Scope Review:
Purity Monitors for ProtoDUNE-II and DUNE

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2020-05-11

Motivation of Purity Monitors

- Detector and cryogenic operation: Argon filling to cryostat during commissioning, alert pump and cryogenic accidents during operation, alert unexpected contamination in cryostat. Incidents alerted by PrMs in ProtoDUNE-I include filter saturation, level gauge fake measurements, pump stoppages, etc.
- Monitoring cryostat purity status during operations such as Xenon doping
- Provide benchmarks LAr purities for recirculation studies and TPC calibration
- Measure e-lifetime for data quality, calibration and analysis. Impurity measured by purity monitors and TPC/CRT in good agreement at ProtoDUNE-I. Provided PrM lifetime to ProtoDUNE-SP analysis group for run-by-run lifetime calibration.
- Measure purity stratification and verify Computational Fluid Dynamics (CFD)

Scope for ProtoDUNE-SP-II

Cryostat:

- Reuse and switch the 2 of the 3 standard (25cm) ProtoDUNE-SP-I PrMs (top and bottom)
- Replace the ProtoDUNE-I middle purity monitor with a new or refurbished long (100 cm) purity monitor to reduce systematic uncertainty in absolute lifetime measurement

Inline:

- Build or refurbish 1 standard PrM within recirculation system (inline), after the LAr filter.

Schedule for ProtoDUNE-SP-II

- Time window: Summer 2020 (when cryostat is warm) to late 2021 after the TCO closure (PrMs can be installed almost last)

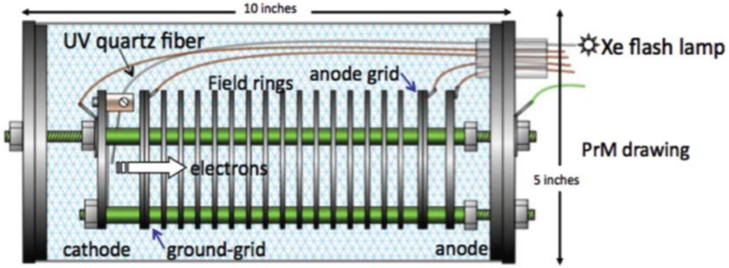
Scope for DUNE

- Build 6 PrMs in the DUNE cryostat, 4 standard and 2 long
- Build 2 standard PrMs within recirculation (inline), before and after LAr filter
- Discussing 2 extra, very short PrMs on the cryostat floor so argon purity will be known right after filling

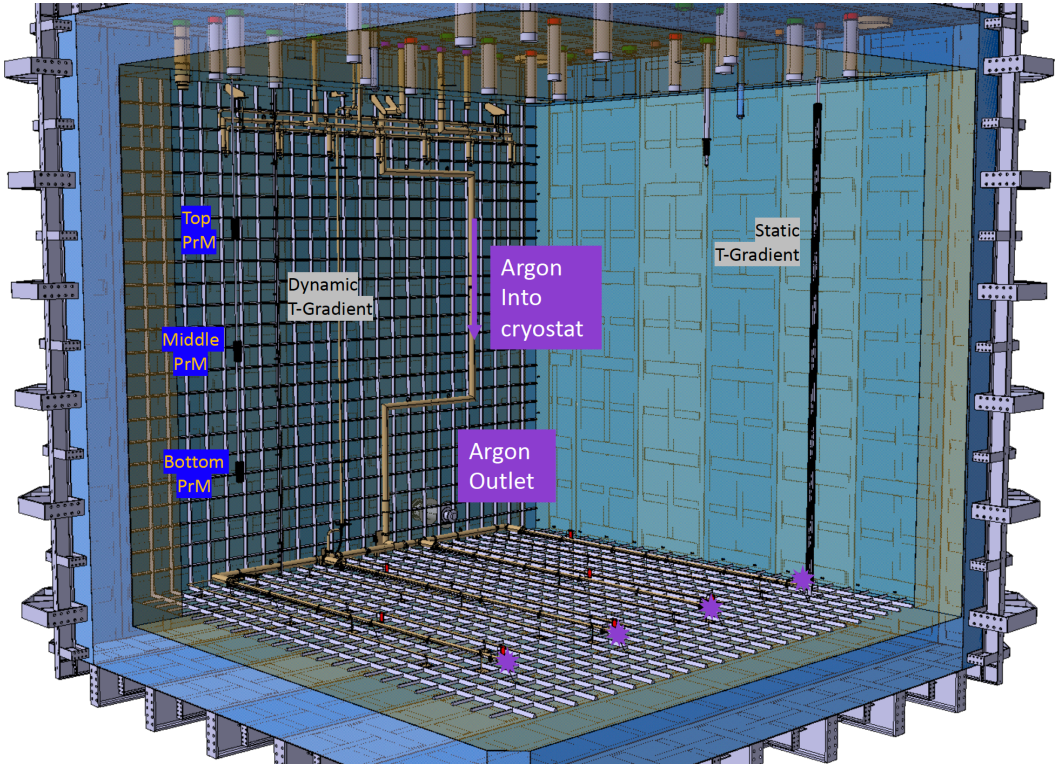
ProtoDUNE-SP Purity Monitors

PrM – miniature TPC using UV on photocathode as electron source,
Measure lifetime τ based on:

$$Q_{anode}/Q_{cathode} = e^{-t_{drift}/\tau}$$



M. Adamowski et al., JINST 9, P07005 (2014).

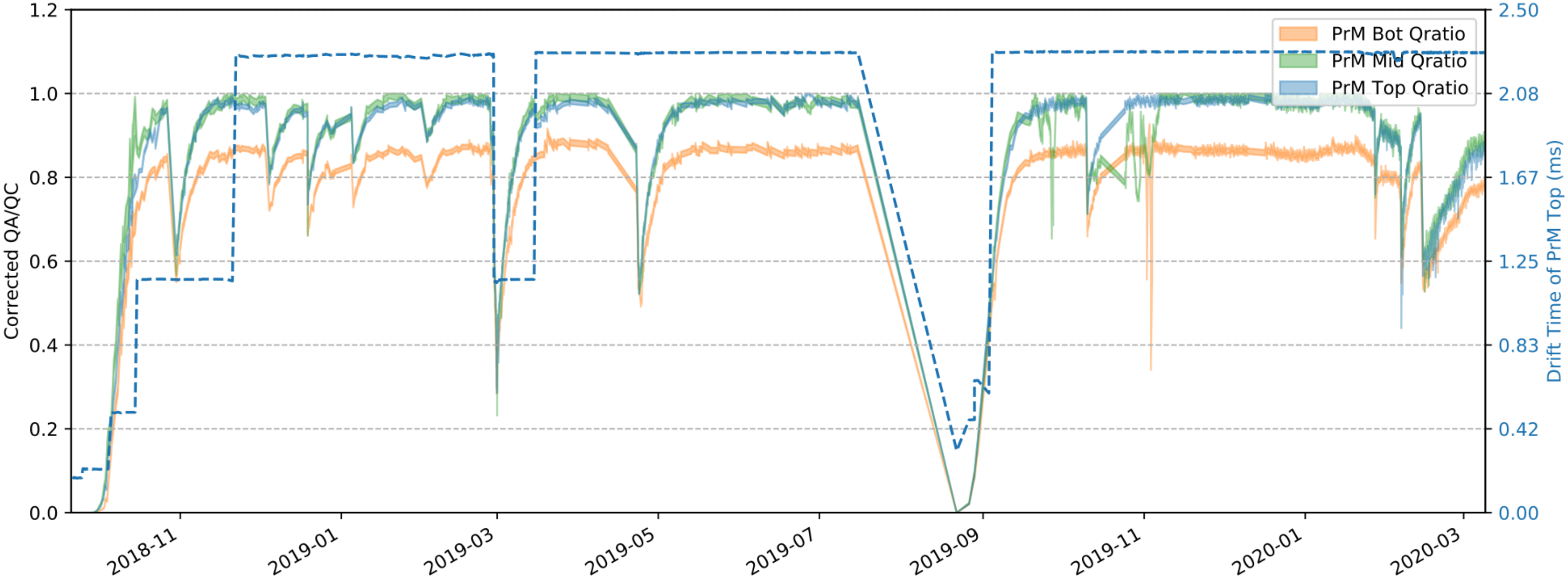


ProtoDUNE-SP-I: all 3 cryostat purity monitors have same length, 25 cm.

ProtoDUNE-SP-II: Reuse and switch top and bottom PrM , replace middle PrM monitor with a new or refurbished long PrM (100 cm)

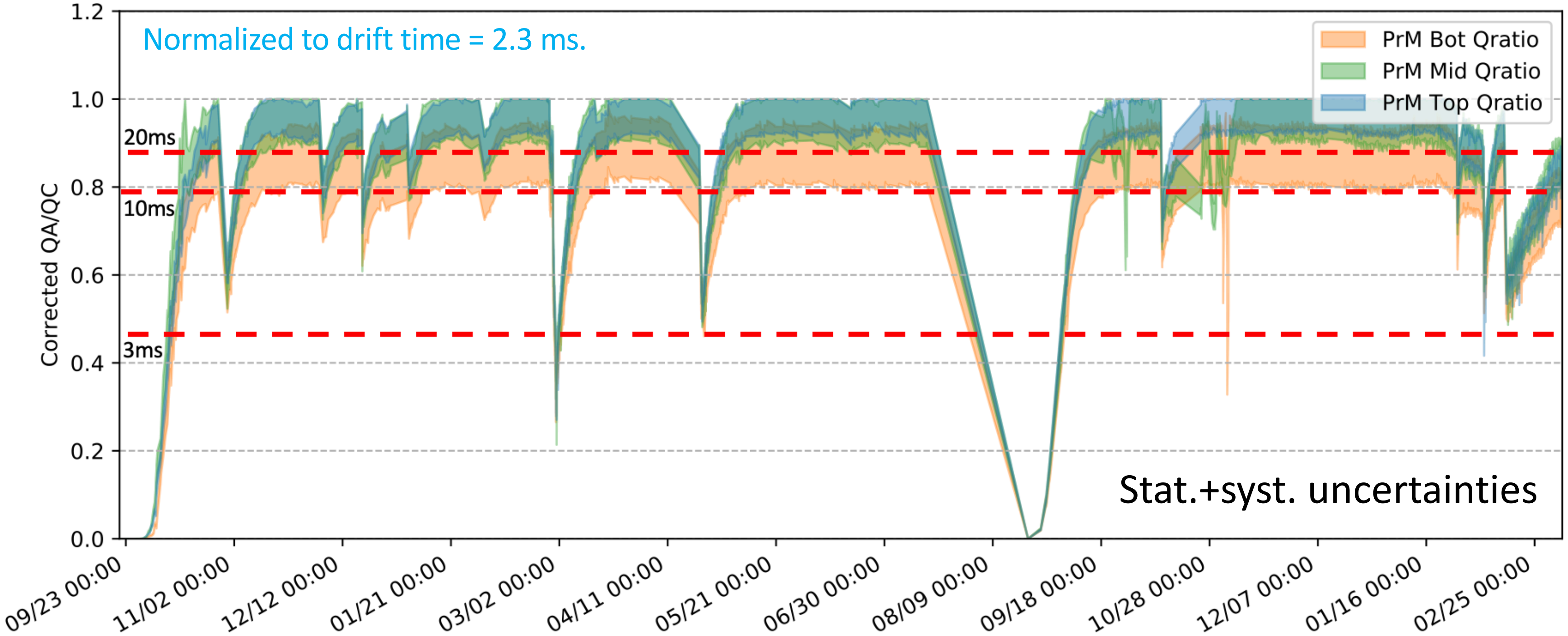
ProtoDUNE-SP-I Cryostat PrMs: Anode/Cathode signal ratio Qa/Qc, statistic uncertainty only

Uncertainties: Statistical and time-dependent fluctuations only → high sensitivity to purity change



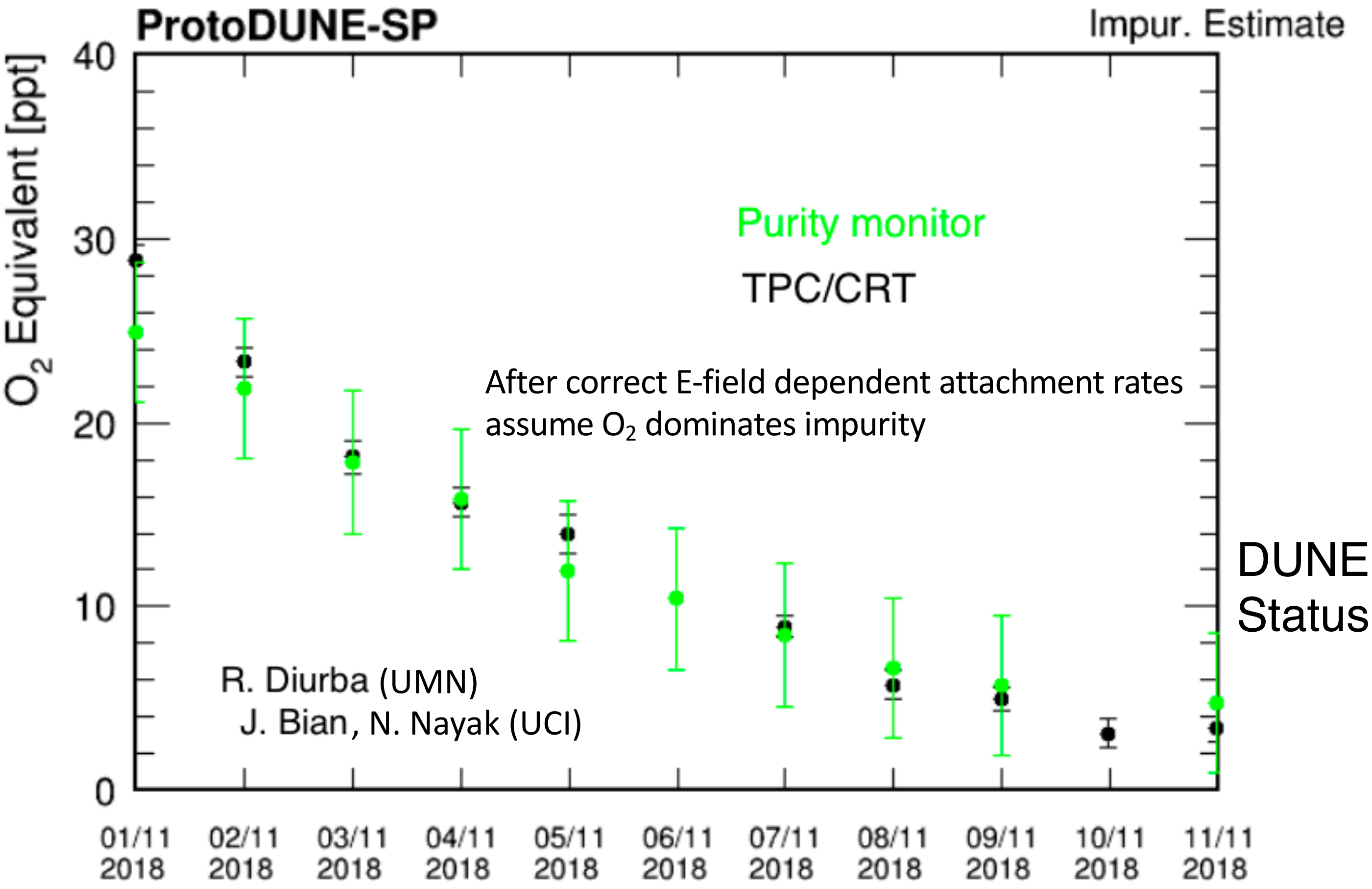
Alerted the experiment solely to serious problems such as filter saturation during LAr filling and recirculation pump stoppages during ProtoDUNE operation (dips).

ProtoDUNE-SP-I Cryostat PrMs: Qa/Qc with offline transparency correction



The purity monitor measurement has been updated with offline analysis. Improvements are made to correct cathode rise time, correct online smoothing process, measure gain difference and recalculated transparency correction. Uncertainties includes statistical and time-dependent fluctuations and uncertainties of grid transparency, others uncertainties found to be small. Top/Mid PrMs measure lifetime>20ms, bottom PrM measures > 10ms. Overall uncertainty on Qa/Qc measurement is ~5%.

Purity monitor and CRT/TPC electron lifetime



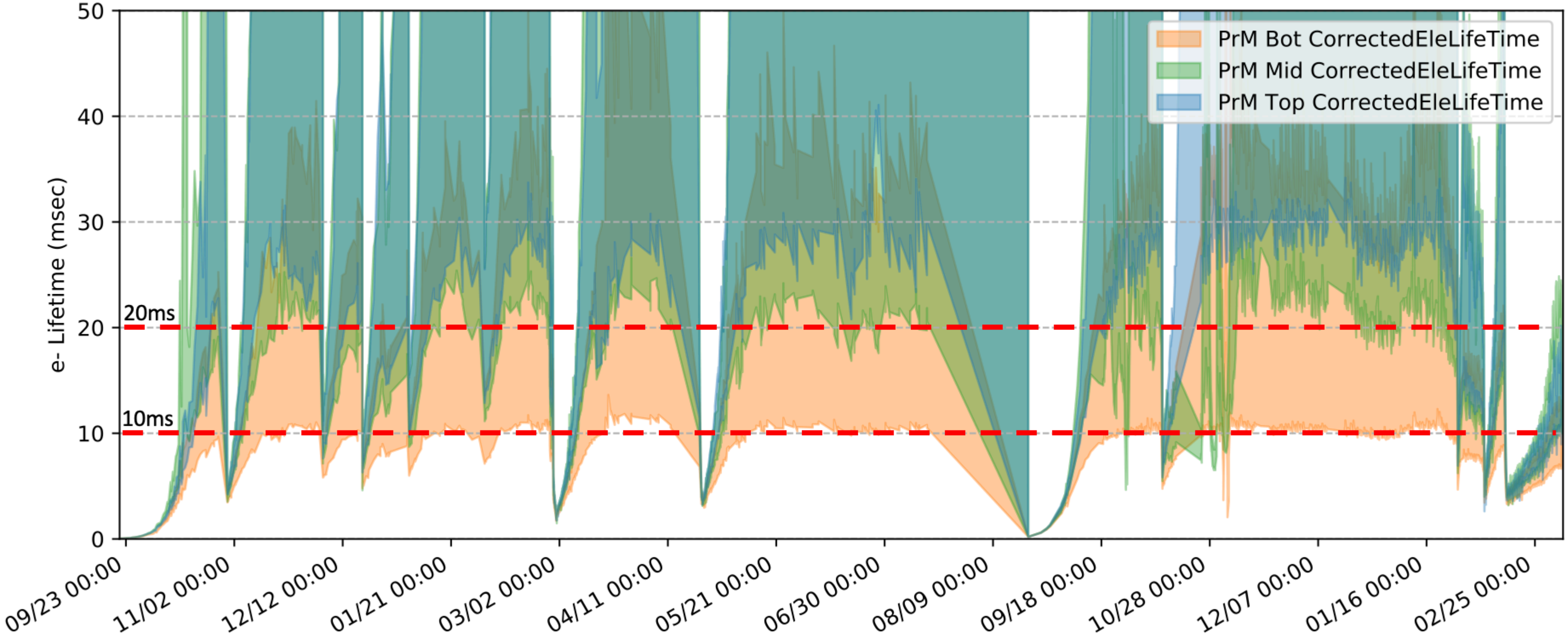
After correct E-field dependent attachment rates assume O_2 dominates impurity

R. Diurba (UMN)
J. Bian, N. Nayak (UCI)

DUNE Project, Monthly Status Report, March 2020

The impurity measured by purity monitors and TPC/CRT are in a good agreement. Provided PrM lifetime to ProtoDUNE-SP analysis group for run-by-run lifetime calibration.

ProtoDUNE-SP-I Cryostat PrMs: Electron Lifetime with offline transparency correction



- Electron lifetimes measured by PrMs indicate that ProtoDUNE-SP has achieved the high liquid argon purity required by DUNE's far detectors.
- Have hints for e-lifetime stratification between top/middle PrM and the bottom PrM. However, due to the large uncertainty caused by transparency correction, the observation of stratification needs to be confirmed with switching top and bottom PrMs. The long PrM does not need transparency correction, so this major uncertainty can be eliminated.

Transparency correction

$$\frac{Q_A}{Q_C} = e^{-\frac{t}{\tau}} \qquad \tau = -\frac{t}{\ln(\frac{Q_A}{Q_C})}$$

For high purity, when drift time *t* is small, $\frac{\mathrm{Q_A}}{\mathrm{Q_C}} \to 1, \ln\left(\frac{Q_A}{Q_C}\right) \to 0$, fluctuation in $\mathrm{Q_A/Q_C}$ causes a large fluctuation in τ measurement, so we run purity monitor at low Anode/Cathode HV (-50/250V, -50/500V) to increase drift time and lower Qa/Qc, improving sensitivity.

However, since the Cathode HV:Anode HV is not 1:20, the cathode grid is not fully transparent, a transparency correction is needed:

$$\left(\frac{Q_A}{Q_C}\right)_{50/250}^{corrected} = \left(\frac{Q_A}{Q_C}\right)_{50/250} \cdot f_{trans}$$

$\left(\frac{Q_A}{Q_C}\right)_{50/250}$: anode-to-cathode signal ratio taken at cathode HV=-50V, anode HV=250V

f_{trans}: transparency correction factor

Transparency correction

$$\left(\frac{Q_A}{Q_C}\right)_{50/250}^{corrected} = \left(\frac{Q_A}{Q_C}\right)_{50/250} \cdot f_{trans}$$

$$f_{trans} = \frac{\left(\frac{Q_A}{Q_C}\right)_{50/1000}^{\left(\frac{t_{50/250}}{t_{50/1000}}\right)}}{\left(\frac{Q_A}{Q_C}\right)_{50/250}} \approx \frac{\left(\frac{Q_A}{Q_C}\right)_{50/1000}^{4}}{\left(\frac{Q_A}{Q_C}\right)_{50/250}}$$

Data taken at low purity when $\left(\frac{Q_A}{Q_C}\right)_{50/1000} < 0.8$

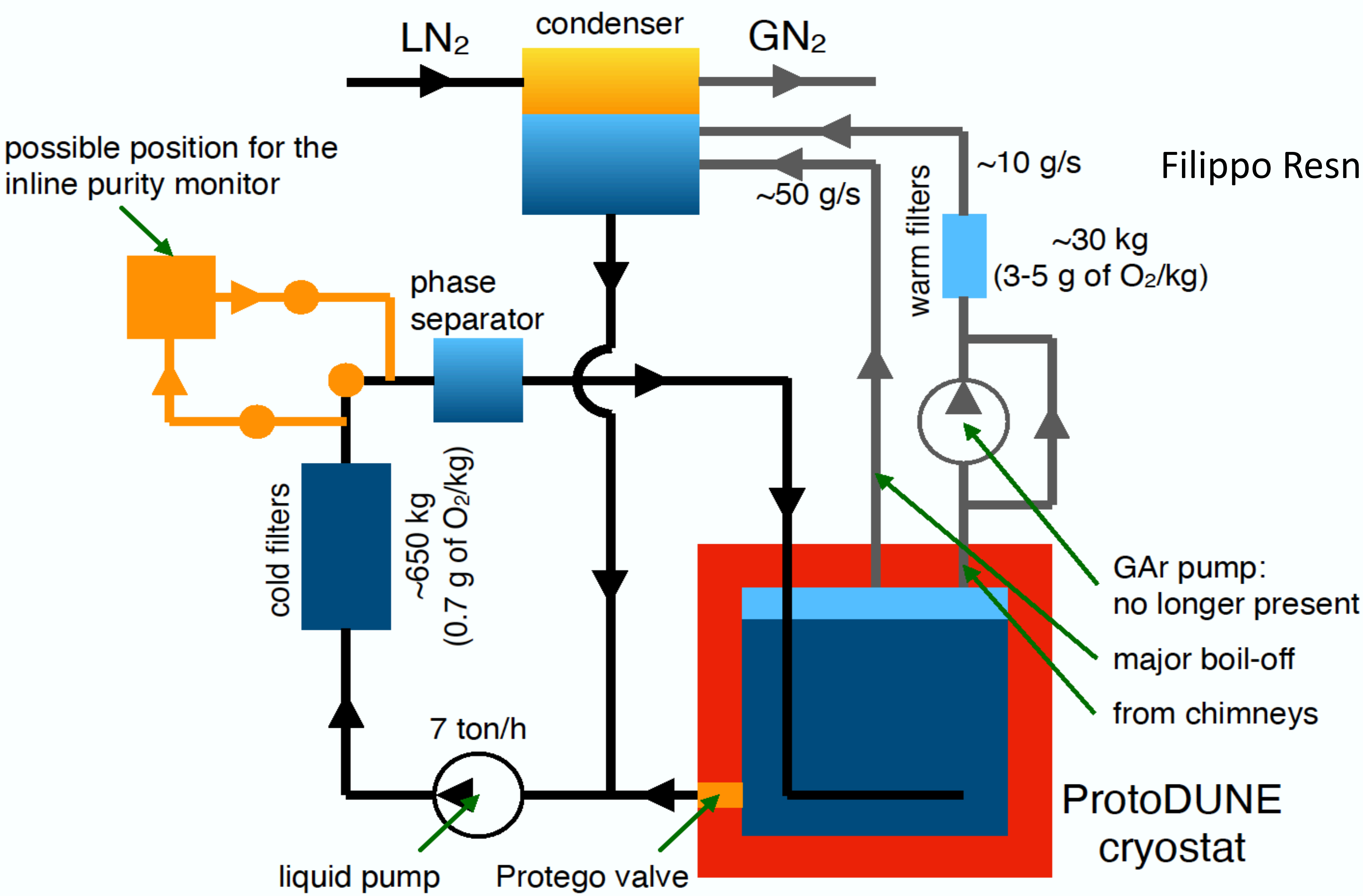
$\left(\frac{Q_A}{Q_C}\right)_{50/1000}$: anode-to-cathode signal ratio taken at cathode HV=-50V, anode HV=1000V

Bias in $(Q_A/Q_C)_{50/1000}$ enlarged by X4 in the transparency correction factor

Purity monitors are very sensitive to relative change in purity, but have a large systematic uncertainty in absolute lifetime measurement due to the online transparency correction

Long PrM does not need transparency correction, overall Q_A/Q_C uncertainty can be reduced from ~5% to ~1.5%

Simplified cryogenic circuit
For ProtoDUNE-SP-II inline purity monitor



Filippo Resnati

Charge Questions

- Does the system have a well-justified role in safeguarding the far detectors and facilitating their operation, and if so, what is the minimum amount of system scope needed to carry out this role? (Cryogenic Instrumentation only)
- Does the system have a well-justified role in facilitating the analysis of far detector data, and if so, what is the minimum amount of system scope required to fulfill this role?
- Have all technical issues related to the feasibility of the system (including those raised in the previous workshops) been resolved?
- Are there any risks to overall detector performance associated with the implementation of the system, and if so, is there a plan in place for mitigating these risks?
- Is there a credible plan in place for demonstrating system performance in ProtoDUNE-II? (inline PrM, switch purity monitors, longer prm to reduce syst. Err)
- Does the functionality of the system justify its overall cost?

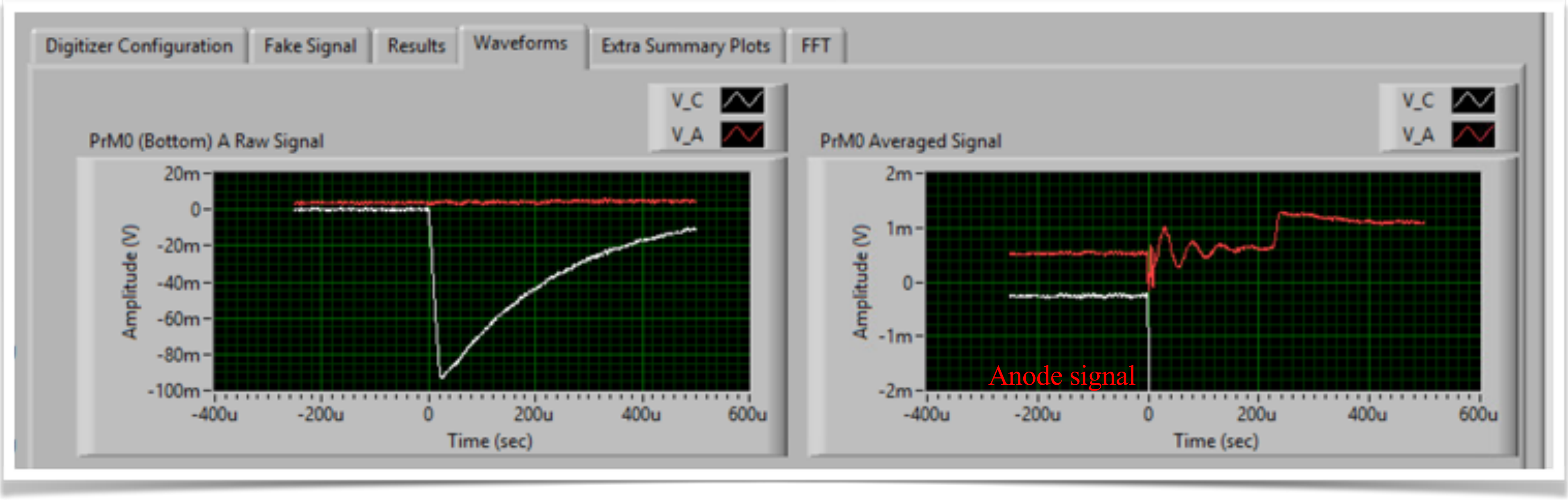
Does the system have a well-justified role in safeguarding the far detectors and facilitating their operation, and if so, what is the minimum amount of system scope needed to carry out this role? (Cryogenic Instrumentation only)

- In ProtoDUNE-SP-I, the purity monitor system was found to be essential for providing reliable real-time monitoring of purity in the detector and to catch purity-related changes in time due to LAr recirculation issues.
- Provide key monitoring during LAr filling, purification and in Xenon doping
- The regular measurement of the LAr purity performed by the purity monitors solely alerted the experiment to problems several times (dips in the Qa/Qc and electron lifetime): Filter saturation, recirculation pump outages, and problems with the cryostat-level gauges. These alerts saved the experiment from termination of data taking

Monitor LAr Purity during filling

Monitor purity during LAr filling, find saturation during the filling

As soon as the lowest purity monitor was immersed: ~40 us -> 7.5 ppb O_2^{eq}
On Thursday 30st of August purity was compatible with ~60 us



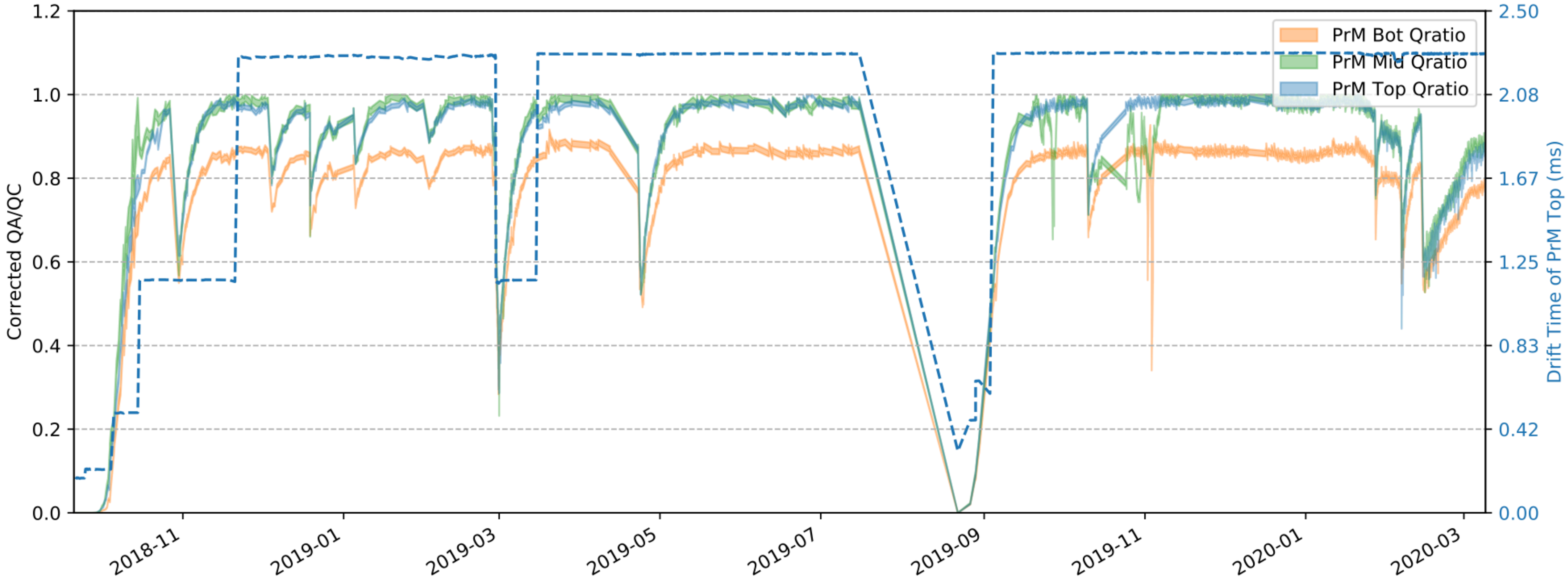
ProtoDUNE-SP: On Friday 31st of August, 2018 the purity of the bulk liquid argon dropped from 40 us purification cartridges needed to be regenerated.
Regeneration took till the 3rd of September. Filling restarted immediately after.

Filippo Resnati - DUNE Collaboration Meeting - CERN - 28th January 2019

Having very short PrMs on the cryostat floor can better monitor this stage— During filling, purity is low (~10us). In DUNE, filling time is much longer than ProtoDUNE (~1 year).

ProtoDUNE-SP-I Cryostat PrMs: Qa/Qc, statistic uncertainty only

High sensitivity to purity change, caught LAr issues and made alerts



Does the system have a well-justified role in safeguarding the far detectors and facilitating their operation, and if so, what is the minimum amount of system scope needed to carry out this role? (Cryogenic Instrumentation only)

DUNE:

In cryostat: 6 PrMs

- To know liquid argon situation in cryostat
- DUNE FD is huge, liquid argon takes hours to flow from one side to the other side. Using strings on opposite sides of cryostat will help to inform where contamination is coming from.
- At 35T (~3m depth), when the tubing break happened, the bottom PrM dropped from 4.5 ms to 0.4 ms while the top PrM only changed from 2.5 ms to 2 ms (Alan Hahn)
- The DUNE far detector is deep (12 m) and we need to know purity at different heights:
  - Monitor purity right after filling → bottom PrM
  - Monitor purity closer to outgas from surface → top PrM
  - Monitor purity at mid-point of the cryostat height→ middle PrM
- Three purity monitors on each side will provide good redundancy for long-term running, guarantee at least one purity monitor in each side working.

Inline: 2 PrMs, before and after LAr filtering, to understand the performance of filtering

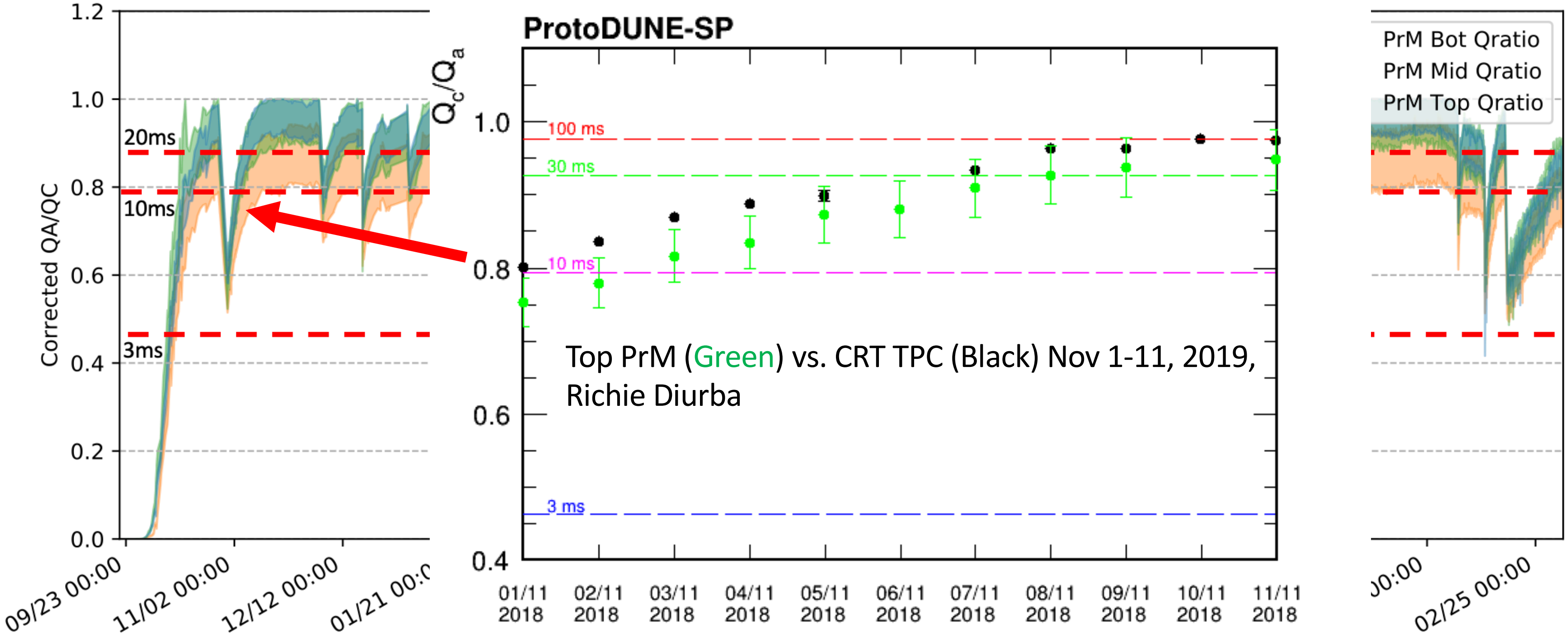
Just started to discuss to add 2 extra, very short (5 cm) PrMs on the cryostat floor to better monitor the very beginning of the filling stage

Does the system have a well-justified role in facilitating the analysis of far detector data, and if so, what is the minimum amount of system scope required to fulfill this role?

- Electron lifetime measured by PrMs referred in the first ProtoDUNE-SP analysis paper
- After correcting E-field difference, PrM electron lifetime is consistent with CRT TPC electron lifetime taken at several points
- PrMs can provide continuous electron lifetime for all ProtoDUNE-SP runs
- Similar technique can be used for DUNE: cosmic rays are rare in DUNE FD but we can accumulate a long time to measure electron lifetime at a few points. After validating the E-field corrected PrM lifetime with CRT TPC lifetime, the PrM can provide continuous electron lifetime measurements to calibrating all DUNE runs
- Three cryostat purity monitors can measure/validate stratification of LAr purity

Qa/Qc with offline transparency correction

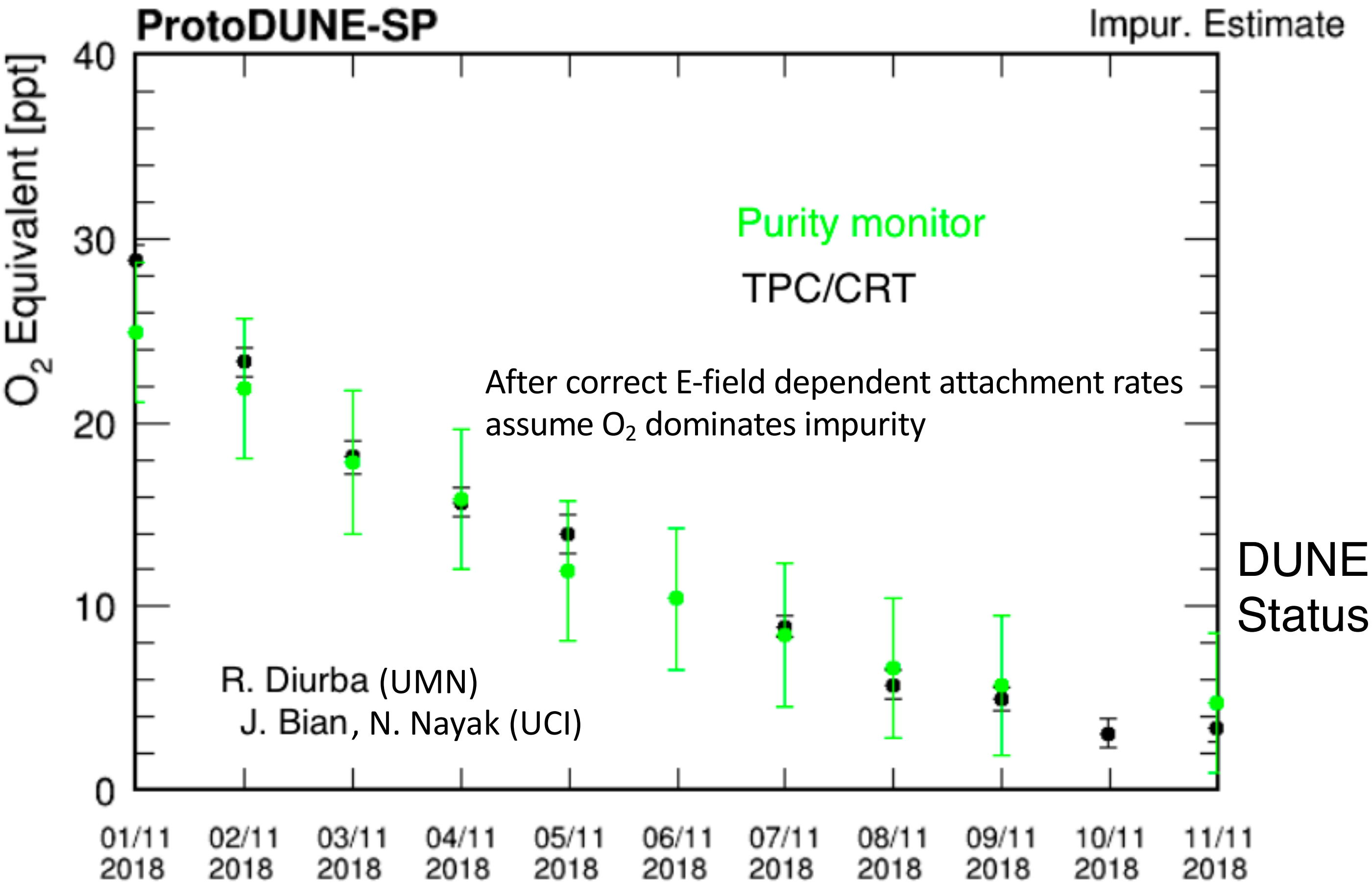
Normalized to drift time = 2.3 ms.



Top PrM (Green) vs. CRT TPC (Black) Nov 1-11, 2019, Richie Diurba

Cosmic Ray Tagger (CRT) cosmic data have independent drift pathlength and drift time measurements, less affected by space charge effects → good source for TPC electron lifetime measurement at ProtoDUNE

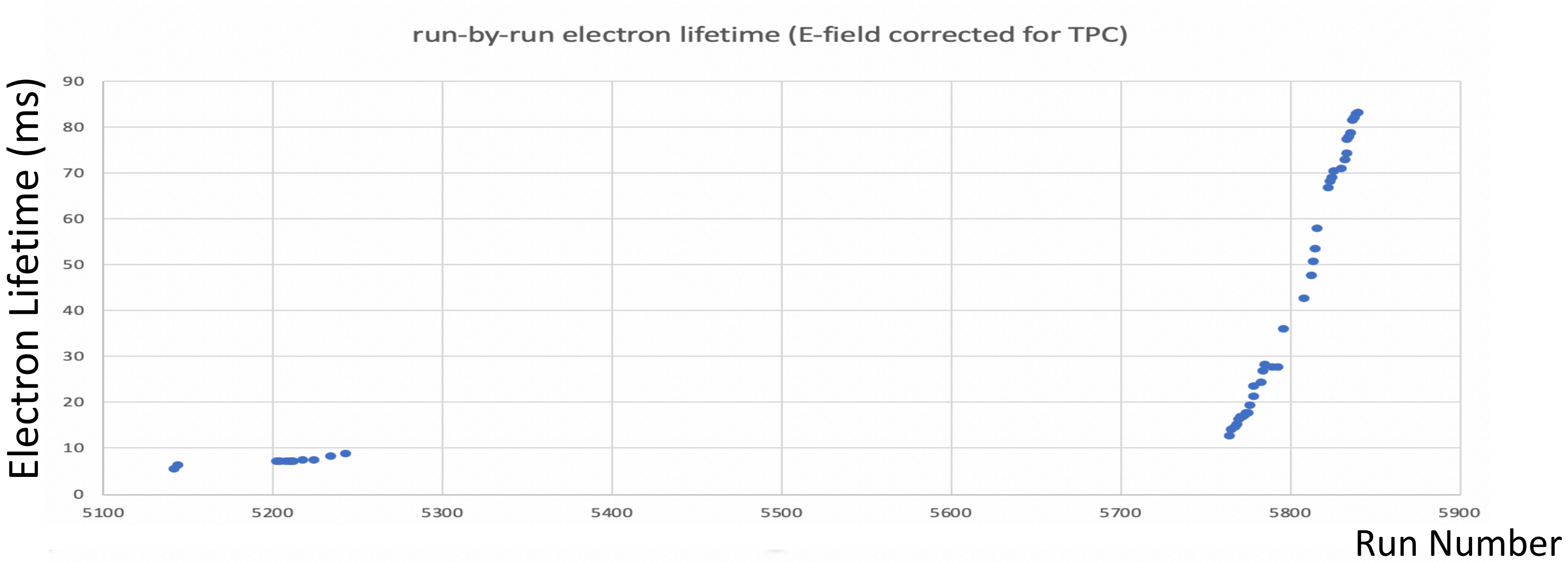
Purity monitor and CRT/TPC electron lifetime



DUNE Project, Monthly Status Report, March 2020

The impurity measured by purity monitors and TPC/CRT are in a good agreement. Provided PrM lifetime to ProtoDUNE-SP analysis group for run-by-run lifetime calibration.

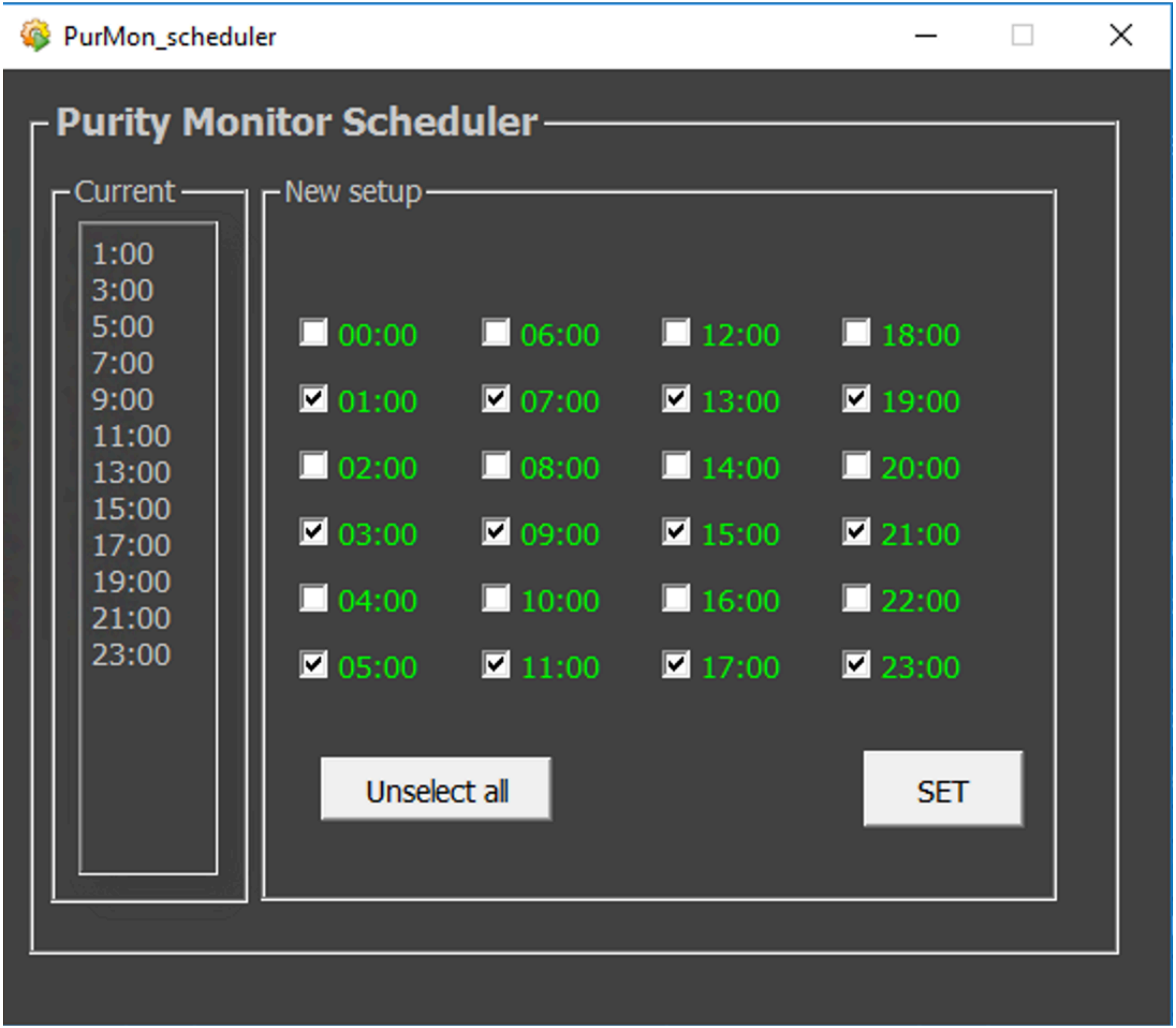
PrM lifetime for run-by-run beam particle dQ/dx calibration



Have all technical issues related to the feasibility of the system (including those raised in the previous workshops) been resolved?

- Have solved feasibility of the system such as installation and operation during the running of purity monitors in ProtoDUNE-SP-I
- ProtoDUNE-SP-II:
  - Strengthen mechanic robustness of PrM mounting rod to simply the installation, in ProtoDUNE-I we needed 4 people to hold and protect the rod when we lift the assembly
  - Operate the long purity monitor and the inline purity monitor
  - Further study photocathodes degradation (only happen when operating purity monitors with high frequency in low purity, daily running doesn’t degrade photocathodes)
  - Study running schedule of cryostat and inline purity monitors, try replacement of inline purity monitor
  - Inline purity monitor has identical detector technique as cryostat purity monitors and has been successfully implemented in previous experiments (35t)

PrM Schedule in DCS



PurMon_scheduler

Purity Monitor Scheduler

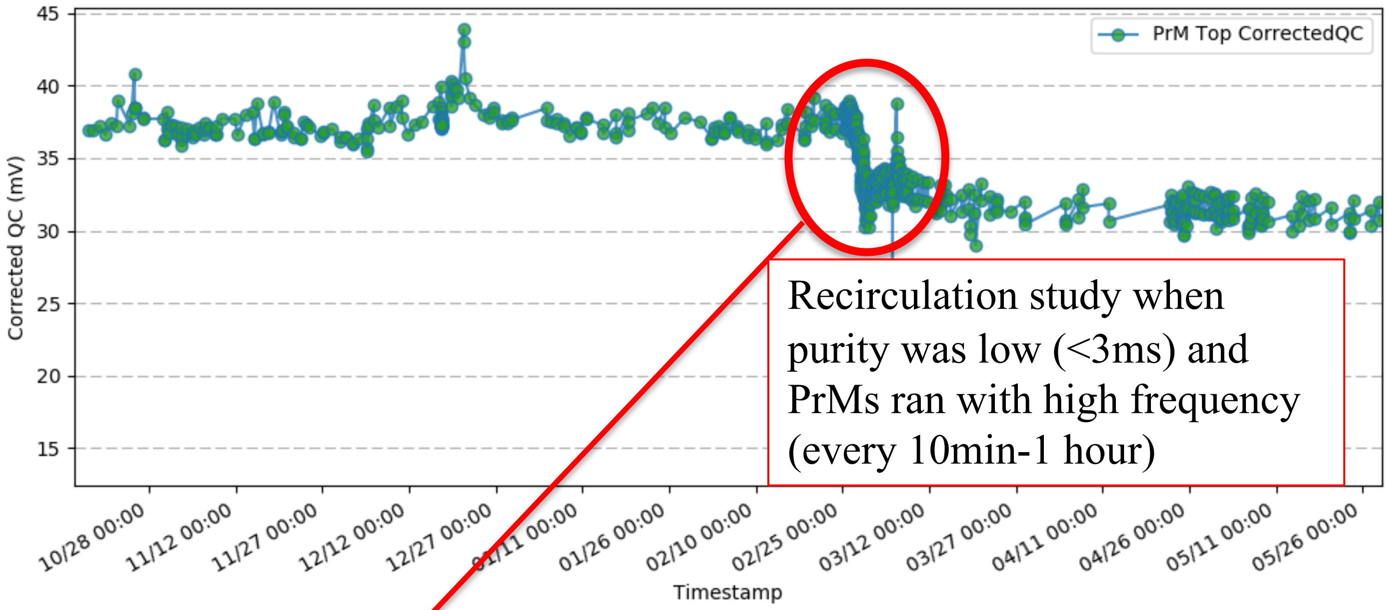
Current

1:00
3:00
5:00
7:00
9:00
11:00
13:00
15:00
17:00
19:00
21:00
23:00

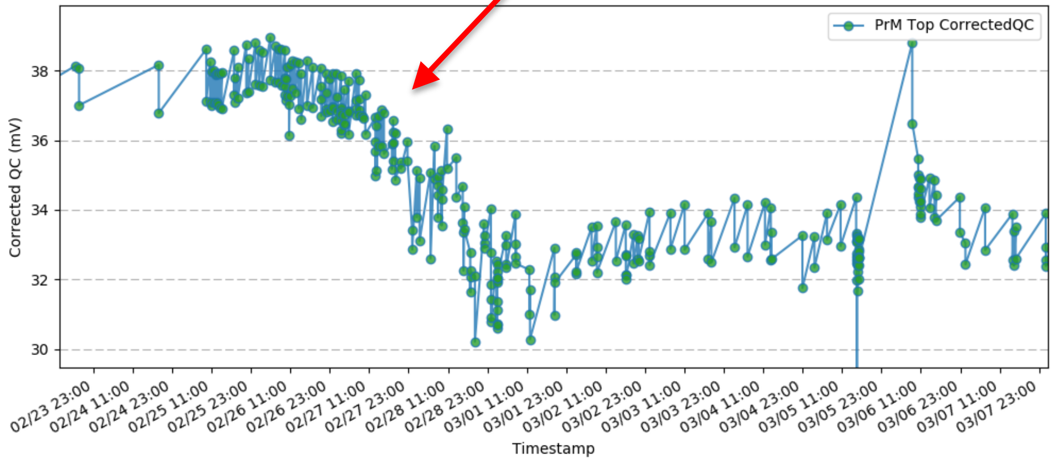
New setup

☐ 00:00 ☐ 06:00 ☐ 12:00 ☐ 18:00
☑ 01:00 ☑ 07:00 ☑ 13:00 ☑ 19:00
☐ 02:00 ☐ 08:00 ☐ 14:00 ☐ 20:00
☑ 03:00 ☑ 09:00 ☑ 15:00 ☑ 21:00
☐ 04:00 ☐ 10:00 ☐ 16:00 ☐ 22:00
☑ 05:00 ☑ 11:00 ☑ 17:00 ☑ 23:00

ProtoDUNE-SP top PrM Cathode Signal over time



Recirculation study when purity was low (<3ms) and PrMs ran with high frequency (every 10min-1 hour)

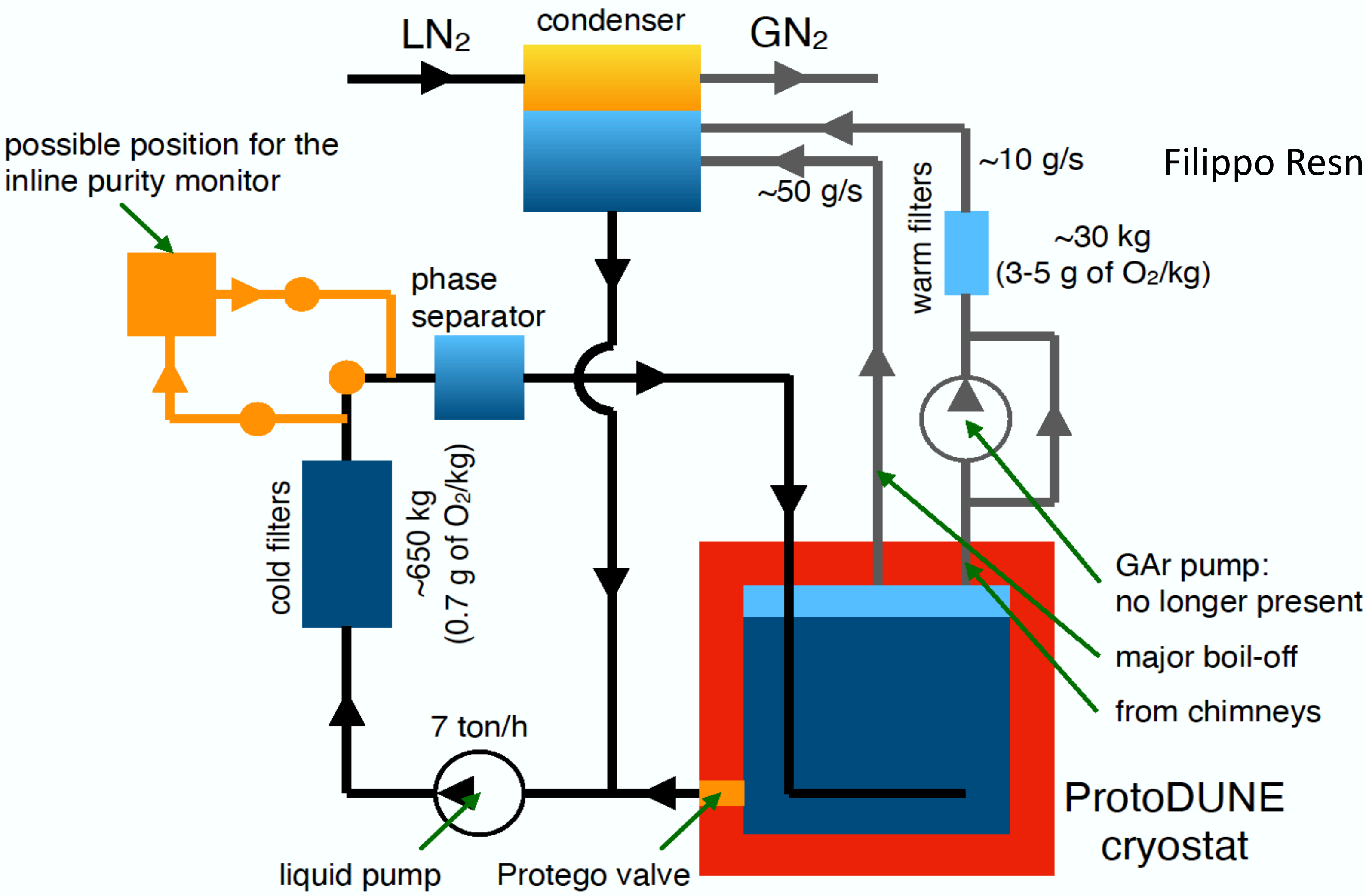


At ProtoDUNE-SP, we found that photocathode degradation only happen when operating purity monitors with high frequency in low purity LAr, daily running doesn’t degrade photocathodes

Simplified cryogenic circuit

For ProtoDUNE-SP-II inline purity monitor

Filippo Resnati



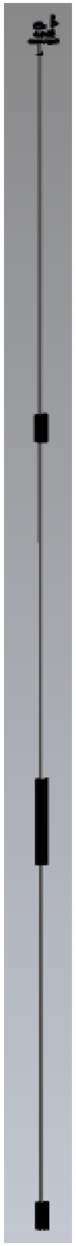
From CERN: The installation of inline PrM must be at least supervised by CERN cryogenic team, system must then be integrated with the cryogenic control.

More on installation of ProtoDUNE-SP-II inline Purity Monitor

From Filippo Resnati@CERN

- The installation must be at least supervised by CERN cryogenic team
- Coordinating the design and the production with CERN, so that everybody agrees on what will be installed well in advance
- There will be pipe welding and vacuum insulation pipes to be modified and added → probably need to rely on cryogenic team at CERN
- The system must then be integrated with the cryogenic control

Total: 12 m

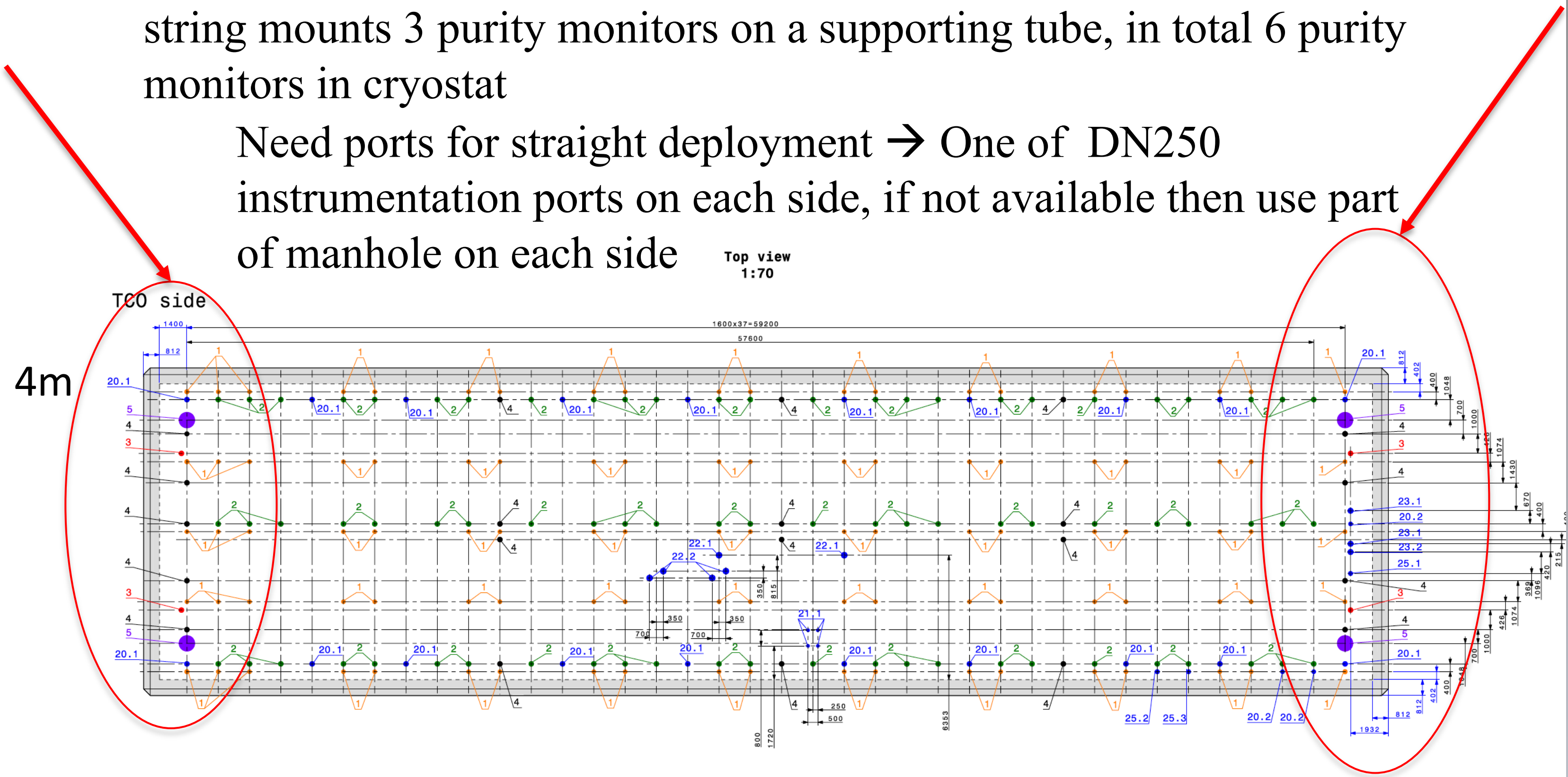


DUNE Cryostat Purity Monitors

4m

Two strings of purity monitor assemblies on TCO and back sides, each string mounts 3 purity monitors on a supporting tube, in total 6 purity monitors in cryostat

Need ports for straight deployment → One of DN250 instrumentation ports on each side, if not available then use part of manhole on each side



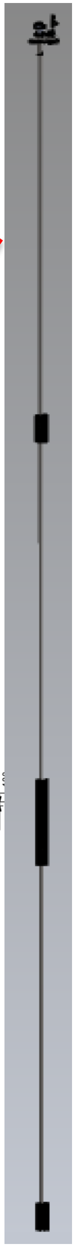
4m

Detector penetrations

3.6 m

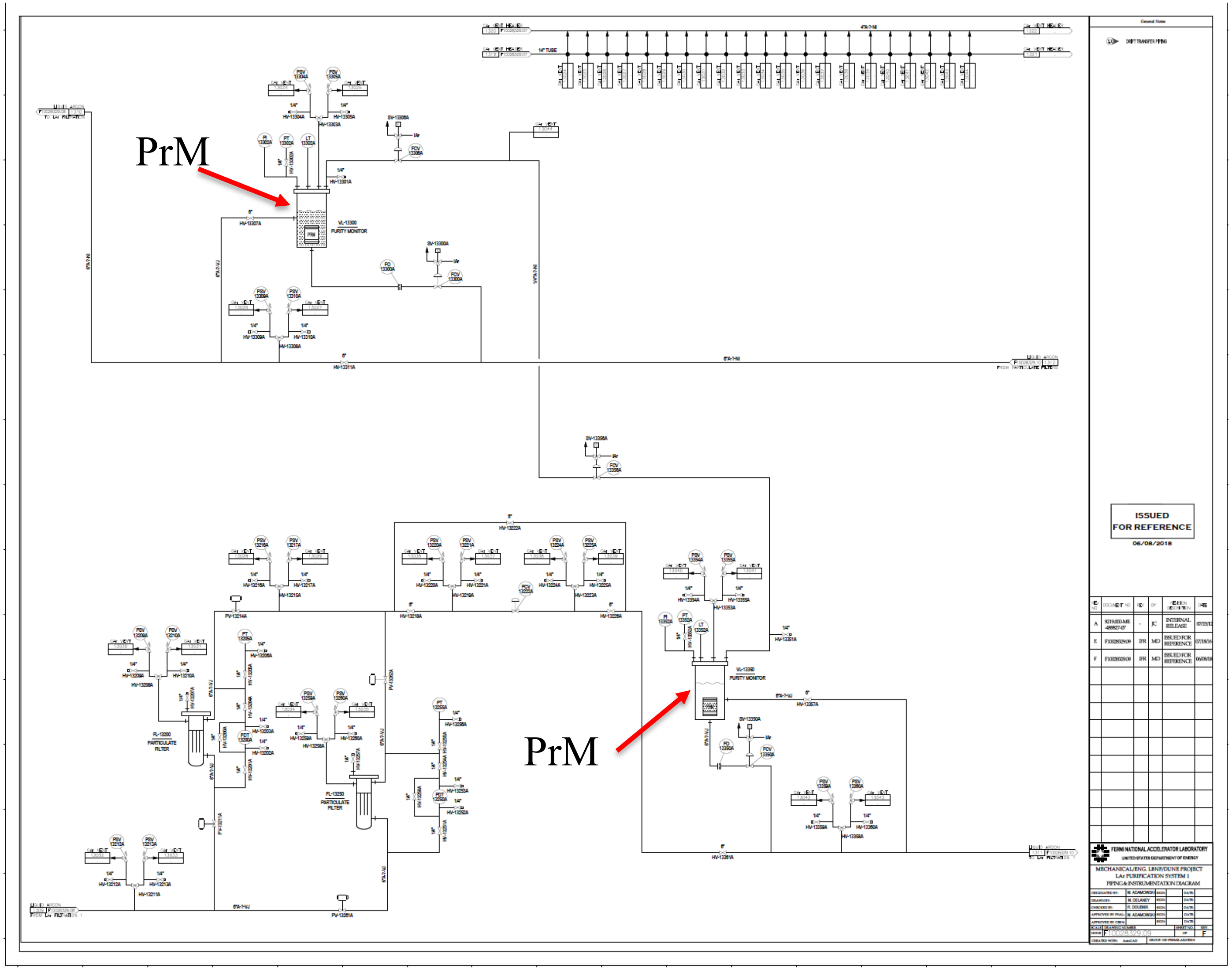
Pos.	Diameter [mm]	Quantity	Description
1	Ø200	100	Support
2	Ø250	75	Cable
3	Ø250	4	High voltage
4	Ø250	21	Instrumentation
5	Ø800	4	Manholes
7	2680x13428	1	Temporary Construction Opening

- Most feasibility issues have been solved in ProtoDUNE-SP-I
- DUNE PrM Mounting rod is ~4m longer than ProtoDUNE, needs to study mechanic robustness



DUNE Inline Purity monitors

2 PrMs outside of cryostat inline with cryogenics system, before and after filtration system



Are there any risks to overall detector performance associated with the implementation of the system, and if so, is there a plan in place for mitigating these risks?

There were minor risks to other systems and they have been considered and mitigated during ProtoDUNE-I’s running:

- Light noise to PDS: schedule PrM running in DCS, automatically lower PDS’s HV during PrM running, include PrM trigger in DAQ
- Electronic noise to TPC: ground PrM and Flash lamp properly, include PrM trigger in DAQ

Is there a credible plan in place for demonstrating system performance in ProtoDUNE-II?

- Reuse and switch the 2 of the 3 standard (25cm) ProtoDUNE-SP-I PrMs (top and bottom) in ProtoDUNE-II to understand purity stratification:
  - Compare results with ProtoDUNE-I after purity stabilized
  - Check if the top/bottom lifetime difference in ProtoDUNE-SP-I is caused by hardware bias
  - Can confirm stratification if still see higher lifetime in top PrM (bottom PrM in ProtoDUNE-I)
- Replace the ProtoDUNE-I middle purity monitor with a new or refurbished long (100 cm) purity monitor in ProtoDUNE-II to eliminate syst. error in transparency correction:
  - Long PrM can reduce overall Qa/Qc uncertainty (dQ/dx uncertainty) from ~5% to ~1.5%
  - The longest purity monitor used before is ~55 cm. A 100 cm is clearly possible but may require more serious engineering.
  - For a 100 cm long PrM, cathode/andoe HV = 50V/4000V gives full grid transparency with 2.3ms drift time (same as TPC drift time)
  - In protoDUNE-I when anode HV>3000V the signal became unstable due to discharge in gas phase, so R&D is needed to optimize long PrM's operation High Voltage, detector length, and improve feedthough

Is there a credible plan in place for demonstrating system performance in ProtoDUNE-II?

- Long PrM R&D:
  - Test long PrM in teststand filled with argon gas, demonstrate required Anode HV in gas phase can be achieved
  - Feedthough: increase thickness of cryo glue and length of G10 tube for better isolation
  - HV optimization: optimize anode/cathode HV
  - Detector Length Optimization: if Anode HV=4000V can not be achieved in argon gas, optimize distance between cathode and grid and distance between grid and anode to reduce required anode HV to 3000V
  - Ideally start R&D this summer and finish by early next year
- ProtoDUNE-II CRT cosmic ray data will be used to valid absolute electron lifetime measured by PrMs
- Run-by-run lifetime (dQ/dx) calibration provided by PrMs can be tested by beam particle dQ/dx in ProtoDUNE-II.
- Inline purity monitor: Build or refurbish 1 standard PrM within recirculation system (inline), after the LAr filter:
  - Study photocathodes degradation with by operating purity monitors with high frequency in low purity
  - Run inline PrM hourly, and design alarming system to quickly response to purity change due to re-circulation accident
  - Test the response speed of this alarming system by stopping pump and/or vent intentionally

Does the functionality of the system justify its overall cost?

- Purity monitors are essential to the operation of the detector, they also provide continuous electron lifetime measurement for data analysis
- Working on pricing for ProtoDUNE-II PrMs

ProtoDUNE2 – Cryostat Purity Monitors

ProtoDUNEII-SP-II, Inline Cryostat Purity Monitors				
Item	Cost/unit	Quantity	Total	Details/Comment
Long PrM structure	$6,000	1	$6,000	
Photocathode, fiber replacement	$2,000	1	$2,000	
4kV Feedthrough for long PrM	$1,000	2	$2,000	Make one extra feedthrough for backup
Total M&S			$10,000	

- Extra hardware to form a full PrM system for long PrM R&D includes: HV supply and crates ($20k), Xenon light source ($3.5k), Flange/tubing ($10k), PrM electronics ($3k), Digitizer ($2k), DAQ PC ($1k). Note that these components will be reused in DUNE.
- If time is plenty, and budget is tight for ProtoDUNE-II, we can ship R&D needed components from CERN to UCI (at least HV) and after finish R&D ship them back to CERN for ProtoDUNE-II

ProtoDUNE2 – Inline Purity Monitor

Detector cost:

ProtoDUNEII-SP, Inline Purity Monitor					
Item	Cost/unit		Quantity	Total	Details/Comment
Refurbished/build new purity monitor parts	$5,000.00*	per PrM	1	$5,000.00	Based on standard length
Xenon Source	$3,500*	each	1	$3,500.00	Hamamatsu Flash Lamp+Discharge Capacitor+HV, Costum Faraday Cage
LV+Optic trigger	$1,000	each	1	$1,000.00	LV: WIENER; Optic Trigger: Thorlab
Fibers	$1,000	each	1	$3,000.00	Molex, ~$25/meter, 8 fibers/purity monitor
Cable+connectors	$500	each	1	$1,500.00	Cable: Jaguar; Connector:digi-key
Digitizer	$2,500	total	1	$2,500.00	Alazar (protoDUNE)
Electronic Box	$3,000*	each	1	$3,000.00	Costum, parts from digi-key
Cable Feedthrough	$1,000	each	1	$1,000.00	CerarmTec
Optic Feedthrough	$1,000	each	1	$1,000.00	Conax
Machine Shop	$1,000	per PrM	1	$1,000.00	Based on UCI machine shop estimate
Total PrM M&S				$19,500	

* Could be saved if existing parts can be used

** if can not share HV power supply with cryostat PrM, need to buy another HV with $15k

Cryogenic cost:

CERN estimate the overall cryogenic cost to be 100k for ProtoDUNE-I, including valves hoses, piping, fittings + labor

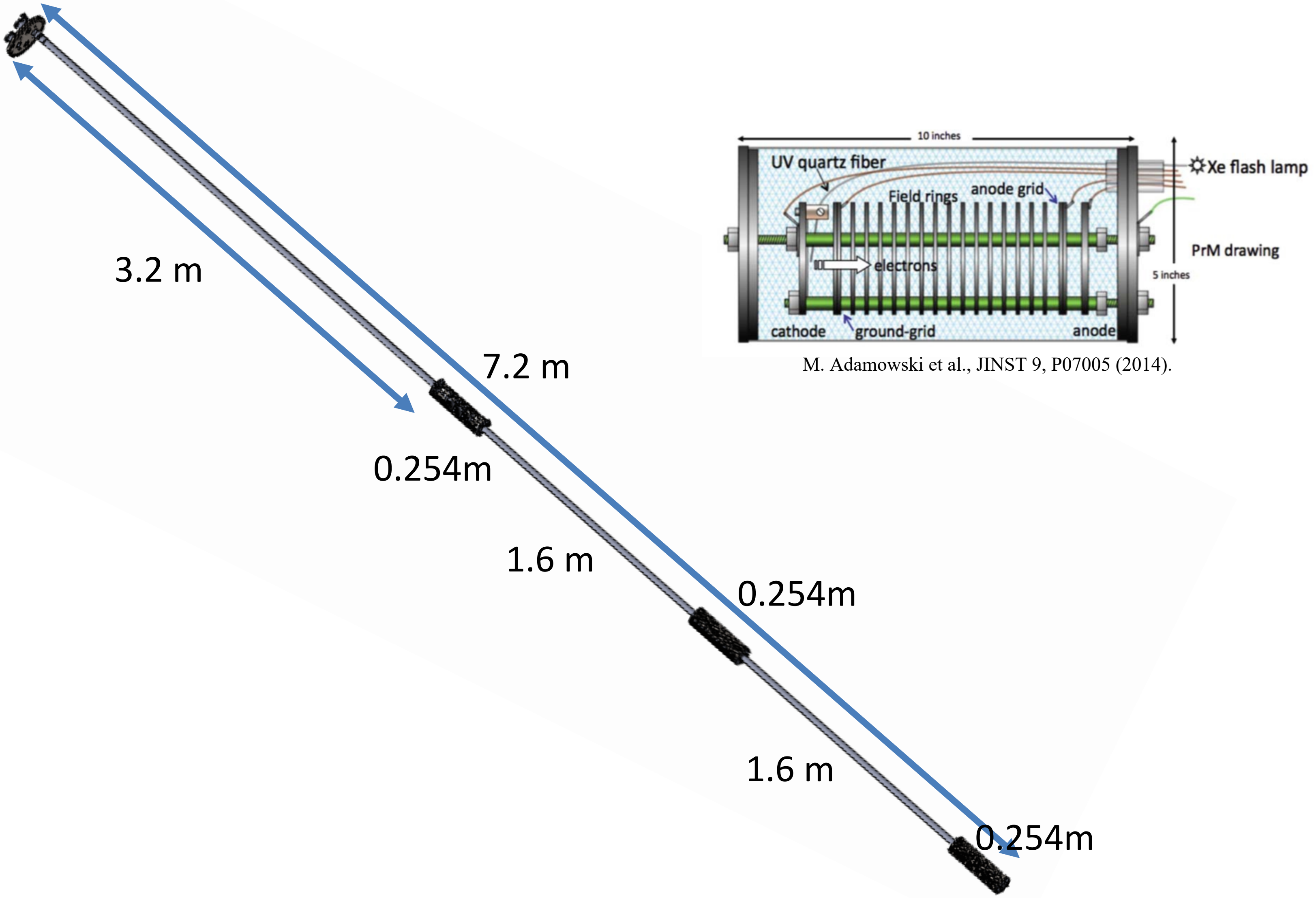
DUNE Purity monitors

Purity Monitors (SP Module)

Item	Cost/unit		Quantity	Total	Details/Comment
PrM Units	$19,000		8	$152,000	6 PrMs in cryostat and 2 inline, including feedthroughs, cables and fibers
Cryostat Flanges	$6,600		2	$13,200	Including tubing, valves, reducer, adaptors et. Al.
Inlinde Flanges	$4,350		2	$8,700	Including tubing, valves, reducer, adaptors et. Al.
Mounting	$5,500		2	$11,000	Mounting needed for 2 strings in each cryostat
Xenon Source	$3,500		3	$10,500	Hamamatsu Flash Lamp+Discharge Capactor+HV, Costum Faraday Cage
High Voltage	$14,700		2	$29,400	ISEG_EHS 8420x_405 8ch, 8460x_105 8ch, Mpod Mini LX
Digitizer Box	$400		4	$1,600	StarTech (ProtoDUNE)
PC	$2,000		2	$4,000	1 PC for cryostat PrMs and 1 for inline monitors, these PCs should be rugged one. (back up PC not included)
Total M&S				$230,400	

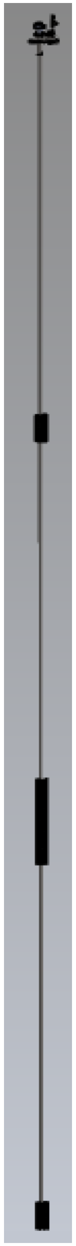
Backup

ProtoDUNE PrM Drawing



M. Adamowski et al., JINST 9, P07005 (2014).

Total: 12 m

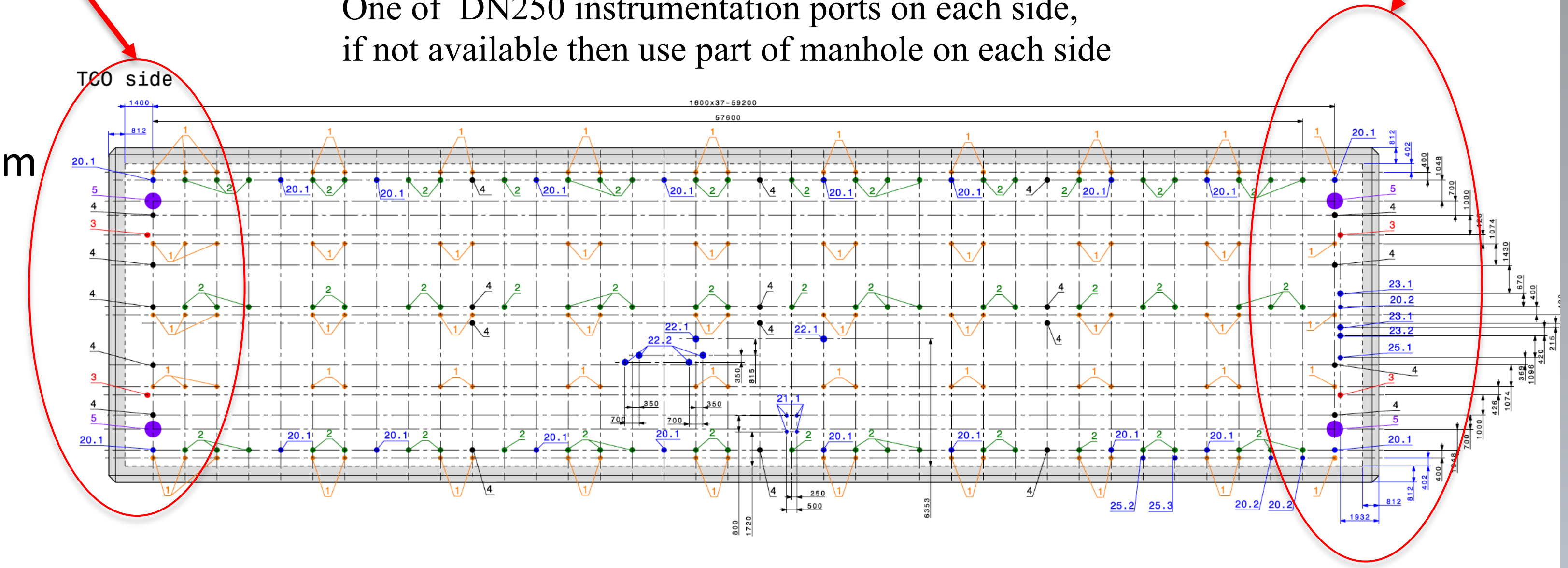


Cryostat Purity Monitors

Two strings of purity monitor assemblies on TCO and back sides, each string mounts 3 purity monitors on a supporting tube, in total 6 purity monitors in cryostat

Need ports for straight deployment

One of DN250 instrumentation ports on each side,
if not available then use part of manhole on each side

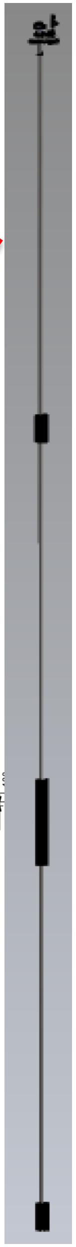


Detector penetrations

Pos.	Diameter [mm]	Quantity	Description
1	Ø200	100	Support
2	Ø250	75	Cable
3	Ø250	4	High voltage
4	Ø250	21	Instrumentation
5	Ø800	4	Manholes
7	2680x13428	1	Temporary Construction Opening

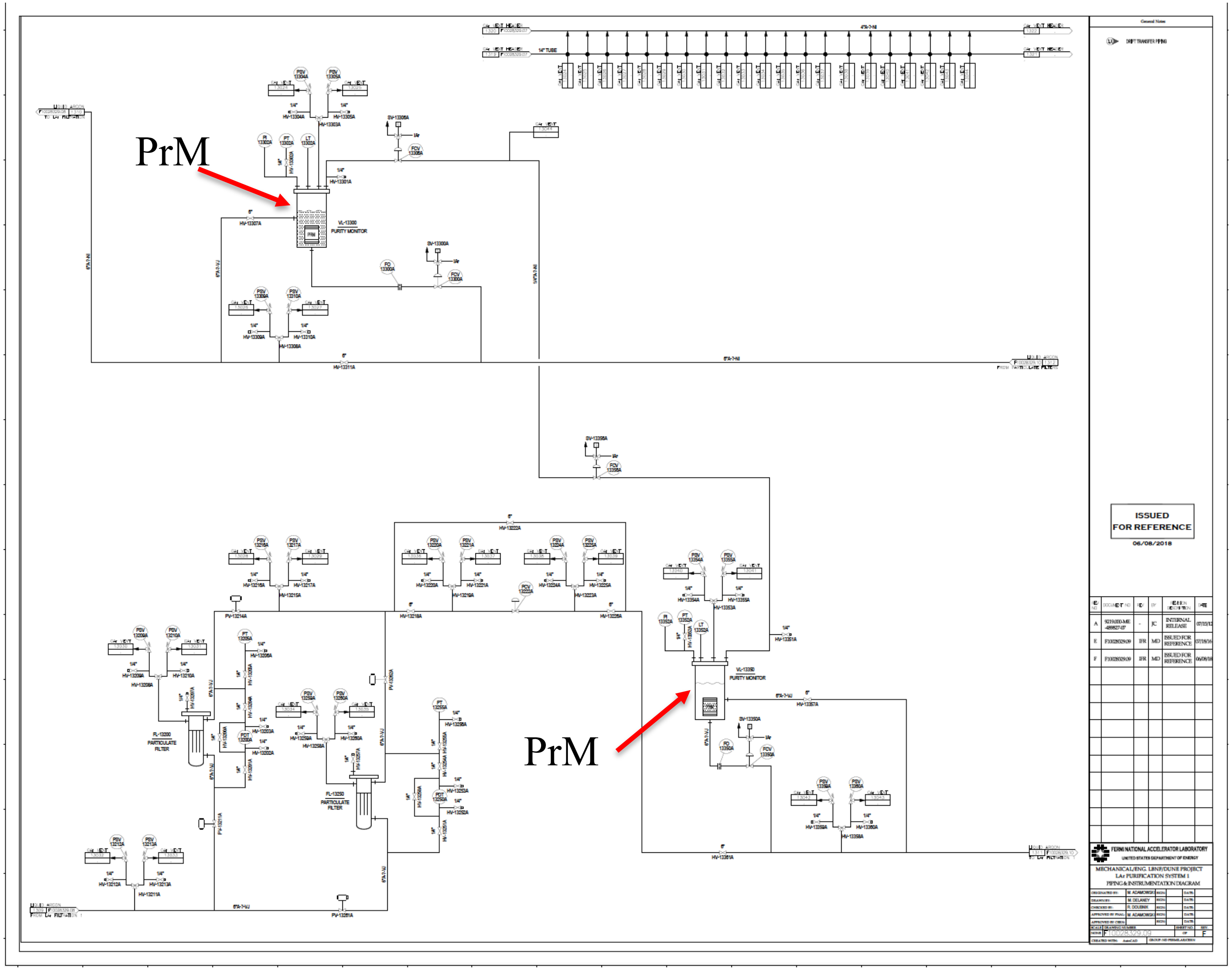
Similar system runs successfully in ProtoDUNE-SP

Locations for Inline Purity monitors under discussion



Inline Purity monitors

2 PrMs outside of cryostat inline with cryogenics system, before and after filtration system



ProtoDUNE-SP Purity Monitors

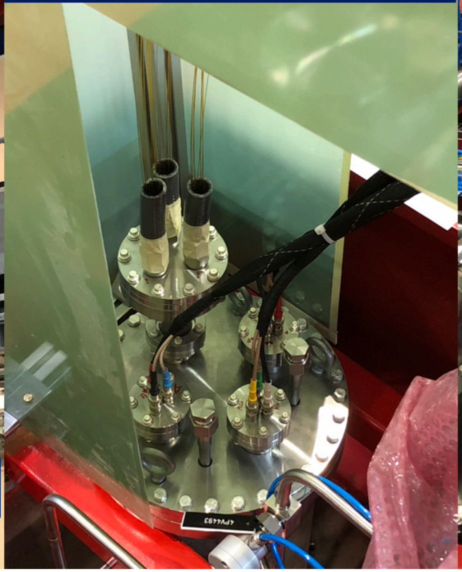
Top PrM

Middle PrM

Bottom PrM

Xenon Light Source

Top Flange



PrM Electronics

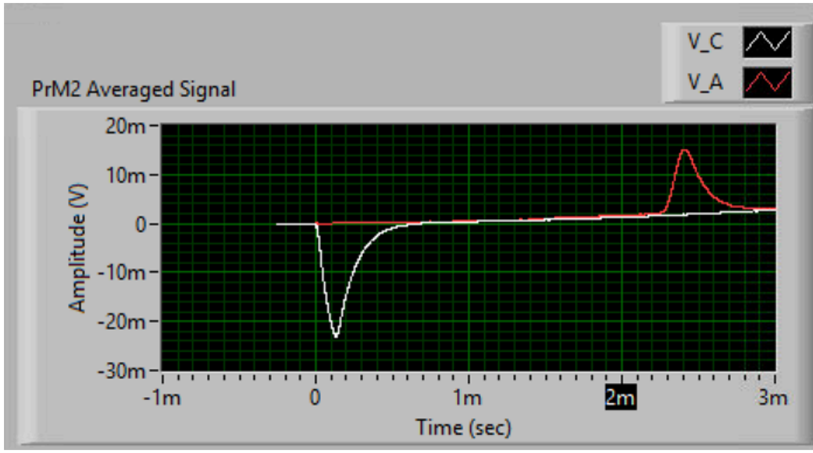
Fiber Protector

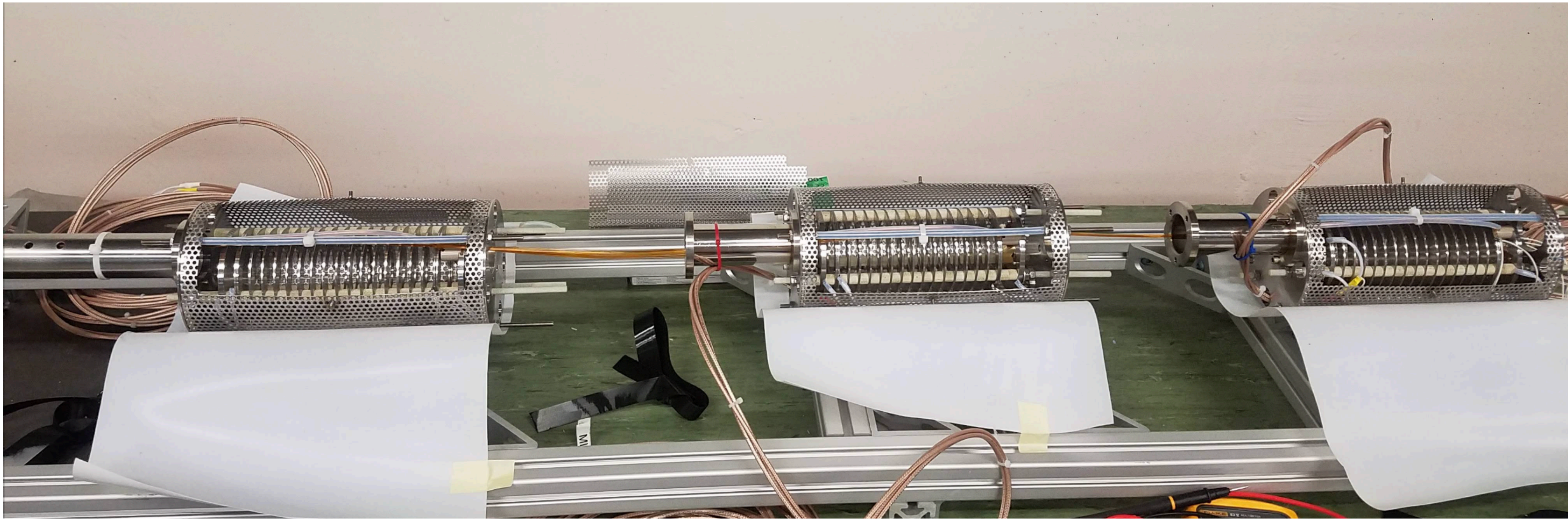
PrM in LAr

Improved PrM Signal in ProtoDUNE-SP

- PrM HV varied from 0.25 kV to 3 kV), allows for range of drift time from 150 us to 3 ms
- Increase UV light on cathodes by using 8 optic fibers for each PrM
- When e-lifetime ~7ms, Qa/Qc ~ 0.7 → anode signal significantly smaller than cathode → no saturation
- Each PrM measurement lasts 20 seconds with 200 UV flashes, provide high precision, localized electron lifetime
- Measured e-lifetime at ProtoDUNE-SP: 35us - 8 ms

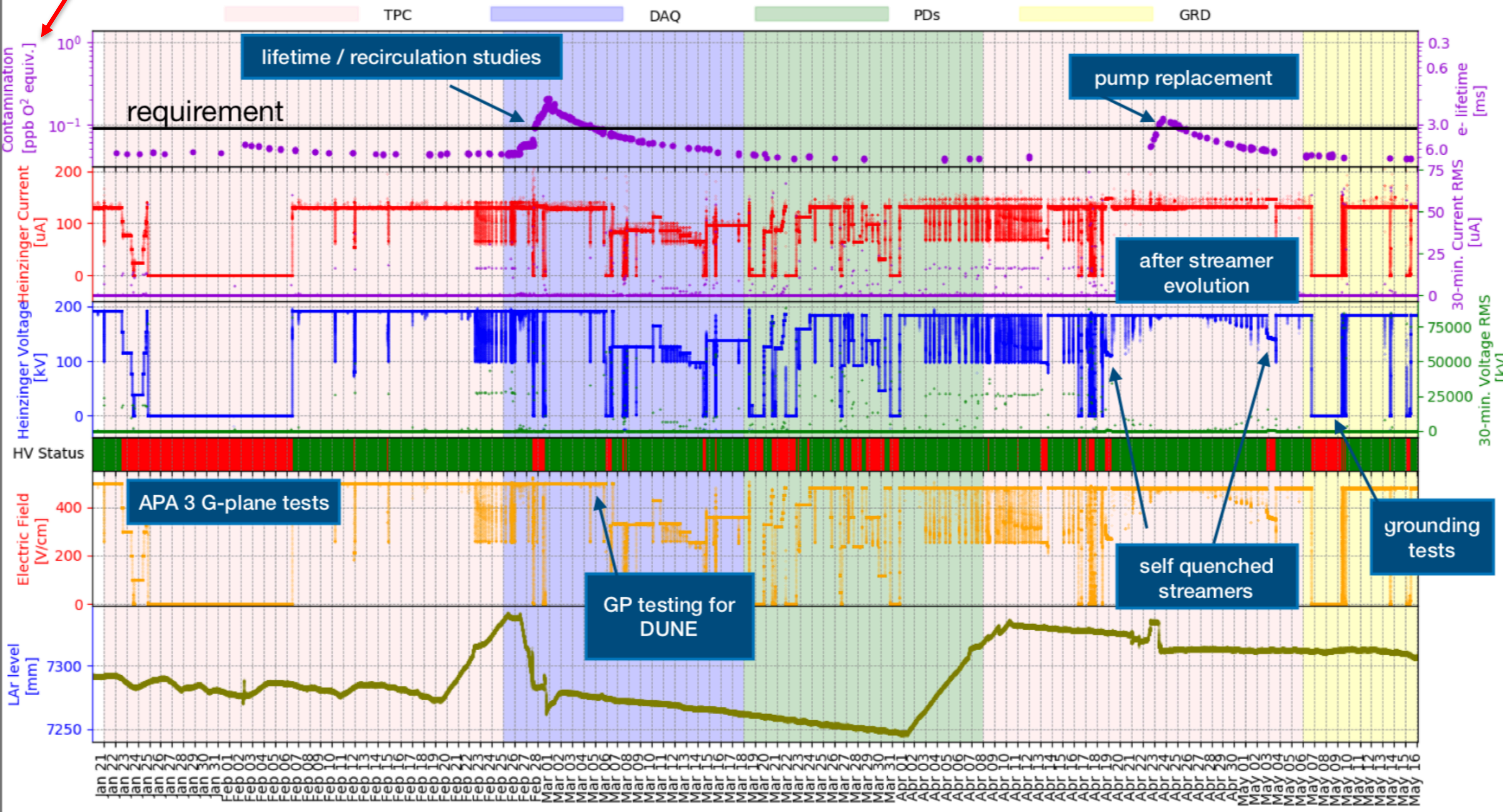
ProtoDUNE PrM signals at e-lifetime = 6 ms





Summary of the protoDUNE-SP activities

Purity from PrMs as benchmark for cryogenic operation and recirculation studies



requirement

lifetime / recirculation studies

pump replacement

after streamer evolution

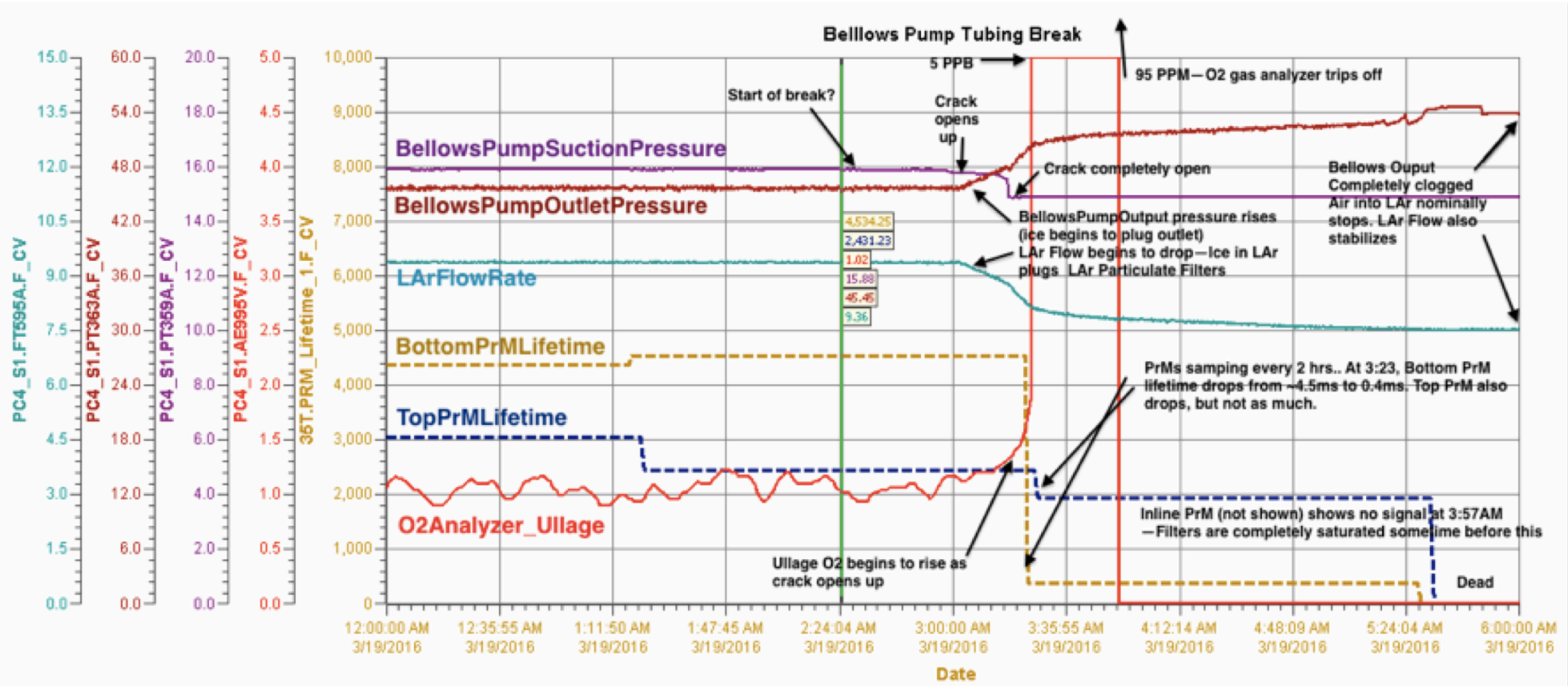
APA 3 G-plane tests

GP testing for DUNE

self quenched streamers

grounding tests

35T Tubing Break Timeline--3/19/2016



Belllows Pump Tubing Break

5 PPB

95 PPM—O2 gas analyzer trips off

Start of break?

Crack opens up

Crack completely open

Bellows Ouput Completely clogged Air into LAr nominally stops. LAr Flow also stabilizes

BellowsPumpOutput pressure rises (ice begins to plug outlet)

LAr Flow begins to drop—Ice in LAr plugs LAr Particulate Filters

PrMs samping every 2 hrs.. At 3:23, Bottom PrM lifetime drops from ~4.5ms to 0.4ms. Top PrM also drops, but not as much.

Inline PrM (not shown) shows no signal at 3:57AM —Filters are completely saturated sometime before this

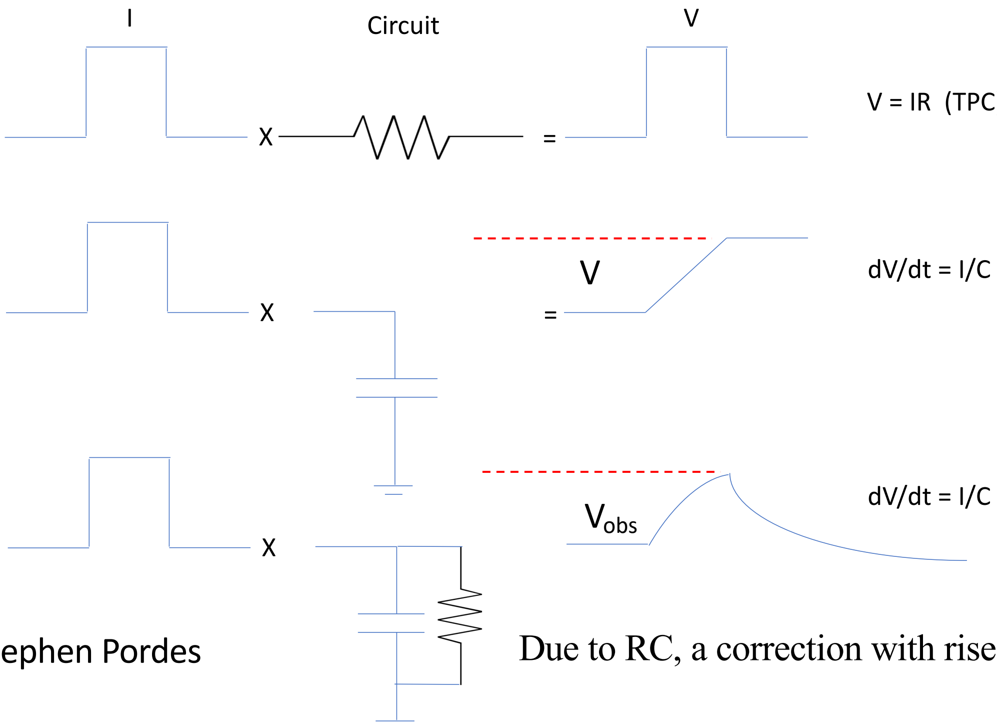
Dead

Ullage O2 begins to rise as crack opens up

Alan Hahn

RC Correction for PrM signal

PrM electronics uses integration circuit to read amplified cathode and anode signals:



V = IR (TPC)

dV/dt = I/C (pure C)

dV/dt = I/C – V/RC (PrM)

Stephen Pordes

Due to RC, a correction with rise time is needed to obtain signal voltage V (∝charge) :

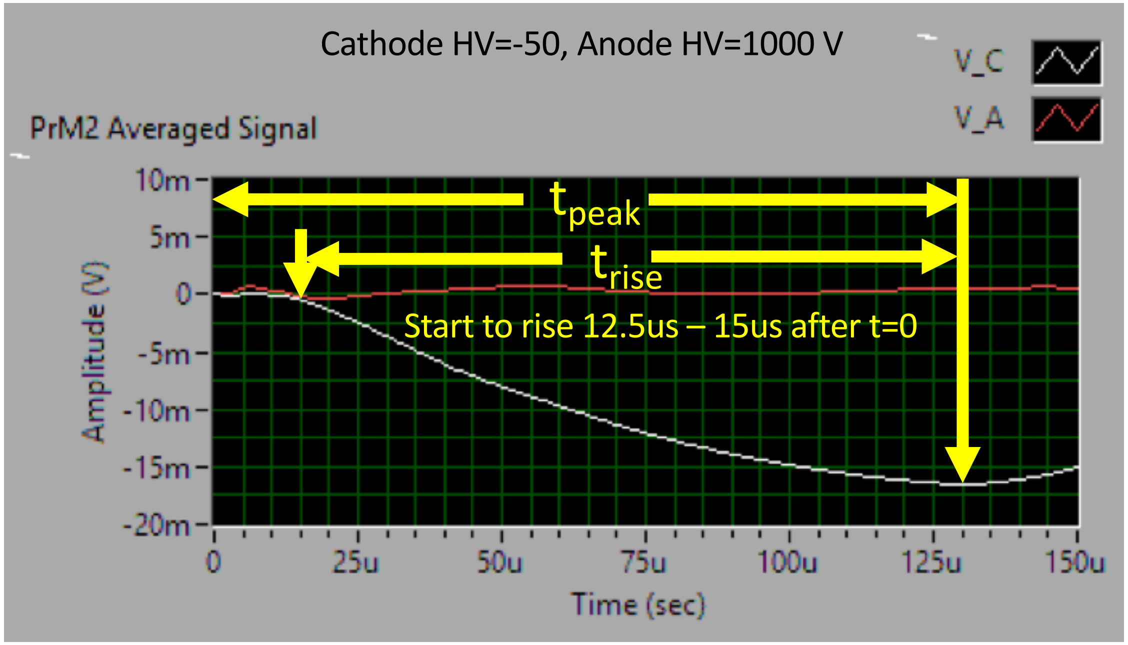
$$V = V_{obs} \cdot \frac{t_{rise}/RC}{1 - \exp(-t_{rise}/RC)}$$

$$V = V_{obs} \cdot \frac{t_{rise}/RC}{1 - \exp(-t_{rise}/RC)}$$

For cathode signal, online algorithm uses peak time t_{peak} as rise time t_{rise}

However, we find cathode signal doesn't start to rise at t=0

This bias increases cathode t_{rise} and Q_C, and decreases Q_A/Q_C and lifetime

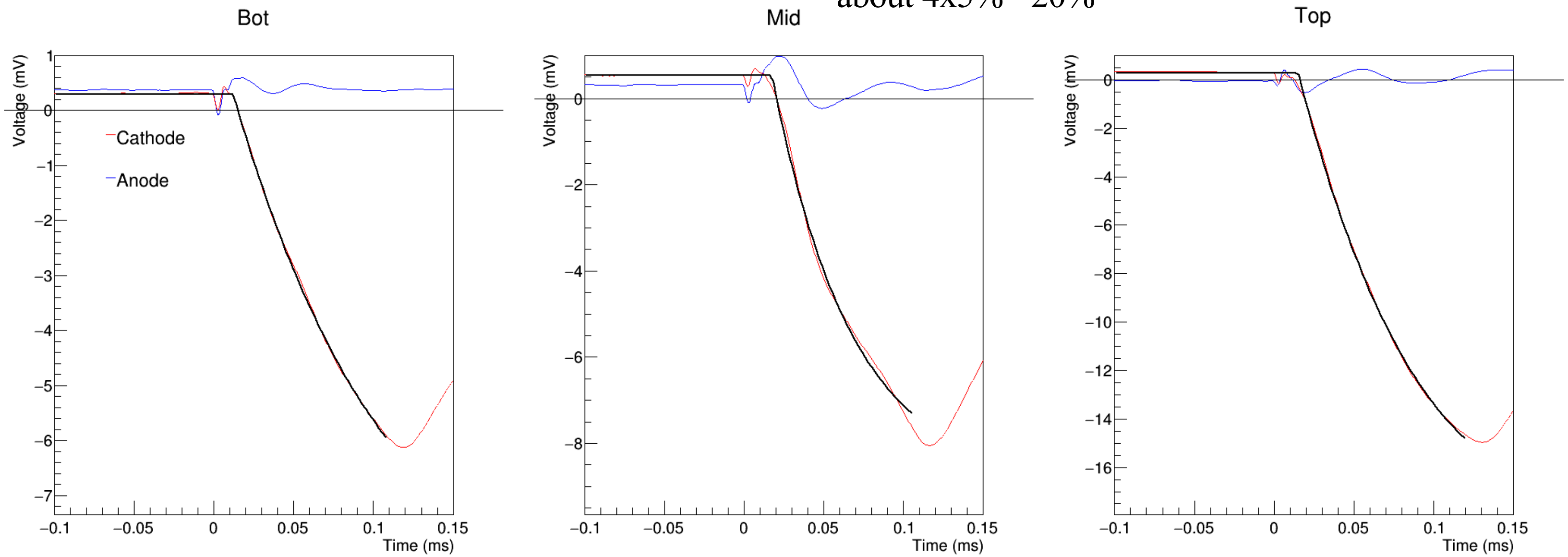


Start to rise 12.5us – 15us after t=0

Rise time for 50/1000V

$$V = V_{obs} \cdot \frac{t_{rise}/RC}{1 - \exp(-t_{rise}/RC)}$$

- Offline analysis finds t_{rise} should be ~15% smaller than t_{peak}
- This bias decreases Qa/Qc at 50/1000V by 5%, decrease Qa/Qa at 50/250V after online transparency correction by about 4x5% =20%



Start time: 12.0us
Peak time: 119.0us
Rise time: 107.0us

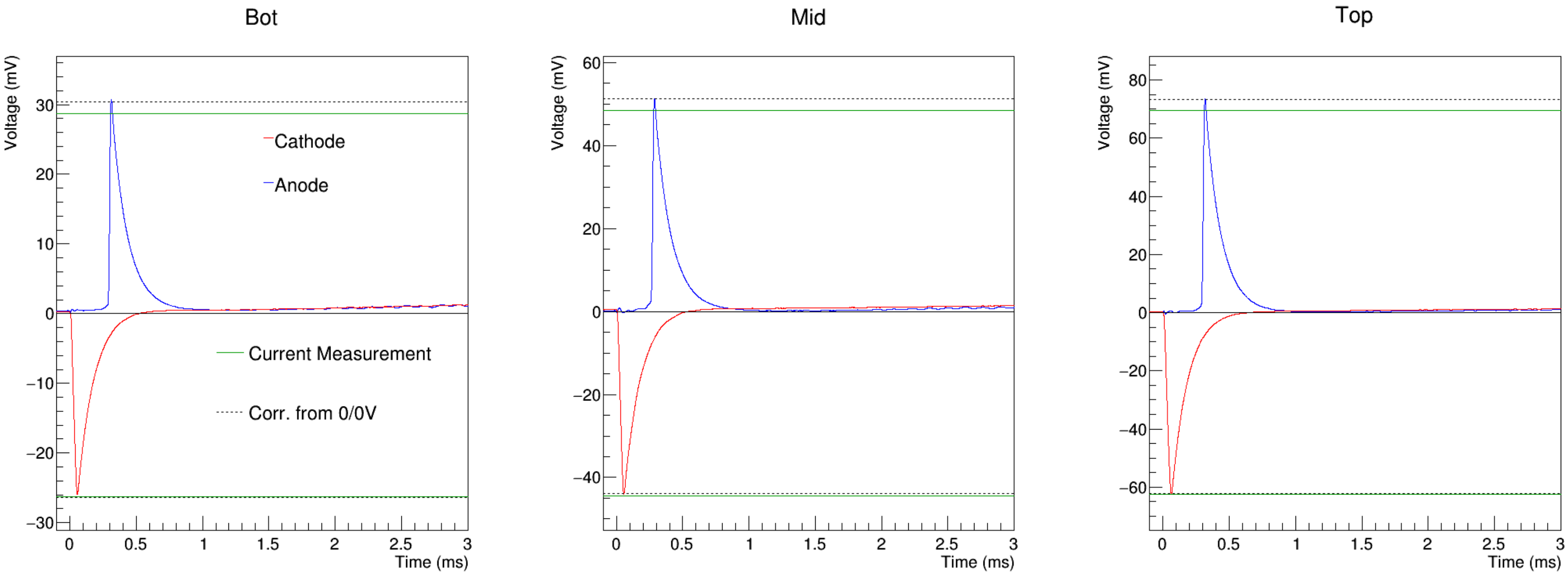
Start time: 17.75us
Peak time: 116.5us
Rise time: 98.75us

Start time 15.32us
Peak time 130.5us
Rise time: 115.18us

Online Peak Value

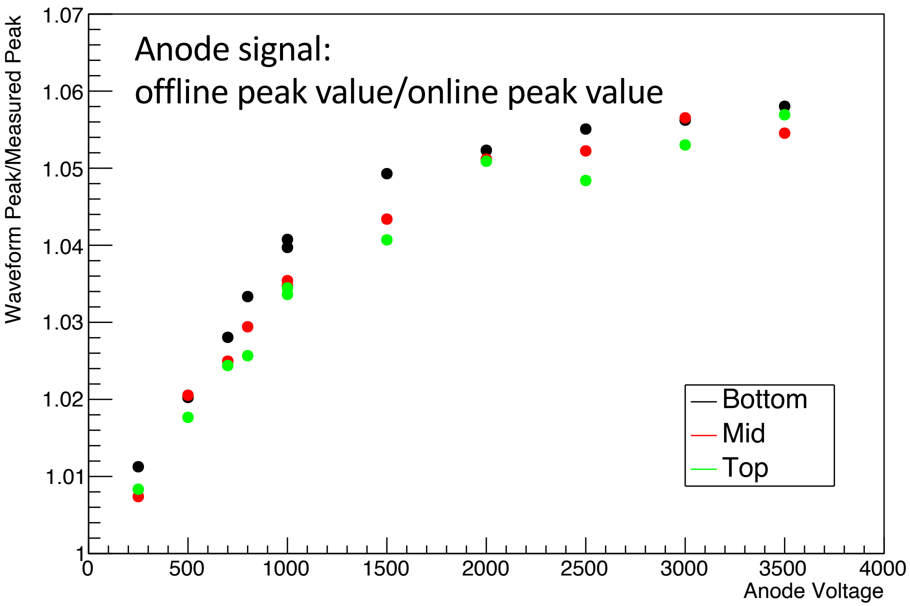
Online PrM algorithm has a smoothing process against noise
This smoothing process lower the peak value of the anode signal when the peak is narrow
This smoothing process is not used on cathode signal, so Q_A/Q_C value is decreased in online algorithm

Green line: online peak value
Dashed line: offline analysis peak value

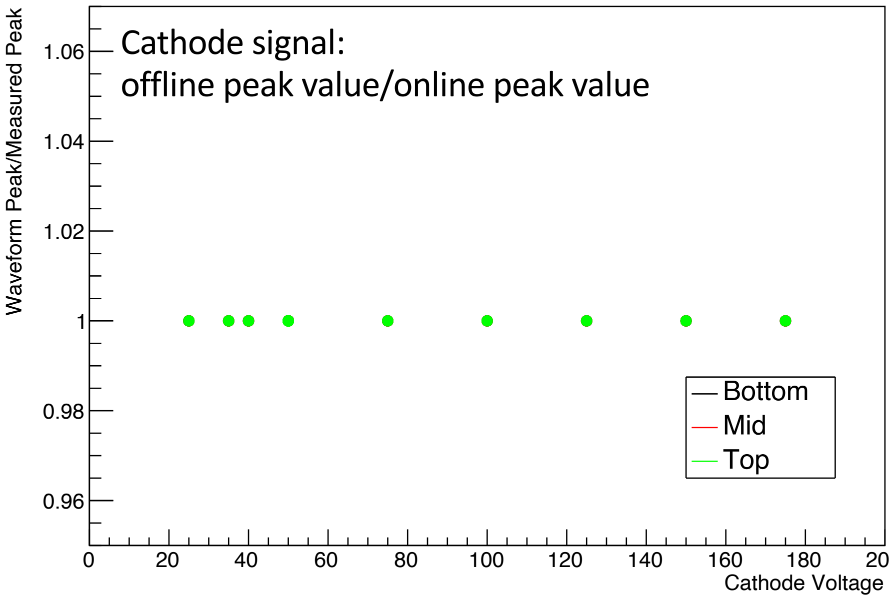


Cathode HV=-50, Anode HV=1000 V

Online Peak Value



Anode signal:
offline peak value/online peak value

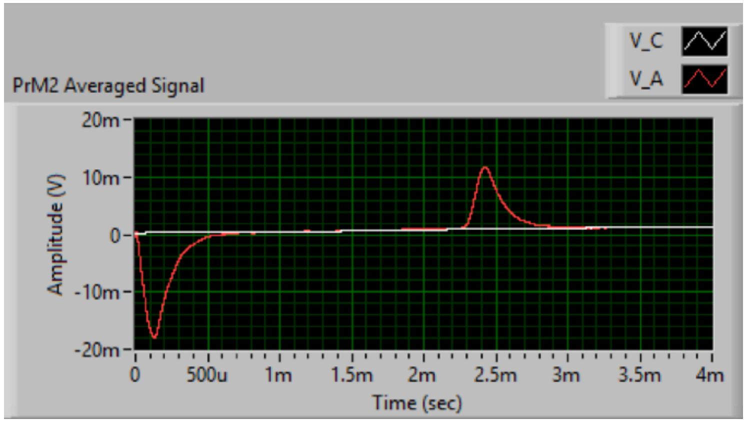


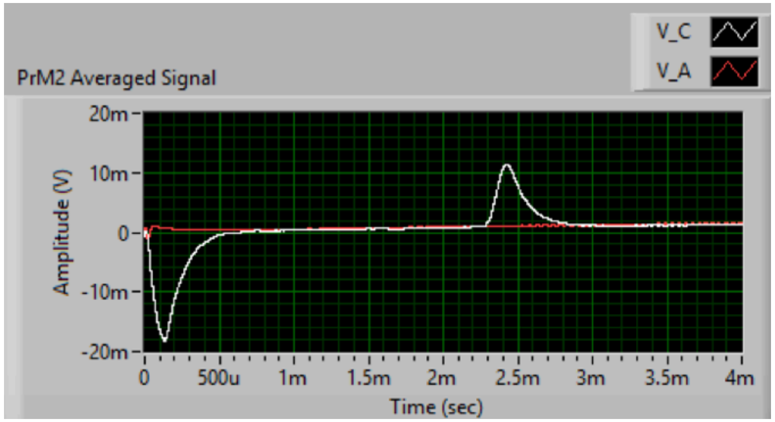
Cathode signal:
offline peak value/online peak value

Offline analysis without the smoothing process finds Q_A should be higher than online Q_A, increasing Q_A/Q_C at 50/1000V by ~3.5%, increase Q_A/Q_C at 50/250V after transparency correction by about 4x3.5% =14%

Gain correction

- The two electronic channels for cathode and anode signals have individual amplifiers, gain difference could cause a bias
- For each purity monitor, switch the cathode and anode signals on the two channels and take data to determine the gain difference
- Q_A/Q_C needs to be lowered by 0.76% (top), 2.32% (middle) and 3.63% (bottom) to correct the gain difference
- Note gain corrections are same for different HVs





Offline (new) Transparency correction

- Offline analysis shows that transparency correction for Q_A/Q_C is underestimated by ~20-30% in online algorithm→ need to re-determine transparency correction factors
- Take new data with full-transparency E-field (Cathode:Anode HV=1:20) at different voltages: 40/800V, 50/1000V, 75/1500V, 100/2000V, 125/2500V, 150/3000V, 175/3500V, use Q_A/Q_C vs. drift time to measure lifetime
- Use measured lifetime to calculate expected anode-to-cathode signal ratio $(Q_A/Q_C)_{expected}$ at 50/250V and 50/500V. The offline (new) transparency correction factor is determined by: $f_{trans} = (Q_A/Q_C)_{expected} / (Q_A/Q_C)_{observed}$

QA/QC vs Anode HV

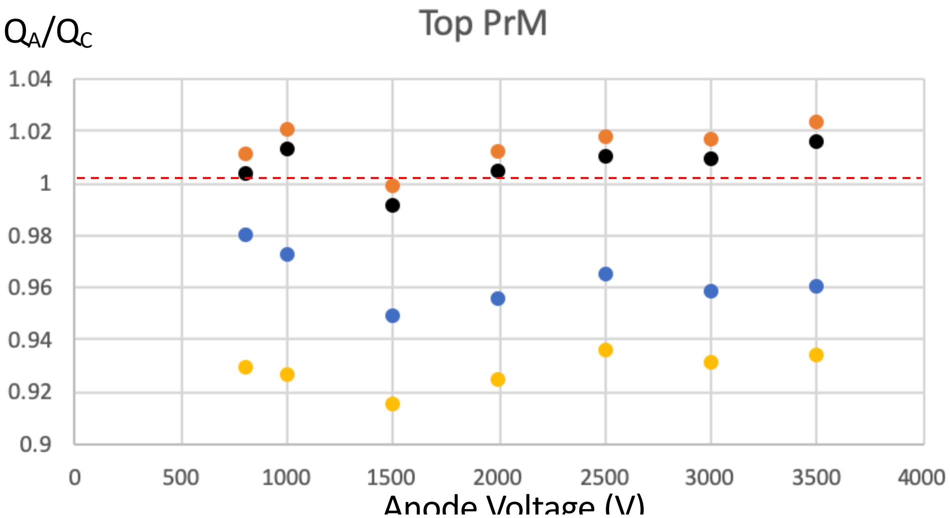
Take new data on Jan 11, 2020 with full-transparency E-field (Cathode:Anode HV=1:20) at 40/800V, 50/1000V, 75/1500V, 100/2000V, 125/2500V, 150/3000V and 175/3500V

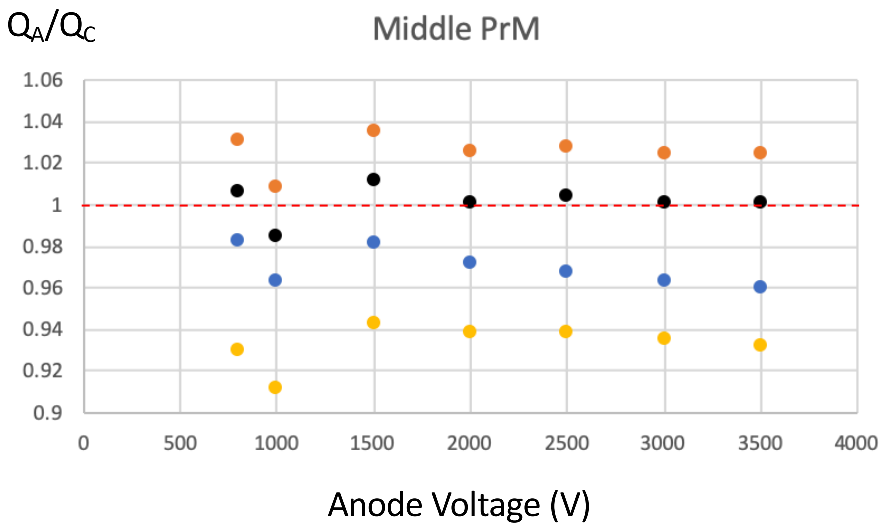
Yellow: online Q_A/Q_C value

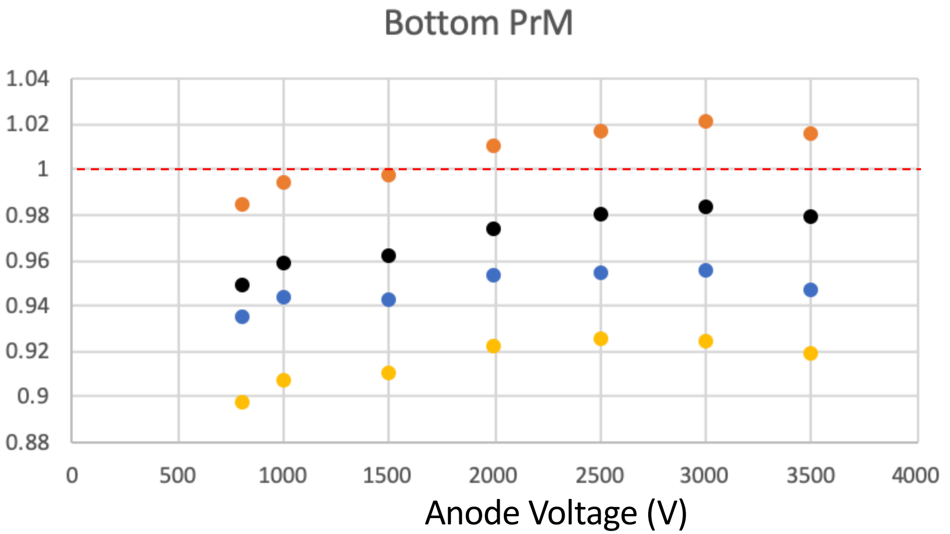
Blue: correct rise time

Orange: correct rise time + smoothing process

Black: correct rise time + smoothing process + gain difference







Q_A/Q_C vs Drift time

Yellow: online Q_A/Q_C value

Data taken on Jan 11, 2020

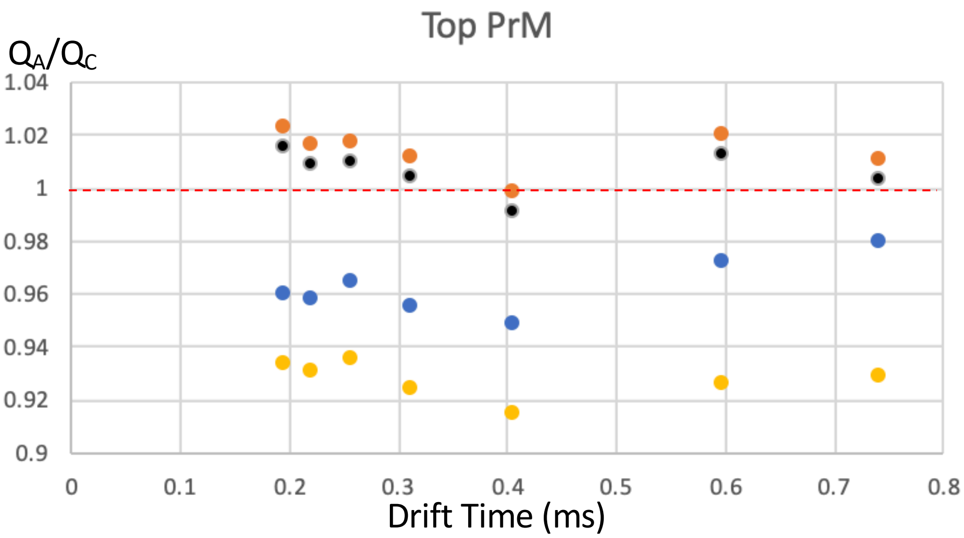
Blue: correct rise time

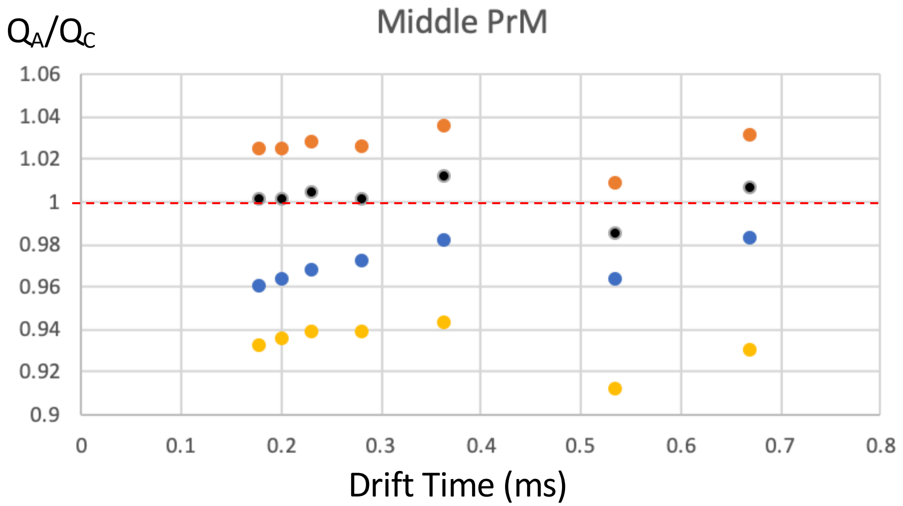
Orange: correct rise time + smoothing process

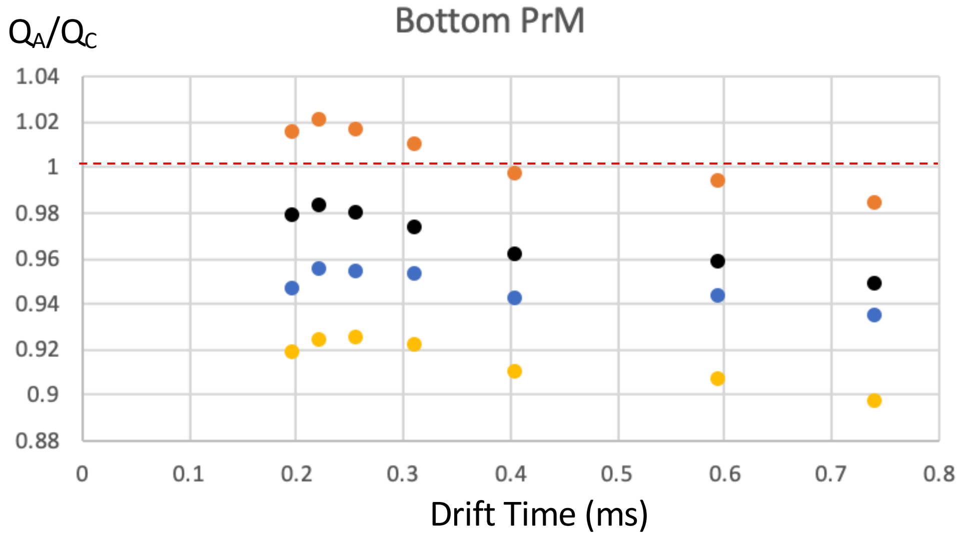
Black: correct rise time + smoothing process + gain difference

After offline corrections, Q_A/Q_C in top and middle PrM close to one and doesn't decrease over drift time → very high lifetime

Bottom PrM still shows measurable lifetime

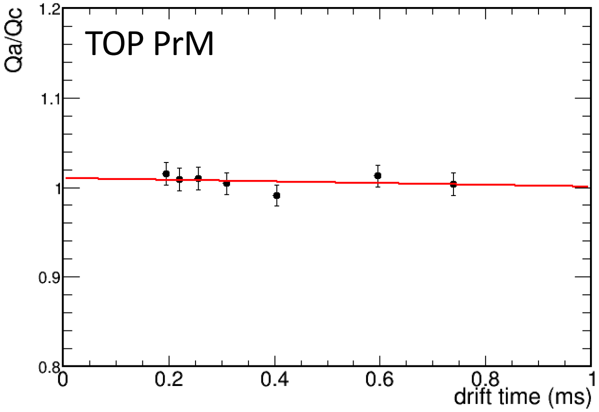






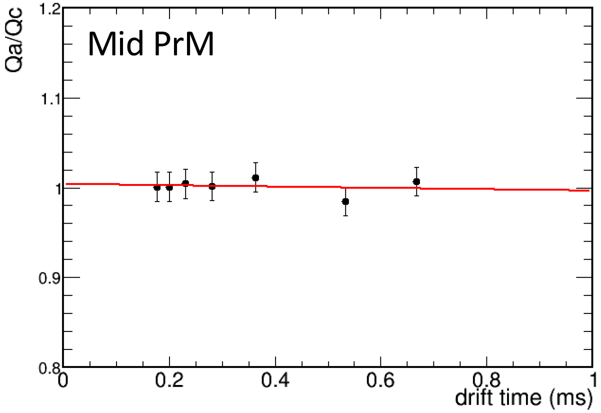
Offline (new) transparency correction

- Fit to full transparency data (2020/Jan/11) after correct rise time, smoothing process and gain difference to obtain expected Qa/Qc values for 50/250V and 50/500V
- Uncertainties include statistical and time-dependent fluctuations and uncertainties of grid transparency, other uncertainties found to be small
- Float Qa/Qc at drift time = 0 ms in the fit so results not affected by gain correction uncertainty and electron loss in leakage



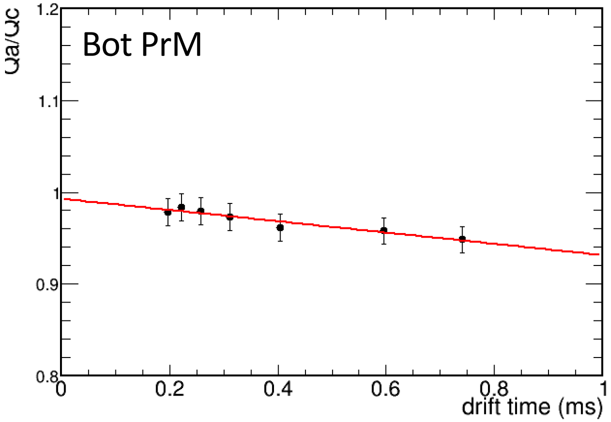
Qa/Qc(t=0ms) 1.010 ± 0.010
1/tau 0.00922 ± 0.02395

Expected Qa/Qc at t=2.3ms, 50/250V:
1.000+0.000-0.0040
Expected Qa/Qc at t=1.2ms, 50/500V:
1.000+0.000-0.0021



Qa/Qc(t=0ms) 1.004 ± 0.01385
1/tau 0.00744 ± 0.0352

Expected Qa/Qc at t=2.0ms, 50/250V:
1.000+0.000-0.0378
Expected Qa/Qc at t=1.0ms, 50/500V:
1.000+0.000-0.0194



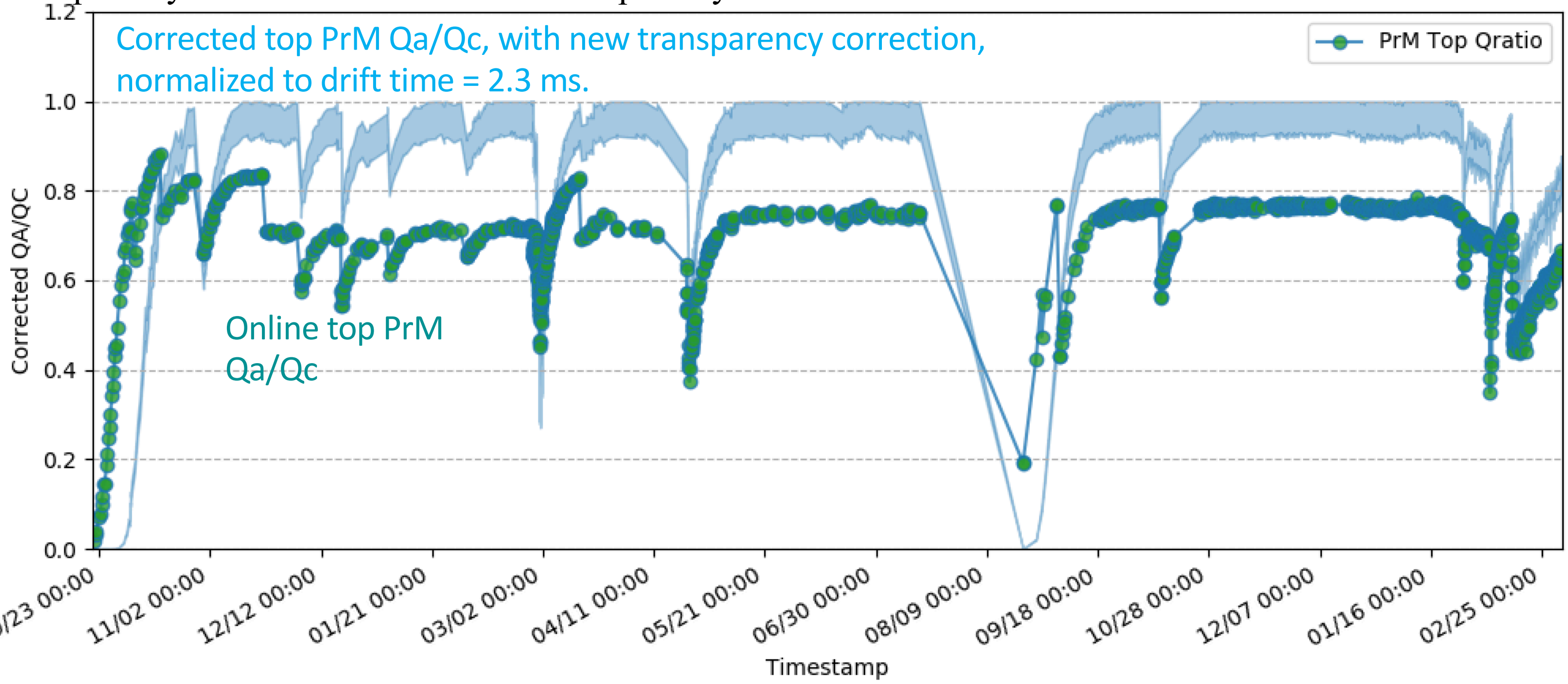
Qa/Qc(t=0ms) 0.99276 ± 0.0125
1/tau 0.061712 ± 0.0282

Expected Qa/Qc at t=2.3ms, 50/250V:
0.8674 + 0.0662 - 0.0546
Expected Qa/Qc at t=1.2ms, 50/500V:
0.9305 - 0.0302 + 0.0311

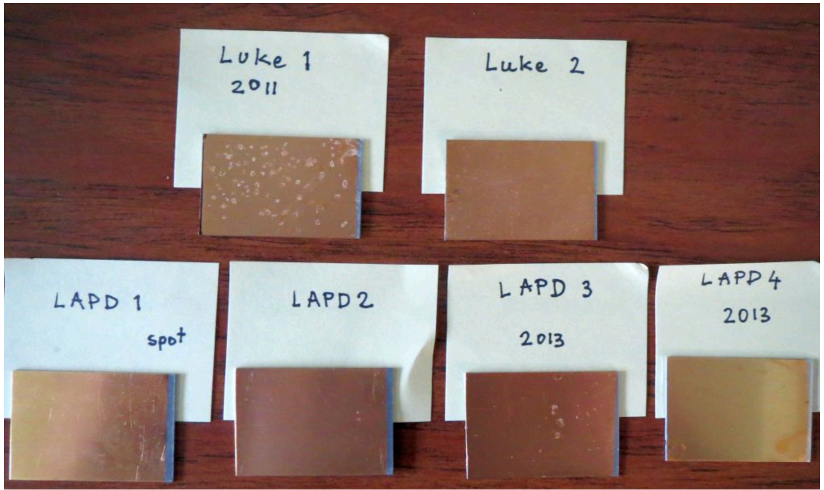
New transparency correction (top PrM)

Expected Qa/Qc at t=2.3ms, 50/250V: 1.000+0.000-0.0040
Expected Qa/Qc at t=1.2ms, 50/500V: 1.000+0.000-0.0021

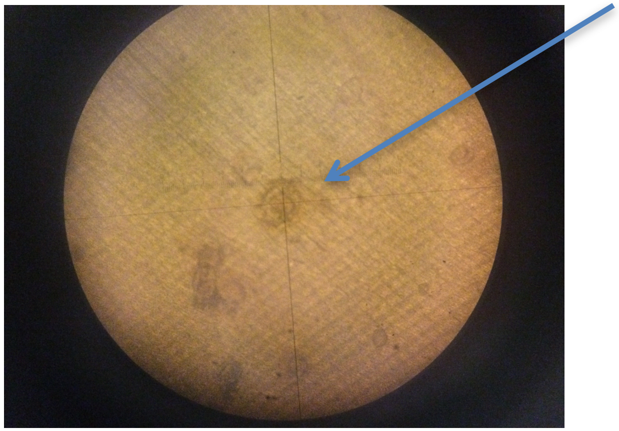
Observed Qa/Qc at t=2.3ms, 50/250V: 0.5631±0.004,
Old transparency correction: 1.355 → new correction: 1.7758+0.0116-0.0185
Observed Qa/Qc at t=1.2ms, 50/500V: 0.7943±0.002,
Old transparency correction: 1.048 → new transparency correction: 1.2012+0.0035-0.0059

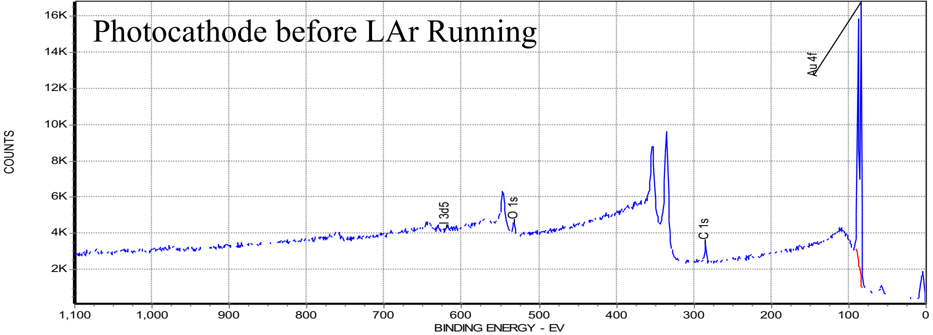


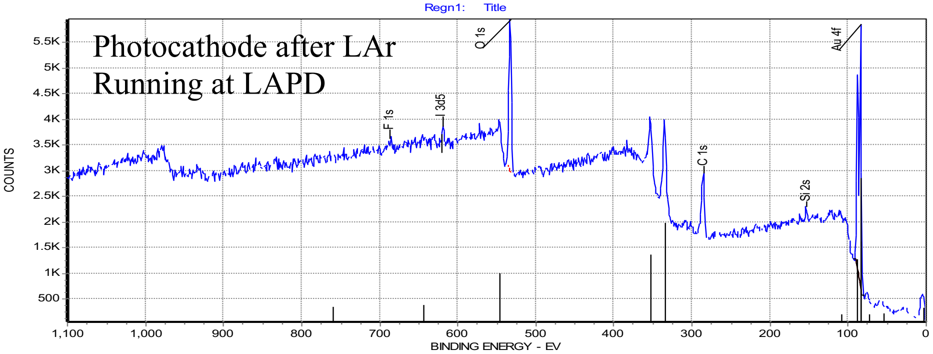
X-ray Photoelectron Spectroscopy (XPS) test at UMN for photocathodes degraded in LAPD/Luke @ Fermilab



organic compound?




Photocathode before LAr Running


Photocathode after LAr Running at LAPD

Elements on the surface of photocathodes

XPS Line	Atom %
Au 4f	51.299
C 1s	37.623
O 1s	10.716
I 3d5	0.361

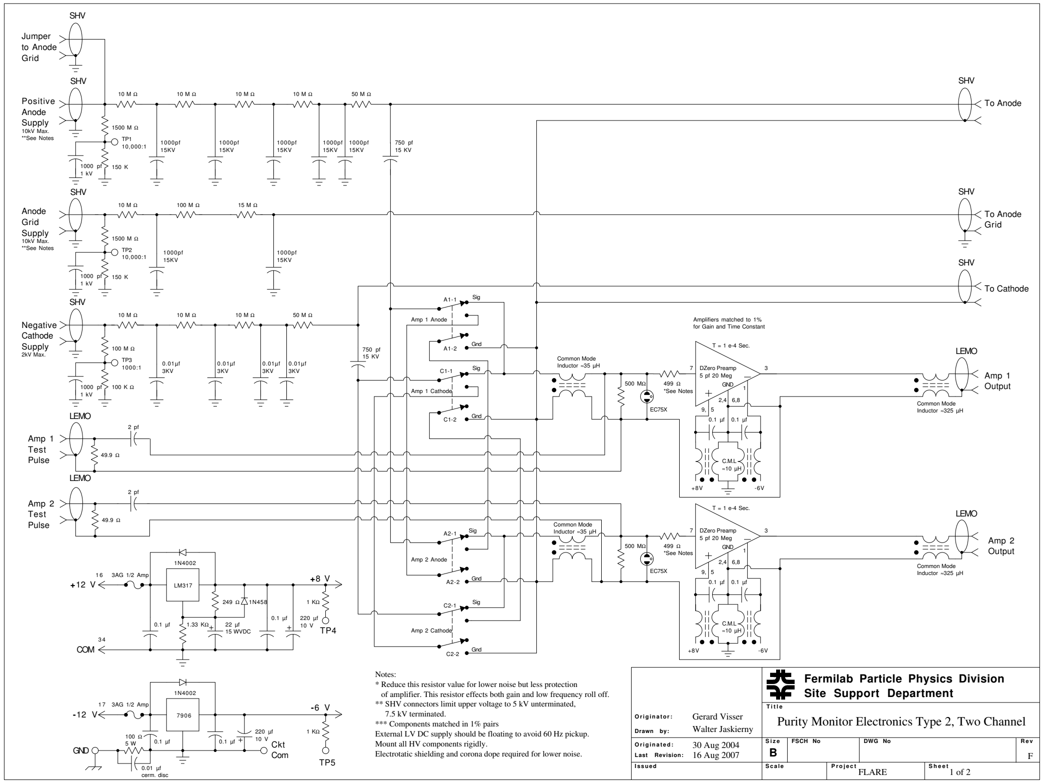
New gold cathode (100% signal)

Contamination consistent with H_2O

XPS Line	Atom %
Au 4f	9.048
Si 2s	3.932
C 1s	45.279
O 1s	38.326
I 3d5	0.535
F 1s	2.88

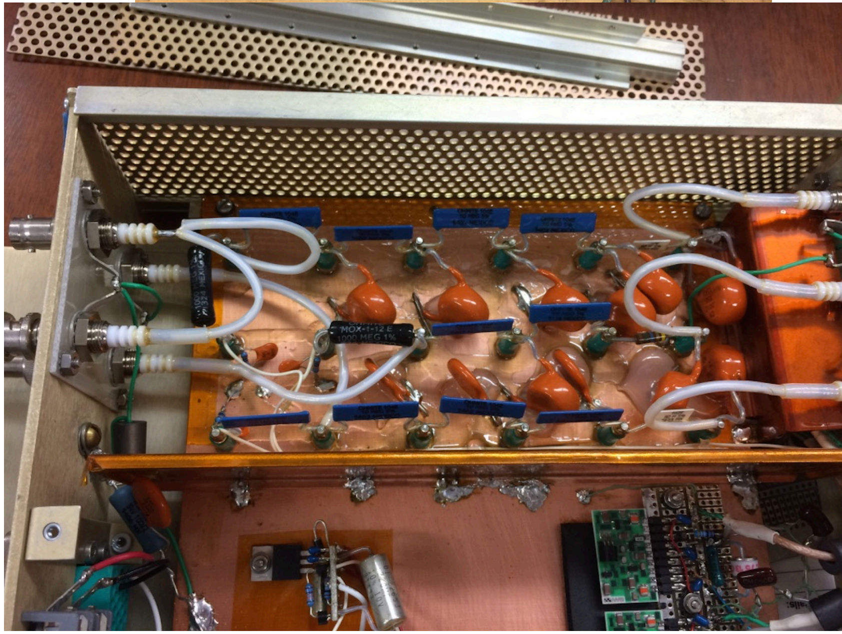
Degraded gold cathode (~50% signal)

Electronics



Notes:
* Reduce this resistor value for lower noise but less protection of amplifier. This resistor effects both gain and low frequency roll off.
** SHV connectors limit upper voltage to 5 kV unterminated, 7.5 kV terminated.
*** Components matched in 1% pairs
External LV DC supply should be floating to avoid 60 Hz pickup.
Mount all HV components rigidly.
Electrotatic shielding and corona dope required for lower noise.

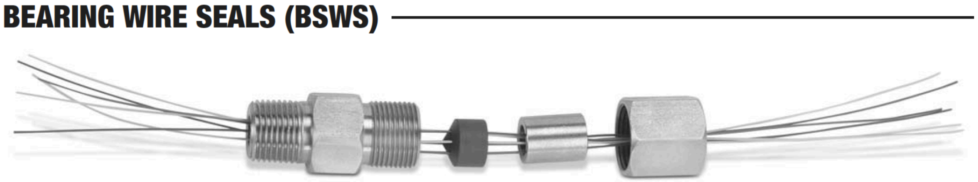
Originator: Gerard Visser
Drawn by: Walter Jaskierny
Originated: 30 Aug 2004
Last Revision: 16 Aug 2007
Issued
Title: Purity Monitor Electronics Type 2, Two Channel
Size: B
FSCH No
DWG No
Rev: F
Scale
Project: FLARE
Sheet: 1 of 2



HV and optical Feedthroughs

HV Feedthroughs: ~ 10kV

Optical Feedthroughs:



HV and Slow control

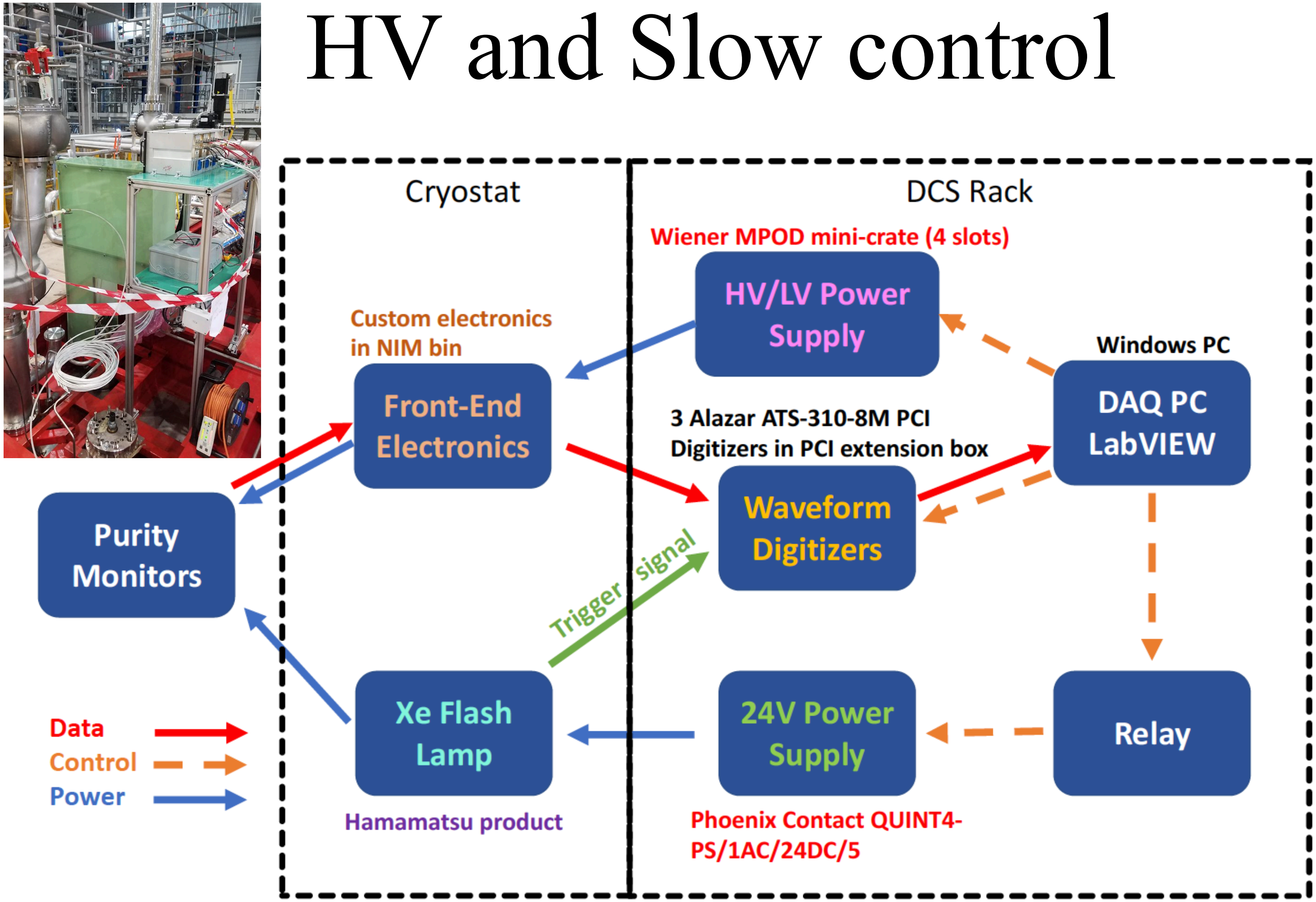


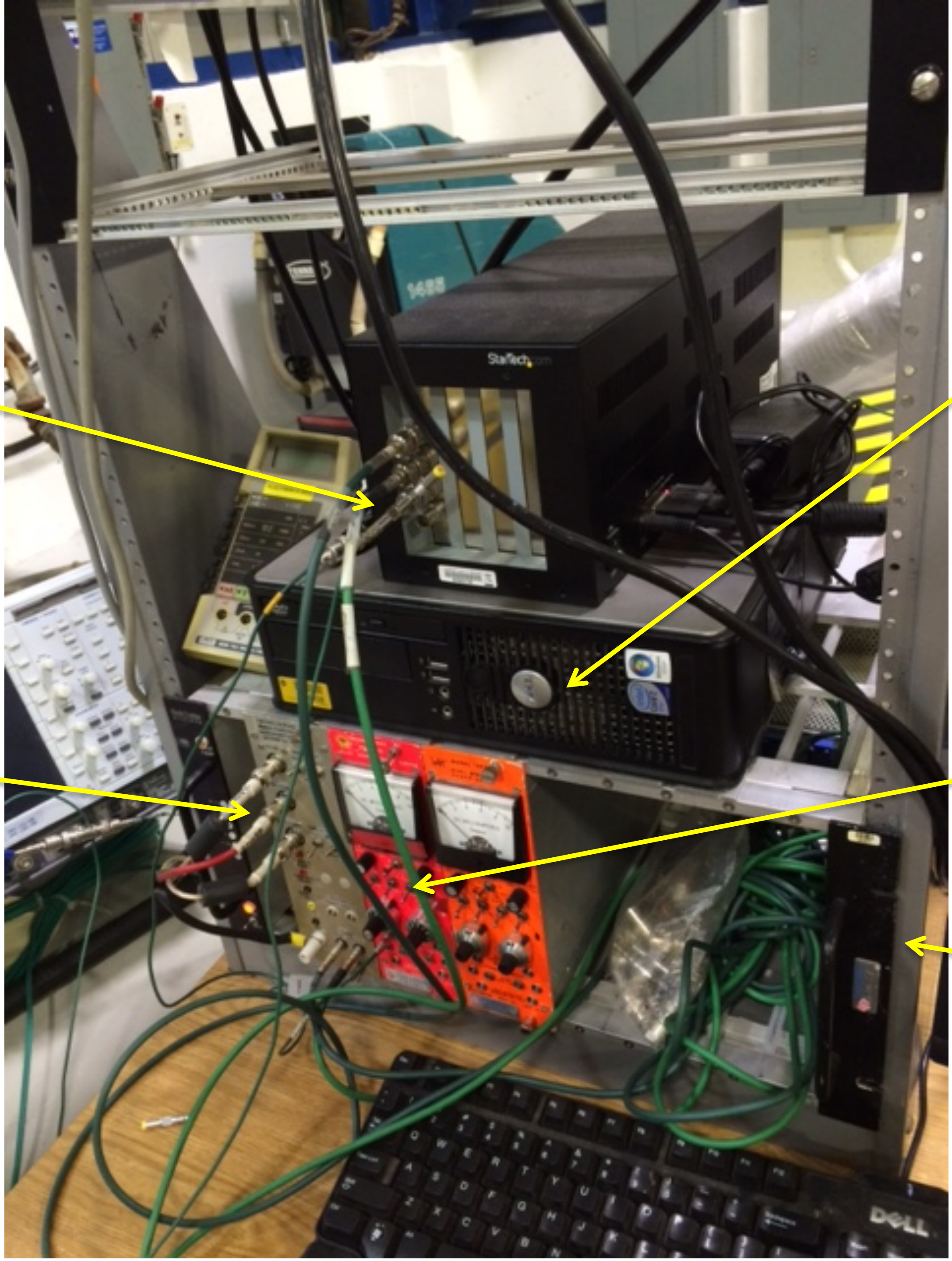
Figure 1.9: Block diagram of the purity monitor system.

- Programmable HV
- Relay board for NIM bin (PrM electronics)
- Relay board for DC power supply for the light source/or Programmable DC power supply for the light source.

Light source

- Hamamatsu Xenon source (1J/flash)
- Faraday cage for grounding

DAQ



Digitizers

PrM electronics
Signal:
2 channels –
cathode, anode
< 5V

Need to
Develop slow
control

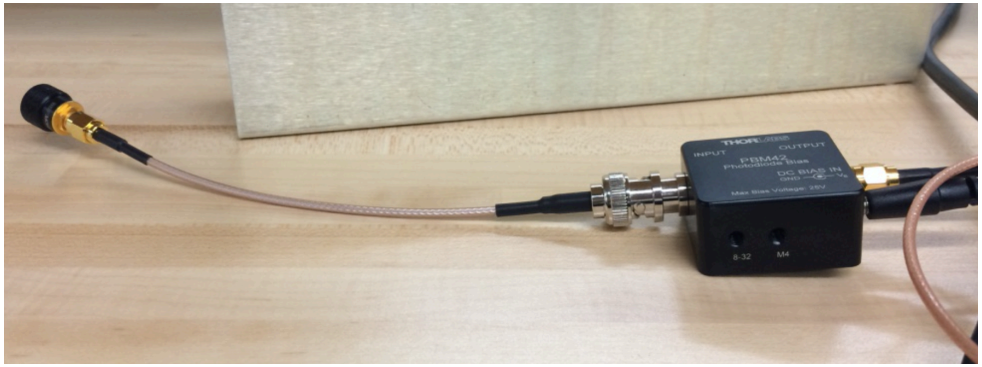
DAQ PC
110V

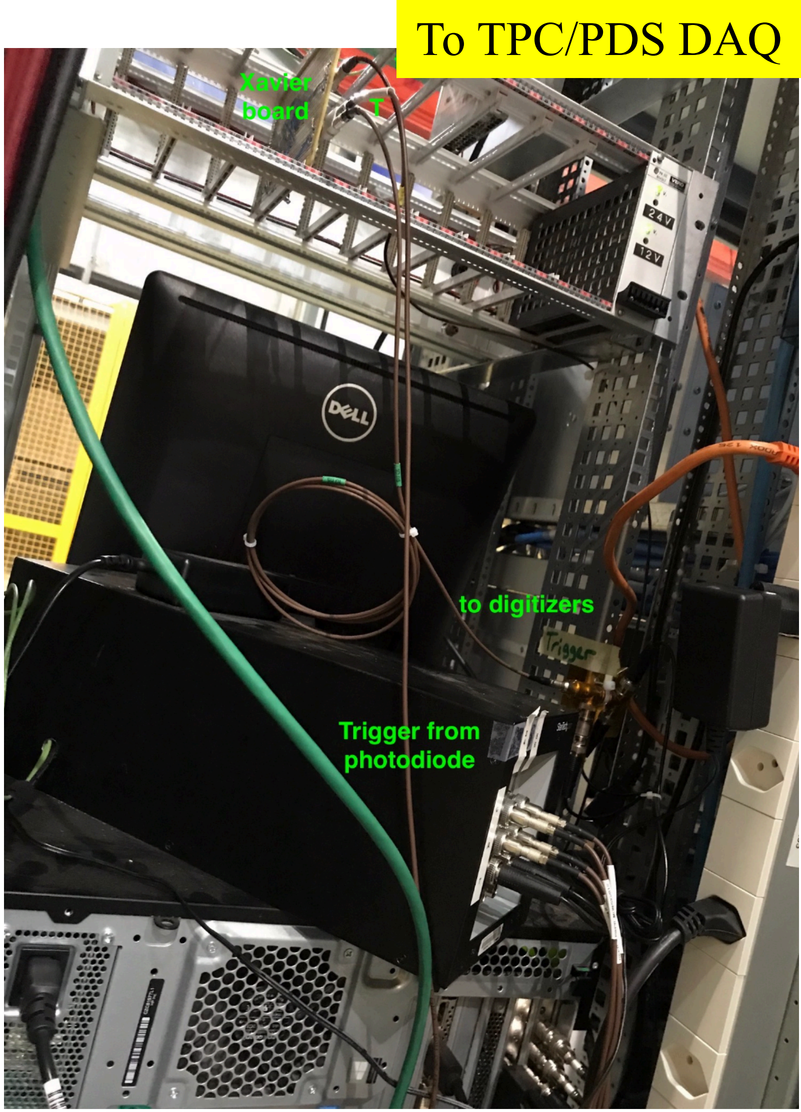
PrM HV
Cathod -150V
Anode 2500V

NIM Bin
110 V

Trigger

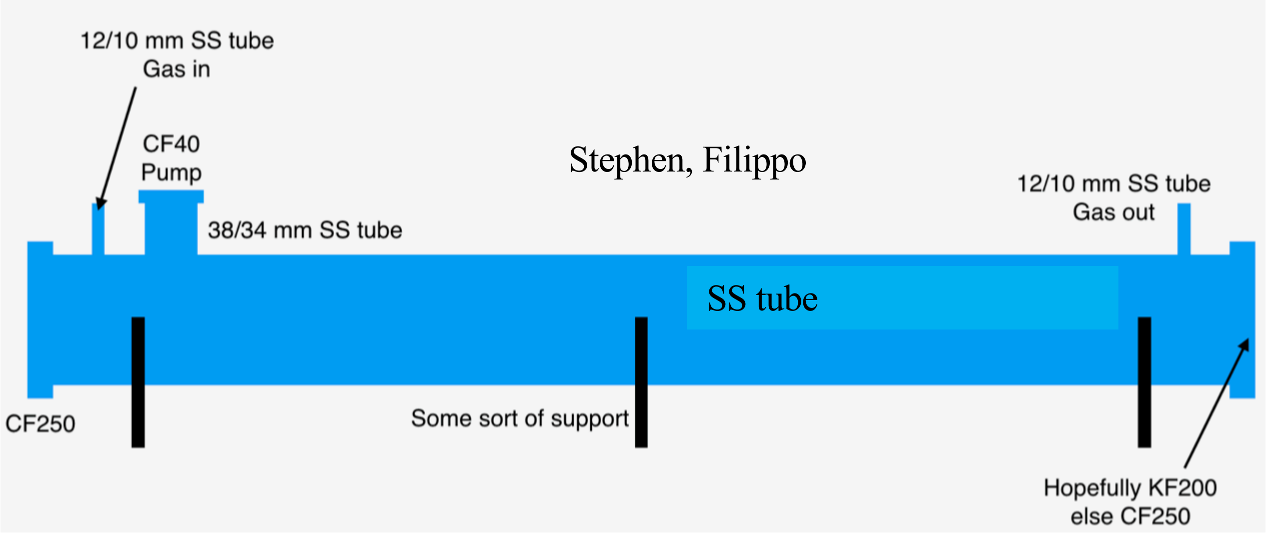
- Photo Diode to trigger the digitizer
- Trigger signal also to TPC/PDS DAQ to prevent possible noise from purity monitor





Test PrMs in long tube

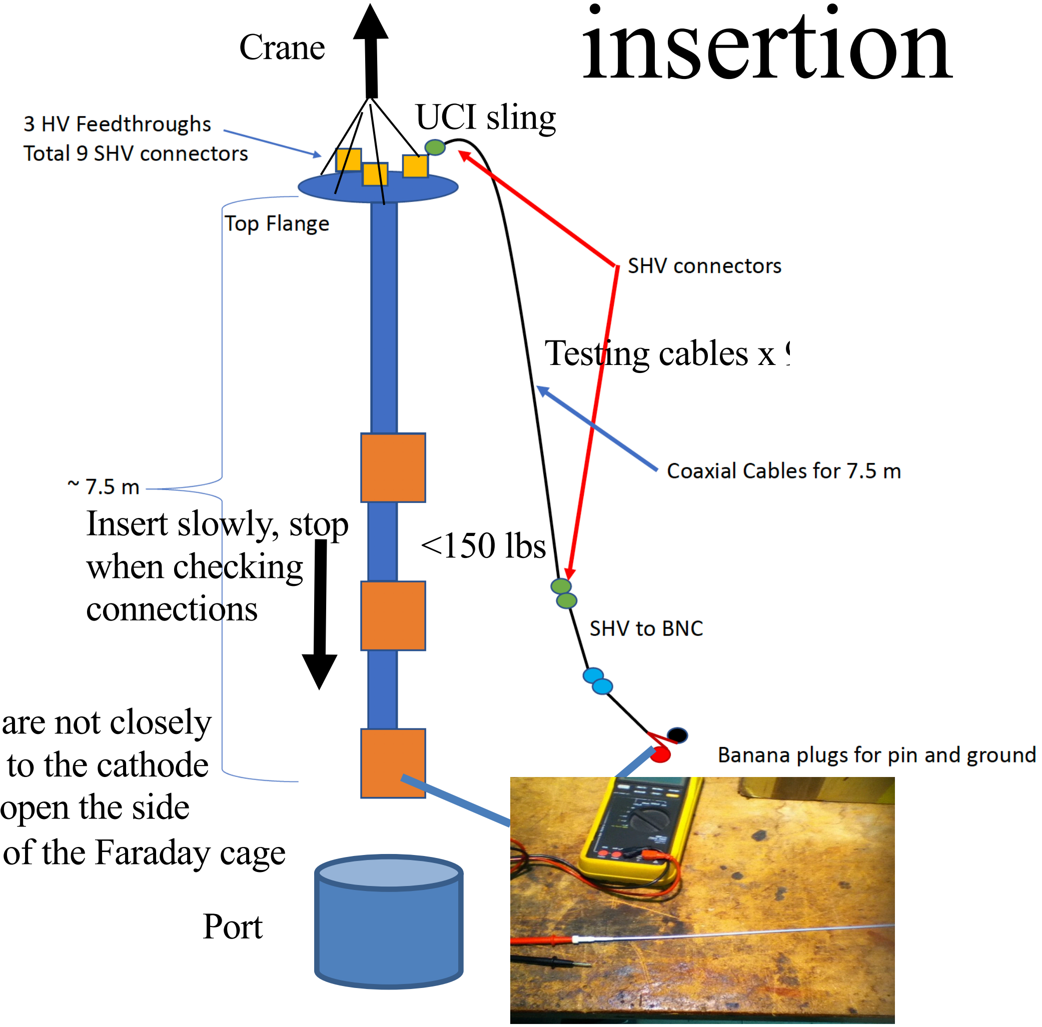
- After assemble PrMs on long supporting rods, test the full assembly in vacuum



Installation procedure at ProtoDUNE-SP

- After assemble PrMs on long supporting rods, check electric/optical connections
- Move the PrM assembly to the corridor
- Use crane, lift and rotate the assembly 90 degrees
- Use crane, move the assembly to the top of the port
- Use crane, start to insert the assembly into the port
- Test connections on each PrM vertically during insertion
- After insertion, test overall resistance and capacitance with electrometer and Capacitance Meter meter
- Mount NIM bin and Xe flash lamp on the PrM.
- Connect cables
- Connect optical fibers to Xe flash lamp
- Make connections to power supplies and slow controls interfaces

Check connections one by one during insertion



Crane

UCI sling

3 HV Feedthroughs
Total 9 SHV connectors

Top Flange

SHV connectors

Testing cables x

Coaxial Cables for 7.5 m

~ 7.5 m

Insert slowly, stop when checking connections

<150 lbs

SHV to BNC

Banana plugs for pin and ground

If fibers are not closely attached to the cathode surface, open the side window of the Faraday cage and tune

Port

Use multimeter to test connectivity to feedthrough/topflange for cathode, anode, anode grid and ground with faraday cage