LArTPC DETECTOR DEVELOPMENT AND THE SBL PROGRAM AT FNAL

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Yale University
(& L'Aquila U.)

PRECISION NEUTRINO PHYSICS HAS ENTERED A NEW ERA

BOTH WITH PRESSING QUESTIONS TO BE ADDRESSED AT SHORT AND LONG BASELINES,

AND WITH STRINGENT PERFORMANCE REQUIREMENTS TO BE FULFILLED BY THE DETECTOR

SHORT&MID TERM OUTLOOK

IN THE US

A PRECISE **TECHNOLOGY CHOICE**

FOR A *state-of-the-art* FINE-GRAINED, HIGH-RESOLUTION *neutrino detection method*

HAS BEEN MADE:

THE LIQUID ARGON TIME PROJECTION CHAMBER (LArTPC)

The LArTPC concept

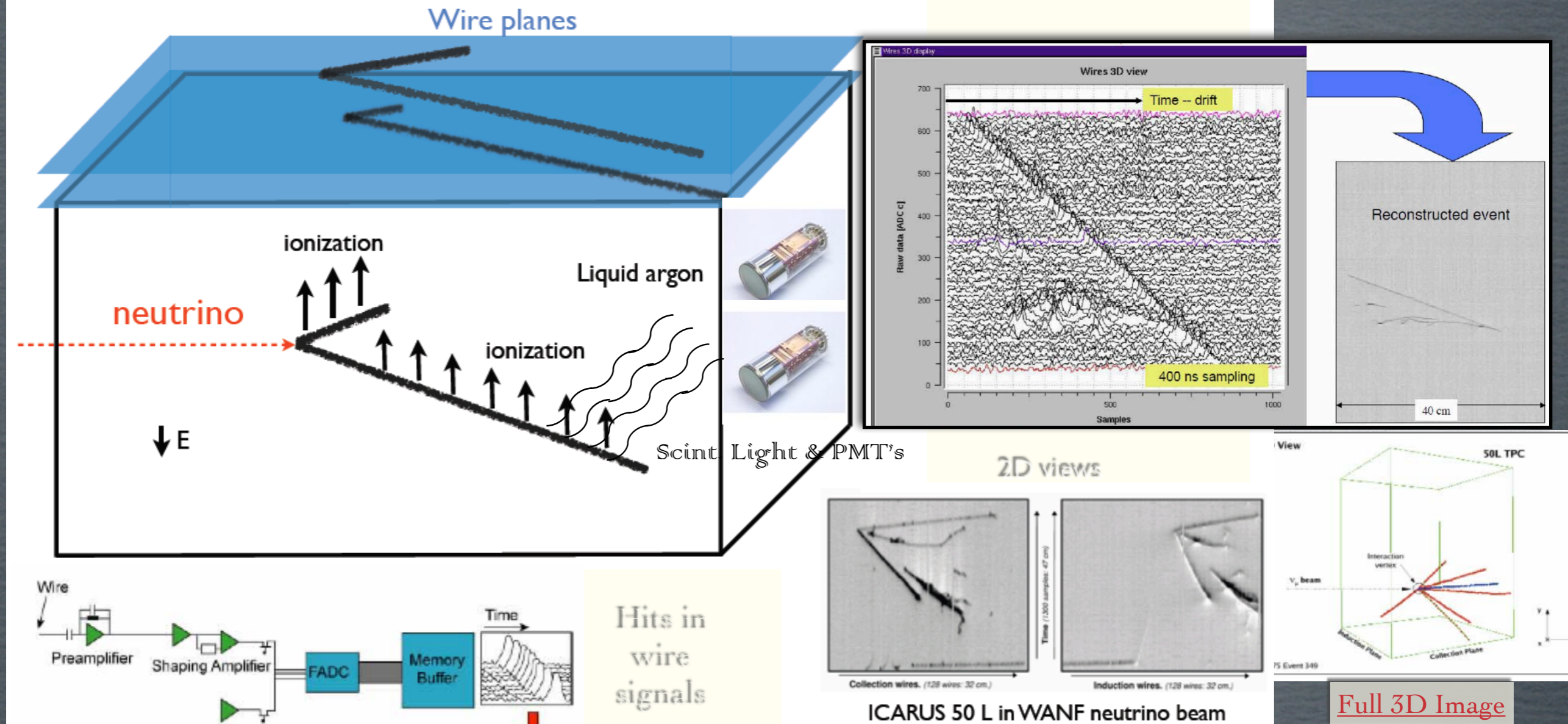

Wire planes

ionization

neutrino

Liquid argon

ionization

Scint. Light & PMT's

E

Wire — Preamplifier — Shaping Amplifier — FADC — Memory Buffer — Time

Hits in wire signals

Wires 3D view — Time -- drift — 400 ns sampling — Raw data [ADC c] — Samples — Reconstructed event — 40 cm

2D views

ICARUS 50 L in WANF neutrino beam — Collection wires. (128 wires: 32 cm.) — Induction wires. (128 wires: 32 cm.)

View — 50L TPC — Interaction vertex — v beam

Full 3D Image

(Neutrino) interactions inside the LAr-TPC produce charged particles ⇒ Ionization Charge & VUV Scintillation Light

- Prompt Scintillation Light is detected (after VUV-Vis w.l. down-conversion) by array of PMTs.
    * Scintillation light collected by PMTs is used for Triggering.
- Free Ionization electrons tracks in EF drift towards anode planes of wires (signal read-out by low-noise charge amplifiers and fast ADCs).
    * Track segments induce hits on corresponding wires: the wire coordinate in the wire plane provide hit position.
    * Multiple (≥ 2) non-destructive wire-planes can be utilized ⇒ (x,y) coordinates.
    * Timing of pulse (T_0 of event from prompt Scint.Light in PMTs ⊕ drift velocity v_d in LAr) determines the hit drift coordinate ⇒ (z)
        ⇒ Multiple 2D views (x,z), (y,z) ⇒ Full 3D Image reconstruction.

    * Collection of the ionization charge on wires of the last plane (hit amplitude) measures the deposited energy
        ⇒ Calorimetric Information and Ptcl.Identification

LAr in USA
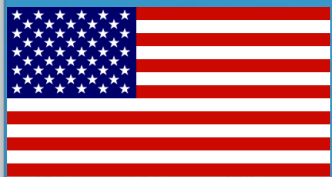
since 2006

Liquid-Argon Time Projection Chambers
Status of R&D Program in the US

FNAL

The first TPCs in the United States:

Yale TPC	Bo	ArgoNeuT	MicroBooNE
Location: Yale University	Location: Fermilab	Location: Fermilab	Location: Fermilab
Active volume: 0.00002 kton	Active volume: 0.00002 kton	Active volume: 0.0003 kton	Active volume: 0.1 kton
Year of first tracks: 2007	Year of first tracks: 2008	Year of first tracks: 2008	Start of construction: 2010
		First neutrinos: June 2009	

FNAL

Test stands to improve liquid-argon technology:

Luke	LAPD	LArSoft
Location: Fermilab	Location: Fermilab	Low charge — High charge
Purpose: materials test station	Purpose: LAr purity demo	ArgoNeuT Data
Operational: since 2008	Operational: 2010	

time 47 cm — Induction Plane Wire

time 47 cm — Collection Plane Wire

90 cm

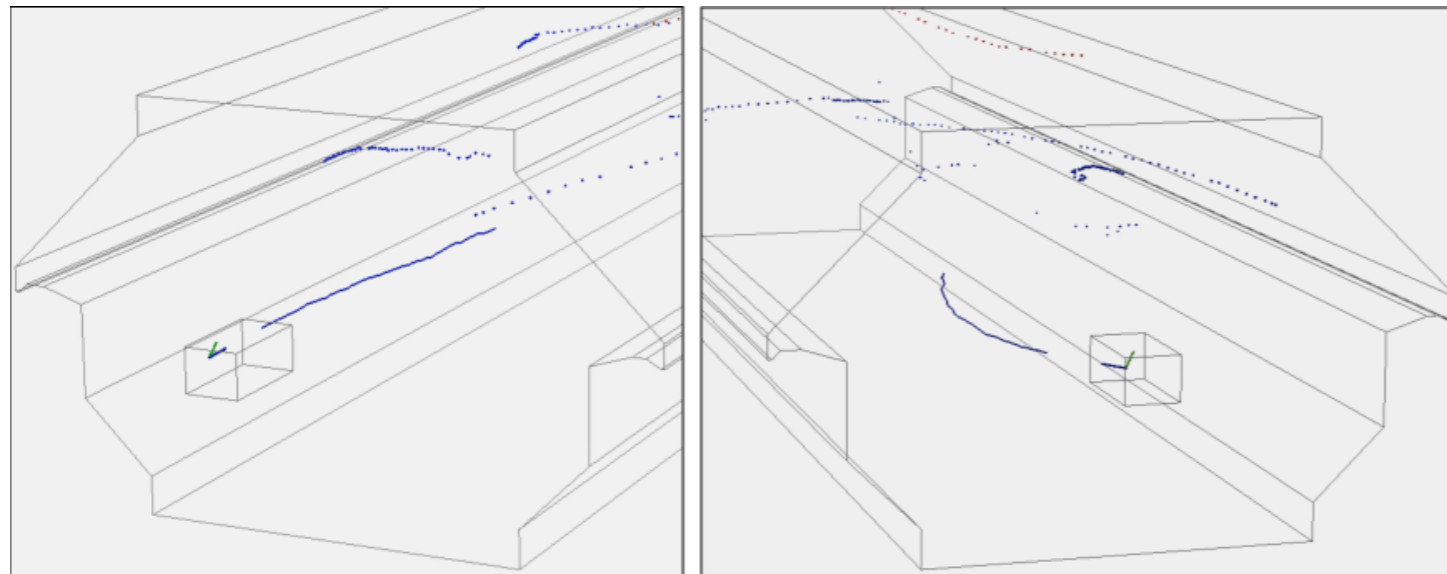# *state-of-the-art neutrino detection method*
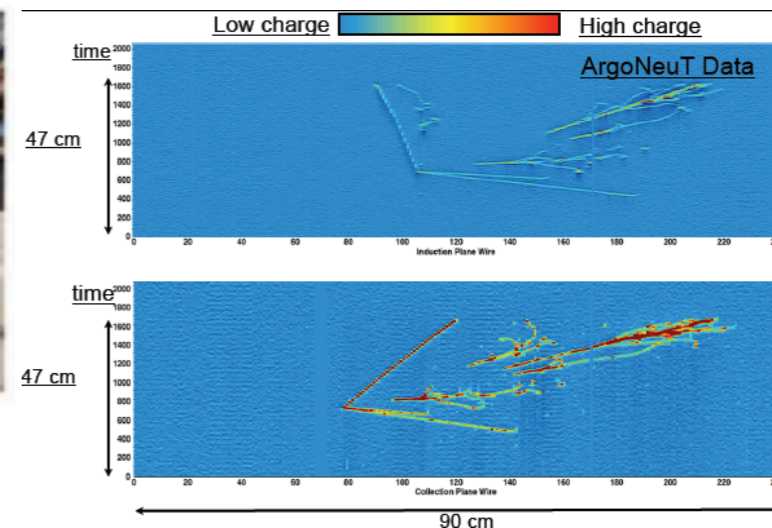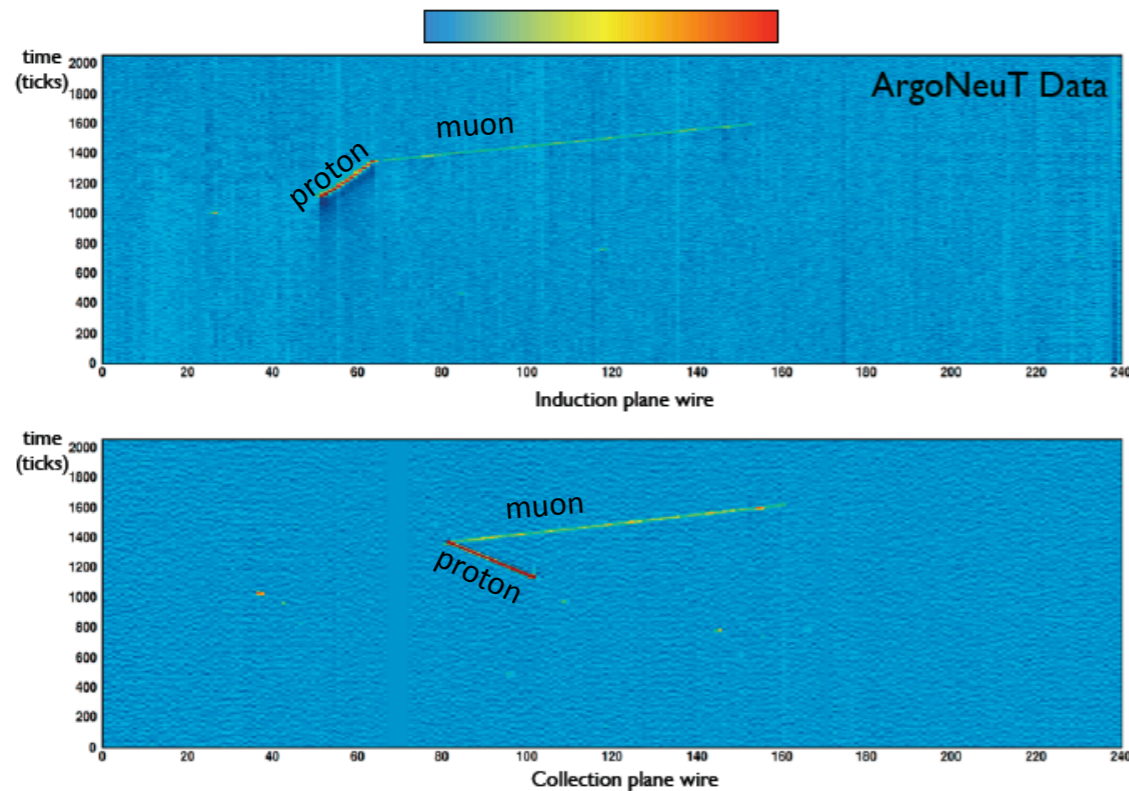
Neutrino event reconstructed in 3D space
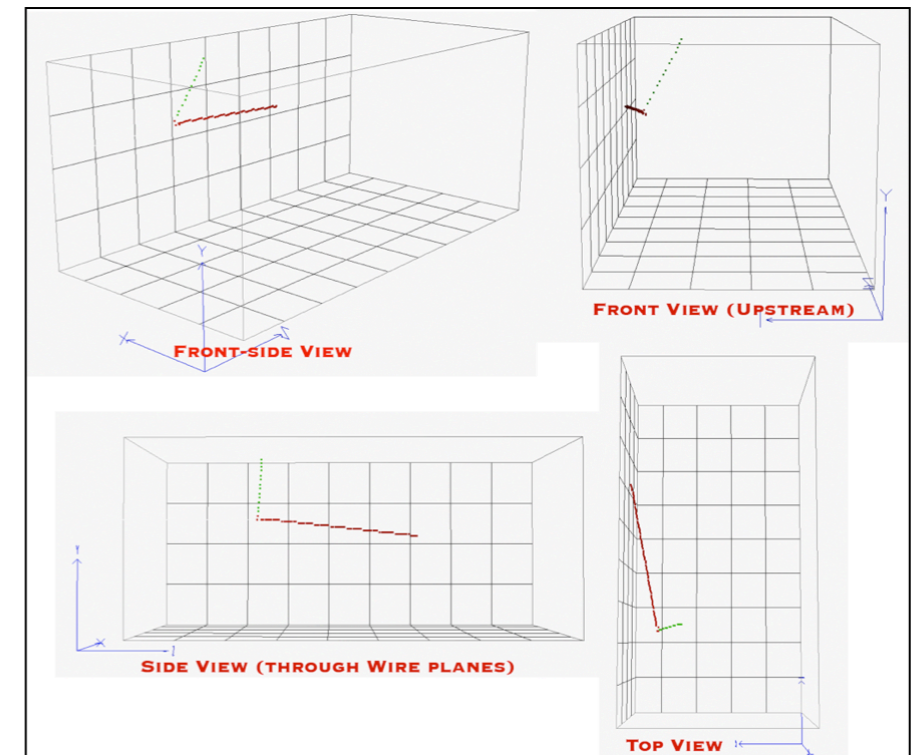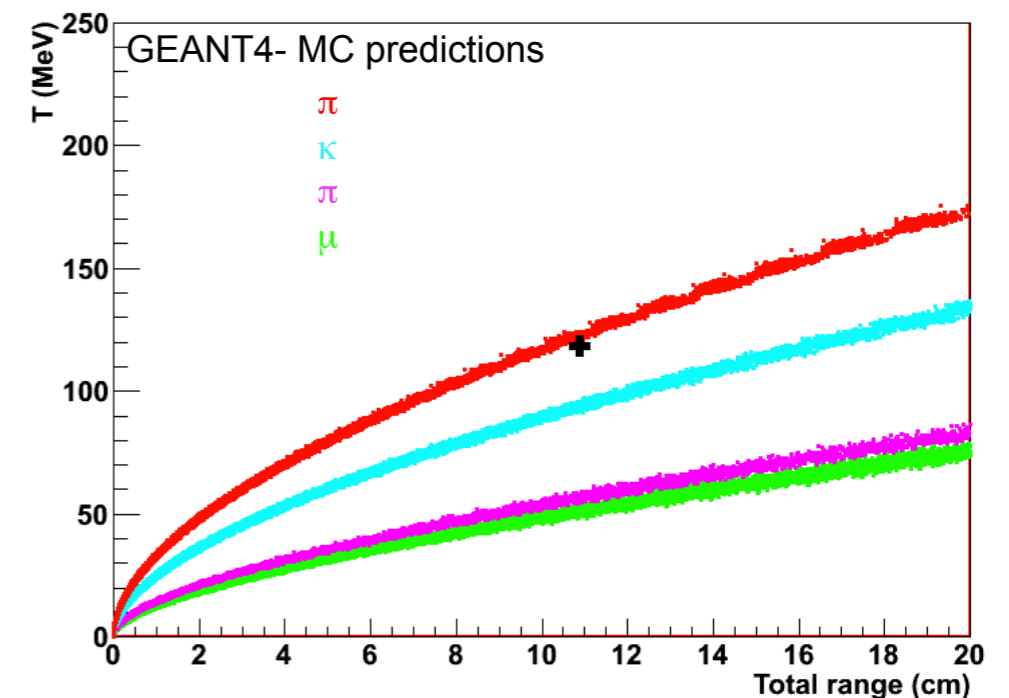
μ- escaping ArgoNeuT (and reaching MINOS-ND downstream)

Full neutrino event reconstruction with 3D ArgoNeuT-MINOS ND track matching

Muon (ArgoNeut+MINOS reconstruction): p=2.85 GeV/c

Proton (ArgoNeuT reconstruction):
track length= 10.88 cm,
T=118 MeV, p=0.485 GeV/c

$E_\nu = p_\mu \cos\theta_\mu + p_h \cos\theta_h$ Reconstructed Neutrino Energy= 3.1 GeV

CURRENT DEVELOPMENTS ON LAR TECHNOLOGY

MAIN LINES OF DEVELOPMENT

- [LAr Purity (materials' compatibility & selection) and LAr Purification]

- Ionization Charge signal extraction: alternatives to wires

- Scintillation Light signal extraction   *(the most promising line of development)*

- Electron Charge Drift over long distance

- Cryostat Insulation schemes and developments

- Cold read-out electronics vs. Warm electronics

- Event Reconstruction and Off-line code developments

- LAr Response Characterization:
   Charge recombination and calorimetry

LArTPC ResponseCharacterization
at the FNAL Test BeamS Facility

required for a range of energies - $\mathcal{O}(0.5\text{-}5.)$ GeV - relevant to forthcoming experiments like MicroBooNE, and to future experiments like LAr1 and Long baseline LAr detectors at the Intensity Frontier.

A staged program:

Phase-1: Single track reconstruction:

"calibration" = <u>charge</u> to <u>energy</u> conversion

i.e. determination of the charge Recombination factors for

Proton identification and p to K separation

Kaon identification and K to π/μ separation

and study of

Electron to γ ($\rightarrow e+$ $e-$ pair) separation

Phase-2: Collective topology reconstruction

"calibration" = <u>detected energy</u> to <u>incident energy</u> conversion

i.e. $e \rightarrow$ el.m. cascade: size and features

$\pi \rightarrow$ hadron cascade: invisible component and features

and e/π Ratio

Lar Detector Test Beam Calibration AT FNAL (FTBF)

Calibration is a critical step to understanding the detector output

FNAL test beam (FTBF) is an ideal Facility, providing a range of known energies (with secondary and low momentum tertiary beam lines) and a selection of particles of different types and both polarity.

It also provides a controlled environment in which to tune simulations and to develop tools for particle identification (PID), calorimetry, and event reconstruction (without relying solely on simulation).
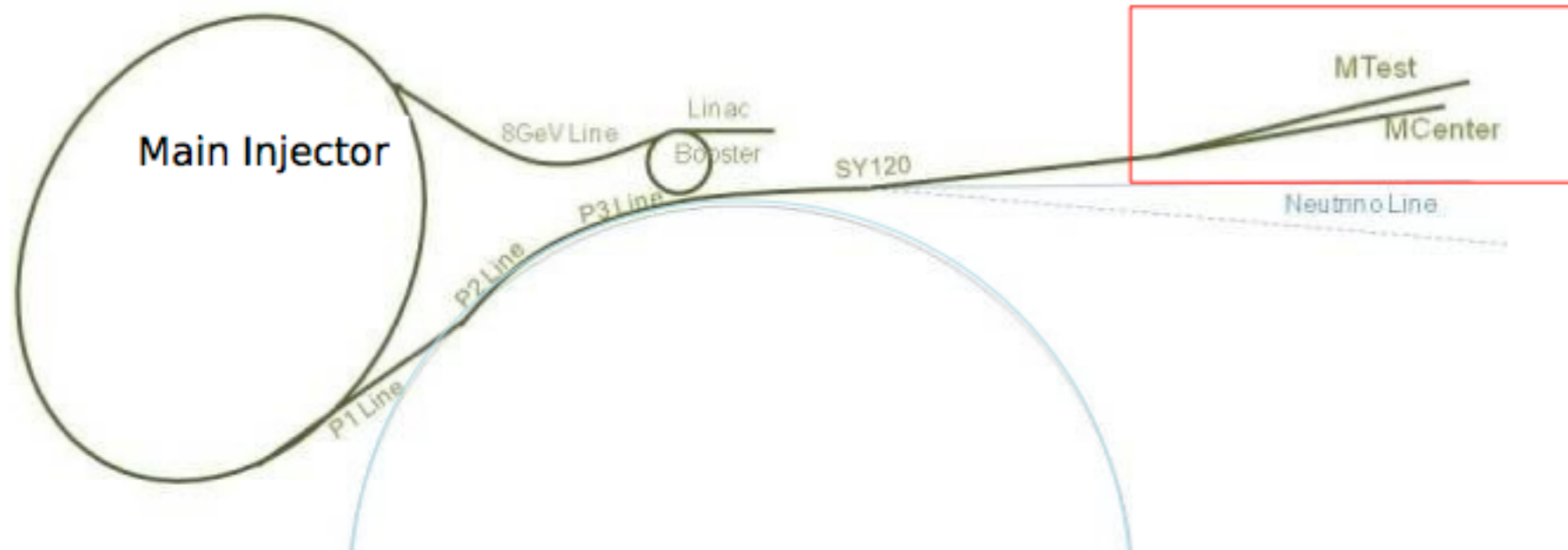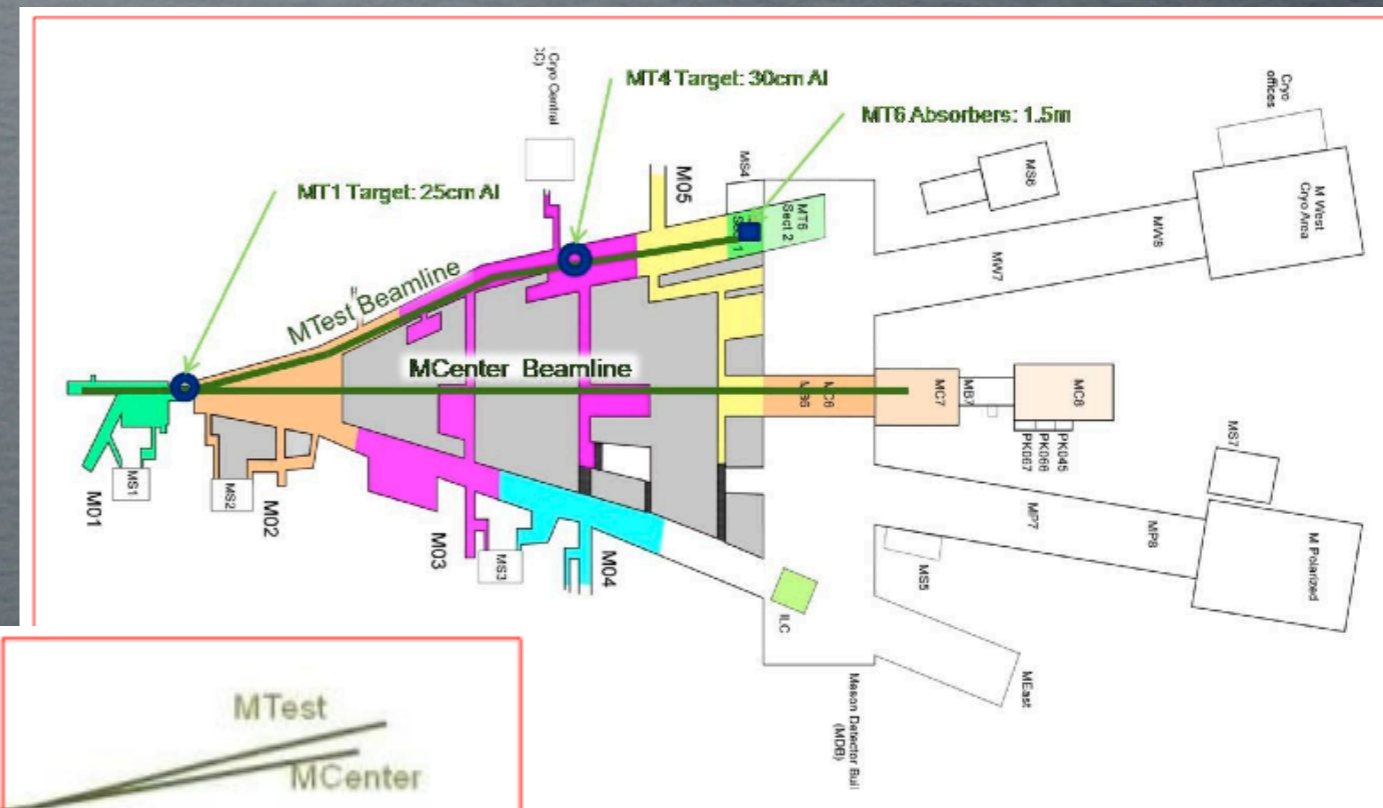
M-Center: A PERMANENT TESTBEAM FACILITY FOR LAr DETECTORS
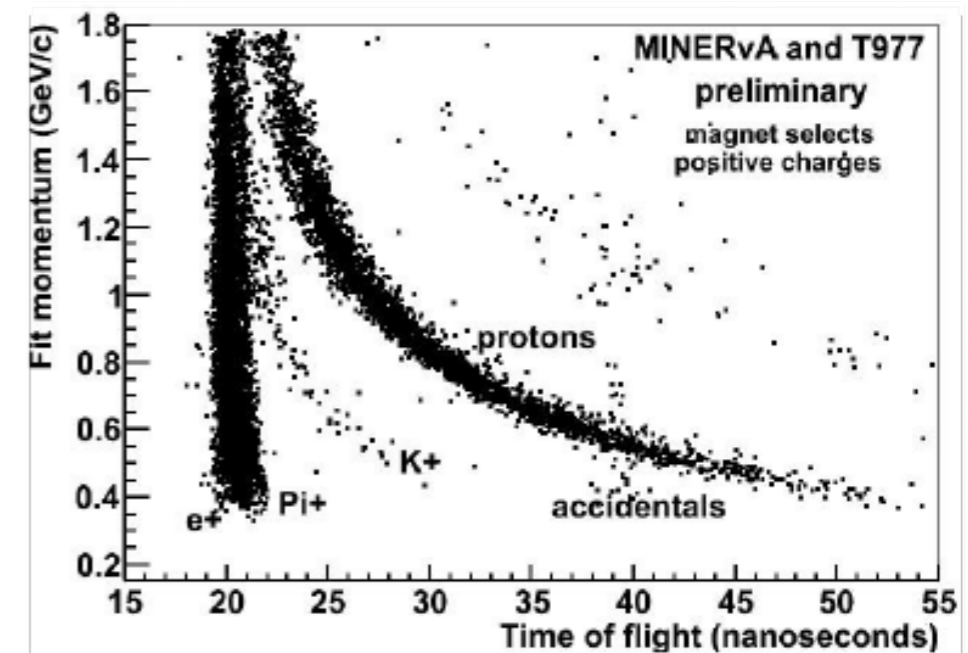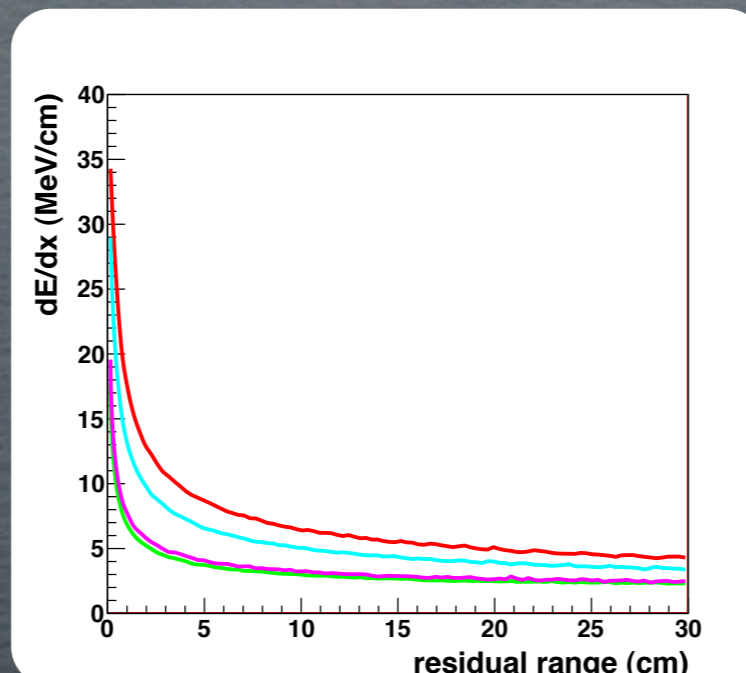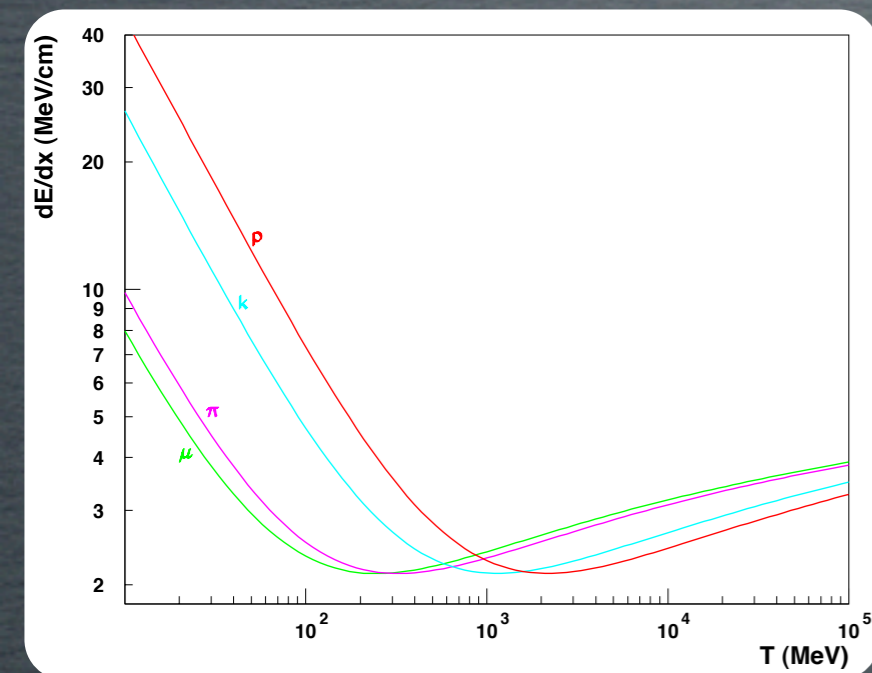
NEEDS:

PURE **LOW MOMENTUM** (TERTIARY) **BEAM** OF MUONS, PIONS, KAONS, AND PROTONS THAT PENETRATE, SLOW DOWN AND STOP IN THE LAR VOLUME.

⇒ SMALL VOLUME LARTPC DETECTOR (ARGONEUT).

Stop. Ptcl. Type	Dep.En.≡ Inc. kin. En.	Inc. Beam Mom.	dE/dx Interval
μ	205 MeV	290 MeV/c	2.1 ÷ 13 MeV/cm
π	210 MeV	320 MeV/c	2.1 ÷ 14 MeV/cm
K	285 MeV	600 MeV/c	2.8 ÷ 23 MeV/cm
p	380 MeV	940 MeV/c	3.1 ÷ 33 MeV/cm

FTBF Tertiary Beam
(from MINERvA set-up)

MAIN GOALS:

(1) PRECISE MEASUREMENTS OF ELECTRON-ION RECOMBINATION IN ARGON OVER AN EXTENDED RANGE OF ENERGY DEPOSITION (dE/dx), FOR DIFFERENT ELECTRIC FIELDS, AND AT DIFFERENT TRACK-TO-ELECTRIC-FIELD ANGLES.

Fig. 5. Birks fit of the inverse of the recombination factor vs. stopping power. Data are from the 3 ton prototype at different electric fields.
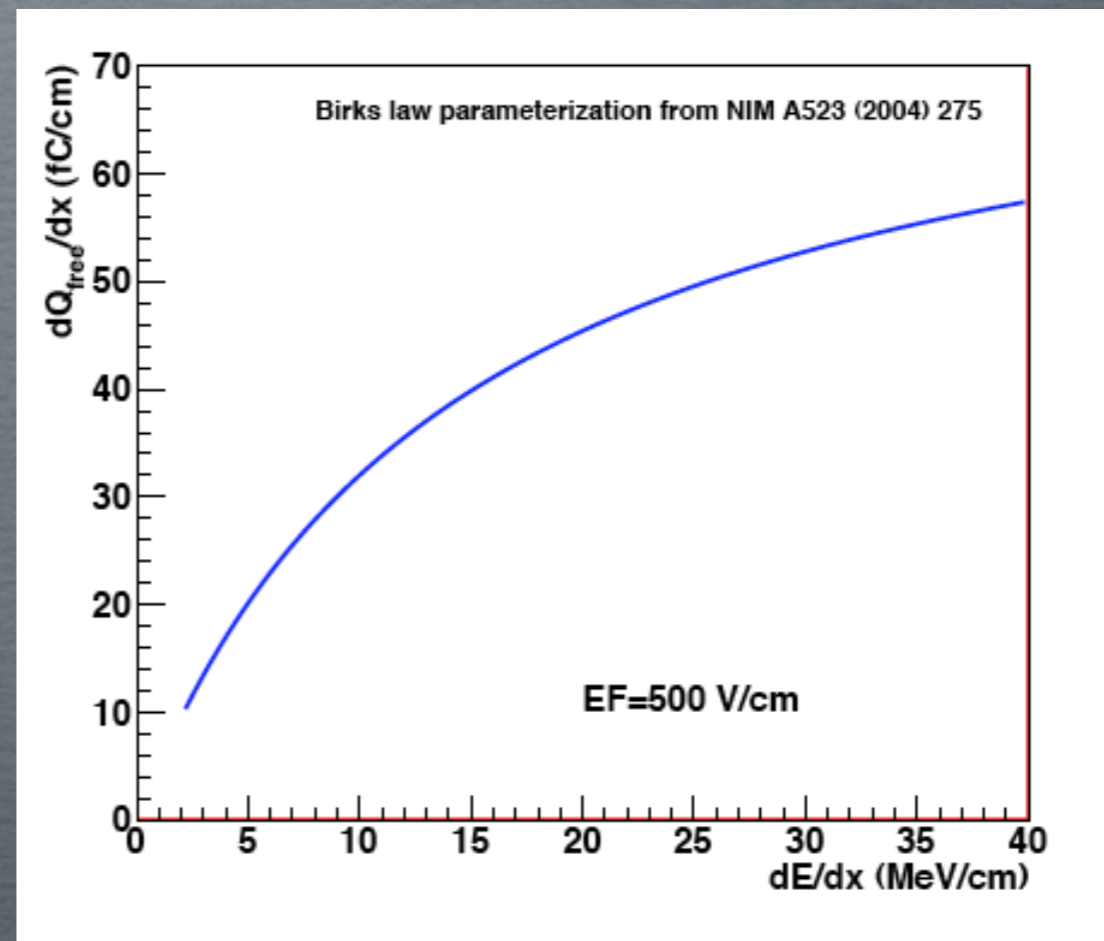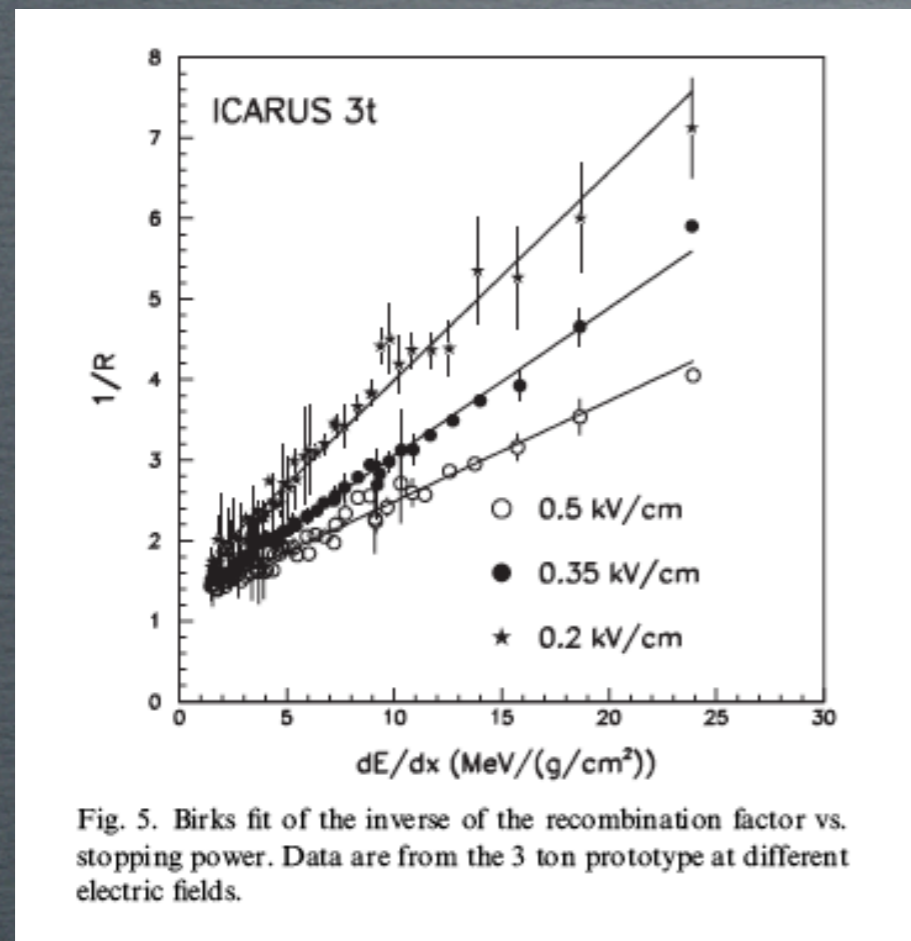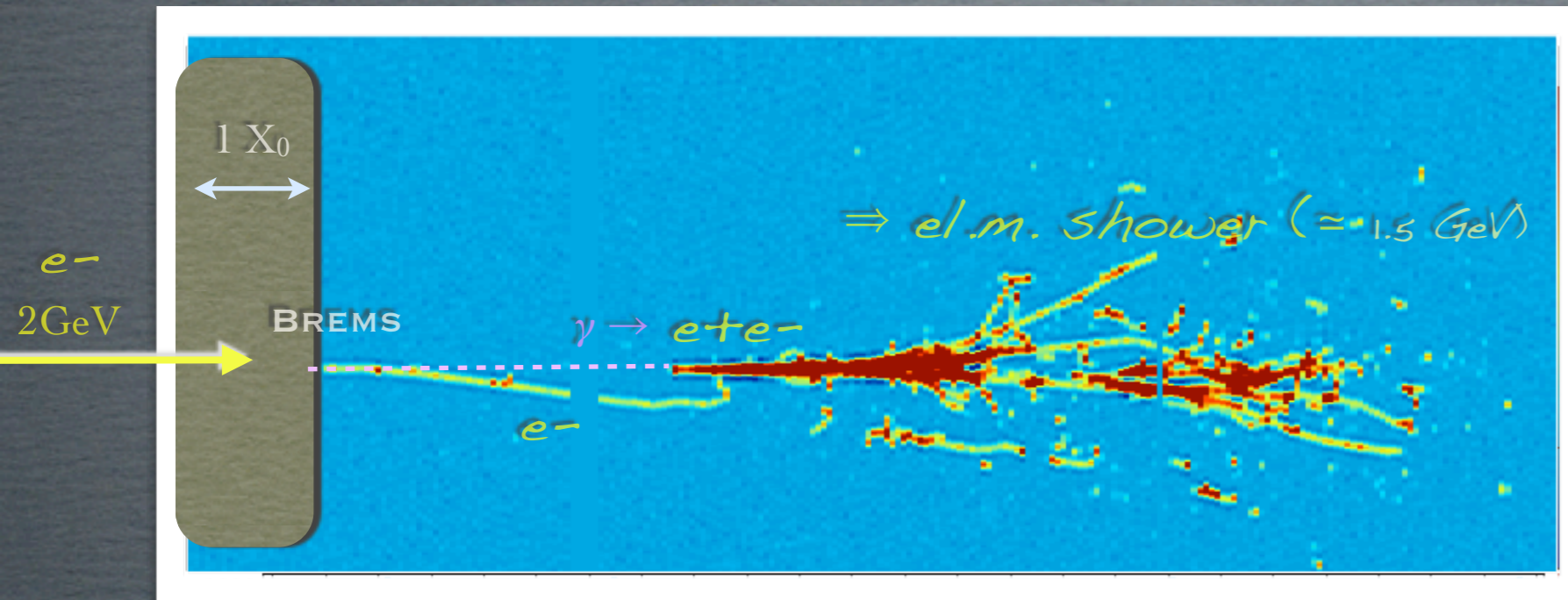

Precision in charge deposition reconstruction along the track is fundamental
for Calorimetry and Particle Identification
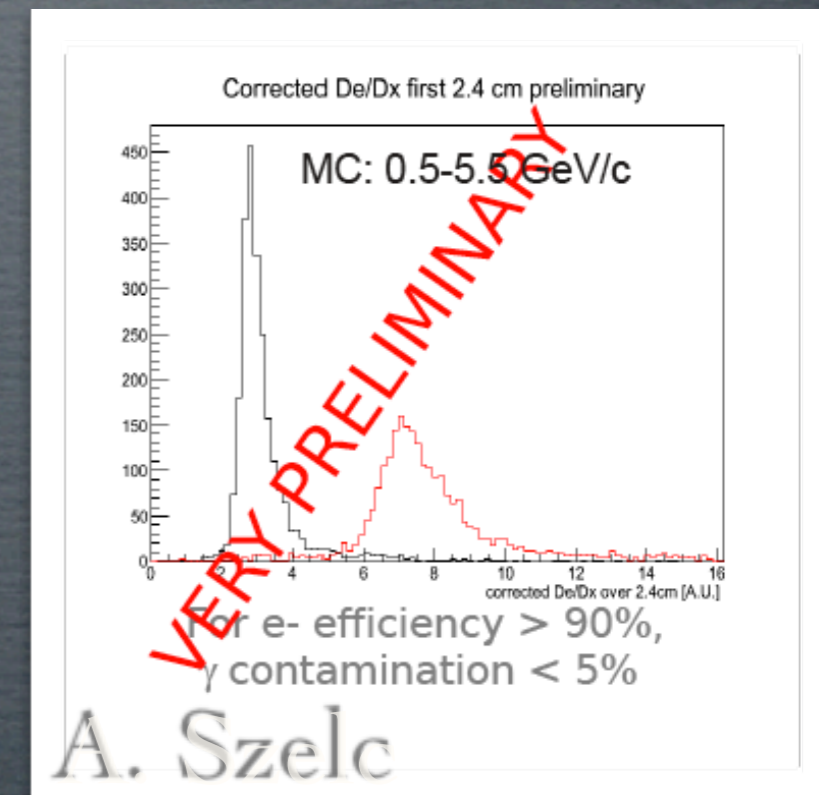
Phase 1 (2013/14): *Single track reconstruction*

MAIN GOALS *(continued)*:

(2) DIRECT MEASUREMENT OF electron to γ ($\rightarrow e^+ e^-$ PAIR) SEPARATION WITH LarTPC

"PHOTON BEAM" GENERATED BY BREMS FROM ELECTRON BEAM ON $1X_0$ PRESHOWER
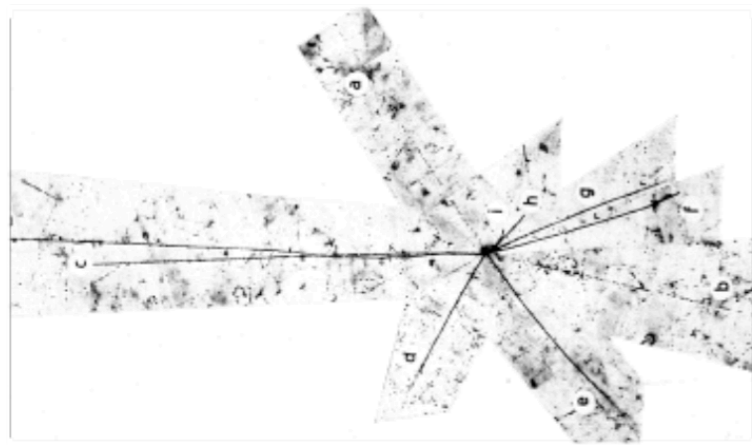
needed for optimization and direct test of

e/ γ separation

from MC simulations

A. Szelc

Phase 1 (2013/14): *Single track reconstruction*

OTHER GOALS:

- $\bar{p}$ BEAM (LOW MOM.): HADRON STAR TOPOLOGY STUDY FROM $p\bar{p}$ ANNIHILATION IN AR

(RELEVANT FOR $n\bar{n}$ OSCILLATION SEARCH WITH FUTURE LARGE LArTPC DETECTORS)

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*

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

- SCINTILLATION LIGHT COLLECTION

(HQE PMT ARRAY IN LAr $\oplus$ WLS FILM

ON REFLECTOR SURFACE)

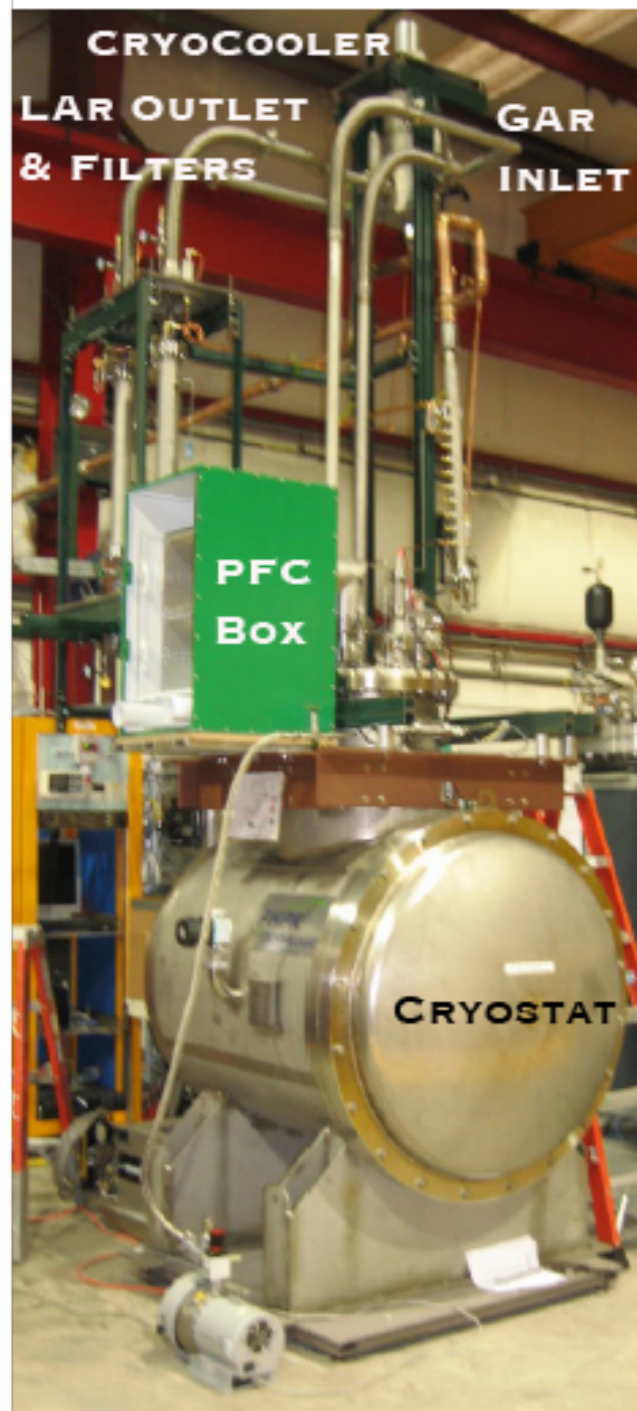*complementary to charge for evt. recosntruction*

- WARM VS. COLD ELECTRONICS:

TEST AND CHARACTERIZATION

for wire Signal-to-Noise improvement

LArTPC

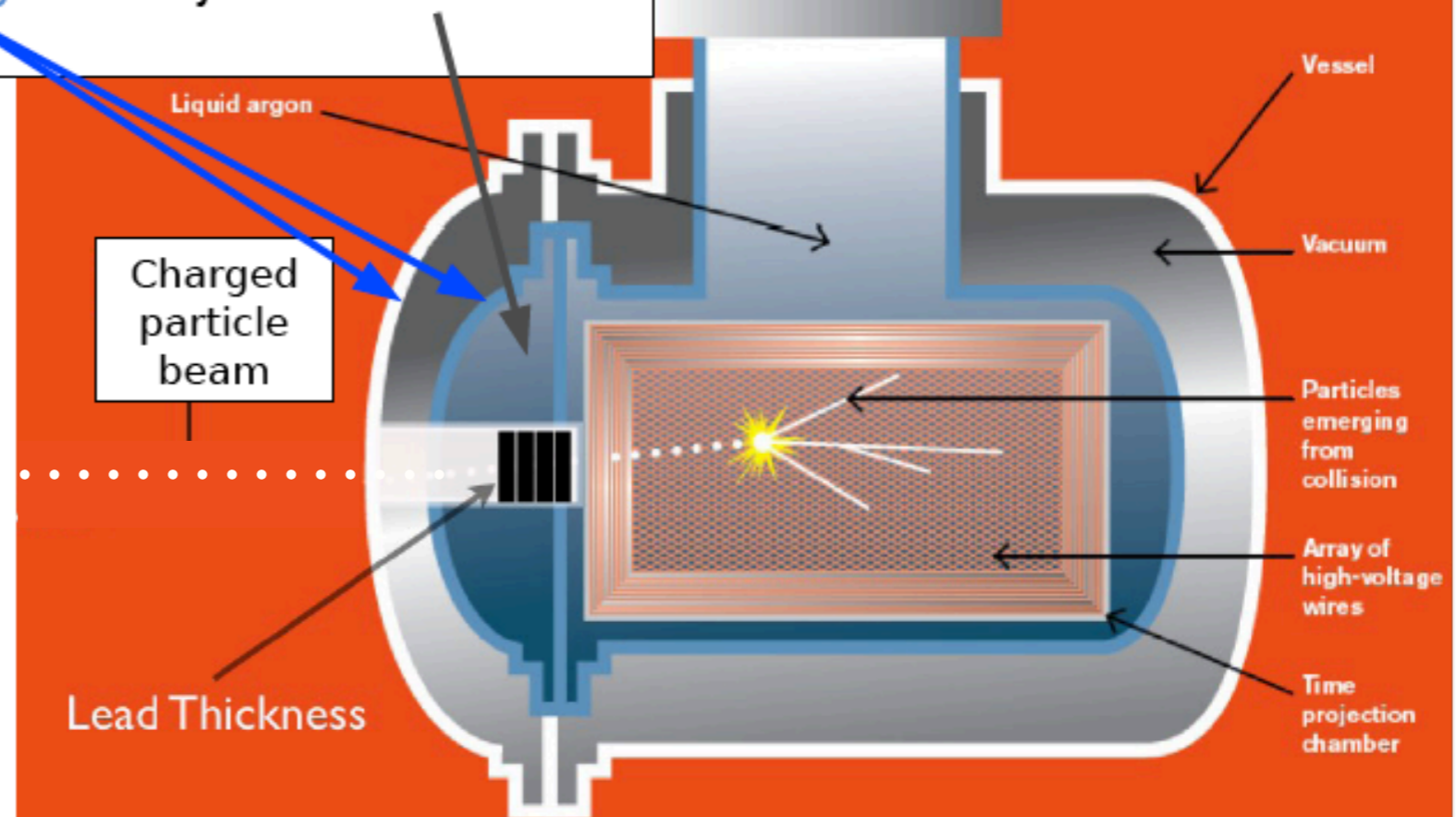CRYOCOOLER
LAR OUTLET & FILTERS
GAR INLET
PFC Box
CRYOSTAT
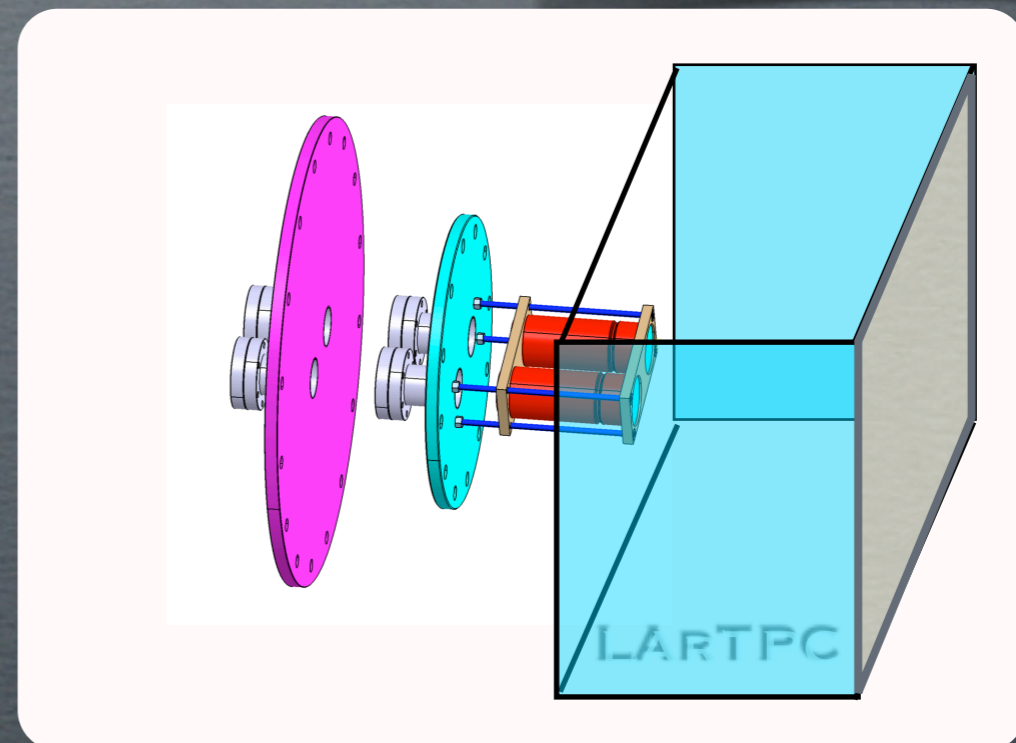
Modified ArgoNeuT in FTBF

Beam Window

The ArgoNeuT LArTPC active volume is separated from the outside by 2 thick **front-flanges** and by a thick LAr dead layer

Charged particle beam

Lead Thickness

Liquid argon

Vessel

Vacuum

Particles emerging from collision

Array of high-voltage wires

Time projection chamber
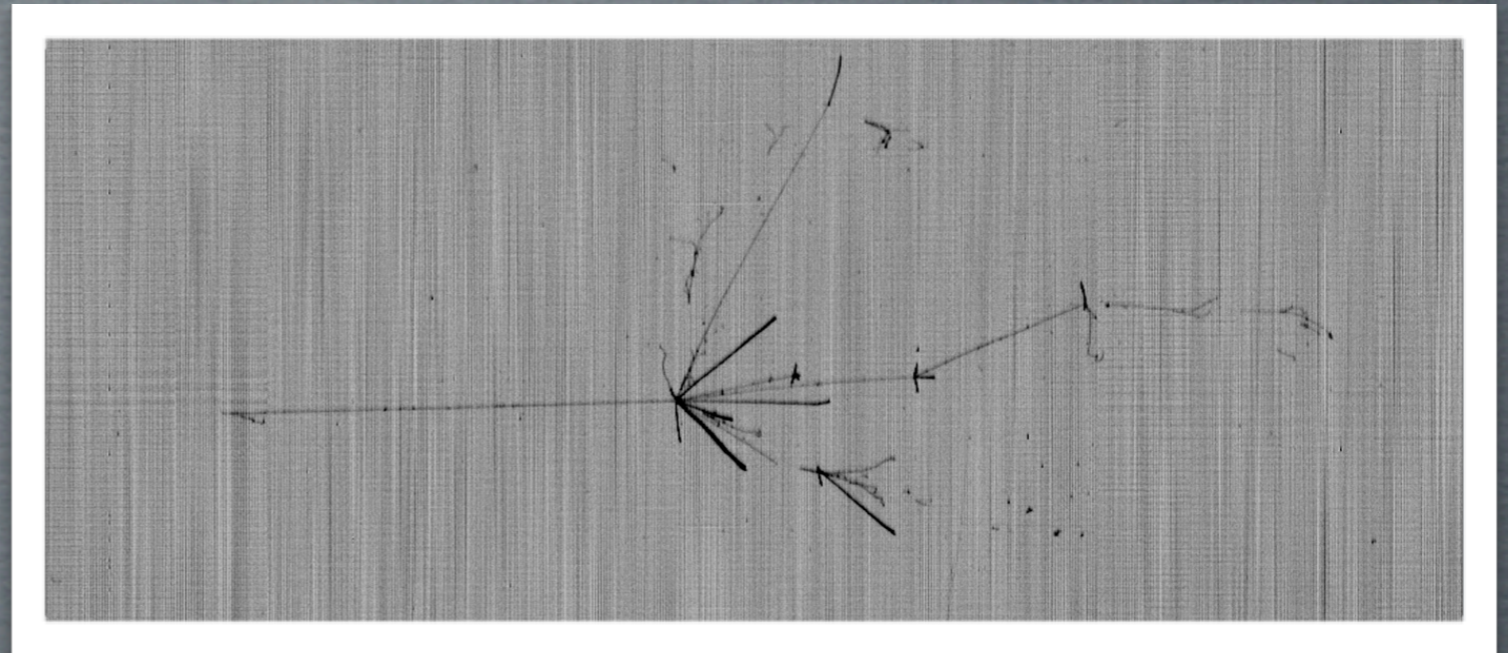
A pipe for the beam, where a pre-shower inducer (e.g., made by a changeable thickness of lead slabs) can be housed, must be designed before ArgoNeuT can be used in a test beam
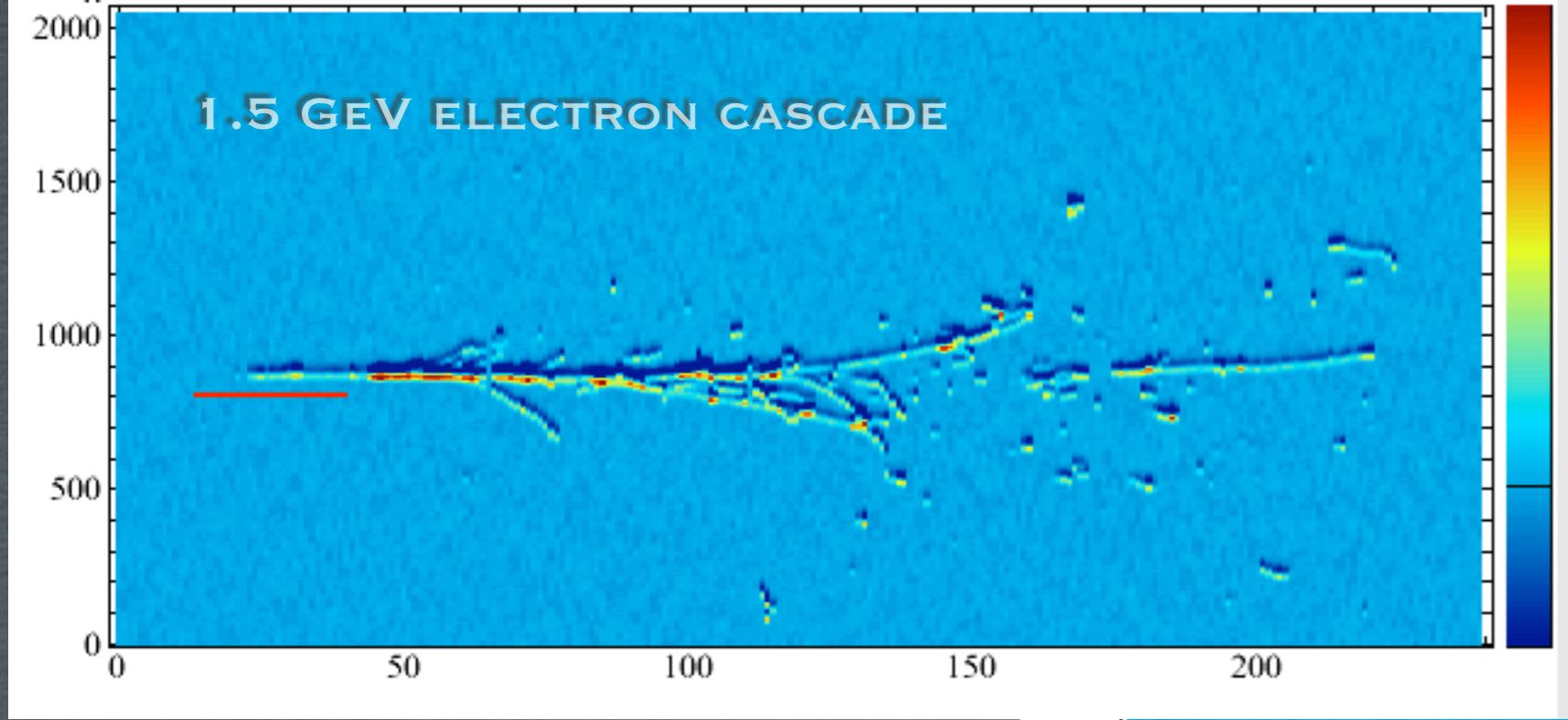
Phase 2 (>2014): *Collective Topologies reconstruction*

FINAL STATE PTCL.S (*Hadrons* AND *electrons*) FROM NuMI-LE/BOOSTER NEUTRINO INTERACTIONS INDUCE "**LOW-POPULATED CASCADES**".


ICARUS T600 events (cosmics at surface)

MAIN GOAL OF PHASE-2 AT FTBF IS TO DETERMINE THE "INVISIBLE BUDGET" IN THE TOTAL DEPOSITED ENERGY FOR EACH TYPE OF PARTICLE AS A FCN. OF ITS INCIDENT ENERGY (CONTRIBUTIONS FROM SOFT γ'S, NEUTRONS, BINDING ENERGY, NEUTRINOS,...)

1.5 GeV electron cascade

(A.Szelc-Yale)

MC study for Phase2:
low energy/low trk multiplicity cascades
from electrons and pions

1.2 GeV pion
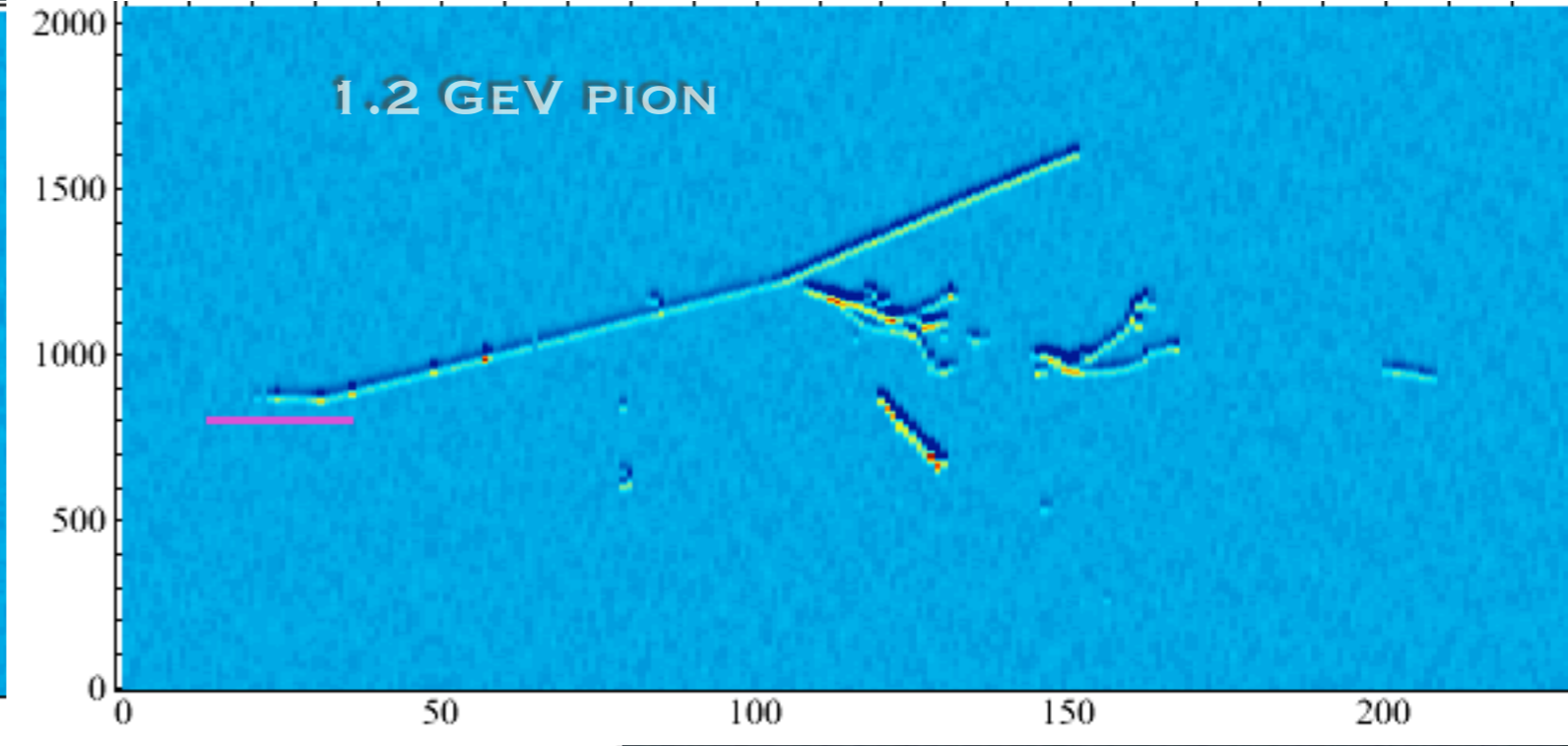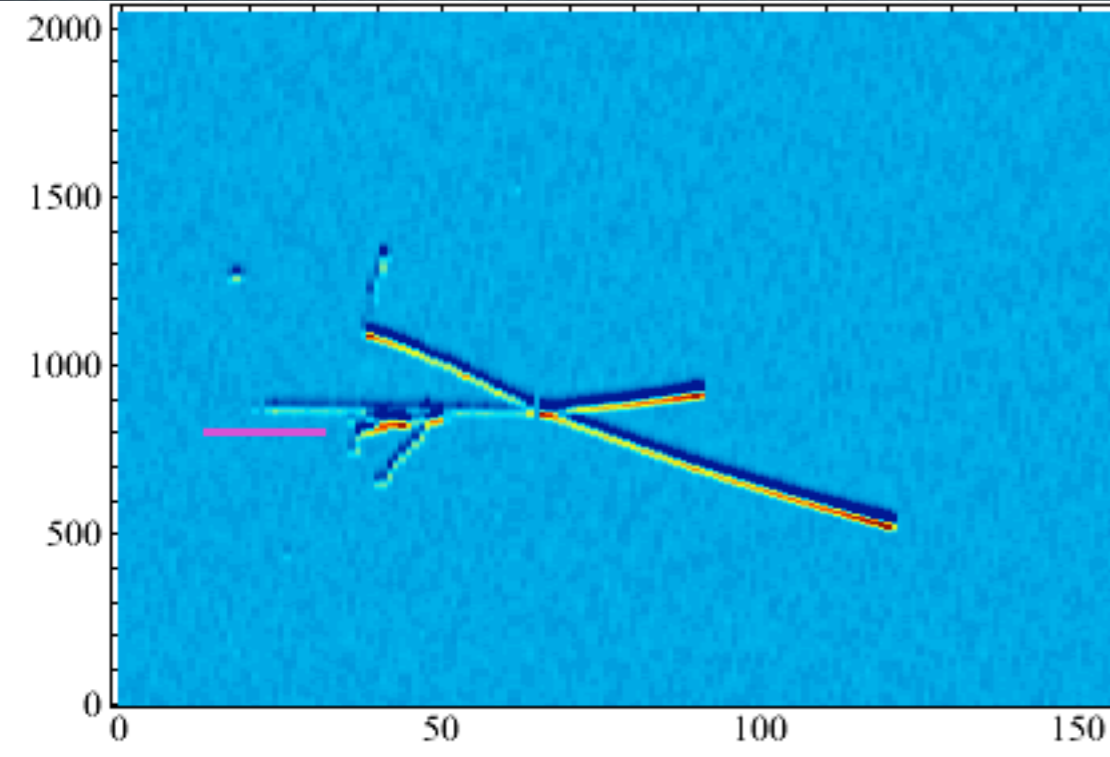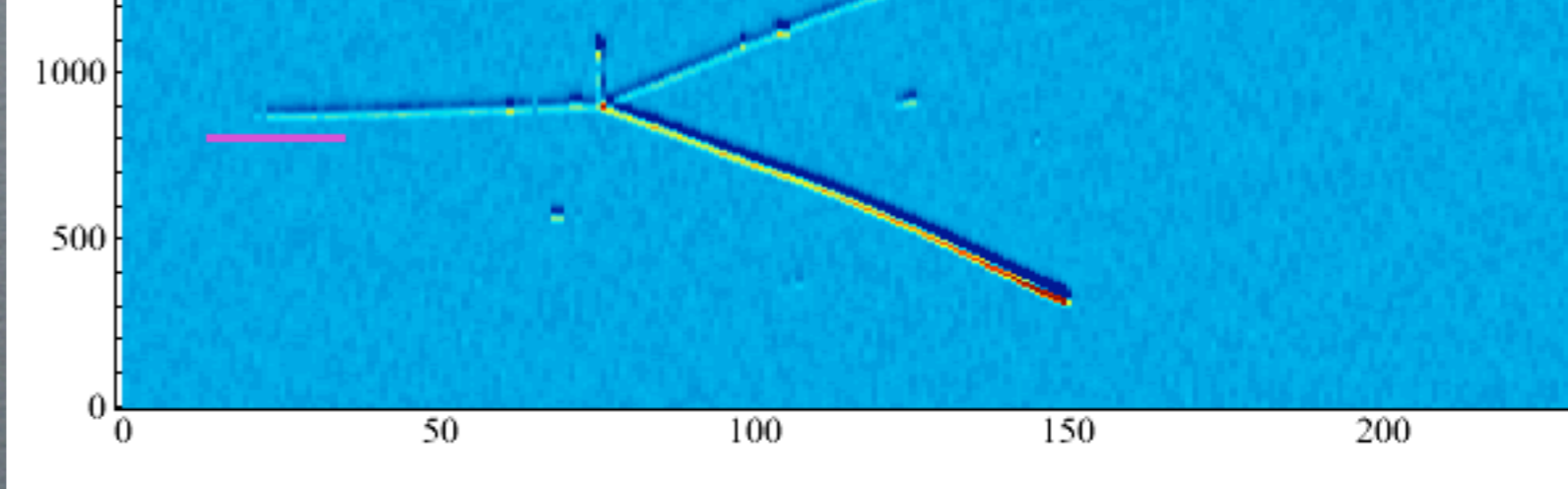
Phase 2 (>2014): Collective Topologies reconstruction

electrons in LAr

$X_0 = 14$ cm $\varepsilon_c = 30$ MeV

$t_{max} = 2.5\ X_0$ [=35 cm]   (for ~1 GeV electron)

$t_{95\%} = 13.5\ X_0$ [=190 cm] (for ~1 GeV electron)

$R_{95\%} = 22$ cm   (about 2 R_M)

• The elm. energy deposition mechanisms are very well known (⇒ MC simul. very reliable):

 In LAr a substantial fraction of *incident energy* (≈30% - depending on incident energy) goes into soft electrons (< 2 MeV)

• How well the *incident energy* can reliably be reconstructed with a LArTPC ?

   this can be established (only) by test-beam data

hadrons in LAr

•   Development at λ_{int} scale rather than X_0 scale (for LAr $\lambda_{int} \approx 5\ X_0 \approx 80$ cm) ⇒ Containment more difficult

The fraction f_{elm} (%) going to elm fluctuates heavily (after first generation $\langle f_{elm} \rangle \approx 25$ %) and is energy-dependent

A fraction f_n is carried by "soft" neutrons (few tens n/GeV, $\langle f_{elm} \rangle \approx 10$ %).

A fraction f_{inv} (%) is practically undetectable $\langle f_{inv} \rangle$ = ?? in LAr (presumably ≈ 10 %)

In LAr f_{elm}, f_n, f_{inv} were never measured - only inferred by MC.

   these can be established (only) by test-beam data

LArTPC is an imaging detector, but also acts as a homogeneous calorimeter.

The possibility to develop "TPC/imaging-aided calorimetric measurements" may open a new way to investigate energy deposition mechanisms at unprecedented level of detail.

B. Rebel (PAC Meeting - Aspen, June 19, '12)
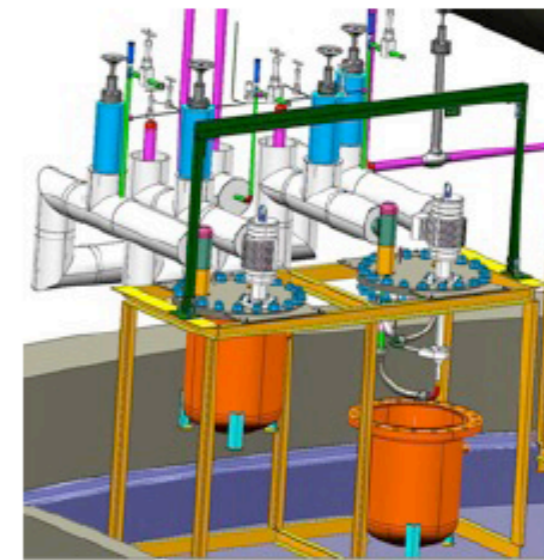
Phase 2: Cryostat and TPC Size

- TPC should have active volume on the scale of 1m x 1m x 5m

- Studies to optimize the size are underway

- MCenter large enough to accommodate a 5m long TPC, cannot go much over 1m transversely

Phase 2: The Facility

MicroBooNE
Filter Skid

MicroBooNE
Pump Skid

- Fermilab would provide the facilities, other groups would provide the active detectors
- The facility will provide a filtration and pumping system that is appropriately sized to the volume of LAr
- Use experience from LAPD and MicroBooNE for cryogenic system design
- Cryostat should have a flanged head to allow convenient access to inside of vessel
- Imagine exchanging electronics, light collection systems, TPCs, etc during several year program

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A NEW INTERNATIONAL COLLABORATION IS BEING FORMED
(AT PRESENT INCLUDES GROUPS FROM US, UK, It)

TOWARD THE INTENSITY FRONTIER

ADDRESSING

THE SHORT-BASELINE ANOMALIES AT FNAL

▸ **MicroBooNE** ≥ 2014 @ Booster (FNAL)
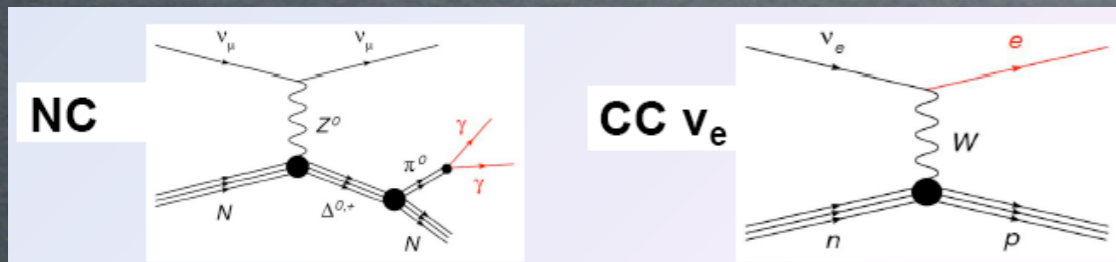
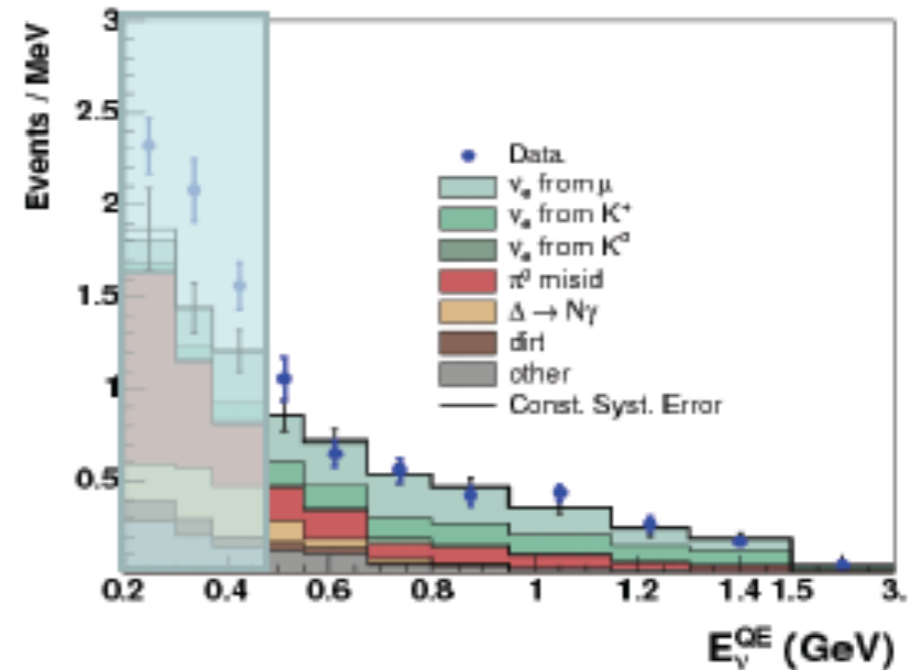*under construction*

▸ **LAR1** ≥ 201? @ Booster (FNAL)

(LoI - PAC Meeting, Aspen - June 19, '12)

MiniBooNE: The low-energy excess (ν-mode)
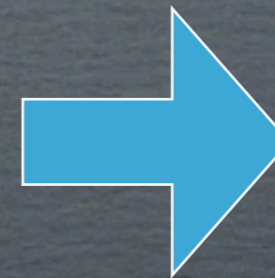
▸ MiniBooNE experiment observed an excess (3σ) of low–energy (200 MeV – 475 MeV) events in <u>neutrino mode</u>

▸ The excess events are electron–like: e^-/γ

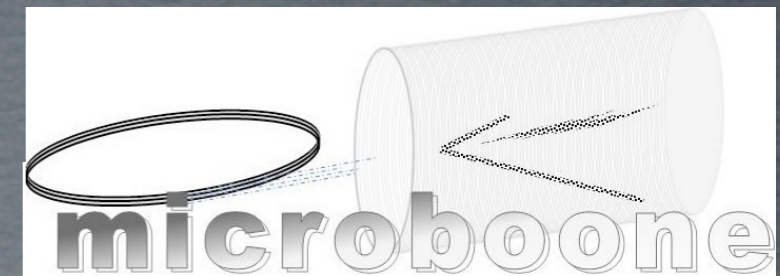▸ MiniBooNE (CerenkoV detector) cannot distinguish between electrons and photons, e.g.

- 6.7e20 POT
- 128.8 ± 20.4 ± 38.3 (3.0σ)
- Fit E=475-1250 MeV

Need of a new detector
(new technology)
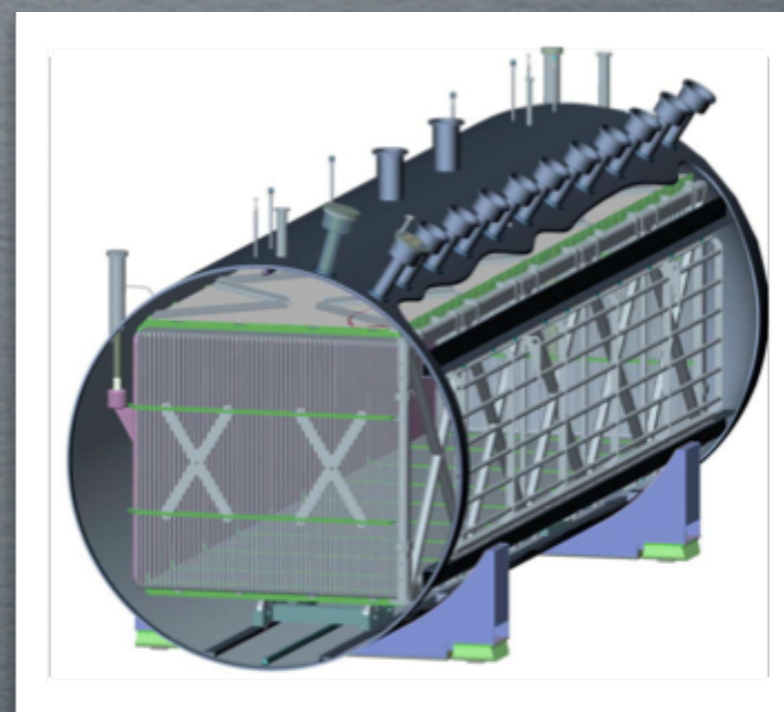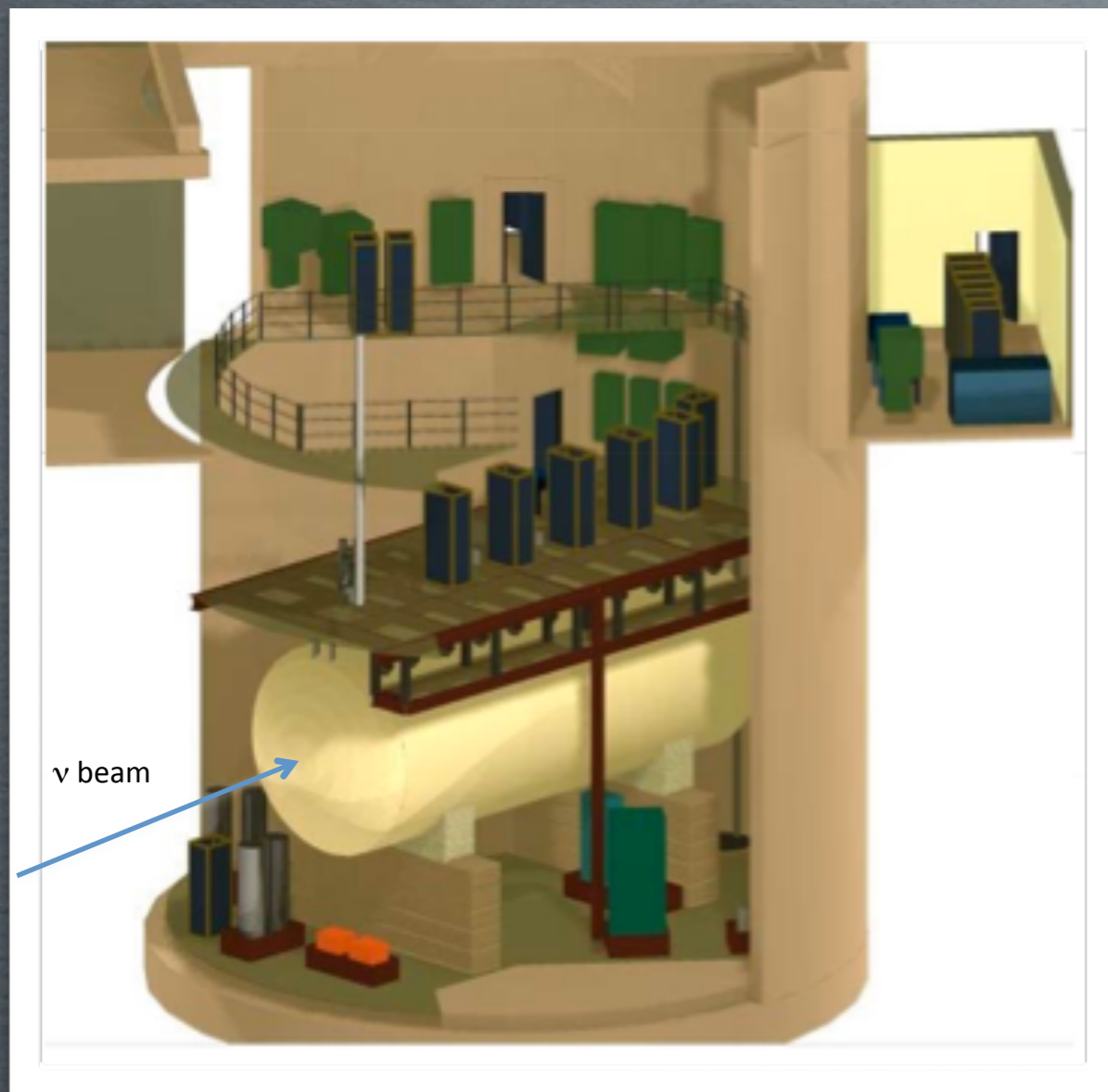to address the MiniBooNE low–energy excess
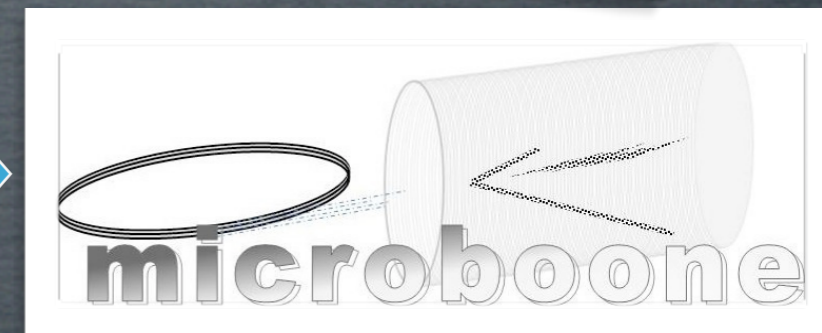
MicroBooNE

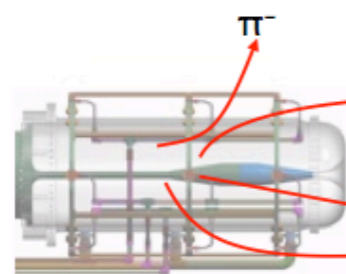**Under Construction Commissioning: early 2014**

- 170 tons total liquid argon
- 86 tons active volume (60t fiducial)
- TPC dimensions: 2.5m x 2.3m x 10.4m
- 30 PMTs

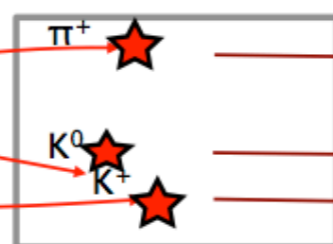*Collaboration:*
BNL, Columbia, FNAL,
KSU, LosAlamos, MIT,
MSU, Princeton,
StMarys,
Syracuse, Cincinnati,
Texas, Yale*

ν beam

π−

π+ ⋆   ν_μ

K⁰ ⋆   ν_e   Oscillations ?
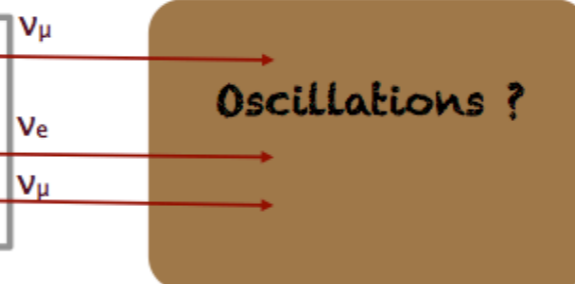
K+ ⋆   ν_μ

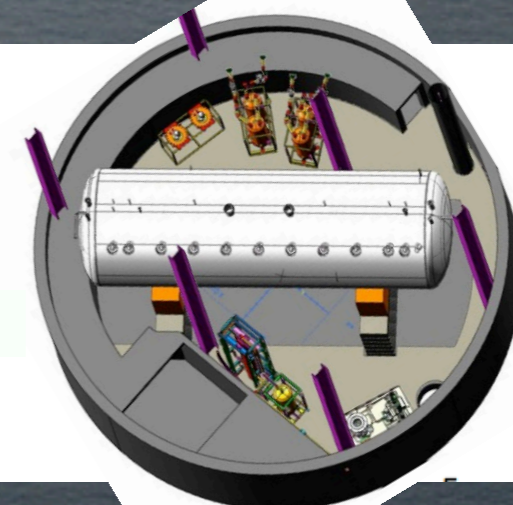FNAL booster
(8 GeV protons)

target and horn
(174 kA)

decay region
(50 m)

dirt
(470 m)

MicroBooNE

March, '12

May, '12

June, '12

...after Summer, '12

MicroBooNE

Detector Components under fabrication
(e.g.: *wire production completed TODAY !*)
Orders placed for main cryogenics and detector elements

Wires at Syracuse
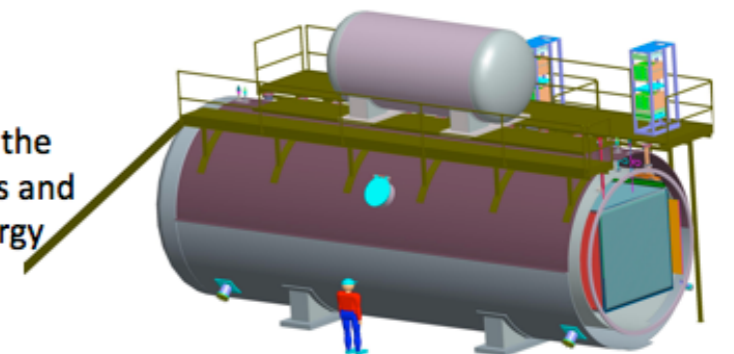
May 18th, 2012   Collaboration Meeting   4

Wire winding machine at Yale

Construction at FNAL
starting during summer '12,
(completion by early '14)

The MicroBooNE Experiment:
LArTPC detector to address the MiniBooNE low energy excess and measure a suite of low energy neutrino cross sections
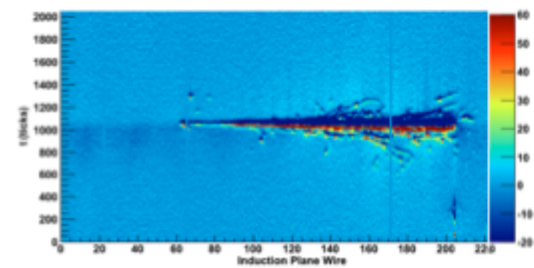
## Need a new experimental technique to address the question...

Capability to resolve particle interactions: reduce backgrounds, identify and improve signal

Liquid Argon Time Projection Chamber

Use topology and dE/dx to differentiate electrons (signal) from gammas (background) indistinguishable in Cerenkov imaging detectors

Electron neutrino candidate from ArgoNeuT

MC-evt : electron shwr

(A.Szelc-Yale)

MC-evt: $\pi^0 \rightarrow 2\gamma \rightarrow \gamma (e^+e^-)$ shwr
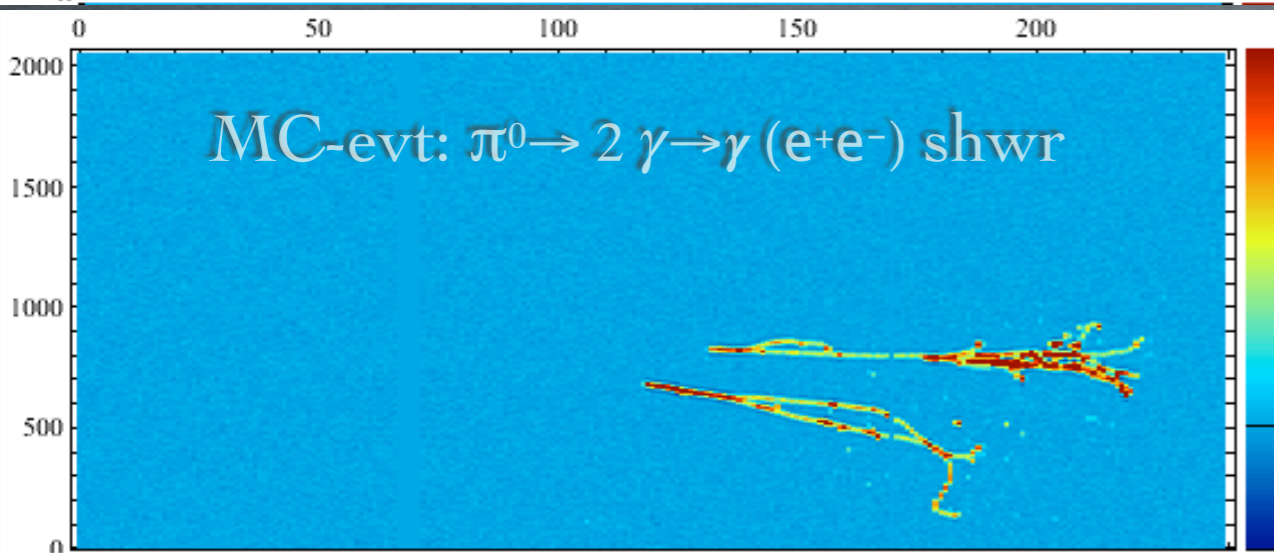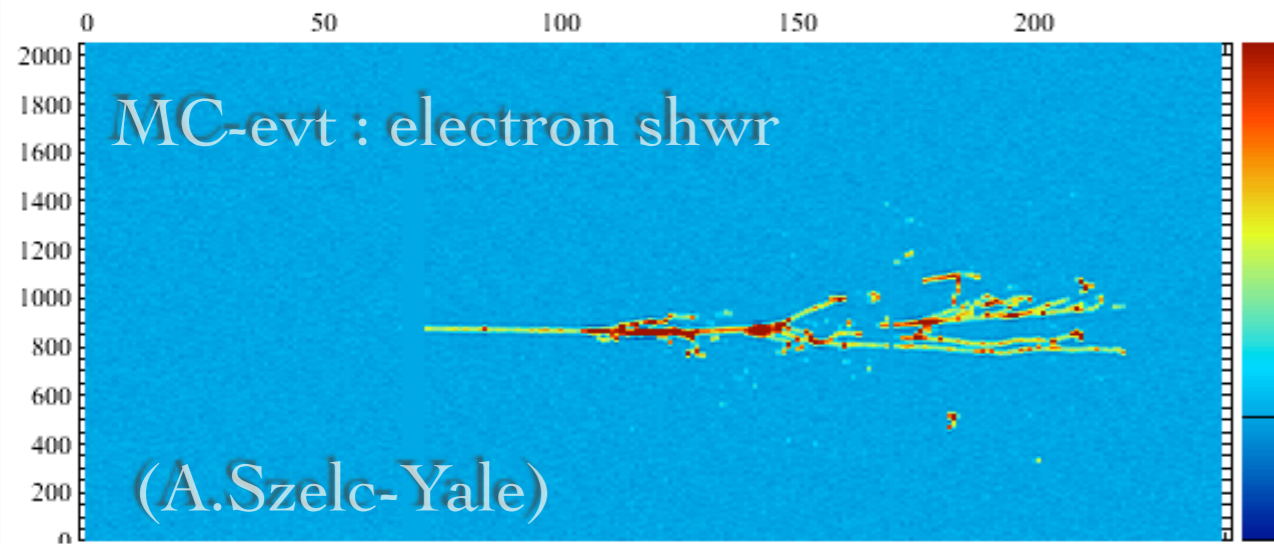
MicroBooNE's LArTPC detection technique: extremely powerful sensitivities in neutrino mode.....
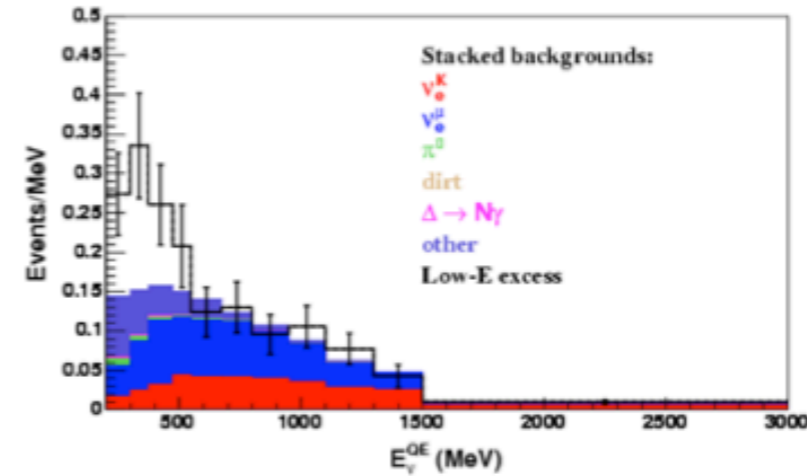
Low energy excess above background if excess is electrons

Low energy excess above background if excess is photons

dE/dx for electrons and gammas in first 2.4 cm of track

24
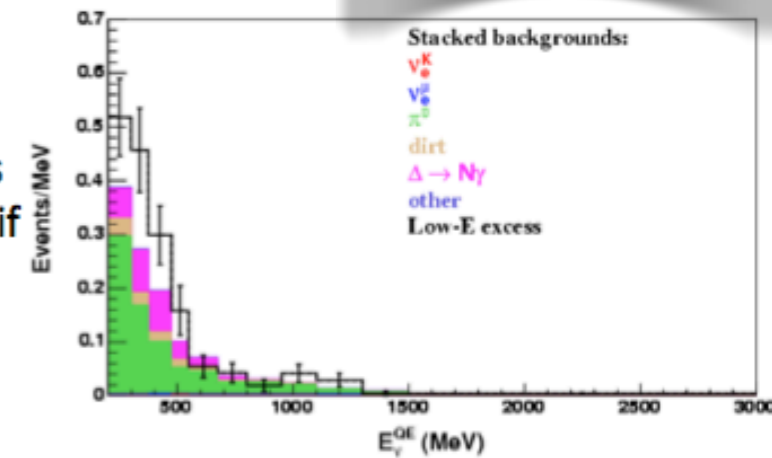
This past year in neutrino physics:

• Developing short baseline oscillation anomalies suggest new physics in neutrino sector (sterile neutrino?) – generate lots of attention...

Hints from Experiments
- LSND anomaly
- MiniBooNE anomalies (recent updates!)
- Reactor Anomaly
- Gallex and Sage data
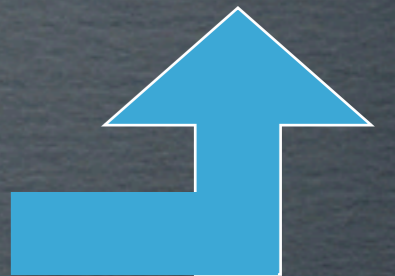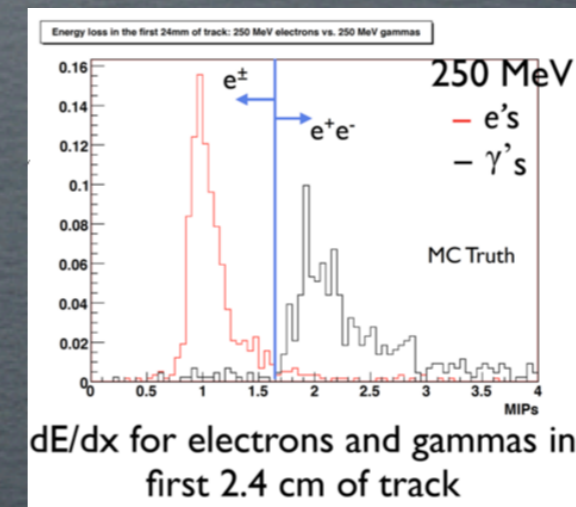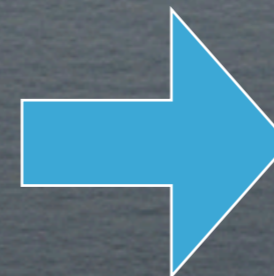
Where to address these? *Two different philosophies....*
- Decay at Rest sources (SNS)
- Reactor and Source experiments
- Accelerator experiments

LAr1

Growing interest in hints, many conferences, papers, and new ideas on how to address them

anti-ν_e CCQE signal candidates w/ 11.3e20 POT

Data (stat err.)
ν_e from $\mu^{+/-}$
ν_e from $K^{+/-}$
ν_e from K^0
π^0 misid
$\Delta \to N\gamma$
dirt
other
Constr. Syst. Error

Events/MeV

E_ν^{QE} (GeV)
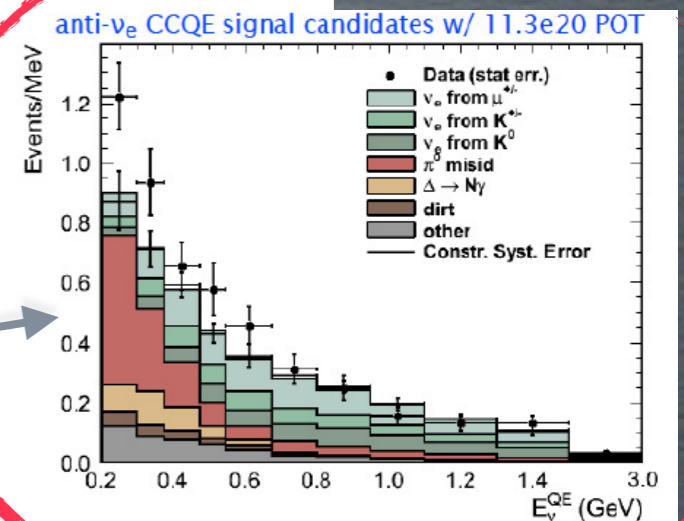
LAr1 AT FNAL BOOSTER

Bonnie Fleming
PAC Aspen, Summer 2012
June 19, 2012

A Letter of Intent for a Neutrino Oscillation
Experiment on the Booster Neutrino Beamline: LAr1
- Motivation for LAr1: Interesting hints from short
baseline oscillation experiments suggest BSM Physics
- Future program to address these at Fermilab:
MicroBooNE and

LAr1: 1kton fiducial volume LArTPC

H. Chen, C. Thorn, D. Lissauer, V. Radeka, B. Yu, G. Mahler, S. Rescia, S. Duffin, Y. Li
Brookhaven National Lab

L. Bartoszek
Bartoszek Engineering

E. Blucher, D. Schmitz
University of Chicago

D. Kaleko, G. Karagiorgi, B. Seligman, M. Shaevitz, B. Willis
Columbia University

B. Baller, H. Greenlee, J. Raaf, R. Rameika, G. Zeller
Fermi National Accelerator Laboratory

M. Messier, S. Mufson, J. Musser, J. Urheim
Indiana University

W. Huelsnitz, W.C. Louis, G.B.Mills, Z. Pavlovic, R.G. Van De Water
Los Alamos National Laboratory

L. Bugel, J. Conrad, T. Katori, C. Ignarra, B. Jones, M. Toups
Massachusetts Institute of Technology

Kirk McDonald   J. Assadi, M. Soderberg
Princeton University   *Syracuse University*
C. Mariani   M. Marshak
Virginia Tech   *University of Minnesota*

F. Cavanna, E. Church, B.T. Fleming, R. Guenette, O. Palamara, K. Partyka, A. Szelc
Yale University

Bonnie Fleming
PAC Aspen, Summer 2012
June 19, 2012

A Letter of Intent for a Neutrino Oscillation Experiment on the Booster Neutrino Beamline: LAr1
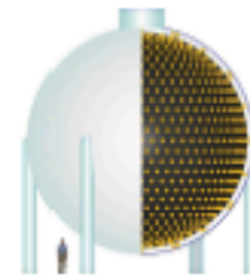
- Motivation for LAr1: Interesting hints from short baseline oscillation experiments suggest BSM Physics
- Future program to address these at Fermilab: MicroBooNE and

LAr1: 1kton fiducial volume LArTPC

A longer term program of short baseline oscillation physics at Fermilab

Booster
Neutrino Beam
Source

MiniBooNE/MicroBooNE team studying physics potential of phased program to address this physics. -- Work in progress...

Example:

2012 •Phase 0: Continued running of MiniBooNE in anti-neutrino mode

A longer term program of short baseline oscillation physics at Fermilab

Booster
Neutrino Beam
Source

MiniBooNE/MicroBooNE team studying physics potential of phased program to address this physics. -- Work in progress...

Example:

2012 •Phase 0: Continued running of MiniBooNE in anti-neutrino mode

2014 •Phase 1: MicroBooNE run in neutrino mode to address low energy excess

A longer term program of short baseline oscillation physics at Fermilab

Booster Neutrino Beam Source

MiniBooNE/MicroBooNE team studying physics potential of phased program to address this physics. -- Work in progress...
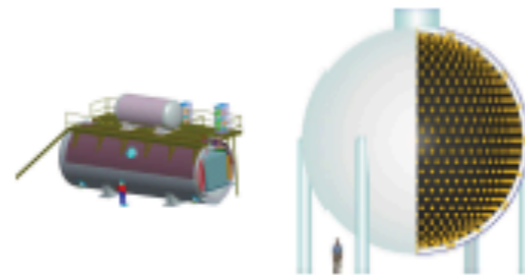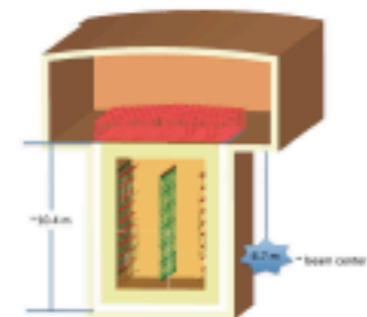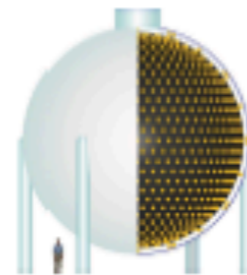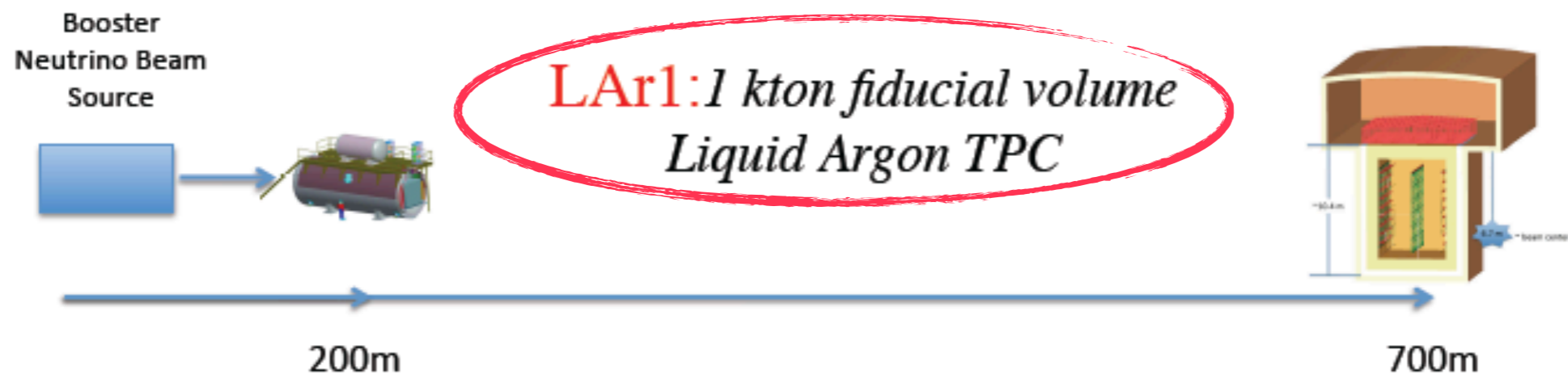
Example:

2012 •Phase 0: Continued running of MiniBooNE in anti-neutrino mode

2014 •Phase 1: MicroBooNE run in neutrino mode to address low energy excess

201? •Phase 2: Near/Far comparison: MicroBooNE (near detector) and Large 1kton scale LArTPC address anti-neutrino results (far detector)

- Located at 700m on the Booster Neutrino Beamline
- MicroBooNE, moved to 200m, serves as its near detector
- $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance search: Near/Far Comparison
- Can also extend reach in $\nu_\mu \rightarrow \nu_e$ appearance
- Physics program is complementary to other programs on site (MicroBooNE, MINOS+)

Combines physics program with development towards LBL experiments: LBNE

Expected event rates

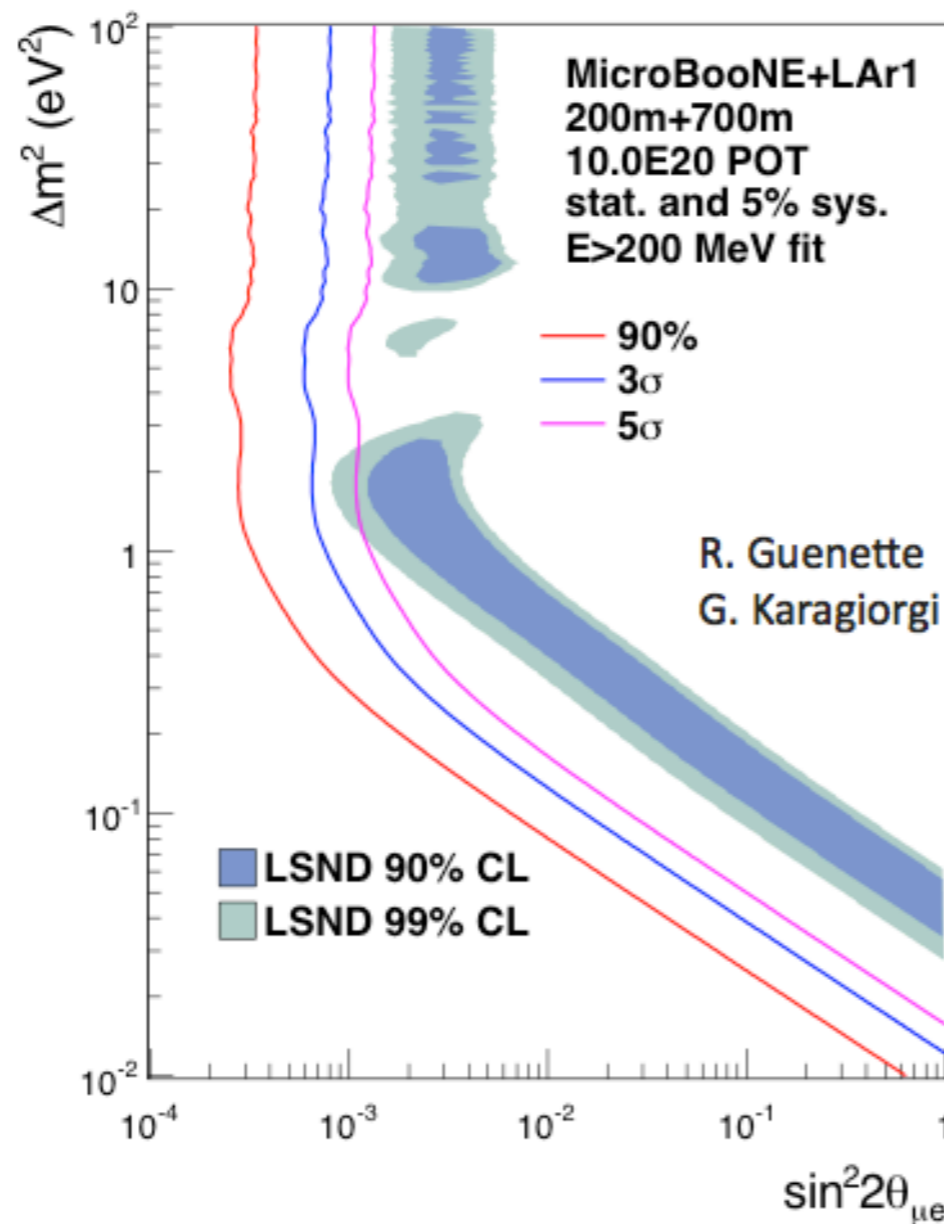| Intrinsic ν_e	Intrinsic $\overline{\nu}_e$	LSND Best Fit $\nu+\overline{\nu}$	ν_μ	$\overline{\nu}_\mu$
200-3000 MeV	200-3000 MeV	200-3000 MeV	200-2000 MeV	200-3000 MeV
1,895	894	257+434	130,126	217,059
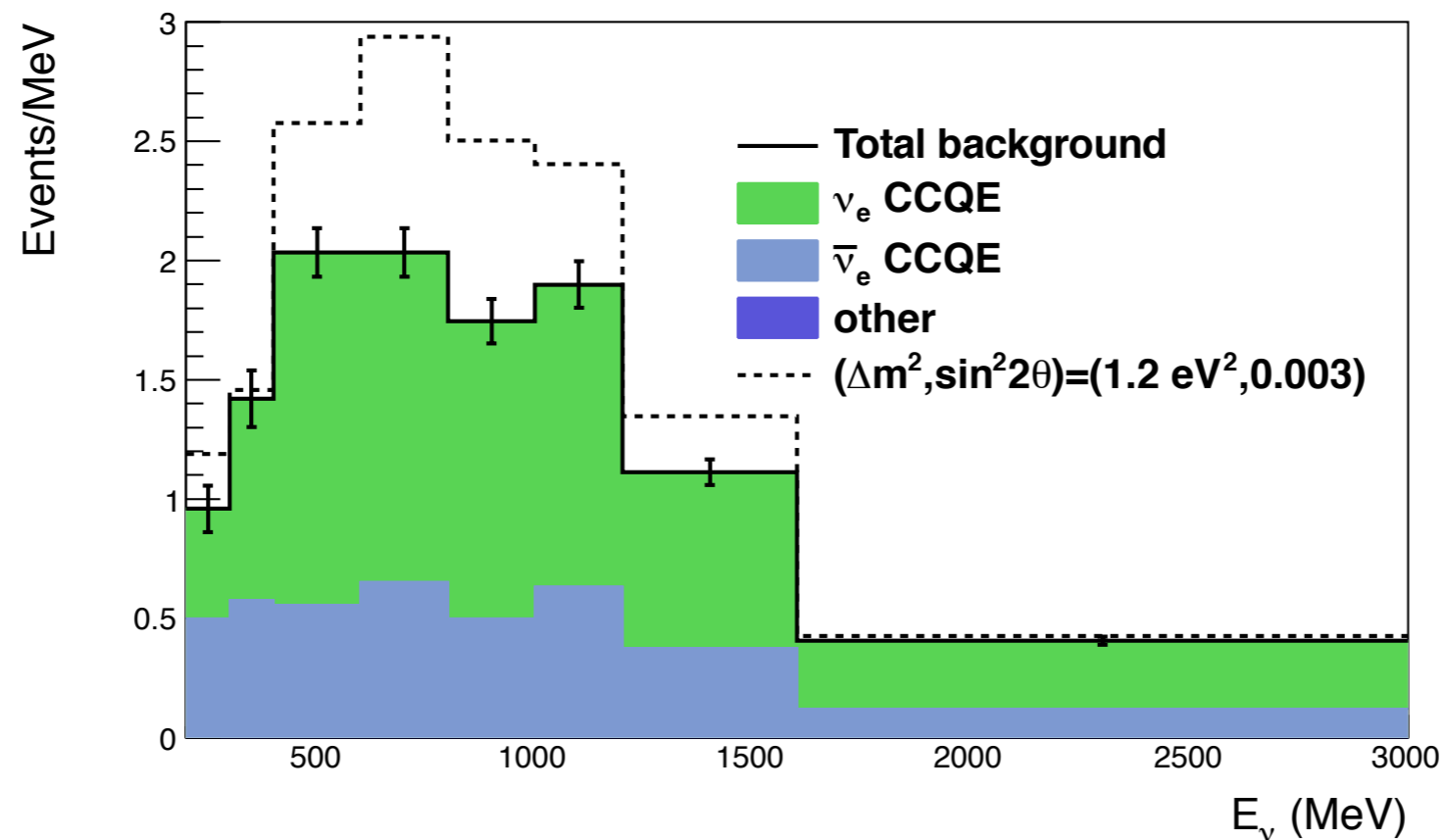
LAr1 sensitivity* to MiniBooNE anti-neutrino anomaly

MicroBooNE at 200m and LAr1 at 700m

MicroBooNE+LAr1
200m+700m
10.0E20 POT
stat. and 5% sys.
E>200 MeV fit

— 90%
— 3σ
— 5σ

R. Guenette
G. Karagiorgi

LSND 90% CL
LSND 99% CL

10.0E20 POT: ~5 years with present running conditions

Fiducial volumes assumed for MicroBooNE and LAr1 are 61 t and ~1 kt respectively.

* 3+1 neutrino model

Conceptual Design

- The conceptual design for LAr1 is the design of the engineering prototype for LBNE
- The present design is a TPC constructed of an array of modular units:
  - Anode Plane Assemblies (APAs 2.5m wide, 7m high and 10cm thick), which contain the wires and scintillation light detection system and instrumented with cold electronics
  - Cathode Plane Assemblies (CPAs 2.5m wide and 7m high), which provide the high voltage electrode to create the drift field
  - Field Cage Panels which shape the uniform electric field of 500 V/cm between the APAs and CPAs

All the active detector elements are arrayed inside a membrane style cryostat and immersed in ultra-high purity LAr, maintained by the cryogenic system.
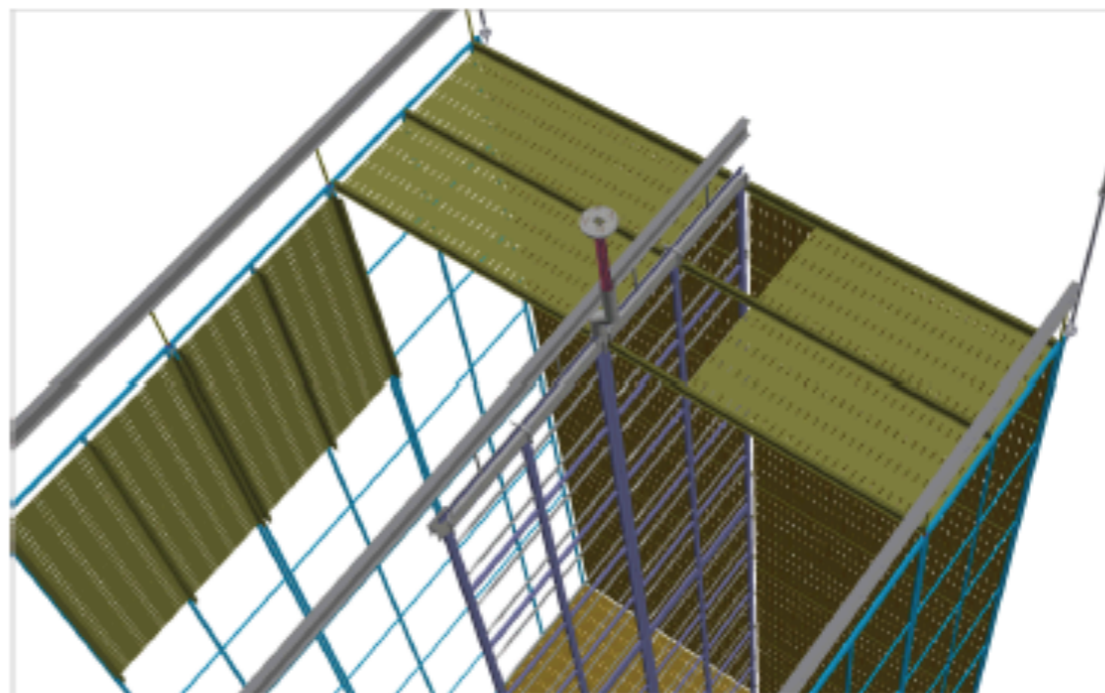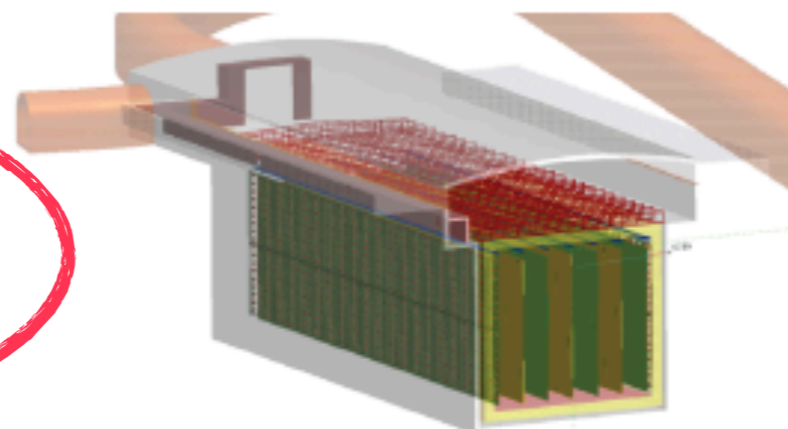
6/13/12
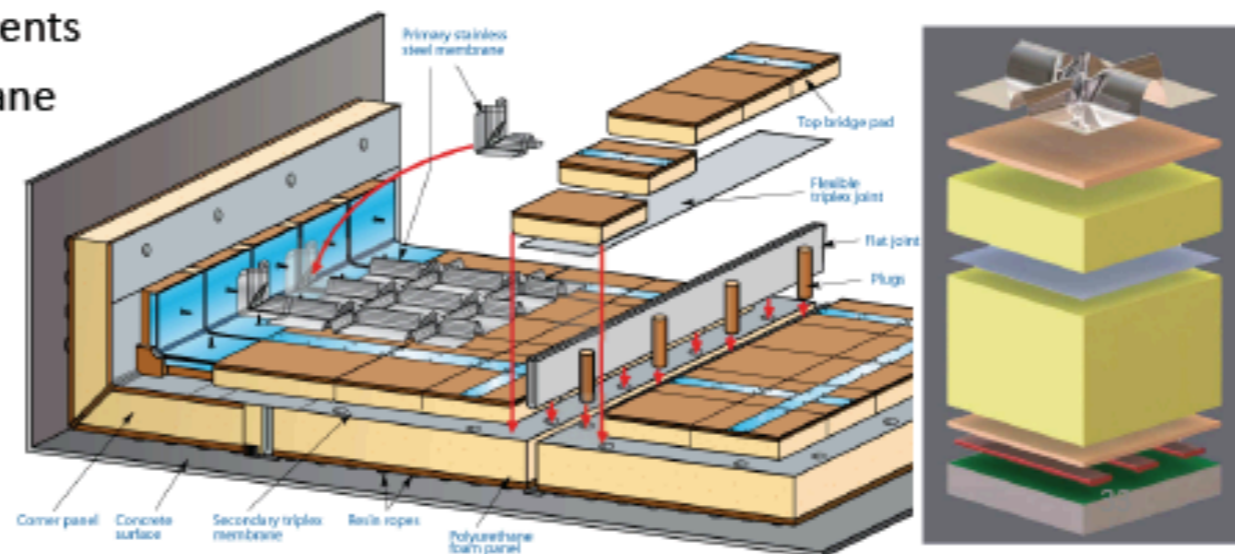
1Kton LAr detector
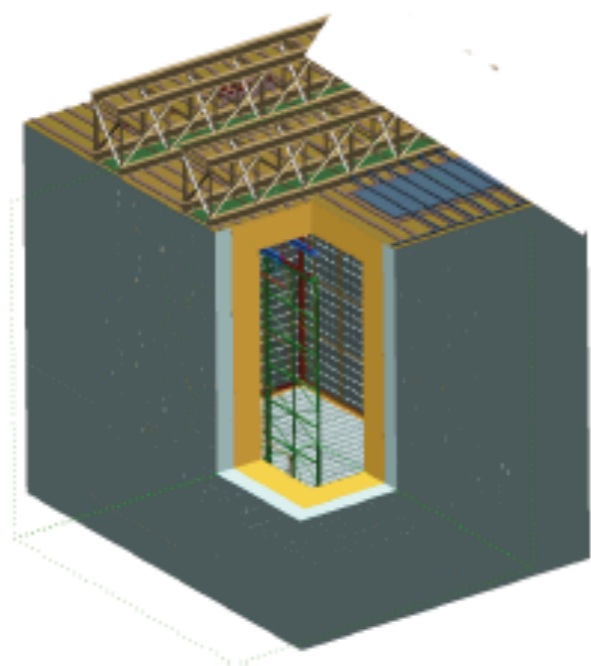
Membrane Cryostat

Arrangement of APAs, CPAs, and field cage panels

In addition to the physics program, LAr1 will have a development program serving as the engineering prototype for LArTPCs for long baseline oscillation searches (eg: LBNE)
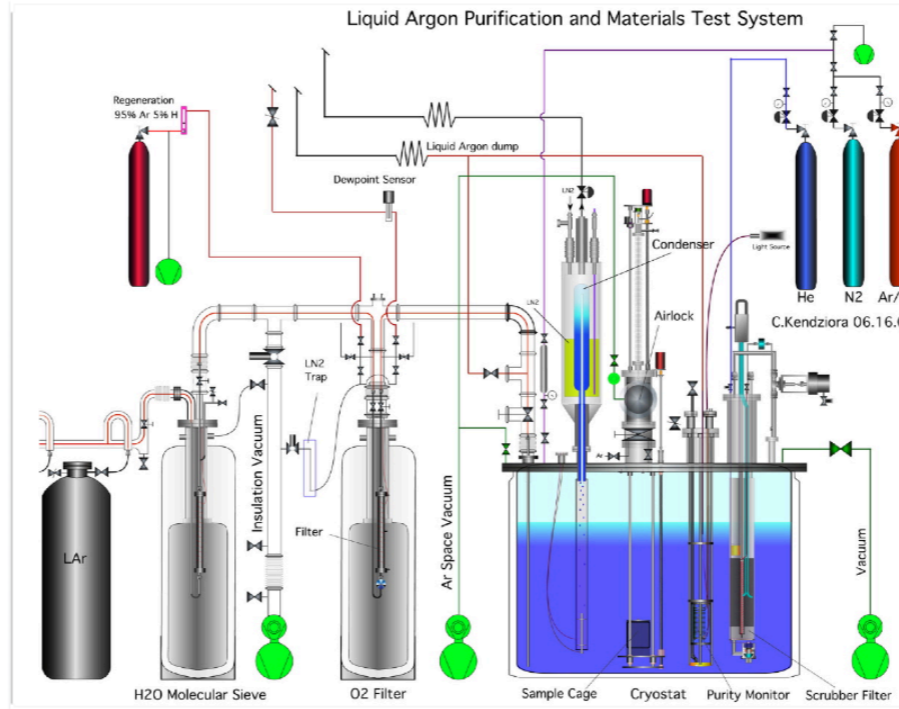
Conclusions

The FNAL Program is very reach:

strong effort for definitive assessment of the LarTPC technology (the beam test program)

the SBL program with MicroBooNE (for MiniBooNE ν-anomaly) and LAr1 for anti-ν-anomaly)

all this can contribute in opening the way toward the Intensity Frontier neutrino program with Project X.

MTS@ FNAL
Material Test Stand

Liquid Argon Purification and Materials Test System

Effects of O$_2$, N$_2$ Contamination in LAr
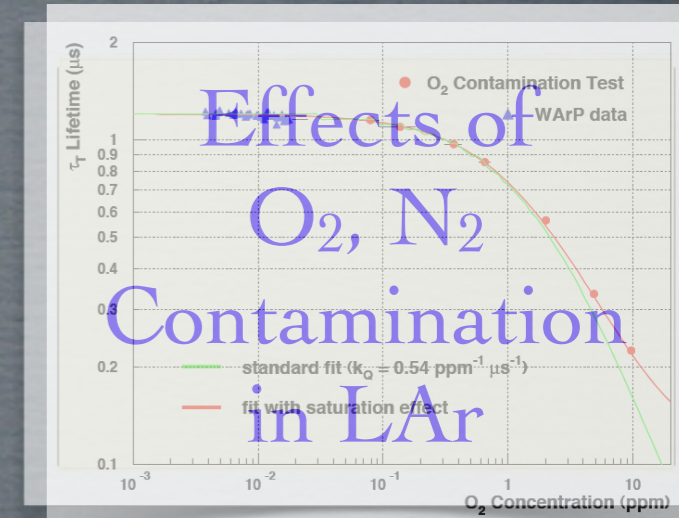
CryoLab@ LNGS

• materials submerged in LAr do not decrease LAr purity
• materials in vapor give off water ⟹ LAr contaminate (out-gassing rate fcn. of T)
• Cold capacity test of Molecular sieves (for H$_2$O) and of new filters (for O$_2$) under way

LAPD @ FNAL - *LAr Purity Demonstrator*

• Current operating systems use evacuation as a first step to achieve purity
• Want an alternative for large vessels: GAr purging (use a GAr piston for several volumes exchange)
⟹ goal < 50 ppm contamination
   (test under way)
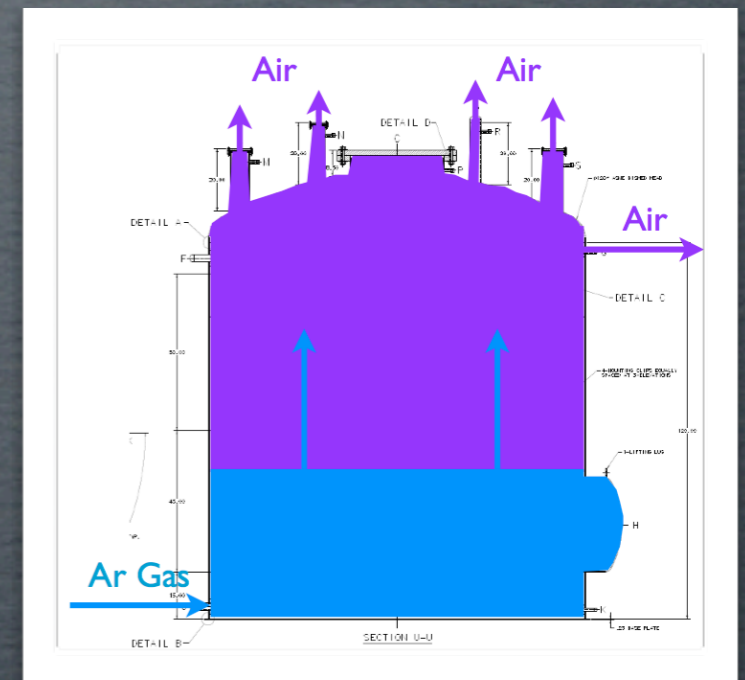
LAr LEM-TPC @ CERN (ETH)

from concept to real detector

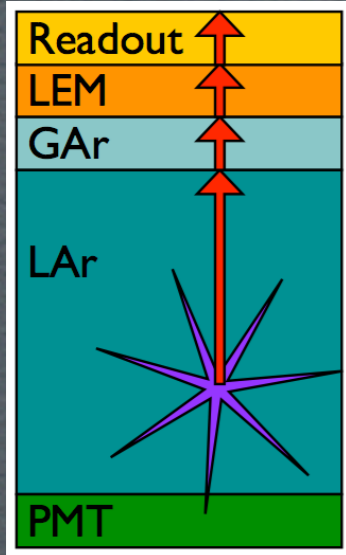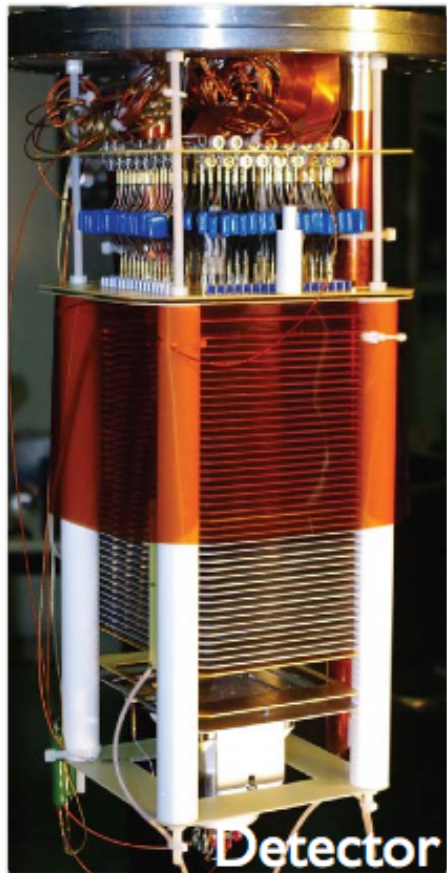Detector

- **LEM**: Double phase Argon Large Electron Multiplier TPC concept provides a 3D-tracking and calorimetric device capable of adjustable charge amplification.

Cosmic muon
Delta ray

xView event display (event 1702)
yView event display (event 1702)
xView event display (event 1765)
yView event display (event 1765)

Micromesh
Microstrips
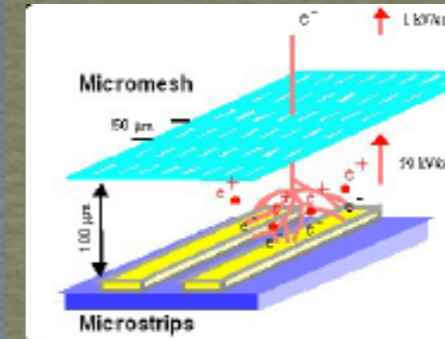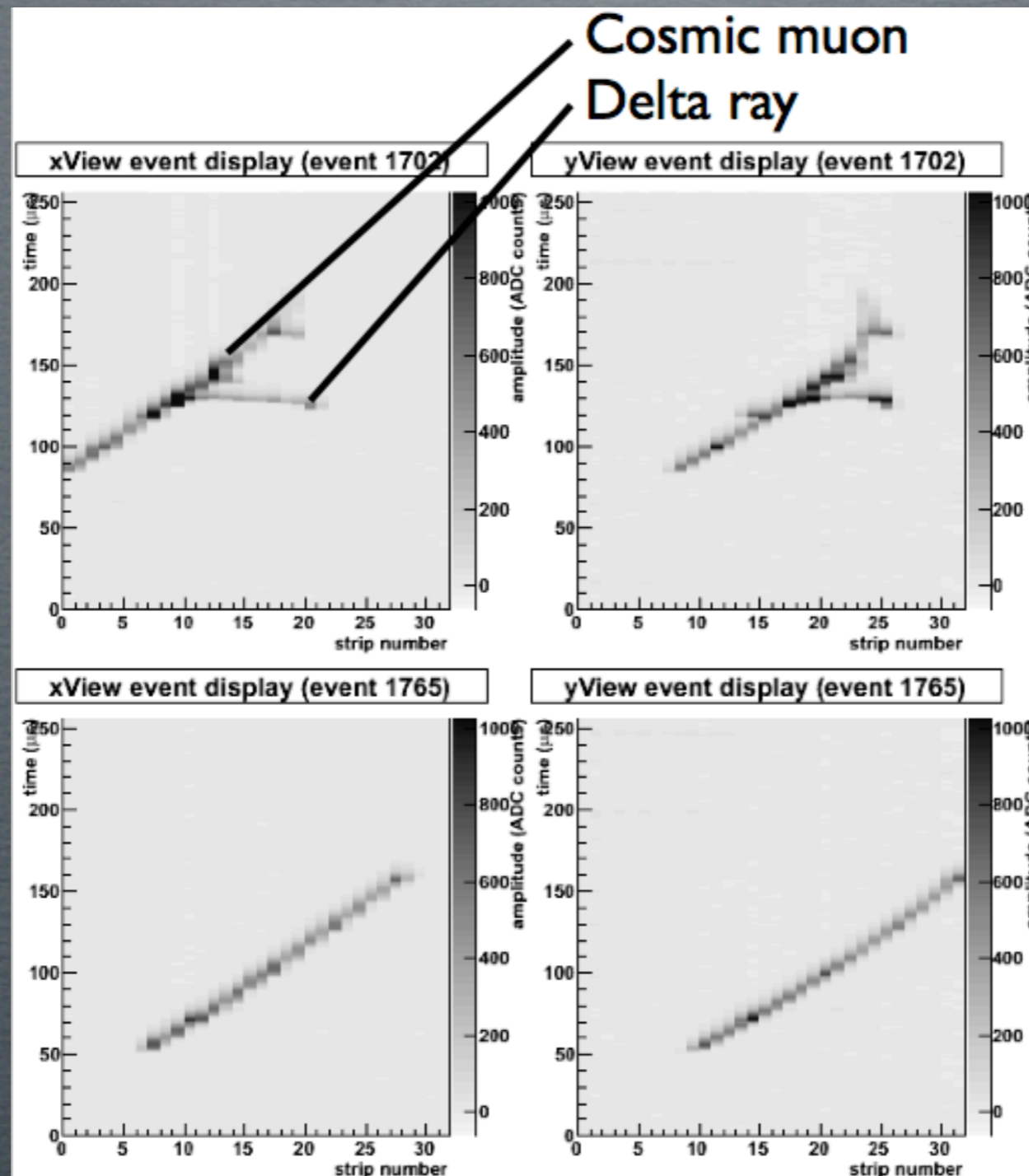
- **MM**: MicroMega concept under study @ CEA-Saclay ⊕ ETH

- It is a promising readout technology for next generation ν-detectors (fine spatial resolution, large active area and gain of the order of 10) and for Dark Matter detectors

Setup @ CERN
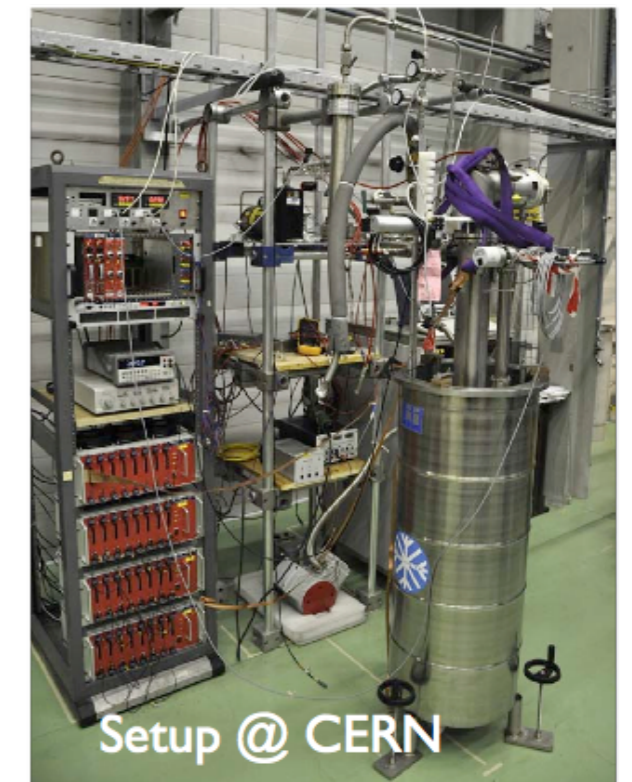
About 50% of the energy deposited by charged ptcl.s in LAr goes into Scint. photons: simultaneous and full exploitation of both Charge and Light signals will be the main line of development of the LAr tech.

VUV LAr Scintillation light (128 nm) needs to be shifted (to Vis) before collection at photosensitive detector areas:

➡ LAr volume surrounded with a highly reflecting layer coated by a thin wls-TPB film (high Light Yield)
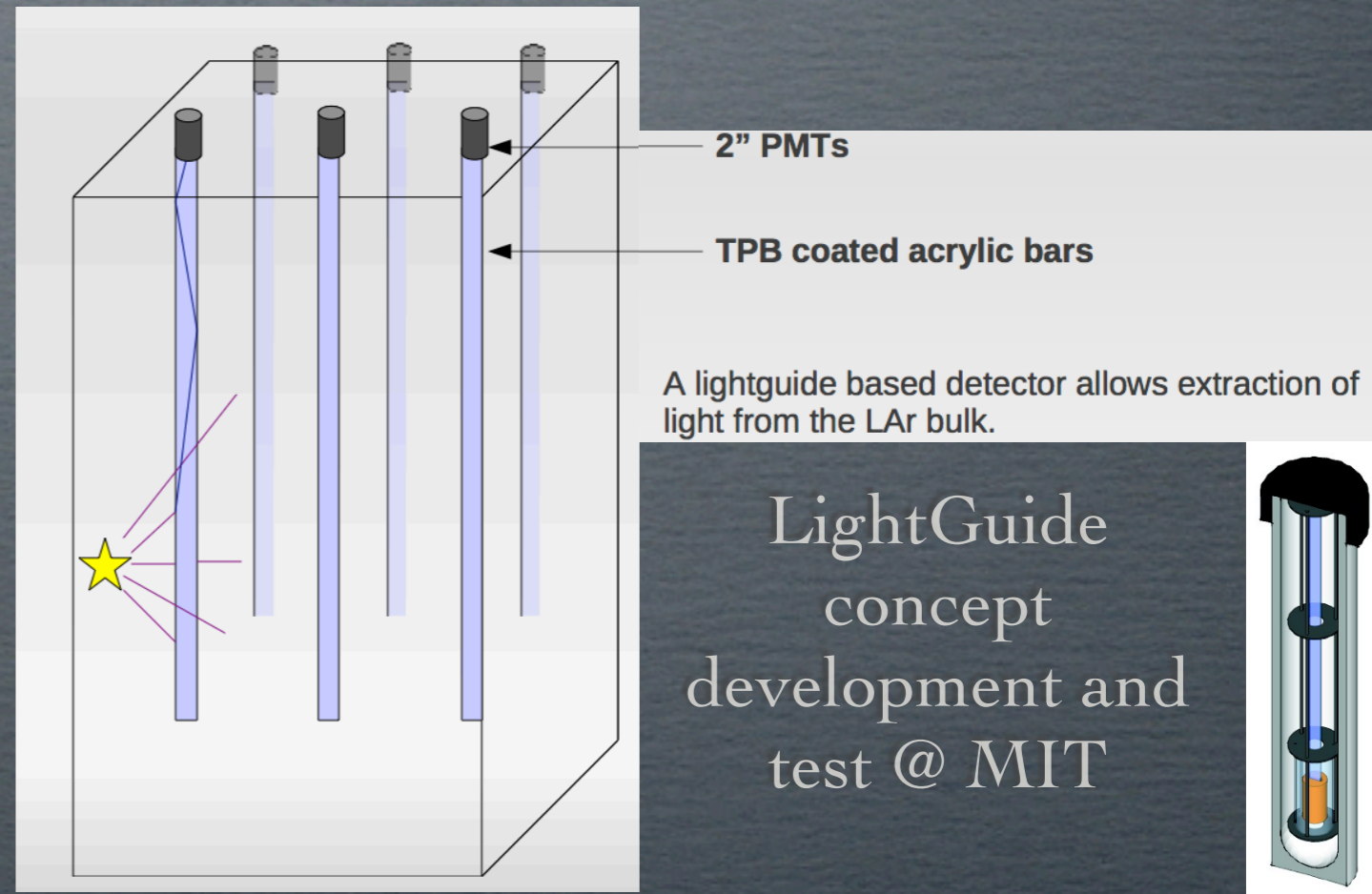
➡ photosensitive detector surface coated by wls-TPB film (easier but lower Light Yield)

Optical systems w/
HQE-PMT
CryoLab @ LNGS

241Am, run912

χ^2 / ndf = 31.51 / 23

Constant	8.223 ± 0.136
Mean	416 ± 0.6
Sigma	28.56 ± 0.46

416 phe @ 59.5 keV ~ 6.99 phe/keV

2" PMTs

TPB coated acrylic bars

A lightguide based detector allows extraction of light from the LAr bulk.

LightGuide concept development and test @ MIT
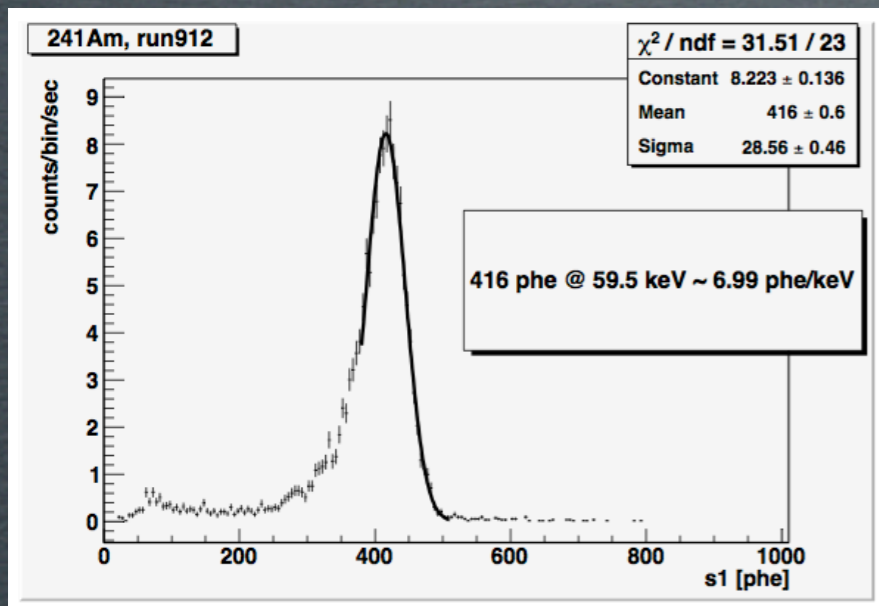
The capability of drifting ionization electrons on long distances (3-5 m) plays a
key role in view of the construction of very large mass neutrino detectors.
Two independent groups are actively working on 5 m long drift tests.

ARGONTUBE
@ Bern

5mDRIFT
@ CERN - by UCLA
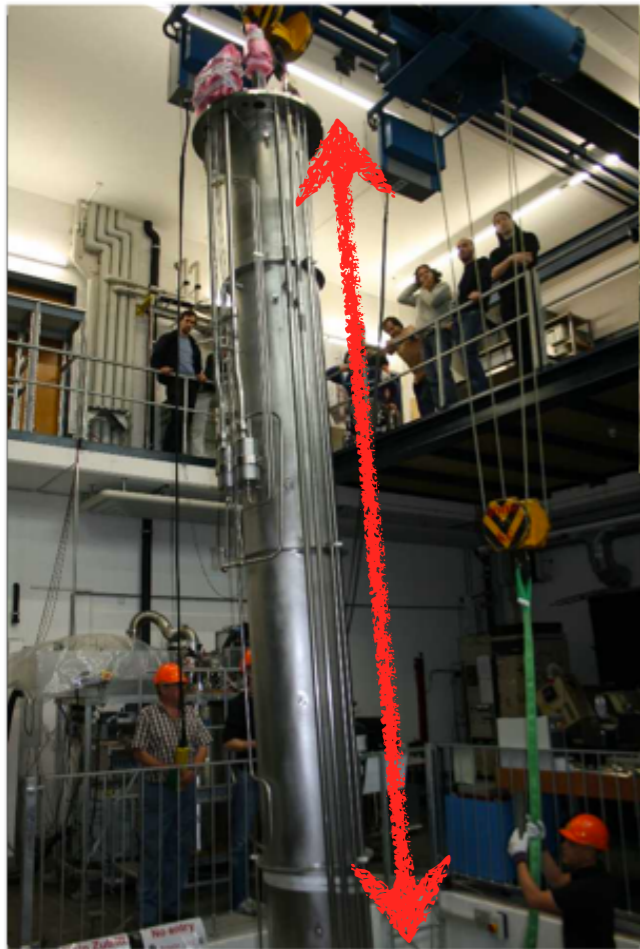
- First Cold Test Succesful

$\oplus$

medium ARGONTUBE

a bench-test for the ARGONTUBE
performed in 2009-10:

- test of new Recirculation system based
on bellow-pumps
- Purity monitor using a laser beam
- test of new high voltage generator
based on a chain of rectifying cells
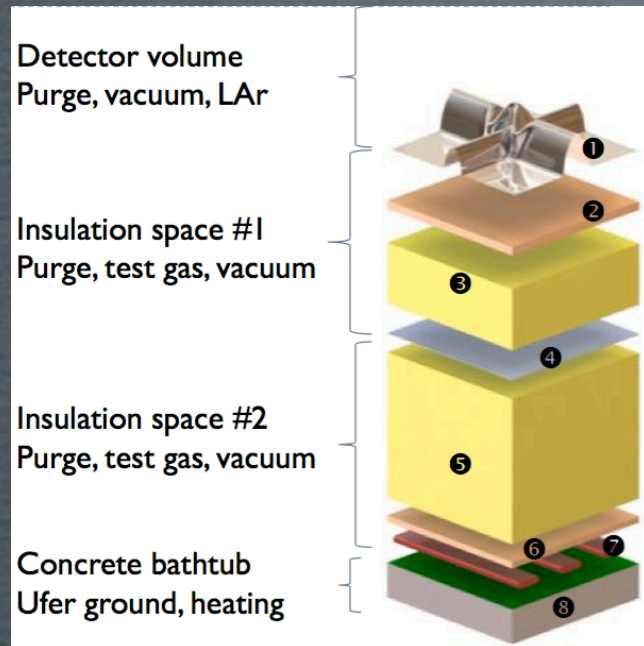- test of new Front-end pre-amplifiers
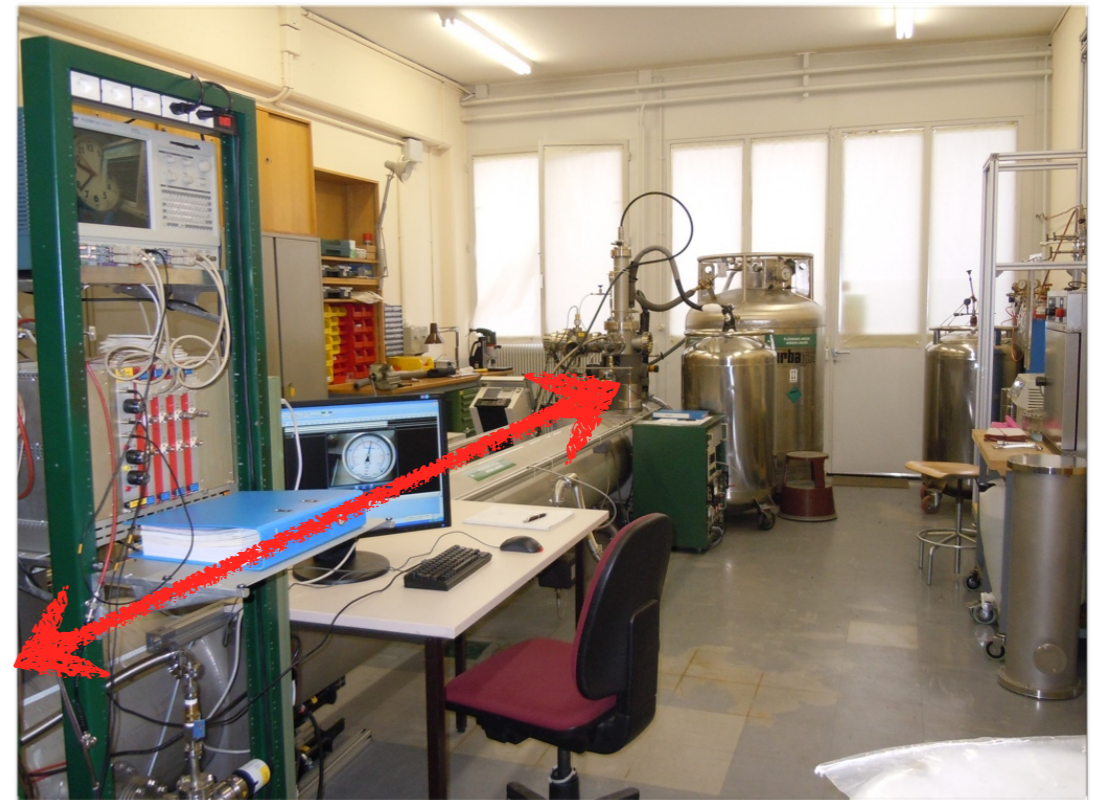
First technical test performed in Mar'11

- very low heat load
- HV test up to 125 kV (1/2 of nominal)
- first Ionization Signals detected

CRYOSTAT INSULATION SCHEMES AND DEVELOPMENTS

Current vacuum insulation (double StSteel wall with SuperInsulation) or hybrid solutions(passive/active insulation) cannot be "straightforwardly" extended to very large Volumes (tens of kton of LAr mass): new solutions are being analyzed (without a priori excluding Vacuum Insulation)

LAr-LBNE @ FNAL

Detector volume
Purge, vacuum, LAr

Insulation space #1
Purge, test gas, vacuum

Insulation space #2
Purge, test gas, vacuum

Concrete bathtub
Ufer ground, heating

Membrane Cryostat

Benefits

- Full containment system
- Long record in LNG industry in more severe service
- ~standard industrial design
- "Cryostat in a kit" construction model
- High fiducial mass fraction

LNG Tanker with Membrane containment systems

Detector Module Cooling Requirement

- Total ~ 40 kW
  - Insulation - 28 kW
    - 1m foam - 5.4 kW/m2
  - LAr Pumps - n x 6 kW
  - Electronics – 5 kW
    - Front end – 10 mW/chan
    - Digital – 5 mW/chan
- LN refrigerators designed for 60 kW cooling

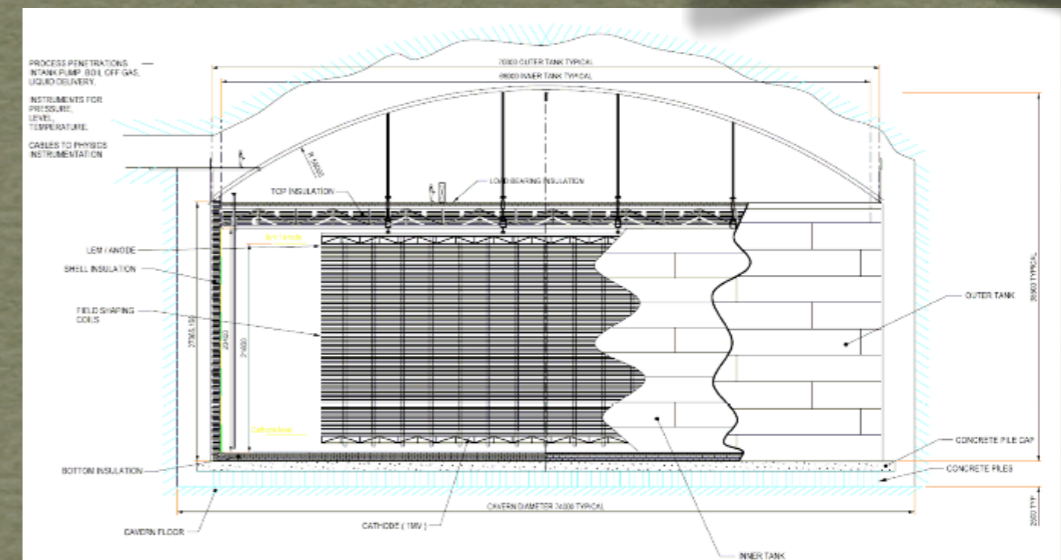### Concerns

- Long weld length on thin sheets
- Rock interactions
  - Freezing
    - Heat the concrete liner
  - Elastic rebound
    - mm - cm movements possible in first few months after excavation

## Vacuum Insulation for very large Volumes: LAr-LBNE @ UCLA

LAGUNA @ ETH

LNG Storage Tank (UnderGround)

- **Initial Concept - 2004**
- **Use existing technology from industry experience**
- **Above ground tank, placed below ground**
- **De-couple the tank from the cavern**
- **Single containment is suitable**
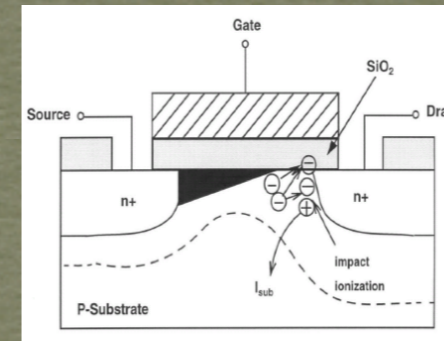 - **Full containment not warranted**
  - **Cavern will contain spill**

U Induction (small, bipolar)

V Induction (small, bipolar)

Y Collection (large, unipolar)
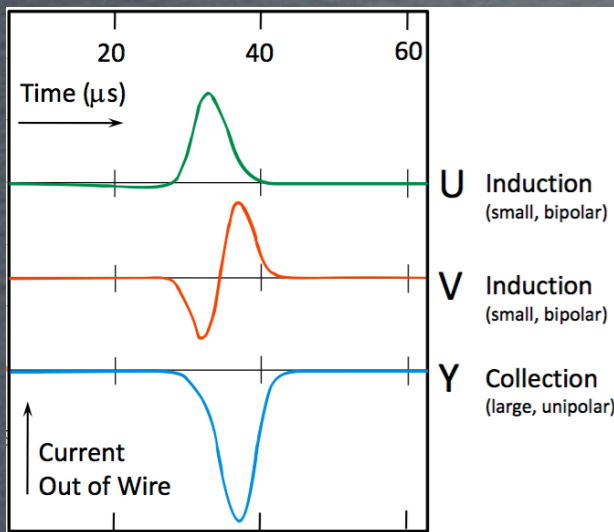
Induction by and Collection of → electrons on wires

COLD Electronics @ Brookhaven & FNAL

CMOS technology at LAr T

CMOS is "happier" in cryogenic environment
At 77-89K, charge carrier **mobility** in silicon increases, **thermal fluctuations** decrease with **kT/e**, resulting in a **higher gain**, higher g_m/I, **higher speed** and **lower noise**

Designing CMOS for low power = long lifetime
> 30 years lifetime using design guidelines consistent with low power design

Low-noise demonstrated:
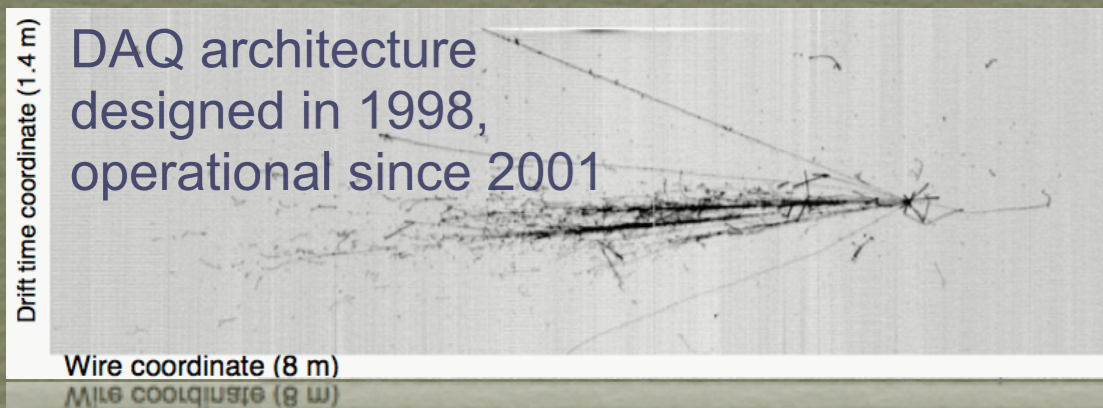• ENC~ 600e- rms at 200pF, ~5mW/ch. (analog part)

Current Development:
single chip, analog FE+ADC+buffer with 128:1 multiplexing

Entire TPC can have uniform calibrated (<1%) charge sensitivity

MicroBoone LAr-TPC at FNAL with COLD electronics

WARM Electronics (ICARUS) @ Padova

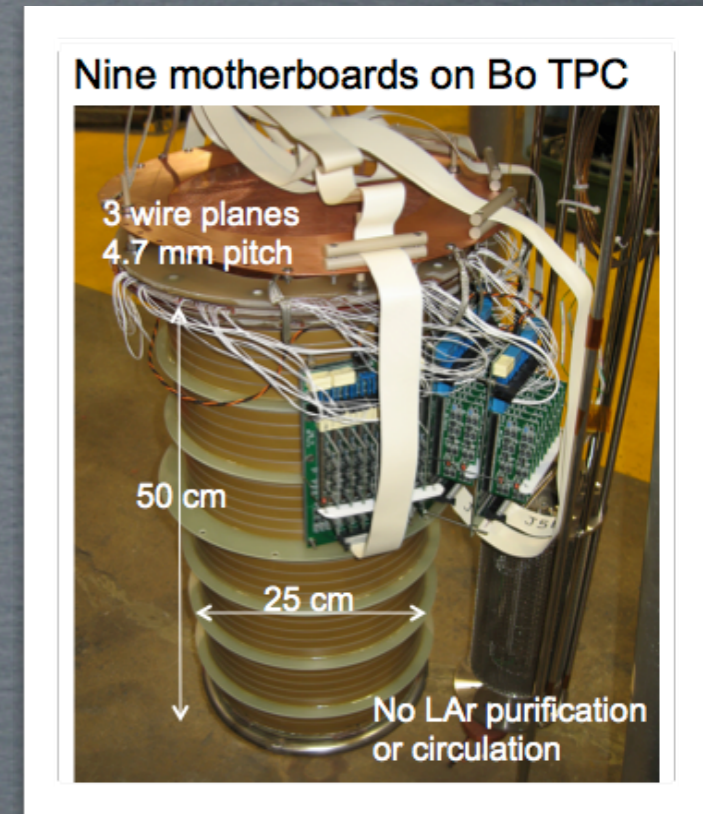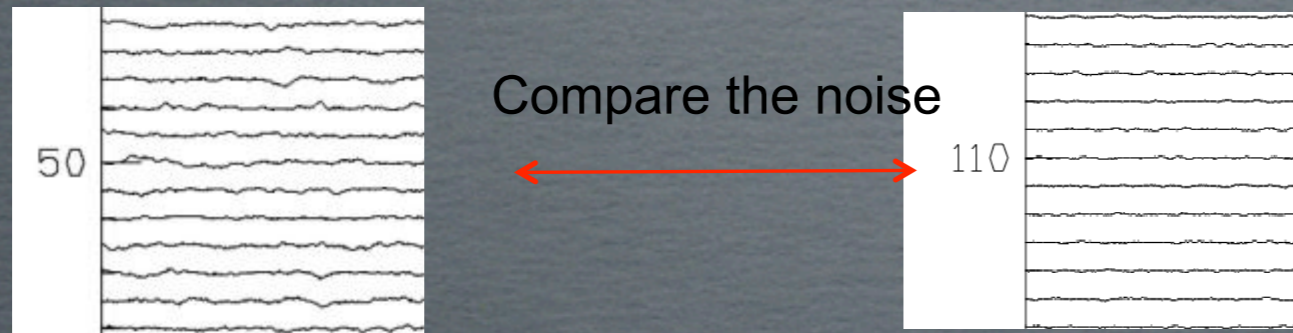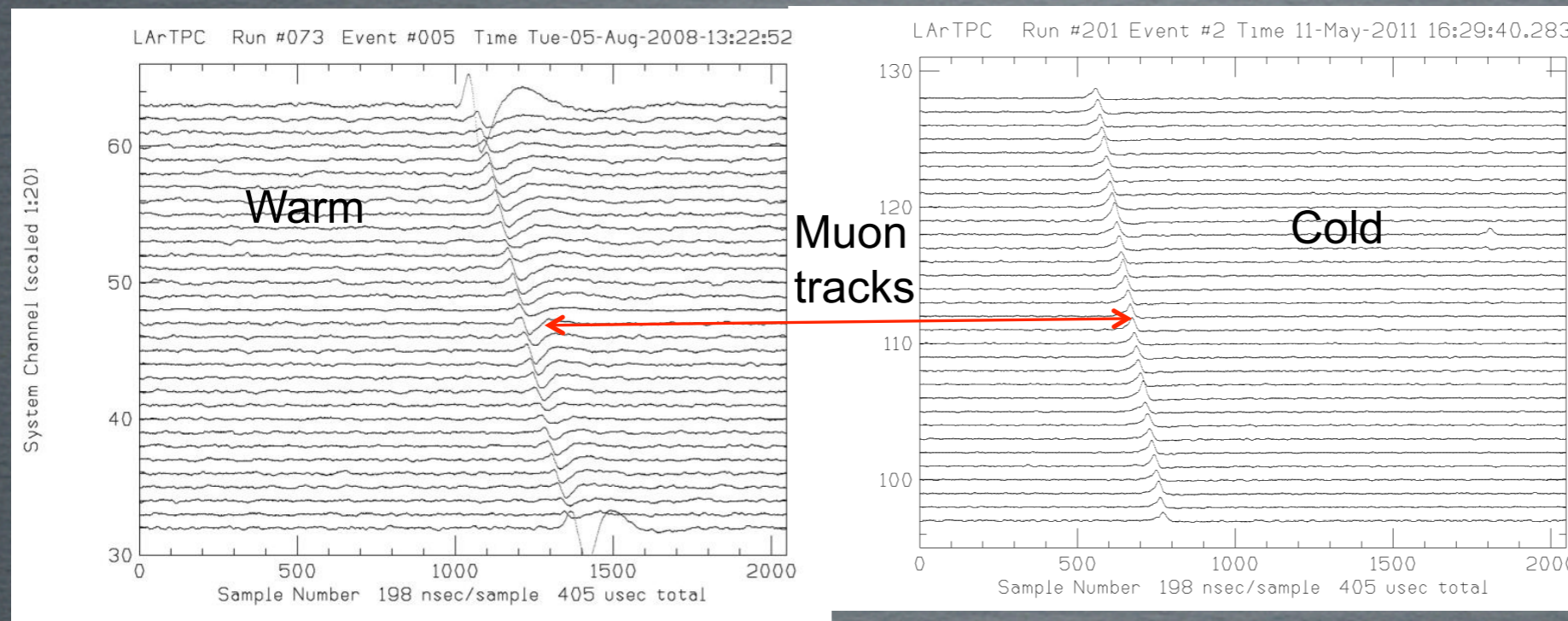DAQ architecture designed in 1998, operational since 2001

5*104 channels.
🖉 analog chain: front-end low noise charge sensitive pre-amplifier, based on a BiCMOS dual channel IC with external j-Fet input stage (S/N > 10)
🖉 Digitizing Stage: (32 chs. MUX) 10*bit* ADC (least count is equivalent to 1000 e) matching with the amplifier noise of ~1200 electrons.
🖉 sampling time 400*ns* per channel.

Icarus choice for warm electronics

🖉 Easily accessible during detector operation
🖉 Large choice of components
🖉 "No limit" on power dissipation (100 mW/cm2 cause LAr boil-off)
🖉 Availability of reliable high-density feed-throughs

Qualitative comparison Warm-Cold preamps

Warm

Cold

Muon tracks

Compare the noise

Nine motherboards on Bo TPC

3 wire planes
4.7 mm pitch

50 cm

25 cm

No LAr purification or circulation

Michigan St. U.
Test @ FNAL (2011)

2

Warm dual-JFET
Signal for muon parallel to wire planes: 22.7 counts   **S/N ~ 14**
Noise RMS noise: 1.62 counts

Cold CMOS
Signal for muon parallel to wire planes: 15.6 counts   **S/N ~ 28**
Noise RMS noise: 0.55 counts

ν-EVENT RECONSTRUCTION
(OFF-LINE SW DEVELOPMENT AND DATA ANALYSIS)

SW development represents the most challenging and "burning" issue in the present LAr-TPC worldwide effort

ν-data are available from ArgoNeuT (NuMI-low-energy) and ICARUS (CNGS-high energy)

LArSoft 🇺🇸

ArgoNeuT
data analysis
⊕

MicroBooNe
LAr1 & larLAr
LAr-LBNE
det/data simulation

Code development @ FNAL
⊕
*Yale, Syracuse, MIT,
MSU, KSU, Nevis
& LNGS (It),
Bern (Su), Warwick (UK)*

ICARUS 🇮🇹 🇵🇱

ICARUS
data analysis

Wire coordinate (~5 m)
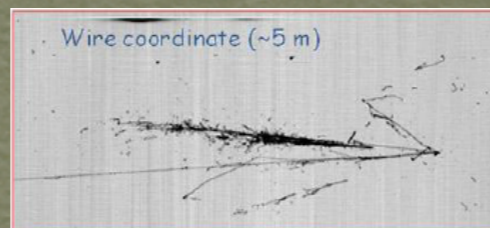
*Code development
@ Milano, Padova,
LNGS, CERN,
Katovice, Cracow, Warsaw*

Qscan 🇨🇭 🇯🇵

Initially developed
(ETH, Granada) for
Icarus, recent revival for
T32 LArTPC Test
Beam data analysis
(@JPARC)

K -> π+π0
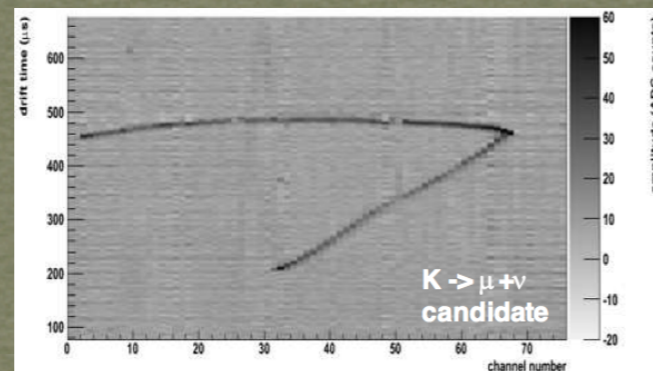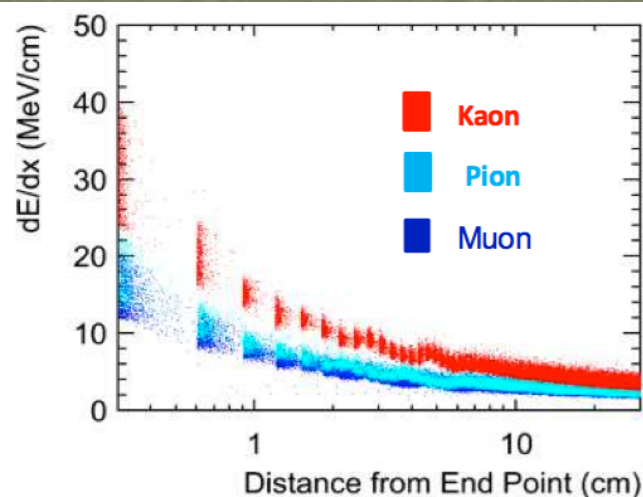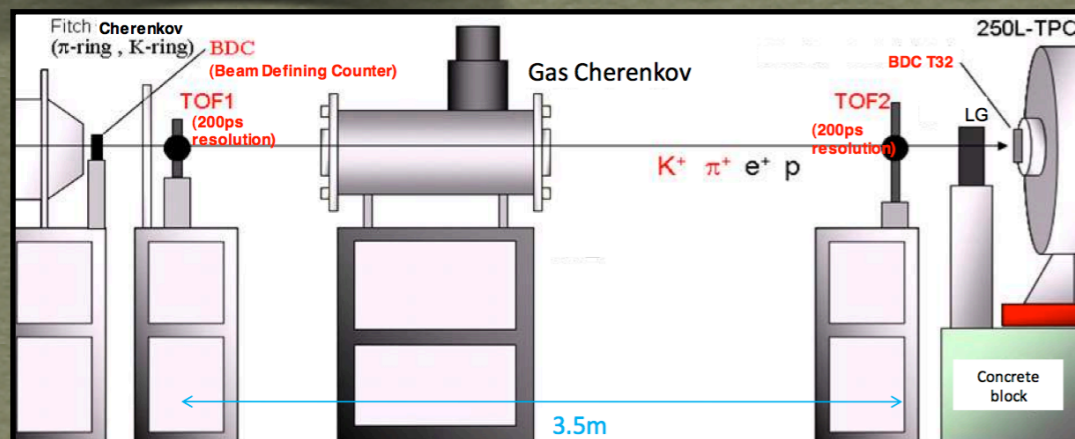Candidate?

*Code development
@ ETH, CERN*

T32 @ J-PARC

(250 lt LArTPC-2010)

ETH,
KEK, Iwate U, Waseda U.

**K+/p+ PID within
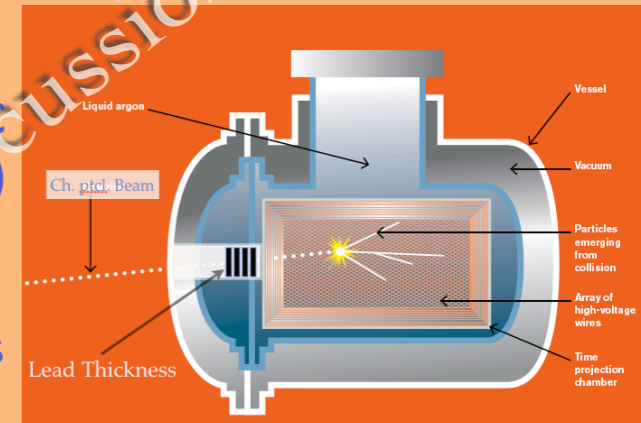proton decay momentum
region ~ 350MeV/c**

Fitch Cherenkov
(π-ring , K-ring) BDC
BDC
(Beam Defining Counter)
Gas Cherenkov
BDC T32
250L-TPC
TOF1
(200ps resolution)
TOF2
(200ps resolution)
LG
K^+ π^+ e^+ p
3.5m
Concrete block

dE/dx (MeV/cm)
Kaon
Pion
Muon
Distance from End Point (cm)

$K \to \mu + \nu$ candidate

ArgoNeuT @ FTBF (FNAL)

**(existing) single-phase LAr TPC
in a low energy (0.5 – 5 GeV/c)
ch.ptcl.beam**

- precise measurements of
charge Recombination factors
– electron to γ separation

Under discussion

Liquid argon
Ch. ptcl. Beam
Lead Thickness
Vessel
Vacuum
Particles emerging from collision
Array of high-voltage wires
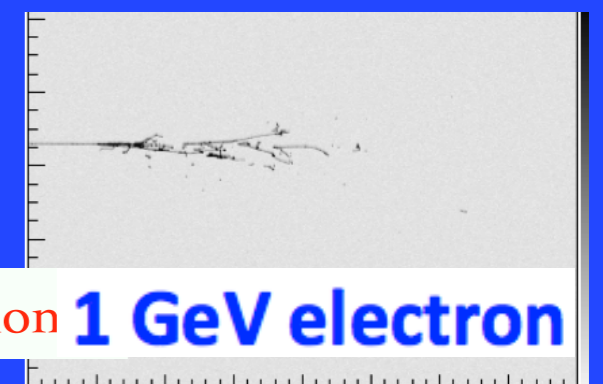Time projection chamber
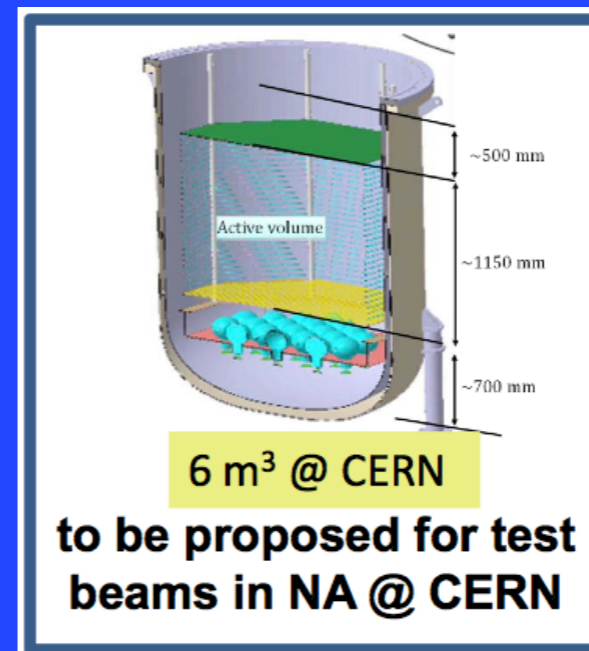
**double-phase LAr TPC in a low
energy (0.5 – 5 GeV/c)
ch.ptcl.beam**

test of particle identification,
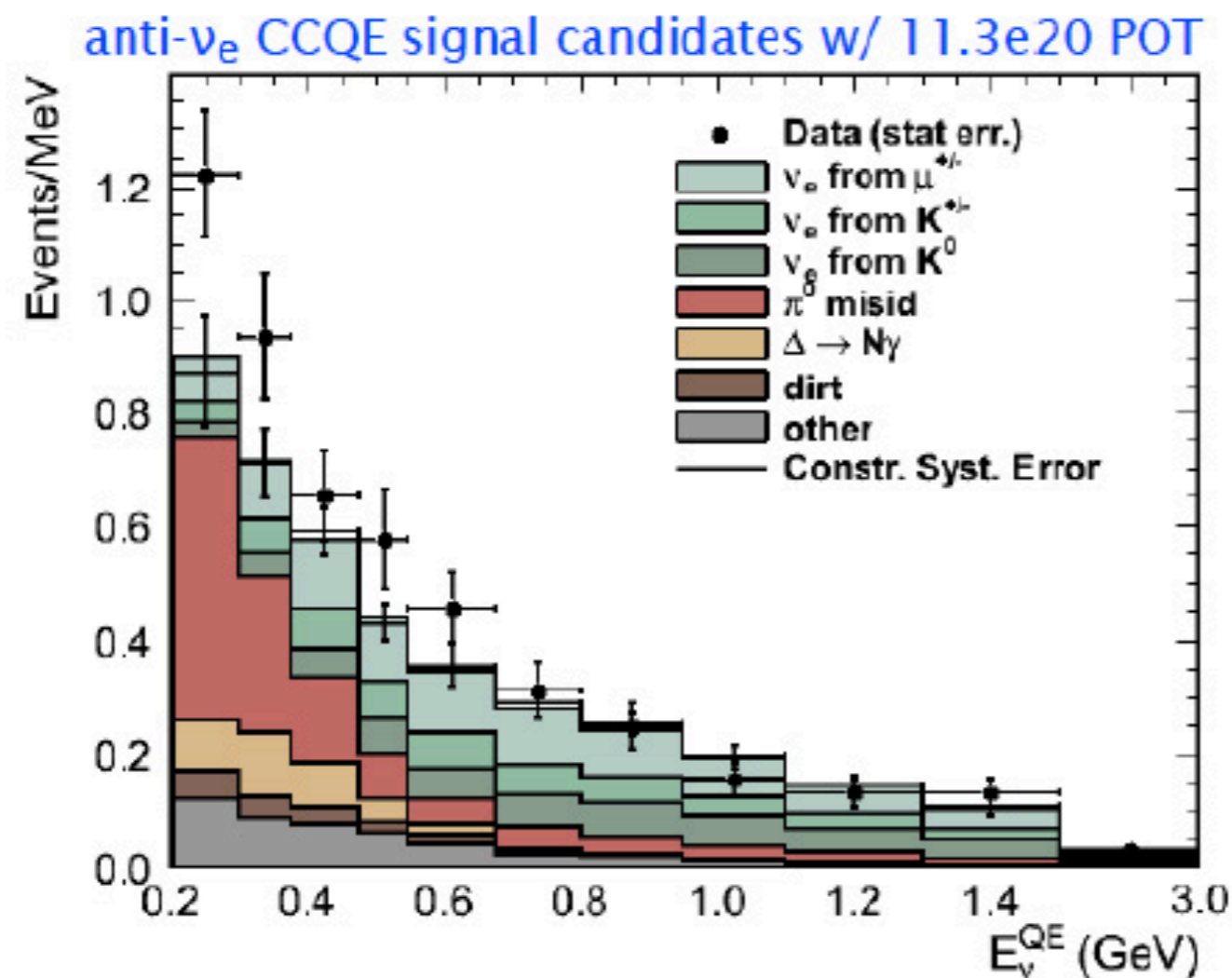calorimetry, hadronic secondary
interactions

~500 mm
~1150 mm
~700 mm
Active volume

6 m³ @ CERN
to be proposed for test
beams in NA @ CERN
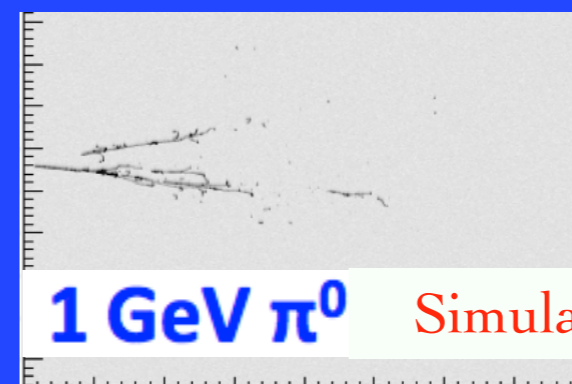
1 GeV π^0 Simulation **1 GeV electron**

MiniBooNE: The excess in anti-ν-mode

MicroBooNE + LAr1 can also probe neutrino mode oscillations...

MicroBooNE+LAr1
200m+700m
6.6E20 POT
stat. and 5% sys.
E>200 MeV fit

— 90%
— 3σ
— 5σ

R. Guenette
G. Karagiorgi

LSND 90% CL
LSND 99% CL

6/20/12

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Thursday, 21June , 2012

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