T0 Calculation in MicroBooNE with PMT Flashes

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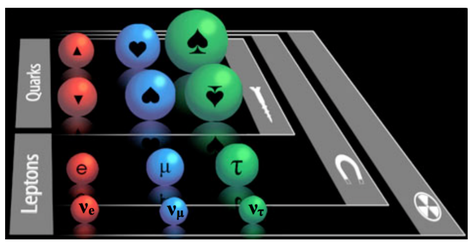
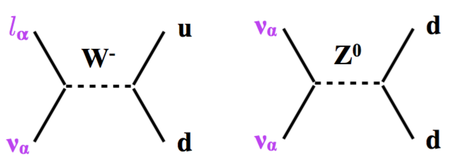
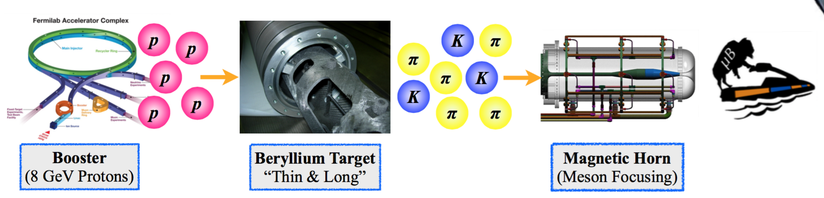


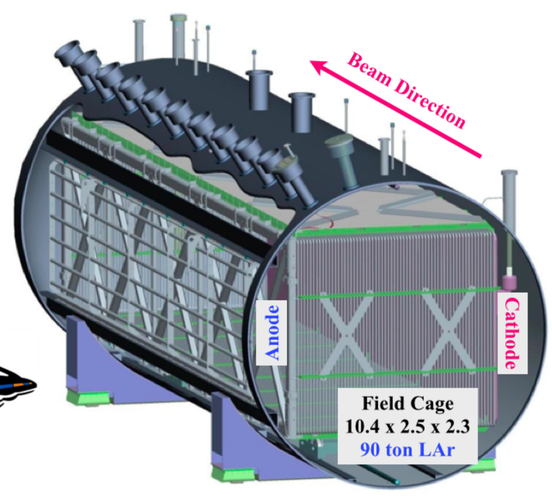
Top: Canonical standard model table showing neutrinos as neutral leptons, only participating in an weak interaction

Bottom: Diagram of how a neutrino of a specific lepton flavor interacts with quarks in a nucleus



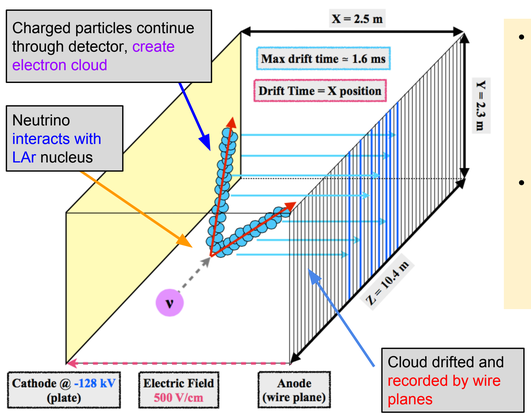
- MicroBooNE is a neutrino oscillation experiment at FermiLab which will detect neutrinos from the Booster Neutrino Beam (BNB) using a 170 ton Liquid Argon Time Projection Chamber (LArTPC)!
- Neutrinos are produced through a decay of mesons such as Pion and Kaon that are produced by protons boosted by BNB hitting a Beryllium target
- Meson decay primarily produces muon flavor neutrinos, but some may oscillate into an electron flavor neutrino through a physics process called neutrino oscillation
- The objective of MicroBooNE is to study a physical nature of neutrino oscillations as well as to establish a large scale LArTPC technology for future experiments



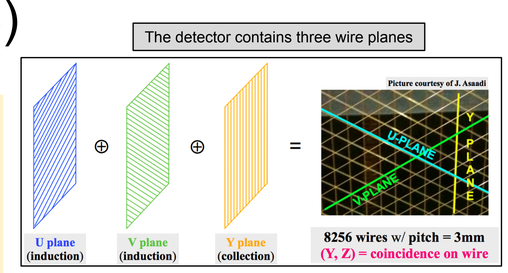


Above: Picture of the MicroBooNE cryostat (container of liquid Argon and TPC detector) being placed in its experimental hall, the Liquid Argon Test Facility (LArTF). **The cryostat is roughly the same size as a schoolbus!**

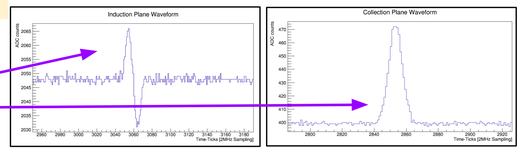
Time Projection Chamber (TPC)



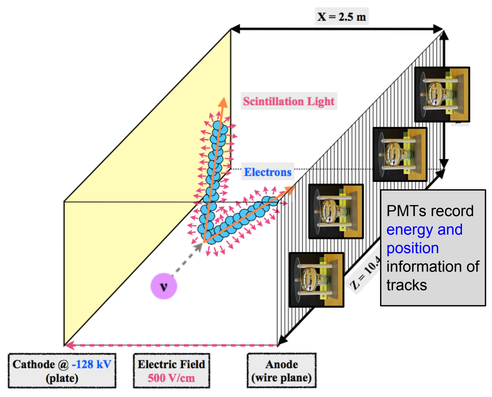
- Neutrinos enter the detector, interact, and charged particles leave an electron cloud
- Electrons drift to wire planes, where position and energy are recorded

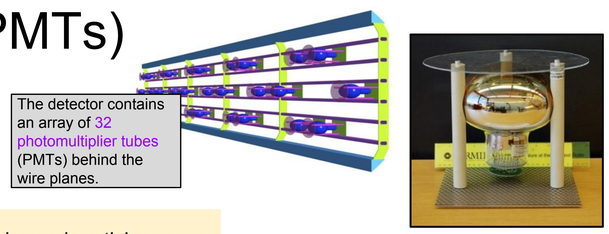


TPC consists of three wire planes. A coincidence in detected signal across planes provide us Y/Z position information. An induction plane carries approximately a bipolar pulse shape (**bottom left**) while the one from the collection plane is a unipolar (**bottom right**)

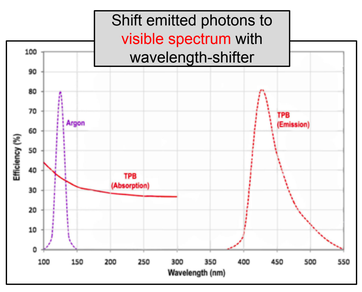


Optical Detector System (PMTs)





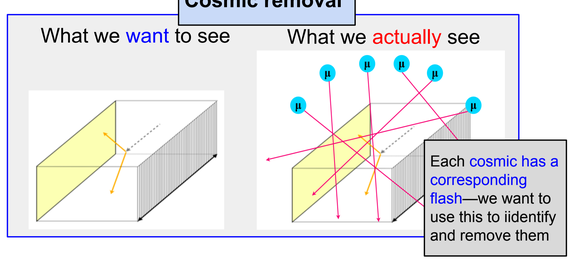
- When charged particles move through detector, they also excite atoms which release photons isotropically
- Photos hit wavelength-shifters, which emit visible light
- PMTs detect visible light and carry position and energy information



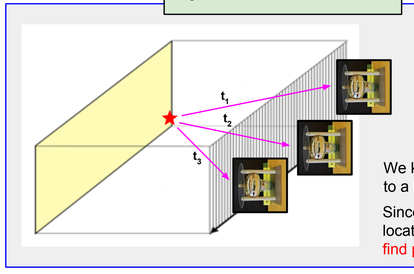
Why T0?

Knowing T0 gives us the tools for two important tasks: identifying/removing cosmics, and calculating absolute X position of an interaction

Cosmic removal



X position information



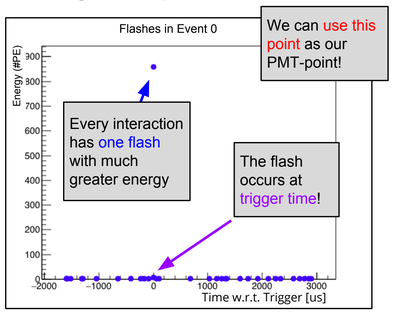
We know location of each PMT, and speed of light in LAr

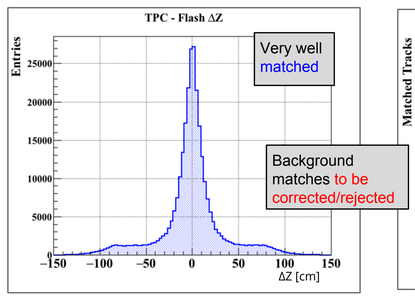
We know that the distance to a PMT is: $d = c_{Ar} * t$

Since we know the PMT locations, we can triangulate to find position of a flash

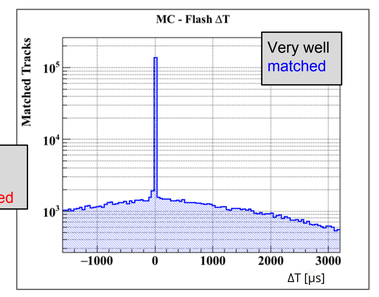
How to extract T0?

Finding a PMT-point





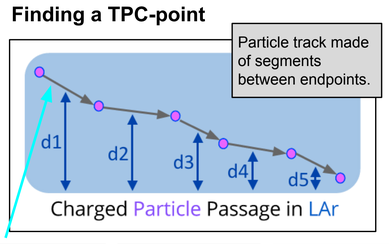
Above: Difference in Z position of matched PMT-point and TPC-point is shown above. Matched pairs with small ΔZ indicates a good match, showing nicely peaked at ΔZ=0.



Top: Reconstructed - MC difference in T0 in log scale. The nice, sharp peak at 0 is consistent with nicely peaked ΔZ distribution, both indicating a nicely matched optical flash with TPC tracks.

Bottom: A zoom into the small ΔT region shows the peak is not exactly at ΔT=0 but around 60 to 75 ns instead, which comes from simulated signal shaping electronics with characteristic time constant of 60 ns.

Finding a TPC-point



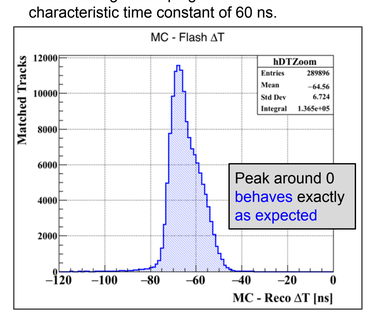
Take midpoints, then weight by energy difference between endpoints

We want to compare with PMTs, which have energy drop off as r^2, so...

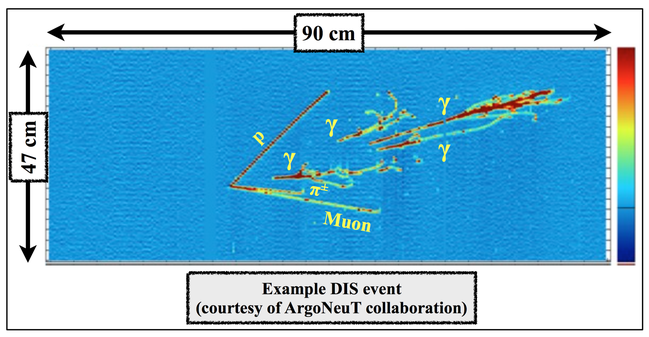
...weight by *relative* x position, and take position average to find our TPC-point!

Reconstructed optical information (called a "flash") carries precise T0 in nanosecond scale as well as Y/Z position information. It can be matched with associated TPC information.

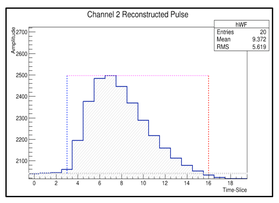
1. Physics "flash" selection
2. Given TPC information, estimate "flash" Z position
3. Match PMT and TPC points based on Z position!
4. Assign T0 from "flash" to a track

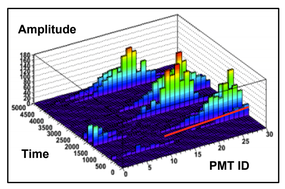


Data Reconstruction



- LArTPC delivers rich information with an image of actual charged particles' trajectory in a detector!
- Y/Z positions are reconstructed from coincidence in a signal over multiple wires (TPC) while X is reconstructed from time (PMT)
- Signal amplitude tells us energy deposition profile as particle moves along its trajectory, and provide important keys for energy reconstruction and particle identification

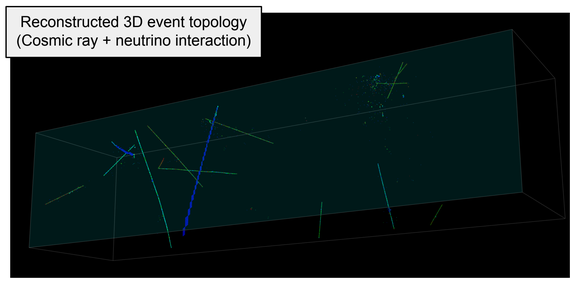




Top Left: Reconstructed **optical hit** in a raw PMT waveform. The dashed line indicates the hit amplitude together with start and end timing. A single photoelectron peak carries an amplitude of roughly 20 ADC count.

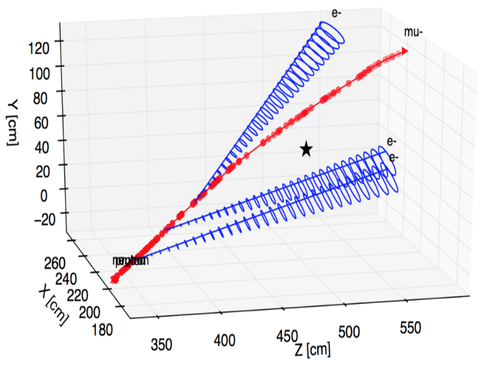
Top Right: Overlay of multiple PMT waveforms. A time-coincident rise in waveform amplitude is identified by time-coincident optical hit, and reconstructed as an **optical flash**. Amplitude distribution over different PMTs allow us to reconstruct the geometrical location of a light source.

Reconstructed 3D event topology
(Cosmic ray + neutrino interaction)



Summary & Future Prospects

- Performed T0 reconstruction study using reconstructed optical flash and TPC tracks from MicroBooNE Monte-Carlo sample
- Established an optical flash selection criteria
- Developed a TPC-point estimation method through which optical flash can be compared and matched with a complex topology TPC objects such as tracks and showers
- Studied a quality of reconstruction using a cosmic ray background Monte-Carlo sample, and showed a working principle by reconstructing correct interaction times for each cosmic-ray muon
- Next step: incorporate the developed technique to enhance signal selection and background rejection in a 3D event reconstruction



Above: reconstructed neutrino interaction from MC simulation with correct T0 assignment using a reconstructed optical flash

August 2015

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