Noise-cut filters: further study plans

Filter performance merits

Multi-objective optimization

Optimization of noise cut filters

Future filters

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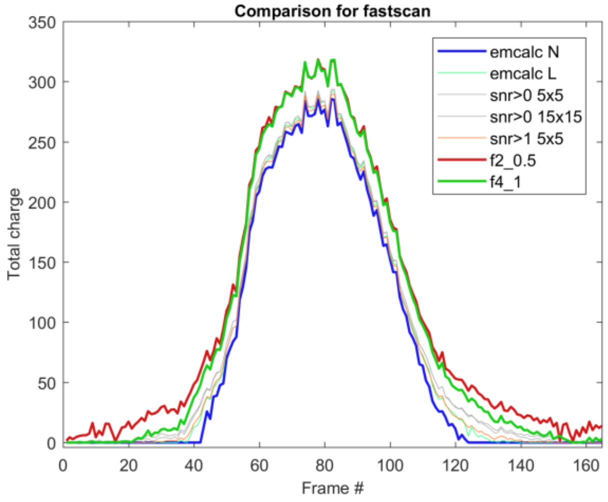
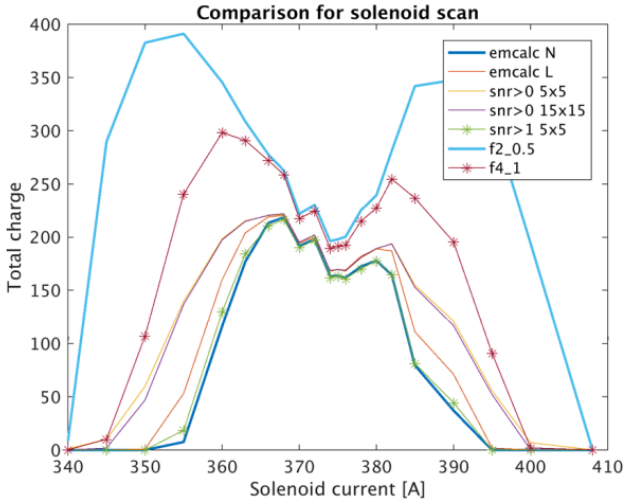
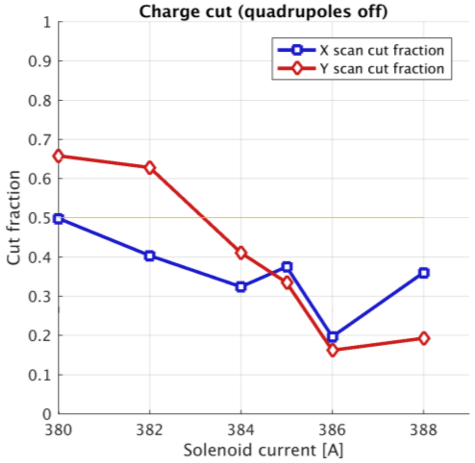
Noise-cut filter summary

Previous results

- Overall low signal to noise ratio (SNR)
    - Signal mixed with noise of similar magnitude
- Noise-cut – mask out noise dominated regions
- Emcalc filter
    - De-facto standard, oldest
- Holger Huck filter
    - Most sensitive
- SNR and median filter
    - SNR utilized, newest
- **Unsatisfactory** performance
    - Large charge cut (on occasion above 50%)
    - Unexpected behavior
    - Thermal emittance, slice emittance, etc.



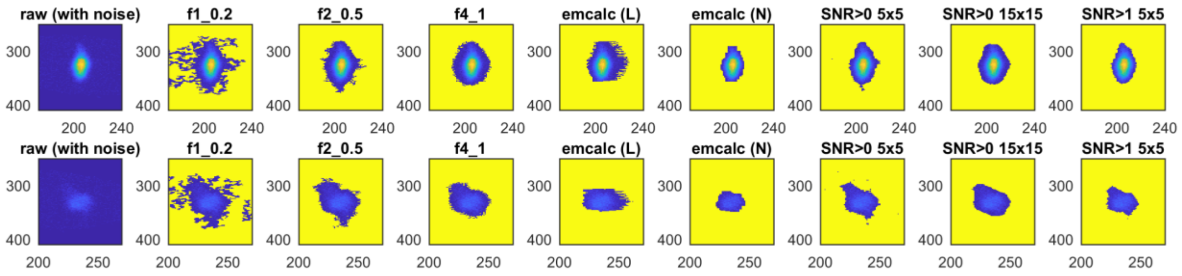




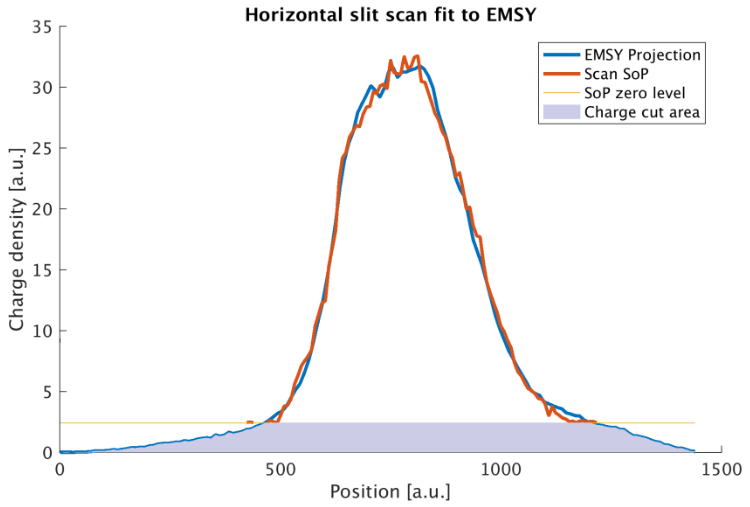
Noise-cut filter performance

Categorizing of performance merits

- Performance indicators split into two groups
- Qualitative
  - Judged by intuition or principles
  - Mask of interest shape
  - Phase space shape
  - Match to reference
  - Any (mis)match to expected trend
- Quantitative
  - Measured numerically
  - Signal preservation
  - Noise elimination
  - Fit parameters
  - Etc.



Ideal filter: removes *all* noise, keeps *all* signal.



Multi-objective optimization

Definitions and terminology

- Multi-objective optimization problem: minimize $\vec{f}(\vec{x})$
- **Objective functions** $y_i = f_i(x_j);\ i = 1 \dots m; j = 1 \dots n$
  - Several competing objectives, $m > 1$
- **Decision space** – n-dimensional space of candidate solutions $\vec{x}$
- **Objective space** – m-dimensional space of objective values $\vec{y}$
  - Decision space is mapped into objective space by $\vec{f}(\vec{x})$
- Decision making
  - A priory – define ideal objective and search for best fit solution (single objective optimization)
  - A posteriory – find optimal set of solutions and then decide on selection
  - Interactive: a priory with dynamically adjusted ideal

Multi-objective optimization is needed when there is a trade-off between different objectives: improving one objective worsens other objective(s). Often trivial scalarization to single objective optimization is *not* applicable.

Examples:

Optimize quality and difficulty of manufacture

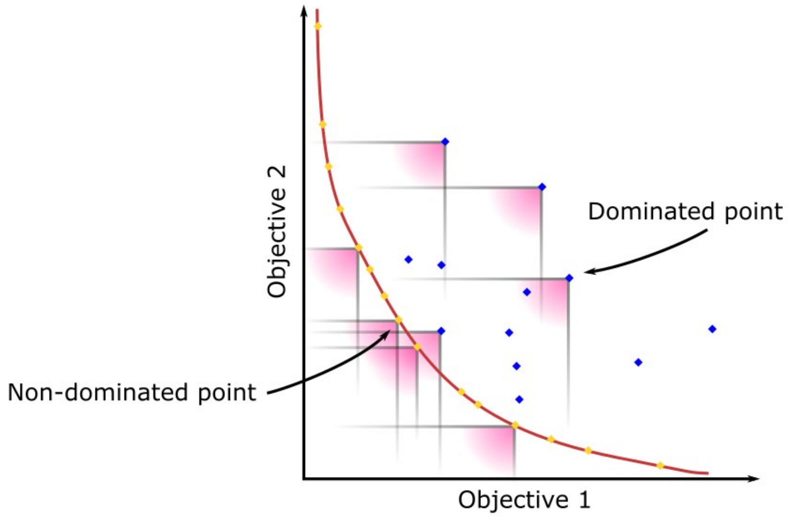
Optimize bunch length and emittance

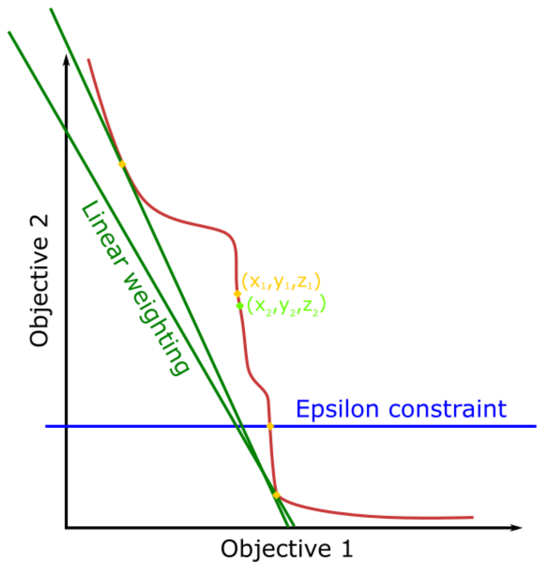
Optimize camera gain and number of pulses for fastscan

Pareto front

Edgeworth-Pareto dominance and Pareto optimal set

- **Edgeworth-Pareto dominance** – a solution is non-dominated if it is better in at least one objective and not worse in any objectives than any other solution
  - $\forall i : y_i^a \leq y_i^b$ and $\exists j : y_j^a < y_j^b$; $\overrightarrow{y^a}$ is non-dominated, $\overrightarrow{y^b}$ is dominated
- **Pareto front** – objective-space front by the minimal set of non-dominated solutions (**Pareto optimal set**)
  - Practically the set of "best" solutions
  - Information on compromises
  - Information on decision-space distance
  - A posteriory decision making
- Scalarization – to single objective optimization
  - Occasionally miss useful information





Optimization of noise-cut filters

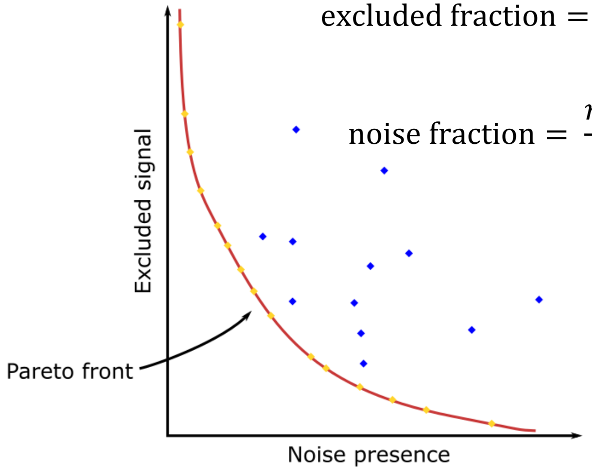
Objective space and decision space

- Filter parameters (on noisy images)
  - Set to remove all noise – much of the signal is removed
  - Set to keep all signal – much of the noise remains
  - What to **compromise**? → multi-objective optimization
  - Objectives: *Excluded signal* and *Noise presence*
- Emcalc filter – 2(+1) parameters
  - Multiplier of $\sigma_{background}$ threshold, number of iterations, L-shape or square shape switch
- Holger Huck filter – 2(+1) parameters
  - Multiplier of $\sigma_{background}$ threshold, Gaussian sigma, truncated size of Gaussian
- SNR and median filter – **3** parameters
  - **SNR** cut plus **multiplier** of $\sigma_{background}$ threshold, median filter size

Ideal filter: removes *all* noise, keeps *all* signal.

$$\text{excluded fraction} = 1 - \frac{noisecut(signal - \overline{background})}{signal - \overline{background}}$$

$$\text{noise fraction} = \frac{noisecut(background - \overline{background})}{background - \overline{background}}$$



SNR and median filter threshold formula (pixel-wise):

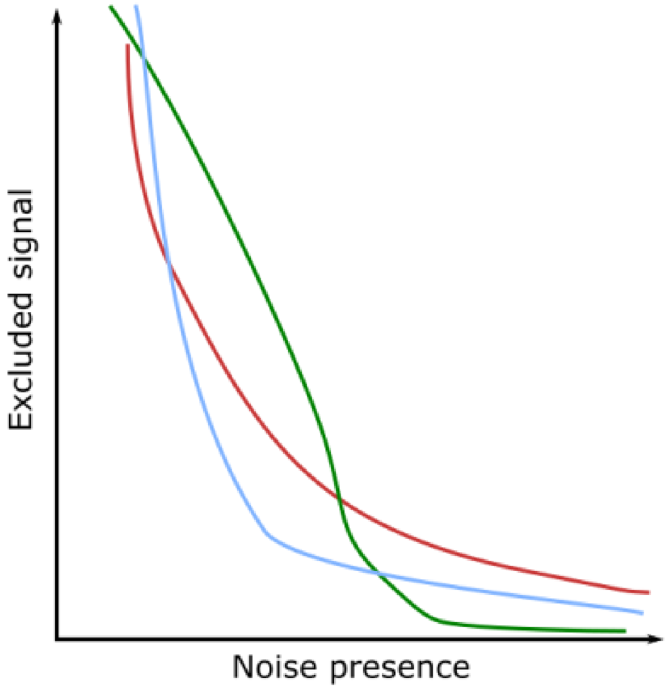
$$signal > SNR_{cut} \times \overline{background} + N \times \sigma_{background}$$

Only the *SNR and median filter* has threshold that combines the **SNR** and $\boldsymbol{\sigma_{background}}$.

Future filters

Proposals for future studies

- Introduction of SNR threshold to Emcalc3 and Holger Huck filters
- Tabulation of “best” working points (subset of Pareto front)
- Multiple data sets
  - Same objectives
    - Comparing Pareto fronts for each set
    - Combined objectives: median, mean, max, 90th percent
  - Data set specific objectives
    - Filter performance over wide range of experiments
- Filter comparison by Pareto front as “signature”
  - Unbiased comparison
- Pareto front based analysis beyond noise cut



Conclusion

Summary and outlook

- Generalized approach to compare and improve
  - Fair
  - Consistent
  - Clear
- More quantitative objectives
  - Case specific
  - Scalarized previous decision (keeps 2D objective space)
- Combination of advantages of noise-cut filters
  - SNR utilizing threshold

Thank you!

References:
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