Neutrinos (2)

Ramon Miquel (ICREA / IFAE Barcelona)
(with input from Maury Goodman)

- Productive period: 48 new measurements (from 66 reviewed papers, 25 with relevant data)
  Deep in the precision-measurements mode ("mature")
- Many structural changes in previous years 2004 → 2006
- Basically no changes in listings in 2010. New oscillation review consolidates previous mini-reviews.
- A few extra changes may be necessary for 2012, but there are uncertainties...

Cast

Maury Goodman	Encoding of accelerator neutrino papers
Don Groom	Overseer emeritus
Dean Karlen	"Number of Light Neutrinos"
Ramon Miquel	Overseer → Cheng-Ju Stephen Lin in Oct. '10
Hitoshi Murayama	Mega-plot with current oscillation parameters
Kenzo Nakamura	Encoding of extraterrestrial neutrino papers
Kenzo Nakamura & Serguey Petcov	"Neutrino Mass, Mixing, and Flavor Change"
Keith Olive	Encoding of Astrophysical papers
Andreas Piepke	Encoding of Nuclear Physics papers
&	"Introduction to the Neutrino Properties Listings"
Petr Vogel	"Note on Neutrinoless Double-Beta Decay"

+ consultants, referees, verifiers…

In Numbers

- # of pages (in web edition --- haven't seen the book yet)
  - Summary table: 1
  - Review section: 53
  - Listings (including mini-reviews): 87

  Neutrinos badly underrepresented in summary tables!

- # of new measurements (papers):
  - Properties: 9 (9)
  - # of neutrino types: 0 (0)
  - $0\nu\beta\beta$ decays: 15 (8)
  - Mixing: 24 (8)
  - Searches for Heavy Neutral Leptons: 0 (0)

SUM OF THE NEUTRINO MASSES, m_{tot}

(Defined in the above note), of effectively stable neutrinos (i.e., those with mean lives greater than or equal to the age of the universe). These papers assumed Dirac neutrinos. When necessary, we have generalized the results reported so they apply to m_{tot}. For other limits, see SZALAY 76, VYSOTSKY 77, BERNSTEIN 81, FREESE 84, SCHRAMM 84, and COWSIK 85.

VALUE (eV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
< 1.1		[54] ICHIKI 09	COSM	
< 1.3		[55] KOMATSU 09	COSM	WMAP
< 1.2		[56] TERENO 09	COSM	
< 0.33		[57] VIKHLININ 09	COSM	
< 0.28		[58] BERNARDIS 08	COSM	
$< 0.17–2.3$		[59] FOGLI 07	COSM	
< 0.42	95	[60] KRISTIANSEN 07	COSM	
$< 0.63–2.2$		[61] ZUNCKEL 07	COSM	
< 0.24	95	[62] CIRELLI 06	COSM	
< 0.62	95	[63] HANNESTAD 06	COSM	
< 1.2		[64] SANCHEZ 06	COSM	

Some of these papers were missed by ou
literature searchers: JCAP, MNRAS..

Found by Keith Olive

Double-β Decay

OMITTED FROM SUMMARY TABLE

A REVIEW GOES HERE – Check our WWW List of Reviews

Half-life Measurements and Limits for Double-β Decay

In most cases the transitions $(Z,A) \rightarrow (Z-2,A) + 2e^- + (0 \text{ or } 2)\ \overline{\nu}_e$ to the 0^+ ground state of the final nucleus are listed. However, we also list transitions that increase the nuclear charge ($2e^+$, e^+/EC and ECEC) and transitions to excited states of the final nuclei (0_i^+, 2^+, and 2_i^+). In the following Listings, only best or comparable limits or lifetimes for each isotope are reported. For 2ν decay, which is well established, only measured half-lives are reported.

$t_{1/2}(10^{21}$ yr)	CL%	ISOTOPE		TRANSITION	METHOD	DOCUMENT ID	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 18.0	90	^{150}Nd	0ν		NEMO-3	[1] ARGYRIADES	09
$(9.11^{+0.25}_{-0.22} \pm 0.63)$E-3		^{150}Nd	2ν		NEMO-3	[2] ARGYRIADES	09
> 0.43	90	^{64}Zn	0ν	β^+EC	$ZnW0_4$ scint.	[3] BELLI	09A
> 0.11	90	^{64}Zn	0ν	ECEC	$ZnW0_4$ scint.	[4] BELLI	09A
$> 4.1 \times 10^{-4}$	90	^{120}Te	0ν	β^+EC	CdZnTe det.	[5] DAWSON	09
> 0.02	90	^{124}Sn	0ν	$\beta\beta$	tin liq. scint.	[6] HWANG	09
$0.55^{+0.12}_{-0.09}$		^{100}Mo	2ν+0ν	$0^+ \rightarrow 0_1^+$	Ge coincidence	[7] KIDD	09
> 3000	90	^{130}Te	0ν		TeO_2 bolometer	[8] ARNABOLDI	08
> 0.004	90	^{64}Zn	0ν	2K	$ZnWO_4$ scint.	[9] BELLI	08
> 0.22	90	^{64}Zn	0ν		$ZnWO_4$ scint.	[10] BELLI	08
> 0.001	90	^{108}Cd	0ν	2K	$CdWO_4$ scint.	[11] BELLI	08B
> 0.0013	90	^{114}Cd	2ν	$\beta\beta$	$CdWO_4$ scint.	[12] BELLI	08B
> 1.1	90	^{114}Cd	0ν	$\beta\beta$	$CdWO_4$ scint.	[13] BELLI	08B

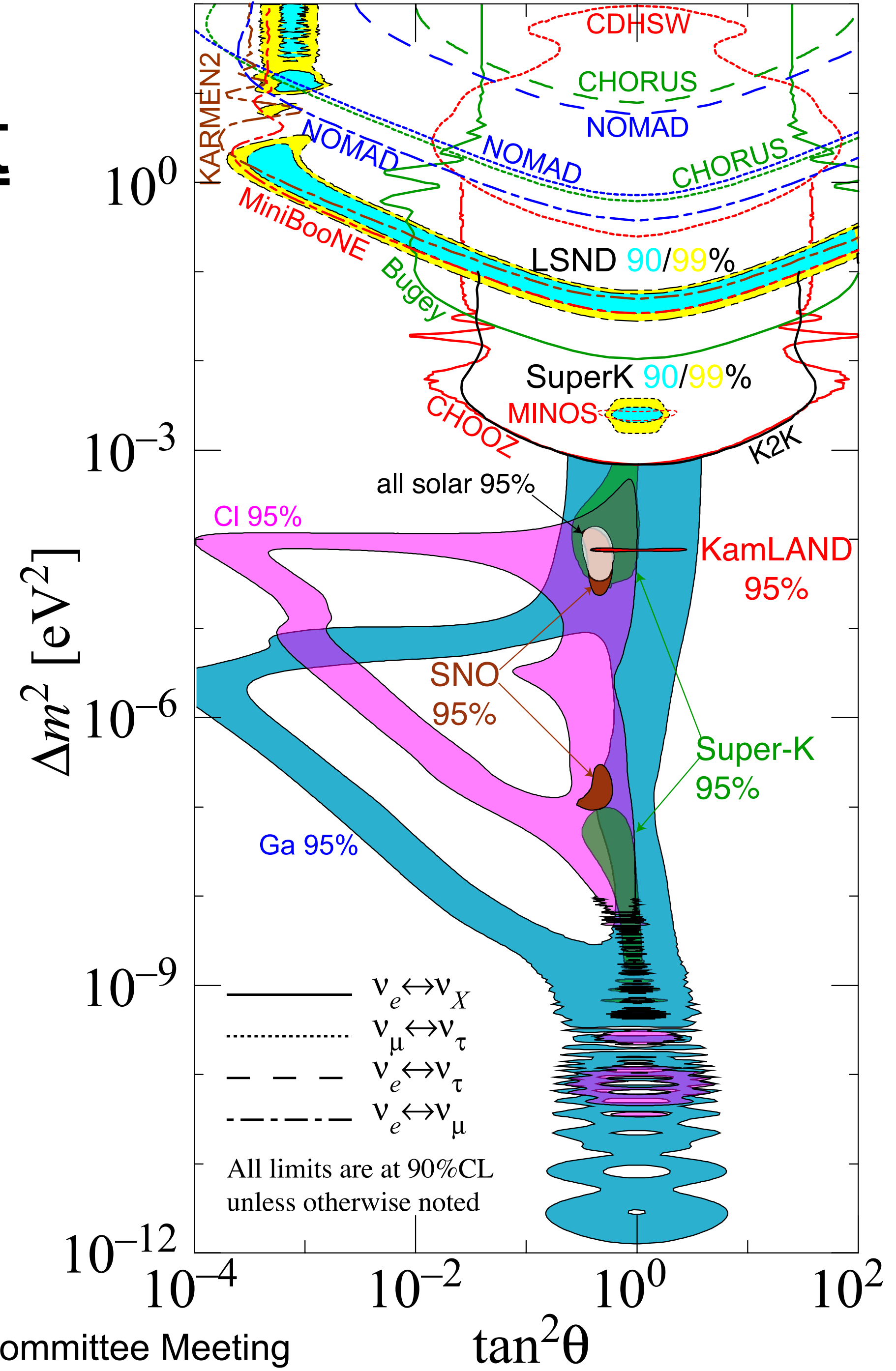
Lots of papers with several measurements (2v, 0v, excited states) each.

Reviews

- Brand-new mass and mixing review (including solar neutrinos) by Nakamura and Petcov.
- Revised intro to neutrino properties review by Vogel and Piepke.
- Revised neutrinoless double-beta decay review by Vogel and Piepke.
- Solar neutrino review by Nakamura merged into overall mixing review.

Oscillation Plot

- By Hitoshi Murayama.
- Combines all two-flavor oscillation data in one figure.
- Solar, atmospheric, reactor and accelerator results available at a glance.
- Included in Nakamura & Petcov's review on neutrino oscillations.



http://hitoshi.berkeley.edu/neutrino

Mixing Results (PDG'10)

- $|\Delta m^2_{32}|$ = $(2.43 \pm 0.13) \times 10^{-3}$ eV^2 MINOS
- Δm^2_{21} = $(7.59 \pm 0.20) \times 10^{-5}$ eV^2 KamLAND + Solar
- $\sin^2(2\theta_{23}) > 0.92$ Super-K
- $\sin^2(2\theta_{12}) = 0.87 \pm 0.03$ KamLAND + Solar
- $\sin^2(2\theta_{13}) < 0.15$ CHOOZ (+MINOS)

Mixing Results (PDG'08)

- $|\Delta m^2_{32}|$ = $(1.9 - 3.0) \times 10^{-3}$ eV^2 Super-K
- Δm^2_{21} = $(8.0 \pm 0.3) \times 10^{-5}$ eV^2 KamLAND + Solar
- $\sin^2(2\theta_{23}) > 0.92$ Super-K
- $\sin^2(2\theta_{12}) = 0.86^{+0.03}_{-0.04}$ KamLAND + Solar
- $\sin^2(2\theta_{13}) < 0.19$ CHOOZ (+Super-K)

Issues: Reviews (from 2008 talk)

- The listings state and assume $\Delta m^2_{atm} \approx \Delta m^2_{31} \approx \Delta m^2_{32}$
- This is appropriate for now.
- However, there is a great deal of interesting physics at the next level, and the reviews allude to this in ways that are not totally consistent.
- They need to be carefully re-edited with this in mind
  Mostly solved with new review

Issues: Listings (from 2008 talk)

- The double beta decay section should be revised:
  - Separating the 0ν and 2ν results
  - Hiding the excited states Some progress
- As a result of the MiniBooNE results, the "Other Neutrino Mixing Results" section should probably be hidden in 2010. NO! Recent results throw even more confusion into the mix
- We should be on the watch for what new nodes (if any) may be needed for new paradigms ($>3\nu$, etc.) Working on it

Issues: Encoding (from 2008 talk)

- Growing number of "cosmo" papers dealing with neutrino mass and number of neutrinos published in journals we do not follow: JCAP, MNRAS... JCAP added to the list of journals we search

- Papers are assigned to encoders according to our old categories: reactor (Vogel and Piepke), accelerator (Goodman), solar + atmospheric (Nakamura), cosmic (Olive). It may be time to revise this. Still pending

Issues: Personnel (from 2008 talk)

- I'm currently planning to leave PDG after the 2010 edition.
- A new overseer for the neutrino sections will be needed.
  Solved: Cheng-Ju Stephen Lin is the new overseer

Issue for PDG
What to encode?

- Six PDG collaborators met at lunch at ν2010 to discuss the issue of what else to encode:
- There was no strong desire to add anything, except maybe NSI
- At Nufact2010 I raised the issue again, and received a request to encode non-standard-interaction parameters

- Many measurements seek to test outside that paradigm
  - ν vs $\bar{\nu}$
  - 4 ν
  - 5 ν
  - Lorentz violation
  - Sterile fractions
  - Non standard Interactions
  - …
  - What is useful?

NSI

- I was referred to and in contact with theorist Sacha Davidson from Lyon who has agreed to help
- One compendium of limits:
- There are notation subtleties I haven't absorbed yet.

$\varepsilon^{\mu e}_{\alpha\beta}$	**Kin. G_F** (L,R)	**CKM unit.** (V)	**Lept. univ.** (A)	**Oscillation** (L,R)
$\varepsilon^{\mu e}_{ee}$	< 0.030	< 0.030	< 0.080	< 0.025
$\varepsilon^{\mu e}_{e\mu}$	$(-1.4 \pm 1.4) \cdot 10^{-3}(\mathbb{R},L)$ < 0.030	$< 4 \cdot 10^{-4}(\mathbb{R})$ < 0.030	$(-0.4 \pm 3.5) \cdot 10^{-3}(\mathbb{R})$ < 0.080	-
$\varepsilon^{\mu e}_{e\tau}$	< 0.030	< 0.030	< 0.080	< 0.087
$\varepsilon^{\mu e}_{\mu e}$	< 0.030	< 0.030	< 0.080	< 0.025
$\varepsilon^{\mu e}_{\mu\mu}$	< 0.030	< 0.030	< 0.080	-
$\varepsilon^{\mu e}_{\mu\tau}$	< 0.030	< 0.030	< 0.080	< 0.087
$\varepsilon^{\mu e}_{\tau e}$	< 0.030	< 0.030	< 0.080	< 0.025
$\varepsilon^{\mu e}_{\tau\mu}$	< 0.030	< 0.030	< 0.080	-
$\varepsilon^{\mu e}_{\tau\tau}$	< 0.030	< 0.030	< 0.080	< 0.087

TABLE II: Bounds (90 % CL) on the purely leptonic charged-current-like NSI $\varepsilon^{\mu e}_{\alpha\beta}$, relevant to the neutrino production through muon decay, *e.g.*, at a Neutrino Factory. The letters L, R, V, A refer to the chirality of the ε which is actually bounded, while $\mathbb{R}$ stands for the real part of the element only. See the text for details.

Conclusions

- Neutrino physics has matured.
- RPP keeps adapting to the changes in our understanding of neutrino physics.
- Updated reviews help the reader follow this rather complicated subject.
- Minor improvements to the listings should be applied for 2012.
- Recent results from MiniBooNE (and MINOS) may point to physics beyond the 3-neutrino paradigm. We need to understand how to deal with this.