CAPTAIN-MINERvA: Neutrino-argon scattering in a medium-energy neutrino beam

Lisa Whitehead, for the CAPTAIN and MINERvA collaborations

January 16, 2015

Fermilab PAC Meeting

Introduction

- We are proposing to install the CAPTAIN detector in MINERvA to study neutrino-argon interactions in the medium-energy NuMI beam
- CAPTAIN would serve as the vertex detector, and outgoing particles could be tracked in MINERvA.
- The MINERvA detector can also be used to measure ratios of interactions on argon to other nuclei (CH)
- The MINOS ND would continue to be used as the downstream muon spectrometer.
- We will study cross-sections, particle ID and event reconstruction important for ELBNF
- Expands the physics reach of both experiments in a way that is complementary to existing LAr R&D

CAPTAIN-MINERvA Physics

- Neutrino experiments must reconstruct the incoming neutrino energy based only on final state particles
- Neutrino interaction data is needed to constrain the models of nuclear effects that are used in oscillation experiments 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.
- There is a lack of neutrino-argon data in the neutrino energy range relevant for the long-baseline program
- CAPTAIN-MINERvA Goals: Neutrino-argon cross sections, event reconstruction, and particle identification in the energy range relevant for ELBNF
  - NuMI's medium energy beam covers the 1st oscillation maximum for ELBNF at a baseline of 1300 km

CAPTAIN-MINERvA Physics

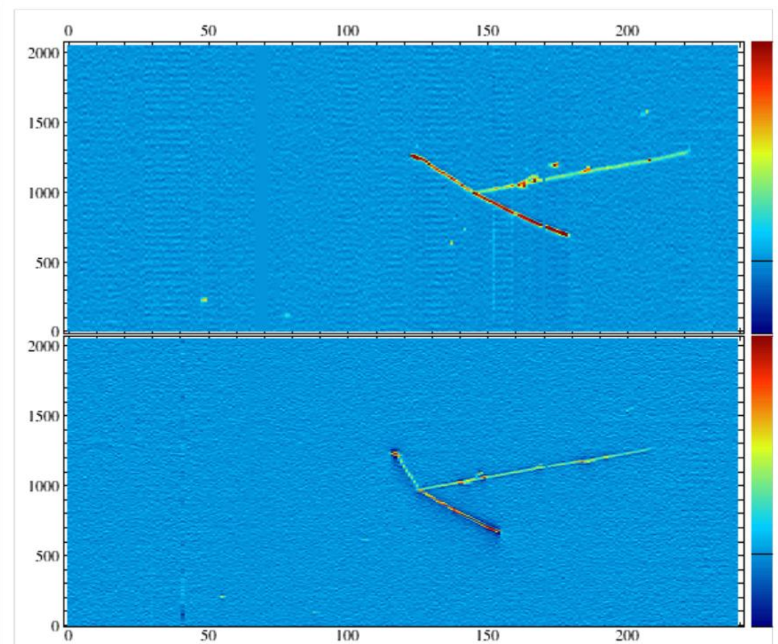
- Interaction models used in generators are constrained based on:
  - Charged lepton data for the vector contribution to neutrino interactions
  - Neutrino data for the axial contribution
  - Pion scattering data for final state interactions
- Neutrino-argon data can be used to test the extrapolations of the models which are mostly based on other nuclear targets
- Importantly for ELBNF, we want to minimize the need for extrapolations by having a large sample of neutrino-argon data to tune the models

How is this program unique?

- Only experiment making high-statistics measurements of neutrino interactions on argon in the medium energy range before ELBNF
- CAPTAIN-MINERvA can measure cross section ratios (i.e., argon to carbon)
  - Study how processes vary on different nuclei
    - Models used in neutrino event generators depend on data from a variety of nuclei
    - For ELBNF, if the near detector has different nuclear targets than the far detector, the near-far comparison will have to precisely account for this difference
  - More stringent tests of the models can be performed with ratios due to cancellation of large systematic uncertainties such as the neutrino flux

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 2^{nd} oscillation maximum at 1300 km; will be complementary to CAPTAIN-MINERvA's measurements at 1^{st} oscillation maximum
  - MicroBooNE interactions will mostly be quasi-elastic (~60%); CAPTAIN-MINERvA will have 87% pion production or DIS (unique ability to study events with large particle multiplicities)

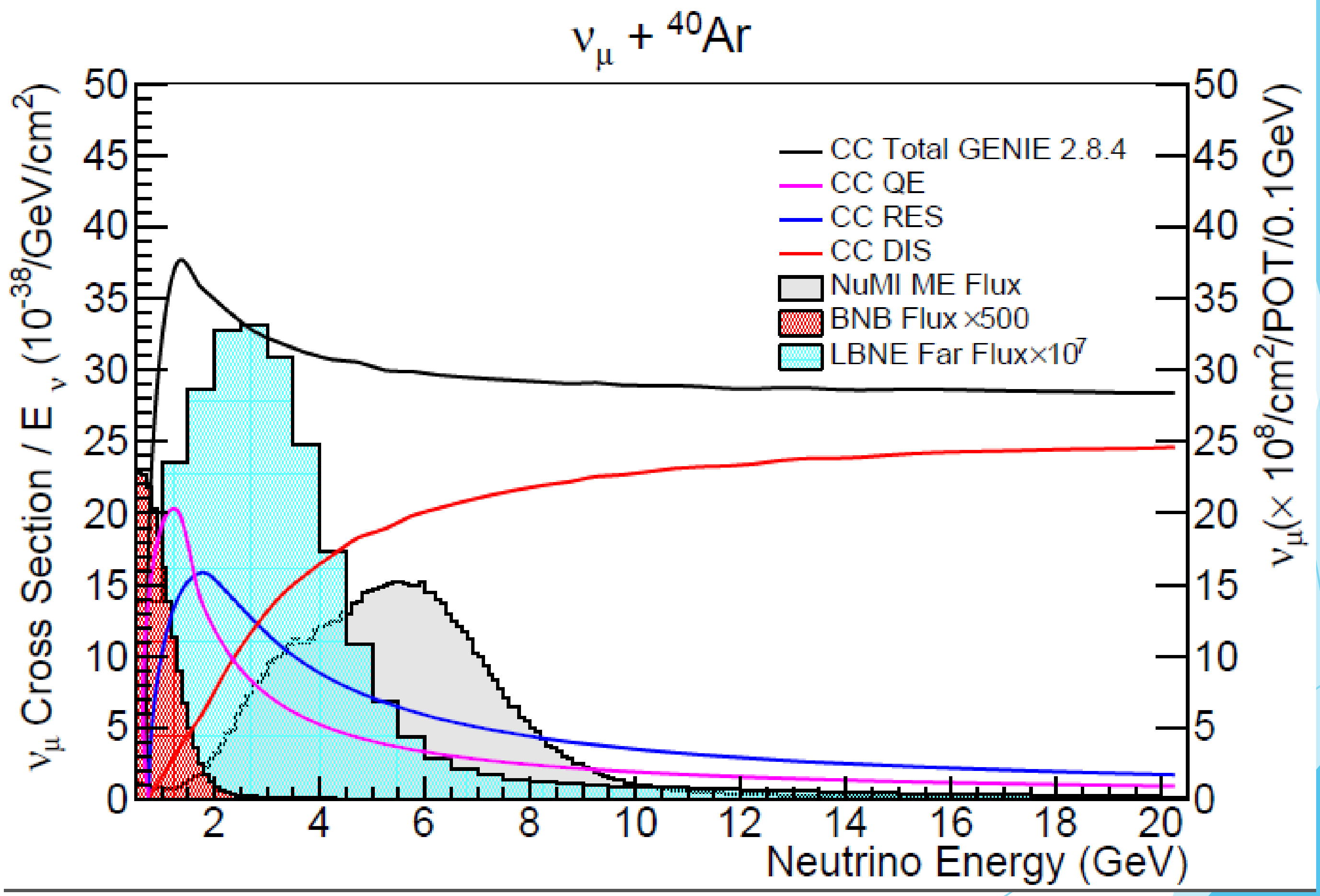


O. Palamara, NuInt 14

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

We expect similarly excellent resolution in CAPTAIN.

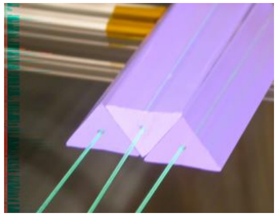
How is this program unique?

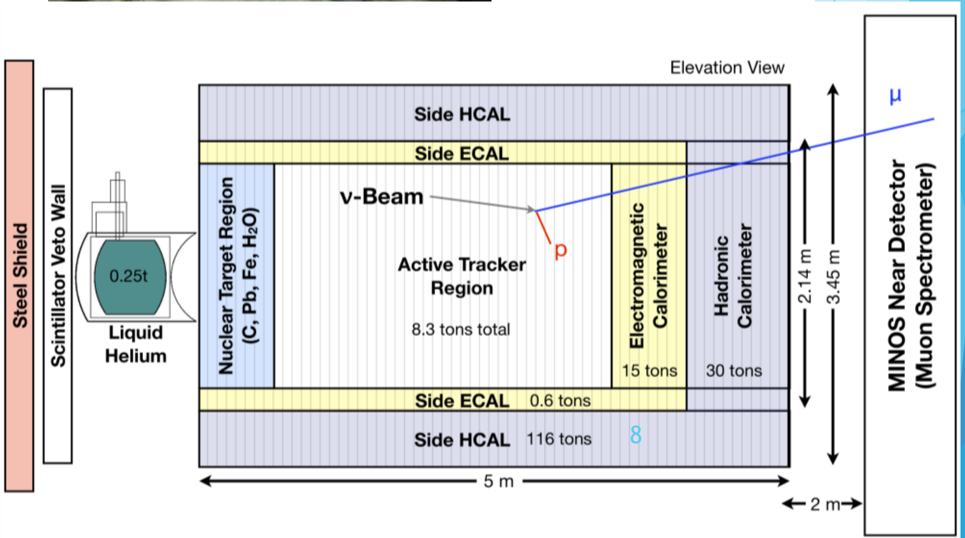


MINERvA's Detector

- 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

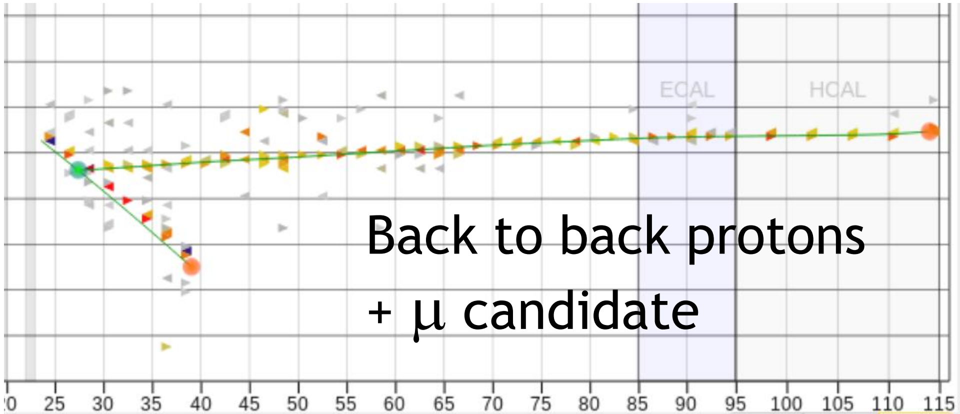
LHe cryotarget

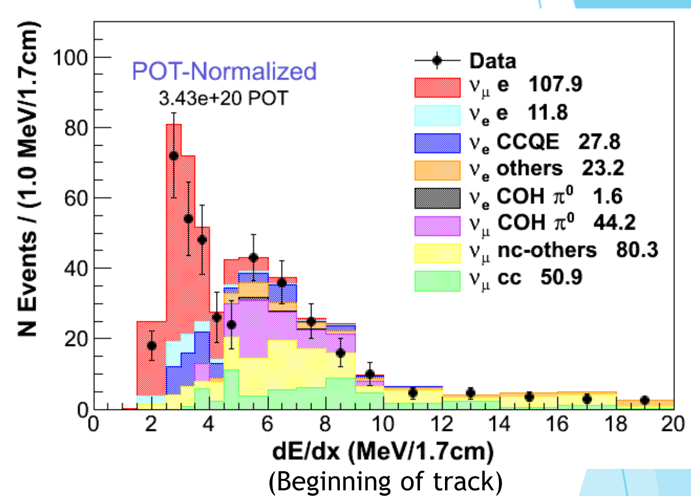


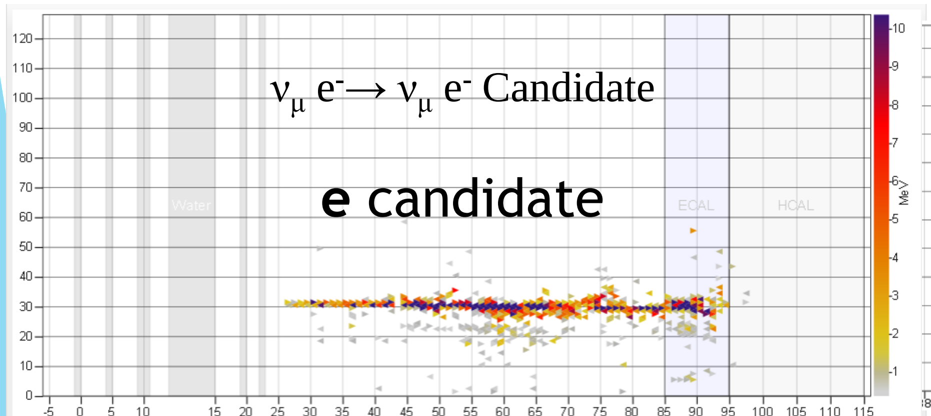


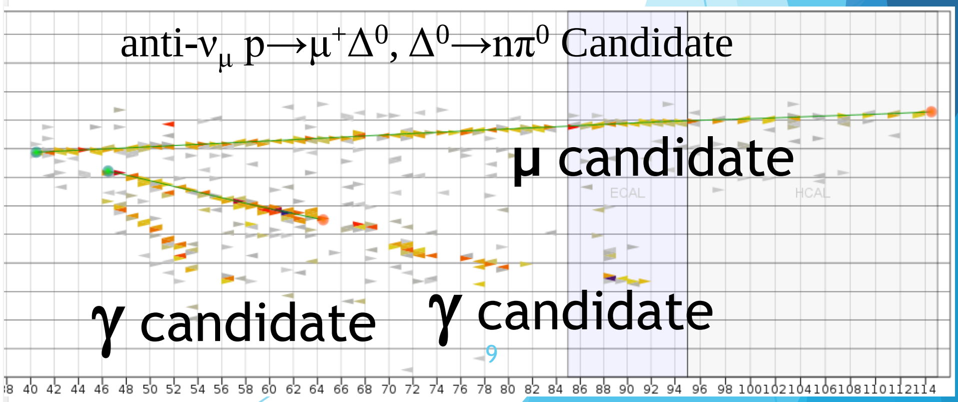
Events in MINERvA

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









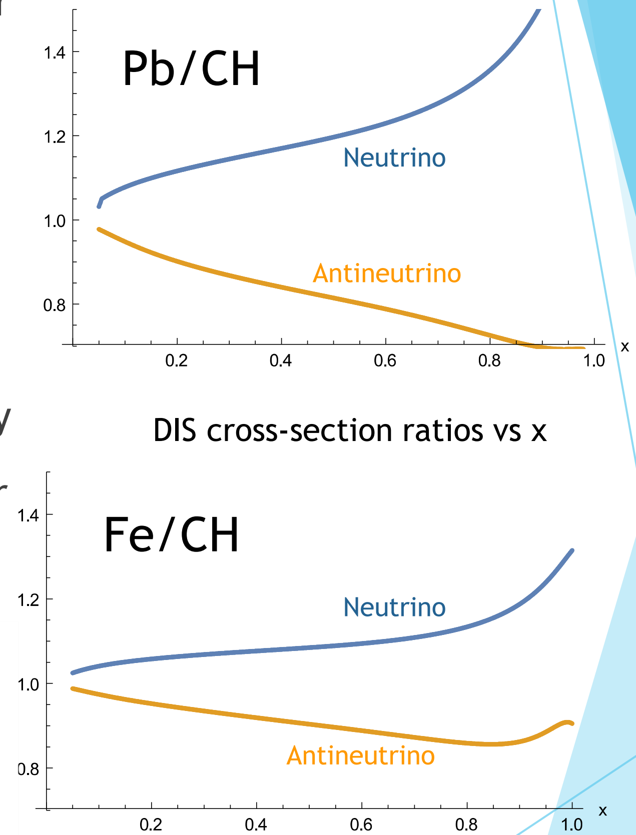
One out of three views shown, color = energy

MINERvA's Analyses in Medium Energy Dataset

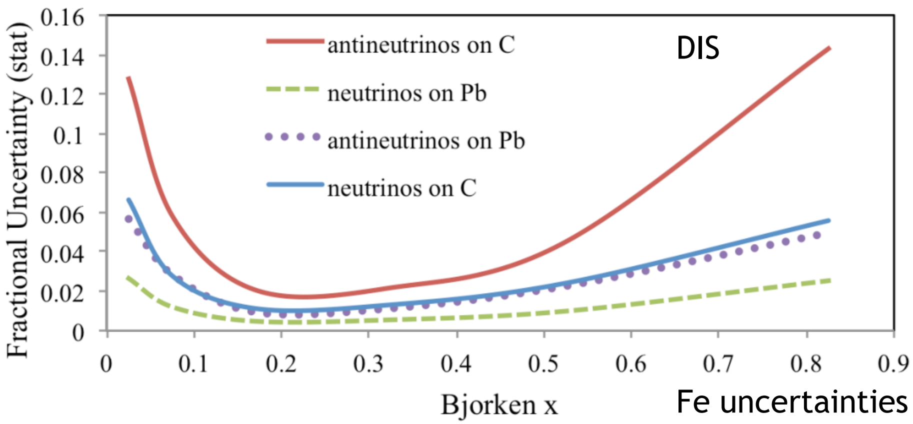
- Medium Energy beam provides
  - Much higher statistics per year (flux and cross section), so we get enough events in nuclear targets for thorough tests using many interaction channels
  - New average neutrino energy to test modeling of energy dependence
- MINERvA detector performance keeping up
  - Upgrade to DAQ to take more events per spill in progress
  - Have completed DAQ upgrade for shorter MI cycle time
- Collaboration is keeping its eye on Medium Energy dataset while finishing Low Energy

Flavor dependence of EMC effect

- EMC effect has been puzzling the community for a long time
- Studying both neutrino and antineutrino data can play a unique role in understanding this
- With 12E20POT in antineutrino mode, MINERvA can map out flavor dependence
- Need high statistics DIS sample and good reconstruction of scaling variable x
- MINERvA has already proven with the low energy data it can get to few percent systematic uncertainties in inclusive cross section ratios for neutrinos, Pb/C and Fe/C surprises at low and high x



DIS cross-section ratios vs x



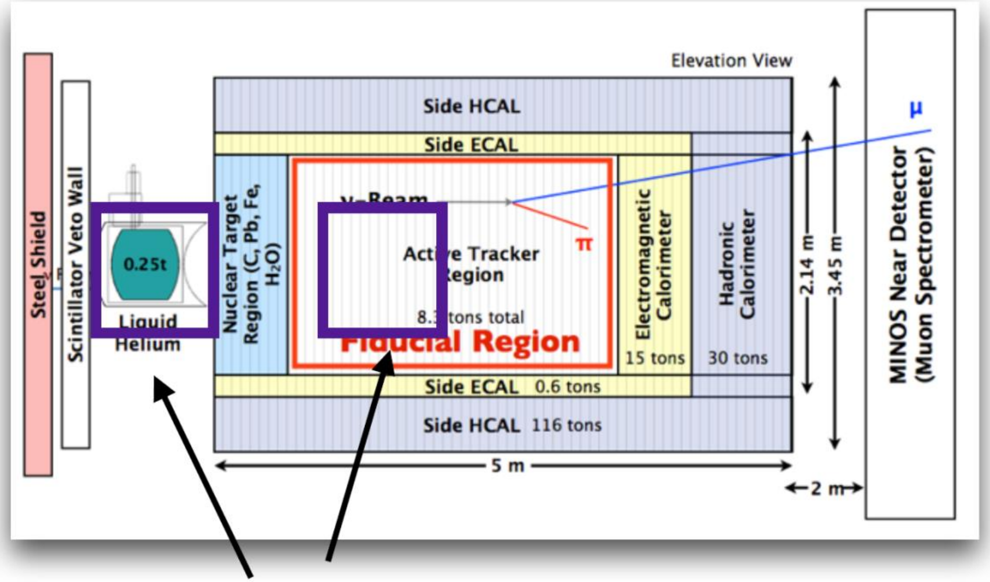
Fe uncertainties are similar to Pb

I. C. Cloet, W. Bentz and A. W. Thomas, Phys. Rev. Lett. 109, 182301 (2012) [arXiv:1202.6401 [nucl-th]].
I. C. Cloet, private communication

CAPTAIN-MINERvA

MINOS/MINERvA Hall

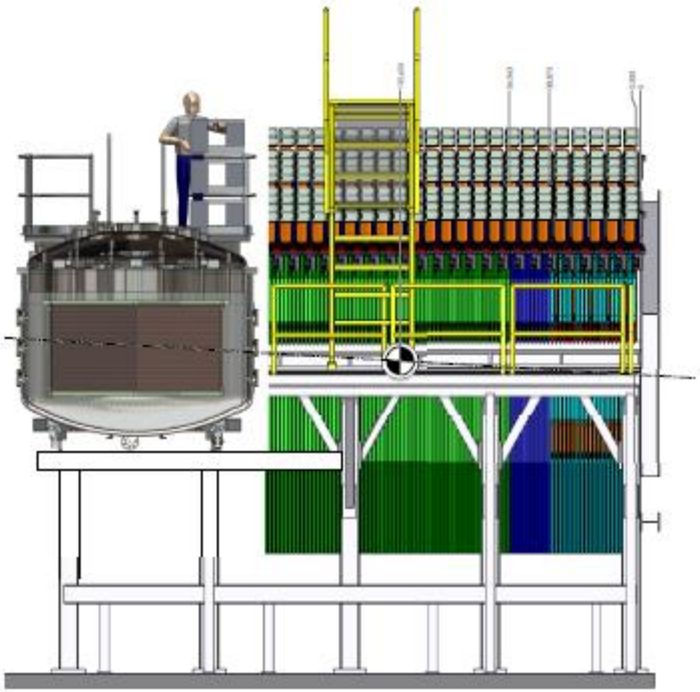
unscaled

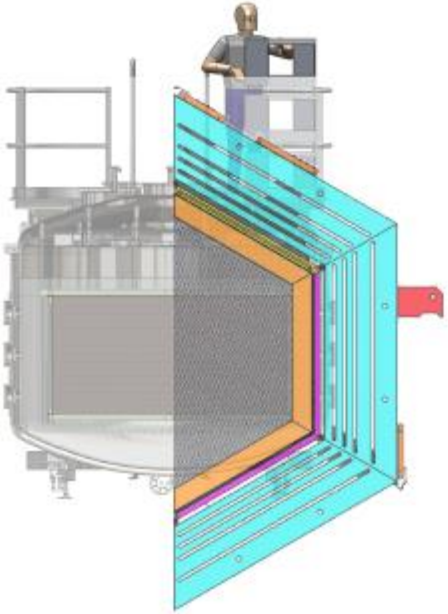


Two possible locations:

1) Replace the He target with CAPTAIN
2) Remove the nuclear targets and part of the tracker (this would only be considered after MINERvA has accumulated 12e20 POT in antineutrino mode)

CAPTAIN-MINERvA





Event rates

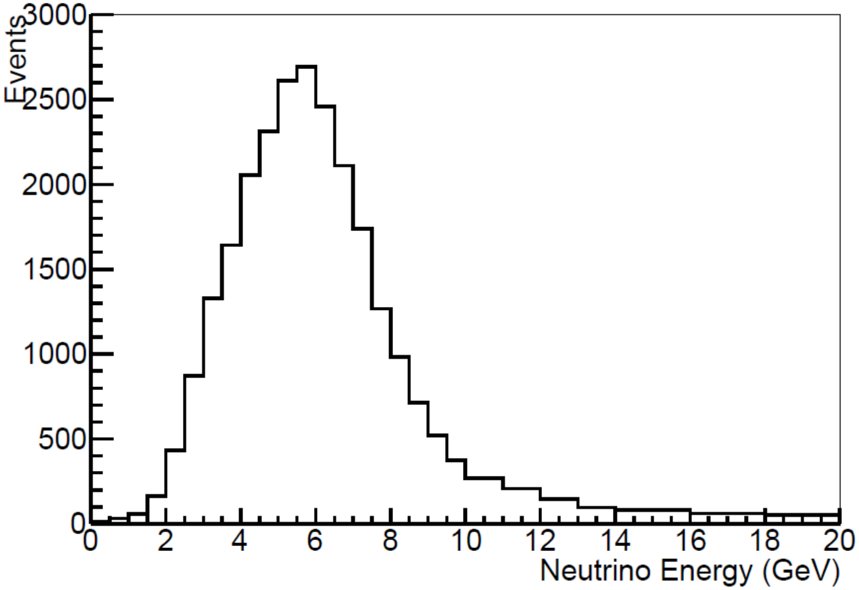
Contained events: events in which all outgoing particles except neutrons and leptons are contained within CAPTAIN; overall containment efficiency is 25%.

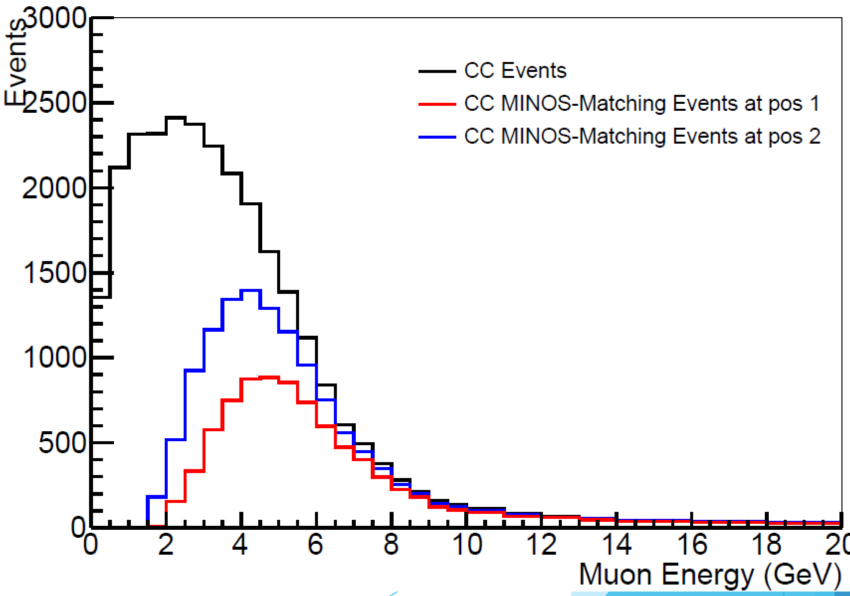
	Contained Events in CAPTAIN	Contained Events in CAPTAIN at pos 1 w/MINOS Match	Contained Events in CAPTAIN at pos 2 w/MINOS Match
CCQE-like	488,250	255,354	339,333
$CC1\pi^{\pm}$	191,250	59,478	88,930
$CC1\pi^{0}$	189,000	48,384	76,167

Table 1: Contained efficiency for CC events with a reconstructed muon using MINOS ND, assuming 6×10^{20} POT exposure.

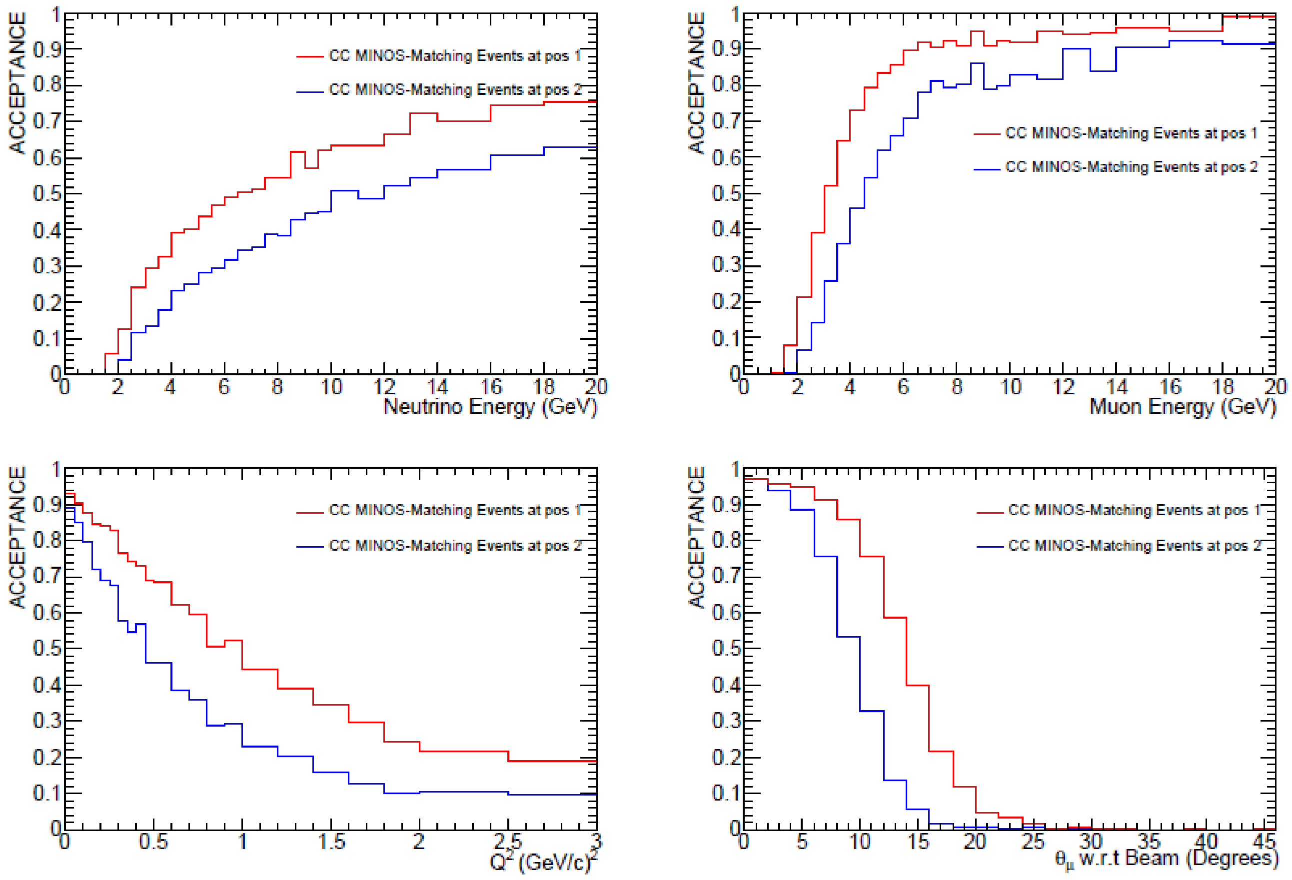
Both positions yield more than adequate statistics to meet our goals.

Muon Acceptance in MINOS ND





Muon Acceptance in MINOS ND



Technical Issues

- Oxygen Deficiency Hazards (ODH)
  - In the event of a catastrophic leak of liquid argon in the cavern, argon gas would quickly displace oxygen.
  - Risk could be mitigated with containment of spilled argon and appropriate ventilation, in addition to personal oxygen supplies for people working underground.
  - Addressing this issue requires some work, but we're confident there's a reasonable solution.
  - ODH concerns have already been addressed for MicroBooNE, and people are working on the issue for ELBNF.
- Remote operations for CAPTAIN detector
  - Cryogenic system and DAQ
  - MINERvA already has remote operations
  - Not practical to have shifters underground at all times
- Liquid argon and nitrogen supply lines from surface
  - Adequate space is available in the shaft for these lines

Collaboration Management

- This proposal falls within in the core mission of both collaborations, and we expect strong participation from both.
- Members of the current collaborations will join together to form a single new collaboration (CAPTAIN-MINERvA)
  - Data taken by the CAPTAIN, MINERvA, and MINOS detectors would be readily accessible to all members
  - Reconstruction software for all three detectors will also be shared
- It is too early to know specifically which members from the current collaborations will participate. For MINERvA members in particular, this will depend greatly on when the CAPTAIN-MINERvA run takes place (next slide).

Schedule

Important factors:

- Availability of the CAPTAIN detector – earliest date CAPTAIN could be moved to Fermilab is 2016
- Time for engineering effort, costing, and installation of new infrastructure
  - CAPTAIN-MINERvA: ODH assessment, ventilation system, plumbing, remote cryogenic controls
  - CAPTAIN-BNB: neutron measurements, construction of new building
- Availability of NuMI and BNB beams – we expect both to be available through at least 2021
- Availability of MINERvA detector and collaboration
  - MINERvA's default plan is to stop collecting data when they have 12e20 POT of antineutrino data. Depends on beamline performance and choice of NuMI running mode, but could be as early as 2018.
  - CAPTAIN-MINERvA data collection should begin by 2018 at the latest to ensure there will be enough participation from MINERvA collaborators for the project to be feasible.

Schedule

- Scenario A
  - CAPTAIN-BNB takes data 2016-2018; CAPTAIN-MINERvA begins taking data in 2018 (CAPTAIN at the downstream position in the tracker)
  - Benefits: Results from CAPTAIN-BNB could influence the design of the photon detection system for the ELBNF far detector (crucial for supernova detection)
  - Potential Risks: Any delays might push the CAPTAIN-MINERvA start date until after MINERvA has stopped taking data, making CAPTAIN-MINERvA less likely to happen.
- Scenario B
  - CAPTAIN-MINERvA takes data 2016-2018 (CAPTAIN at the upstream position in place of He target); CAPTAIN-BNB begins taking data in 2018
  - Benefits: More collaborators from MINERvA would be able to participate; less likely for a delay to push the start date until after MINERvA stops taking data.
  - Potential Risks: CAPTAIN-BNB results might be too late to be of use in ELBNF photon detection system design

Schedule

- Dates could change depending on a number of factors:
  - Details of or changes in the beam schedules
  - A change in MINERvA's expected end date
  - Delay in CAPTAIN's move to Fermilab
  - Delay in new infrastructure for CAPTAIN-BNB and/or CAPTAIN-MINERvA
- Choice of preferred schedule depends on physics priorities, technical considerations, and availability of people.
- Due to the complexities of the issues, we have not yet chosen our preferred schedule. Discussions are ongoing.
- Either scenario requires planning for the new infrastructure requirements for both proposals to begin now.

Summary

- The CAPTAIN and MINERvA collaborations share a core goal: to study neutrino interactions important for the future long-baseline program
- CAPTAIN-MINERvA is a joint proposal from both collaborations to study neutrino-argon interactions in the medium-energy NuMI beam
- Unique and complementary to existing LAr R&D
- The necessary preparations for the MINOS ND hall would need to begin soon to be ready for data-taking in 2016 at the earliest

CAPTAIN Collaboration

University of Alabama
S. Fernandes, I. Stancu

Argonne National Laboratory
Z. Djurcic

Brookhaven National Laboratory
H. Chen, V. Radeka, C. Thorn

University of California, Davis
H. Berns, K. Bilton, D. Danielson, S. Gardiner, C. Grant, E. Pantic, R. Svoboda, N. Walsh

University of California, Irvine
C. Pitcher, M. Smy

University of California, LA
D. Cline, K. Hickerson, K. Lee, E. Martin, J. Shin, A. Teymourian, H. Wang, L. Winslow

Fermi National Accelerator Laboratory
O. Prokofiev, J. Yoo

University of Hawaii
J. Maricic, M. Rosen, Y. Sun,

University of Houston
B. Bhandari, A. Higuera, L. Whitehead

Indiana University
S. Mufson

Lawrence Berkeley National Laboratory
V. Gehman, R. Kadel, C. Tull

Los Alamos National Laboratory
J. Danielson, S. Elliot, G. Garvey, E. Guardincerri, T. Haines, W. Ketchum, D. Lee, Q. Liu, W. Louis, C. Mauger, G. Mills, J. Mirabal-Martinez, J. Ramsey, K. Rielage, C. Sinnis, W. Sondheim, C. Sterbenz, C. Taylor, R. Van de Water, A. Yarritu

Louisiana State University
F. Blaszczky, T. Kutter, W. Metcalf, M. Tzanov, J. Yoo

University of Minnesota
M. Marshak

University of New Mexico
F. Giuliani, M. Gold

South Dakota State University
R. McTaggart

University of South Dakota
C. Zhang

Stony Brook University
C. McGrew, C. Yanagisawa

MINERvA Collaboration

Centro Brasileiro de Pesquisas Físicas
M. Carneiro, H. Da Motta, H. Yepes Ramirez

College of William and Mary
L. Aliaga Soplin, J. Devan, C. Karamitsos, M. Kordosky, J. Nelson, A. Norrick, D. Zhang

Fermilab
M. Betancourt, D. Harris, M. Kiveni, J. Morfin, J. Osta, E. Paschos, G. Perdue, L. Rakotondravohitra, E. Snider, J. Sobczyk

Hampton University
E. Christy

Inst. Nucl. Reas. Moscow
A.V. Butkevich, S. Kulagin

Mass. Col. Lib Arts
E. Maher

Northwestern University
L. Fields, C. Patrick, H. Schellman

Otterbein University
N. Tagg

Pontificia Universidad Catolica del Peru
E. Endress, A. Gago

Rutgers University
T. Le, R. Ransome

Tufts University
O. Altinok, H. Gallagher, T. Mann

Universidad de Guanajuato
V. Castillo-Vallejo, J. Felix, E. Valencia, G. Zavala-Guzman

Universidad Nacional de Ingenieria
G. Salazar, C. Solano Salinas, A. Zegarra

Universidad Tecnica Federico Santa Maria
W. Brooks, R. Galindo, J. Miller

University of Chicago
D. Schmitz

University of Florida
J. Mousseau, H. Ray, D. Rimal, M. Wospakrik

University of Geneva
A. Bravar, Y. Karadzhov

University of Minnesota at Duluth
R. Gran

University of Pittsburgh
S. Dytman, C. McGivern, D. Naples, V. Paolone

University of Rochester
L. Ren, A. Bercellie, A. Bodek, H. Budd, G. Diaz, R. Fine, T. Golan, J. Kleykamp, S. Manly, C. Marshall, K. McFarland, A. McGowan, A. Mislivec, P. Rodrigues, D. Ruterbories, J. Wolcott

Backup

MINERvA and MINOS over time

- Light yield of scintillator + fiber decreases over time
- MINERvA and MINOS monitor & simulate this using muons from upstream interactions in the rock
- MINOS: currently at 2% loss per year, MINERvA at 4% loss
- Both detectors still at many photoelectrons per MIP going through scintillator, position resolution expected to deteriorate by 30% or less over next 15 years