Gaussian to Super-Gaussian Diffractive Optical Elements

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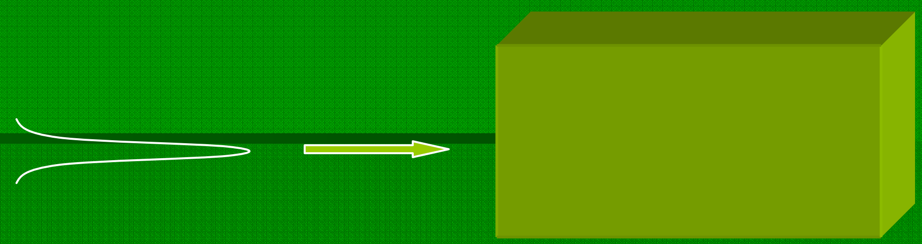
Introduction

- Goals:
  - Laser beam shaping for increased power extraction from slab amplifiers in master oscillator power amplifier systems
    - Gaussian to super-Gaussian conversion to extract more power from wings of beam
    - Gaussian to super-Gaussian conversion to allow larger beams while still avoiding clipping (steeper roll-off)
  - Future LIGO arms may contain resonant mesa beams.
    - Top-hat beam will be more efficient in stimulating this mode

Beam Shaping Problem

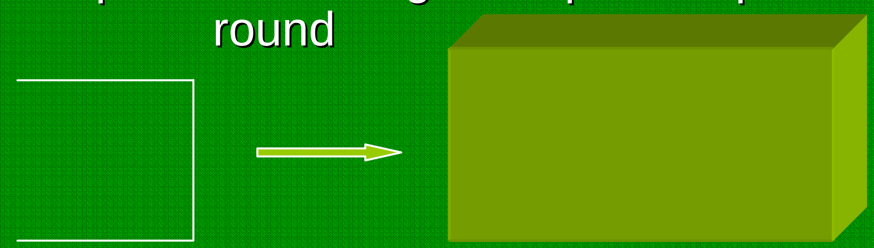
Input to amplifiers is, at the moment, gaussian

- Diffraction limits size of beam
  - Larger beams cause ringing in the output
- Small beam size means that only power from center of slab is extracted

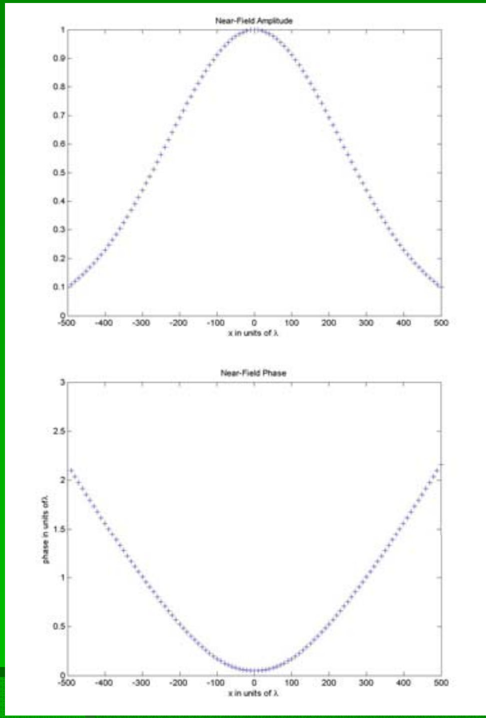


Top Hat beam would fill a larger portion of the slab, extracting power from the outside portion of the slab

- Slabs are rectangular—a square or rectangular top-hat is preferred over round

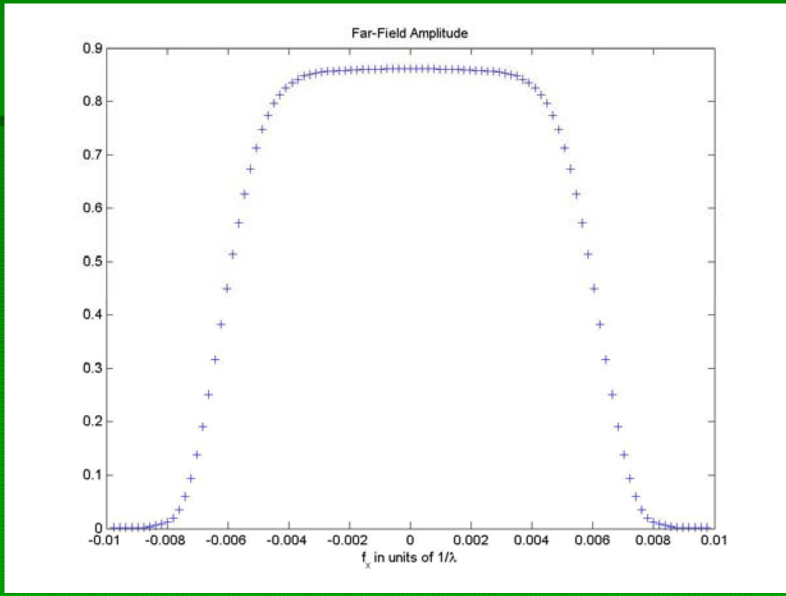


Computing the Required Phase Profile



Amp

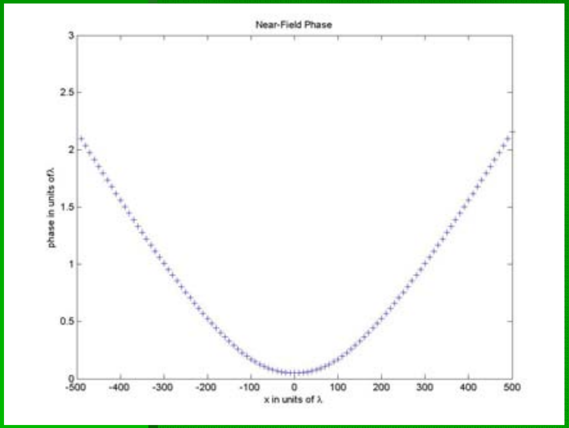
Phase



The Gerchberg-Saxton algorithm was used to compute the phase that, when applied to a Gaussian, yields a 7th-order super-Gaussian in the fourier domain.

Computing the Required Phase Profile (2)

- The phase on the last slide will take a Gaussian and turn it into a super-Gaussian in the far-field.



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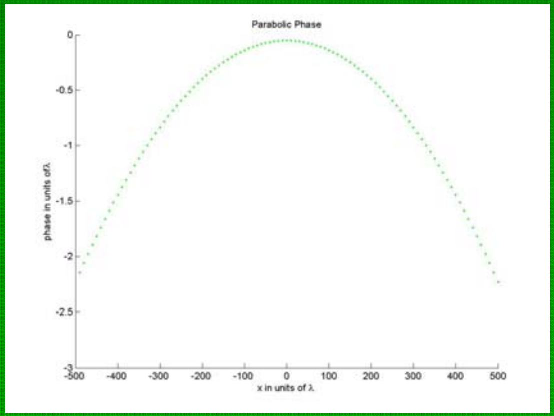

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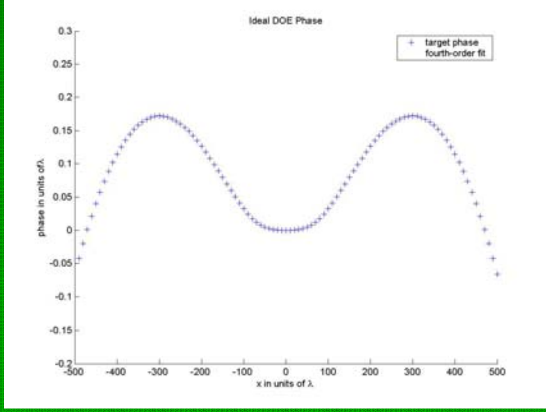
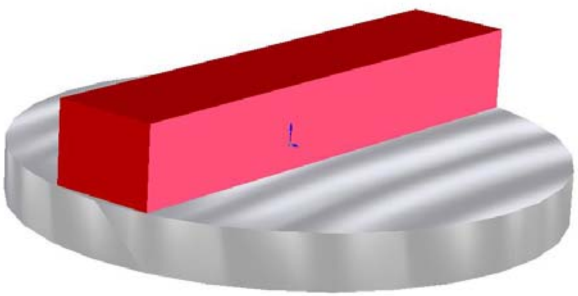


Phase from Gerchberg-Saxton + converging lens = ideal DOE phase
ie, the DOE contains the near-field phase and a converging lens which will create an FT plane

Changing the x-scaling of the near-field phase changes the x-scaling of the supergaussian (they are inversely related). Changing the power of the lens changes the location of the fourier plane. These two variables create a two-dimensional space of possible ideal DOE phases.

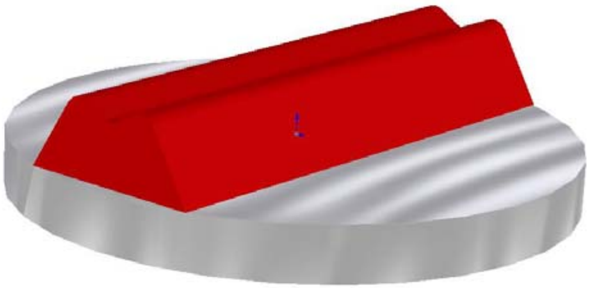
Fabrication

Photoresist is patterned using standard photolithography.



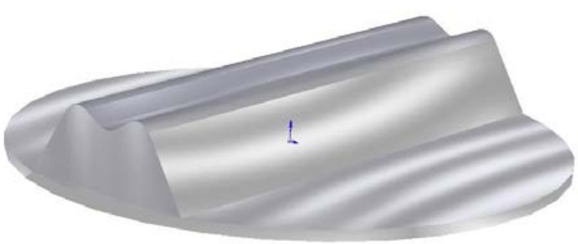
Acetone vapor

After a short exposure to acetone, the photoresist reflows.



Plasma etch

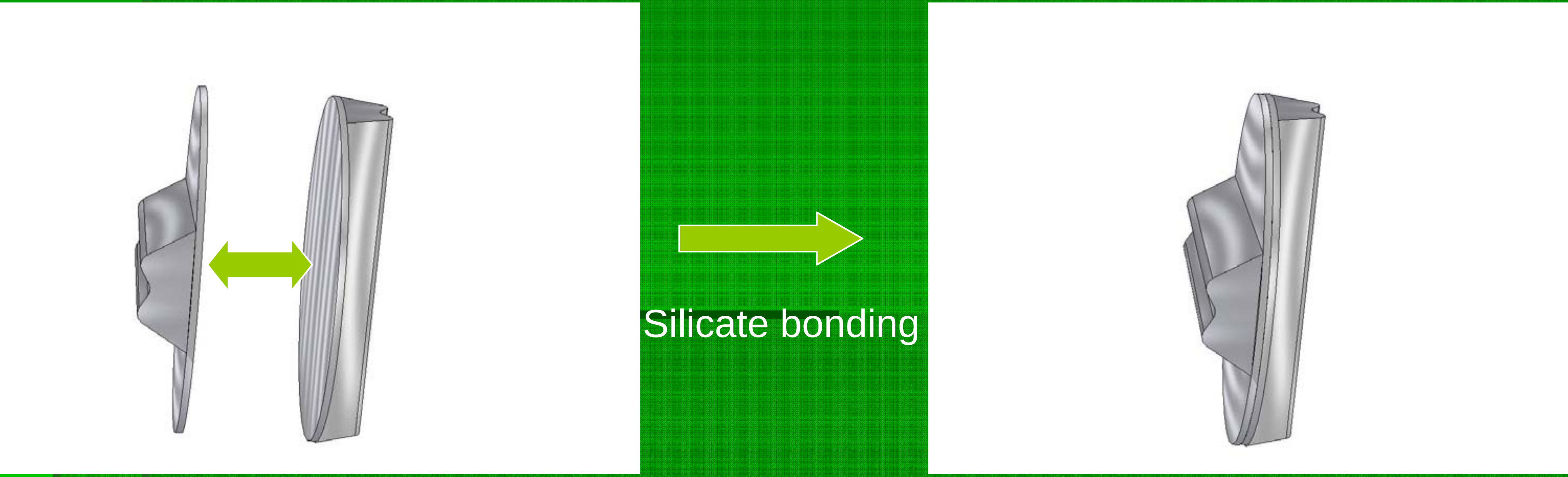
The shape of the photoresist is transferred to the quartz substrate with a CF_4 and O_2 plasma etch.



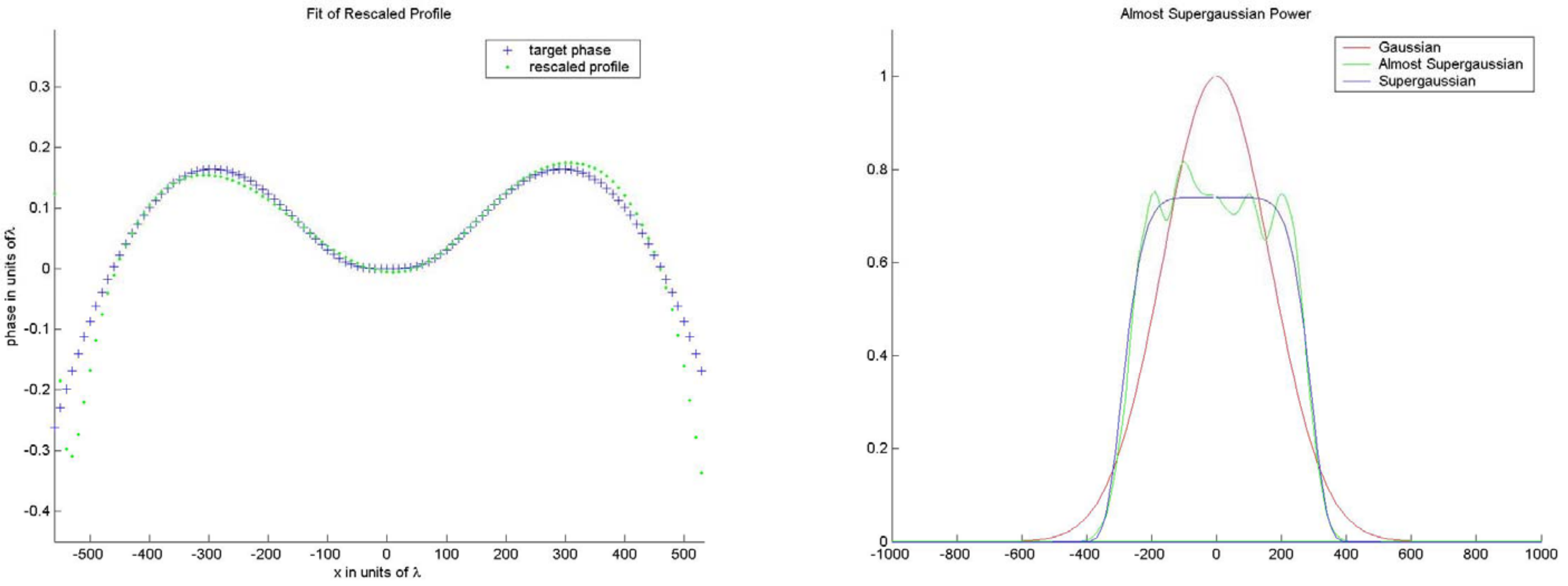
Two types of DOEs were fabricated: those that convert on ONE axis, and those that convert on BOTH axes. This picture shows the linear DOEs.

Fabrication (2)

- For the linear DOEs, two back-to-back optics, orthogonal to each other, are required for conversion on both the x- and y-axes, creating square supergaussian

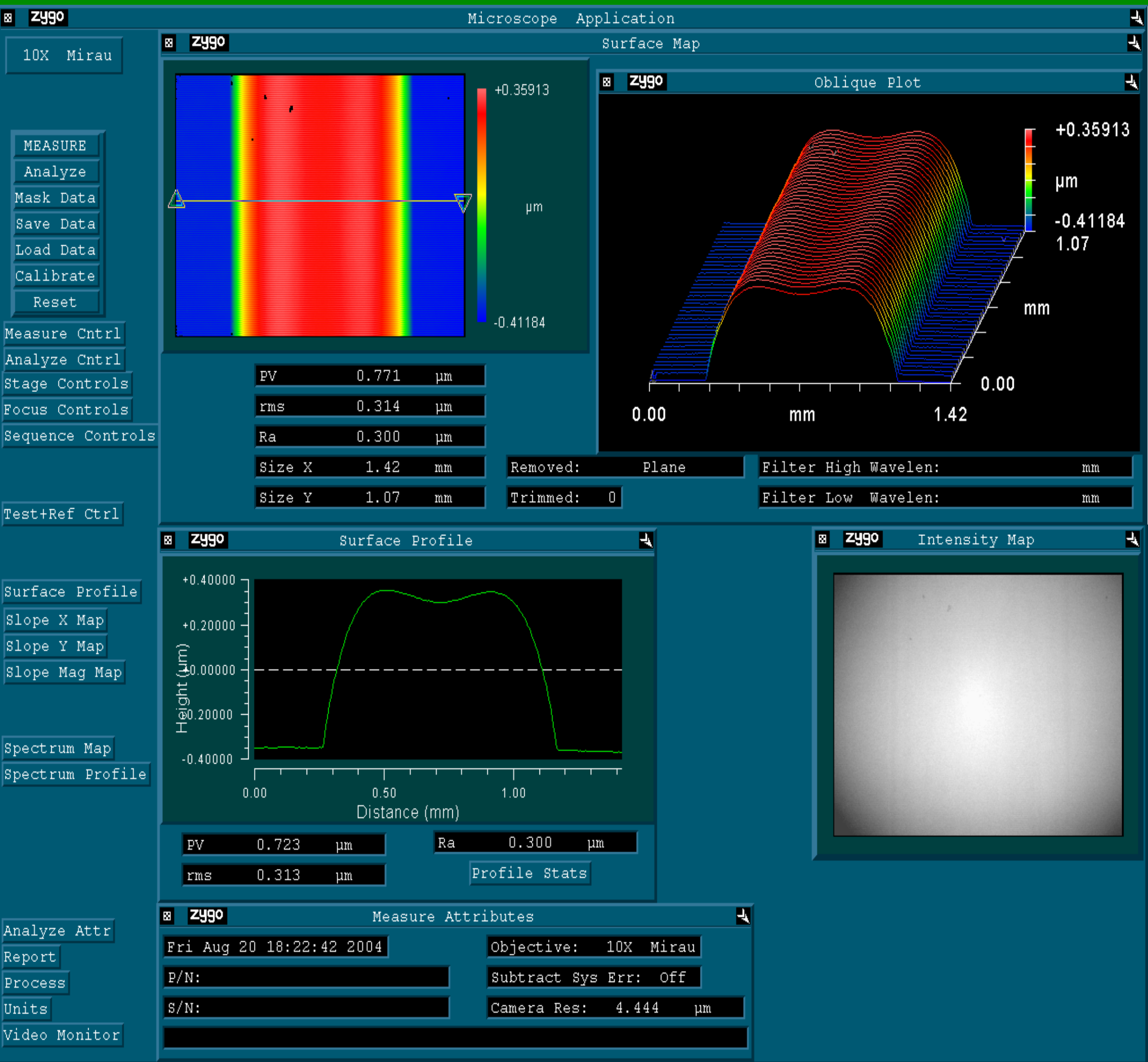


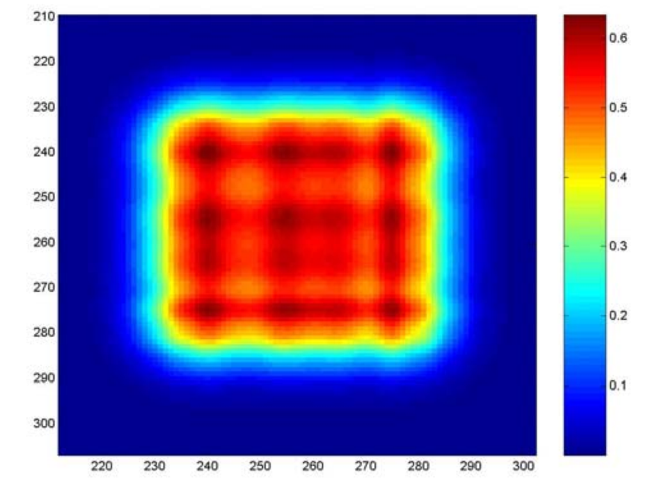
Results for Linear DOE's



- Measured 1-D profile and simulated results

Zygo Measurements + Simulation of Linear DOE's

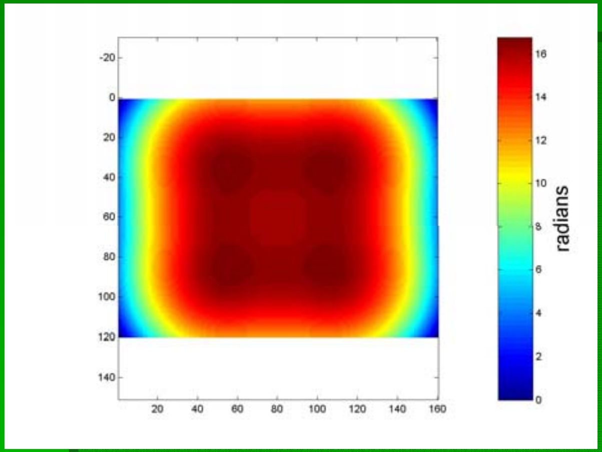




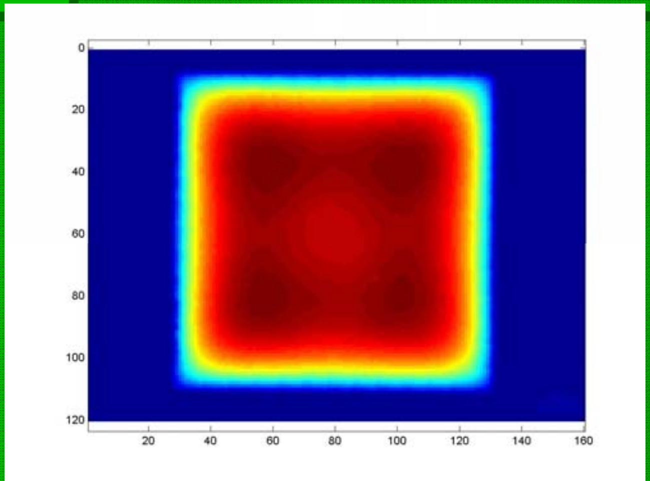
- Simulation of having profile in both 'x' and 'y'
- 5% rms variation in "flat-top" portion
- Physical realization requires two DOE's, one 'x', one for 'y'

Square DOE’s

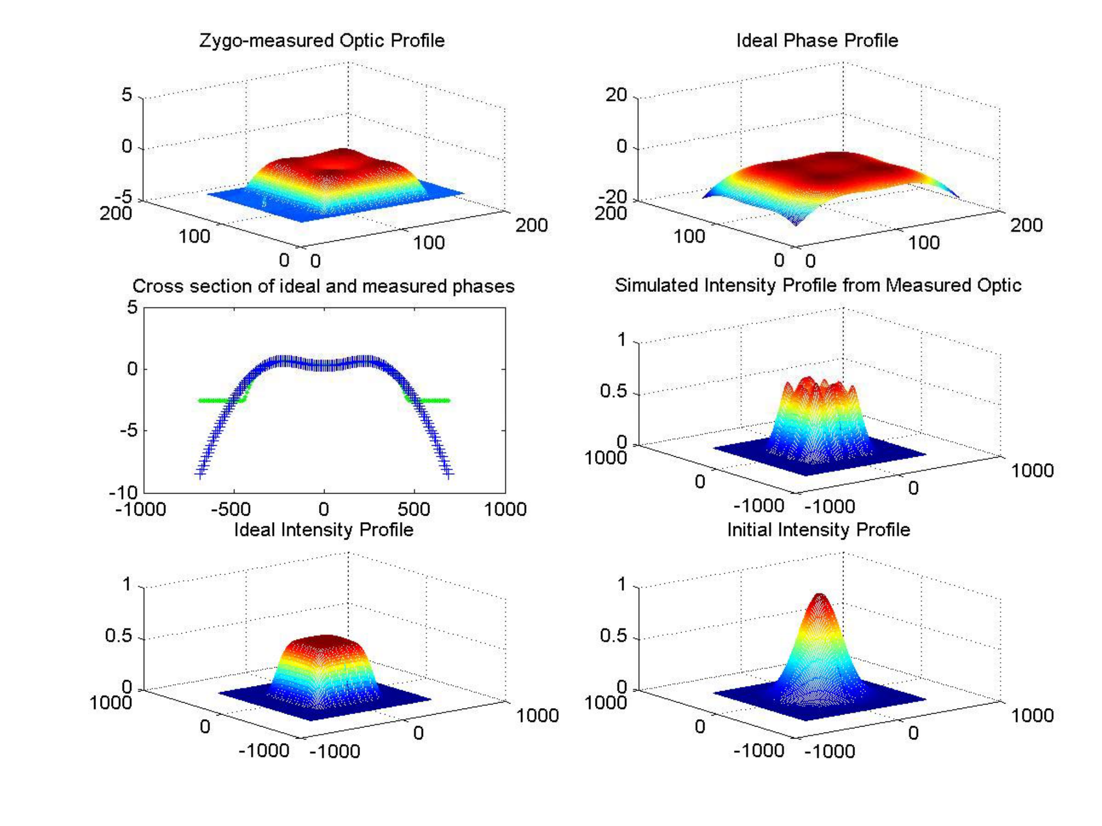
Desired Phase



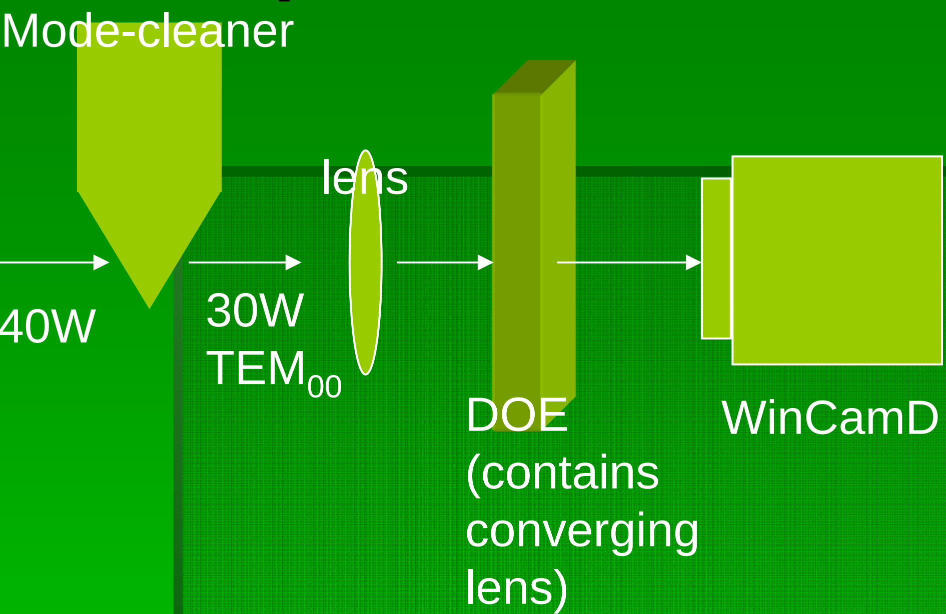
Measured Optic
(using Zygo)

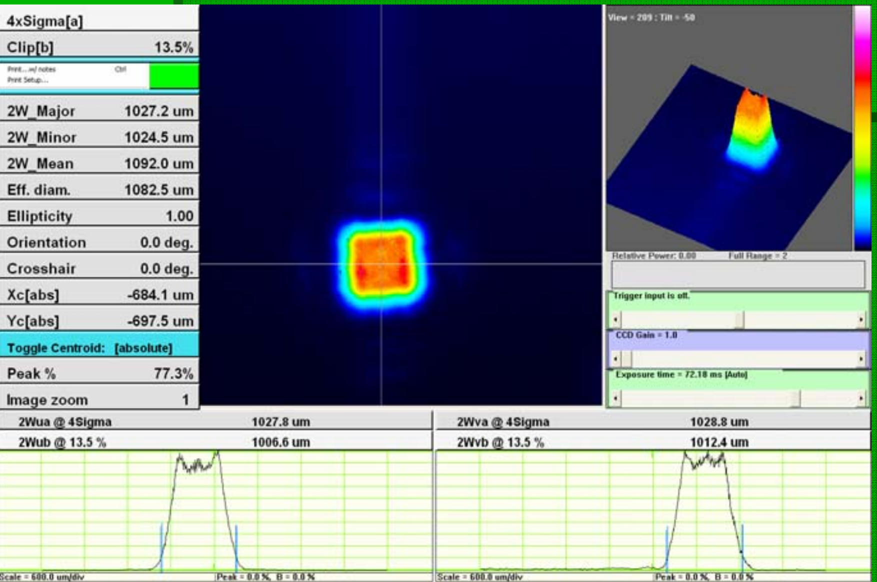


Simulation Results



Experimental

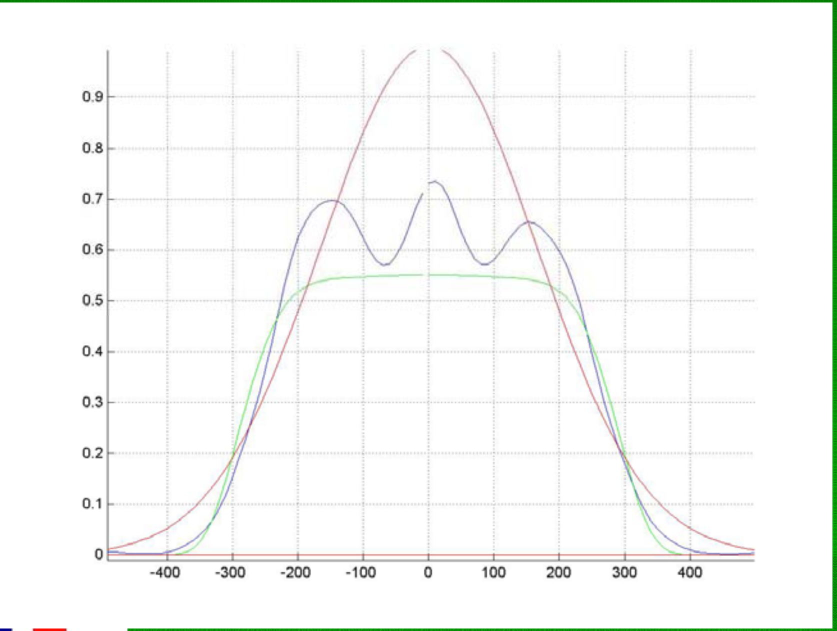


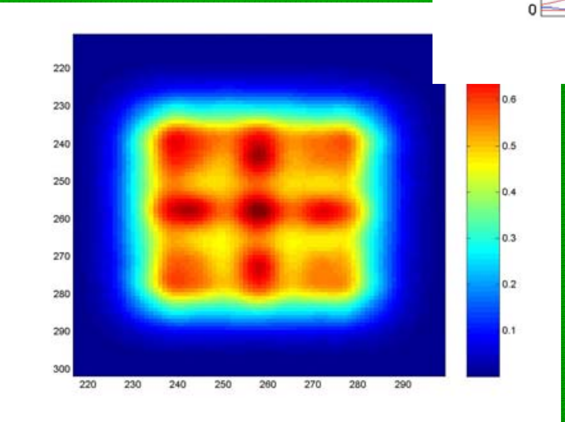


- Beam size (roughly 700 to 800 microns)
- DOE contains a built-in converging lens
- External lens and built-in lens determine location of fourier plane
- Camera needs to be placed at fourier plane

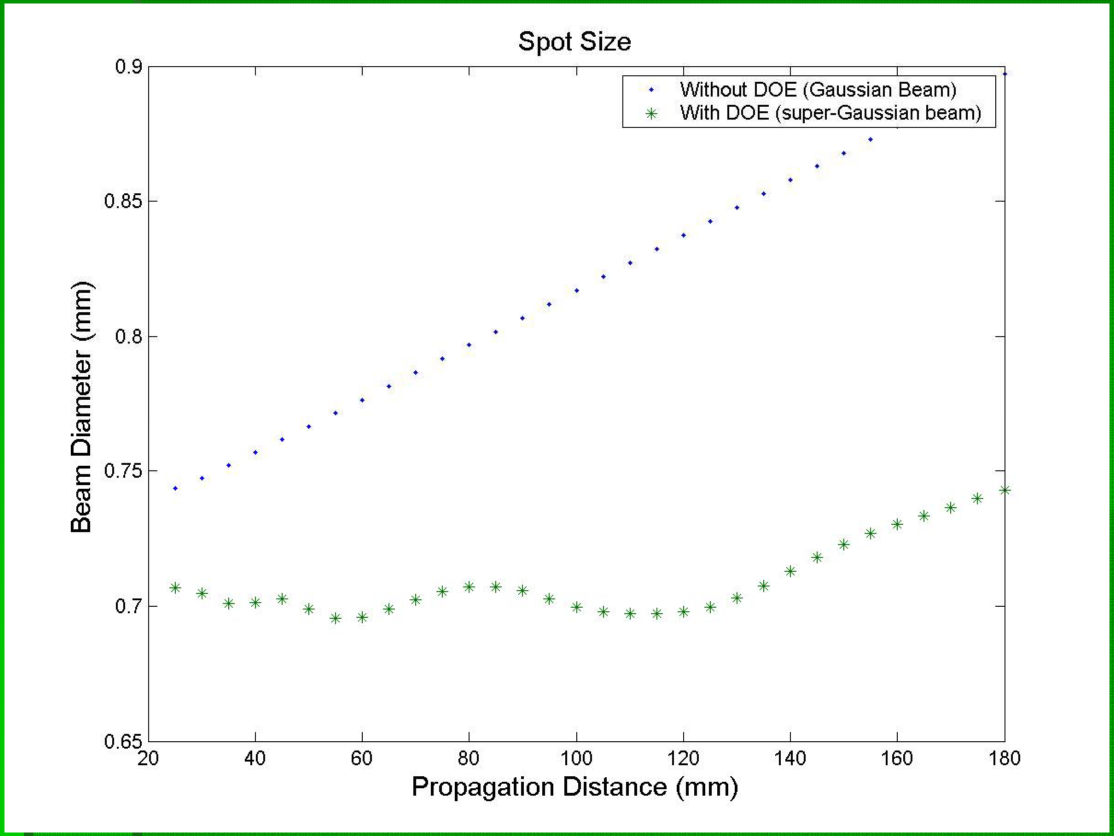
Square DOE – Flatness

- Simulations of measured DOE show an rms deviation of 11% in the top-hat portion of the beam.
- Rolls off as fast as the supergaussian—it can be used to fill a slab amp
- Saturated amplifier will reduce ripples



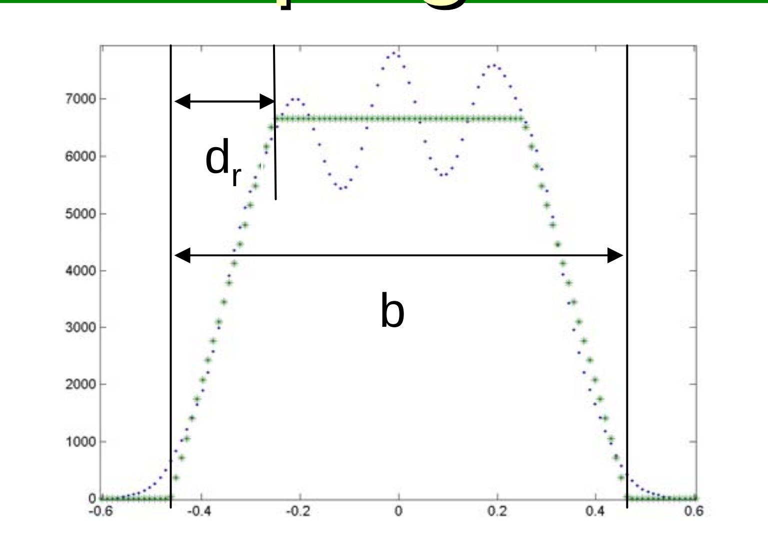


Spot Size vs. Propagation for Collimated Output

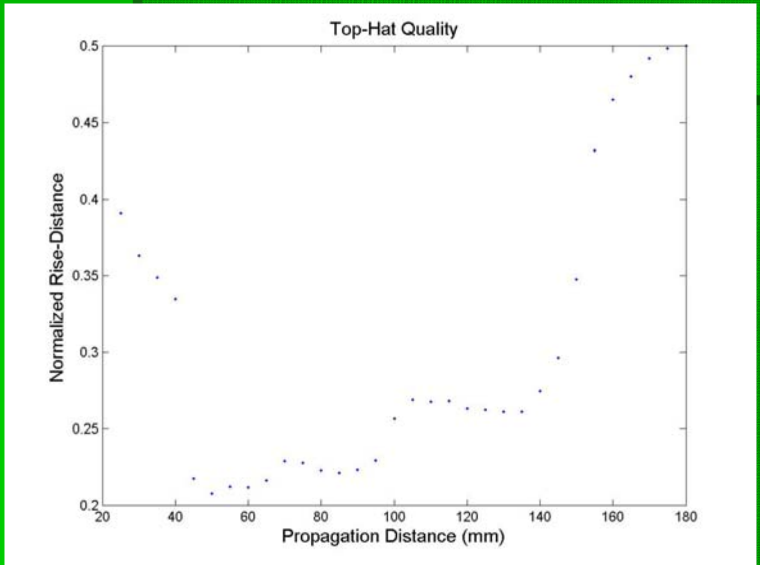


- Curvature of incident Gaussian (750mm ROC) has been adjusted to provide collimated ouput

Top-Hat Quality vs. Propagation



Normalized rise-distance = d_r/b



- Figure of merit: normalized rise-distance (derived from the trapezoidal approximation)
- From 45mm to 95mm the beam profile is a viable top-hat
- Target slab has an effective length of 6cm/1.82 = 3.3cm

Future Work

- Make better diffractive optical elements
  - Customize the size of the optic for Shally's amplifier (.9mm x 1.11mm). Consider making asymmetrical DOEs
  - Achieve a more accurate profile with squareish DOEs.
- Create an optic which will convert back from the super-Gaussian profile.
- Experiment with an available amplifier to show improved extraction.

Conclusions

- DOEs have been fabricated which convert 700μm-diameter Gaussian beams into comparable-sized super-Gaussian beams
- The super-Gaussian beams have lateral dimensions which are close to that of slab amplifiers, and retain their top-hat shape for 5cm, which exceeds the effective length of many amplifiers.
- A similar process may yield round top-hat beams which can efficiently stimulate cavities with mexican-hat mirrors.