LArTPC Testbeam: CAPTAIN and LArIAT

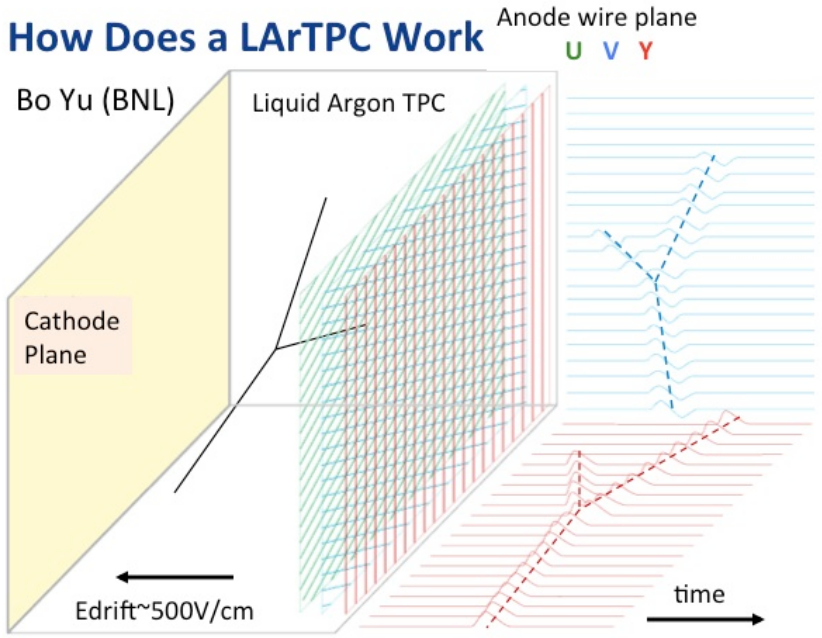
Jason St. John, University of Cincinnati
On behalf of the LArIAT Collaboration and for the CAPTAIN Collaboration

NuFact 2015, Rio de Janeiro

Outline

<u>miniCAPTAIN (neutrons) & LArIAT (charged species)</u>

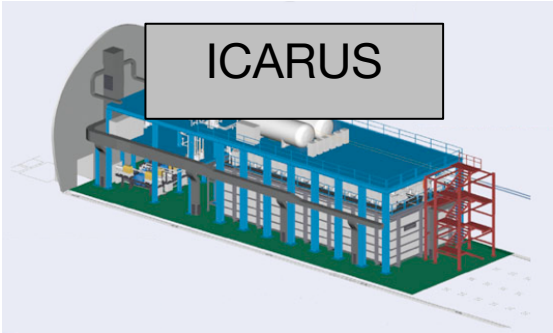
- Liquid Argon TPC Test Beams for Neutrino Physics
  - Physics goals
  - R&D goals
- Experimental Setups
  - Incident Beams
  - Inside the cryostat
- Beautiful data
- Future plans

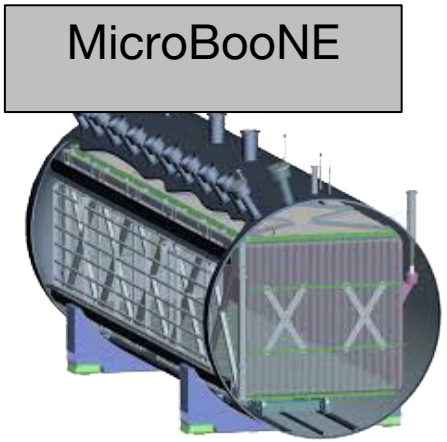


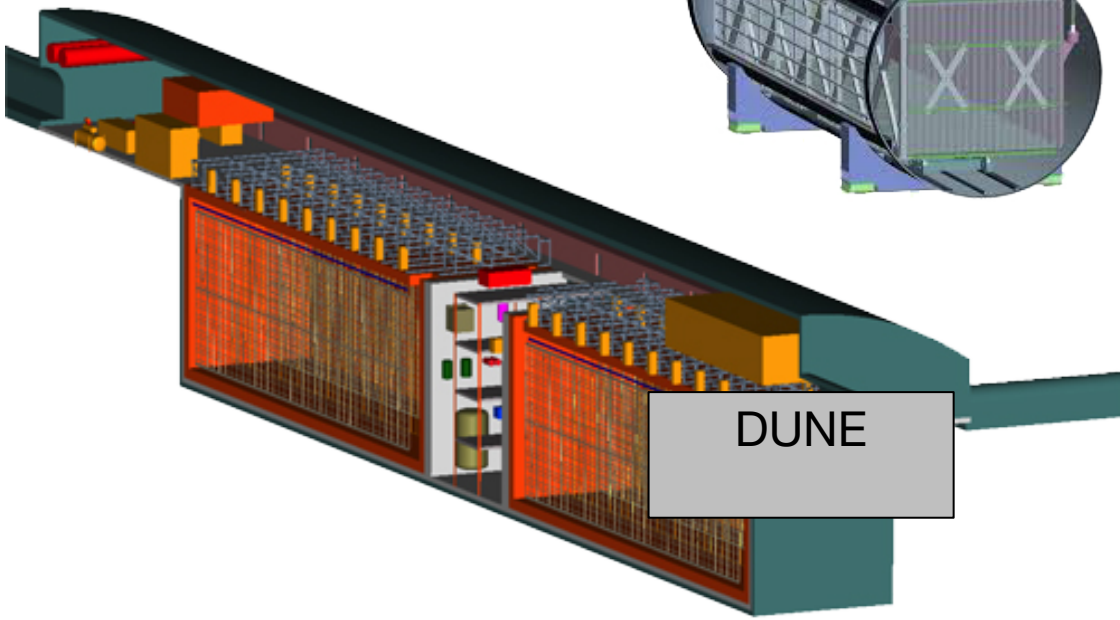
LArTPCs Test Beams for Neutrino Physics

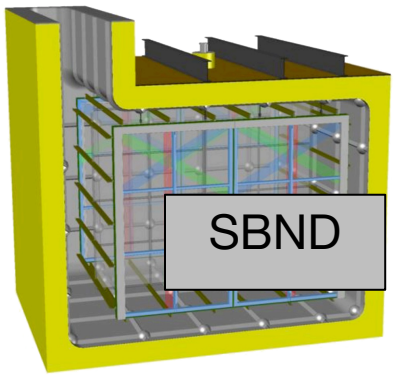
Liquid argon time projection chambers (LArTPCs) capture neutrino interaction final products in unprecedented detail

Dedicated calibration effort needed









MiniCAPTAIN

Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos

MiniCAPTAIN

1m Ø LArTPC in neutron beam at Weapons Neutron Research facility

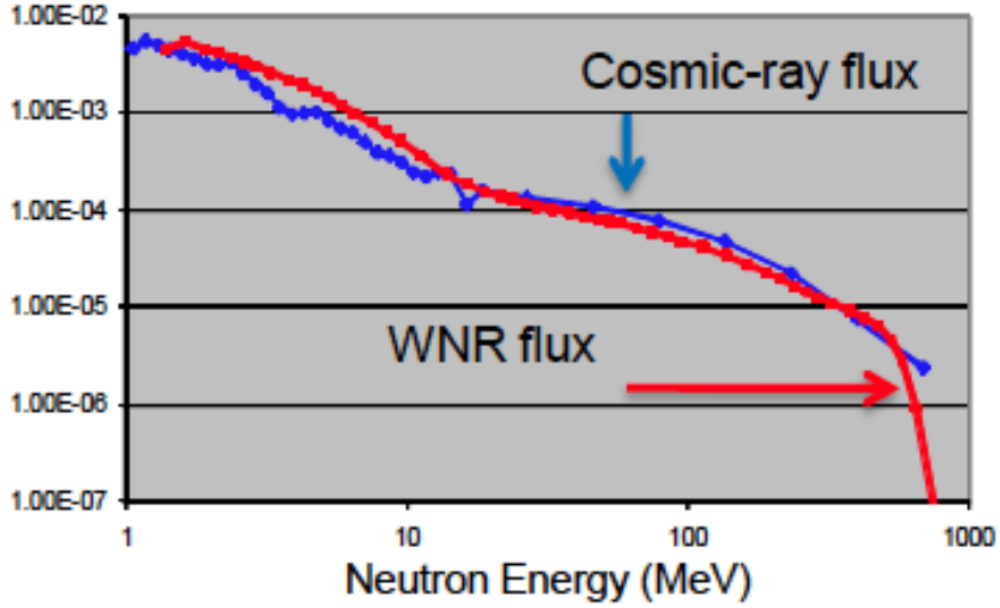
Physics goals:

- Ar* nuclear de-excitations
- Neutron scatters at known E_n
- Neutron-induced $\pi^{\pm}$ production

The mini-CAPTAIN cryostat

Los Alamos National Lab
Los Alamos Neutron Science Center

Incident Beam

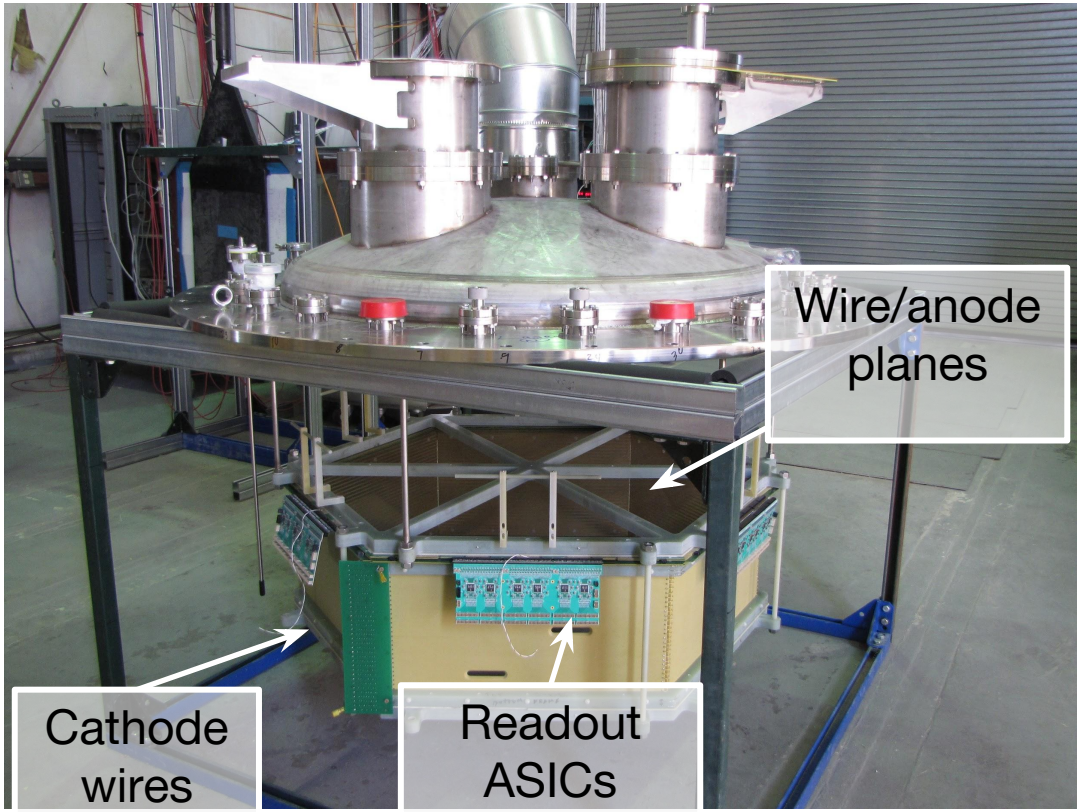


Known neutron energy from Time of Flight

- Beam on target starts clock
- Cryogenic PMTs stop it

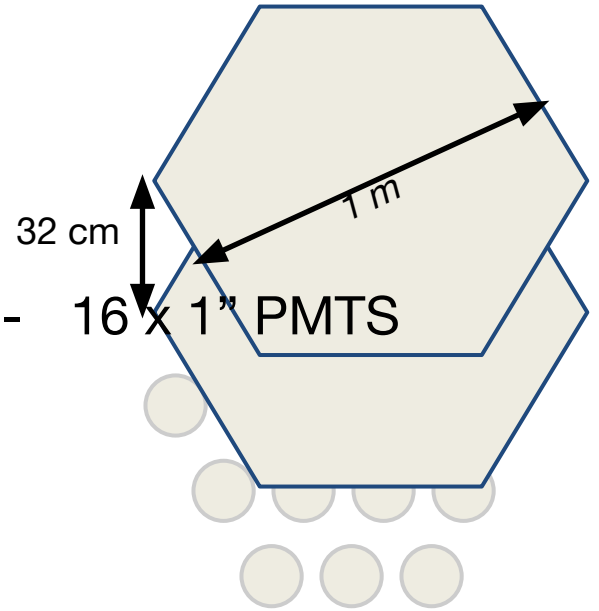
Neutron beam energy spectrum will be closely matched to cosmic-induced neutron energy spectrum

Inside the cryostat



The time projection chamber

- MicroBooNE cold electronics
- 3 planes @ 3 mm pitch
- Drift field ~500 V/cm



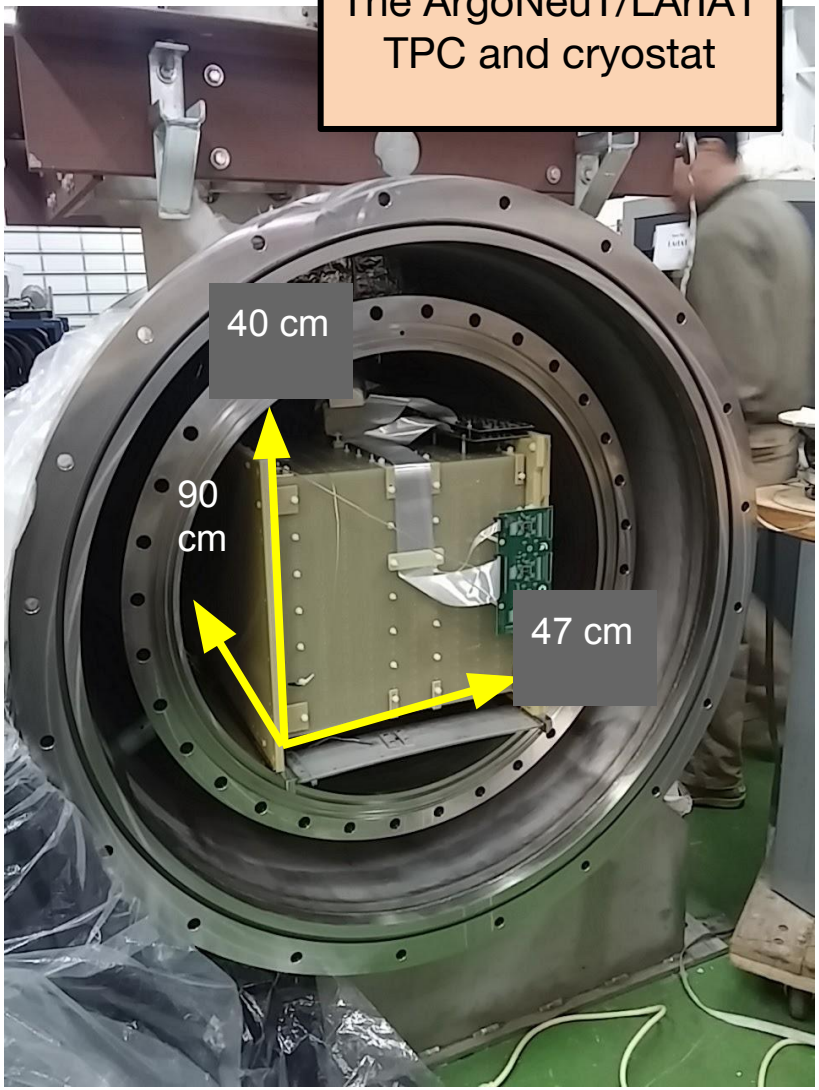
LArIAT

Liquid Argon In A Testbeam

LArIAT

"Table-top" (170L) LArTPC in a test beam at Fermilab Test Beam Facility

- Repurposed ArgoNeuT detector
- **Physics goals:**
  - π-Ar interactions
  - e/γ shower ID
  - μ-Ar capture
  - non-magnetic charge determination
  - kaon studies
  - Geant4 validation
- **R&D goals:**
  Optimize PID algorithm, calorimetry with charge & light, and 2D/3D event reconstruction



The ArgoNeuT/LArIAT TPC and cryostat

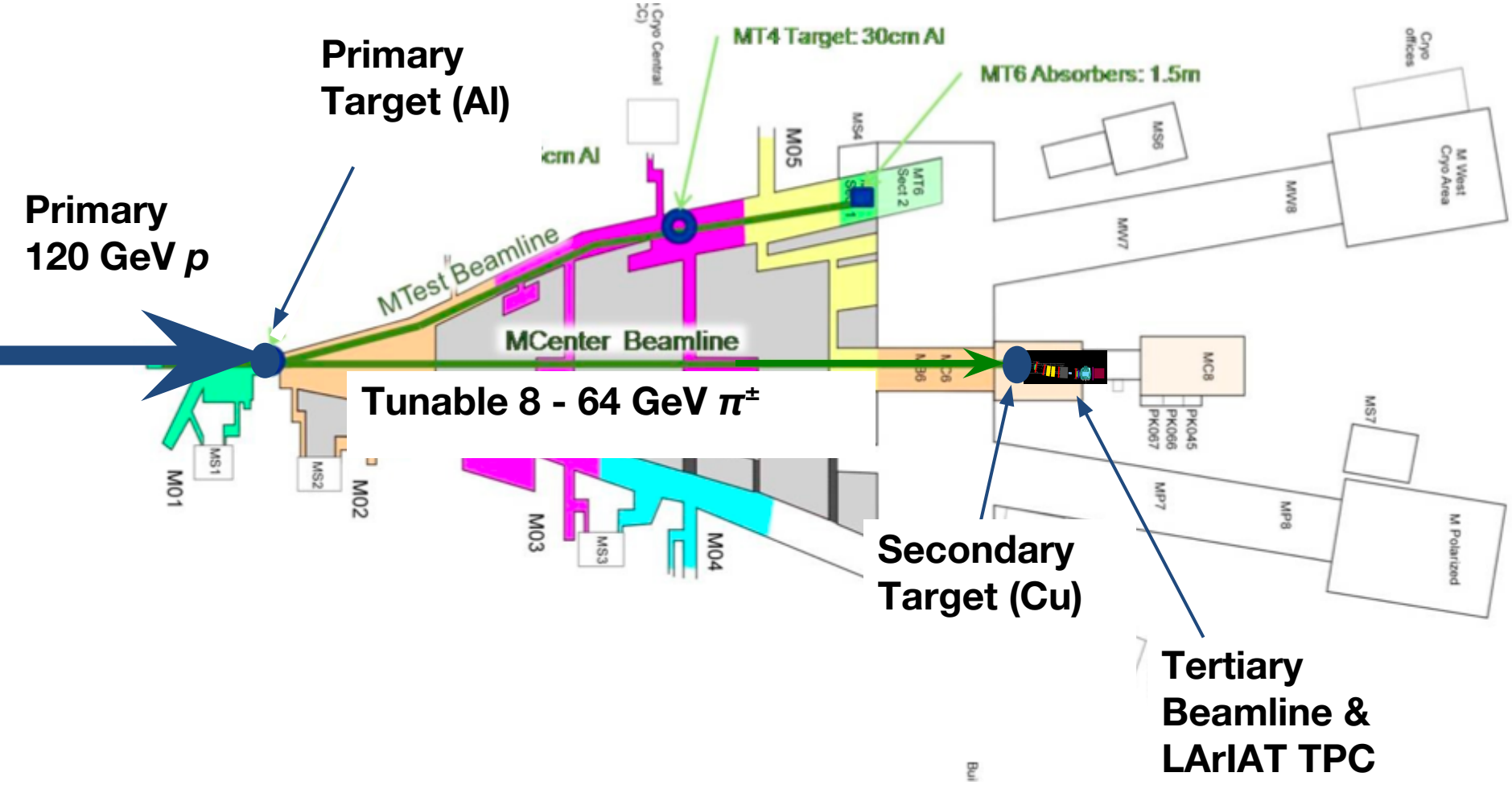
Fermilab Test Beam Facility

Linac

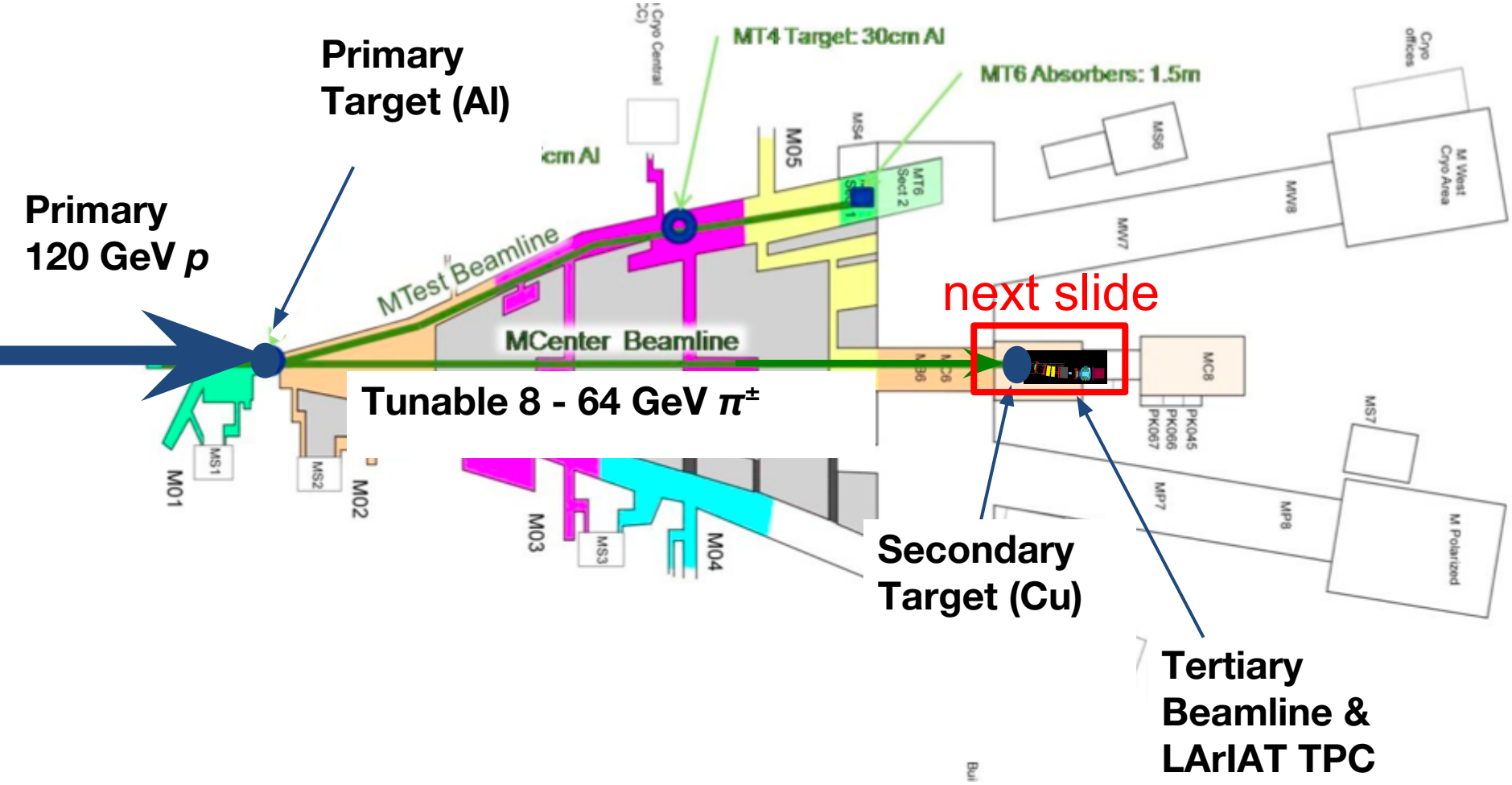
Booster

Main Injector

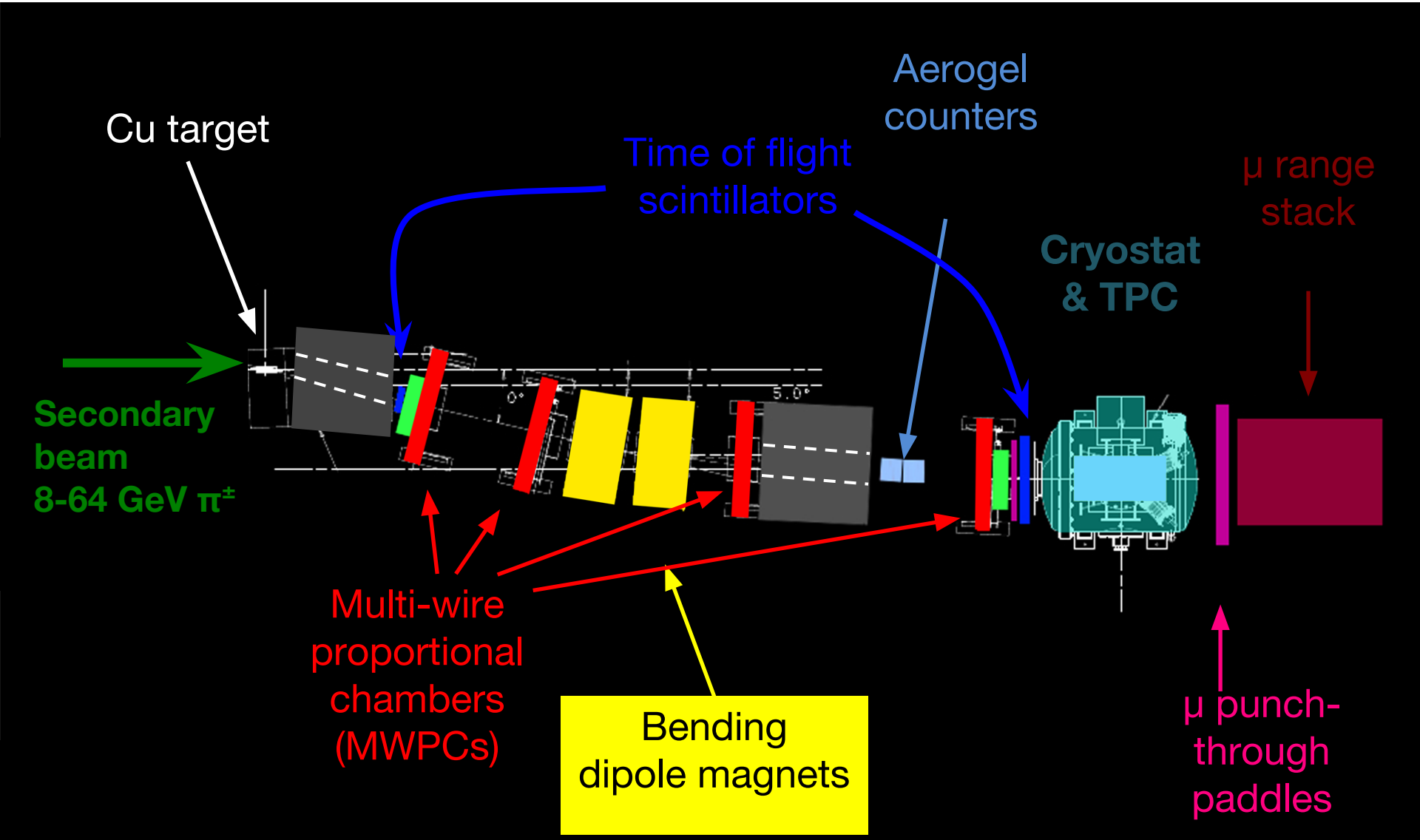
Beamline Plan View



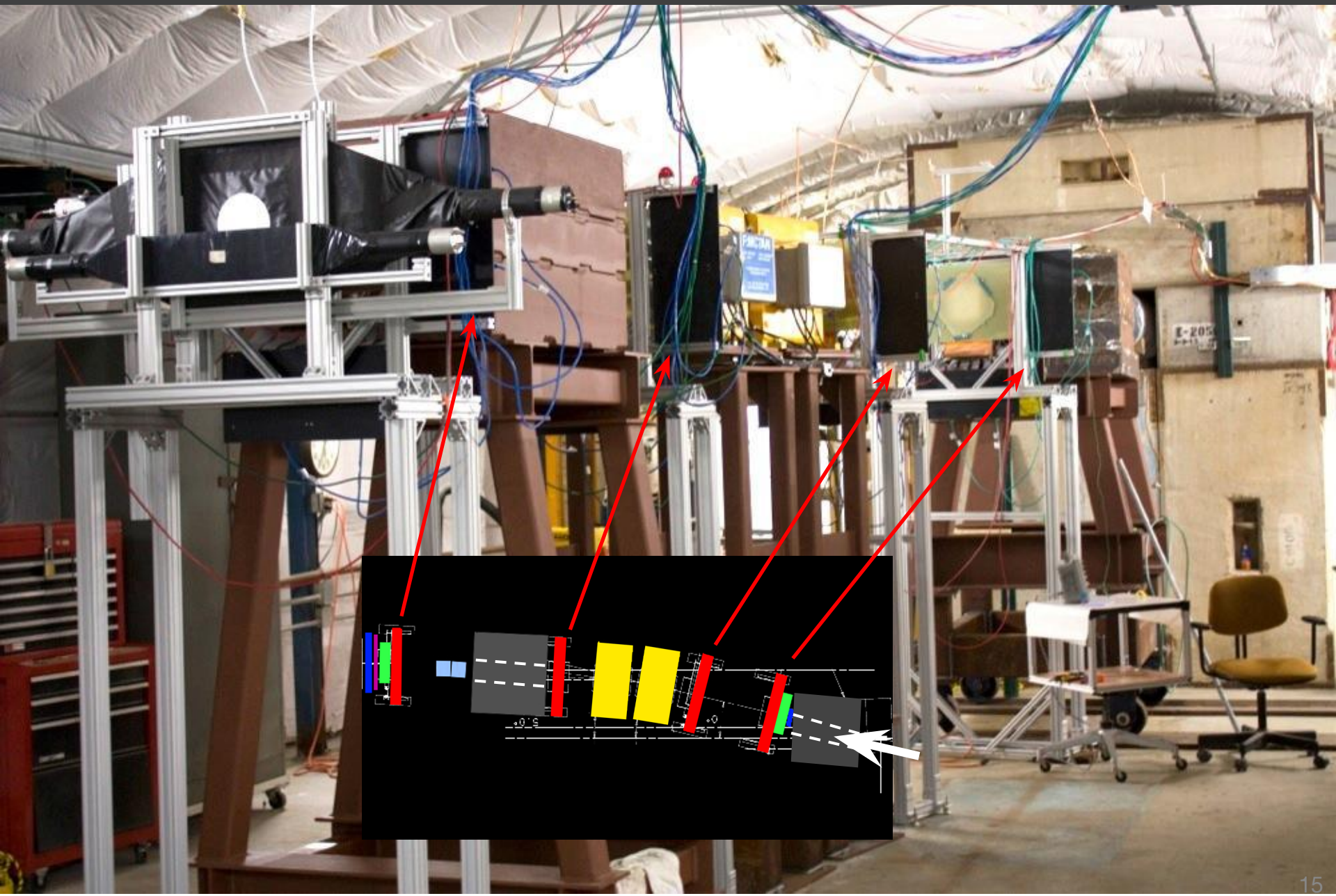
Beamline Plan View



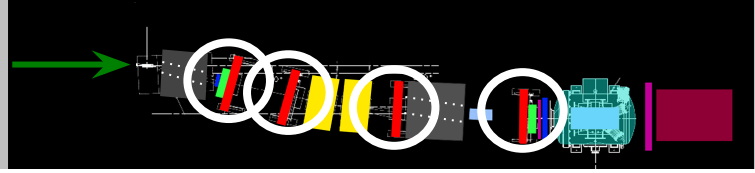
Tertiary Beamline

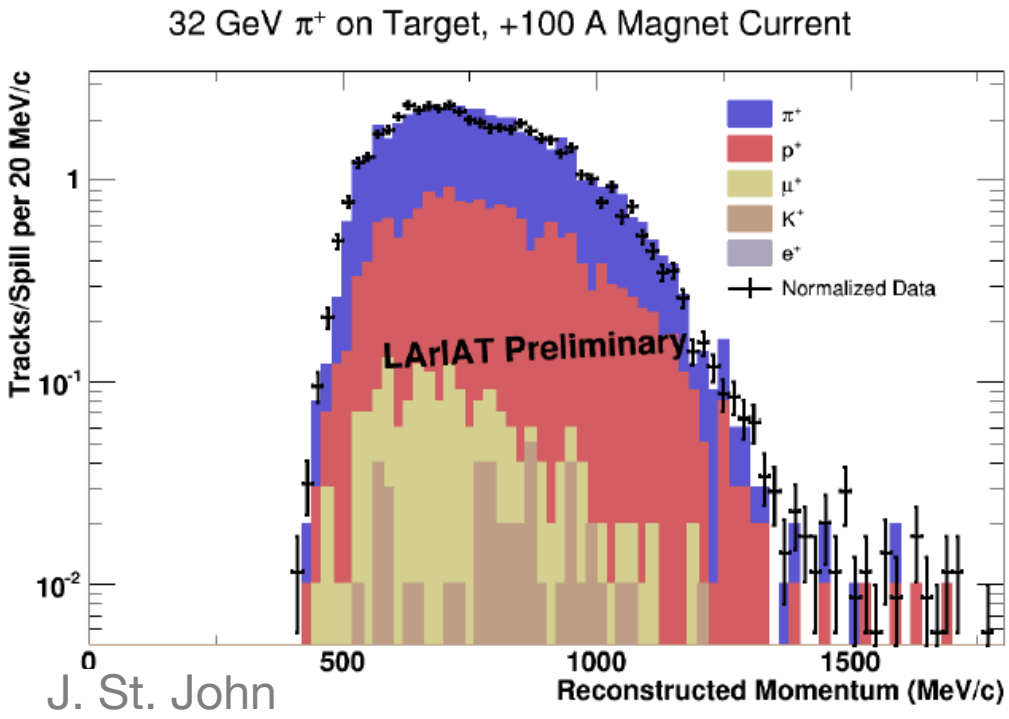


Tertiary Beamline



Incident Particle Beam

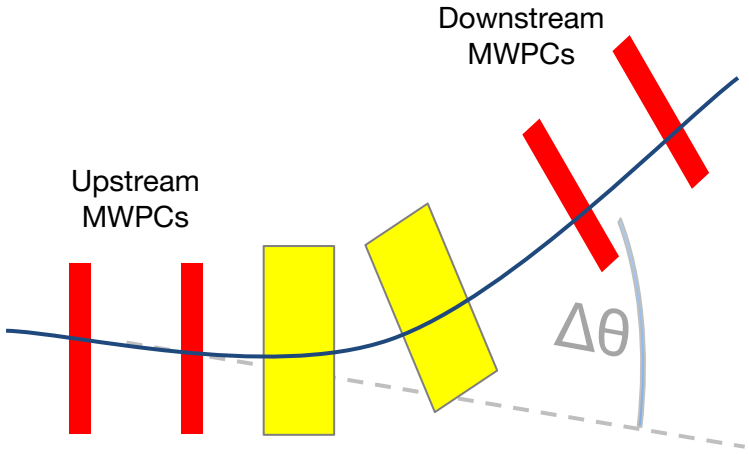




J. St. John

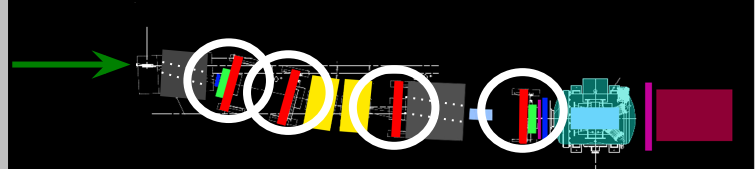
MWPCs + bending magnet

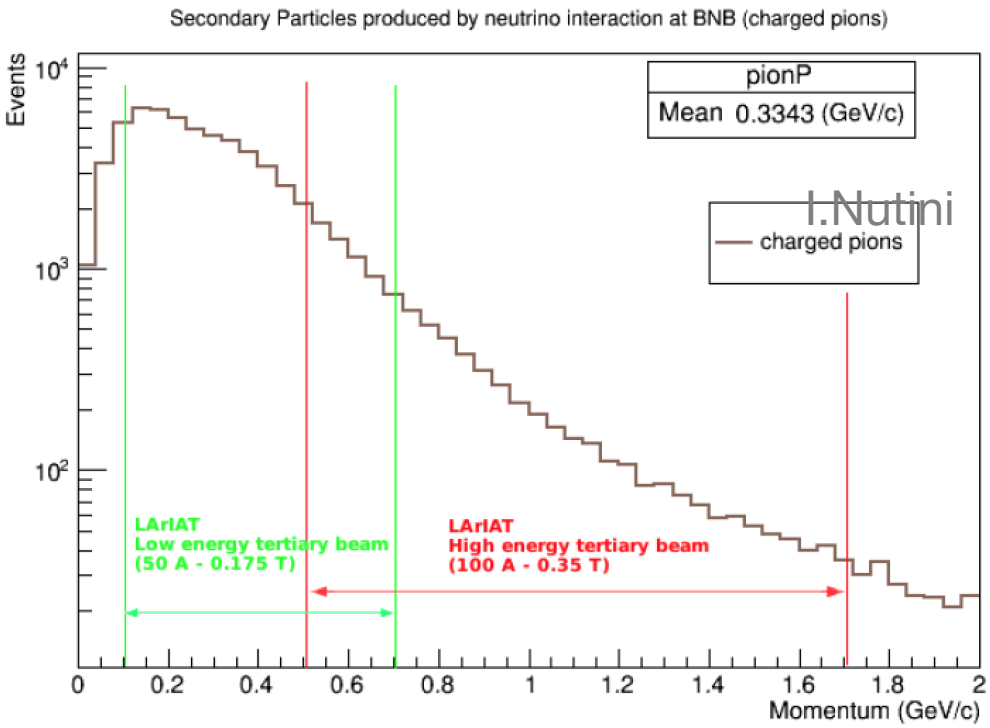
- Charge-selected beam 200 - 1200 MeV/c
- Single-particle momentum measurements



Momentum windows in excellent agreement with simulation

Incident Particle Beam

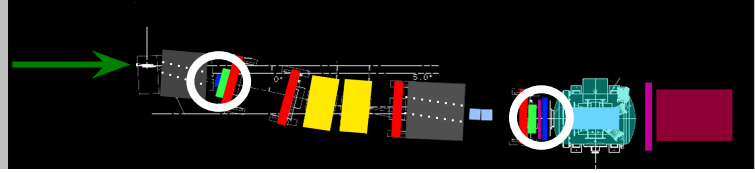


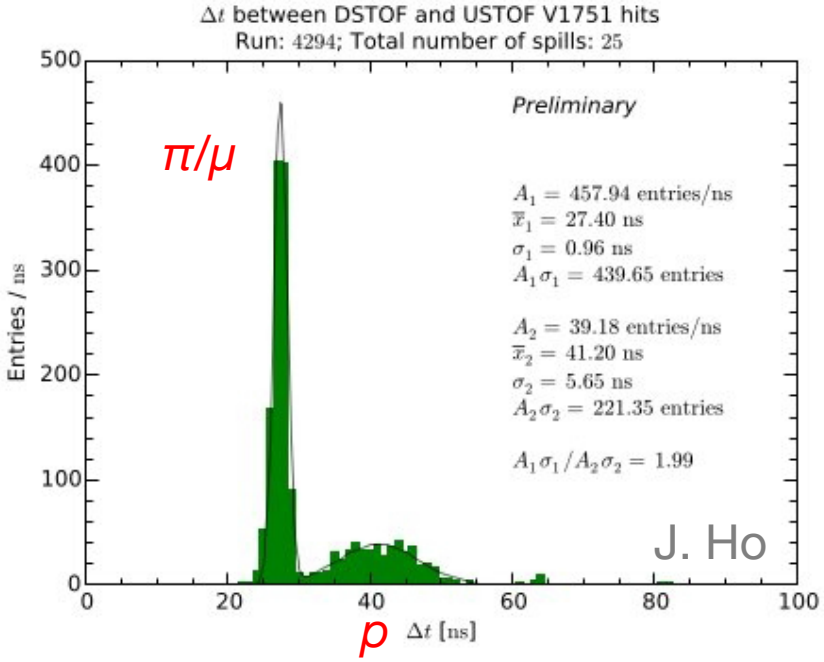


MWPCs + bending magnet

Full and Half momentum settings/magnet currents cover MicroBooNE neutrino event secondary momentum range

Incident Particle Beam

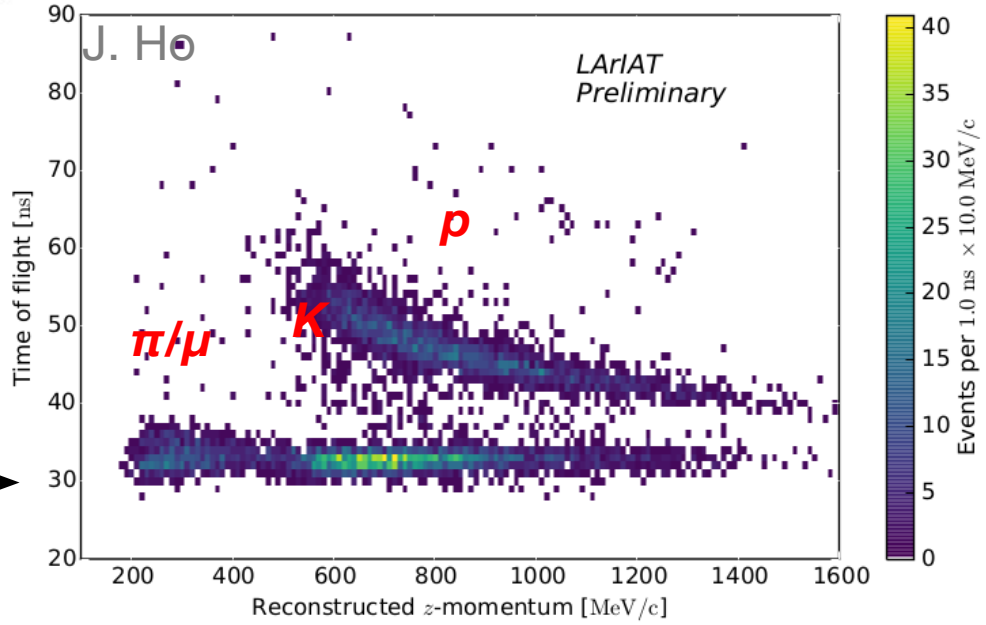




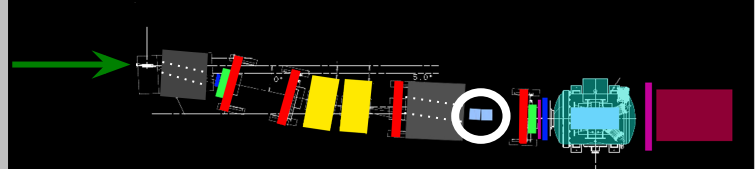
← **Time of flight (TOF)** for separation between *π*'s/*μ*'s and protons

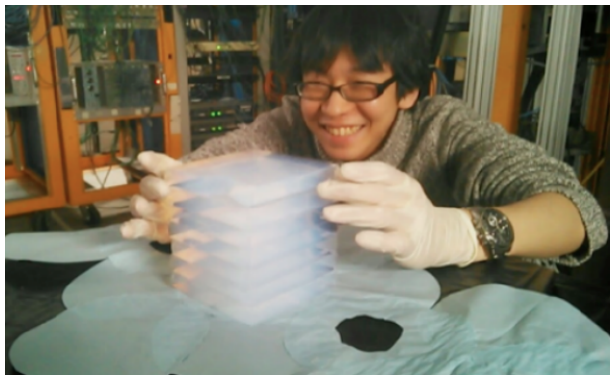
~2:1 ratio of *π/μ* to *p*

TOF vs reconstructed momentum →



Incident Particle Beam

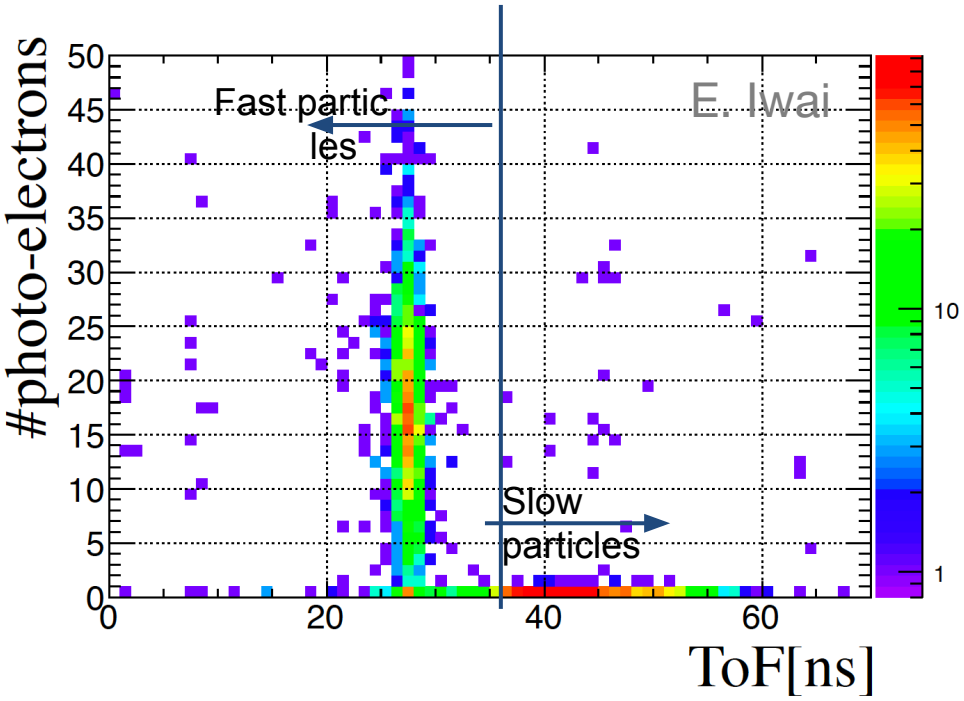




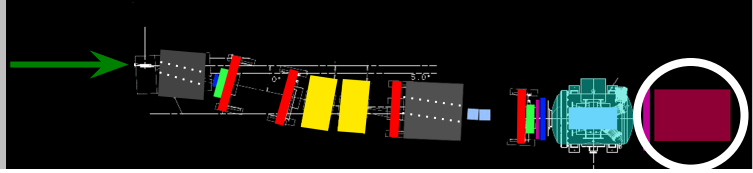
Aerogel Cherenkov counters for further PID

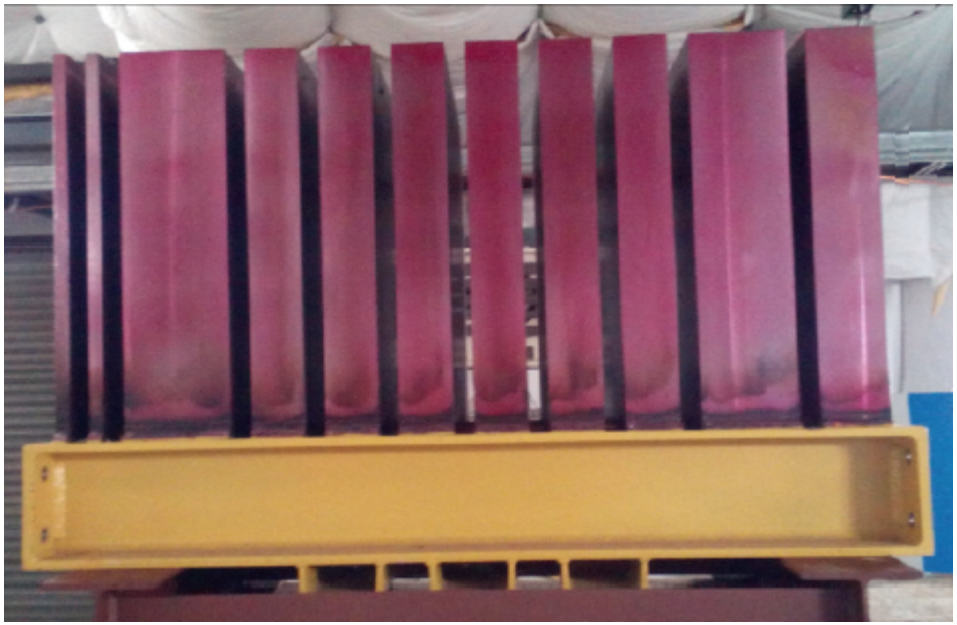
Possible π vs. μ discrimination using combination of thresholds and pulse height

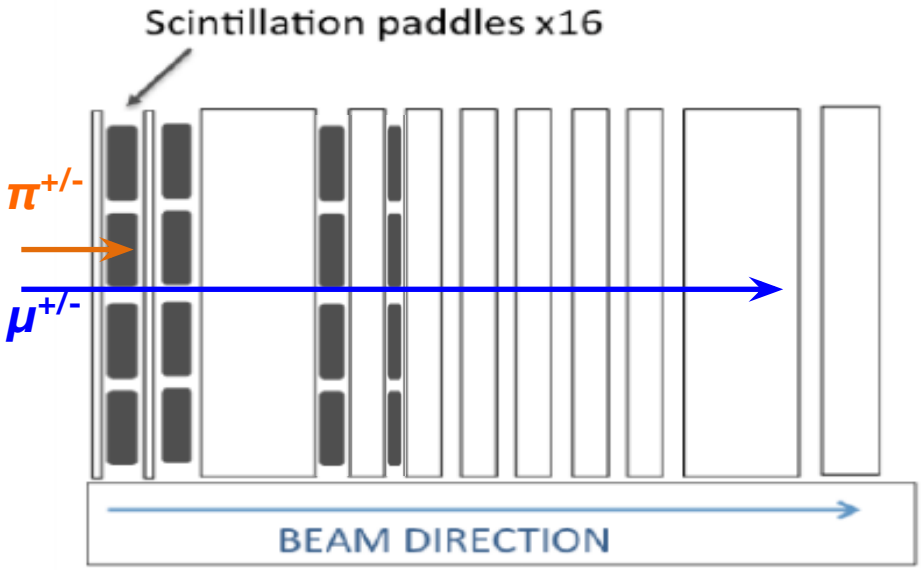
Effective for TPC-contained π/μ range: 230-400 MeV/c



Incident Particle Beam





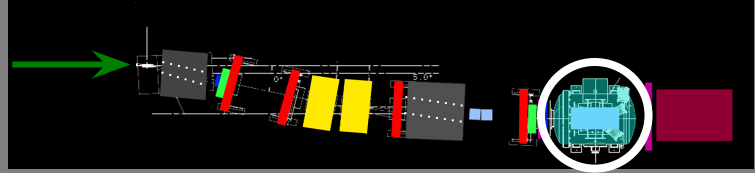


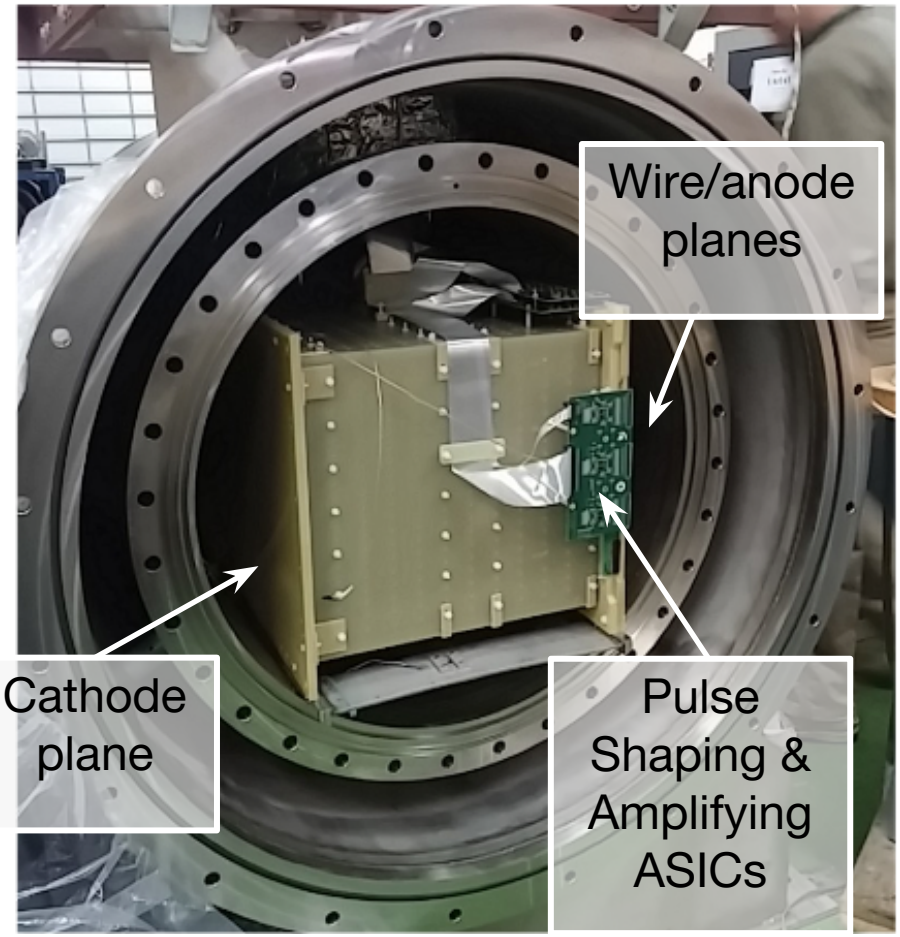
Muon range stack for discrimination of through-going muons/pions

Effective for high-p π/μ range: 400+ MeV/c

Some commissioning still ongoing

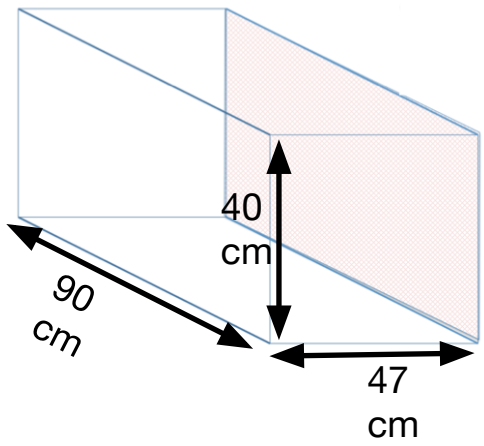
Inside the cryostat



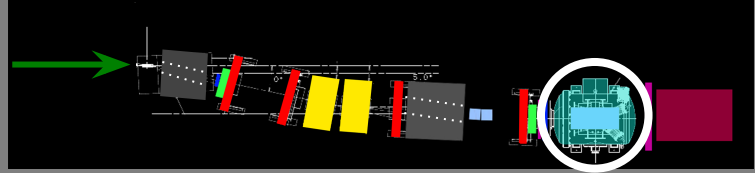


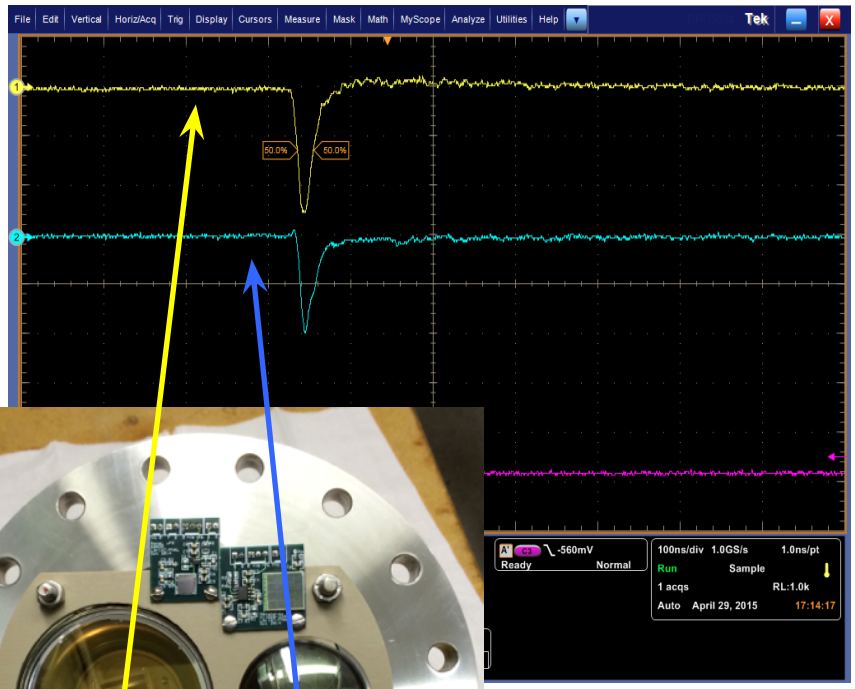
The time projection chamber

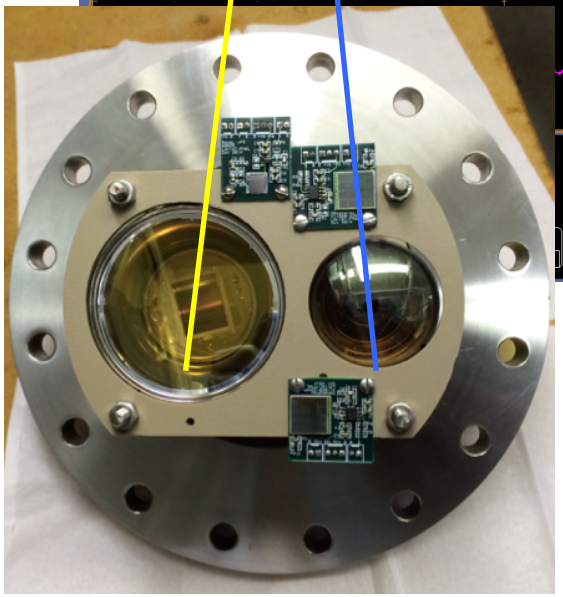
- Repurposed from ArgoNeuT
- New wire planes, 240 wires each
  - shield
  - induction
  - collection
- Drift field ~500 V/cm



Inside the cryostat



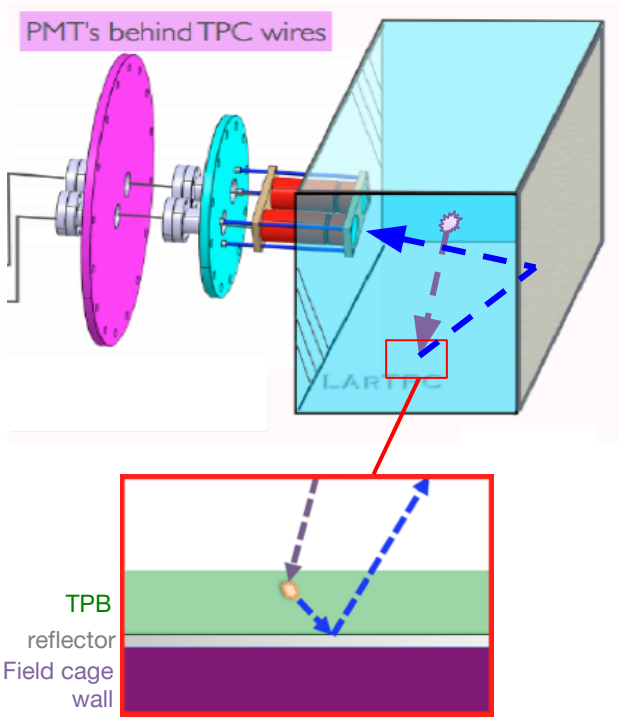




Light collection system

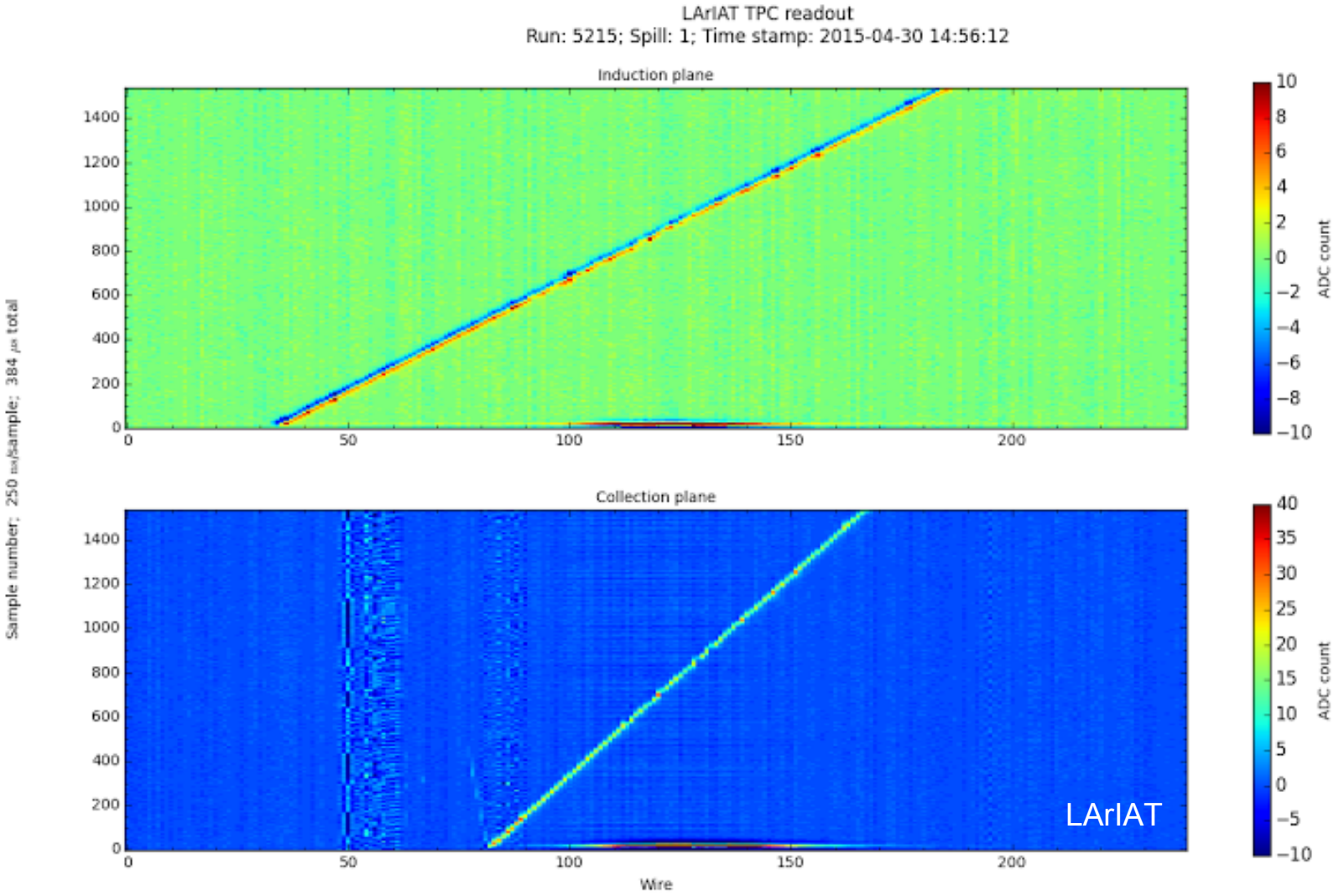
- 2 PMTs + 3 SiPMs
- VUV scintillation light wavelength-shifted at TPB-coated reflector foils lining field cage

Photoelectron yield:
~40 p.e./MeV
at zero E-field



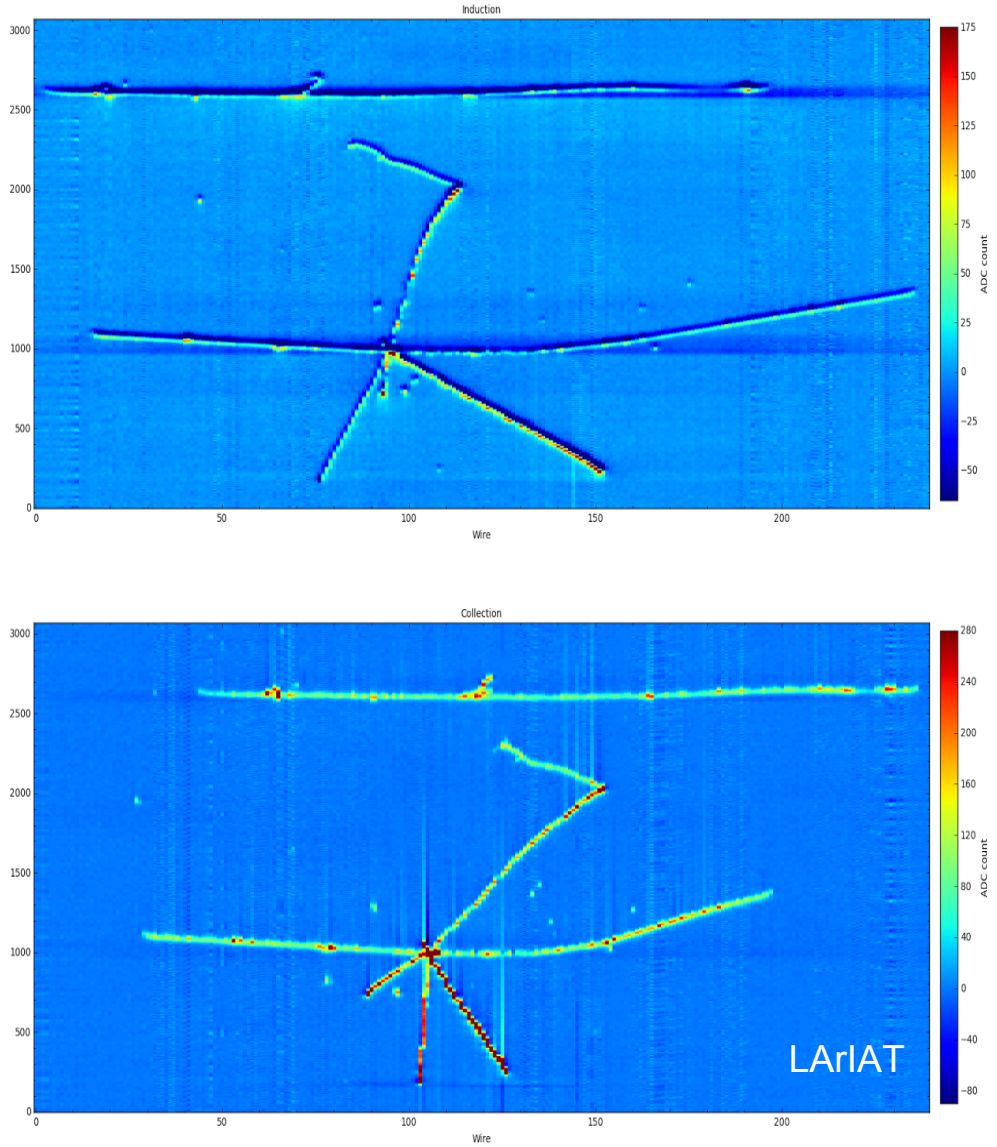
First data

- April 30, 2015 – TPC turned on, first cosmic-triggered track!



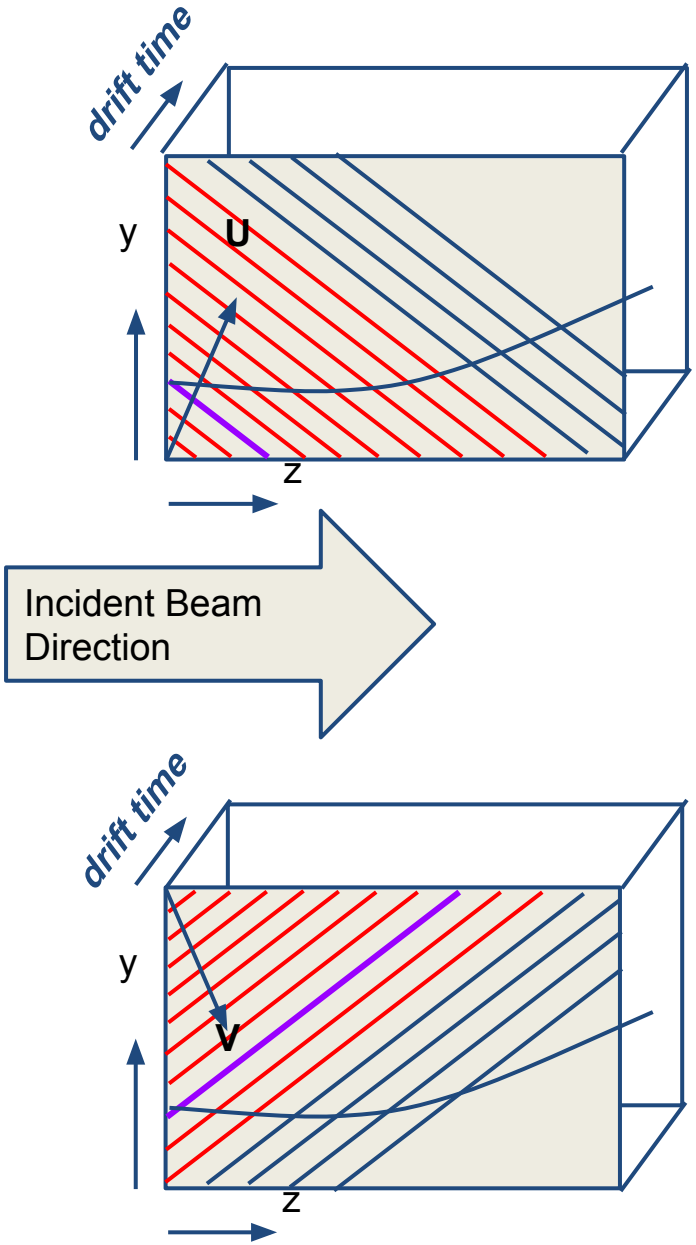
First data

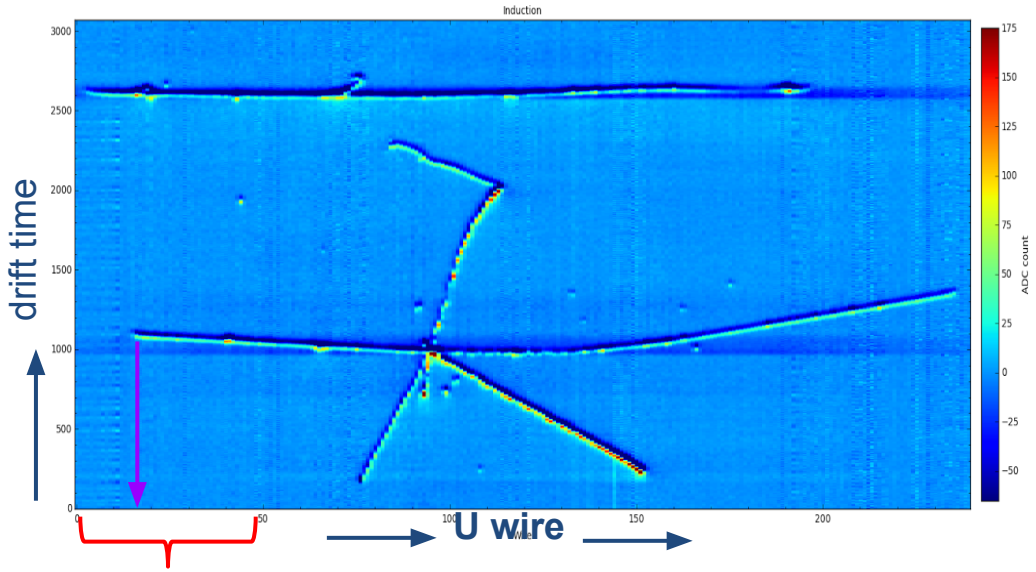
…and first beam events soon after…

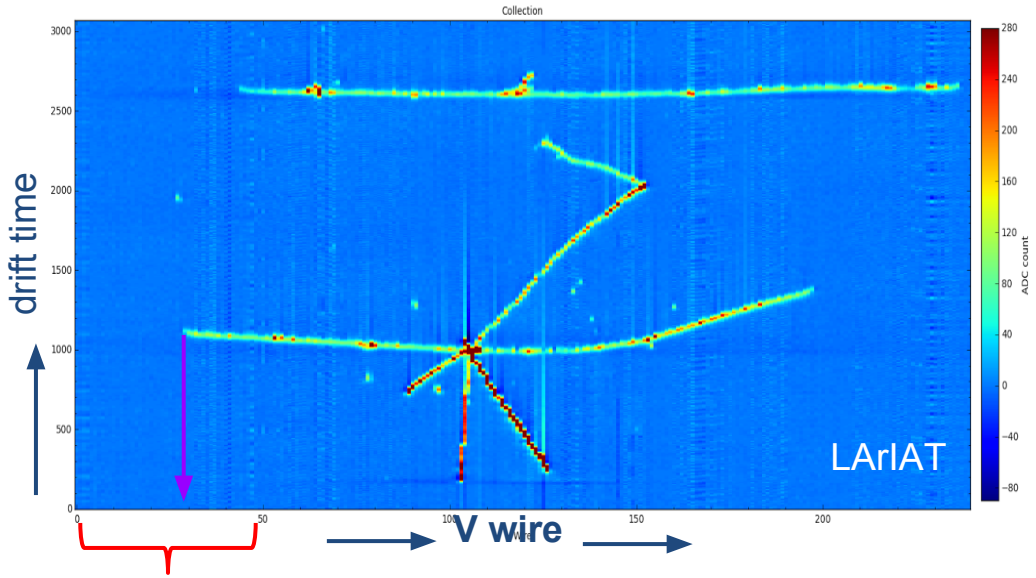


Tired, Happy Scientists

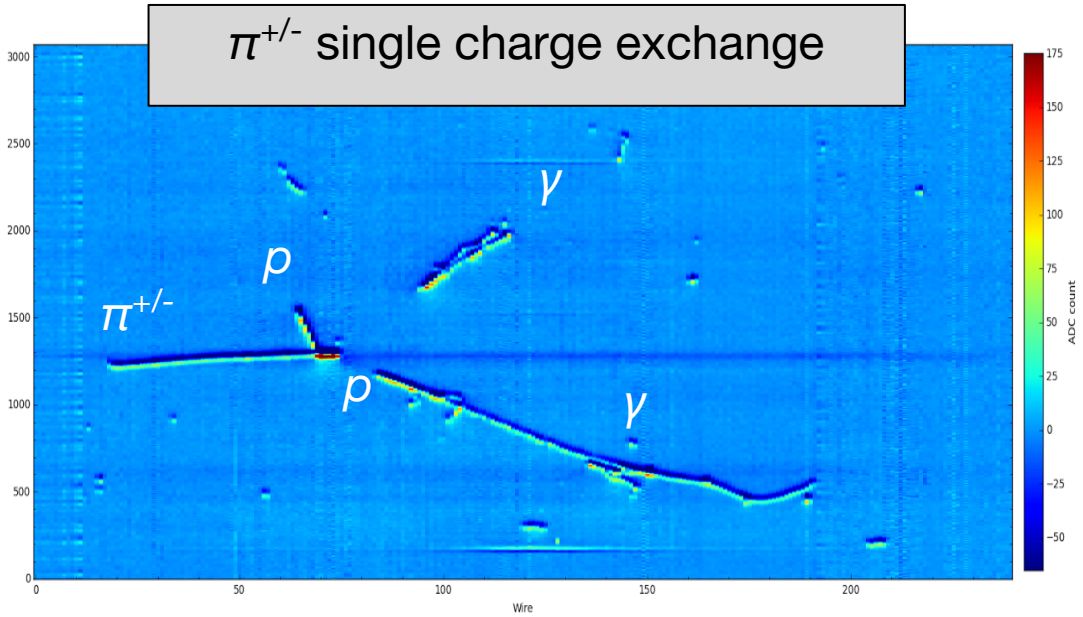
Primer on beam events

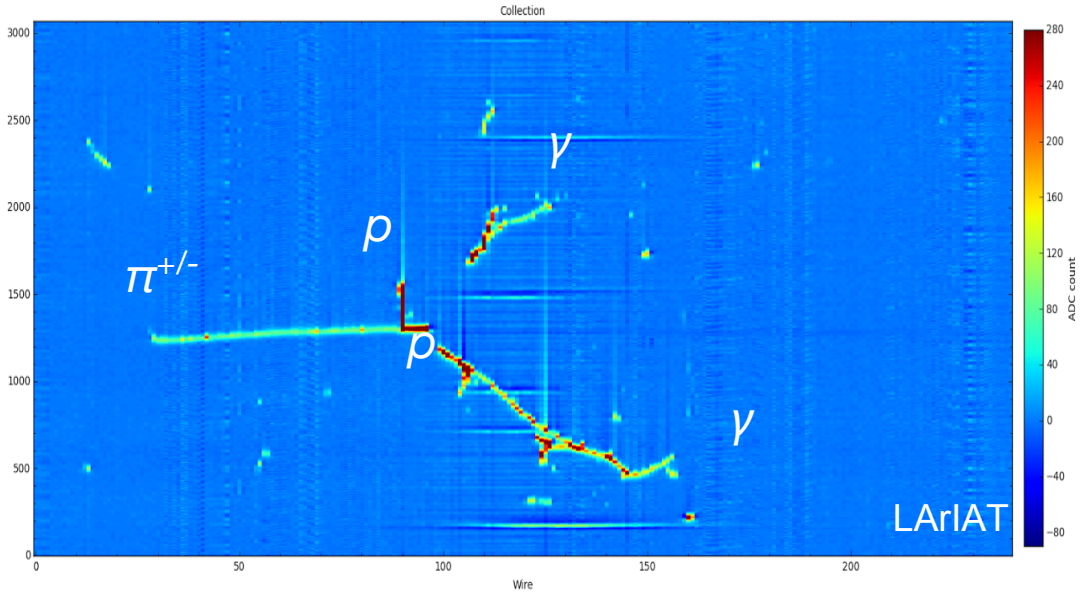






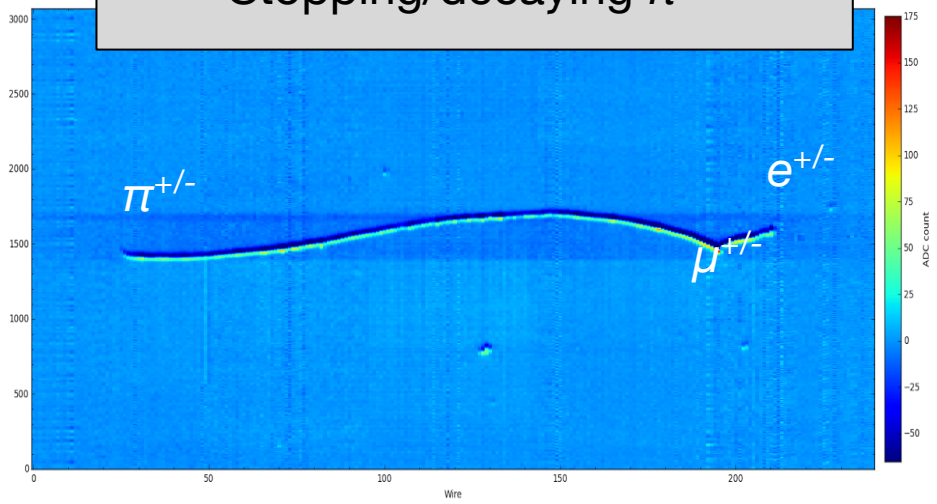
Some event topologies seen by LArIAT



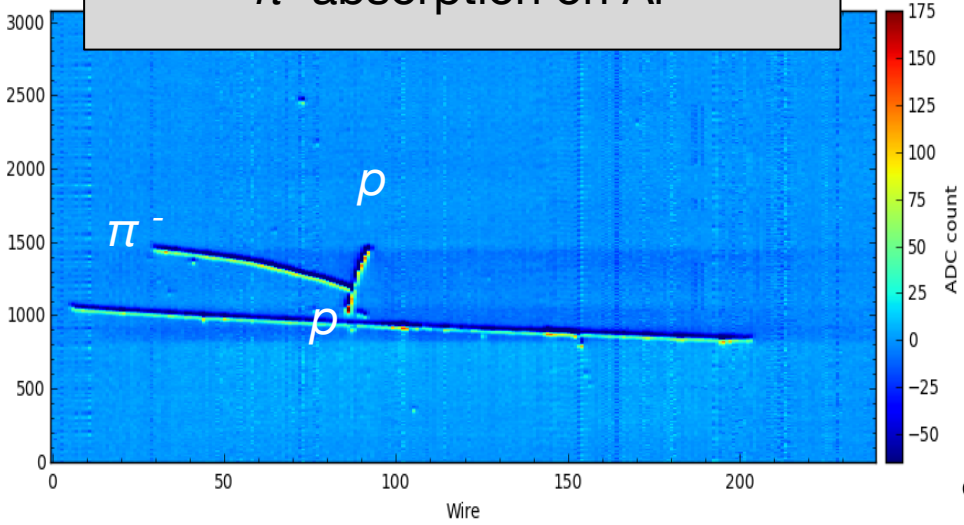


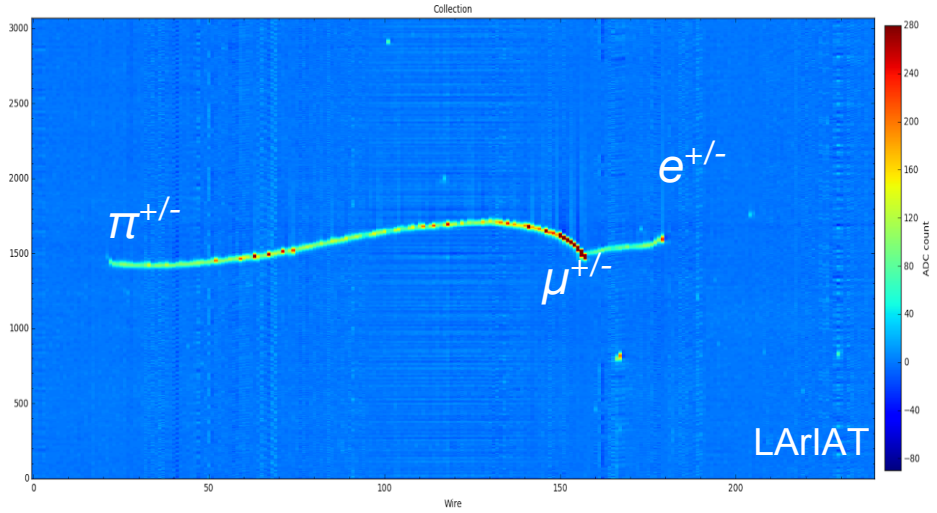
Some event topologies seen by LArIAT

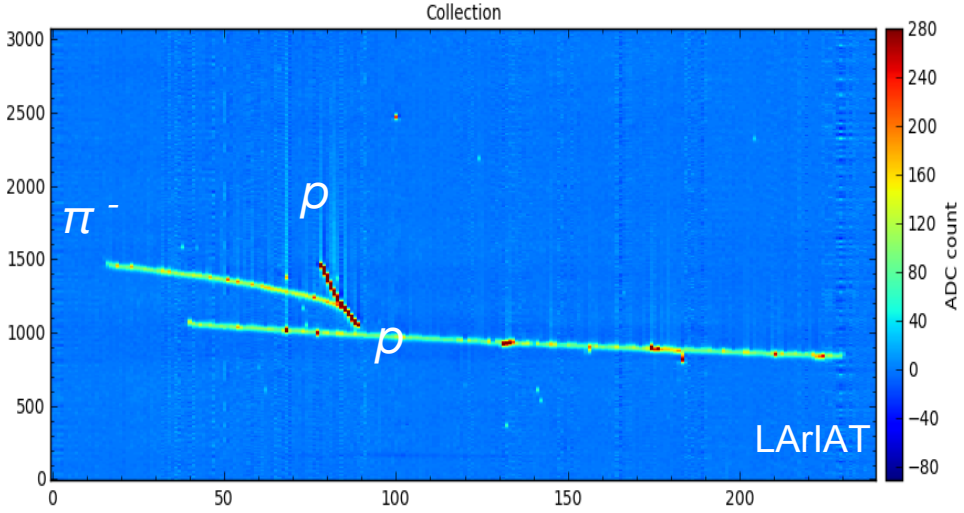
Stopping/decaying $\pi^{+/-}$



π^- absorption on Ar

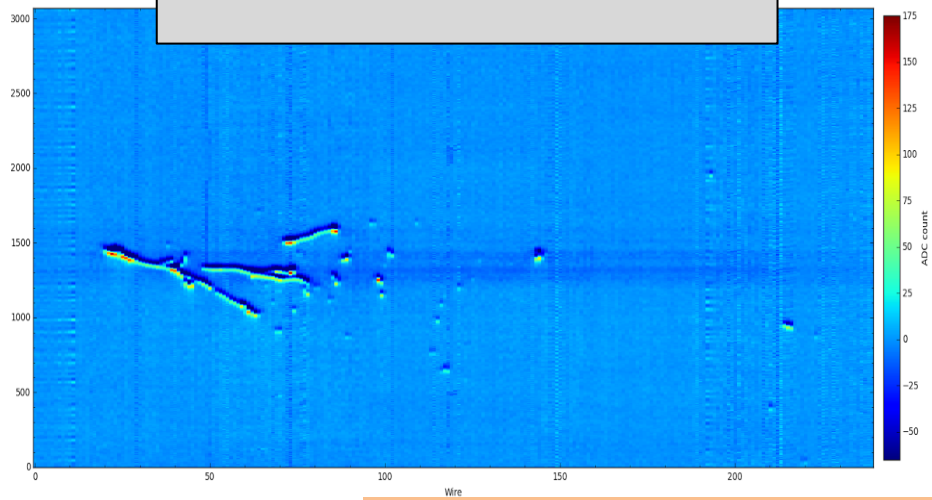




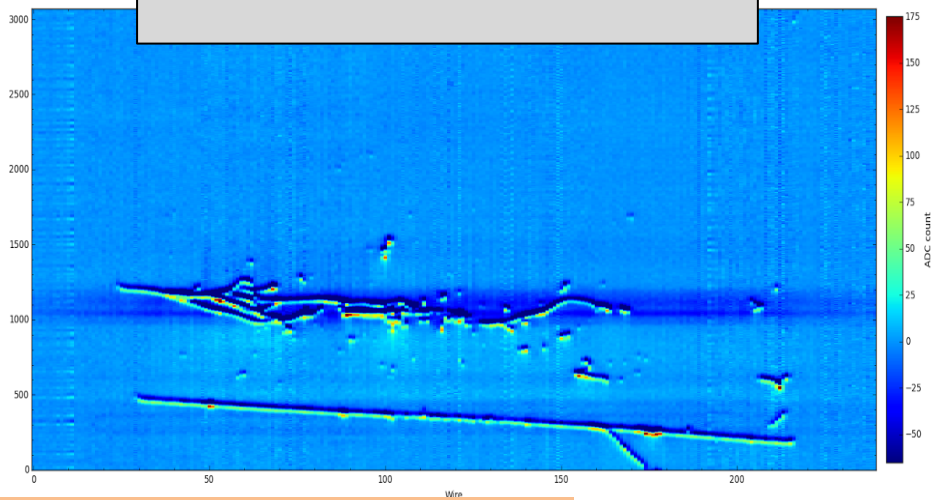


Some event topologies seen by LArIAT

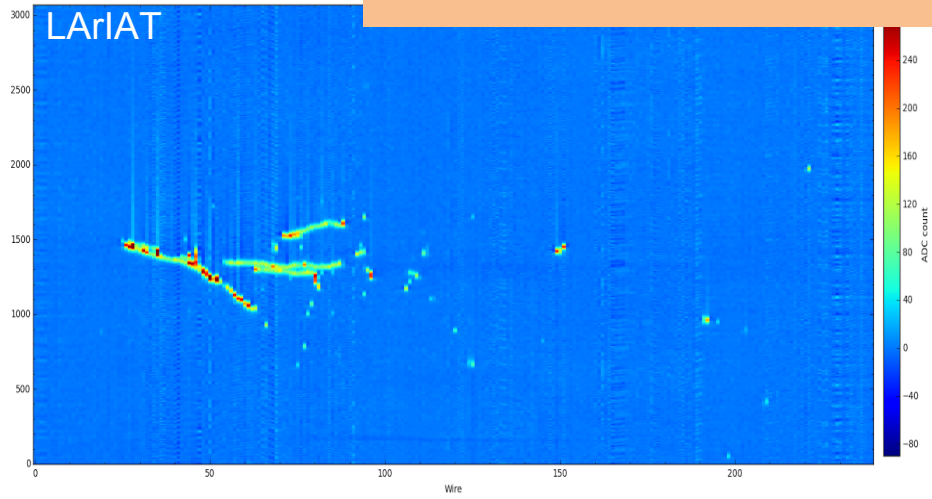
Photon-initiated shower

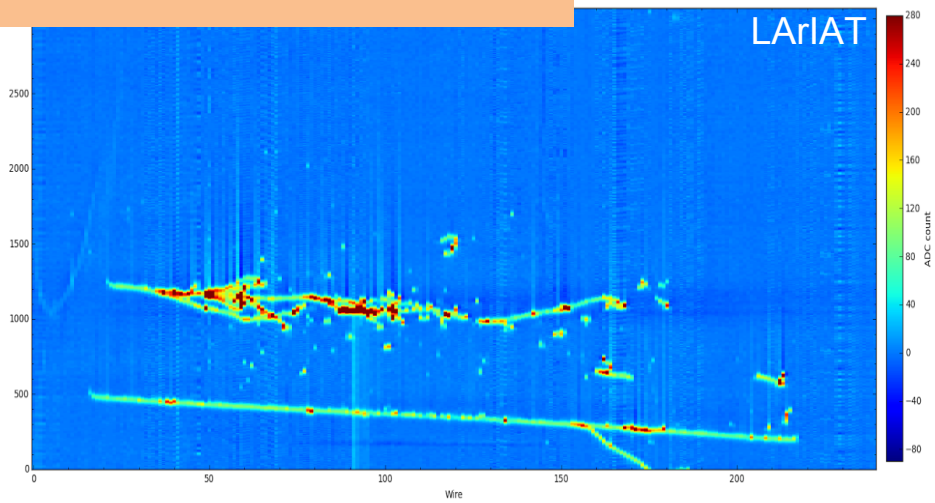


$e^{+/-}$ -initiated shower

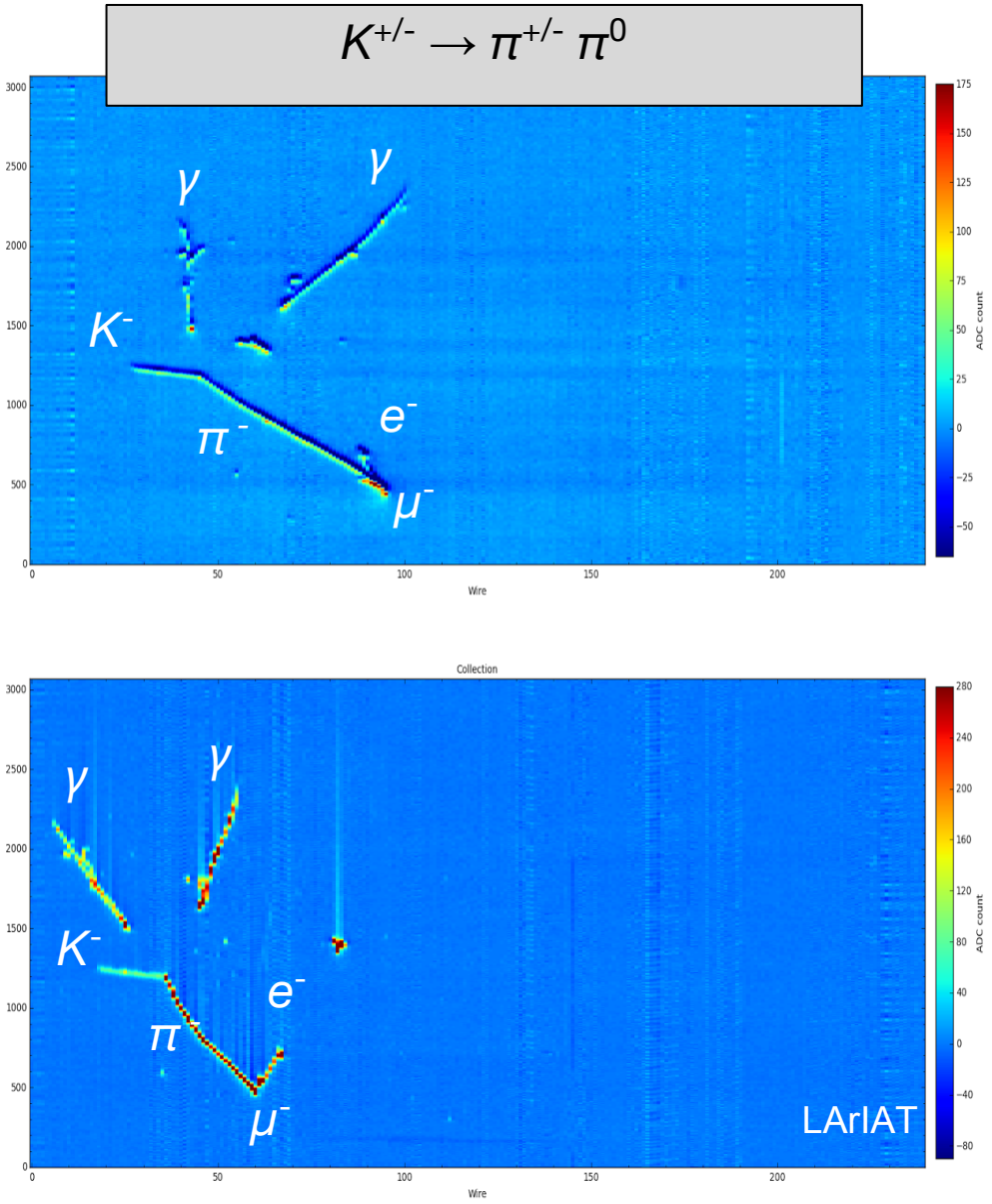


Distinguishable using dE/dx at start of shower





Some event topologies seen by LArIAT



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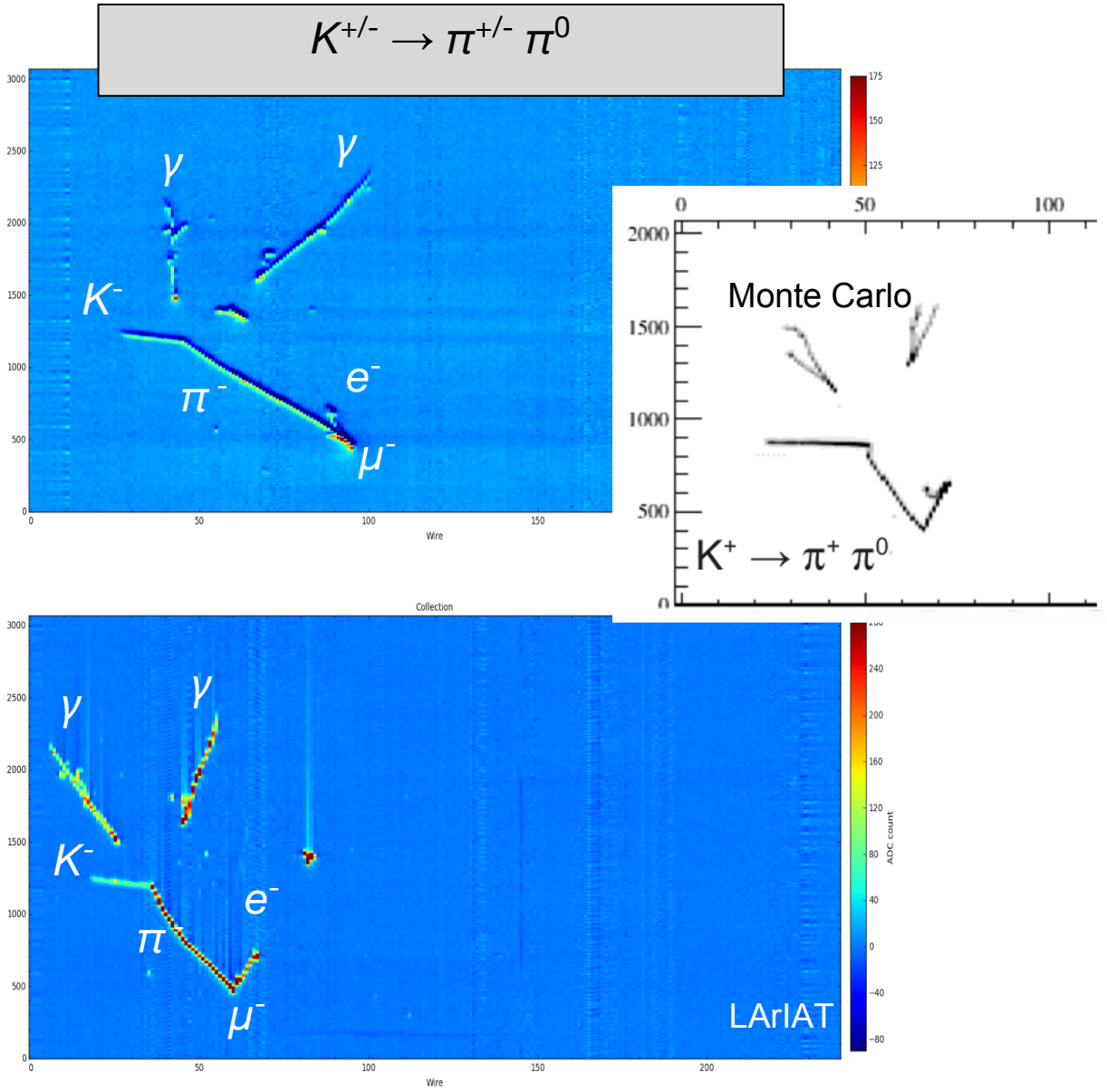
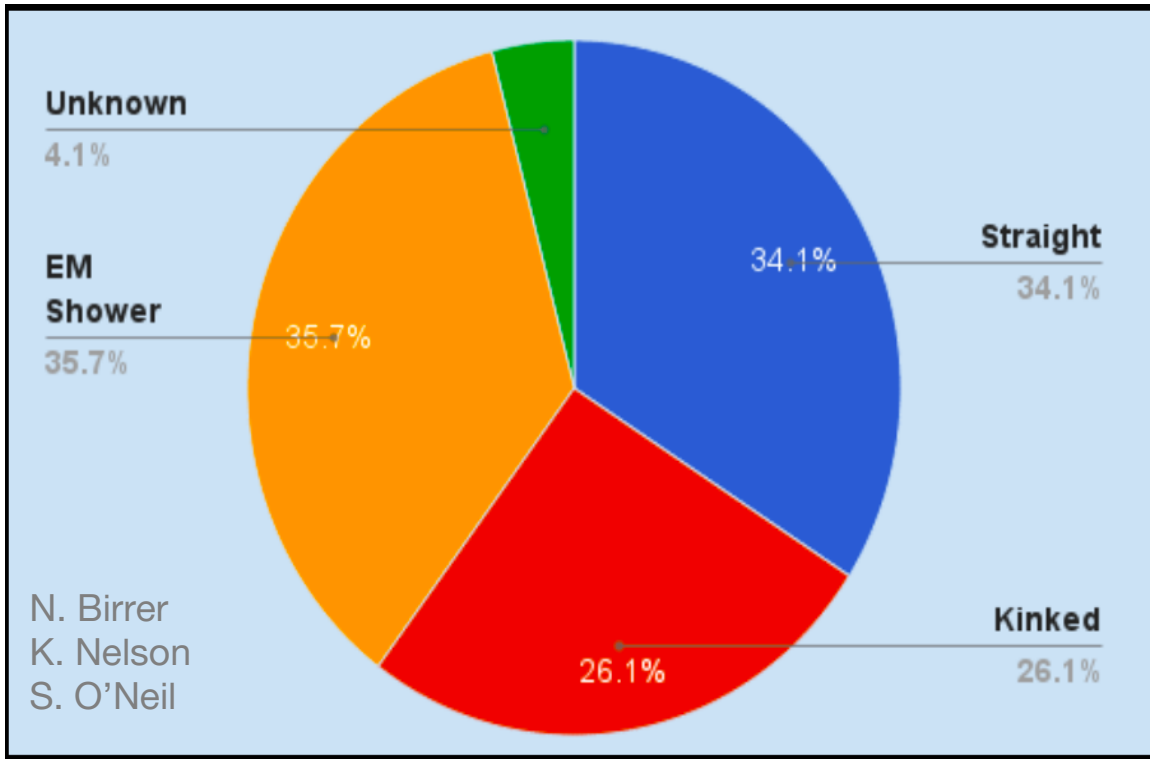


A few ongoing analyses…

Eye scan of a small fraction of the data

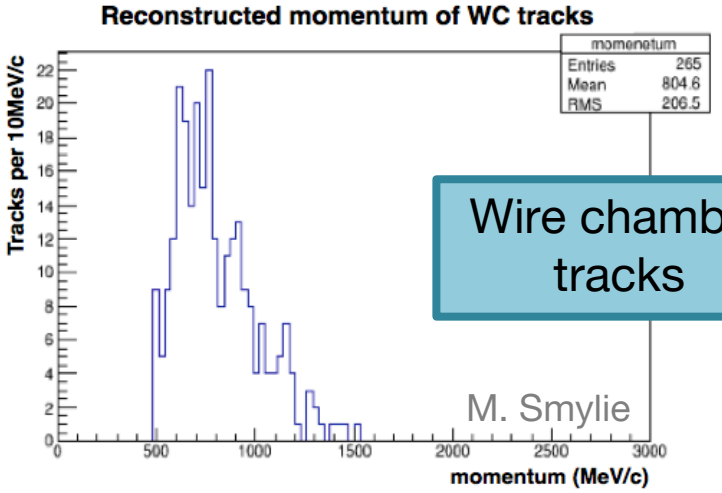
Topology breakdown among the unambiguous, single-track events

A rich physics program will emerge from analyses!



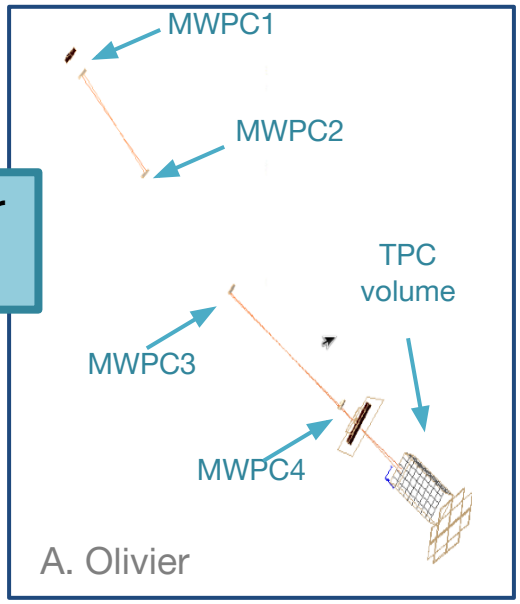
Reconstruction status

Rapid progress in reconstructing both **beamline** & **TPC** ionization tracks

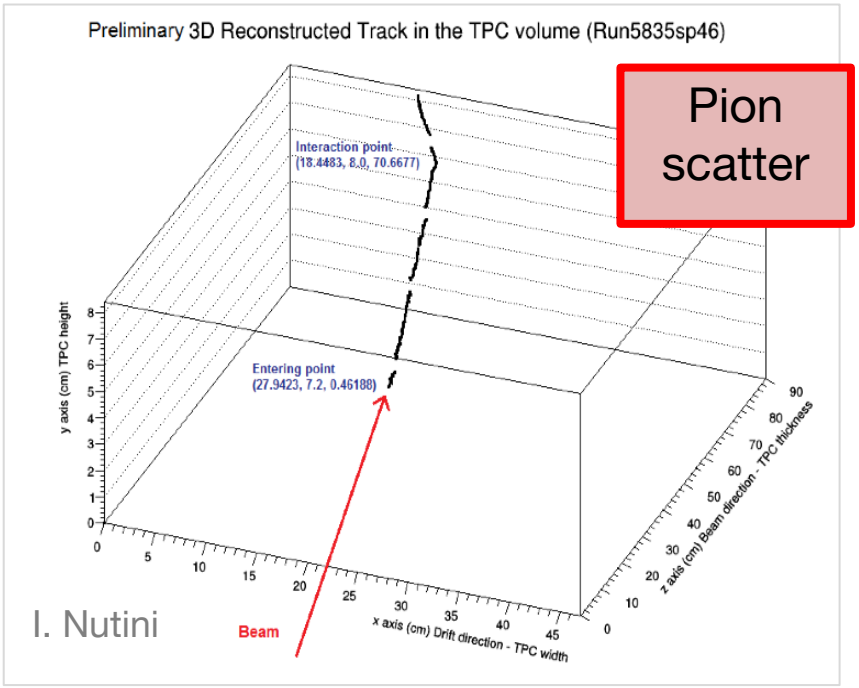


Wire chamber tracks

M. Smylie



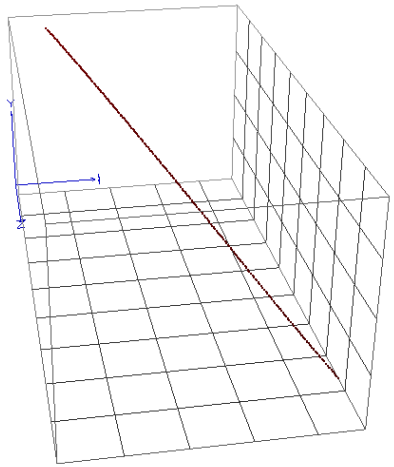
A. Olivier



Pion scatter

I. Nutini

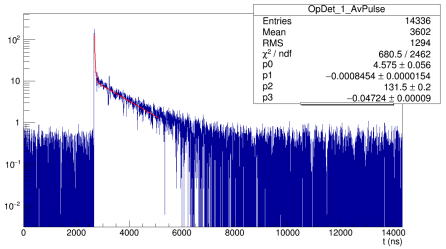
Cosmic μ



R. Acciarri
T. Yang

N_2 levels with scintillation light

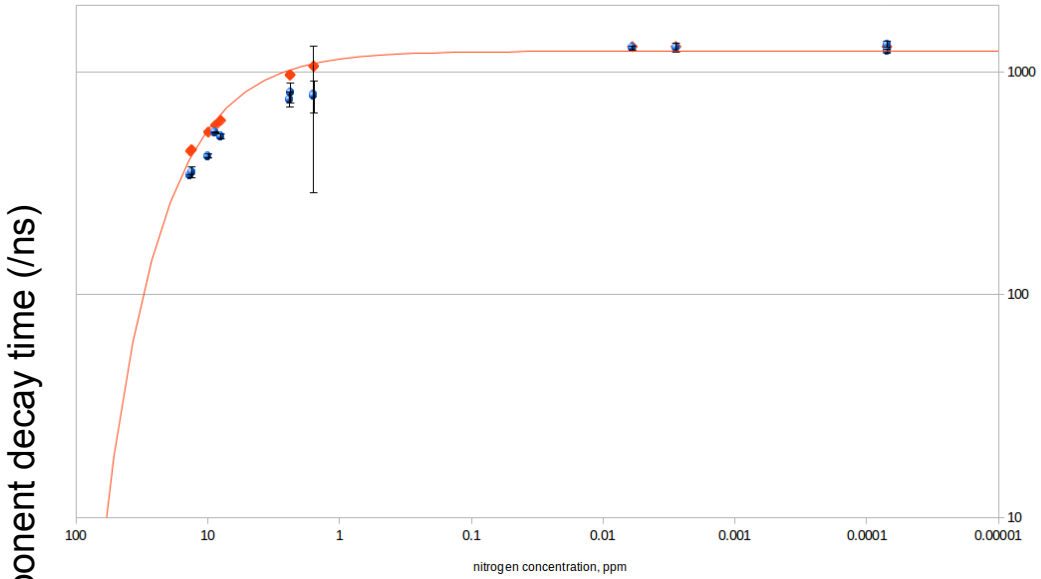
N_2 content in LAr suppresses scintillation light



From fits to scintillation light extract "late" light time component and determine N_2 concentration

Results agree with gas analyzers

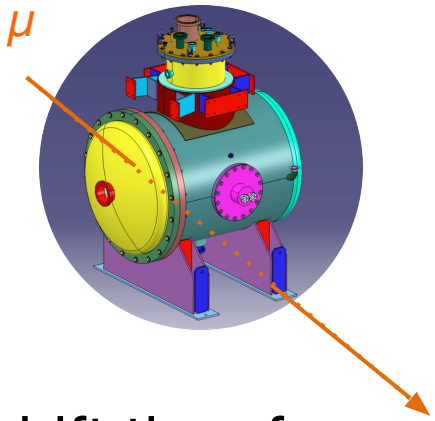
Nitrogen contamination
Comparison with model from WArP

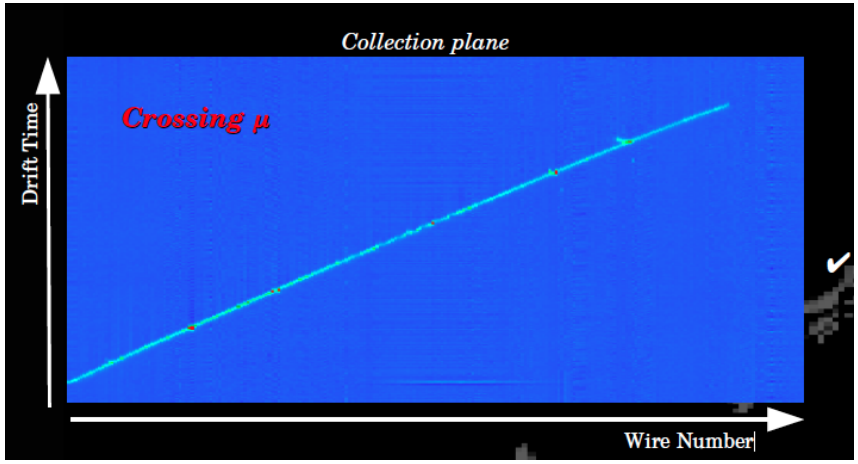


P. Kryczynski
A. Szelc

Electron lifetime / O_2 levels with cosmic μ's

Dedicated paddles for cosmic-μ triggers

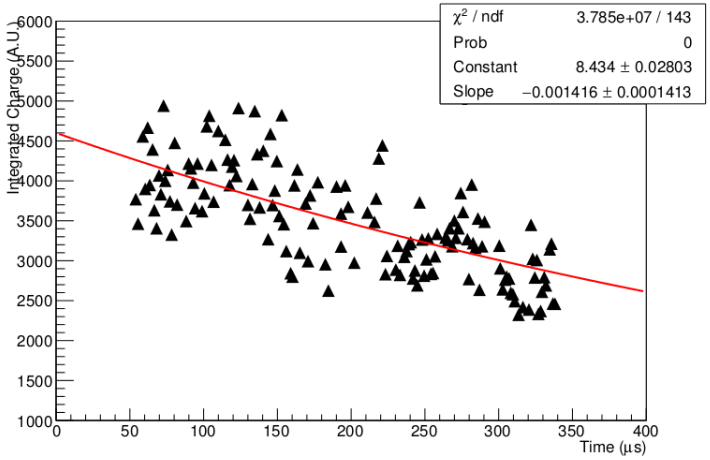




Fit to charge vs. drift time for measurement of electron lifetime

Able to calculate O_2 concentration below sensitivity of our gas analyzers

Current results show O_2 < 1ppb, agreement with gas analyzers



R. Acciarri

Pion interactions I – elastic scattering

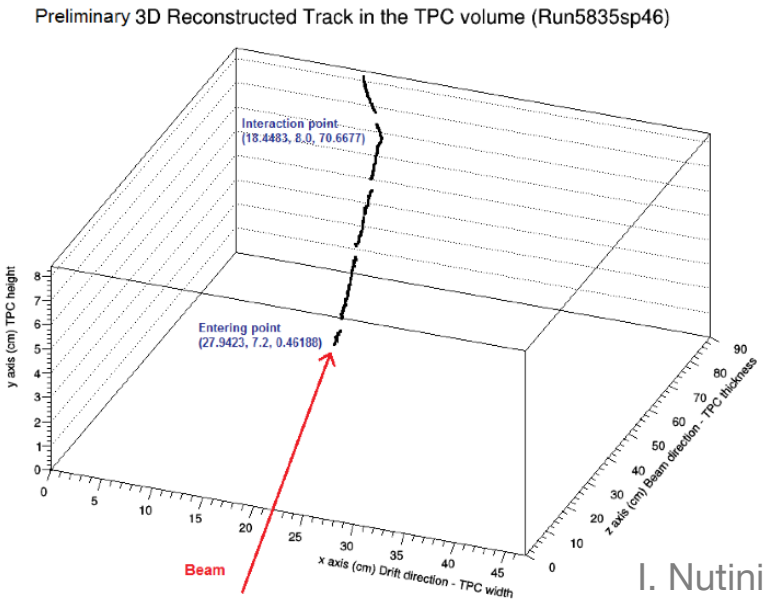
$$\sigma_{tot} = \sigma_{el} + \sigma_{reac}$$

$$\sigma_{reac} = \sigma_{inel} + \sigma_{abs} + \sigma_{chex} + \sigma_{\pi prod}$$

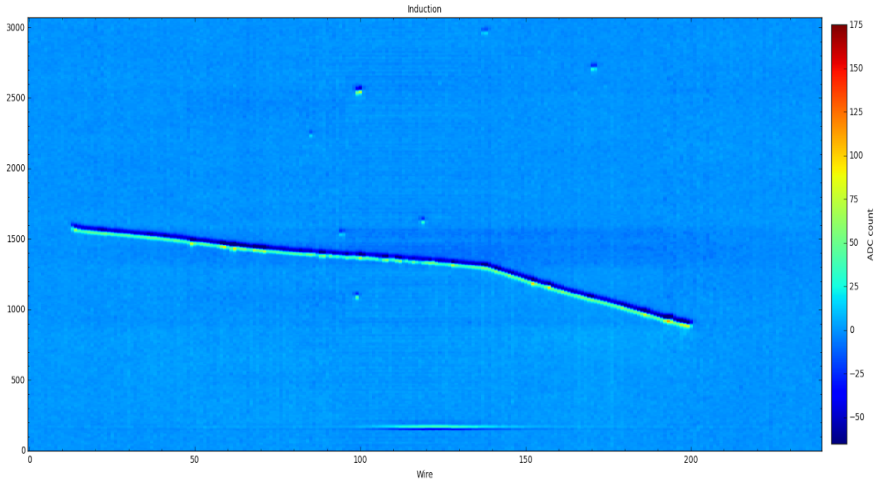
inelastic scatter | absorption on Ar | charge exchange | pion production

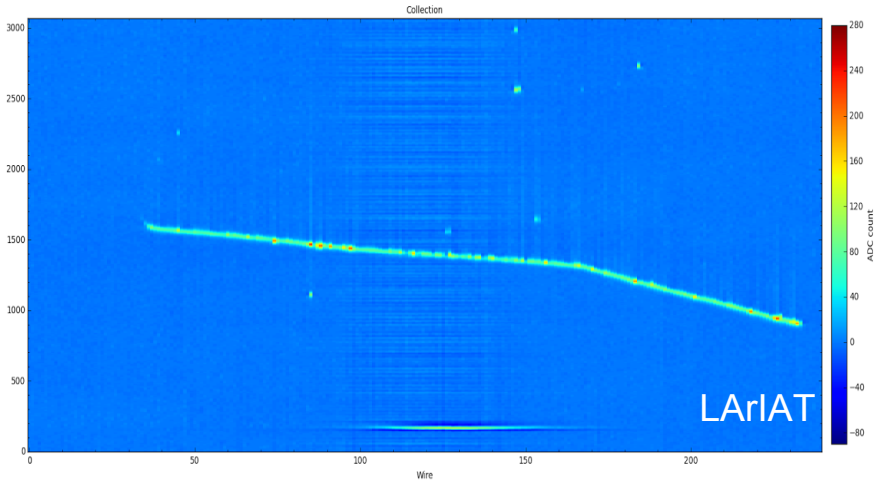
Pion-Argon elastic scattering

Look for kinks in incoming pion-tagged tracks



I. Nutini

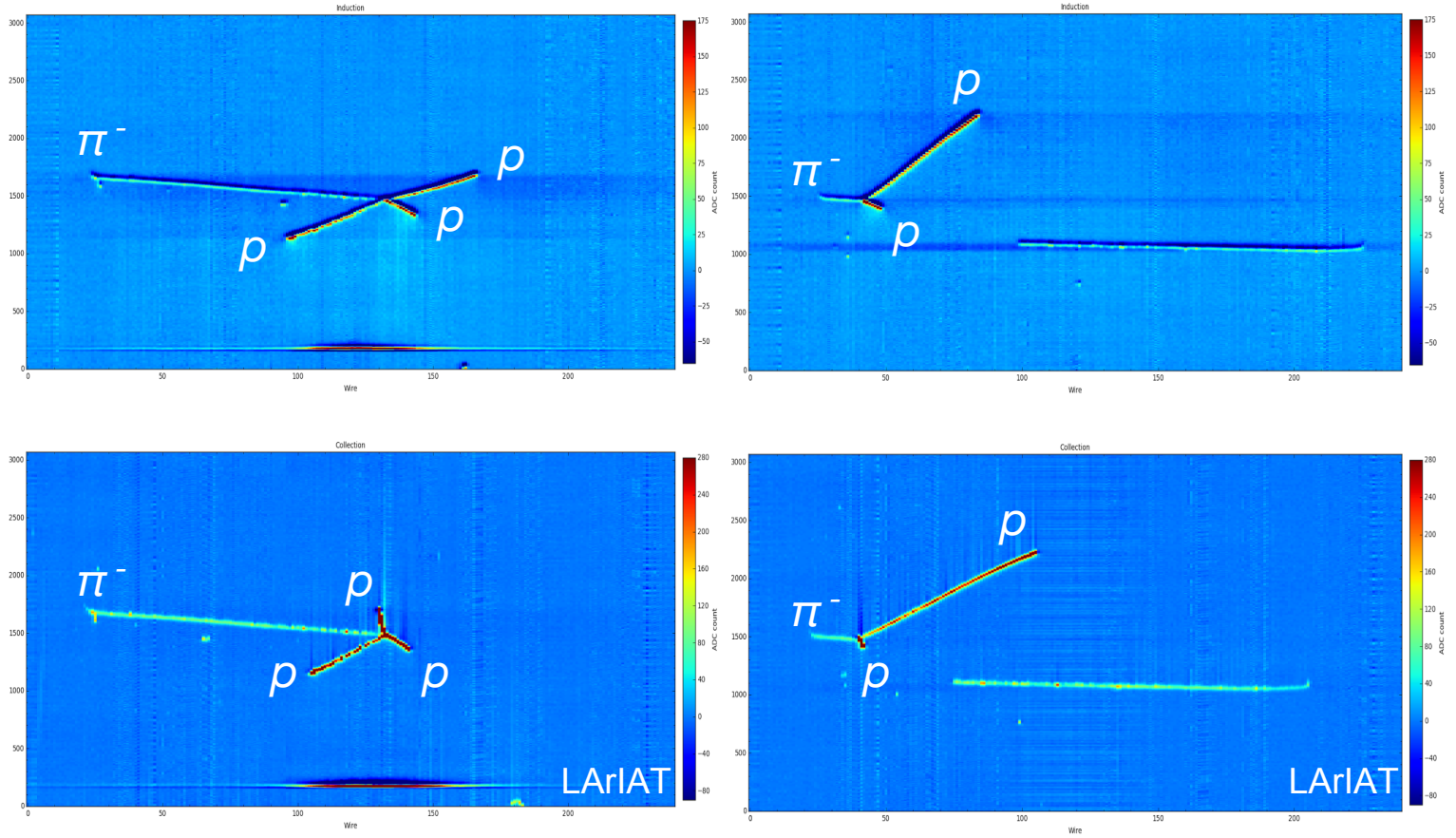




Pion interactions II – absorption

Pion absorption

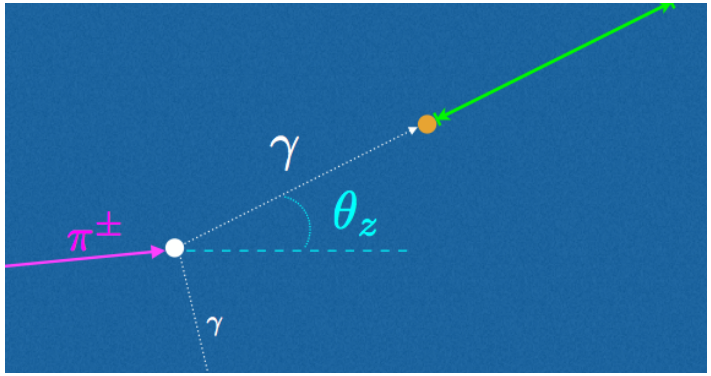
- Incident tagged π, no π's in final state
- Often accompanied by protons/neutrons



Pion single charge exchange

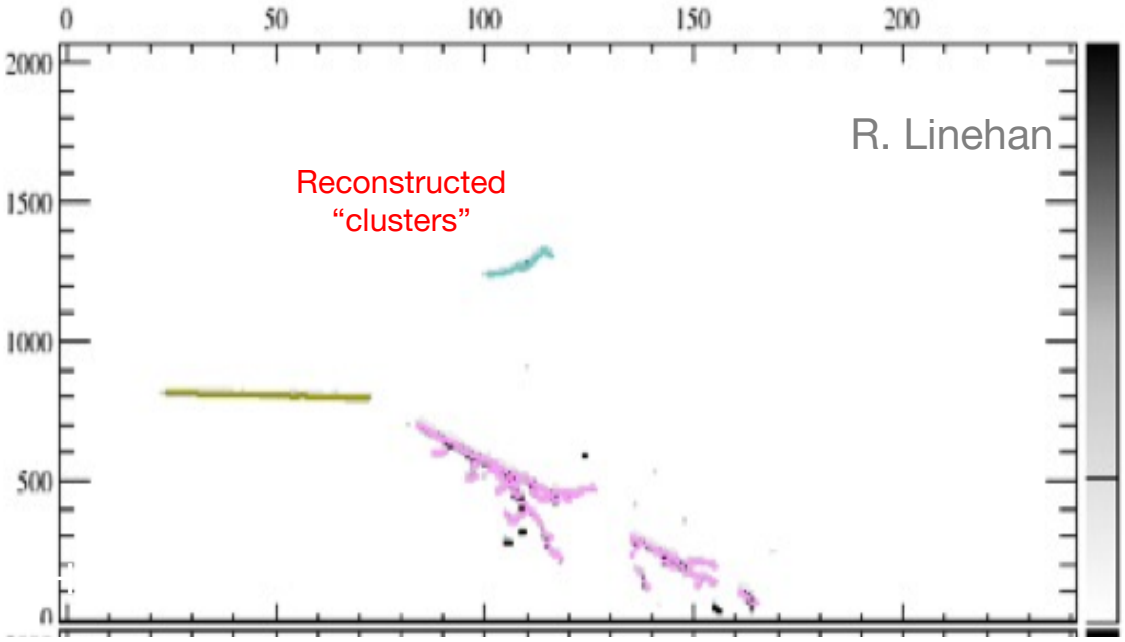
$$\pi^+ + n \rightarrow \pi^0 + p$$

$\pi^0 \rightarrow \gamma\gamma$



Active effort to ID and reconstruct
- π^0 mass peak from $m_{\gamma\gamma}$
- Cross section

MC studies to understand containment of these events in TPC



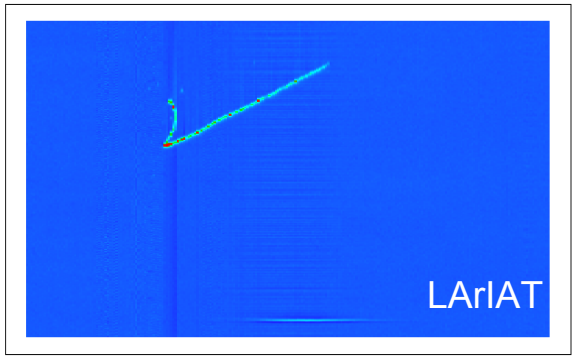
Michel electrons

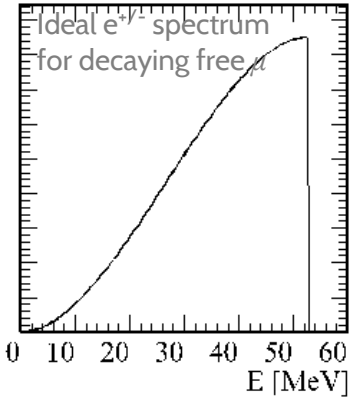
LAr scintillation-based trigger to record stopping/decaying cosmic μ's

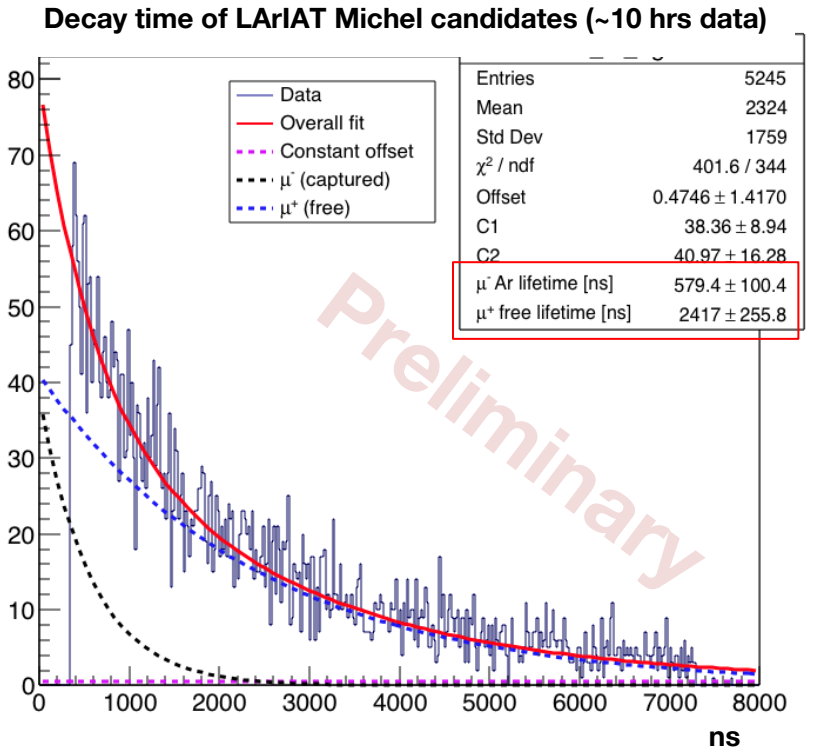
Initial reconstruction focused on light signals only

- Track/shower algorithms to follow

Eventual use as energy calibration source and measurement of μ^- nuclear capture rate







Summary

LArTPC test beams are getting underway!

MiniCAPTAIN has just seen its calibration laser track
- Neutron beam running will begin soon

LArIAT's run 1 was a success – lots of new data to analyze
- Offline event reconstruction actively evolving day-by-day
- Several analyses underway with more to come
- Actively preparing for **Run II** this Autumn

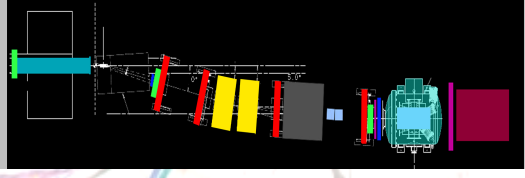
Detailed calibration, cross sections, etc. on the horizon!

Thank you!

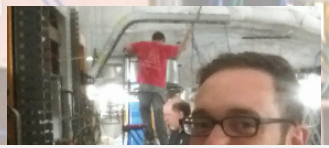
- **Federal University of ABC, Brazil (UFABC)** Marcelo Leigui, Célio A. Moura, Laura Paulucci
- **Federal University of Alfenas, Brazil (UNIFAL-MG)** Gustavo Valdiviesso
- **Boston U.** Flor de Maria Blaszczyk, Dan Gastler, Ryan Linehan, Ed Kearns, Daniel Smith
- **Caltech** Ryan Patterson
- **U. Campinas, Brazil (UNICAMP)** Carlos Escobar, Pedro Holanda, Ernesto Kemp, Ana Amelia B. Machado, Ettore Segreto
- **U. Chicago** Will Foreman, Johnny Ho, Dave Schmitz
- **U. Cincinnati** Randy Johnson, Jason St. John
- **Fermilab** Roberto Acciarri, Michael Backfish, William Badgett, Bruce Baller, Flavio Cavanna[†] (also INFN, Italy), Alan Hahn, Doug Jensen, Hans Jostlein, Mike Kirby, Tom Kobilarcik, Paweł Kryczyński (also Institute of Nuclear Physics, Polish Academy of Sciences), Sarah Lockwitz, Alberto Marchionni, Irene Nutini, Ornella Palamara (also INFN, Italy), Jon Paley, Jennifer Raaf[†], Brian Rebel[‡], Michelle Stancari, Sam Zeller
- **Federal University of Goiás, Brazil (UFG)** Ricardo A. Gomes
- **Istituto Nazionale di Fisica Nucleare, Italy (INFN)** Flavio Cavanna (also Fermilab), Ornella Palamara (also Fermilab)
- **Imperial College London, UK** Morgan Wascko
- **KEK** Eito Iwai, Takasumi Maruyama
- **LANL** Christopher Mauger
- **Louisiana State University** William Metcalf, Andrew Olivier, Martin Tzanov
- **U. Manchester, UK** Justin Evans, Pawel Guzowski, Andrzej Szelc
- **Michigan State University** Carl Bromberg, Dan Edmunds, Dean Shooltz
- **U. Minnesota, Duluth** Rik Gran, Alec Habig
- **U. Pittsburgh** Steve Dytman, Matthew Smylie
- **Syracuse University** Jonathan Asaadi, Jessica Esquivel, Mitch Soderberg
- **U. Texas, Arlington** Amit Bashyal, Amir Farbin, Seongtae Park, Sepideh Shahsavarani, Timothy Watson, Andy White, Jae Yu
- **U. Texas, Austin** Will Flanagan, Karol Lang, Dung Phan, Brandon Soubasis (also Texas State University)
- **University College London** Anna Holin, Ryan Nichol
- **William & Mary** Mike Kordosky[‡], Matthew Stephens
- **Yale University** Bonnie Fleming, Elena Gramellini

Backup

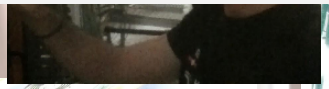
Beam commissioning

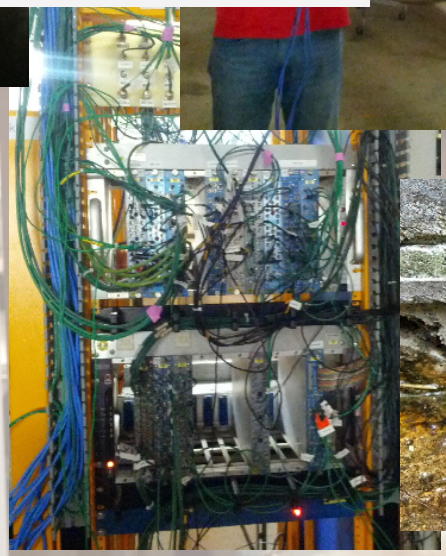


Installation of beamline detectors and TPC-less running to test them (and characterize the beam)

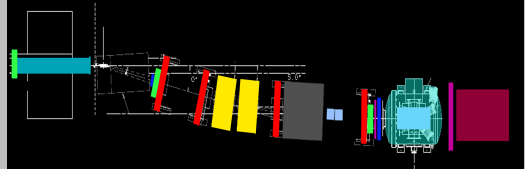


Completed summer 2014

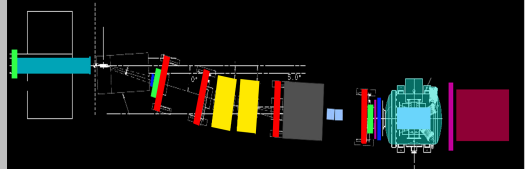




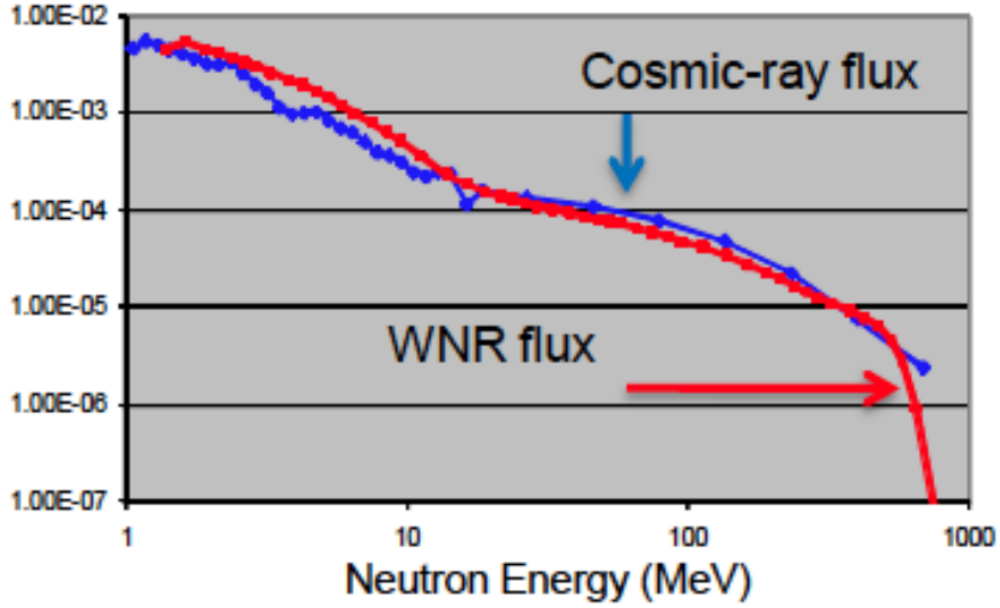
Cryogenic Ultra-Pure LAr



Powerful, flexible trigger system



Incident Beam



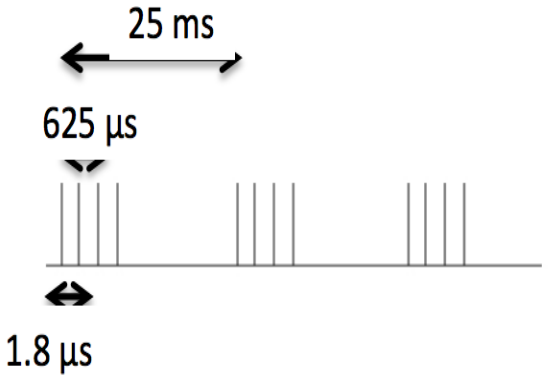
Time of Flight → E_n

- Beam on target starts clock
- Cryogenic PMTs stop it

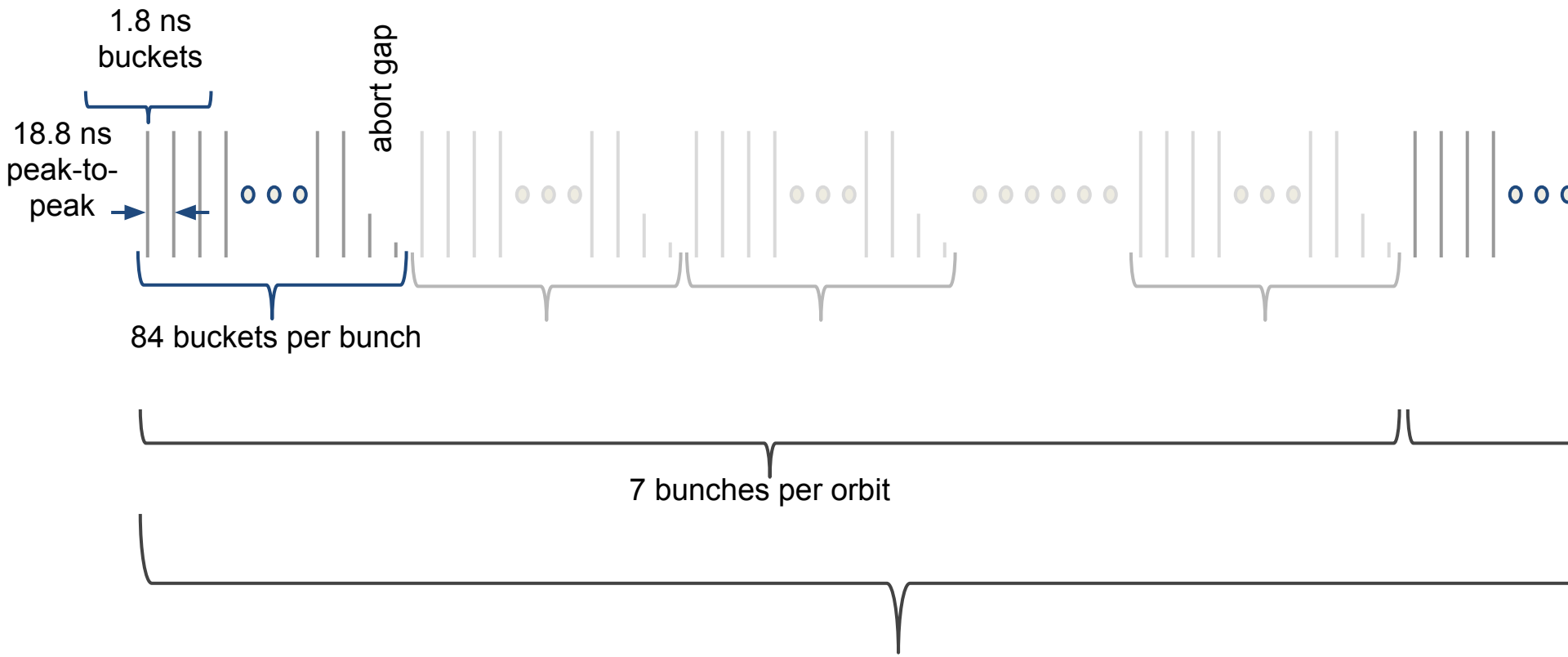
Time structure of *n* beam:

- 625 μs macropulses of sub-ns micropulses @ 1.8 μs
- 40 Hz macropulse rate

Neutron beam closely matched to cosmic-induced neutron spectrum



Time Structure of the Beam



4.2 seconds of beam per spill
= 380k orbits * 18.8 ns * 7 * 84

1 spill every 60.8 seconds

Summary of Run I

Beam data taking ran about 2 months