Liquid Argon In A Test-beam

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Fermilab Intensity Frontier Seminar

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Outline

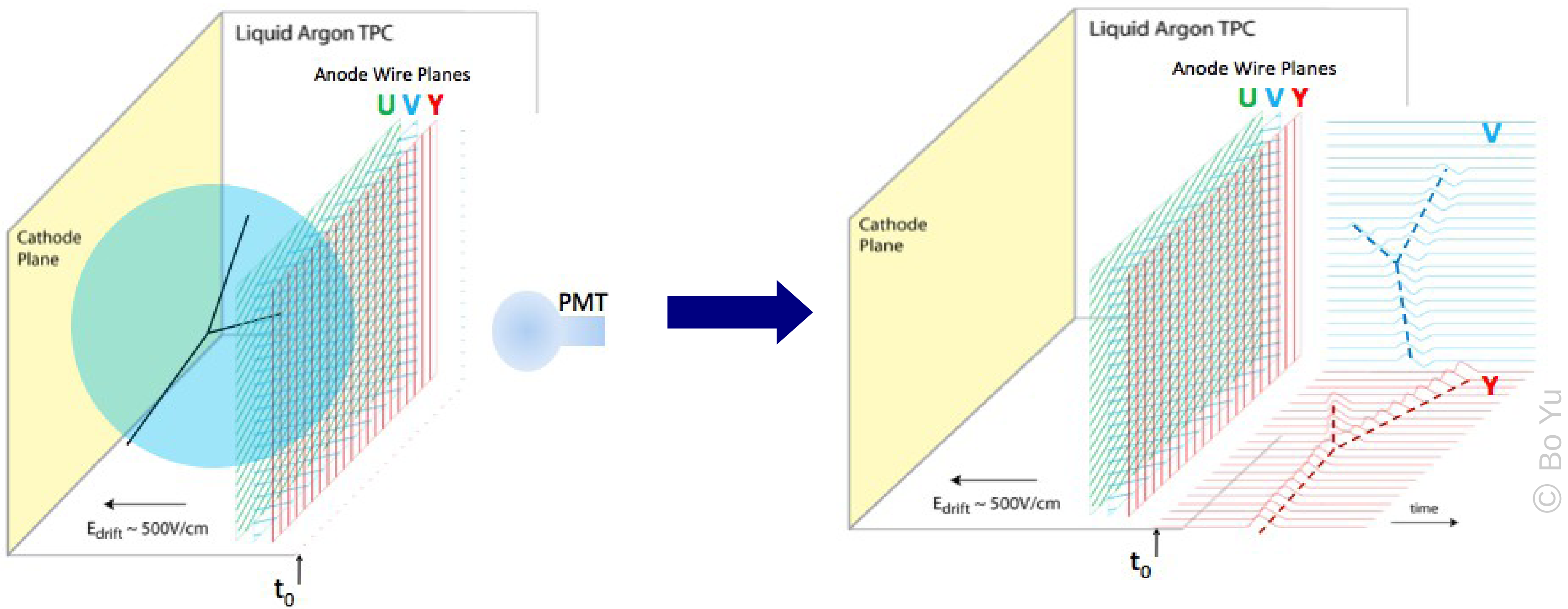
- Introduction : Liquid Argon Time Projection Chambers
- LArIAT:
  - Physics goals
  - The test-beam
  - The TPC design
- Current status
- Conclusion

Introduction: Liquid Argon TPCs

Liquid argon TPCs

- ICARUS was the first experiment to use large scale LAr TPC for neutrino physics
- Liquid argon TPCs are becoming popular in the neutrino community because:
  - They can discriminate photons from electrons, one of the most challenging backgrounds in ν_e appearance studies
  - Charged particles are detected both through ionization (3D tracking) and scintillation (trigger, calorimetry) with great precision
  - Ionization electrons can be drifted over long distances → large detectors possible
  - Study low energy neutrinos → detection of supernovae neutrinos
  - Cross-section measurements over a wide energy range
  - Search for proton decays
- Liquid noble gas detectors have been used for the past few years in dark matter experiments such as DarkSide, MiniCLEAN, LUX, Xenon, XMASS ...

Time projection chambers



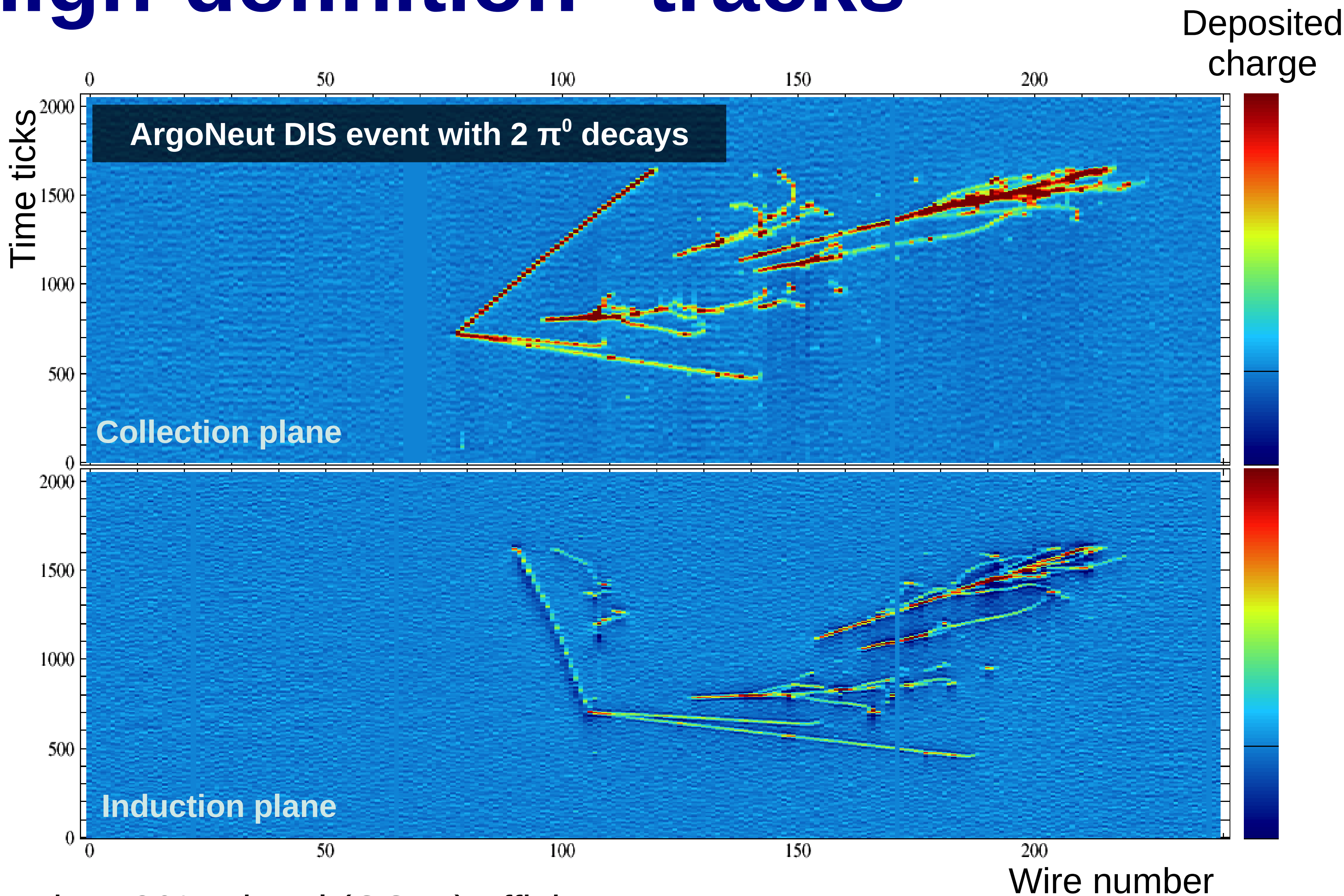
- Time projection chambers allow the 3D reconstruction of charged particles.
- Charged particles crossing the detector ionize the gas / liquid, producing electrons that are drifted towards the readout planes.
- In this case the readout is a series of wire planes, where at least one is an induction plane and the other a collection plane.
- The 3rd coordinate is proportionnal to the drifting time. An external trigger is typically used to set the reference time t_0. If scintillation light is produced, that can also be used as trigger.

Why liquid Argon?

	Water	He	Ne	Ar	Kr	Xe
Boiling Point [K] @ 1atm	373	4.2	27.1	87.3	120.0	165.0
Density [g/cm^3]	1	0.125	1.2	1.4	2.4	3.0
Radiation Length [cm]	36.1	755.2	24.0	14.0	4.9	2.8
Scintillation [γ /MeV]	-	19,000	30,000	40,000	25,000	42,000
dE/dx [MeV/cm]	1.9		1.4	2.1	3.0	3.8
Scintillation λ [nm]		80	78	128	150	175

- Noble liquids are good neutrino targets:
  - if purified, long drifts are possible → large detectors
  - high light yield → triggering and calorimetry (dark matter experiments)
- Argon is abundant (~1% of the atmosphere)
- Liquid argon is cheap: $ 2/L vs $ 3000 /L for Xe or $ 500 / L for Ne

“High-definition” tracks

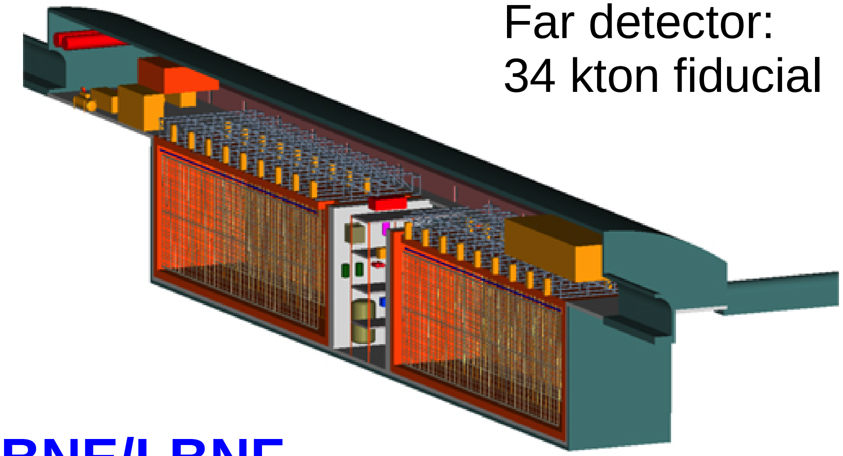


- Better than 80% signal (CC ν_e) efficiency
- ν_e appearance background rejection (π^0) → photon / electron discrimination possible

Large US LArTPCs

MicroBooNE

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

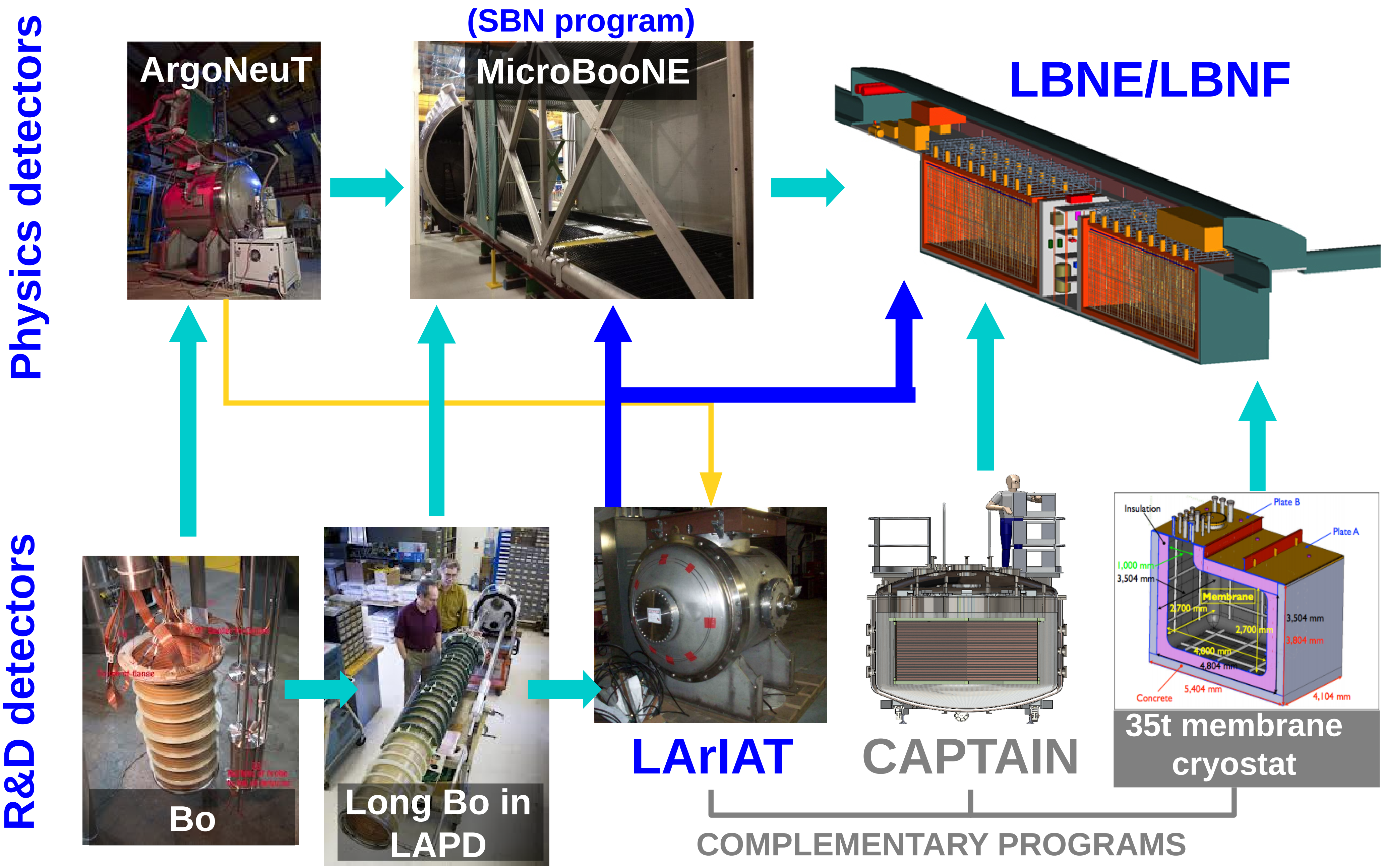


LBNE/LBNF

- 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 an improvement of LArTPC physics tools are needed.

Working together ...

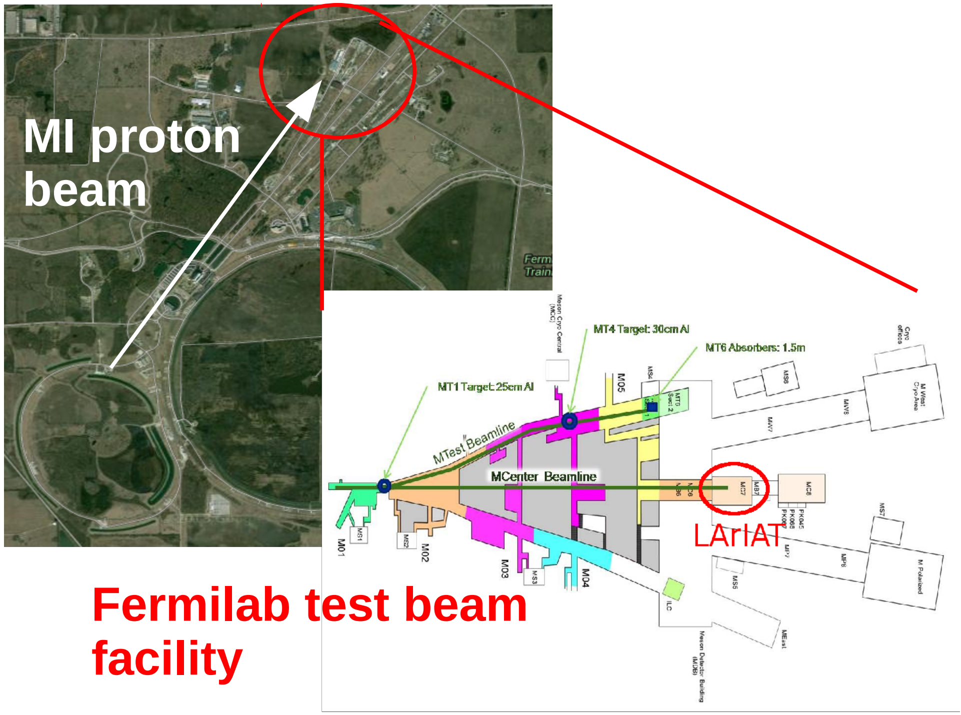


Liquid Argon In A Test-beam

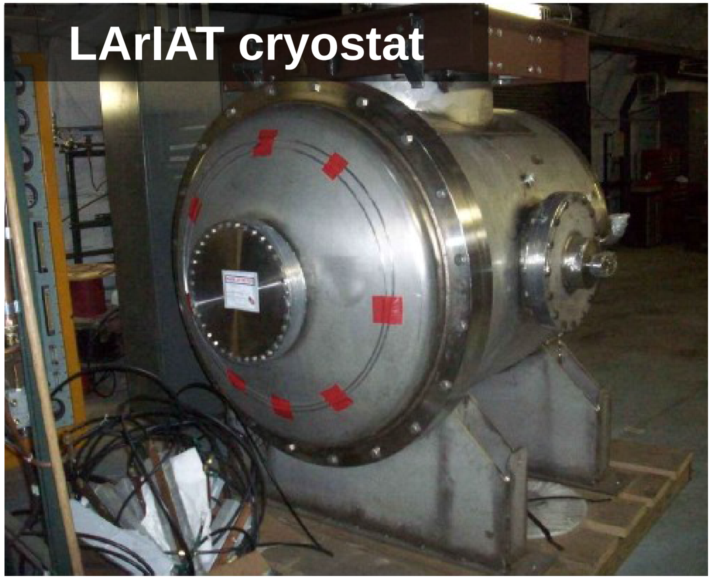
LArIAT

“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:**
  - Pion / kaon cross-sections on LAr
  - Charge/energy calibration
  - Electron / photon shower separation
  - Optimization of particle identification
  - Muon sign determination without magnetic field



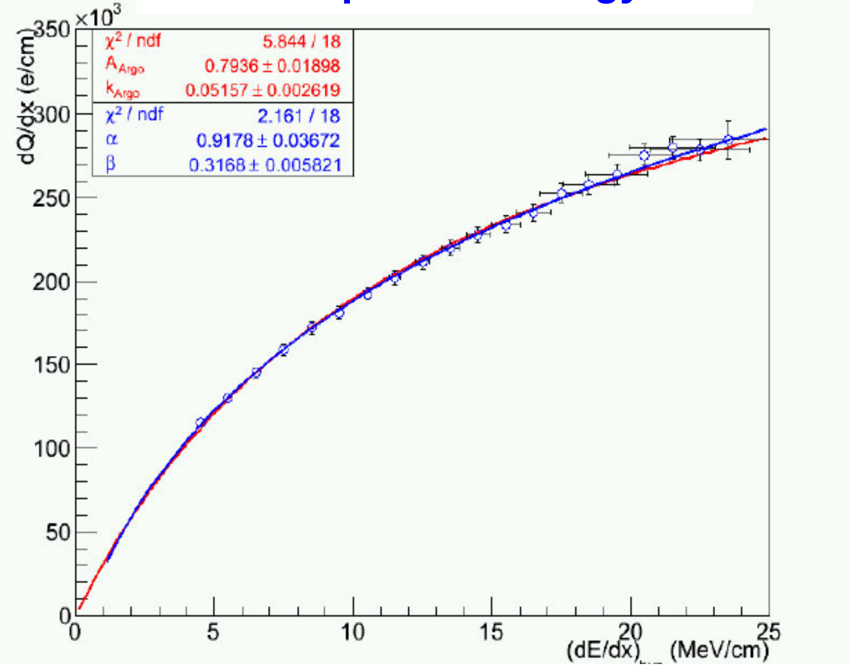
Study neutrino interaction outgoing particles with a dedicated test-beam!

Charge / energy calibration

- Improve energy resolution by combining information from scintillation light and ionization charge signals

  → to maximize light collection efficiency, TPB reflector foil lining has been added to the TPC
- Since there is not a linear correlation between dE/dx and dQ/dx a calibration is needed
- ICARUS and ArgoNeut have provided data to validate the Birks parametrization / Box model up to ~ 20-25 MeV / cm
- LArIAT will study different stopping particles up to ~400 MeV
  - Extend energy deposition range (dE/dx)
  - Different electric field values (0.3 → 1 kV / cm)
  - Different track to field angles

Collected ionization charge vs deposited energy



ArgoNeut, arXiv:1306.1712v1

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: single (e^-) vs double ($\gamma \rightarrow e^+ e^-$) ionization discrimination

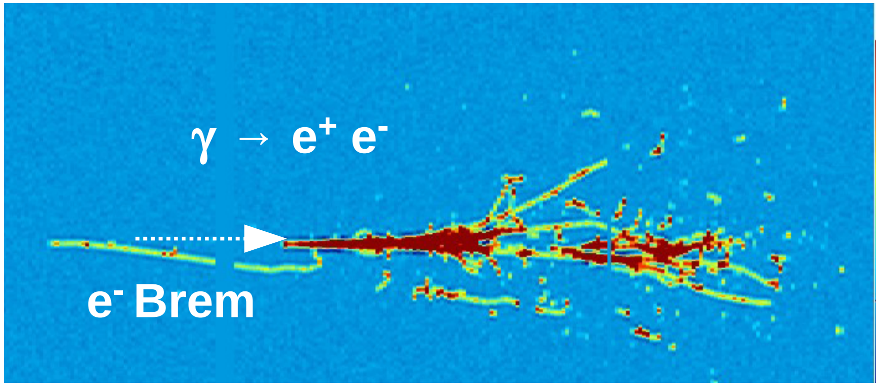
- LArIAT will have a sample of electron and γ events:

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

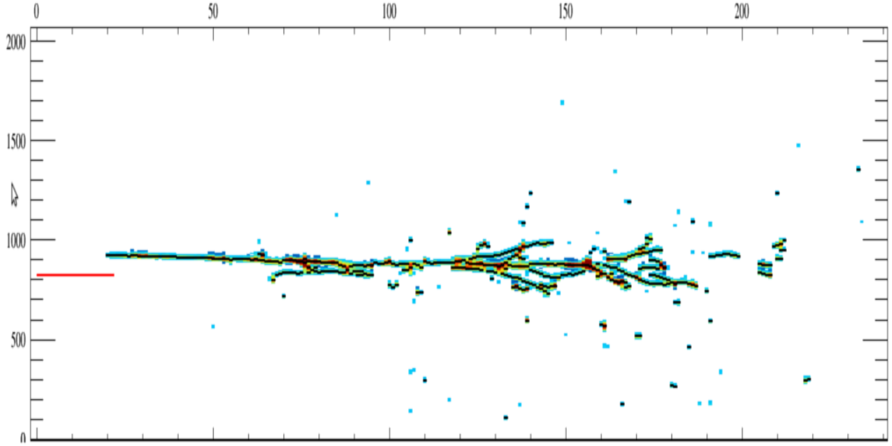
  → tune Monte Carlo simulation

  → develop / optimize algorithms

LArIAT MC: photon shower



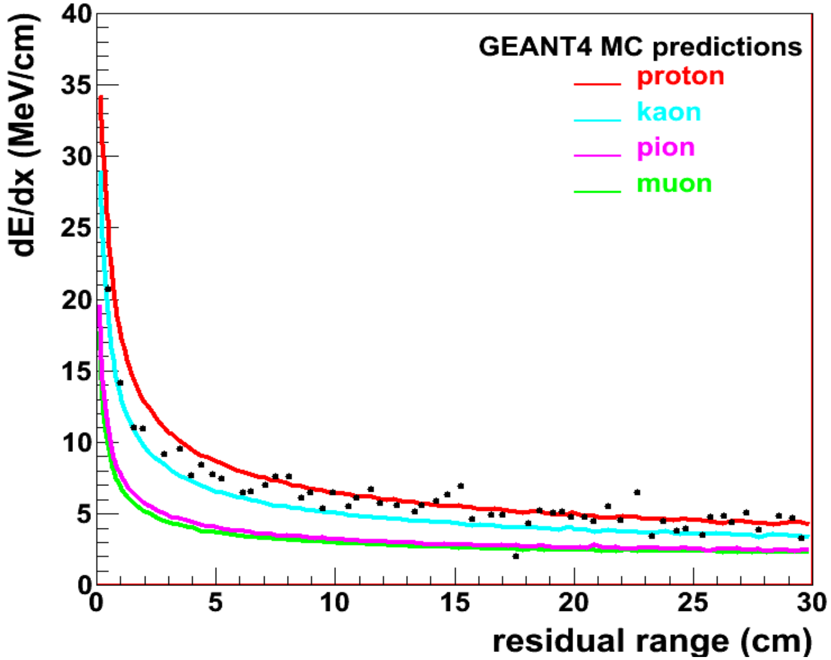
LArIAT MC: electron shower

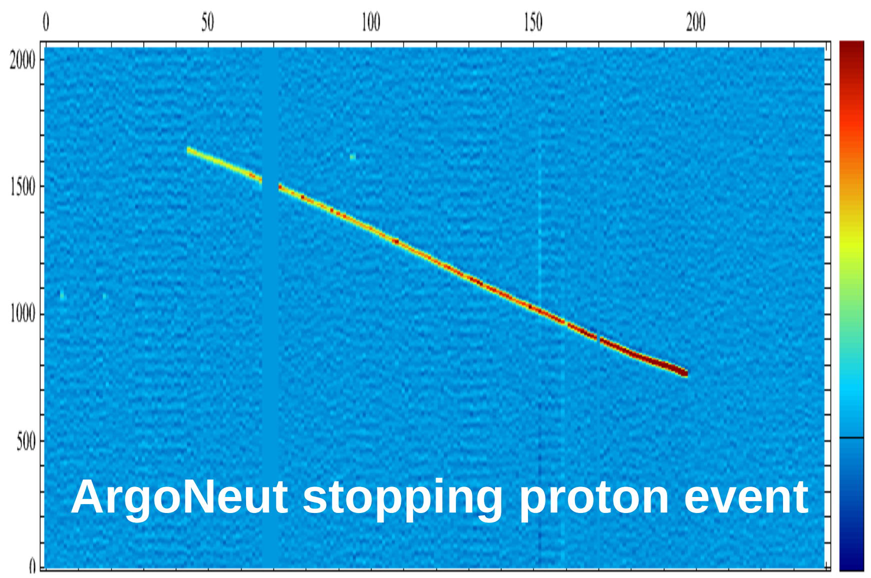


Only the initial part of the shower is necessary for e-γ separation.

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



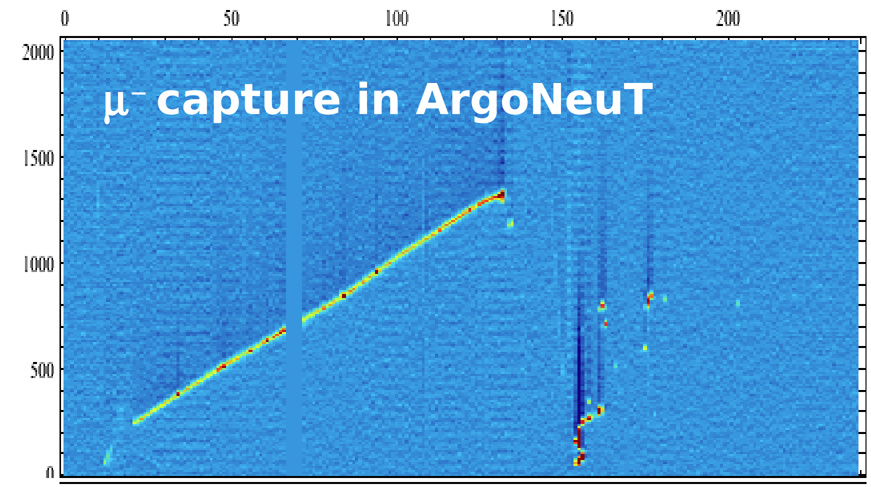


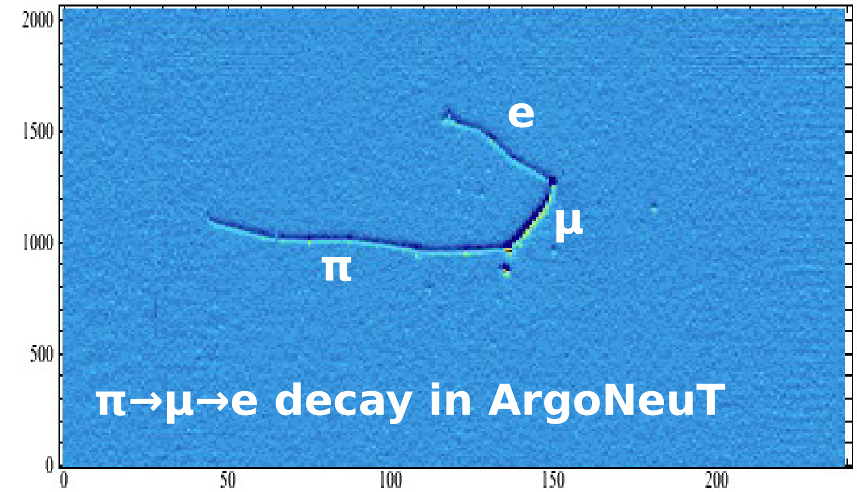
Charge sign determination w/o magnetic field

- 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 followed by γ / n emission ~ 75% vs decay rate ~25%

    → capture rate higher in Ar than in lighter elements

    → systematic study of μ^- capture with LAr TPCs 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)





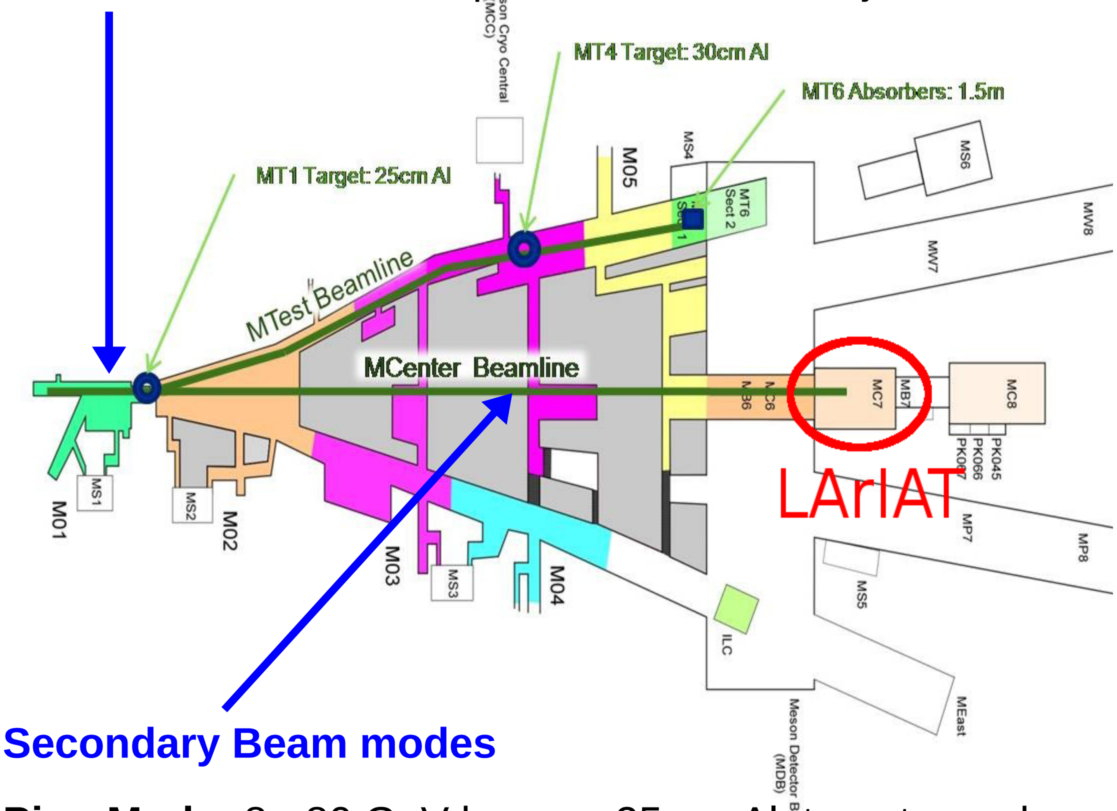
LArTPC sign determination capability has yet to be explored

Test-beam @ Fermilab

Primary Beam

Proton Mode: 120 GeV protons from Main Injector

Fermilab Test-Beam Facility (FTBF)



Secondary Beam modes

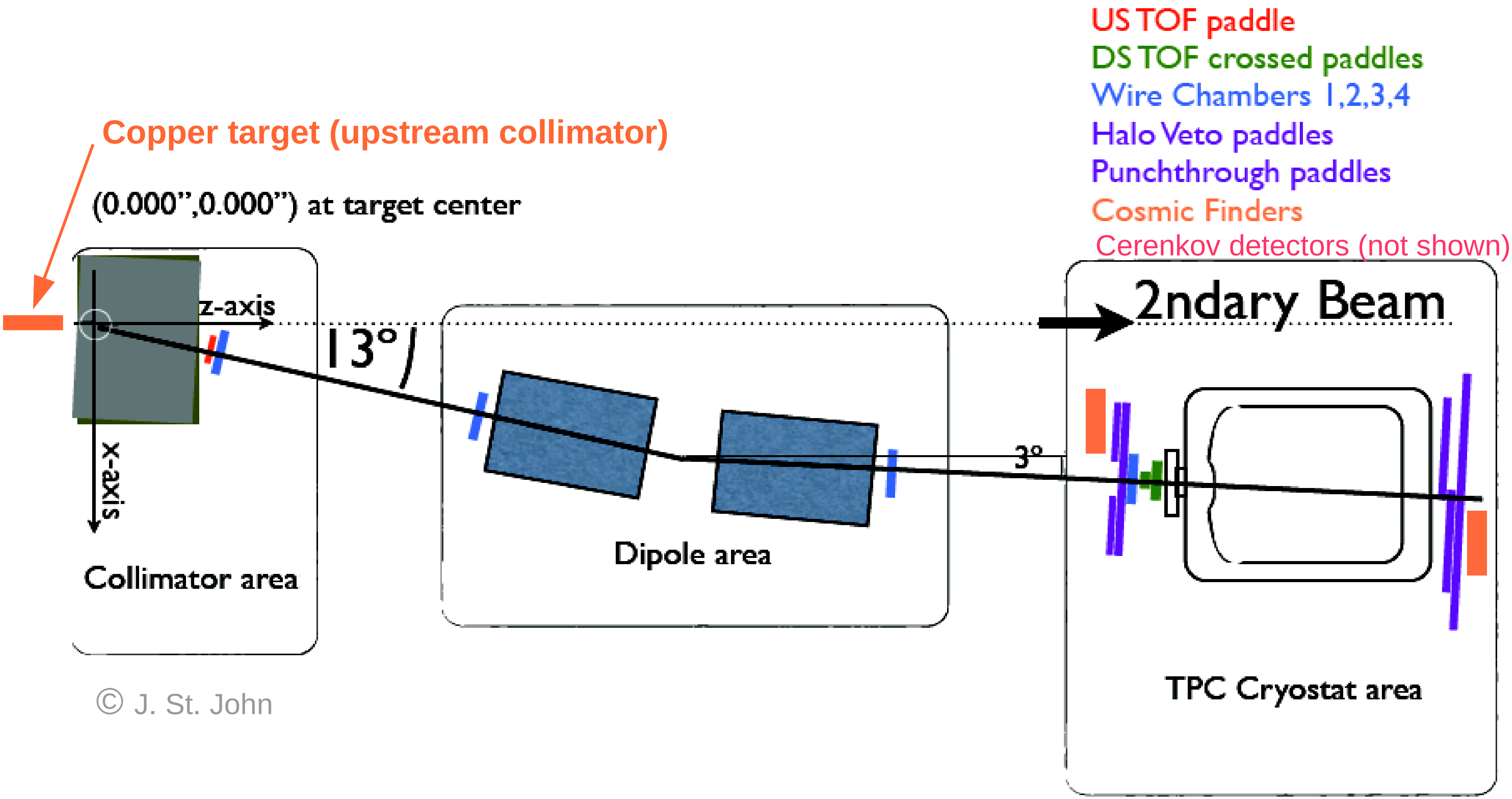
Pion Mode: 8 - 80 GeV beam – 25 cm Al target, quadrupoles off

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

Muon Mode: Any target, MT6 beam absorbers closed.

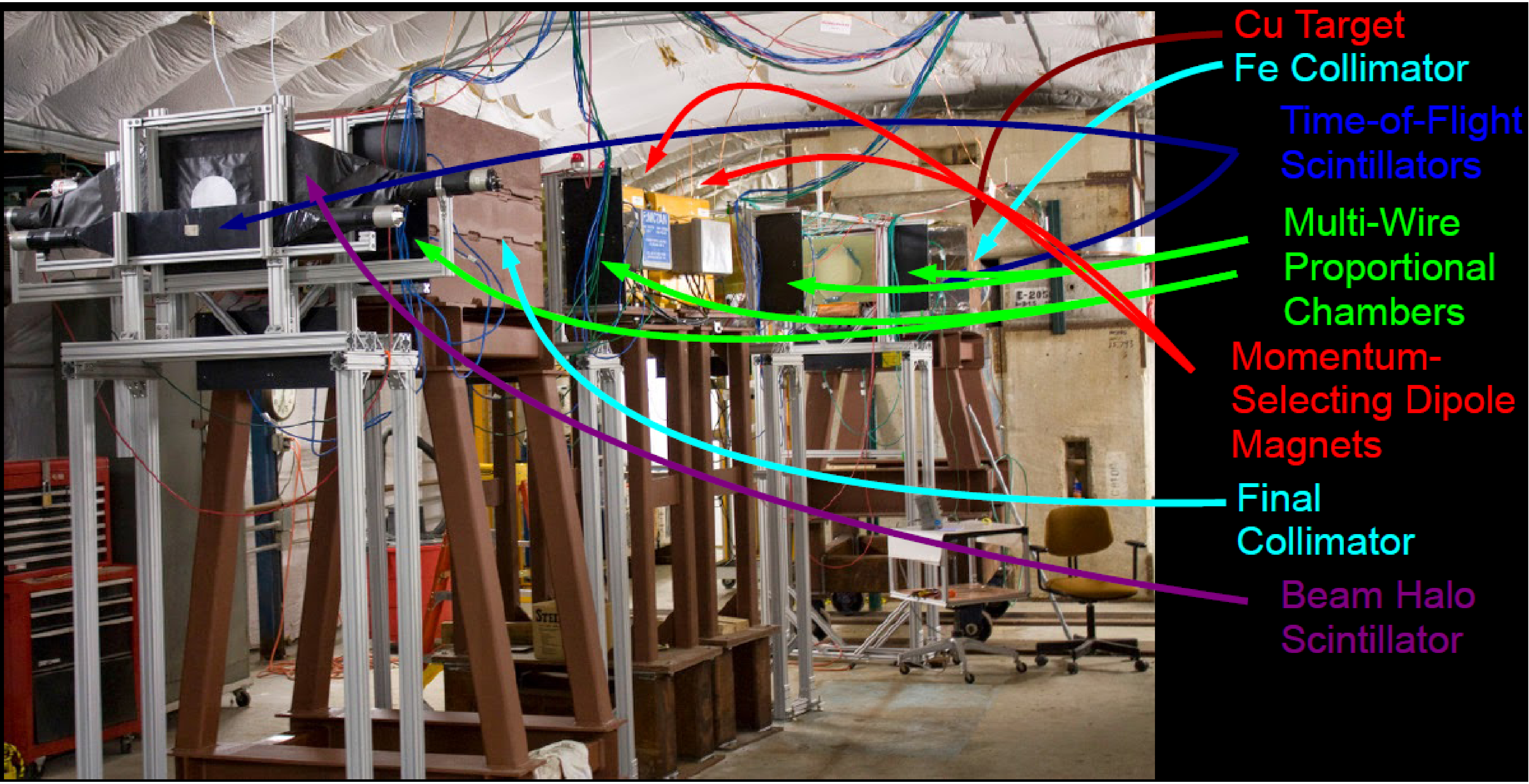
→ best rates in Low E Pion Mode at 32 GeV

LArIAT tertiary beamline



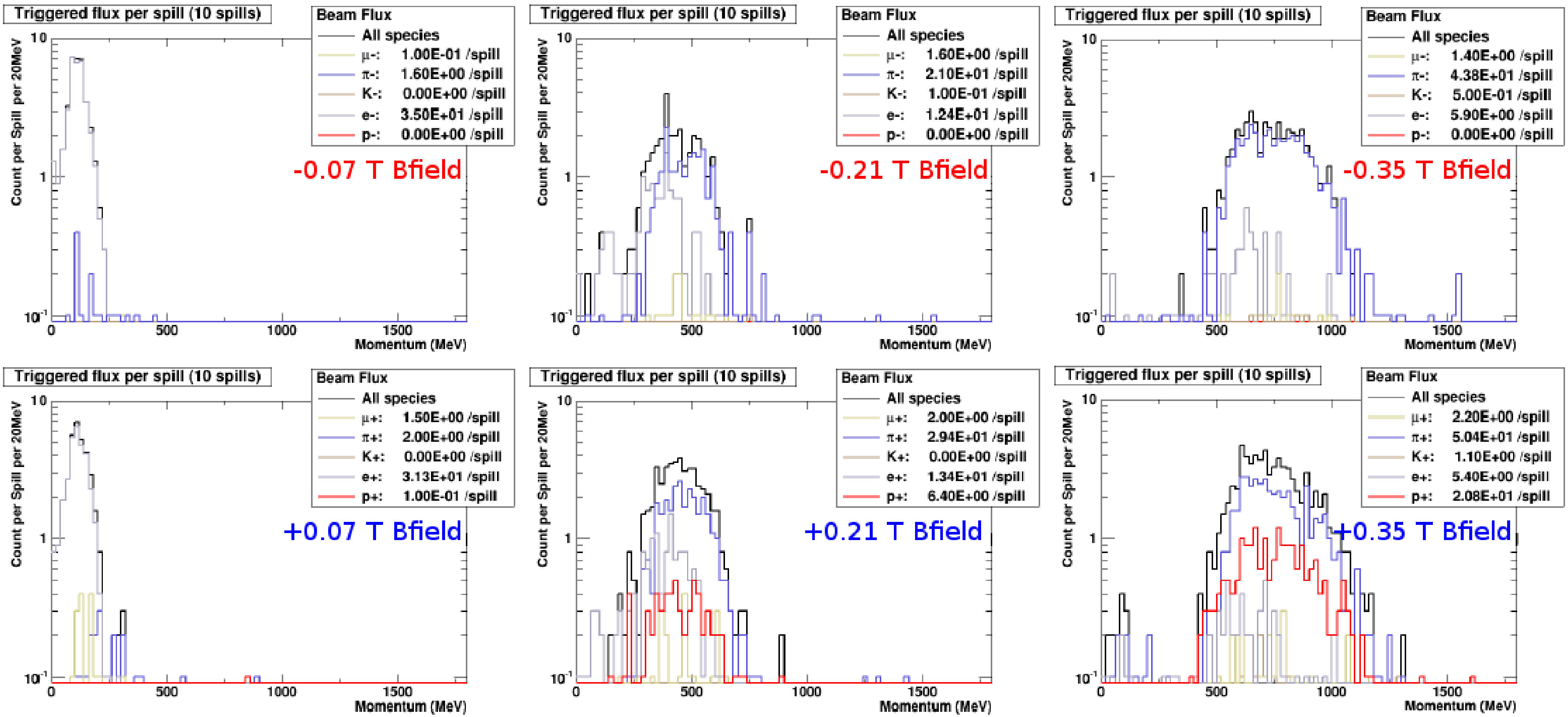
- Dedicated new beam line (0.2 – 2 GeV) → relevant energies for µBoone and LBNE/LBNF.
- The time-of-flight detectors and the wire chambers along the beamline allow the identification of the charged particles entering LArIAT → known particle beam
- A combination of fast detectors is used to trigger the DAQ

Tertiary beamline (upstream view)



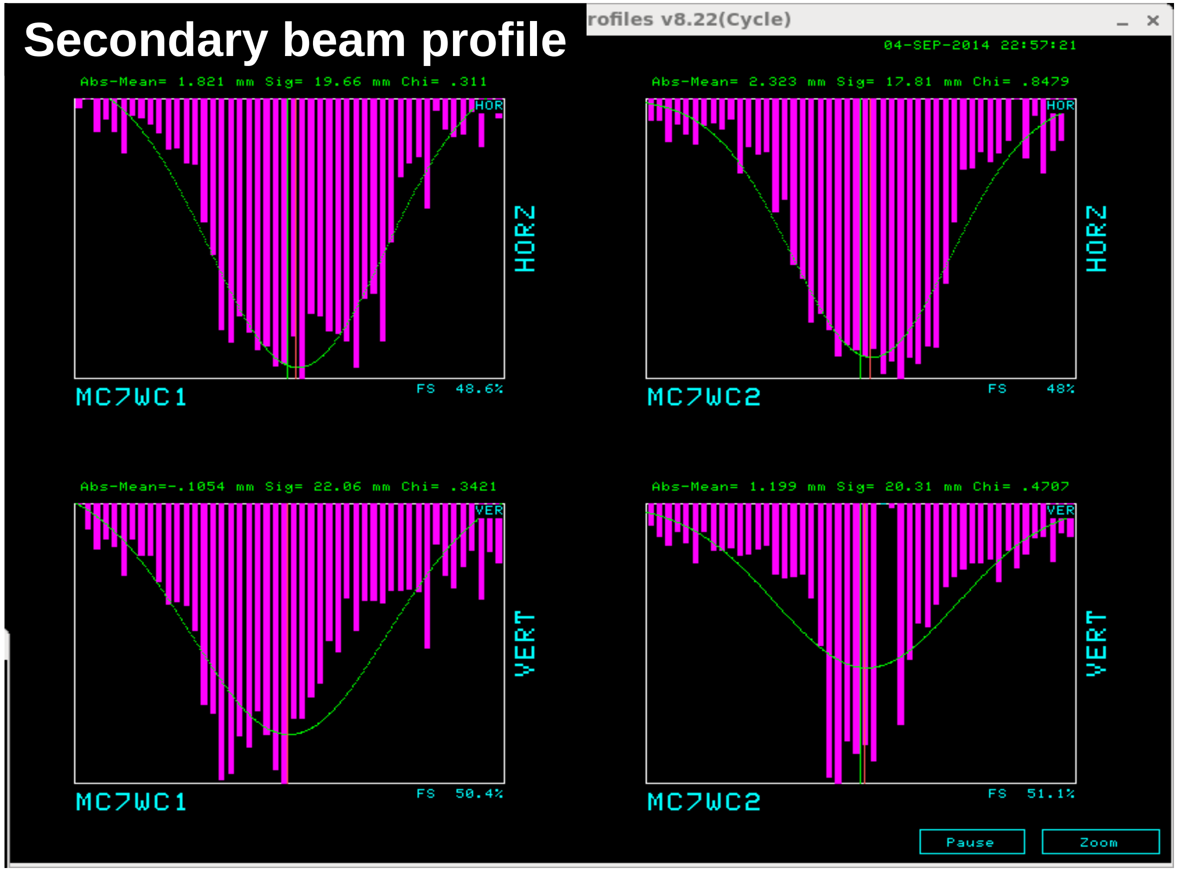
Tertiary beam composition (MC only)

80 GeV π^+ on target



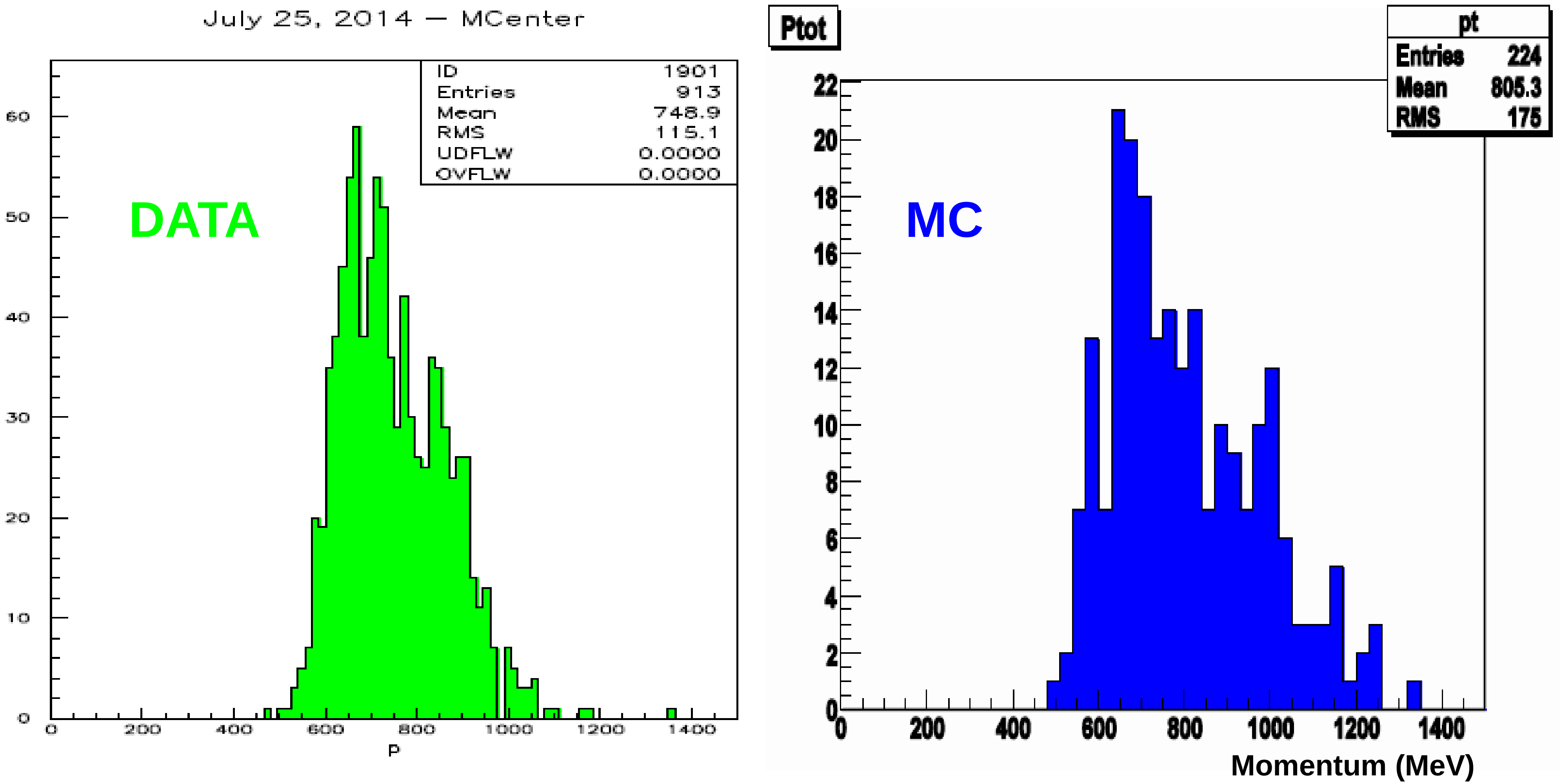
- Secondary and tertiary beam polarities can be switched
- Mostly pions but depending on the energy of the secondary beam and the magnetic field it is possible to change beam composition

Beam commissioning



- Secondary beam successfully commissioned, good beam up to 80 GeV energy!
- Data was collected before the shut down @ 8, 32 and 80 GeV energies with different magnet currents (20, 40, 50 and 100 A)
- Thanks to all the FTBF and Accelerator Division people who did an awesome job in refurbishing the beamline!

Beam data analysis

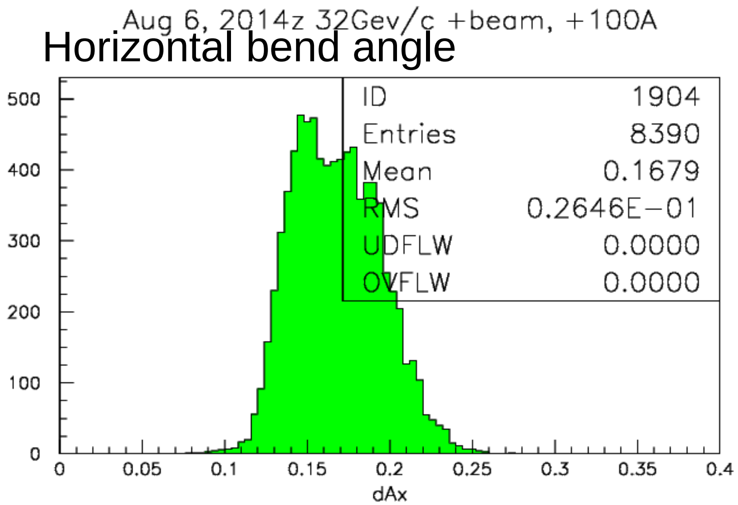


- 32 GeV pions on target (secondary beam)
- Preliminary momentum reconstruction shows that MC is in good agreement with data

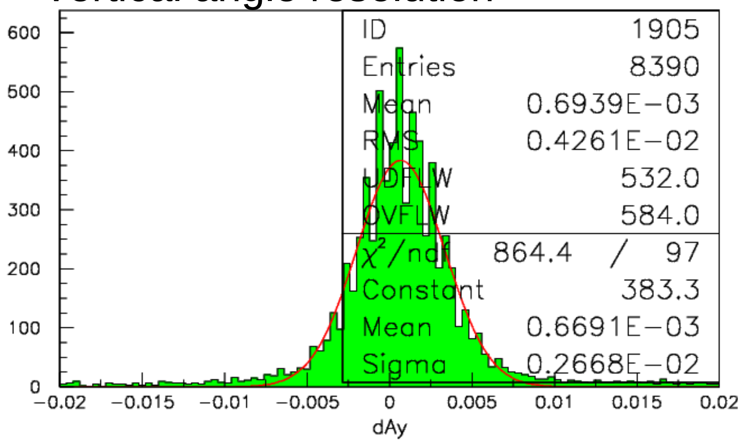
Beam data analysis

32 GeV, 100 A

Horizontal bend angle

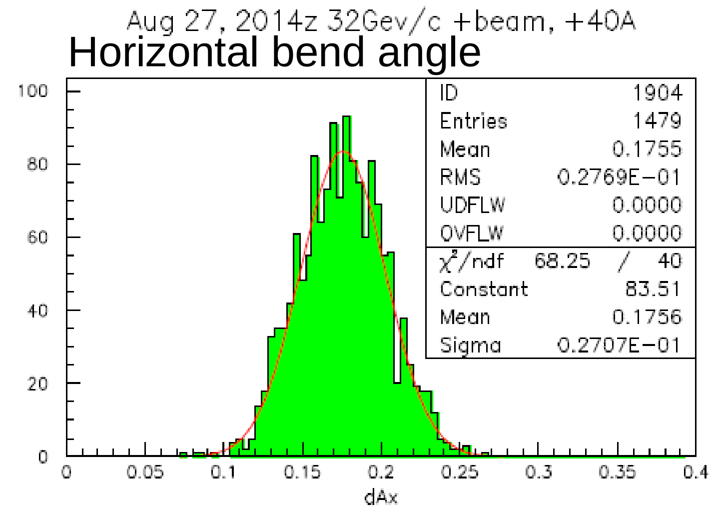


Vertical angle resolution

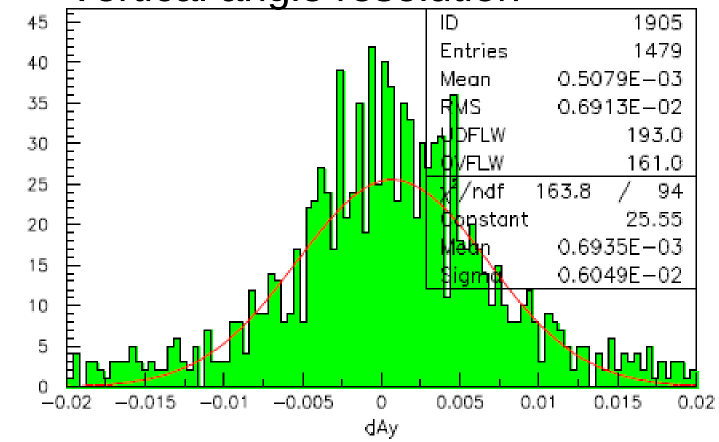


32 GeV, 40 A

Horizontal bend angle



Vertical angle resolution



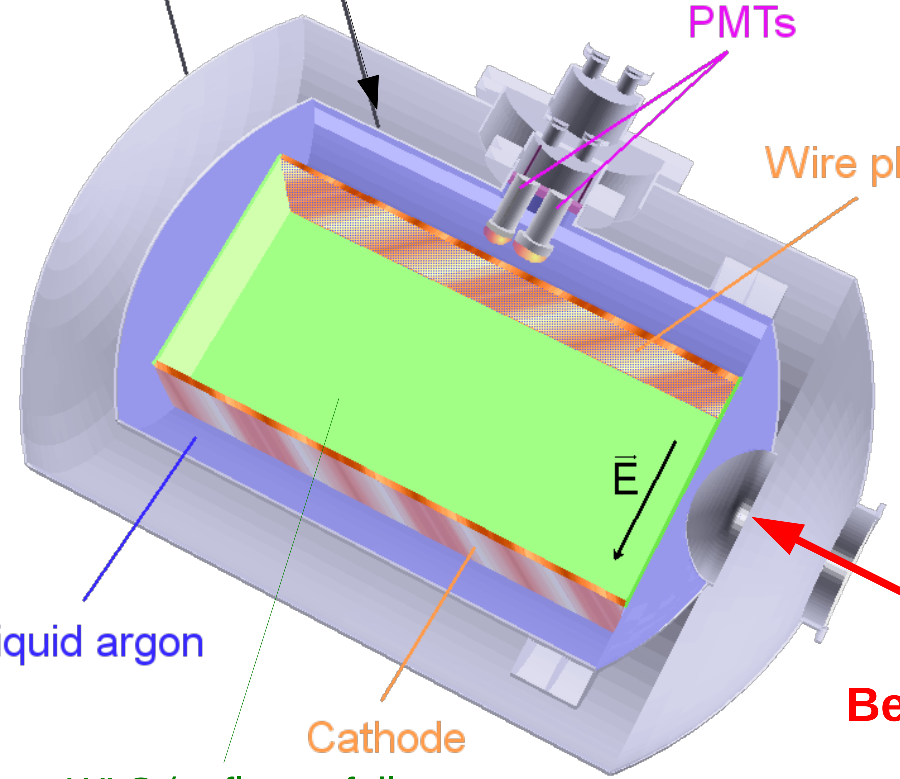
- Momentum resolution from vertical and horizontal angle distributions
  - @ 100 A → $\Delta p / p$ is 1.6 %
  - @ 40 A → $\Delta p / p$ is 3.4 %

$$\Delta p / p = dA_y / A_x$$

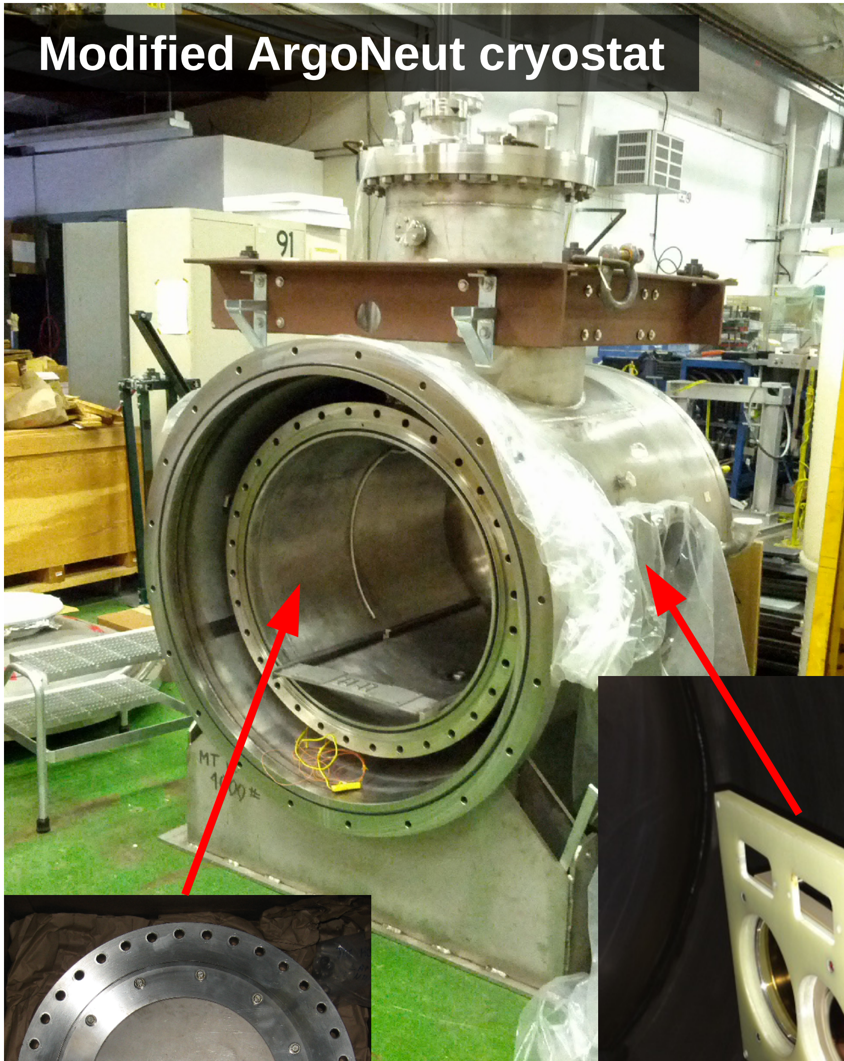
LArIAT TPC / Cryostat Design

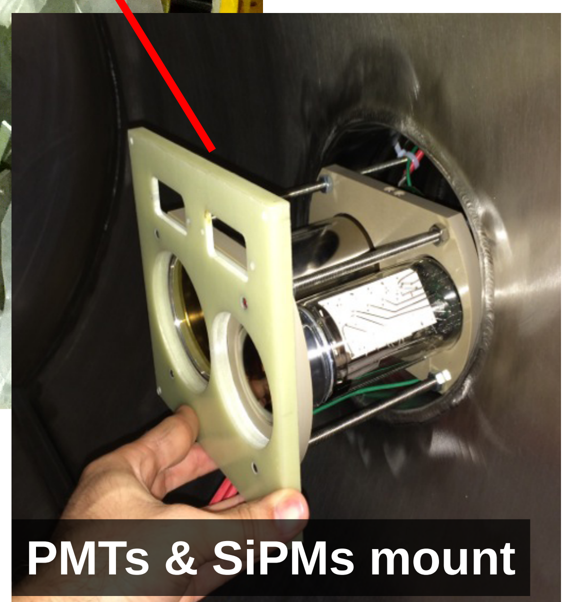
- Refurbished ArgoNeut TPC and cryostat.
- **Specifications:**
  - Modified cryostat (Ti beam window, PMT side port, LAr circulation bottom port)
  - Active volume: 175 L (550 L cryostat)
  - 90 cm x 40 cm x 47.5 (drift) cm TPC
  - 3 wire planes: 1 induction, 1 collection, 1 shield (4mm wire spacing, ~240 wires/plane)
  - Nominal electric field: 500 V/cm (tunable)

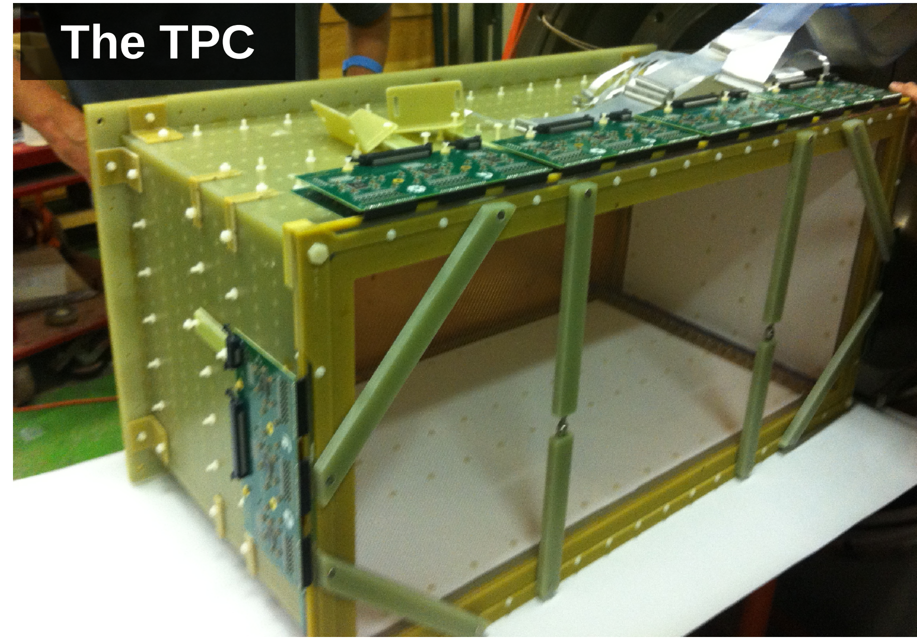
    → ~300 µs max drift time
  - Scintillation light collection: 2 standard PMTs + 2 SiPM + wavelength shifting reflector foils
  - Cold readout electronics

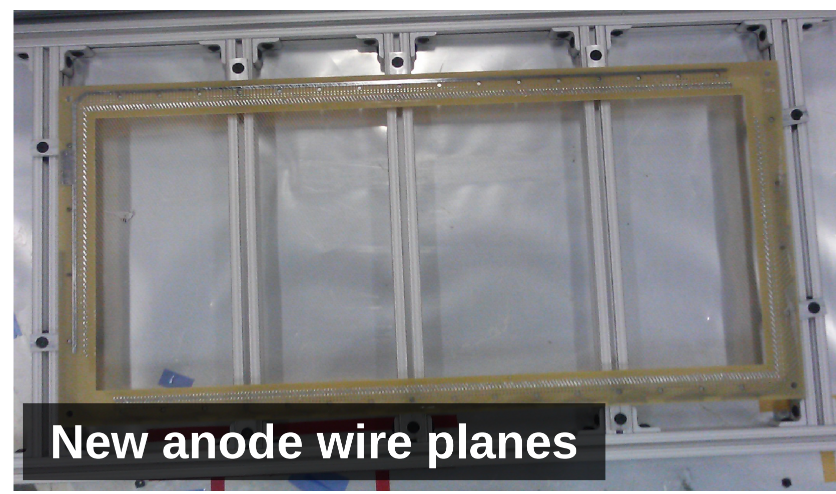


LArIAT TPC / cryostat

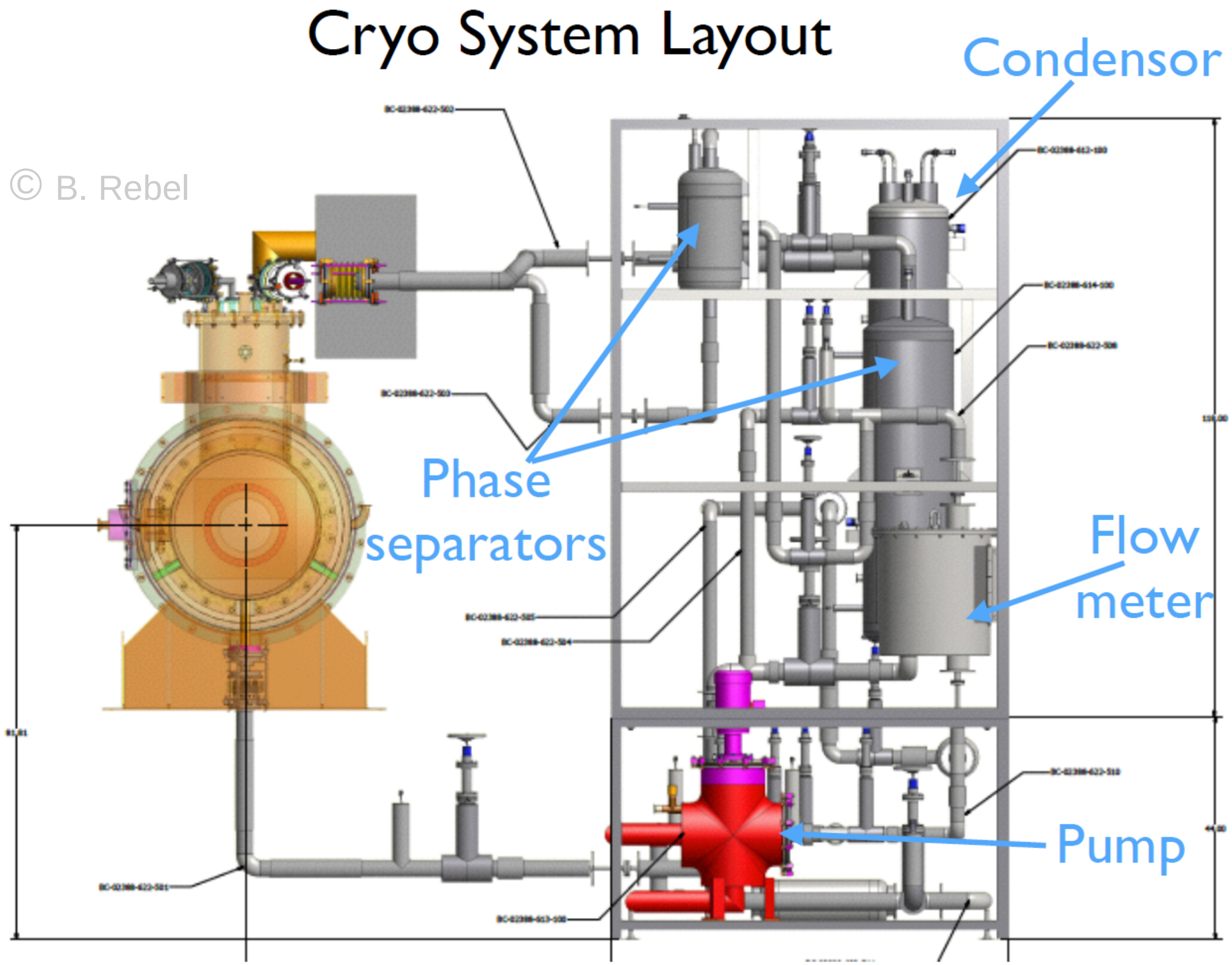






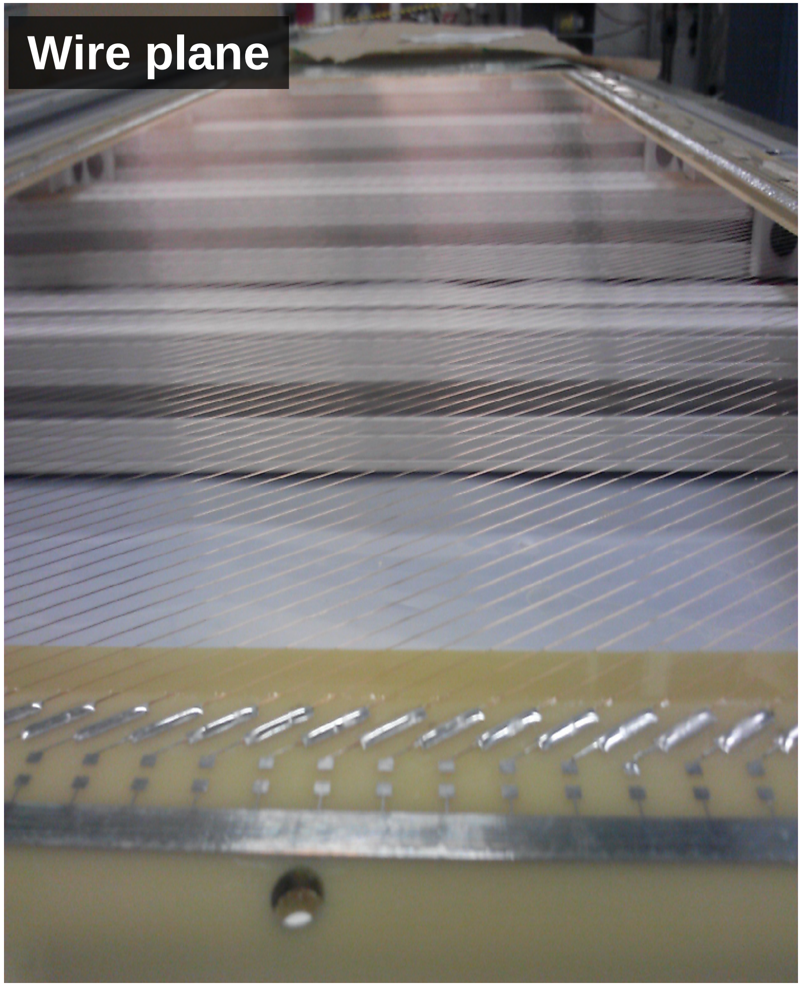


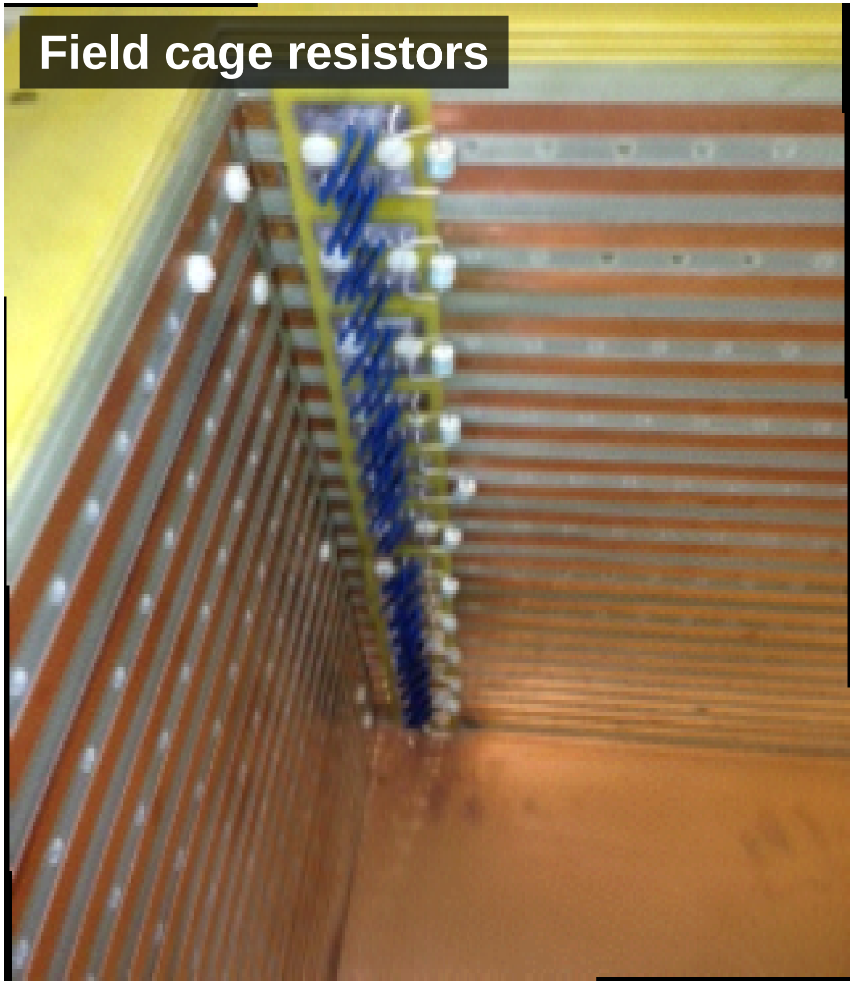
Cryogenic system



- Recirculation + purification system big enough to be used also with LArIAT phase II
- Some elements are ready, the full system should be ready by the end of the year
  → the pressure vessels passed the code inspections
- Meanwhile LArIAT will run without recirculation system and let the liquid argon boil off as soon as beam comes back

Wire planes and field cage

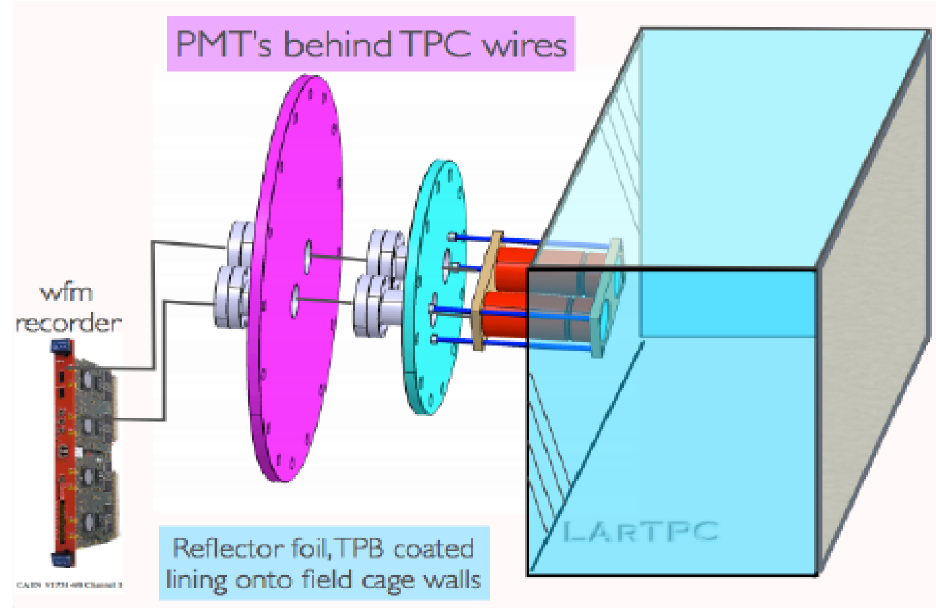


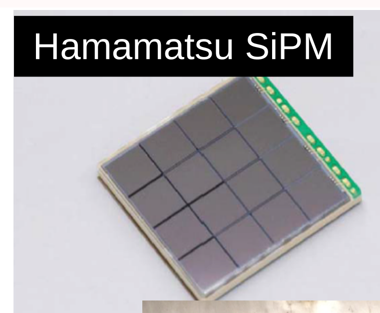


- All 3 new anode wireplanes are ready and mounted
- New resistor chain installed inside the TPC, replacing old resistors by 1 GΩ Slim-Mox
- Tension bars and electronics stand-offs have been mounted

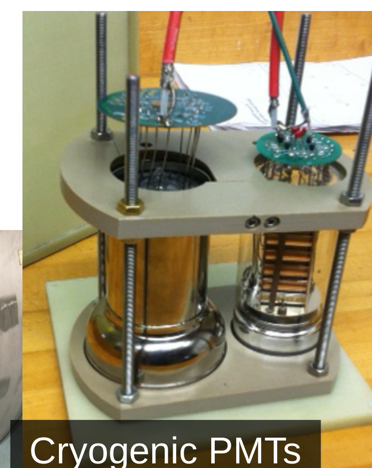
Light collection system

- **Light collection system**
  - 2 cryogenic PMTs: 2” ELT (QE 20%) and 3” Hamamatsu (high QE 30%)
  - 2 Hamamatsu SiPMs (QE 50%)
  - TPB wavelength shifting reflector foils
- **Status:**
  - Side port added to the cryostat to accommodate the PMTs
  - PMTs mount dry-fit test done
  - Cryogenic PMTs tested and U. Chicago and Fermilab
  - SiPMs bias voltage and pre-amplification circuits have been designed, built and tested



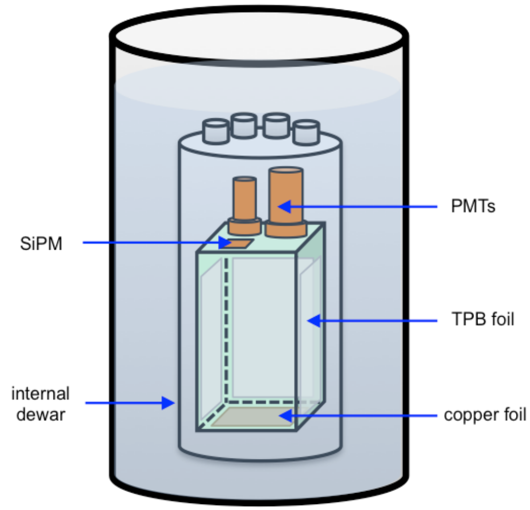

Hamamatsu SiPM

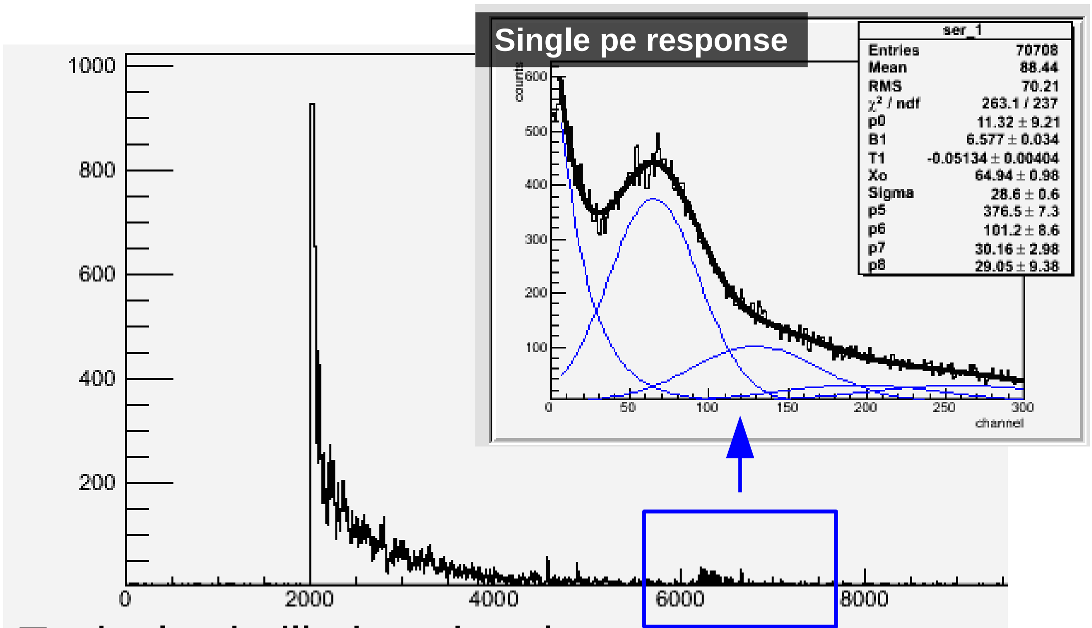

Cryostat side port


Cryogenic PMTs

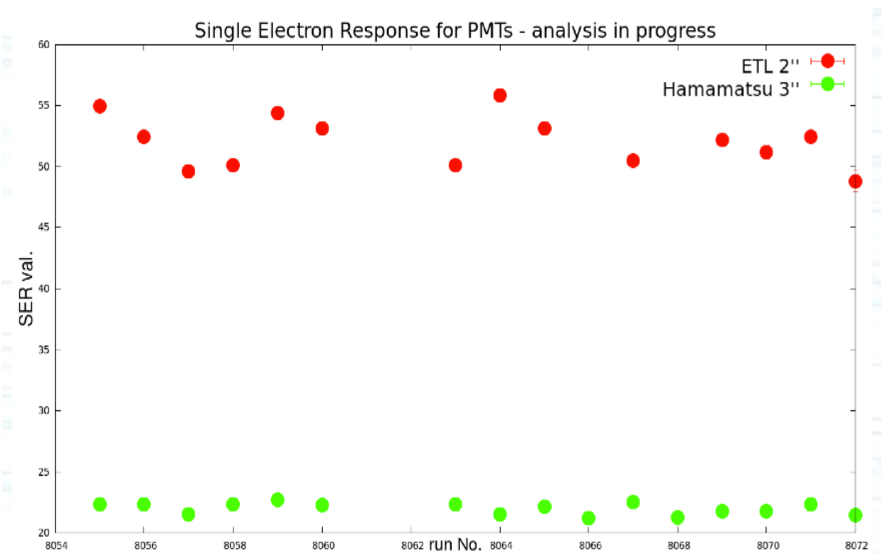
Light collection system tests

- **Tests done (@ U. Chicago)**
  - PMTs mounted on a mock TPC (G10 + TPB foils)
  - Feed-throughs were also tested and a few minor problems were corrected
  - Tests done also at Fermilab with ACNet controlled power supplies
  - Measurement of the single photo-electron response (SER) → gain and stability studies





Typical scintillation signal



Stability of the SER over the runs

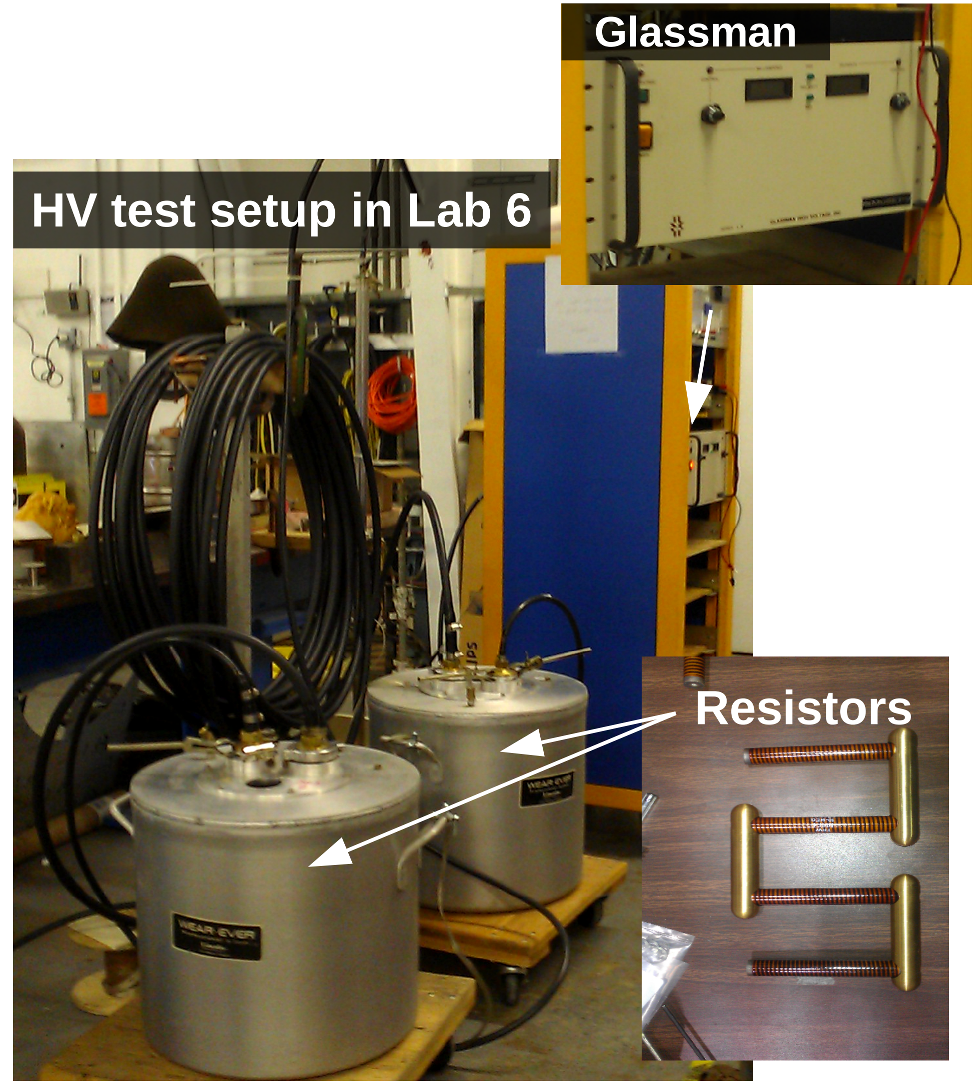
High voltage tests

- **Cathode HV system:**
  - Glassman LX125 → nominal voltage -25 kV
  - 2 filter pots with 4 x 10 MΩ resistors each
  - 1/2" and 1" cables
- **Tests performed:**
  - Voltage holding: reached -40 kV in air without any problem
  - Measured resistance of the whole system: 77.6 MΩ
  - Ripple measurement:

  → Before pots: 2.5 V peak-to-peak

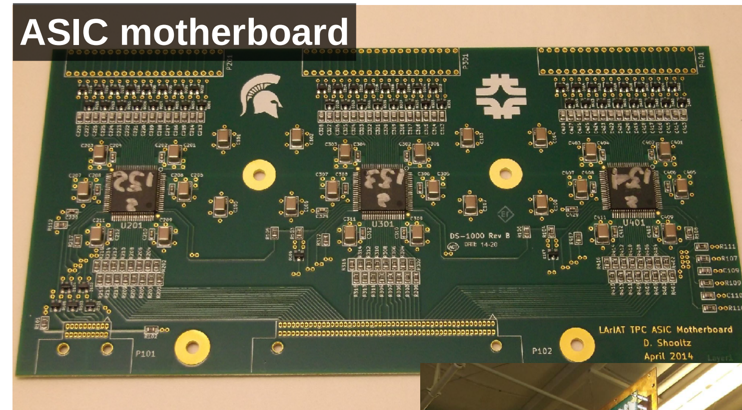
  → After 1st pot: < 0.2 mV

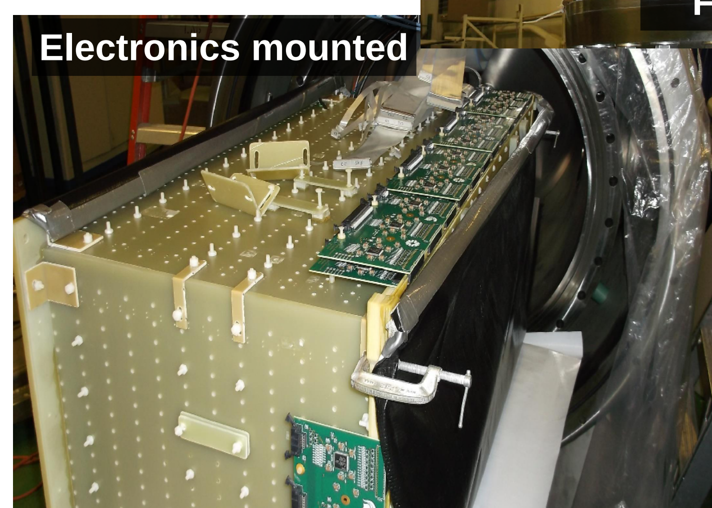
  → ripple shouldn't affect the stability of the electric field or readout electronics



LArIAT front-end electronics

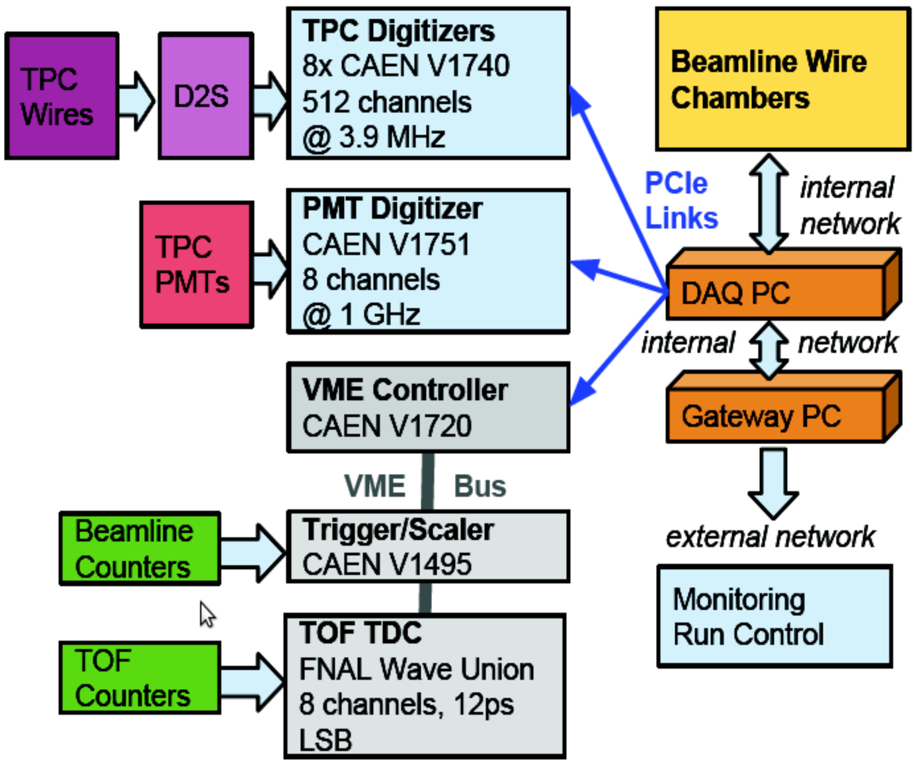
- **Features:**
  - Custom new cold electronics
  - 10x 48 channel ASIC cards (cold)
  - 10x 48 channel receiver cards (warm)
  - Differential to single-ended cards
- **Status:**
  - ASIC cards and cryostat feed-through backplane have been manufactured, assembled, and mounted
  - Cabling from inside the cryostat to feed-through done
  - Tests done with liquid nitrogen
  - Other elements in production / undergoing tests
  - Tests after mounting show no dead channels found

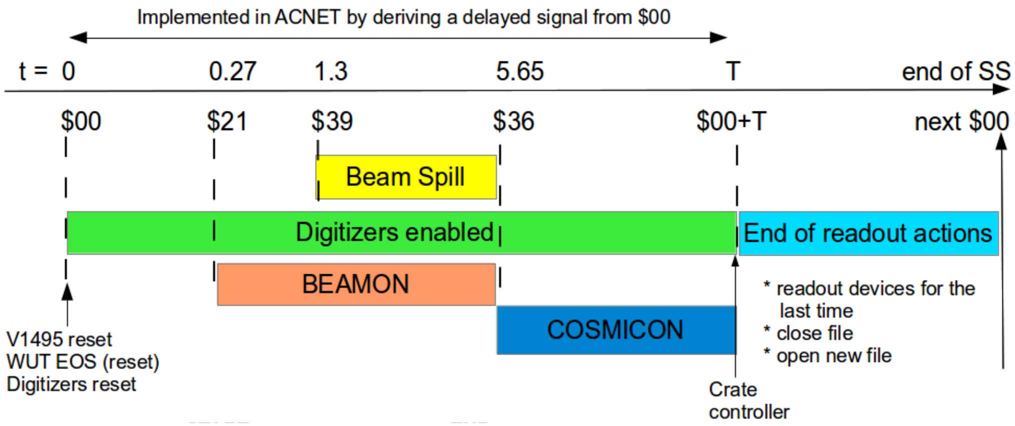




LArIAT DAQ and trigger

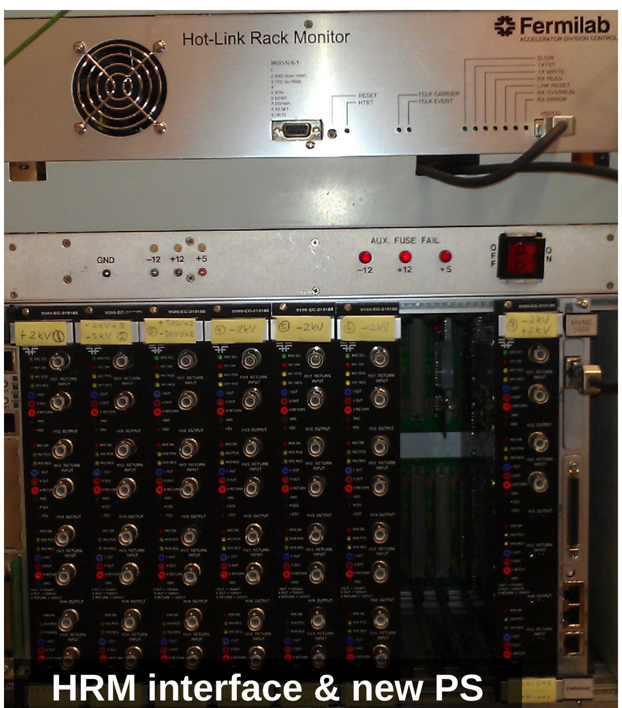
- Two DAQ systems:
  - Simple wire chamber mini-DAQ → very helpful to test and commission full DAQ
  - Full LArIAT FPGA-based trigger and DAQ
- Several trigger configurations possible by combining different beamline detectors
- Full LArIAT DAQ based mostly on CAEN VME electronics and some NIM bins (not shown)
- DAQ software system based on artdaq



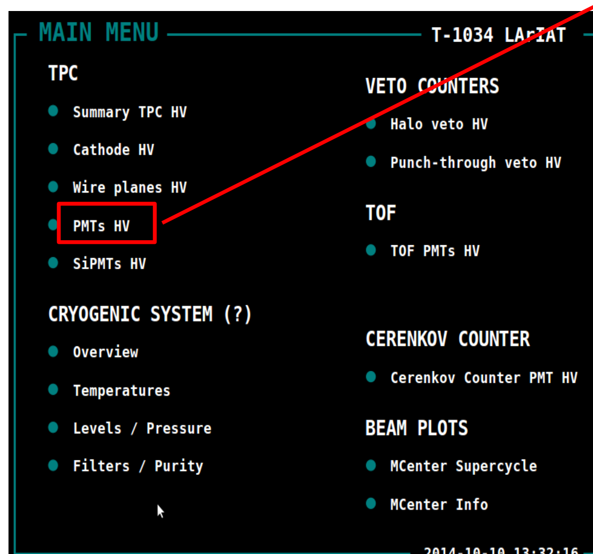


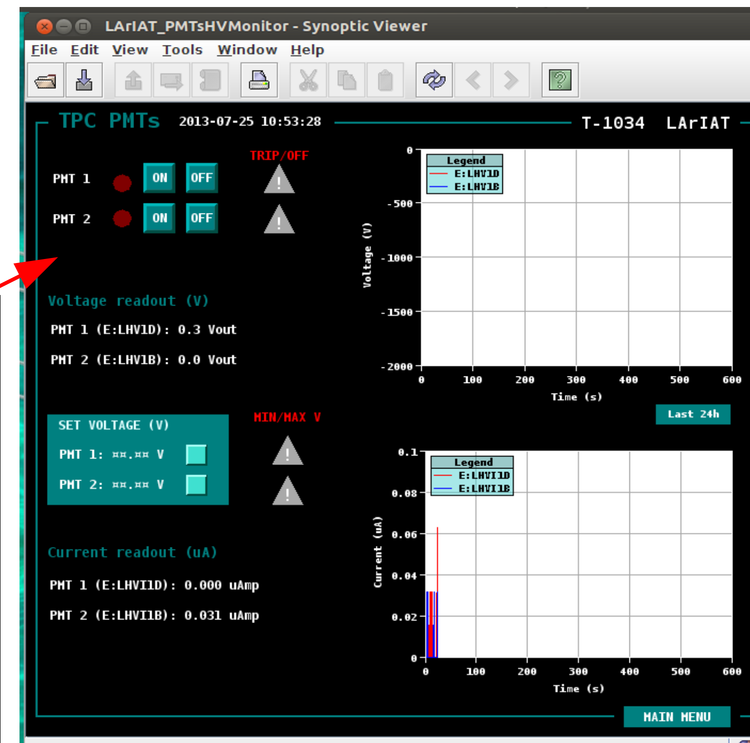
Online monitoring and slow control

- Ready and functional! Uses ACNet and Java GUI Synoptic
- Both web accessible and interactive Java applications
- All devices are being logged (IFBeam + Lumberjack) for offline use
- A special interface was built to monitor / control devices that were not ACNet ready (Glassman and Zener voltage divider)
- Some older power supplies were replaced to facilitate their control / monitoring



HRM interface & new PS





Current status & Schedule

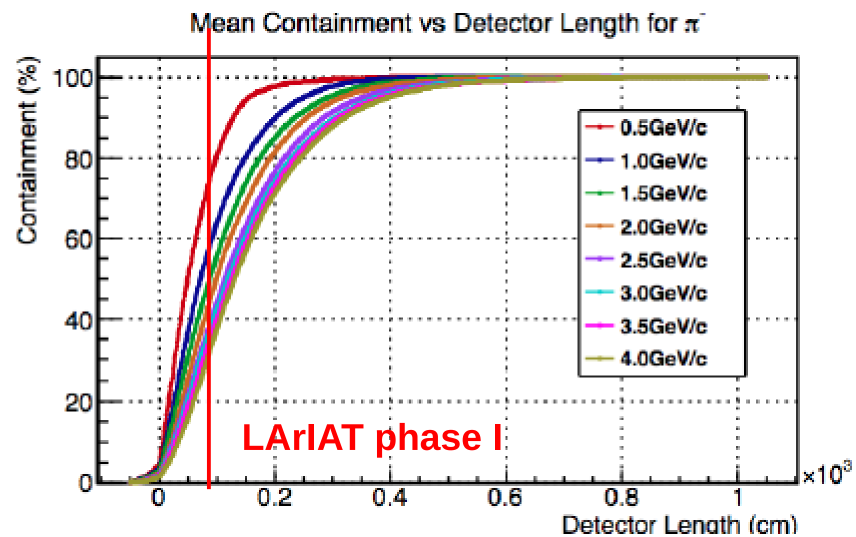
- Primary, secondary, and tertiary beams have been commissioned
- Light readout system tested, cryostat, DAQ, power supplies, and control room ready
- Front-end electronics, and wire planes have been mounted on the TPC
- **The cryostat is being closed right now!** It'll be then moved to the MC7 enclosure
- LArIAT phase-I will collect high statistics datasets for a variety of particles in the momentum range relevant to short- and long-baseline neutrino experiments

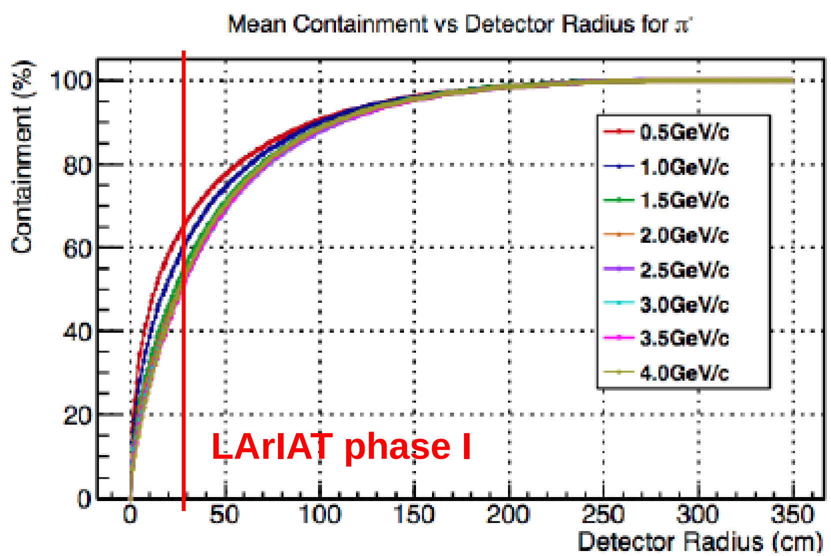
Data taking will start after moving into the enclosure, when beam comes back!

What's next? LArIAT phase-II

- Use same cryogenic system
- LArIAT phase-I containment ~50%
- Much larger detector will allow to repeat same measurements but with much better containment

  → study hadronic showers in liquid argon
- Detailed calorimetry studies
  - Ionization electrons
  - Scintillation light
  - Topology information
- Cosmic ray background studies





Conclusions

- A new LArTPC experiment will start taking data this year!
- The results provided will be critical for future neutrino experiments such as MicroBooNE and LBNE/LBNF
- Numerous cross-sections at energies ranges relevant for neutrino experiments will be measured
- Reconstruction and PID algorithms will be optimized
- Exciting results ahead!

The collaboration

Imperial College London

University of Cincinnati

Los Alamos National Laboratory EST. 1943

Boston University

Manchester 1824 The University of Manchester

Fermilab

California Institute of Technology 1891

Syracuse

The University of Chicago

W&M

Michigan State University

UCL

Argonne National Laboratory

The University of Texas at Austin

University of Texas Arlington

LSU Louisiana State University

Yale University

UMD Duluth

KEK-JAPAN

University of Pittsburgh

Back-up

32 GeV beam simulation