ATLAS LAr Calorimeter Performance in LHC Run-2

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on behalf of the ATLAS Liquid Argon Calorimeter Group

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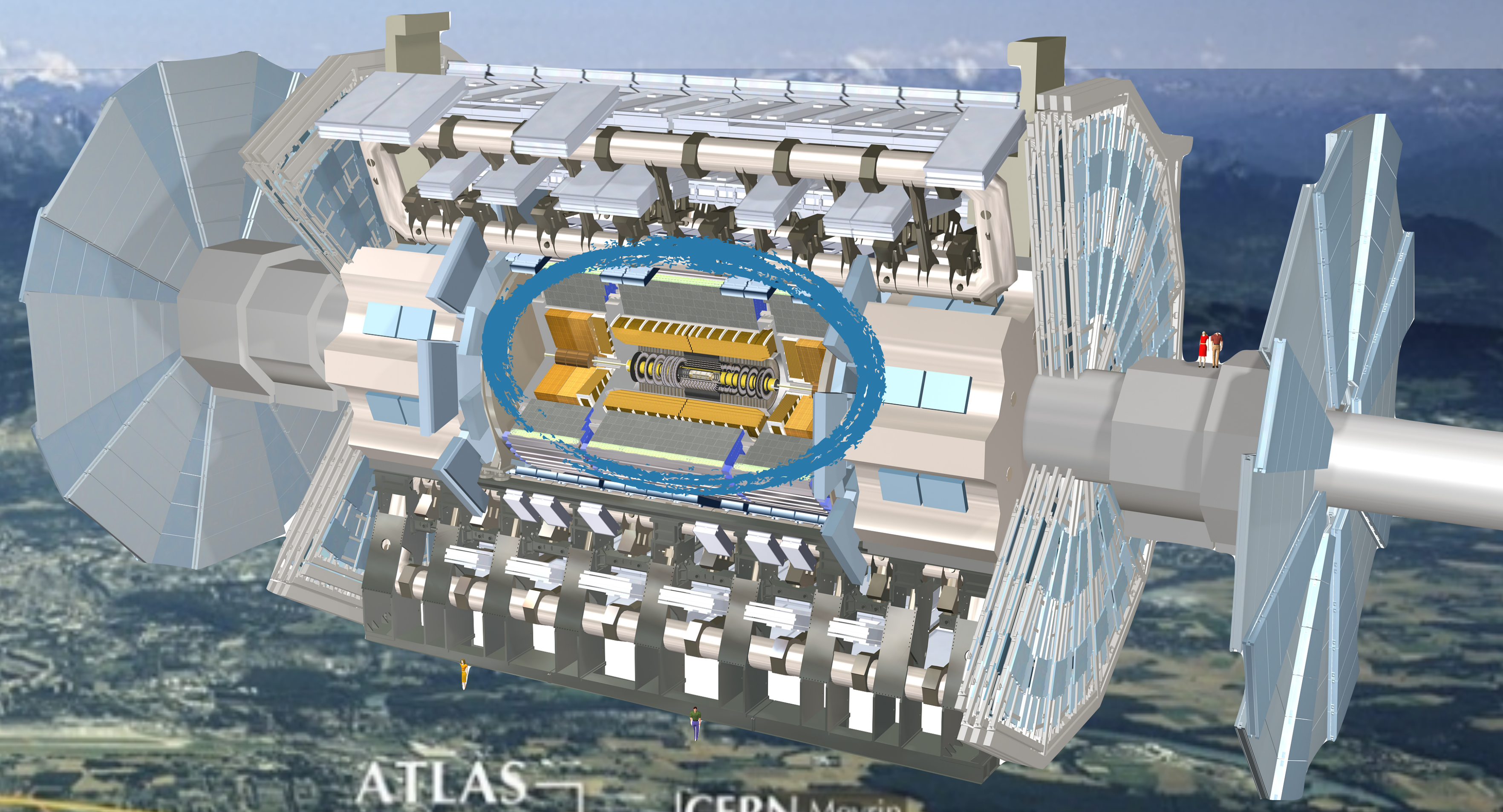
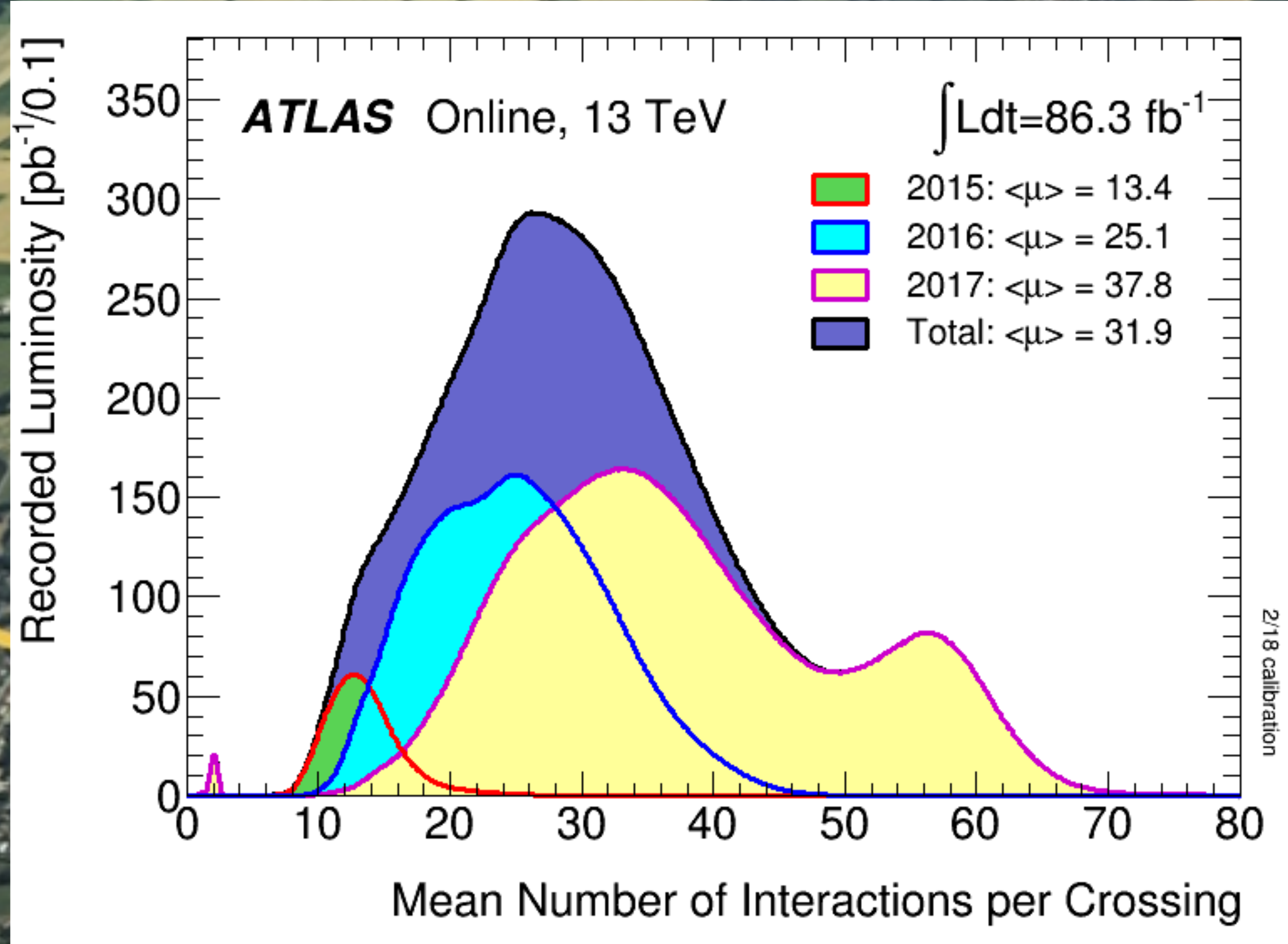
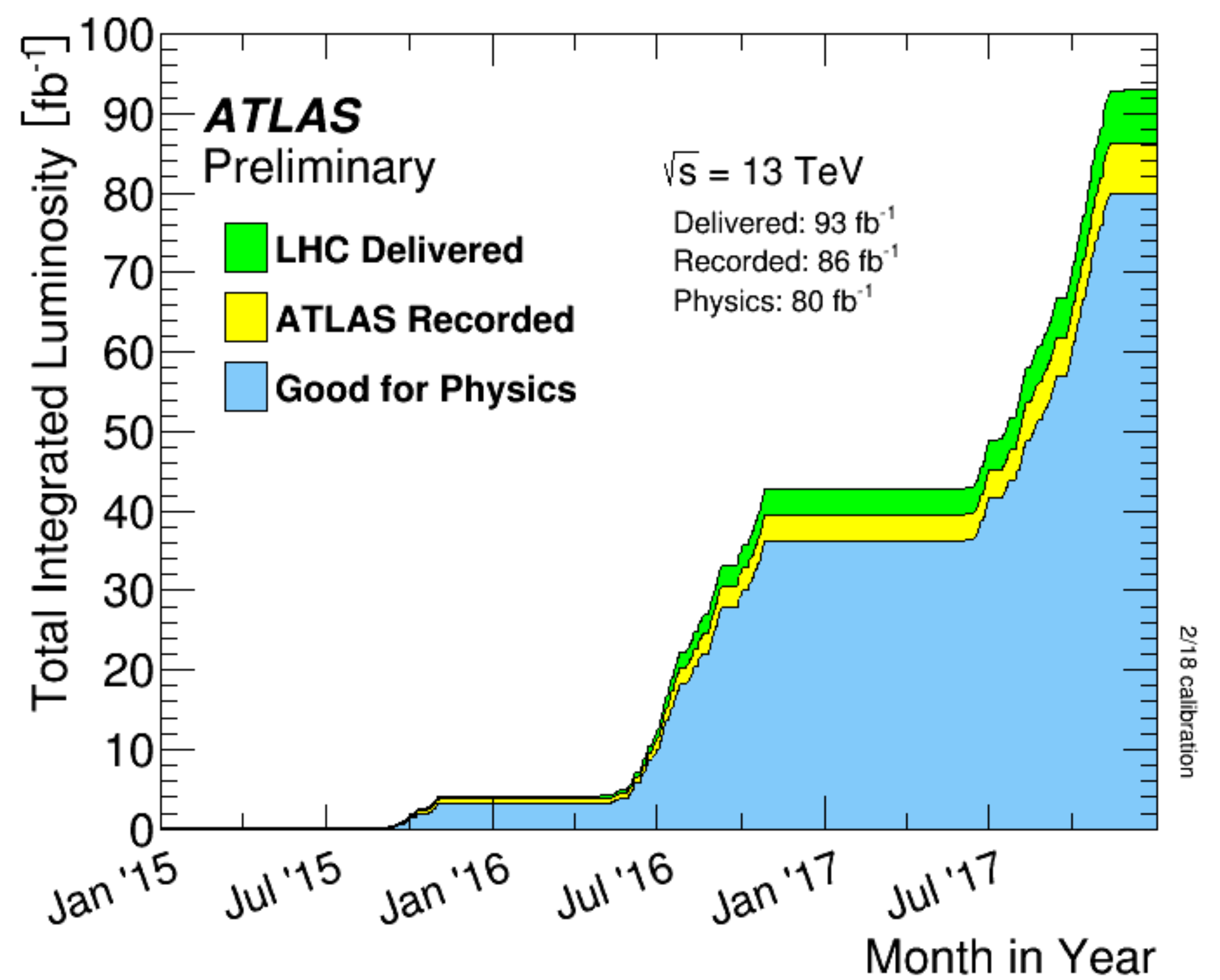
LHC & ATLAS in Run-2

- LHC run-2 2015 – 2018
- Centre-of-mass energy $\sqrt{s} = 13$ TeV (pp)
- Bunch spacing 25 ns
- $<\mu> = 31.9$, $\mu_{max} \sim 80$
- Peak luminosity 2.14×10^{34} $cm^{-2}s^{-1}$





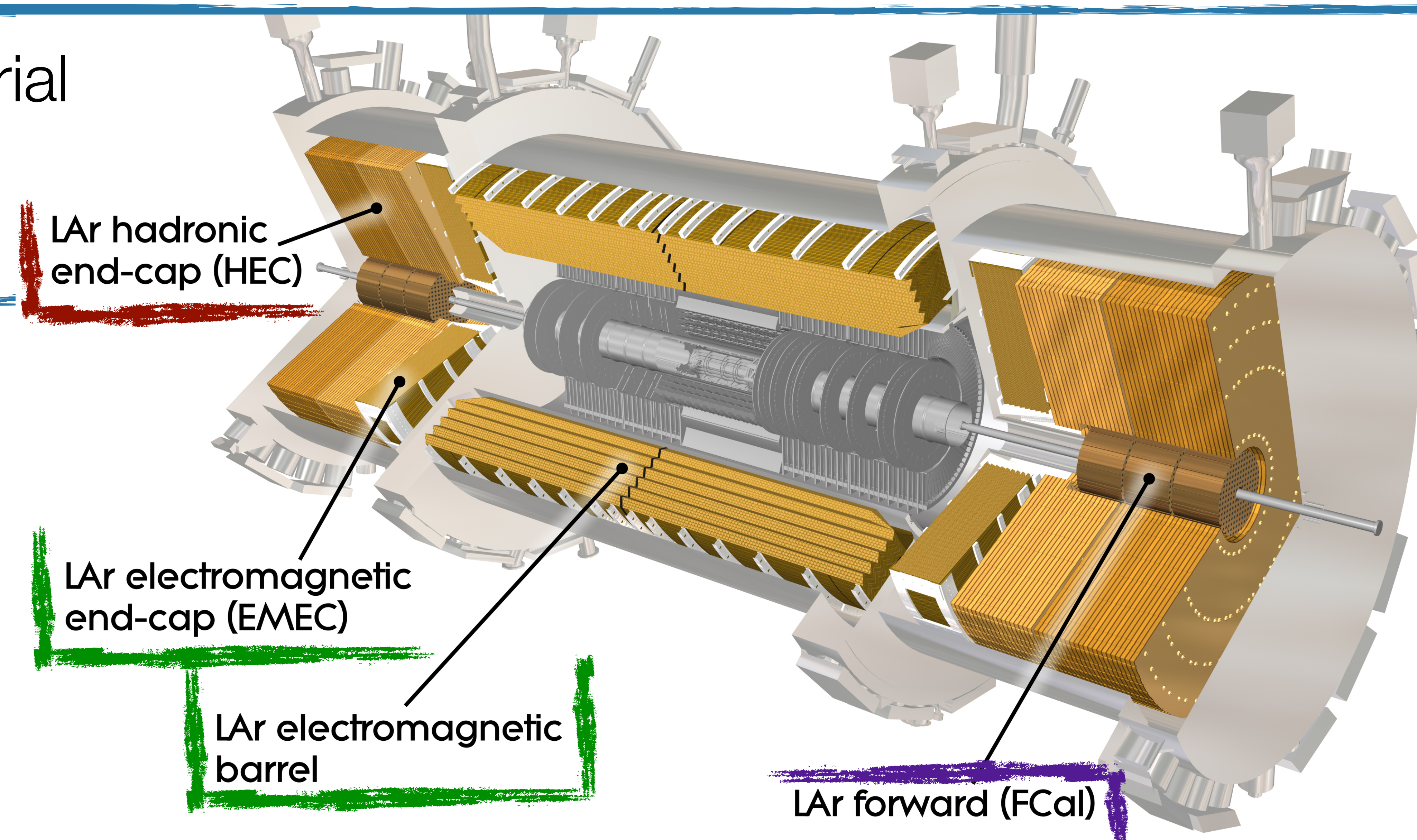


ATLAS recording efficiency ~93%

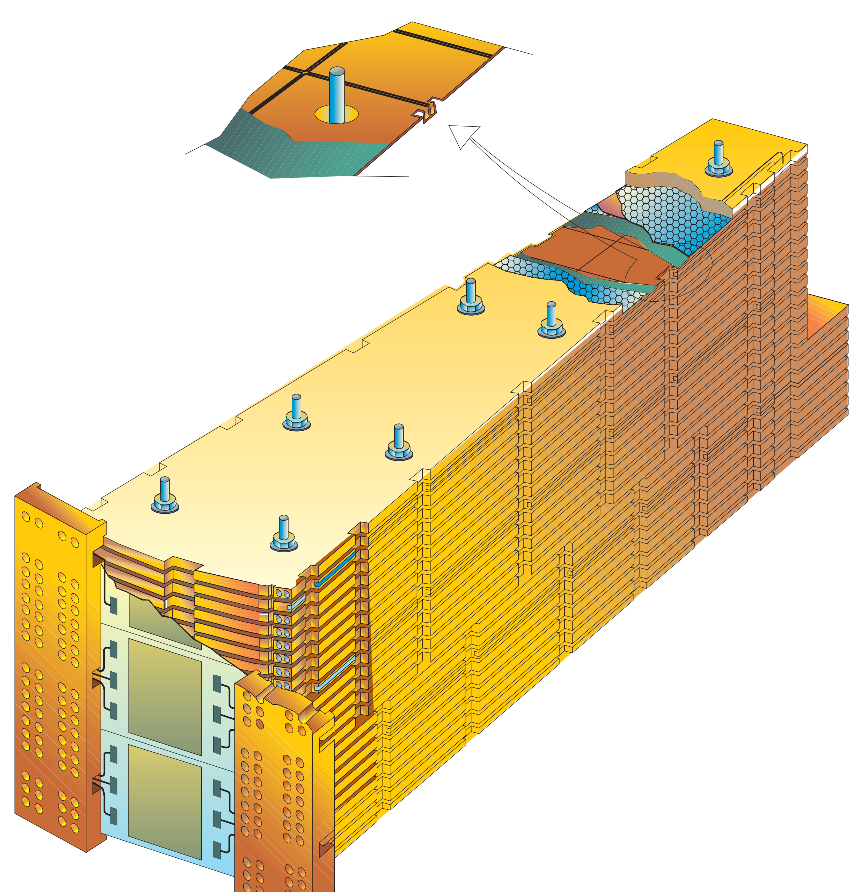
2015: 3.9 fb^{-1}
2016: 35.6 fb^{-1}
2017: 40.5 fb^{-1}

ATLAS Liquid Argon Calorimeter

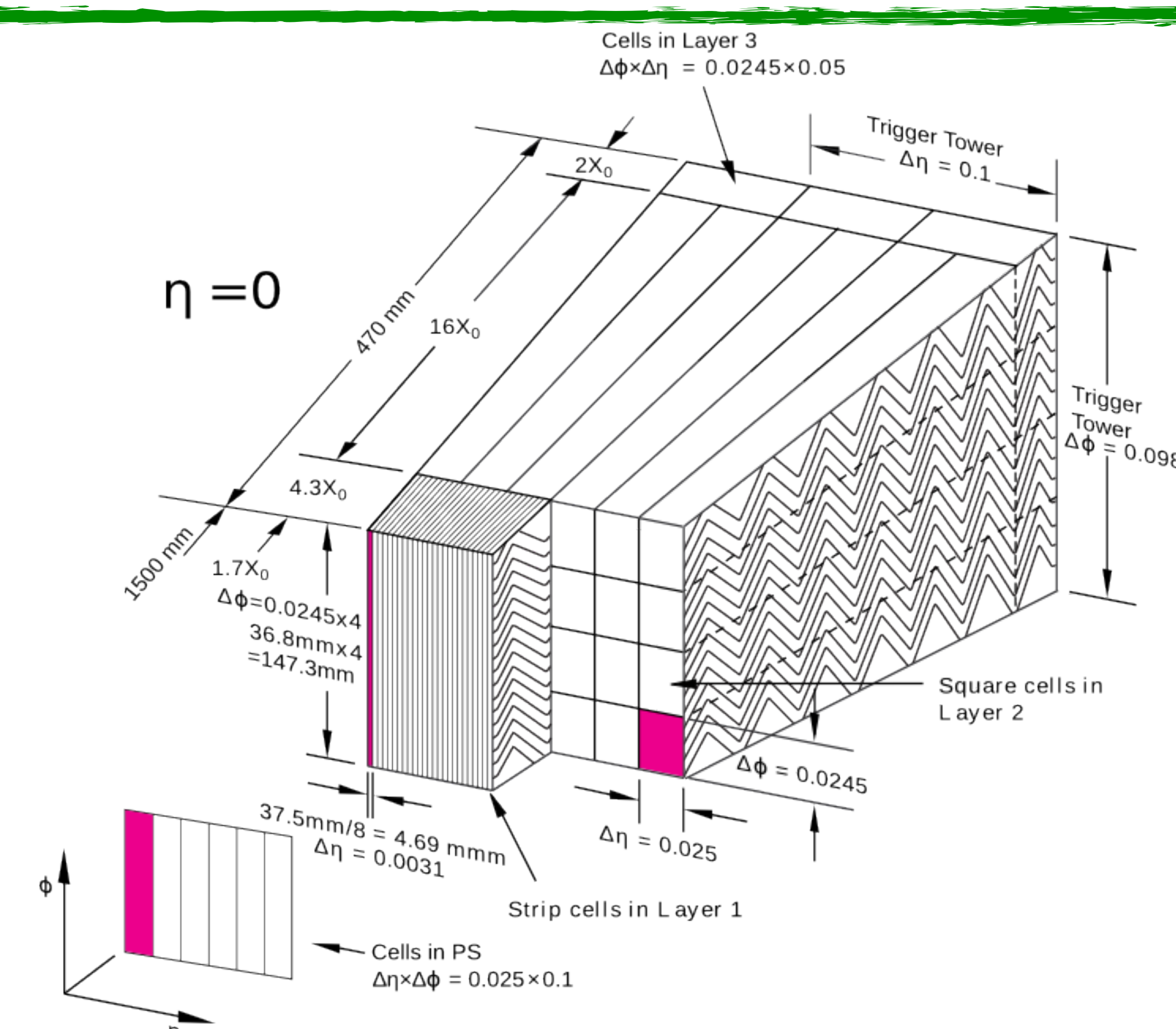
Liquid Argon as active material
- Inherently linear
- Hermetic coverage
- Inherently radiation hard
- Fast read-out possible



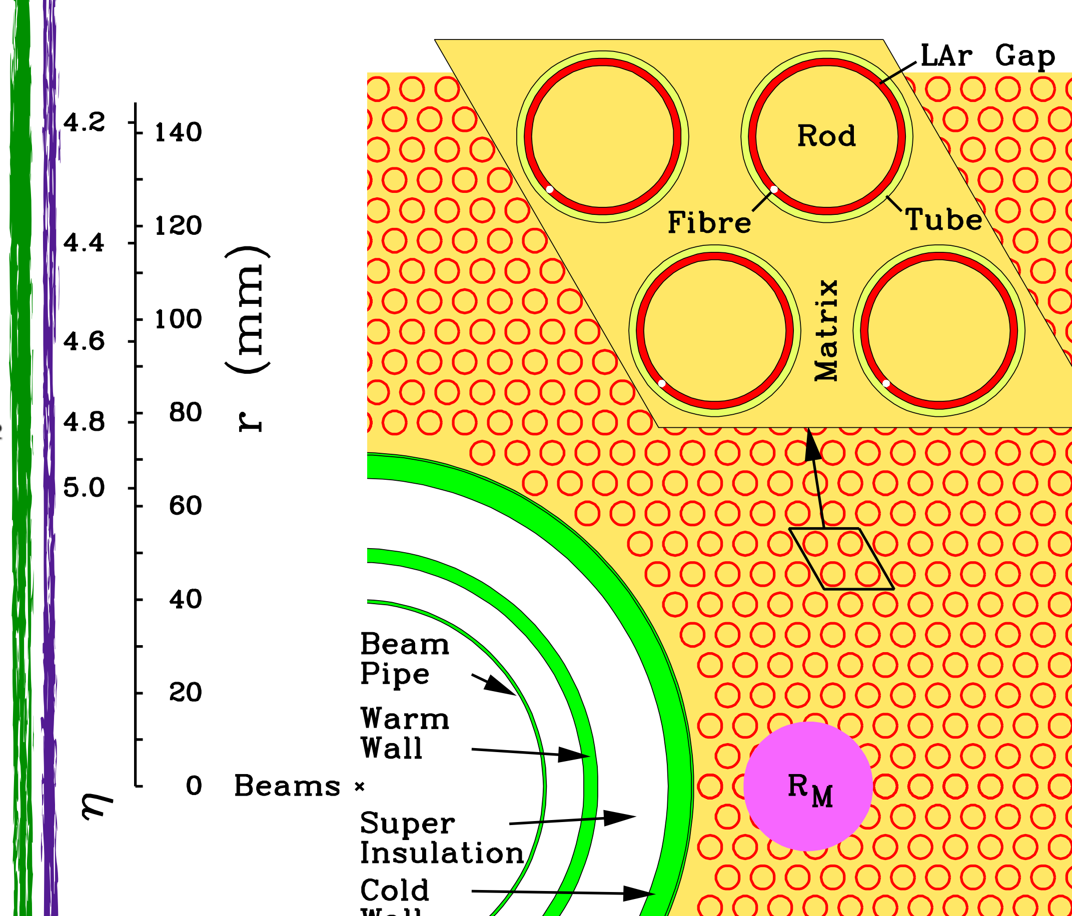
Had end-cap
- Coverage $1.5 < |\eta| < 3.2$
- Cu absorber
- Plates
- 4 longitudinal layers
- 5’632 channels



EM barrel & end-cap
- Coverage $|\eta| < 3.2$
- Lead absorber
- Accordion geometry
- 3 longitudinal layers + presampler ($|\eta| < 1.8$)
- 109’568 + 63’744 channels



FCAL
- Coverage $3.1 < |\eta| < 4.9$
- Honeycomb holes in Cu/W absorber matrix
- 3 longitudinal layers
- 3’524 channels



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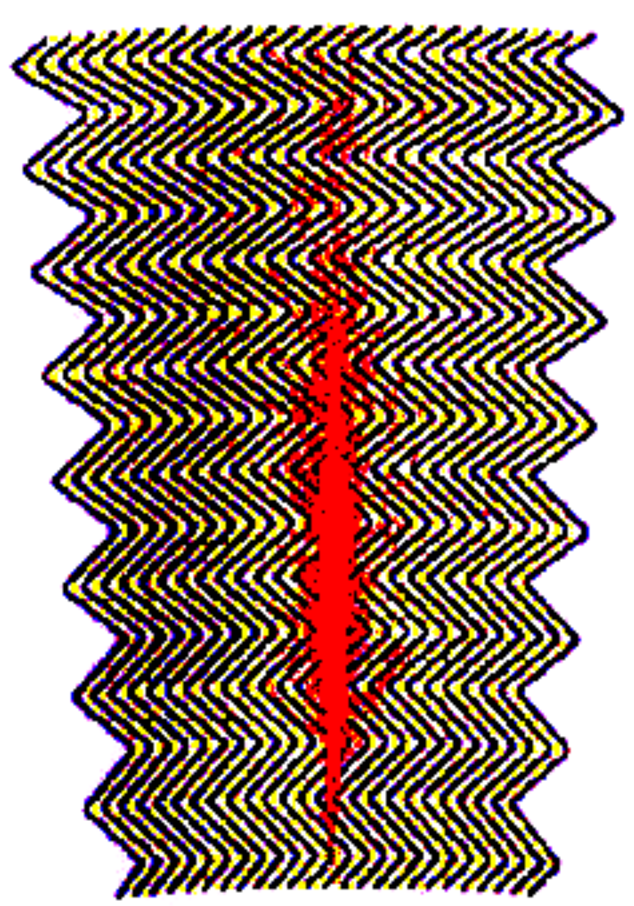
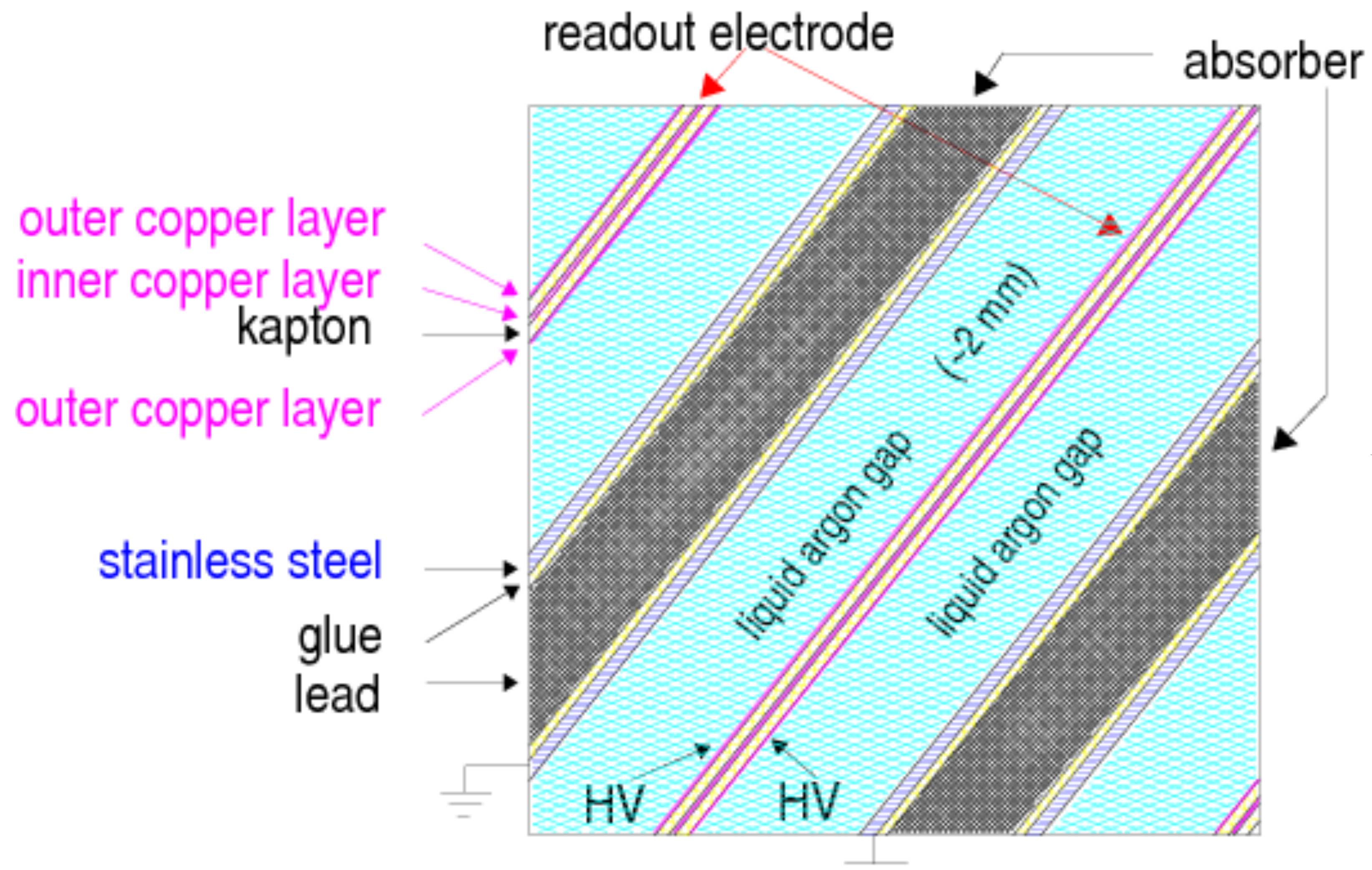
Operation Principle

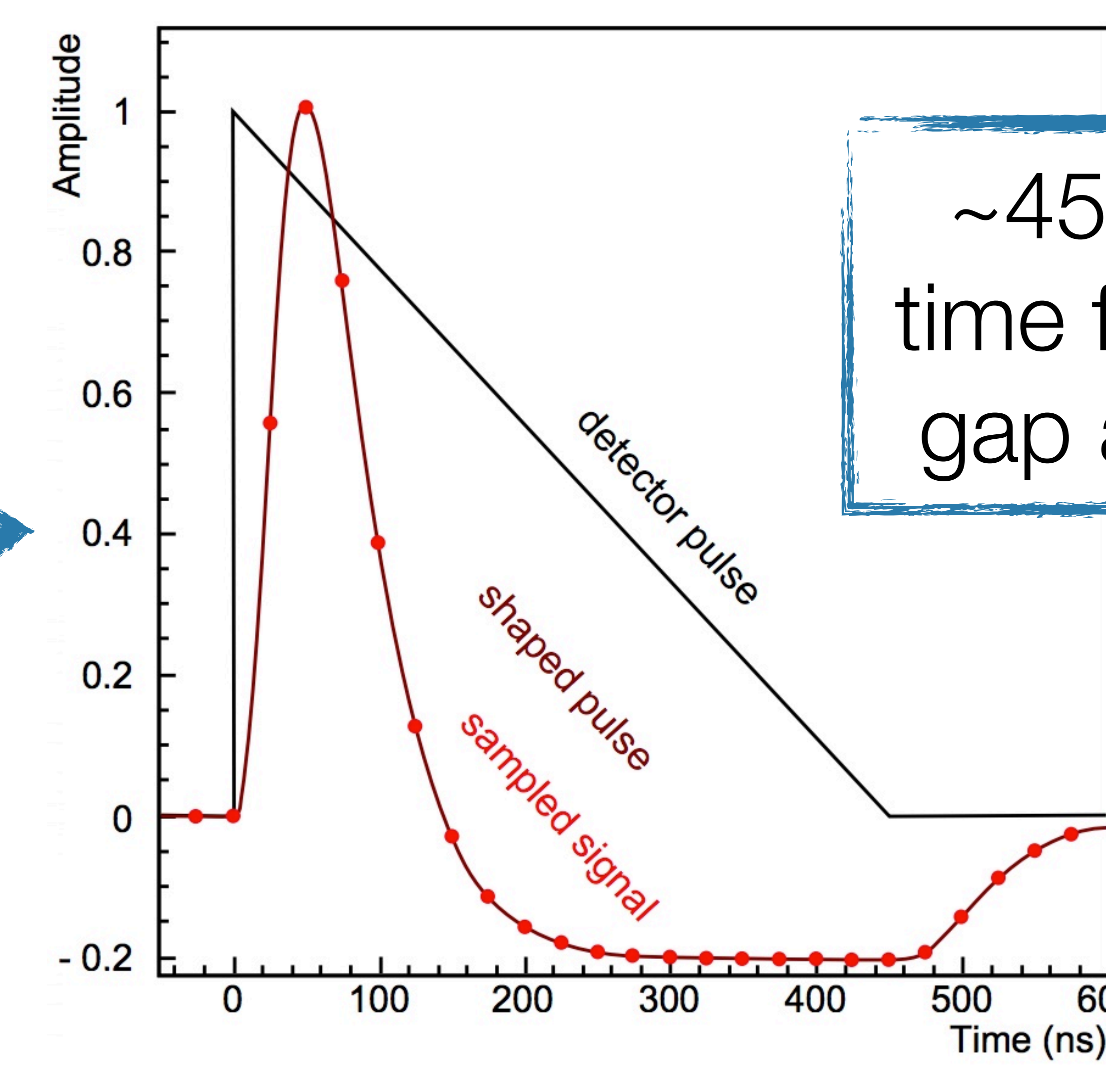
- Incoming particle passes through absorber
  → Electromagnetic shower
- Shower particles ionise liquid argon
- Ionisation electrons drift to electrode thanks to HV applied in LAr gap
  → Current collected by read-out electrodes

- Signal amplified, shaped and split into 3 gains at Front-End-Board (FEB)
- Sampled signal stored in analog memory awaiting trigger decision (at 40 MHz)
- Positive L1 trigger decision
  → Optimal gain selected
  → 4 samples are digitised (at 100 kHz)

- Sampled signal amplitude is evaluated using a set of optimal filter coefficients (OFCs)
  → Energy
  → Signal time
  → Quality factor wrt ideal pulse shape
- Digitised samples converted into energy deposits in cells







~450 ns drift time for ~2 mm gap at 2000 V

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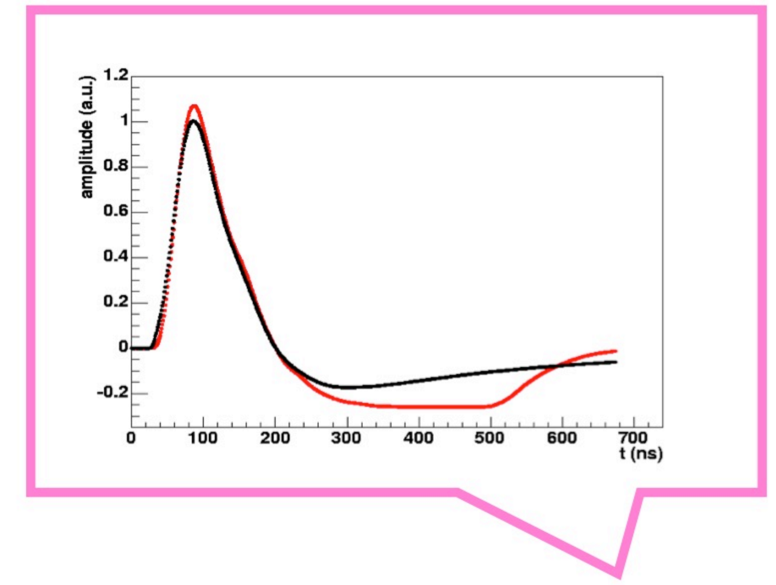
From Digits to Raw Cell Energy

- Several calibration constants involved
- Daily(weekly) electronics calibration performed by injecting calibration signal to measure response
  - → Gain
  - → Pedestal and noise
  - → Calibration pulse shape → Physics pulse shape → OFCs



$$E_{\text{cell}} = F_{\mu A \to \text{MeV}} \cdot F_{DAC \to \mu A} \cdot \frac{1}{\frac{M_{\text{phys}}}{M_{\text{cali}}}} \sum_{i=1}^{M_{\text{ramps}}} R_i \left[\sum_{j=1}^{N_{\text{samples}}} a_j \left(s_j - p \right) \right]^i$$

Cell energy

Sampling fraction

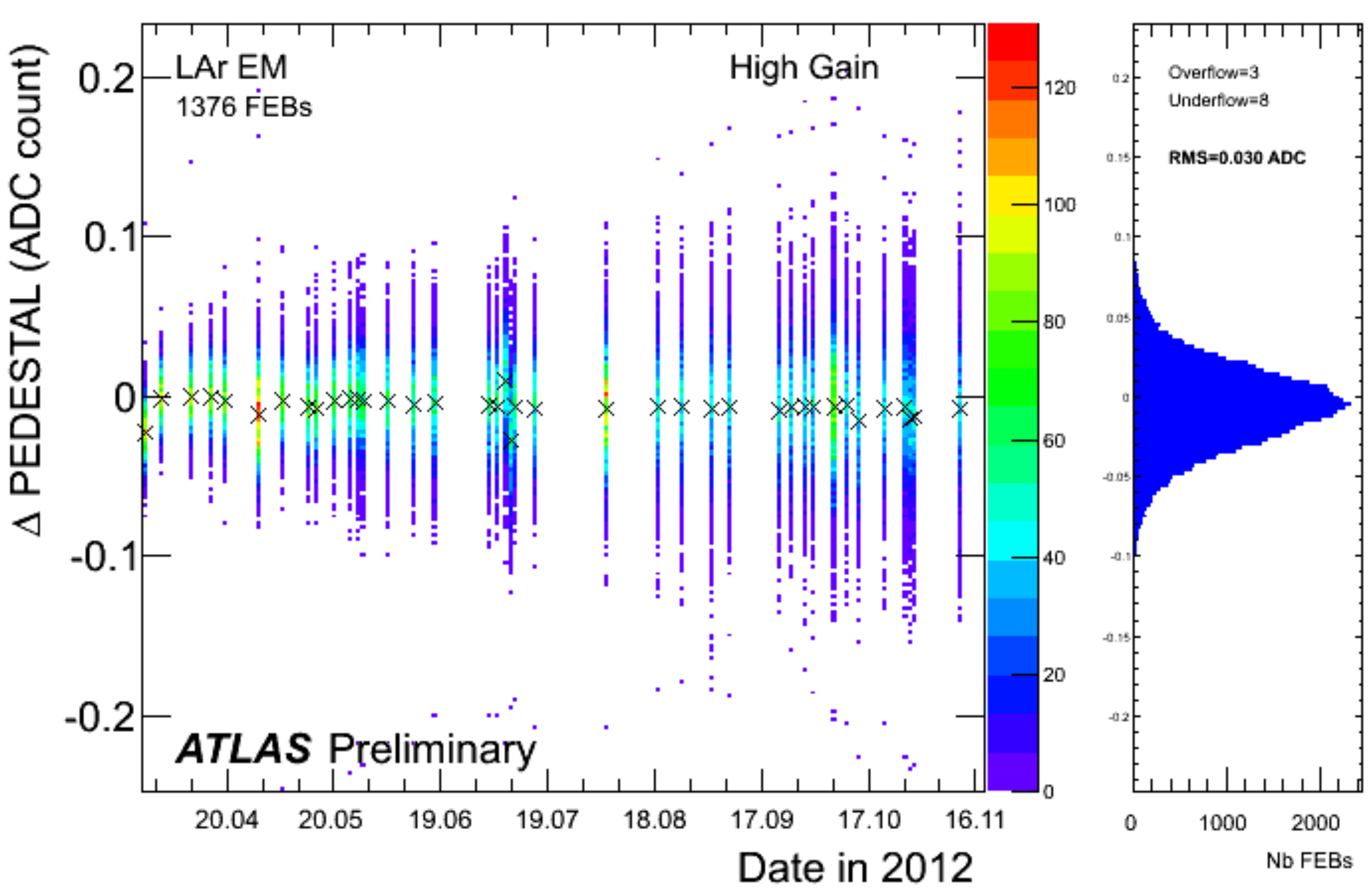
Calibration board

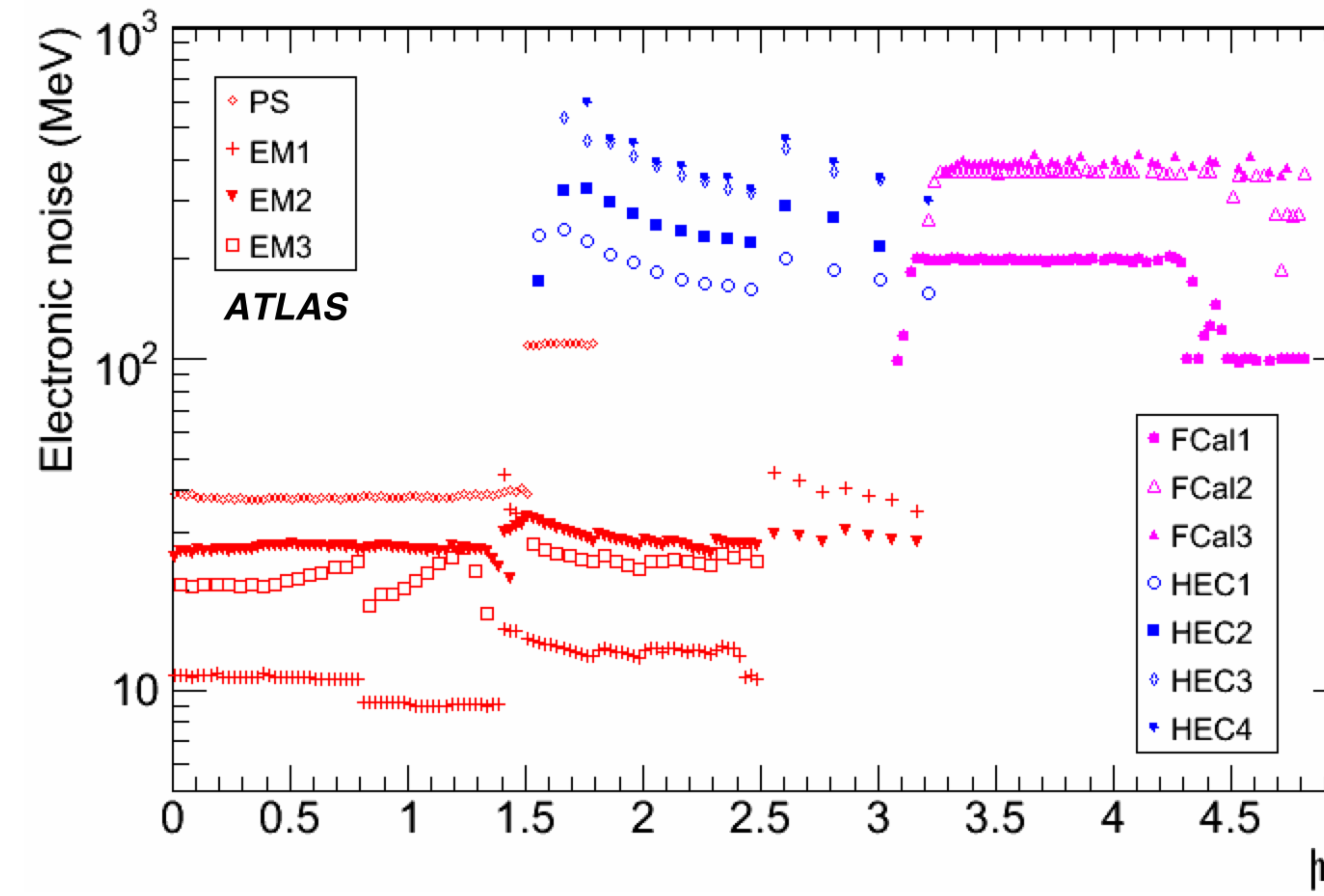
ADC to DAC (Ramps)

Pulse Samples

Optimal Filtering Coefficients

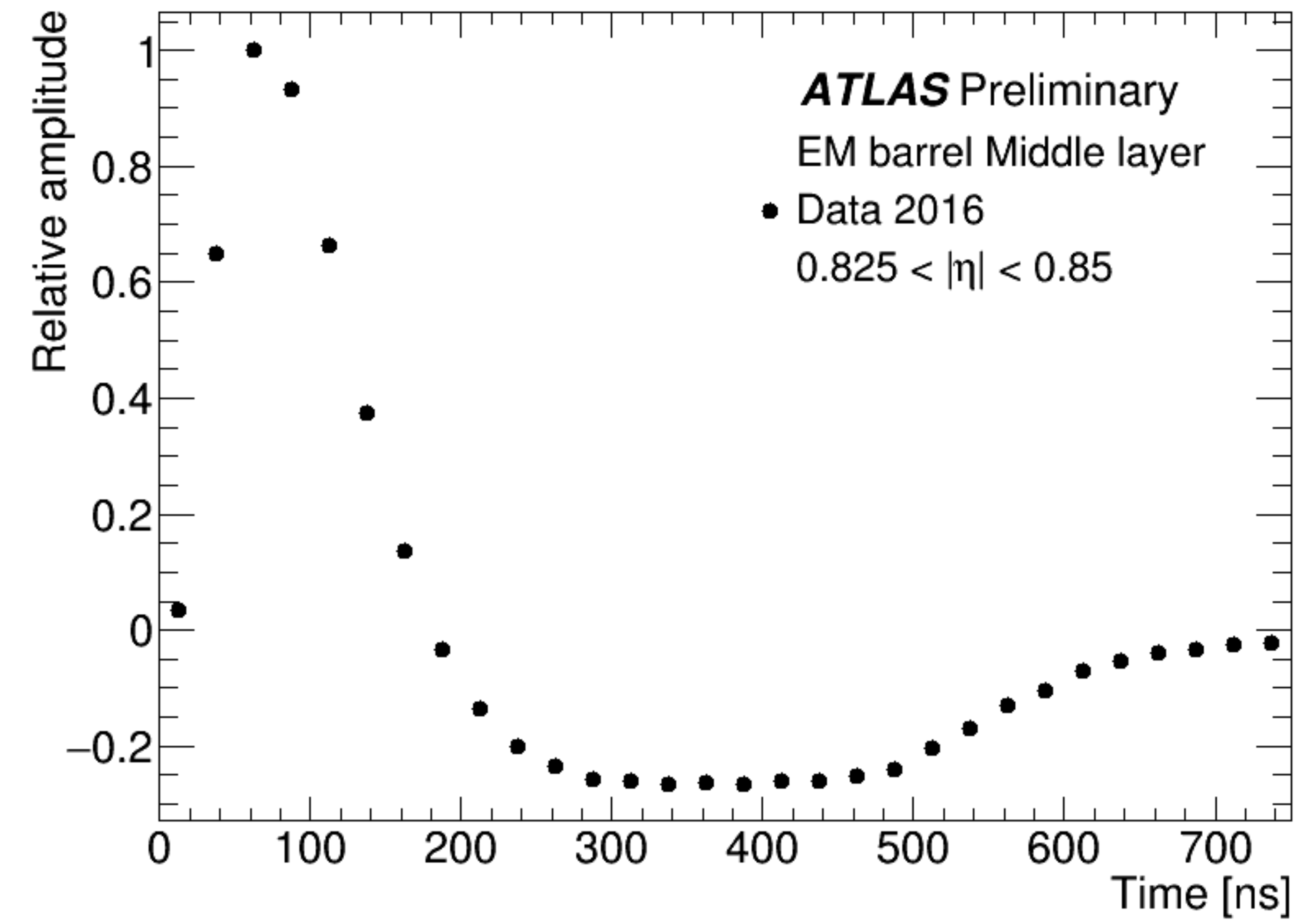
Pedestals

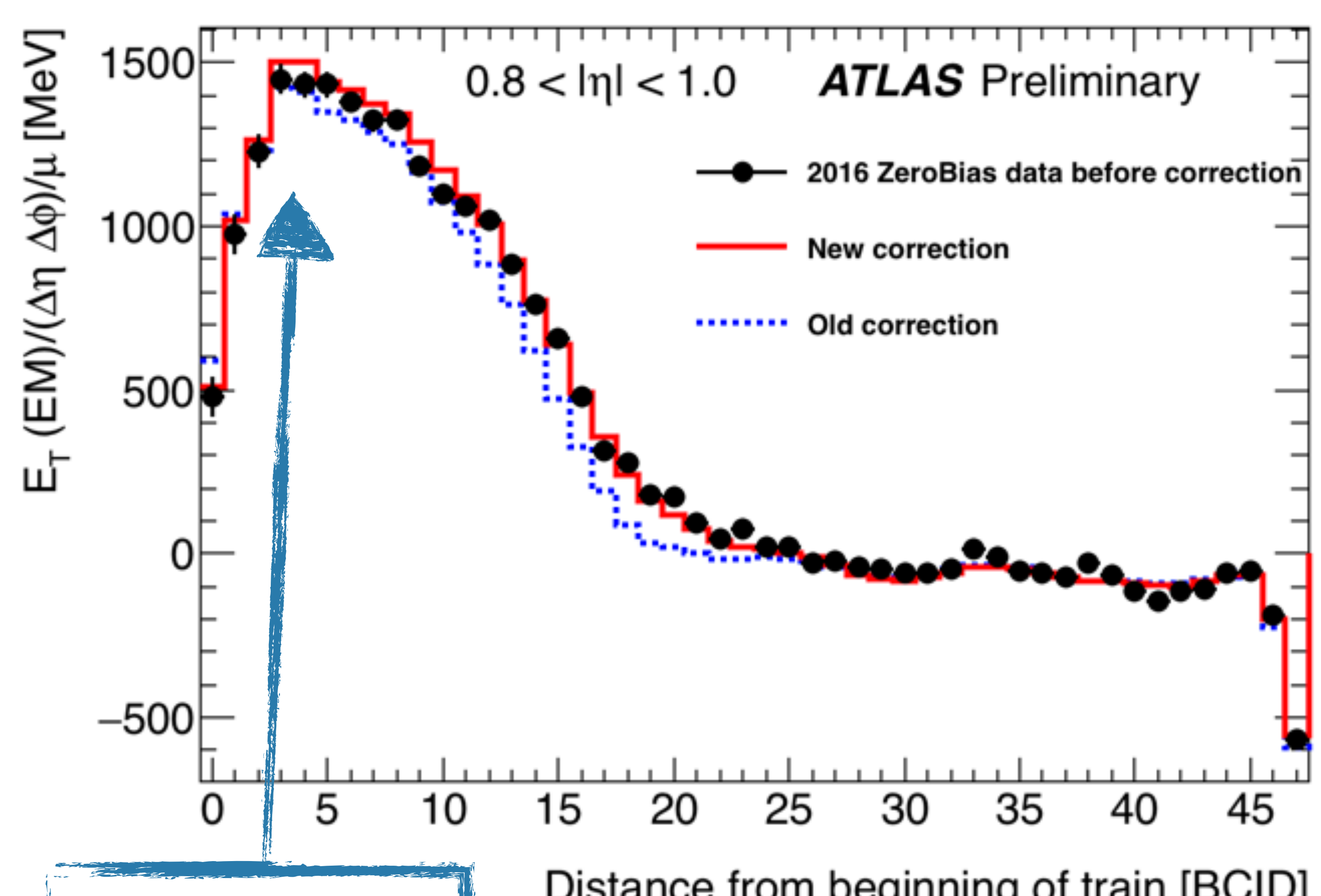




Ionisation Pulse Shape & Baseline Correction

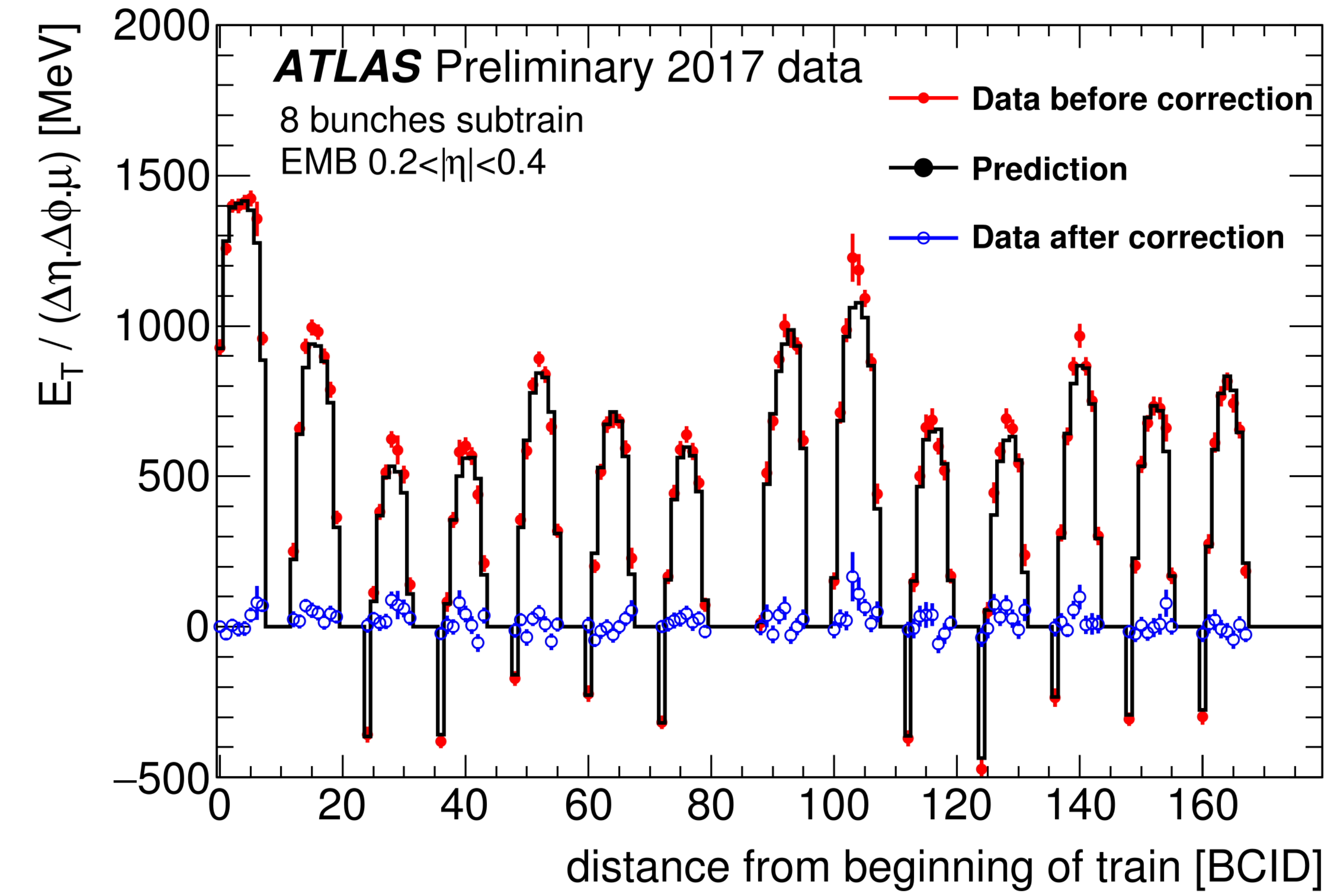
- Bipolar pulse-shape to cancel positive and negative energy contributions from in-time and out-of-time pile-up
  - → In the beginning of a bunch train out-of-time pile-up contribution missing
  - → Pedestal correction to account for energy shift
- Measured in special runs with isolated colliding bunches
  - → Extract all samples (32) of one pulse with high granularity





800 MeV per cluster at μ = 40

typical EM cluster 3×0.025×7×0.025=0.013

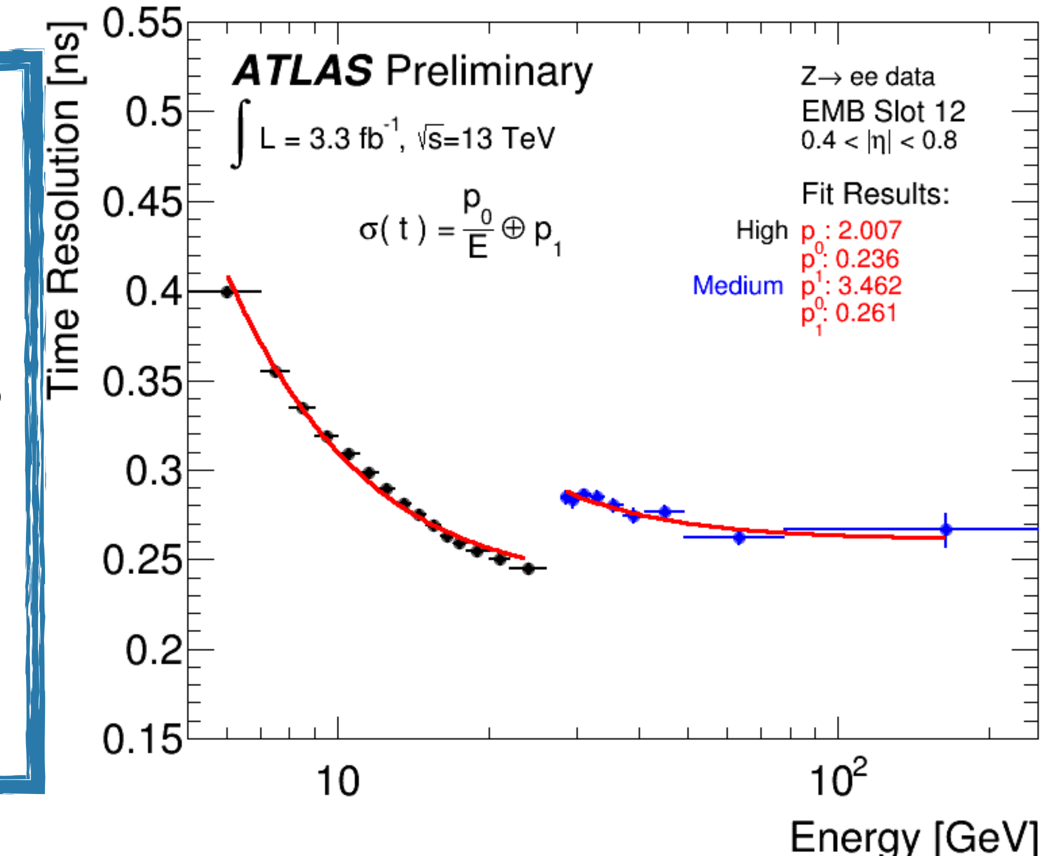


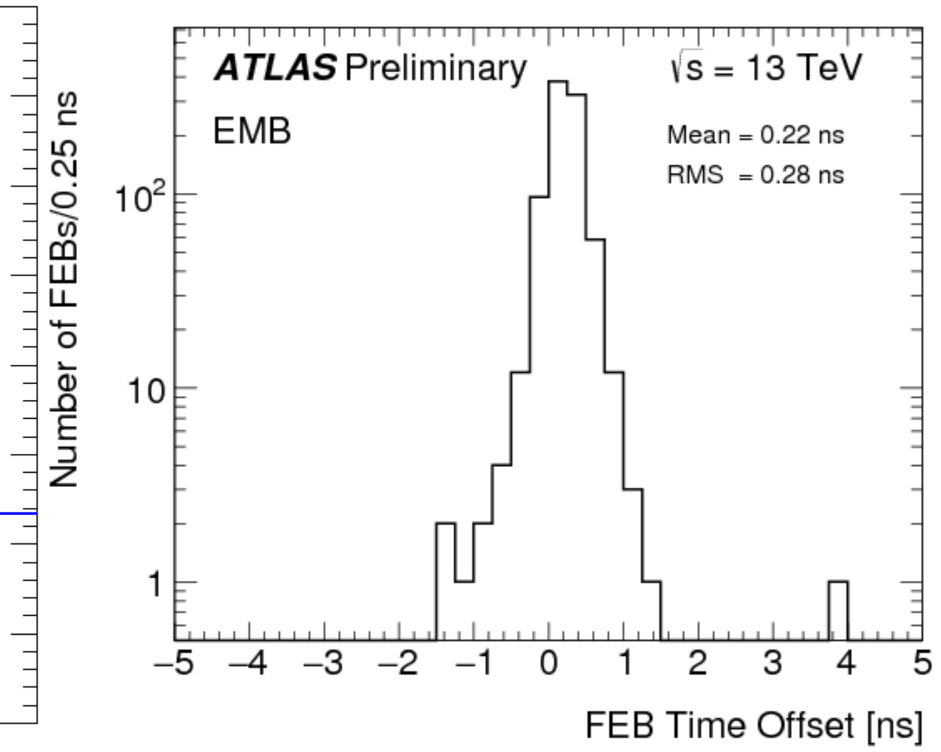
→ Accuracy of pile-up correction has been improved significantly in run-2

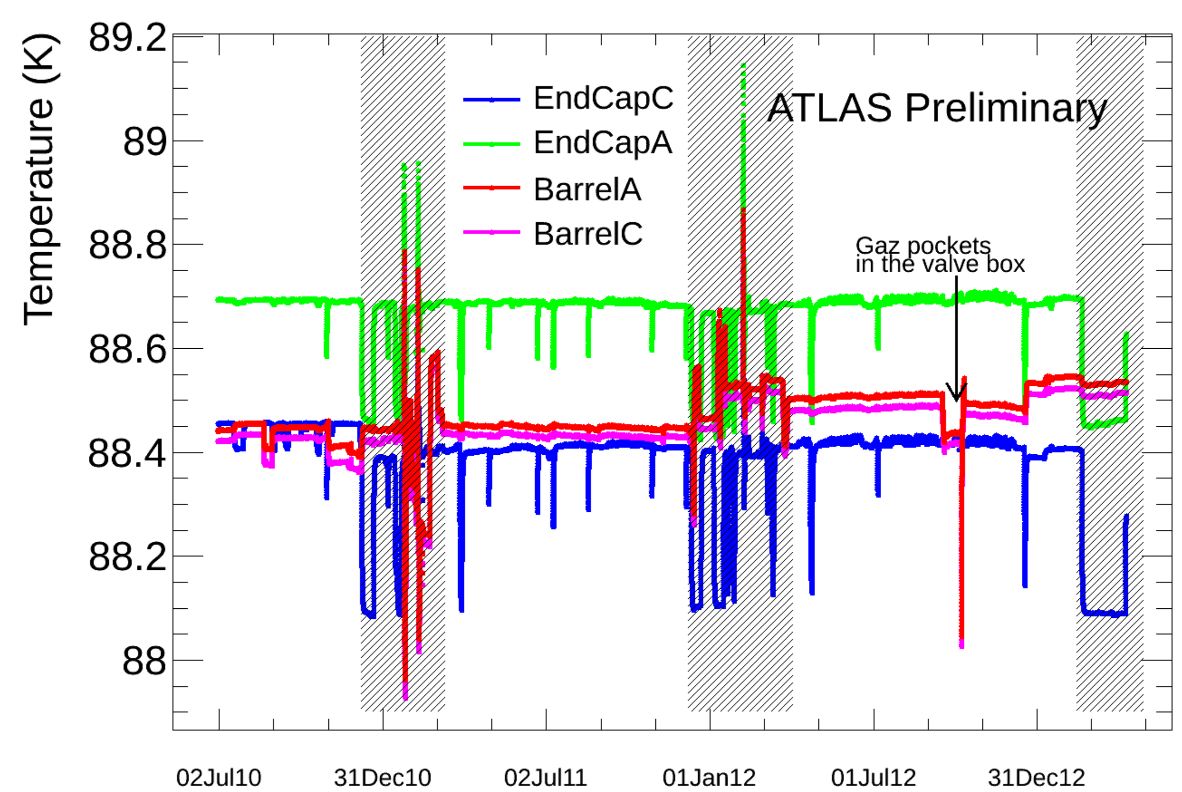
Signal Timing & Liquid Argon Monitoring

Signal timing

- Precise timing to measure out-of-time signals, veto cosmic background, reject beam-induced background, search for LLPs
- Fine adjustments for FEB synchronisation based on beam-splashes and early collision data → σ(t) < 1ns over all boards





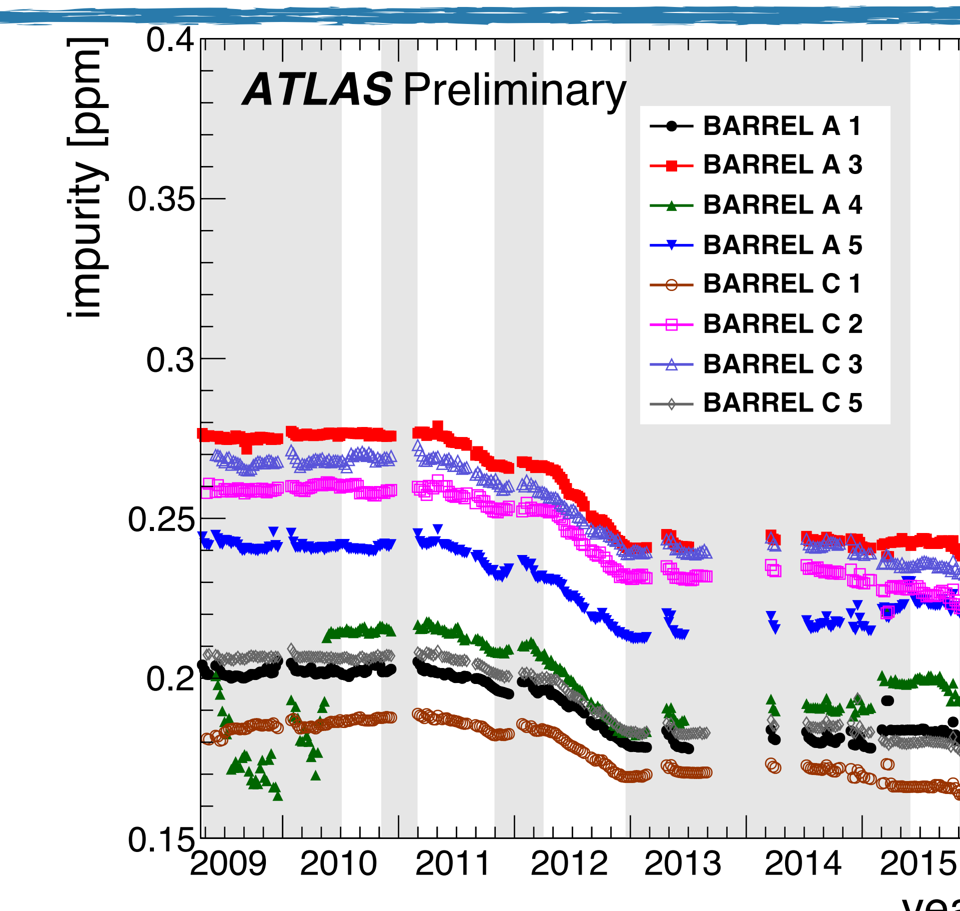


Liquid argon temperature

- Changes in temperature impact LAr density and drift time → ΔT ~ 1K → Δ(ΔE/E) ~ -2%
- 508 monitoring probes are used to check temperature stability → ΔT ~ 0.02K in barrel (<0.1K required)

Liquid argon purity

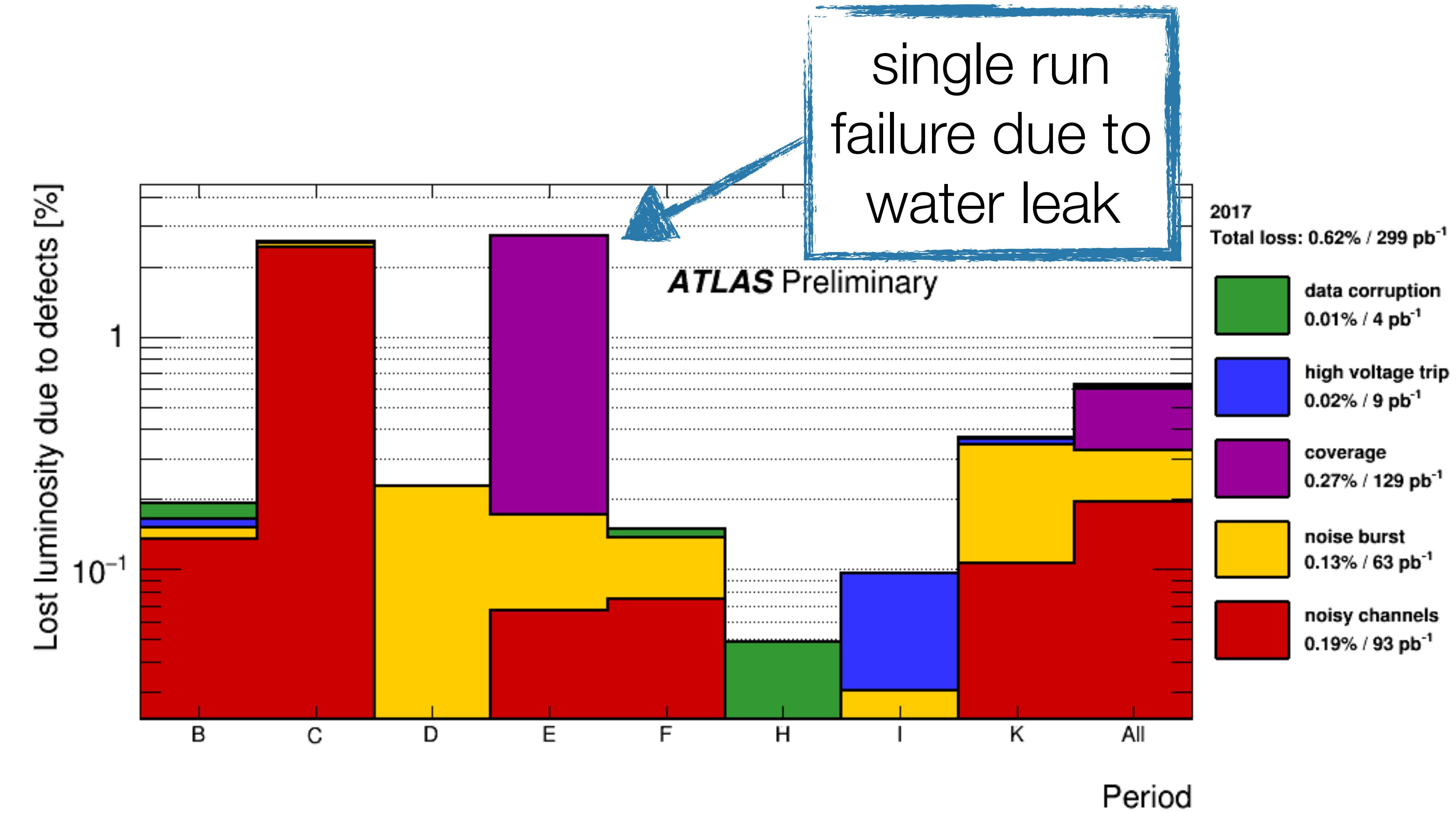
- Impurities (e.g. O_2) can capture drifting electrons and degrade the signal measurement
- 30 purity monitors measure impurity level → Impurity <300 ppb (<1000 ppb required)

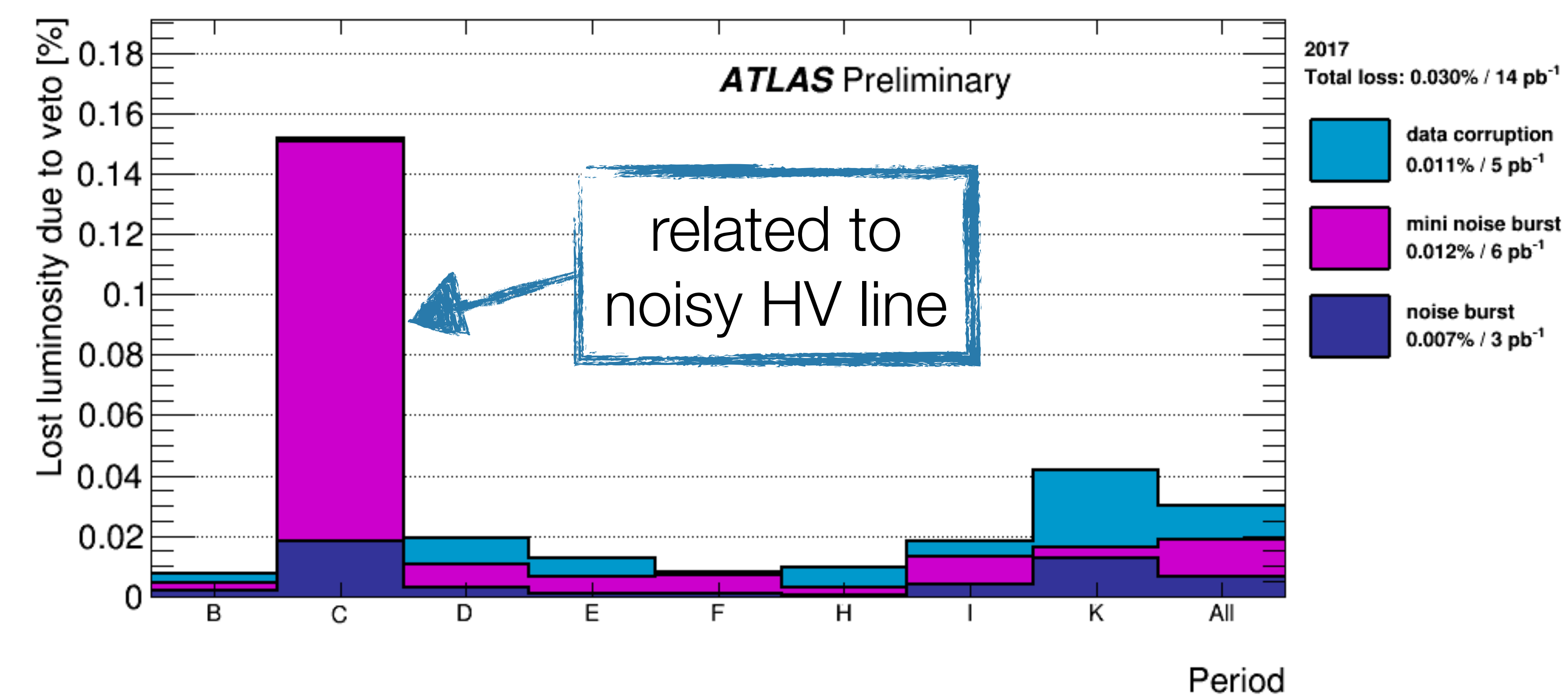


Data-Taking Efficiency & Data Quality

- Noisy channels are masked based on inter-train data
  - ➝ Based on quality factor
  - ➝ Energy averaged from neighbouring cells
- Data not suitable for physics analysis are rejected by two complementary means:
  - Assigning defects to lumi block (1 minute data loss per lumi block)
  - Defining time veto windows (<1 minute data loss per veto period)

main source	treatment	2015&2016	2017
High voltage trips	defect	0.37%	0.02%
Noise bursts	defect & time veto	0.09%	0.14%
Mini noise bursts	time veto	0.10%	0.012%
Improper treatment of noisy channels	defect	0.10%	0.19%





99.9% operational channels
99.5% good quality data

Coherent Noise

Noise Bursts

Burst over a large region

Mainly end-caps

During short time period (~1μs…1ms)

Mini Noise Burst

Repeated burst in one FEB ($\mathcal{O}$(10) cells)

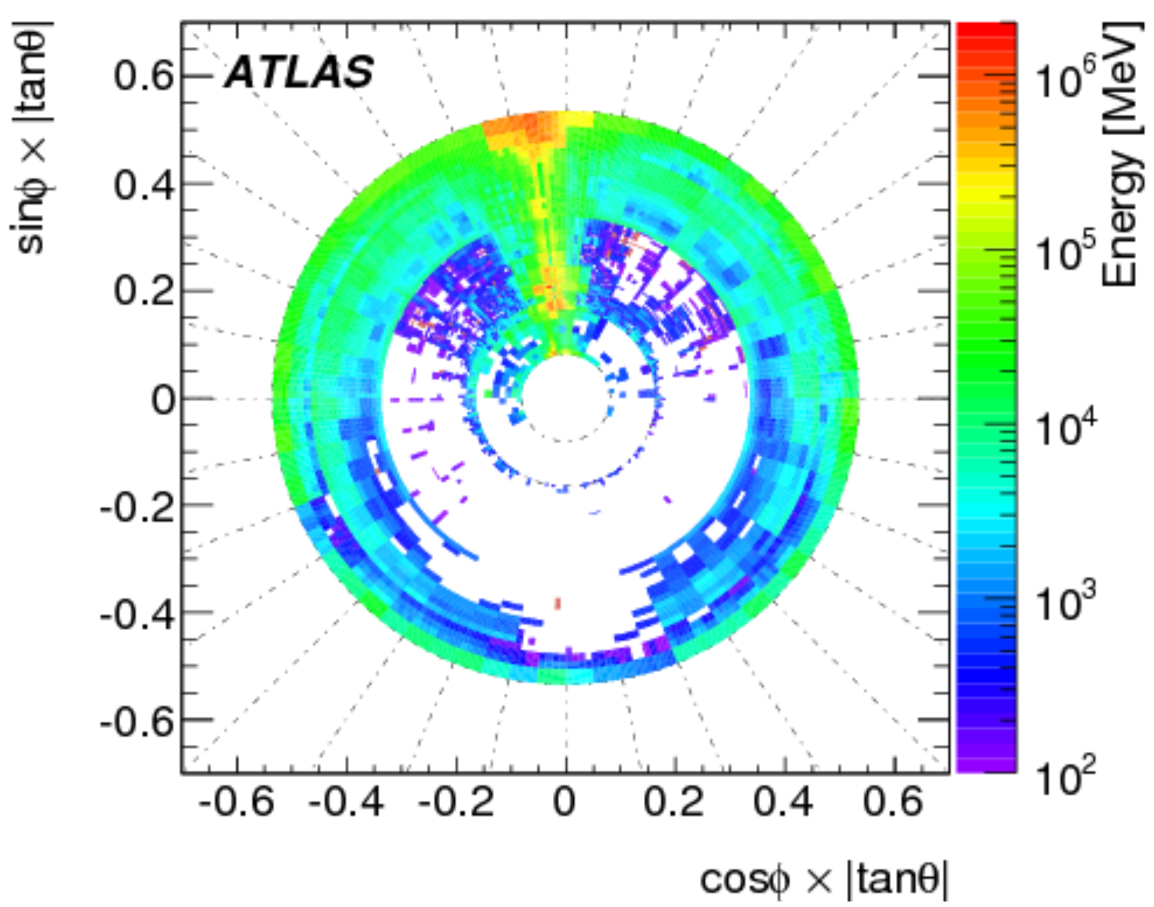
Mainly barrel

During very short time period (<1μs)

High number of channels with bad quality factor

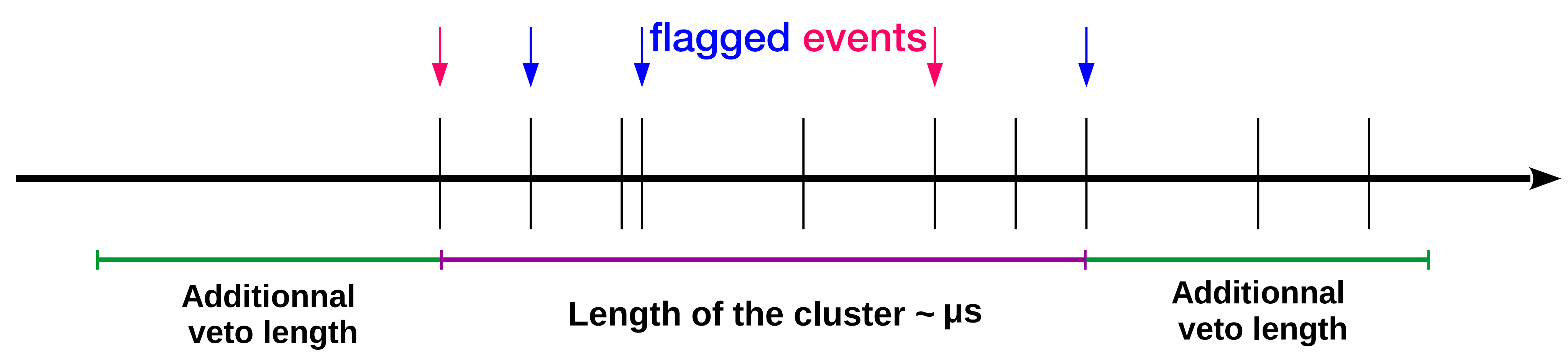
Treatment

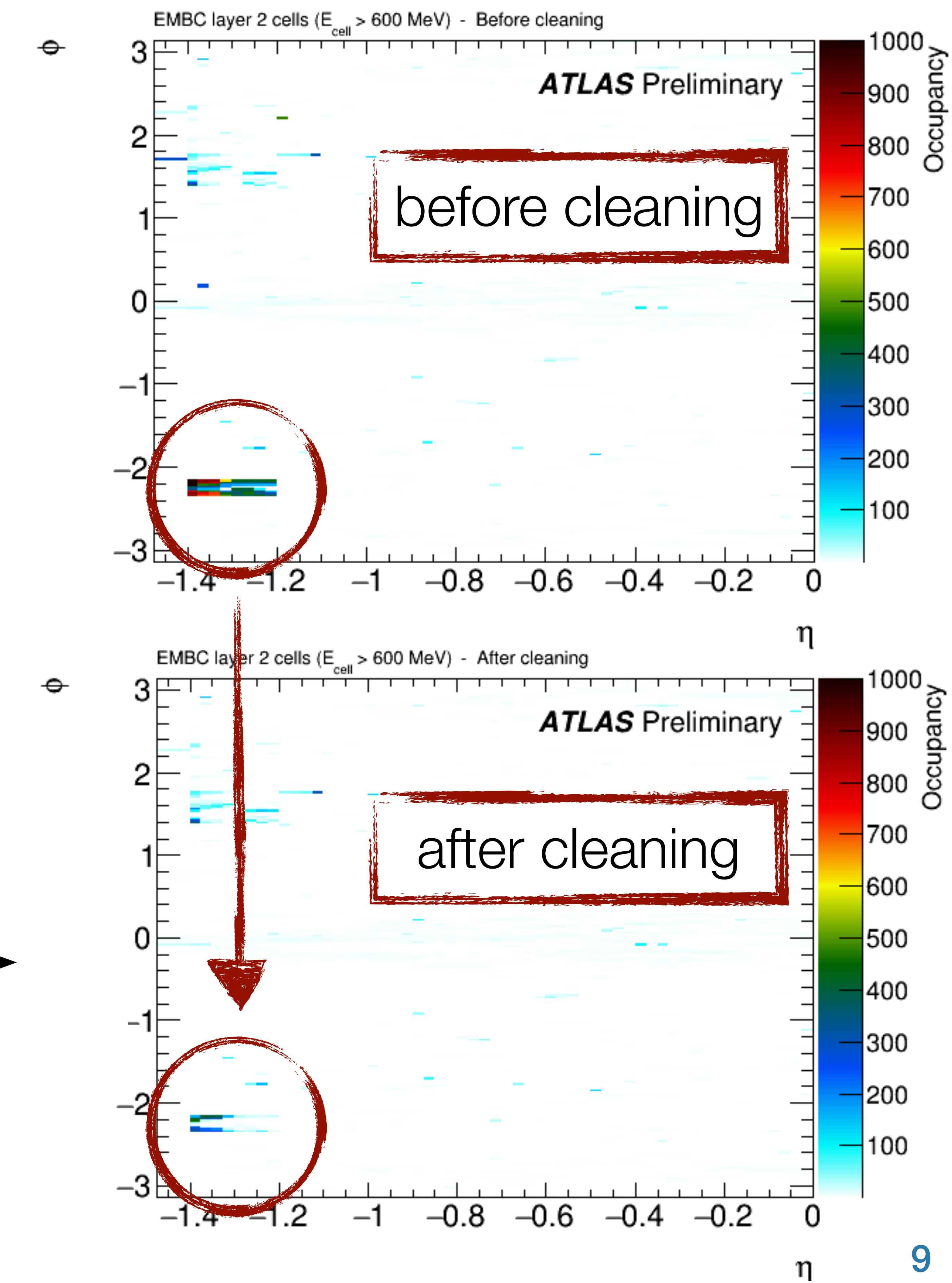
Define time window (1ms) around noise burst candidate events and veto this time period



If too many time veto window periods

→ Lumi block rejected





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High Voltage Trips

Monitoring

- High voltage condition impact the amount of signal collected by electrodes → energy computation
- Constantly monitored online and stored in conditions database

Treatment

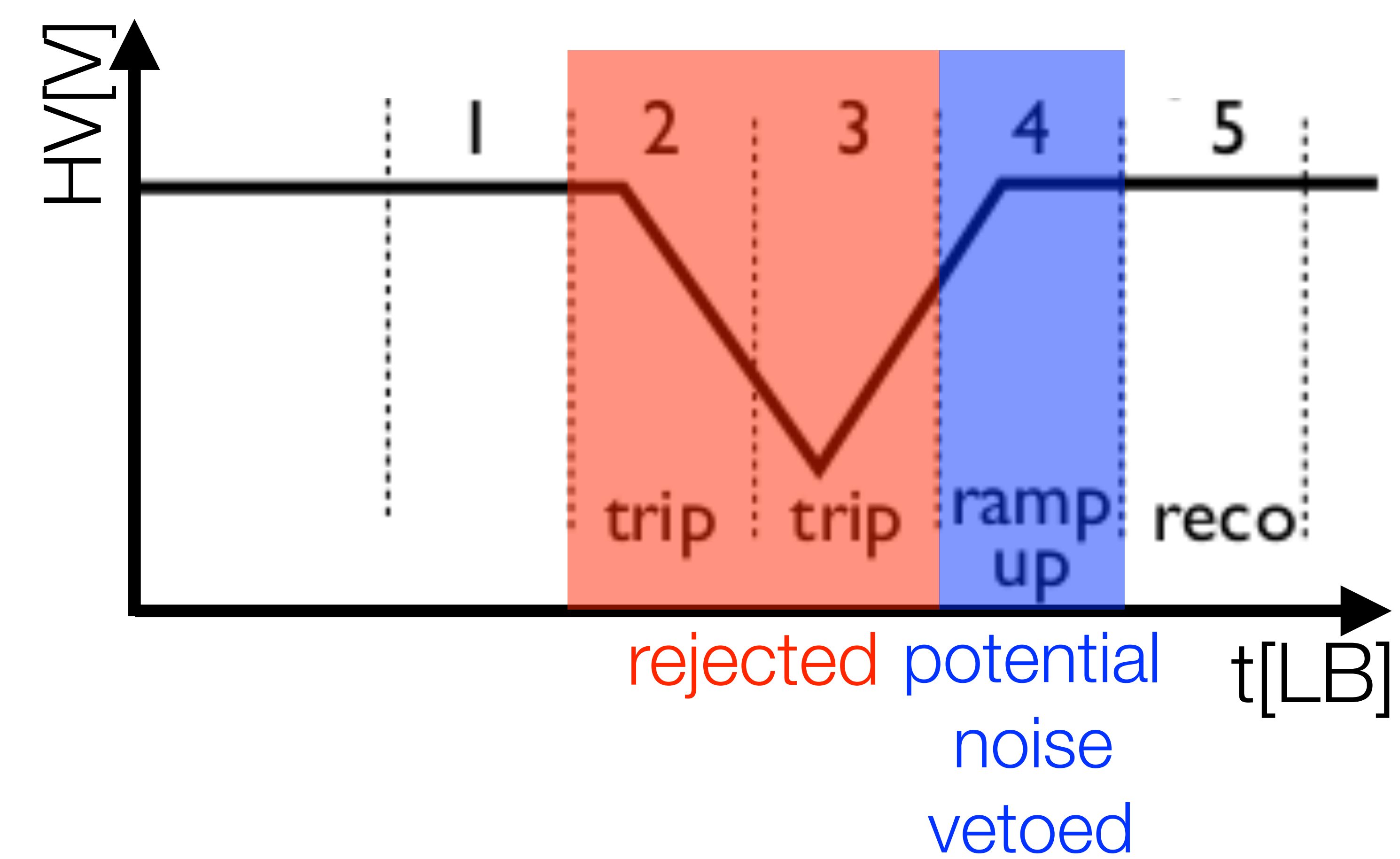
- HV trips might occur during data taking and usually auto-recover
  - Lumi block(s) where trip occurred are rejected mainly because of non-reliable HV correction factor
  - Lumi block(s) during ramp-up with induced noise are treated by a time window veto

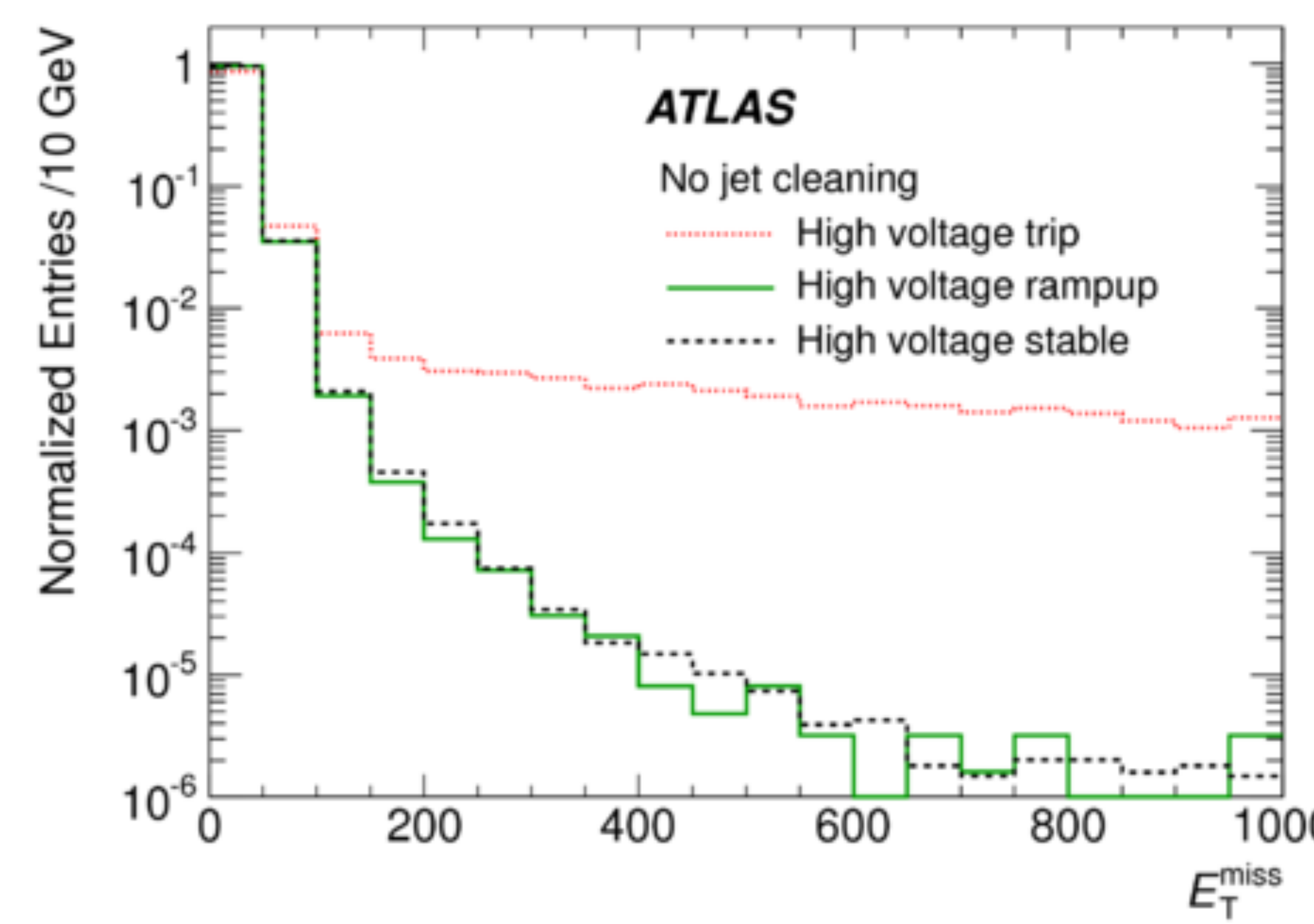
Improvements

- New high voltage supplies have been installed to cope with temporary increase in current

  → Significant reduction in associated data loss:

  2015: 0.37% → 2016 & 2017: 0.01…0.02%





From Cell Energies to Physics Objects

Energy reconstruction

- Calorimeter cells are combined to clusters
- Containing most of the energy deposit of the electromagnetic shower
- Identified as e±, (un)converted γ

Energy correction

Simulation based calibration + data driven layer inter-calibration & uniformity corrections

Energy scale

$$E_{\mathrm{i}}^{\mathrm{Data}} = E_{\mathrm{i}}^{\mathrm{MC}}(1+\alpha_{\mathrm{i}})$$

- Derived from $Z \to ee$
- $\Delta\alpha$(2015-16) < 0.2% caused by luminosity related heating of LAr and HV currents

Energy resolution

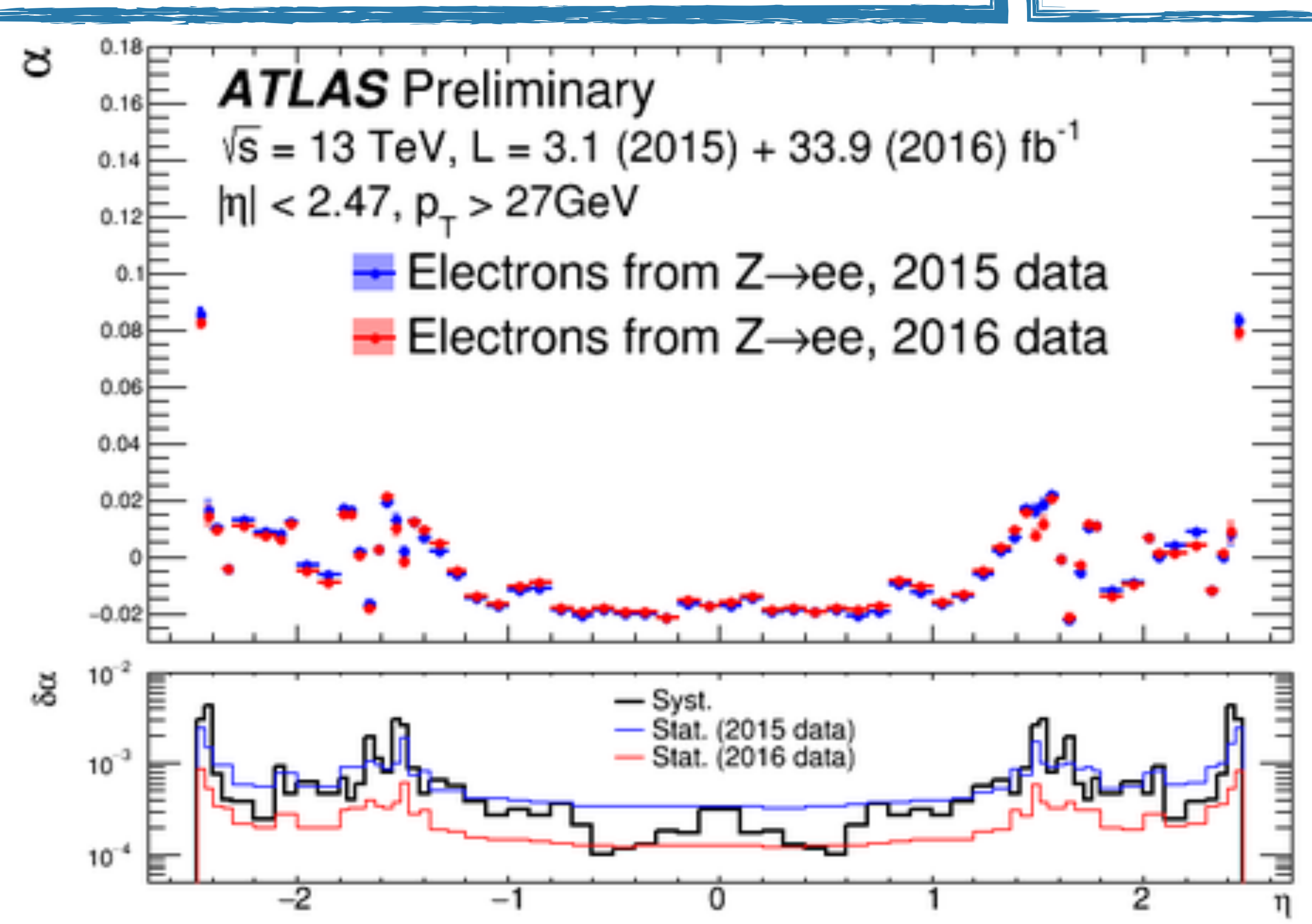
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

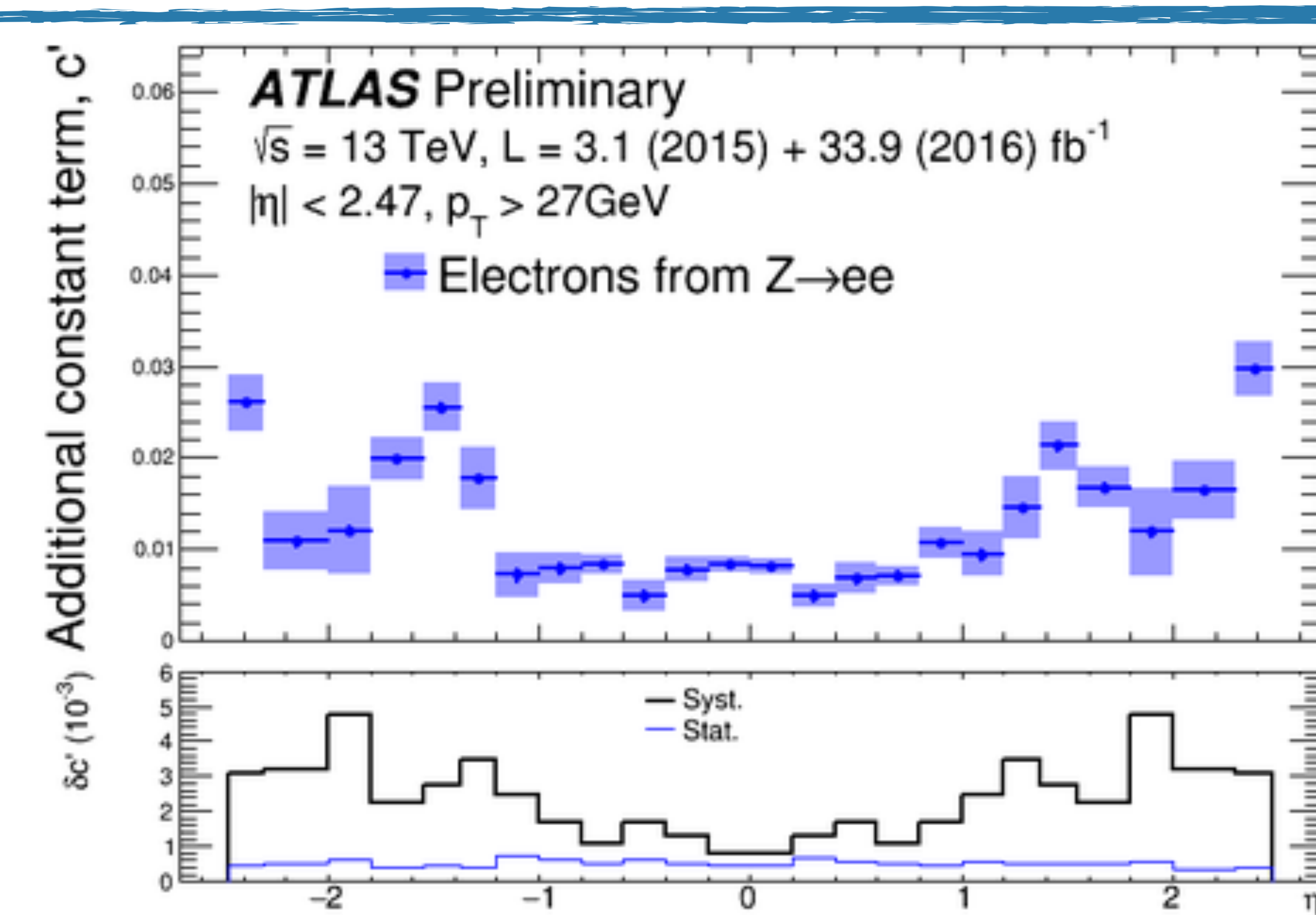
sampling, noise, constant term

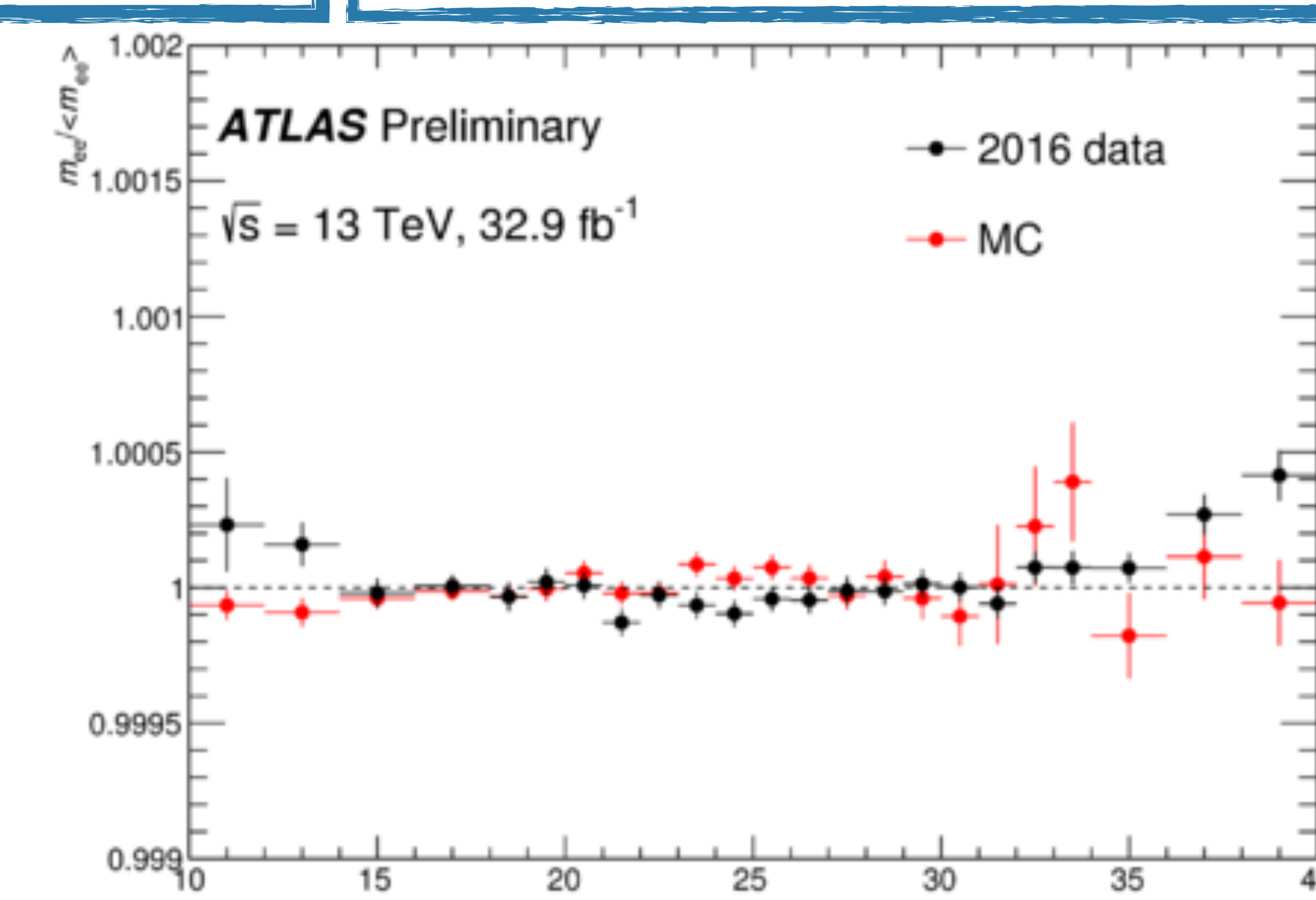
- Assumption: simulation models data well up to constant term c
- Derived from $Z \to ee$

Energy stability with pile-up

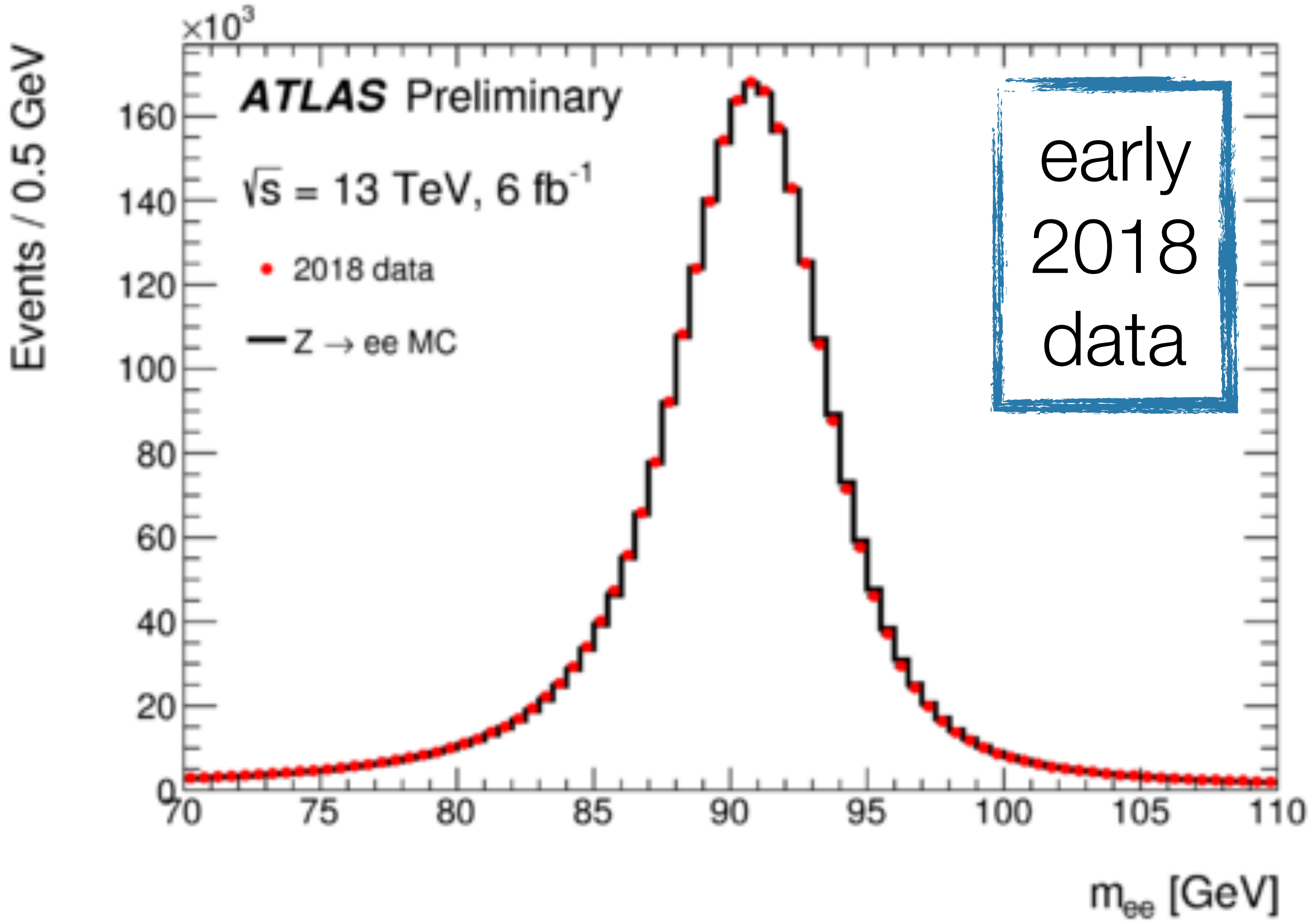
- High pile-up → higher pile-up noise → worse energy resolution (~80 MeV · √μ)
- Probed with $Z \to ee$
- Stability <0.05% integrated over η



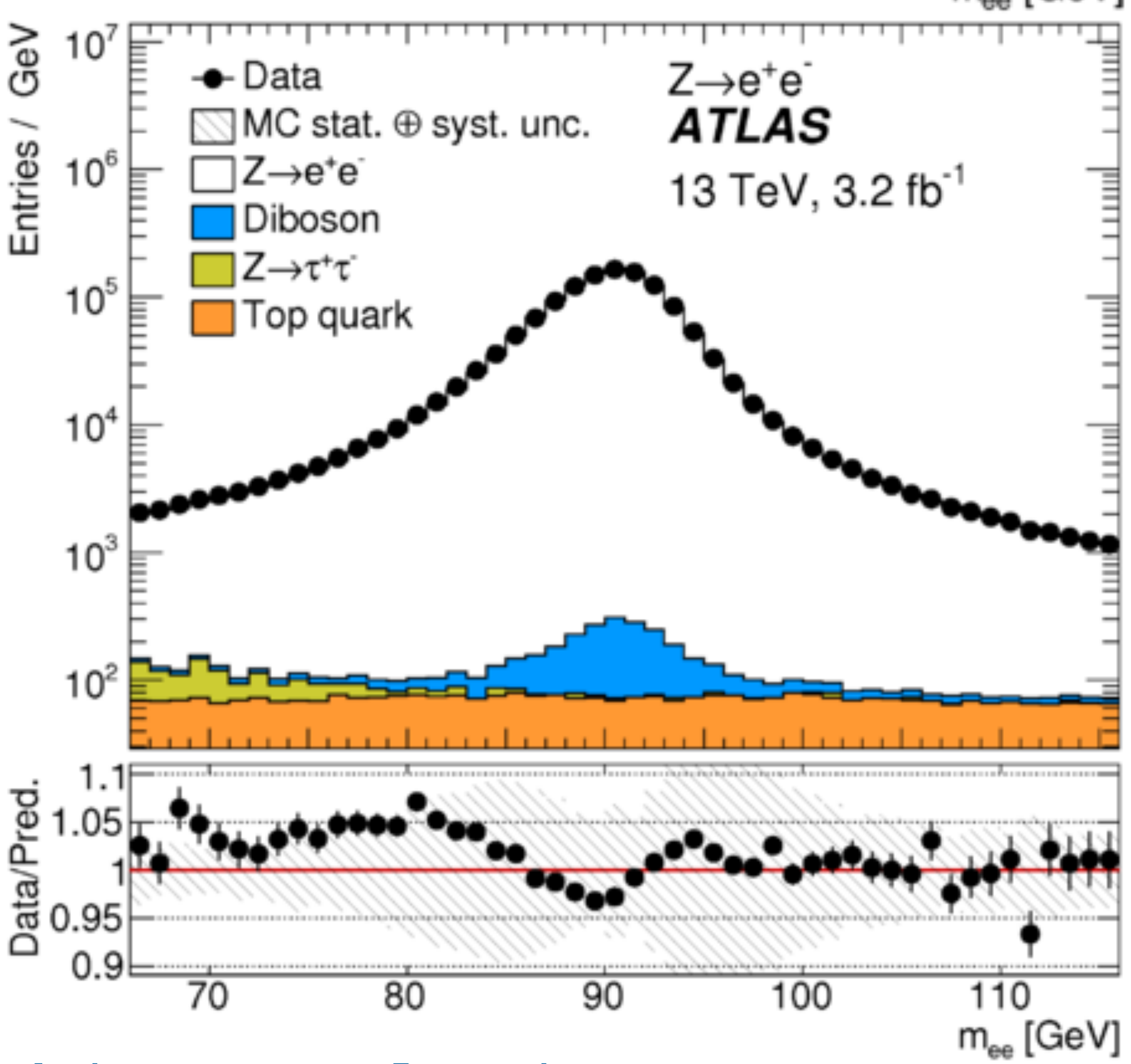


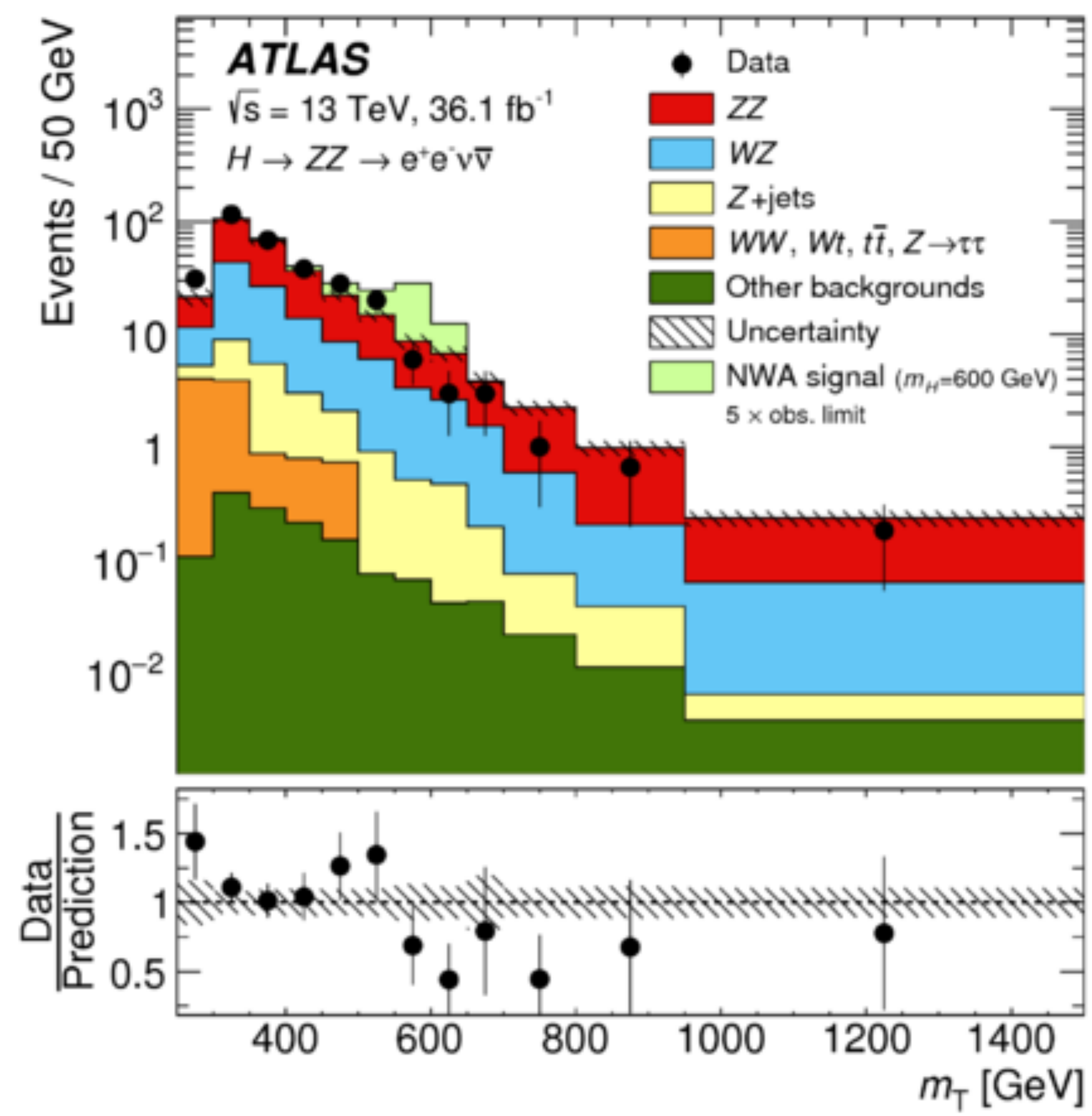


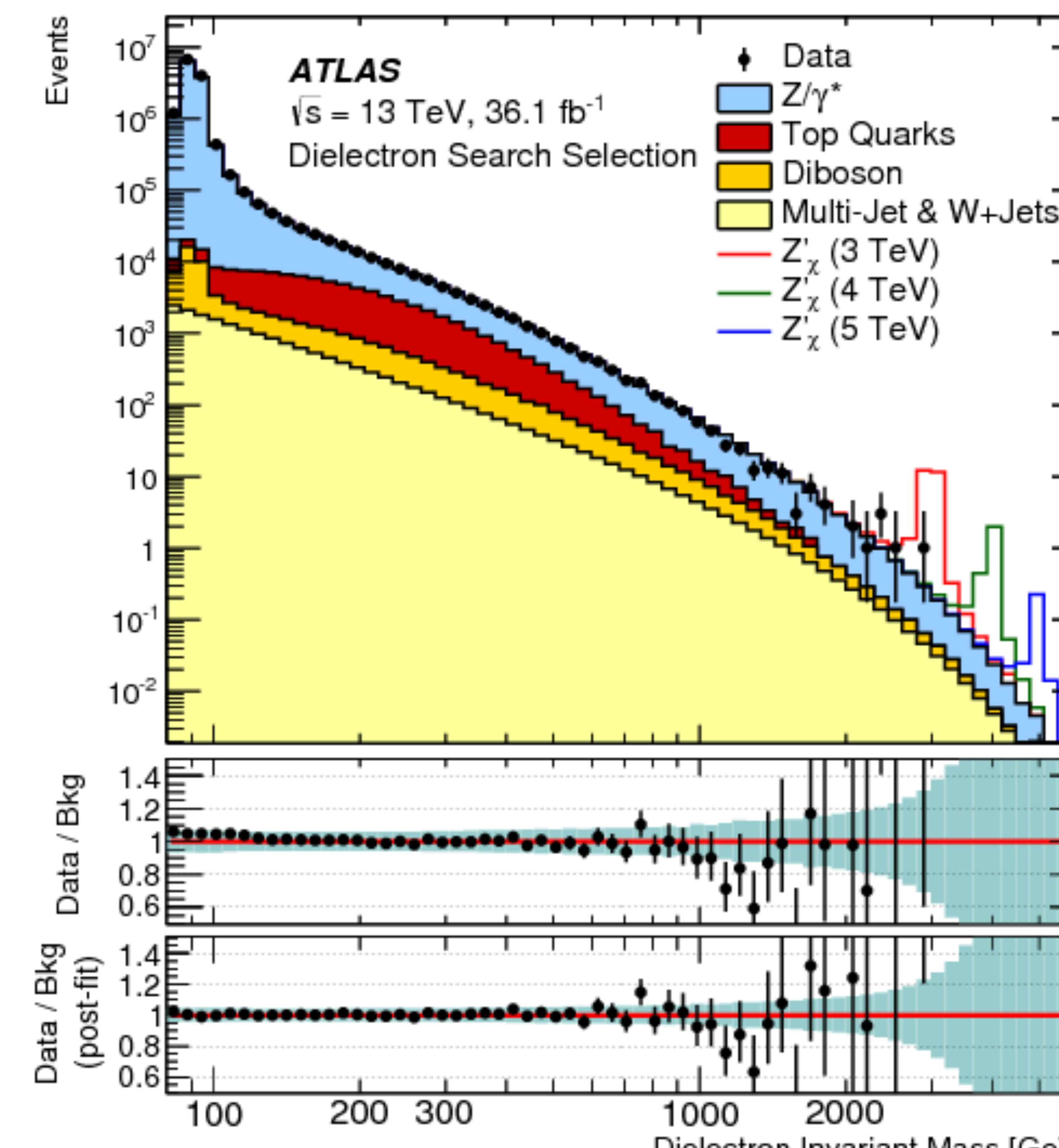
Run-2 Measurements



- Precise knowledge of energy scale and resolution crucial for many physics analyses, both searches and precision measurements
- 13 TeV data reveals excellent performance in wide energy range







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Summary

- The liquid argon calorimeter of ATLAS shows excellent performance during LHC Run-2
- With consistently high operation and data quality efficiency of above 99%
- Proven by the stability of the EM scale over time and pile-up
- Continuous effort to improve performance

Thanks for your attention!
Questions?

You want to know more about the ATLAS LAr Calorimeter and its future?
→Christopher Anelli's talk on Friday
→Yi-Lin Yang's poster