Liquid Argon Detector Technology

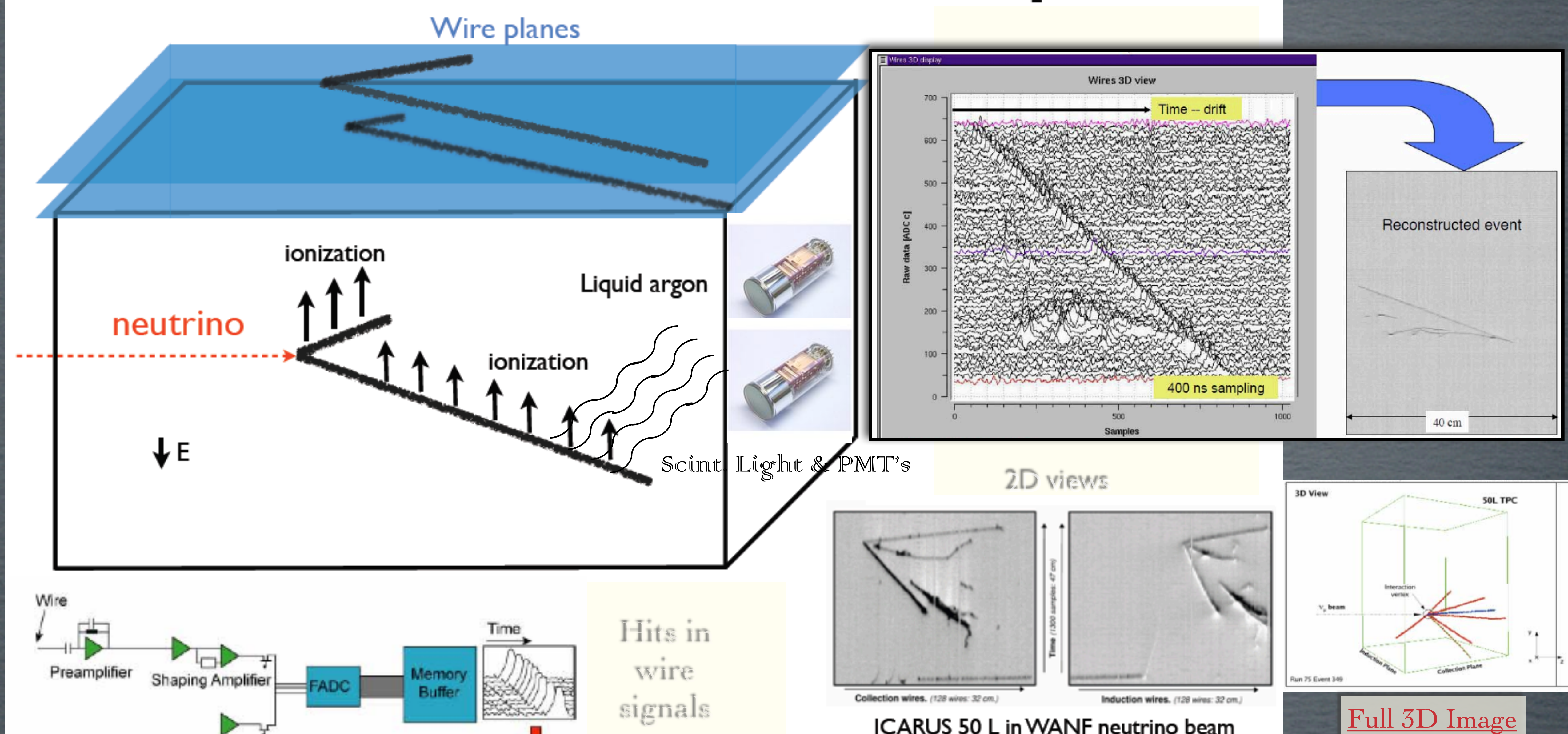
1)**"technical developments with LAr detector for ν-physics":**
- main features of the LAr-TPC technology
- the worldwide path to LAr detectors for ν-physics
- updates on current developments on LAr technology
  (from dedicated R&D's or tests)
- status of event reconstruction development in LAr detectors

2) **Status of present LAr ν-experiments**
(running or under construction)

3) **"Perspectives for next generation LAr ν-experiments:**
- conceptual designs and current proposals
  in **US, Eu** and **Japan** ("**the global LAr effort"**)
  for next generation ν-oscillation studies and the "intermediate steps".

Flavio Cavanna
L'Aquila U. - Italy

The LArTPC concept



(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.
In EF, free Ionization electrons tracks 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 wireplanes can be utilized ➠ (x,y) coordinates.
Timing of pulse information (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.

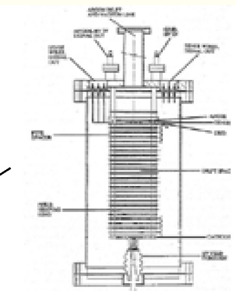
Collection of the ionization charge on wires of the last plane (hit amplitude) measures the deposited energy
⇒ Calorimetric Information and Ptcl.Id

Scintillation light collected by PMTs used for triggering.

THE PATH TO LAR DETECTORS FOR ν-PHYSICS: THREE LINES OF DEVELOPMENT

CERN

The Liquid-argon time projection chamber: a new concept for Neutrino Detector, C. Rubbia, **CERN-EP/77-08 (1977)**



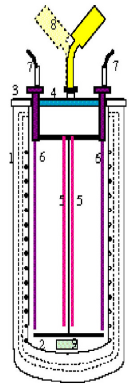
24 cm drift wires chamber

CERN

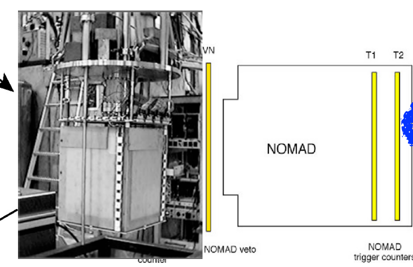
1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

CERN

3 ton prototype



1991-1995: First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.



50 litres prototype
1.4 m drift chamber

CERN

1997-1999: Neutrino beam events measurements.

ICARUS Genealogy

INFN-Pavia

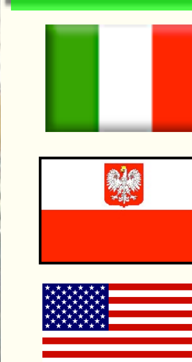
10m³
←Prototype – Detector→

1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.

ICARUS
← T300
test on surface

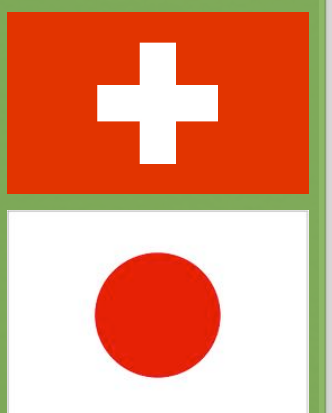
T600 (2010)→
running exp.
at LNGS

INFN-GranSasso



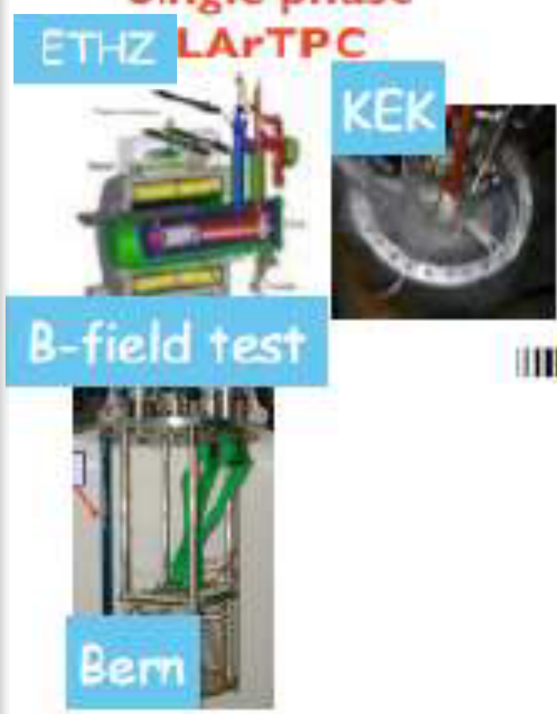
The path to LAr Detectors for ν-Physics

LAr in Japan / Suisse

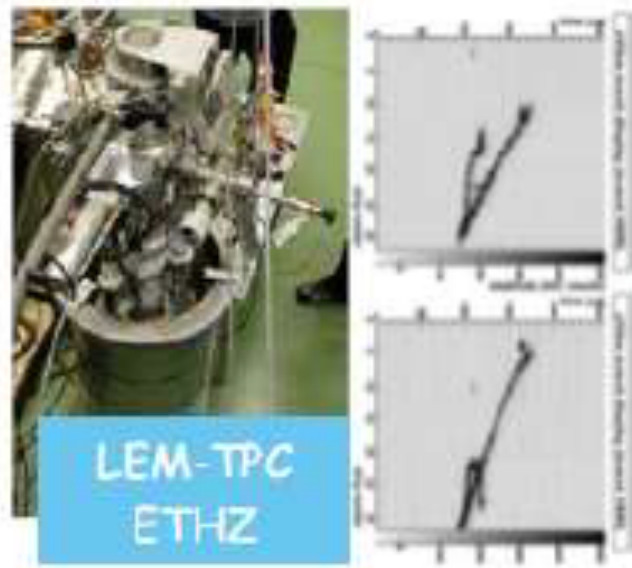


since 2005

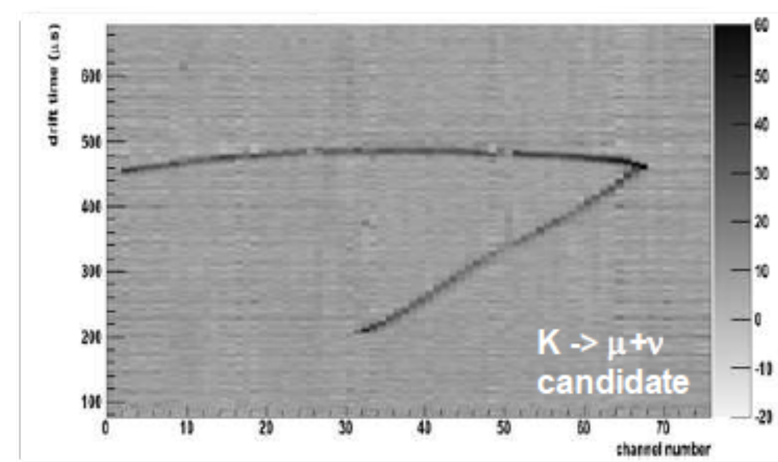
Single phase LArTPC



Double phase LAr-LEM TPC

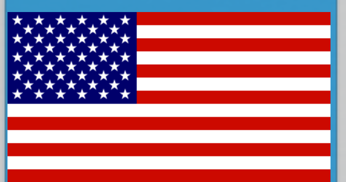


P32@JPARK test beam in 2010



The path to LAr Detectors for ν-Physics

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

Location: Yale University
Active volume: 0.00002 kton
Year of first tracks: 2007

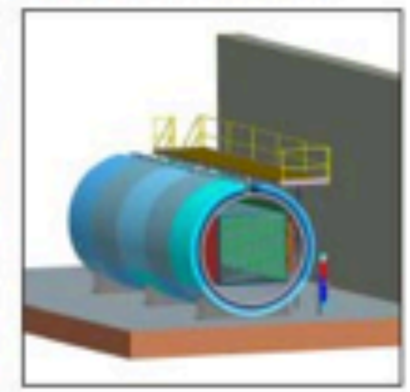
Bo

Location: Fermilab
Active volume: 0.00002 kton
Year of first tracks: 2008

ArgoNeuT

Location: Fermilab
Active volume: 0.0003 kton
Year of first tracks: 2008
First neutrinos: June 2009

MicroBooNE



Location: Fermilab
Active volume: 0.1 kton
Start of construction: 2010

FNAL

Test stands to improve liquid-argon technology:

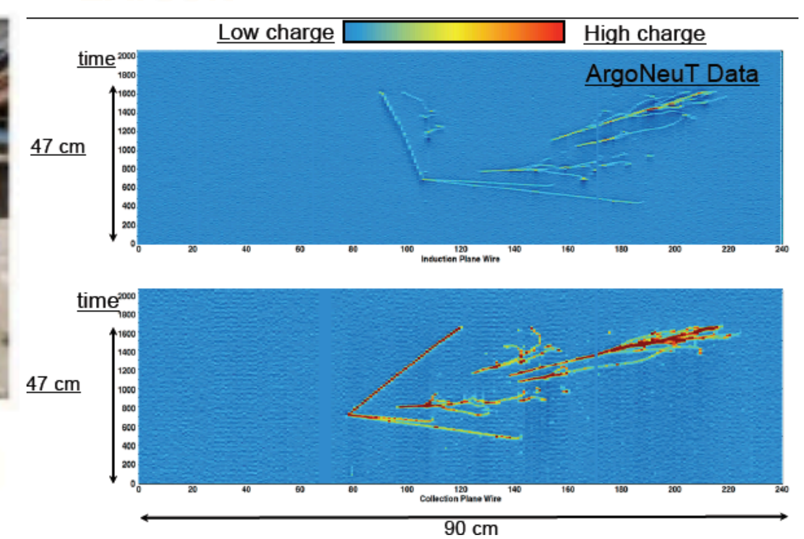
Luke

Location: Fermilab
Purpose: materials test station
Operational: since 2008

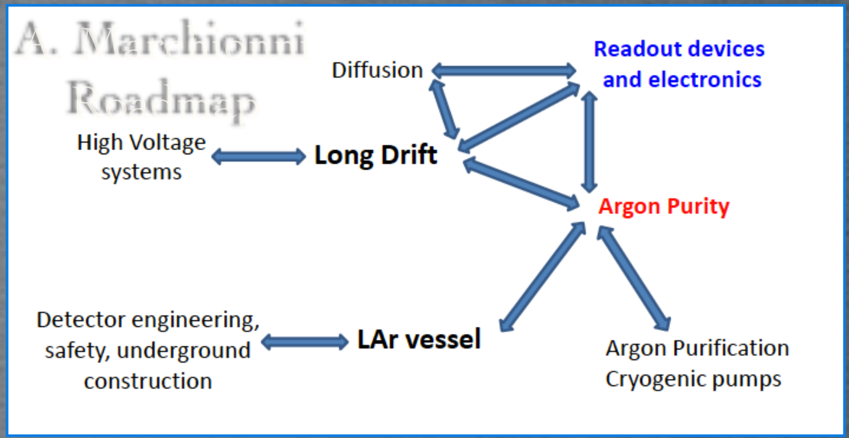
LAPD

Location: Fermilab
Purpose: LAr purity demo
Operational: 2010

LArSoft



Current developments on LAr Technology



Main Issues in LAr Tech:

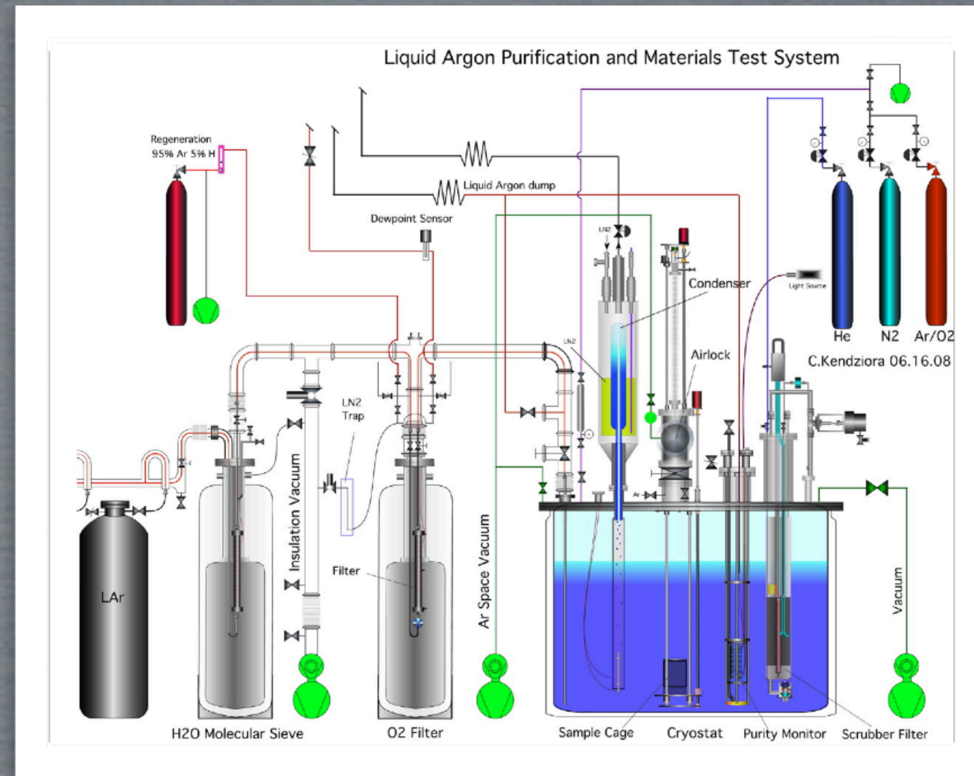
Caveat:
the list is very long (and incomplete) and cannot be covered in total nor in details
Apologize for the selection (purely based on personal choice)

- LAr Purity (materials' compatibility & selection) and LAr Purification
- Alternatives to wires for Ionization Charge signal extraction
- Scintillation Light signal extraction: HQE PMT developments and alternatives
- Electron Charge Drift over long distance
- Cryostat Insulation schemes and developments
- Cold read-out electronics vs. Warm electronics

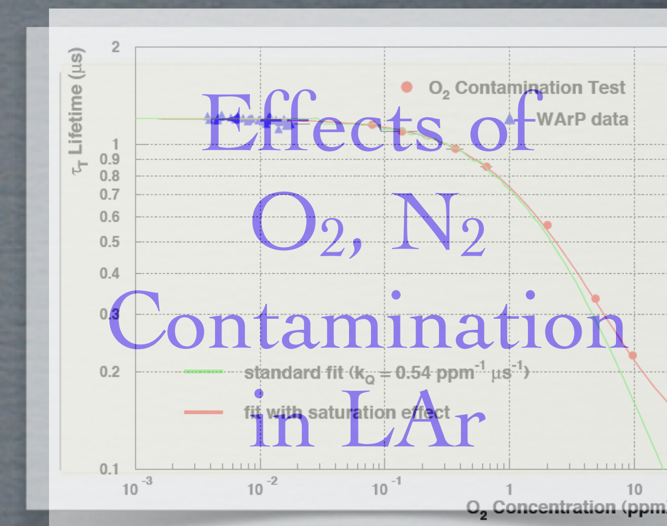
- Event Reconstruction and Off-line code developments

- LAr response characterization:
  charge recombination and calorimetry (e/π ratio)

· LAr Purity (contaminants and materials' compatibility) and LAr Purification



MTS@ FNAL
Material Test Stand



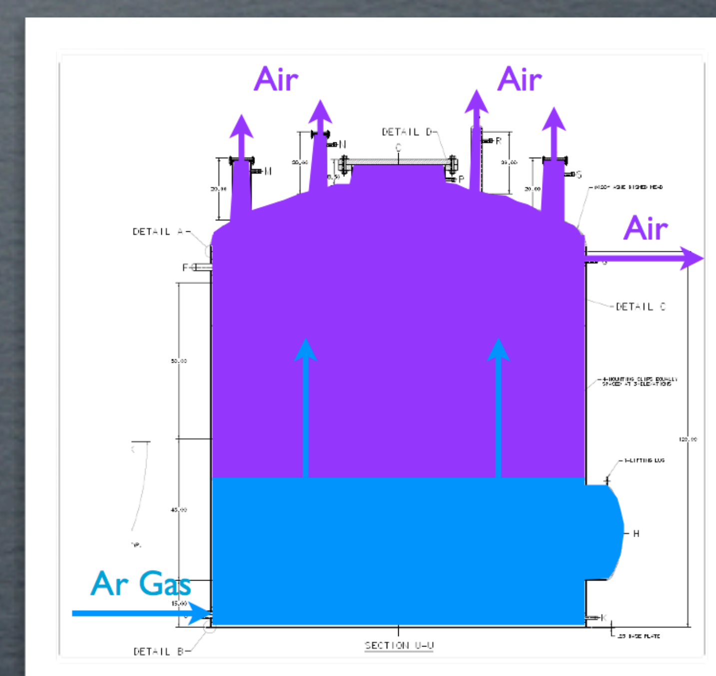
CryoLab@ LNGS

- 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_2O) and of new filters (for O_2) under way

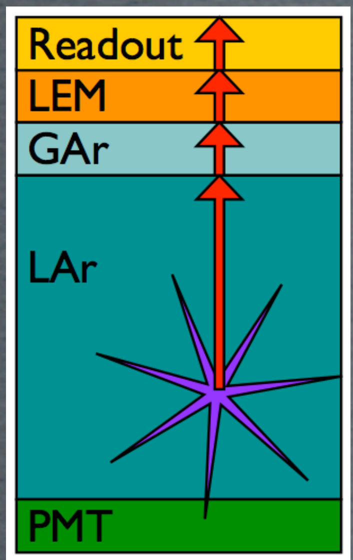
LAPD @ FNAL - *LAr Purity Demonstrator*

- 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)

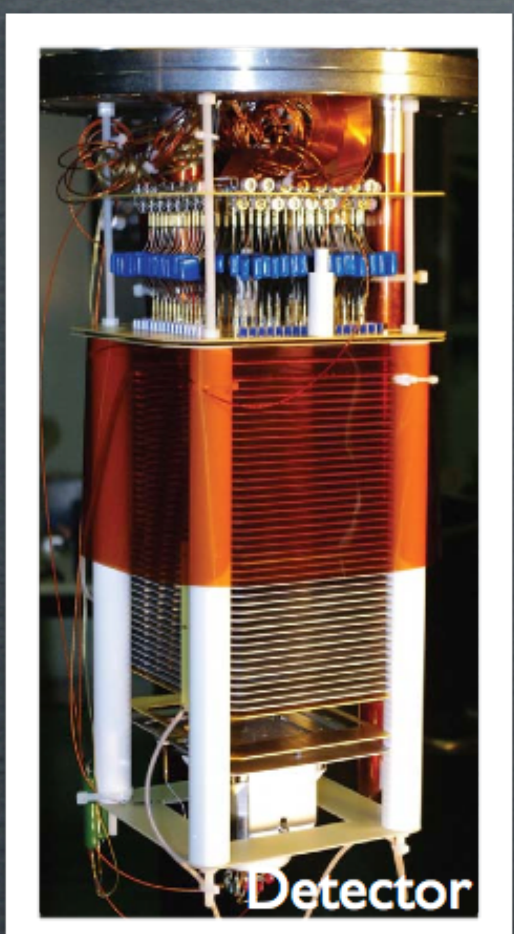
➠ goal < 50 ppm contamination (test under way)



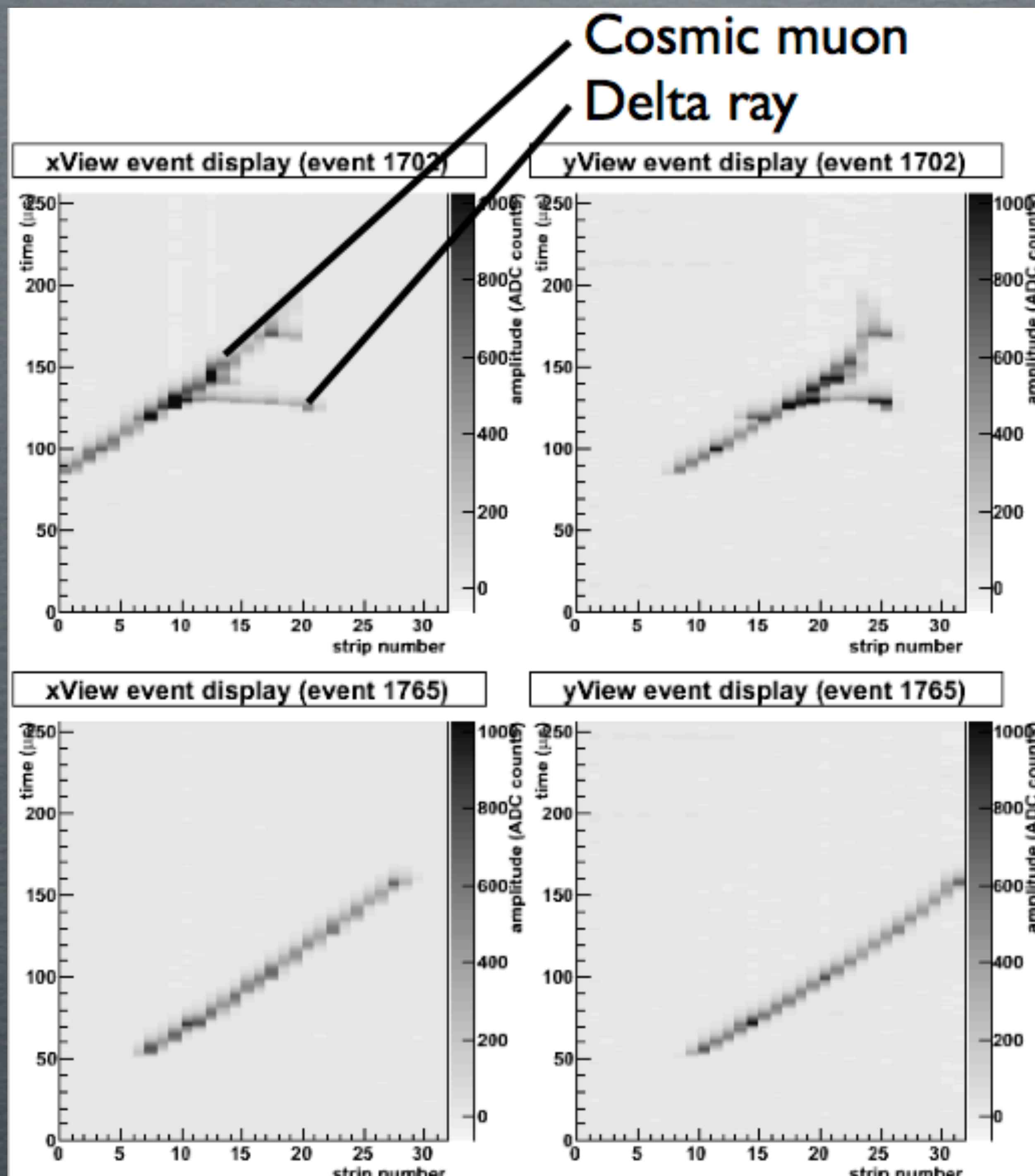
LAr LEM-TPC @ CERN (ETH)

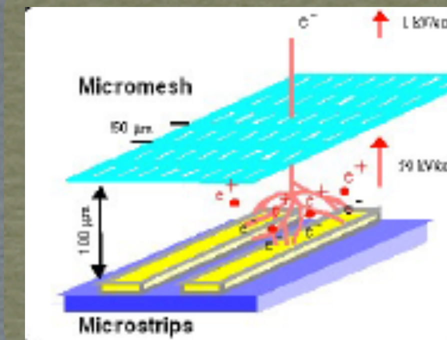


from concept to real detector



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

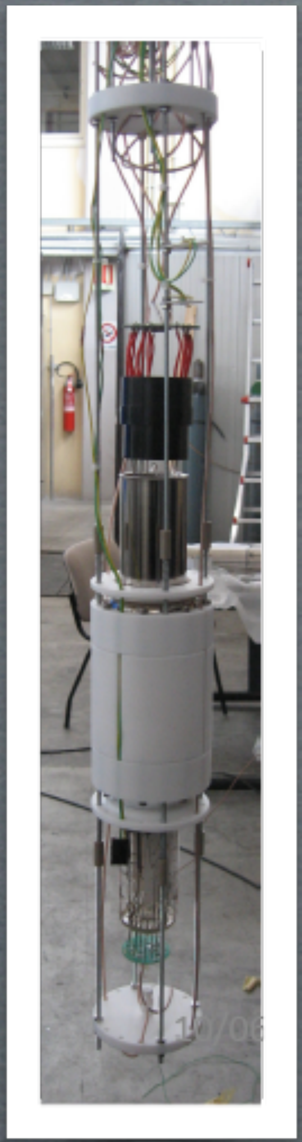




- MM: MicroMega concept under study @ CEA-Saclay ⊕ ETH

- 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

SCINTILLATION LIGHT SIGNAL COLLECTION & READ-OUT

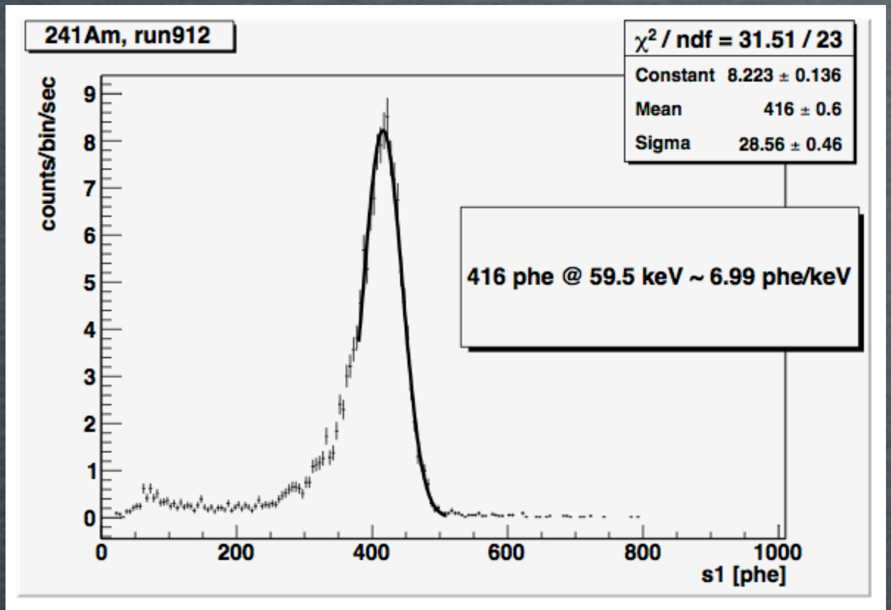


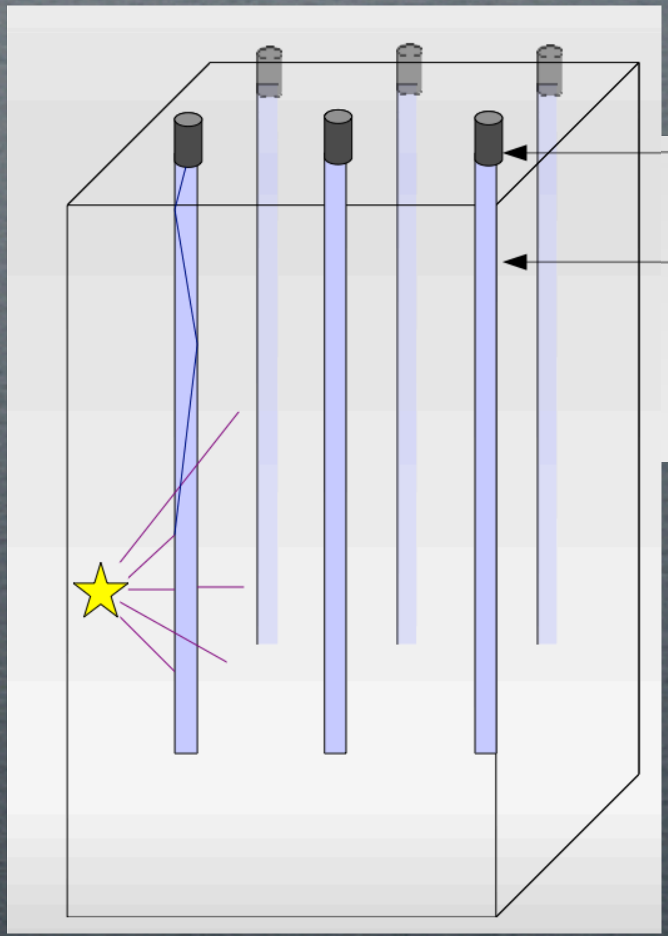
About 50% of the energy deposited by charged ptcl.s in LAr goes into Scint. photons: simultaneous and full exploitation of both Charge and Light signals will be the main line of development of the LAr tech.

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)

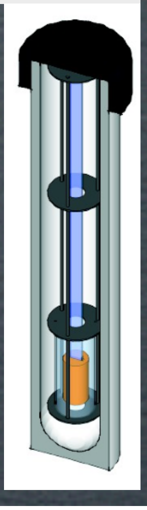
Optical systems w/ HQE-PMT CryoLab @ LNGS





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

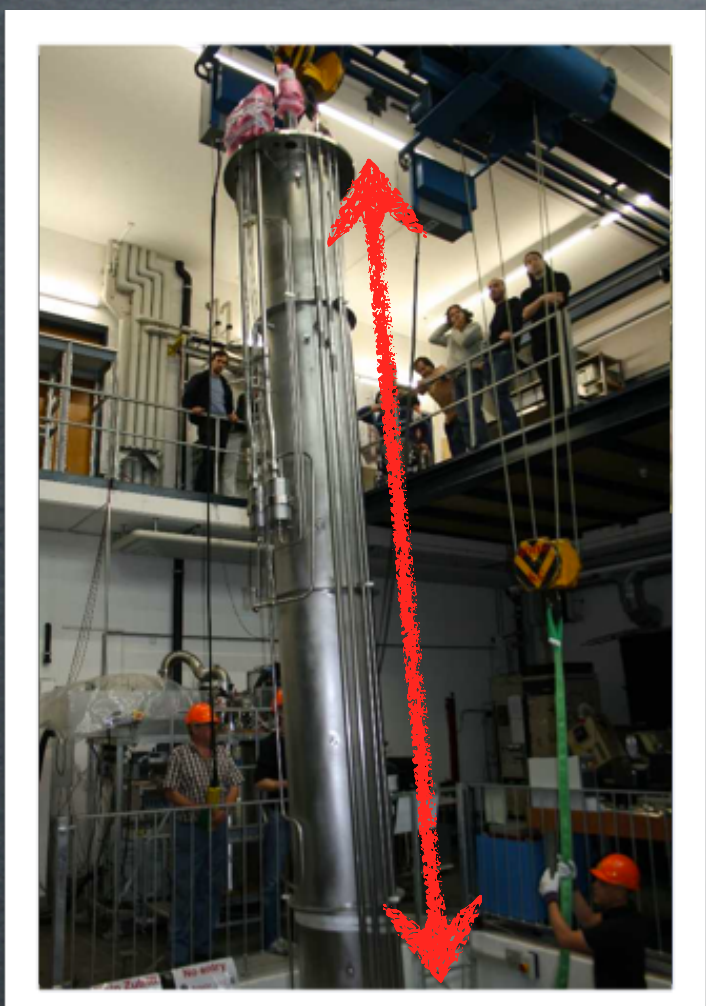
LightGuide concept development and test @ MIT



Electron charge drift over Long Distance

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



- First Cold Test Succesful

⊕

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

5mDRIFT
@ CERN - by UCLA

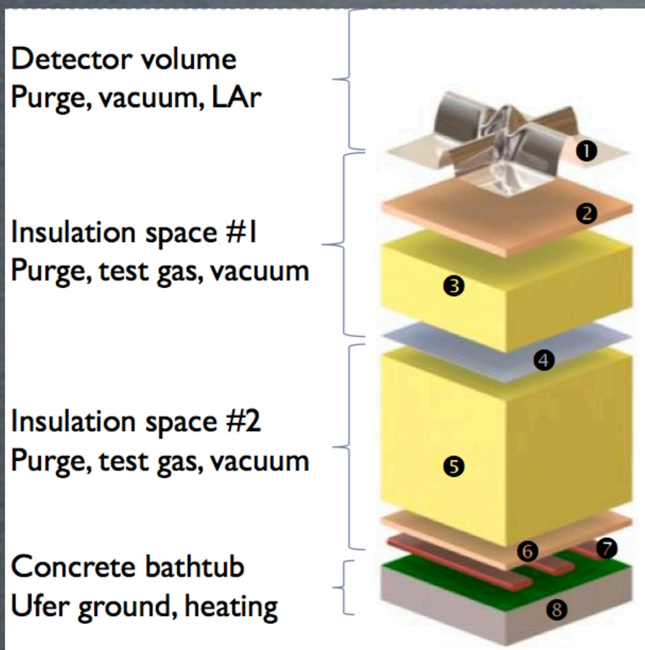
First technical test performed in Mar'11

- 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



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

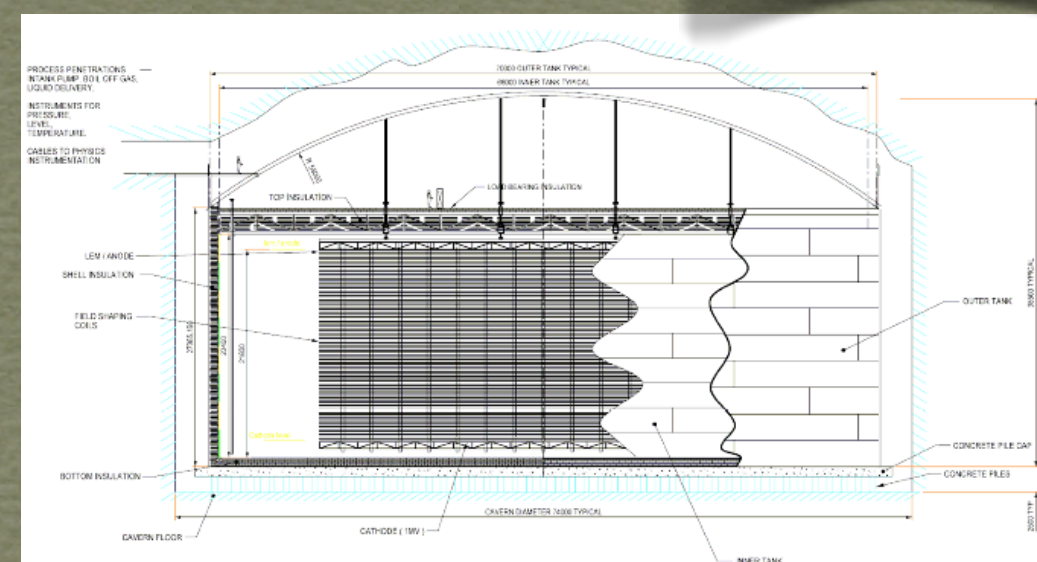
Concerns

- 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

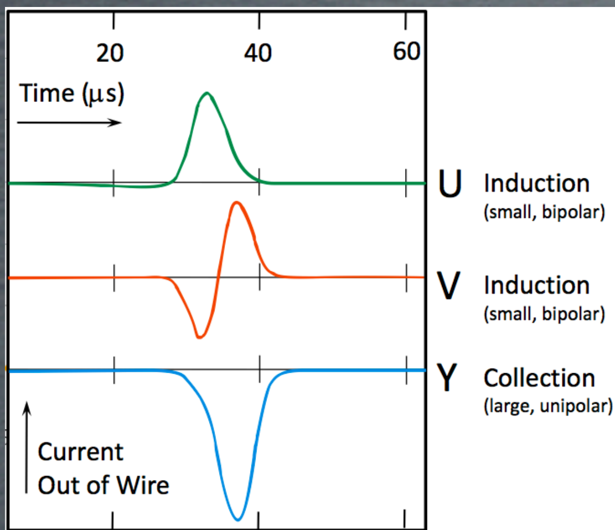
LAGUNA @ ETH

LNG Storage Tank (UnderGround)



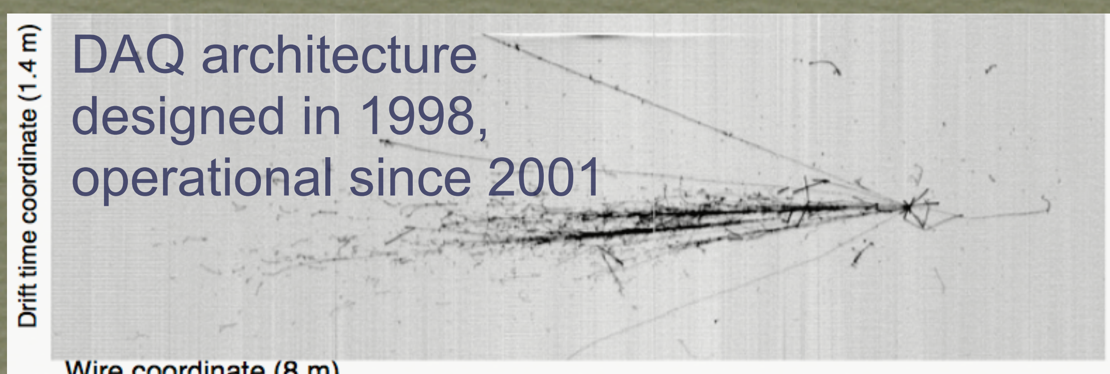
- **Initial Concept - 2004**
- **Use existing technology from industry experience**
- **Above ground tank, placed below ground**
- **De-couple the tank from the cavern**
- **Single containment is suitable**
  - **Full containment not warranted**
  - **Cavern will contain spill**

LAr-TPC Signal read-Out: Cold vs Warm Electronics



Induction by and Collection of } electrons on wires

WARM Electronics (ICARUS) @ Padova



DAQ architecture designed in 1998, operational since 2001

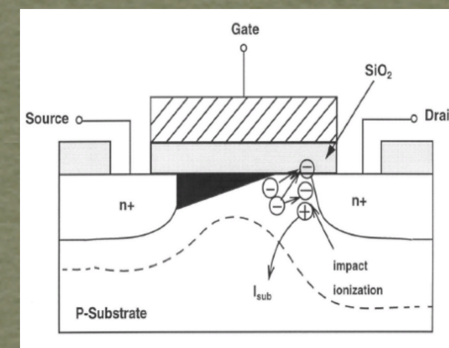
5*104 channels.

- 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

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)

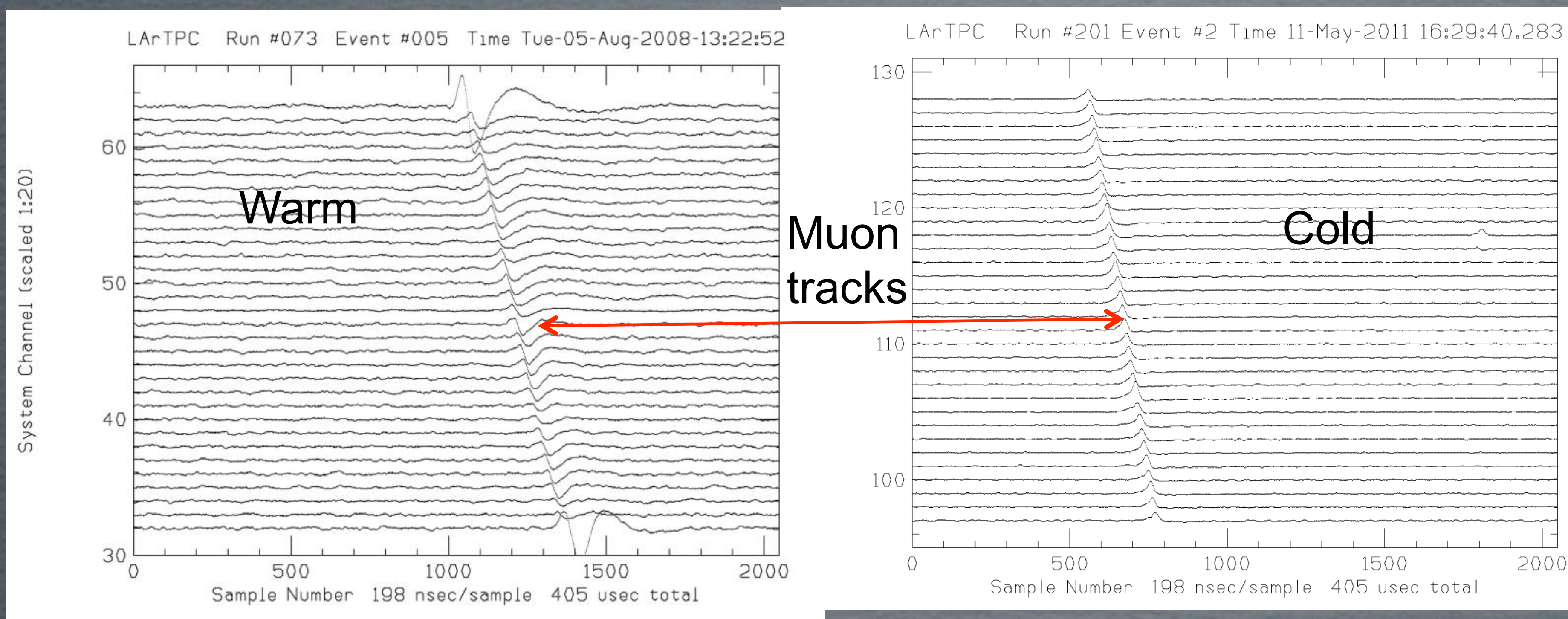
Current Development:
single chip, analog FE+ADC+buffer with 128:1 multiplexing

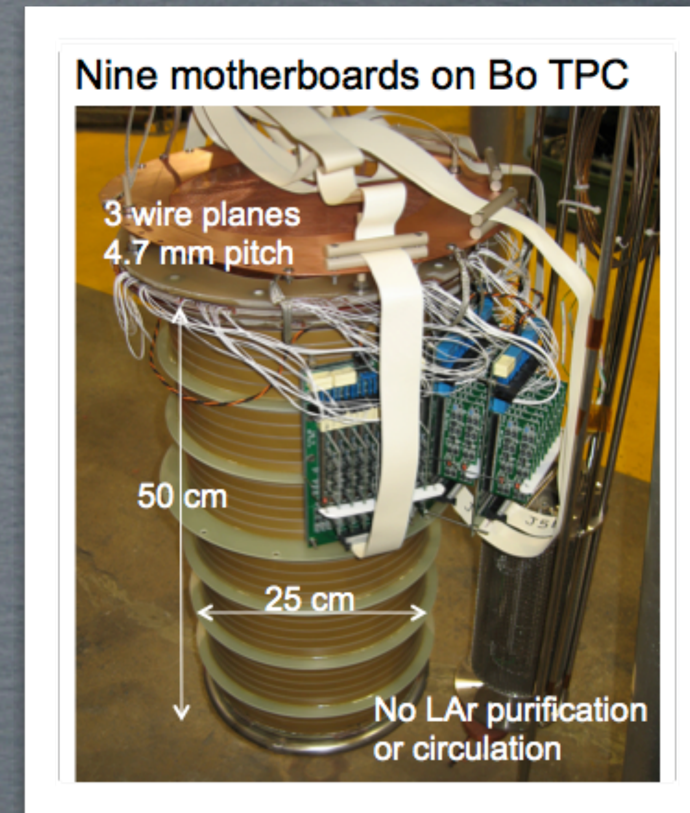
Entire TPC can have uniform calibrated (<1%) charge sensitivity

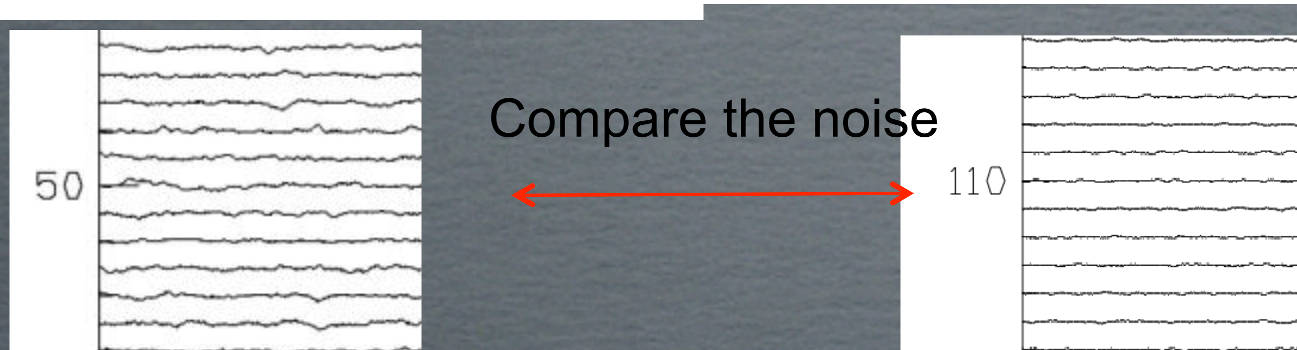
MicroBoone LAr-TPC at FNAL with COLD electronics

LAr-TPC Signal read-out: Cold vs Warm Electronics

Qualitative comparison Warm-Cold preamps







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)

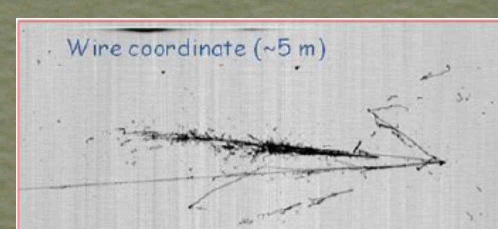
LArSoft

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



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)

Code development
@ ETH, CERN

LARSOFT

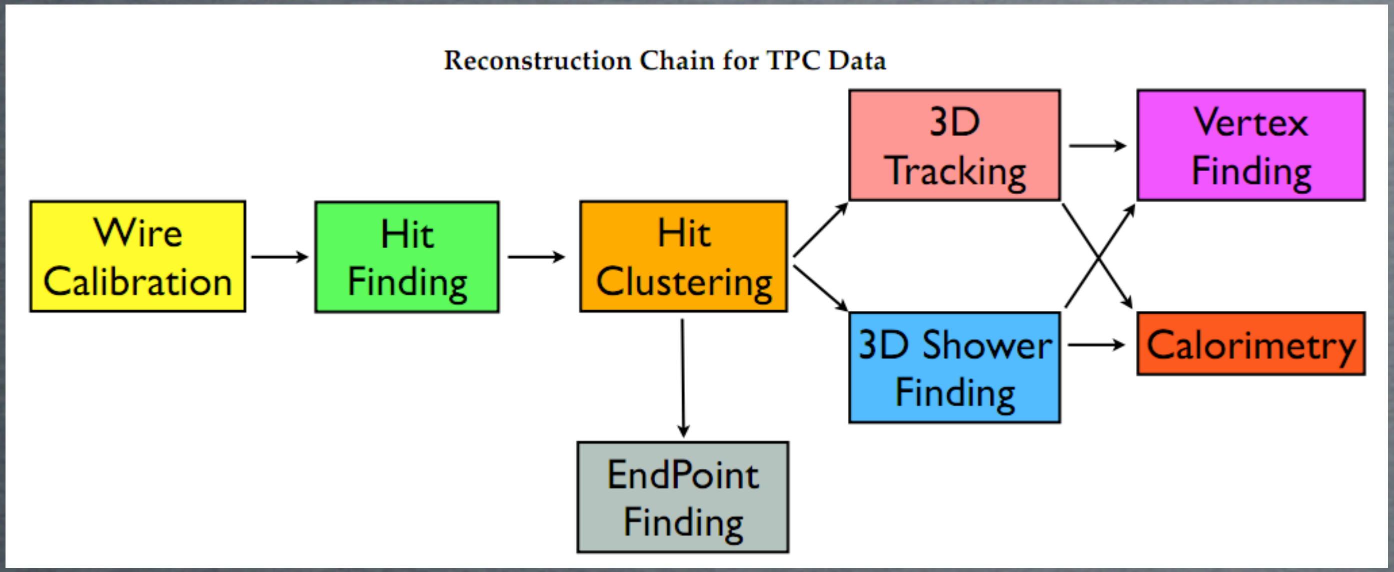
LArSoft is a complete set of Simulation/Reconstruction/Analysis tools.

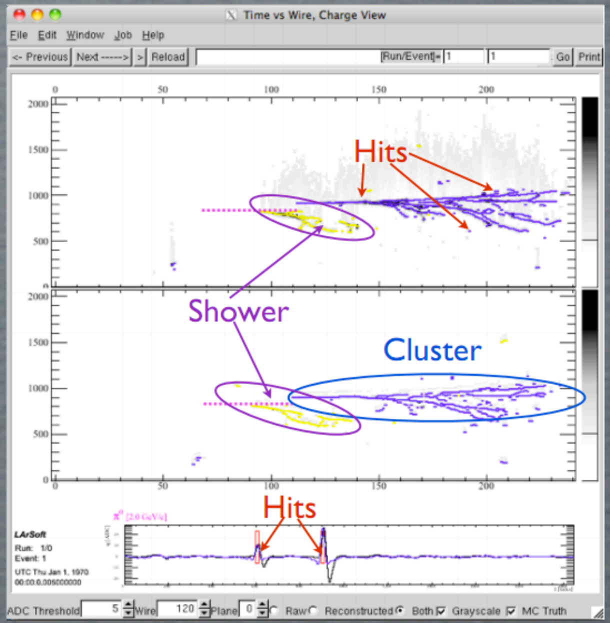
Philosophy: LArSoft code to be shared by all LArTPC experiments.

Codebase lives at FNAL with Computing Division support.

Analysis and Reconstruction Toolkit (ART), derived from CMSSW, is the framework.

User chooses which experiment to run on, and sets parameters to get at geometry and electronics specific to that experiment



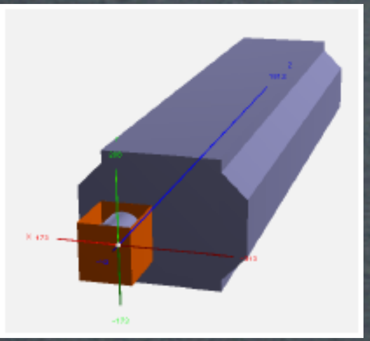


Data: (ArgoNeuT): RawDigits

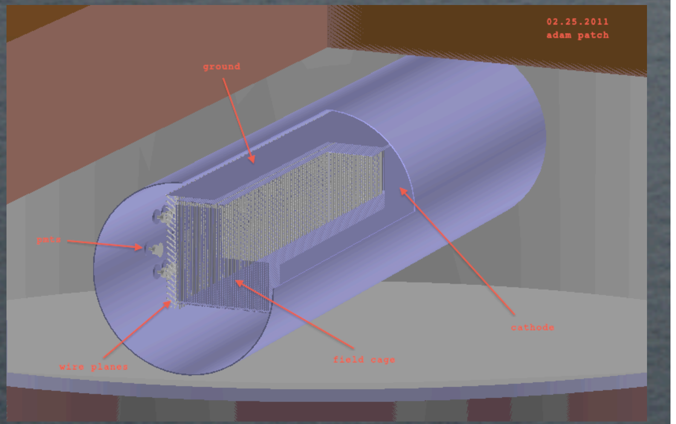
Create events in the detector: GENIE/NuANCE/CRY/ SingleParticle/FileParticles

Simulate: Geant4 (with drift electrons)+DetSim

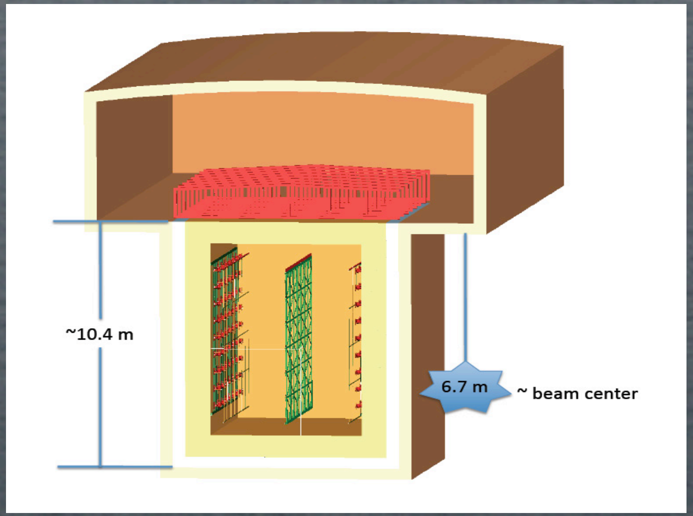
ArgoNeuT



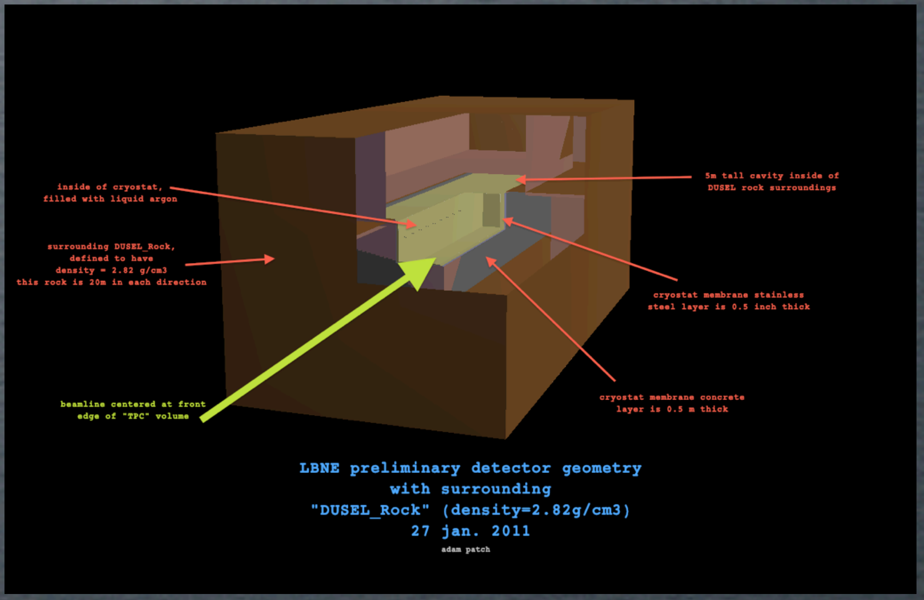
MicroBooNE



LAr1



LAr-LBNE



LAr Response Characterization: the Need of dedicated Test BeamS

Every "new" detector (eg trackers, calorimeters) is "always" (usually) *calibrated* (before physics application)

Only when the *Input* (ptcl. Type and Energy) is a priori known, the detector *Output Response* can be "*calibrated*" (➠ test-beam).

Single track reconstruction:

"calibration" = charge to energy conversion

(i.e. determination of the charge Recombination factors)

μ to π separation (?) and kaon, proton identification (based on dE/dx)

Collective topology reconstruction

"calibration" = detected energy to incident energy conversion

electron to γ (→ e^+ e^- pair) separation

π → had. shower: size and features

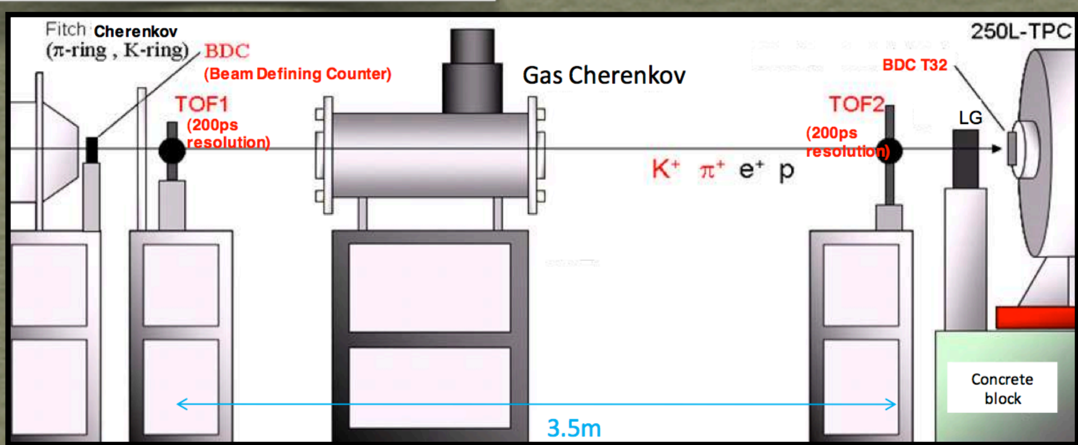
LAr Response testbeam Characterization

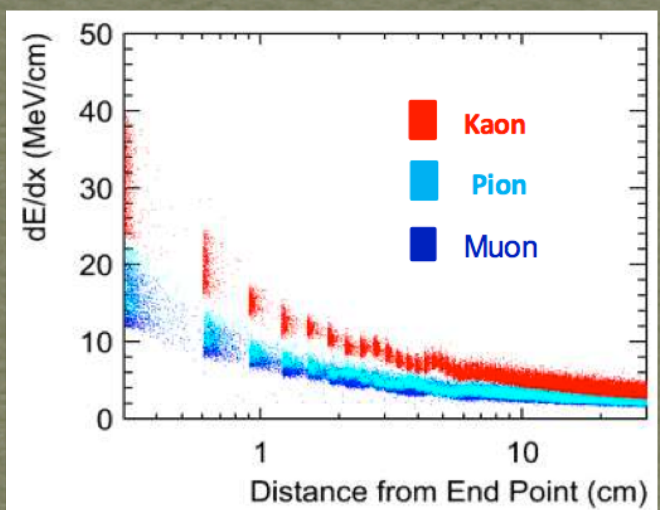
T32 @ J-PARC

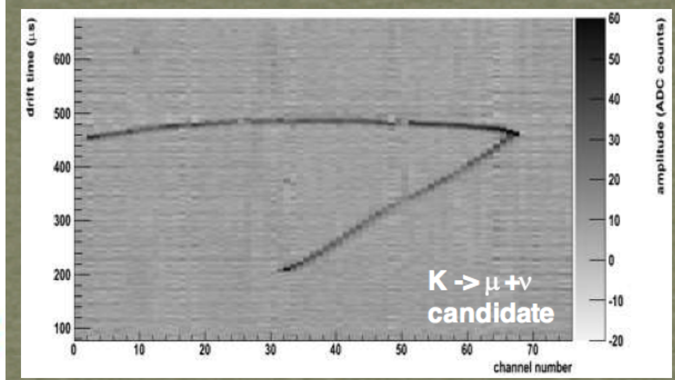
(250 lt LArTPC-2010)

ETH,
KEK, Iwate U, Waseda U.

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



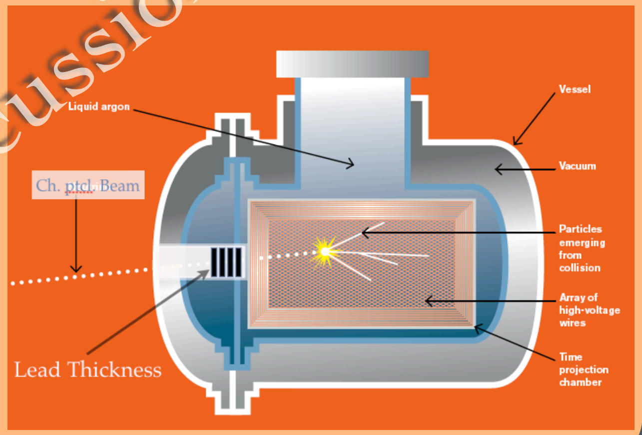


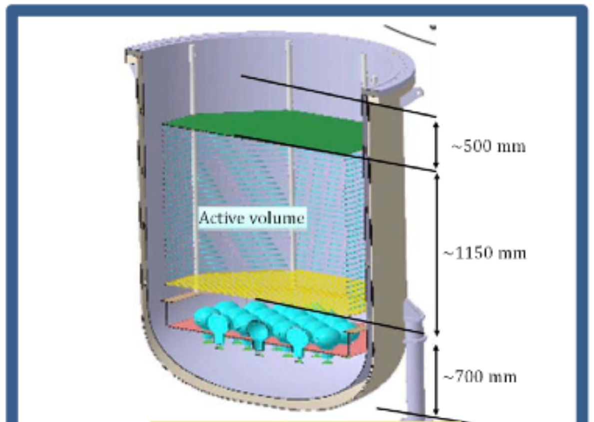


ArgoNeuT @ FTBF (FNAL)

(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



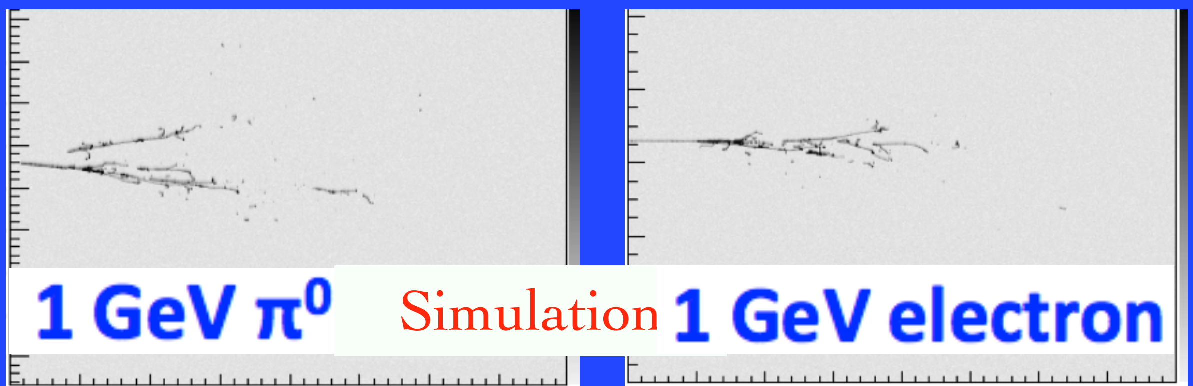


6 m³ @ CERN

to be proposed for test beams in NA @ CERN

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

test of particle identification, calorimetry, hadronic secondary interactions



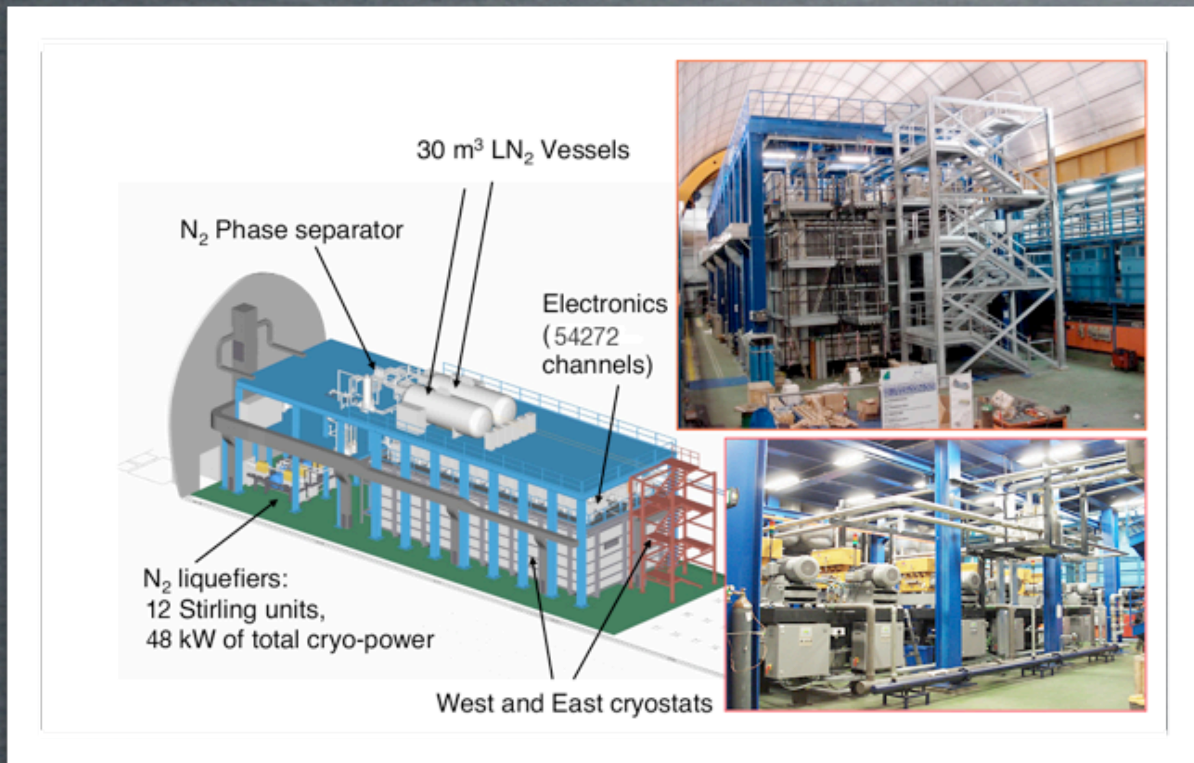
LAr ν-Experiments: Present generation

ArgoNeuT: 2009-10 @ NuMI-LE (FNAL) - [small LAr-TPC]
run completed (data analysis in progress - see talk by O. Palamara)

ICARUS T600: ≥ 2010 @ CNGS (LNGS) - [first large LAr-TPC]
running (see talk by D. Stefan)

MicroBooNE: ≥ 2013 @ Booster (FNAL) -
under construction (see talk by B. Jones)

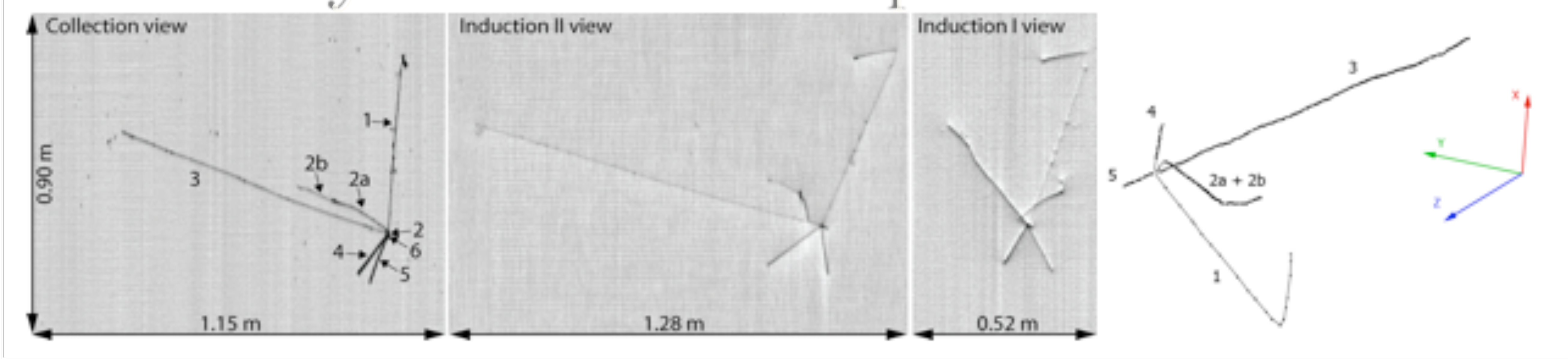
I C A R U S



The present worldwide credit on the LAr-TPC technology is largely due to the brave and tireless dedication of the Icarus Collaboration over the last two decades.

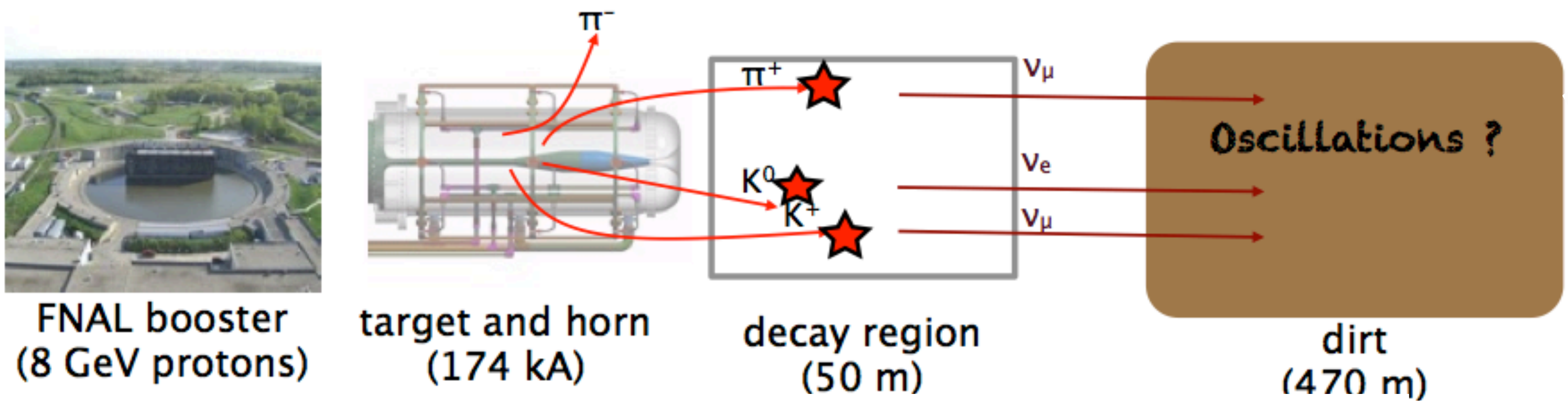
ICARUS is the first large LArTPC built and operated underground. It is running since Jun'10.

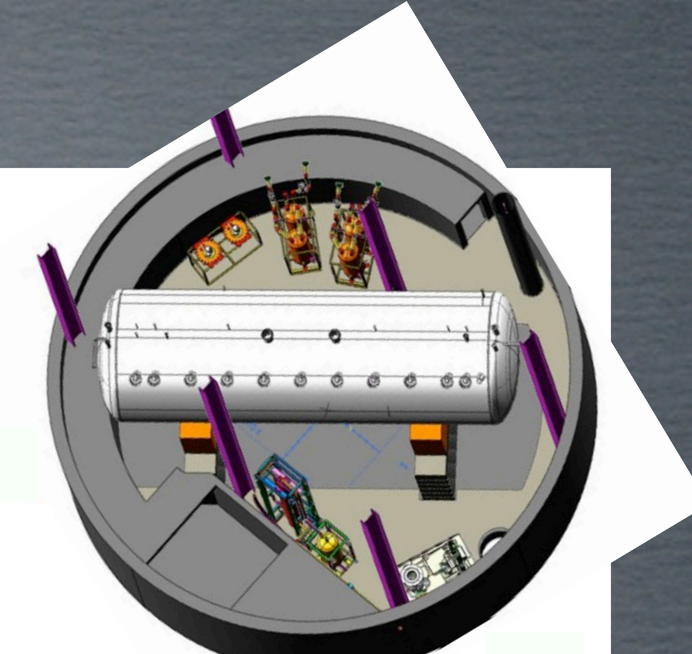
Fully reconstructed atmospheric ν-event



Physics results from CNGS (high energy) lbl ν-beam and atmospheric ν's are expected soon.

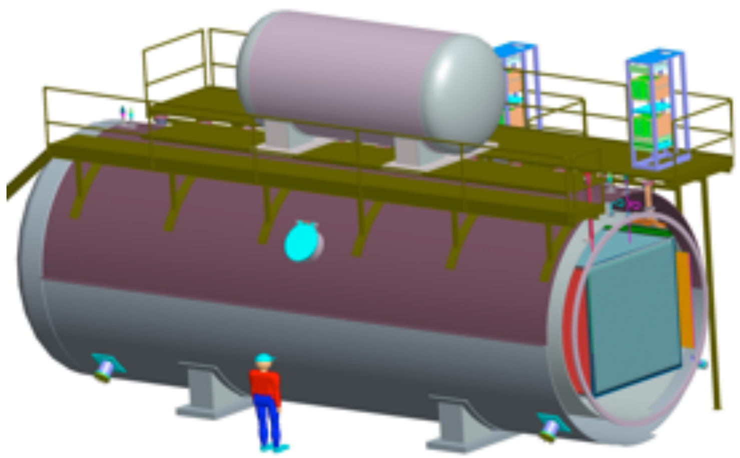
MicroBooNE





MicroBooNE current status

- Stage 1 approval in 2008
- CD-0 in 2009
- CD-1 in 2010

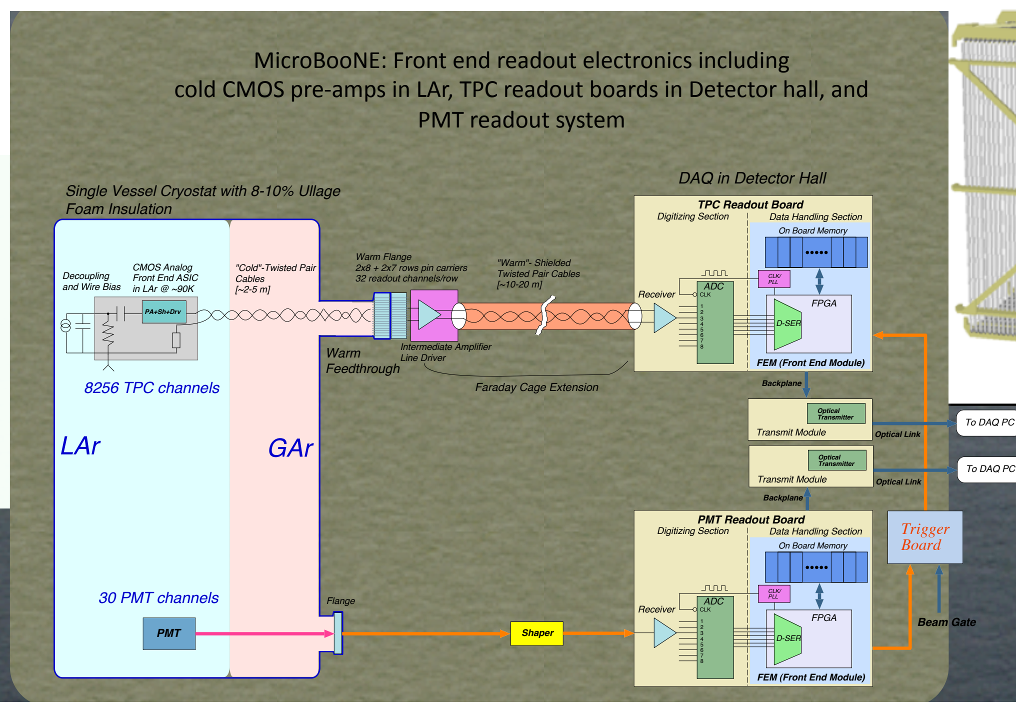


- CD-2/3a **anticipated** this Summer 2011 → Begin construction

You are here

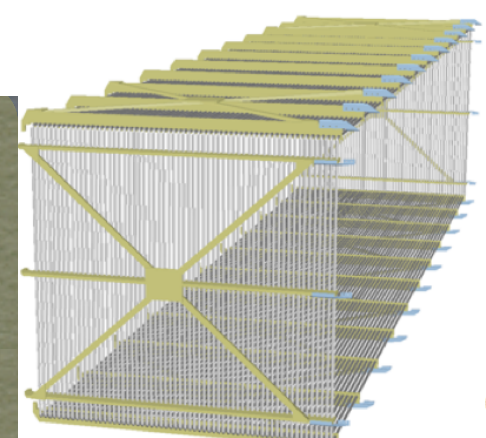
Data taking in 2013

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

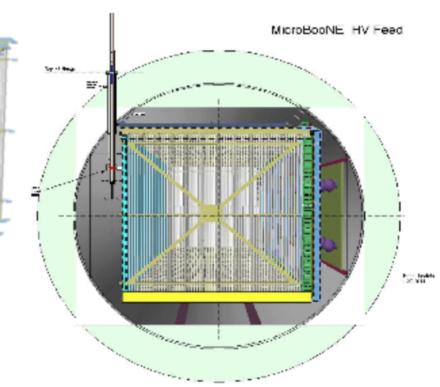


The microBooNE detector

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



Field cage

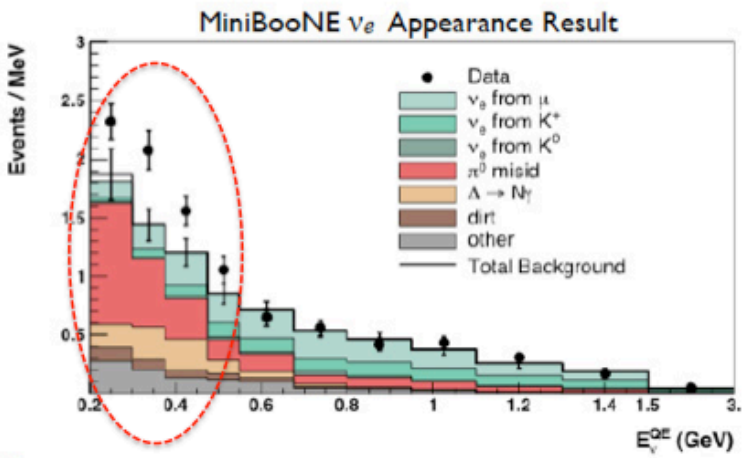


Cross section of TPC inside cryostat [7]

MicroBooNE: the physics case

MiniBooNE low energy excess

- MiniBooNE observed a 3σ excess of events at low energies in neutrino mode.
- Events are electromagnetic – electrons or photons
- Extensive work to understand backgrounds and signal
- MiniBooNE (and most conventional neutrino detectors) cannot differentiate electrons from photons



MiniBooNE Neutrino-Mode Excess

200-300MeV: 45.2±26.0 events

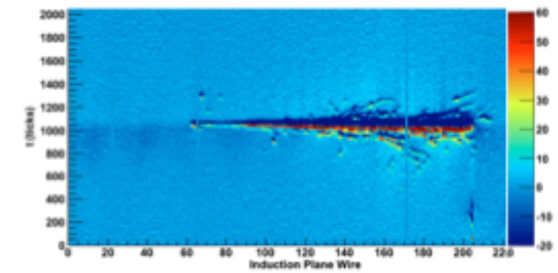
300-475MeV: 83.7±24.5 events

PRL 102, 101802 (2009), $6.46 \cdot 10^{20}$ POT

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

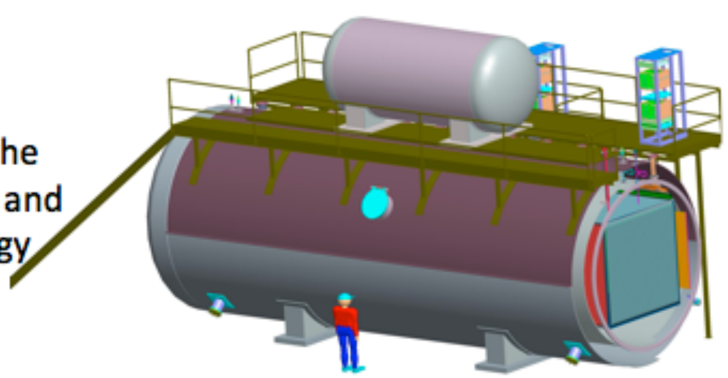


Use topology and dE/dx to differentiate electrons (signal) from gammas (background) indistinguishable in Cerenkov imaging detectors

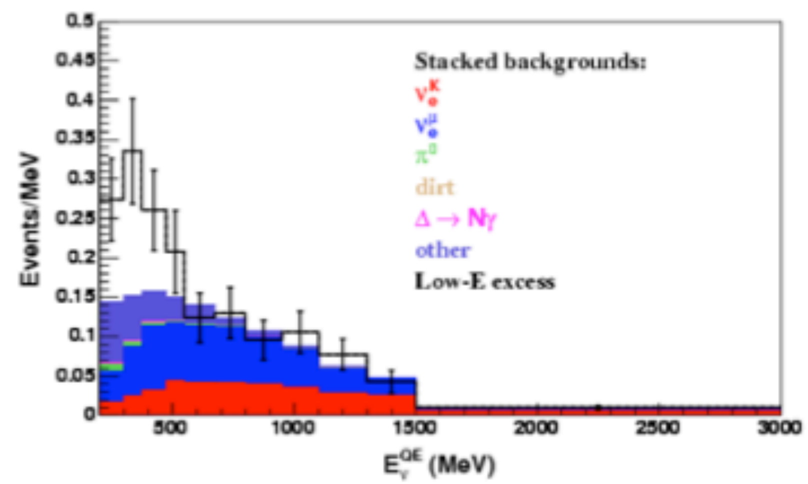
Electron neutrino candidate from ArgoNeuT

The MicroBooNE Experiment:

LArTPC detector to address the MiniBooNE low energy excess and measure a suite of low energy neutrino cross sections

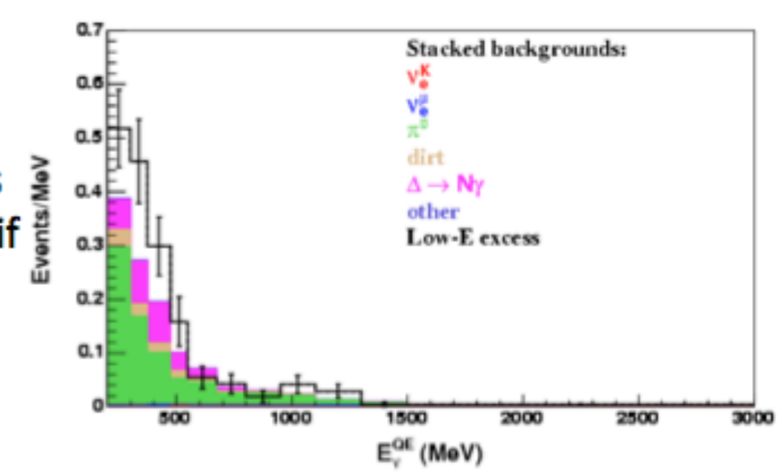


MicroBooNE's LArTPC detection technique: extremely powerful sensitivities in neutrino mode.....



Low energy excess above background if excess is electrons

Low energy excess above background if excess is photons



The Global LAr effort: next generation ν-oscillation experiments

A staged approach towards high-intensity facilities

- ~1MW an important (necessary) barrier

JPARC	T2K (300km) - 0.11MW operation in 2010	T2K (300km) - expected 0.75MW gradually ~2014	T2K (300km) T2O(658km) - expected 1.66MW operation, by >2014
FNAL	NUMI/MINOS (700km) - 0.3MW sustained operation	NUMI/NOVA (700km off-axis) - 0.75MW upgrade (~2013)	LBNE/DUSEL (1300 km) - 2MW operation requires Project-X
CERN	CNGS (732km) - 0.3MW sustained operation, 0.5MW if no beam sharing	CNGS+ (732km) or CN2PY (2300km) - 0.75MW "ultimate", requires SPS and injector upgrade	CN2PY(2300km) CN2FR(130km) - 2MW operation requires LP-SPL+HPPS, or HP-SPL+Accum

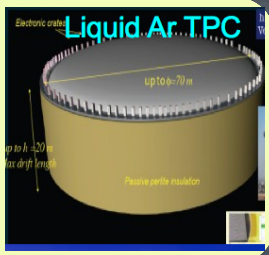
LAGUNA-LBNO, EUROν FP7 Design Studies

Ilias Efthymiopoulos - GLA2010 - June 7, 2011 15

Giant LArTPC Detectors (conceptual design)

J-Park to Okinoshima

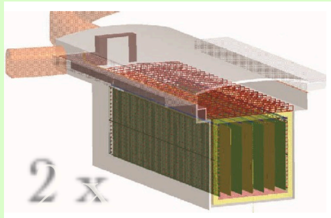
100kt-LAr



FNAL to DUSEL

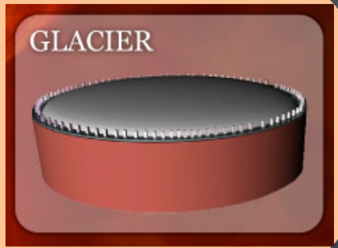
LBNE-LAr40

2 x



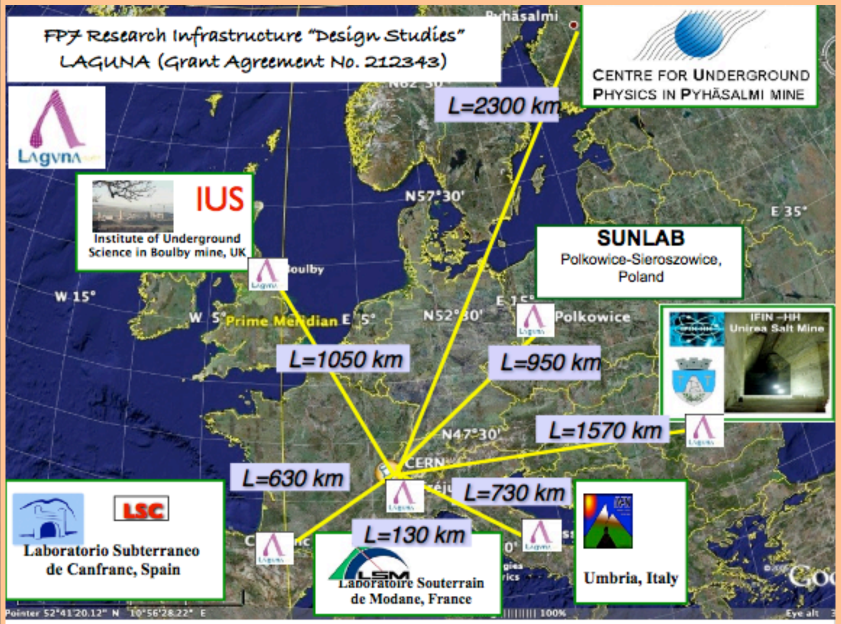
CERN to ?
(EU sites tbd)

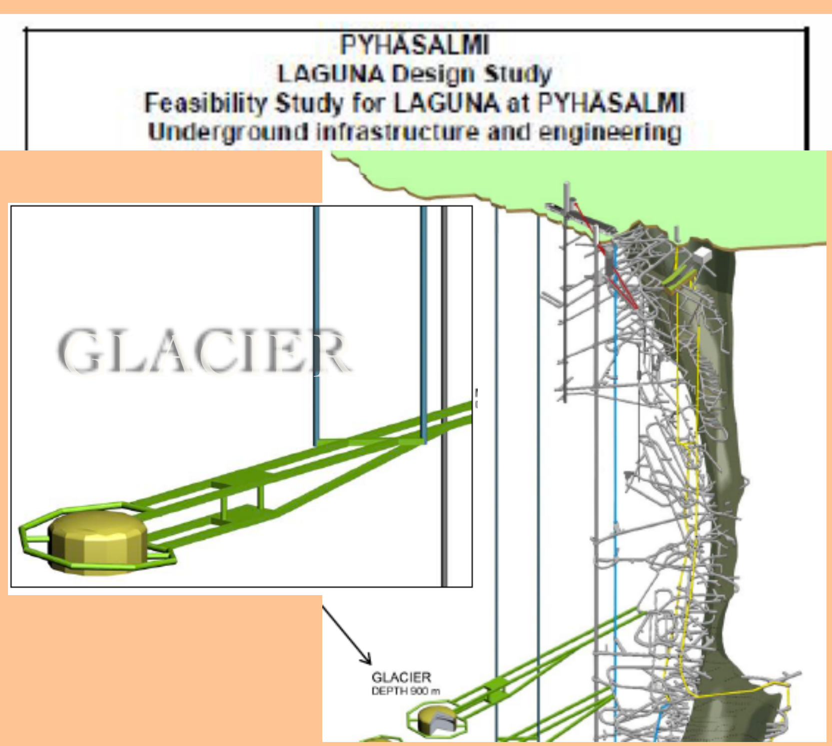
GLACIER



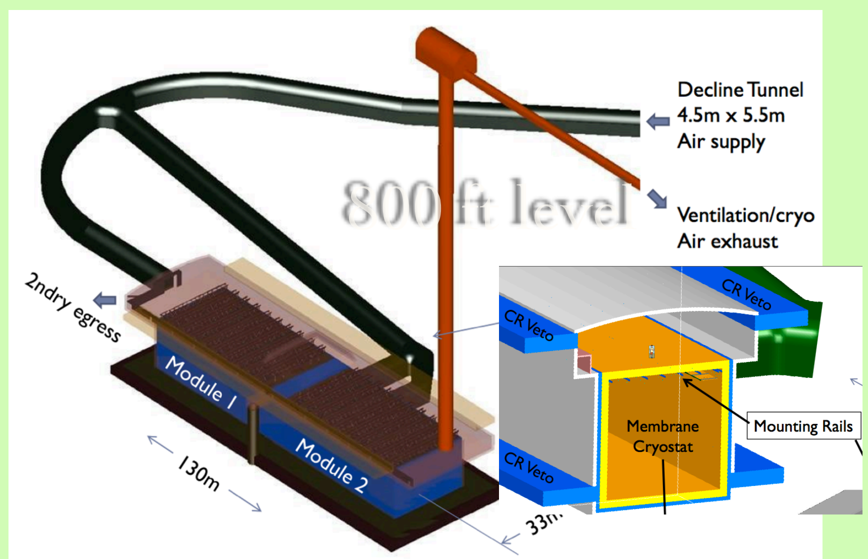
The Global LAr effort: next generation

GLACIER




PYHASALMI
LAGUNA Design Study
Feasibility Study for LAGUNA at PYHÄSALMI
Underground infrastructure and engineering

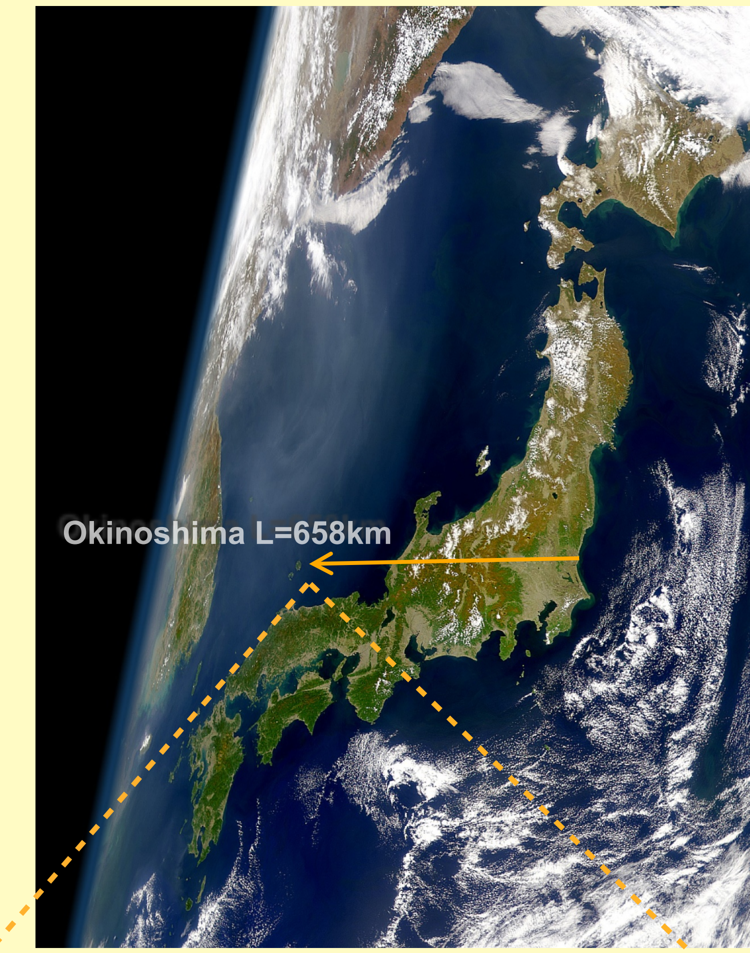
LBNE-LAr40

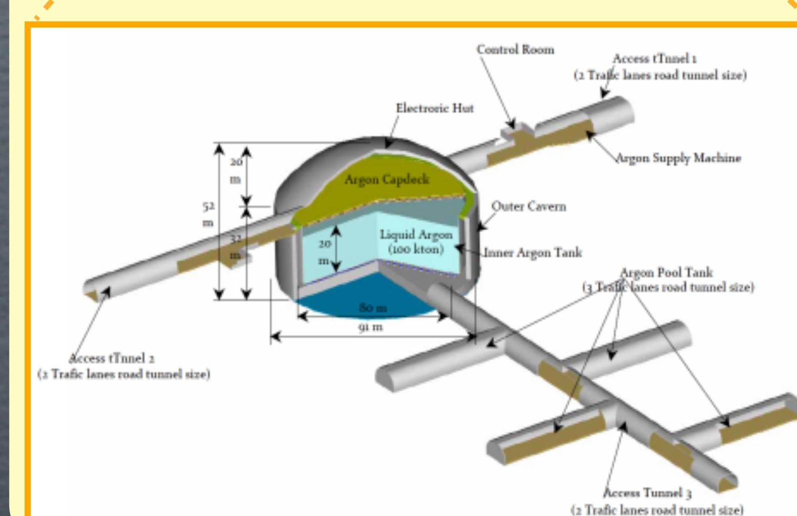


Reference Design - Key Parameters

- Detector module configuration
  - 2 high x 3 wide x 18 long = 108 Anode Plane Assemblies (APA)
    - 5mm wire spacing
    - Four wire planes: Grid, Induction 1, Induction 2, Collection
    - 3 readout channels/APA
      - 2462 readout wires x 4x redundancy / 3840 MUX
    - 3.67m drift
  - 16.4 kt fiducial mass, 19.4 kt active mass, 25 kt total mass
  - Cooling required – 40 kW nominal, 57 kW max
- Two detector modules in one cavern – 32.9 kton ~ 200 kton Water Cherenkov detector equivalent

100kt-LAr





The Global LAr effort: next generation

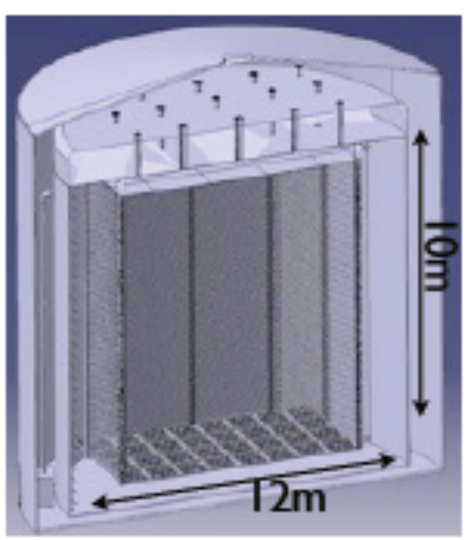
How to build a Giant Liquid Argon detector ?

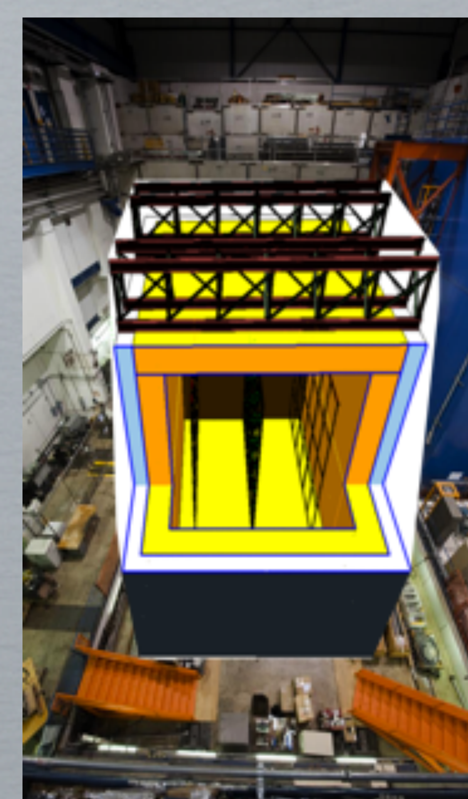
- The realization of a 100 kton LAr TPC demands concrete R&D in several areas. Although correctly relying on the pioneering efforts, it cannot be simply "linearly" extrapolated from the current state-of-art.
- To address this point, a series of workshops dedicated to these issues was initiated to bring together researchers having common interest in realizing a giant neutrino observatory based on the liquid Argon time projection chamber technology combining next-generation searches for proton decay and neutrino physics with natural and artificial sources.

A. Rubbia - GLA2011

GLACIER prototype kton-scale

Full engineering demonstrator for larger detectors, with a stand-alone short baseline physics programme or underground ?





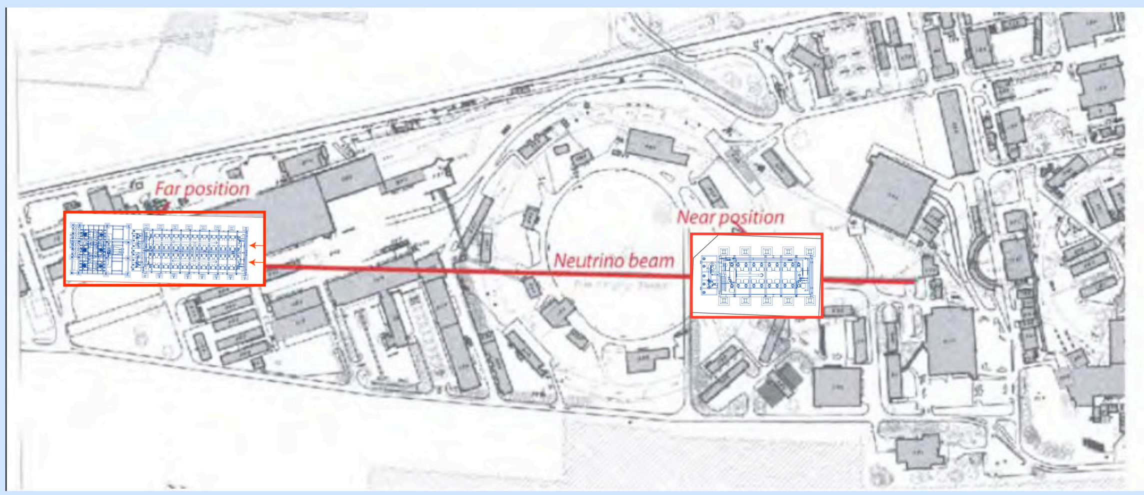
LBNE-LAr40 prototype

LAr1 (1 kton) Liquid Argon Engineering Prototype at FNAL in the D0 Hall

STEPS TOWARD THE NEXT GENERATION

Addressing the LSND/+MiniBooNe both antineutrino and neutrino $\nu_\mu \to \nu_e$ oscillation anomalies

Two LAr-TPC detectors at the CERN-PS neutrino beam

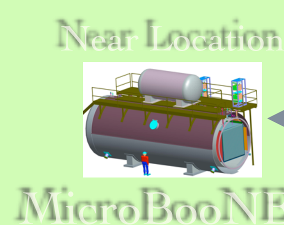


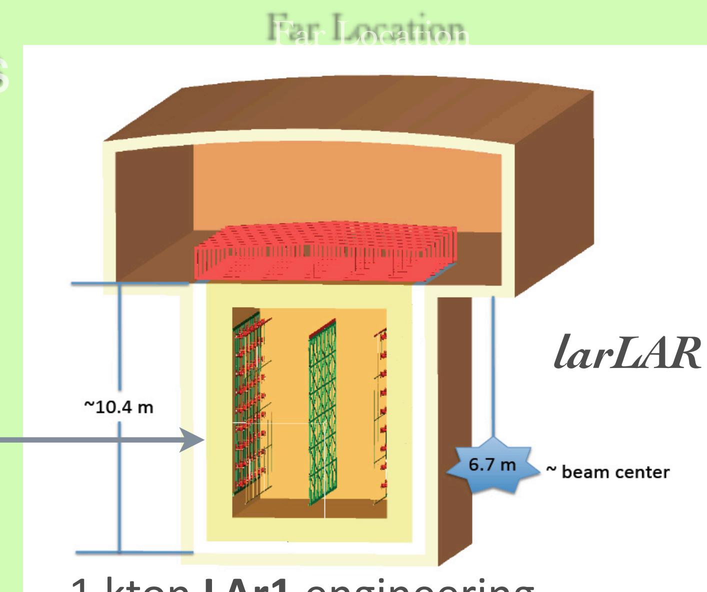
see talk by F. Pietropaolo

Far detector : ICARUS T600 -
It can be transported to CERN in 2013, after the CNGS programme completion , ensuring the new experiment operation again in 2014

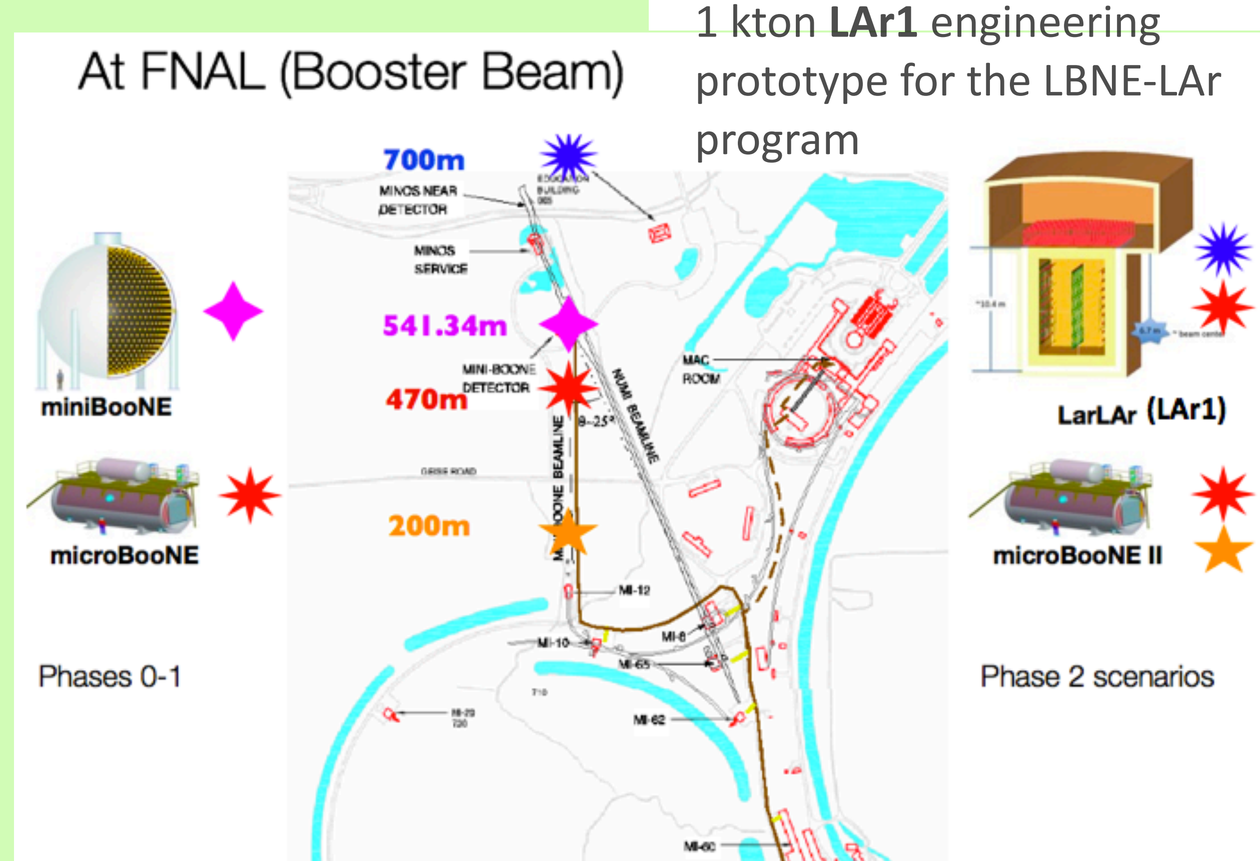
Near detector: to be constructed anew, with a mass of 150 t, a clone of a Icarus half-module with the length reduced by a factor 2.

Two LAr-TPC detectors at the FNAL-Booster ν-beam





1 kton **LAr1** engineering prototype for the LBNE-LAr program



Conclusions

LArTPC technology starts to play and even more in the future will keep playing a key role for precise ν-Physics measurements