Reducing image noise

Improving the quality of the electron beam image by means of reducing noise.

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Reducing image noise
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HELMHOLTZ
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Motivation

The Photo-Injector Test facility at DESY in Zeuthen develops and optimizes sources for high brightness and short wavelength FELs.

The main source of information is an image of the transverse distribution of the electron beam obtained with a CCD camera. The main aim for a representative measurement is to get an image that **correctly describes** the electron beam transverse distribution.

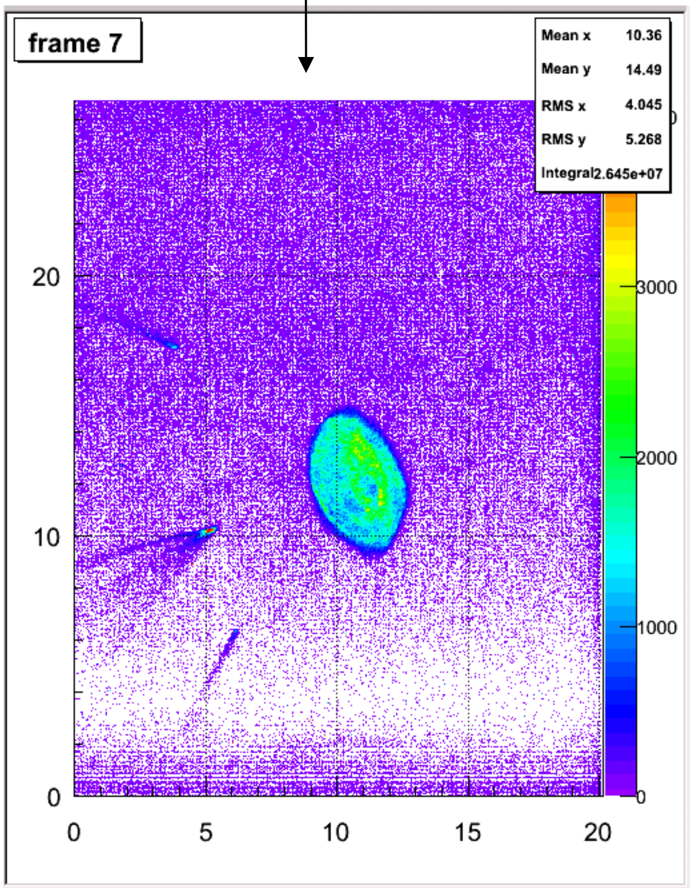
Obstacle: the photodetector signal is combined with noise.

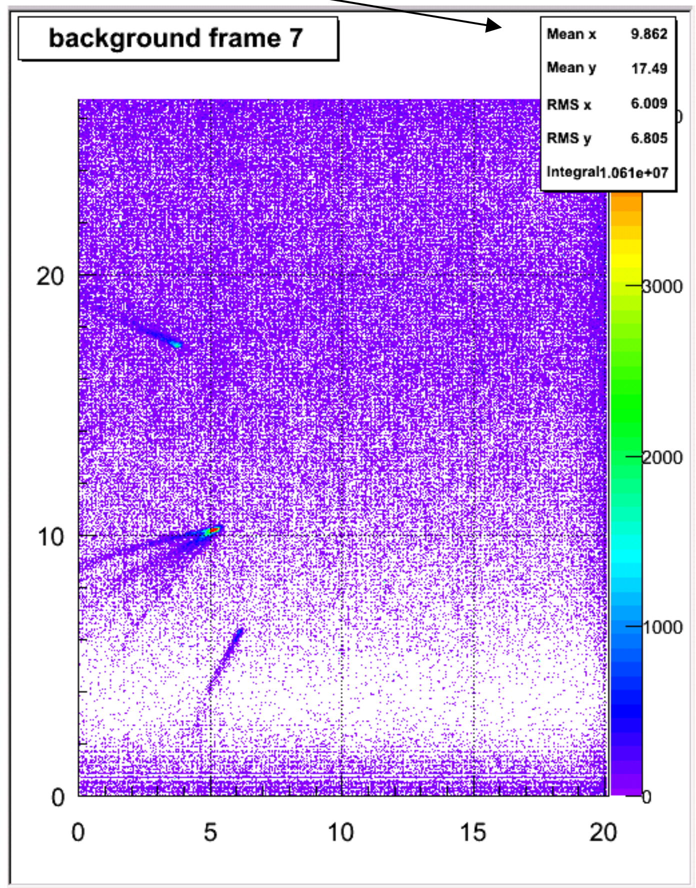
Problem statement: get a high quality image by means of noise reduction.

PITZ image structure

$$\text{Result of measurement} = \{\text{shot}_1, \text{shot}_2, \ldots \text{shot}_n\}$$

Shot = signal frame + background frame

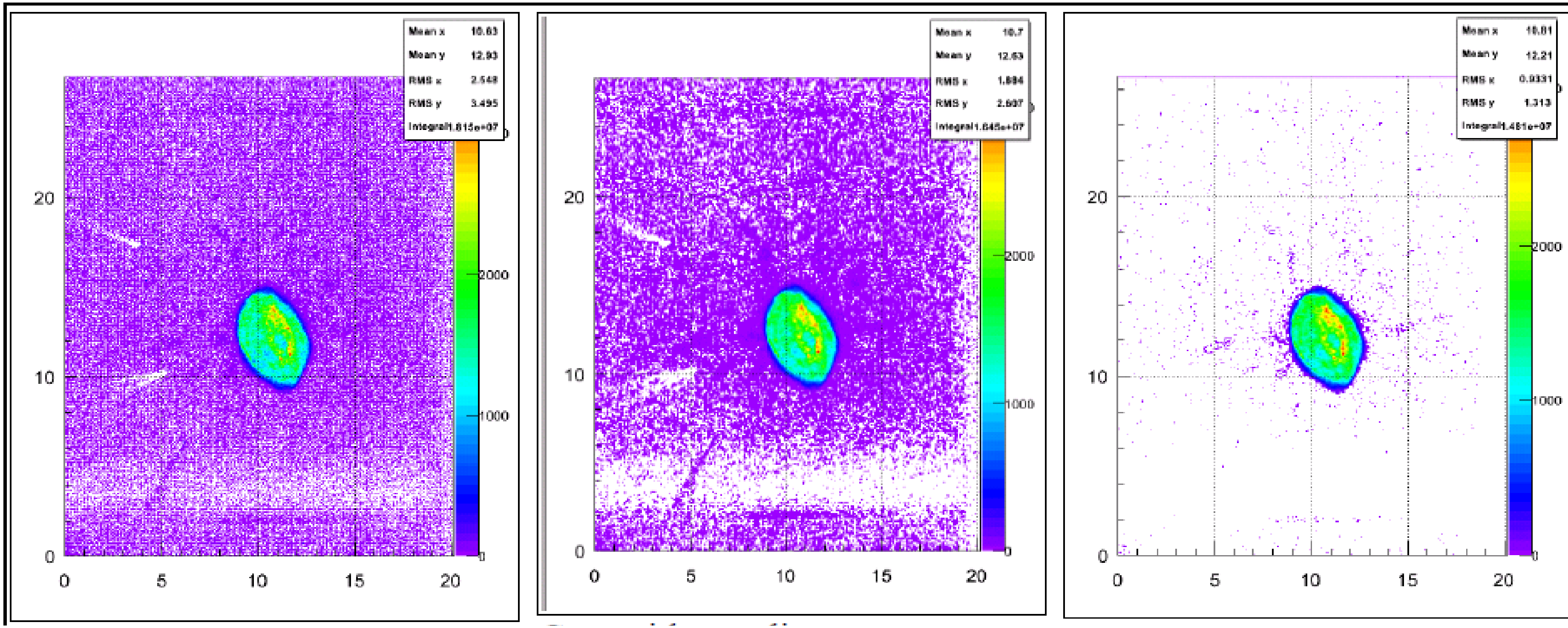




Noise sources:

- dark current
- CCD enhanced
- cables
- electronics
- X-rays
- etc.

Noise. Influence of noise on the measurement precision.



Filter (1)

σ_x = 2.5 mm
σ_y = 3.5 mm

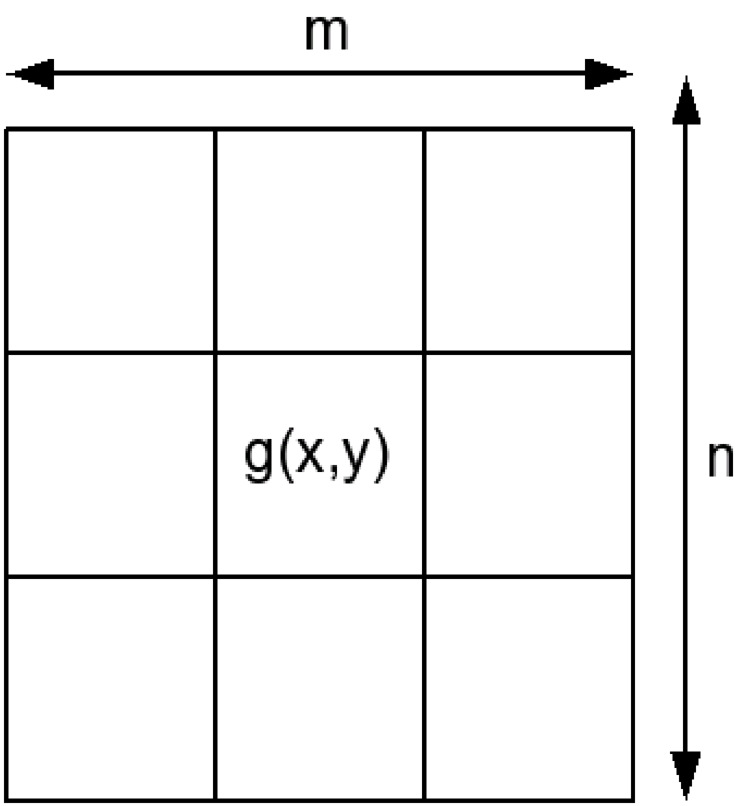
Filter (2)

σ_x = 1.9 mm
σ_y = 2.6 mm

Filter (3)

σ_x = 0.9 mm
σ_y = 1.3 mm

Notations



S_{xy} rectangular neighbourhood with the size m*n and central coordinates (x, y) .

g(x,y) – measured value in pixel (x,y)

f(x,y) – real wanted value of pixel (x,y).

Remark:

g(x,y) = <signal> – <background>,

<foo> - mean arithmetic value of pixel foo over the frames

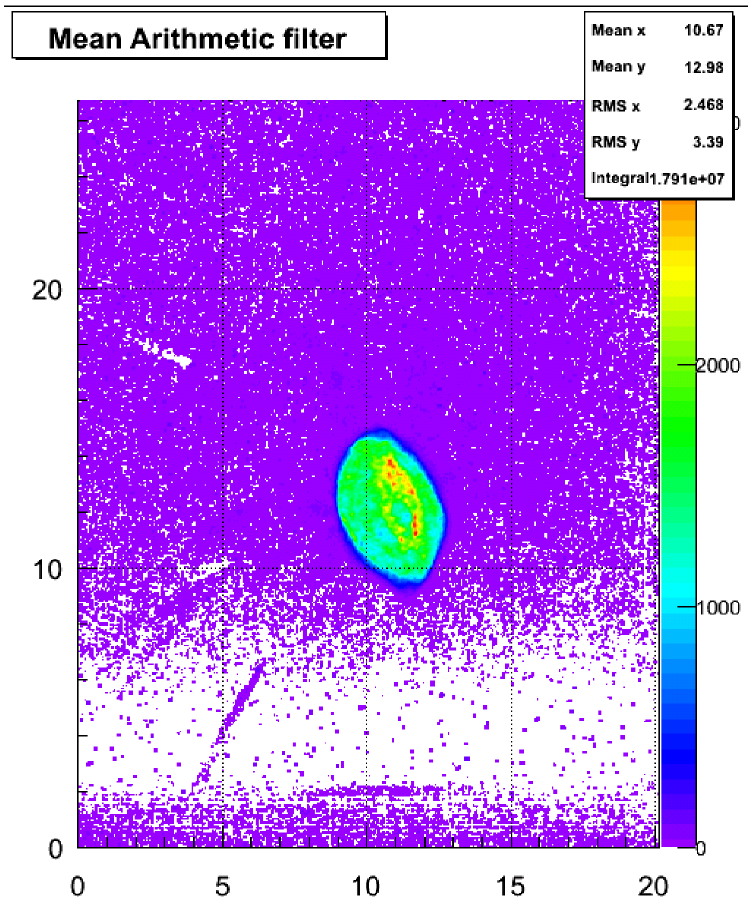
Filters group

- Averaging filters
- Order statistics filters
- Statistics filters
- Adaptive filters

Averaging filters

Mean Arithmetic filter:

$$f(x,y)=\frac{1}{mn}\sum_{(s,t)\in S_{xy}} g(s,t)$$



(5 + 3 + 4 + 3 + 10 + 5 + 3 + 4 + 5)/(3*3) = 4,6

5	3	4
3	**10**	5
3	4	5

input

5	3	4
3	**4,6**	5
3	4	5

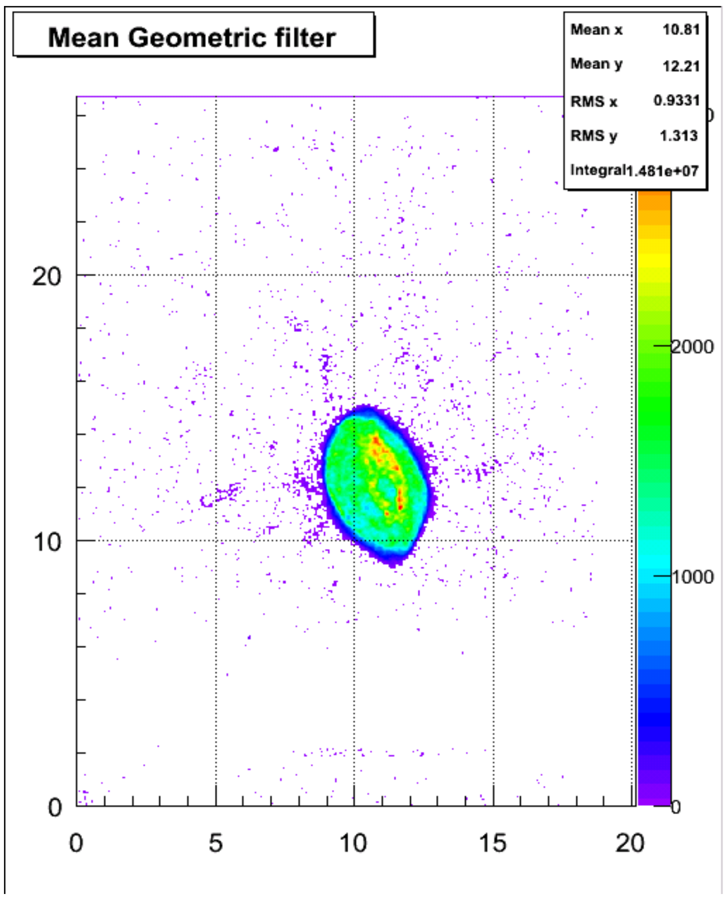
output

> smooths local variations of the image intensity

Averaging filters

Mean Geometric filter:

$$f(x,y)=\left[\prod_{(s,t)\in S_{xy}} g(s,t)^{\frac{1}{mn}}\right]$$



$$(5*3*4*3*10*5*3*4*5)^{\frac{1}{3*3}}$$

input

5	3	4
3	10	5
3	4	5

output

5	3	4
3	4,3	5
3	4	5

> similar to the Mean Arithmetic filter, but it loses smaller amount of the little details

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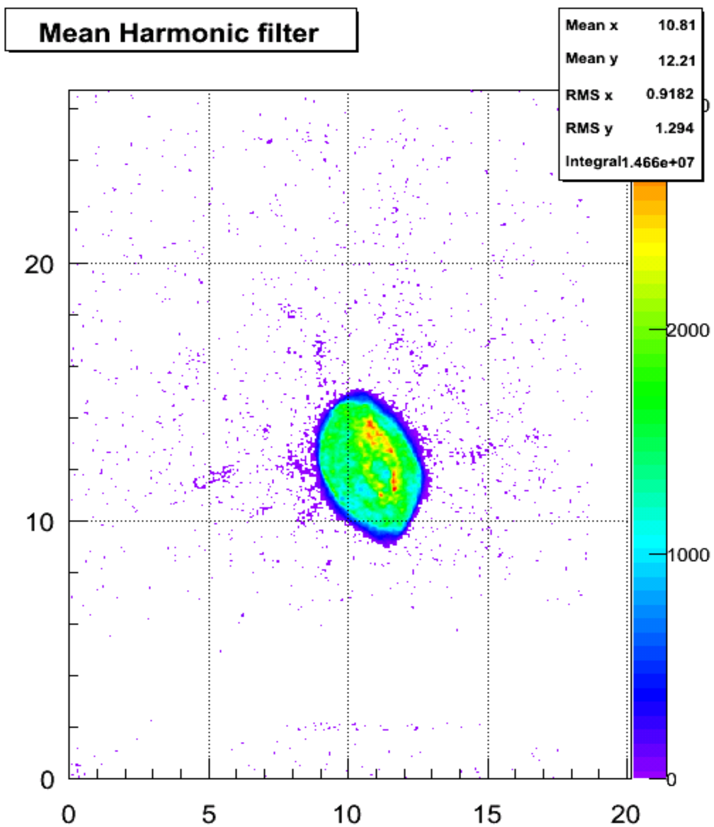
Averaging filters

Mean Harmonic filter:

$$f(x,y)=\frac{mn}{\sum_{(s,t)\in S_{xy}}\frac{1}{g(s,t)}}$$



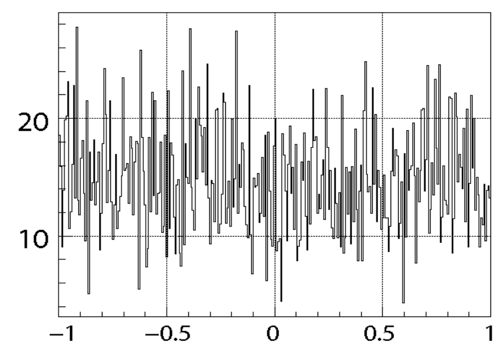
$$3*3/(\frac{1}{5}+\frac{1}{3}+\frac{1}{4}+\frac{1}{3}+\frac{1}{10}+\frac{1}{5}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5})=4{,}09$$

5	3	4
3	10	5
3	4	5

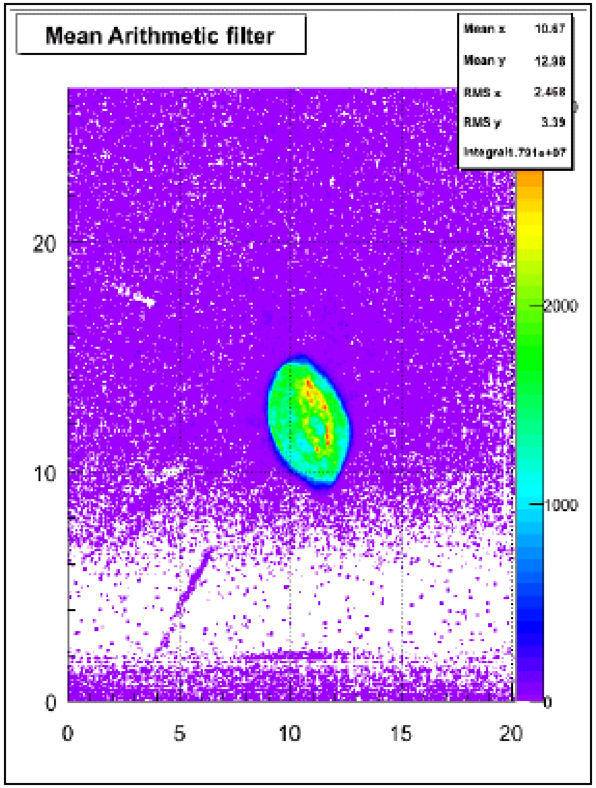
→

5	3	4
3	4,09	5
3	4	5

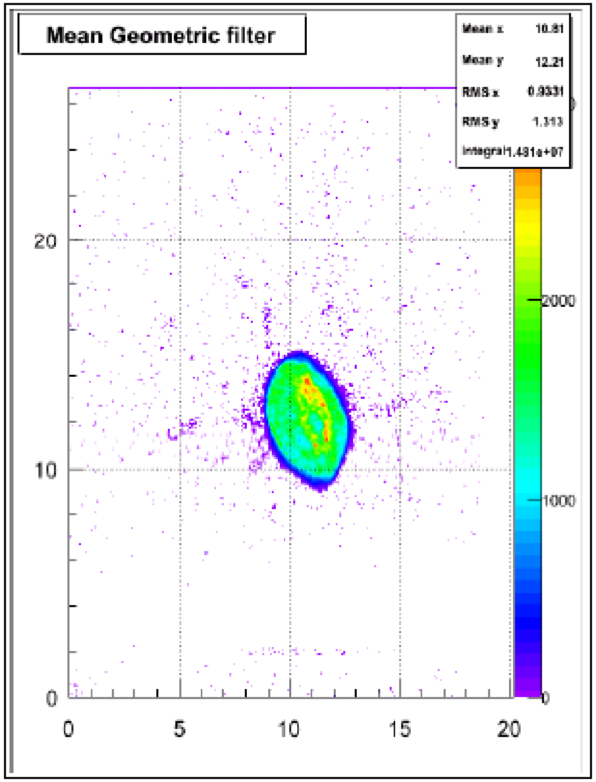
This filter is useful in the case of the white Gaussian noise



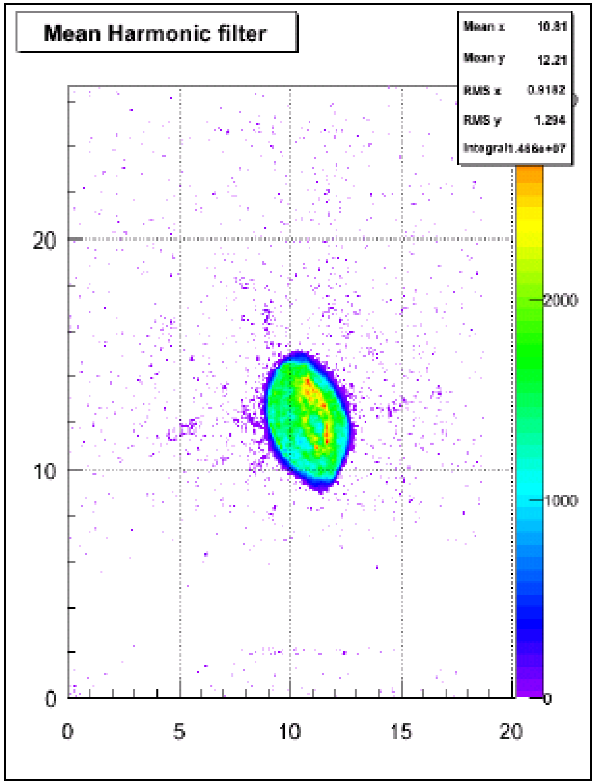
Examples of averaging filters



Mean Arithmetic

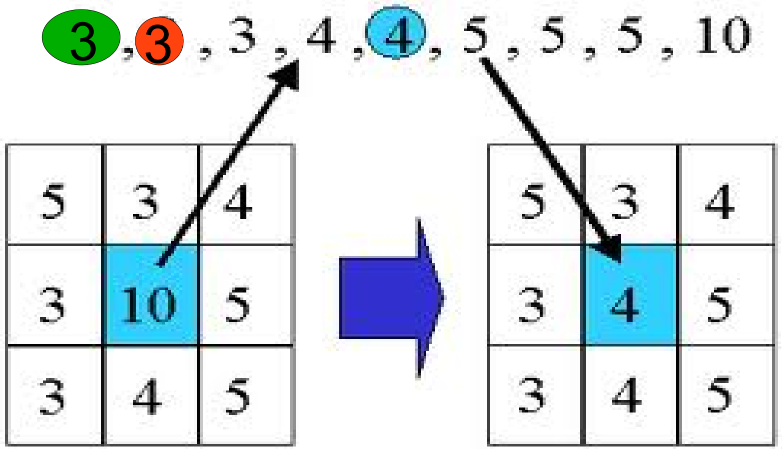


Mean Geometric



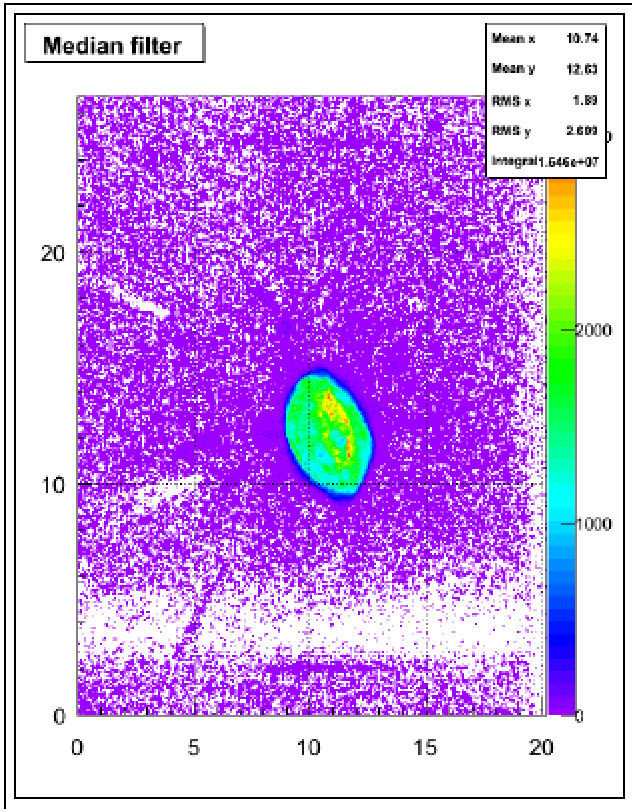
Mean Harmonic

Order statistic filters

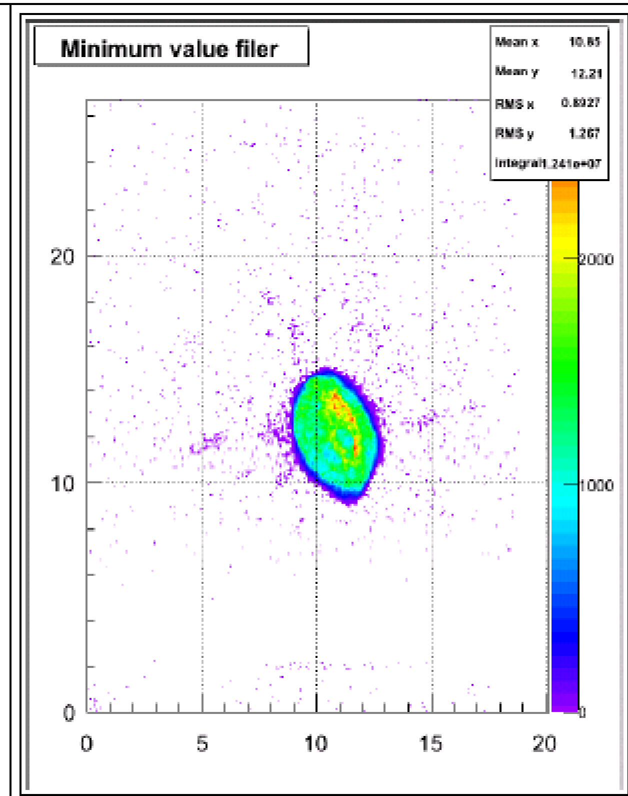


- Median filter: $f(x,y) = med\{g(s,t) : (s,t) \in S_{xy}\}$
- Minimum value filter: $f(x,y) = min\{g(s,t) : (s,t) \in S_{xy}\}$
- Modified minimum value filter: $f(x,y) = next \;\; after \;\; min\{g(s,t) : (s,t) \in S_{xy}\}$

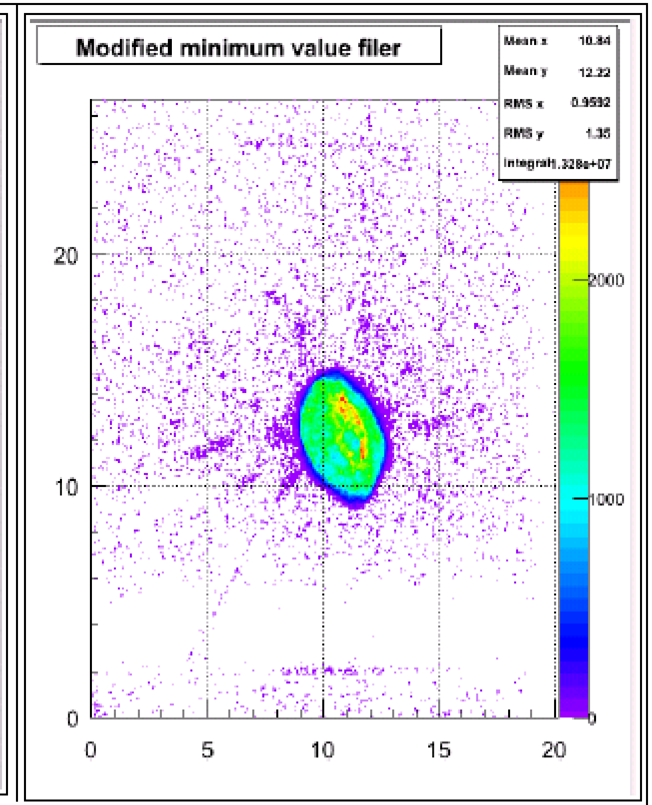
Example of Order statistic filters



Median Filter



Minimum Value



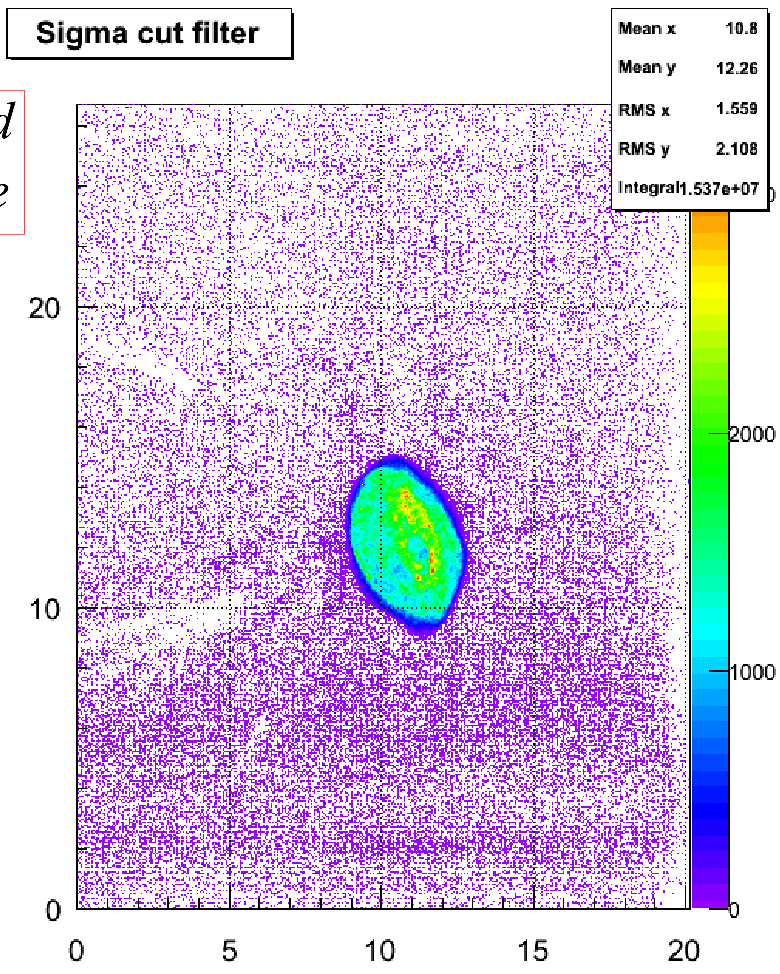
Modified Minimum Value

Statistics filters

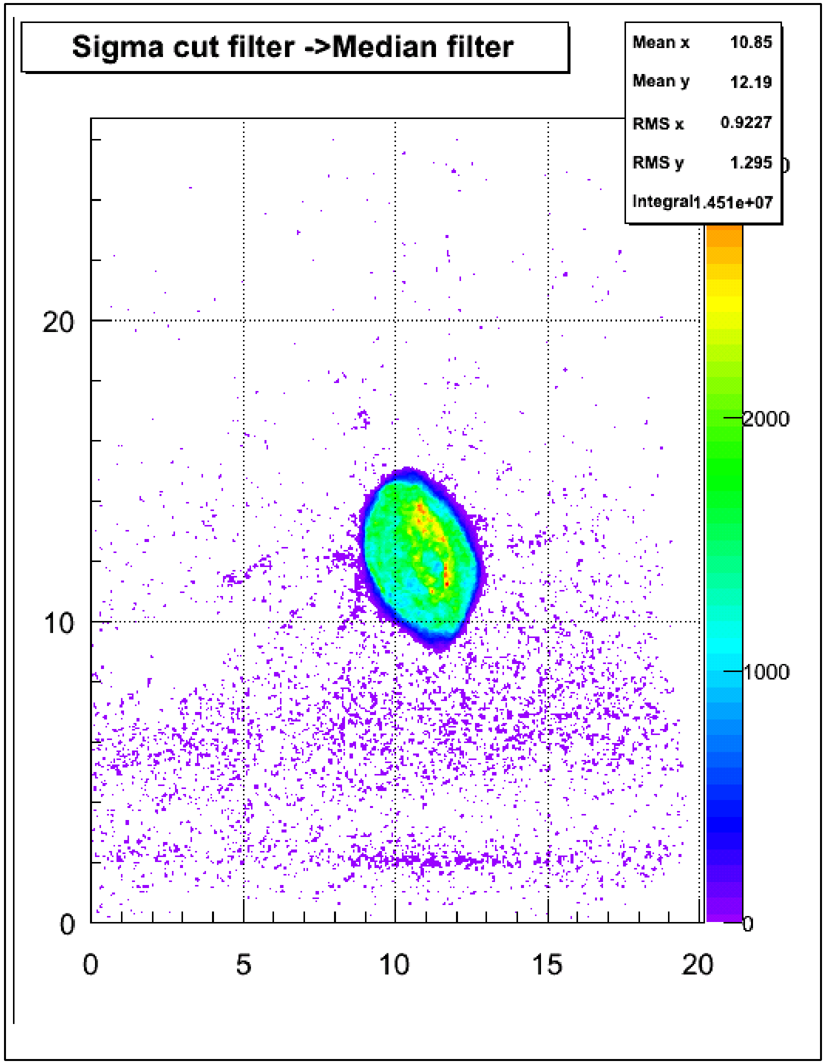
Sigma cut filter:

$$f(x,y)=\begin{cases}0, & (g(x,y)-\sigma_{noise}(x,y))<Threshold\\ g(x,y) & else\end{cases}$$

This filter is useful when the signal pixel intensity is much bigger than one sigma of the noise pixel intensity. Its idea is that high Intensity signal is regarded as the electron beam signal, low signal - as noise.



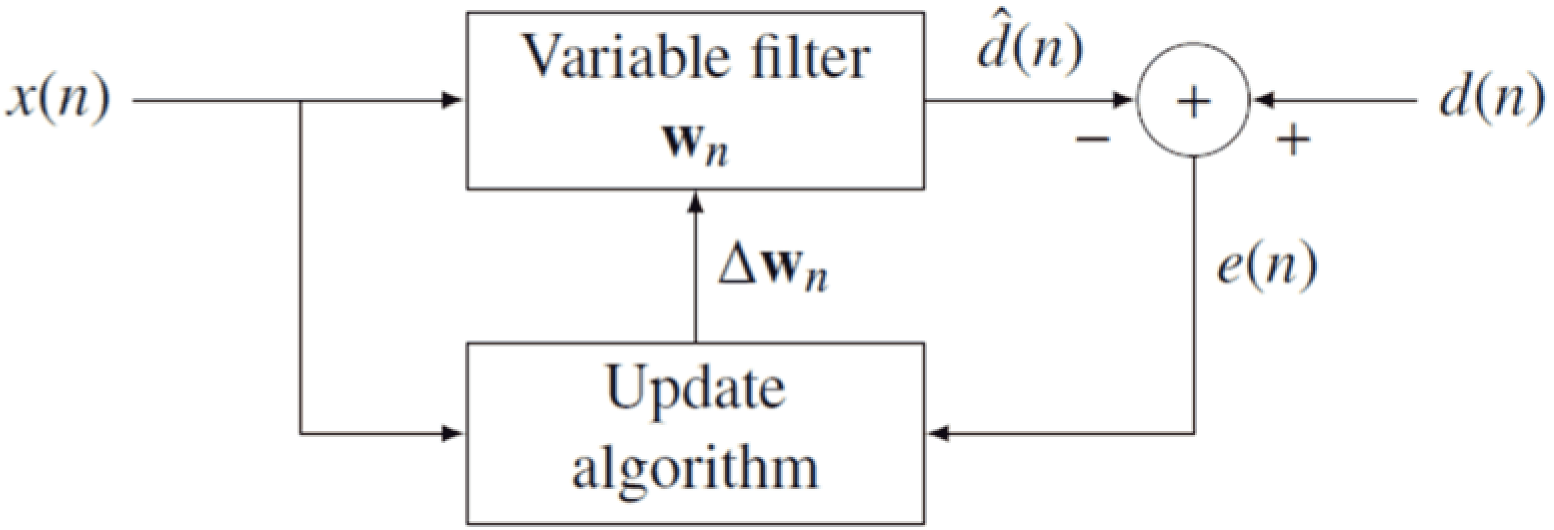
Example of filter combination



Sigma cut filters is a good filter for preparing the data image before applying another filter. It is rarefies noise well. Afterwards filters, which work with big amount of the noise unsuccessful, demonstrates enough good result.

Adaptive filters

An adaptive filter is a filter that self-adjusts its transfer function according to an optimizing algorithm.



Wiener filter, Least Mean Squares filter

Conclusion

Result:

> Several filters were applied, none of them delivers satisfactory result

> Future work:

- apply different combination of filters
- apply filters to each frame and then calculate average image
- analyze adaptive filtering, especially LMS filter

Thank you for your attention

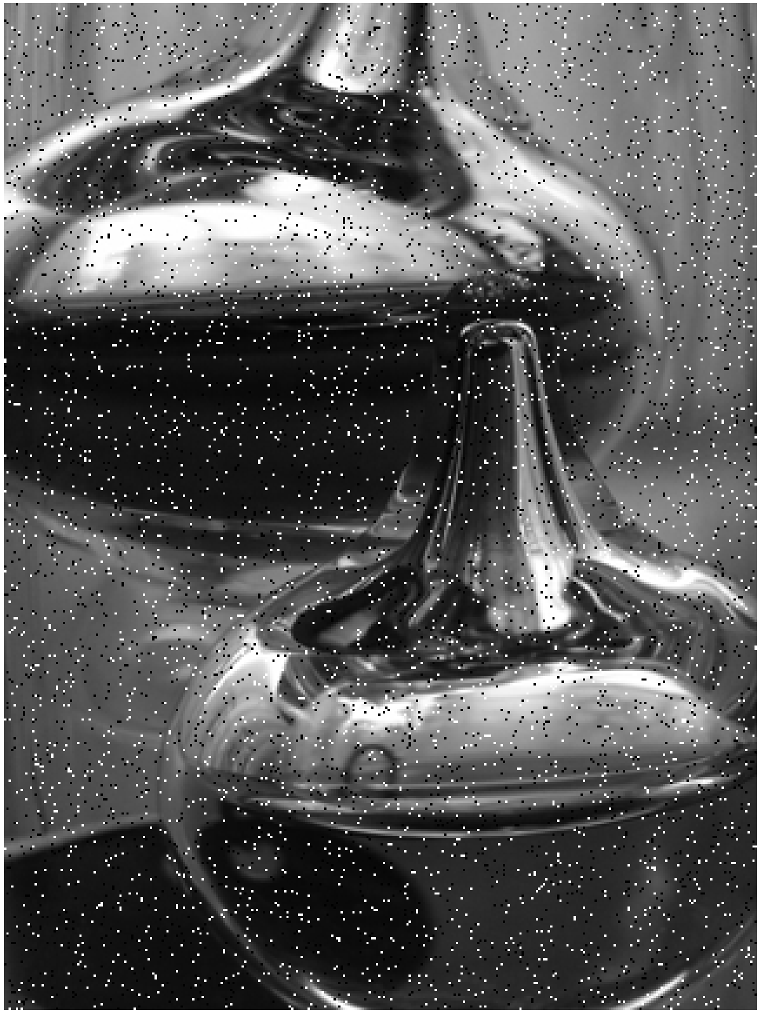
A priori noise information

Types of noise:

- “salt and pepper” noise →
- Gaussian noise:

$$p(z)=\frac{1}{\sqrt{2\pi\sigma}}*e^{-(z-\mu)^2/2\sigma^2}\quad ,$$

where p(z) is probability density function, μ and σ^2 are the mean and the variance.



Denoising

Denoising (noise reduction, noise reducing) is the extraction of a signal from a mixture of signal and noise.

Filters with finite impulse response (FIR) . FIR is a property of signal processing systems. FIR filter is a type of a discrete-time filter. The impulse response, the filter's response to a Kronecker delta input, is finite because it settles to zero in a finite number of sample intervals.

Filters with infinite impulse response (IIR). IIR systems have an impulse response function that is non-zero over an infinite length of time.

Digital image -> finite impulse response