Liquid Argon Work at Fermilab

Stephen Pordes Fermilab

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Work on Liquid Argon started for massive detectors for high energy (GeV) Neutrino physics.

Started as small R & D to do Materials Qualification for long-drift (> 2m) Liquid Argon TPC

now encompasses

Laboratory studies:

Material tests, purging of large volume cryostat, filtration, and contaminant studies,

TPC readout electronics development with small (50 liter, 50 cm drift TPC)

Beam studies:

ArgoNeut Expt– 0.25 ton in NuMI (few GeV) Neutrino Beam (taken data)

ν – experiments:

MicroBooNE Expt - 200 ton (75 tons fiducial) (E-974) to take data in 2013 on

Long Baseline Neutrino Experiment (LBNE) aimed at DUSEL

Dark Matter:

DarkSide - 50 (E-1000)

Depleted Argon Distillation Column

Acknowledge fundamental contribution of ICARUS and other European programs

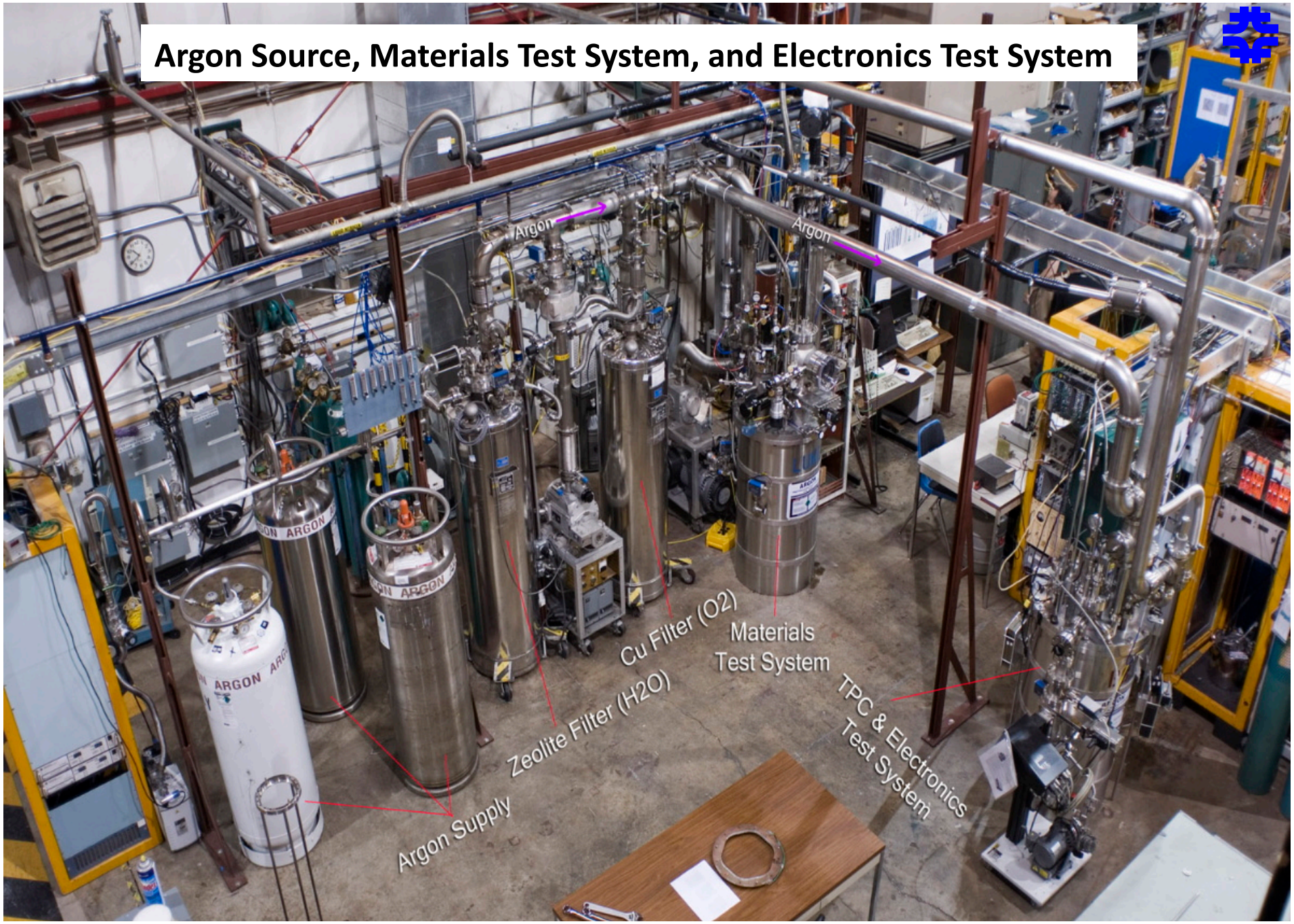
Technical Issues for Multi-ton Argon Dark Matter detector:

- Chemical purity to allow electron drift (10's ppt O2 equivalent),
- Chemical purity to allow light propagation (N2 < 1 ppm)
- Radio purity of Argon
- HV feedthroughs (>100 kV) in Argon gas
- TPC design
- Light Detection
- Data Acquisition
- Cryogenics (and associated safety issues)
- Detector Materials Qualification
- Shielding from environment radiation
- Radio-purity of detector materials

Technical Issues for Multi-ton Argon Detector:

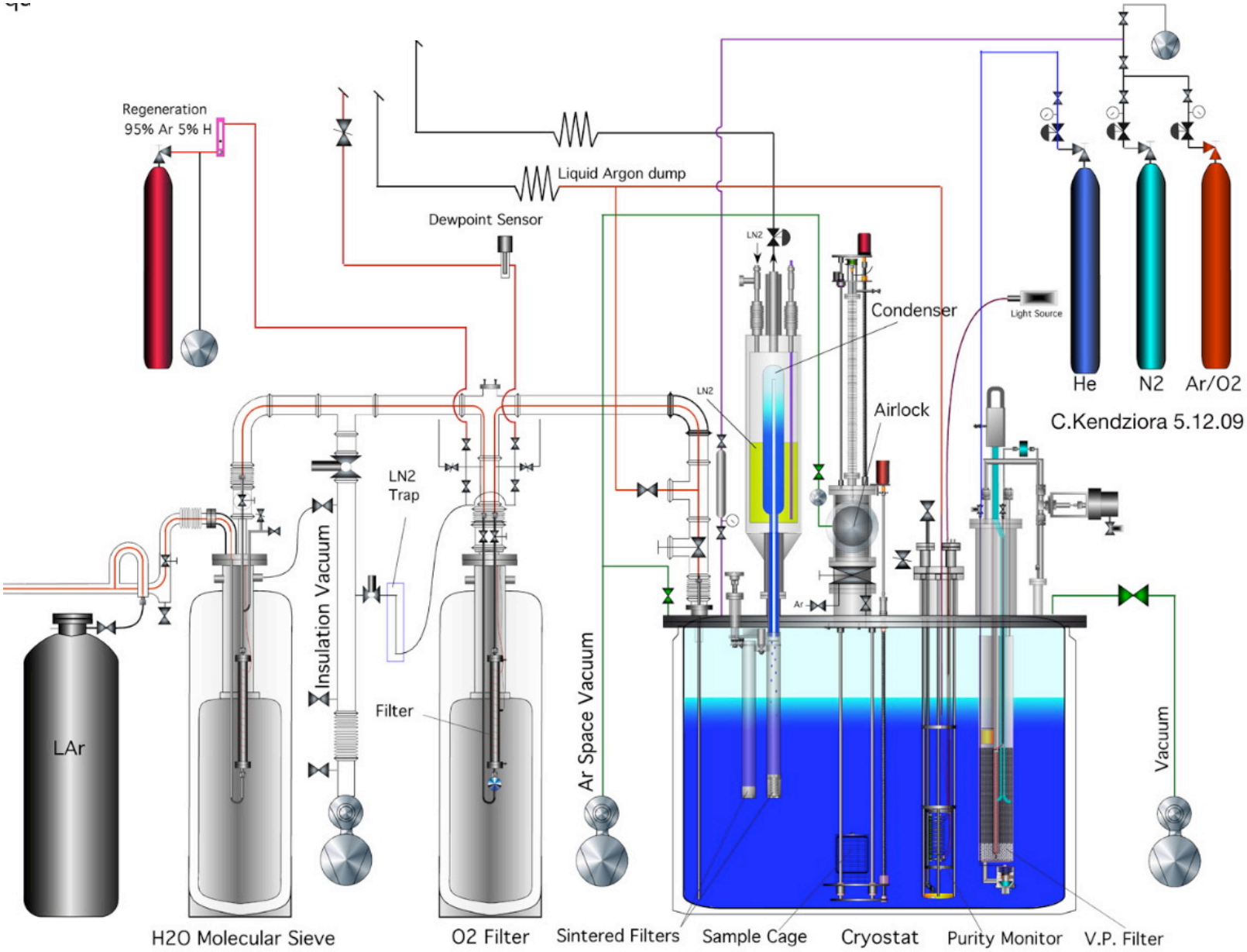
- Chemical purity to allow electron drift (10's ppt O2 equivalent), ***(ν and DM)***
- Chemical purity to allow light propagation (N2 < 1 ppm) ***(ν and DM)***
- Radio purity of Argon (*DM) (also affects underground ν)*
- HV feedthroughs (>100 kV) in Argon gas ***(ν and DM)***
- TPC design ***(ν and DM)***
- Light Detection ***(ν and DM)***
- Data Acquisition ***(ν and DM)***
- Cryogenics (and associated safety issues) ***(ν and DM)***
- Detector Materials Qualification ***(ν and DM)***
- Shielding from environment radiation (*DM)*
- Radio-purity of detector materials (*DM)*

Argon Source, Materials Test System, and Electronics Test System

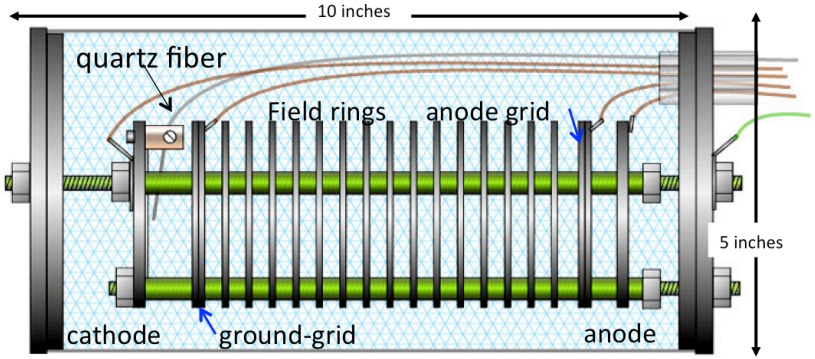


Materials Test Stand

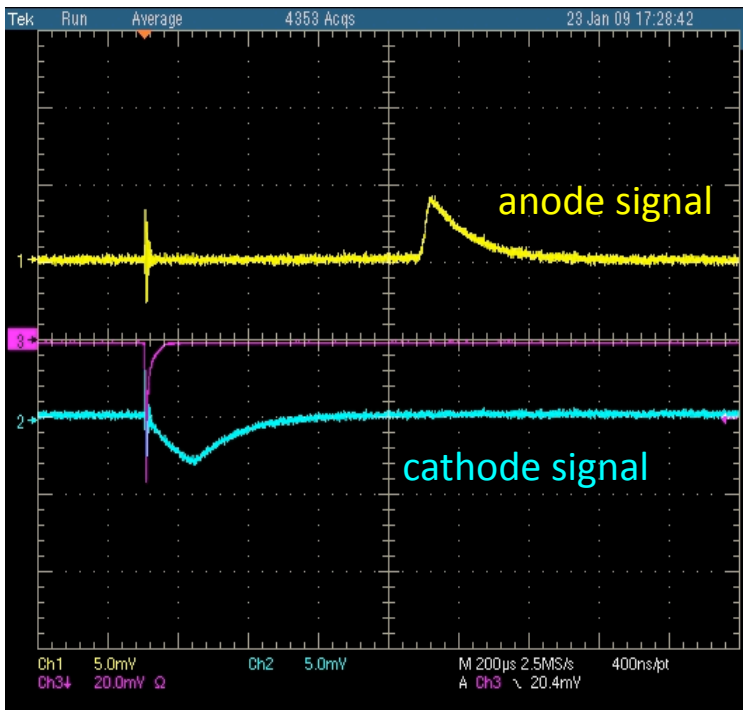
Schematic of Materials Test Stand



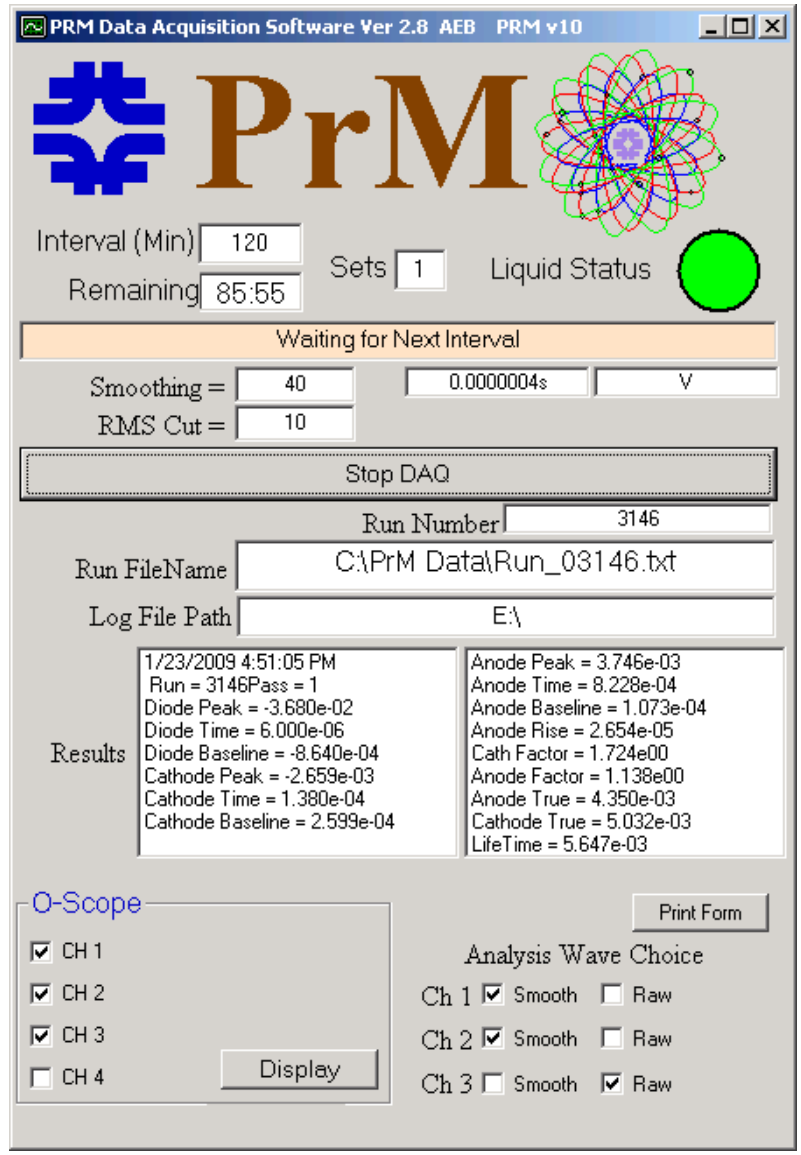
Electron Drift Lifetime Measurement



Purity Monitor (ICARUS invention)

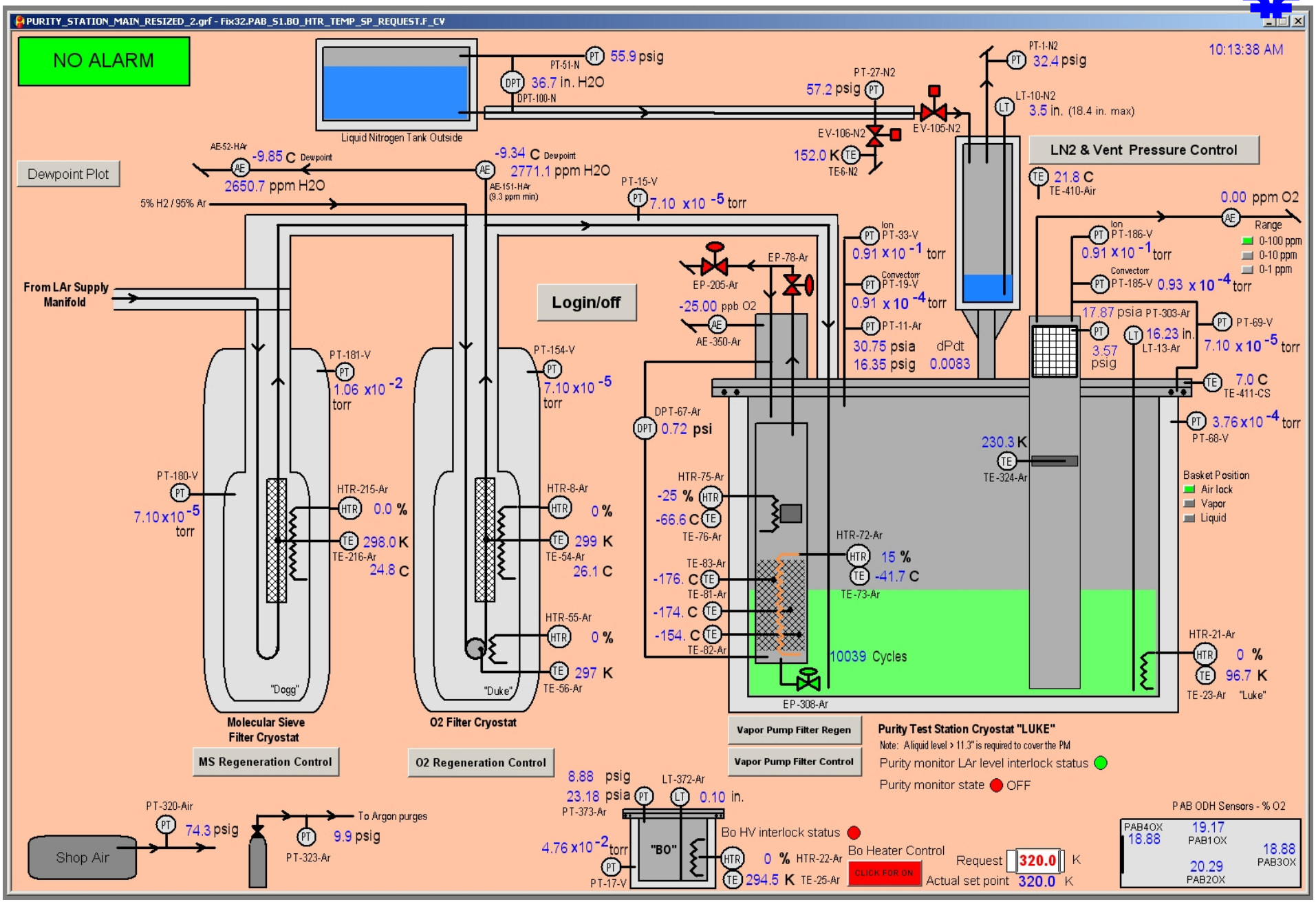


Purity Monitor signals



Purity Monitor automation software

Cryogenics Control Screen



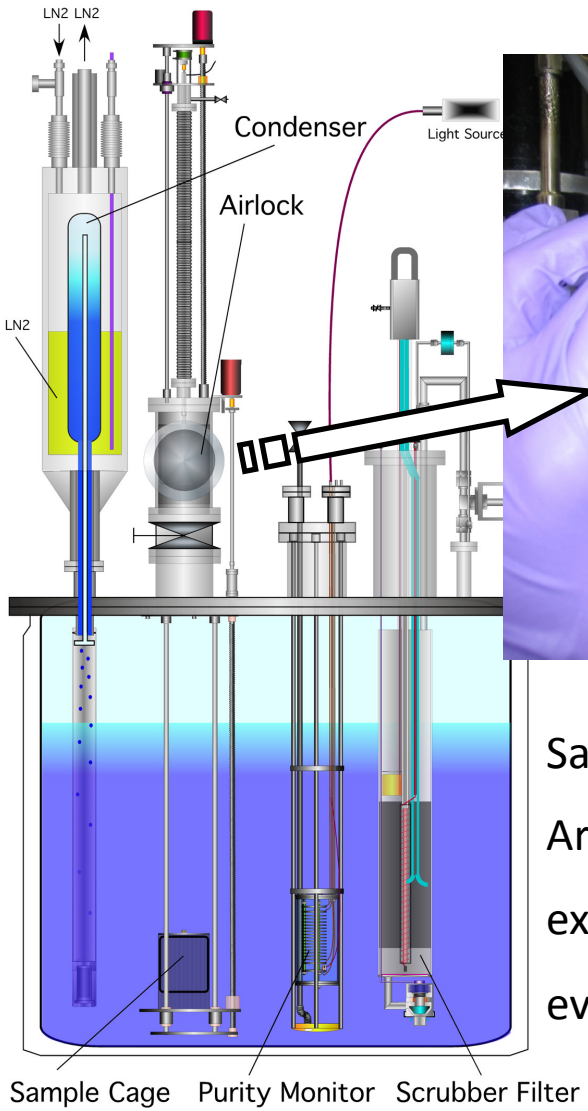
Features of Materials Test Stand

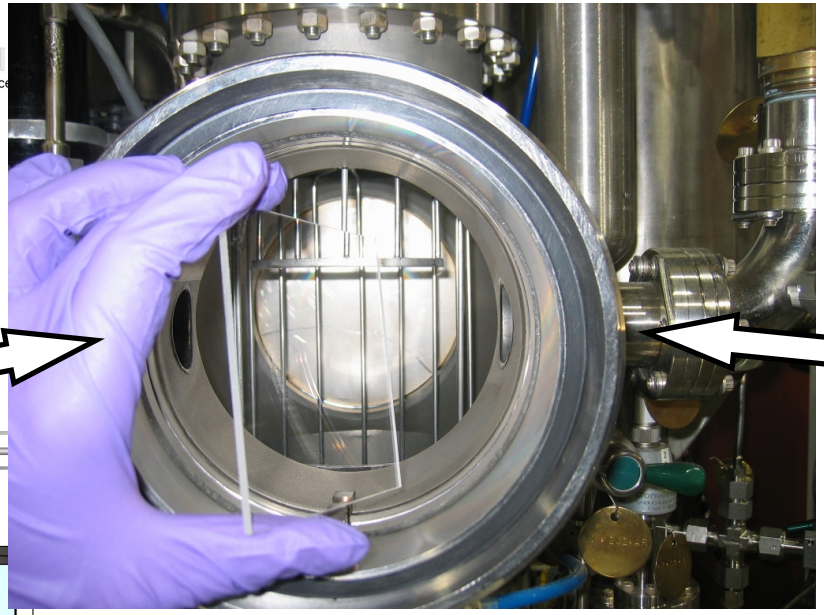
- Can insert materials into known clean argon
- Can insert materials after purging only or after pumping on them.
- Can position materials into liquid and into ullage with range of temperatures.
- Can insert known amounts of contaminant gases
- Nitrogen-based condenser can maintain liquid for long (weeks) studies
- Internal filter-pump can remove contamination introduced by materials – 2hr cycle
- Sample points at Argon Source, after single-pass filters, in cryostat gas and liquid

Measurement Features of Materials Test Stand

- Measure electron drift lifetime (0.5 milliseconds to 10 milliseconds)
- Measure Oxygen (0.3 ppb sensitivity) with oxygen meter (Delta-F & Tiger Optics)
- Measure H20 in gas (0.3 ppb sensitivity) with water meter (Tiger Optics)
- Cryogenic data, Lifetime Data, analytic instrumentation data in single data-base
- Runs 24/7 unattended except for filter regeneration and argon refills

Insertion of a material sample into the airlock (argonlock) basket

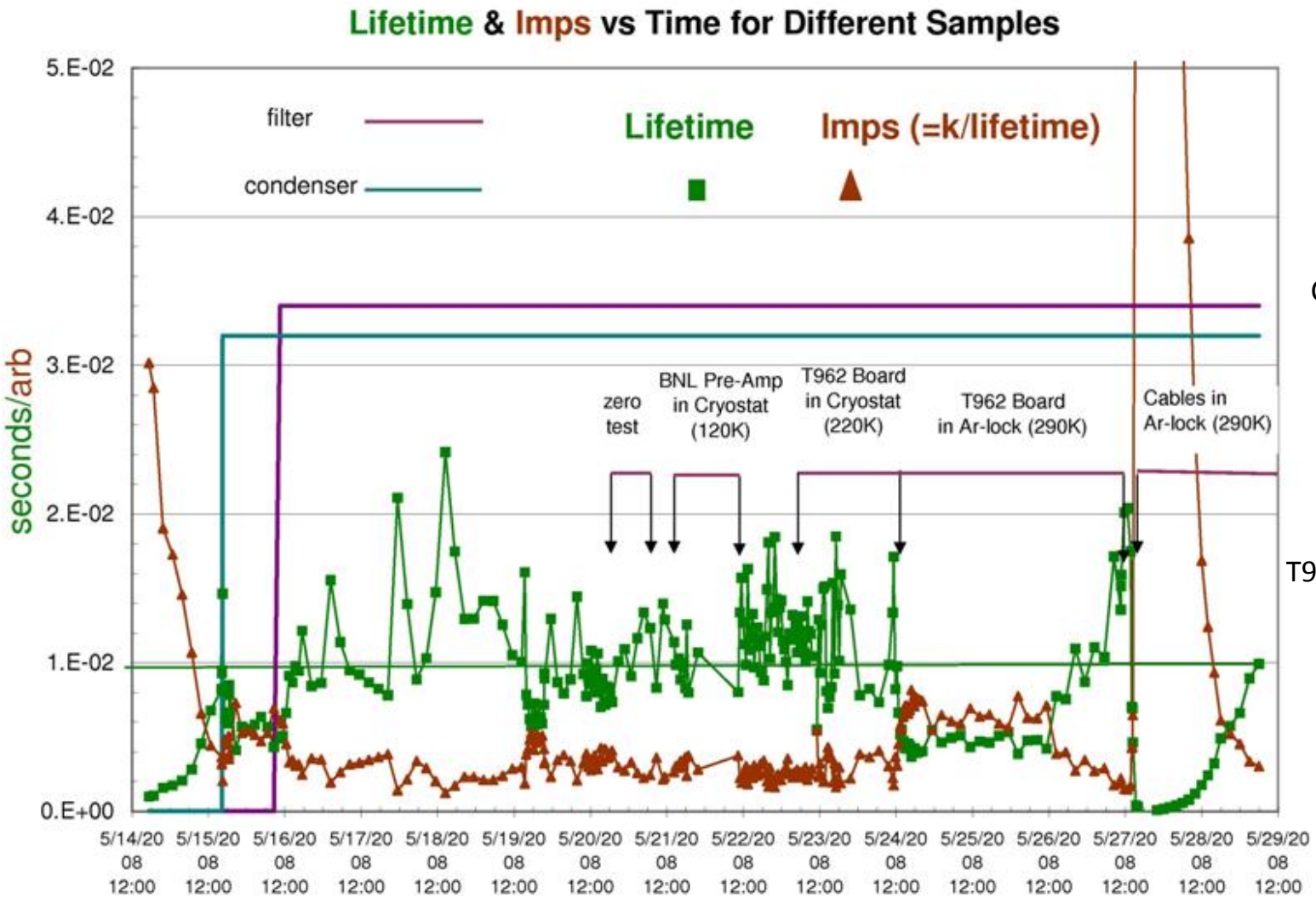


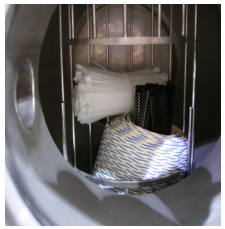


Sample volume 10 cm x 10 cm x 10 cm

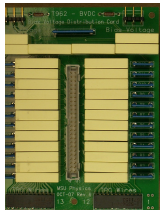
Argonlock can be purged with external argon, cryostat argon, and/or evacuated

An example set of measurements with the Materials Test System





Cables & Cable ties



T962 Decoupling Board

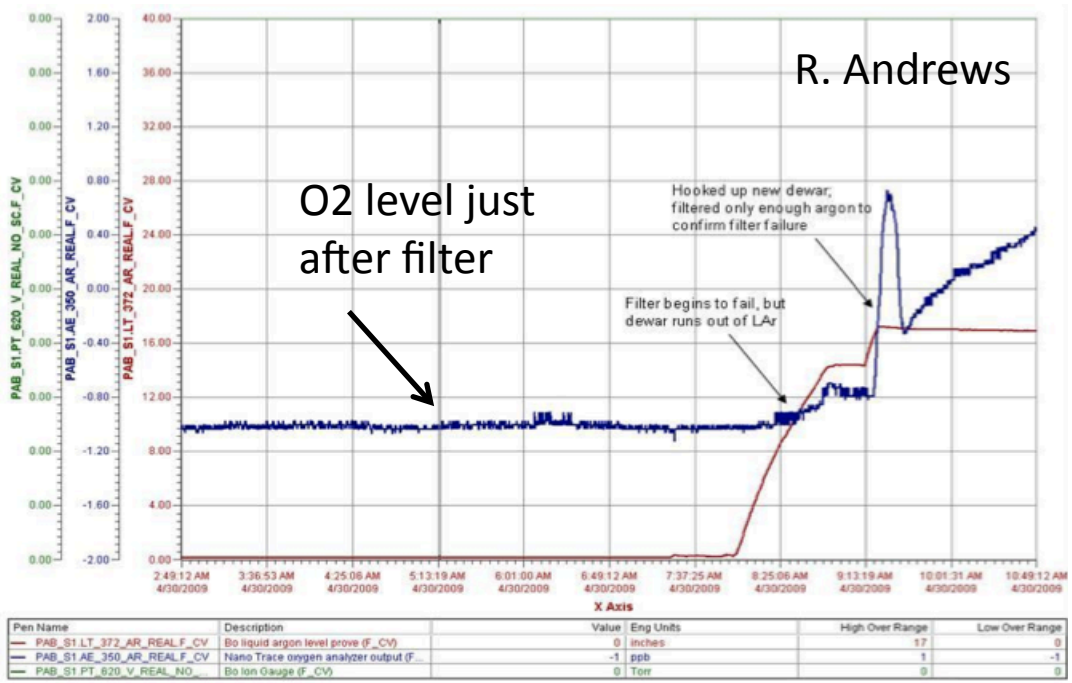
Cold pre-amp

Filter Materials

We make and regenerate our own filters using material from BASF (originally Engelhard) for O2 and Molecular Sieve from Aldrich

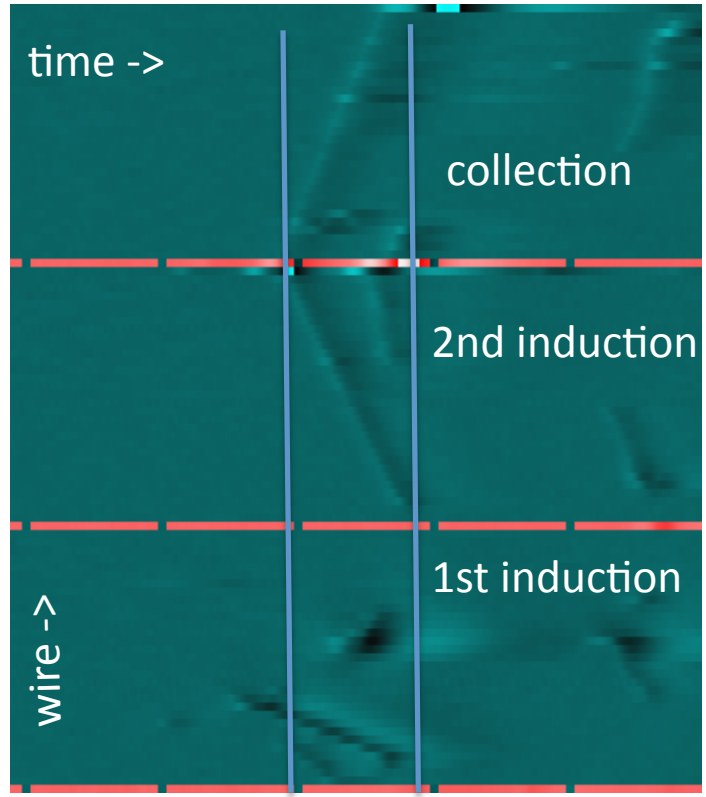
We have the capability to use other materials but have not pursued that yet.

We are interested in **the capacity of filter materials before `breakthrough'** - the capacity seems much much less than one would calculate from curves at room temperature.

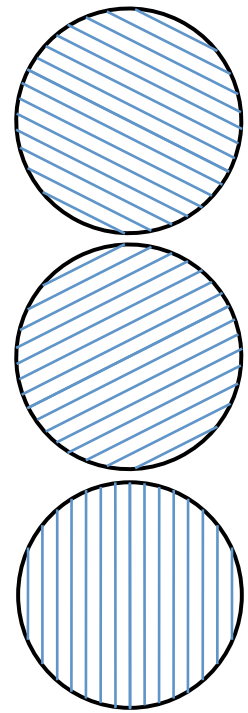


Plot of O2 level after ~ 0.5 g O2 through filter.
Note the `breakthrough' style of behavior.

TPC for electronics (and HV feed-through) development



typical cosmic ray

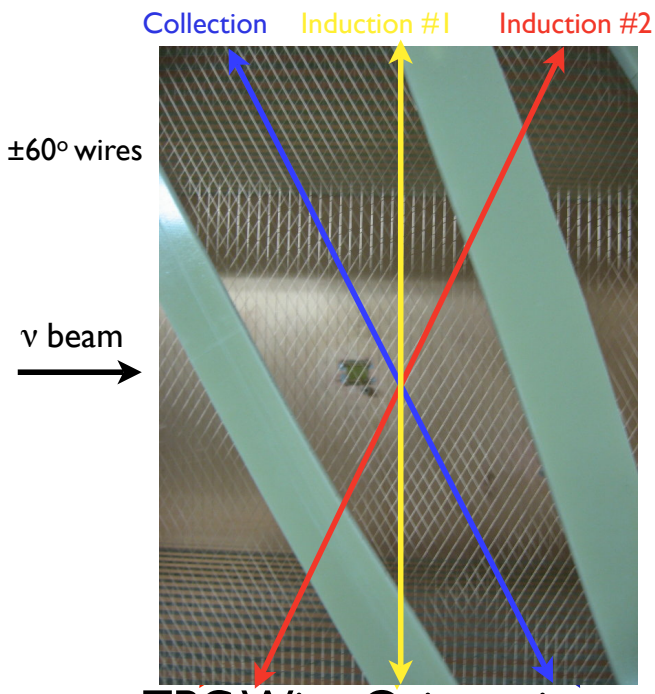


wire orientations

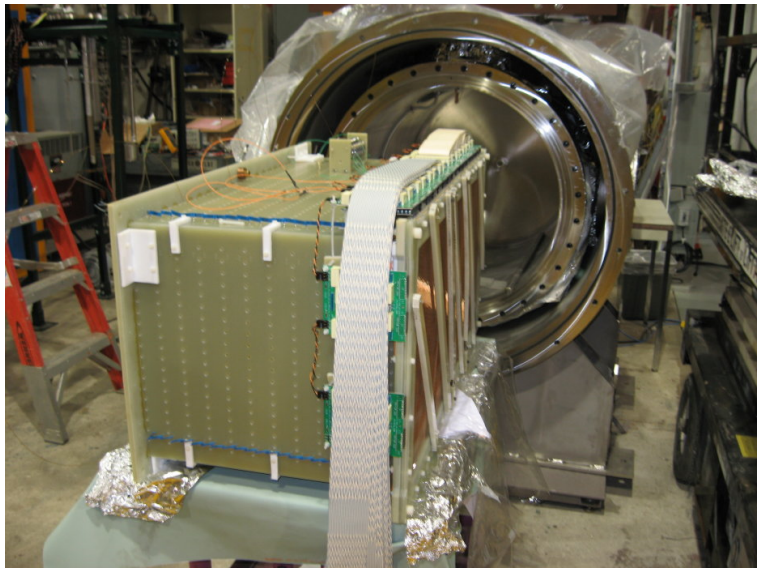
Full Test: **ArgoNeuT** (Yale/Michigan State/Fermilab) (B. Fleming & M. Soderberg) exposed to the **NuMI neutrino and antineutrino beams**

Cryostat Volume	500 Liters
TPC Volume	175 Liters
# Electronic Channels	480
Wire Pitch	4 mm
Electronics Style (Temperature)	JFET (293 K)
Max. Drift Length (Time)	0.5m (330μs)
Light Collection	None

Moving underground (lowering down 350 ft. shaft)

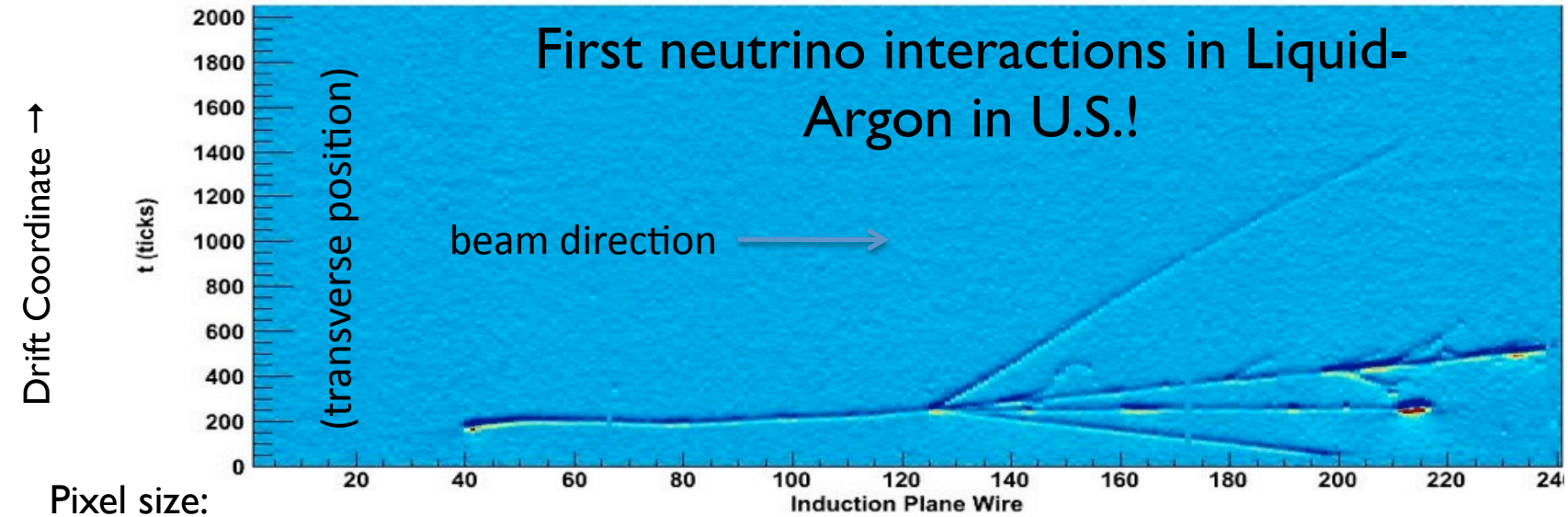


TPC Wire Orientations



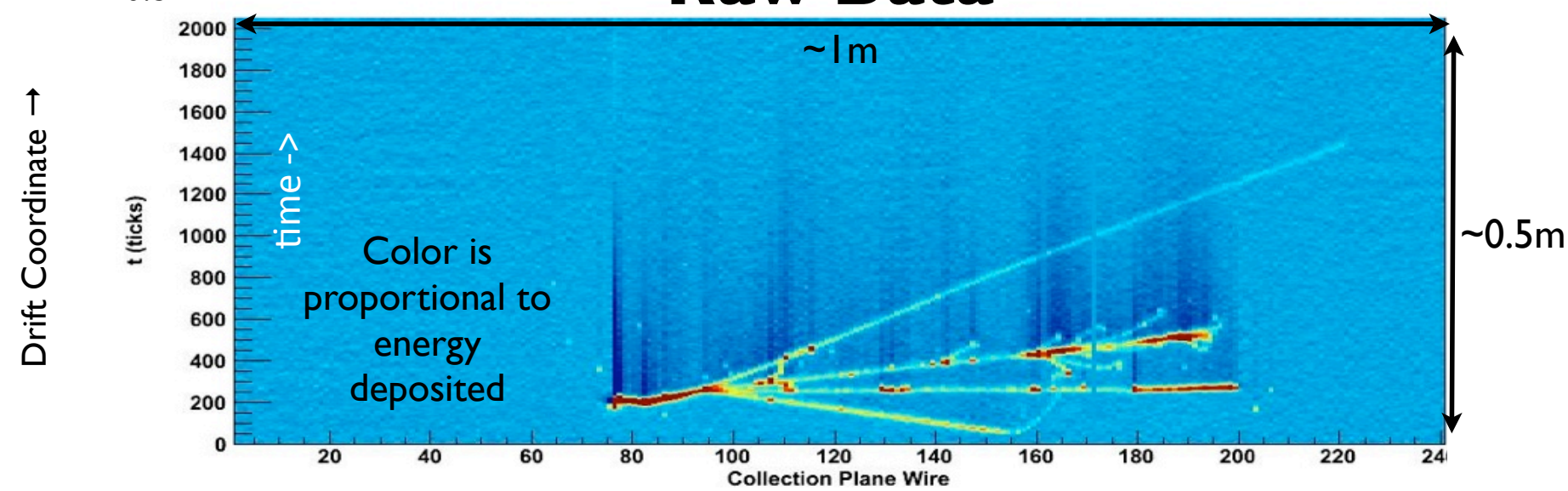
TPC outside of vacuum-insulated cryostat

ArgoNeuT Neutrino Event



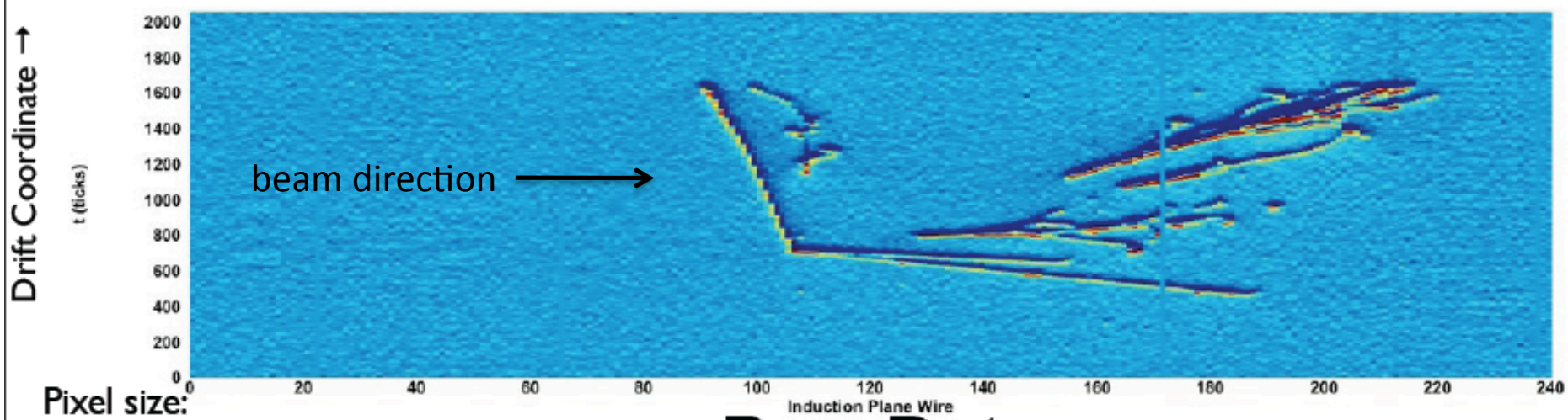
Pixel size:
4mm x 0.3mm

Raw Data



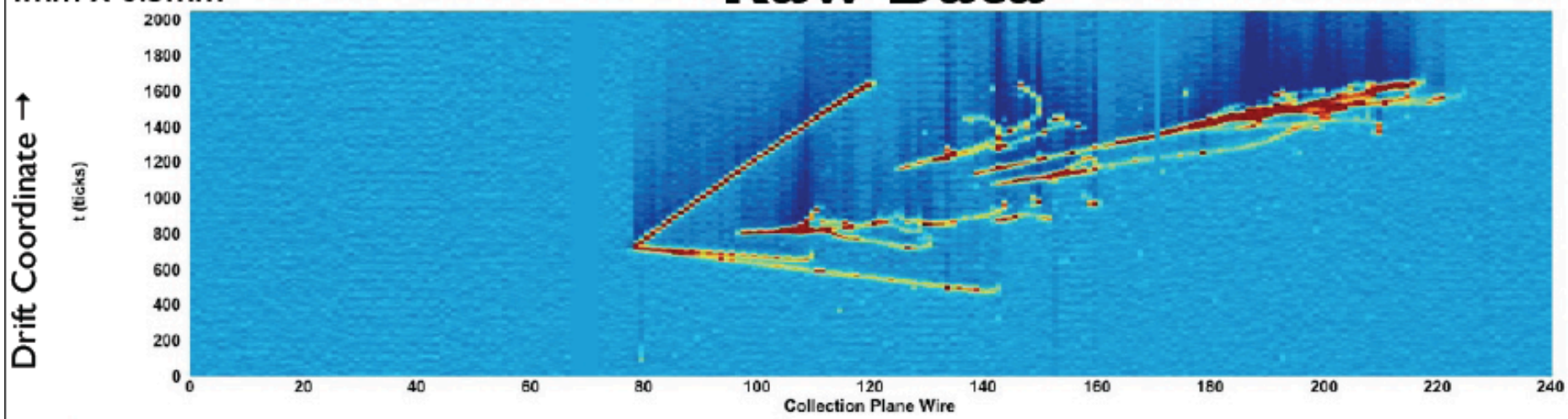
ArgoNeuT event with 2 π^0 particles

1 meter



Pixel size:
4mm x 0.3mm

Raw Data



from Mitchell Soderberg Yale/Syracuse/FNAL

ArgoNeuT goals and early results

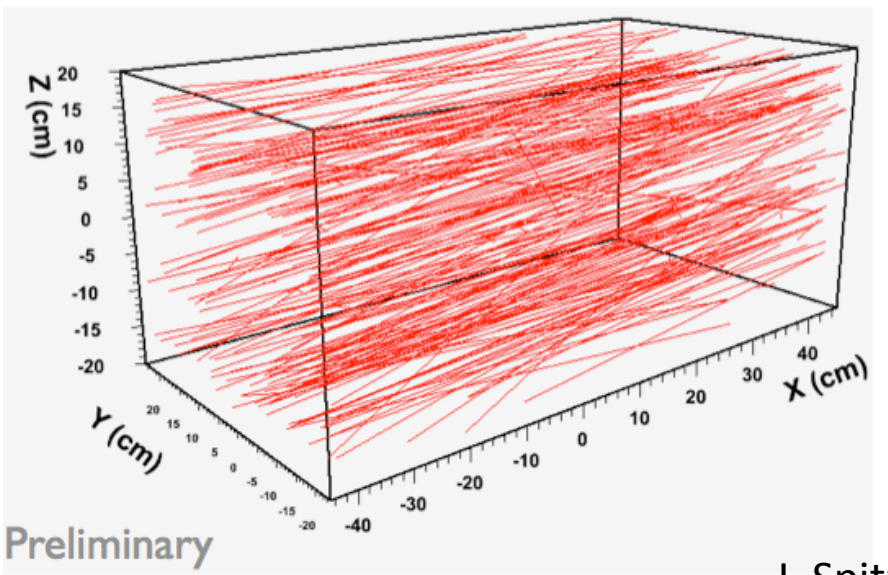
Demonstrate capability in the US to provide all the elements of a liquid argon TPC

- electronics, TPC construction and HV, argon purification, operation underground

Provide real data (as distinct from simulations) on detector capabilities with a large sample of events

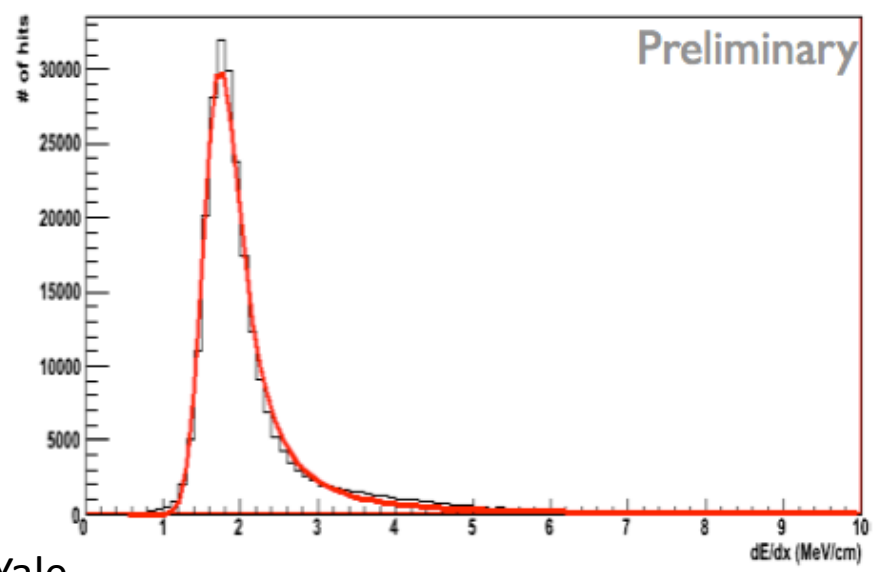
- single electron vs conversion pair, vertex activity

Provide data and motivation for development of automated reconstruction



3D-reconstruction of muons

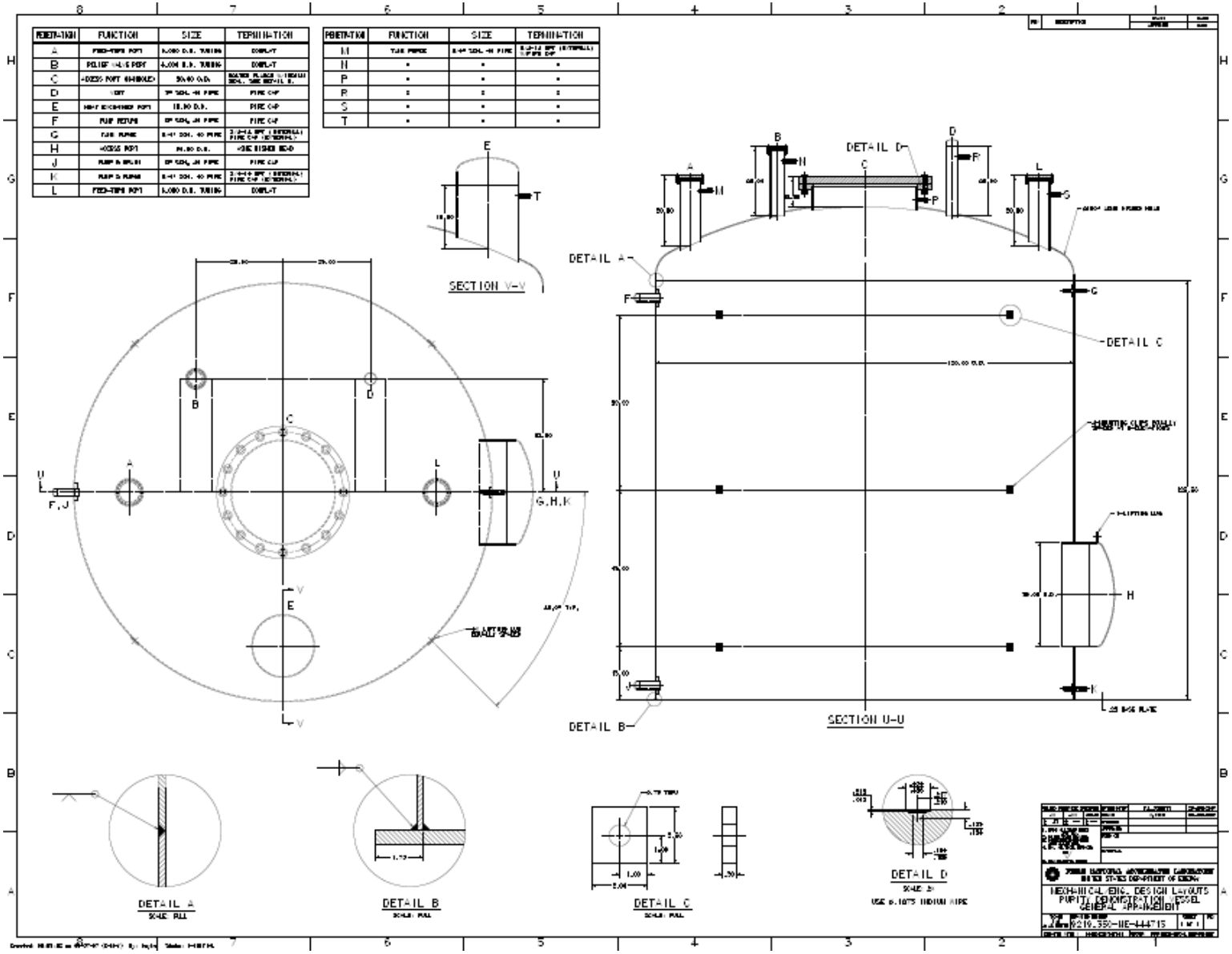
J. Spitz, Yale



Muon calorimetry (dE/dx)

Clean Argon in an unevacuated (and non-evacuable) cryostat

Liquid Argon Purity Demonstration – L.A.P. D. – aimed at multi-kiloton detectors



Purity Demonstrator Tank (in experiment Hall where the Upsilon was discovered)

Purity Demonstration Tank behind filtration System

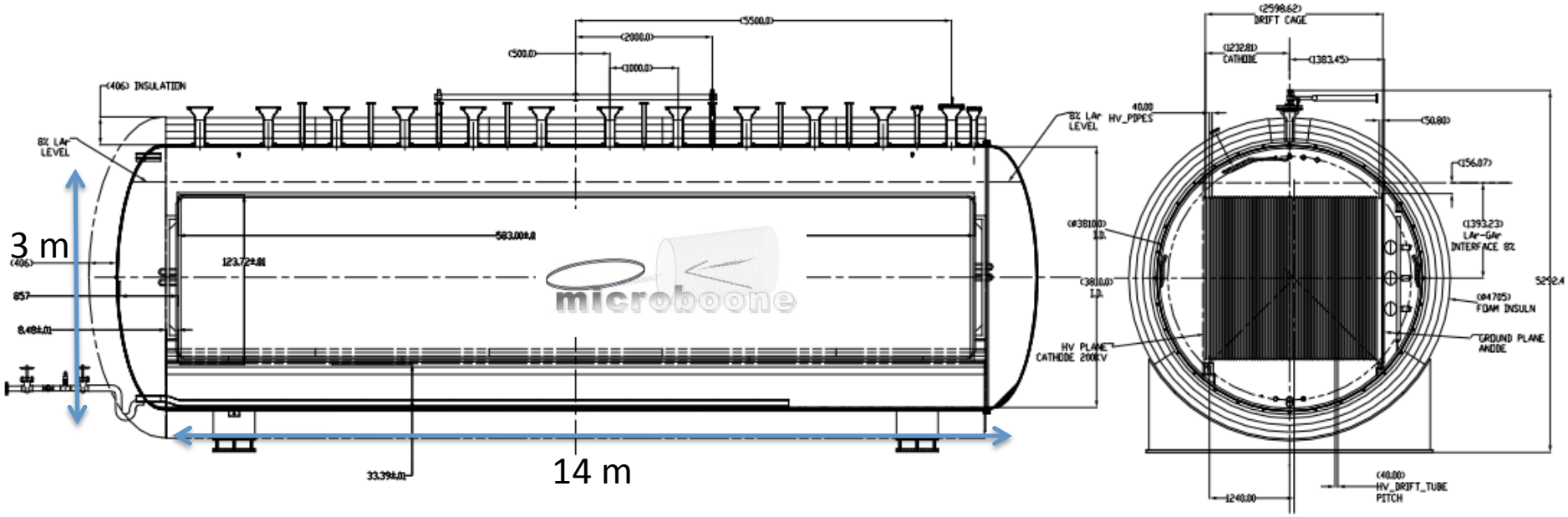
MicroBooNE

200 tons total, 75 tons liquid argon fiducial in Booster (8 GeV) Neutrino Beam

~ 9,000 Wire TPC – drift distance 2.6 m

Investigate MiniBooNE anomaly (excess of low E events (< 300MeV)) and ν−Argon cross sections

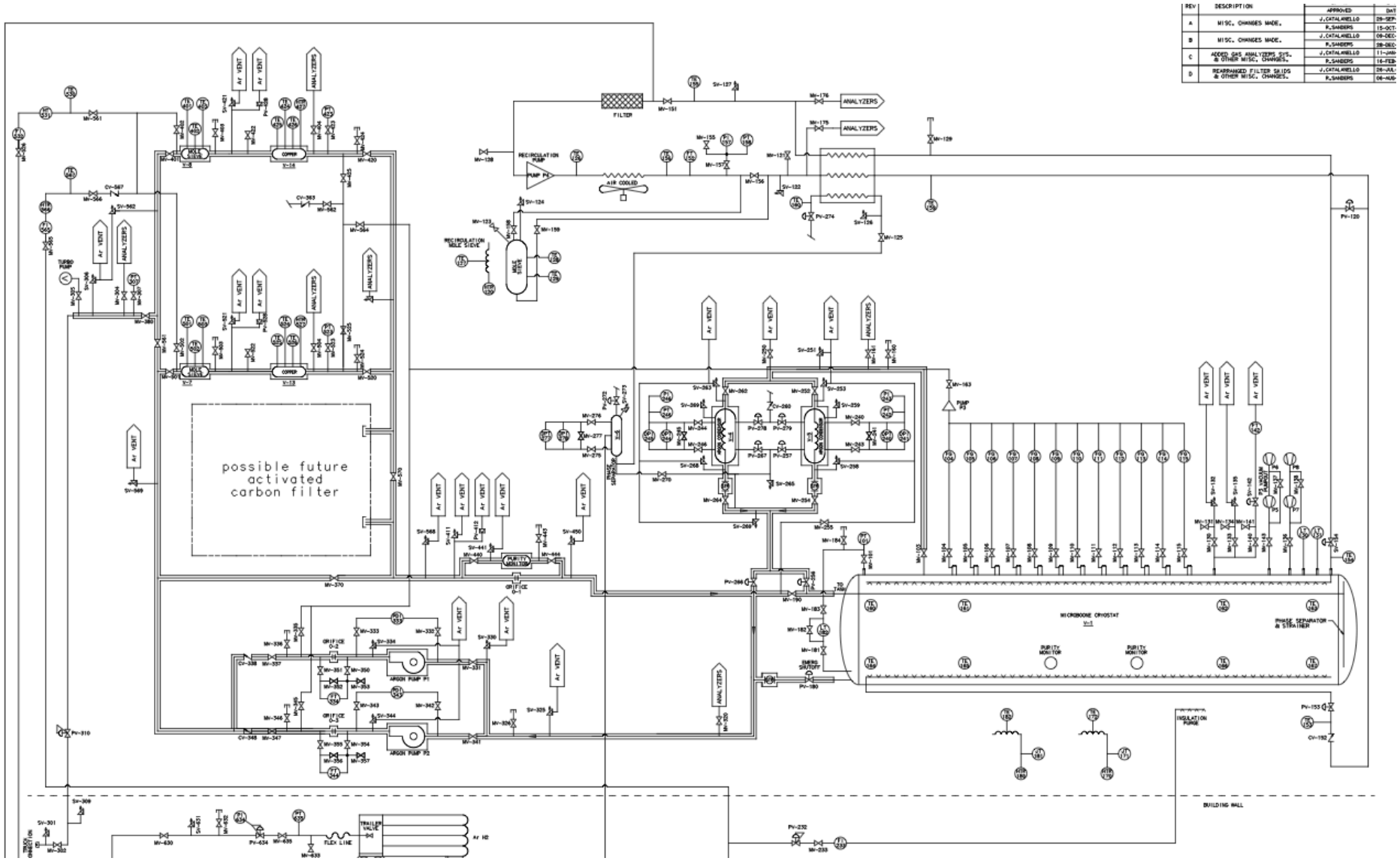
Scheduled to take data in 2013



Technical R & D

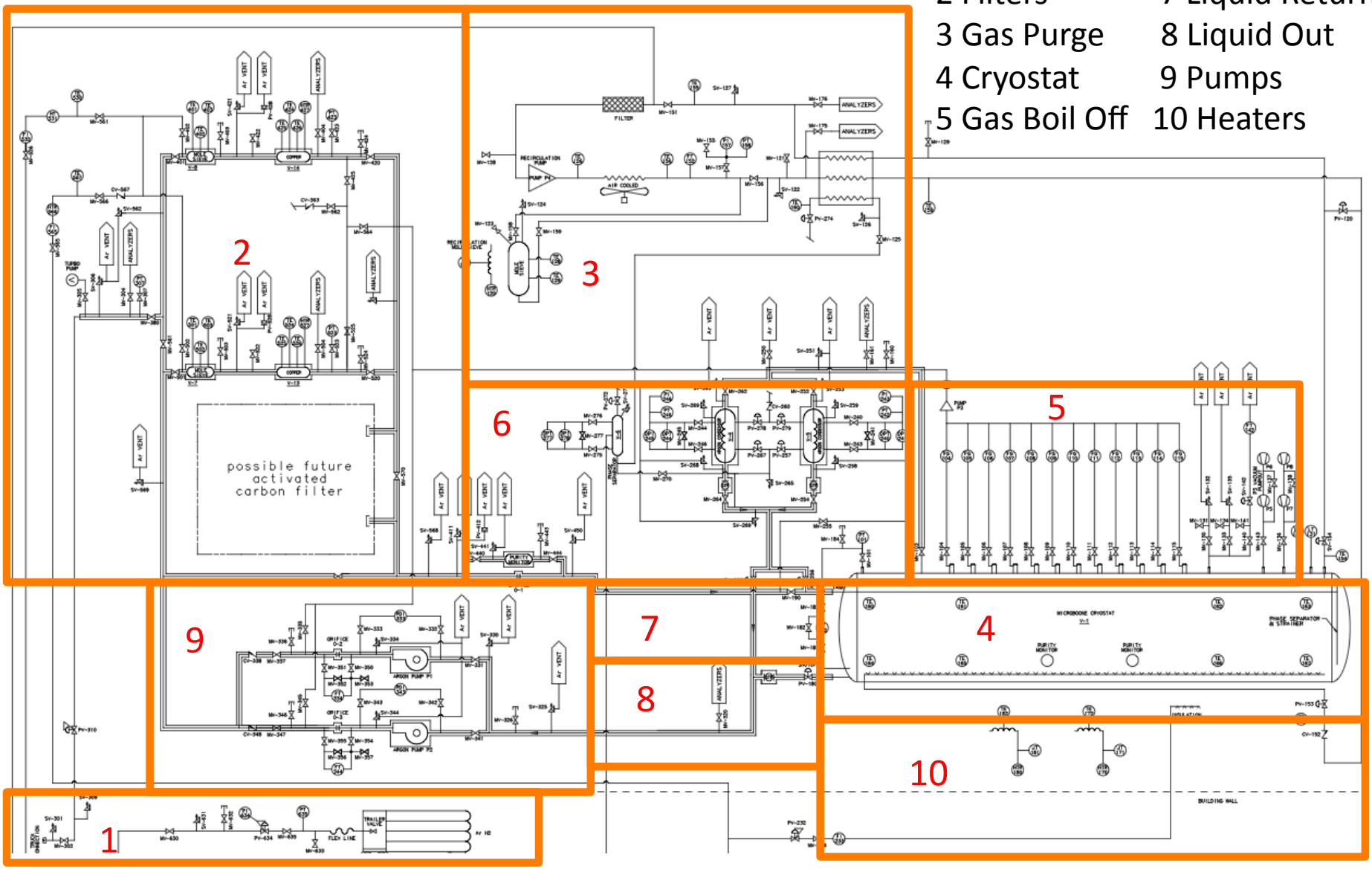
- Purging to purity (i.e. not evacuating – maybe essential for LBNE)
- Amplifiers in the liquid (ASIC developed at Brookhaven National Laboratory)
- Data acquisition development (continuous readout for non-beam physics)
- Event reconstruction & identification

MicroBooNE Cryogenic Schematic

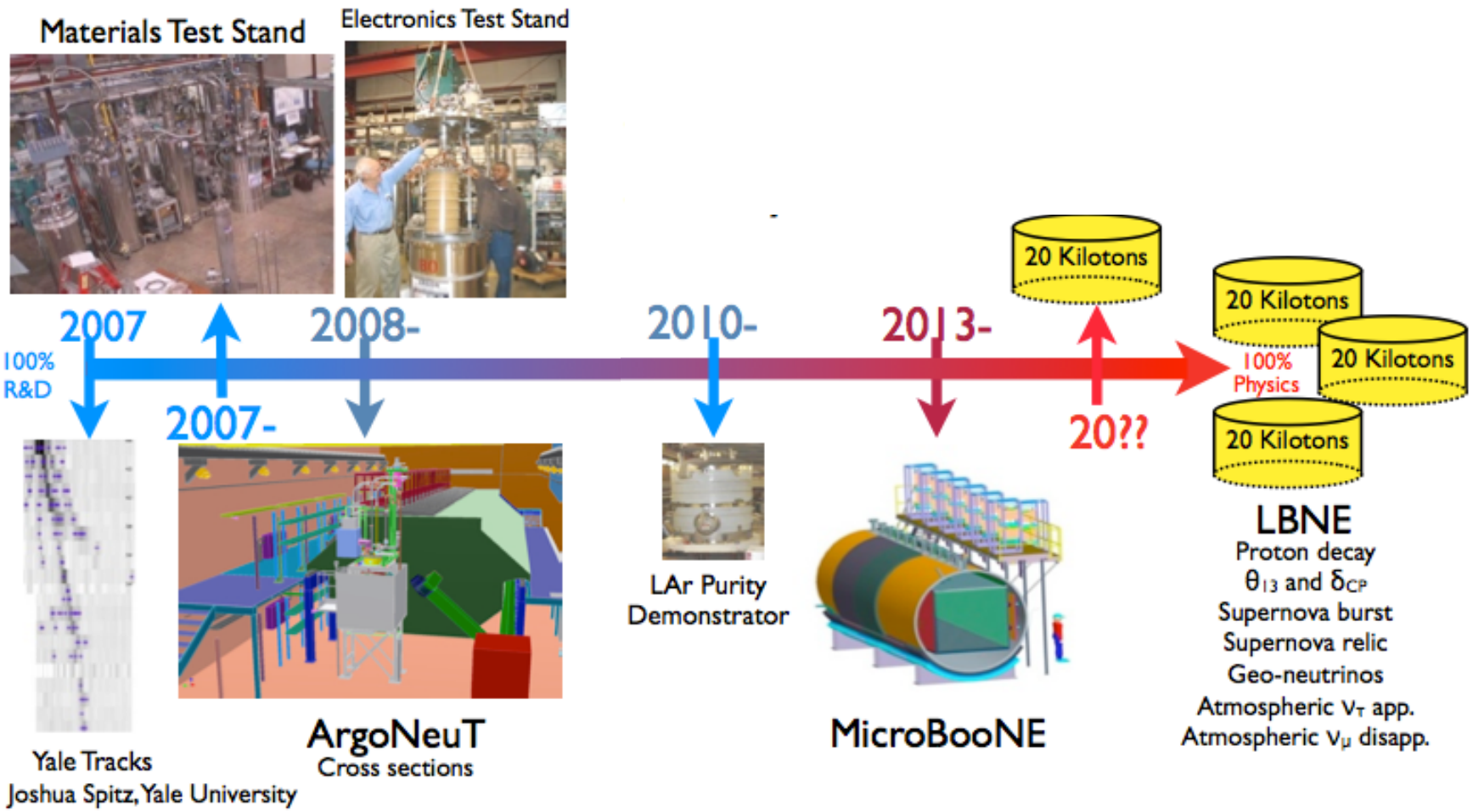


MicroBooNE Cryogenic Schematic

1 Supply
2 Filters
3 Gas Purge
4 Cryostat
5 Gas Boil Off
6 Condenser
7 Liquid Return
8 Liquid Out
9 Pumps
10 Heaters



Liquid Argon Neutrino Timeline



A Liquid Argon Detector for the Long Baseline Neutrino Experiment

20,000 ton module,

in a `shallow' (800 ft deep) site,

Liquefied Natural Gas Tanker Ship technology for the cryostat (GTT, France)

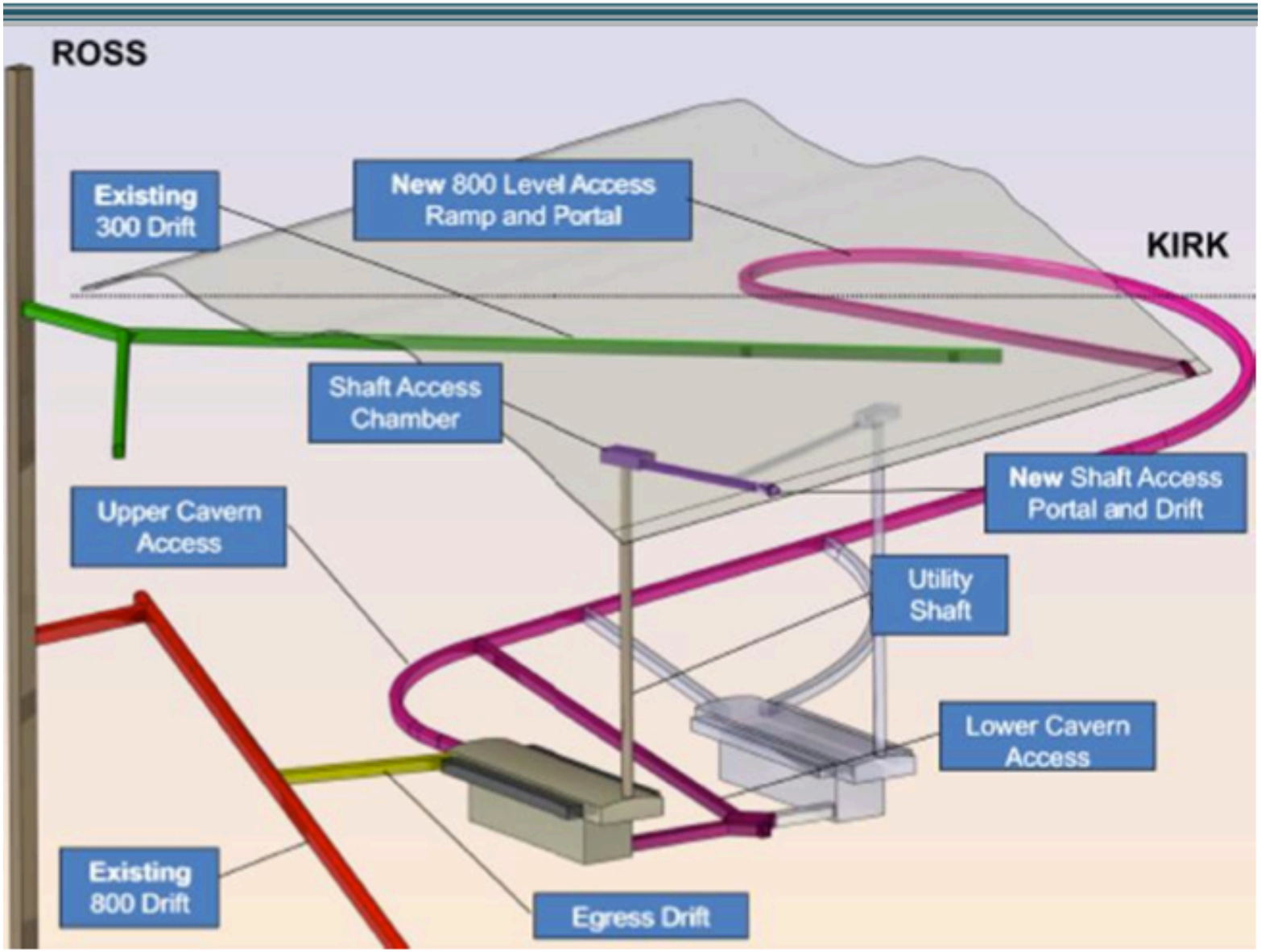
Competitive with Water Cerenkov:

- general cost advantage
  can operate at shallow depth
- for electron neutrino appearance
  more efficient at distinguishing single electrons from photon conversions
- can detect kaon in proton decay to $K^+ \nu$

Significant team from Fermilab, Brookhaven, and Universities ..

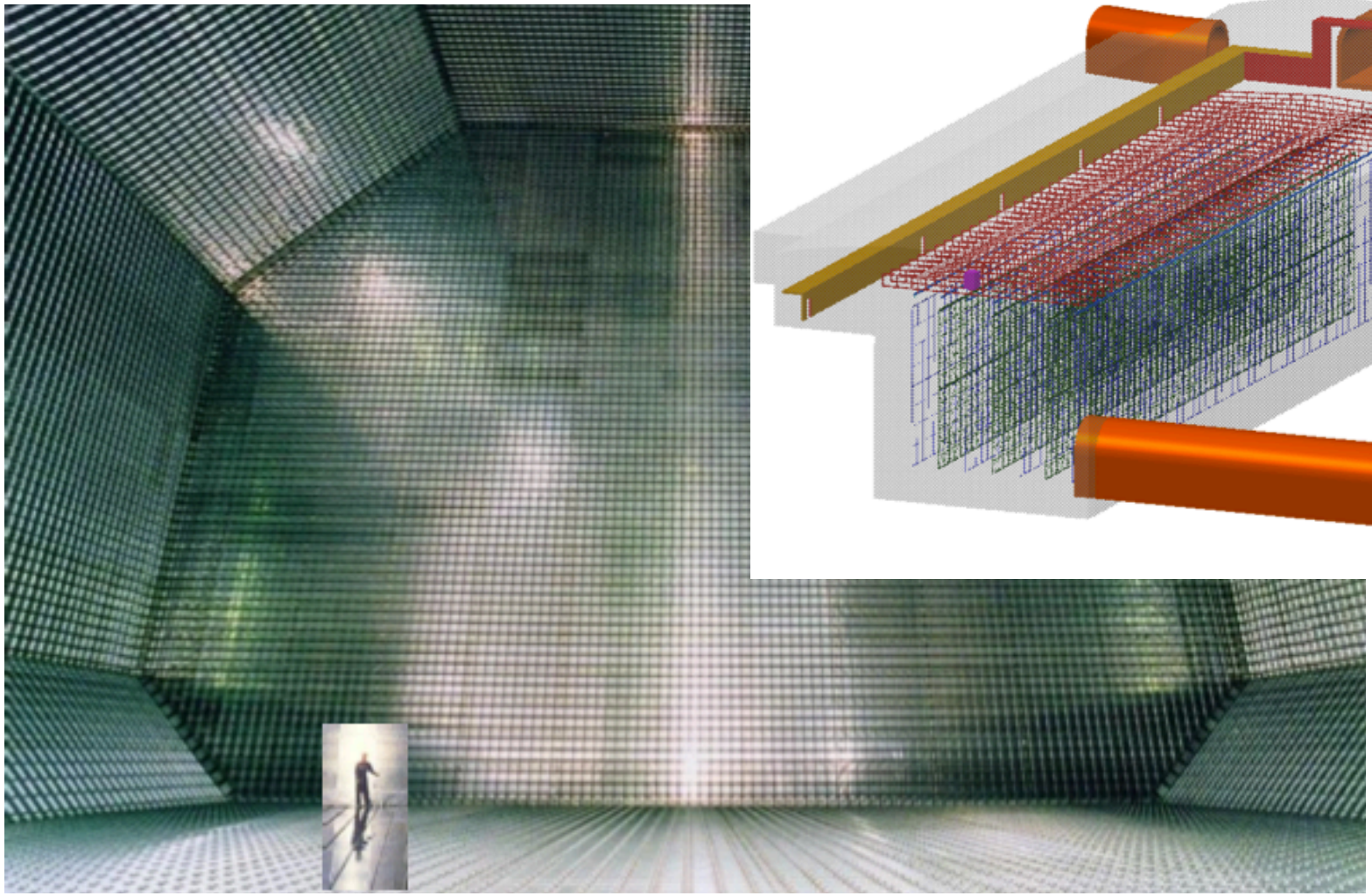
Fermilab working on cryostat, cryogenics, TPC construction, digital part of readout

Schematic of 2 caverns each for a 20 kiloton LArTPC at Lead, South Dakota

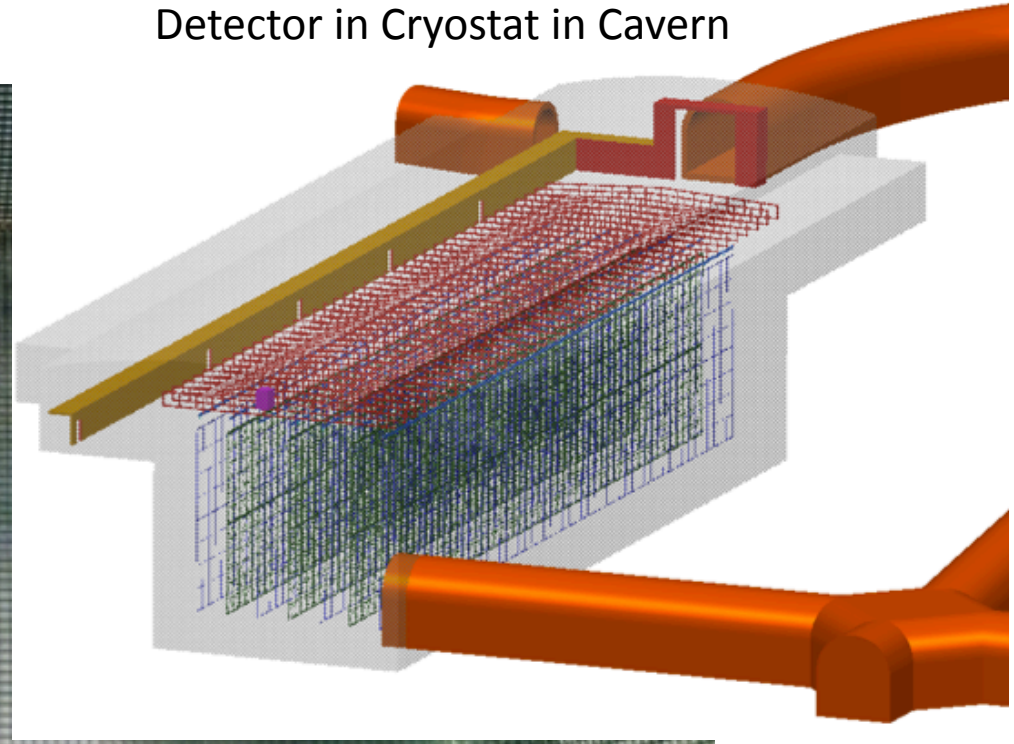


Cryostat based on Liquefied Natural Gas Tanker technology (GTT France)

Membrane Hull of Gas Tanker



Detector in Cryostat in Cavern



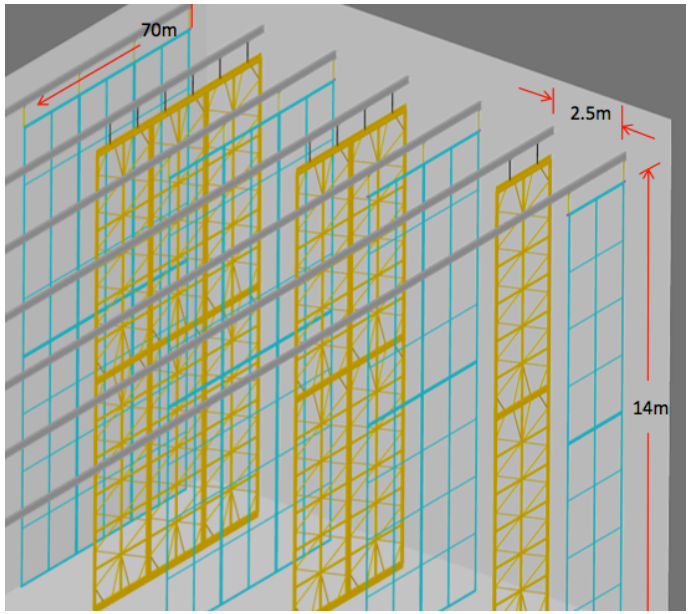
LBNE development program

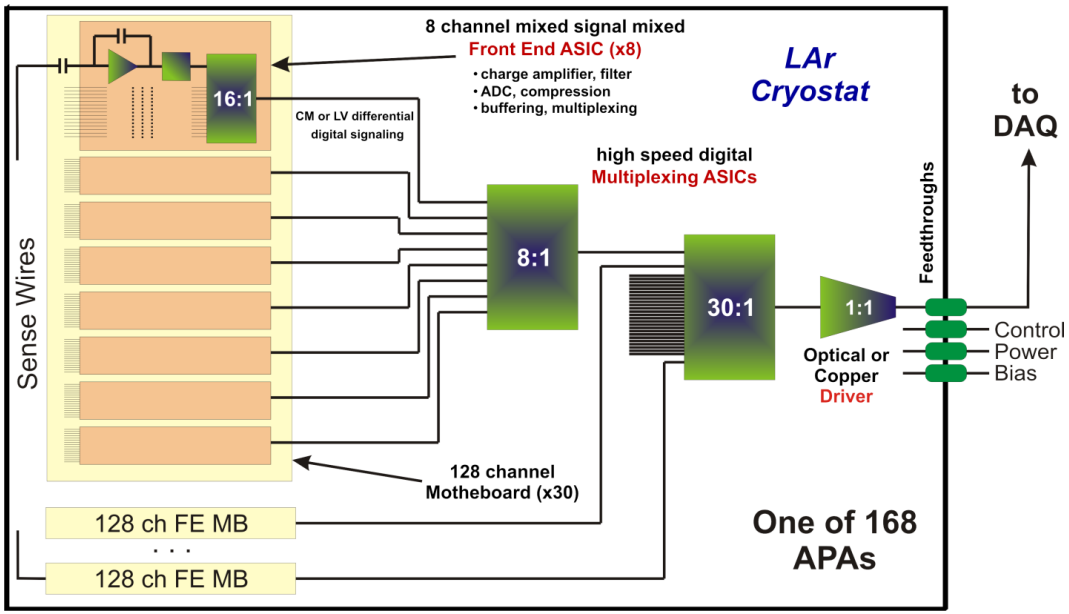
35 ton prototype cryostat to see if argon purity can be achieved in process (DM) ;

1,000 ton prototype equipped with TPC in proposal stage

TPC design development in proces

Front-End electronics development ongoing





Hanging TPC Anode and Cathode

Amplifier, ADC, Multiplexer in liquid in Cryostat

From Fermilab Director – 12/2009

Dear Cristiano,

Thank you for the proposals on the search for dark matter using depleted-argon detectors, first using a 50 kg detector (DarkSide, which we have designated P-1000) and, secondly, in preparation for a larger detector at DUSEL (MAX, the R&D for which we have designated P-1001). I also thank you for your presentation at the recent Physics Advisory Committee (PAC) meeting, and the responses to the PAC's questions. In response to my charge, the PAC wrote the attached comments.

I share the PAC's enthusiasm for the depleted argon approach to search for dark matter, and accept the recommendation that P-1000 receive Stage I approval. I hereby grant that approval, and wish you the best of luck in your search for dark matter. In taking the next steps toward Stage II approval, including the preparation of a Memorandum of Understanding between the Laboratory and the DarkSide experiment (E-1000), it will be important to answer the questions posed by the PAC.

It would be great to detect dark matter in a DarkSide detector! Failing that, dark matter might appear in a larger depleted-argon detector at DUSEL, and we will attempt to provide some Laboratory resources to make progress on the design of MAX. We have designated this effort separately as P-1001. You should discuss the most important needs for the preliminary engineering of MAX with appropriate Division Heads and the Fermilab Center for Particle Astrophysics. Formal approval will depend on arriving at a plan in which Fermilab can provide the requested resources.

Good luck!

Sincerely,

Piermaria Oddone

Dan Bauer (deputy head Fermilab Center for Particle Astrophysics) report to the Fermilab Program Advisory Committee on the FCPA presentation to the DOE 12/2010

We believe that we articulated a coherent FCPA strategy at the non-accelerator review, with participation in three technologies that have the best intrinsic background

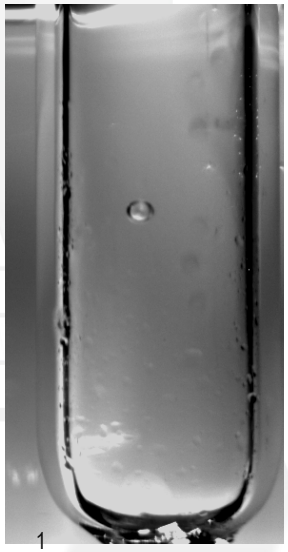
three: solid-state (CDMS), bubble-chamber (COUPP), noble liquid (DarkSide)

The Dark Matter Program at Fermilab

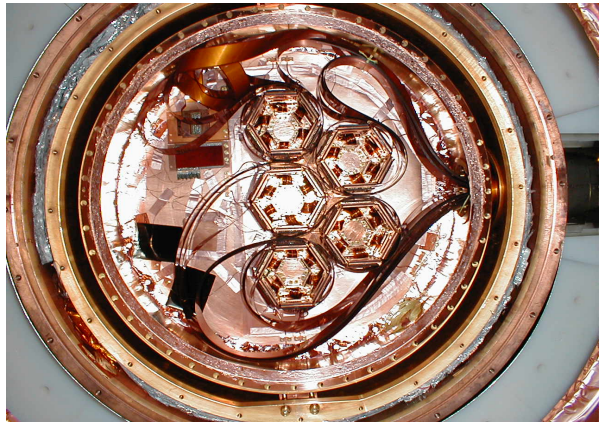
Dan Bauer, Fermilab

DOE Non-Accelerator Review, September 29, 2010

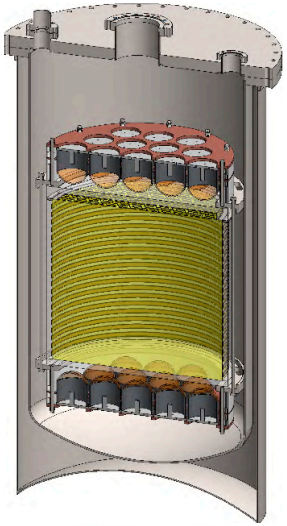
COUPP



CDMS



DarkSide



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Dan Bauer, Fermilab, DOE KA13 Review

Fermilab

Depleted Argon Distillation Column

to separate depleted Argon from accompanying Nitrogen (and Helium)

- Design capacity ~ some kg/day
- Design purity ~ 99.999% Ar

E-1000 (DarkSide) gets stage 1 approval at FNAL Nov 12 2009

Proposal from CG at end of November 20 2009 to build column at FNAL

Visit by Fermilab engineers to Princeton December 11 2009

Agreement by Fermilab management to accept column December 28 2009

Pieces of column arrive Jan 11 2010

Safety Review completed January 2011 – first commissioning with argon last week

(David Montanari's talk)

Summary

Liquid argon is an attractive target material for neutrinos and dark matter.

Many of the challenges to realizing detectors are common to both types of physics.

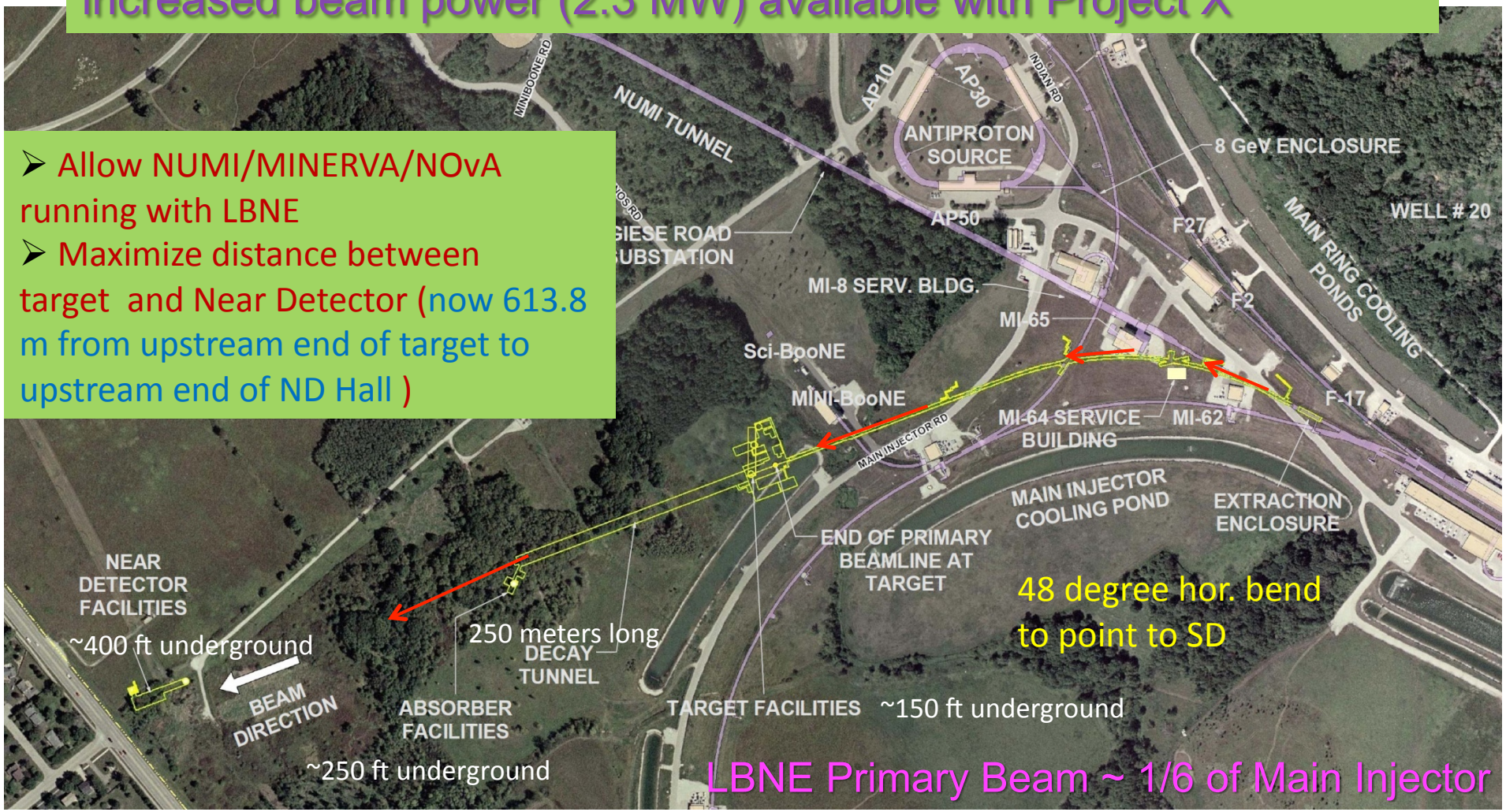
Fermilab has a varied and exciting program to study many interesting challenges in cryogenics, purification, in TPC design, and in electronics.

There is plenty of work to do, and enjoyment to share, to uncover the secrets of Mother Nature.

Back-up on LBNE Beam

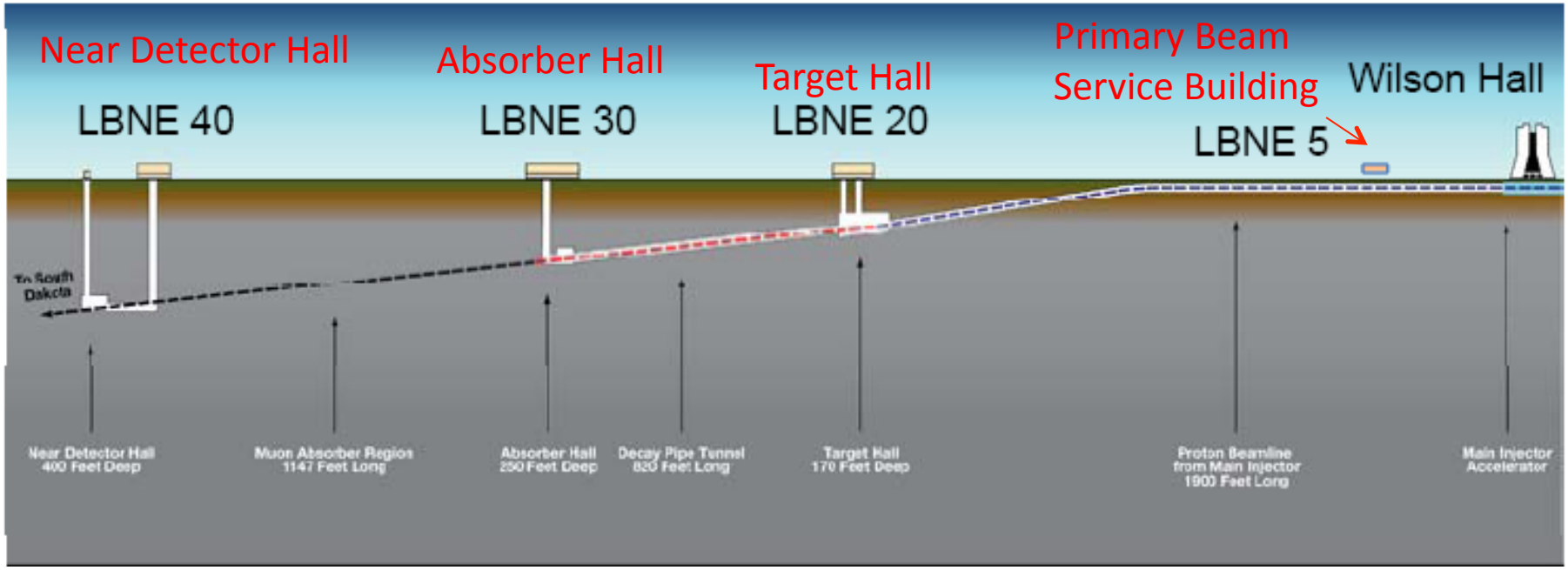
The Neutrino Beam Facility at Fermilab

Start with a 700 kW beam, and then take profit of the significantly increased beam power (2.3 MW) available with Project X



Primary beam energy (protons from the Main Injector) from 60 to 120 GeV

The Neutrino Beamline Facility



Primary Beam (magnets, magnet power supplies, LCW, vacuum, beam instrumentation, beam optics and beam loss calculations)

Neutrino Beam (window, baffle, target, 2 focusing horns, horn power supplies, decay pipe, absorber, RAW, tritium mitigation, target pile, remote handling, modeling, storage of radioactive components)

System Integration (controls, interlocks, alignment, installation infrastructure)

Primary Beam Design Parameters

Beam Parameter	Value
Protons per cycle	4.9×10^{13}
Cycle time (120/60 GeV)	1.33/0.76 sec
Pulse duration	1.0×10^{-5} sec
Proton beam energy	60 to 120 GeV
Beam power at 120 GeV	708 kW
Operational efficiency	59%
Protons at target per year	6.8×10^{20}
Beam size at focus	1.5 mm
Beam divergence x,y	0.017 mrad