ArgonCube LBNC

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

Near Detector Workshop
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Questions from the Alan

Is the (sub-component) plausible and achievable?

What are the (SC) strengths w/r to the oscillation analysis? **This is the priority**

What are the detector requirements?

Is the detector complexity, size well motivated?

What are the cost drivers?

What are the (SC) technical risks?

ArgonCube Strengths w/r to the Oscillation Analysis

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

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

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%.

Constrain electron neutrino contamination.
Use e/γ separation to reduce NC background.

Is the ArgonCube plausible and achievable?

LArTPCs of this scale and larger have been demonstrated. The primary goal of ArgonCube was mitigating the risks normally associated with LArTPCs.

All novel aspects of ArgonCube have been prototyped:

Charge R/O – arXiv:1801.08884, JINST 13 (2018) no.10, P10007
Light R/O – Instruments 2 (2018) no.1, 3
Field shell – Instruments 3 (2019) no.2, 28

All the design elements will be incorporated into ~⅔ scale ND prototype (ProtoDUNE-ND) that will operate on-axis in NuMI in 2020.

Bern has secured funding for production of 4 modules.
FNAL is providing support for facilities to deployment in NuMI.
JINR is providing the light R/O.
LBNL has secured funding for the charge R/O (supplemented by Bern).
SLAC is providing the mechanical module design and production of TPC components.

What are the detector requirements?

Provide a high fidelity picture of how neutrino interactions will appear in the far detector, addressing both neutrino interaction and detector systematics (secondary interactions, recombination, etc.) in a high multiplicity environment.

Essential requirements:

- Unambiguous charge R/O
- Modularisation (short drift length, optical segmentation).

The detector size is determined by containment of ionizing particles produced by neutrino interactions, aside from neutrons and forward-going high-energy muons. Overall signal acceptance versus final state kinematics is a driving factor, while modest efficiencies are tolerable given the large statistics for most neutrino interaction channels.

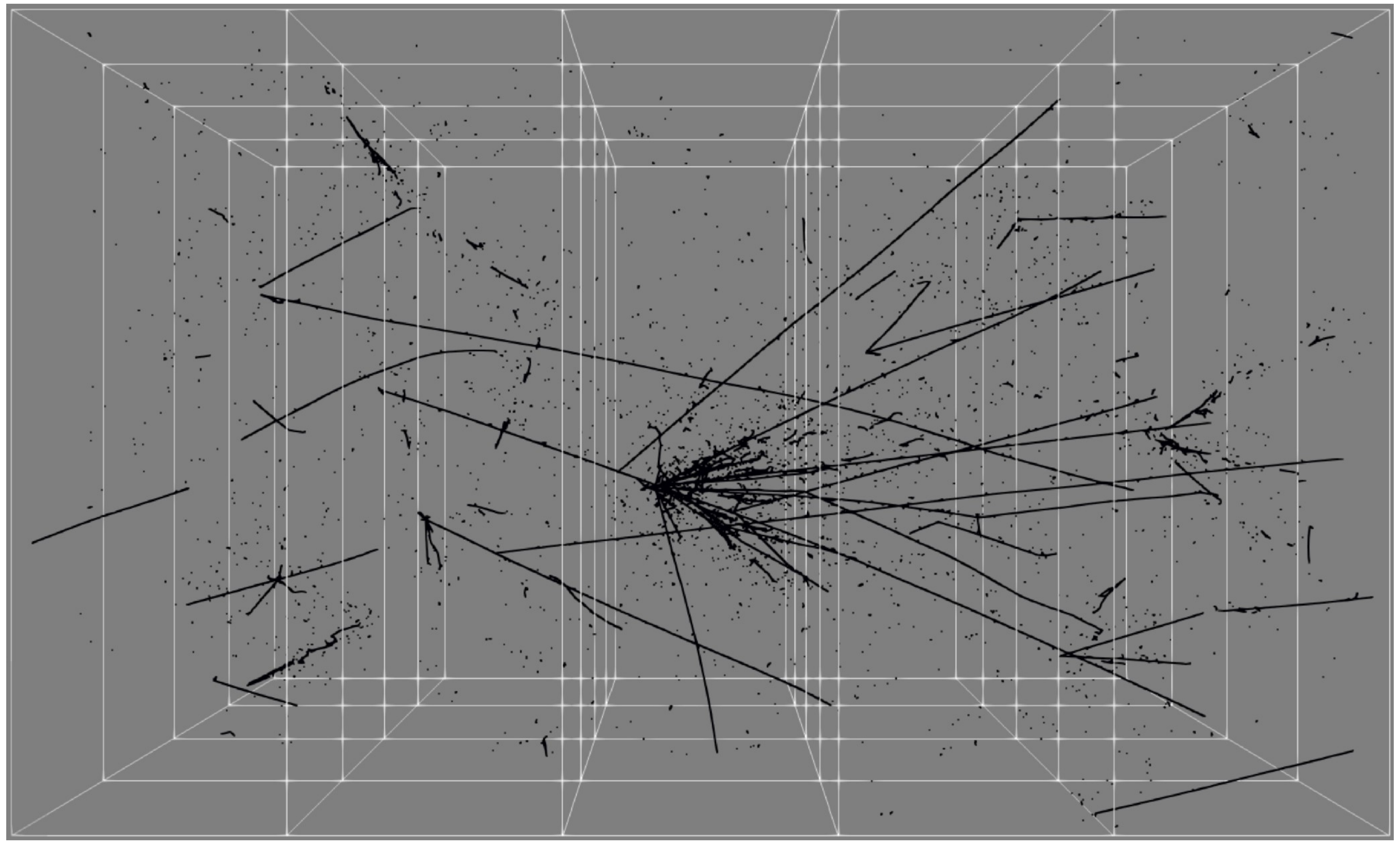
Not feasible to build a LArTPC larger enough to contain muons at the near site

Assume coupling to a down-stream muon spectrometer with **good geometric acceptance**

Is the detector size well motivated (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 charge readout window.



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

Is the detector size well motivated (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 ideally 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

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.

Significantly larger structure to prevent wall deflection – more dead material between active volumes.

Is the detector size well motivated (Detector)?

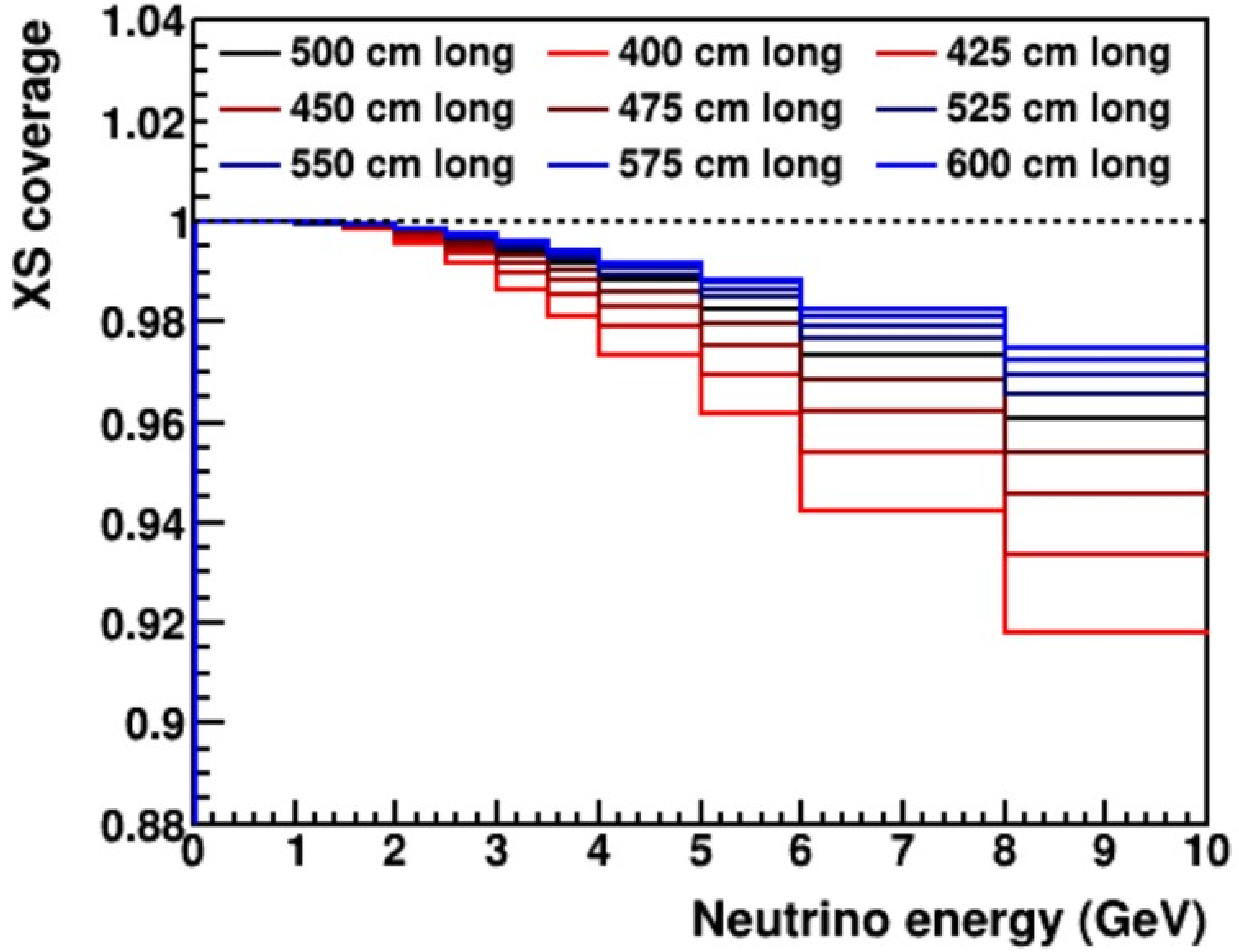
Detector dimensions set by need to measure hadronic showers directly to avoid reliance on models to correct for unobserved energy, across a wide range of neutrino interaction kinematics. See Chris' talk DUNE-doc-13133-v1

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

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.

*7 m wide to mitigate the need for a side muon spectrometer.

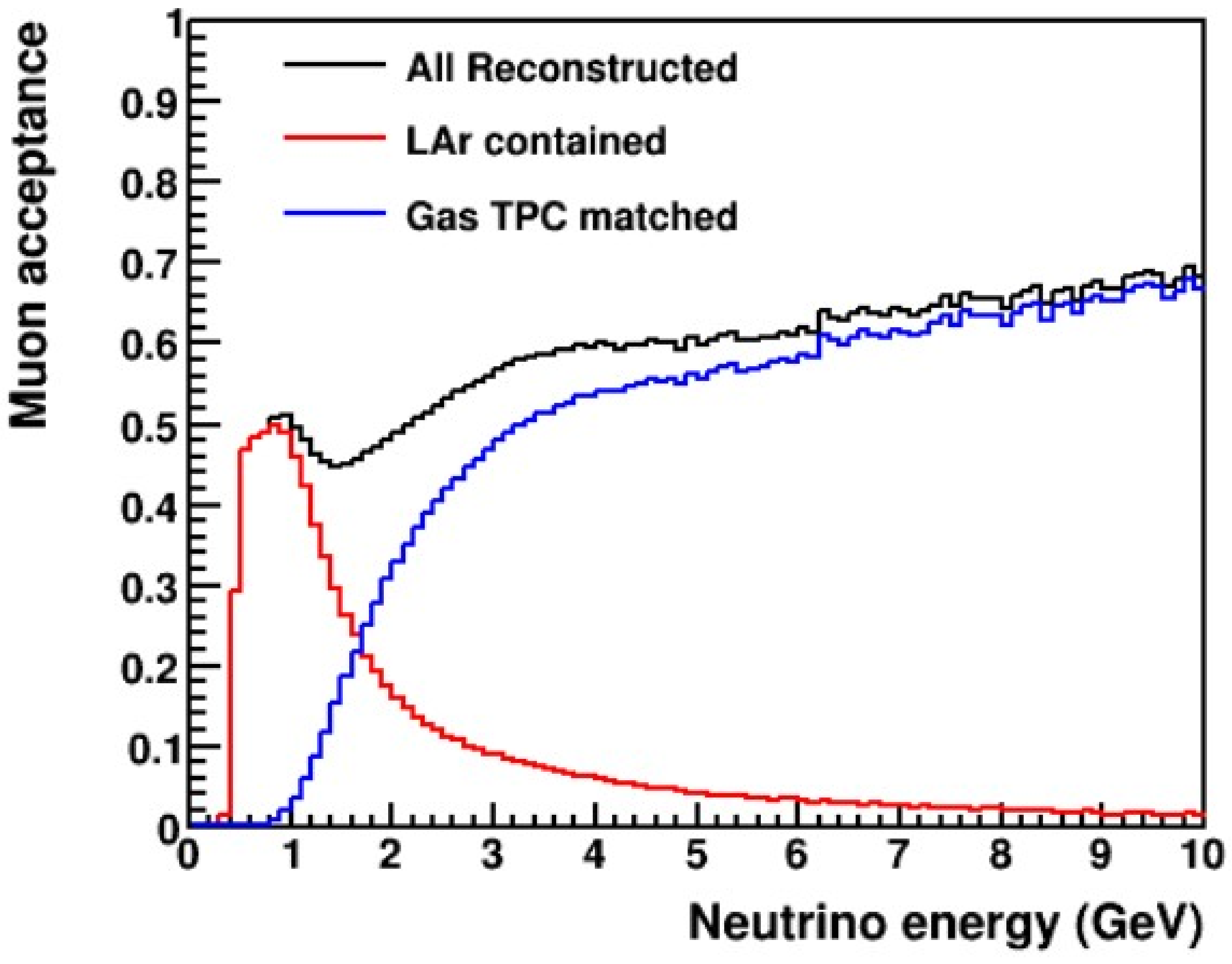
Is the detector size well motivated (Detector)?

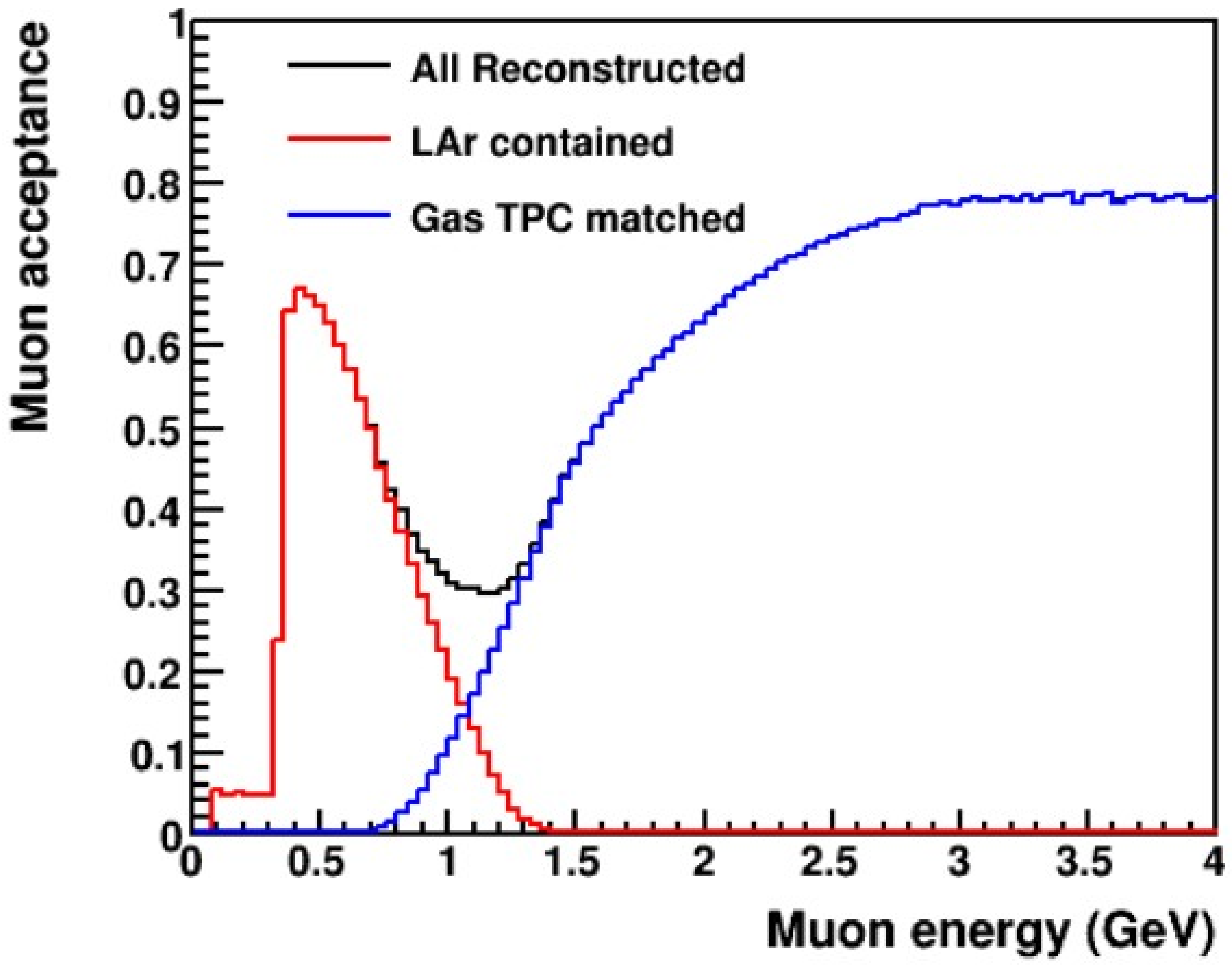


Influence of detector length on cross-section coverage as a function of neutrino energy. The optimal length is 5 m. Going beyond 5 m does little to improve cross section coverage, but reducing to 4 m begins to limit coverage at higher energies. 1 minus the cross section coverage gives the fraction of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

Is the detector size well motivated (Detector)?

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 geometric 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%.

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 dead material and costs.

Is the Detector Complexity Well Motivated?

The complexity of the detector is driven by the modularization and pixel readout. Modularization introduces physical boundaries within the overall LAr volume, which requires significant additional considerations of mechanical design, dead material, LAr flow, etc.

The pixel readout is driven by the pixel pitch, which drives the channel count. The pixel pitch is set to be similar to the wire pitch of the far detector, so that we can achieve similar granularity in sampling the ionization activity in the detector.

As noted above, we believe that both modularization and pixelisation are essential to meeting the detector requirements.

What are the Cost Drivers?

In order of scale:

- Cryostat (if engineering costs are to be included).
- Light R/O.
- Cryogenics.
- Charge R/O.

Costs for the light and charge R/Os scale approximately with area/segmentation - the number of modules.

Response to Specific comments

Response to be given now:
Discussion of nue/photon separation and FV (45, 63*)

Proton recoils from neutrons/energy fraction, and neutron pile-up (16, 17, 59)

Dimensions of the detector and geometric acceptance (12, 14)

E-field with ArClight (11*),

Response pending studies and/or 2x2 results:

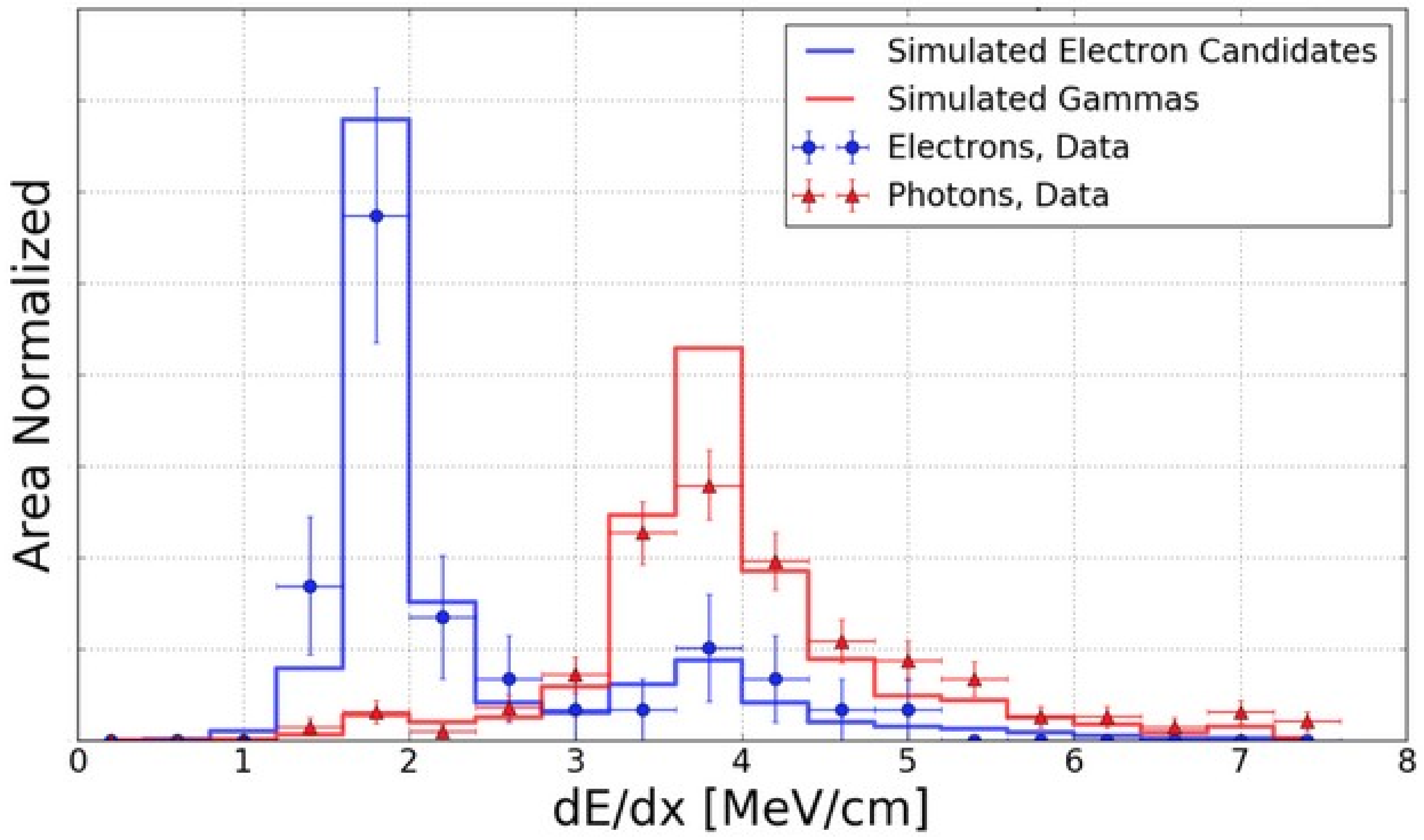
*E-field with ArClight (11),
Utility of pi0 peak for calibration (15)
e/γ separation (63)

Response to Specific comments

Discussion of nue/photon separation and FV (45, 63*)

FV of 2+ radiation lengths (50 cm total) applied to prevent mis-ID of gammas converting in the detector.

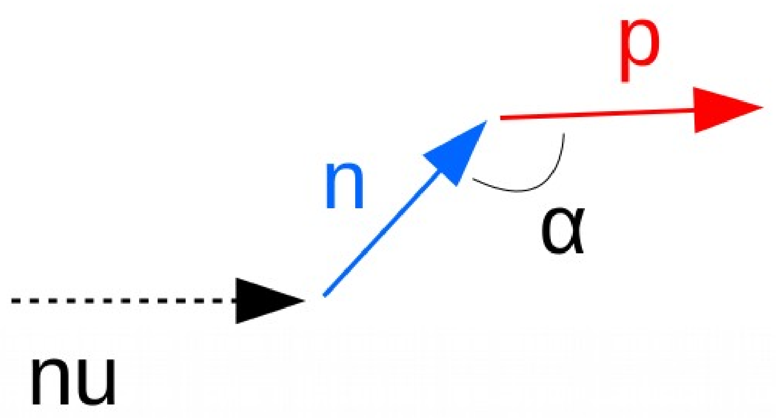
Make use of e/γ separation as in ArgoNeut (Phys. Rev. D95 072005 2017)

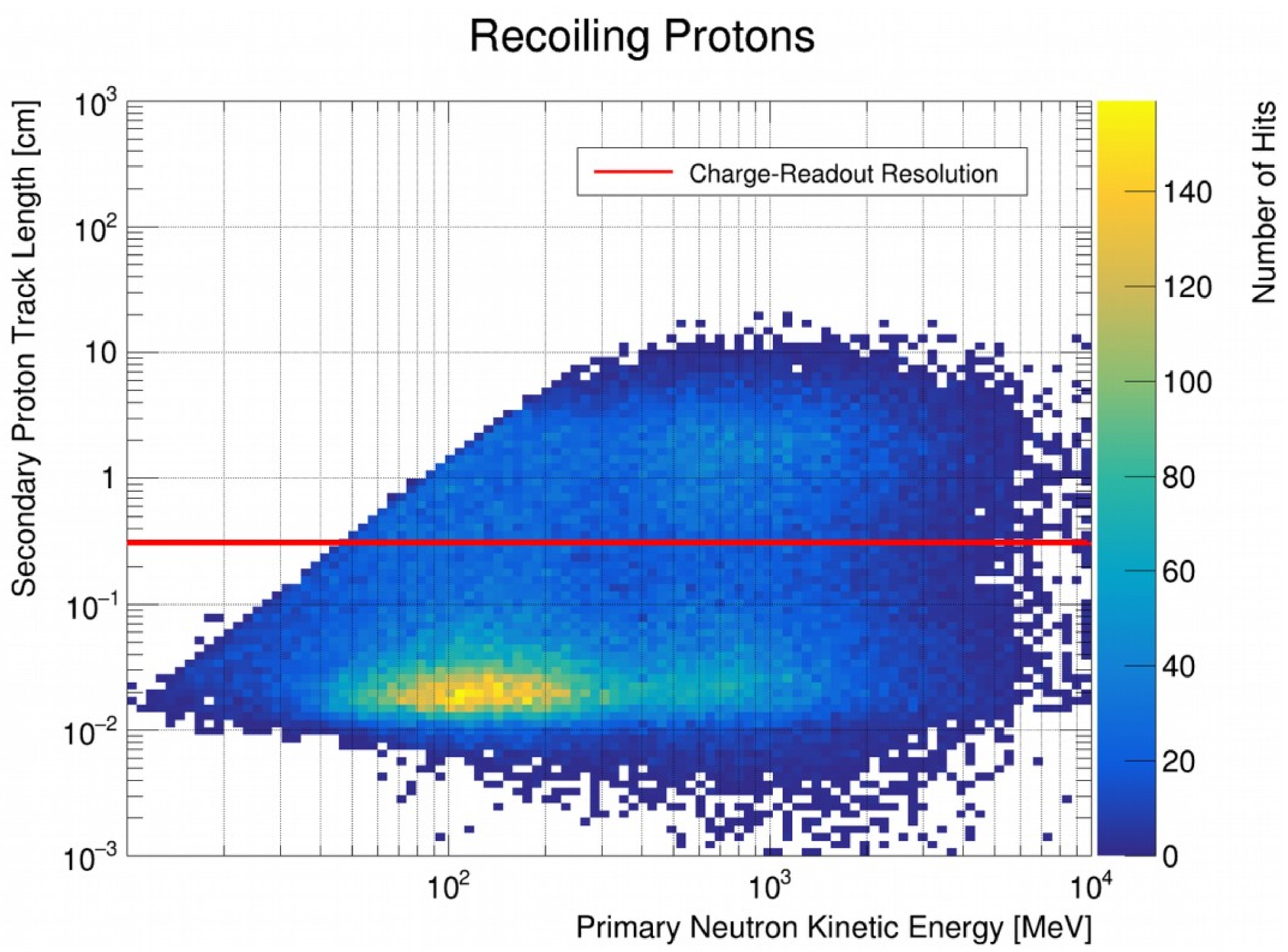


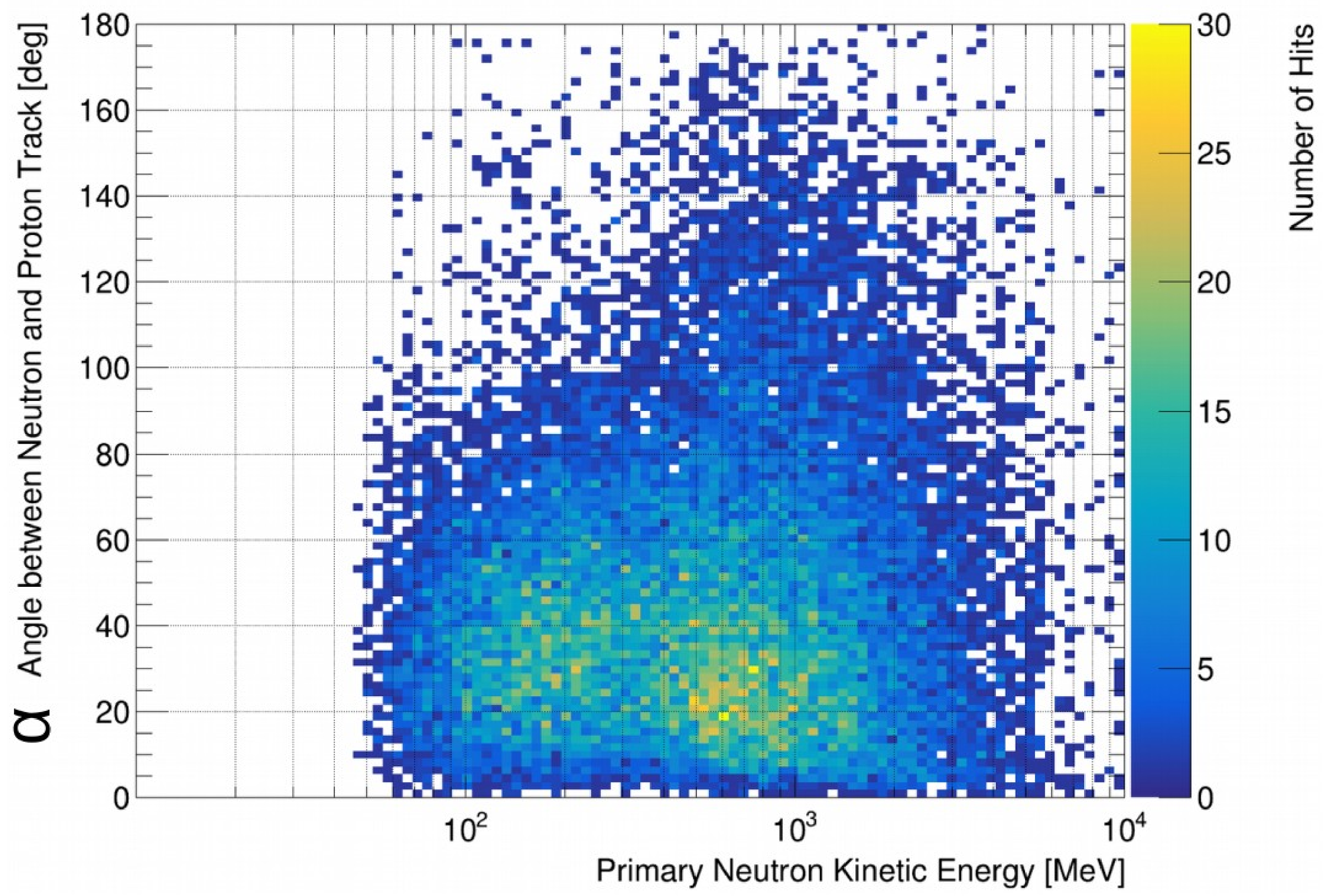
Response to Specific comments

Proton recoils from neutrons/energy fraction, and neutron pile-up (16, 17, 59)

Recoiling Protons







→ Start to see tracks from recoiling protons at neutron energies > 50 MeV

→ ~30% of all recoiling protons

→ No correlation between angle and neutron energy

→ No point-back / **no energy reconstruction**

→ **Only option: n-tagging with protons**

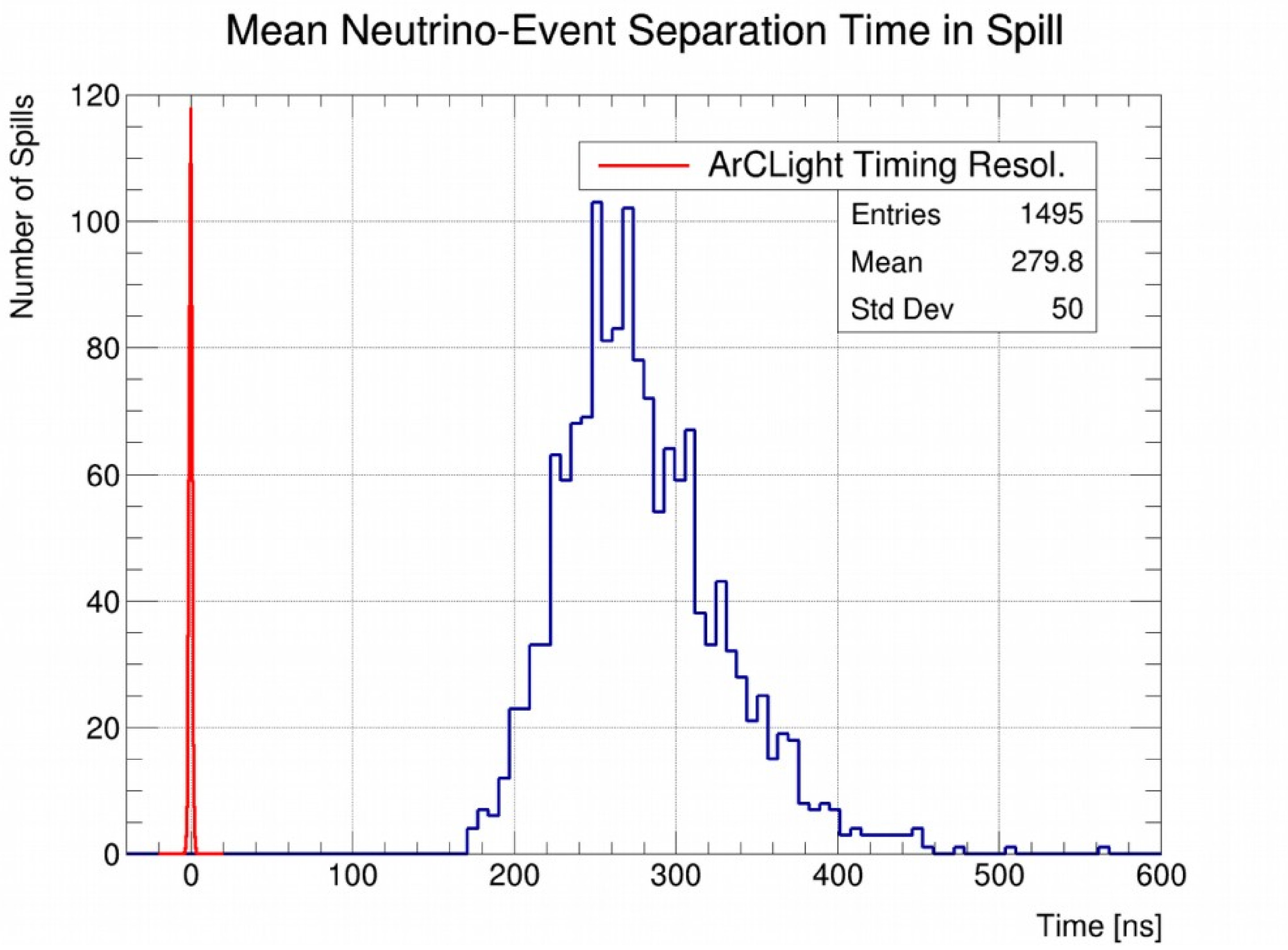
Response to Specific comments

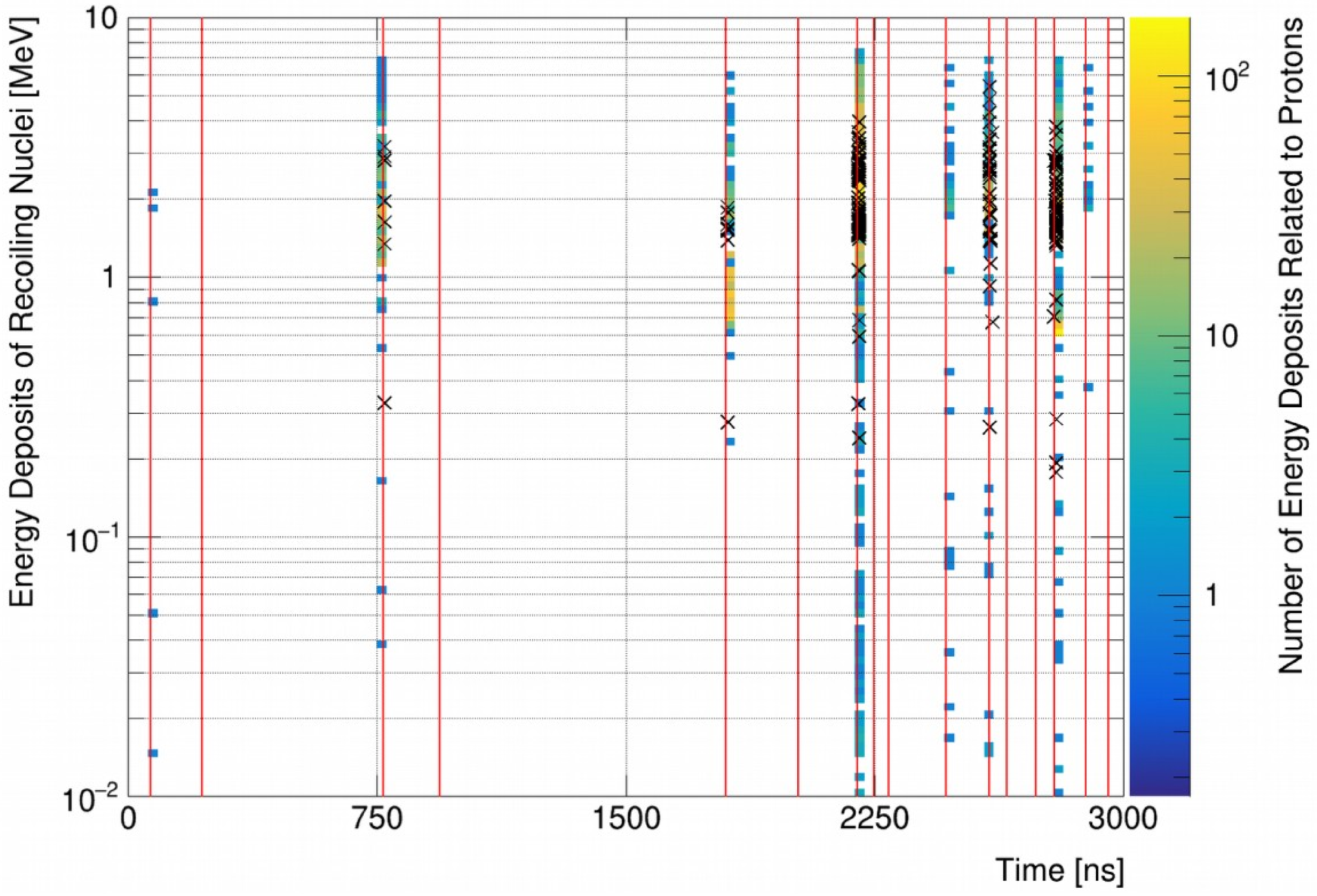
Proton recoils from neutrons/energy fraction, and neutron pile-up (16, 17, 59)

see section 1.3.2.6 “fast neutron tagging”

Neutron ↔ Neutrino Association: ArCLight

- Spill length: 10 us,   Spill frequency: ~1 Hz
- Drift window at 1 kV/cm: ~227 us → **too slow!**
- ArCLight resolution: ~1 ns → **fast!**



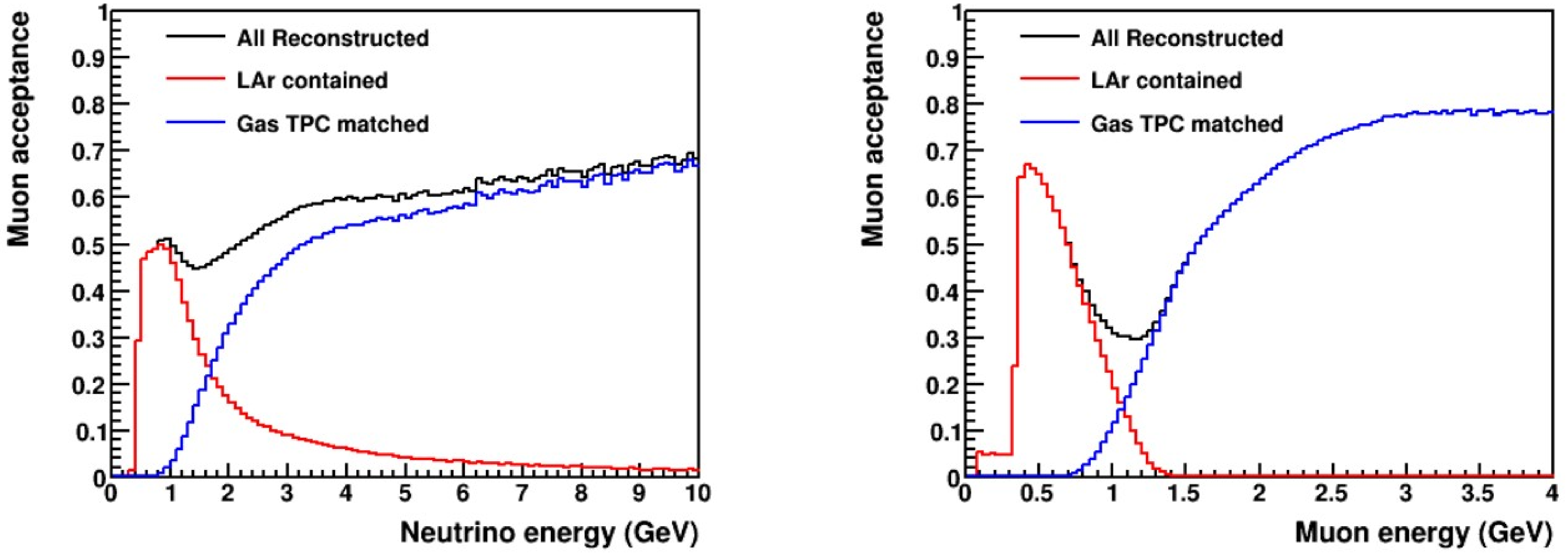


→ Use prompt light from protons and vertex to associate tagged neutrons with correct neutrino-interactions.

Response to Specific comments

Dimensions of the detector and **geometric** acceptance (12, 14)

Please read section 1.3.2.4 “ND Dimensions”

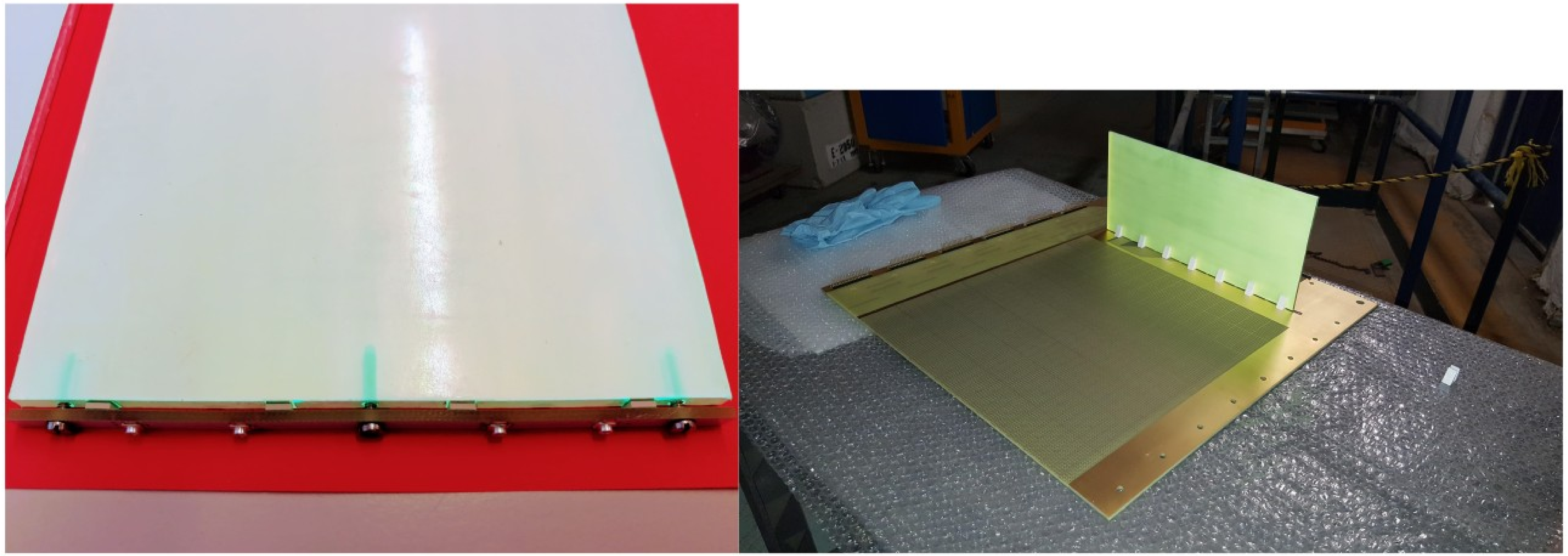


Given the dead material between the LArTPC and MPD, ~1 GeV muons can exit the side of the LArTPC or stop in the intervening dead material, reducing efficiency. Given the very high rate of interactions in the LArTPC, we are less worried about the total efficiency, and more focused on variation of efficiency with energy. MCS may provide an additional handle on these muons, but this is not included in this conservative study.

Response to Specific comments

E-field with ArClight (11)

This was done in PixLAr, see Figure 1.6 (b)



(a) ArCLight paddle (b) ArCLight mounted on a pixel readout PCB

Figure 1.6: (a) A prototype ArgonCube light readout paddle. The paddle is 50 cm long and 10 cm wide, with four SiPMs coupled to one end. Reproduced from Ref. [?]. (b) ArCLight paddle mounted on the PixLAr pixelated charge readout plane, as used in test beam studies at Fermilab.

Fully Operational

We start to make headline OA measurements in a year or two, but that assumes that we have the LAr in place.

ArgonCube should be immediately operational!

Milestones

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Physics Milestone	Exposure (staged years, $\sin^2\theta_{23} = 0.580$)
5σ Mass Ordering $\delta_{CP} = -\pi/2$	1
5σ Mass Ordering 100% of δ_{CP} values	2
3σ CP Violation $\delta_{CP} = -\pi/2$	3
3σ CP Violation 50% of δ_{CP} values	6
5σ CP Violation $\delta_{CP} = -\pi/2$	7
5σ CP Violation 50% of δ_{CP} values	11
3σ CP Violation 75% of δ_{CP} values	14

Also have milestones for δ_{CP} and θ_{13} resolutions