A decomposition algorithm for streak camera data

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1) **Understand amplitudes in recorded images in terms of photoelectron counts to allow standard statistical analysis**
2) **Investigate resulting ultimate time resolution of inter-image features**

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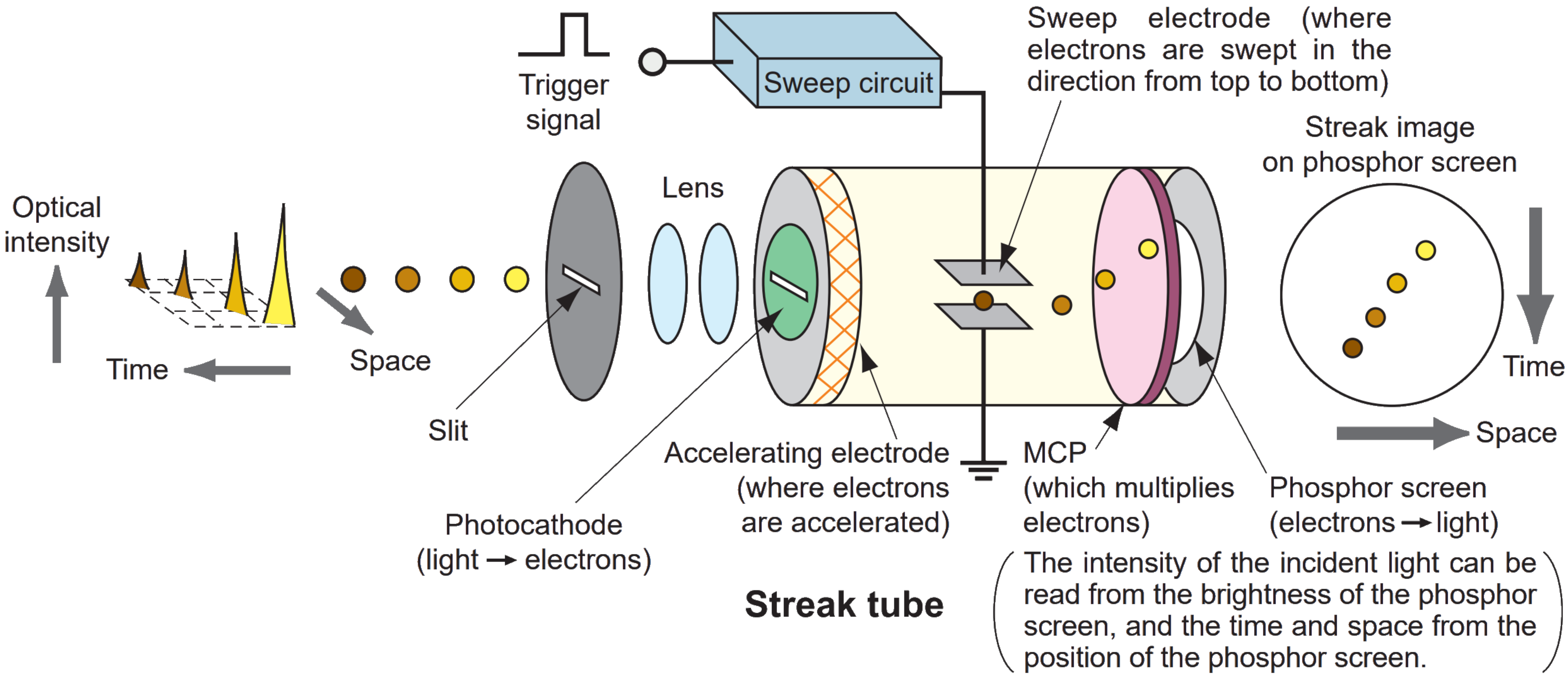
Hamamatsu Streak Camera



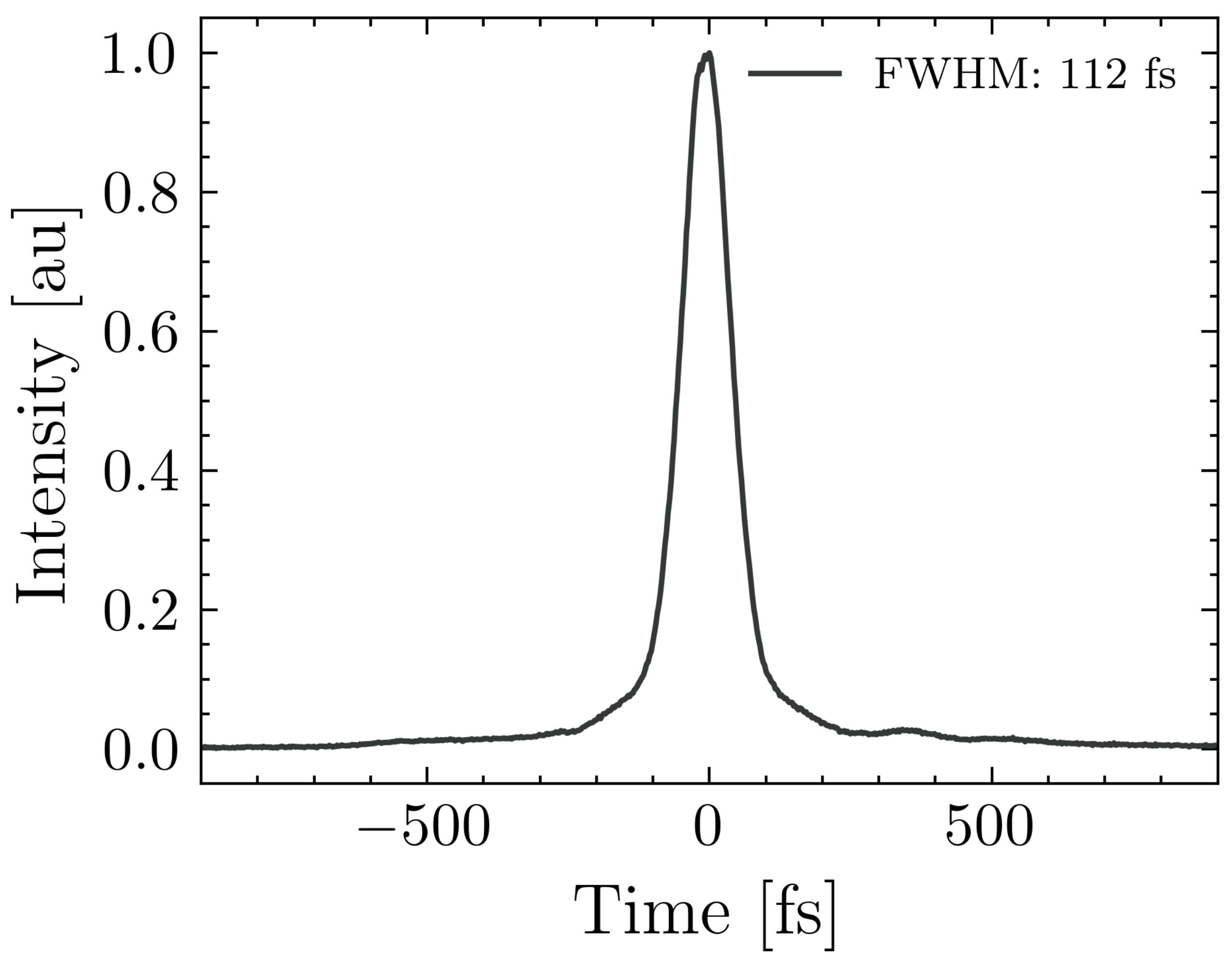
Data

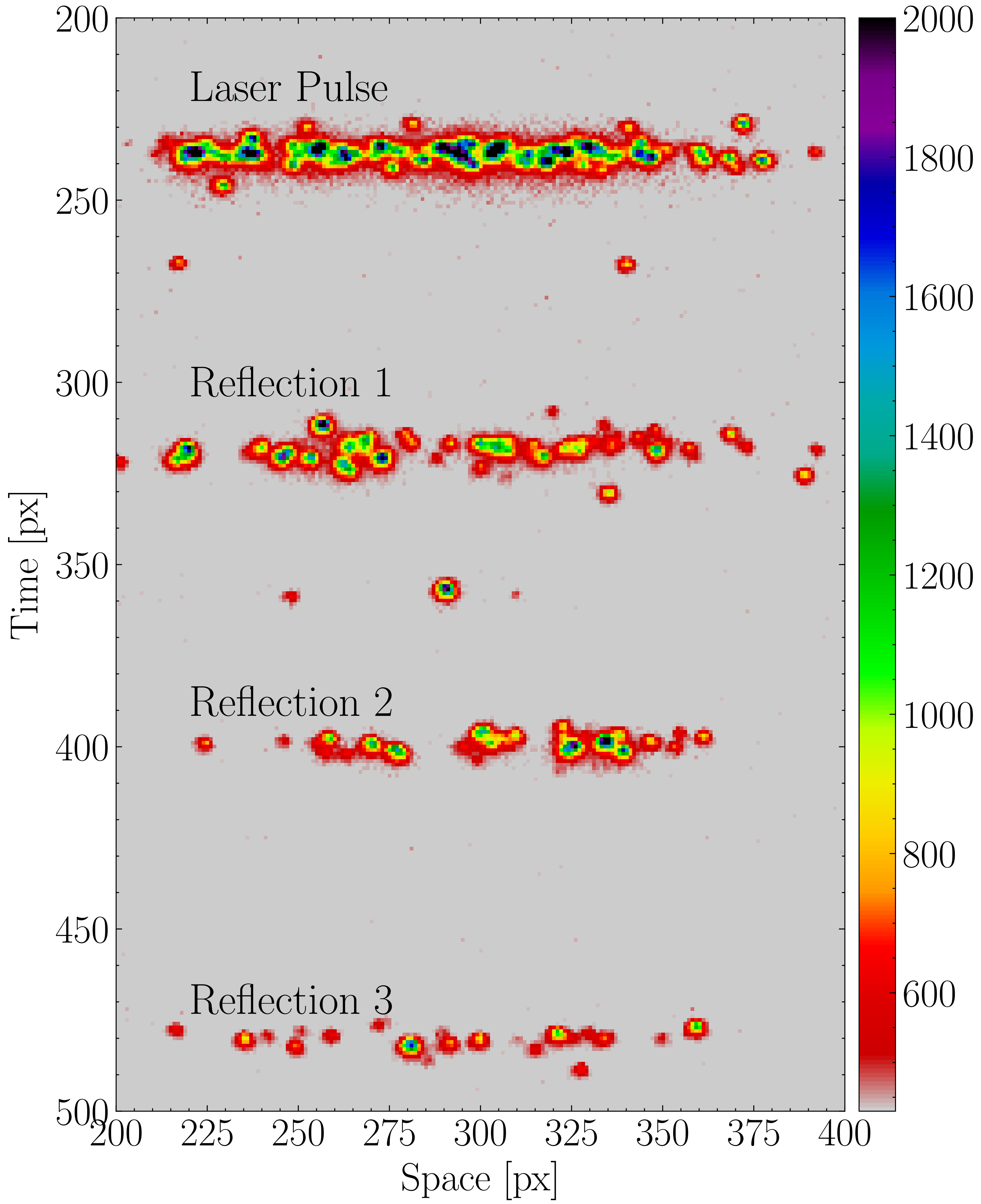
Primary Data Set:

- 1000 streak camera images of laser pulse propagated through thin glass slab
- 210 ps sweep time

Setup & data from Fabian Batsch

F. Batsch, *Setup and Characteristics of a Timing Reference Signal with sub-ps Accuracy for AWAKE*, *J. Phys. Conf. Ser.* **1596** (2020) 012006 [1911.12201].

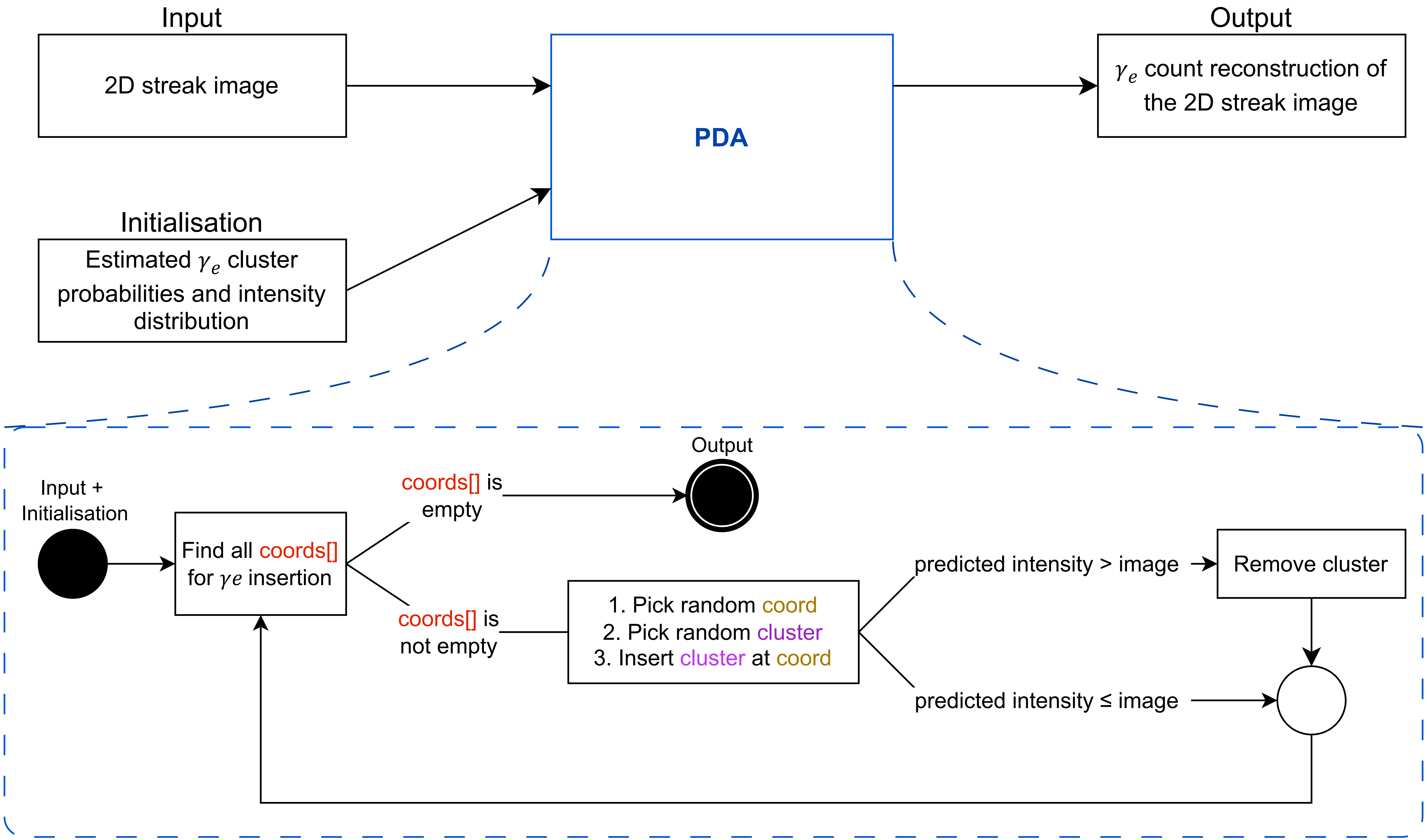




Additional Data Set:

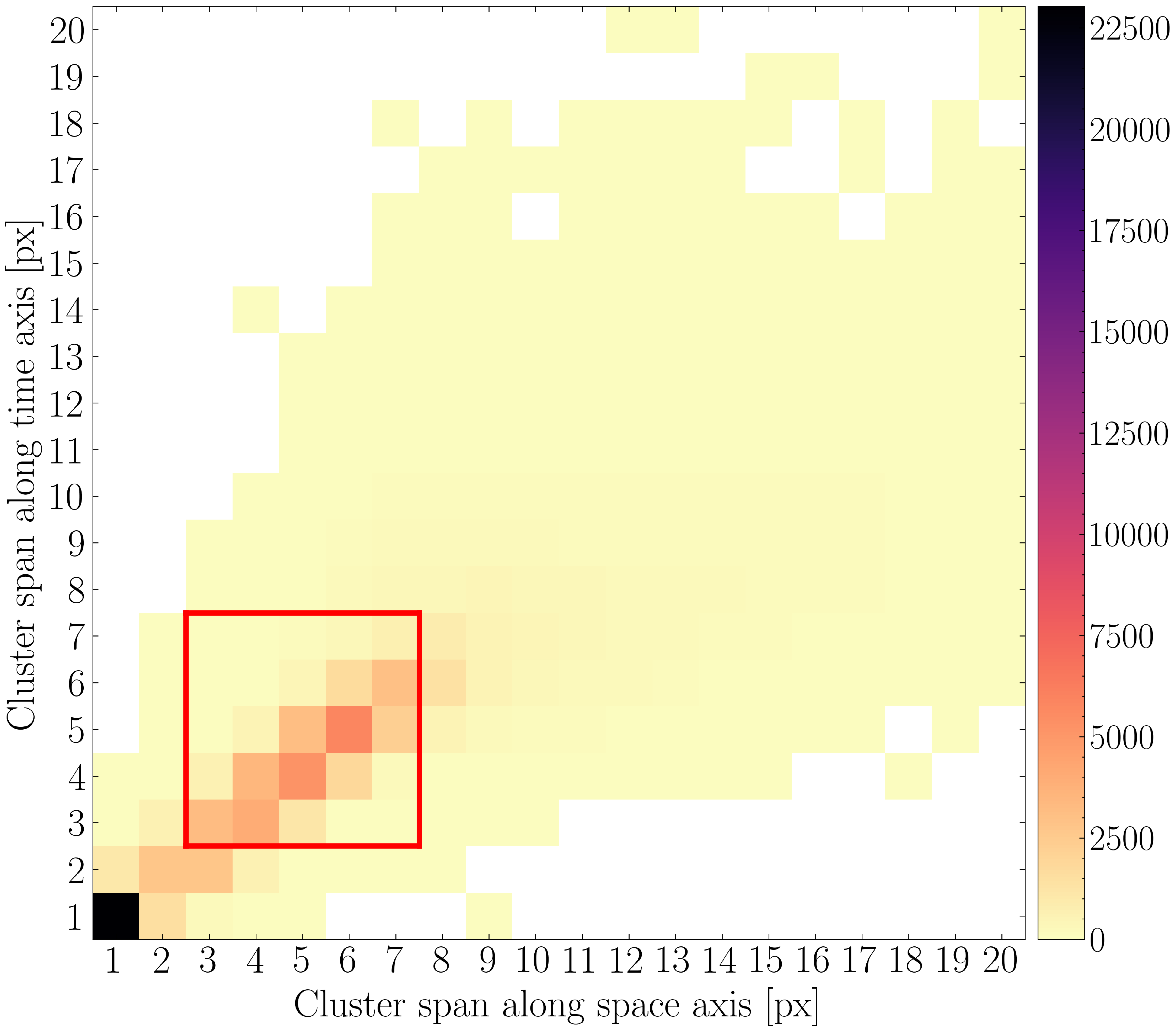
- 200 streak camera images of proton bunch modulation data
- 73 ps sweep time
- artificial 0-distance reflection was simulated in the data by dividing the recorded laser pulse image into two sets of pixels along the spatial direction

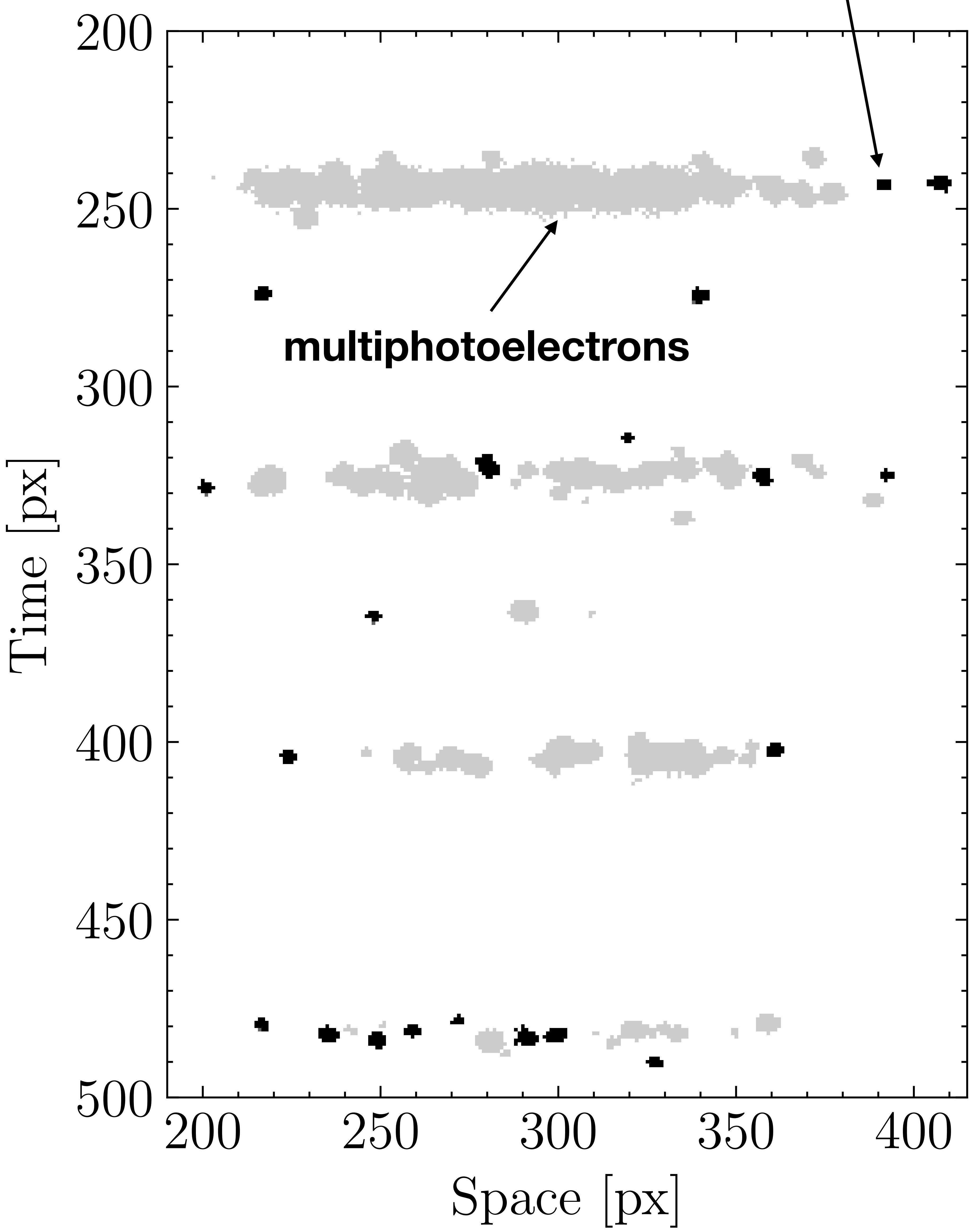
Photoelectron Decomposition Algorithm



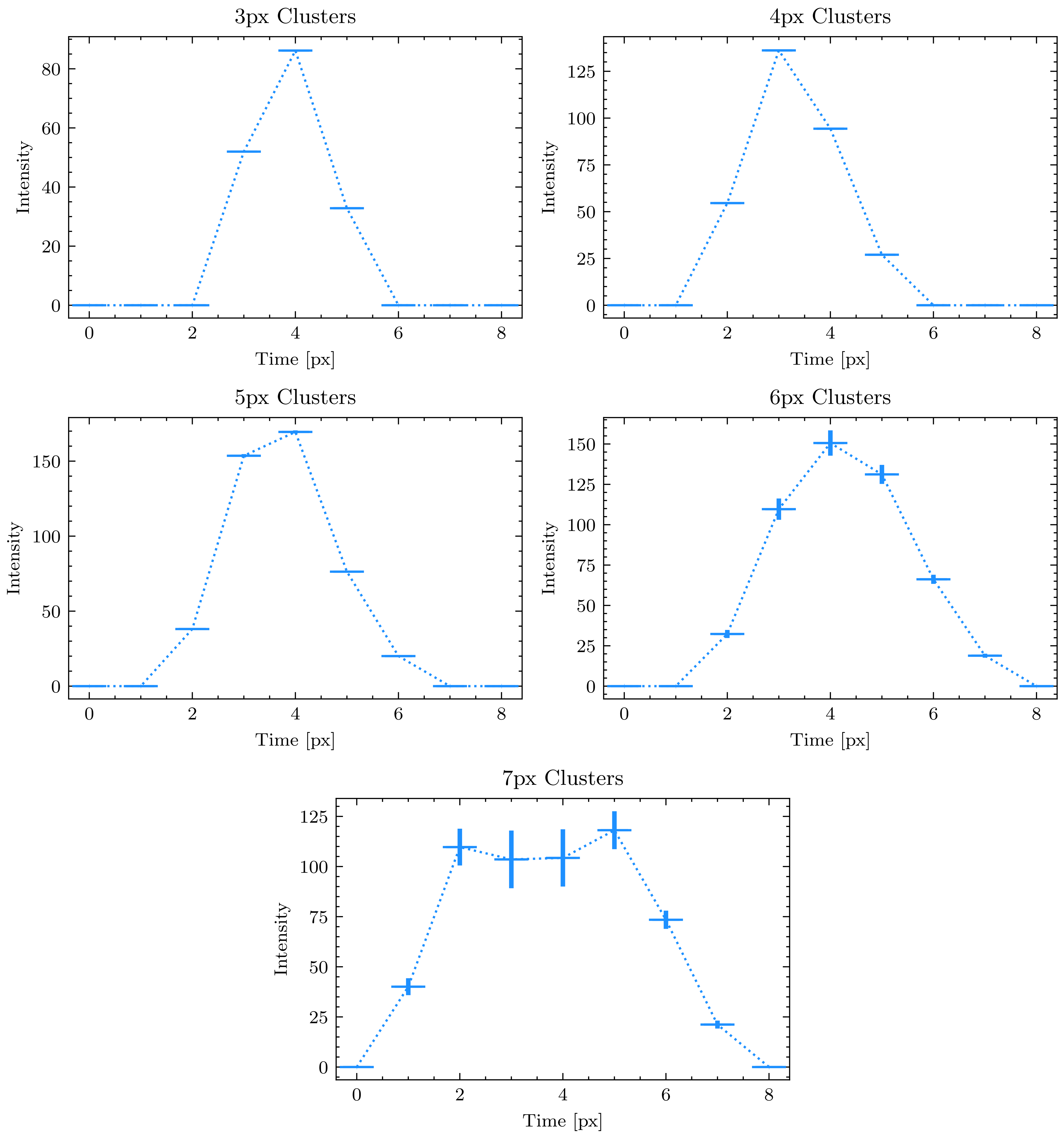
Binary Filter to select 'hit' pixels

Cluster Selection Mask





Photoelectron Cluster Distribution



Interested here in timing aspects: clusters summed along the spatial axis and categorized according to resulting width in the time axis.

Cluster Class	**3 px**	**4 px**	**5 px**	**6 px**	**7 px**
Detected Count	6099	11497	6283	881	309
Probability	0.243	0.459	0.251	0.035	0.012

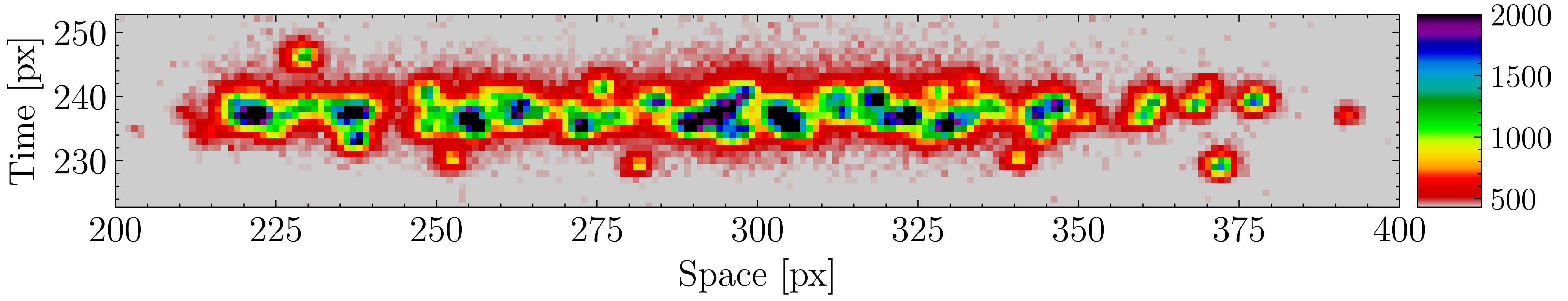
Cluster size distribution in pixels does not depend on the streak camera sweep speed - it is a result of the MCP & phosphor screen action.

Analysis is therefore performed in units of pixels and later transformed to time.

Parameters of photoelectron clusters were extracted for the 210ps sweep data but later applied to the 73ps sweep data.

Pulse Decomposition Example

Analysis of a primary laser pulse image



Projected on the time axis and decomposed into numbers of photoelectrons in time pixel bins

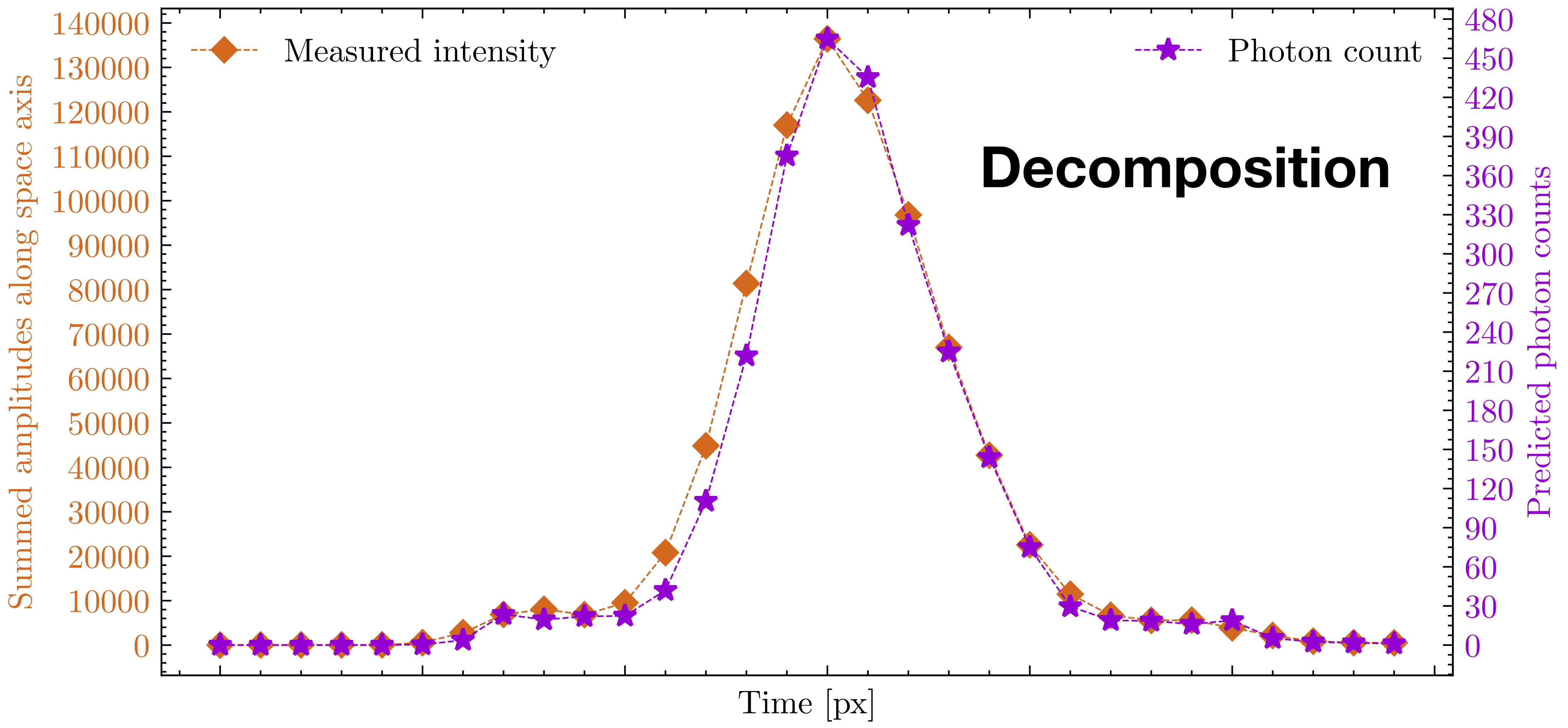
Scheme:

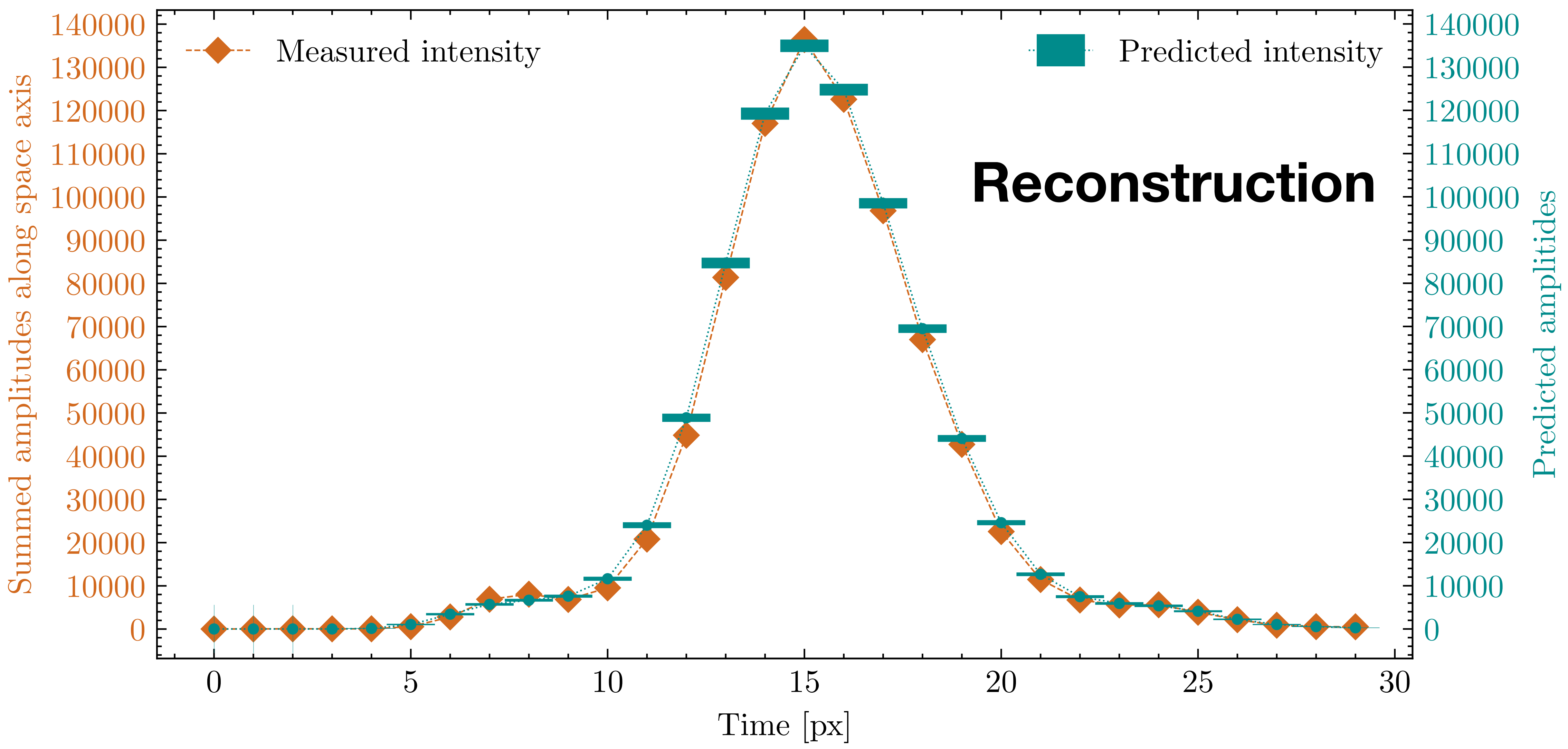
1) choose a location along the time axis

2) pick a photoelectron pulse shape according to probability distribution

3) add it if original amplitude not exceeded

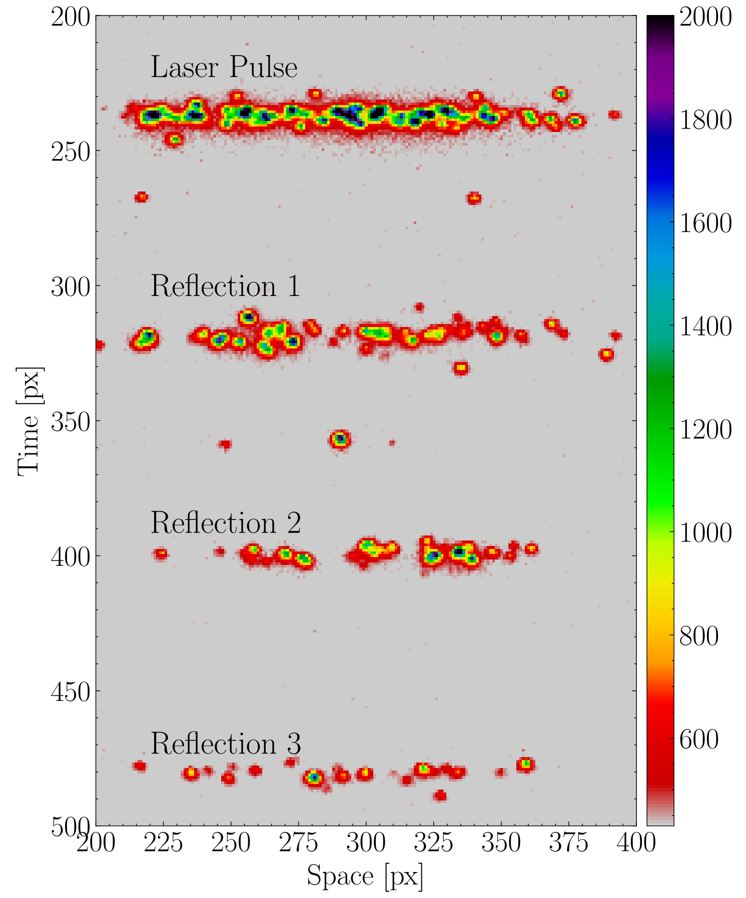
4) repeat until no valid location

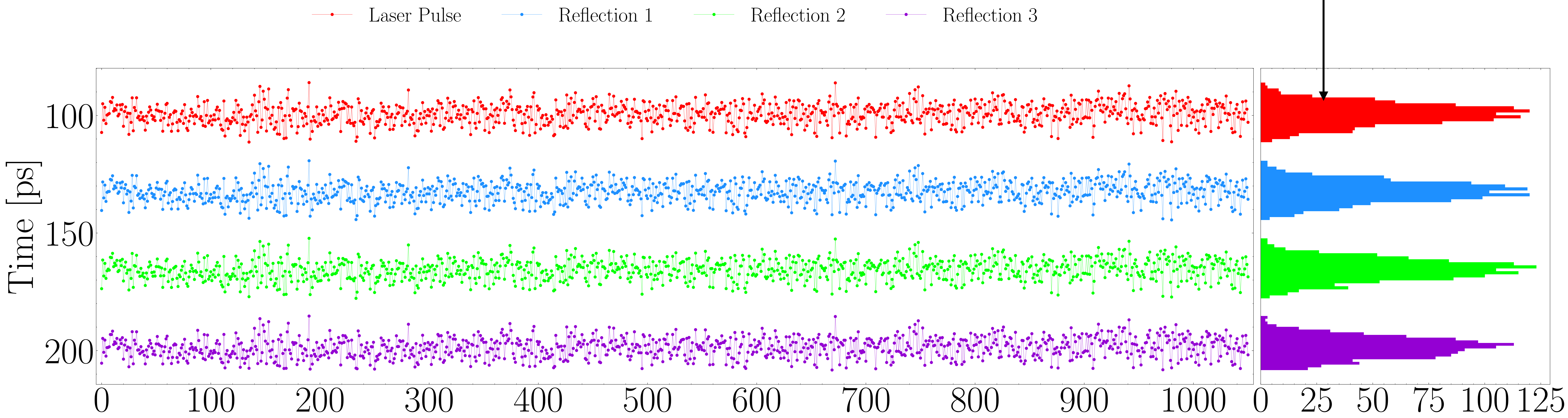




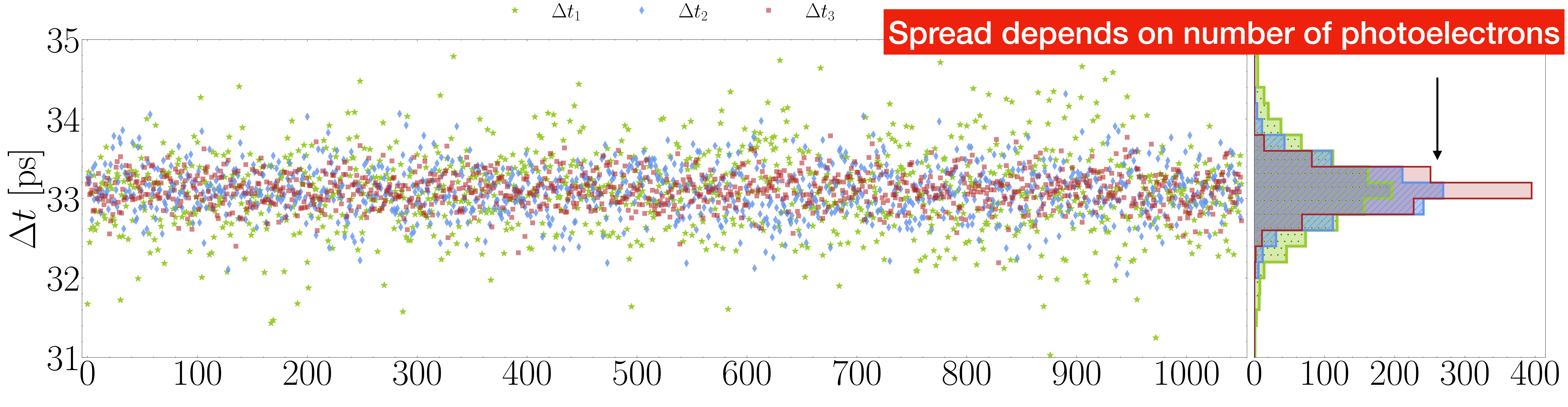
Analysis

Spread due to trigger jitter of streak camera





Spread depends on number of photoelectrons



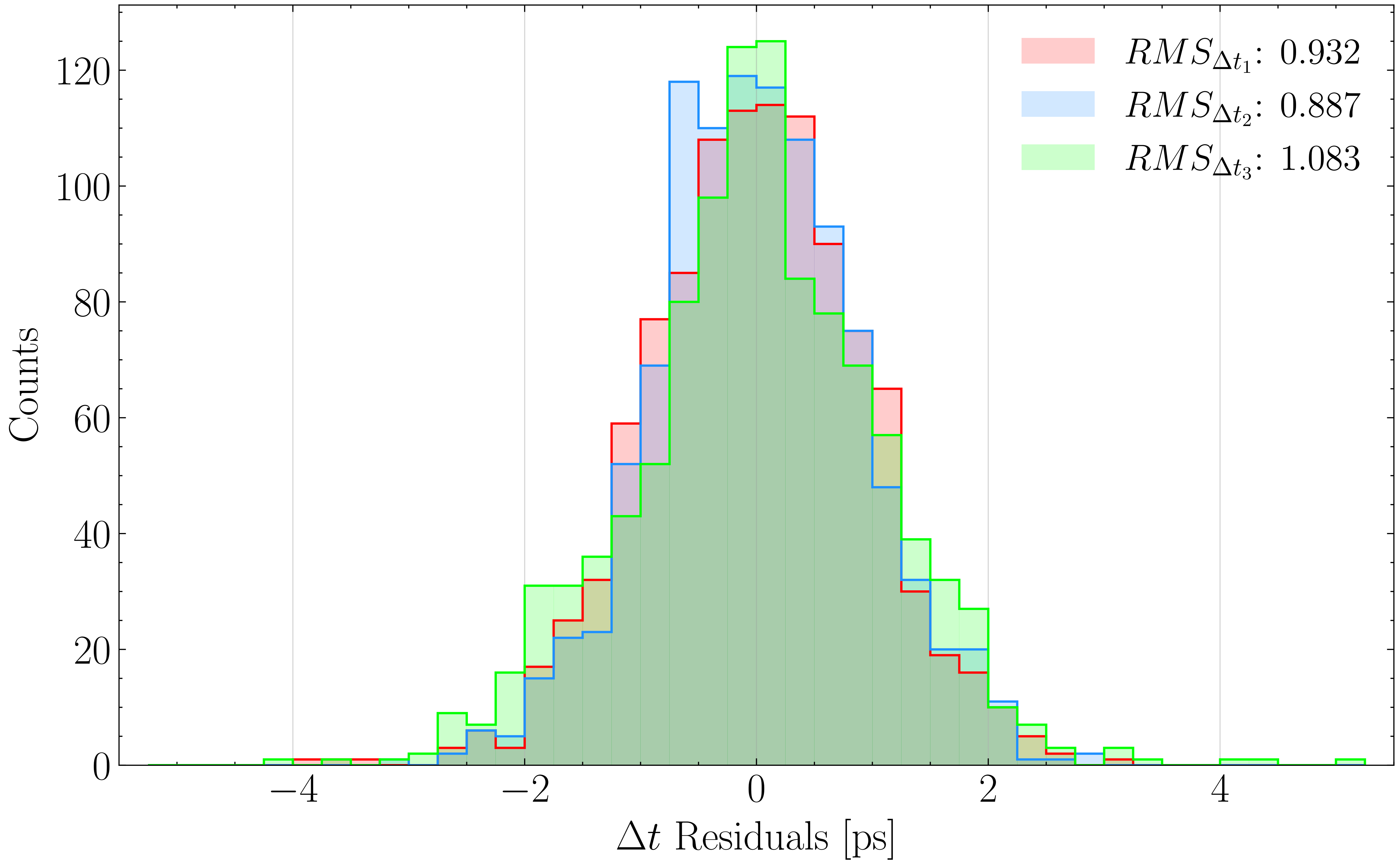
Image

Performance

Parameterization: $\sigma_t(px) = \frac{18.28}{\sqrt{n_\gamma}}$ Convert to time in ps given sweep time.

Statistics: if the uncertainty parameterization is valid, the residuals $r_i = \frac{\Delta t_i - \overline{\Delta_t}}{\sqrt{\sigma^2_{t,i,pulse} + \sigma^2_{t,i,reflection}}}$ should follow a unit Normal distribution

Works for all reflection data



Time resolution (210 ps sweep) : $\sigma_t = \frac{7.50}{\sqrt{n_\gamma}}\ ps$

for $400 \leq n_\gamma \leq 3000$

For 73 ps sweep, predict $\sigma_t = \frac{2.61}{\sqrt{n_\gamma}}\ ps$

tested on 73 ps sweep data: expected RMS of split laser pulse data was 180 fs, found 200 fs.

I.e., simple parametrization works adequately.

Summary

Kaan has developed a streak image decomposition algorithm that allows for standard statistical analysis of features in the data

The relative timing of features in the image can then be calculated together with an uncertainty on the timing on an image-by-image basis.

The time resolution attained can reach the limit of the laser pulse width (100 fs)

Please ask Kaan for his algorithm if you want to try it out!