# Liquid Argon R & D at Fermilab

**Charge Detection**

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

**Light Detection and Production**

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

**High Voltage**

- **Breakdown in noble liquids (workshop this Friday)**

# Liquid Argon R & D at Fermilab

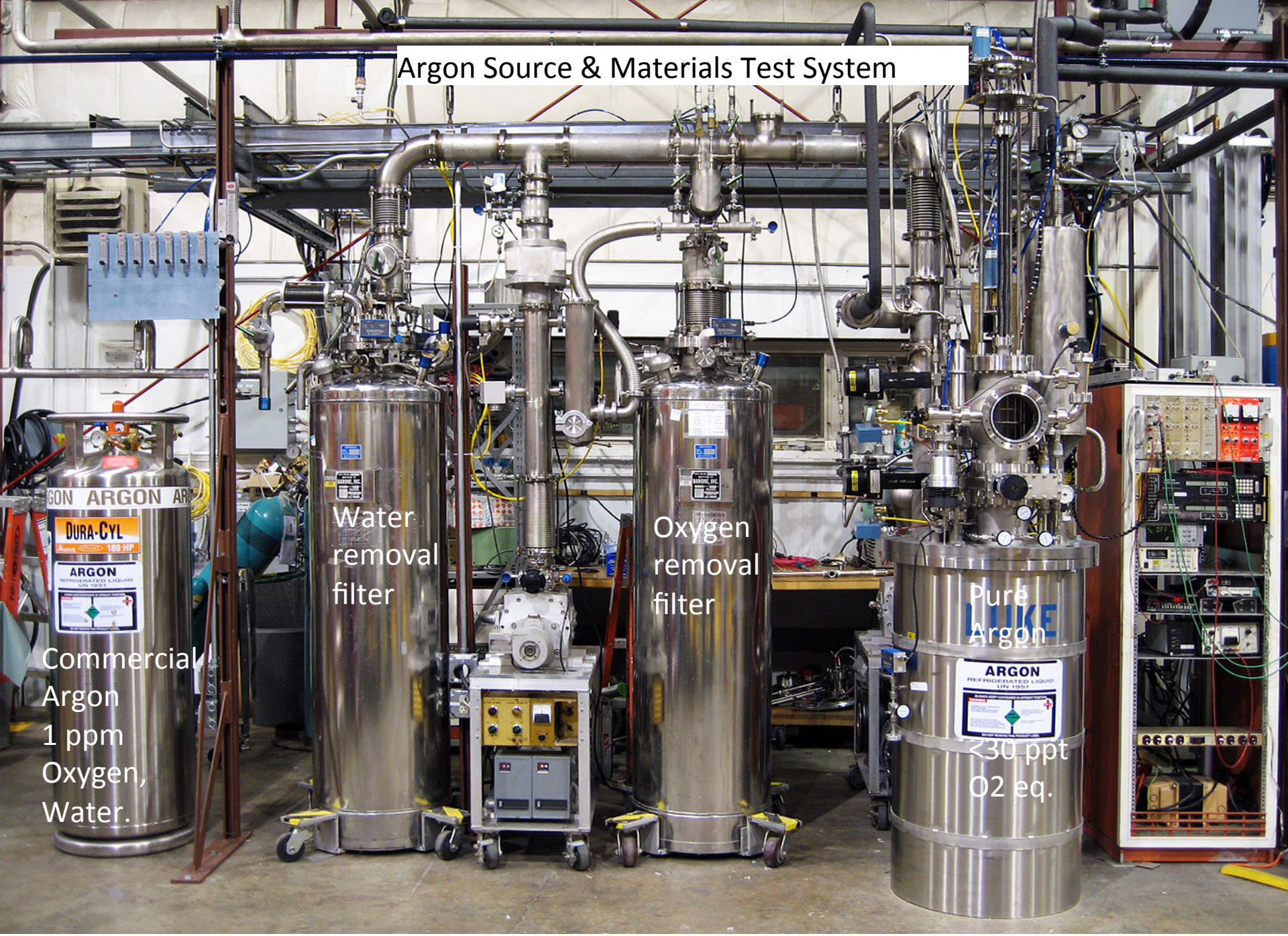
**Neutrino Specific**

- **TPC performance with electronics and HV ->**
  **BO TPC and Long BO TPC**
- **Detailed behavior of particles in liquid Argon ->**
  **Test beam into LArTPC (LArIAT)**

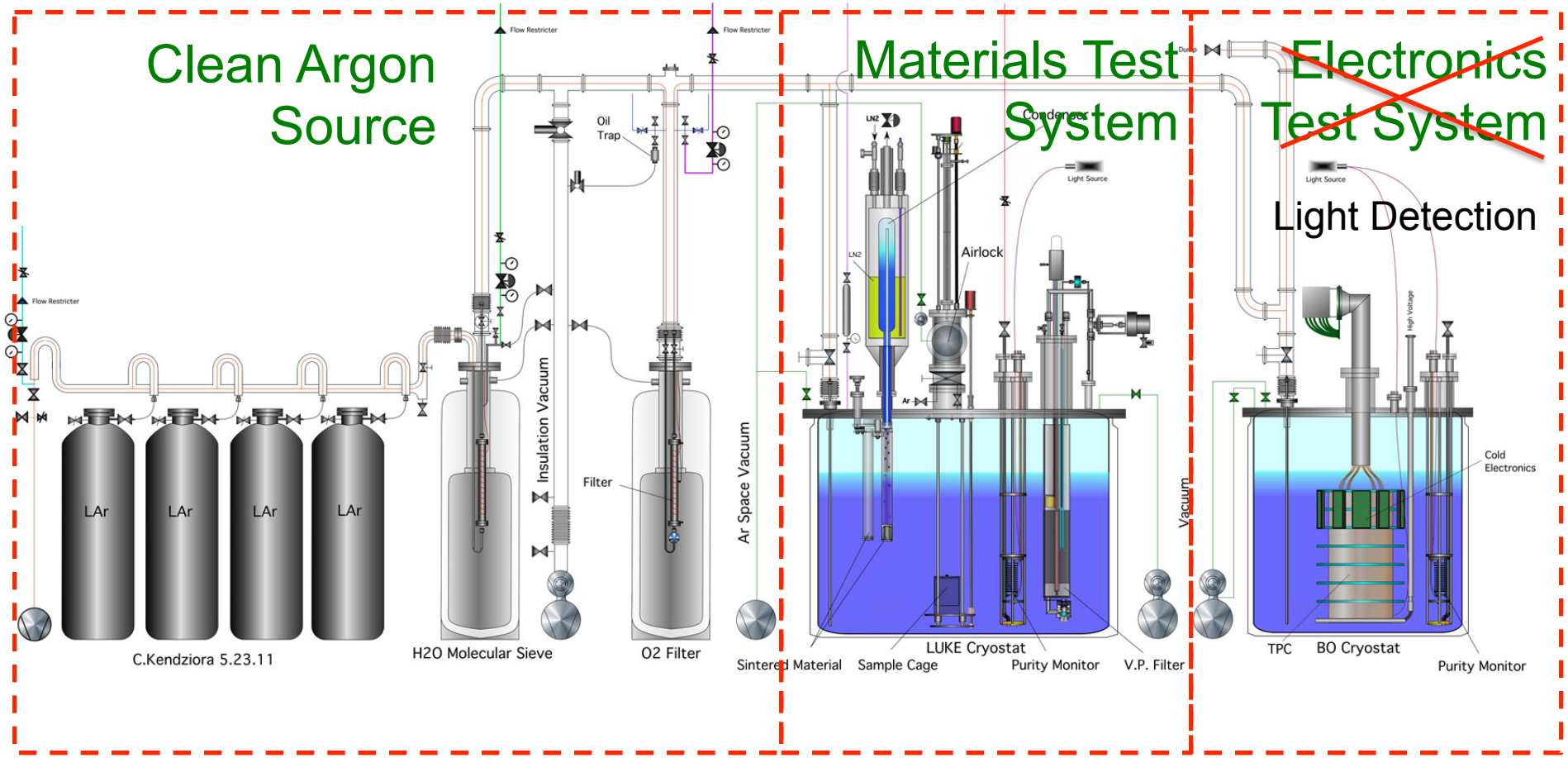
**Dark Matter Specific**

- **Light yield from nuclear recoils at low energy (<50 keV)**
  **SCENE (Scintillation Efficiency of Noble Elements) experiment**
- **Argon for low-background experiments**
  **Purification of underground argon**

# Argon Source & Materials Test System



# Liquid Argon Setup at the PAB




Schematic of Materials and ~~Electronics~~ Test Systems
Light Detection

# Materials Test System

`A system to test the effects of materials on the electron drift lifetime in liquid argon and observations on the effect of **water**' R. Andrews *et al.*, Nucl.Instrum.Meth.A608:251-258,2009.

| Material | Date test started | Preparation | Tests | Water [ppb] | Lifetime [ms] | LogBook # |
|---|---|---|---|---|---|---|
| Cleaning Solution | 6/29/09 | evac. 24 h | vapor/liquid | 4 | 5 | 946 |
| Vespel | 7/9/09 | evac. overnite | liquid/vapor | 5-7 | 2-5, 4-6 | 960 |
| MasterBond glue | 7/16/09 | purged 18 h | vapor/liquid | 1.6 | 1.3- 2.9 | 974 |
| LEDs | 7/31/09 | purged 38 h | vapor | 3.5 | 5 | 993 |
| Carbon filter material | 8/12/09 | evac. 24 h | liquid/vapor | 2 | 4-9 | 1000 |
| 962 FeedTru Board V2 | 10/12/09 | evac. 24 h | vapor/warm | 85 | 1-5 | 1062 |
| Teflon cable | 1/9/10 | purged 28 h | warm/liquid/vapor | 8-20 | 2-5 | 1175 |
| 3M "Hans" connectors | 1/29/10 | purged 46 h | warm/liquid/vapor | 5-12 | 3 | 1198 |
| 962 capacitors | 3/2/10 | evac. 24 h | warm/liquid/vapor | 6-14 | 3-6 | 1228 |
| 962 polyolefin cable | 4/12/10 | evac. 16 days | warm | 25-60 | 2 | 1237 |
| Rigaku feedthrough | 4/20/10 | purged 7.5 h | warm | 15 | 3 | 1250 |
| Rogers board (Teppei) | 4/23/10 | purged 26 h | warm/liquid/vapor | 40 | 2, 6-10 | 1254 |
| Arlon Board (Teppei) | 5/14/10 | evac. 0.5 h, pur.2 days | warm/vapor | 300, 80 | 1.3, 3.5 | 1263 |
| Polyethylene tubing | 5/24/10 | evac. 6 h, pur. 66 h | warm | 300-500 | 1 | 1278 |
| Teflon tubing | 5/27/10 | evac. 1 h, pur.17 h | warm | 9-13 | 4-5 | 1283 |
| Jonghee board | 5/28/10 | evac. 6 h, pur. 1.5 h | warm/vapor | 100,28 | 1.2, 5-8 | 1285 |
| Jonghee connectors | 6/4/10 | evac. 3.5 h, pur. 16 h | warm/vapor | 50 | 2-3 | 1290 |
| PVC cable | 6/14/10 | evac. 29 h, pur.1 h | warm | 120 | 1-2 | 1296 |
| Teppei TPB samples | 8/3/10 | purged 26 h | warm | 600-1600 | 0.7 | 1342 |
| Teppei TPB samples | 9/4/10 | purged 37 h | liquid /vapor | 15, 300 | 6 | |
| PrM feed tru (baked) | 10/5/10 | purged 25 h | warm/vapor | 35, 20 | 3, 2 | 1396 |
| Copper foil on mylar film | 10/14/10 | purged 26 h | warm/liquid/vapor | 15, 10, 9 | 3, 8, 7 | 1409 |
| Teppei SHV connector | 10/25/10 | purged 25 h | warm/vapor/liquid | 35, 11, 0 | 2, 6, 6 | 1415 |
| FR4 | 11/16/10 | purged 25 h | warm/liquid/vapor | 180, 20, 65 | 1.5, 6, 2.5 | 1429 |
| Gaskets | 3/11/11 | purged 24 h | warm/liquid/vapor | 8, 10 | 2.5, 8 , 7 | 1521 |
| LBNE AP-219 Color. Developer | 4/13/11 | purged 25 h | warm/vapor | 65, 15 | 4, >6 | 1722 |
| LBNE RPUF Foam | 4/22/11 | evac. 26 h, pur.1 h. | warm | 800 | 0.2 | 1729 |
| LAPD LEDs | 5/12/11 | purged 49 h | vapor | 0.6 ppb | 10 | 1769 |

Sample data on different materials (bad, good,OK in liquid)

# Liquid Argon Purity Demonstration

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

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

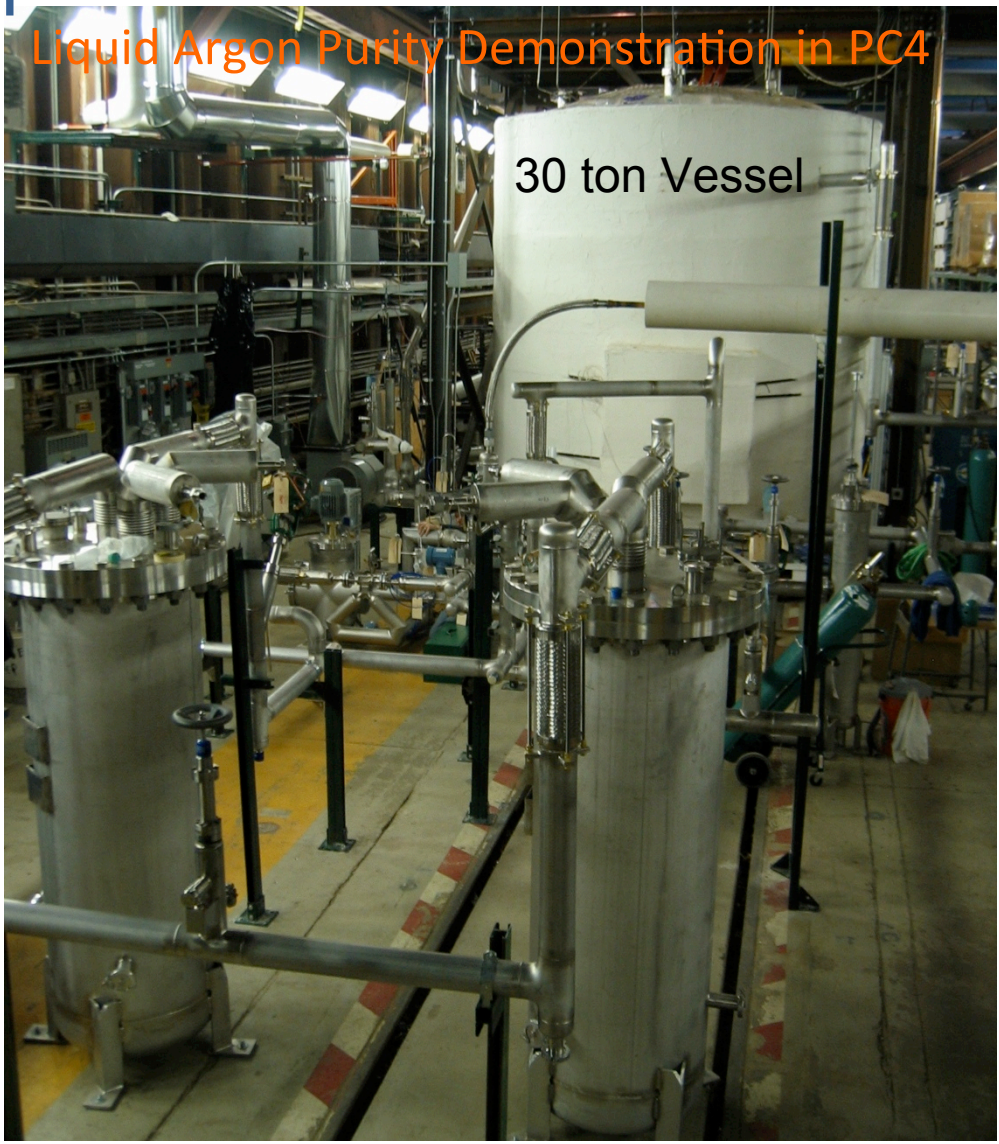
First multi-ton purification system designed and built at Fermilab.

Commissioning started in October 2011

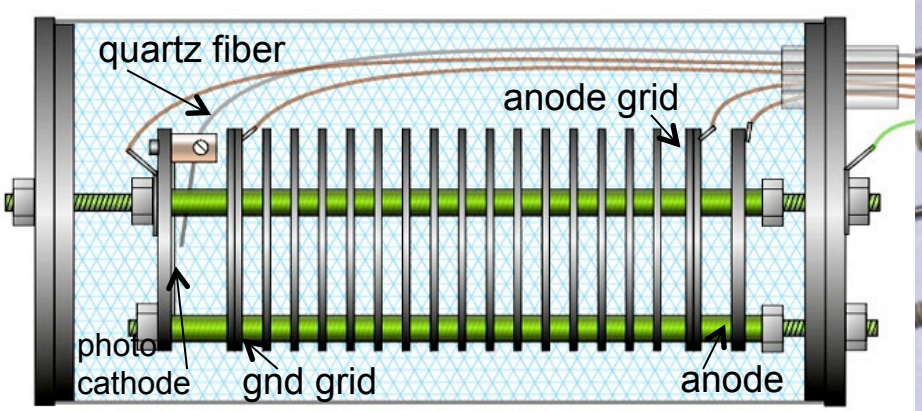
Stage 1 – bare tank & Instrumentation

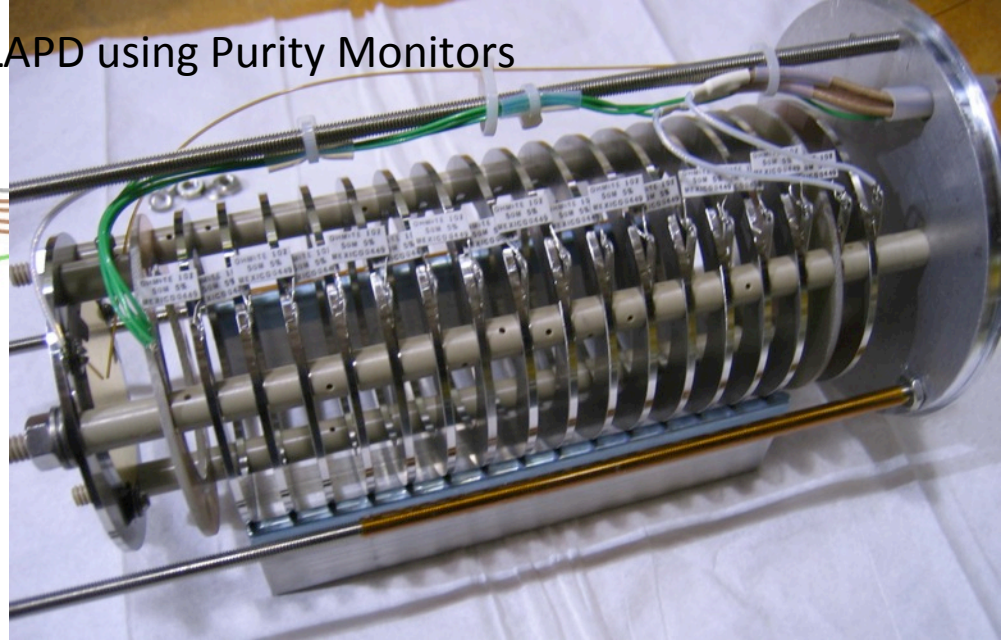
- Sniffers for evolution of gas purge
- Analyzers – for $O_2$, $N_2$, and $H_2O$ levels
- RTDs – for temperature (gradients)
- Purity Monitors - for drift-lifetime

Stage 2 – Operation with long TPC

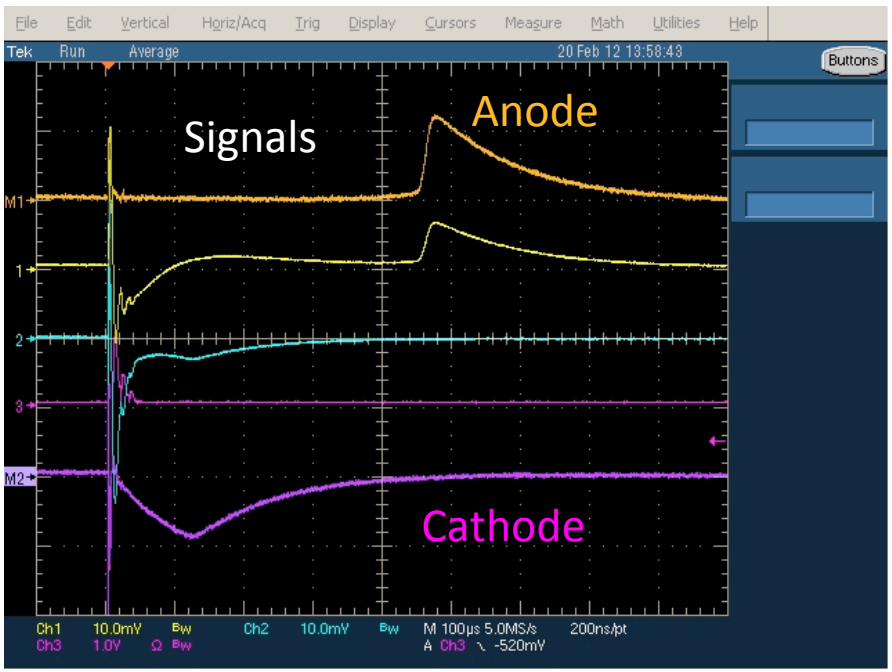


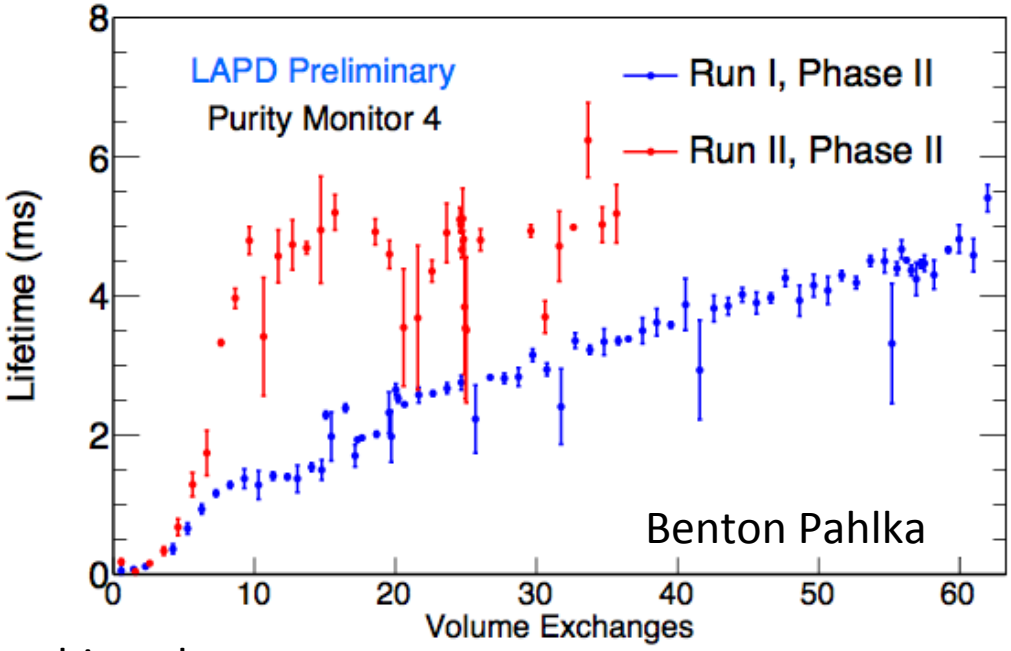
# Electron Drift Lifetime Measurements in LAPD using Purity Monitors



$$Q_A/Q_C = e^{-t/\tau}$$

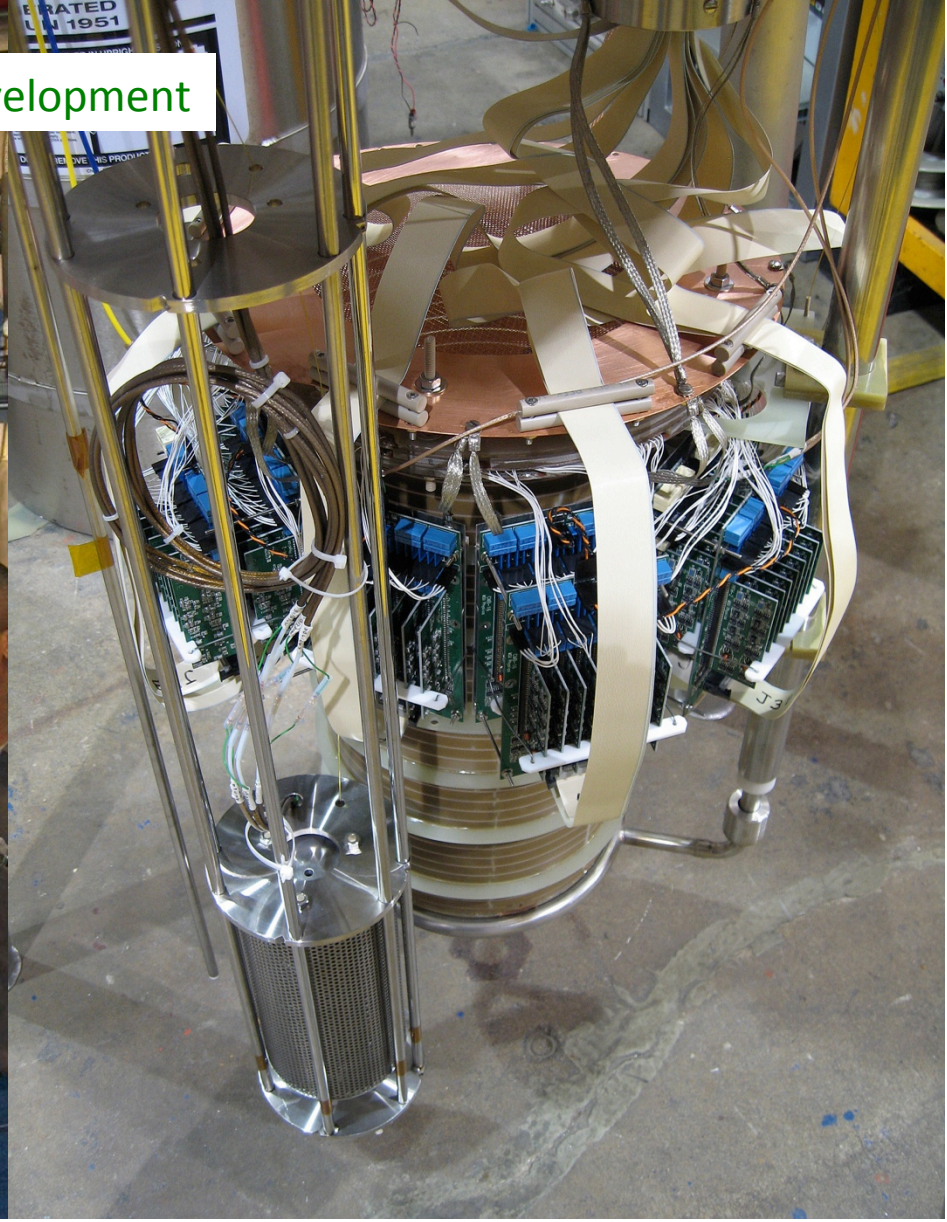



> 5 millisecond lifetime achieved

# TPC Electronics Development

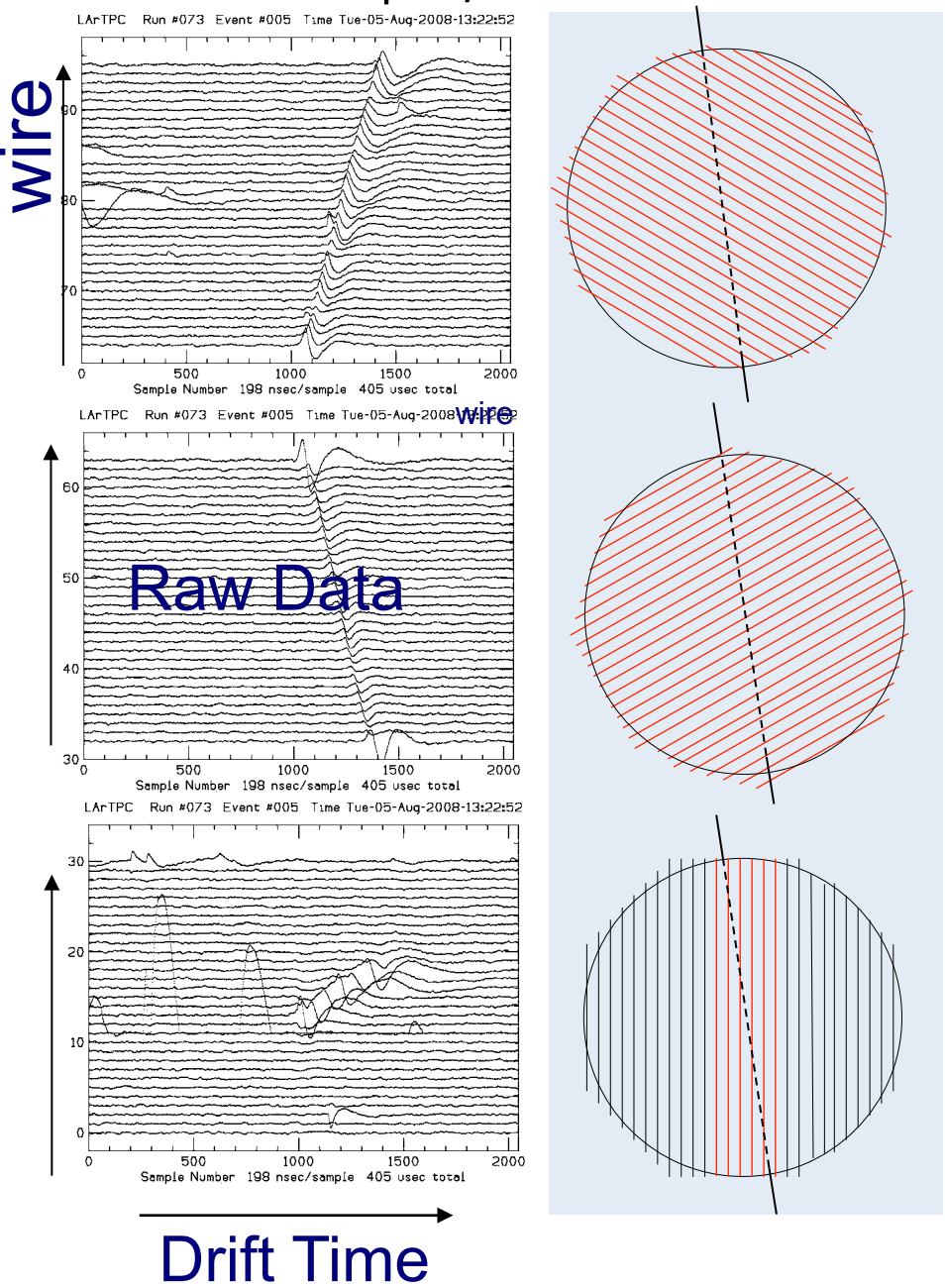
Original Bo TPC
Electronics outside cryostat (Mich. S.U)

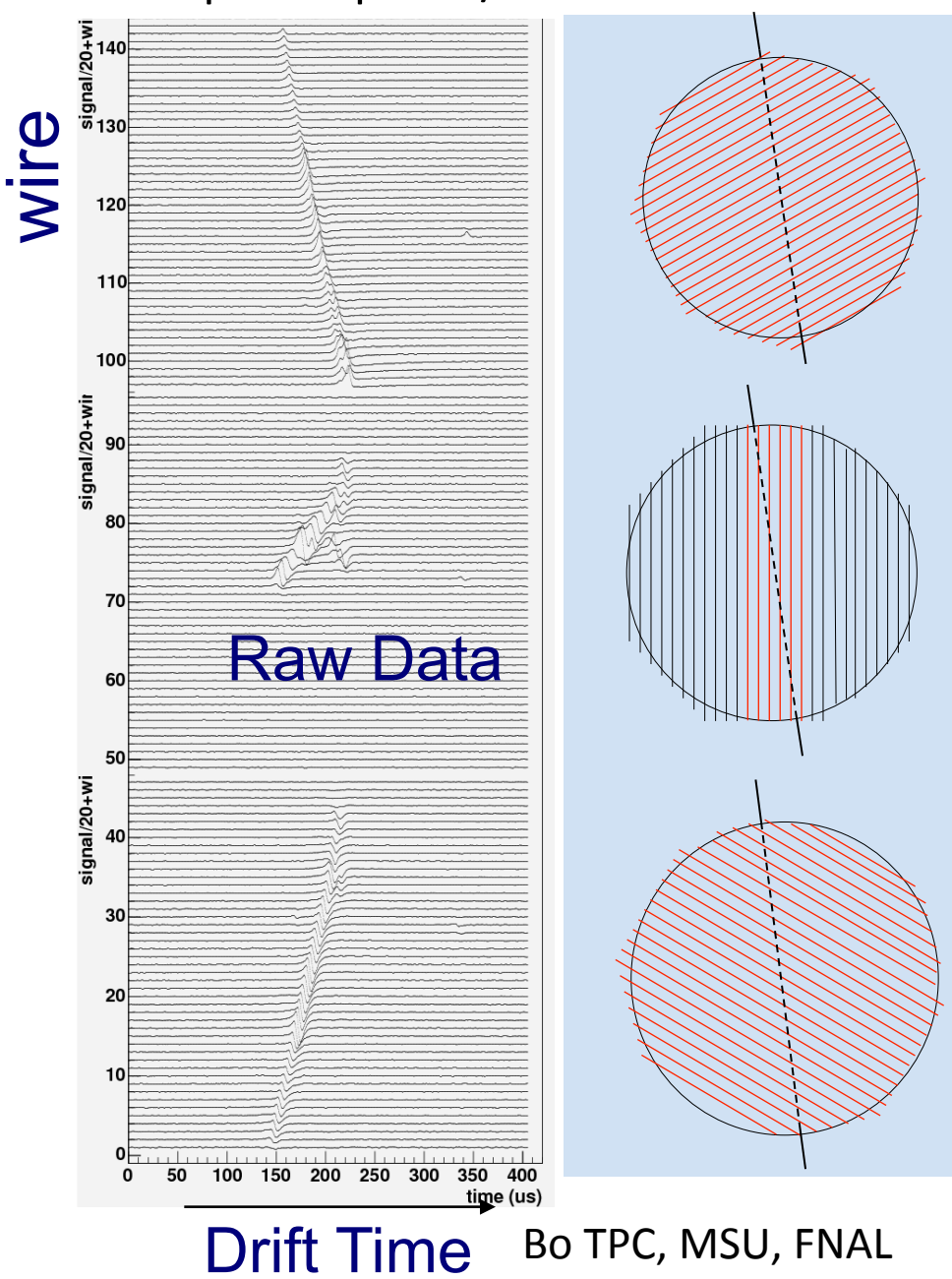


Bo TPC with
Electronics in liquid argon

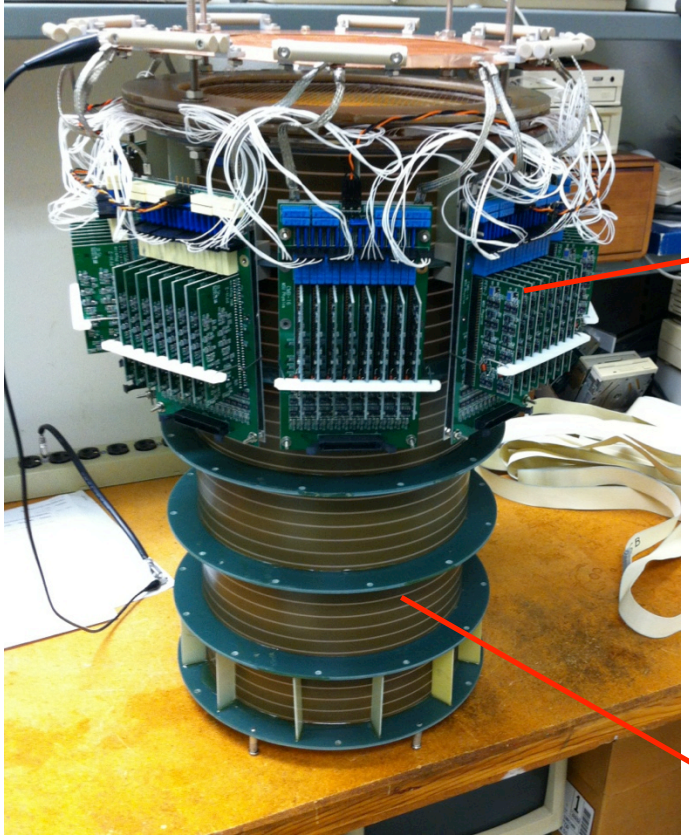
Warm amps S/N = 15

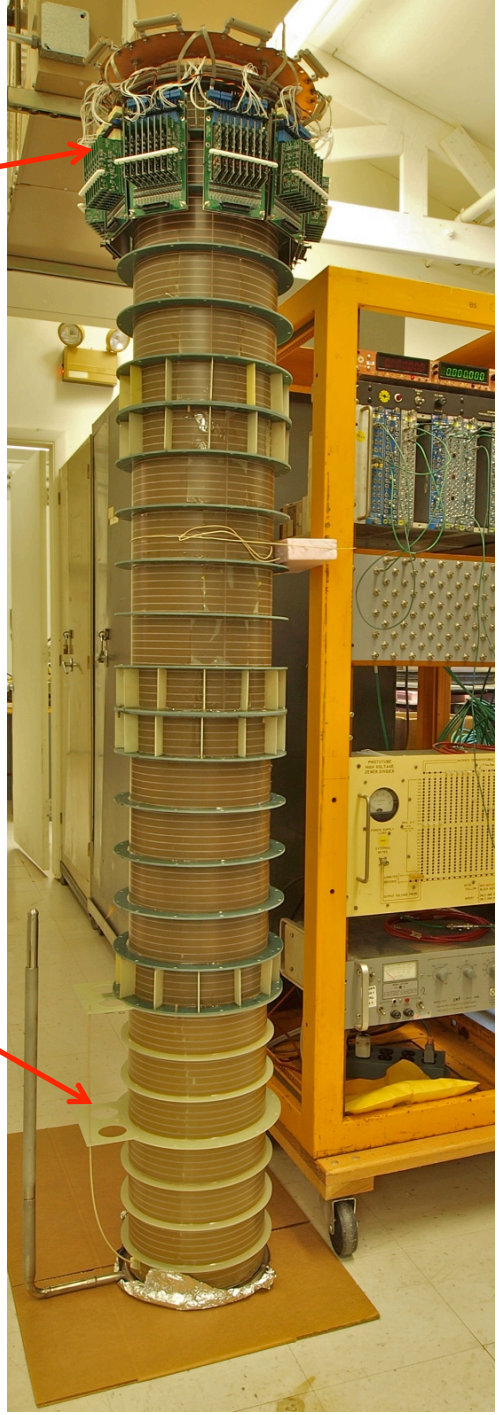
Amps in liquid S/N >30




Bo TPC, MSU, FNAL





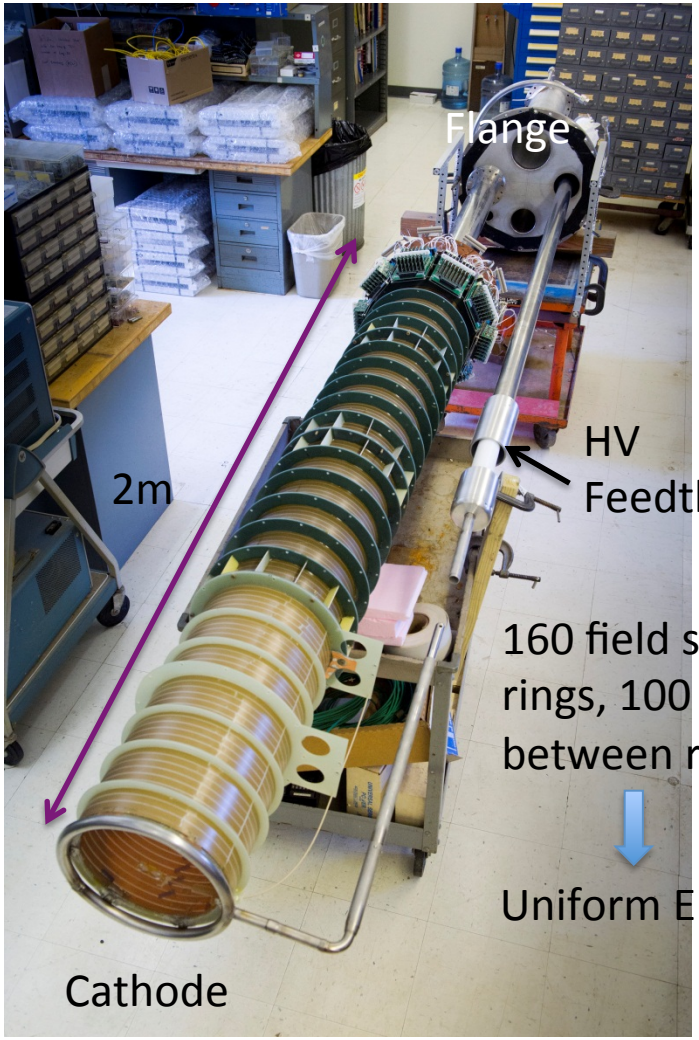
Long Bo

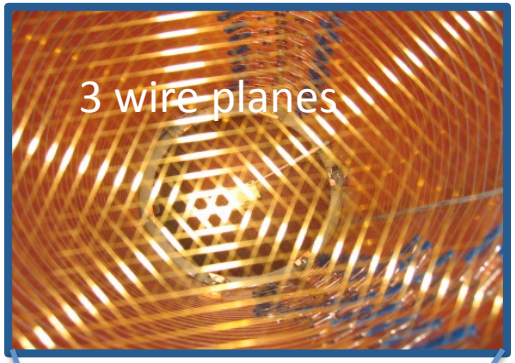
Bo to LongBo(w)

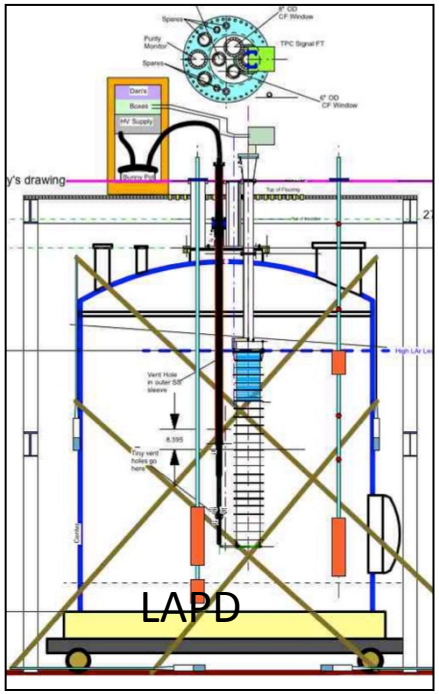
If you don't watch carefully …

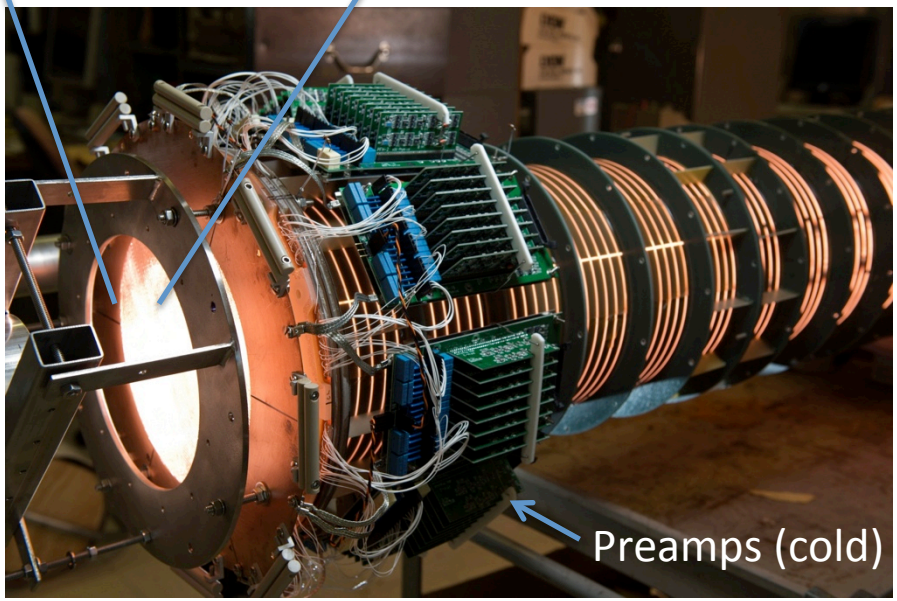
# LongBo TPC in LAPD

MSU FNAL

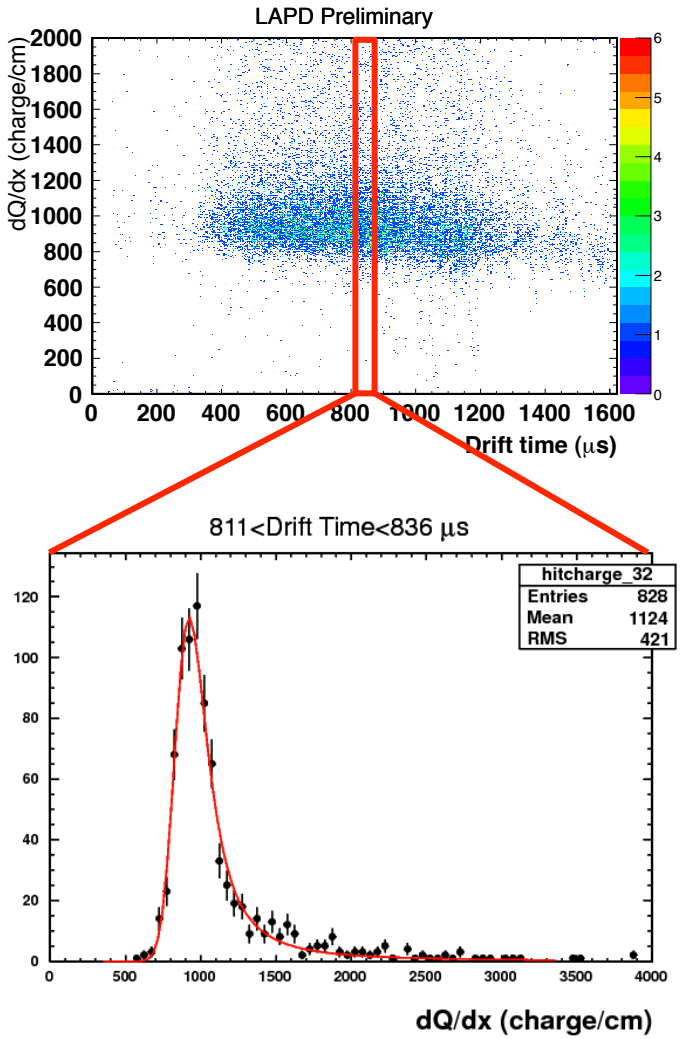


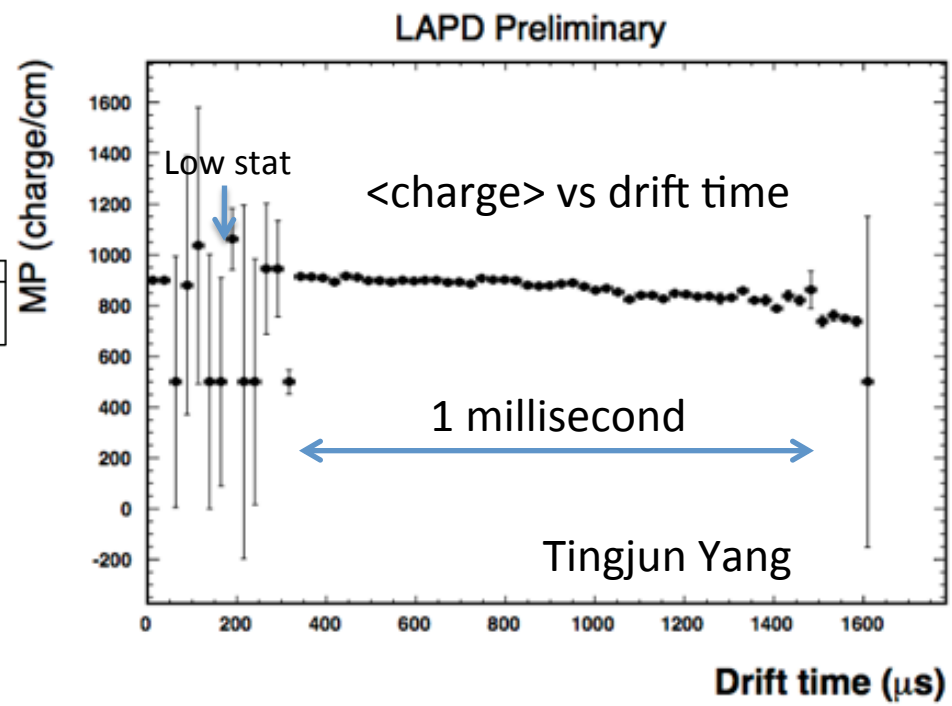
# LongBo TPC in the LAPD triggered on Cosmic Rays

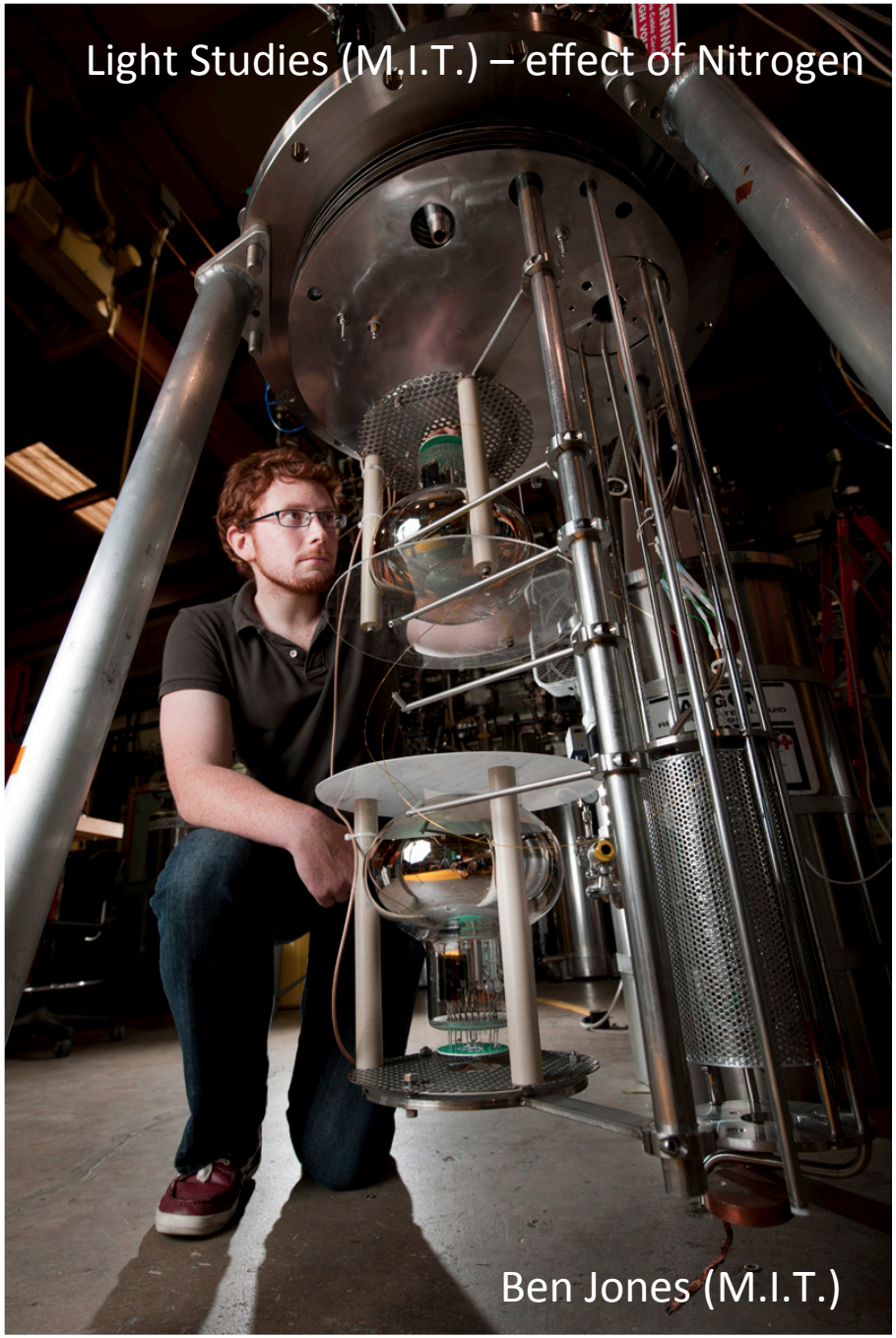


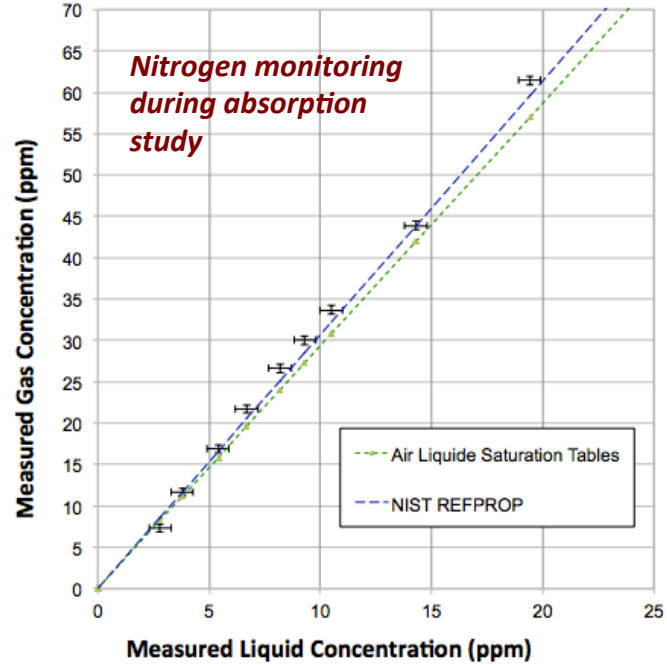

— Select single muon events between $50° < \theta < 70°$ and remove $\delta$ rays

— Use dQ/dx of muon hits as a function of drift time to measure charge attenuation

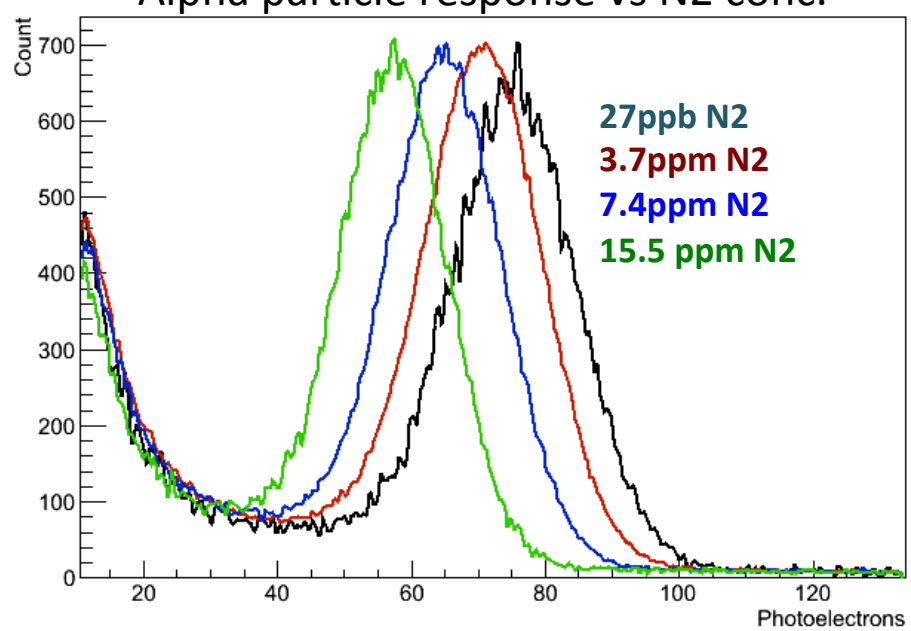
— Less than 20% attenuation over 1.5 m



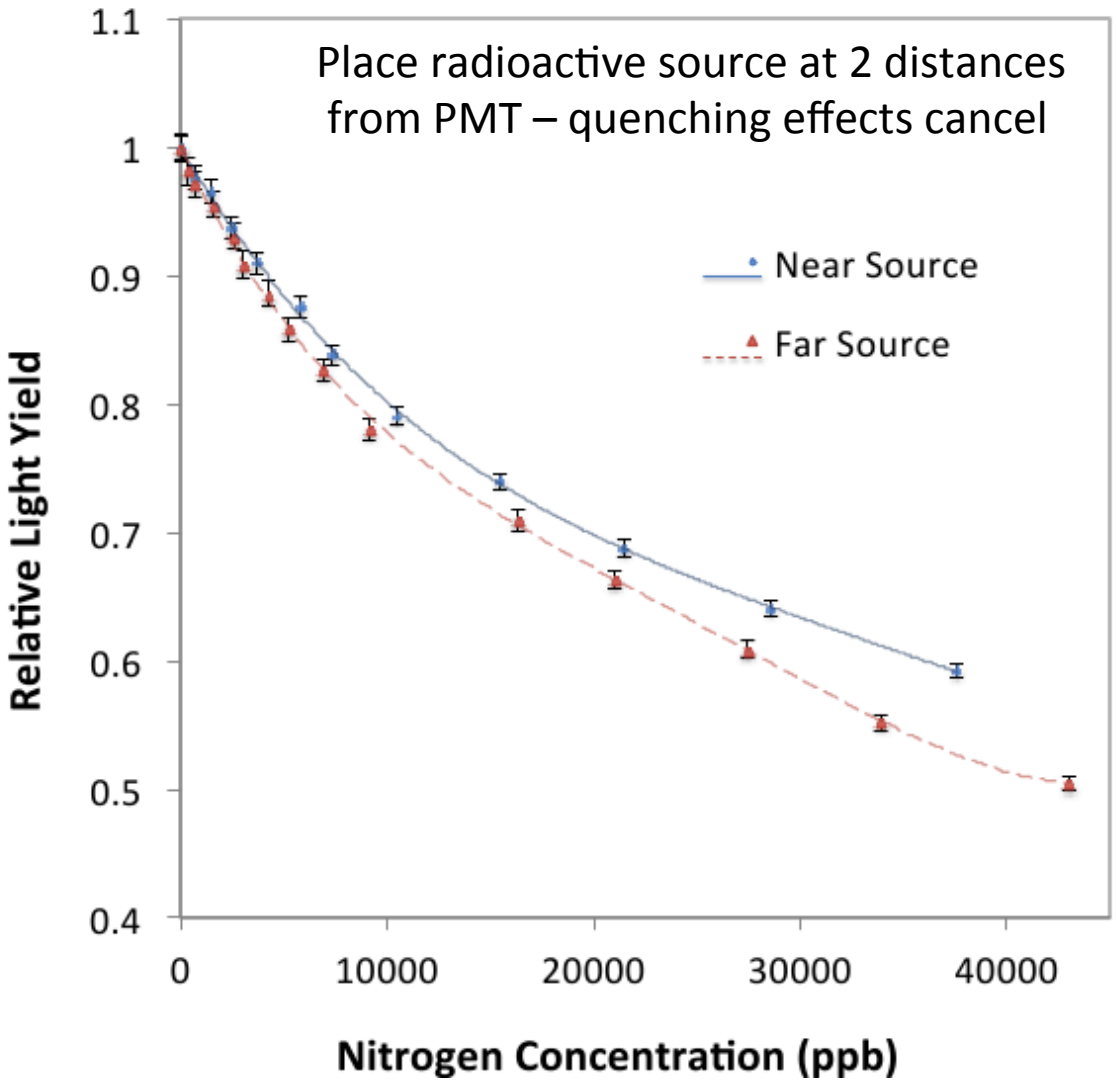



Alpha particle response vs N2 conc.



# Nitrogen Attenuation Data




Divergence of the two lines shows the attenuation by N2 and allows extraction of the absorption strength of nitrogen in LAr

arXiv:1306.4605 & JINST

similar business with Methane

arXiv:1308.3658

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

Scintillator Paddle Prototype for LBNE hanging on TallBo lid

TallBo in operation

**Test of 16 prototype bars**

3 Silicon Photomultiplier (SiPM) light detectors at end of each bar (6 mm x 6 mm)

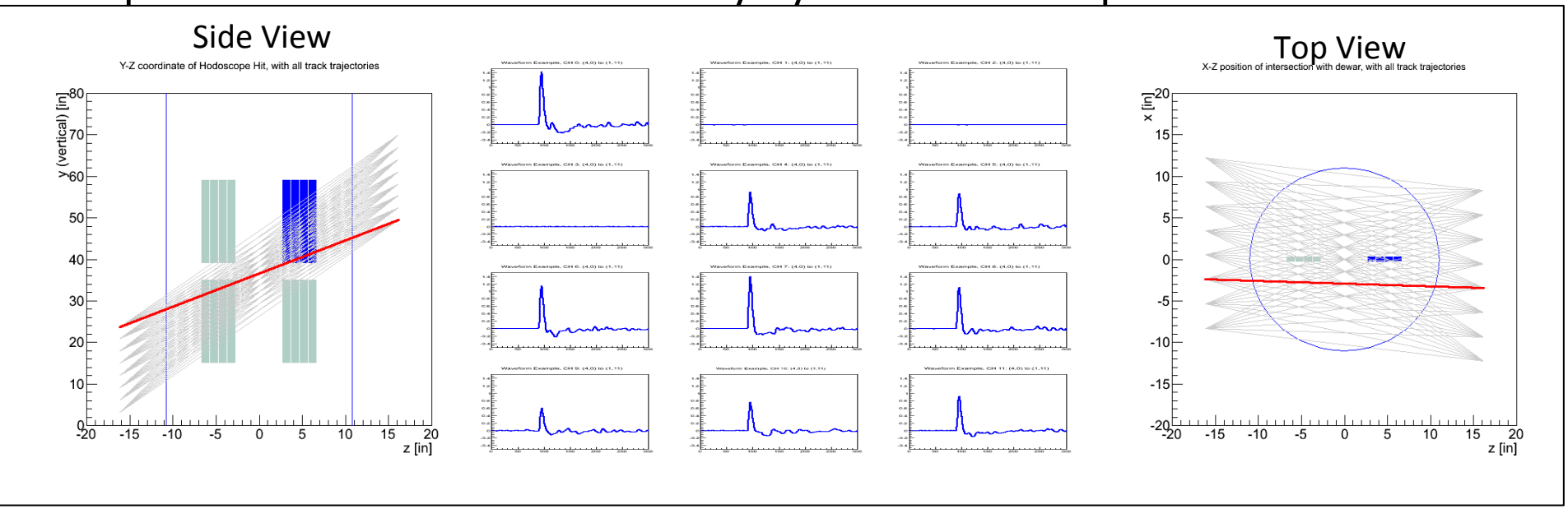
Study relative light yields from various waveshifter options (type and quantity, TPB and BisMSB)

Study quality of bars with different manufacturing technique (artisanal and mass production)

Study effect of Xenon doping

Argonne, Indiana U., M.I.T., LBNE (S.Mufson)

Example track viewed simultaneously by SiPMs in multiple bars



# LArIAT (Liquid Argon in A Test (Beam))

18 Institutions
50+ physicists

# LArIAT Physics Program

Measurements to be made include

- EM shower energy resolution (Phase 1, Phase 2)
- Hadronic shower energy resolution, visible vs invisible energy (Phase 2)
- Directionality of through going particles using delta rays (Phase 2)
- Particle identification (Phase 1 and Phase 2)
- dE/dx for several particle species (Phase 1 and Phase 2)
- Light collection efficiency (Phase 1 and Phase 2)
- Surface operation in a high cosmic ray rate environment (Phase 2)
- Studies of proton decay backgrounds (Phase 2)
- Diffusion studies over long drift distances (Phase 2)

Fermilab provides the facilities, other groups provide the active detectors

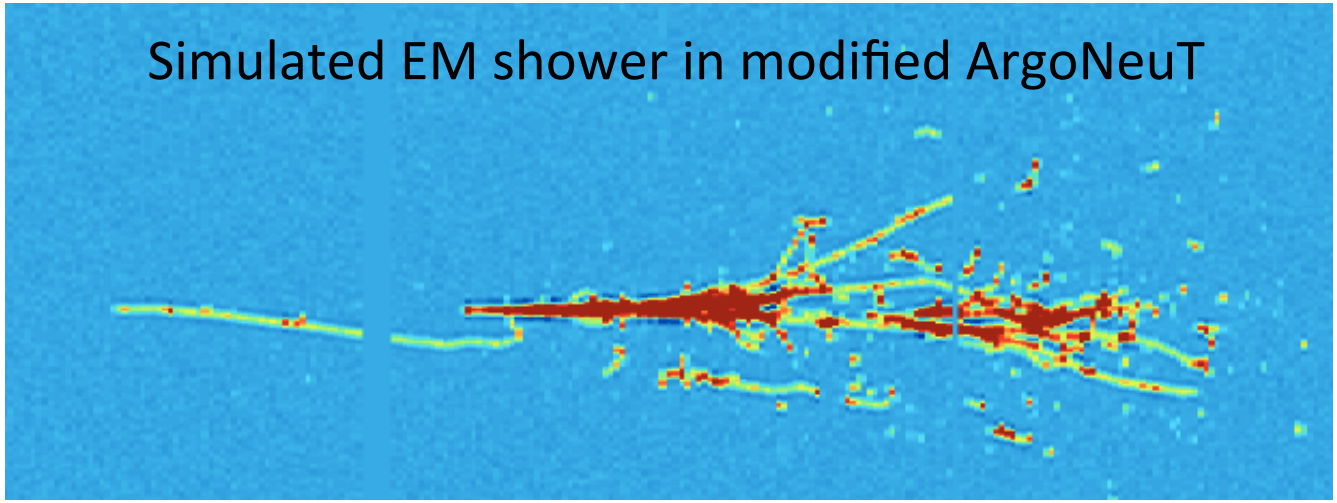
- Cryogenic pumping and filtration system under construction now
- Optimizing tertiary beam used for MINERvA underway
- Phase 2 Cryostat design to allow convenient access to inside of vessel
- Allow for exchange of electronics, light collection systems, TPCs, etc, in several year program

Get started quickly

- Upgraded ArgoNeuT Vessel modified to minimize material between the beam and LAr
- PMT to detect scintillation light
- Upgraded filtration system

  Study charge to energy conversion with single track topologies

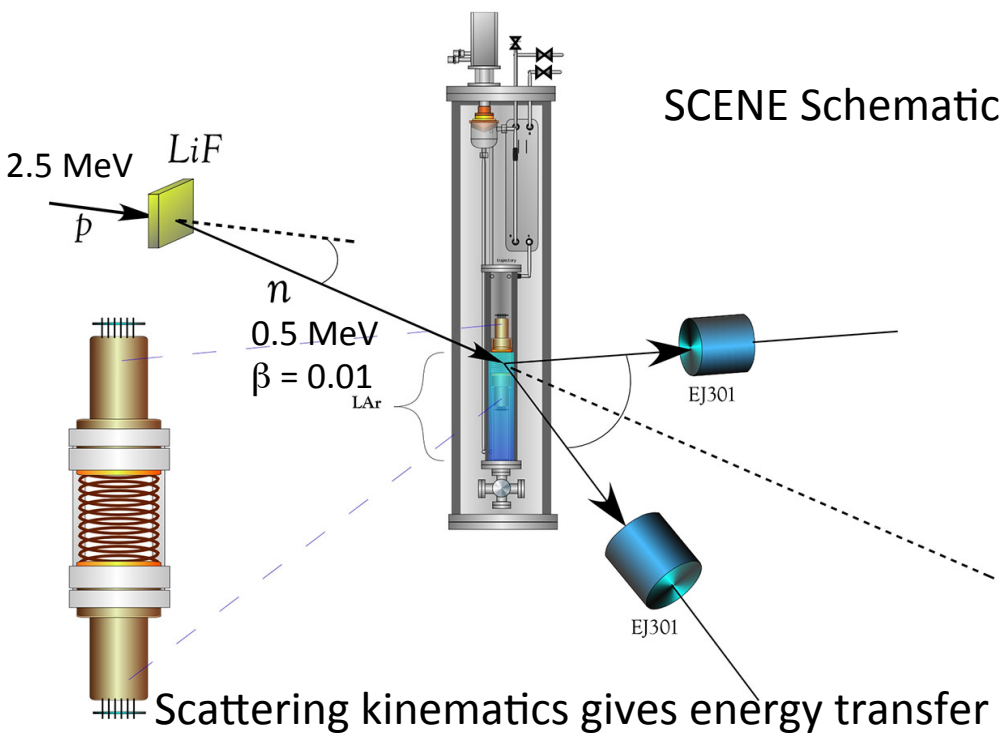
  Study initial ionization for e/γ separation

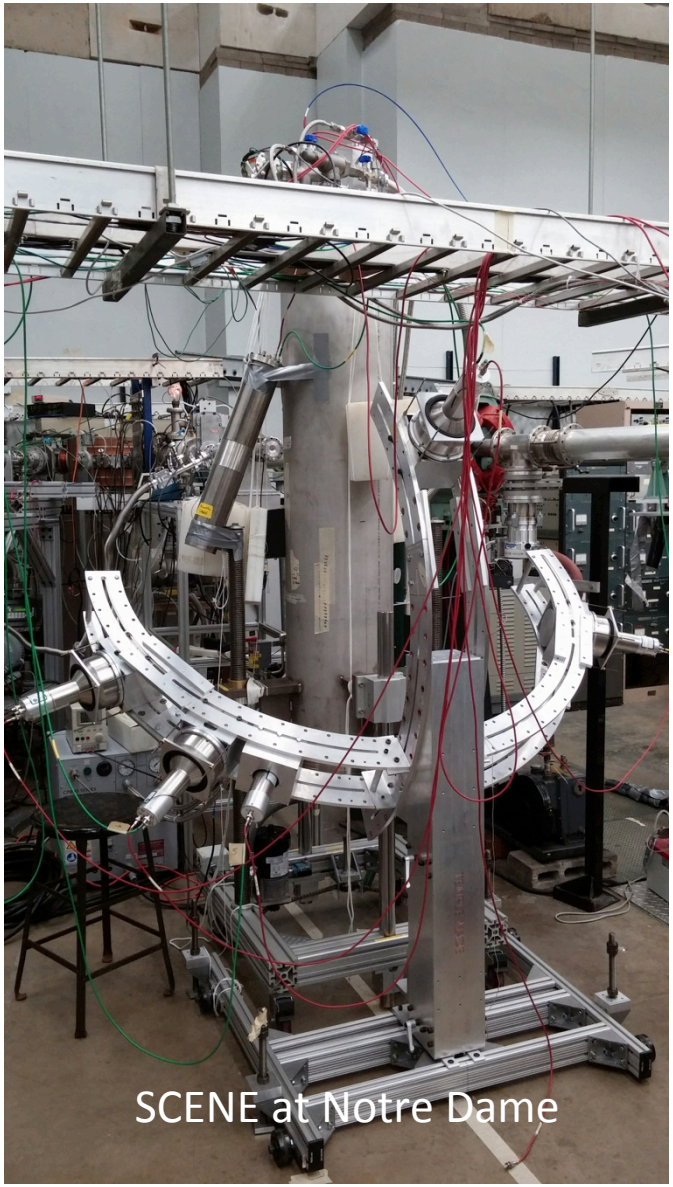


# SCENE – Scintillation Efficiency of Noble Elements

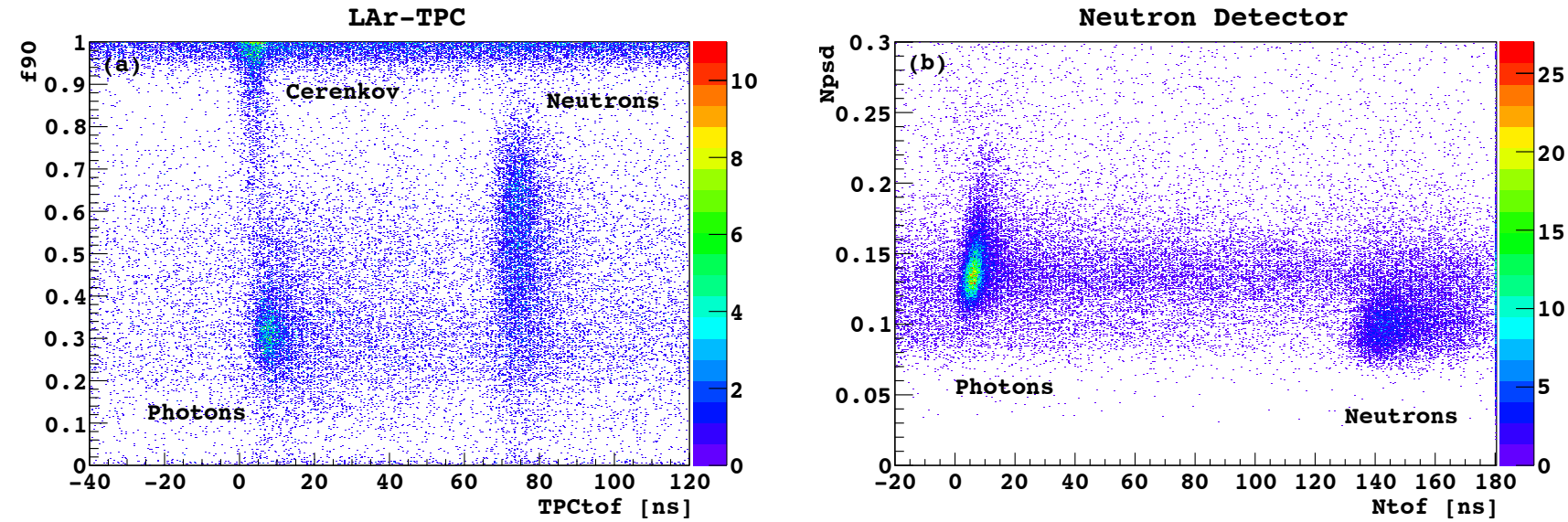
Precision measurement of light output of Argon nuclear recoils in a dual-phase LArTPC using monoenergetic, low energy, pulsed Neutron Beam at Notre Dame

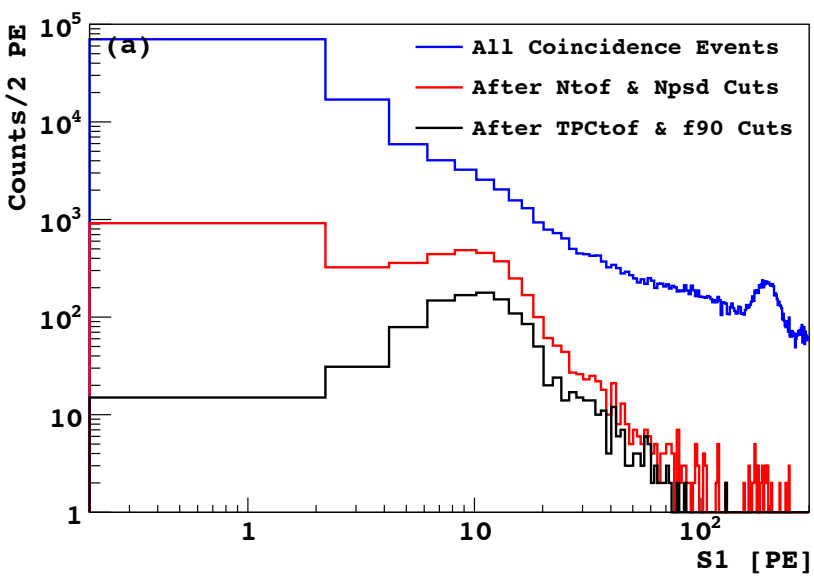
(Chicago, Fermilab, Princeton, Naples, Notre Dame, Temple, UCLA)

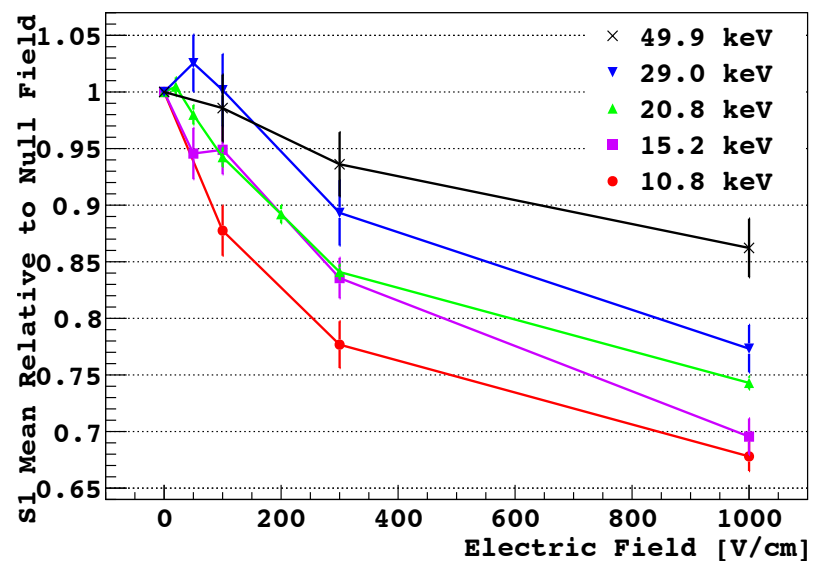


# SCENE - Time of Flight vs Pulse Shape Discriminant in LArTPC & Neutron Counters




Take away - less light at lower energy in presence of electric field – **unexpected result & affects operating parameters for argon dual-phase TPCs searching for Dark Matter**

# Purification of low-radioactivity argon from underground

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

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

Ar (600 ppm) from certain $CO_2$ wells in Co has < 0.01 Bq/kg (arXiv:1204.6011)

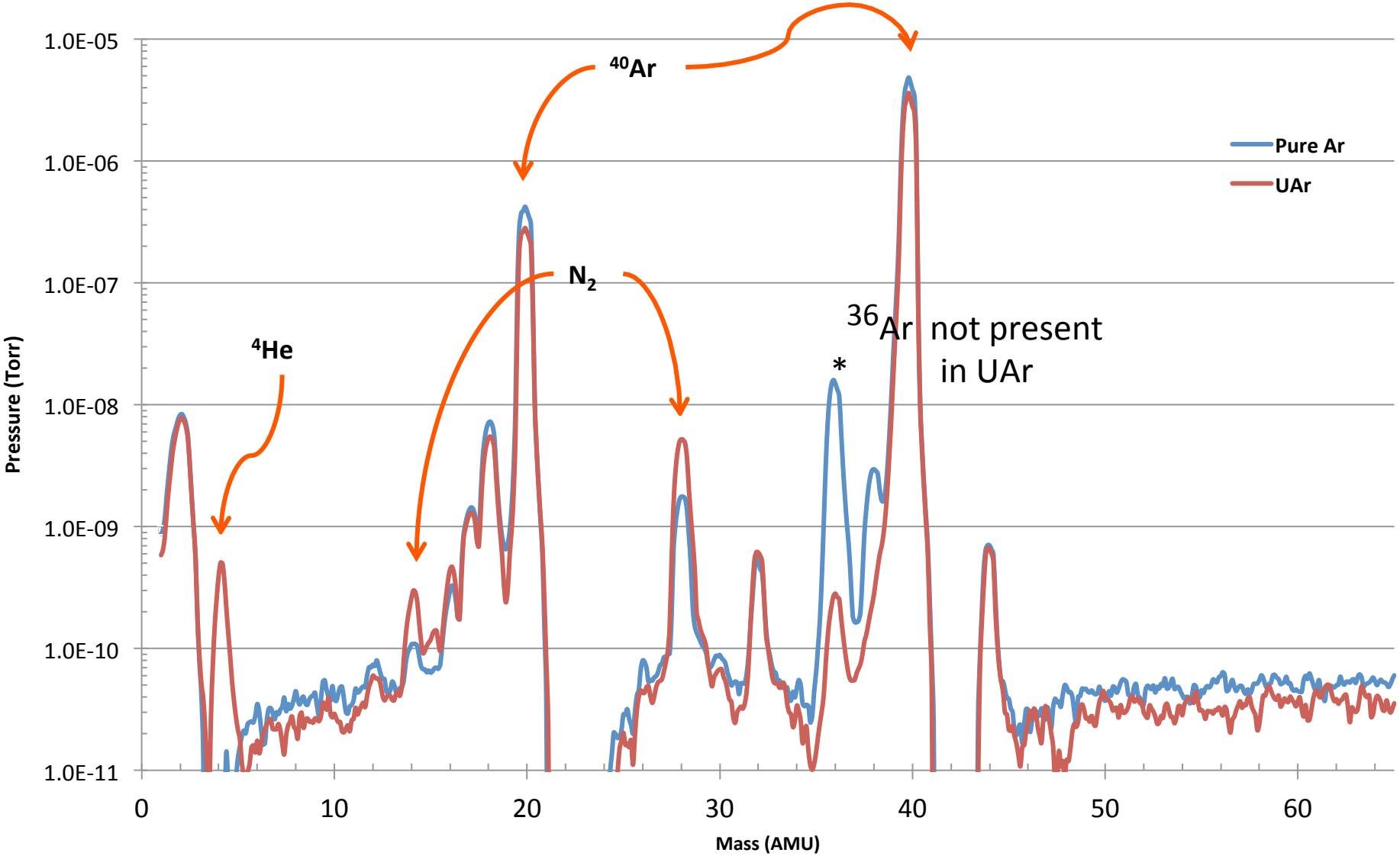
Mixture of ~4% Ar, 6%$N_2$, 90% He comes to Fermilab; have to distill the $N_2$ off.

Column commissioned with atmospheric Ar mixture 99.95% pure;

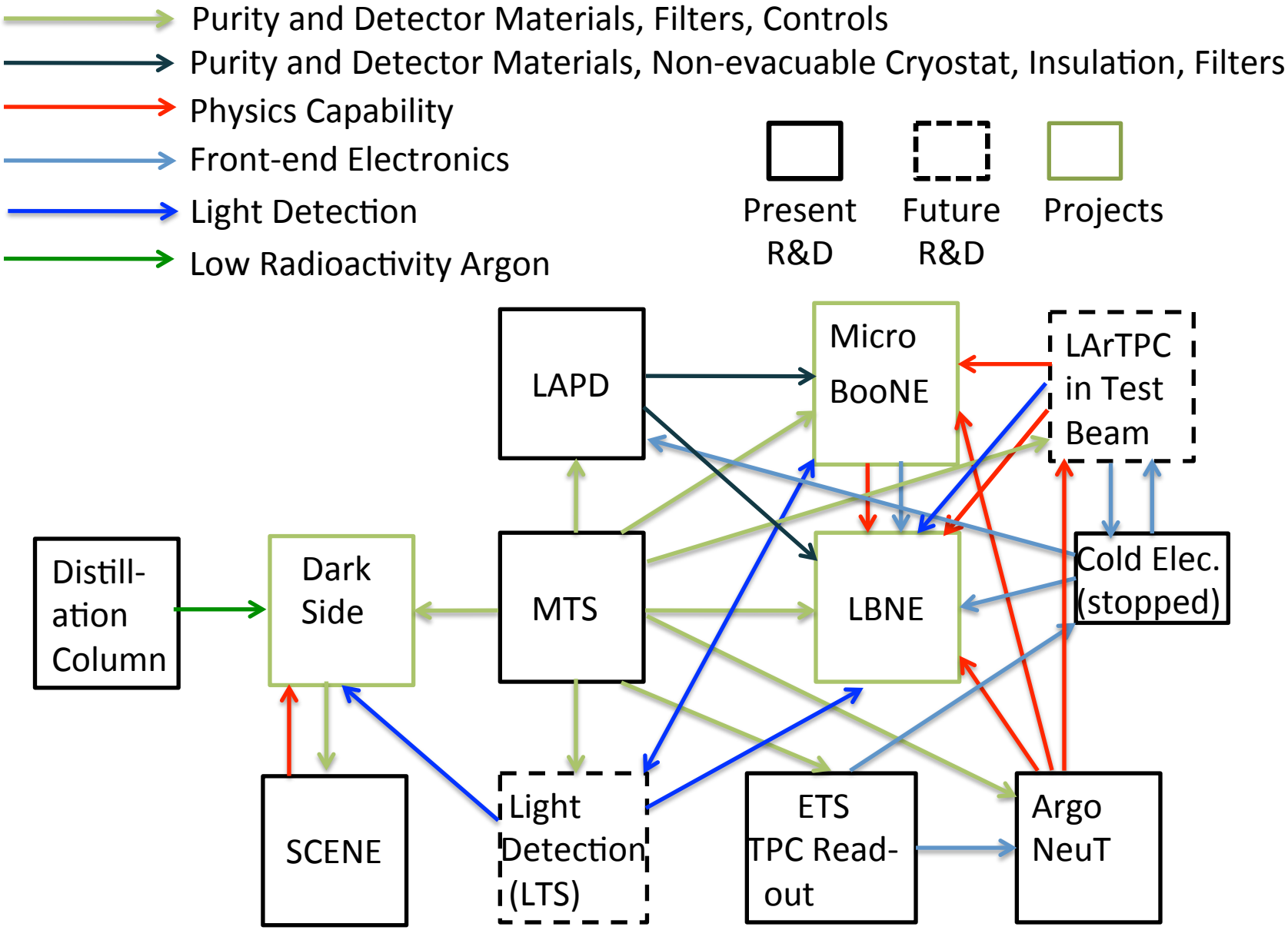
15 kg processed;

Aimed at DarkSide and DEAP

# Comparison of Darkside Ar and Airgas (atmospheric) pure Ar



## Relationships Between Present Activities



# Summary for Liquid Argon

Facilities: In use – provide broad service; have expanded with a cryostat for `light' work

TPC work - Generating physics papers (ArgoNeuT), stimulating software development

LAPD - Demonstrating good lifetime without evacuation – testbed for long drift TPC

Dark Matter - Important and unique contributions to LAr for Dark Matter searches

LArIAT - Exciting project for high quality information on particle behavior in LAr

Overall - maintain close contact/direct relevance to approved LAr projects
- encourage University participation
- hands-on hardware opportunities for `young' physicists.