Roxanne Guenette – Lecture 2 Questions

Questions marked in green were answered during the Q&A session. No attempt was made to correct grammar/spelling issues. Where a slide number was given it is shown.

Q1 (slide 5): what properties of the fluid make it ideal to detect oscillation?

Ans: Here, I am not entirely sure what drove Davis to choose the cleaning fluid. I would think that since he needed something that would produce an "interesting" product out of the beta-decay reaction and he needed something easily available and cheap, he opted for 37Cl. This would produce 37Ar, which can decay giving a clear signal in a proportional counter. In addition, as Ar is part of the Noble group, he knew that he could use regular Ar to collect that individual 37Ar, as all isotopes of Ar would behave the same in the gas separation techniques he used. I highly recommend reading the full paper of this experiment, as it is truly amazing (THE ASTROPHYSICAL JOURNAL, 496:505È526, 1998 March 20)

Q2 (slide 5): How did Davis manage to observe every single argon atom?

Ans: This is the real amazing achievement! But note that he did not achieve a 100% efficiency at tagging the 37Ar. That's why it took a very long time to assess ALL the different efficiency at all stages of the experiment. In order to extract a flux estimation from the number of 37Ar collected, one needs to understand very well where things can be lost. In their paper (THE ASTROPHYSICAL JOURNAL, 496:505È526, 1998 March 20), they explain in great details how this worked and it's phenomenal!

Q3 (slide 8): why are the error bars in theoretical predictions large where the error bars in the experimental observations are less and vice - versa in the plot ?

Ans: For the theory points, they started with the solar flux (that has some uncertainty) then added the experimental effects to the flux to convert it to something experiments could compare to. I am not sure what they assumed in the flux to detector rate conversion here, but since experiments make the "real" measurement and they should understand all their errors, they quote the observed errors. Again, as I am not sure who and how they made that plot, I would assume more conservative estimate of errors from the theory side...

Q4 (slide 11): Can you explain again neutrinos why coming from the bottom were important to detect?

Ans: Here it's a direct test of a potential probability of oscillation. If you have oscillation, allowing for longer travel distance should give you higher probability of oscillation (well, within some parameters of course). By comparing neutrinos coming from the atmosphere directly above the detectos (at maximum ~10km), where the probability of oscillation is lower, with the ones from the bottom, produced in the atmosphere the *other* side of the Earth (now traveling 1200km through the Earth), you have a much higher chance to see oscillation from those bottom neutrinos. This is indeed what was observed.

Q5 (slide 13): After adding NaCl, there would be neutral current reaction but the earlier CC reaction would still occur? Is there a way to identify from the event signal whether the event was a result of NC or CC?

Ans: Yes, and this is something that all experiments exploit now a days. As you can see on that slide, a nue CC interaction will produce an electron (also an numu CC interaction will produce a muon). The *signature* of CC interactions is the identification of the charged lepton (directly associated to the flavor of the neutrino). Therefore SNO was always able to identify clearly the CC interactions by seeing an electron, which can be easily identified. When looking at NC, the signal of this interactions (from the de-excitation of the Cl) is very different than an electron. NC cannot allow for identification of the neutrino flavor). So they could always get results with CCnue (⅓ of events) and NC (all the events). Going from ⅓ when looking at 1 type of neutrino to 1 when looking at them all was the proof that solar neutrino had oscillated and were now in equal part (⅓ each).

Q6: Do annular modulations appear in solar neutrino oscillation experiments?

Ans: I did not recall at the time if it had been observed or not, but by looking it up, yes! Borexino, the leading solar detector that we have, saw it: Astroparticle Physics, Volume 92, June 2017, Pages 21-29.

Q7 (slide 39): how does baseline affect our Neutrino detection experiments ?

Ans: This can be understood in a nutshell by looking at the 2-nu oscillation probability, where the probability of oscillation is directly related to the baseline (L). Since the L is inside a sin(), it will allow for an oscillatory behavior in function of L. We will see in the next lecture how the baseline gets complicated by CP violation effects and matter effects.

Q8 (slide 43): How does knowing the source fix the v energy since beta decay is a continuous spectrum?

Ans: Very good point! It gives you the energy spectrum in this case. There are some sources (like powerful radioactive sources of ve) that will give you mono-energetic neutrinos, but the sun, reactors and beams will indeed give you a wider spectrum of energies… But you still know that spectrum (to a certain degree) which is good.

Q9: Have we progressed at all from Lederman, Schwartz and Steinberger's 60s neutrino beam made by pion decay? Looking onward, would current mysteries in neutrino physics be answered better if we develop better neutrino beam technology?

Ans: This is a great question and the answer is that it's not that easy to produce neutrinos in a better way. People have been looking at "neutrino factories" where among other things they would accelerate muons in large storage rings (see MICE experiment for example) to produce very clean nue beams from the decay of muons, and have great control of the energy. But storage rings are not yet there technically speaking, and despite great progress, we are still a way away. And note that it would (at this time) cost a lot of money to build those. Hopefully in the future we will get there!

Q10 (slide 25): Why neutrino experiments with neutrinos coming from different sources are sensitive to the specific mixing angles shown in the matrices? Does the picture change for antineutrinos?

Ans: In a nutshell, if you look at the 2-nu probability of oscillation, you will see there that the theta is the parameter of interest. When fixing L and E (baseline and source), you then access specific values of the theta parameters. By playing with this equation, you can get a feel that the amplitude of the oscillation (coming from the theta) gets better accessed a different baselines/E. In reality, the probability of oscillation is much more complicated with the 3 neutrinos and matter effects, but the dominant conclusions remain true by looking at the 2-nu P.

Q11 (slide 51): Why are there two peaks in the muon neutrino spectra?

Ans: This comes from the oscillatory behavior, which gives several peaks and valleys. In DUNE (the plot shown there), you are able to distinguish the first 2 maxima and the first minima. We will show that more clearly at the next lecture.

Q12 (slide 51): Why does the flux decrease as 1/r^2 if we produced a forward-momentum beam? Wouldn't the neutrinos move mostly in forward direction as well to conserve momentum?

Ans: It would be great if we were indeed able to produce "laser-beam" of neutrinos. Unfortunately, the decays of mesons is not completely forward (even if a large fraction is because of the Lorentz boost). This produce a beam that is extending like 1/r^2...

Q13 (slide60): Did they see 6 total events, or 6 events above a predicted background? If your uncertainty is even 1 of those events you get huge % uncertainties, so how do you make constraint plots?

Ans: They did see 6 events at that time with an expected background of 1.5 events, making it clear that they were not background. It is indeed very important to understand all errors when having such low number of events. Luckily, they took more data and the number of events grew significantly and now there is no doubt at all, within errors that nue do appear.

Q14 (slide 60): What is the favored statistical methodology in these experiments?

Ans: Collaborations are very conscientious about analysing their data, especially when having low statistics. Nowadays, most will analyse data with both frequentist and Baysian statistics.

Q15 (slide 60): Why the reactor constraint shown by the green band is not sensitive to the Dirac CP phase at all?

Ans: Reactor experiments are looking at anti-nue disappearance at baselines of ~few km. This will not be sensitive to the delta-CP. This can be understood when looking at the oscillation probability and it's not totally intuitive. But by remembering that each experiment (energy, baseline) is sensitive to different phase space of the different parameters, one can get a feel for it.

Q16: Is there any particular experimental setup for sterile neutrino detection? What exact hints talk about the existence of a fourth flavor of neutrinos?

Ans: Yes! This will be covered in details in the next lecture.

Q17: Can you describe the significance of T2K's recent delta CP restriction (published this year in Nature?) What's the takeaway of this most recent result?

Ans: The take away, is that their data seems to suggest (as 68-90%C.L.) that deltaCP is large and around 3Pi/2. However, the experiment is not supposed to be that sensitive, so they were “lucky” to see a larger effect than they should, probably due to statistical fluctuations (remember we are not talking about many events here). But this is still how we do experiments, so their results is exciting because it gives us a glimpse that may be deltaCP is large, which would allow future experiments to measure it quickly.

Q18: About Opera: though a heroic effort, the unfortunate thing about the experiment is its remembered by man for a claim of FTL neutrinos.. is there a better way of double-checking such results before they are announced?

Ans: This is an excellent sociological questions. When performing very complex experiments, the only thing scientist can do is to cross-check things as much as they can until they run out of idea. This is what the Opera collaboration did. They sat on their results for over 1 year to make as many cross-checks as possible until they did not know anymore what else to check. Loose cables (when you have thousands of cables!) is not something we go around routinely to do. They were unlucky that the effect stays the same (usually a loose cable will give a flaky connection that changes in function of time). It is important that collaboration are not “afraid” to publish surprising results, otherwise, nobody in the future would dare showing results that are not consistent with what is expected, and that would be bad for science. Another point is the media coverage of such results. Despite the fact that most collaborations are careful in the interpretation of their results, media only want the punchline, which makes it harder to explain later if something was wrong.

Q19: Can you please explain LSND anomaly?

Ans: I will! In the next lecture….