Data transfer for future detectors

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Current technology used at LHC

Vertical Cavity Emitting Lasers (VCSEL) coupled to multimode optical fibers

Example: ATLAS Liquid Argon Calorimeter with 1520 readout board

Runs 1 and 2 : single VCSEL for each readout board with 2 Gbps speed
Total data transfer: 1 fiber, 1.6 Gpbs/board. 2.43 Tbps for the detector

Run 3 : 2 dual VSCELs for each readout board, each with 5 Gbps speed
Total data transfer: 2 fibers, 20 Gbps/board. 30.4 Tbps for the detector

Run 4 : 8 quad VCSEL for each readout board, each with 10 Gbps data transfer
Total data transfer: 22 fibers on the readout board, 3 fibers to the rigger,
220 Gbps/board. 344.4 Tbps for the detector

Observation: Increase in data rate – factor of ~100
Increase of VCSEL speed - factor of ~10
We need to explore alternative technologies.

Common requirements for future detectors

- Increased segmentation
- Increased signal type: electrical, time of arrival, optical
- Increased frequency of signal

→. All lead to an increased data rates. Is a factor of 100 attainable ?

Can we handle much larger data sample generated by the detectors ?

Two possible architectural solutions:

- Increase data transfer for single fiber
- Integrate elements of the trigger with the readout board

Comment: The need to transfer massive data rate from sensors to the trigger should be a part of the architecture design for the detector. Leaving the problem to a late stage of design leads to many unnecessary complications and compromises.

Increase the speed of data transfer for each fiber:

- For existing, tested technology – small increases will be possible with development of 20 Gbps VCSELs
  and use of PAM4 – 4 signal levels transmission doubling the number of bits
  for each transfer together with multi-mode fibers.
- Large increase of speed is already in practical use in the data centers and telecom applications.
  The technology uses <u>single-mode</u> fibers and multiwavelength VCSEL arrays
  with signal modulation. This is a fast-moving field driven b y rapid growth of data
  centers, cloud storage,…
  Systems capable of 400 Gbps per single fiber are already in production
  eg. , Cohernet. Current development are expected to double the speed
  in 2025. Speed reaching 1.6 Tbps is expected by 2027. The data transfer up
  to 100 km has been achieved with single mode fiber in some applications.
  The concept uses arrays of VCSELs with different wavelength emission.
  CWDM – Coarse wavelength division multiplexing 4 -6 wavelengths
  DWDM - Dense wavelength division multiplexing 100 – 160 wavelengths

The application of the data center's technology to particle physics experiment will require extensive testing of the radiation tolerance of the singe mode fibers and of all components of the the VCESL's arrays and receiver diodes. Another critical issue will be a sufficient miniaturization of the transmission components to fit to the readout boards requirements.

Integration of trigger elements with the front readout electronics

Basic initial functions of the trigger are usually based on FPGA technology.

We need to evaluate Rad-hard FPGA to allow changes in trigger algorithms after fabrication.
It looks like Xilinx has their Versal in a rad-hard version which would be especially useful for potentially enabling more complicated trigger algorithms. This is the chip family (not rad-hard version) that is currently planned for Global Trigger in ATLAS.
(https://www.xilinx.com/content/dam/xilinx/publications/product-briefs/xilinx-xqr-versal-product-brief.pdf)

The demo kit with the rad hard version of the FPGA exist.

SMU resources and expertise

The SMU ATLAS group has expertise in both areas of optoelectronics and trigger hardware and software.

The optoelectronic lab has built and maintains ATLAS data links for Liquid Argon calorimeter readout boards and for the trigger system. It is currently working on the production and testing of the link for HL-LHC upgrade.
The group benefits from close contacts with the SMU Electrical Engineering department with ties to the telecom industry.

The optoelectronic lab has been also involved in the development o f the components for the calorimeter trigger and is currently working on the global ATLAS trigger development.

A collaboration with groups interested in this problem is welcome.

Budget

The estimate of the support needed for these studies will require more detailed workout.

The equipment for tests of the high-speed data transfer is pricey:
High – speed signal generators on the market cost ~$ 75k – 120k.
Optical components, cables etc. can be obtained for ~ $ 12 – 15 K

Rad- hard FPGA evaluation kit costs ~$ 40k

Beam tests will require travel ~$ 10k - 15k

Ideally , we would like to I get support for a postdoctoral fellow and a graduate student.