# 4442 Particle Physics
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# Week 11

http://www.hep.ucl.ac.uk/~markl/teaching/4442



**WEEK 11 : NEUTRINOS + REVISION**

- review of the neutrino

    - what is the mass scale
    - Majorana or Dirac
    - do they exhibit CP violation

- revision…..

Neutrinos had always thrown up surprises - so they are worth the effort of studying despite their tiny interaction cross sections.

Quotes from the 1980s-1990s after SM was well established:

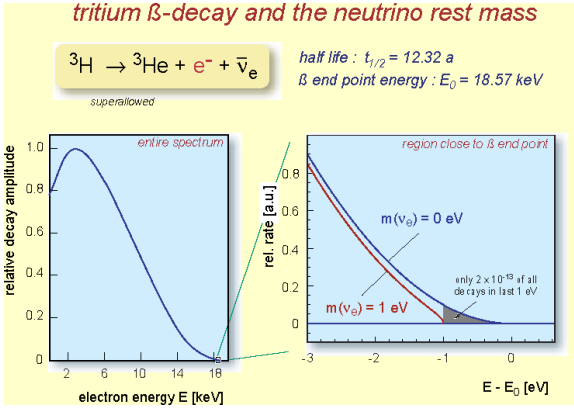
~~"Any unbiased observer who has not been "brainwashed" by recent speculations concerning supersymmetry, axions, or galaxy formation would undoubtedly conclude that the leading "suspect" in the dark matter puzzle must be the light neutrino…at the relevant mass range of 15-65 eV."~~

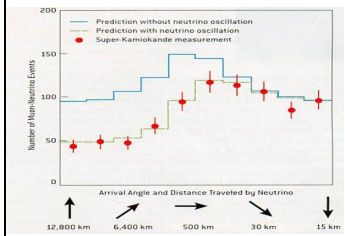
~~"…angle $\theta_{12}$ mixes adjacent generations. It is analogous to $\theta_{23}$ in the quark sector…. The pattern of the charged lepton mass ratios is not very much different from that of the quark mass ratios. Most theoretical models expect mixing angles to be somehow related to fermion masses."~~

~~"Most likely the solar neutrino problem has nothing whatsover to do with particle physics. It is a great triumph that astrophysicists are able to predict the number of $B^8$ neutrinos coming from the sun as well as they do, to within a factor of 2 or 3."~~



Traditional method to measure neutrino mass is to measure max KE of electron from single β decay. This has shown mass of neutrino < 2 eV. Next generation experiments to probe 0.5 eV. But best evidence for scale of neutrino mass is neutrino oscillations.

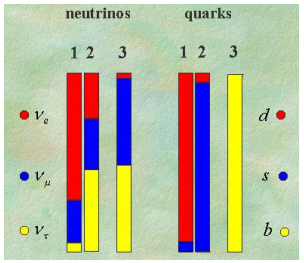




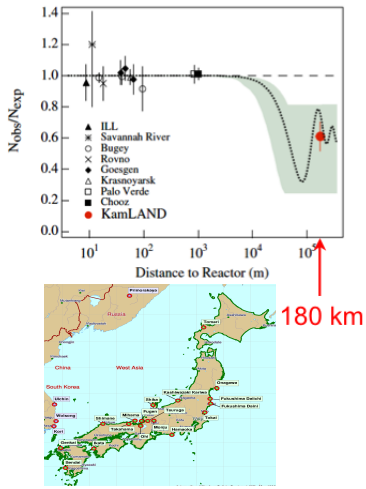

Unambigious evidence of neutrino oscillations is from the zenith angle dependence of the muon neutrino flux from cosmic rays compared to the prediction [(Super)Kamiokande]

Mixing is very different (much larger) than the quark case.

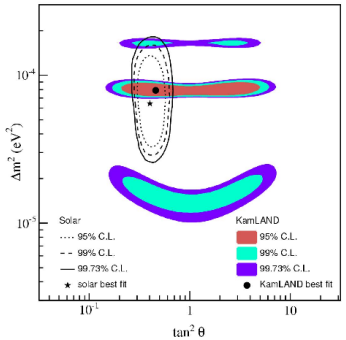
Mass hierarchy is not yet known.






Solar ($\nu_e$) [SNO] and reactor (anti-$\nu_e$) [KAMLAND] determine $\theta_{12}$ and $(\Delta m_{12})^2$



Implications of neutrino mass on non precision beta decay is unmeasurable *

Mass scale from oscillations ~ 0.01 eV
Cosmology : $\Sigma m\nu$ <~ 1 eV
Single Beta Decay : $m\nu$ <~ 2 eV

Scale of mass is difficult to naturally accommodate in SM.
It is not yet known whether neutrino is its own anti-particle like the $\pi^0$ or not

The detection of zero neutrino double beta decays would mean the neutrino is Majorana and offers an insight into GUT scale physics

The favoured model for generating tiny neutrino masses is the seesaw mechanism - this generally predicts two Majorana neutrino neutrinos - one very light and one very massive (GUT scale).



Quark mixing matrix (CKM matrix) has 3 angles and 1 phase ($\delta$).

$\delta$ is vital since its presence means "T" parity is violated and hence by virtue of CPT conservation that "CP" is violated ie matter anti-matter asymmetry.
But CP measured in quark sector is insufficient to explain the baryon anti-baryon asymmetry in the universe.

Neutrino mixing (PMNS matrix) also has 3 angles and 1 phase ($\delta$)
The hope is that CP violation in neutrino sector can be the mechanism to generate the universe's baryon anti-baryon asymmetry.

But observed size of any CP violating effects in neutrino sector are modulated by $\sin^2\theta_{13}$ which is known to be small. If it is too small then the CP violating effects may to too small to observe.

It is also believed that the heavy sterile Majorana neutrino may have decayed asymmetrically to +/- charged leptons at the start of the universe to generate a Lepton asymmetry. This needs the mythical sphaleron particle to QM tunnel this leptogenesis to a baryon asymmetry !!!