Software-based data acquisition system for Level-1 end-cap muon trigger in ATLAS Run-3

Kosuke Takeda (Kobe University) on behalf of the ATLAS Collaboration
The ATLAS experiment will be upgraded for Run-3 (2021-2023).

- The beam energy: $\sqrt{s} = 13 \rightarrow 14$ TeV
- Luminosity: $L = 2 \times 10^{34} \rightarrow 3 \times 10^{34}$ cm$^{-2}$s$^{-1}$

New inner muon station will be installed.

- New trigger electronics has been developed for the Level-1 endcap muon trigger.
  - Maximum Level-1 trigger rate is limited to 100 kHz even in an increasing energy/luminosity.
  - More precise trigger logics needed to suppress the Level-1 trigger rate.

The existing DAQ electronics also has been reformed.

- Software-based data acquisition system (SROD)
ATLAS Trigger and Data Acquisition System

**Muon CTP Interface**

**Central Trigger Processor**

**Trigger electronics**

**SROD**

**ReadOut System (ROS)**

**Sub-Farm Output (SFO)**

**Region Of Interest**

**High Level Trigger**

**HLT processing**

**High-Level Trigger**

**Level-1 Accept**

**40 MHz**

**100 kHz**

**1 kHz**

**TGC, NSW**

Other muon detectors, Calorimeter

4VC'BSN0VUQVU
Figure 1.1: Cut-away view of the ATLAS detector. The dimensions of the detector are 25 m in height and 44 m in length. The overall weight of the detector is approximately 7000 tonnes.

The ATLAS detector is nominally forward-backward symmetric with respect to the interaction point. The magnet configuration comprises a thin superconducting solenoid surrounding the inner-detector cavity, and three large superconducting toroids (one barrel and two end-caps) arranged with an eight-fold azimuthal symmetry around the calorimeters. This fundamental choice has driven the design of the rest of the detector.

The inner detector is immersed in a 2 T solenoidal field. Pattern recognition, momentum and vertex measurements, and electron identification are achieved with a combination of discrete, high-resolution semiconductor pixel and strip detectors in the inner part of the tracking volume, and straw-tube tracking detectors with the capability to generate and detect transition radiation in its outer part.

High granularity liquid-argon (LAr) electromagnetic sampling calorimeters, with excellent performance in terms of energy and position resolution, cover the pseudorapidity range $|\eta| < 3$. The hadronic calorimetry in the range $|\eta| < 1.7$ is provided by a scintillator-tile calorimeter, which is separated into a large barrel and two smaller extended barrel cylinders, one on either side of the central barrel. In the end-caps ($|\eta| > 1.5$), LAr technology is also used for the hadronic calorimeters, matching the outer $|\eta|$ limits of end-cap electromagnetic calorimeters. The LAr forward calorimeters provide both electromagnetic and hadronic energy measurements, and extend the pseudorapidity coverage to $|\eta| = 4.9$.

The calorimeter is surrounded by the muon spectrometer. The air-core toroid system, with a long barrel and two inserted end-cap magnets, generates strong bending power in a large volume within a light and open structure. Multiple-scattering effects are thereby minimised, and excellent muon momentum resolution is achieved with three layers of high precision tracking chambers.

Thanks to the software-based system:
- it is flexible for modifications.
- it is easy to debug.

SROD can take advantage of the latest developments in computing industry.
Endcap muon trigger logic boards calculate muon $p_T$.

- **Send the results to Central Trigger Processor.**

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Magnetic fields bends the track

(For example, $1.03 < |\eta| < 1.9$)

Experimental hall

Counting room

Central trigger processor

Special Interface Electronics

Distributor of Timing, Trigger and Control signal
Level-1 trigger decision is done by CTP.

- **Muon system receives a signal related to the Level-1 trigger.**

(For example, $1.03 < |\eta| < 1.9$)

Experimental hall

Counting room

Level-1 Trigger

The maximum rate is **100 kHz**
To record raw data related to the Level-1 trigger

- Each board sends the hit information to SROD via Ethernet.

Data size ~ 2000 bit/event/board

Data size : 160 bit/event

(For example, $1.03 < |\eta| < 1.9$)
To record raw data related to the Level-1 trigger:

- Each board sends the hit information to SROD via Ethernet.

Central trigger processor

This unit:
- trigger logic boards $\times 12$
- Sync-signal distributor $\times 1$
- SROD $\times 1$

is for 1/6 endcap muon system.

(For example, $1.03 < |\eta| < 1.9$)
To record the hit information related to the Level-1 trigger:

- Each board sends the hit information to SROD via Ethernet.

Central trigger processor

SROD: Multi-process architecture

- **Software-based ROD on PC**
  - MsgReporter
  - TTCCollector
  - SLCollector
  - RunControlDriver
  - EventBuilder

10 GbE Network switch

Sync-signal distributor

(For example, $|\eta| > 1.9$)

Cavern

Counting room

Ethernet
To record the hit information related to the Level-1 trigger:

- Each board sends the hit information to SROD via Ethernet.

Central trigger processor

A TLAS Muon Desk Shifter Training - General Introduction

The ATLAS Muon Spectrometer

- Sub-systems:
  - CSC – Cathode Strip Chambers
  - MDT – Monitored Drift Tubes
  - RPC – Resistive Plate Chambers
  - TGC – Thin Gap Chambers

- Precision chambers
- Trigger chambers

- on-detector electronics

- other detector on-detector electronics

- Counting room
- Cavern

Ethernet

(For example, $|\eta| > 1.9$)

10 GbE

Network switch

Special Interface

Electronics

Sync-signal distributor

Trigger logic boards ×12

- Collector processes:
  - The total number of processes is 13.
  - collect data from each electronics.
    - The number of these processes equal to the number of boards.
  - write it to the subsequent shared memory.
Ring buffer:

- The total number of memories is 13.
- is the shared memory to absorb arrival delays.
  - The number of the share memory equal to the number of the collector processes.
- has control parameters.
  - The collector processes check this parameter when they write data to this buffer.
To record the hit information related to the Level-1 trigger:
- Each board sends the hit information to SROD via Ethernet.

Central trigger processor

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Precision chambers

Trigger chambers

on-detector electronics
other detector electronics

Ethernet (For example, $|\eta| > 1.9$)

Special Interface

Electronics

Sync-signal distributor

Trigger logic boards x 12

Event builder process:
- builds an event.
  - Read data from the ring buffers
  - Check the IDs
- sends it to ROS.
  - By using the special PCIe card.
To record the hit information related to the Level-1 trigger, each board sends the hit information to SROD via Ethernet.

**Sub-systems:**
- **CSC – Cathode Strip Chambers**
- **MDT – Monitored Drift Tubes**
- **RPC – Resistive Plate Chambers**
- **TGC – Thin Gap Chambers**

**Message Reporting System Process (MsgReporter):**
- Collects messages from each process and posts them to the ATLAS message reporting system.

**RunControlDriver Process:**
- To synchronize the process sequence with the central system.

**SROD: Multi-process architecture**
After building an event, SROD sends it to ROS via S-LINK.

- S-LINK is a CERN specification.
  - ROS collects data and serve it to high-level trigger.

New PCIe card for S-LINK connection[2]

- Developing with TokushuDenshiKairo Inc.
  - Using Xilinx Kintex-7 FPGA XC7K160T
  - PCIe x4

- Three types of output ports
  - Optical output × 2 (SFP+)
    - To send data to subsequent systems
  - Open-drain output
    - To send BUSY signal to the external system
  - NIM output × 1 and NIM input × 2

[2] Owen Boyle, et al., The S-LINK Interface Specification, 27 March 1997
The SROD performance has been measured.

- In Run-3:
  - The average Level-1 trigger rate is 100 kHz.
  - The average event size is ~ 2000-bit.

SROD has good performance.

- The processing speed is higher than the requirement.
  - This bottleneck is coming from the network switch.
Software-based DAQ system has been developed for the Level-1 endcap muon trigger at higher luminosity run.

- To receive trigger data from new trigger logic boards.
  - Current DAQ system can’t handle these large data at high rate.

- Basic concepts:
  - Multi-process architecture
  - A special PCIe card is implemented.

Performance test has been done.

- This system can run at 100 kHz.
- The measured processing speed on SROD is enough good to use at Run3.
  - Current error handling procedures should be improved.
  - Monitoring functions should be more enhanced.
backup slides
The upgrade motivation

- Fake triggers will be more reduced by the new inner detectors.
  - New Small Wheel
    - $1.3 < \eta < 2.4$
  - RPC BIS 7/8
    - $1.0 < \eta < 1.3$ in small sectors

The coincidence between TGC-BW and these detectors will be used in Run-3

The existing inner detector:

- Tile Calorimeter
  - $1.0 < \eta < 1.3$
- EIL4
  - $1.0 < \eta < 1.3$ in Large sectors

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- Tile Calorimeter
  - $1.0 < \eta < 1.3$
- EIL4
  - $1.0 < \eta < 1.3$ in Large sectors
Firmware has two main flows.

- Trigger data can be used for the online monitoring, trigger analysis, and commissioning.

1. Readout for new trigger logic board

![Diagram of trigger path and readout path]

- This technology connects FPGA to Ethernet.
  - SROD can correct data using TCP/IP.

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[1] T. Uchida, *Hardware-Based TCP Processor for Gigabit Ethernet*, Nuclear Science, IEEE Transactions on 55 (2008) no. 3, 1631–1637.
The trigger Logic board for Run-3

Optical inputs and outputs
- SFP+ with GTX in FPGA
- 12 optical inputs from NSW, Tile Calorimeter, RPC BIS 7/8.
- 2 optical outputs to MuCTPi. (10 optical outputs for spares.)

Optical inputs
- SFP RX + G-Link RX chip
- 14 optical inputs from TGC-BW and EIL4.

CPLD (XC2C256-7PQ208C)
for VME control

BPI (PC28F256P30TF)
for FPGA configuration

FPGA (Xilinx Kintex-7 XCK410T)

RJ45 connector
for readout (SiTCP)

16-pin connector
for TTC

LEMO IN/OUT
## Data size

### Input data to SROD

- This input data will be suppressed at the trigger logic board.
  - [31:16] : header
  - [15:0] : data

| [31:16] | [15:0] |
|---------|--------|
| Trigger decision data | 256 bit (Fixed) |
| Trigger decision data | 256 bit (Fixed) |
| Data from NSW | 1152 bit |
| Data from NSW | 1152 bit |
| Data from NSW | 1152 bit |
| Data from NSW | 1152 bit |
| ID information from NSW | 192 bit (Fxed) |
| ID information from NSW | 192 bit (Fxed) |
| Data from new RPC | 192 bit |
| Data from new RPC | 192 bit |
| Data from new RPC | 192 bit |
| ID information from new RPC | 32 bit (Fxed) |
| ID information from new RPC | 32 bit (Fxed) |
| Data from Tile Calorimeter | 96 bit |
| Data from TGC-BW | 96 bit |
| Data from TGC-BW | 96 bit |
| Data from TGC-BW | 96 bit |
| Data from inner TGC | 32 bit |
| Data from inner TGC | 32 bit |

96 bit [Header&trailer] + (256 + 192 + 32)×4 + (1152 + 192 + 96 + 200 + 32)×10⁻³ = 1922 bit/event/board