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

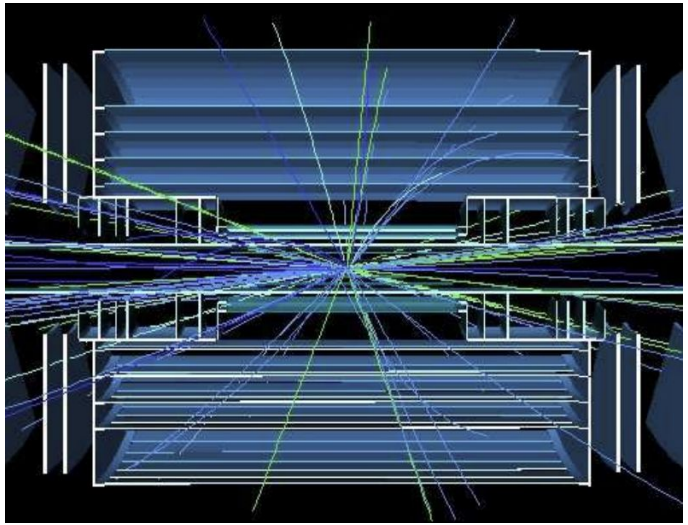
Eli Cohen, PhD Student
McGill University
Supervisor: Professor Brigitte Vachon
63rd Winter Nuclear & Particle Physics Conference
12–15 Feb 2026. Banff, Alberta

McGill UNIVERSITY

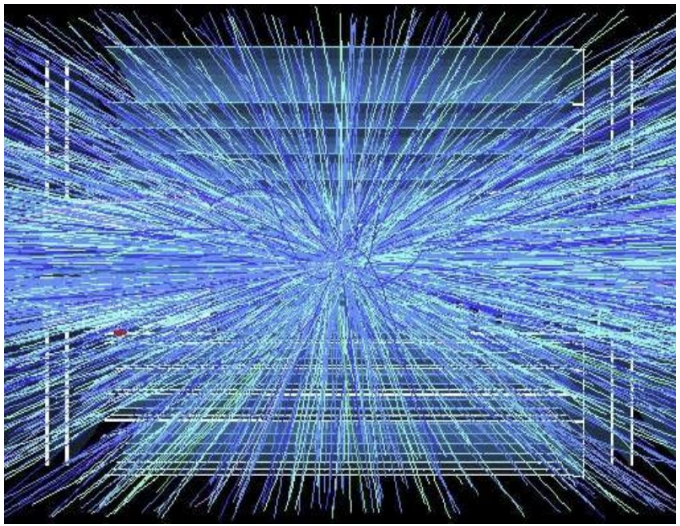
ATLAS EXPERIMENT

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

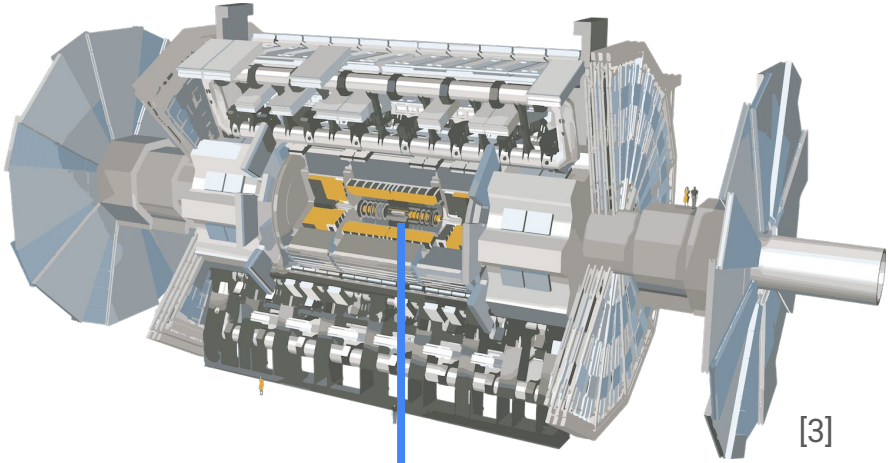
and the Liquid Argon (LAr) Calorimeter

ATLAS: general-purpose detector at the LHC

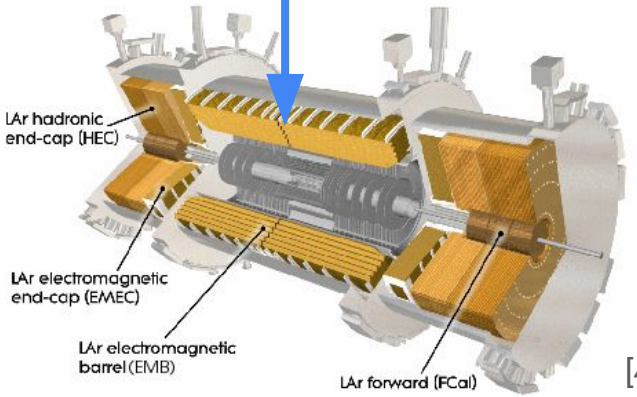
- Made up of multiple subdetectors, each designed for specific measurements

LAr Calorimeter: subdetector

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



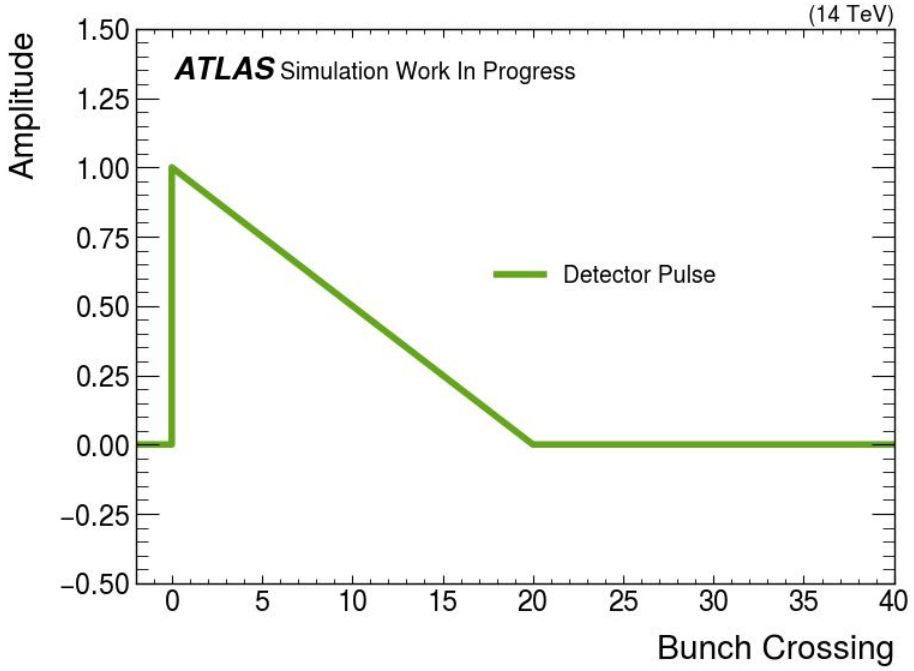
[3]



[4]

How the LAr Calorimeter Works

Charged particles induce ionization in LAr



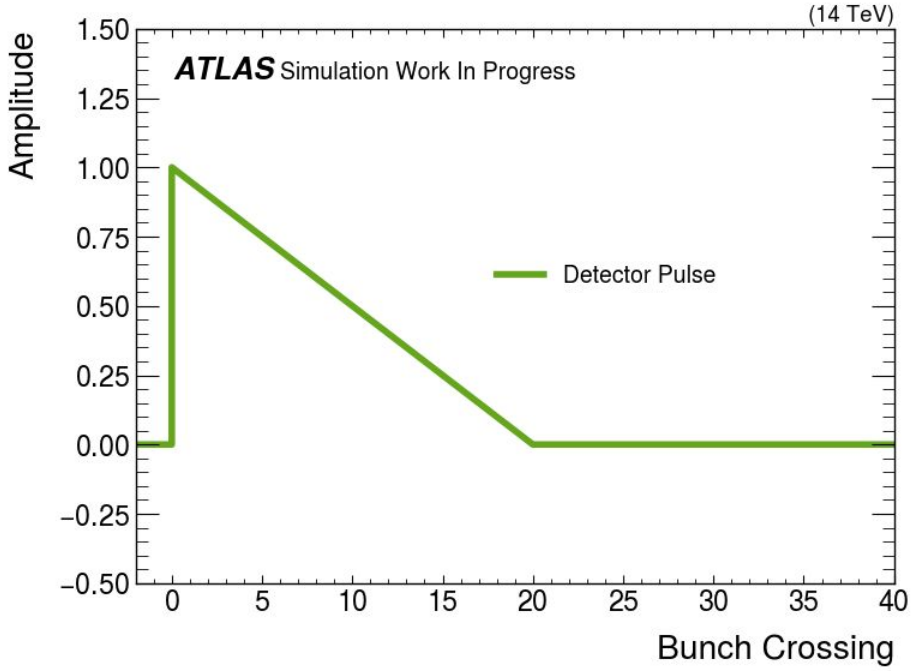
[5]

How the LAr Calorimeter Works

Charged particles induce ionization in LAr

↓

Ions/e^- drift under an electric field and create current



[5]

How the LAr Calorimeter Works

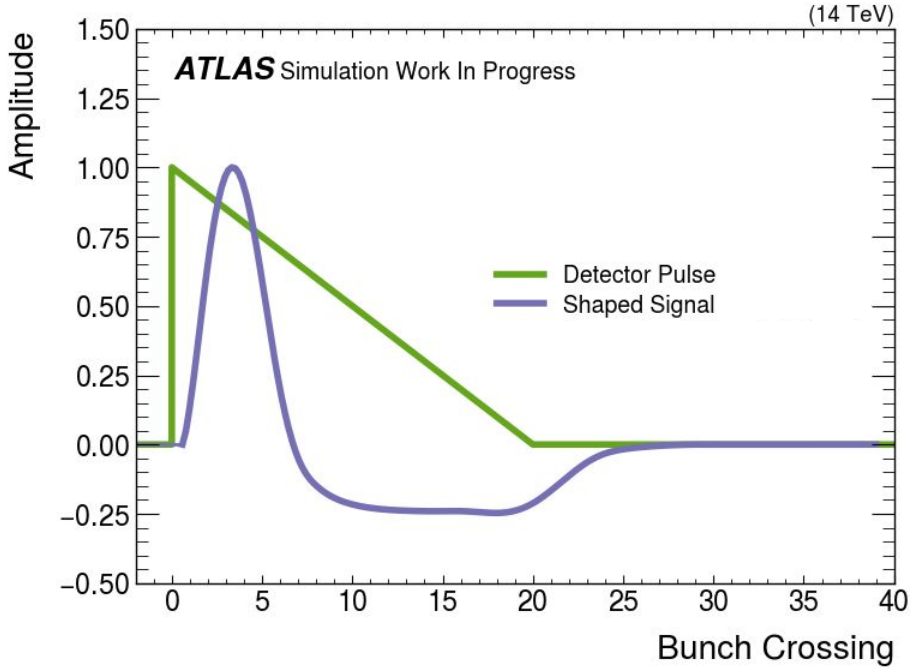
Charged particles induce ionization in LAr

↓

Ions/e^- drift under an electric field and create current

↓

Current amplified/shaped by front end electronics



[5]

How the LAr Calorimeter Works

Charged particles induce ionization in LAr

↓

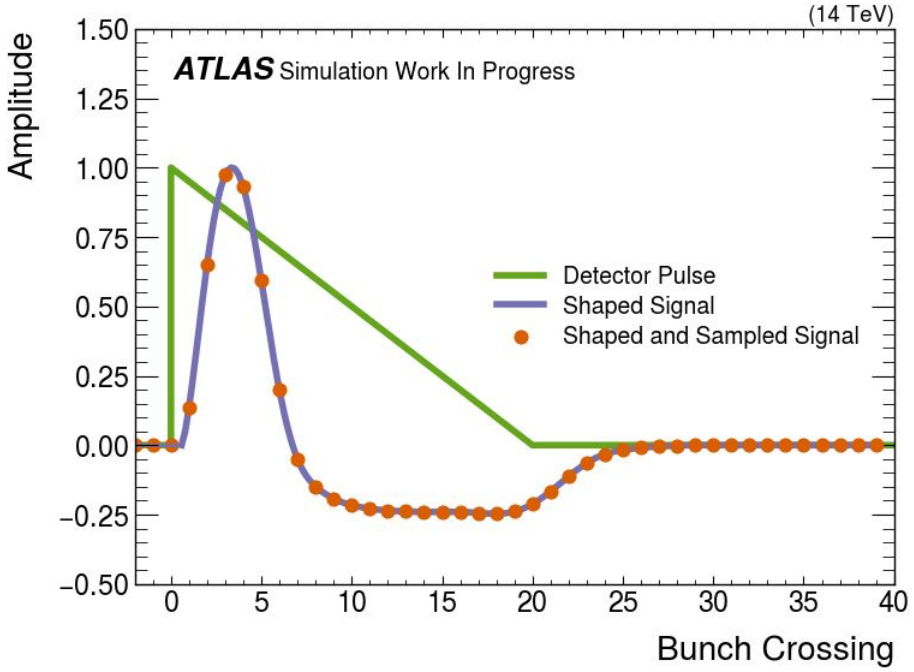
Ions/e^- drift under an electric field and create current

↓

Current amplified/shaped by front end electronics

↓

Signal is digitized at 40 MHz (BC Frequency)



Digitized signal is called ADC

[5]

How the LAr Calorimeter Works

Charged particles induce ionization in LAr

↓

Ions/e^- drift under an electric field and create current

↓

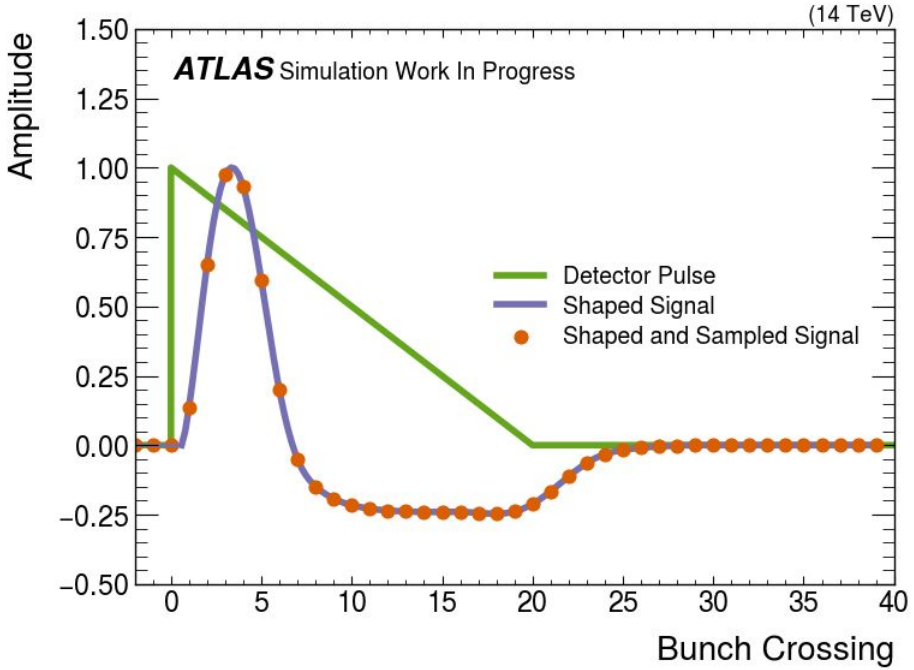
Current amplified/shaped by front end electronics

↓

Signal is digitized at 40 MHz (BC Frequency)

↓

Energy is reconstructed via signal processing



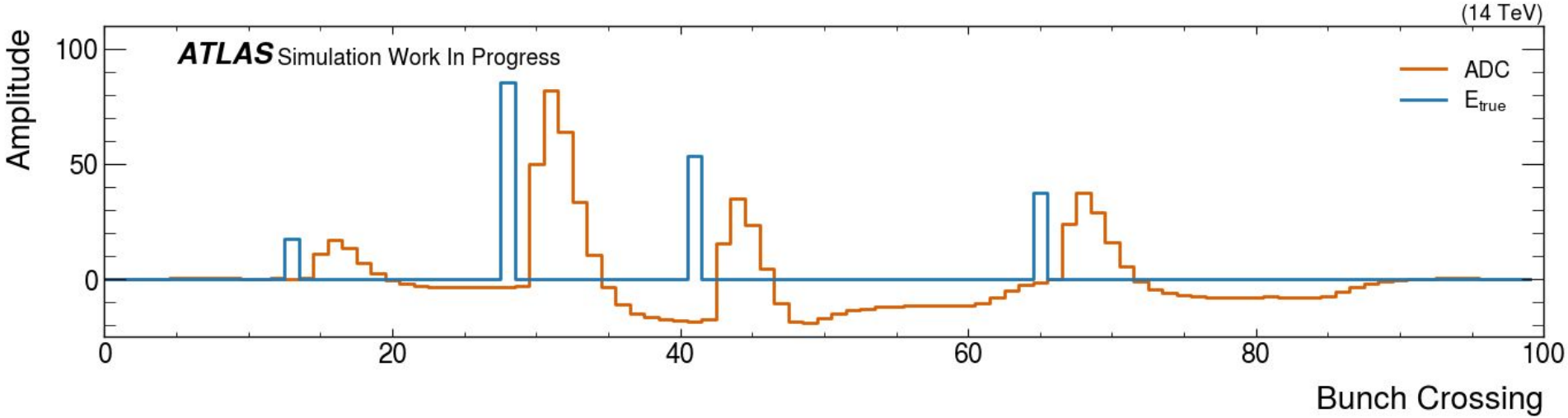
Digitized signal is called ADC

[5]

Challenges with LAr Signal Detection

Pulse height is proportional to energy deposited

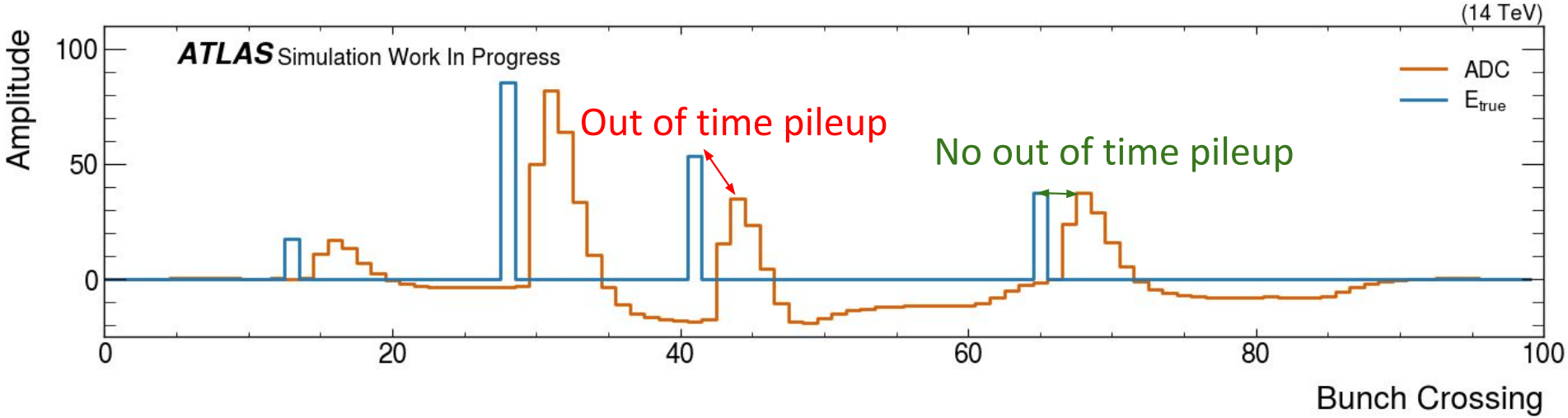
Out of time pileup: Because of low ion mobility, detector takes a long time to reset
→ Previous pulses can bias energy reconstruction



Challenges with LAr Signal Detection

Pulse height is proportional to energy deposited

Out of time pileup: Because of low ion mobility, detector takes a long time to reset
→ Previous pulses can bias energy reconstruction

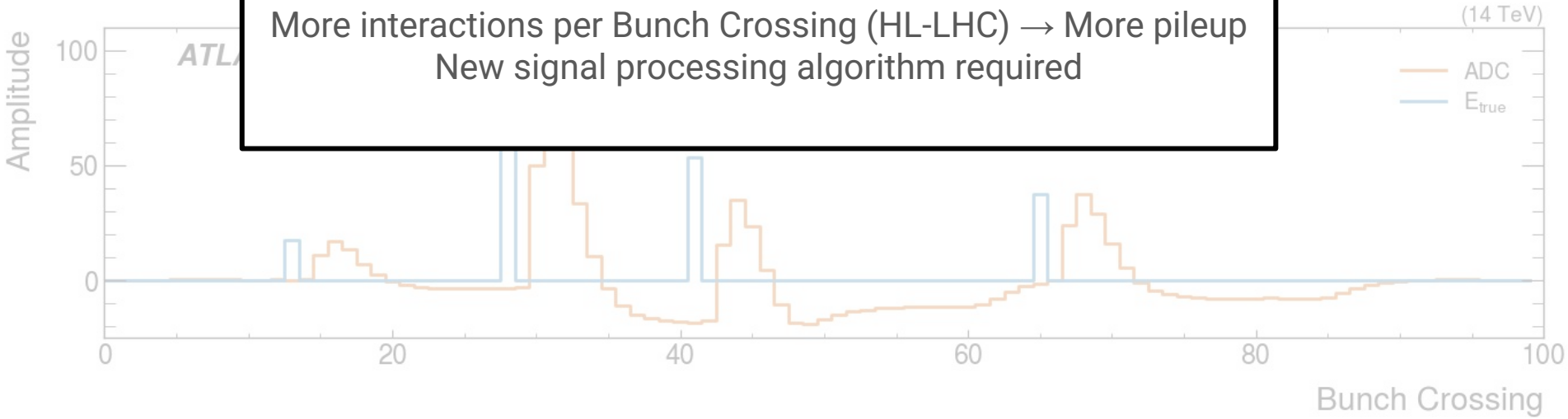


Challenges with LAr Signal Detection

Pulse height is proportional to energy deposited

Out of time pileup: Because of low ion mobility, detector takes a long time to reset
→ Previous pulses can bias energy reconstruction

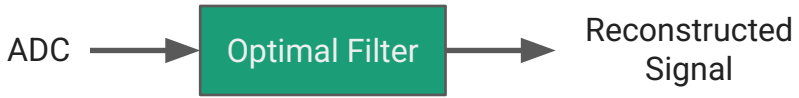
More interactions per Bunch Crossing (HL-LHC) → More pileup
New signal processing algorithm required



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



Current Approach

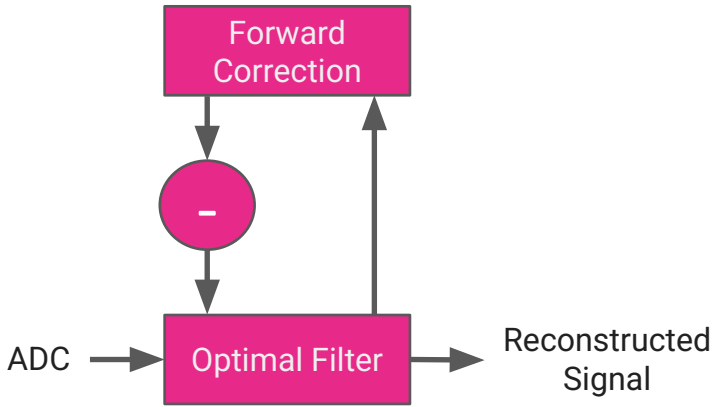
Optimal Filter (OF)

- 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

Proposed Approach

Optimal Filter + Forward Correction (OFFC)

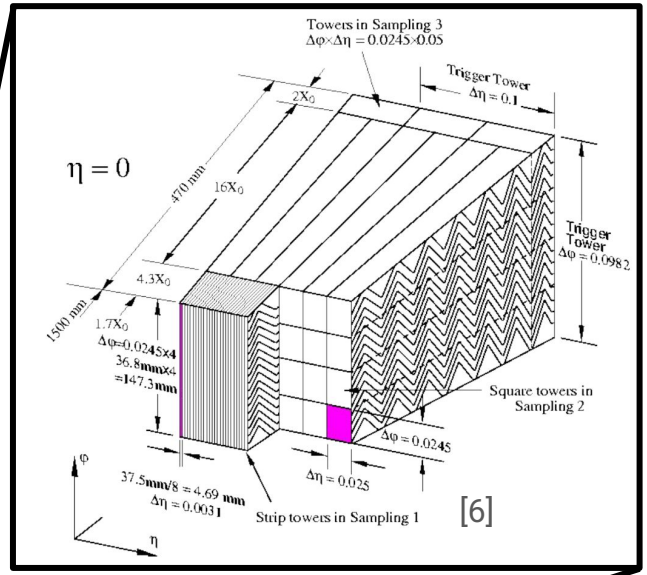
- Stores reconstructed energy and multiplies by known pulse shape
- Subtracts off scaled pulse shape to remove out of time pileup

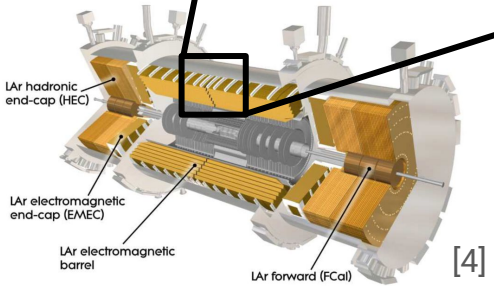


Model Validation

Single Cell Studies

- Tests stability and long term performance
- One cell for a “long” time
  - 20 million Bunch Crossings (BC)
- Realistic simulation and noise
- Randomly injected signals
- 200 interactions per BC





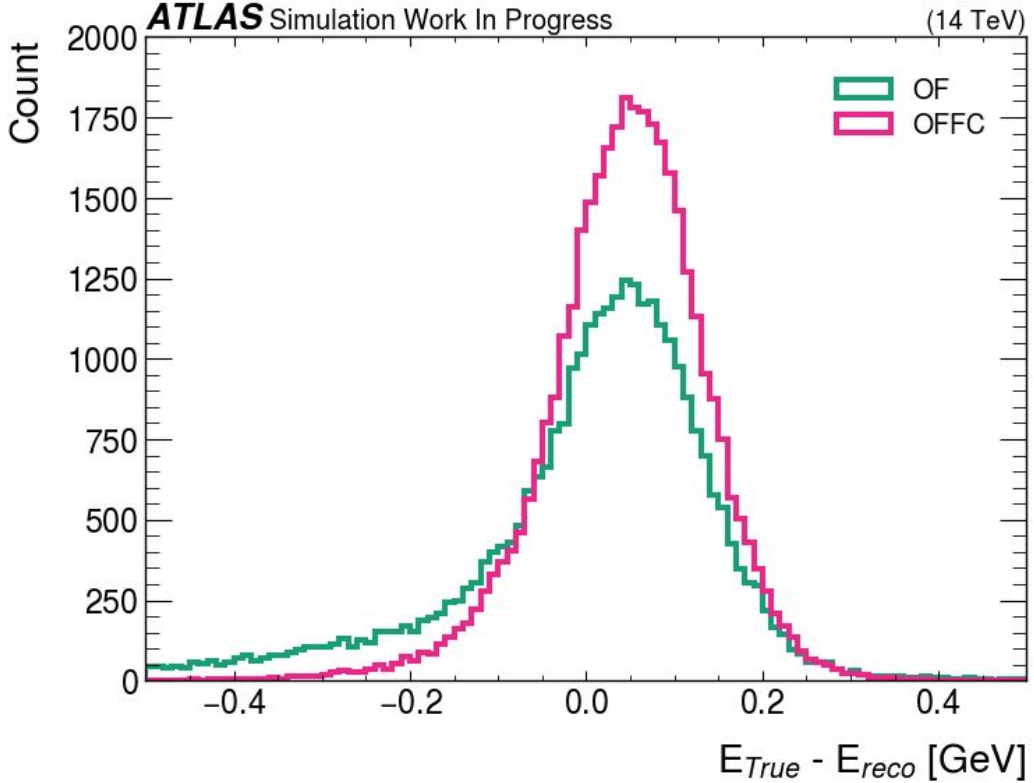
Out-of-time Pileup Effects

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

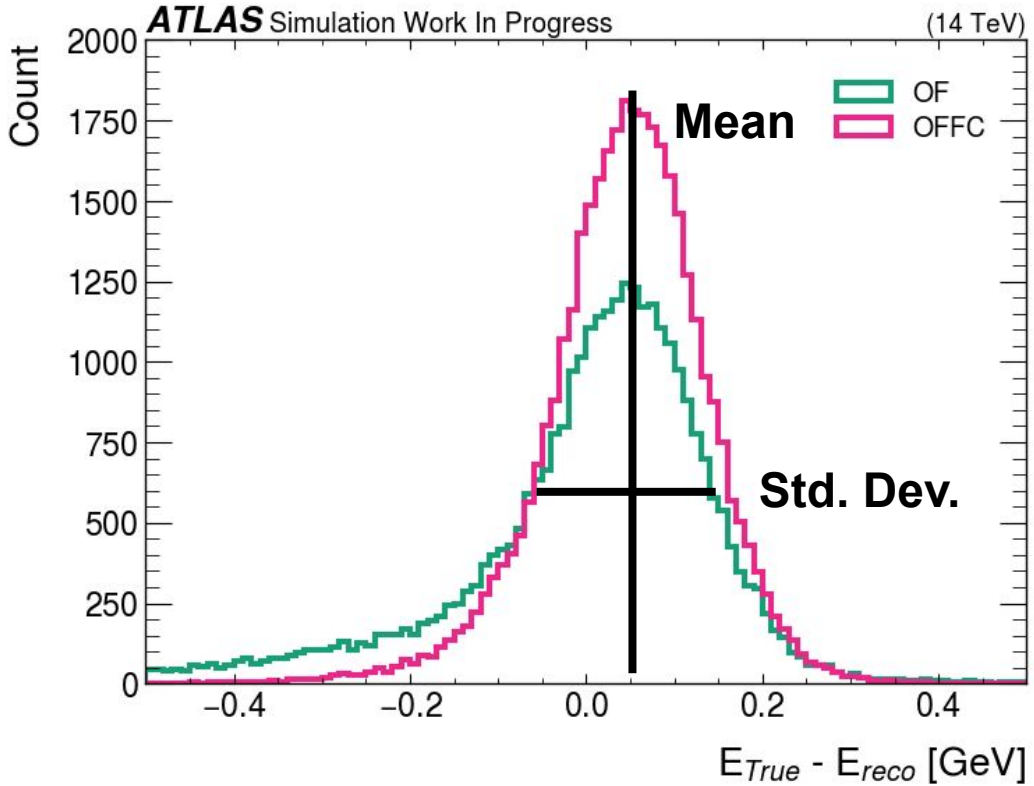
Out-of-time Pileup Effects

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

Underflow

OF: 768 counts

OFFC: 55 counts



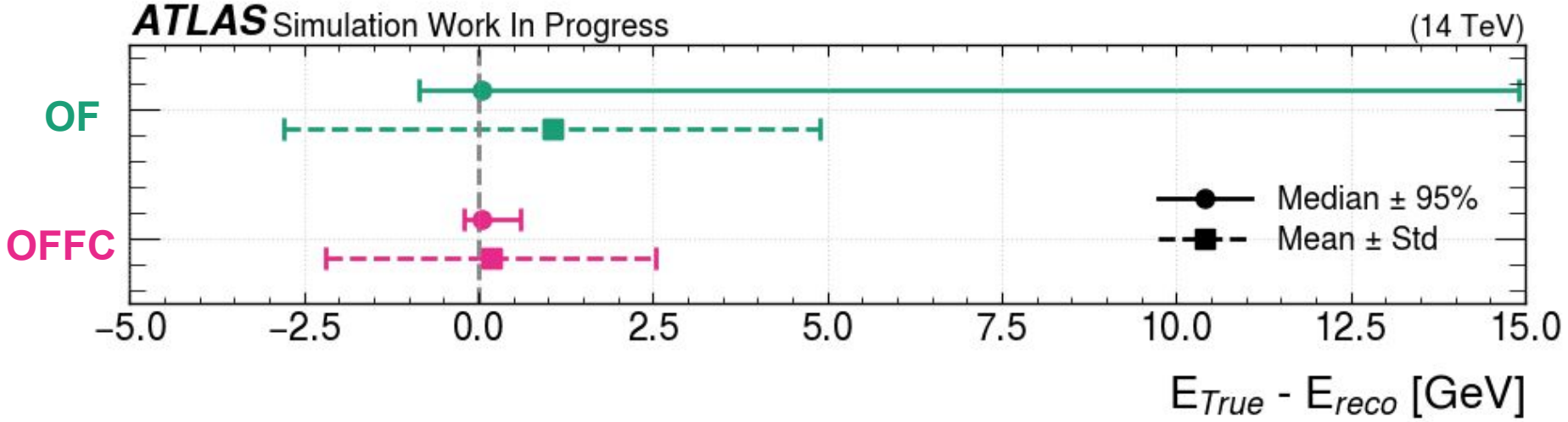
Overflow

OF: 6818 counts

OFFC: 1885 counts

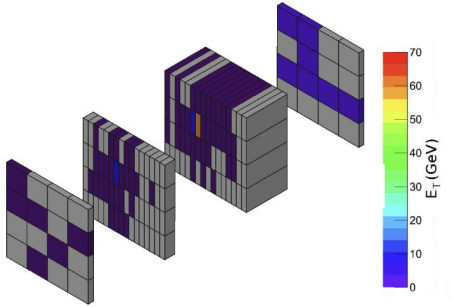
Performance Metrics

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

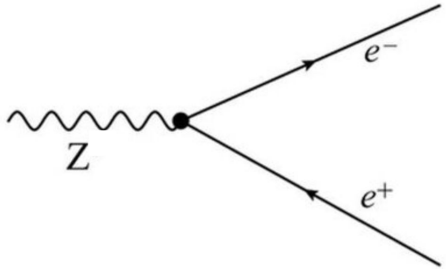


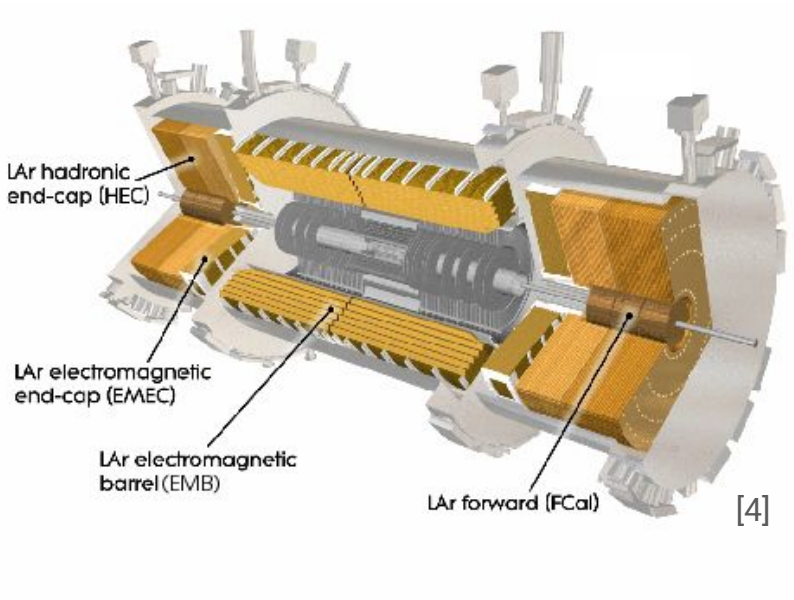
Multi Cell Studies

- Tests real detector performance
- 182,468 independent cells for a “short” time (32 BC)
- Realistic simulation and noise
- Signals simulated from Z⟶ee events
  - **Goal** is to **estimate energy of e**



[7]

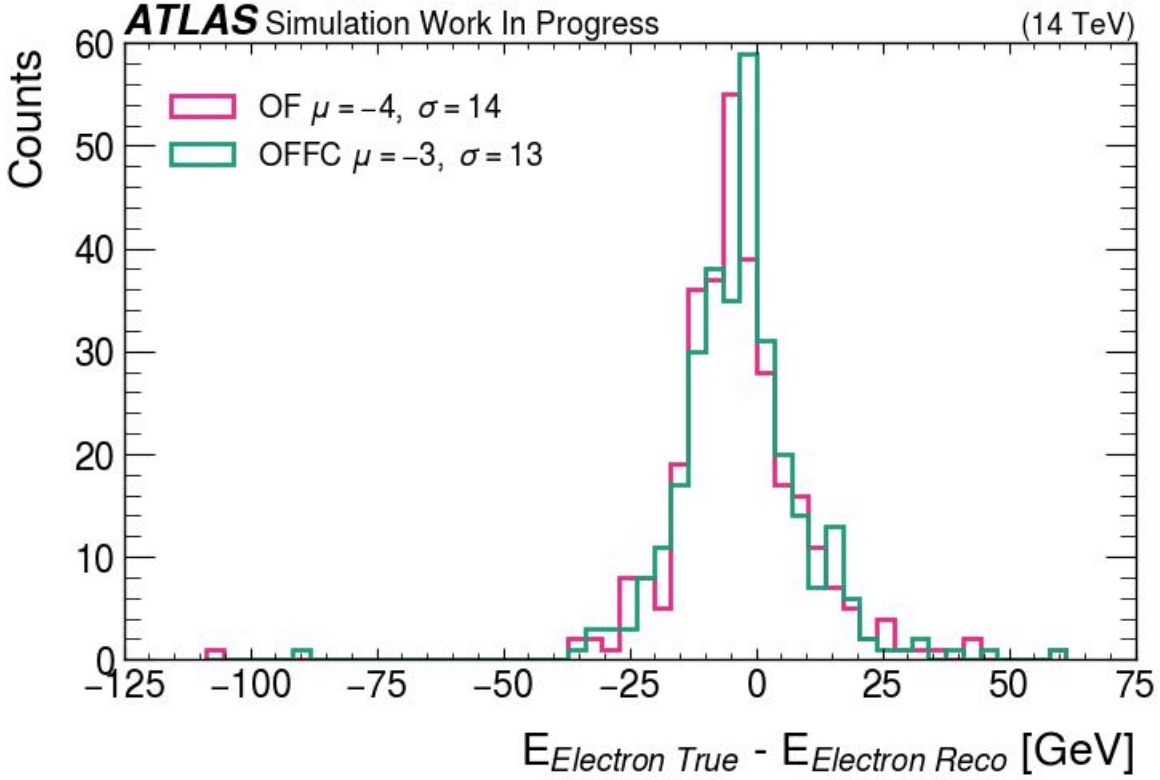




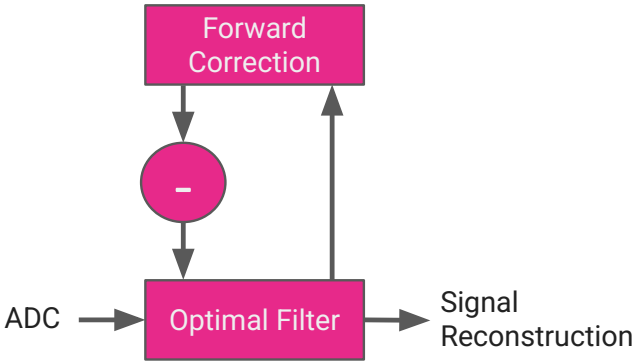
[4]

Energy of Reconstructed Electrons

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

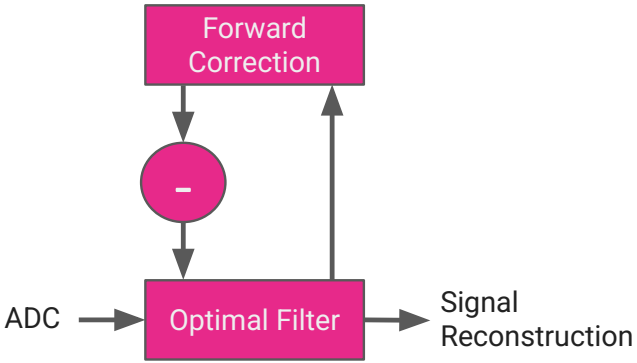


Conclusion - Forward Correction Works



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

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

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*