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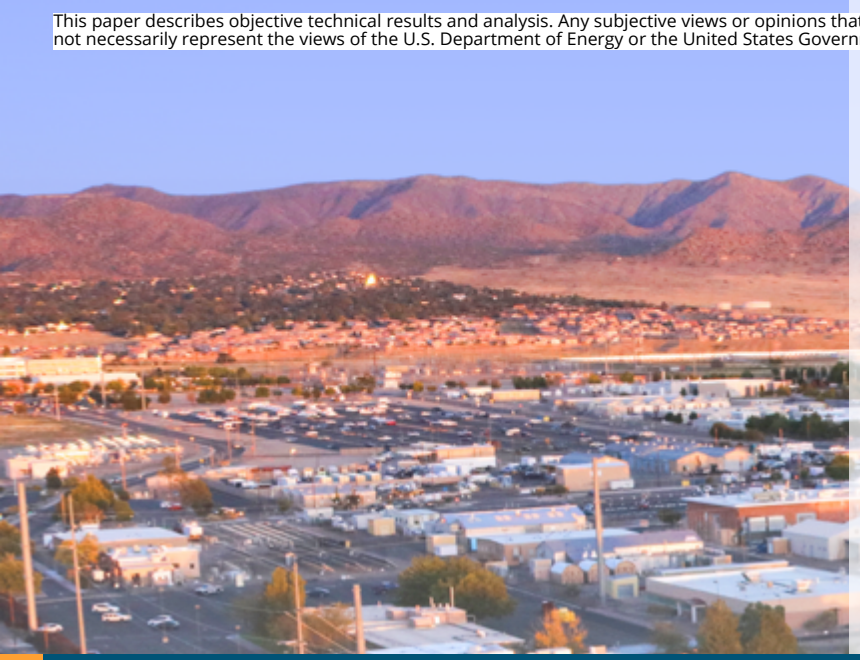

Steering incoherent emission from metasurfaces with machine learning

Saaketh Desai, Remi Dingreville, Prasad Iyer, Igal Brener

Center for Integrated Nanotechnologies

Sandia National Laboratories

MRS Spring 2023 - 12th April 2023

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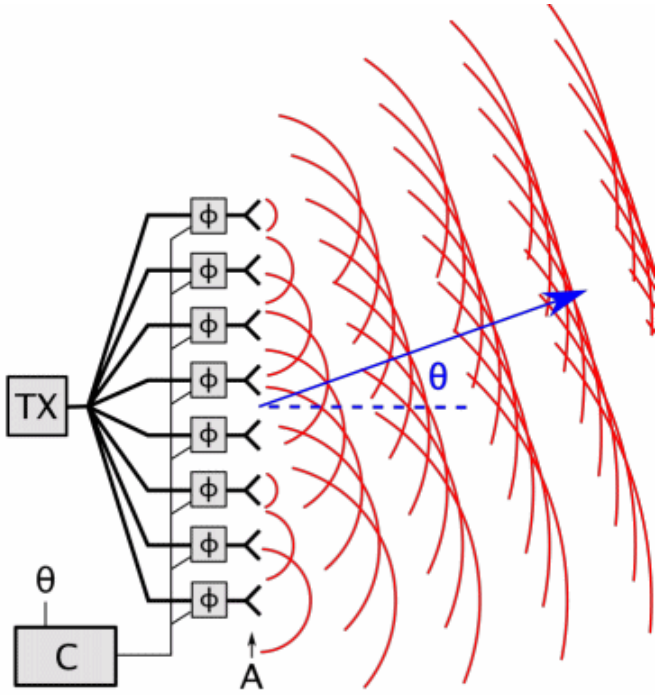
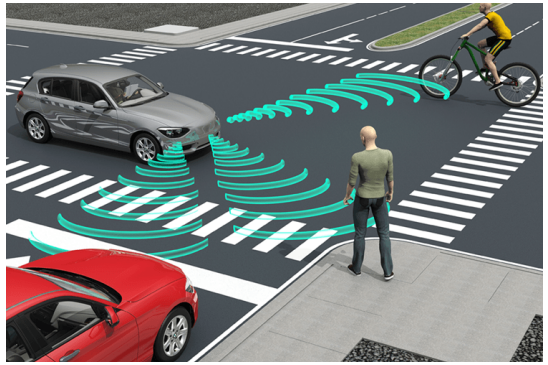
Controlling incoherent emission is challenging



Phased array optics control emission from coherent sources

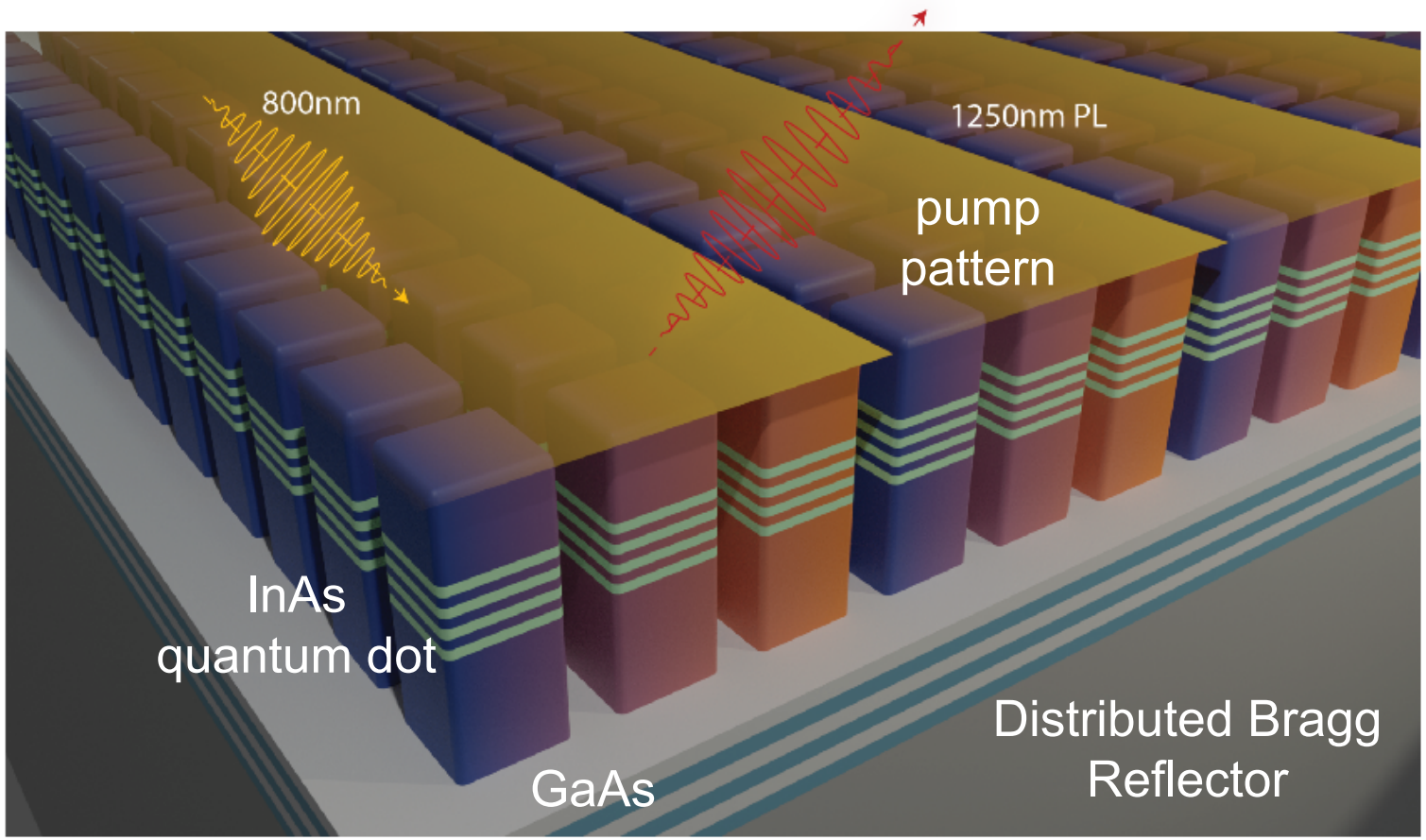
holographic display

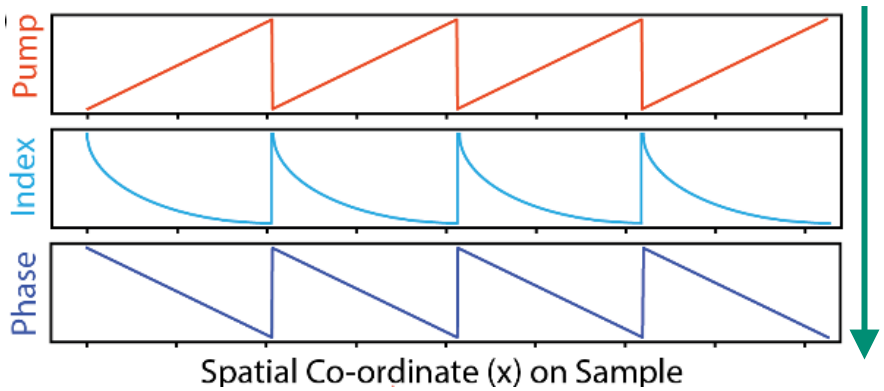


remote sensing

How do we control incoherent sources such as LEDs?

How can we steer incoherent emission?

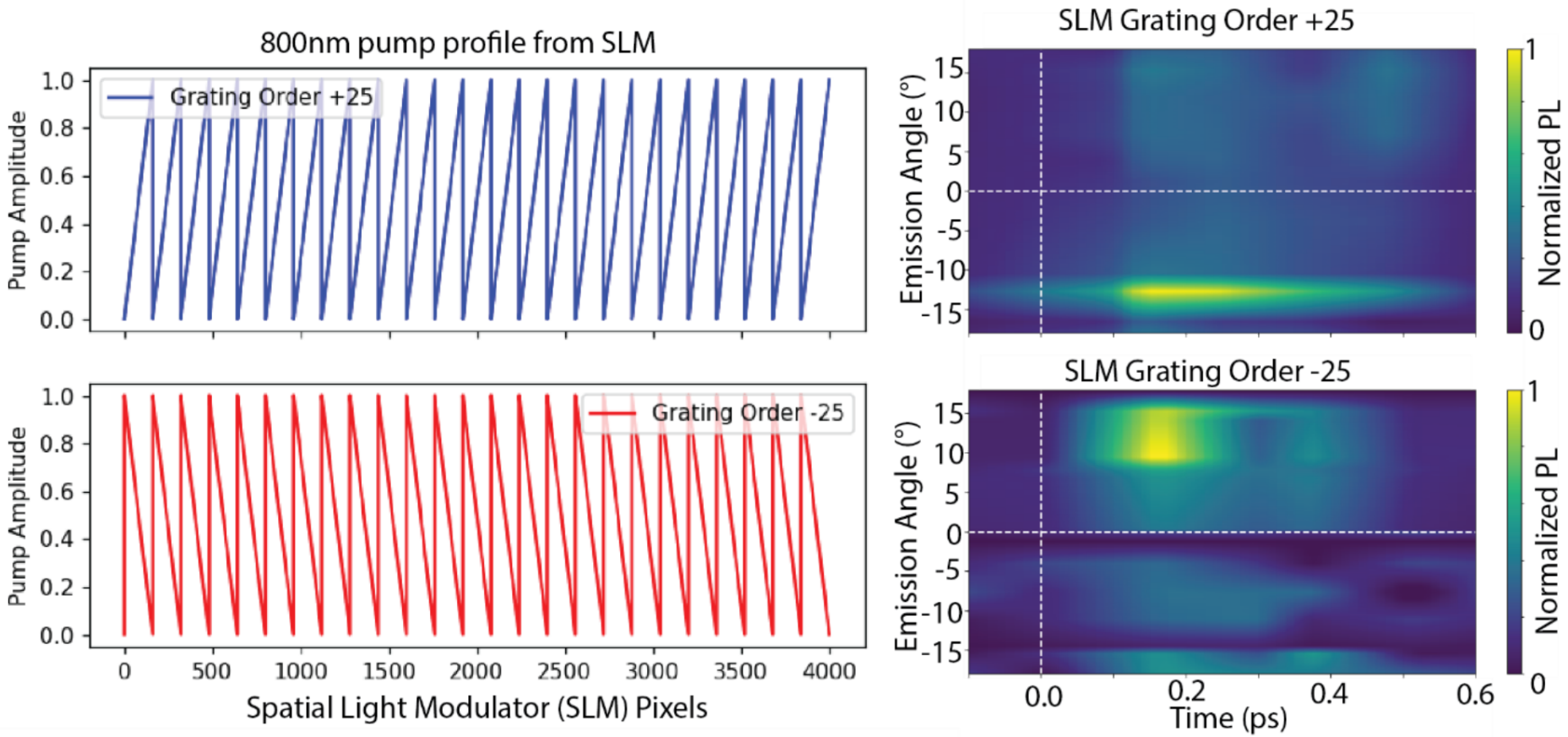


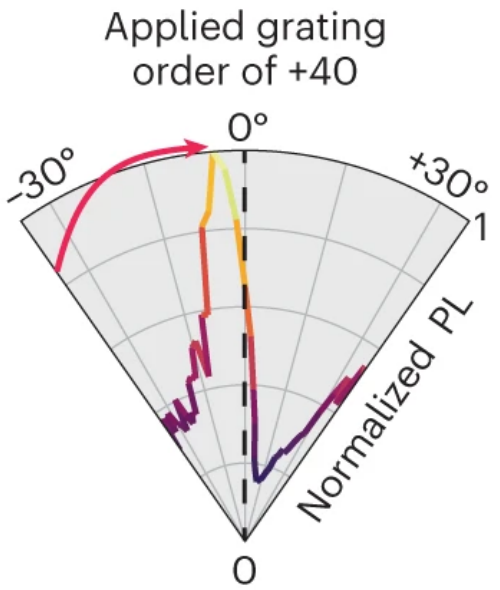


PP Iyer et. al. *Nature Photonics* (2023)

Spatially varying refractive index profiles steer incoherent emission from metasurfaces

What affects the direction of beam steering?





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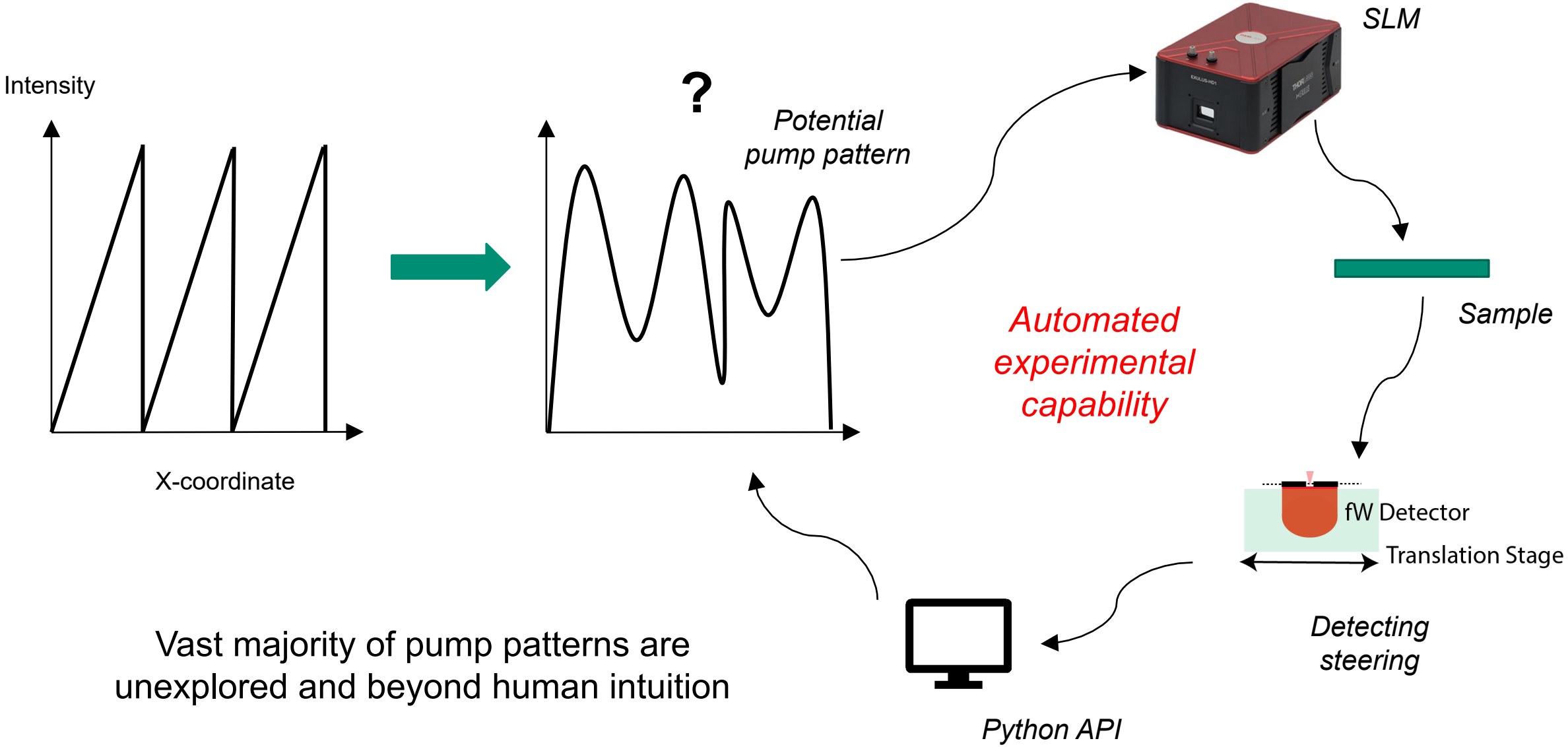
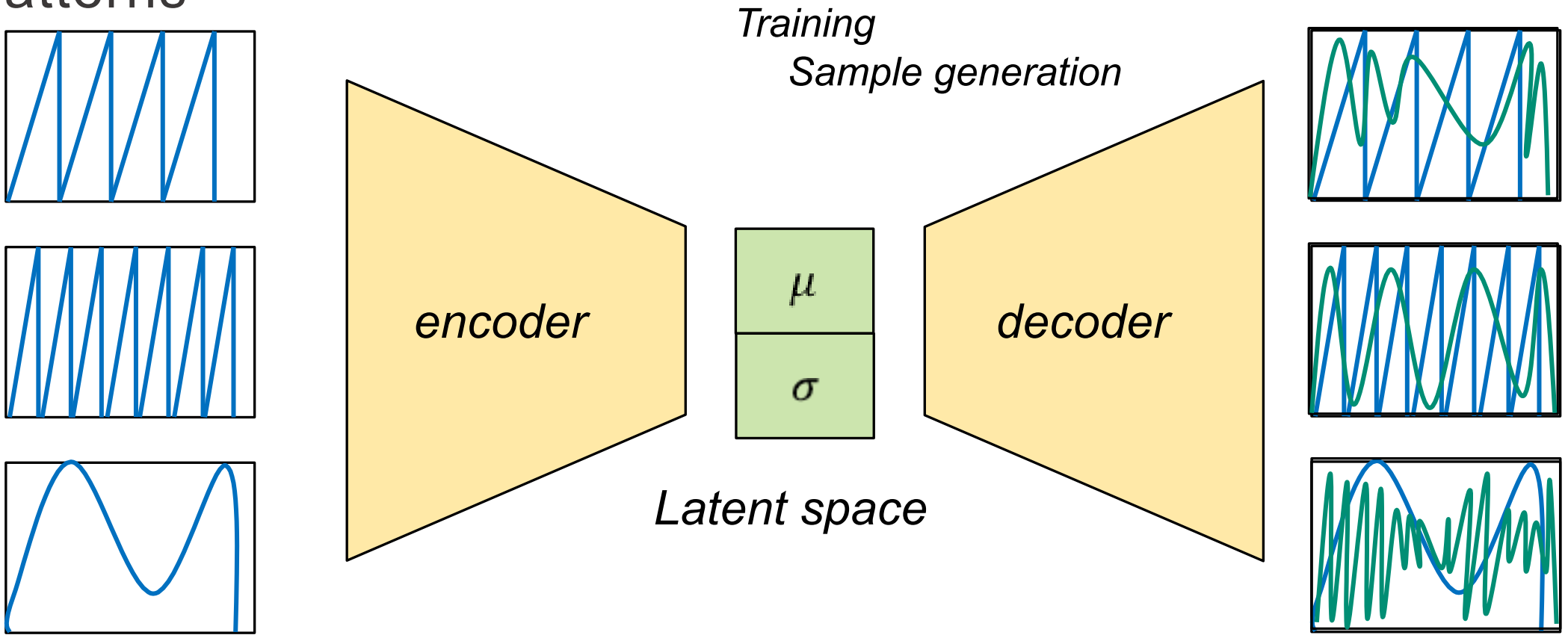
Periodicity of pump patterns decides emission (steering) angle

Steering towards you?



Vast majority of pump patterns are unexplored and beyond human intuition

Variational autoencoders can generate a wide variety of patterns



$$Objective = -\left(Reconstruction\ loss + Regularization\ term\right)$$

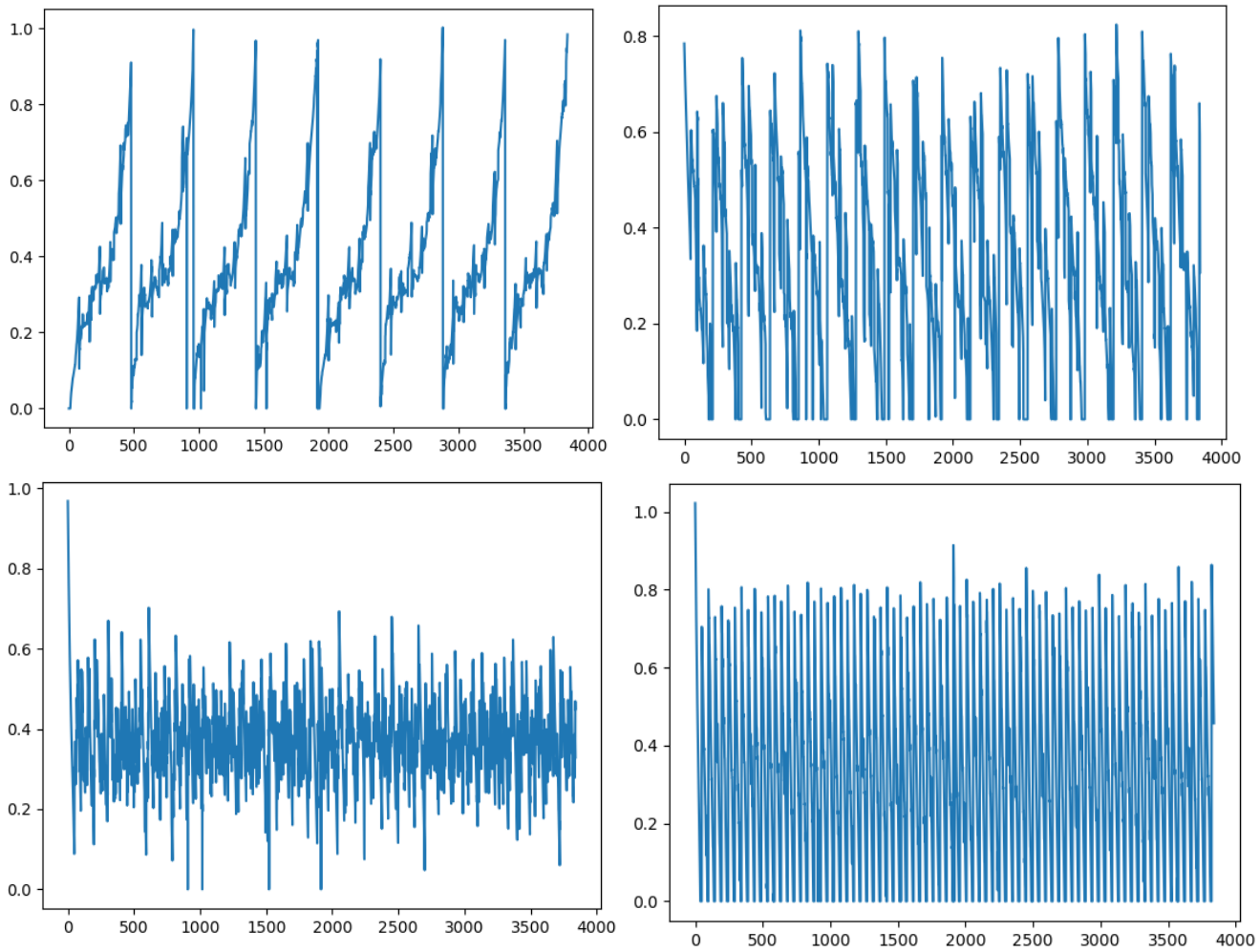
Evidence lower bound (ELBO) loss

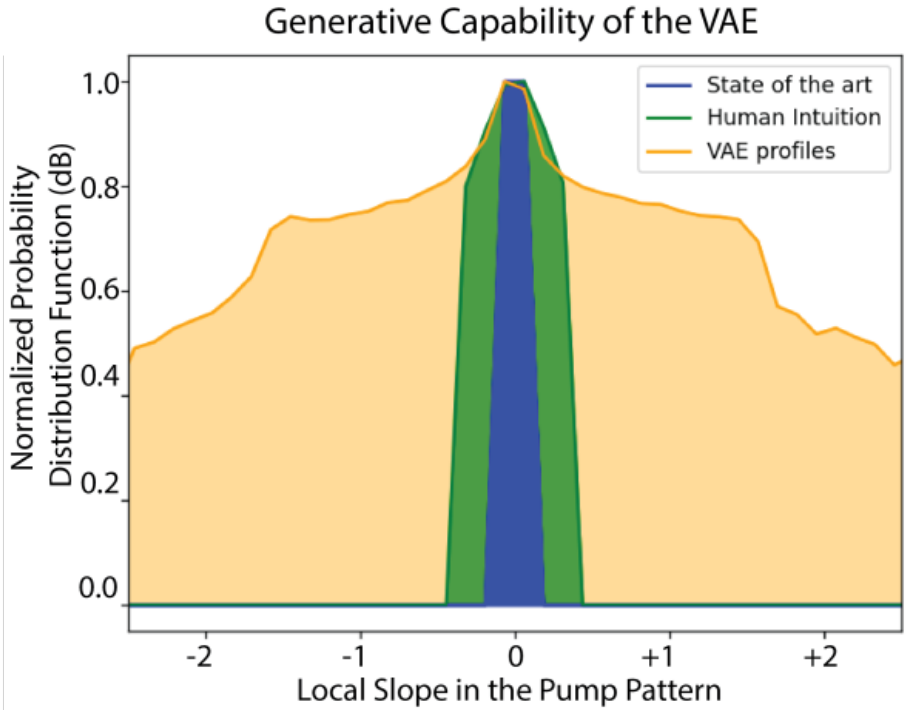
Helps generate high quality patterns

Ensures small changes in latent space give similar images

Generative capability of the VAE

Patterns generated by the VAE

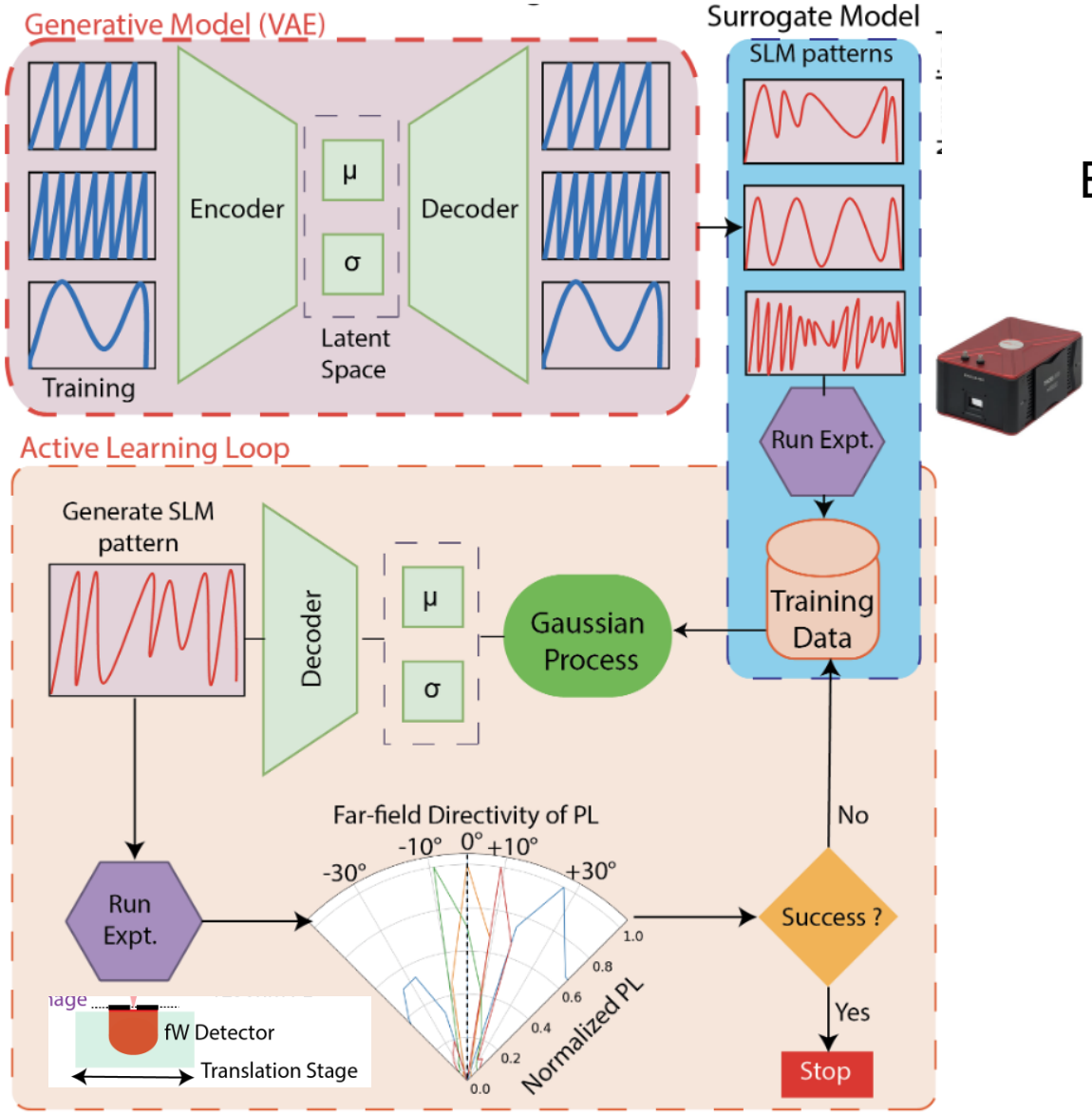




VAE patterns significantly expand on human intuition

Iyer, Desai et. al. *Winter Conference on Applications of Computer Vision (WACV) 2023*

Bayesian optimization to find beam steering candidates



Bayesian optimization on latent space of VAE can efficiently find patterns with high beam steering

Measure of success

Intensity at a specific angle

$$Directivity = \frac{I(\theta_i)}{\sum_{j=1}^{n} I(\theta_j)}$$

Sum of intensities at all angles

Search for patterns with Maximum Expected Improvement on Directivity

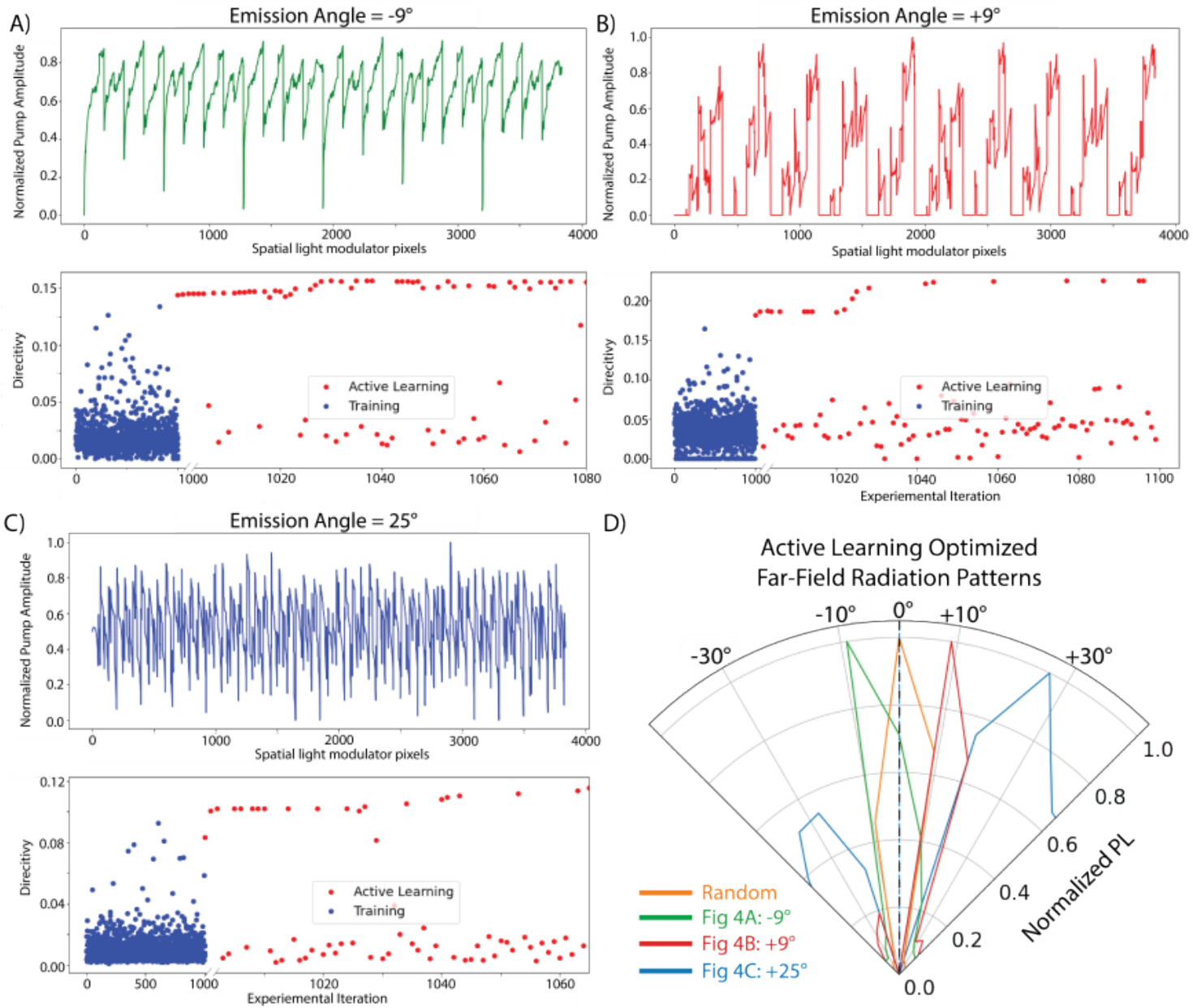
Finding optimal patterns for various steering angles

$$Directivity = \frac{I(\theta_i)}{\sum_{j=1}^{n} I(\theta_j)}$$

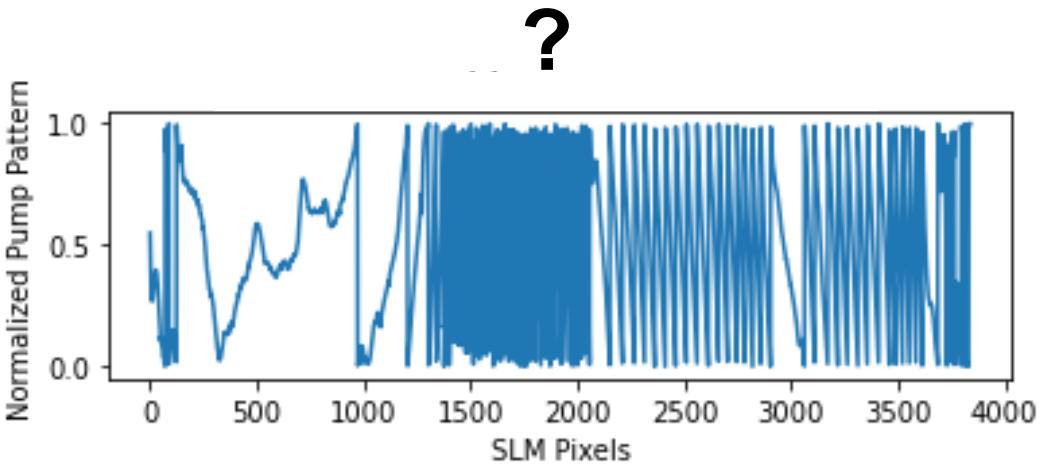
Intensity at a specific angle

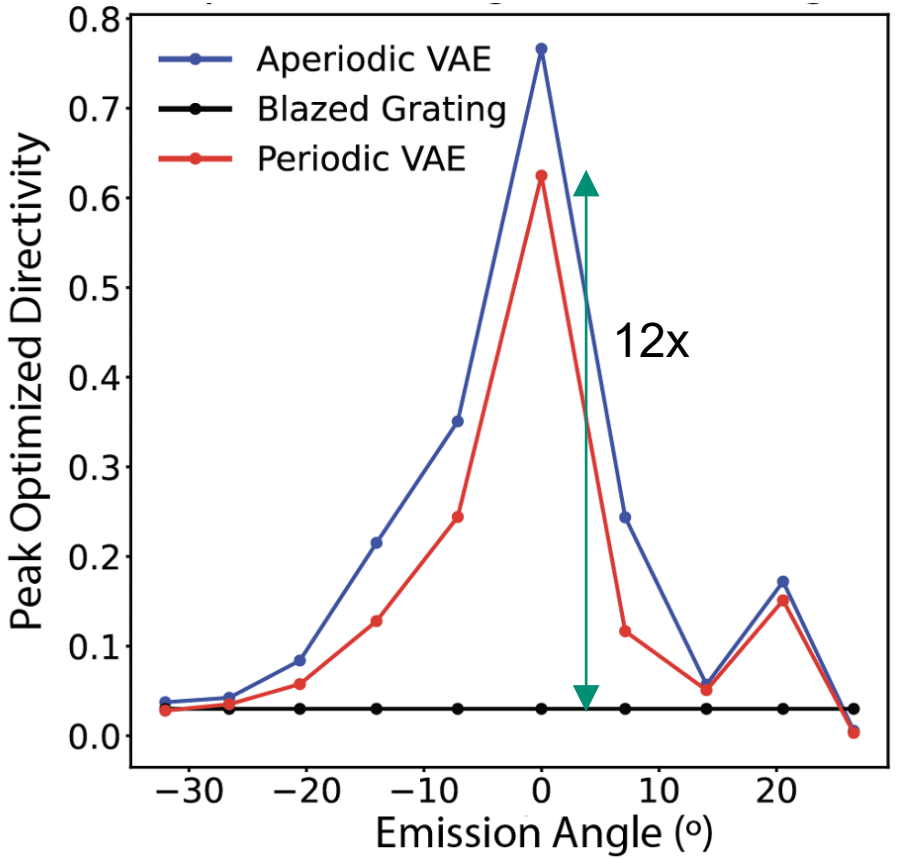
Sum of intensities at all angles

Pump patterns beyond human intuition result in beam steering at various angles



Expanding the search to aperiodic patterns

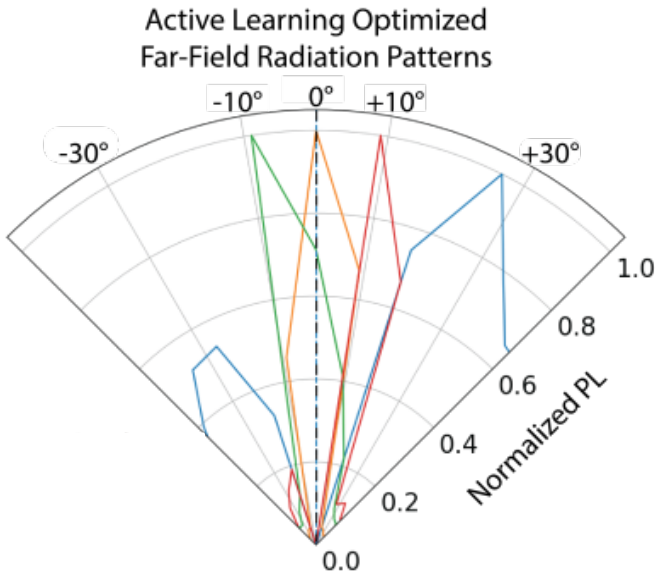




Aperiodic patterns can be even more efficient at beam steering

Summary

- Coupled a generative model with Bayesian optimization to discover pump patterns that achieve optimal steering
- Discovered pump patterns show 12x better steering than human intuition based patterns
- What is the search space?: Use active learning to identify patterns that “inform” us about the underlying physics
- Interpreting the search space?: Relate pump patterns to beam steering via an equation derived from data



Email: saaketh.desai@sandia.gov

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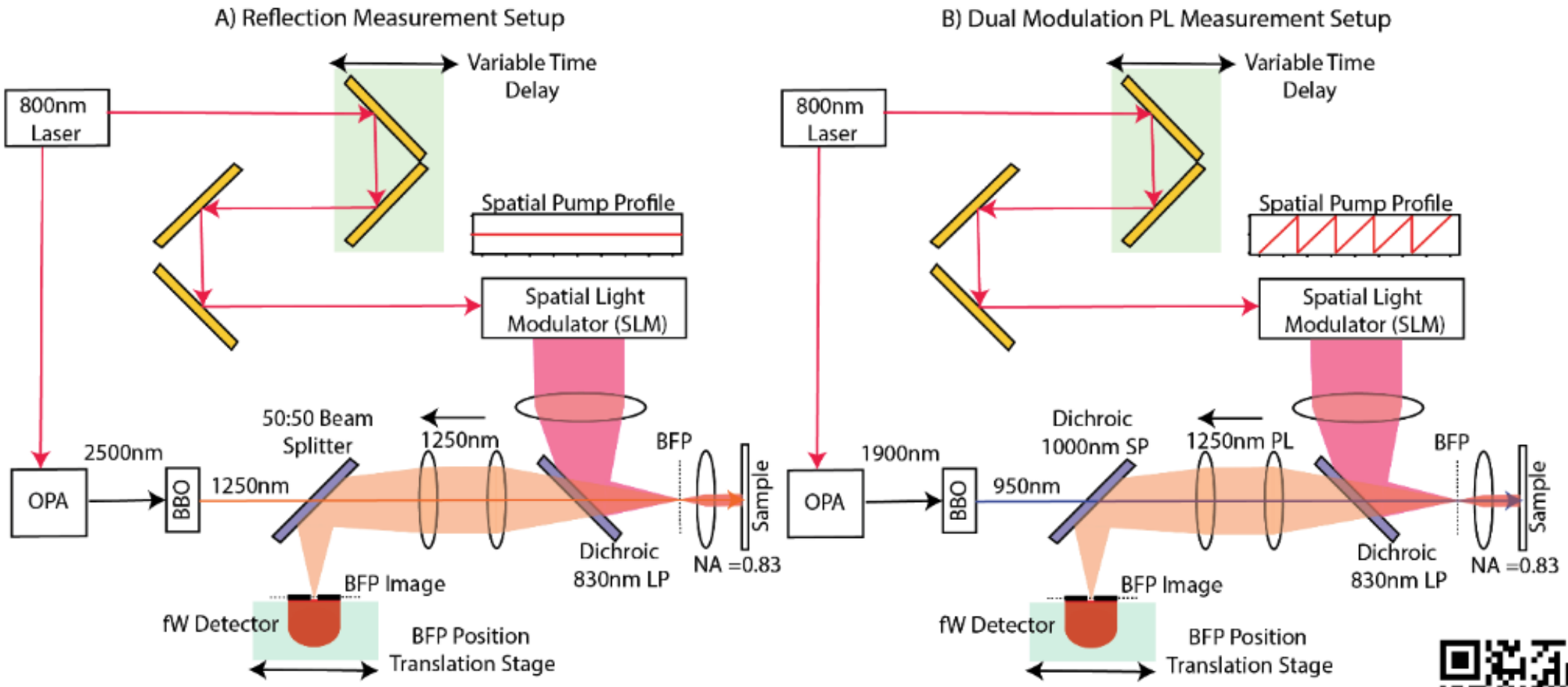
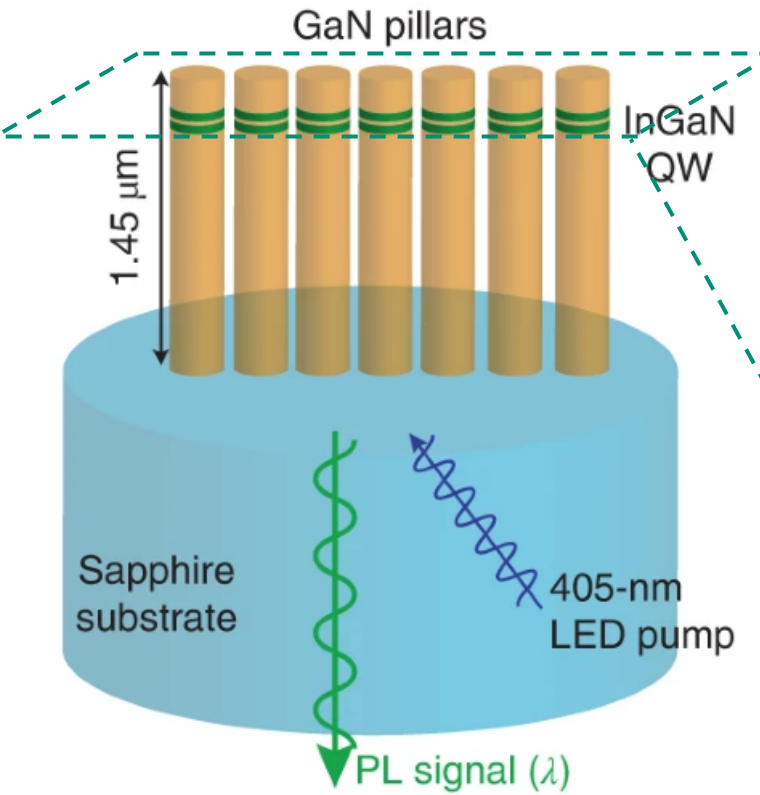
Backup slides

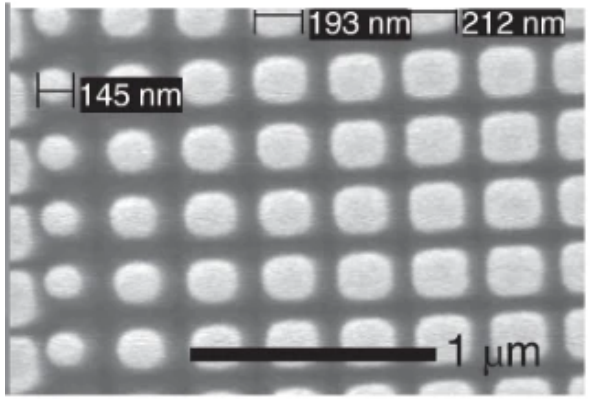
Measurement setup

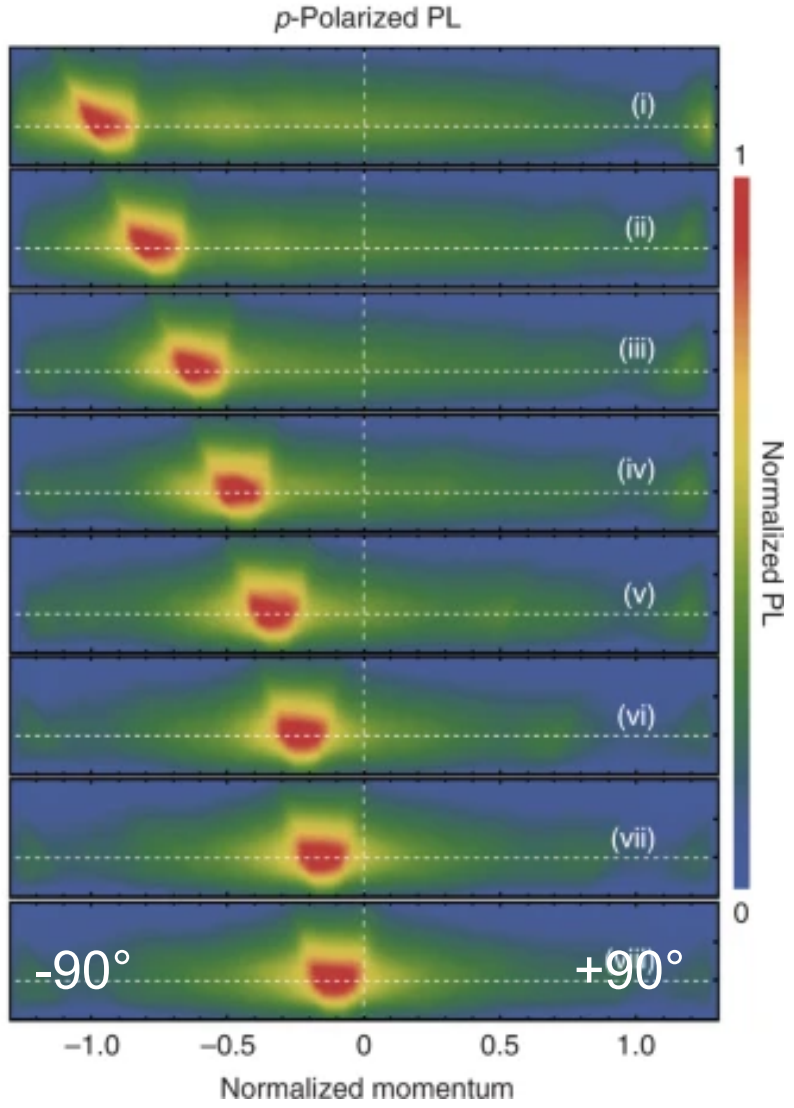


PP Iyer et. al. *Nature Photonics* (2023)

Static metasurfaces can control incoherent emission



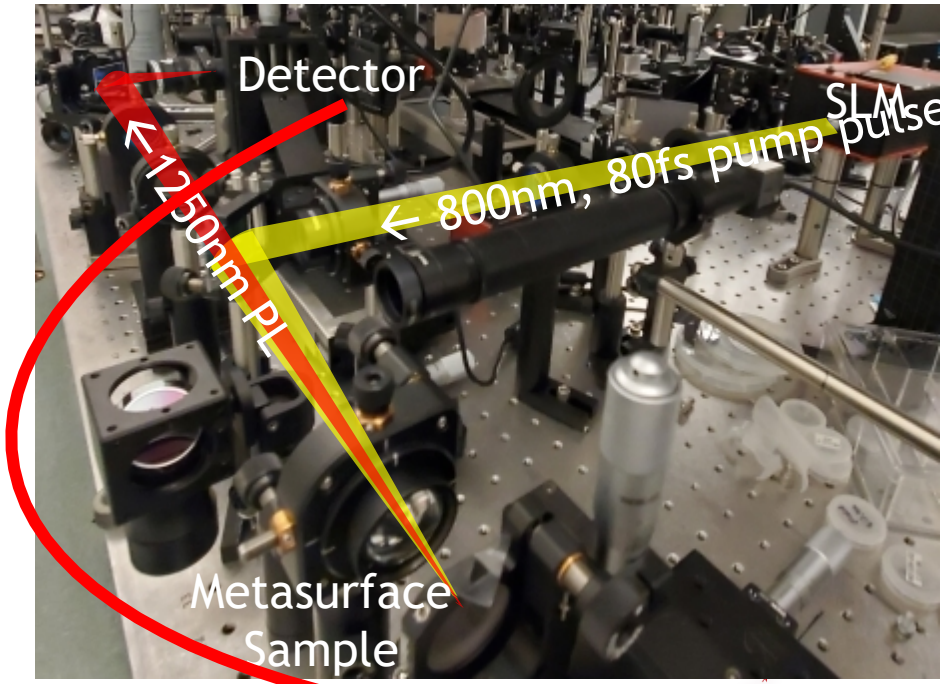


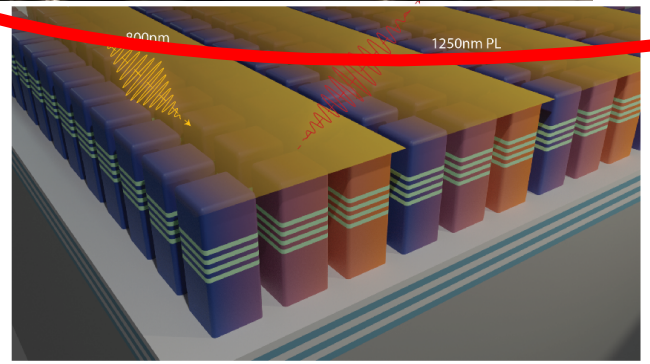


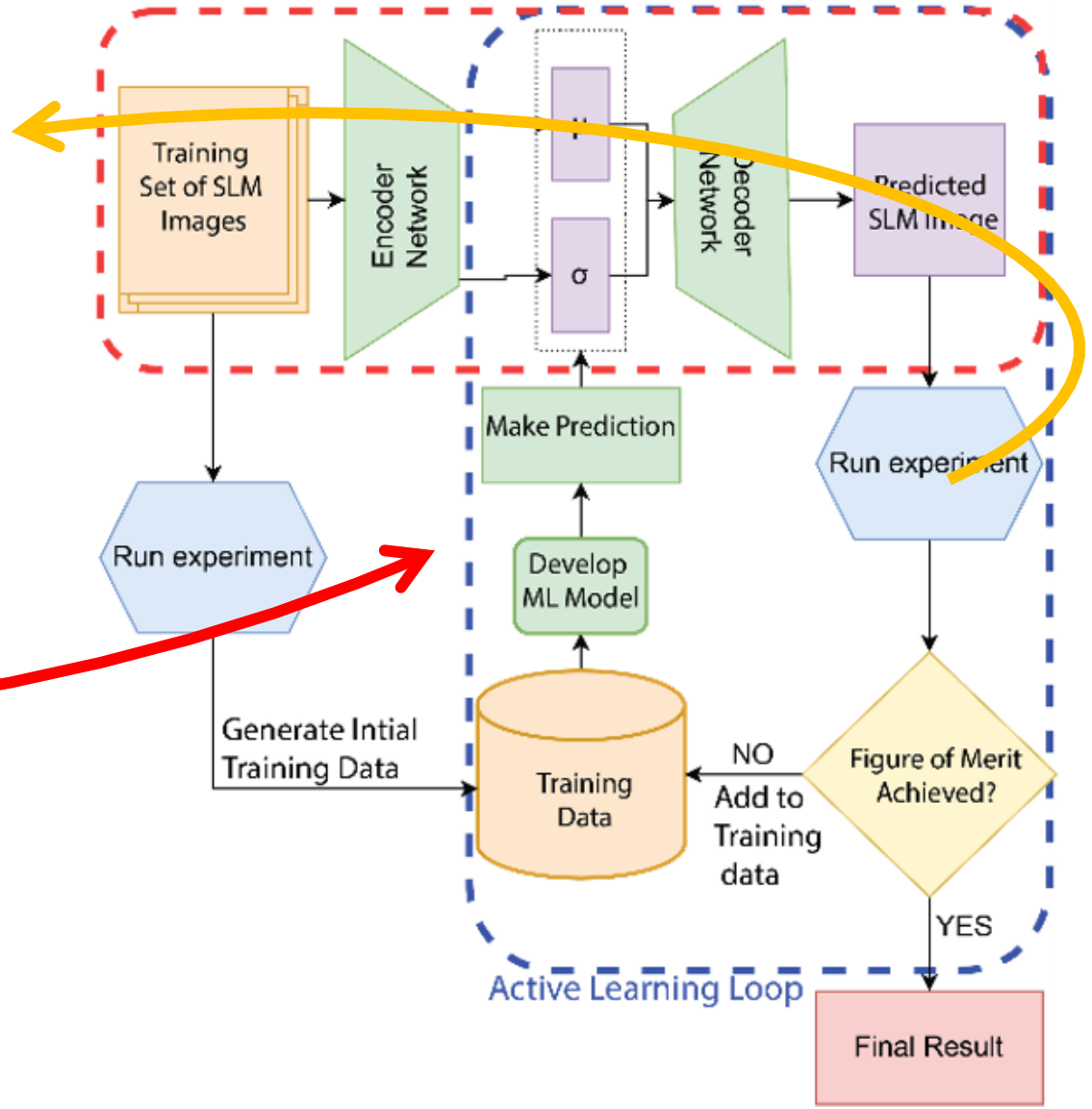
Pillar width periodicity controls beam steering

PP Iyer et. al. *Nature Photonics* 2020

Bayesian optimization to find beam steering candidates

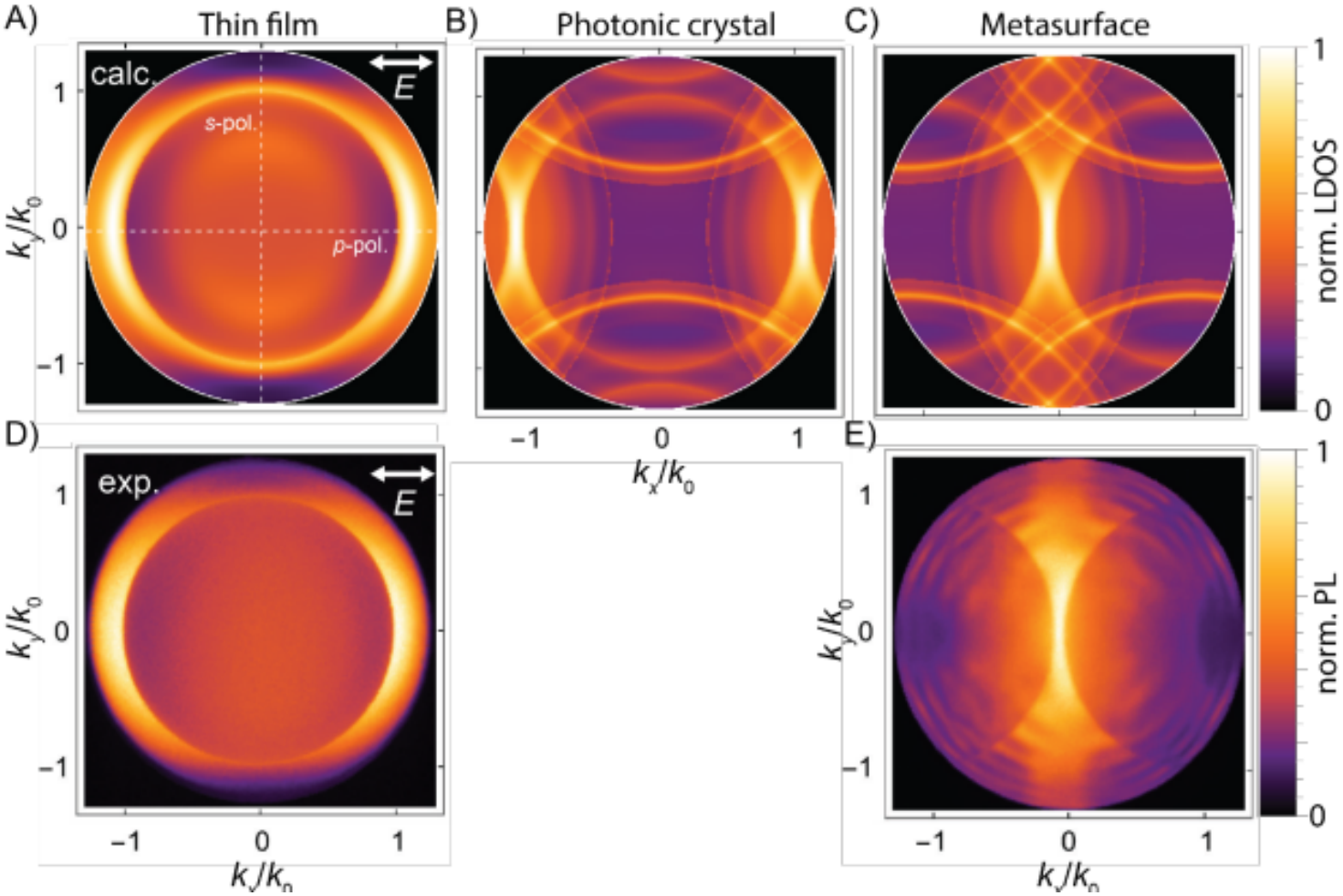






Bayesian optimization on latent space of VAE can efficiently find patterns with high beam steering

Why does this work?

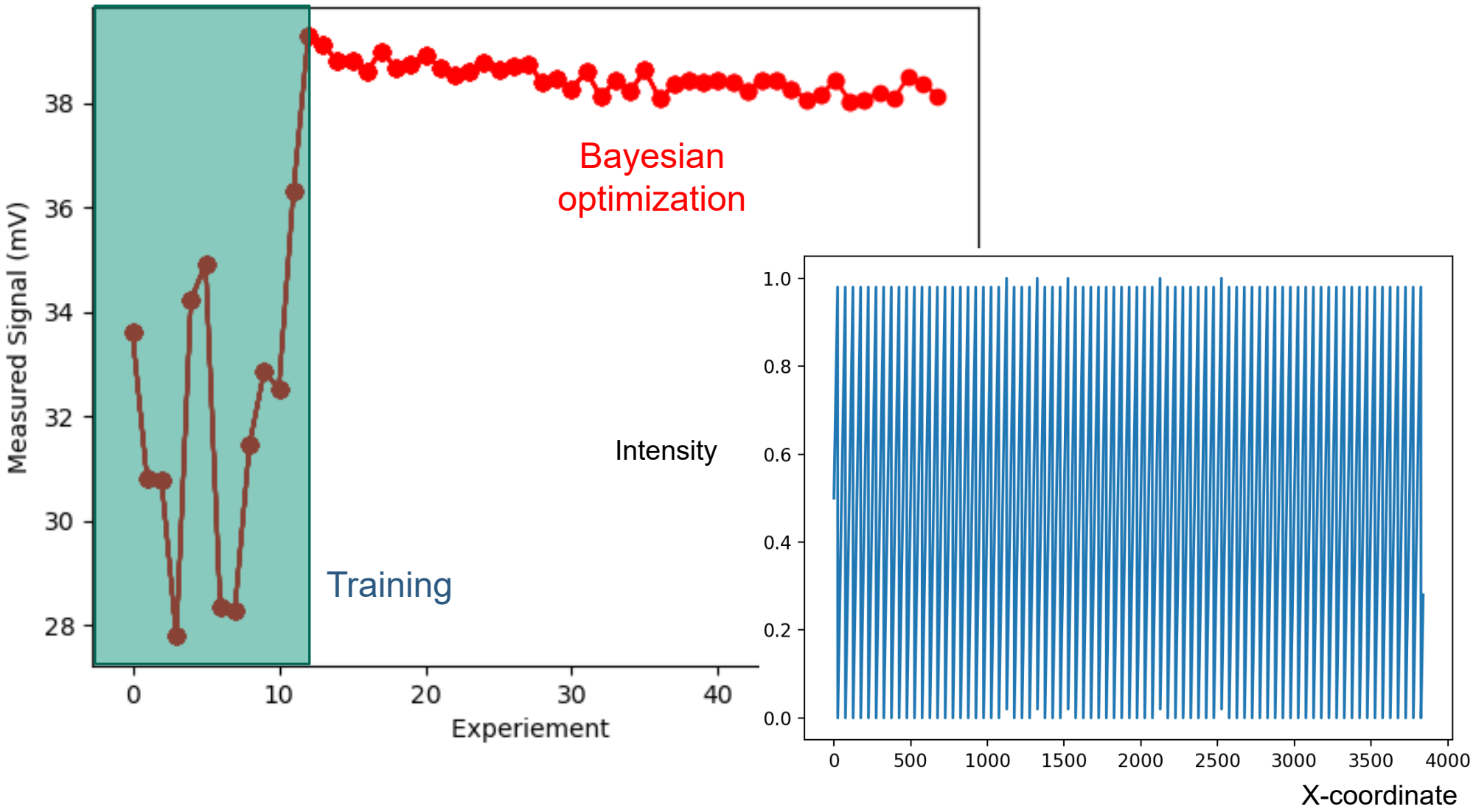


Source: Volkswagen

Source: EPC

Dynamic pump patterns modify local density of states of emitters

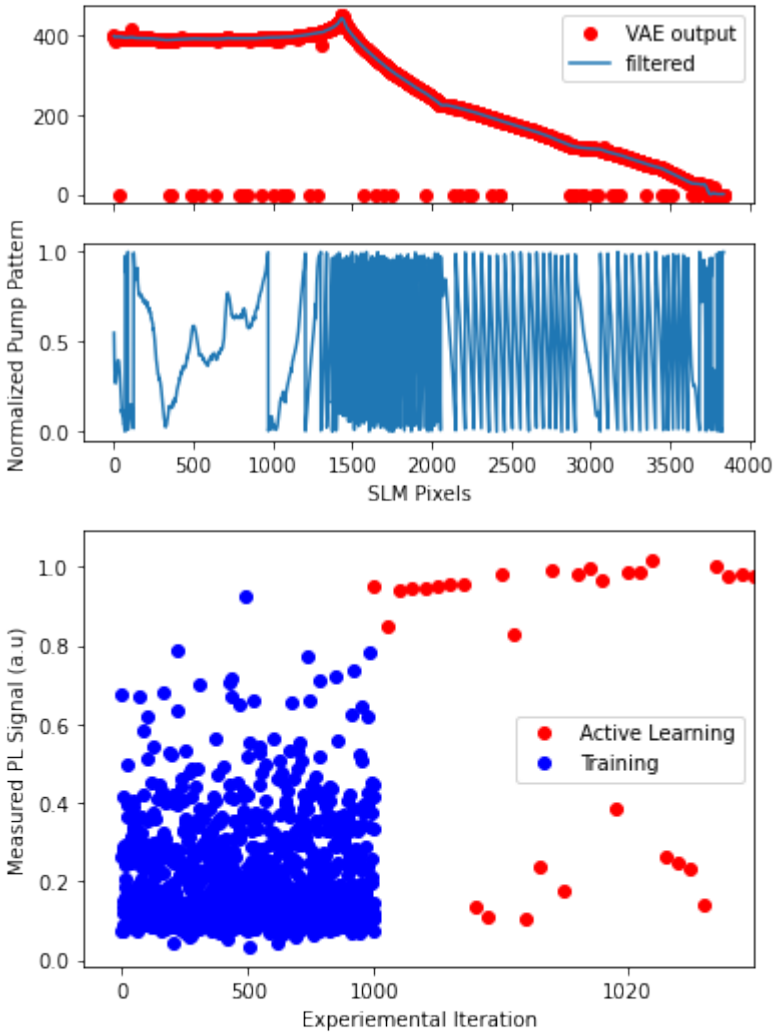
Rediscovering a known result

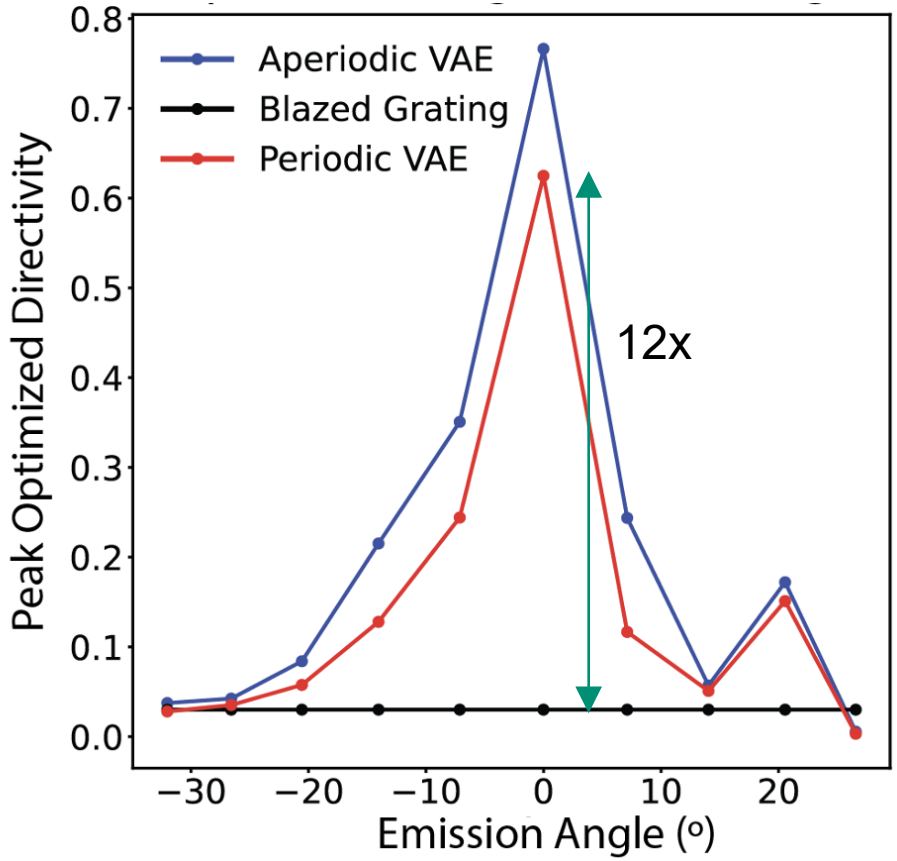


Bayesian optimization rediscovers grating order of 80 to have maximum output

Expanding the search to aperiodic patterns

Emission Angle -38°





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