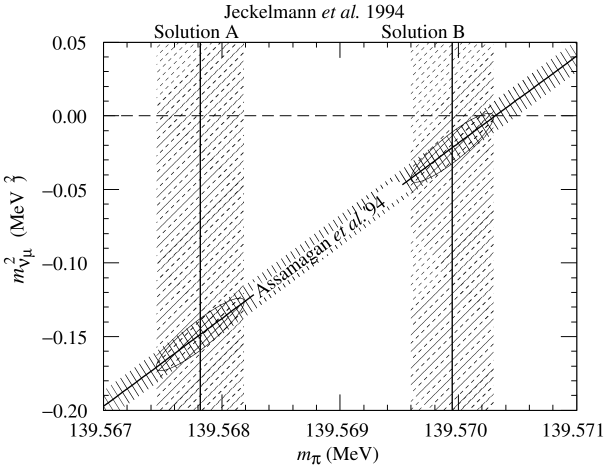

Figure 1: $m^2_{\nu_\mu}$ as a function of $\pi^\pm$ mass. The ASSAMAGAN 94 measurement of the momentum of the muon in π^+ decay at rest is represented by the diagonal line with the 1σ error band from uncertainties in p_μ and m_μ. The two solutions for the π^- mass from the JECKELMANN 94 reanalysis are shown by the vertical lines, along with their 1σ error bands. Also shown are the 1σ error ellipses from the combined fits.

Since $m^2_{\nu_\mu}$ must be nonnegative and to obtain the more conservative limit, we choose the new JECKELMANN 94 Solution B for the pion mass, and take the corresponding value $m^2_{\nu_\mu} = 0.001 \pm 0.044$ MeV^2. Using a Bayesian procedure with a flat prior distribution, we find $m^2_{\nu_\mu} < 0.073$ MeV^2 at the 90% CL, and so list $m_{\nu_\mu} < 0.27$ MeV at the 90% CL.

If, instead, we apply the same procedure using p_μ from the as yet unpublished ASSAMAGAN 94 and the Solution B pion mass from JECKELMANN 94, we obtain $m^2_{\nu_\mu} = -0.022 \pm 0.023$ MeV^2, or $m_{\nu_\mu} < 0.17$ MeV at the 90% CL.

Notes and References

* This note was prepared with extensive help from F. Boehm, R. Frosch, P.F.A. Goudsmit, Y.K. Lee, H.J. Leisi, R.G.H. Robertson, and P. Vogel

1. R.G.H. Robertson, p. 140 in *Proceedings XXVI International Conference on High-Energy Physics*, ed. J.R. Sanford (Dallas, TX, 6–12 August, 1992).
2. R. Frosch, private communication (May 1994).

ν_μ MASS

Applies to ν_2, the primary mass eigenstate in ν_μ. Would also apply to any other ν_j which mixes strongly in ν_μ and has sufficiently small mass that it can occur in the respective decays. (This would be nontrivial only for $j \geq 3$, given the ν_e mass limit above.) See also the Listings in the Neutrino Bounds from Astrophysics and Cosmology section.

VALUE (MeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
<0.27 (CL = 90%) OUR EVALUATION		DAUM 91 and JECKELMANN 94; see Note.			
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.17		[1] ASSAMAGAN	94	SPEC	$m^2 = -0.022 \pm 0.023$
<0.48		[2] ENQVIST	93	COSM	Nucleosynthesis
<0.003		[3,4] MAYLE	93	ASTR	SN 1987A cooling
< 0.025–0.030		[4,5] BURROWS	92	ASTR	SN 1987A cooling
		MAMEDOV	92	RVUE	
<0.3		[6] FULLER	91	COSM	Nucleosynthesis
<0.42		[6] LAM	91	COSM	Nucleosynthesis
< 0.028–0.15		[7] NATALE	91	ASTR	SN 1987A
<0.028		[4] GANDHI	90	ASTR	SN 1987A
<0.014		[4,8] GRIFOLS	90B	ASTR	SN 1987A
<0.06		[4,9] GAEMERS	89		SN 1987A
<0.27	90	[10] ABELA	84	SPEC	$m^2 = -0.097 \pm 0.072$
<0.50	90	ANDERHUB	82	SPEC	$m^2 = -0.14 \pm 0.20$
<0.52	90	[11] LU	80	CNTR	$m^2 = 0.102 \pm 0.119$
<0.65	90	CLARK	74	ASPK	$K_{\mu 3}$ decay

[1] ASSAMAGAN 94 result is from a new measurement of p_μ from $\pi^+ \to \mu^+ \nu_\mu$ at rest combined with JECKELMANN 94 Solution B pion mass. It is not used in "OUR EVALUATION" because it is not yet published. See Note above.

[2] ENQVIST 93 bases limit on the fact that thermalized wrong-helicity Dirac neutrinos would speed up expansion of early universe, thus reducing the primordial abundance. FULLER 91 exploits the same mechanism but in the older calculation obtains a larger production rate for these states, and hence a lower limit. Neutrino lifetime assumed to exceed nucleosynthesis time, ~ 1 s.

[3] MAYLE 93 recalculates cooling rate enhancement by escape of wrong-helicity Dirac neutrinos using the Livermore Supernova Explosion Code, obtains more restrictive result than the "very conservative" BURROWS 92 limit because of higher core temperature.

[4] There would be an increased cooling rate if Dirac neutrino mass is included; this does not apply for Majorana neutrinos. Limit is on $\sqrt{m^2_{\nu_\mu} + m^2_{\nu_\tau}}$, and error becomes very large if ν_τ is nonrelativistic, which occurs near the lab limit of 31 MeV. RAJPOOT 93 notes that limit could be evaded with new physics.

[5] BURROWS 92 limit for Dirac neutrinos only.

[6] Assumes neutrino lifetime >1 s. For Dirac neutrinos only. See also ENQVIST 93.

[7] NATALE 91 published result multiplied by $\sqrt{8}\sqrt{4}$ at the advice of the author.

[8] GRIFOLS 90B estimated error is a factor of 3.

[9] GAEMERS 89 published result (< 0.03) corrected via the GANDHI 91 erratum.

[10] ABELA 84 used the PDG 84 value for $\pi^\pm$ mass, in conjunction with μ momentum measurement in $\pi \to \mu \nu_\mu$ decay to obtain $m < 0.25$ and $m^2 = -0.16 \pm 0.08$. The values shown here for mass and m^2 are corrected values obtained by JECKELMANN 86 from the ABELA 84 data using the more accurate $\pi^\pm$ mass of JECKELMANN 86.

[11] LU 80 combines DAUM 79 $\pi^+ \to \mu^+ \nu_\mu$ measurement with new LU 80 π^- mass and replaces DAUM 79. LU 80 is not independent of ABELA 84.

$m_{\nu_2} - m_{\overline{\nu}_2}$

Test of *CPT* for a Dirac neutrino. (Not a very strong test.)

VALUE (MeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.45	90	CLARK	74	ASPK	$K_{\mu 3}$ decay