Development of LBNE Photon Detector Front End Electronics
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- Long-Baseline Neutrino Experiment (LBNE) is a comprehensive program to measure neutrino oscillations.

- LBNE will consist of:
  - an intense neutrino beam (≥1.2 MW) from Fermilab to Sanford underground lab 1500 km away.
  - a near detector systems at Fermilab.
  - a 34 kt liquid argon time-projection chamber (TPC) at Sanford Laboratory at 4850 foot depth.

- Physics Goals
  - LBNE will discover and characterize CP Violation in the neutrino sector.
  - resolve the neutrino mass hierarchy unambiguously.
  - precision measurements of oscillation parameters.
  - precision measurements of neutrino interactions with matter.
  - search for new physics (non-standard interactions, sterile neutrinos).
  - search for nucleon decays and set limits models of Grand Unification Theories.
  - detection of neutrinos from core collapse.

- Photon detection technique
  - wave-length shifter coated cast acrylic bars 25 mm x 6 mm x 1.05 m bars
  - 4 bars per paddle with SiPM readout
  - 3 SiPMs (channels) per bar
  - 20 photon detector units in a TPC APA
  - 9600 channels for far detector

- A new high-performance data acquisition system - the Silicon Photomultiplier Signal Processor (SSP) - has been developed for reading out the photon detectors as part of the R&D for the Far Detector of LBNE.

- An SSP consists of 12 readout channels packaged in a self-contained 1U module.
  - Each channel consists of a differential voltage amplifier
  - 14-bit, 150 MSPS ADC for digitizing charge signals from SiPMs with no dead time.
  - separate adjustable bias for SiPMs.
  - The data streams from the ADCs are received by a Xilinx Artix-7 FPGA that performs signal processing algorithms on the sampled waveforms to obtain timing across the system to better than 3 nS resolution.
  - Xilinx Zynq FPGA is used for read-out and slow control over Gigabit Ethernet or USB.

- Key SSP features:
  - single p.e. resolution capable.
  - 14-bit dynamic range (1.8 V full range).
  - timing resolution ≤ 5 ns.
  - data buffer length 13 μs: enables late light detection.
  - individual channel voltage biasing.
  - charge injection to calibration.
  - system highly configurable.

- LBNE Far Detectors: two 5 kt fiducial volume liquid argon TPCs are shown.

- Liquid argon TPC parameters
  - cosmic events ~0.1 Hz, beam events ~9 kHz.
  - drift = 3.5 m, field: 500 V/cm.
  - readout: x, y, z, pitch: 5 mm, wrapped wires.
  - Max Yield: ~9000 e/mm/ MIP, 10000 ph/mm/MIP.

- Scintillation light characteristics
  - LAr scintillation light has wavelength of 128 nm.
  - 1/3 of light emitted promptly within 6 ns, 2/3 comes later with time constant 1.6 μs.
  - Long attenuation length in argon but 90 cm Raleigh scattering length at λ=128 nm.

- Motivation for scintillation light detection
  - Although the TPC provides unprecedented spatial resolution it cannot provide an absolute event location by itself.
  - The detection of scintillation light in coincidence with ionizing tracks in a LAr TPC can be used as an absolute time measurement (t0) to determine spatial location of the ionizing event.
  - The scintillation light may be used to provide additional information i.e.,
    - Determine if events originate within fiducial volume of the detector.
    - Correct for energy loss during drift.
    - Provide trigger for non-beam events.
    - Improve reconstruction of overlapping events.

- Summary and Future Prospects
  - We have developed the Silicon Photomultiplier Signal Processor (SSP) to be used for reading out the photon detectors of the LBNE.
  - by measuring the time of arrival of the photons, as well as the pulse height, the PD system can provide a “time zero” reference for the reconstruction of the event, as well as help identify the spatial coordinates of the event by triangulating between different photon detector elements in the detector.
  - in addition the detection of scintillation light may be used as a trigger for the TPC.
  - measurement of the “late” light that arises from triplet states, which can be useful as a particle identification tool.
  - these physics related features of photon detection system with SSP board will be tested in 35-ton LBNE prototype being built at Fermilab.

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