Environmental monitoring using subatomic physics technologies

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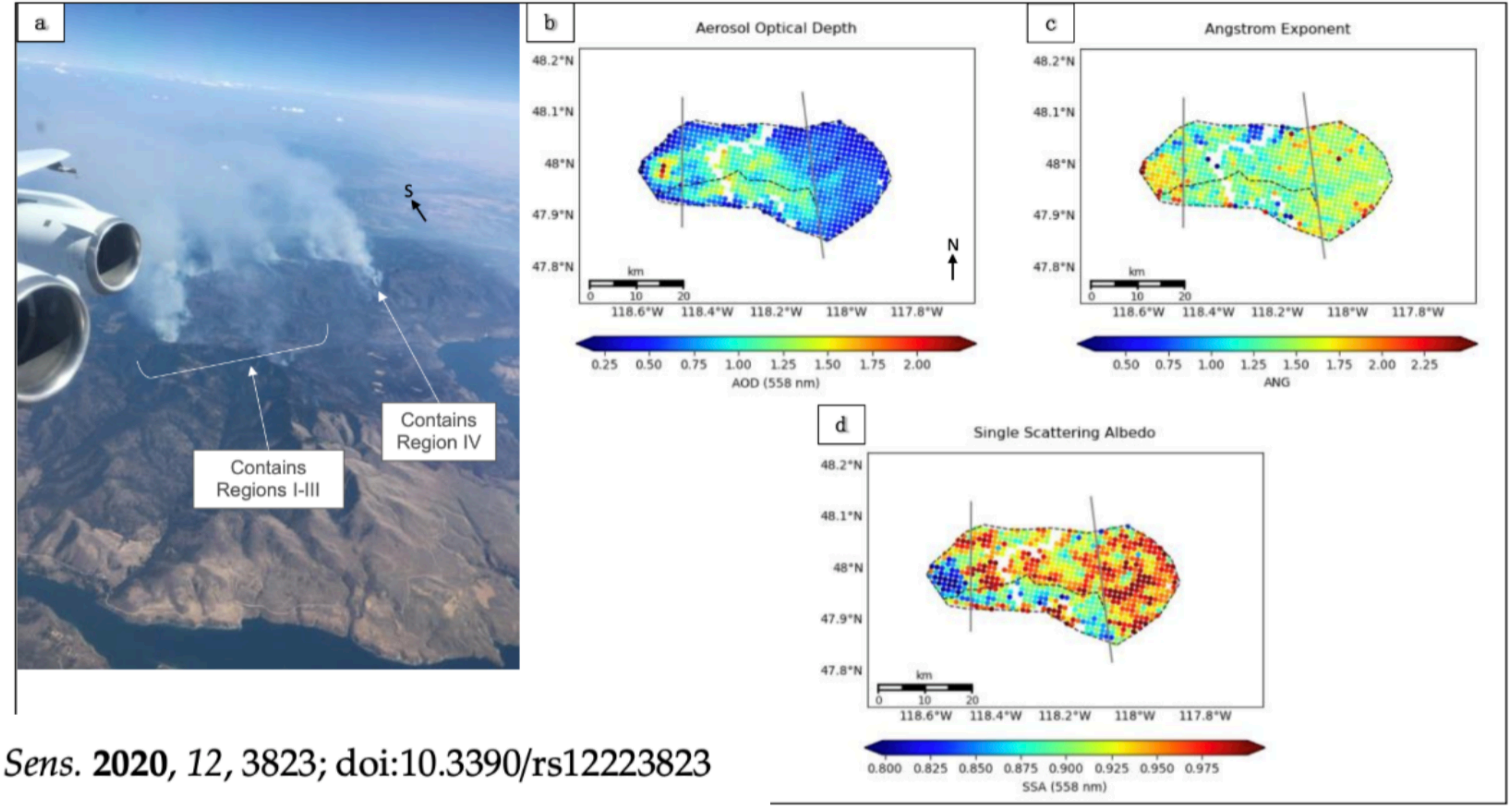
Environmental monitoring with optical method

- 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 photodetector technology
  - Synergies with neutrino (HyperK) and dark matter projects (nEXO/ARGO)

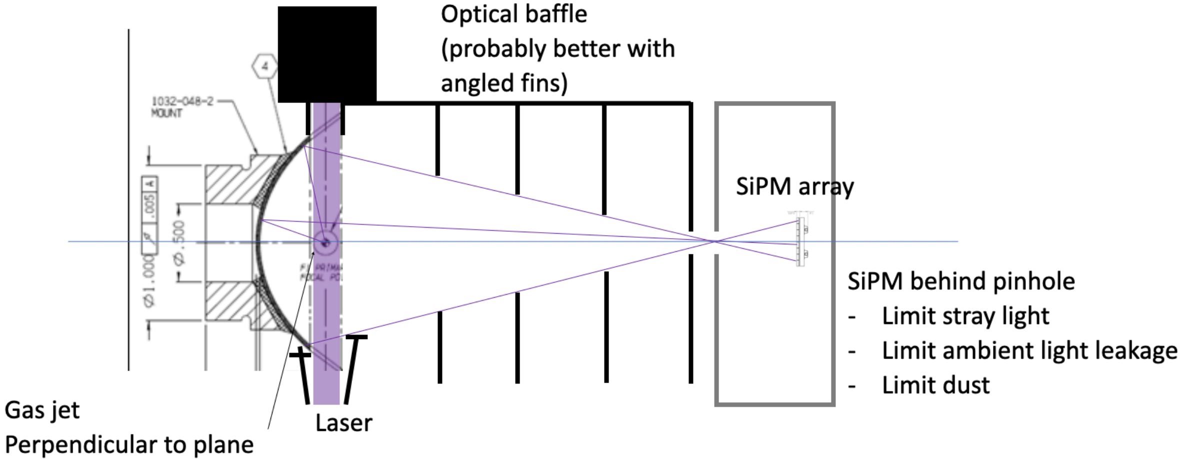
Early detection and management through smoke characterization?

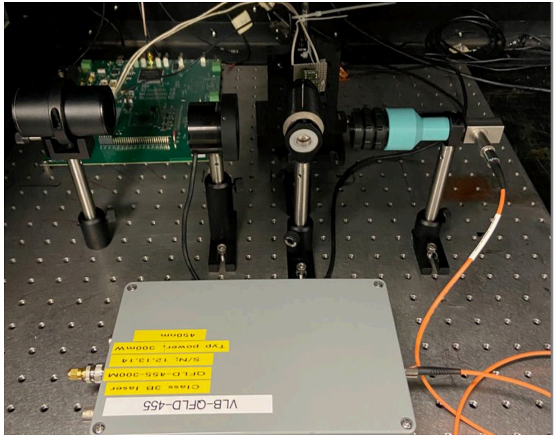


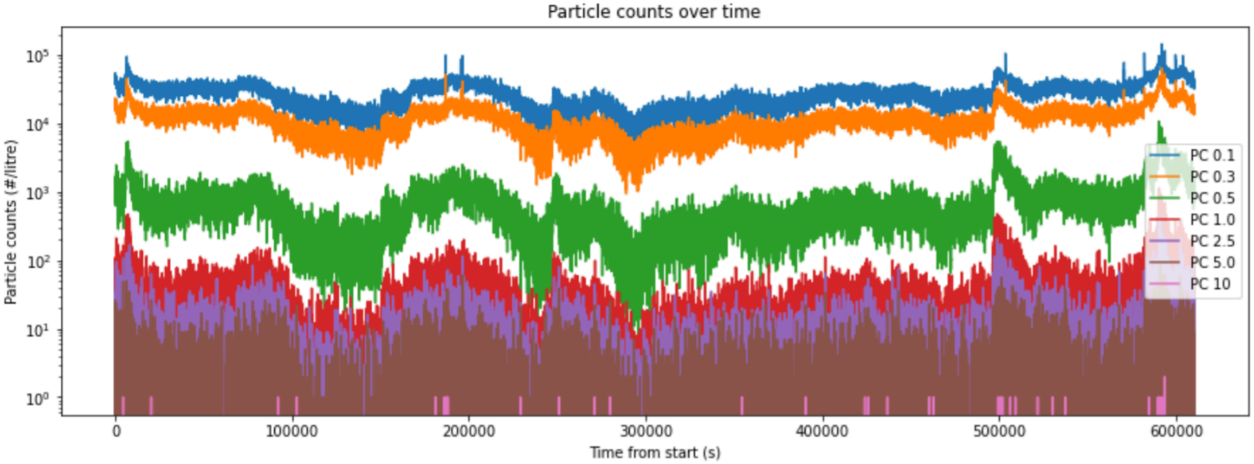
Remote Sens. **2020**, *12*, 3823; doi:10.3390/rs12223823

Single Photon Air Analyzer (SPAA) project

- Diffractive light scattering from particulates in the sample gas jet
  - Laser photons are 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

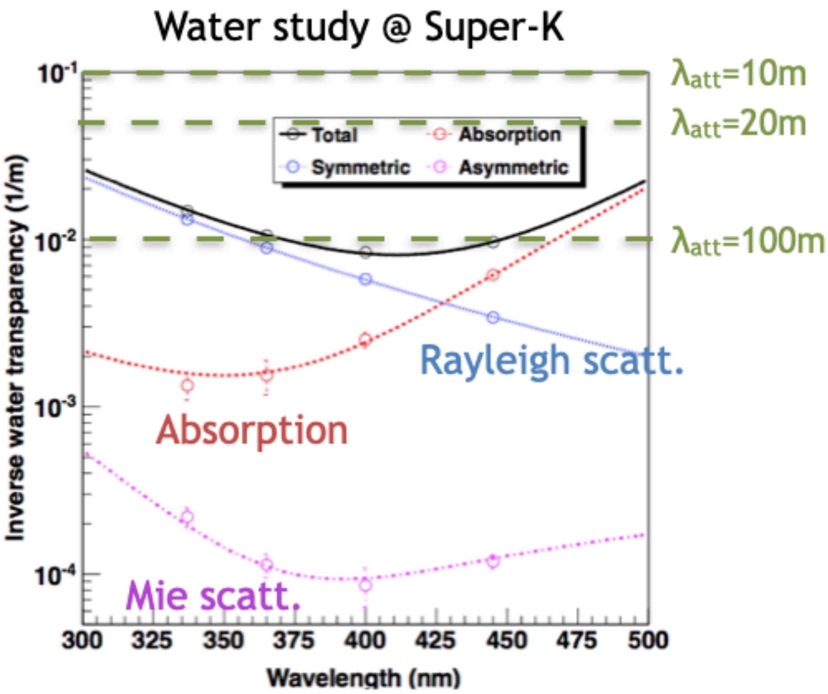






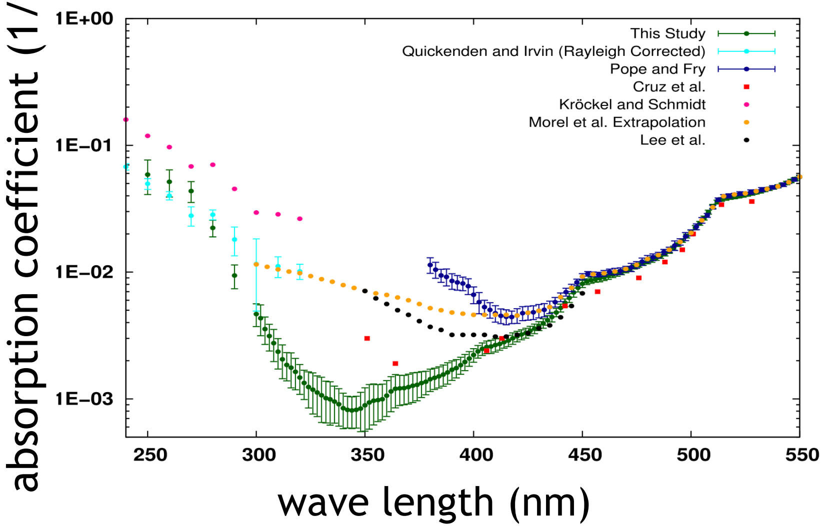
- Low-cost air quality monitor by Piera systems
  - Sensitivity improves significantly by SiPM photon counting
- Proof-of-principle project funded by McDonald Institute is in progress
  - Develop NSERC Alliance proposal in partnership with a gas jet engineer (S. Rogak, UBC) and Piera systems
    - Supported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

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



light scattering/absorption parameters
in pure water are needed in oceanography:
carbon fixing (Phytoplankton), heat budget

Applied Optics 25 (2016)7163



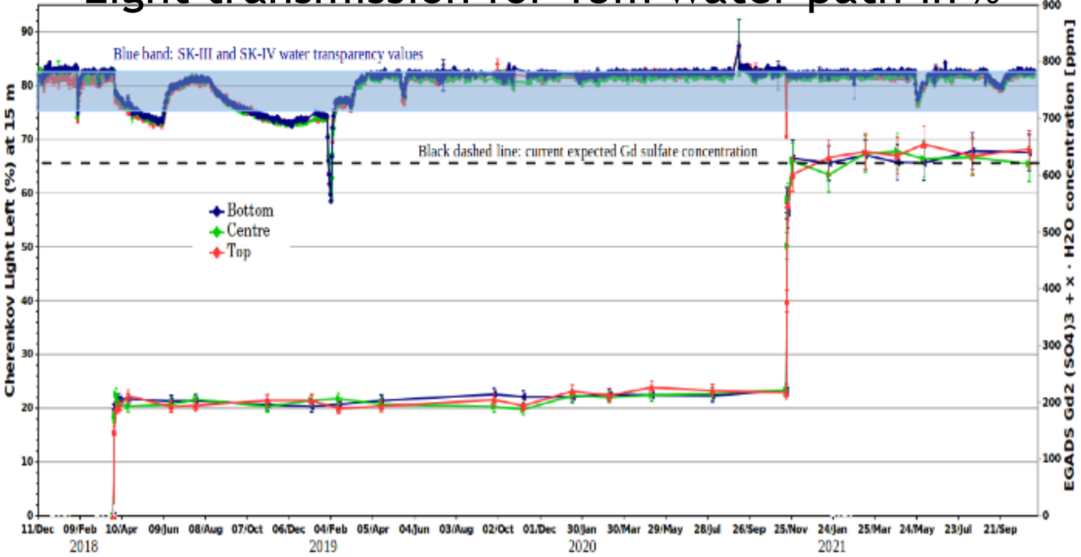
The results in this study shift the wavelength for the minimum absorption of pure water from 418 to 344 nm. Many scientists in the large detector field have already been operating under the assumption that the true minimum of water was found at a wavelength near 350 nm [25]. On the long wave-

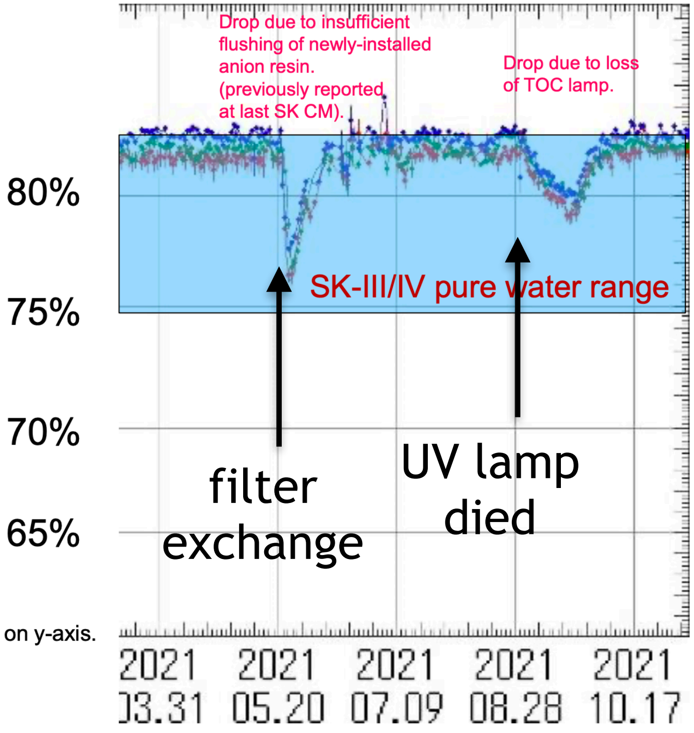
Old SuperK paper is cited

Continuous water monitoring of SuperK detector

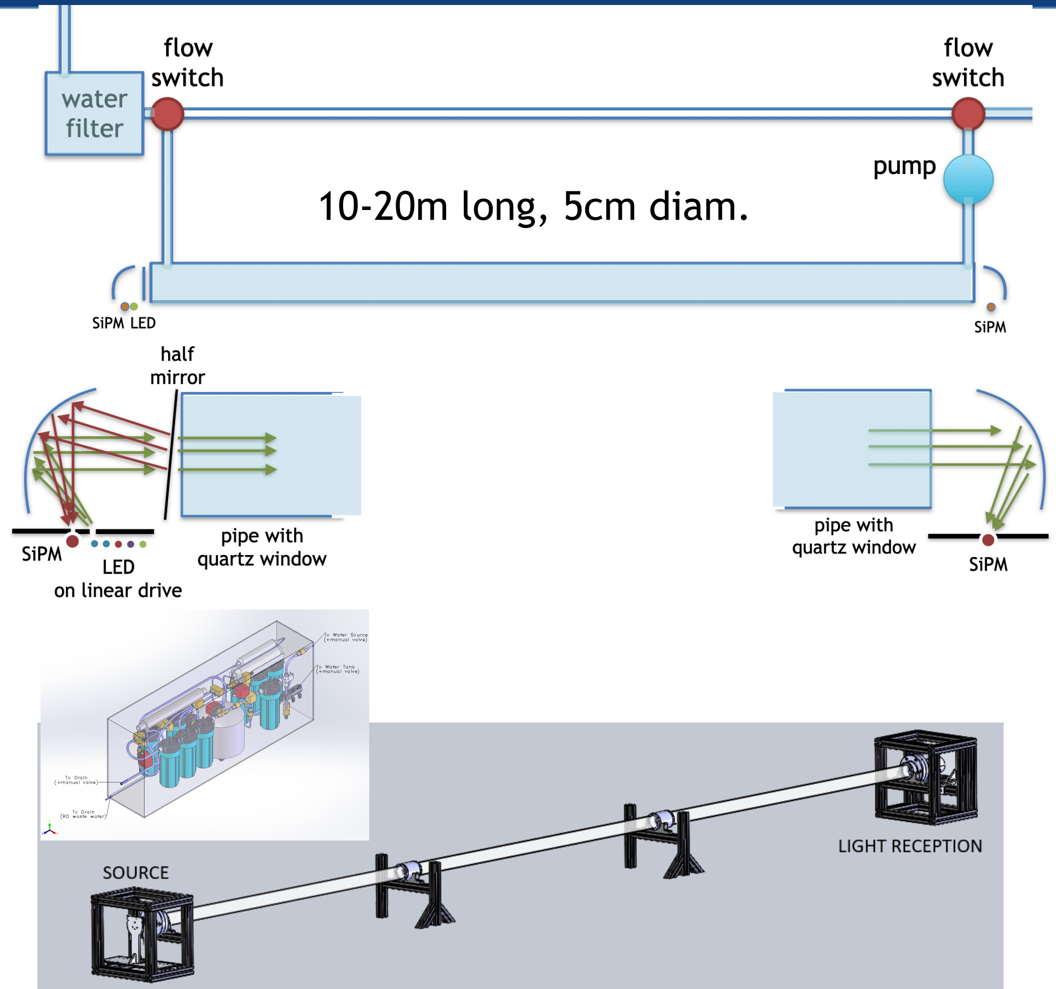
- Transmission continuously monitored
  - time correlation is a powerful tool in identifying the source
- Huge impact in water monitoring
  - instead of water sampling and lab. test

Light transmission for 15m water path in %





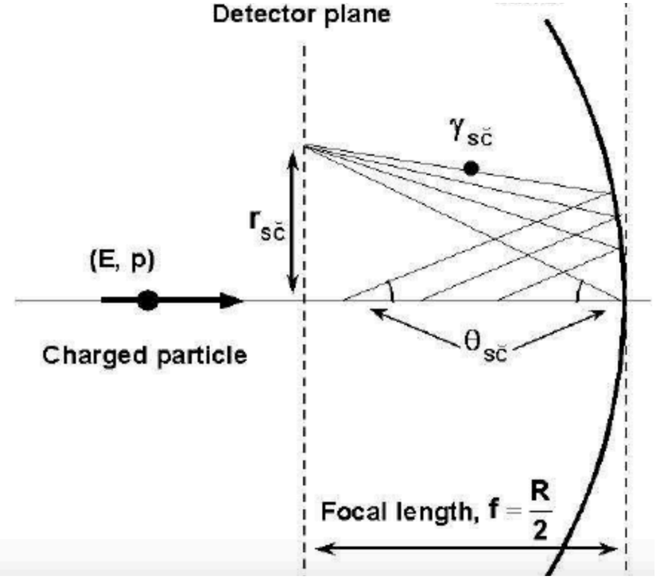
Water monitoring concept

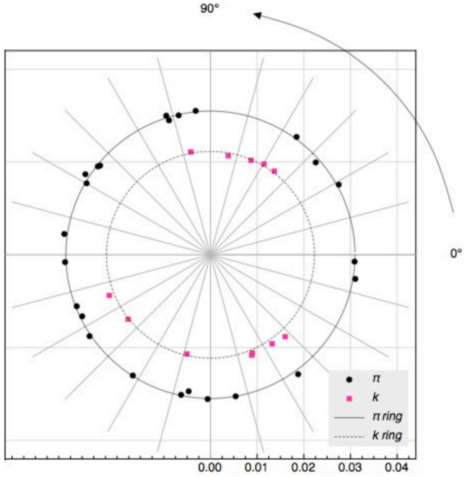


- In-line continuous monitoring of the water
- Pulsed LED light through 10-20m sample water
  - 230 - 700nm
  - parabolic mirror focus
  - Relative measurement by SiPM at source/reception
- Relative to purified water
  - ultra-pure (RO)
  - particle filter (MF,NF)
  - ion exchange resins
  - UV steriliser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

Point-to-parallel focus mirror used at the twin tower site

Angle-to-point focus ring imaging gas Cherenkov





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 : x1000
- Absorption in 10m water with deep UV light provides enough sensitivities for drinking water monitoring
  - Benzene: common toxin in oil spills
  - Microcystin: toxin from blue-green Algae
  - NDMA: disinfection byproduct after water treatment

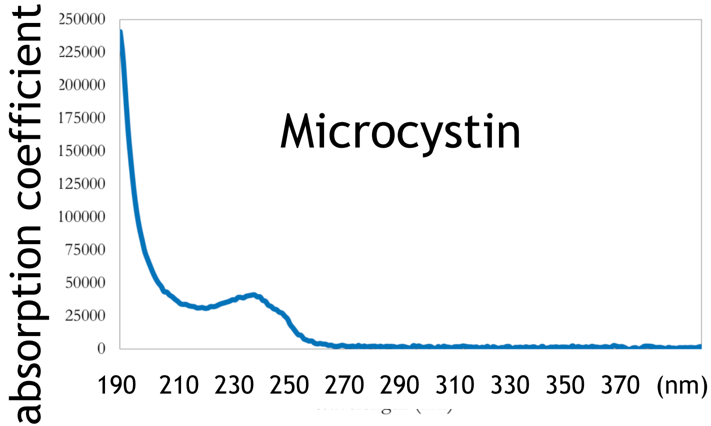


Figure 3.5: Molar Absorption Coefficients of MC-LR at Different Wavelengths

	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 of Cowessess First Nation
  - 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

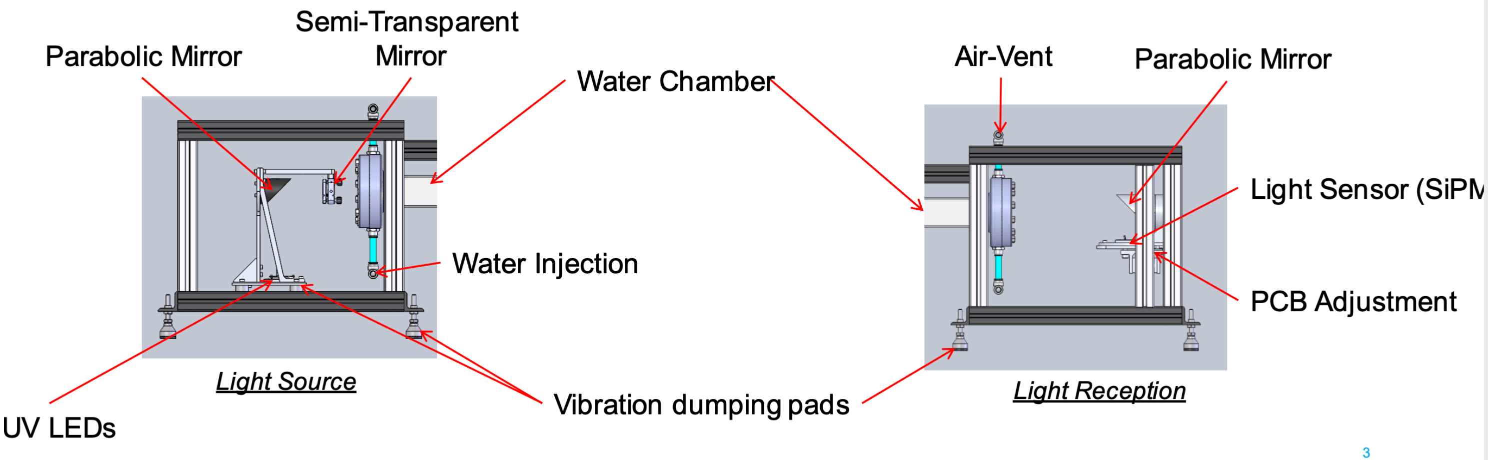
Sustainability

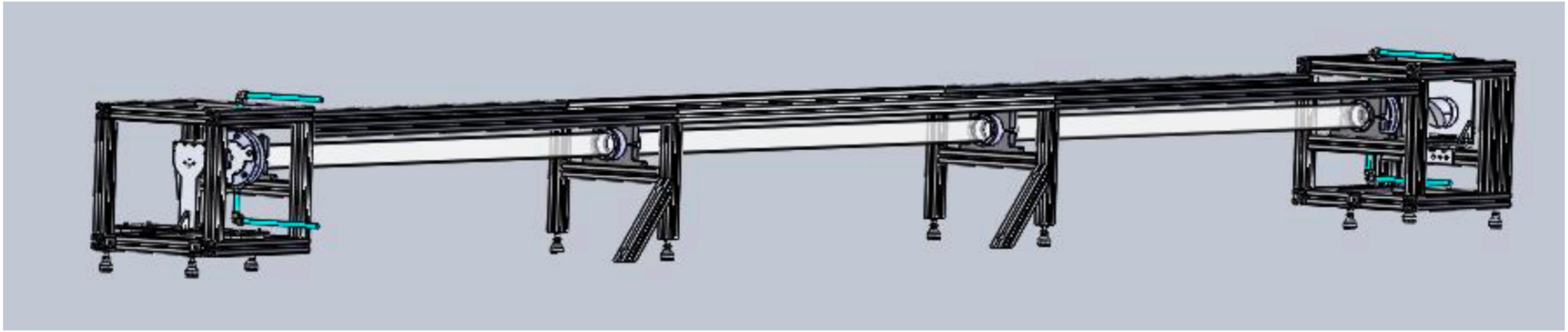
- Sustainable operation is a major challenge
  - water purification systems at First Nations communities were abandoned due to maintenance problems
- Multi-layer approach to support local communities in the operation
  - Detector development at TRIUMF with an experience of SuperK
    - Engineering test 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 in 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

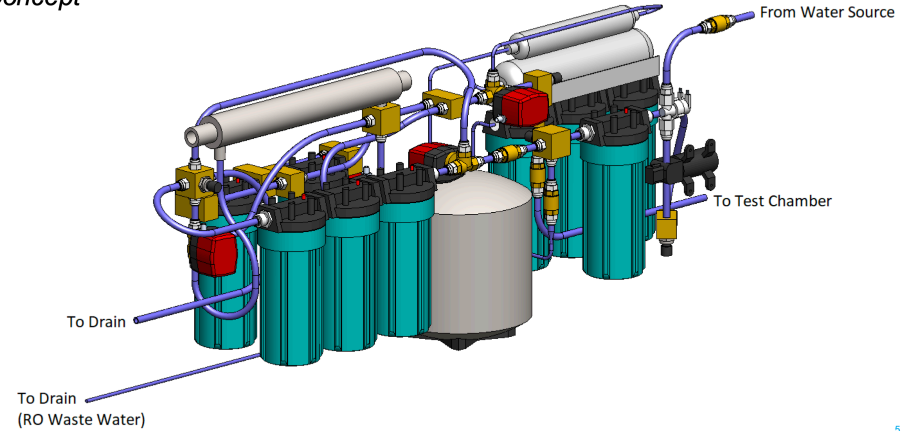
- Environmental monitoring plays a key role in prevention (Green Technology)
  - clean air, clean water
  - climate change makes the situation more challenging
  - prevention is more cost-effective than clean-up after contaminations
- Subatomic physics technology could make a difference in environmental monitoring
  - 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 at TRIUMF
    - 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 to EDI and HQP training

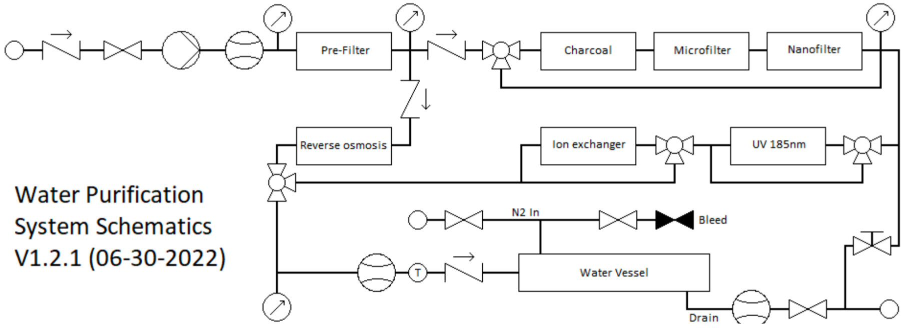




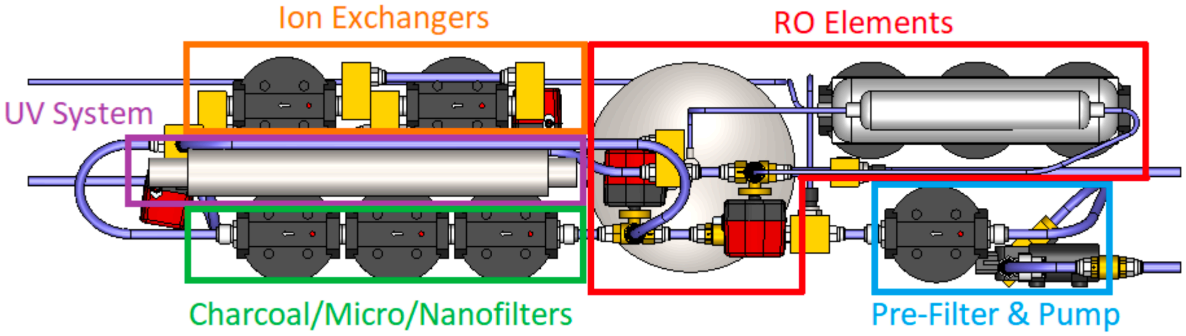
modular design for assembly and maintenance

Concept



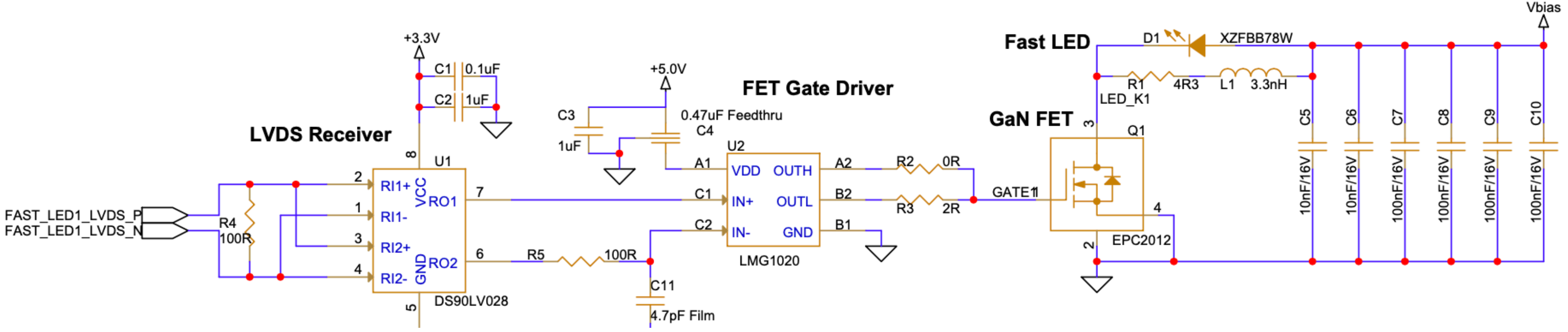


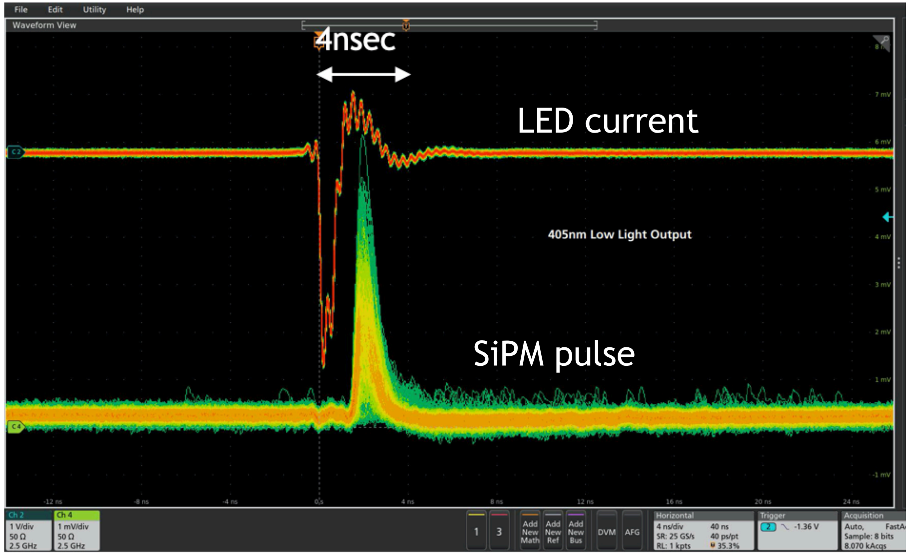
Water Purification System Schematics V1.2.1 (06-30-2022)



- use home water purification parts
- valve and sensor control using Rasberry-pi

Sub-nsec pulsed LED: Nick Braam (UVic)

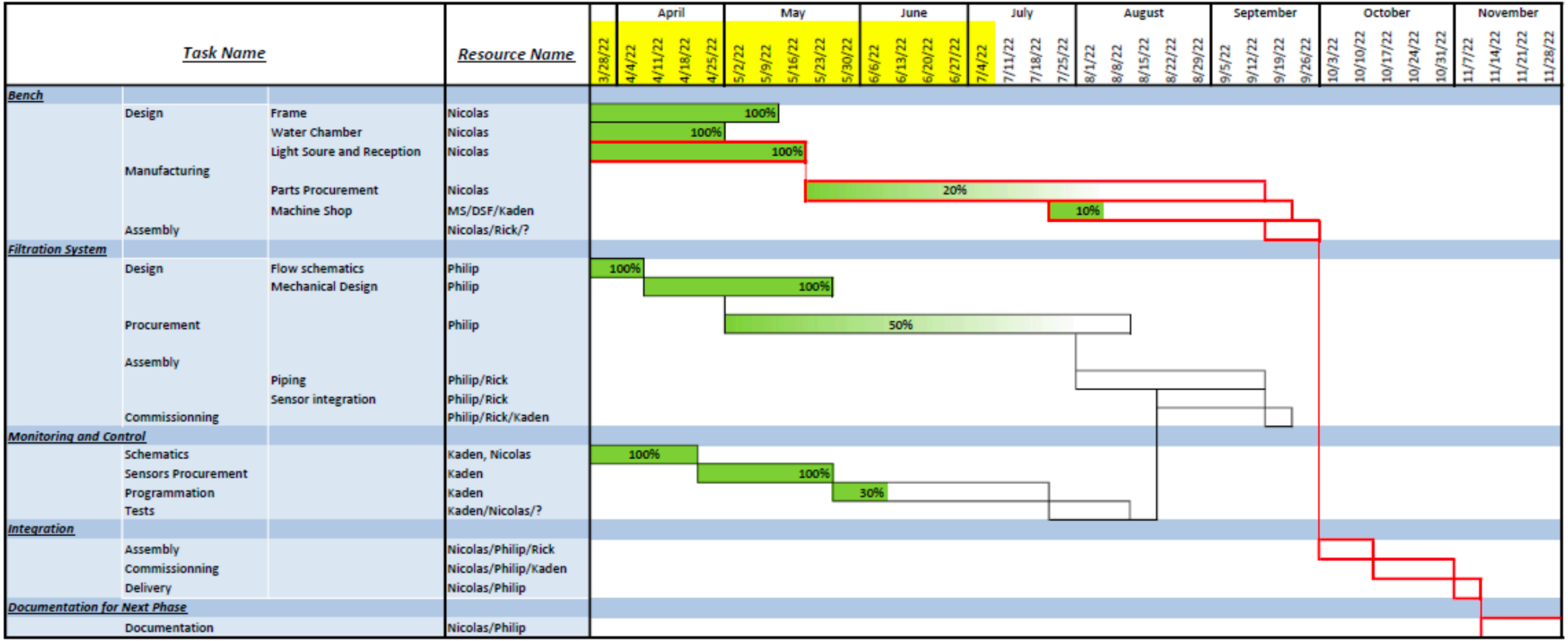




- LED: deep UV-LED available
  - 230nm - 700nm
  - a pulse width of 0.6nsec FWHM achieved
- Driver circuit
  - GaN gate FET (new technology)
  - Capacitor bank to over-drive
- Low cost: $15-25 per channel
  - except for LEDs below 270nm (~$100)

- parabolic mirror test to develop
  - 1mrad collimation (1cm @ 10m)
  - stray light
    - baffle design
  - vibration effect
  - alignment method

Prototyping status

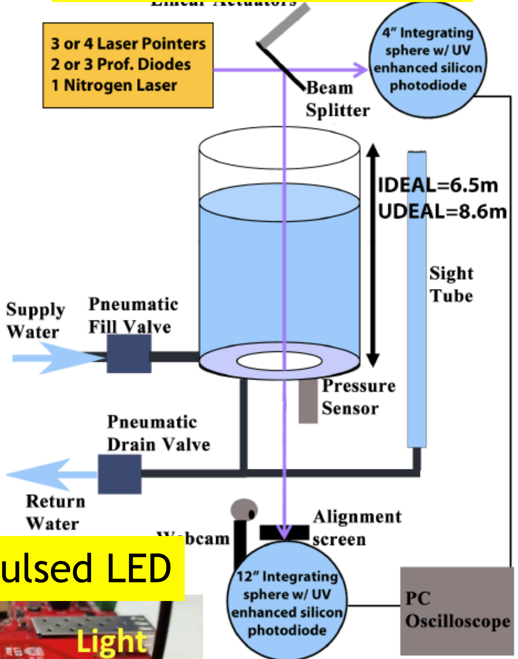


The first full prototype will be ready in November 2022 for testing

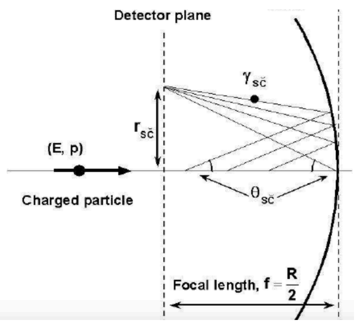
Adopted detector technologies

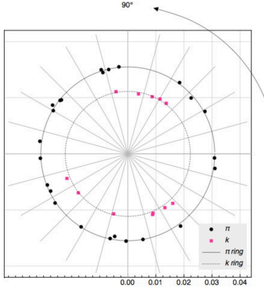
Point-to-parallel focus mirror

SK UDEAL
8m-tall water monitor

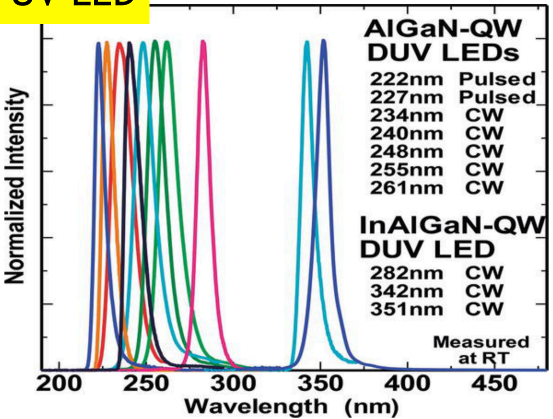


Angle-to-point focus
ring imaging Cherenkov

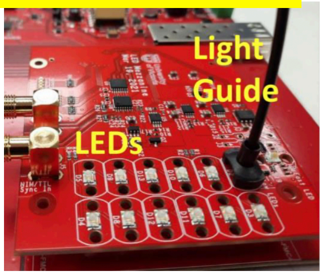




UV-LED

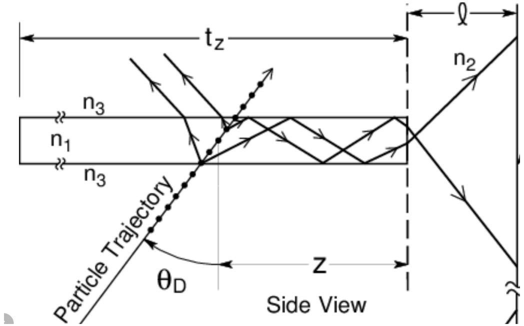


mPMT pulsed LED



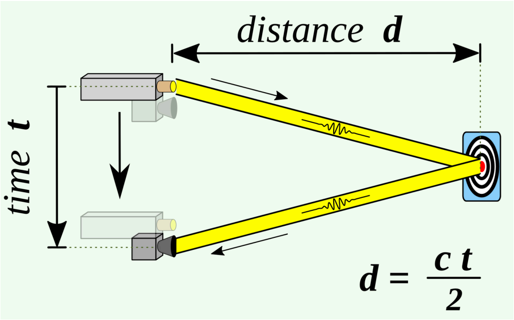
SiPM

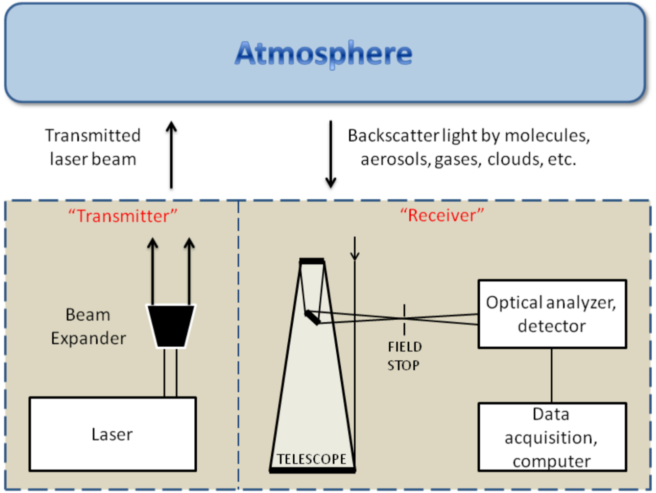
DIRC quartz Cherenkov



Potential application to Oceanography

- Lidar
  - time of flight on back scattered light
    - scattering position is reconstructed
- Atmospheric Lidar
  - backscattering from aerosols, clouds etc.
  - precise monitoring of the atmosphere
- Lidar for Oceanography
  - precise monitoring of ocean water
    - backscattered light for a collimated and pulsed LED light
    - Phytoplankton (heat budget, carbon fixing)
  - pure water parameter measurements
    - SuperK/HyperK detector as 4π Lidar
    - main components without contamination





multi-PMT with LED calibration system (CFI-2023)

- 200 multi-PMT (mPMT)
  - in-situ monitor of water
    - collimated light source
    - transmission and scattering
    - back-scattered light for intensity monitoring

- Technology can be used for the Ocean monitoring
  - similar mPMT developed for P-One at Ocean Network

Ref: **LLC79N7**
Narrow Collimator
Ø 45 mm narrow beam silicone collimator.

Optical silicon collimator
32mmΦ 1.81 Euro
FWHM 3.4 degree