Title:
Novel radiation-hard fiber optic sensors for environmental and radiation-dose monitoring

Abstract:
We propose to develop a system for humidity, temperature and radiation-dose monitoring to avoid equipment damage and poor performance related to environmental conditions. The system must be radiation hard and remain sensitive in extreme dryness. We will investigate Fiber Optic Sensing (FOS) technologies for radiation-hard humidity sensing in harsh radiation environments such as those of the ATLAS High Luminosity Upgrade and the EIC. Optical fibers constitute a low-mass solution for silicon trackers; with specific coating, such as Long Period Grating (LPG), they can be sensitive to humidity and other environmental parameters. With specific coating, optical fibers can absorb and expel water molecules, in proportion to humidity; this would result in a change in length and refractive index of the fiber. A light pulse through the fiber can be detected in transmission or reflection mode, through wavelength-dependent modulation. The wavelength modulation is a measure of the absorbed water, thus the humidity. We will study other optical fiber types to measure temperature, e.g. fiber Bragg Grating (FBG), insensitive to the radiation dose. Radiation dose may cause a drift in the absorption wavelength of the LPG; a dose-sensitive FGB sensor can track this drift. Ultimately then, the combination of different FOS may allow for measurement and monitoring of humidity, temperature and dose. FOS could be applicable to study the effects of Total Ionizing Dose (TID) on silicon sensors or devices built with semiconductor junctions (processors, RAMs, controllers, FPGAs).

A fault condition in the detector cooling system, such as a leak, is expected to lead to a local temperature drop well below the cooling temperature, reaching even -55C. The dryness specification for the ATLAS ITk is therefore a dewpoint of $T_{dp} > -60$C, even lower than this. If the dryness of the ATLAS ITk environment were not sufficient, it would mean condensation on the detector sensors or electronics, leading to failures at these points. The N_2 flush gas has a dryness of about $T_{dp} > -80$C. There will be moisture release from detector materials over time, also back diffusion of water vapor from the N_2 flush exhaust pipe, and also small leaks at the various feedthroughs. The sensor network should be able to measure the relative humidity of the ITk environment at these very dry conditions.

The EIC general purpose detector ePIC is extremely compact, having a compact solution measuring temperature and humidity would be critical to keep space for services under control, particularly for the low mass MAPS micro-vertex tracker. In Particular, the dual radiator RICH detector, whose SiPM based photon matrix, sitting behind a quartz-window, is operated at -40C and +100C. It needs precise temperature control. Because of increased humidity, the quartz window would become foggy. This would significantly impact the photon transparency of the window.

BNL has been instrumental in getting South Africa to join ATLAS in 2010. Since then, BNL has maintained collaboration with South African groups and helped in the visibility of these groups in ATLAS. Such impact, though commendable, has mostly been effective in physics analysis. Many students, co-mentored and co-advised by BNL staff have grown as independent and successful early career researchers. However, Africa lacks critical expertise in instrumentation and detector capability—it is in this area that BNL could extend impact for Africa. Therefore, if

a project identified in the ITk / EIC could strengthen collaborations with African groups in instrumentation and detectors, that would be a great extension to supporting African countries in ATLAS and EIC. Within the scope of the ITk, the University of Johannesburg, under the leadership of Prof. Simon Connell, is also interested in the FOS. Together, we aim to keep the innermost detector of ATLAS dry, i.e. to develop the R&D and Quality Assurance of the novel First-of-a-Kind radiation-hard Humidity Sensors based on FOS technology. This will also be useful for the EIC, where to-date, seven African countries have joined the EIC user group. Through this project, we expect to create a path for these countries to contribute effectively, with a unique technology, to the EIC efforts. The proposed project supports the mission of BNL on the ATLAS ITk and on the EIC; furthermore, it supports a broader impact by empowering developing countries for impactful contributions in ATLAS and EIC. The return of investment is the development of a technology to control humidity and other environmental parameters for optimal performance of the ATLAS ITk and EIC, and to enhance capacity of the developing countries involved in these large-scale international projects. Applications at the NSLS-II are also possible where light sources can be used to study the effects of TID on silicon sensors or devices built with semiconductor junctions.