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

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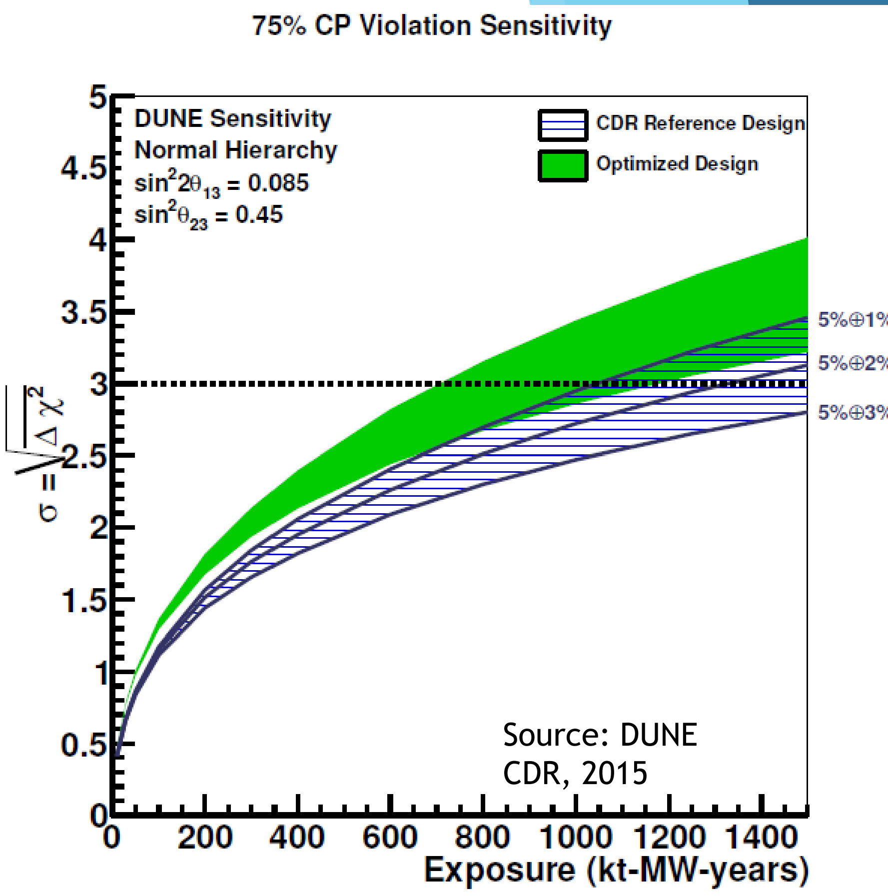
Fermilab PAC Meeting

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 proposal 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

CAPTAIN-MINERvA Proposal

- 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 Near Detector would continue to be used as the downstream muon spectrometer.
- We will study cross-sections, particle ID and event reconstruction important for DUNE
- 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 are 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.
  - 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 the long-baseline program

CAPTAIN-MINERvA Physics

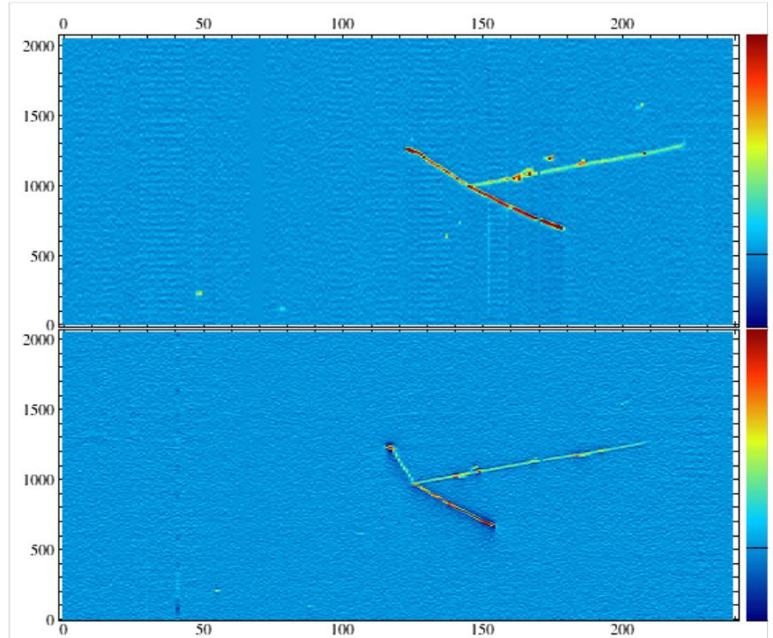
- Interaction models used in generators are constrained by:
  - Charged lepton data for the vector contribution to neutrino interactions
  - Neutrino data for the axial contribution and multi-nucleon initial states
  - Pion scattering data for final state interactions
- Neutrino-argon data can be used to test the extrapolations of the models which are mostly based on other nuclear targets
- Importantly for DUNE, we want to minimize the need for extrapolations by having a large sample of neutrino-argon data to tune the models
  - Can provide constraints that are independent from DUNE’s near detector measurements (and in a different flux)

How is this program unique?

- Only experiment making high-statistics measurements of neutrino interactions on argon in the medium energy range before DUNE
- 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)
  - 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 far detector compared to the near detector → different energy-dependent nuclear effects in the two detectors
- CAPTAIN-MINERvA could serve as a model for the DUNE near detector system
  - DUNE near detector reference design is a fine-grained tracker; a possible enhancement being considered is the addition of an upstream LAr TPC

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

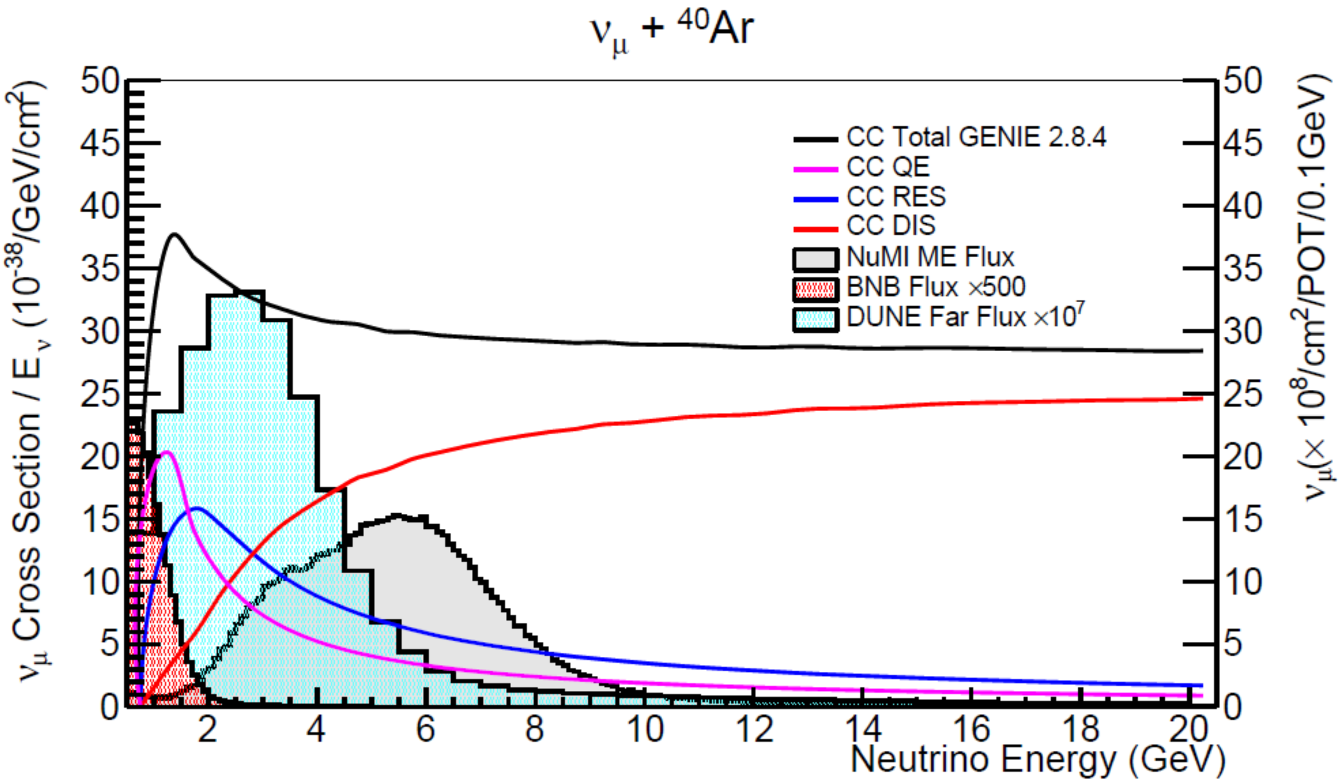


O. Palamara, NuInt 14

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

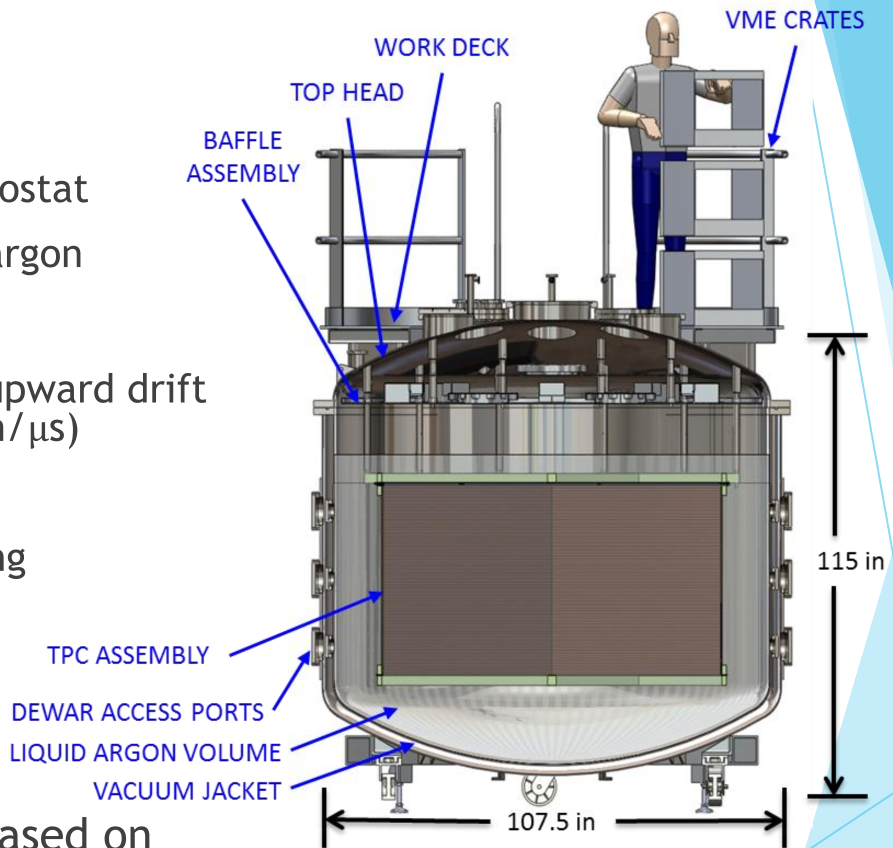
We expect similarly excellent resolution in CAPTAIN.

How is this program unique?



CAPTAIN

- Liquid argon TPC detector:
  - Portable and evacuable cryostat
  - 5-ton 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
- MicroBooNE cold electronics
- Purification system design based on MicroBooNE and LAPD
- Mini-CAPTAIN: a smaller prototype detector



Mini-CAPTAIN Status

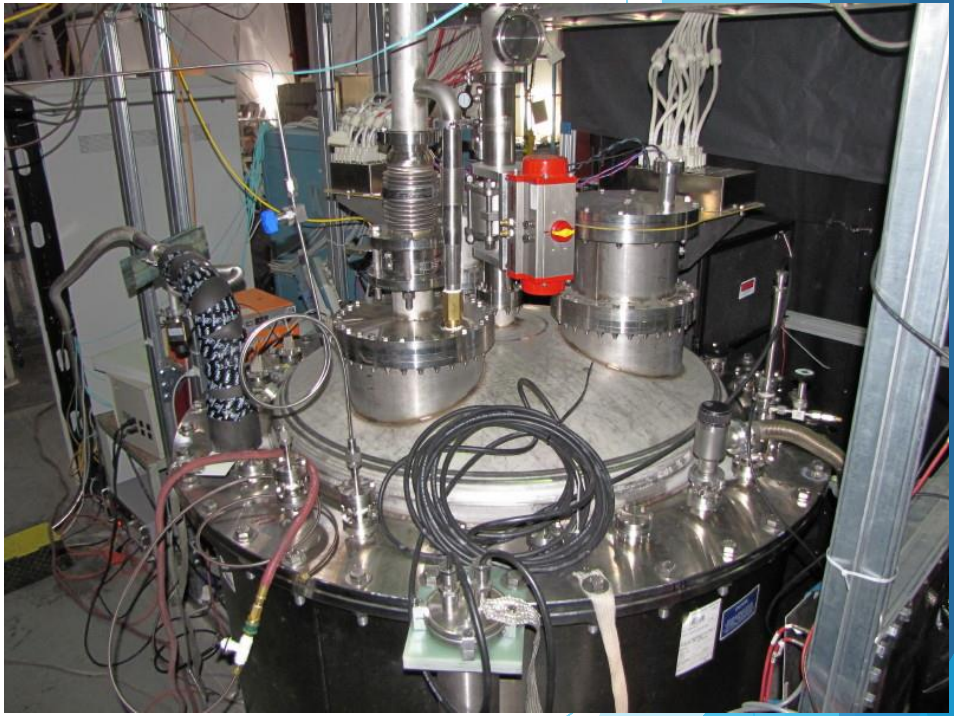
- 30 cm upward drift, 1 m width, 400 kg instrumented liquid argon
- Liquid nitrogen fill in Summer 2014: test electronics and TPC, test heat load
- 1^{st} LAr engineering run in Fall 2014: development of filling procedure, test cryogenic and purification system, DAQ development, laser system testing
- 2^{nd} LAr engineering run in March 2015: further development of above items plus installation of recirculation system, integration with muon system
- 3^{rd} LAr engineering run began last week: more development of electronics and recirculation system
  - Focus on purity
- A Mini-CAPTAIN neutron run is anticipated during the next beam cycle at LANL
  - One week run between Oct 2015 and Jan 2016

Liquid nitrogen run

Mini-CAPTAIN Status

TPC being pulled out after
liquid nitrogen run

Fall 2014 LAr run



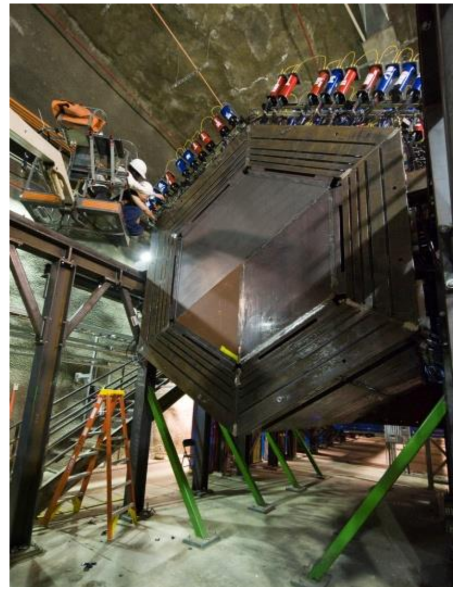
CAPTAIN Status

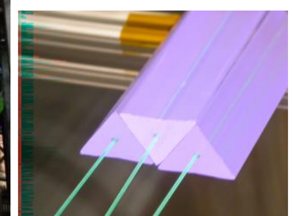
- Cryostat, electronics, field cage in hand
- Purification system at vendor (expect delivery ~Fall 2015)
- Planned TPC wiring at UC Irvine
- Earliest date that CAPTAIN could be moved to Fermilab would be Fall 2016

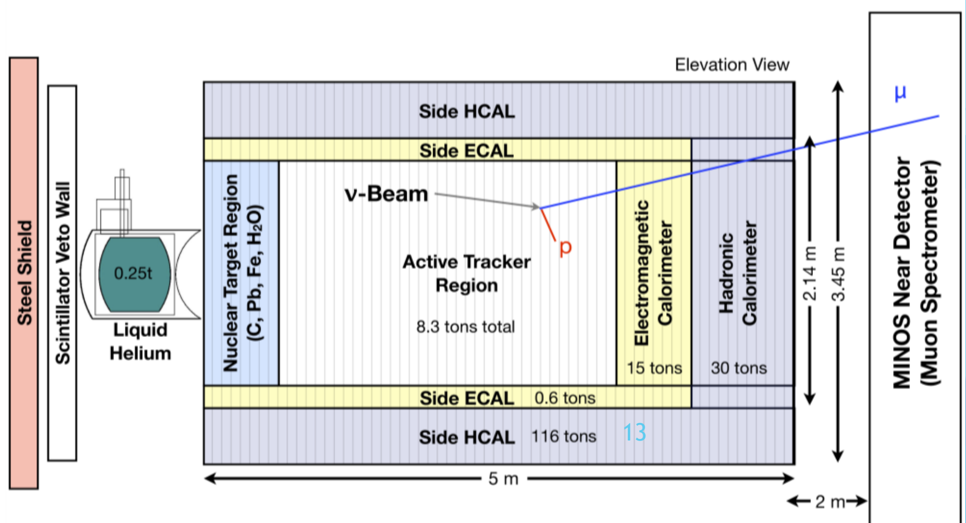
MINERvA's Detector

LHe cryotarget

- 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

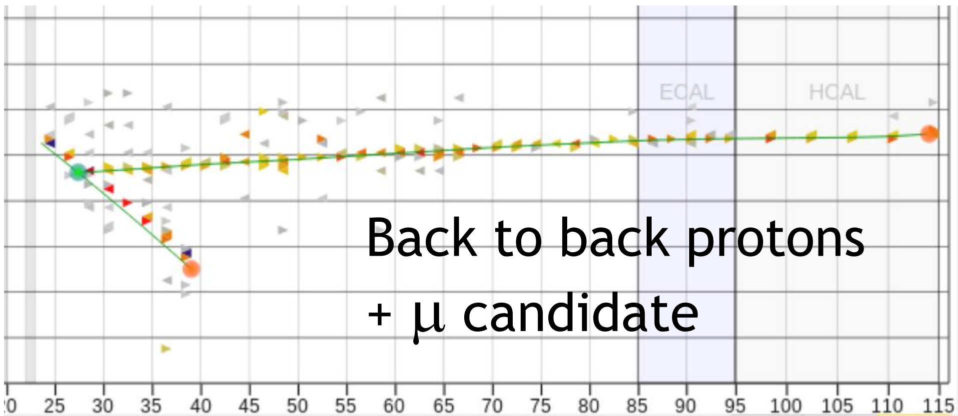


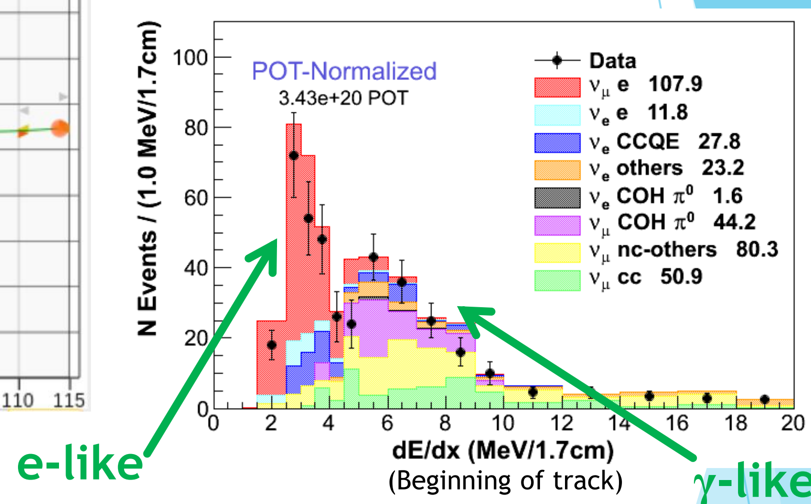


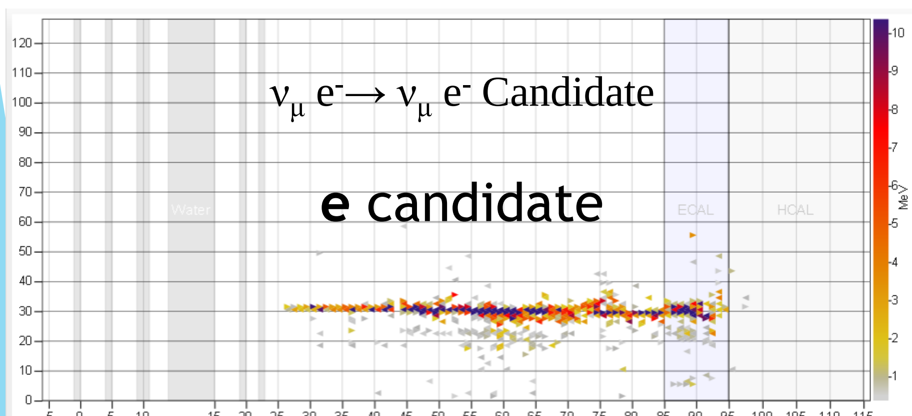


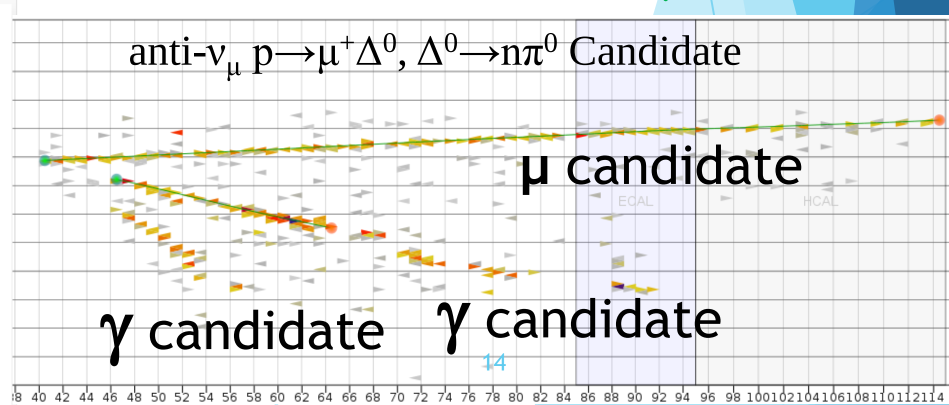
Events in MINERvA

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



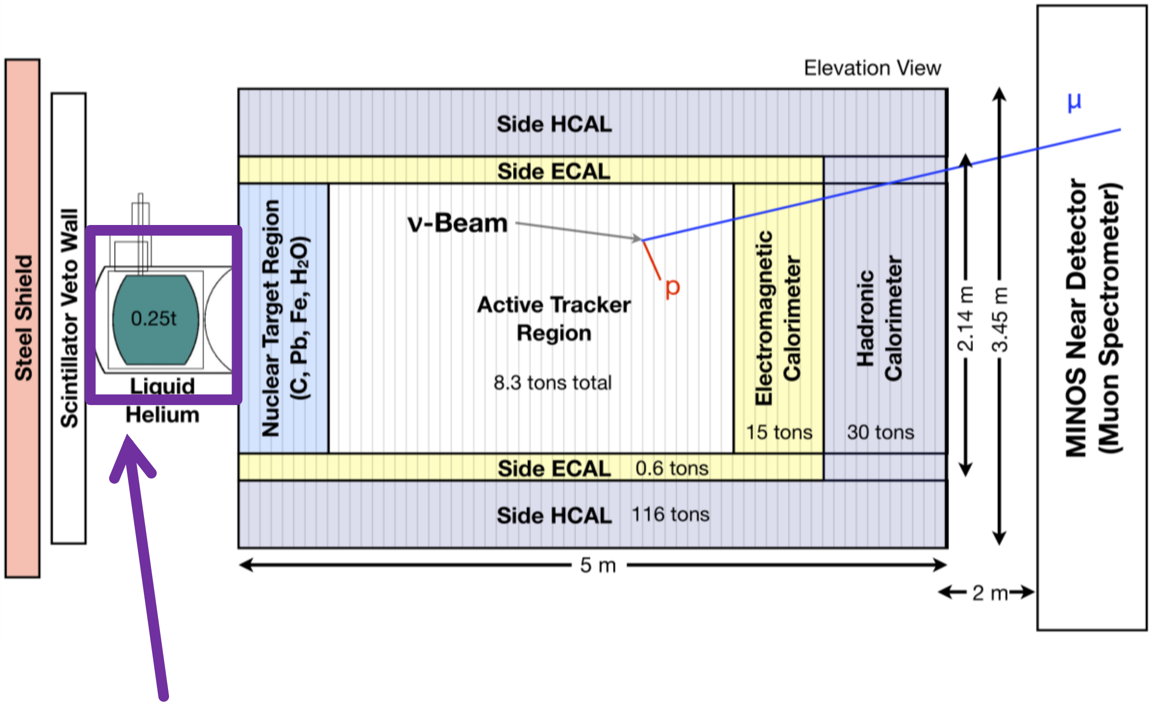






One out of three views shown, color = energy

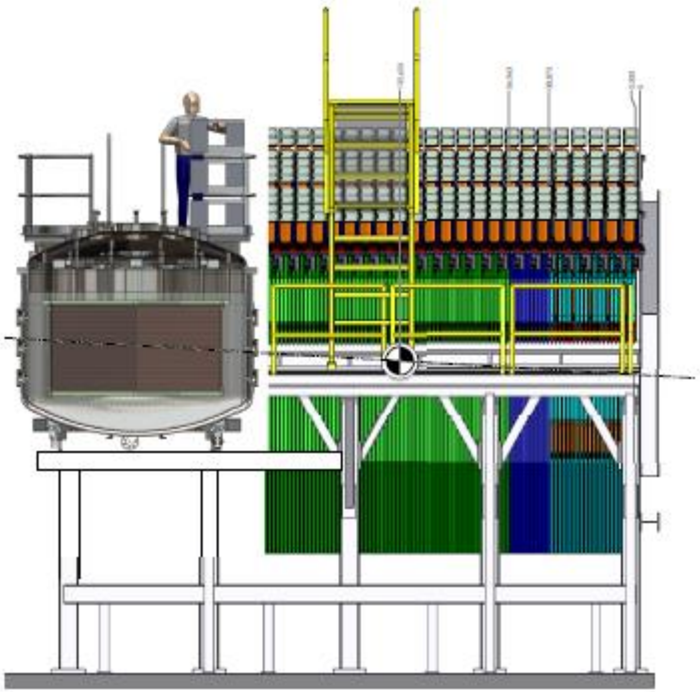
CAPTAIN-MINERvA

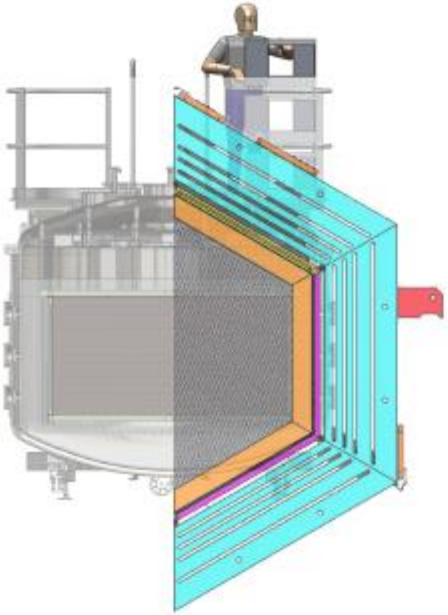


Studies presented here assume we will replace MINERvA's He target with CAPTAIN

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

CAPTAIN-MINERvA

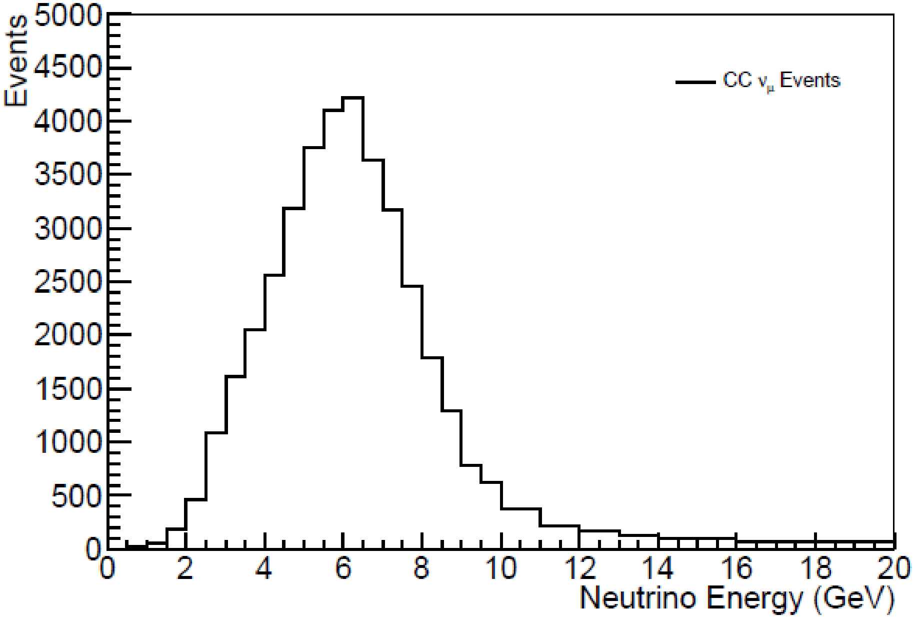


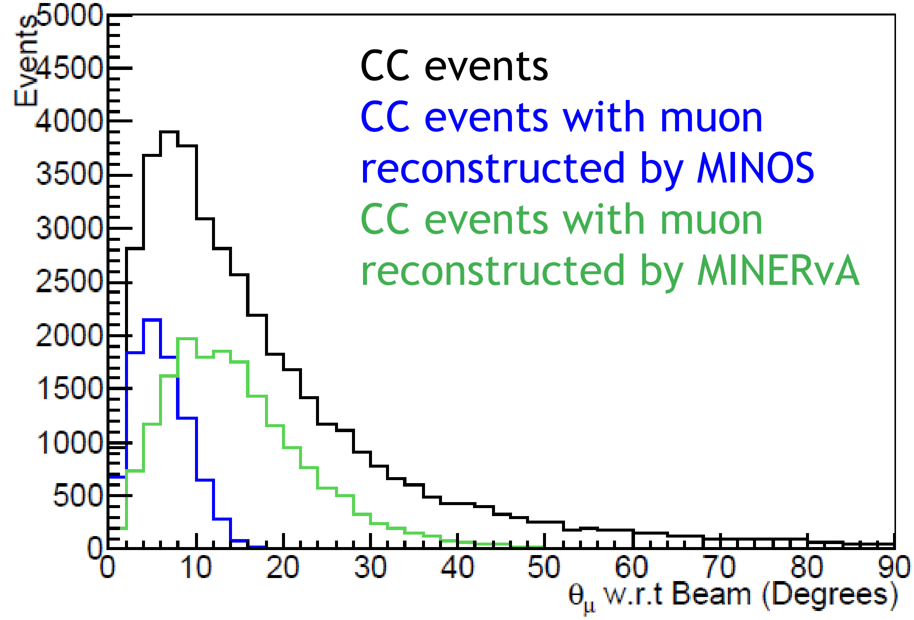


Simulation Study

- Neutrino interactions on LAr generated within the CAPTAIN TPC upstream of the MINERvA detector (He target location)
- MINERvA detector is simulated with a tuned GEANT4-based program
- 12.5M charged-current (CC) interactions within the TPC for an exposure of 6×10^{20} POT
- For muons that reach the MINOS ND, the track and charge sign can be reconstructed
- For muons that pass through MINERvA (but not MINOS), MINERvA can provide a reconstructed track (but not the charge sign)

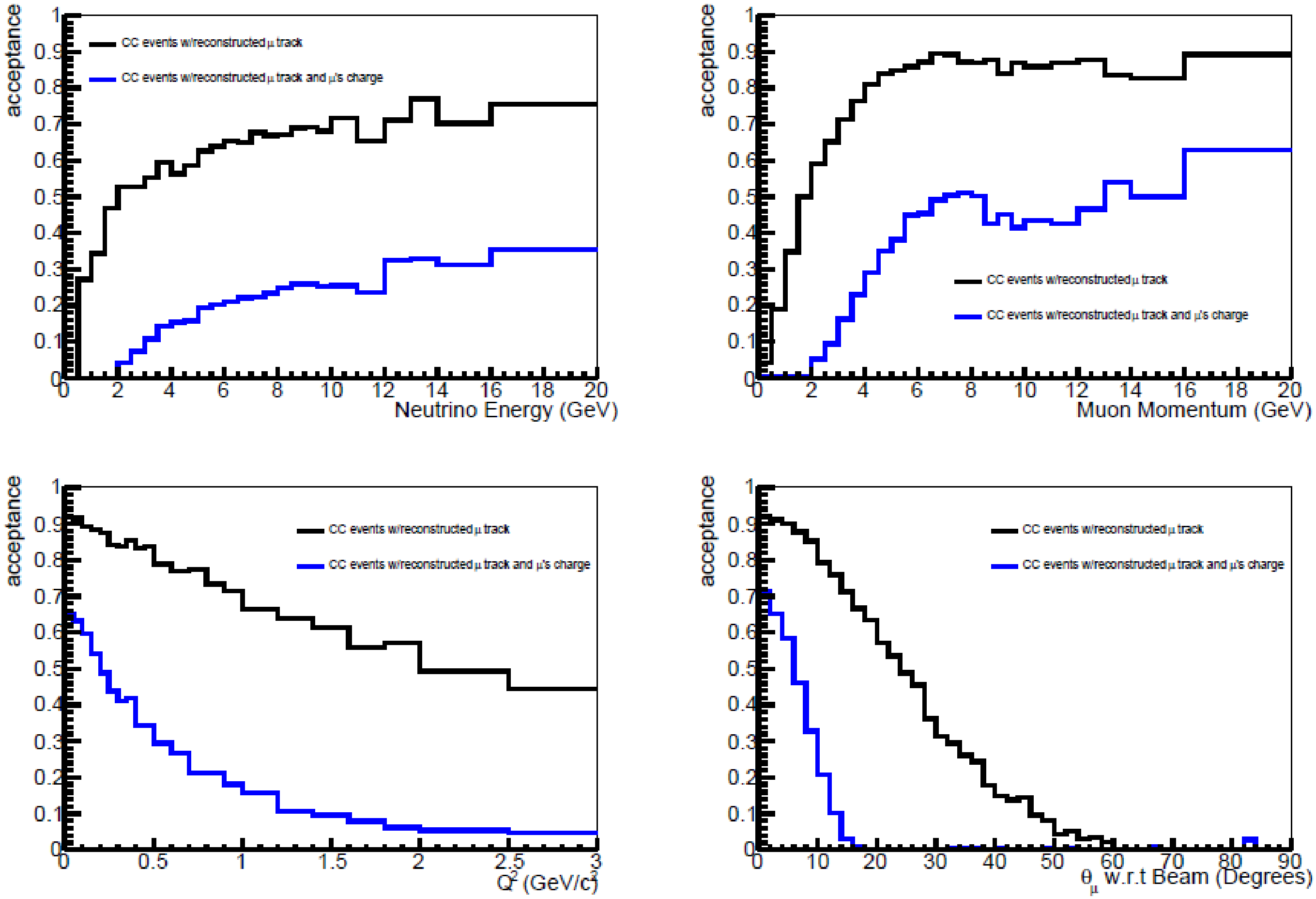
Charged-Current Interactions





- 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

Muon Acceptance



CC events with muon reconstructed (MINOS or MINERvA)

CC events with muon reconstructed by MINOS

Event rates

6x10^{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

These statistics are adequate for the physics goals; the downstream position would yield higher statistics.

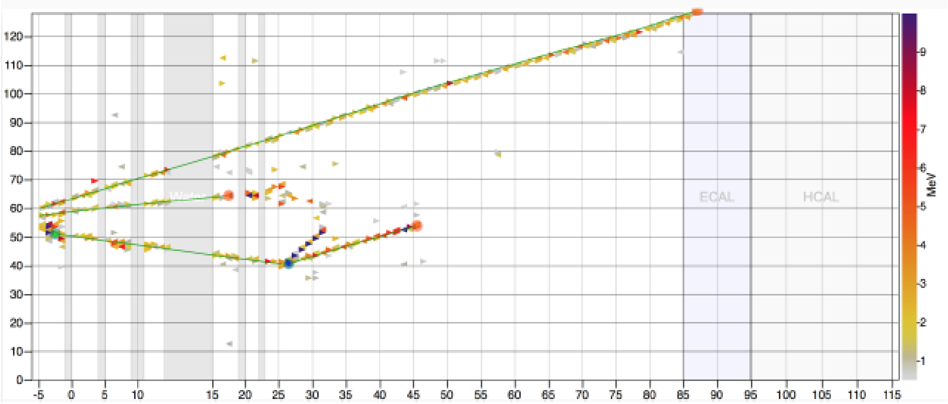
Results presented here show only neutrino mode; we hope to run for 2 years and acquire 6x10^{20} POT in neutrino mode plus 6x10^{20} POT in antineutrino mode.

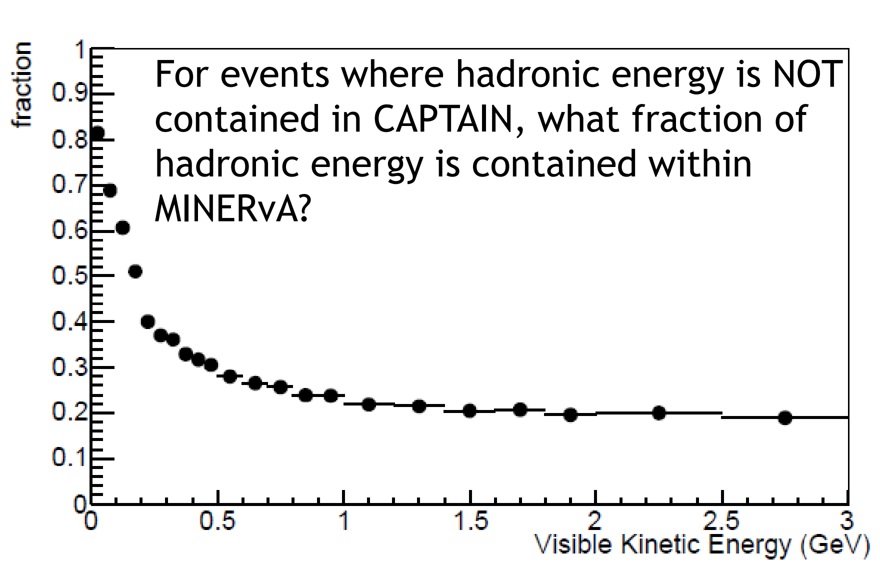
Energy reconstruction

- Depends on containment of hadronic energy and reconstruction of the outgoing muon
  - Hadronic energy containment criteria does not include neutrons
- For CC interactions, around 20% will have the hadronic energy contained within the TPC
- This means 10-15% of CC interactions will have all the hadronic energy contained AND have a muon reconstructed by MINOS or MINERvA
  - Muon reconstruction efficiency (64%) * Containment efficiency for CC events (20%)
  - This subset of events will have the best reconstructed energy resolution

Energy Containment

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





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

Installation and Operation

- Installation
  - MINOS shaft and crane are adequate for lowering the CAPTAIN vessel into the hall
- Oxygen Deficiency Hazards (ODH)
  - In the event of a catastrophic leak of liquid argon in the cavern, argon gas would quickly displace oxygen.
  - Risk will be mitigated with containment of spilled argon and appropriate ventilation, in addition to personal oxygen supplies for people working underground.
- Remote operations for CAPTAIN detector
  - Cryogenic system and DAQ
  - MINERvA already has remote operations
  - Not practical to have shifters underground at all times

Computing: Data Storage and Processing

	CAPTAIN	Simulation	Total
Beam triggers per year	1.2×10^7	3.6×10^7	4.8×10^7
Size per beam trigger	8.4 MB	14.2 MB	22.6 MB
Size per year	272 TB	512 TB	784 TB

	CAPTAIN	Simulation	Total
Processing per trigger	3.4 s	3.75 s	N/A
Processing per year	472 cpu-days	1563 cpu-days	2035 cpu-days
Reprocessing per year	3	3	N/A
Total processing per year	1415 cpu-days	4689 cpu-days	6104 cpu-days

Reconstruction only – not considering CPU time for analysis.

We expect MINERvA to have similar storage and processing needs as they do now.

FY16 estimates: 1.2×10^6 cpu-days; ~2 PB

MINERvA estimates include reconstruction processing and analysis.

Computing: Offline

- Software framework
  - CAPTAIN: software framework based on the T2K ND280 software
  - MINERvA: Gaudi software framework
- CAPTAIN-MINERvA joint reconstruction will be based on separately reconstructed objects in each detector
  - Joint reconstruction within the same software framework is not a requirement for the physics we want to do
  - Reconstruction will be similar to the way MINERvA/MINOS, T2K (beamline, ND280, SK, external inputs) operate
- Results from the CAPTAIN-MINERvA program are intended to benefit DUNE or other LAr experiments
  - With or without LArSoft, algorithms/knowledge will be shared

Computing: Offline

- CAPTAIN-MINERvA could serve as a model for a DUNE near detector system, and DUNE will use LArSoft within the art software framework
- Long-term goal of CAPTAIN-MINERvA: Demonstrate joint reconstruction within an art-based framework (including LArSoft for CAPTAIN)
  - Would require migration to a new framework for both CAPTAIN and MINERvA
  - For MINERvA this would require at least 6 months of full time effort from a physics applications developer and effort from the collaboration
- Framework migration offers other benefits to MINERvA
  - Gaudi not supported by Fermilab Computing Division, and long-term support for Gaudi by the collaboration is time consuming

Computing: Online

- DAQ software
  - CAPTAIN: based on artdaq; similar (but not identical) to the DAQ software used by MicroBooNE (Note: artdaq is supported by Fermilab Computing)
  - MINERvA: based on a JLAB program called ET (Event Transfer)
- If MINERvA changes offline frameworks, it could make sense to also switch to artdaq
  - CAPTAIN and MINERvA detector monitoring systems could be integrated

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 have agreed to 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
- Author list (see last slide) represents the current members of both collaborations who expect to contribute to CAPTAIN-MINERvA
  - 128 collaborators (61 from CAPTAIN + 67 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

Resource Requirements

- All estimates assume that CAPTAIN would be installed in place of the MINERvA He target
- Everything else would stay as currently configured in the hall
- We assume CAPTAIN will be cooled by cryocoolers (rather than by running a heat exchanger with liquid nitrogen) while operating at Fermilab; two 600 W units will be adequate
- Labor and time estimates based on MicroBooNE or MINERvA as appropriate
- Thanks to Jim Kilmer for most of this work
  - Jim's had significant project roles in other Fermilab experiments, including MINERvA project mechanical engineer and Level 2 Manager for cryogenics in MicroBooNE

Cost of Materials

Item	Cost (FY15 k$)
Cryocoolers	184
Liquid argon	18
Controls hardware	27
Indium seals	12
Cryostat hardware	45
Temporary clean room	13
PPE/Clean room gear	7
Cabling	10
Vacuum insulated piping and valves	50
Shipping	25
Total Base	391
Contingency	120
Total	511

Labor: Engineering and Drafting

Task	Duration (Days)
Develop Piping and Instrumentation Diagram	5
Design vent stack	10
Complete Oxygen Deficiency Hazard calculations	30
Design heat exchangers for 600 W refrigerators	5
Design manifold box for refrigerators	15
Size piping	3
Layout equipment in cavern	3
Pressure vessel notes for CAPTAIN	20
Produce Engineering note for CAPTAIN support frame	5
Produce Engineering note for TPC installation frame	5
Assemble Instrument and valve list	3
Develop Operating procedures	3
Produce Piping engineering notes	20
Size relief valves	5
Total	132
Add 40% Contingency	184

Engineering Tasks

Task	Duration (Days)
Draw Piping and Instrumentation Diagram	10
Draw Vent line	20
Draw support frame	5
Draw TPC installation frame	5
Draw layout of equipment in cavern	20
Draw up refrigerator box	20
Solid model of piping and physical arrangement	60
Piping fabrication drawings	60
Total	200
Add 40% contingency	280

Drafting Tasks

Labor: Tasks requiring a mechanical technician

Ventilation

Removing He target

Move in cryostat and assemble CAPTAIN

Position CAPTAIN

Task	Duration (Days)	Technicians Needed	Technician Days
Clean cavern prior to start	1	4	4
Install new 6" vent pipe	20	3	60
Remove roof, section supports, camera, alarms, VESDA	1	4	4
Remove Veto Walls	4	4	16
Empty Helium target	10	4	40
Remove helium target vacuum pumps, water cooling, refrigerator	2	4	8
remove target piping top platform	2	4	8
Remove helium target stand and target	3	4	12
Prefab support frame for captain	10	2	20
Assemble support frame in cavern	2	4	8
Bring down CAPTAIN	1	4	4
Position and assemble new cryo system	120	2	240
Prefabrication and installation of TPC maintenance frame	15	2	30
Install detectors in captain	3	4	12
Reposition vessel on stand	1	4	4
Re-install Veto walls	4	5	20
Total Mechanical Technician work			490
Add 40% contingency			686

Labor: Other tasks

Task	Duration (Days)
Weld support frame	10
Weld TPC frame	10
Weld vent line	20
Weld cryogenic piping	40
Total welding	80

Welding Tasks

Controls Labor Needed	Person-days
Electrical Engineer	54
Electrical Technician	79
PC Administrator	13
Drafter	15.5
Calibration	9
Electrician	9

Labor for controls system

Labor: Electrical Safety Review Labor

Step	Electrical Engineer	Electrical Technician	Mechanical Technician
SEDR	10 days	12 days	4 days
pORC at test location	12 days	12 days	4 days
pORC at Experiment	5 days	12 days	4 days
Final ORC walk-through	2 days	-	-
Total	29 days	36 days	12 days

SEDR = Safety Engineering Design Review
ORC = Operational Readiness Clearance
pORC = partial ORC

Technically-Driven Schedule

- A rough plan has been put together
  - Shows ~15 months are needed for the experiment to be ready to take data
    - If the CAPTAIN detector arrived onsite as early as Fall 2016, engineering would need to begin in Summer 2015 in order for the infrastructure to be ready
- Details on next two slides
- Plan assumes the following labor in units of person-weeks:

Resource	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5
Mechanical Technician	20	16	5	30	24
Electrical Technician	0	0	0	15	3
Mechanical Engineer	22	11	0	0	0
Controls Engineer	12	0	0	0	0
Mechanical Drafter	7	8	14	12	0
Electrical Drafter	3	0	0	0	0

Example of a Technically-Driven Schedule

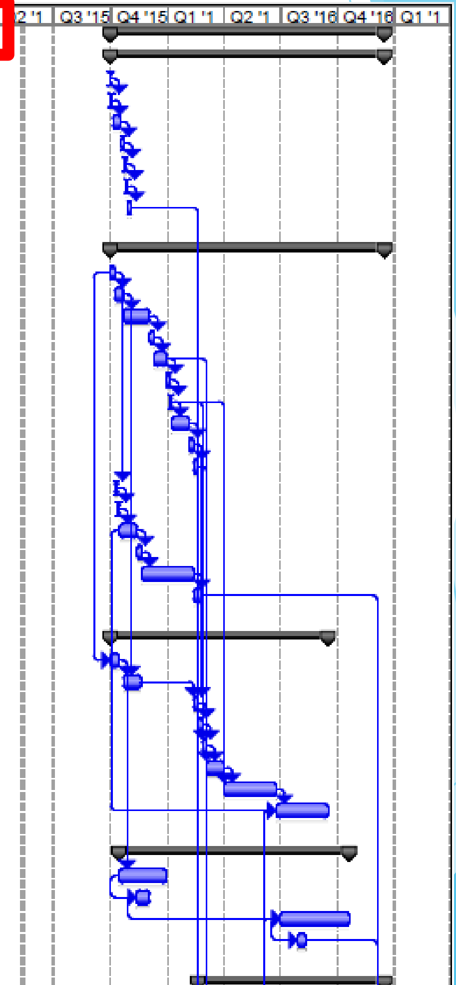
ID		Task Name	Duration	Start	Finish
1		**Project Start**	**316 days?**	**Thu 10/1/15**	**Thu 12/15/16**
2		**Preparation Work**	**316 days?**	[illegible]	[illegible]
3		Clean Cavern Prior to Start	1 day	Thu 10/1/15	Thu 10/1/15
4		Remove Roof, supports, Cameras, alarms, VESDA	1 day	Fri 10/2/15	Fri 10/2/15
5		Empty helium target and warm up	10 days	Mon 10/5/15	Fri 10/16/15
6		Remove Veto walls	4 days	Mon 10/19/15	Thu 10/22/15
7		Remove HE target vacuum pumps, water cooling, compressor	2 days	Fri 10/23/15	Mon 10/26/15
8		Remove target vent piping and top platform	2 days	Tue 10/27/15	Wed 10/28/15
9		Remove helium target and stand	3 days	Thu 10/29/15	Mon 11/2/15
10					
11		**Engineeering Design**	**316 days?**	**Thu 10/1/15**	**Thu 12/15/16**
12		Develop P&ID	5 days	Thu 10/1/15	Wed 10/7/15
13		Design vent stack	10 days	Thu 10/8/15	Wed 10/21/15
14		ODH calculations	30 days	Thu 10/22/15	Wed 12/2/15
15		Design Heat exchangers for 600 Watt refrigerators	5 days	Thu 12/3/15	Wed 12/9/15
16		Design Manifold box for refrigerators	15 days	Thu 12/10/15	Wed 12/30/15
17		Size piping	3 days	Thu 12/31/15	Mon 1/4/16
18		Layout Equipment in Cavern	3 days	Tue 1/5/16	Thu 1/7/16
19		Pressure vessel note for Captain Vessel	20 days	Fri 1/8/16	Thu 2/4/16
20		Engineering note for Captain Support frame	5 days	Fri 2/5/16	Thu 2/11/16
21		Engineering note for TPC installation frame	5 days	Fri 2/12/16	Thu 2/18/16
22		Instrument and Valve summary	3 days	Thu 10/8/15	Mon 10/12/15
23		Operating Procedures	3 days	Tue 10/13/15	Thu 10/15/15
24		Piping Engineering notes	20 days	Fri 10/16/15	Thu 11/12/15
25		Size relief valves	5 days	Fri 11/13/15	Thu 11/19/15
26		Get approval for safety documents from CSS	60 days	Fri 11/20/15	Thu 2/11/16
27		ORC for cryo operations	10 days?	Fri 2/12/16	Thu 2/25/16
28					
29		**Drafting effort**	**251 days**	**Thu 10/1/15**	**Thu 9/15/16**
30		Draw P&ID	10 days	Thu 10/1/15	Wed 10/14/15
31		Draw Vent line	20 days	Thu 10/22/15	Wed 11/18/15
32		Draw Support Frame	5 days	Fri 2/12/16	Thu 2/18/16
33		Draw TPC Installation Frame	5 days	Fri 2/19/16	Thu 2/25/16
34		Draw Layout of equipment in Cavern	5 days	Fri 2/26/16	Thu 3/3/16
35		Draw up Refrigerator Manifold box	20 days	Fri 3/4/16	Thu 3/31/16
36		Solid model of piping and physical arangement	60 days	Fri 4/1/16	Thu 6/23/16
37		Piping fabrication Drawings	60 days	Fri 6/24/16	Thu 9/15/16
38					
39		**Controls**	**265 days**	**Thu 10/15/15**	**Wed 10/19/16**
40		Engineer system and safety documents	54 days	Thu 10/15/15	Tue 12/29/15
41		Draft controls system	15 days	Thu 11/12/15	Wed 12/2/15
42		Fabricate controls	79 days	Fri 7/1/16	Wed 10/19/16
43		Electrician effort	9 days	Fri 7/29/16	Wed 8/10/16
44					
45		**Fabrication and Installation**	**215 days?**	**Fri 2/19/16**	**Thu 12/15/16**

Removing He target

Engineering: design and documents

Drafting

Design and implement controls

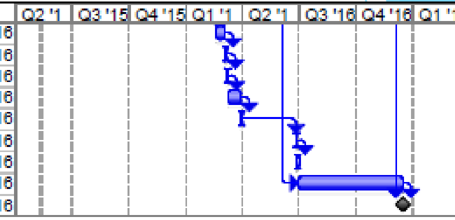


Project: Captain Installation Project
Date: Mon 5/11/15

Task	Rolled Up Task	External Tasks
Progress	Rolled Up Milestone	Project Summary
Milestone	Rolled Up Progress	Group By Summary
Summary	Split	Deadline

Example of a Technically-Driven Schedule

ID		Task Name	Duration	Start	Finish
46		Prefab support frame for Captain	10 days	Fri 2/19/16	Thu 3/3/16
47		Assemble support frame in Cavern	2 days	Fri 3/4/16	Mon 3/7/16
48	Installation	Bring Captain into Cavern	1 day?	Tue 3/8/16	Tue 3/8/16
49		Prefab and install TPC maintenance frame	15 days	Wed 3/9/16	Tue 3/29/16
50		Install Detectors in Captain	3 days	Wed 3/30/16	Fri 4/1/16
51		Reposition vesssel on stand	1 day	Mon 6/27/16	Mon 6/27/16
52		Reinstall veto walls	4 days	Tue 6/28/16	Fri 7/1/16
53		Position and assemble new Cryo system	120 days	Fri 7/1/16	Thu 12/15/16
54		Ready for Operations	0 days	Thu 12/15/16	Thu 12/15/16



Project: Captain Installation Project
Date: Mon 5/11/15

Task, Progress, Milestone, Summary, Rolled Up Task, Rolled Up Milestone, Rolled Up Progress, Split, External Tasks, Project Summary, Group By Summary, Deadline

This schedule is very preliminary – external constraints have not been included

- For example, installing CAPTAIN during a MINERvA shutdown to minimize loss of data is not considered

But it shows engineering is critical path

- Significant engineering resources are needed early in the process

CAPTAIN-BNB

- A separate LOI was submitted to the PAC in January 2015 to place CAPTAIN in an off-axis position in the BNB to study neutrino-argon interactions in the few tens of MeV energy region, important for detection of supernova bursts in DUNE
- Requires
  - Neutron background measurements outside the BNB target building
    - These are expected to be conducted by the SciBath collaboration in Summer 2015
  - Designing the new structure
    - Exact location and necessary shielding based on neutron background
  - Building the new structure
  - ~2 years of data
- A technically-driven schedule will be developed based on the neutron background measurements near the BNB target building.

CAPTAIN-MINERvA Schedule

Important factors:

- Availability of the CAPTAIN detector – earliest date CAPTAIN could be moved to Fermilab is Fall 2016
- 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 the participation of MINERvA collaborators. A significant time gap between the end of MINERvA's data collection and the beginning of CAPTAIN-MINERvA's run will make it difficult for interested MINERvA collaborators to participate.
- Installation of necessary infrastructure at Fermilab (see technically-driven schedule)
- Operating both CAPTAIN-MINERvA and CAPTAIN-BNB on a timescale such that they can both provide useful information for DUNE

CAPTAIN-MINERvA Schedule

- Assumption for this proposal is that CAPTAIN-MINERvA will run before CAPTAIN-BNB
  - We request that the engineering resources necessary for CAPTAIN-MINERvA be provided based on this assumption
- But the running order is not finalized
  - Once the technically-driven schedule for CAPTAIN-BNB is understood, the final decision can be made, based on physics priorities (DUNE), technical considerations, and/or availability of people.
  - Decision can be reached probably by early 2016 provided we have sufficient resources

Summary

- CAPTAIN-MINERvA would study neutrino-argon interactions in the medium-energy NuMI beam
  - Ideally $6x10^{20}$ POT in both neutrino and antineutrino mode
- The proposal is signed by members of both collaborations
- Unique and complementary to existing LAr R&D
- We are requesting resources so that the engineering work can begin as soon as possible
  - Allows us to be ready for the earliest possible run date (2016)

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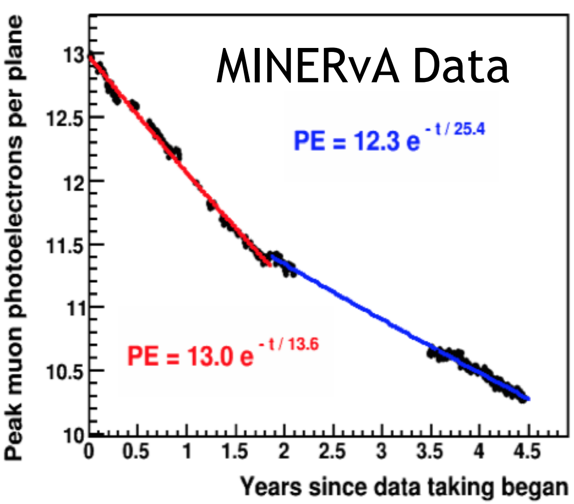
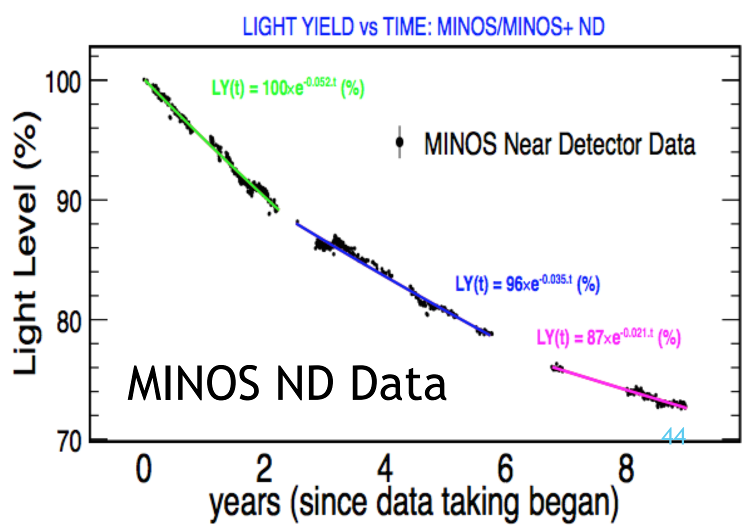
Backup

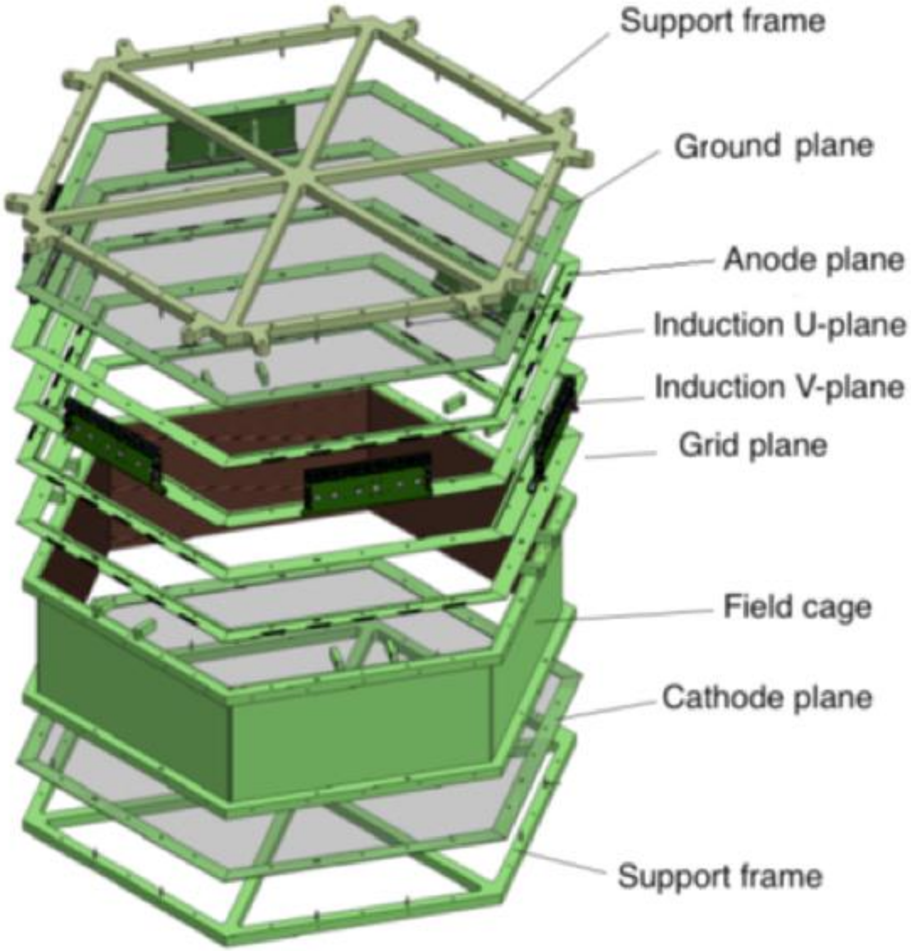
MINERvA and MINOS over time

- 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





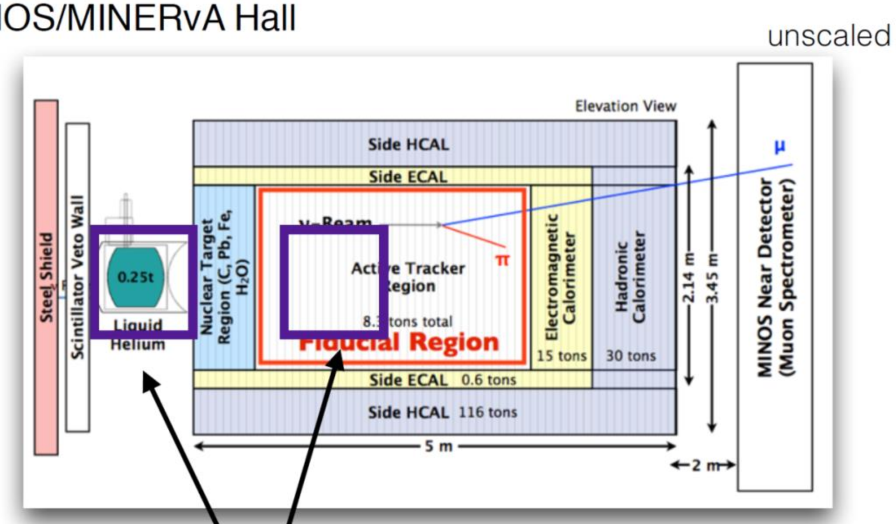
CAPTAIN TPC


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



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

Neutrino Energy Spectrum