THE UPGRADE OF THE ATLAS FIRST LEVEL CALORIMETER TRIGGER

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▶ Introduction

- ▶ ATLAS Liquid Argon calorimeter and level-1 trigger
- ▶ Challenges toward high luminosity runs

▶ Upgrading ATLAS level-1 calorimeter trigger

- ▶ New Liquid Argon calorimeter trigger readout
- ▶ New system architecture for trigger processing
- ▶ Expected performances

▶ Summary

► Liquid Argon (LAr) electromagnetic calorimeter

- Lead absorber, LAr as active material and copper/kapton electrode
- Has fine segmentation: 4 layers, ~200k readout channels in total

► Hadronic calorimeters : Tile (steel&scintillator), LAr endcap/forward

► Plays a major role in identifying/measuring e , γ , τ , jet and missing E_T (offline) and provides inputs for their triggers at the hardware level (L1Calo triggers)

- Higgs discovery! Lots of searches in variety of channels, precise measurements, ..

LHC and ATLAS trigger upgrade timelines

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Staged upgrade plan:

● Run 1 (2010-2012)

7-8TeV, $L \sim 0.8 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, $\langle \mu \rangle \sim 20$

⇐ LS1/**Phase-0** upgrade (2013-2014)

● Run 2 (2015-2017)

13-14TeV, $L \sim 1.6 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, $\langle \mu \rangle \sim 40$

⇐ LS2/**Phase-1** upgrade (2018-2019)

● Run 3 (2020-2022)

14TeV, $L \sim 3.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, $\langle \mu \rangle \sim 80$

⇐ LS3/Phase-2 upgrade (2018-2019)

● Run 4 (2025-2027)

14TeV, $L \sim 7.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, $\langle \mu \rangle \sim 200$

► Instantaneous luminosity getting increased!!

- Number of interactions per bunch crossing (μ) doubled, tripled and much more..

► “Pile-up effects” significantly degrade the trigger performance:

- **Degraded LAr signal due to its long drift time:** $\sim 450 \text{ ns}$ drift time (with 2mm gap at 2 kV) vs. 25ns LHC bunch spacing (40MHz)
- **Triggering electromagnetic objects suffers from huge multi-jets background**

General upgrade concept

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- Utilize more calorimeter shower shape information & event topology as in software algorithms — high-level triggers use this information as well.

e.g. e/jet separation

$$R_\eta = \frac{E_{T, \Delta\eta \times \Delta\phi = 0.075 \times 0.2}^{(2)}}{E_{T, \Delta\eta \times \Delta\phi = 0.175 \times 0.2}^{(2)}}$$

$$f_3 = \frac{E_{T, \Delta\eta \times \Delta\phi = 0.2 \times 0.2}^{(3)}}{E_{T, \Delta\eta \times \Delta\phi = 0.075 \times 0.2}^{(1)} + E_{T, \Delta\eta \times \Delta\phi = 0.075 \times 0.2}^{(2)} + E_{T, \Delta\eta \times \Delta\phi = 0.2 \times 0.2}^{(3)}}$$

- Already partially implemented in Run-2: L1Calo provides trigger capabilities based on event topologies.

- New module “**L1Topo**” installed. Can apply selection with topological variables as $\Delta\phi$, $\Delta\eta$, ΔR , H_T , ...

General upgrade concept (2)

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► To achieve these trigger features, develop new hardware for trigger readout and processing.

- **LAr trigger readout**

- Fully digitized readout with finer granularity & digital filtering for out-of-time pile-up correction and bunch-crossing identification

- **L1 Calo trigger processing**

- Pile-up subtraction, employ selection fully based on object features and event topology information

► Challenges:

- Highly dense electrical&optical circuit boards & high-speed optical links (up to ~10 Gb/s)
- Signal mapping and data duplication among readout modules

Upgrading LAr trigger readout: Super Cells

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Trigger tower

Analog sum in $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ (60 cells)

Run-2 readout geometry

Super Cells

(box: minimal readout element)

► Finer granularity: trigger tower $\Rightarrow$ 10 Super Cells (SCs)

- 60 cells $\Rightarrow$ 4-8 cells in each layer

► Analog readout $\Rightarrow$ 40MHz digital readout

Upgrading LAr trigger readout: Scheme

Existing cell-readout

Sampled at 40MHz, stored in analog pipelines.

Digitized and transmitted when Level-1 accept received.

“Layer-sum board” renewed
to produce SCs

New LAr Trigger Digitizer front-end Board (LTDB)

New LAr Digital processing back-end Board (LDPB)

To Tower Builder Board

LTDB

- 12-bit ADC (custom ASIC) @40MHz
 - Multiplexing 8 channels to 5.12Gb/s optical link, 200Gb/s for each board
- Handle up to 320 SC signals
- 124 boards in total

LDPB

- ATCA standard, 4 Advanced Mezzanine Cards (AMCs) for each
- AMC:
 - high-speed optical transceivers to process 320 SCs with a short latency
 - Energy&timing measurements by FPGA digital filtering

Both LTDB and LDPS prototypes integrated in the detector system and being demonstrated during Run-2 running.

LTDB & LDPS

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To Tower Builder Board

LTDB

LDPS

- ATCA s
- Cards (A
- AMC:
 - high-s
 - 320 S
 - Energy digital

Both LTDB and LDPS prototypes integrated in the detector system and being demonstrated during Run-2 running.

SC signal reconstruction by digital filtering

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- ▶ LDPB can enhance performance on the SC energy reconstruction by processing 40MHz ADC samplings with dedicated digital filtering.
- ▶ Filtering algorithms under study.
 - ▶ e.g. Wiener filter:
 - Nice “energy reconstruction” and “bunch-crossing identification”
 - Expected to be pile-up robust by adopting an active forward pile-up correction

Upgraded L1Calo: System architecture

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Feature extractor modules integrated for Run-3.

eFEX:

Identify $e/\gamma/\tau$ using isolation & cluster shape variables. Flexible rejection algorithms.

jFEX:

Identify jet/ τ and calculate H_T , missing E_T .

Enables pile-up suppression using event energy density

gFEX:

For global event processing, e.g. large-area jets for dedicated physics cases (boosted bosons, ...)

Expected performance: single-object triggers

► EM trigger rate:

- Adopting jet rejection using shape variables, the threshold can be lowered by 7 GeV
- Compared at reference points of 20kHz (Run-2 rate budget) and 95% efficiency
- Can maintain high photon efficiency (>96%)

► Better trigger turn-on for jet and missing E_T triggers

- Thanks to pileup suppression and dedicated jet reconstruction algorithm

- ▶ Upgrade activities ongoing in order to explore full physics of the high-luminosity LHC runs.
- ▶ ATLAS is developing new hardware and system for calorimeter trigger readout and processing.
 - Expect improved trigger performances with the upgraded system even in severe pile-up conditions.
 - R&D, design and production in progress toward installation in 2018-2019 (Phase-1 upgrade)
 - Some of them are already integrated for ATLAS Run-2 running:
 - ▶ LTDB & LDPS prototypes for demonstration
 - ▶ Topological trigger with new L1Calo architectures

Backup

► Trigger tower $\Rightarrow$ 10 Super Cells (SCs)

Trigger towers

Super Cells

	Elementary Cell	Trigger Tower	Super Cell		
Layer (barrel)	$[\Delta\eta \times \Delta\phi]$	$[n_\eta \times n_\phi]$	$[\Delta\eta \times \Delta\phi]$	$[n_\eta \times n_\phi]$	$[\Delta\eta \times \Delta\phi]$
Presampler (layer 0)	0.025×0.1	4×1	0.1×0.1	4×1	0.1×0.1
Front (layer 1)	0.003125×0.1	32×1		8×1	0.025×0.1
Middle (layer 2)	0.025×0.025	4×4		1×4	0.025×0.1
Back (layer 3)	0.05×0.025	2×4		2×4	0.1×0.1

LTDB

- Handle up to 320 SC signals
- 12-bit ADC @40MHz with low power consumption (custom ASIC)
 - <145 mW/channel
- Multiplexing 8 channels to 5.12Gb/s optical link, 200Gb/s for each board
- 124 boards in total (25Tb/s)

LDPS

- ATCA standard, 4 Advanced Mezzanine Cards (AMCs) for each
- AMC designed with FPGA and high-speed optical transceivers to process 320 SCs with a required latency (17 bunch crossings)
- Energy measurement & bunch-crossing identification by FPGA digital filtering
- Receive 25Tb/s (from LTDB) and transmit 41Tb/s (to L1Calo)

Upgraded L1Calo: Run-2 system architecture

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Phase-0 upgrade (for Run 2)

New Multi Chip module (nMCM):

- ASIC $\rightarrow$ FPGA replacement for digital signal processing
- Better treatment of pile-up (autocorrelation FIR filter & dynamic pedestal subtraction)
- Dedicated calibration for EM and hadron energy scale using dual-channel ADCs

New(extended) Common Merger Module (CMX):

- 160Mb/s backplane (data from processor modules), multiplicities $\rightarrow$ trigger objects.
- Link to L1Topo (24 opt. fibers at 6.4Gb/s)

Topological trigger module (L1Topo):

- Enables composite triggers using trigger objects. Topological algorithms.

► L1Topo (already installed for Run-2)

- Can apply selection with topological variables: $\Delta\varphi$, $\Delta\eta$, ΔR , H_T , ...
- Challenging analyses will benefit from that.
 - $ZH \rightarrow \nu\nu b\bar{b}$, di-tau etc.

► jFEX (Run-3)

- Gaussian filter: jet energy reconstruction using Gaussian weights
 - Less sensitive to pile-up, significant rate reduction thanks to improved trigger turn-on.
 - Expect much better performance by adopting calibrations and optimizing in terms of pile-up.