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DEPARTMENT OF PHYSICS

CAPTAIN
NuMI and Low Energy Physics Programs

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On behalf of the CAPTAIN Collaboration

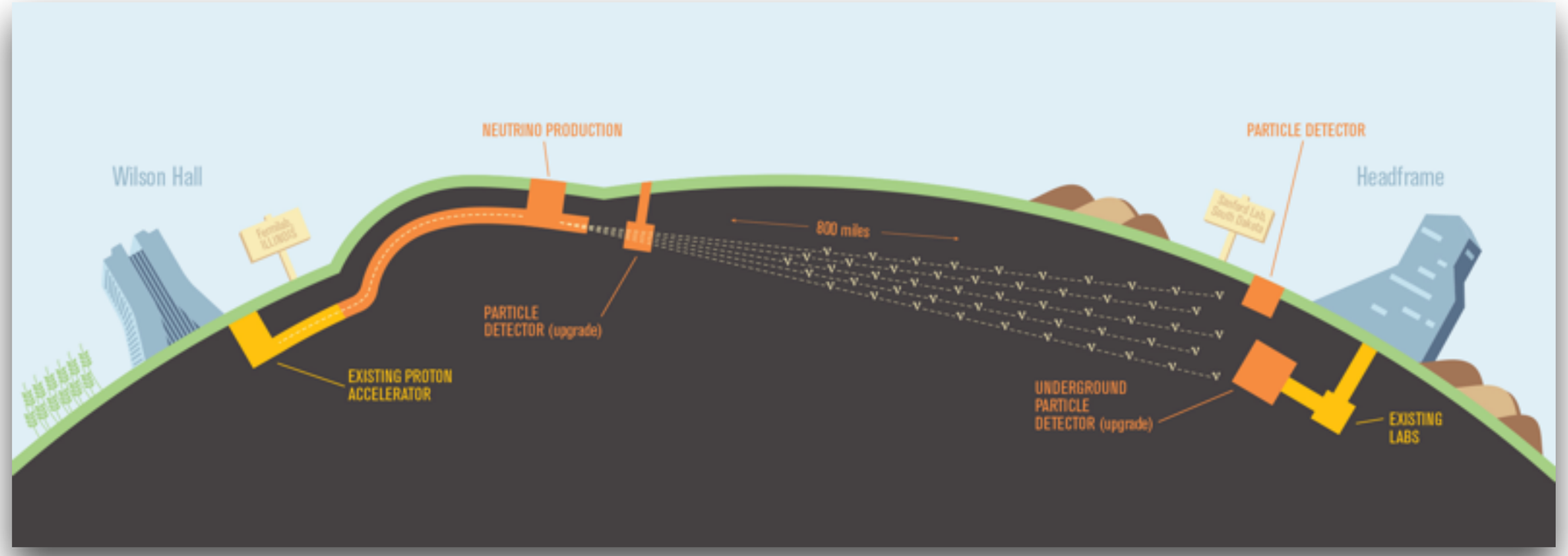
Outline

- ✤ Physics Motivation
- ✤ CAPTAIN
- ✤ NuMI (CAPTAIN/MINERvA) Physics Program
- ✤ Low energy Physics Program
- ✤ CAPTAIN Status
- ✤ Summary

Physics Motivation

DEEP UNDERGROUND NEUTRINO EXPERIMENT

- DUNE will be a world-leading experiment, a 40kt LAr TPC, deep underground with the most intense neutrino beam (LBNF) in the world
  - CP-violation in the neutrino sector
  - Mass hierarchy
  - Neutrinos from supernova
  - Proton decay

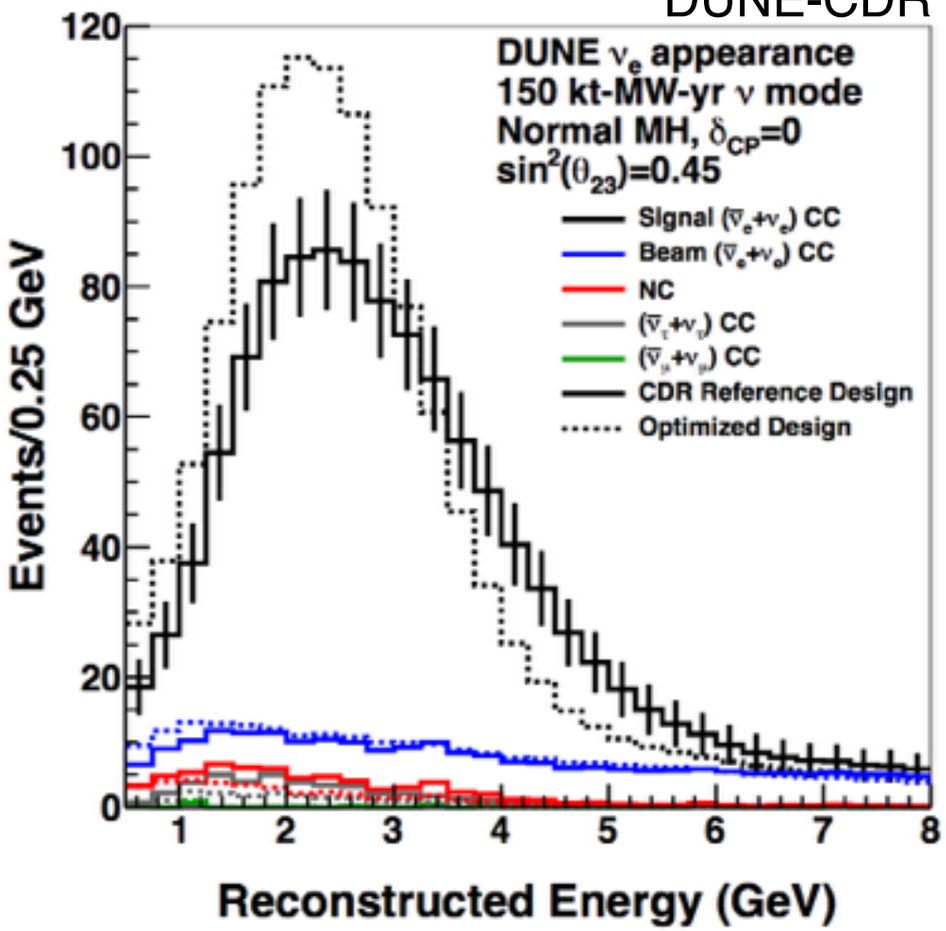


Physics Motivation

DEEP UNDERGROUND NEUTRINO EXPERIMENT

- We are facing a precision era
- Successful discoveries rely on detailed understanding of neutrino-argon interactions

DUNE-CDR



DUNE-CDR

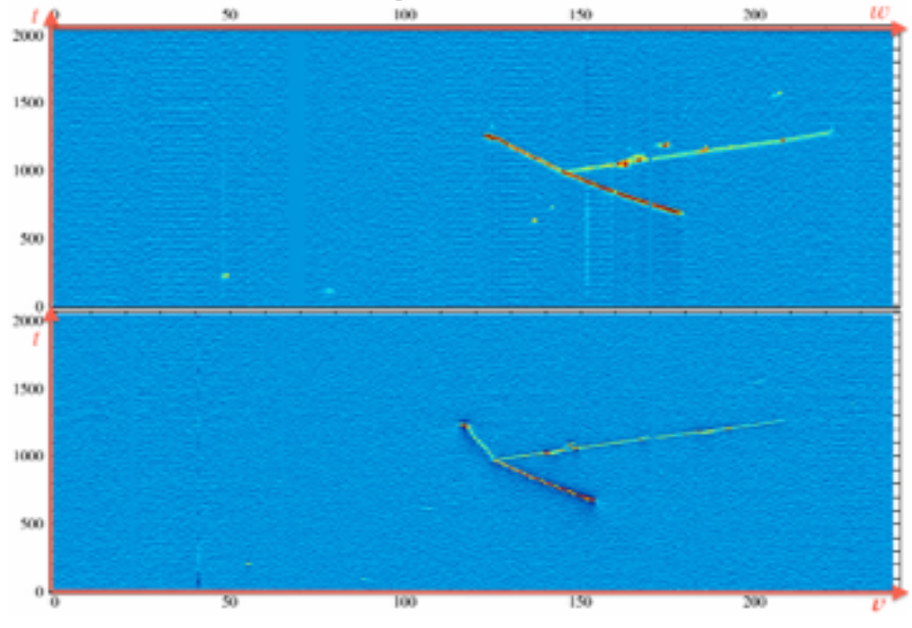
Source of Uncertainty	MINOS ν_e	T2K ν_e	DUNE ν_e
Beam Flux after N/F extrapolation	0.3%	3.2%	2%
Interaction Model	2.7%	5.3%	$\sim 2\%$
Energy scale (ν_μ)	3.5%	included above	(2%)
Energy scale (ν_e)	2.7%	2.5% includes all FD effects	2%
Fiducial volume	2.4%	1%	1%
Total	5.7%	6.8%	3.6 %
Used in DUNE Sensitivity Calculations			$5\% \oplus 2\%$

Physics Motivation

DEEP UNDERGROUND NEUTRINO EXPERIMENT

- Is necessary to develop a coherent plan that would contribute to the successful of DUNE
  - ArgoNeuT
    - Mini LAr TPC
    - Exposure to NuMI beam at Fermilab
    - First measurements of neutrino-argon cross-sections
    - Data is statistically limited
    - We need more data!!

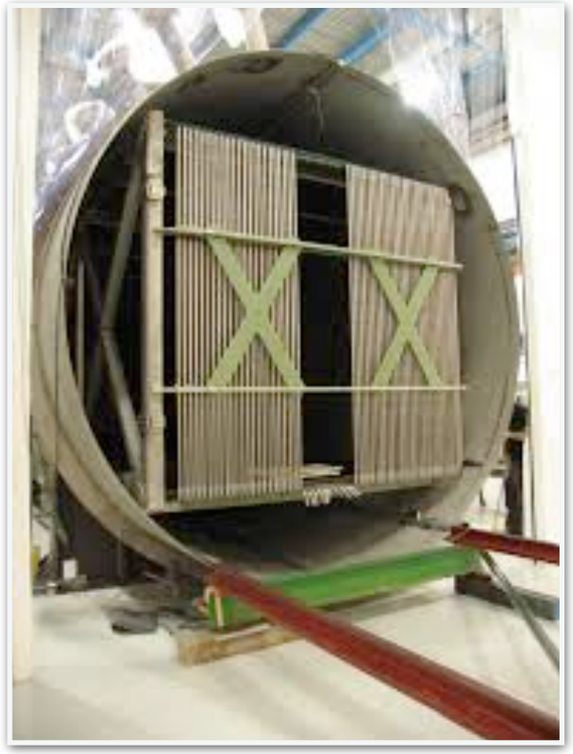
ArgoNeuT PRD 90, 012008 (2014)

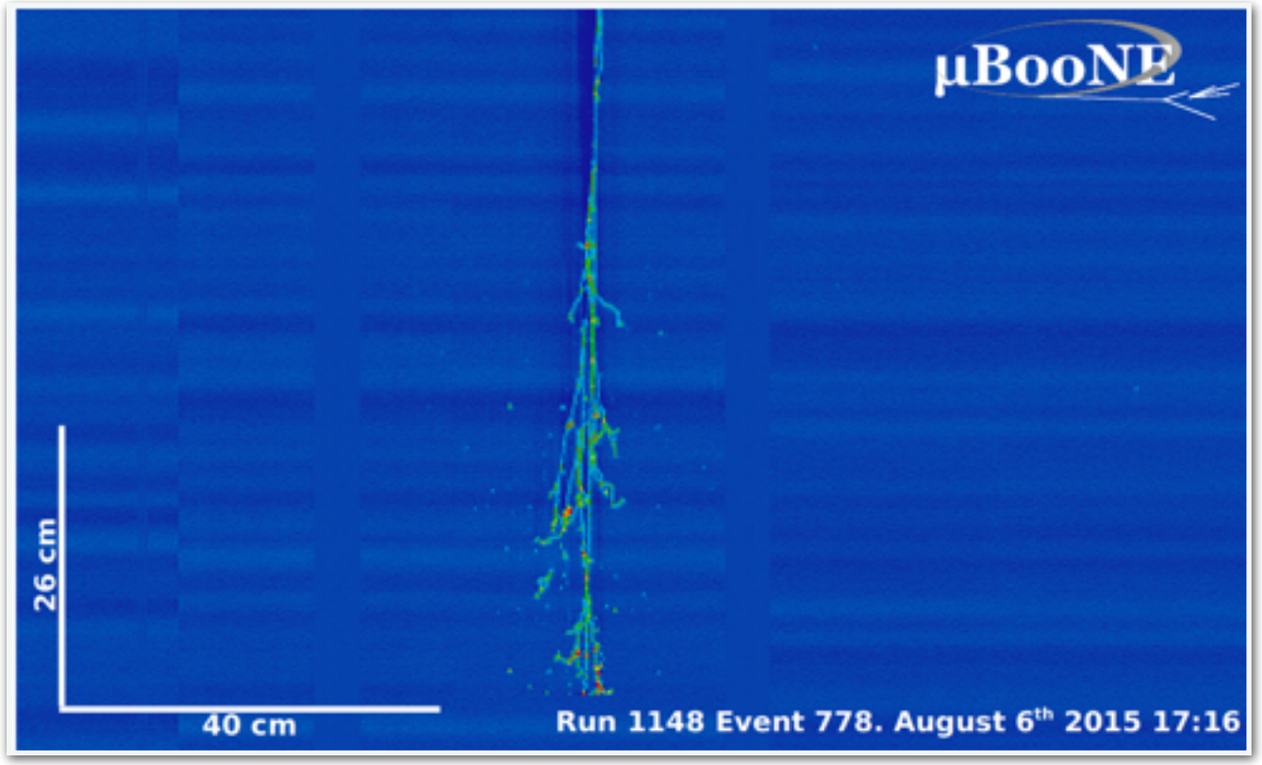


Physics Motivation

DEEP UNDERGROUND NEUTRINO EXPERIMENT

- MicroBooNE
  - LAr TPC that will use neutrinos from the Booster (Fermilab)
  - Determine the nature of ν_e-like events in MiniBooNE
  - MicroBooNE technology specially developed for e/γ identification
  - High-statistics measurements on LAr neutrino cross-section
  - Develop extensive reconstruction algorithms for LAr TPC

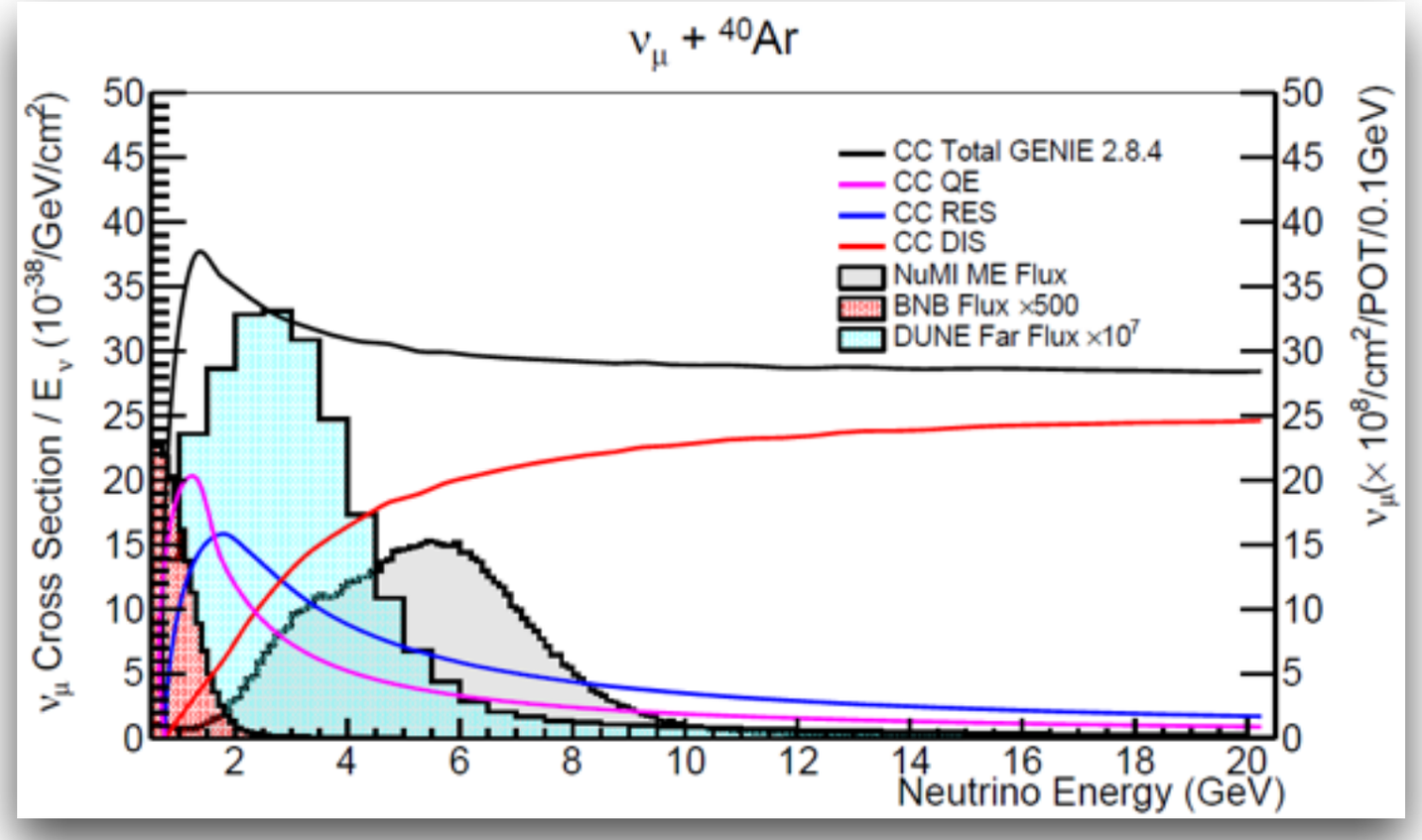




Physics Motivation

DEEP UNDERGROUND NEUTRINO EXPERIMENT

- ✤ BNB with neutrino energy ~1 GeV, consistent with 2nd oscillation maximum at baseline 1300 km
- ✤ NuMI medium energy beam overlaps the 1st oscillation maximum for DUNE
- ✤ A LAr TPC in the NuMI could provide crucial measurements for DUNE

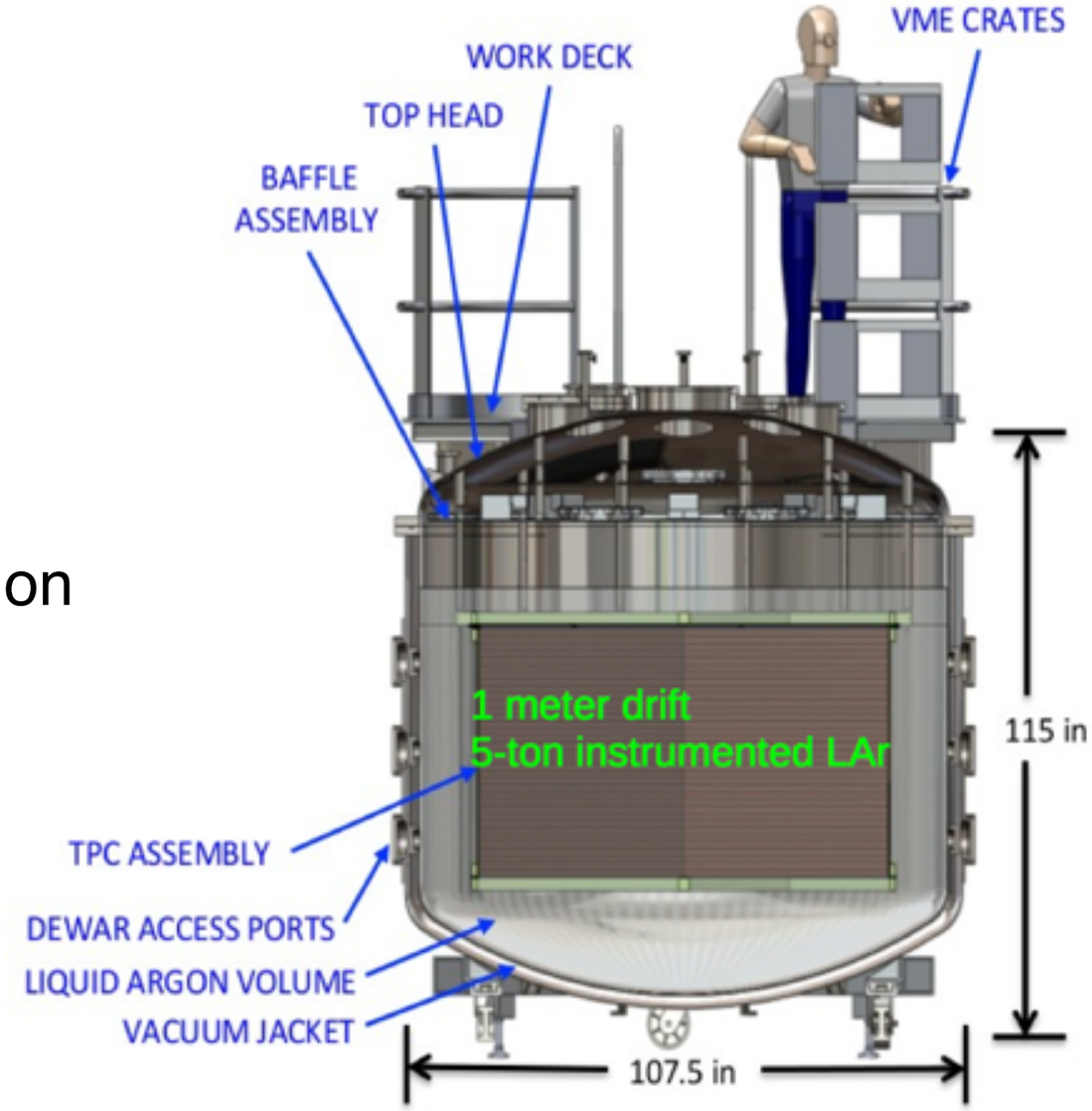


CAPTAIN NuMI Physics Program

- ✤ CAPTAIN, Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos
- ✤ CAPTAIN 5-ton LAr TPC currently being constructed at LANL
- ✤ We are proposing to install the CAPTAIN detector in the NuMI beamline to study neutrino-argon interactions in the medium-energy beam
- ✤ Place CAPTAIN detector in front of MINERvA detector (CAPTAIN/MINERvA)
- ✤ CAPTAIN would serve as the vertex detector and outgoing particles could be tracked in MINERvA and MINOS Near Detector
- ✤ The MINOS ND would be used as the downstream muon spectrometer
- ✤ CAPTAIN will study cross sections, particle ID and event reconstruction important for DUNE to expands the physics in a way that is complementary to existing LAr R&D

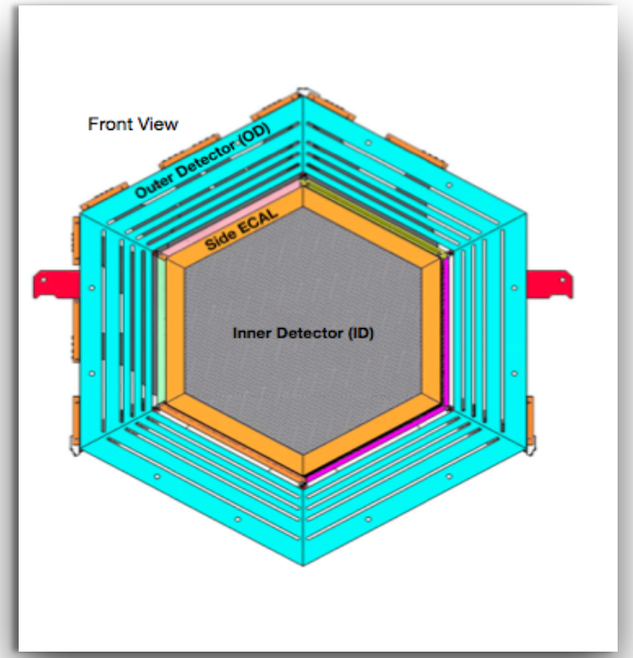
CAPTAIN Detector

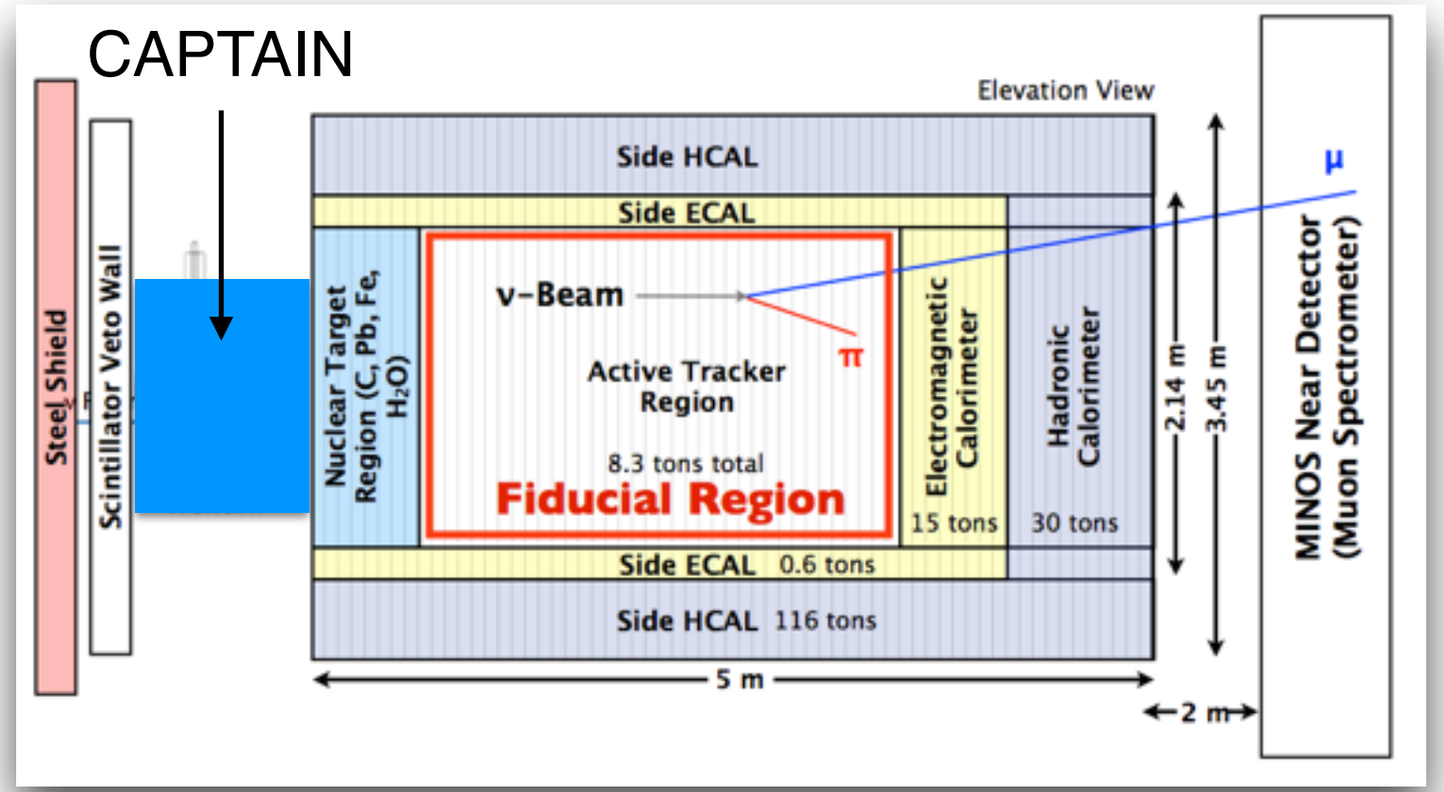
- CAPTAIN, Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos
- LAr TPC detector
- Portable and evacuable cryostat
- 5-ton instrumented liquid argon
- U, V and X plane (3mm wire pitch)
- MicroBooNE cold electronics
- Photon detection system
- Purification system designed based on MicroBooNE and LAPD
- Laser calibration system
- Mini-CAPTAIN smaller prototype detector (30 cm upward drift)
  - 400 kg instrument mass
  - 1K channels



MINERvA Detector

✤ Main Injector Neutrino ExpeRiment v-A





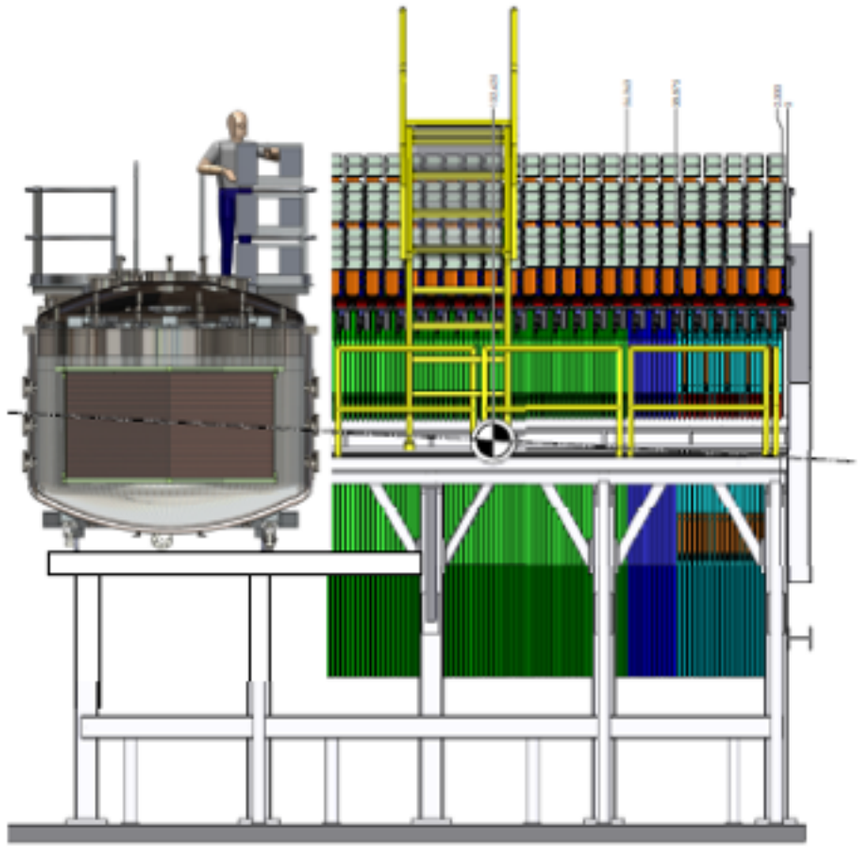
✤ Active region (CH) passive targets, Fe, Pb, C

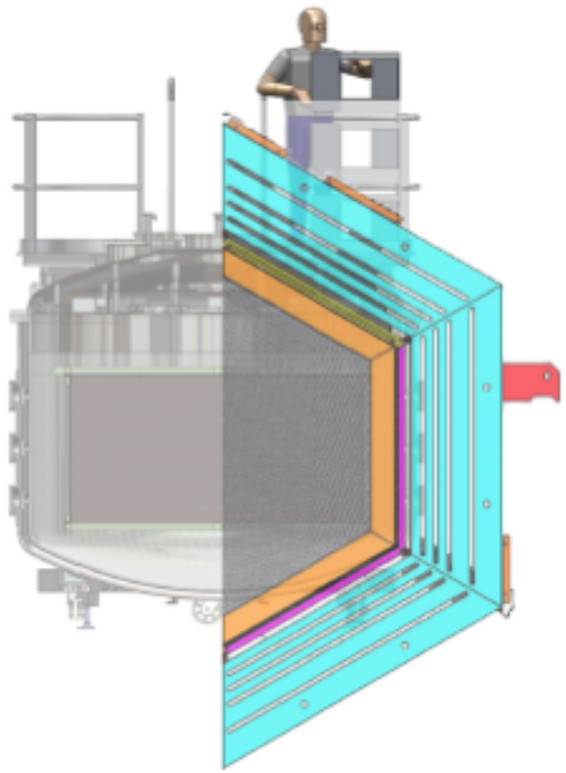
✤ 120 modules 32k channels

✤ EM and hadronic calorimeter

✤ MINOS ND as muon spectrometer

CAPTAIN/MINERvA

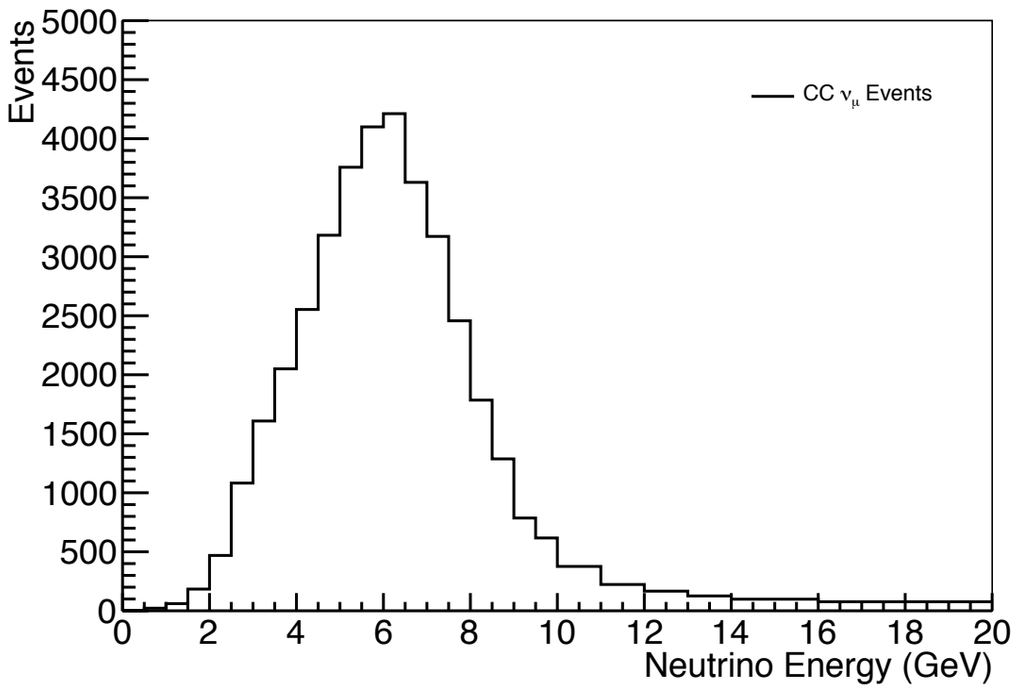


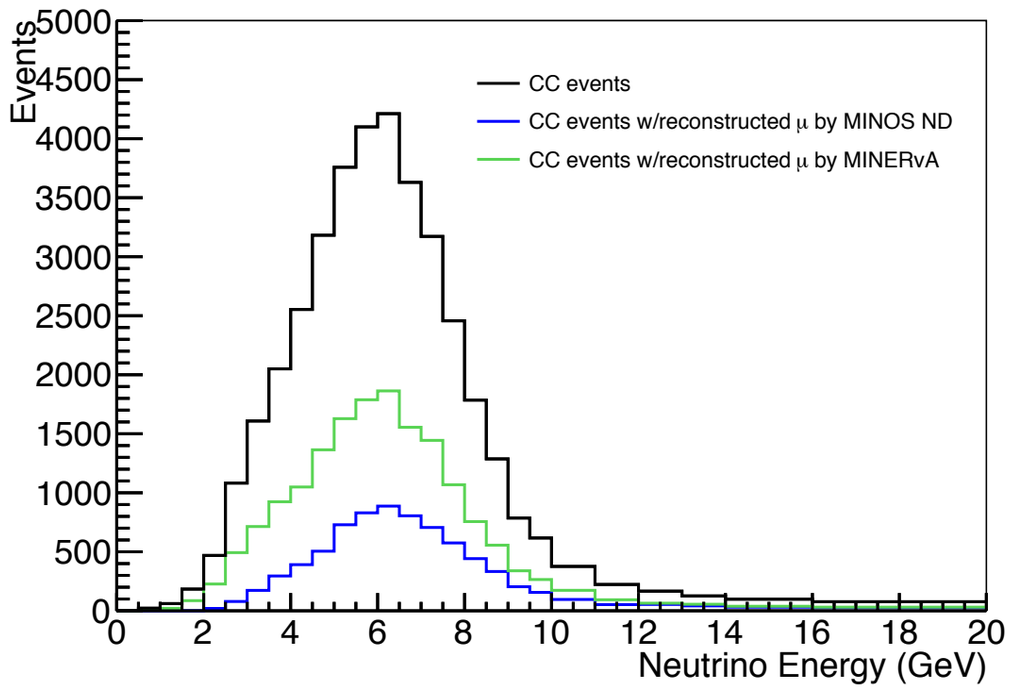


- CAPTAIN-MINERvA can measure cross section ratios (i.e., argon to carbon)
  - Study how processes vary on different nuclei (models used in neutrino event generators depend on data from a variety of nuclei)
  - More stringent tests of the models can be performed with ratios due to cancellation of large systematic uncertainties such as the neutrino flux

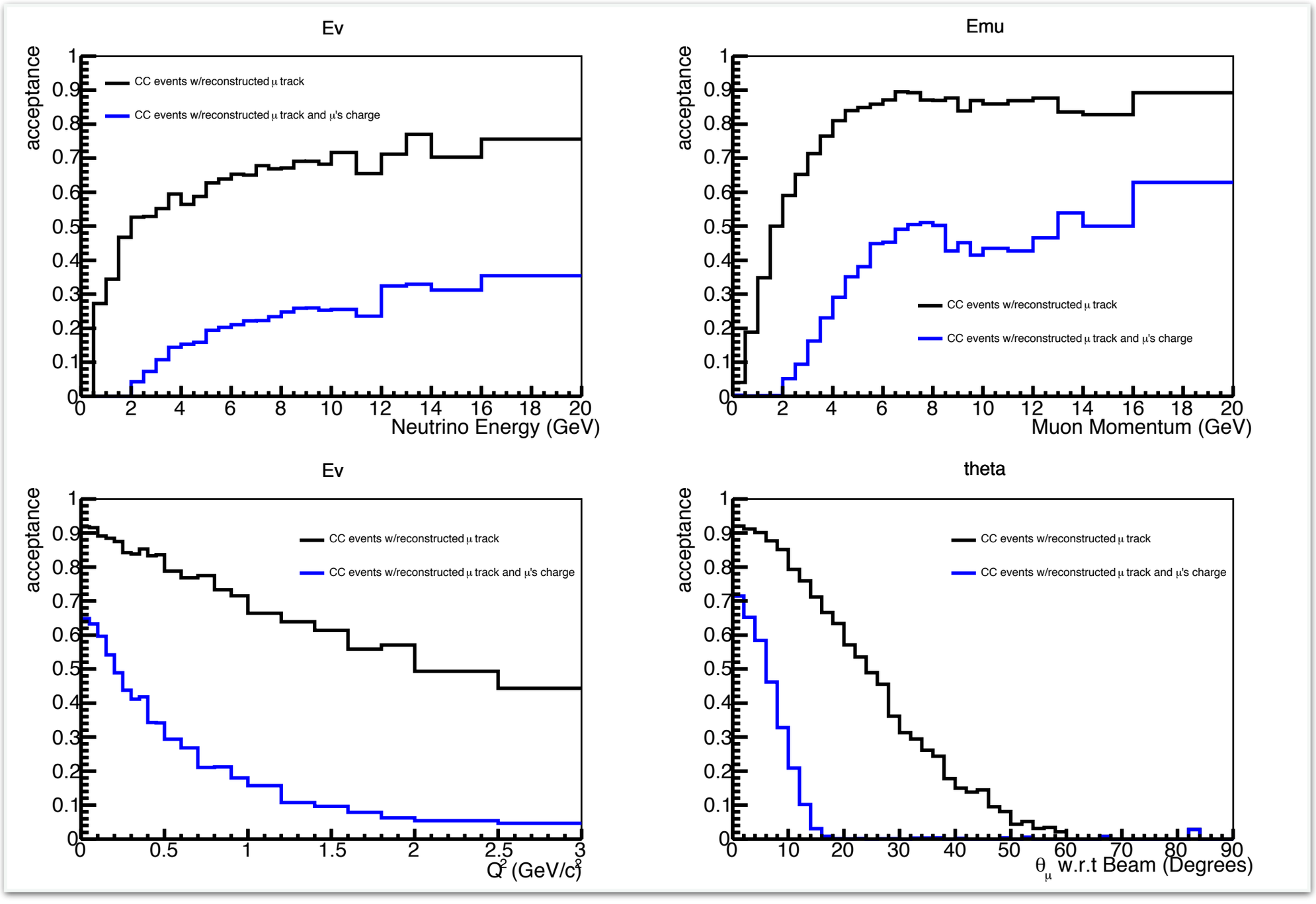
CAPTAIN/MINERvA Studies

- ✤ Neutrino interaction on LAr were simulated with GENIE 2.8.4
- ✤ Incoming neutrino energy using NuMI ME beam flux
- ✤ CC events were propagate through MINERvA and MINOS ND
- ✤ Muon momentum can be reconstructed either by MINERvA or MINOS ND
- ✤ Approximately 68% of interactions at the NuMI ME will have a pion in the final state – gives us a unique opportunity to study events with pion production and large particle multiplicities (relevant for DUNE)





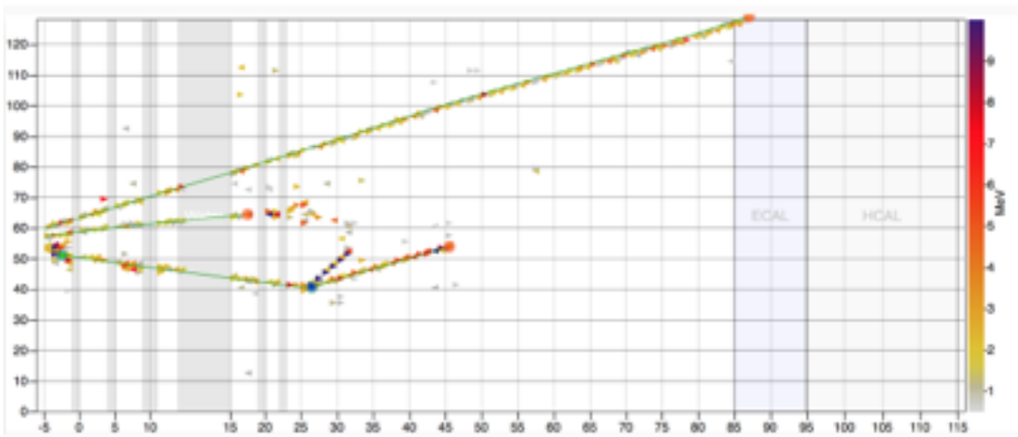
CAPTAIN/MINERvA Studies

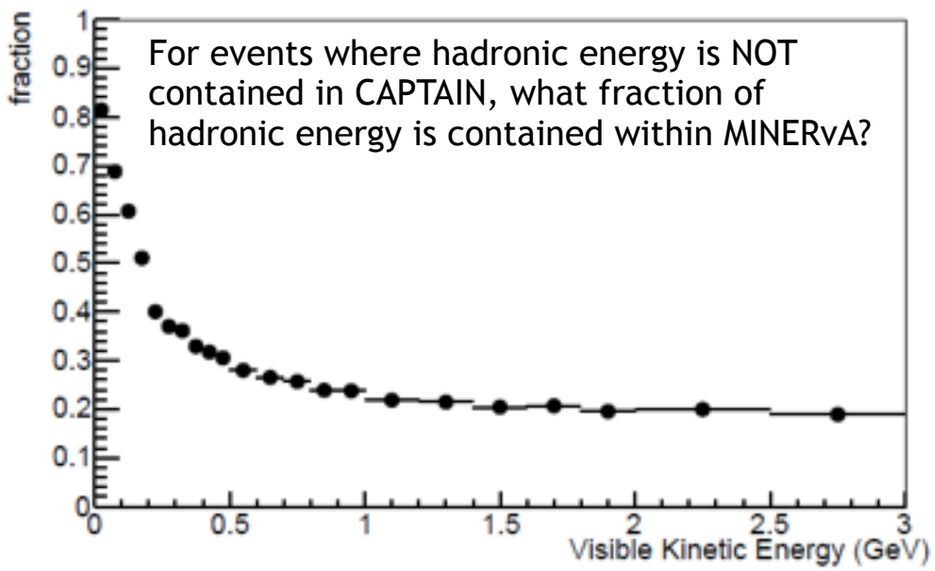


CAPTAIN/MINERvA

- Energy reconstruction
  - Depends on containment of hadronic energy and reconstruction of the outgoing muon in the case of CC interactions
  - For CC interactions, around 20% of events 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 ND or MINERvA

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





CAPTAIN/MINERvA Studies

	CC events with muon reconstructed (MINOS or MINERvA)	CC events with muon reconstructed by MINOS
$6x10^{20}$ POT Neutrino mode	Events w/ reco μ	Events w/ reco μ and charge
CCQE-like	916k	784k
$CC1\pi^{\pm}$	1953k	966k
$CC1\pi^{0}$	1553k	597k

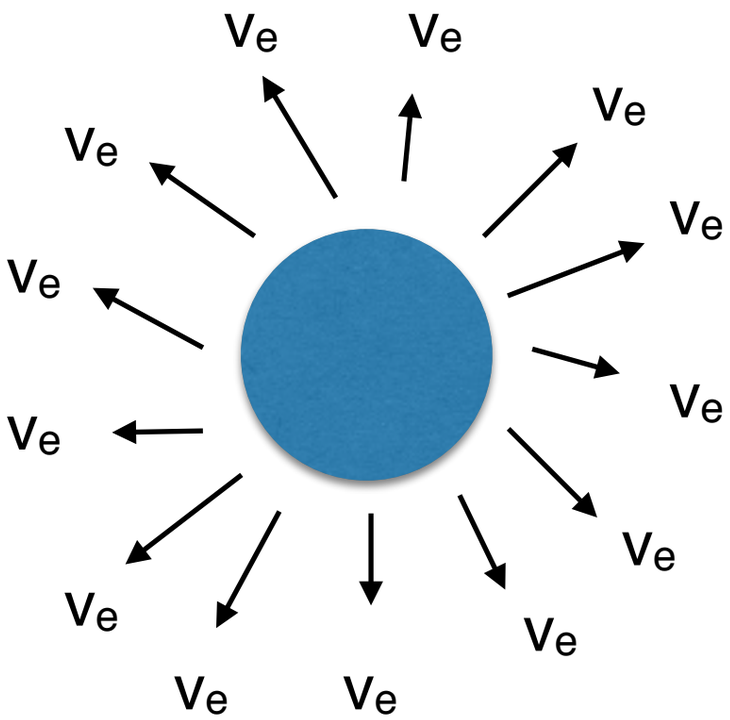
- ✤ High statistics
- ✤ Two year run will accumulate $6x10^{20}$ POT in neutrino mode plus $6x10^{20}$ POT in antineutrino mode
- ✤ Only experiment making high-statistics measurements of neutrino interactions on argon in the medium energy range before DUNE

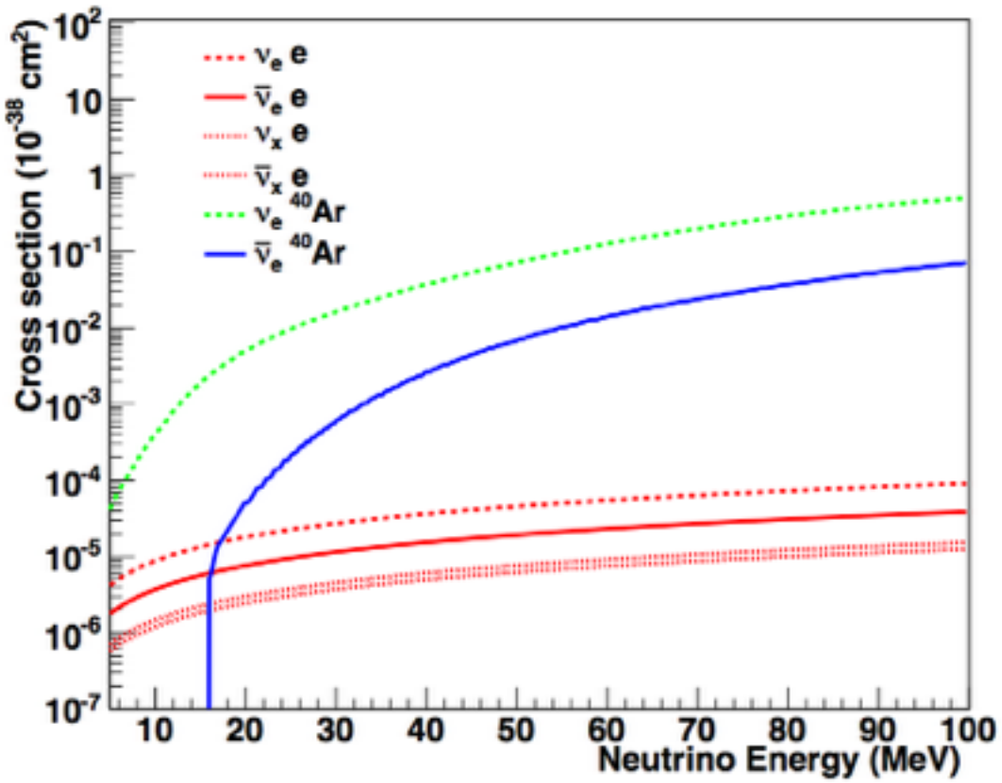
Physics Motivation

DEEP UNDERGROUND NEUTRINO EXPERIMENT

✤ Successful discoveries rely on detailed understanding of neutrino-argon interactions

$$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}Ar^*$$





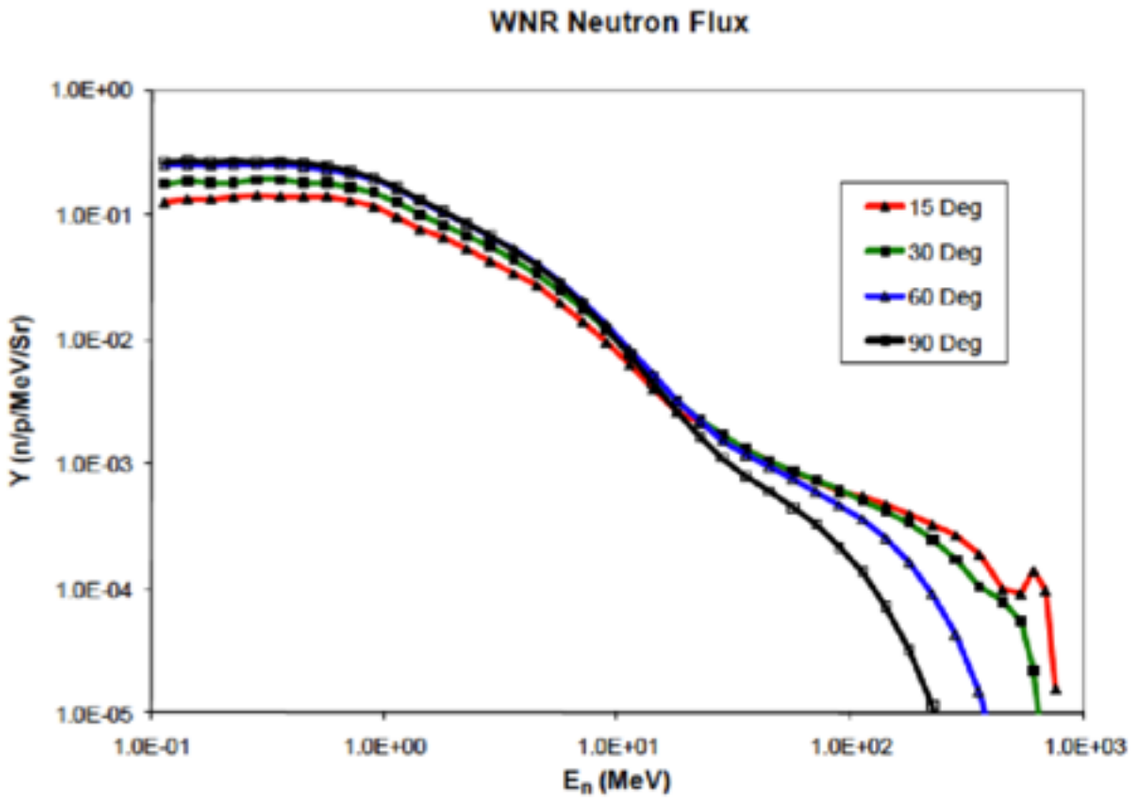
Very important to reject neutron spallation backgrounds

CAPTAIN Low Energy Program

- Neutron studies at Weapon Neutron Research (LANL)
- n + ^{40}Ar —> ^{40}Ar* + X
- Neutron scattering on Ar has not been measured
- We expect mini-CAPTAIN to run for one week in the neutron beam in the next beam cycle, which happens from October 2015 to January 2016
  - High intensity run
  - Low intensity run

CAPTAIN Low Energy Program

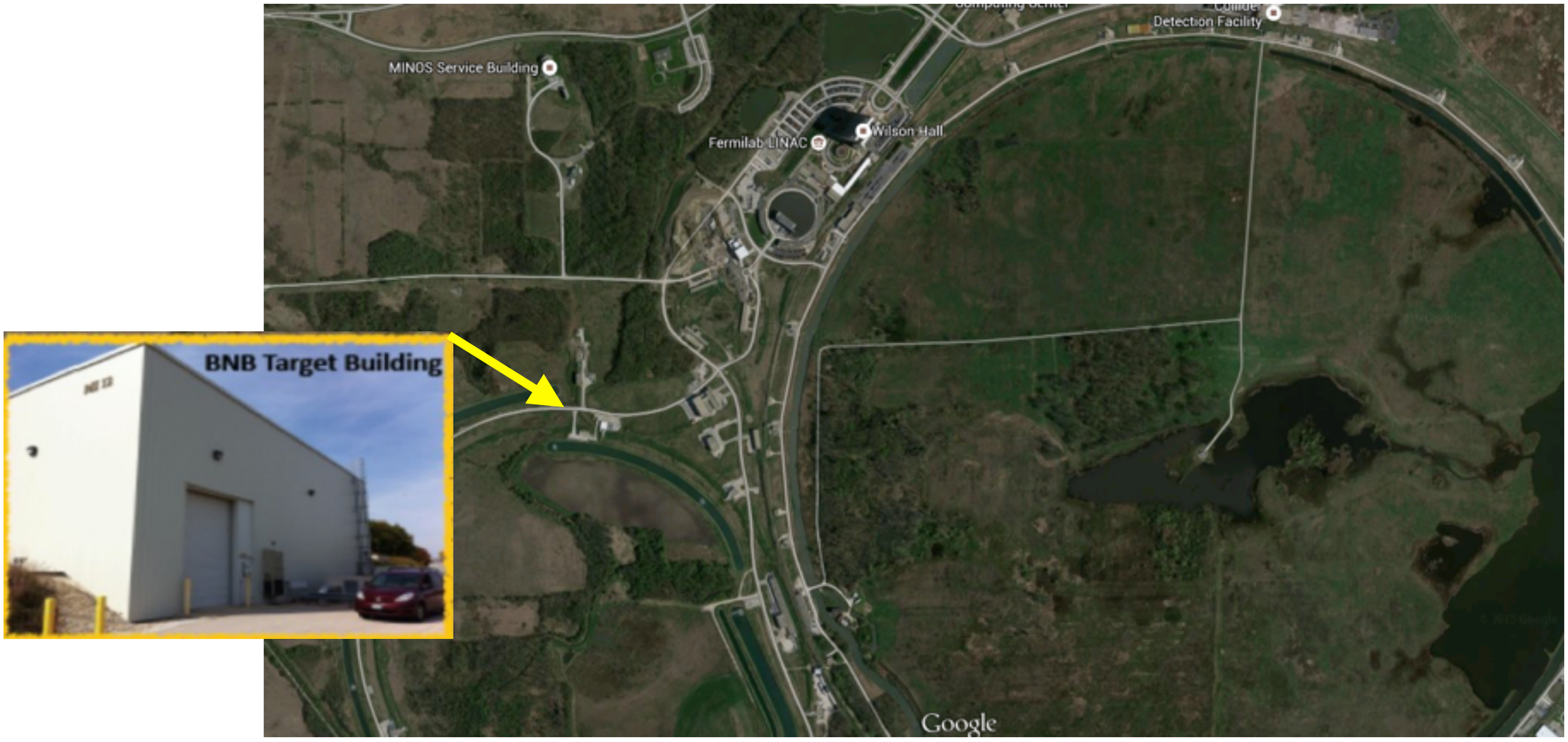
- High intensity neutron run
  - Neutron production of isotope Cl constitutes an important background for SN neutrino detection
  - A day of run produce ~year of neutron spallation events



- Low intensity run
  - Study reconstruction capabilities of $^{40}Ar^{*}$ de-excitation in LAr TPC
  - Characterization of neutron interactions to understand neutron energy in neutrino interaction on Ar (essential for neutrino energy reconstruction, DUNE)

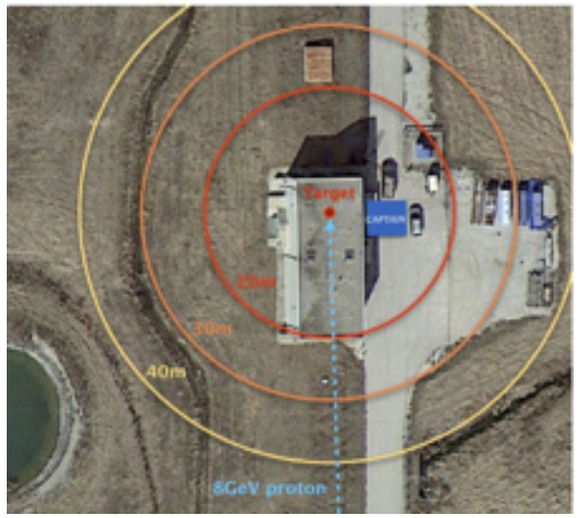
CAPTAIN at BNB Low Energy Program

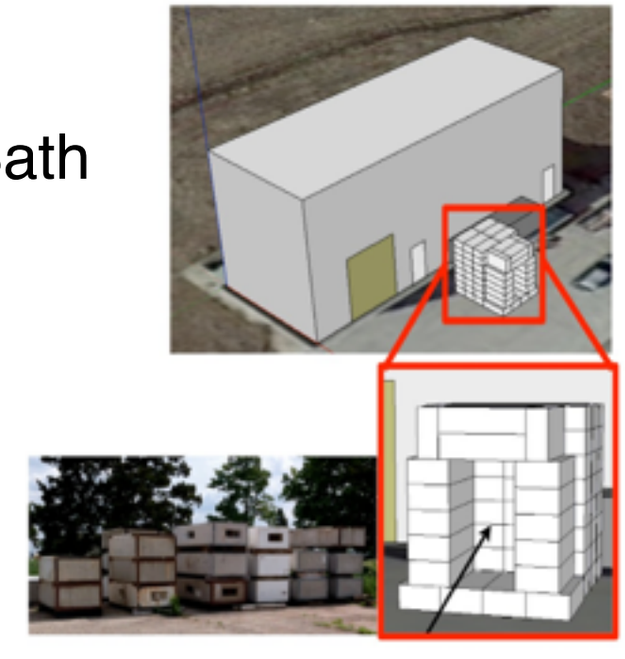
✤ CAPTAIN at BNB, Fermilab



CAPTAIN at BNB Low Energy Program

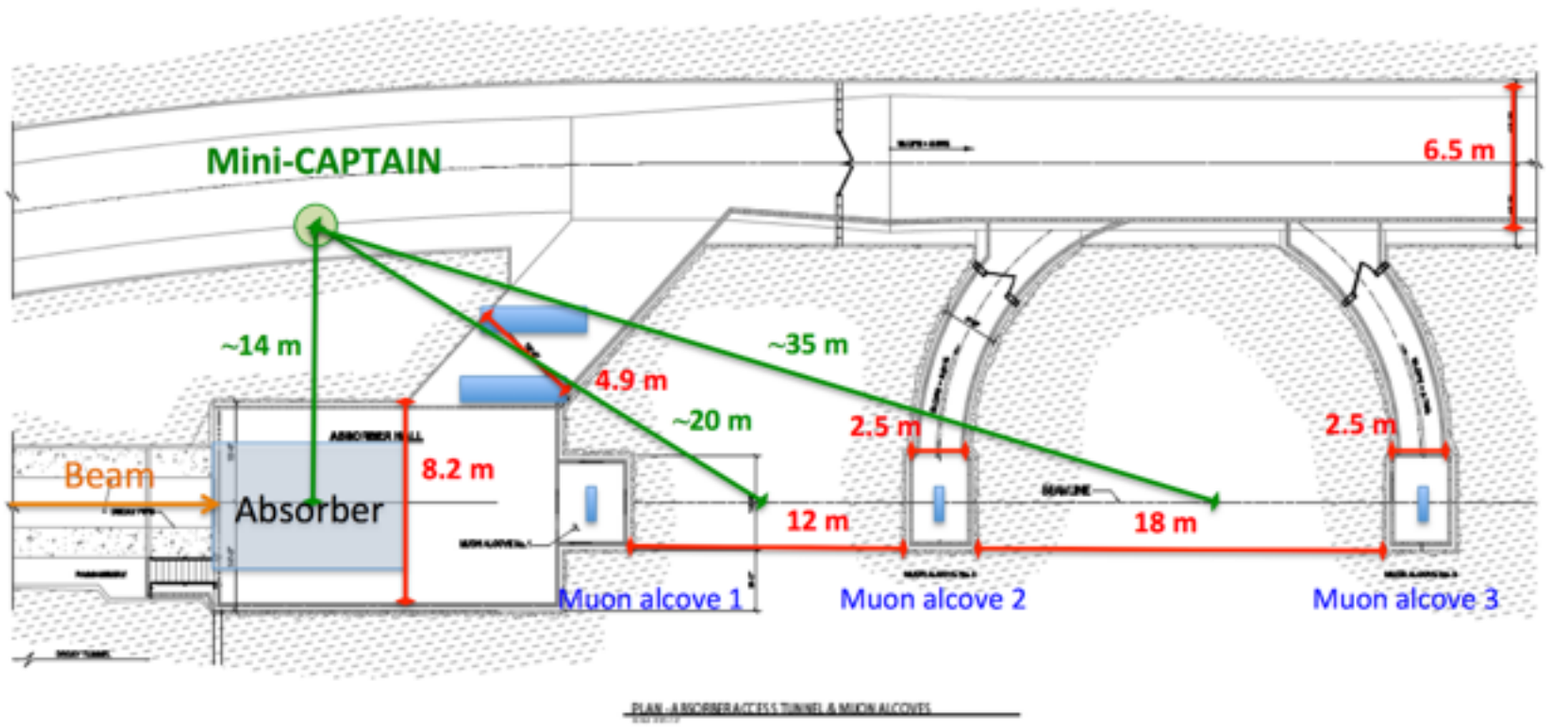
- CAPTAIN at BNB, Fermilab
- P5 recommendation “The (ELBNF) experiment should have the demonstrated capability to search for SN burst…”
- v-Ar cross-section at low energies has never measured and has a theoretical uncertainties of 10~15%
- Goal, measure the neutrino-Ar cross-section to 10%
- Test the ability of LAr TPC of detecting SN-like topologies
- Need neutron background measurements from SciBath to determine exact location and necessary shielding
- More detail flux simulation
- LOI has been submitted to Fermilab PAC





Mini-CAPTAIN at NuMI Absorber

- Another source of low-energy neutrino beam comes from the NuMI beam
- Mini-CAPTAIN at NuMI absorber
- To study v-Ar interactions at low-energies
- Feasibility studies are underway
  - A more detailed NuMI flux simulation
  - Measurements of backgrounds in the access tunnel
  - Determine amount of shielding

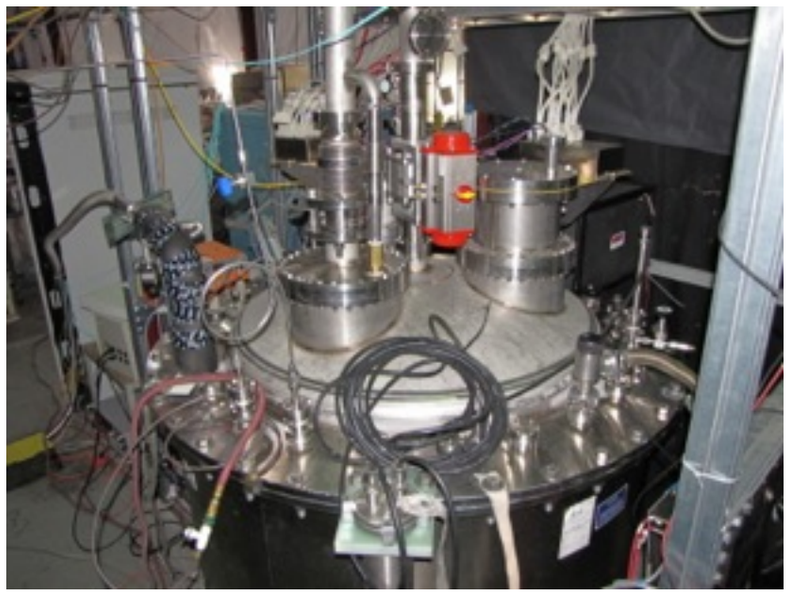


CAPTAIN Status

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

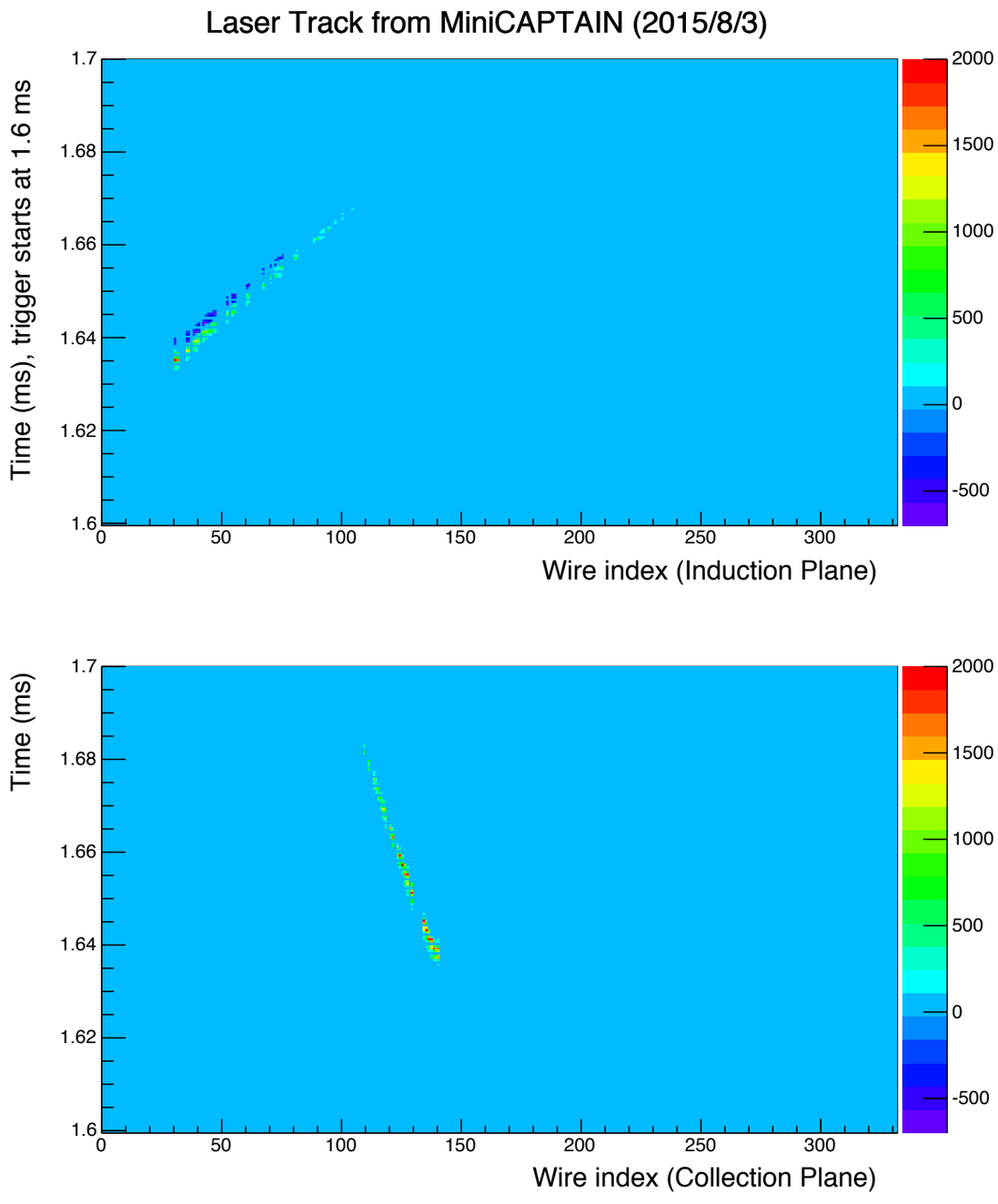
Mini-CAPTAIN Status

- Liquid nitrogen fill in Summer 2014: test electronics, TPC and test heat load
- Most recent LAr engineering run began mid-June: focus on purification
- A Mini-CAPTAIN neutron run is anticipated at the end 2015 or beginning of 2016



Mini-CAPTAIN Status

- First demonstration of an ionization track from a laser calibration system in the Mini-CAPTAIN detector
- The data were collected on the 3rd of August and were created with a high-intensity UV laser pulse traversing the TPC
- The detector is currently running with one collection plane and one induction plane



Summary

- CAPTAIN will play a significant role to the DUNE R&D program
- CAPTAIN will make unique measurements, from high-energy to low-energy neutrino-argon interactions
- CAPTAIN/MINERvA can constrain nuclear models of argon by measuring the energy dependence of nuclear effects convolved with cross section
- CAPTAIN/MINERvA only experiment making high-statistics measurements of neutrino interactions on argon in the medium energy range before DUNE
- CAPTAIN/MINERvA proposal was presented at the last PAC(Fermilab) meeting
- PAC report

The committee "…thanks the CAPTAIN/MINERvA collaboration for their detailed and extensive proposal, which lays out a very strong science case for the experiment". The PAC recommends Stage 1 approval for the experiment…

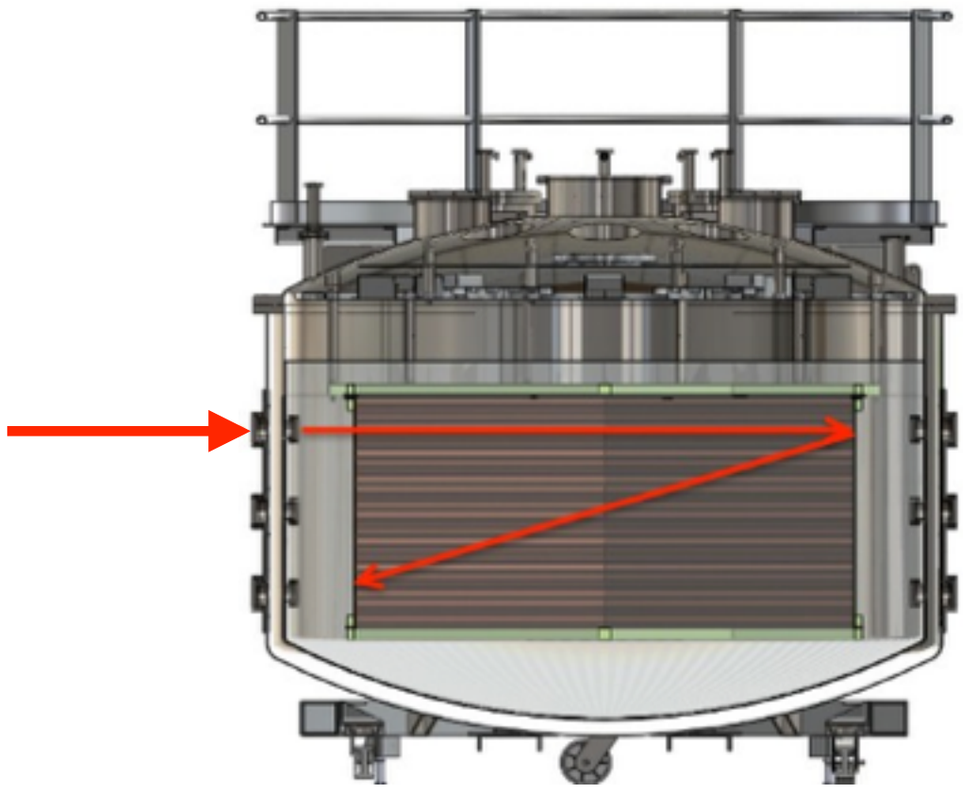
- Fermilab's director accepts PAC's recommendation

Thanks for listening

Backup

Laser Calibration System

- ✤ Nd-YAG laser (high intensity UV laser pulse)
- ✤ Ionization is proportional to the square of the laser intensity
- ✤ We can measure the electron life time in-situ and determine the drift field with the TPC
- ✤ mini-CAPTAIN TOC employs optical access on the sides of the detector



Photon Detection System

- Simulations show a few PE/MeV for MIP in the TPC would improve projected energy resolution by 10~20%
- Anti-correlation between scintillation photons and ionization electrons observed in liquid Xenon
  - Need to be tested in LAr
  - Can be used for neutron energy determination by measuring TOF
  - Will test a variety of techniques for DUNE photon detection system
    - Wavelength shifters
    - Lighit guides or doped panels
    - SiPMs
    - Calibration System