CAPTAIN-MINERvA and the connection to DUNE

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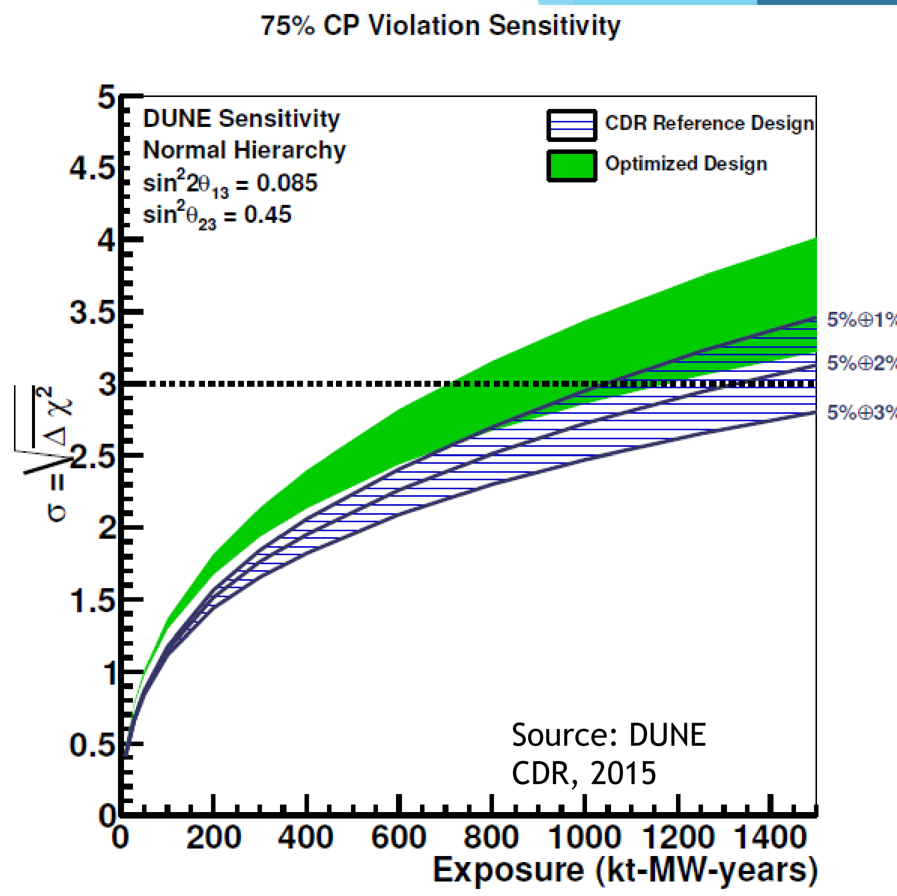
for the CAPTAIN-MINERvA collaboration

October 2, 2015

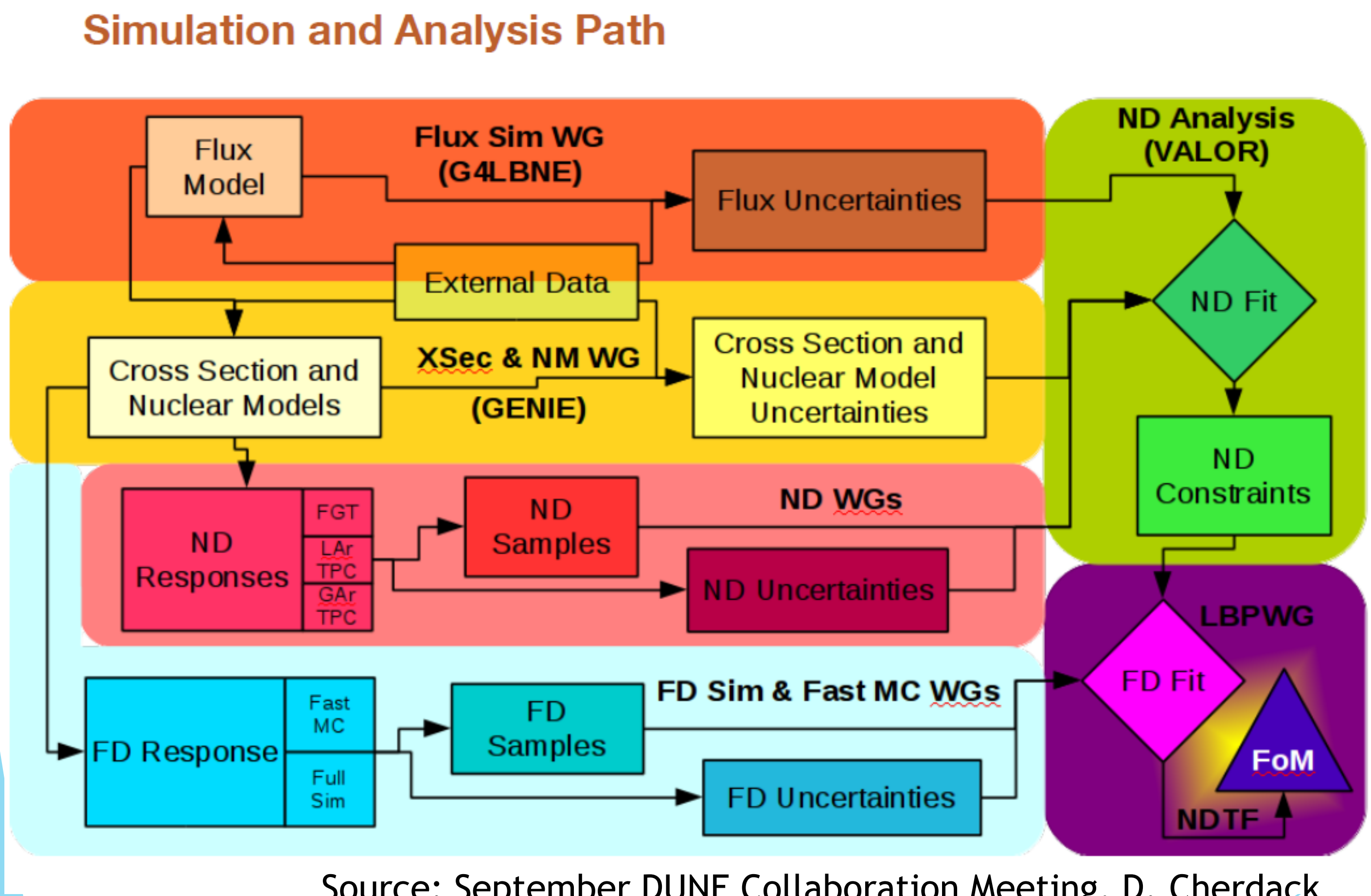
Motivation

- DUNE will measure neutrino oscillations in a liquid argon TPC
- One of the main systematic uncertainties in neutrino oscillation measurements is uncertainty in the neutrino interaction model
- CAPTAIN-MINERvA Goals: Neutrino-argon cross sections, event reconstruction, and particle identification in the energy range relevant for DUNE
  - NuMI's medium energy beam covers the 1st oscillation maximum for DUNE at a baseline of 1300 km
  - Only plan to make neutrino-argon measurements in this energy range before DUNE!



Evolution of DUNE's sensitivity to CP violation as a function of exposure; width of each band represents a range in the signal normalization uncertainty

DUNE Oscillation Analysis



Source: September DUNE Collaboration Meeting, D. Cherdack

DUNE Oscillation Analysis

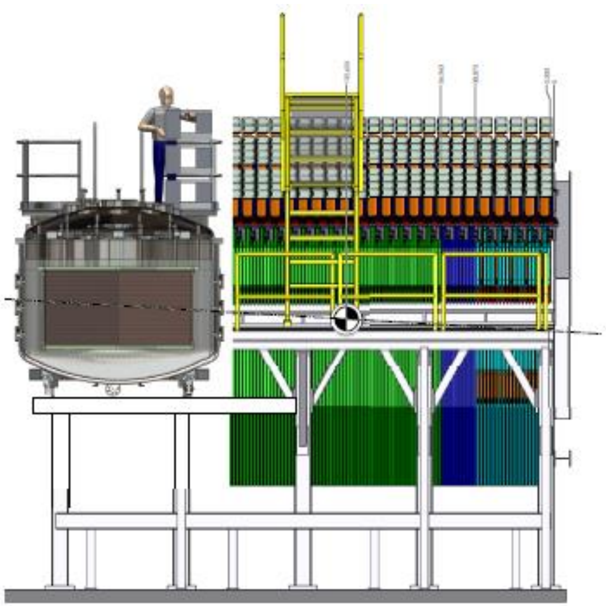
- The incoming neutrino energy must be reconstructed based only on final state particles
- Neutrino interaction data are needed to constrain the models of nuclear effects that will be used for true-to-visible energy conversions (important because the oscillation probability is energy-dependent), predictions of signal and background rates in the far detector based on near detector data, etc.
  - Particularly important: an understanding of the effects of the nuclear environment on underlying neutrino-nucleon interactions
- There is very little neutrino-argon data in the neutrino energy range relevant for DUNE

DUNE Oscillation Analysis

- Interaction models used in neutrino event generators are constrained by:
  - Charged lepton data for the vector contribution to neutrino interactions
  - Neutrino data for the axial contribution and multi-nucleon initial states
  - Pion scattering data for final state interactions
- The models are mostly based on nuclear targets other than argon
- A high-statistics neutrino-argon data set can be used to
  - Test the extrapolations of the models for different nuclei
  - Improve the models
  - Test energy-dependence of models

CAPTAIN-MINERvA Proposal

- We plan to install the CAPTAIN detector in MINERvA to study neutrino-argon interactions in the medium-energy NuMI beam
- CAPTAIN will serve as the vertex detector, and outgoing particles will be tracked in MINERvA.
- The MINOS Near Detector will continue to be used as the downstream muon spectrometer.



How is this program unique?

- Only experiment making high-statistics measurements of neutrino interactions on argon in the medium energy range before DUNE
  - Neutrino-argon cross-sections
  - Development of neutrino event reconstruction in LAr
    - Part of CAPTAIN collaboration charter: Make formal agreement with DUNE to share some set of data for algorithm development
- CAPTAIN-MINERvA can measure cross section ratios (i.e., argon to carbon)
  - Study how processes vary on different nuclei
  - More stringent tests of the models can be performed with ratios due to cancellation of large systematic uncertainties such as the neutrino flux
- CAPTAIN-MINERvA can constrain the essentially unknown nuclear model of argon by measuring the energy dependence of nuclear effects convolved with cross section.
  - The incoming neutrino energy distribution is different in the DUNE far detector compared to the DUNE near detector → different energy-dependent nuclear effects in the two detectors

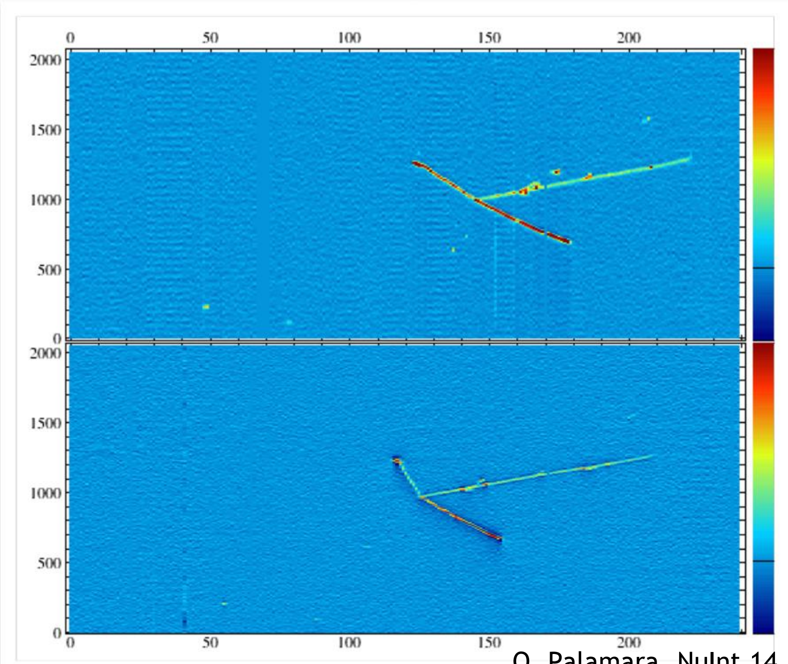
Event rates

6×10^{20} POT Neutrino mode	CC events with muon reconstructed (MINOS or MINERvA) Events w/ reco μ	CC events with muon reconstructed by MINOS Events w/ reco μ and charge
CCQE-like	916k	784k
$CC1\pi^{\pm}$	1953k	966k
$CC1\pi^{0}$	1553k	597k

Results presented here show only neutrino mode; we hope to run for 2 years and acquire 6×10^{20} POT in neutrino mode plus 6×10^{20} POT in antineutrino mode.

How is this program unique?

- Compared to ArgoNEUT
  - Took data in NuMI low-energy configuration (peak energy ~3 GeV)
  - With 20x the fiducial mass and roughly 10x more POT in neutrinos in one year, CAPTAIN will have more statistics and better containment
- Compared to MicroBooNE
  - BNB with neutrino energy ~1 GeV, consistent with 2nd oscillation maximum at 1300 km; will be complementary to CAPTAIN-MINERvA's measurements at 1st oscillation maximum
  - MicroBooNE interactions will mostly be quasi-elastic (~60%); approximately 68% of interactions in CAPTAIN-MINERvA will have a pion in the final state – gives us a unique opportunity to study events with large particle multiplicities

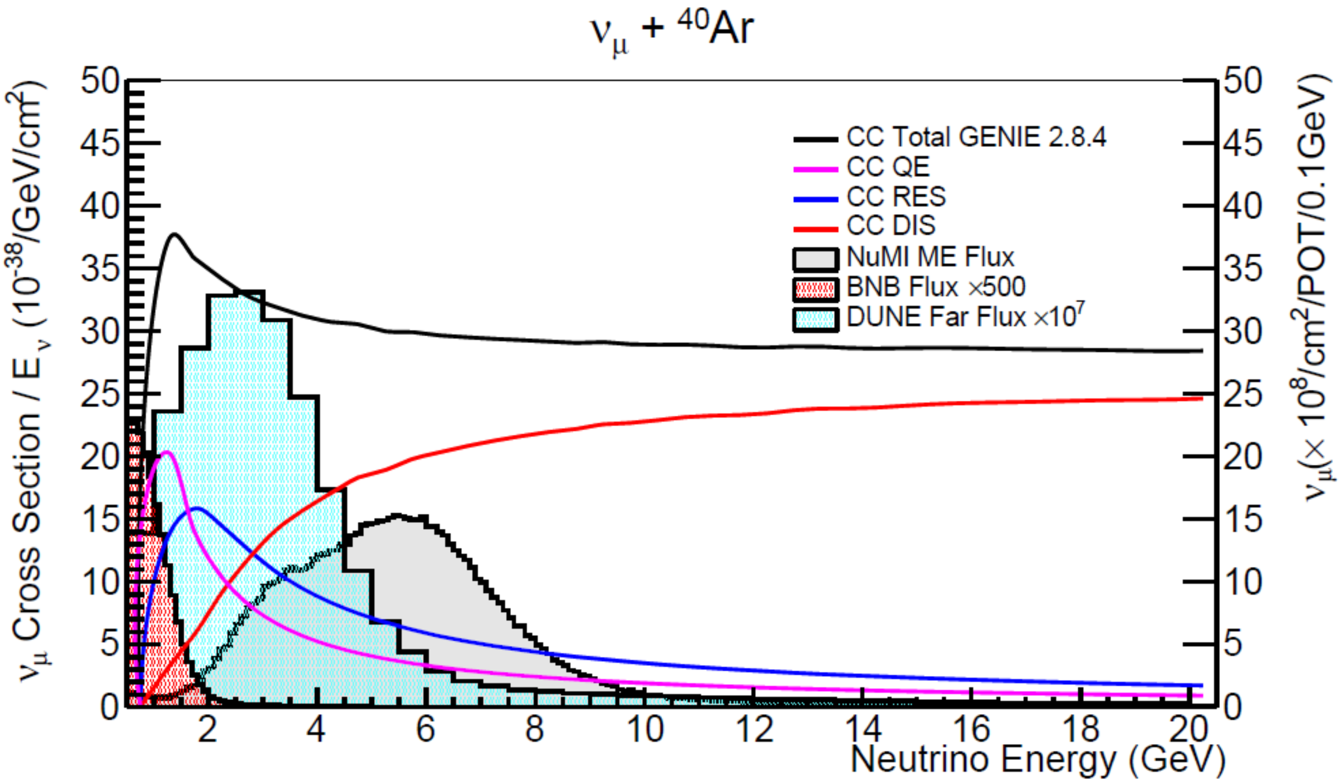


O. Palamara, NuInt 14

Real neutrino event in ArgoNEUT (back-to-back proton + muon candidate).

We expect similarly excellent resolution in CAPTAIN.

How is this program unique?



CAPTAIN-MINERvA Status

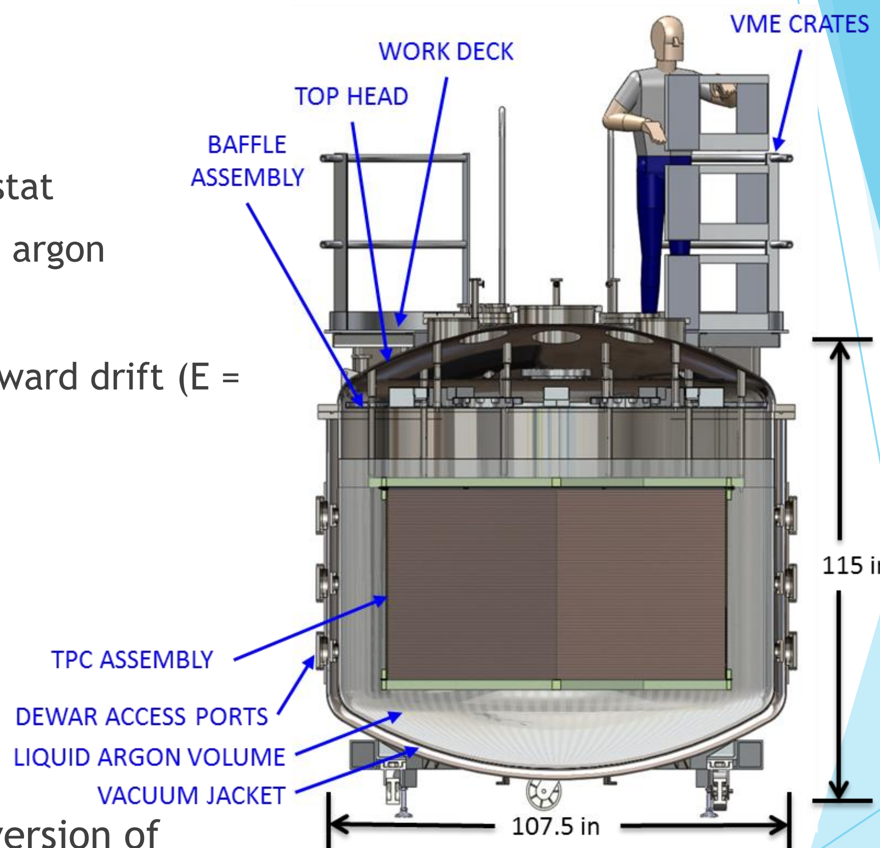
- Presented LOI to the Fermilab PAC in January 2015
- Presented proposal to Fermilab PAC in June 2015
- Received Stage 1 approval from Fermilab Director in July 2015
- Submitted proposal for funding from DOE's Intermediate Neutrino Research Program ~1 month ago
- The CAPTAIN detector will be commissioned at a surface location at Fermilab beginning in ~2017, with preparations beginning in 2016
- Neutrino data with CAPTAIN-MINERvA beginning in ~2018
- One year ($6x10^{20}$ POT) in neutrino mode + one year in antineutrino mode (contingent on NuMI schedule)

Collaboration

- Members of the current CAPTAIN and MINERvA collaborations will join together to form a single new collaboration (CAPTAIN-MINERvA)
- Author list (see last slide) represents the current members of both collaborations who expect to contribute to CAPTAIN-MINERvA
  - 127 collaborators (61 from CAPTAIN + 66 from MINERvA)
  - 30 institutions (15 from CAPTAIN + 15 from MINERvA)
  - Note there is currently no overlapping membership between the CAPTAIN and MINERvA collaborations
- Additional collaborators will be welcome!!! Please contact me if you are interested.
- Official formation of CAPTAIN-MINERvA collaboration is in progress

CAPTAIN

- Liquid argon TPC detector:
  - Portable and evacuable cryostat
  - 5 tons of instrumented liquid argon
- TPC:
  - Hexagonal prism, vertical upward drift (E = 500 V/cm, v_d = 1.6 mm/μs)
  - 2001 channels (667/plane)
  - 3 mm pitch and wire spacing
- Laser calibration system
- Photon detection system
- Electronics chain is the same as MicroBooNE
- Purification system is a scaled version of MicroBooNE's, similar to LArIAT, based on LAPD experience
- Mini-CAPTAIN: a smaller prototype detector (400 kg of instrumented liquid argon)



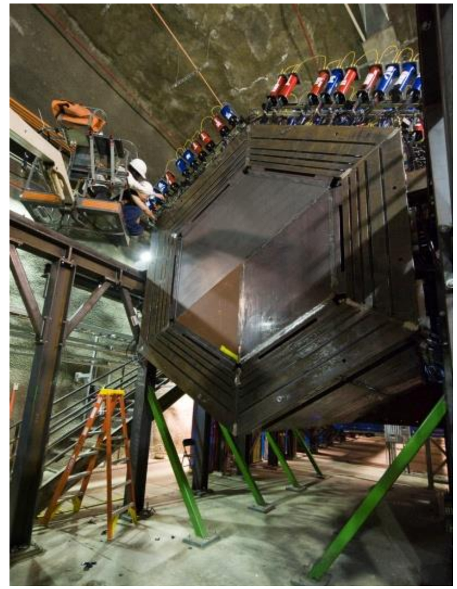
CAPTAIN Status

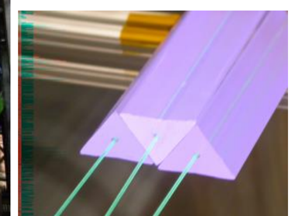
- Cryostat, electronics, field cage in hand
- Purification system at vendor (expect delivery ~Fall 2015)

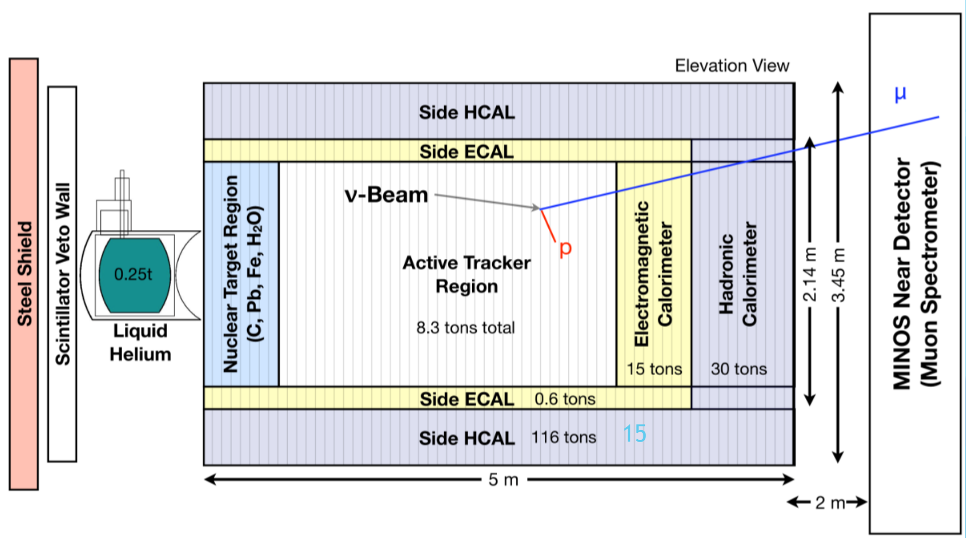
MINERvA

- Nuclear Targets
  - Allows side by side comparisons between different nuclei
  - Pure C, Fe, Pb, LHe, water
- Solid scintillator (CH) tracker
  - Tracking, particle ID, calorimetric energy measurements
  - Low visible energy thresholds
- Side and downstream electromagnetic and hadronic calorimetry
  - Good event energy containment
- MINOS Near Detector
  - Provides muon charge and momentum

LHe cryotarget

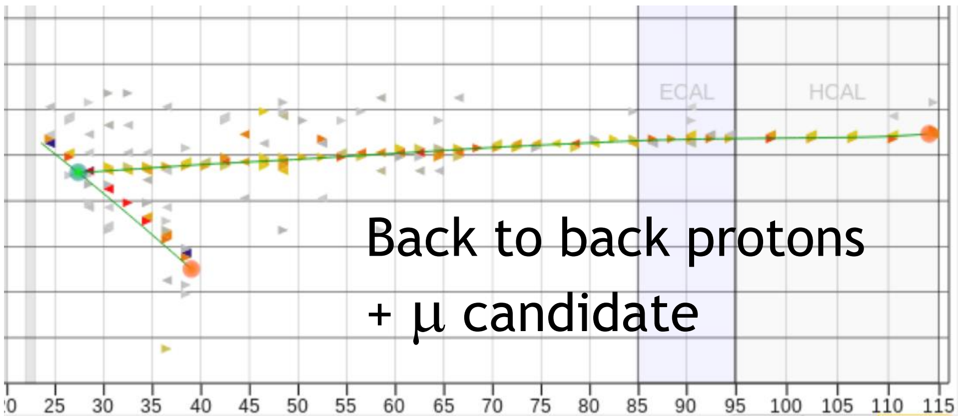


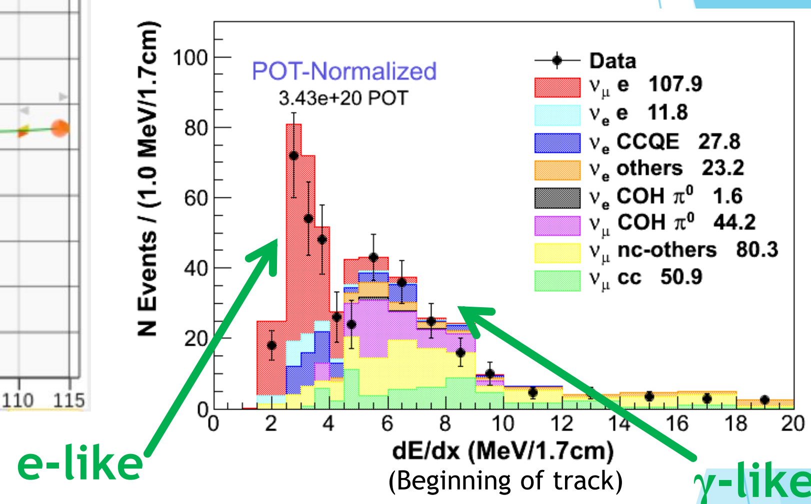


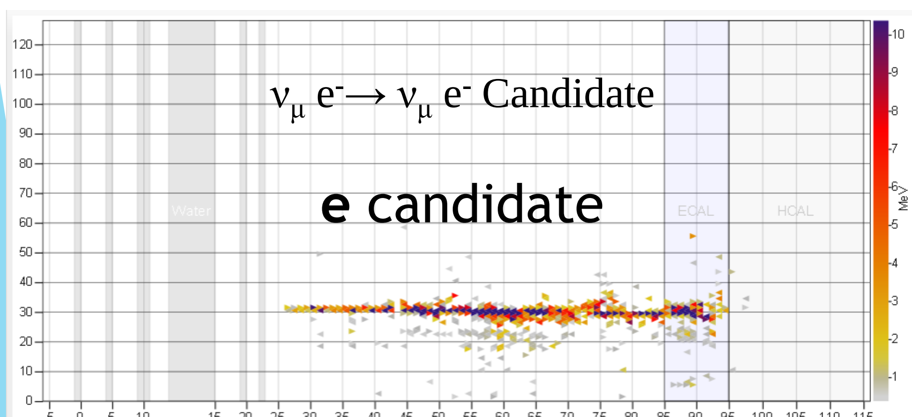


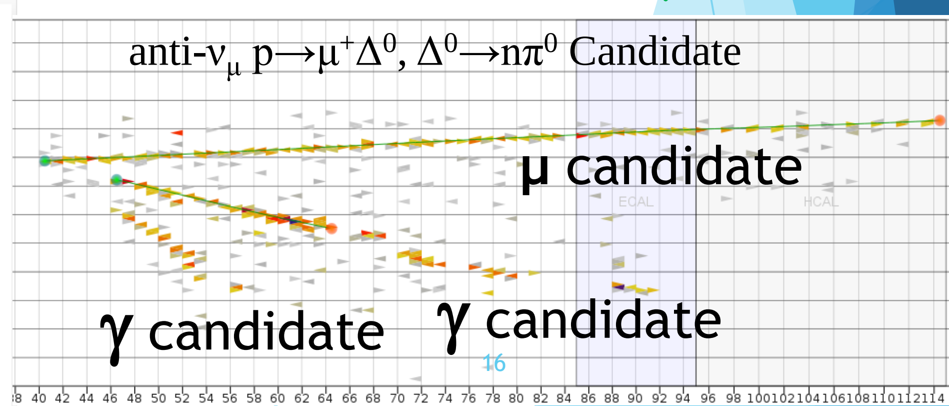
Events in MINERvA

Fine granularity allows exclusive state reconstruction,
a close look at the vertex of events, and good e/γ separation!



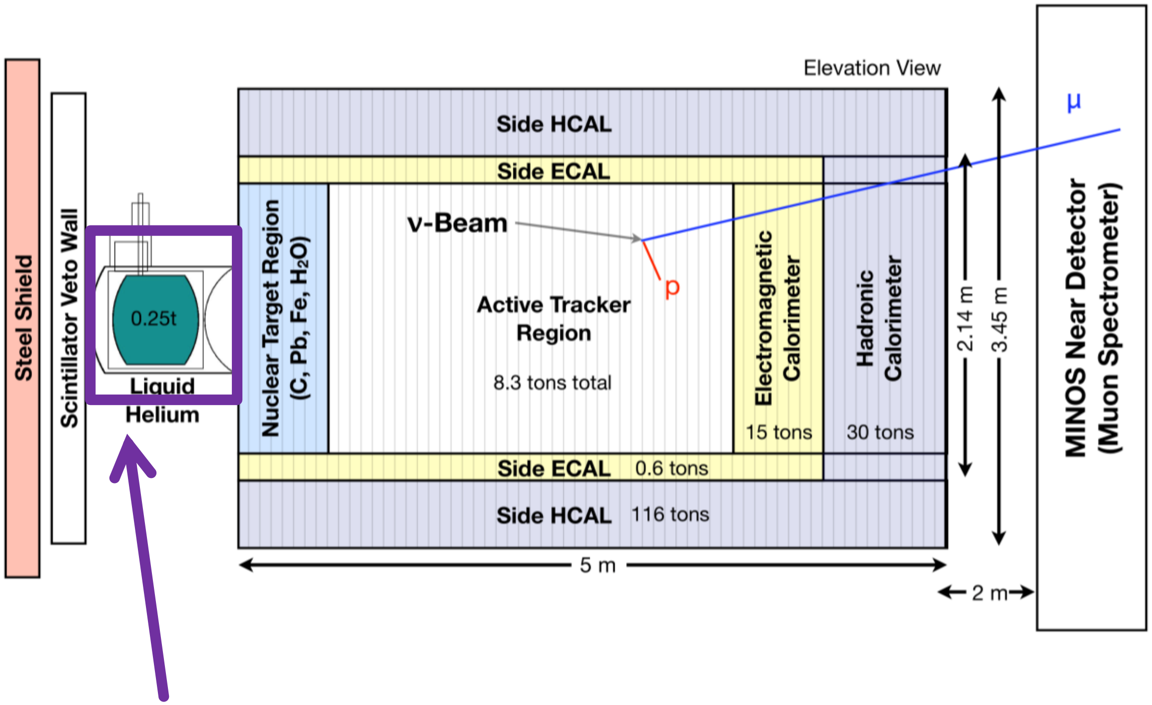






One out of three views shown, color = energy

CAPTAIN-MINERvA



Studies presented here assume we will replace MINERvA's He target with CAPTAIN

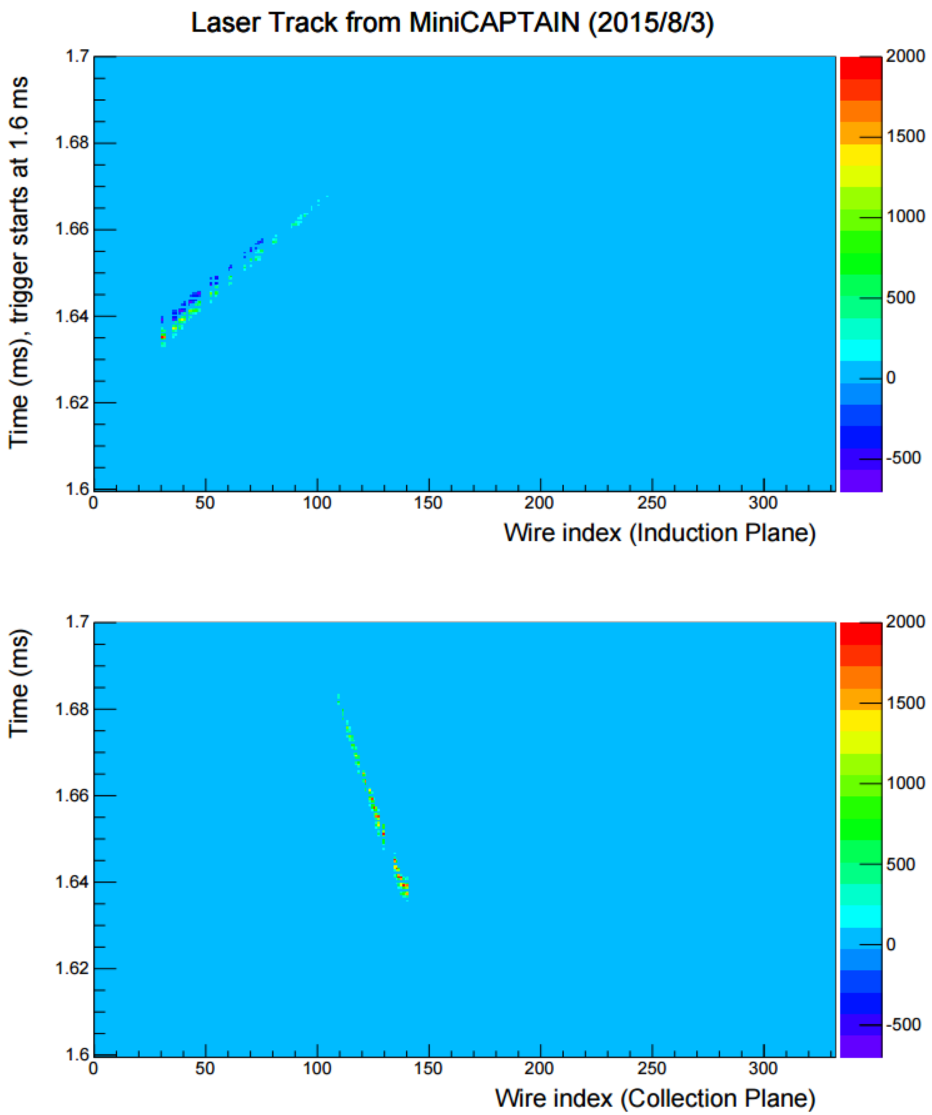
Minimal impact on MINERvA operations - they don't need the He target for the antineutrino running

Mini-CAPTAIN Status

- 30 cm upward drift, 1 m width, 400 kg instrumented liquid argon
- Liquid nitrogen fill in Summer 2014: test electronics and TPC, test heat load
- 1st LAr engineering run in Fall 2014: development of filling procedure, test cryogenic and purification system, DAQ development, laser system testing
- 2nd LAr engineering run in March 2015: further development of above items plus installation of recirculation system, integration with muon system
- Commissioning run in Summer 2015: more development of electronics and recirculation system – achieved sufficient purity to see tracks
- A Mini-CAPTAIN neutron run is anticipated during the next beam cycle at LANL
  - Run in Jan 2016, again in Oct 2016 (the following beam cycle)

Liquid nitrogen run

Laser Track in Mini-CAPTAIN

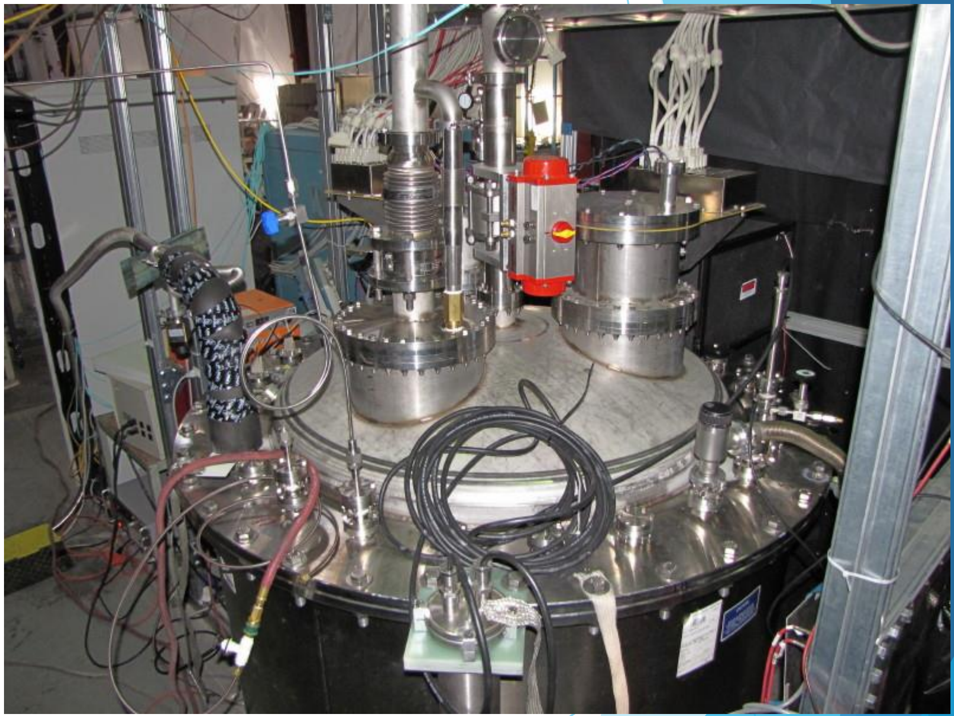


An ionization track from the laser calibration system in Mini-CAPTAIN. The data were collected on August 3, 2015 and were created with a high-intensity UV laser pulse traversing the TPC. The detector was running with one collection plane and one induction plane. The color represents ADC value.

More laser and cosmic-ray data is under analysis.

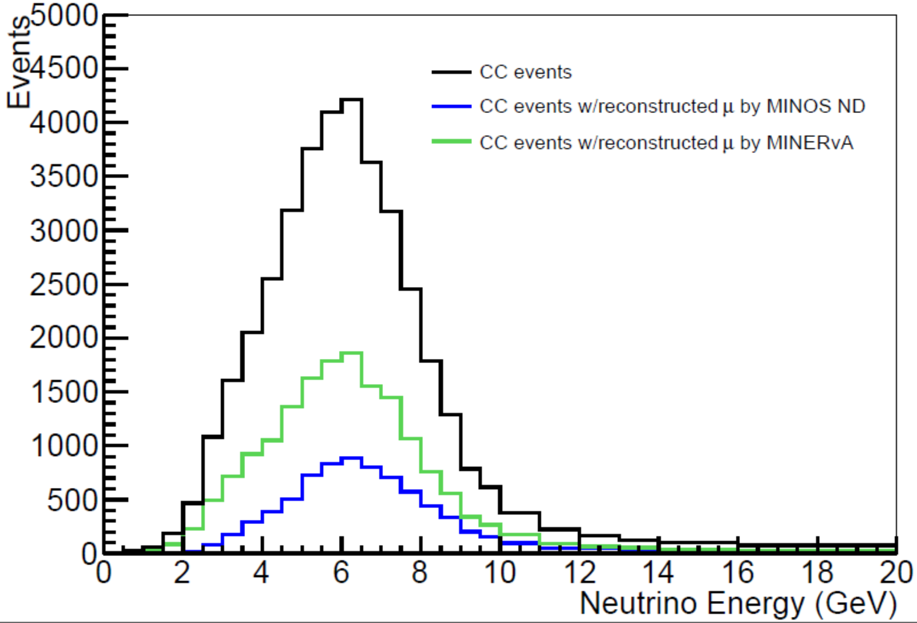
Mini-CAPTAIN Status

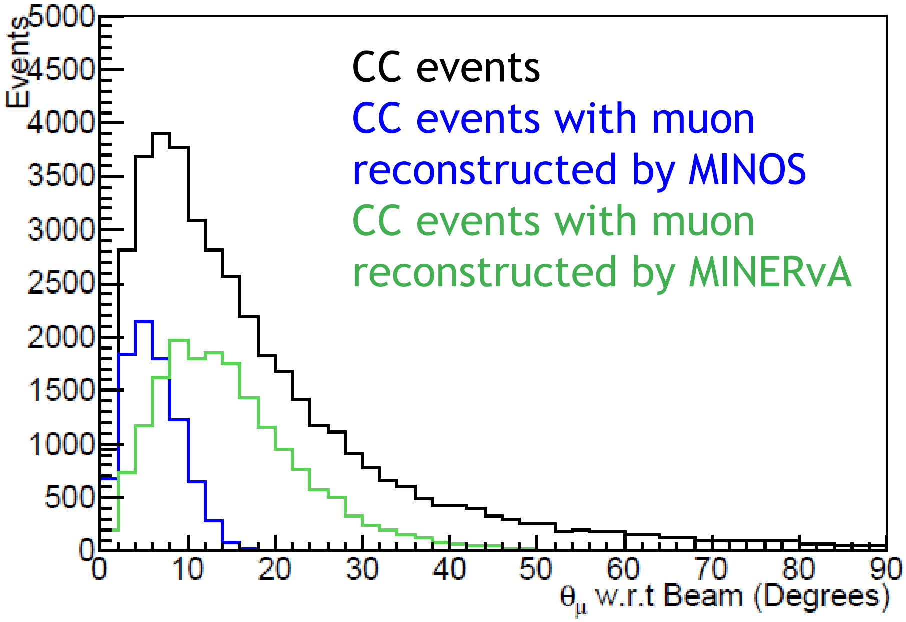
Fall 2014 LAr run



TPC being pulled out after liquid nitrogen run

Charged-Current Interactions

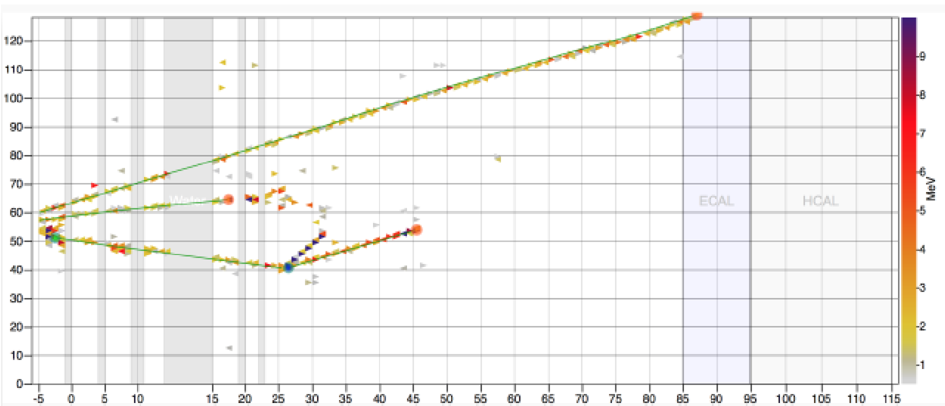


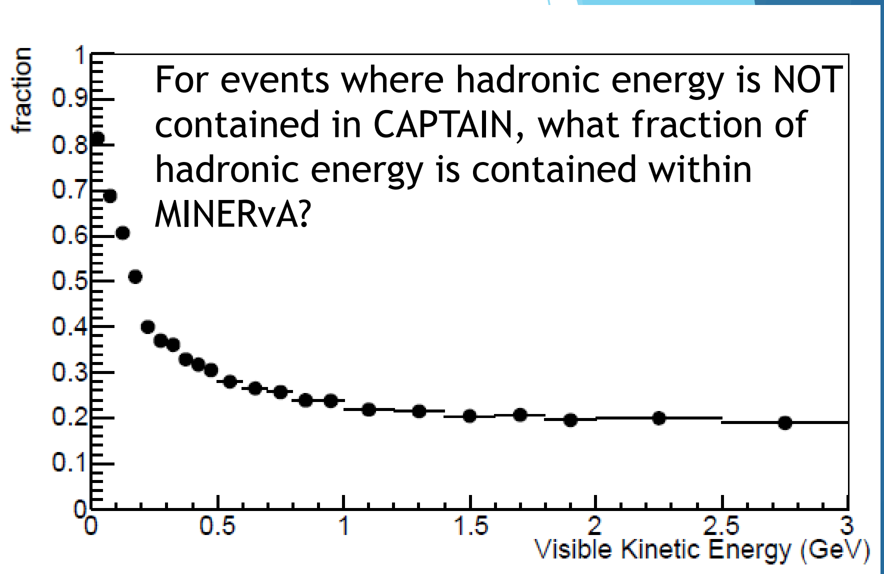


- Muon reconstruction by MINOS or MINERvA
  - Consider solid angle, minimum number of plans to form a track, etc
  - 64% of CC events will have muon reconstructed by MINOS or MINERvA (23% MINOS + 41% MINERvA)
- For remaining CC interactions, CAPTAIN will have some ability to tag muons that miss MINERvA or MINOS by looking for MIP-like tracks

Energy Containment

A neutrino interaction on LAr upstream of the MINERvA detector; the hadronic system is fully contained within MINERvA.





~10-15% of CC interactions will have the hadronic energy contained in CAPTAIN and have a muon reconstructed by MINOS or MINERvA.

MINERvA will be used as a hadronic calorimeter for events where final state particles exit CAPTAIN.

Summary

- CAPTAIN-MINERvA will be part of Fermilab's intermediate neutrino program, making measurements highly relevant for DUNE
- Unique capabilities for measuring neutrino-argon cross sections and testing nuclear models
- We are seeking new collaborators!

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Centro Brasileiro de Pesquisas Físicas
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Fermilab
L. Bagby, M. Betancourt, L. Fields, D.A. Harris, J. Kilmer, M. Kiveni, J.G. Morfin, J. Osta, G.N. Perdue, L. Rakotondravohitra, E.L. Snider, J.T. Sobczyk

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Lawrence Berkeley National Laboratory
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Los Alamos National Laboratory
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College of William and Mary
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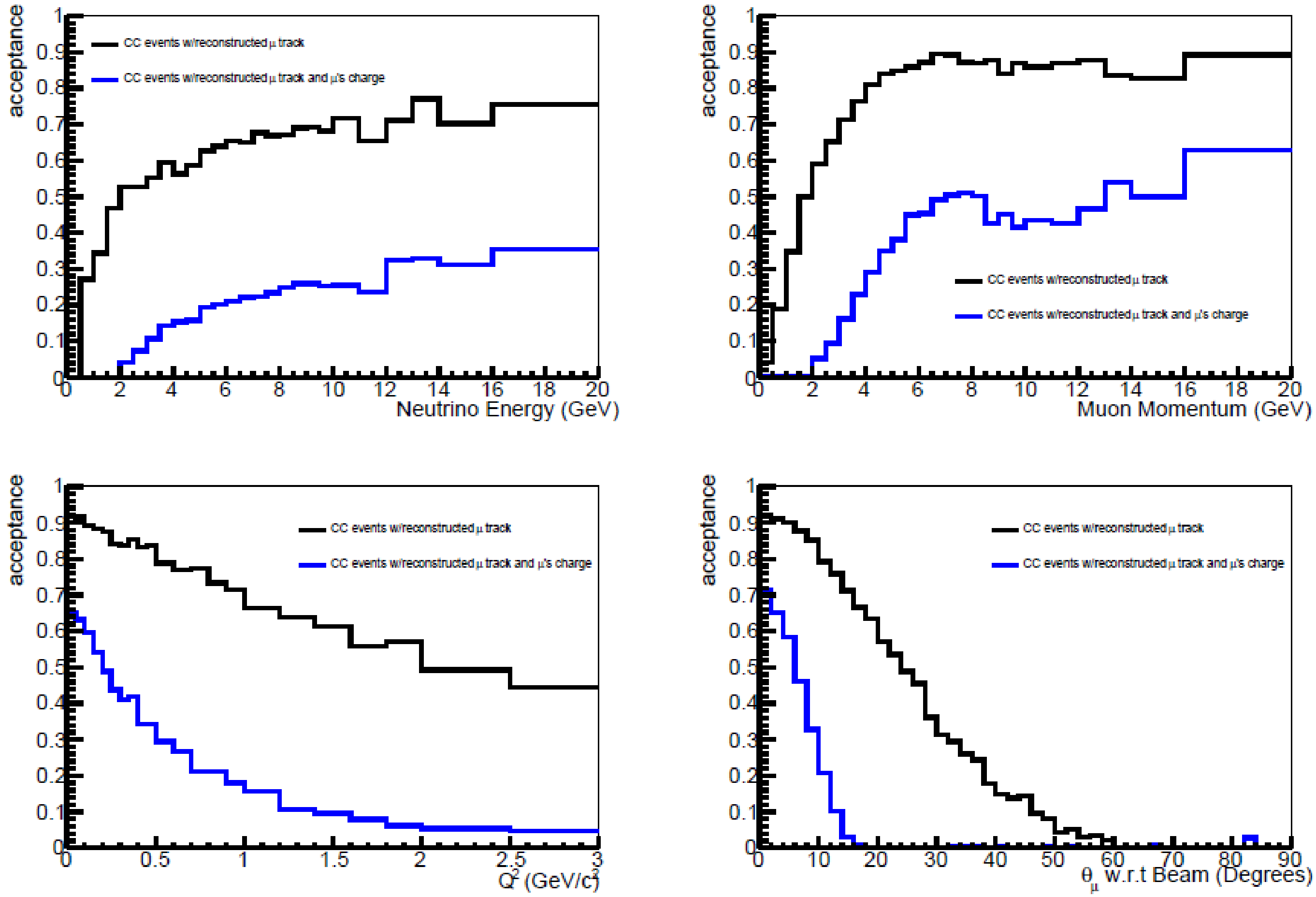
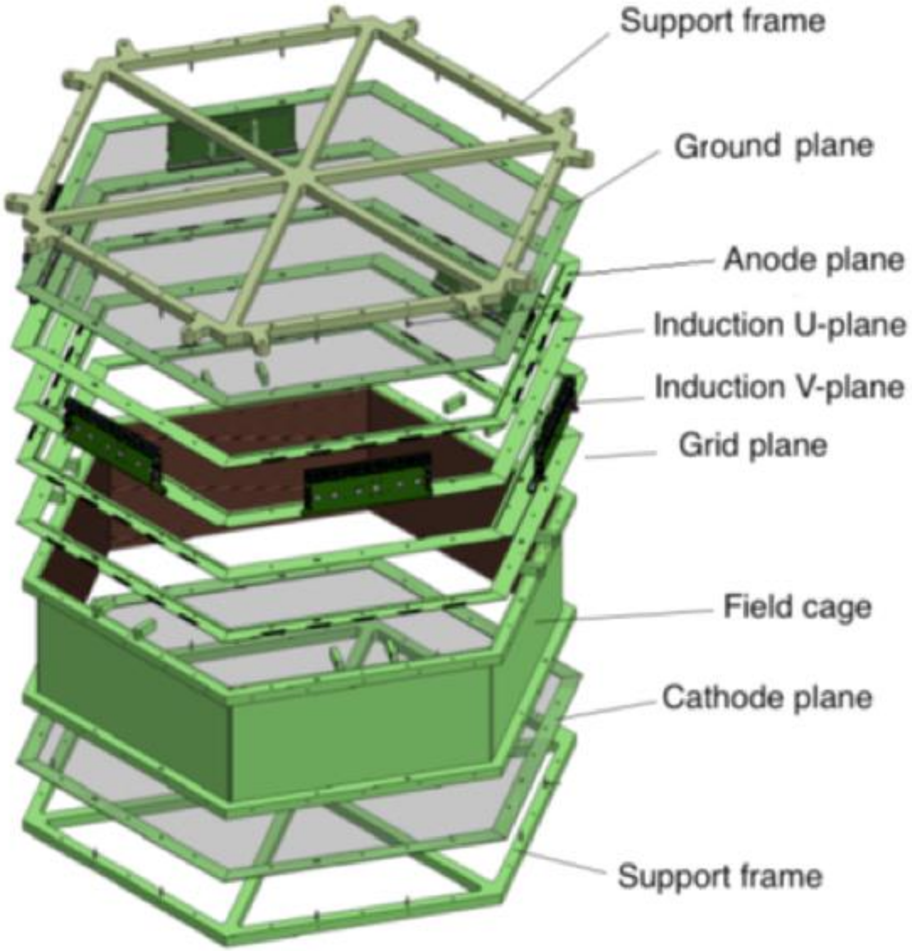
Backup

Muon Acceptance



CC events with muon reconstructed (MINOS or MINERvA)
CC events with muon reconstructed by MINOS

CAPTAIN TPC

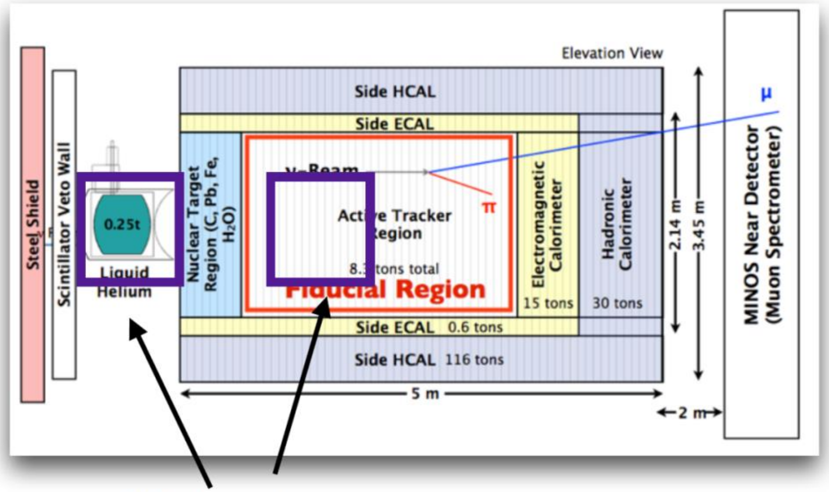

Support frame
Ground plane
Anode plane
Induction U-plane
Induction V-plane
Grid plane
Field cage
Cathode plane
Support frame

Pulling out extra MINERvA modules

- In order to remove MINERvA's helium target and install CAPTAIN, we estimate 1.5 months of downtime when MINERvA cannot take data.
- In order to remove enough modules to remove the nuclear target region and half the tracker region, it would take another 3 months.
- For a 1-year run or longer it makes sense to take the extra time, if MINERvA has already received its 12E20POT in antineutrino running

MINOS/MINERvA Hall

unscaled



Two posible locations

a) at the position of the He target
b) at the module 30 (removing half of the tracker)

Channel	ratio
CCQE-like	1.33
CC 1 π^+	1.51
CC 1 π^0	1.58