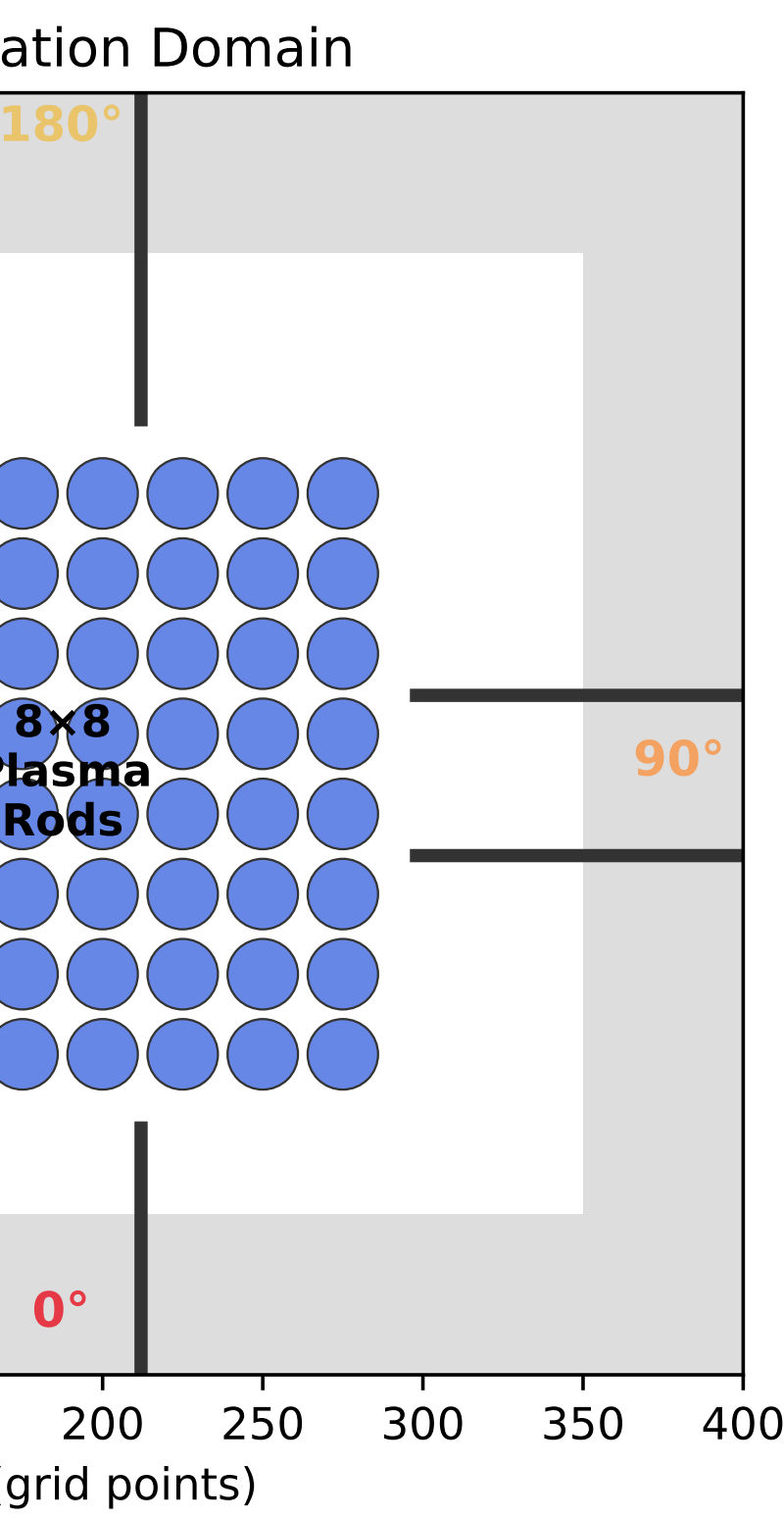


# Conditional Beam Steering in Plasma Photonic Crystals via Evolutionary Search

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## Physical System

Gradient-free optimization match gradient-based methods for inverse EM design?



**Plasma rods:**  $\varepsilon(\rho) = 1 - (\rho \cdot \omega_p^{\max}/\omega)^2$ ,  $\varepsilon \in [-5.25, 1]$   
**Design space:**  $\rho \in [0, 1]^{64}$  (64 rod densities)  
**Simulation:** FDTD solver,  $400 \times 400$  grid, 6 GHz

## Methods

**ES-Single:** Separate designs for each  $\theta^* \in \{0^\circ, 90^\circ, 180^\circ\}$

$$R = P_{\theta^*} - 0.5 \sum_{\theta \neq \theta^*} P_\theta$$

**ES-Multi:** One design for all angles

$$R = \sum_{\theta} P_\theta - 0.5 \cdot \text{Var}(P_\theta)$$

**ES+NN:** Neural network  $f_\phi: [\sin \theta, \cos \theta] \mapsto \rho_{8 \times 8}$

## ES Algorithm

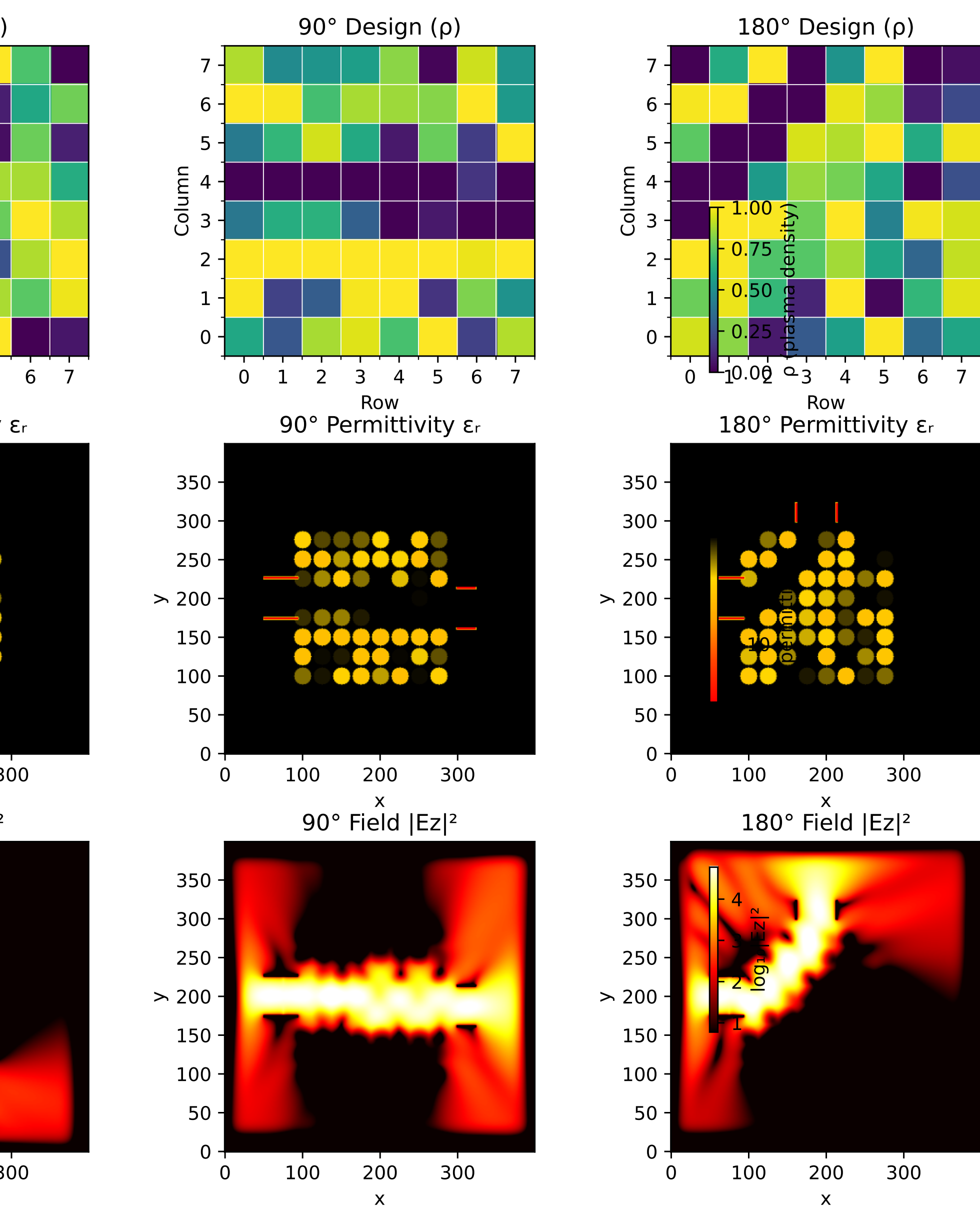
1. Sample  $N = 100$  perturbations  $\epsilon_i \sim \mathcal{N}(0, I)$
2. Evaluate  $R_i = R(\theta + \sigma \epsilon_i)$  in parallel
3. Estimate gradient:  $\hat{g} = \frac{1}{N_\sigma} \sum w_i \epsilon_i$
4. Update with Adam ( $\eta = 0.02$ ,  $\sigma_0 = 0.3$ )

**ES+NN:** Same procedure, but  $\theta$  are NN weights (20,928 params). Network: 4-layer MLP,

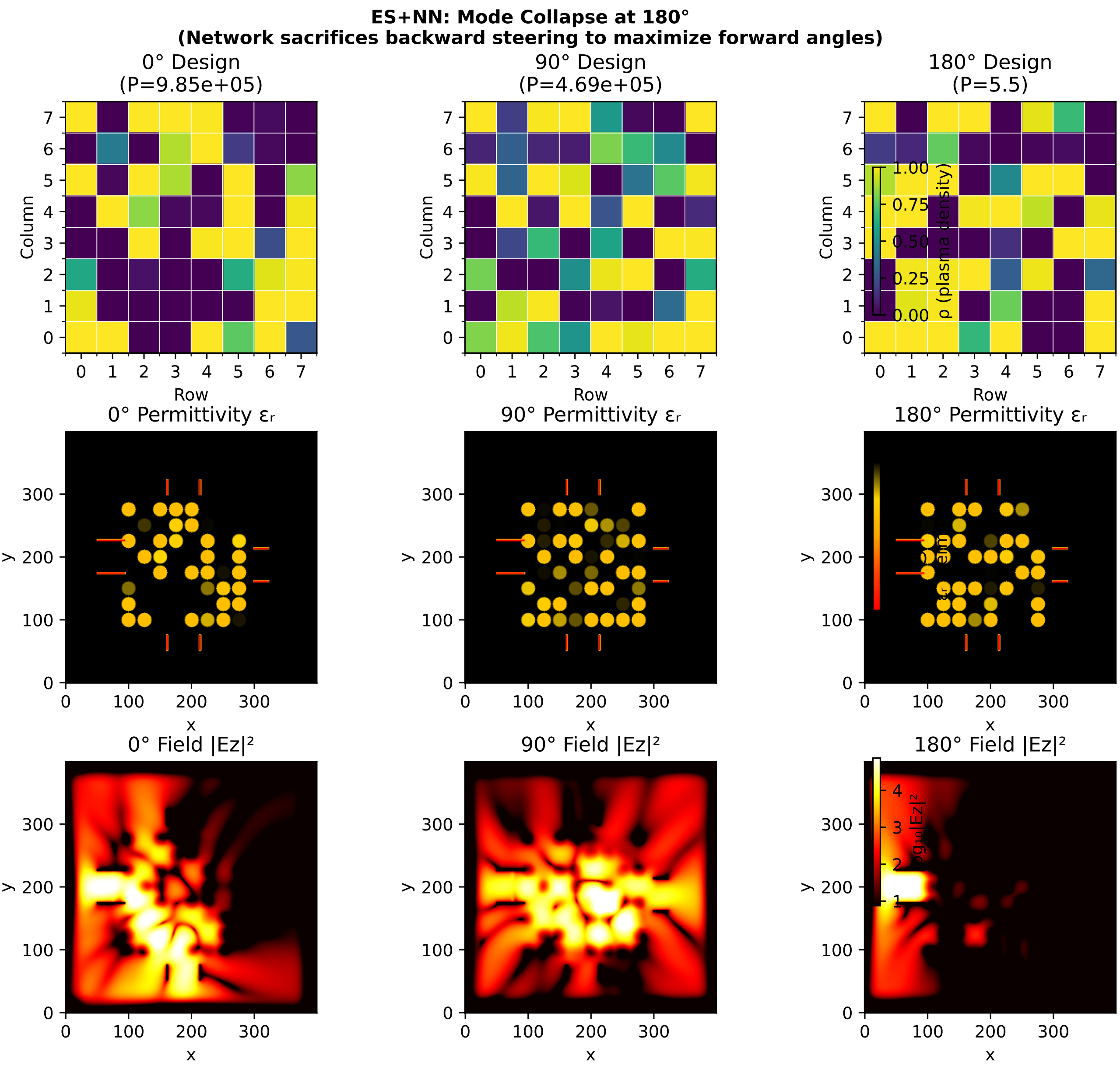
## Conclusions

- **ES-Single** achieves <0.005% crosstalk
- **ES-Multi** confirms no universal design
- **ES+NN** reveals:  $0^\circ/90^\circ$  compatible, 180° incompatible
- Gradient-free approach is **viable**

Code: [github.com/szertan/cs229-beam-steering](https://github.com/szertan/cs229-beam-steering)



ES-Single: <0.005% crosstalk



ES+NN:  $P_0 = 9.8 \times 10^5$ ,  $P_{90} = 4.7 \times 10^5$ ,  $P_{180} = 5.5$