Snowmass2021 Letter of Interest: Wavelength Division Multiplexed high speed optical readout

T. Dorch[1], S. Estrella[1], M. Garcia-Sciveres[2], P. Merkel[3], A. Prosser[3], D. Renner[1], C. Schow[4]
[1]Freedom photonics, LLC, [2]Lawrence Berkeley National Lab, [3]Fermi National Accelerator Lab,
[4]U. Of California at Santa Barbara

Thematic Areas: *IF3: Solid State Detectors and Tracking*
IF4: Trigger and DAQ
IF7: Electronics/ASICs

Contact Information: *mgs@lbl.gov*

New silicon tracking detectors, such as for the ATLAS and CMS High Luminosity LHC upgrades, will have data rates more than 30 times higher than current detectors, and even higher readout rates are desirable in the future. Trigger rates for the above detectors are limited by readout bandwidth. If bandwidth permitted it, triggerless readout would open up new science possibilities.

While the first meter or few meters away from the active elements (modules) use electrical cables for data transmission, the bandwidth bottleneck is in the conversion of these signals to optical, which takes place in the detector volume. Small footprint, low power, radiation hard multiplexing of many electrical signals (typically at 1.28 Gbps each) onto as few fibers as possible is needed.

The only available solution at present is the CERN-developed low power Giga-Bit-Transciever system (lpGBT), including the Versatile Link optical package. This system may be able to (just) meet the needs of upgrades currently under design, but has larger footprint, power, and cost than desirable, and does not scale to higher bandwidth, as will be desired when inner layers are replaced as part of the High Luminosity LHC program. The maximum number of 1.28 Gbps inputs that an lpGBT chips can accept is 7, and this is a rigid limit with no upgrade path envisioned. The ATLAS pixel Phase 2 upgrade, for example will require over 5000 lpGBT chips if each can be efficiently utilized.

The limitations of the lpGBT system are inherent in its architecture. It is based on bitstream time domain multiplexing carried out in a ASIC (the lpGBT), which takes multiple electrical inputs at up to 1.28 Gbps and produces a single electrical output at 10 Gbps. This output is then converted to a binary optical signal by a laser driver in the Versatile Link. The lpGBT must be a complex, radiation hard CMOS ASIC. The combination of high speed switching and radiation damage is very challenging, and such an ASIC is necessarily costly and power-hungry. The architecture requires that all signals to be aggregated onto one fiber be brought to a common point, from data sources that are uniformly distributed in a large volume.

We propose a different architecture using Wavelength Division Multiplexing (WDM), where no bit rate up-conversion is needed, and it is possible to collect data from distant modules onto the the same fiber. In this proposal, based on SBIR-supported development by Freedom Photonics, LLC, all complex electronics are outside the radiation environment and only modulators on silicon photonic chips must reside in the detector volume. Furthermore, this method does not require a specific bit rate or synchronization for the signals to be multiplexed, even allowing signals with different bit rates to be combined on the same fiber. The footprint and power in the radiation environment are small, as there is no ASIC needed inside the detector. There is no hard limit on the number of signals that can multiplexed onto one fiber, permitting evolution to ever higher bandwidth detectors.

The proposed concept is shown in Fig.1. Multiple laser wavelengths are combined onto a single fiber off-detector. Each wavelength is a CW (Continuous Wave) carrier that will be modulated on-detector using a ring resonator. While Current technology is already demonstrating 20Mbps modulation, the radiation hard data sources (detector front end chips) are expected to remain at the 1Gbps level, as this simplifies radiation tolerant design, and a typical detector consists of many “low” bandwidth sources rather than few high bandwidth ones.

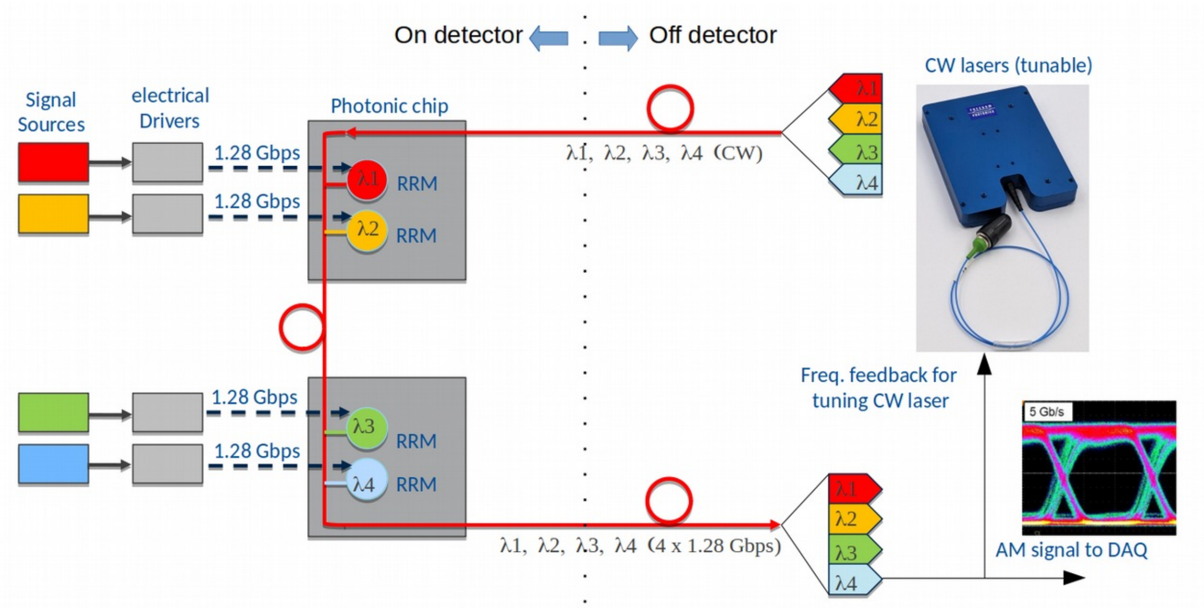

Figure 1: WDM readout system proposed architecture. RRM stands for Ring Resonator Modulator.

The off-detector tunable laser sources can be commercial grade and already exist: a picture of a Freedom Photonics tunable source is shown in the figure. The on-detector amplitude modulation is carried out by Ring Resonator Modulators (RRM) on a photonic chip. These must be radiation hard, and such technology is being developed with SBIR and other support. The electrical drivers to feed the RRM’s are analog circuits that can be separate CMOS chips or possibly integrated into the detector readout chips. As RRMs are also implemented in a (silicon photonic) CMOS process, there is also potential to integrate drivers and RRM’s on the same chip, further reducing mass, complexity, and cost, while increasing performance. Commercial demodulating technology (off-detector) also exists.

The Fig. 1 concept includes distant detector elements multiplexed onto the same fiber. This would allow a macro-assembly to have just one input and one output fibers, with the total bandwidth required dictating how many laser frequencies are needed. Each RRM works at a specific wavelength, but that wavelength can drift, for example due to temperature. The incoming wavelength must track these shifts, so a feedback mechanism is needed. The architecture allows for this by monitoring the return signals on the output fiber. The feedback can be implemented either by adjusting the laser wavelength or by acting on the RRM (for example with a heater). The method used will depend on practical considerations of a given implementation.

The WDM readout architecture proposed here will enable higher bandwidth, lower mass, highly scalable readout of future tracking detectors.