Roxanne Guenette – Lecture 1 Questions

Questions marked in green were answered during the Q&A session. I haven't tried to correct grammer/spelling. Where a slide number was given it is shown.

Q1 (slide 5): Cab you please again why nobel elements are sort of transparanet towards the emitted scintillation light? Can't this light be absorbed by ground state argon atoms, to excite them?

Ans: This is indeed an important property of Noble Elements. The scintillation light produced at 128nm for Ar or 175nm for Xe, happens to not be an energy that can excite Ar or Xe atoms respectively. We know from chemistry that all atoms have very specific excited states that can be accessed with the right energy. In the case of noble element, it just turns out that we are lucky (well, I am sure chemists would have a more fundamental reasons than chance!).

Q2: (slide 14): For 0vbb, TPB might need to be ultra radio pure so that it does not contribute to background radiation? Do we have means to produce such ultra pure TPB? are there alternatives that people are planning to use/already using?

Ans: This is indeed an important point. At the current scale of detectors, the radio-contaminant of TPB remains negligible (compared to many other radioactive backgrounds, like the PMTs themselves!). In the future, since we are in Xe and the scintillation is at 175nm, we are hoping to use UV-sensitive photon detectors, to get rid of the TPB...

Q3 (slide 2): Since the detectors for neutrinos and dark matter are similar, can we use present neutrino detectors for dark matter detection and vice versa

Ans: This would be great! As it would combine ressources of future very large detectors. However, the requirements of each science is so different that it's almost impossible to do that. For example, the future kiloton-scale detector for DUNE will be full of "radioactive" backgrounds, because it would cost WAY too much to get radiopure materials (like Dark Matter experiments do). The energy ranges looked at by different experiments are also too different to allow for unique detector readout systems. However, people are thinking about this for the future! Potential great technical ideas could make it possible...

Q4 (slide 14): Recombination basically decreases your ionization signal and increases scintillation signal, but that can skew your ability to identify the interaction type. So how do you define your recombination probability in practice so that you can account for this in real signals? (Calibration source, or atomic physics knowledge?)

Ans: Good point! Indeed, each experiment has to extract its own recombination factors (and along the time of the experiment, as it can change based on purity of the medium and potential changes in EField). One way to do this, if you are on the surface, is to use cosmic rays. This high-energy muons cross the whole detectors (often!) and leave very well known amount of energy as they are mips. Calibration is also another way of doing that.

Q5 (slide 18): Typically what is the order of magnitude thickness of the TPB sheet in front of the PMTs?

Ans: This will depend on the method of putting the TPB. Most experiments evaporate TPB, which will provide coatings of the order of ~microns. Some, like MicroBooNE, "painted" the TPB on top of the acrylic plate, which is then much thicker.

Q6: Why do we typically make our detectors rectangular or cylindrical instead of spherical, which would increase our detector efficiency and fiducial volume, and thus decrease run time?

Ans: For neutrino physics, it's because you want to have a long detector in the direction of the beam. Most neutrino interactions will produce particles in the forward direction, and having more length will help containing more of the interaction. In dark matter and 0nubb, you will notice that the dimensions get more symmetric (diameter vs drift length), the exact shapes also often come from the practical/technical reasons. There are limits to how large a diameter can be when put under intense EFiled (for electroluminescence for example), as it can deform the material under electrostatic pressure. The drift length also depends on how high you can reach with your high voltage system… Note that there are spherical TPCs (see the NEWS experiment).

Q7: why are the wires in TPC bent at an angle ?

Ans: When orientating the wires in a TPC, one wants to consider the following: 1) Have a set of wires perpendicular to the beam direction. Since the particles produced in neutrino interaction will mainly go forward, perpendicular wires have the best chance to see the interactions over many wires. 2) You need a different orientation for the second wire plane if you want to reconstruct a 3D image from two 2D views that are different. The 3 wires planes (or 4th if you have more) can be optimised to lower the potential for reconstruction ambiguities...

Q8 (slide 22): Why liquid argon detectors are best for neutrinos? Why cannot we choose other lighter/heavier nobel elements ?

Ans: That is a great point! I should have mentioned it in my lecture, as it does matter. Indeed, when looking at the properties of Noble element for particle physics, Xe comes out much better choice. But the cost of Ar is ~1$/litre and the cost of Xe is about 3000$/litre (note that the exact price is complicated, as the market fluctuates depending on if you will be building or note several ton-scale of Xe detectors! ;)). So at the end, since Ar is "so cheap" and it does the job, we picked it...

Q9: Are there issues with incoming charge being too high in energy prior to acceleration by the induction wires?

Ans: This would indeed be an issue, so we need to first study the ideal EField configuration in between the wire planes to ensure full "transparency" (allow the charge to go through). Then, since particles are spanning many wires, even the most energetic ones will not create too much charge.

Q10 (slide 24): How is the spatial resolution defined as a function of the distance between two parallel wire? Is there a minimum distance by which the wires need to be separated?

Ans: The first thing you want to consider if the intrinsic possible resolution which is governed by the electron diffusion. It is useless to have wire separation smaller than the amount of diffusion that would happen (this can be ~0.5mm in some cases). After that, it's an optimisation game. What wire separation is ideal depends on the physics requirements of your experiment. For example, DUNE opted for 5mm wire separation after many studies...

Q11: What factors can be important when deciding between capturing charge or light in a TPC?

Ans: This is also part of the optimisation game. Ideally, one wants ti get it all. Perfectly combining both is very powerful (And expensive!). Depending on the energy you are at (low energy usually do better with light and higher energy with charge), you can decide which one to prioritize.

Q12 (slide 33): It appears that recombinations are intrinsic to the Argon or Xenon, meaning even if you had 100% pure noble element, you would still get the same recombination probability as a very dirty detector. Thus, how do we tell the difference between recombinations and electronegative impurities?

Ans: This is an important microphysics question. Indeed, both of these concepts play a different role (which result the same way if decreasing the charge collected). Ideally, you would know both perfectly to correct for them individually. In practice, you can't do that and one has to measure and calibrate both in one single way.

Q13 (slide 34): why dont we shield the detectors from cosmic rays to prevent the problems mentioned

Ans: We would *always* prefer to shield detectors for sure! But when you are talking about detectors that are very large (ton-scale and above), shielding becomes very expensive. So depending of your physics goals, you may tolerate cosmics, if you can reject them well enough (like in neutrino detectors). For dark matter and 0nubb, you cannot afford this, so you go deep underground.

Q14 (slide 25): You mentioned that the drift electrons are accelerated behind the induction planes. Wouldn't this bias the observed drift times of the electrons?

Ans: Since this acceleration happens at the very end of the travel, and the wire planes spacing is the order of mm, this would be negligible. Also, we know well the field there, so we could correct for it.

Q15 (slide 37): As of now we only know that Dark Matter interacts only gravitationally. How will liquid Noble elements produce scintillation, a process that is predominantly electromagnetic.

Ans: If Dark Matter doesn't interact with regular matter other than gravitational, we are in trouble with direct detection experiments! However, there are strong theoretical arguments towards dark matter interacting via *some process* with ordinary matter, making it very worthwhile looking for!

Q16 (slide 39): Why can't WIMPs recoil off of electrons?

Ans: They can! But for this you need to have much lighter WIMPS. The GeV WIMPS will predominantly produce nuclear recoils, as they are too "big" for single electrons. But very light dark matter particles, in the low MeV or keV would indeed produce electronic recoils and people are looking into this...

Q17 (slide 43): In a scintillation-only detector, how do you reconstruct the total energy as well as the S1/S2 discrimination that tells you whether you saw an electronic or nuclear recoil?

Ans: In single phase detectors, indeed, you only have access to primary scintillation (S1). But since this light is very fast (~ns), it can be used for positioning, which helps background identification. There are also other ways that you can use the details of the scintillation light. As argon produce a fast (~ns) light signal and a slower one (~1500ns), it is still possible to use some pulse shape discrimation (DEAP-3600 showed this), it's just a different one than when having access to S2 from the charge...

Q18: Can you go more in depth as to why are detectors such as DEAP 3600 less favored for the future in comparison to ones like DarkSide?

Ans: I cannot really comment on why these collaborations made this choice. They discussed it for sure. I would ask someone on these experiments :)

Q19 (slide 48): What does "rotated energy" mean, exactly?

Ans: This comes from the fact that if you plot the energy reconstructed via scintillation in function of the one reconstructed via charge (which are both correlated due to the recombination), it was notices that if you use an energy axis that is parallel to the correlation between the two ("rotated axis"), you can obtain much better energy resolution, because you now use both complementary measurements at the same time. This is what is referred to as "rotated energy".

Q20 (slide 48): Why aren't the SiPMs used in high pressure xenon chambers to measure the energy?

Ans: This is an excellent question and in the future we want to do that! Right now however, the SiPMs we are using (1mm^2) do not remain linear when recording high amount of light (coming from the amplified electroluminescence region). This means that some cells can saturate, making it hard to collect all the energy, leading to worst energy resolution. We are hoping that this can be fixed with future R&D on larger SiPMs that usually do not saturate as easily.

Q21 (slide 41): How quickly is Ar39 produced from CR exposure? Will this be a concern for the time scale of an experiment?

Ans: This is a very important point, as you don't want to ruin the underground Ar by activating it… What people do is they extract it from the ground and store it as quick as possible underground. Once deep underground, the cosmic-ray rate is very low and this is not an issue anymore...

Q22 (slide 53): How do we differentiate between what's a big "blob" and what's a small "blob" (i.e., how do we determine if there are two big blobs and thus it's an event, or if it's just one big blob and one small blob and thus is background)?

Ans: It is true that sometimes, the blobs are hard to identify. This is why we do not get 100% reconstruction efficiency and that we still have background contamination cause by mis-identification. Deep Neural Networks have shown to do quite well are identifying the blobs...

Q23 (slide 54): Is there a reason why the signal decays present much wider peaks (distributed) than the background? Is this more process or detector related?

Ans: This is a zooming effect I think (if I understand the question right). The selected signal events in these images are slightly shorter than the selected background events, making them look “fatter”.