Cubism - Braque’s Bottle and Fishes, Paris c.1910-12

Response to Spokes’

NDDG Fortnightly Meeting
April 17 2019
James Sinclair, LHEP

Questions from the Spokes

1. Articulate (concisely) the goals of the LAr system with regard to measurements that will be performed to impact the neutrino oscillation measurements at DUNE.

2. Investigate and propose other configurations that minimize cost, including the possibility of:
   - building larger modules, reducing the total number of modules
   - reducing the size of the overall detector, either by reducing the number of modules or adjusting the size of each module.

Please describe the trade-offs/compromises between these descoped systems and the current concept with regards to impact on the DUNE oscillation measurements.

Goals of the LAr System

Sample the unoscillated beam using the same target material as the far detector.
Essential in order to constrain uncertainties on neutrino cross sections.

The energy and angular resolution and mass is sufficient to extract a high-statistics sample of neutrino-electron elastic scattering events, which have a known cross section.
Can be used to constrain the flux to better than 2%.

Similar technology as FD, reduces detector systematics between ND and FD.
Differences in design driven by intensity at near site.

Not feasible to build a LArTPC larger enough to contain muons at the near site
Assume coupling to a down-stream muon spectrometer

Building Larger Modules/Fewer Modules

Module dimensions (foot print) are set to simplify reconstruction, through unambiguous light and charge readout.

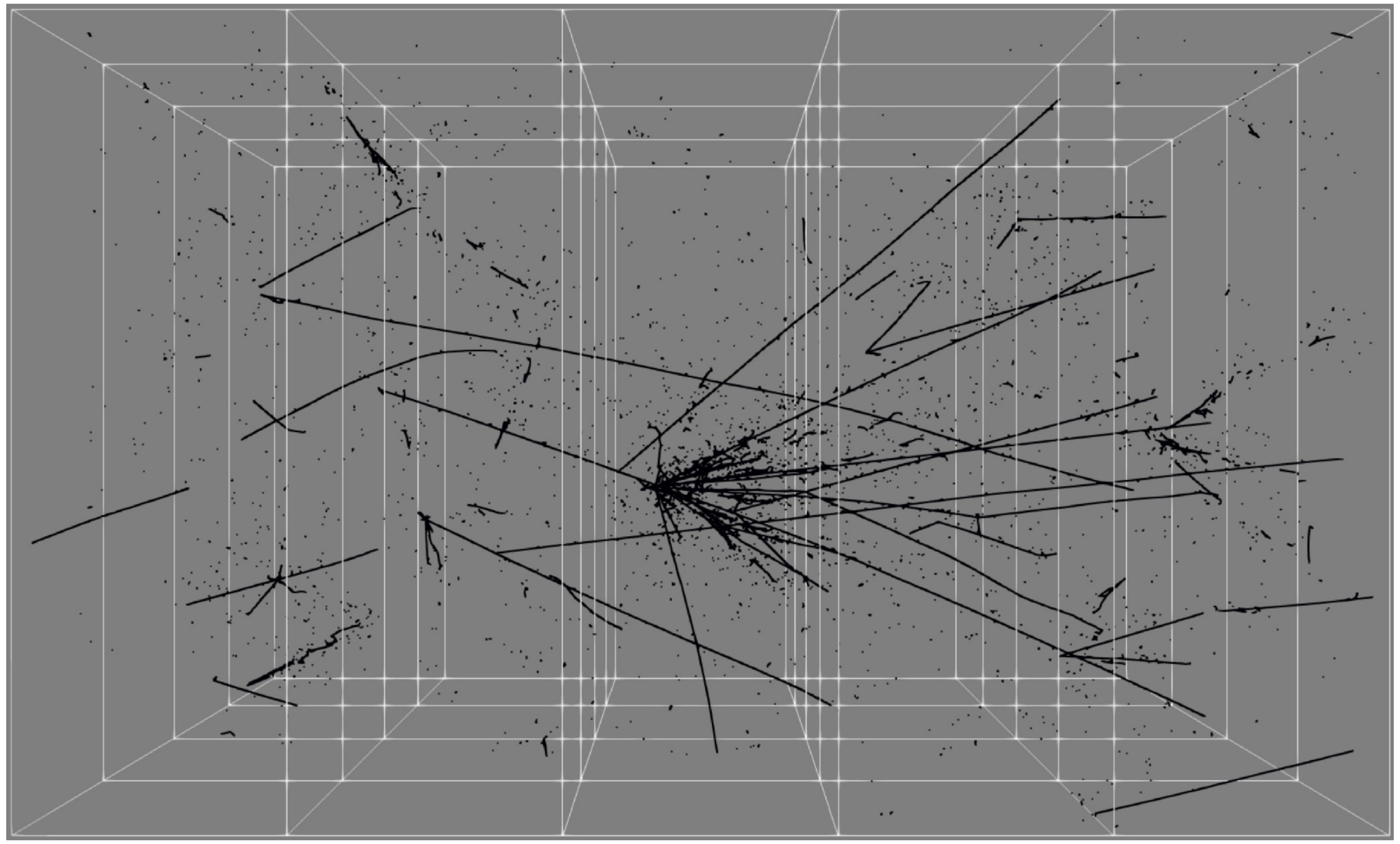
Light:
Prompt scintillation (τ = 6.2 ns) used for precise trigger and to associate detached energy deposits to correct vertex.
Optical path must be less than Rayleigh scattering length (66 cm), and E-field must be maximal to suppress slow scintillation component.

Charge:
Diffusion must be much less than pixel pitch (3 mm). Readout window (drift time) must be short to minimise pileup.
13 cm^2/s diffusion at 1 kV/cm, 50 cm drift length give readout window of 250 us and transverse diffusion of 0.8 mm.

Building Larger Modules/Fewer Modules

Module (TPC): 3 m tall, 1 m x 1 m foot print, central cathode 50 cm drift, 50 kV bias.

2.1 t active LAr per TPC, 0.21 neutrino events per module per spill. Many more crossing tracks and detached energy deposits. Prompt timing needed to disentangle events from the 10 us spill in 250 us readout window.



1 MW 3 horn optimised spill, FHC, including rock. 4x5 geometry. Colouring by charge R/O.

Building Larger Modules/Fewer Modules

Larger modules will:

Require higher bias voltages – appropriate feedthroughs, clearance volumes (more dead space), power supplies, also lead to more stored energy.

Increase dependence on LAr purity – longer required electron lifetime means less robust against loss in purity

Increase optical path – Rayleigh scattering smears-out prompt component by O(10) ns for distances of O(1) m.

Increase transverse diffusion – smear the spatial resolution of the charge readout, reduce angular resolution.

Increase charge readout window – more energy deposits from different events within the same readout window.

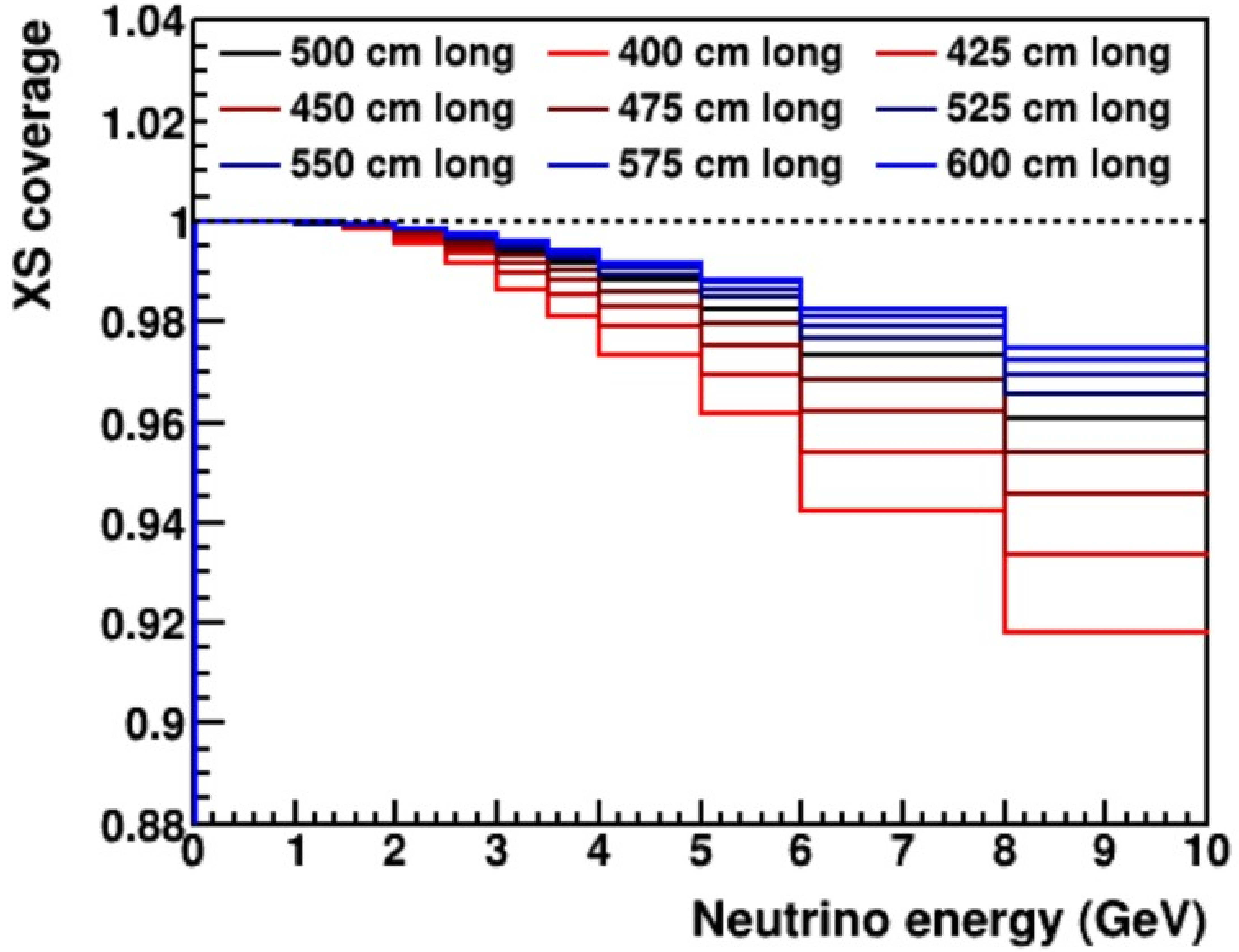
Reducing Overall Detector Dimensions

Detector dimensions set by need to measure hadronic showers directly to avoid reliance on models to correct for unobserved energy, across a wide range of neutrino interaction kinematics. See Chris' last talk DUNE-doc-13133-v1

The optimal size is 4 m wide, 3 m tall, and 5 m in the beam direction.

A fiducial volume can be defined to exclude 50 cm around the sides of the detector and 150 cm from the downstream end, in which the acceptance does not change rapidly as a function of hadronic energy, or position of the interaction vertex.

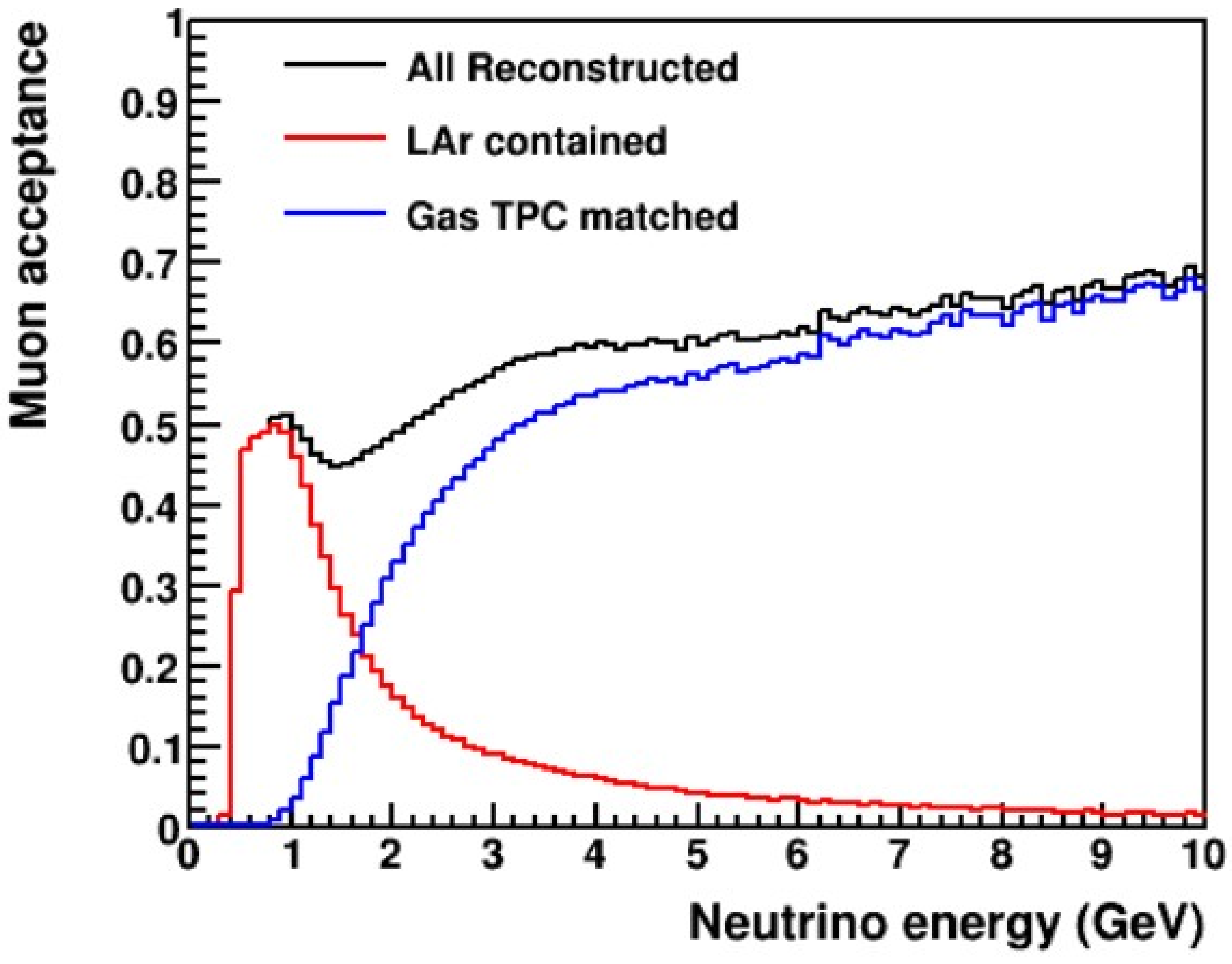
Reducing Overall Detector Dimensions

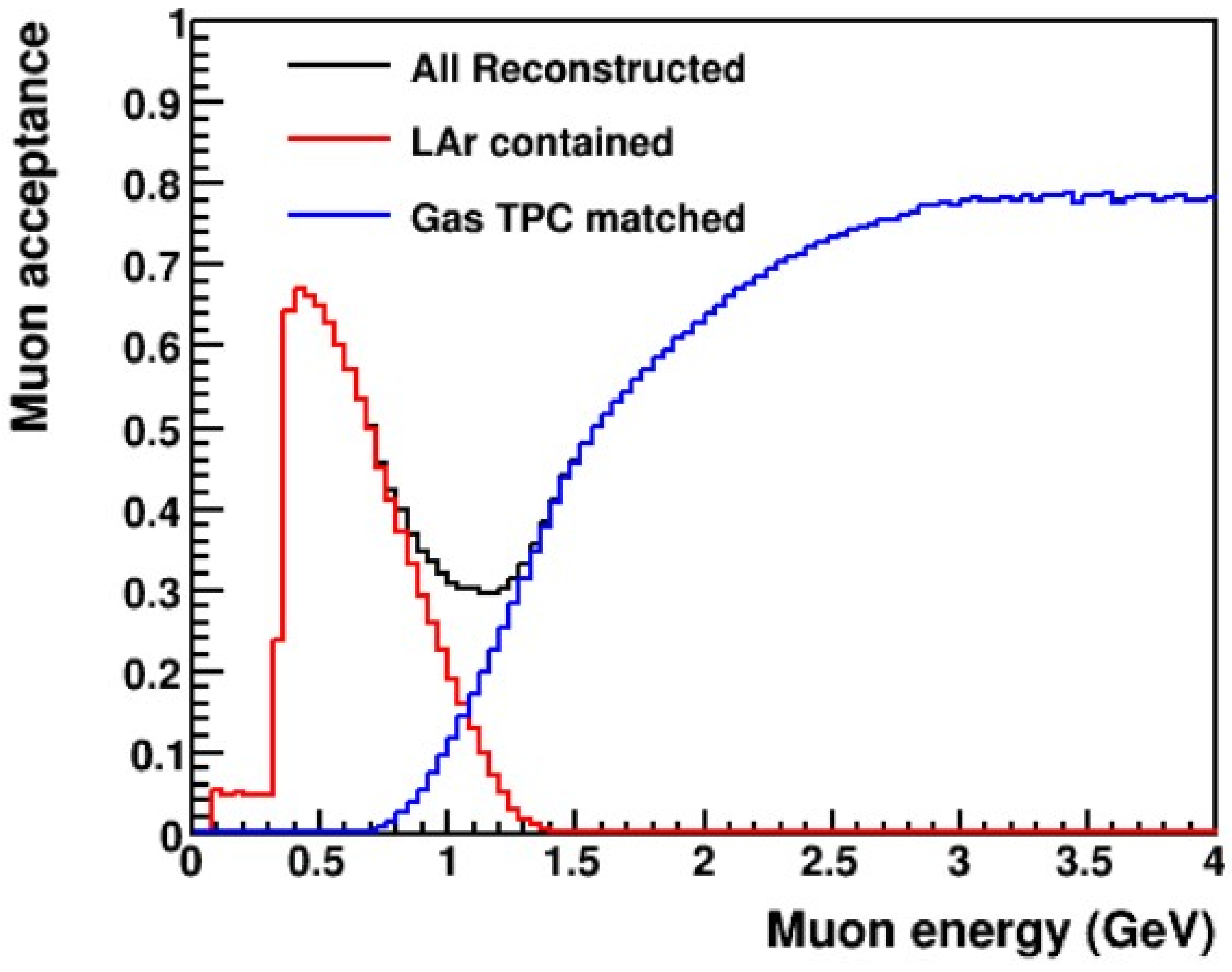


Influence of detector length on cross-section coverage as a function of neutrino energy. The optimal length is 5 m. Going beyond 5 m does little to improve cross section coverage, but reducing to 4 m begins to limit coverage at higher energies. 1 minus the cross section coverage gives the fraction of events that can never be well reconstructed.

Reducing Overall Detector Dimensions

Also important to consider muons. Muons can be measured when they stop in ArgonCube or when they pass into the spectrometer. Muons that stop between the two regions cannot be reconstructed accurately. ArgonCube must be long enough so that there is no hole in the acceptance as a function of muon momentum.





Reducing Overall Detector Dimensions

The effect on the fiducial volume is important to consider when deducing detector dimensions. A 2 m buffer volume is required around the fiducial volume to achieve good containment, therefore a 5 m long detector has a 3 m fiducial volume. Reducing the length to 4 m would reduce the fiducial volume to 2 m, i.e. a 20% reduction in length reduces the fiducial volume by 33%. This has particularly concerning implications for measurements of nu-e scattering, where the statistics would be cut by 33%.

Reducing Overall Detector Dimensions

The current detector width is 7 m across the beam to mitigate the need for a side muon spectrometer. The width could be reduced to 4 m, but this will entail the inclusion of a side muon spectrometer plus all additional costs.