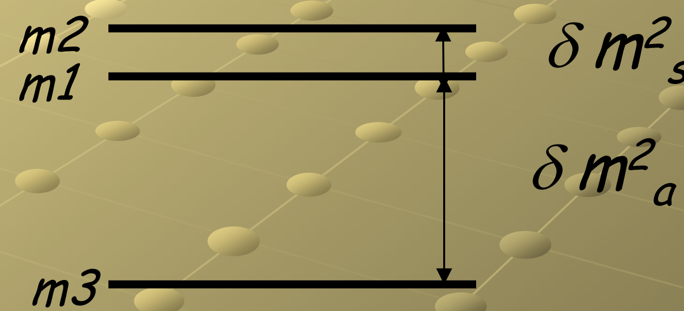
$$\Sigma = m_1 + m_2 + m_3$$

$$\delta m_a^2 = m_3^2 - m_1^2$$
$$\delta m_s^2 = m_2^2 - m_1^2$$

- *Hierarchy – inverted or normal?*



Normal



Inverted

- *Dirac or Majorana?*

Neutrinos masses: Dirac versus Majorana

Simplest extension of the SM:

$$L_{aL} = \begin{pmatrix} \nu_a \\ l_a \end{pmatrix}_L, \quad a = 1, 2, 3; \qquad N_{bR}, \quad b = 1, 2, 3.$$

Gauge-invariant Yukawa interactions

$$-\mathcal{L}_Y = \sum_{a=1}^{3} \sum_{b=1}^{n} f_{ab}^{\nu} \, \overline{L_{aL}} \, \hat{H} N_{bR} + h.c.$$

$$\Rightarrow \sum_{a=1}^{3} \sum_{b=1}^{n} \overline{\nu_{aL}} \, m_{ab}^{\nu} \, N_{bR} + h.c.$$

lead to three generations of Dirac neutrinos.

If there are Majorana mass terms:

$$\sum_{b,b'=1}^{n} \overline{N^c{}_{bL}}\, B_{bb'}\, N_{b'R} + h.c.$$

then The full neutrino mass terms read

$$\frac{1}{2}\left(\overline{\nu_L} \quad \overline{N^c{}_L}\right)\begin{pmatrix} 0_{3\times 3} & m^{\nu}_{3\times n} \\ m^{\nu T}_{n\times 3} & B_{n\times n} \end{pmatrix}\begin{pmatrix} \nu^c{}_R \\ N_R \end{pmatrix} + h.c.$$

The diagonalized masses read

$$-\mathcal{L}^{\nu}_m = \frac{1}{2}\left(\sum_{m=1}^{3} m^{\nu}_m\, \overline{\nu_{mL}}\, \nu^c_{mR} + \sum_{m'=4}^{3+n} M^N_{m'}\, \overline{N^c_{m'L}}\, N_{m'R}\right) + h.c.$$

All Majorana neutrinos:

$$\nu_{aL} = \sum_{m=1}^{3} U_{am}\nu_{mL} + \sum_{m'=4}^{3+n} V_{am'}N^c_{m'L},$$

$$N_{bR} = \sum_{m=1}^{3} X^*_{bm}\nu^c_{mR} + \sum_{m'=4}^{3+n} Y^*_{bm'}N_{m'R},$$

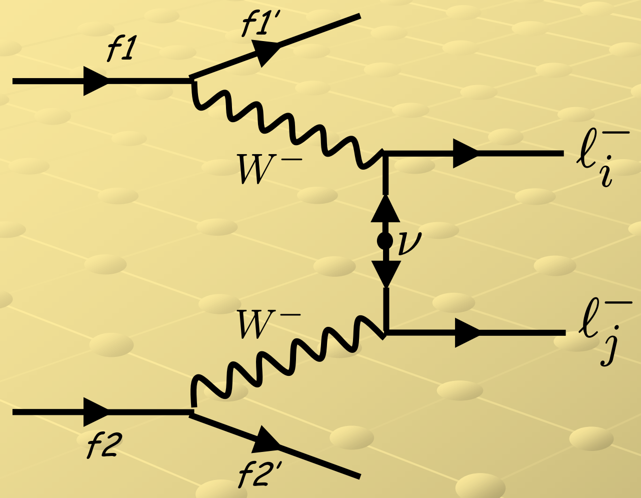
$$UU^\dagger + VV^\dagger = I, \quad XX^\dagger + YY^\dagger = I,$$

Charged current and Neutral current

$$
\begin{aligned}
-\mathcal{L} &= \frac{g}{\sqrt{2}} W_\mu^+ \sum_{\ell=e}^{\tau} \sum_{m=1}^{3} (U^\dagger O_L)_{m\ell} \bar{\nu}_m \gamma^\mu P_L \ell + \text{h.c.} \\
&+ \frac{g}{\sqrt{2}} W_\mu^+ \sum_{\ell=e}^{\tau} \sum_{m'=4}^{n} (V^\dagger O_L)_{m'\ell} \bar{N}^c_{m'} \gamma^\mu P_L \ell + \text{h.c.} \\
&+ \frac{g}{2cos\theta_W} Z_\mu \sum_{m_1=1}^{3} \sum_{m'_2=4}^{n} (U^\dagger V)_{m_1,m'_2} \bar{\nu}_{m_1} \gamma^\mu P_L N^c_{m'_2} + \text{h.c.} \\
&+ \frac{g}{2cos\theta_W} Z_\mu \sum_{m_1=1}^{3} \sum_{m_2=1}^{3} (U^\dagger U)_{m_1,m_2} \bar{\nu}_{m_1} \gamma^\mu P_L \nu_{m_2} + \text{h.c.} \\
&+ \frac{g}{2cos\theta_W} Z_\mu \sum_{m'_1=1}^{3} \sum_{m'_2=4}^{n} (V^\dagger V)_{m'_1,m'_2} \bar{N}^c_{m'_1} \gamma^\mu P_L N^c_{m'_2} + \text{h.c.}
\end{aligned}
$$

$$
U^{\ell\nu} = O_L^\dagger U, V^{\ell N} = O_L^\dagger V, U^{\nu N} = V^\dagger U, U^{\nu\nu} = UU^\dagger, V^{NN} = VV^\dagger
$$

ΔL = 2 process ➔ Majorana nature of neutrino



generic diagram

The transition rates are proportional to:

- for light neutrino [1]

$$\langle m \rangle^2_{\ell_1\ell_2} = |\sum_i U^{\ell\nu}_{\ell_1 i} U^{\ell\nu}_{\ell_2 i} m_i\ |^2$$

- for intermediate mass neutrino [2]

$$\propto \frac{|V^{\ell N}_{\ell_1 4} V^{\ell N}_{\ell_2 4}\ |^2}{\Gamma_{\nu_4} m_4}$$

- for heavy neutrino [3]

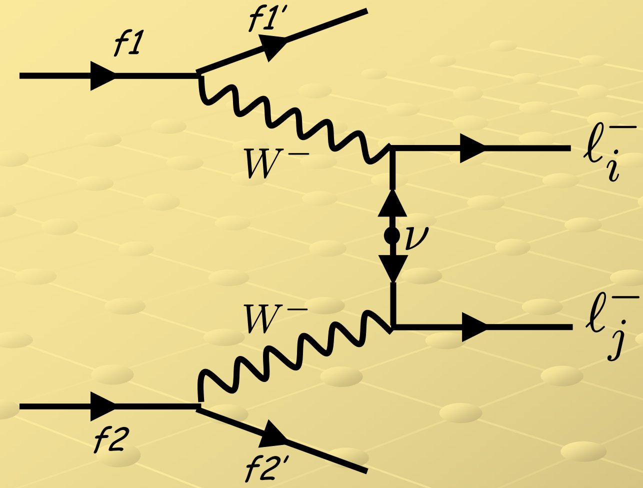
$$\left\langle m^{-1} \right\rangle^2_{\ell_1\ell_2} = \frac{|\sum_i V^{\ell N}_{\ell_1 i} V^{\ell N}_{\ell_2 i}\ |^2}{m_N^2}$$

[1] AA, V Barger, T Han, Phys. Rev. D 71, 113014 (2005) [arXiv:hep-ph/0502163]

[2] AA, T Han, S Pascoli to appear

[3] T Han, B Zhang [arXiv:hep-ph/0604064]
AA, T Han, S pascoli, B Zhang to appear

Light (active) Majorana neutrino



$$\propto \langle m \rangle^2_{\ell_1\ell_2} = | \sum_i U^{\ell\nu}_{\ell_1 i} U^{\ell\nu}_{\ell_2 i} m_i |^2$$

We have six effective neutrino masses

$\langle m \rangle_{ee}$: $0\nu\beta\beta$, rare meson decay

$\langle m \rangle_{e\mu}$: μ^- e^+ conversion, rare meson decay

$\langle m \rangle_{\mu\mu}$: rare meson decay

$\langle m \rangle_{e\tau}$: τ decay

$\langle m \rangle_{\mu\tau}$: τ decay

$\langle m \rangle_{\tau\tau}$: none

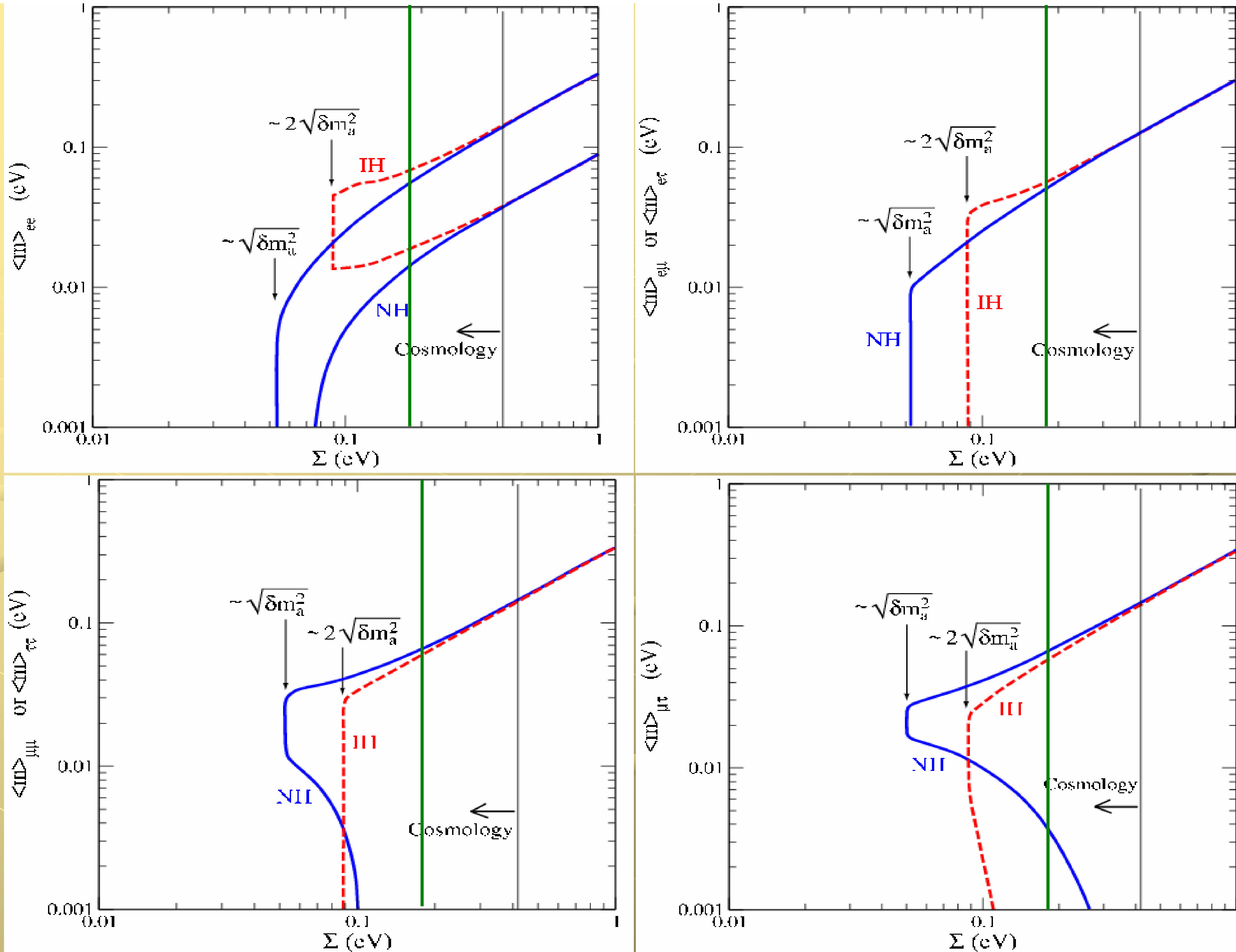
Determination of effective neutrino masses

$$\langle m \rangle^2_{\ell_1 \ell_2} = |\sum_i U^{\ell\nu}_{\ell_1 i} U^{\ell\nu}_{\ell_2 i} m_i|^2$$

- 3 masses: m_1, m_2 and m_3
- $\Sigma = m_1 + m_2 + m_3$ and δm^2_a and δm^2_s
- 3 mixing angles: θ_a, θ_s and θ_x
- 3 phases: δ, ϕ_2 and ϕ_3

Parameter	*Input*
$\lvert\delta m_a^2\rvert$	1.9×10^{-3} eV^2 - 3.0×10^{-3} eV^2
$\lvert\delta m_s^2\rvert$	90% CL δm^2_s vs $\tan^2\theta_s$ plot
θ_a	90% CL δm^2_a vs $\sin^2 2\theta_a$ plot
θ_s	90%CL δm^2_s vs $\tan^2\theta_s$ plot
θ_x	90% CL CHOOZ exclusion plot
δ	0 to 2π
ϕ_2	0 to 2π
ϕ_3	0 to 2π
Σ	0.42 eV at 95% CL

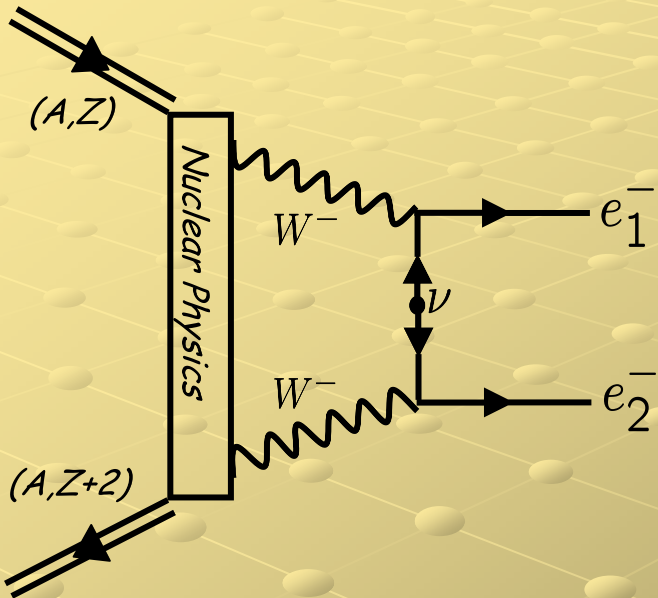
AA, V Barger, T Han, Phys. Rev. D 71, 113014 (2005) [arXiv:hep-ph/0502163]



$\langle m \rangle_{ee}$ (eV)
$\sim 2\sqrt{\delta m_a^2}$
IH
$\sim \sqrt{\delta m_a^2}$
NH
Cosmology
Σ (eV)
$\langle m \rangle_{e\mu}$ or $\langle m \rangle_{e\tau}$ (eV)
$\sim 2\sqrt{\delta m_a^2}$
$\sim \sqrt{\delta m_a^2}$
IH
NH
Cosmology
Σ (eV)
$\langle m \rangle_{\mu\mu}$ or $\langle m \rangle_{\tau\tau}$ (eV)
$\sim \sqrt{\delta m_a^2}$
$\sim 2\sqrt{\delta m_a^2}$
IH
NH
Cosmology
Σ (eV)
$\langle m \rangle_{\mu\tau}$ (eV)
$\sim \sqrt{\delta m_a^2}$
$\sim 2\sqrt{\delta m_a^2}$
IH
NH
Cosmology
Σ (eV)

Neutrinoless Double Beta Decay (0νββ)

$$(A,Z) \to (A,Z+2) + e^- + e^-$$



Isotope	Half-life (yrs)	$\langle m \rangle_{ee}$ (eV)	Year
^{48}Ca	> 1.4×10^{22}	<7.2 - 44.7	2004
^{76}Ge	> 1.9×10^{25}	<0.35	2001
^{76}Ge	> 1.6×10^{25}	<0.33 – 1.35	2002
^{76}Ge	= 1.2×10^{25}	= 0.44	2004
^{82}Se	> 2.7×10^{22}	<5	1992
^{100}Mo	> 5.5×10^{22}	<2.1	2001
^{116}Cd	> 1.7×10^{23}	<1.7	2003
^{128}Te	> 7.7×10^{24}	<1.1 - 1.5	1993
^{130}Te	> 5.5×10^{23}	<0.37 – 1.9	2004
^{136}Xe	> 4.4×10^{23}	<1.8 - 5.2	1998
^{150}Nd	> 1.2×10^{21}	< 3.0	1997

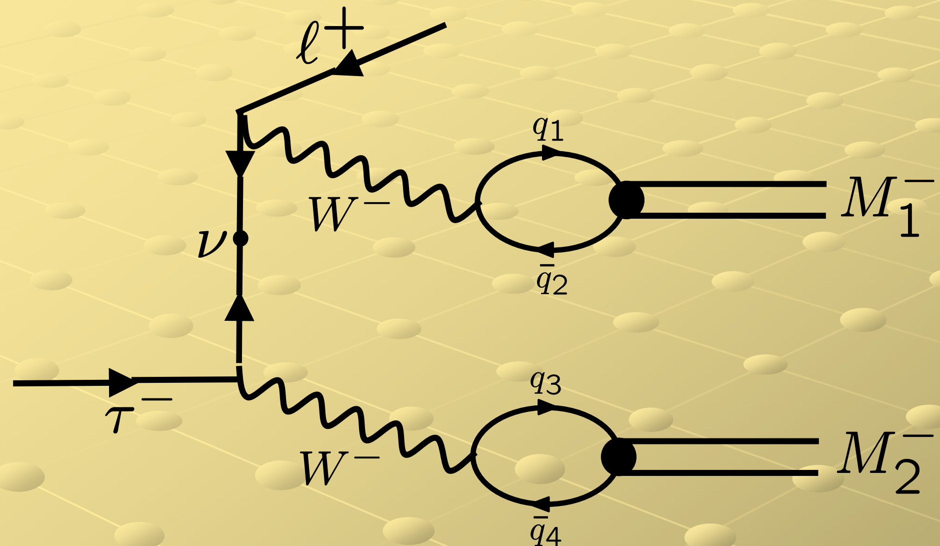
S.R. Elliott and J. Engel, J. Physics G30 (2004) R183, [arXiv:hep-ph/0405078]

$$[T_{\frac{1}{2}}]^{-1} = G(\Delta E)|\mathcal{M}_{nucl}|^2 \langle m \rangle_{ee}^2$$

$\langle m \rangle_{ee}^{max}$ *= 0.14 (0.06) eV*

Lepton Number Violating Tau Decays

$$\tau^- \rightarrow \ell^+ + M_1^- + M_2^-$$



Decay Mode	B_{exp}	$\langle m \rangle_{\ell\tau}$
$\tau^- \rightarrow e^+ \pi^- \pi^-$	1.9×10^{-6}	12 TeV
$\tau^- \rightarrow e^+ \pi^- K^-$	2.1×10^{-6}	46 TeV
$\tau^- \rightarrow e^+ K^- K^-$	3.8×10^{-6}	730 TeV
$\tau^- \rightarrow \mu^+ \pi^- \pi^-$	3.4×10^{-6}	20 TeV
$\tau^- \rightarrow \mu^+ \pi^- K^-$	7.0×10^{-6}	100 TeV
$\tau^- \rightarrow \mu^+ K^- K^-$	6.0×10^{-6}	1000 TeV

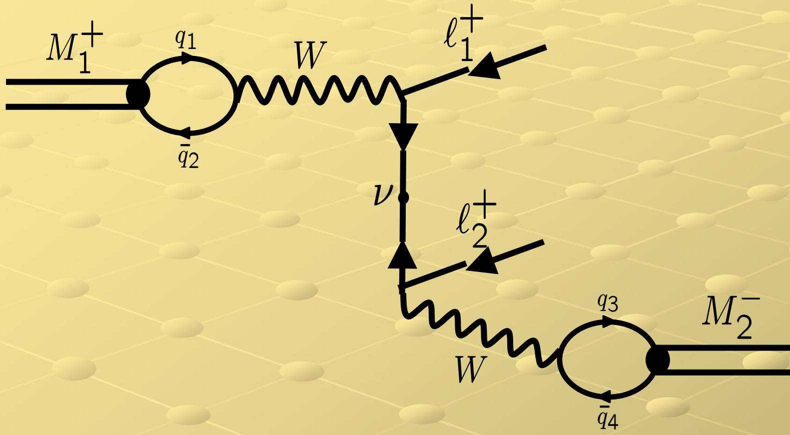
CLEO Collaboration, D.Bliss et al., Phys. Rev. D 57 (1998) 5903, [arXiv:hep-ex/9712010]

$$B \approx 10^{-33} |V_{M_1}^{CKM} V_{M_2}^{CKM}|^2 \left(\frac{f_{M_1}^2 f_{M_2}^2}{(100MeV)^2}\right)^2 \left(\frac{1777MeV}{m_\tau}\right)^2 \left(\frac{\langle m \rangle_{\ell\tau}}{1eV}\right)^2 \Phi$$

Rare Meson Decays

$$M_1^+ \to M_2^- + \ell_1^+ + \ell_2^+$$

$$B \approx 10^{-29} |V_{M_1}^{CKM} V_{M_2}^{CKM}|^2 \left(\frac{\tau_{M_1}}{1.0 \times 10^{-8} s}\right) \left(\frac{f_{M_1}^2 f_{M_2}^2}{(100 MeV)^2}\right)^2 \left(\frac{m_{M_1}}{1 GeV}\right)^3 \left(\frac{\langle m \rangle_{\ell_1 \ell_2}}{1 eV}\right)^2 \Phi'$$



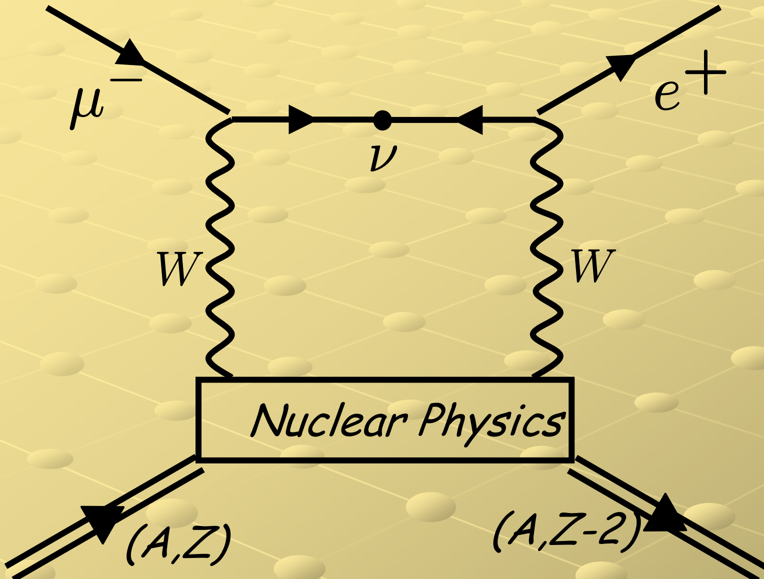
Decay Mode	B_{exp}	$\langle m \rangle_{\ell_1 \ell_2}$ TeV
$D^+ \to \pi^- e^+ e^+$	9.6×10^{-5}	320
$D^+ \to \pi^- \mu^+ \mu^+$	4.8×10^{-6}	76
$D^+ \to \pi^- e^+ \mu^+$	5.0×10^{-5}	170
$D_s^+ \to \pi^- e^+ e^+$	6.9×10^{-4}	200
$D_s^+ \to \pi^- \mu^+ \mu^+$	2.9×10^{-5}	42
$D_s^+ \to \pi^- e^+ \mu^+$	7.3×10^{-4}	150
$B^+ \to \pi^- e^+ e^+$	1.6×10^{-6}	420
$B^+ \to \pi^- \mu^+ \mu^+$	1.4×10^{-6}	400
$B^+ \to \pi^- e^+ \mu^+$	1.3×10^{-6}	270

Decay Mode	B_{exp}	$\langle m \rangle_{\ell_1 \ell_2}$ TeV
$D^+ \to K^- e^+ e^+$	1.2×10^{-4}	1900
$D^+ \to K^- \mu^+ \mu^+$	1.3×10^{-5}	670
$D^+ \to K^- e^+ \mu^+$	1.3×10^{-4}	1500
$D_s^+ \to K^- e^+ e^+$	6.3×10^{-4}	990
$D_s^+ \to K^- \mu^+ \mu^+$	1.3×10^{-5}	150
$D_s^+ \to K^- e^+ \mu^+$	6.8×10^{-4}	740
$B^+ \to K^- e^+ e^+$	1.0×10^{-6}	1300
$B^+ \to K^- \mu^+ \mu^+$	1.8×10^{-6}	1800
$B^+ \to K^- e^+ \mu^+$	2.0×10^{-6}	1300

$K^+ \to \pi^- e^+ e^+$	6.4×10^{-10}	0.11
$K^+ \to \pi^- \mu^+ \mu^+$	3.0×10^{-9}	0.48
$K^+ \to \pi^- e^+ \mu^+$	5.0×10^{-10}	0.09

Muon – Positron Conversion

$$\mu^- + (A, Z) \rightarrow (A, Z-2) + e^+$$



$$B = \lambda \left(\frac{\langle m \rangle_{e\mu}}{m_e} \right)^2$$

$\langle m \rangle_{e\mu} \leq$ 17(82) MeV

K. Zuber, [arXiv:hep-ph/0008080]

$$B = \frac{\Gamma(Ti + \mu^- \rightarrow e^+ + Ca_{gs})}{\Gamma(Ti + \mu^- \rightarrow \nu_\mu + Sc)} < 1.7 \times 10^{-12}$$

SINDRUM II Collaboration, J. Kaulard et al., Phys. Lett. B 422 (1998) 334

Summary

$\langle m \rangle_{\ell_1 \ell_2}$	Cosmo Bounds	Exp Bounds	Experiment
$\langle m \rangle_{ee}$	0.14 (0.06) eV	0.33 eV	$0\nu\beta\beta$
$\langle m \rangle_{e\mu}$	0.14 (0.06) eV	17 MeV*	μ^- - e^+ conversion
$\langle m \rangle_{e\tau}$	0.14 (0.06) eV	12 TeV	$\tau^- \to e^+ \pi^- \pi^-$
$\langle m \rangle_{\mu\mu}$	0.14 (0.06) eV	480 GeV	$K^+ \to \pi^- \mu^+ \mu^+$
$\langle m \rangle_{\mu\tau}$	0.14 (0.06) eV	19 TeV	$\tau^- \to \mu^+ \pi^- \pi^-$
$\langle m \rangle_{\tau\tau}$	0.14 (0.06) eV	none	$B^- \to M^- \tau^+ \tau^+$

* 90 GeV from $K^+ \to \pi^- e^+ \mu^+$

*Intermediate mass Majorana neutrino **

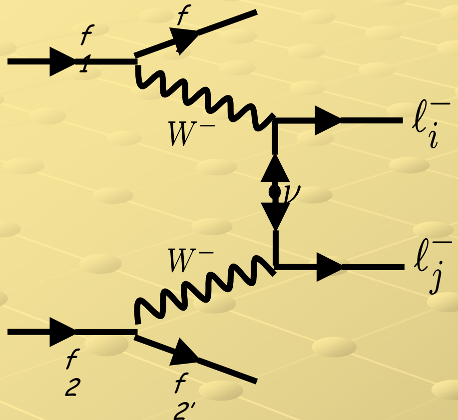
$$-\mathcal{L} = \frac{g}{\sqrt{2}} W_\mu^+ \sum_{\ell=e}^{\tau} \sum_{m=1}^{3} (U^\dagger O_L)_{m\ell} \bar{\nu}_m \gamma^\mu P_L \ell + \text{h.c.}$$

$$+ \frac{g}{\sqrt{2}} W_\mu^+ \sum_{\ell=e}^{\tau} \sum_{m'=4}^{n} (V^\dagger O_L)_{m'\ell} \bar{N}^c_{m'} \gamma^\mu P_L \ell + \text{h.c.}$$

$$+ \frac{g}{2cos\theta_W} Z_\mu \sum_{m_1=1}^{3} \sum_{m_2'=4}^{n} (U^\dagger V)_{m_1,m_2'} \bar{\nu}_{m_1} \gamma^\mu P_L N^c_{m_2'} + \text{h.c.}$$

$$+ \frac{g}{2cos\theta_W} Z_\mu \sum_{m_1=1}^{3} \sum_{m_2=1}^{3} (U^\dagger U)_{m_1,m_2} \bar{\nu}_{m_1} \gamma^\mu P_L \nu_{m_2} + \text{h.c.}$$

$$+ \frac{g}{2cos\theta_W} Z_\mu \sum_{m_1'=1}^{3} \sum_{m_2'=4}^{n} (V^\dagger V)_{m_1',m_2'} \bar{N}^c_{m_1'} \gamma^\mu P_L N^c_{m_2'} + \text{h.c.}$$



$$U^{\ell\nu} = O_L^\dagger U, V^{\ell N} = O_L^\dagger V, U^{\nu N} = V^\dagger U, U^{\nu\nu} = UU^\dagger, V^{NN} = VV^\dagger$$

- *resonant enhancement, transition rates* $\propto \frac{|V^{\ell N}_{\ell_1 4} V^{\ell N}_{\ell_2 4}|^2}{\Gamma_{\nu_4} m_4}$
- *tau decay, rare meson decay*

** AA, T Han and S Pascoli, to appear*

Width of Intermediate mass Majorana neutrino

$$U^{\ell\nu} = O_L^\dagger U, V^{\ell N} = O_L^\dagger V, U^{\nu N} = V^\dagger U, U^{\nu\nu} = UU^\dagger, V^{NN} = VV^\dagger$$

2 body decays :

- *CC decays →* $\ell^- P^+, \ell^- V^+ \propto \frac{G_F^2}{16\pi} f_M^2 m_4^3 |V_{\ell 4}^{\ell N}|^2$
- *NC decays →* $\nu_i P^0, \nu_i V^0 \propto \frac{G_F^2}{\lambda\pi} f_M^2 m_4^3 \sum_{\ell_1=e}^{\tau} |V_{\ell_1 4}^{\ell N}|^2 (1 - \sum_{\ell_2=e}^{\tau} |V_{\ell_2 4}^{\ell N}|^2)$

3 body decays:

- *CC decays →* $\nu_i \ell_1^- \ell_2^+ \propto \frac{G_F^2}{192\pi^3} m_4^5 |V_{\ell_1 4}^{\ell N}|^2 (1 - |V_{\ell_2 4}^{\ell N}|^2)$
- *NC decays →* $\nu_i \nu_j \bar{\nu}_j \propto \frac{G_F^2}{192\pi^3} m_4^5 \sum_{\ell_1=e}^{\tau} |V_{\ell_1 4}^{\ell N}|^2 (1 - \sum_{\ell_2=e}^{\tau} |V_{\ell_2 4}^{\ell N}|^2)$
- *CC + NC decays →* $\nu_i \ell^- \ell^+ \propto$ *combination of CC + NC mixings*

TABLE I: Mass and mixing elements of sterile neutrino probed and the decay mode constraining them with the corresponding experimental bounds on branching fractions. Bounds for $\Delta L = 2$ tau decays are from Ref. [82] and rare meson decays are from Ref. [83]. The bounds for $D^+ \to e^+e^+\pi^-(K^-)$ are from [84].

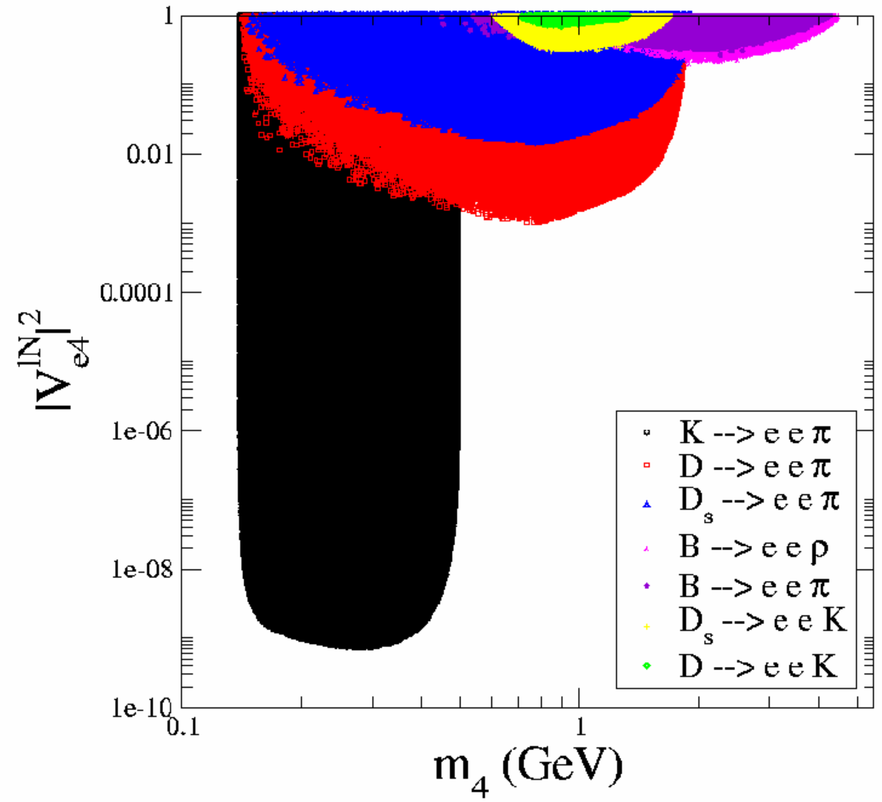
Mixing element	range of m_4(MeV)	decay mode	B_{exp}
$\lvert V_{e4}\rvert^2$	140 - 493	$K^+ \to e^+e^+\pi^-$	6.4×10^{-10}
	140 - 1868	$D^+ \to e + e^+\pi^-$	3.6×10^{-6}
	494 - 1868	$D^+ \to e^+e^+K^-$	4.5×10^{-6}
	140 - 1967	$D_s^+ \to e^+e^+\pi^-$	6.9×10^{-4}
	494 - 1967	$D_s^+ \to e^+e^+K^-$	6.3×10^{-4}
	140 - 5278	$B^+ \to e^+e^+\pi^-$	1.6×10^{-6}
	494 - 5278	$B^+ \to e^+e^+K^-$	1.0×10^{-6}
	776 - 5278	$B^+ \to e^+e^+\rho^-$	2.6×10^{-6}
	892 - 5278	$B^+ \to e^+e^+K^{*-}$	2.8×10^{-6}
$\lvert V_{\mu 4}\rvert^2$	245 - 388	$K^+ \to \mu^+\mu^+\pi^-$	3.0×10^{-9}
	245 - 1763	$D^+ \to \mu^+\mu^+\pi^-$	4.8×10^{-6}
	599 - 1763	$D^+ \to \mu^+\mu^+K^-$	1.3×10^{-5}
	881 - 1763	$D^+ \to \mu^+\mu^+\rho^-$	5.6×10^{-4}
	997 - 1763	$D^+ \to \mu^+\mu^+K^{*-}$	8.5×10^{-4}
	245 - 1862	$D_s^+ \to \mu^+\mu^+\pi^-$	2.9×10^{-5}
	599 - 1862	$D_s^+ \to \mu^+\mu^+K^-$	1.3×10^{-5}
	997 - 1862	$D_s^+ \to \mu^+\mu^+K^{*-}$	1.4×10^{-3}
	245 - 5173	$B^+ \to \mu^+\mu^+\pi^-$	1.4×10^{-6}
	599 - 5173	$B^+ \to \mu^+\mu^+K^-$	1.8×10^{-6}
	881 - 5173	$B^+ \to \mu^+\mu^+\rho^-$	5.0×10^{-6}
	997 - 5173	$B^+ \to \mu^+\mu^+K^{*-}$	8.3×10^{-6}
$\lvert V_{e4}V_{\mu 4}\rvert$	140 - 493	$K^+ \to e^+\mu^+\pi^-$	5.5×10^{-10}
	140 - 1868	$D^+ \to e^+\mu^+\pi^-$	5.0×10^{-5}
	494 - 1868	$D^+ \to e^+\mu^+K^-$	1.3×10^{-4}
	140 - 1862	$D_s^+ \to e^+\mu^+\pi^-$	7.3×10^{-4}
	494 - 1967	$D_s^+ \to e^+\mu^+K^-$	6.8×10^{-4}
	140 - 5278	$B^+ \to e^+\mu^+\pi^-$	1.3×10^{-6}
	494 - 5278	$B^+ \to e^+\mu^+K^-$	2.0×10^{-6}
	776 - 5278	$B^+ \to e^+\mu^+\rho^-$	3.3×10^{-6}
	892 - 5278	$B^+ \to e^+\mu^+K^{*-}$	4.4×10^{-6}
$\lvert V_{e4}V_{\tau 4}\rvert$	140 - 1637	$\tau^- \to e^+\pi^-\pi^-$	2.7×10^{-7}
	140 - 1637	$\tau^- \to e^+\pi^-K^-$	1.8×10^{-7}
	494 - 1283	$\tau^- \to e^+K^-K^-$	1.5×10^{-7}
$\lvert V_{\mu 4}V_{\tau 4}\rvert$	245 - 1637	$\tau^- \to \mu^+\pi^-\pi^-$	0.7×10^{-7}
	245 - 1637	$\tau^- \to \mu^+\pi^-K^-$	2.2×10^{-7}
	599 - 1283	$\tau^- \to \mu^+K^-K^-$	4.8×10^{-7}

23

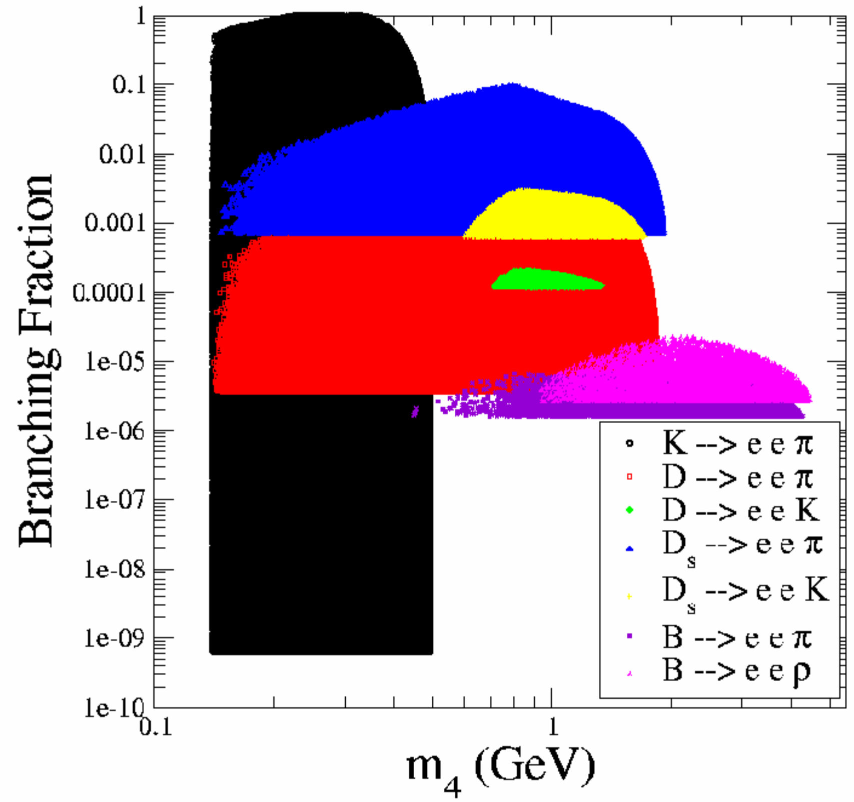
36 decay modes to look for lepton number violation !!!!

Parameters for MC sampling

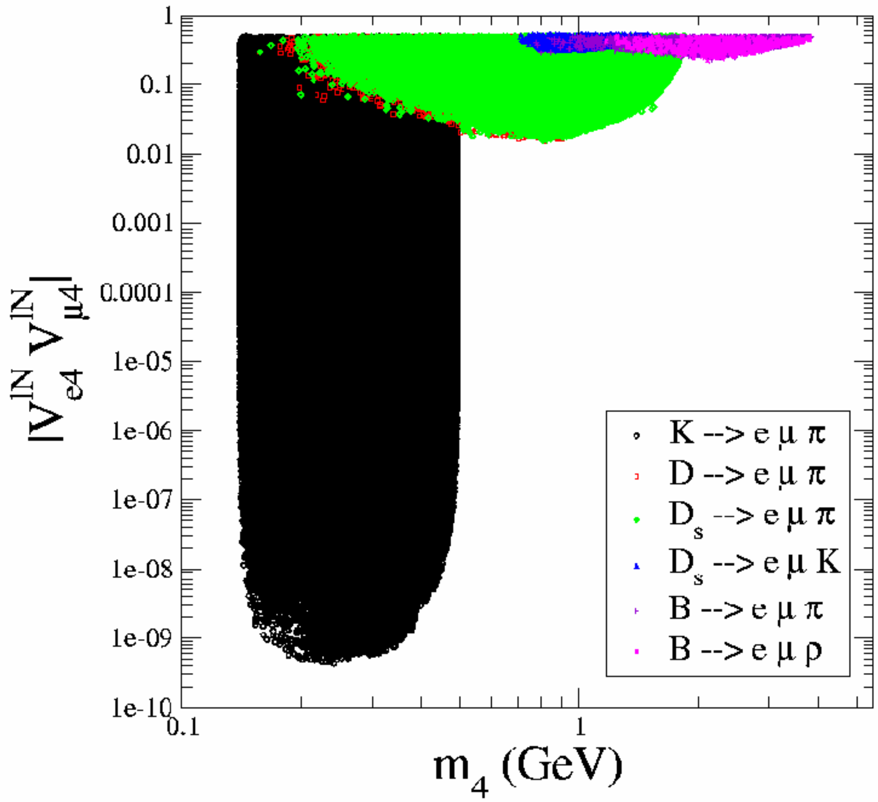
- *mass of neutrino m_4 resonant mass region*
- *three mixings ~ 0 to 1*



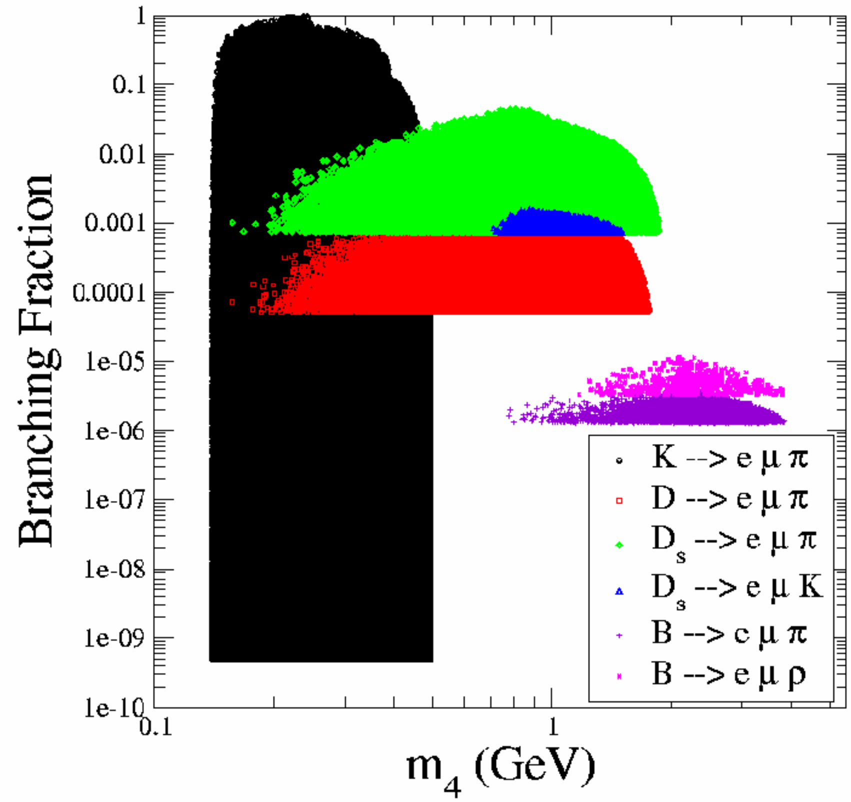
1
0.01
0.0001
1e-06
1e-08
1e-10
0.1
1
$|V_{e4}^{lN}|^2$
m4 (GeV)
K --> e e π
D --> e e π
Ds --> e e π
B --> e e ρ
B --> e e π
Ds --> e e K
D --> e e K



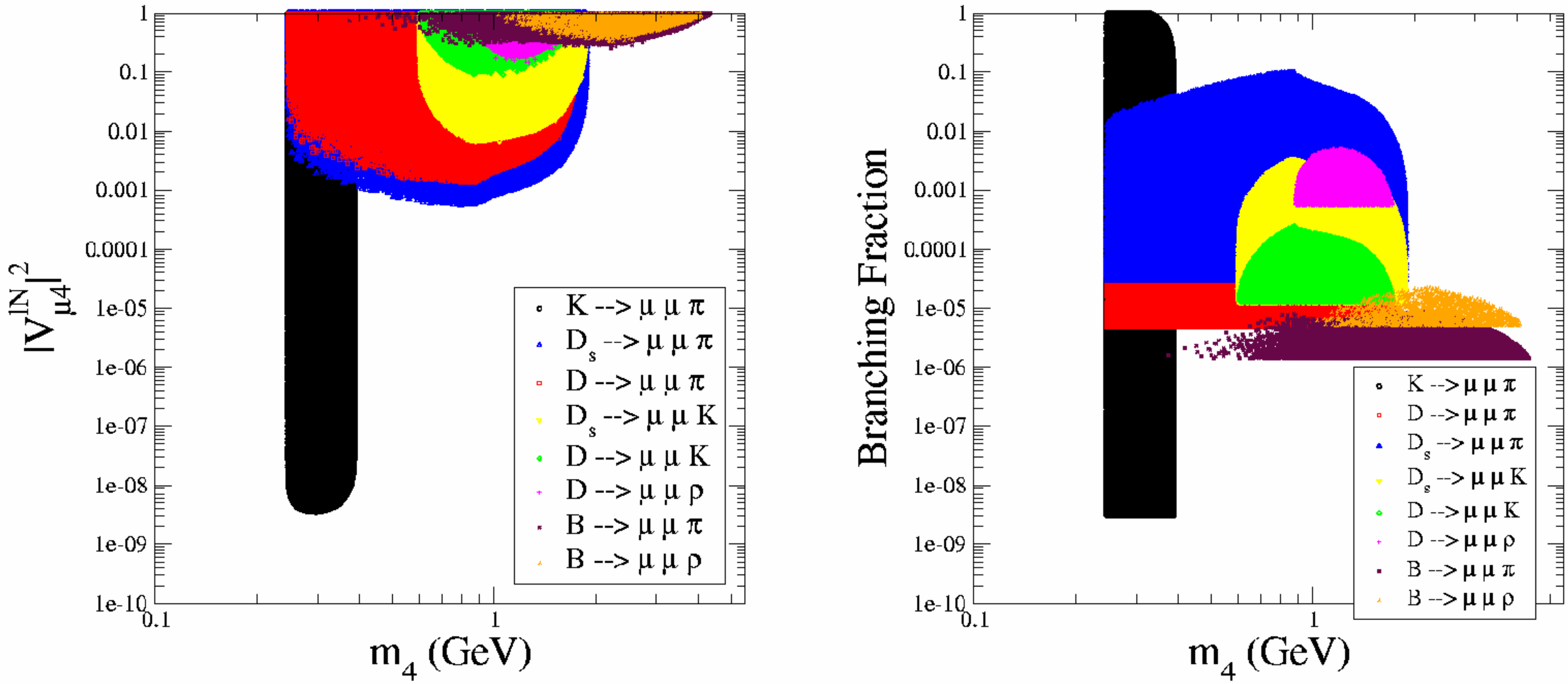
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
0.1
1
Branching Fraction
m4 (GeV)
K --> e e π
D --> e e π
D --> e e K
Ds --> e e π
Ds --> e e K
B --> e e π
B --> e e ρ



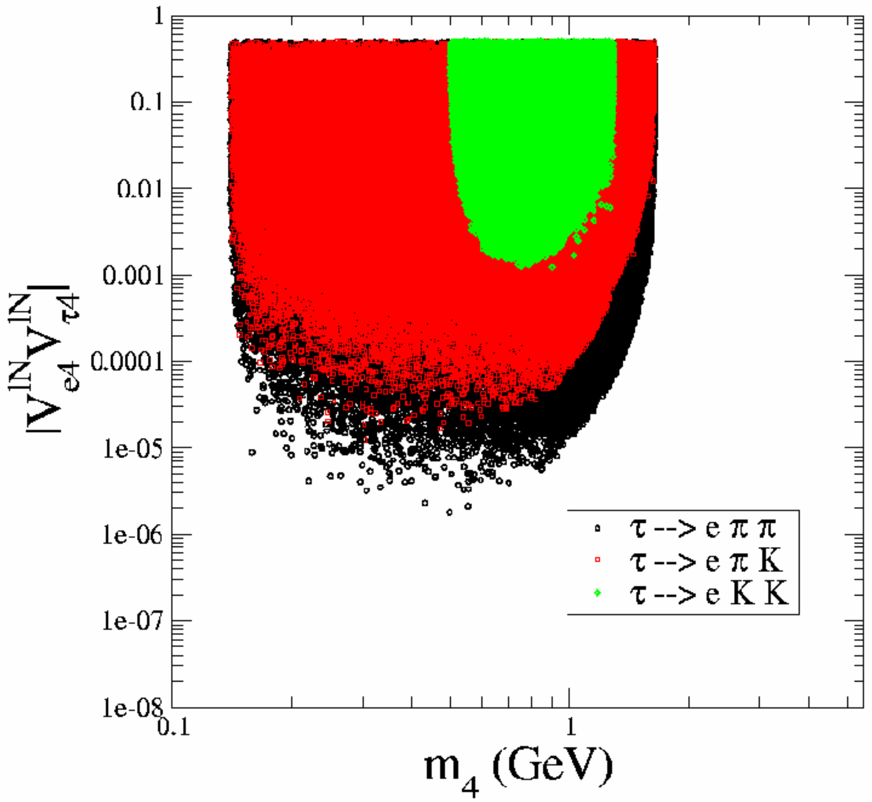
$|V_{e4}^{lN} V_{\mu4}^{lN}|$
m4 (GeV)
K --> e μ π
D --> e μ π
Ds --> e μ π
Ds --> e μ K
B --> e μ π
B --> e μ ρ



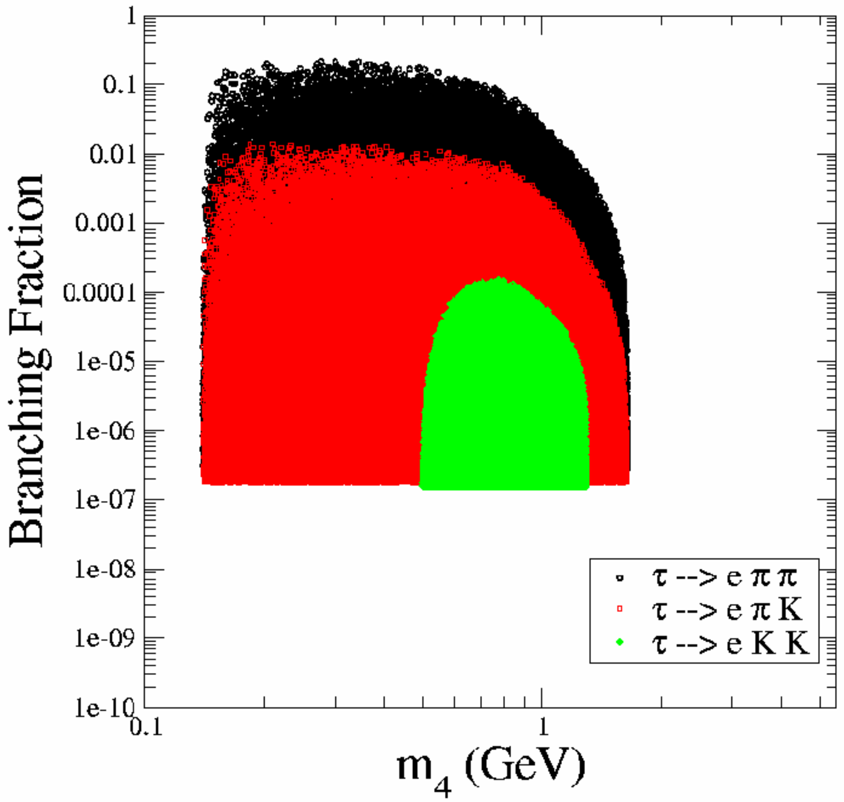
Branching Fraction
m4 (GeV)
K --> e μ π
D --> e μ π
Ds --> e μ π
Ds --> e μ K
B --> e μ π
B --> e μ ρ



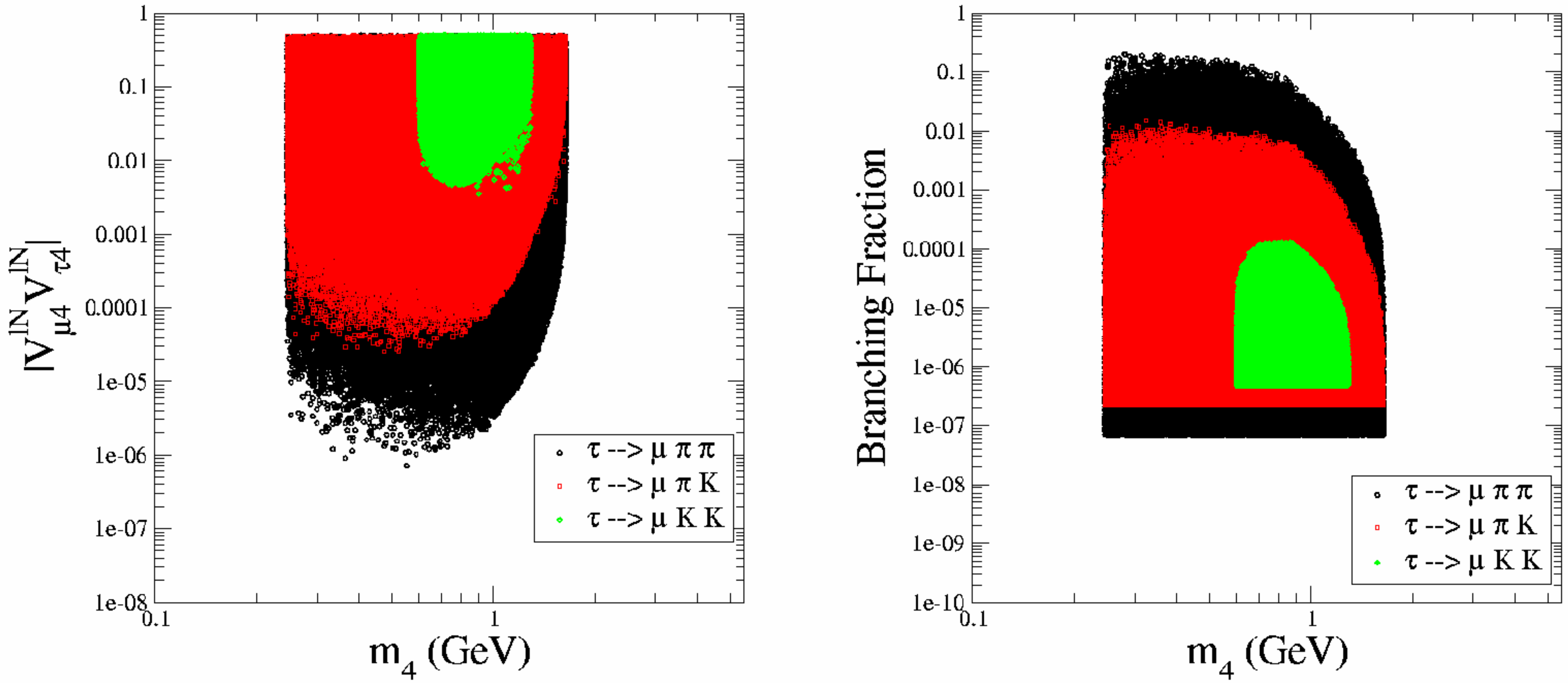
$|V_{\mu 4}^{IN}|^2$
m4 (GeV)
K --> μ μ π
Ds --> μ μ π
D --> μ μ π
Ds --> μ μ K
D --> μ μ K
D --> μ μ ρ
B --> μ μ π
B --> μ μ ρ
Branching Fraction
m4 (GeV)



$|V_{e4}^{lN} V_{\tau 4}^{lN}|$
m_4 (GeV)
τ --> e π π
τ --> e π K
τ --> e K K



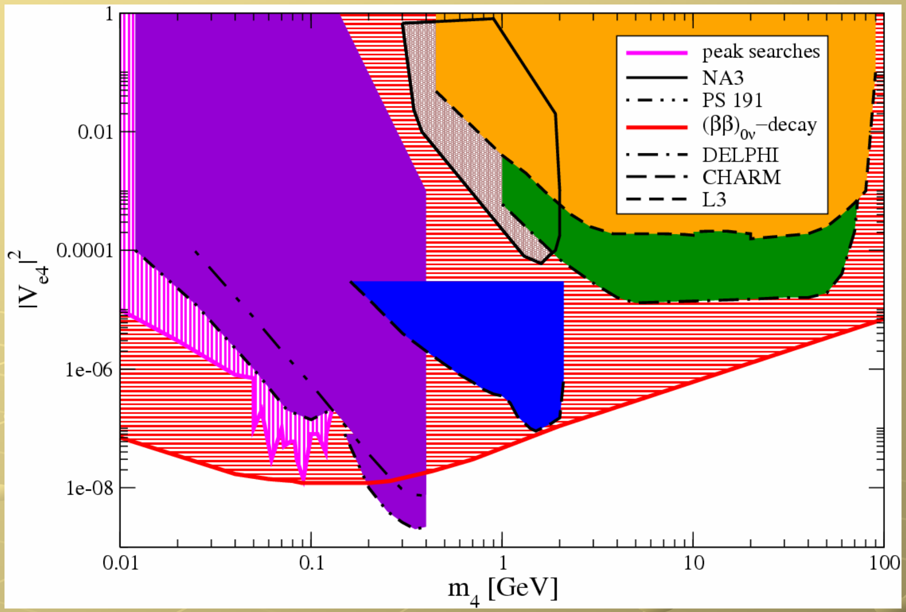
Branching Fraction
m_4 (GeV)
τ --> e π π
τ --> e π K
τ --> e K K

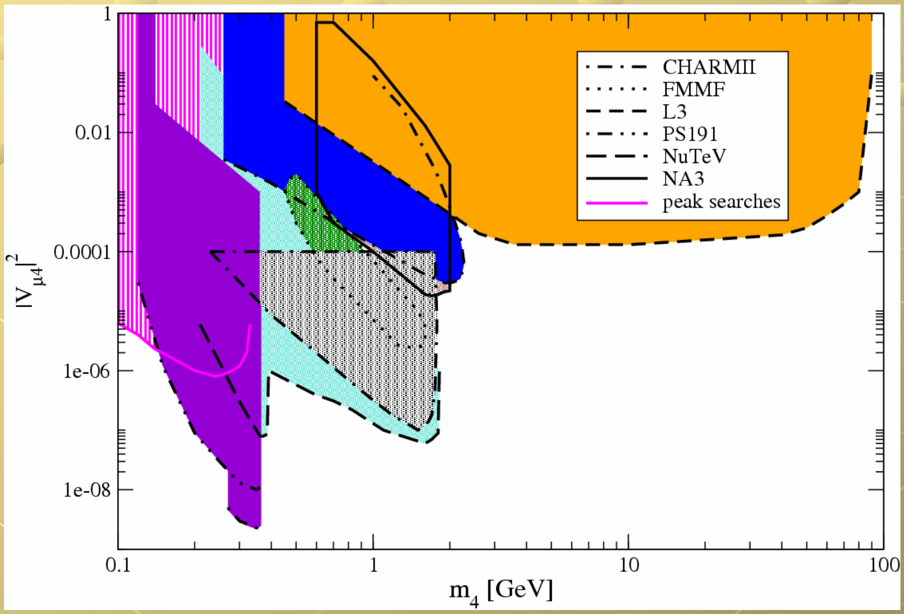


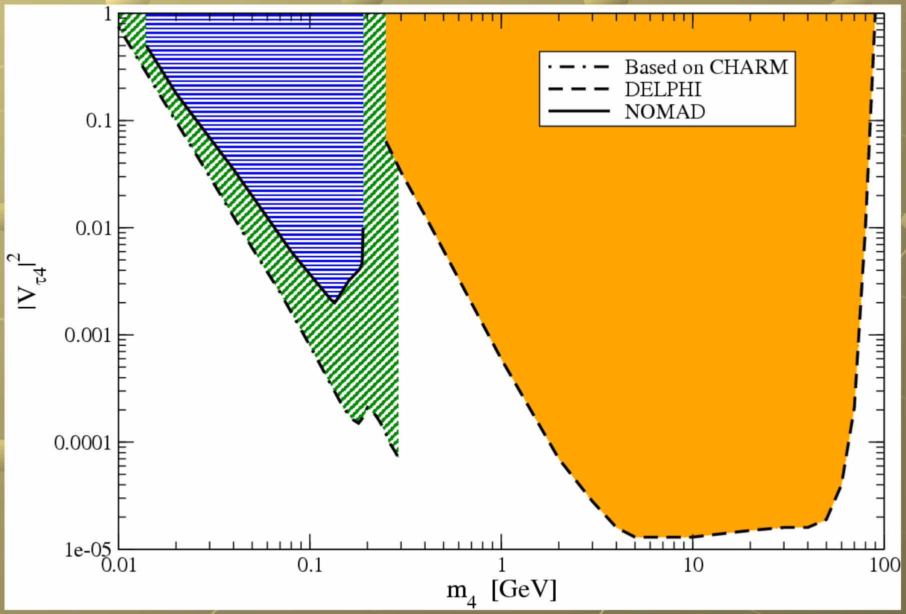
$|V^{lN}_{\mu 4} V^{lN}_{\tau 4}|$
m$_4$ (GeV)
τ --> μ π π
τ --> μ π K
τ --> μ K K
Branching Fraction
m$_4$ (GeV)
τ --> μ π π
τ --> μ π K
τ --> μ K K

Current bounds on sterile neutrino:

- peak searches
- accelerator searches
- heavy atmospheric neutrinos
- cosmology, BBN, WMAP







- It is of fundamental importance to verify Majorana nature of neutrinos

- We look for genuine $\Delta L = 2$ processes

- For the three active ν's $0\nu\beta\beta$ is the best hope

- For a sterile neutrino N (or ν_4)

  - Rare τ and meson decays are sensitive to

    $140 \text{ MeV} < m_4 < 5 \text{ GeV}, 10^{-9} < |V_{l4}|^2 < 10^{-2}$

- Depending on the unknown mixing and mass ν_4 can show up in any channel

- Other processes to look for
  $B^+ \to e^+ \tau^+ M^-$, $B^+ \to \mu^+ \tau^+ M^-$, $B^+ \to \tau^+ \tau^+ M^-$

Thank You !!!!!