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A wavefront propagation study of the effect of apertures in laser transports on the beam profile achieved with relay imaging illuminated circular masks

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Running rings around relay imaging

- Do you have a laser transport involving the relay imaging of an illuminated mask?
- Have you ever wondered why the image has rings or other structures in it?
- If so, read on…

Wavefront propagation study

- The Daresbury wavefront propagation code FOCUS* is used to study the effect of transport apertures on the final image
- A simplified model is adopted to just show the effect of apertures
- The target beam profile, e.g. a truncated Gaussian or top-hat, is created as a source
- This is propagated to the position of the aperture and the field is truncated by zeroing all field components outside the aperture
- The modified field is then reverse-propagated back to the original position.
- The deviation from the target profile that the aperture causes can now be seen

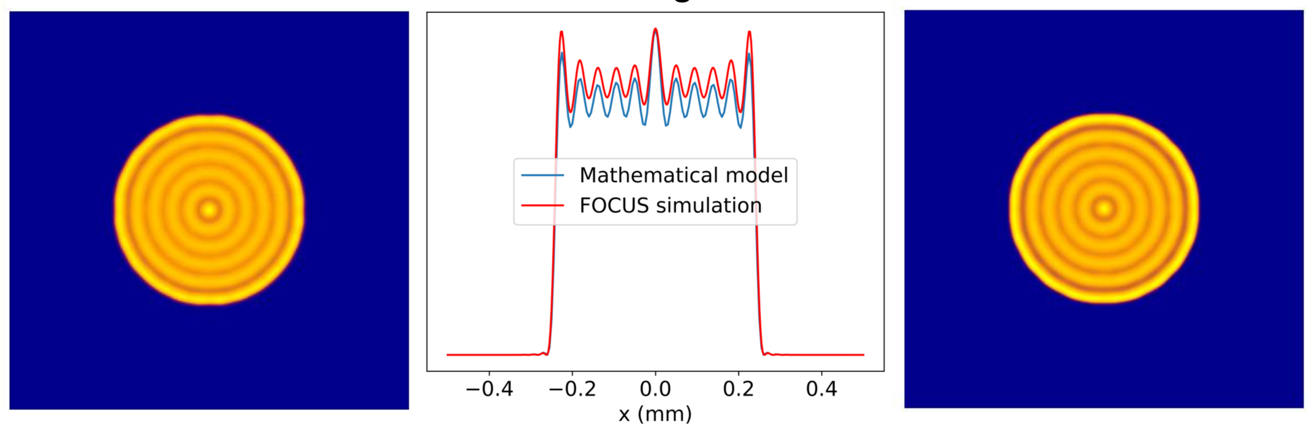
*FOCUS – a new wavefront propagation code, M Bowler & S Higgins https://www.esrf.fr/files/live/sites/www/files/events/conferences/2009/SMEXOS/talkBowler.pdf

Introduction

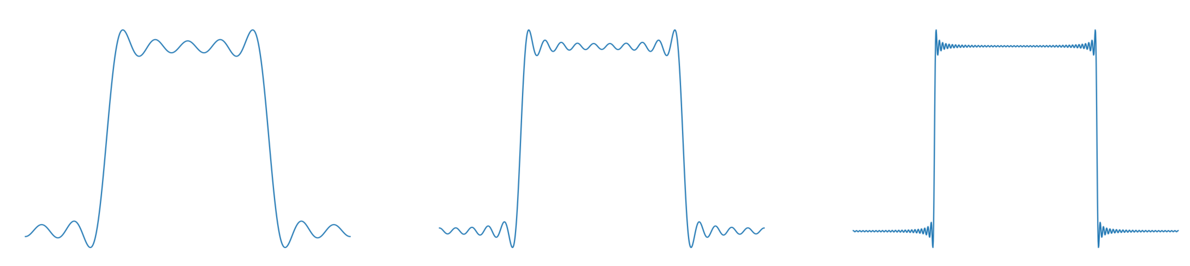
- Relay imaging an illuminated mask is a common technique when projecting a laser beam onto the photocathode of a photoinjector (PI) electron gun.
- Used when a laser beam profile with sharp edges is required, e.g. a truncated Gaussian or 'top-hat'.
- Gives lower e-beam emittance and a stable position
- The laser beam illuminates a circular mask and an optical relay images the mask onto the photocathode.
- Geometrical optics sets the imaging properties of the relay, magnifying or demagnifying the mask onto the cathode to give the beam spot size required.
- However, we mustn't forget that the laser beam is a coherent wave.
- Reconstructing the sharp edge to the image requires a series of spatial harmonics to be transported by the relay.
- The Gibb's phenomenon shows that an infinite series is required to give a perfect sharp edge. Truncating the series at **any** point leaves an overshoot at the edge and ripples over the beam.
- Any real transport has a finite aperture and so the relayed image will always show imperfections.
- Injecting a laser into a photo-injector gun often involves passing the laser beam through small apertures and the effect on the beam image can be profound.

Mathematical model

- In the far-field, a uniformly filled circular mask propagates to an Airy pattern, the square of the Fourier transform of a disc
- The effect of an aperture can be seen by truncating the Fourier transform and then inverse FT to get the modified image
- The figure shows the case of a 0.5 mm diameter top-hat beam truncated after the 10th ring in the far-field.



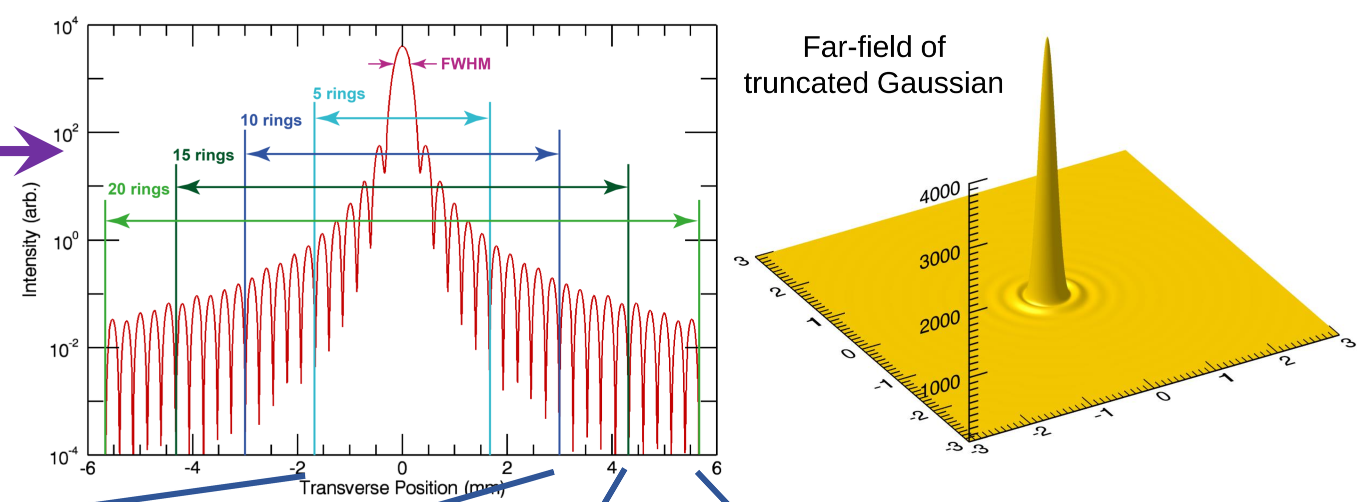
Gibbs Phenomenon

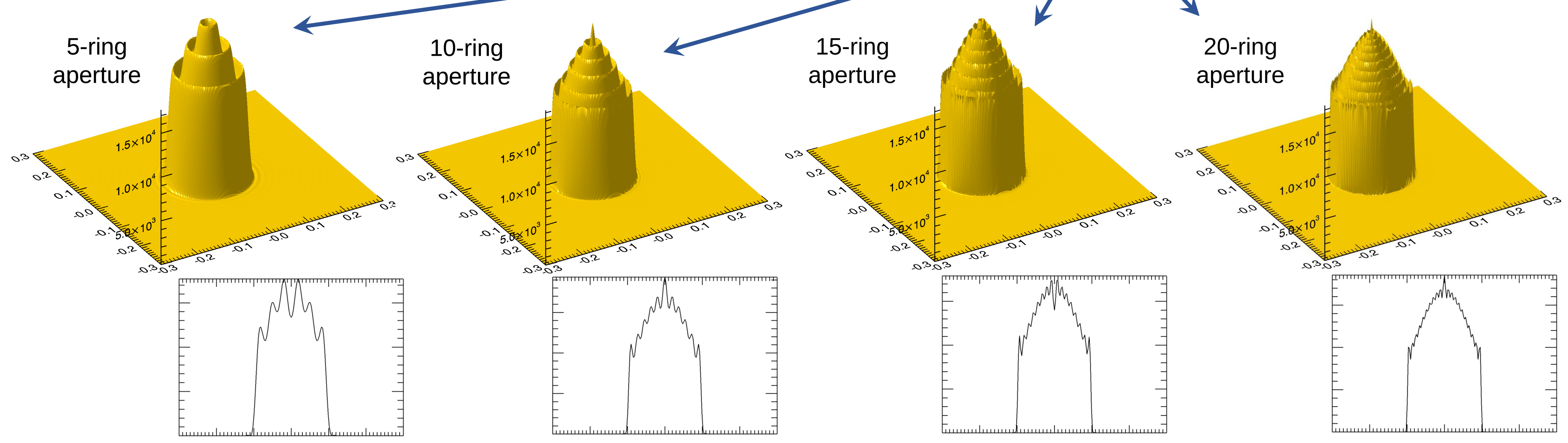


Synthesised Top Hat profile with 5, 10 and 50 harmonics. All show overshoot and ringing. This remains until an infinite number of harmonics is included.

Propagation results with a symmetric aperture

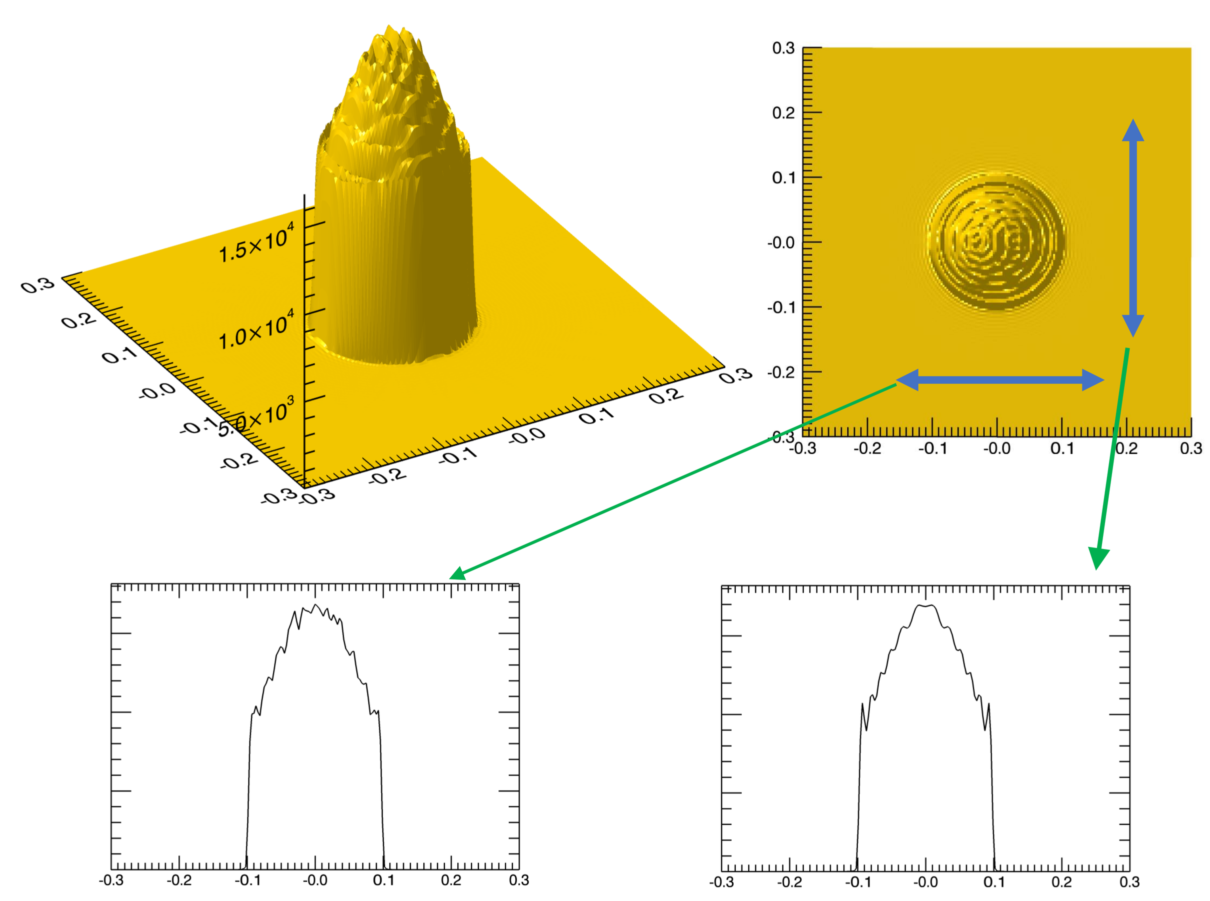
- Start: 0.2 mm FWHM truncated Gaussian
- Propagate 200mm, the Airy-like profile is shown
- Cut with apertures at 5, 10, 15 & 20 rings
- All apertures transmit >99.8%
- Reverse propagate 200 mm; results below
- The number of rings in the image correlates to the number of rings inside the truncation





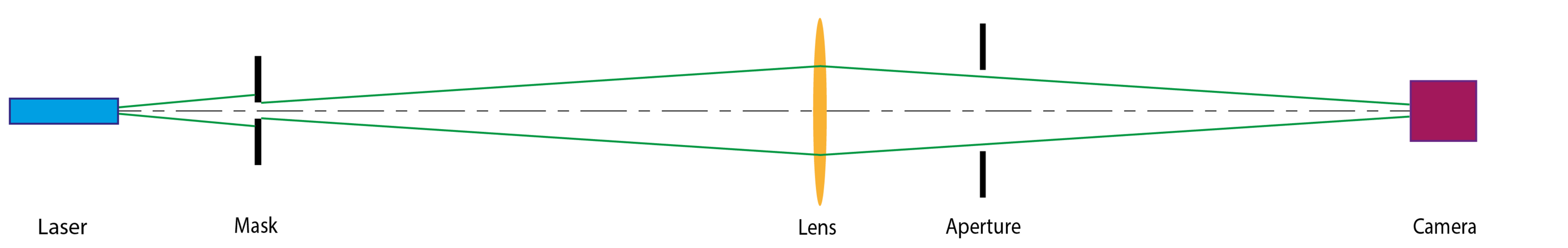
Asymmetric apertures

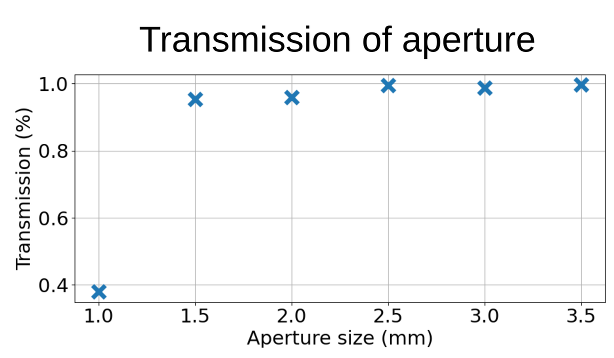
When a laser is injected into a photoinjector gun, the beam is not centred in the gun apertures. The impact on the final laser profile is more complicated. This example show the '15-ring' aperture offset to truncate at '5 rings' on one side.

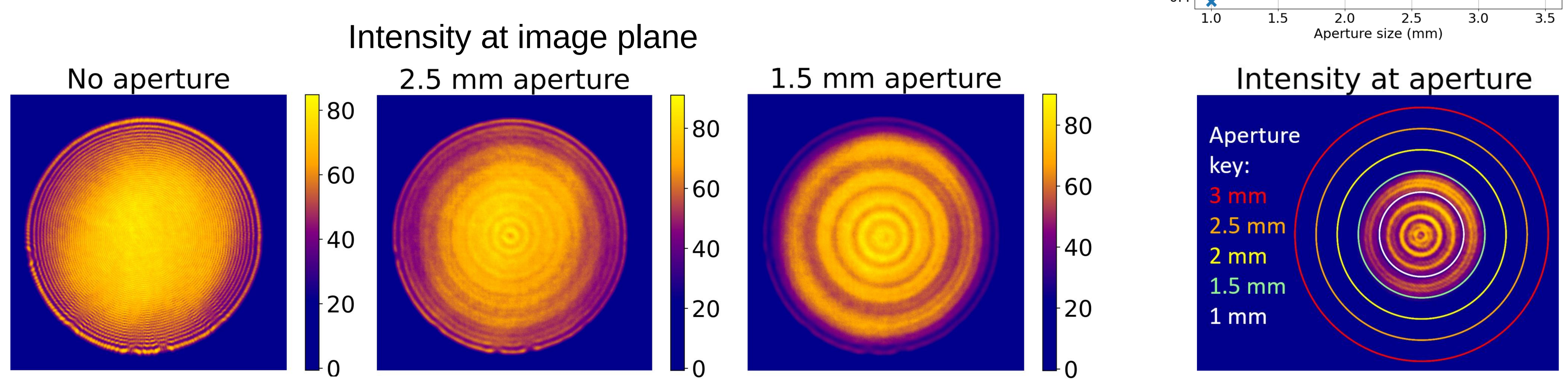


Practical demonstration

The figure shows a simple experiment using a diode laser, circular mask (1.5 mm diameter), relay imaging lens (150 mm focal length) and camera to record the image of the mask. The beam is apertured between the lens and camera. This system is not in the far-field, so we don't have an Airy disc at the aperture plane. We do see the rings in the final image even when the aperture transmits effectively all the light intensity. We also see rings with 'no aperture' because the lens has a finite aperture (25 mm diameter).







Summary

- A laser beam profile with a perfectly sharp edge cannot be generated through relay imaging an illuminated mask.
- Transport apertures will add additional structure to the beam.
- Even when an aperture transmits effectively 100%, the image is still affected.
- Laser injection into photo-injectors frequently requires passing the laser close to the edge of apertures and there will be an asymmetric impact on the laser beam.
- Virtual Cathode monitors should include any apertures in the path to the actual cathode to accurately record the beam on the cathode.

We have shown that relay imaging an illuminated mask will never give a perfect replica of the beam at the mask position. In the context of photoinjectors, do the imperfections impact on the e-beam quality? We are starting simulations to answer this question.
We welcome your feedback on this work.