Liquid Argon – Why

Liquid Argon is a bright Scintillator (40,000 photons/MeV) and allows free electrons to drift meters under E fields of ~ kV/cm. It has a density of 1.4 tonne/m^3, and is readily available.

Liquid Argon presents an attractive Target & Detection Medium for:

Neutrino interactions

Liquid Argon TPCs can produce bubble-chamber quality event images with topology *and* ionization density -> particle ID/calorimetry

Dark Matter searches

The time development of the light pulse and the ratio of the amount of free charge to light produced by interactions in Argon provide powerful rejection of electron and photon background in WIMP searches

FROM

(Some) Liquid Argon R & D at Fermilab

Charge Detection

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

Light Detection and Production

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

High Voltage

- **Breakdown in noble liquids**

(Some) Liquid Argon R & D at Fermilab

Neutrino Specific

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

Dark Matter Specific

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

(Some) Liquid Argon R & D at Fermilab

Policies & Disclaimers

- **Relevant to `the current program' but not exclusively so**
- **Maintain close relations with University groups, encourage use of existing facilities, and support developments for new work**
- **Work in areas where we can exploit expertise at Fermilab**
- **Design equipment for R & D - if available may be used to develop equipment for a specific experiment (useful shakedown)**
- **Not the only LAr R & D at Fermilab**
  both MicroBooNE and LBNE are doing interesting stuff &
  there is a program called LArIAT (Liquid Argon tpc In A Test beam) which is not part of the review

Argon Source & **Materials Test System**

Materials Test System

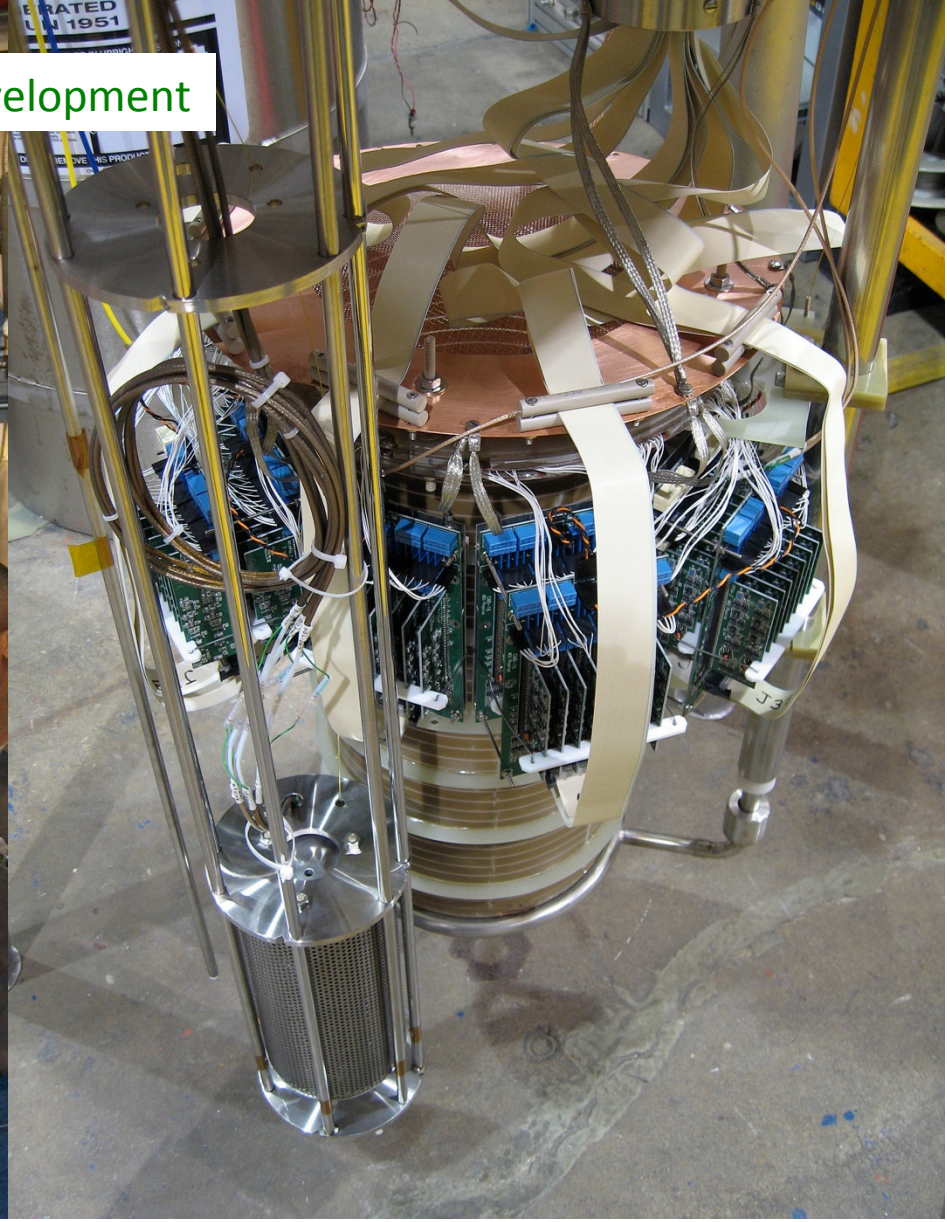
`A system to test the effects of materials on the electron drift lifetime in liquid argon and observations on the effect of **water**' R. Andrews *et al.*, Nucl.Instrum.Meth.A608:251-258,2009.

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)

TPC Electronics Development

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



Bo TPC with
Electronics in liquid argon (Michigan S. U.)

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**.

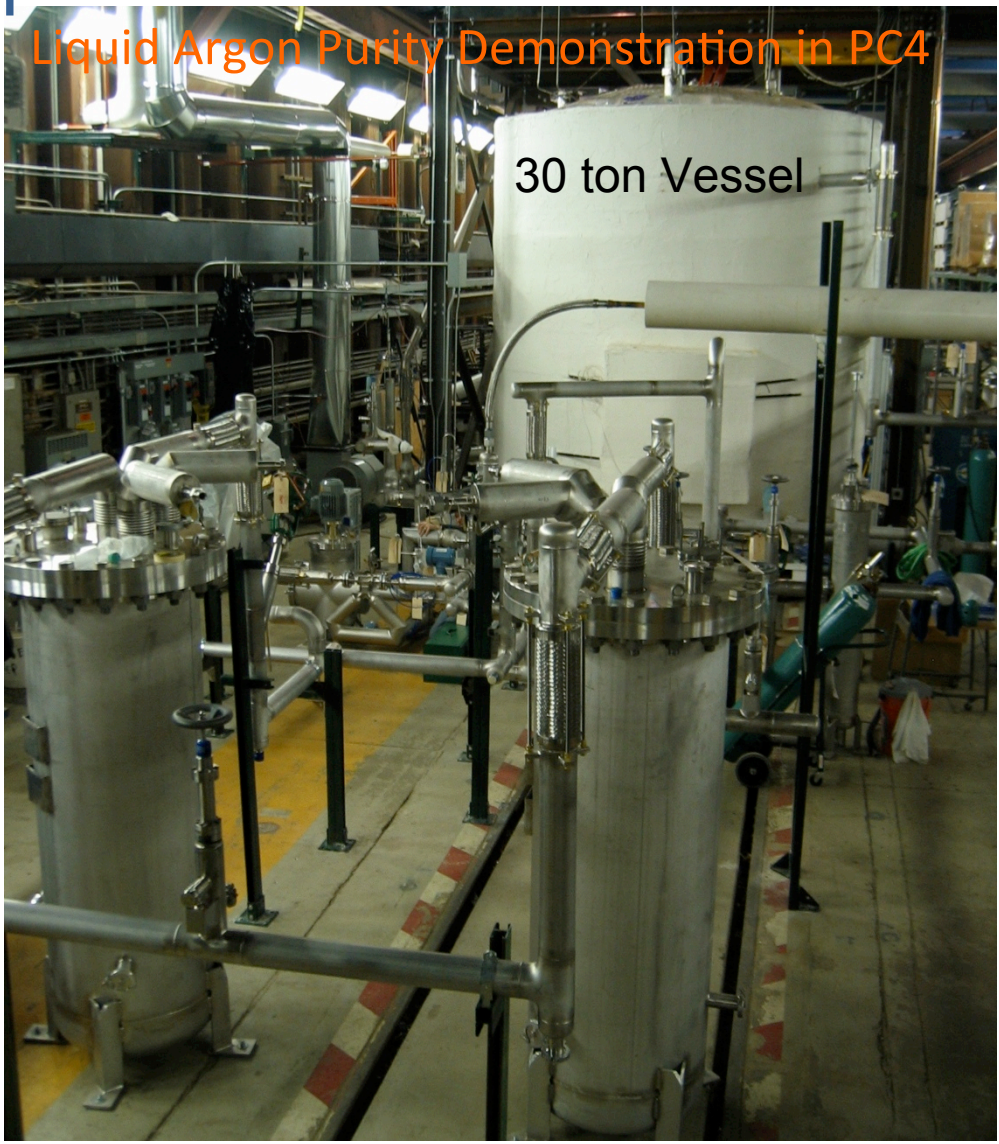
First multi-ton purification system designed and built at Fermilab.

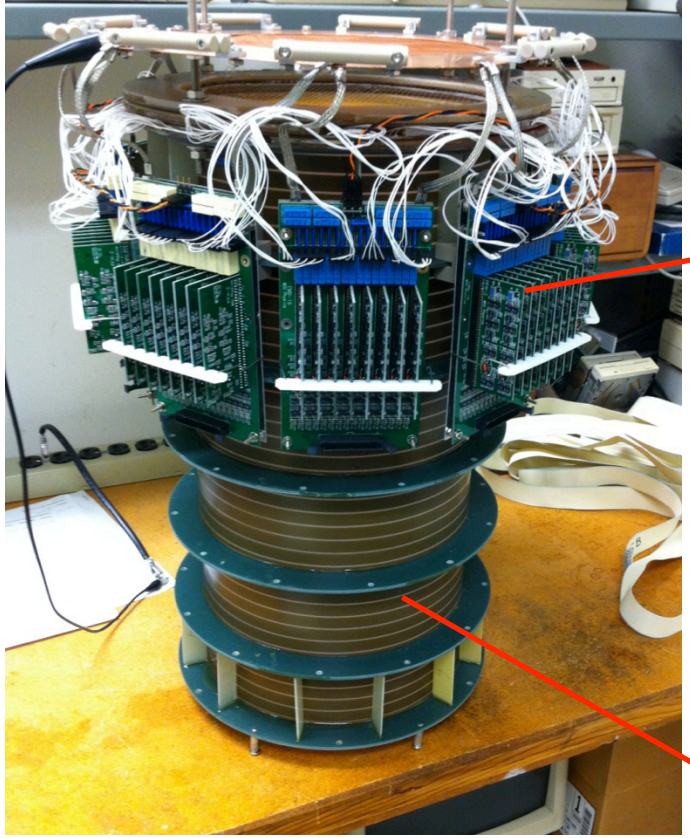
Commissioning started in October 2011

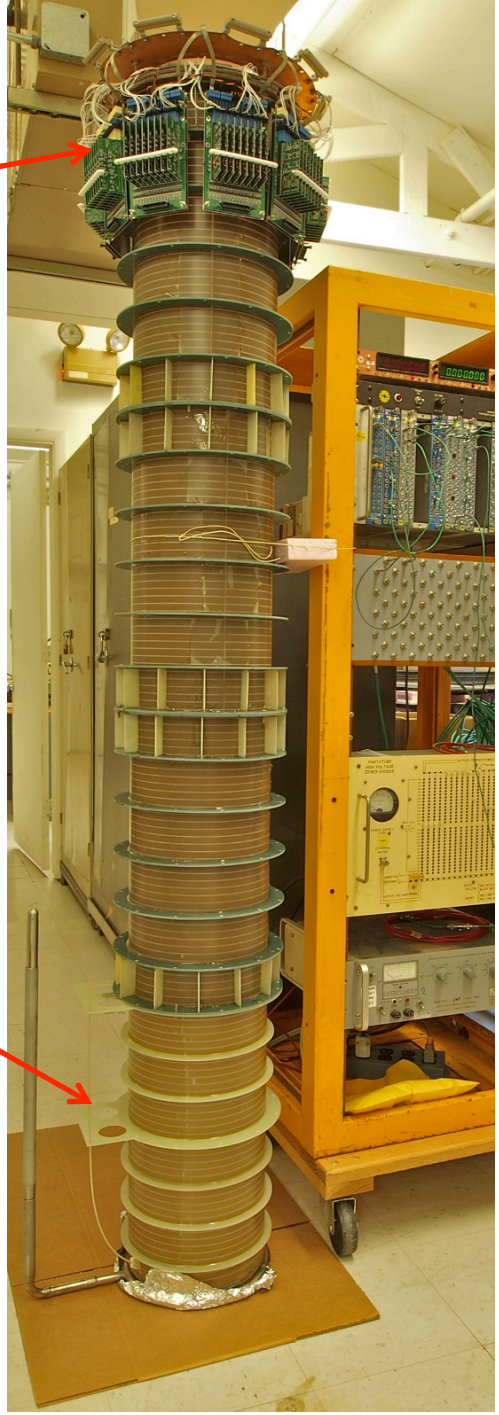
Stage 1 – bare tank & Instrumentation

- 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





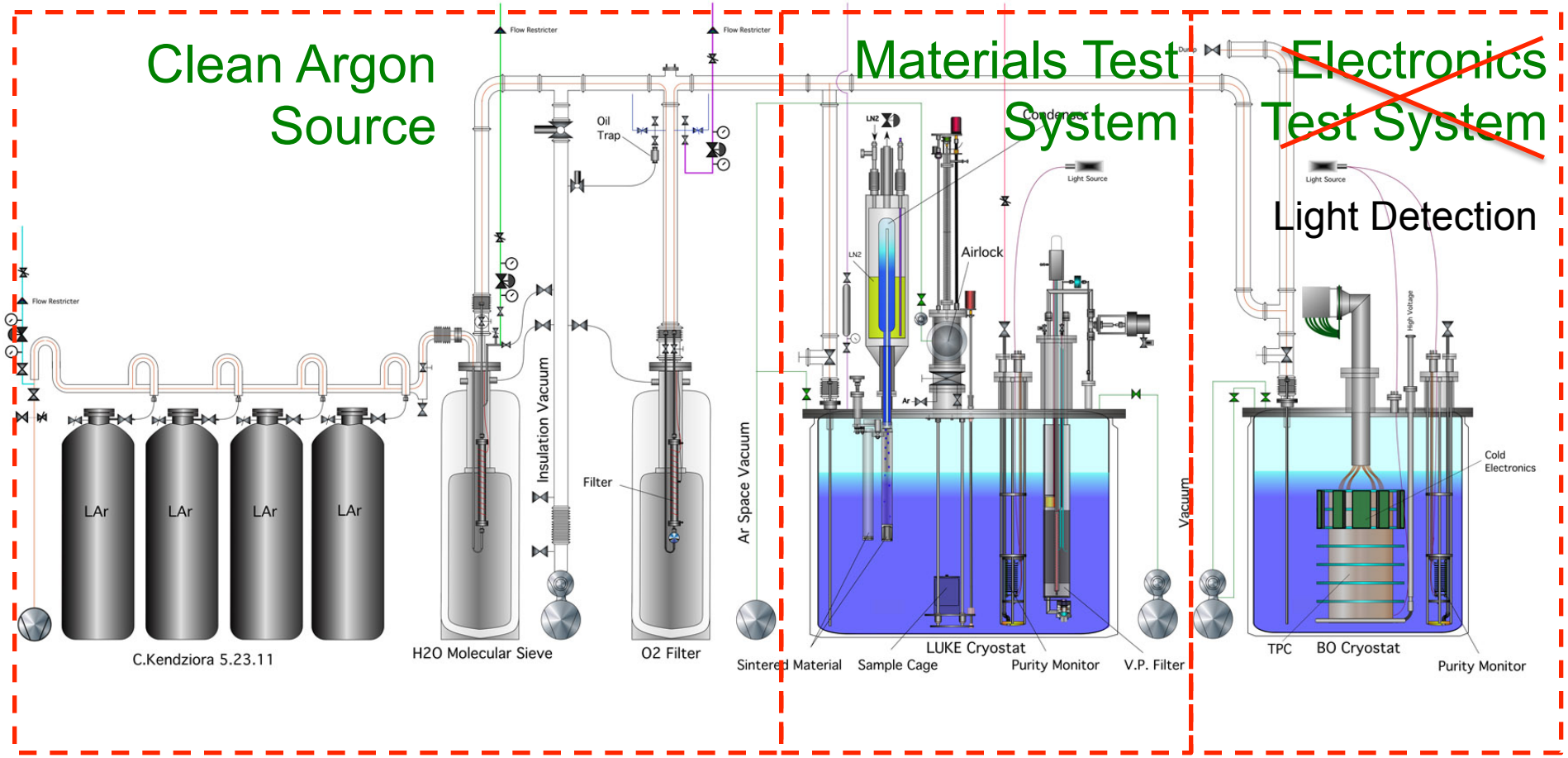


Long Bo

Bo to LongBo(w)

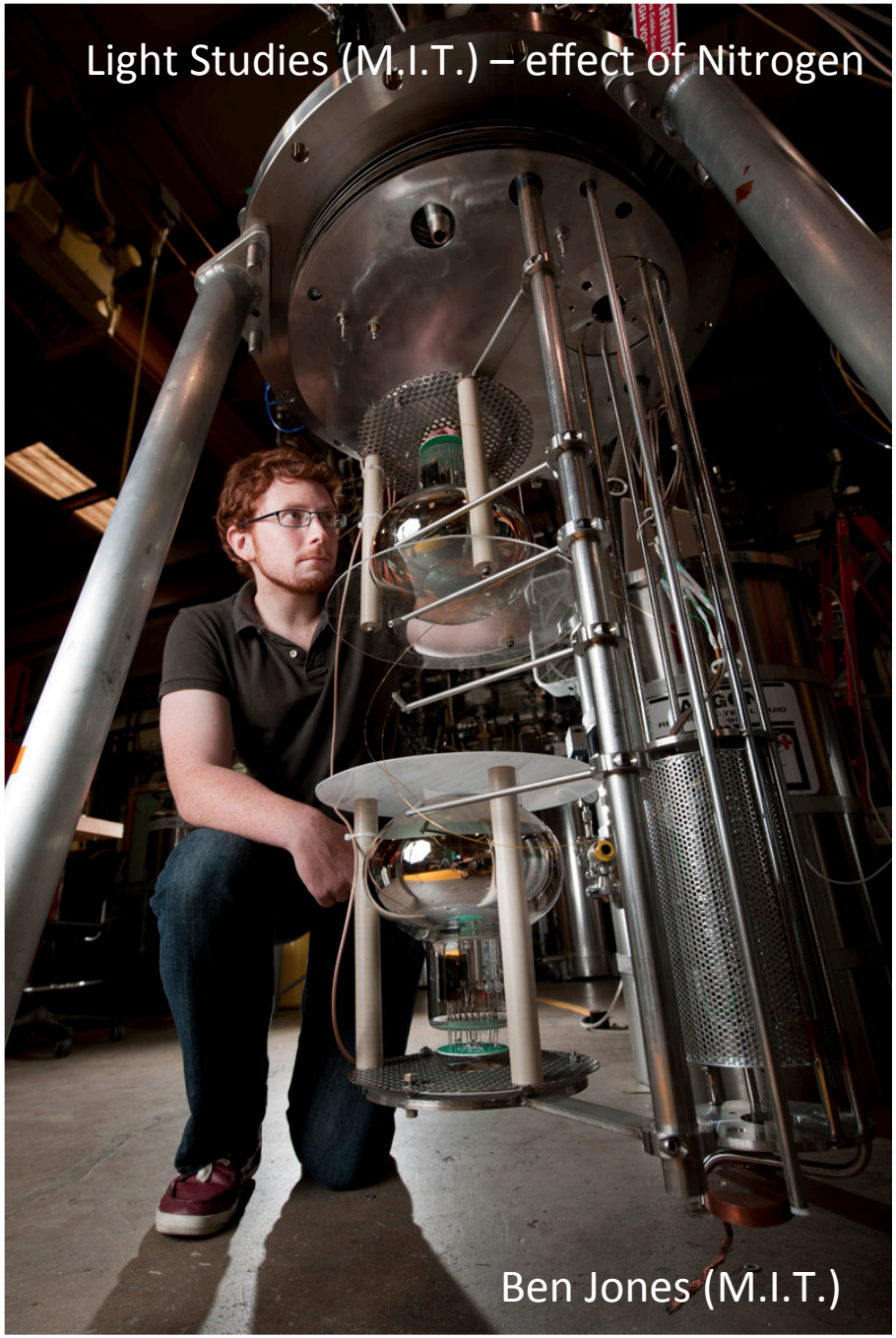
If you don’t watch carefully …

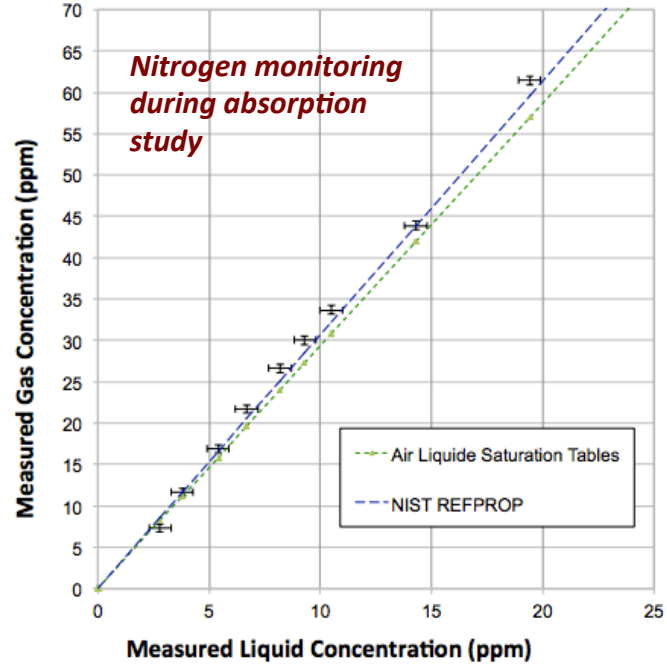
Liquid Argon Setup at the PAB



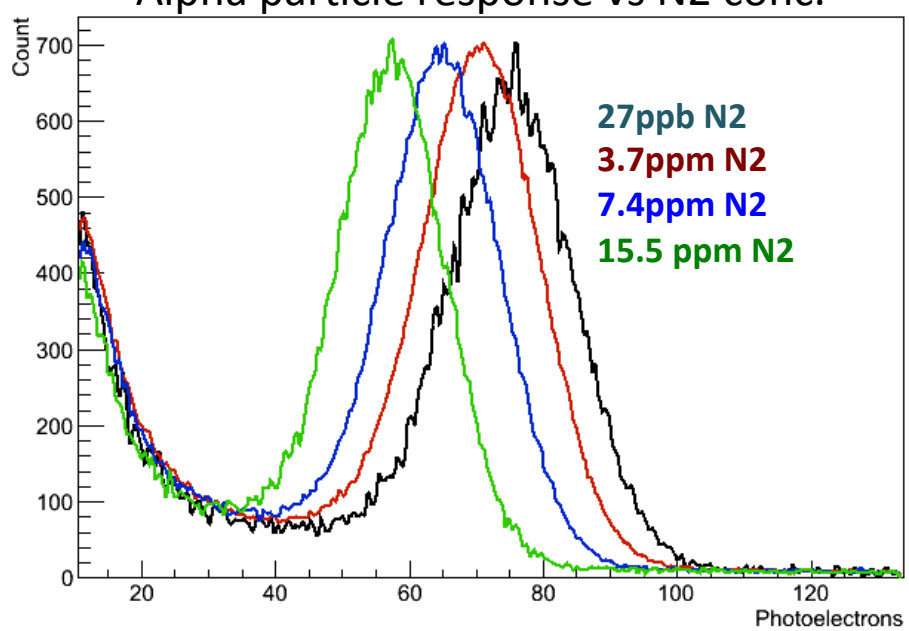
Schematic of Materials and ~~Electronics~~ Test Systems
Light Detection

Light Studies (M.I.T.) – effect of Nitrogen





Alpha particle response vs N2 conc.



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

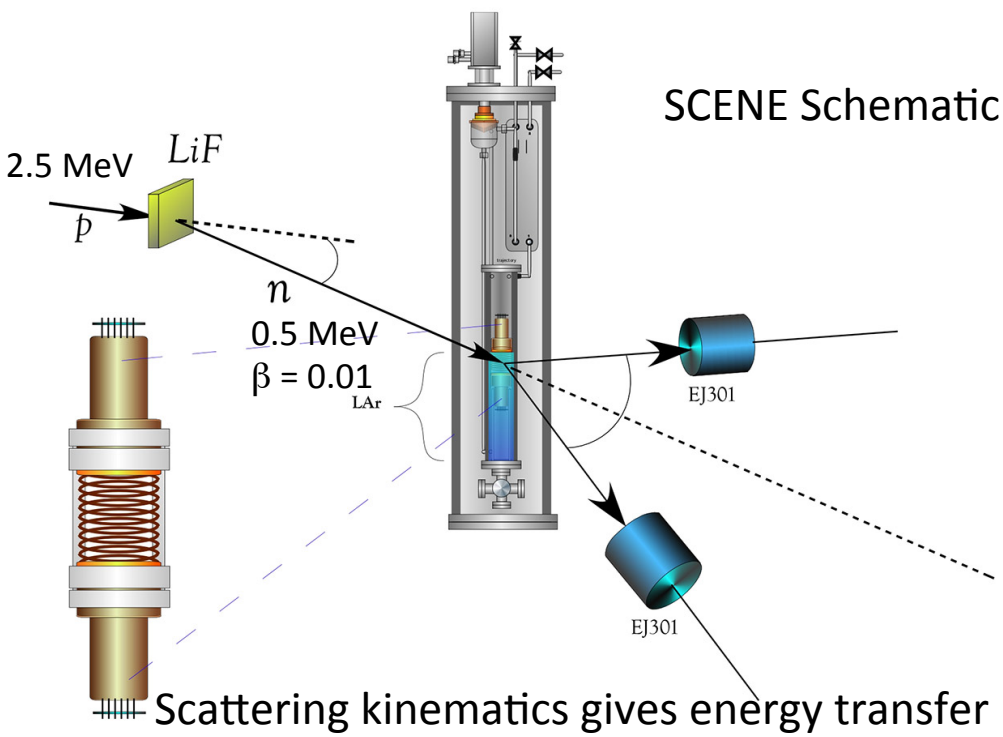
Scintillator Paddle Prototype for LBNE hanging on TallBo lid

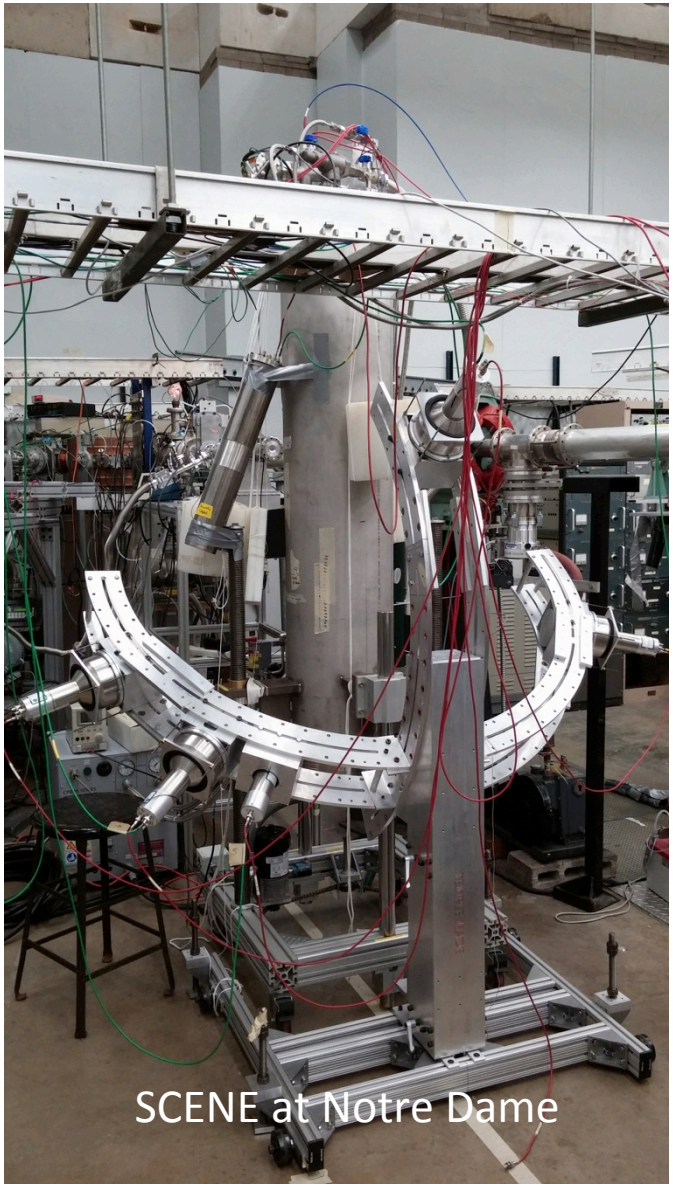
TallBo in operation

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

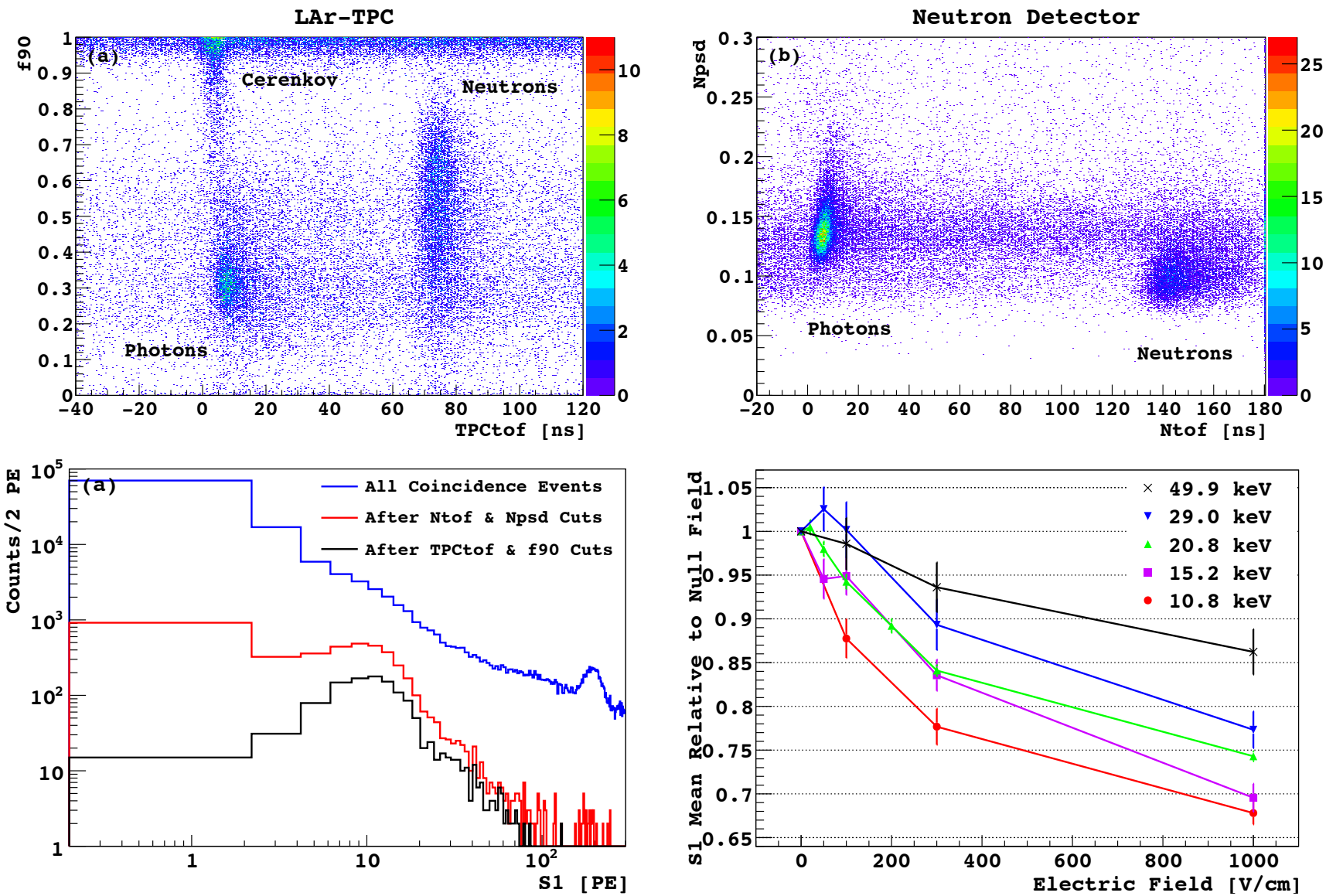
(Chicago, Fermilab, Princeton, Naples, Notre Dame, Temple, UCLA)





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

Less light from nuclear recoils in presence of electric field – **unexpected result & affects optimal operating parameters for argon (and possibly xenon) 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)

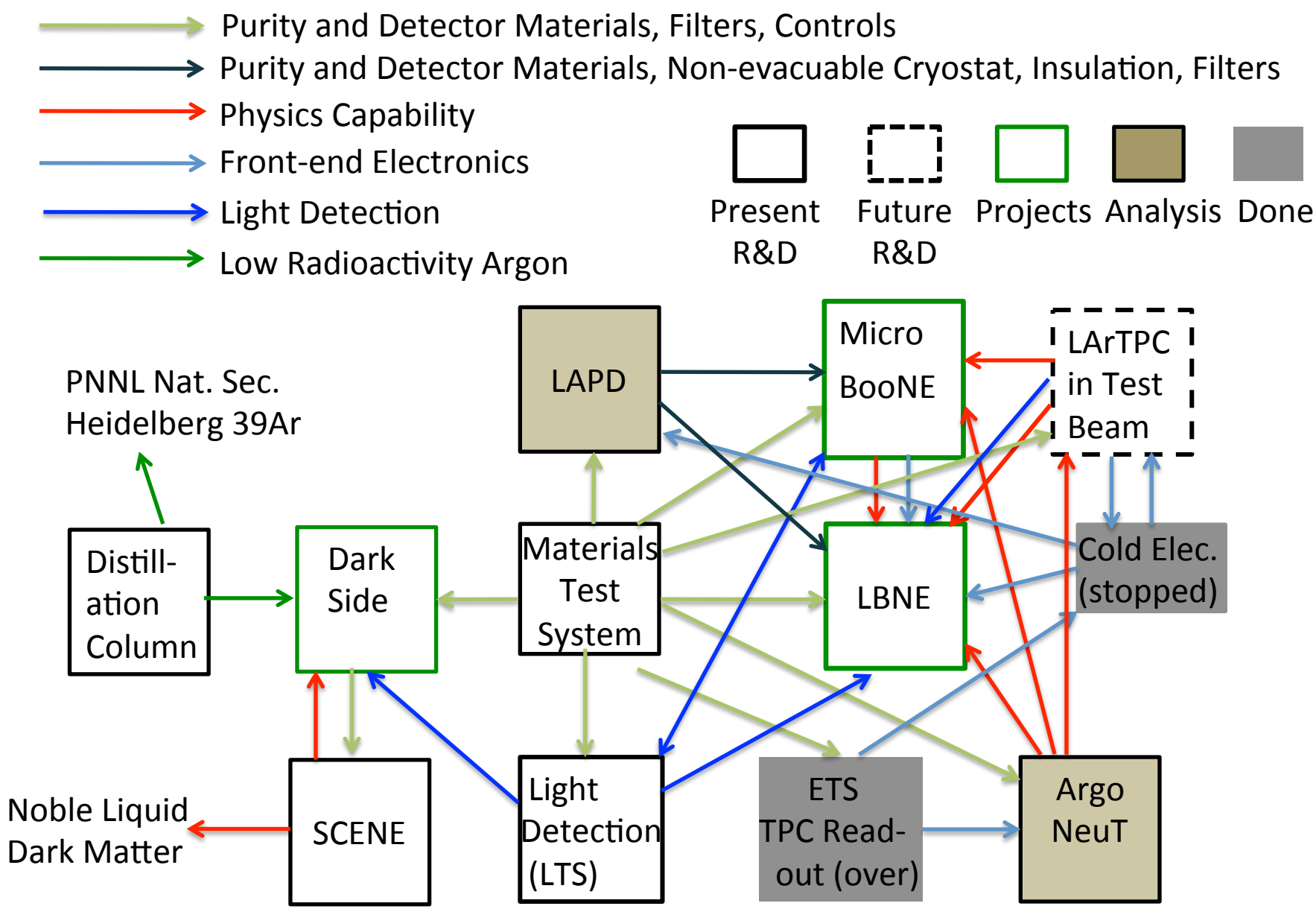
Mixture of ~4% Ar, 6%N_2, 90% He comes to Fermilab; have to distill the N_2 off.

Column commissioned with atmospheric Ar mixture 99.95% pure;

15 kg processed;

Aimed at DarkSide and DEAP

Relationships Between Activities



Summary of Achievements of Liquid Argon R & D program

- In-house production of filtrations systems to produce pure argon (<30 ppt O_2 equivalent)
- Construction of system for measuring effects of materials on electron drift-lifetime without being exposed to vacuum
- Identification of major source of reduction of electron drift-lifetime in clean, tight systems
- Identification of useful analytic equipment (in particular H2O analysers)
- The first U.S. electronics for TPC readout - generation 1 in the warm outside cryostat and then the first CMOS, in liquid, electronics.
- An invaluable set of data from ArgoNeuT (250 kg LAr TPC in NuMI beam)
- In-house experience in construction of multi-ton pure argon production
- Demonstration of many millisecond electron drift-lifetime in an unevacuated, industrial vessel
- In-house experience in construction of HV feed-throughs and measurements on breakdown
- Measurements of effects of contaminants such as Nitrogen and Methane on light transmission
- Measurement of effect of electric field on light and ionization production by recoil argon nuclei (important for dark matter searches using noble liquids (argon & xenon))
- Purification of underground argon for Dark Matter -also National Security and Climate Studies
- Development of new approaches to light detection – both photon collectors and transducers
- Cadre of young physicists with interest and skills in detectors and analysis of data therefrom.
- A work-force - technicians and engineers - with experience and expertise in cryogenics.
- Sliced bread .

Enabling factors:

- ICARUS – showed what was possible
- Benevolent Management
- Significant material funding
- A home
- Highly competent individual personnel

  Resident engineer at the PAB for the first systems

  Resident technical group at the PAB (Leader and 4 technicians)
- Relationships with Universities

  (M.I.T., Michigan State, Princeton, Yale .. and developing more)