Lindley Winslow Lecture Questions

Questions marked in green were answered during the Q&A session. Original questions listed without correction for grammar/spelling. Where a slide number was given it is shown.

Q1 Can you please explain how the neutrinoless double beta decay can help explain the matter-antimatter asymmetry.

Leptogenesis is a theory where a lepton violating process in the early universe is transformed via sphaleron processes into a baryon number asymmetry (the matter-antimatter asymmetry we currently observe). We have never observed a lepton number violating process. The discovery of neutrinoless double-beta decay would be the first and a strong clue that Leptogenesis is the right set of theories to pursue.

Q2 [slide 14] How is lepton number not conserved?

Conserved quantum numbers emerge from symmetries of the underlying theory. If lepton number is violated then lepton number is not a fundamental symmetry of particle physics. It doesn't mean it is not useful for understanding particle physics, just that it is not fundamental. Isospin is a good example of a quantum number that is very useful for understanding processes, but not a fundamental quantum number.

Q3 [slide 13] Does this mean that there is heavy neutrino for each of the 3 light neutrinos, leading to 6?

There are 3 flavors of light neutrinos that do not align with the 3 mass eigenstates. Flavor and mass are decoupled concepts, but one would assume that the heavy neutrinos have flavor too. We do know that the heavy neutrinos need to violate CP in their decays, so 3 flavors analogous to the particles we know is a logical construction.

Q4 [slide 17] What IS the energy scale of the Ns?

Somewhere around 10^16 GeV. There is some wiggle room by a few orders of magnitude on either side.

Q5 For the sea saw mechanism, why do we call these Majorana neutrinos if there were both Dirac and Majorana terms in the Lagrangian?

A Majorana neutrino can have Dirac and Majorana mass terms because you can add to the Lagrangian any terms that are not forbidden. A Dirac neutrino cannot have a Majorana mass term because that would violate lepton number.

Q6 [slide 27] But if the neutrinos are Majorana, then they are their own antiparticles--is it reasonable at all to assign any lepton number, whether positive or negative, to neutrinos?

Lepton number will still work for understanding the processes we have already observed. It is only in a process like neutrinoless double-beta decay that you can't use it anymore.

Q7 [slide 30, 32] Could you explain the reasons for the shape of these graphs again?

Let's think about single beta decay. A neutron turns into a proton ejecting an electron and an antineutrino. We only measure the energy of the electron (the recoil of the proton/nucleus is neglected). The energy of the decay is shared by the electron and antineutrino, so you get the characteristic beta-decay spectrum shape where it is unlikely for either the electron or the neutrino to take all fo the energy of the decay. On slide 30, the spectrum of the sum of the two electron's from the two-neutrino double-beta decay is shown. You see the same shape as single beta decay since the two antineutrinos are sharing the energy. Now, if you are looking for neutrinoless double-beta decay, there are no neutrinos to to share the energy and you just measure the full energy available to the decay (with some width depending on the energy resolution of your detector).

Q8 [slide 60] How we validate the isotopes to be neutrinoless double beta decay candidate? What are the properties of neutrinoless double beta decay candidate?

This requires a bit more nuclear physics knowledge, but you are looking for nuclei where the daughter nucleus is less bound than the parent. There is the "empirical mass formula" which puts together the main factors determining the binding of nuclei and you can go from there to look through the Table of Isotopes. Thankfully people have done this and we have the list of the highest energy candidate isotopes in the talk.

Q9 [CUORE Slides] What were the factors influencing the choice of CUORE's Tellurium crystal size and shapes?

We wanted the largest crystals that could be reasonably grown to reduce surface to volume (surfaces are where radioactive contaminants like to stick). This leads naturally to a chrysler on the scale of 5cm x 5 cm x 5 cm. This is on the larger end of what is easily grown in normal furnaces. This is also a reasonable size for cooling down.

Q10 How do Particle Physicists always find the way to make the name of their experiments actually fun?

This is not even the favorite of my experiments' names. If I was giving a talk on axion dark matter, I could have told you about ABRACADABRA!

Q11 [slide 80] Are the periodic flat parts in the spectrum calibrations, or just routine maintenance? On that note, how do you calibrate this type of detector?

There were several periods where we were doing upgrades to the cryostat to enable more stable running. This is the world's largest dilution refrigerator, so this was a feat in itself. Once those upgrades were in place we have been running very consistently. We calibrate two ways: There is a system of cables that can pull radioactive sources into the space right near the crystals. We can also place sources outside of the cryostat. The later does not illuminate the detector as evenly but is less invasive during normal data taking. This is an ongoing optimization.

Q12 What does pileup mean in Cuore?

Pileup means the same in CUORE as it does in collider experiments. It is two events that happen within the same event. Our event rate is very low mHz but our detectors are slooooow (1s), so this can lead to backgrounds if the events happen to add up to the energy of the double-beta decay (2.5 MeV).

Q13 [slide 84] Isn't the majorana mass, from the seesaw mechanism, supposed to be much much later? how does this result fit in with that?

The current results from experiments set limits are an effective Majorana mass of the neutrino of ~100 meV. The next generation of experiments is looking at 1-10 meV. The mass of the electron is MeV, so 6 orders of magnitude. This is exactly what the see-saw mechanism can explain!

Q14 [slide 81] Although it's not the most probable scenario, how does one deal with potential signal events that happen near the edge of the Te crystal (so you might get some contamination in another crystal because of this)? Just for the sake of background, are these events rare enough where it's not too much of a loss?

We simulate this effect with Geant4 and it goes into our calculation of the efficiency for detecting neutrinoless double-beta decay.

Q15 In general, is the goal of 0vBB to see if the neutrinos that we know about ARE Majorana, or are we looking for NEW neutrinos that are Majorana?

In 0vBB we are looking to see if the neutrinos we know about are Majorana. There are models that could make heavy neutrinos at the TeV-scale and there are searches at the LHC for such heavy neutrinos.

Q16 Can KamLAND-Zen look for WIMP dark matter with the XENON, and have there been any interesting DM limits set with this detector?

KamLAND's energy threshold is ~1MeV where WIMP recoils are down at ~1keV. KamLAND's total volume is 1kT where XENON is 1T. It's easier to be big and warm, but you need to be cold to get down to those low energies to look for WIMP dark matter. KamLAND can look for the product of WIMP annihilation in the sun or earth, and those are analyses we do, in addition to more exotic dark matter candidates.

Q17 You mentioned that a good energy resolution is a key feature to search for neutrino-less double beta decay, what about dark matter experiments that can achieve good energy resolution. Can you comment on that ?

Dark matter experiments need very low energy thresholds (~keV) which is slightly different than having good energy resolution at the neutrinoless double-beta decay region of interest (2-3 MeV for most isotopes). The critical backgrounds are neutrons for dark matter searches vs. high energy gammas for neutrinoless double-beta decay. The detector technologies do overlap between neutrinoless double-beta decay but the optimizations are slightly different. At the current scale of experiments, it has not been cost-effective to combine them. This may not be true for the next generation of experiments, and this is a point of discussion.

Q18 [slide 31] Is it possible that the two neutrinos annihilate and emit two photons?

Yes, but you would need to have a lot of neutrinos. A neutrino beam experiment is happy to have with 10^22 protons on target. Note that there are 6.02 x 10^23 nuclei per gram of isotope and we are instrumenting 1 ton of isotope. We have a lot more opportunities to observe this very rare process. In supernova, there may be enough neutrinos to start seeing collective effects that would let you tease out the Majornna vs. Dirac nature of the neutrino, but that work can't be verified until we have a supernova in our galaxy :)