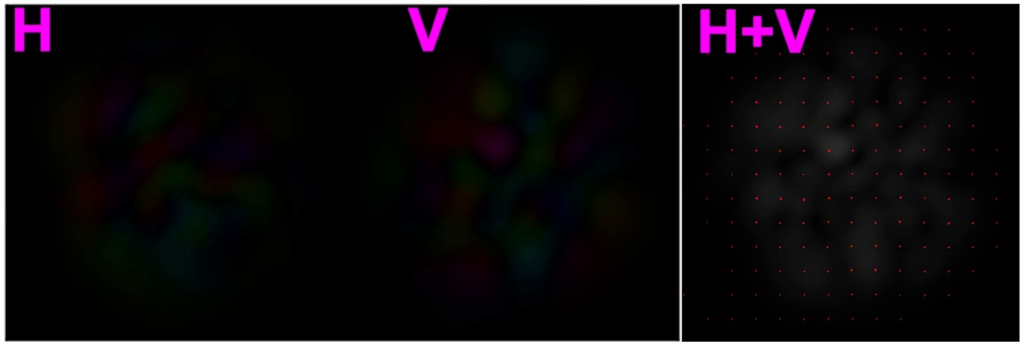
On-The-Fly Calculation of Holographic Masks to Generate Arbitrary Spatiotemporal Beams

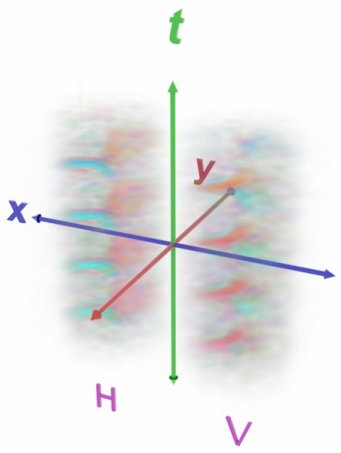
Andrew V. Komonen

Martin Plöschner, Marcos M. Morote, Daniel S. Dahl, Nicolas K. Fontaine, Joel Carpenter and Mickael Mounaix

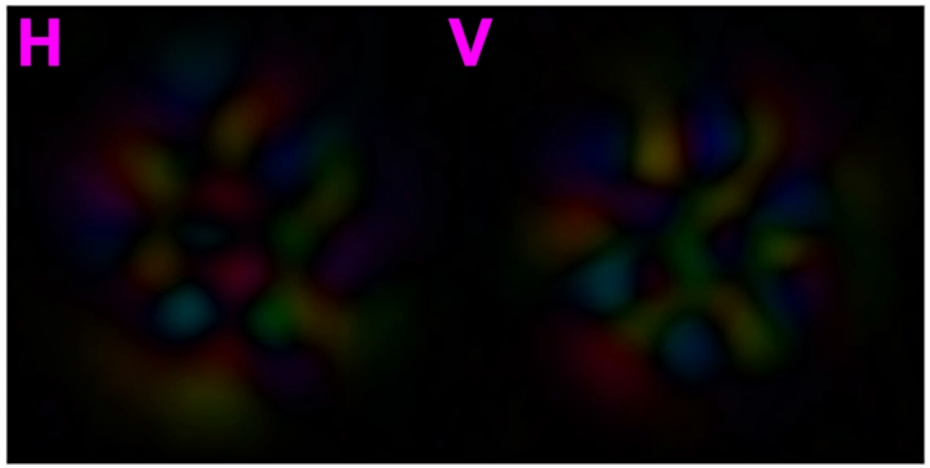
3D Printer of Light Beams

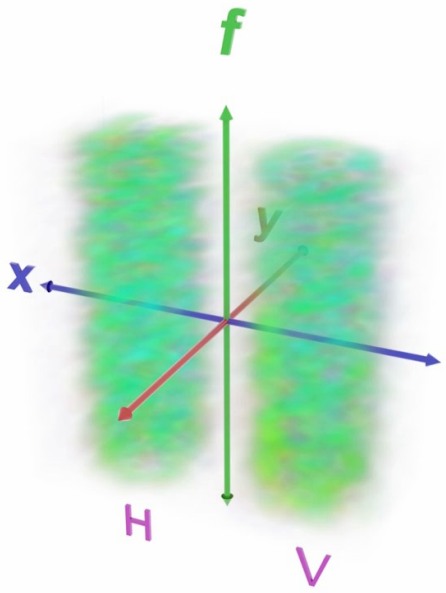
t (ps)= -11.989





λ (nm)=1533.625

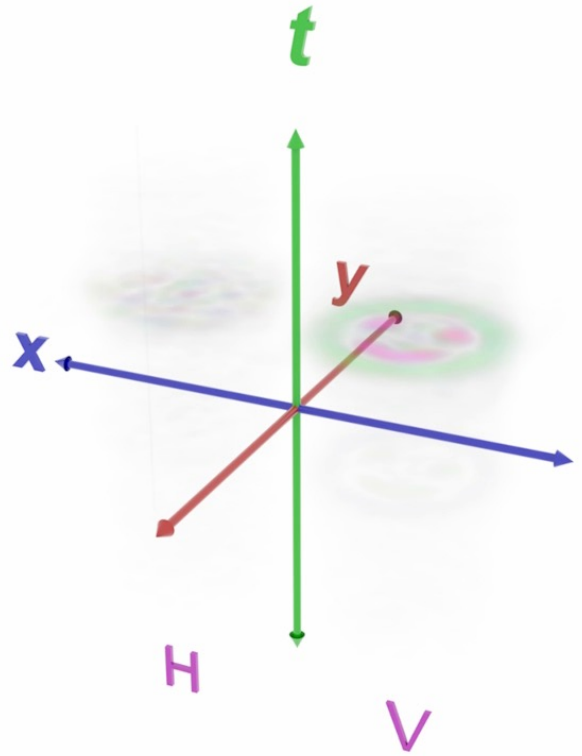




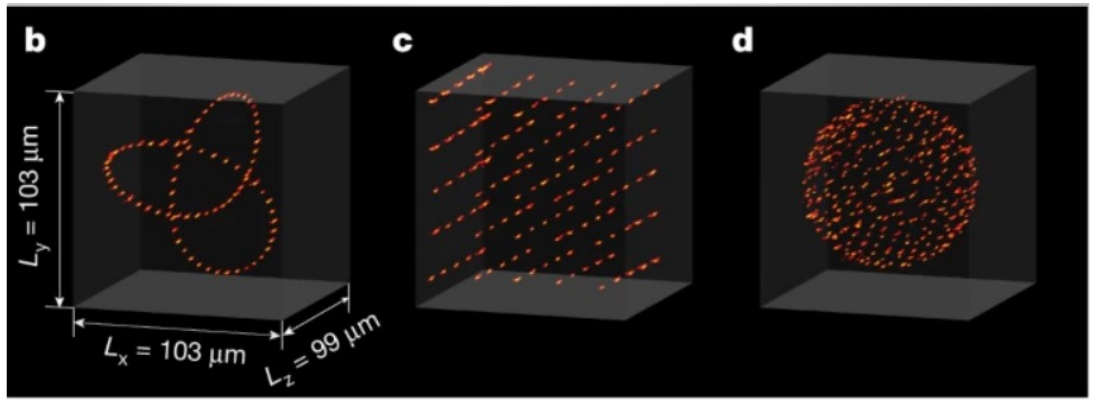
Bandwidth:
36nm @ 1560nm

45 Hermite
Gaussian Modes

450 wavelength/time
steps for each
polarisation

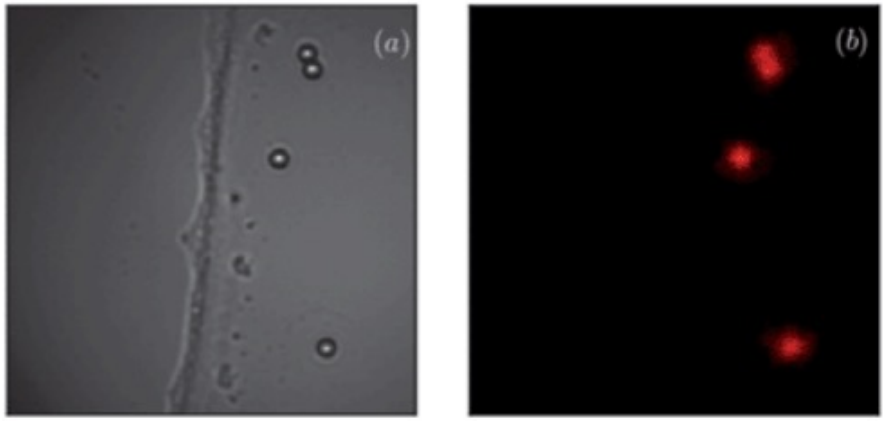


Applications of Time Reversal System



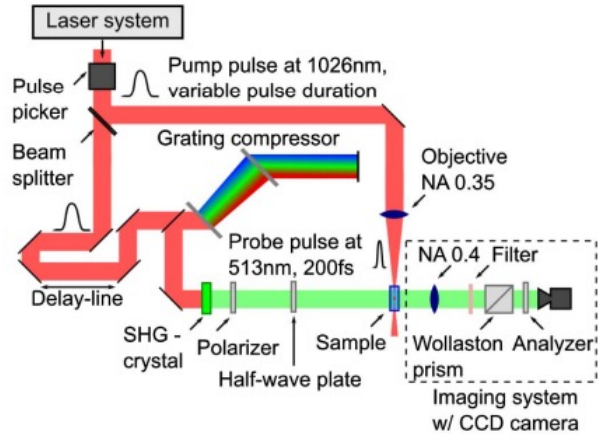
Optical trapping beam shapes

D. Barredo, et al., Nature, Sep. 2018 doi: 10.1038/s41586-018-0450-2.



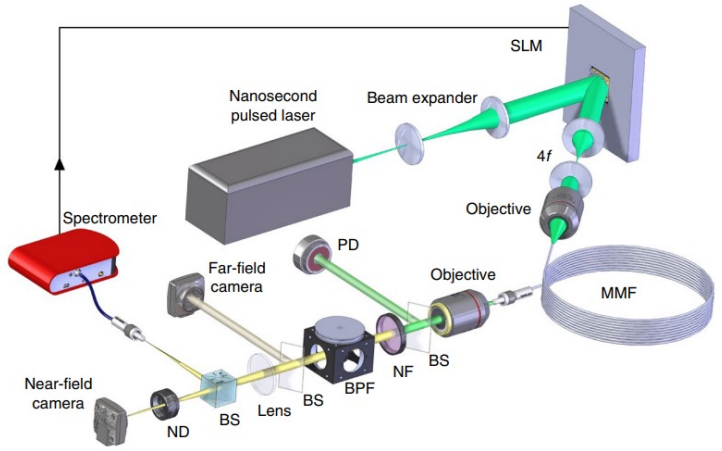
Scanning Florescence microscopy

S. Bianchi, et al., Lab Chip, 2012. doi: 10.1039/C1LC20719A.



Micromachining

K. Bergner, et al., Appl. Opt., Jun. 2018. doi: 10.1364/AO.57.004618.



Nonlinear Interactions

O. Tzang, et al., Nature Photon., 2018. doi: 10.1038/s41566-018-0167-7.

Time Reversal System Setup

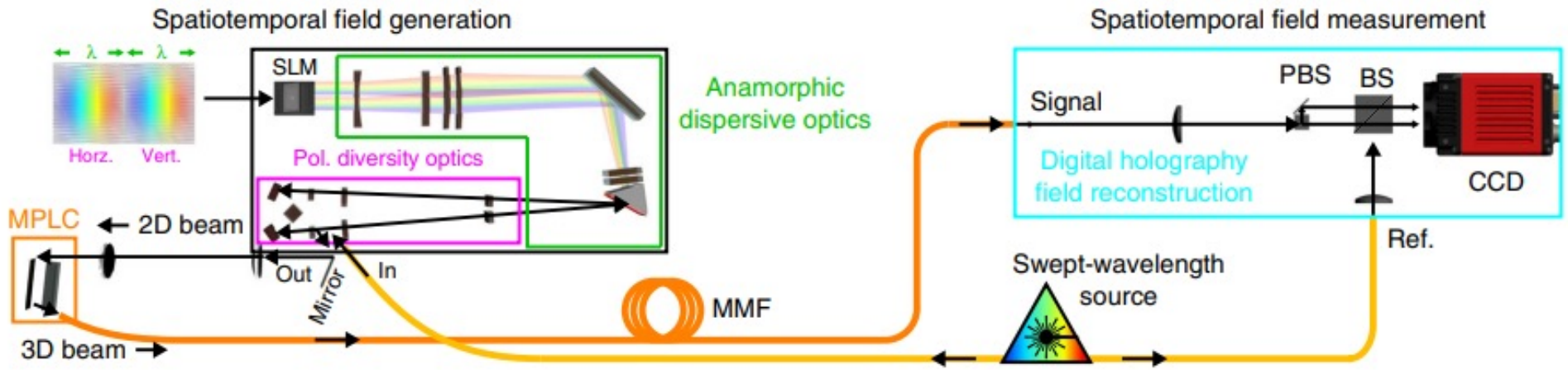
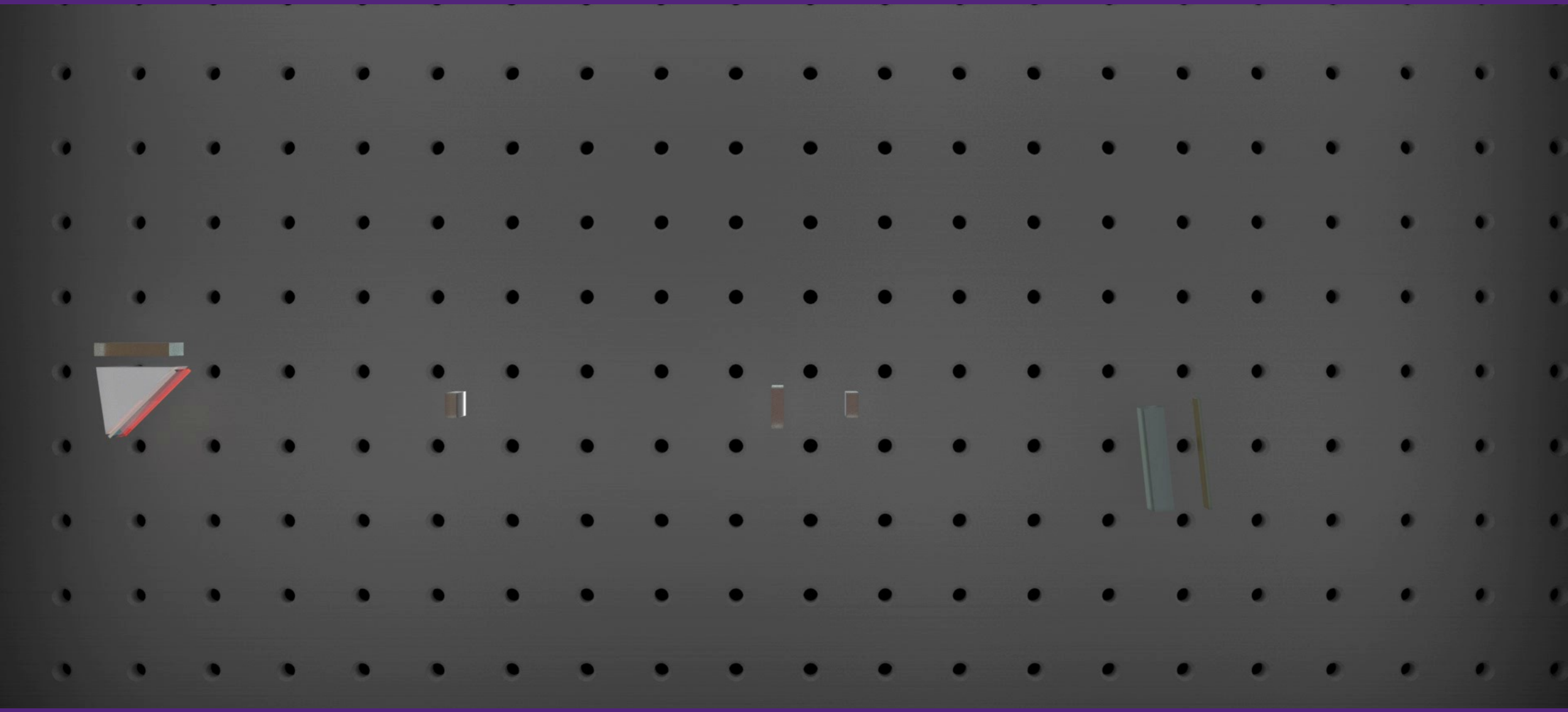
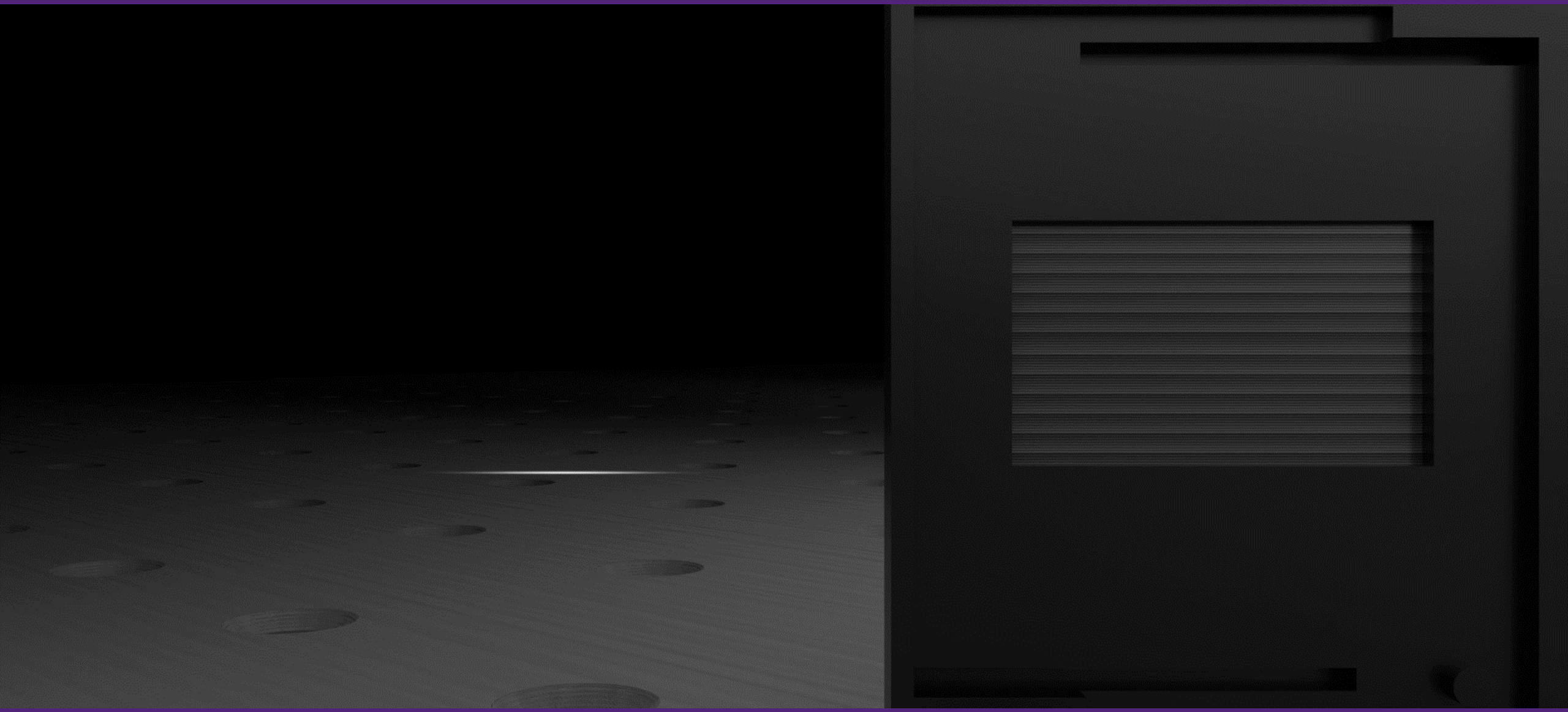


Fig. 2 Schematic of spatiotemporal field generation and characterisation apparatus. A polarisation and spatially resolved spectral pulse shaper for generating arbitrary vector spatiotemporal states, in conjunction with a swept-wavelength digital holography system for characterisation. All characterisation and results are measured in the frequency domain.

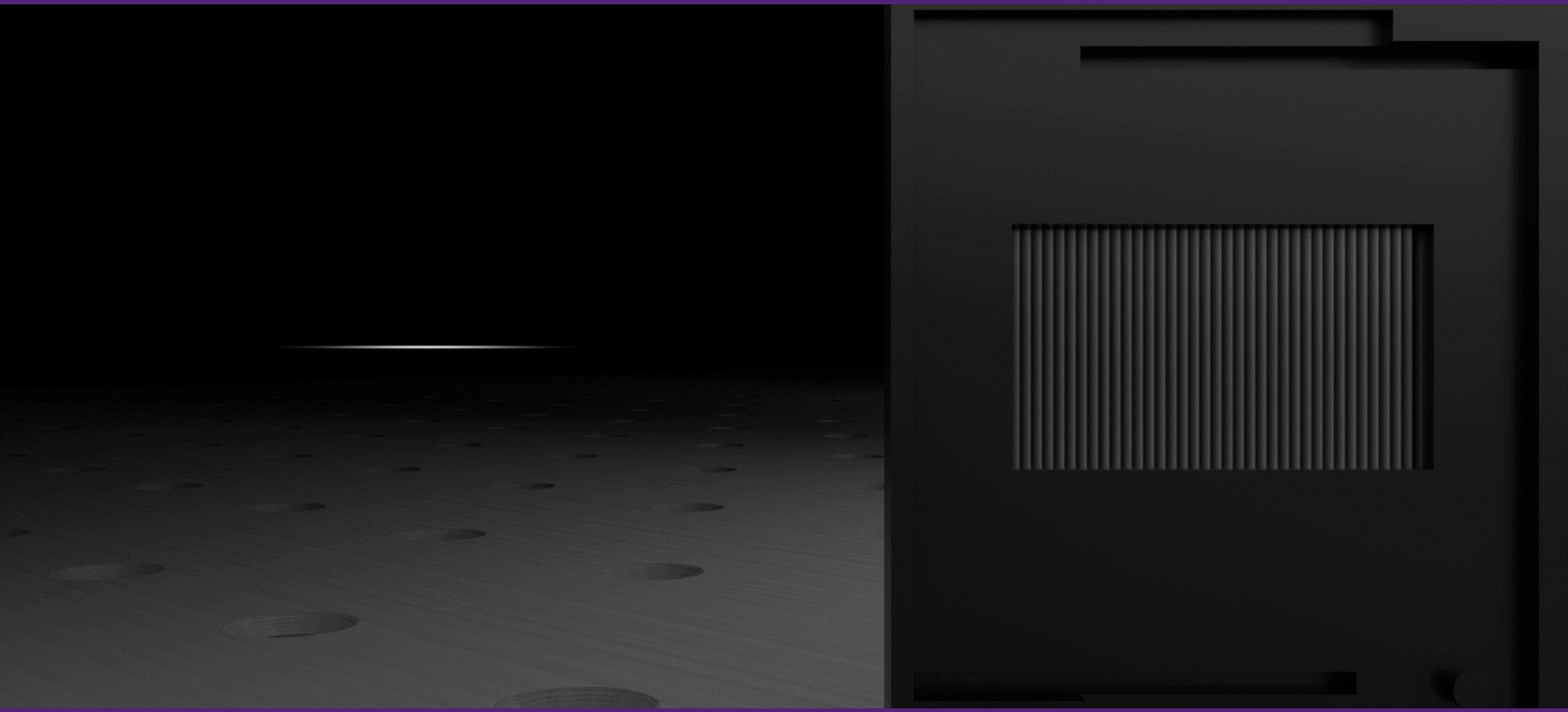
Pulse Shaper Subsystem
Grism



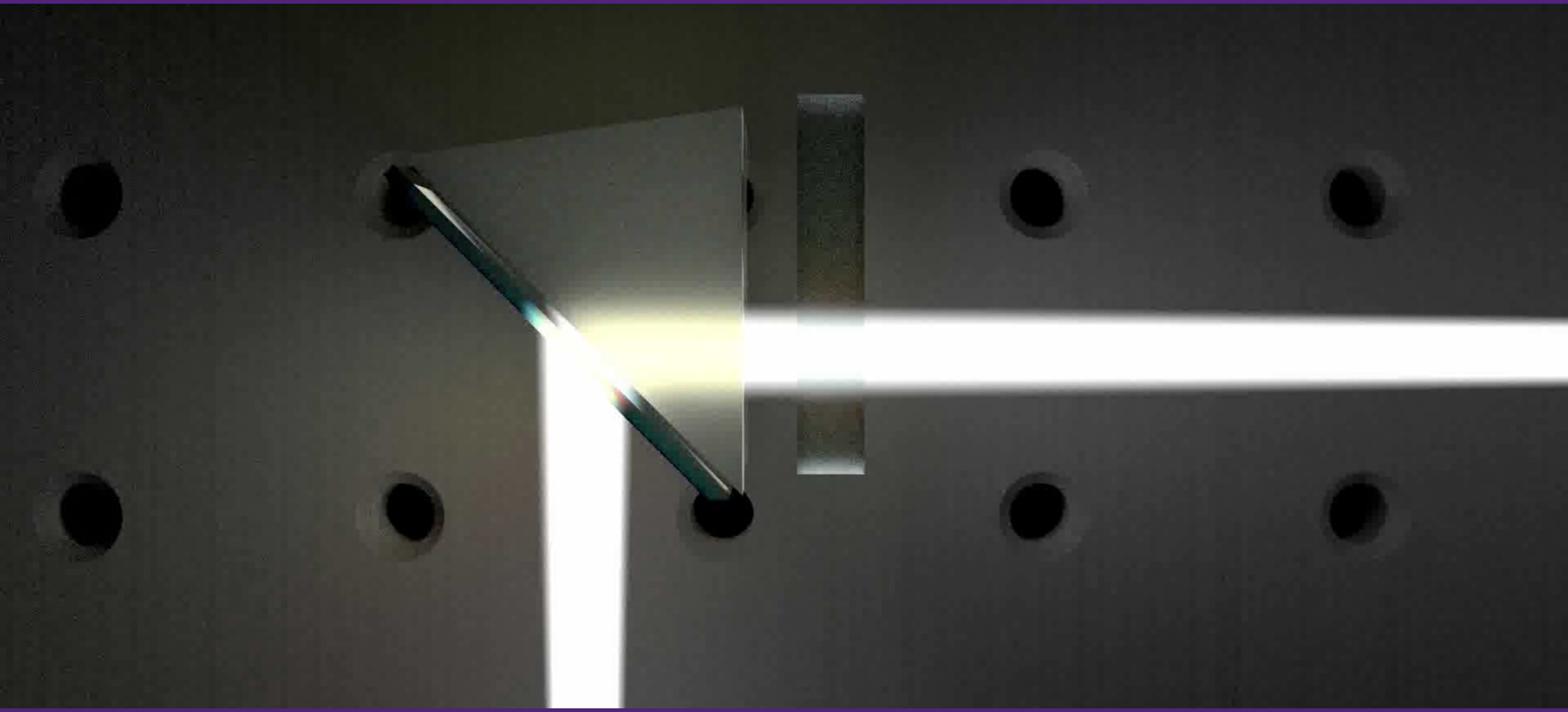
Pulse Shaper Subsystem
SLM Control



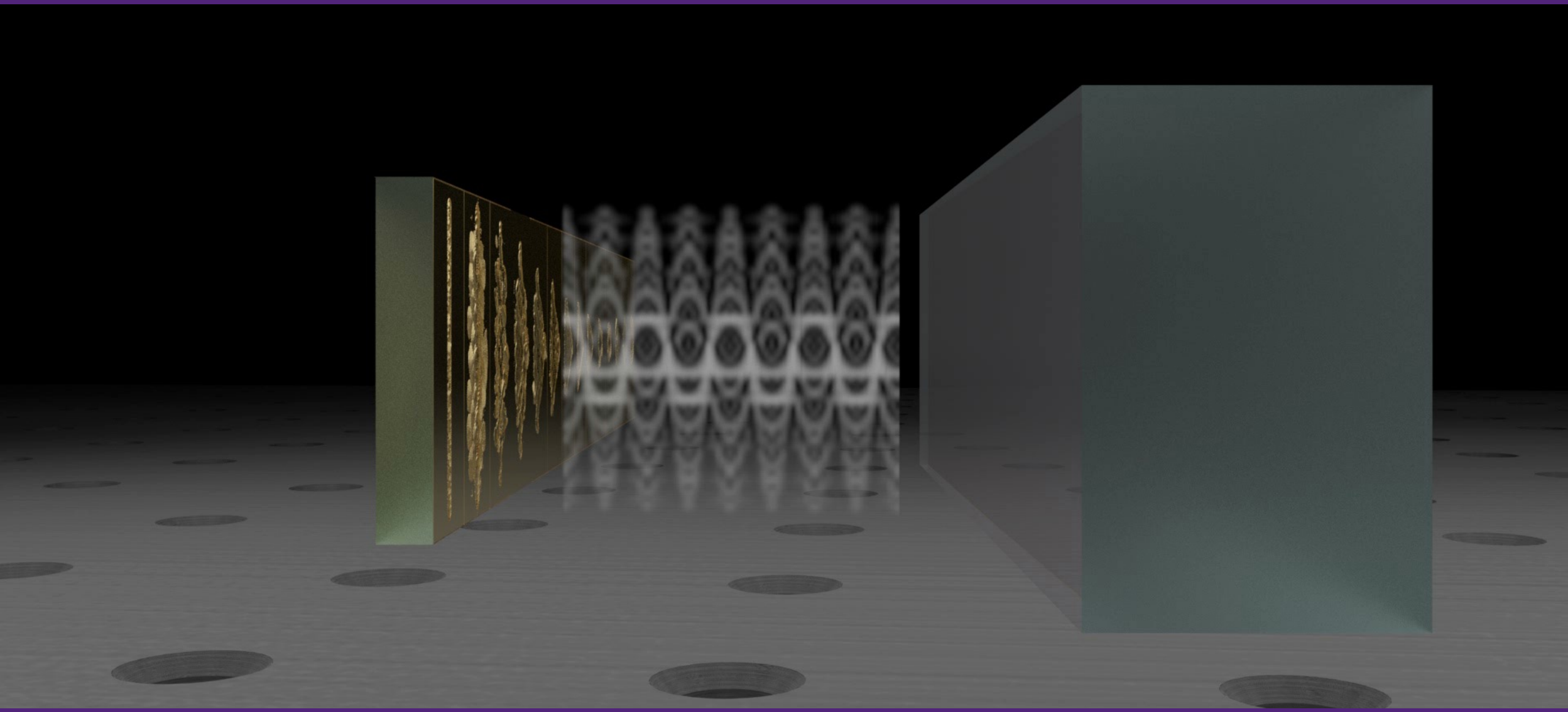
Pulse Shaper Subsystem
SLM Control



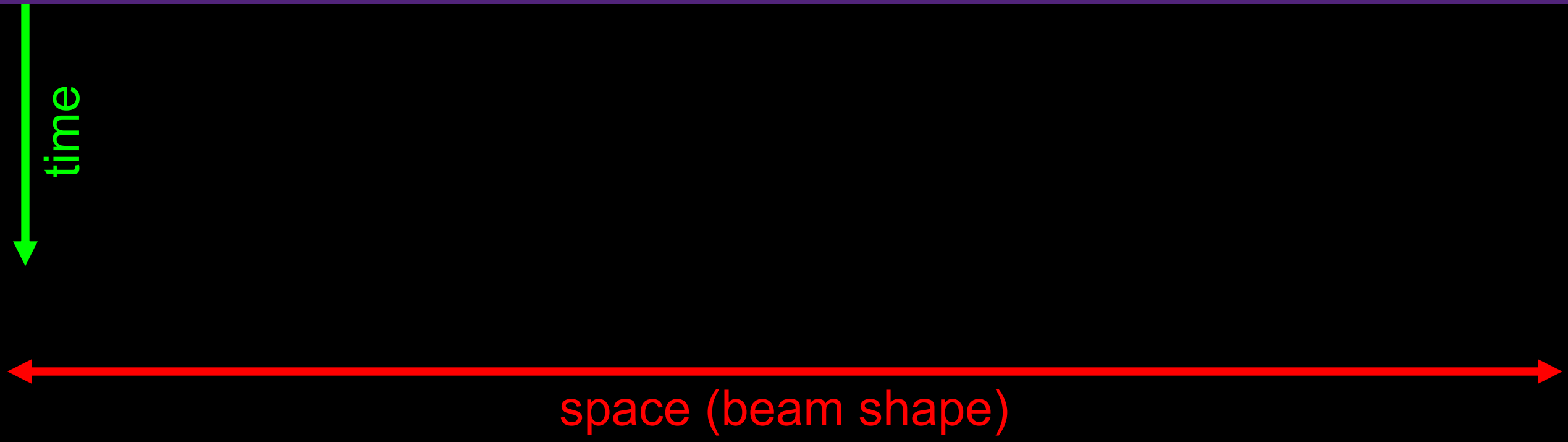
Pulse Shaper Subsystem
Temporal Control (Delay)



MPLC Subsystem

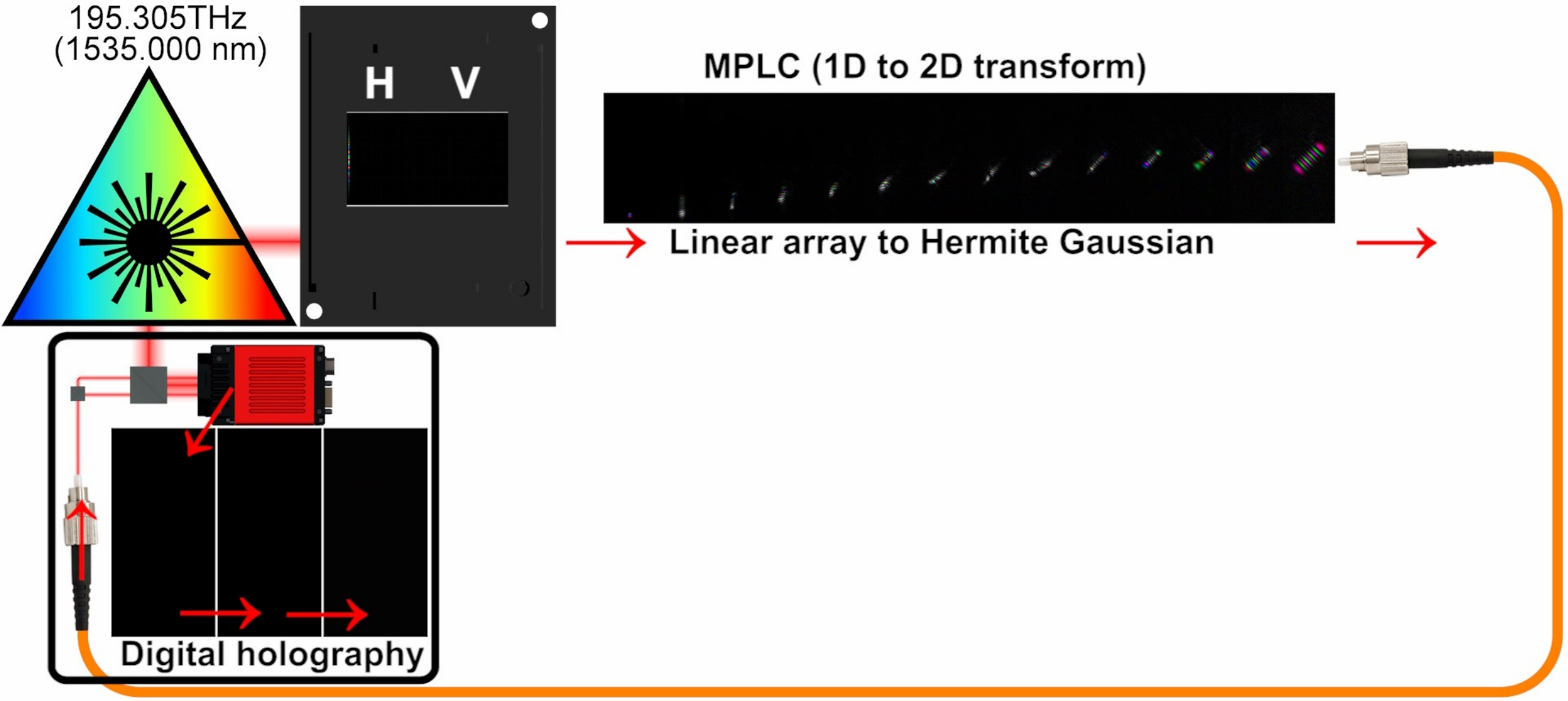


MPLC Subsystem Working Principle



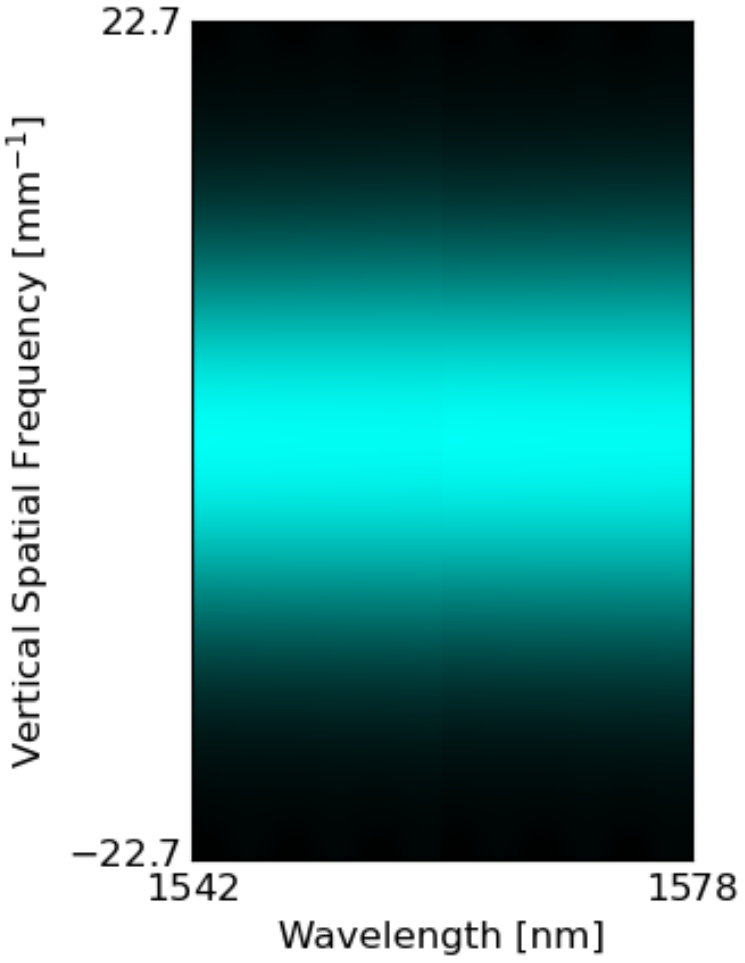
Total beam →

Digital Holography Subsystem



Gerchberg Saxton (GS) Algorithm

SLM Plane
Amplitude defined

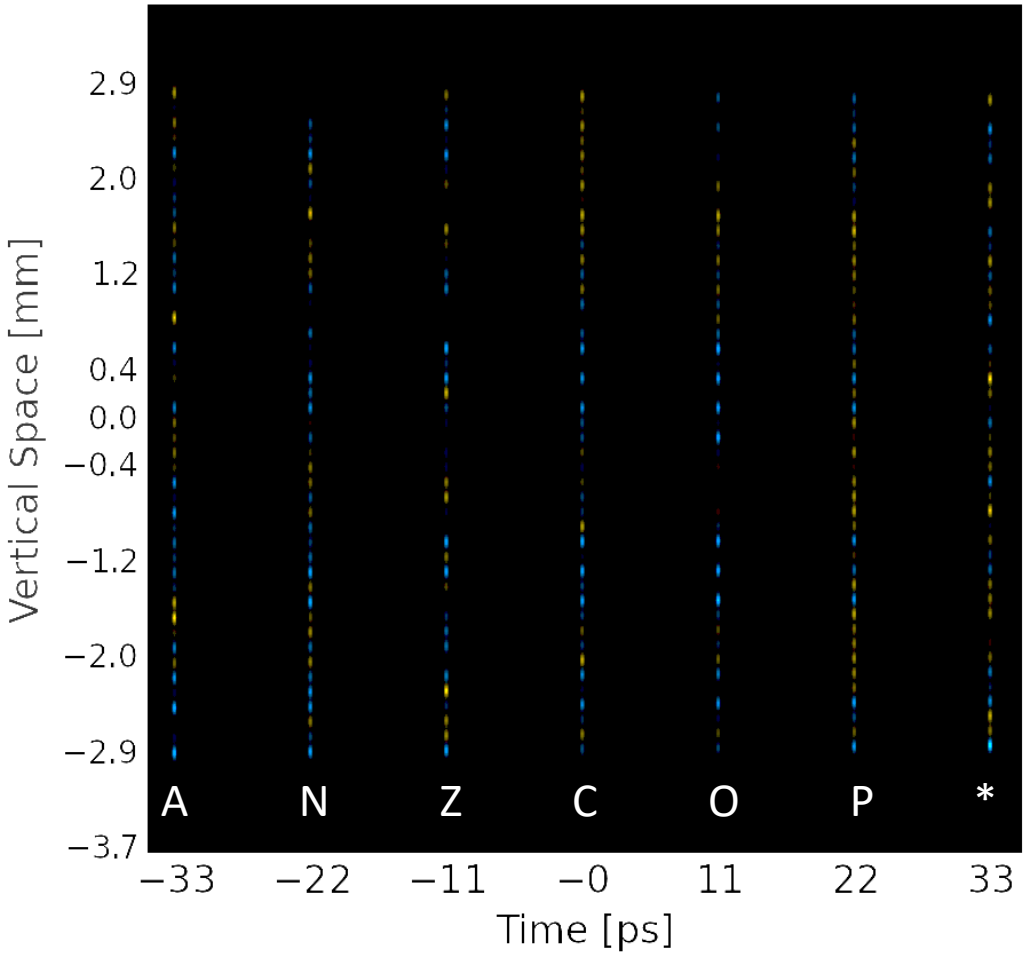


$\mathcal{F}^{-1}(k_y, \lambda)$

Contrast decreased
Brightness increased

$\mathcal{F}(y, t)$

Pulse Shaper Output Plane
Amplitude and Phase defined

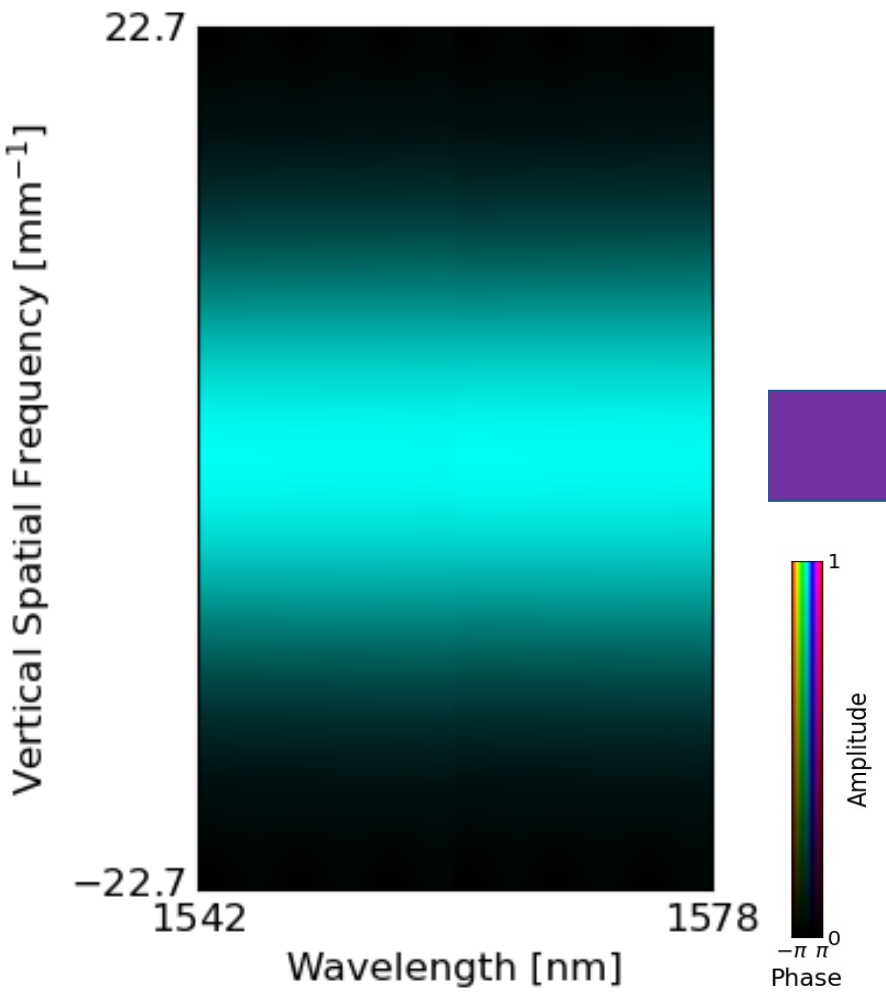


Gerchberg Saxton (GS) Algorithm Phase Mask Generation

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

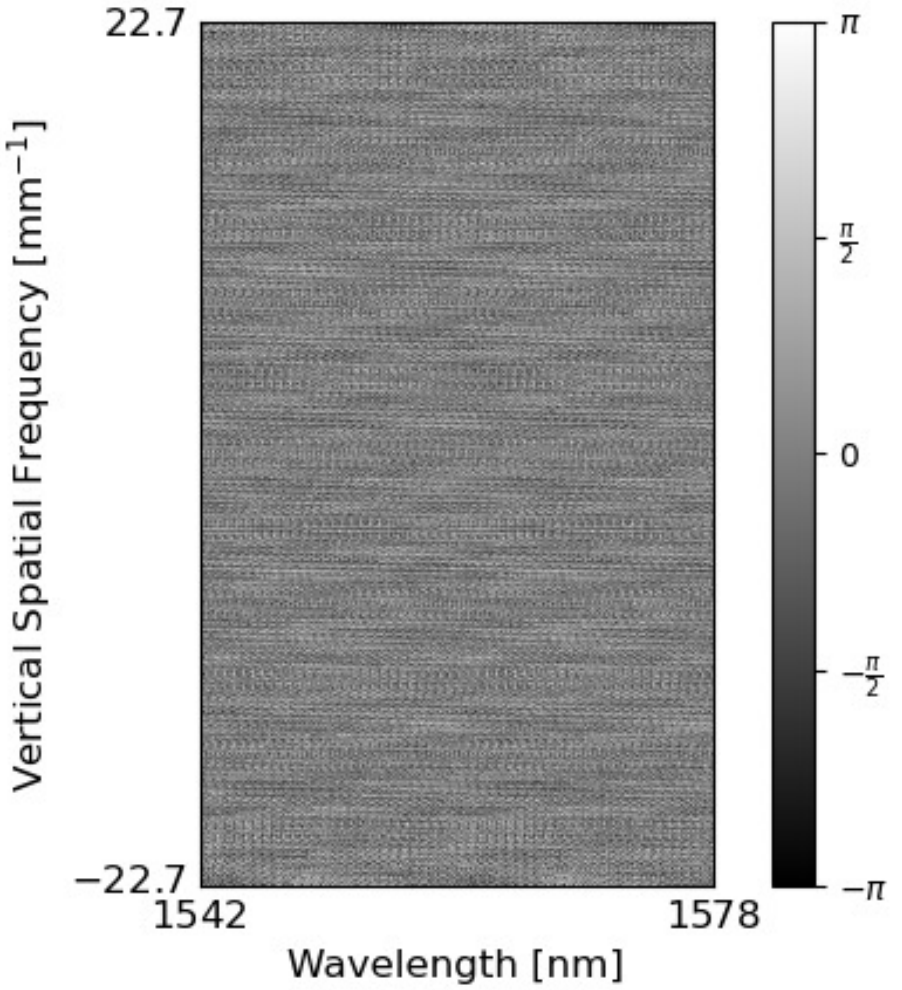
NOKIA Bell Labs

Incoming beam onto SLM

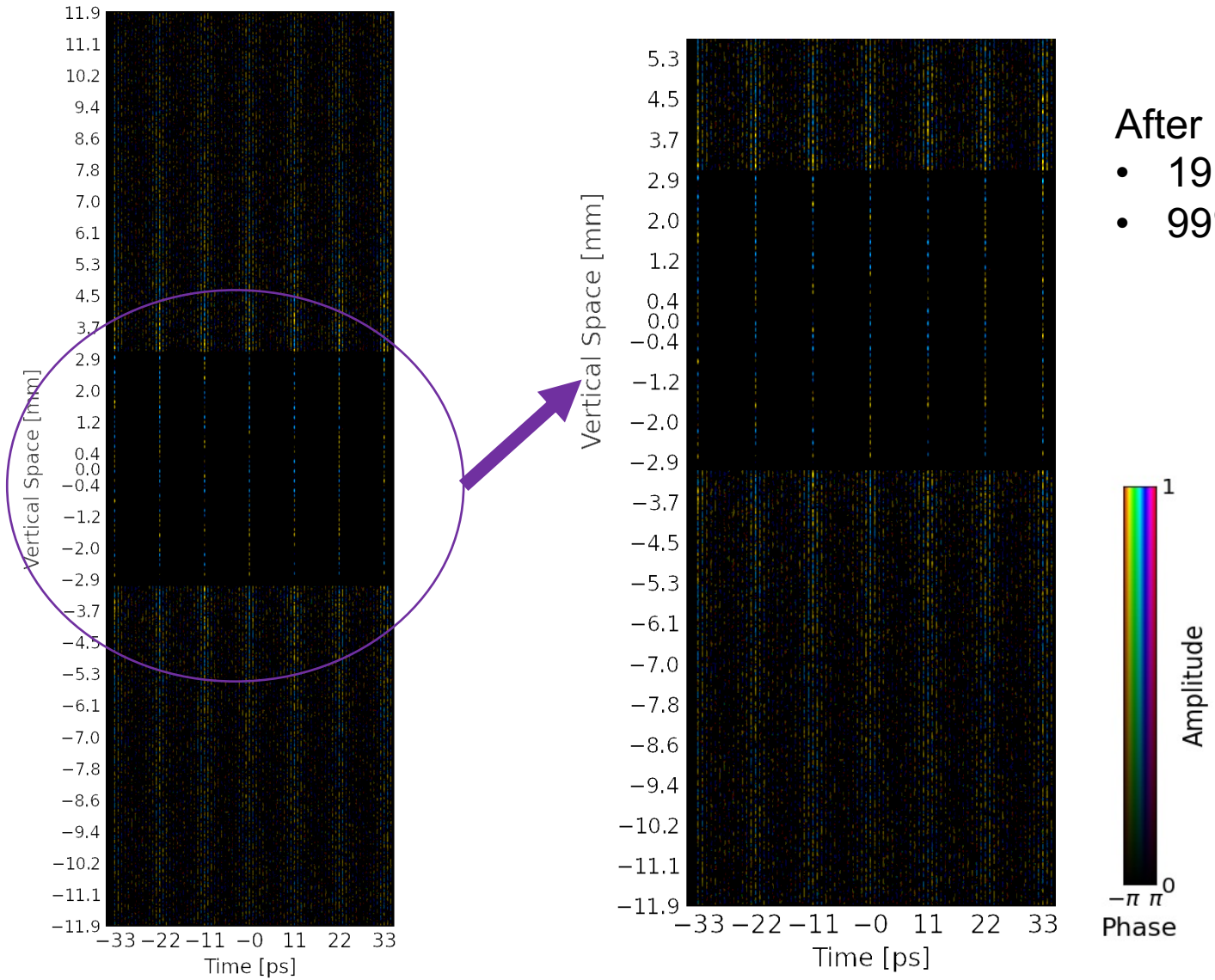


$\times e^{j\phi}$

Phase mask displayed on SLM



Gerchberg Saxton (GS) Algorithm Simulated Goal Field

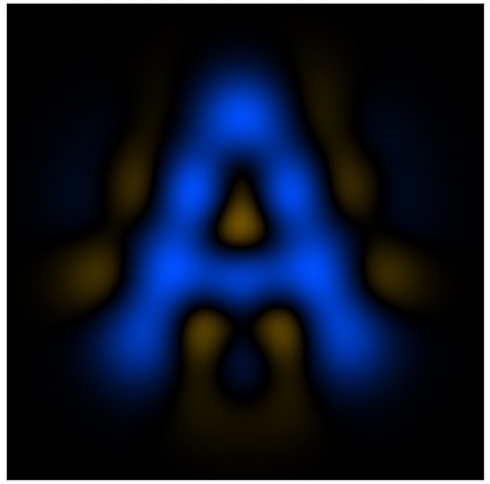


After 119 GS iterations

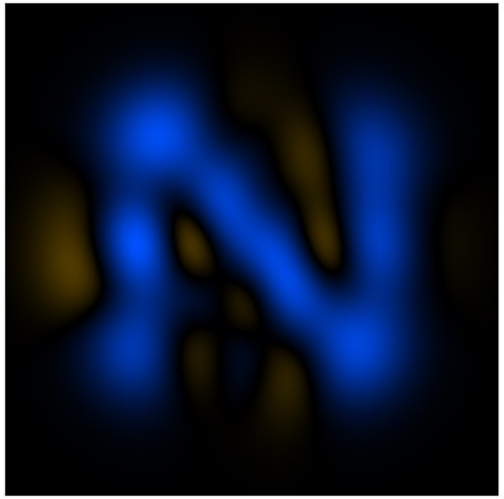
- 19.6% power in array
- 99% beam quality

Beams After Simulation

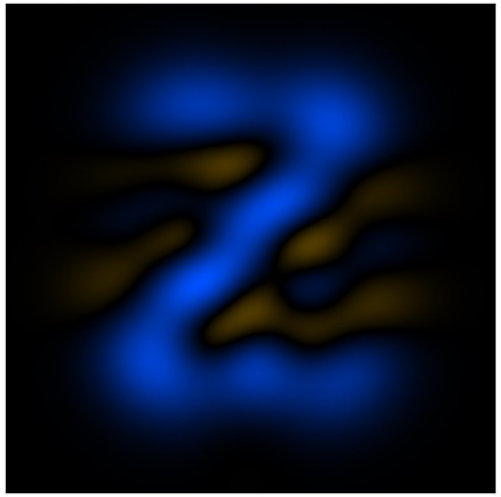
Simulated -33ps Slice



Simulated -22ps Slice



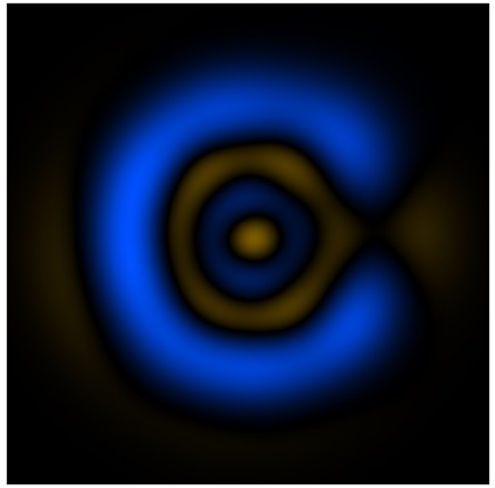
Simulated -11ps Slice



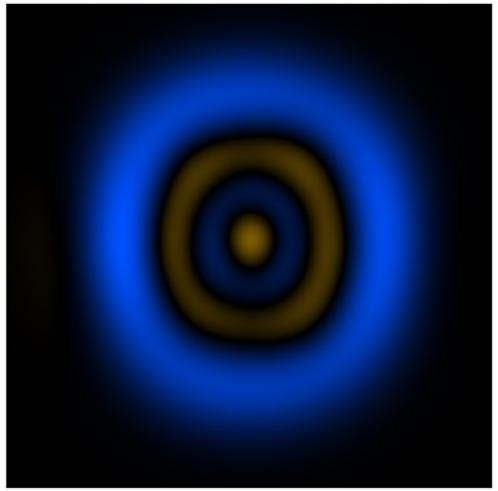
Average overlap of all slices 99% to best possible images using 45 HG modes

Worst overlap 99%

Simulated 0ps Slice

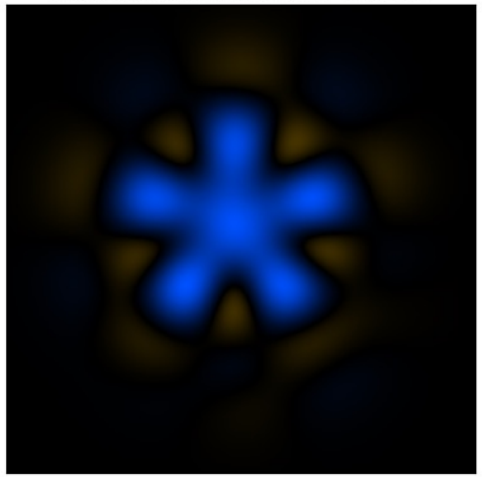


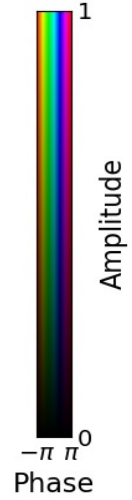
Simulated 11ps Slice



Simulated 22ps Slice

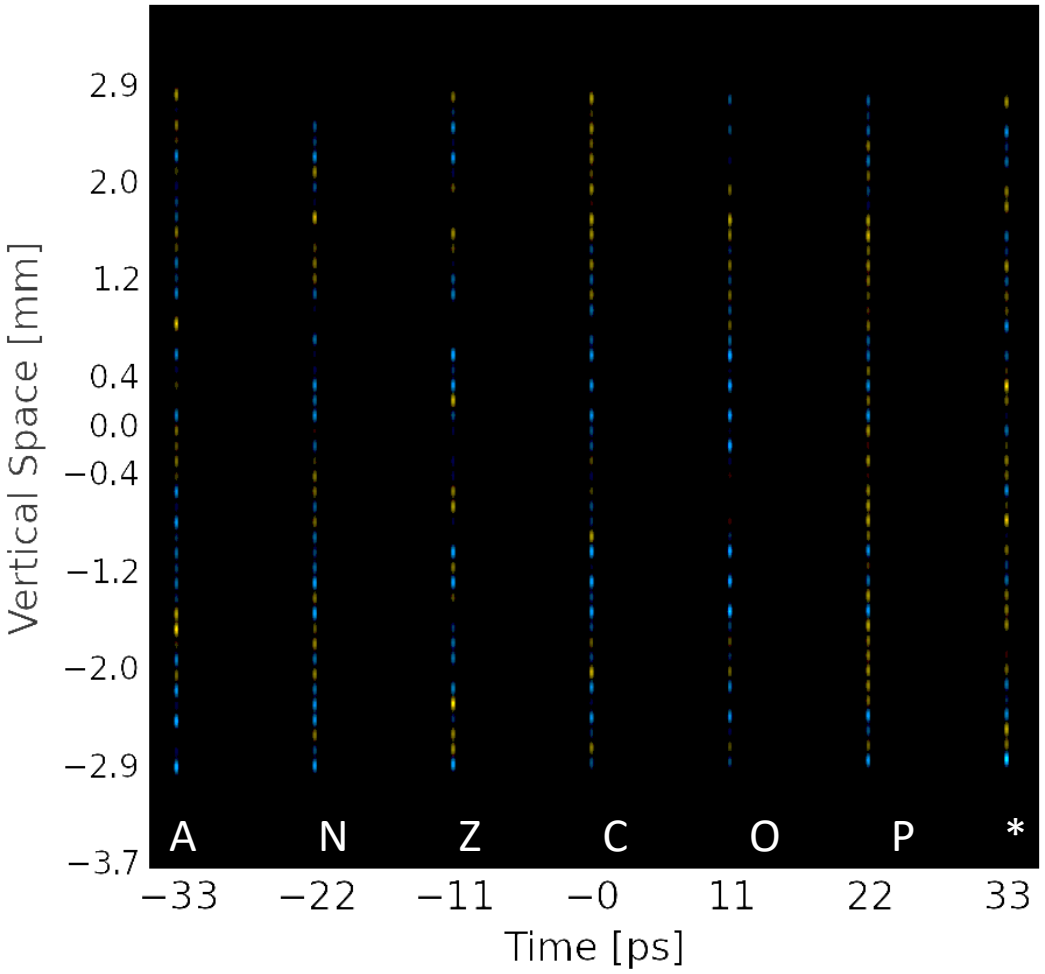
Simulated 33ps Slice

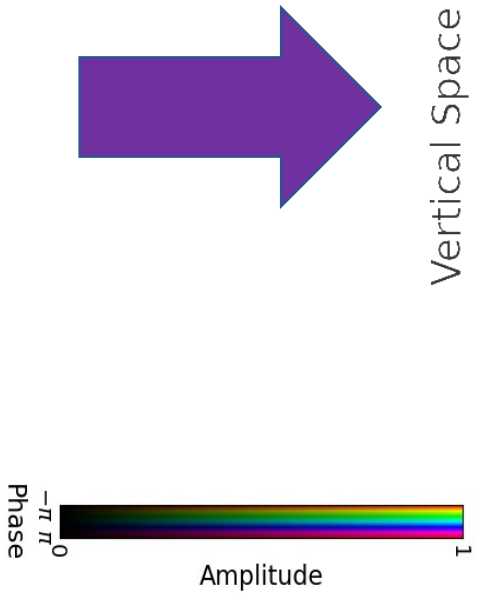




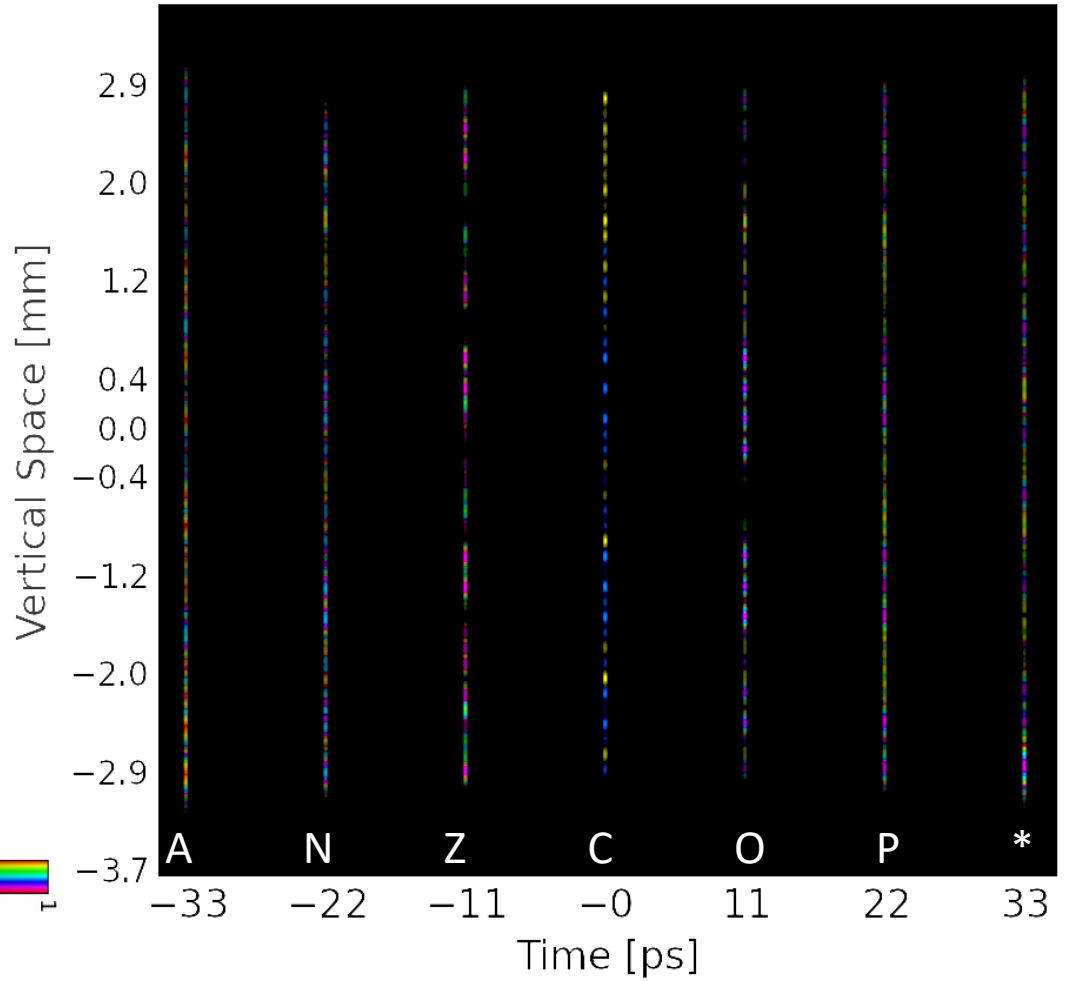
Effect of Defocus

Pulse shaper goal field assuming no defocus



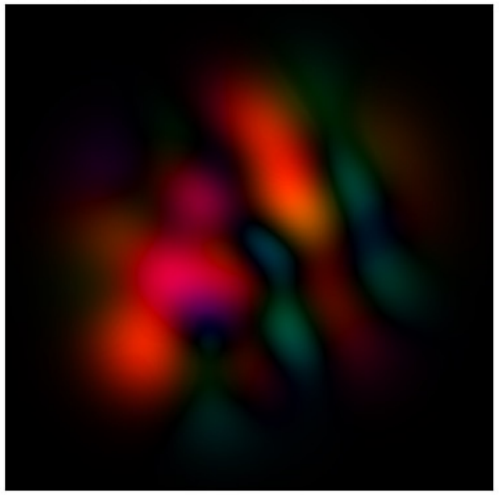


Pulse shaper goal field with defocus

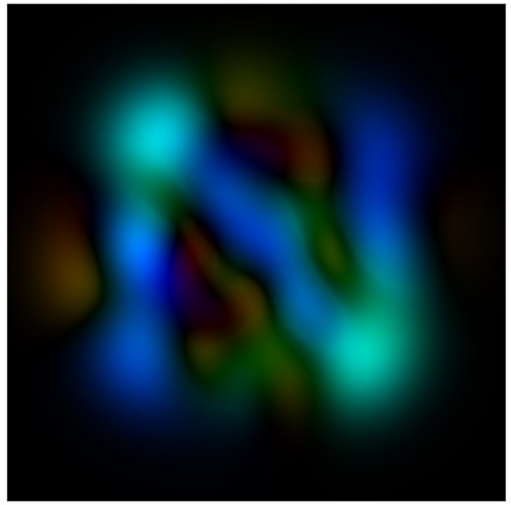


Defocused Beams After Simulation

Simulated -33ps Slice



Simulated -22ps Slice

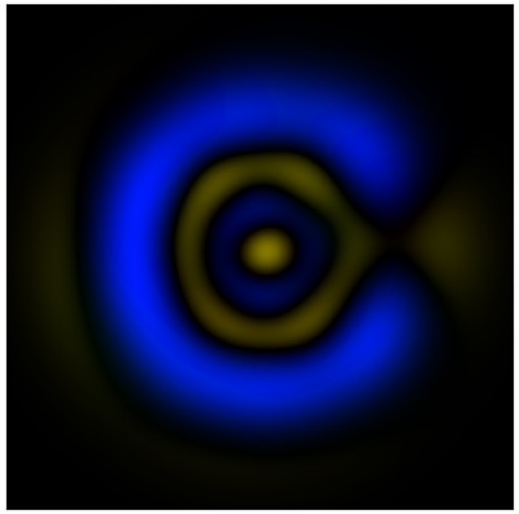


Simulated -11ps Slice

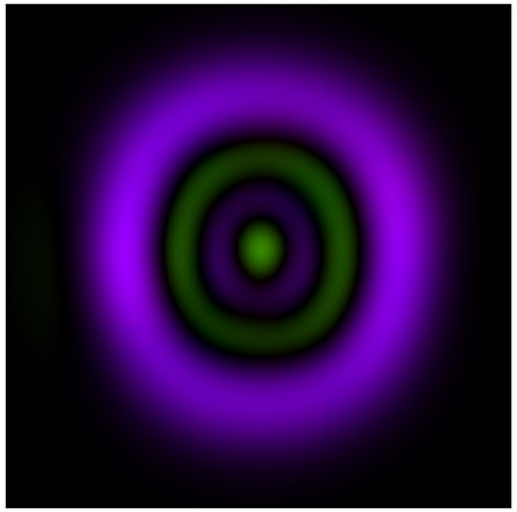
Average overlap with theoretical best 86%

Worst overlap is A at 61%
Followed by * at 73%

Simulated 0ps Slice

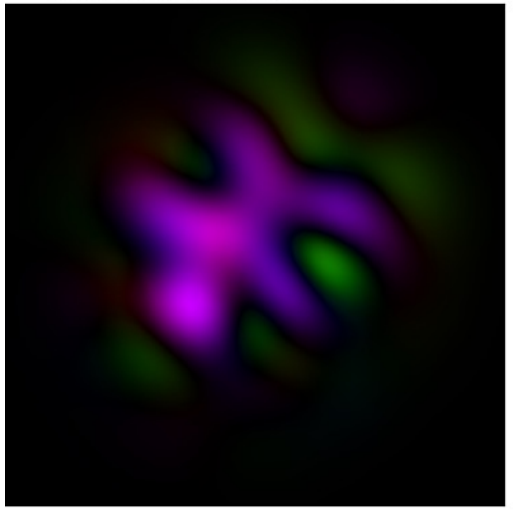


Simulated 11ps Slice



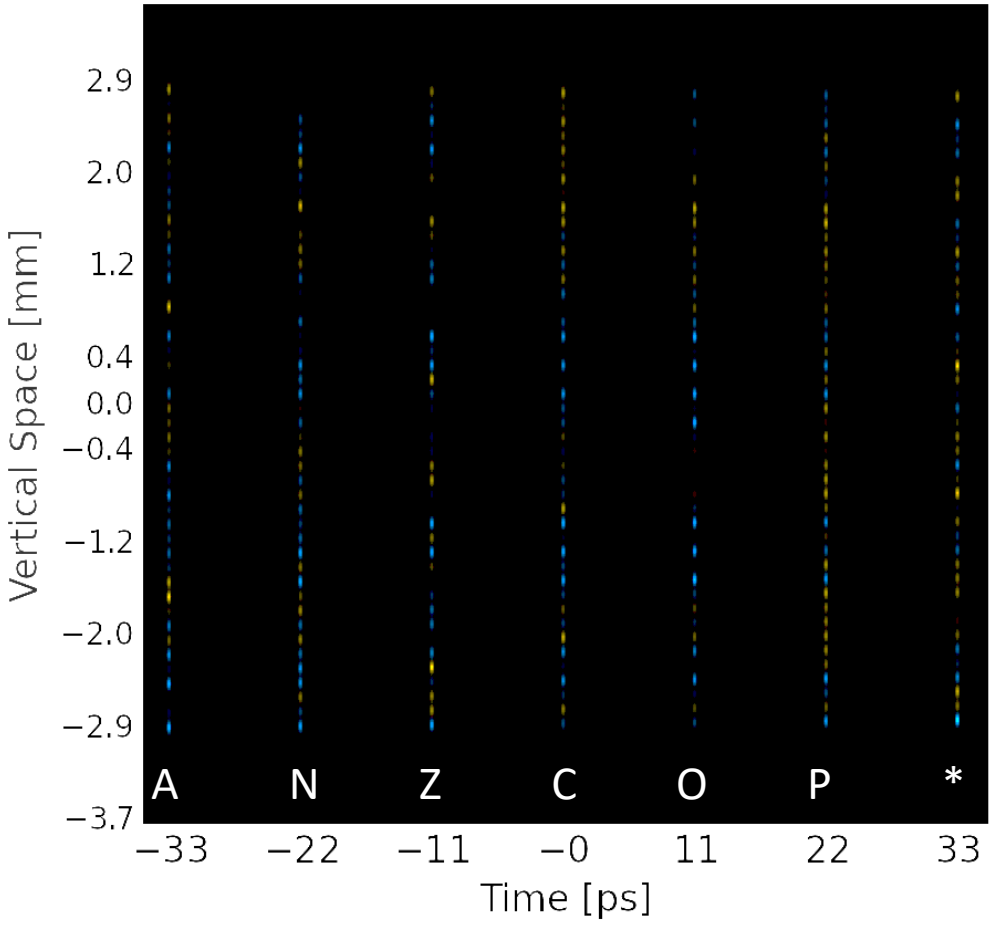
Simulated 22ps Slice

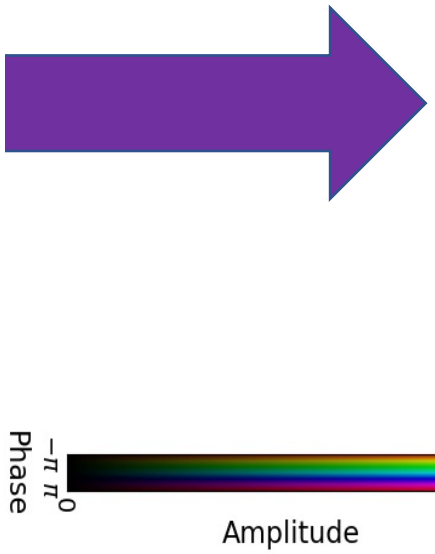
Simulated 33ps Slice



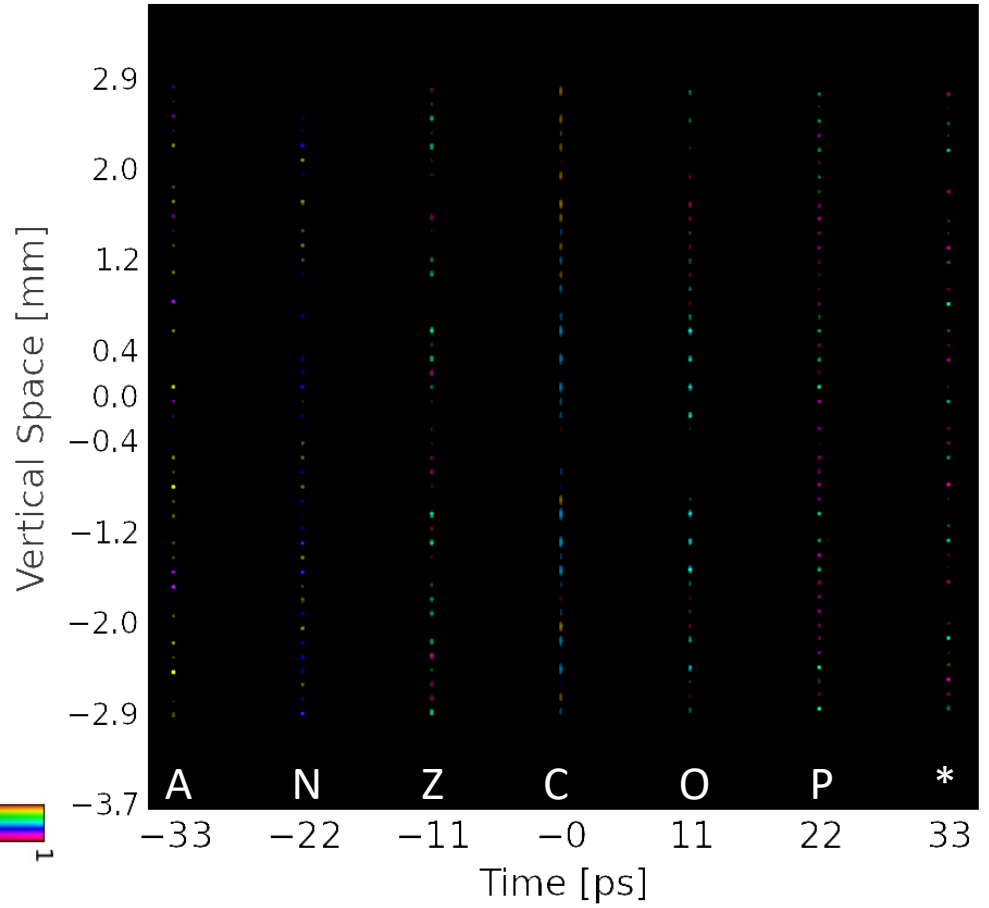
Defocus Compensation

Pulse shaper goal field assuming no defocus

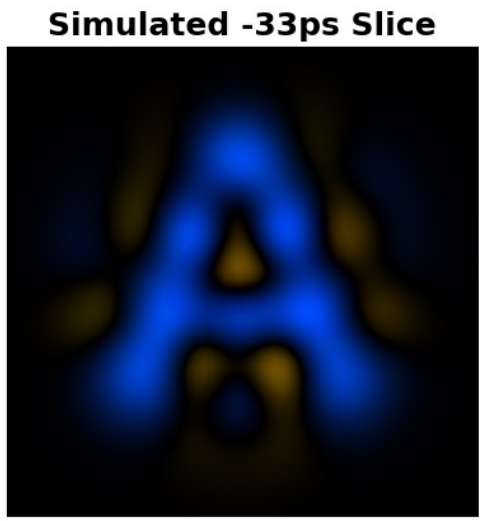


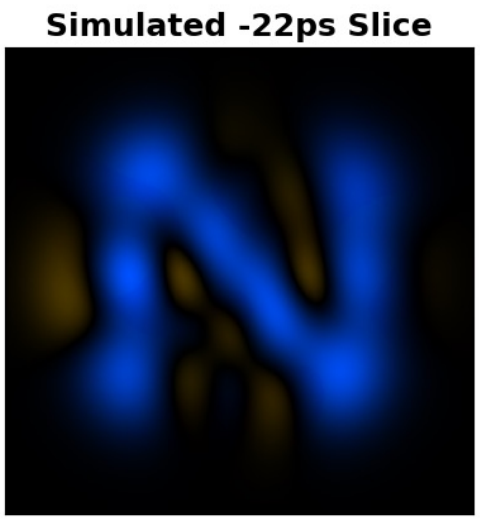


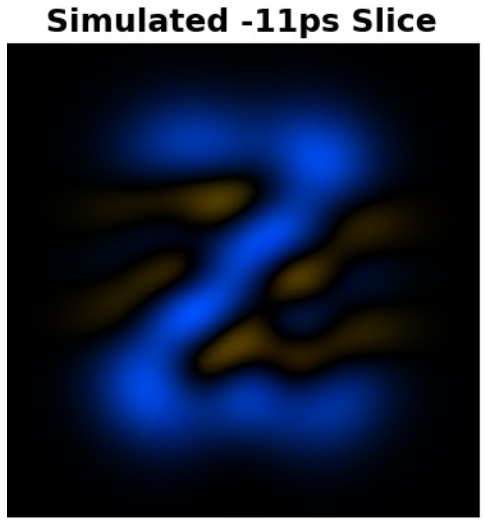
Pulse shaper goal field compensating for defocus



Defocus Compensated Beams After Simulation

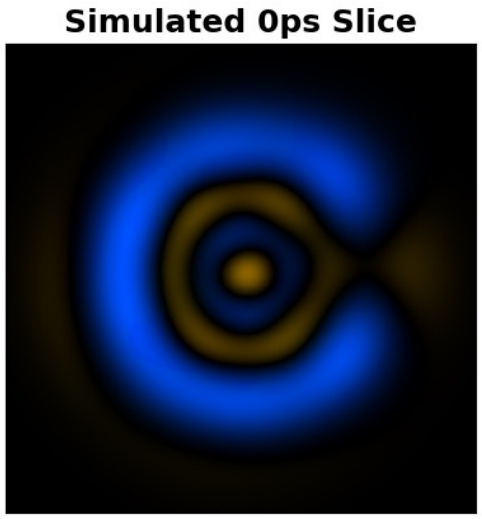


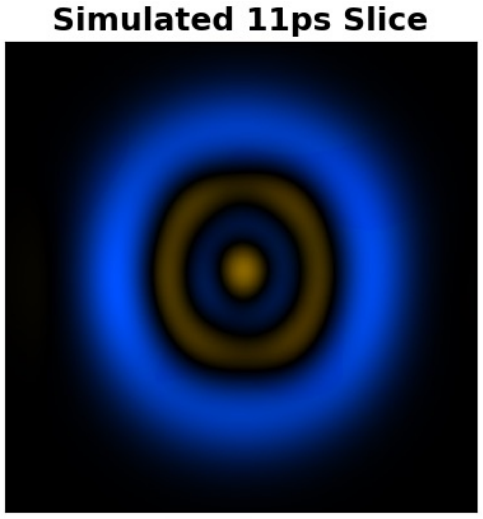


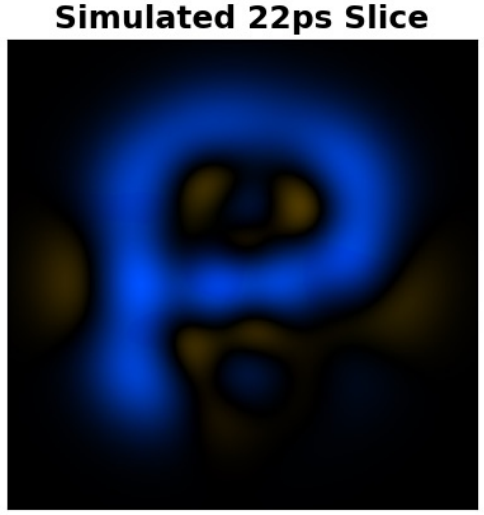


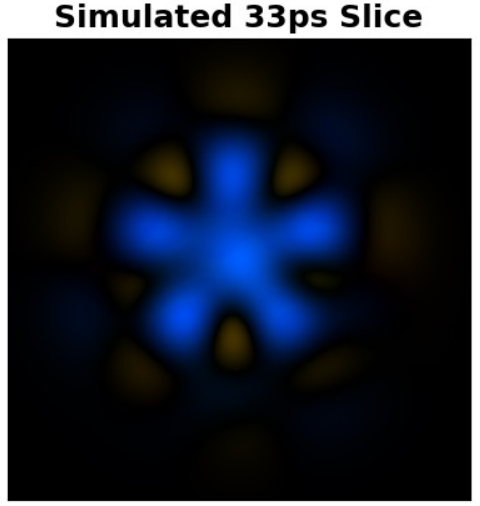
Average overlap with theoretical best 99%

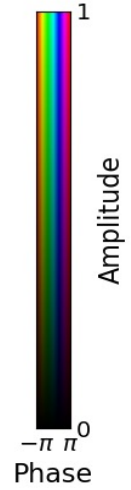
Worst overlap is A and * at 98%





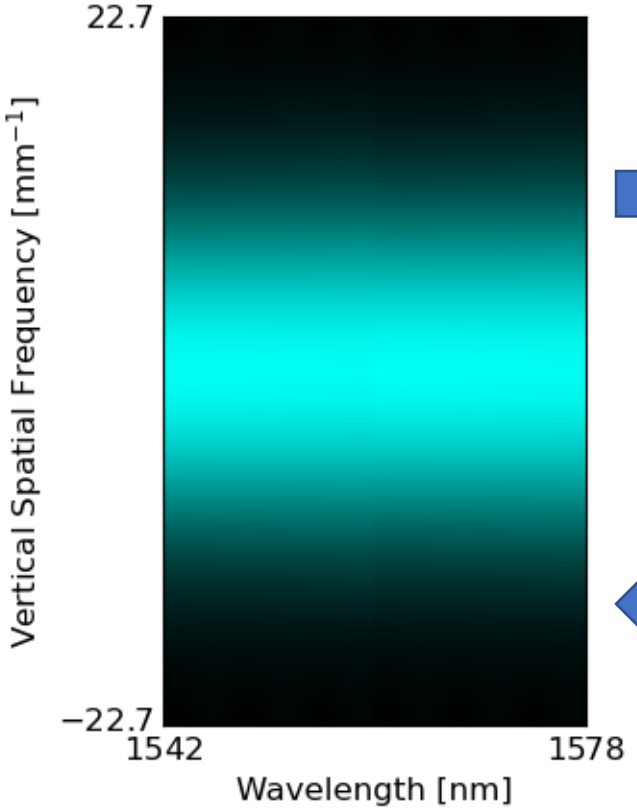






Acceleration of Phase Mask Simulations 1D GS Method

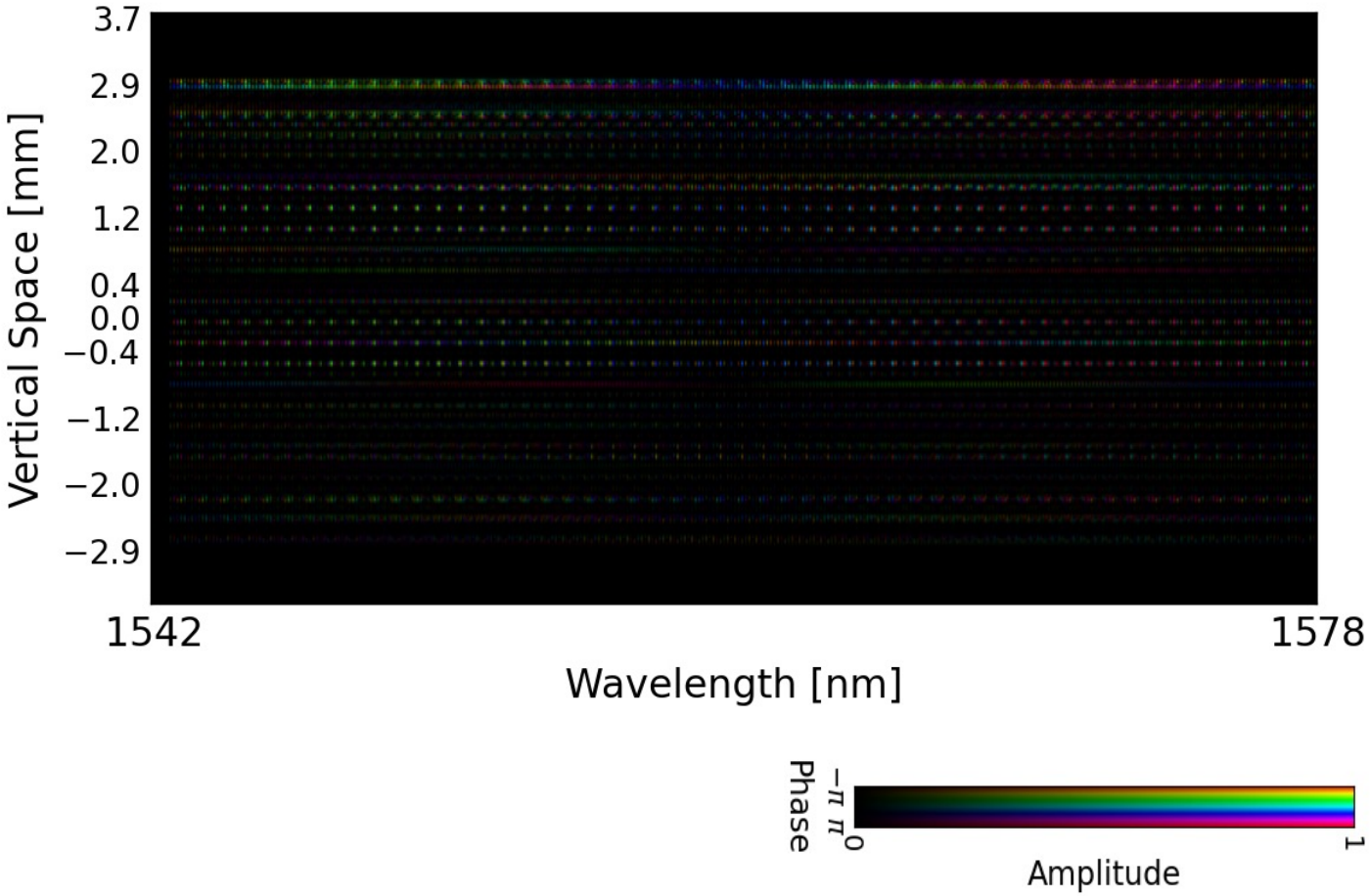
SLM Plane
Amplitude defined



$\mathcal{F}^{-1}(k_y, \lambda)$

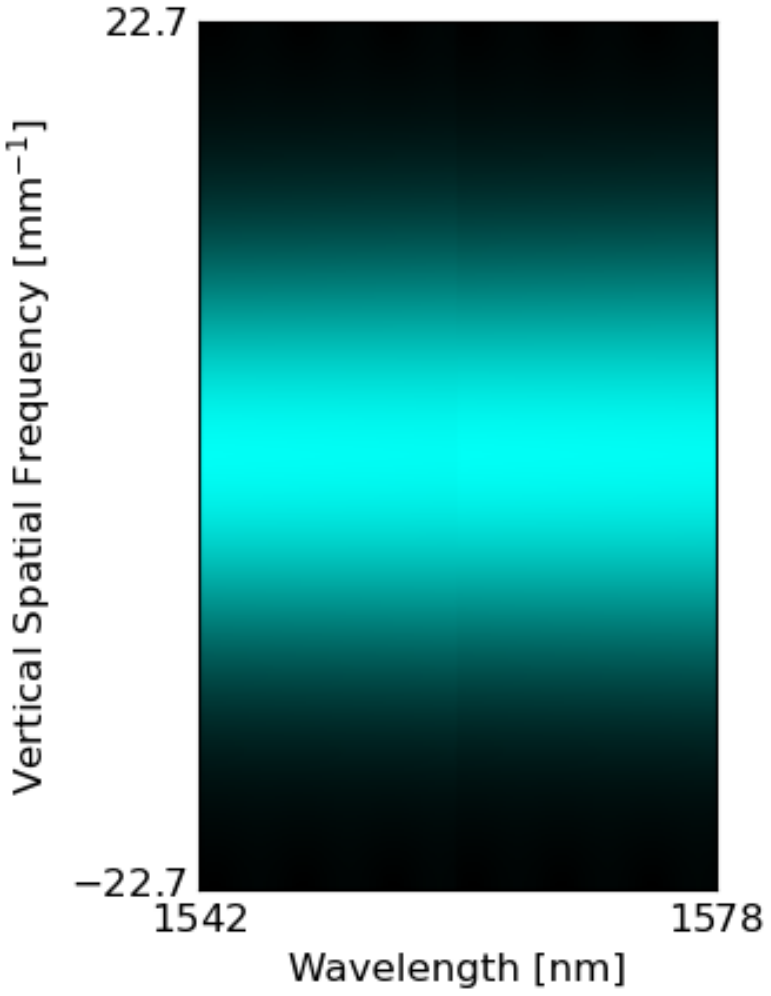
$\mathcal{F}(y, \lambda)$

Pulse Shaper Output Plane
Amplitude and Phase defined



Acceleration of Phase Mask Simulations 2D GS Method

SLM Plane
Amplitude defined

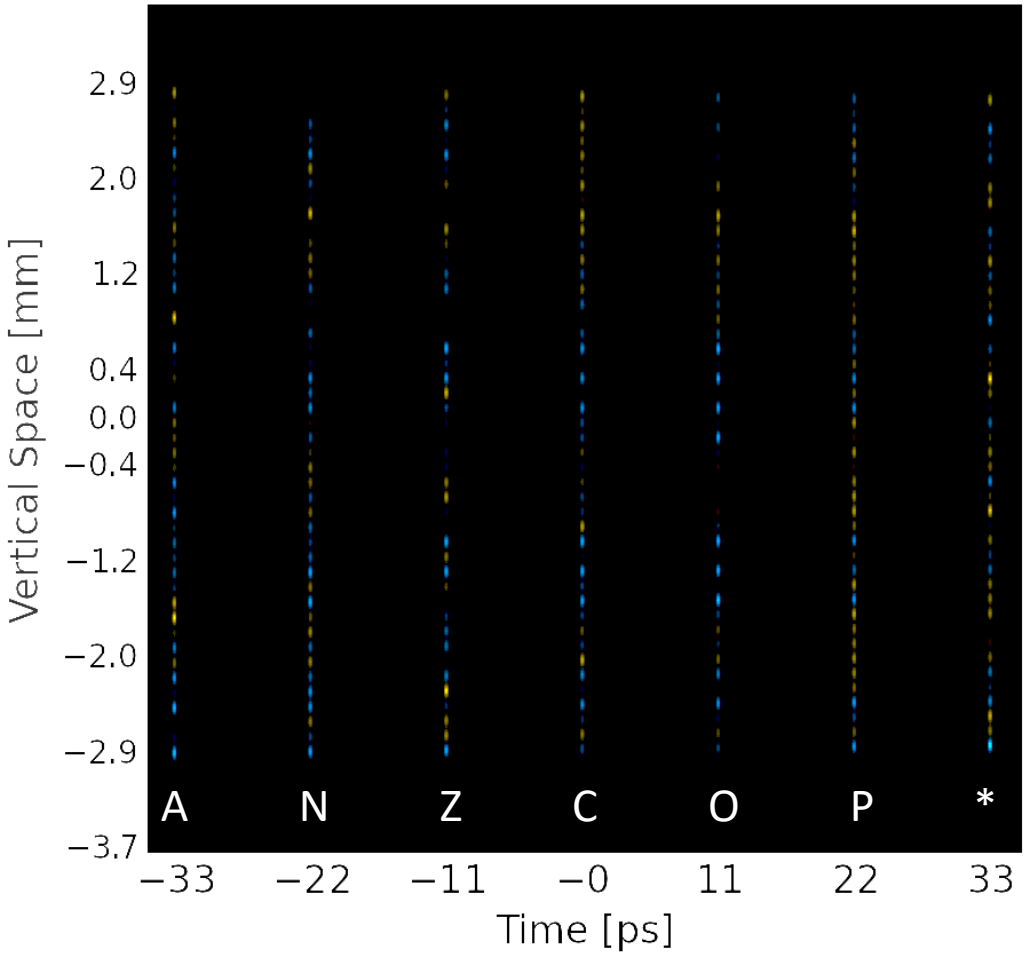


$\mathcal{F}^{-1}(k_y, \lambda)$

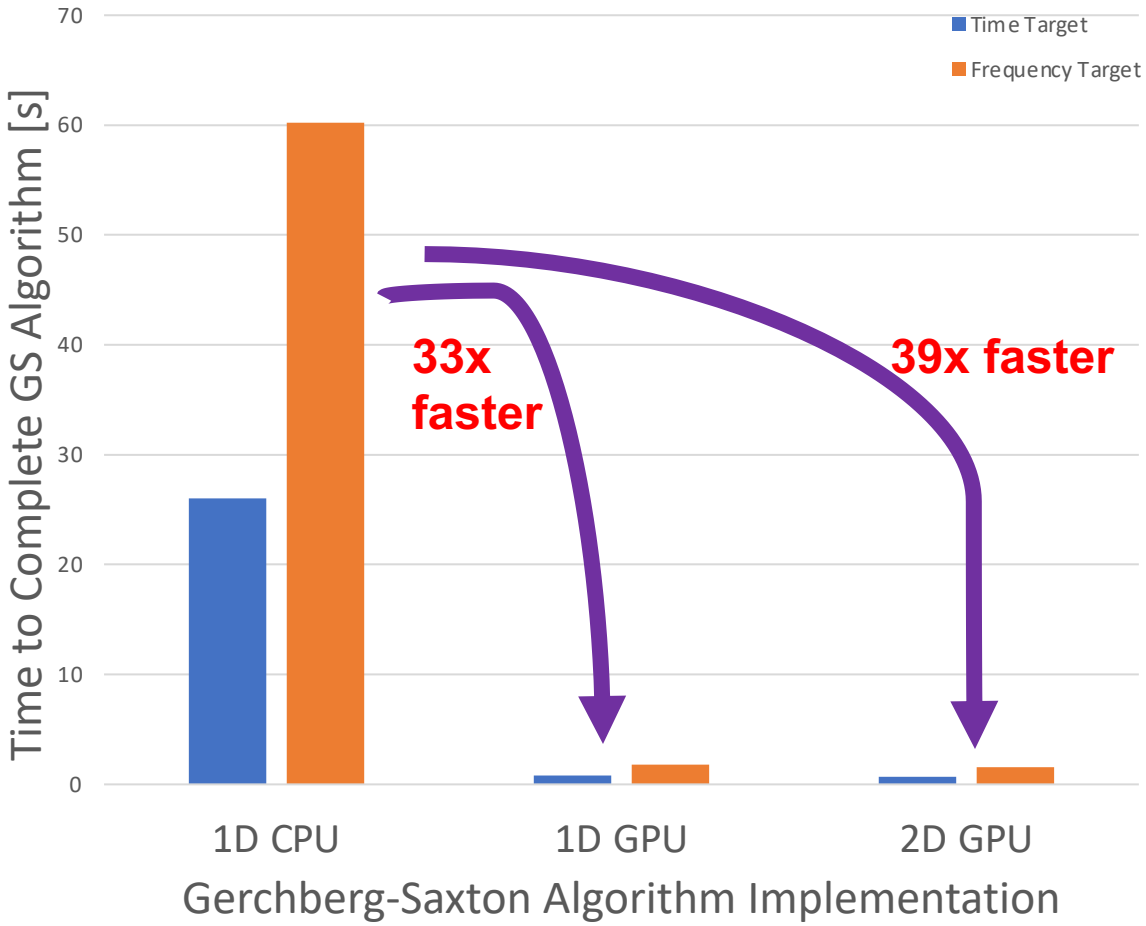
Contrast decreased
Brightness increased

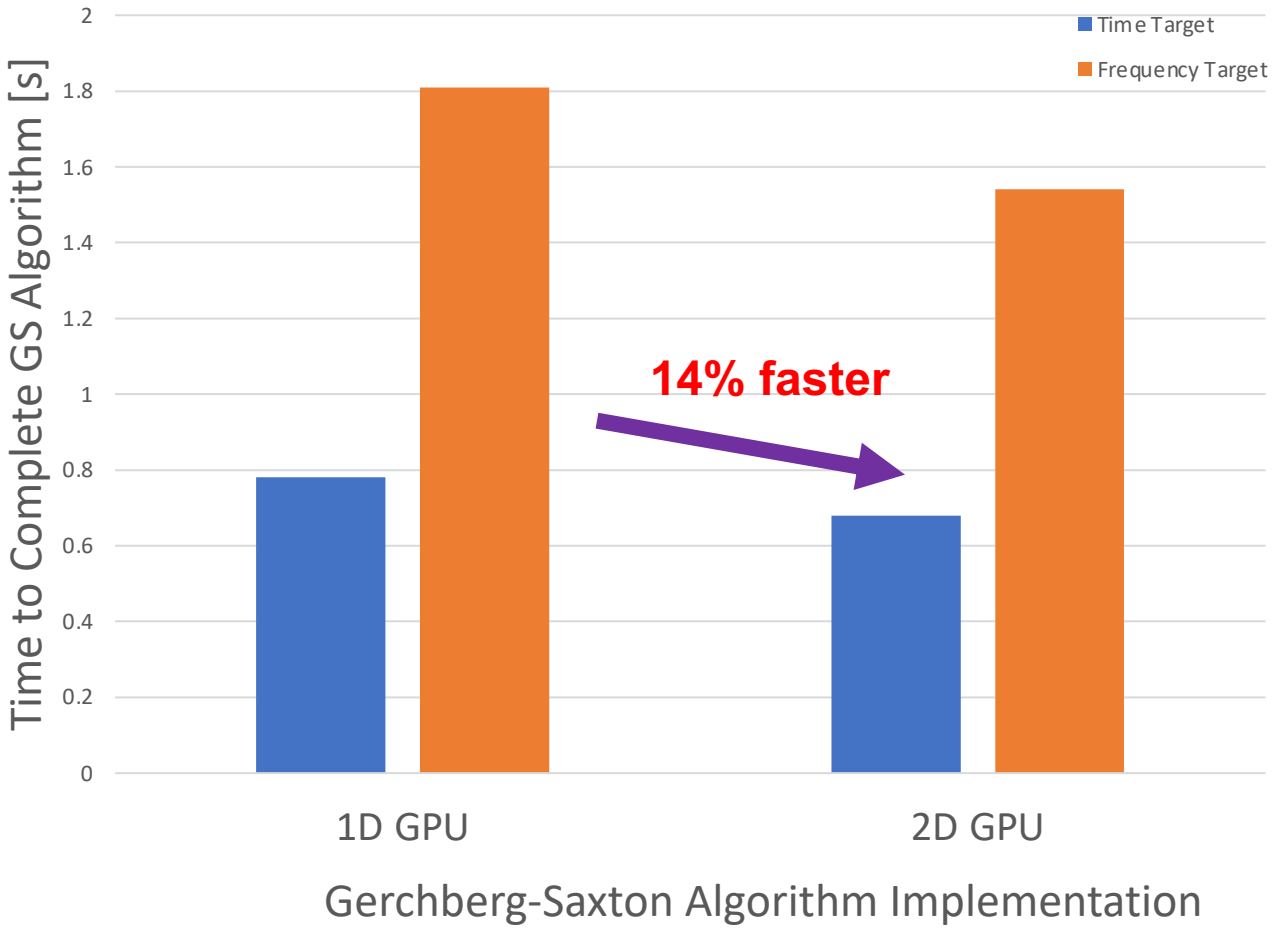
$\mathcal{F}(y, t)$

Pulse Shaper Output Plane
Amplitude and Phase defined



Why 2D Graphics Processing Unit (GPU) GS?





Targets are the previously used ANZCOP* pattern in one polarisation with no simulated defocus
CPU – Intel Core i7-5820K @ 3.30GHz, GPU – NVIDIA GeForce GTX TITAN X

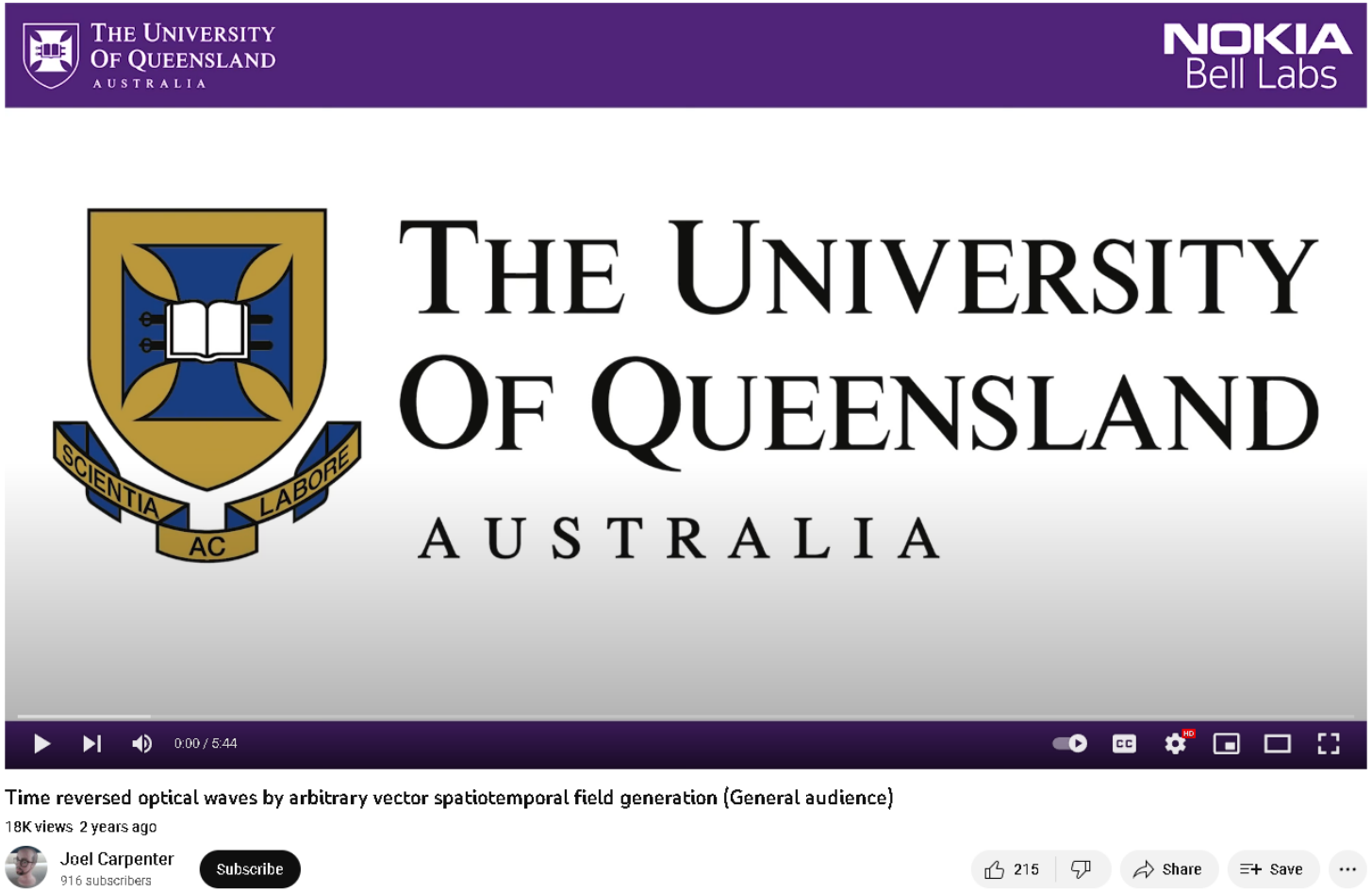
Thanks for Listening

Questions?

Email: a.komonen@uq.net.au

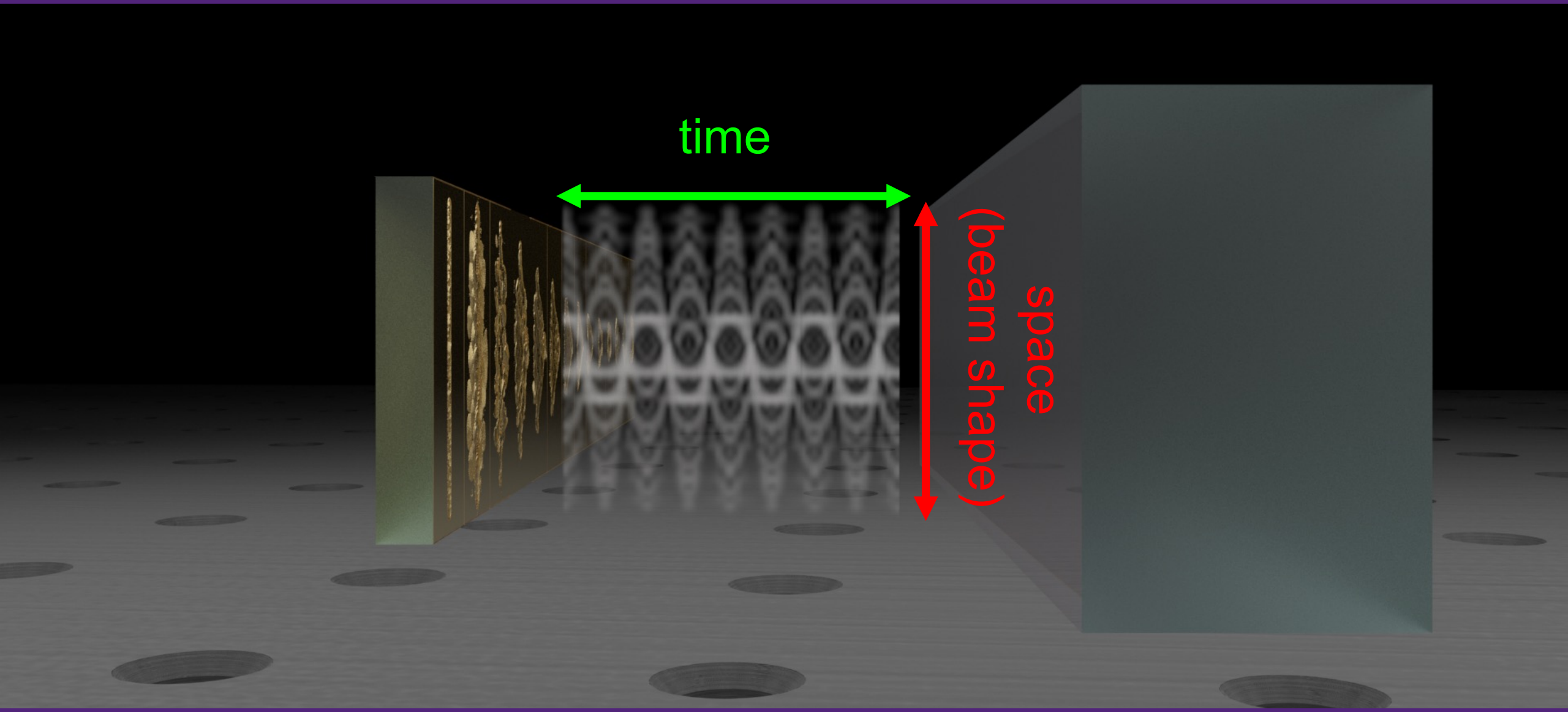
Time reversal video found:
https://www.youtube.com/@joelacarpenter/videos

Animations see Joel Carpenter on YouTube



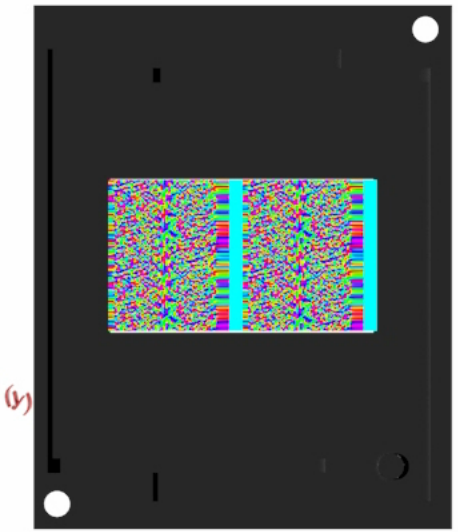
Australian Government
Australian Research Council

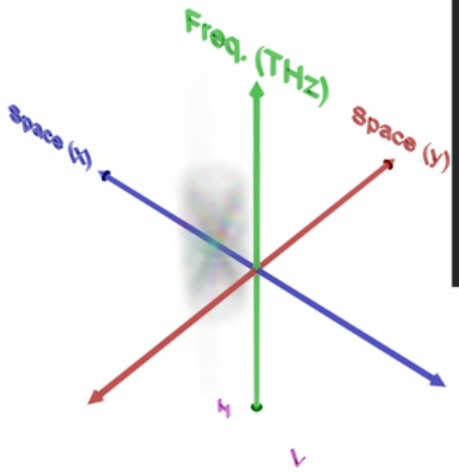
Pulse Shaper Subsystem Output Beam



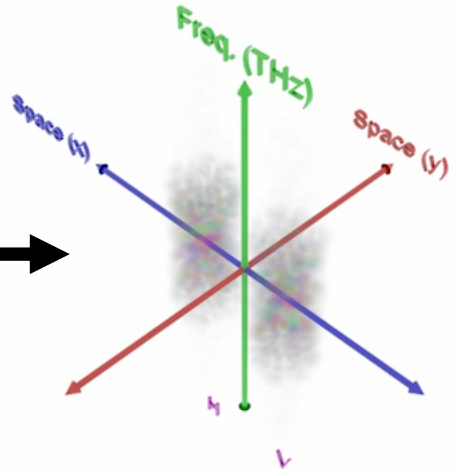
J. Carpenter https://youtu.be/9hVEJvfWjRQ

Time Reversed State



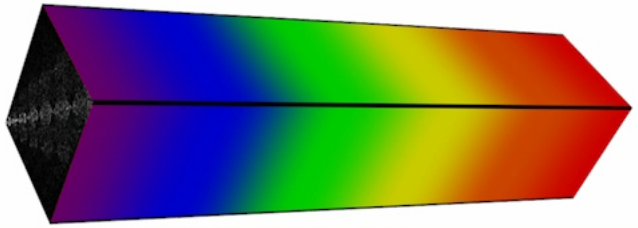


Calculate SLM mask to generate this time reversed state…



Required input state both poles (mode vs. wavelength)

Transfer matrices both poles mode in vs. mode out vs. wavelength



Backpropagate desired output state both poles (mode vs. wavelength)

Defocus of Gaussian Beam

$$E(r,z) = E_0 \frac{w_0}{w(z)} e^{-\frac{r^2}{w(z)^2}} e^{-i\left(kz + k\frac{r^2}{2R(z)} - \psi(z)\right)}$$

Gouy phase after travelling z distance

Radius at which the beam amplitude is $\frac{1}{e}$ of max after travelling z distance

Radius of curvature of beam after travelling z distance