Virtual Pepper-Pot Experiment: method status and filters

Georgi Georgiev, December 11th 2018

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Virtual pepper pot

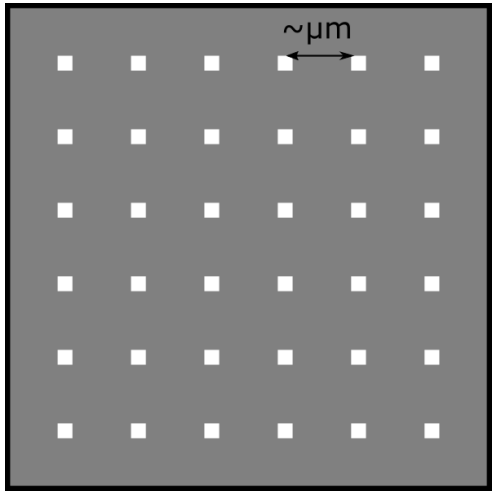
- Pepper pot mask
  - 4D transverse beam matrix
  - 4D phase space and emittance
  - Transverse correlations
- Reasons
  - Emittance optimization
  - Asymmetry compensation
  - Simulation model
  - Studies of the cause

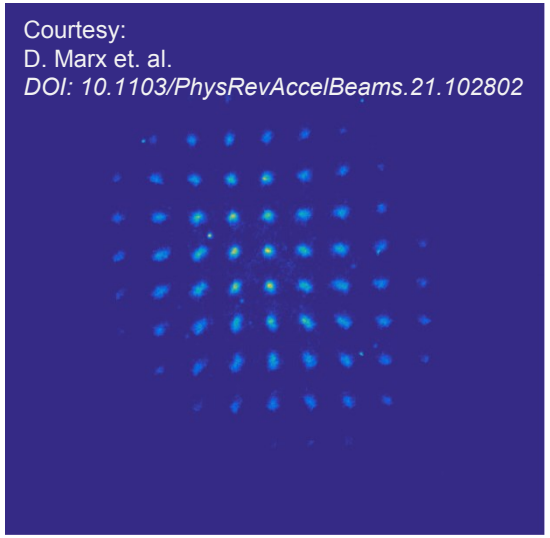
"The 4D beam phase space information is extremely important for the characterization of nonround beams."
D. Marx et. al., *DOI: 10.1103/PhysRevAccelBeams.21.102802*

$$\varepsilon_{tr}^{4} = \begin{vmatrix} \langle xx \rangle & \langle xpx \rangle & \langle xy \rangle & \langle xpy \rangle \\ \langle xpx \rangle & \langle pxpx \rangle & \langle ypx \rangle & \langle pxpy \rangle \\ \langle xy \rangle & \langle ypx \rangle & \langle yy \rangle & \langle ypy \rangle \\ \langle xpy \rangle & \langle pxpy \rangle & \langle ypy \rangle & \langle pypy \rangle \end{vmatrix}$$

Further information:

M.Krasilnikov, PPS, 21.04.2009,
On an estimation of x-y correlation from slit scans





Virtual pepper pot

- Pepper pot mask
  - 4D transverse beam matrix
  - 4D phase space and emittance
  - Transverse correlations
- Reasons
  - Emittance optimization
  - Asymmetry compensation
  - Simulation model
  - Studies of the cause
- Virtual pepper pot at PITZ
  - Pepper pot mask → difficult manufacture
  - **Virtual** pepper pot: from slit scan
    - X and Y scan beamlets crossing
  - **Asymmetric** beam and structures

"The 4D beam phase space information is extremely important for the characterization of nonround beams."
D. Marx et. al., *DOI: 10.1103/PhysRevAccelBeams.21.102802*

$$\varepsilon_{tr}^{4} = \begin{vmatrix} \langle xx \rangle & \langle xpx \rangle & \langle xy \rangle & \langle xpy \rangle \\ \langle xpx \rangle & \langle pxpx \rangle & \langle ypx \rangle & \langle pxpy \rangle \\ \langle xy \rangle & \langle ypx \rangle & \langle yy \rangle & \langle ypy \rangle \\ \langle xpy \rangle & \langle pxpy \rangle & \langle ypy \rangle & \langle pypy \rangle \end{vmatrix}$$

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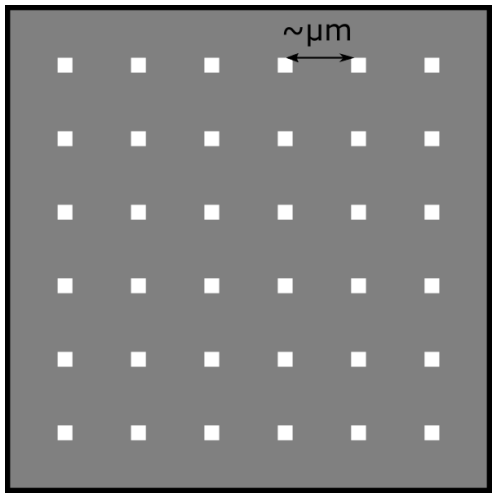
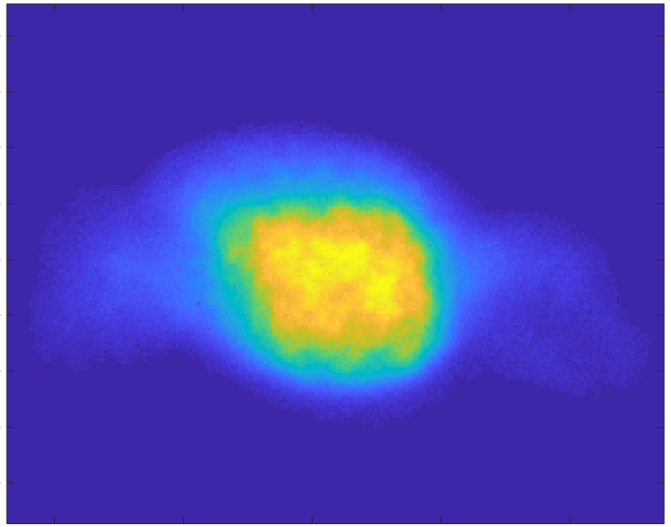
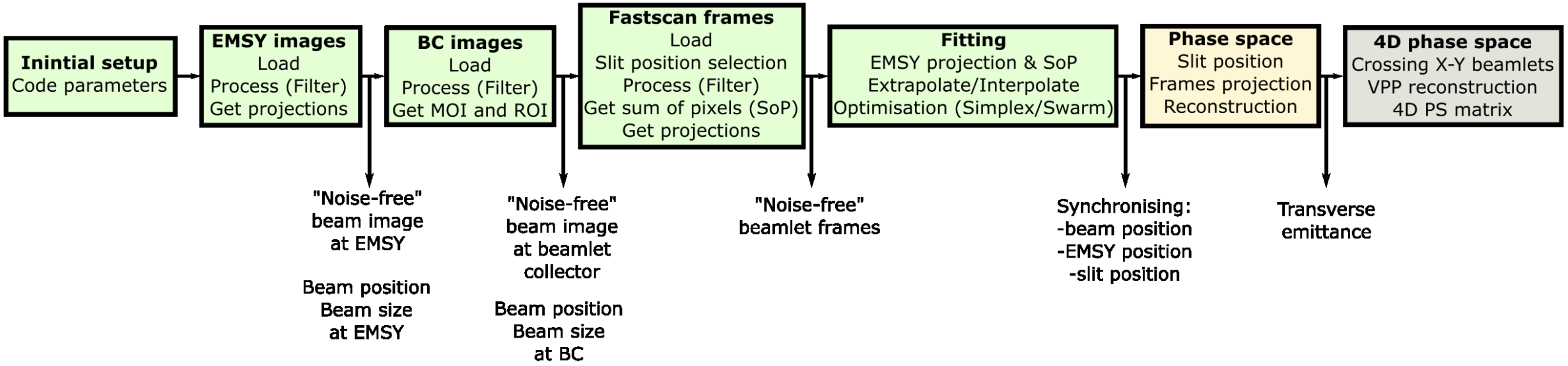




VPP code layout



- Green → (nearly) complete
- Yellow → in development
- Gray → not started

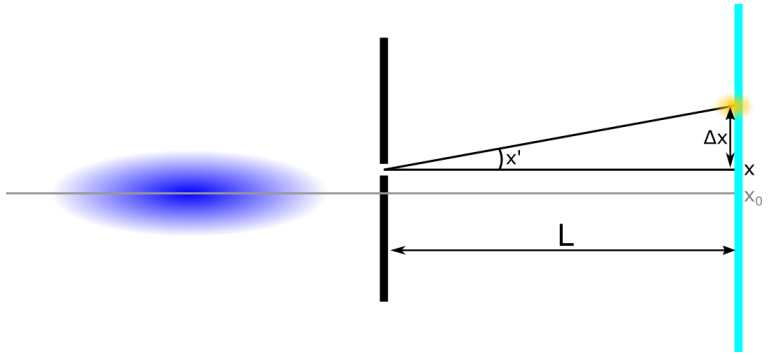
Further information:

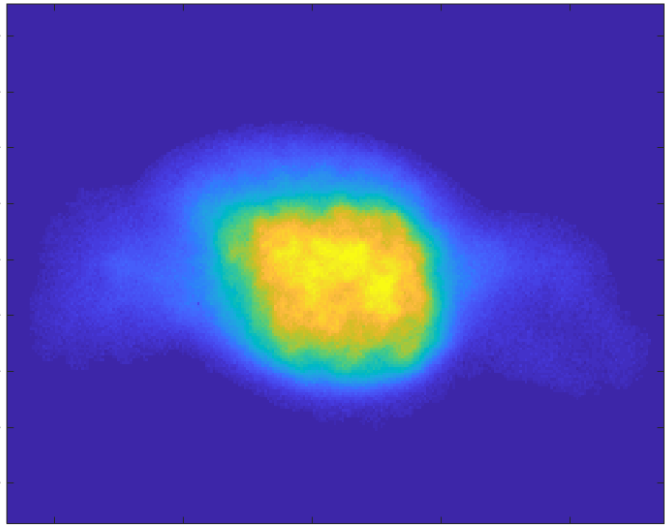
M.Krasilnikov, PPS, 13.10.2011,
Phase space reconstruction from the slit scan data

Methods for noise filtering (1)

- Motivation – overall low SNR
  - Low beamlet charge
  - Small charge beam structures
  - Limited number of pulses
  - Camera gain – electronic noise
  - Noise filtering preceding any analysis
- Three applicable filters selected
- General similarities
  - Utilize average (and RMS) images
  - Separate signal from background

    <s> = <v> - <b> - sigma
  - Pixel-wise mask of interest (MOI)
  - Values outside of MOI to zero





Further information:

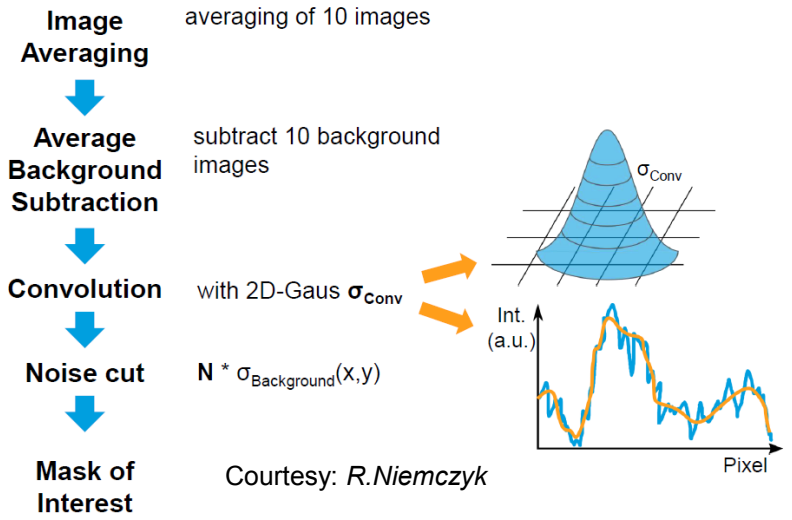
R.Niemczyk, PPS, 13.03.2018,
Progress towards slice emittance measurements at PITZ

H.Huck, PPS, 12.04.2018,
Image Filtering for PITZ

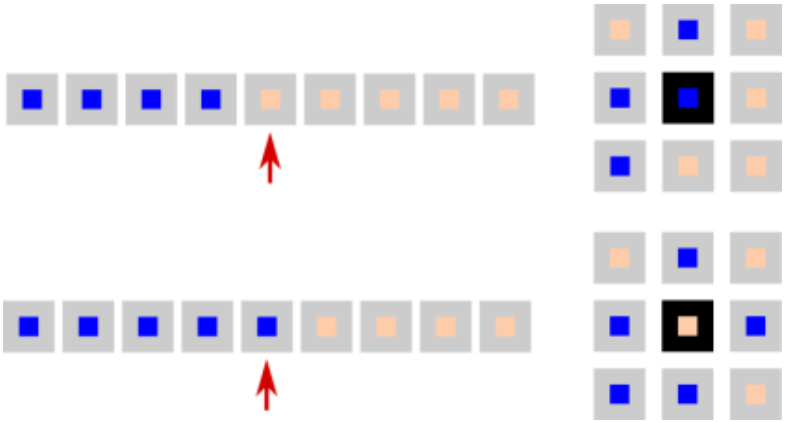
G. Vashchenko, A. Shapovalov, PPS, 10.01.2013,
Image analysis in emcalc2

Methods for noise filtering (2)

- Emcalc
  - Widely used at DESY
  - Initial MOI from signal above 3 times background RMS image
  - 3 rounds of removing and restoring
  - L-shape or closest neighbors
- Holger Huck f**s_t**
  - Gaussian blurred image above fraction **t** of background RMS image
  - MOI from largest value area(s)
- SNR and median
  - Initial MOI from pixel-wise SNR
  - Median filter on MOI
    - Salt-and-pepper noise removal
    - Smoothing



Courtesy: *R.Niemczyk*



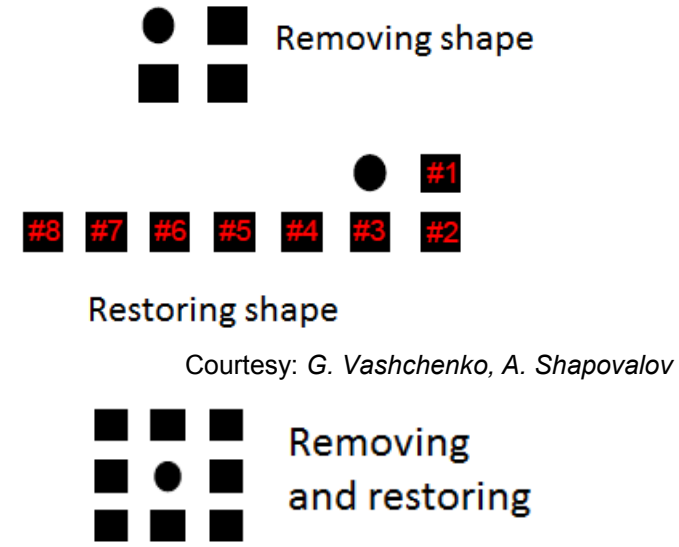


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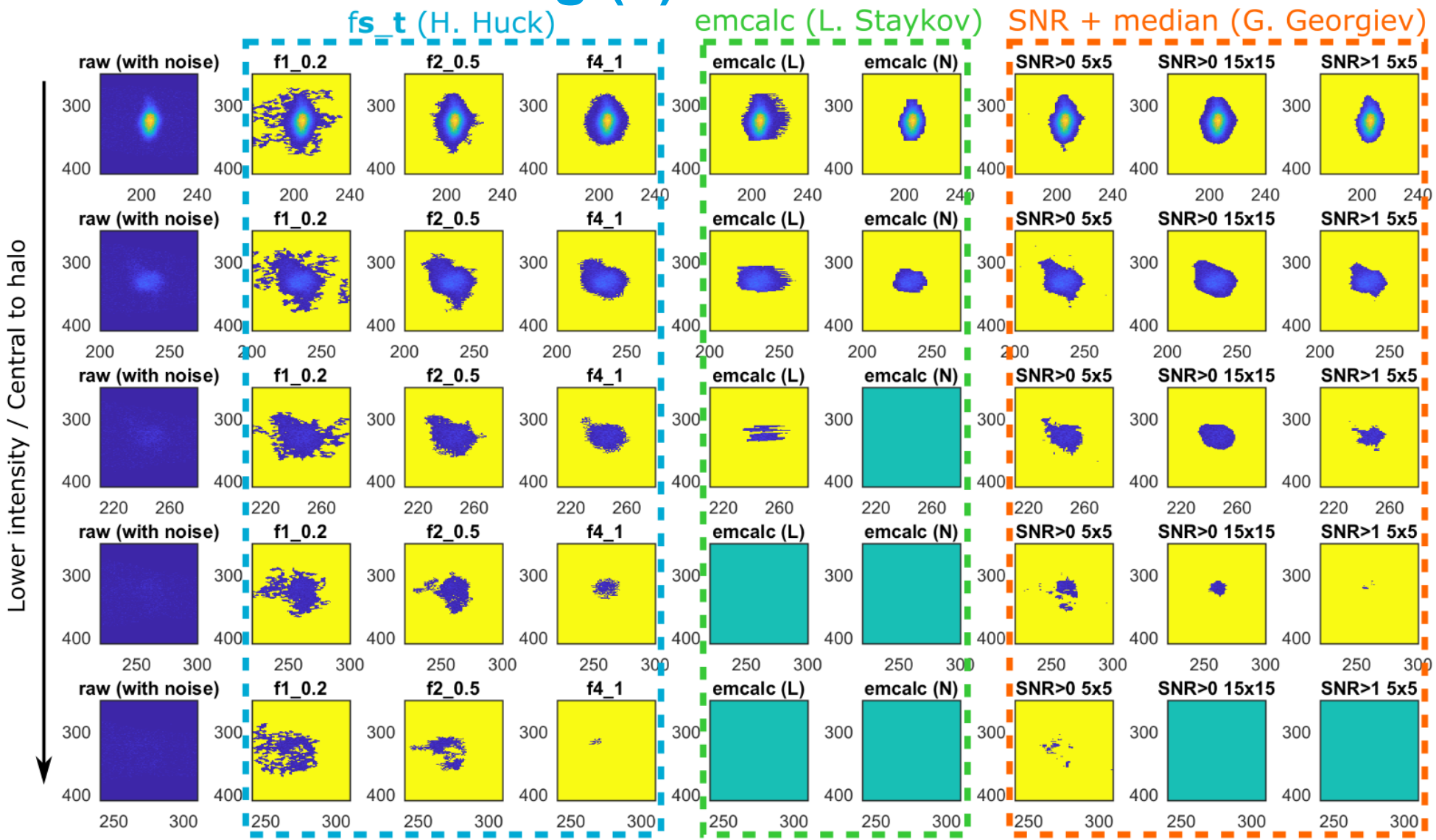
Image analysis in emcalc2

Methods for noise filtering (3)



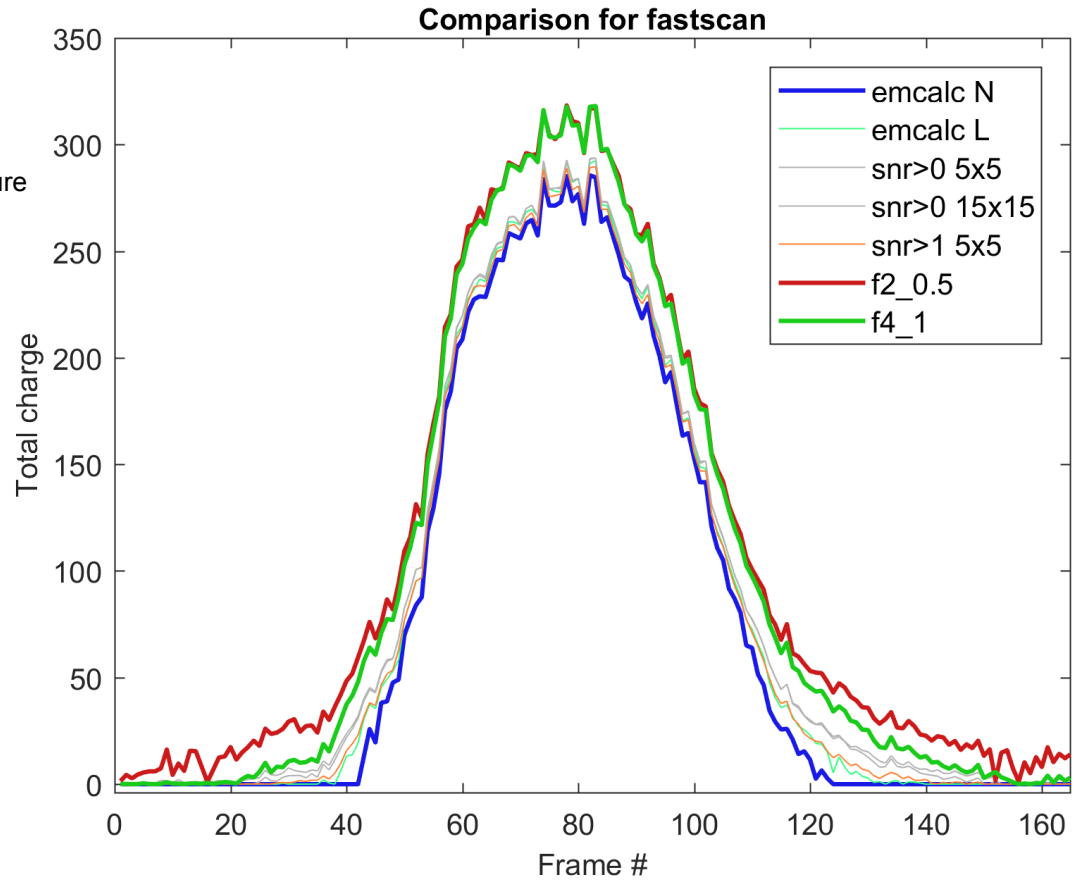
Fastscan filtering results (1)

SoP / total charge

- Fastscan scan method
  1. Take many background images
  2. Move slit at constant velocity
  3. Capture video of screen
     - **Single** frame for each slit position
  - Quick measurement, but **no averaging**
- H.H. filters are **upper envelope**
- Emcalc with closest neighbors is **lower envelope**
- The rest in between
  - Odd shape features preserved in all
  - SNR>1 filter and Emcalc with L-shape overlap
  - At SNR>0 no difference beteween 5x5 and 15x15 median

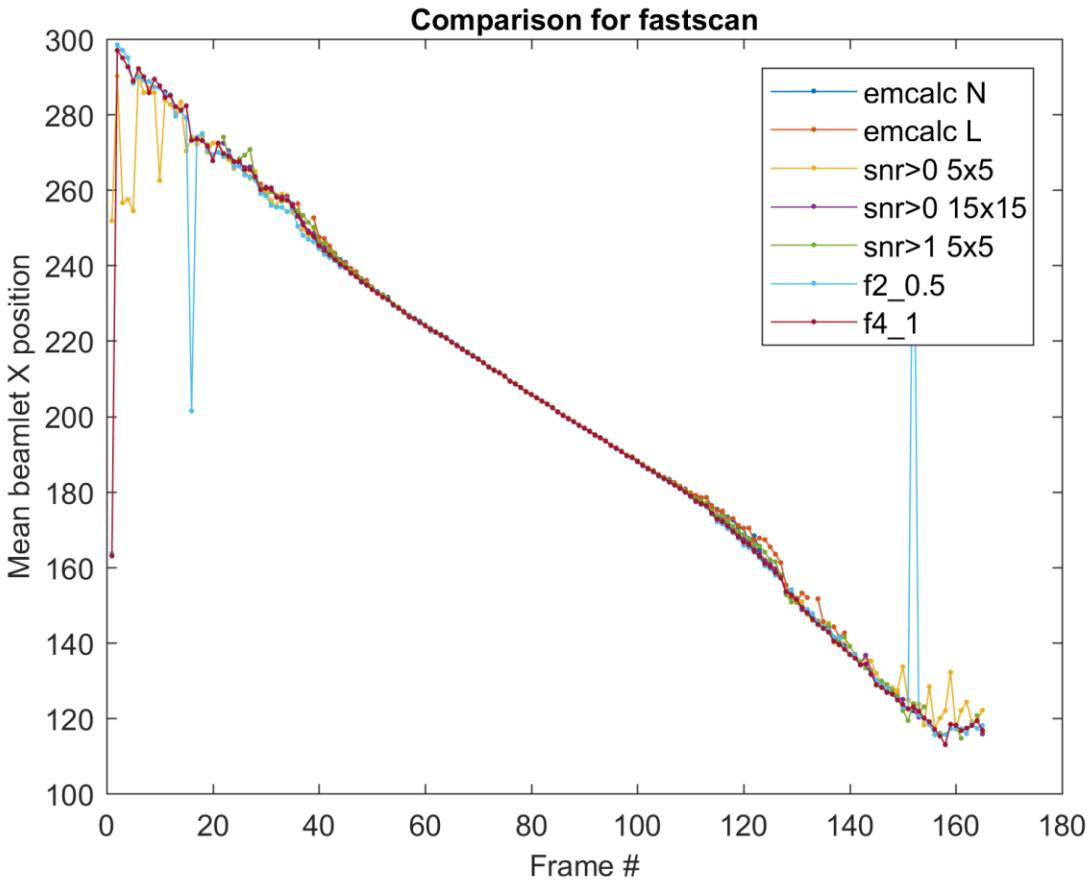
Further information:

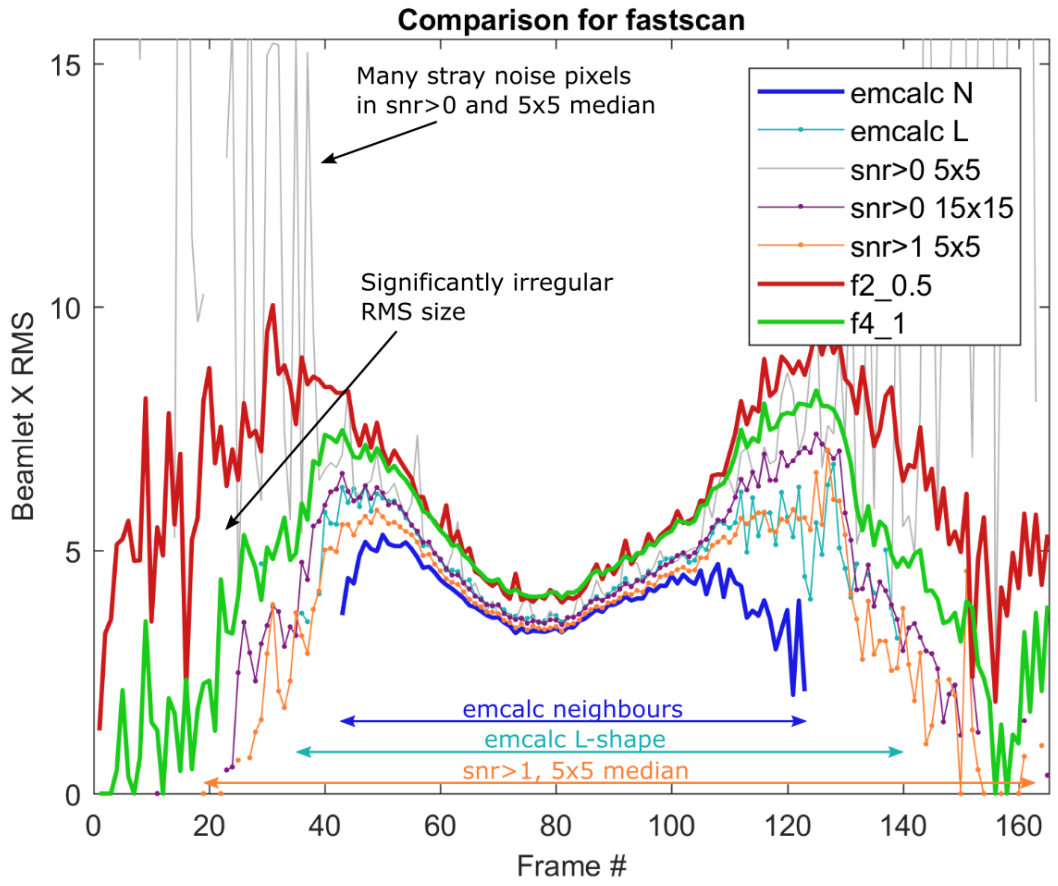
L.Staykov, PPS, 10.06.2008,
EMWiz toward AutoME, upgrade of the automated measurement procedure



Fastscan filtering results (2)

Position and size

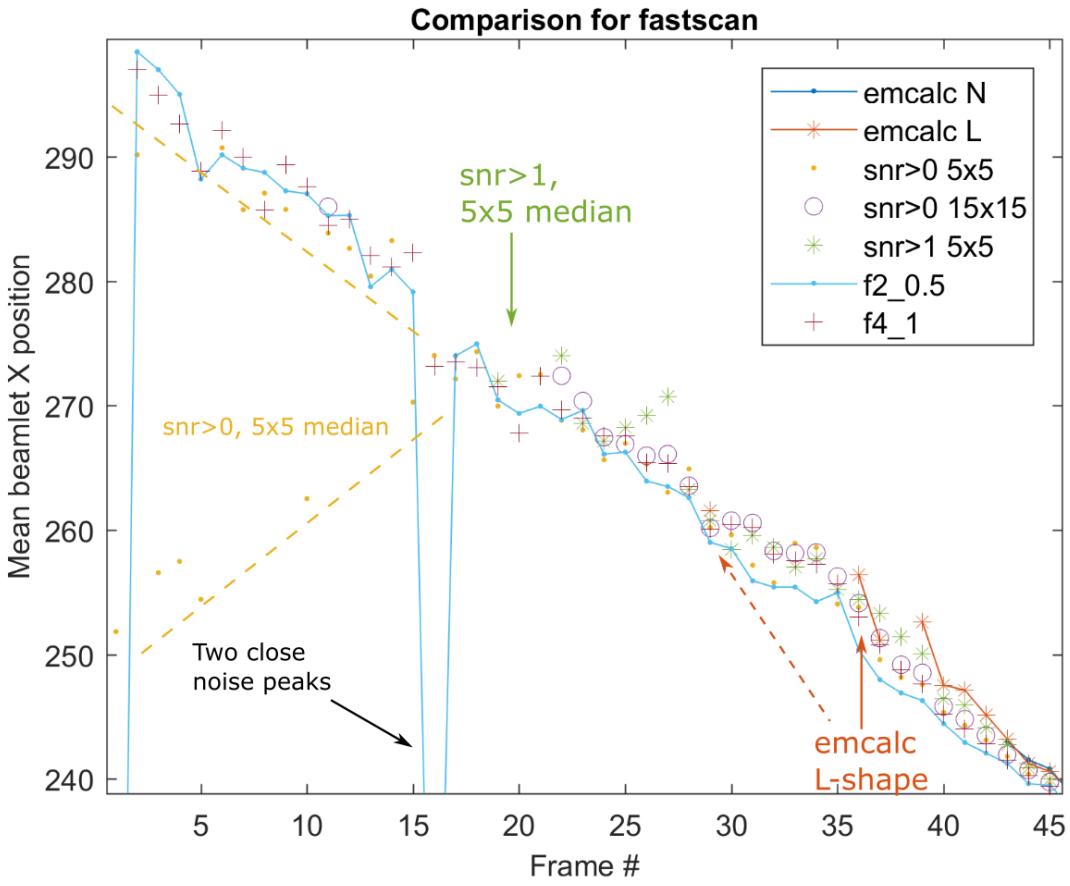


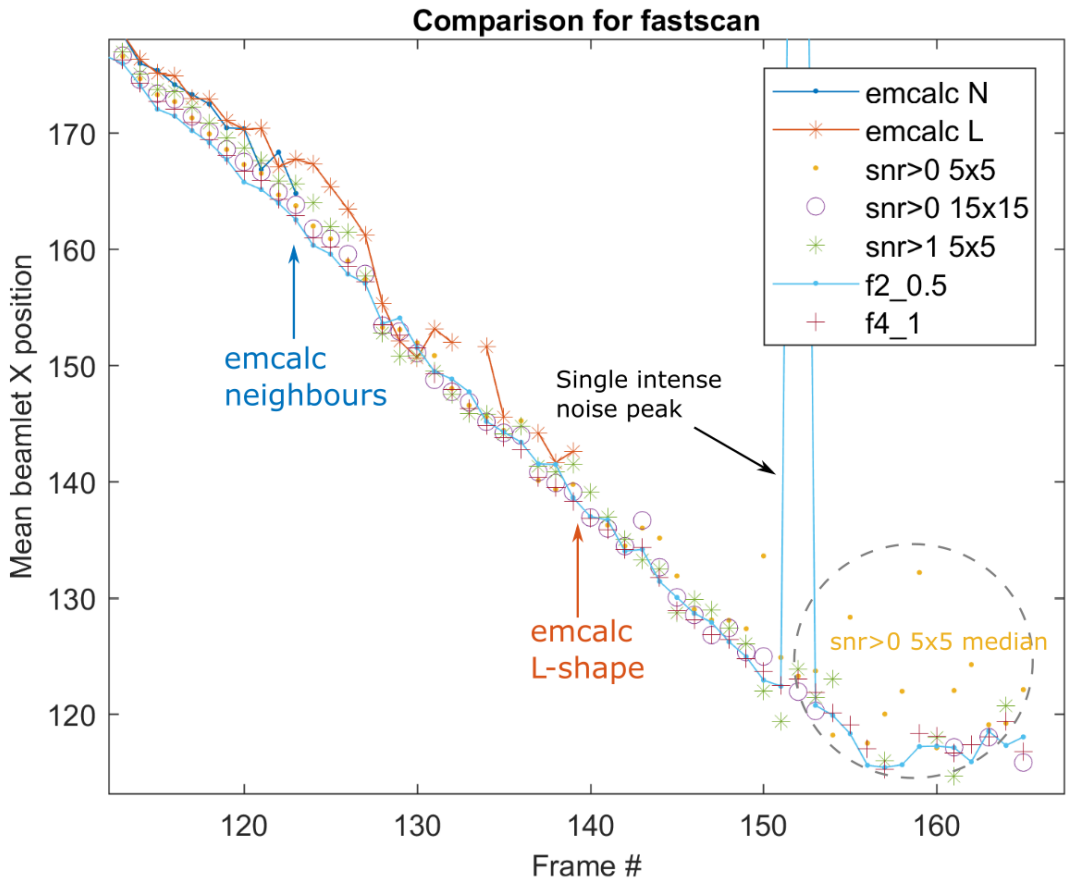


Visible noise caused spikes, outer region in noise dominated.
SNR>1 filter outperforms Emcalc filter.

Fastscan filtering results (3)

Position close-up





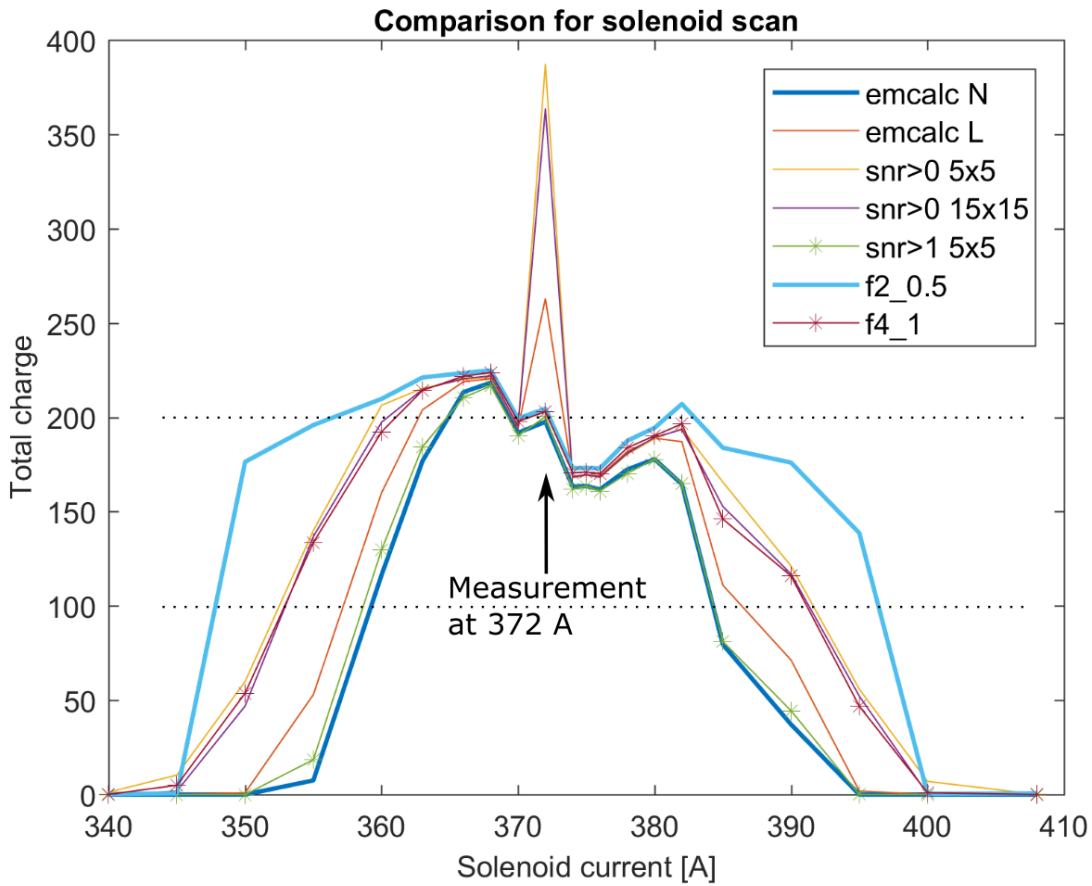
X-ray filter was not applied – needed for f2_0.5.

Solenoid scan filtering results (1)

SoP / total charge

- Change main solenoid current and focusing
  - Significant changes in beam size
  - Significant changes in peak intensity
  - Beam position does not change
  - Integrated beam **current does not change**

  Filters must preserve summed charge and intensity!
- f2_0.5 is **upper envelope**
  - Preserves most charge
  - Not end-to-end
- Emcalc N (and SNR>1 filter) is **lower envelope**
  - Worst charge preservation
- Single image strange results (next slide)
  - Few filters **not influenced**



Solenoid scan filtering results (2)

SoP / total charge

- Change main solenoid current and focusing
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  - Worst charge preservation
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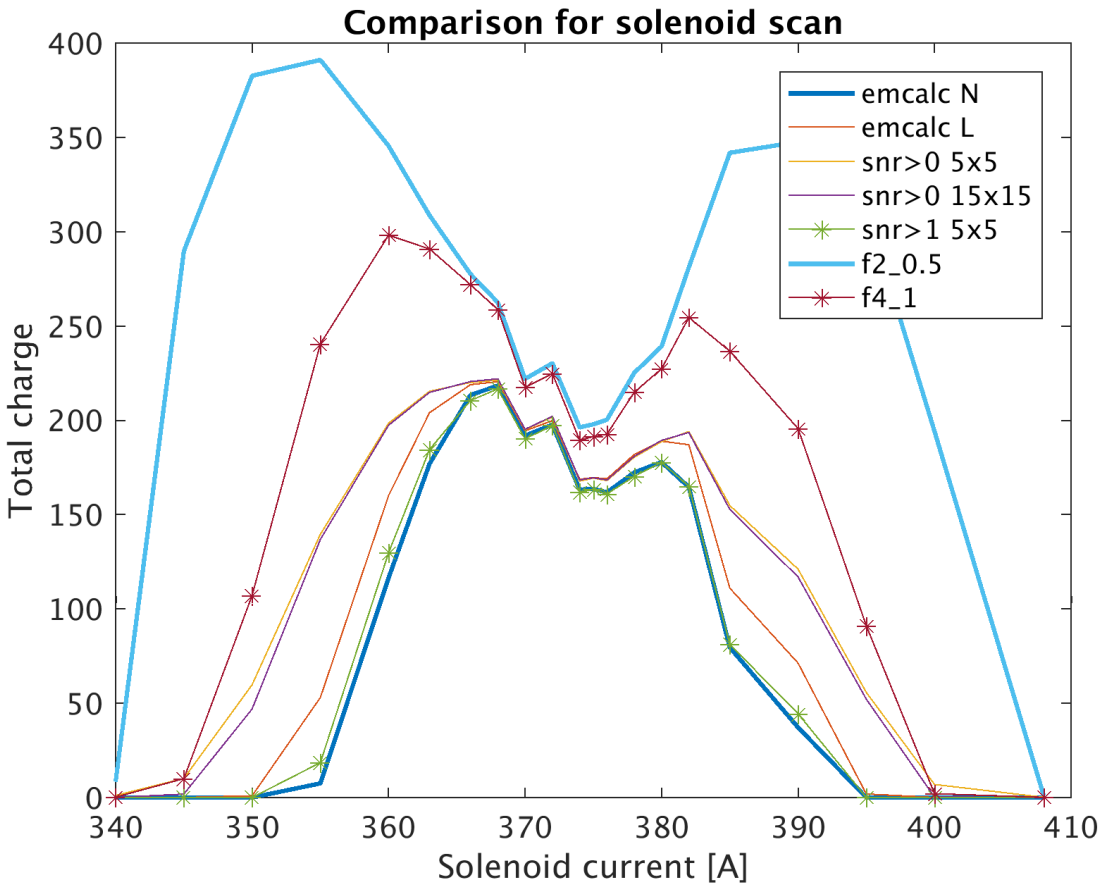
  - Few filters **not influenced**

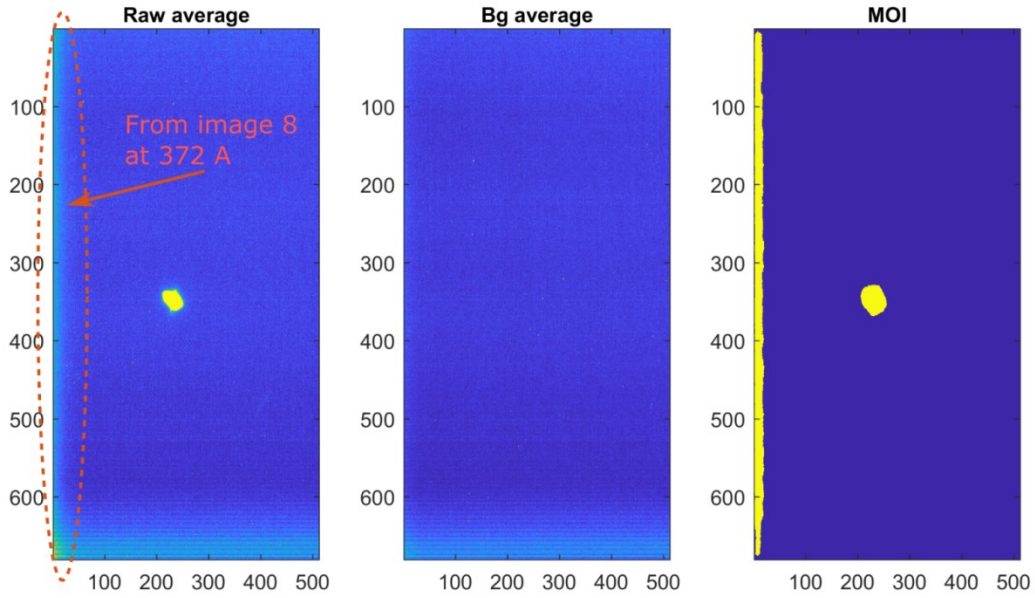
With square MOI before filtering

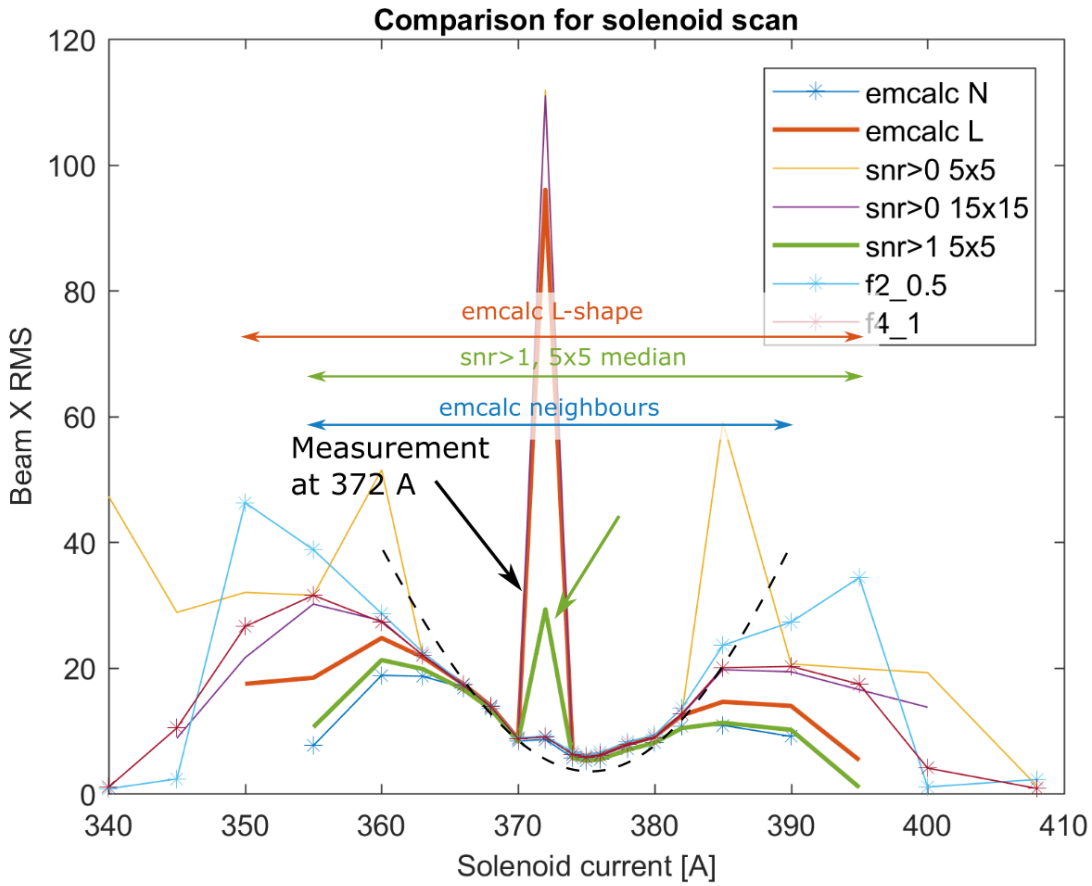


More noise included in larger area? Noise subtraction underestimation.?

Solenoid scan filtering results (3)

Momentary edge glow

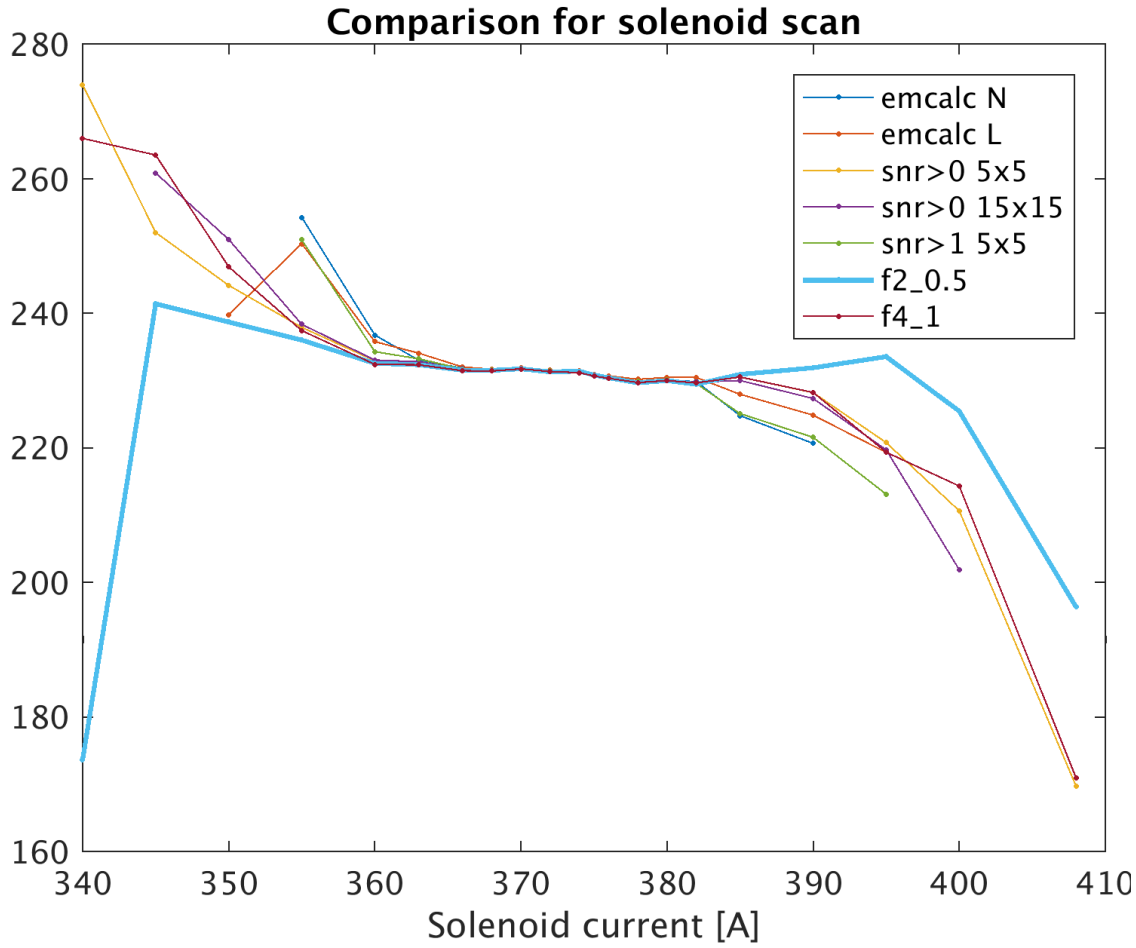


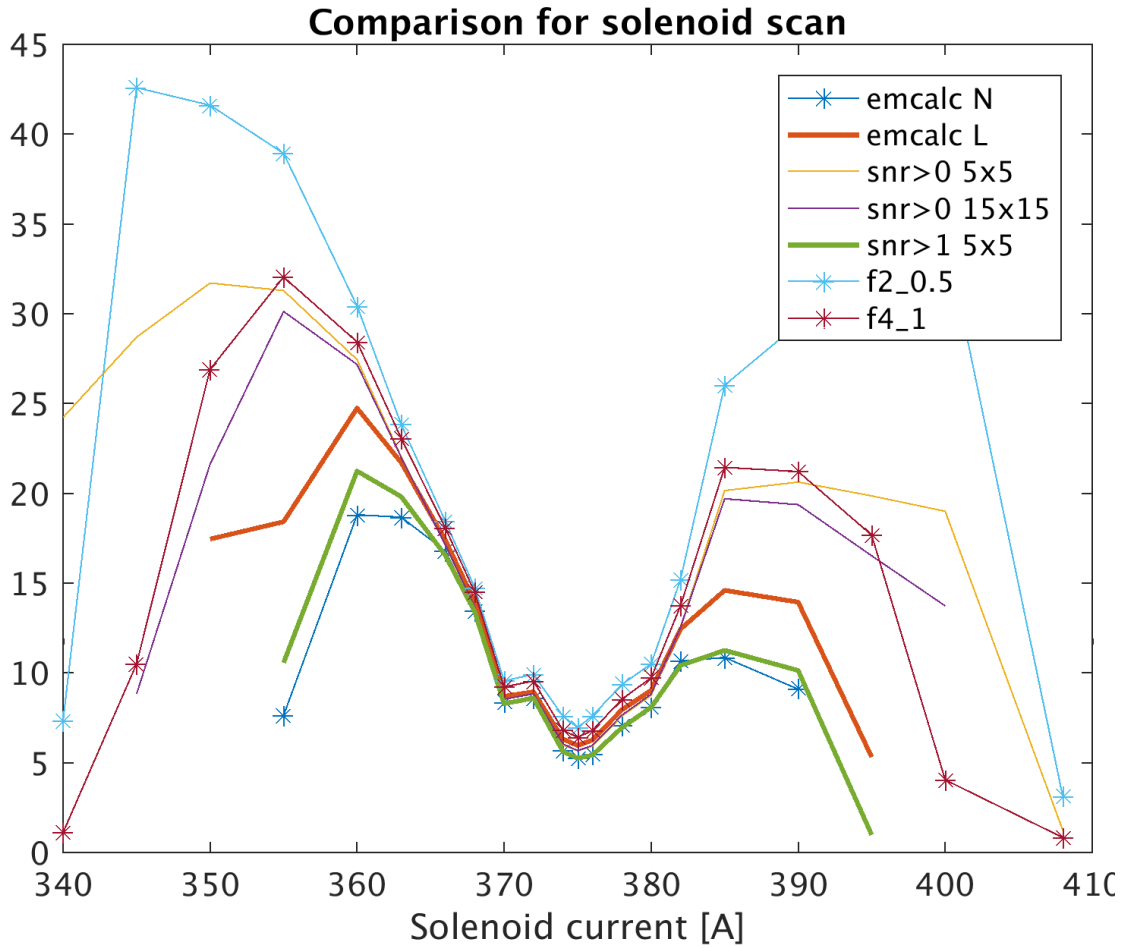


Mask of interest must be applied before automated MOI from each filter!

Solenoid scan filtering results (4)

Position and size



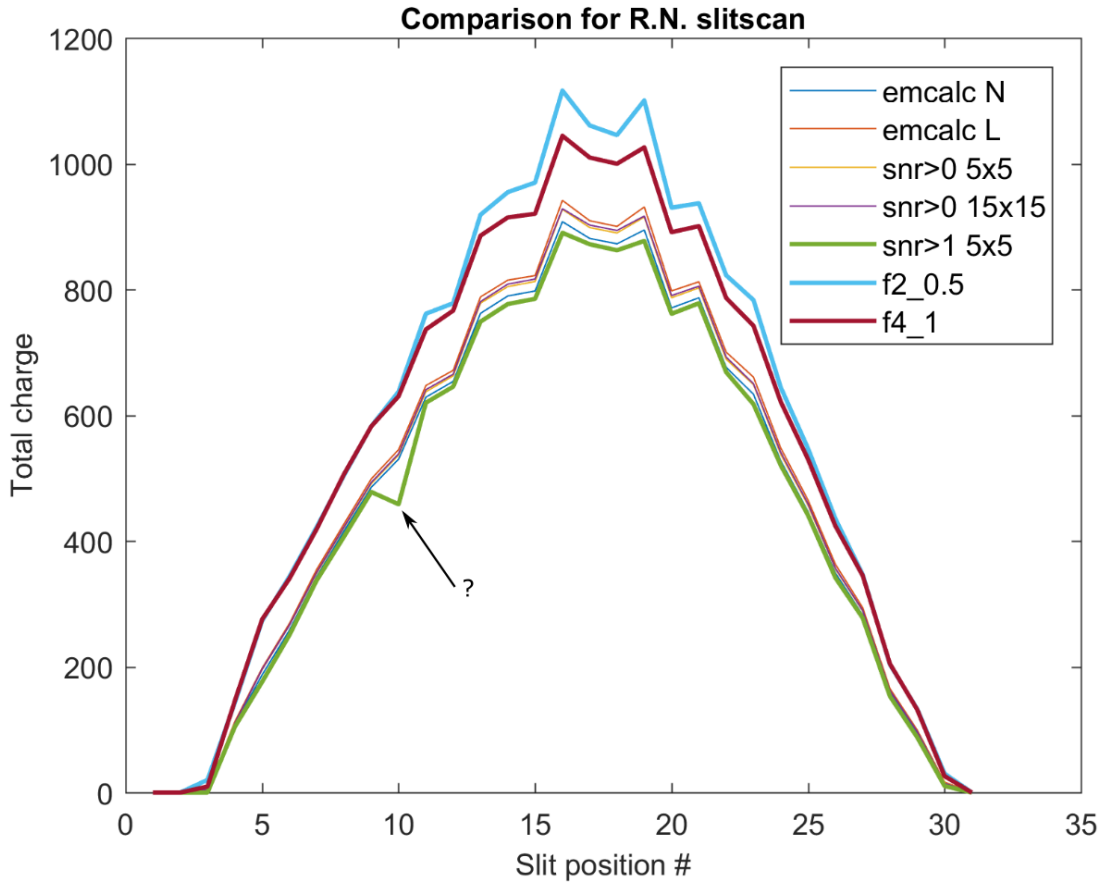


SNR>1 filter does not outperform Emcalc filter.

R.N. scan filtering results (1)

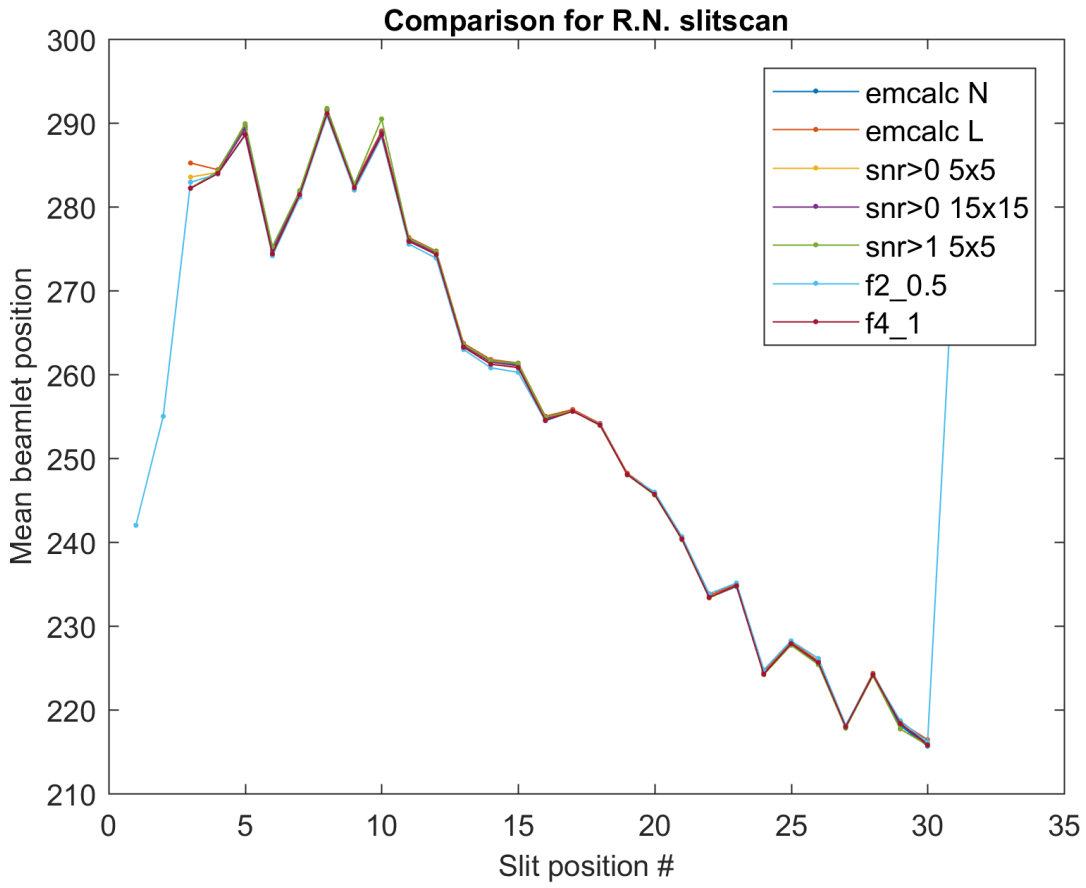
SoP / total charge

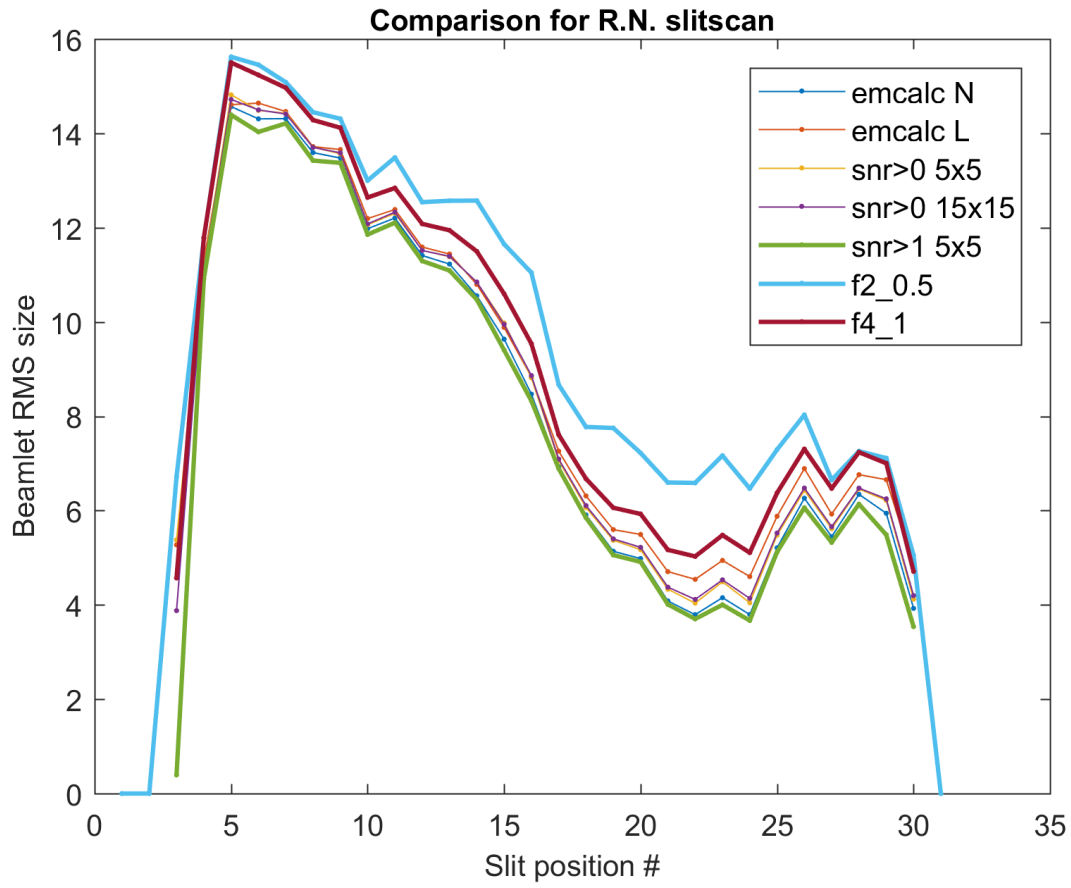
- Raffael Niemczyk scan procedure
  - Currently in development
  - Full beam MOI included
  - At each slit position
    1. Take 10 images with beam
    2. Take 10 background images
  - Slow measurement, but **averaging possible**
  - Data from TDS slit scan
- H.H. filters are **upper envelope**
- SNR>1 filter is lower envelope
  - Single odd drop, unknown cause



R.N. scan filtering results (2)

Position and size





No visible noise spikes. Consistent performance about end to end.

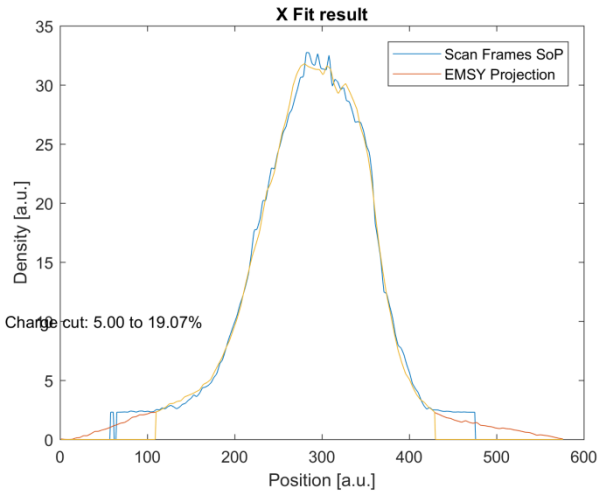
Noise filters summary

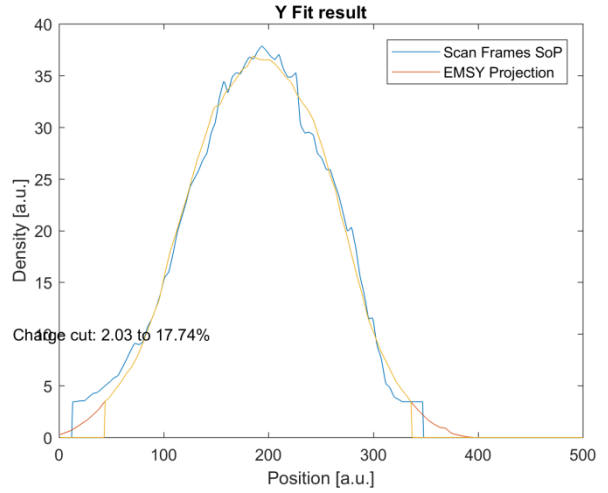
- General MOI must be applied before noise filter
  - Automatic MOI from filter on full beam (when available)
- Averaging of images: **important**
- Filter performance depends on experiment
  - H. Huck fs_t filter more sensitive, comparably robust
    - Most suitable for small low intensity beamlets
  - Similar performance of SNR>1 with 5x5 median and Emcalc
    - SNR>1 with median more robust
- Further study
  - More data sets
  - Different parameters
  - Replacing median filter

Fitting

X and Y positions matching of EMSY screen, slit position and mean beam center

- Slice charge ~ EMSY projection at slit position
- Expected: SoP matches EMSY projection
- Slit position offset and intensity scale difference
- Charge cut
  - Weak signal not detected
  - **Tails cut** or **zero level** difference
- Simplex (*only for X*) or particle swarm optimization





Filter	Tail cut (X / Y) %	Level cut (X / Y) %
f2_0.5	0.03 / 1.96	0.97 / 15.8
f4_1	0.97 / 1.76	8.51 / 14.7
SNR > 0 & 5x5 median	2.47 / 2.23	13.9 / 18.0
SNR > 1 & 5x5 median	5.00 / 2.03	19.1 / 17.7
emcalc L-shape	5.72 / 2.61	20.8 / 20.7
emcalc neighbours	7.58 / 2.47	25.8 / 19.9

Phase space reconstruction

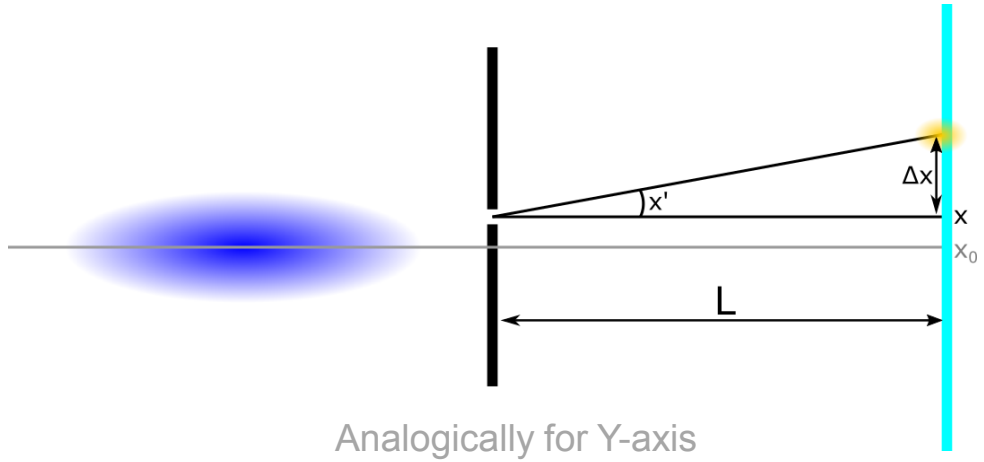
X and Y phase spaces

- Slit position – beamlet position
- Beamlet projection – angular distribution
- Matching of position and angle

Further information:

M.Krasilnikov, PPS, 13.10.2011,
Phase space reconstruction from the slit scan data

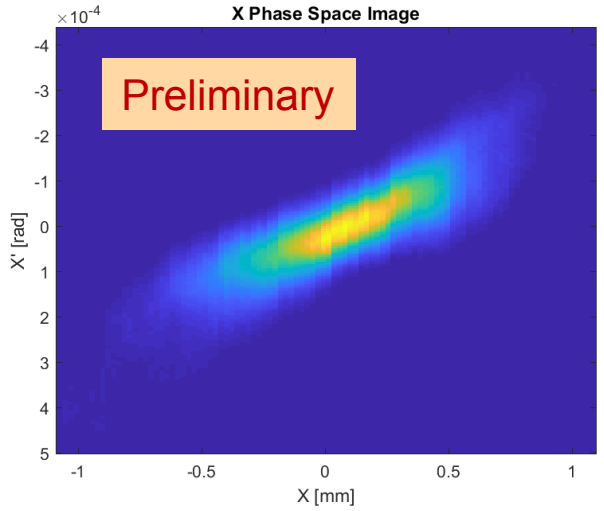
Emcalc3 reference values
$\varepsilon_{nonscaled}$=0.780 [mm mrad]
ε_{scaled}=1.130 [mm mrad]



Analogically for Y-axis

Preliminary

Filter	Nonscaled emittance X [mm mrad]
f2_0.5	1.7180
f4_1	1.2315
SNR > 0 & 5x5 median	1.1183
SNR > 1 & 5x5 median	0.8149
emcalc L-shape	0.8229
emcalc neighbours	0.6840



Y phase space:
Work in progress

Conclusion

- Virtual pepper pot experiment for PITZ
  - 4D transverse beam studies
  - Slit scan measurements
- Status
  - Phase space reconstruction (only X at the moment)
  - Next steps
    - X-Y beamlets crossing
    - 4D transverse beam matrix
    - 4D transverse emittance
- Noise filtering
  - Sensitivity against robustness
  - H.Huck filter most suitable
  - Further studies

Thank you!

Acknolwedgements

R. Niemczyk for details on his scan method and early data

M.Krasilnikov. for solenoid scan idea

Signal to noise ration in SNR filter

Backup slide

<s> = <v> - <b>

<s'> = <v> - <b'>

SNR = <s> / <b> ≈ <s'> / <b'> = (<v> - <b'>) / <b'>

MOI = (<v> - (SNR+1) * <b'>) / <b'> **>** 0