A Readout Driver for the ATLAS LAr-Calorimeter at a High Luminosity LHC

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Outline

- ATLAS detector and current LAr calorimeter read-out system
- upgrade to HL-LHC
- readout scheme for HL-LHC
- hardware development status
- summary and outlook

- 4 high granularity LAr calorimeters

- 182486 readout channels
- 40MHz proton-proton collision rate
- front-end and trigger-sum electronics
 - mounted on detector,
 - operates in radiation environment
- back-end electronics and additional trigger logic
 - in counting room outside the experimental cavern

- 1524 front-end boards (FEB)
 - up to 128 channels
 - preamp, pulse shaping, buffer and sampling
- analog signal to L1 calorimeter trigger (@ 40MHz)
- readout clock is synchronous with LHC bunch-crossing (25 ns)

- connected to off-detector electronics by
 - 58 copper trigger cables
 - 1600 optical links

- 192 read-out driver boards (ROD)
 - digital filter
 - data transferred only after L1 accept @ 100kHz

- 800 optical links to DAQ PCs
- 68 read-out buffer PCs (ROB)
 - DAQ and high-level trigger buffer

Upgrade to High Luminosity LHC

- Several reasons for upgrade:
 - radiation tolerance of front-end electronics: HL-LHC reaches up to 3000 fb^{-1}
 - qualified for $\sim 700 \text{ fb}^{-1}$ (+ safety margin)
 - not possible to operate hardware until end of HL-LHC
 - ageing / reliability concerns of current electronics:
 - some parts exceed 20 years age at HL-LHC start
 - limited size of on-detector data buffers:
 - current readout architecture does not allow increase in L1 latency nor bandwidth
 - if readout is upgraded → chance to increase granularity of trigger input
- HL-LHC challenges:
 - ~ 5x higher radiation levels for on-detector electronics
 - ~ 5x higher total ionization dose for on-detector electronics
 - ~ 5x more simultaneous proton-proton interactions and pile-up background

- Current LAr latency:
 - 96 bunch-crossings (BC)
 - +10 reserve BC
- Scenario with new trigger design:
 - example: modified muon trigger
 - trigger violates the LAr latency by 6.5 BC
 - would create dead-time

- larger buffer size needed
- digital buffer on new ROD planned to replace the analog buffer

- current performance limitations:
 - fixed analog trigger sums
- read-out and trigger upgrade at HL-LHC:
 - ROD prepares digital data for hardware triggers
 - higher granularity for better isolation of photons and electrons and pion tagging

	today	upgrade scenario
hardware triggers	L1	L0 and L1
trigger input	analog	digital
trigger tower size in $\Delta\eta \times \Delta\phi$	0.1 x 0.1	up to 0.025 x 0.025
trigger tower depth	4 layers summed	4 layers separate
data size / 0.1 x 0.1 tower	16 bit	~200 bit
latency up to trigger input	1.2 μs (L1)	1.2 μs (L0) 6.4 μs or more (L1)

- Front-end electronics
 - preamp, shaping, digitization of data @ BC rate 40MHz (no buffering anymore)
 - high performance, radiation tolerant optical links needed for 100Gbps (see talk by A. Liu)
- Read-out driver (ROD)
 - 40MHz input rate, connected to 14 front-end boards if possible
 - digital calculation of energy, time, quality factor for each calorimeter cell
 - perform L0/L1 sum digitally based on raw data → higher granularity, flexible
 - send digitized data to L0 trigger @40 MHz
 - local data buffer, send data to read-out buffer (ROB) after L1A @ 100 kHz

Readout Scheme for HL-LHC

- each ROD receives $14 \times 100\text{Gbit/s} = \sim 1.4\text{Tbit/s}$
- high speed parallel fiber optical transceiver (e.g. 12 fibers @ 10Gbps)

- ongoing ROD R&D:
 - use FPGAs for high performance SERDES
 - use FPGAs for parallel data processing with high bandwidth
 - follow up and explore technology evolution (FPGA, ATCA)

- Sub-ROD and ROD Injector design:
 - ATCA form factor
 - 75 Gbps fiber-optic link
 - SNAP-12 parallel optical connector
 - FPGA SERDES: Xilinx Virtex 5 FX on Sub-ROD and Altera Stratix II GX on Injector
 - Control and Power logic (IPMI, power conversion, hot plug, ...)
 - Sub-ROD: standard design
 - Injector: proprietary
- integration tests:
 - ATCA power and control scheme functioning
 - 6.25 Gbps per link reached → 75 Gbps total
 - used as platform for latency tests

Block Diagram of AdvancedMC SubROD

- AMC format Sub-ROD Processing Unit can be tested in a low cost MicroTCA crate or on an ATCA carrier board
- MMC (Module Management Controller) is based on ARM processor for IPMI
- Precision clock circuitry and DC-DC converters for power management
- Based on high performance Xilinx Virtex-6 HXT series FPGA which has both GTX (6.6Gb/s) and GTH (11Gb/s) transceivers
- High speed (12x10Gb/s) parallel fiber optical transceiver from Avago
- Versatile interface through AMC edge connector, PCIe Gen2, GbE, LVDS and GTX

- parallel development of ATCA based ROD board
- 10 Gb Ethernet is tested with commercial ATCA computing blades
- first design of proprietary ATCA board is ready
- R&D goals:
 - understand IPMI and power control
 - develop control software framework
 - on board communication between FPGAs
- full ROD demonstrator will use ALTERA Stratix IV FPGA

ROD Demonstrator

- read-out driver and read-out buffer test system:
- evaluate communication between ROD and ROB using 10 Gb Ethernet
 - server PC is a ROB prototype
 - planned to be a commercial ATCA blade in future
- hardware used:
 - Radisys ATCA crate with dual star backplane
 - 1 ATCA Sub-ROD equipped with Xilinx Virtex-5
 - 24 x 10 Gbps switch with XFP transceiver
 - optical 10 GbE connection to server PC
 - PC with dual Xeon 5550 CPU, 24 GB RAM, 4 Myricom 10 GbE dual port NICs
- ROB server performance reached:
 - 79 Gbps @ 30% CPU load
- ROD prototype goals reached:
 - 10 Gb XAUI interface implemented in Virtex-5 FPGA
- currently working on:
 - 10 Gb Ethernet MAC in FPGA
 - File system on PC-RAM via direct network access

- FIR filter prototype as core data processing unit
- incoming raw data
 - 2 bit gain factor and 12 bit for energy $\rightarrow$ gg xx EEEE EEEE EEEE

- outgoing data: energy sum

$$S = \sum_{i=1}^5 a_i^{(gain)} \cdot (E_i^{(gain)} + Ped_i^{(gain)})$$

- 2 bit range factor and 14 bit for energy sum $\rightarrow$ rrsS SSSS SSSS SSSS
- test hardware
 - FPGA: Xilinx Virtex 5 XC5VFX70T
 - testboard: Xilinx ML507
 - Communication PC $\leftrightarrow$ FPGA:
 - 1 GbE, UDP/IP

- DSP modules used for energy sum calculation
- filter operates correctly up to 350 MHz
- filter internal latency is 3+2 clock cycles (due to DSP)
→ much less than 1 bunch-crossing (40 MHz)
- dynamic loading of calibration constants possible w/o FPGA firmware update

- Datasheet: DSPs can operate at up to 550 MHz → full speed not yet reached
 - could process 12 interleaved channels
- 128 DSP slices allow implementation of 25 filter units → 2 FEBs with 128 channels

Summary and Outlook

- several reasons for updating / upgrading current LAr read-out environment
 - a HL-LHC with advanced trigger logic with respect to granularity and flexibility
- new read-out scheme → change in functionality of FEB and ROD/ROB systems
- ROD planned to have additional capabilities to generate L0/L1 digital sums, perform optimal filtering based on digitized raw data and digital buffer of raw data
 - first ROD prototypes in ATCA format
 - SERDES test results with Xilinx/Altera FPGAs: 75 Gbps → 100 Gbps required
 - FIR energy filter: 4 channels at 350 MHz in FPGA → need Nx128 at 500 MHz
 - evaluate 10 GbE communication to ROB
- further studies:
 - event buffering and identification in FPGA
 - evaluate integration of all tasks in FPGA(s) on ATCA ROD
 - evaluate resource limits

Thank you for your attention!

- LAr detector gives a triangular signal
- on-detector: pre-amplifying, shaping, analog buffering, analog-digital-conversion, transmission to ROD
- off-detector: optimal filtering applied to obtain optimum S/N ratio

- energy
- time
- quality factor
- monitoring

Readout scheme for HL-LHC

- read-out buffer: high-level-trigger and DAQ buffer (as today)
 - ROD is planned to be 10GbE interface to ROB
- new:
 - event data is stored as files directly in RAM of ROB (use proper file format)
 - Idea: use of standard components and protocols (ATCA, commercial computing boards, 10GbE, UDP, ...)
- Status:
 - Dual Xeon 5550 PC (4 cores, 6.4GT, 24GB RAM)
 - 4 x Myricom 10GbE dual port NICs
- performance:
 - ~80Gbps @ 60% CPU (9.9Gbps, MTU9000)
 - HT on: ~30% CPU
- to be done:
 - data transfer from ROD FPGA to ROB PC
 - TDAQ software tests