Discrimination of Multiple Scatter BGs to enhance the sensitivity of the LZ Detector to $0\nu\beta\beta$ decay

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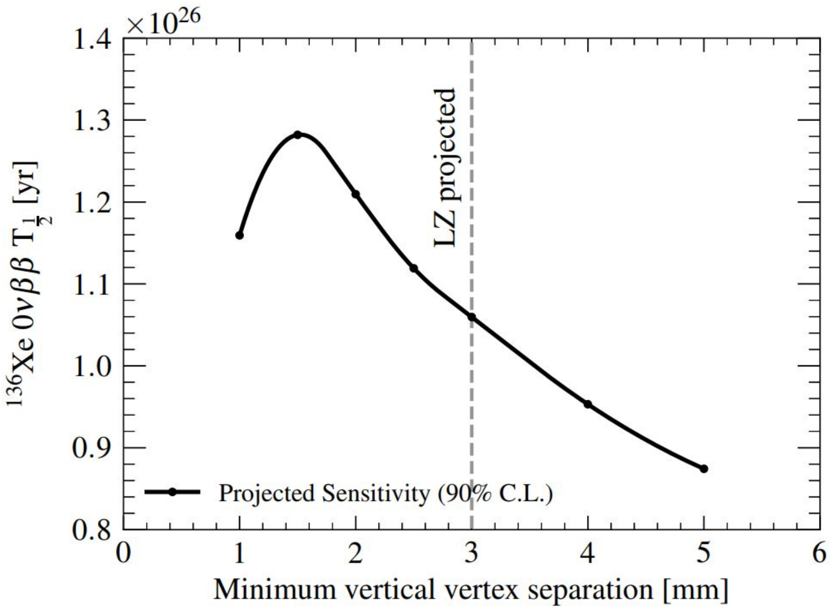
Motivation

The sensitivity of LZ for the 0νββ is dependent on the vertical vertex separation.

LZ analysis framework is able to reconstruct MS high energy events separated by **4 mm** or more.

The objective was to improve these limits and possibly reach a separation of **1.5 mm**.

- Tradeoff between signal acceptance and background rejection.



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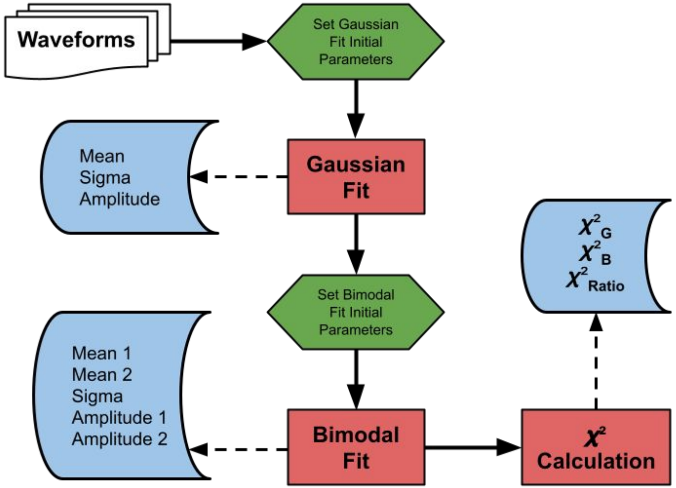
Algorithm

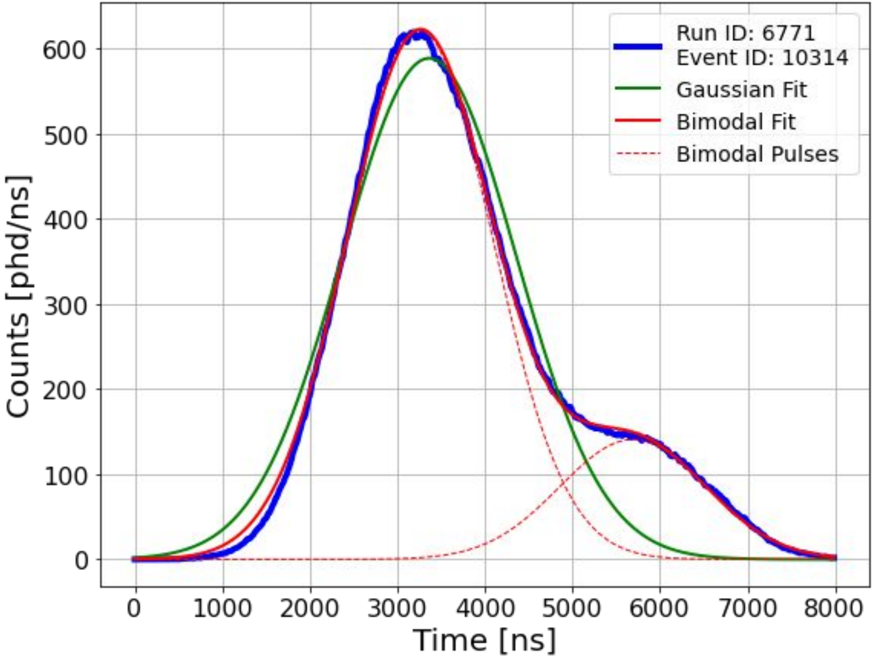
An algorithm based on **nonlinear least squares** (NLS) regression was developed.

- Parameter of the Fits
  - **Gaussian** (Green)
    - Mean, Sigma, Amplitude
  - **Bimodal** (Red)
    - Mean1, Mean2, Sigma, Amplitude1, Amplitude2

$$f_2(x; \bar{x}, \sigma, A) = A \cdot \exp\left\{ -\frac{(x-\bar{x})^2}{2\sigma^2} \right\}$$

$$f_3(x; \bar{x_1}, \bar{x_2}, \sigma, A_1, A_2) = A_1 \cdot \exp\left\{ -\frac{(x-\bar{x_1})^2}{2\sigma^2} \right\} + A_2 \cdot \exp\left\{ -\frac{(x-\bar{x_2})^2}{2\sigma^2} \right\}$$





LZ Science Run 1 (SR1) Data

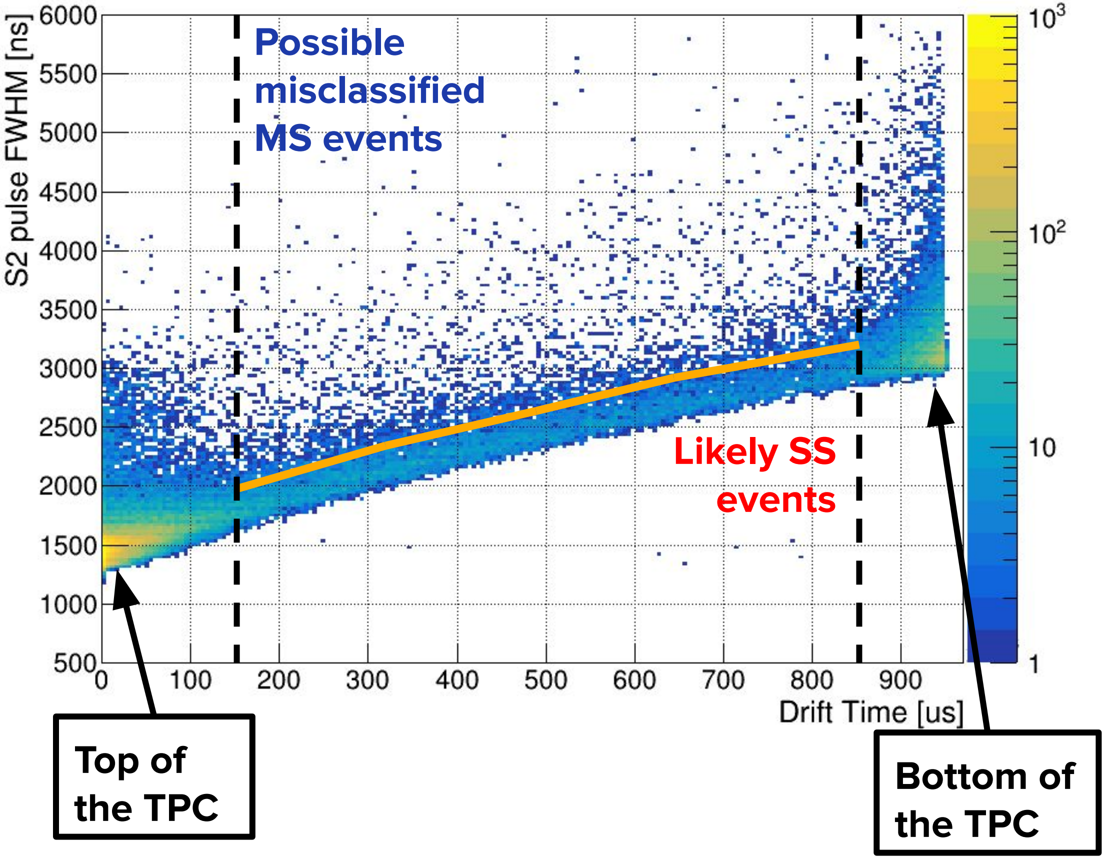
The target events selected were:

- Pulses classified as single scatter (SS)
- E > 1 MeV (high energy events)

Drift Time boundaries:

- Min = 150 µs
- Max = 850 µs

To exclude events with additional effects to diffusion.



Regular SS Pulses

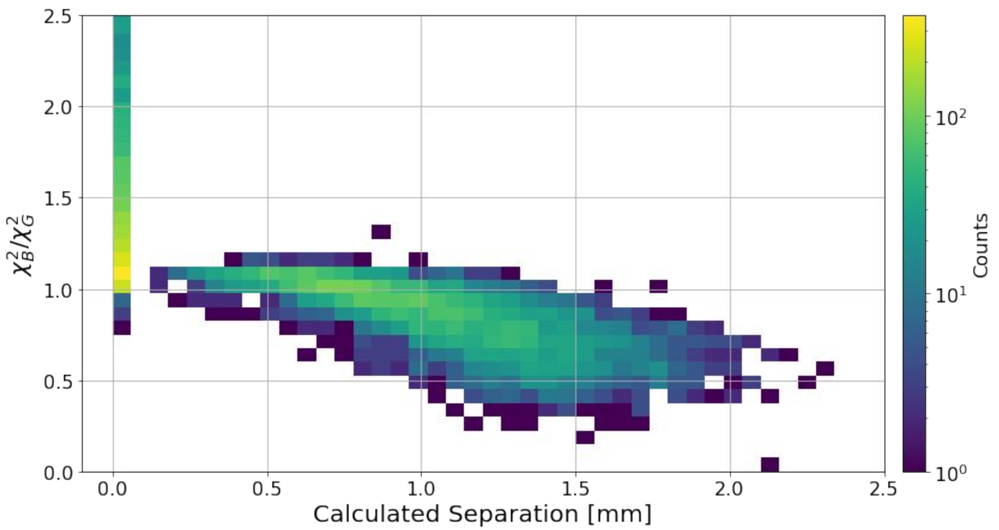
- ➢ Some of the pulses may be MS events.
- ➢ 15.6% were reconstructed with zero separation.

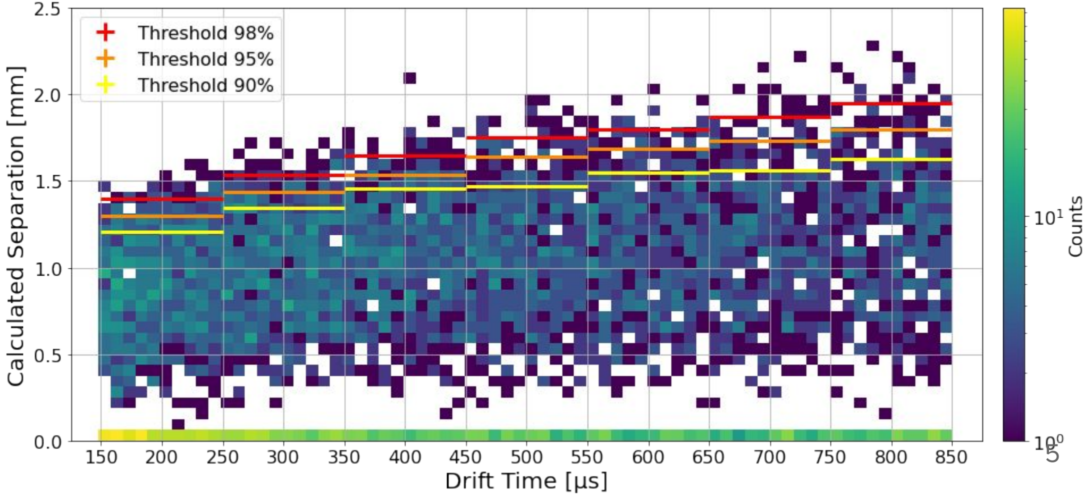
Χ² Ratio

- Bigger concentration near the unit value.

Threshold

- Defined as the percentile 90%, 95% and 98% of the <u>reconstructed separations</u>;
- Dependency over Drift Time different than pulse width.





Wider SS Pulses

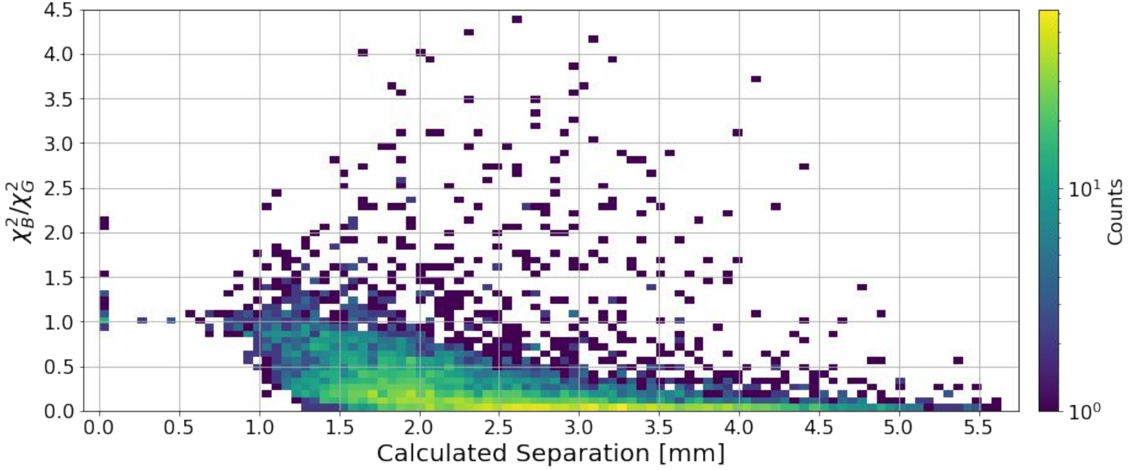
➢ Some pulses still reconstructed with separation zero (Possible real SS contamination)

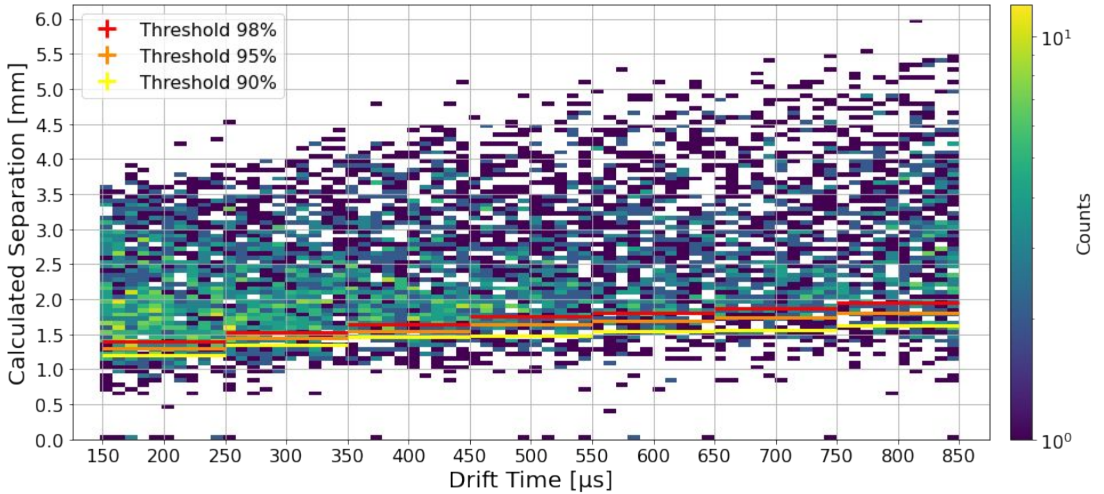
χ^2 Ratio

- Bigger concentration near zero (Better Bimodal fit)
- Lower fit efficiency for some high separation pulses

Comparing with the previous Threshold

- Most events reconstructed above the threshold;
- Capability to distinguish SS from MS down to **1.5 mm**.





Conclusions

This algorithm was able to **improve** over the vertical pulse separation in LZ, which was the initial objective:

- **2 mm** close to the bottom of the detector;
- < **1.5 mm** for the top.

Around **15%** improvement on the LZ sensitivity to **$0\nu\beta\beta$** (preliminary).

The algorithm can be used in **LZ** and in the next-generation xenon TPC detectors.

Future work will explore:

- Higher multiplicity scatter analysis;
- Machine Learning algorithms;
- XY plane separation (S2 diffusion pattern);
- Next-generation (XLZD) sensitivity studies.

Thank you!

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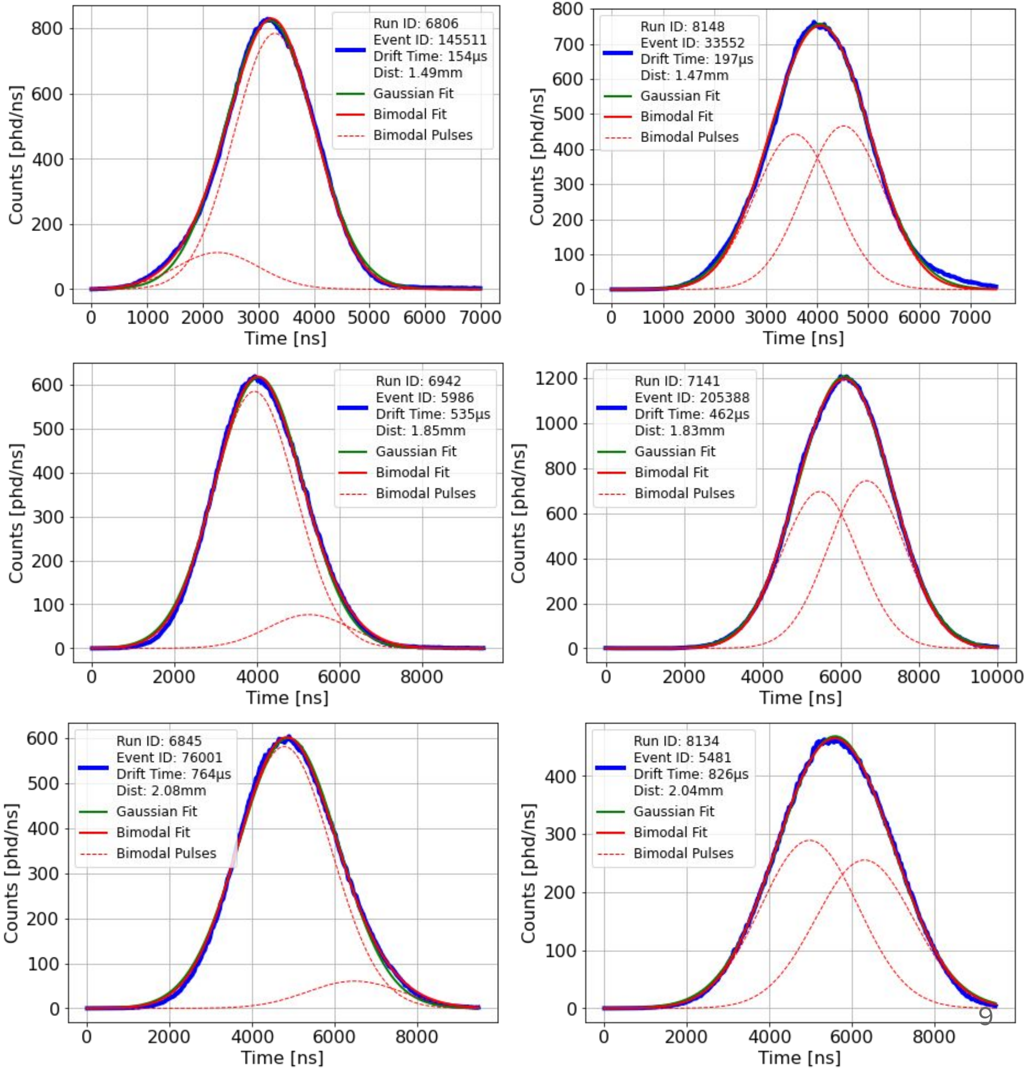
Separation Limits

Looking for the Drift Times near the top, middle and bottom:

1. [148;250] µs
   a. THR98 = 1.397 mm
2. [450;550] µs
   a. THR98 = 1.753 mm
3. [750;850] µs
   a. THR98 = 1.950 mm

Examples represent events reconstruction with **Maximum** and **Minimum** asymmetries.



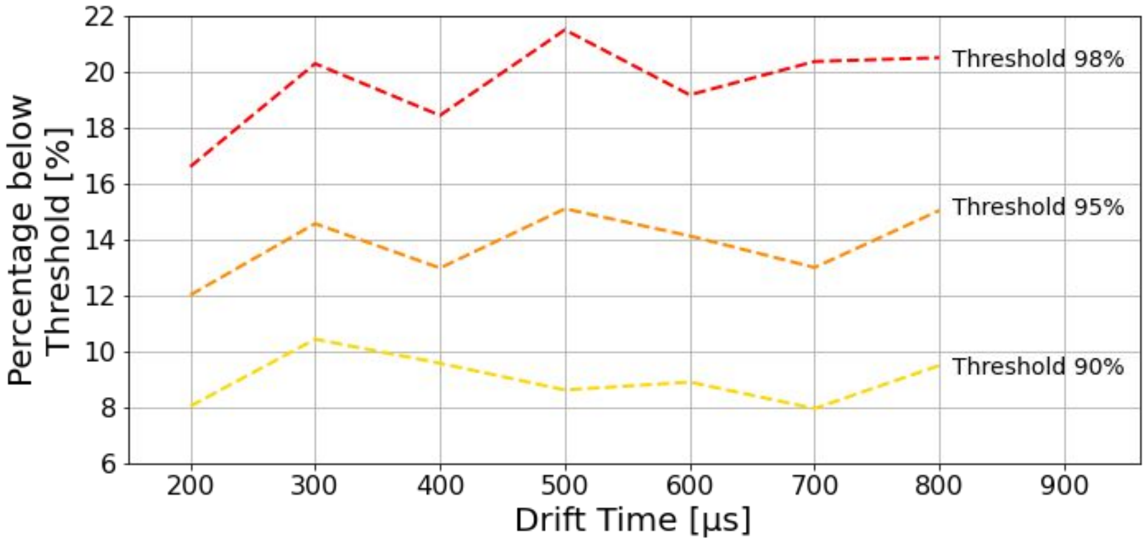
Contamination in Wider SS Pulses

Contamination defined as:

- Pulses reconstructed below the threshold.
- Contamination levels are relatively **constant** with Drift Time.

Median Contamination:

- 9.0% (THR90)
- 13.8% (THR95)
- 19.6% (THR98)

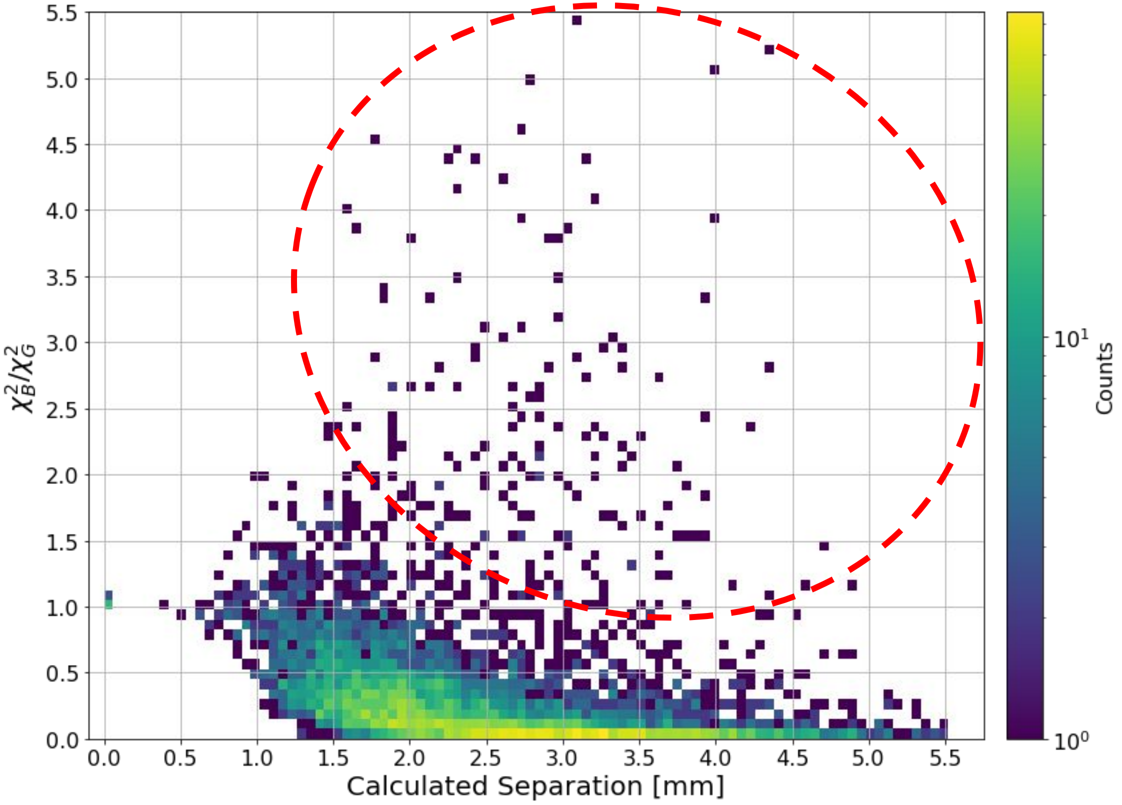


Trimodal Fit

Some pulses do not fit either the a Gaussian or Bimodal distribution properly.

- Trimodal distribution:
  - Mean1, Mean2, Mean3, Sigma, Amplitude1, Amplitude2, Amplitude3

Using the same constraints as the Bimodal.



Triple Scatters Candidates

Most of triple scatters are found near the top (probably related with the event density)

Discrimination potential with χ^2 of the Trimodal