Beam Simulations for the Long Baseline Neutrino Experiment

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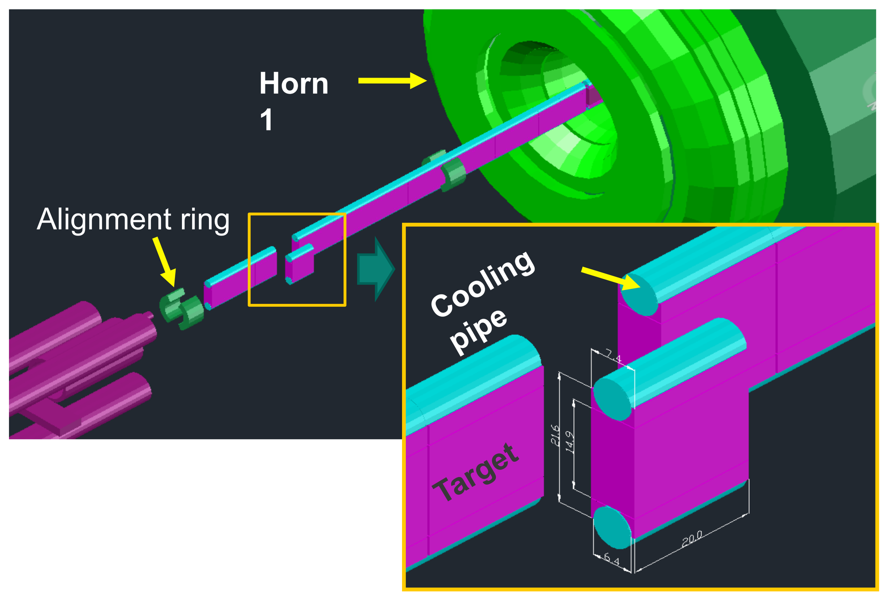
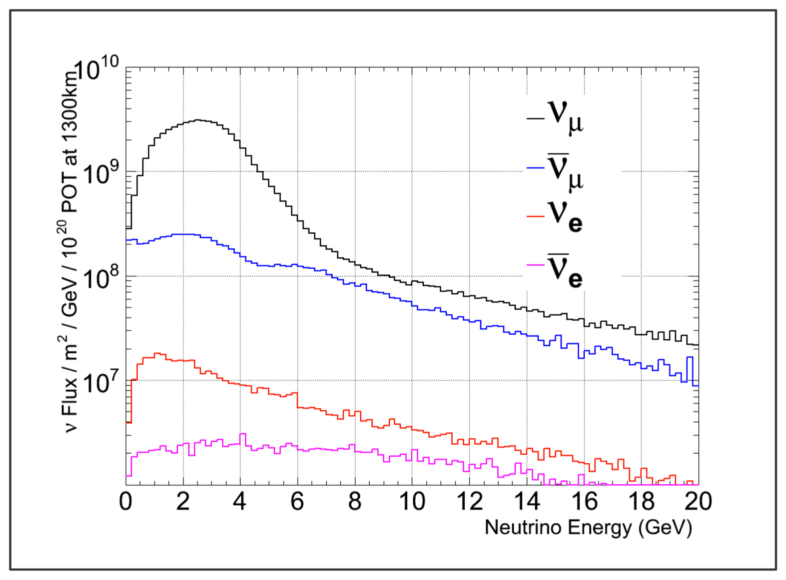
G4LBNE is a GEANT4-based simulation of the Long Baseline Neutrino Experiment (LBNE) beamline, a conventional neutrino beam that originates with 120 GeV protons impinging on a graphite target. Resulting hadrons are focused through a pair of horns and allowed to decay, producing a neutrino beam peaked at ~2.5 GeV and aimed at the Homestake mine in South Dakota. G4LBNE is a detailed and flexible simulation designed to identify optimal beam designs for measuring CP violation in the neutrino sector and to estimate the impact of beam systematics on those measurements.

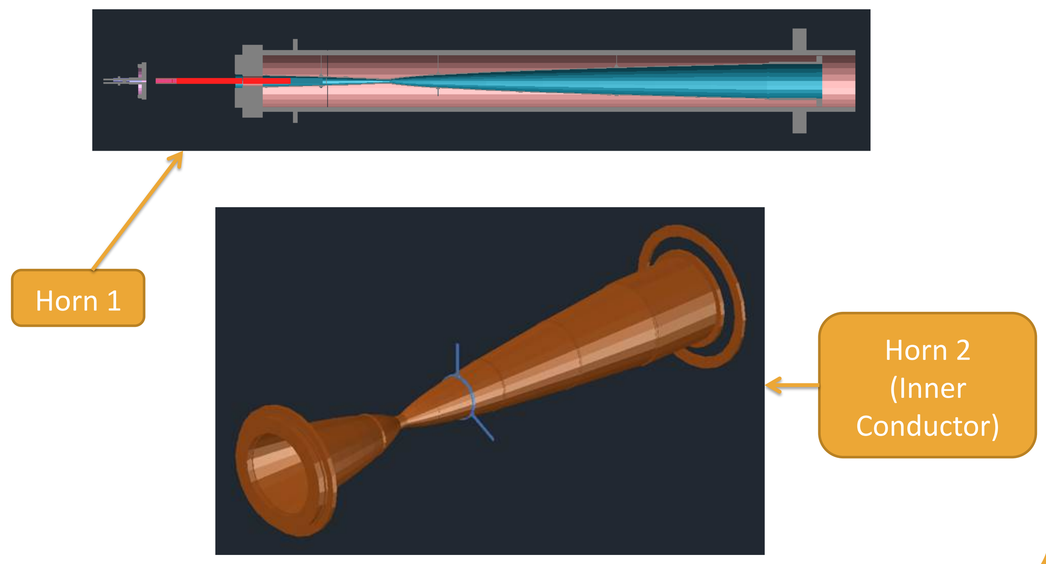
Target





Estimated LBNE neutrino fluxes when horn currents are configured to focus positively charged hadrons

Focusing Horns

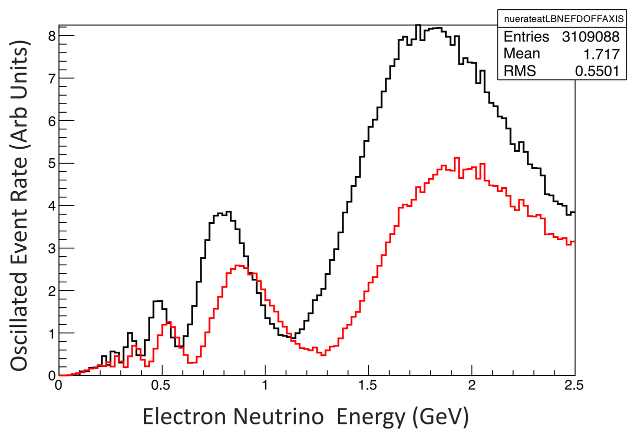


Beamline Optimization

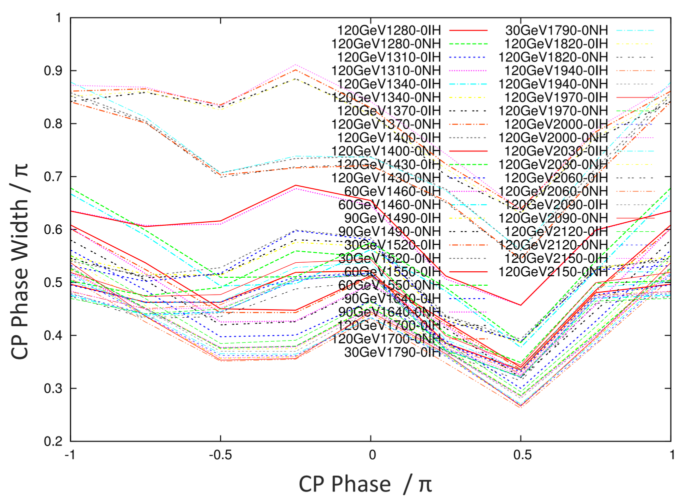
Goals and Criteria

- Aim is to optimize resolution of CP violating phase of the PMNS matrix
- Achieved by maximizing events at first and second oscillation maxima (E_ν~ 2 GeV and E_ν ~ 800 MeV) while minimizing high energy tail that produces backgrounds

Comparison of oscillated event rates for two different values of the CP violating phase



A metric for CP phase resolution versus CP Phase for many beam configurations



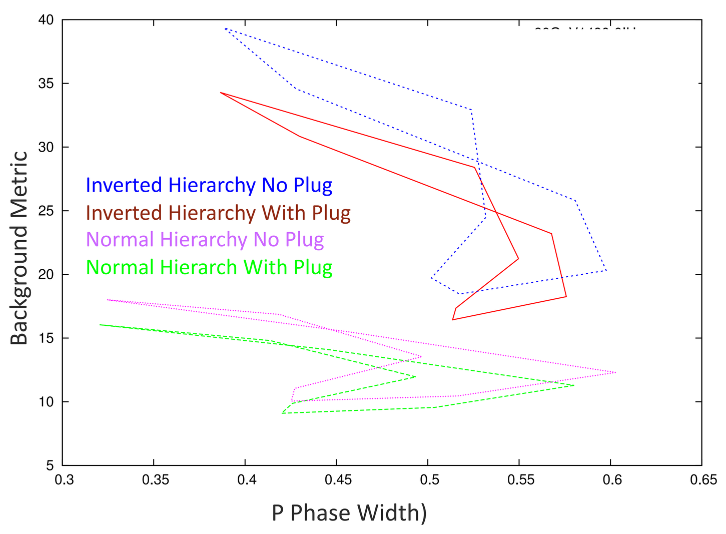
Optimum beam designs identified by this analysis include insertion of a beam plug and lower proton energies

- Chisquare comparisons of oscillated event rates at different values of CP phase produce a metric for CP phase resolution
- This quickly identifies beam designs that should be studied with the full LBNE oscillation analysis infrastructure

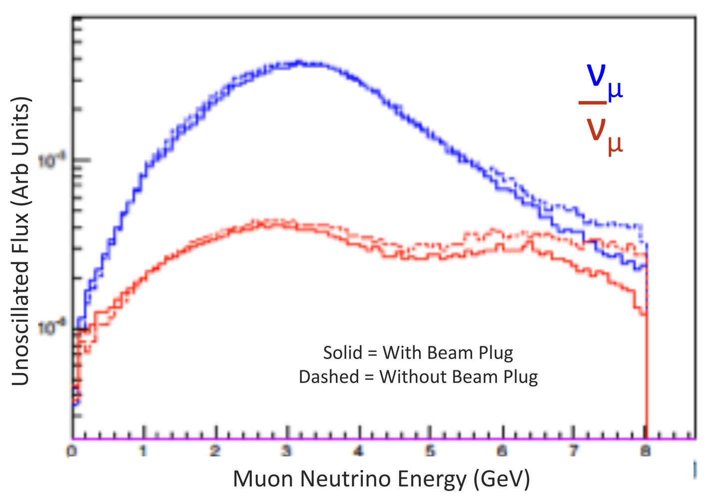
Effect of a Beam Plug

One way of optimizing resolution of the CP phase is the addition of a "beam plug", a second target downstream of the first horn

Background vs CP phase resolution; shapes are created by sampling 8 different combinations of CP phase and mass hierarchy



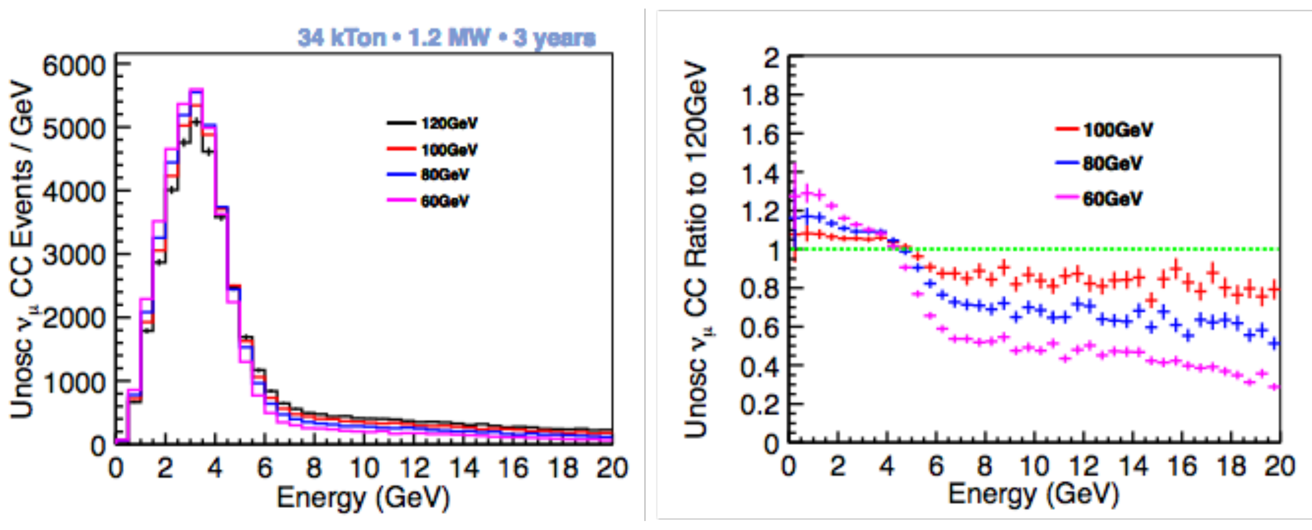
Muon Neutrino and Antineutrino fluxes, with and without a beam plug



A beam plug acts a second source of desirable low energy hadrons and reduces flux in the high energy tail, leading to improved resolution of the CP phase

Beam Power Comparisons

Lowering the proton beam energy (while increasing the spill rate to preserve the beam power) is an another way of increasing flux at the first and second oscillation maximum and decreasing flux in the high energy tail



Alignment Uncertainties

Goals of Study

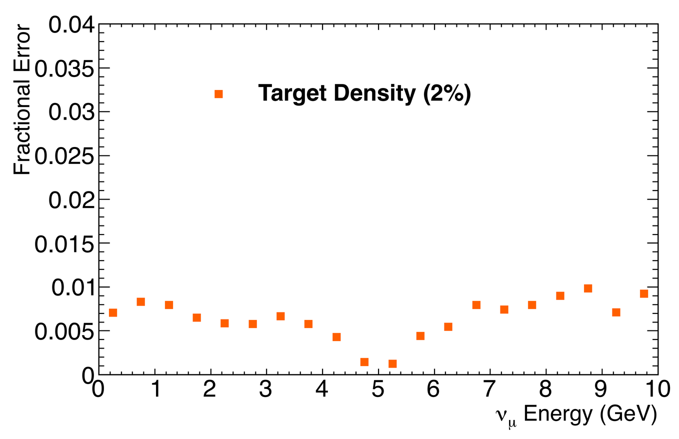
- Estimate the systematic uncertainty on the LBNE muon neutrino flux at the near and far detectors due to misalignments of beamline elements
- Determine whether any of the preliminary beamline tolerances should be reduced to achieve LBNE physics goals
- Determine whether any of the tolerances can be increased without adversely affecting LBNE physics goals
- The resulting understanding beamline tolerances will inform the design (underway now) of instrumentation needed for beam alignment (such as hadron monitors)

Preliminary NuMI-based alignment tolerances

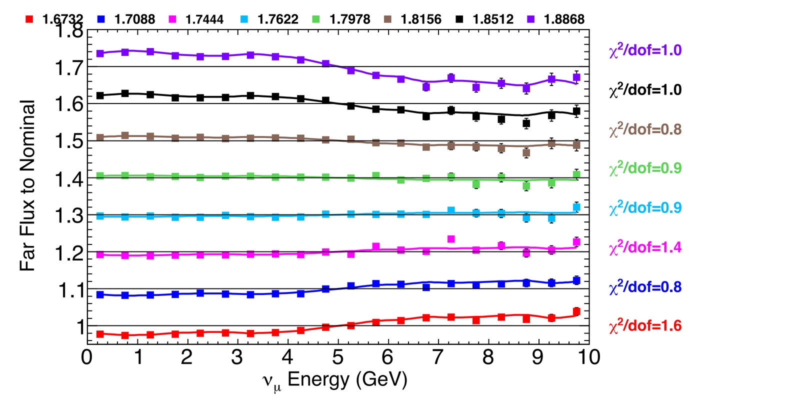
Target Position (each end)	0.5 mm
Horn 1 Position (each end)	0.5 mm
Horn 2 Position (each end)	0.5 mm
Far Detector position	21 m
Decay pipe position	20 mm
Decay pipe radius	0.1 m
Horn current	2 kA
Horn water layer thickness	0.5 mm
Beam size at target	0.1 mm
Alignment of shielding blocks	1 cm
Baffle scraping	0.25%
Beam position at target	0.45 mm
Beam angle at target	70 μrad
Near detector position	25 mm
Horn conductor skin depth	6 mm
Target density	2%

Procedure

The effect of a particular misalignment on the neutrino flux is estimated by simulating several values of misalignment and comparing the resulting fluxes to that of a perfectly aligned beam



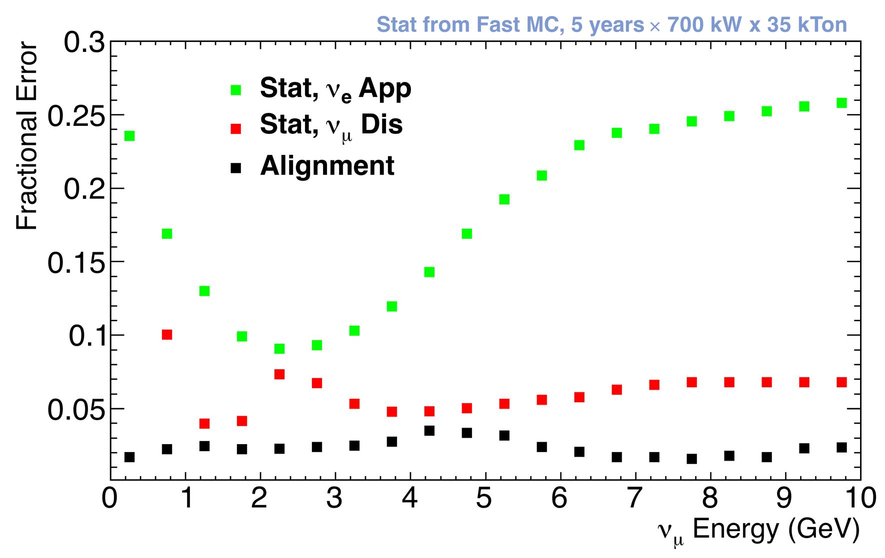
Fractional systematic uncertainty on the far detector flux due to target density



Ratio of misaligned fluxes for several values of target density compared to the nominal flux (points) and the results of fits used to extract the systematic uncertainty (lines)

Fits are performed that extract the dependence of the change in flux on the amount of misalignment; these fits are used to estimate systematic uncertainties assuming the preliminary tolerances shown above

Results



- The total uncertainty on the far detector flux due to all considered sources of beam misalignment is < 3 % for the region of interest to oscillation measurements
- The total uncertainty on the near/far flux ratio is < 1% in the same region

- The largest sources of alignment uncertainty on the neutrino flux are the horn currents, the thickness of the water cooling layer on the horns and the thickness of the decay pipe