35 Ton Run 2 Cryo (+Drift HV) Overview

Alan Hahn

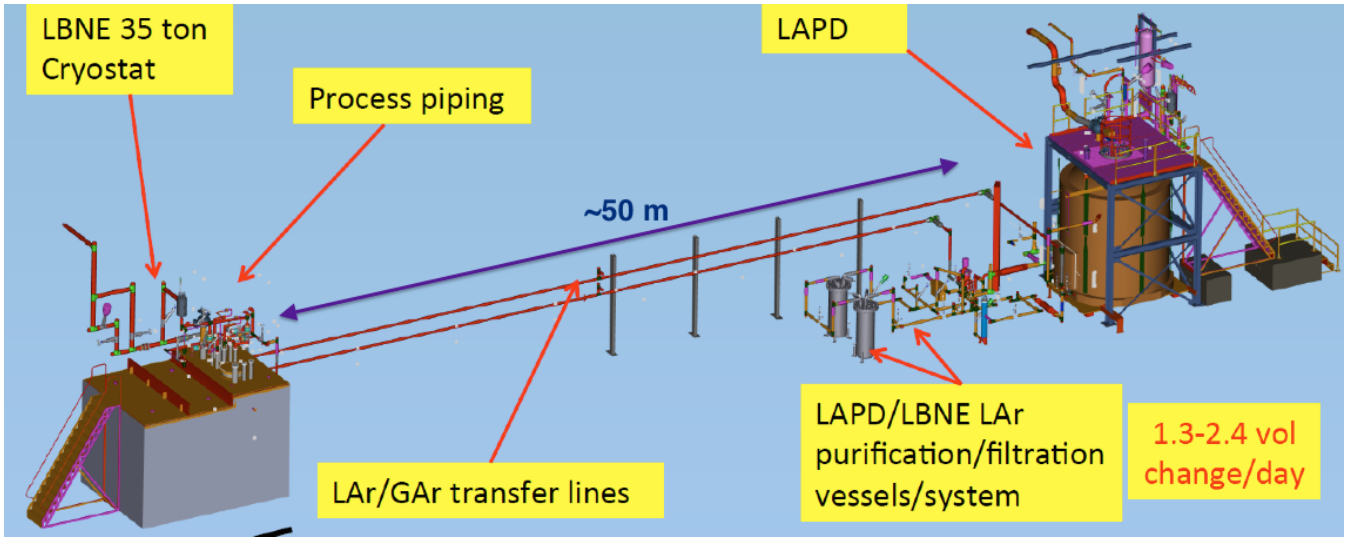
Organization

- Cryo Operations
  - Cryo Timeline
- HV Operations

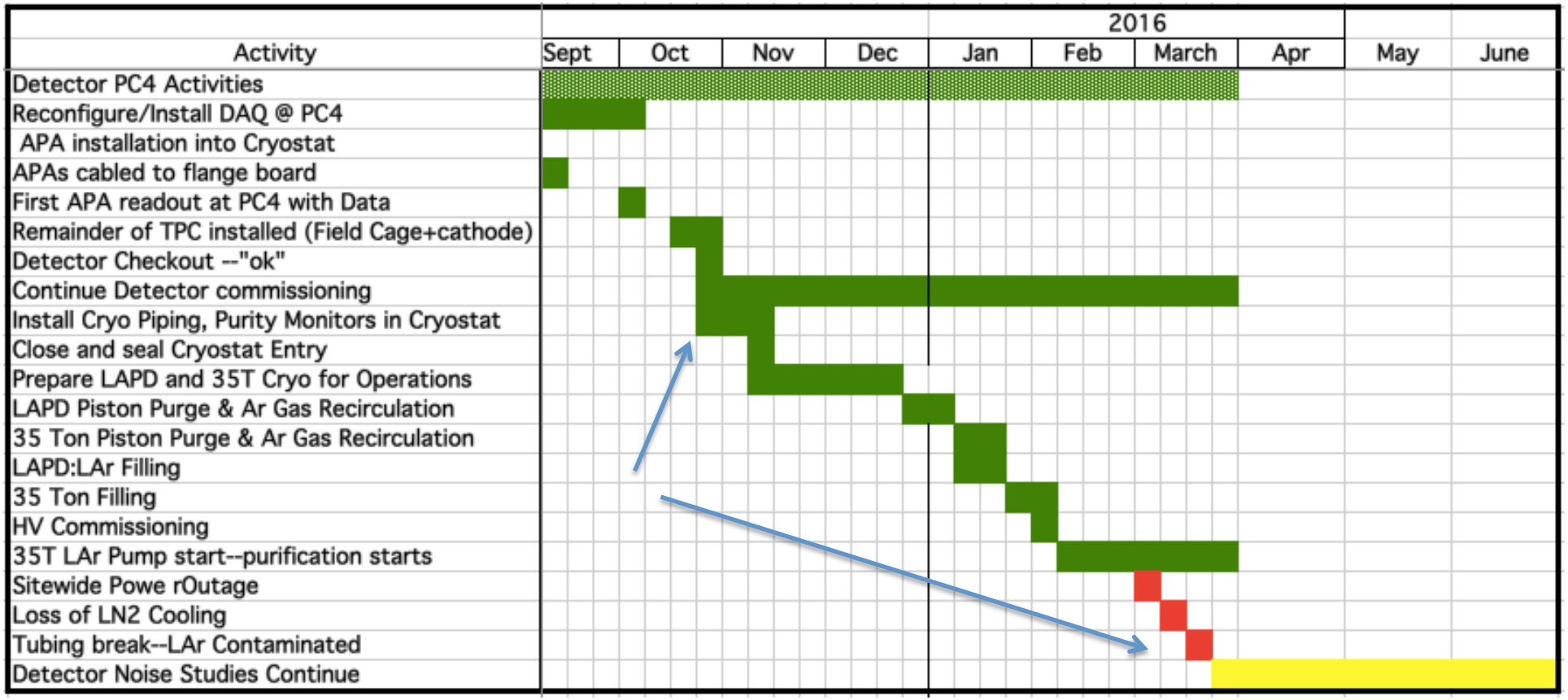
Cryo Operations

- Use LAPD Cryostat as a storage Dewar for LAr Deliveries from vendor
  - LAPD can supply 35T with ~70% of needed LAr
  - One last vendor delivery into LAr Trailer and then directly into 35 Ton.
- All LAr into 35T passes first through filtration system
  - Measurements with inline Purity Monitor during this fill show the filtered LAr to have e^- lifetimes in ~30 ms range—very pure)
- Normal 35 Ton operation circulates the LAr from 35T cryostat, to filtration and back to 35 Ton.
  - ~2.5 volumes/day (~10 gal/minute)

35Ton and LAPD at PC4

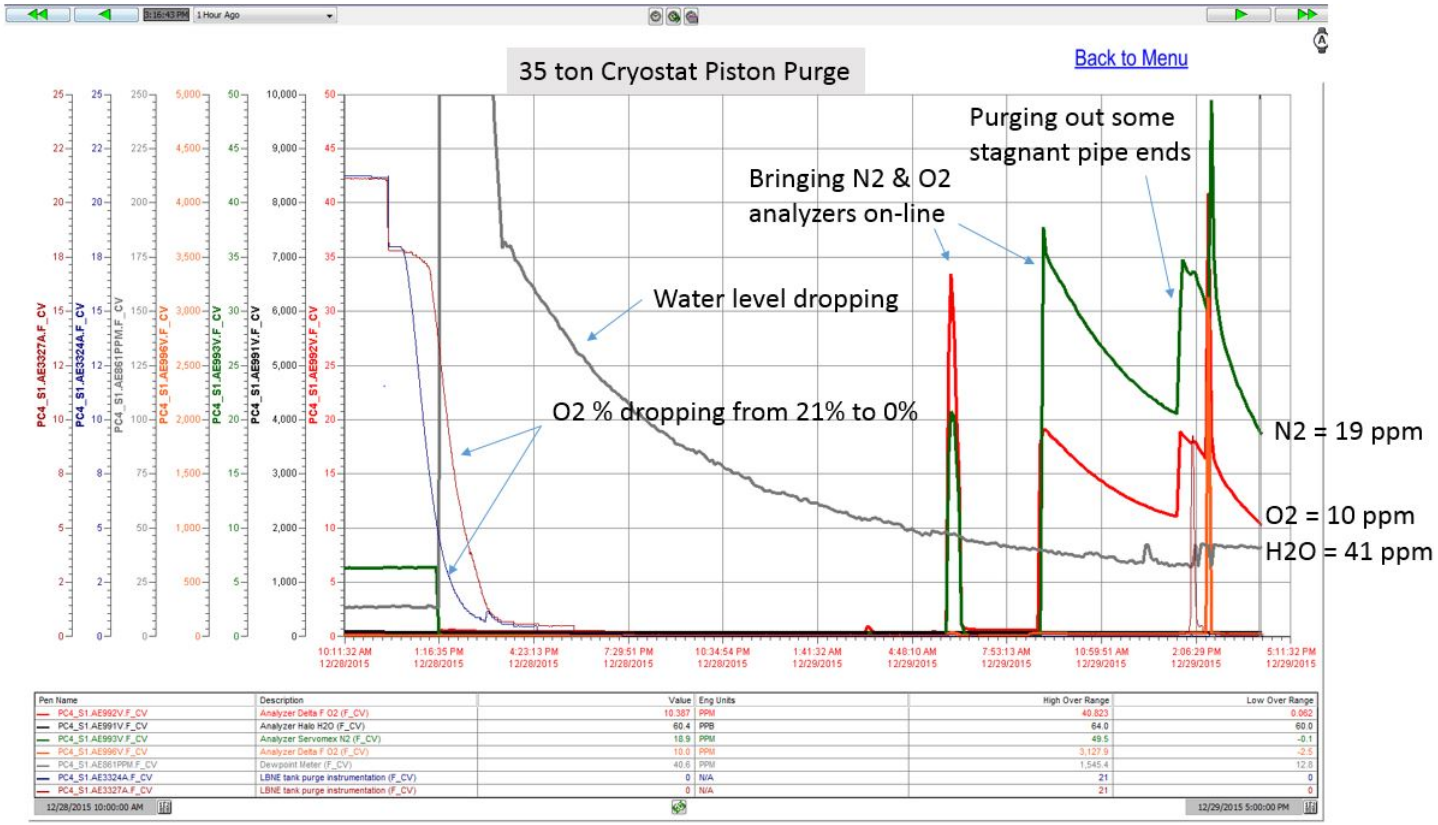


Cryo Time Line

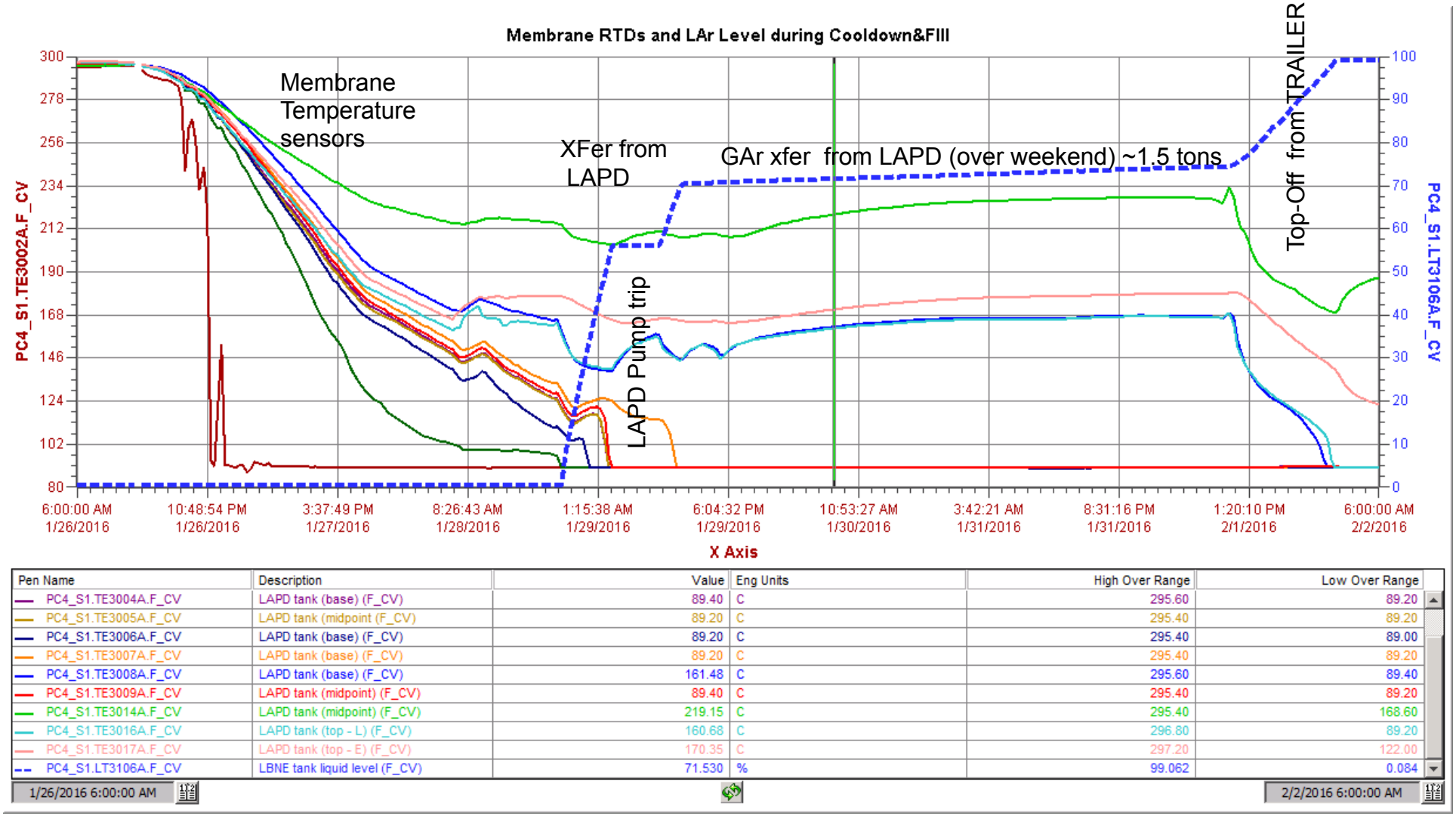


Piston Purge and Ar Recirculation

- Piston Purge removes ambient air by flowing Ar gas into bottom of cryostat
  - Argon flow is higher than diffusion, so as level rises in cryostat, the air being lighter is displaced upward and vented to atmosphere.
- After levels are in the ~10 ppm level (few days), we change from flowing GAr and venting to recirculating the GAr in cryostat through the purification filters to remove the O_2 and H_2O (at ~ppm level) (few weeks)



Run: 35T Cooldown and Filling



Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range
PC4_S1.TE3004A.F_CV	LAPD tank (base) (F_CV)	89.40	C	295.60	89.20
PC4_S1.TE3005A.F_CV	LAPD tank (midpoint (F_CV)	89.20	C	295.40	89.20
PC4_S1.TE3006A.F_CV	LAPD tank (base) (F_CV)	89.20	C	295.40	89.00
PC4_S1.TE3007A.F_CV	LAPD tank (base) (F_CV)	89.20	C	295.40	89.20
PC4_S1.TE3008A.F_CV	LAPD tank (base) (F_CV)	161.48	C	295.60	89.40
PC4_S1.TE3009A.F_CV	LAPD tank (midpoint) (F_CV)	89.40	C	295.40	89.20
PC4_S1.TE3014A.F_CV	LAPD tank (midpoint) (F_CV)	219.15	C	295.40	168.60
PC4_S1.TE3016A.F_CV	LAPD tank (top - L) (F_CV)	160.68	C	296.80	89.20
PC4_S1.TE3017A.F_CV	LAPD tank (top - E) (F_CV)	170.35	C	297.20	122.00
PC4_S1.LT3106A.F_CV	LBNE tank liquid level (F_CV)	71.530	%	99.062	0.084

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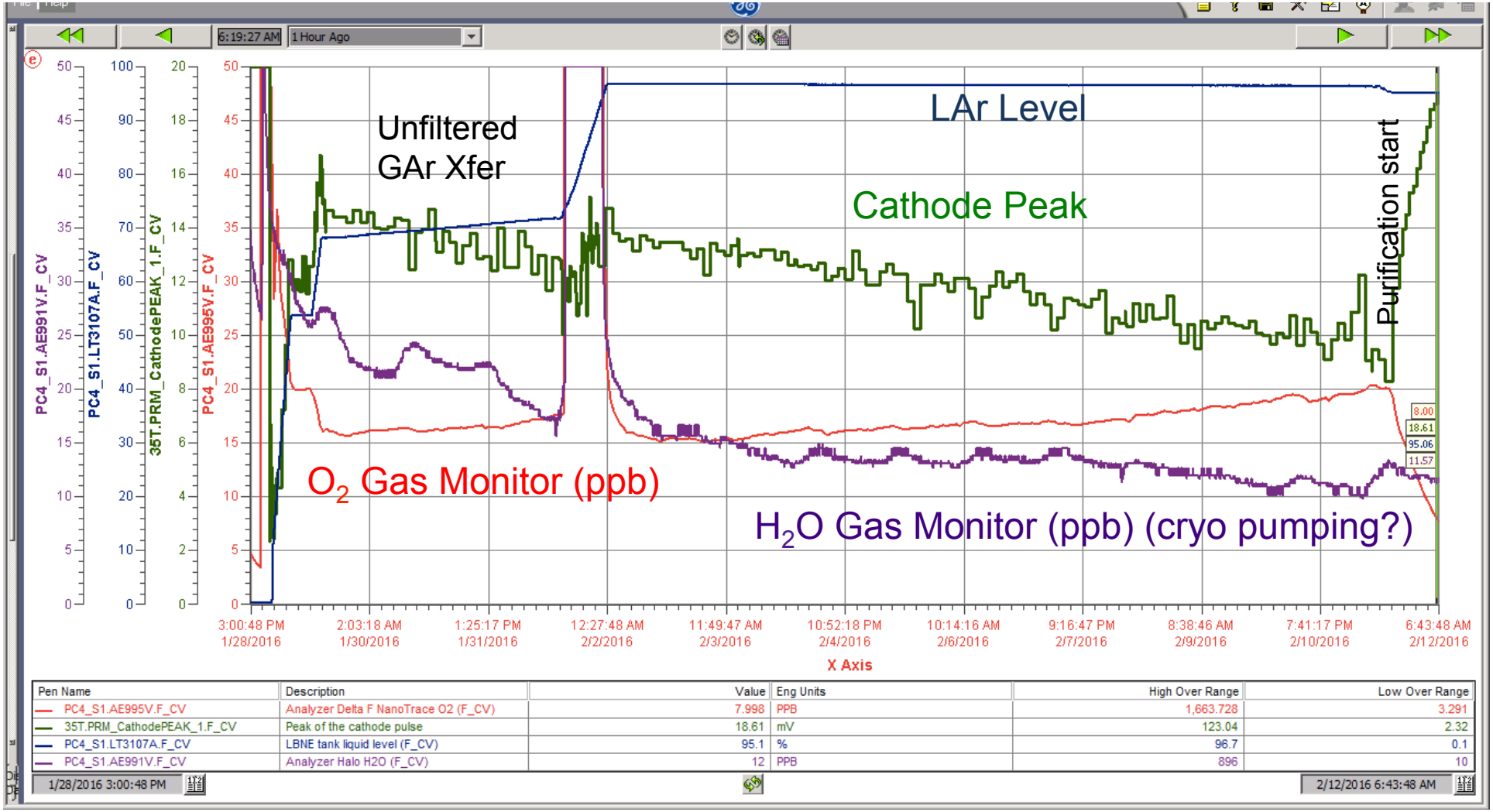
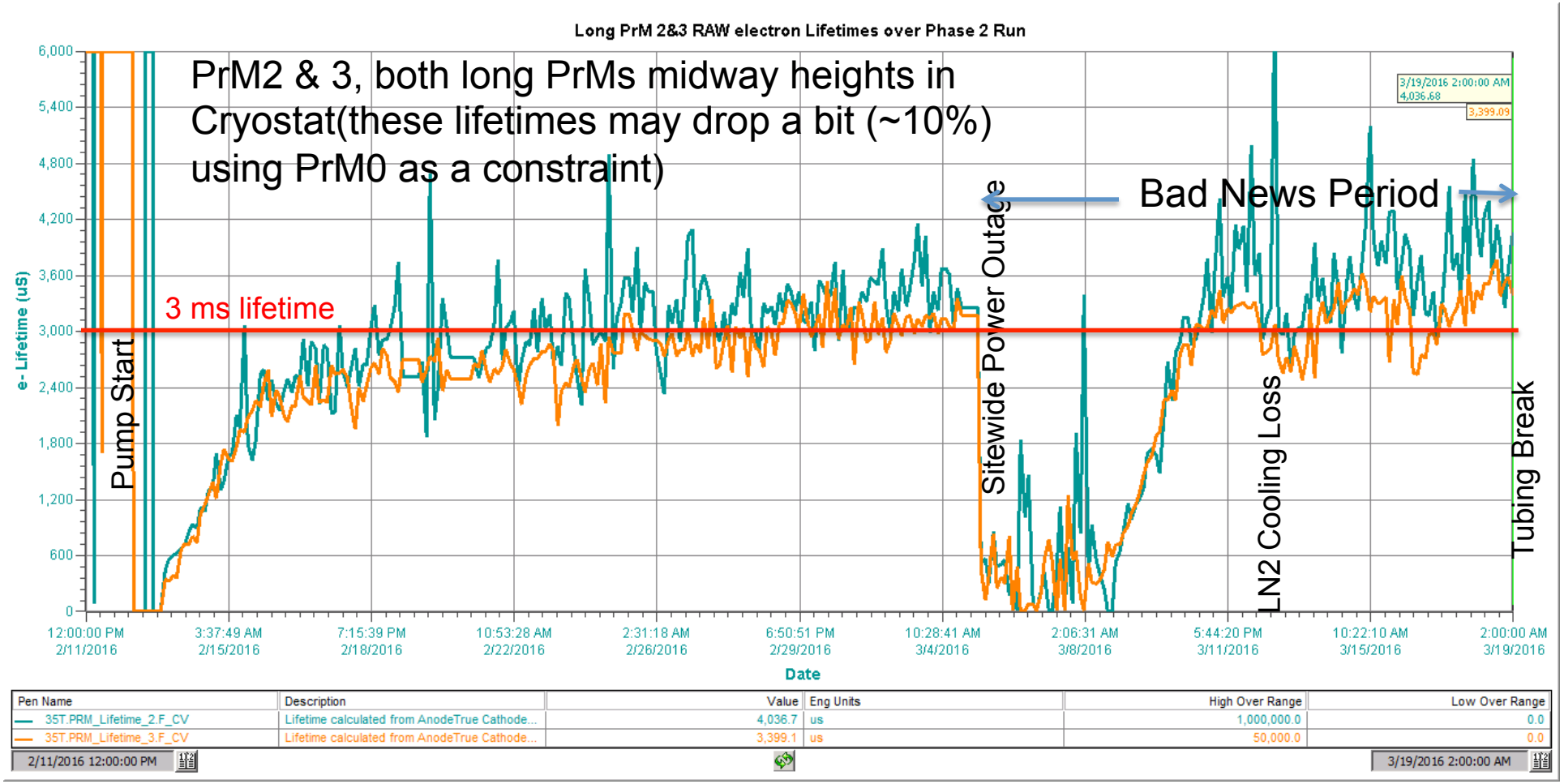
PrM Cathode Peak Height during Fill and Pump Start

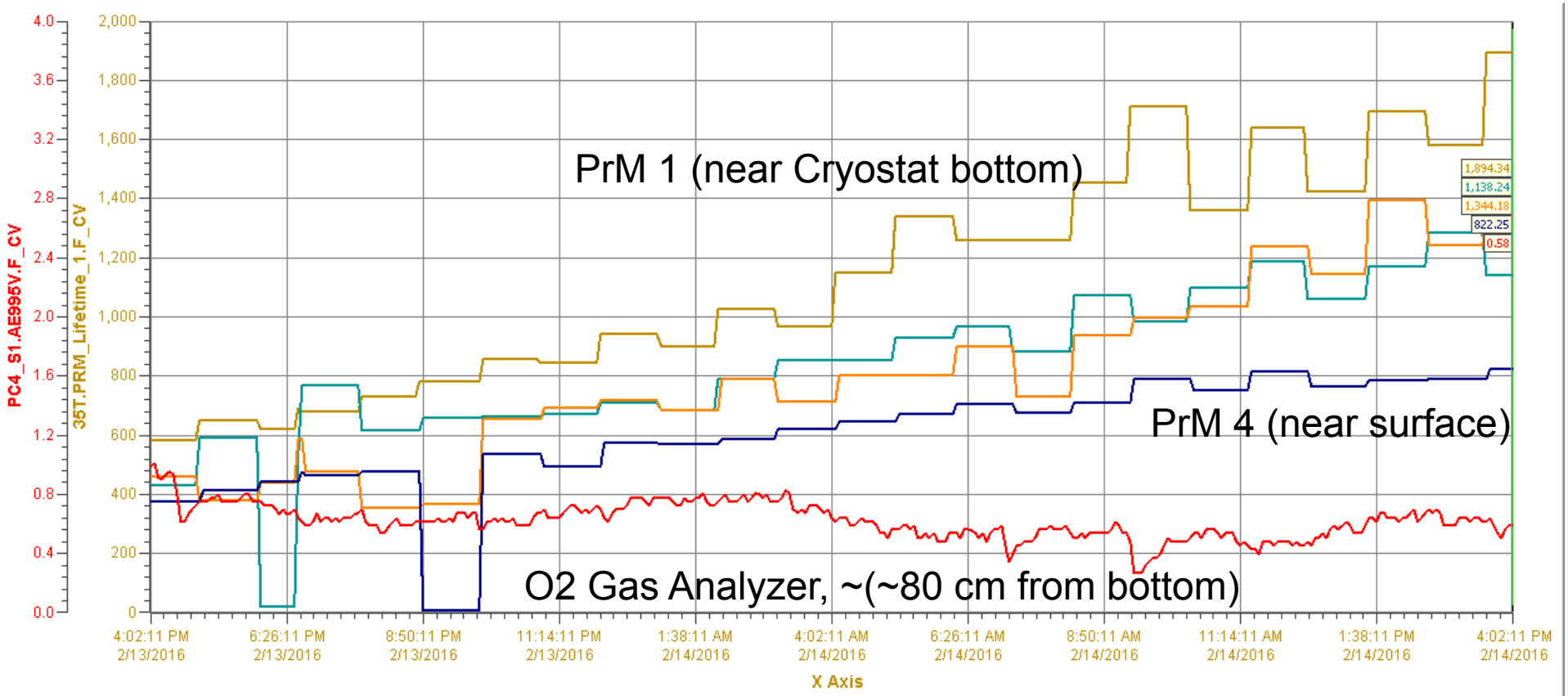
Peak rises during LAr Fill—correlated with O_2 monitor



e^- Lifetime over Phase 2 Run



Immediately Notice Purity Stratification after pump start and purification



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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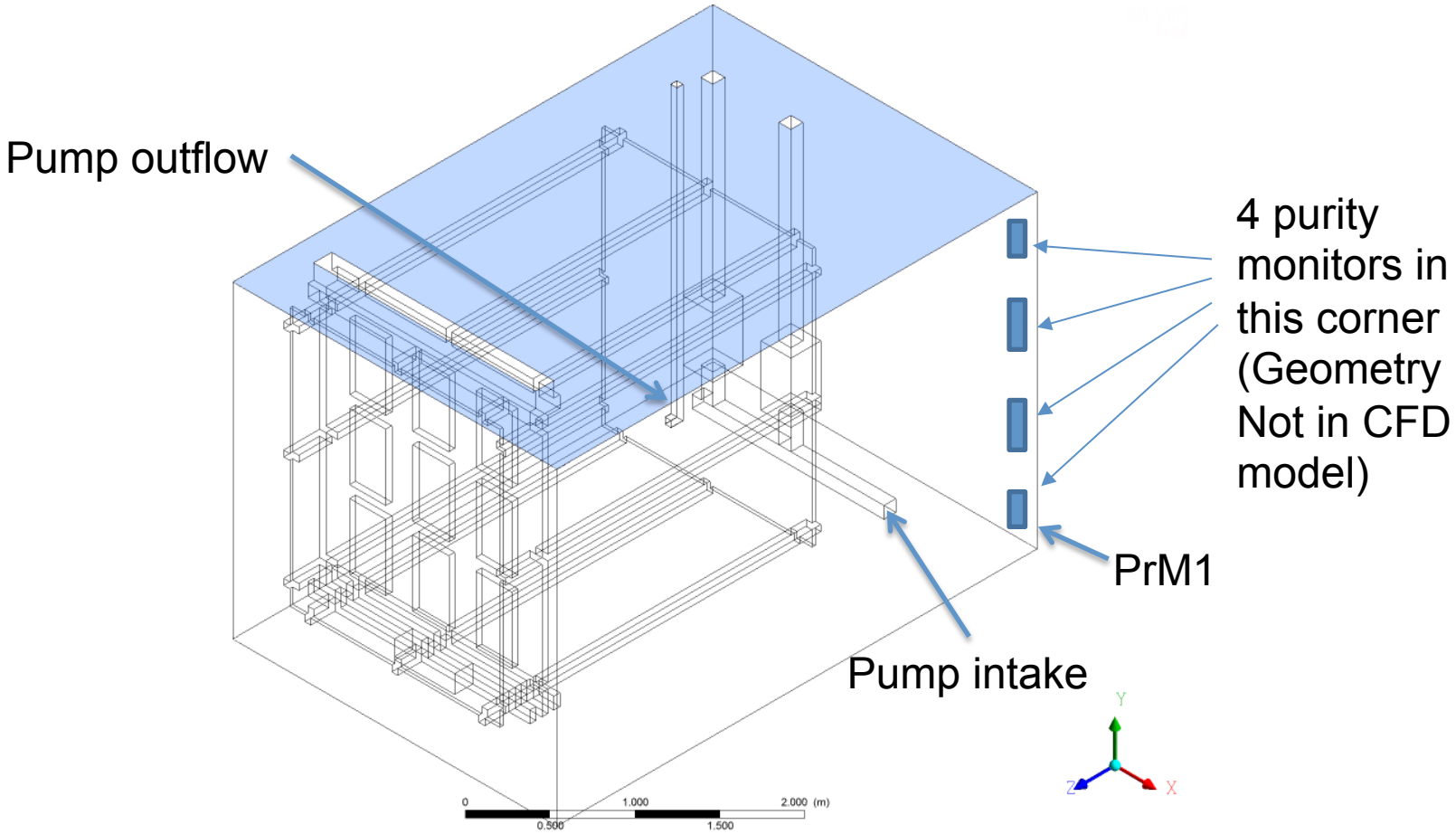
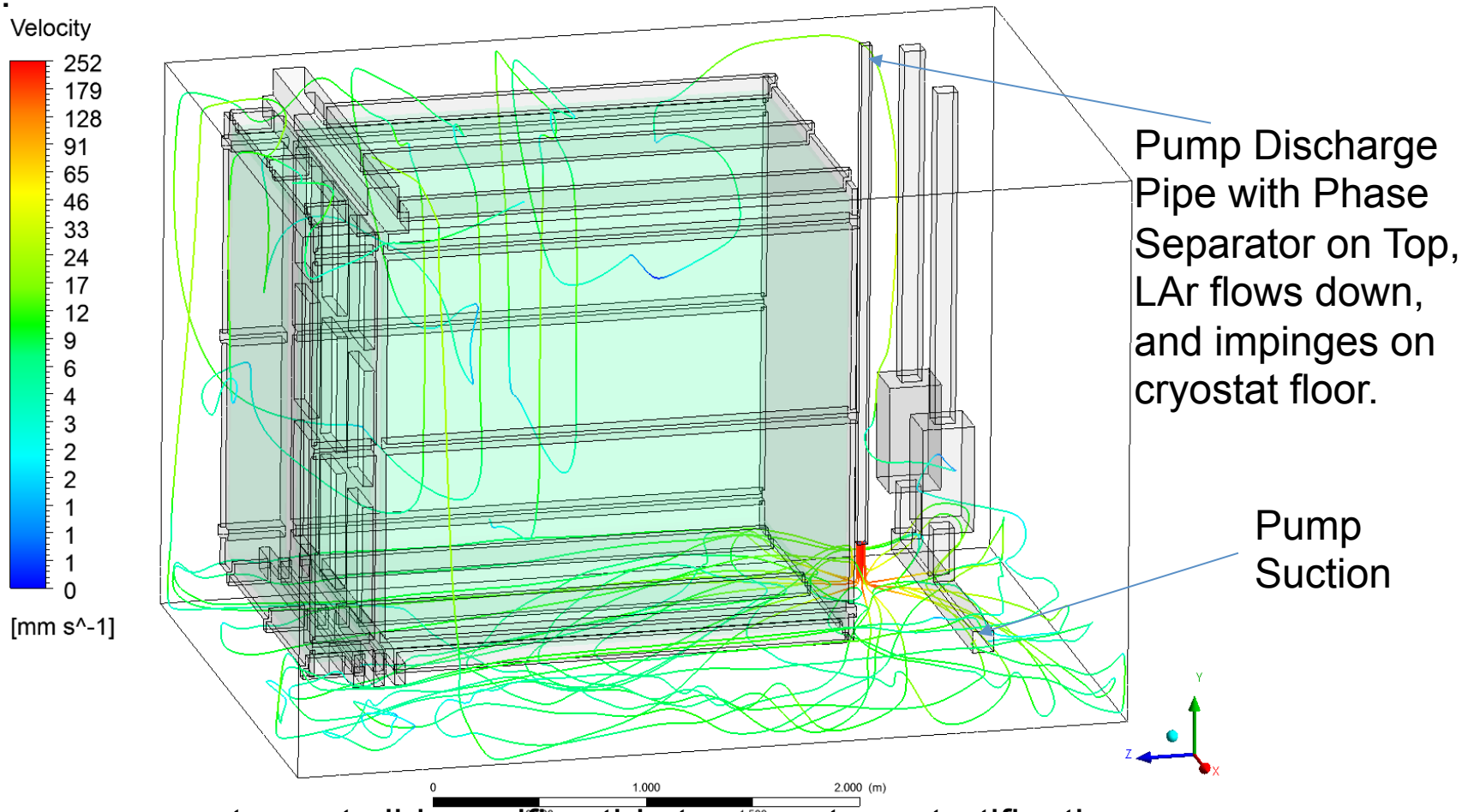
E.Voirin recent 35 Ton FEA calculations to see if he can match this stratification Dune DocDb 1156



Discussion of Results / Lessons Learned

New constraint

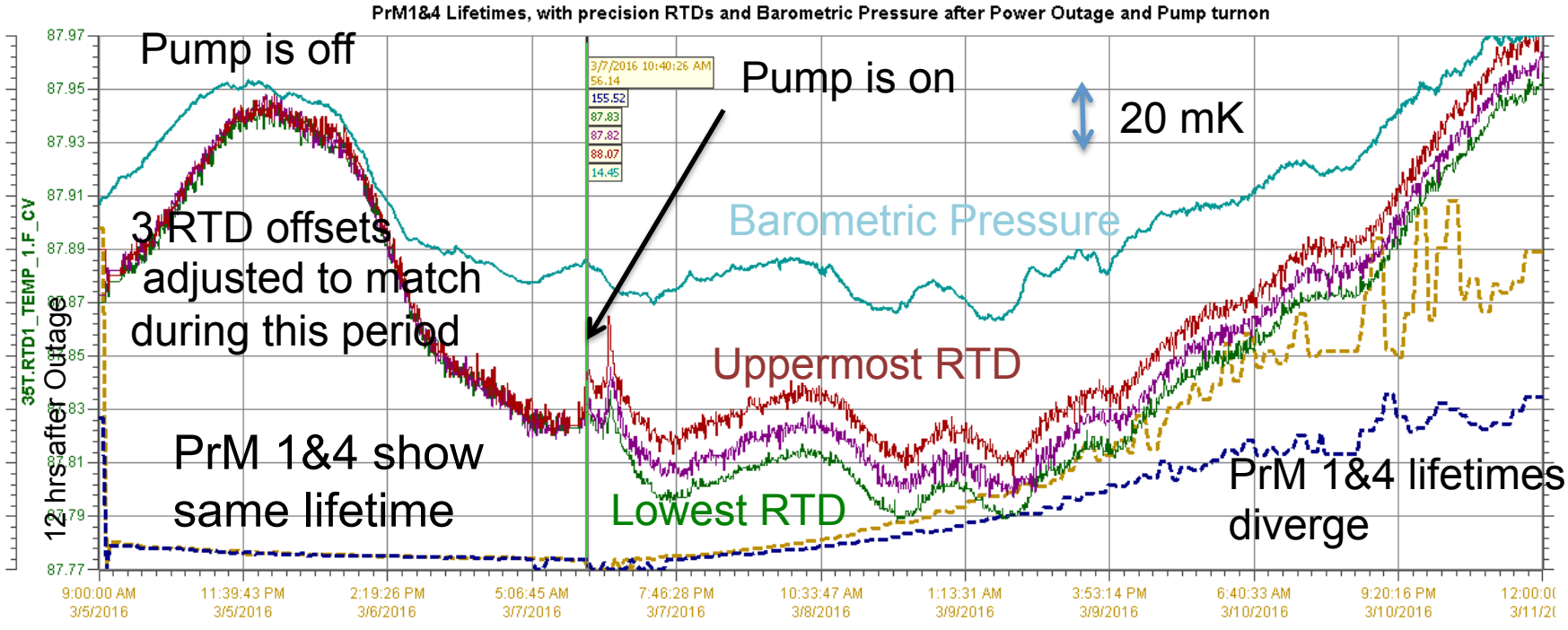
Phase separator cools inlet flow to approach saturation temperature, which is below the "bulk temperature" of the argon. This cooler, more dense layer of argon tends to stay at the bottom, and not mix well with the rest of the argon. Back pressure control at the phase separator could allow us to flow in warmer argon, which would then mix well with the bulk.



RTD measurements next slide verifies this temperature stratification

Power Outage (and pump off) provides another opportunity to verify the stratification.

PrM1&4 with 3 Precision RTDs (also at different heights in Cryostat)



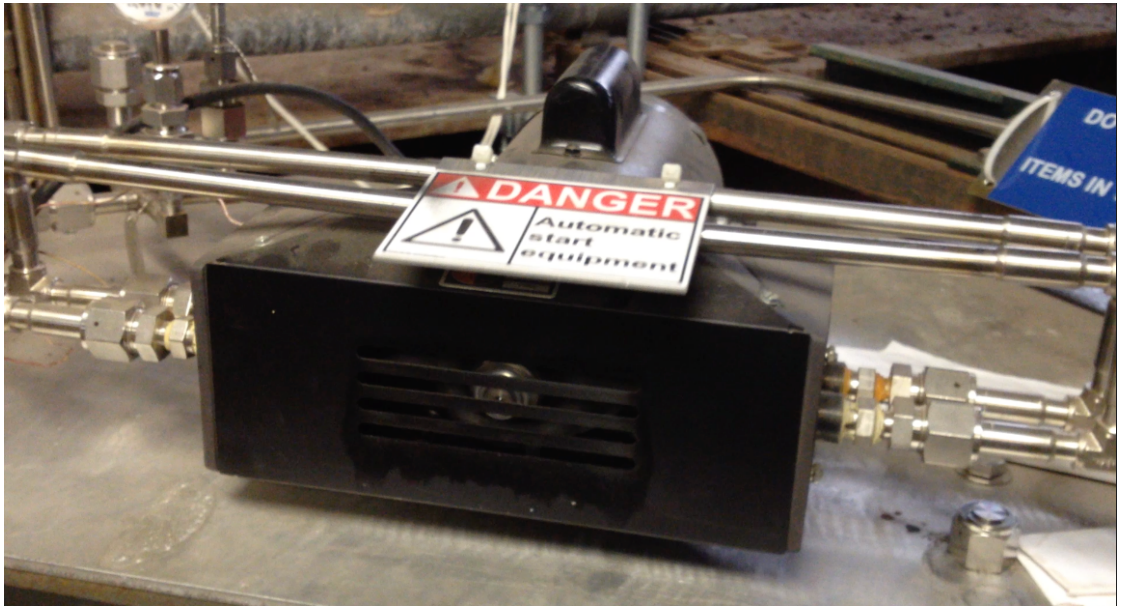
	Description	Value	Eng Units	High Over Range	Low O
RM_Lifetime_1.F_CV	Lifetime calculated from AnodeTrue Cathode...	56.1	us	6,208.7	
RM_Lifetime_4.F_CV	Lifetime calculated from AnodeTrue Cathode...	155.5	us	2,945.4	
TD1_TEMP_1.F_CV	Temperature of the top RTD (#1) on spooler #1	87.829	K	87.956	
TD1_TEMP_2.F_CV	Temperature of the middle RTD (#2) on spool...	87.820	K	87.952	
TD1_TEMP_3.F_CV	Temperature of the bottom RTD (#3) on spoo...	88.074	K	88.202	
S1.PT267_PSIA.F_CV	Barometric Pressure in PSIA (F_CV)	14.455	PSIA	14.512	

9:00:00 AM 3/11/2016 12:00:00

March Woes

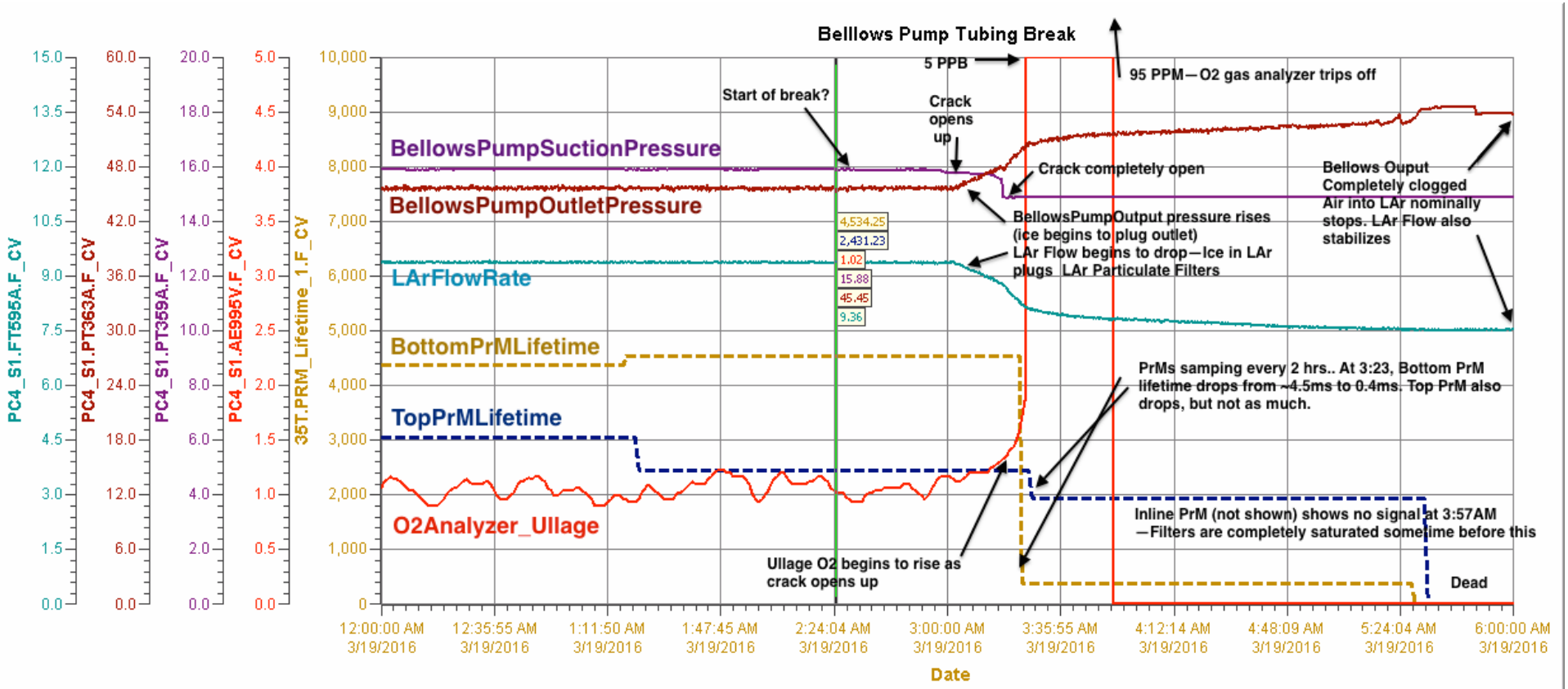
- Three consecutive “events” ~each one week apart and all on weekends
  1. Site-wide power outage stopped our recirculation and dropped the LAr Purity (3/4—Friday Night)
     - See the loss of purity due to outage on previous slides.
  2. Loss of LN_2 Cooling (broken valve) caused a loss of LAr (~1/2 ton through boil off) (3/12--Saturday)
     - Amount of loss because Autodialer Alarm had not been reset since the previous week’s Power Outage—Doh!
       - Only noticed on Sunday and fixed in afternoon
     - Dropped LAr level below desired HV-precaution level
  3. Unrecoverable Contamination of LAr (3/17-Saturday 2 AM)
     - Small tube attached to GAr Bellows Pump that was being used to transfer GAr between LAPD and 35Ton broke- pulling in air and injecting it into the LAr stream.
       - Estimate it would take ~20 weeks of filtering/filter regeneration to remove just the O_2, N_2 would not be removed.
     - Went from 100 ppt to 30 ppm O_2 in about 3/4 hr.

This broken tubing is on the suction side of pump that was pulling GAr out of LAPD, compressing it and injecting it into the LAr coming from 35T just before the purification filters.
This was how we were raising the LAr level in the Cryostat



Bellows Pump

Tubing Break Timeline--3/19



Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range
35T.PRM_Lifetime_1.F_CV	Lifetime calculated from AnodeTrue Cat...	4,534.2	us	4,534.2	0.0
35T.PRM_Lifetime_4.F_CV	Lifetime calculated from AnodeTrue Cat...	2,431.2	us	3,044.0	0.0
PC4_S1.AE995V.F_CV	Analyzer Delta F NanoTrace O2 (F_CV)	1.020	PPB	96,572.172	-0.043
PC4_S1.PT359A.F_CV	suction line to vent purge bellows pump...	15.9	PSIA	15.9	14.8
PC4_S1.PT363A.F_CV	vent purge bellows pump outlet (F_CV)	45	PSIA	55	45
PC4_S1.FT595A.F_CV	from argon pump to first filter (F_CV)	9.4	GPM	9.4	7.5

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Cryo Issues

- Cryo Support
  - Due to many schedule slippages, FNAL reorganization with Neutrino Division, and low priority within ND
    - Continuity of Cryo Engineers was difficult to maintain.
    - At end, we were well supported, but we were lacking people in summer to early fall of 2015.
- Failed to recognize early enough that our Cryo plan meant bringing both LAPD and 35T online
  - In Phase 1, LAPD was already commissioned and filled.
    - That's why it was so easy!
  - Could have started LAPD preparation earlier than we did.
- Pumping
  - Had problems establishing the 35Ton Internal LAr Pumping
  - Pumps had been rebuilt after Phase 1, but had never been run in.
  - Finally putting 3 phase 208 AC on pump motor broke it free.
    - Then normal AC Drive worked fine.
  - Lesson learned—nothing goes into cryostat without a functionality test
    - Even if it worked fine last time (e.g. Phase 1).

Cryo Issues (2)

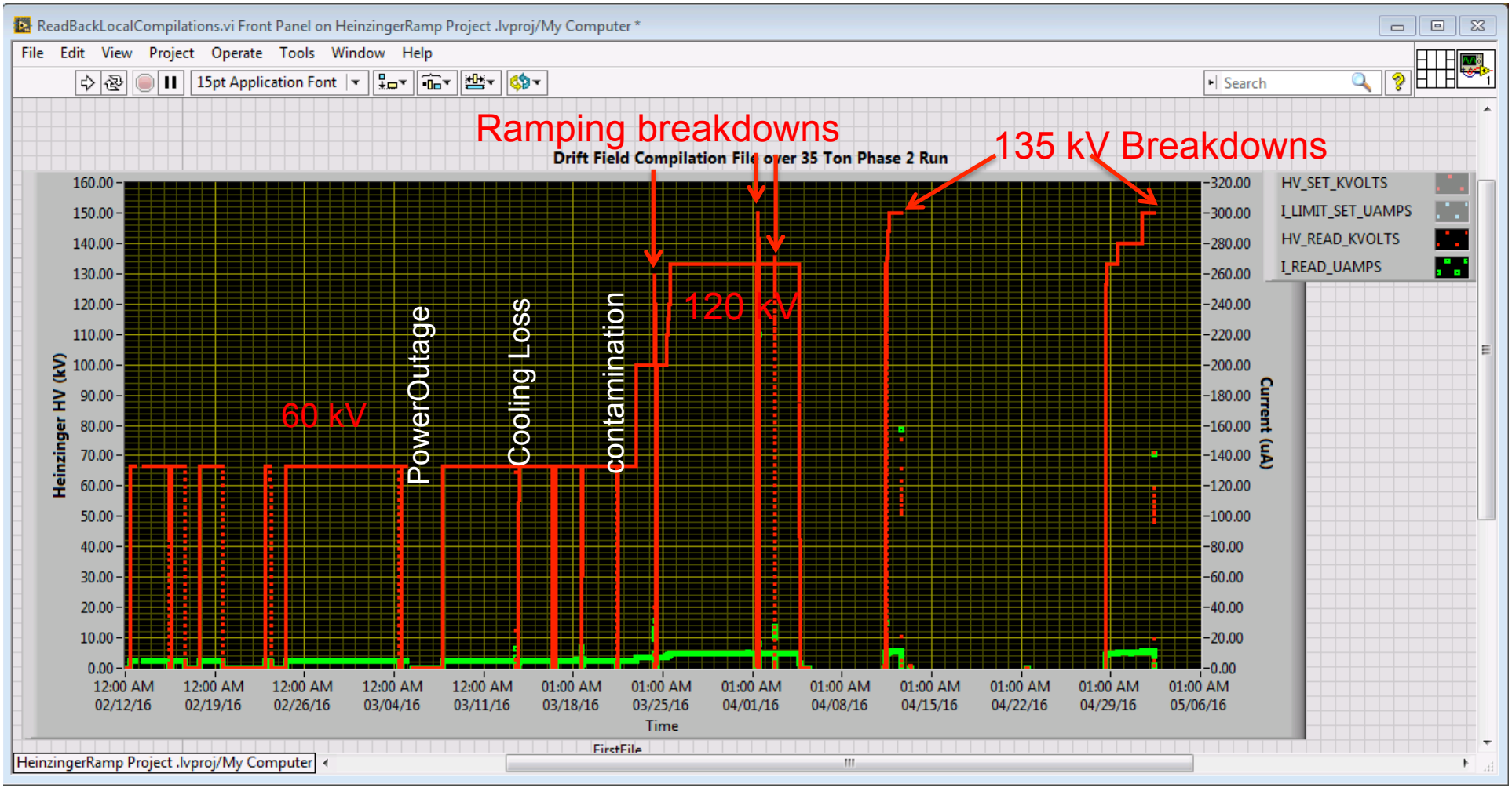
- Need a better interface into Controls and Alarms
  - Autodialer not working cost us LAr level when LN2 valve stopped functioning.
  - Painful to use the Cryo Interface at times
  - incredible slow downs.
    - Discourages one from looking at trends if it takes forever to get up and run.
- Massive Contamination of LAr
  - There was a review of the root cause of the problem
    - Basic conclusion was that we didn't completely analyze the consequences of using LAPD Ar boiloff and this pump to be the supplier of the 35 Ton Make-up Gas
  - Recognition of how fast you can completely contaminate a sizeable amount of LAr
  - How to identify other similar modes that might cause same problem.
  - Perhaps a way to quickly and automatically respond to an event since there is almost no time for people to recognize what is going on.

Drift Field HV

- Our experience here at FNAL is that HV breakdowns are sensitive to the purity of LAr.
- Phase 2 HV
  - 60 kV on Cathode, ~3 ms e^- lifetimes
    - No trips
  - 90 kV,120 kV on Cathode, low purity (30 ppm O_2)
    - No trips—120 kV held for 1 week
  - 135 kV, low purity,
    - trips after ~24 hrs
  - I am concerned that we may have had issues with 120 kV with purified LAr.
- Major disappointment that the LAr Contamination occurred before we had a chance to raise the HV to ~120kV (on Cathode) to achieve the design E Field of 500 V/cm.

Drift HV History over Run

120 kV at Cathode ~ 500V/cm



HV History

- 60 kV on Cathode, ~3 ms e^- lifetimes
  - No trips over ~ 5 weeks
- 90 kV,120 kV on Cathode, low purity (30 ppm O_2)
  - No trips—120 kV held for 1 week.
- 135 kV, low purity,
  - trips after ~24 hrs--twice
- Conclusion is that I am concerned that we may have have issues with 120 kV in purified LAr.

Why didn't we raise the HV sooner?

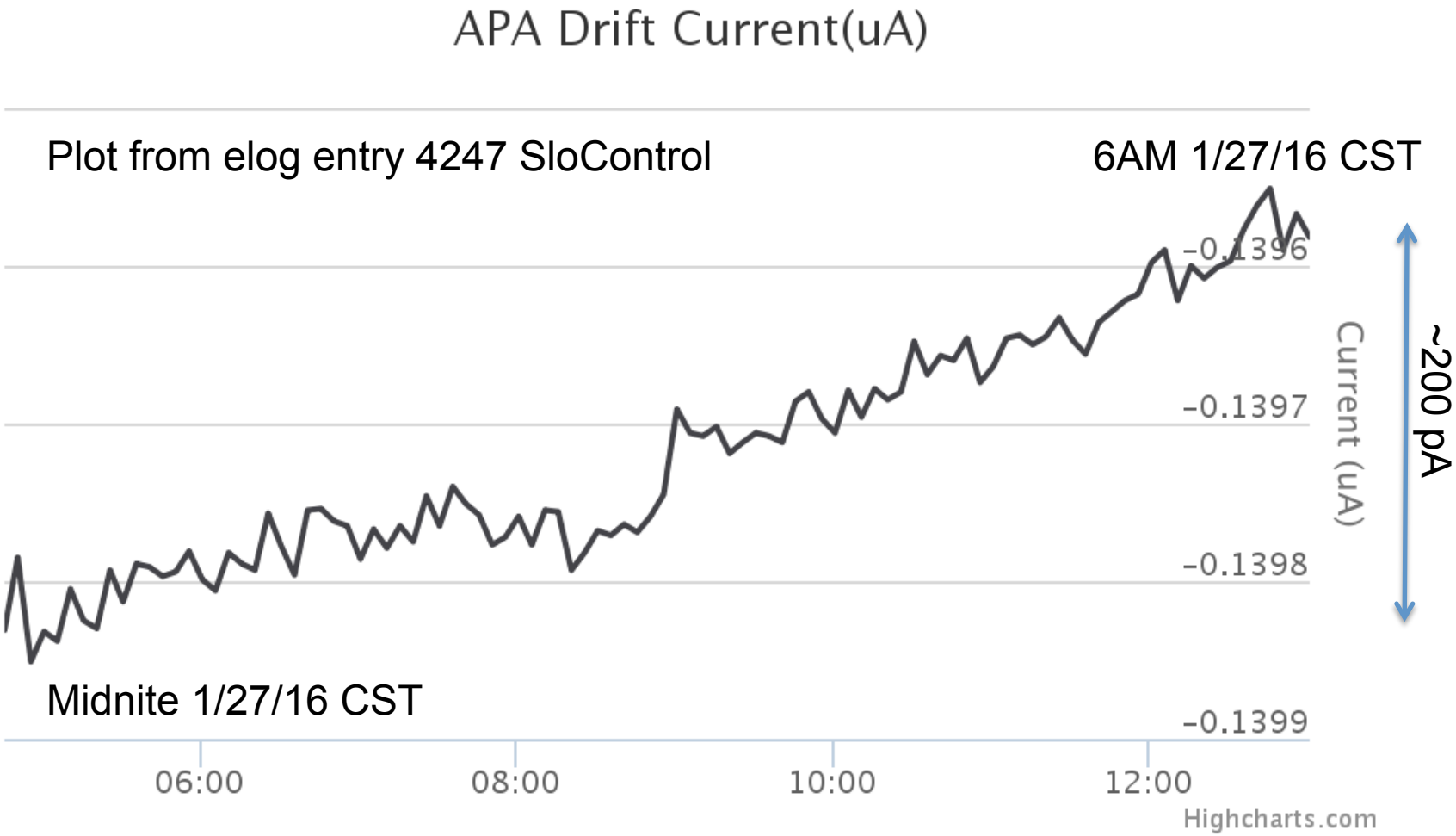
- Gun shy
  - At least a few of us had experienced LAPD where the Long Bo field cage was damaged immediately after filling when HV was being raised to full design value (also ~120kV)
    - Caveats—LAPD suffered an accident where a ribbon cable floated into the field cage, shorting out the cage and damaging the resistor chain
    - So perhaps unfair comparison.
- We had decided to initially run at ½ design field (250 V/cm or 60 kV on 35T cathode) until we acquired enough data to do some of our desired measurements.
  - Then we would raise the HV.
  - However due to the very high noise in the TPC, good runs were not plentiful, and even these runs were noisy, preventing any reasonable (future) zero suppression
    - Result was a DAQ max sustained rate of ~ 1Hz
  - Word from Analysis people was that enough data was in hand by 3/16 to consider a higher voltage.
- We desired that the SS Membrane Cryostat "corrugation" be covered by ~1 " LAr just to keep the stray fields between the Cathode and the grounded membrane "reasonable".
- Due to loss of LAr during the cooling loss the previous weekend 3/12, we needed to makeup some of the LAr Level (~1 ").
  - Hence the LAPD-35T gas transfer that failed on 3/17 and contaminated the LAr.
  - We were expecting to have a sufficient LAr level by 3/19-20, and intended to raise the HV at that point.

LAr Level Concern

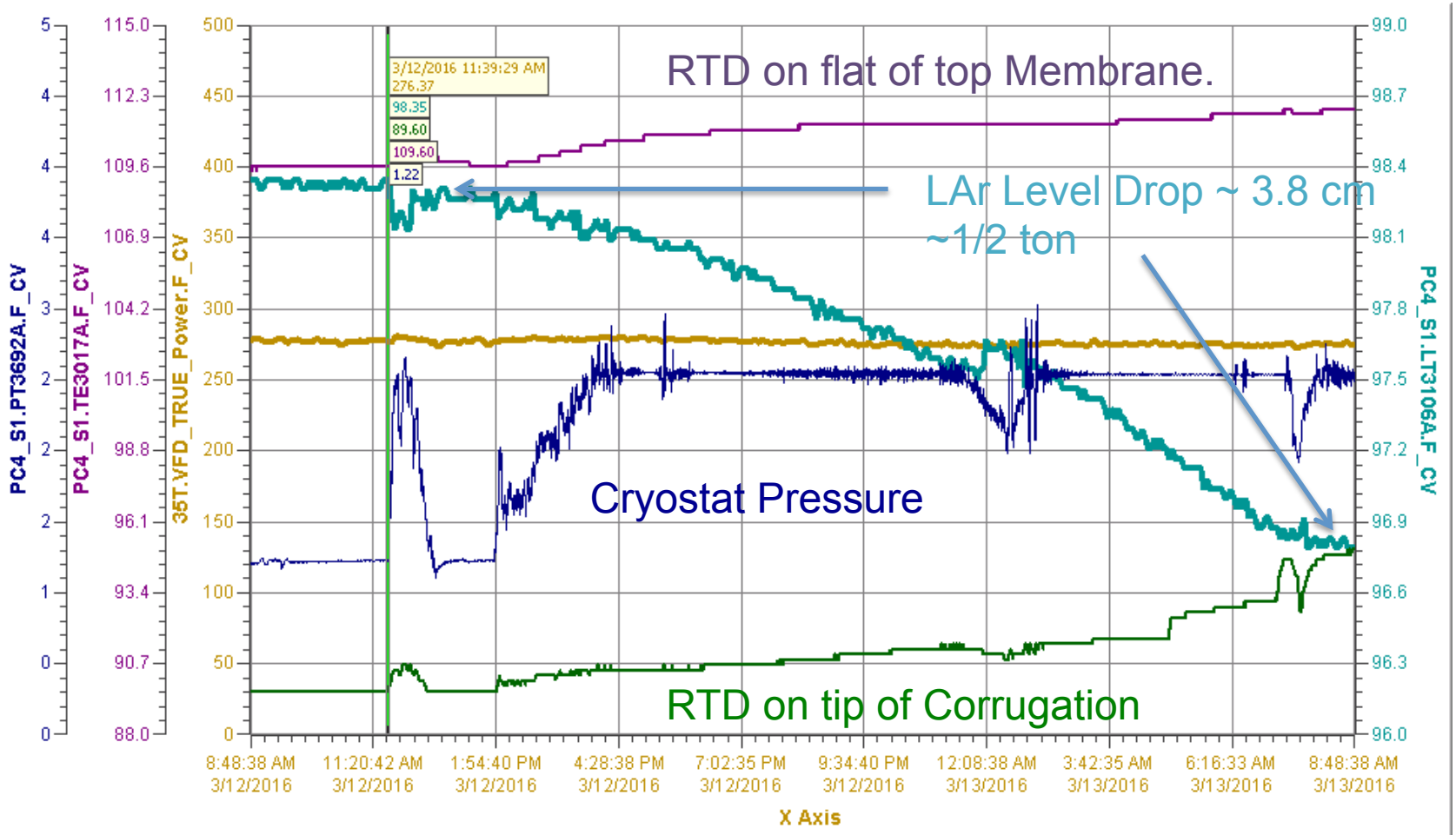
Xtra Slides

Drift Field Monitoring During Cooldown

Current dropping as cryostat cools (applied V = 1.8kV)



Loss of N_2 Cooling 3/12/16



Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range
35T.VFD_TRUE_Power.F...	Power Output of the 6000LS ...	276.37	Watts	280.27	271.64
PC4_S1.LT3106A.F_CV	LBNE tank liquid level (F_CV)	98.35	%	98.35	96.78
PC4_S1.TE3016A.F_CV	LAPD tank (top - L) (F_CV)	89.6	C	95.0	89.6
PC4_S1.TE3017A.F_CV	LAPD tank (top - E) (F_CV)	109.60	C	111.80	109.40
PC4_S1.PT3692A.F_CV	LAPD tank vapor pressure tra...	1	PSID	3	1

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