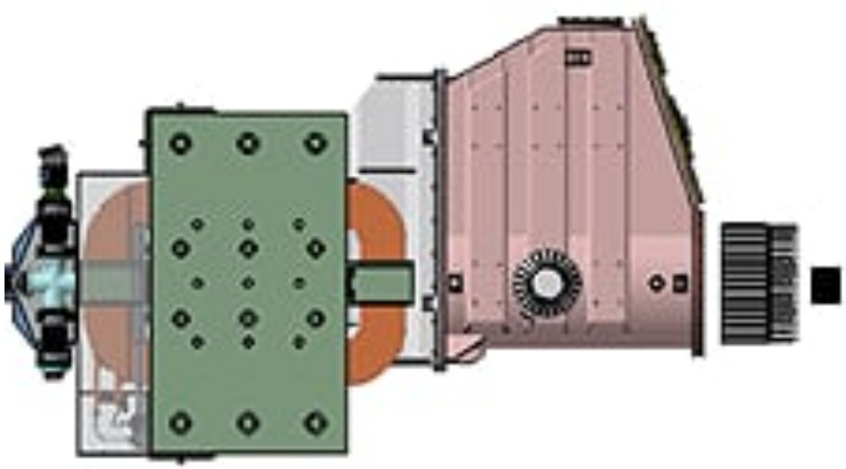
SAPIENZA
UNIVERSITÀ DI ROMA

# Simulation and Processing of Signals in the Vetoes of the PADME Experiment

## 106 Congresso Nazionale SIF 2020



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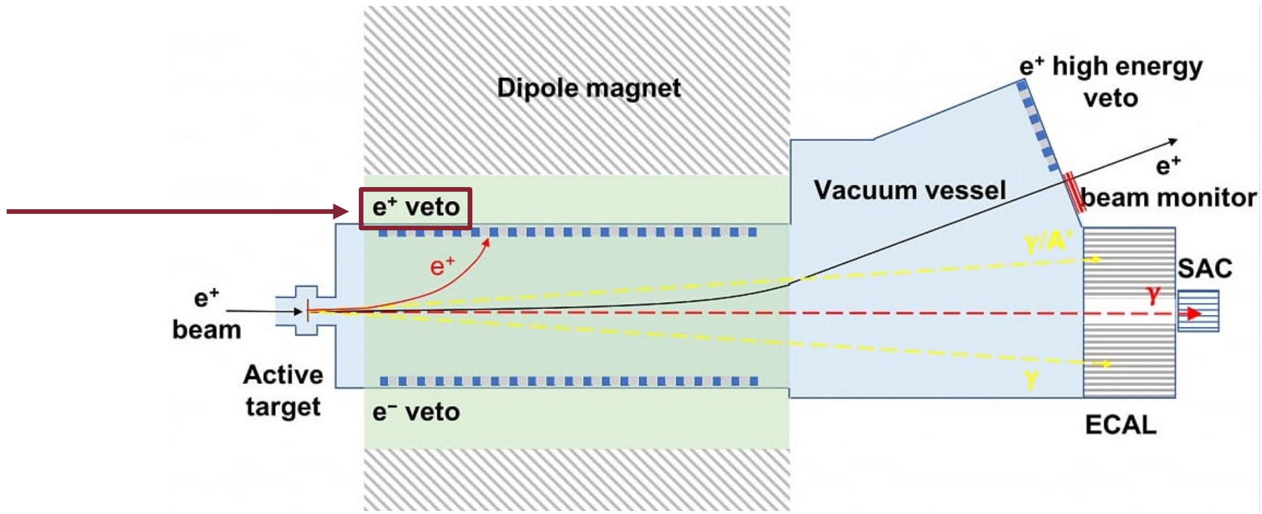
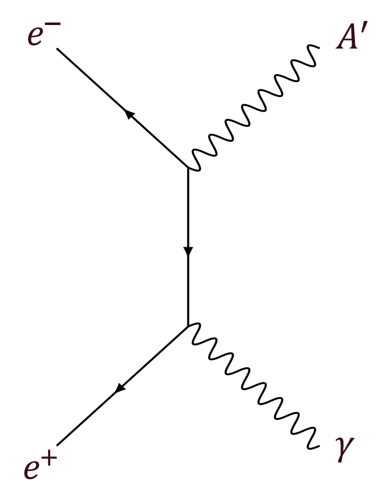
# The PADME Experiment

- The Positron Annihilation to Dark Matter Experiment searches for a dark photon $A'$ in the process $e^+e^- \to A'\,\gamma$.
- The principle background is Bremsstahlung from positrons on target (in red in the diagram below).
- To detect positrons which have undergone Bremsstrahlung, we use a Positron Veto (PVeto) made of plastic scintillators in a magnetic field.



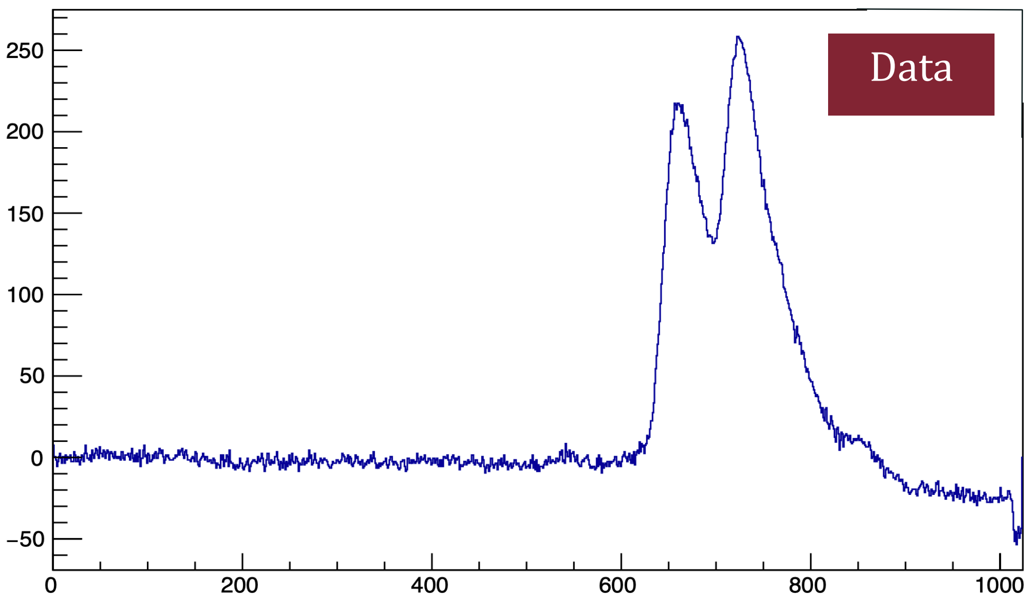



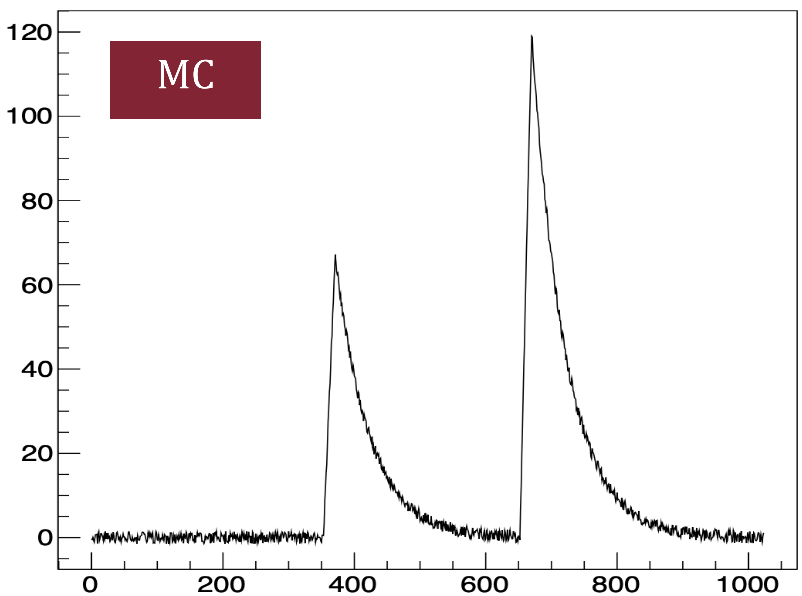
# Studying Signals

- The high rate of particles entering the vetoes makes distinguishing between particles difficult.
- To study the performance of different approaches to separating particle hits, we used a toy MC that creates signals.

# Veto Signals

- The simulated signals have a linear rise time of 7ns and exponential fall with $\tau$ of 20ns.
- The number of hits per event ~ Poisson(3), arrival time ~Uniform[80ns,280ns], amplitude ~ Landau(50,12)



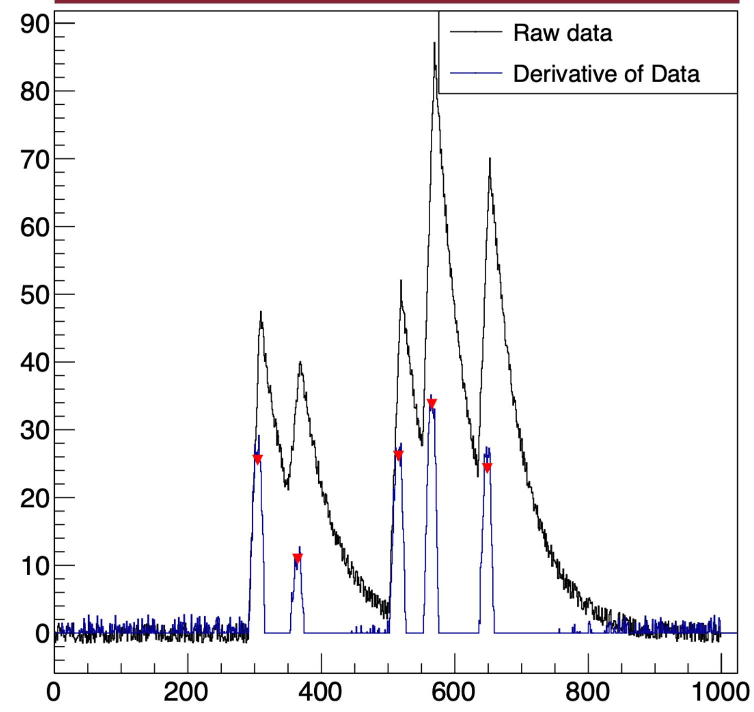




1024 digitizer samples = 400ns

# Raw Data + Derivative + TSpectrum

- The signal derivative is approximated by $V_{Deriv}(t) = V(t) - V(t - 4ns)$, where V($t$) is the height of the signal at time $t$ (ns).
- If the derivative is negative, it is set to **0**.
- The derivative is passed to TSpectrum - a built-in Gaussian peak finder in ROOT.
- TSpectrum returns the number and position of the peaks it finds.

Red markers indicate the position of peaks found by TSpectrum.



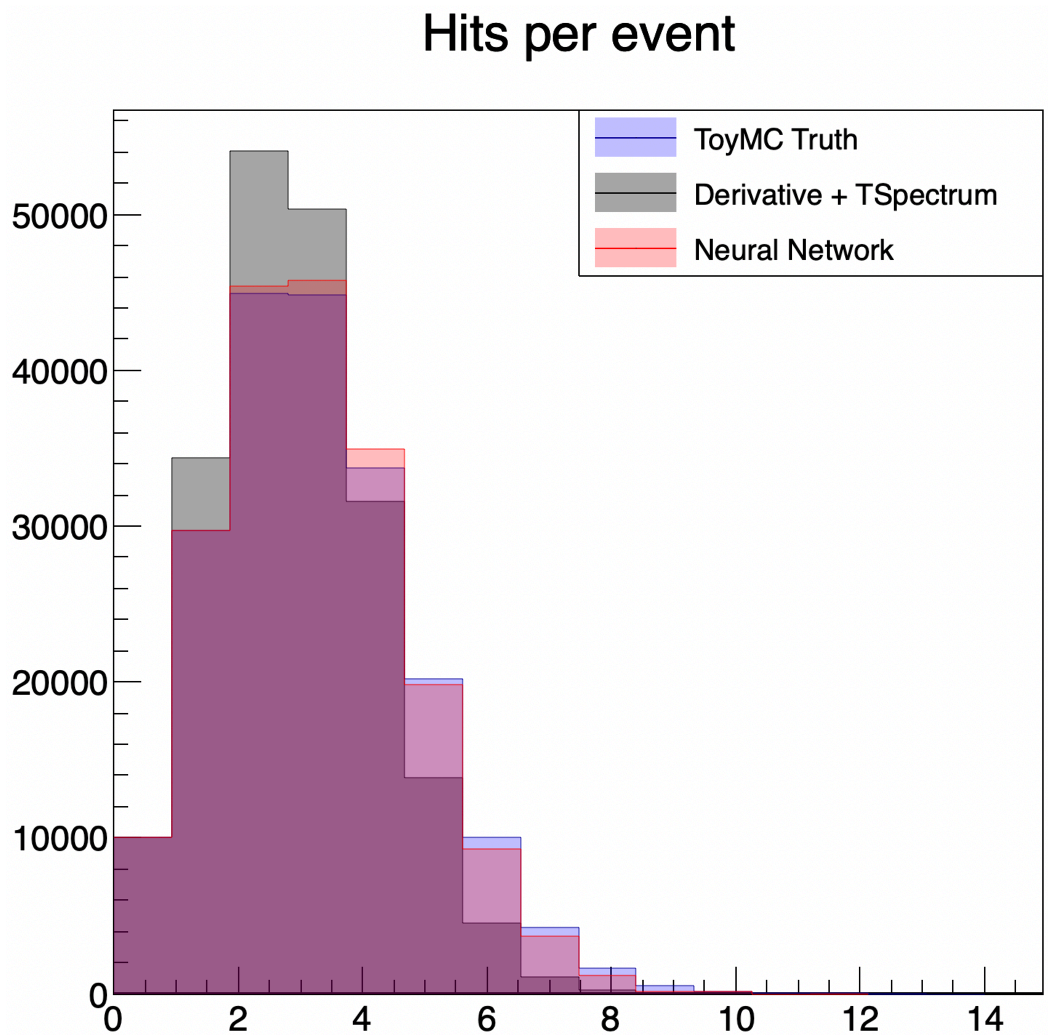
# Convolutional Neural Network (CNN)

- A simple CNN was constructed to count the number of hits present in a waveform.
- Input: raw (unprocessed) waveforms
- Output: textfile of number of hits reconstructed per event
- Trained on 200,000 training and 100,000 validation events.
- Tested on 200,000 events.

| Layer (type) | Output Shape | Param # |
|---|---|---|
| input_3 (InputLayer) | [(None, 1024, 1)] | 0 |
| Conv_1 (Conv1D) | (None, 1022, 16) | 64 |
| leaky_re_lu_6 (LeakyReLU) | (None, 1022, 16) | 0 |
| MaxPool_1 (MaxPooling1D) | (None, 511, 16) | 0 |
| Conv_2 (Conv1D) | (None, 509, 16) | 784 |
| leaky_re_lu_7 (LeakyReLU) | (None, 509, 16) | 0 |
| MaxPool_2 (MaxPooling1D) | (None, 254, 16) | 0 |
| Conv_3 (Conv1D) | (None, 252, 32) | 1568 |
| leaky_re_lu_8 (LeakyReLU) | (None, 252, 32) | 0 |
| MaxPool_3 (MaxPooling1D) | (None, 126, 32) | 0 |
| Flatten (Flatten) | (None, 4032) | 0 |
| Dense_1 (Dense) | (None, 64) | 258112 |
| ReLU_dense_1 (ReLU) | (None, 64) | 0 |
| dropout_2 (Dropout) | (None, 64) | 0 |
| Dense_2 (Dense) | (None, 64) | 4160 |
| ReLU_dense_2 (ReLU) | (None, 64) | 0 |
| Output (Dense) | (None, 14) | 910 |

Total params: 265,598
Trainable params: 265,598
Non-trainable params: 0

# Results: Number of Hits Per Event



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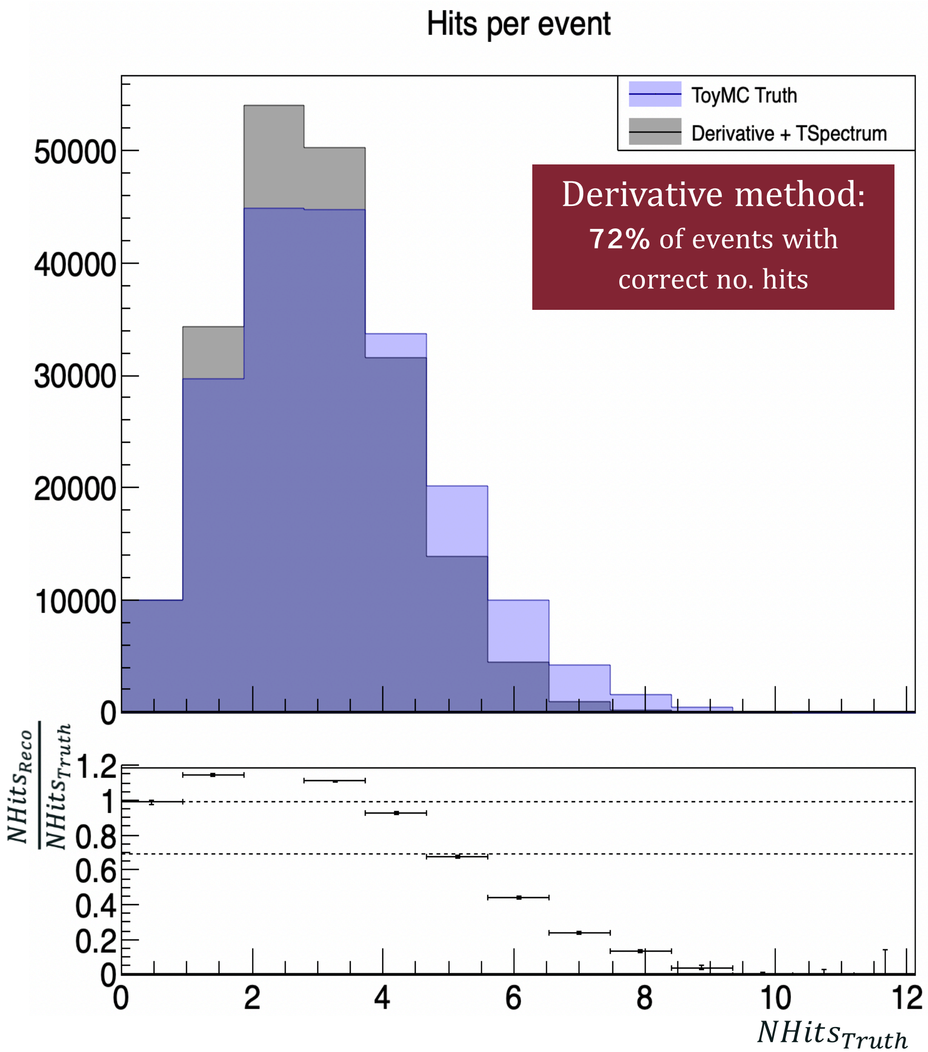
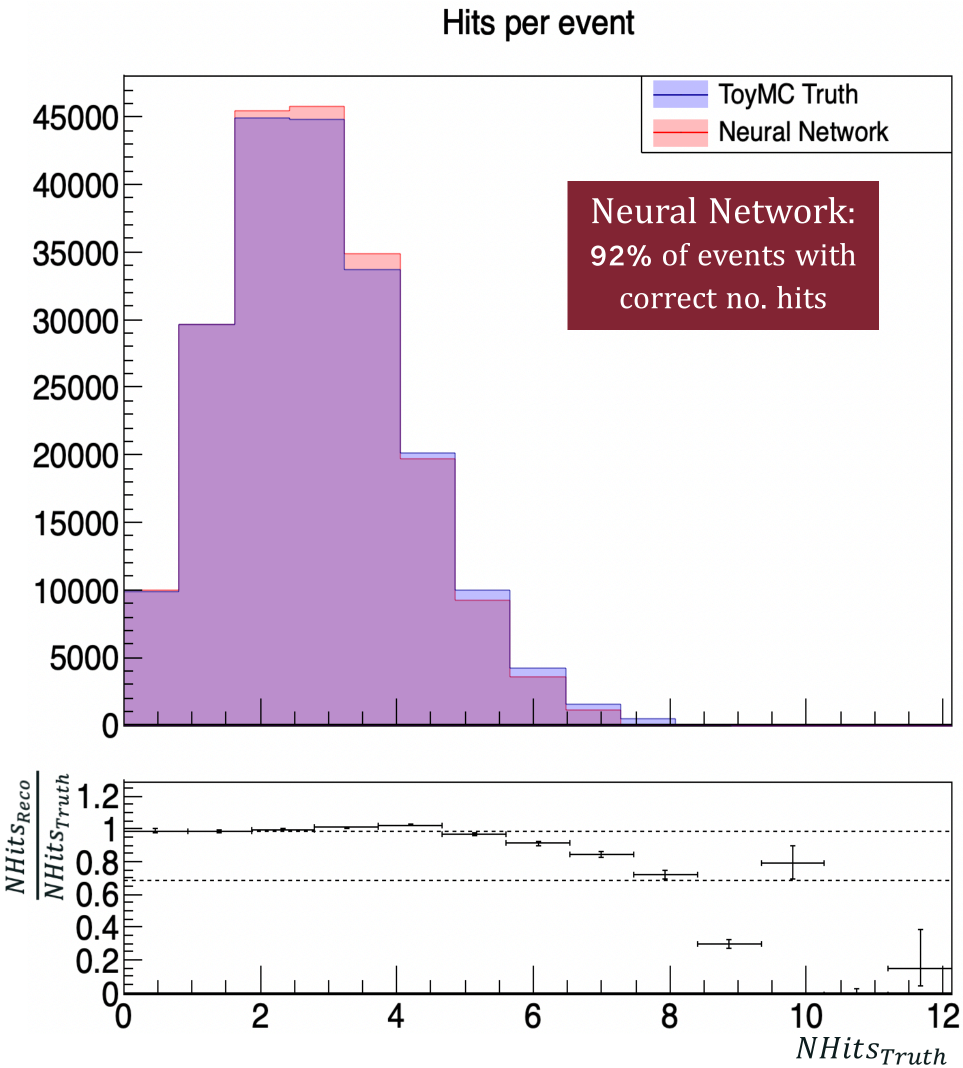
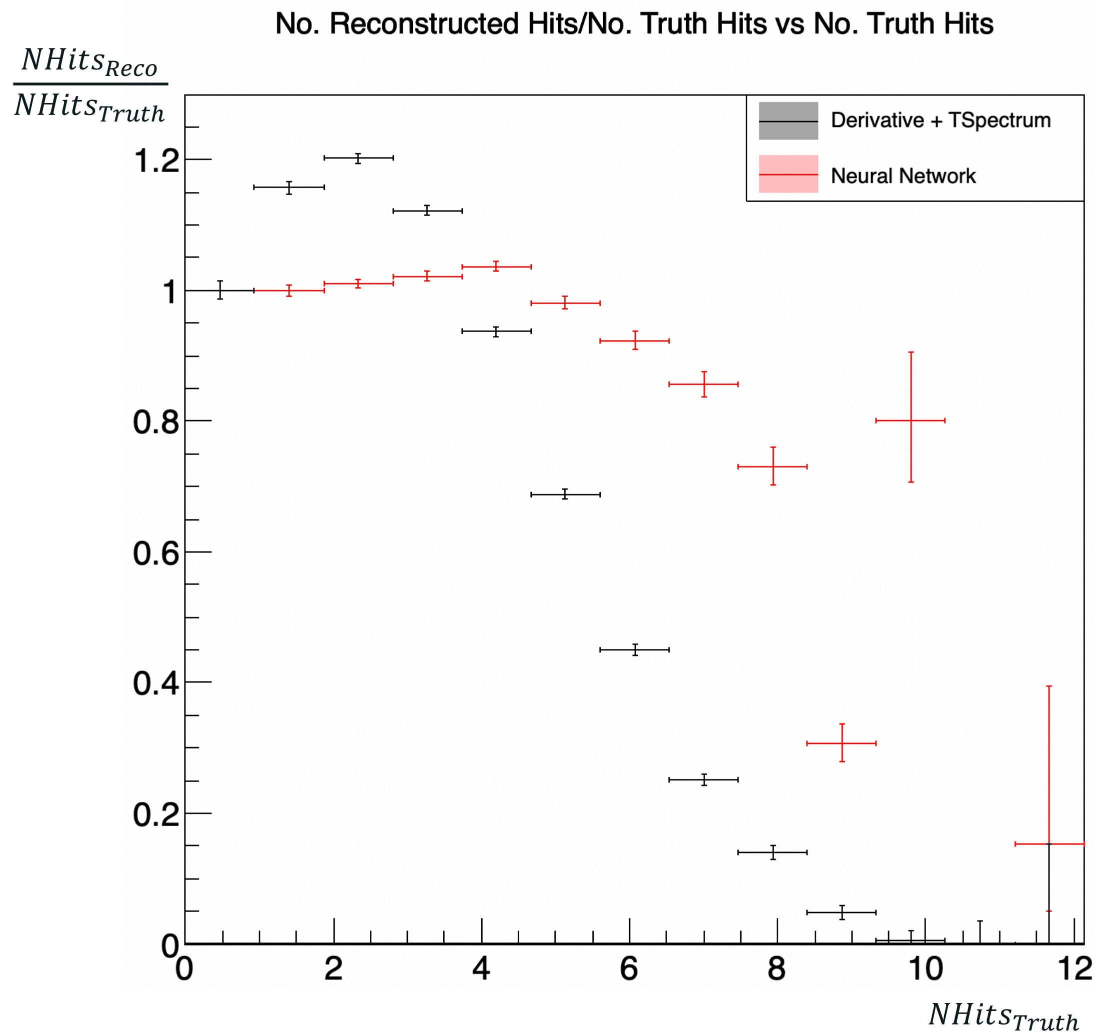


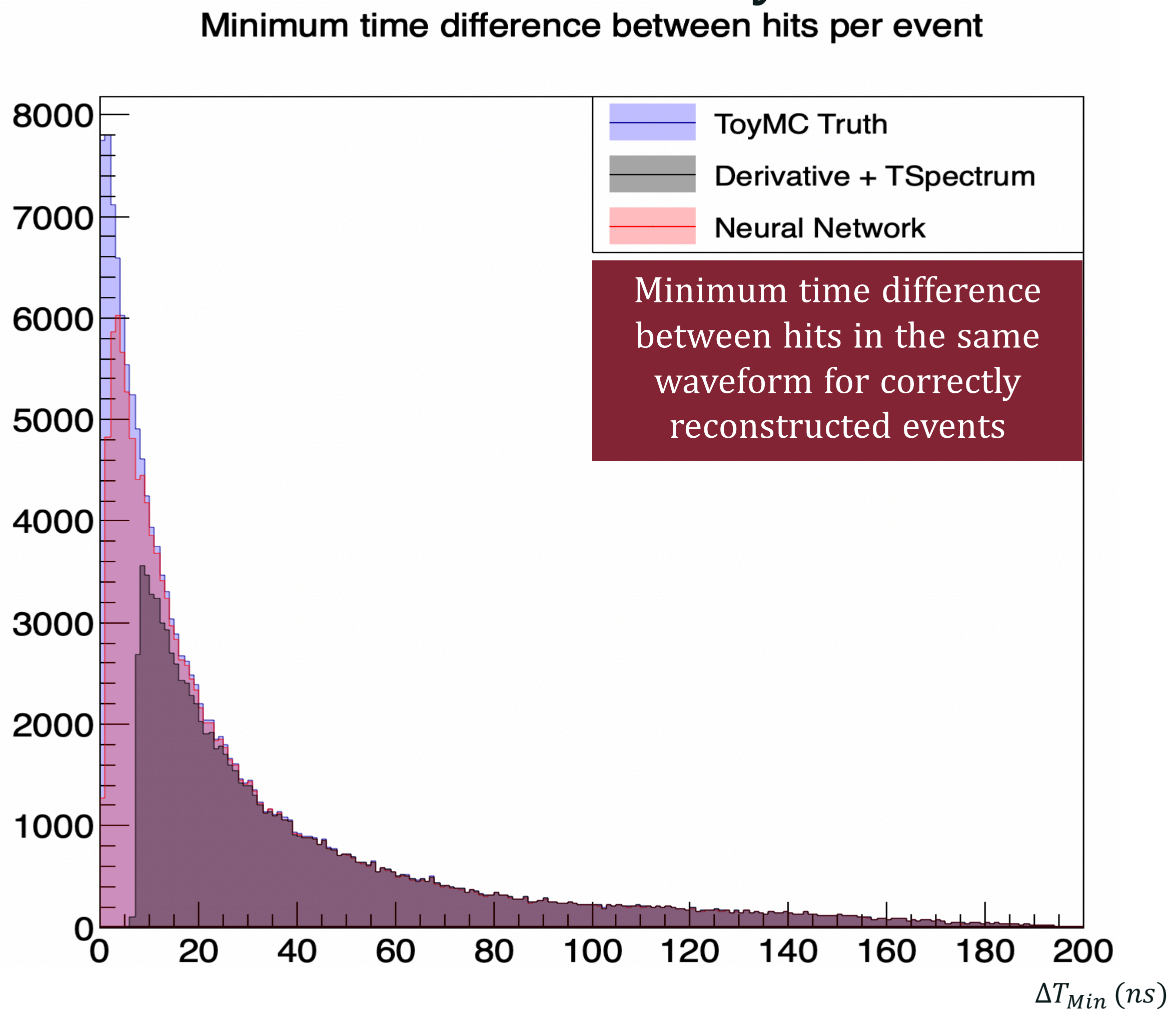



# Results: Reconstruction Efficiency Ratios

- For the CNN, efficiency remains ~1 for $NHits_{True} \leq 5$
- Using the derivative + TSpectrum:
  - Number of events with $NHits_{True} \leq 3$ is overestimated
  - Number of events with $NHits_{True} > 3$ is underestimated

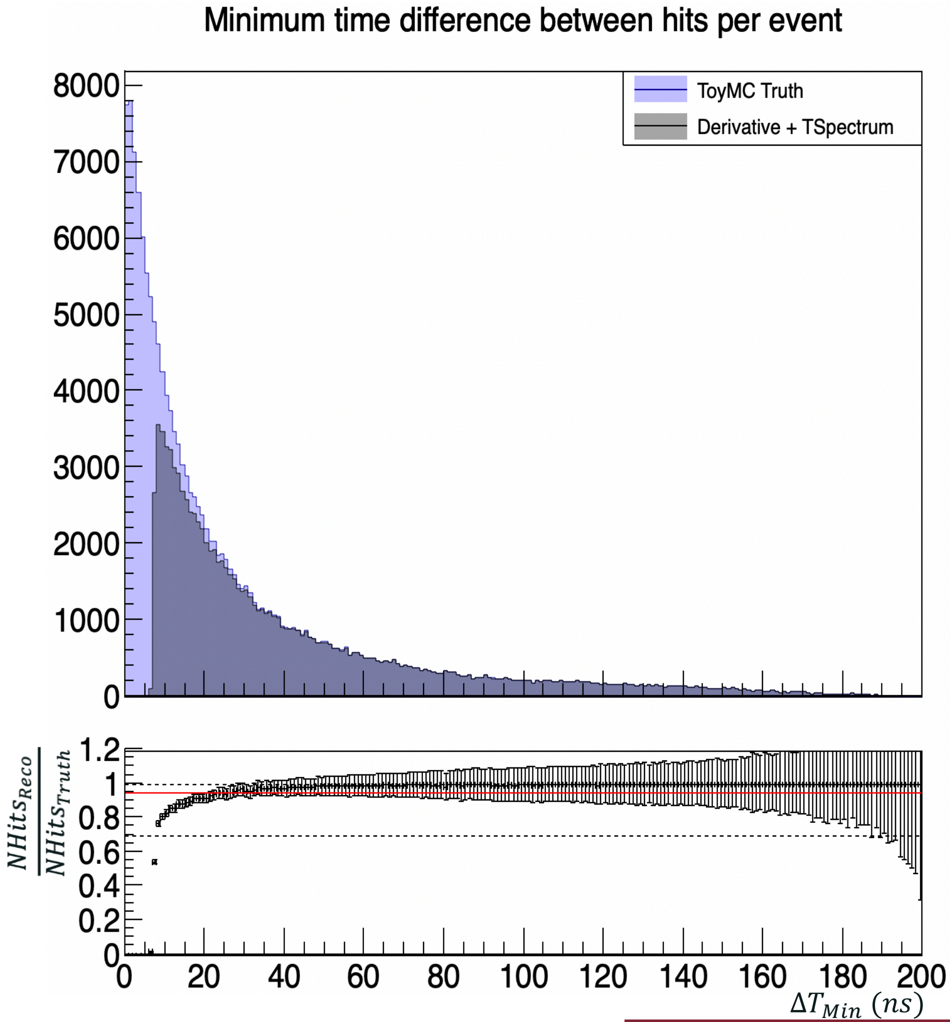


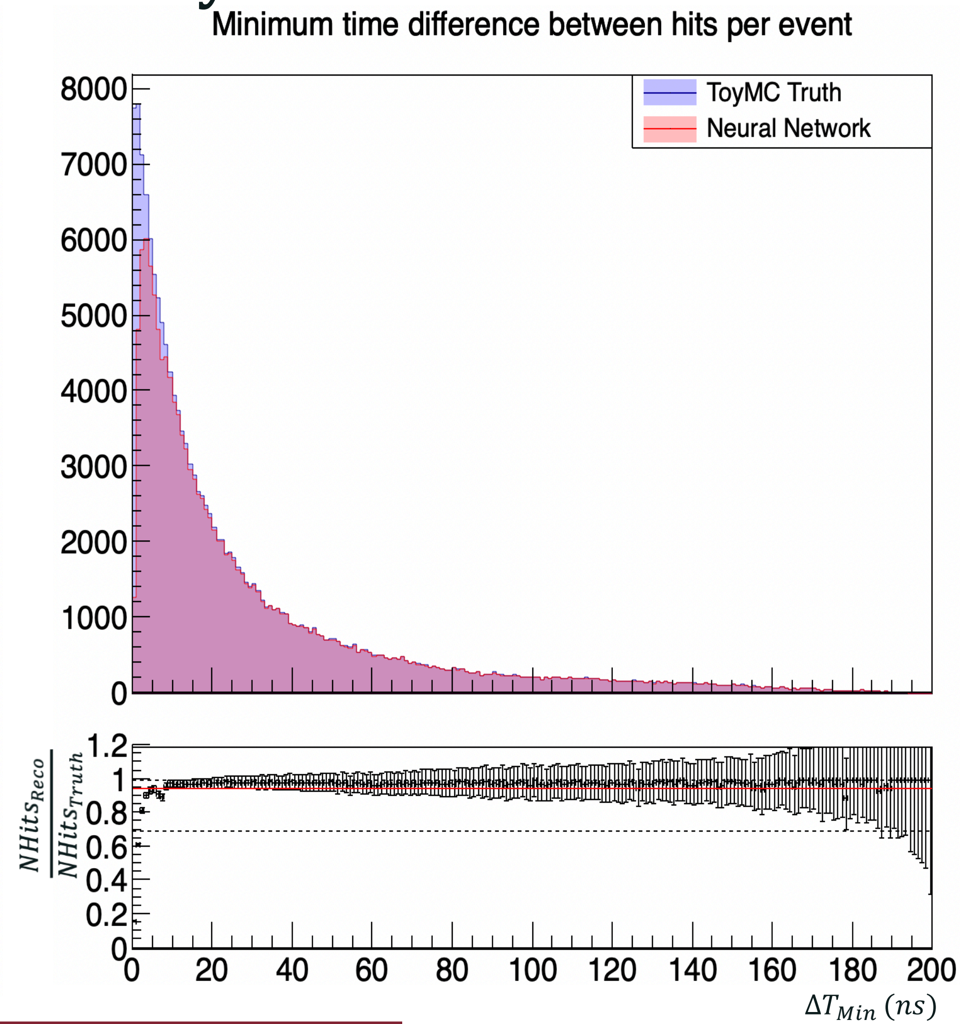
# Results: Reconstruction Efficiency vs Time




Minimum time difference between hits in the same waveform for correctly reconstructed events

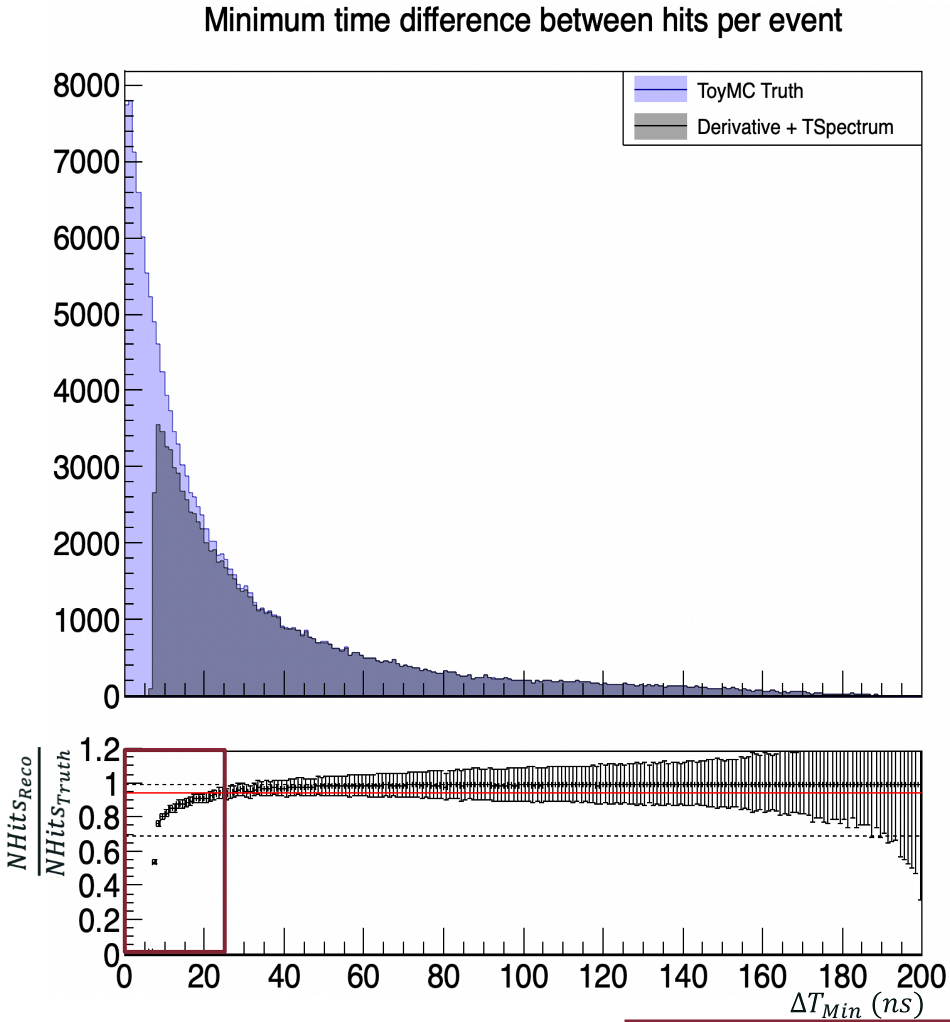
# Results: Reconstruction Efficiency vs Time

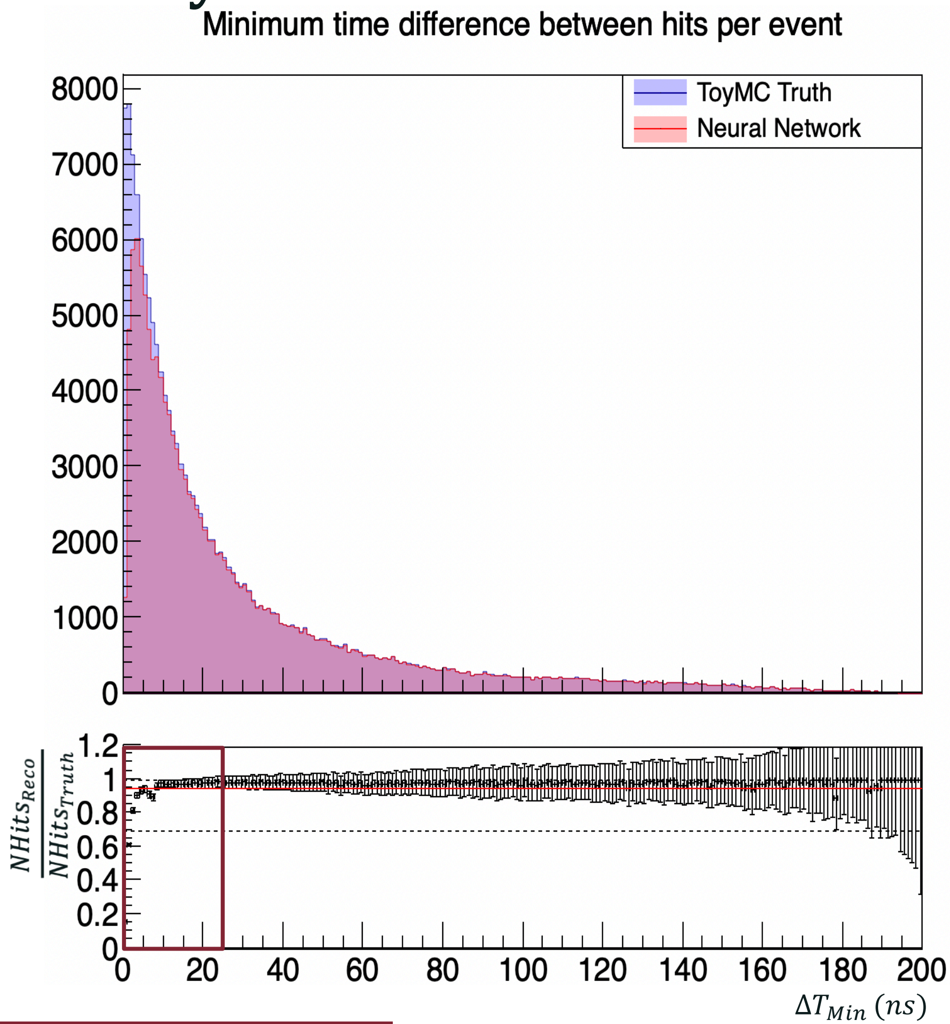



Red line (95%) = separability threshold:
Minimum $\Delta T$ at which hits are considered separable

# Results: Reconstruction Efficiency vs Time

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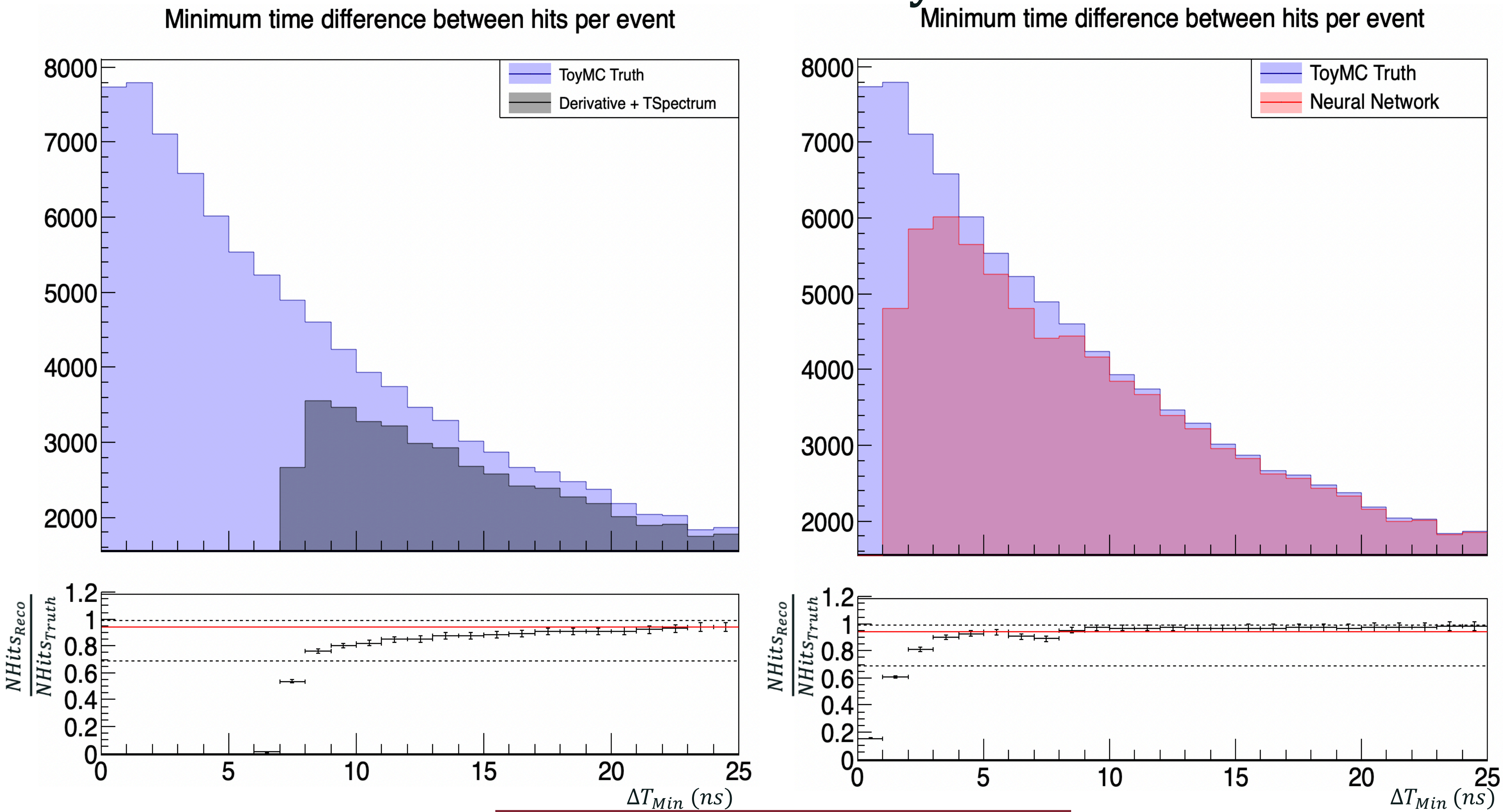


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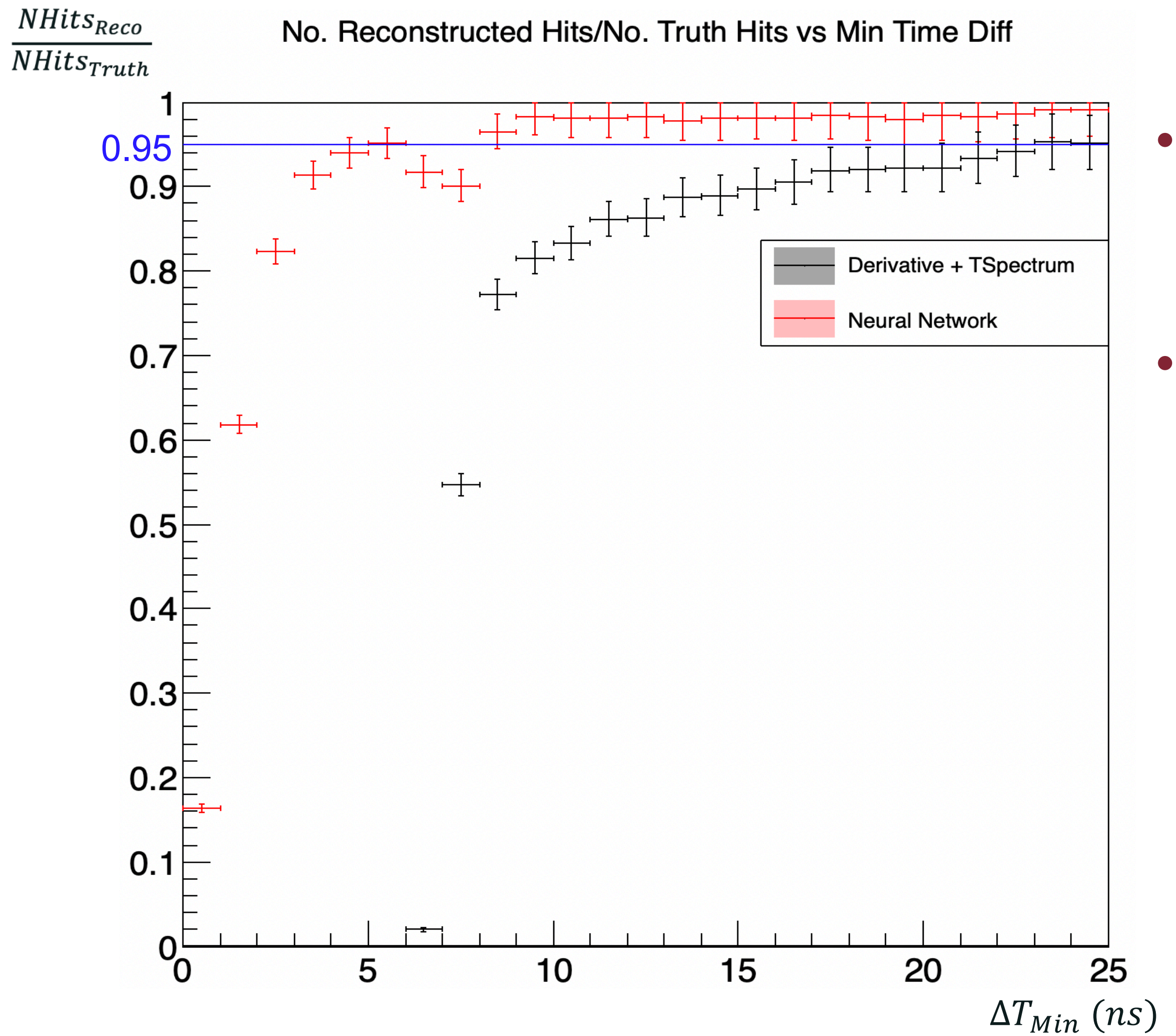


- The CNN reaches separability (95% efficiency) at 8ns
- With the derivative + TSpectrum separability is reached at ~20ns

# Summary

- The global efficiency of the CNN at reconstructing the number of hits per event is 92%, while the derivative + TSpectrum method is only 72% efficient.
- 95% efficiency in hit separation is reached at:
  - $\Delta T_{Min} \geq 8$ns for CNN
  - $\Delta T_{Min} \geq 20$ns for derivative + TSpectrum
- This shows that using a CNN is a good way of reconstructing the number of hits that have produced a simulated waveform.
- Next steps are to study how well this works on data and how to recover hit times.

Thank you for your attention.