Time dispersion of the SPE signal

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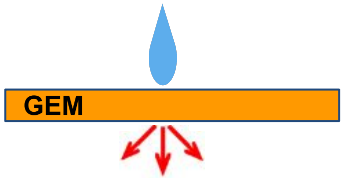
Introduction

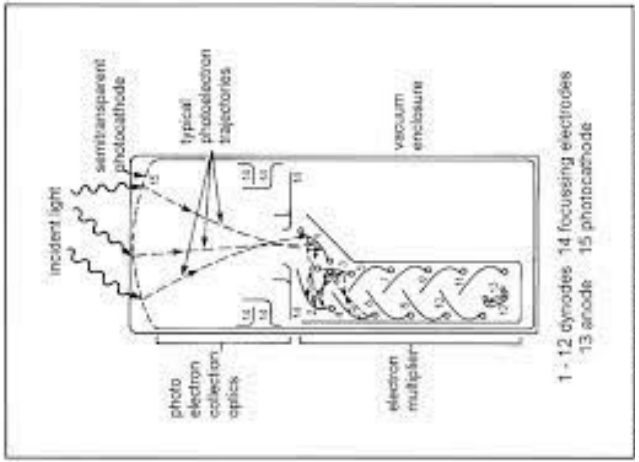
Previously…

- **The proposed simulation is based on a sum of SPE:**

Dispersions:

- **PMT** (electron multiplication process)
- **TPC electron longitudinal diffusion** (z dependent)
- **GEM time response** (light production process)

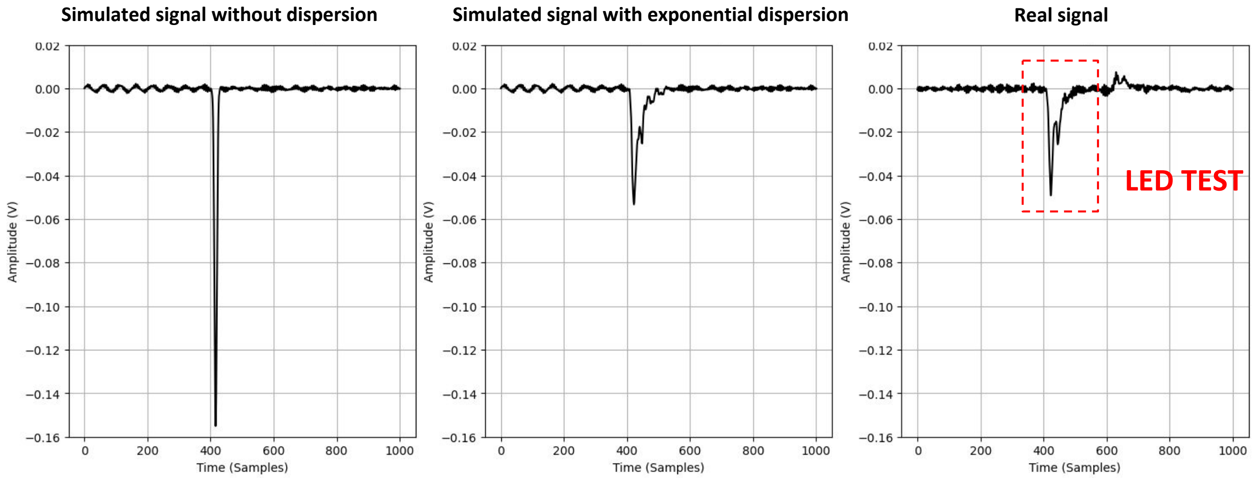




Introduction

Previously…

- **Time dispersion of the SPE signal characterization:**



…/PMT-Test-270922/BA1642/900V

Used database:

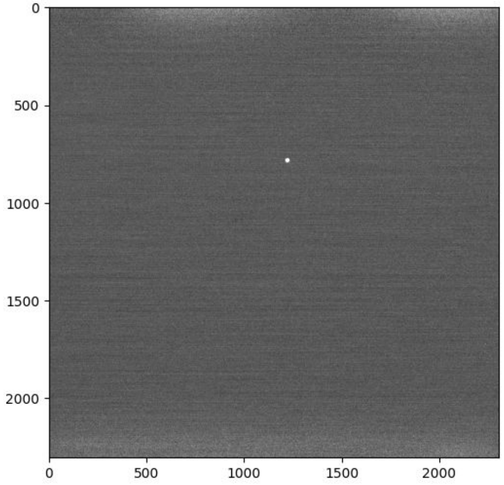
- LED emitting photons to a PMT
- Sampling rate 5 GS/s
- ~1000 acquisitions

Introduction

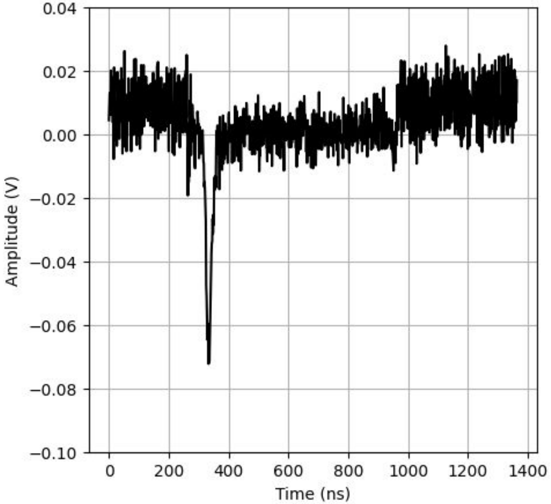
Fe55 database

Images with one cluster: [1, 13, 38, 57, 74, 83, 118, 122, 143, 147, 187, 212, 225, 273, 290, 301, 334, 362, 374]

img 187



PMT signal



Used database:

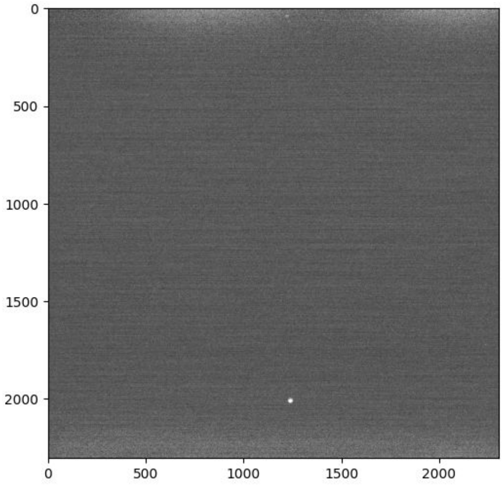
- Run 12261
- Fe55 clusters emitting photons to a PMT
- Sampling rate 750 MS/s
- 402 images

Introduction

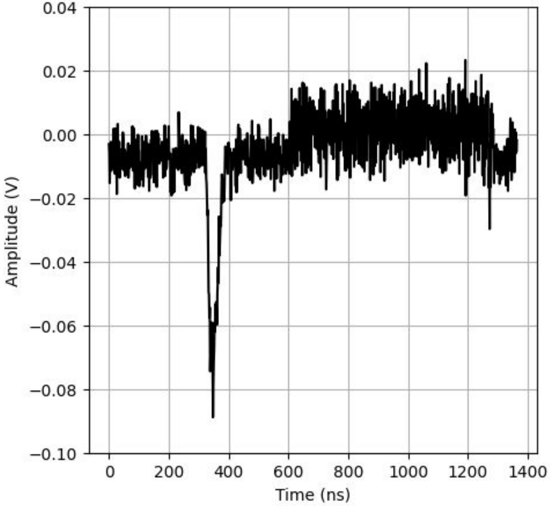
Fe55 database

Images with one cluster: [1, 13, 38, 57, 74, 83, 118, 122, 143, 147, 187, 212, 225, 273, 290, 301, 334, 362, 374]

img 122



PMT signal



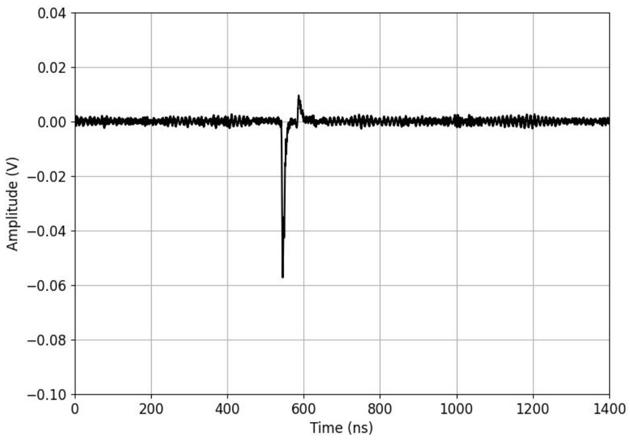
Used database:

- Run 12261
- Fe55 clusters emitting photons to a PMT
- Sampling rate 750 MS/s
- 402 images

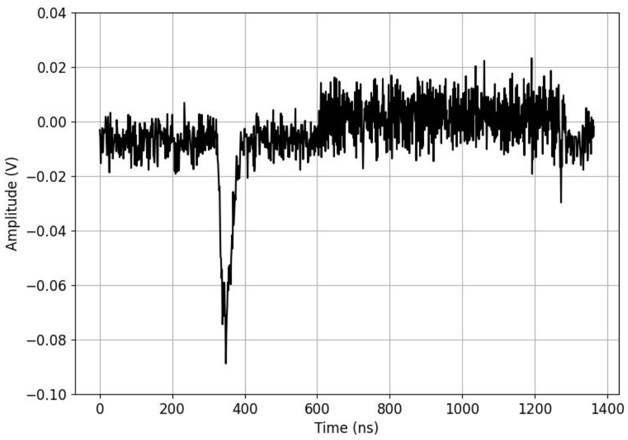
Introduction

Comparison between LED and Fe55 database

LED database signal



Fe55 database signal



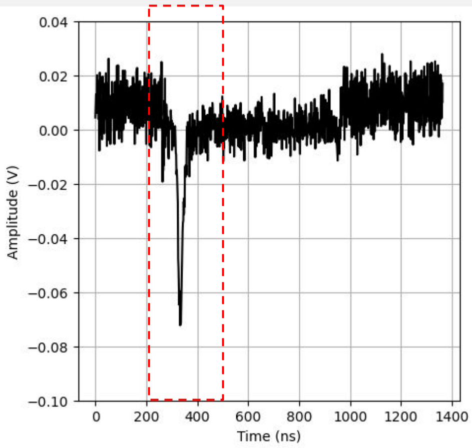
- **We need to characterize the time dispersion of the SPE signal**

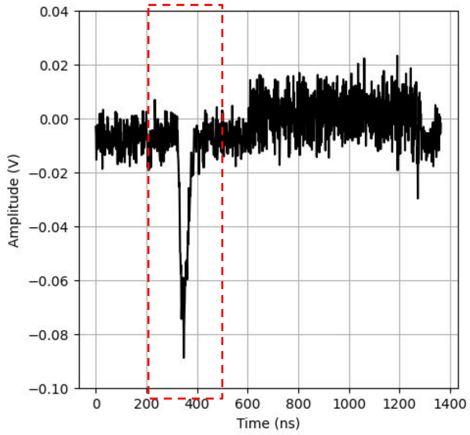
Dispersion characterization

Dispersion characterization

To start characterizing the dispersion, we can do a signal analysis based on:

- FWHM
- Peak
- Rise Time
- MSE

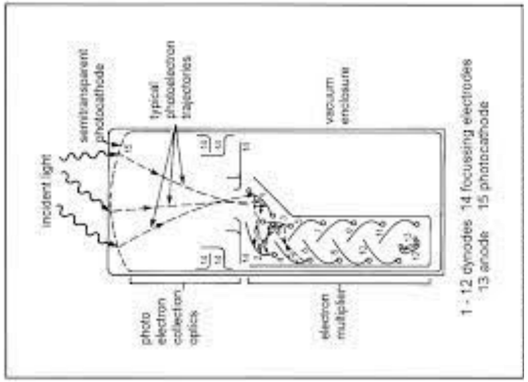


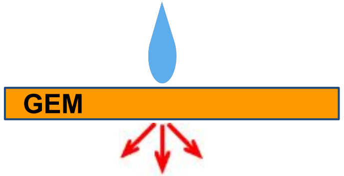


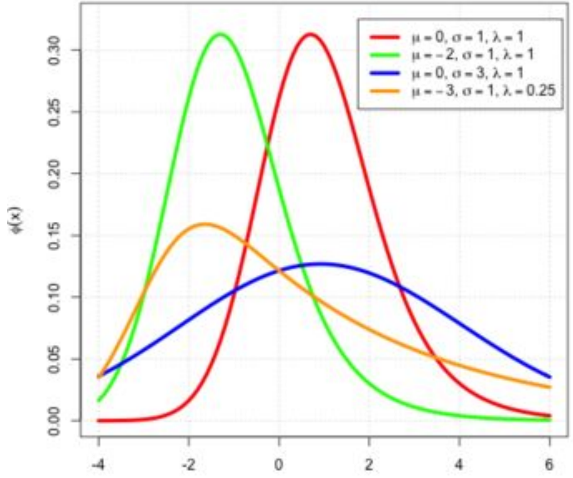
Dispersion characterization

Approach idea: Exponentially modified Gaussian distribution

Before: Exponential distribution (LED database)







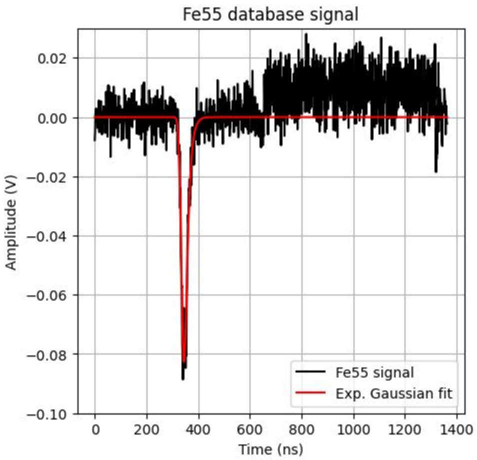
SPE time dispersion

Dispersion characterization

Finding the best Exp. Gaussian distribution parameters

- We can fit the signals from the Fe55 database with a Exp. Gaussian model

Example:

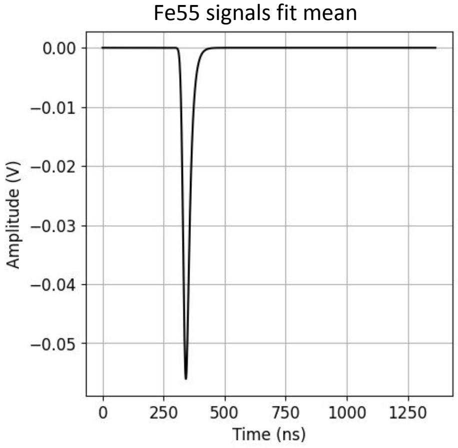


- FWHM = 27.49 ns
- Peak = -0.083 V
- Rise Time = 16 ns

Dispersion characterization

Finding the best Exp. Gaussian distribution parameters

- Fitting each signal from the Fe55 database with a Exp. Gaussian fit
  - Get the parameters of the signals fit mean



- FWHM = 29.64 ns
- Peak = -0.056 V
- Rise Time = 17.33 ns

Exp. Gaussian fit parameters:

- σ = 8.87 ns
- λ = 0.068

Dispersion characterization

Exponentially modified Gaussian distribution

Probability density function:

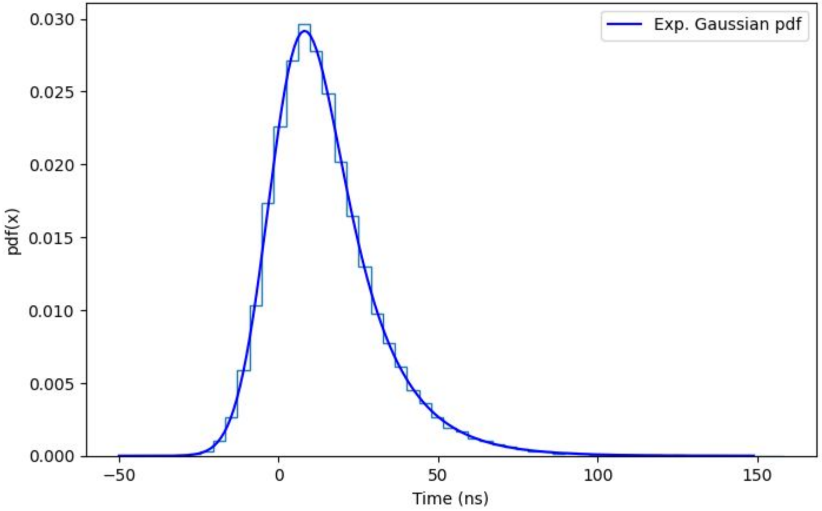
$$f(x;\mu,\sigma,\lambda) = \frac{\lambda}{2} e^{\frac{\lambda}{2}(2\mu+\lambda\sigma^2-2x)} \operatorname{erfc}\left(\frac{\mu+\lambda\sigma^2-x}{\sqrt{2}\sigma}\right)$$

μ = 0

σ = 8.87 ns

$\boldsymbol{\lambda}$ = 0.068

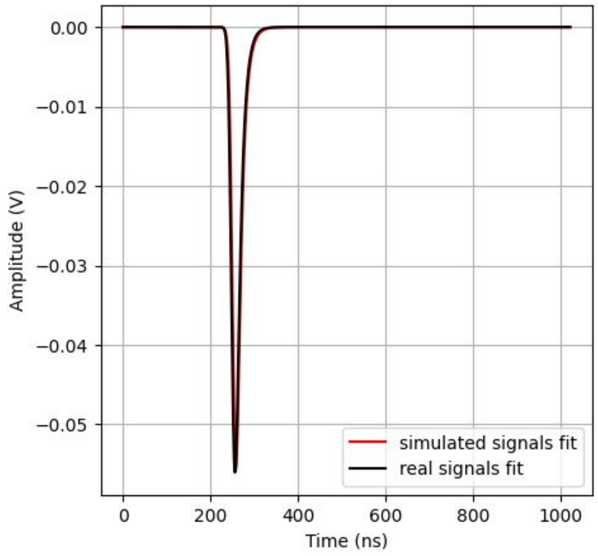
SPE signal time dispersion distribution



Dispersion characterization

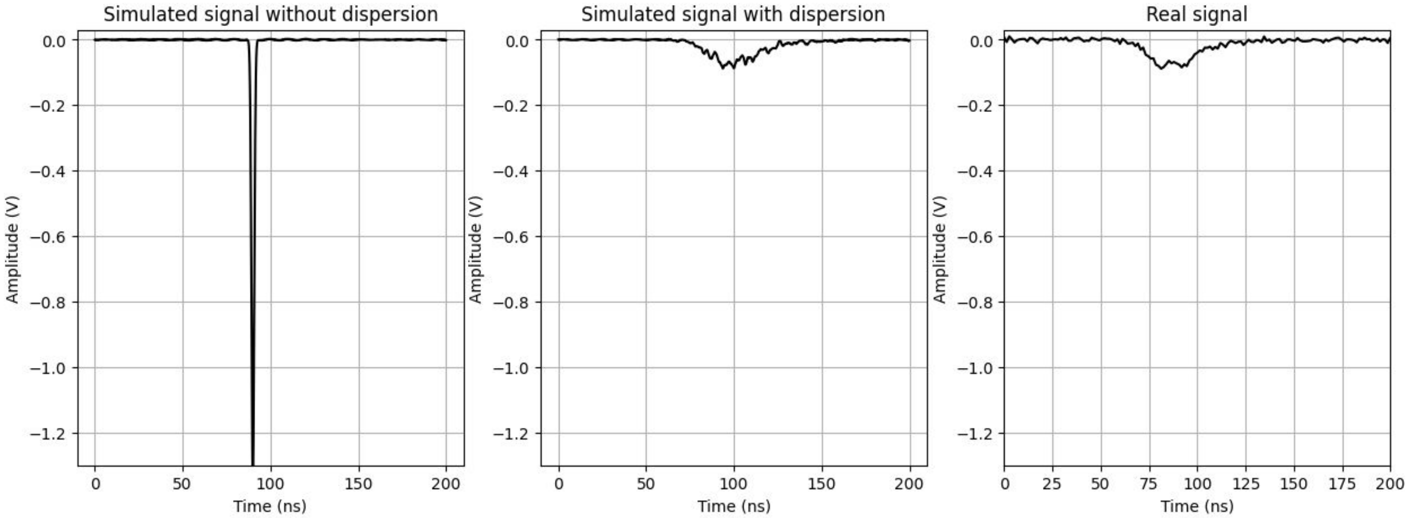
Simulation results

- Get the parameters of the simulated signals fit mean and compare with the real data
- For the minimum value of MSE:
  - **N = 372.8 ± 8.2 photoelectrons**
  - Δ_{FWHM} = 0.15 ±0.51 ns
  - Δ_{Peak} =0.00076 ± 0.00113 V
  - $\Delta_{Rise\ Time}$ = 0.00 ± 0.84 ns
    - Simulated signals fit rise time = 17.33± 0.84 ns
    - Real signals fit rise time = 17.33 ns
  - MSE = 0.000001091 ± 0.000000067



Dispersion characterization

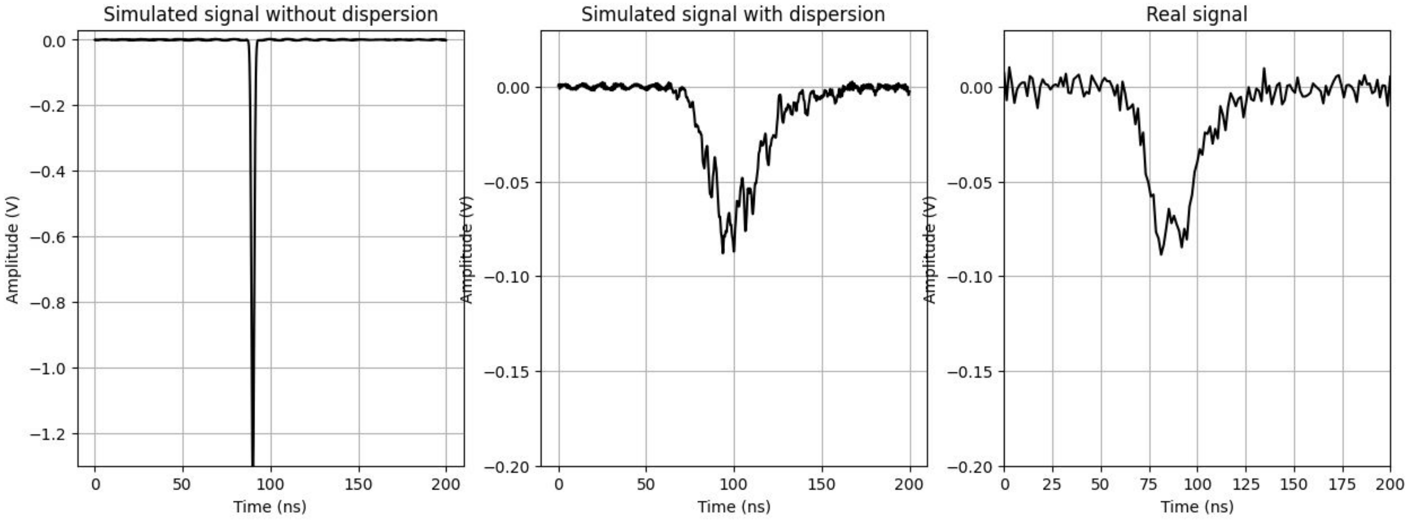
Comparison between simulated and real signal



Simulating with the LED database noise (~200 ns), for 500 photoelectrons

Dispersion characterization

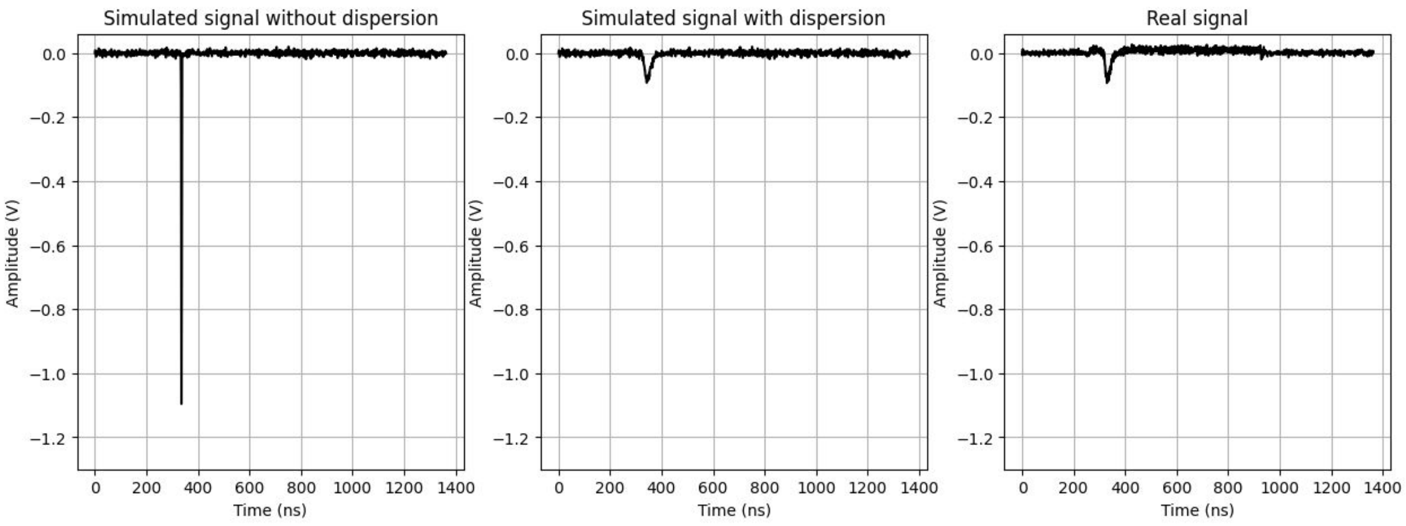
Comparison between simulated and real signal



Simulating with the LED database noise (~200 ns), for 500 photoelectrons

Dispersion characterization

Comparison between simulated and real signal

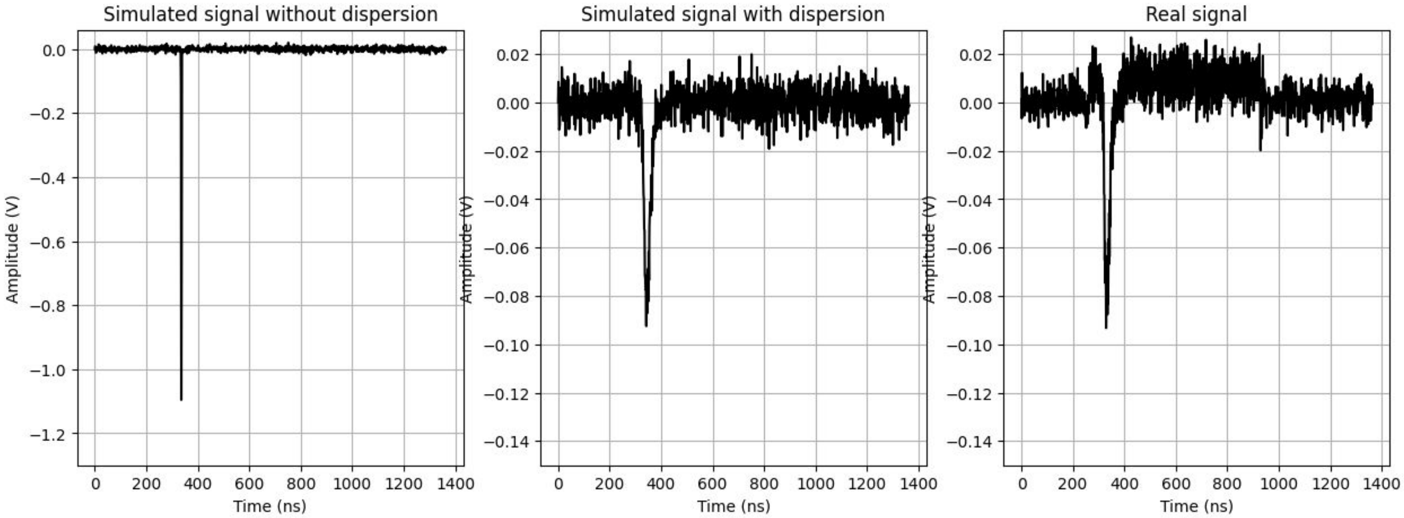


Simulating with the Fe55 database noise (~1400 ns), for 500 photoelectrons

Dispersion characterization

Comparison between simulated and real signal

Changing amplitude scale

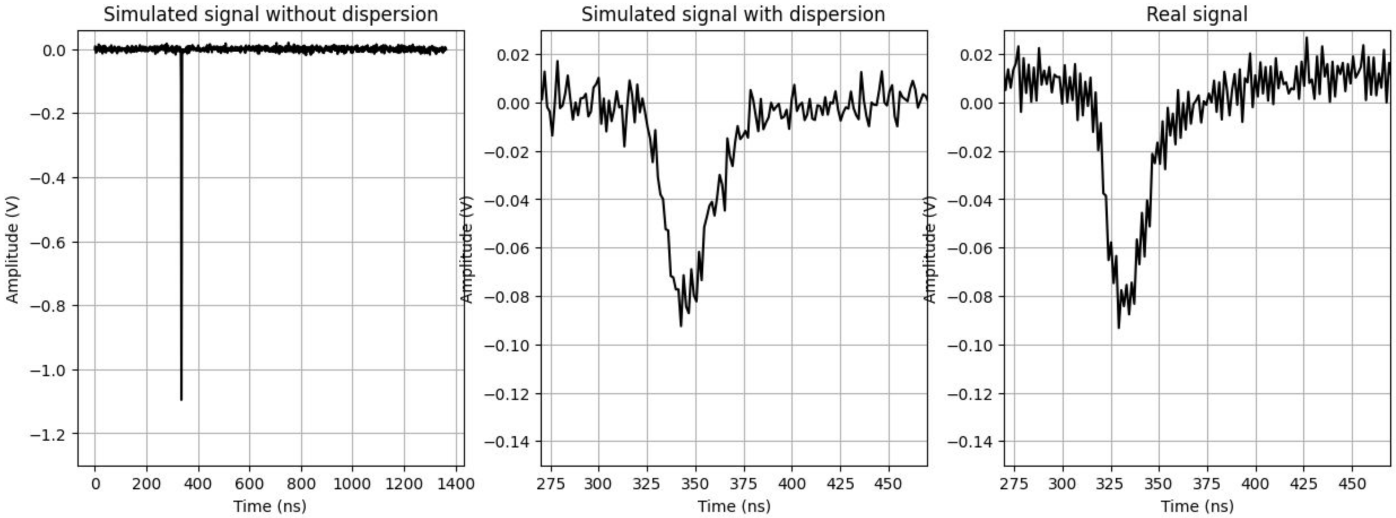


Simulating with the Fe55 database noise (~1400 ns), for 500 photoelectrons

Dispersion characterization

Comparison between simulated and real signal

Changing amplitude and time scale



Simulating with the Fe55 database noise (~1400 ns), for 500 photoelectrons

Example

- A particle with 3 clusters and 100000 photons each, was simulated in the following GEM positions:
  - Cluster 1: x = y = 50
  - Cluster 2: x = y = 100
  - Cluster 3: x = y = 150
- The PMTs are in a distance z = 134 from the GEM
- Each cluster arrives 2 ns after the other.

```
# Input parameters:
x0 = np.array([50, 100, 150])
y0 = np.array([50, 100, 150])
n_fotons = np.array([100000, 100000, 100000])
arr_times = np.array([0, 2, 2])
```

↓

```
ptc_object = PhotonPropagation(x0, y0, n_fotons, arr_times)
pmt_hits = ptc_object.pmt_hits()
```

↓

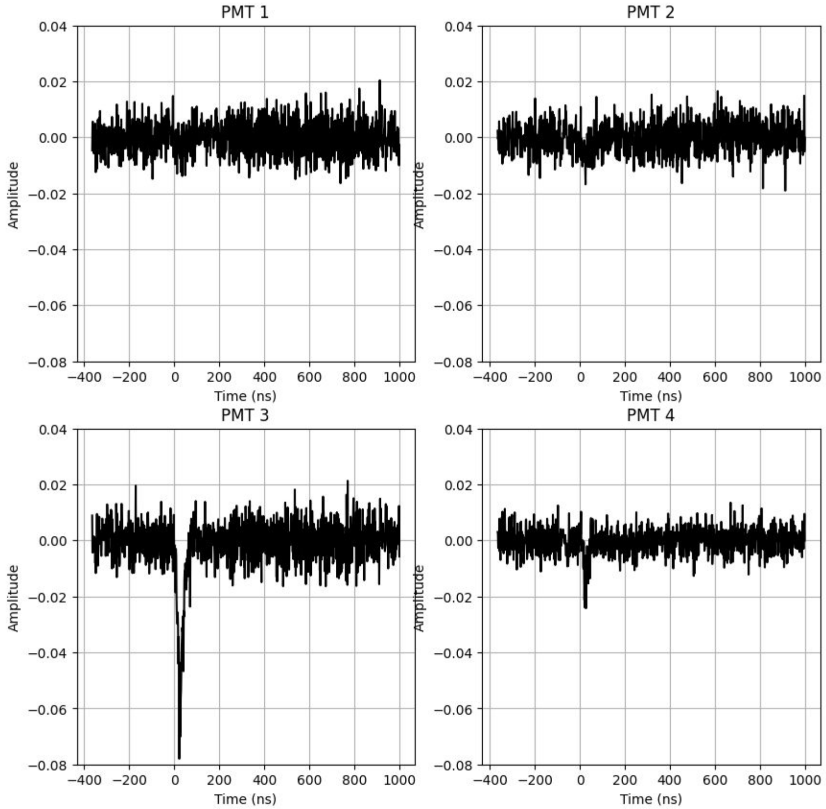
```
pmt_hits = {'cluster_0': {'pmt1': 7,  'pmt2': 16,  'pmt3': 177,
                          'pmt4': 17,  'arrival_time': 0},
            'cluster_1': {'pmt1': 16,  'pmt2': 17,  'pmt3': 98,
                          'pmt4': 18,  'arrival_time': 2},
            'cluster_2': {'pmt1': 19,  'pmt2': 22,  'pmt3': 44,
                          'pmt4': 39,  'arrival_time': 2}}
```

Example

- Using a PMT quantum efficiency of 95%, the particle previously simulated in the photon generation part produced the following signal in PMTs:

```
pmt_hits = {'cluster_0': {'pmt1': 7,  'pmt2': 16,  'pmt3': 177,
                          'pmt4': 17,  'arrival_time': 0},
            'cluster_1': {'pmt1': 16,  'pmt2': 17,  'pmt3': 98,
                          'pmt4': 18,  'arrival_time': 2},
            'cluster_2': {'pmt1': 19,  'pmt2': 22,  'pmt3': 44,
                          'pmt4': 39,  'arrival_time': 2}}
```

```
ptc_simulation = SignalSimulation(pmt_hits)
pmts_signal = ptc_simulation.simulated_signals()
```



Conclusions

Conclusions

- The dispersion analysis includes the PMT and TPC electron longitudinal diffusion dispersions (not considering the z dependence)
- The simulation code is available on github (https://github.com/luangmc/pmt_simulation)
- Next steps:
  - Finish noise characterization for Fe55 database
    - We have done for the LED database

Proposed simulation model

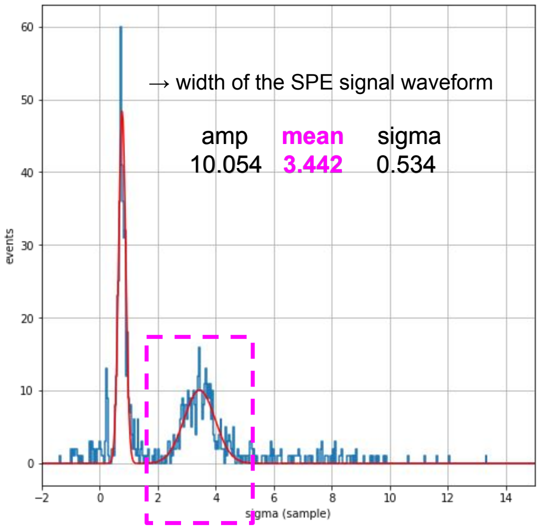
SPE signal - Gaussian shape

- Sigma = 3.4 samples (0.68 ns)
- Amplitude
  - mean = 0.0030 V
  - sigma = 0.0014 V

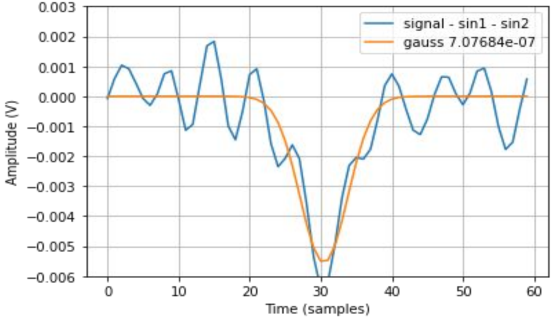
Sum of SPE signals

- **SPE characterization:**

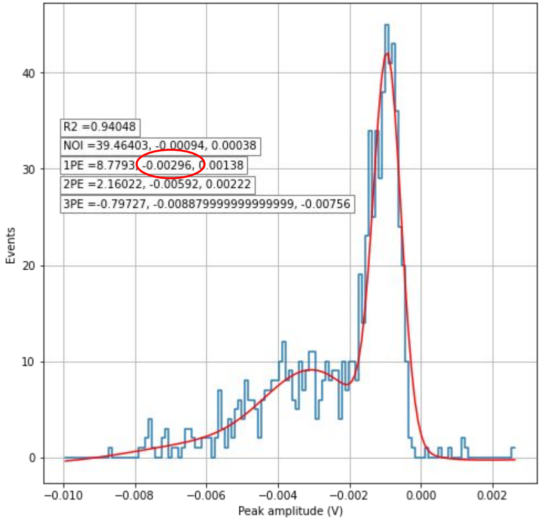
Sigma of the gaussian fits



Typical SPE signal



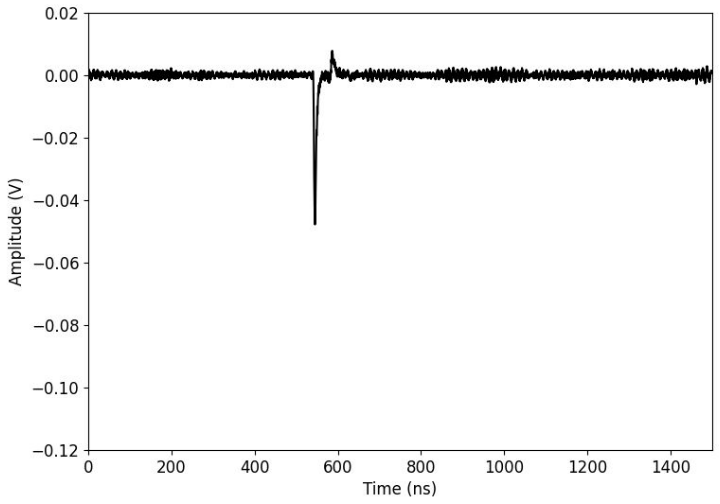
Peak amplitude distribution



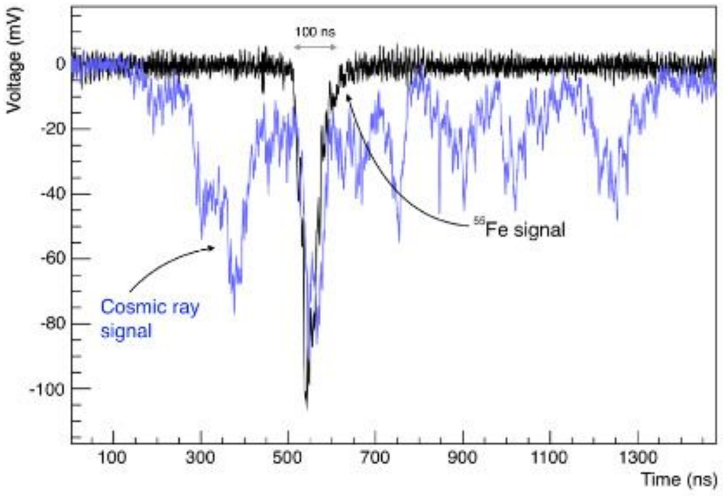
Dispersion characterization

Comparison between LED and Fe55 database signals

LED signal



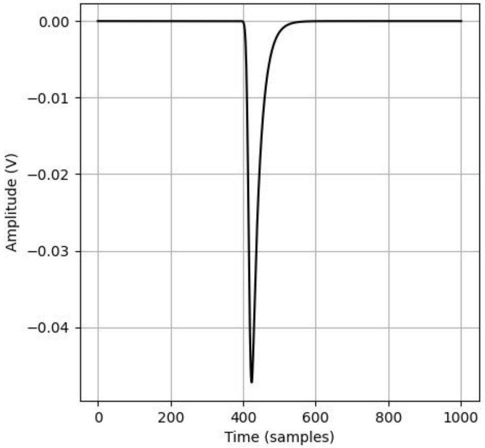
Fe55 signal



Dispersion characterization

Finding the best exponential parameter alpha ⟹ $e^{-\alpha x}$

- Selecting only signals from the dataset with peak mean of -0.05V
    - Fit each signal with a expgaussian and get the fit parameters mean
    - Create a fit with these values



- FWHM = 26.862 Samples
- Peak = -0.0472 V
- Rise Time = 11 Samples

`The simulation results will be compared to this fit`