TRIUMF

Leveraging Water-Cherenkov Experiment Experience for Drinking Water Monitoring

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WCTE

NSERC CRSNG

INNOVATION Canada Foundation for Innovation Fondation canadienne pour l'innovation

McDonald Institute

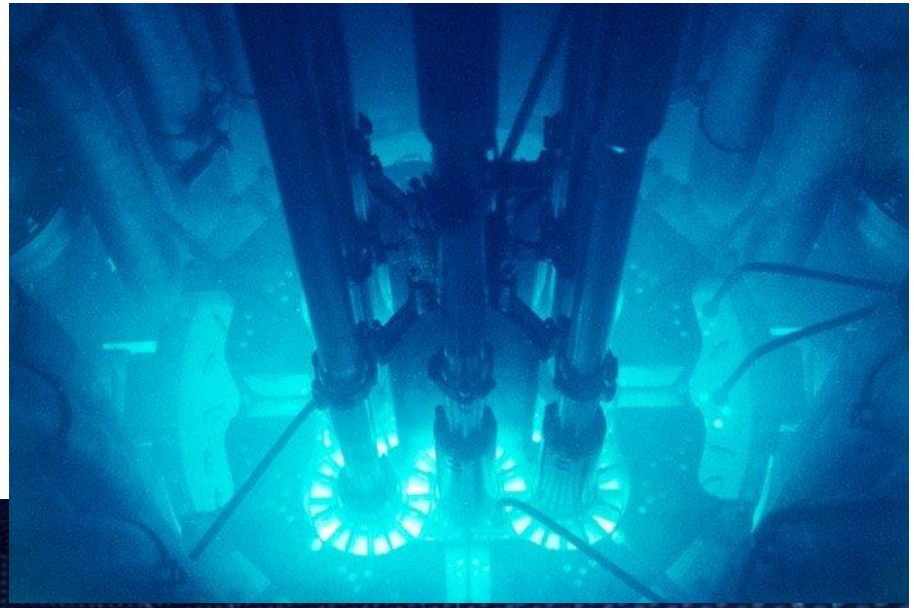
Water Purity in Water Cherenkov

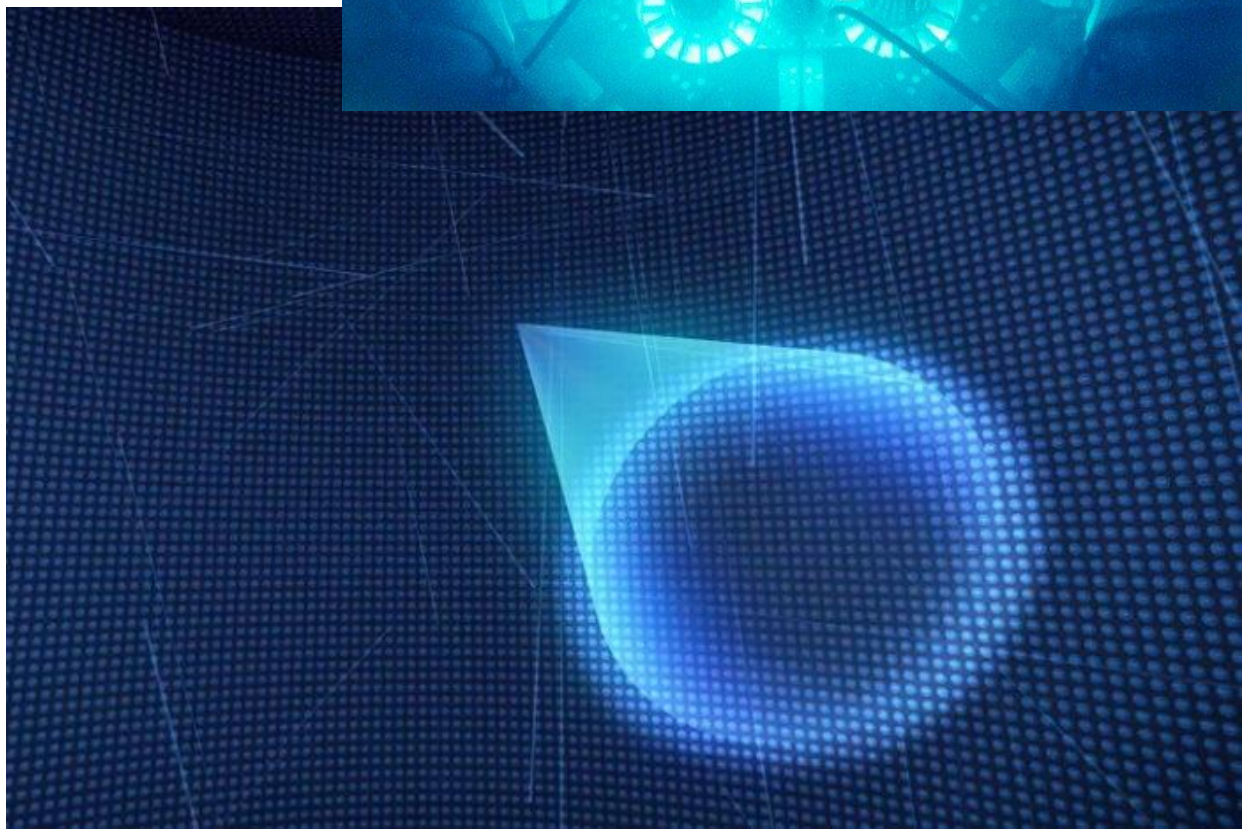
For Super-Kamiokande (et al), Cherenkov light is emitted by energetic charged particles resulting from neutrino interactions.

Amount of light and geometric layout of detected light tell us about the physics involved and the particles that produced the light.

In these experiments, we need to control the quality of the water!

Even trace water impurities can have adverse impacts on absorption and scattering lengths of light in water.





Real-World Water Monitoring

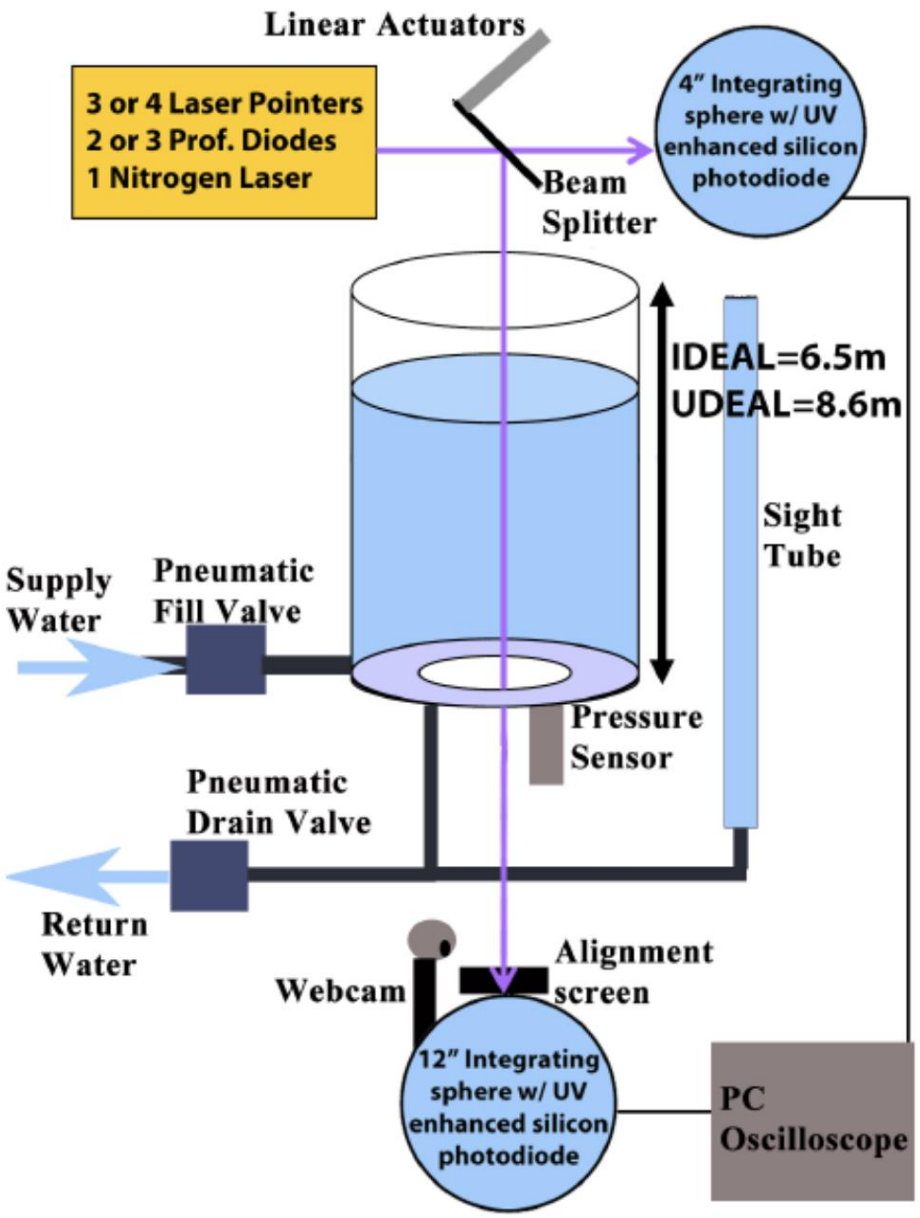
- Live, in-situ, monitoring is limited:
  - Turbidity (sediments in water)
  - pH
  - Chlorine content
  - Conductivity
- Water sampling tests are costly and can take weeks!
  - Cannot be done on-site and requires expensive laboratory equipment. Water samples are concentrated to reach SNR needed to reach drinking water limits
- Contaminants can be problematic before detectable by scent and taste.

There is an urgent need for an affordable, sensitive, real-time, and on-site water monitoring system!

Super-Kamiokande - UDEAL

- Water Cherenkov detectors like SK use more sophisticated quality monitoring systems
- Laser light input, monitoring change of light intensity after passing through vertical column of sample water
- Measurements at different water heights to characterize attenuation length
- Limitations
  - water surface conditions + laser position
  - Limited wavelengths accessible (no UV!), limits on sensitivity to pollutants
  - Discrete water samples taken, non-continuous monitoring

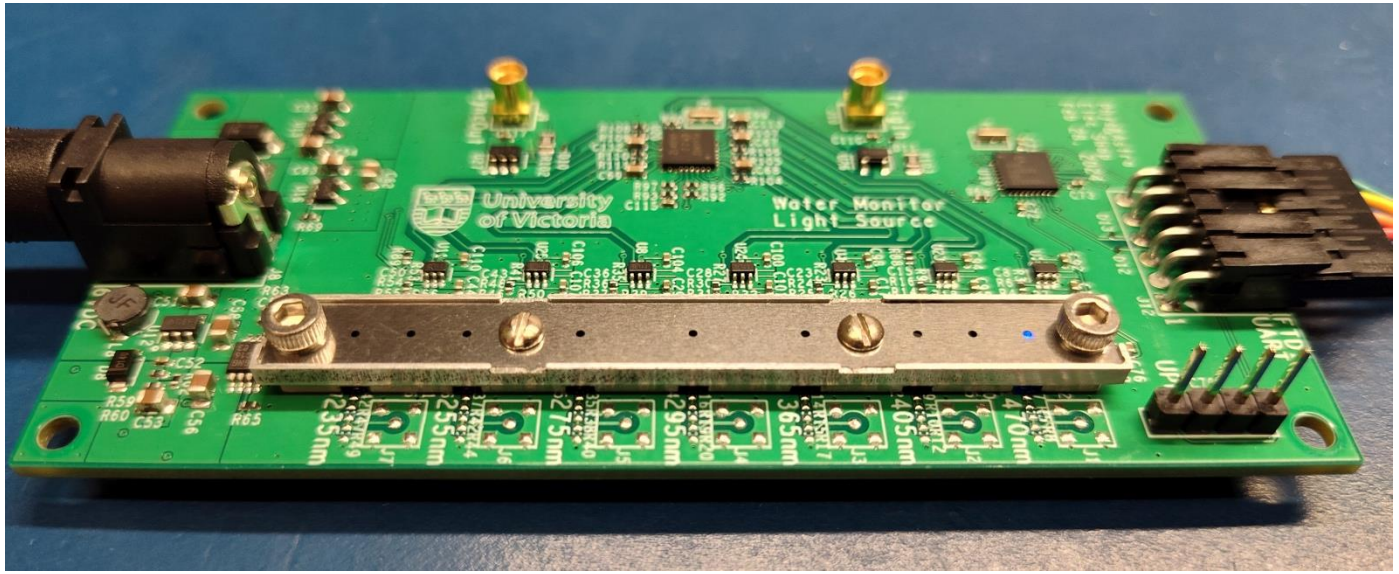
How can we build upon this?

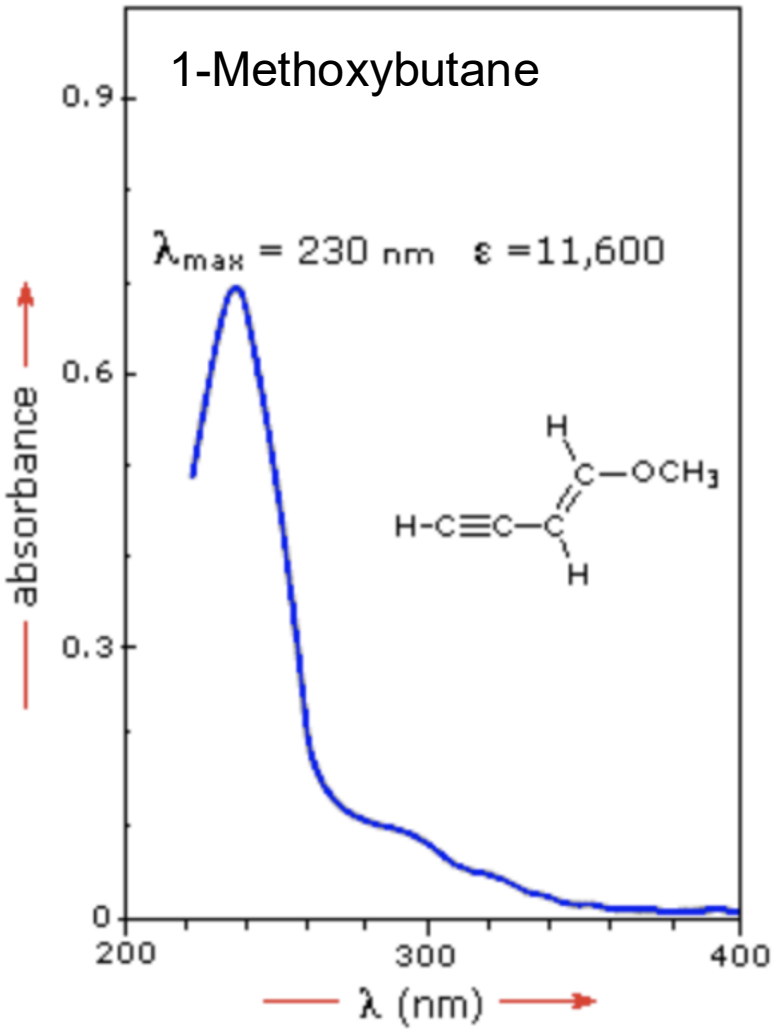


New Progress in UV/Blue LEDs and Ultra-fast LED Flashers

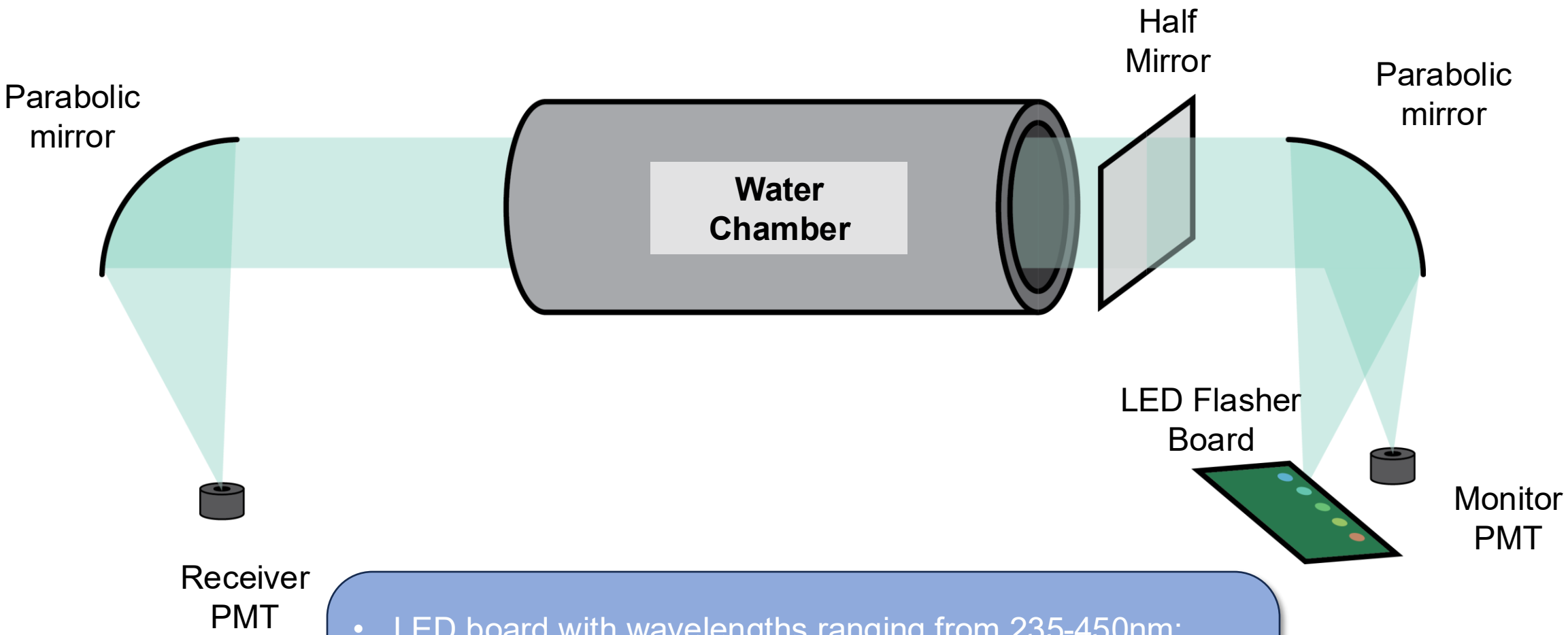
- 2014 – Nobel Prize for dramatically improved blue LEDs
  - Blue/UV light takes us into the excitation energies of organic molecules!

- **Sub-ns pulsed LED board** enables cheap photon counting in the UV range, and sensitivity to organic molecules
  - LEDs are easier to work with than lasers
  - Also being used in HK and P-ONE as calibration sources
  - Developed by N. Braam at U-Vic – [read the paper!]



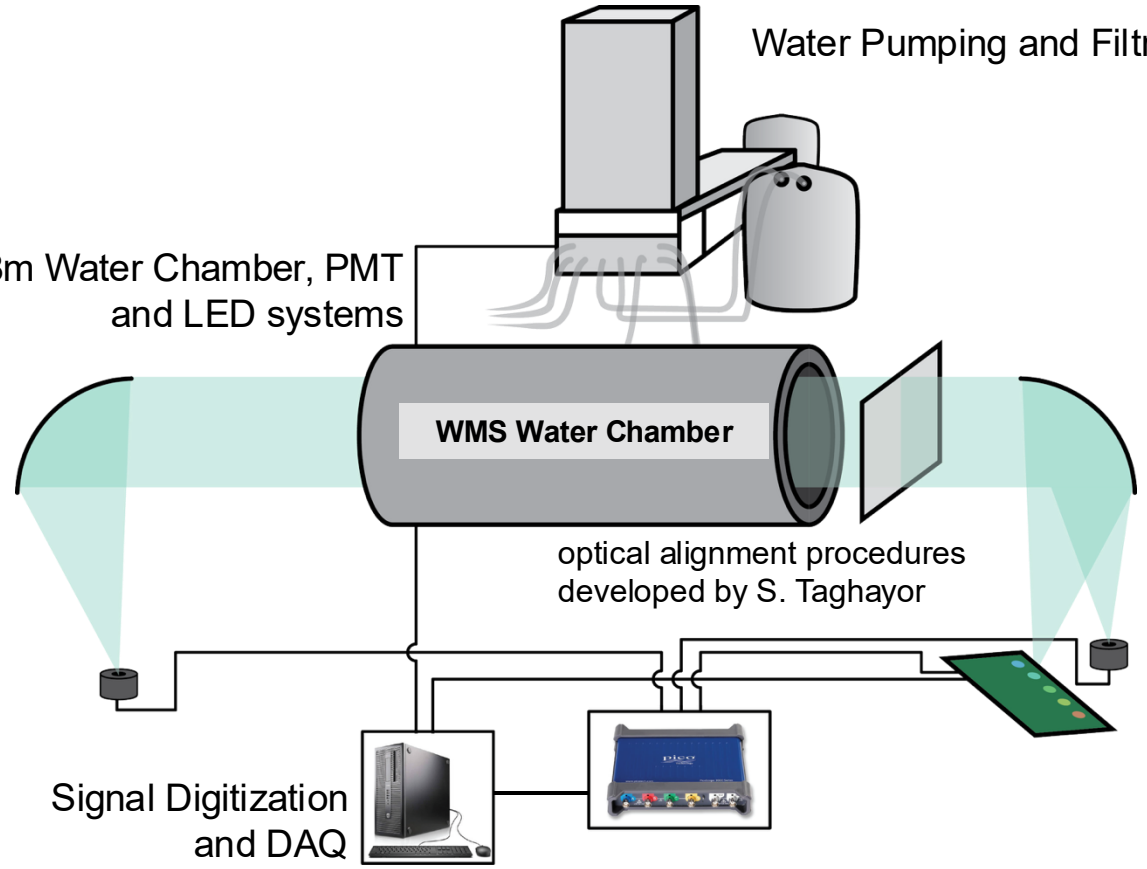


High Precision - Photon Counting



- LED board with wavelengths ranging from 235-450nm; piezoelectric linear stage aligns individual LEDs with optics
- Track intensity at monitor and receiver PMTs on either end
- Run the LEDs at 0.15pe level – ideal for photon counting
- Pulse board at 2.7MHz – extremely high counting rates

The Water Monitoring System



Improvements over UDEAL

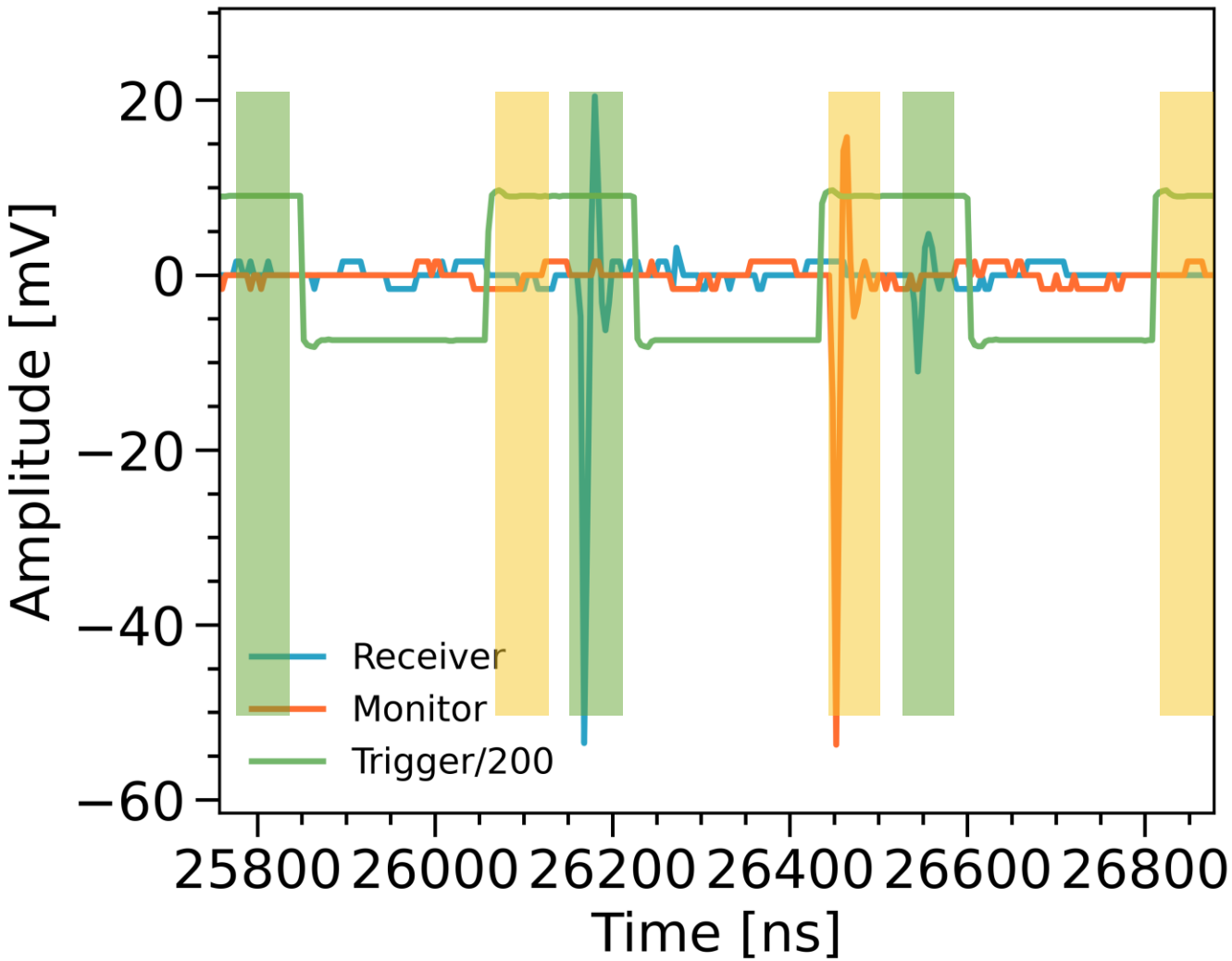
- Laser → pulsed LEDs for photon counting
- vertical → horizontal
- Interrupted → continuous flow water monitoring

High sensitivity and cost effective

- long water pipe, large attenuation potential
- Signal digitization and timing cuts to minimize background
- **8.5m distance provides 850x optical signal over a conventional 1cm lab sample**

Designed and built by TRIUMF SciTech group, N. Massacret in particular

Photon Counting



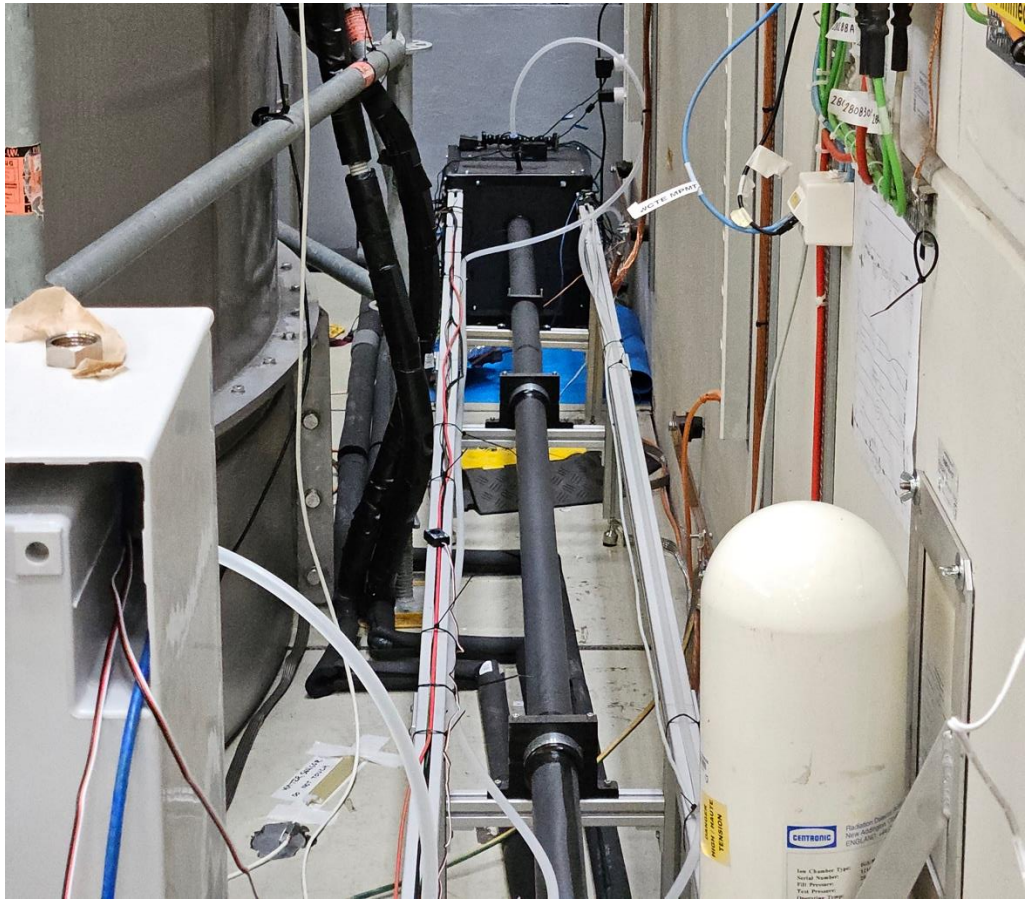
- Readout whole waveforms, use a fixed-threshold for hit finding
- Hits in the appropriate windows are counted as hits, use off-time hits to monitor background rate
- Grab ~5G samples and count total number of on-time (signal) hits, triggers, and off-time hits hits to determine mean number of PEs per trigger

$$\mu_{PE} = -\log\left(\frac{N_{triggers} - N_{hits}}{N_{triggers} - N_{dark}}\right)$$

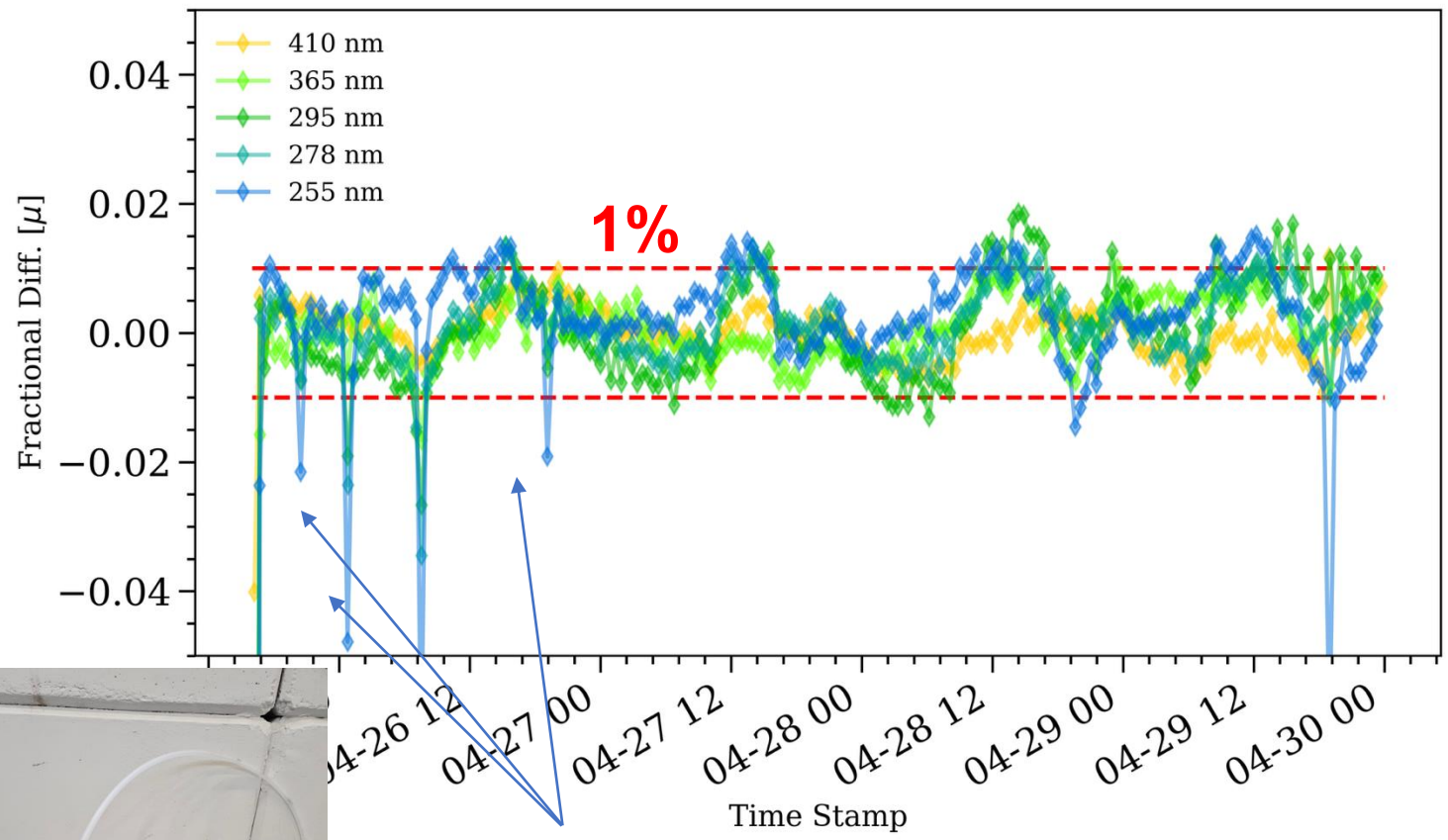
Deployment for WCTE @ CERN

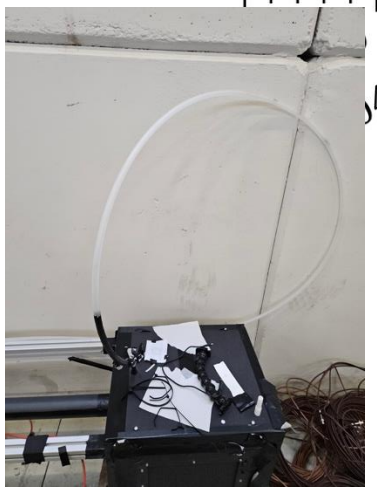
WMS prototype was recently used to monitor water quality for the Water Cherenkov Test Experiment using the PS/SPS beam at CERN – see Jasmine's talk today at 5:15pm in Room 134.

Shipping back to TRIUMF this week!



Real-Time Water Monitoring





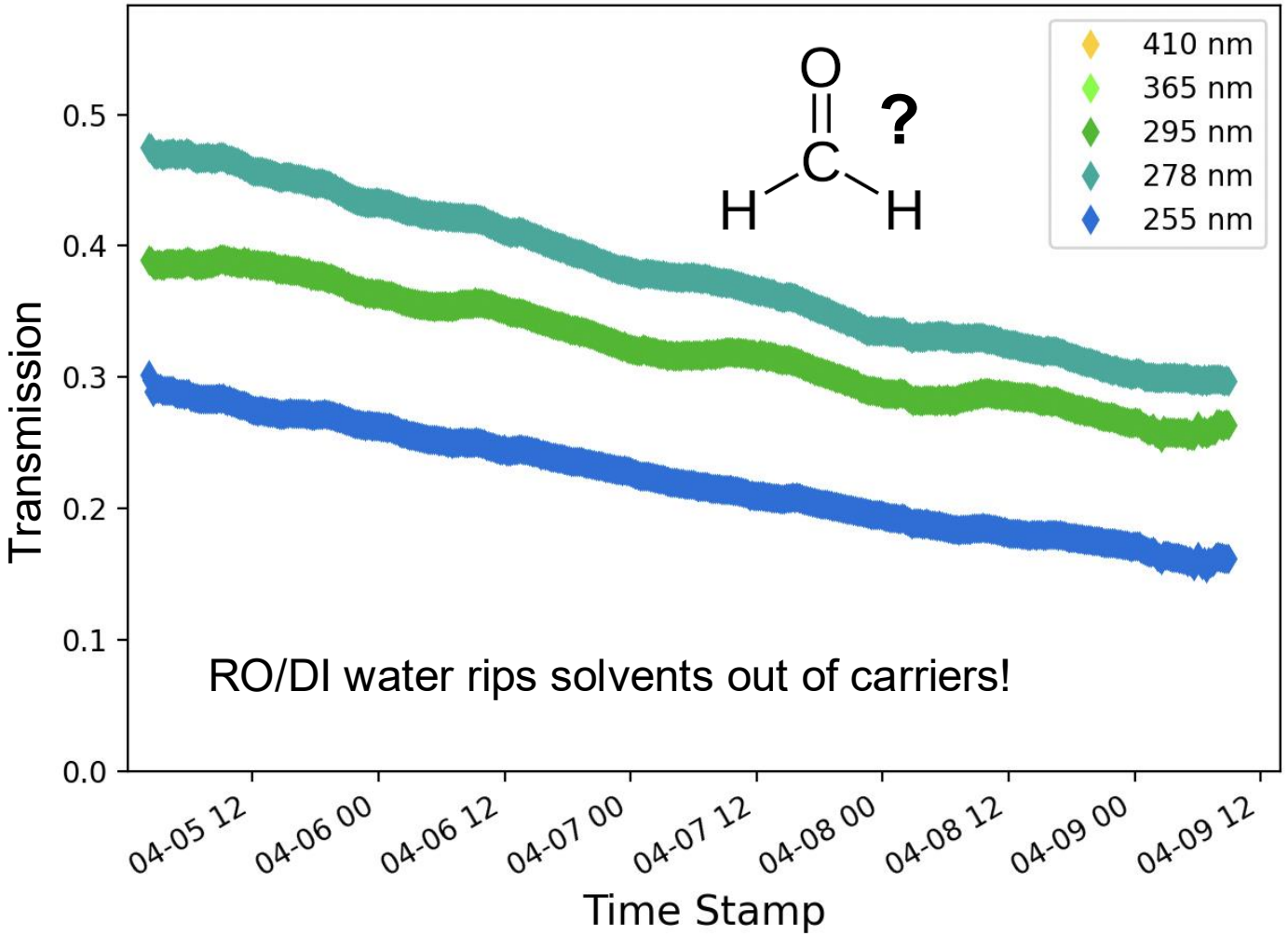
Spikes associated with times when water circulation is paused briefly – overflow line backwash.

Run system with a continuous flow of sample water through the chamber – we measure a **time-dependent change in transmission**.

This type of measurement is impossible in traditional water testing methods and yields dramatically improved sensitivity!

Diurnal variation correlates strongly with temperature. Real effect - also seen in another independent water monitoring system.

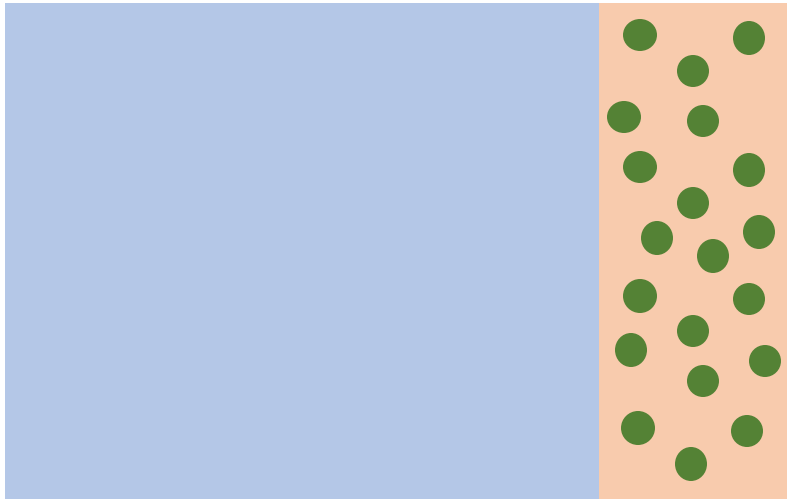
Possible Chemical Leaching?



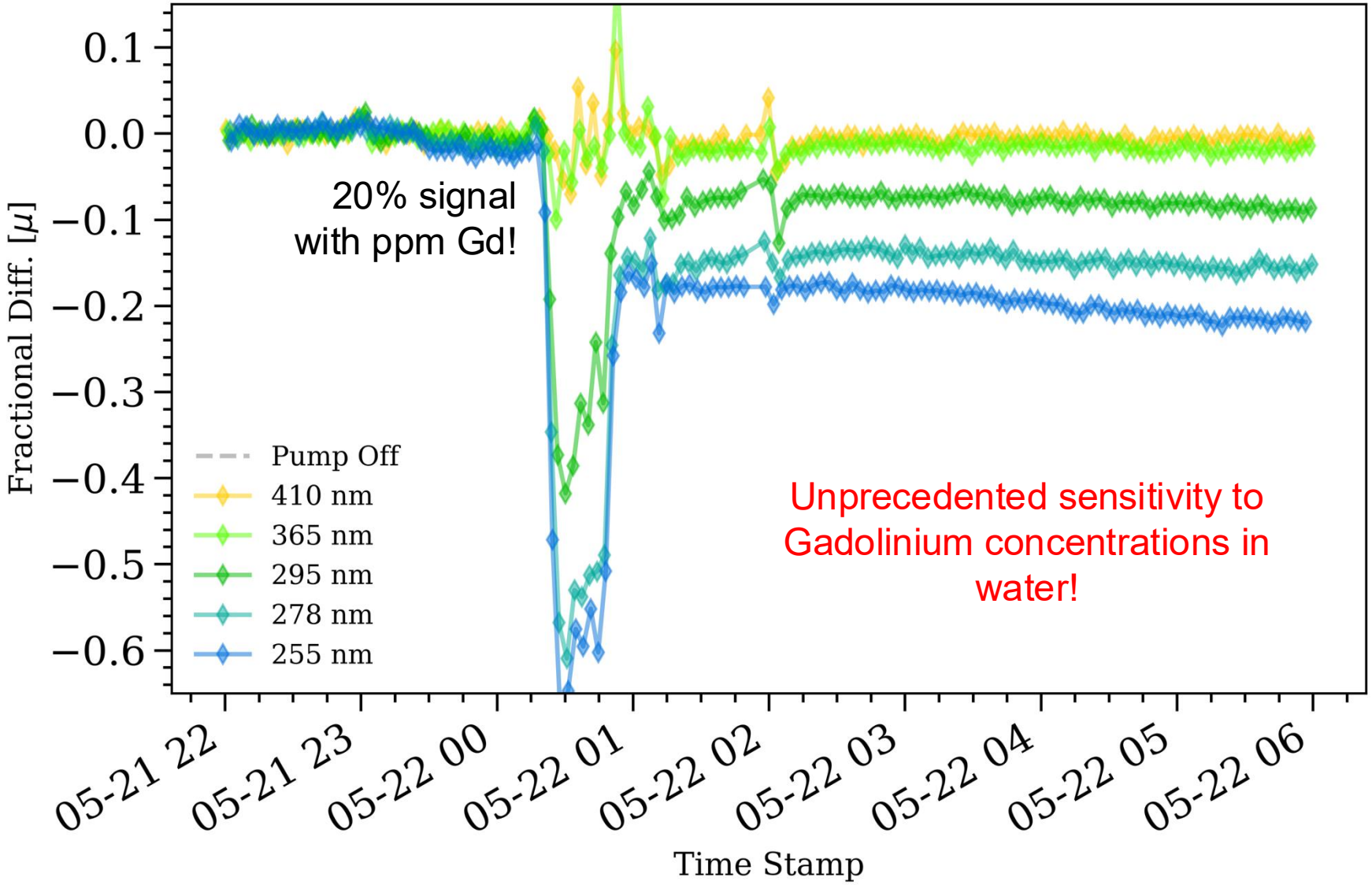
Studied DI water left in chamber for several days. UV wavelengths saw a 20% drop in transmission per day!

This is suspected to be due to formaldehyde leaching out of the acrylic tube – and could be a 150ppb per day increase in its concentration – right at the detection limit.

Likely also related to the backwash problem causing spikes on pressure loss.



First Gadolinium Loading

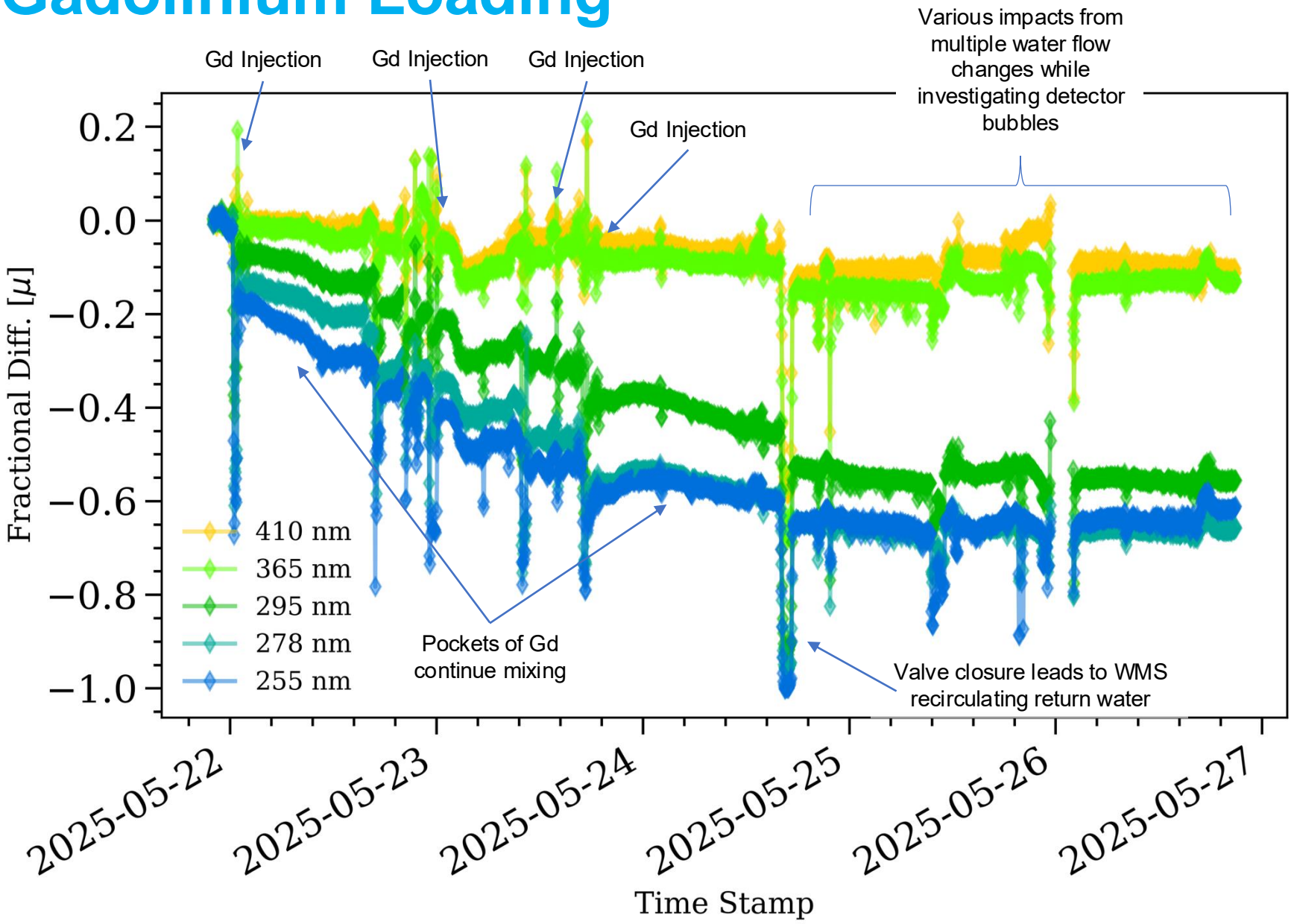


WCTE Gd loading to 0.004% mass fraction – improved neutron capture cross section

Small pockets of Gd continued to dissolve into WCTE tank water over the next 12+ hours, absorption eventually stabilized.

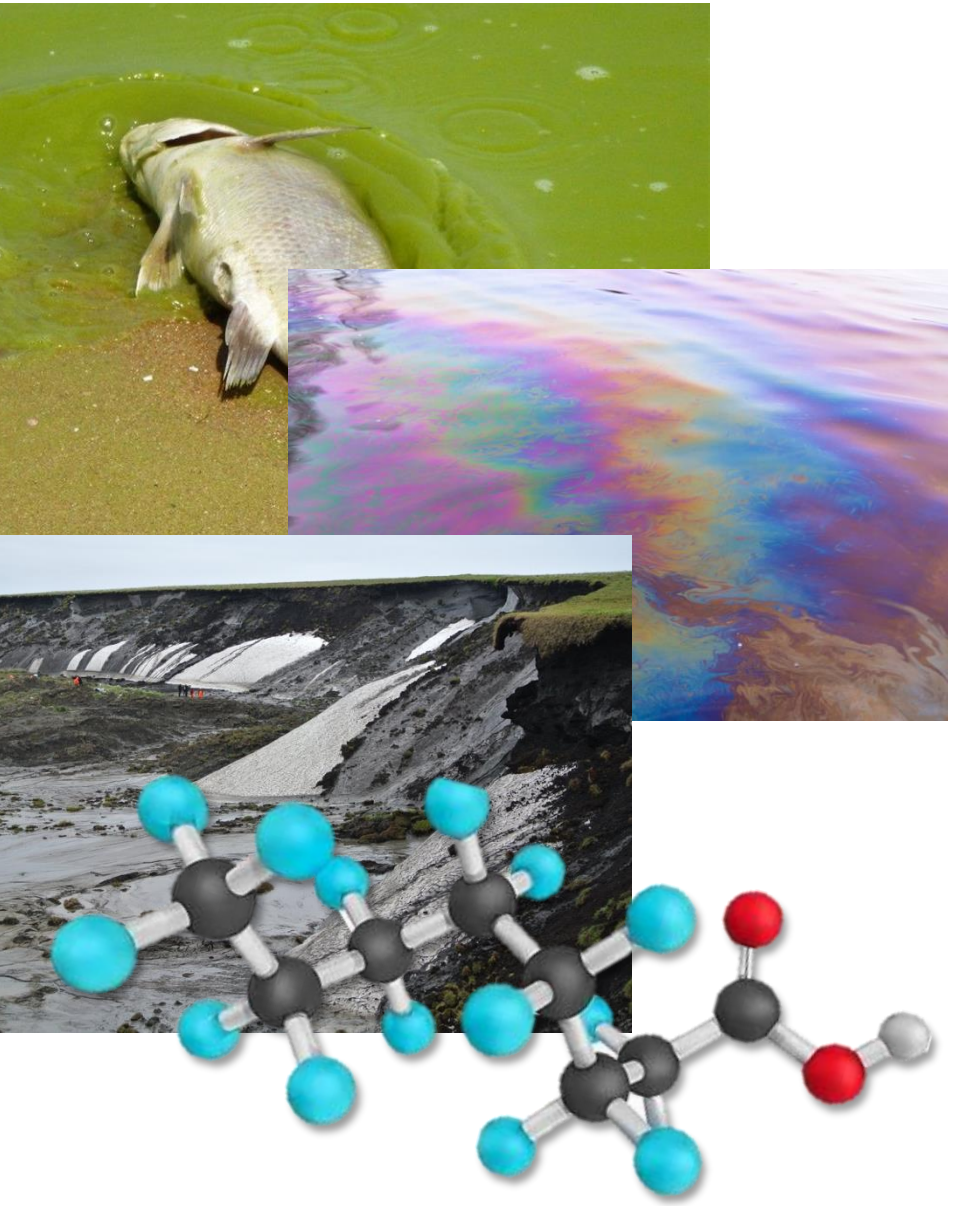
Percent-scale dip at 11:00pm resulted from slight beginning of Gadolinium-mixing

Full Gadolinium Loading



Transmission eventually settles at new baseline

Closing Thoughts



- Water monitoring system with capabilities for time-dependent water quality monitoring in real time - c**ould be a solution to limited and expensive water quality testing systems**

- First deployment of WMS prototype at WCTE – studied system stability, chemical leaching, sensitivity to Gadolinium
- WCTE physics-focused talk - *Time-of-flight monitoring techniques for the Water Cherenkov Test Experiment*
  - Jasmine Zhang @ 5:15pm in Room 134

- Future Plans
  - Controlled response measurements to various pollutants
  - More diagnostics for sample water contamination identification
  - Community deployments with the Cowessess First Nation and the Wayburn wastewater treatment facility
  - Future deployments for HK and IWCD

- TRIUMF SciTech Group committed a huge amount of work to make this project succeed; funding from NSERC, CFI, NRC, and MI made it possible

Thank you for your time

Backup

Water Monitoring is Important!

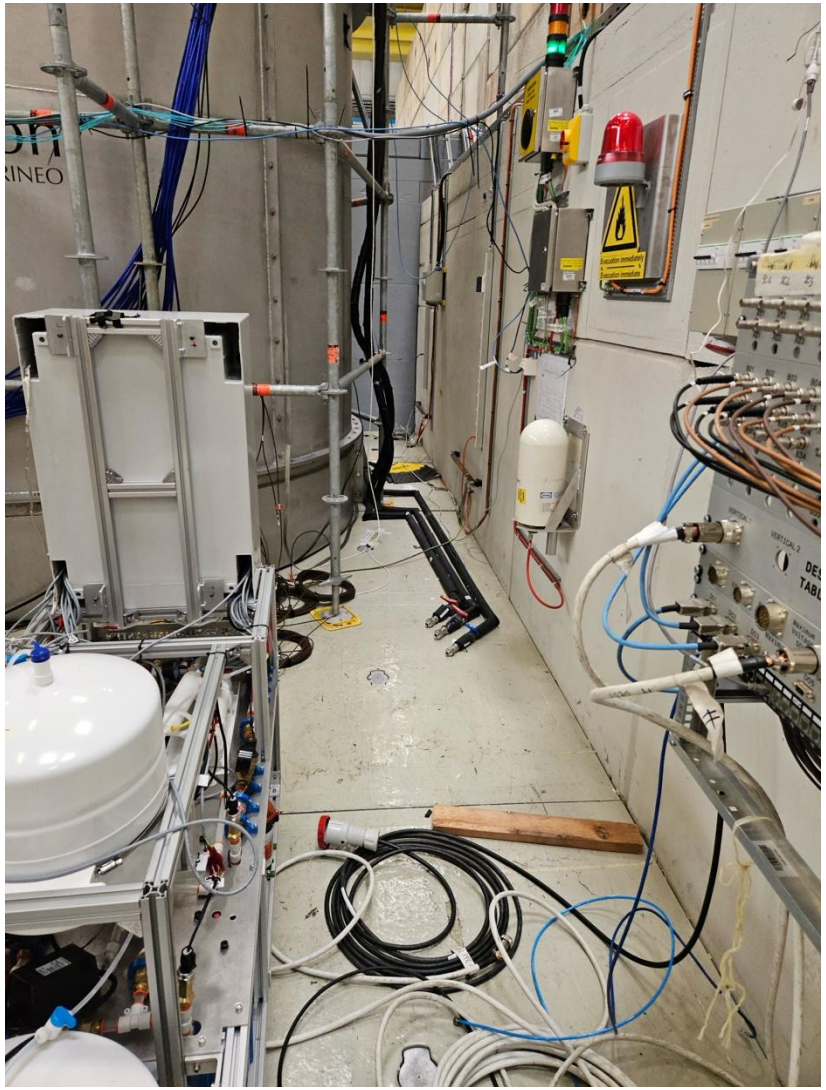
In late September 2021 in Nunavut, an Iqaluit resident noticed a suspicious chemical smell in his kitchen tap.

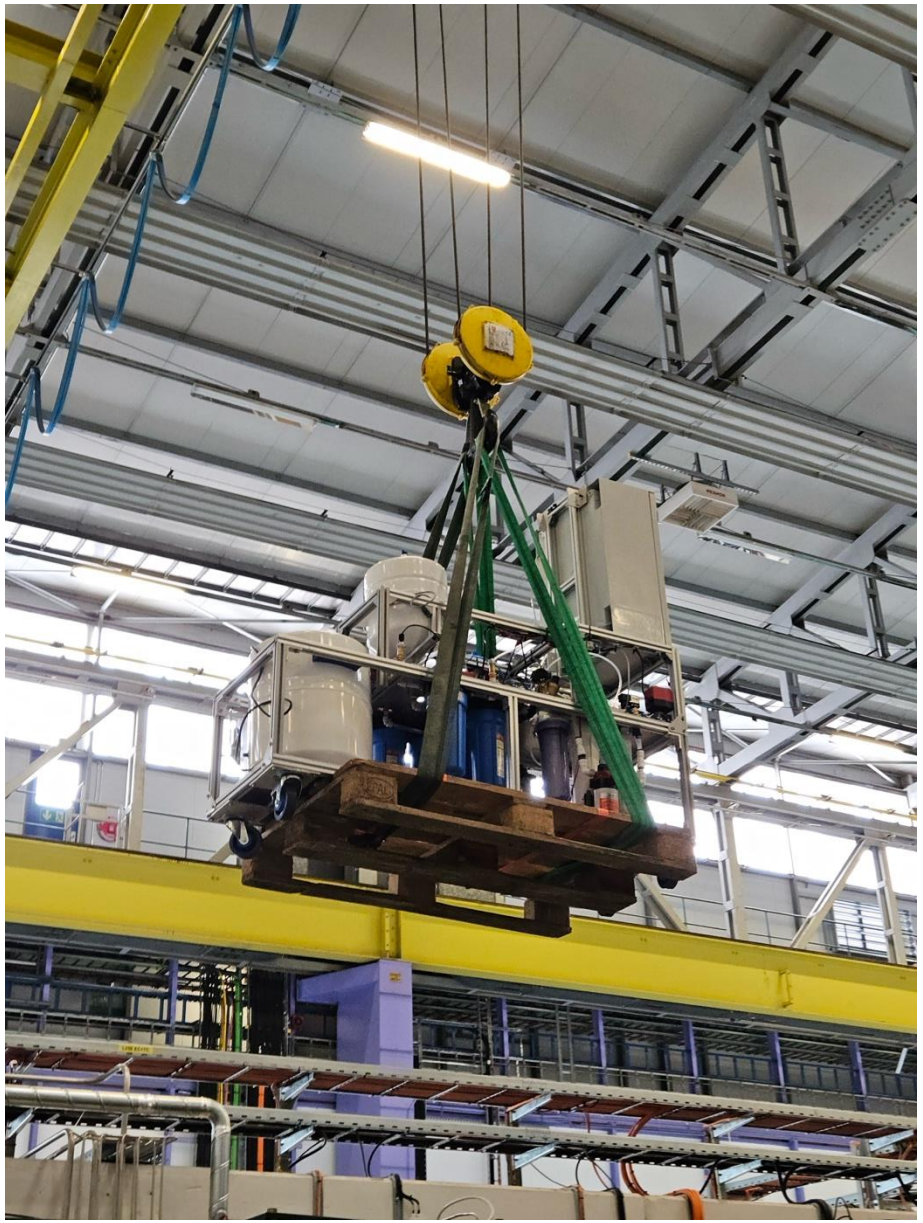
Officials ignored the issue until numerous complaints came in, after which they confirmed that fuel had contaminated the water supply.

From there, the city was without potable water for over a month.

Water testing kits were in short supply, boiling was insufficient to clean the water, and ultimately the CAF had to be deployed to treat water and transfer it to water depots.

Decommissioning @ CERN





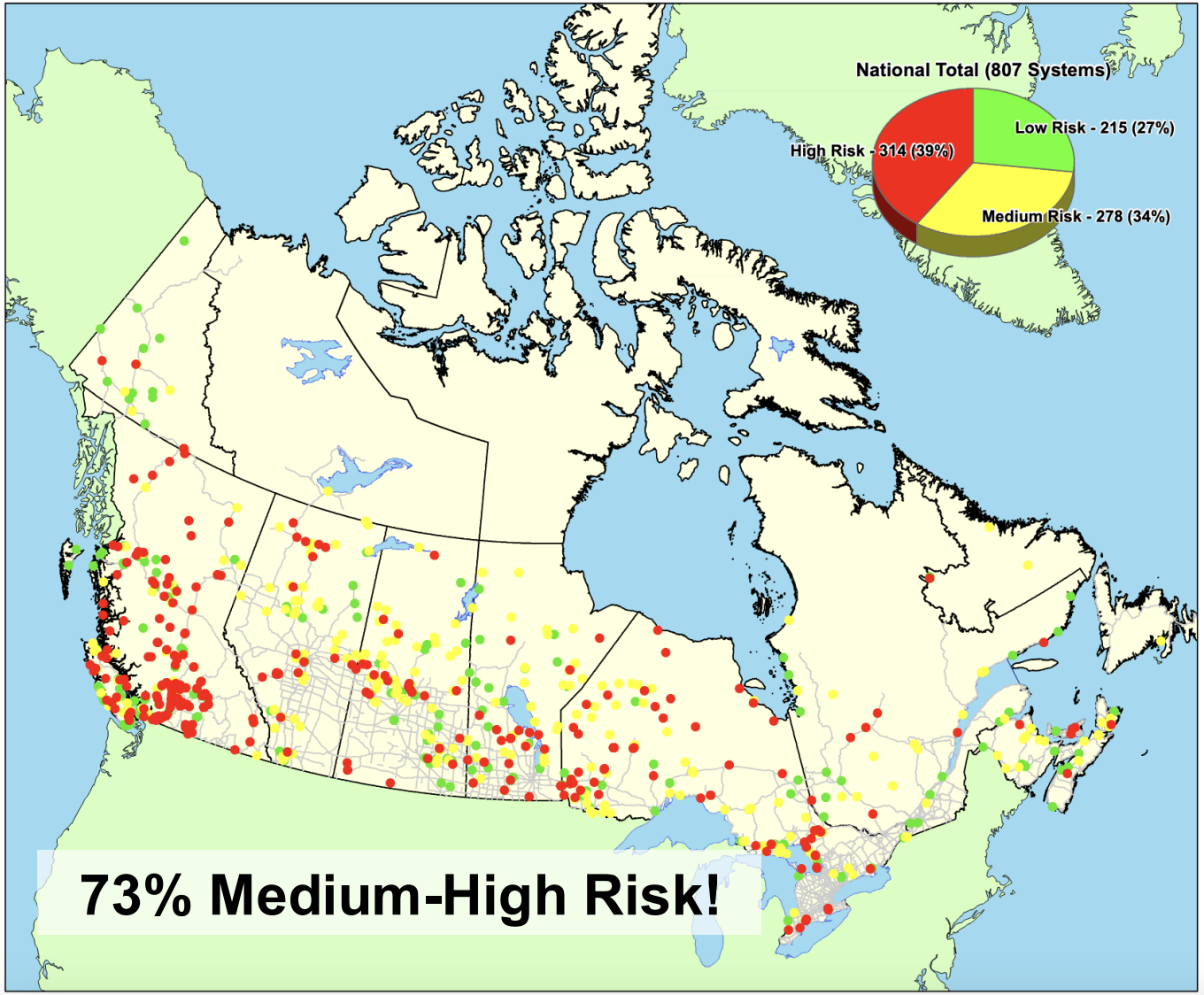
Disproportionate Risk for First Nation Communities

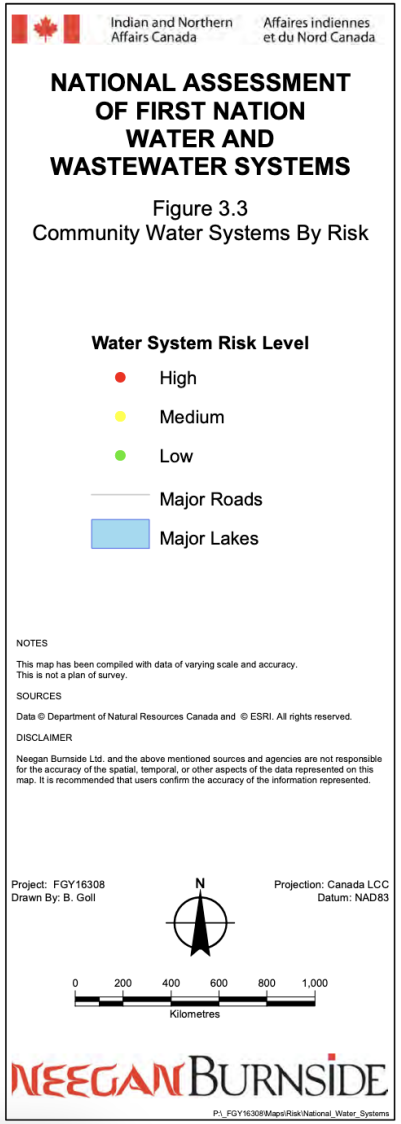
A 2011 assessment found that 39% of water systems were at "high risk"

These systems require immediate intervention due to health and safety concerns.

Even today, 31 long-term drinking water advisories persist.

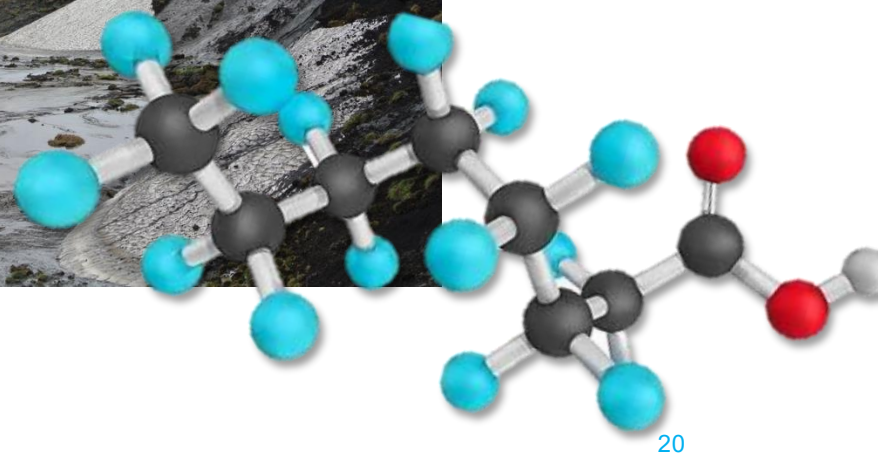
In the last few years, First Nations communities were finally compensated by the Federal government after a long legal battle.





A Growing Need!

- The need is expected to grow over time – expected signals at different wavelengths.
  - Benzene from oil spills (1.47% @ 254nm)
  - Microcystin from algal blooms (4.5% @ 254nm and 13.2% at 240nm)
  - NDMA, a water treatment disinfection byproduct (1.2% @ 240nm)
  - Melting permafrost could yield significant amounts of mercury
  - Forever chemicals (PFAS), microplastics, pharmaceuticals
  - Industrial waste



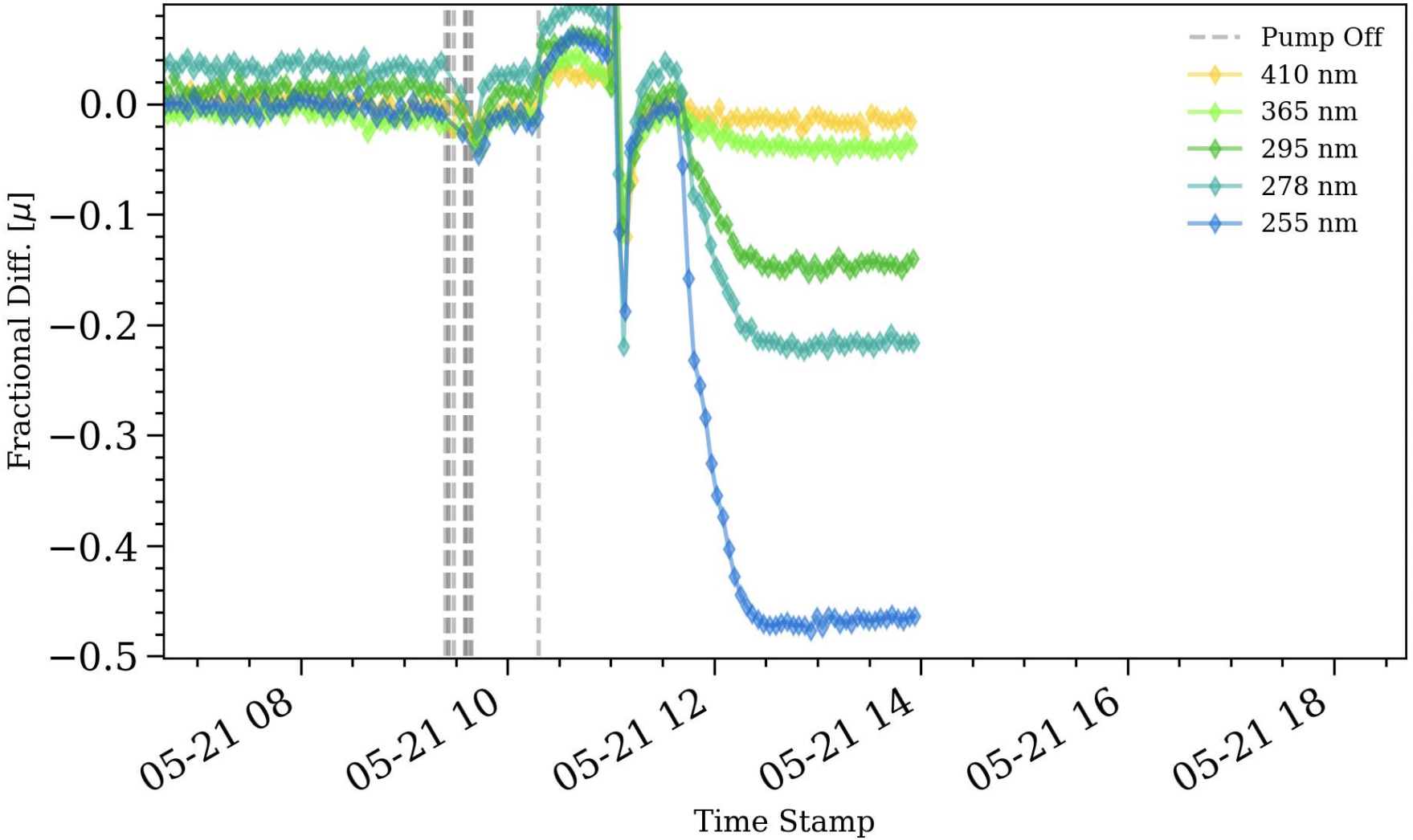
Introduction of Organic Resins

Big drop in UV transmission observed in WMS. Everything indicated water quality problem

- no dark rate jump
- No odd pump changes
- No flow changes
- No pressure changes

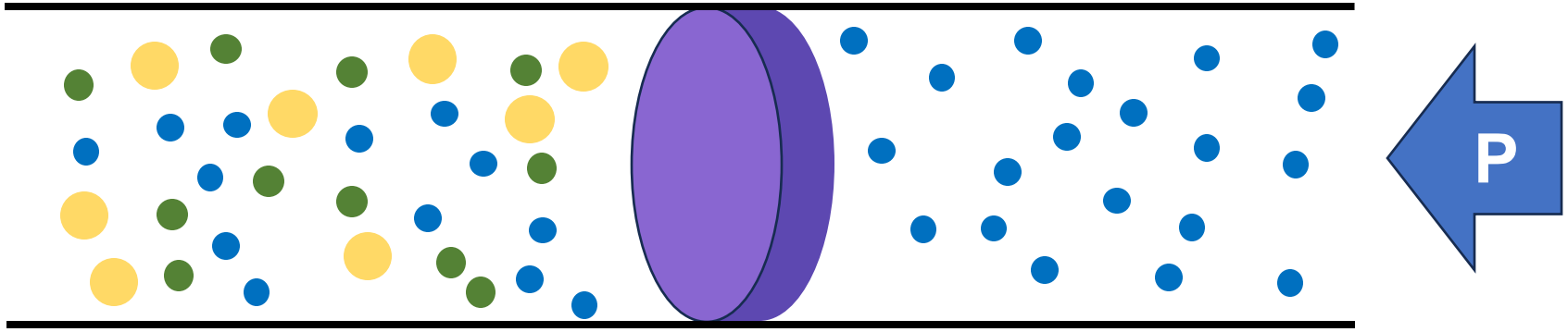
Patrick had recently added new “organic” resins, these took a bit of time to make it to WMS

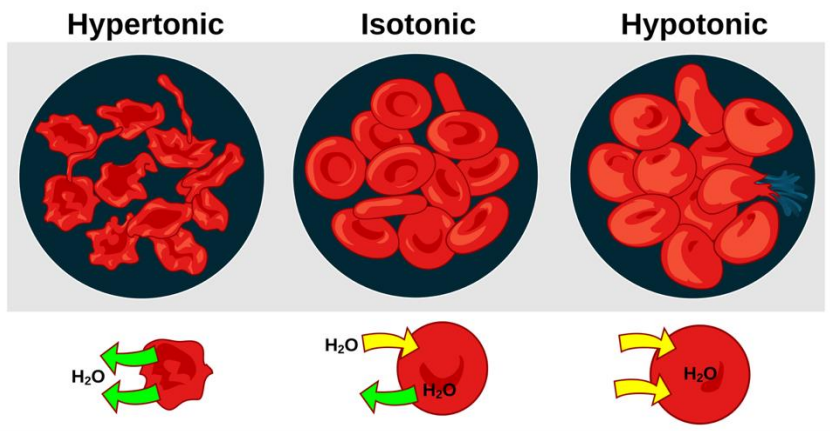
Eventually settled at a new baseline.



Osmosis

(semi-permeable membrane)



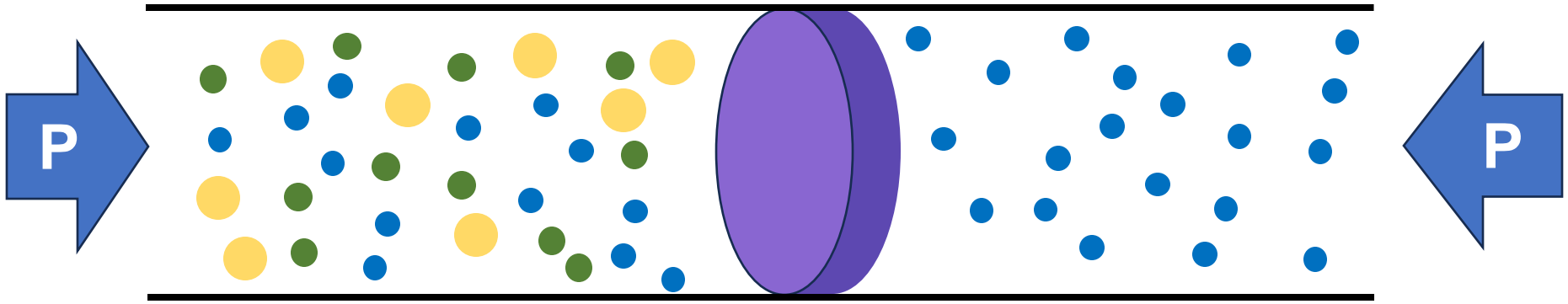


This is why you shouldn't drink distilled/deionized water! Cells can swell up and even burst if they absorb enough water!

Nature hates dramatic differences!

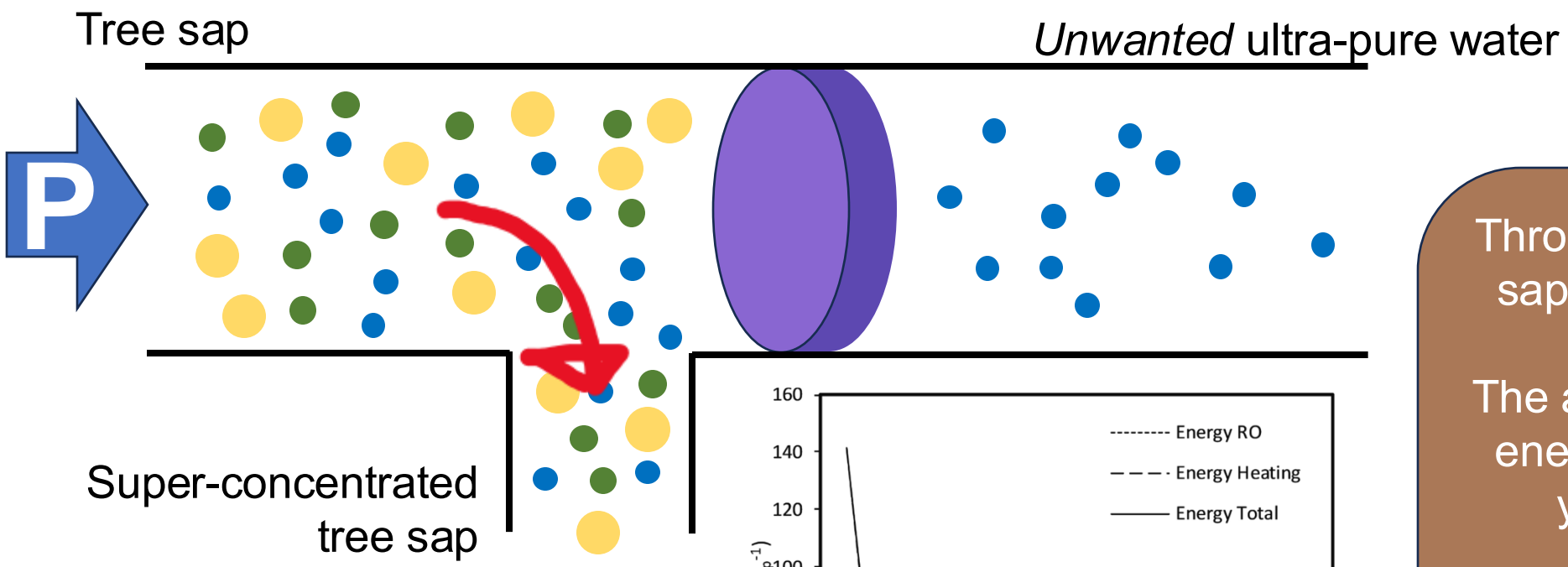
In general - the solvent (water) will flow through the barrier until both sides have an equal concentration of solute (salt). **That's osmosis.**

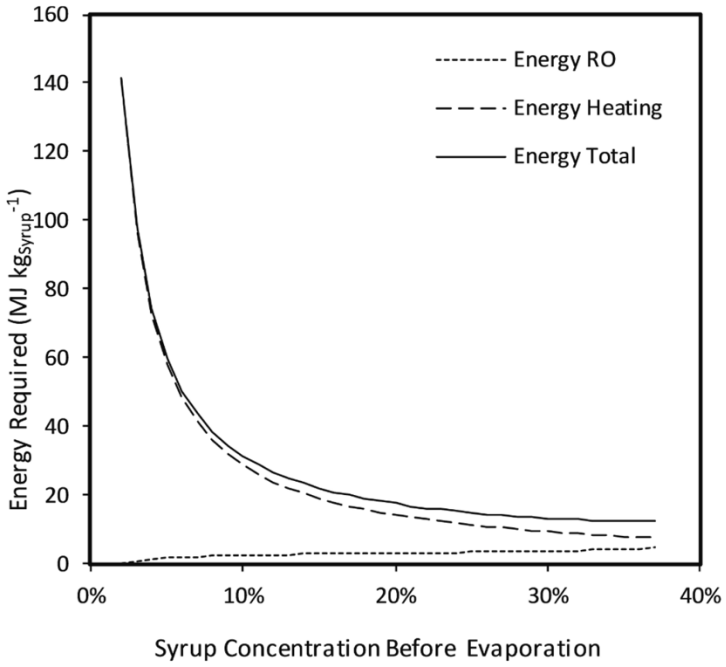
Osmosis



If you pressurize the concentrated side to the **osmotic pressure** – you prevent the flow of water.

Fun Fact – RO In Maple Syrup Production





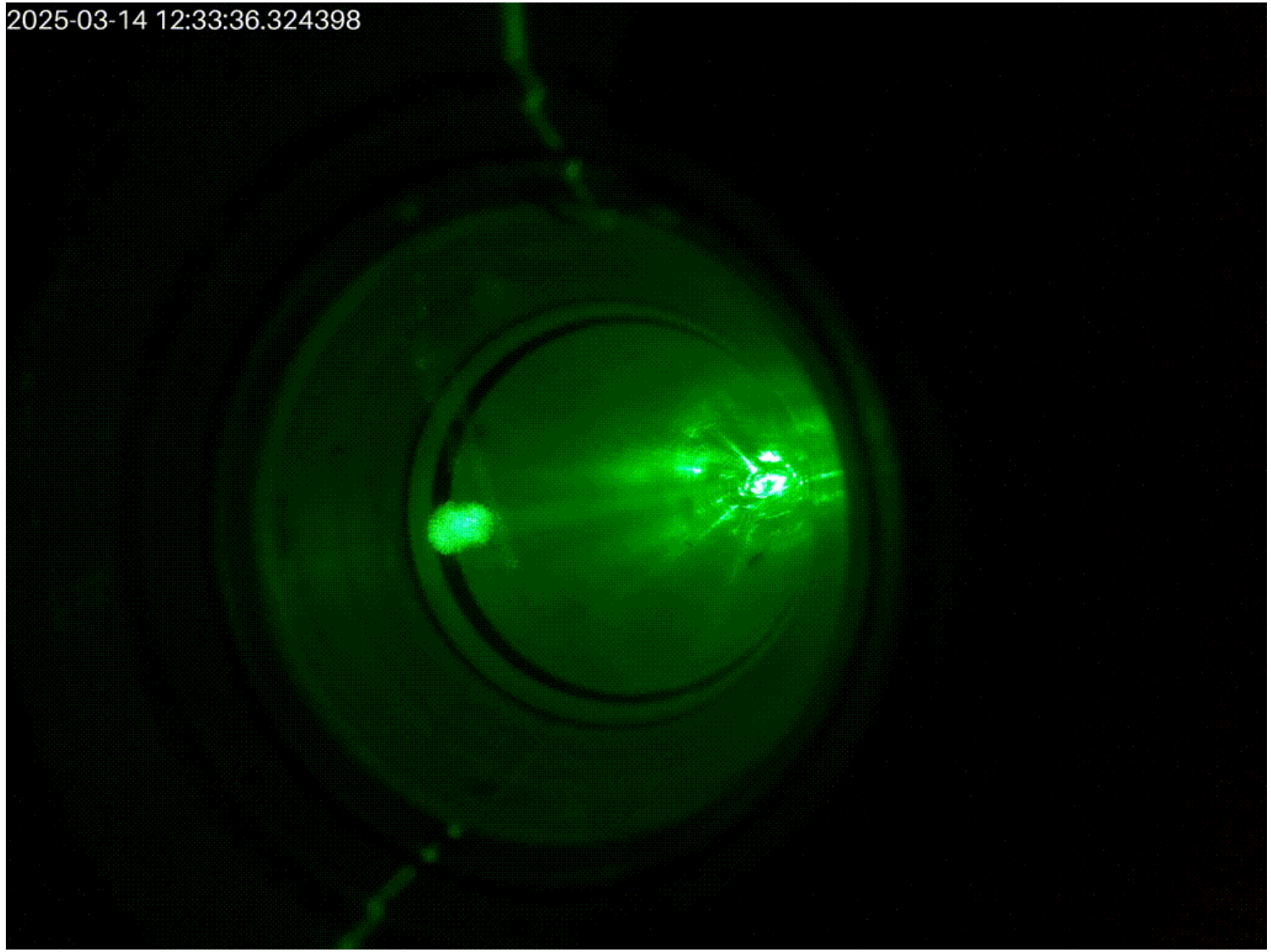
Through RO systems, tree sap is pre-concentrated.

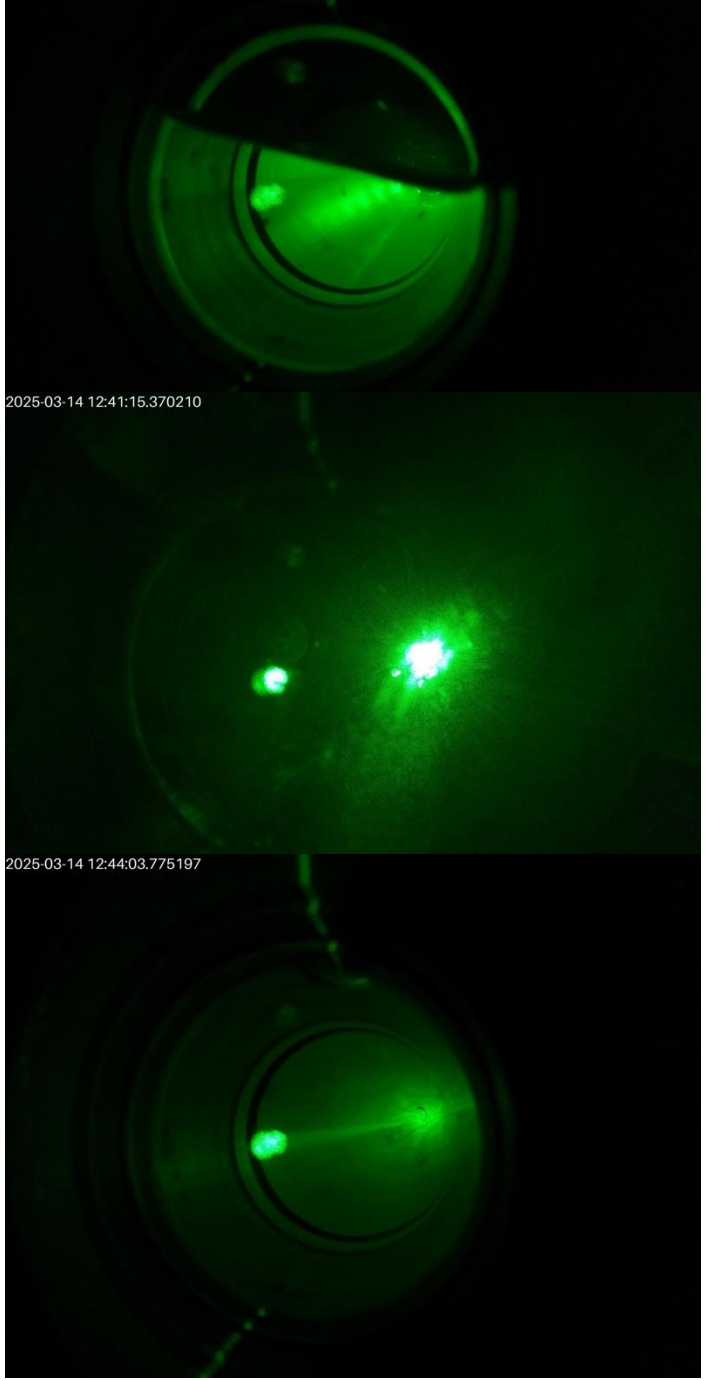
The amount of boiling, and energy used, required to yield pure syrup is reduced.

Used by some large-scale syrup producers, not all.

Journal of Food Engineering 273 (2020) 109823

Chamber Filling / Draining





WMS Control GUI

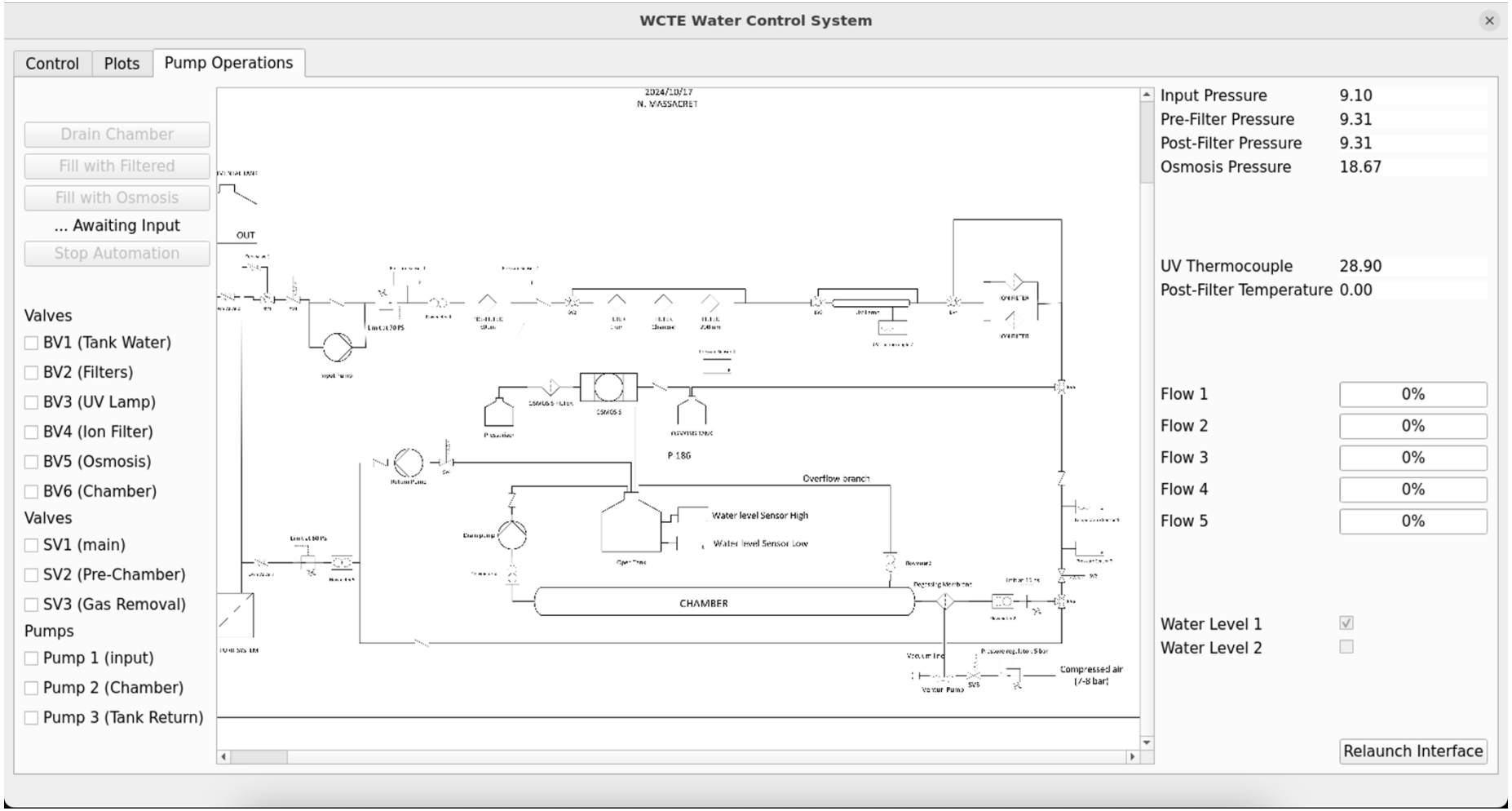
Pressures, temperature, and flow will be logged with timestamps going forwards

Auto Drain/Fill

Choose Filters

Open Valves

Toggle Pumps



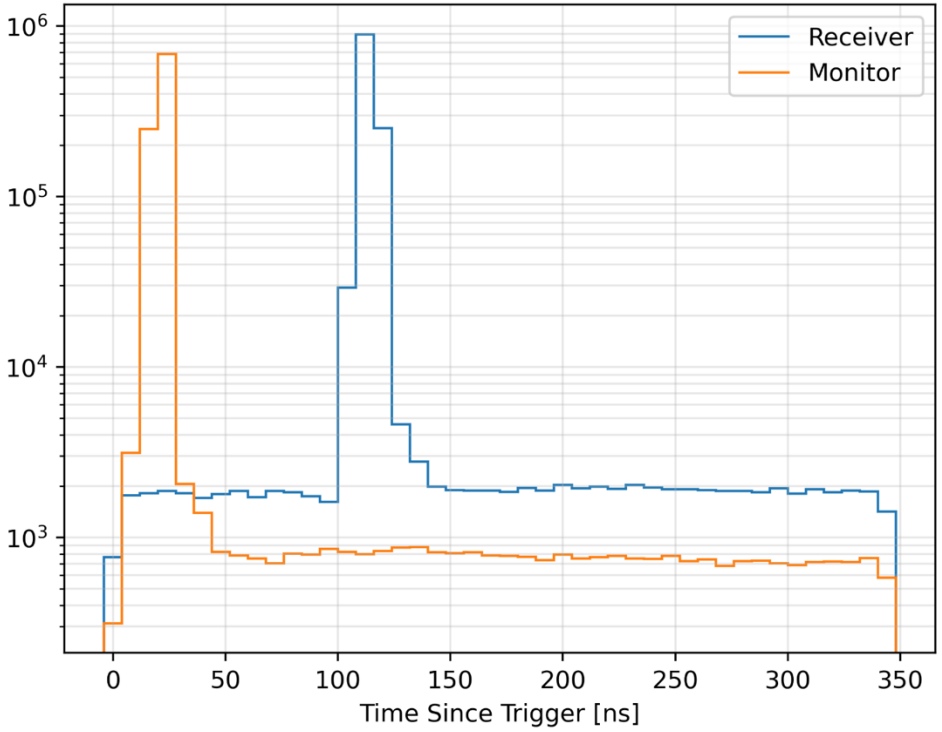
Monitor Pressure

Monitor Flow

Contributions from reflections?

Reflected light would arrive late, and be counted in the dark rate – this would yield an over-correction in the dark rate correction since this reflected light could not arrive on-time.

No evidence of reflected light seen



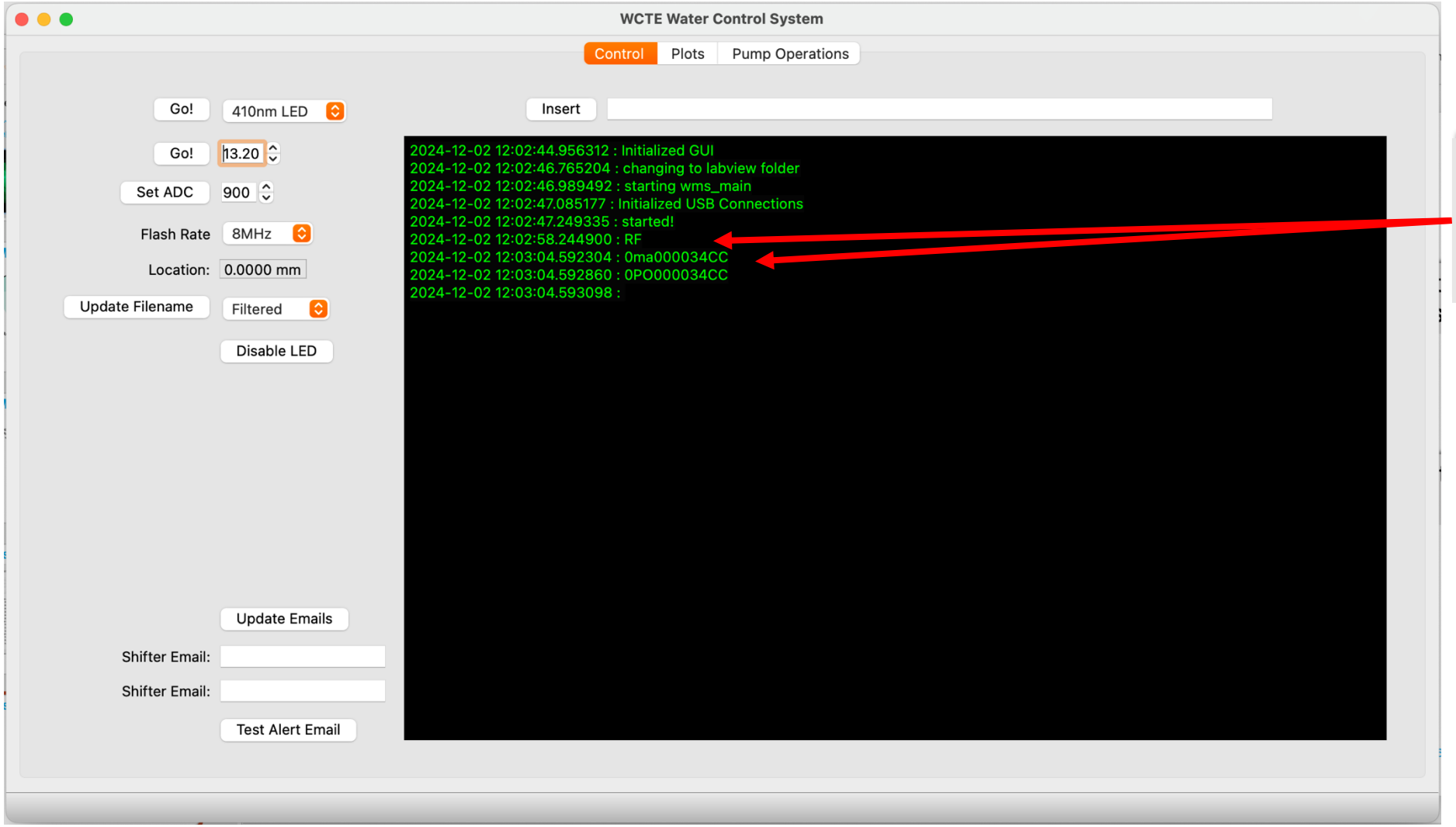
LED+Stage Control GUI

LED Control

Stage Control

Set Output Filename

Alert Emails



Command and Error Log

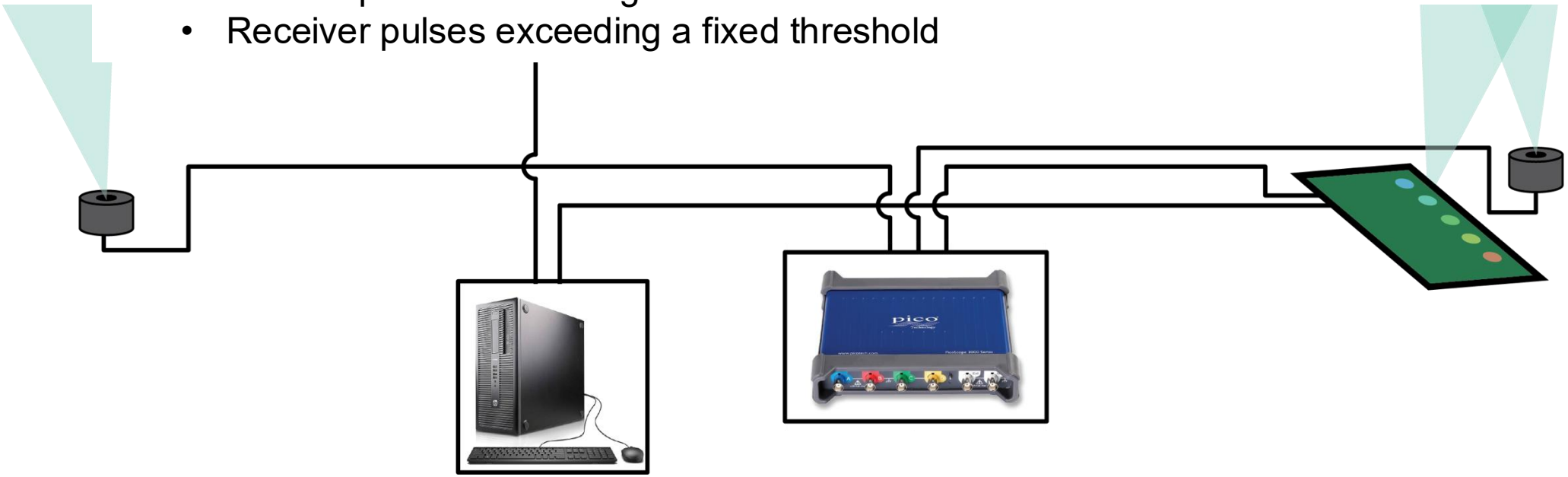
The LED + Linear stage controller, the Pi-Controlling, and the GUI all were moved onto separate computer threads.

Data Readout

The amplified PMT signals are digitized using a PicoScope 3406D MSO. The LED board outputs its trigger signal to the PicoScope. Electronic noise effected the receiver amplifier; had to be shielded with aluminum.

DAQ PC extracts a window with 250k 2ns-samples while pulsing the LED at 8MHz. We then want to count all

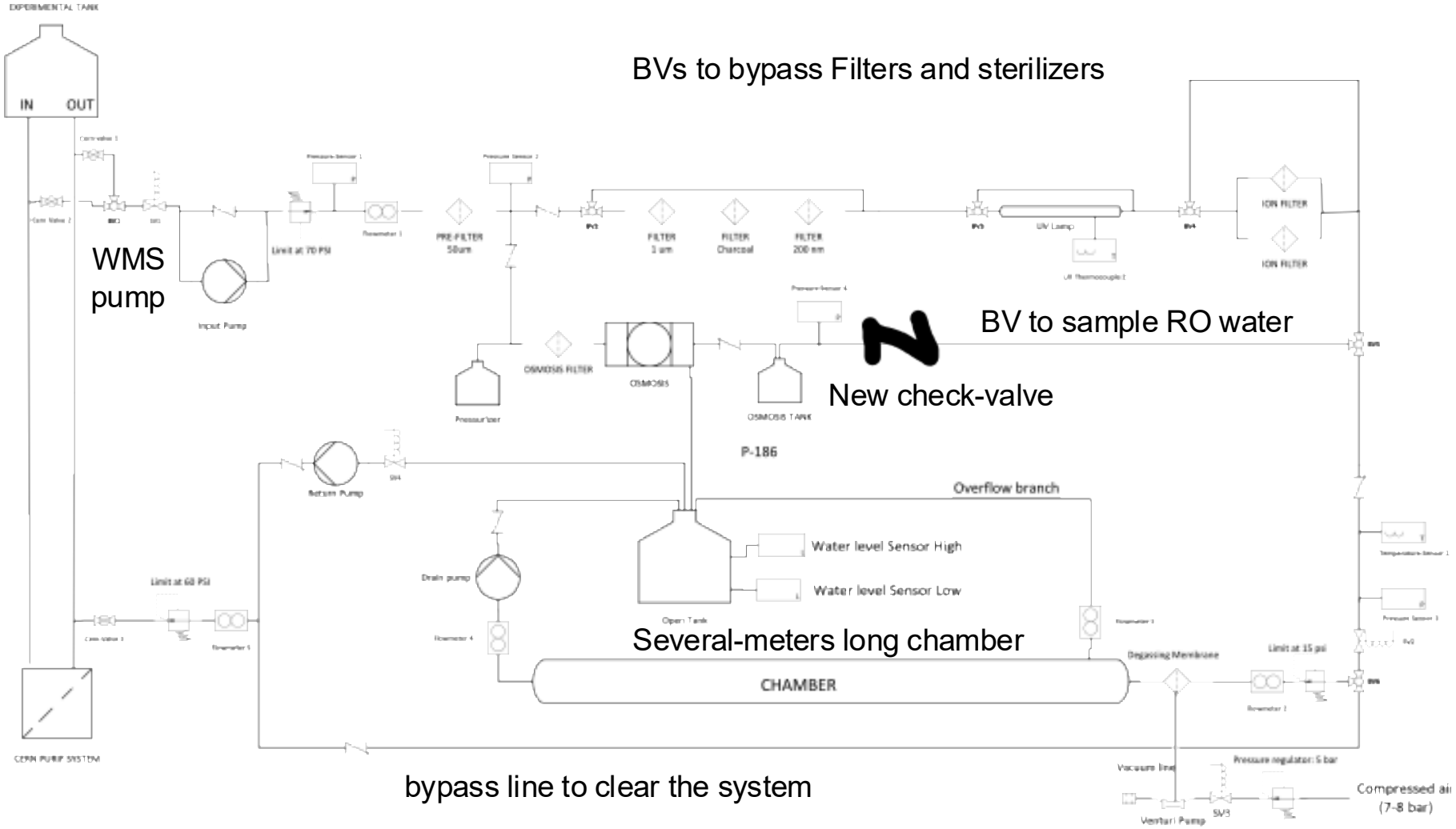
- LED board triggers
- Monitor pulses exceeding a fixed threshold
- Receiver pulses exceeding a fixed threshold



WMS Schematic Layout

Ball valve (BV) switches input source – WCTE Return or supply water

BVs to bypass Filters and sterilizers



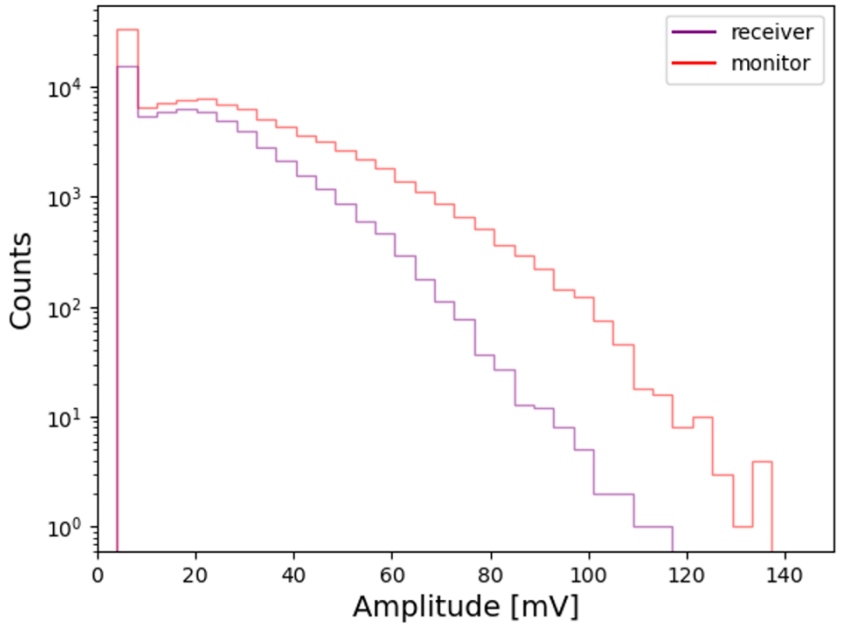
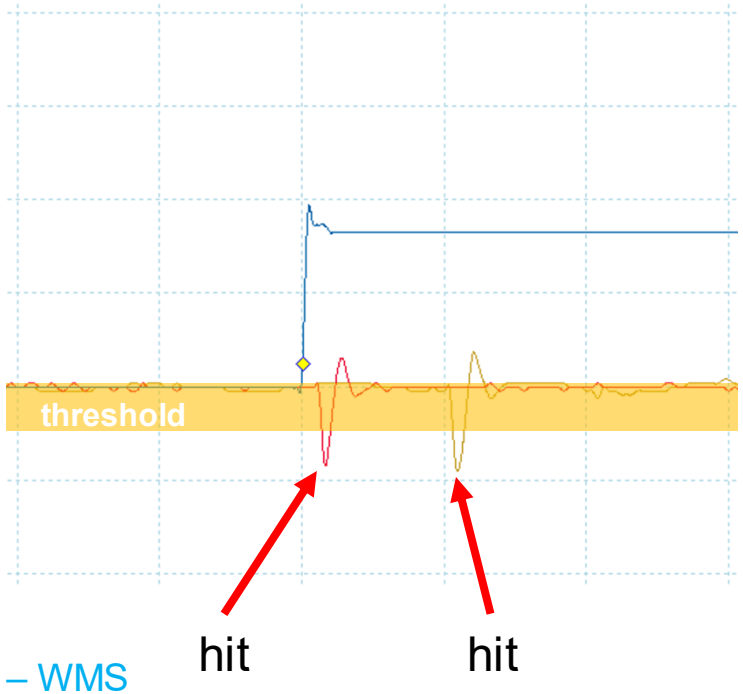
BV to sample RO water

New check-valve

bypass line to clear the system

What is a “Hit”

“Hits” are anywhere the PMT waveforms exceed a threshold determined from the pulse-height distributions from the PMTs.

A -25mV threshold is used.

With this threshold, a dark rate of 180 Hz was measured for each PMT. This was measured by setting the LED bias ADC as low as possible and measuring pulse rates normally.