LHC-ATLAS Phase-1 upgrade: Calibration and simulation of new trigger readout system of the Liquid Argon calorimeter

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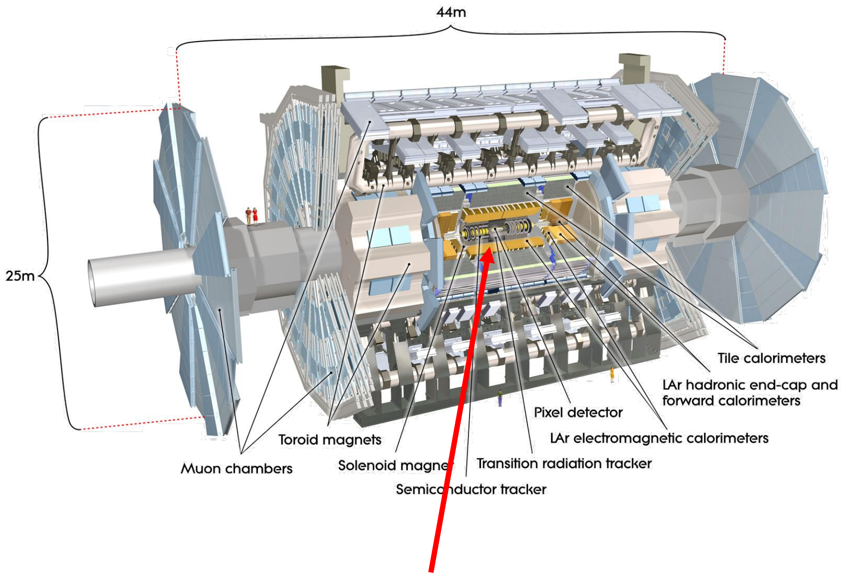
on behalf of ATLAS LAr Calorimeter collaboration

ICEPP
The University of Tokyo

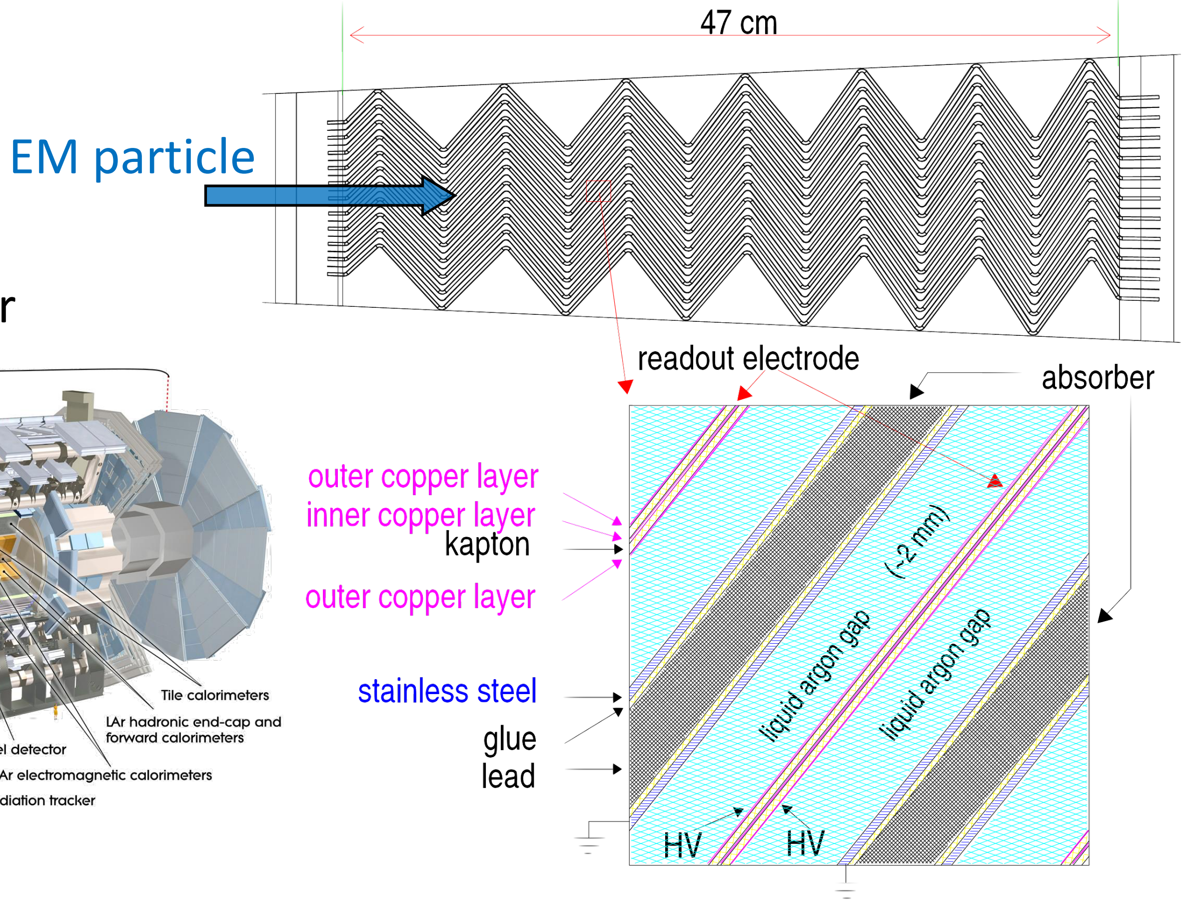
ATLAS EXPERIMENT

LAr calorimeter in LHC-ATLAS experiment

ATLAS detector



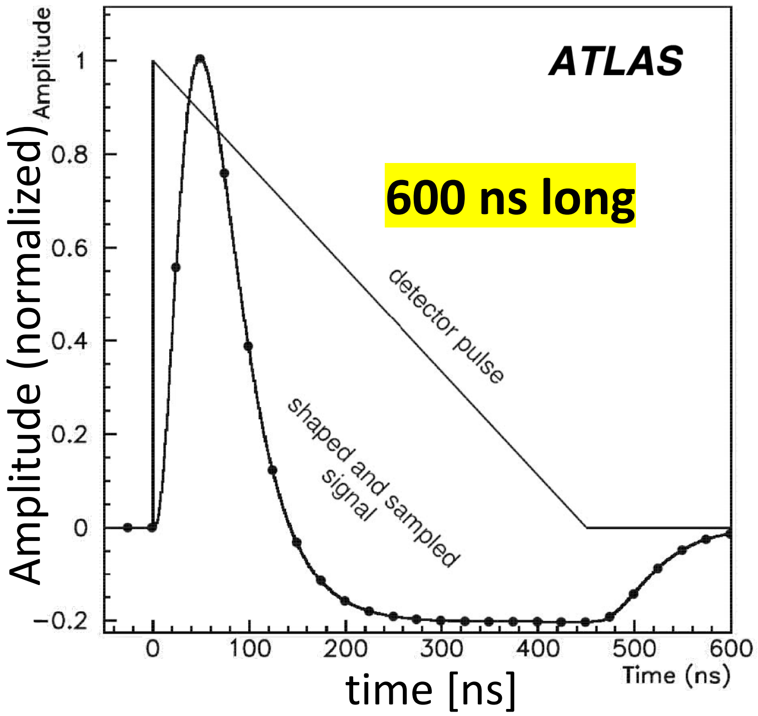
LAr calorimeter



EM shower in lead layer

⬇

Ionization in LAr layer



triangle -> bipolar convert

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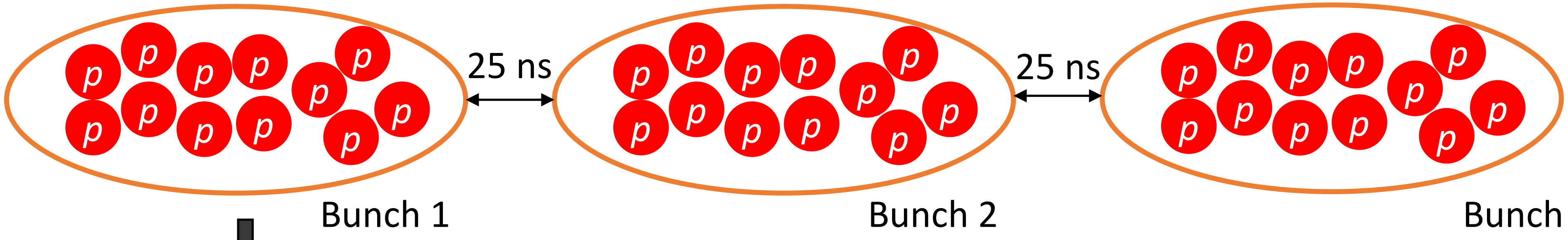
- **Pulse height $\propto$ energy**
- Integral = 0

Phase-I upgrade

Luminosity is going to be high in the future. (Run 3, High Luminosity LHC) ← 2.0×10^{34} $cm^{-2}s^{-1}$ for Run3

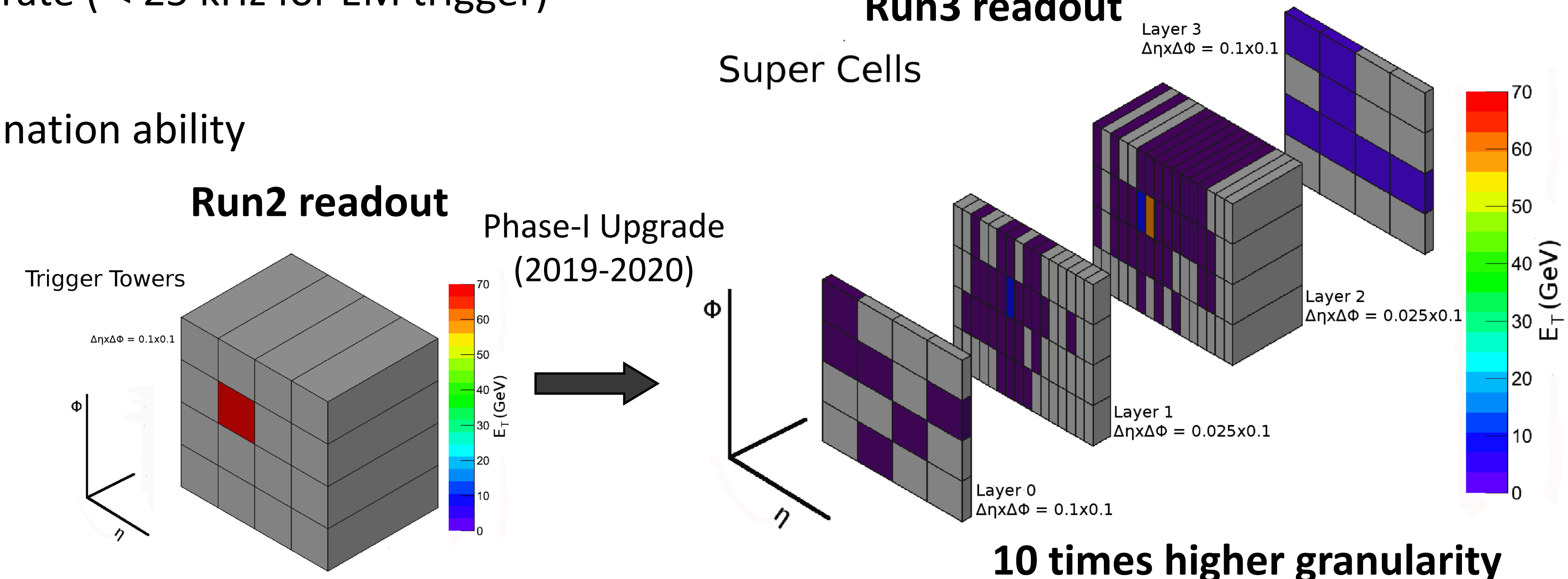


~10^{11} protons in each bunch

Need to control trigger rate (< 25 kHz for EM trigger)

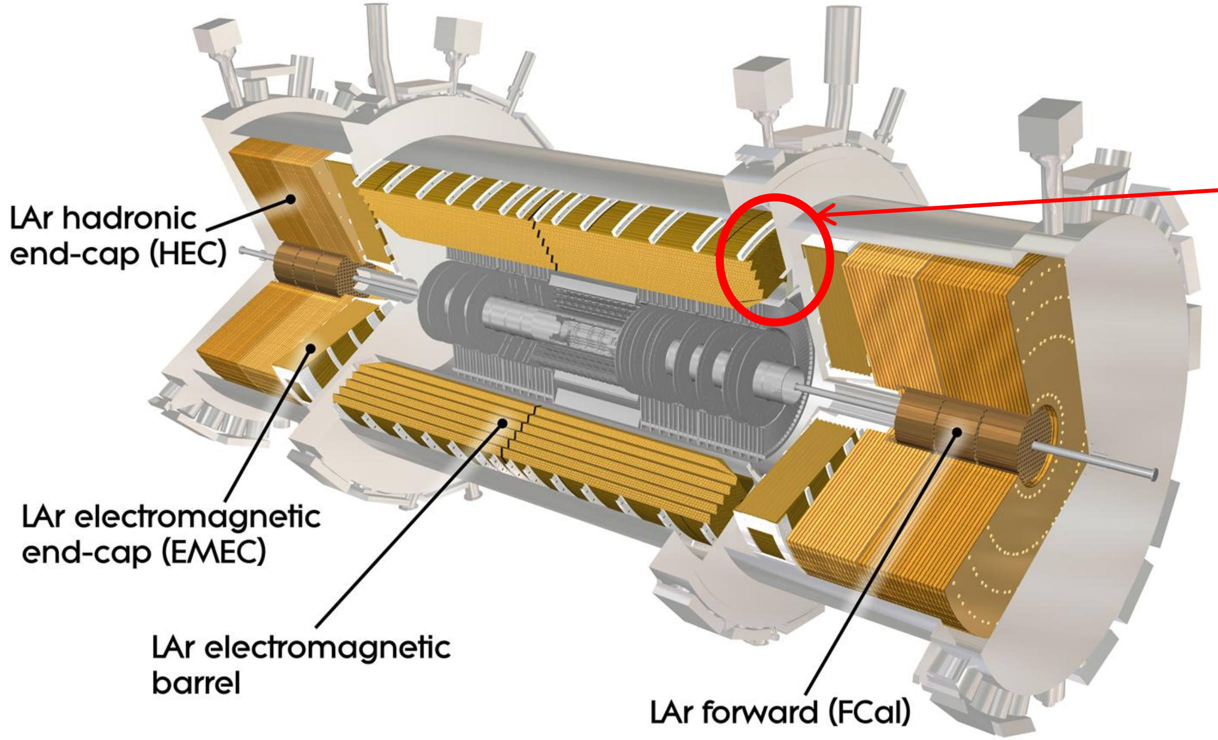
Improve object discrimination ability

Use object shape

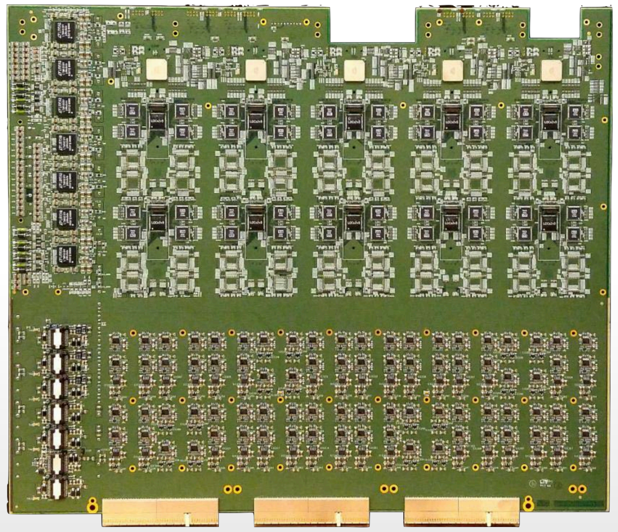


10 times higher granularity

The new trigger readout electronics



ADC at the front-end



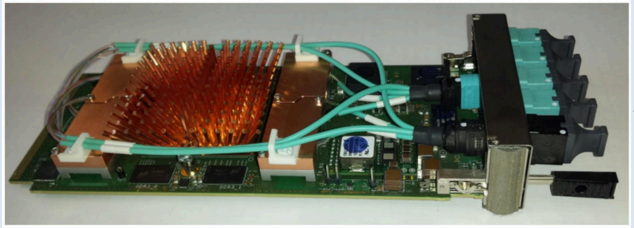
124 **Digitizer boards** (LTDBs)

~80 m

Board for energy & timing calculation

◆LATOME - LAr Trigger Processing Mezzanine

- INTEL™ Arria™ 10 FPGA
- 2 GB DDR3
- 48 input fibers 5.12 Gb/s per fiber
- 48 output fibers 11.2Gb/s per fiber



- Capable up to 320 channels

http://cds.cern.ch/record/2319878/files/ATL-LARG-SLIDE-2018-287.pdf

Energy & timing calculation at the back-end

124 LATOMEs

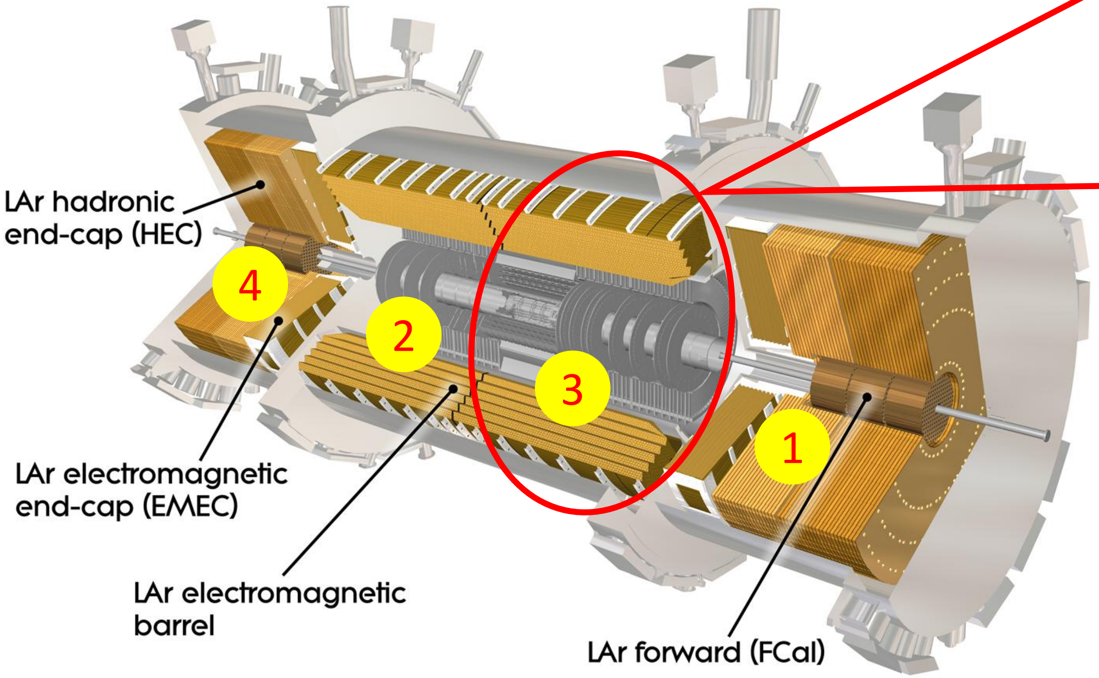
Electronics update schedule

Front-end board update schedule		
1	FEB-APL 2019	Endcap A-side
2	APL-JUL 2019	Barrel C-side
3	SEP-DEC 2019	Barrel A-side
4	JAN-MAR 2020	Endcap C-side

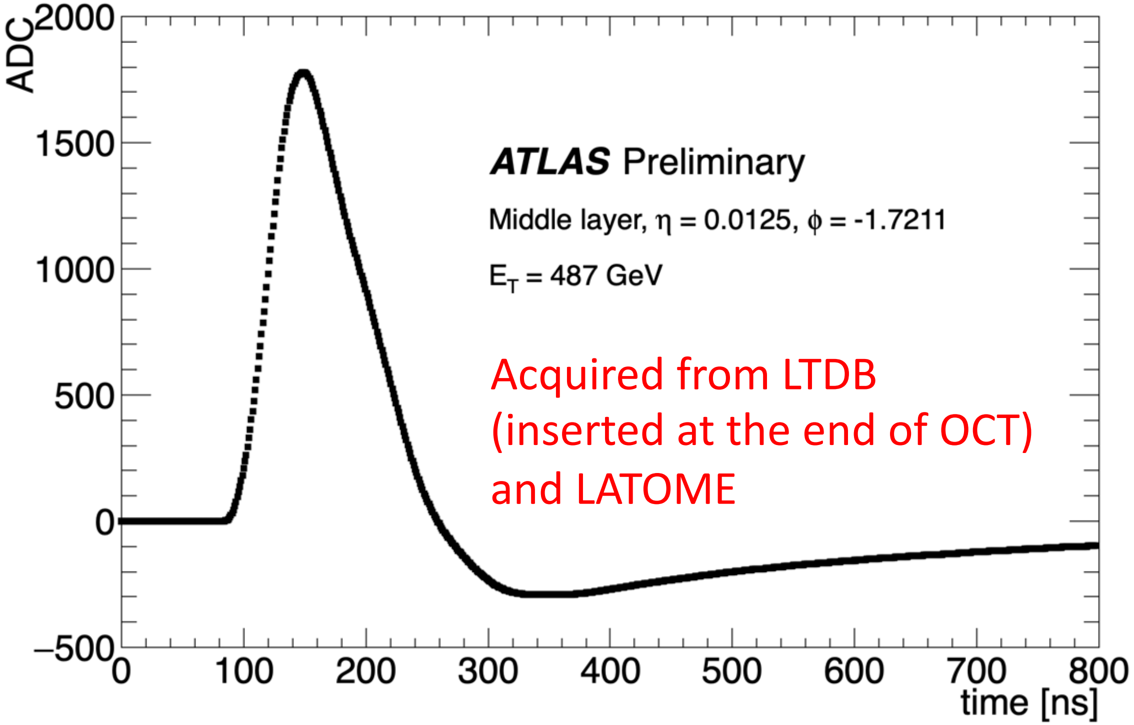
➡ **Acquire data and calibrate LATOME sequentially when updated**

This summer: acquired data of the new electronics for the first time

This autumn: confirmed the consistency of acquired data for the first time



Acquired pulse shape by injecting test pulse into the detector in Barrel C-side

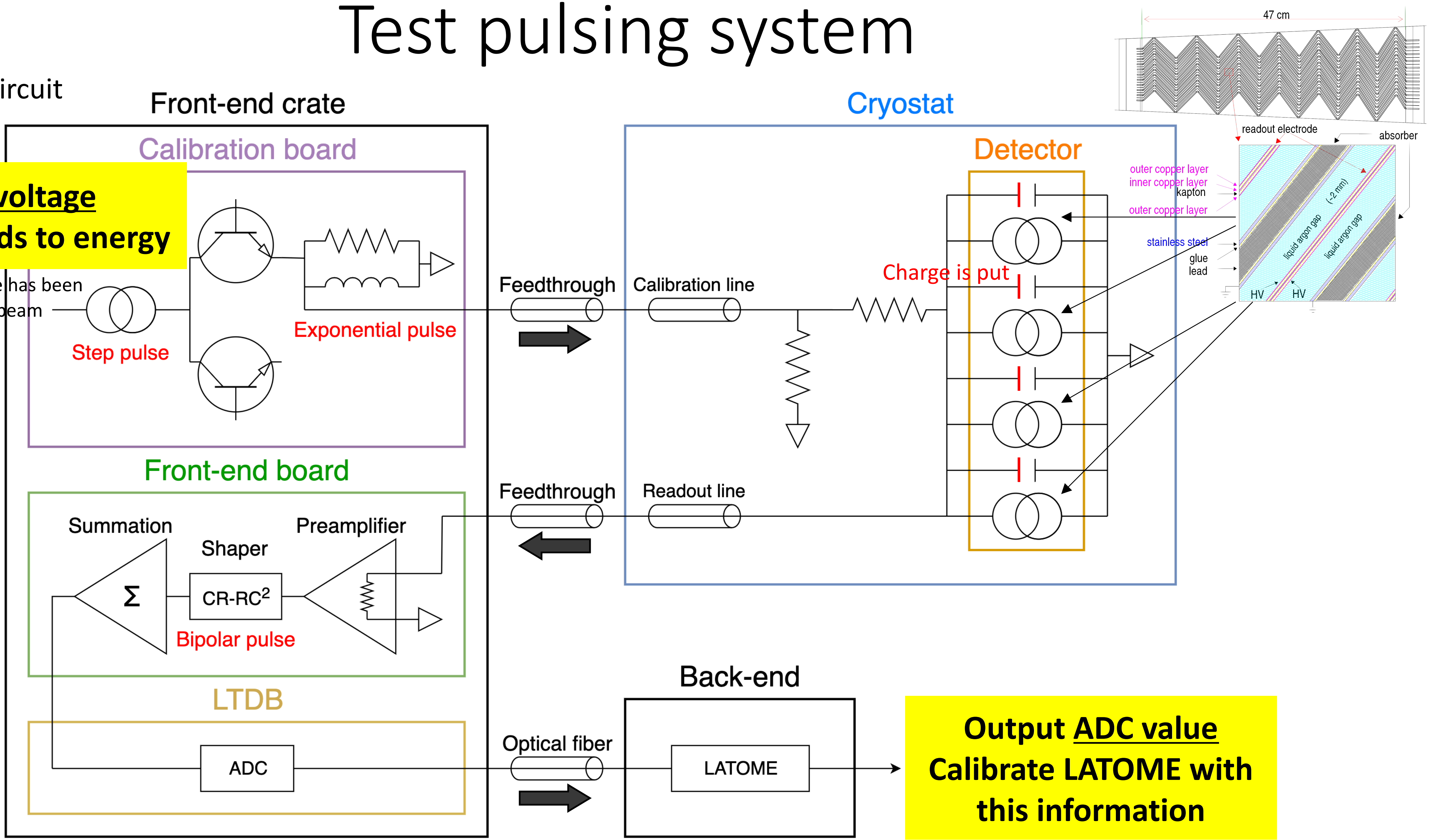


Test pulsing system

Equivalent circuit

Input voltage
- corresponds to energy

The correspondence has been determined by test beam



Output ADC value
Calibrate LATOME with this information

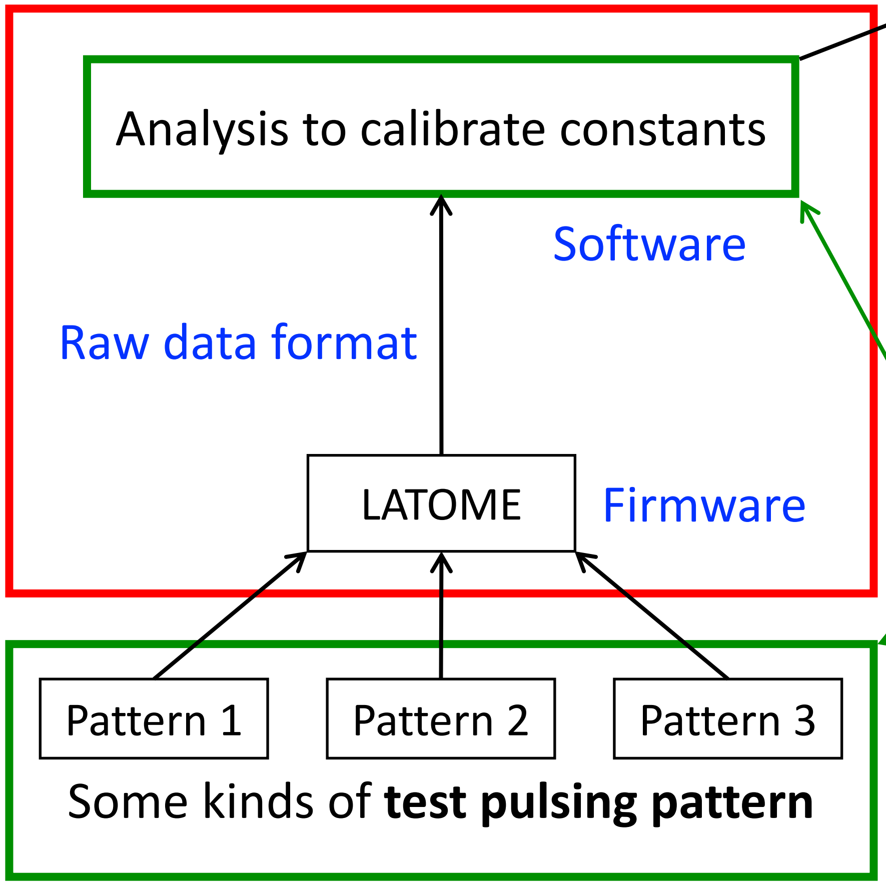
Calibration framework

Need to know energy from pulse amplitude for triggering ➡ { **Wave form**, **Pedestal**, **E_T/bit** } etc. are needed **in each cell**

E_T: transverse energy

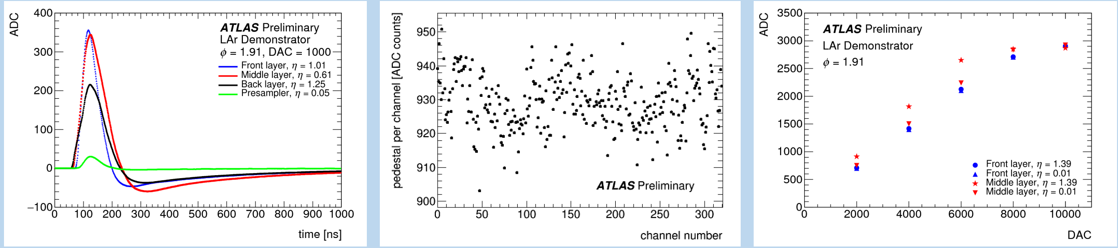
Output

Calibration framework for trigger readout



Cell constants e.g.

Wave form | Pedestal | E_T/bit

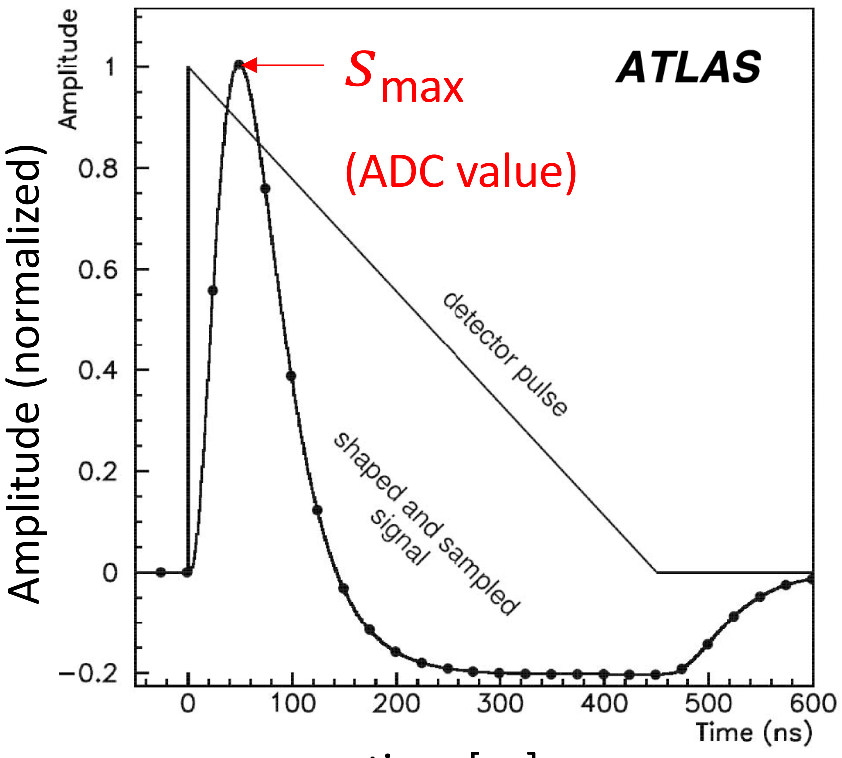


Use the existing calibration scheme for main readout

Develop firmware, raw data format and software so that the calibration framework works correctly for trigger readout

E_T/bit consistency

Pulse height ∝ energy



s_{max}

(ADC value)

time [ns]

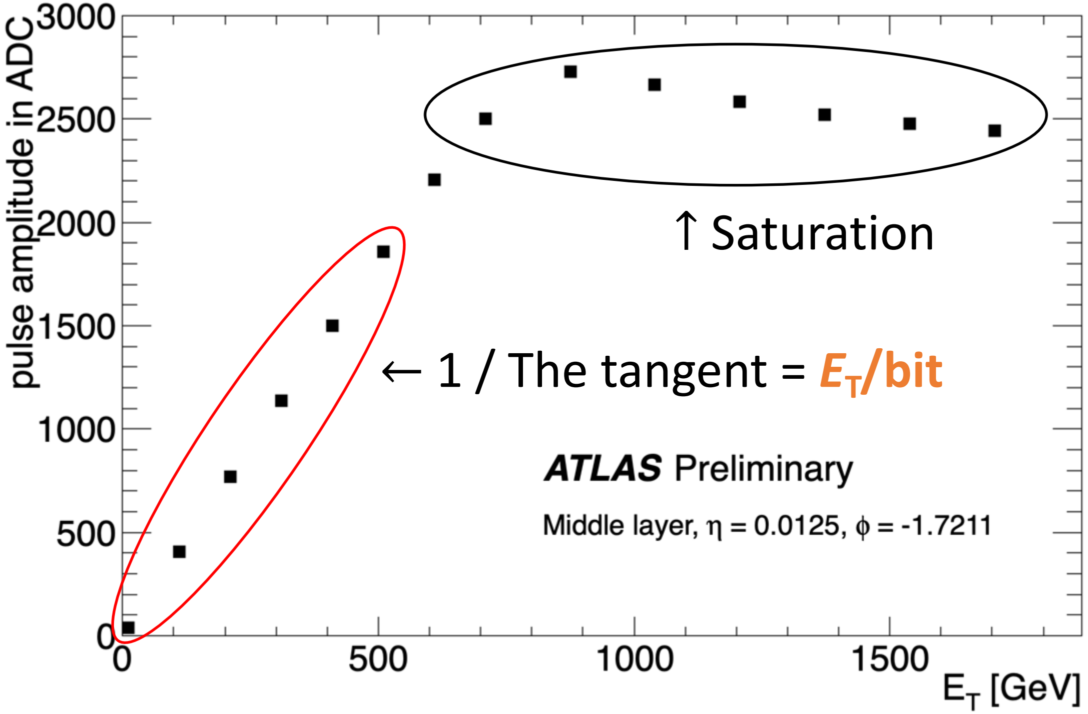
$$E_T = R s_{max}$$

Transverse energy per 1 bit: **E_T/bit**

E_T/bit is determined **in each cell** when designed, but uncertainty > 10 %

Set **E_T/bit** by calibration (ramp run)

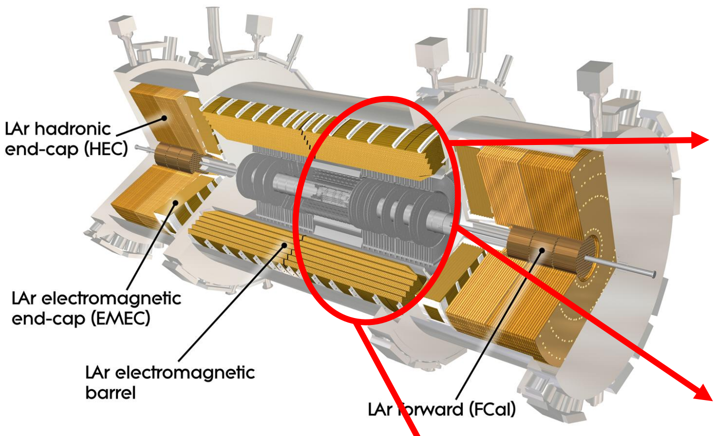
Relation between injected transverse energy and ADC value **in a cell**



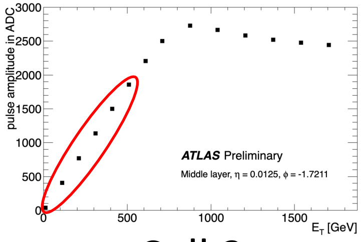
↑ Saturation

← 1 / The tangent = **E_T/bit**

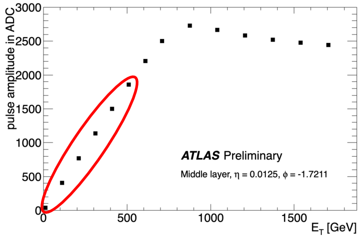
E_T/bit consistency



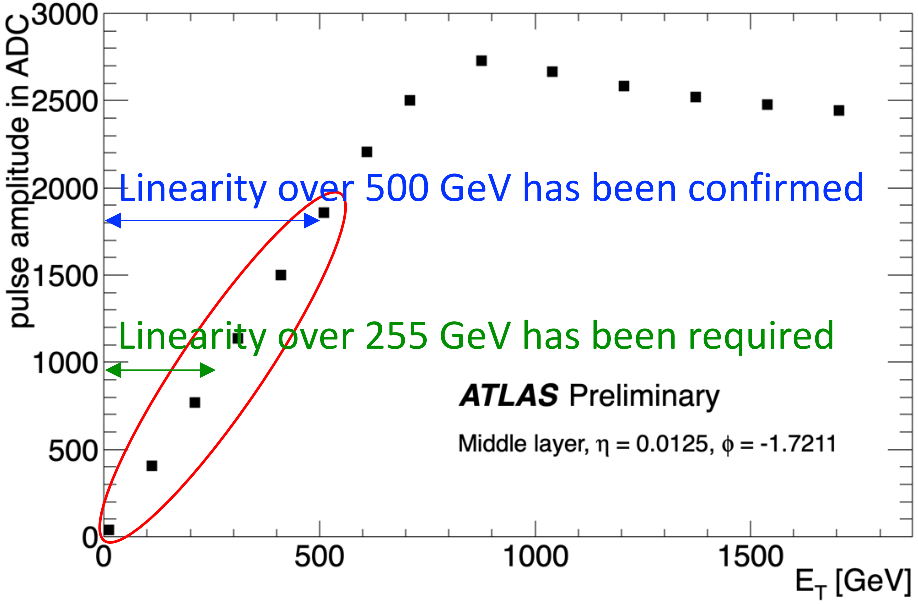
Cell 1



Cell 2

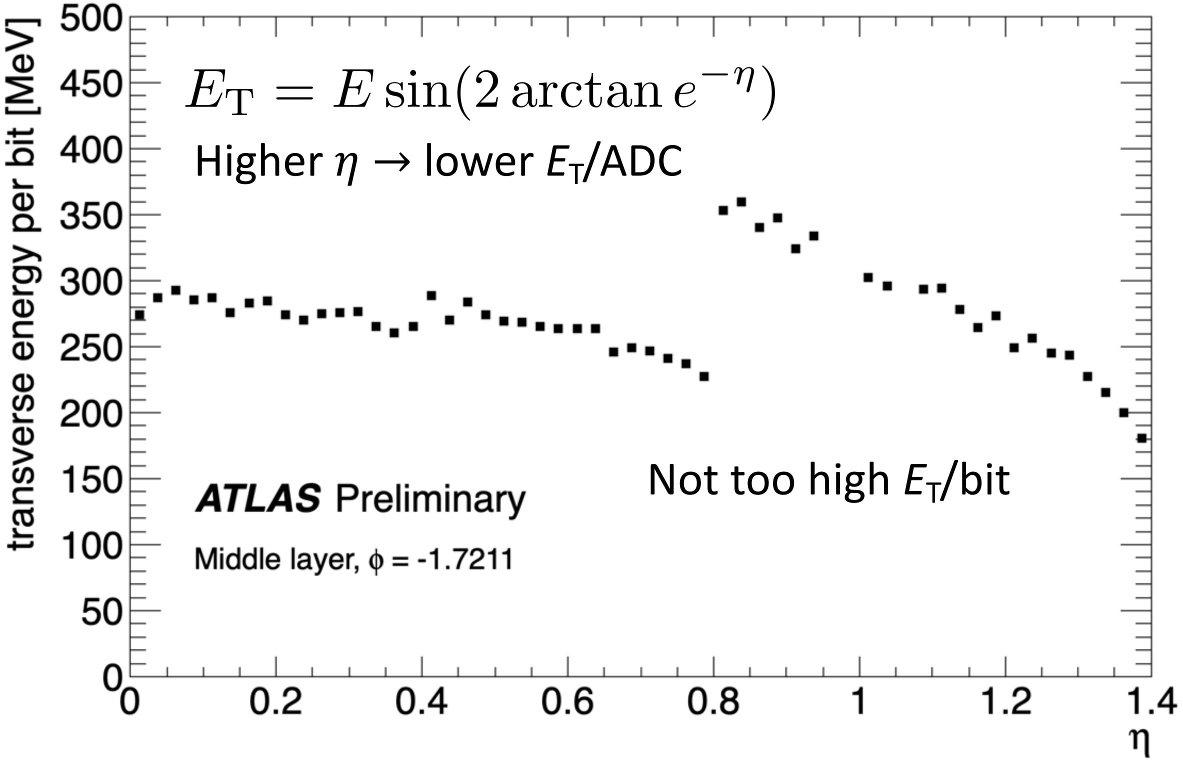


Cell 3



⋮

E_T/bit in each cell



$$E_\mathrm{T} = E \sin(2 \arctan e^{-\eta})$$

Higher η → lower E_T/ADC

Not too high E_T/bit

200-400 MeV per bit: **consistent with designed values**

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The calibration framework for trigger readout have been successfully set up

Simulator development

There are another kind of constants used to calculate energy: **optimal filter coefficients**

E_T/bit, **OFC**, ADC, pedestal, baseline

$$E_{\mathrm{T}i} = R\sum_{j=i}^{i+3} a_j (s_j - p - b_j)$$

OFCs depend on

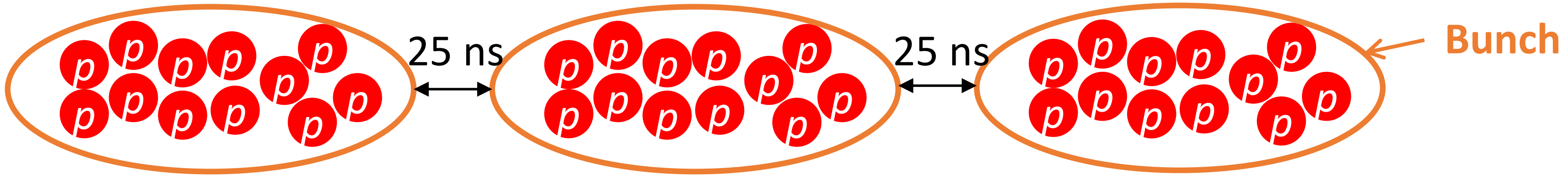
- Noise ← determined by pedestal run
- Wave form ← determined by delay run
- **LHC train structure**
- **Instantaneous luminosity**

Need to be simulated (LHC train structure, Instantaneous luminosity)

Input calibrated constants to the simulator

What to take into account:

1. Bunch structure: ~10^{11} protons form a bunch → Bunches collide with each other



2. Train structure: Some bunches are empty in a periodic manner

3. In-time pileup: Low energy collision in a bunch that event originate
4. Out-of-time pileup: Low energy collision in a bunch that **no** event originate

Simulation scheme

Input energy **in each cell** assuming train structure, luminosity and hit sample

Use this wave form multiplying the amplitude according to input energy

Wave form

Bunch crossing 1 — Input energy

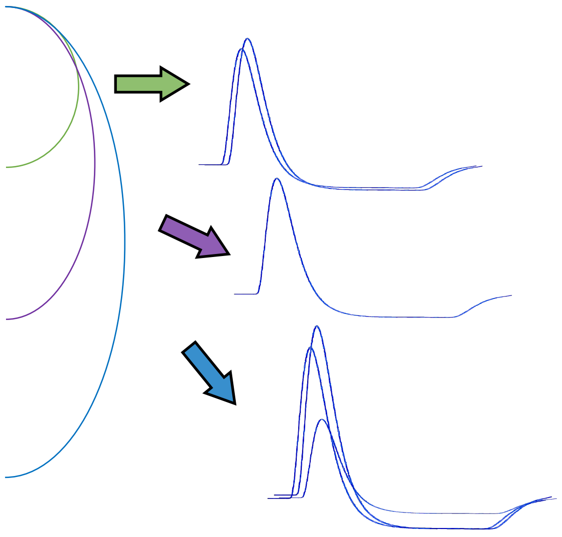
25 ns

Bunch crossing 2 — Input energy

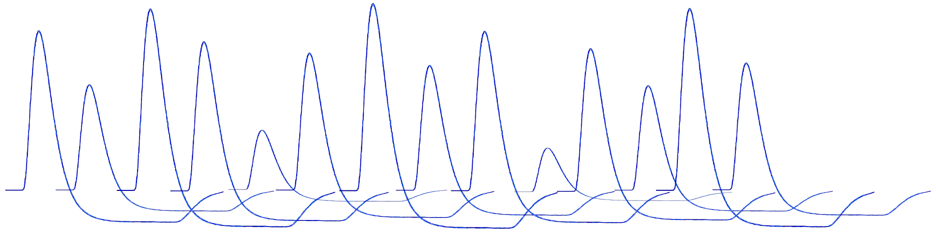
25 ns

Bunch crossing 3 — Input energy

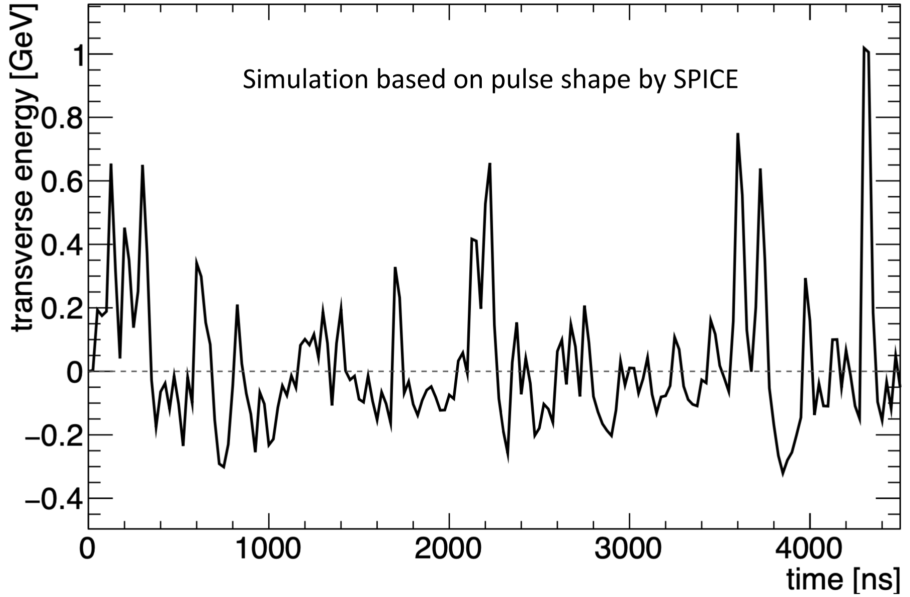
⋮



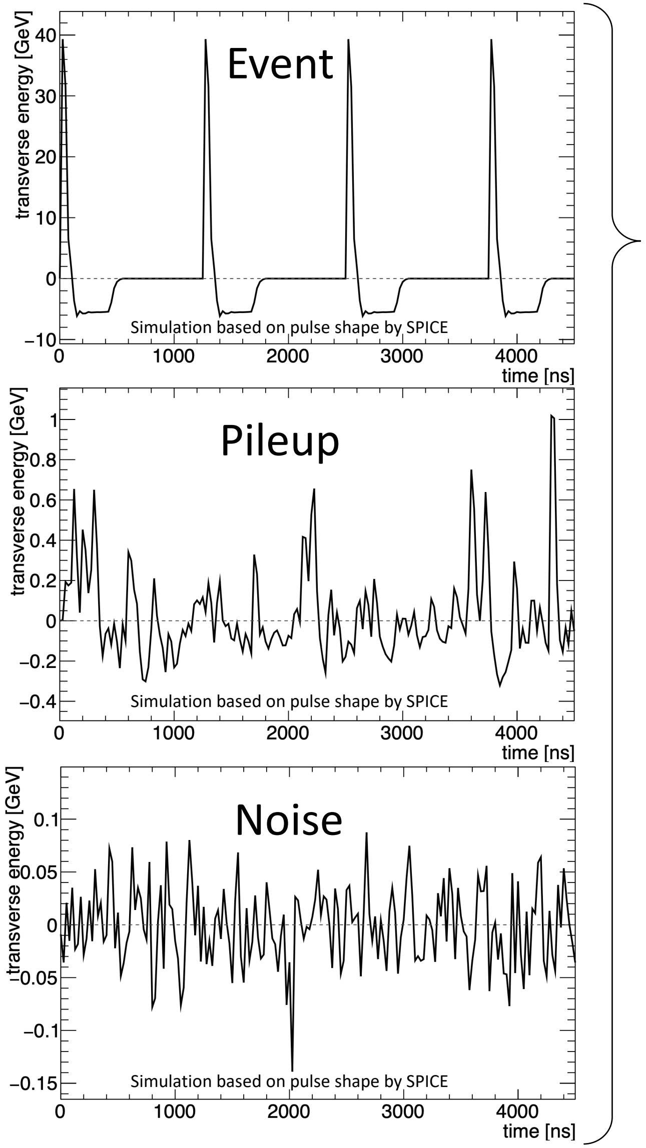
Generate sequence of bipolar pulse in each cell



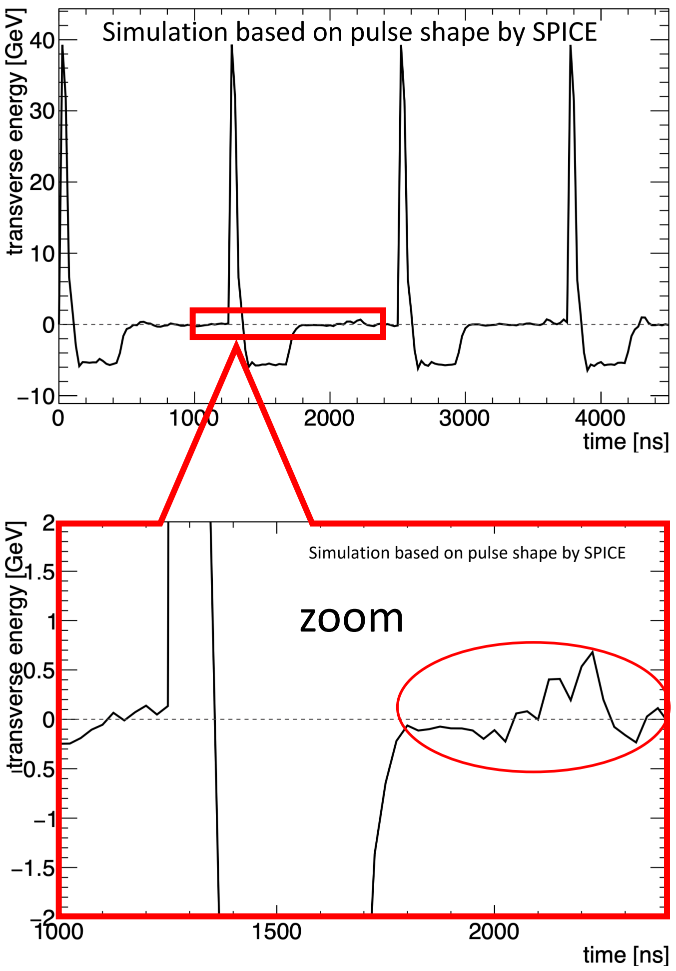
Sum at each time



Simulation scheme

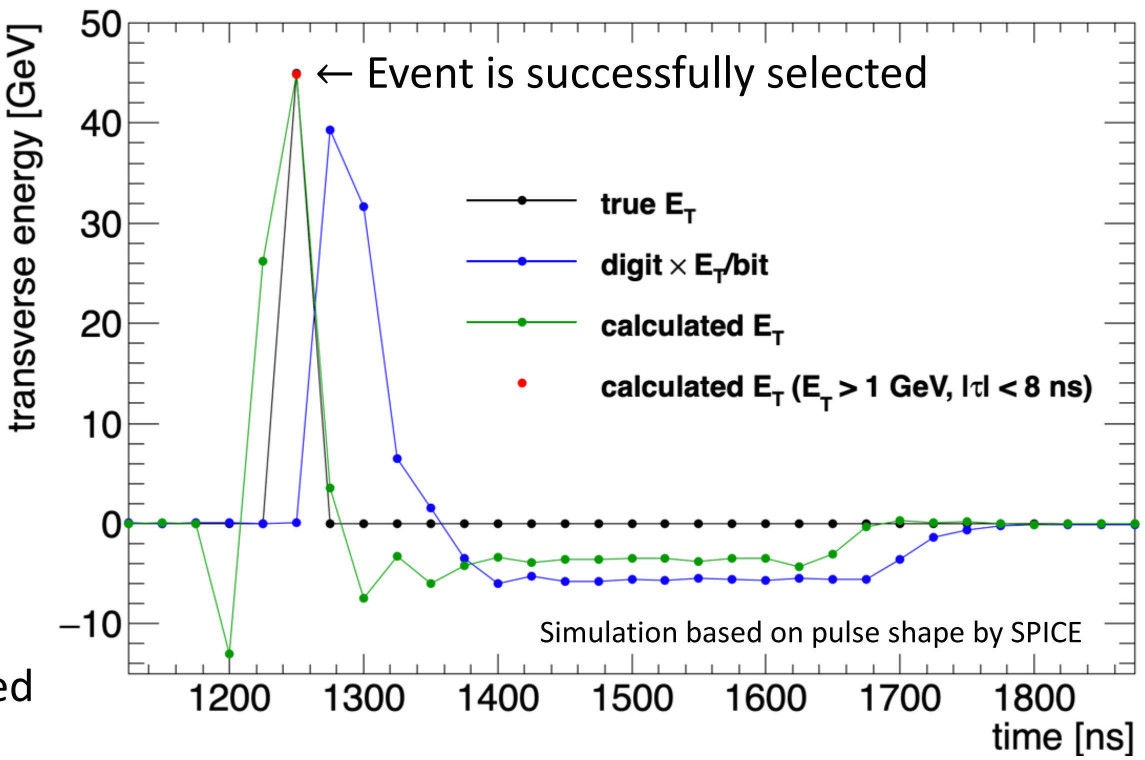


Result of summation



Effect of pileup & noise is reflected

1. Digitization
2. Energy and timing calculation by optimal filtering
3. Selection of output of optimal filter by energy and timing



Summary & future tasks

- Confirmed consistency of E_T/bit in LAr calorimeter barrel C side
  - **First time to check consistency of calibrated constants of the new on-detector board**
  - Keep on measuring and validating calibration constants for cells in each region
- Simulation is needed to determine optimal filter coefficients
  - Confirmed the simulator works correctly
  - Process simulation assuming train structure, instantaneous luminosity and hit sample
  - **Input wave form and calibration constant determined by real data**
  - What to research:
    - Seek the optimal way to determine OFC (optimal filter coefficient)
      - Especially, we need to understand it for high η region whose wave forms are not well known for now
    - Estimate triggering rate by missing transverse energy (“MET”)
    - Estimate triggering rate by object shape selection (“isolation”)

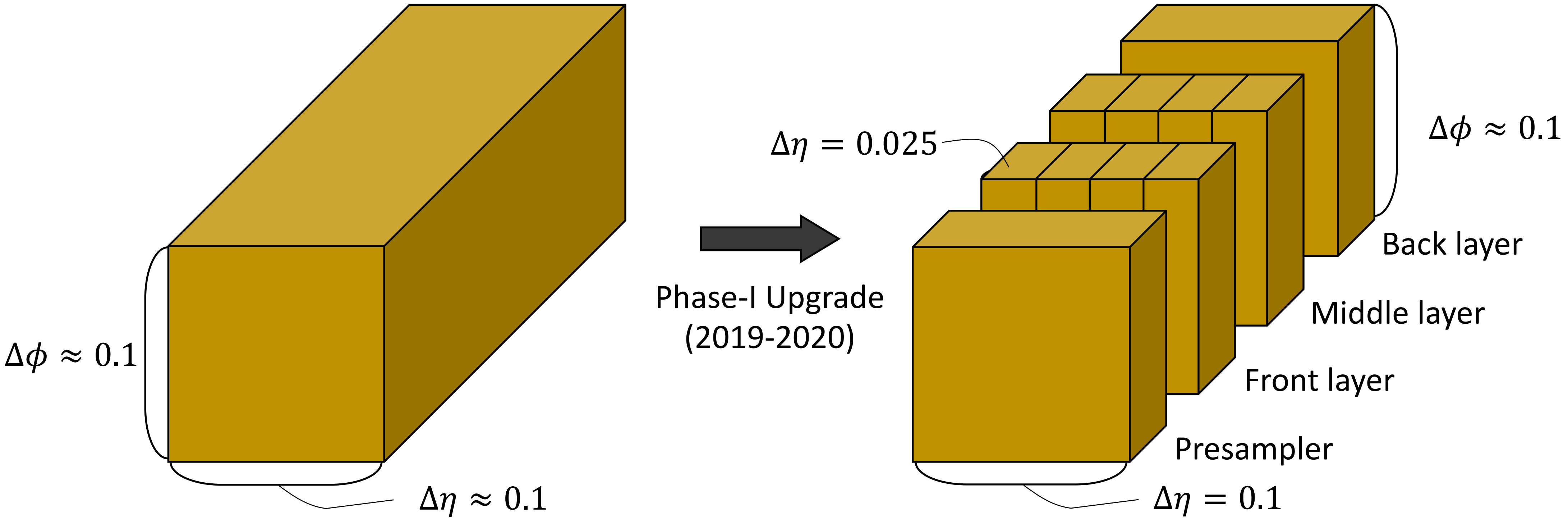
Backup slides

Trigger readout by Super Cell

Improve object discrimination ability and control trigger rate

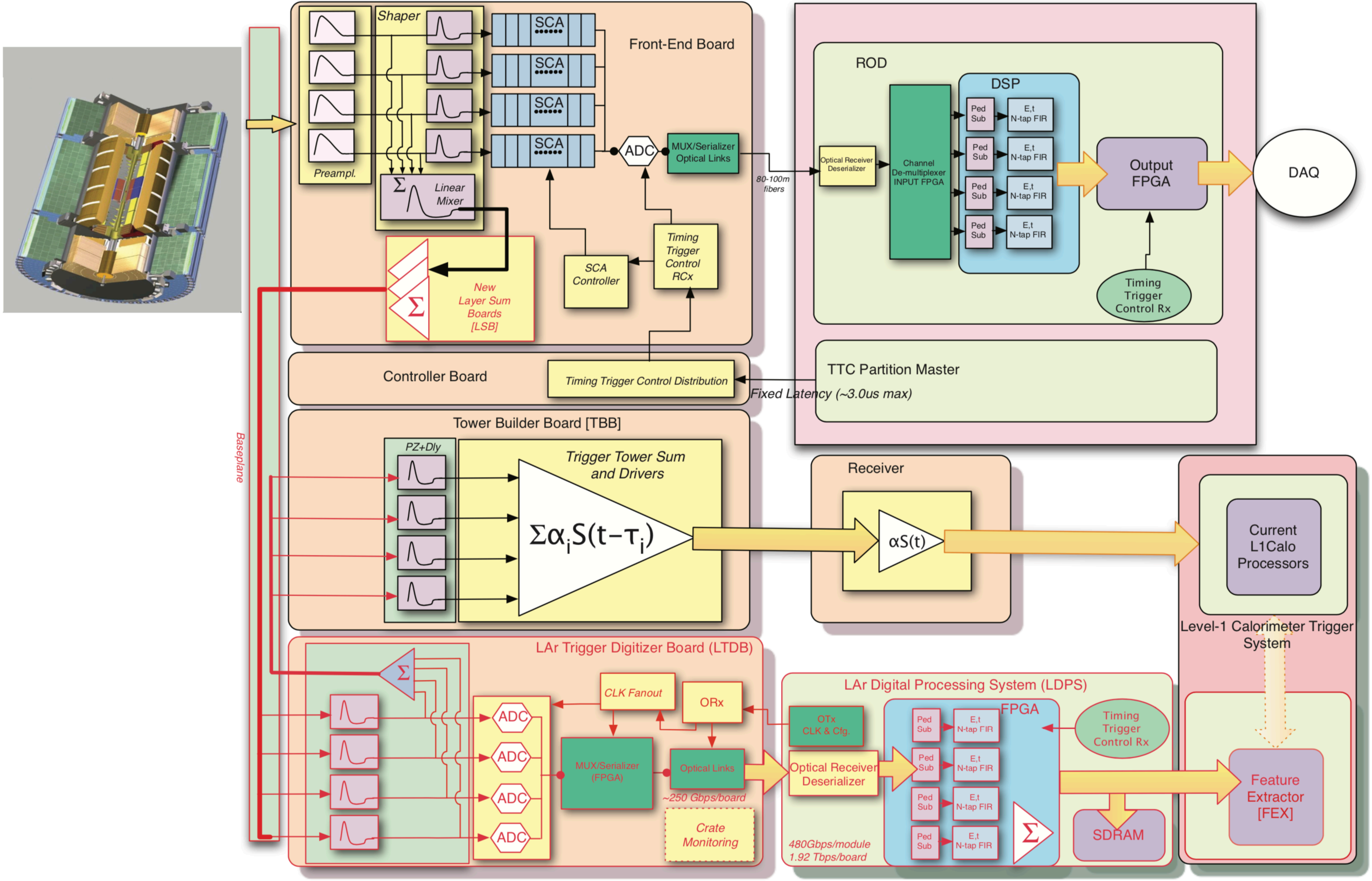
Run2 readout: Trigger Tower

Run3 readout: Super Cell



Summed all the signals
in this region so far

10 times higher granularity
→ Discrimination between e/γ and hadron
with difference of shower shape

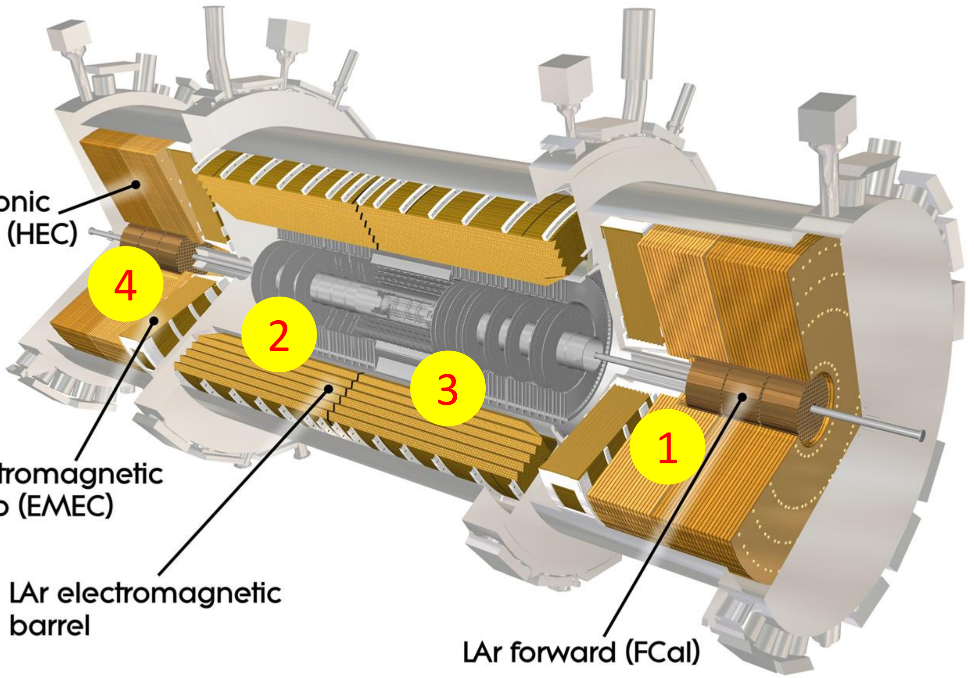


Front-End Board
Shaper
SCA
SCA
SCA
SCA
Preampl.
Linear Mixer
ADC
MUX/Serializer Optical Links
80-100m fibers
New Layer Sum Boards [LSB]
SCA Controller
Timing Trigger Control RCx
Controller Board
Timing Trigger Control Distribution
ROD
DSP
Optical Receiver Deserializer
Channel De-multiplexer INPUT FPGA
Ped Sub
E,t N-tap FIR
Output FPGA
DAQ
Timing Trigger Control Rx
TTC Partition Master
Fixed Latency (~3.0us max)
Baseplane
Tower Builder Board [TBB]
PZ+Dly
Trigger Tower Sum and Drivers
$\Sigma\alpha_i S(t-\tau_i)$
Receiver
$\alpha S(t)$
Current L1Calo Processors
Level-1 Calorimeter Trigger System
LAr Trigger Digitizer Board (LTDB)
CLK Fanout
ORx
ADC
MUX/Serializer (FPGA)
Optical Links
~250 Gbps/board
Crate Monitoring
LAr Digital Processing System (LDPS)
OTx CLK & Cfg.
Optical Receiver Deserializer
FPGA
Timing Trigger Control Rx
SDRAM
Feature Extractor [FEX]
480Gbps/module
1.92 Tbps/board

Electronics update schedule

Front-end board update schedule		
1	FEB-APL 2019	Endcap A-side
2	APL-JUL 2019	Barrel C-side
3	SEP-DEC 2019	Barrel A-side
4	JAN-MAR 2020	Endcap C-side

ongoing (1–3)

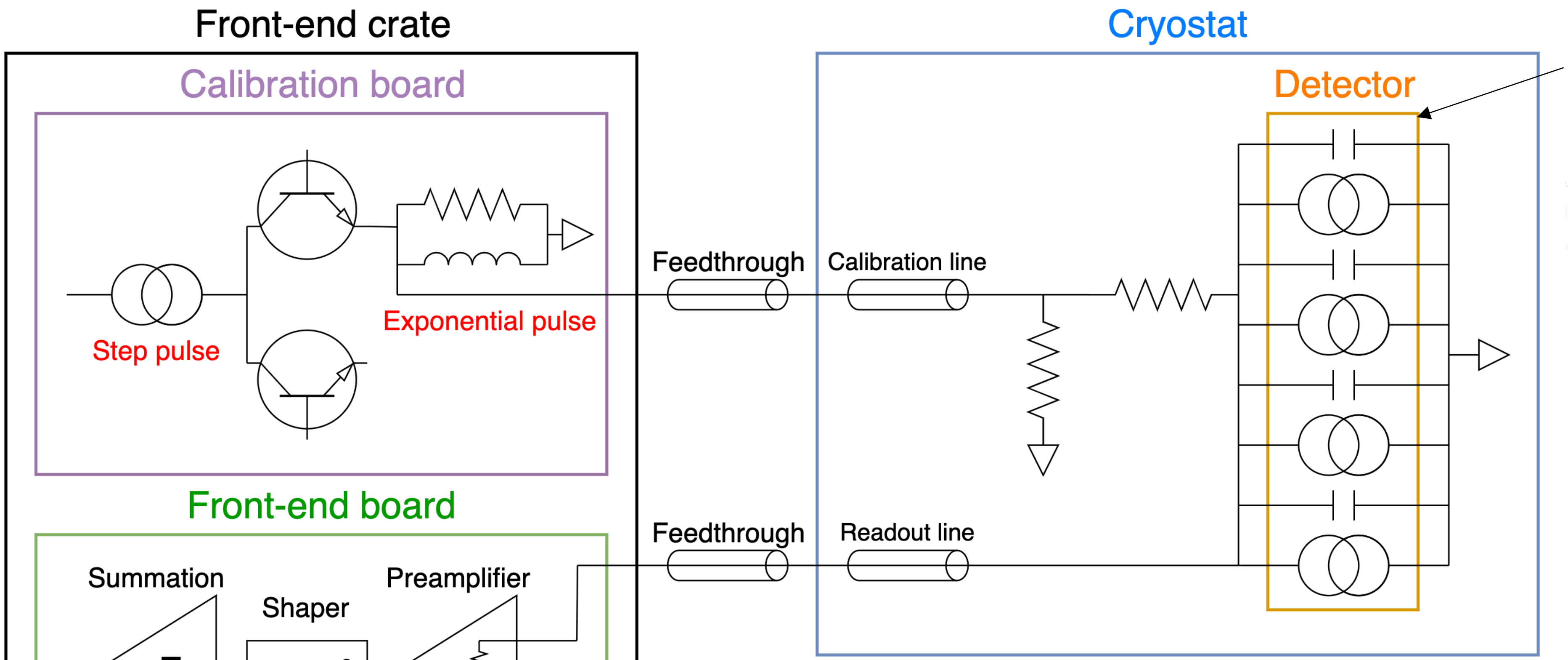
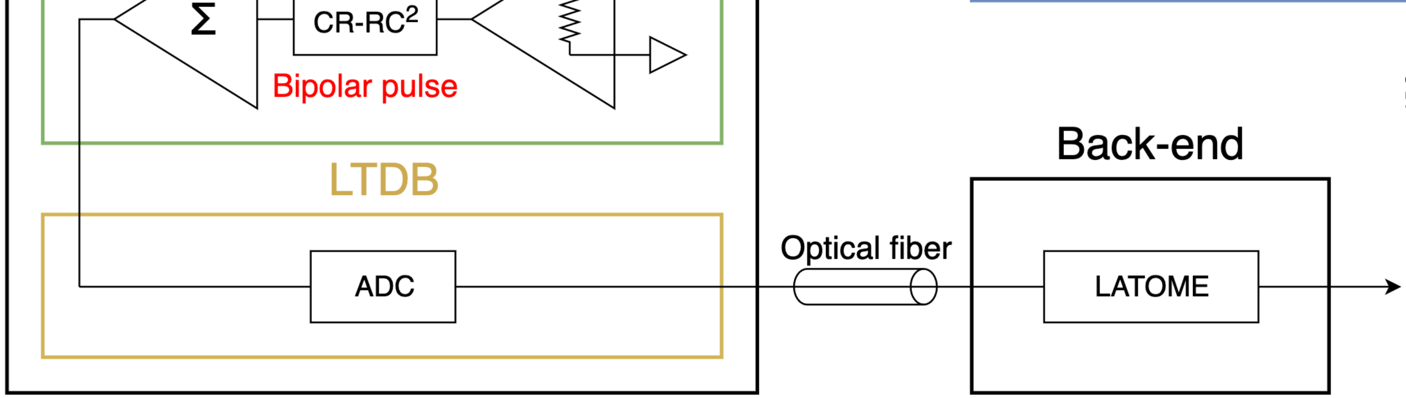


- Take out front-end board
- Update the front-end board on the ground
- Update the base plane of the front-end crate
- Maintenance of cooling pipes
- Reinstall front-end board
- Check the cooling water circulation system
- Install LTDB (digitizer board)
- Test the cable connection and the readout

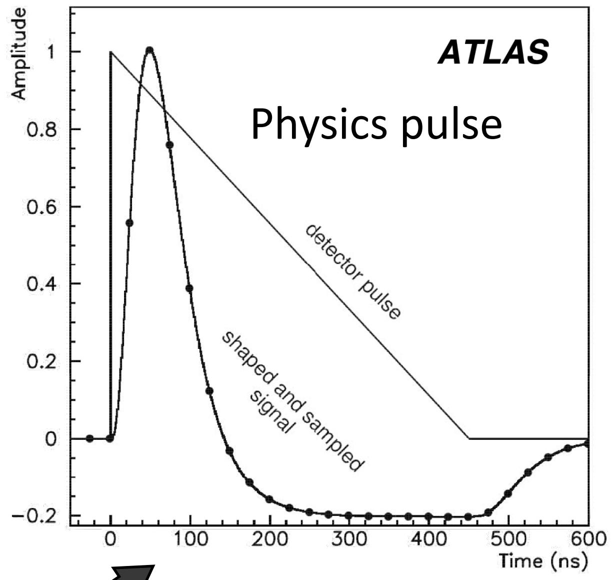
LTDB Type	Channels	LTDB per region
EMB	290	64
EMEC Std	312	32
EMEC Spc 0	240	8
EMEC Spc 1	160	8
HEC	192	8
FCAL 0	192	2
FCAL 1	192	2
Total		124

Calibration pulse conversion

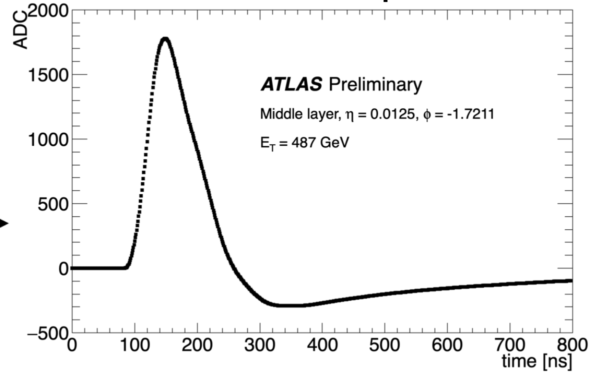
Equivalent circuit

In actual physics run, triangular pulse is generated in the detector



Calibration pulse



Converted using circuit constants

OFCs include the conversion factor

Calibration scheme

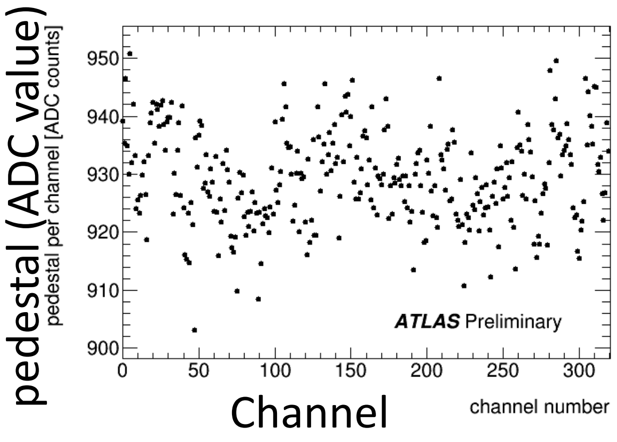
Need to know energy from pulse amplitude for triggering → **Wave form**, **Pedestal**, **E_T/bit** are needed **in each cell**

(E_T: transverse energy)

Using the framework of main readout
→ **Raw data format, firmware and software is set up**

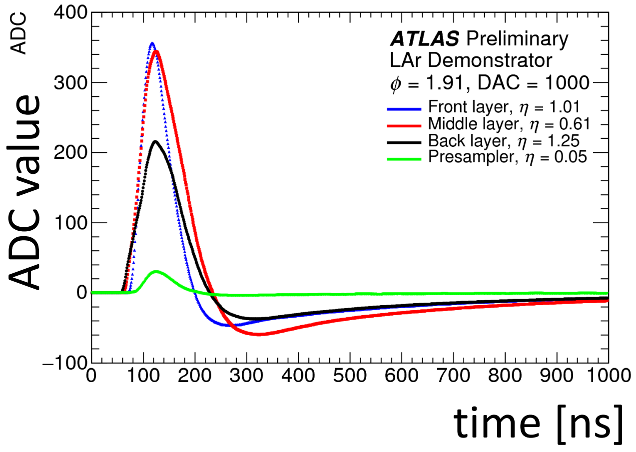
Pedestal run

Acquire **pedestal in each cell** by averaging ADC values without pulsing



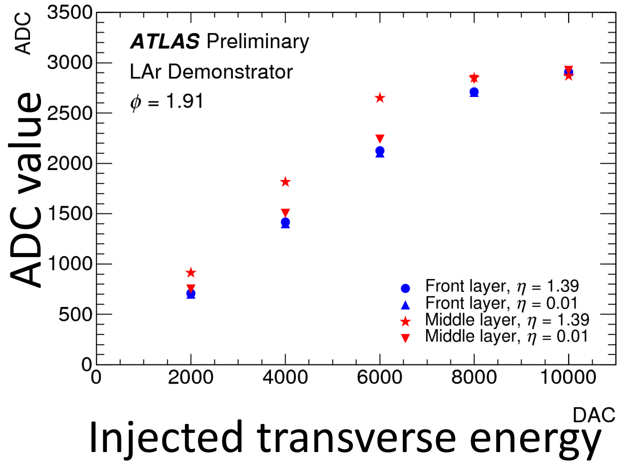
Delay run

Acquire **wave form in each cell** by high rate sampling



Ramp run

Acquire **E_T/bit** with error < 1 % **in each cell** by injecting different energies



Optimal filtering

To execute object discrimination by its shape,
accurate energy and time in each cell are needed.

⬇

Algorithm to maximize signal-to-noise ratio
= Optimal Filter

$$E_{\mathrm{T}i} = R \sum_{j=i}^{i+3} a_j (s_j - p - b_j)$$

- E_{T}/bit → R
- **OFC** → a_j
- ADC → s_j
- pedestal → p
- baseline → b_j
- $(s_j - p - b_j)$: ADC value correction
- $\sum_{j=i}^{i+3} a_j (s_j - p - b_j)$: Linear summation
- $R \sum_{j=i}^{i+3} a_j (s_j - p - b_j)$: Convert to transverse energy