Signal deconvolution for energy estimation considering the TileCal upgrade

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Objective

- Adapt the algorithm to read the pulse signal which came from the calorimeter - free running format.
- Application of the signal deconvolution linear method for the amplitude estimation[1].
- Determine the ideal window by the mean of the estimation error and the standard deviation analysis (K-Fold).

[1] De A Filho et al. "Calorimeter response deconvolution for energy estimation in high-luminosity conditions". In: *IEEE Transactions on Nuclear Science 62.6 (2015): 3265-3273* (2015).

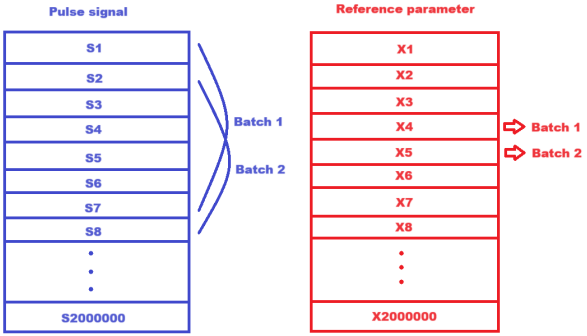
Pulse signal data simulated computationally with the pulse generator code

- Pulse Generator repository on GitHub[2].
- The data of the occupations were simulated considering:
  amplitude distribution: exponential with mean equal to 100 ADC Count.
  phase distribution: integer uniform ranging from -5 to 5 ns.
  Pedestal: 30 ADC Count.
  Deformation level: 0.01 ADC Count.
  Number of events: 2,000,000.
  K-Fold = 100 blocks.

[2] G. I. Gonçalves. *Pulse Generator Repository*. Last accessed 19 May 2024. 2021. URL: https://github.com/ingoncalves/calorimetry-pulse-simulator/tree/master.

New upgrade of LHC - Free running data format

Figure: Model of interpretation of signals data in free running format according to the window size.



Source: the author, 2024.

Signal convolution

- In this case, linear time-invariant model - LTI is considerate for the digitized data by the calorimeter.
- The received signal $y[n]$ is modeled as a convolution between the target signal $a[n]$ and the signal transmitted by the answer channel $h[n]$ summed with a noise part $w[n]$. Mathematically (equation 1):

$$y[n] = \sum_{i=-\infty}^{+\infty} (h[i]\, a[n-i]) + w[n]\,. \tag{1}$$

Signal deconvolution

- For $P = N$, the covariance matrix $\mathbf{C}$ modeled based in the white gaussian can be disregarded, which simplifies the method for the following equation 2:

$$\hat{\mathbf{a}}_P = \mathbf{H}^{-1}\mathbf{y}. \tag{2}$$

- The estimated amplitude a_{est} is the central element of the vector $\hat{\mathbf{a}}_P$.
- The $\mathbf{H}^{-1}$ matrix is denominated the deconvolution matrix (DM).
- Amplitude estimation error is the difference between the reference amplitude minus the estimated (equation 3):

$$e = a_{ref} - a_{est} \tag{3}$$

H matrix

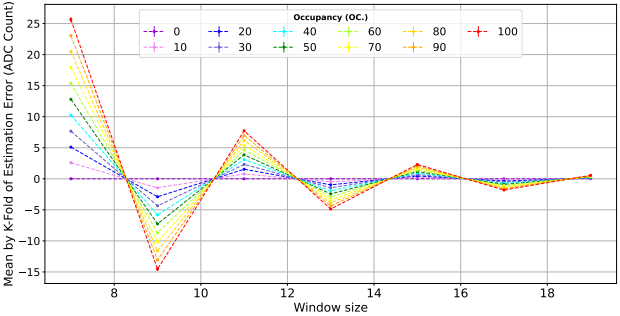
- The H matrix has in the central column all the values of the reference pulse, while the others lines are the shifted versions of these pulses[3]. This is an example of the matrix H for a 7-window case (equation 4):

$$\mathbf{H_P} = \begin{bmatrix} h_4 & h_5 & h_6 & h_7 & 0 & 0 & 0 \\ h_3 & h_4 & h_5 & h_6 & h_7 & 0 & 0 \\ h_2 & h_3 & h_4 & h_5 & h_6 & h_7 & 0 \\ h_1 & h_2 & h_3 & h_4 & h_5 & h_6 & h_7 \\ 0 & h_1 & h_2 & h_3 & h_4 & h_5 & h_6 \\ 0 & 0 & h_1 & h_2 & h_3 & h_4 & h_5 \\ 0 & 0 & 0 & h_1 & h_2 & h_3 & h_4 \end{bmatrix} \tag{4}$$

[3] Sarita de Miranda Rimes et al. "Filtragem inversa não-linear para estimação de sinais em calorímetros operando a alta taxa de eventos". In: *Dissertação de mestrado* (2021).

Result of the mean of the amplitude estimation error by the K-fold cross-validation technique

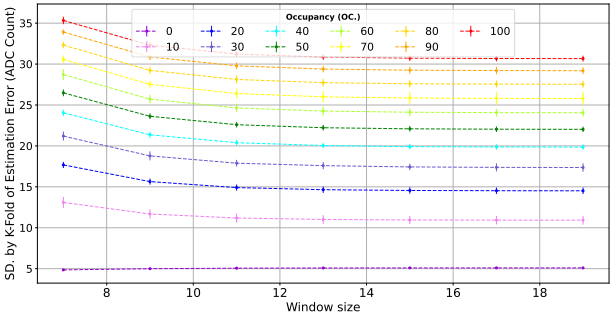
Figure: Analysis of the mean of the amplitude estimation error for each window according to occupation.



Source: the author, 2024.

Result of the standard deviation of the amplitude estimation error by the K-fold cross-validation technique

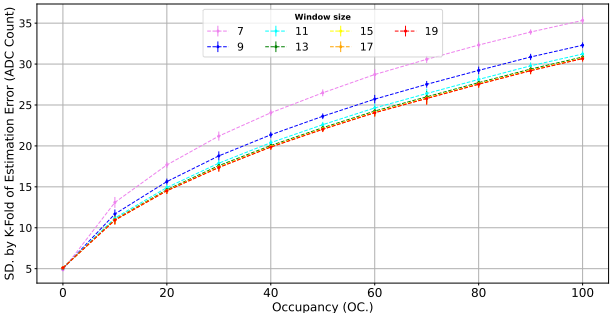
Figure: Analysis of the mean standard deviation of the amplitude estimation error for each window according to occupation.



Source: the author, 2024.

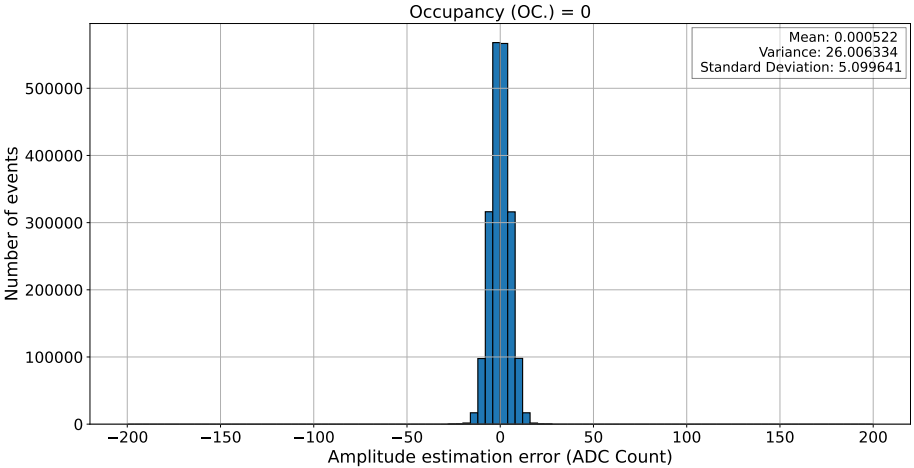
Result of the standard deviation of the amplitude estimation error by the K-fold cross-validation technique

Figure: Analysis of the mean standard deviation of the amplitude estimation error for each occupation according to the window size.



Source: the author, 2024.

Amplitude estimation error histograms for optimal window 15



Final considerations

- According to the deconvolution method, window 15 can be considered ideal.
- As future improvements to the method of decovolution can be studied the implementation of alternative versions of this method.
- Using the Lorenzetti Shower Simulator for further analysis.
- Results and codes are available in the GitHub repository[4].

[4] G. Morett. *Método da desconvolução*. Last accessed 19 May 2024. 2024. URL: https://github.com/MorettGuilherme/Codigos_Metodo_Desconvolucao_Amplitude.

Acknowledgements

thanks!

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