Forward Correction for Real-Time Processing of ATLAS Liquid Argon Calorimeter Signals

Eli Cohen, PhD Student
McGill University
Supervisor: Professor Brigitte Vachon
63rd Winter Nuclear & Particle Physics Conference
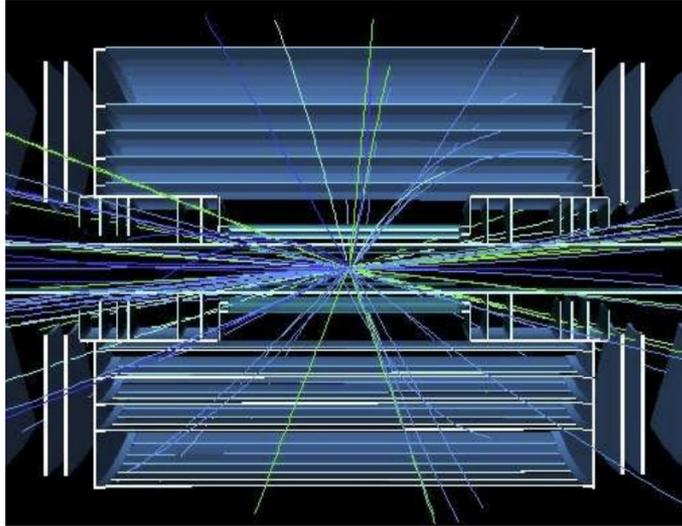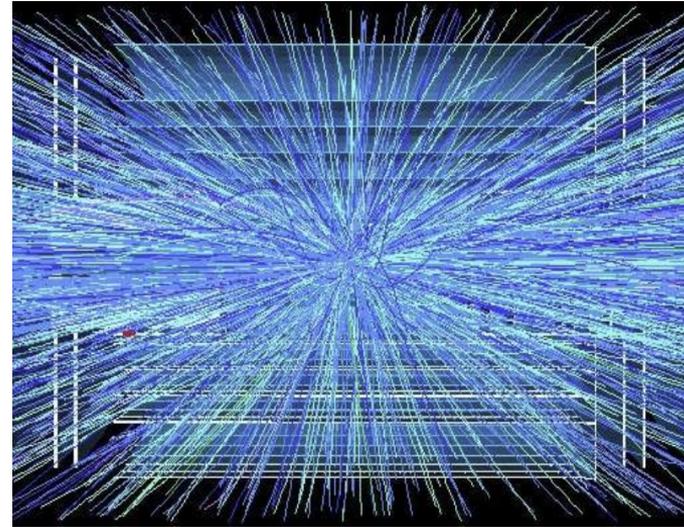12−15 Feb 2026. Banff, Alberta

High-Luminosity - LHC Operating Conditions

LHC

High-Luminosity - LHC

[1]

- Proton beam intensity increased by more than a factor of 2
- Increase average number of interactions per Bunch Crossing (BC) from 60 to 200
- Significant increase in detector occupancy
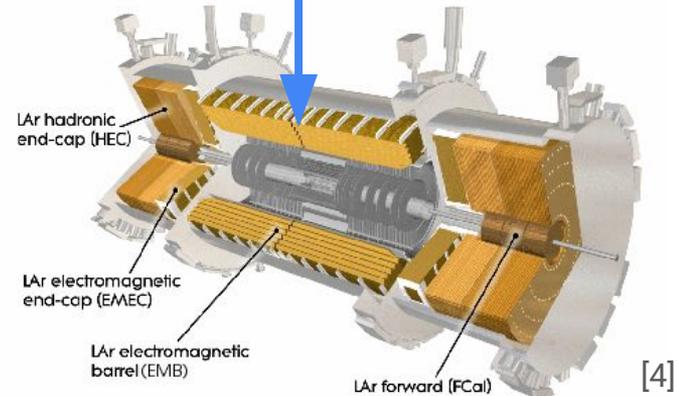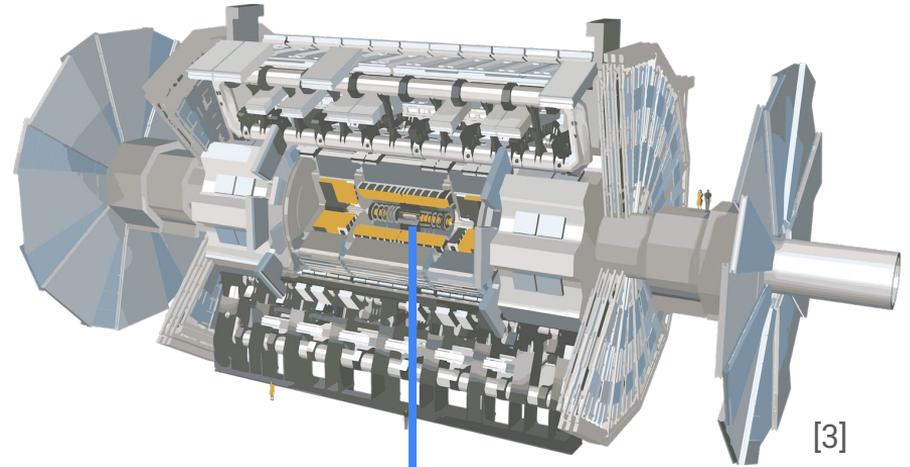- Detectors have to be upgraded to maintain physics performance [2]

ATLAS
and the Liquid Argon (LAr) Calorimeter

ATLAS: general-purpose detector at the LHC

- Made up of multiple subdetectors, each designed for specific measurements
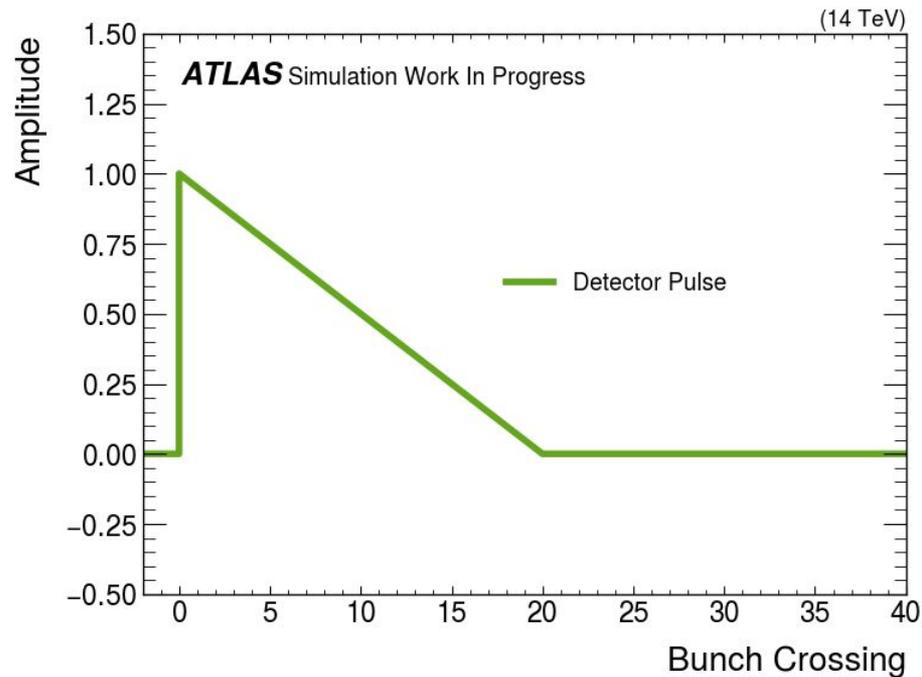
LAr Calorimeter: subdetector

- Measures energy of **electrons**, **photons**, and hadrons

[3]

[4]

LAr hadronic end-cap (HEC)

LAr electromagnetic end-cap (EMEC)

LAr electromagnetic barrel (EMB)

LAr forward (FCal)

3

How the LAr Calorimeter Works
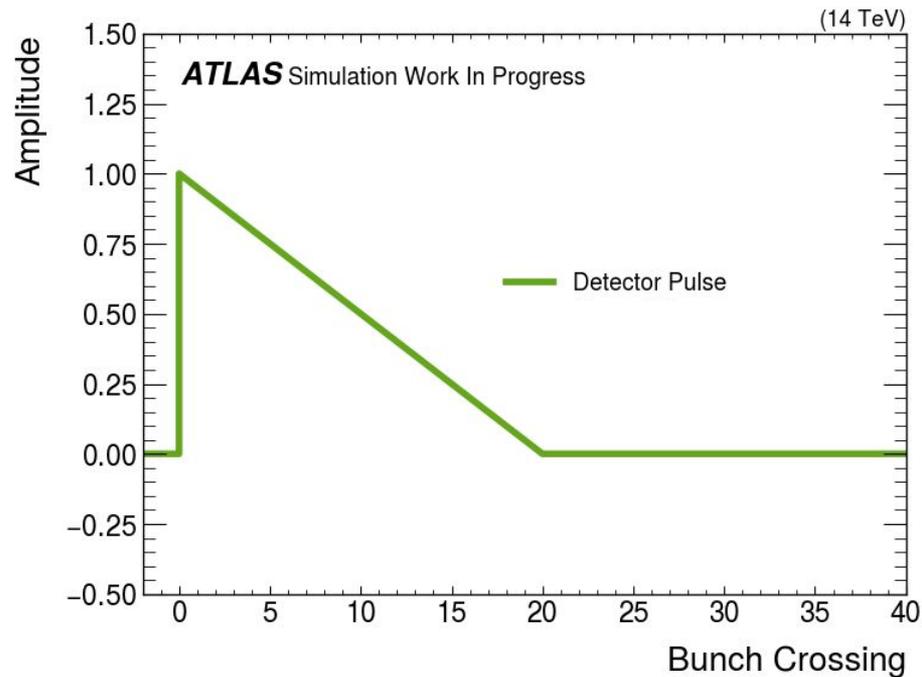
Charged particles induce ionization in LAr

[5]

How the LAr Calorimeter Works
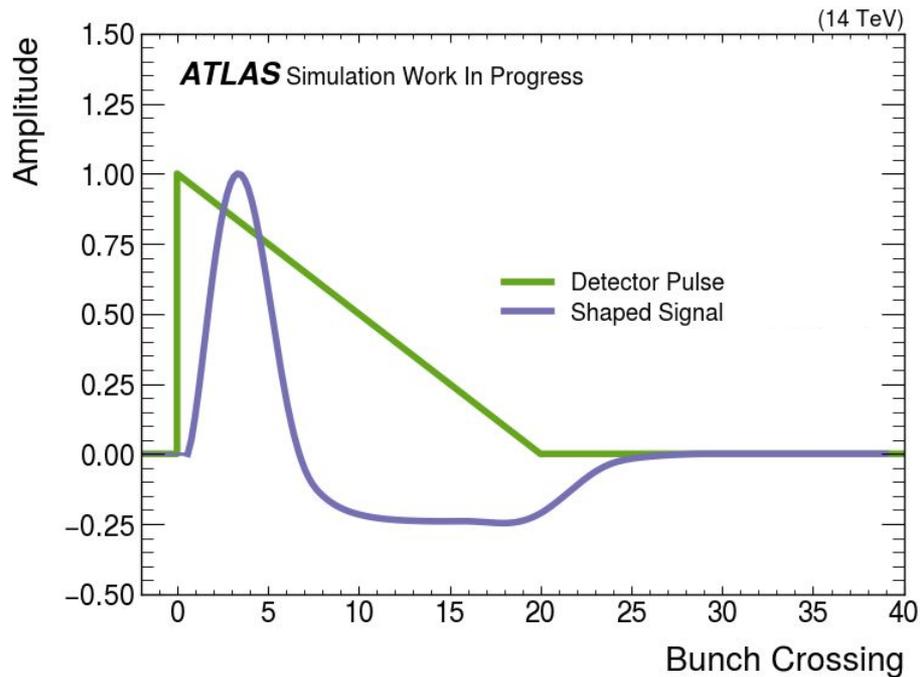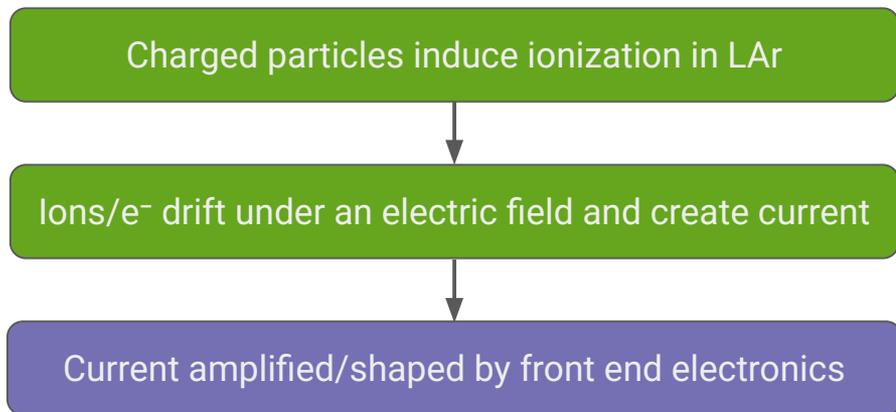
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Ions/e⁻ drift under an electric field and create current

[5]

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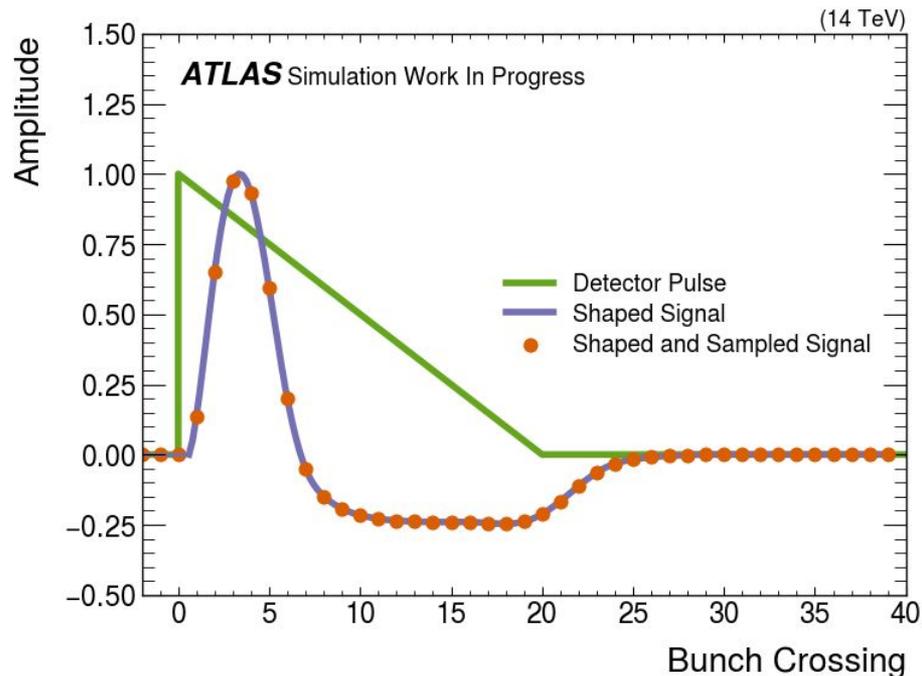Current amplified/shaped by front end electronics

Signal is digitized at 40 MHz (BC Frequency)

(14 TeV)

ATLAS Simulation Work In Progress

Detector Pulse
Shaped Signal
Shaped and Sampled Signal

Amplitude

Bunch Crossing

Digitized signal is called ADC Samples

[5]

4

How the LAr Calorimeter Works
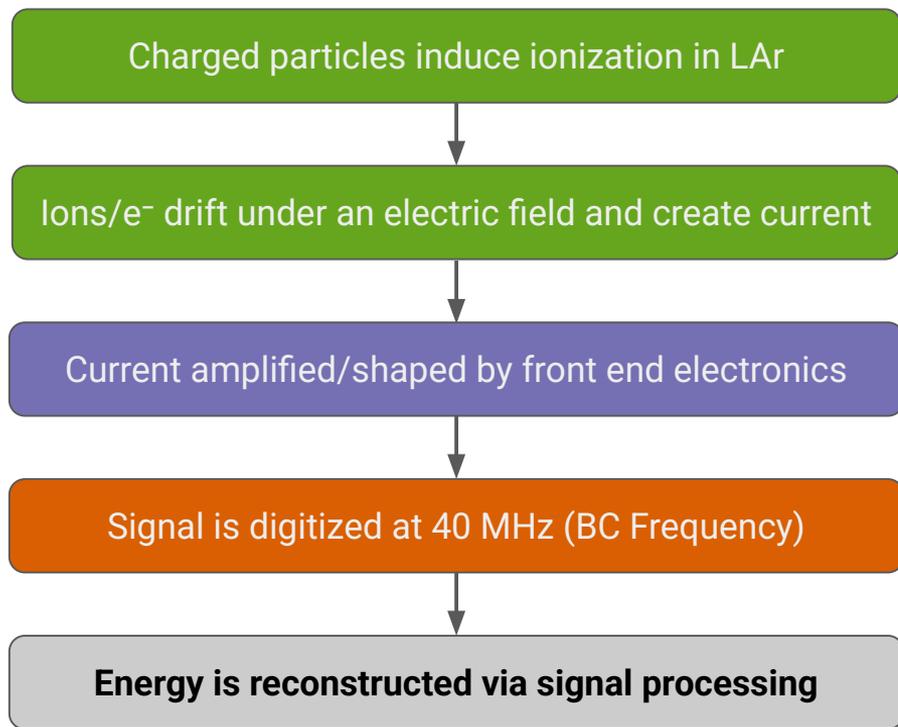
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Ions/e⁻ drift under an electric field and create current

Current amplified/shaped by front end electronics

Signal is digitized at 40 MHz (BC Frequency)

Energy is reconstructed via signal processing

(14 TeV)

ATLAS Simulation Work In Progress

Detector Pulse
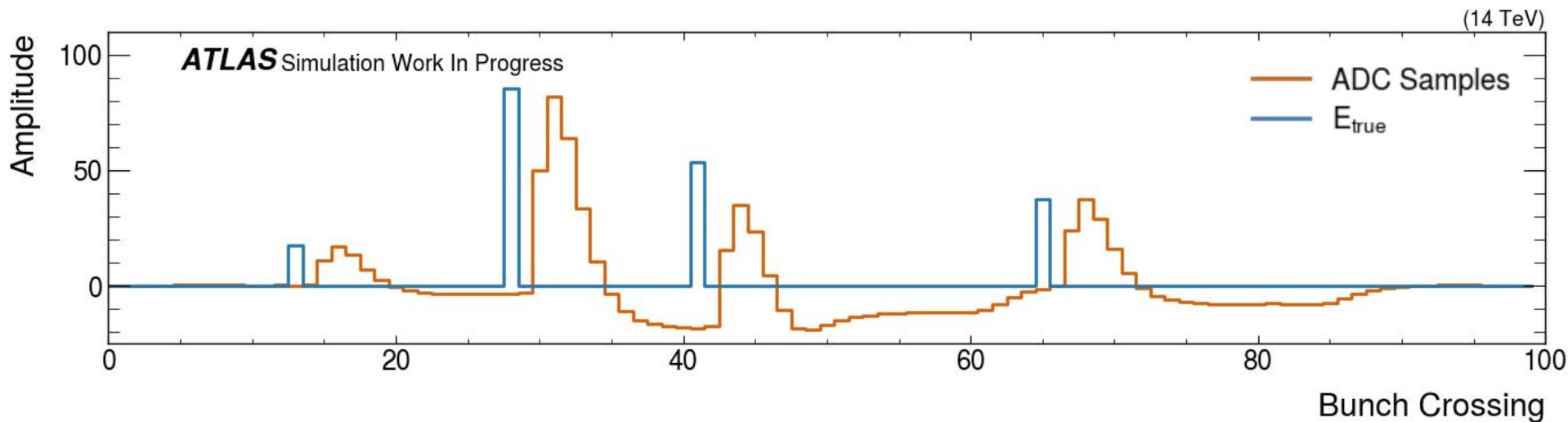Shaped Signal
Shaped and Sampled Signal

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Challenges with LAr Signal Detection
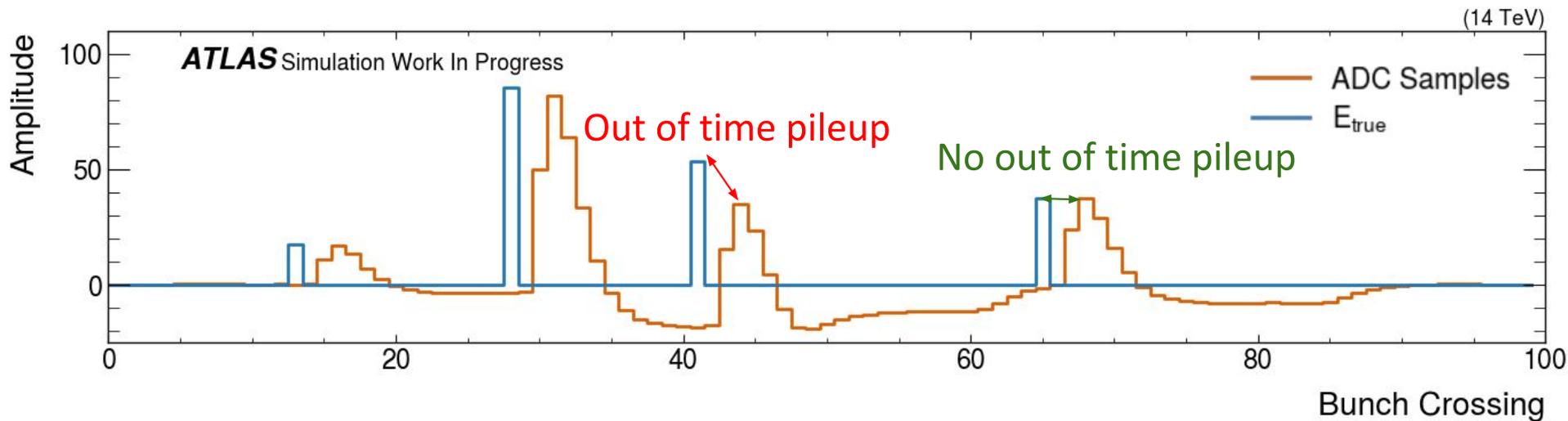
Pulse height is proportional to energy deposited

Out of time pileup: Because of lower ion mobility, detector pulses last 625 ns (~ 25 BC)
→ Previous pulses can bias energy reconstruction

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More interactions per Bunch Crossing (HL-LHC) → More pileup
New signal processing algorithm required
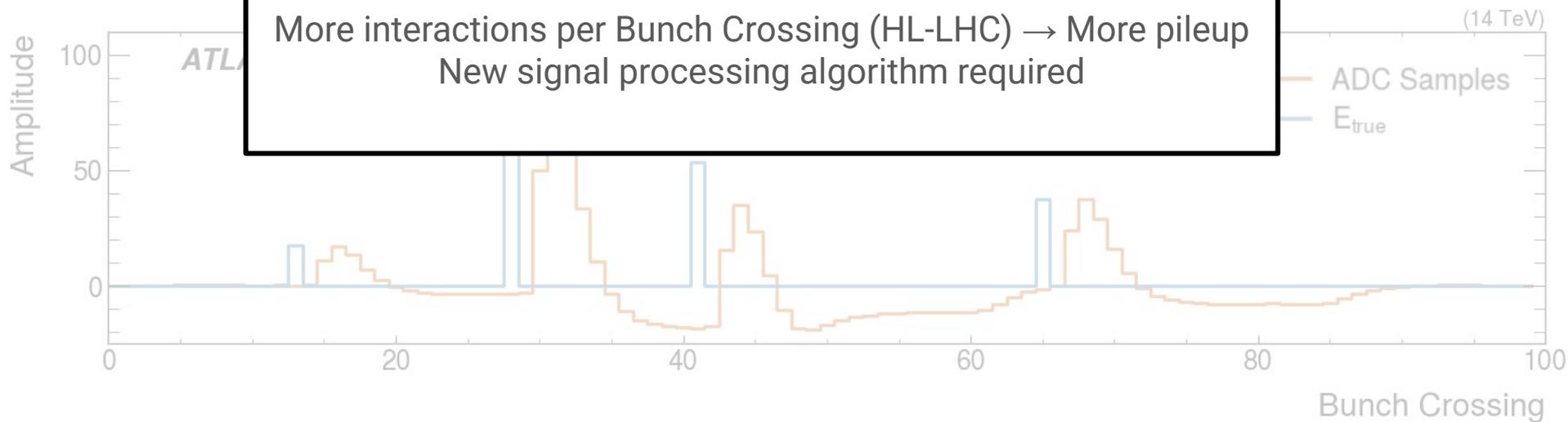
Current Approach

Optimal Filter (OF)

- Estimates energies using weighted sum of **latest** ADC samples **in real time**
- Weights are derived to maximize signal to noise ratio
- **But...** can be biased in the presence of out-of-time pileup

ADC → Optimal Filter → Reconstructed Signal

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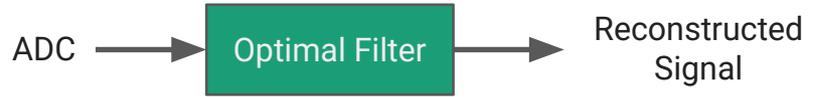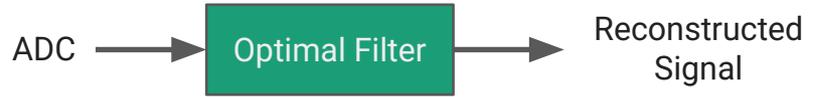
# Proposed Approach

Optimal Filter + Forward Correction (OFFC)

- Stores reconstructed energy and multiplies by known pulse shape
- Subtracts off scaled pulse shape <u>to remove out of time pileup</u>

Forward Correction

−

ADC → Optimal Filter → Reconstructed Signal
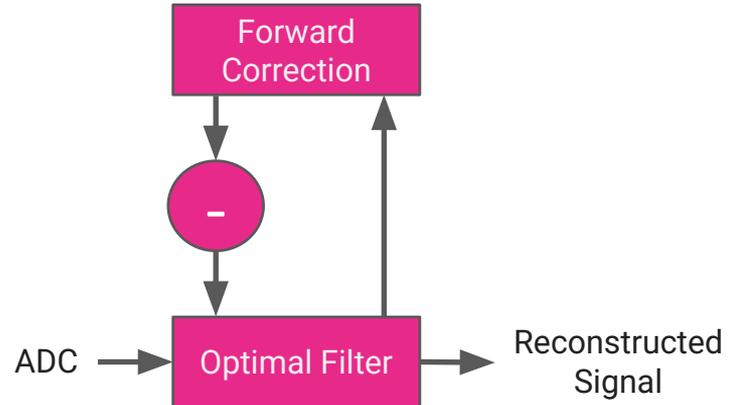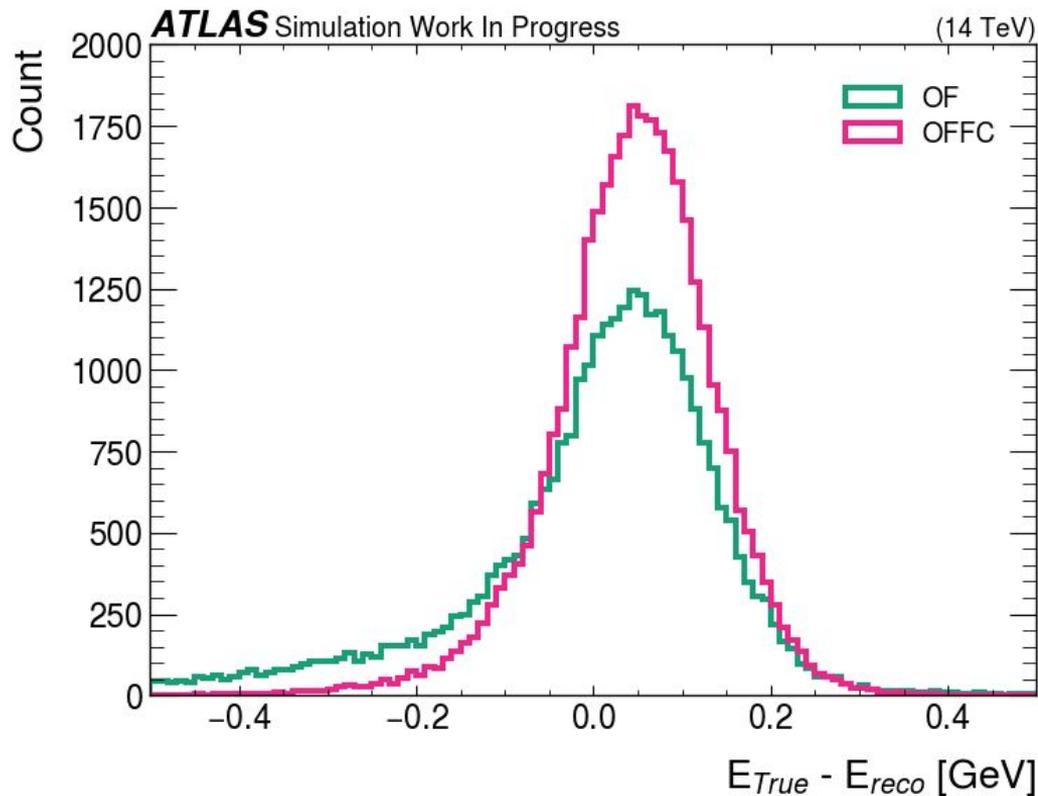
Model Validation

Single Cell Studies

- **Simulate signals from one calorimeter cell**

- Realistic electronic response and noise

- 20 millions Bunch Crossing (BC)

- 200 interactions per BC

- Randomly injected signals in the cell
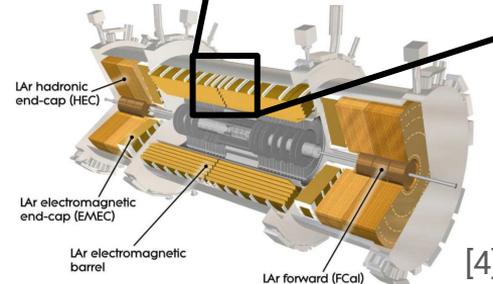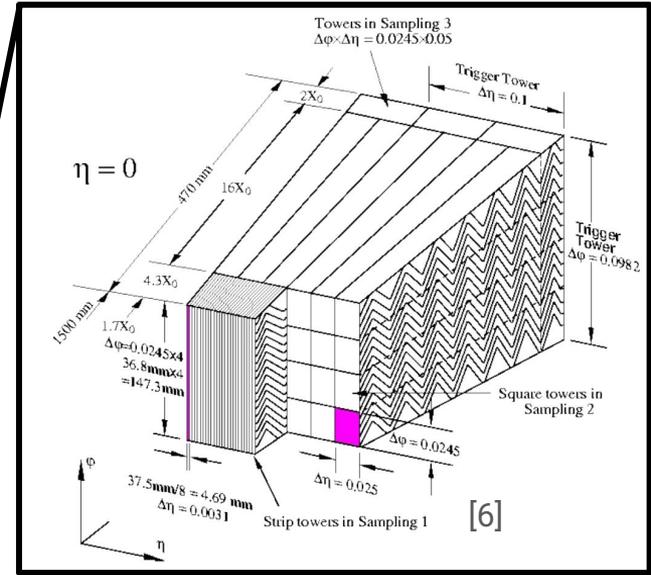
[6]

[4]

Out-of-time Pileup Effects

Plotting only BC with a signal **and** <30 BC since most recent pulse

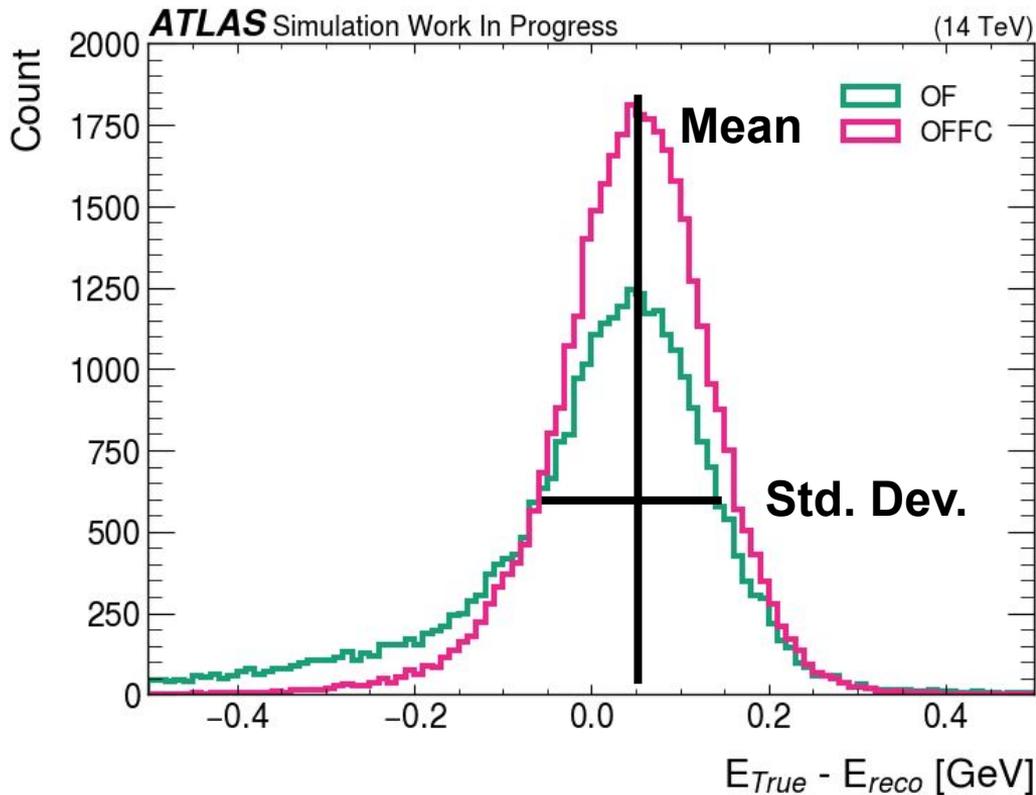**Underflow**
OF: 768 counts
OFFC: 55 counts

Overflow
OF: 6818 counts
OFFC: 1885 counts

9

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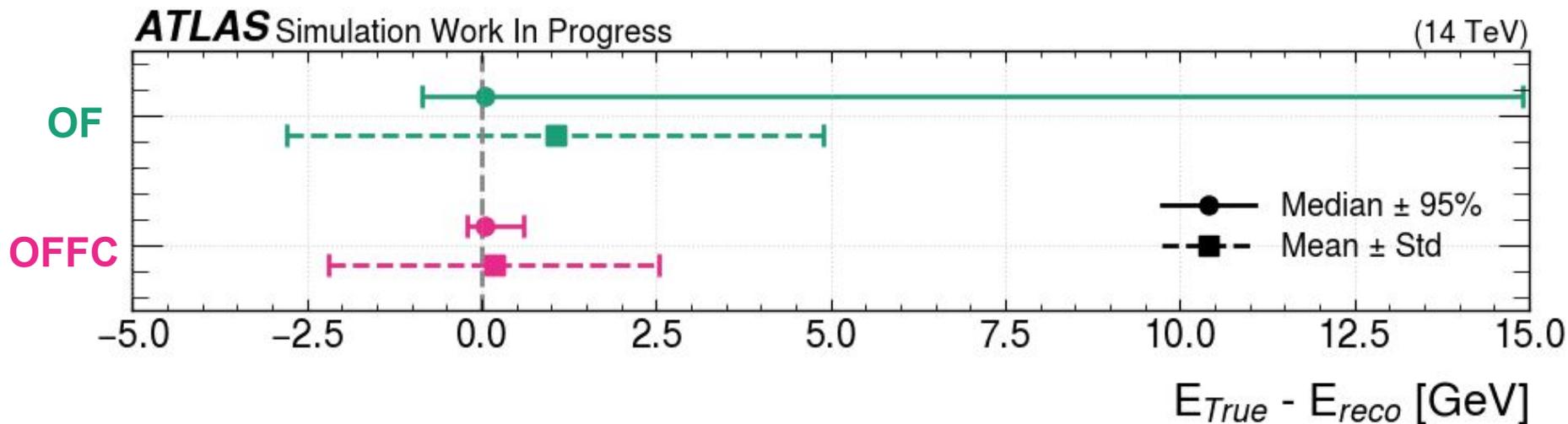
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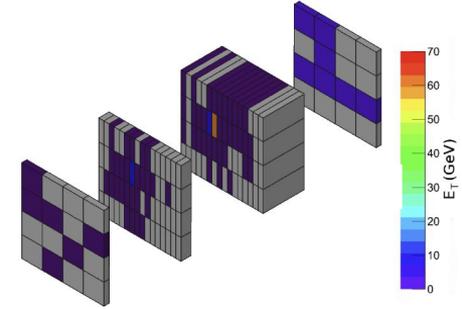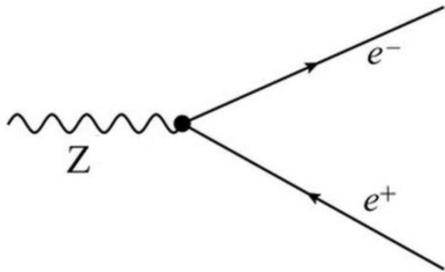OF: 6818 counts
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Performance Metrics

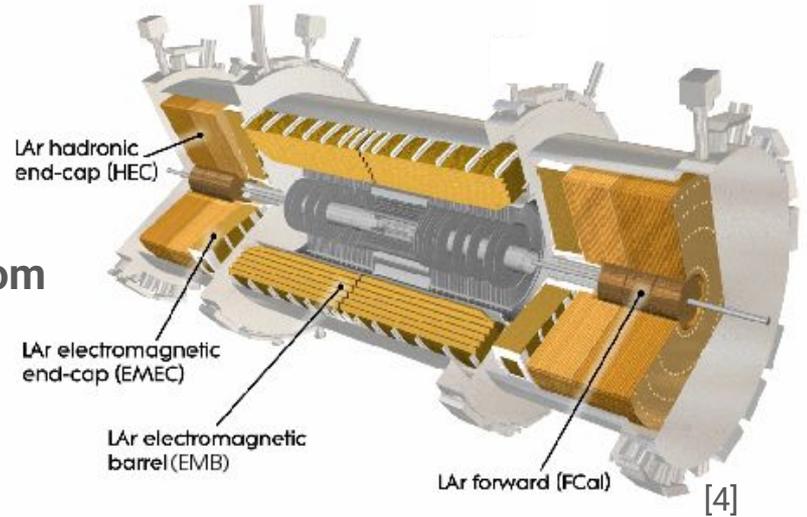Plotting only BC with a signal **and** <30 BC since most recent pulse

Multi Cell Studies

[7]

- **Study expected detector performance**

- Simulate response of all 182,468 calorimeter cells

- Realistic electronic response and noise

- 200 interactions per bunch crossing

- Signals simulated from Z→ee events

  - **Goal** is to **estimate energy of electrons from reconstructed energy in cluster of cells**

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LAr electromagnetic end-cap (EMEC)
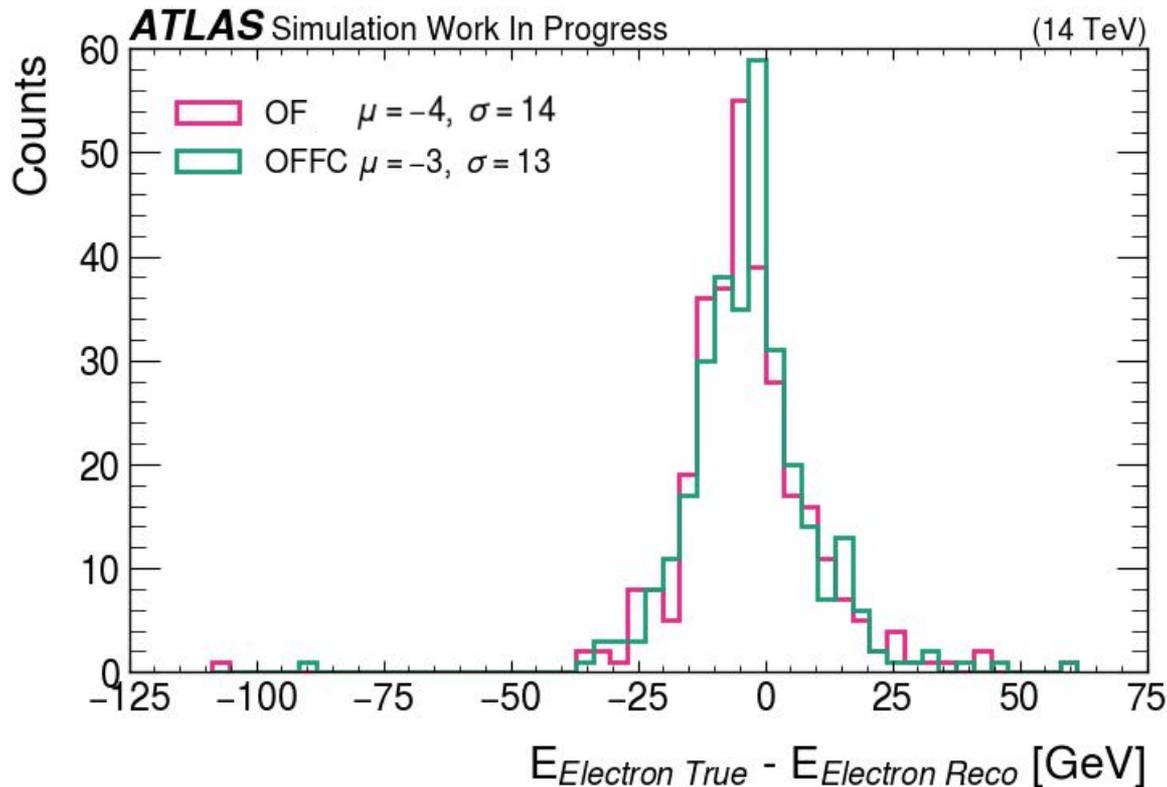
LAr electromagnetic barrel (EMB)
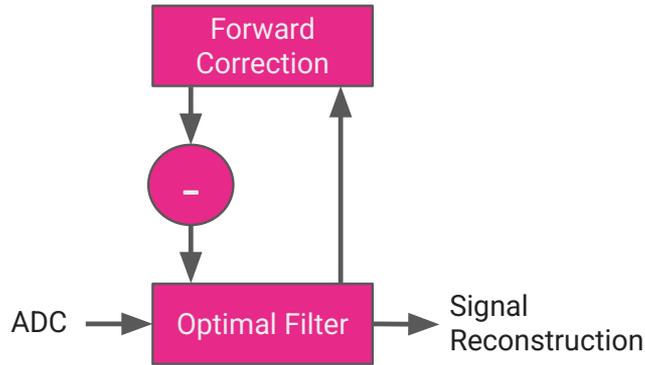
LAr forward (FCal)

[4]

Energy of Reconstructed Electrons

Plotting electrons reconstructed in **high pile up** regions

Conclusion - Forward Correction Works

1. **Eliminates out-of-time pileup** with better handling of overlapping signals
2. **Improves performance** with low additional computational cost
3. **Is stable** as demonstrated by the single cell studies
4. **Works in realistic environments** as demonstrated by the multi cell studies
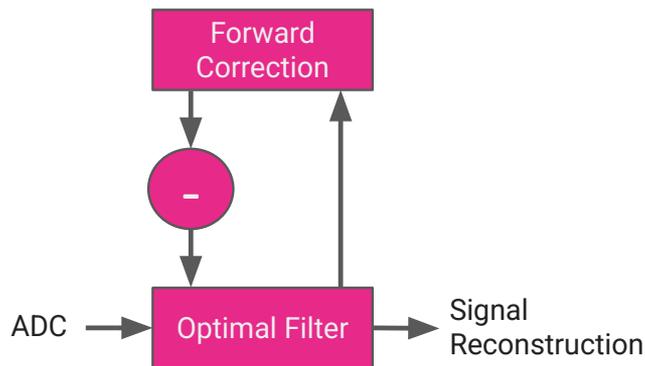
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Next Steps

1. Use more data in multi-cell studies
2. Compare the performance of forward correction algorithms with deep learning
3. Develop and implement forward correction of HL-LHC hardware (FPGAs)

References

[1] Abdel Abdesselam (2010)

[2] Apollinari, G. *et al.* (2016) *High luminosity large hadron collider HL-LHC*

[3] *Detector & Technology* (no date) *ATLAS Experiment at CERN*. Available at: https://atlas.cern/Discover/Detector

[4] ATLAS Collaboration (2010) *Readiness of the ATLAS Liquid Argon Calorimeter for LHC Collisions*

[5] Adapted from ATLAS Collaboration (2008) *The ATLAS Experiment at the CERN Large Hadron Collider*

[6] ATLAS Collaboration (1996) *ATLAS liquid-argon calorimeter : Technical Design Report*

[7] ATLAS Collaboration (2013) *ATLAS Liquid Argon Calorimeter Phase-I Upgrade Technical Design Report*