Environmental monitoring using subatomic physics technologies

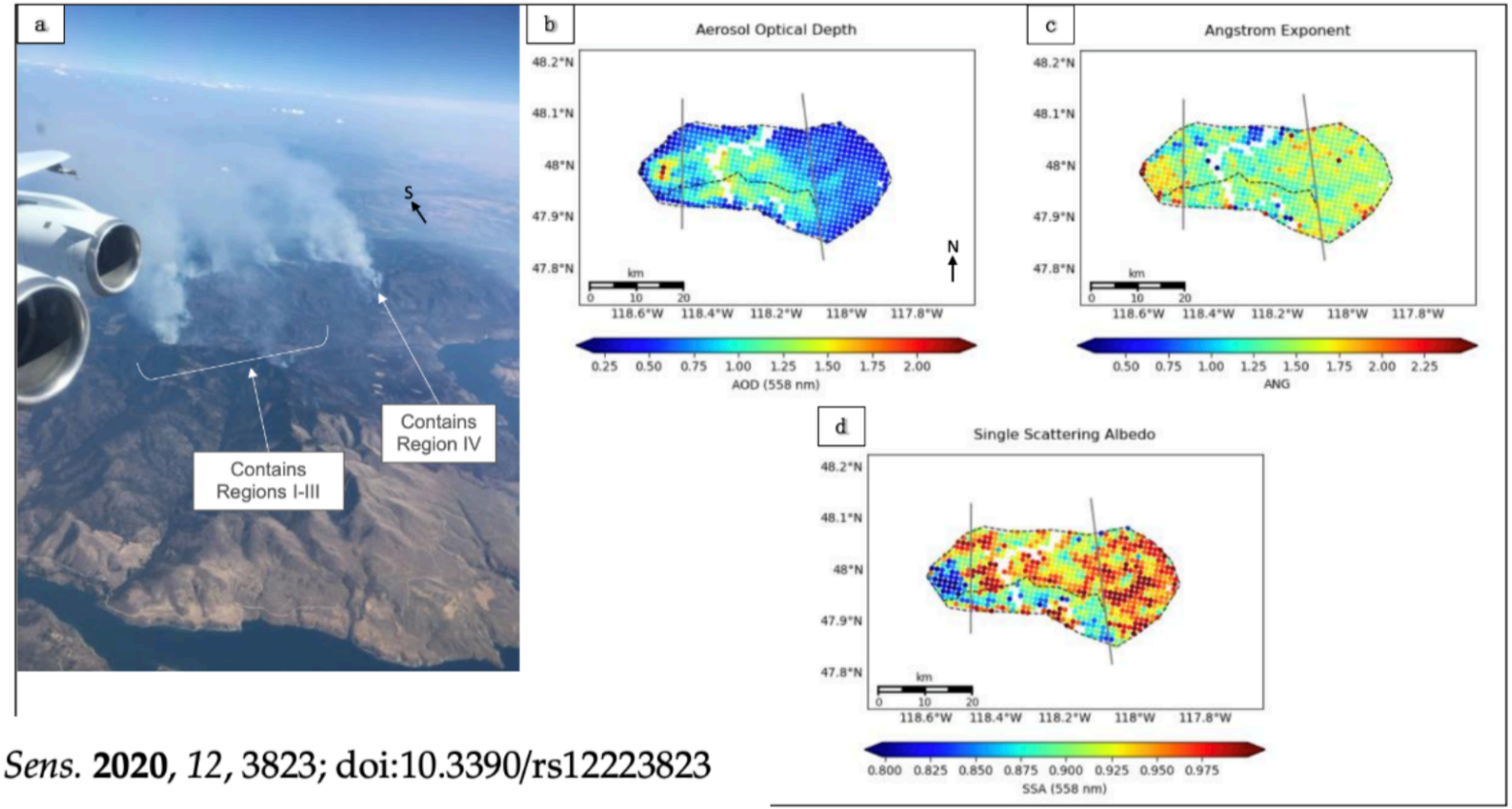
Akira Konaka (TRIUMF)

July 22, 2022

Environmental monitoring with optical method

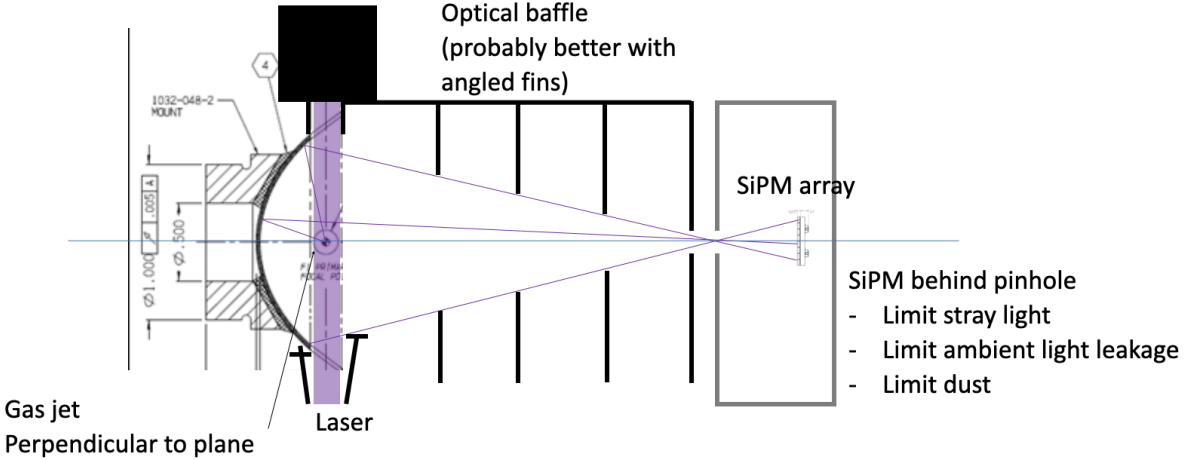
- Environmental challenges in particular due to global warming
  - Clean air
    - air pollution due to forest fire, coal burning, automobile exhaust, etc.
  - Clean water
    - water pollution due to algae growth, pesticides, oil spills, etc.
- Optical monitoring provides powerful information
  - Continuous monitoring
    - time correlating to identify contamination sources, sending alerts
  - Technology advancement in photosensor and light source
    - SiPM enables low-cost photon counting, deep UV LEDs, UV-sensitive SiPM
- Opportunity to transfer subatomic physics technologies
  - Synergies with neutrino (HyperK) and dark matter projects (nEXO/ARGO)

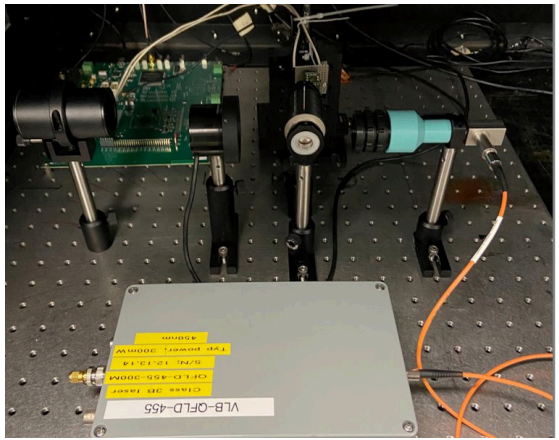
Early detection and management through smoke characterization?



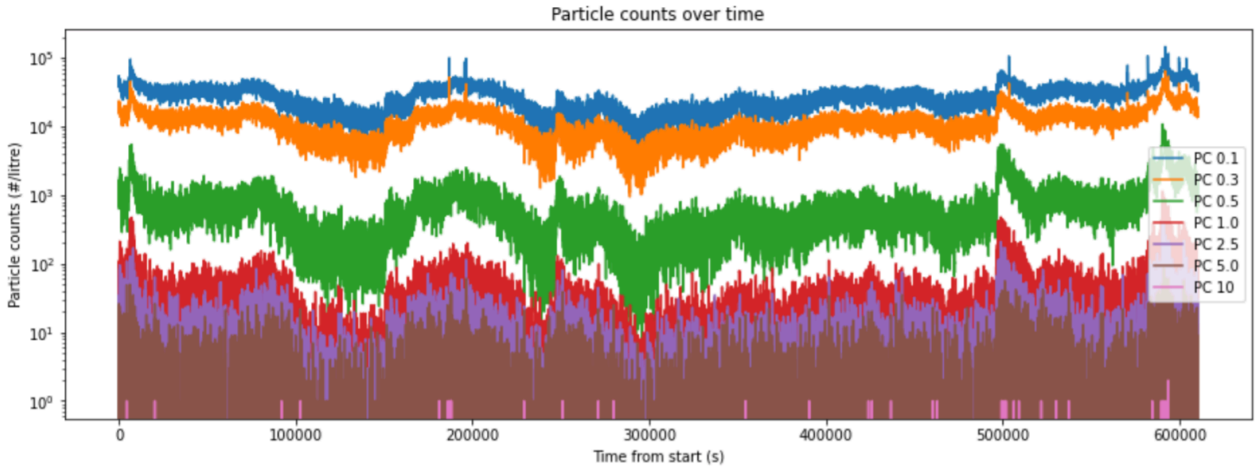
Remote Sens. **2020**, *12*, 3823; doi:10.3390/rs12223823

- Diffractive light scattering from particulates in the sample gas jet
  - Laser photons scattered from each particle in the sample gas
    - count rate corresponds and scattering angle → particle size and density
  - Scattered lights are focused by an elliptic (point-to-point focus) mirror
- Innovation based on dark matter detector experience
  - High sensitivity photon-counting SiPM array and high counting rate DAQ



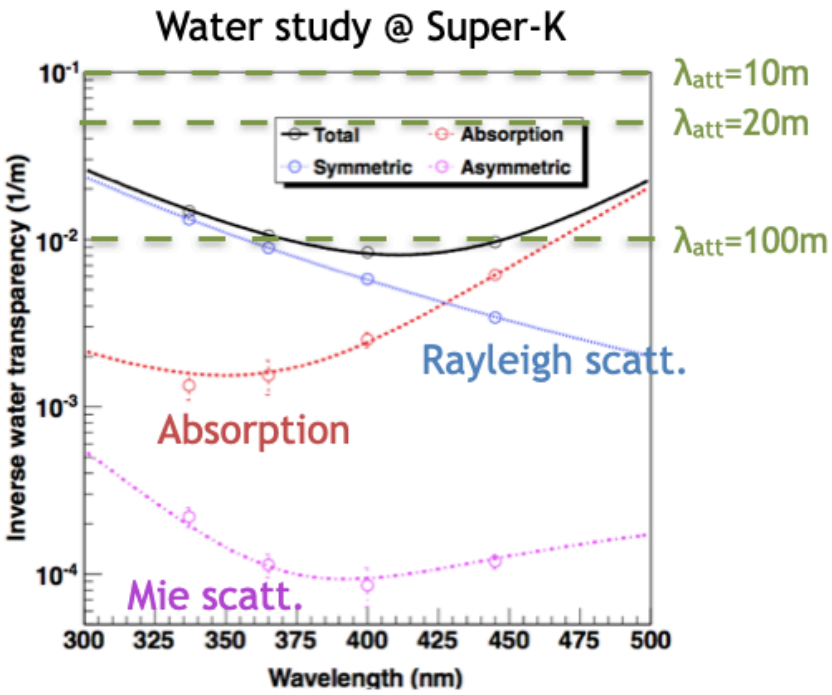


Commercialization of SPAA



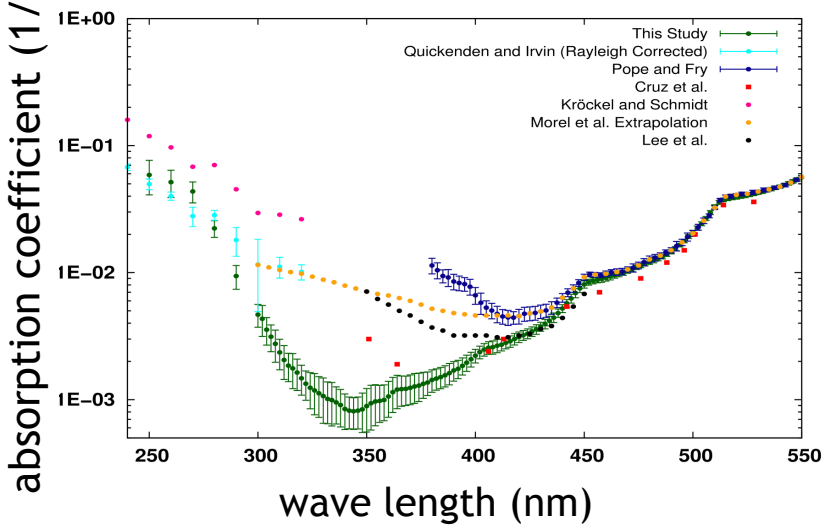
- Low-cost air monitor by Piera systems
  - Sensitivity improves significantly by SiPM photon counting
- Proof-of-principle project funded by McDonald Institute in progress
  - Develop NSERC Alliance proposal in partnership with a gas jet engineer (S. Rogak, UBC) and Piera systems
    - Supported by TRIUMF Innovations

SuperK water monitoring is the state-of-the-art



light scattering/absorption in pure water is essential in oceanography (Phytoplankton)

Applied Optics 25 (2016)7163



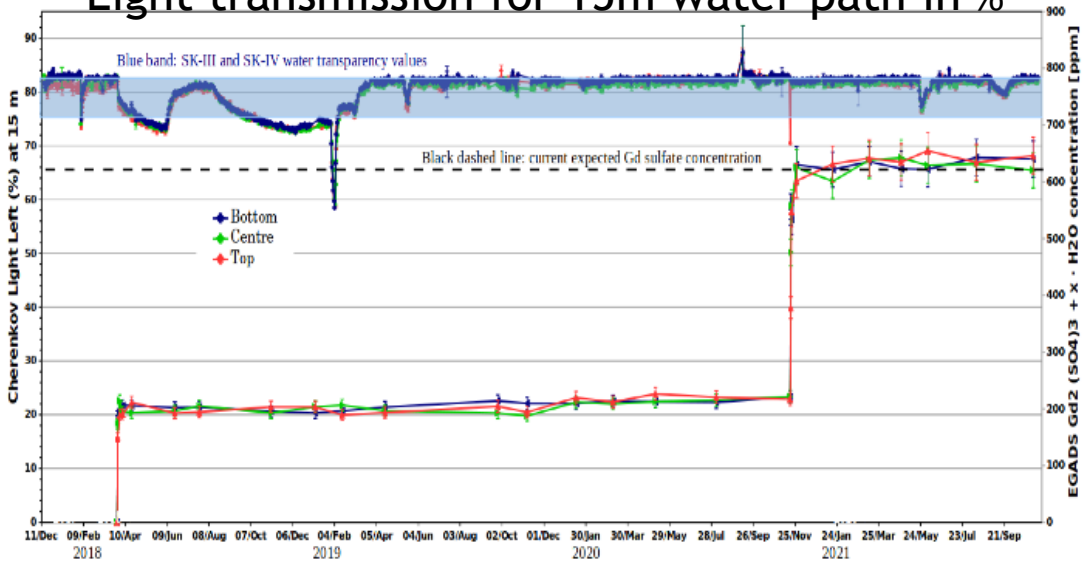
The results in this study shift the wavelength for the minimum absorption of pure water from 418 to 344 nm. Many scientists in the large detector field have already been operating under the assumption that the true minimum of water was found at a wavelength near 350 nm [25]. On the long wave-

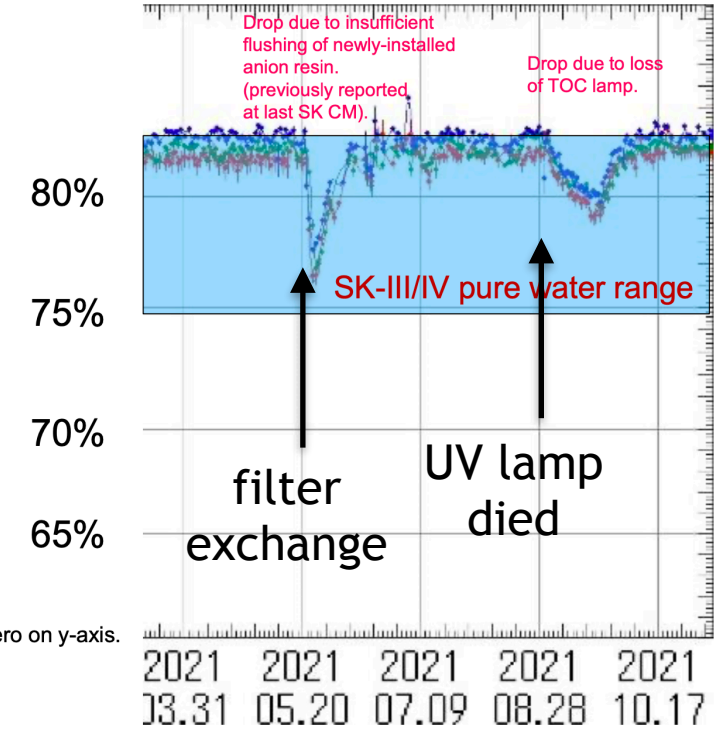
Old SuperK paper is cited

Continuous water monitoring of SuperK detector

- Transmission continuously monitored
  - time correlation is a powerful tool in identifying the source
- Huge impact in water monitoring
  - instead of water sampling and lab. test

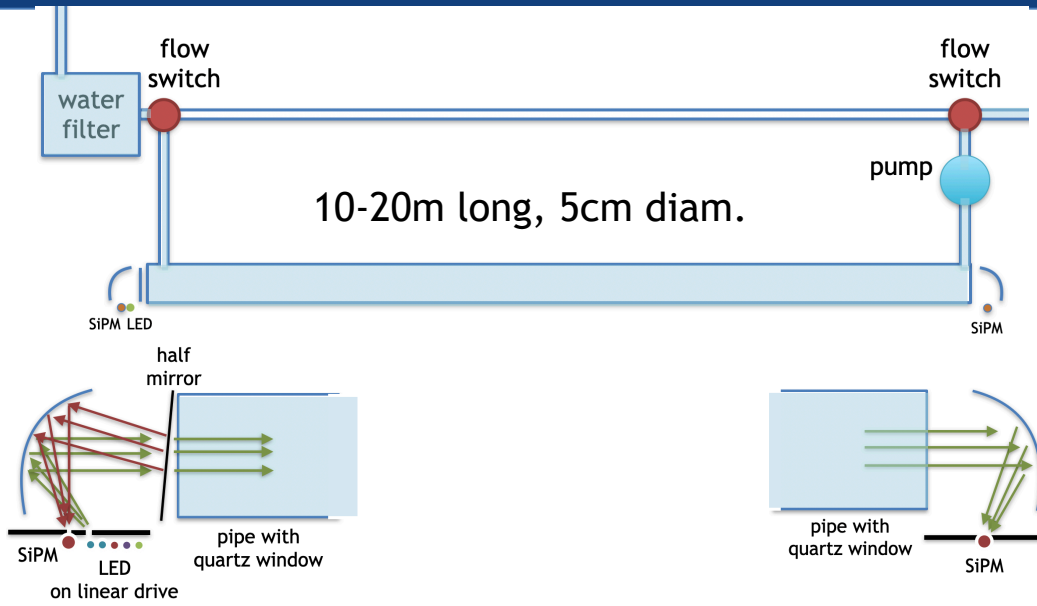
Light transmission for 15m water path in %

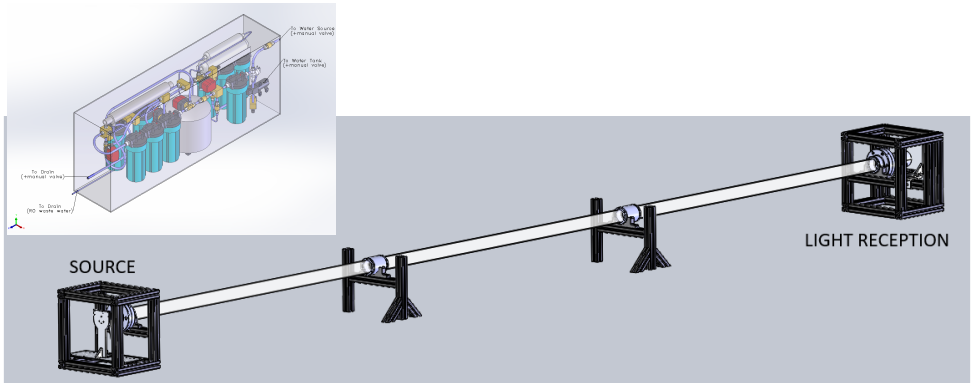




sed zero on y-axis.

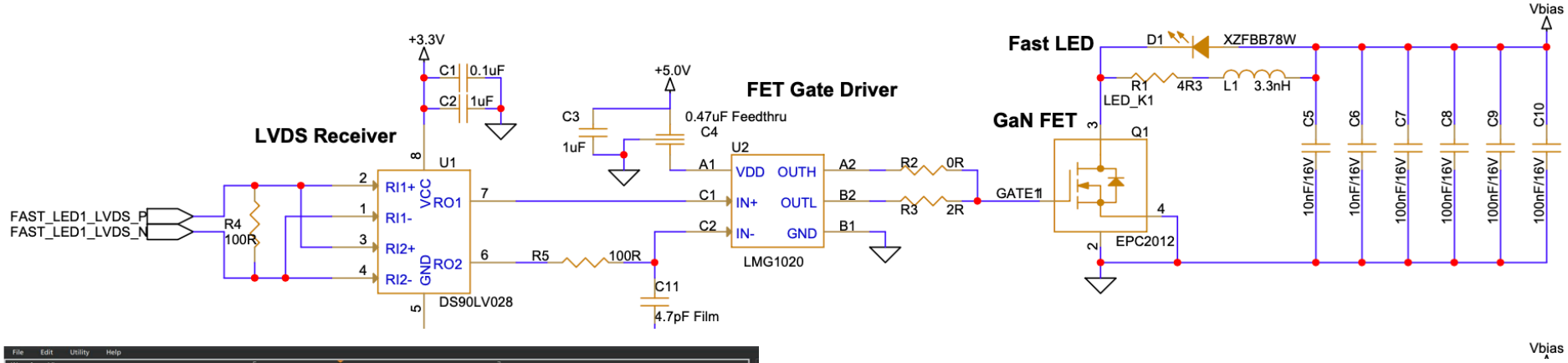
Water monitoring detector concept

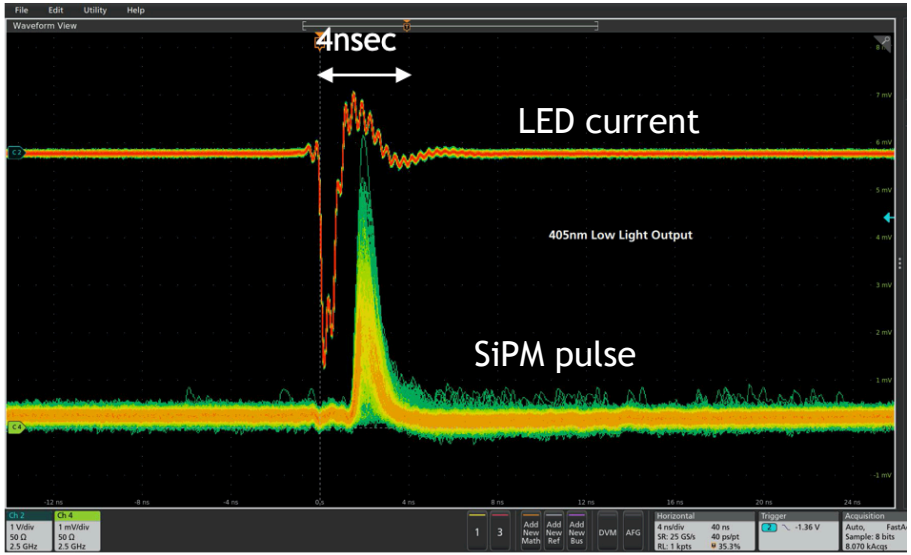




- Pulsed LED light through 10-20m sample water
  - 230 - 700nm
  - parabolic mirror focus
  - SiPM at source/reception
- Relative to purified water
  - ultra-pure (RO)
  - particle filter (MF,NF)
  - ion exchange resins
  - UV steriliser (organic)

Sub-nsec pulsed LED: Nick Braam (UVic)





- LED: deep UV-LED available
  - 230nm - 700nm
  - a pulse width of 0.6nsec FWHM achieved
- Driver circuit
  - GaN gate FET (new technology)
  - Capacitor bank to over-drive
- Low cost: $15-25 per channel
  - except for LEDs below 270nm (~$100)

Does it help drinking water monitoring?

- Spectrophotometer: typical sample size is ~1cm
  - Concentrating the sample to enhance the sensitivity
- SuperK solution: ~10m-long water pipe
- Absorption in 10m water would provide enough sensitivities for drinking water monitoring
  - Benzene: common toxin in oil spills
  - Microcystin: toxin from blue-green Algae
  - NDMA: disinfection byproduct after water treatment

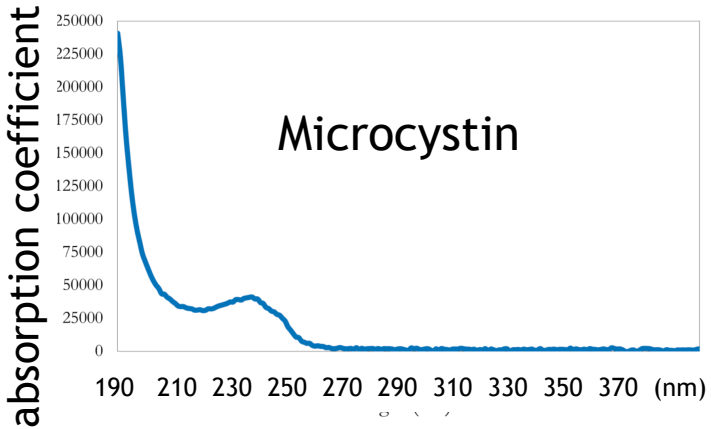


Figure 3.5: Molar Absorption Coefficients of MC-LR at Different Wavelengths

	drinking water limit	absorption coeff.	absorption in 10m	absorption in 1cm
Benzene	5 µg/L	240 /mol/cm @254nm	1.47% @254nm	0.00147%@254nm
Microcystin	1.5 µg/L	13,225 mol/cm @254nm	4.5% @254nm	0.0045% @254nm
	1.5 µg/L	40,000 mol/cm @240nm	13.2% @240nm	0.0132%@240nm
NDMA	0.04 µg/L	10,000 /mol/cm @240nm	1.2% @240nm	0.0012%@240nm

Deployment of the water monitoring system

- HyperK project
  - Water Cherenkov Test experiment at CERN (2024)
  - HyperK near and far water Cherenkov detectors (2027)
- First Nations communities
  - initial fieldwork by Arzu Sardarli (First Nations University of Canada)
    - Agreements at Cowessess First Nation, Ahtahkakoop Cree Nation
      - Community members taught by Arzu, including the Chief
  - Potential to identify the sources of contamination
    - one of the communities has water quality issues
    - involvement of high school students in the operation and data analysis
- Water treatment facility
  - initial fieldwork by Jinkai Xue (U.Regina, engineering)
    - Agreement with a full-scale water treatment plant: Weyburn water treatment facility
  - “Paradigm change” by dynamically adjusting the water treatment parameters

Sustainability

- Sustainable operation is a major challenge
  - water purification systems at First Nations communities were abandoned due to maintenance problems
- Multi-layer approach to support local communities in the operation
  - Detector development by TRIUMF with an experience of SuperK
    - Engineering test of the first prototype
  - University groups to test and support the system:
    - Five prototypes for beta testing at the participating University groups
      - operation, maintenance, testing, and calibration
    - Gain experience to support the maintenance and operation at communities
  - Development of expertise at the local communities
    - First Nations communities with the involvement of students and teachers
    - The municipal water treatment facility in collaboration with water research scientists
  - Environmental scientists to develop a network to analyze the data
    - Development of data analysis and interpretation in collaboration with local communities
    - Development of distributed water monitoring network to maintain and expand support.

HQP training

- Environmental monitoring project attracts HQP for training
  - Proof-of-principle project for SPAA attracts students
    - two SFU-TRIUMF MSc students and Edinburgh student
  - One UVic MSc student and two engineering students on water monitoring
  - potential Swiss post-doctoral fellowship candidate on both project
- Water monitoring project for the First Nations students
  - extra-curricular program for First Nations high schools
    - interest by First Nations high school teachers
  - potential to participate in the Kirkness program
    - Master class for indigenous high school students
  - Regional Centre of Expertise on education for sustainable development (RCE, under UNESCO)
    - Preparing to become a project of RCE Saskatchewan
- Potential program for Particle Physics Master class

Summary

- Environmental monitoring plays a key role in the prevention (Green Technology)
  - clean air, clean water
  - climate change makes the situation more challenging
  - prevention is more cost-effective than clean-up after contamination
- Subatomic physics technology can make contributions
  - Optical monitoring allows continuous and distributed monitoring
    - highly sensitive photon counting (SiPM) with fast DAQ
    - along with rapid developments in UV LED technology
  - Two initiatives are being developed
    - air pollution monitoring:
      - early detection of forest fires
    - drinking water monitoring
      - First Nations communities: identify the contamination sources and send an alert
      - Municipal water treatment plant: dynamically adjusting water treatment chemicals
- The program has an important contribution in EDI and HQP training