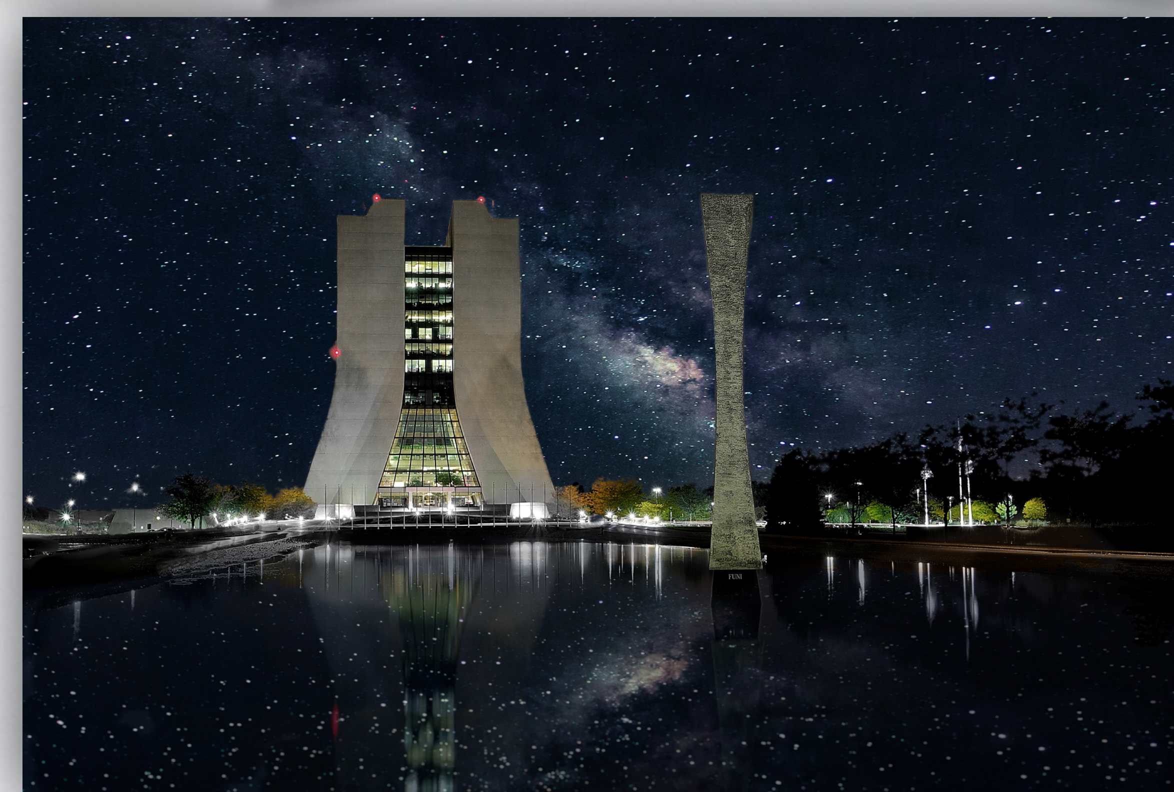
7th International Symposium on "Large TPCs for Low-Energy Rare Event Detection"

Paris
December 16th, 2014

The LArTPC R&D Program at FERMILAB

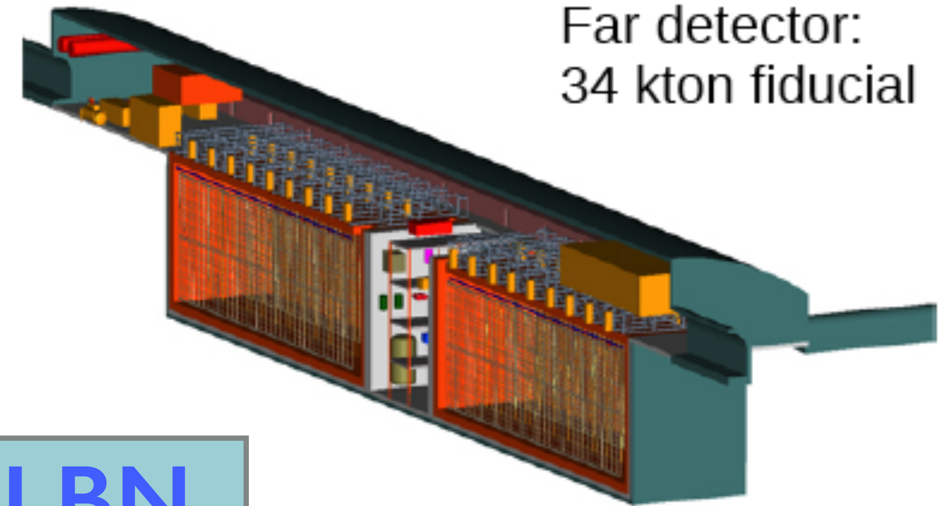


Flavio Cavanna
FERMILAB - Neutrino Division

Large US LArTPCs

MicroBooNE

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



Far detector:
34 kton fiducial

LBN

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

SBN

- Sterile Neutrino Search

FNAL Mission: develop the expertise to enable the SBN & LBN Program

Develop hands-on experience and (new) infrastructure

- filters, cryogenics, HV feed-throughs, readout electronics

Look at technical topics which may not have been fully explored previously

- material tests, in-liquid electronics, **light detection**

Put a LArTPC in a neutrino beam to exercise a complete system (and physics)

- ArgoNeuT

Demonstrate good electron lifetime *in an* ***unevacuated commercial vessel***

- LAPD (Liquid Argon Purity Demonstration)

Expose LArTPC to a beam of known energy and different particle types

- LArIAT (Liquid Argon In A Test beam)

Develop an integrated system test that incorporates as many aspects of the far detector design as possible.

- the ***35 t*** Program

Exploit synergies with Dark Matter detectors

- DarkSide Program

(Some) Liquid Argon R & D at Fermilab

Charge Detection

- **Certification of detector materials**
  - **Materials Test System (MTS)**
- **Production of clean argon without evacuation**
  - **Liquid Argon Purity Demonstration (LAPD)**

Light Detection and Production

- **Effect of contaminants and additives (quenching, attenuation)**
- **Detector Performance (light collection, photosensors)**
  - **BO and TallBO cryostat systems**
  - **LArIAT Experiment**

High Voltage

- **Breakdown in noble liquids**

(Some) Liquid Argon R & D at Fermilab

Neutrino Specific

- **TPC performance with electronics and HV ->**

  BO TPC and Long BO TPC

- **Detailed behavior of particles in liquid Argon ->**

  Test beam into LArTPC (LArIAT)

Dark Matter Specific

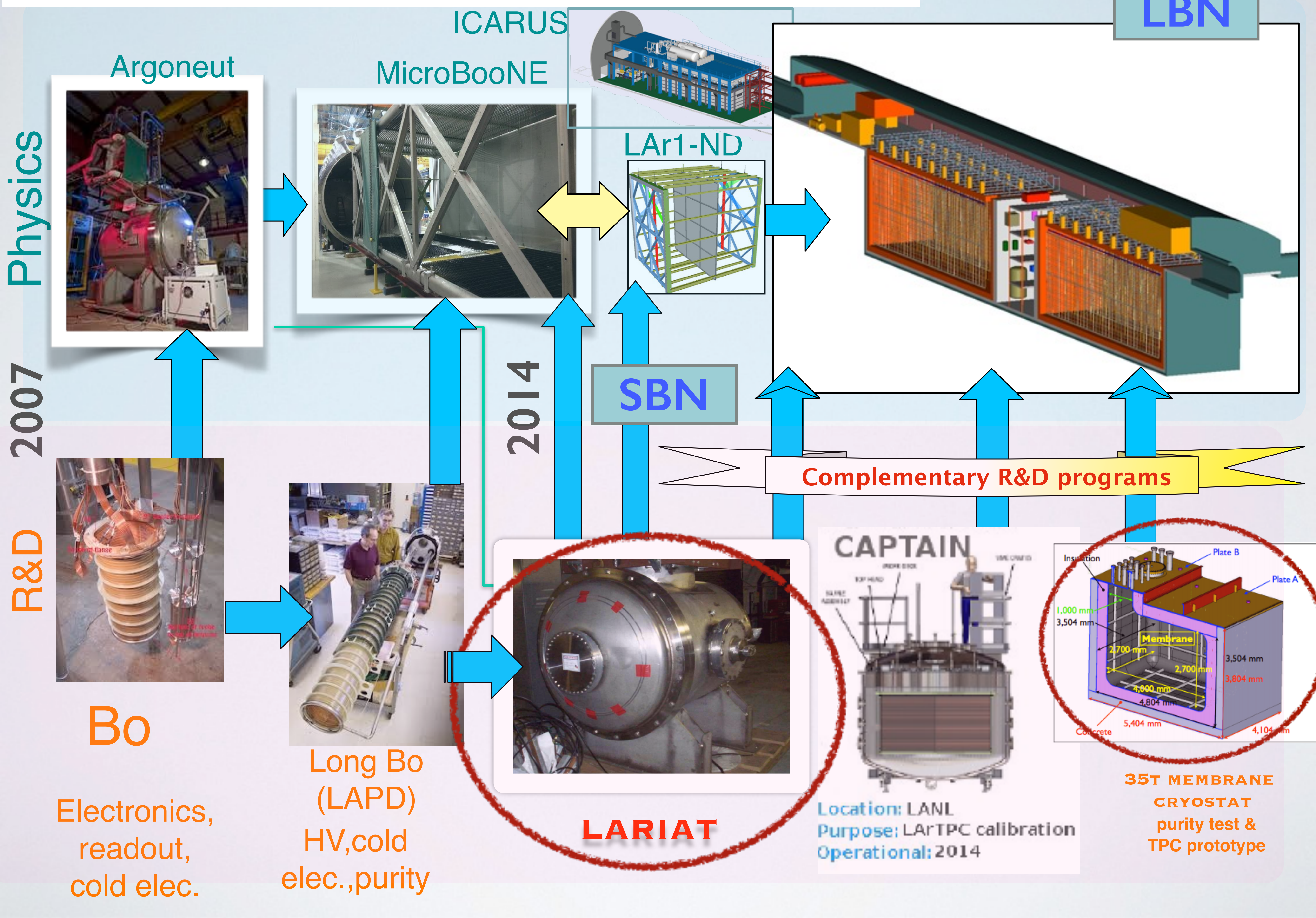
- **Light yield from nuclear recoils at low energy (<50 keV)**

  ScENE (Scintillation Efficiency of Noble Elements) experiment

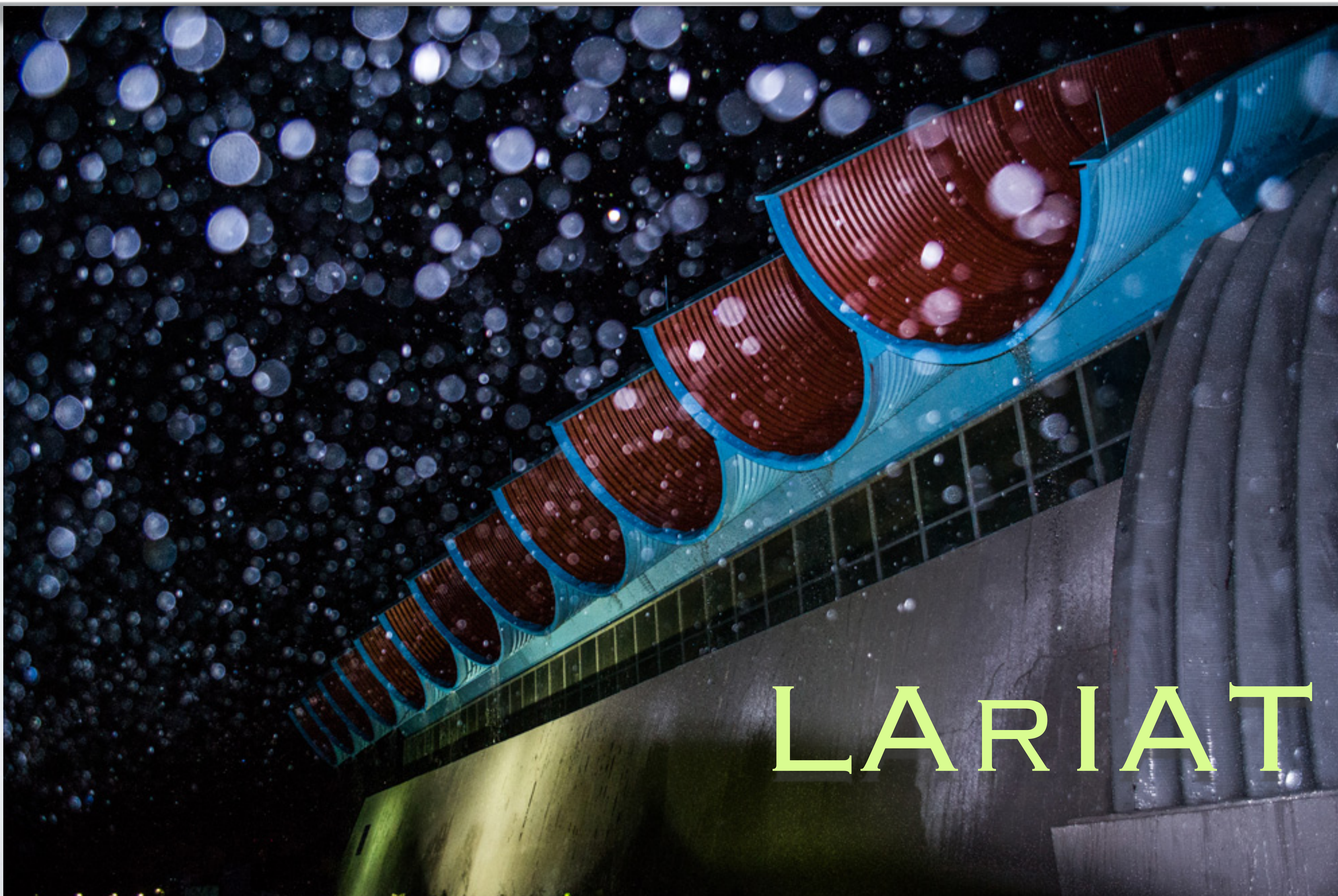
- **Argon for low-background experiments**

  Purification of underground argon

TOWARDS THE SB & LB NEUTRINO PROGRAM



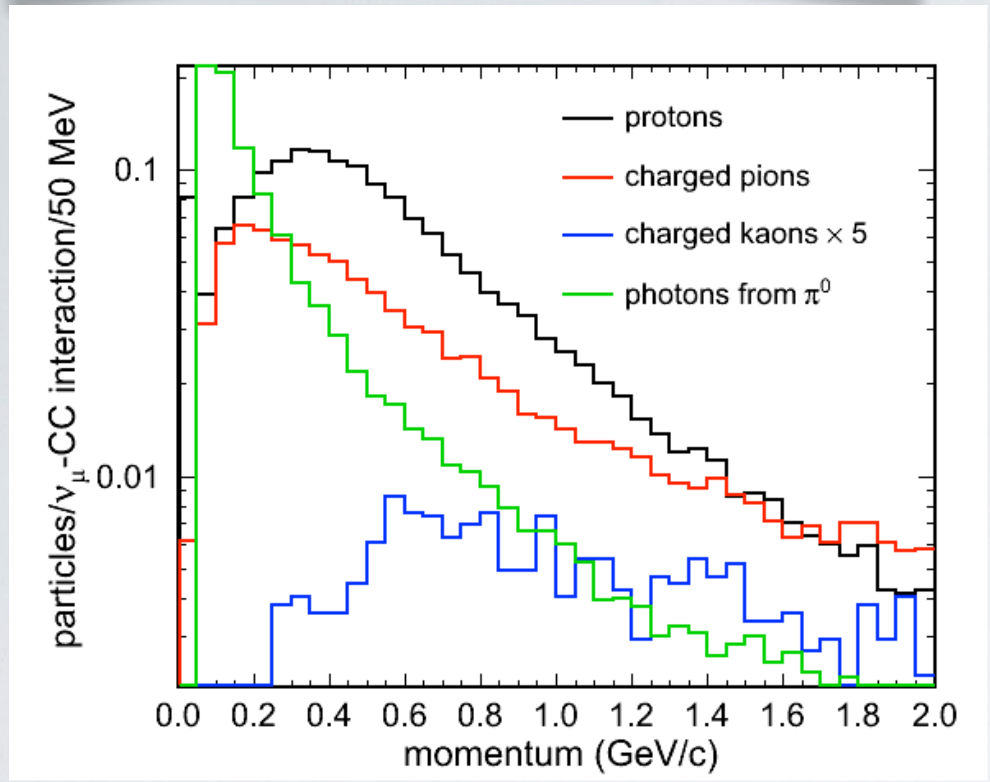
Liquid ARgon TPC In A Testbeam



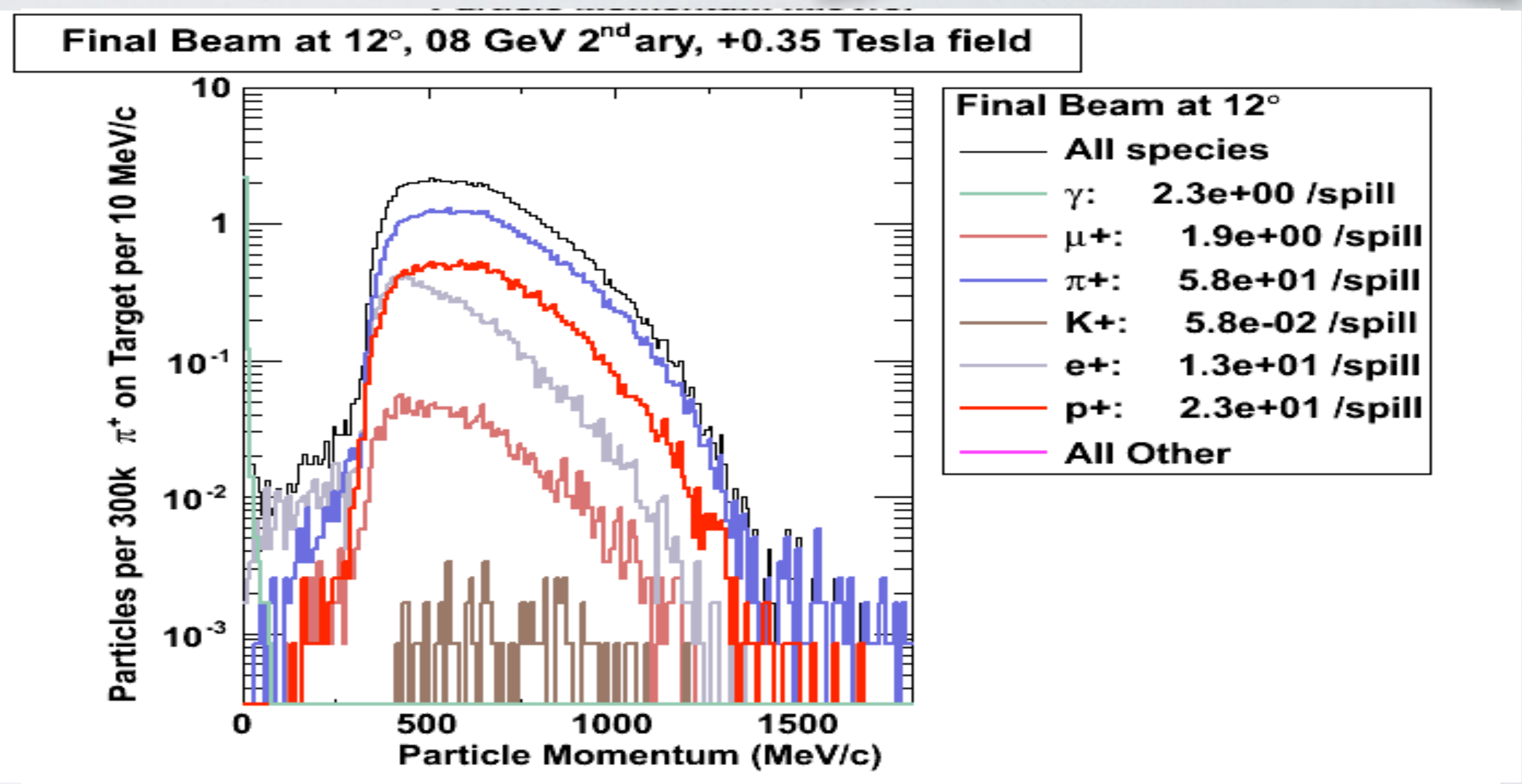
MOTIVATION

LARIAT

METHOD



NuMI LE on-axis Beam
M. Kordoski



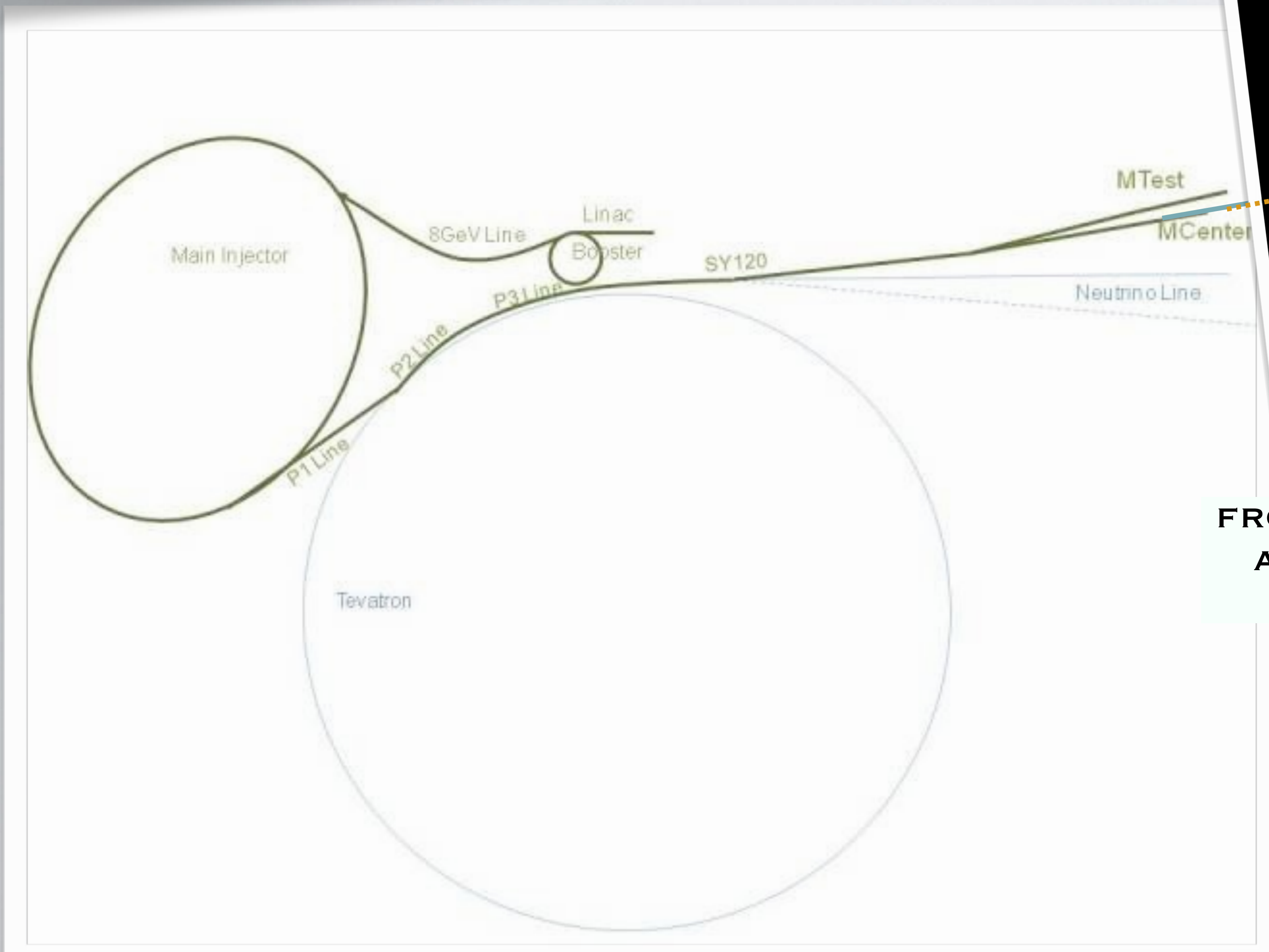
LArIAT Test Beam

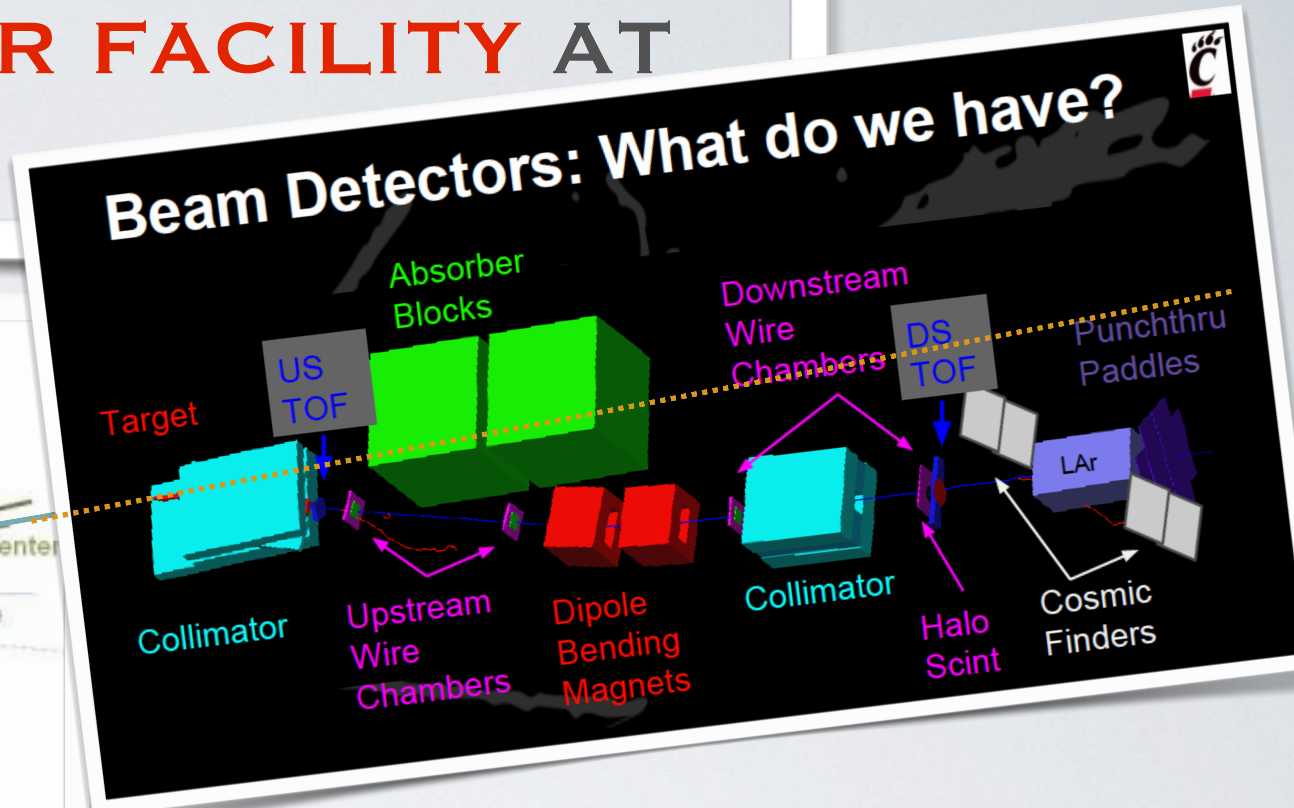
Study in LArTPC
Particles emerging from
ν Interactions
(in the energy range
relevant for
SBN & LBN)

→

Study in LArTPC
Particles emerging from a suitably designed Beam-line
with appropriate momentum range

BASIC CONCEPT:
A (SEMI-PERMANENT) LAR FACILITY AT FTBF





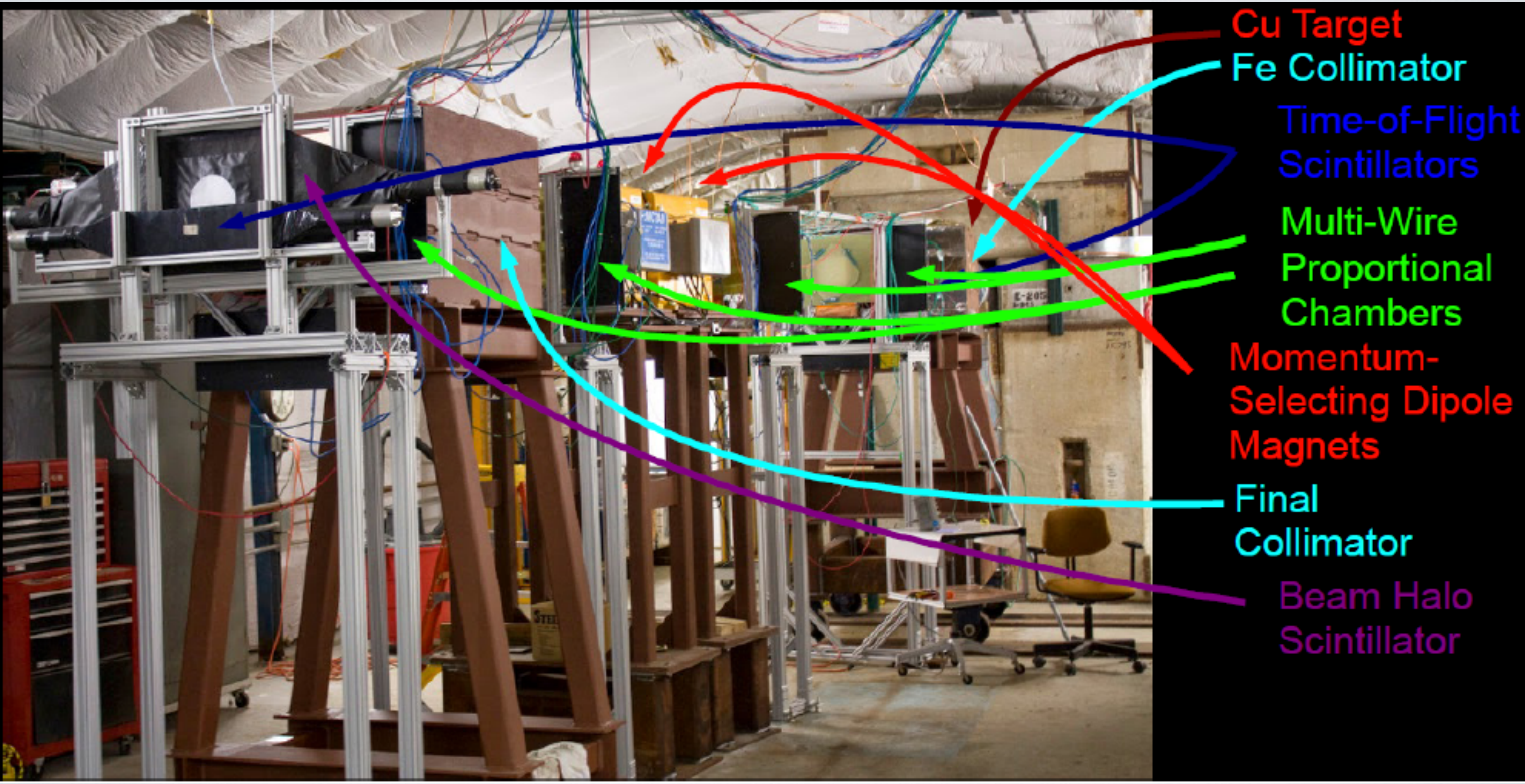
FROM THE SECONDARY PION MCENTER BEAM-LINE AT FTBF, A DEDICATED LOW MOMENTUM TERTIARY BEAM LINE HAS BEEN DESIGNED, INSTALLED AND TESTED

A **fully operational TB/cryo-Facility** will allow for any future test of different components in experimental conditions

(e.g. different designs for TPC, Light Det. system, Electronics)

The LArIAT Beam Line is now fully operational

result of a great effort: FTBF team & LArIAT grps (FNAL, Cincinnati, LSU,BU, …)

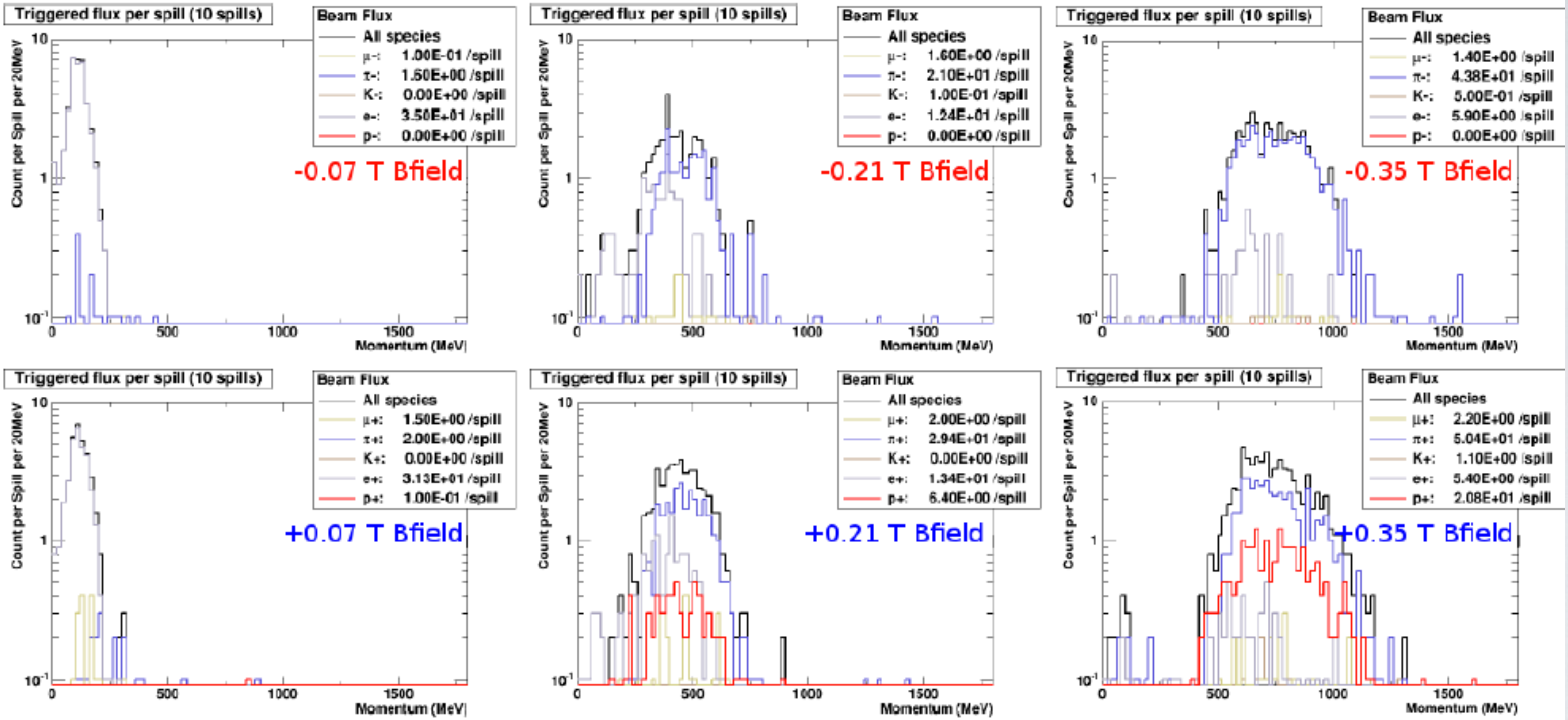


New Detectors are being built/tested/installed:

3 Cherenkov counters (Yale, Duluth, KEK, UT Austin) and μ-stacker (FNAL)

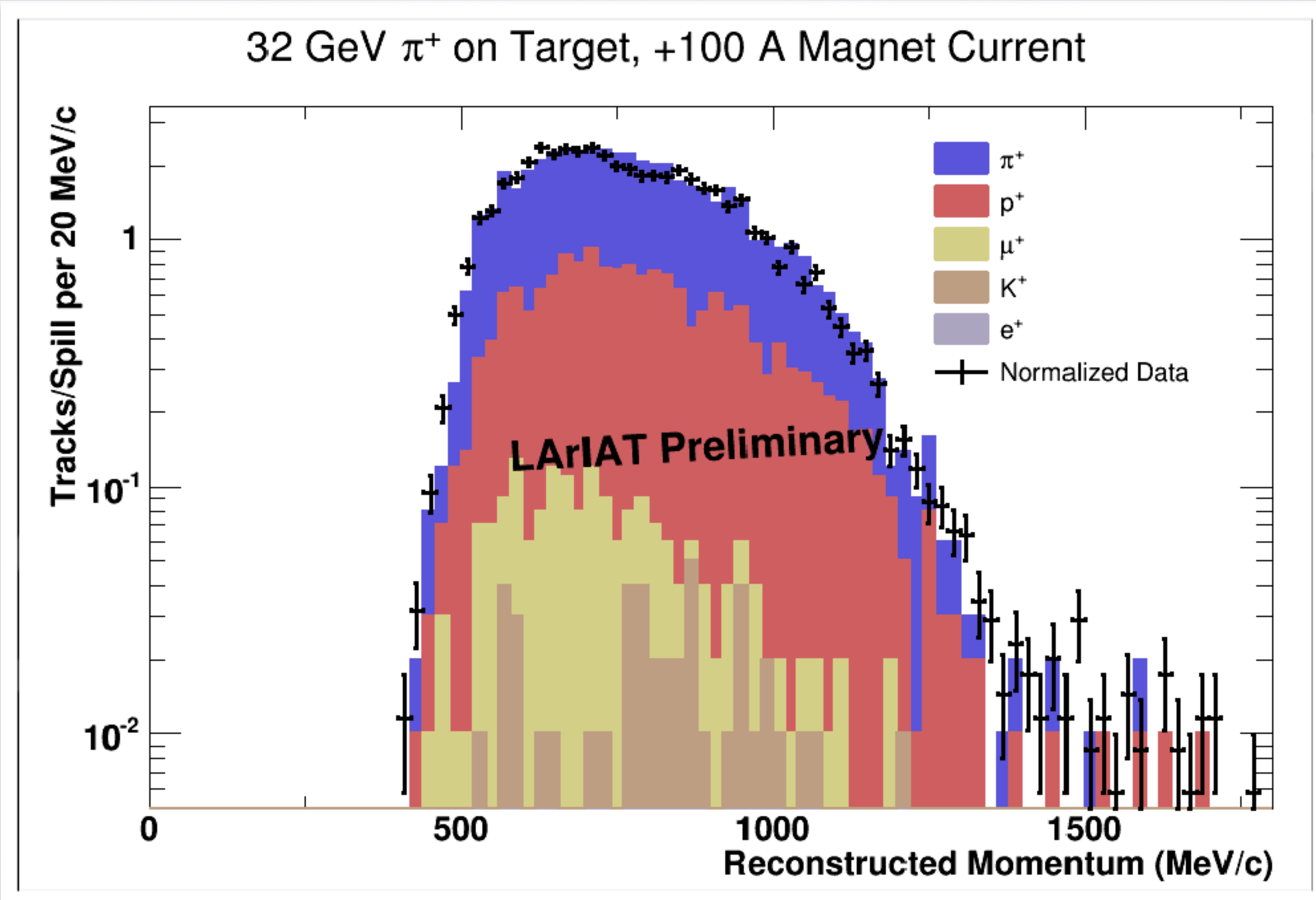
Tertiary beam composition (MC only)

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

LArIAT beam: Momentum Distribution



REAL DATA vs MC expectation

J. St.John

SCIENCE OUTLOOK:

ELECTRON VS PHOTON SHOWER DISCRIMINATION

Experimental confirmation for the separation efficiencies (MC determined) - key feature of LArTPC technology

MUON SIGN DETERMINATION (W/OUT MAGNETIC FIELD)

Explore a LArTPC feature never systematically considered (decay vs capture in LAr)

STUDY OF NUCLEAR EFFECTS

Pion Absorption, π^0 from $\pi^\pm$ Charge Exchange, Elastic & Inelastic Cross-Section

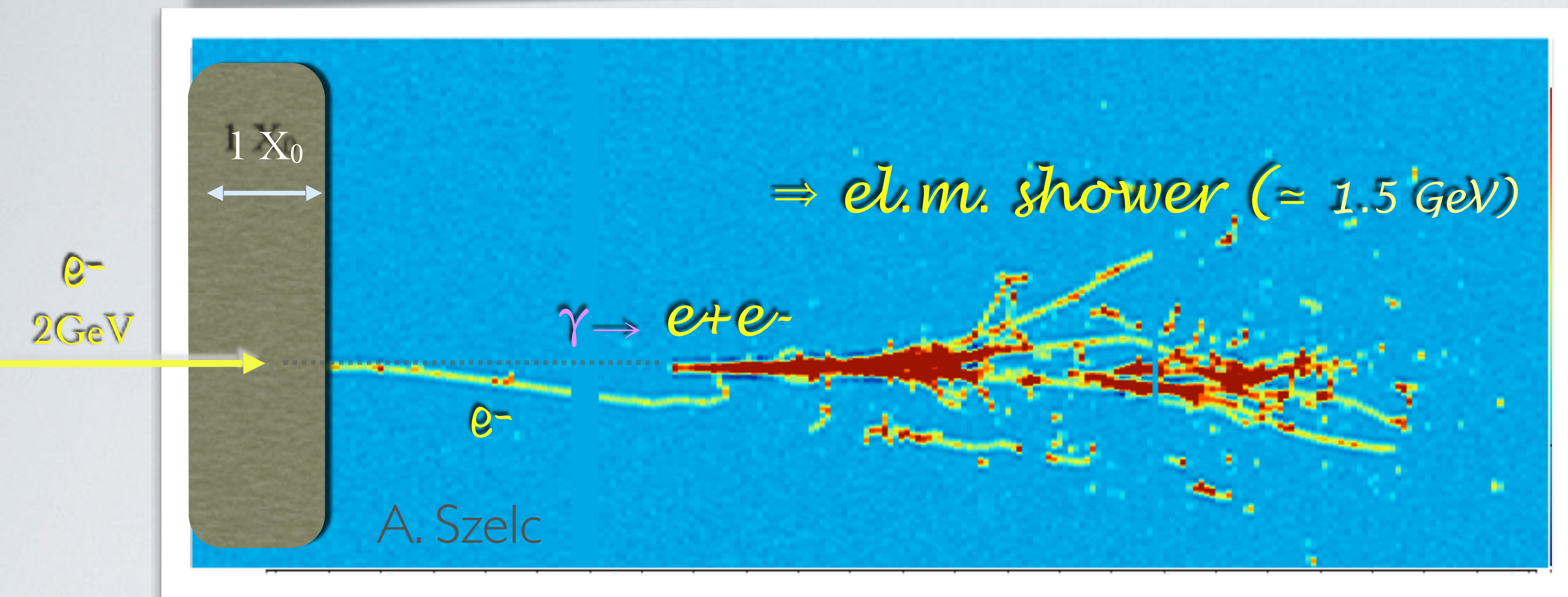
Kaon interaction channels

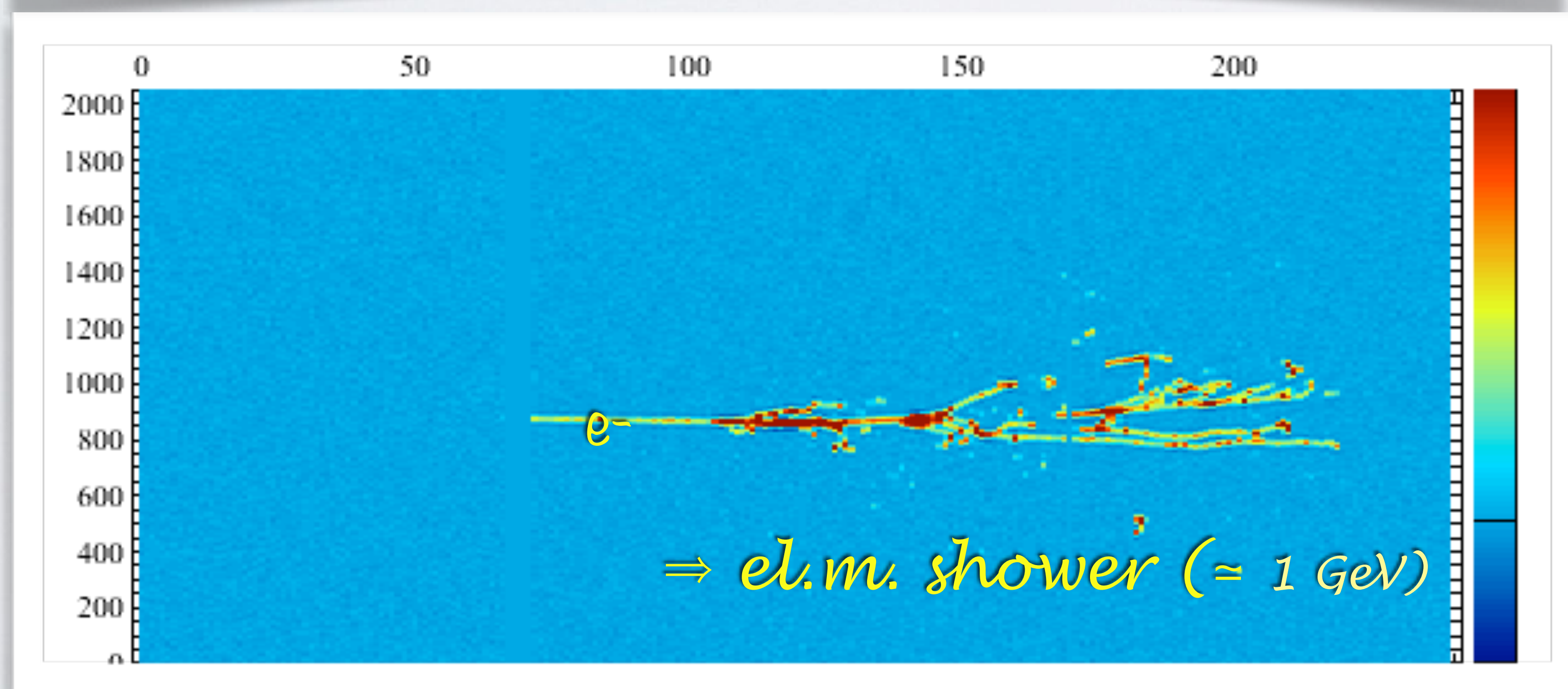
Antiproton annihilation (relevant for n-nbar oscillations)

DEVELOPMENT OF A NEW CONCEPT FOR LAR SCINTILLATION LIGHT COLLECTION

Relate energy deposited to charge and light for an improved calorimetric energy resolution

ELECTRON VS PHOTON SHOWER DISCRIMINATION





Bremsstrahlung from upstream radiator plate

Tagged with incoming electron PID in beamline + deviated track + gap.

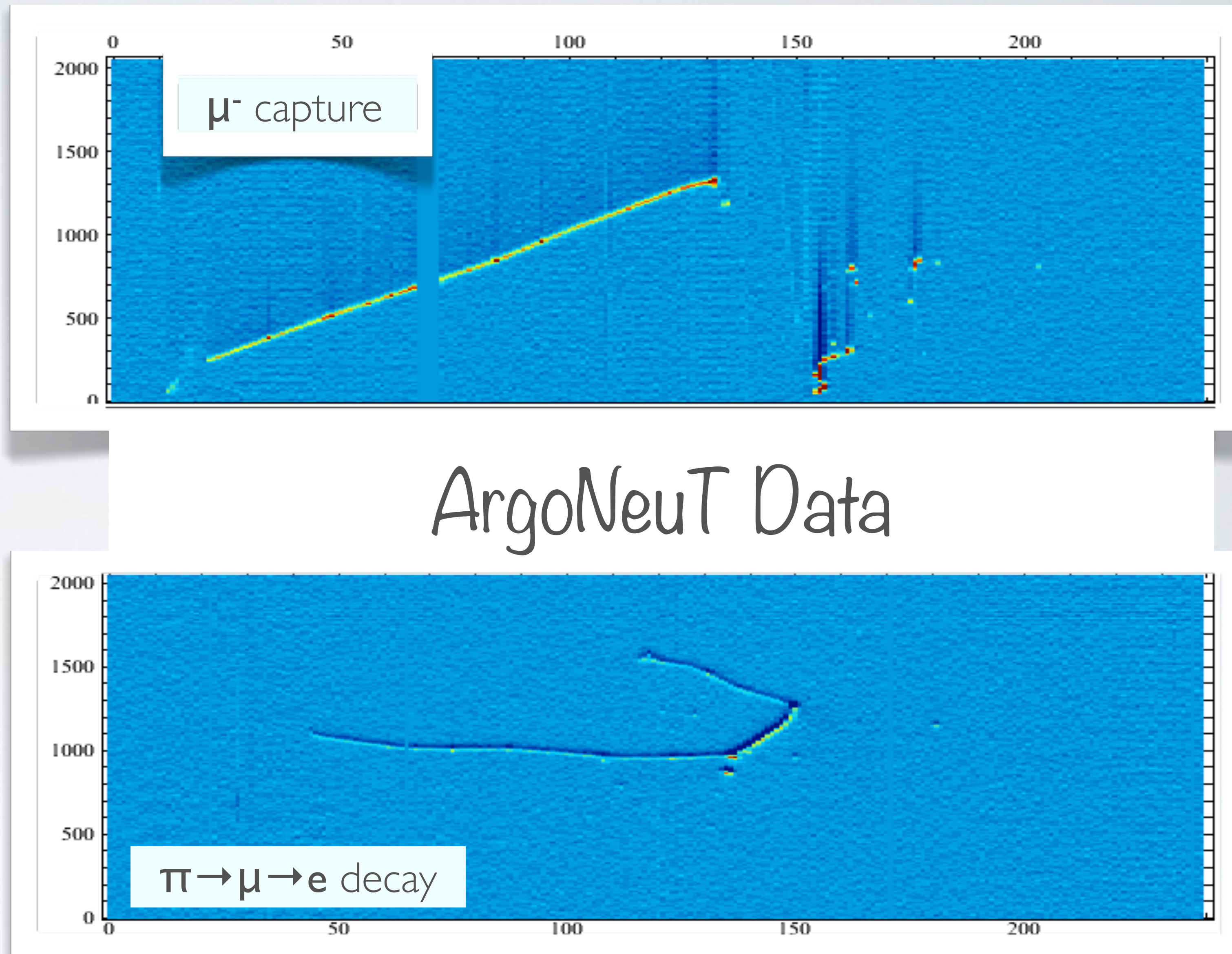
Muon sign determination (w/out magnetic field)

Charge sign determination (w/o 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

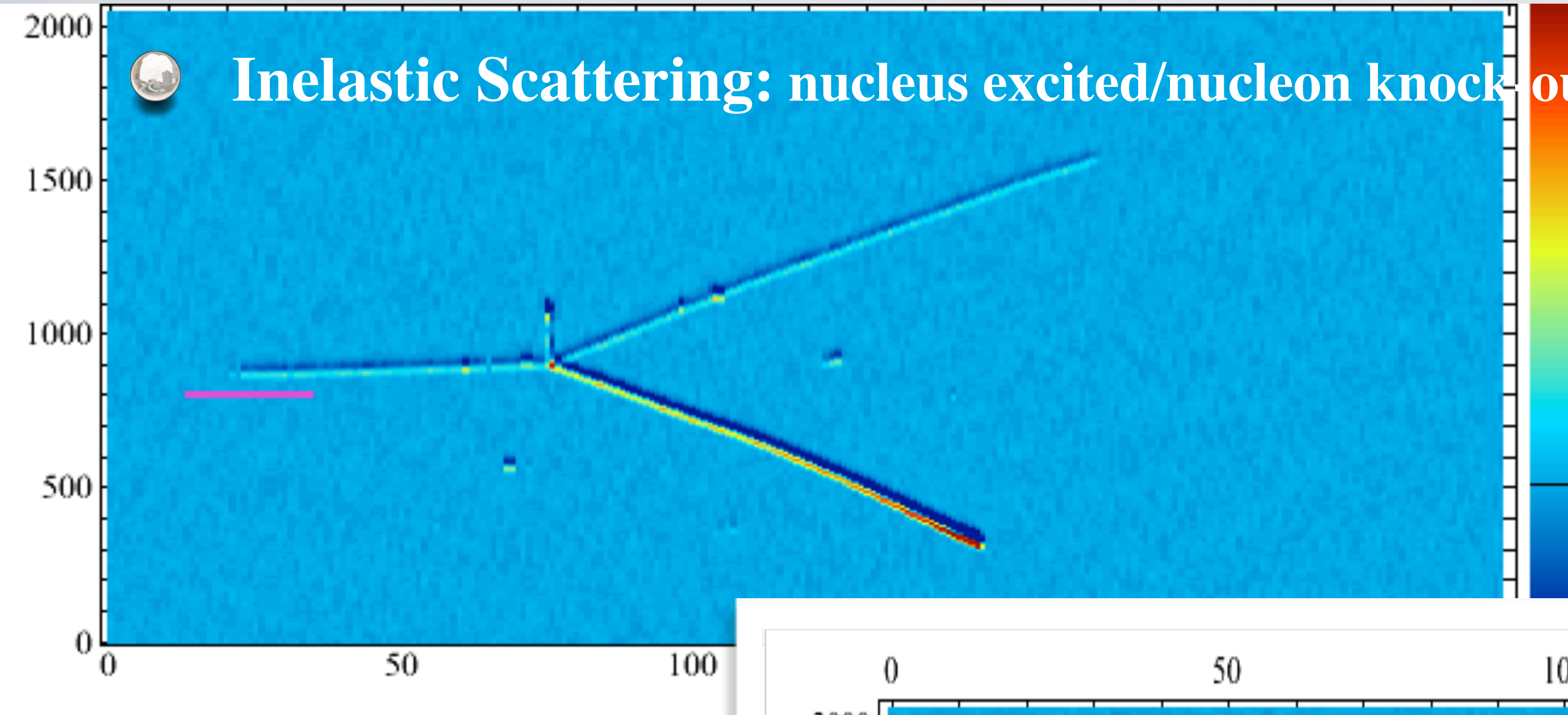
- Beam tunable polarity will provide data for direct measurement of the sign separation efficiency and purity for muons (might be possible for pions)

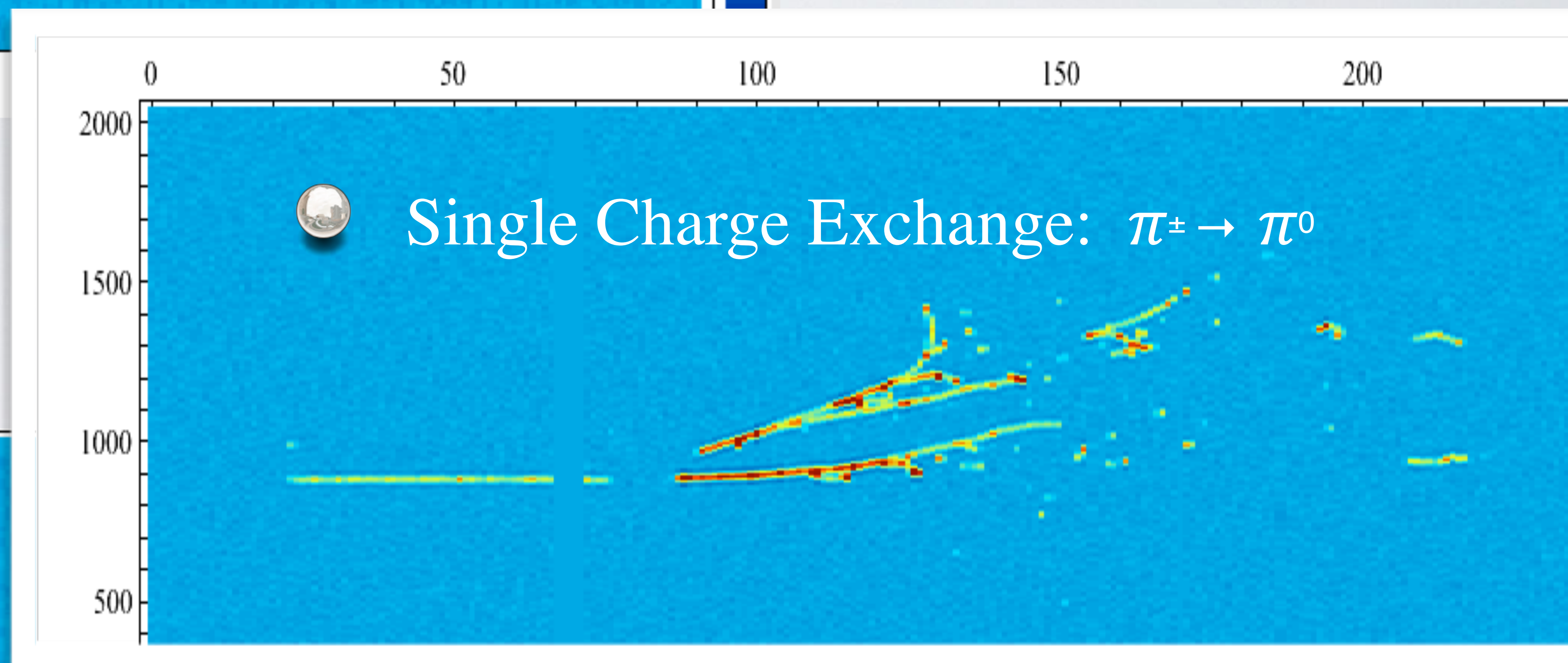


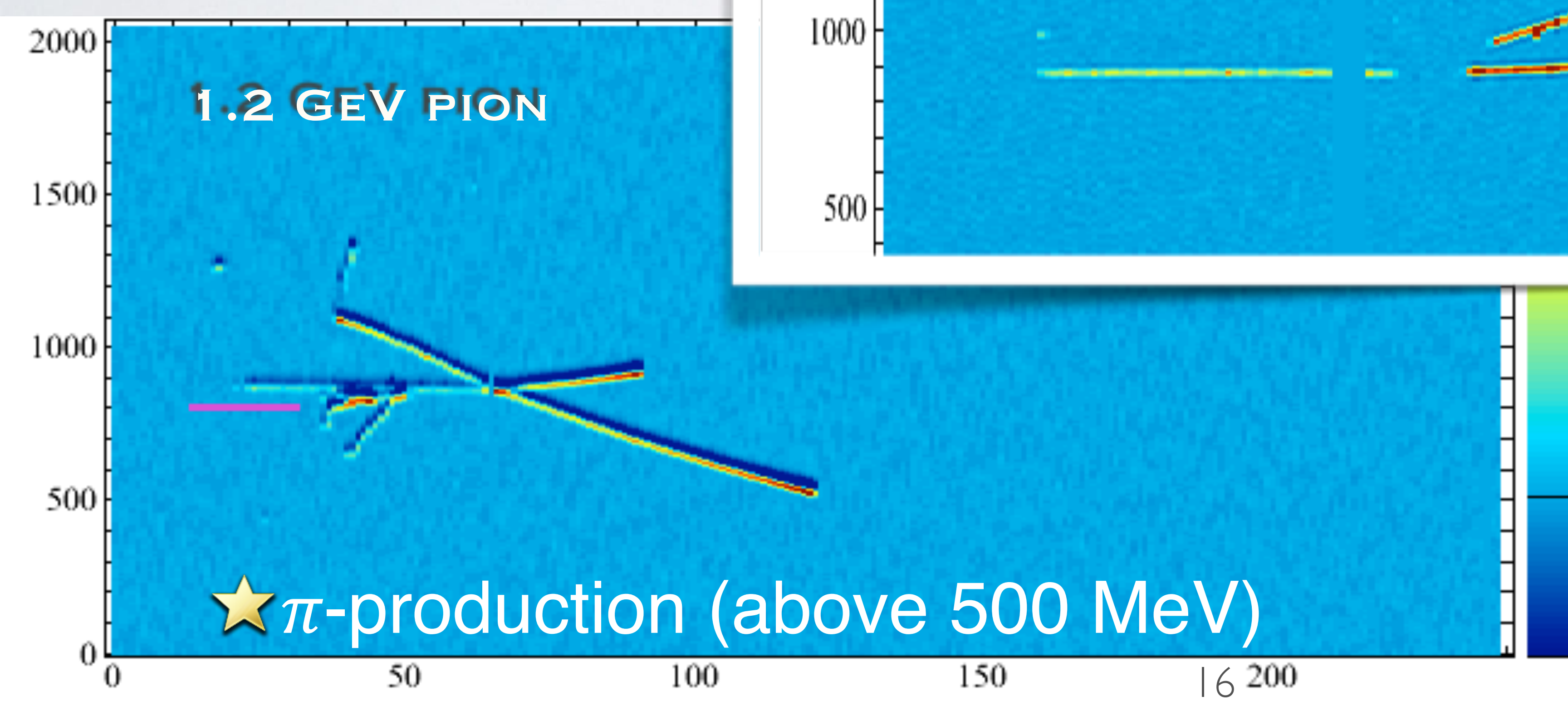
LArTPC sign determination capability has yet to be explored

- Constrain the capability to charge-ID the primary lepton in muon neutrino CC interactions of particular interest
- for CP violation with LBNE

Charged π's in LAr

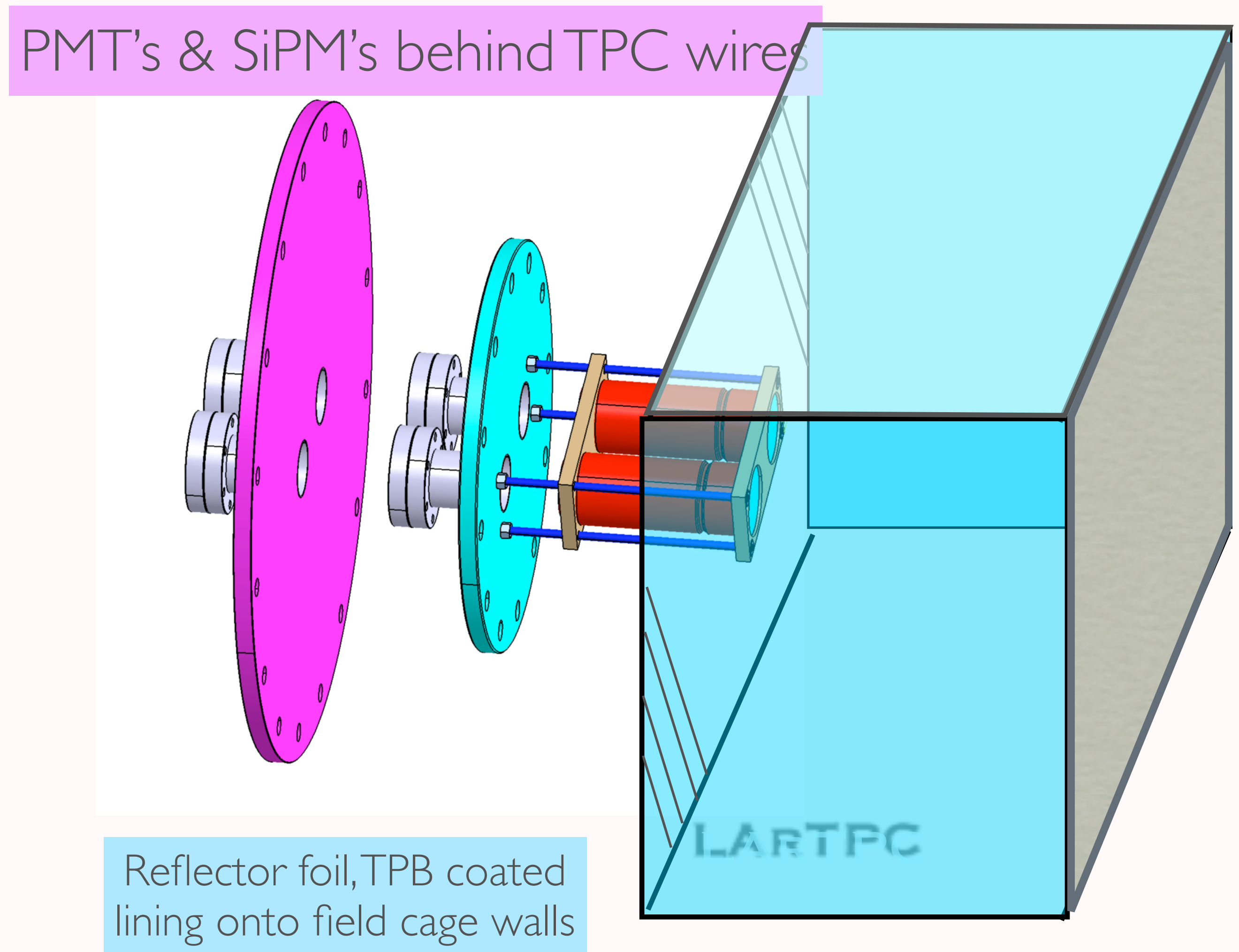






(A.Szelc-Yale)

Development of a new concept in LAr Scintillation Light Collection

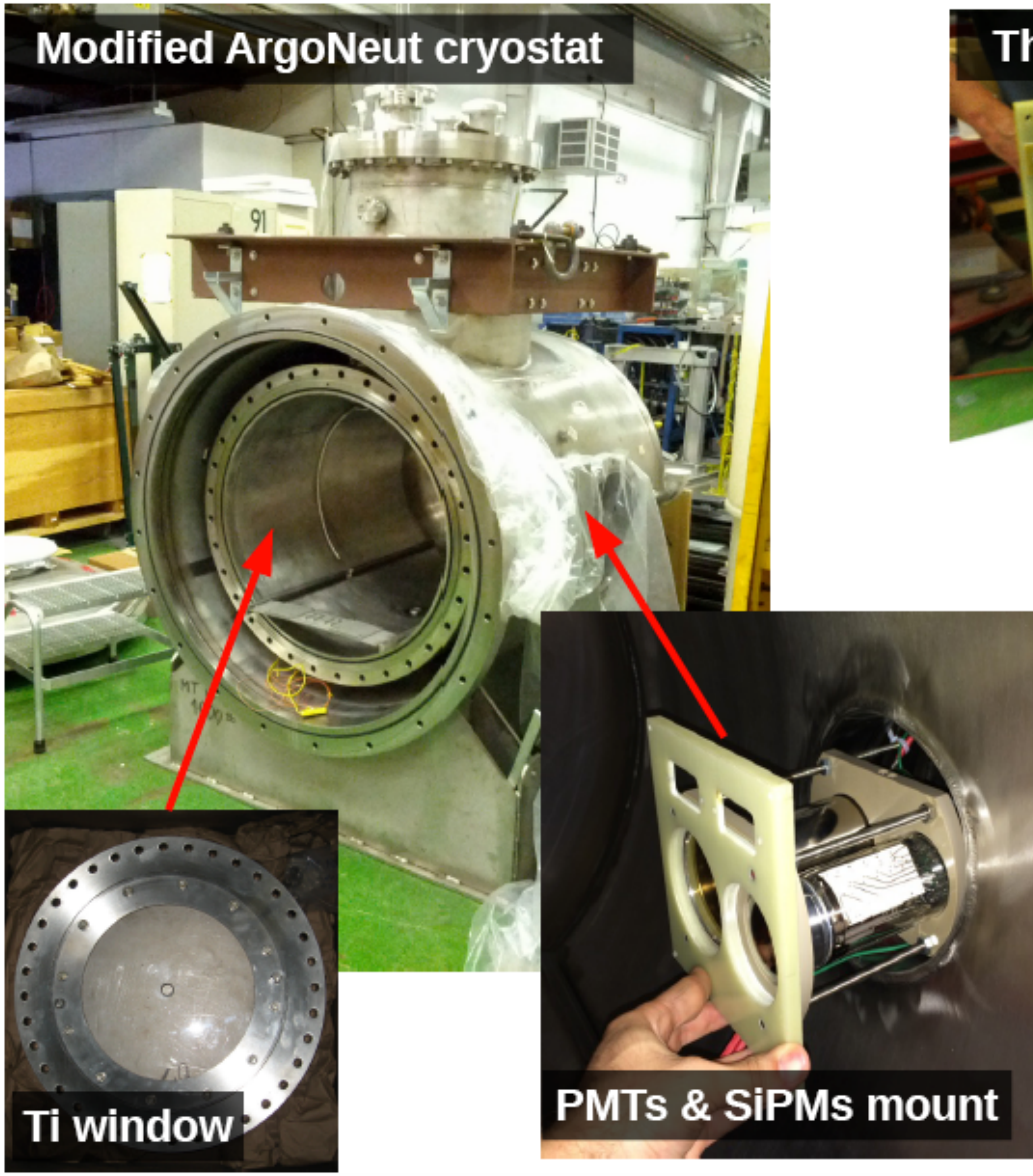


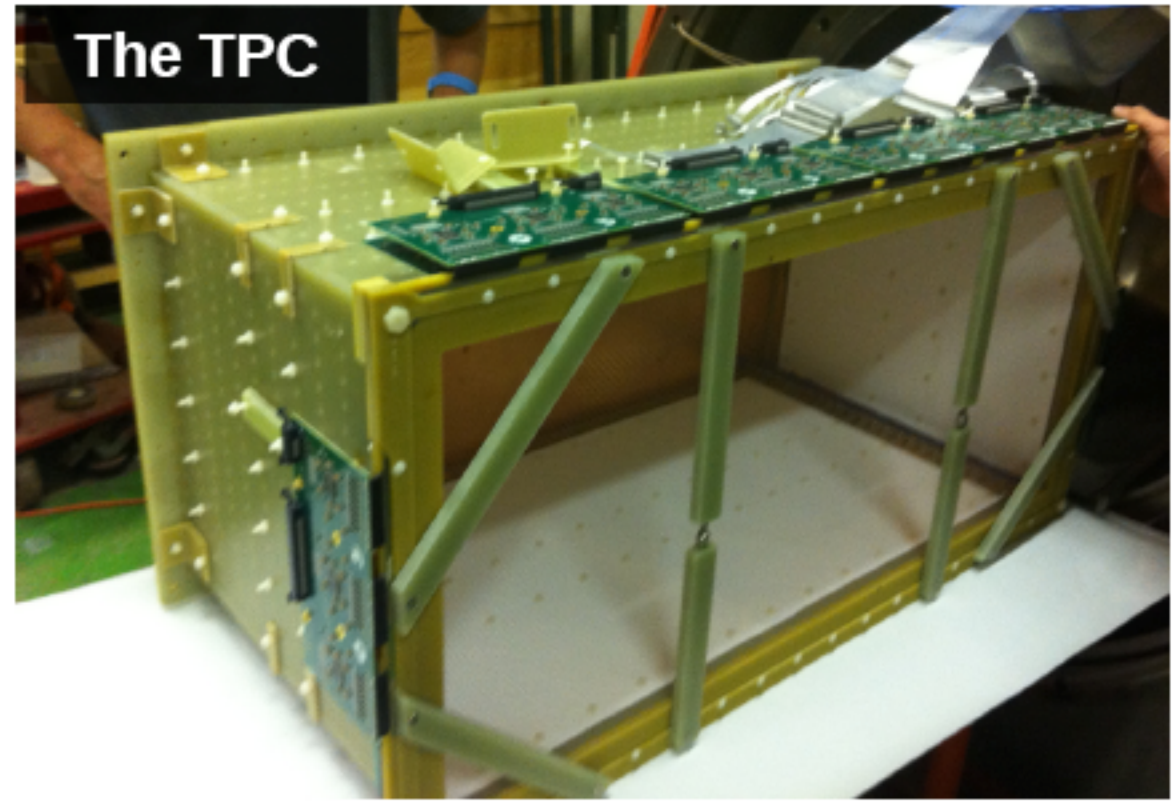
To enhance efficiency of light collection one has to increase the detector active surface.

This can be achieved by increasing the n. of PMTs (expensive) OR by adding a reflector coated by wl.s. on the boundary of the detector volume. Scintillation VUV photons thus are wl.shifted when hitting the TPB and then reflected from the mirror surface beneath multiple times up to collection at the PMT

Relate energy deposited into CHARGE AND LIGHT for an improved calorimetric energy resolution

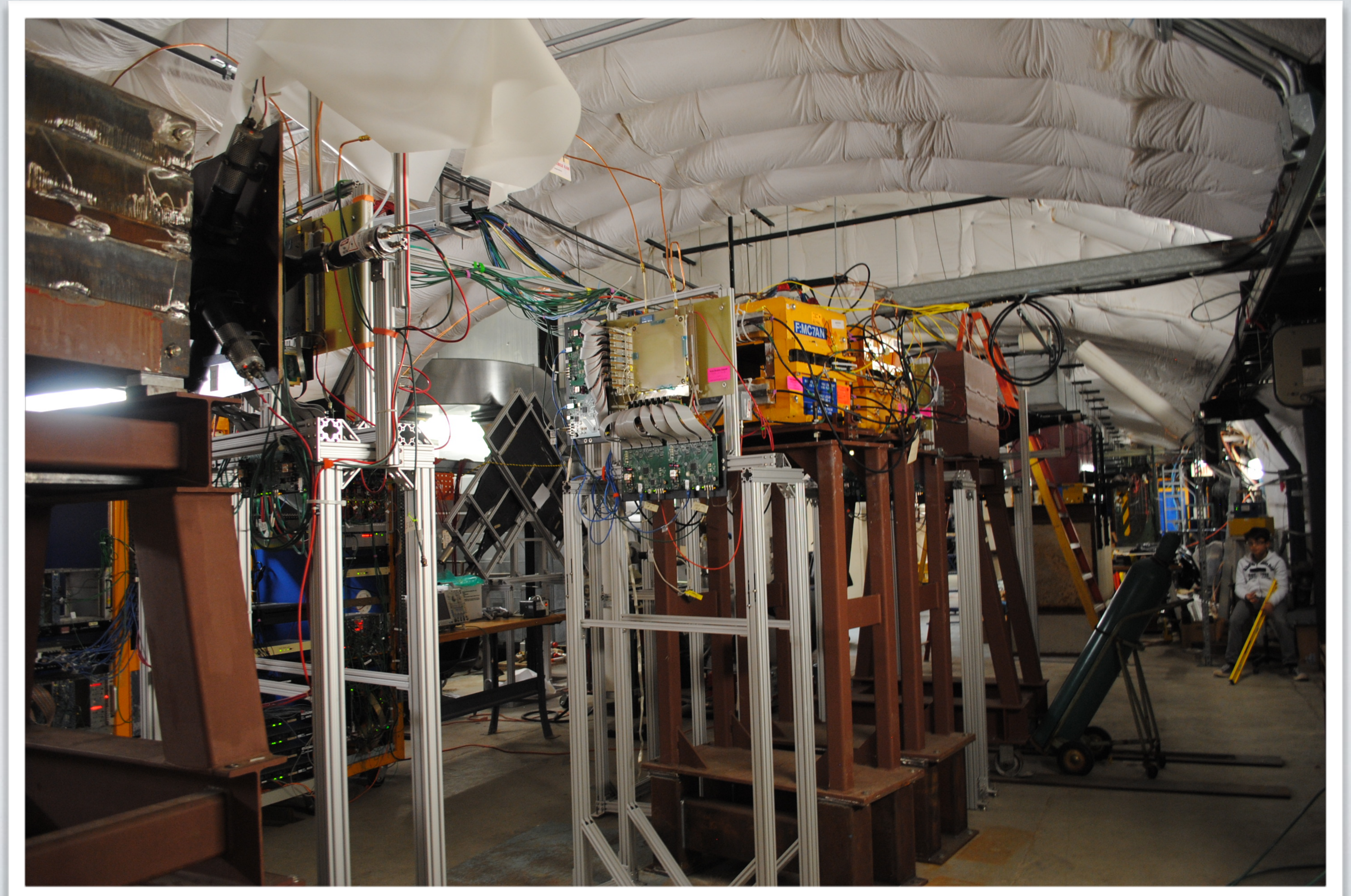
LArIAT TPC / cryostat





LArIAT cryostat sealed yesterday (Dec. 15)

…today moving the cryostat/TPC into the enclosure…



First Run (engineering run - completed, Sept. '14):

- Secondary Pion Beam Commissioned - June '14
- DAQ & Trigger Commissioned - July/Aug '14
- Tertiary Beam Commissioned - Aug./Sept. '14
- *Beam DATA (rate, momentum, mom. resolution, PID in excellent agreement w/ MC expectations)*

Beam shutdown (Sept.-Nov. '14)

- Cryo-System Delivery & Assembly
- LArTPC/Cold Electronics & Scintillation Light System Test

Second Run (starting asap):

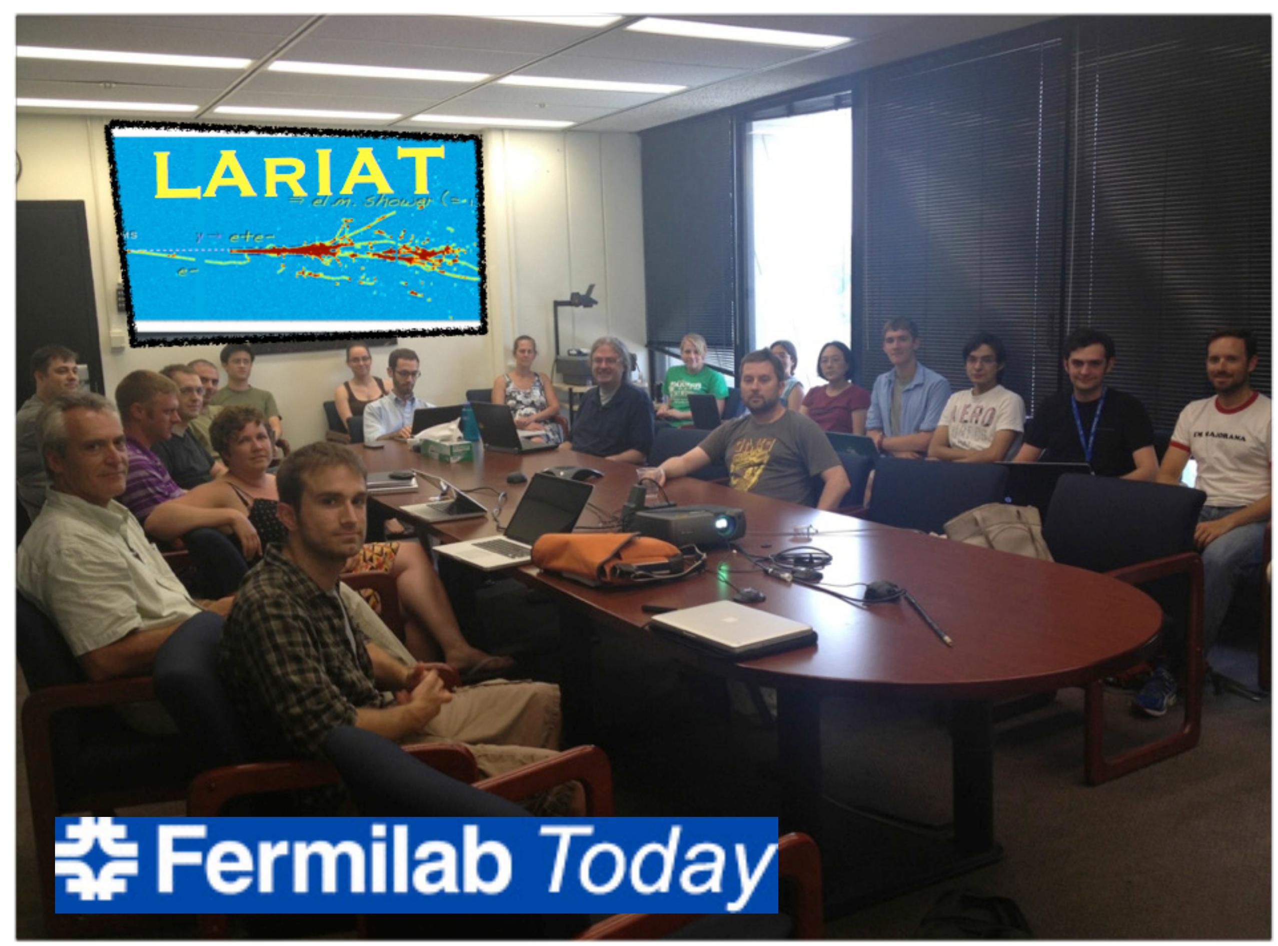
- *Installation in test-beam enclosure (ongoing now…)*
- Cryo-System Commissioning (LAr filling)
- LAr detectors (TPC, PMT & SiPM) Commissioning
- *Physics Run*

THE COLLABORATION

- **68 Collaborators**
- 3 US national labs
- 12 US universities
- 5 foreign institutions
- *and 20+ students in summer*

new groups are showing interest to join

Argonne	J. Paley
Boston U.	E. Kearns, D. Gastler and R. Linehan
Caltech	R. Patterson
Chicago	W. Foreman, J. Ho, D. Schmitz
Cincinnati	R. Johnson, J. St John
Fermilab	R. Acciarri, P. Adamson, M. Backfish, W. Badgett, B. Baller, A. Hahn, D. Jensen, H. Jostlein, T. Junk, M. Kirby, T. Kobilarcizk, P. Kryczynski, S. Lockwitz, H. Lippincot, A. Marchionni, K. Nishikawa, J. Raaf*, E. Ramberg, B. Rebel, M. Stancari, G. Zeller
Imperial Col. London	M. Wascko
KEK (joined in 2014)	T. Maruyama, E. Iwai, S. Kunori
Los Alamos	C. Mauger
Louisiana State	F. Blazsczyk, W. Metcalf, A. Olivier, M. Tzanov
Manchester	J. Evans, P. Guzowski
Michigan State	C. Bromberg, D. Edmunds, D. Shooltz
Minnesota – Duluth	R. Gran, A. Habig, K. Kaess
Pittsburgh (joined in 2014)	S. Dytman
Syracuse	J. Asaadi, M. Soderberg, J. Esquivel
Texas – Arlington	A. Farbin, S. Park, J. Yu
Texas – Austin	W. Flanagan, J. Huang, K. Lang
University Col. London	R. Nichol, A. Holin
William and Mary	M. Kordosky, M. Stephens, P. Vahle
Yale	F. Cavanna*, E. Church, B. Fleming, E. Gramellini, O. Palamara, A. Szelc

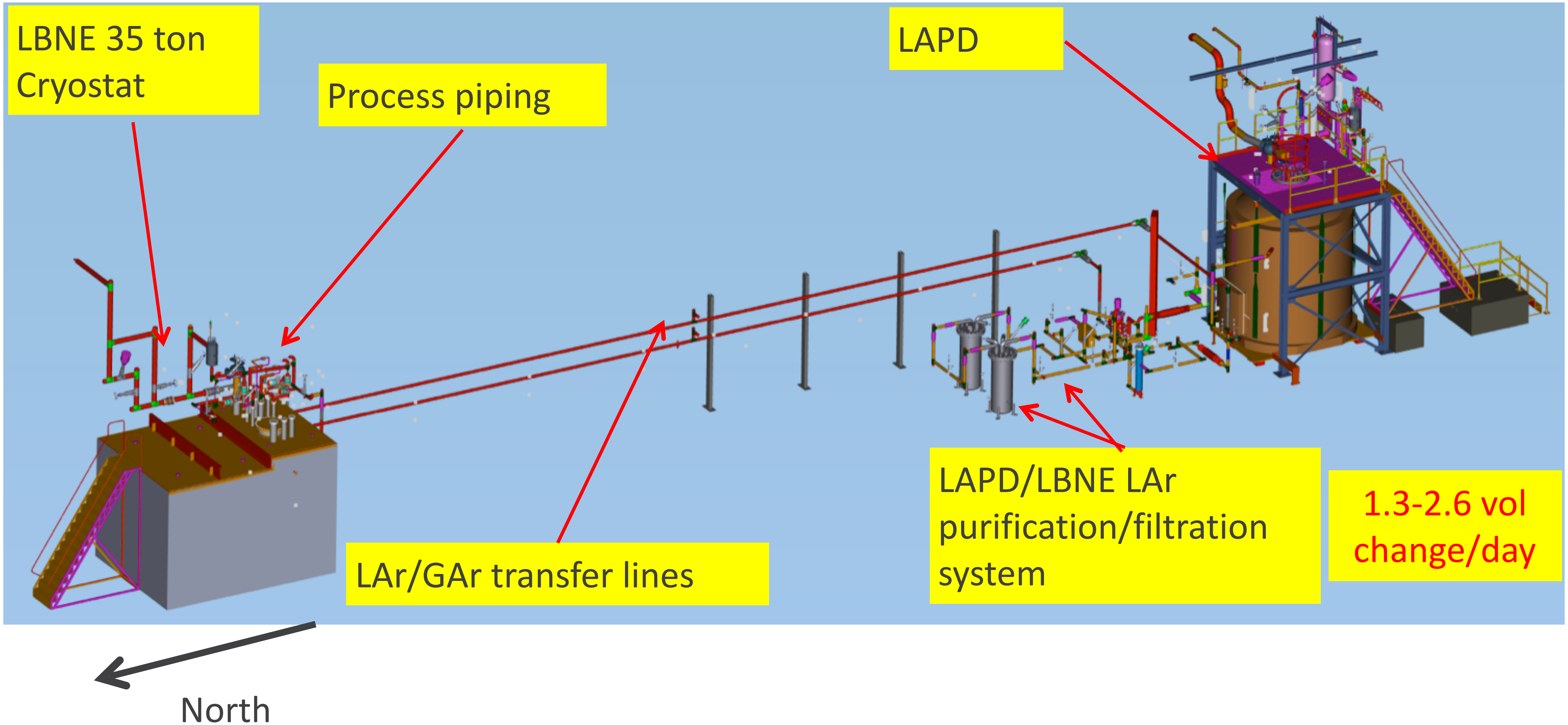


http://intensityfrontier.fnal.gov/lariat.html

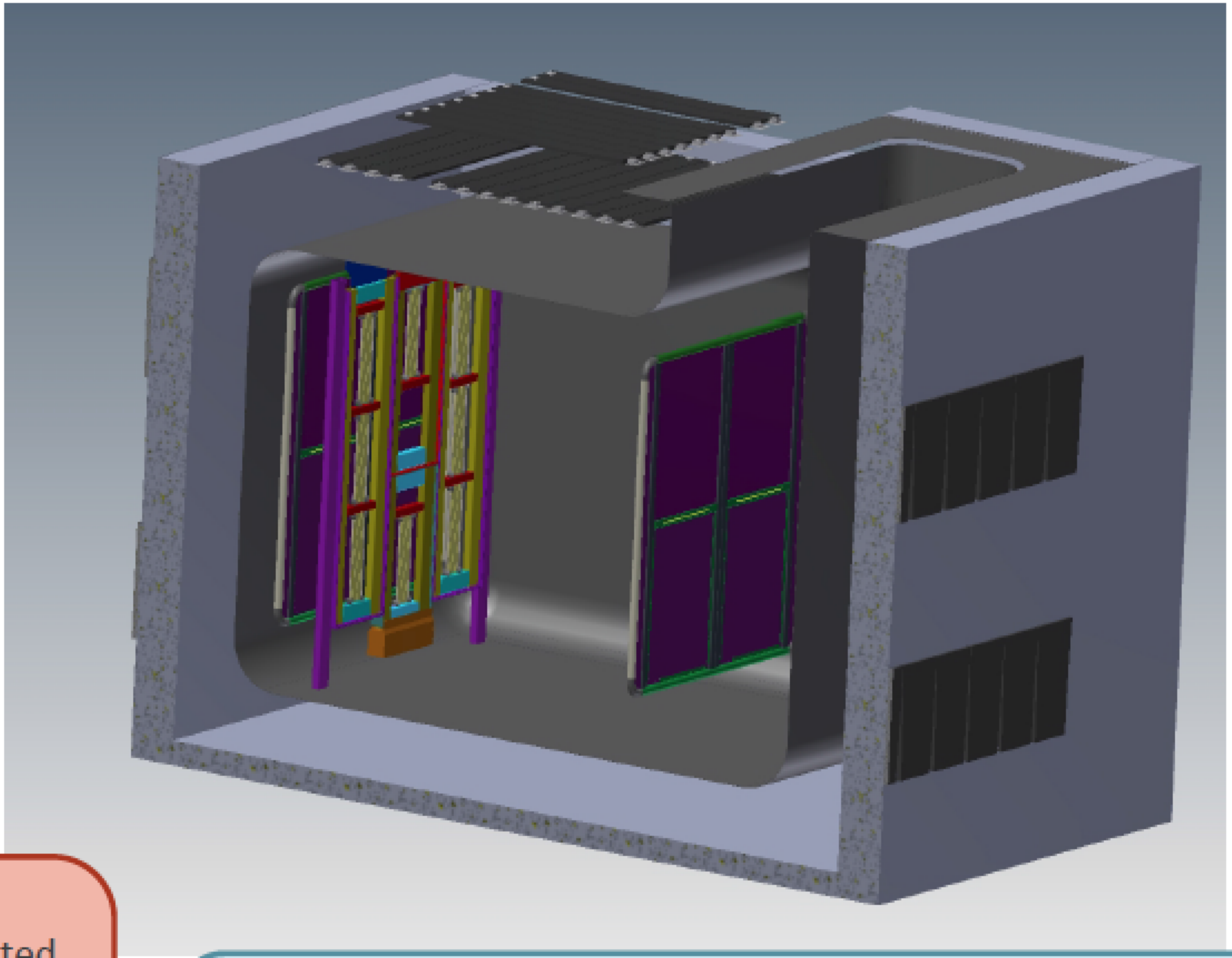
* elected spokespersons

The LBNE 35 ton Membrane Cryostat

Layout



LBNE 35-ton prototype (what makes it special)



Cryostat
Membrane cryostat technology from LNG industry

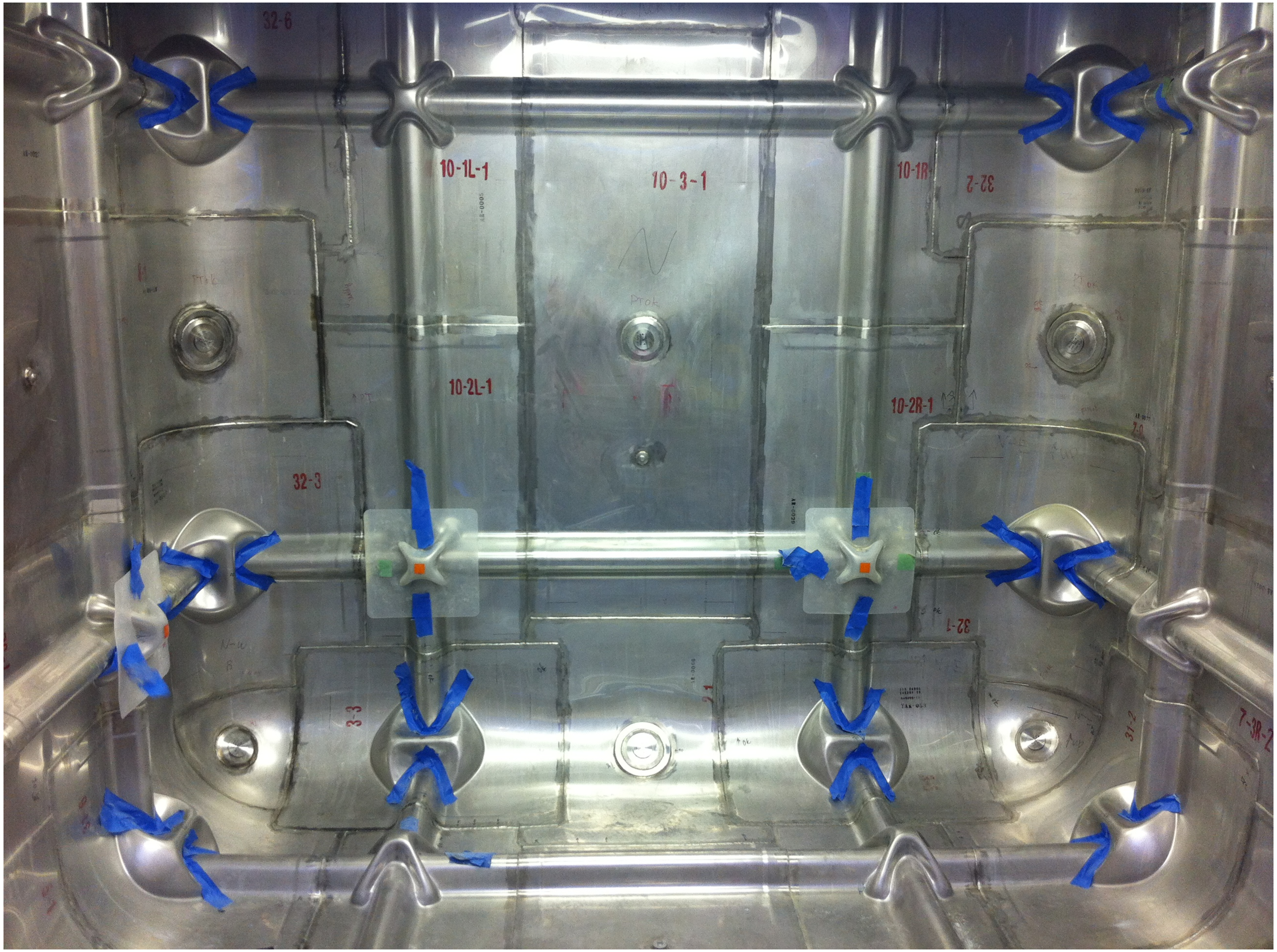
Cold Electronics
Amplify and digitize signals inside cryostat

DAQ
Continuous readout of TPC and Photon Detectors

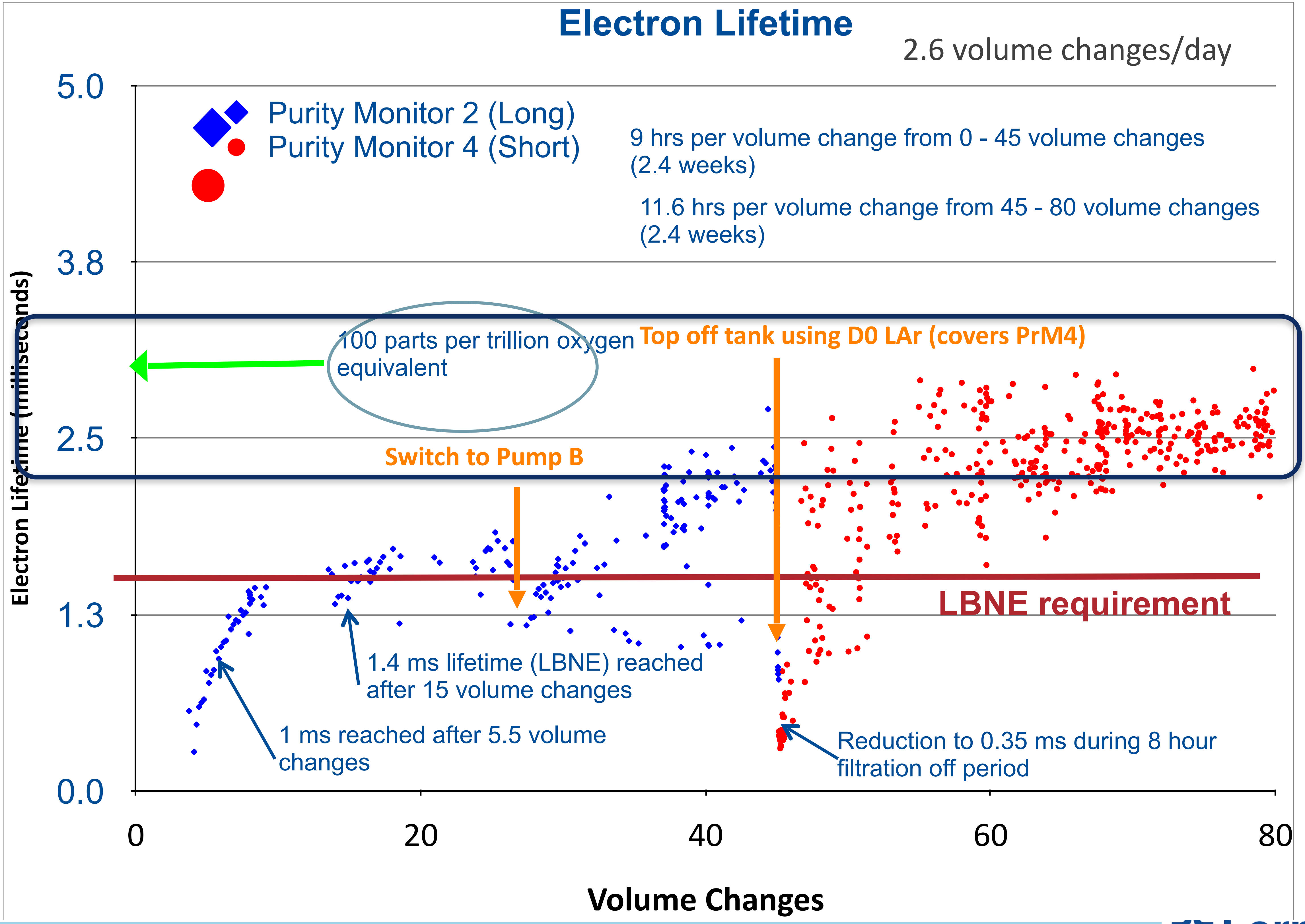
Photon Detectors
- TPB (wavelength shifter) coated light guides with SiPMs
- Absolute SiPM calibration being developed
- Simulation of light production and collection

TPC
- Cathode HV up to 200 kV, 2.2 m electron drift
- Wrapped wire planes (ambiguity associating induction plane hits to drift volume)
- 8 sets of wire planes, 8 drift volumes, 2 drift directions

Inside view



Purity



Electron Lifetime
2.6 volume changes/day
Purity Monitor 2 (Long)
Purity Monitor 4 (Short)
9 hrs per volume change from 0 - 45 volume changes (2.4 weeks)
11.6 hrs per volume change from 45 - 80 volume changes (2.4 weeks)
100 parts per trillion oxygen equivalent
Top off tank using D0 LAr (covers PrM4)
Switch to Pump B
LBNE requirement
1.4 ms lifetime (LBNE) reached after 15 volume changes
1 ms reached after 5.5 volume changes
Reduction to 0.35 ms during 8 hour filtration off period
Electron Lifetime (milliseconds)
5.0
3.8
2.5
1.3
0.0
0
20
40
60
80
Volume Changes

35ton Measurements – High priority

Detector sensitivity

- Measure S/N with MIPs (through-going muons)
- **Note:** S/N depends on electronics noise, wire length, wire spacing, drift field, purity, and ??? We have 3 different wire lengths

Tracking resolution

- Measure tracking performance for through going muons ***

Energy resolution

- Measure dE/dx vs residual range for muons (MIPs), electrons (Michel), protons? and compare with simulation ***

Time resolution

- Measure event time resolution of the photon detectors, using external scintillators as truth

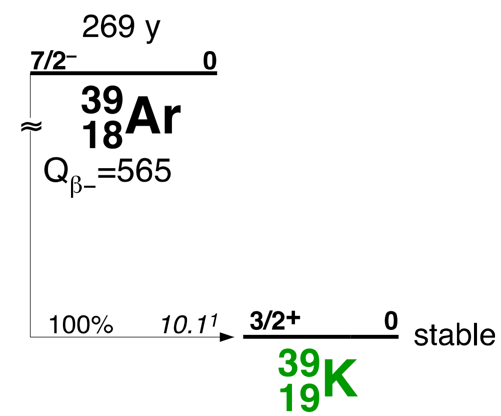
Characterize photon detectors

- Simulate light production and collection, tune to match data

*** with special attention to gaps between APAs and edge effects near field cage/APA

Low Radioactivity Underground Argon

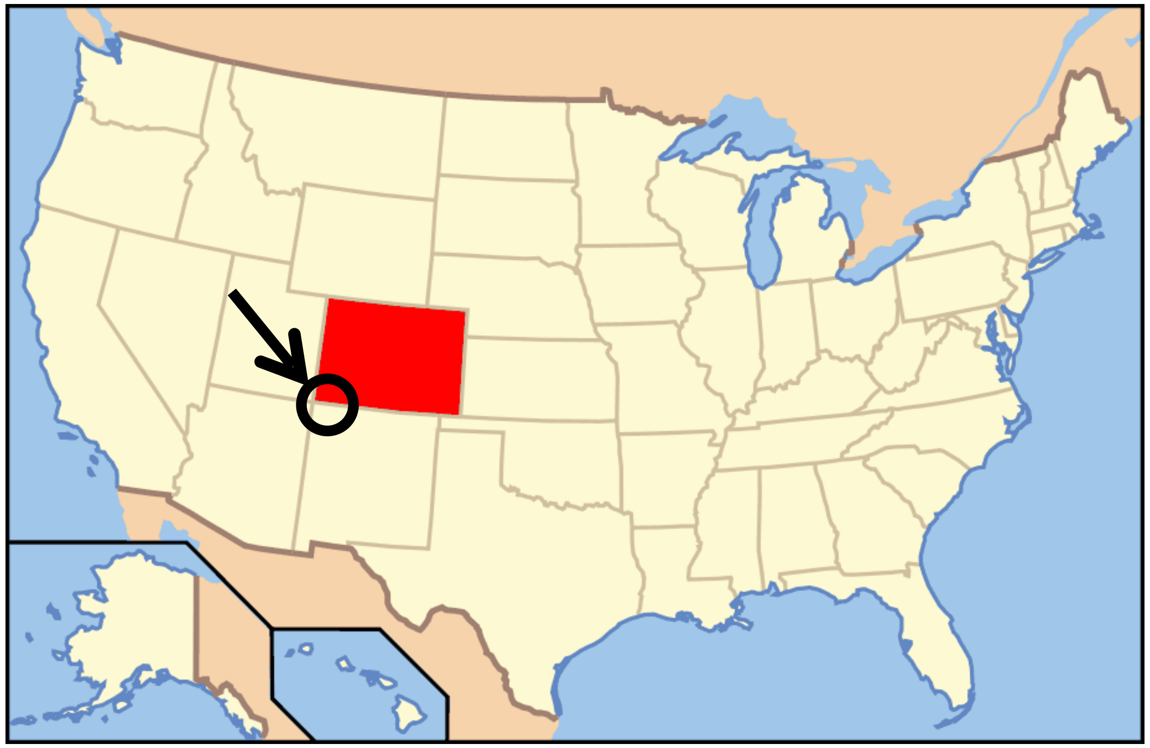
Atmospheric Argon Limit
for low level detectors
(e. g., Darkmatter detectors)



- Atmospheric Argon (AAr)
  - Contains beta emitter ^{39}Ar at a concentration of 8×10^{-16}
  - Radioactivity of AAr = 1 Bq/kg
- Underground Argon (UAr)
  - Concentration of ^{39}Ar is at least 150 times less than AAr
  - Radioactivity of UAr < 7mBq/kg

ref. (arXiv:1204.6011)

Low Radioactivity Underground Argon source in South Western Colorado



Carbon dioxide well used for oil industry

Purification of low-radioactivity argon from underground

Atmospheric argon ~ 1Bq/kg from ^{39}Ar;

This background limits the size of dual-phase Argon TPCs to < 1 tonne for dark matter searches because of pile up.

Ar (600 ppm) from certain CO_2 wells in Co has < 0.01 Bq/kg (arXiv:1204.6011) Mixture of ~4% Ar, ~5%N_2, ~90% He comes to Fermilab; have to distill the N_2 off.

Column has processed > 100 kg Ar

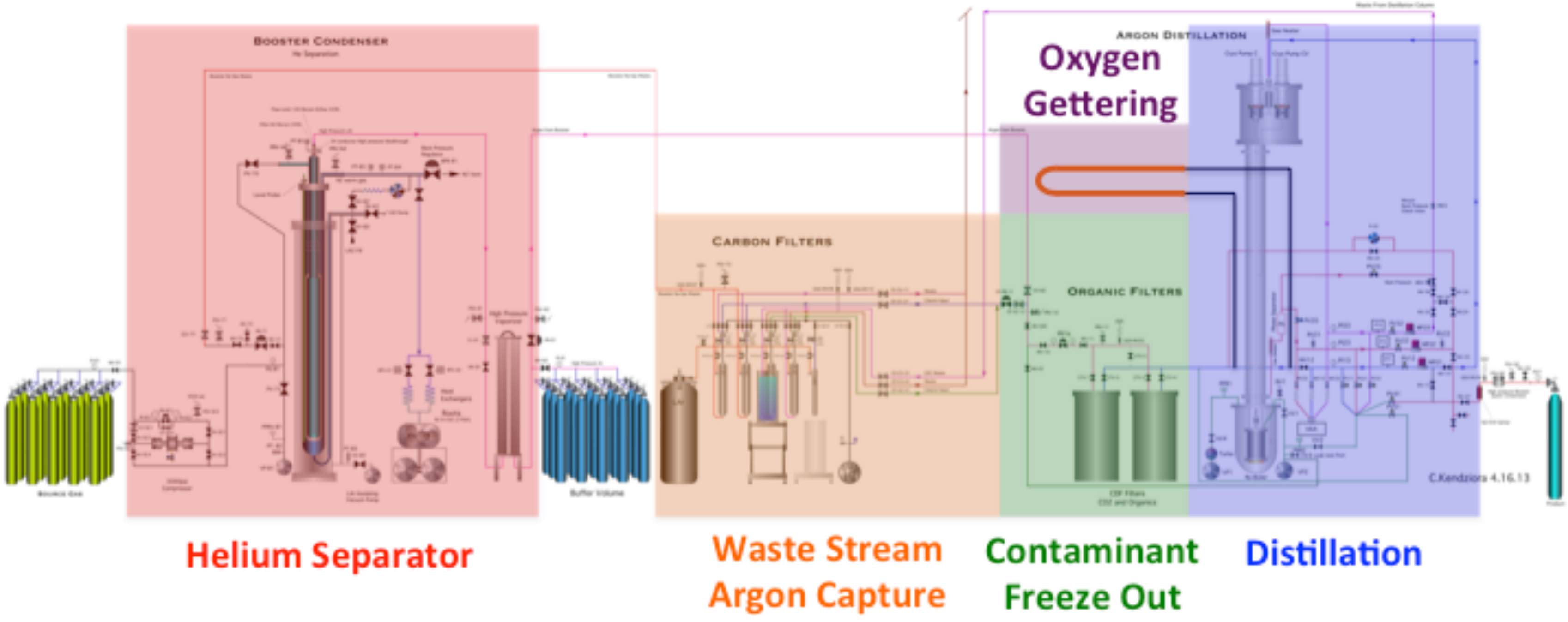
Aimed at DarkSide and DEAP programs

Getting to the UAr

Extracting Argon in Colorado

- Well gas is primarily CO_2 with 500 ppm argon contamination
- Extraction plant in Colorado produces crude gas mixture
  - 5% Argon
  - 5% Nitrogen
  - 90% Helium

Purification at Fermilab



- The Purification Process at Fermilab
  1. Separate Helium for Ar-N_2 mix
  2. Freeze out any residual contaminants (e.g., CO_2)
  3. Capture residual oxygen before entering distillation column
  4. Distillation Column separates N_2 and Ar
  - System also has argon recovery for residual argon in helium waste

The Success

Purified UAr mass – 145 kg

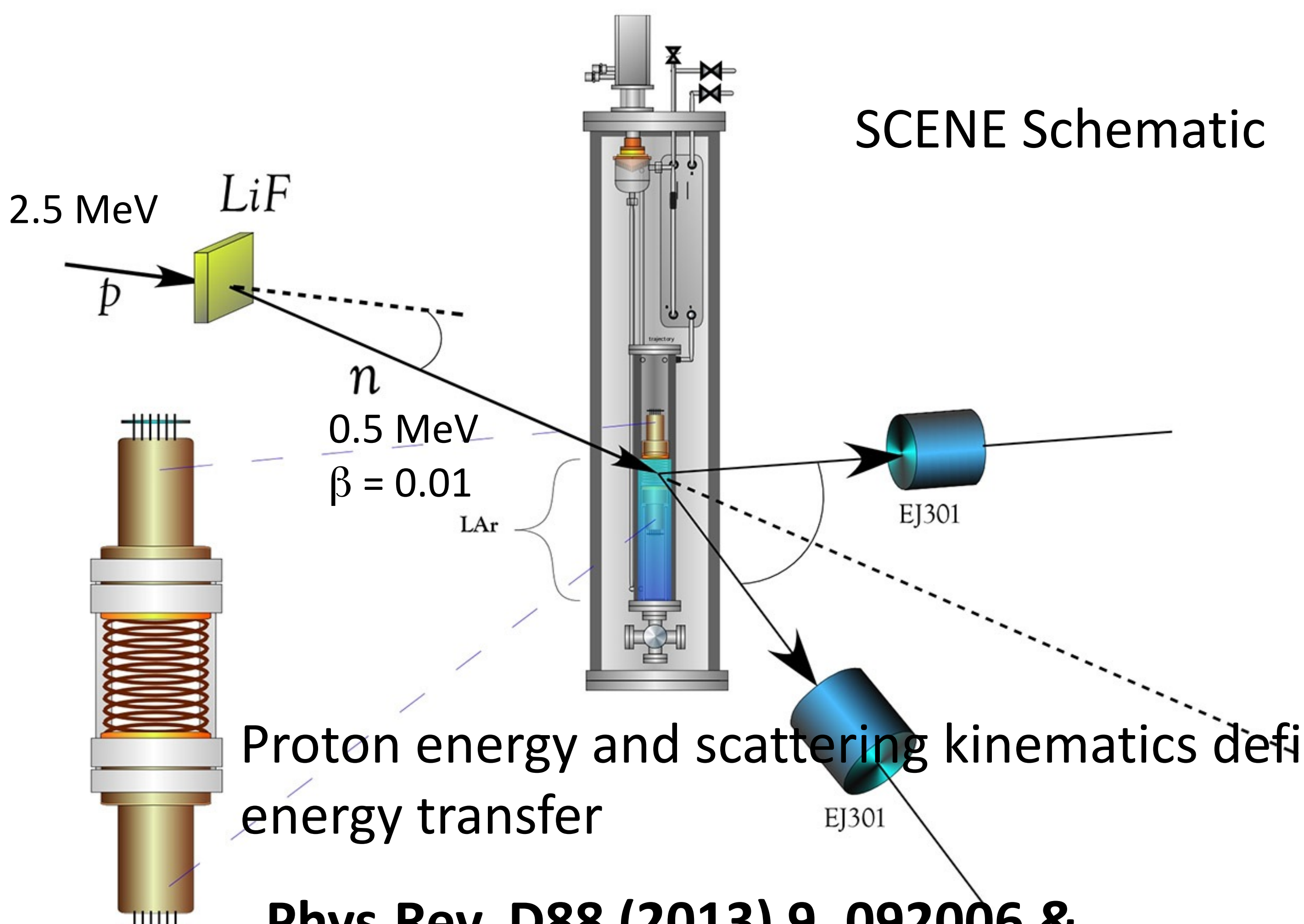
Required for Darkside-50 target – 160 kg

Expected completion Feb. 2015

SCENE – Scintillation Efficiency of Noble Elements

Precision measurement of light output of Argon nuclear recoils in a dual-phase LArTPC using monoenergetic, low energy, pulsed Neutron Beam at Notre Dame

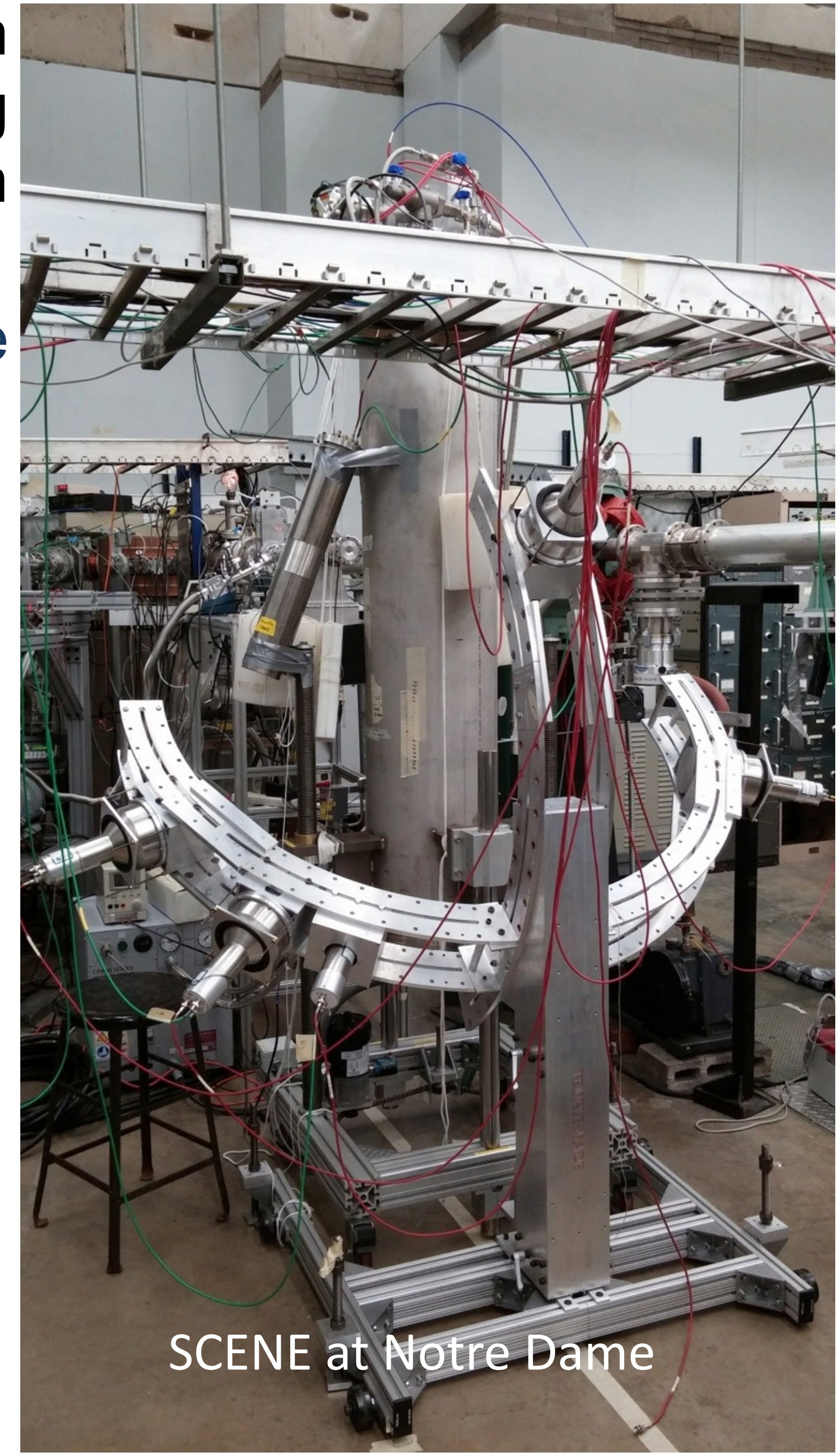
(Chicago, Fermilab, Princeton, Naples, Notre Dame, Temple, UCLA)



SCENE Schematic

Proton energy and scattering kinematics define energy transfer

Phys.Rev. D88 (2013) 9, 092006 & arXiv:1406.4825



SCENE at Notre Dame

The LArTPC R&D at FERMILAB - SUMMARY

Construction of LAr1-ND and run of LArIAT are the big items.

Test LBN TPC design with 35 t Prototype

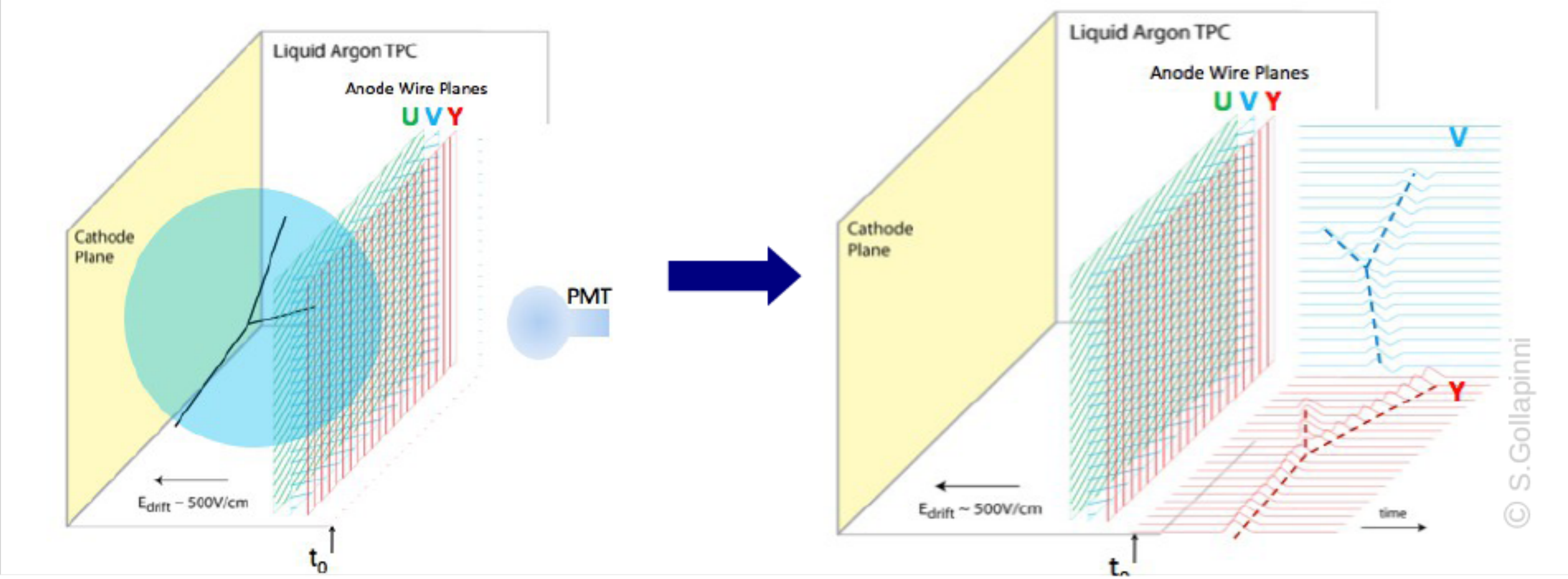
Integration of the HV cryostat on argon source at PAB

Argon Purification
HV studies
Light detection studies
Materials Tests
ScENE studies

Infrastructure wish-list:
Device to move radioactive sources up and down inside a cryostat
Material test stand to measure water outgassing rates from – 100 C to 0 C.
Lightweight under water (argon) camera

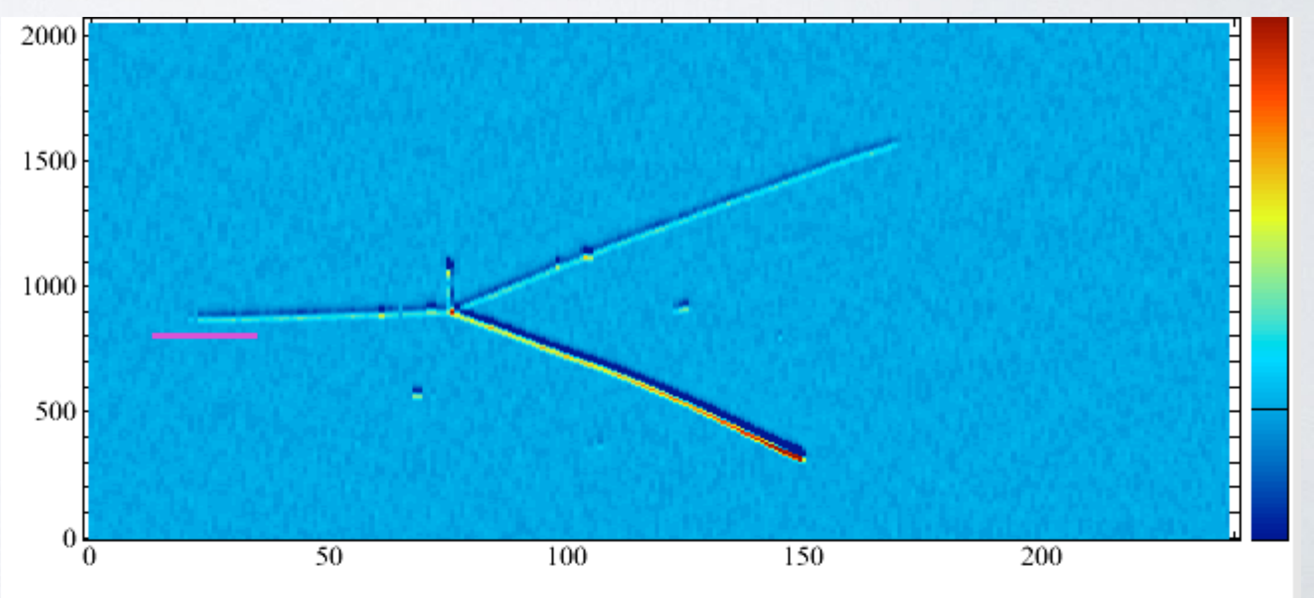
BACK-UP SLIDES

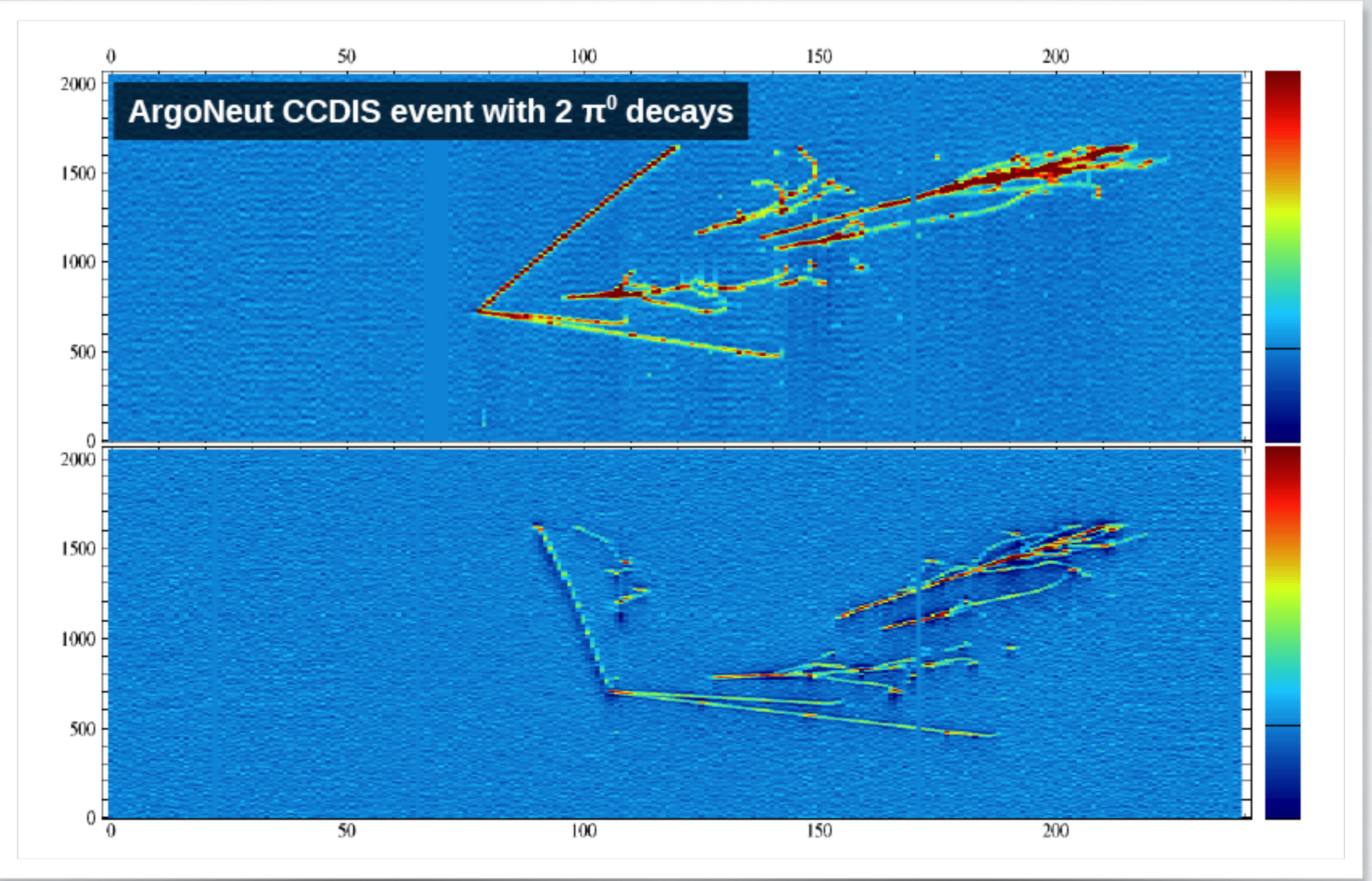
Time projection chambers



LAr-Time Projection Chambers allow multiple 2D and the 3D reconstruction of charged particles tracks.

- Charged particles crossing the detector ionize the liquid, producing free electrons that are drifted towards the readout wire-planes and produce digitized signals.
- The 3rd coordinate is determined from measuring the drift time. Scintillation light gives the reference t_0 time.
- The total charge is prop to the deposited Energy ⇒ calorimetry. (note: also scintillation light is prop to dep Energy)
- dE/dx along the track ⇒ PId





ν_e appearance background rejection
$\pi^0 \rightarrow$ photon / electron discrimination possible

ORIGIN OF THE CURRENT LARTPC TEST BEAM EFFORT (IN US)

Integrated Plan for LArTPC neutrino detectors in the US

Prepared for the FNAL Director's Review of LArTPC R&D Planning
LArTPC Planning Group, B. Baller and B. Fleming, Editors
November 18, 2009

1 LBNE and LAr Science and Project Goals

Experimental results from the last decade have revolutionized n
first conclusive evidence that neutrinos oscillate and have mass
ago. While this seminal discovery has answered many questions
even more. Particularly interesting is the question of CP Viol
neutrinos and anti-neutrinos oscillate at the same rate? The ans
neutrinos are the key to our matter dominated universe.

Long baseline neutrino oscillation searches are proposed
ences. Moreover, these experiments are the only ones that can si
unknown in the 3x3 neutrino mixing matrix, a CP violating ph
the neutrino mass eigenstates.

The US particle physics community is developing idea
baseline oscillation experiments beyond NOνA. To be sensitive to

most of the indicated LArR&D items in the list successfully accomplished in the meantime!!

In summary form, the plan consists of the following pre-existing components:

- The Materials Test Stand program, now in operation at Fermilab, addressing questions pertaining to maintenance of argon purity
- Exisiting electronics test stands at FNAL and BNL
- The Liquid Argon Purity Demonstrator (LAPD) now being assembled at Fermilab
- The ArgoNeuT prototype LArTPC, now running in the NuMI beam
- The MicroBooNE experiment, proposed as a physics experiment that will advance our understanding of the LArTPC technology, now completing its conceptual design phase.
- A software development effort that is well integrated across present and planned LArTPC detectors.

We are proposing to add to these efforts the following:

- A membrane cryostat mechanical prototype to evaluate and gain expertise with this technology.
- An installation and integration prototype, to understand issues pertaining to detector assembly, particularly in an underground environment.
- A $\sim$ 5% scale electronics systems test to understand system-wide issues as well as individual component reliability.
- A calibration test stand that would consist of a small TPC to be exposed to a test beam for calibration studies, relevant for evaluation of physics sensitivities.

and discussed again
at LBNE Integrated Plan – May 2010
and
at LBNE/LAr Working Group mtg
June 2/3 2011

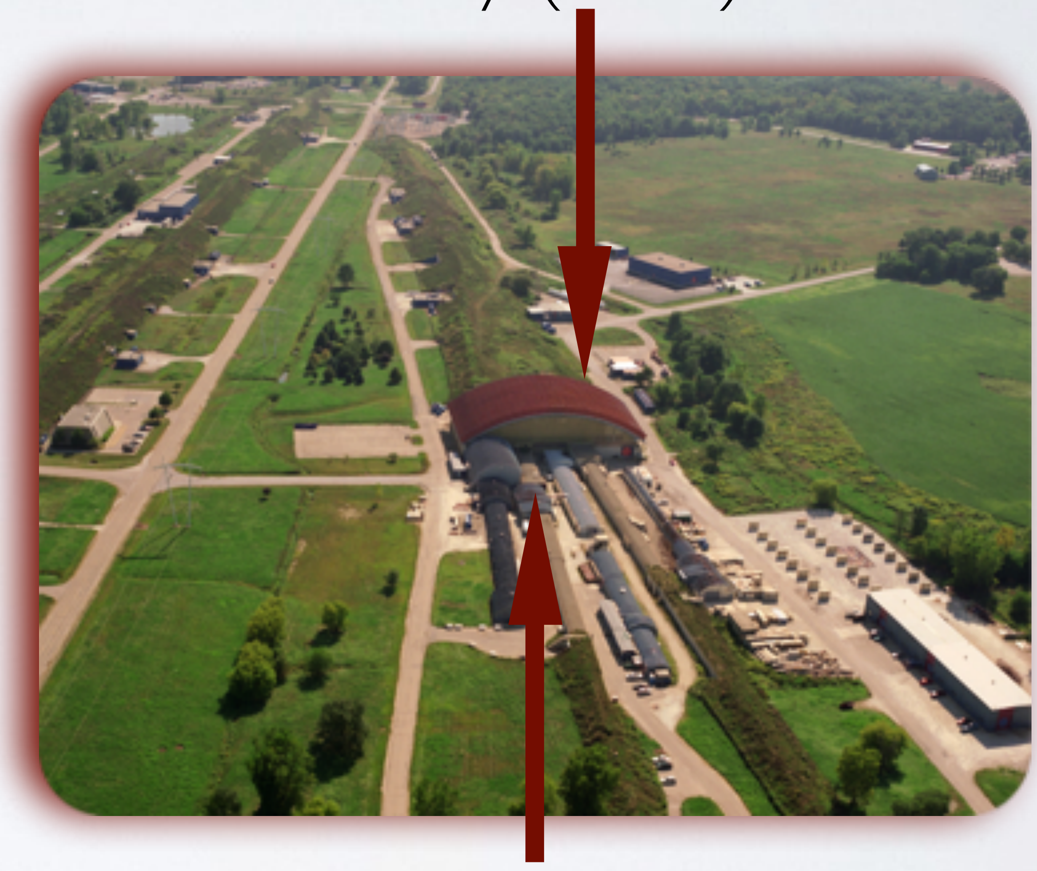
Feb. 2012 – formed LArIAT Collaboration

Data taking about to start

LArIAT: what, where, when, why

- LArIAT is a test beam experiment designed to measure details of the detector response to charged particles of known energy and type.
  - LArIAT is the first precision **charged particle** test beam with LAr TPC !

  (Only earlier LAr-TPC test beam was T32 at JPARC with coarser strip, single plane read-out)
- The experiment is being assembled at FNAL Test Beam Facility (FTBF).

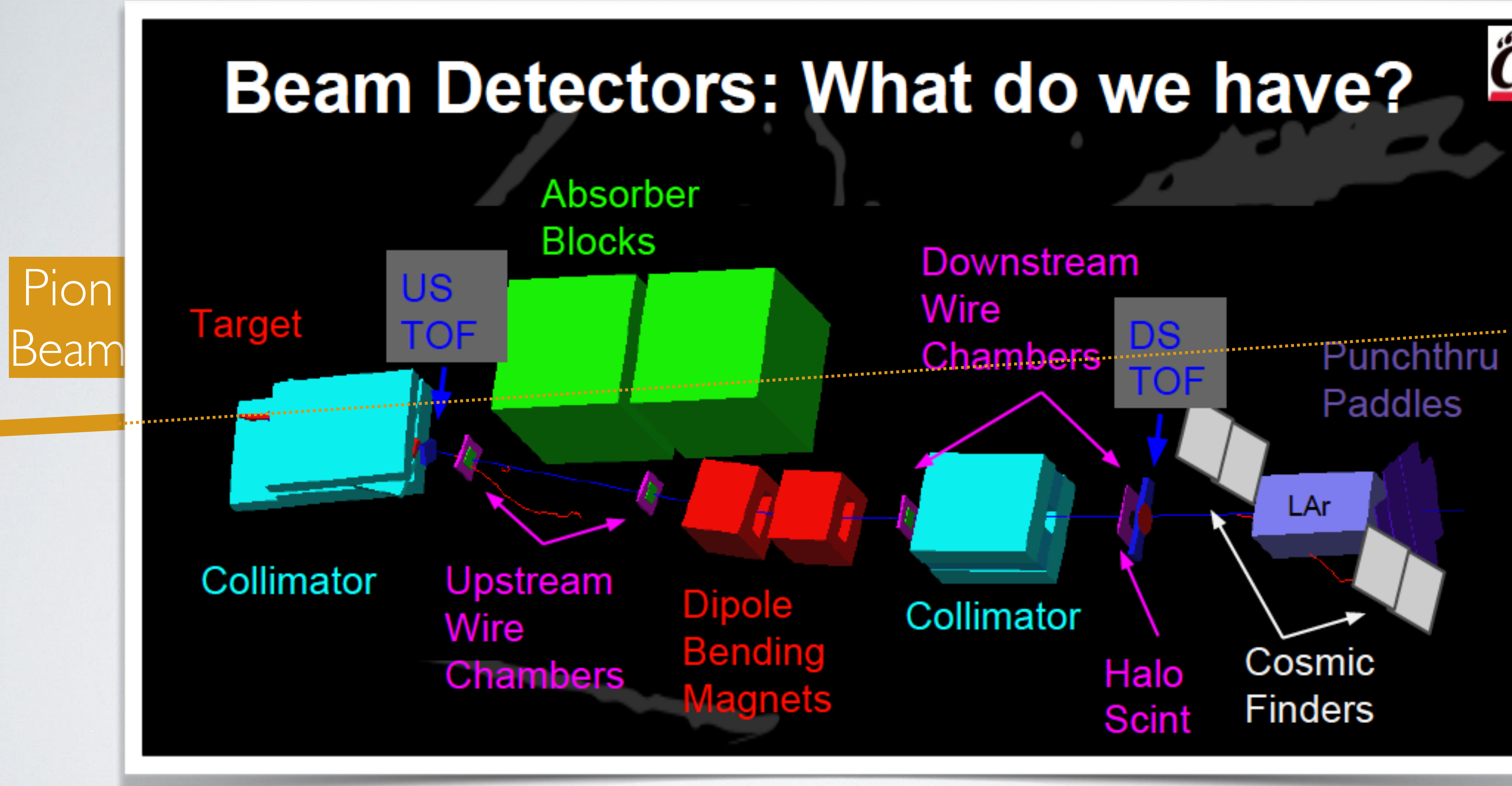


FROM THE RESUMED MCENTRAL BEAM-LINE AT FTBF, A DEDICATED TERTIARY BEAM LINE HAS BEEN DESIGNED, INSTALLED AND IS NOW READY TO OPERATE

- The experiment is foreseen as taking place in several phases
  - *Phase I* renovate the ArgoNeuT cryostat&TPC and add a new cryogenics system, new cold electronics, new scintillation light read-out and new DAQ.
  - *Phase II* will re-use the cryogenics system and add a new cryostat&TPC. ***New innovative solutions are being considered.***
- *Phase I* should take data soon (Run 2014-15)
- *Phase II* could take data starting in ≥ 2016

The LArIAT Beam Line and Detectors

(shown by J. St.John-Cincinnati, LArIAT Run Coordinator)



from Box Schematic to Real Hardware

The LArIAT Beam Line: data collected during summer '14 Run

Beam Detectors : What do we get?

In trigger:

- "good" track along beam path (WC's, $\overline{\text{Halo}}$)
- timing measurement (TOF)
- cosmic near TPC diagonal (cosmic finders)

In data, trigger info plus:

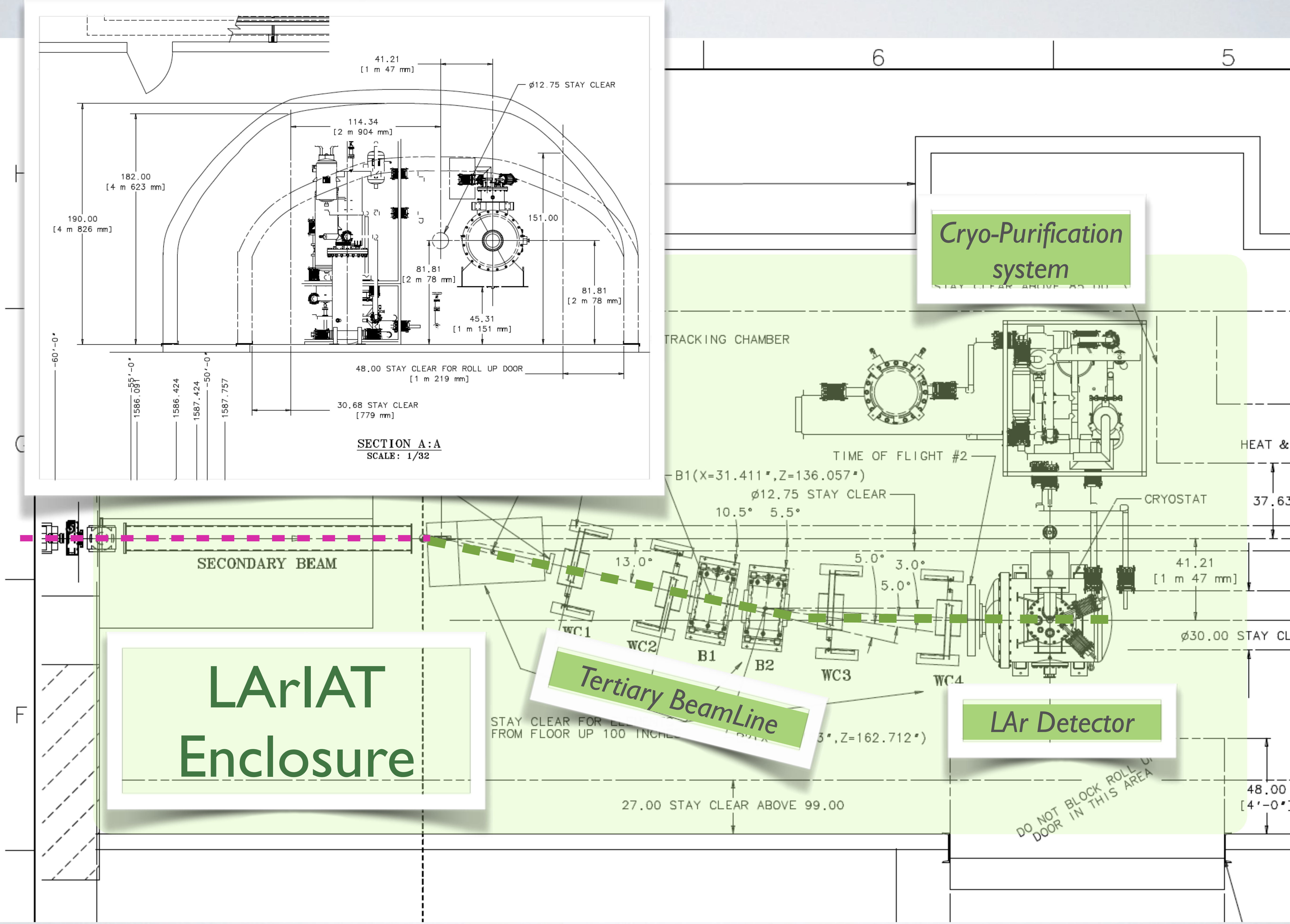
- track momentum (WC's)
- track position (WC's)
- particle beta (TOF)
- track punches through (...punchthrough)

track momentum (WC's) + particle beta (TOF) → Mass estimate → PID

coming soon:

e, μ, π ID by a pair of threshold aerogel Cherenkov counters (n=1.05 & n=1.11)

μ ID by a downstream Iron/Scint muon stack ranger



41.21
[1 m 47 mm]
ø12.75 STAY CLEAR
114.34
[2 m 904 mm]
182.00
[4 m 623 mm]
190.00
[4 m 826 mm]
151.00
81.81
[2 m 78 mm]
81.81
[2 m 78 mm]
45.31
[1 m 151 mm]
48.00 STAY CLEAR FOR ROLL UP DOOR
[1 m 219 mm]
30.68 STAY CLEAR
[779 mm]
SECTION A:A
SCALE: 1/32
6
5
Cryo-Purification system
TRACKING CHAMBER
TIME OF FLIGHT #2
HEAT &
B1(X=31.411",Z=136.057")
ø12.75 STAY CLEAR
CRYOSTAT
37.63
10.5° 5.5°
13.0°
5.0° 3.0°
5.0°
41.21
[1 m 47 mm]
ø30.00 STAY CL
SECONDARY BEAM
WC1
WC2
B1
B2
WC3
WC4
LArIAT Enclosure
Tertiary BeamLine
LAr Detector
27.00 STAY CLEAR ABOVE 99.00
48.00

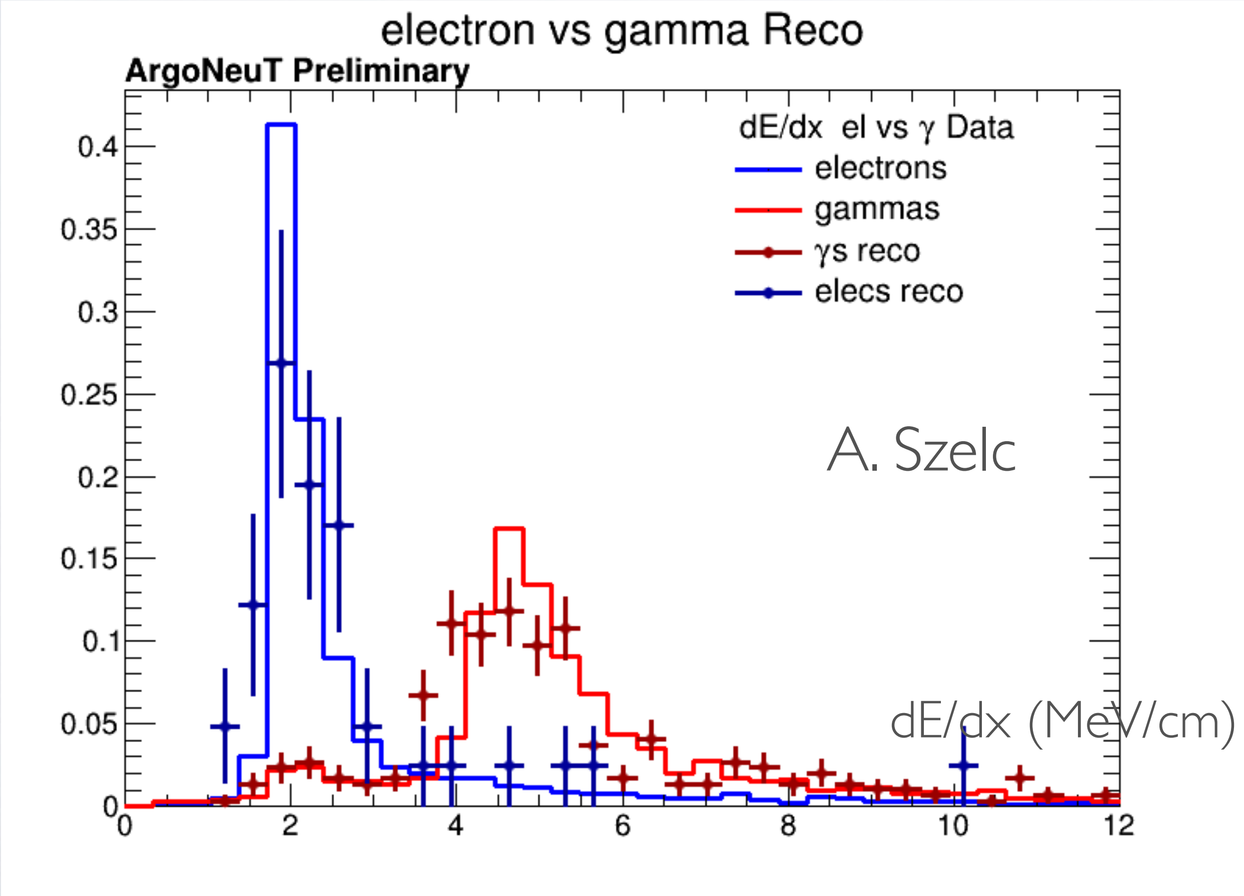
→ experimentally measure separation efficiency and sample purity for

e-induced vs. γ-induced showers

→ tune Monte Carlo simulation

→ develop / optimize algorithms

- Study of the *MiniBooNE* low-energy excess *(MicroBooNE goal)*
- Support measurement of the CP violating phase from oscillation into electron (anti)neutrinos *(LBN goal)*



high stat test beam data

will come soon

μ^- Capture

A meso-atom is formed after muon slows down in the target;
in this case, the muon relaxes to the *1s* state, emitting a cascade of meso-X-ray photons (μX).

A muon located in the *1s* state may undergo two alternative processes:

- **decay** with the partial lifetime τ_d = 2197.03 ns into an electron and muon neutrino or
- **be captured** by the nucleus τ_c = 570 ns:

$$(Z, A) + \mu^- \rightarrow (Z-1, A) + \nu_\mu$$

When a muon is captured, an excited daughter nucleus is formed. It will relax in different ways:

- electromagnetic transitions (if the excitation energy is less than about 6MeV) or
- emission of one or several nucleons

Ar

	Isotopes	Isotopic yield per stopped muon, %
$^{40}Ar + \mu^- \rightarrow {}^{40}Cl + \nu$	^{40}Cl	7.12 ± 0.17
$^{40}Ar + \mu^- \rightarrow {}^{39}Cl + n + \nu$	^{39}Cl	48.7 ± 1.38
$^{40}Ar + \mu^- \rightarrow {}^{38}Cl + 2n + \nu$	^{38m}Cl	1.6 ± 0.1
	^{38}Cl	15.45 ± 0.9
$^{40}Ar + \mu^- \rightarrow {}^{39}S + p + \nu$	^{39}S	0.22 ± 0.10
$^{40}Ar + \mu^- \rightarrow {}^{38}S + d + \nu$	^{38}S	<1.2

μ^-capture: ***Sum = 74 %***

μ^- decay: **26 %**

μAr* → μAr + Xray (626 KeV)

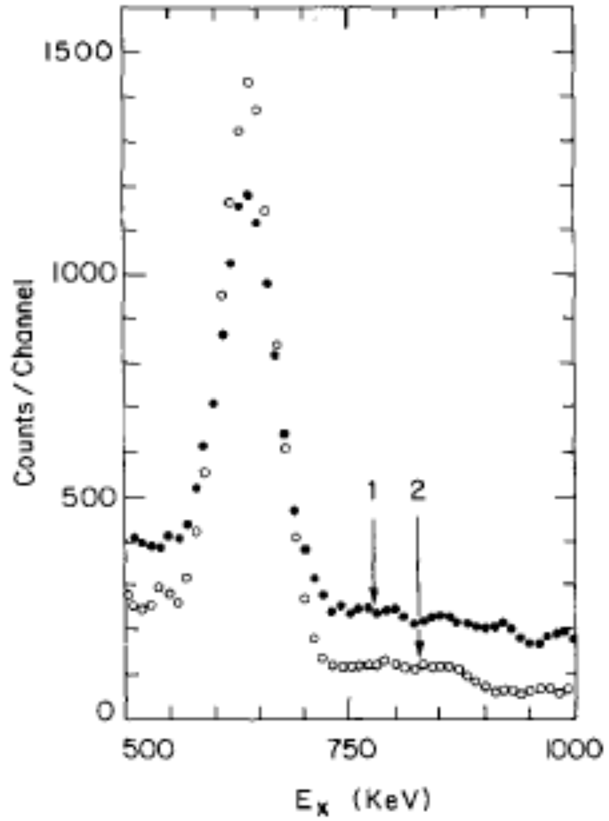
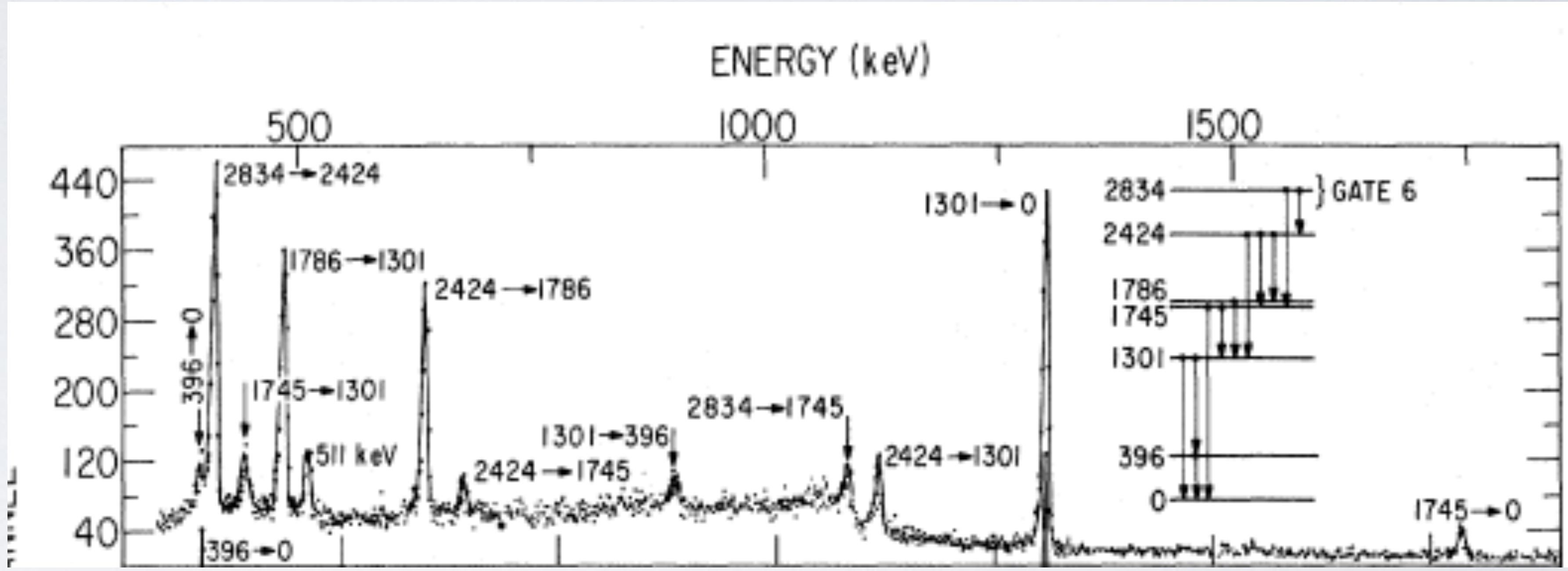
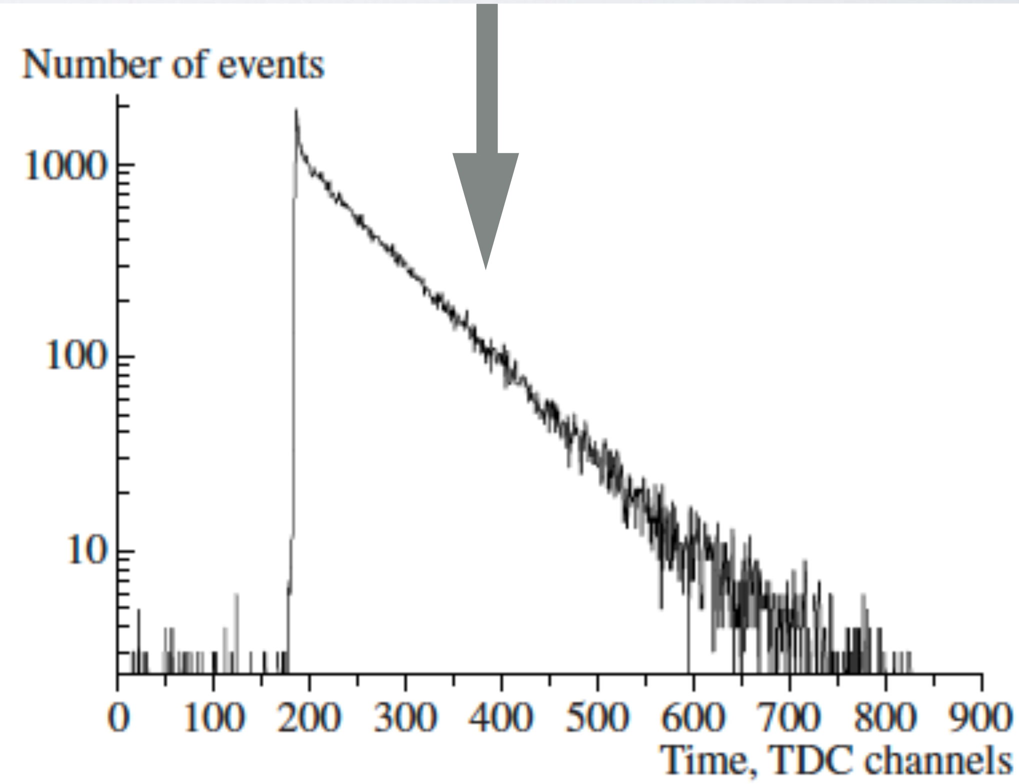


Fig. 2. Energy spectrum of the μAr prompt X-rays. 1:3 abs atm; 2:6 abs atm runs.

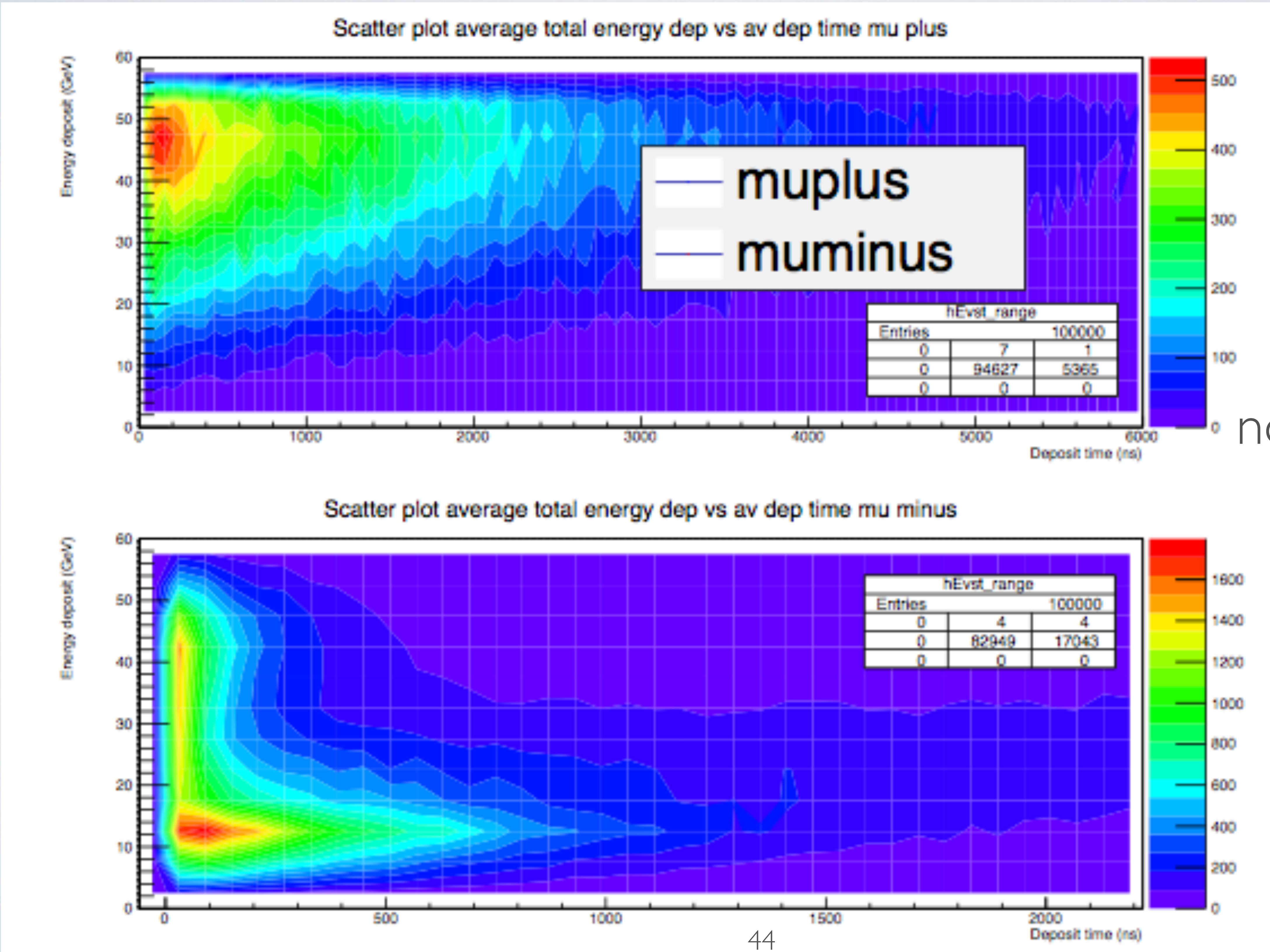


^{39}Cl* lines



Time evolution of 1301-keV γ lines.

by I. Nutini, INFN Summer Student at FNAL (and H. Wenzel, G4 Team at FNAL)



note different hor. scale

Charged π's in LAr in the [100 - 500] MeV range

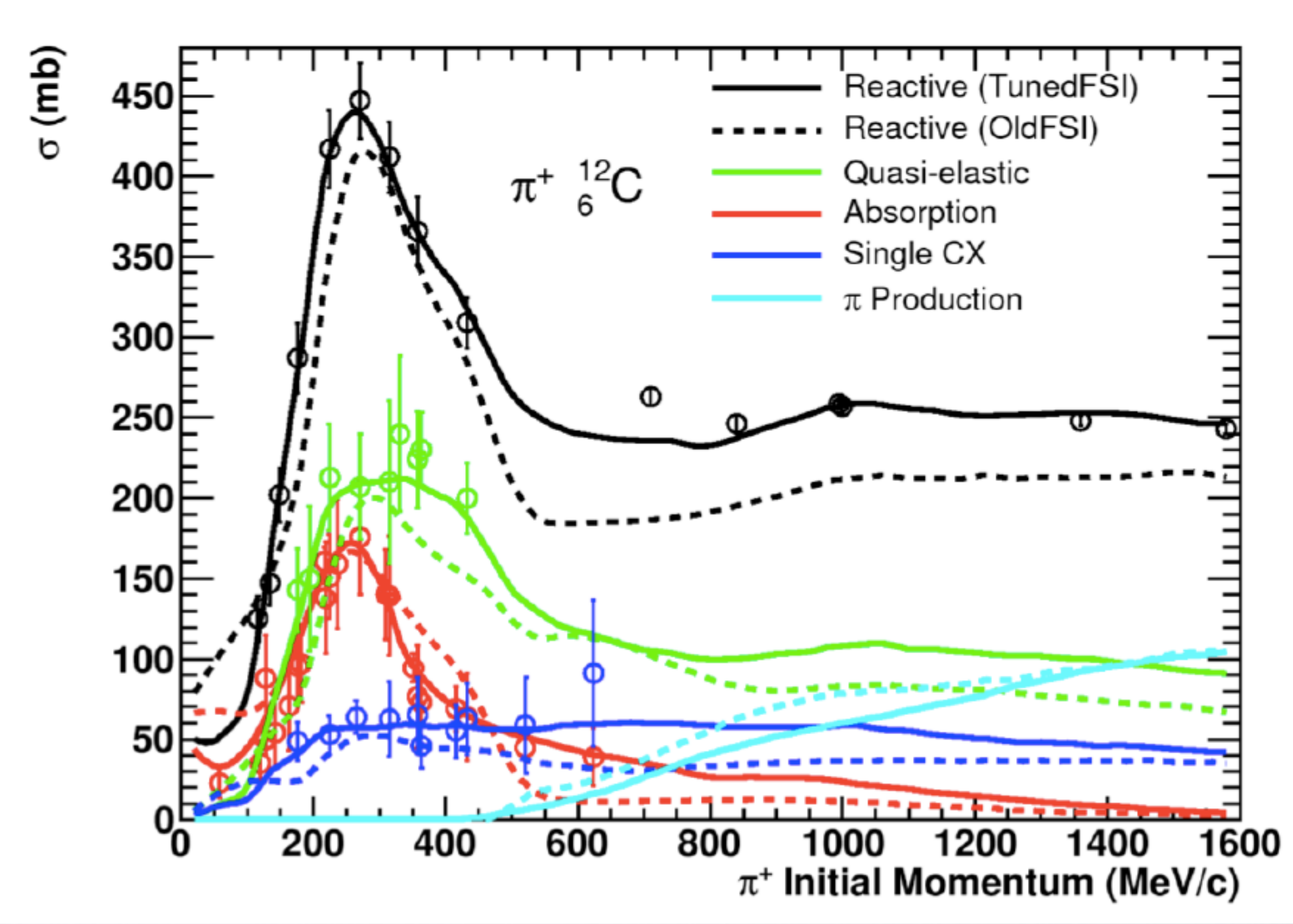
In the intermediate energy range (100-500 MeV) the pion interaction is dominated by the strong Δ resonance (Δ resonance peaks for pion kinetic energy of ~200 MeV).

Pion-Nucleus interaction has four main components:

- Elastic Scattering: nucleus left in ground state
- Inelastic Scattering: nucleus excited/nucleon knock-out
- Absorption: no pion in the final state
- Charge Exchange: $\pi^{\pm} \rightarrow \pi^{0}$

☆ π-production *(above 500 MeV)*

All processes (below 500 MeV) are dominated by Δ excitation



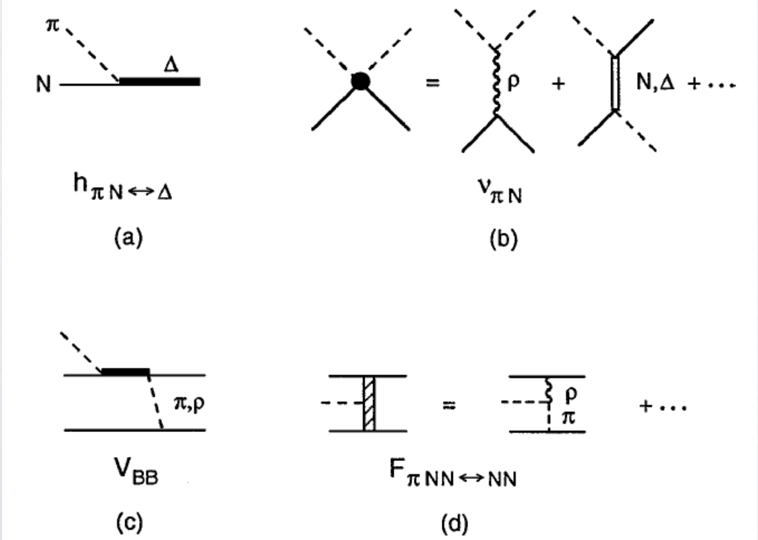
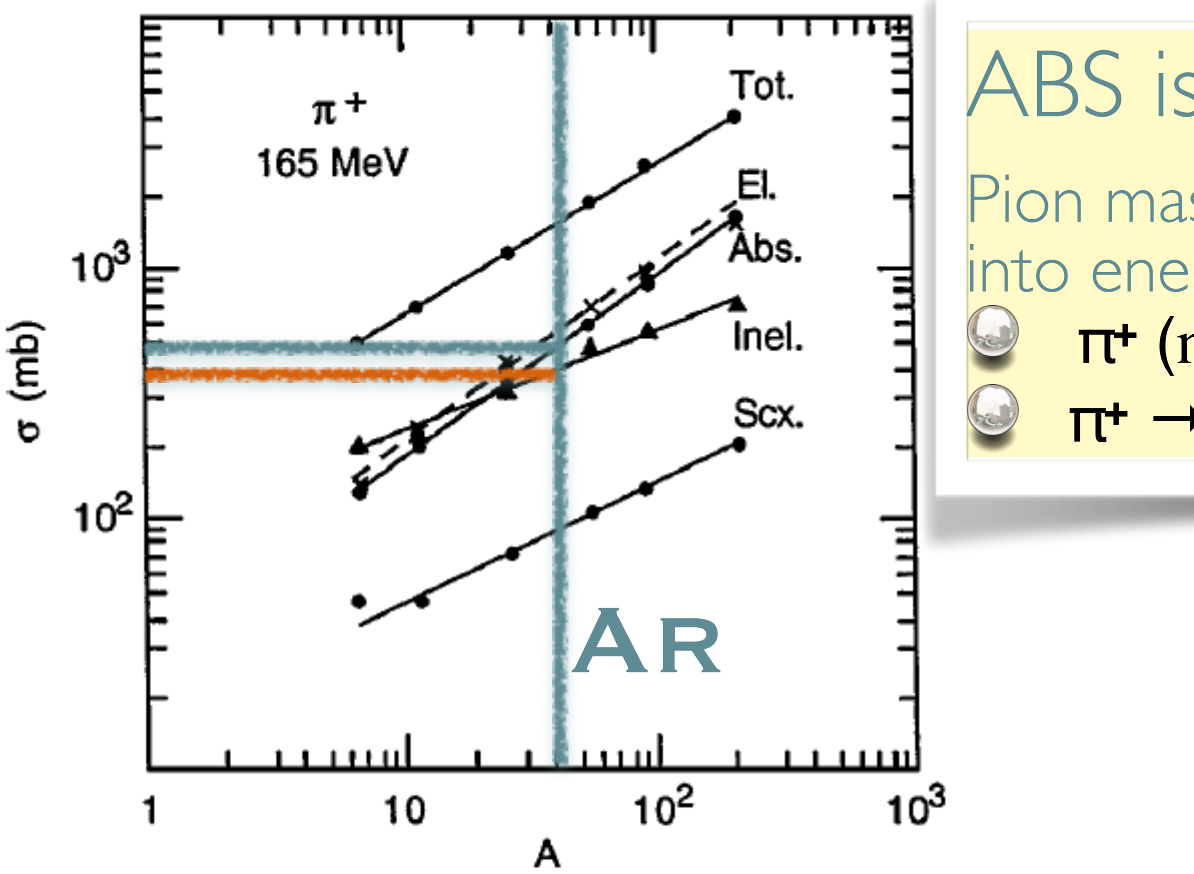


Figure 4 Graphical representations of some basic mechanisms of pion-nucleus interactions.



Nuclear mass (A)–dependence of pion-nucleus interaction cross sections

ABS is the dominant process in Ar (0.5 b !!)

Pion mass and kinetic energy mainly goes into energetic nucleons:

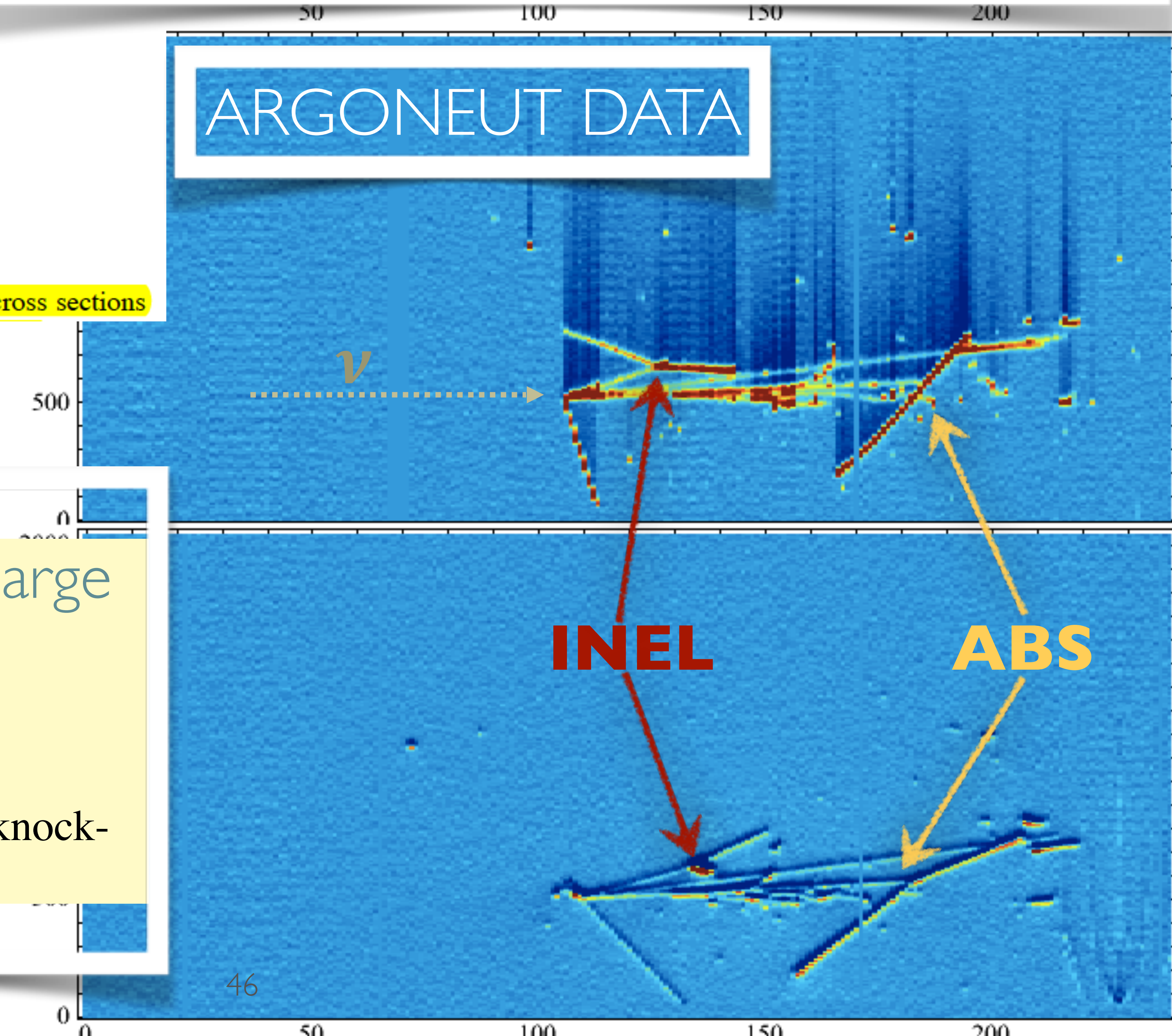
- π^+ (np) → pp or π^- (np) → nn (QDA 2-body reaction)
- π^+ → ppn or π^- → nnp (3-body reactions)

Charged π's in LAr

INEL Xsect is also very large in Ar (0.4 b !!)

typical reaction:

- π^+ p → Δ^{++} → π^+ p (with p knock-out in final state)

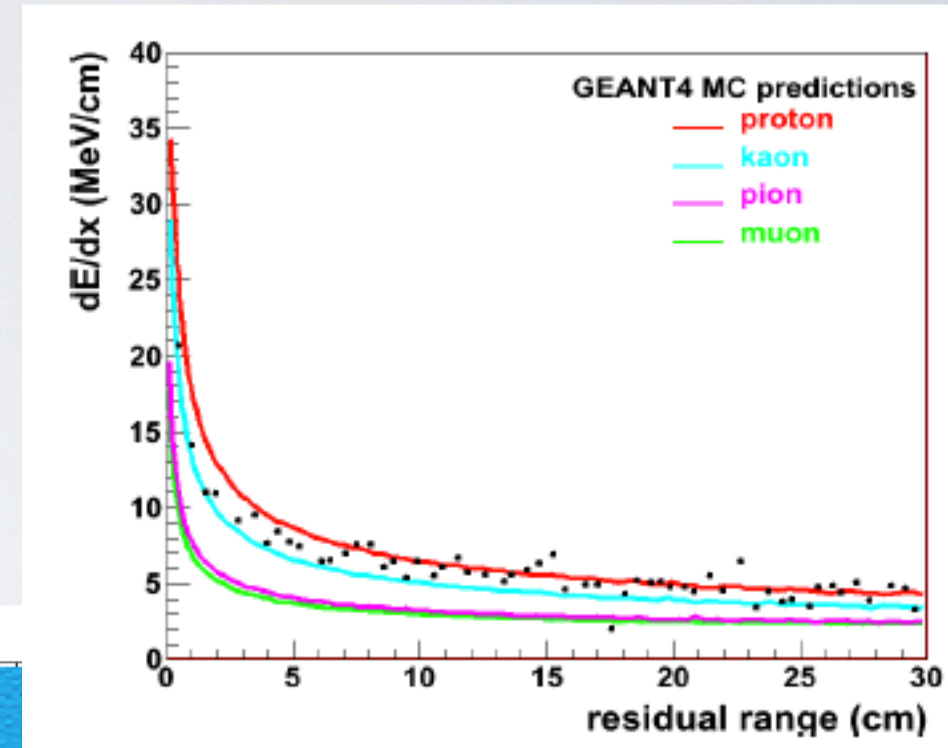


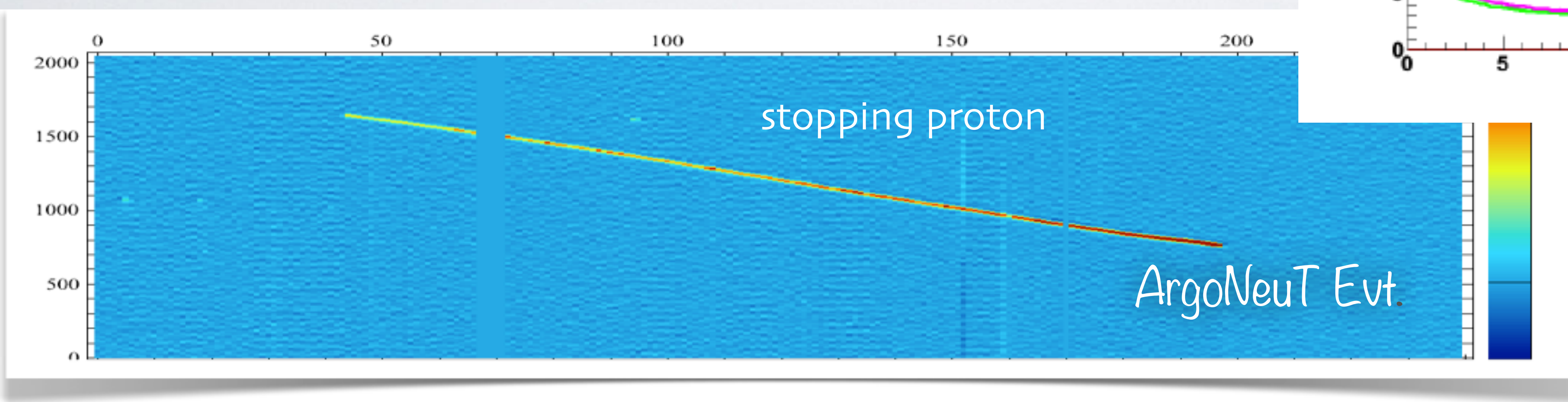
PARTICLE IDENTIFICATION

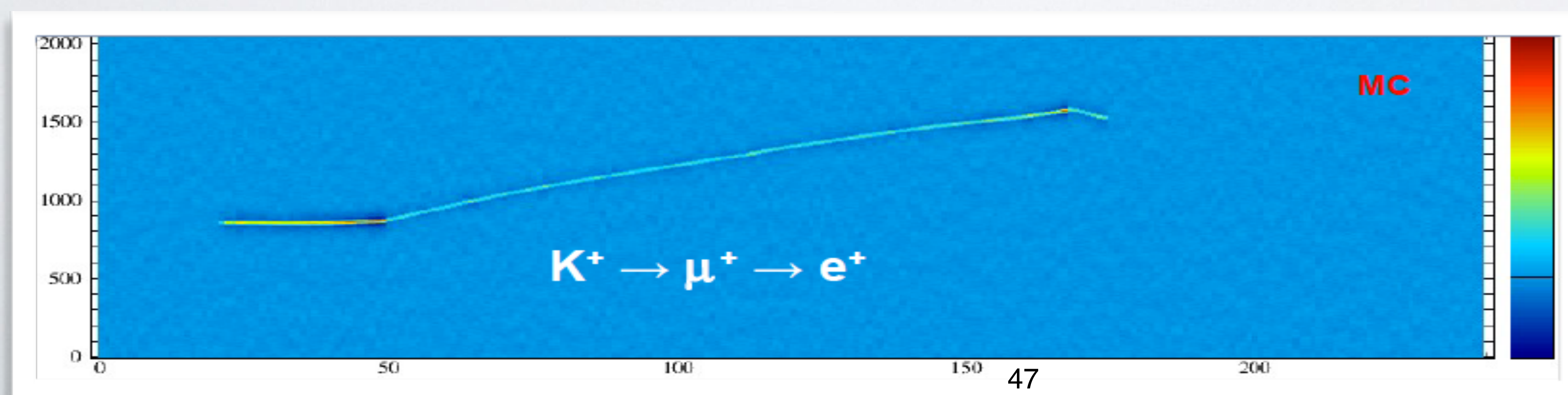
Study recombination along stopping tracks:

- Kaon to proton separation
- Kaon to pion separation

p-decay
(LBNE/F UG)





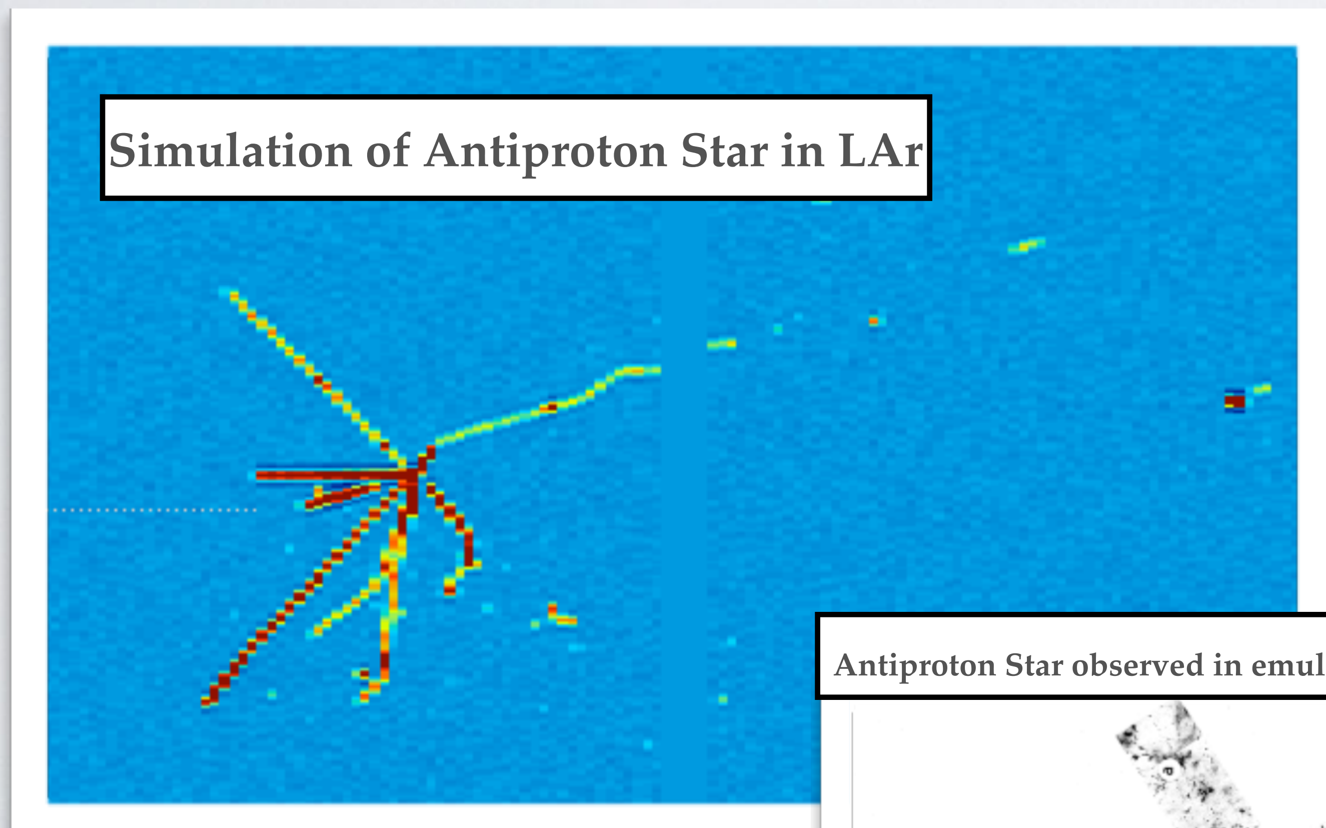


Study Nuclear Effects

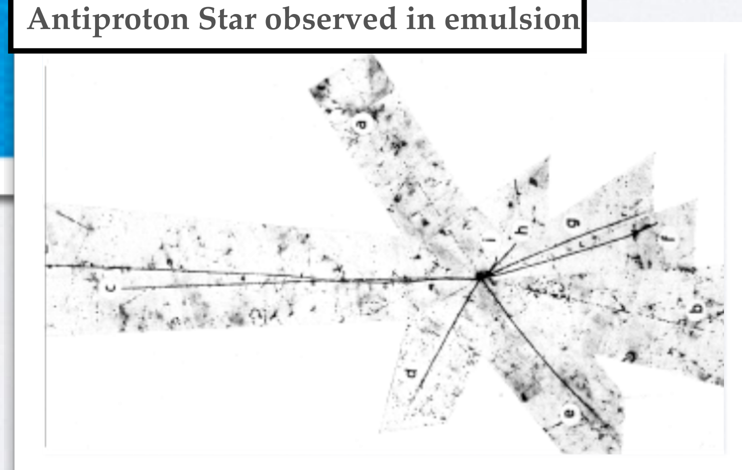
- Nuclear effects are always an unknown for neutrino experiments

- Anti-p: HADRON STAR TOPOLOGY STUDY FROM ppbar ANNIHILATION IN Ar

(RELEVANT FOR nnbar OSCILLATION SEARCH WITH FUTURE LArge LArTPC DETECTORS)



π, K,.. multiplicity in
hadron stars with
LAr imaging detector



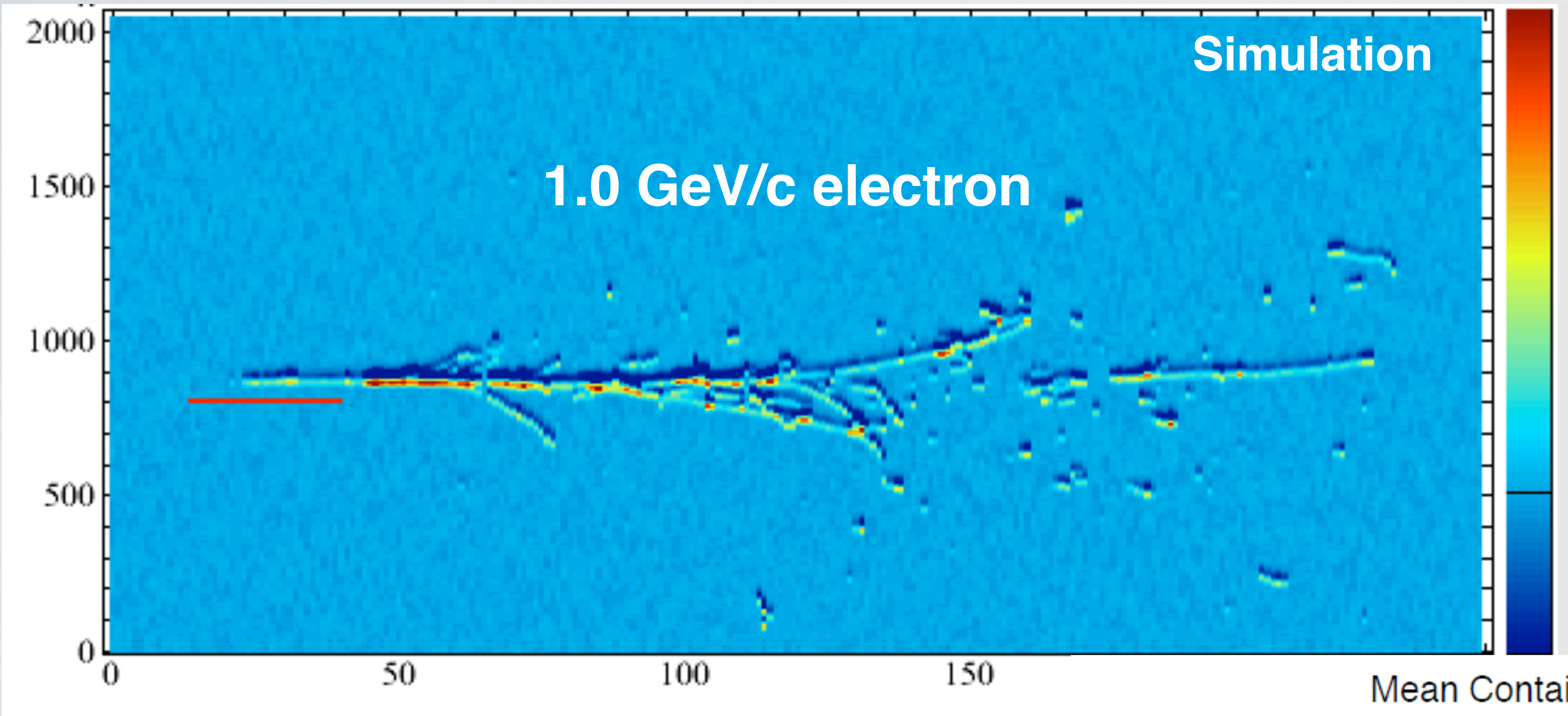
Antiproton Star Observed in Emulsion*

O. Chamberlain, W. W. Chupp, G. Goldhaber, E. Segrè, and C. Wiegand, *Radiation Laboratory, Department of Physics, University of California, Berkeley, California*

and

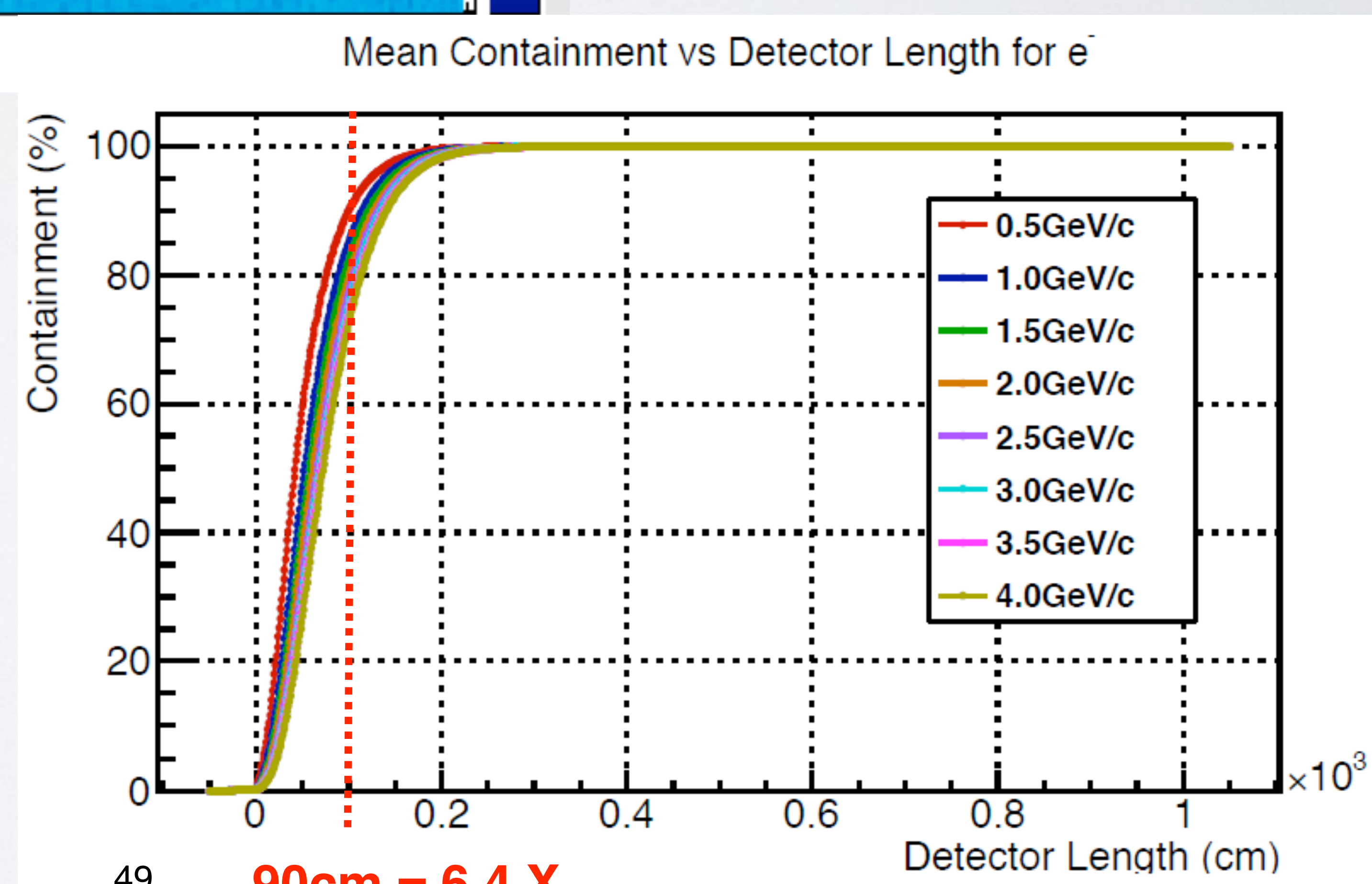
E. Amaldi, G. Baroni, C. Castagnoli, C. Franzinetti, and A. Manfredini, *Istituto di Fisica della Università, Roma Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Italy*

ENERGY MEASUREMENTS



Benchmark MC

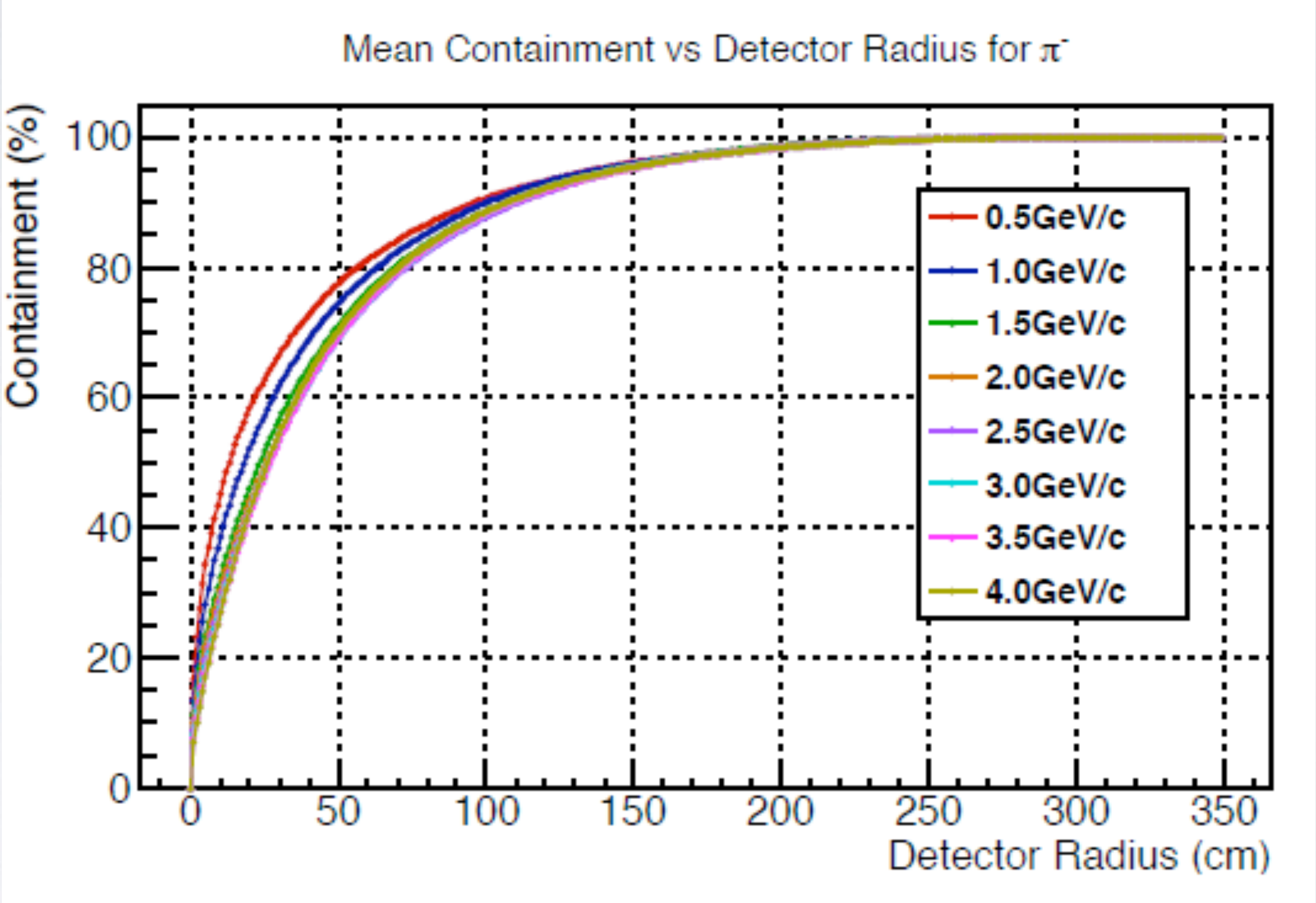
Junting Huang

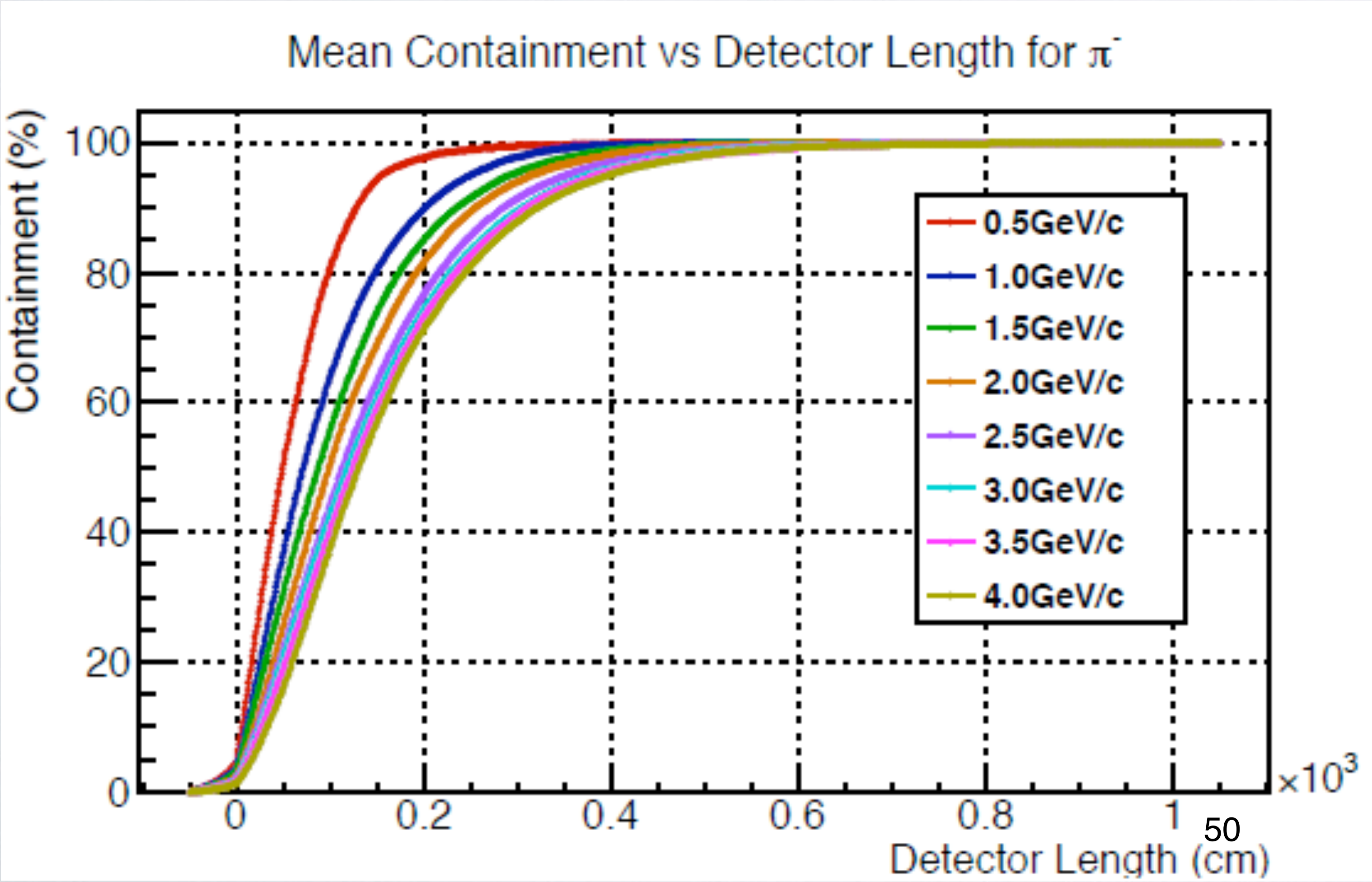


<u>Electrons</u>

~85% containment in ~1 m of LAr for el. momenta <1 GeV/c

PION CONTAINMENT





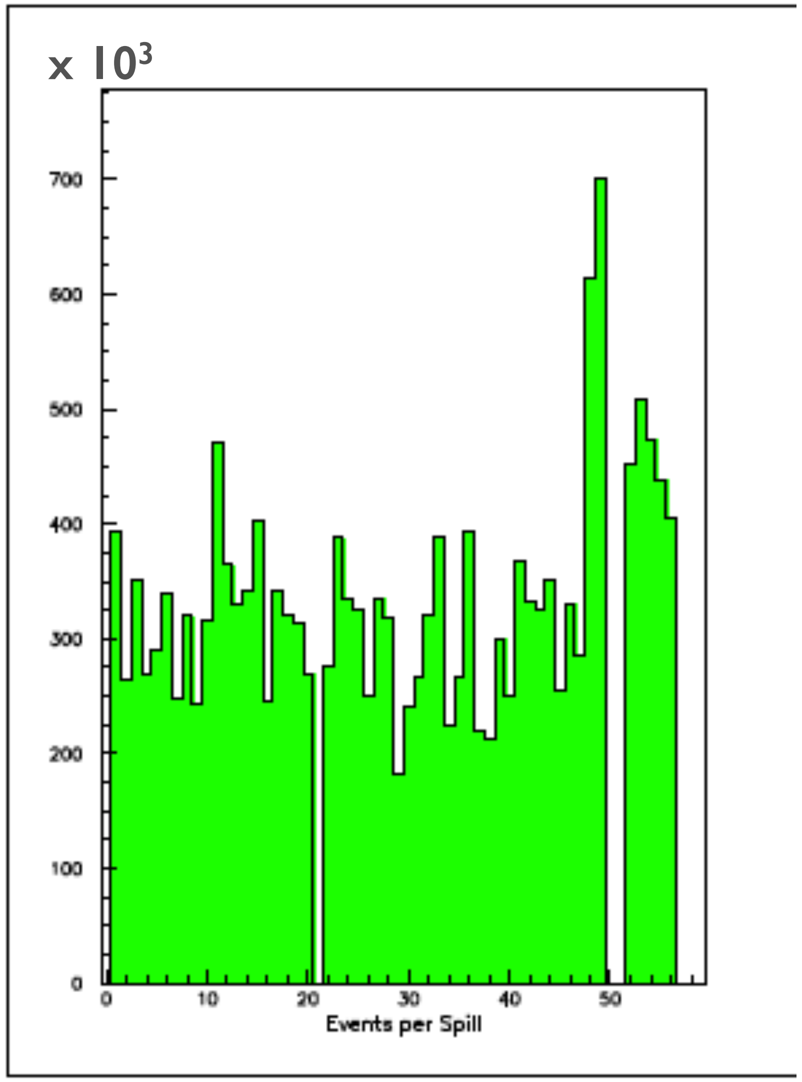
Junting Huang

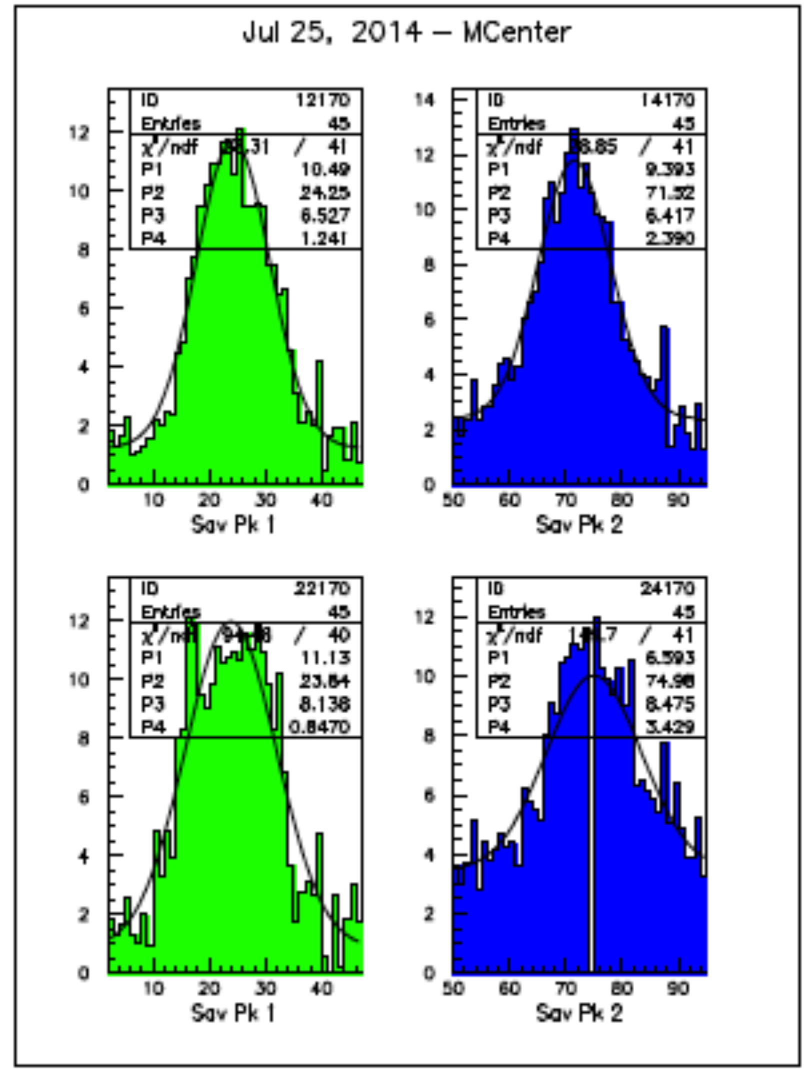
Beam commissioning

July-Sept.'14

M. Backfish,
T. Kobilarcik
FNAL

Secondary Beam intensity
(n.of pi/spill)





Secondary Beam
profile

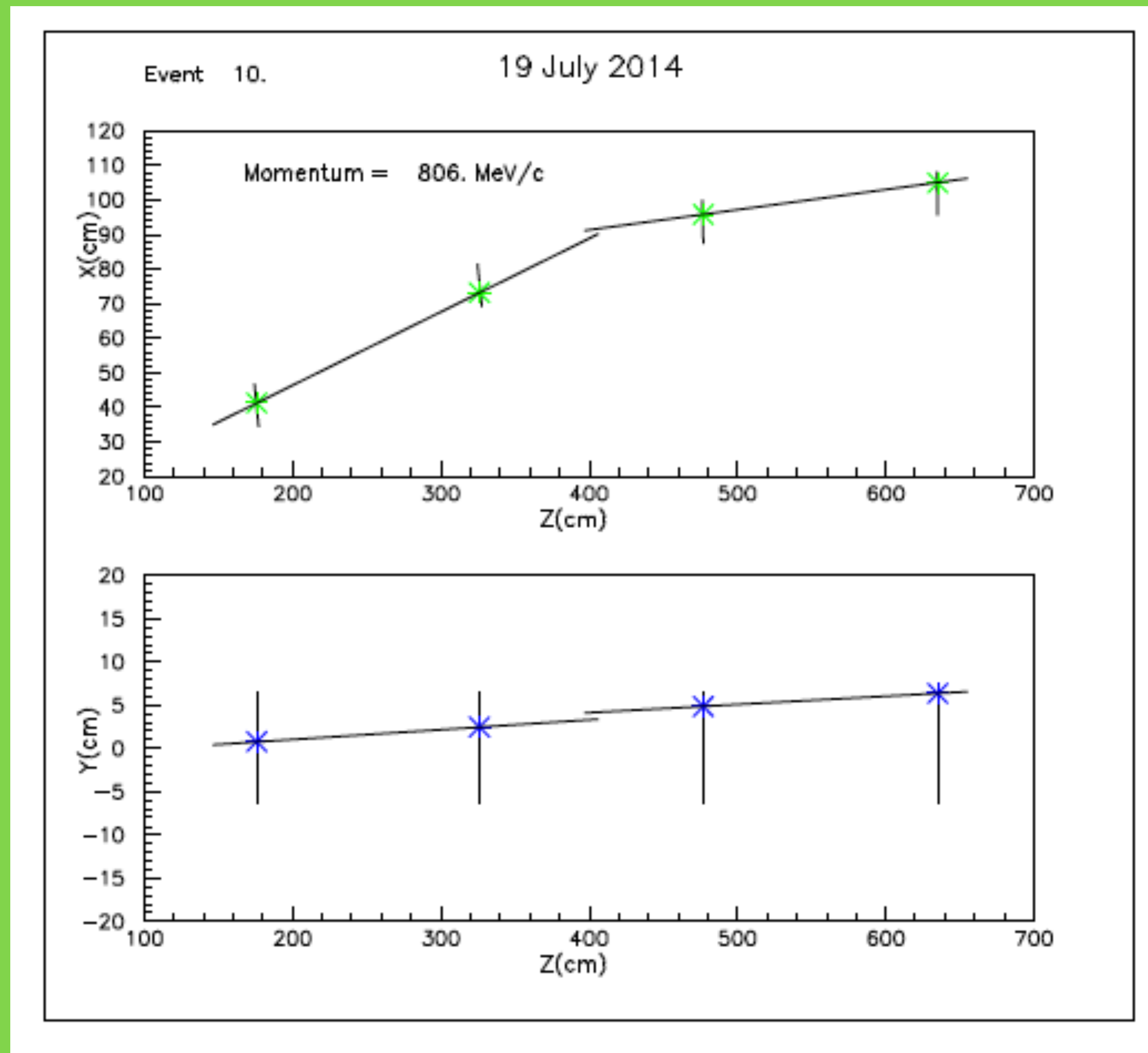
- Secondary beam successfully commissioned, good beam up to 80 GeV energy!
- Data was collected before the shut down @ 8, 32 and 80 GeV energies with different magnet currents (20, 40, 50 and 100 A)
- Thanks to all the FTBF and Accelerator Division people who did an awesome job in refurbishing the beamline!

Beam data analysis

D. Jensen

(x,z) plane

(y,z) plane



- Momentum resolution from vertical and horizontal angle distributions

  - @ 100 A → Δp / p is 1.6 %

  - @ 40 A → Δp / p is 3.4 %

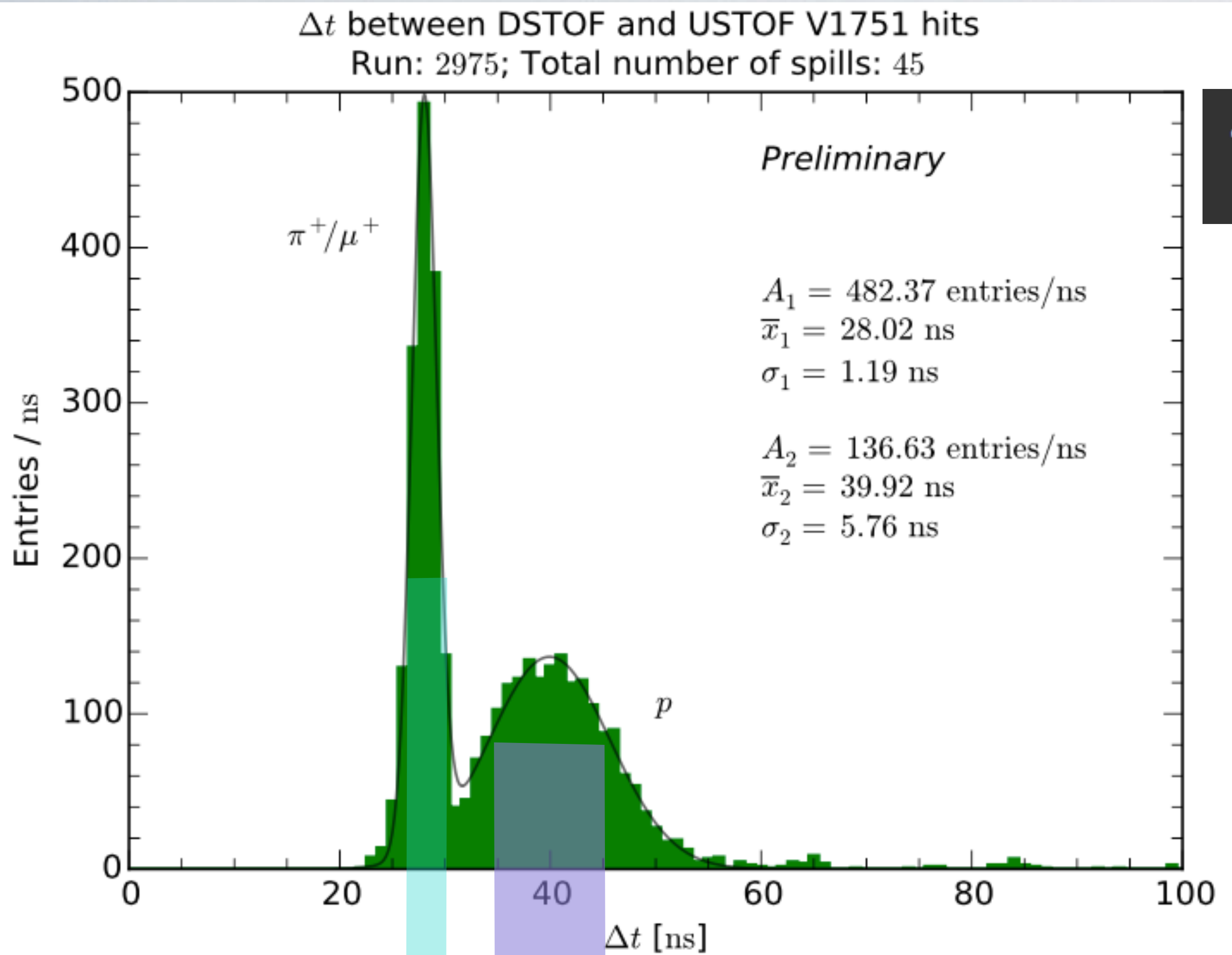
LArIAT beam: Momentum Resolution

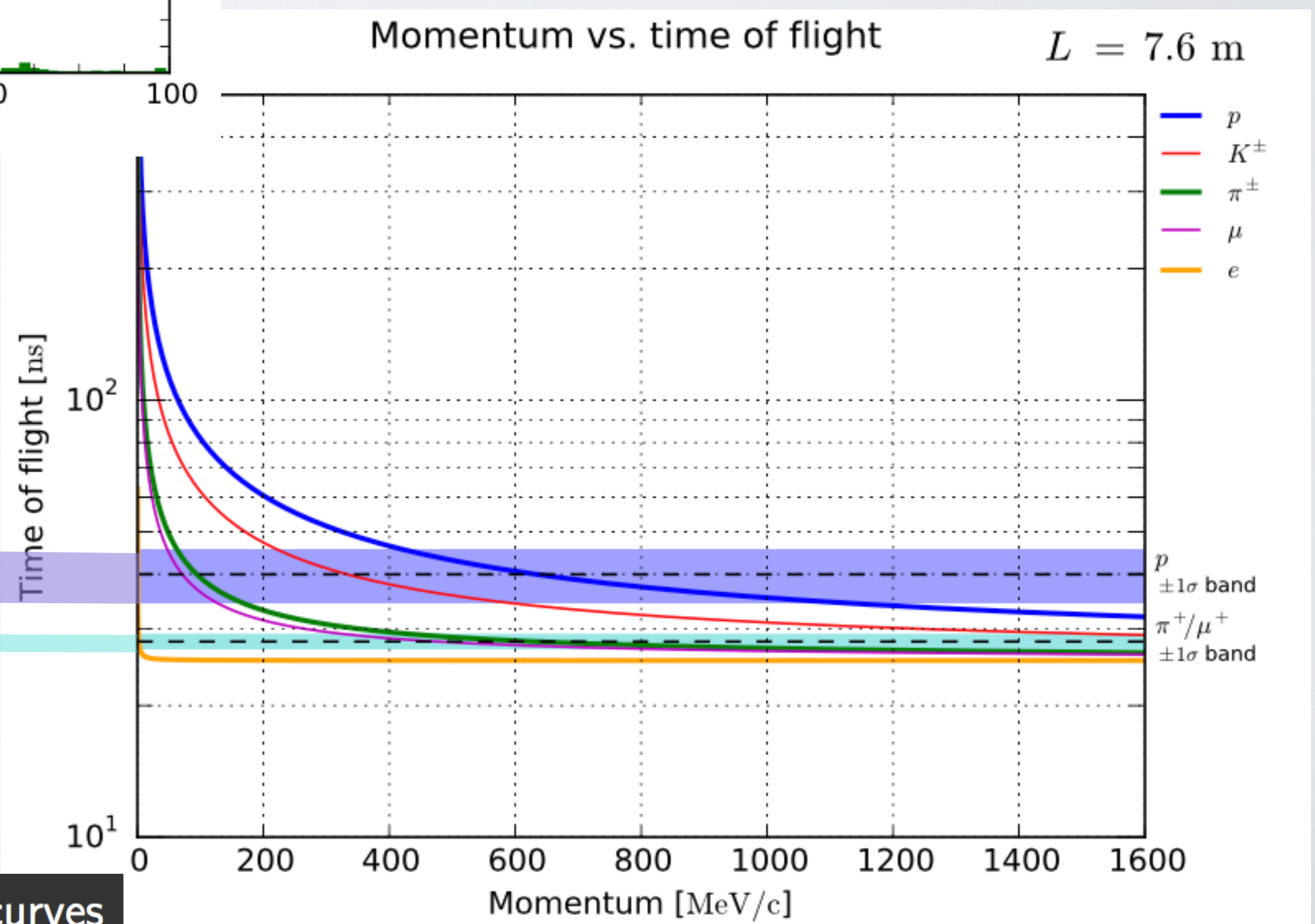
$\Delta p / p = dA_y / A_x$

Time-of-flight distribution from data

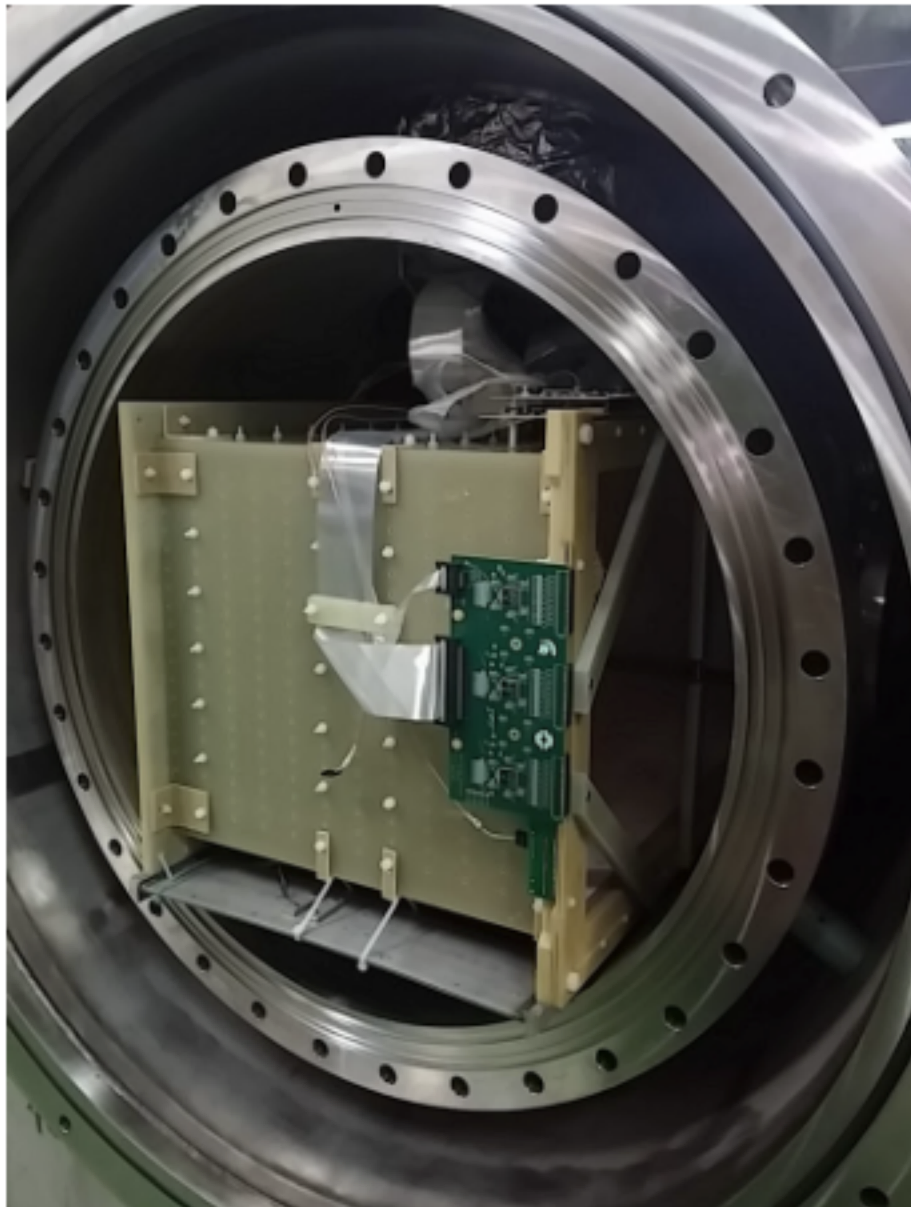
LArIAT beam: Ptcl. Identification by ToF

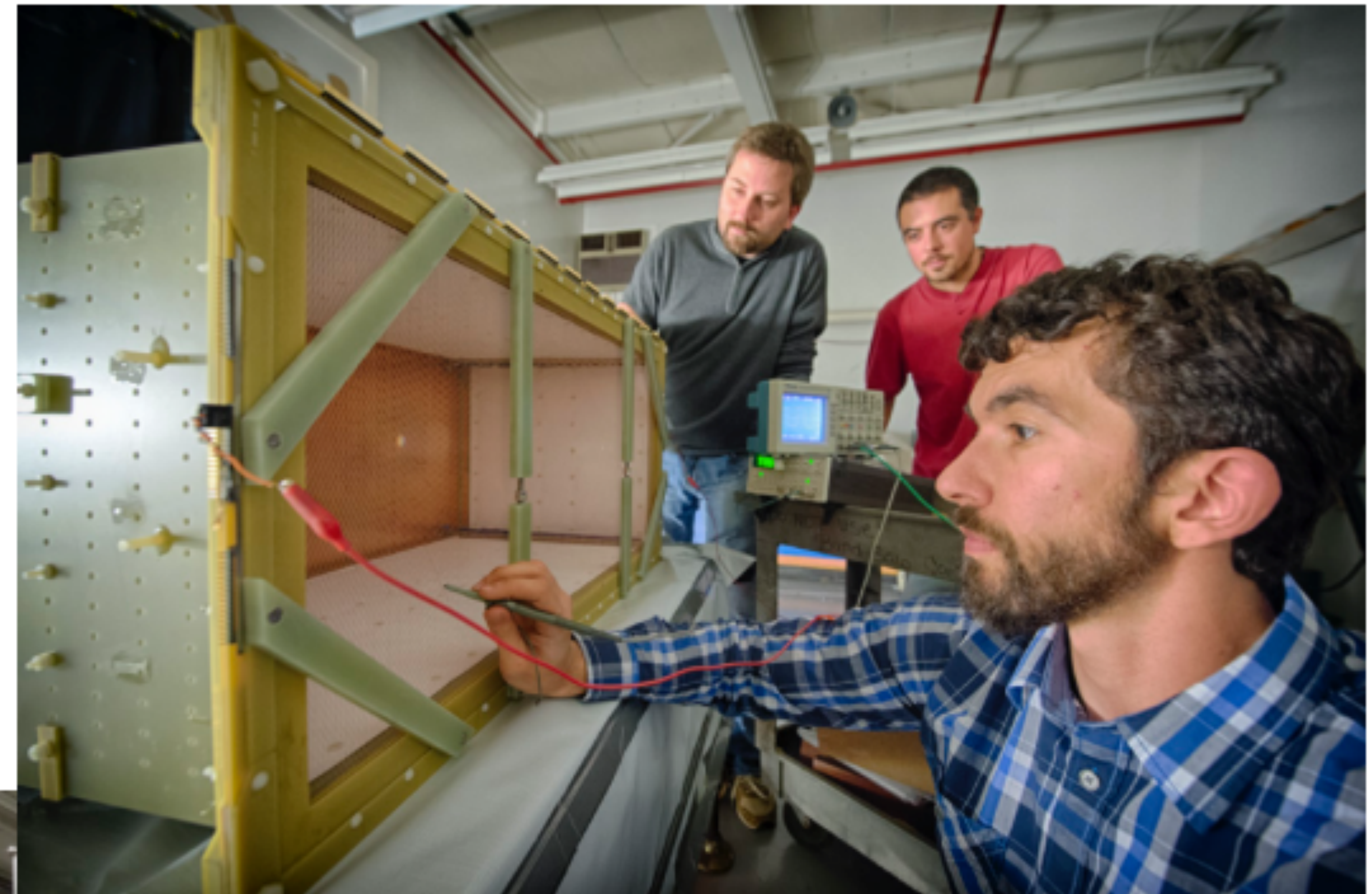
Johnny Ho





Theoretical momentum vs. time of flight curves

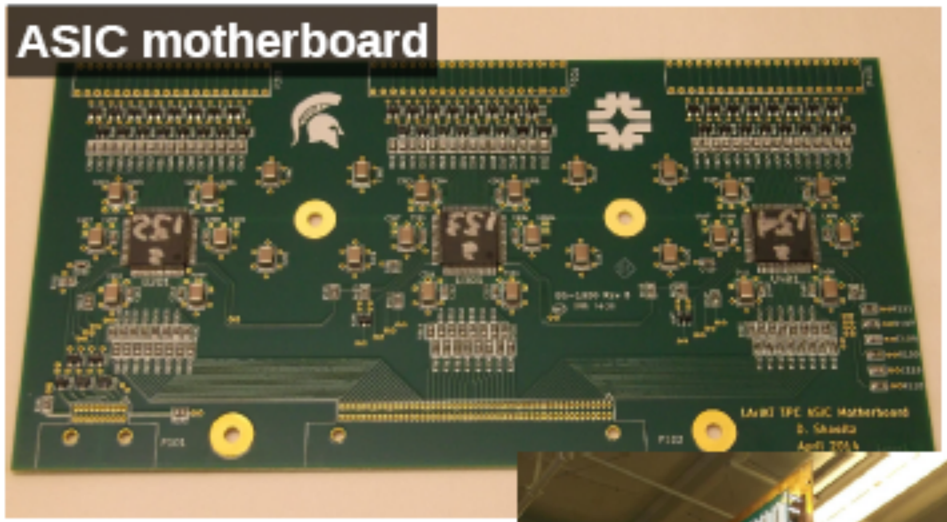


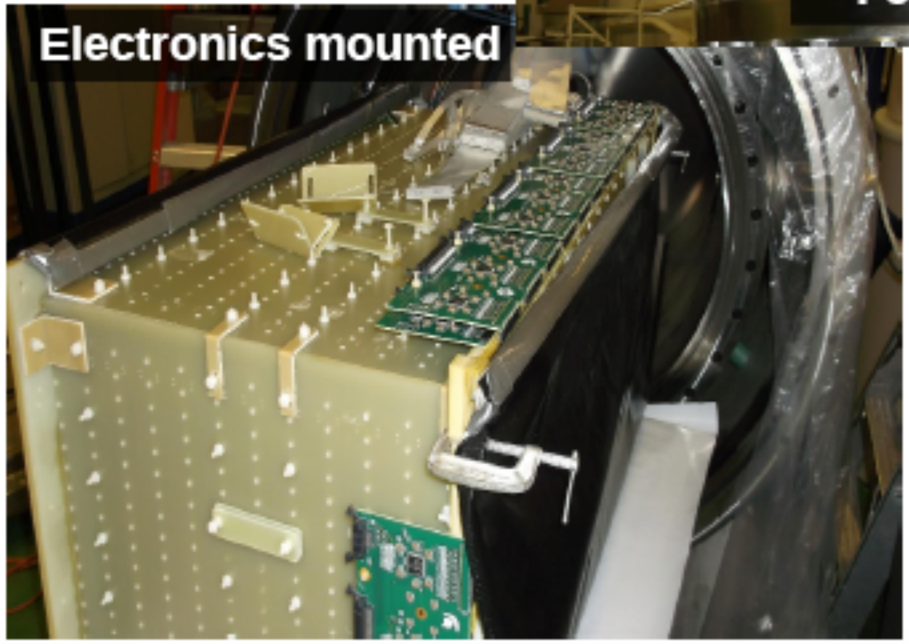


ArgoNeuT
becomes
LArIAT

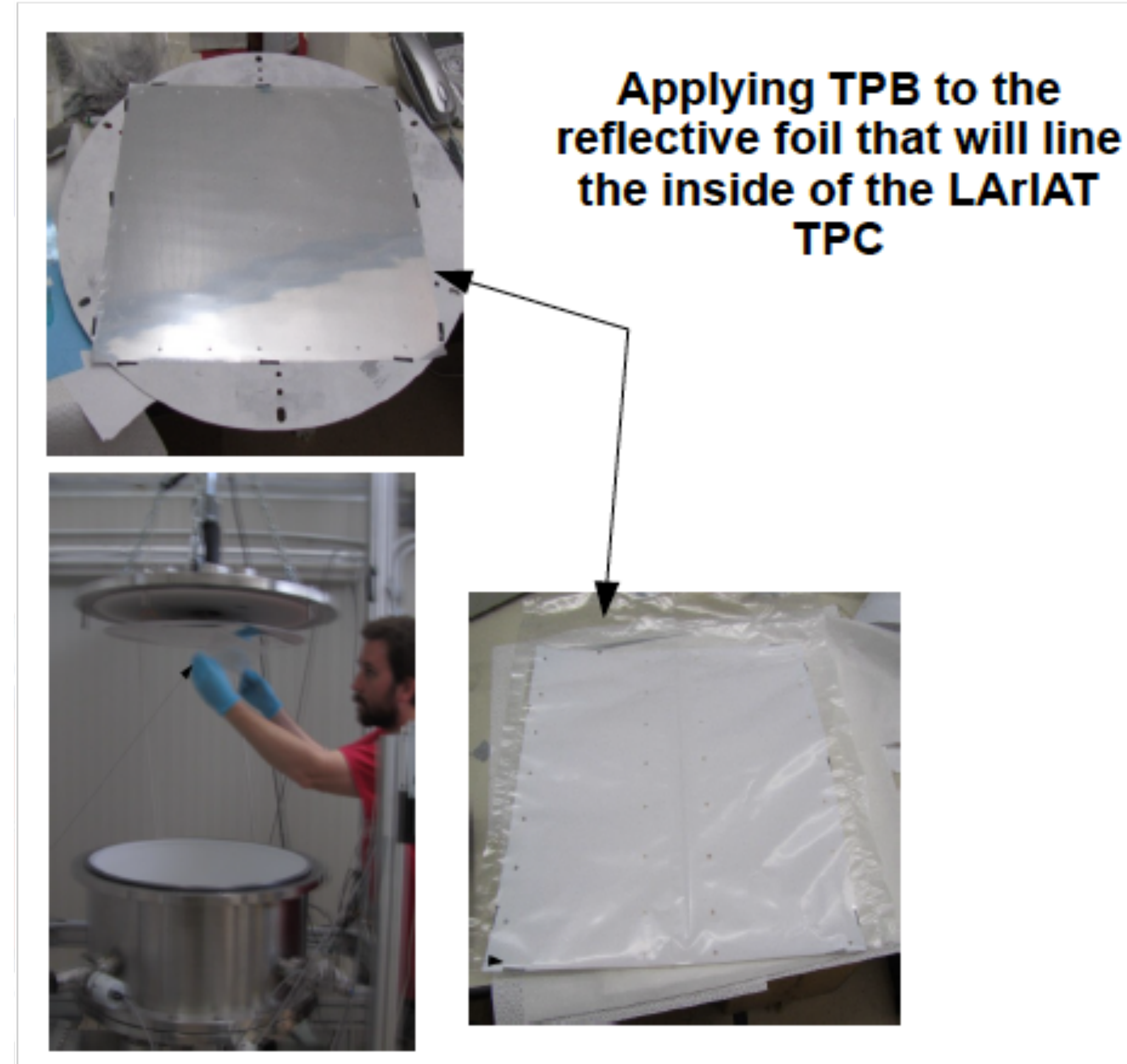
LArIAT front-end electronics

- **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

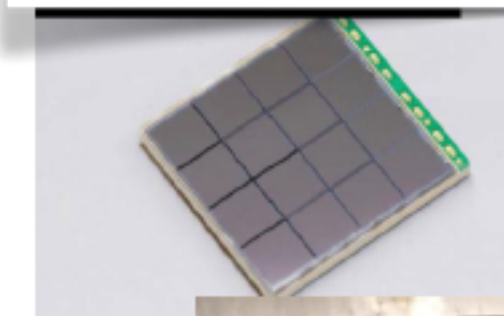


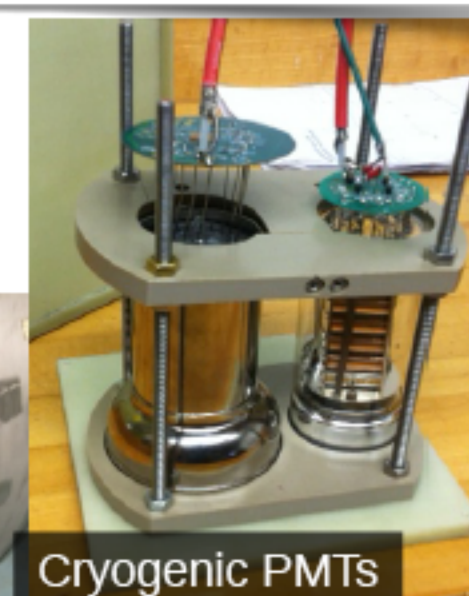


Light collection sys

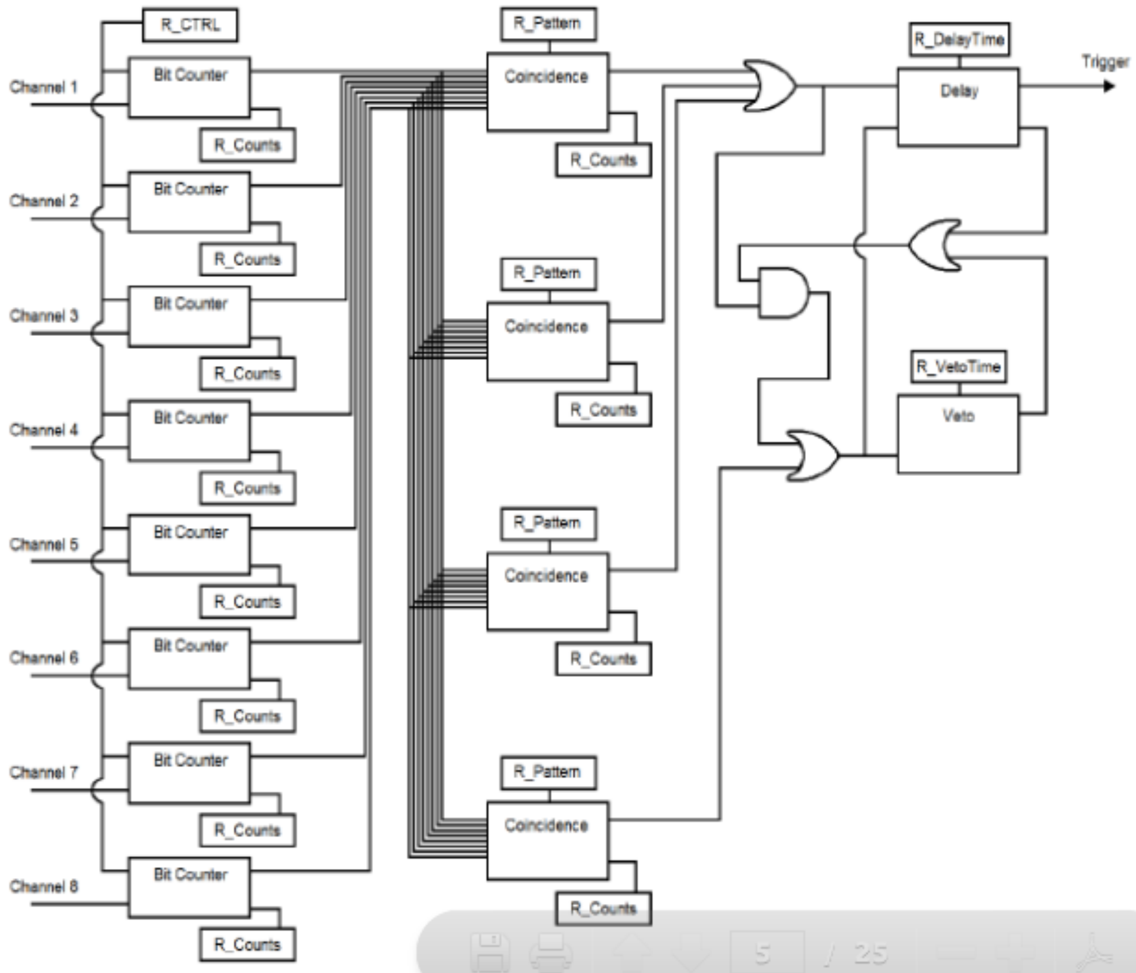


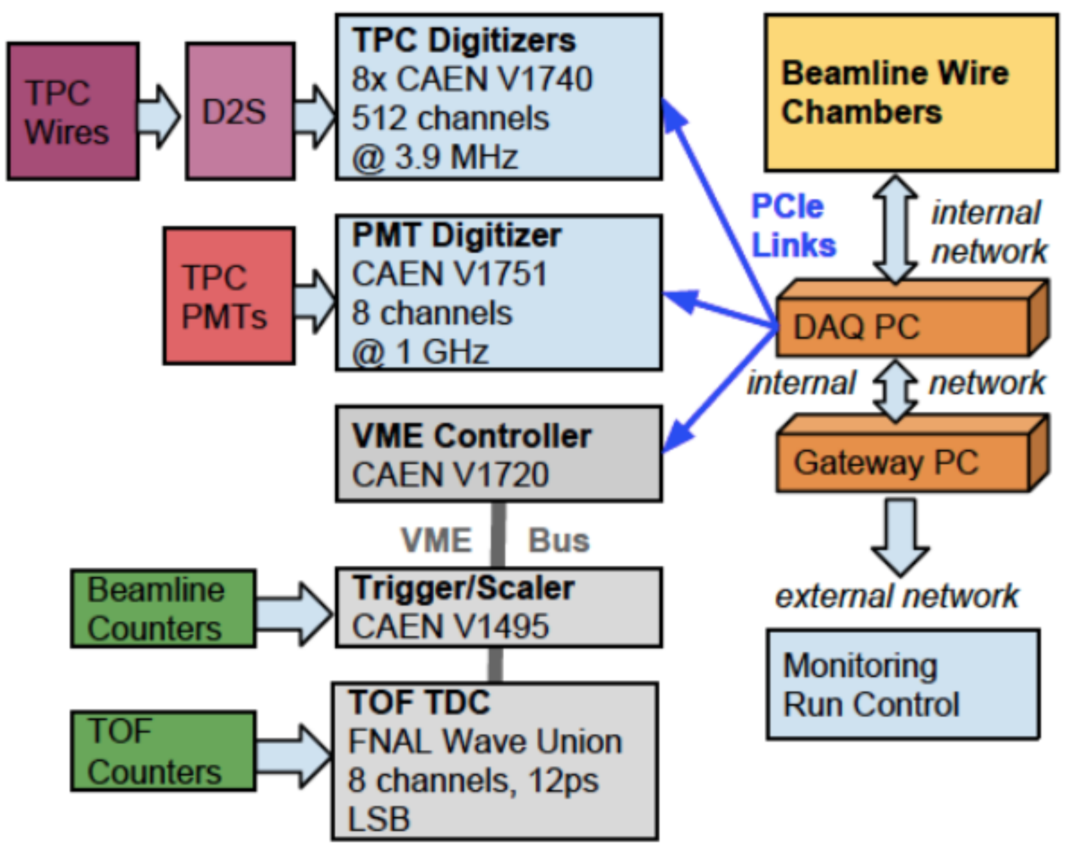
- **Light collection system**
  - 2 cryogenic PMTs: 2” ELT (QE 20%) and 3” Hamamatsu (high QE 30%)
  - 2 Hamamatsu SiPMs (QE 50%)
  - TPB wavelength shifting reflector foils
- **Status:**
  - Side port added to the cryostat to accommodate the PMTs
  - PMTs mount dry-fit test done
  - Cryogenic PMTs tested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





Trigger System and DAQ





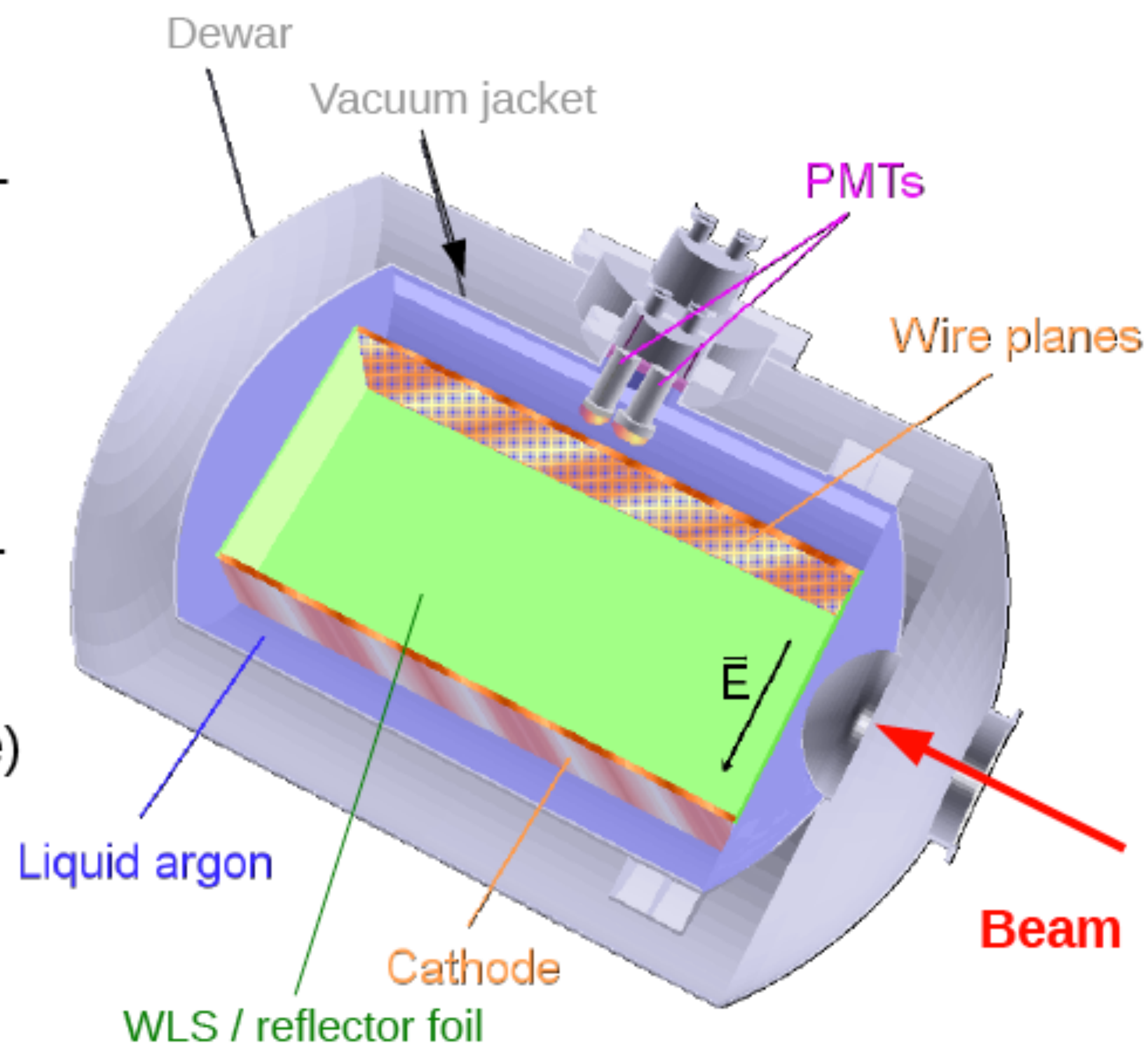
Mike Kordosky
William Badgett
Flor Blaszczyk
Pawel Kryczynski
Jason St. John
Ryan Linehan

W&M, FNAL, LSU, Cincinnati, BU

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)

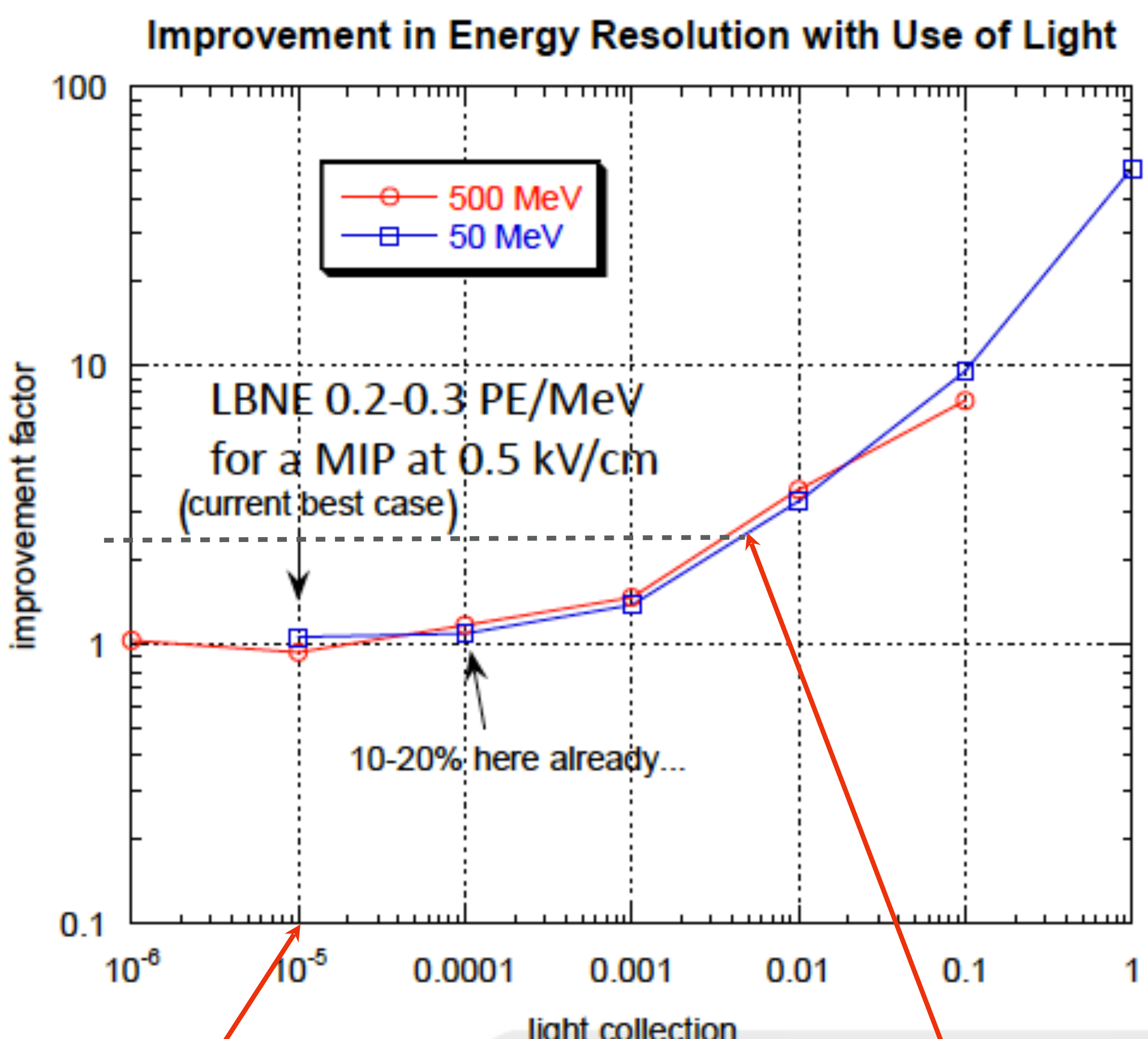
    → ~300 μs max drift time
  - Scintillation light collection: 2 standard PMTs + 2 SiPM + wavelength shifting reflector foils
  - Cold readout electronics



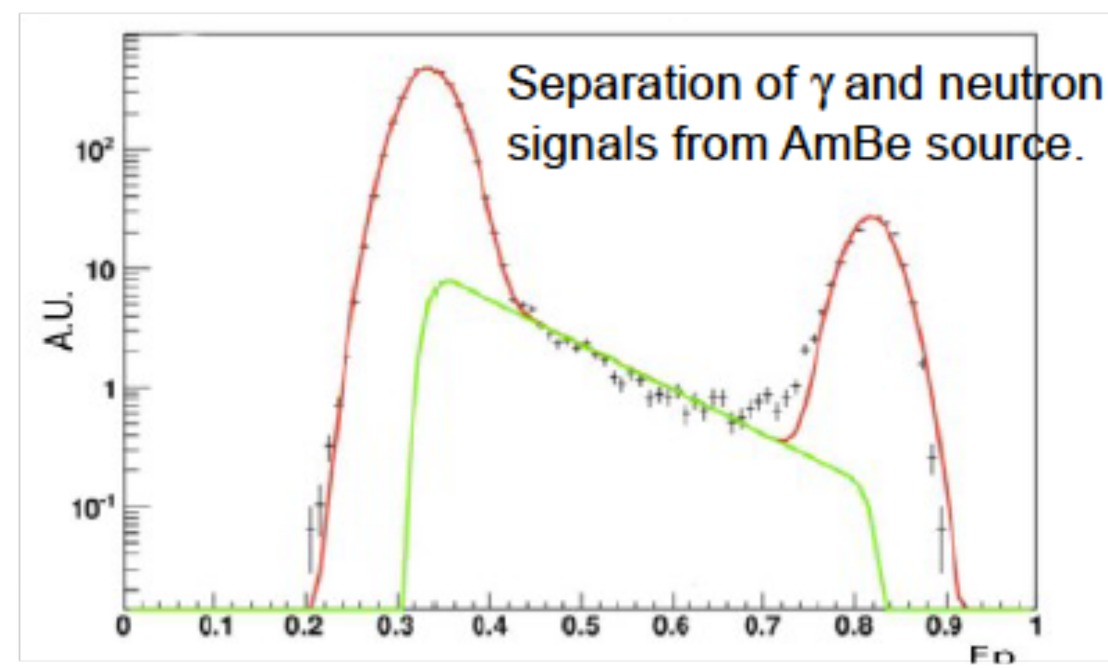
Matthew Szydagis, UC Davis

FNAL, Software Workshop, Thursday 3-21-13

Energy Resolution



	LC (frac)	CY [%]	LY [%]	comb [%]	opt [%]	<-- with	improv
500 MeV	1.00E-06	0.33	79.32	0	0.32	0.001	1.0313
	1.00E-05	0.31	9.07	3.28	0.33	0.1	0.93939
	1.00E-04	0.34	3.96	1.19	0.29	900	1.1724
	0.001	0.34	1.2	0.33	0.23	300	1.4783
	0.01	0.36	0.72	0.12	0.1	90	3.6
	0.1	0.27	0.48	0.037	0.036	11	7.5
50 MeV	1.00E-06	0.98	100				
	1.00E-05	1.21	29.01	10.96	1.14	0	1.0614
	1.00E-04	1.01	9.95	3.51	0.92	900	1.0978
	0.001	0.93	3.8	1.11	0.67	300	1.3881
	0.01	1.11	2.39	0.37	0.34	90	3.2647
	0.1	1.05	2.18	0.11	0.11	10	9.5455
	1	0.97	1.91	0.019	0.019	1	51.053

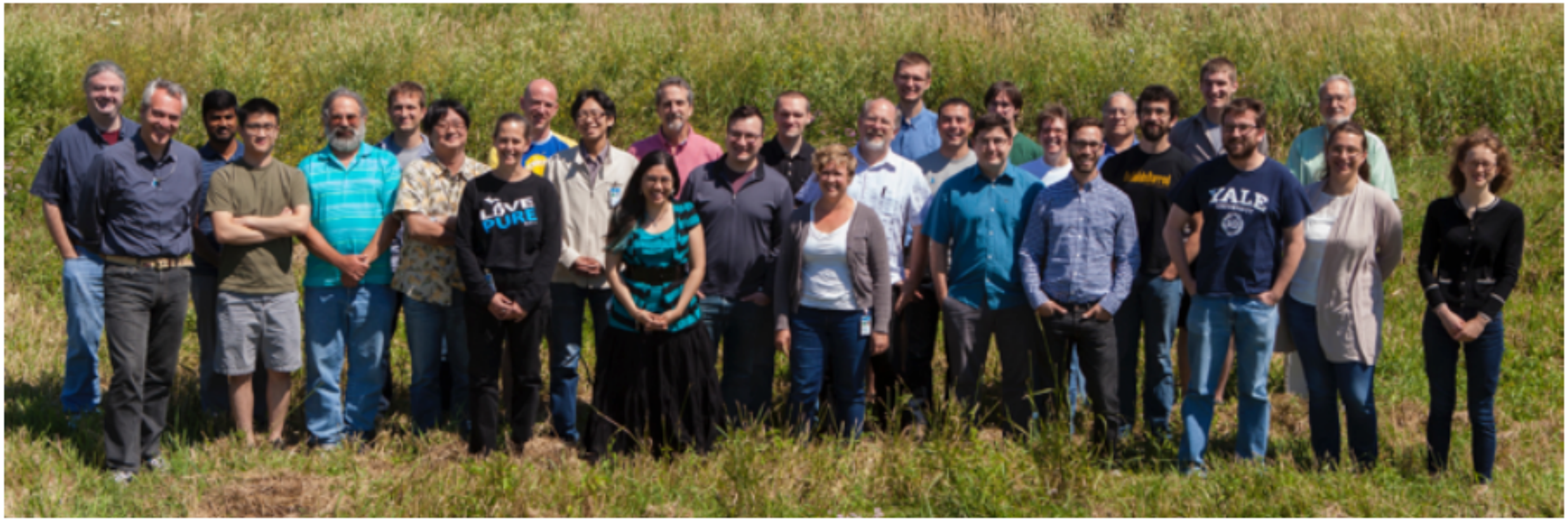


0.2 PE/MeV ≈ 10 ppm
of the available light

~100 PE/MeV ≈ 1%
of the available light

➪ factor >2 improvement
in energy resolution

The LArIAT Collaboration



- Broad community interest in LArIAT:
  - 20 institutions; 16 US, 3 UK, 1 Japanese
  - 66 collaborators; 11 gradstudents, 8 postdocs, 48 senior scientists
  - Perfect opportunity for students and postdocs to build and run an experiment
  - Drawing foreign institutions into collaborations and can be seen as a gateway to US neutrino program

LArIAT Reference Paper

LArIAT: Liquid Argon In A Testbeam

F. Cavanna — *Yale University*
M. Kordosky — *William & Mary*
J. Raaf, B. Rebel — *FNAL*

for the LArIAT Collaboration

June, 2014

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Argonne (US): J. Paley
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Caltech (US): R. Patterson
U. Chicago (US): W. Foremen, J. Ho, D. Schmitz
U. Cincinnati (US): R. Johnson, J. St.John
Fermilab (US): R. Acciarri, P. Adamson, M. Backfish, W. Badgett, B. Baller, A. Hahn, D. Jensen, T. Junk, M. Kirby, T. Kobilarcik, P. Kryczynski, H. Lippincott, A. Marchionni, K. Nishikawa, J. Raaf, E. Ramberg, B. Rebel, M. Stancari, G. Zeller
Imperial College London (UK): M. Wascko,
KEK (Japan): T. Maruyama, E. Iwai, S. Kunori
LANL (US): C. Mauger
U. L'Aquila (Italy): F. Cavanna (presently at *Yale U.*)
LNGS-INFN (Italy): O. Palamara (presently at *Yale U.*)
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Manchester U. (UK): J. Evans, P. Guzowski
Michigan State U. (US): C. Bromberg, D. Edmunds, D. Shooltz
U. Minnesota Duluth (US): R. Gran, A. Habig, K. Kaess
U. Pittsburgh (US): S. Dytman
Syracuse U. (US): J. Asaadi, M. Soderberg, J. Esquivel
U. Texas Arlington (US): A. Farbin, S. Park, J. Yu
U. Texas Austin (US): J. Huang, K. Lang
U. College London (UK): R. Nichol, A. Holin, J. Thomas
William and Mary Coll. (US): M. Kordosky, M Stephens, P. Vahle
Yale U. (US): B.T. Fleming, F. Cavanna, E. Church, E. Gramellini, O. Palamara, A. Szelc

Liquid Argon Time Projection Chambers (LArTPCs) are ideal detectors for precision neutrino physics. These detectors, when located deep underground, can also be used for measurements of proton decay, and astrophysical neutrinos. The technology must be completely developed, up to very large mass scales, and fully mastered to construct and operate these detectors for this physics program. As part of an integrated plan of developing these detectors, accurate measurements in LArTPC of known particle species in the relevant energy ranges are now deemed as necessary. The LArIAT program aims to directly achieve these goals by deploying LArTPC detectors in a dedicated calibration test beam line at Fermilab. The set of measurements envisaged here are significant for both the short-baseline (SBN) and long-baseline (LBN) neutrino oscillation programs in the US, starting with MicroBooNE in the near term and with the adjoint near and far liquid argon detectors in the Booster beam line at Fermilab envisioned in the mid-term, and moving towards deep underground physics such as with the long-baseline neutrino facility (LBNF) in the longer term.

Introduction

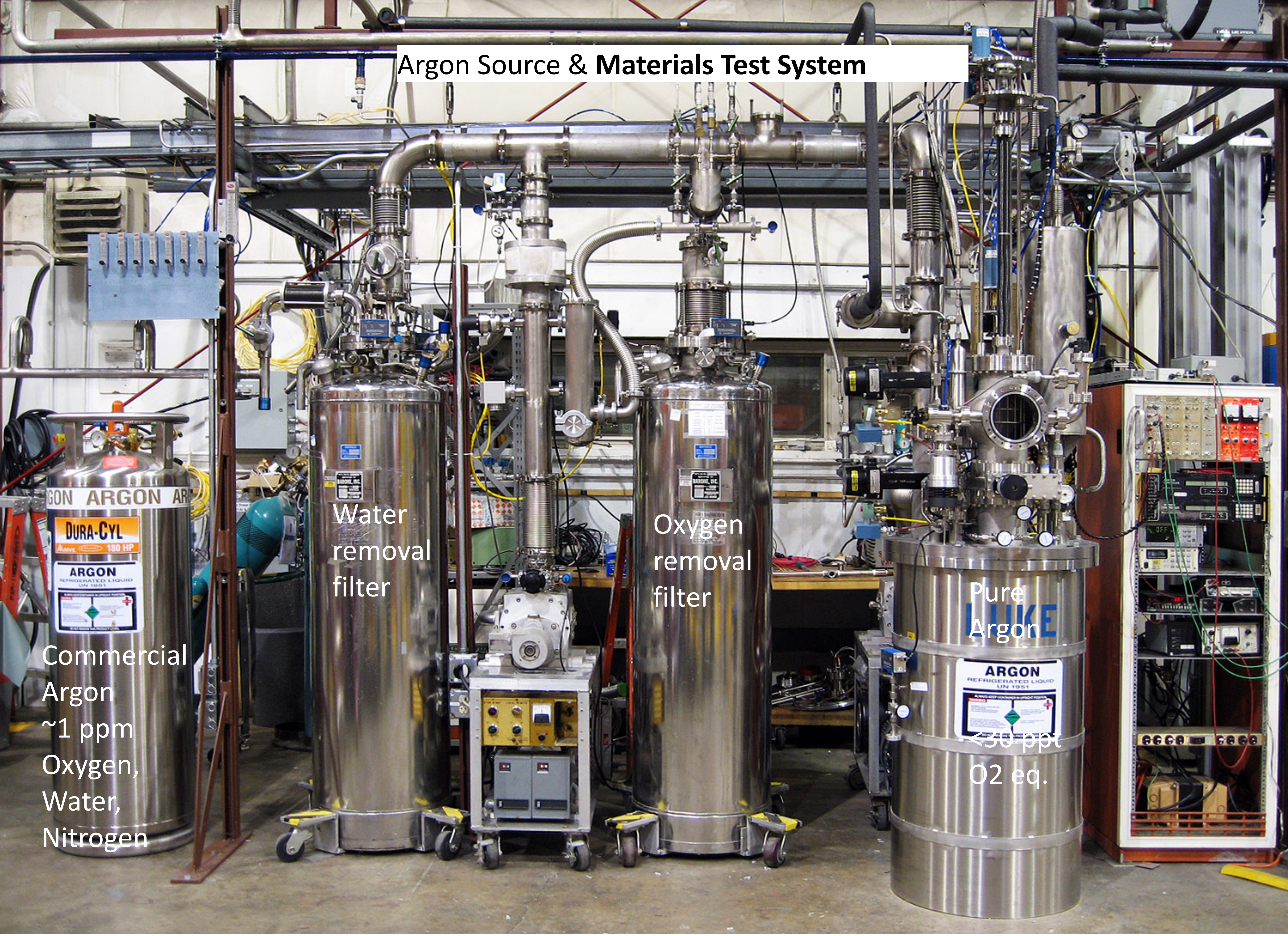
The LArTPC detector with its full 3D-imaging, excellent particle identification (PID) capability and precise calorimetric energy reconstruction represents the most advanced experimental technology for neutrino physics. The LArTPC technology is also recognized as a powerful tool in searches for

1st LArIAT Collaboration Meeting *(> 45 attendees)*

7/10-7/11 FERMILAB

Thursday July 10, 2014	***Invited Talks from OUTSIDE LArIAT***	*Time Slot*
Afternoon Session	1) The new MCentral beam line: history, plans, perspectives - ***FTBF Team*** ***[JJ Schmidt]*** 2) Experience from ***T32*** ***[T. Maruyame]*** 3) Expectations for LArIAT contributions to GEANT4 MC - ***GEANT4 Team*** ***[H. Wenzel]*** 4) Expectations for LArIAT contributions to GENIE MC - ***GENIE Team*** ***[S. Dytman]*** 5) Perspectives from an augmented Scintillation Light Detection system - ***external*** ***[M. Sorel]*** 6) CAPTAIN: perspectives from neutron Test Beam - ***CAPTAIN Coll.*** ***[R. Van der Water]*** 7) LBNE and LArIAT, from the LBNE standpoint - ***LBNE Coll.*** ***[Z. Djurcic]*** 8) Expectations from ***LAr TestBeam at CERN*** ***[M. Nessi]***	2:00 pm 4:30 pm
Friday July 11, 2014	***Status of the Experimental Set-up***	*Time Slot*
Morning & Afternoon Sessions Soc.Dinner / BBQ	**20 talks from the LArIAT Collaboration**	6:00 pm 8:45 am 6:30 pm

Argon Source & **Materials Test System**



Liquid Argon Purity Demonstration

All existing LArTPC detectors have been evacuated before filling. Probably not practical for kiloton detectors.

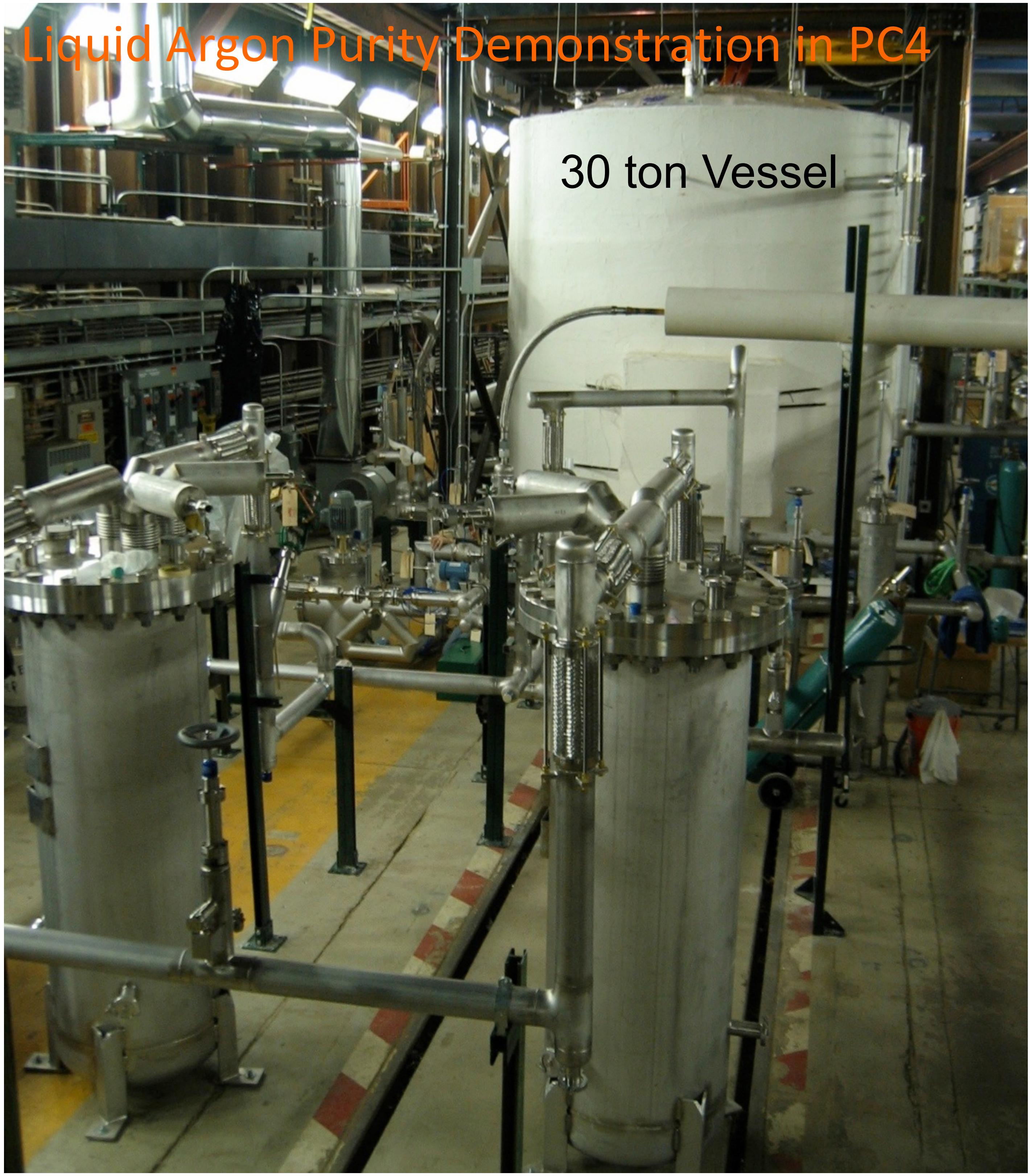
Goal: Demonstrate good life-time **in an industrial vessel without evacuation**.

First multi-ton purification system designed and built at Fermilab.

Stage 1 – bare tank & Instrumentation

- Sniffers for evolution of gas purge
- Analyzers – for O_2, N_2, and H_2O levels
- RTDs – for temperature (gradients)
- Purity Monitors - for drift-lifetime

Stage 2 – Operation with long TPC (LongBo)



Light Detection R & D in new 80 inch cryostat, TallBo


Scintillator Paddle Prototype for LBNE hanging on TallBo lid


TallBo in operation