Filter Study for Use in L1 Triggering at SNOLab

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Outline

- Introduction
- Sensitivity of box-car filters, optimal filters
- Performance Comparison
- Conclusions

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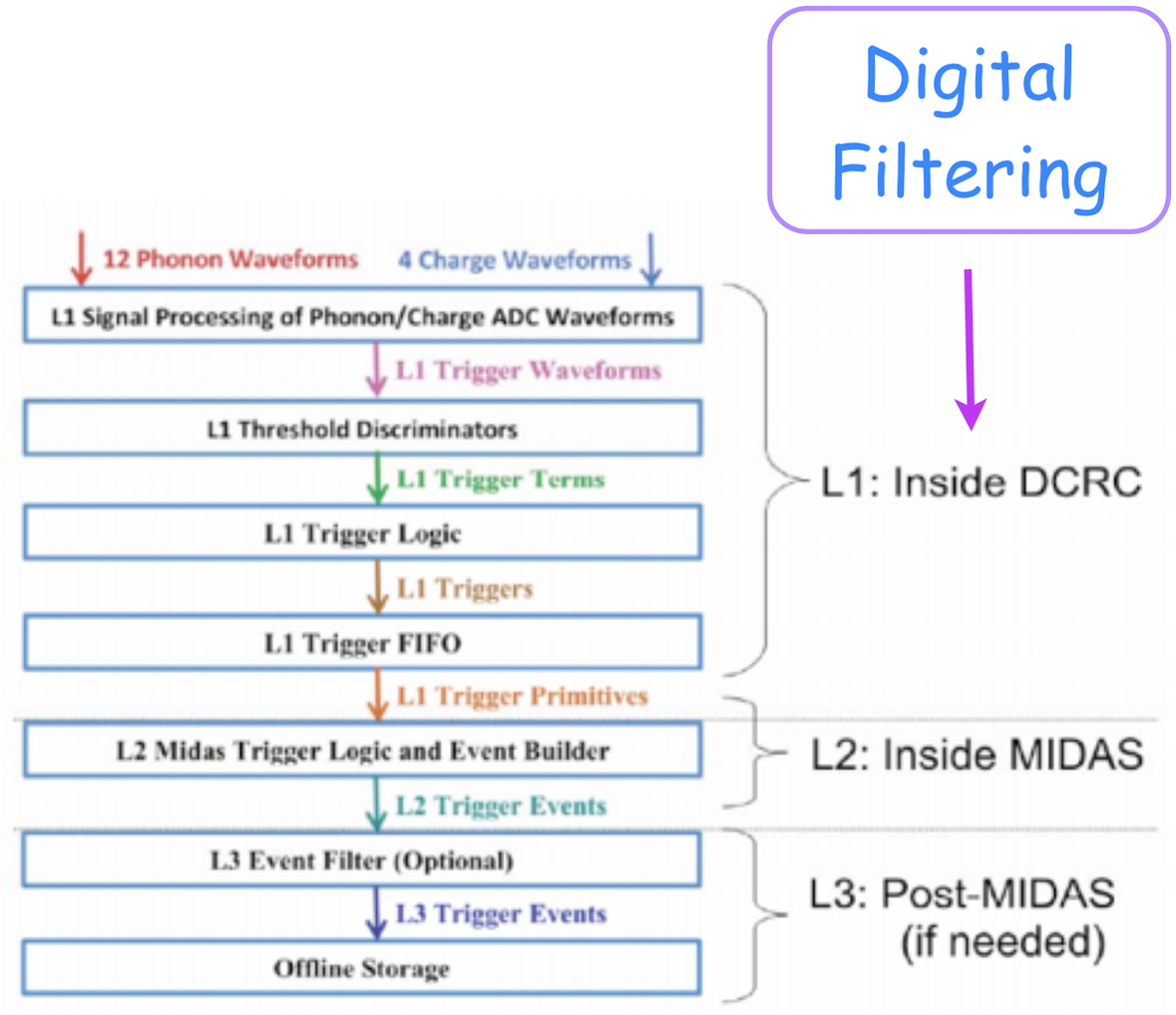
SNOLab Trigger System

- Trigger will be made of three systems: L1, L2, L3
- Use of DCRCs allow digital filtering
- We are exploring different strategies for filter design in L1



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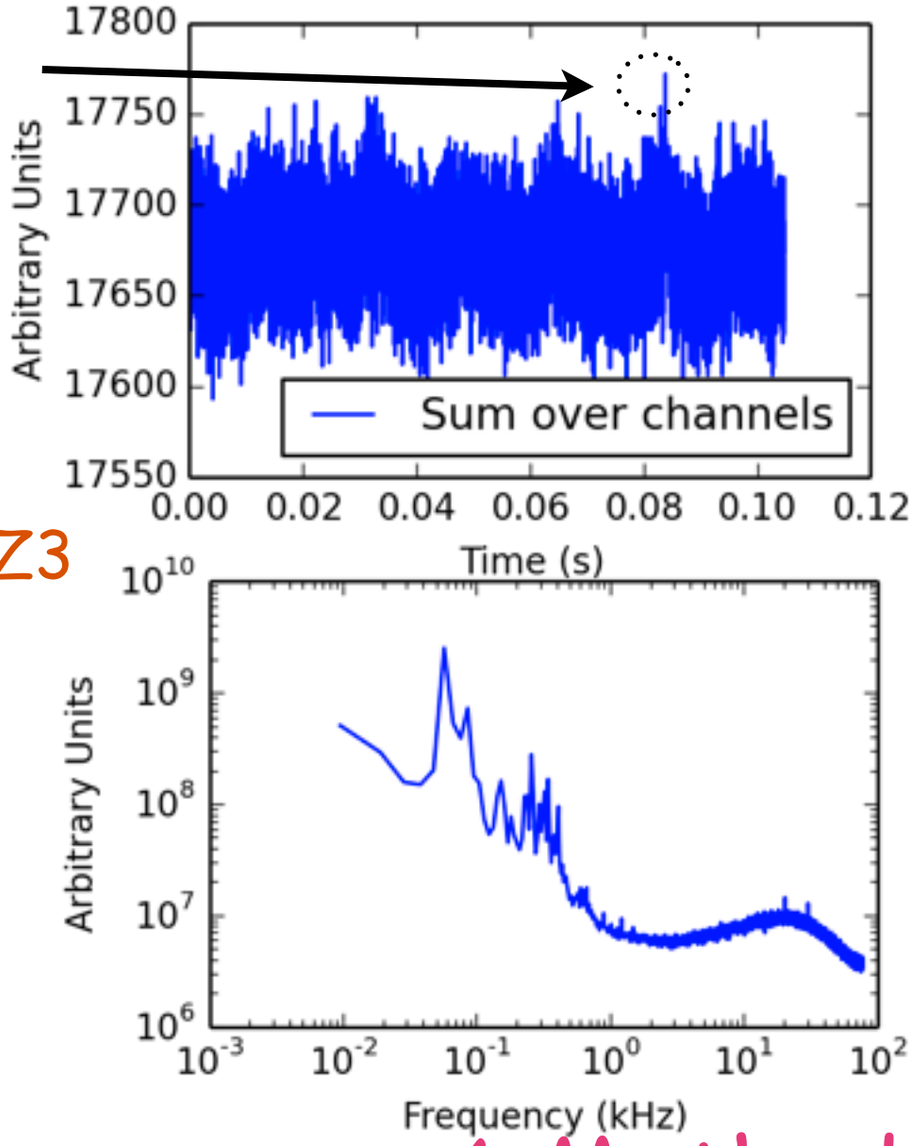
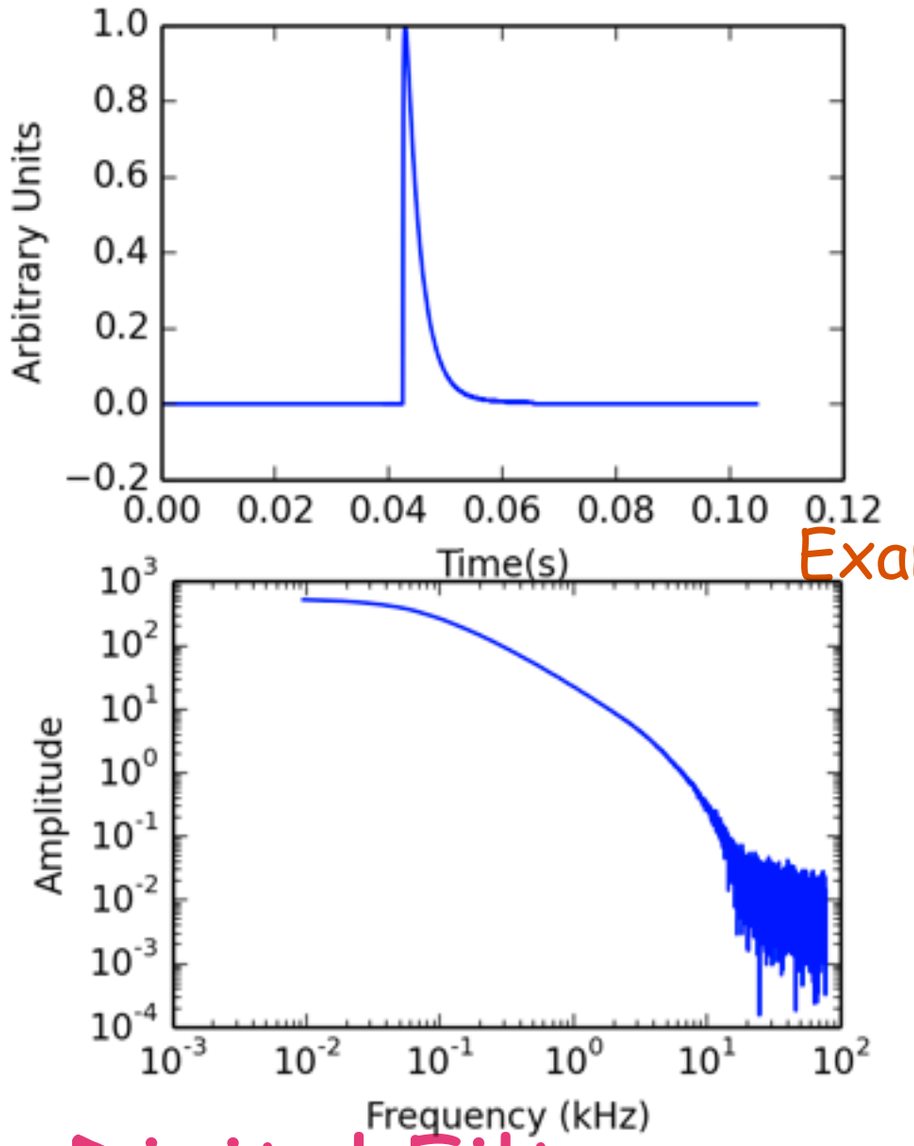
How to Extract Signal From Noise ?

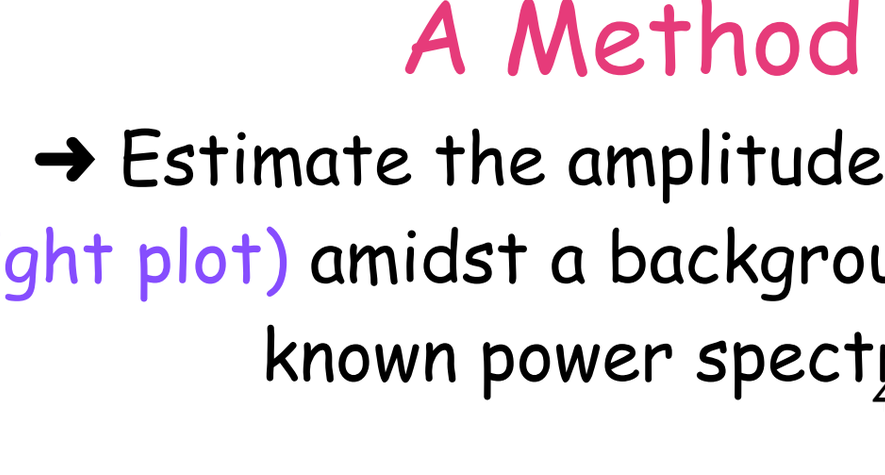
Extract a signal peak





Noise of T1Z3

Example Signal



A Method - Digital Filter

➜ Estimate the amplitude of a signal of known shape (right plot) amidst a background of gaussian random noise of known power spectral density (left plot)

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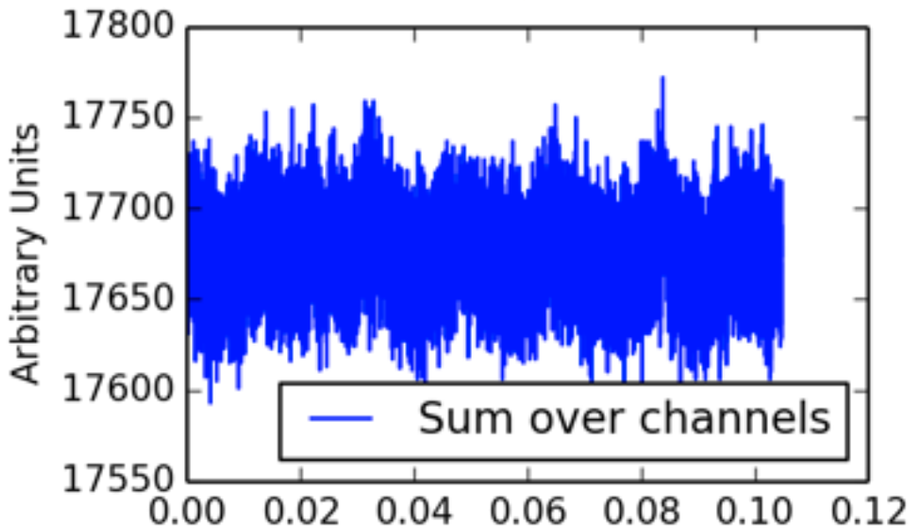
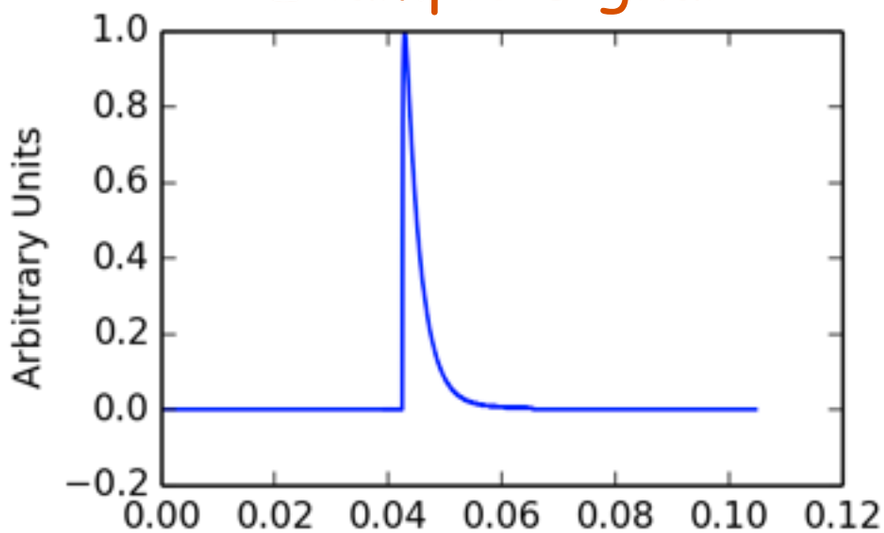
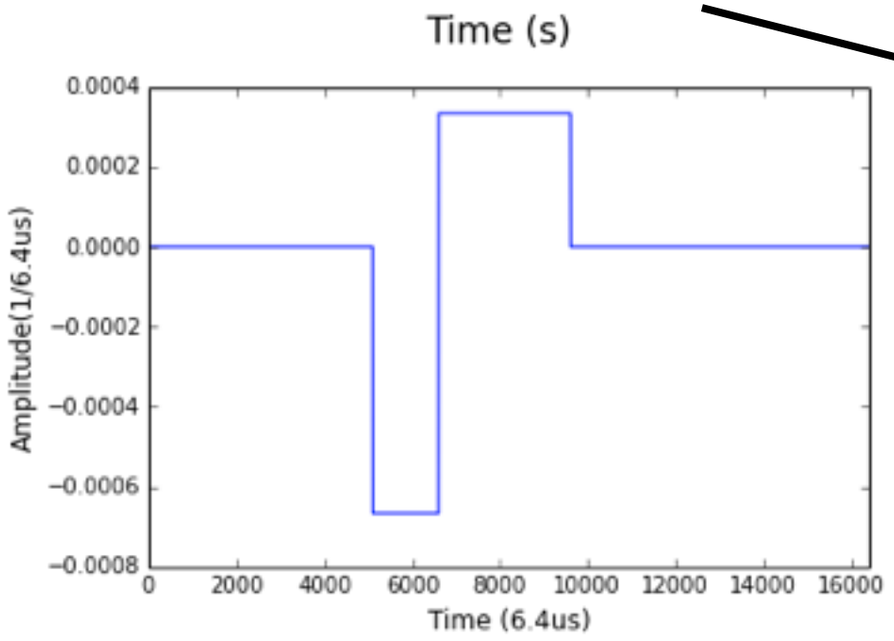
How to Apply Filter on Data?

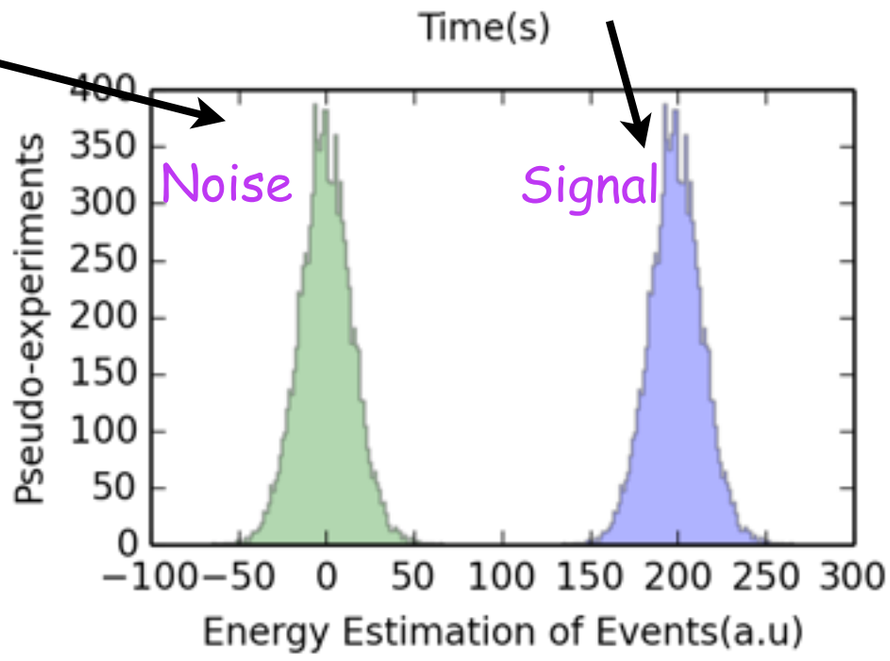
Noise of T1Z3



Example Signal







Sum(filter_weight * data) = Estimated signal amplitude

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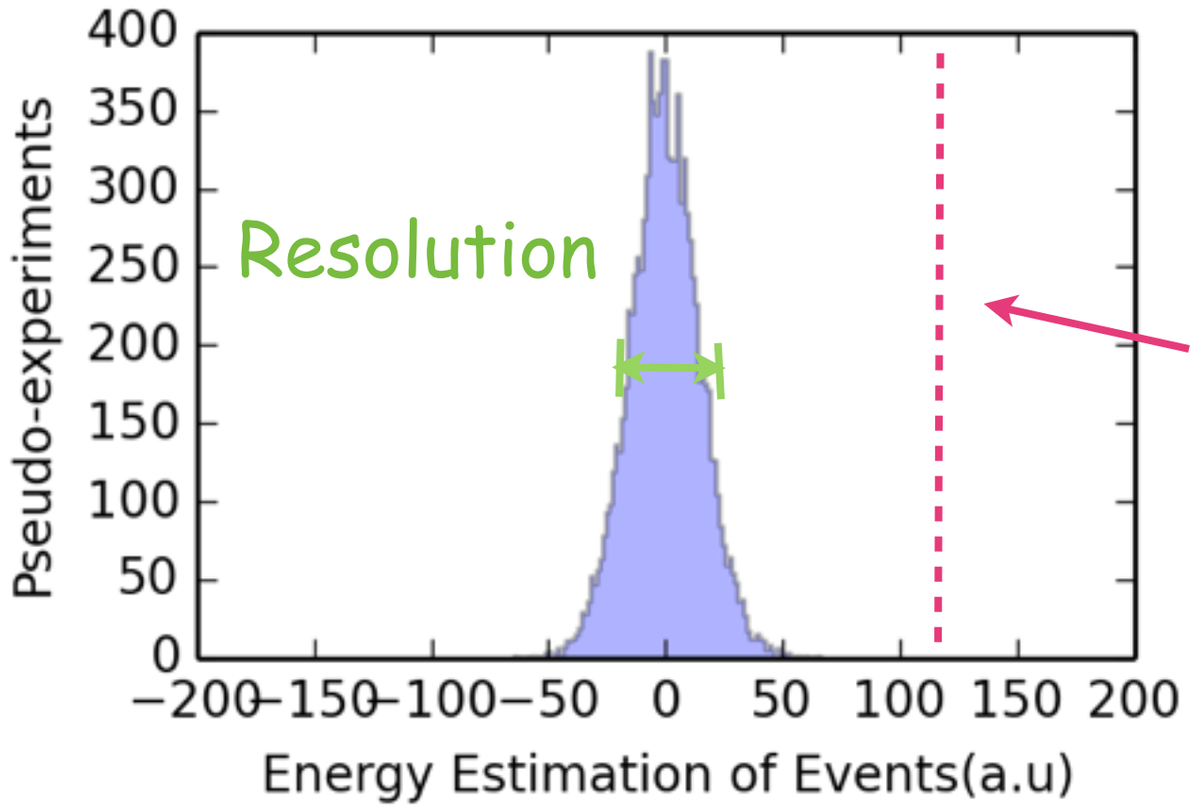
How to Calculate Resolution of Filter?

Distribution of the energy estimates of events



trigger threshold (5-7 sigma range)

- This example uses Monte Carlo method to calculate the resolution, while we calculate it analytically for the rest of the study
- Resolution reflects how small of a signal we can pick out from background
- Better filter ➜ smaller resolution ➜ lower threshold ➜ lower mass WIMP sensitivity
- 5 - 7 sigma range above noise

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Filter Design Strategies

Resolution for various proposals

Robustness to noise variation

Drive the selection of a filter

Consider 2 filter candidates:
- box-car filters and optimal filters

(Start by determining the resolution for each assuming the Soudan background noise and signal shapes.)

We have 11 detectors and 2 "optimization" filters for each. Run all the other detectors through each two optimizations and compare.

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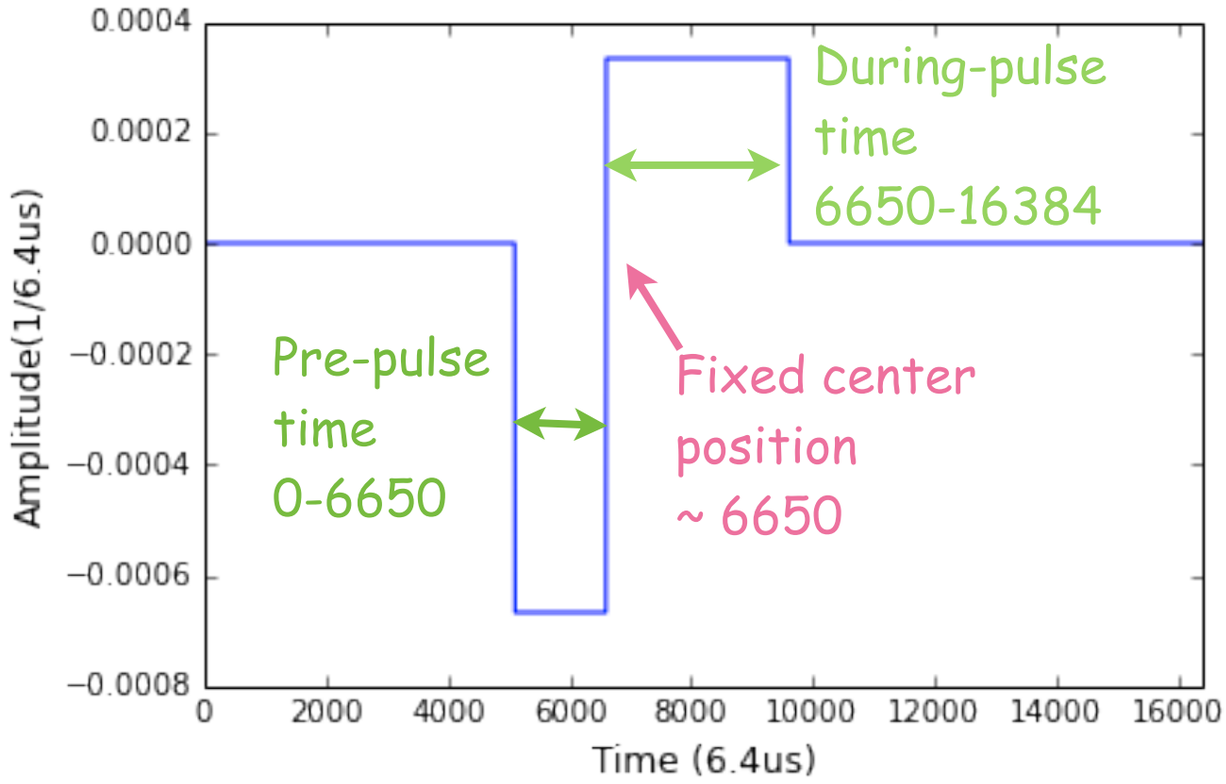
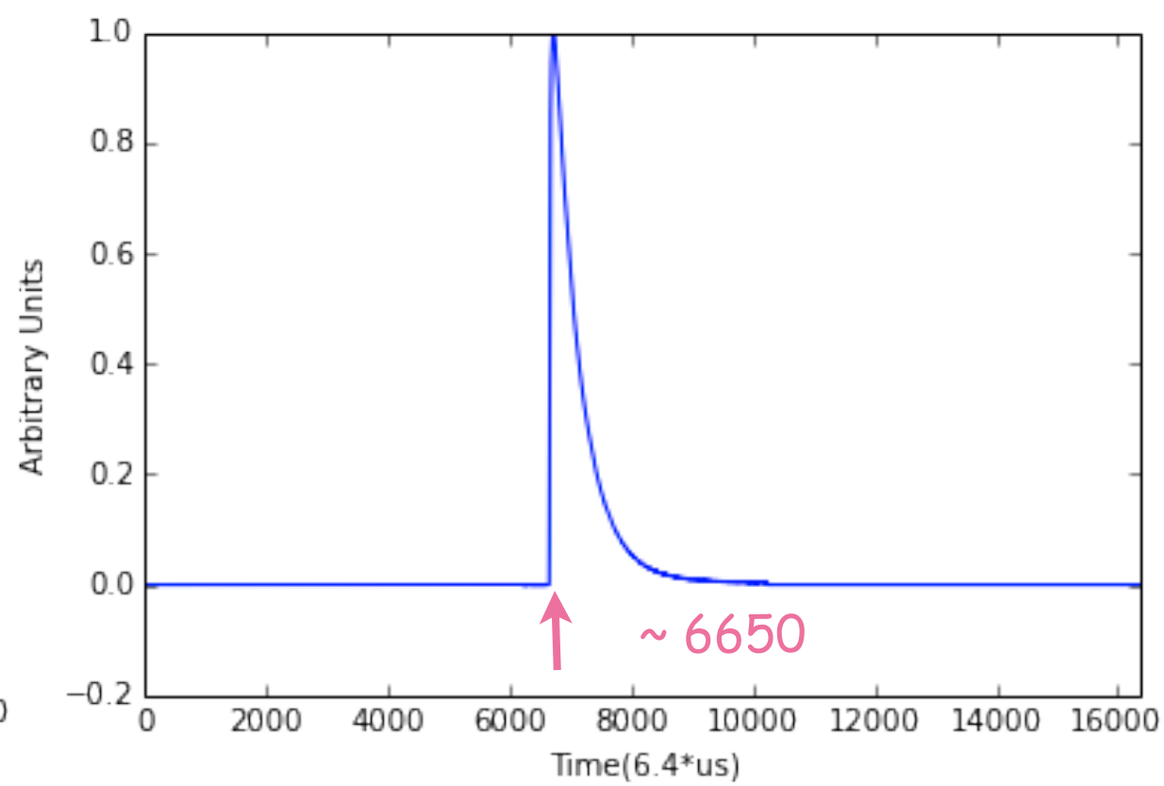
How to Calculate Box-car Filter?





- Define a box-car through two parameters
- Fixed the center position at ~6650
- Optimizing the boxcar filter by changing pre-pulse time, during pulse time

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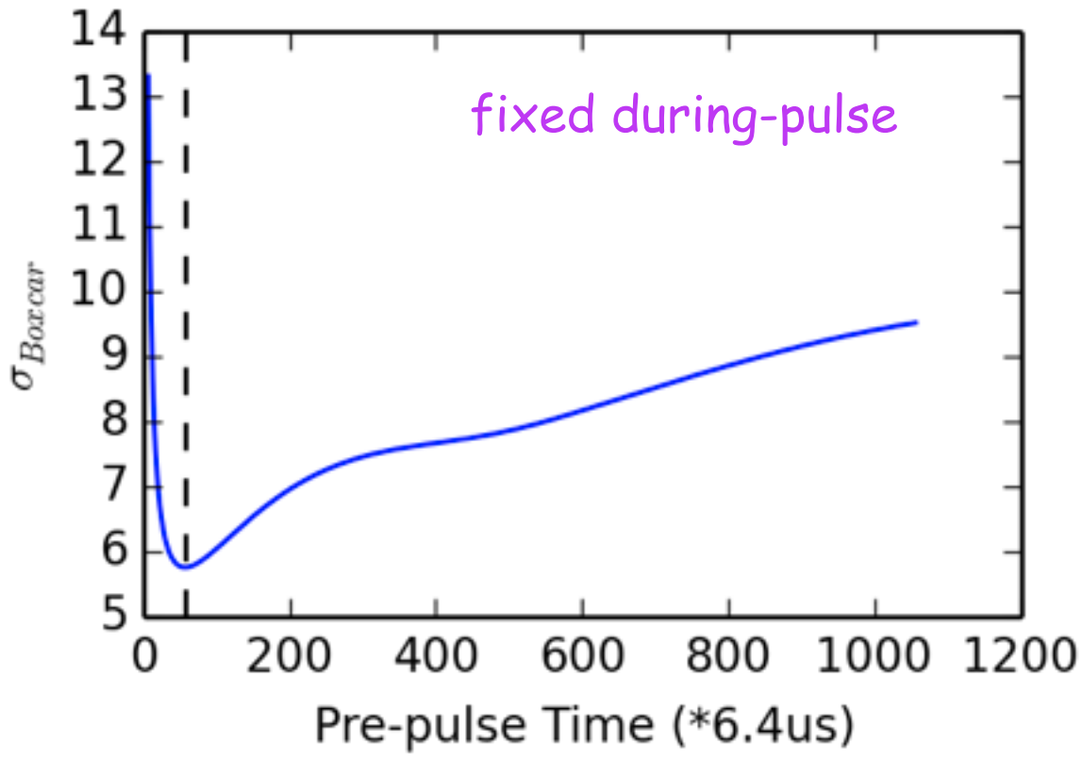
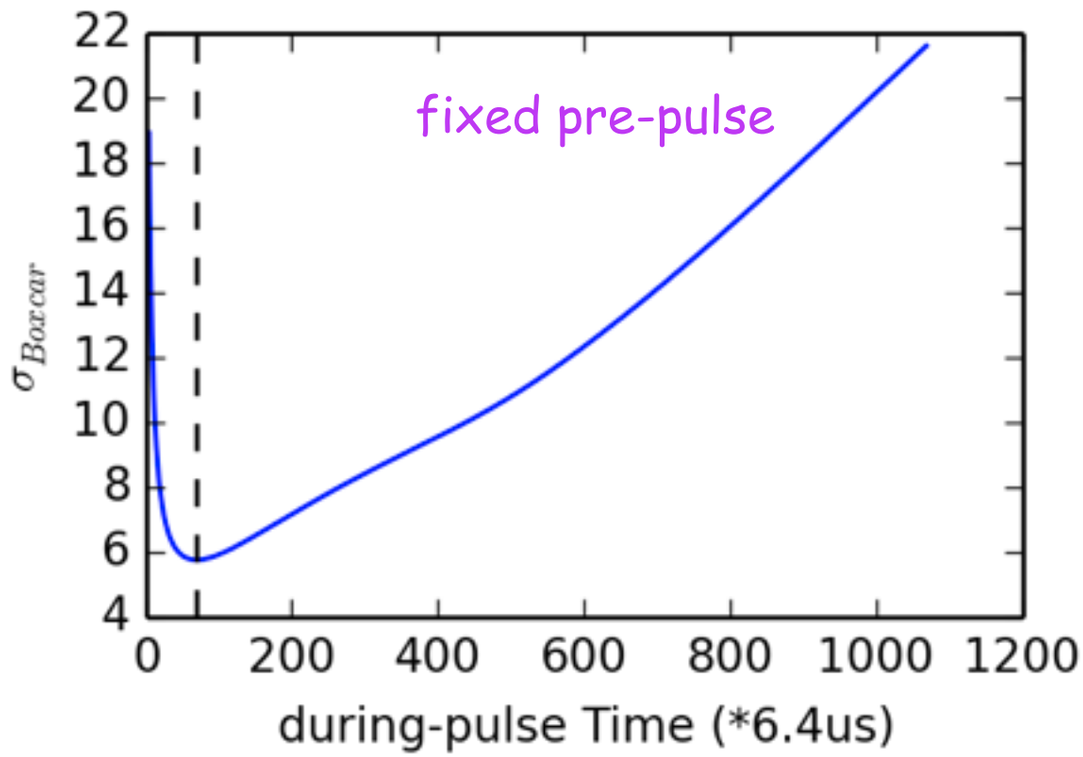
Box-car Filter Optimization

How the resolution varies with the two parameters?





- Change pre-pulse time and during pulse time and
- Determine the box-car filter parameters of minimum resolution by using numerical optimization method in python, double check with grid search

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What is Optimal Filter ?

- Optimized through calculation
- Signal traces $S(t) = aA(t) + n(t)$

  a - signal amplitude ← Estimate a

  $A(t)$ - known signal template

  $n(t)$ - noise realization with noise PSD

Optimal technique for amplitude estimation

(*Filippini Thesis):

➜ Calculate ChiSquare in frequency domain

➜Minimize the ChiSquare

➜Obtain optimal a

➜Obtain optimal filter

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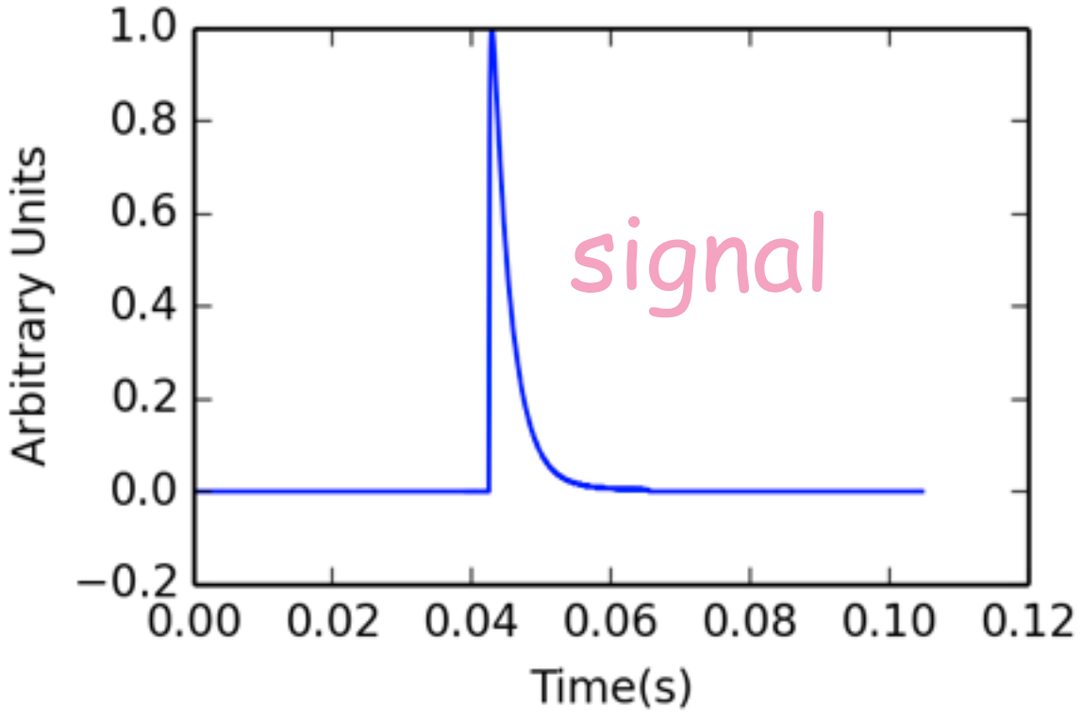
Optimal Filter Study



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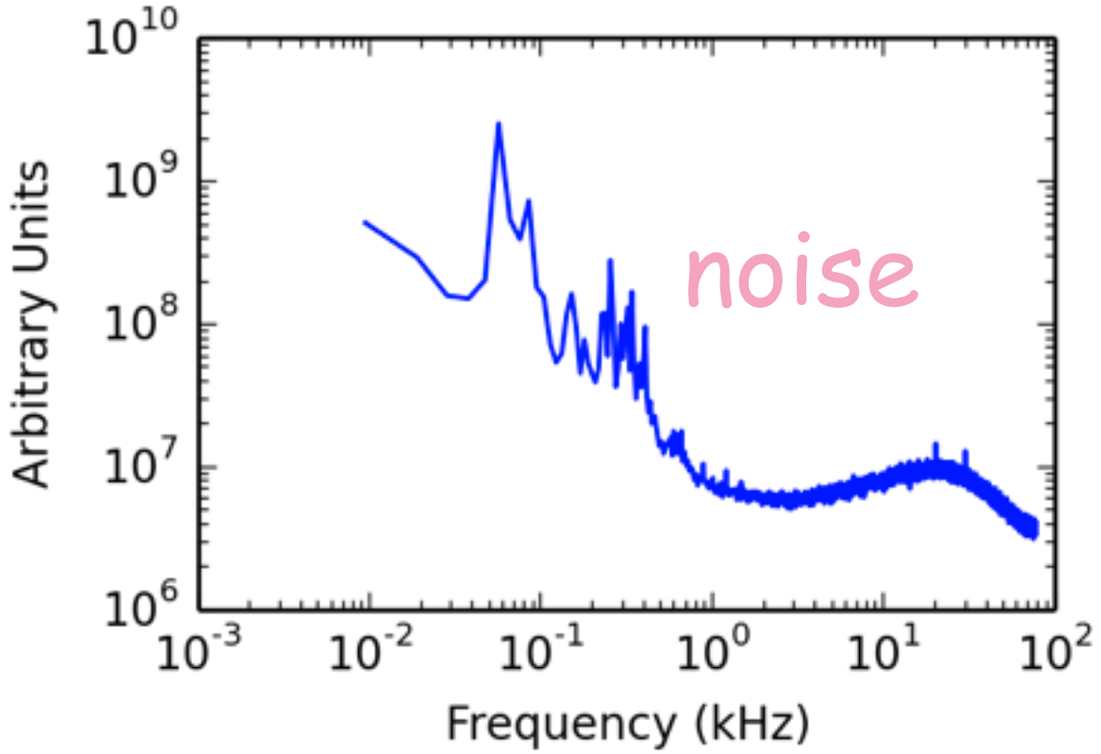
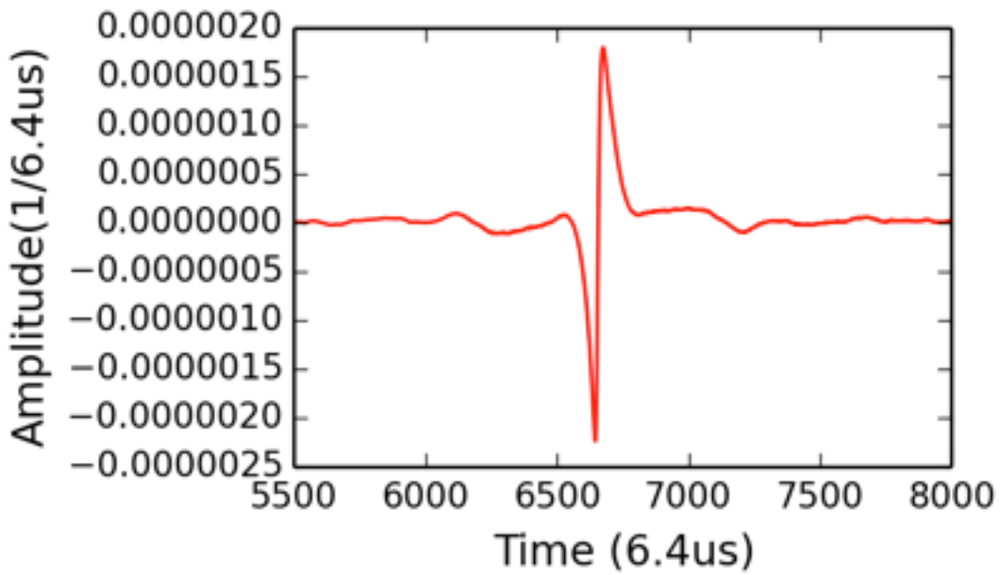


optimal filter



- Calculate optimal filter by using signal template and noise

How similar this is to the boxcar filter?

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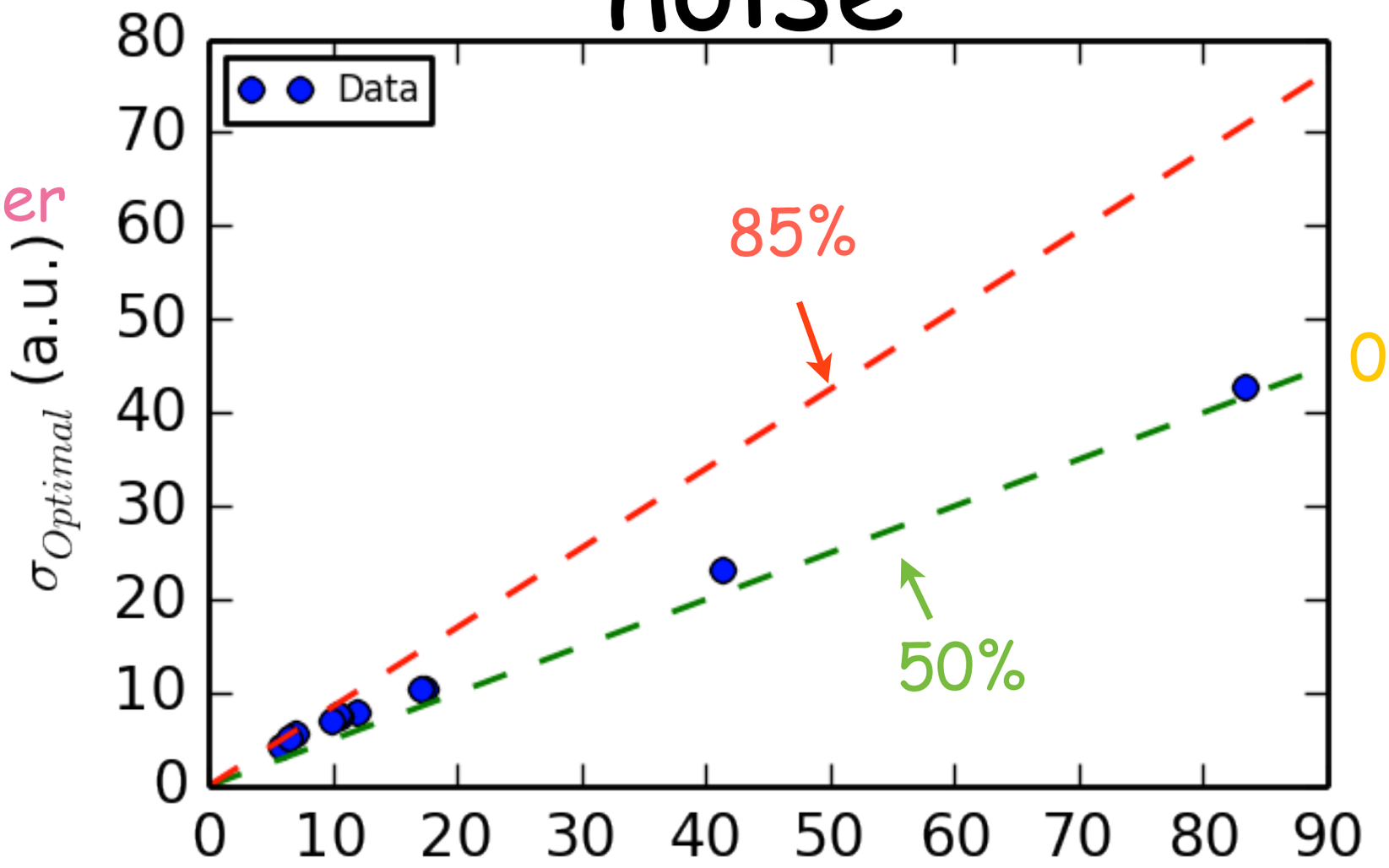
Apply two filters on original noise

how well optimal filter works



how well boxcar filter works

Conclusion:

- The optimal filter always have better resolution.
- The resolution of optimal filter is between **50%** and **85%** of the boxcar.

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How Robust is the Filter?

- Build filter under given noise conditions
- Noise conditions **change over time**
- Need to examine how each filter strategy will perform under noise conditions that differ from the noise conditions assumed the filter were built

There is no perfect filter, and no perfect way to estimate how noise changes so we overestimate the fluctuations to ask

How bad it could be?

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How Robust is the Filter?

Compare resolution

to examine the performance of each filter under different noise?

Optimize the filters on original noise

how well works for original noise

Next step

Apply the optimized filters for the noise from a different detectors

how well works for other noise

We have 11 detectors and 2 "optimization" filters for each. Run all the other detectors through each two optimizations and compare.

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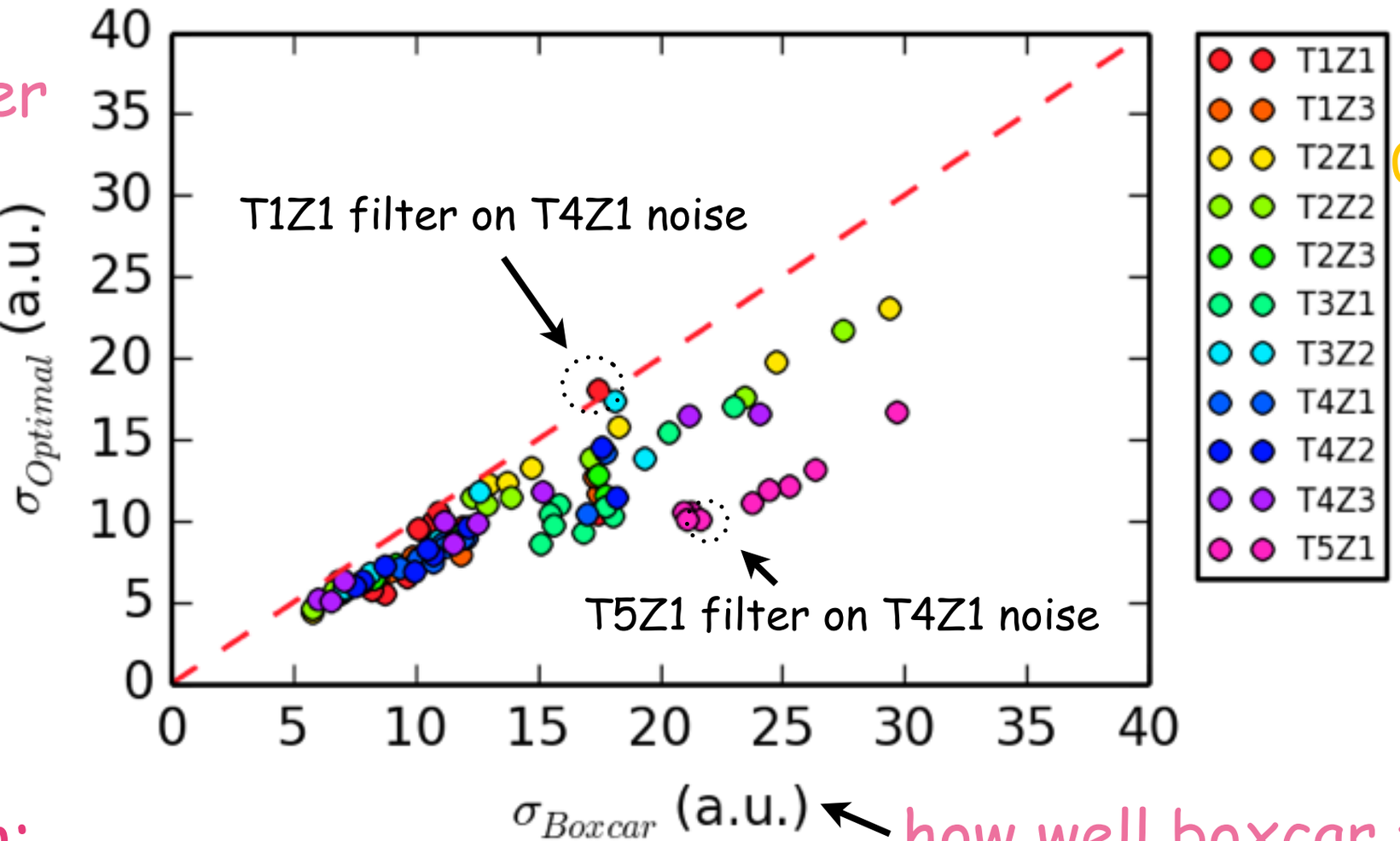
Apply optimized filters

how well optimal filter works



†Data 01140523_1642

Most data below red line

how well boxcar filter works

Conclusion:

- Optimal filter works better than boxcar filter in most cases
- Boxcar filter works better than optimal filter in some special cases (e.g T1Z1 filter on T4Z1 noise)

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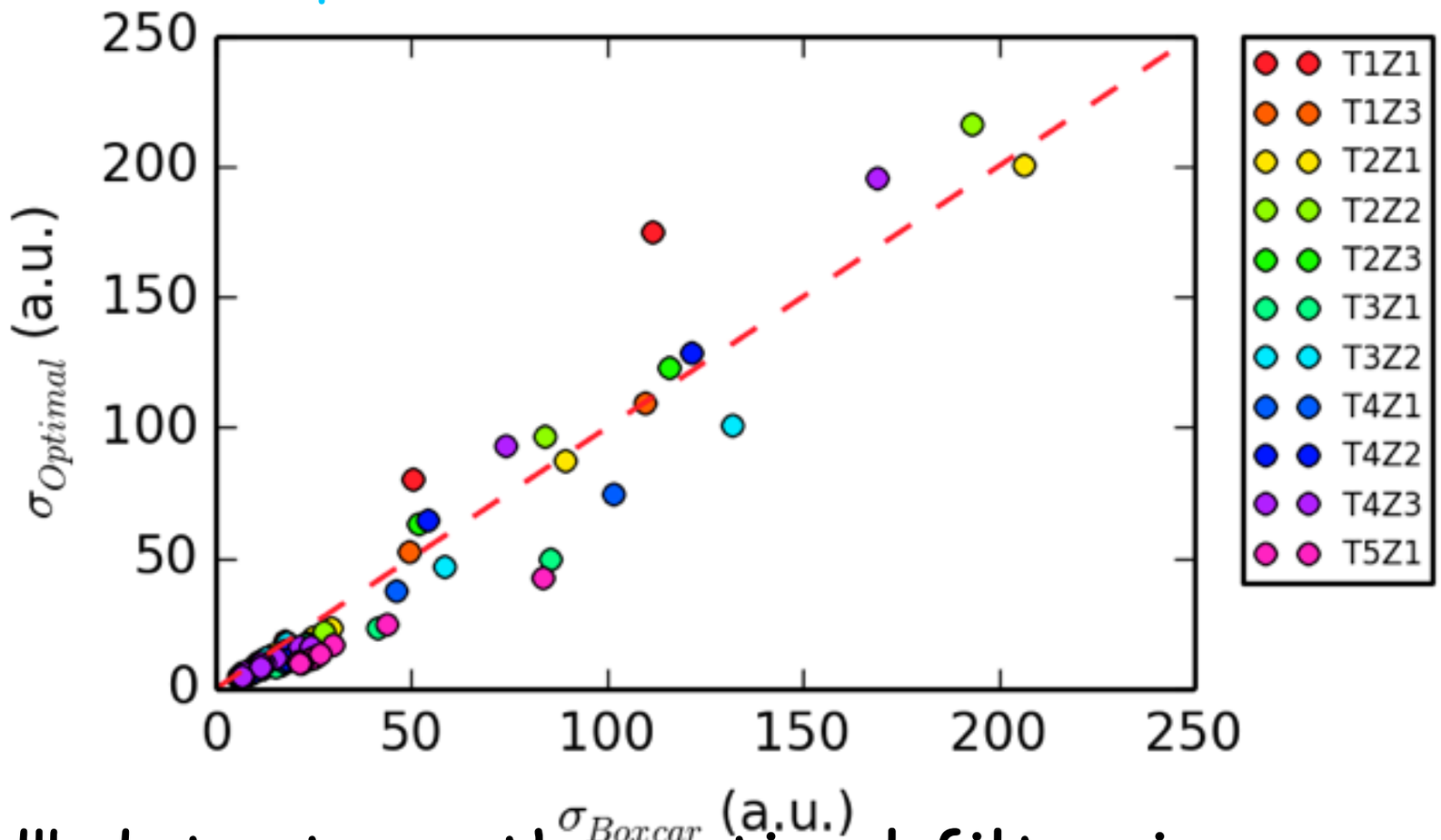
Apply optimized filters

The same plot as the previous one, but with extended x- and y-axis ranges



Conclusion:

- For "good" detectors, the optimal filter is more robust than the boxcar filter,but for "bad" detectors, they are about equally robust
- The "good" detectors very well(resolution<50), while this plot also shows the "bad" detectors.

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Conclusions

- The sensitivity of the filter choice in Level 1is the key to experiment sensitivity.

- We have calculated the sensitivity for optimal filter and optimized boxcar filter and found that the Optimal Filter always works better by approximately 15% to 50%.

- We have studied the robustness of the filters by over estimating the variation of the noise in each detector (after optimization on its expected noise) and found that the optimal filter also works better than boxcar filter when the noise is changing except for special cases like when the optimized filter is not good.

- Our next steps include studying a study on bandpass filter to see how it compares.

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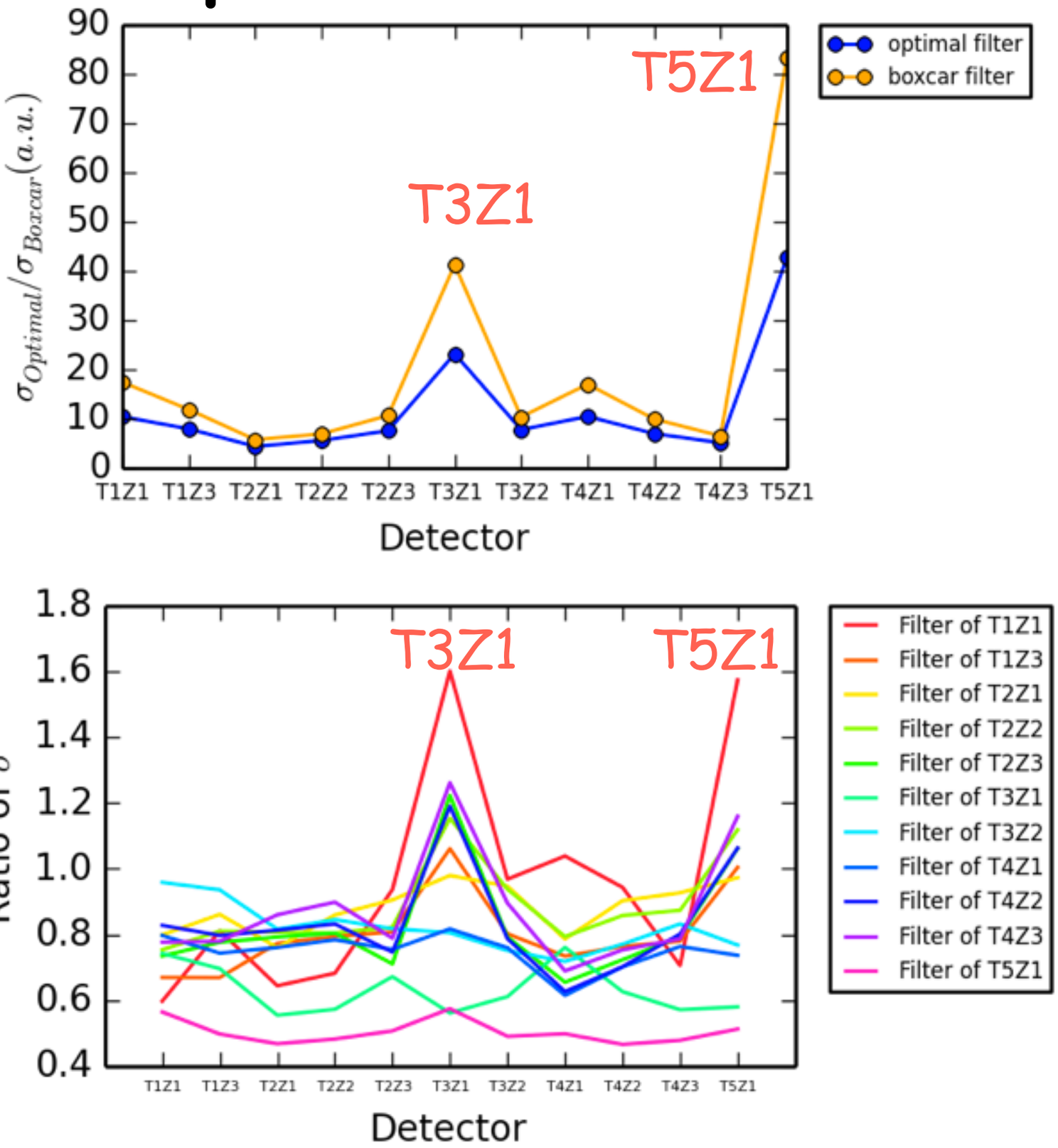
Special Case



How to Calculate Optimal Filter ?

- Estimate the amplitude of a signal of known shape $A(t)$ amidst a background of gaussian random noise of known power spectral density (PSD) $J(f)$
- Signal traces $S(t) = aA(t) + n(t)$ ← Estimate a

$A(t)$ - known template

$n(t)$ - noise realization with $J(f)=\langle n(f) \rangle$

Optimal technique for amplitude estimation:
perform a frequency-domain ChiSquare:

$$\chi^2(a) = \sum_n \frac{\left|\tilde{S}_n - a\tilde{A}_n\right|^2}{J_n}.$$ Minimize it ➜ $$\hat{a} = \frac{\sum_n \frac{\tilde{A}_n^* \tilde{S}_n}{J_n}}{\sum_n \frac{|\tilde{A}_n|^2}{J_n}}.$$

The estimate of a

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