Large-scale discovery of experimental designs in Super-Resolution Microscopy with XLuminA

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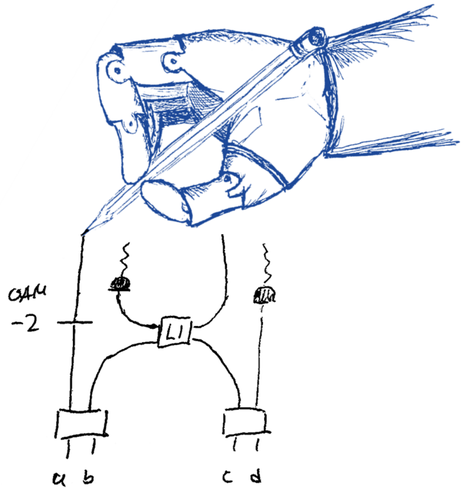

arXiv:2310.08408

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ICML
International Conference
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ABSTRACT SPACE OF ALL EXPERIMENTAL SETUPS

Contains all the **discrete arrangements** of the optical elements and their variable **optical parameters** (e.g., phase)

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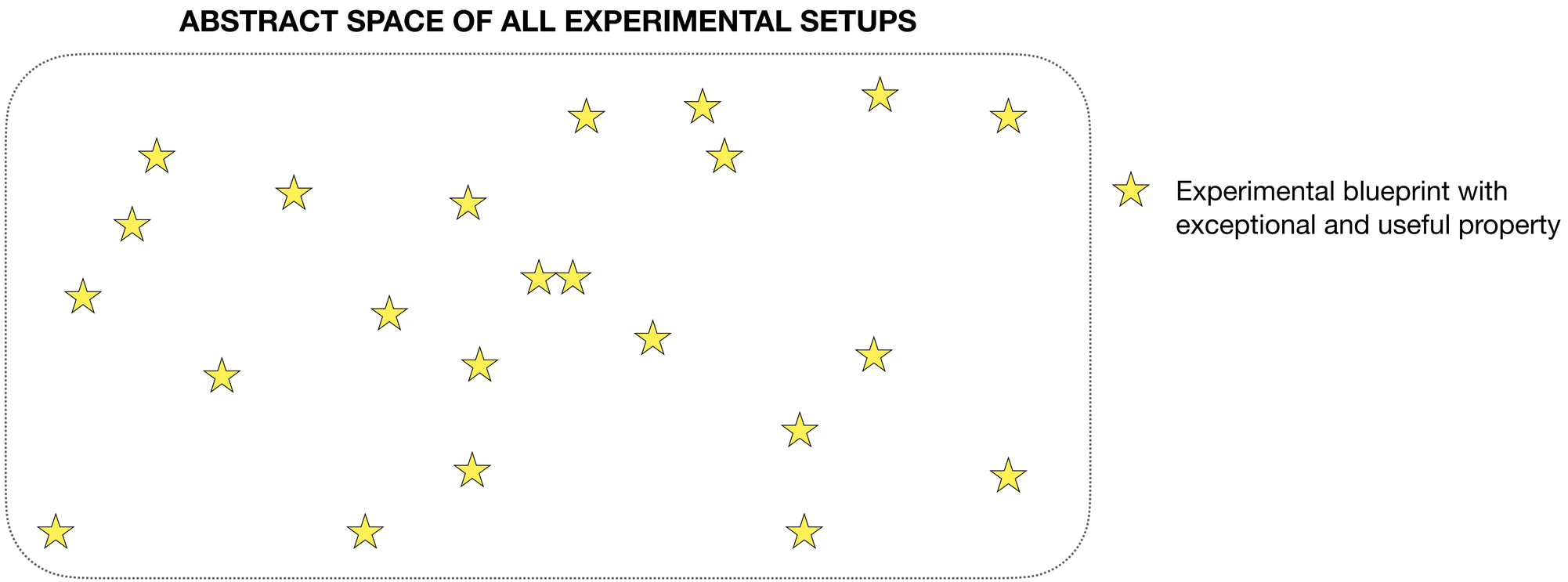

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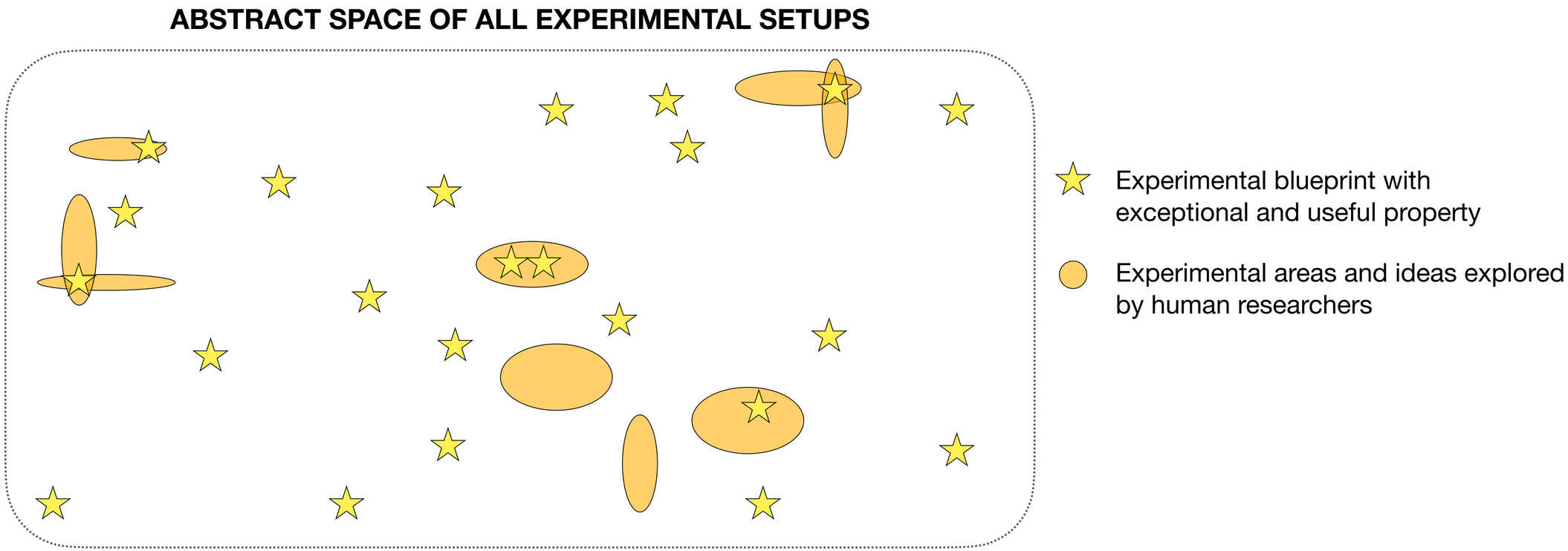

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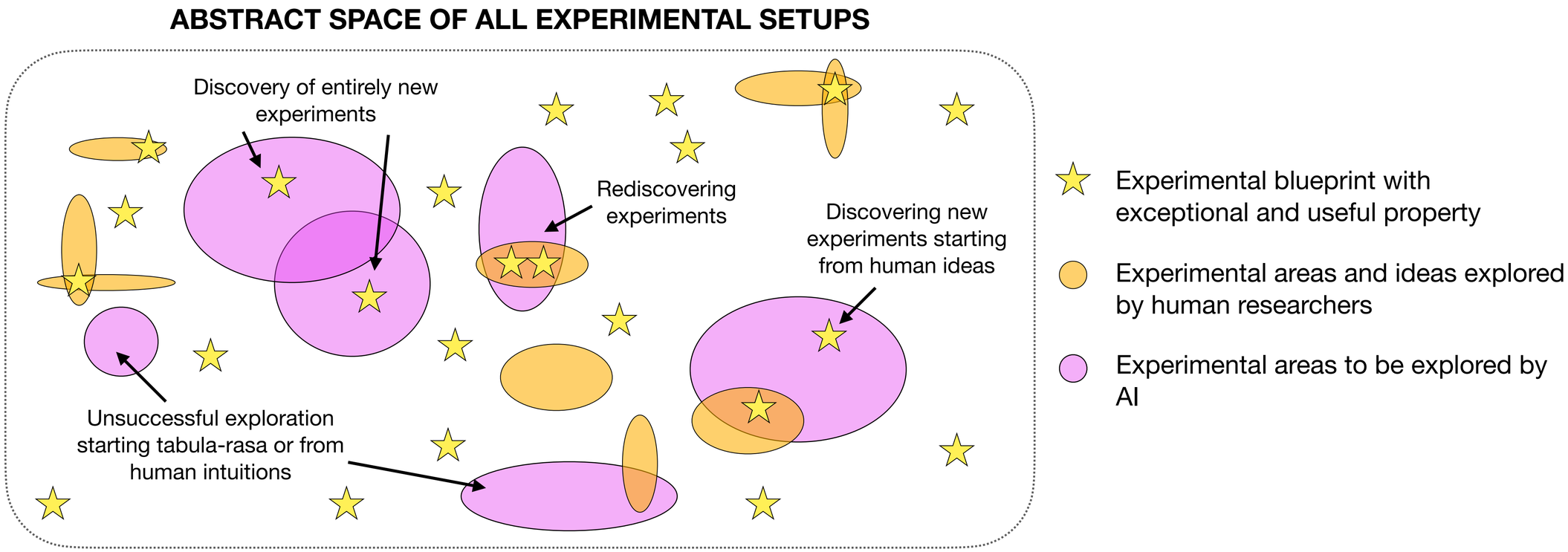
ABSTRACT SPACE OF ALL EXPERIMENTAL SETUPS
Discovery of entirely new experiments
Rediscovering experiments
Discovering new experiments starting from human ideas
Unsuccessful exploration starting tabula-rasa or from human intuitions
Experimental blueprint with exceptional and useful property
Experimental areas and ideas explored by human researchers
Experimental areas to be explored by AI

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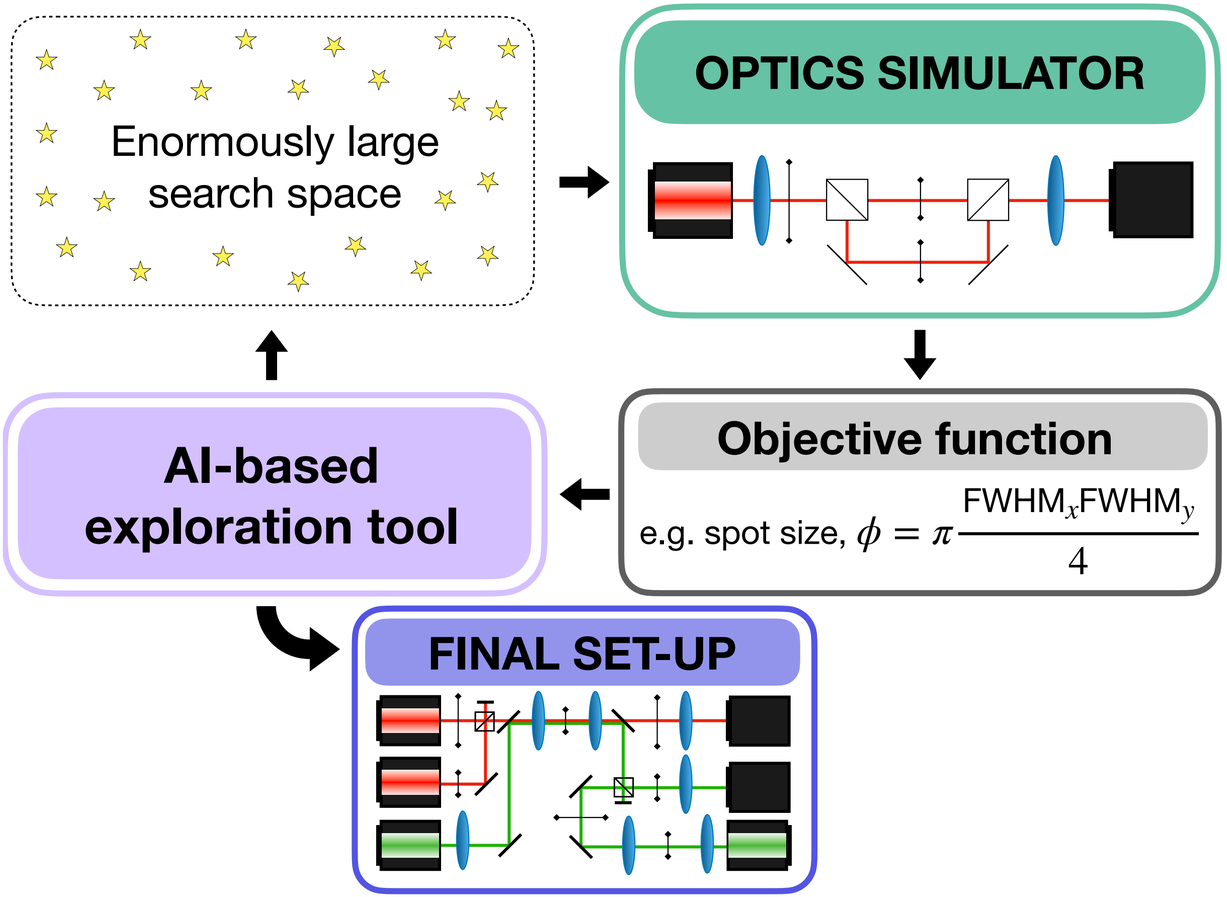
XLUMINA's workflow



AI discovery tool for SR microscopy.

Optics simulator: the most computationally expensive part of the optimization loop!

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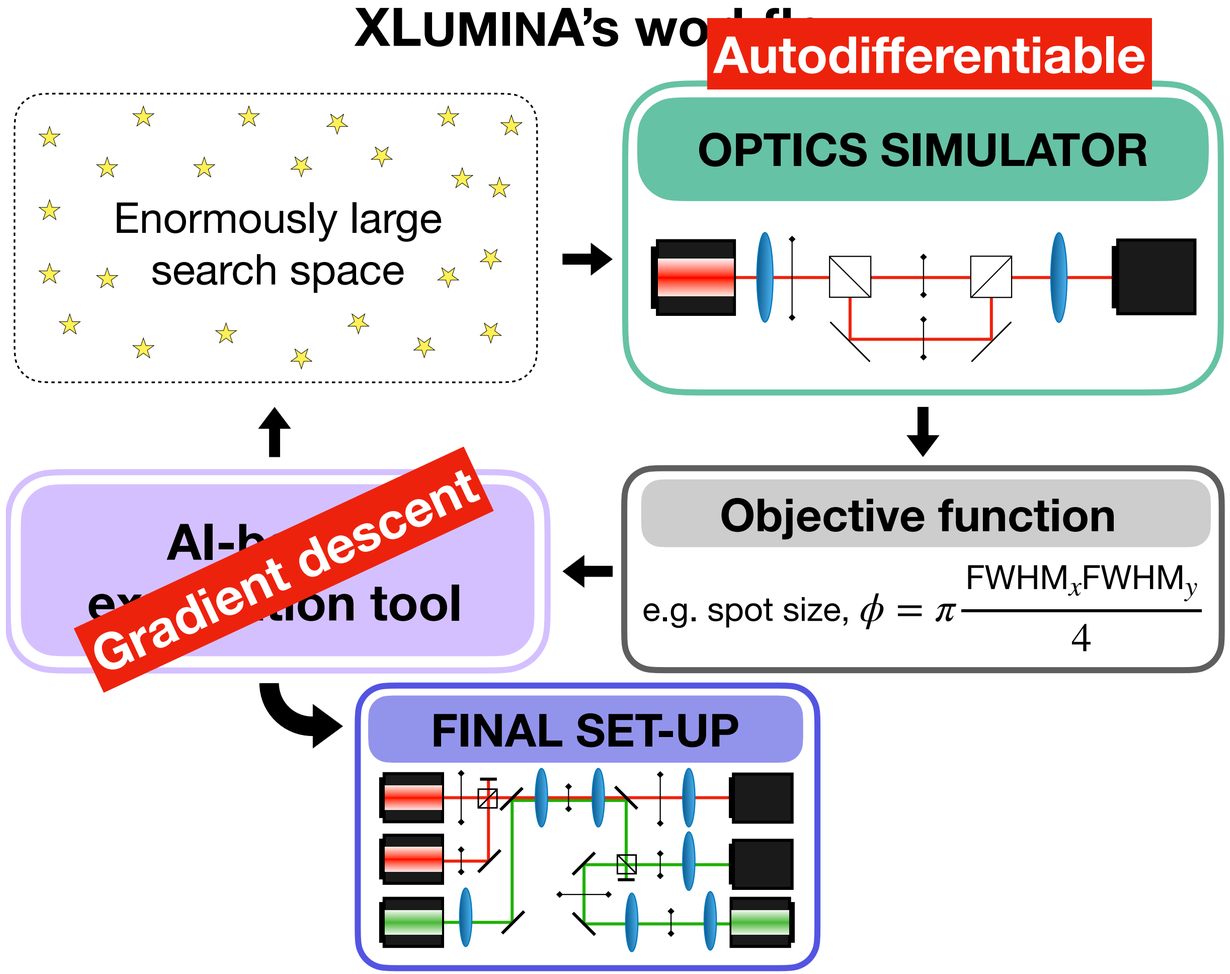

AI discovery tool for SR microscopy.

Very efficient framework!

1. **XLA + just in time compilation**
2. **Auto-differentiation capabilities**
3. **Seamlessly integrated GPU compatibility**

Performance of XLuminA

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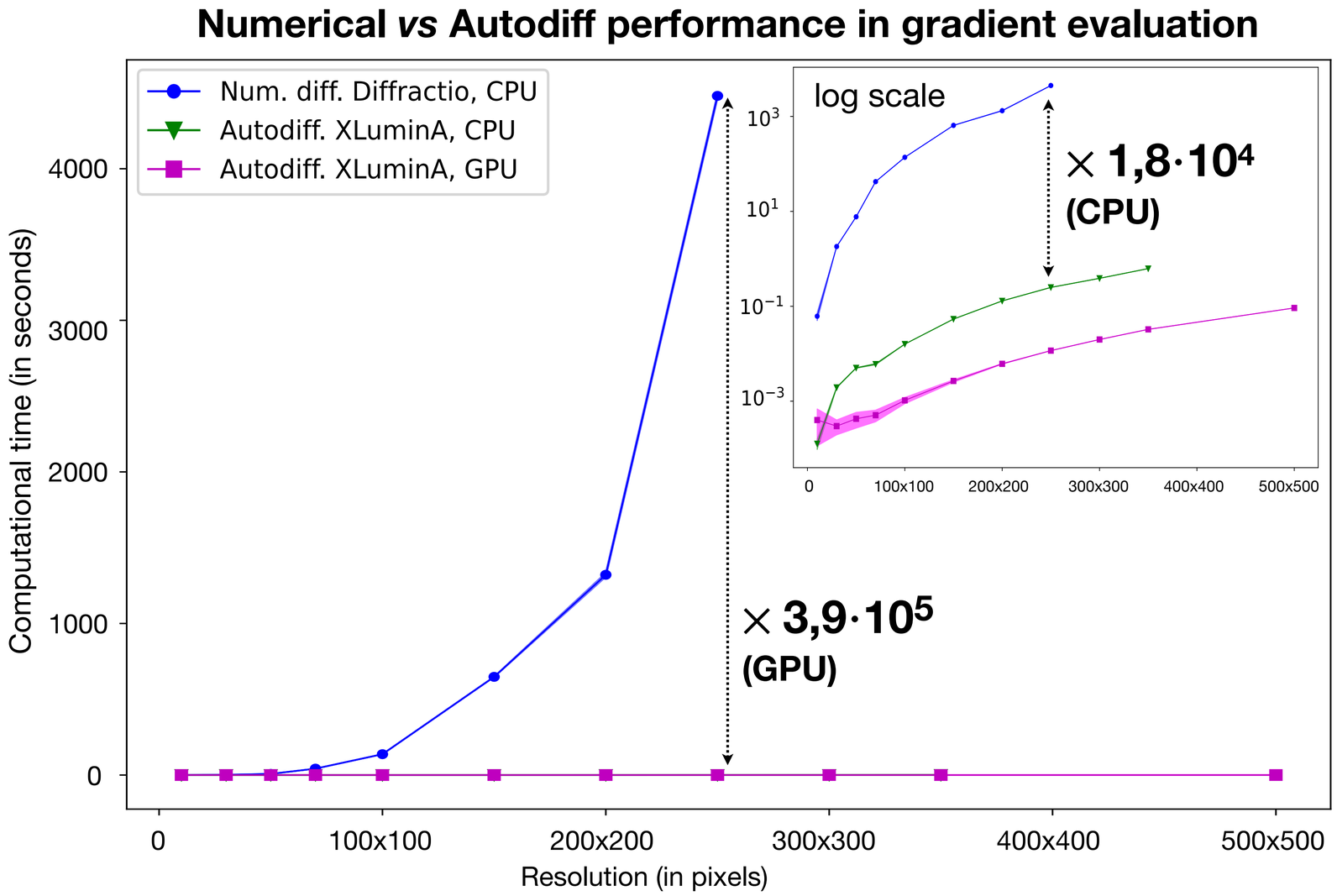

Gradient eval. times in *XLuminA* are up to

5 orders of magnitude faster

than using available *open-source* optics simulators

(NumPy-based, restricted to CPU)

Diffractio, python module for diffraction and interference optics (2019)

Large-scale discovery framework

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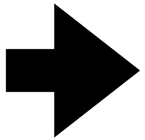
Optics discovery is a discrete-continuous problem: configuring the optical network topology + settings of the optical elements (e.g., phase masks)

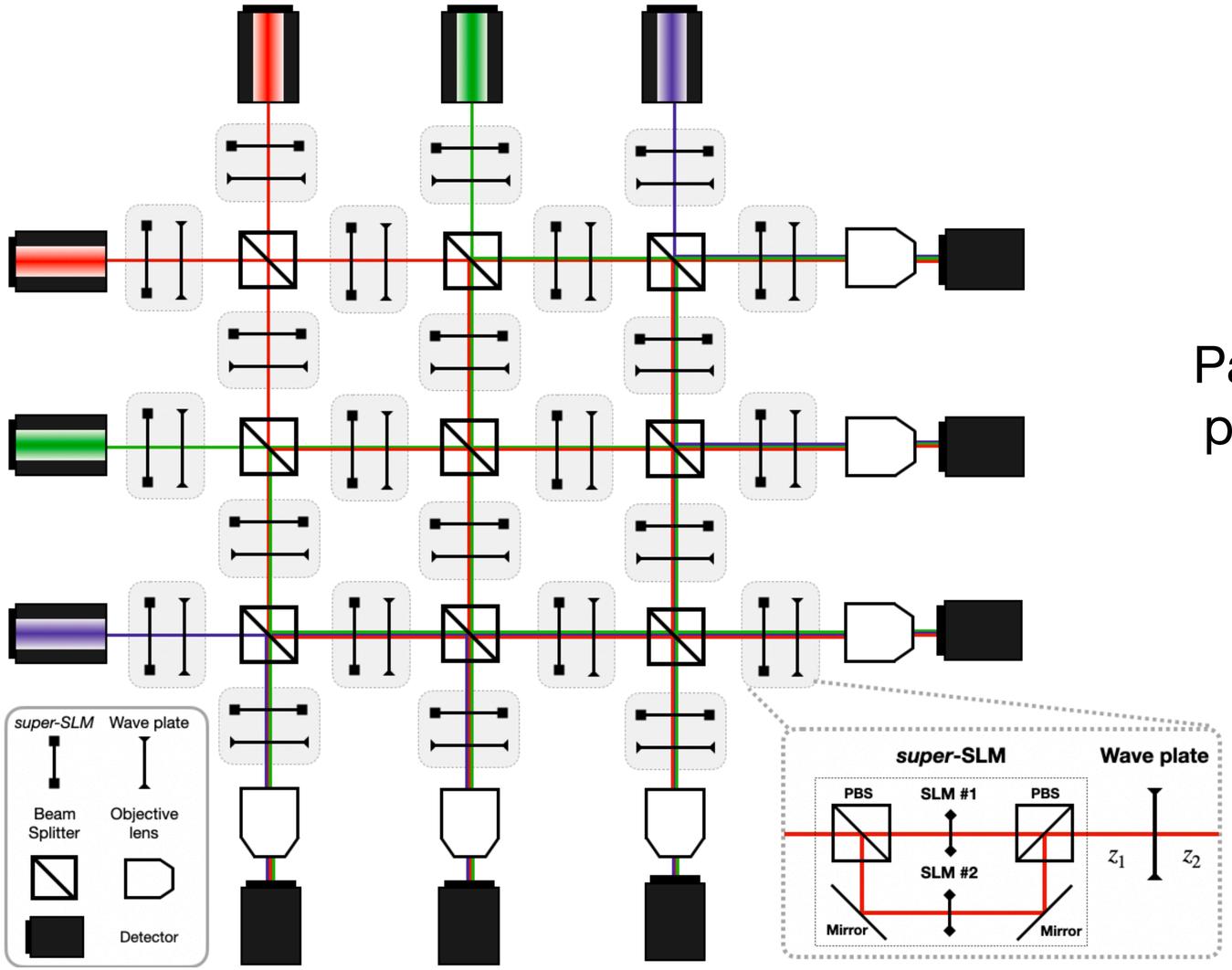


We translate the hybrid discrete-continuous optimization into a **purely continuous optimization**

Large-scale discovery framework

arXiv:2310.08408

Computational ansatz:



Parameters are **continuous** (e.g., phases, distances, beam splitter reflection/transmittance)

Benchmarks

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Rediscovery of **2 foundational experiments** covering different areas in optics:

1. Polarization-based beam shaping as used in STED microscopy

   [Hell and Wichmann, 1994]

2. Sharper focus for a radially polarized light beam

   [Dorn, Quabis and Leuchs, 2004]

Rediscovery through exploration

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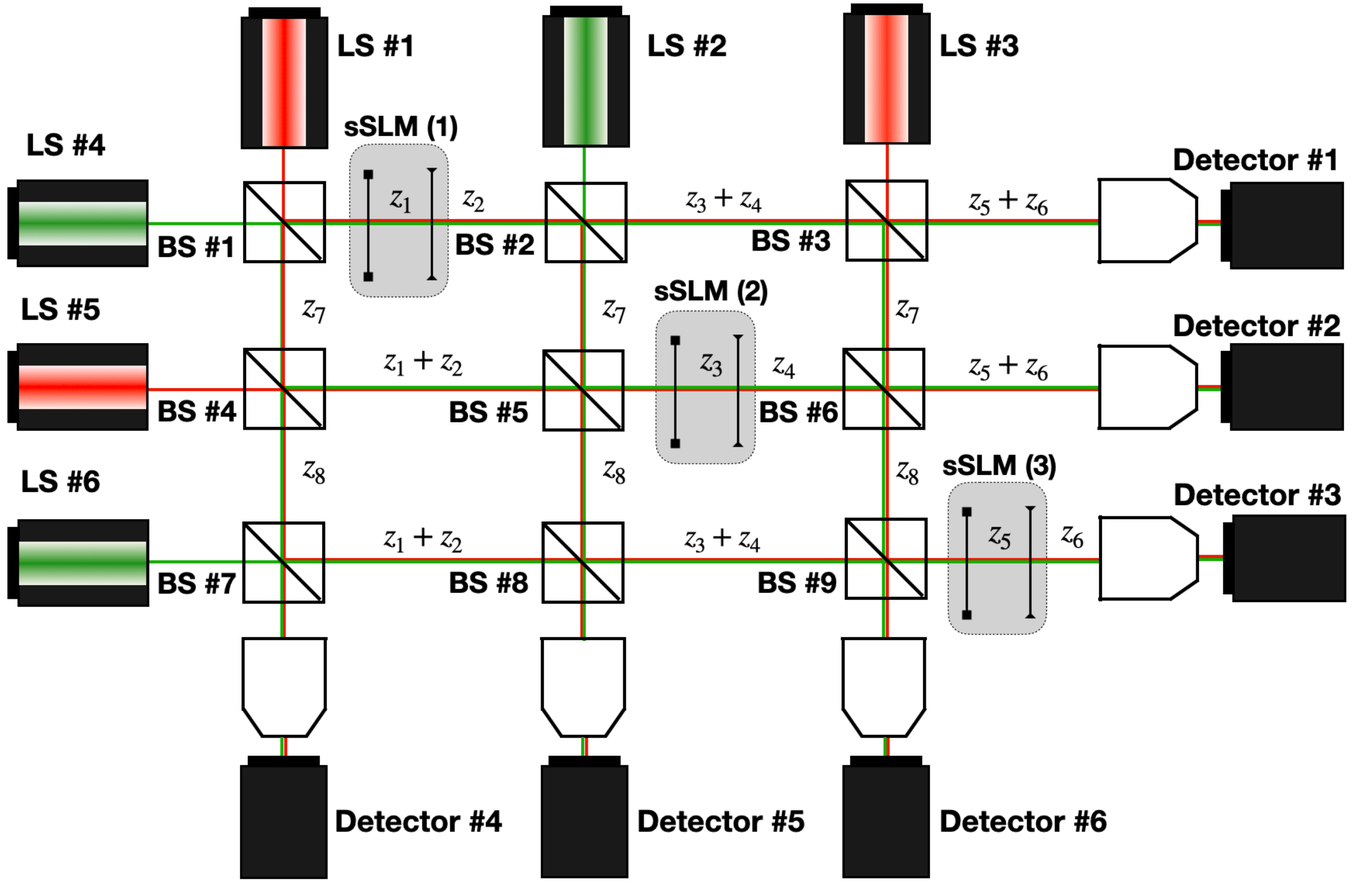
Ansatz:

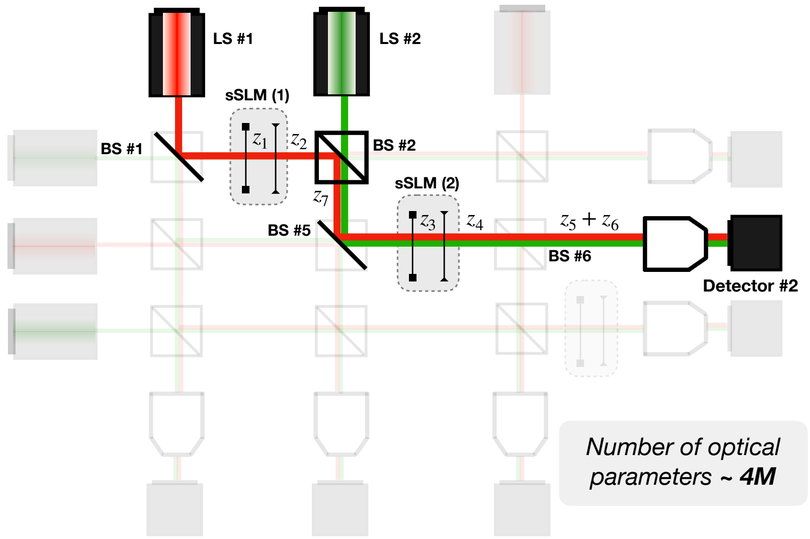


$$\mathscr{L} = \frac{1}{\text{Density of the detected light}}$$

Rediscovery through exploration: *STED microscopy*

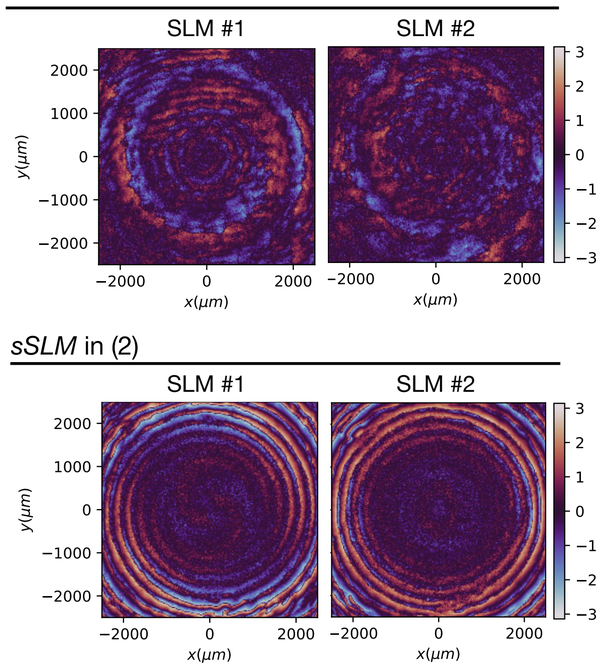
arXiv:2310.08408

Discovered optical layout for Hell and Wichmann (1994)

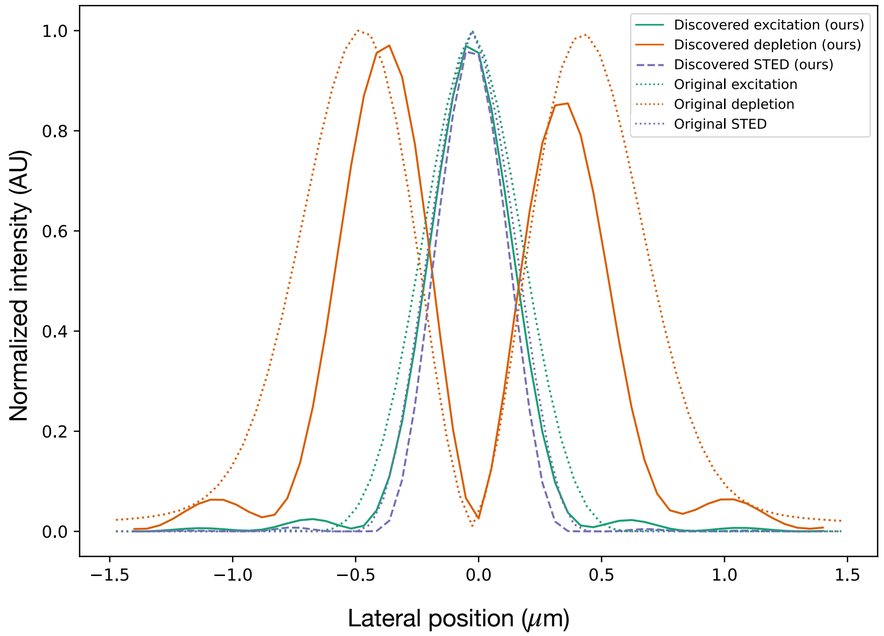


Number of optical parameters ~ ***4M***

Discovered phase masks



Radial intensity profile at focal plane



Rediscovery through exploration: *the sharper focus*

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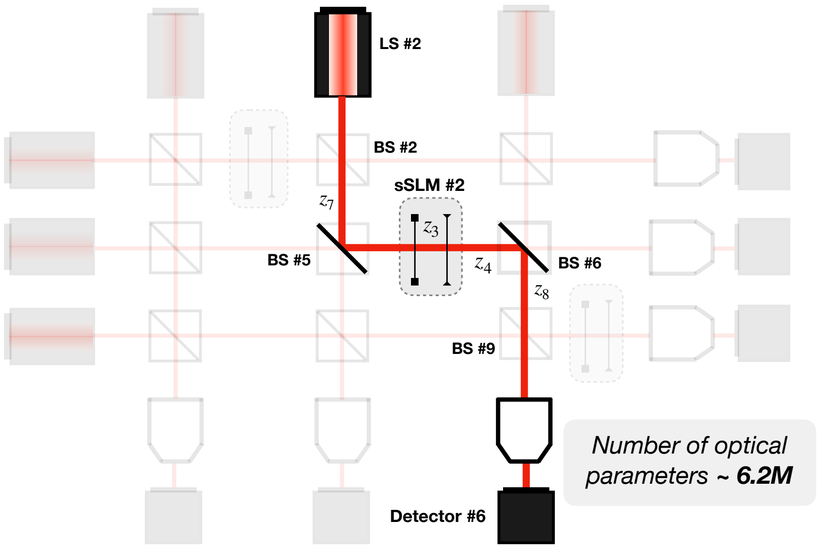
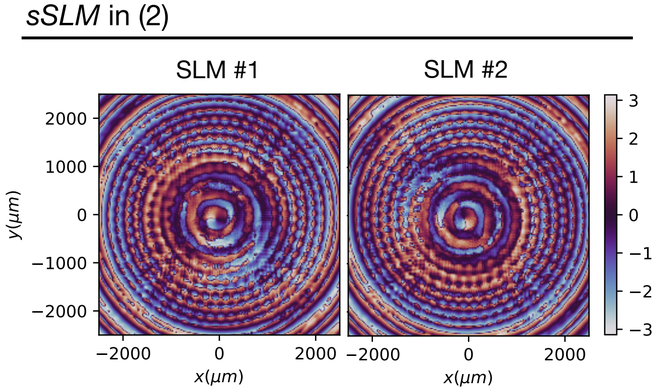
Discovered optical layout for Dorn, Quabis and Leuchs (2004)

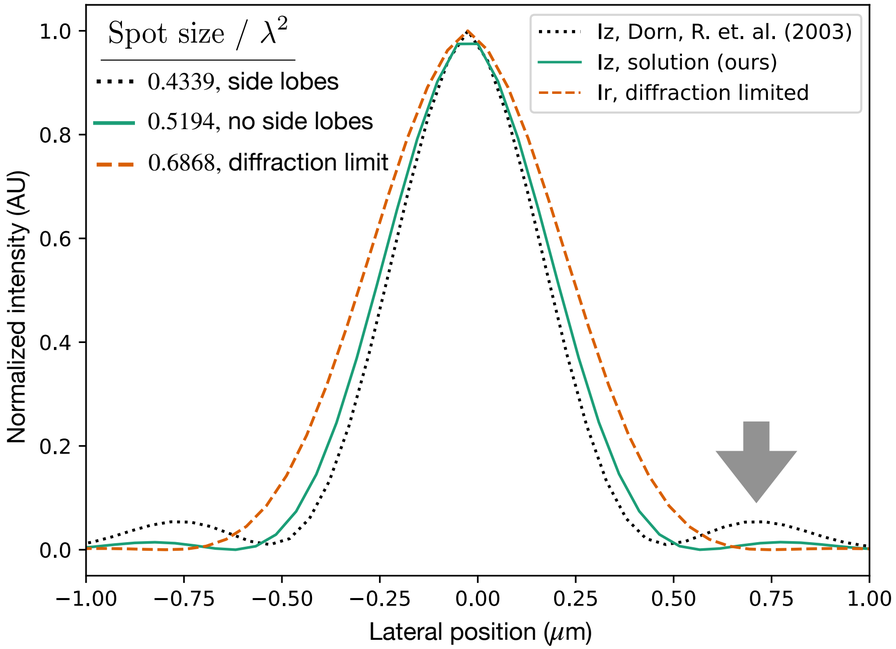


Number of optical parameters ~ ***6.2M***

Discovered phase masks



Longitudinal intensity profile at focal plane



Rediscovery through exploration: *scaling*

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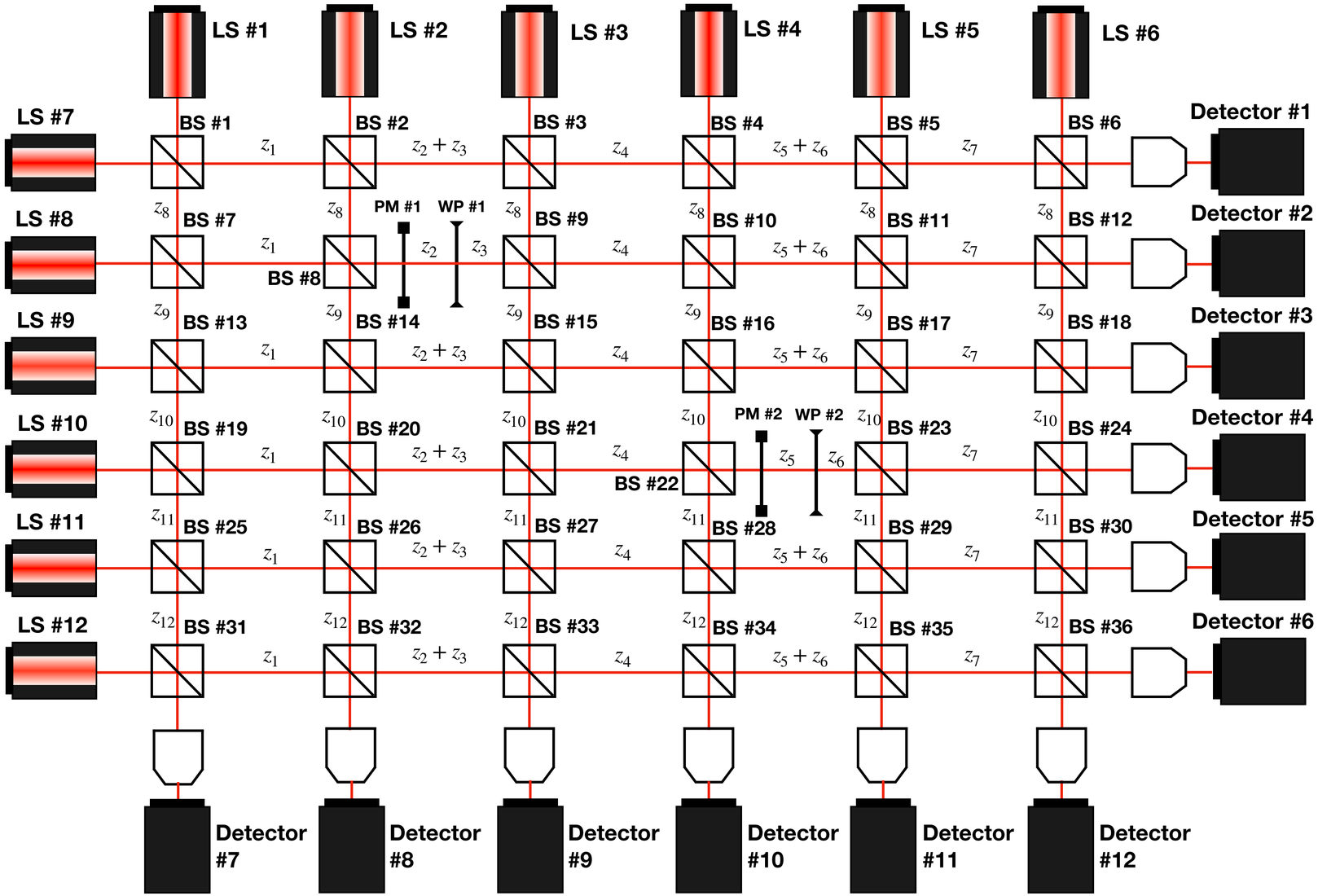
Ansatz:



Rediscovery through exploration: *scaling the larger focus*

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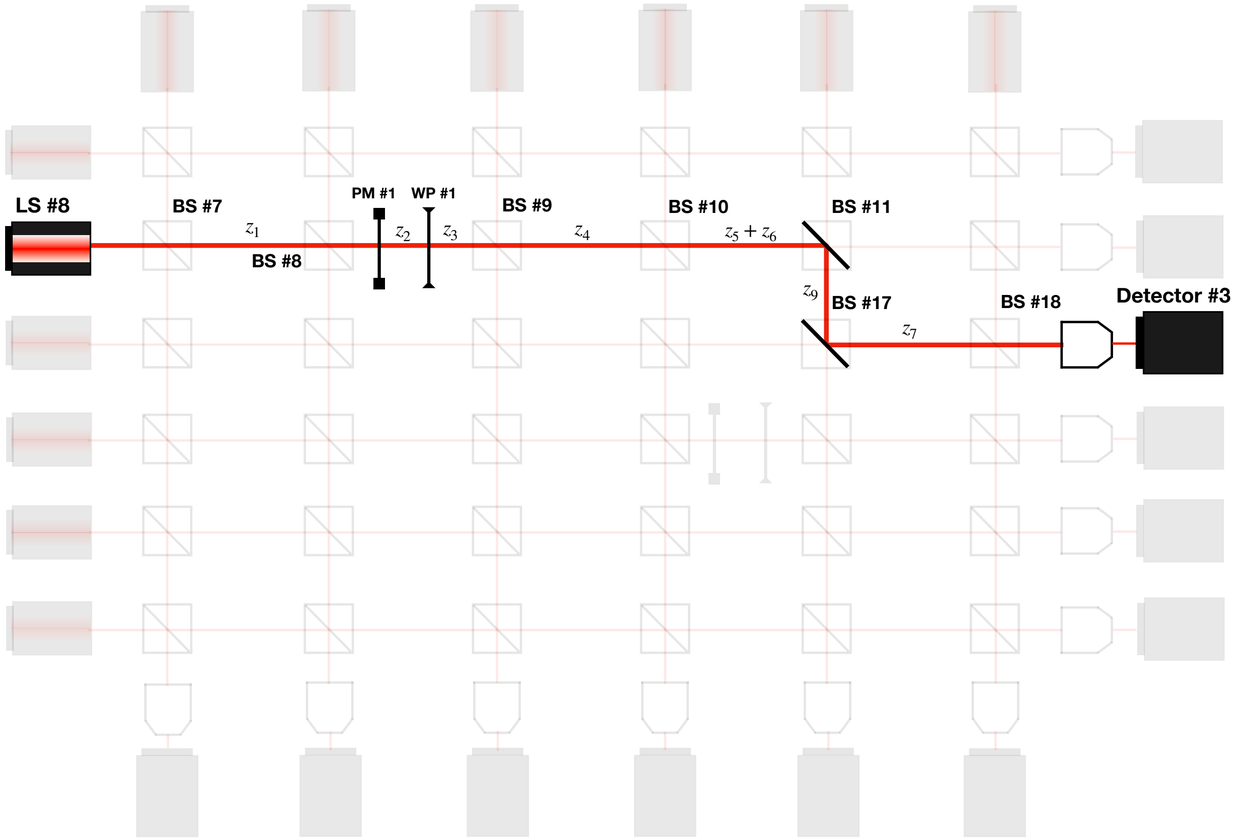
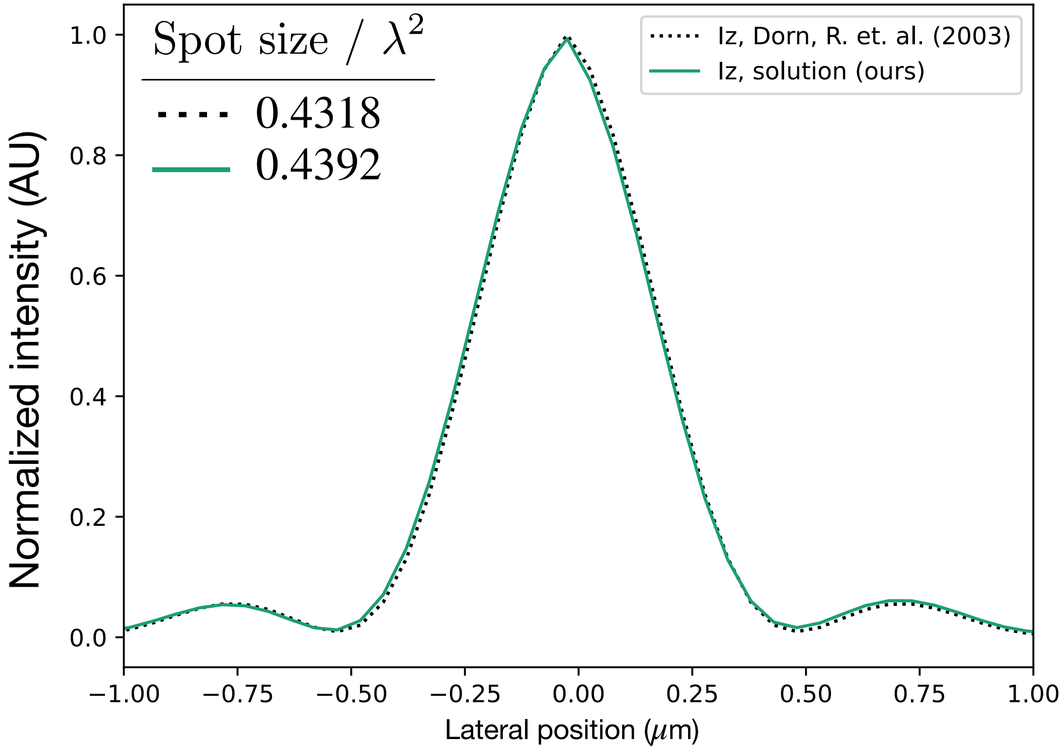
Pure topological discovery for Dorn, Quabis and Leuchs (2003)



Longitudinal intensity profile at focal plane



Discovery of a new experimental blueprint

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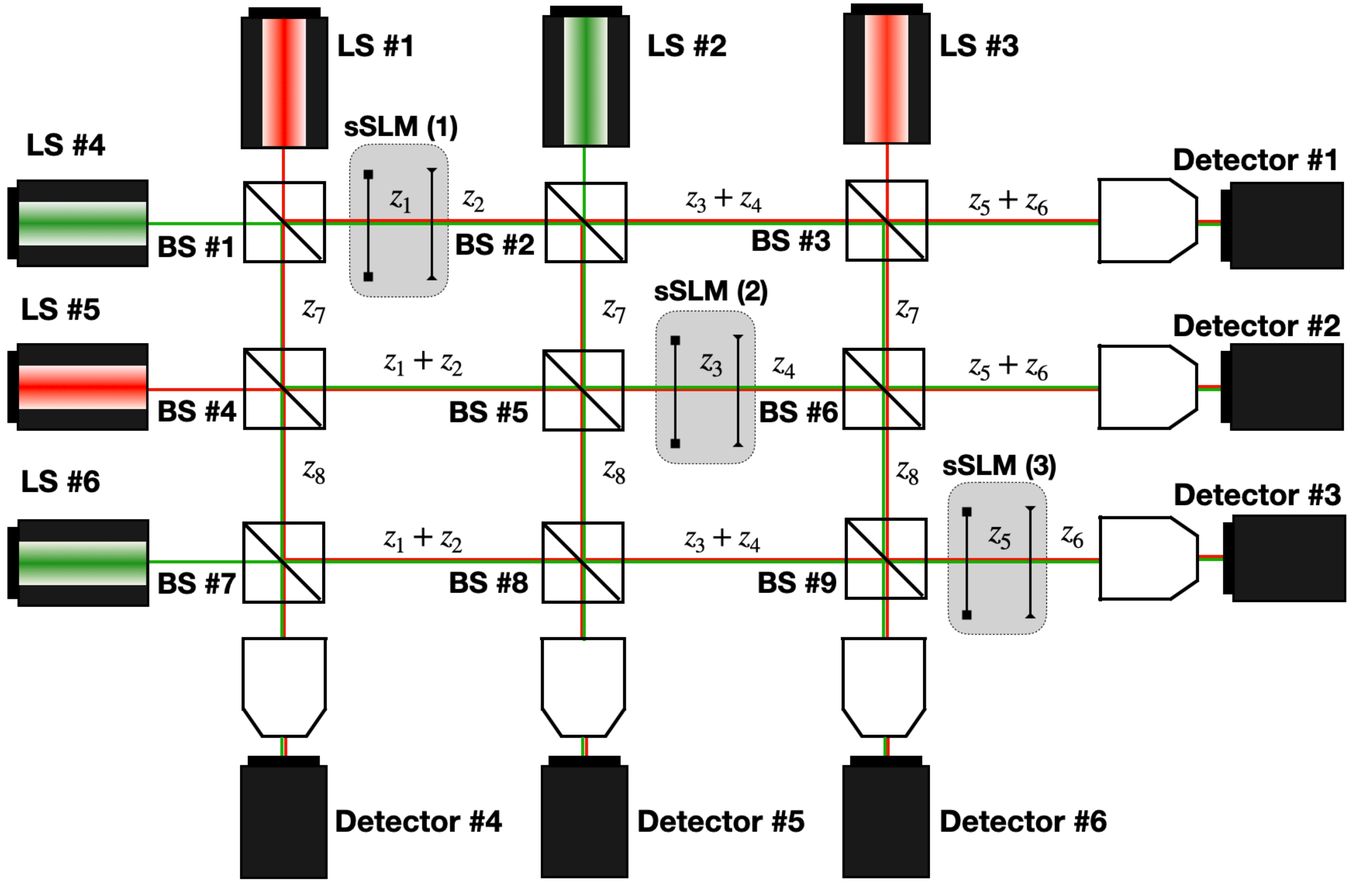
Ansatz:



$$\mathscr{L} = \frac{1}{\text{Density of the detected light}}$$

Discovery of a new experimental blueprint

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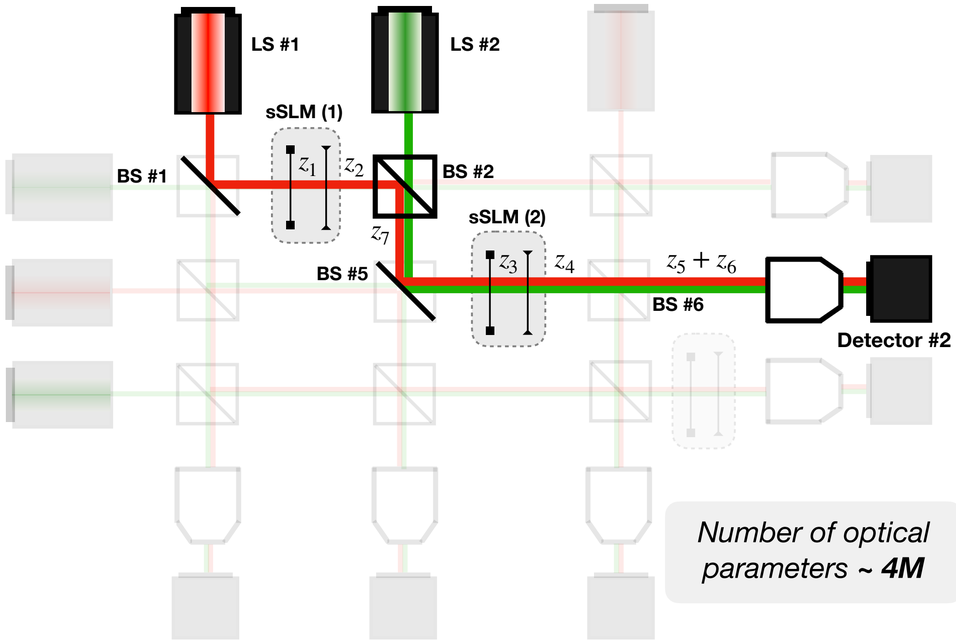
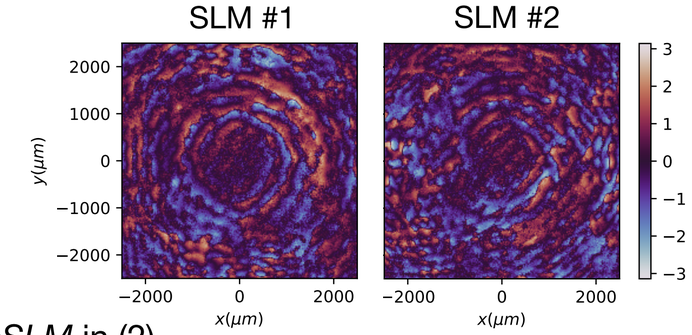
Discovered optical layout



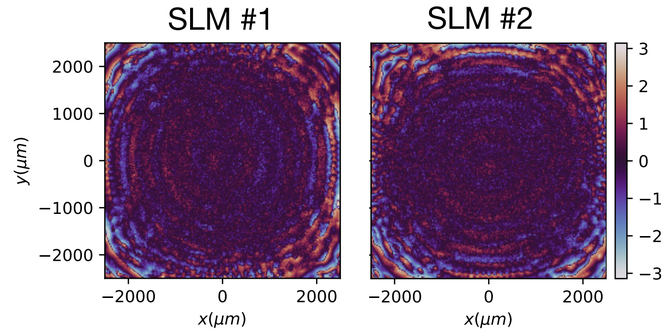
Number of optical parameters ~ ***4M***

Discovered phase masks

sSLM in (1)



sSLM in (2)



Discovery of a new experimental blueprint

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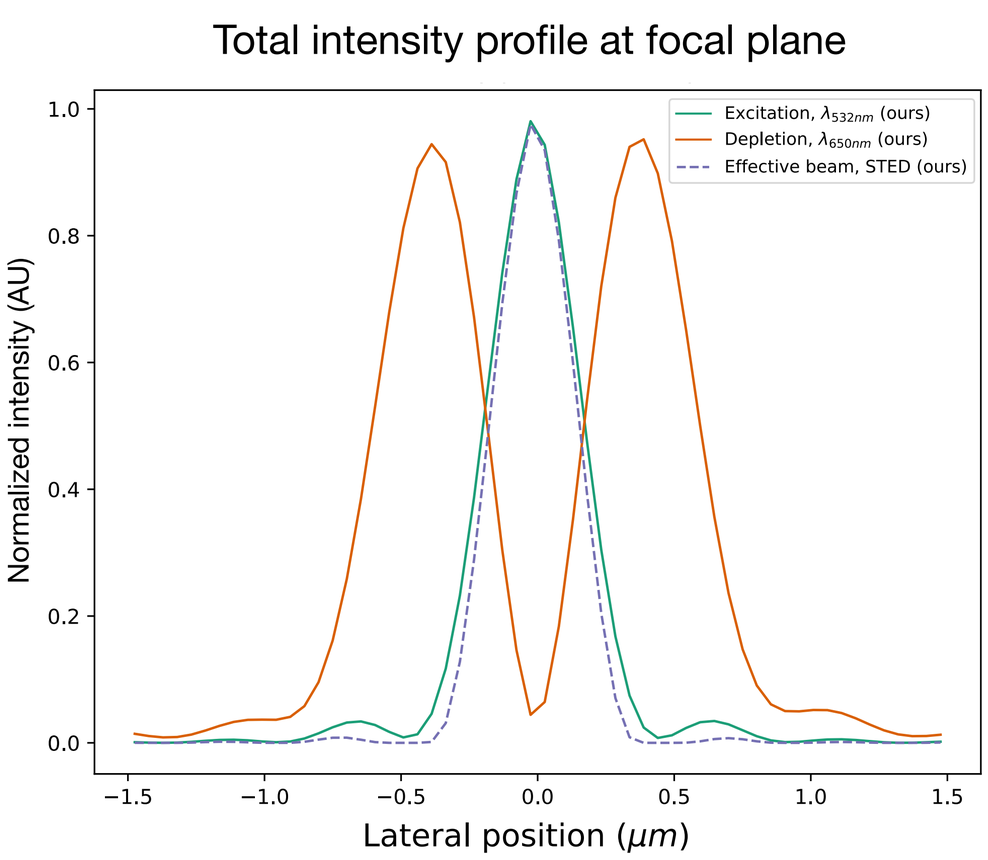
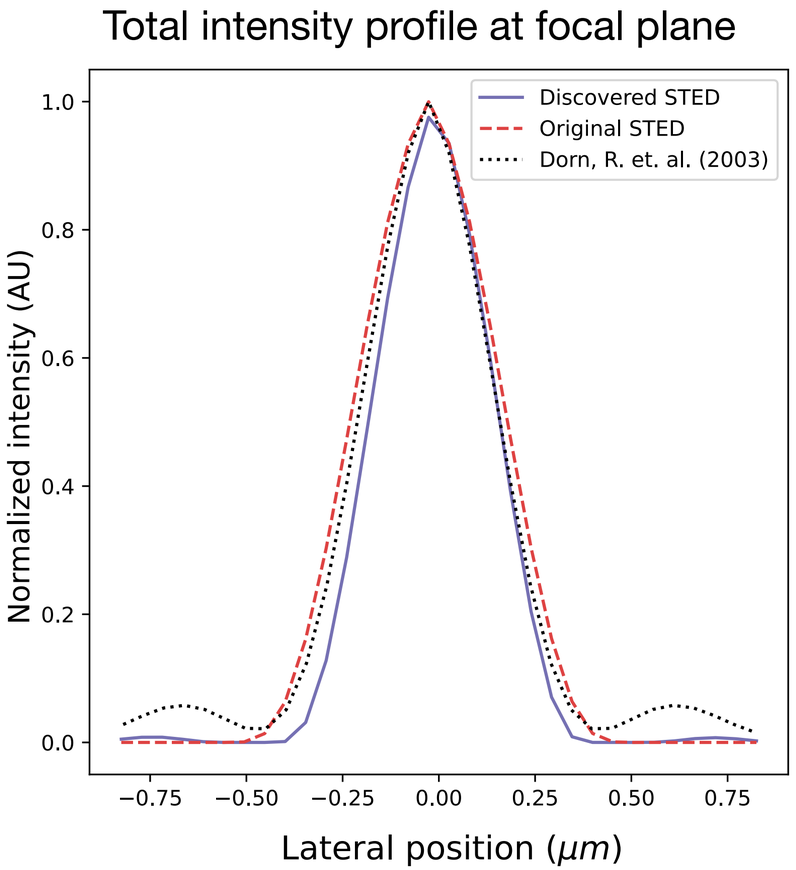




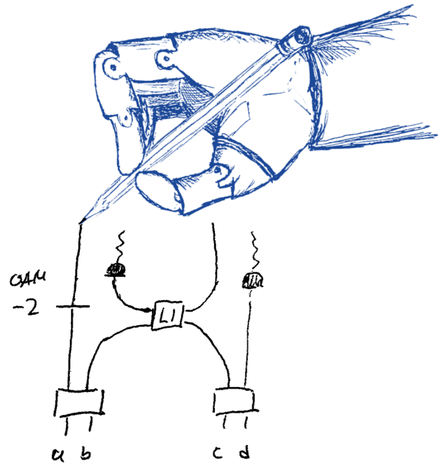
Thank you!

The team

Link to the paper

GitHub repo

Group website



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