Peak Search in Muon Capture

Limits on $|U_{2j}|^2$ as function of m_{ν_j}

VALUE	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$<1 \times 10^{-1}$	DEUTSCH	83	m_{ν_j}=45 MeV
$<7 \times 10^{-3}$	DEUTSCH	83	m_{ν_j}=70 MeV
$<1 \times 10^{-1}$	DEUTSCH	83	m_{ν_j}=85 MeV

Searches for Decays of Massive ν

Limits on $|U_{2j}|^2$ as function of m_{ν_j}

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<6.2 \times 10^{-8}$	95	ADEVA	90S	L3	m_{ν_j} = 20 GeV
$<5.1 \times 10^{-10}$	95	ADEVA	90S	L3	m_{ν_j} = 40 GeV
all values ruled out	95	[42] BURCHAT	90	MRK2	m_{ν_j} < 19.6 GeV
$<1 \times 10^{-10}$	95	[42] BURCHAT	90	MRK2	m_{ν_j} = 22 GeV
$<1 \times 10^{-11}$	95	[42] BURCHAT	90	MRK2	m_{ν_j} = 41 GeV
all values ruled out	95	DECAMP	90F	ALEP	m_{ν_j}= 25.0–42.7 GeV
$<1 \times 10^{-13}$	95	DECAMP	90F	ALEP	m_{ν_j}= 42.7–45.7 GeV
$<5 \times 10^{-4}$	90	[43] KOPEIKIN	90	CNTR	m_{ν_j} = 5.2 MeV
$<5 \times 10^{-3}$	90	AKERLOF	88	HRS	m_{ν_j}=1.8 GeV
$<2 \times 10^{-5}$	90	AKERLOF	88	HRS	m_{ν_j}=4 GeV
$<3 \times 10^{-6}$	90	AKERLOF	88	HRS	m_{ν_j}=6 GeV
$<1 \times 10^{-7}$	90	BERNARDI	88	CNTR	m_{μ_j}=200 MeV
$<3 \times 10^{-9}$	90	BERNARDI	88	CNTR	m_{μ_j}=300 MeV
$<4 \times 10^{-4}$	90	[44] MISHRA	87	CNTR	m_{ν_j}=1.5 GeV
$<4 \times 10^{-3}$	90	[44] MISHRA	87	CNTR	m_{ν_j}=2.5 GeV
$<0.9 \times 10^{-2}$	90	[44] MISHRA	87	CNTR	m_{ν_j}=5 GeV
<0.1	90	[44] MISHRA	87	CNTR	m_{ν_j}=10 GeV
$<8 \times 10^{-4}$	90	BADIER	86	CNTR	m_{ν_j}=600 MeV
$<1.2 \times 10^{-5}$	90	BADIER	86	CNTR	m_{ν_j}=1.7 GeV
$<3 \times 10^{-8}$	90	BERNARDI	86	CNTR	m_{ν_j}=200 MeV
$<6 \times 10^{-9}$	90	BERNARDI	86	CNTR	m_{ν_j}=350 MeV
$<1 \times 10^{-6}$	90	DORENBOS...	86	CNTR	m_{ν_j}=500 MeV
$<1 \times 10^{-7}$	90	DORENBOS...	86	CNTR	m_{ν_j}=1600 MeV
$<0.8 \times 10^{-5}$	90	[45] COOPER-...	85	HLBC	m_{ν_j}=0.4 GeV
$<1.0 \times 10^{-7}$	90	[45] COOPER-...	85	HLBC	m_{ν_j}=1.5 GeV

[42] BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89C, and WENDT 87.

[43] KOPEIKIN 90 find no m_{ν_j} in the interval 1–6.3 MeV at 90%CL for maximal mixing.

[44] See also limits on $|U_{3j}|$ from WENDT 87.

[45] COOPER-SARKAR 85 also give limits based on model-dependent assumptions for ν_τ flux. We do not list these. Note that for this bound to be nontrivial, j is not equal to 3, i.e. ν_j cannot be the dominant mass eigenstate in ν_τ since m_{ν_3} <70 MeV (ALBRECHT 85I). Also, of course, j is not equal to 1 or 2, so a fourth generation would be required for this bound to be nontrivial.

Limits on $|U_{3J}|^2$ as a Function of m_{ν_J}

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<6.2 \times 10^{-8}$	95	ADEVA	90S	L3	m_{ν_j} = 20 GeV
$<5.1 \times 10^{-10}$	95	ADEVA	90S	L3	m_{ν_j} = 40 GeV
all values ruled out	95	[46] BURCHAT	90	MRK2	m_{ν_j} < 19.6 GeV
$<1 \times 10^{-10}$	95	[46] BURCHAT	90	MRK2	m_{ν_j} = 22 GeV
$<1 \times 10^{-11}$	95	[46] BURCHAT	90	MRK2	m_{ν_j} = 41 GeV
all values ruled out	95	DECAMP	90F	ALEP	m_{ν_j}= 25.0–42.7 GeV
$<1 \times 10^{-13}$	95	DECAMP	90F	ALEP	m_{ν_j}= 42.7–45.7 GeV
$<5 \times 10^{-2}$	80	AKERLOF	88	HRS	m_{ν_j}=2.5 GeV
$<9 \times 10^{-5}$	80	AKERLOF	88	HRS	m_{ν_j}=4.5 GeV

[46] BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89C, and WENDT 87.

Limits on $|U_{aJ}|^2$

Where a = 1, 2 from ρ parameter in μ decay.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1 \times 10^{-2}$	68	SHROCK	81B	THEO	m_{ν_j}=10 MeV
$<2 \times 10^{-3}$	68	SHROCK	81B	THEO	m_{ν_j}=40 MeV
$<4 \times 10^{-2}$	68	SHROCK	81B	THEO	m_{ν_j}=70 MeV

Limits on $|U_{1J} \times U_{2J}|$ as Function of m_{ν_J}

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<3 \times 10^{-5}$	90	[47] BARANOV	93		m_{ν_j}= 80 MeV
$<3 \times 10^{-6}$	90	[47] BARANOV	93		m_{ν_j}= 160 MeV
$<6 \times 10^{-7}$	90	[47] BARANOV	93		m_{ν_j}= 240 MeV
$<2 \times 10^{-7}$	90	[47] BARANOV	93		m_{ν_j}= 320 MeV
$<9 \times 10^{-5}$	90	BERNARDI	86	CNTR	m_{ν_j}=25 MeV
$<3.6 \times 10^{-7}$	90	BERNARDI	86	CNTR	m_{ν_j}=100 MeV
$<3 \times 10^{-8}$	90	BERNARDI	86	CNTR	m_{ν_j}=200 MeV
$<6 \times 10^{-9}$	90	BERNARDI	86	CNTR	m_{ν_j}=350 MeV
$<1 \times 10^{-2}$	90	BERGSMA	83B	CNTR	m_{ν_j}=10 MeV
$<1 \times 10^{-5}$	90	BERGSMA	83B	CNTR	m_{ν_j}=140 MeV
$<7 \times 10^{-7}$	90	BERGSMA	83B	CNTR	m_{ν_j}=370 MeV

[47] BARANOV 93 is a search for neutrino decays into $e^+ e^- \nu_e$ using a beam dump experiment at the 70 GeV Serpukhov proton synchrotron.

(B) Bounds from ν Reactions

NOTE ON NEUTRINO OSCILLATION EXPERIMENTS

Experimental results on neutrino oscillations are often presented as allowed regions on a plot of $|\Delta m^2|$ as a function of $\sin^2 2\theta$, where $\Delta m^2 = m^2_{\nu_i} - m^2_{\nu_j}$. Although there are three flavors, data are usually analyzed assuming an oscillation between just two of them, *e.g.*, $\nu_\tau \leftrightarrow \nu_e$. The same remark applies to lepton-number violating mixing between two states, *e.g.*, $\nu_e \leftrightarrow \overline{\nu}_\mu$ or $\nu_\mu \leftrightarrow \overline{\nu}_\mu$.

The simplest situation occurs in an "appearance" experiment, where one searches for interactions by neutrinos of a variety not expected in the beam. An example is the search for $\overline{\nu}_e$ interactions in a beam of neutrinos from the π^+ decay chain, which (among other possibilities) might be taken as evidence for $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$. For oscillation between two states, the probability that the "wrong" state will appear is given by Eq. 5 in Shrock's "Note on Neutrinos" at the beginning of the Quark and Lepton Full Listings. For our present purposes, this may be rewritten as

$$P = \sin^2 2\theta \, \sin^2(1.27\Delta m^2 L/E) \;, \tag{1}$$

where L is the distance from the neutrino's production point to its interaction point, and E is its energy. In the above, $|\Delta m^2|$ is in eV^2 and L/E is in km/GeV or m/MeV. Since in a real experiment L and E have some spread, one must average P over the appropriate distributions. As an example, let us make the somewhat unrealistic assumption that $b \equiv 1.27L/E$ has a Gaussian distribution with standard deviation σ_b about a central value b_0. Then:

$$\langle P \rangle = \tfrac{1}{2}\sin^2 2\theta[1 - \cos(2b_0\Delta m^2)\exp(-2\sigma_b^2(\Delta m^2)^2)] \tag{2}$$

The value of $\langle P \rangle$ is set by the experiment. For example, if 230 interactions of the expected flavor are detected and none of the wrong flavor are seen, then $P = 0.010$ at the 90% CL. We can then solve the above expression for $\sin^2 2\theta$ as a function of $|\Delta m^2|$. This function is shown in Fig. 1 for the parameter assumptions given in the caption. Note that:

(a) since the fast oscillations are completely washed out by the resolution for large $|\Delta m^2|$, $\sin^2 2\theta = 2\langle P \rangle$ in this region;