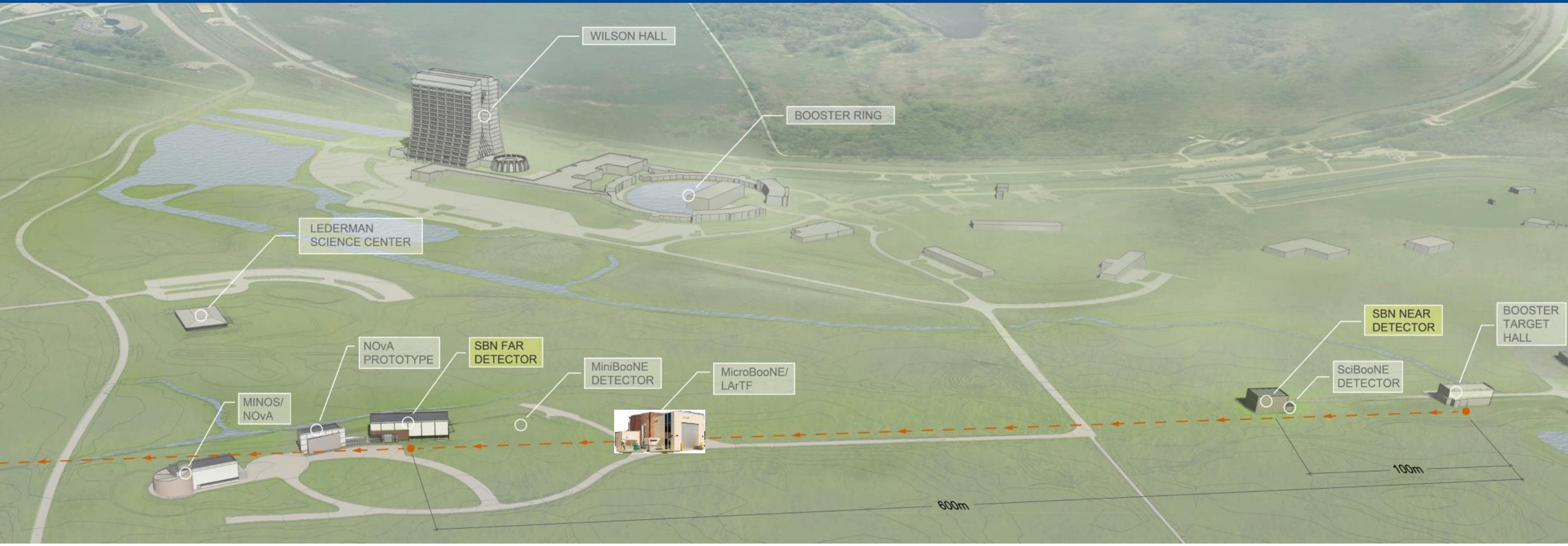

Cryogenics: Experience from MicroBooNE and the DUNE 35-T Prototype

M. Zuckerbrot

Joint DUNE/SBN Meeting: Lessons Learned
Fermilab, 15 May 2017

Presentation Outline

- Modes of Operation
- Cryogenic System Process Flow Diagram
  - Differences between the systems (cooldown, pumps, cryostat…)
- MicroBooNE Experience
  - Lessons from Filling
  - LAr Pump Failure
  - Purity Achieved and System Reliability
- 35T Experience
  - Recirculation Vapor Pump Failure
  - Cooldown
  - Chimney Vapor Pump
  - Internal LAr Pumps
  - Purity Stratification and Maintenance
- Summary

Modes of Operation

- Piston Purge
  - Achieves ppm levels of contaminants
  - Purity dependent on cryostat contents and geometry, flow velocity and routing etc.
  - Balance of minimizing turbulence and overcoming back diffusion
- Gas recirculation
  - Achieves ppb levels of H2O and O2
  - Purity dependent on cryostat contents (outgassing) and volume change rate
  - Troubleshooting for leaks - unfiltered contaminants rise due to outgassing
- Cooldown
  - Slowly cool detector/cryostat to ~100 K
- Liquid Purification
  - Scientific requirement of 3 ms

MicroBooNE PFD

- Cryostat ASME pressure vessel (vacuum – 30 psig)
- Redundant filters, pumps, condensers
- Cooldown/gas recirculation system (not shown) consisted of compressor and LN2 cooled heat exchanger

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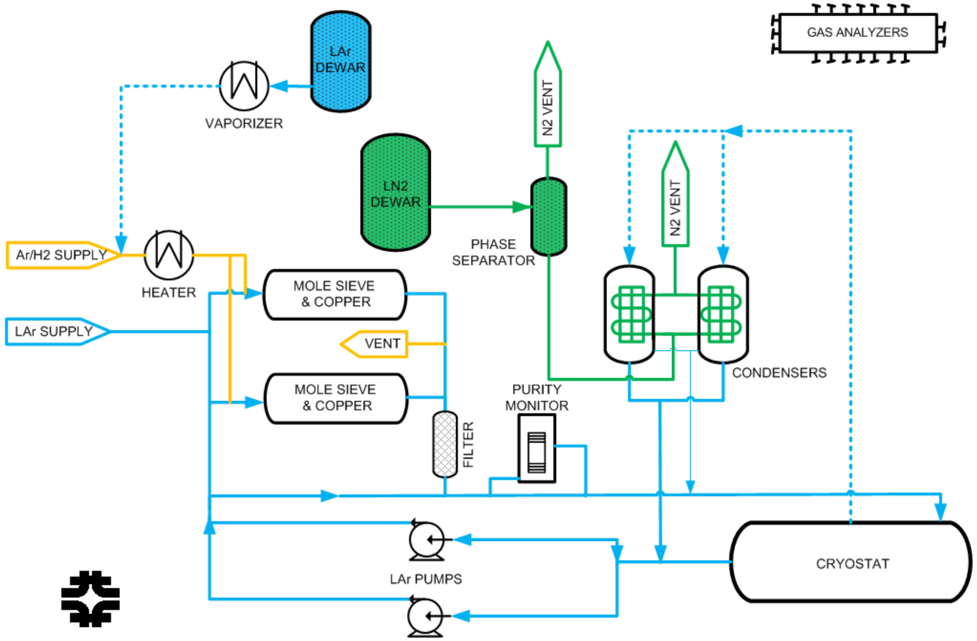
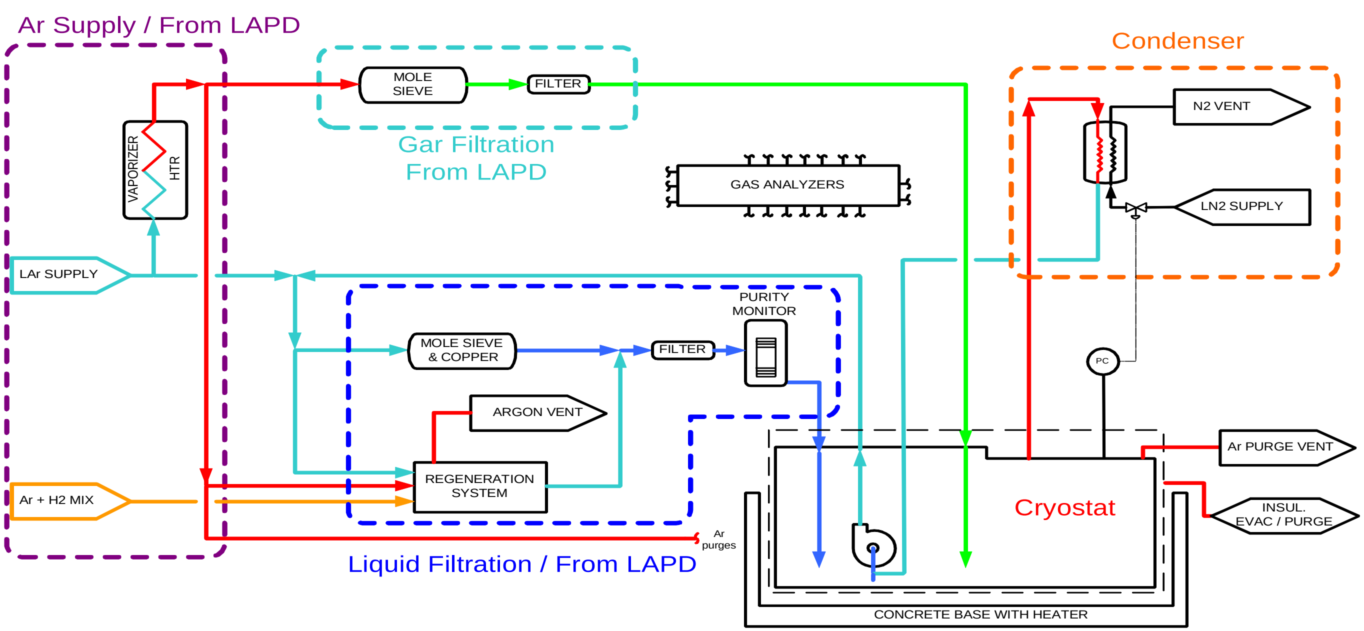


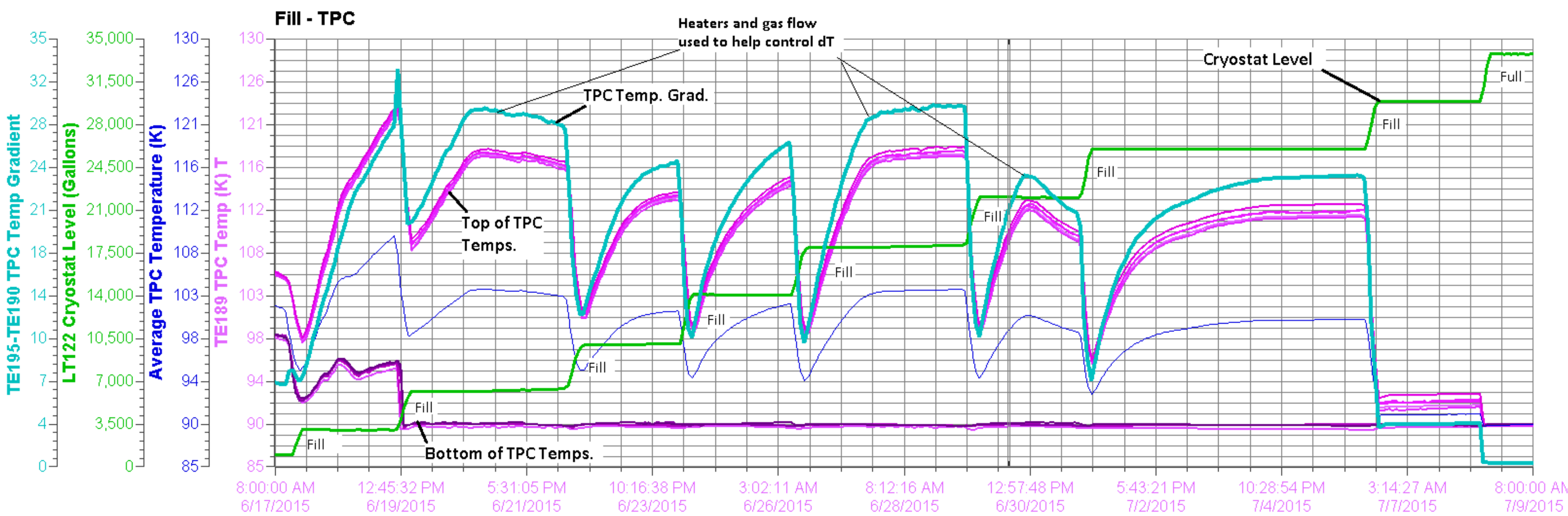
35T PFD

- Membrane cryostat (3 psig)
- Redundant submersible LAr pumps
- Cooldown/gas recirculation system (not shown) consisted of separate compressor and LAr/Gar atomization and momentum nozzles internal to the cryostat



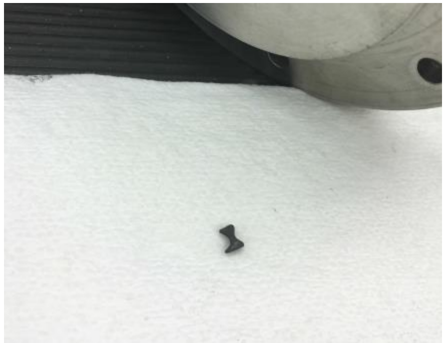
MicroBooNE Experience – Lessons from Filling

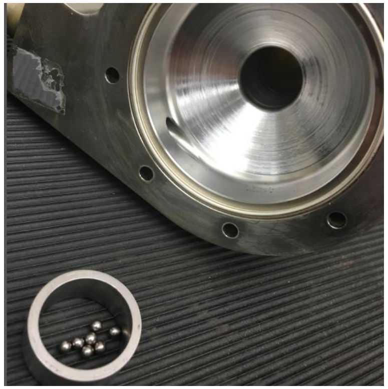
- Contractual issues: Vendors hesitant to sign contract due to tight N2 requirements and aggressive schedule
- Temperature gradients develop when liquid level is low
  - Controlled with shell heaters and bottom-up gas flow to increase convection in the ullage

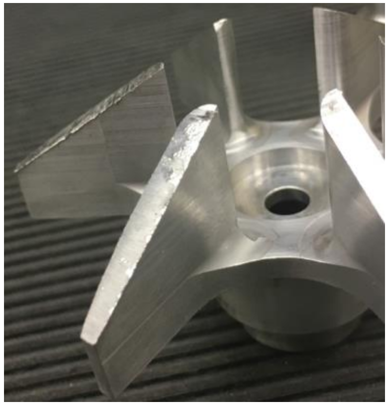


MicroBooNE Experience – LAr Pump Failure

- Barber Nichols LAr Pumps
  - Startup: Difficult to start without first bypassing the filters then slowly cooling them, likely amplified by downstream throttle valve
- LAr Pump Bearing Failure
  - Detected audibly
  - Lower cold bearing (cage)
  - ~6000 hours of operation
  - Possible cause: Prior failure of discharge pressure transmitter caused pump to ramp up/down for several hours
  - Likely caused cavitation and shortened bearing life

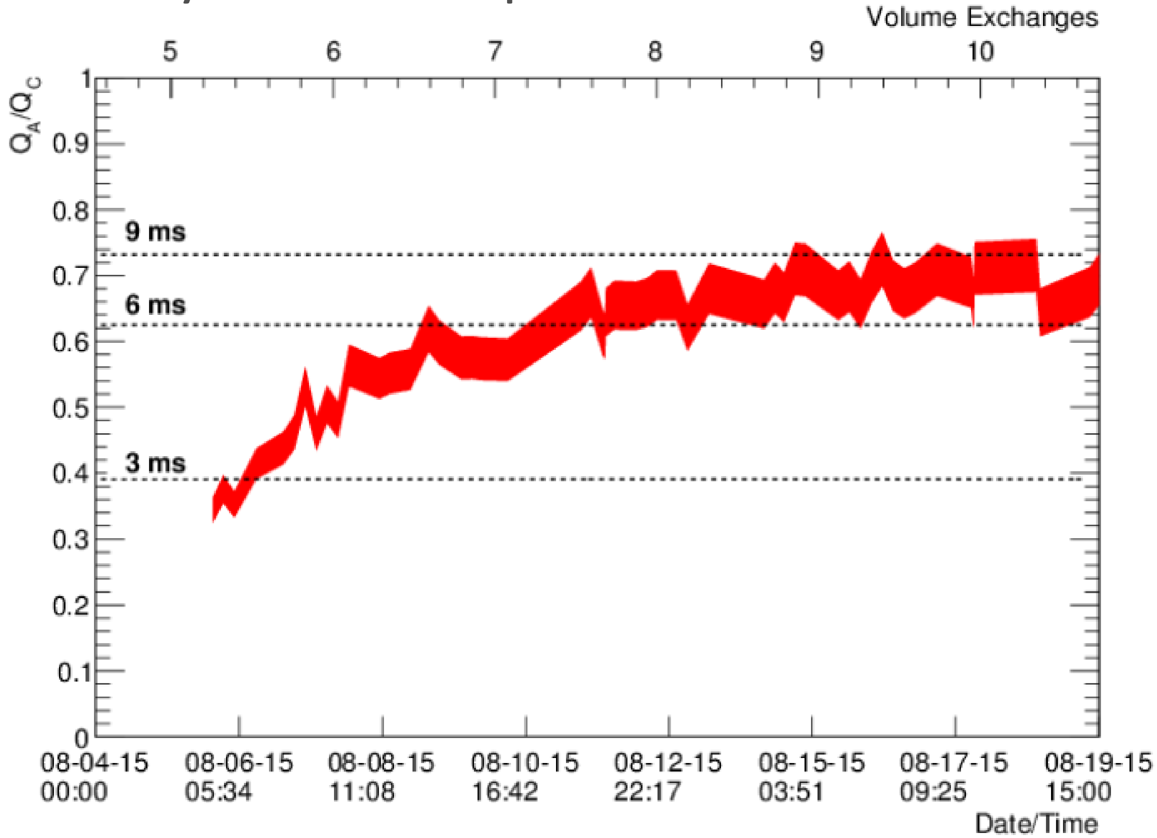






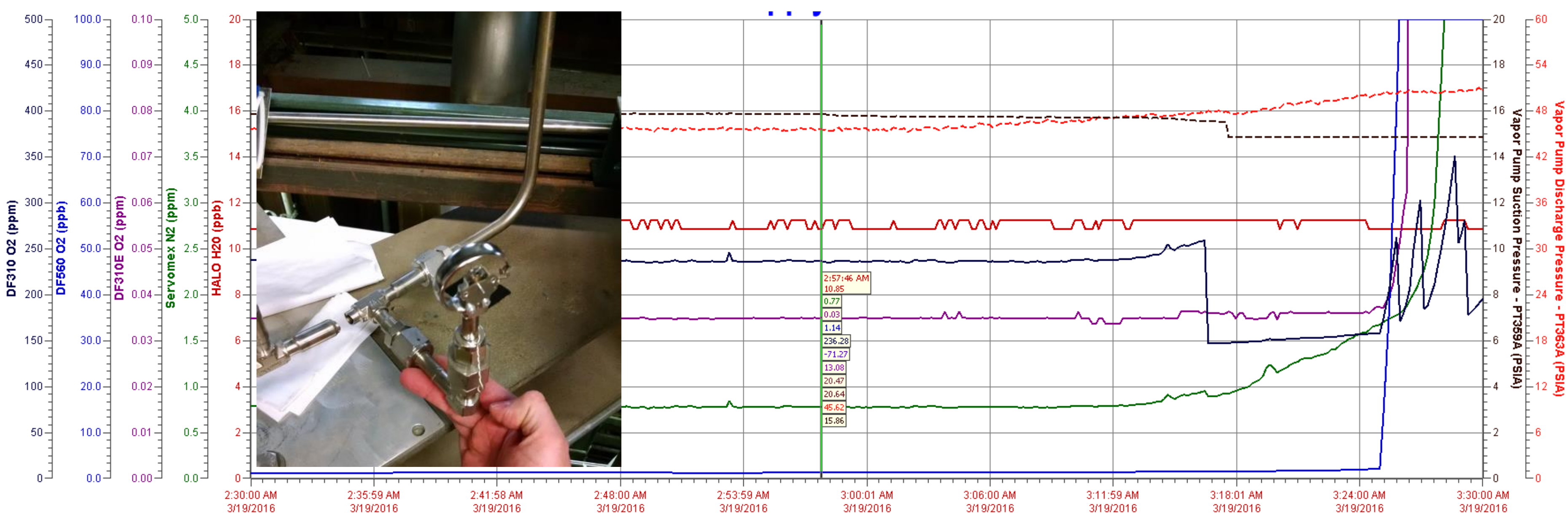
MicroBooNE Experience – Purity and System Reliability

- Cryostat filled without filtering – purity acceptable in < 1 week
- Electron Lifetime: Currently > 9 ms
- System Reliability: > 98.9% up time



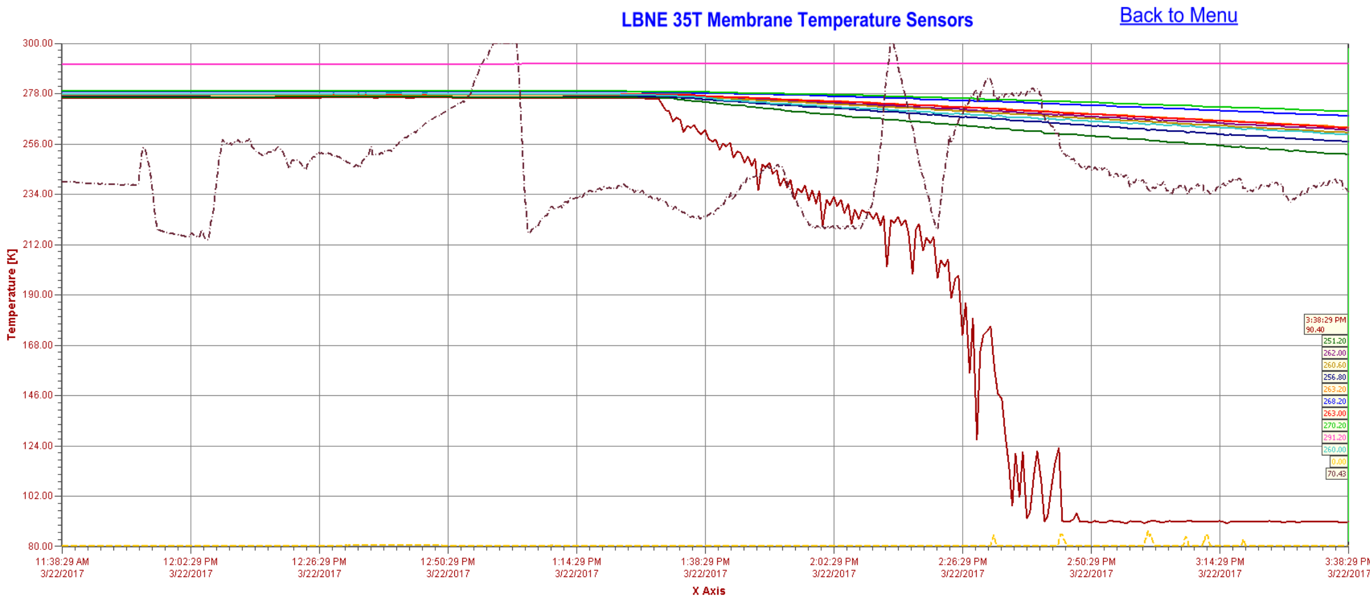
35T Experience – Recirculation Vapor Pump Failure

- Tubing on compressor suction sheared from vibration
- Gas analyzers sampling from ullage space
- Filters saturate, see response from analyzers within 20 minutes
- Complete loss within 30 minutes ending the (previous) run
- Doesn’t take much contamination to spoil total load of argon



35T Experience – Cooldown

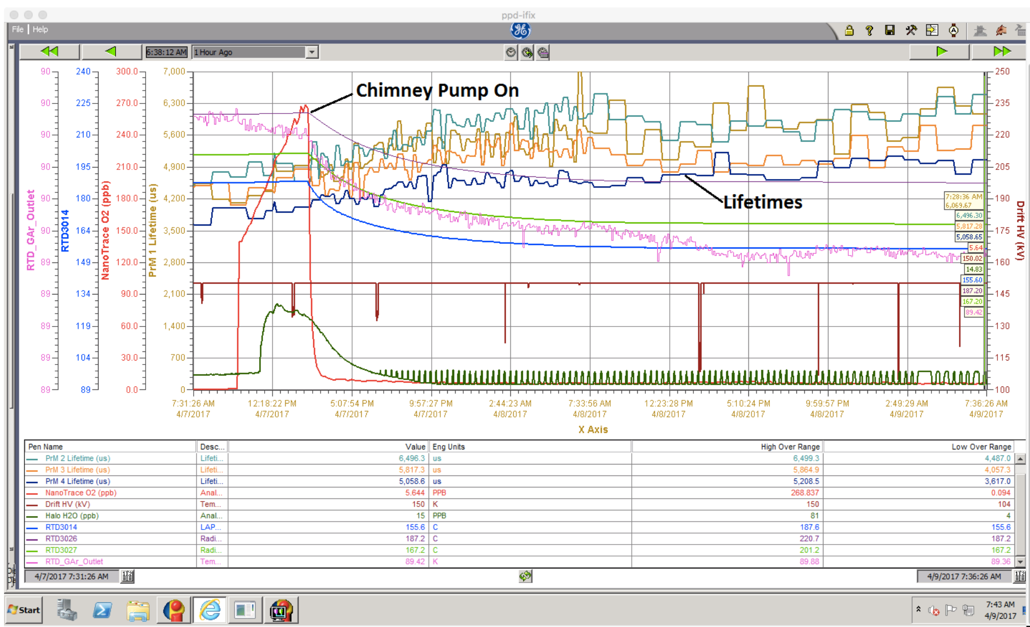
- LAr pooled under nozzles even after phase 2 piping modifications
- Heaters installed but decommissioned for technical reasons
- Adds minimal contaminants
- Possibly due to low inlet pressure to nozzles

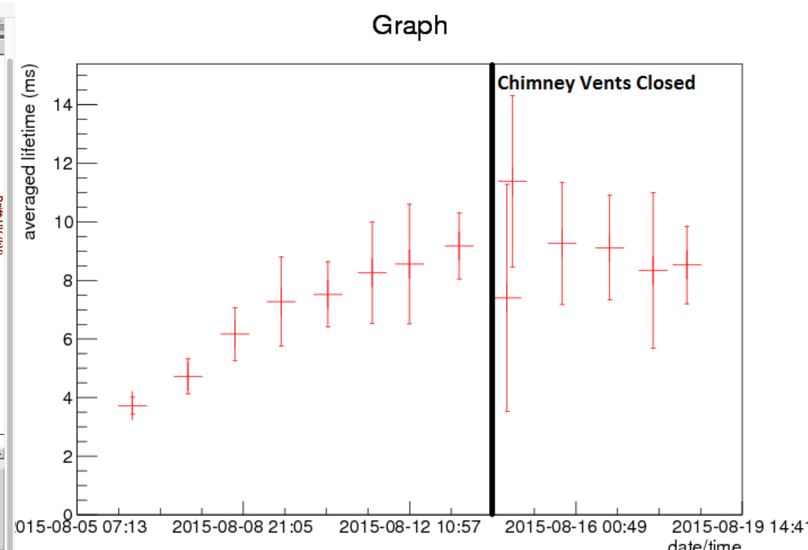


Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range
PC4_S1.TE3005A.F_CV	LAPD tank (midpoint (F_CV)	260.60	C	277.60	260.60
PC4_S1.TE3006A.F_CV	LAPD tank (base) (F_CV)	256.80	C	277.20	256.80
PC4_S1.TE3007A.F_CV	LAPD tank (base) (F_CV)	263.20	C	277.40	263.20
PC4_S1.TE3008A.F_CV	LAPD tank (base) (F_CV)	268.20	C	278.60	268.20
PC4_S1.TE3009A.F_CV	LAPD tank (midpoint) (F_CV)	263.00	C	277.80	263.00
PC4_S1.TE3014A.F_CV	LAPD tank (midpoint) (F_CV)	270.20	C	279.20	270.20
PC4_S1.TE3015A.F_CV	LAPD tank (base) (F_CV)	291.20	C	291.20	290.60
PC4_S1.TE3016A.F_CV	LAPD tank (top - L) (F_CV)	260.00	C	278.20	260.00
PC4_S1.LT3333A.F_CV	LBNE condenser liquid level instrumentat (F_CV)	0.00	N/A	0.05	0.00
PC4_S1.PT266A.F_CV	argon utility gas	70.43	psig	102.92	60.94

35T Experience – Chimney Vapor Pump

- Can actively pull gas from the chimneys/ullage
  - Goal of reducing contaminants from the gas to liquid
- Never activated at MicroBooNE though chimneys were vented
- Minimal effect seen at 35T, venting possibly helped at MicroBooNE
  - Difference likely due to uBooNe's angled chimneys

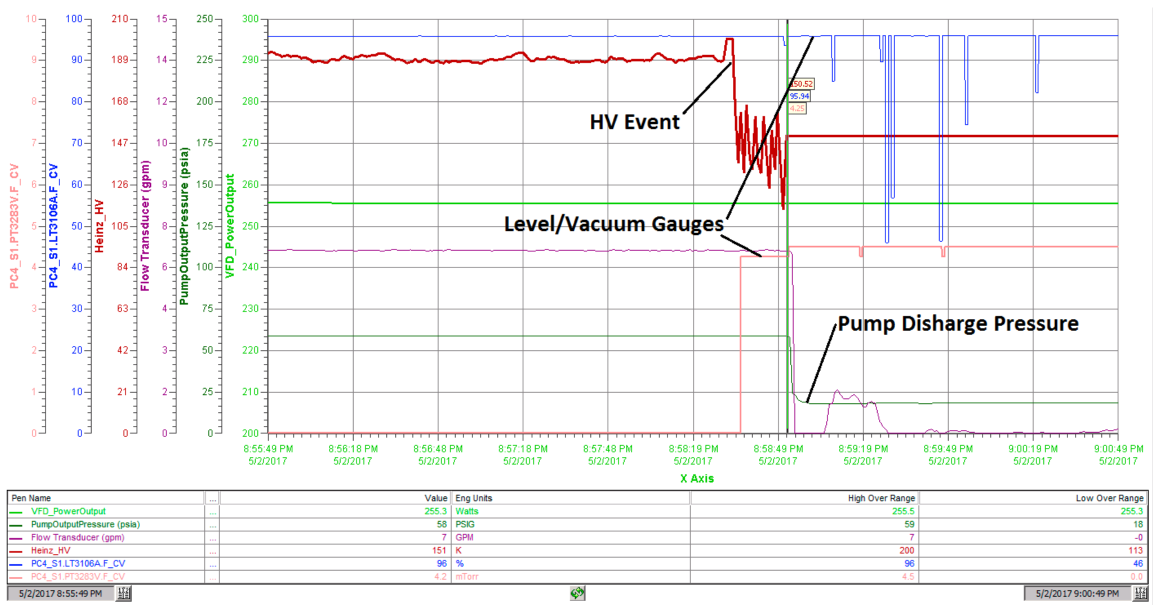




uBooNE

35T Experience – Internal LAr Pumps

- ACD submersible AC32 Pumps
- Two main issue seen
  - 1) During last two runs found to be seized after fill
    - Controls group bypassed fast acting fuses with disconnect fuses and installed simple ON/OFF switch to bump motor several times
  - 2) High voltage event likely caused pump to trip ending this run



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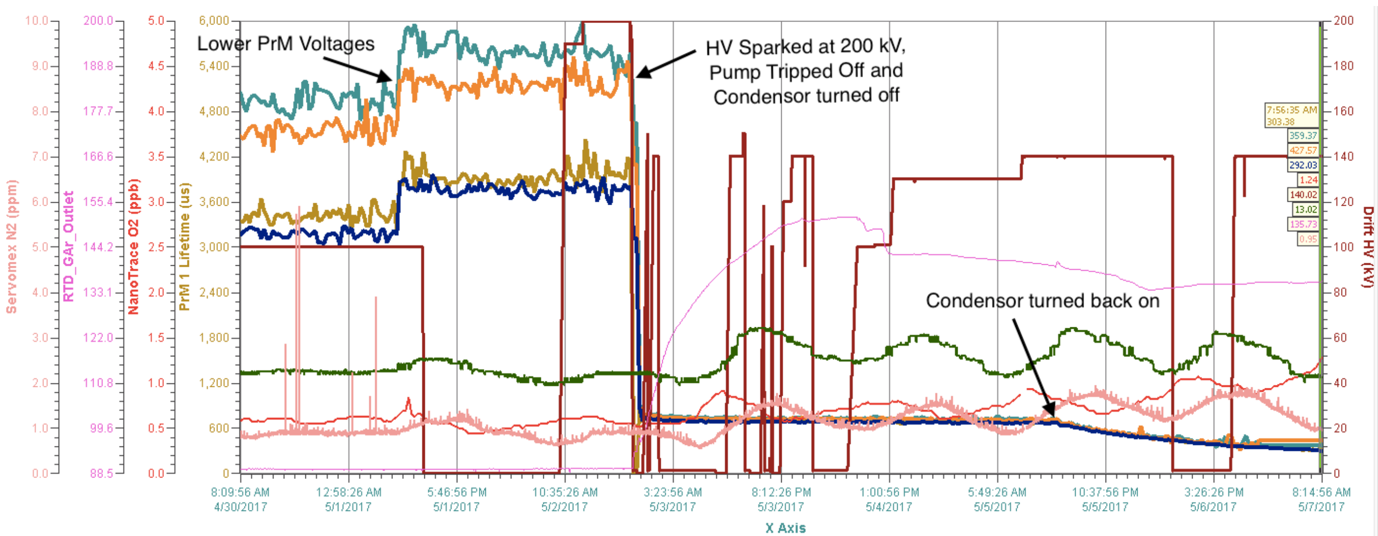
35T Experience – Purity Maintenance

- Purity degrades rapidly when liquid circulation is interrupted
- Can be slowed down by a couple methods
  - 1) Shutting down cooling and allowing argon to vent
  - 2) Controlling the turbulence of return boil off from piping



Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range
PrM 1 Lifetime (us)	Lifetime calculated from AnodeTrue CathodeTr...	303.4	us	4,427.8	0.0
PrM 2 Lifetime (us)	Lifetime calculated from AnodeTrue Ca...	359.4	us	5,998.3	332.7
PrM 3 Lifetime (us)	Lifetime calculated from AnodeTrue CathodeTr...	427.6	us	5,529.2	292.9
PrM 4 Lifetime (us)	Lifetime calculated from AnodeTrue CathodeTr...	292.0	us	3,961.6	287.4
NanoTrace O2 (ppb)	Analyzer Delta F NanoTrace O2 (F_CV)	1.238	PPB	1.273	0.438
Drift HV (kV)	Temperature of the top RTD (#1) on spooler #1	140	K	200	0
Halo H2O (ppb)	Analyzer Halo H2O (F_CV)	13.0	PPB	19.2	11.6
RTD_GAr_Outlet	Temperature of the middle RTD (#2) on spoole...	135.73	K	151.78	88.78
Servomex N2 (ppm)	Analyzer Servomex N2 (F_CV)	1.0	PPM	5.9	0.5

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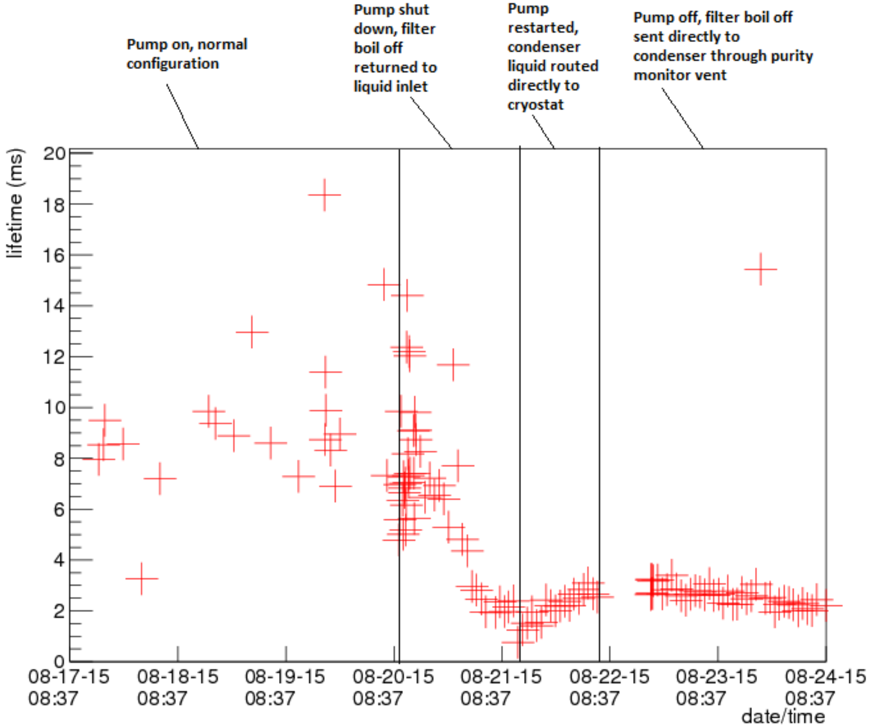
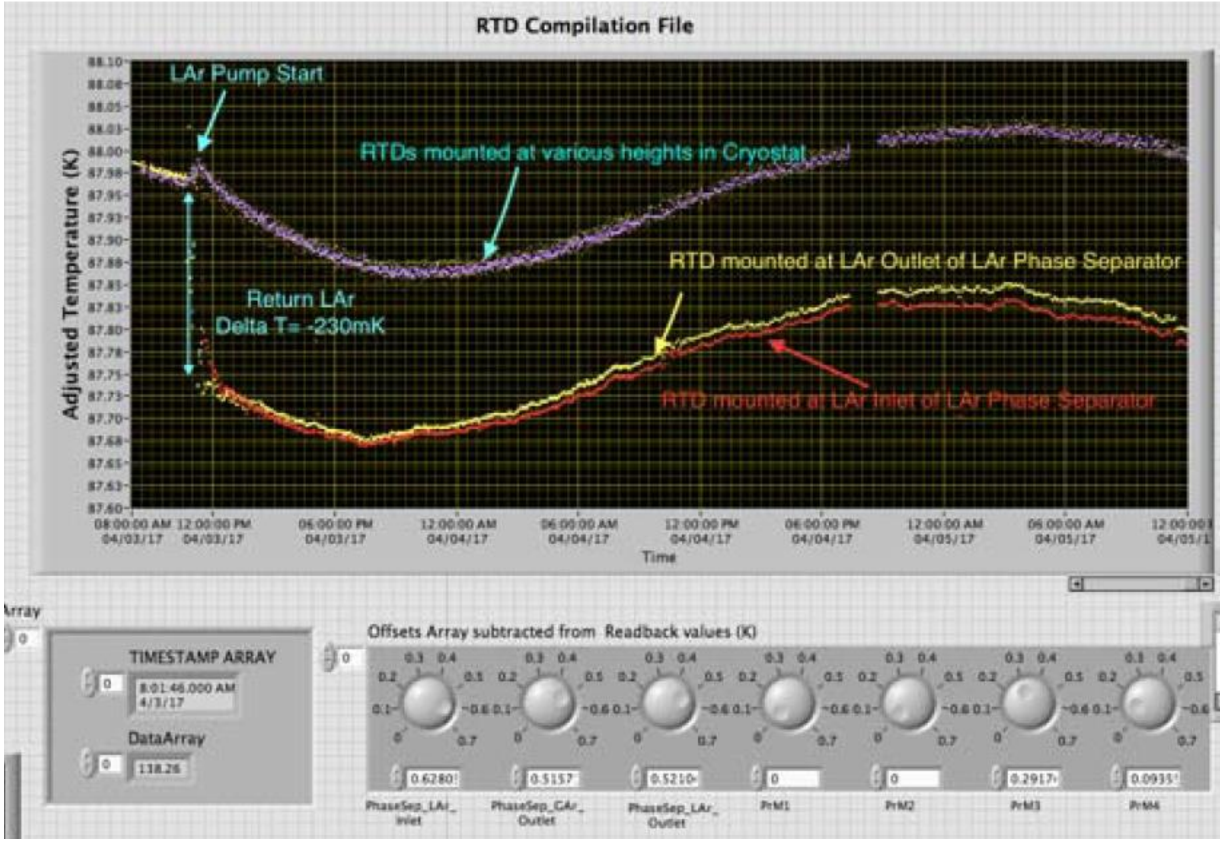
35T Experience – Purity Maintenance

- Purity degrades rapidly when liquid circulation is interrupted
- Can be slowed down by a couple methods
  - 1) Shutting down cooling and allowing argon to vent
  - 2) Controlling the turbulence of return boil off from piping



35T Experience – Purity Stratification

- Underlying issue is temperature stratification
- Liquid returning to the cryostat is at saturation temperature
  - Colder than the bulk liquid by ~230 mK



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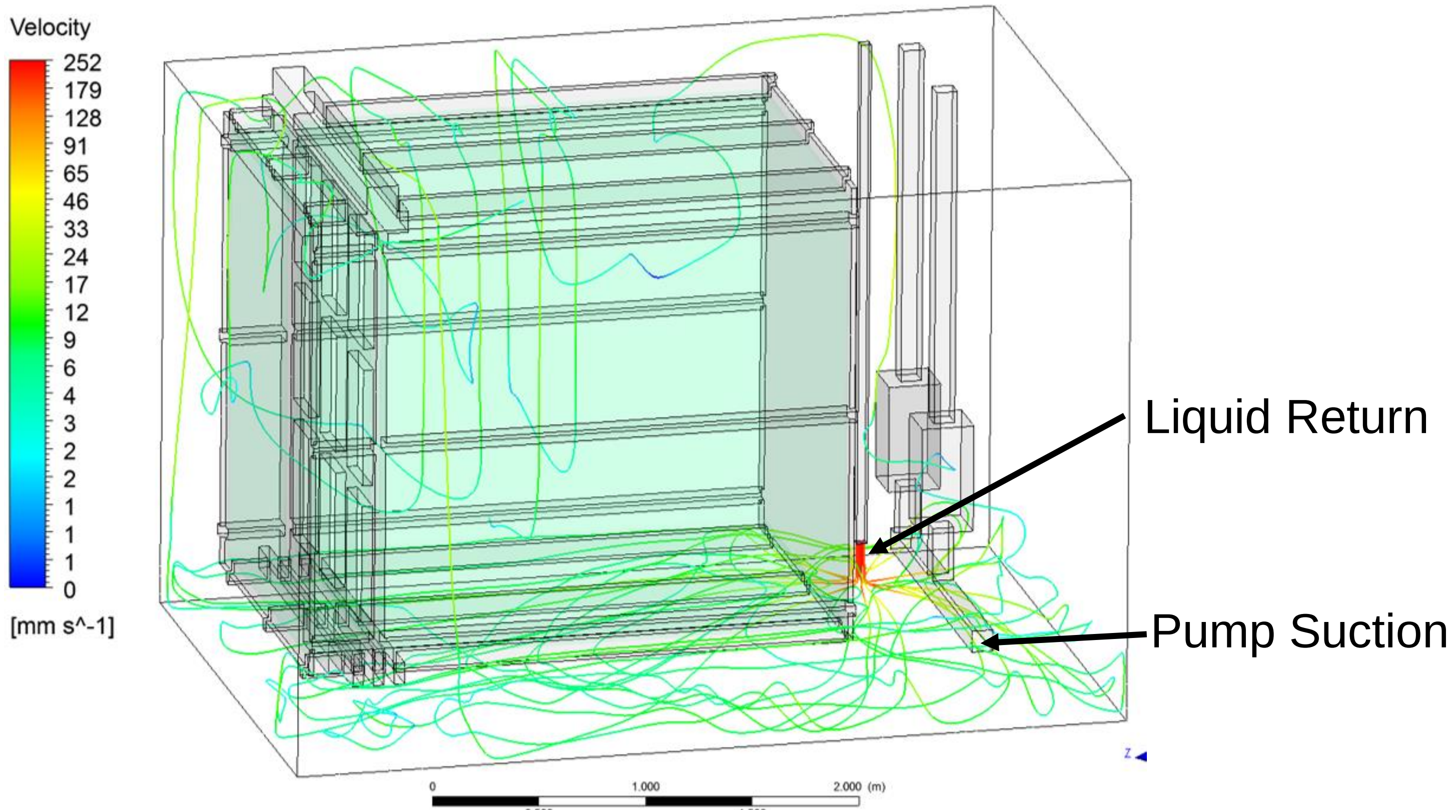
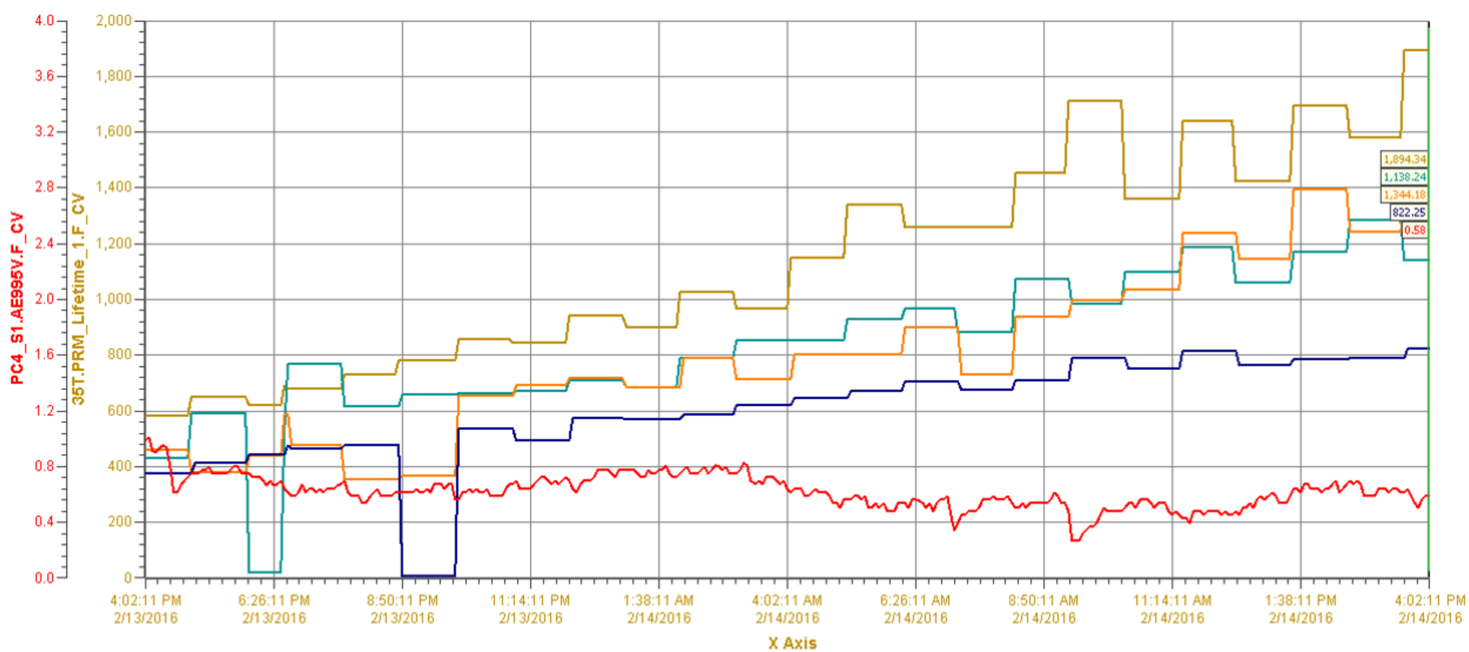
35T Experience – Purity Stratification

- CFD (E. Voirin) produced to study stratification seen in phase 2
- Return liquid injected at bottom near pump suction
- Produces minimal mixing of the bulk liquid



35T Experience – Purity Stratification

- Purity monitors mounted in the corner of the vessel distributed vertically (shorts on the top/bottom, longs in center)
- Vertical stratification can be seen as soon as purification begins



Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range
35T.PRM_Lifetime_1.F_CV	Lifetime calculated from AnodeTrue Cat...	1,894.3	us	1,894.3	578.2
35T.PRM_Lifetime_2.F_CV	Lifetime calculated from AnodeTrue Cat...	1,138.2	us	1,281.4	15.0
35T.PRM_Lifetime_3.F_CV	Lifetime calculated from AnodeTrue Cat...	1,344.2	us	1,393.3	352.6
35T.PRM_Lifetime_4.F_CV	Lifetime calculated from AnodeTrue Cat...	822.2	us	822.2	1.6
PC4_S1.AE995V.F_CV	Analyzer Delta F NanoTrace O2 (F_CV)	0.582	PPB	1.005	0.257

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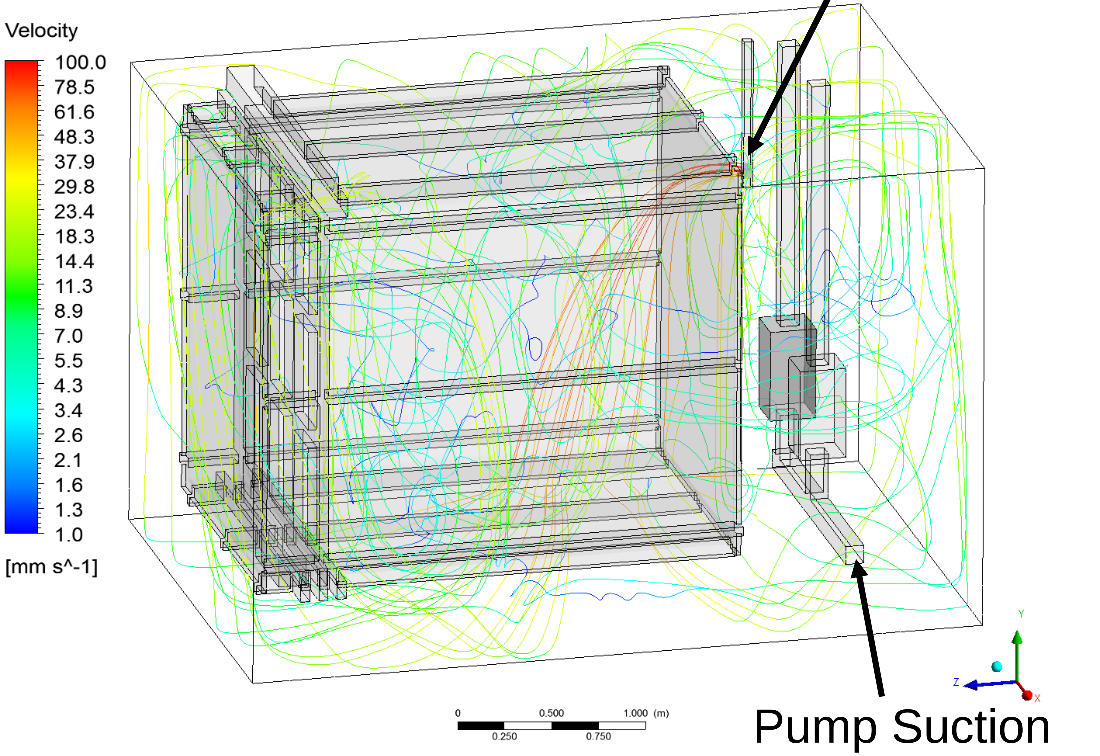
35T Experience – Purity Stratification

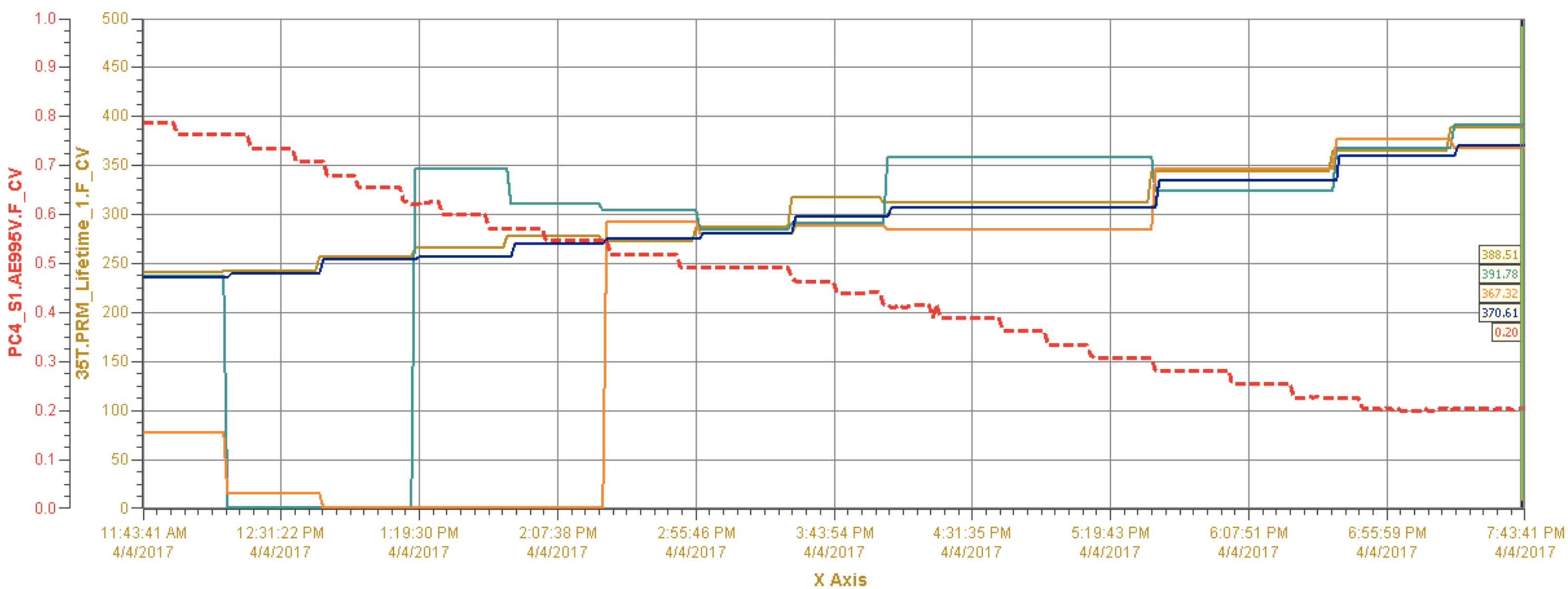
- In most recent run liquid return line modified to sit at about 2/3 elevation of the tank (closer to the uBooNE setup)
  – Angled to face aisle way between membrane and field cage
- CFD predicted far better mixing

Liquid Return



35T Experience – Purity Stratification

- Stratification noticeably improved
- Likely can be improved more if the return pipe was modified to just under top of liquid level and moved to opposite side than pumps



Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range
35T.PRM_Lifetime_1.F_CV	Lifetime calculated from AnodeTrue Cat...	388.5	us	388.5	240.7
35T.PRM_Lifetime_2.F_CV	Lifetime calculated from AnodeTrue Cat...	391.8	us	391.8	0.0
35T.PRM_Lifetime_3.F_CV	Lifetime calculated from AnodeTrue Cat...	367.3	us	377.3	0.0
35T.PRM_Lifetime_4.F_CV	Lifetime calculated from AnodeTrue Cat...	370.6	us	370.6	235.5
PC4_S1.AE995V.F_CV	Analyzer Delta F NanoTrace O2 (F_CV)	0.203	PPB	0.788	0.199

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Summary

- Purity Achieved
  - uBooNE: > 9 ms
  - 35T: > 4.5 ms in most recent run
  - Differences likely dominated by 35T warm top plate and liquid return as well as run duration
- MicroBooNE
  - Filling is largest source of thermal gradients, can be controlled by increasing convection
  - Contracts for LAr supply can be an issue
- 35T
  - Chimney vapor pump has minimal contribution on purity
  - Internal submersible pumps can be problematic
  - During downtime purity degradation can be slowed by controlling routing of liquid boil off
  - Purity stratification can be controlled by liquid return location
    - Good to have it on opposite side of pumps, top fill if liquid returns colder
- Questions?