Chris Stanford
Fermilab

LIDINE- 9/22/2022

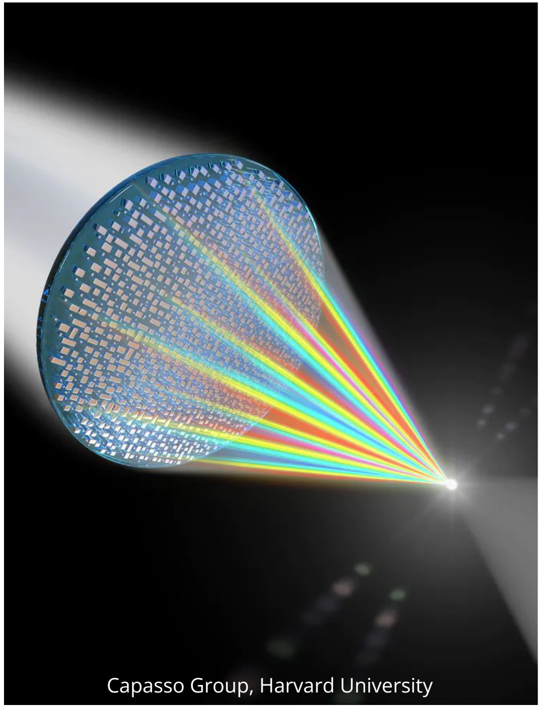
Assessing the performance of metalenses to enhance the light collection of silicon photomultipliers

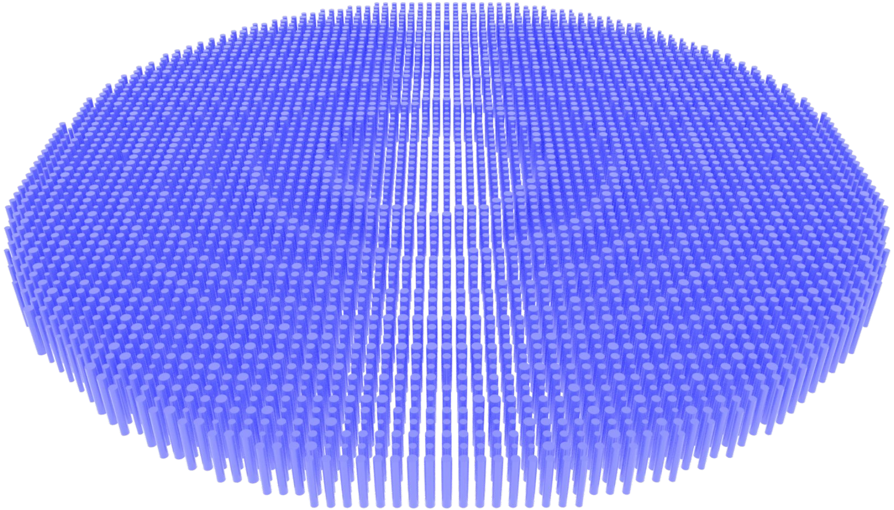
Roxanne Guenette
Justo Martin-Albo
Augusto Martins
Taylor Contreras
Fabian Kellerer

Carlos Escobar
Adam Para
Michelle Stancari
Benjamin Lawrence-Sanderson

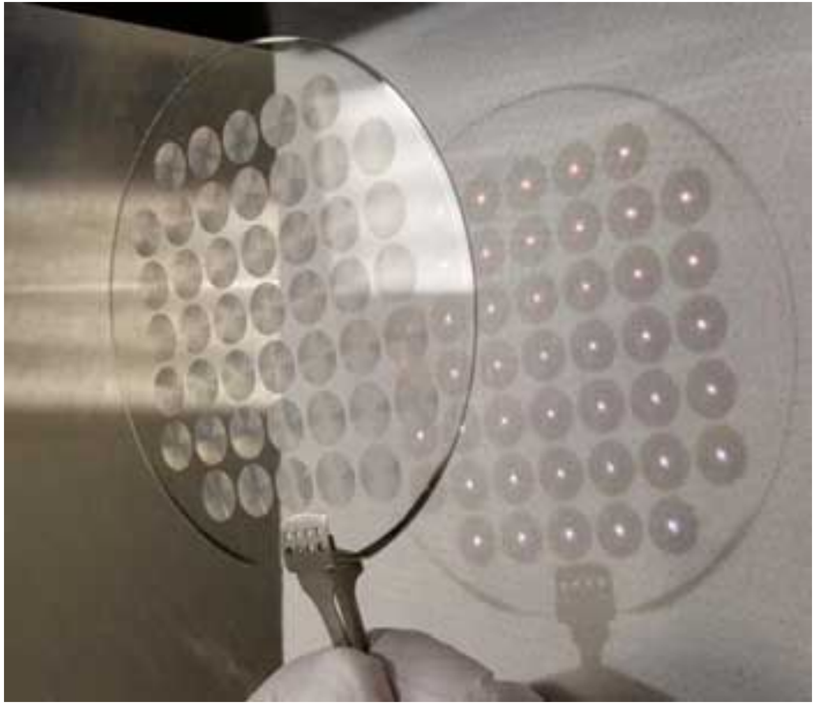
What are metalenses?

Metalenses are flat optics designed to focus light, much like traditional lenses





What are metalenses?

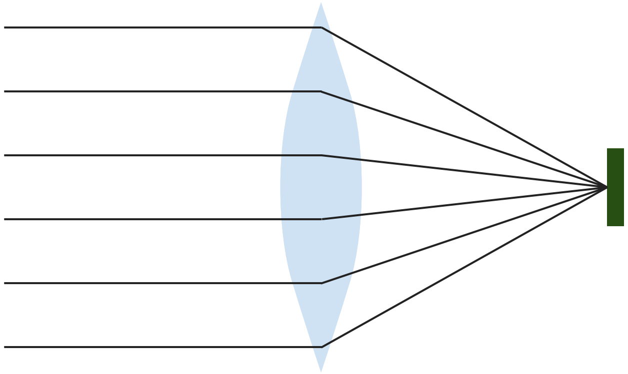


Capasso Group, Harvard University

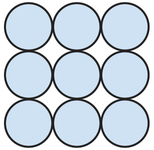
Why “meta”?

Traditional

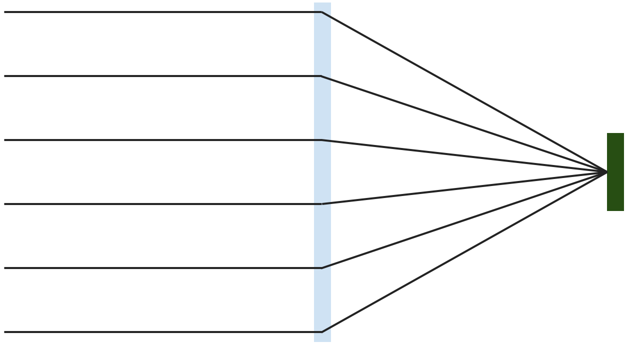
vs



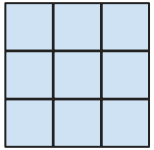
- Bulky
- Expensive
- Optical limitations



Meta

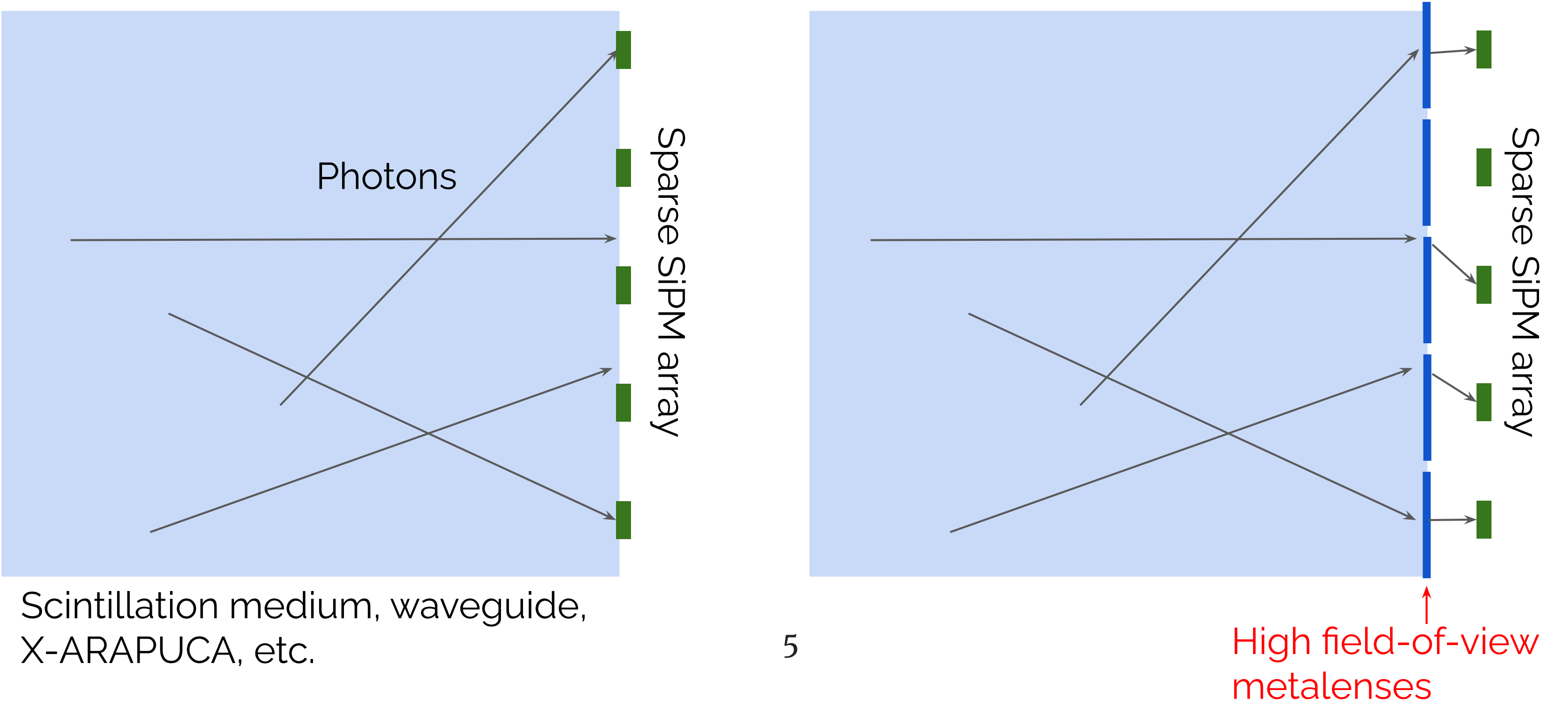


- Thin and lightweight
- Cheap, easy to mass-produce, $1/ea
- More flexible



Applications in physics detectors

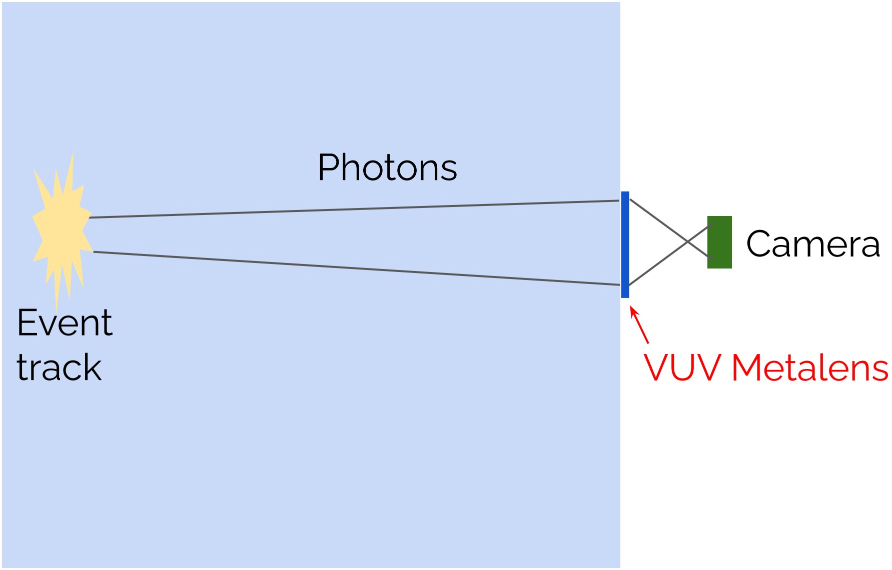
Metalenses could augment any proposal involving a sparse SiPMs to allow us to collect more light.



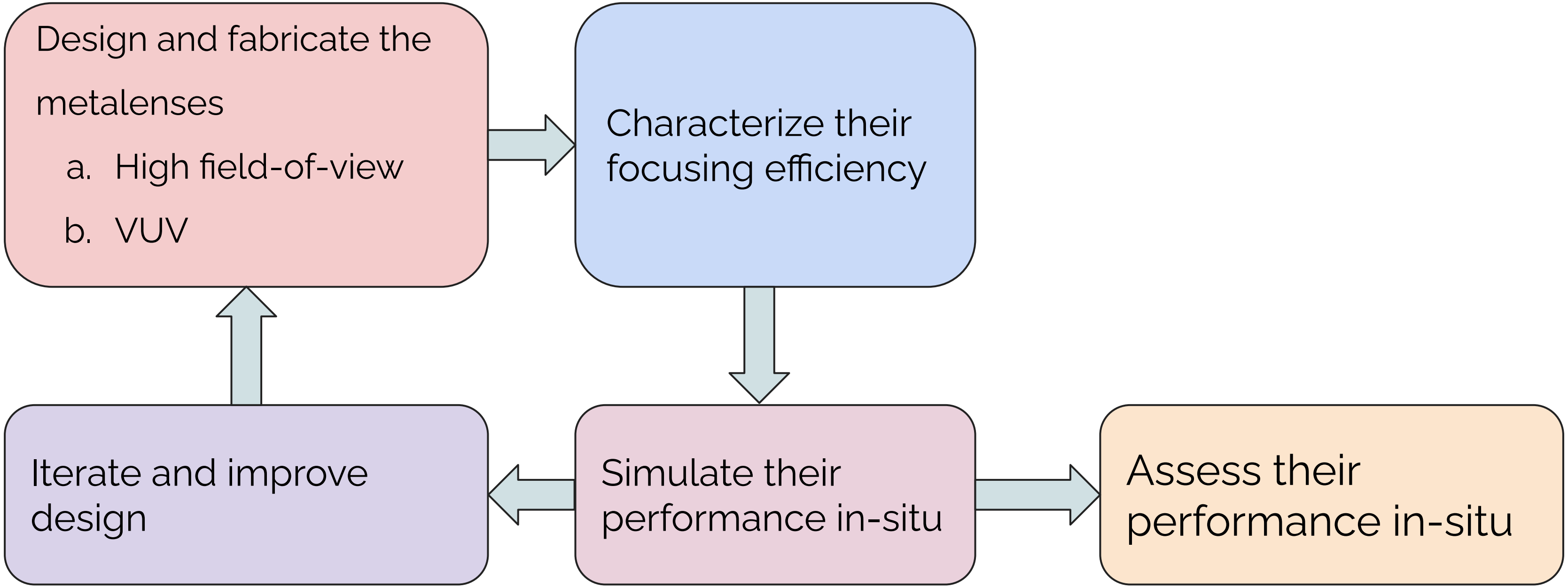
Scintillation medium, waveguide, X-ARAPUCA, etc.

Applications in physics detectors

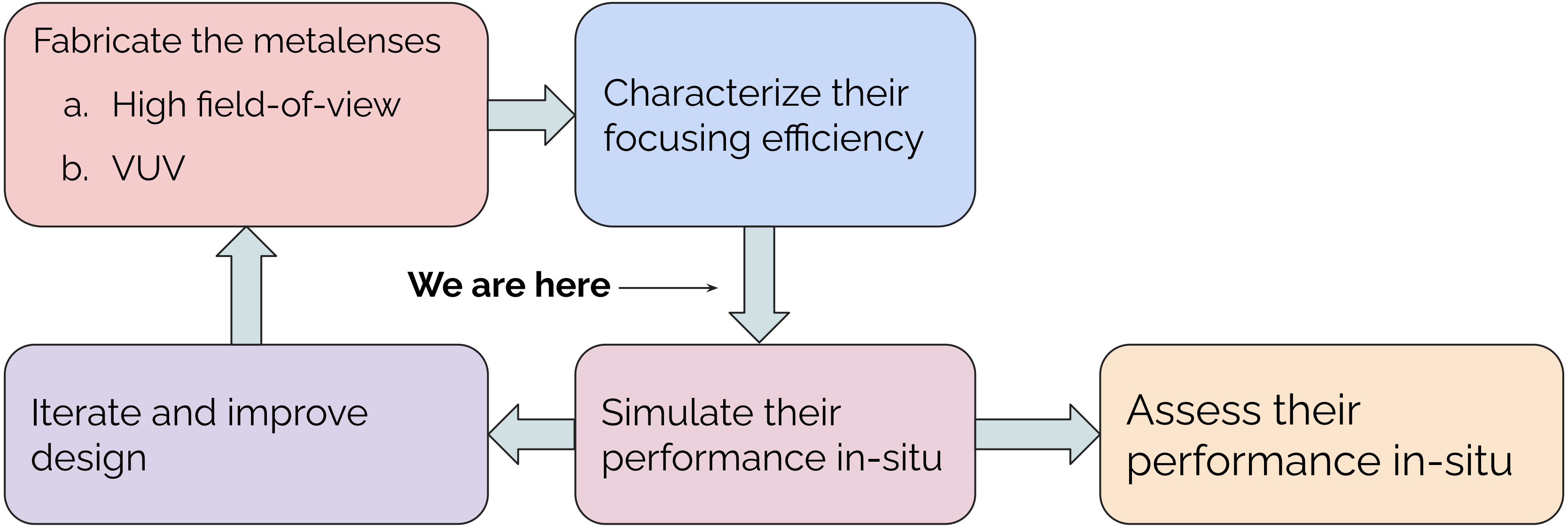
They could also be used for event imaging.



Procedure


Design and fabricate the metalenses
a. High field-of-view
b. VUV
Characterize their focusing efficiency
Simulate their performance in-situ
Iterate and improve design
Assess their performance in-situ

Procedure

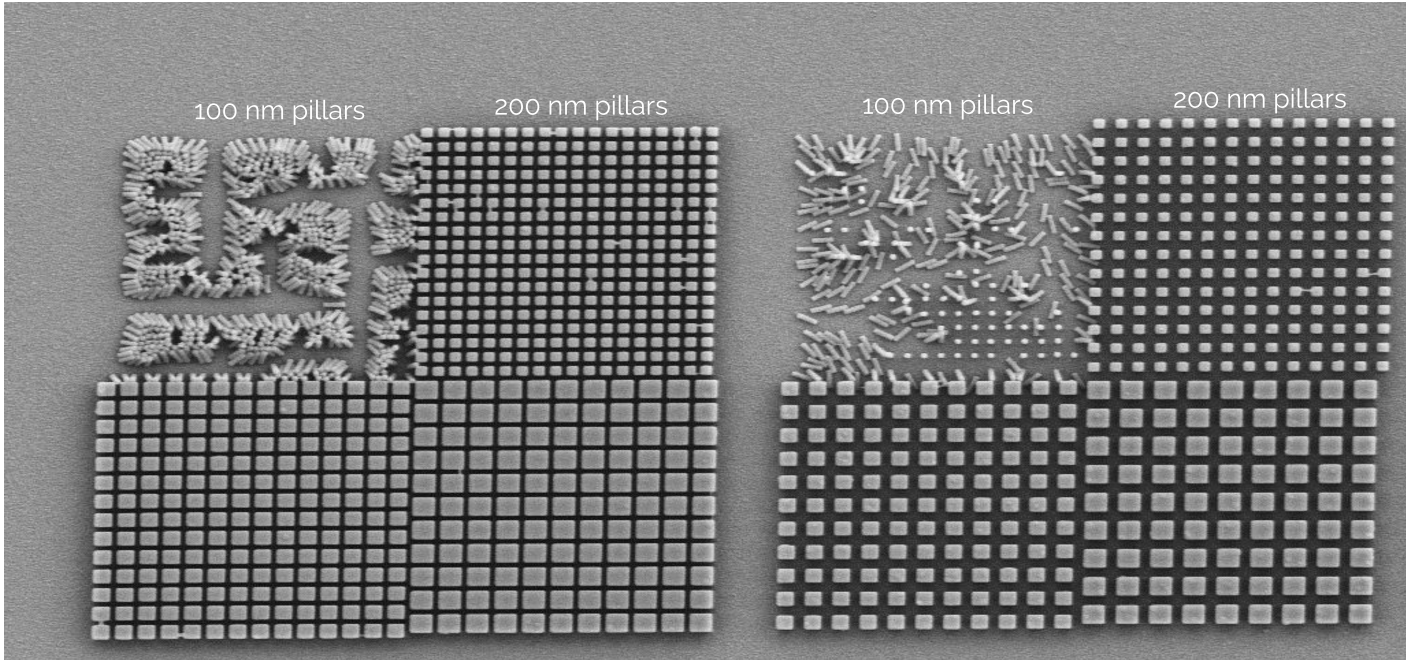

Fabricate the metalenses
a. High field-of-view
b. VUV
Characterize their focusing efficiency
We are here
Iterate and improve design
Simulate their performance in-situ
Assess their performance in-situ

Fabrication Results

by Augusto Martins

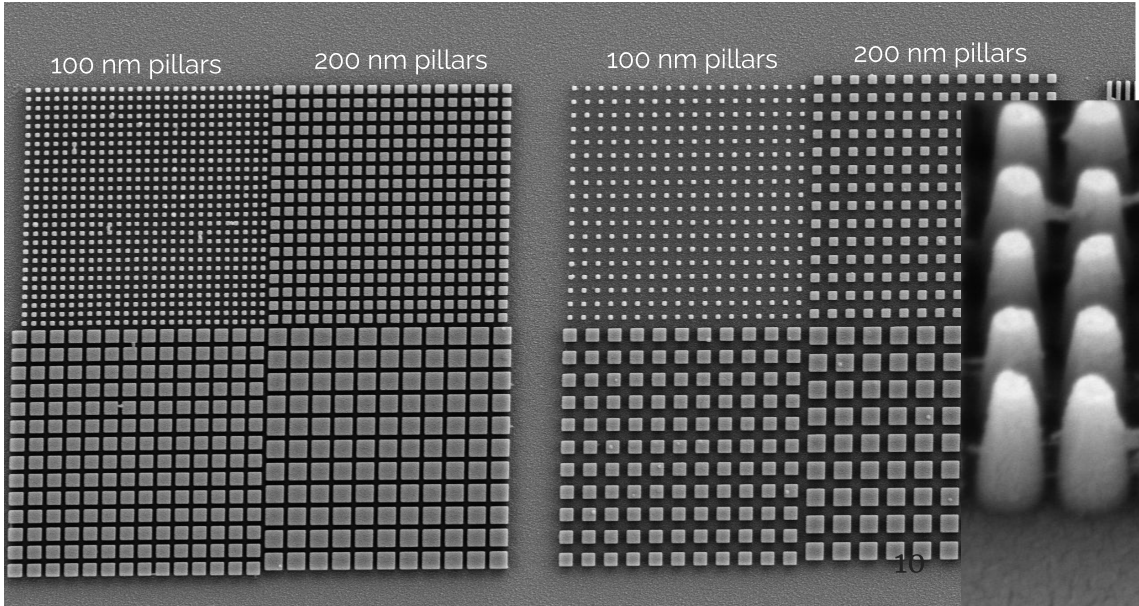
Metalenses require nanopillars that are significantly smaller than the wavelength of the light (~80 nm-wide pillars for 175 nm light).

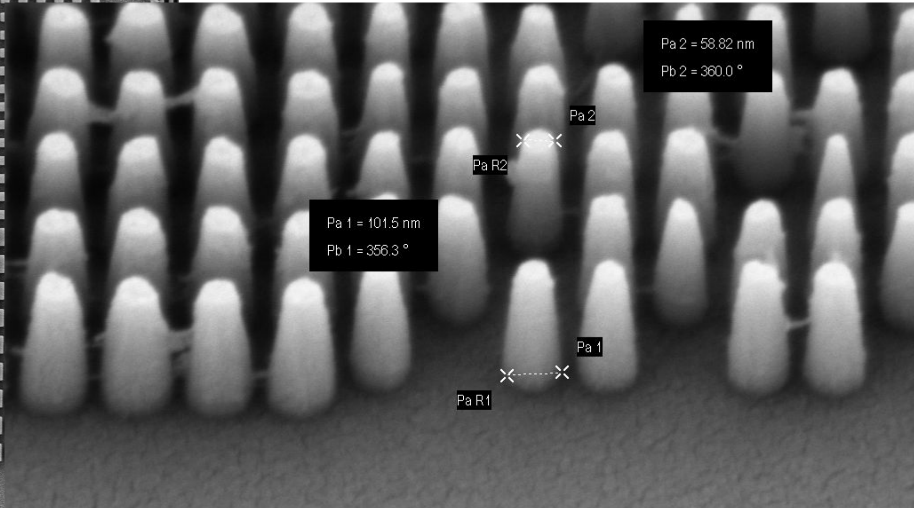
Due to the difficulties in fabricating such small pillars, this has never been achieved before.



Fabrication Results

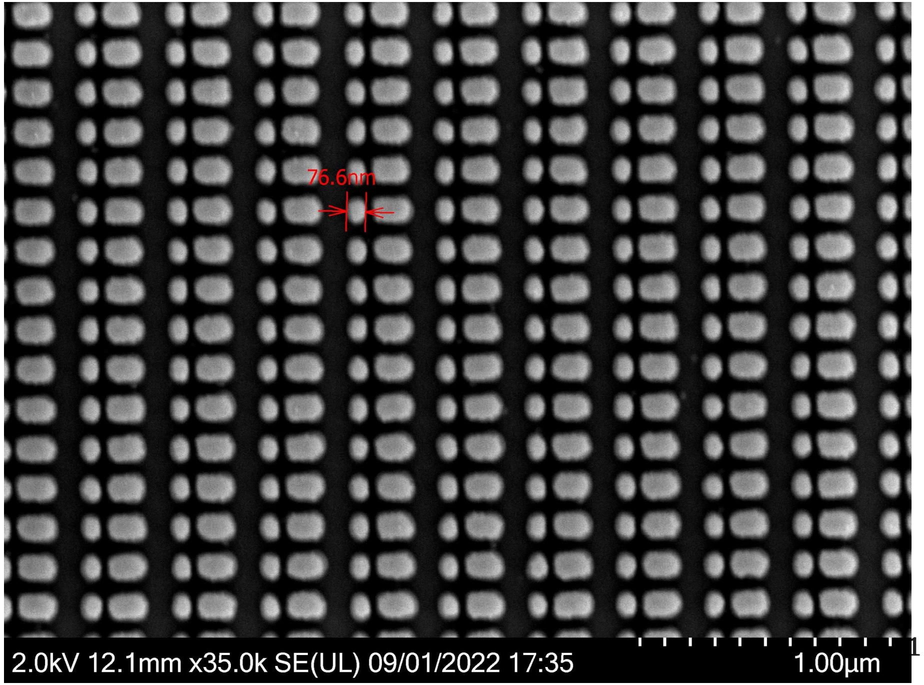
With several months of improving the fabrication recipe, we have been able to push the minimum stable pillar size to new frontiers.

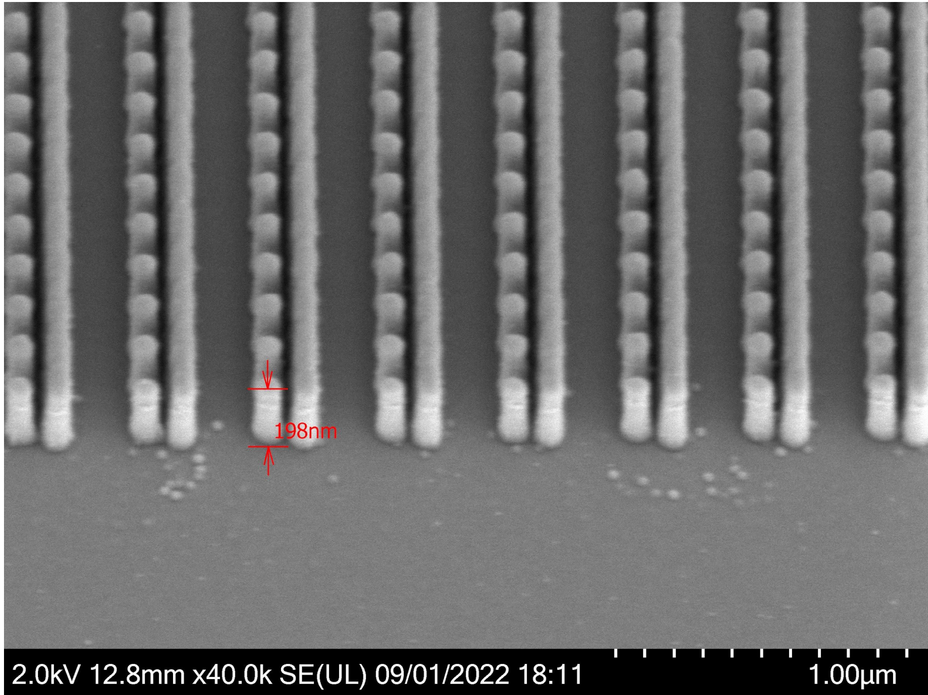




Fabrication Results

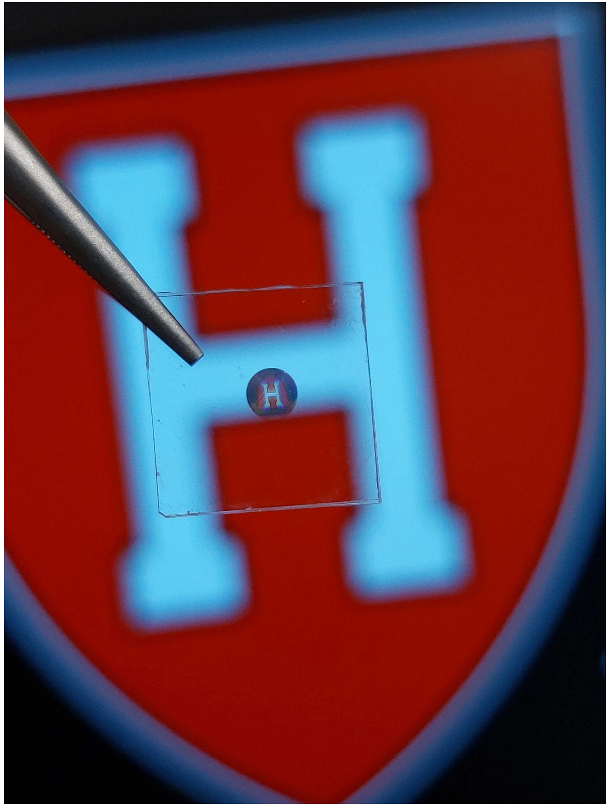
With several months of improving the fabrication recipe, we have been able to push the minimum stable pillar size to new frontiers.





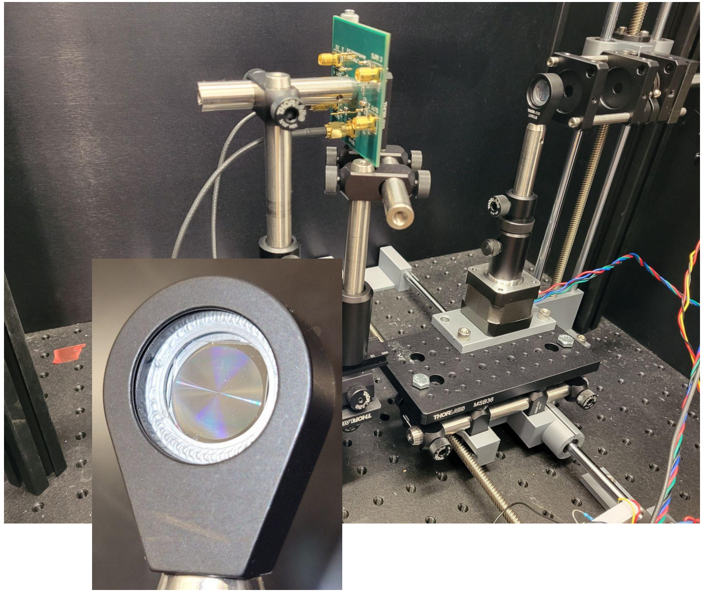
Fabrication

We have also achieved high field-of-view metalenses in the visible range, with NA > 0.5.

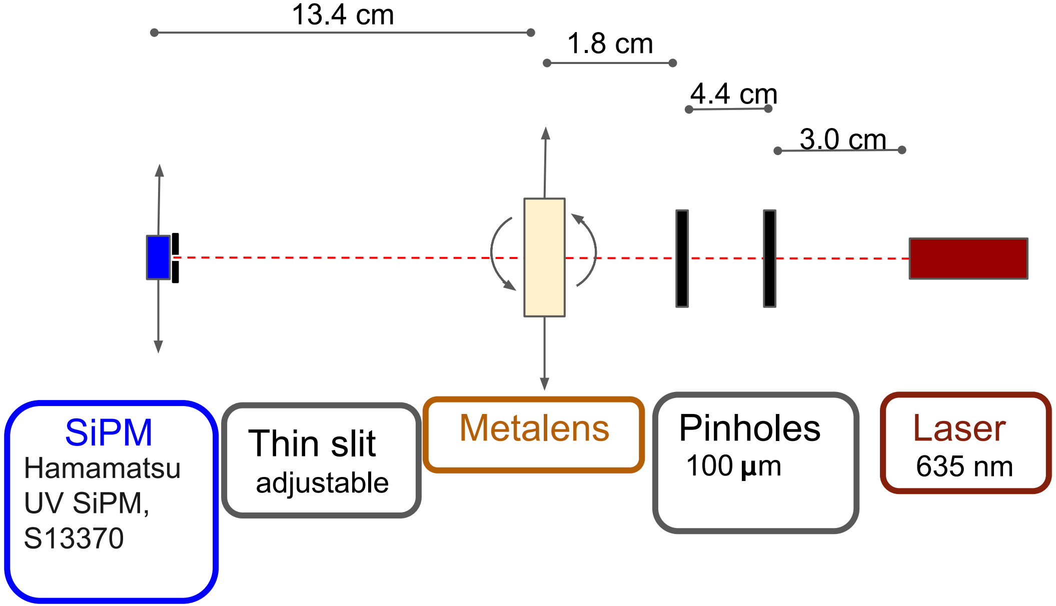


Metalens Characterization

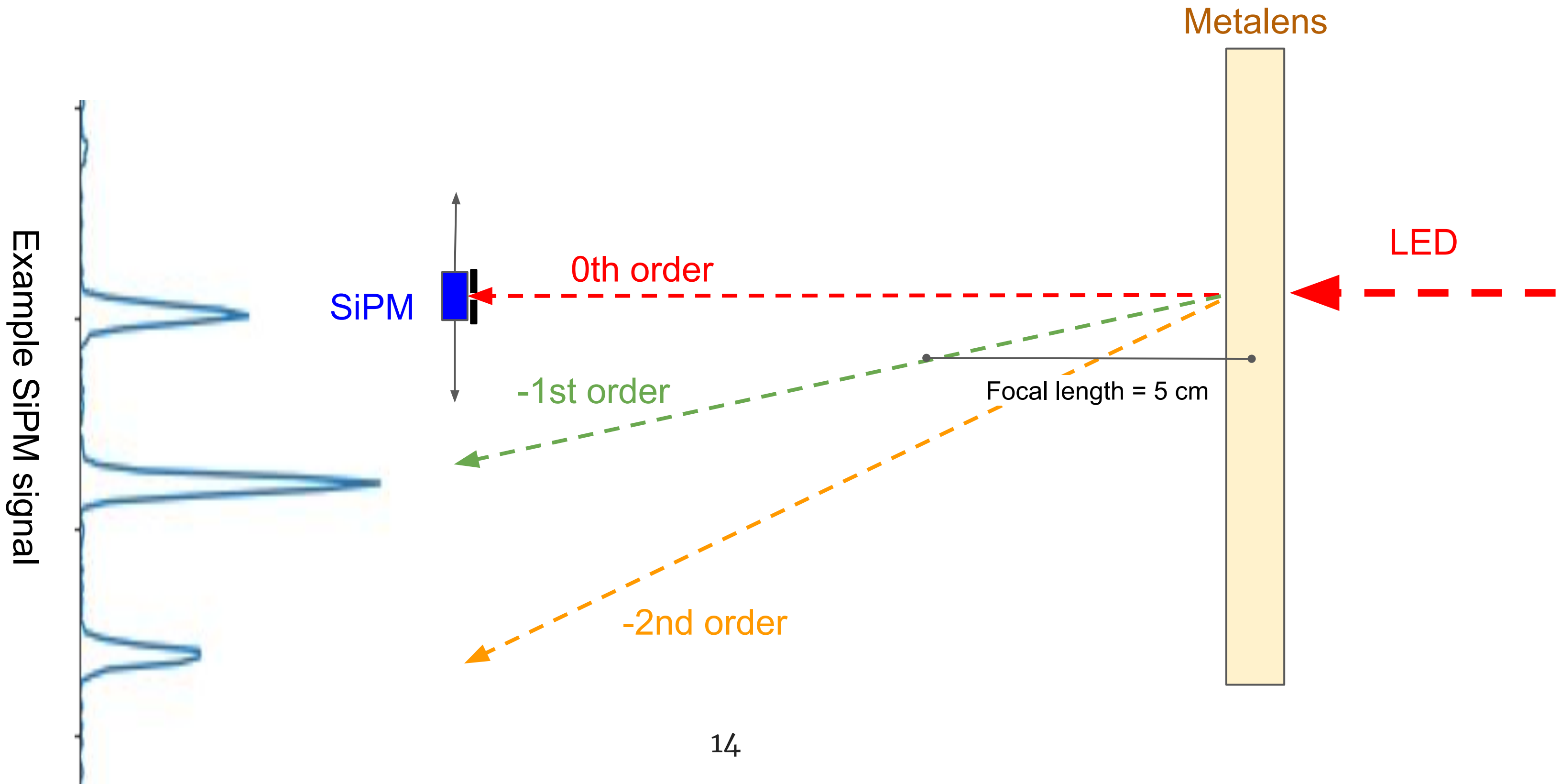
By Taylor Contreras



Face down View of Setup

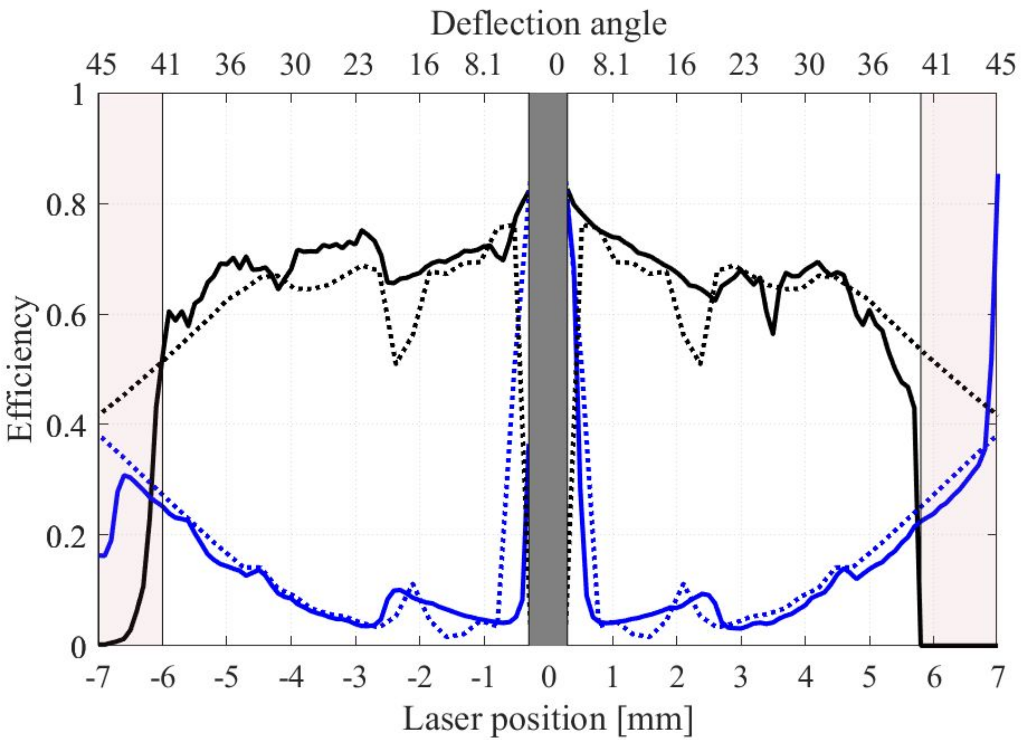


Metalens Characterization



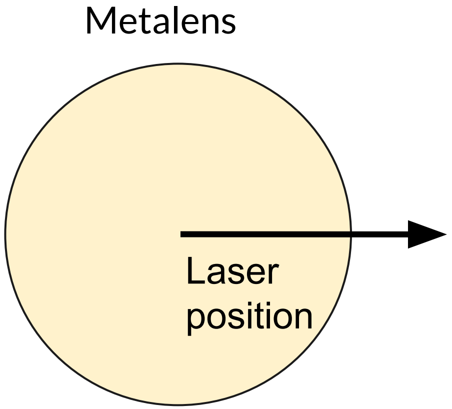
Characterization Results

From latest high field-of-view metalens



0th order (goes straight through)

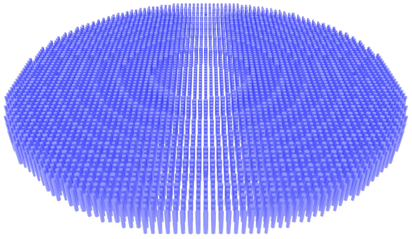
1st order (deflected toward focal point)



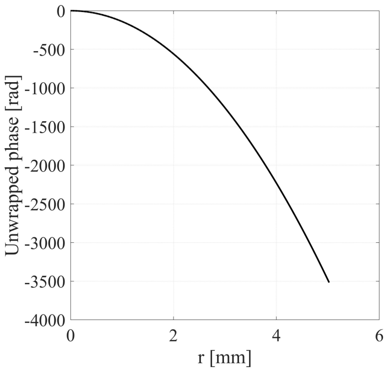
Simulated Performance

by Augusto Martins

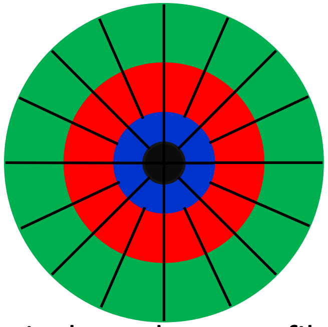
Metalens Ideal



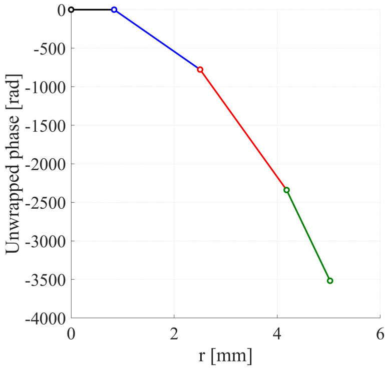
Equivalent phase profile:



Metalens model



Equivalent phase profile:



After we characterize a metalens, we would like to see how it would perform in a physics detector.

In a physics detector, light rays can come from all angles. Due to the time it takes to characterize a lens at one input angle, we are not able to directly characterize every metalens at every input angle.

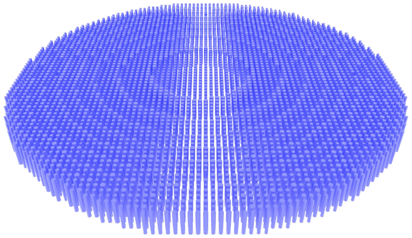
Traditional metalens simulation methods are used to simulating only one input angle, and take 10s of CPU hours. To simulate a metalens for a physics detector in this way would take weeks.

Instead, we use an approximation with a piece-wise linear phase profile.

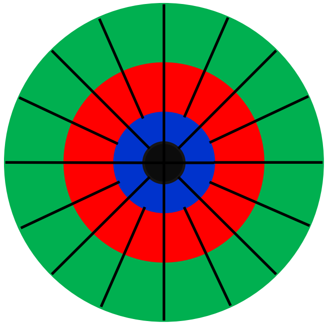
Simulated Performance

by Augusto Martins

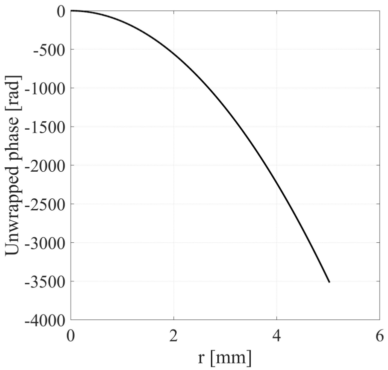
Metalens Ideal



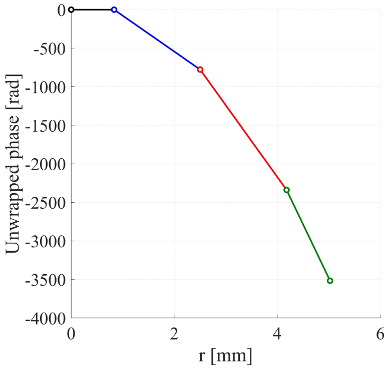
Metalens model



Equivalent phase profile:



Equivalent phase profile:



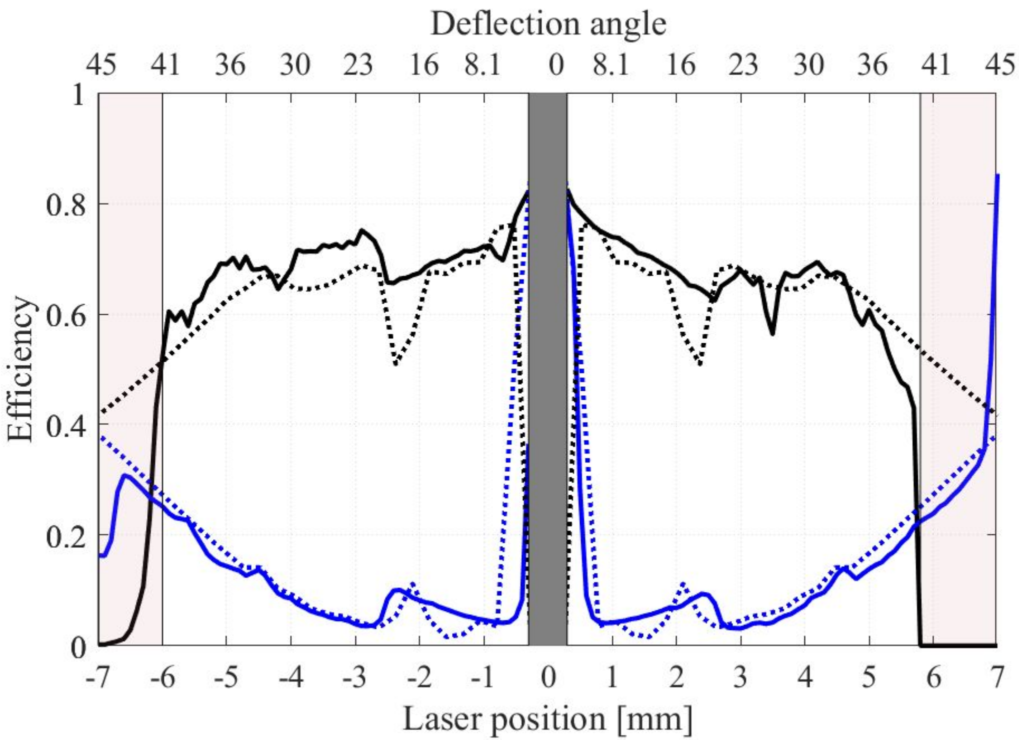
Each color represents a region with a radial blazed binary grating with constant period P.

Then we only need to rigorously simulate N parts to obtain the transfer function for each region.

Each transfer function contains the complex amplitude of all diffraction orders scattered by each piece as function of the angle of incidence for different polarization states.

Simulation Results

From latest high field-of-view metalens



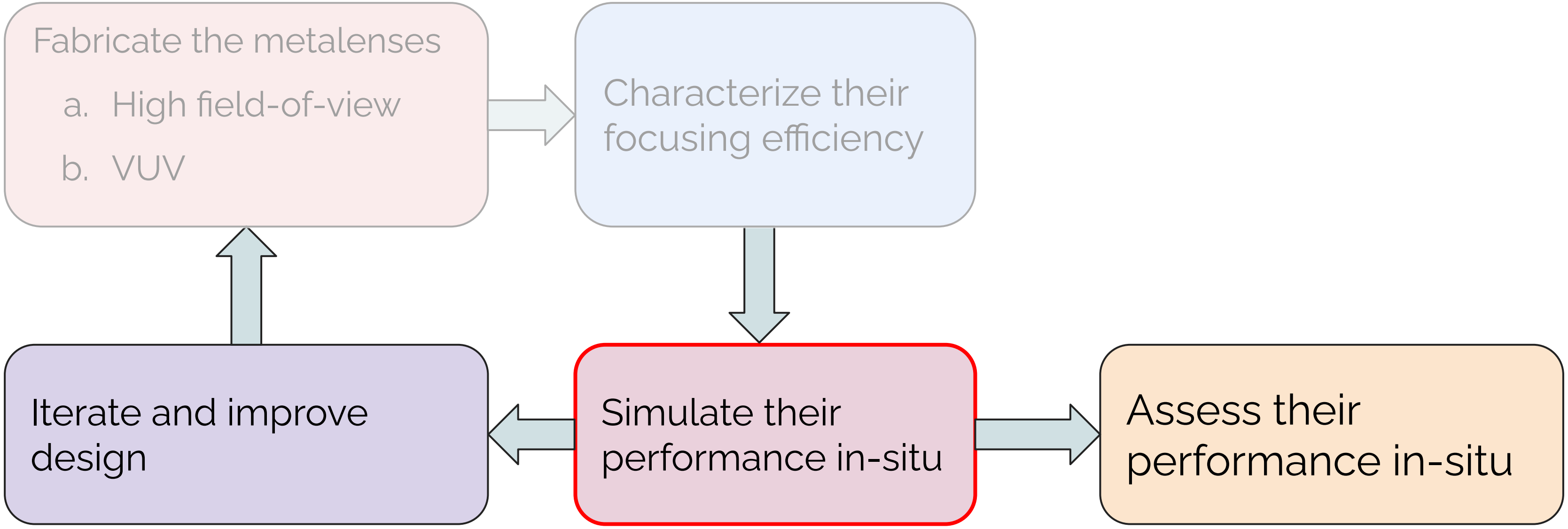
0th order (goes straight through)

1st order (deflected toward focal point)

This approximation holds up very well with our characterization measurements.

This gives us the confidence and ability to assess the efficiency of new metalens designs before we fabricate them.

Next steps


Fabricate the metalenses
a. High field-of-view
b. VUV
Characterize their focusing efficiency
Simulate their performance in-situ
Iterate and improve design
Assess their performance in-situ

Summary

- Metalenses are cheap diffractive lenses that can be used in place of traditional lenses.
- We have refined our fabrication recipe and are now able to produce VUV and hi field of view metalenses.
- We have developed a technique for the rapid characterization and simulation of metalens designs, and confirmed its accuracy via experiment.
- We are using these tools to assess a variety applications for metalenses in physics detectors, and continuing to iterate on our designs for further improvement.

Thank You