LArTPC R&D:
CAPTAIN & LArIAT

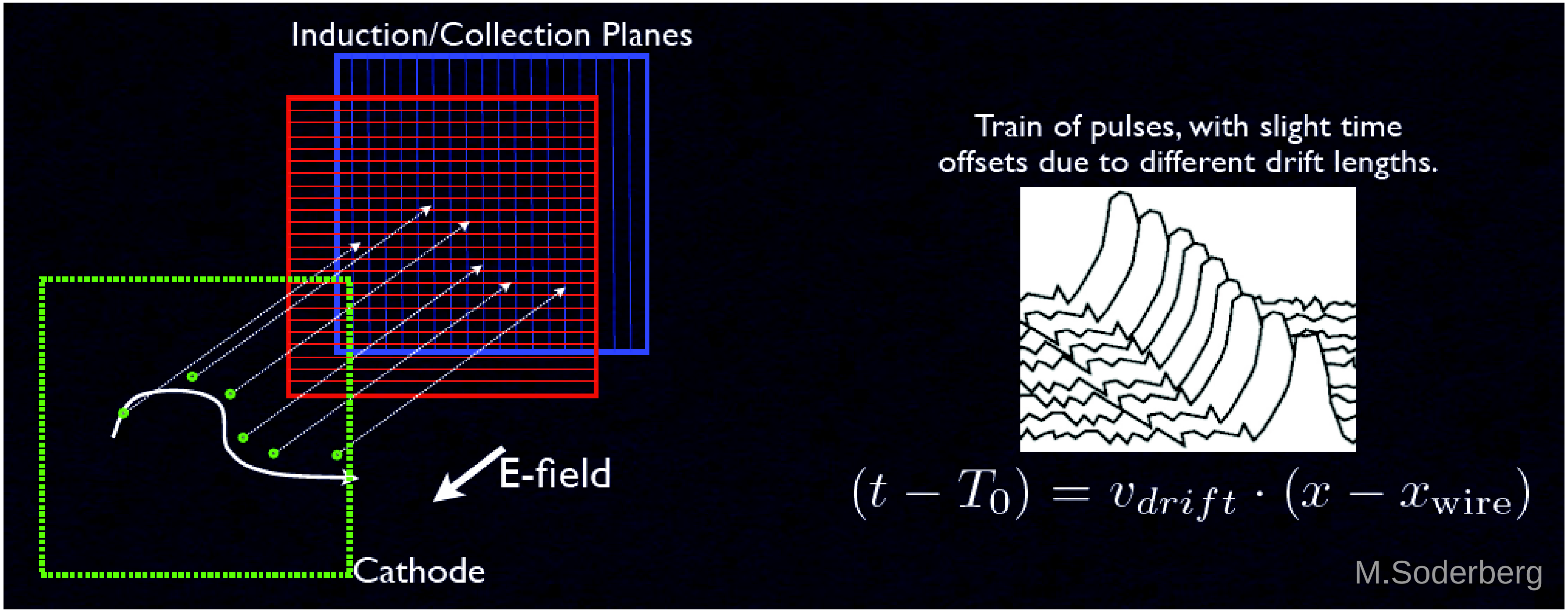
NuInt 2014, May 22nd

F. Blaszczyk - Louisiana State University

Outline

- Liquid Argon Time Projection Chambers
- A test-beam LArTPC: LArIAT
- A neutron / neutrino beam LArTPC: CAPTAIN
- Conclusion

Liquid argon TPCs

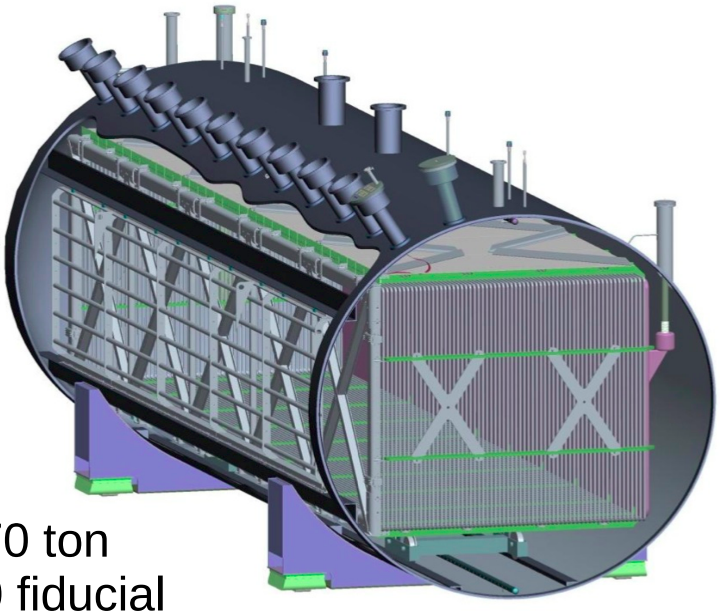


- Small neutrino cross-sections → massive detectors needed
- Detection through ionization (3D tracking) and scintillation (trigger, calorimetry)
- Ionization electrons can be drifted over long distances → large detectors possible
- Liquid argon is cheap and easy to obtain
- Better than 80% signal (CC ν_e) efficiency
- ν_e appearance background rejection (π^0) → photon / electron discrimination possible

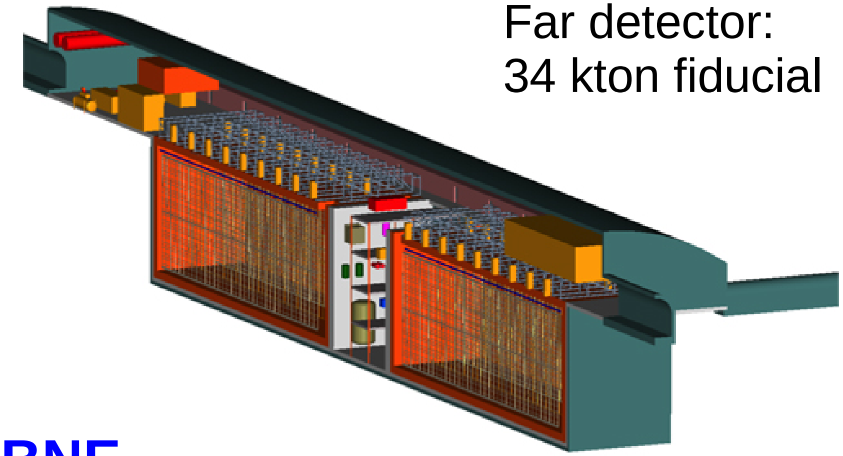
Large US LArTPCs

MicroBooNE
→ see S. Gollapinni talk

- Study MiniBooNE low-energy excess
- Cross-section measurements.



170 ton
70 fiducial



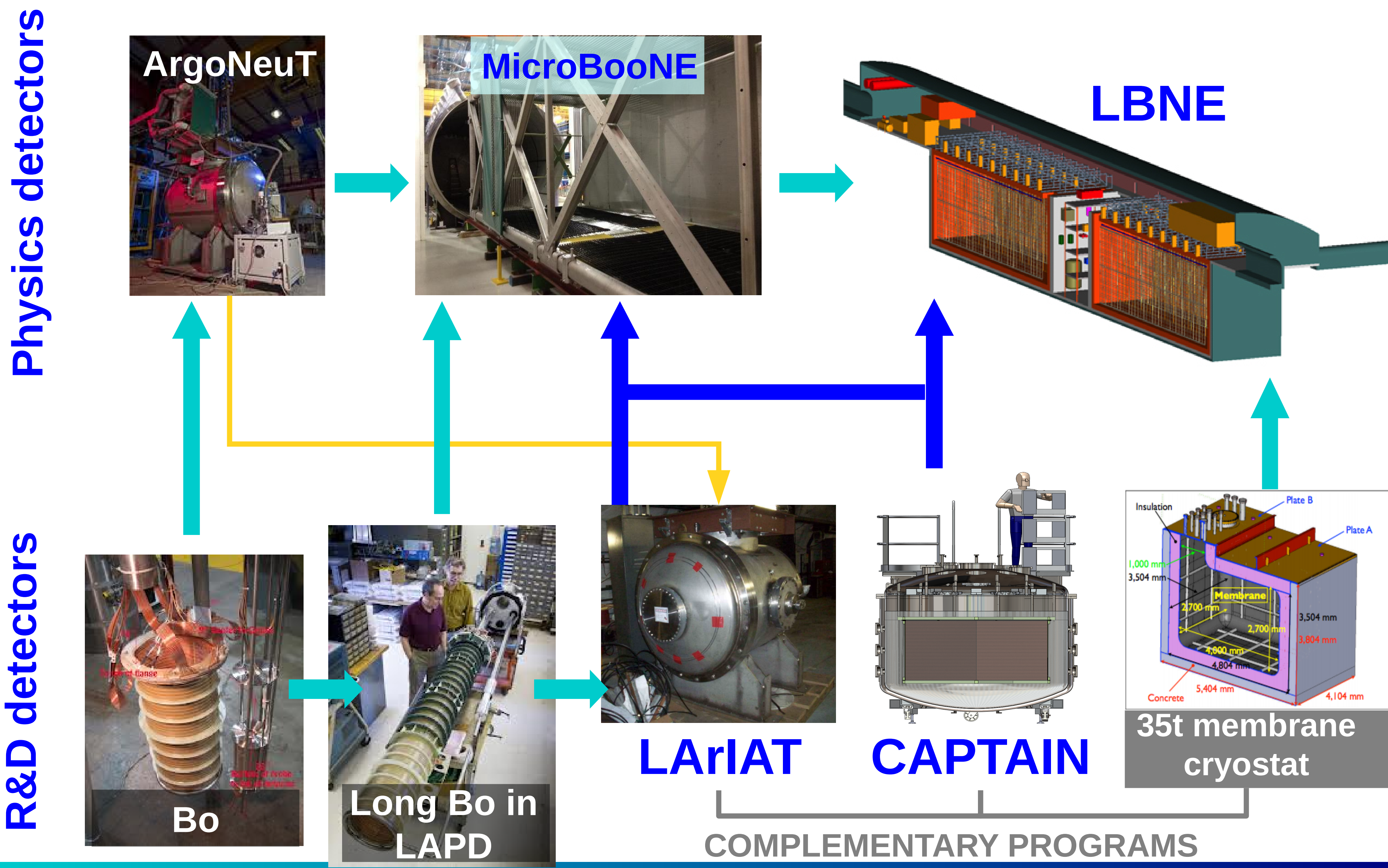
Far detector:
34 kton fiducial

LBNE

- CP-violating phase δ and θ_{13} measurement (ν_e appearance)
- Mass hierarchy
- Supernova burst and atmospheric neutrinos, proton decay

→ To maximize the reach of these experiments and to minimize systematics, calibration and a better understanding of LArTPCs are needed.

Working together ...



Liquid Argon In A Test-beam
(LArIAT)

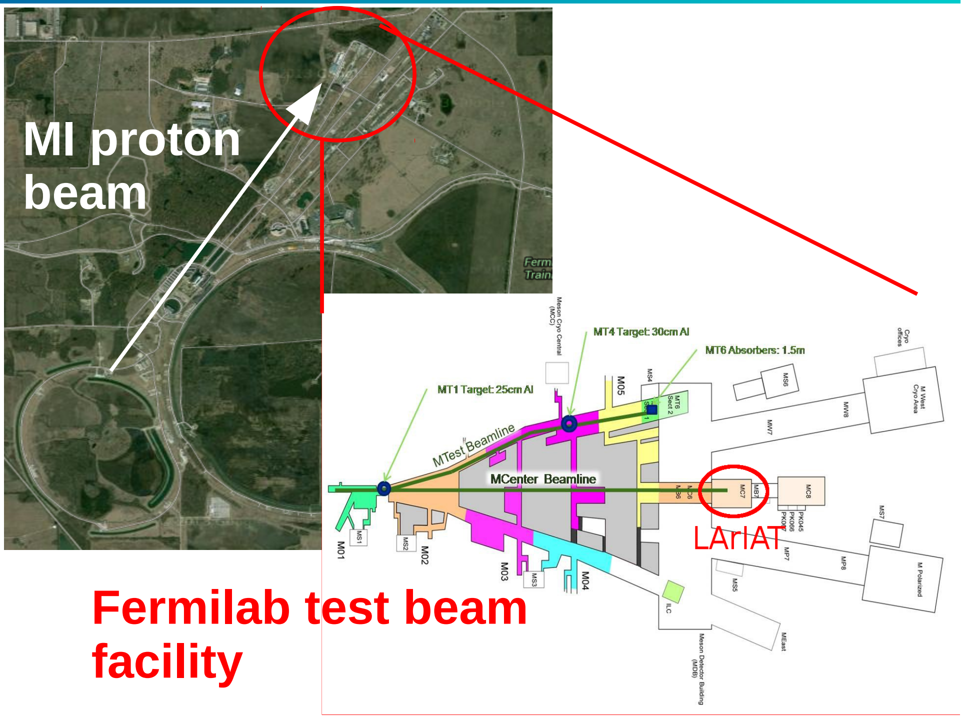
LArIAT

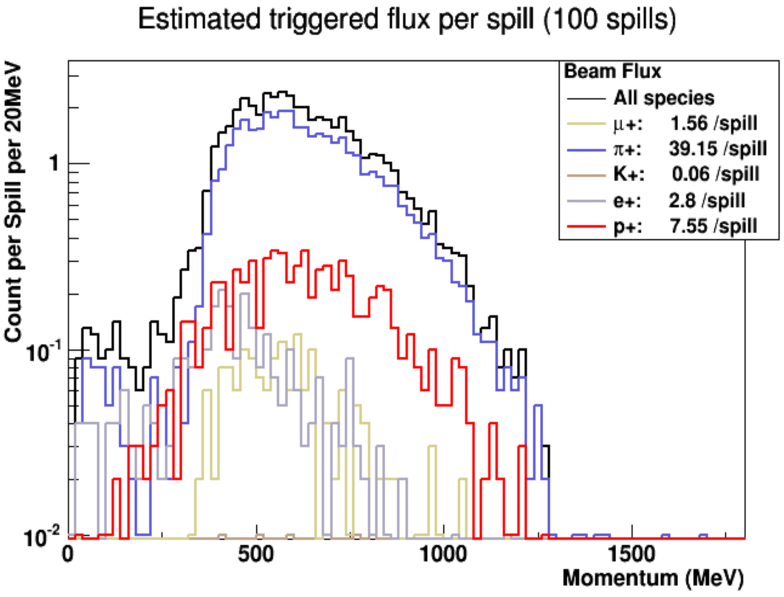
"How well known are the energy resolution and particle identification capabilities of LArTPCs?"

→ Place a LArTPC in a dedicated charged particle test beam = LArIAT is born!

- **Goals:**
  - Electron / photon shower separation
  - Optimization of particle identification
  - Muon and pion sign determination without magnetic field
  - Pion / kaon cross-sections in LAr

Study neutrino interaction outgoing particles with a dedicated test-beam!



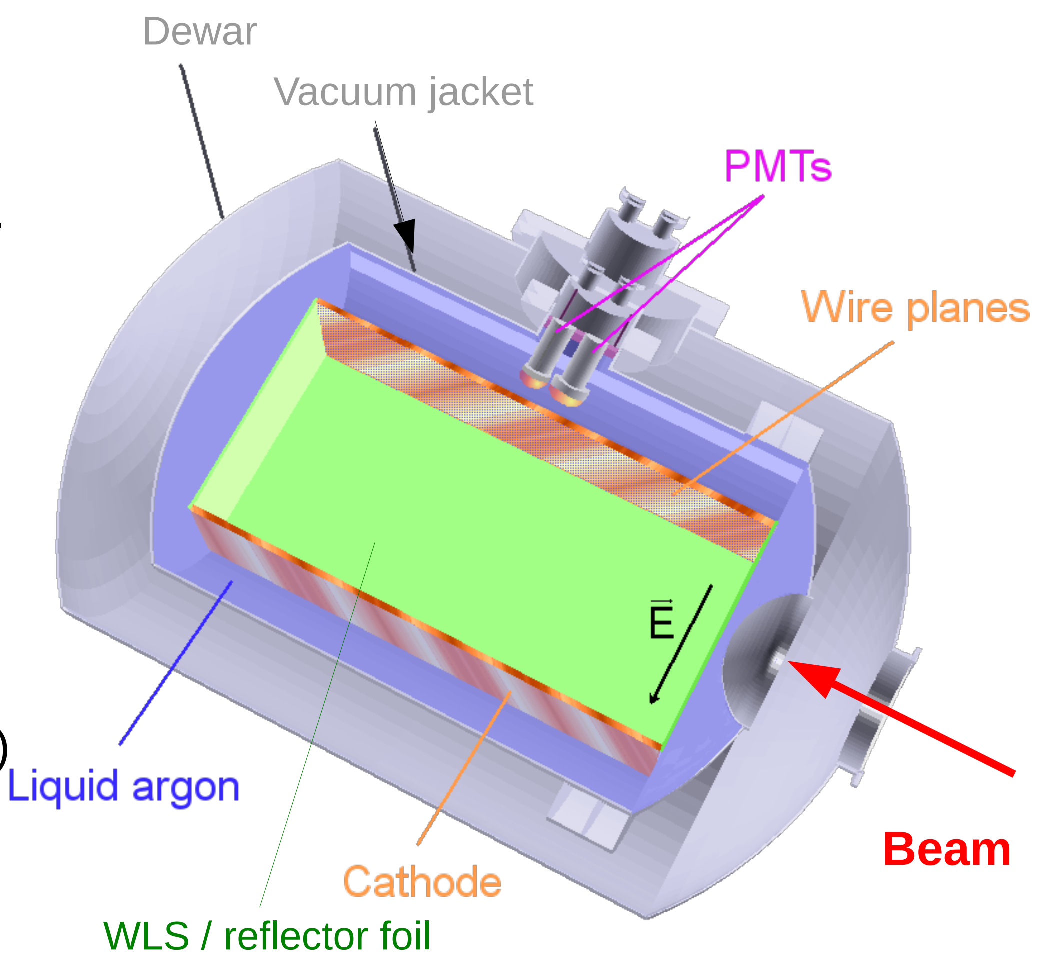


LArIAT Design

- **Features:**
  - Dedicated new beam line (0.2 – 2 GeV)

  → relevant energies for μBoone and LBNE.
  - Refurbished ArgoNeut TPC and cryostat.
- **Specifications:**
  - Active volume: 175 L (550 L cryostat)
  - 90 cm x 40 cm x 47.5 (drift) cm TPC
  - 3 wire planes: 1 induction, 1 collection, 1 shield (4mm wire spacing, ~240 wires/plane)
  - Nominal electric field: 500 V/cm (tunable)

    → ~400 μs max drift time
  - Scintillation light collection: 2 standard PMTs + 2 SiPM + wavelength shifting reflector foils
  - Cold readout electronics



Sliced top view

Electron / photon separation

- π^0 are one of the largest backgrounds in ν_e appearance analyses:

  → γ from π^0 decay vs e^- from ν_e CC events.

  → e / γ separation is a key feature of LArTPC technology

- LArIAT will have a sample of electron and γ events:

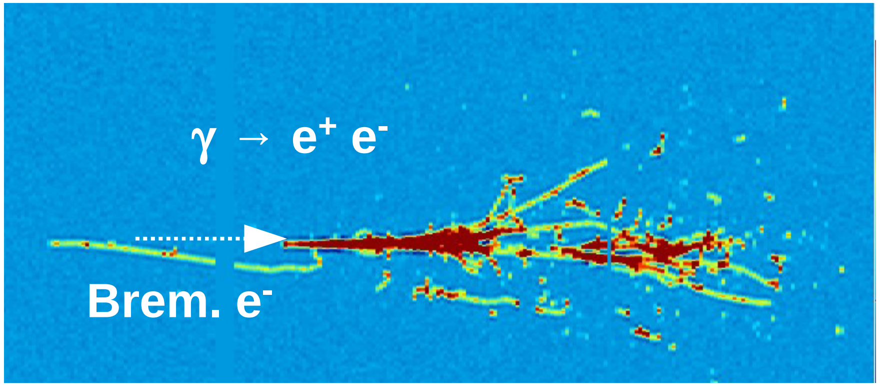
  → experimentally measure separation efficiency and sample purity for e-induced vs. γ - induced showers

  → tune Monte Carlo simulation

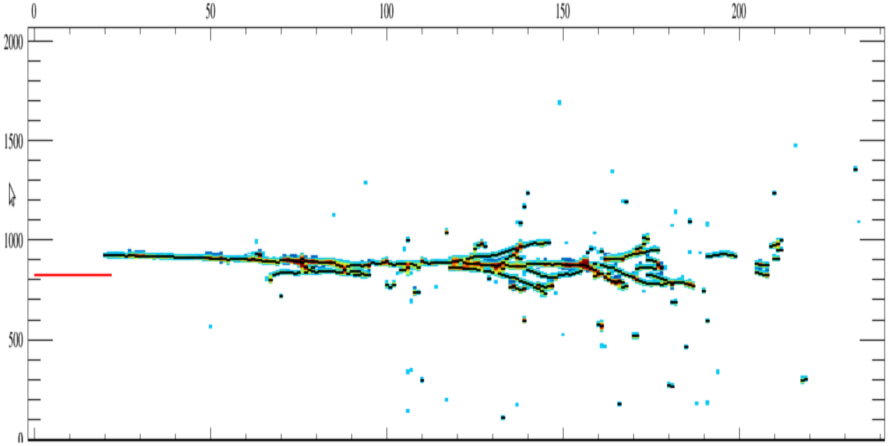
  → develop / optimize algorithms

More details: J. Asaadi talk on Saturday

LArIAT MC: photon shower



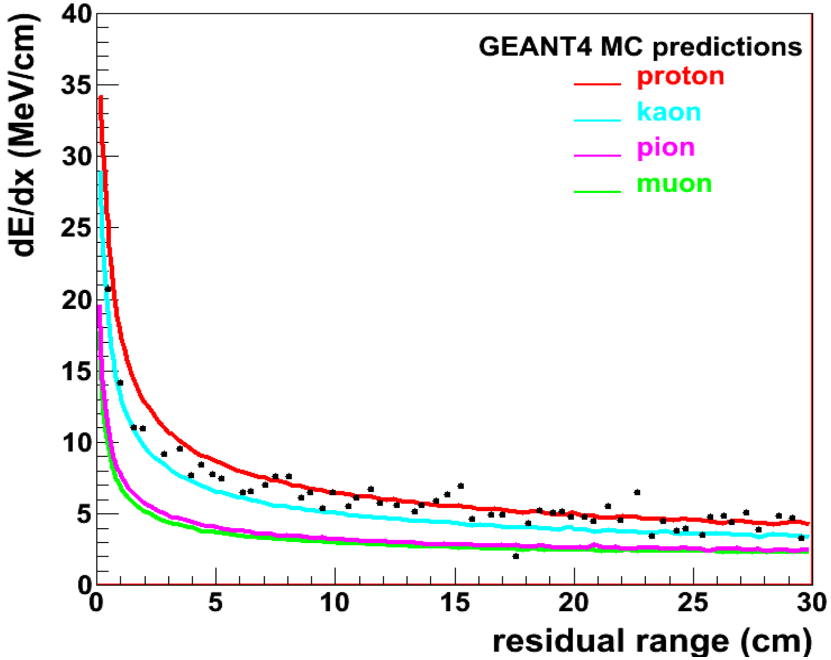
LArIAT MC: electron shower

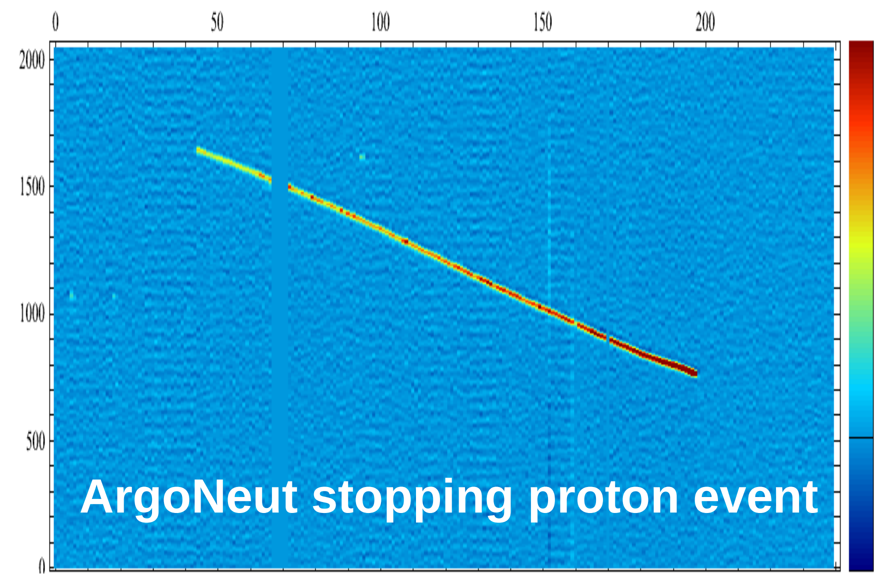


Only the initial part of the shower is necessary for e-γ separation.

Particle identification

- Optimize PID for neutrino oscillation / neutrino cross-section experiments and proton decay searches with known particle beam
- dE/dx vs residual range for contained tracks + recombination study along stopping tracks:
  - → Proton ID, proton vs Kaon separation
  - → Kaon ID, Kaon vs π/μ separation



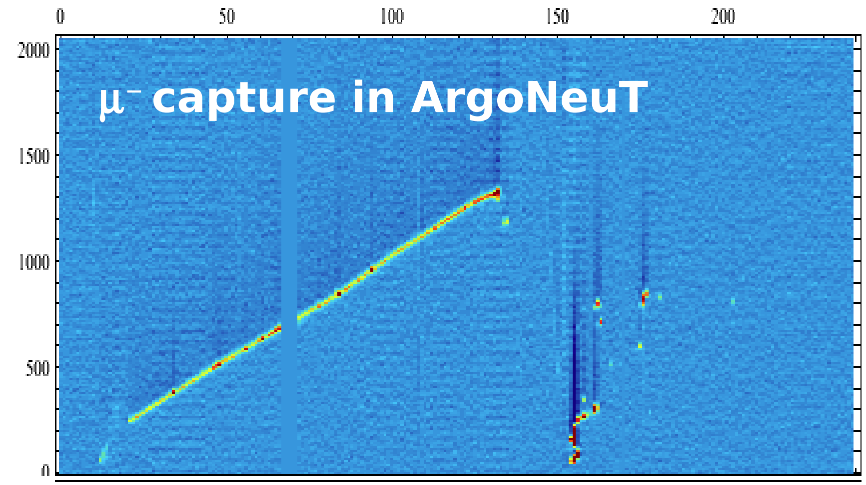


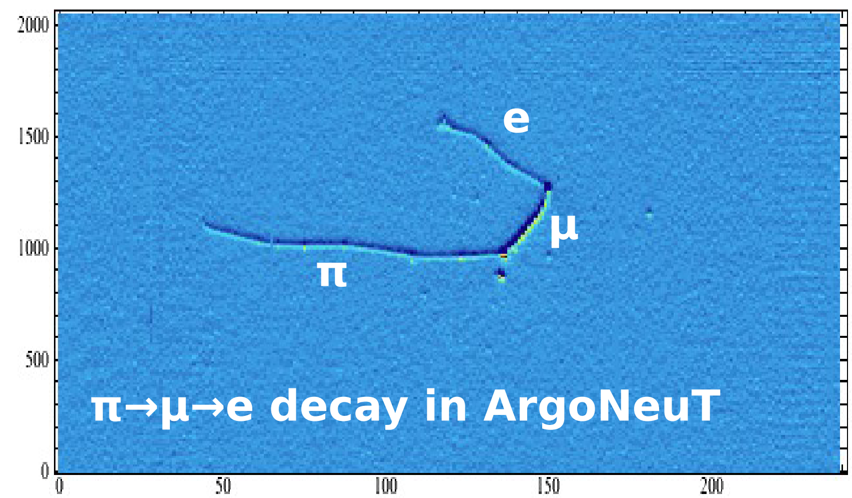
Charge sign determination w/o magnetic field

- Charge sign determination (w/o a magnetic field) for fully contained muons using statistical analysis :
  - μ^+ decay rate with e^+ emission of a known energy spectrum = 100 %
  - μ^- capture on nuclei rate + γ / n emission ~ 75% vs decay rate ~25%

    → capture rate higher in Ar than in lighter elements

    → systematic study of μ^- capture in LAr has never been performed
- Beam tunable polarity will provide data for direct measurement of the sign separation efficiency and purity for muons (might be possible for pions)



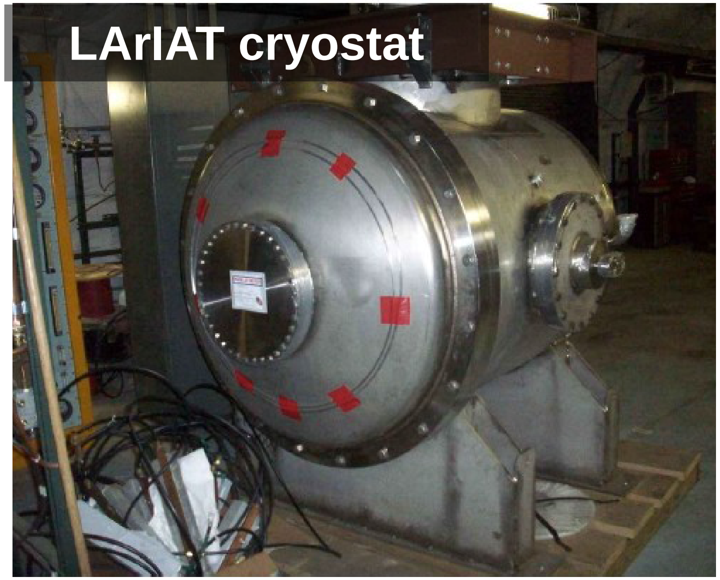


LArTPC sign determination capability has yet to be explored

Current status & Schedule

- Primary and secondary beam commissioned, tertiary beam in progress
- Light readout system tested, cryostat, DAQ, power supplies, and control room ready
- Cold electronics undergoing tests
- LArIAT phase I expected to have results for LBNE CD2 review in 2017
- Planning LArIAT phase II with a μBooNE sized detector (same cryogenic / purification system)

Tertiary beamline


LArIAT cryostat

Data taking starts this summer 2014!

Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos (CAPTAIN)

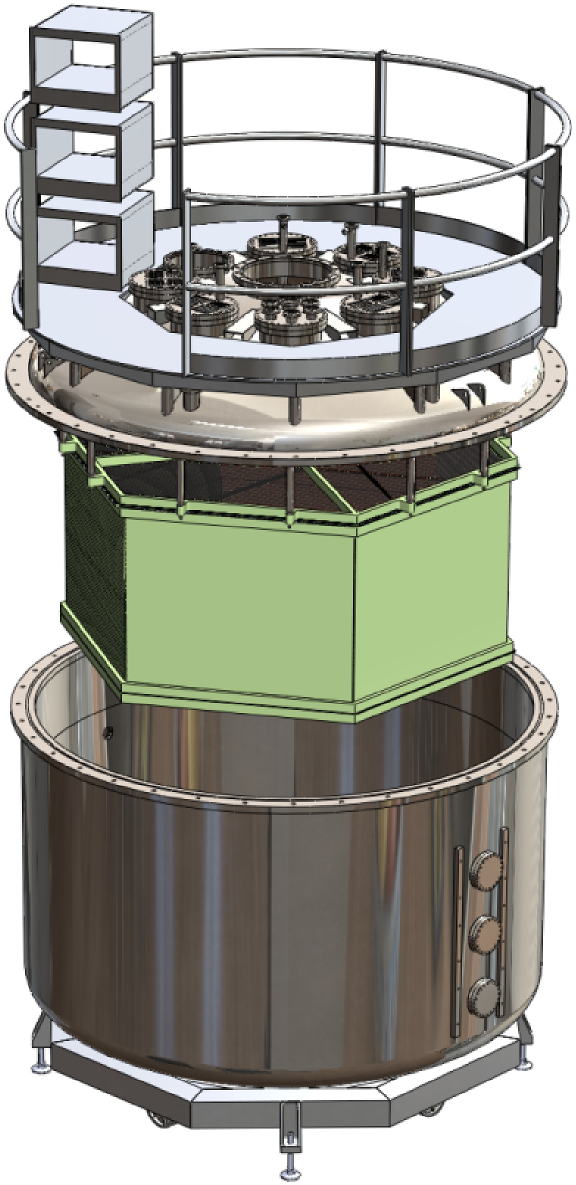
CAPTAIN

- **Goals:**
  - Gain experience with LArTPCs.
  - Address issues relevant for future neutrino oscillation experiments like LBNE
- **Physics program:**
  - Neutron beam run @ Los Alamos

    → spallation studies, background for ν_e appearance
  - NuMI beam run (2-10 GeV) @Fermilab

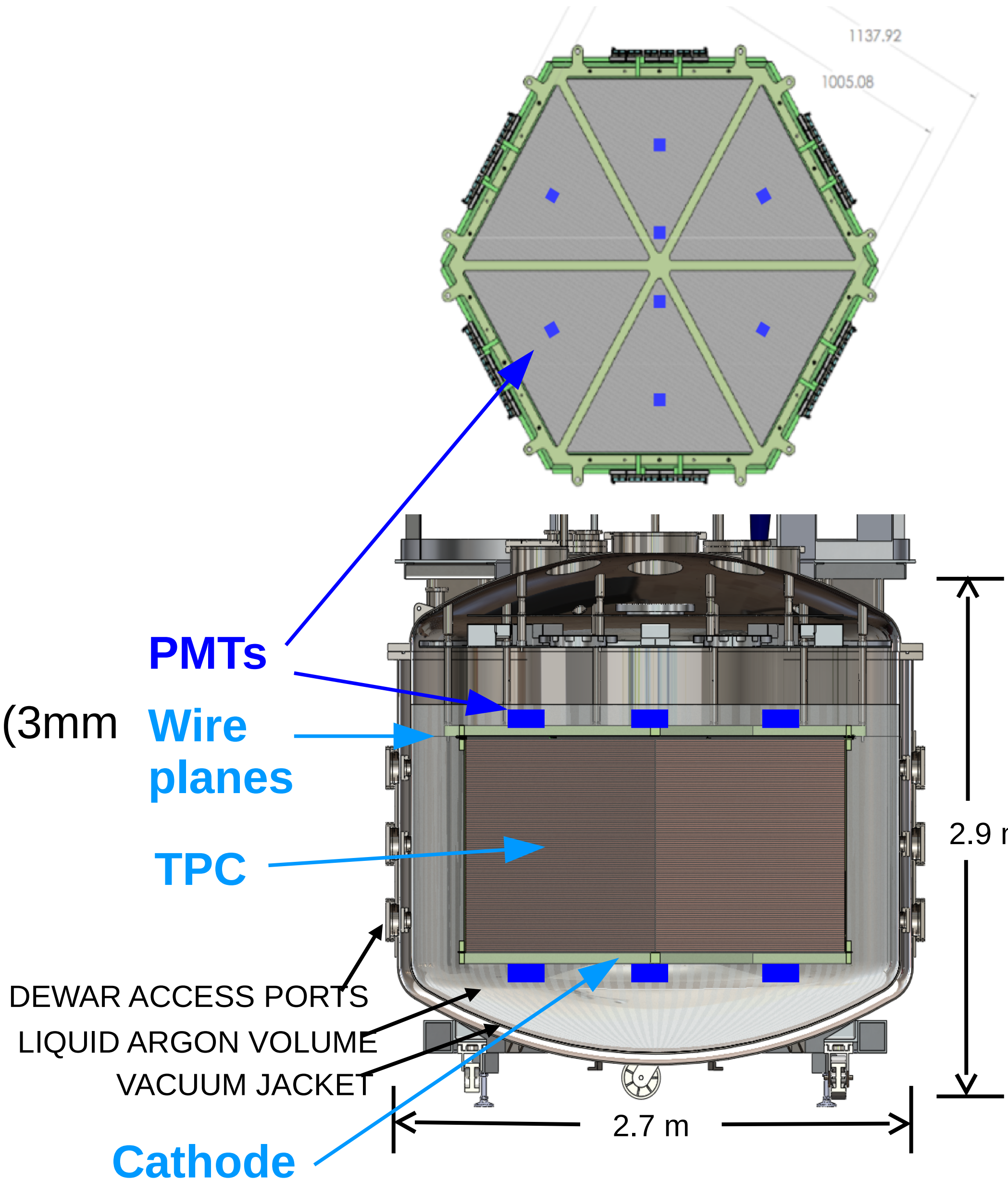
    → neutrino oscillations, cross-sections
  - Stopped pion neutrino run (~50 MeV) @ Fermilab (Booster ν beam)

    → supernova neutrinos, cross-sections



CAPTAIN Design

- **Features:**
  - Portable and evacuable cryostat
  - Portable purification system
  - Hexagonal-shape TPC (1m apothem)
- **Specifications:**
  - 7700 L / 5-ton instrumented
  - 1 m drift distance
  - 500 V/cm drift field
  - 3 wire planes: 2 induction, 1 collection (3mm wire spacing, 667 wires/plane)
  - Mesh cathode
  - µBoone electronics
  - ~20 Hamamatsu PMTs (1 inch)
  - Nd-YAG laser calibration system



Neutron run

- Neutron run at Los Alamos Neutron Science Center WNR facility

  → cosmic-ray energy spectrum

- Study LArTPC response to neutrons

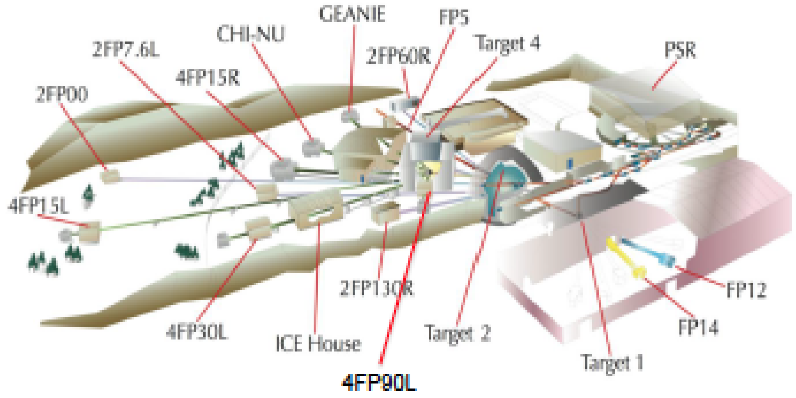
  → characterize reconstruction efficiency (multi-particle events at high energy)

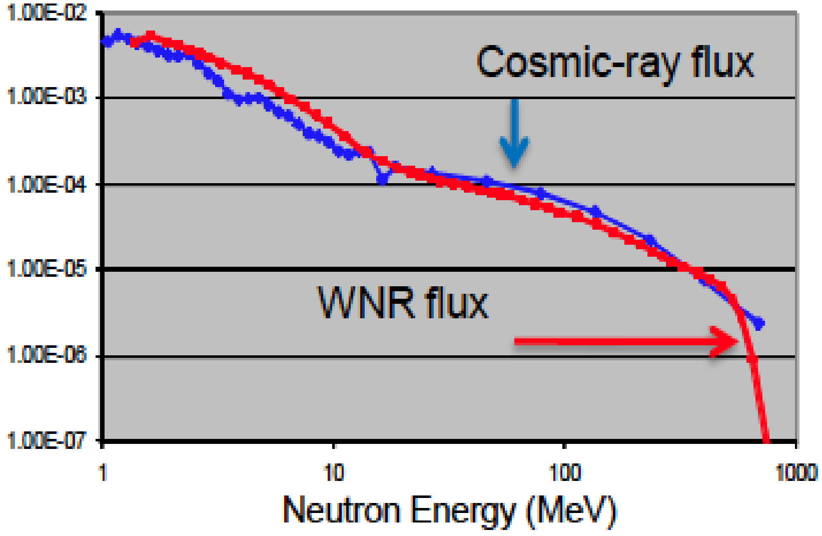
- Measure neutron production and event signatures

→ constrain number and energy of emitted neutrons in ν interactions

→ single particle mode allows independent neutron kinetic energy measurement with TOF

- Study high-energy neutron-induced processes that can be backgrounds to ν_e appearance





Medium-energy neutrinos

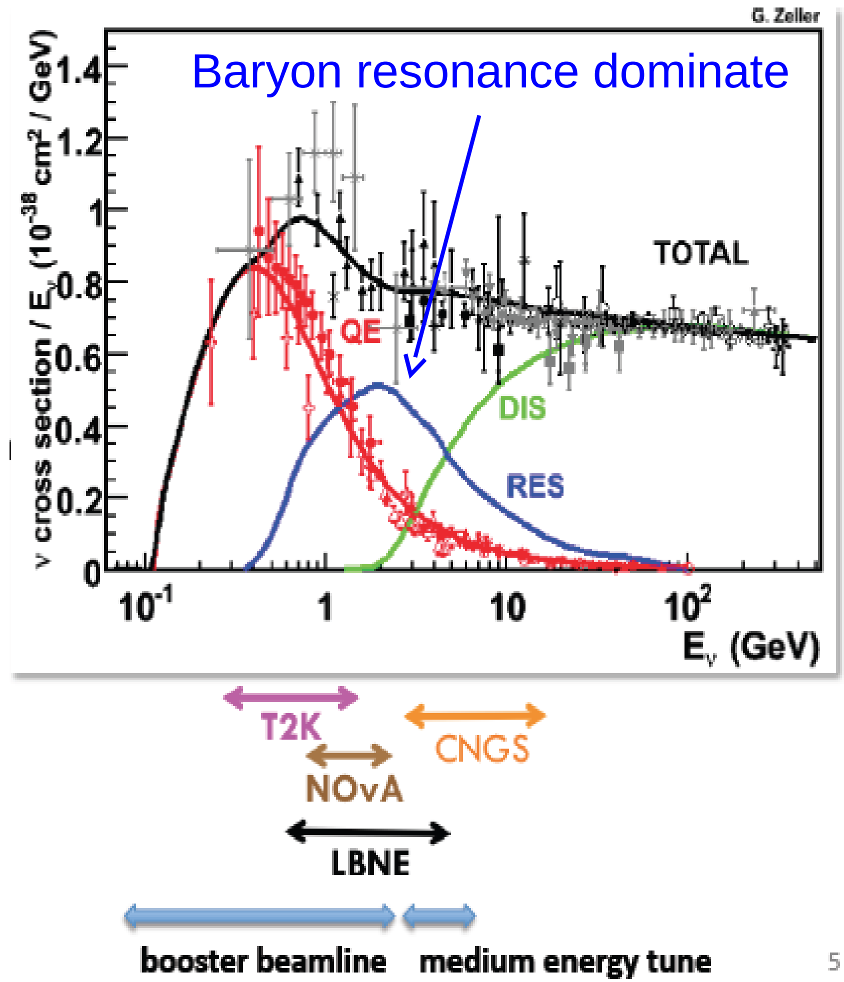
- Use NuMI beam medium energy tune at Fermilab (on axis)

  → ~ 2 – 10 GeV neutrinos

- ~ 25% of events will be contained, excluding muons and neutrons
- **Expect 10^6 contained events/year** (~ 670k CC and ~300k NC)
- Measure inclusive and exclusive CC and NC ν-Ar cross sections in resonant and DIS region → explore threshold region for multi-pion and kaon production
- Develop reconstruction algorithms for:

  → PID in high multiplicity events

  → total ν energy reconstruction with neutron energy



E_ν complementary to μBooNE

Low energy neutrinos

- Place detector near target in the Booster neutrino beamline (~stopped pion source)

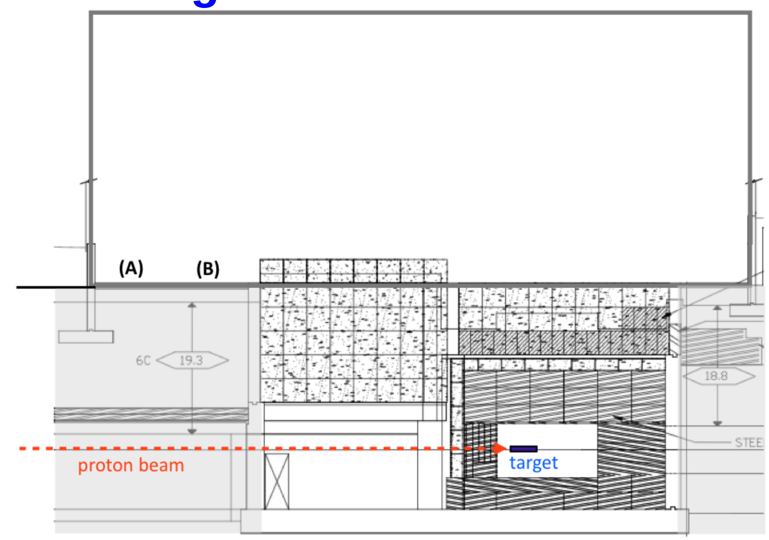
  → neutrinos < 50 MeV, same range as supernova neutrinos

- Expected events / year: few hundred @ 10m from target
- Reduce background (neutrons) by adding shielding
- Measure the neutrino CC and NC cross-sections on argon

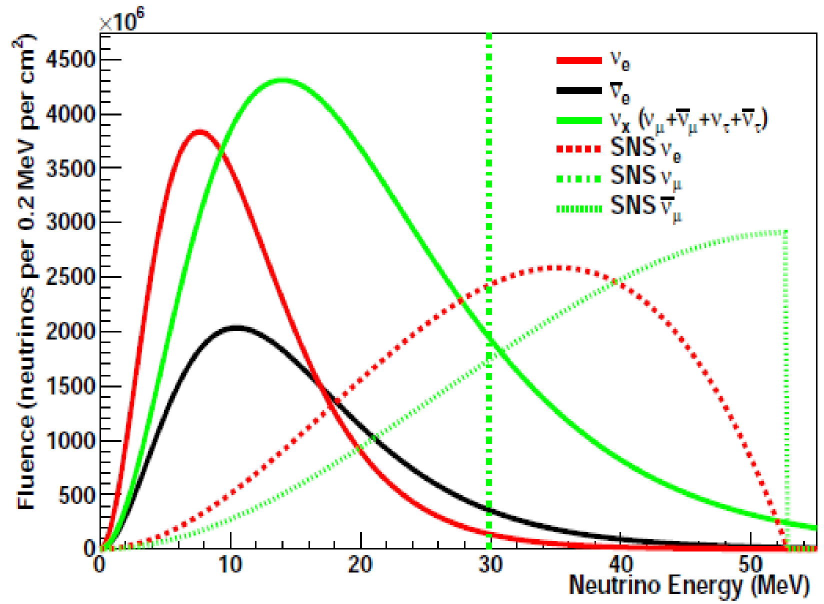
  → first time measurement at this energy!

- Study the correlation visible energy vs. true neutrino energy

BNB target hall



Supernova ν spectra



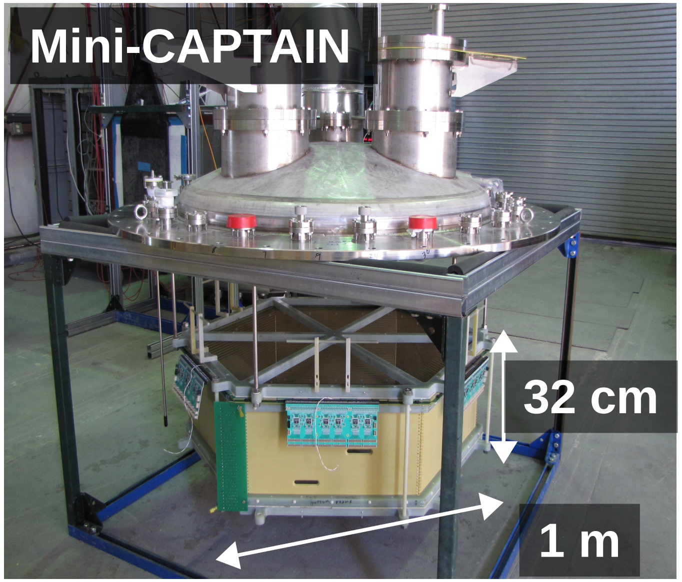
Current status & Schedule

- CAPTAIN prototype "Mini-CAPTAIN" (1m diameter, 32cm drift):

  → commissioning with cosmic rays: summer 2014

  → neutron run @ Los Alamos: fall 2014

- Full sized detector should be ready by the end of the year



Conclusions

- Two new complementary LArTPCs will start taking data this year!
- The results provided by both will be critical for future neutrino experiments such as MicroBooNE and LBNE
- Numerous cross-sections at energies ranges relevant for neutrino experiments will be measured
- Reconstruction and PID algorithms will be optimized
- You are welcome to join the adventure!

The collaborations

LArIAT

Imperial College London

University of Cincinnati

Boston University

Manchester 1824 The University of Manchester

Caltech

The University of Chicago

W&M

Syracuse

UCL

The University of Texas at Austin

Michigan State University

University of Texas Arlington

Yale University

UMD Duluth

KEK-JAPAN

CAPTAIN

Los Alamos National Laboratory EST. 1943

Fermilab

Argonne National Laboratory

LSU Louisiana State University

UC Davis University of California

The University of Alabama

Brookhaven National Laboratory

University of South Dakota

South Dakota State University

UCLA

Stony Brook University

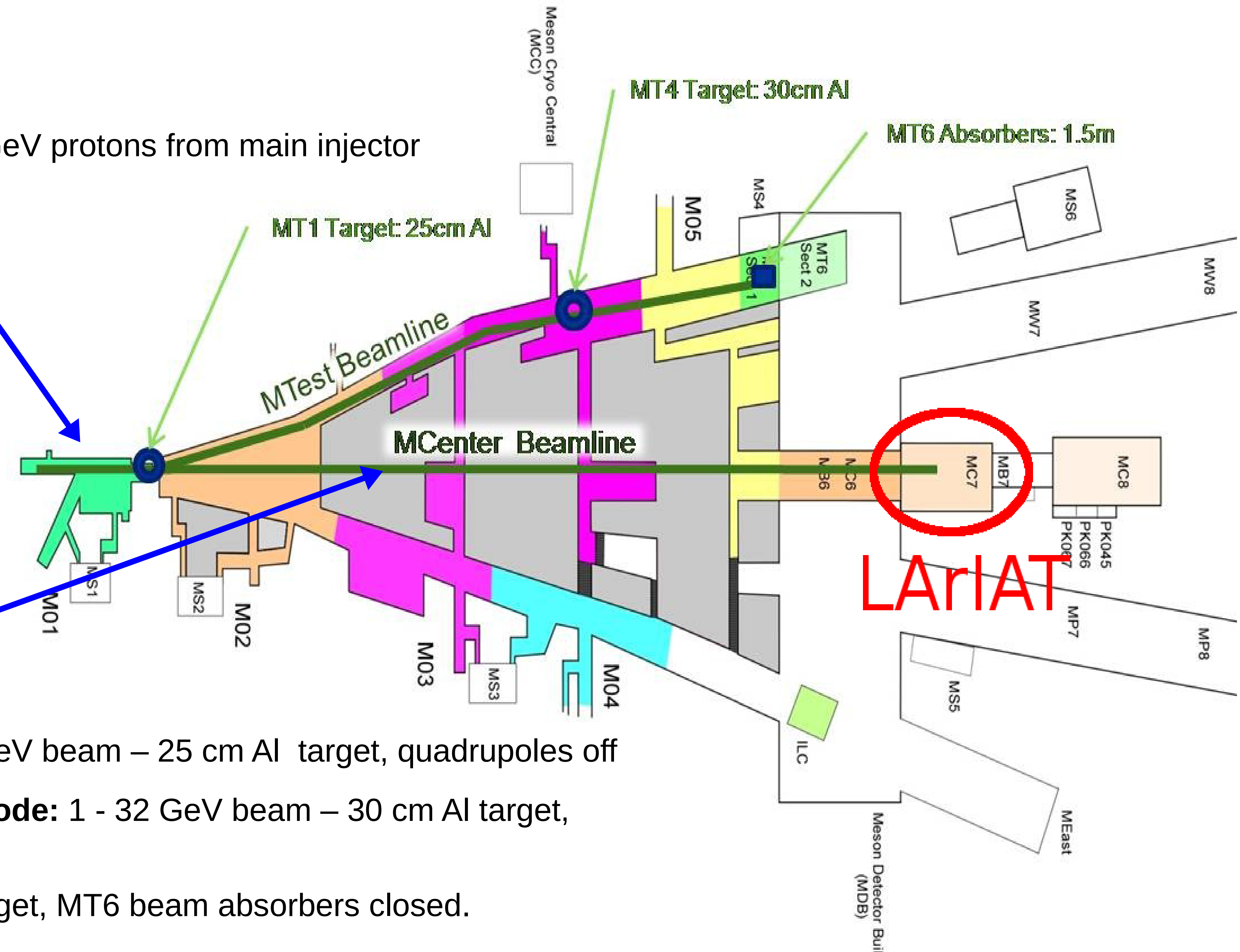
Berkeley Lab

Back-up

Test-beam @ Fermilab

Primary Beam

Proton Mode: 120 GeV protons from main injector



Secondary Beam

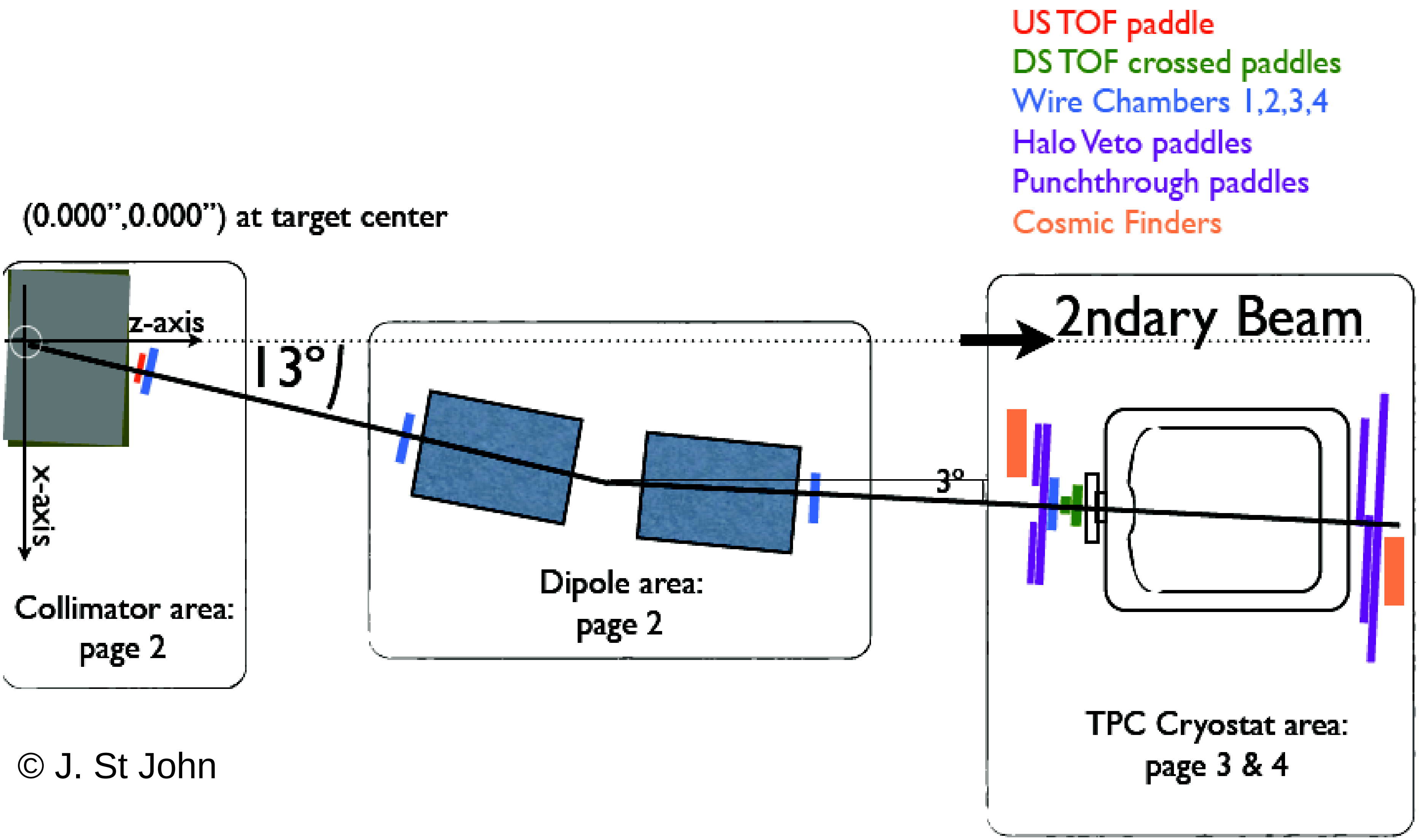
Pion Mode: 8 - 66 GeV beam – 25 cm Al target, quadrupoles off

Low Energy Pion Mode: 1 - 32 GeV beam – 30 cm Al target, quadrupoles on

Muon Mode: Any target, MT6 beam absorbers closed.

→ best rates in Low E Pion Mode at 32 GeV

Tertiary beamline instrumentation



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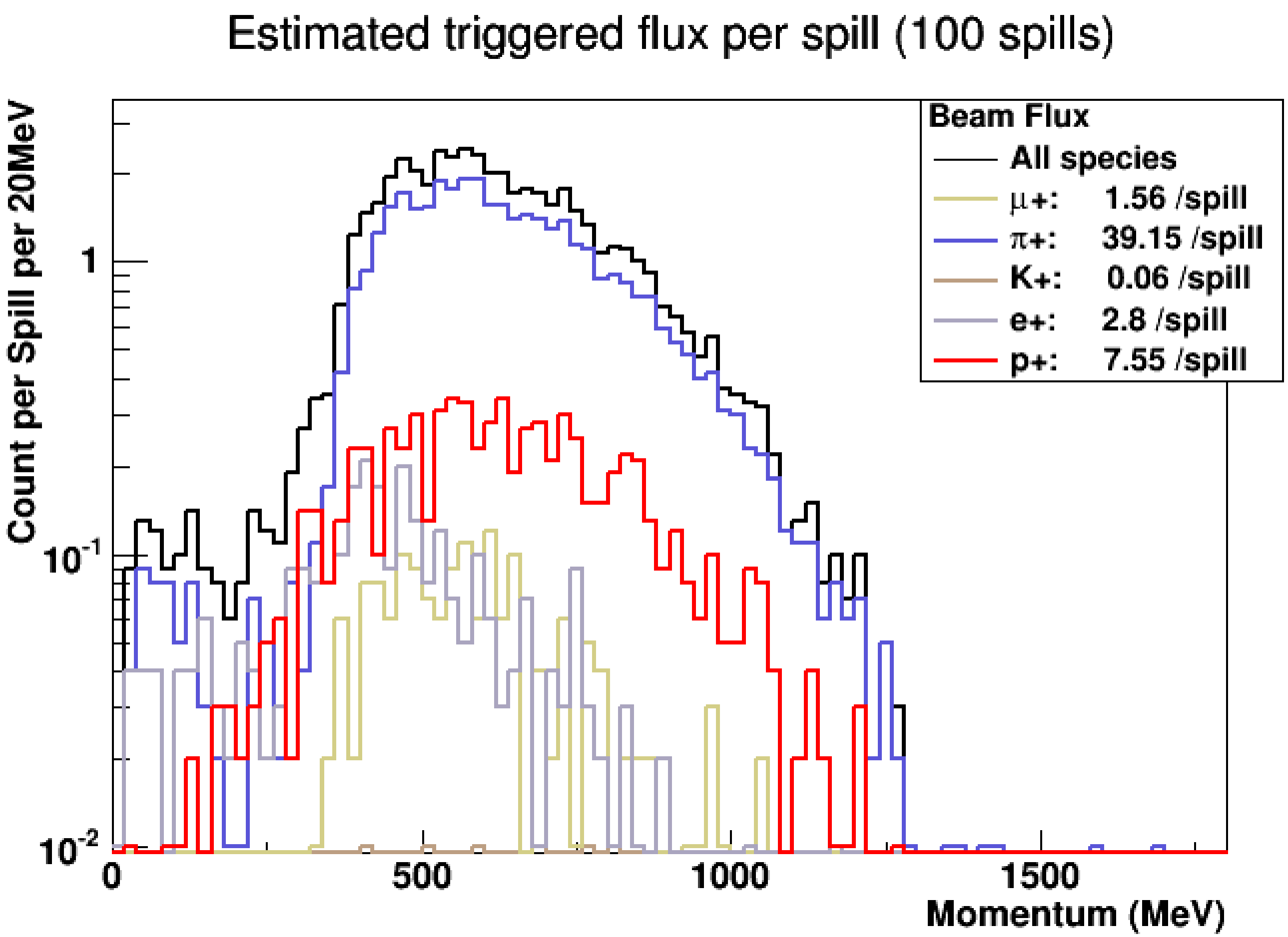
Tertiary test-beam at Fermilab



Signal detection

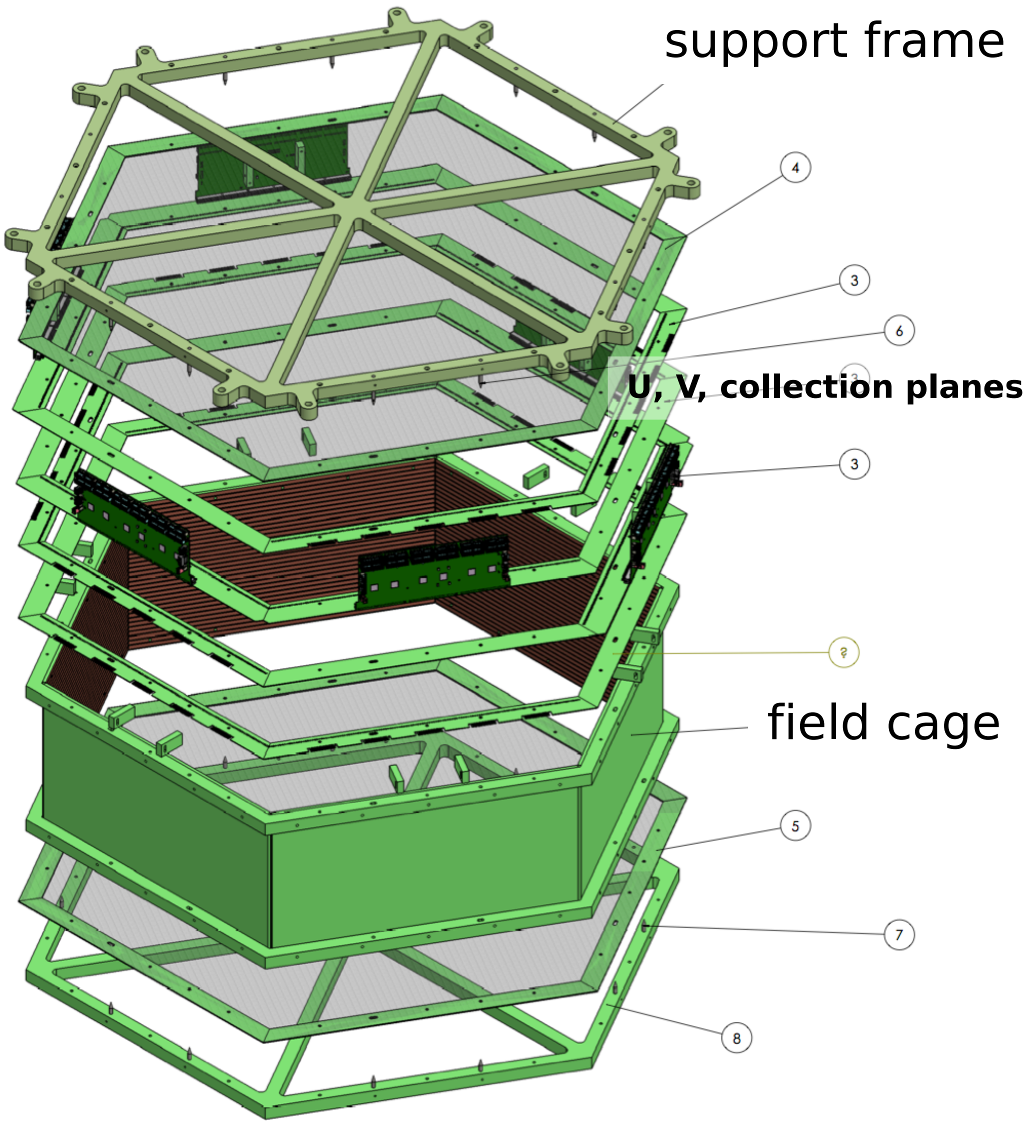
3 detection planes (U, V, collection)
667 wires each plane, 3 mm space
~2000 readout channels
75 µm diameter CuBe wire

Frames are made of FR4 glass fiber composite

1m maximum drift distance (vertical)

Electric field 500 V/cm
Drift velocity 1.6 mm/µs

Same electronics as MicroBooNE



Photon detection

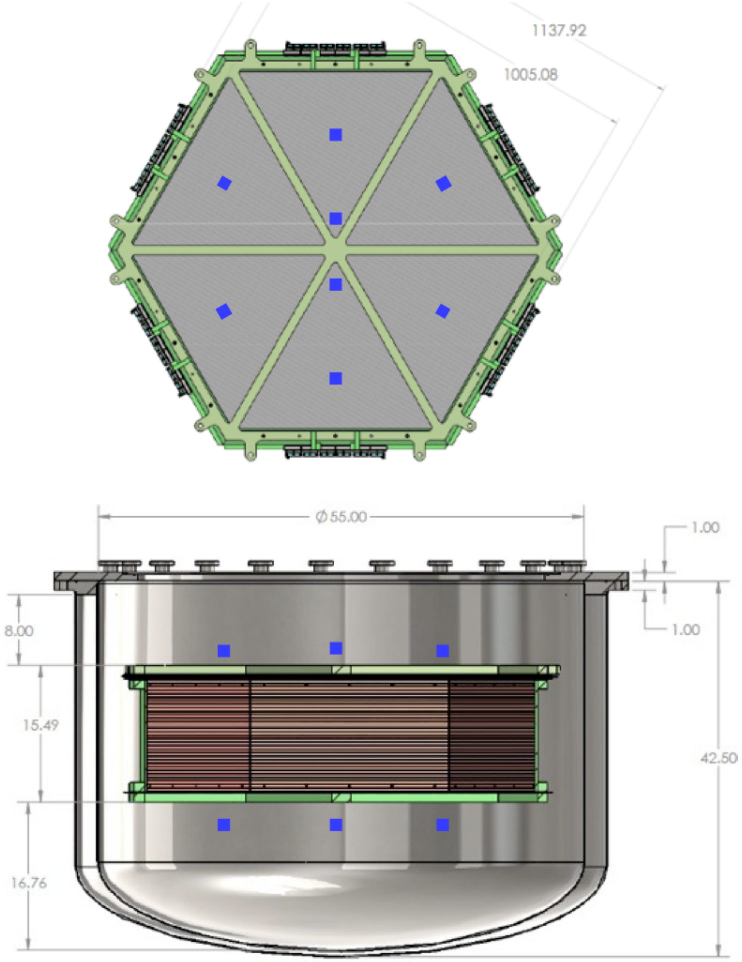
16 Hamamatsu R8520-500 PMT

Trigger for non-beam events

Can help improving the energy resolution

Serves as TOF for neutron run

Test other types of wavelength shifter and PMTs for LAr detectors



Laser Calibration System

Quantel "Brilliant B" Nd-YAG laser

Wavelength	1064 nm	532 nm	266 nm
Pulse Energy	850 mJ	400 mJ	90 mJ
Pulse Duration	6 ns	4.3 ns	3 ns
Peak Power	133 MW	87 MW	28 MW
Peak Intensity	1500 GW/cm^2	985 GW/cm^2	317 GW/cm^2
Photon Energy	1.17 eV	2.33 eV	4.66 eV
Photon Flux	8E30 γ/(s·cm^2)	2.6E30 γ/(s·cm^2)	0.42E30 γ/(s·cm^2)

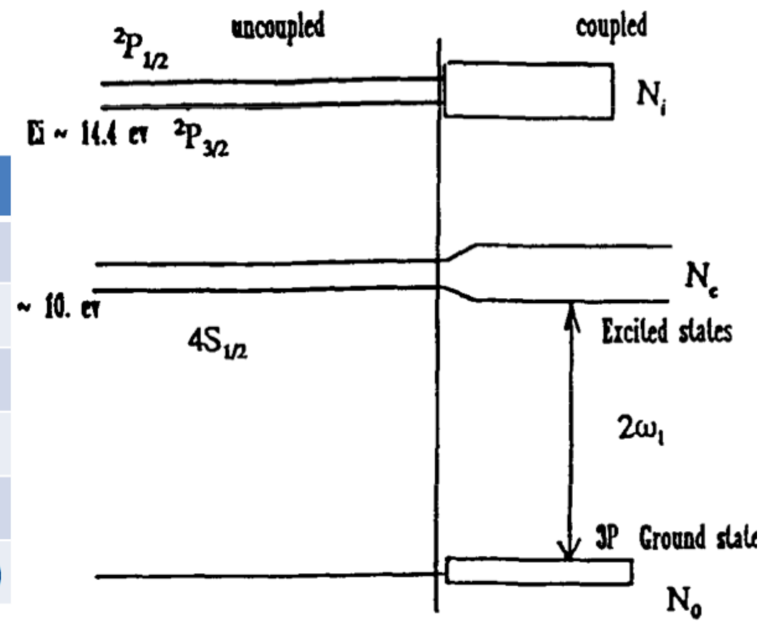
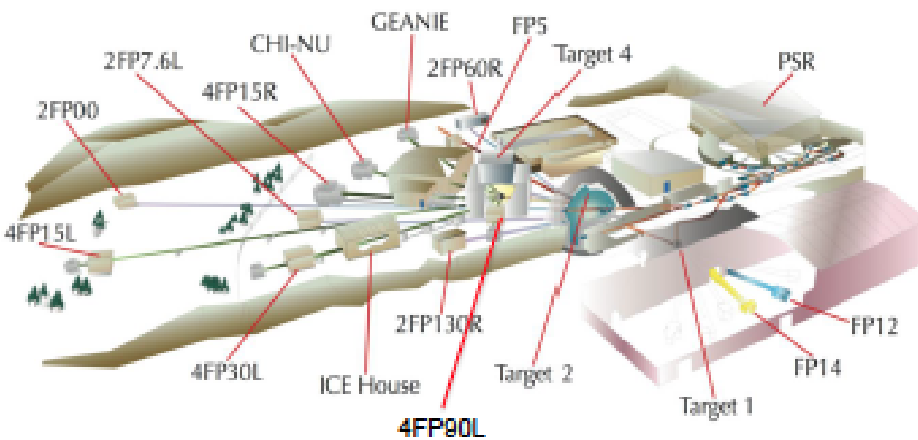


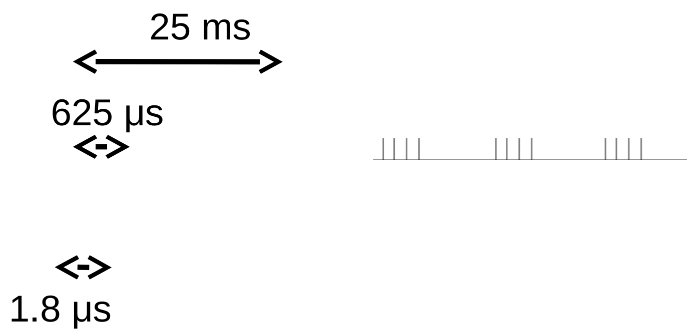
Fig. 5. Liquid argon atom energy level sketch.

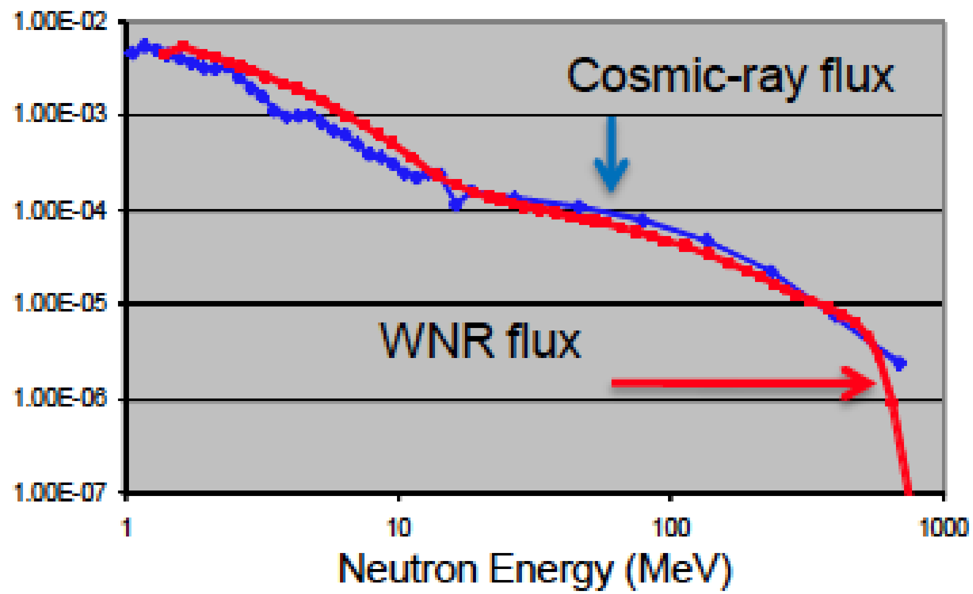
Neutron beam at LANL

- Los Alamos Neutron Science Center WNR facility provides a high flux neutron beam with a broad energy spectrum similar to the cosmic-ray spectrum at high altitude

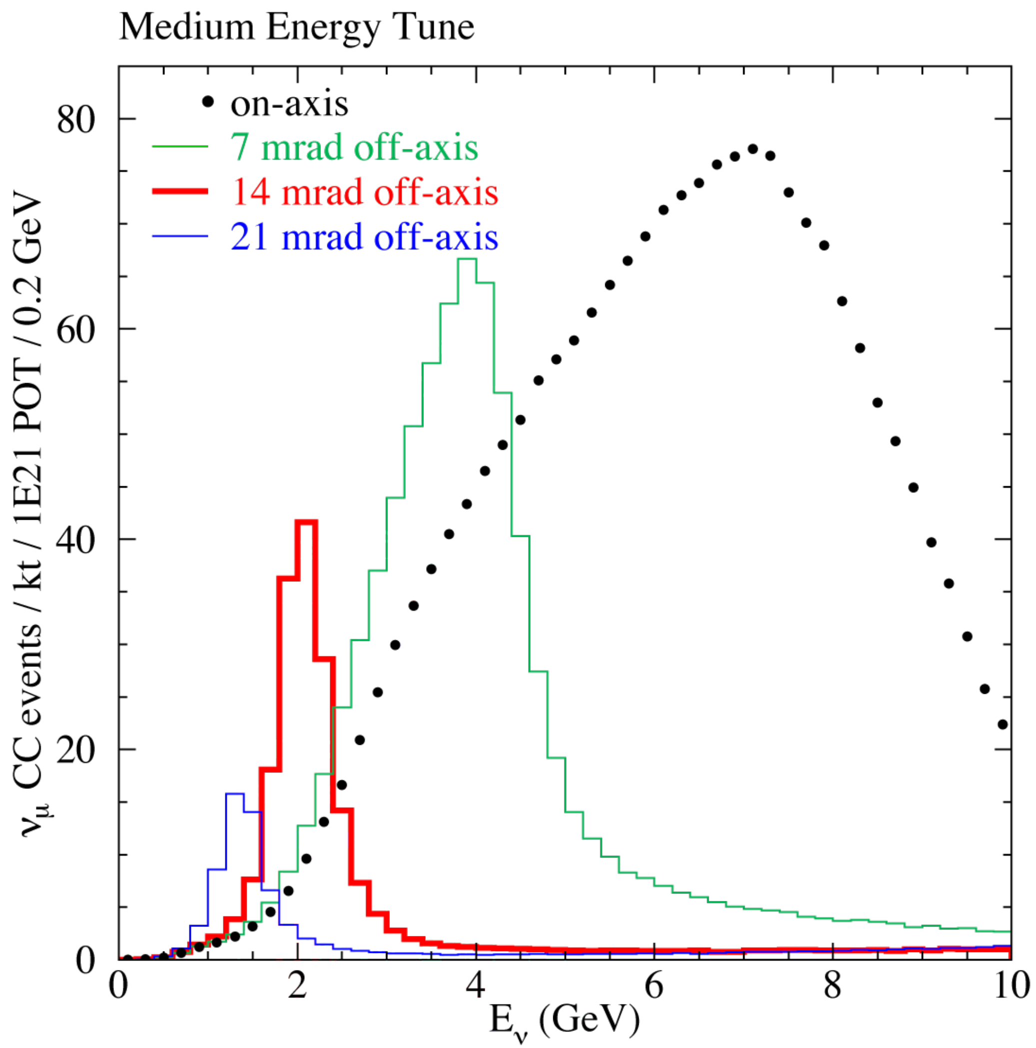


- Time structure of the beam:
  - Sub-nanosecond micro pulses 1.8 μs apart within a 625 μs long macro pulse
  - Repetition rate: 40 Hz



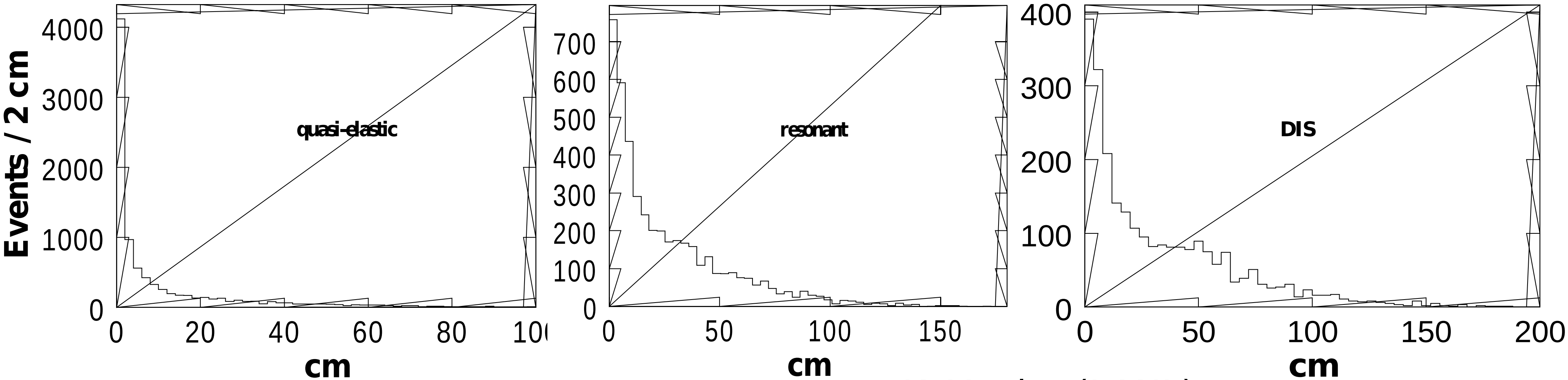


NuMI energy


Medium Energy Tune
on-axis
7 mrad off-axis
14 mrad off-axis
21 mrad off-axis
ν_μ CC events / kt / 1E21 POT / 0.2 GeV
0
20
40
60
80
0
2
4
6
8
10
E_ν (GeV)

Medium Energy Neutrino Run

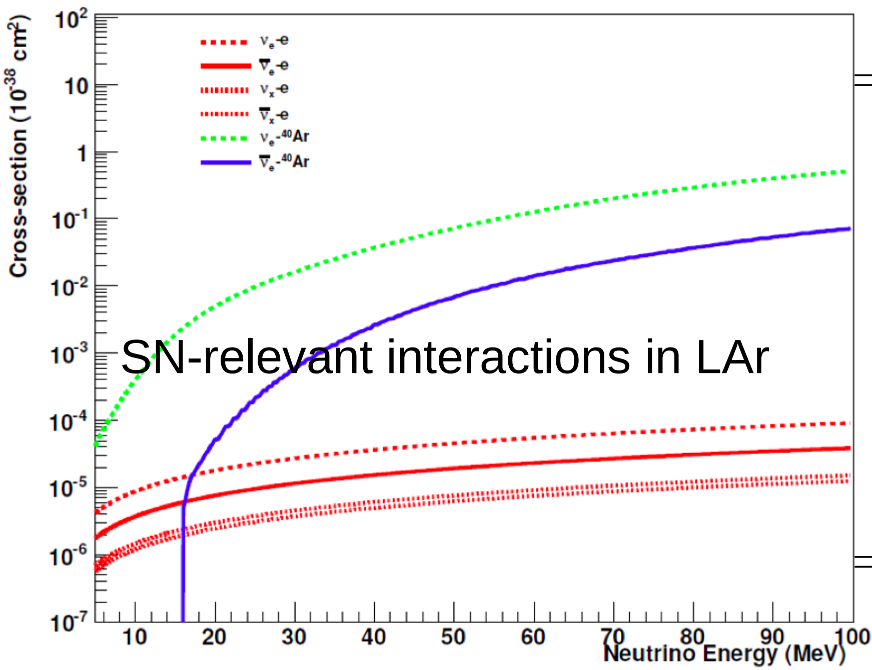
- Plots show the distance from the vertex to the endpoint of the longest track for contained events
- Contained event: particles, except muon/neutron, are contained in the detector
- 10% containment with the chosen size for CAPTAIN
- 106 neutrino interaction per 10^{20} POT; anticipate 4 $x10^{20}$ POT/year
- Expect 370,000 contained CC events/year during a NuMI medium energy run



K. Yarritu (LANL)

Supernova Neutrino (<50 MeV)

- Supernova neutrino studies are great interests to both particle physics and astrophysics
- LBNE: 34 kton LarTPC would detect more than 3000 events from SN at 10kpc
- It also enables mass hierarchy determination



SN-relevant interactions in LAr

		Evts/10 kT LAr@10 kpc (K. Scholberg)
CC	$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$	~ 700 events
CC	$\bar{\nu}_e + {}^{40}Ar \rightarrow e^+ + {}^{40}Cl^*$	~ 60 events
ES	$\nu_x + e^- \rightarrow \nu_x + e^-$	~ 85 events preserve direction
NC	$\nu_x + {}^{40}Ar \rightarrow \nu_x + {}^{40}Ar^*$	~ 70 events Preliminary A. Hayes