Simulation implementation
(How the CALOROC measurement is implemented & How the digitized quantities are stored)

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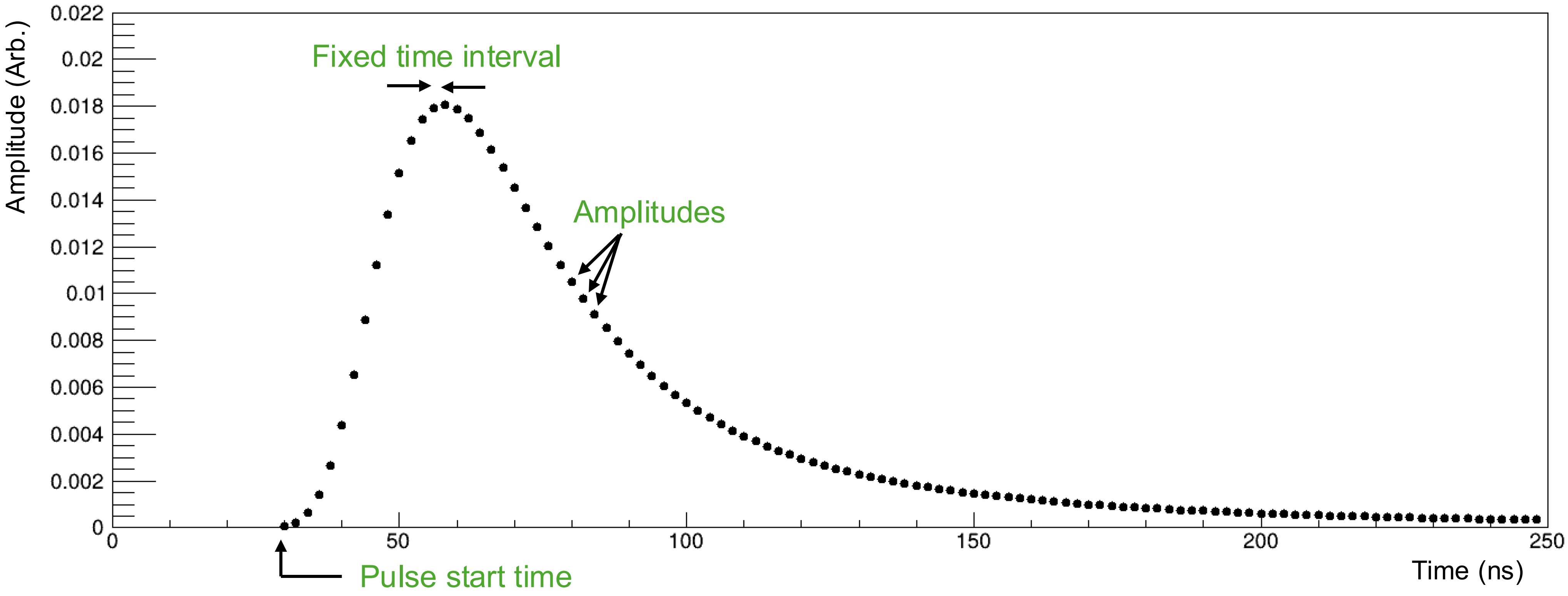
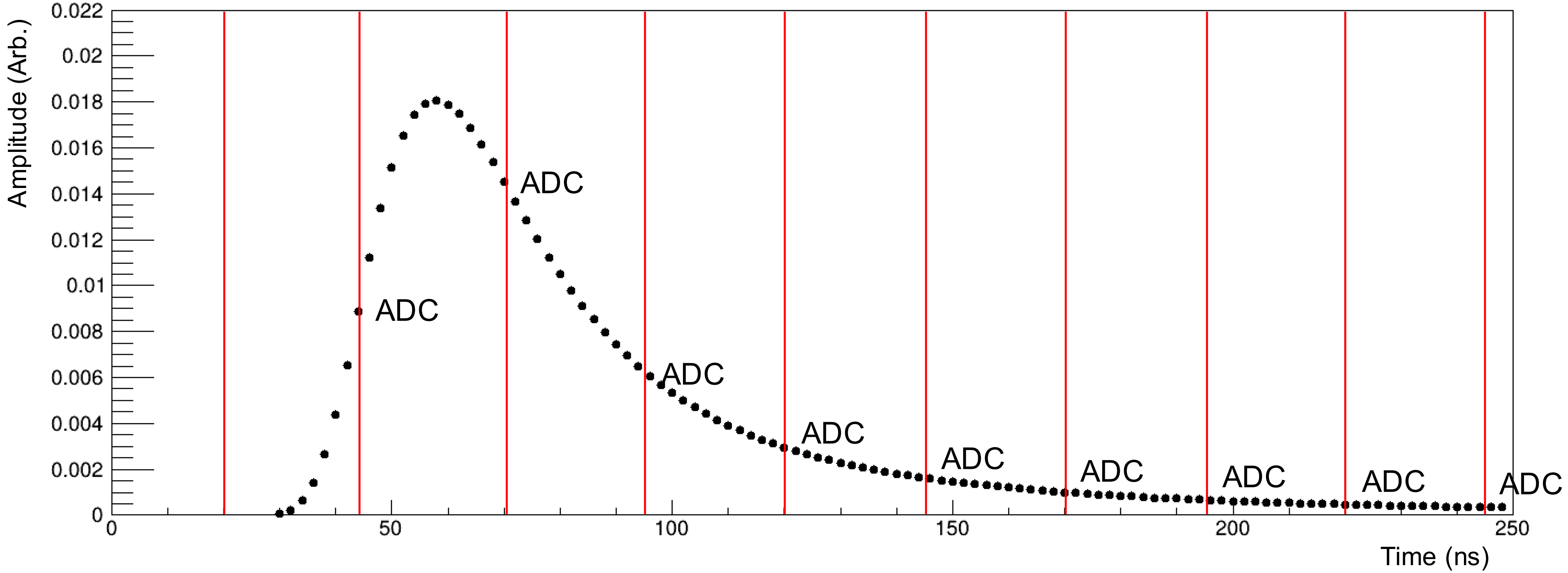
Argonne NATIONAL LABORATORY

Data model for pulse (SimPulse)



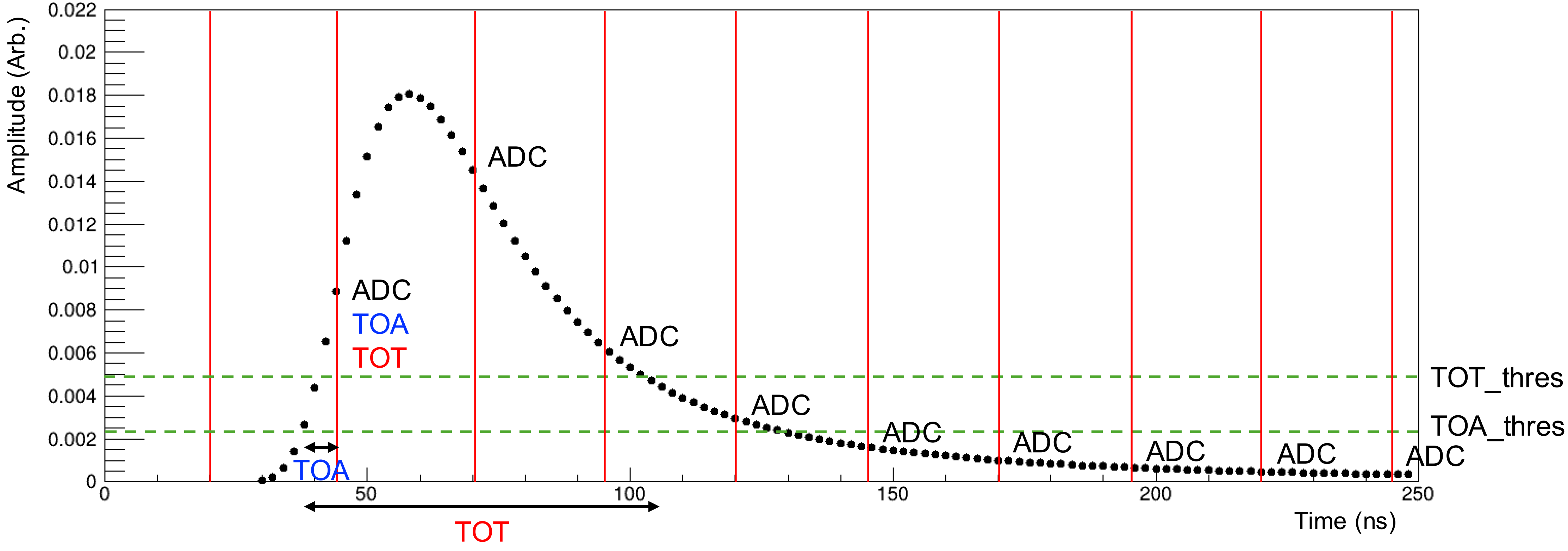
- SimPulse doesn’t store the pulse shape curve itself. Instead, it stores amplitudes at fixed time interval and the pulse start time.
- SimPulse allows us to reconstruct the pulse waveform on the time axis.

Digitized quantities (ADC)



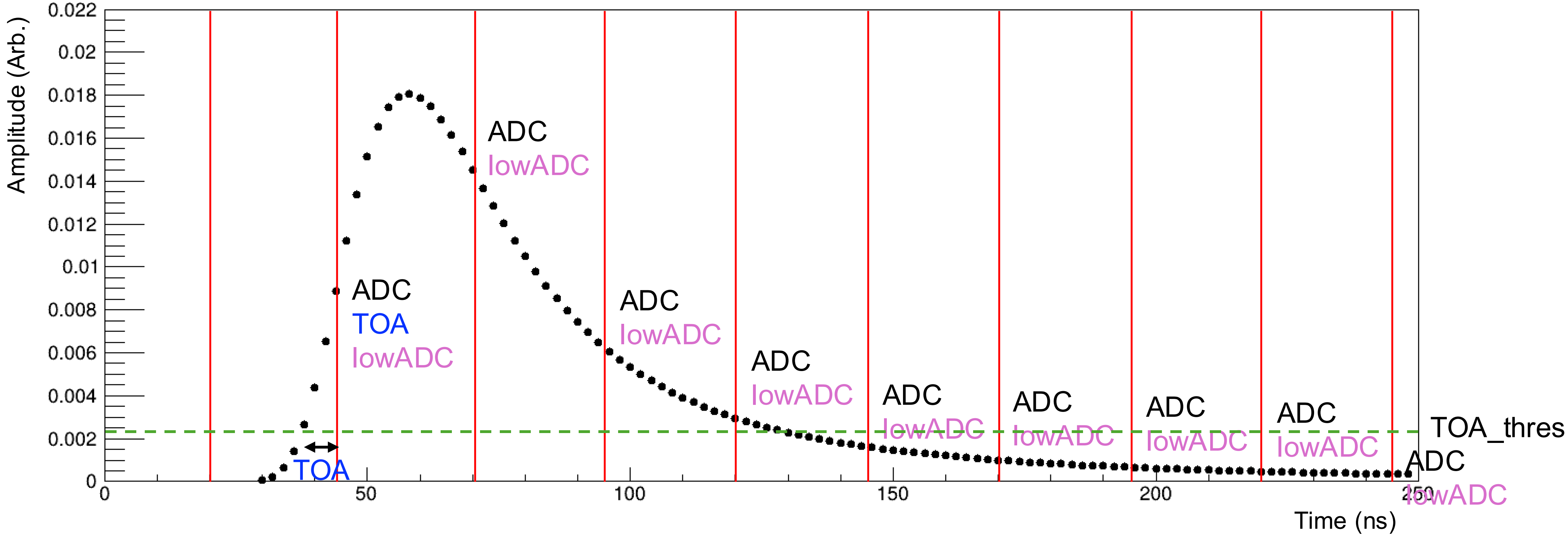
- Now, CALOROC measures the pulse every 25 ns and the samples that overlap with the pulse have the ADC values.

Digitized quantities (TOA & TOT)



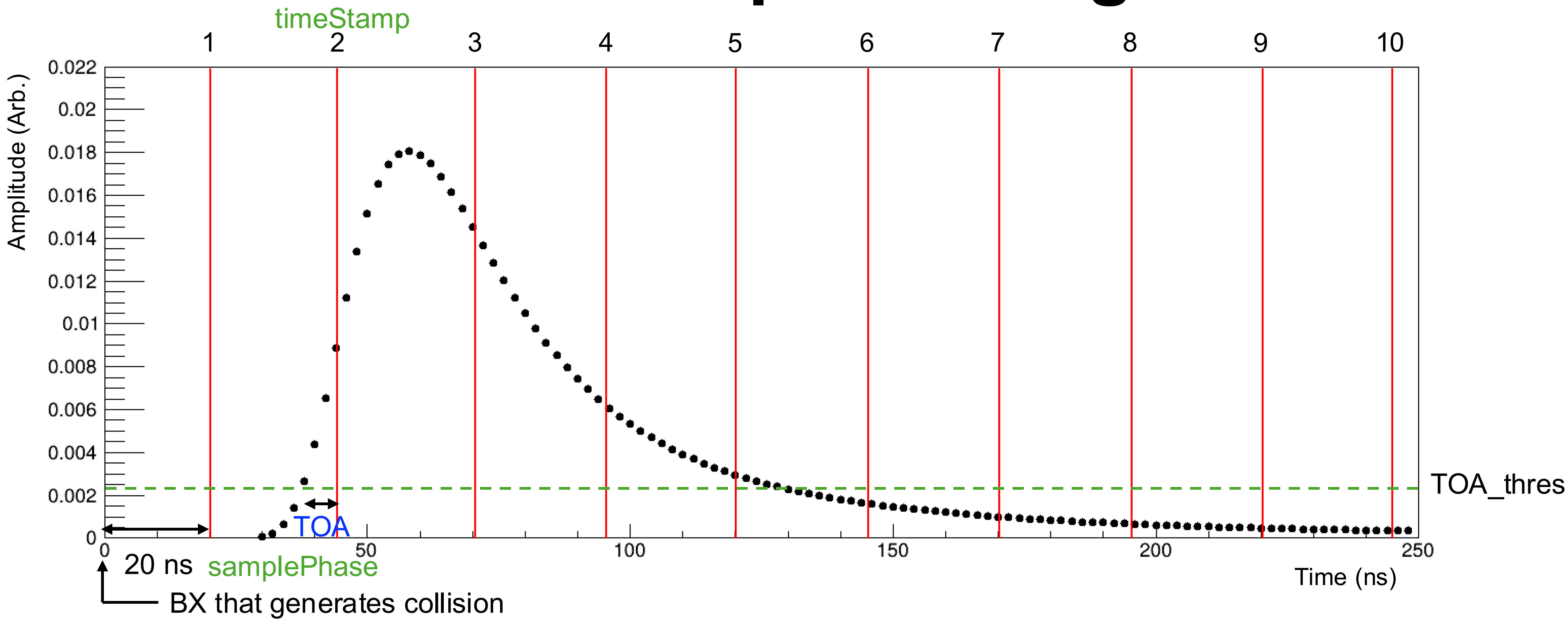
- If the pulse exceeds the TOA_thres, the TOA is defined as the time difference between the up-crossing time at the TOA_thres and the earliest sample after that and it is stored in that earliest sample.
- If the pulse exceeds the TOT_thres, TOT is defined as the time difference between the up-crossing time at the TOA_thres and the down-crossing time at the TOT_thres and it is stored in the same sample where the TOA is stored.
- Here, CALOROC1A chip measures and stores ADC, TOA, and TOT.

Digitized quantities (lowADC)



- CALOROC1B chip measures the same ADC and TOA, but measures low gain ADC (lowADC) instead of the TOT.

How to determine the up-crossing time



- We can’t determine the up-crossing time from the TOA alone.
- To determine the up-crossing time, in real experiment, CALOROC also records the phase difference between the sample and the BX, and the sample index relative to the BX.
- In simulation, assuming 0 s is the BX that generates collision, the phase difference between the first global sample and the BX, and the sample index of the first measurement sample are stored as samplePhase and timeStamp to determine the up-crossing time.

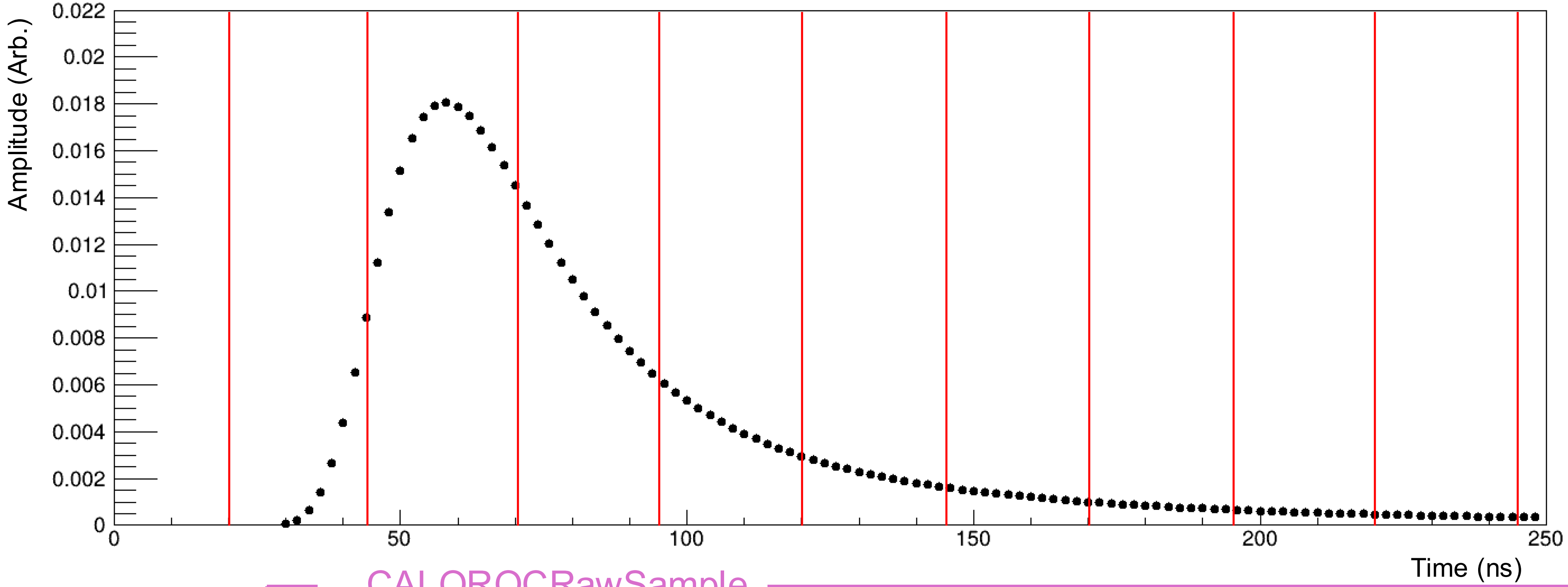
Data model for digitized quantities

```
edm4eic::RawCALOROCHit:
  Description: "Raw hit from a CALOROC1A/B chip"

  Members:
    - uint64_t cellID
    - int32_t  samplePhase
    - int32_t  timeStamp
  VectorMembers:
    - edm4eic::CALOROC1ASample aSamples
    - edm4eic::CALOROC1BSample bSamples
```

```
edm4eic::CALOROC1ASample:
  Members:
    - uint16_t ADC
    - uint16_t timeOfArrival
    - uint16_t timeOverThreshold

edm4eic::CALOROC1BSample:
  Members:
    - uint16_t lowGainADC
    - uint16_t highGainADC
    - uint16_t timeOfArrival
```

- Finally, the digitized quantities are stored in a data model called RawCALOROCHit.
- This data model has been approved at the S&C meeting last week (PR).
- A digitization algorithm that reproduces the CALOROC measurements is being implemented now (PR).

How the digitization algorithm works

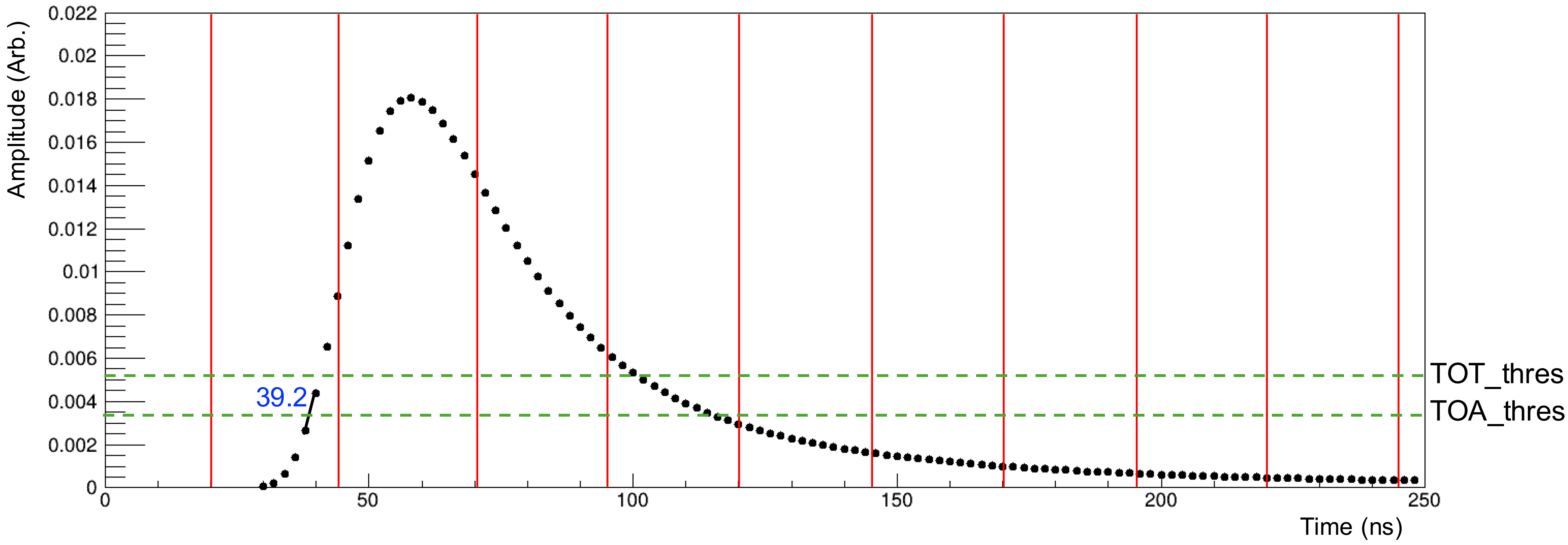


CALOROCRawSample

ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}
TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

- A class CALOROCRawSample is defined. In CALOROCRawSample, a struct that contains ADC, TOA, and TOT is defined and the CALOROCRawSampe has a vector member of that struct.
- First of all, we pre-size the vector member referring to the number of samples to be measured.

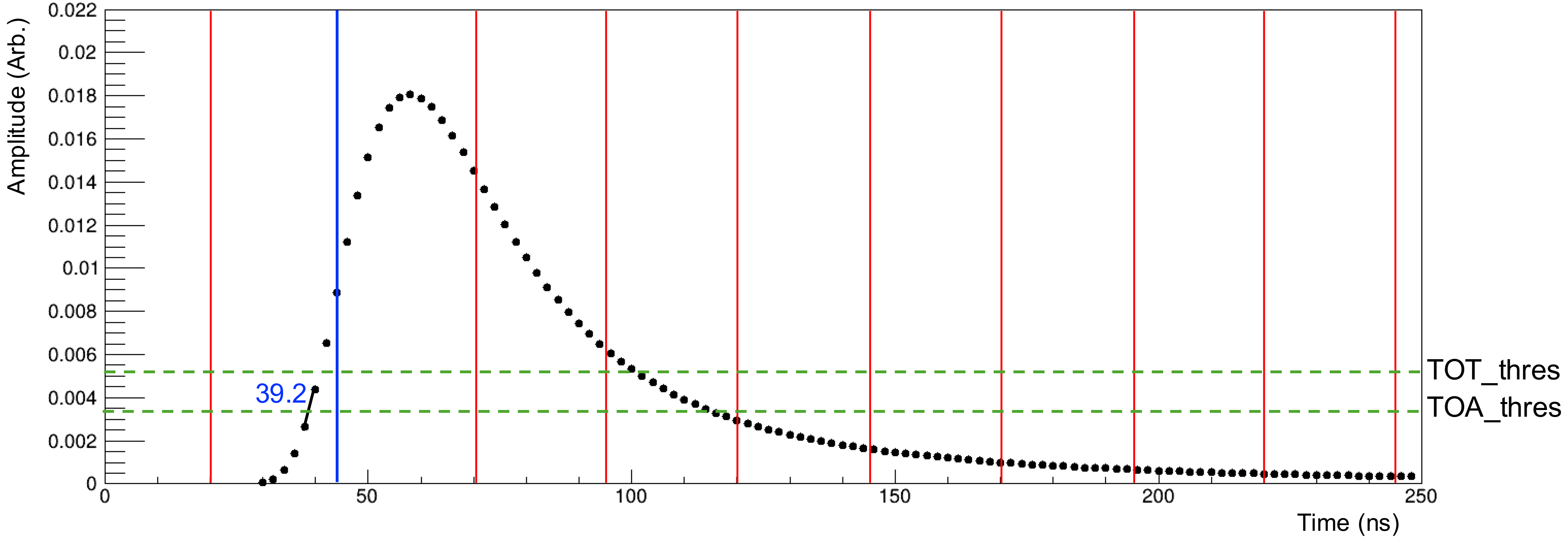
How the digitization algorithm works



CALOROCRawSample

ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}
TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

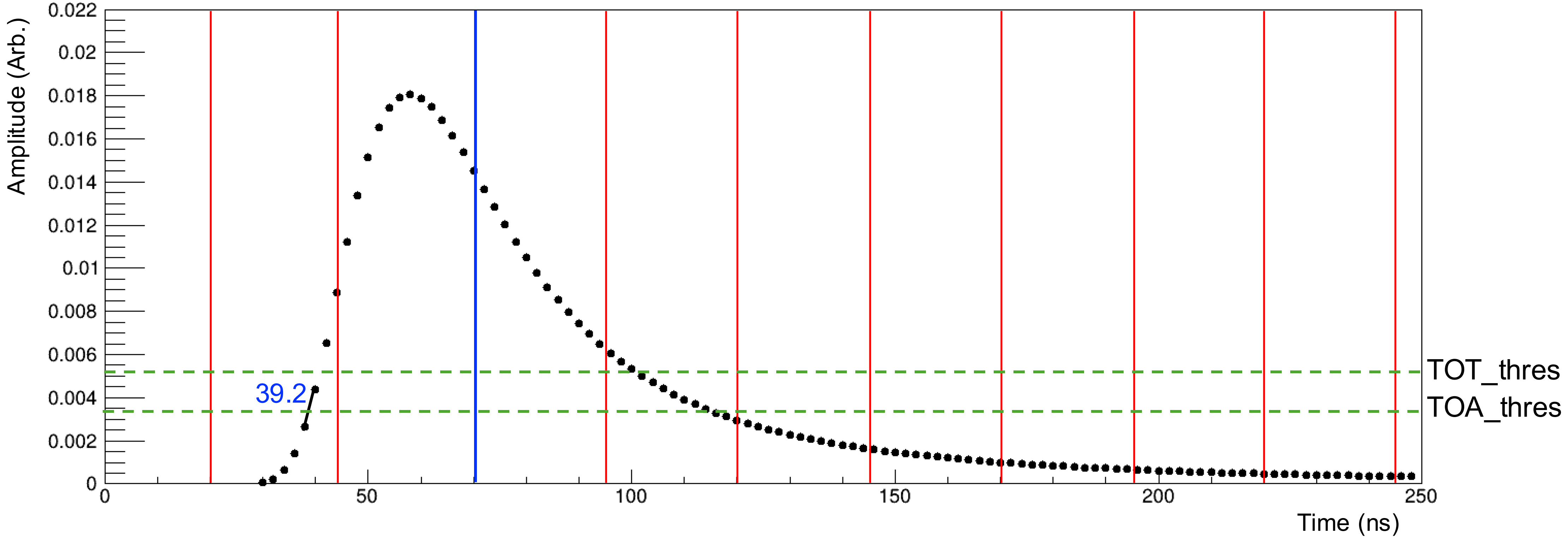
How the digitization algorithm works



CALOROCRawSample

ADC{**0.0087**}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}
TOA{**5.80**}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

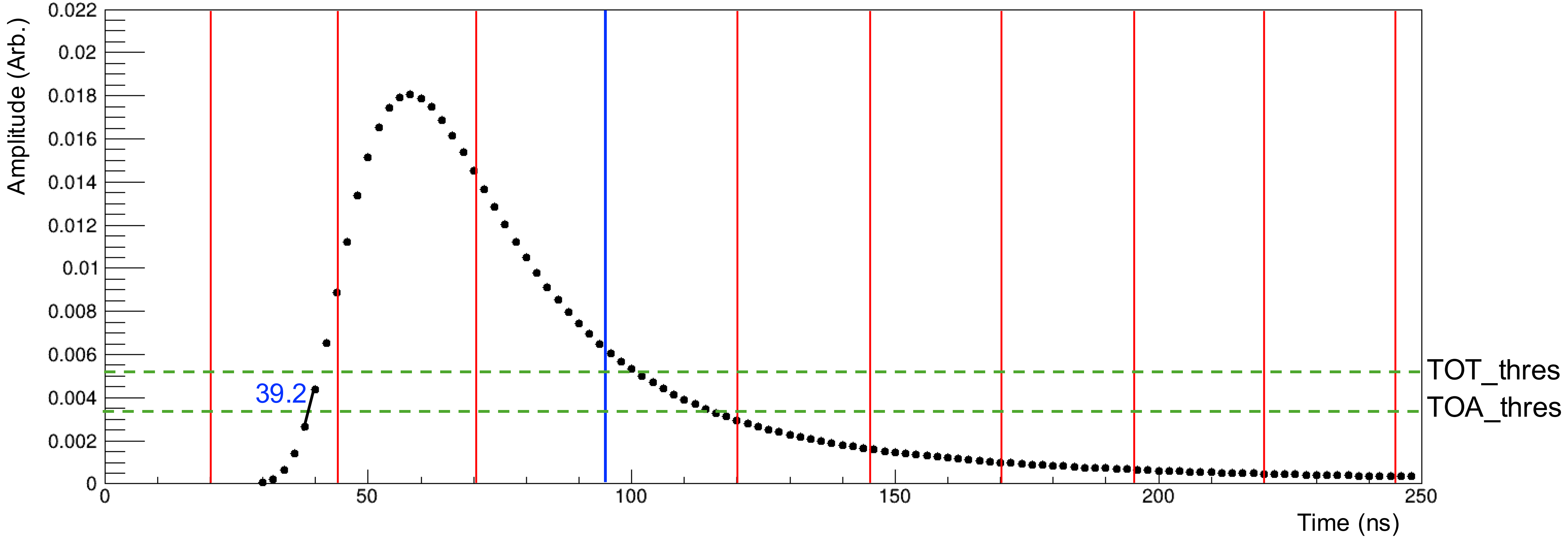
How the digitization algorithm works



CALOROCRawSample

ADC{0.0087}	ADC{**0.0144**}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}
TOA{5.80}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

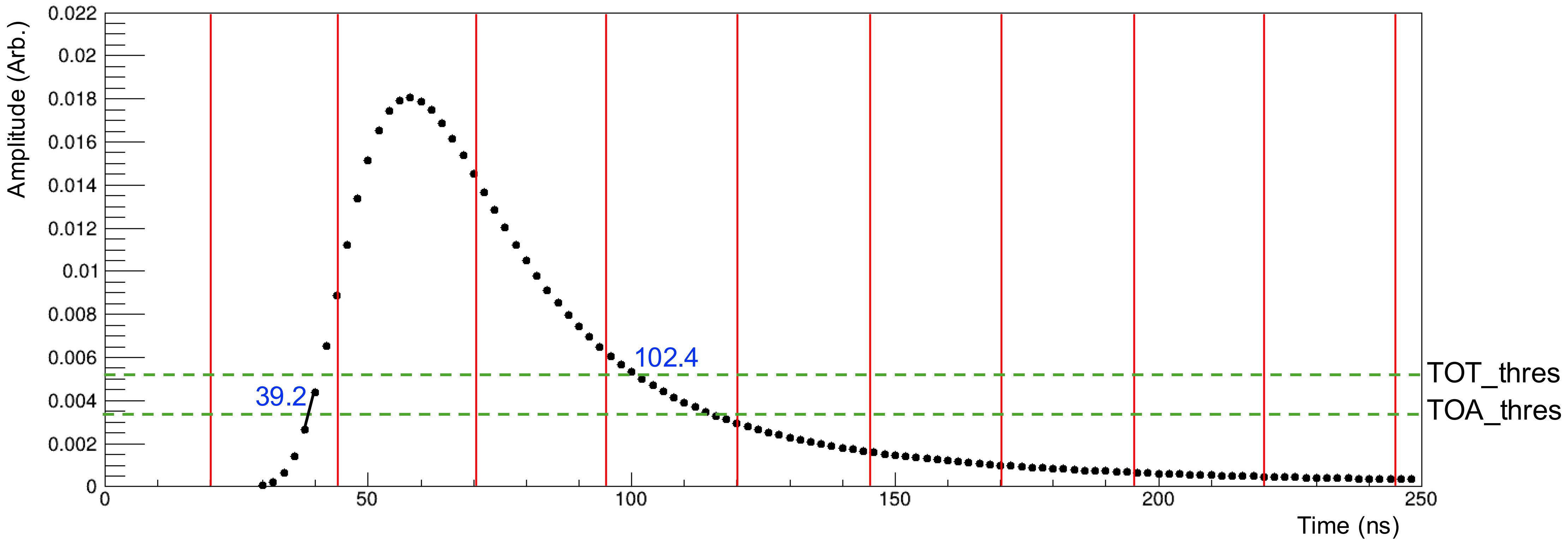
How the digitization algorithm works



CALOROCRawSample

ADC{0.0087}	ADC{0.0144}	ADC{**0.0064**}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}
TOA{5.80}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

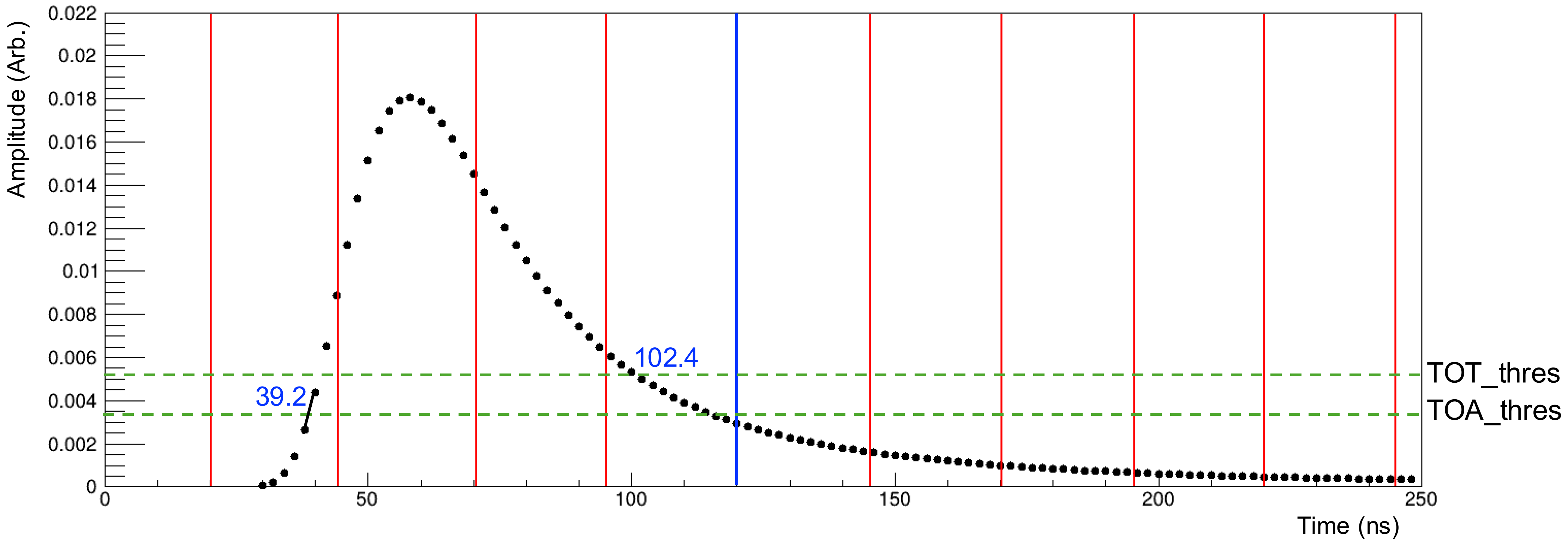
How the digitization algorithm works



CALOROCRawSample

ADC{0.0087}	ADC{0.0144}	ADC{0.0064}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}
TOA{5.80}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{**63.2**}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

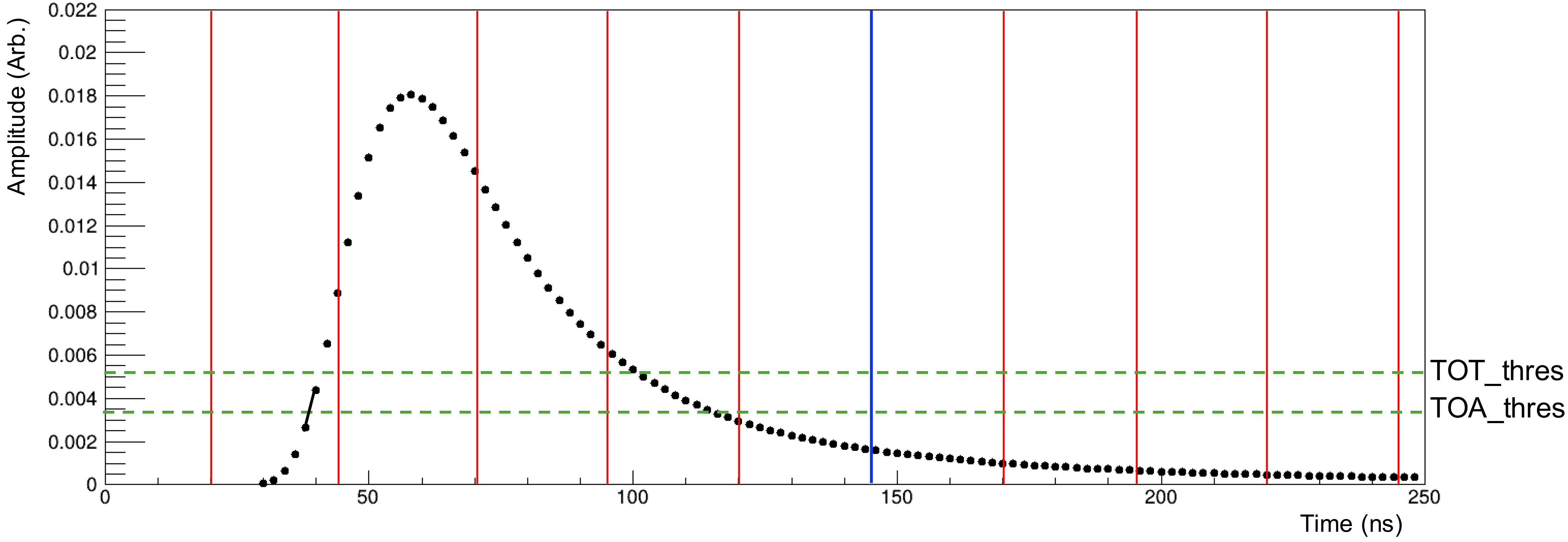
How the digitization algorithm works



CALOROCRawSample

ADC{0.0087}	ADC{0.0144}	ADC{0.0064}	ADC{**0.0031**}	ADC{0}	ADC{0}	ADC{0}	ADC{0}	ADC{0}
TOA{5.80}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{63.2}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

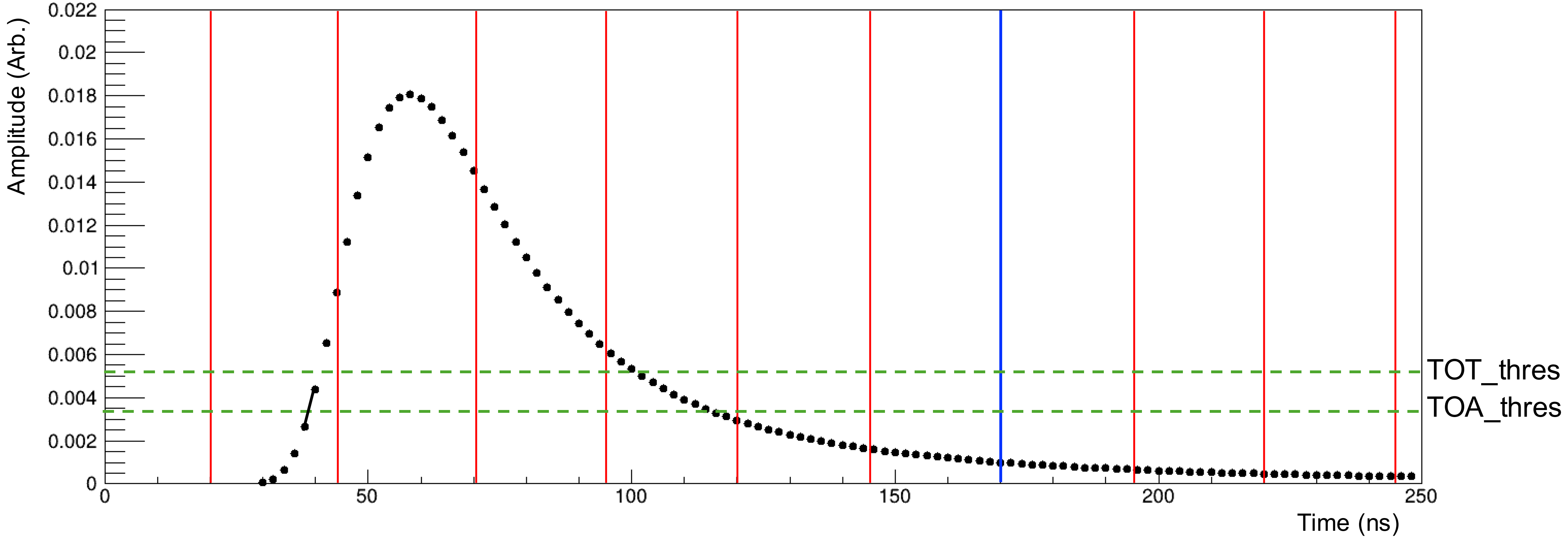
How the digitization algorithm works



CALOROCRawSample

ADC{0.0087}	ADC{0.0144}	ADC{0.0064}	ADC{0.0031}	ADC{**0.0018**}	ADC{0}	ADC{0}	ADC{0}	ADC{0}
TOA{5.80}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{63.2}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

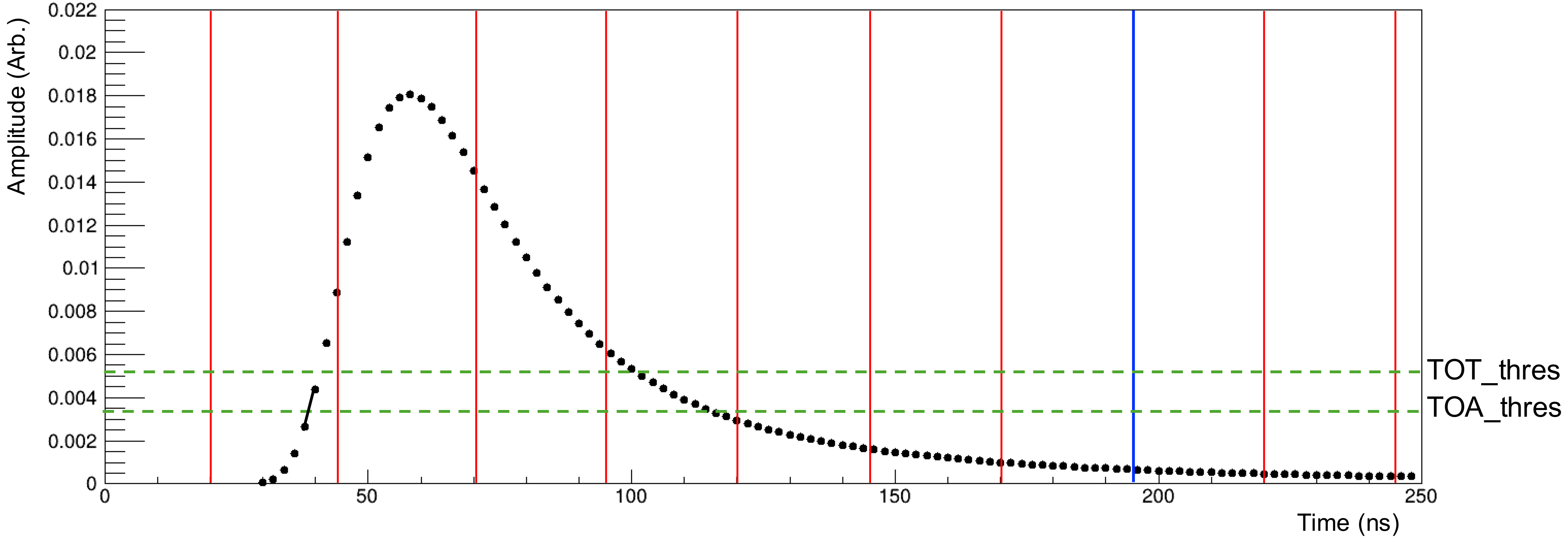
How the digitization algorithm works



CALOROCRawSample

ADC{0.0087}	ADC{0.0144}	ADC{0.0064}	ADC{0.0031}	ADC{0.0018}	ADC{**0.0016**}	ADC{0}	ADC{0}	ADC{0}
TOA{5.80}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{63.2}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

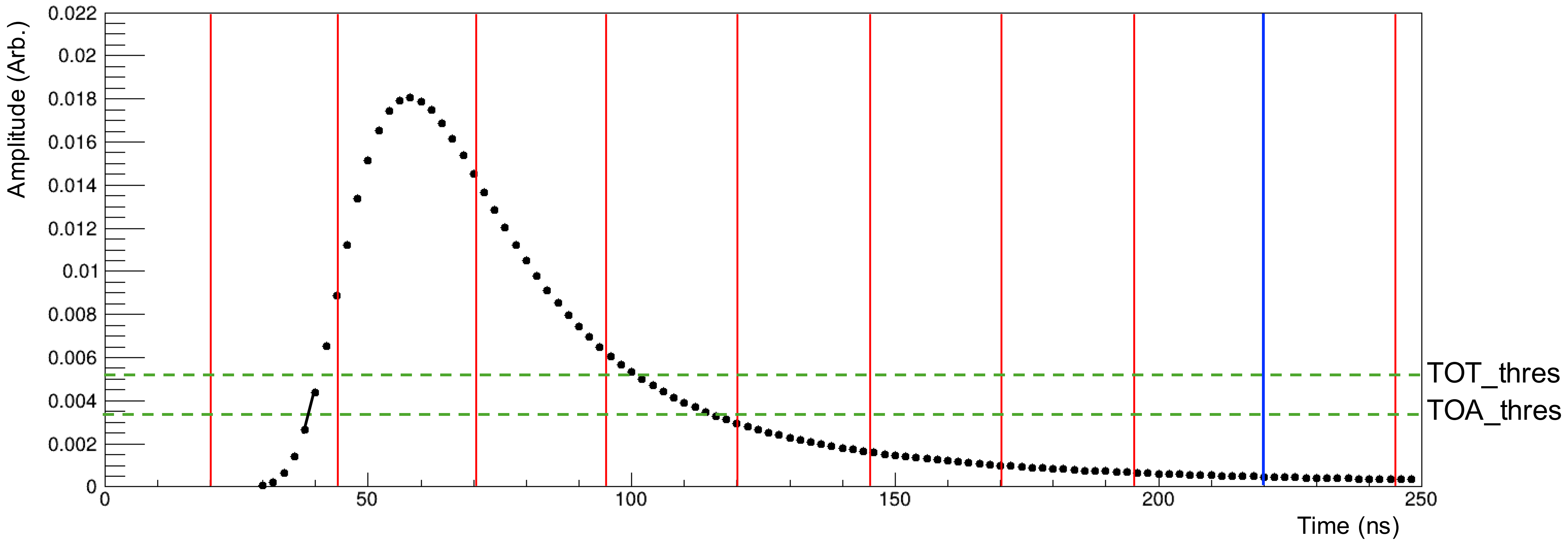
How the digitization algorithm works



CALOROCRawSample

ADC{0.0087}	ADC{0.0144}	ADC{0.0064}	ADC{0.0031}	ADC{0.0018}	ADC{0.0016}	ADC{**0.0009**}	ADC{0}	ADC{0}
TOA{5.80}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{63.2}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

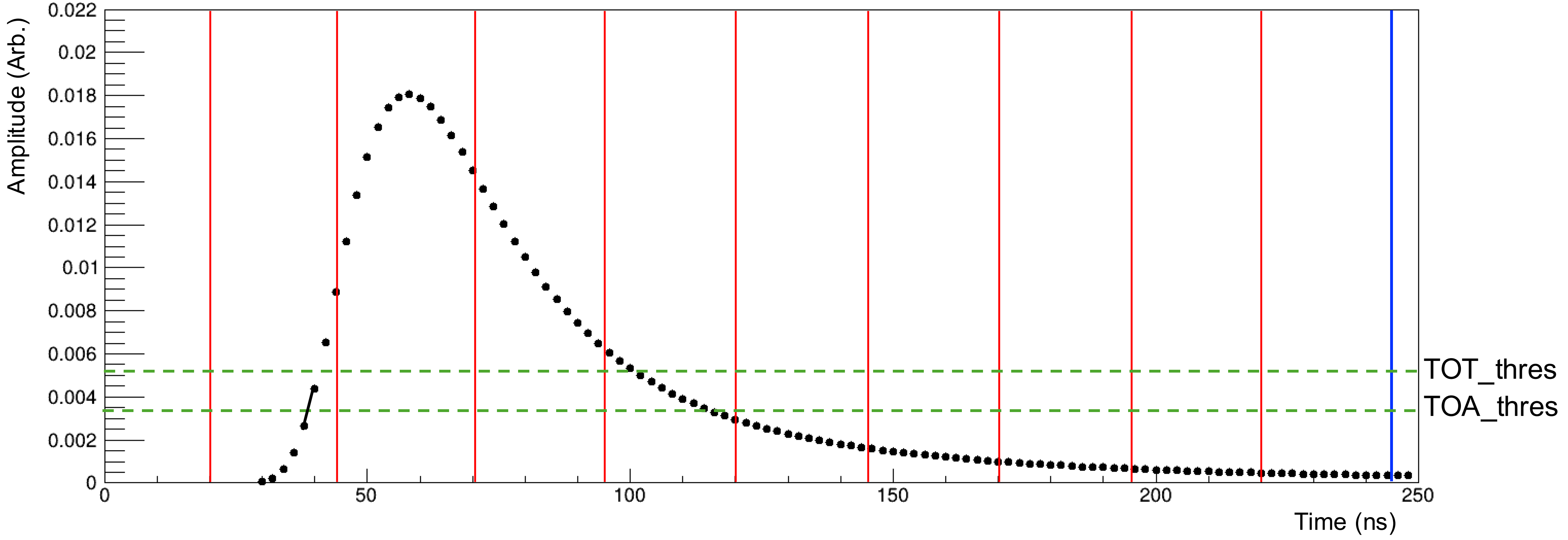
How the digitization algorithm works



CALOROCRawSample

ADC{0.0087}	ADC{0.0144}	ADC{0.0064}	ADC{0.0031}	ADC{0.0018}	ADC{0.0016}	ADC{0.0009}	ADC{**0.0008**}	ADC{0}
TOA{5.80}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{63.2}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

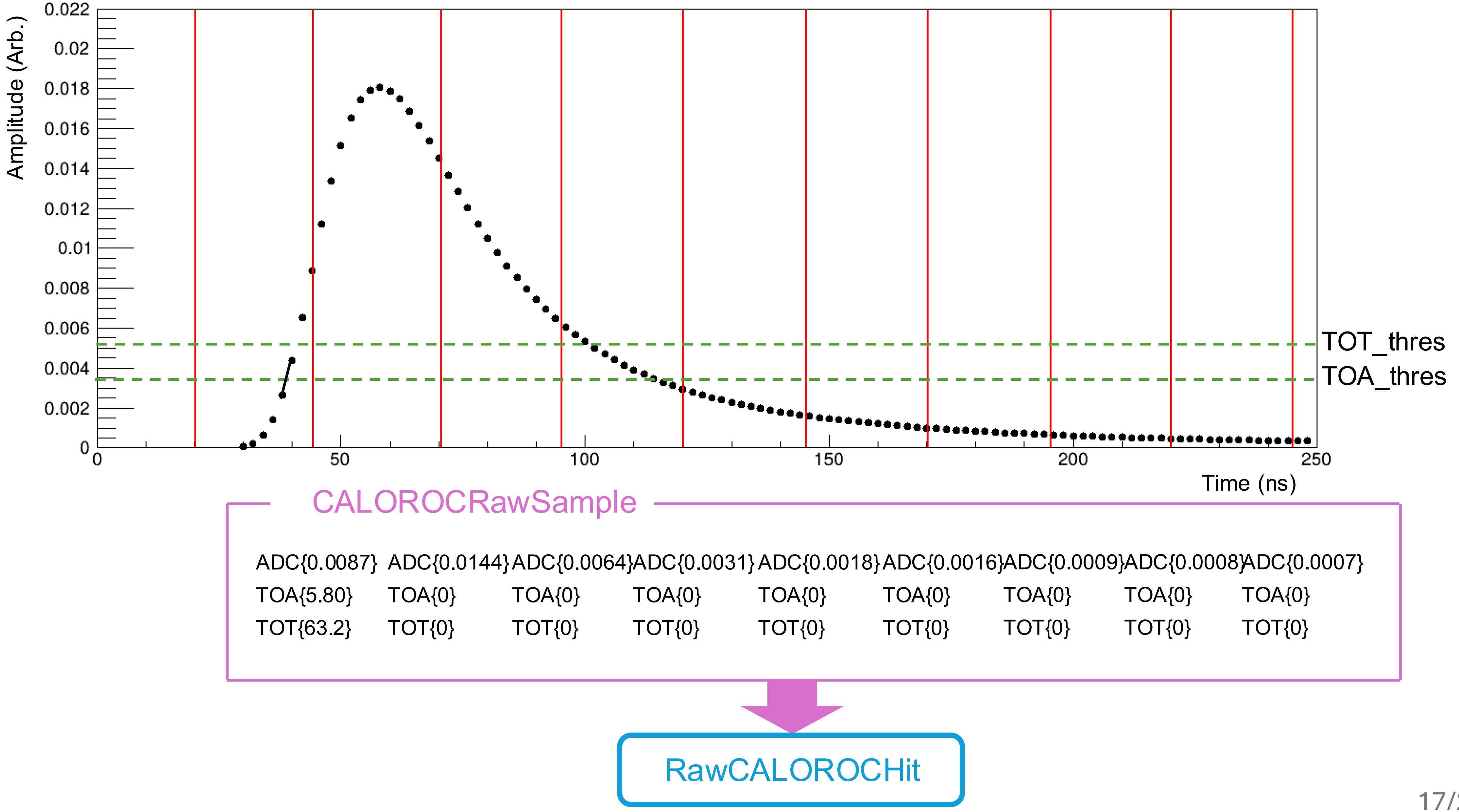
How the digitization algorithm works



CALOROCRawSample

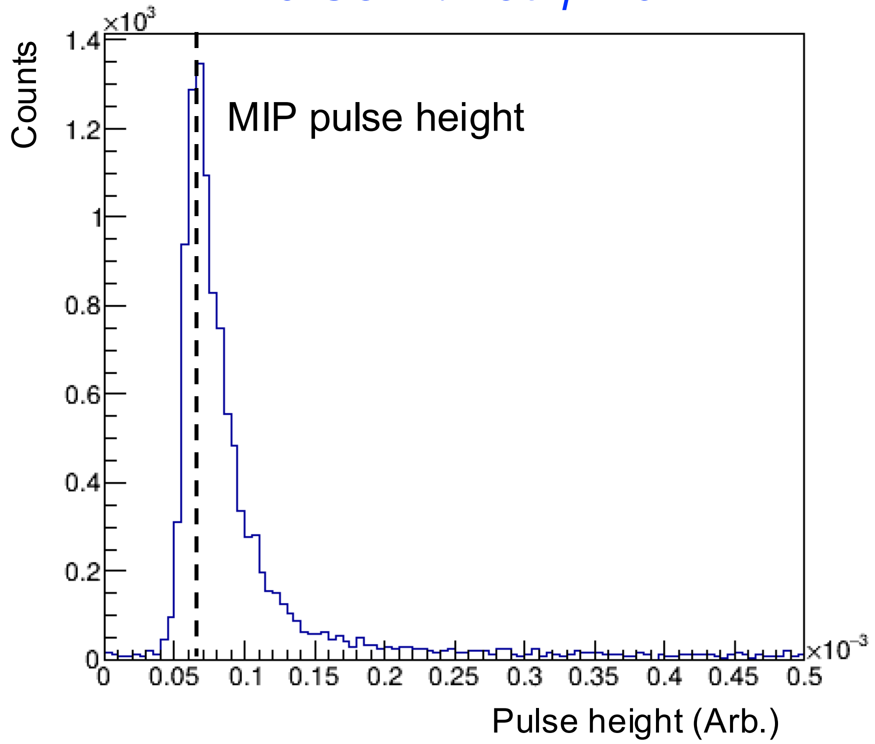
ADC{0.0087}	ADC{0.0144}	ADC{0.0064}	ADC{0.0031}	ADC{0.0018}	ADC{0.0016}	ADC{0.0009}	ADC{0.0008}	ADC{**0.0007**}
TOA{5.80}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}	TOA{0}
TOT{63.2}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}	TOT{0}

How the digitization algorithm works

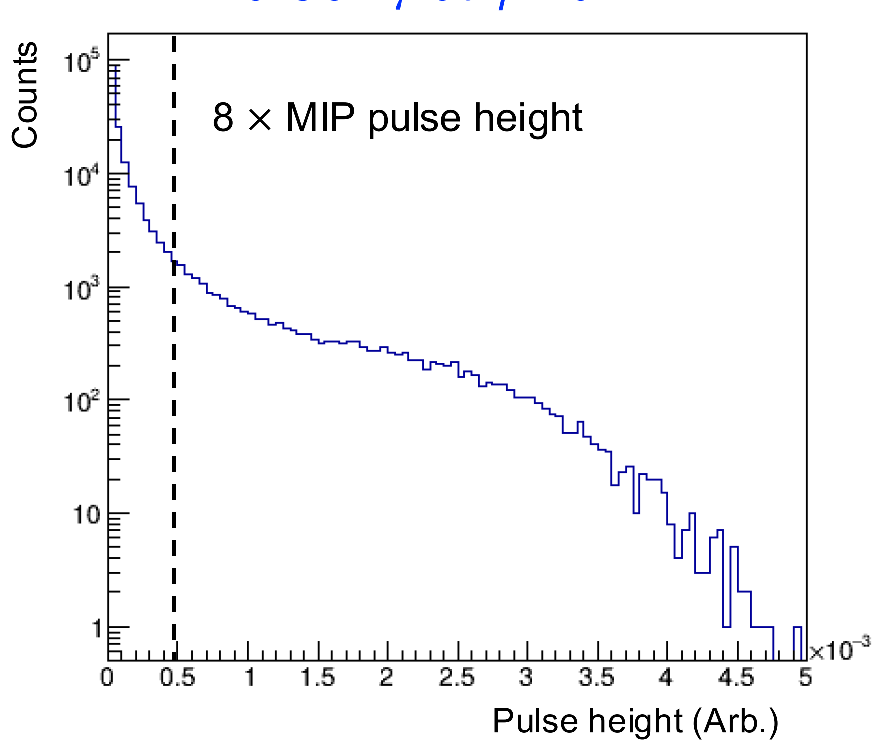


Sanity checks (TOA and TOT thresholds)

20 GeV π^- at $\eta = 0$



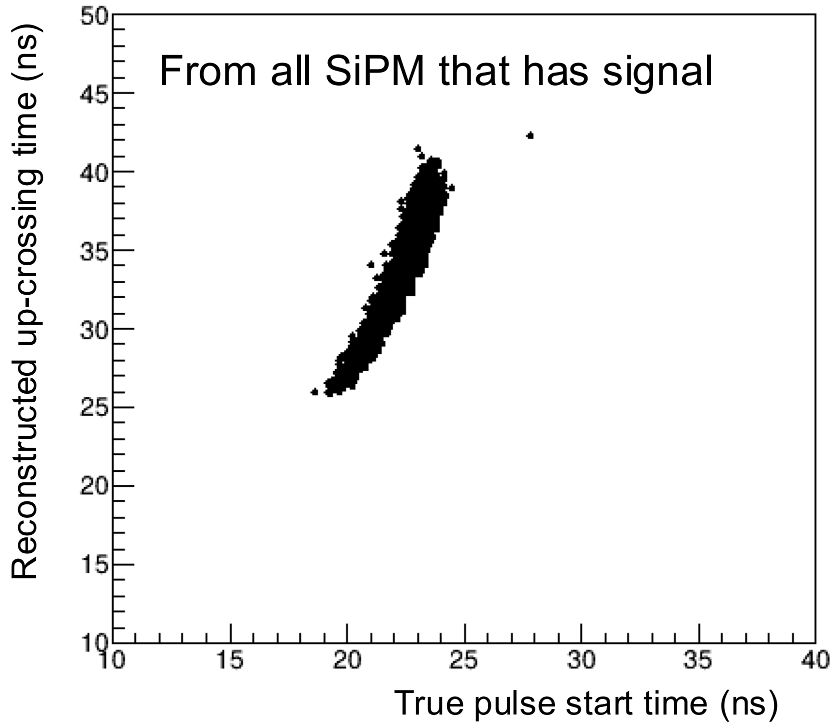
5 GeV γ at $\eta = 0$



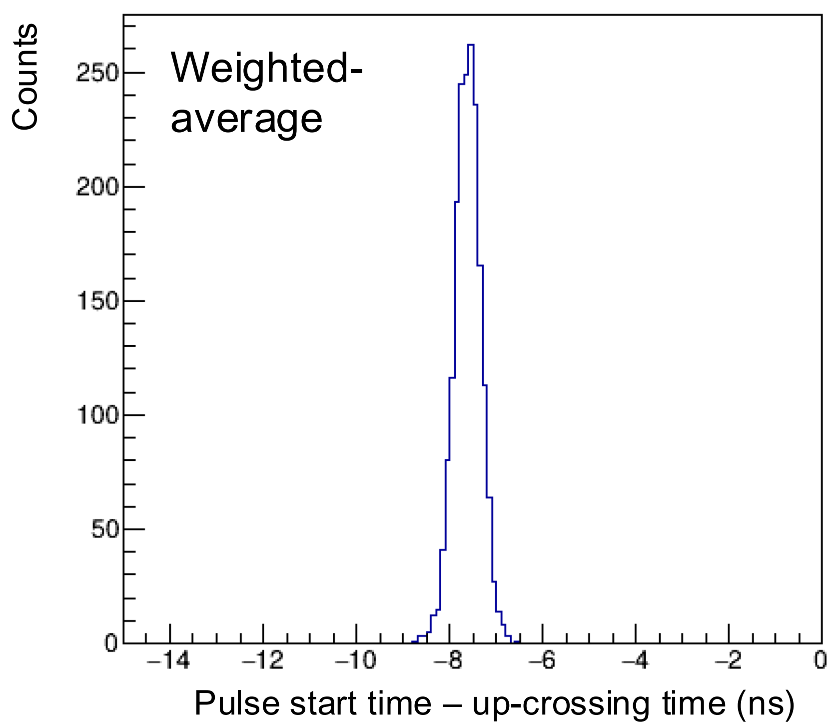
- Currently, the pulse height in this study is simply proportional to the energy deposit sum. Conversion to number of photoelectrons and the corresponding Poisson smearing was not applied yet.
- Barrel Imaging Calorimeter data was used for sanity checks.
- About 8 times of MIP equivalent pulse height (~0.0005) was used as the TOA and TOT thresholds.

Sanity checks (TOA)

5 GeV γ at η = 0

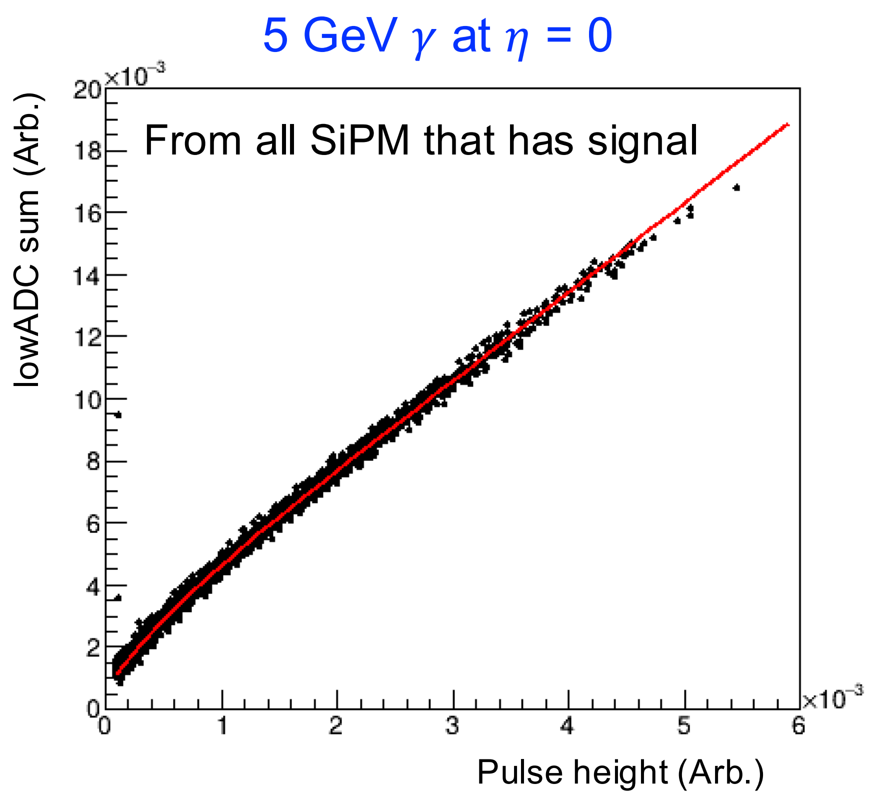


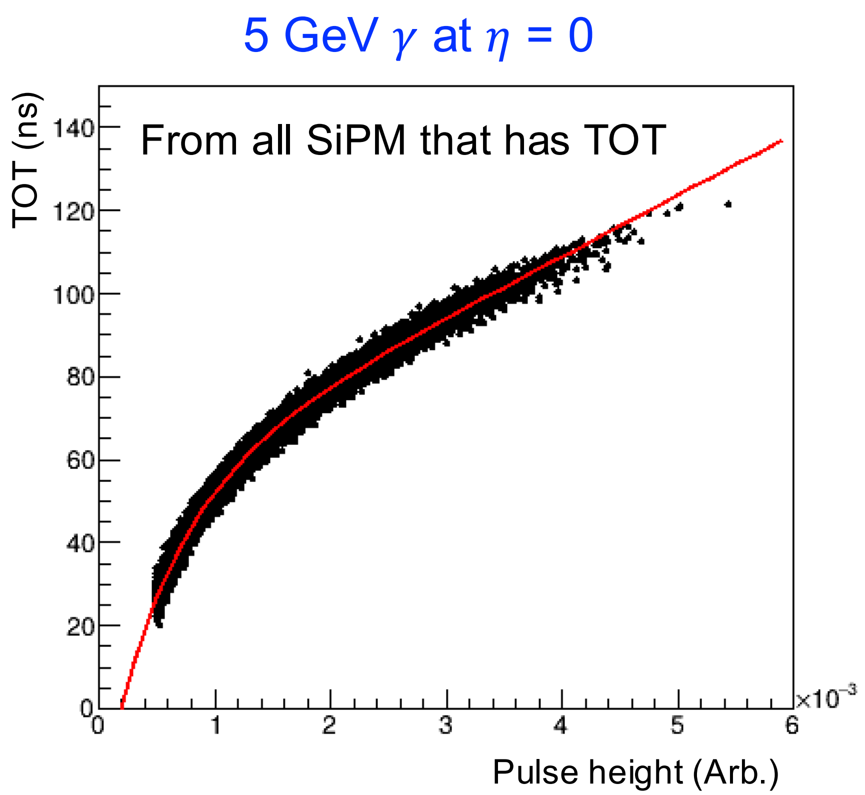
5 GeV γ at η = 0



- The up-crossing time was reconstructed using the TOA, timeStamp, and samplePhase.
- The correlation between the pulse start time and the up-crossing time, and the corresponding weighted pulse time – up-crossing time distribution look reasonable.

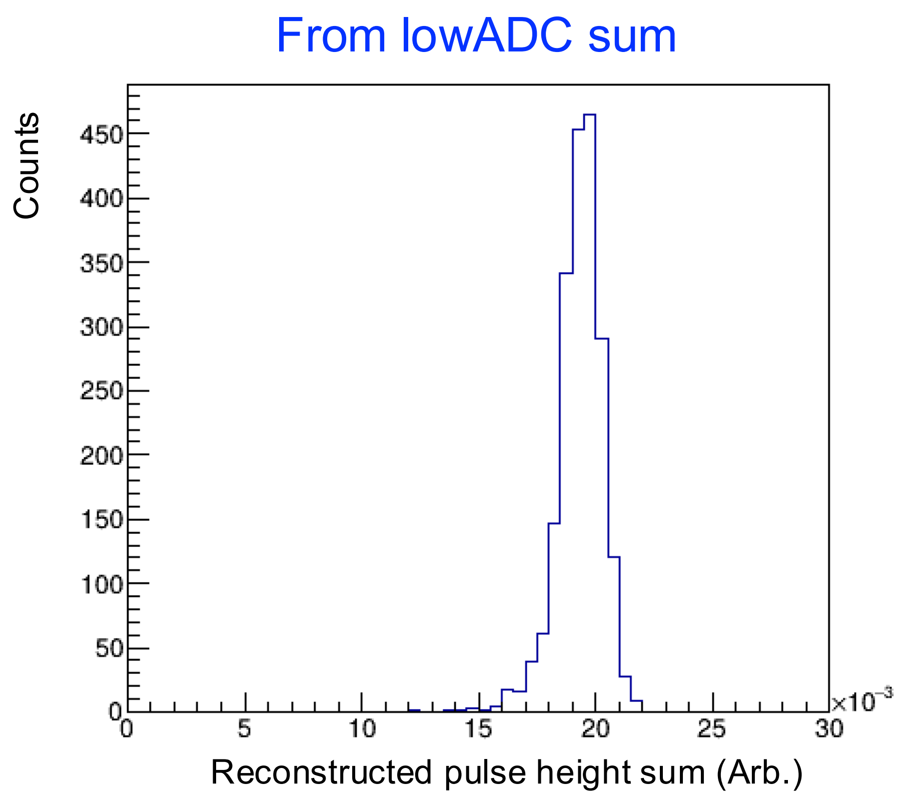
Sanity checks (ADC & TOT)

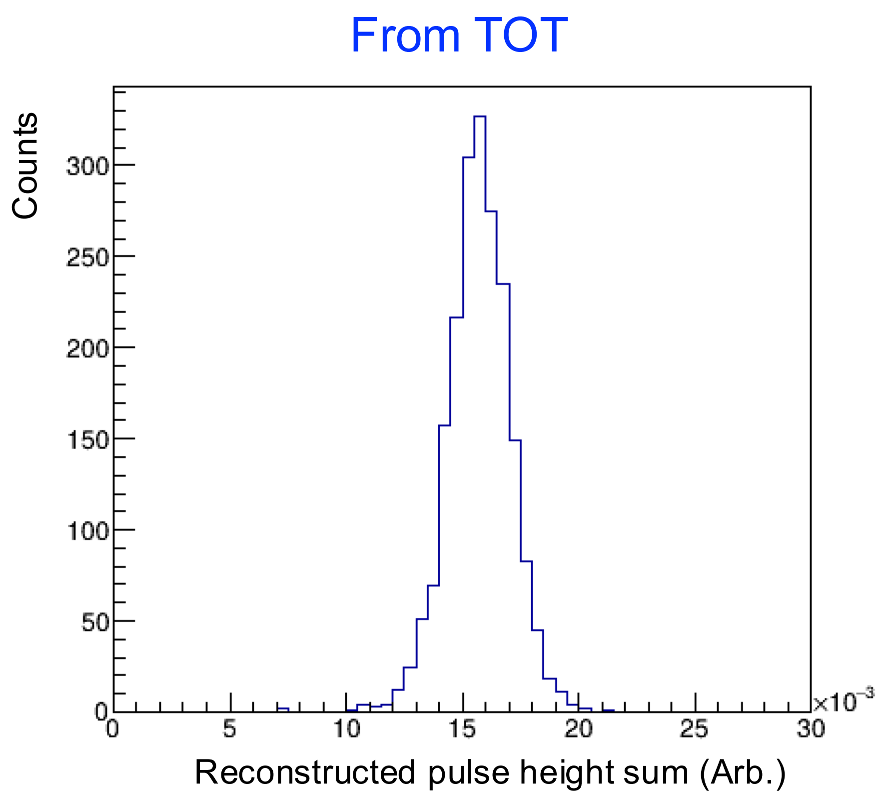




- ADC and TOT measurements also seem to be working properly.
- We can fit the low ADC / TOT vs. pulse height distribution and using the fitting function, we can roughly compare the energy reconstruction performance of the CALOROC1A and 1B.

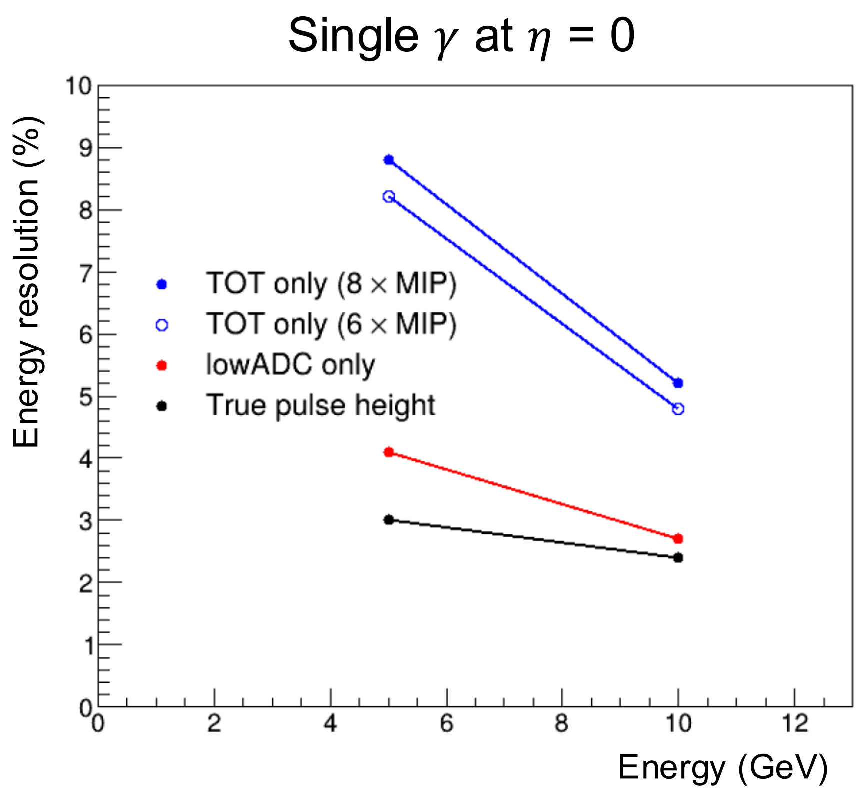
Energy reconstruction (first level)





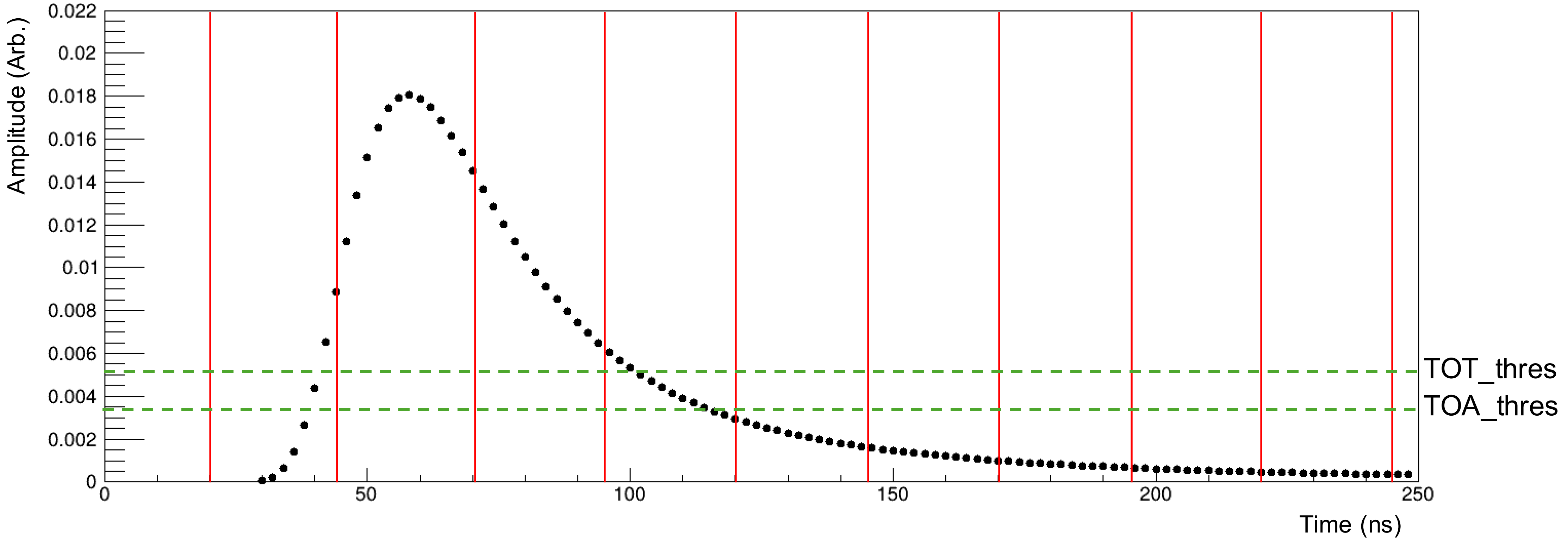
- The pulse height sum distribution from the lowADC looks less fluctuated since more SiPM channels are used.

Energy reconstruction (first level)



- Energy reconstruction from the lowADC sum shows a better performance than the TOT only.
- Each resolution could be improved by
  - lowADC: fitting the ADC data points.
  - TOT: including the ADC values from the SiPMs that have no TOT value.

How to improve the energy reconstruction



Next plan

- Will complete the digitization algorithm and implement the corresponding reconstruction algorithm.
- With the completed digitization and reconstruction algorithms, the CALOROC measurement performance will be studied in more detail.

A

- B