Pulse Shapes for Signal Reconstruction in the ATLAS Tile Calorimeter

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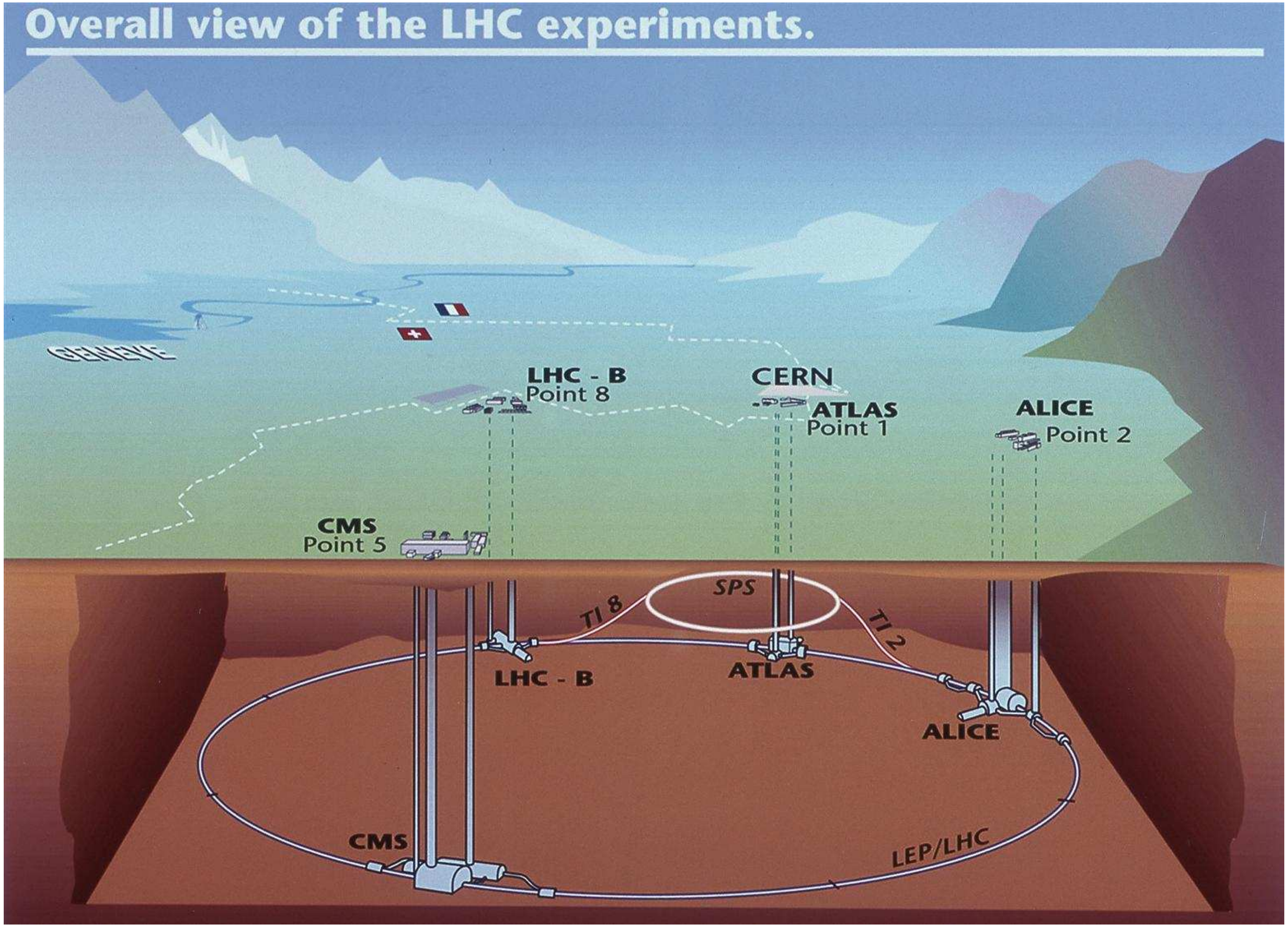
Maja Tylmad

for the ATLAS Tile Calorimeter System

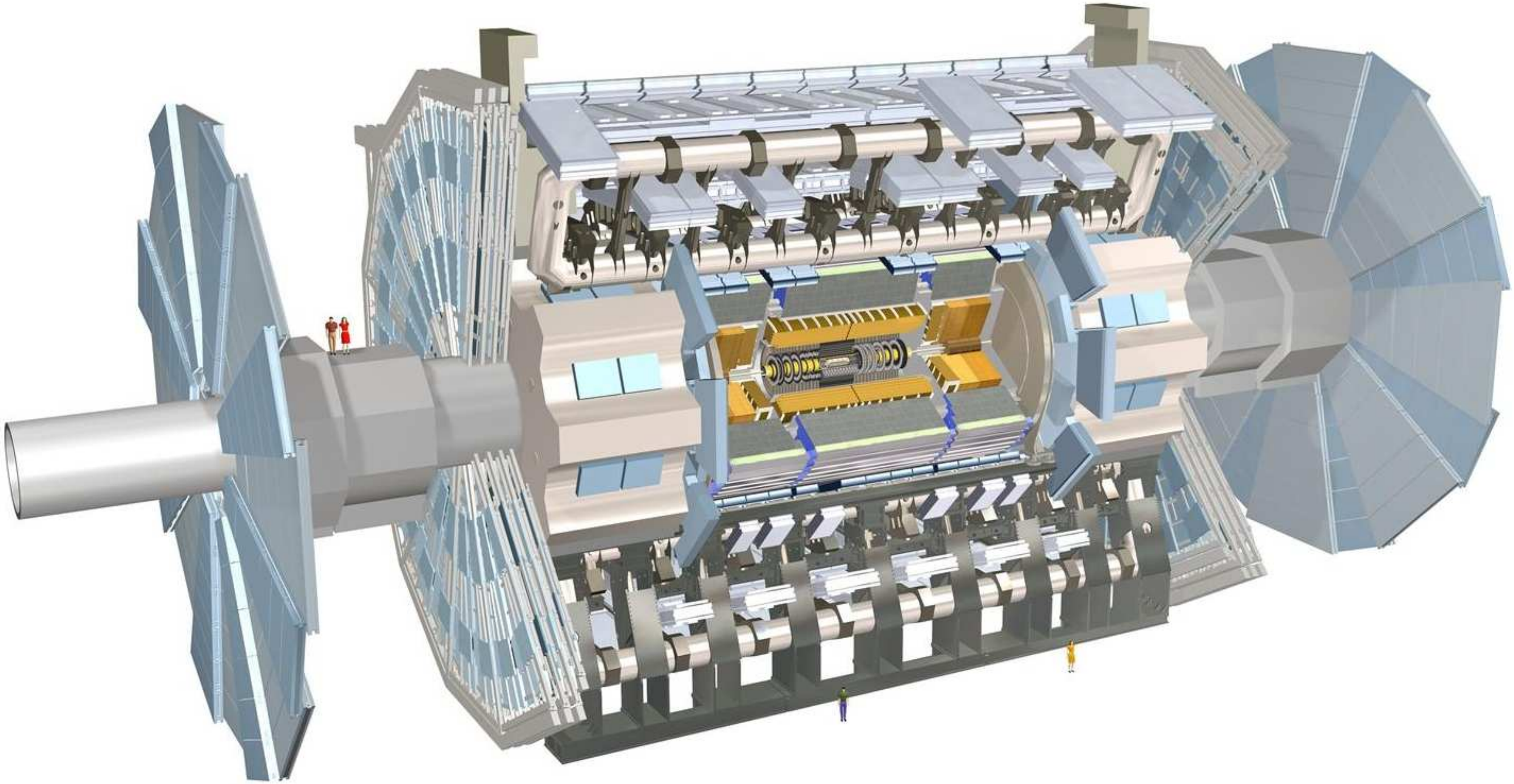
Department of physics, Stockholm University, Stockholm, Sweden

The Large Hadron Collider, LHC

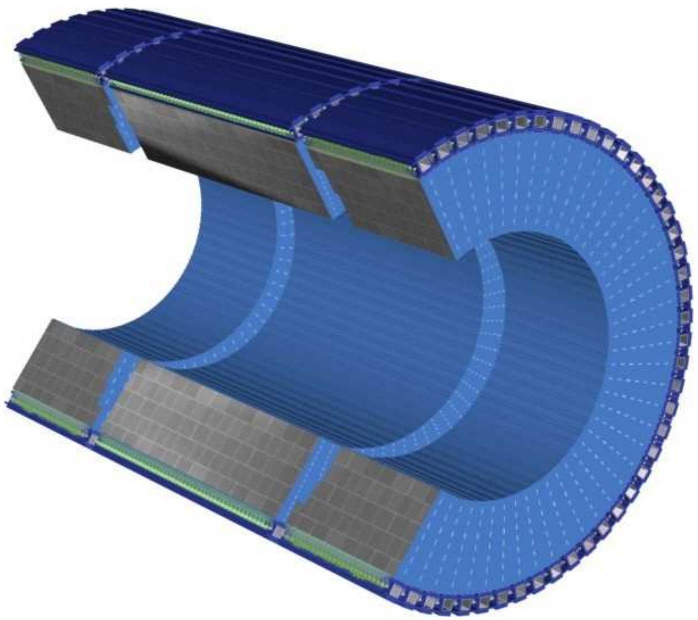


When operational, the LHC will collide protons at $\sqrt{s} = 14$ TeV.

The ATLAS detector

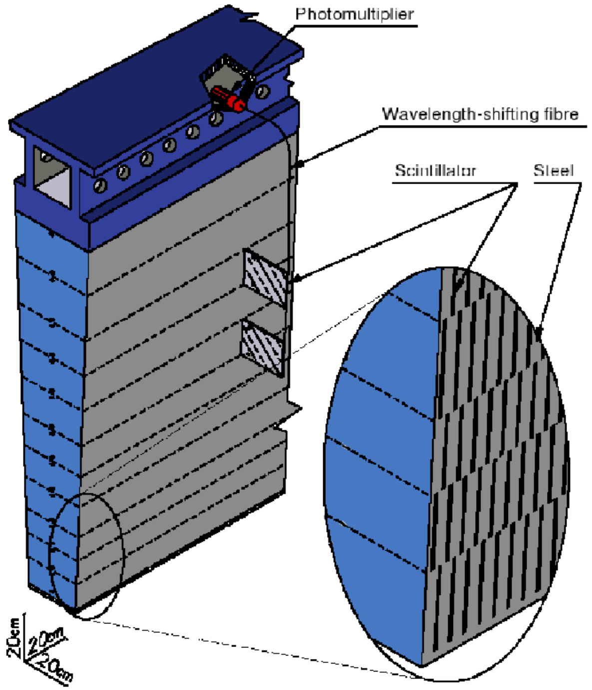


The Tile Calorimeter

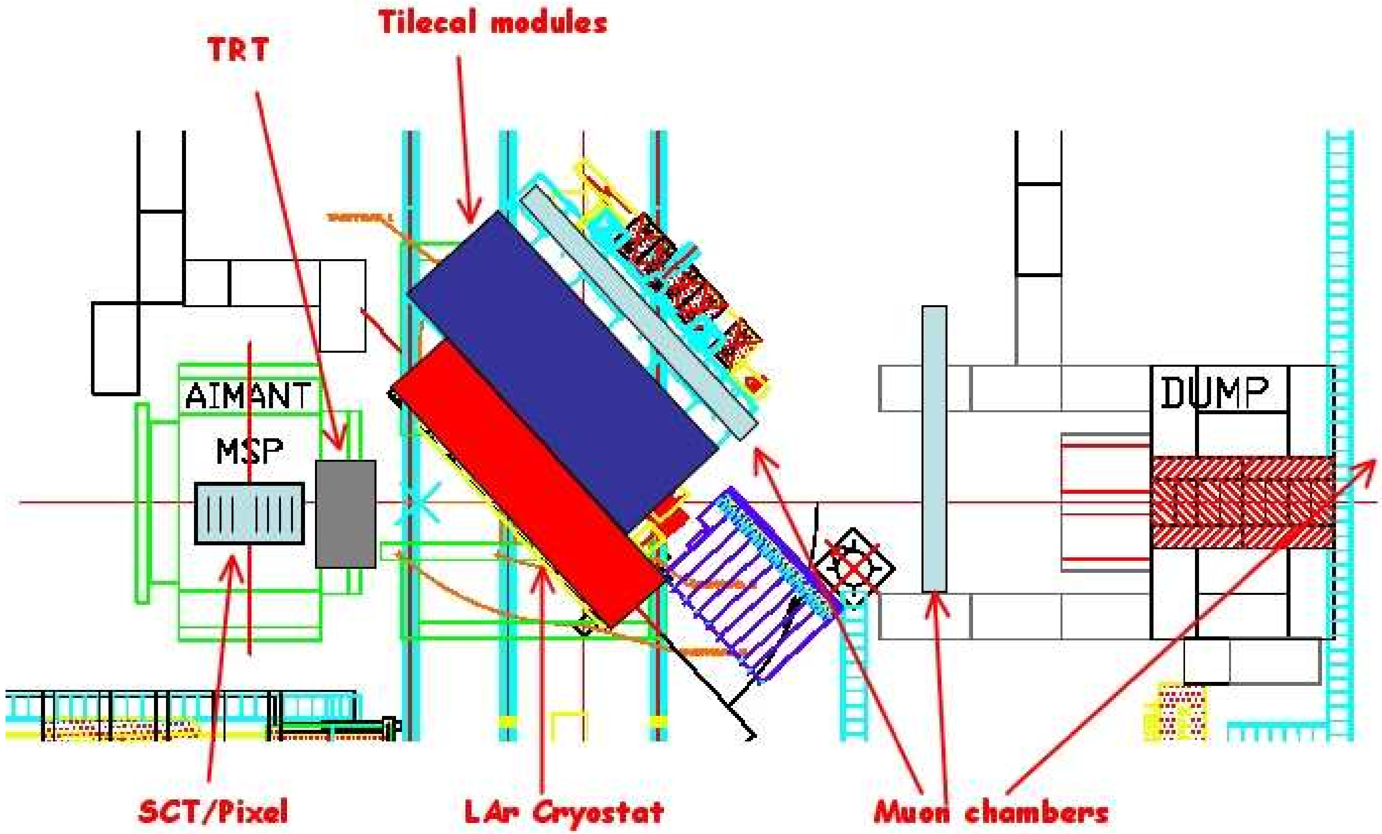


- Signal from each PMT is digitized by 2 ADCs, amplification ratio 64 (low and high gain).
- The signal is sampled every 25 ns.
- 9 consecutive samples are stored as one pulse.

- 4 partitions, 2 barrel and 2 extended barrel.
- Each partition contains 64 modules.
- Each module is divided into 22 cells, each cell is read out by 2 PMTs.



The Combined Test Beam, CTB



Pions were fired at detector parts setup simulating ATLAS geometry.

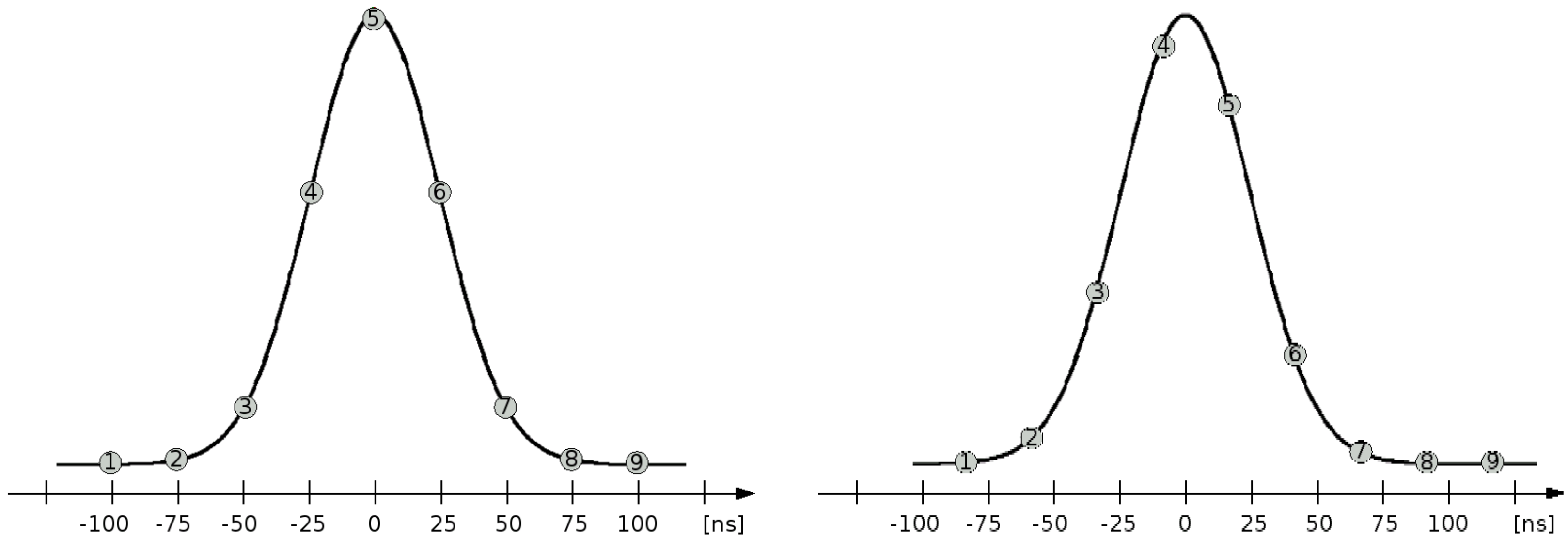
- 11 different incident energies, ranging from 20-350 GeV
- 6 different incident angles ranging from $\eta = 0.20$ - 0.65

Motivation

- Measurements of particle energies and missing energy will be important.
- The calorimeters of the ATLAS detector will provide this information.
- A thorough understanding of the pulse shapes in the calorimeter is required for an accurate energy reconstruction.

Pulse shapes

TileCal electronics sample a signal every 25 ns. Nine consecutive samples are stored for each event and are used to reconstruct the amplitude of the pulse.



Many pulses with random phases overlaid will produce a more or less continuous shape, we call this *pulse shapes*.

Fit Method and Normalization

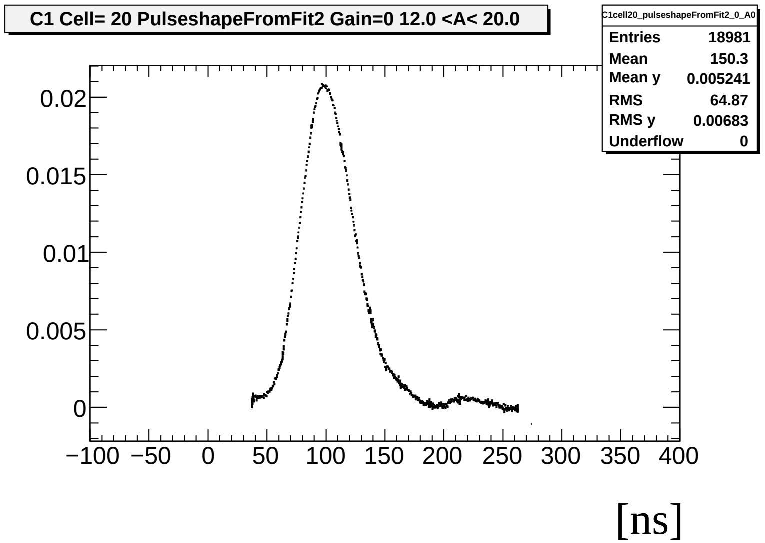
The amplitude of the PMT signal is reconstructed using the *Fit method*. A predefined function $g(t - t_0)$ is fitted to the nine samples:

$$f(t) = A_{fit} \cdot g(t - t_0) + c$$

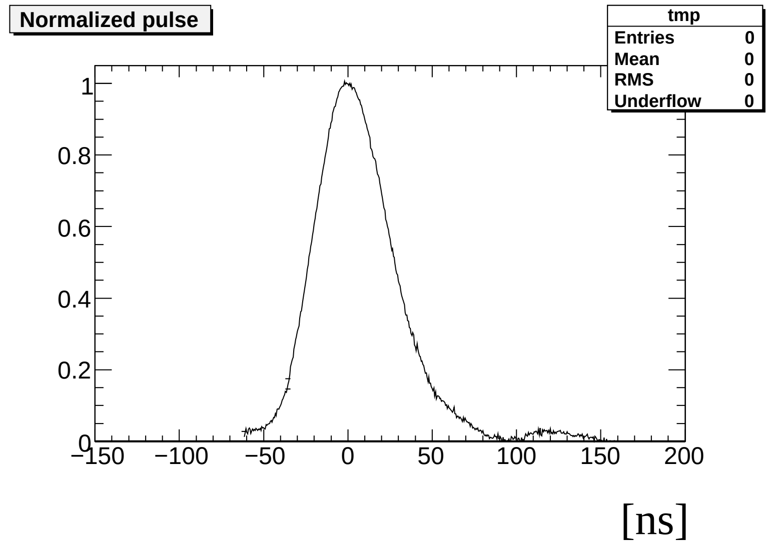
A_{fit} is the reconstructed amplitude, t is time, t_0 is peak position in time and c is the pedestal.

Pulse shapes are normalized to unit amplitude and shifted to peak at $t = 0$.

Pulse shape before normalization:



Normalized pulse shape:



Energy bins, “Q-bins”

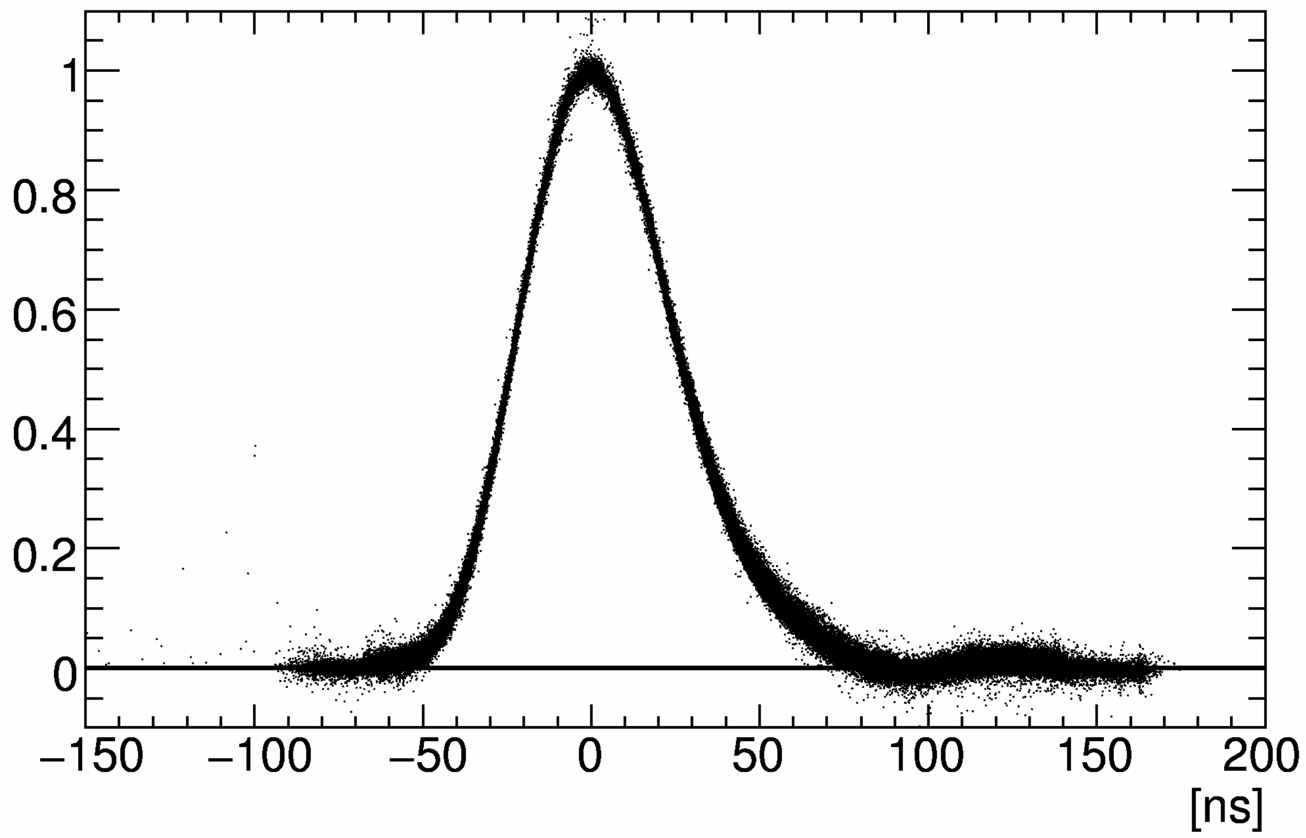
Define “Q-bins”, a measure of the energy of the pulse:

$$Q = \sum_{i=1}^{8} S_i - 8 \cdot S_0$$

	Low gain	High gain
Q-bin	Q-value (counts)	Q-value (counts)
Q0	$30 < Q < 50$	$0 < Q < 10$
Q1	$50 < Q < 70$	$10 < Q < 50$
Q2	$70 < Q < 90$	$50 < Q < 100$
Q3	$90 < Q < 140$	$100 < Q < 200$
Q4	$140 < Q < 200$	$200 < Q < 400$
Q5	$200 < Q < 250$	$400 < Q < 800$
Q6	$250 < Q < 300$	$800 < Q < 1200$
Q7	$300 < Q < 350$	$1200 < Q < 1600$
Q8	$350 < Q < 400$	$1600 < Q < 2000$
Q9	$400 < Q < 800$	$2000 < Q < 10000$

Pulse-to-pulse variations

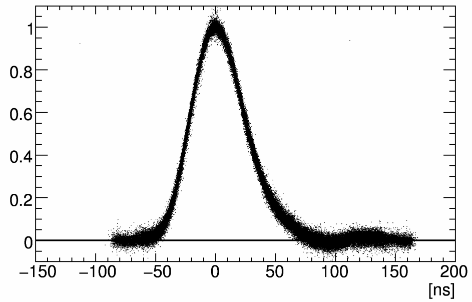
Pulse shapes from all cells and energies overlaid. The width of the band indicates the maximum pulse-to-pulse variations.



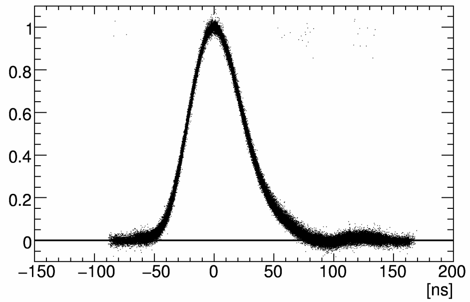
Sort pulses into energy bins to get a handle on the energy dependence.

Pulse-to-pulse variations in energy bins

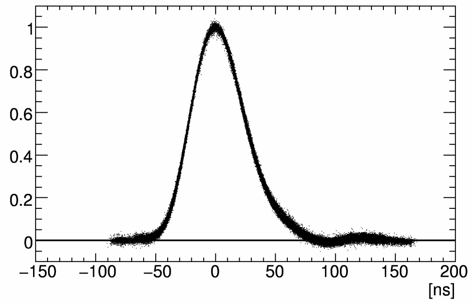
Energy bin 0



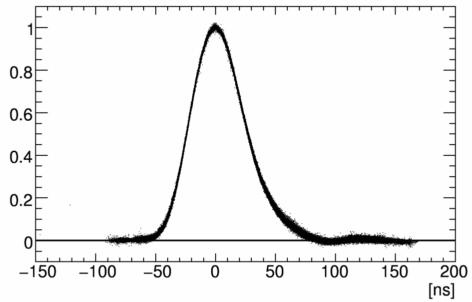
Energy bin 1



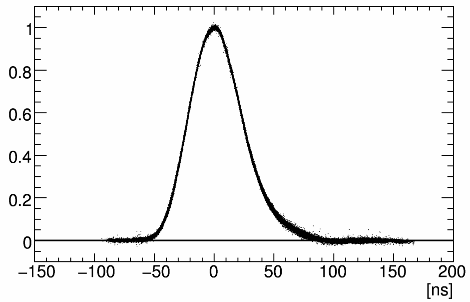
Energy bin 2



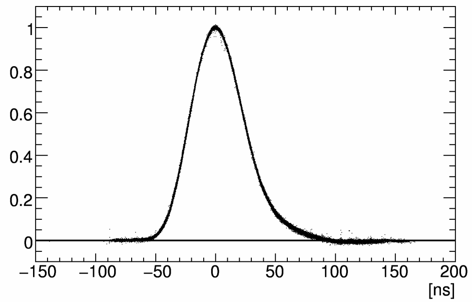
Energy bin 3



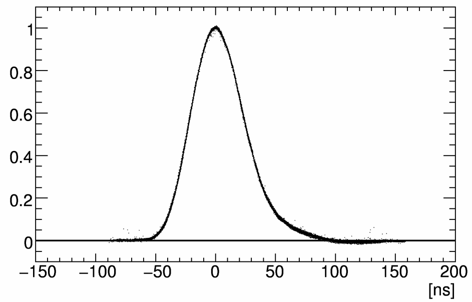
Energy bin 4



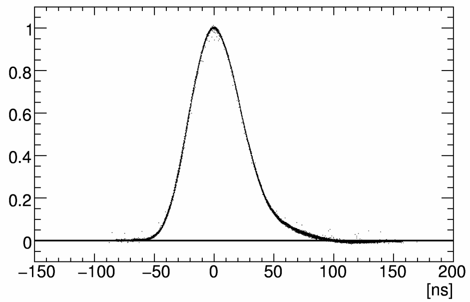
Energy bin 5



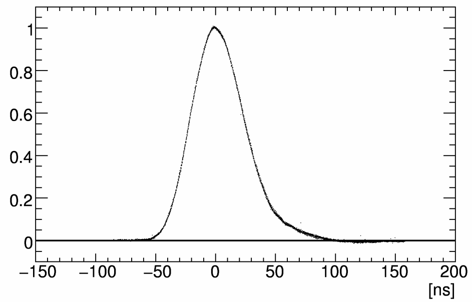
Energy bin 6



Energy bin 7

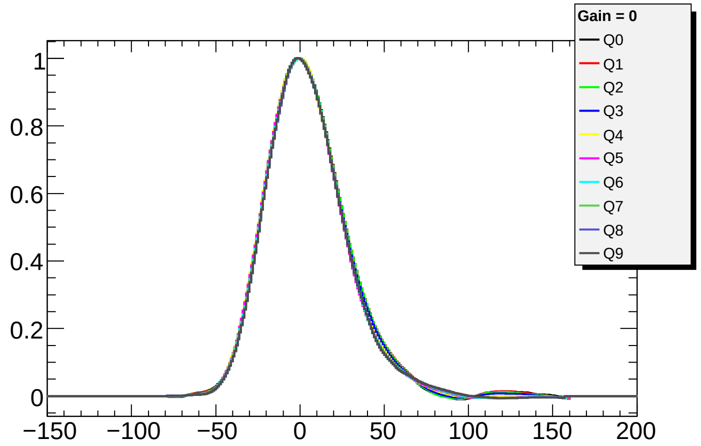


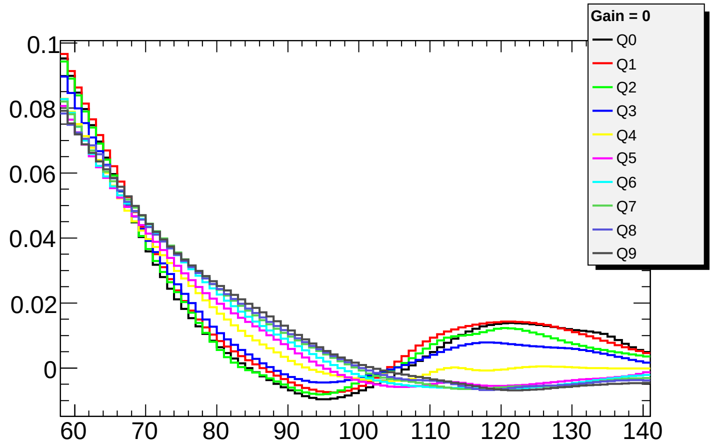
Energy bin 8



Variations between energy bins

Comparing mean pulse shapes from different Q-bins in low gain.





The rightmost plot is a zoom of the tail region. Low energy bins show fluctuations in the tail.

- What effect do these variations have on the reconstructed amplitude?

Toy Monte Carlo

To study the energy bias introduced by variations in pulse shapes we use a toy Monte Carlo technique, using a slightly deformed pulse shape in the fit method.

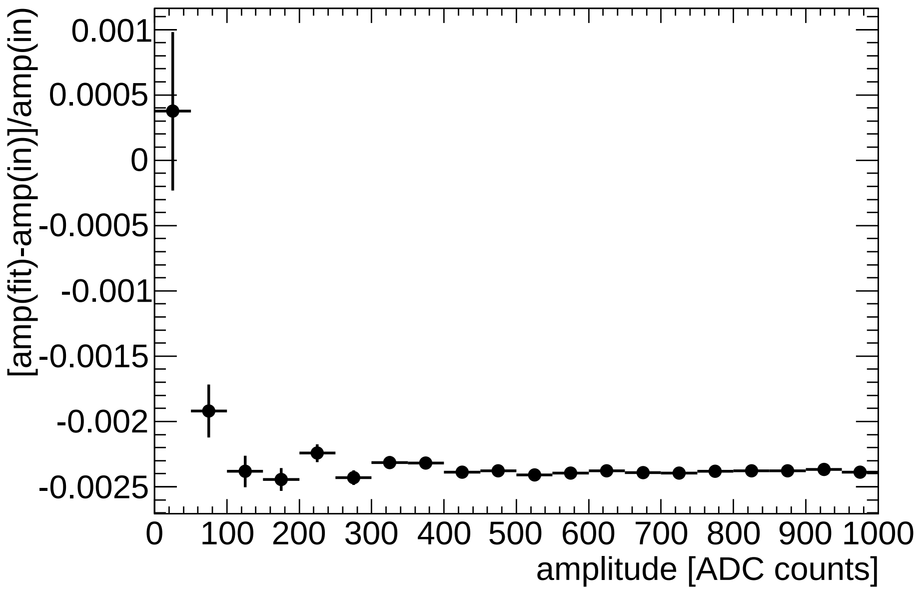
- The mean pulse shape from each energy bin is used to generate pseudo-events.
- The average pulse shape over all energy bins is used to reconstruct the shapes.
- For each amplitude 10,000 pseudo-events are generated, error of each sample is taken to be Gaussian with $\sigma = 1.5$, representing electronics noise.

Energy bias

Define the energy bias b:

$$b = \frac{\langle A_{rec} \rangle - A_{in}}{A_{in}}$$

A_{in} is input amplitude, $\langle A_{rec} \rangle$ is the mean reconstructed amplitude.



Pulse shape from energy bin 4, low gain, used to generate pseudo-events.

Results

Q-bin	Low gain	High gain
0	0.21 %	No data
1	0.14 %	No data
2	0.15 %	0.35 %
3	-0.12 %	0.01 %
4	-0.22 %	-0.06 %
5	-0.30 %	-0.19 %
6	-0.52 %	-0.30 %
7	-0.63 %	-0.31 %
8	-0.71 %	-0.34 %
9	-0.79 %	-0.35 %

Energy bias in different energy bins.

Results

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2	0.15 %	0.35 %
3	-0.12 %	0.01 %
4	-0.22 %	-0.06 %
5	-0.30 %	-0.19 %
6	-0.52 %	-0.30 %
7	-0.63 %	-0.31 %
8	-0.71 %	-0.34 %
9	-0.79 %	-0.35 %

Energy bias in different energy bins.

Q-bin	Low gain	High gain
0	-0.03 %	No data
1	-0.01 %	No data
2	0.04 %	0.22 %
3	-0.06 %	0.03 %
4	0.06 %	-0.01 %
5	0.10 %	-0.14 %
6	-0.01 %	-0.24 %
7	-0.06 %	-0.27 %
8	-0.09 %	-0.29 %
9	-0.13 %	-0.29 %

Energy bias for pulse shapes cutoff at 60 ns.

Conclusions

- We see a 0.5 % underestimate of the energy when entire pulse shape is fitted.
- For low signals, there is a small overestimate.
- The problems arise in the tail region, if the tail is not fitted the energy is more stable.

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Thank you!