Large Dynamic Range Transverse Beam Profile Measurements

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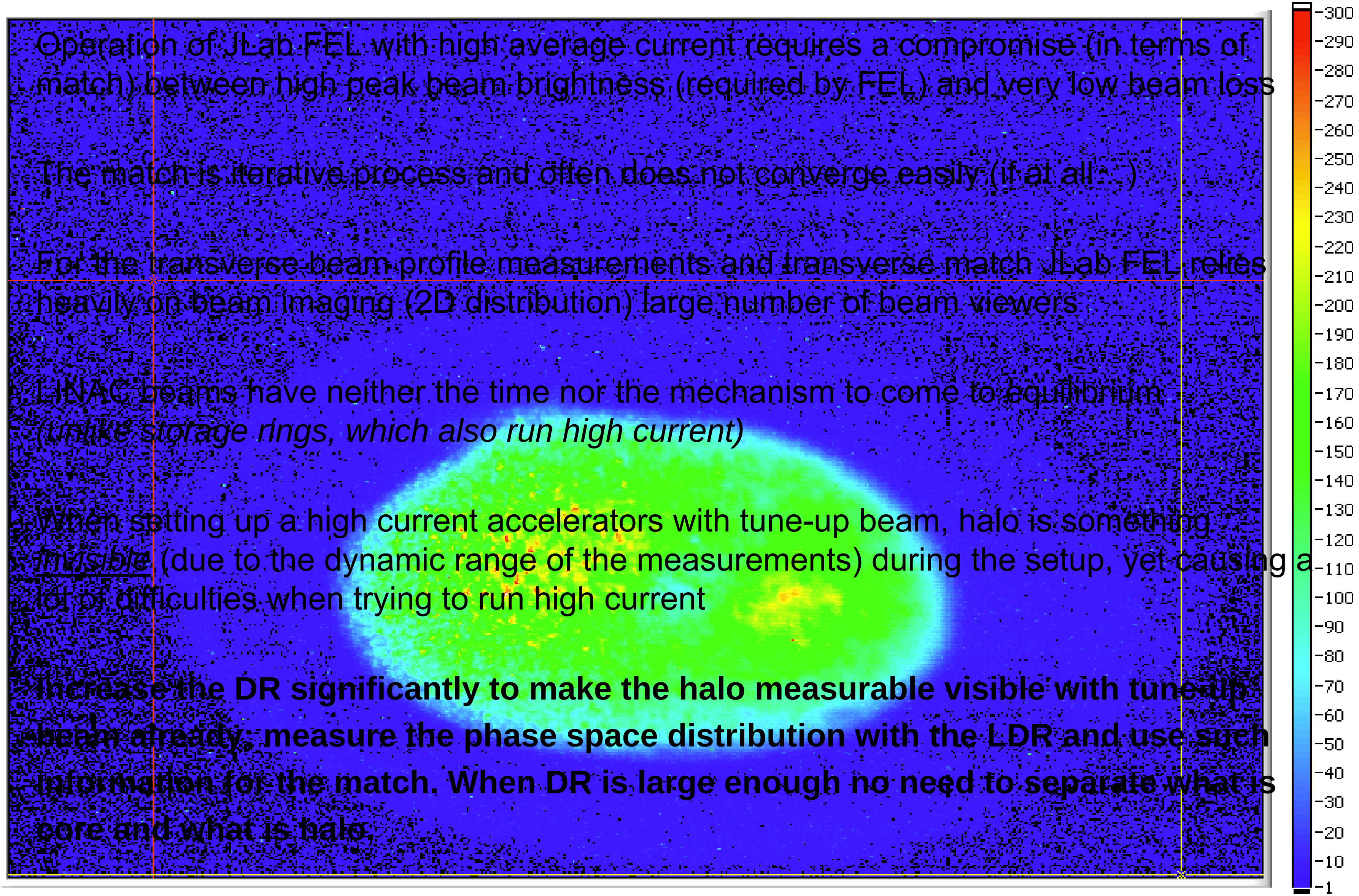
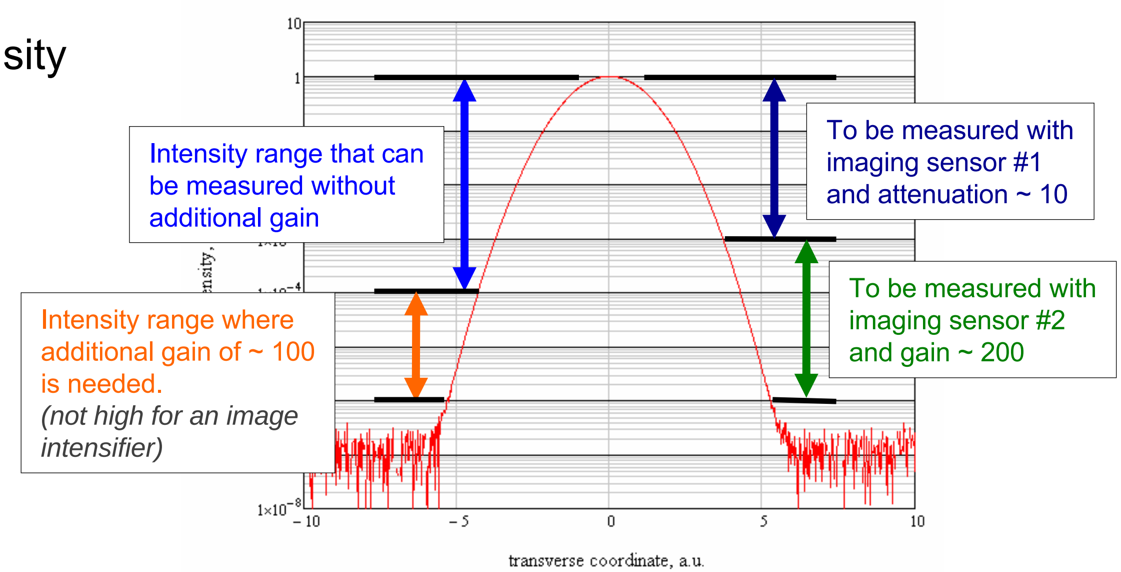
Motivation, etc.



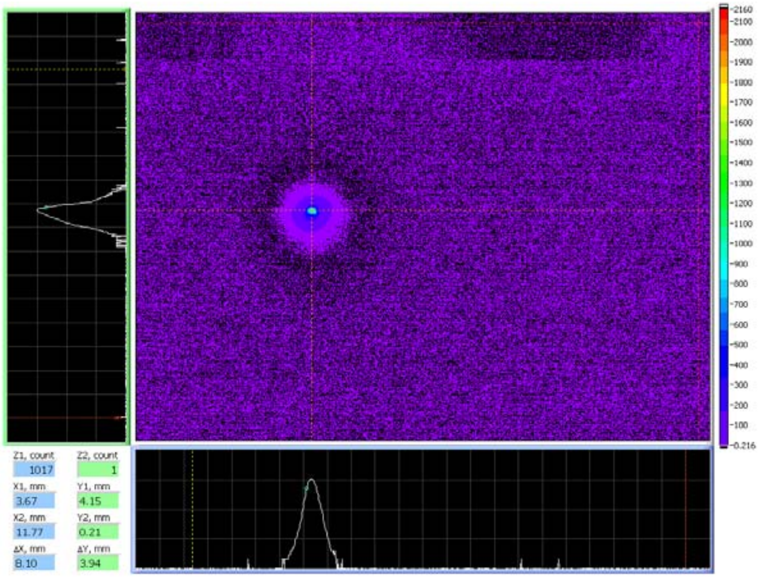
- Operation of JLab FEL with high average current requires a compromise (in terms of match) between high peak beam brightness (required by FEL) and very low beam loss
- The match is iterative process and often does not converge easily (if at all…)
- For the transverse beam profile measurements and transverse match JLab FEL relies heavily on beam imaging (2D distribution) large number of beam viewers
- LINAC beams have neither the time nor the mechanism to come to equilibrium *(unlike storage rings, which also run high current)*
- When setting up a high current accelerators with tune-up beam, halo is something *invisible* (due to the dynamic range of the measurements) during the setup, yet causing a lot of difficulties when trying to run high current
- **Increase the DR significantly to make the halo measurable visible with tune-up beam already; measure the phase space distribution with the LDR and use such information for the match. When DR is large enough no need to separate what is core and what is halo.**

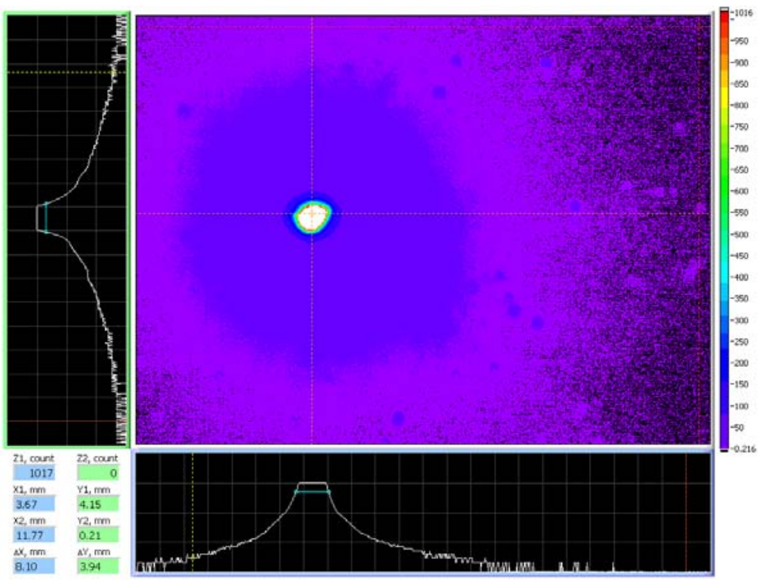
Imaging Sensor(s) Dynamic Range

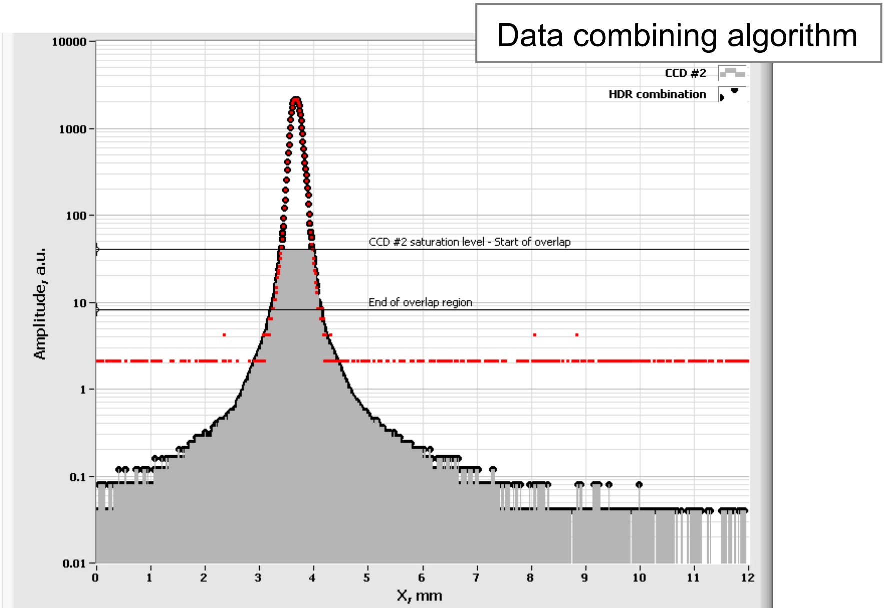
- **The first issue to overcome is the DR of a single imaging sensor**
- **The main principle is to use imaging with 2 or 3 sensors with different effective gain simultaneously and to combine data in one LDR image digitally**
  (single sensor dynamic range 500..1000 if cost is kept reasonable)
- From experience (calculations tested by experiments) we know the safe level of beam current/power for a low duty cycle (tune-up) beam
- With typical beam size of few hundred μm OTR signal is attenuated by ~ 10 to keep CCD from saturation. For phosphor or YAG:Ce viewers attenuation of at least 100 is used.
- Using OTR there is enough intensity to measure 4 upper decades; lower two decades need gain of about 100 to be measured.
- The key elements:
  - image intensifiers
  - alignment and linearity
  - combining algorithm(s)
  - understanding CCD saturation



Raw images and combining algorithm

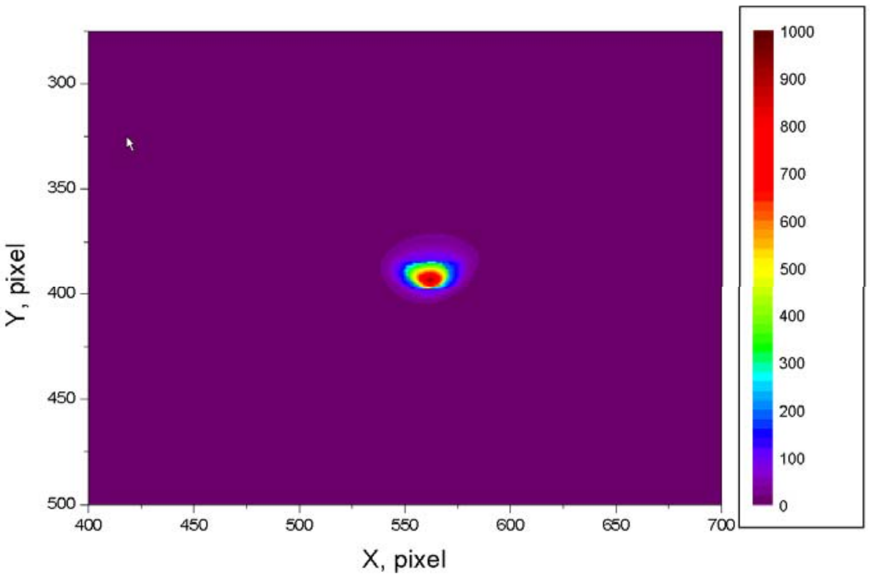


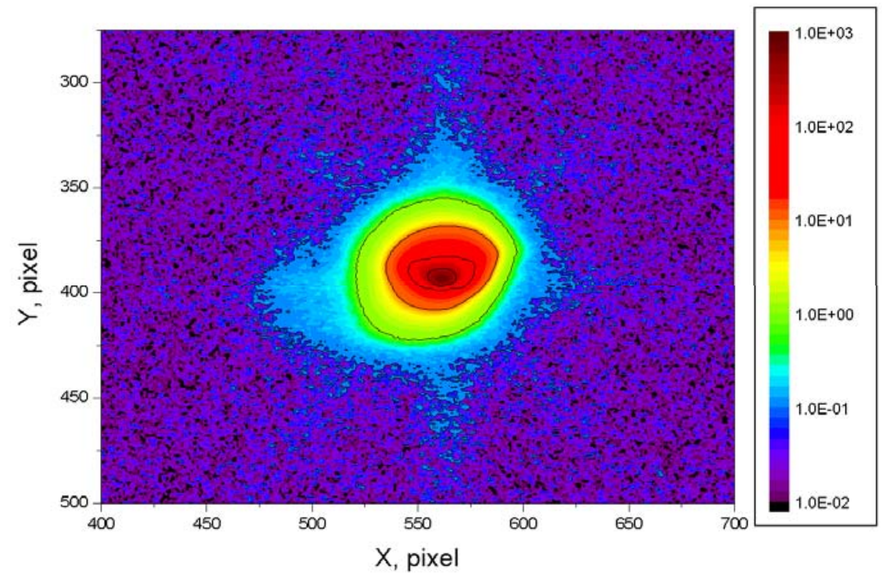




- Two images (on the left) measured simultaneously with integration times 20 us and 400 us
- Background measurements and subtraction is crucial! Made separately for two sensors and subtracted on-line.
- Combining algorithm is efficient enough to provide 5 Hz rep. rate for 1024x768 images
- At the time of measurements was limited by the flexibility of DLPC
- Demonstrated dynamic range of ~ 5E+4 (factor of 100 increase)
- Integration time is used for normalization and overlap (sufficient)
- Averaging also improves SNR and therefore DR (beam stability)

linear & log; the "trouble" with the RMS

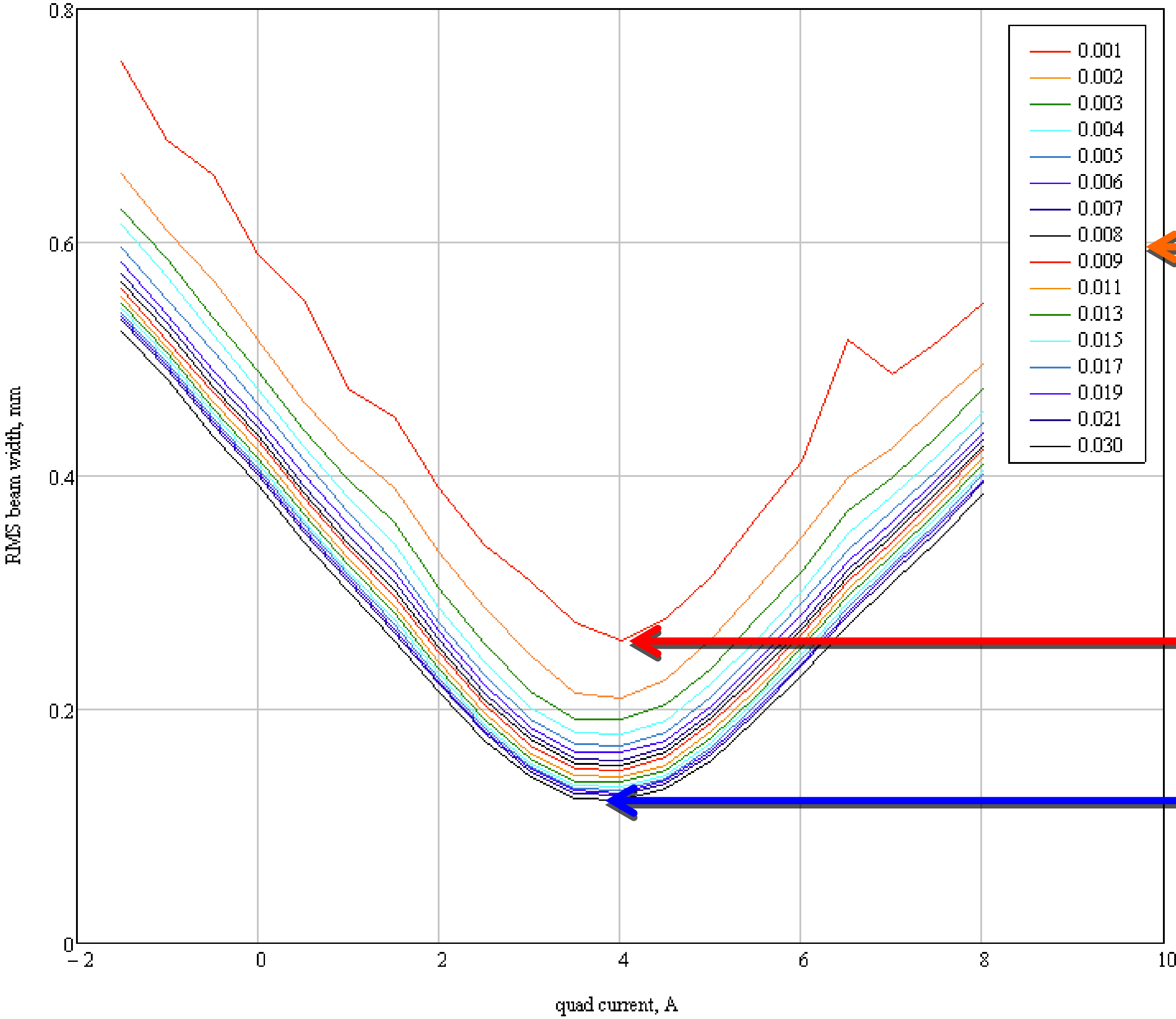




- The two images show exactly the same data (beam profile - (x,y)) but in linear and log scale
- Next step is to use such measurements for beam characterization, emittance and Twiss parameters measurements (add x' and y')
- Ultimately tomographic measurements are planned; but first just quad scan
- **For non-Gaussian beam RMS beam width is a tricky thing! It depends on how much of *tails* of the distribution function f(x) is taken in to account.**

$$w^X_{RMS} = \int x^2 f(x) dx$$

Quadrupole scan raw data

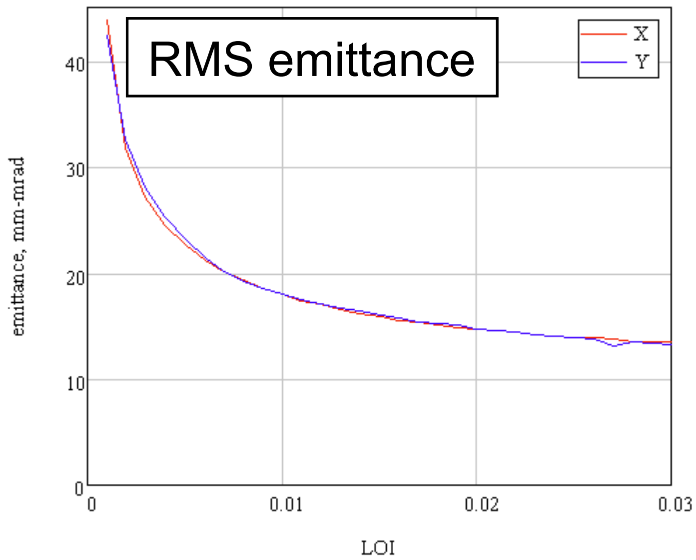


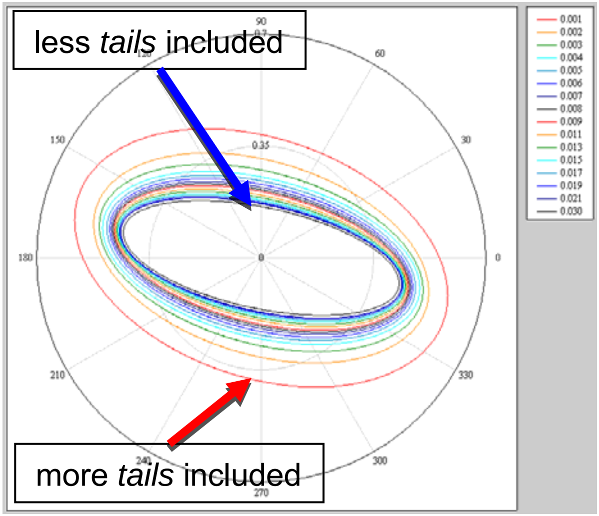
Level of interest (LOI)

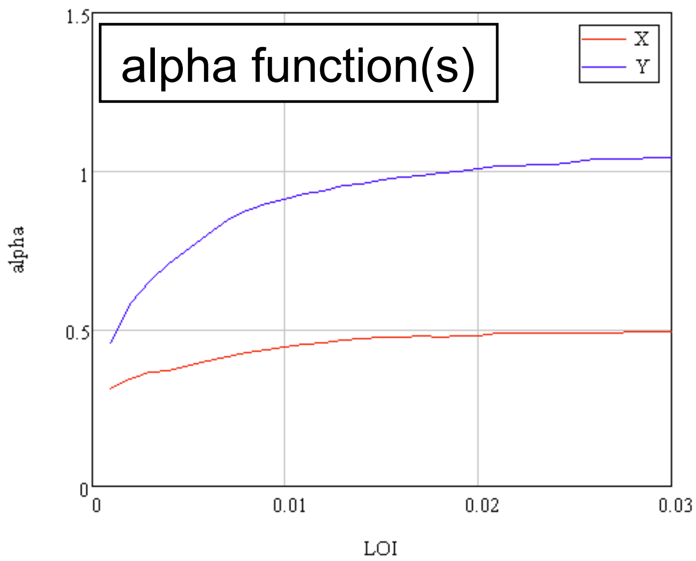
more *tails* included

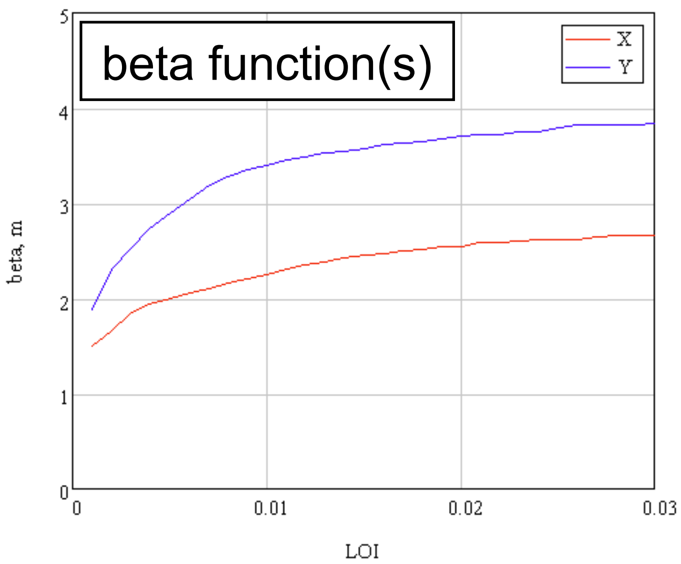
less *tails* included

Emittance and Twiss parameters



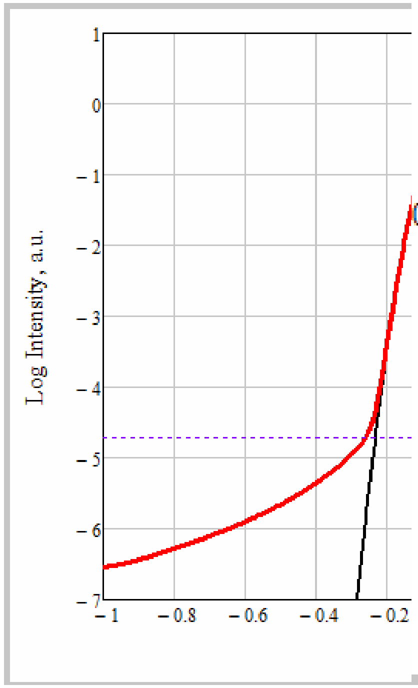


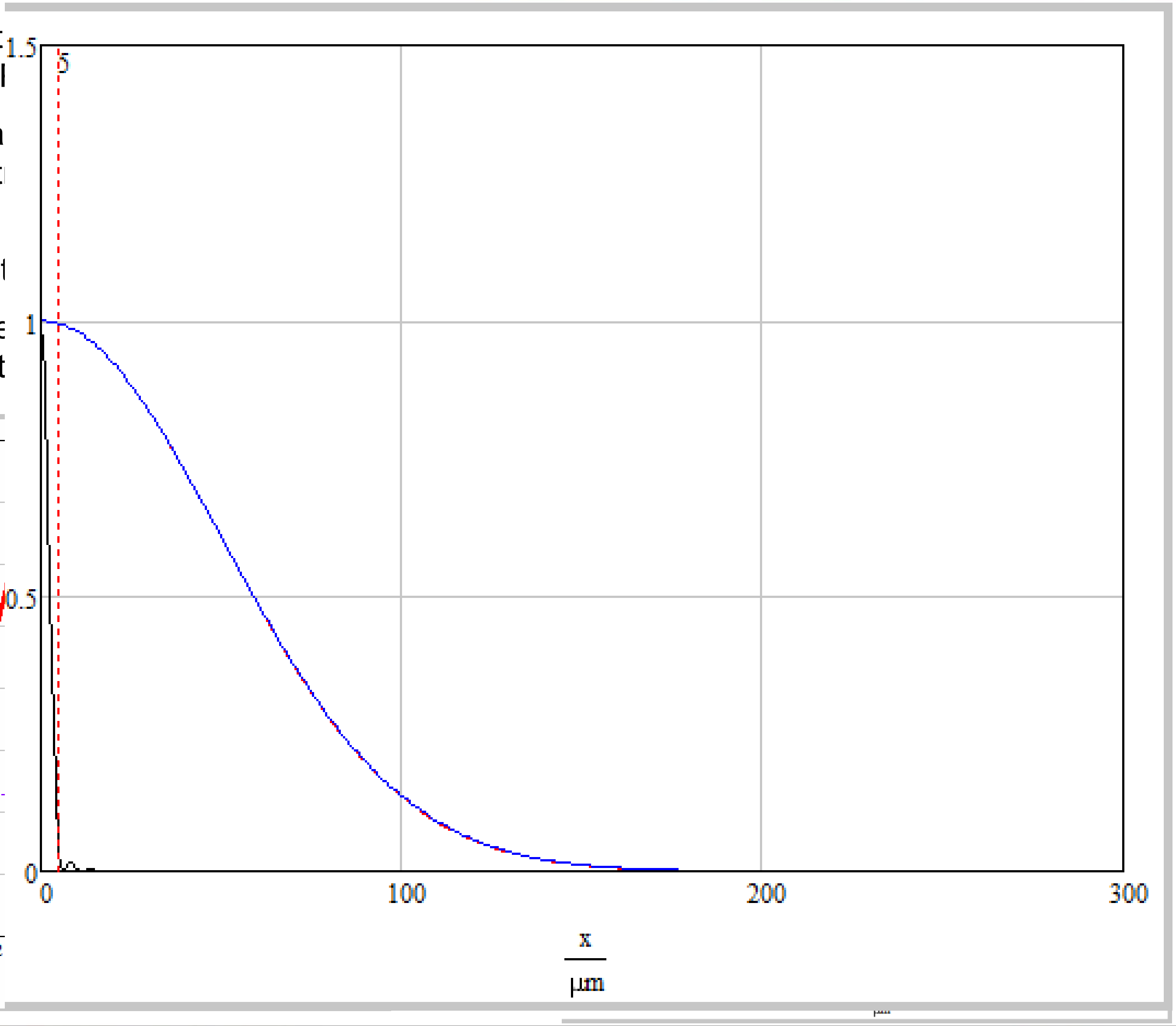




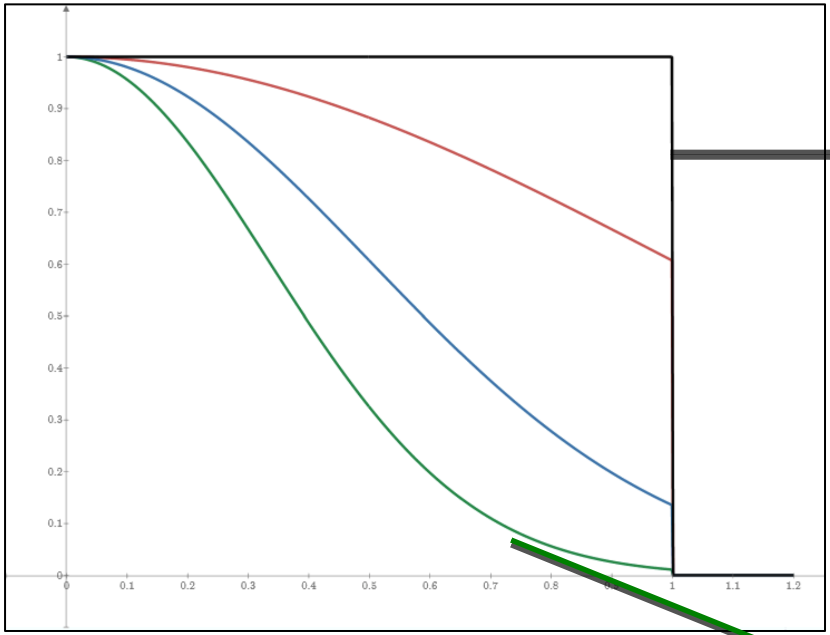
Diffraction limit and PSF

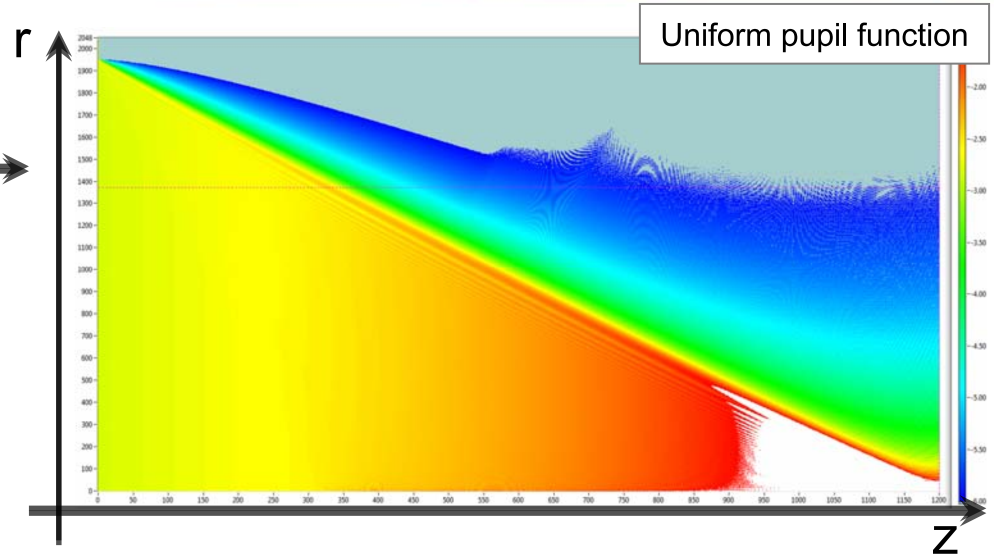
- Imaging ➔ measured dist
distribution and so-called I
- PFS determined by optica
by the source angular dist
different PSF.
- **Diffraction** determines rat
- Ways to mitigate: increase
filter, coronagraph-like opt

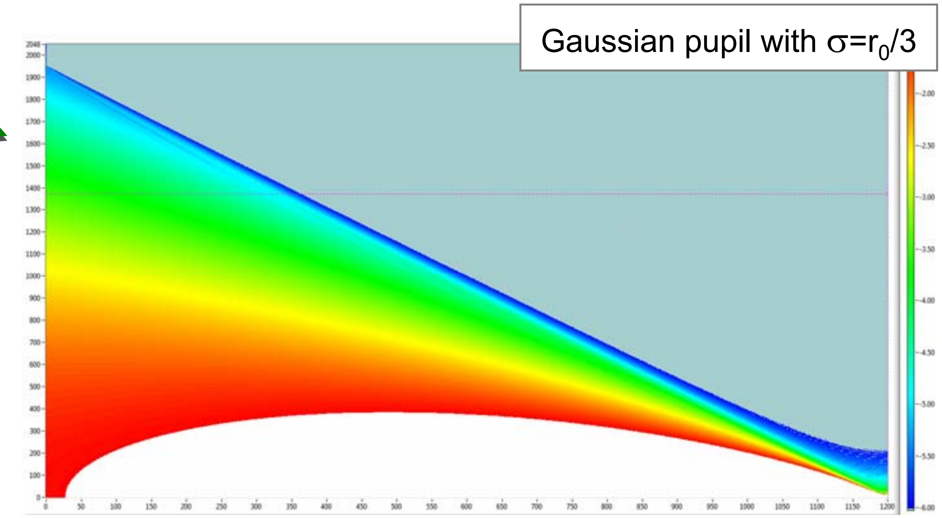




Objective Lens Pupil Apodization

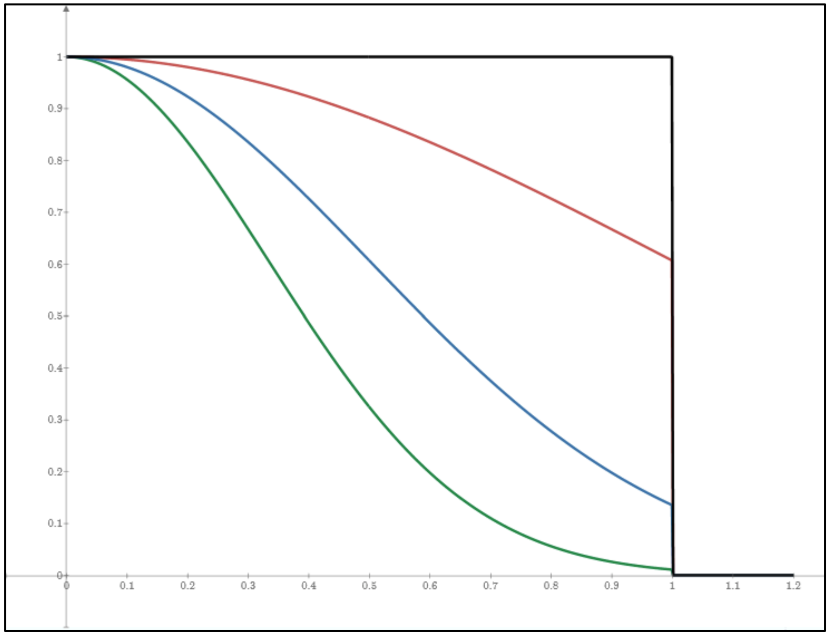


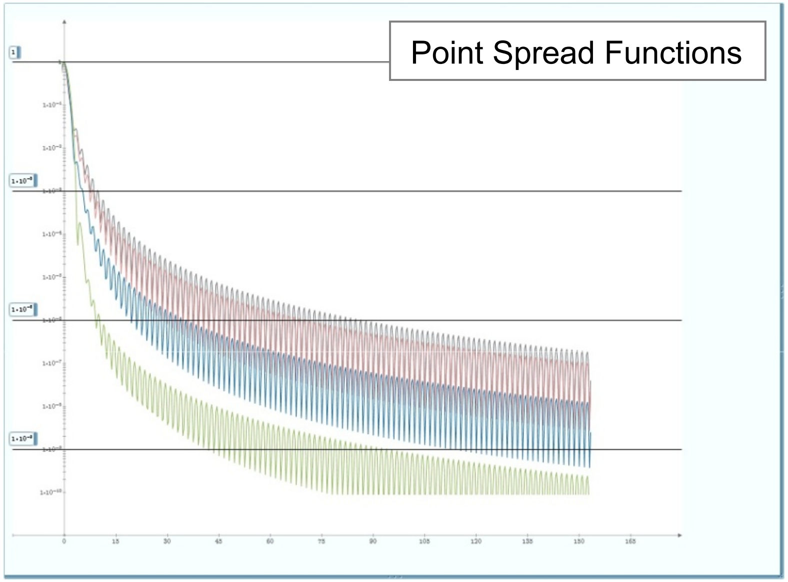


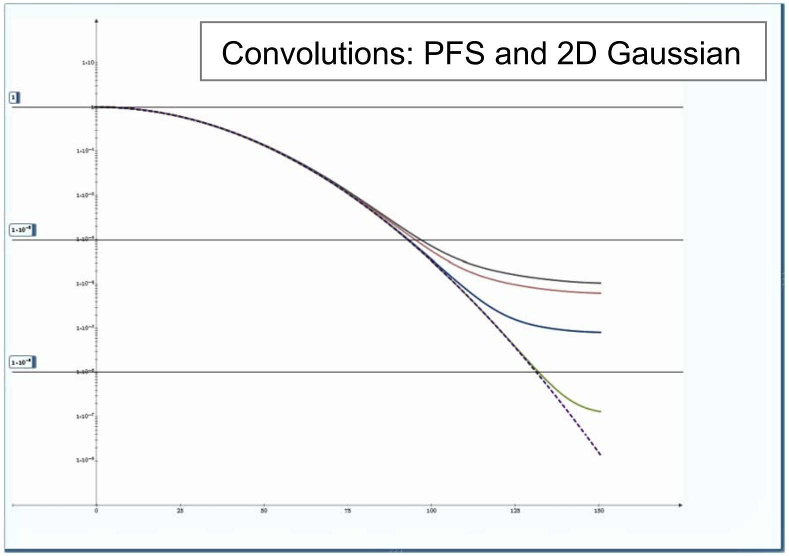


- Fourier optics ➔ mage plane = Fourier transform of pupil function for a point source (this is the PSF)
- Then it is easy to see that the uniform pupil function, i.e., the harp lens edge is the problem *(besides the uncertainty principal, which also adds to the problem)*
- Apodization – modification of the pupil function; First considered Gaussian amplitude apodization

Objective Lens Pupil Apodization







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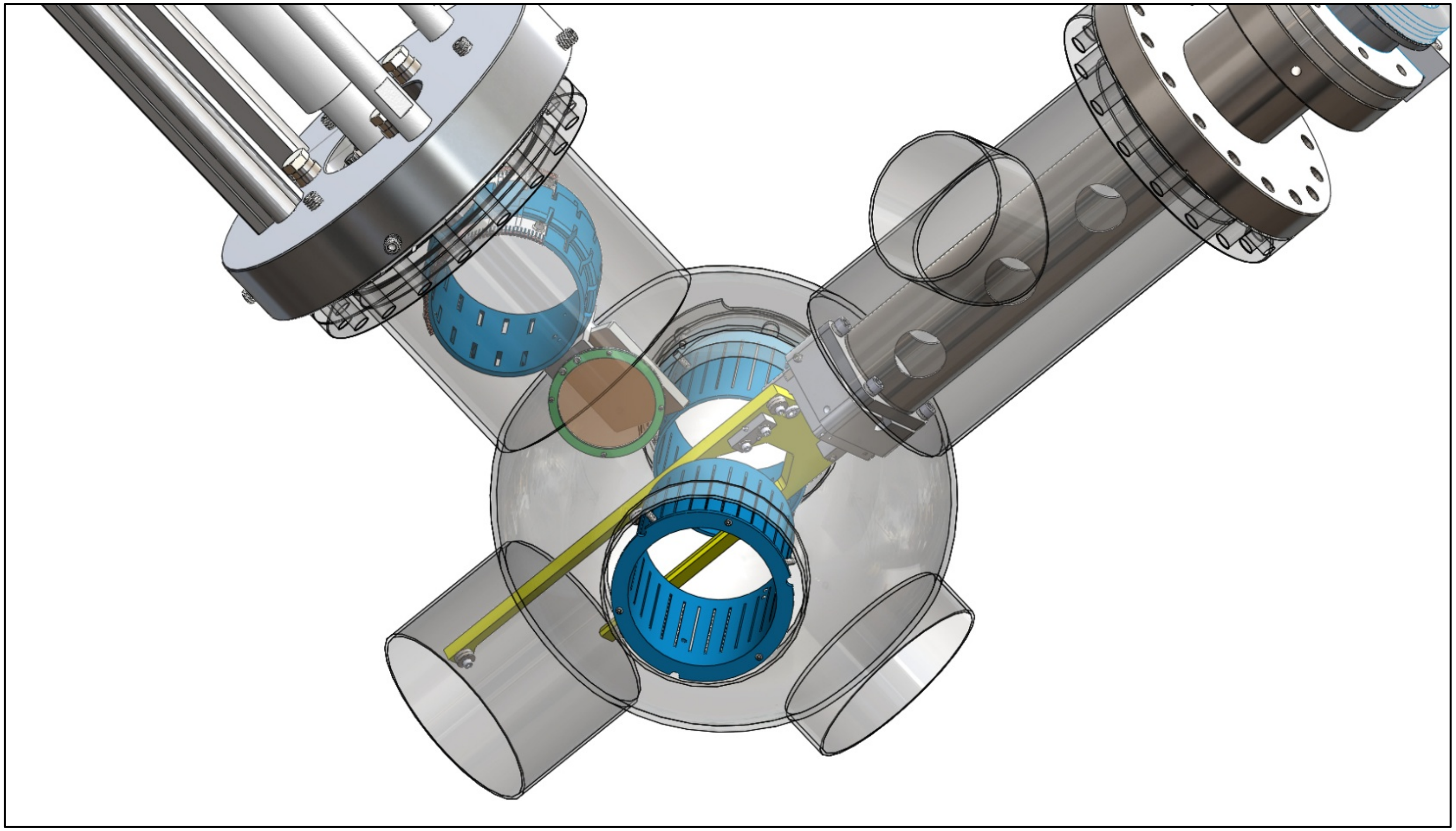
Beam viewer wire-scanner combination

- Must have impedance shield
- Two diagnostics at one location
- Can use YAG:Ce or OTR viewer with easy switch
- Shielded, 3 position viewer design for FEL



In conclusion

- we have demonstrated beam imaging with DR increased by ~ 100
- applied the LDR imaging to beam characterization and have shown that for LINAC non-Gaussian beam the DR has strong impact on the measurements results
- have modeled optics required to improve the DR range to reach 10^6
- new diagnostic station for LDR imaging and cross-check with wire scanner was designed and built
- next1 - practical implementation of the apodization optics (manufacturing, error sensitivity study, optimization)
- next2 - beam measurements with new diagnostics (tomographic phase space measurements based on LDR imaging)