LARIAT

Liquid **AR**gon TPC **I**n **A** **T**estbeam

FNAL-T1034

NSF Visit – July 23, 2013

Carl Bromberg, Flavio Cavanna, Rik Gran,

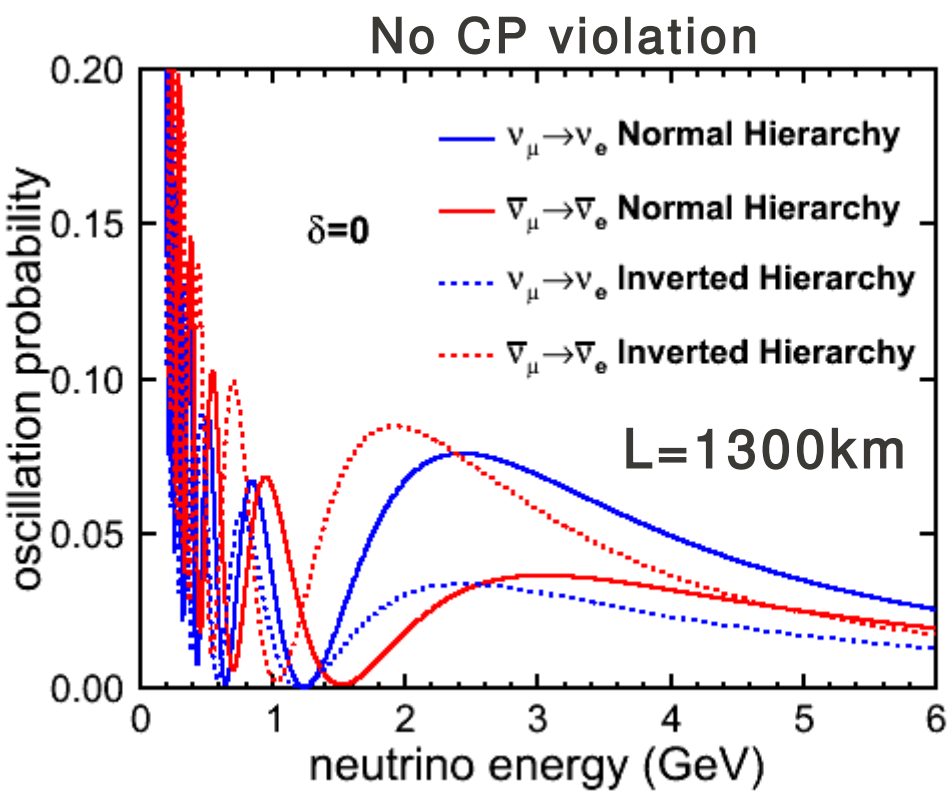
Mike Kordosky, Jenn Raaf, Mitch Soderberg

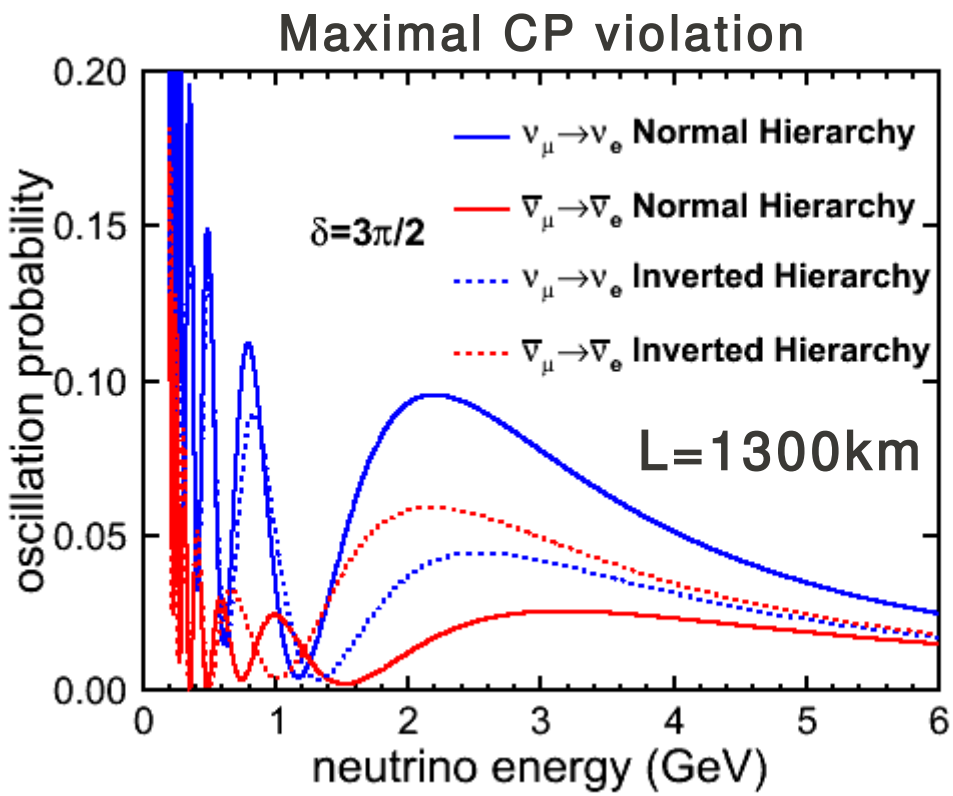
Purpose of this visit

- Motivation for LARIAT
- Scope and goals of the experiment
- Where LARIAT fits in the LAr TPC research portfolio
- Current status and plans
- Who is working on LARIAT? What are they doing?
- How involvement in LARIAT advances NSF goals and NSF groups

Motivation

Mass hierarchy, CP phase and PMNS unitarity





<u>Must measure:</u> neutrino flavor, energy, flux

Motivation

Your typical neutrino event

Incoming neutrino

Flavor: unknown

Energy: unknown

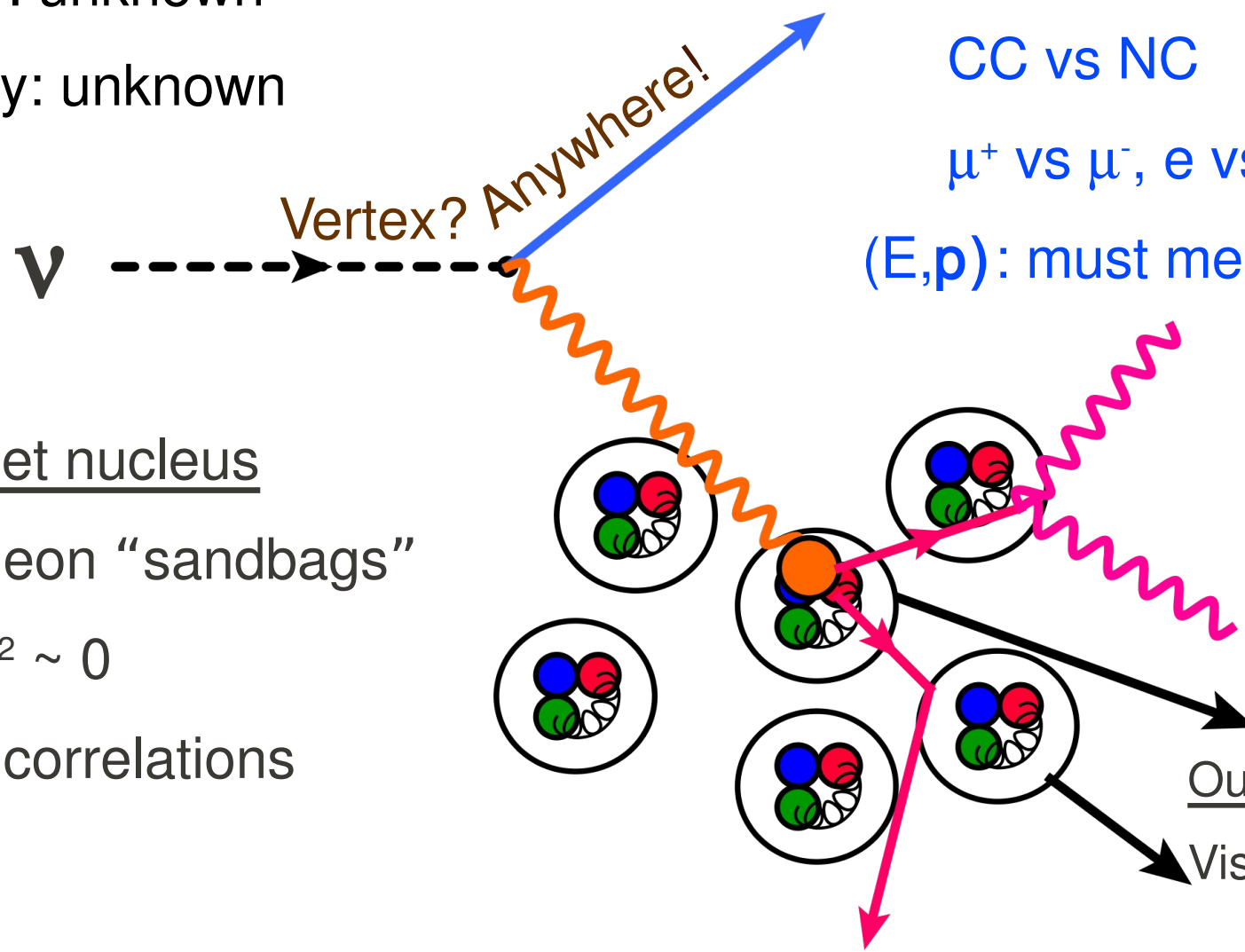
Outgoing lepton

Flavor ID:

CC vs NC

μ^+ vs μ^-, e vs γ, τ?

(E,**p**): must measure



Target nucleus

Nucleon "sandbags"

at $Q^2 \sim 0$

N N correlations

Mesons

FSI!

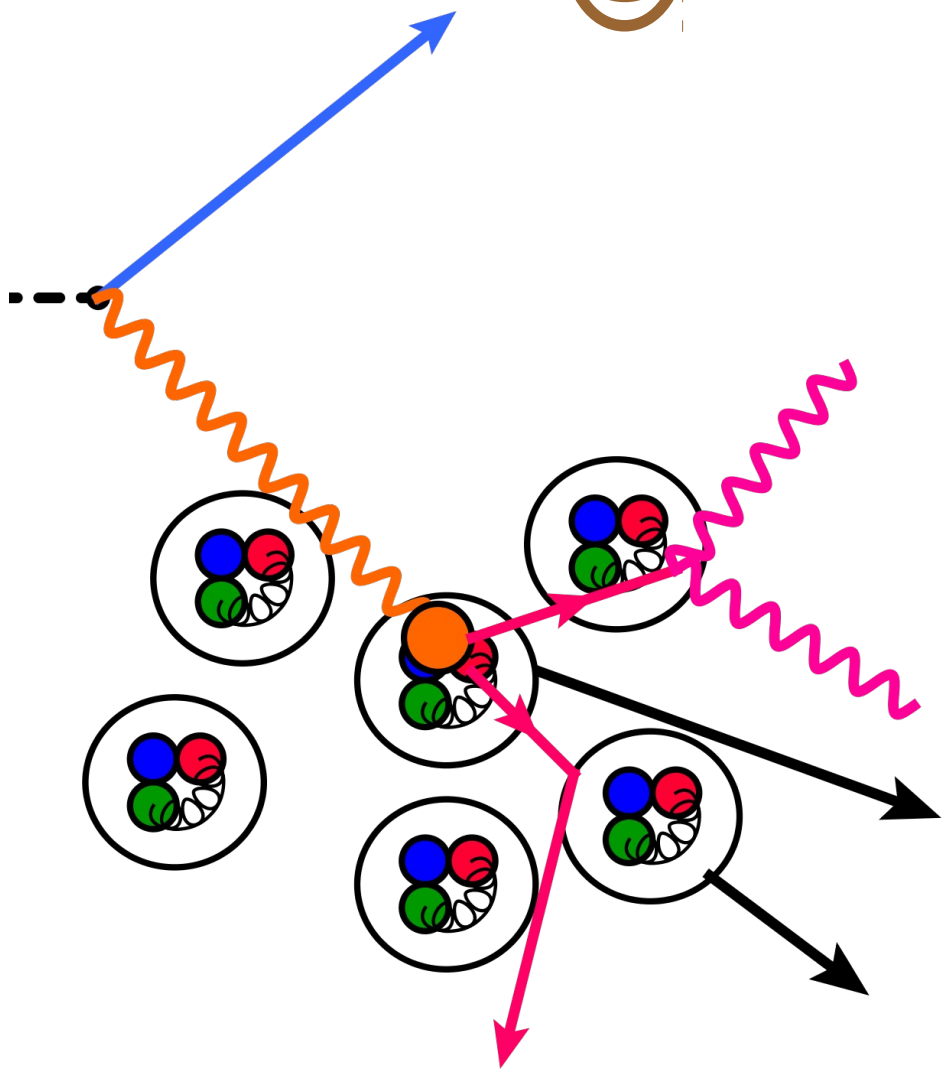
Energy?

Identity?

Outgoing nucleons

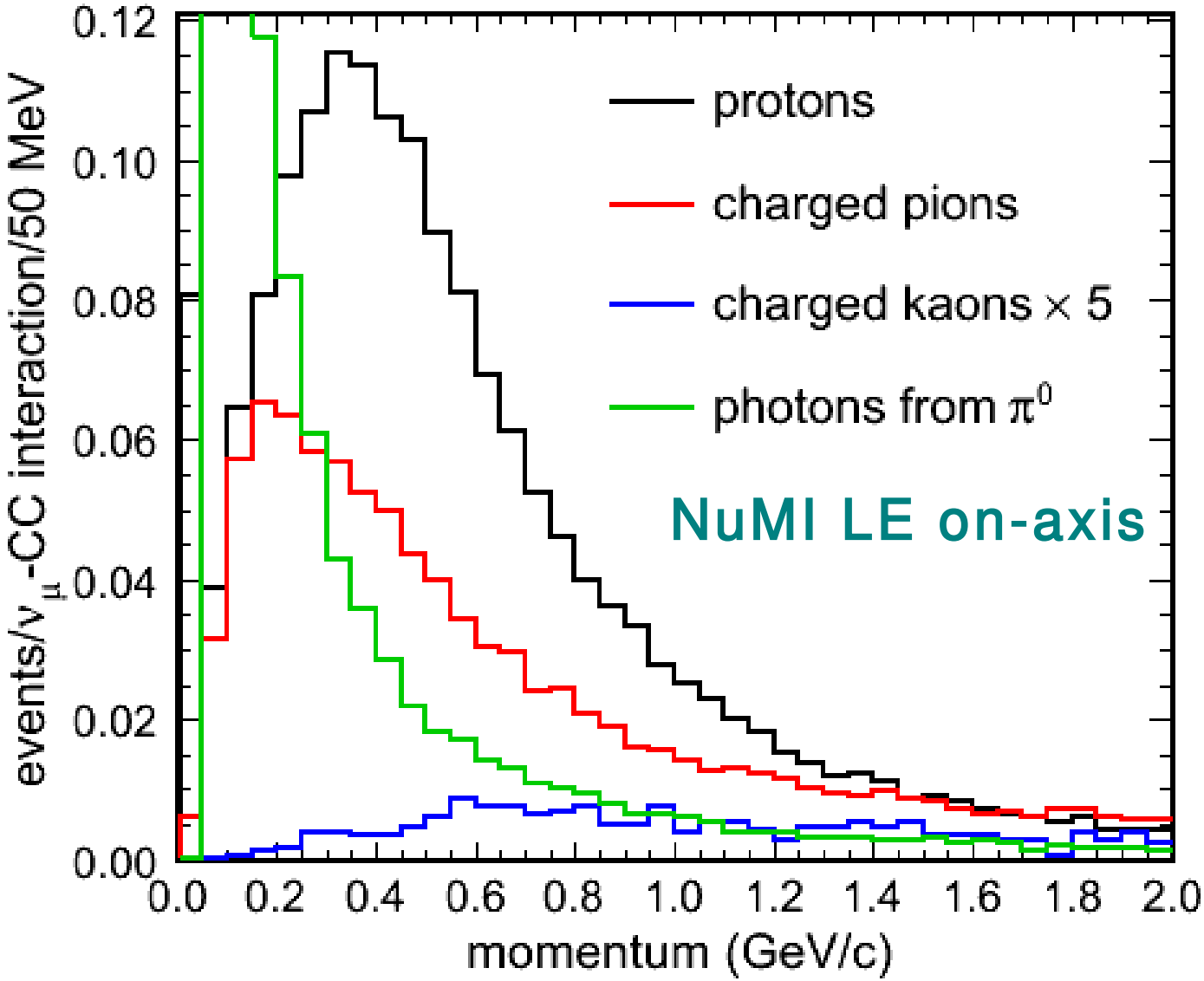
Visible? Energy?

LARIAT final state

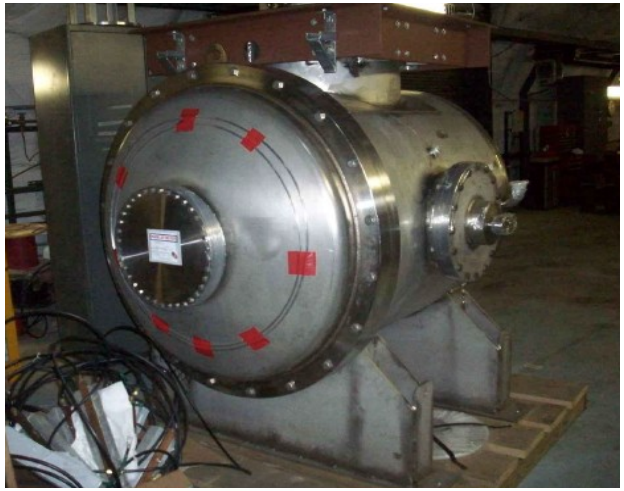


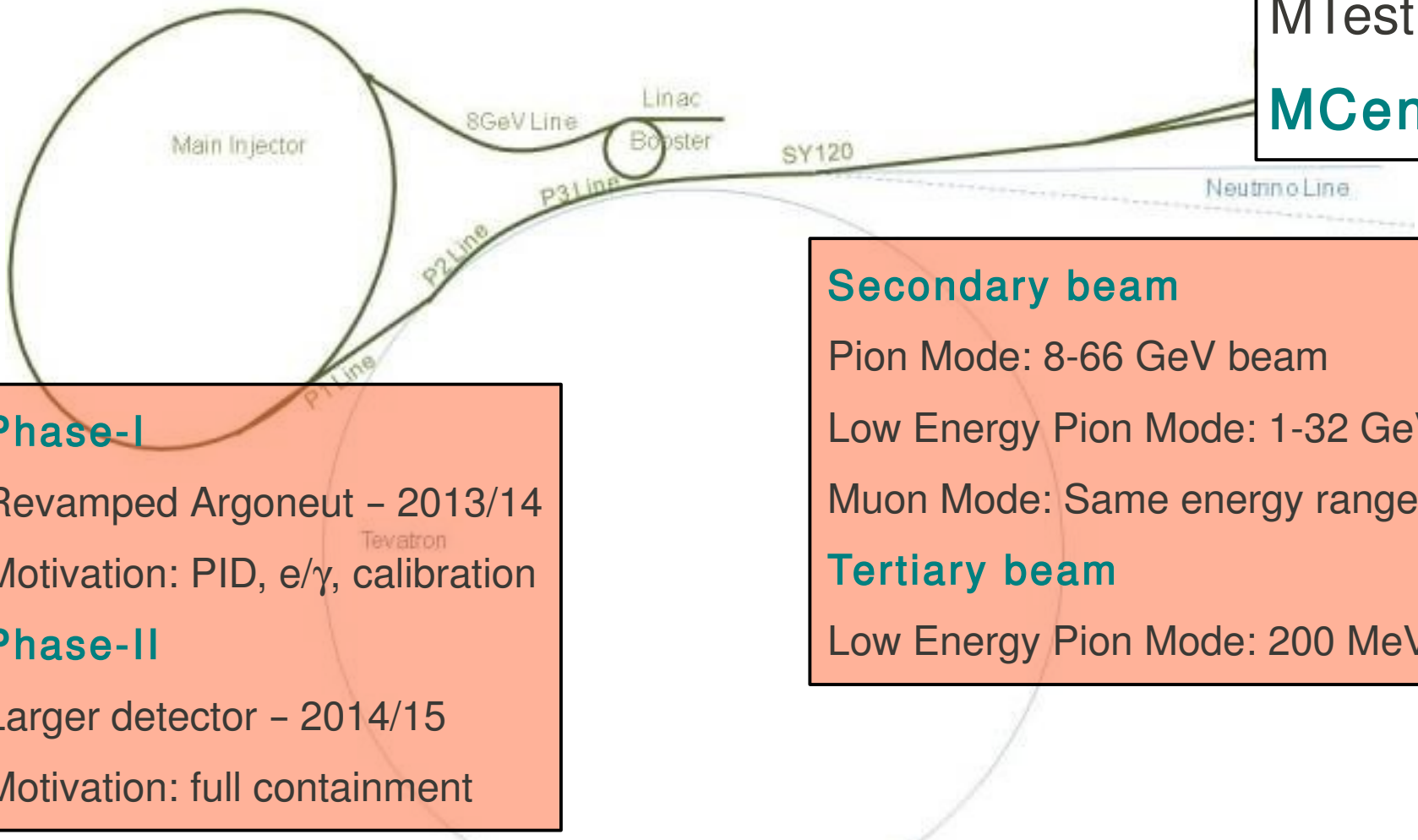
- Visible energy calibration of LAr
- Particle identification
- Event reconstruction
- Calorimetric response and resolution
- hadron + Ar scattering

Particles from ν interactions



Basic concept: LArTPC + FTBF





MTest

MCenter

Secondary beam

Pion Mode: 8-66 GeV beam

Low Energy Pion Mode: 1-32 GeV beam

Muon Mode: Same energy range as above

Tertiary beam

Low Energy Pion Mode: 200 MeV - 3 GeV

Phase-I

Revamped Argoneut – 2013/14

Motivation: PID, e/γ, calibration

Phase-II

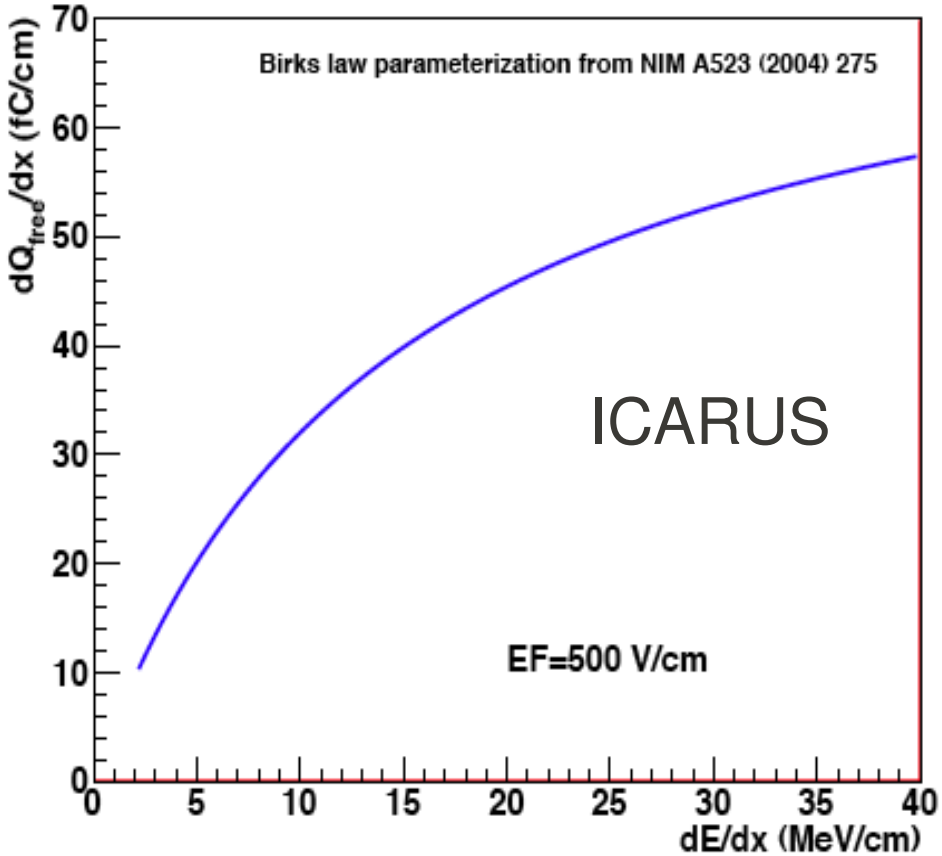
Larger detector – 2014/15

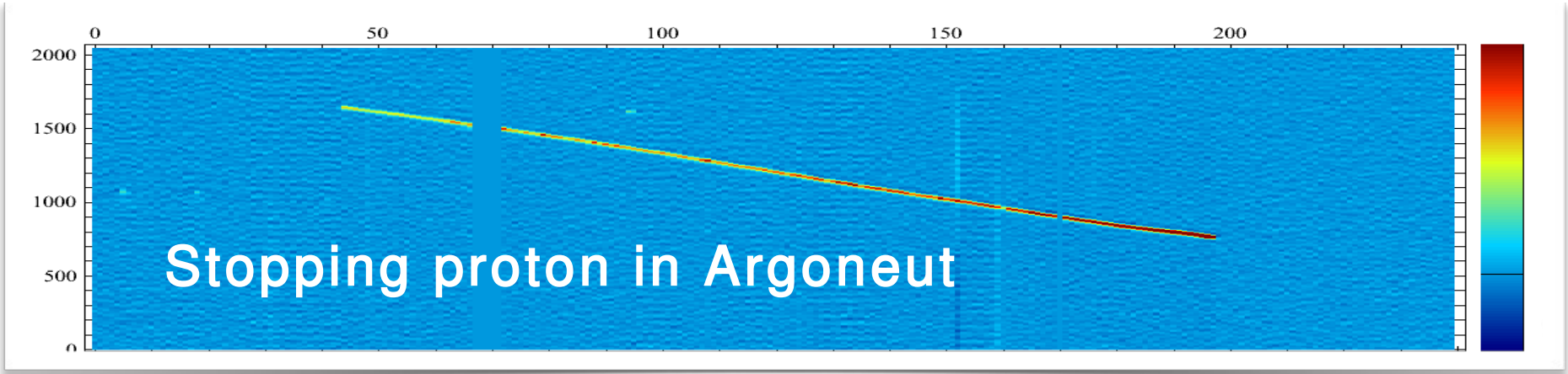
Motivation: full containment

Physics Goals

Visible energy calibration

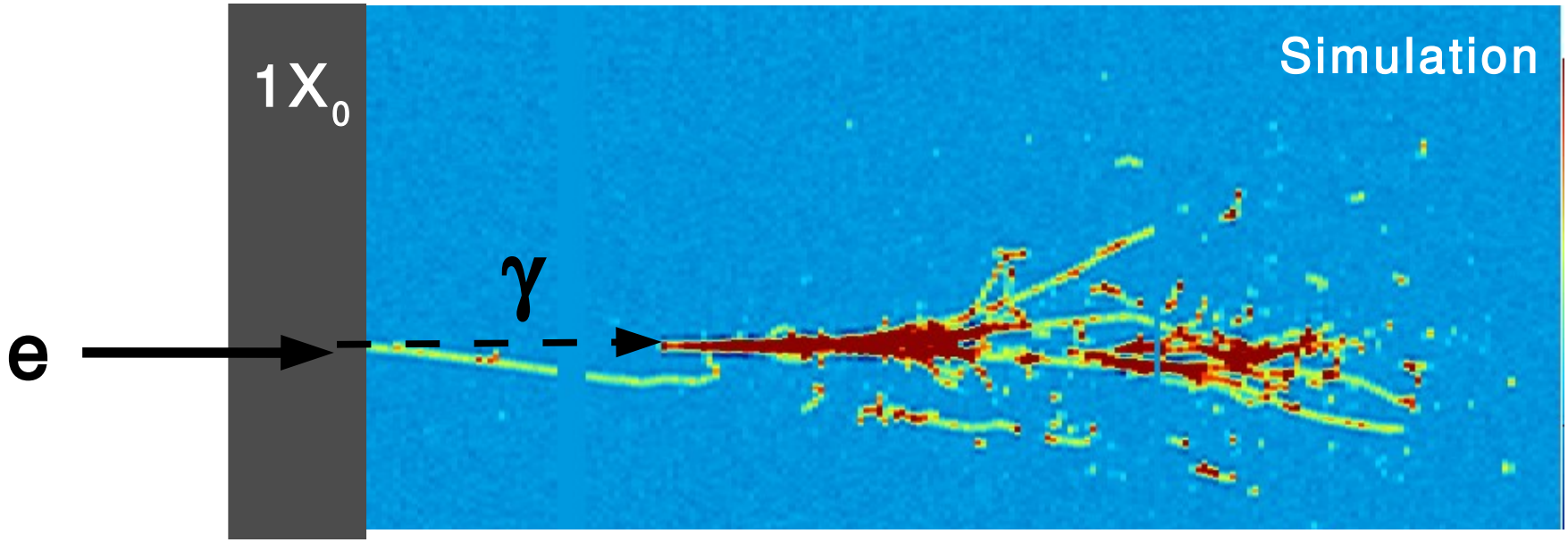
- Need **dE/dx** for particle ID and energy
- Relate **energy deposited** to **charge** and **light** collected
- Study **recombination** along stopping tracks





Particle identification

electron vs photon discrimination



Bremsstrahlung from upstream radiator plate

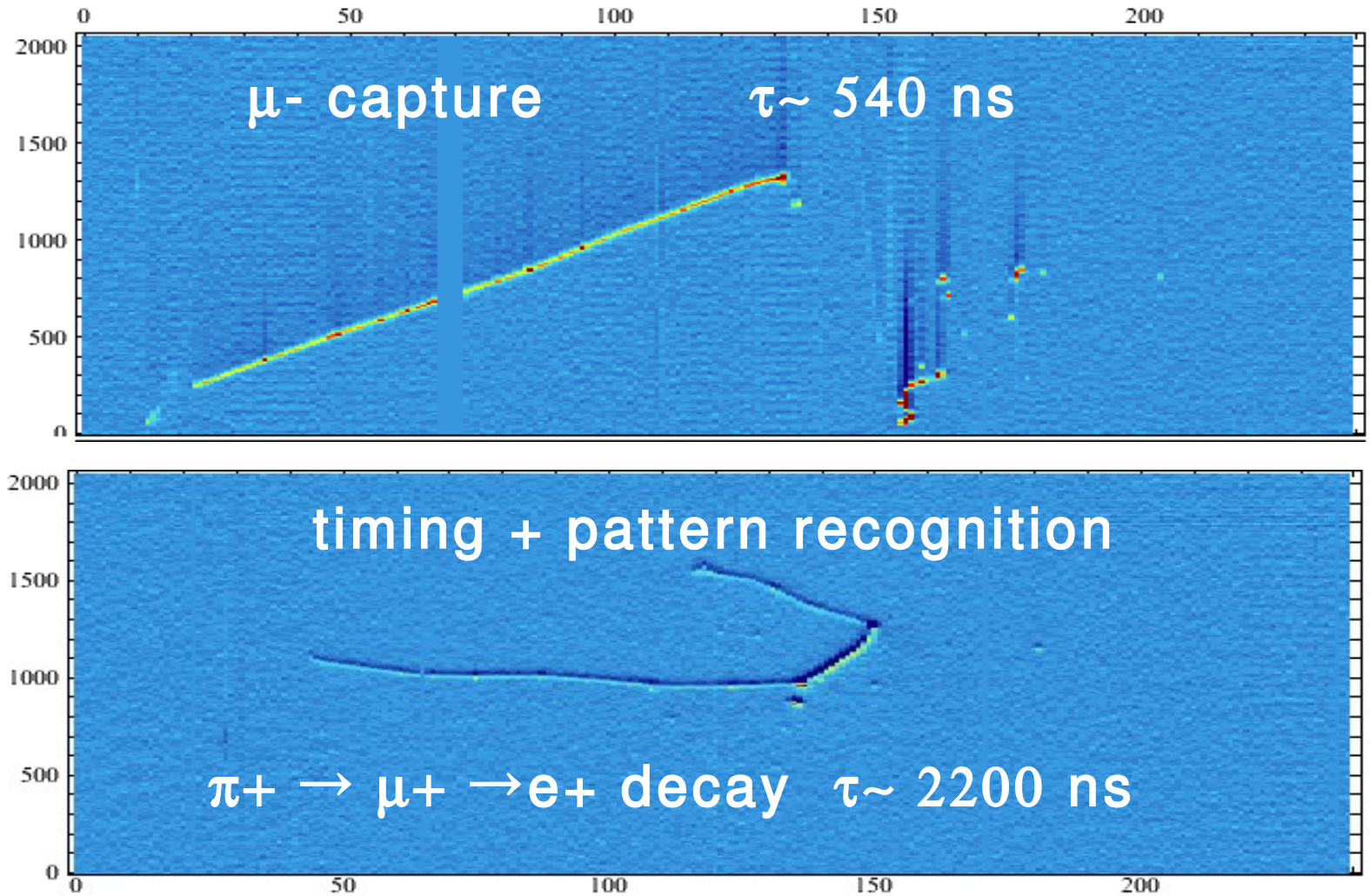
Tagged with incoming electron PID in beamline

+ deviated track + gap.

Important for oscillations

Particle identification

muon sign determination



Important for oscillations

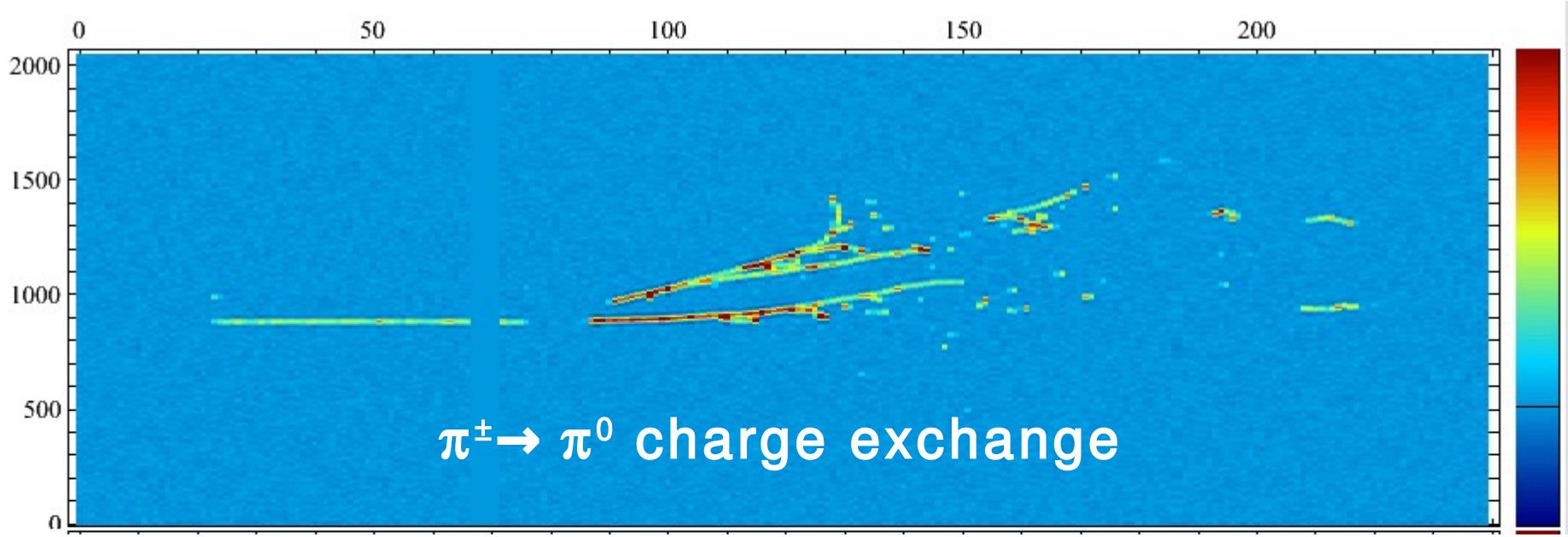
Particle Identification

1 and 2 γ reconstruction

N* production & decay

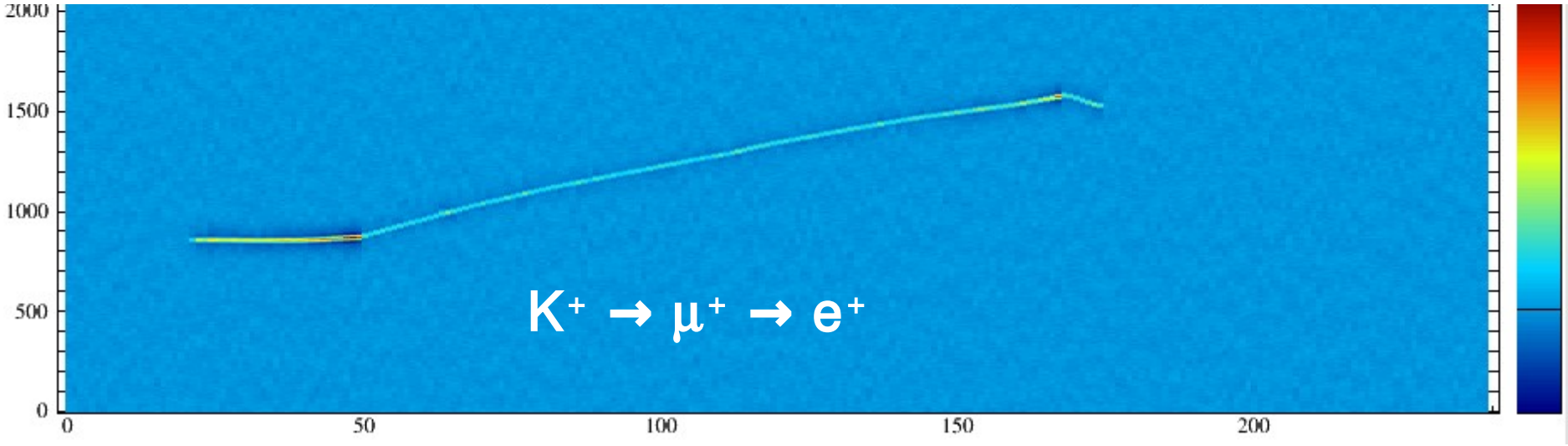
π^0 from $\pi^\pm$ CEX

Important for oscillations



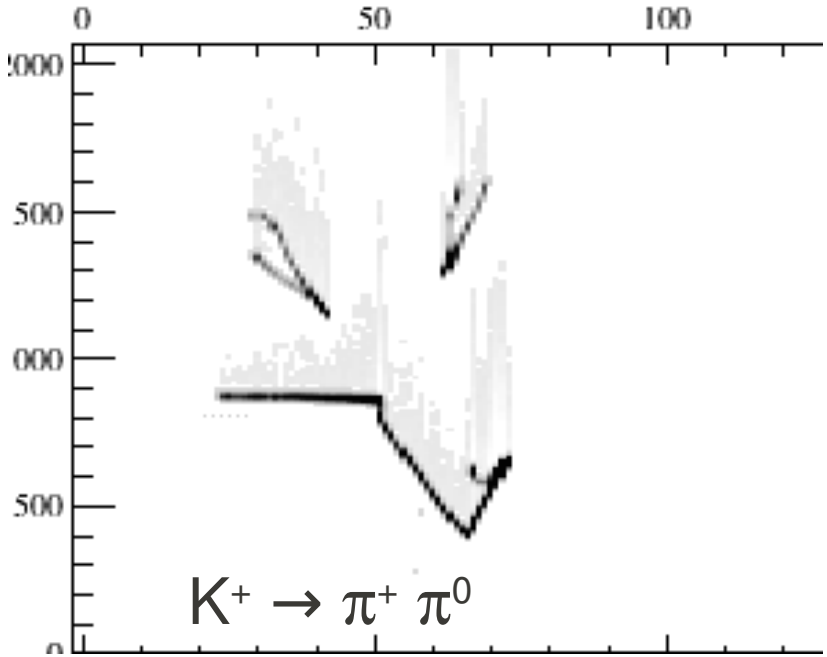
Particle Identification

$K^{\pm}$ reconstruction

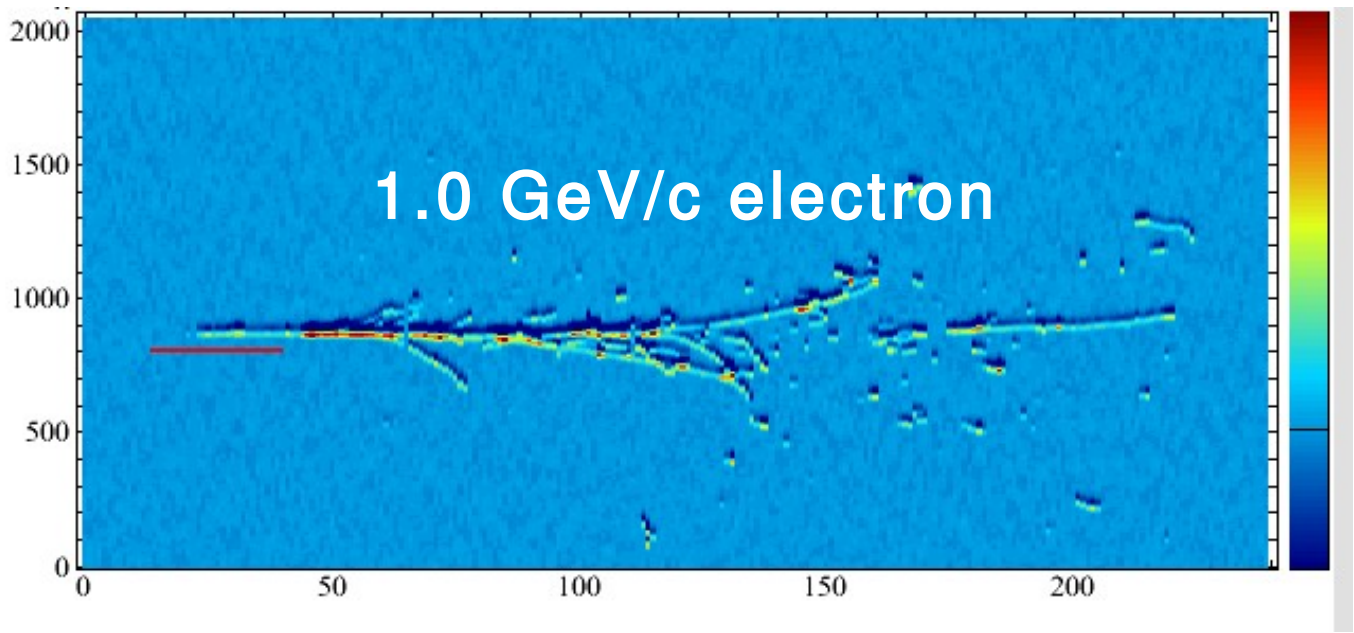


Important for proton decay

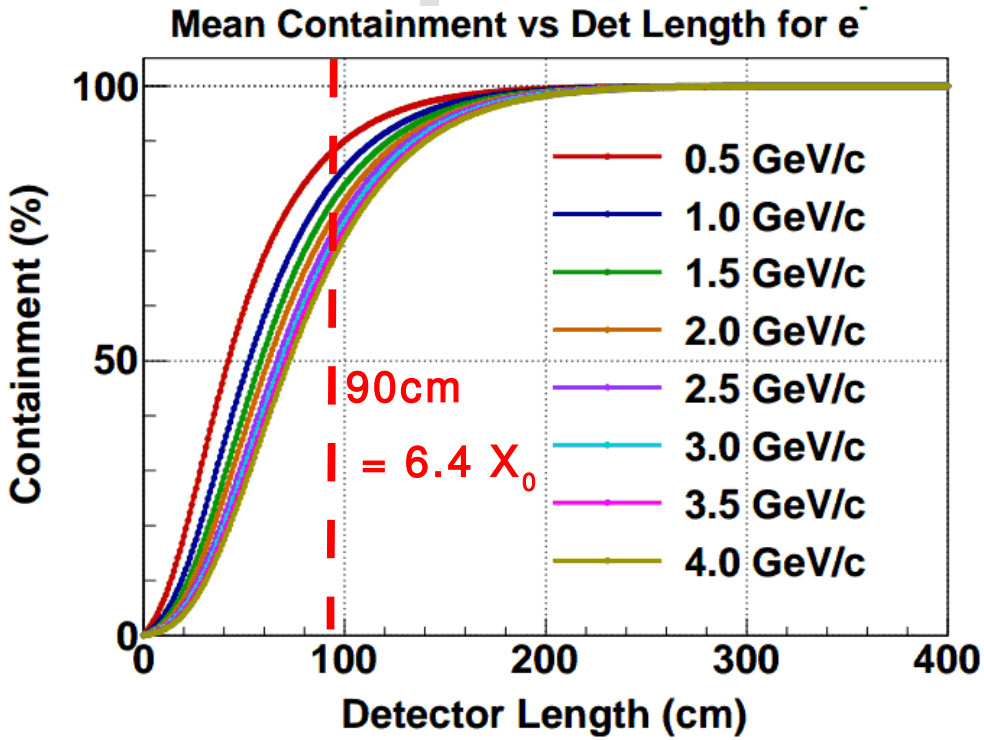
Will benefit from a smart trigger.



Energy measurements



Benchmark MC



<u>Electrons</u>

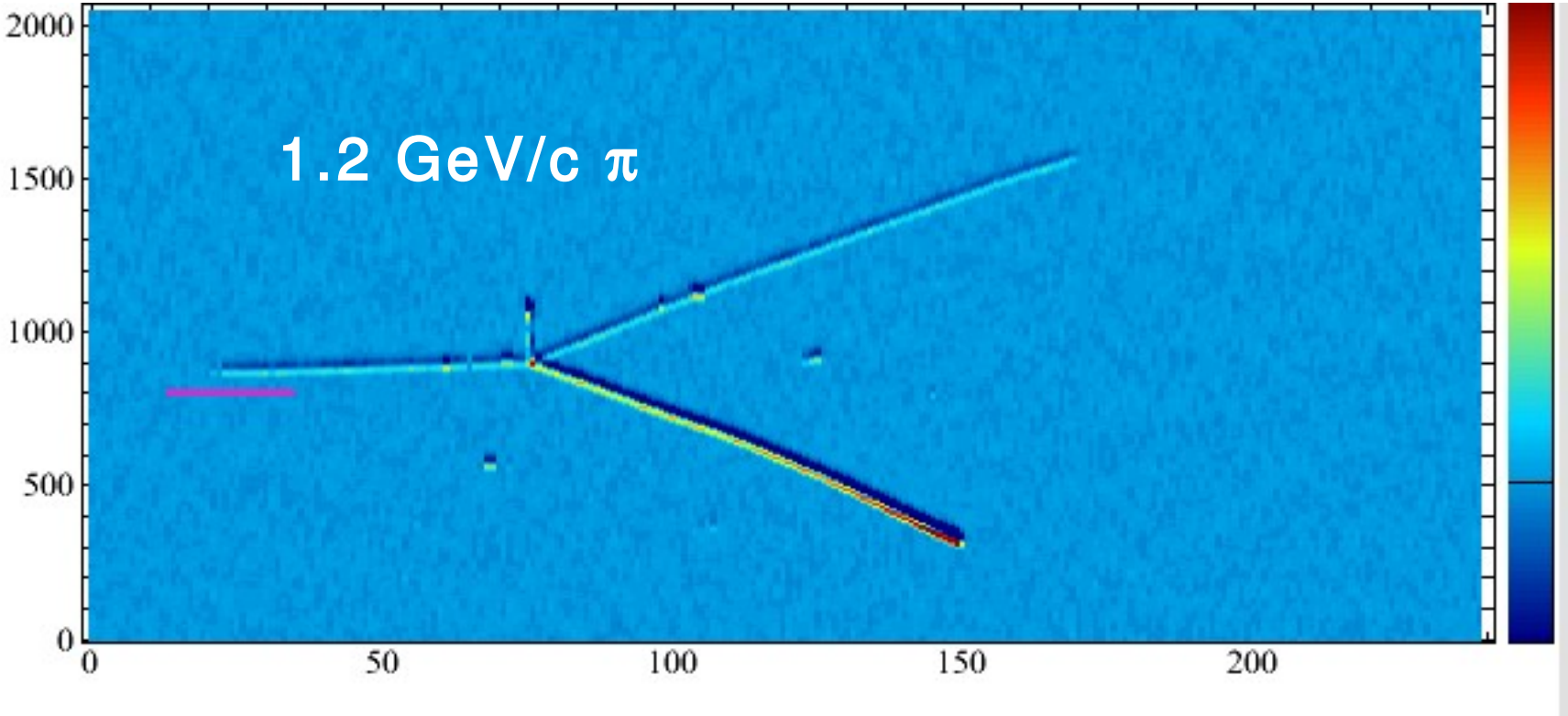
~80% containment

for p <1 GeV/c

<u>Stopping range</u>

protons p<1 GeV/c

Hadronic Interactions

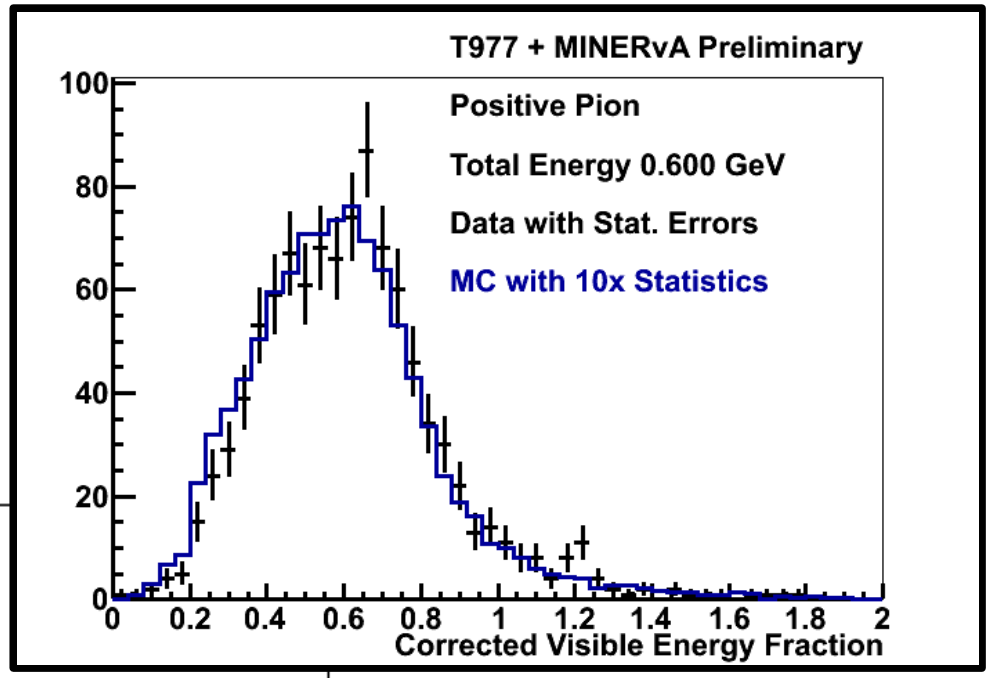


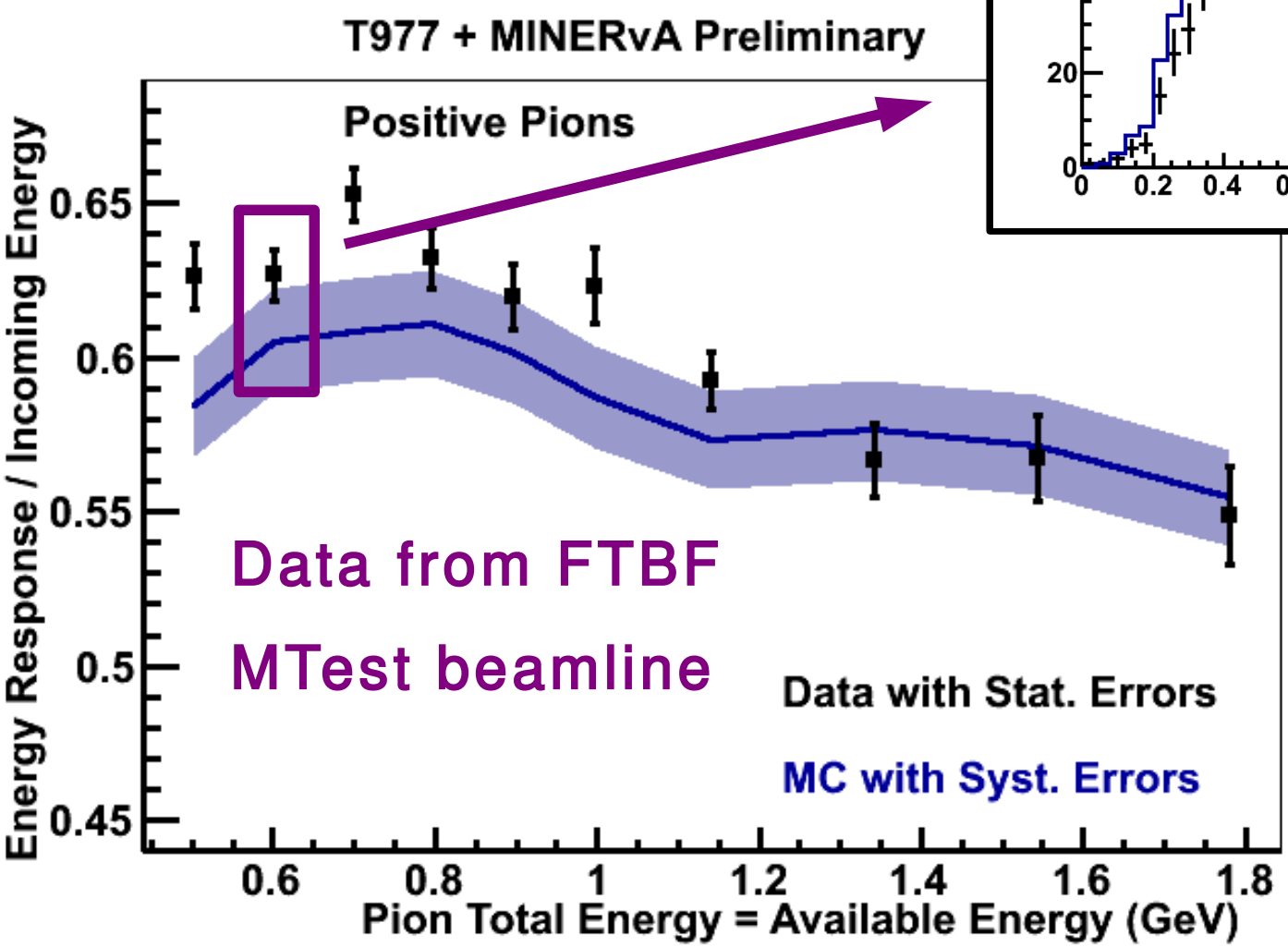
- $\sigma_{REACTION}$ seems doable.

Benchmark MC

- Motivation: FSI, reco. syst., calorimetry (study shower beginning)
- Naively, poor containment. Can one do better by incorporating topology? EM fraction?

Testbeam use in MINERvA





Data from FTBF

MTest beamline

π+ agreement ~ 5%

π− a bit better

p a bit worse (10%)

Resolution well modeled

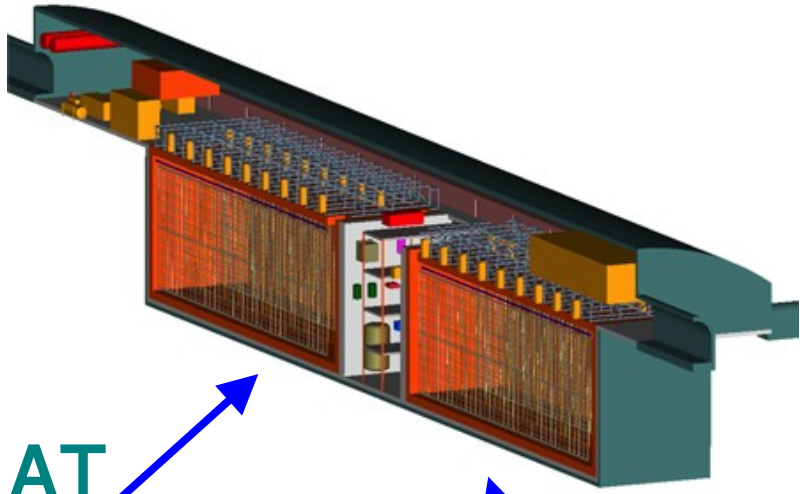
LARIAT and the LAr R&D program

Working toward LBNE

Physics

Argoneut

MicroBooNE



LARIAT

R&D

Bo

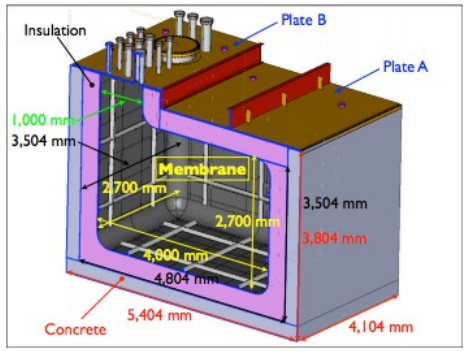
Electronics, readout, cold elec.

Long Bo

HV,cold elec.,purity

LARIAT

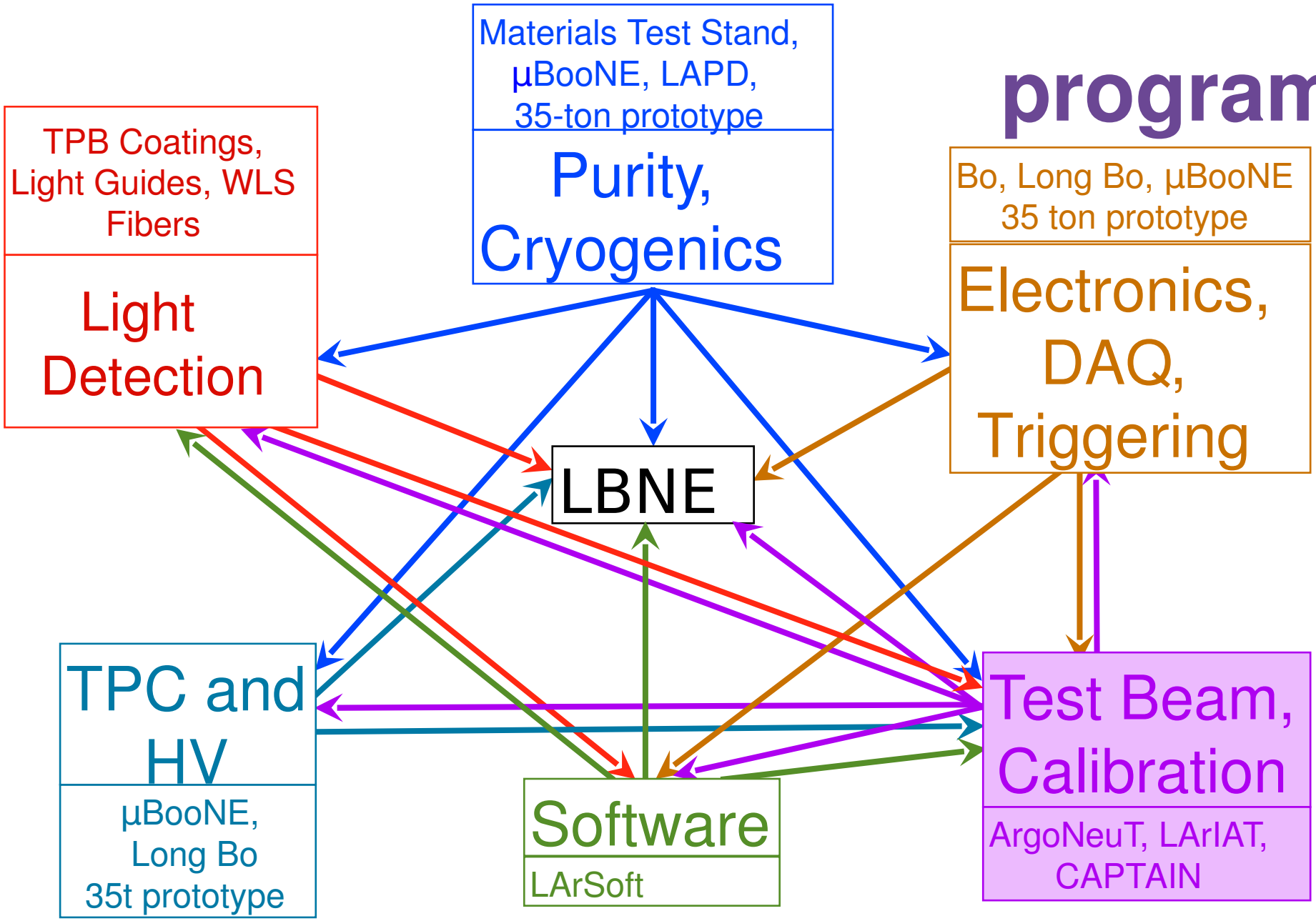
35t membrane cryostat



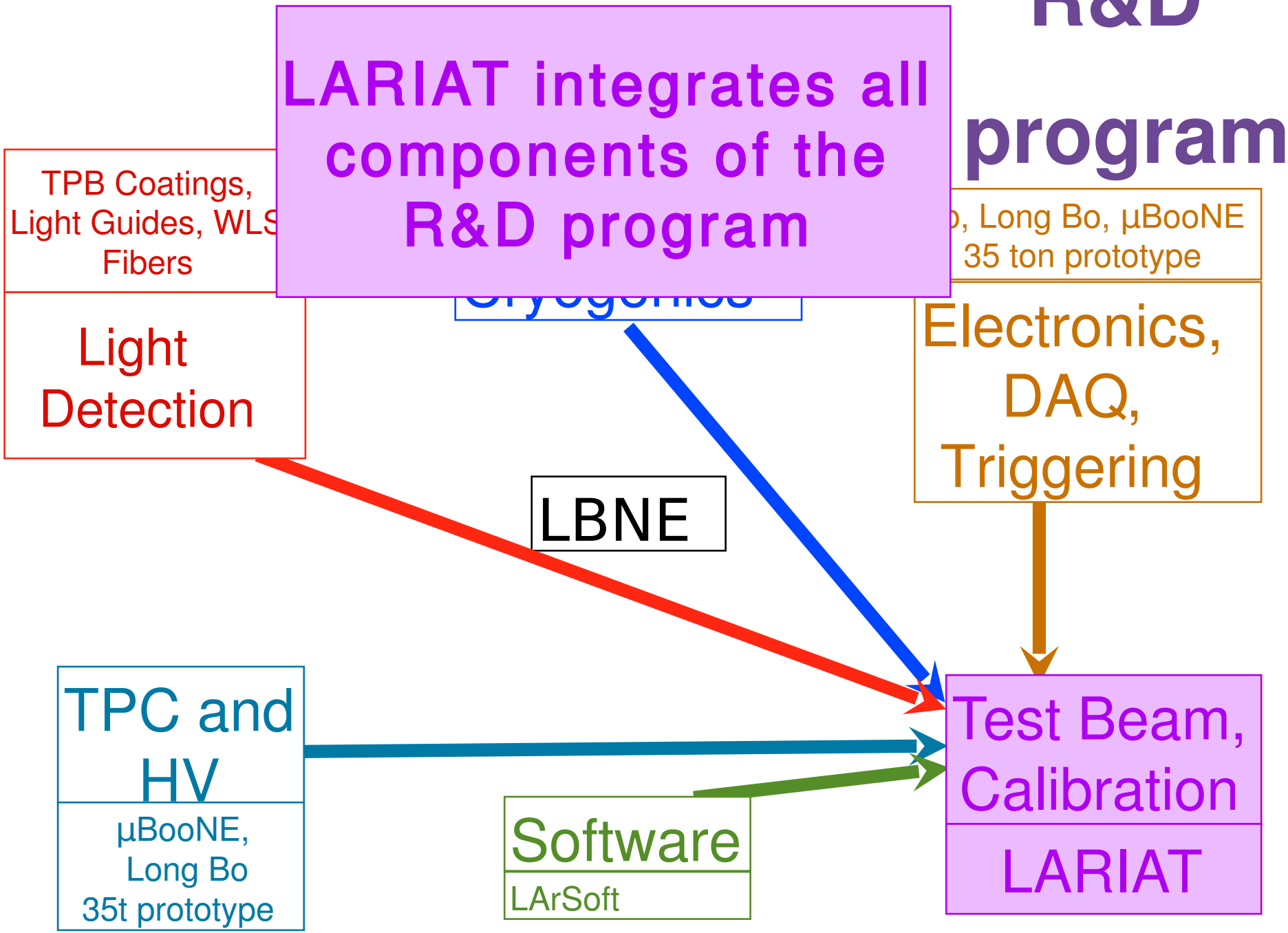
purity test &

TPC prototype

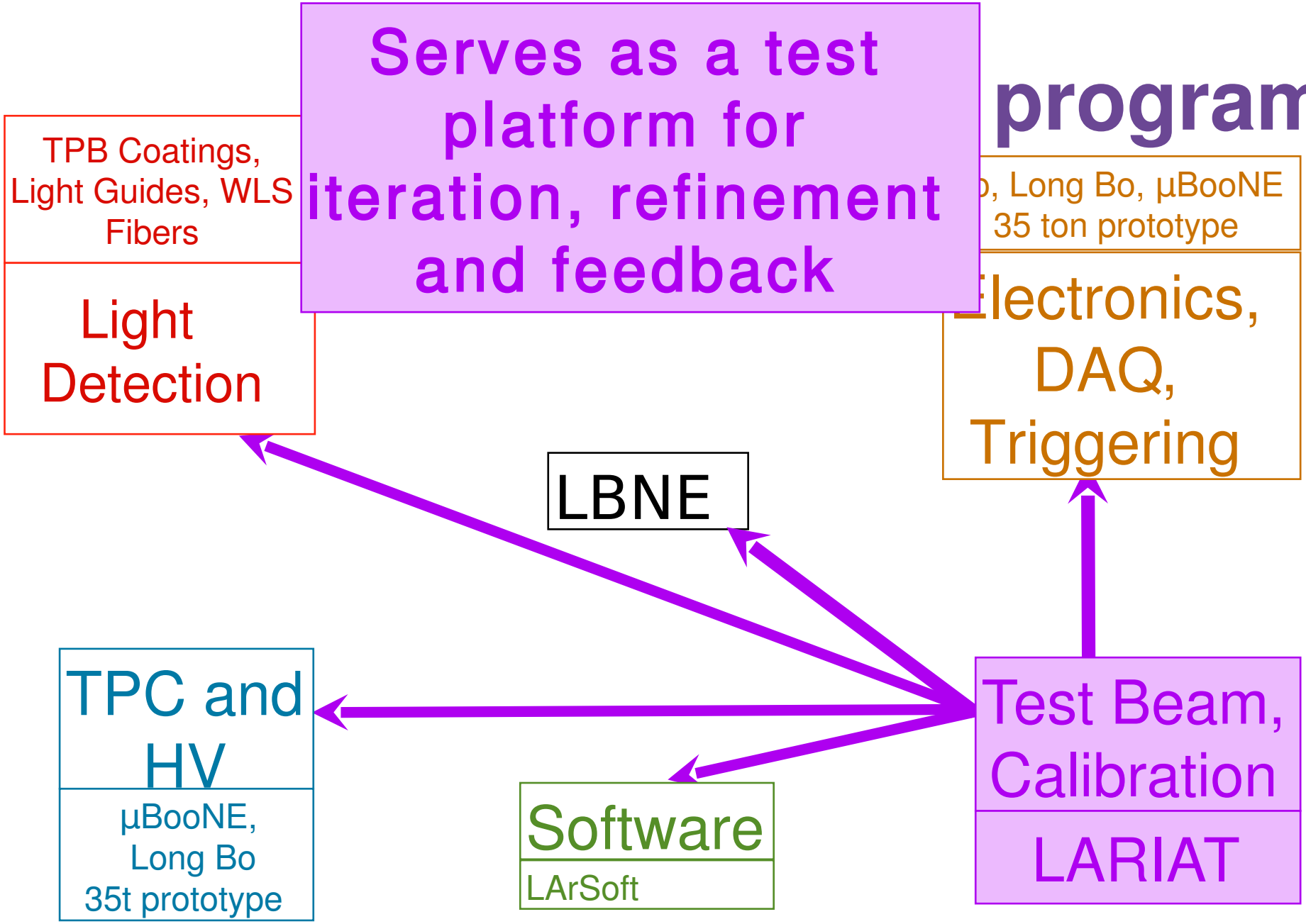
R&D program


Materials Test Stand, µBooNE, LAPD, 35-ton prototype
Purity, Cryogenics
TPB Coatings, Light Guides, WLS Fibers
Light Detection
Bo, Long Bo, µBooNE 35 ton prototype
Electronics, DAQ, Triggering
LBNE
TPC and HV
µBooNE, Long Bo 35t prototype
Software
LArSoft
Test Beam, Calibration
ArgoNeuT, LArIAT, CAPTAIN

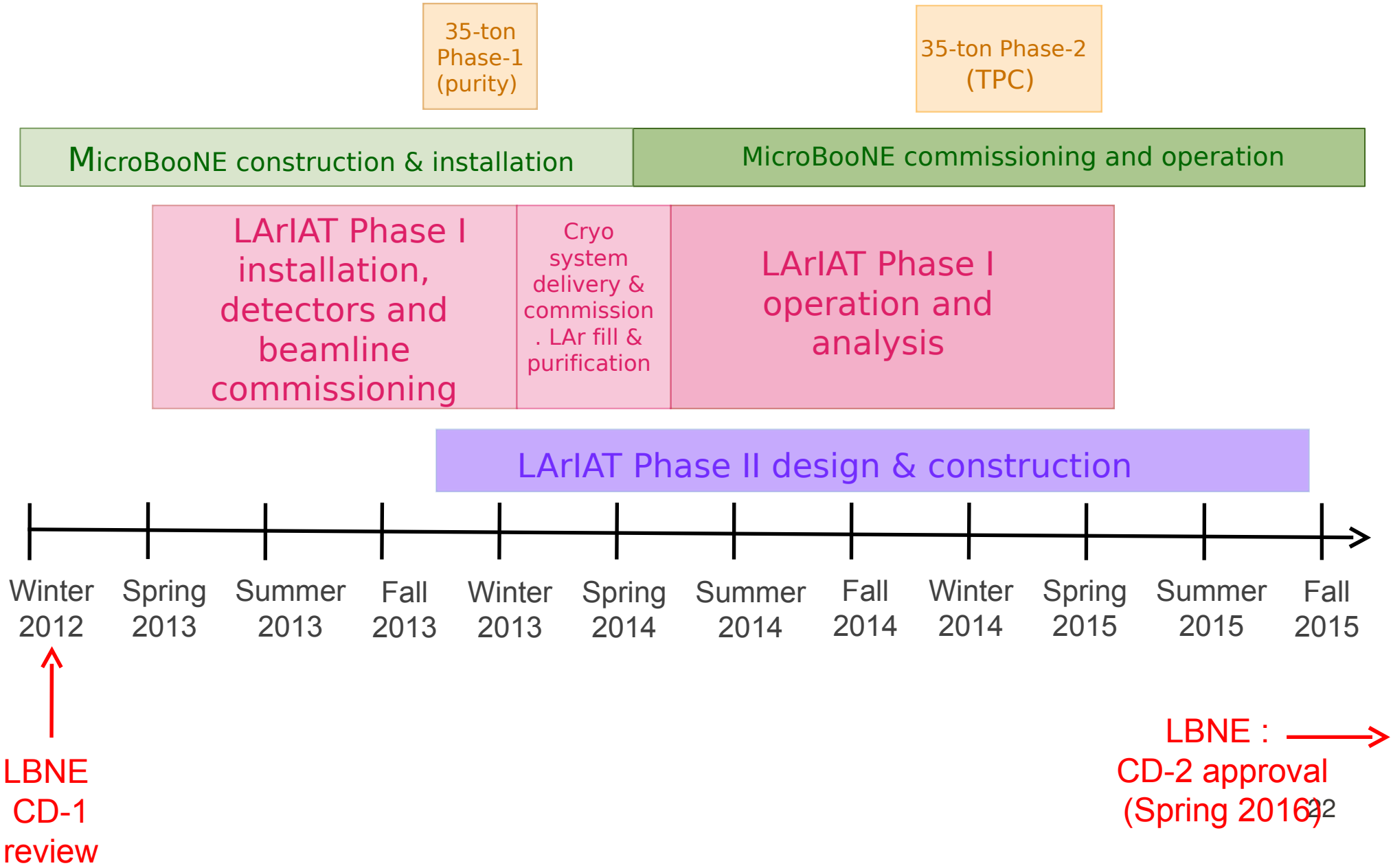
R&D program


LARIAT integrates all components of the R&D program
TPB Coatings, Light Guides, WLS Fibers
Light Detection
Cryogenics
o, Long Bo, µBooNE 35 ton prototype
Electronics, DAQ, Triggering
LBNE
TPC and HV
µBooNE, Long Bo 35t prototype
Software
LArSoft
Test Beam, Calibration
LARIAT

R&D program


Serves as a test platform for iteration, refinement and feedback
TPB Coatings, Light Guides, WLS Fibers
Light Detection
o, Long Bo, µBooNE 35 ton prototype
Electronics, DAQ, Triggering
LBNE
TPC and HV
µBooNE, Long Bo 35t prototype
Software
LArSoft
Test Beam, Calibration
LARIAT

LAr R&D Timeline



LARIAT-I ,-II and CAPTAIN

- LARIAT-I: 200 MeV – 3 GeV with Argoneut
  - PID: e/γ, μ+/μ-
  - Low energy calorimetry (protons & electrons)
  - Single track charge → energy calibration
- LARIAT-II: 200 MeV – 3 GeV with 2-3 m^3 detector
  - Good containment for calorimetry of higher energy showers
  - PID studies of π/K/p via dE/dx.
  - Surface operation in high cosmic ray environment
  - Diffusion studies over long drift distances
- CAPTAIN (LANL LDRD): Low energy
  - LANL neutron beam studies
  - SNS neutrino cross-section studies
  - Install in NuMI?

Complementary Programs

Current Status

The Collaboration

Argonne	J. Paley
Boston U.	E. Kearns
Caltech	R. Patterson
Chicago	W. Foreman, J. Ho, D. Schmitz
Cincinnati	R. Johnson, J. St John
Fermilab	R. Acciarri, P. Adamson, B. Baller, A. Hahn, D. Jensen, T. Junk, M. Kirby, H. Lippincot, A. Marchionni, K. Nishikawa, J. Raaf, E. Ramberg, B. Rebel, M. Stancari, G. Zeller
Imperial Col. London	M. Wascko
Los Alamos	C. Mauger
Louisiana State	F. Blaszczyk, W. Metcalf, M. Tzanov
Manchester	J. Evans, P. Guzowski
Michigan State	C. Bromberg, D. Edmunds, D. Shooltz
Minnesota – Duluth	R. Gran, A. Habig
Syracuse	J. Asaadi, M. Soderberg
Texas – Arlington	A. Farbin, S. Park, J. Yu
Texas – Austin	J. Huang, K. Lang
University Col. London	R. Nichol, J. Thomas
William and Mary	M. Kordosky, P. Vahle
Yale	F. Cavanna*, E. Church, B. Fleming, O. Palamara*, A. Szelc

- 49 Collaboration members
- 3 US national labs
- 12 US universities
- 4 foreign institutions

*Also, L'Aquila & INFN– Gran Sasso

The Collaboration

Argonne	**J. Paley**
Boston U.	**E. Kearns**
Caltech	**R. Patterson**
Chicago	W. Foreman, J. Ho, D. Schmitz
Cincinnati	R. Johnson, J. St John
Fermilab	R. Acciaari, **P. Adamson**, B. Baller, A. Hahn, **D. Jensen, T. Junk**, M. Kirby, **H. Lippincot, A. Marchionni, K. Nishikawa**, J. Raaf, **E. Ramberg**, B. Rebel, **M. Stancari**, G. Zeller
Imperial Col. London	**M. Wascko**
Los Alamos	**C. Mauger**
Louisiana State	**F. Blaszczyk, W. Metcalf, M. Tzanov**
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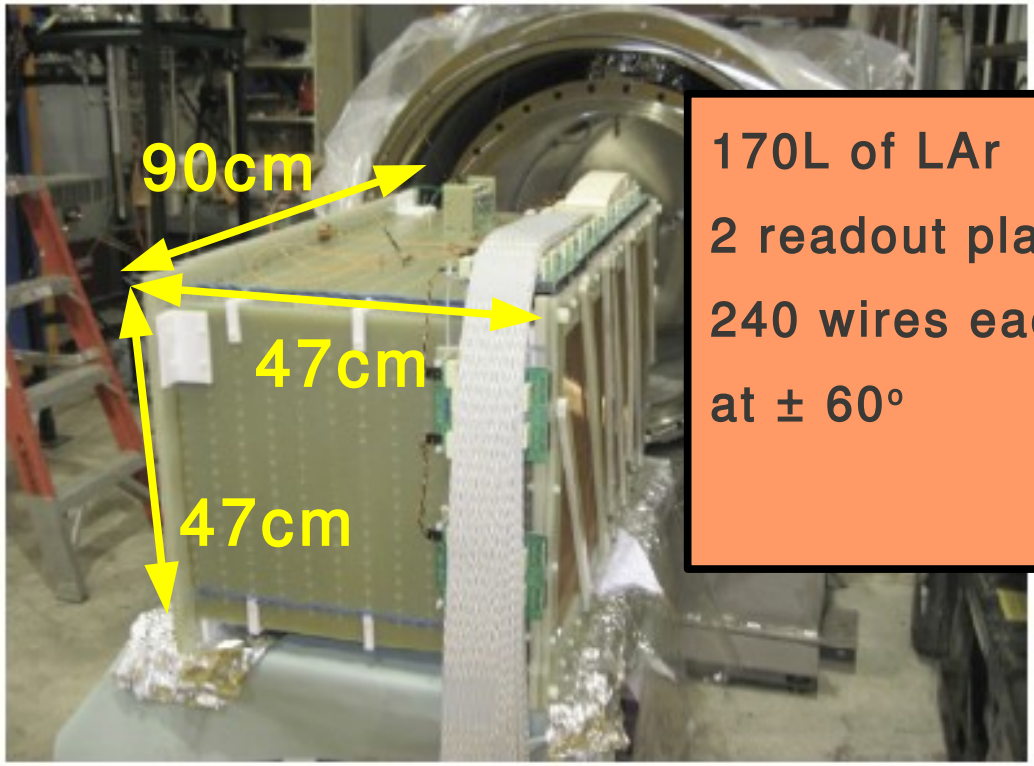
New to LAr (Not on Argoneut or MicroBooNE)

LAr TPC

Capitalize on ArgoNeuT effort and infrastructure

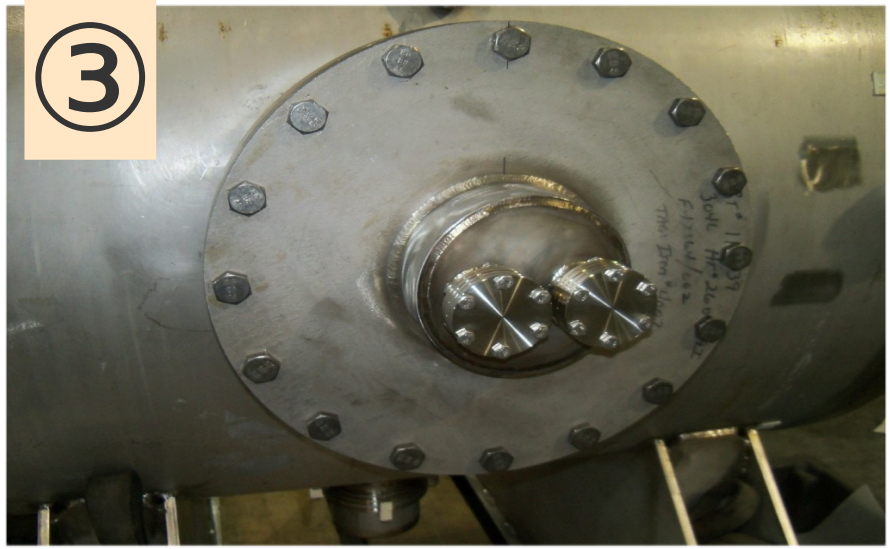
Leverages NSF's initial investment



170L of LAr
2 readout planes
240 wires each
at ± 60°

Cryostat Modifications

DOE/Yale



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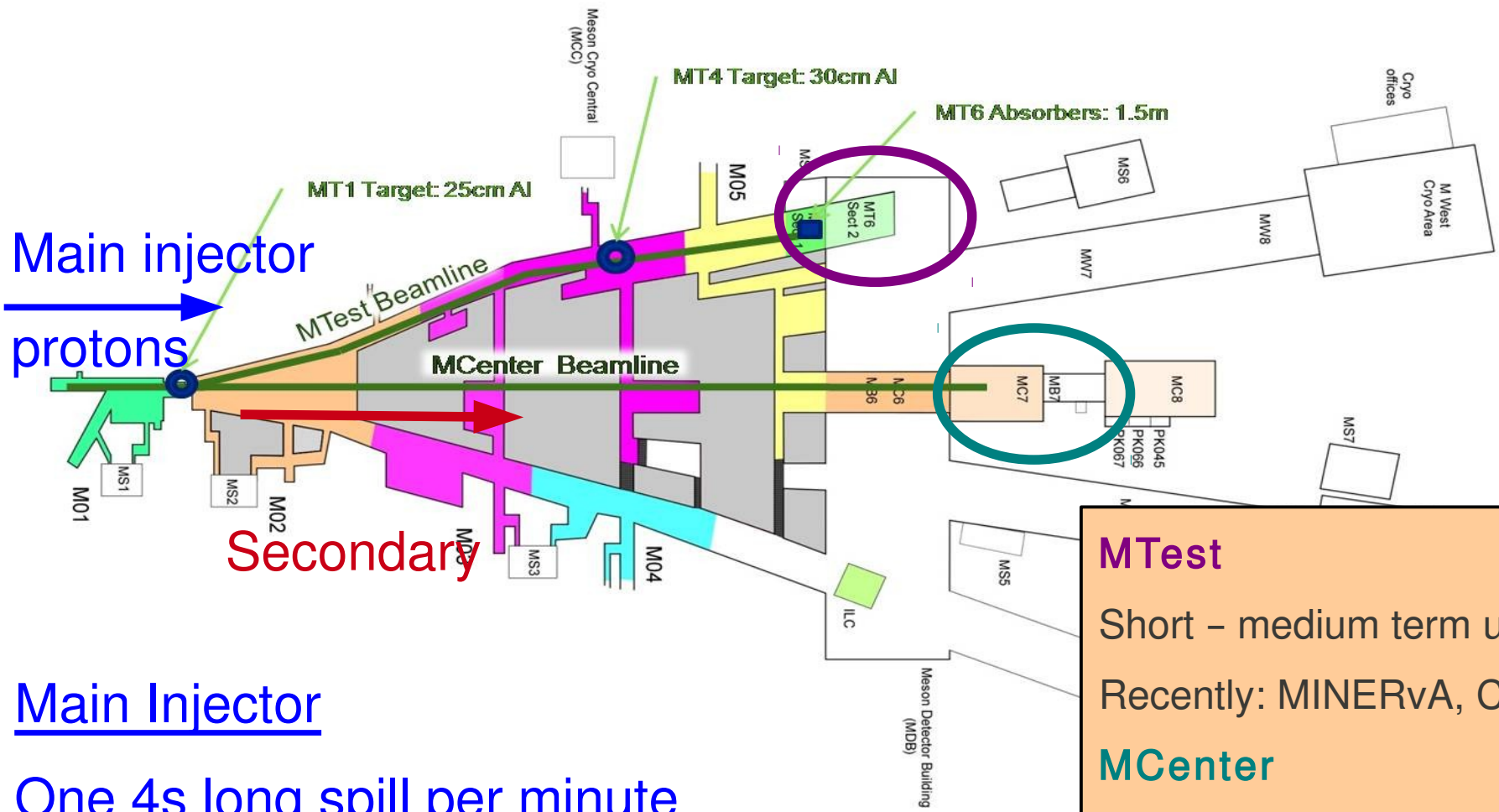
Fermilab Testbeam Facility



MTest

Short – medium term user facility

Recently: MINERvA, CALICE

MCenter

Long term LAr R&D facility

Generic cryo. plant in MC7/8

Reserved for LARIAT-I & -II

Main Injector

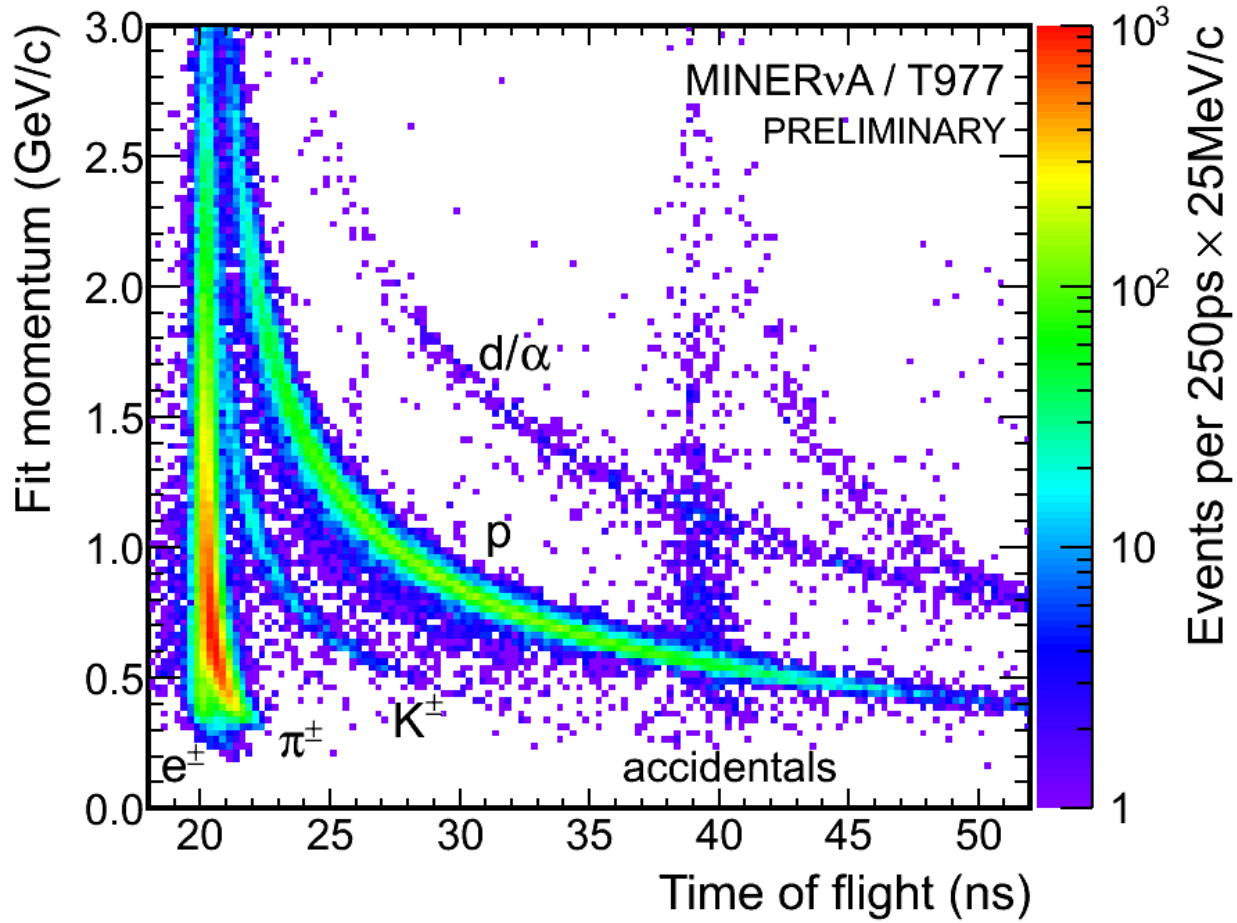
One 4s long spill per minute

Secondary beam

max 300k particles/spill

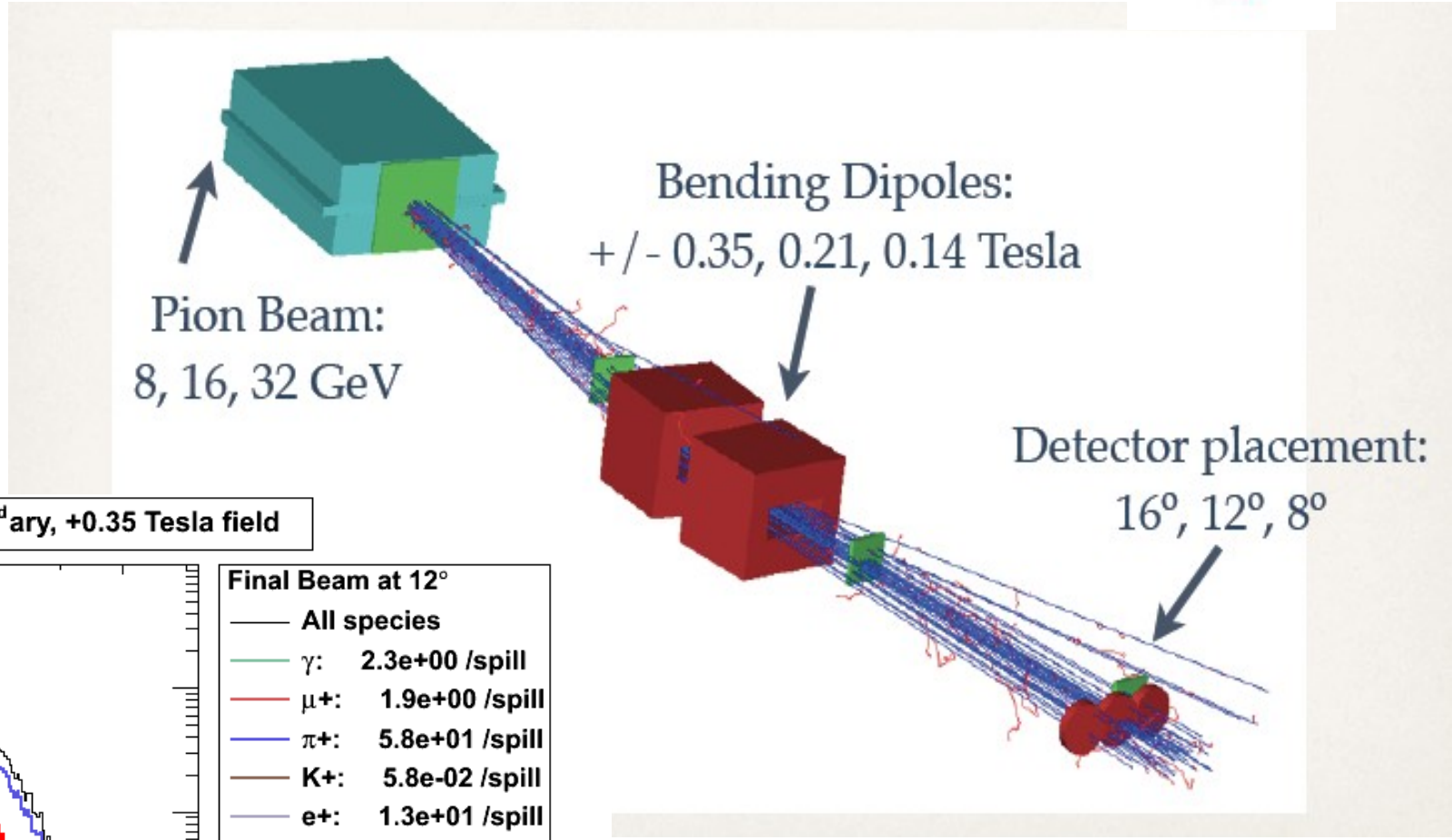
MINERvA Experience

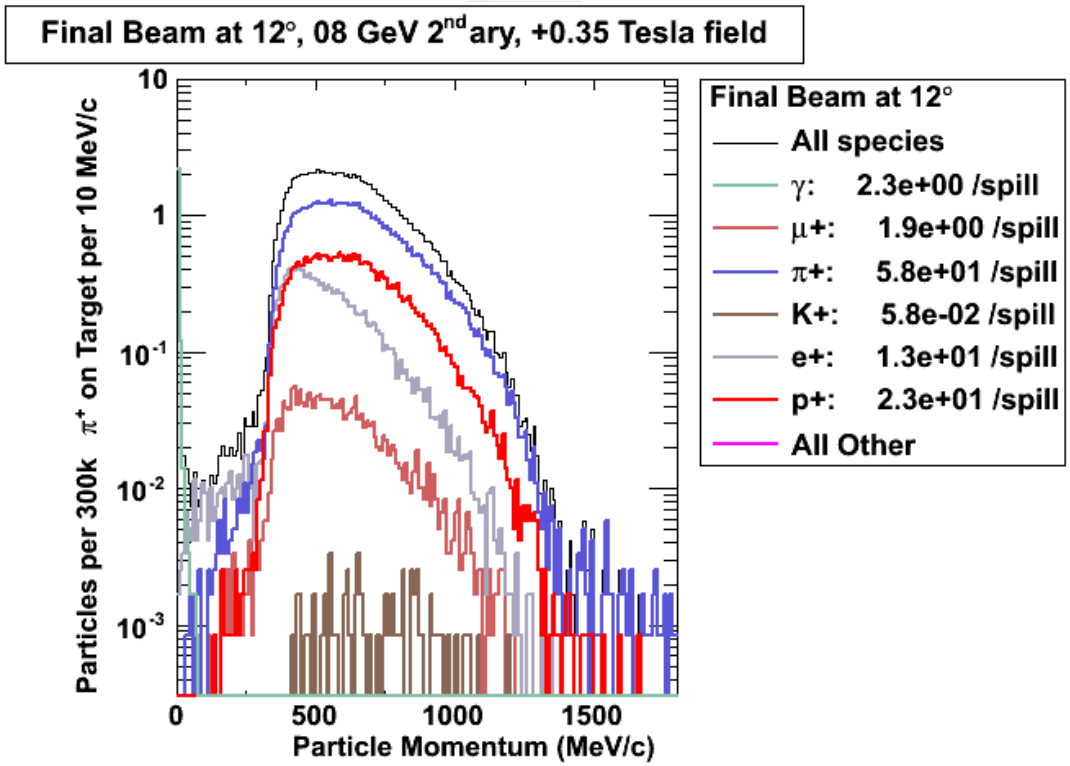
- Tertiary Cu target collimated at 16°
- Dipole pair + MWPC for event by event momentum
  - 2% accuracy
- Time of flight



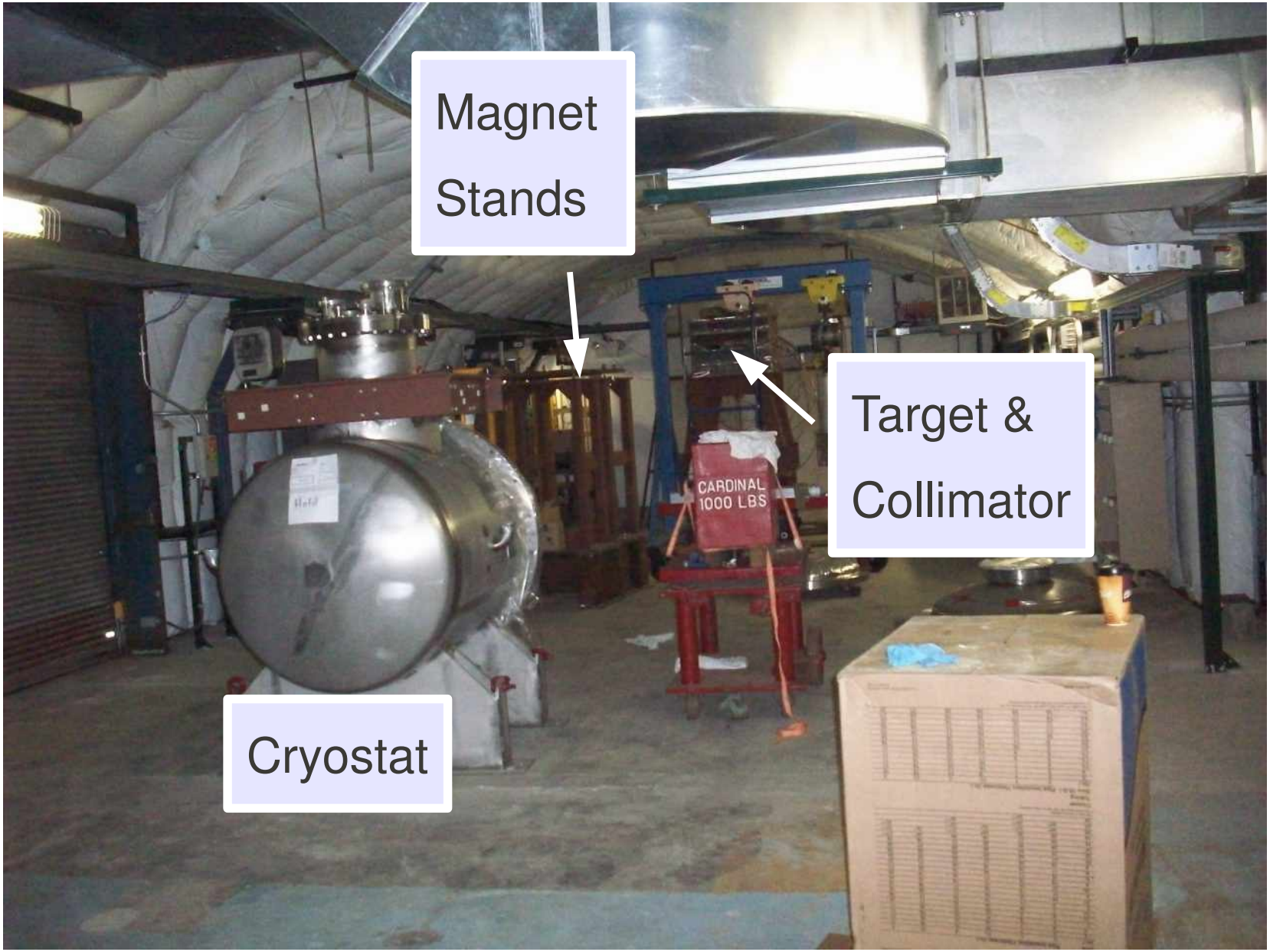
Beamline elements have been moved to MCenter

Beamline studies



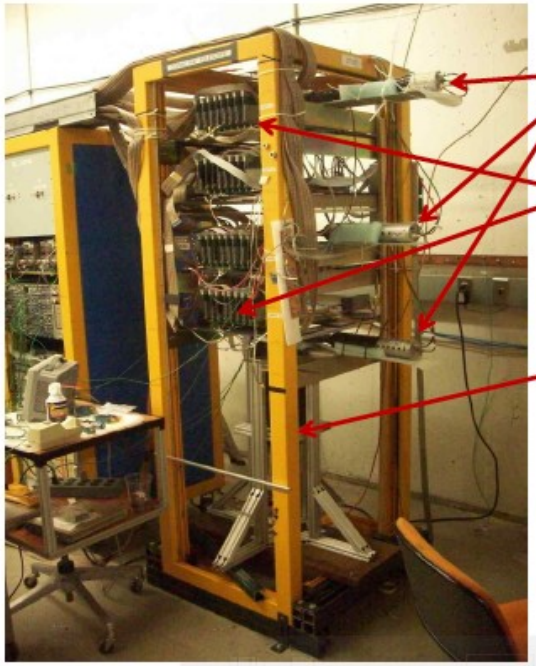


Experiment setup in progress

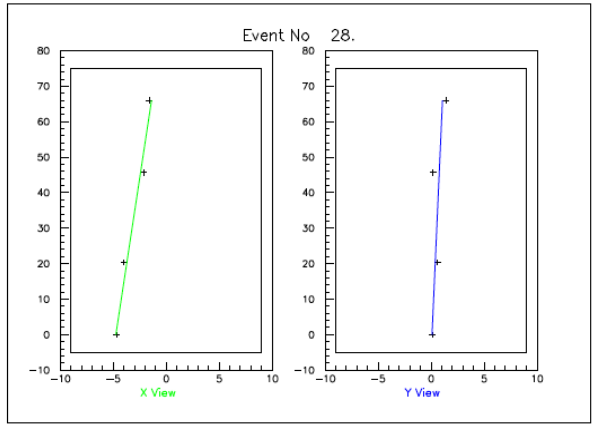


Beamline instrumentation

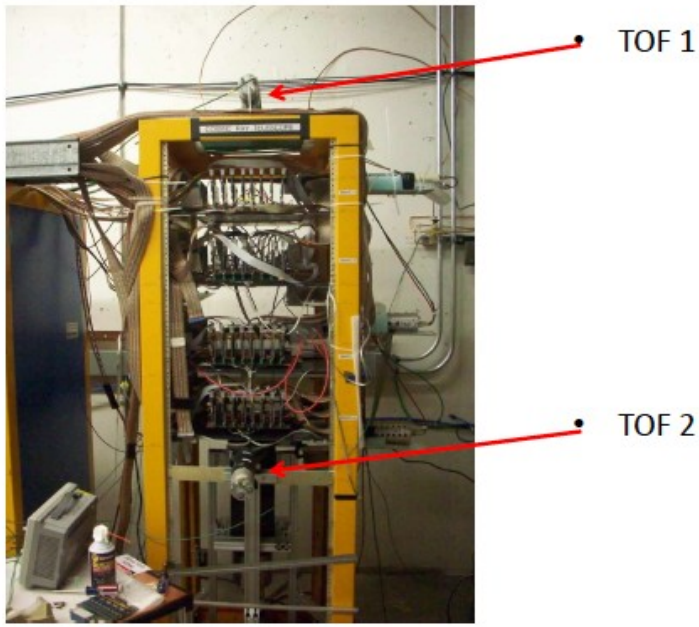
Cosmic Ray Telescope at FTBF



Reconstruction



TOF1 and TOF2 being added to telescope



- Wire chambers are 'Fenker Chambers'
  - 128 wires per view, 1 mm spacing: X, Y
  - Originally Ar – CO_2
  - Now – 'Magic Gas' Ar, C_4H_8, ($C_3H_8O_2$)
- Current Plan 4X, 4y planes

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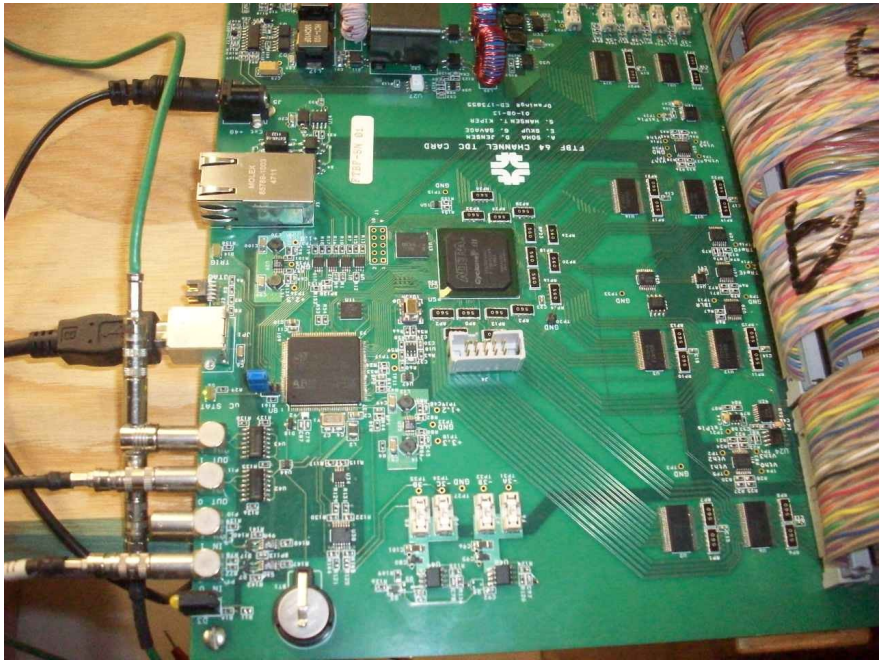
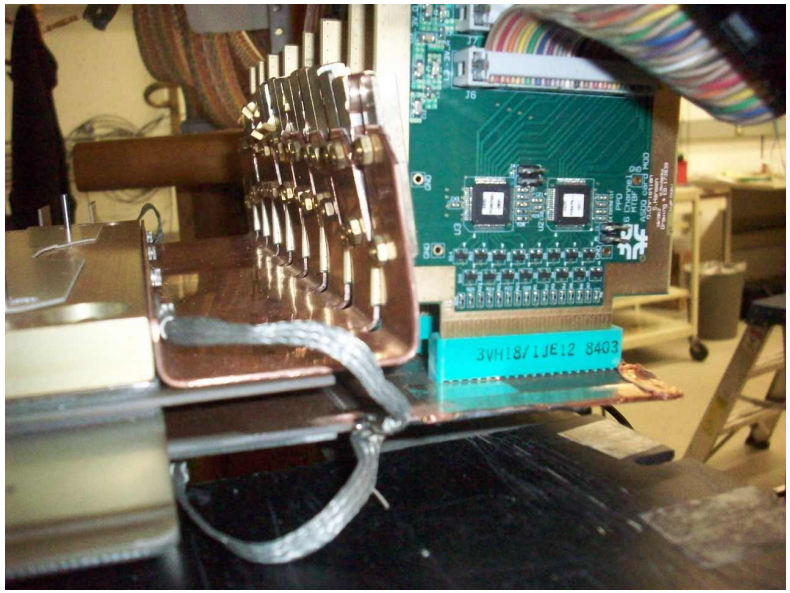
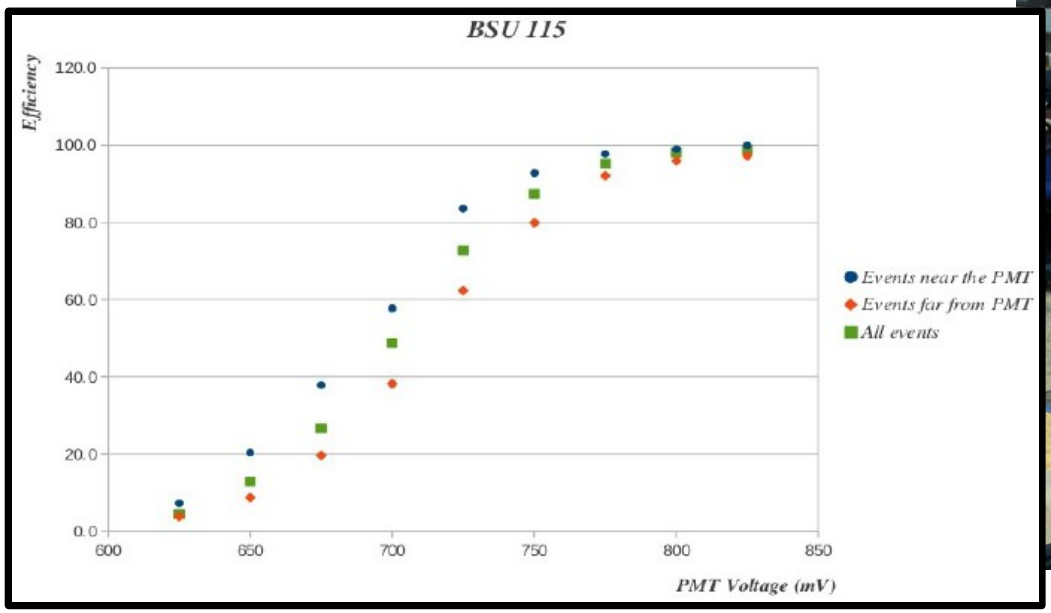
MWPC readout upgrades





Cosmic & Veto Counters

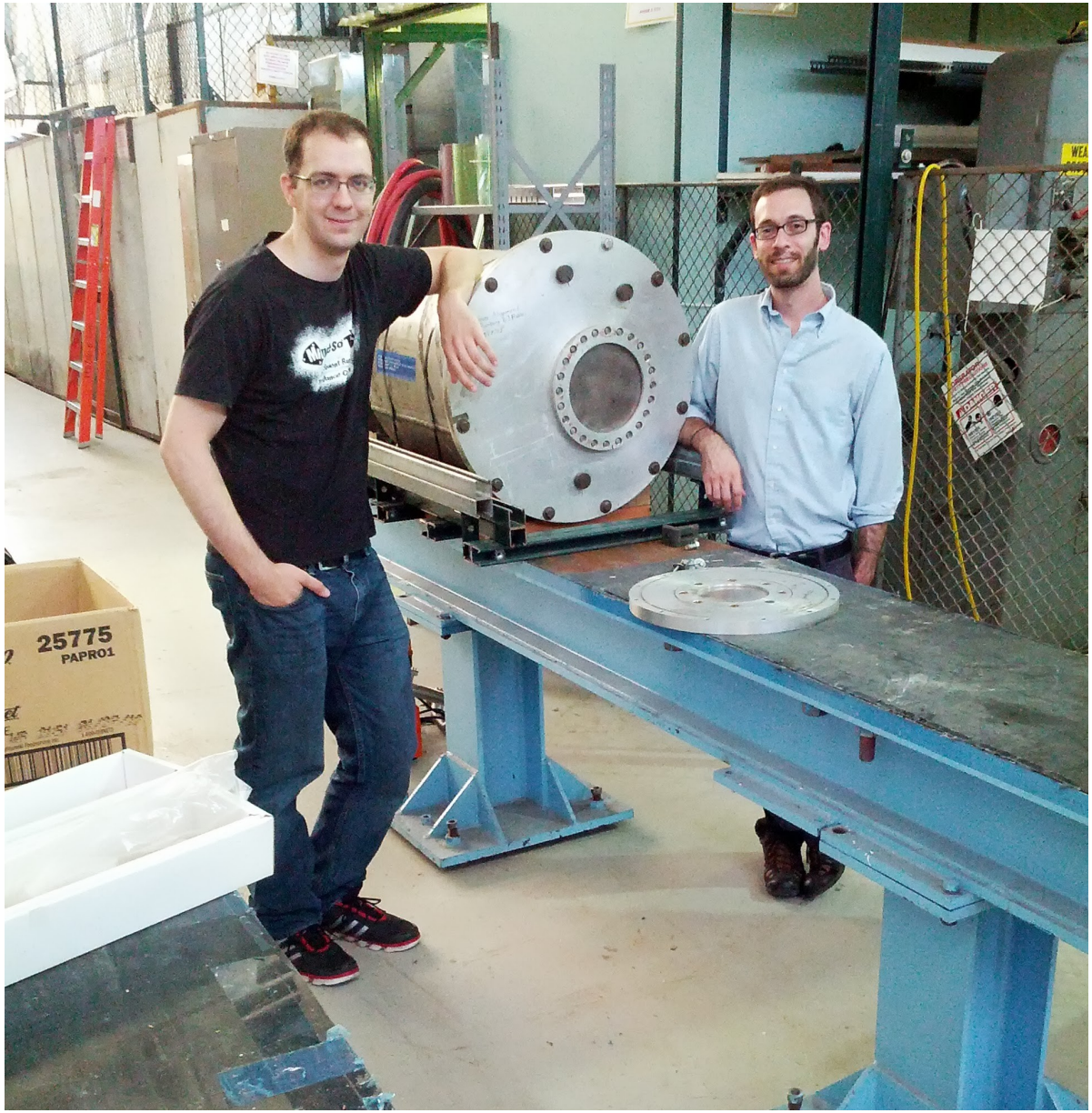
Counters salvaged from CDF



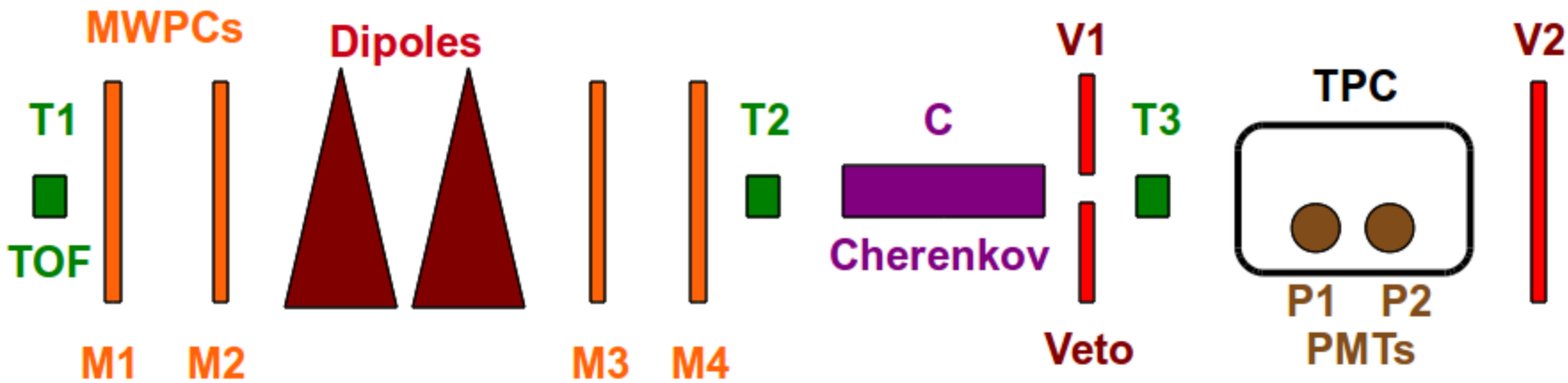
Test stand in

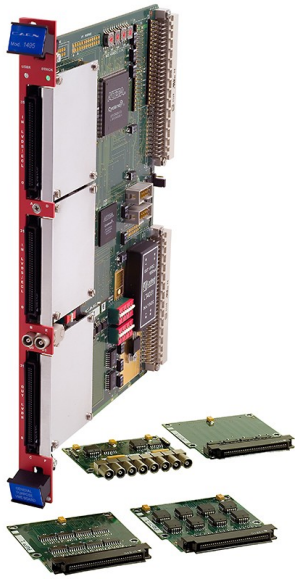
Wideband hall

Cherenkov Counter



Trigger System

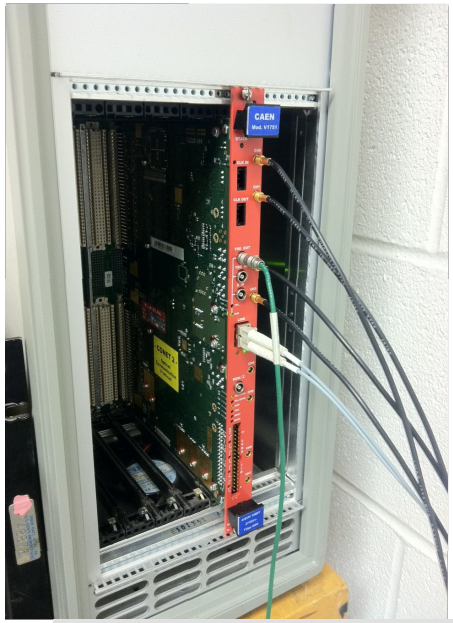


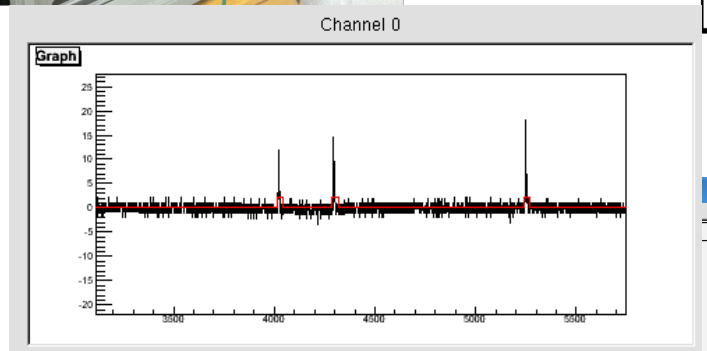


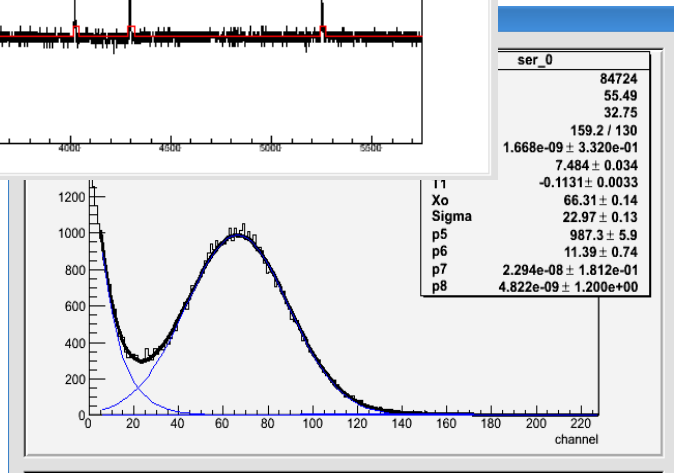
- Basic trigger: (T123 and M1234 and not V1)
- Pileup: need for a delayed veto. Vdrift = 1.5 m / msec
- Initially NIM electronics. Upgrade to VME FPGA.
- TOF in trigger? TAC + discriminator.
- Upgrade: device readout and discrimination via VME FADC.

PMT Readout

- Setting up to test PMTs and SiPMs in LAr
- 2” ETL, 3” Hamamatsu + 3 SiPMs
- G10 box submerged in LAr
- Readout via CAEN digitizer
- DAQ tests w/ LED pulser (not in LAr yet)
  - Have recorded and analyzed waveforms
- Goal: observe cosmic rays and LED flashes in argon. Estimate light yield and determine full setup.







DAQ upgrade

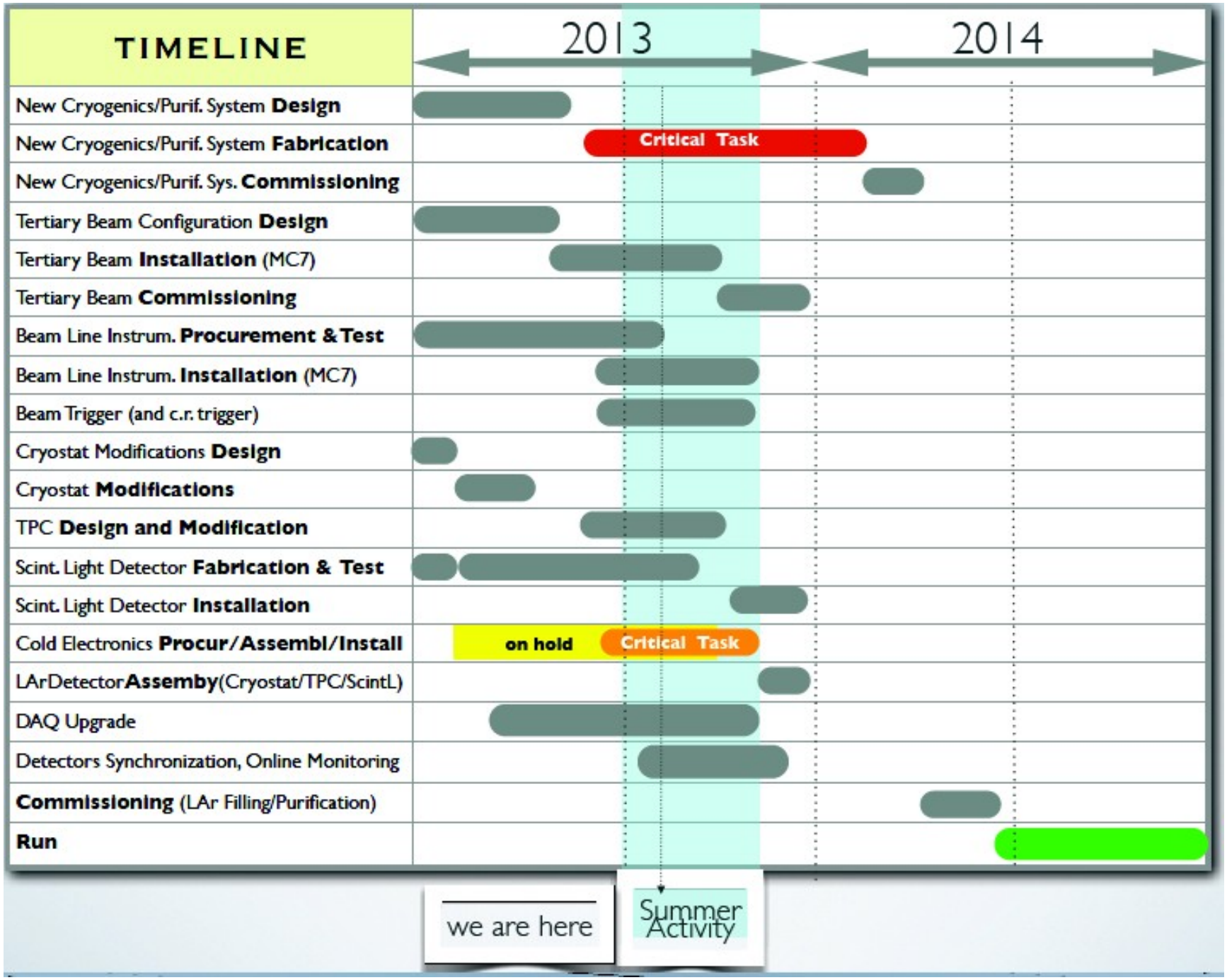
- Argoneut readout ~ 1Hz is not fast enough
- Effort to improve DAQ rate by > x10
  - Goal: 5-10 Hz good trigger rate → 20-40 events / spill
- Speed increase 1:
  - Block transfers for ADF2 readout. Yields ~ x2-x4
- Speed increase 2: **In progress @ FNAL**
  - Parallel readout of ADF2 cards. Yields x8.

Cryogenic infrastructure

- TPC cryostat, filter skid and LAr pump are in hand

- Basic engineering done at FNAL for rest of system
- RFQ for LAr system now out. Closes 7/26.
- Provides for condenser, phase separator, LAr piping, installation

Timeline


TIMELINE
2013
2014
New Cryogenics/Purif. System Design
New Cryogenics/Purif. System Fabrication
Critical Task
New Cryogenics/Purif. Sys. Commissioning
Tertiary Beam Configuration Design
Tertiary Beam Installation (MC7)
Tertiary Beam Commissioning
Beam Line Instrum. Procurement & Test
Beam Line Instrum. Installation (MC7)
Beam Trigger (and c.r. trigger)
Cryostat Modifications Design
Cryostat Modifications
TPC Design and Modification
Scint. Light Detector Fabrication & Test
Scint. Light Detector Installation
Cold Electronics Procur/Assembl/Install
on hold
Critical Task
LArDetector Assemby (Cryostat/TPC/ScintL)
DAQ Upgrade
Detectors Synchronization, Online Monitoring
Commissioning (LAr Filling/Purification)
Run
we are here
Summer Activity

Task List

New Cryogenics/Purif. System **Design**	
New Cryogenics/Purif. System **Fabrication**	funded by FNAL PPD
New Cryogenics/Purif. Sys. **Commissioning**	under FNAL PPD responsibility
Tertiary Beam Configuration **Design**	
Tertiary Beam **Installation** (MC7)	under FNAL FTBF
Tertiary Beam **Commissioning**	under FNAL FTBF
Beam Line Instrum. **Procurement & Test**	under FNAL FTBF
Beam Line Instrum. **Installation** (MC7)	under FNAL FTBF
Beam Trigger and C.R. trigger	funded by DoE/Yale + FNAL/PPD
Cryostat Modifications **Design**	
Cryostat **Modifications**	funded by DoE/Yale
TPC **Design and Modification**	funded by DoE/Yale
Scint. Light Detector **Fabrication & Test**	in kind (L'Aquila U. /LArIAT) + Yale + UoC support
Scint. Light Detector **Installation**	Yale + UoC support
Cold Electronics **Procur/Assembl/Install**	not yet funded
LArDetector **Assemby** (Cryostat/TPC/ScintL)	Support requested from FNAL/PPD + university group contributions
DAQ Upgrade	FNAL PPD (+ university groups?)
Detectors Synchronization, Online Monitoring	LSU (+ other university groups)
Commissioning (LAr Filling/Purification)	under FNAL/PPD
Run	

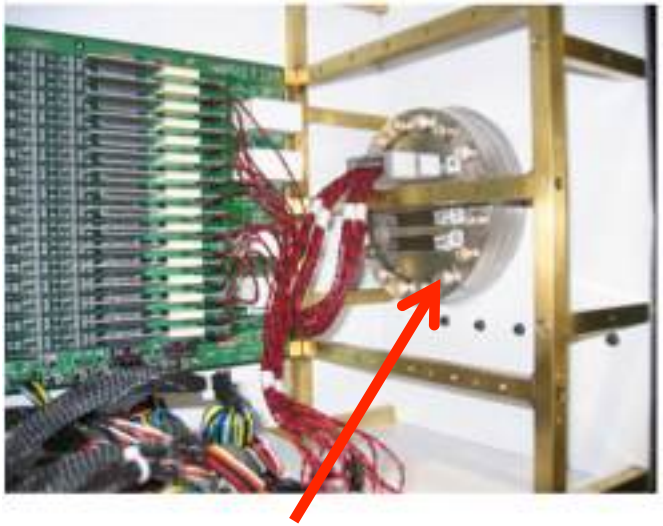
Cold Electronics

Outline

LArTPC historical perspective
ArgoNeuT w/warm electronics
R&D on cold electronics
Cold electronics for LArIAT

Bo TPC w/ICARUS style electronics (2005)

Feed through & warm preamp card w/dual-jFET



96 channels in the RF-shield box

ADF2 - 32 ch. Digitizer/FPGA

Signal feed-thru carries Bias-V

$V_{1,2,3}$ = –350V, zero-V , +400 V

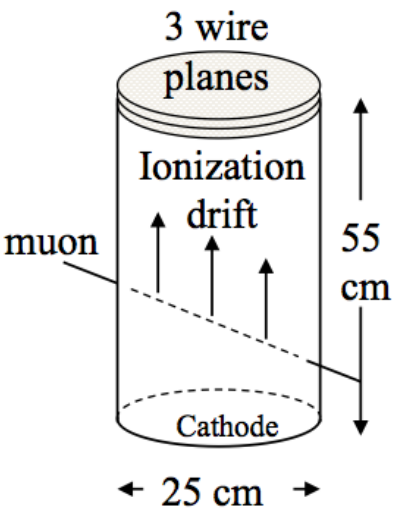
Also, trigger counters & DAQ provided by MSU

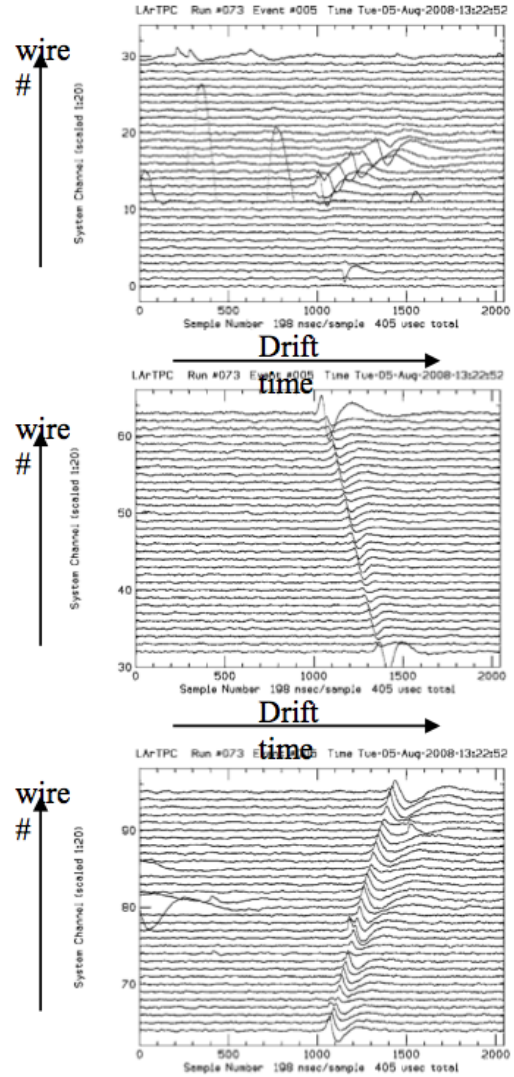
Dan Edmunds (MSU)

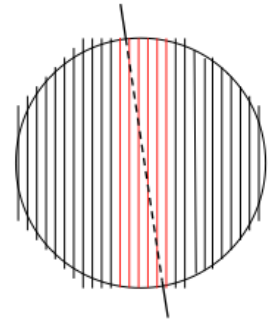
Tracks !

EVENT # 5

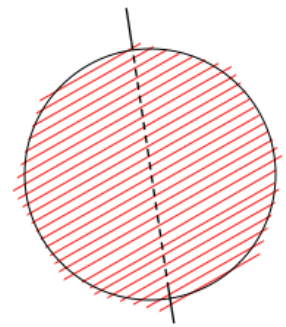
Most triggers look like this:



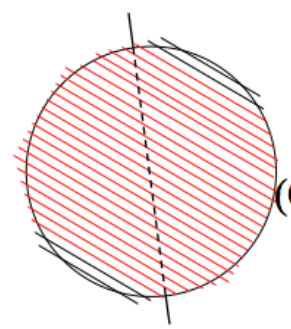




Plane 1 (Induction, 0°)



Plane 2 (Induction, +60°)



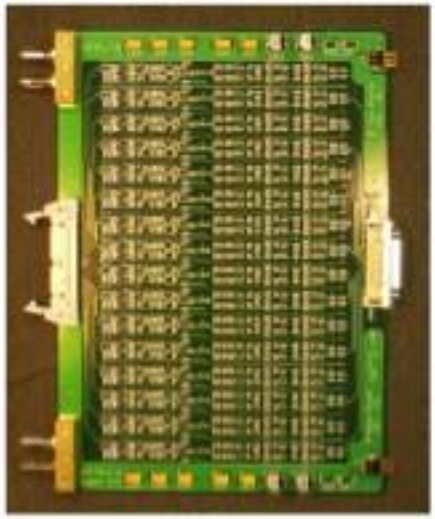
Plane 3 (Collection, –60°)

ArgoNeuT (2006-2010)
First LArTPC neutrino data

480 channels of warm preamp

Bias-V distribution moved onto the TPC

Warm preamp



(MSU) Dan Edmunds

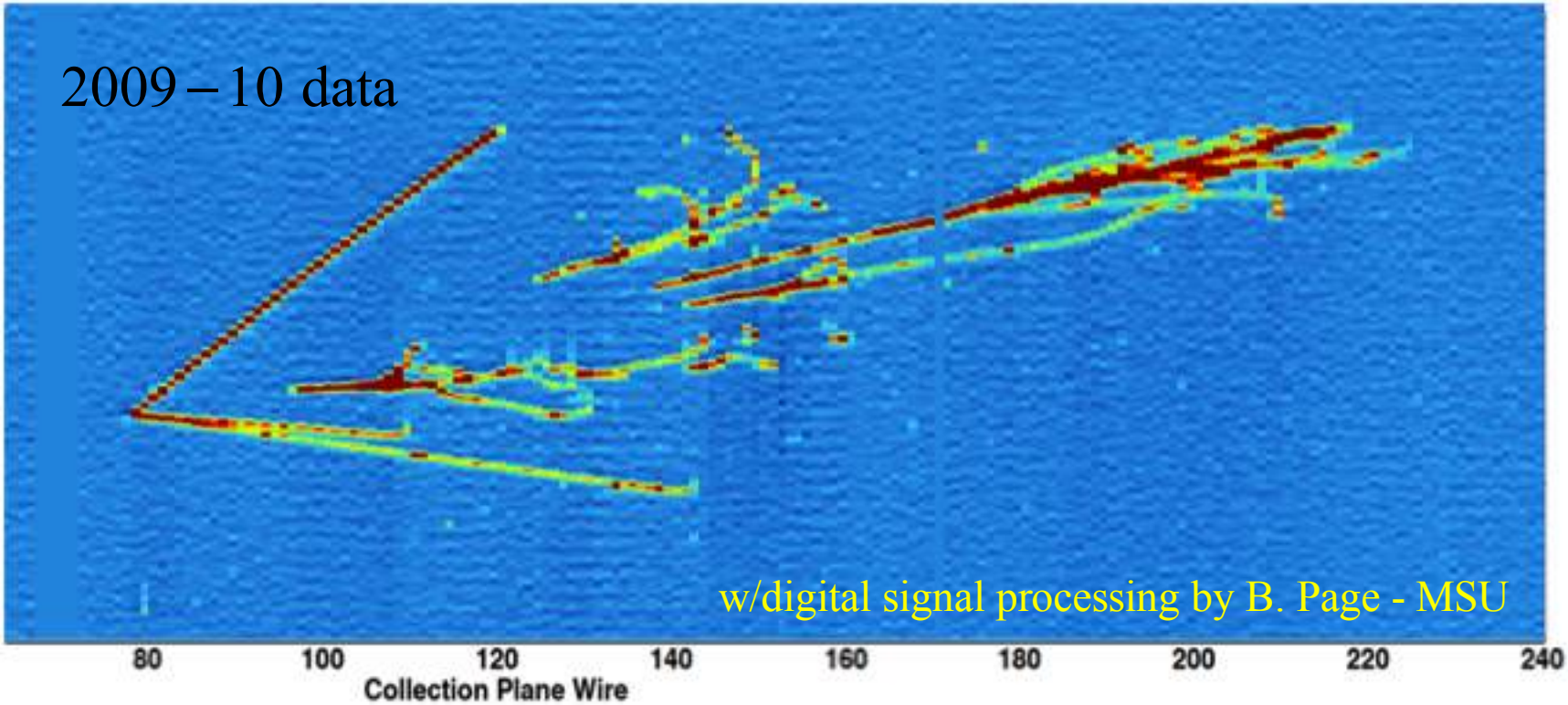
Preamp card file

Also ADF2 digitizer/ DAQ

Uses
Double shielded box
Feed-thru inside box
Forced air cooling

Must disassemble to service.
Completely disassembled
when removed from NuMI

Remarkable!

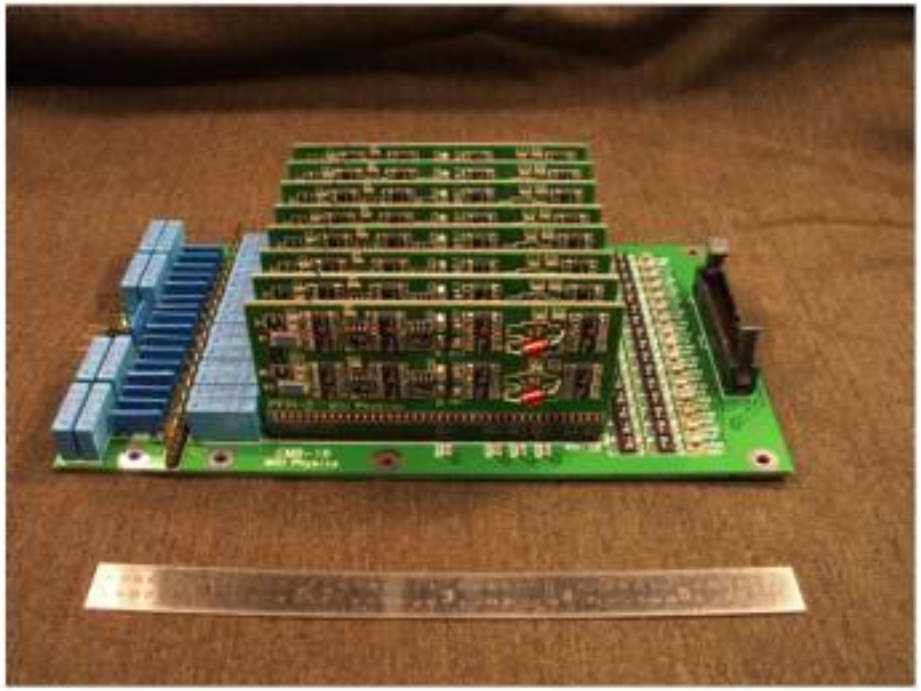


Three papers published - more on the way

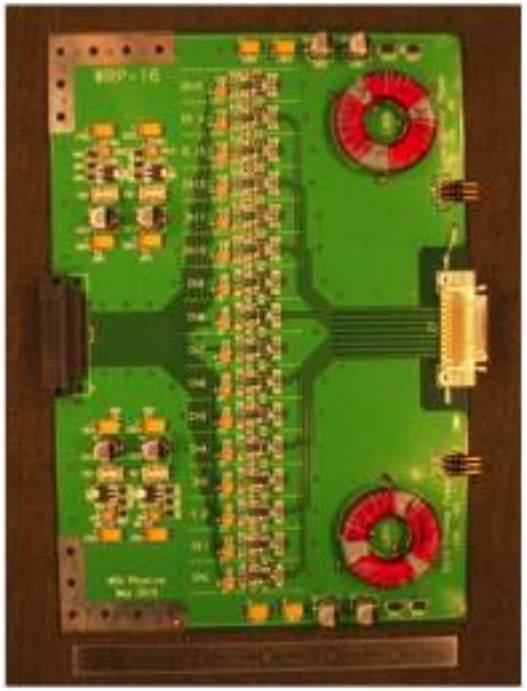
Put preamps in the LAr (2010-2011)

First cold CMOS preamps!

CMOS 2ch. preamp hybrids for the Bo-TPC



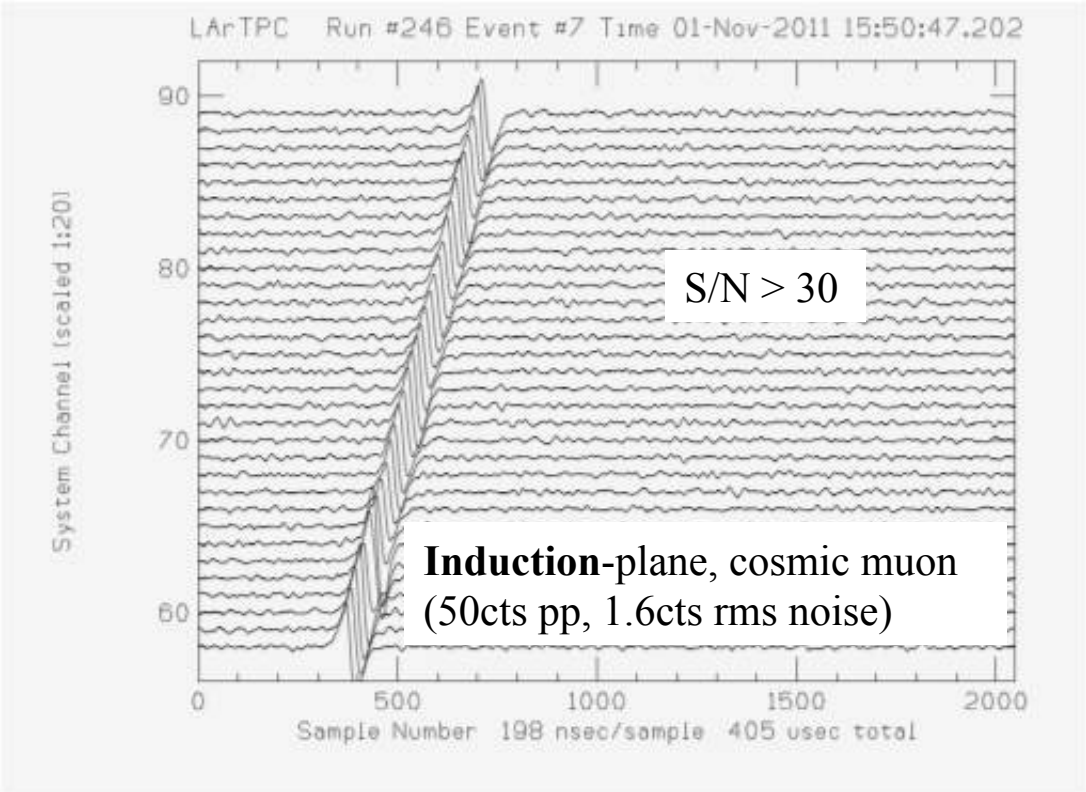
Warm signal receiver with drivers for long cables and supply preamp power



Dan Edmunds - MSU

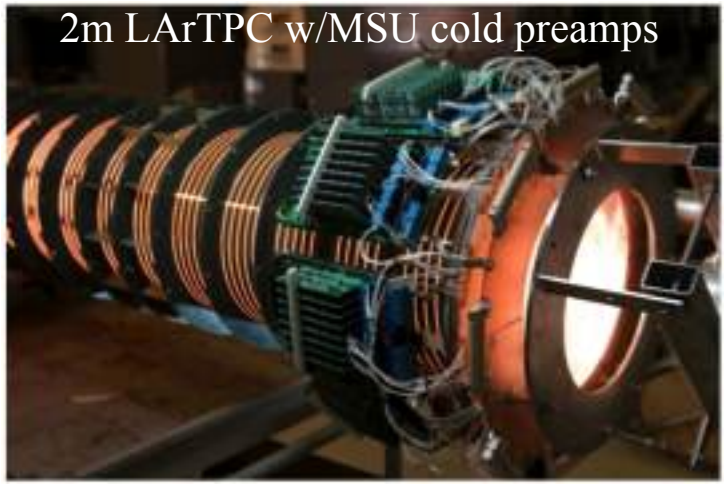
Second cold-electronics run (2011)

Noise was so low in run 1, increased gain x 4 to see it.



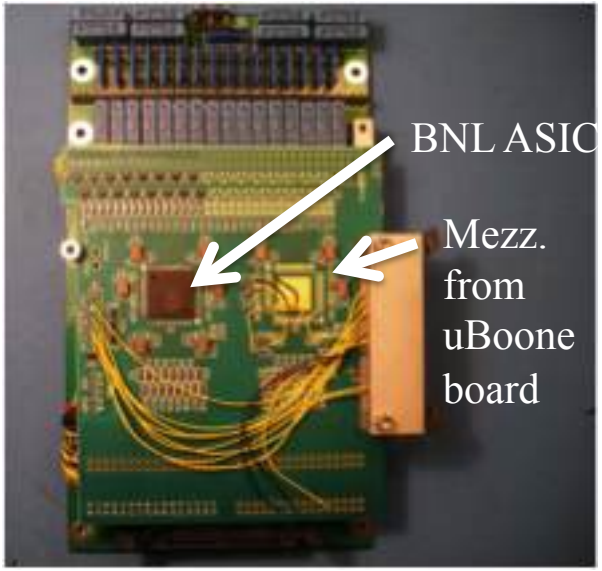
2012 selection of LArTPC technology for LBNE !

2011-2013 Liquid Argon Purity Demonstrator long-Bo TPC

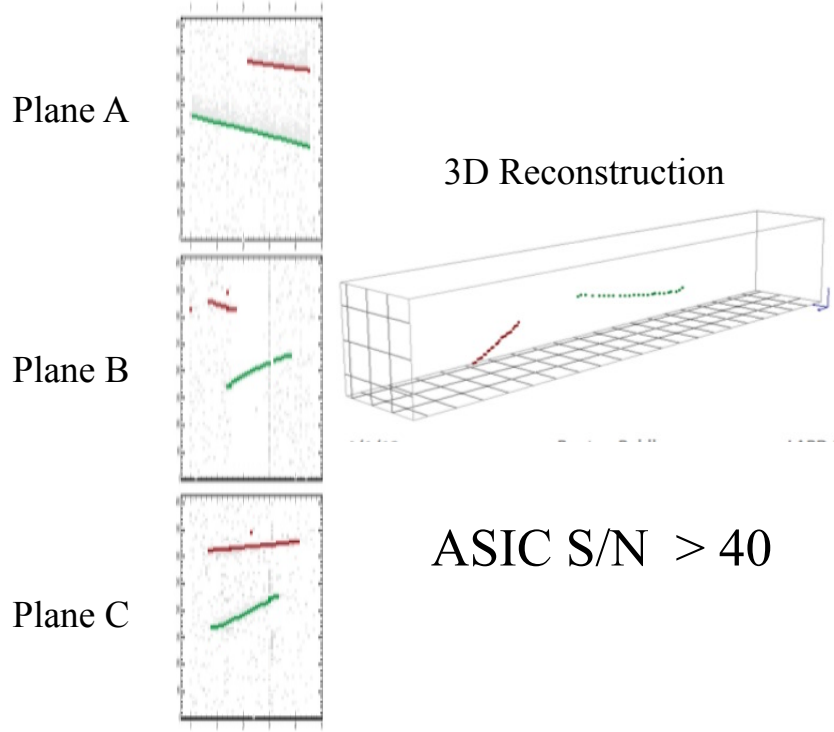


Modified one MSU 16-channel card to use a BNL ASIC. Installed on the central induction plane

Dean Shooltz - MSU



Long-Bo Tracks



ASIC S/N > 40

Cold electronics for LArIAT

ArgoNeuT was an R&D project designed over 6 years ago, superceded by 2 generations of cold electronics with significantly better S/N.

Cryostat provides hermetic shielding of cold preamps from external coherent noise. No need for RF shielding box.

Reassembly of old warm preamp shielding box not anticipated. Extensive testing required, and replacement parts difficult or impossible to obtain.

Internal cables/connectors must be replaced to remove water contamination issues.

Cold Electronics Components, Tasks, Personnel

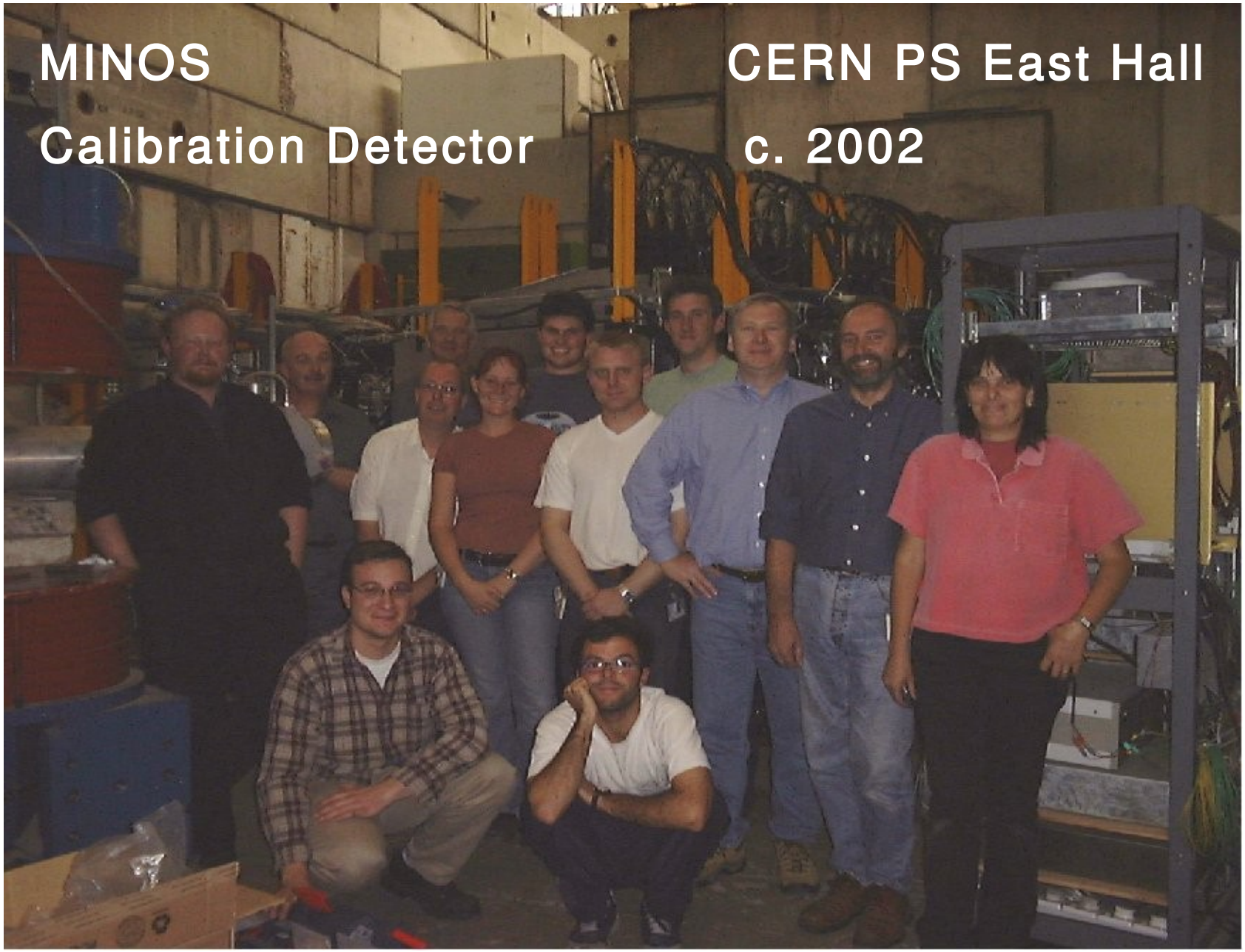
- Components
  - TPC mounted preamp motherboards (30) and cables to feed-thru
  - Preferred use of 30 BNL ASIC chips - Excess MicroBoone production
  - Warm receiver/power for preamps and driving long twisted-pair cables
  - ADF2 digitizers w/firmware modifications
- MSU Tasks
  - Preamp motherboard design – integrated with new TPC wire planes
  - Selection of internal cables, connectors, and design of routing
  - Component purchasing and QA prior to assembly
  - Assembly and testing of premaps, warm receivers, and cables
  - Installation of premaps, cables, warm receivers, twisted-pair cables
  - Fimware modifications to ADF2 digitizers for improved readout speed
  - Warm checkout of system followed by cold commissioning
- Personnel
  - Carl Bromberg, PI
  - Dan Edmunds, EE (MSU staff member)
  - Dean Shooltz (Ph.D) contract engineer

Conclusions

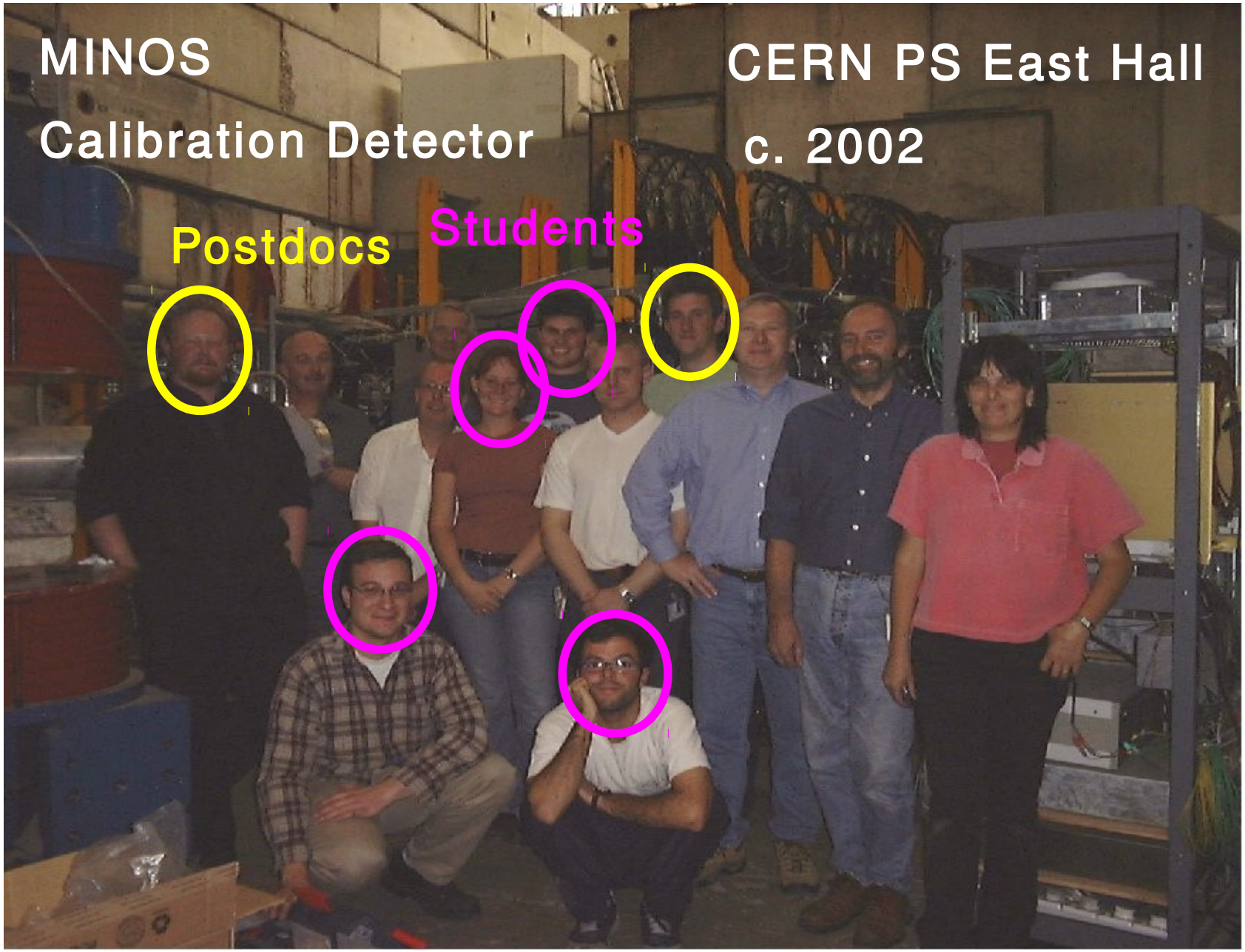
LARIAT and NSF

- LARIAT will create a new cadre of experimenters with deep experience in LArTPC technology
- Augments the NSF investment in MicroBooNE
  - Controlled testbeam conditions buttress MicroBooNE findings
- Active program collecting and analyzing LArTPC data years before LBNE. Tip of the spear.
- Data and conclusions available to global LArTPC community
  - Already an international collaboration
- Long history of test beam exposures prior to major experiments. We know this is the right thing to do.

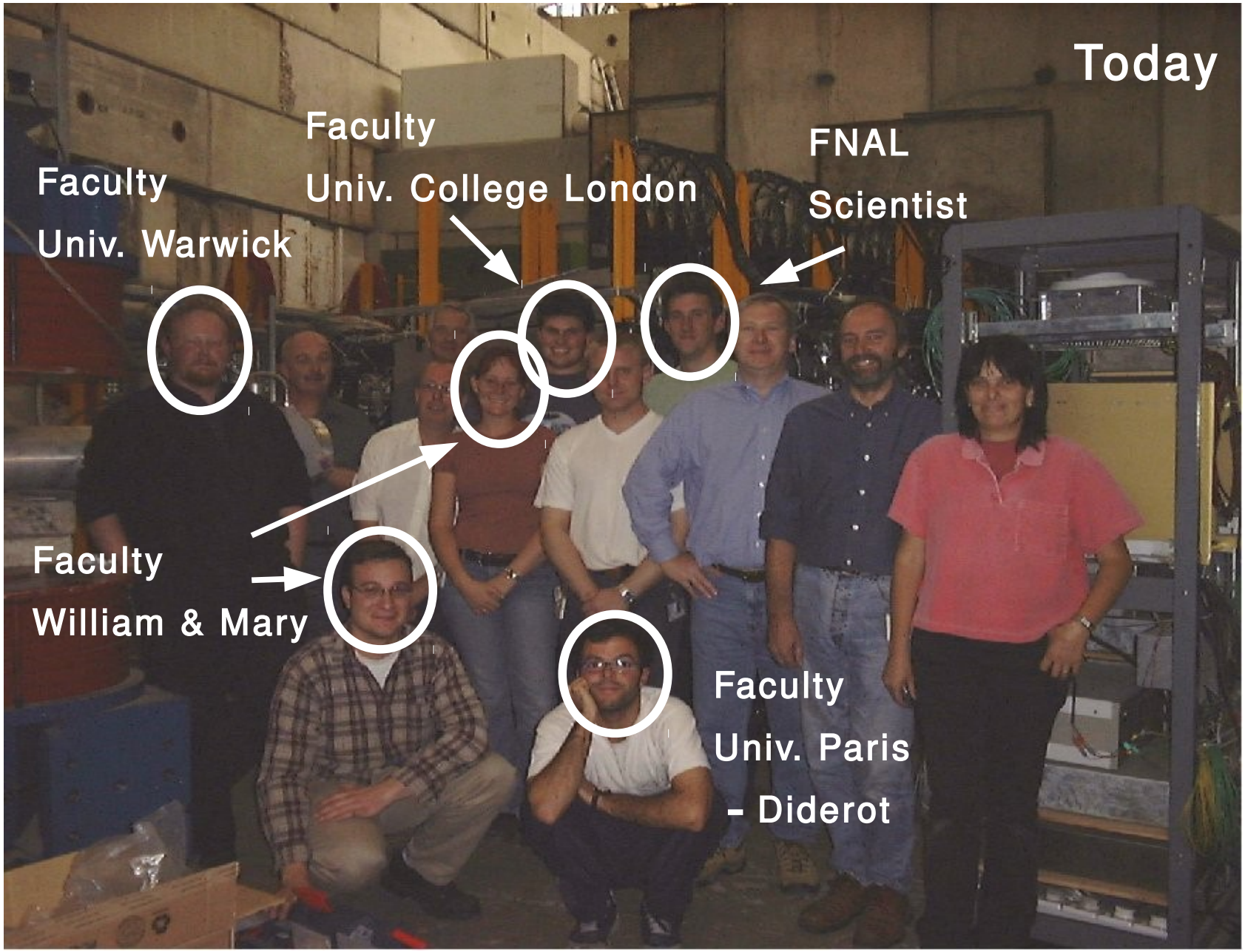
Historical note



Investing in test beams...



... pays off


Today
Faculty
Univ. Warwick
Faculty
Univ. College London
FNAL
Scientist
Faculty
William & Mary
Faculty
Univ. Paris
- Diderot

A new crew

Summary

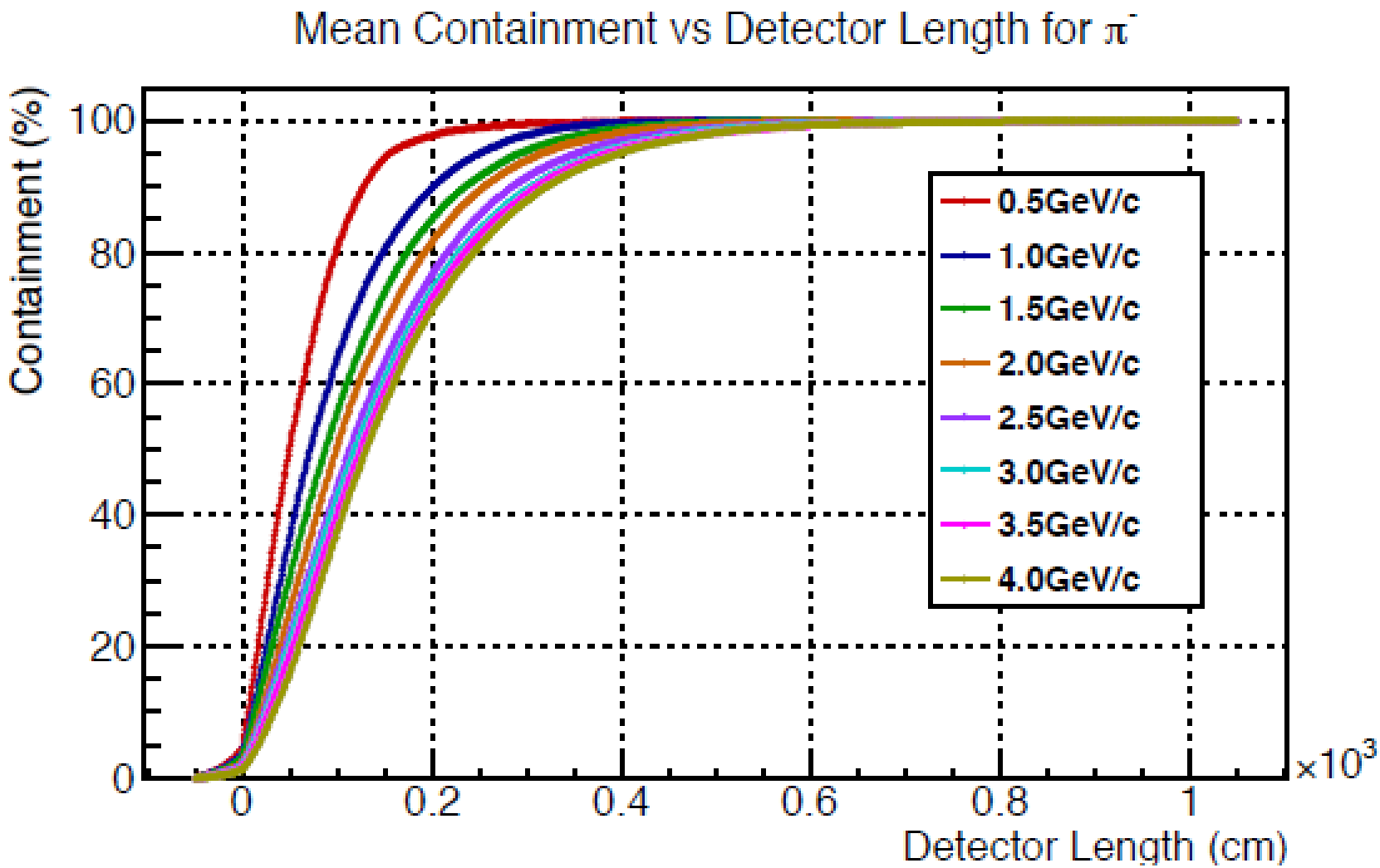
- LARIAT is an important component of the LAr R&D program
- FNAL review concluded “a very worthwhile investment”
- LBNE R&D Needs Evaluation committee:
  - “unique” contribution to the “state of the art” acknowledged as “crucial component”
- Wide support in LAr community
- Well aligned with MicroBooNE and LBNE

Summary

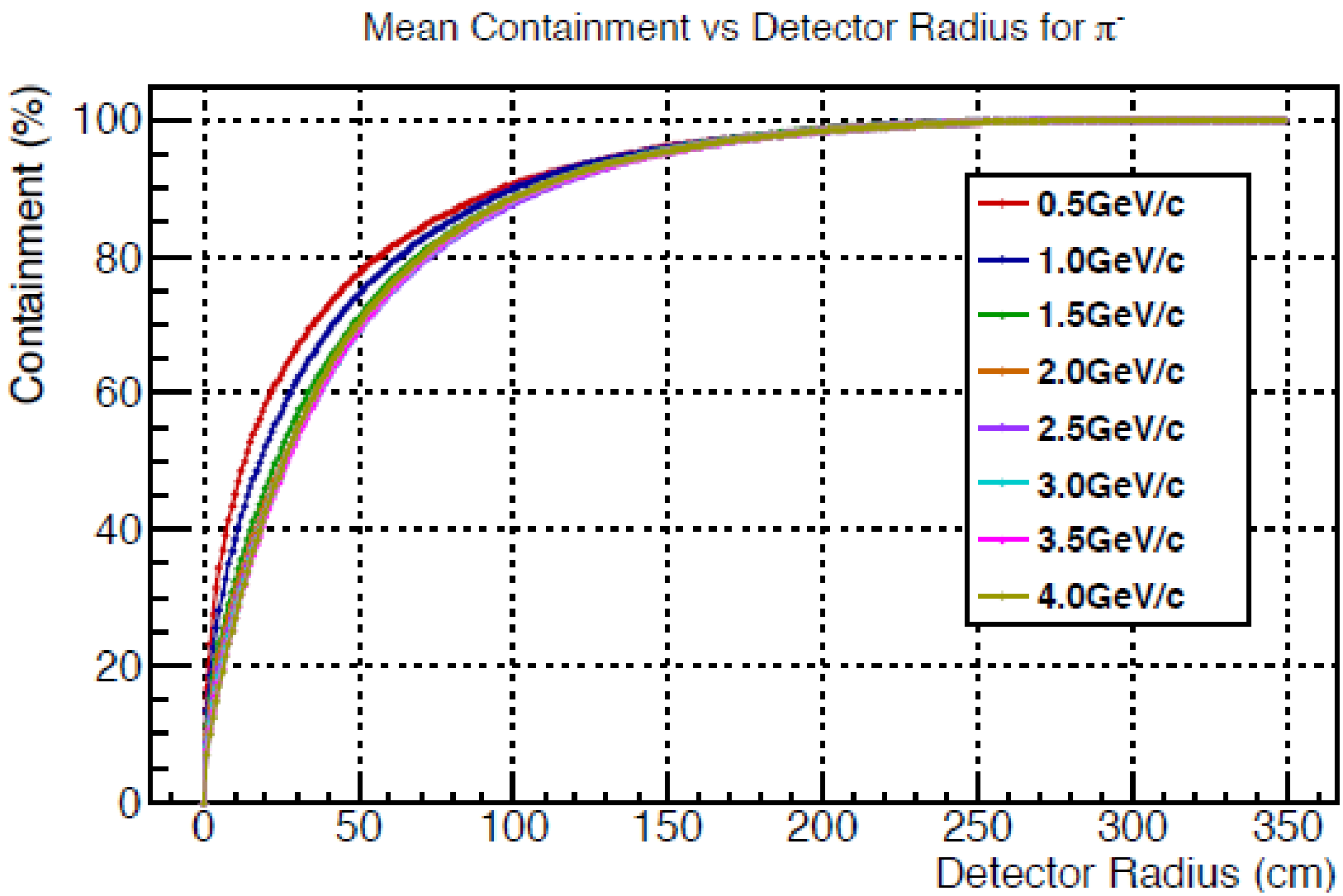
- DOE/Yale funding permitted modifications to Argoneut
- TPC refurb/modifications underway
- Trigger, counters and beamline work underway
- Strong support from FNAL:
  - $450k M&S / $460k SWF in 2013
- Significant additional effort from lab & university scientists.
- Largest remaining item: cold electronics

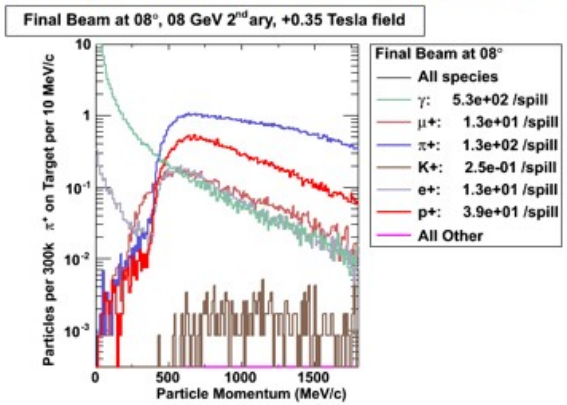
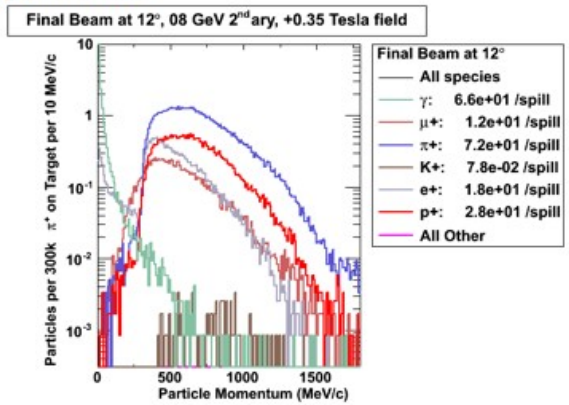
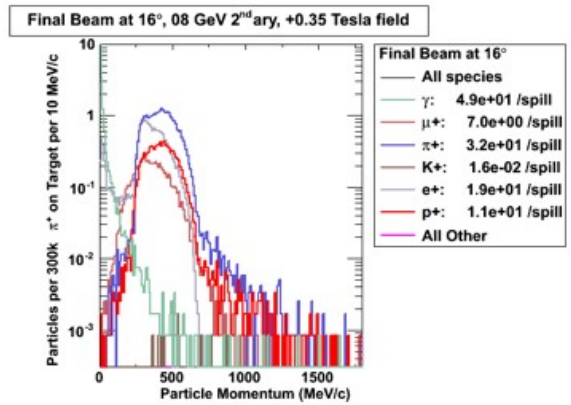
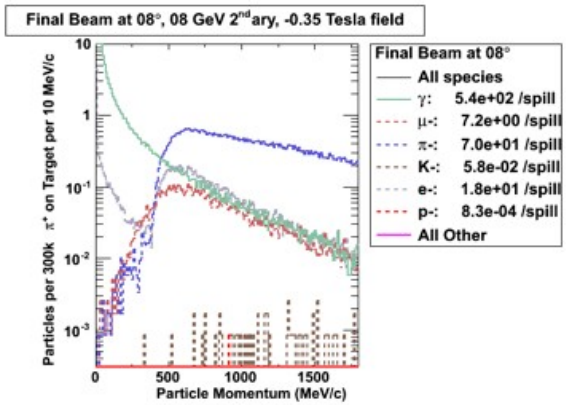
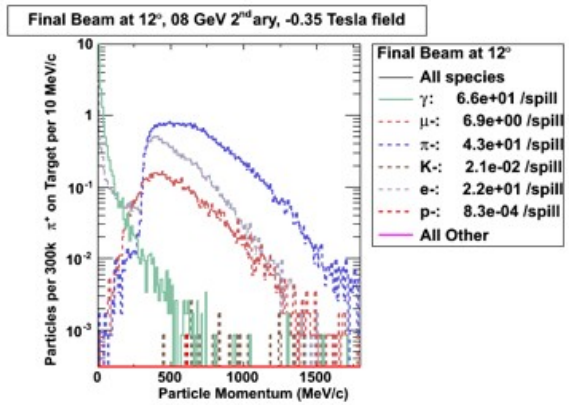
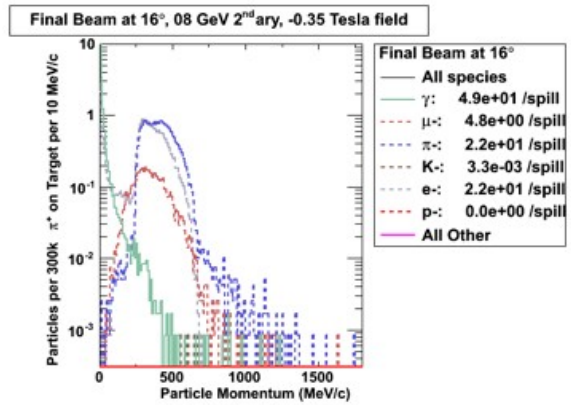
Backup Slides

pion containment



pion containment



Beam Studies

8 GeV pi+ beam, 0.35 Tesla bending field, three detector placements