Open Questions for Photon Detection in LAr

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Outline

- Purpose of Talk
- Overview of light collection in LArTPCs
- Physics requirements, reconstruction, and simulation
- ^{39}Ar and other R&D
- Additional open questions more project-aligned

Caveats and Purpose of This Talk

- This is an "outsider's" perspective on open questions facing the DUNE photon detection system
  - Some of these questions (I know) are already being or have already been at least partially addressed
  - But many of these questions haven't been addressed yet
- Some of the items I mention overlap with other working groups, implying an interface
- The purpose of this talk is to give a sense for the great number of opportunities that exists for collaborators to make important contributions to the DUNE photon detection system
  - This is not an exhaustive, prioritized, or time-ordered list
  - However, it can used it as a starting point

Potential Uses of LAr Light Information

- Triggering
- Timing (to correct the TPC energy measurement for non-beam events or to correlate with the beam timing)
- Position information
- Event reconstruction (identify particle decay sequences in the pattern of detected light)
- Particle ID information (prompt-to-late light ratio)
- Improved energy resolution (by adding the charge and light)
- Lowering energy thresholds

Physics Requirements For Photon Detection System

- Are these purely driven by supernova burst neutrinos (SBNs)?
  - Trigger on ~5 MeV electrons?
  - Reconstruct time of 5 MeV electrons to ~1 μs
- Is pile-up from ^{39}Ar a problem, especially at low energies
  - What is the upper limit on the single PE rate per photon detector in order to detect SBNs?
  - How localized should the reconstructed light signal be?
- Can timing be used to study the beam in some way?
- Do we need to instrument the LAr outside the active TPC because of dirt backgrounds?
- Is there a requirement for detecting de-excitation gammas?
- Is there any requirement on the uniformity of the light collection system response?
- Is there any requirement on the energy resolution coming just from the light collection system?
- What about flash-counting to, for example, identify Michel electrons from π^+/μ^+ final state particles?
- Late light detection requirements?

Studies of reconstructed light information

- Michel identification (and rejection) to obtain a sample of ($CC\nu_\mu$ + $CC\bar{\nu}_\mu$) events enriched in $CC\nu_\mu$
- Supernova burst neutrinos (SBNs)
  - Does ^{39}Ar contamination impose constrains on position and time resolution?
  - How can de-excitation gammas be used to help identify SBNs?

– Particle ID in real neutrino events (prompt/late light ratio and light flash pattern recognition), etc.

Improve validation of LAr light simulations

- Do we have VUV reflectivity numbers we can trust on various detector surfaces?
- What will the Rayleigh scattering length be in DUNE (with real density fluctuations, etc.)? How will it affect reconstruction?
- What is the absorption length of VUV light in LAr with realistic purity values and how will it (along with Rayleigh scattering) affect reconstruction?
- Will we see light outside the current drift region in which the interaction occurred (do double-sided light guide bars help or hurt)?
- Do we have light yield and prompt/late light simulations we trust for at varying levels of nitrogen contamination?

Improve LAr Light Simulations

- Can we add precise timing information into the Monte Carlo?
- Should we model light propagation in light guide bars?
- Can we develop a method to study change in optical model as a function of detector parameters (e.g. multi-dimensional spline fits)
- Can importance sampling be used to speed up photon simulations?
- Can GPUs accelerate photon simulation, either in Geant4 or alternatives such as Chroma?

Impact of ^{39}Ar

- Measure impact of ^{39}Ar on photon detection system
  - Dominates the SiPM dark rate by two orders of magnitude
  - Also produces a correlated 2 PE rate
- Test at FNAL?
  - Roughly all of the Ar depleted in ^{39}Ar in the world passes through Fermilab
  - Can we borrow some of this Ar for a dedicated test at Fermilab?
- Test Underground?
  - Could this be studied in a test underground with atmospheric LAr if dark rate, cosmic rates, etc. are all well-known?

Other R&D

- Doping LAr (with for example Xenon)
- Anode-coupled readout
- 128-nm sensitive SiPMs
- LAPPDs?
- TPB-coated reflector foils?

Long-term stability Tests

- SiPMs
  - Long term tests of SiPMs in LAr (lifetime, gain stability, dark rate stability)
    - If SiPMs mounted on boards, long term tests of these in LAr
  - Cryo-cycle tests of SiPMs
  - Develop reliable handling procedures (can we achieve < 1% mortality rate?)
- Light guide bars
  - Long term tests of light guide bars in LAr (stability of light output)
  - Cryo-cycle tests of light guide bars

Dip-coated light guide bar production

- Light guide bar production
  - Acrylic sheet cutting and polishing procedure
  - Acrylic qualification procedure (bulk attenuation length, losses per bounce)
  - Acrylic annealing procedure
- Dip-coating procedure
  - Environmental controls (temperature, humidity, ?)
  - Dipping and retraction speed

Quality Assurance (QA)

- QA on light guide bars
  - Coating thickness measurement
  - Attenuation measurements
    - This can be done warm
  - Absolute light yield measurements
    - Can this be done warm?
  - At least a sub-sample should be tested in LAr
    - Tests thermal stresses (crazing) and with 128 nm light

Characterize SiPM Response Individually vs. Ganged Together

- How to gang SiPMs together?
  - In parallel or in series (or something else)?
  - Before or after pre-amplifier (or both)?
  - Cold or warm (or both)?
- Robustness of ganging SiPMs together
  - How is the signal affected if one SiPM dies?
    - Given known failure rates, what fraction of detector will be affected by this as a function of time?
- Voltage tuning
  - Is this necessary or can we apply the same voltage to a set of SiPMs (either selected randomly or deliberately)?
- Time and Charge Resolution
  - How do the signals degrade in the presence of noise as a function of the number of SiPMs ganged together?

Cables, Connectors, and Feedthroughs

- Do vetted alternatives to the Atlas high channel density cold feedthrough exist?
  - Can we develop other solutions?
  - What is the maximum channel density?
- Are there alternatives to the current photon detection system cable plant design?
  - Use cold pre-amplifiers to lower cable noise rejection requirements
  - Use digital SiPMs?

Photodetector Electronics

- Dynamic range
- Time/charge resolution
- Do we need to collect the late light?
- Do we need to read out full waveforms?
- Triggering?

Conclusion

- There are an incredible amount of open questions for DUNE photon detection
- Lots of opportunities exist to make an impact
- We need to get started now