

OSA Annual Meeting, Orlando, Oct. 9, 2013

FW4E.6



Exploring high-Q/V mode using optimization algorithm

Akihiro Fushimi and Takasumi Tanabe*

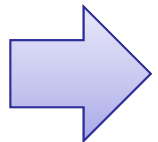
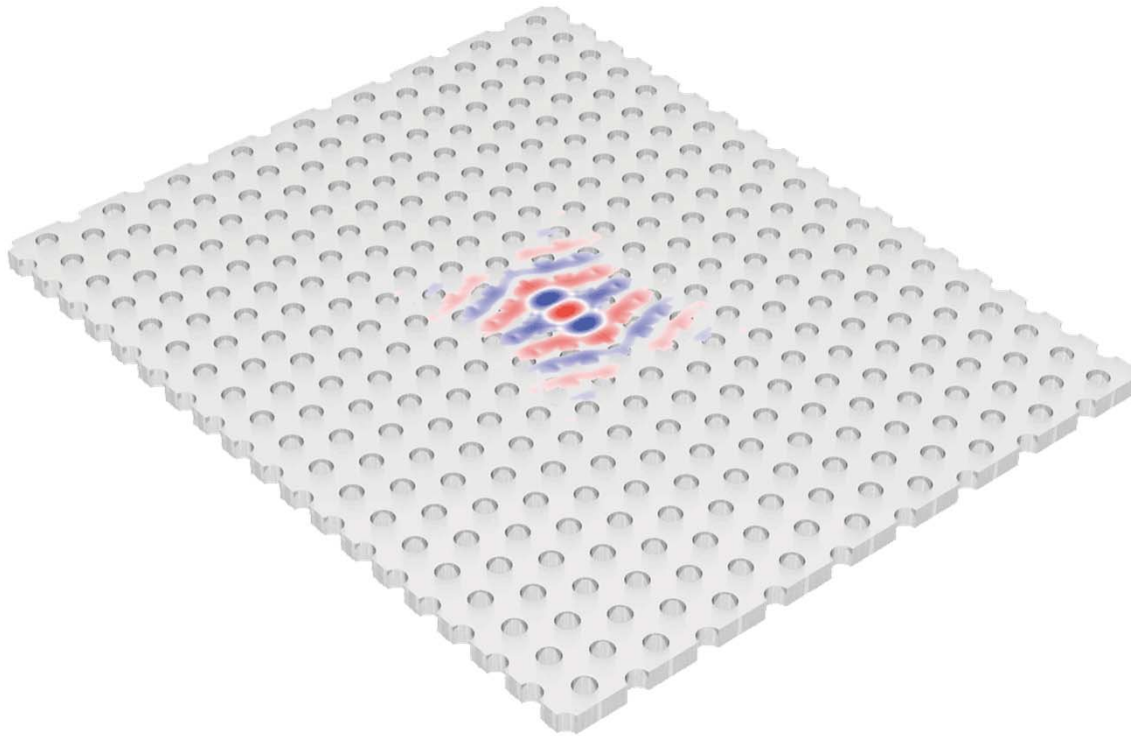
*takasumi@elec.keio.ac.jp

Department of Electronics and Electrical Engineering,
Faculty of Science and Technology,
Keio University, Japan

Losses in PhC nanocavity



- ▶ Loss channels in PhC nanocavity

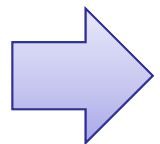
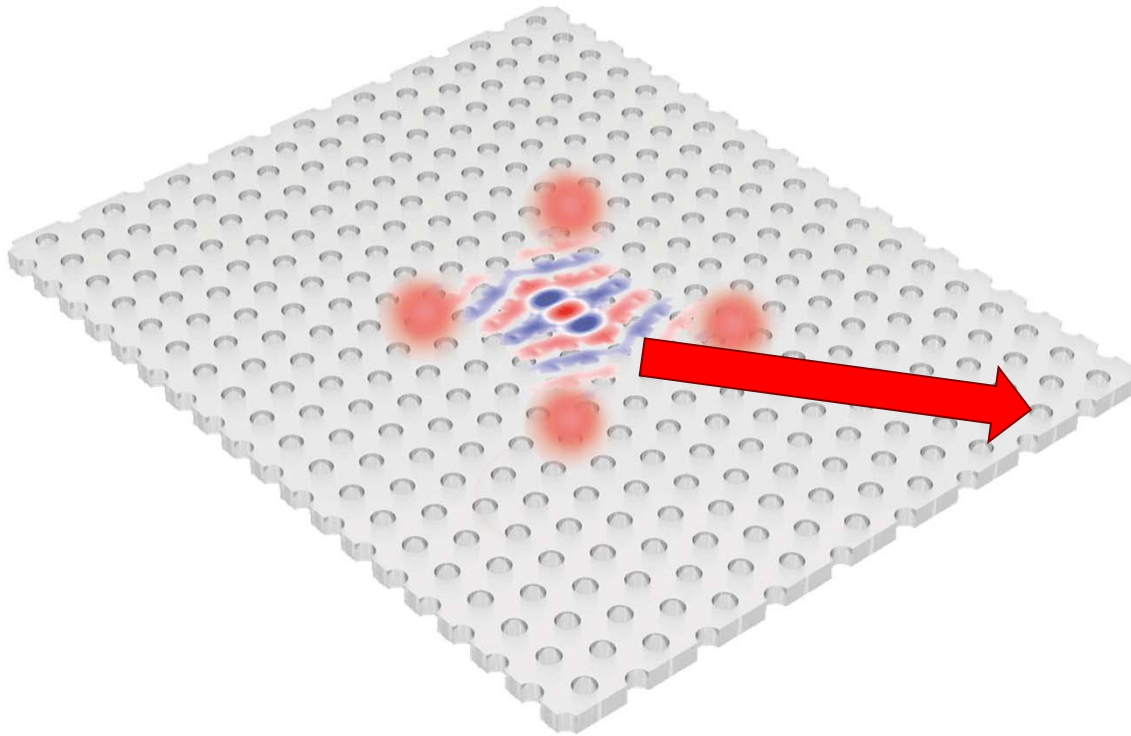


**Material absorption
Less dominant**

Losses in PhC nanocavity



► Loss channels in PhC nanocavity

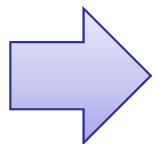
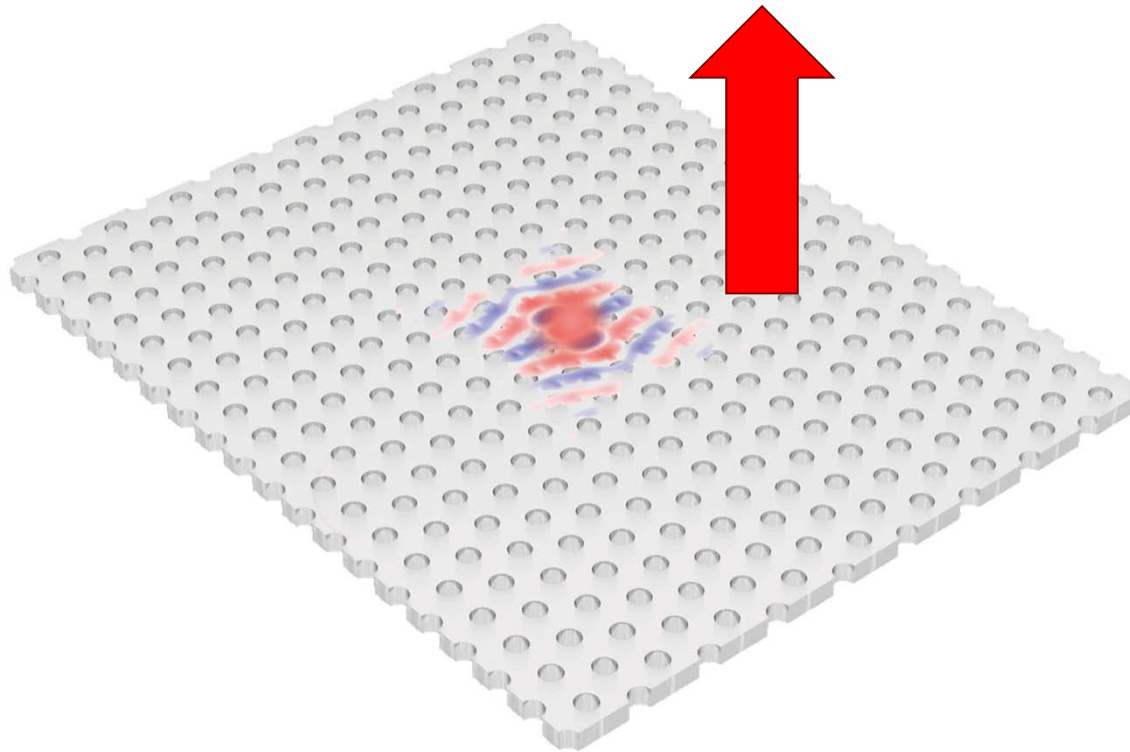


**Horizontal scattering
Less dominant**

Losses in PhC nanocavity



- ▶ Loss channels in PhC nanocavity



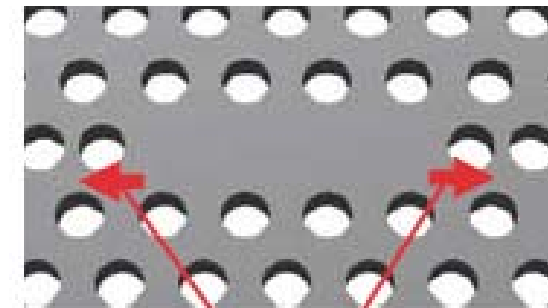
**Out-of-slab radiation
Dominant**

Need to reduce radiation

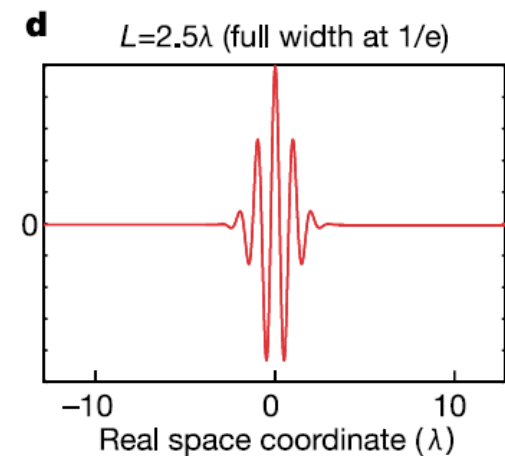
- ▶ Gaussian profile design

High- Q photonic nanocavity in a two-dimensional photonic crystal

Yoshihiro Akahane^{1,2}, Takashi Asano¹, Bong-Shik Song¹
& Susumu Noda¹



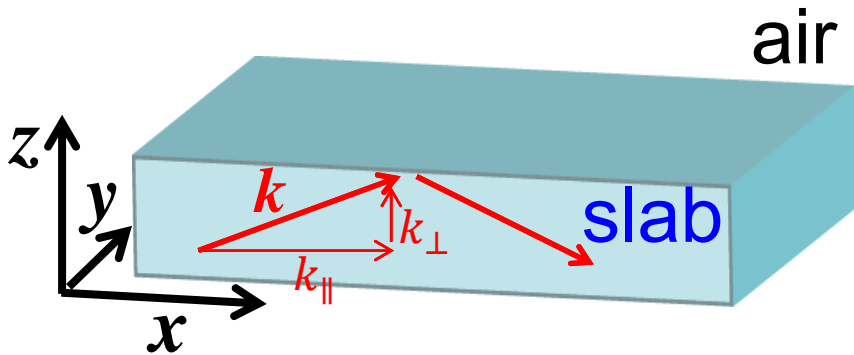
Shift



Radiation of 2D PhC cavity



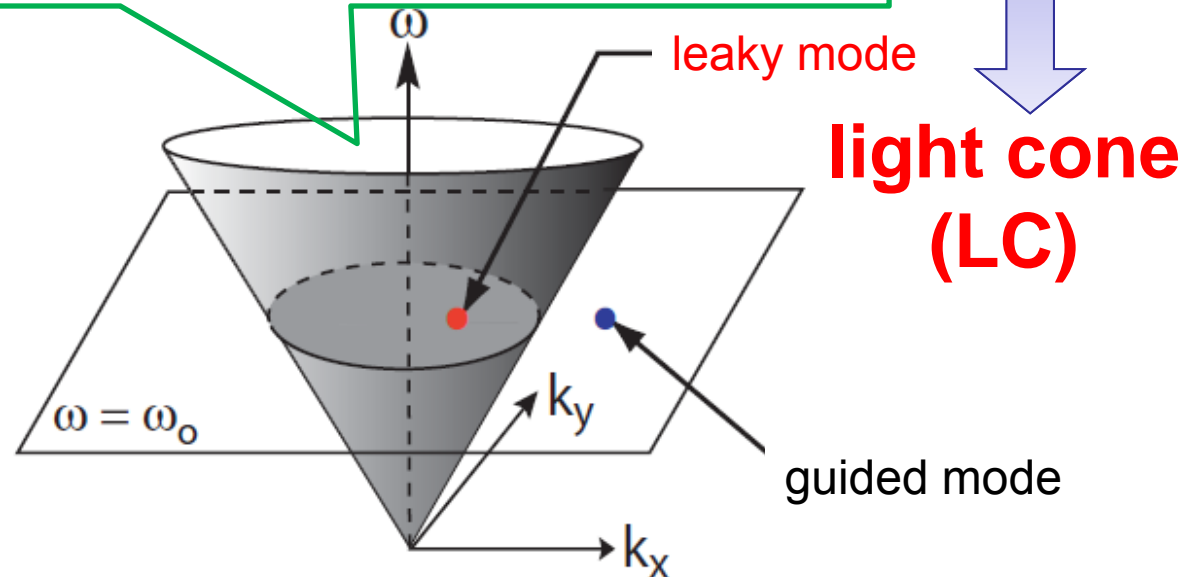
► Total internal reflection



$$k^2 = \left(\frac{n\omega_0}{c}\right)^2 = k_{\parallel}^2 + k_{\perp}^2$$

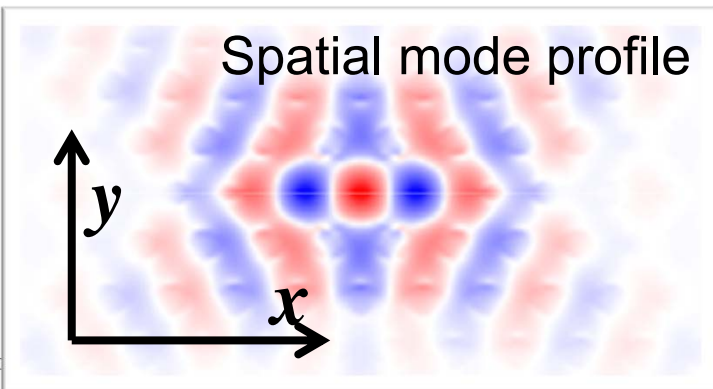
$$k_{\parallel}^2 \geq (\omega_0/c)^2$$

In-plane momentum components $|k_{\parallel}|$ less than ω_0/c will leak

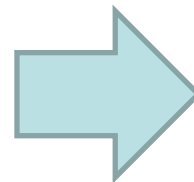


K. Srinivasan and O. Painter, Opt. Express **10**, 670 (2002).

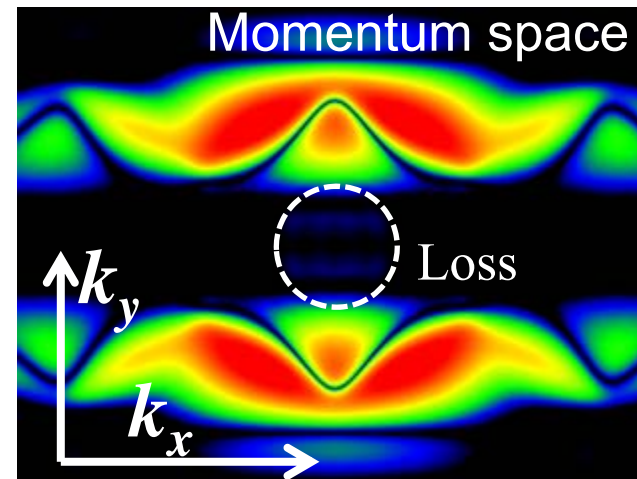
Spatial mode profile



FT



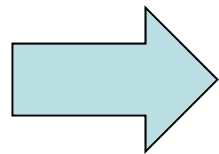
Momentum space





Motivation

Want to know the best mode profile
for obtaining high Q

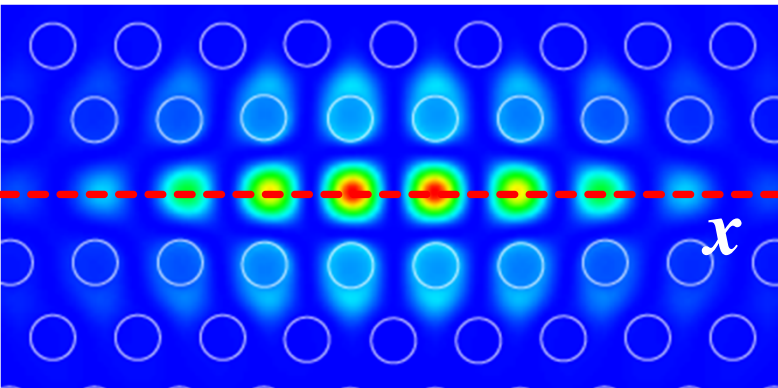


Optimization algorithm

Basic strategy



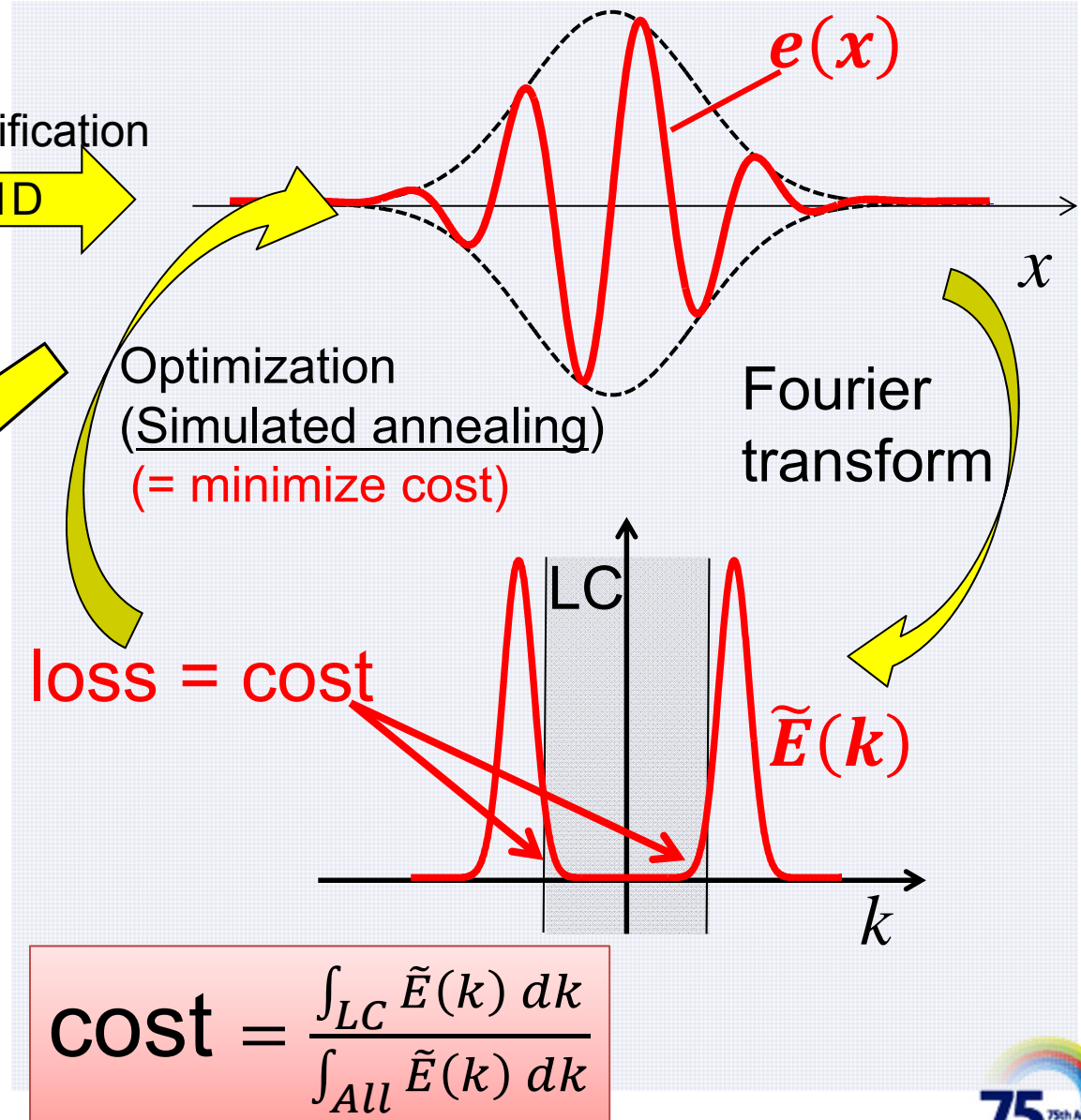
► PhC mode profile



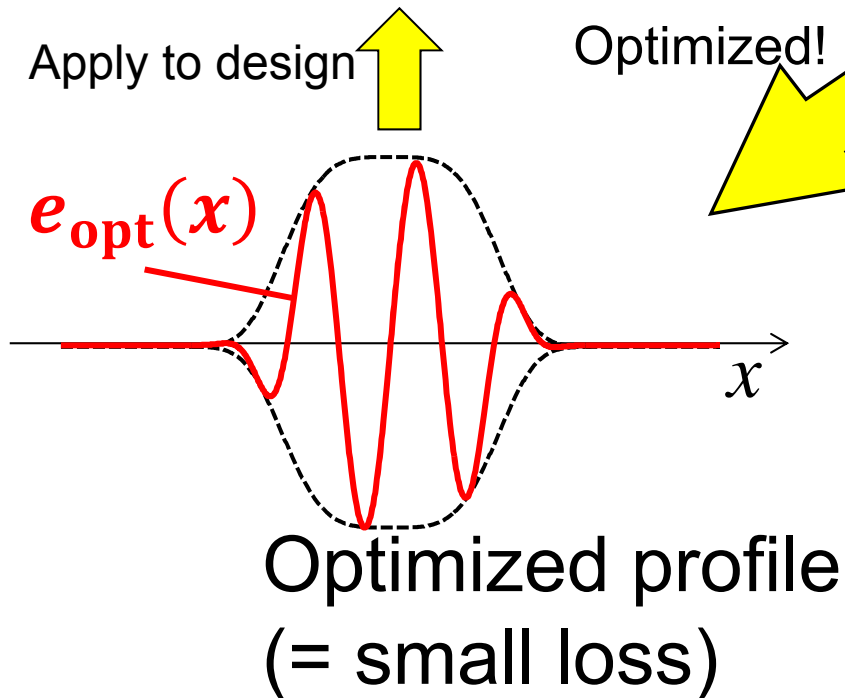
simplification

1D

► Optimization by simulated annealing



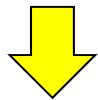
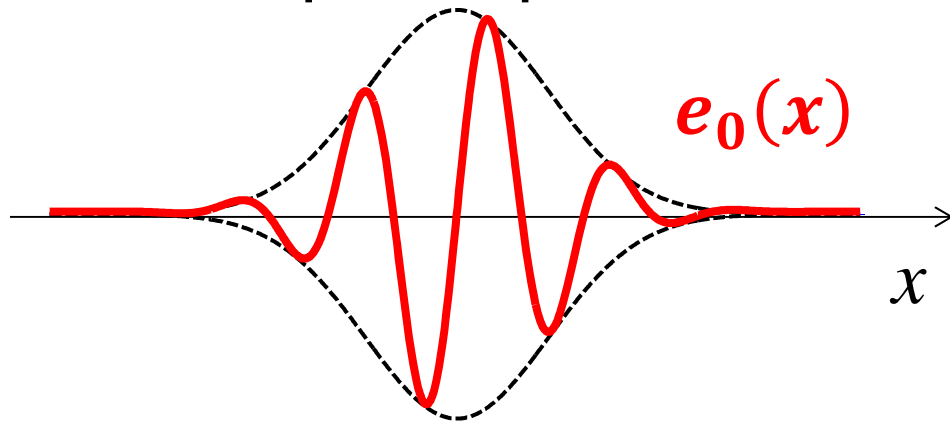
$$\text{cost} = \frac{\int_{LC} \tilde{E}(k) dk}{\int_{All} \tilde{E}(k) dk}$$



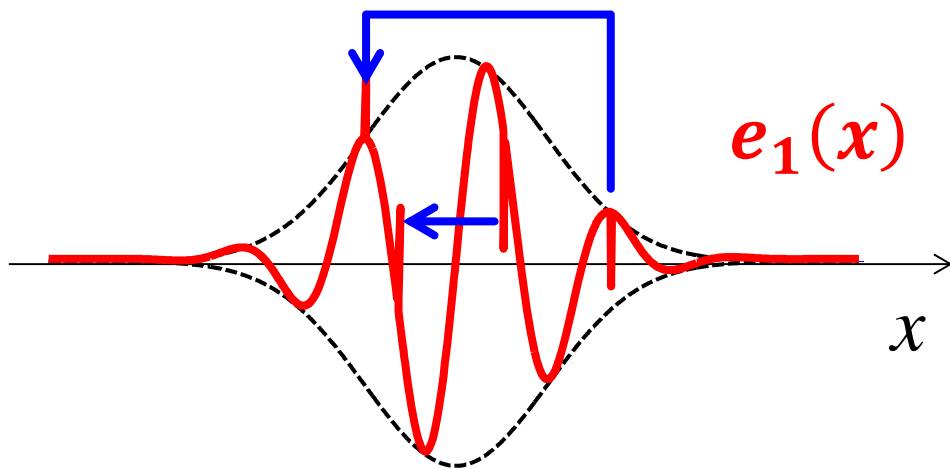
Optimization



► Pixel-to-pixel optimization

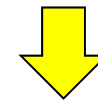
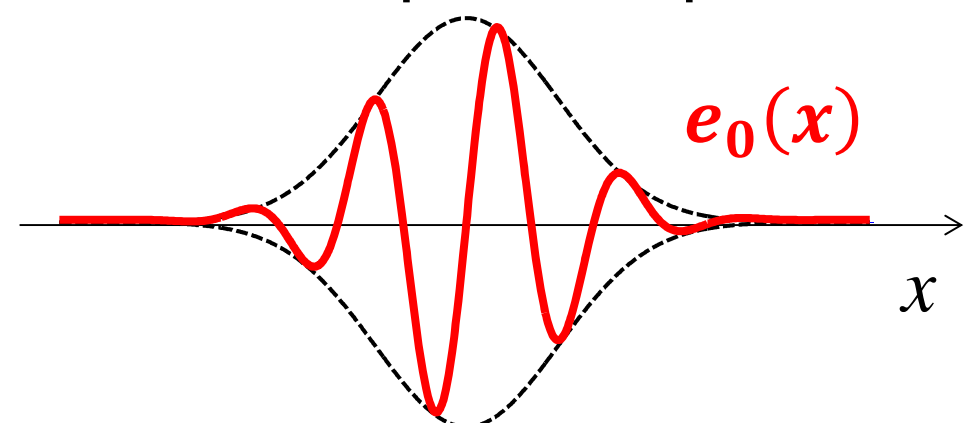


Pixelate and move

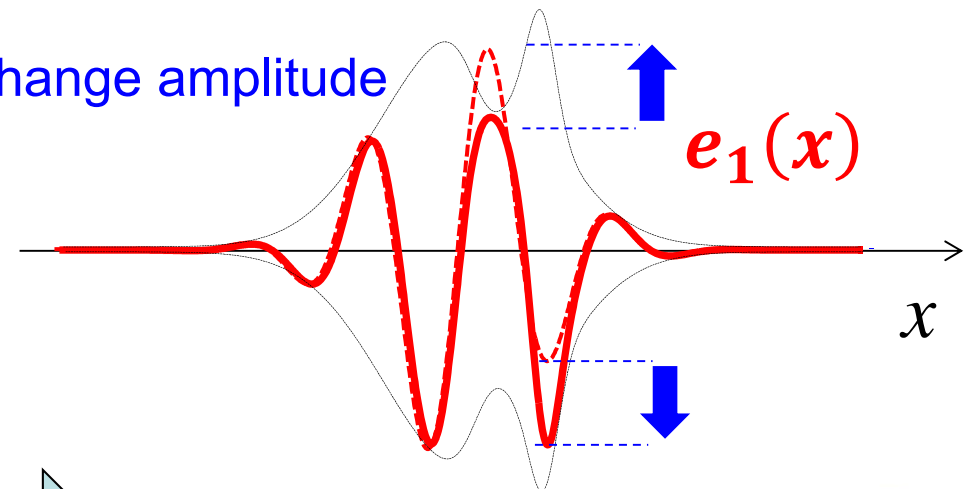


➡ Small boundary condition

► Cosine amplitude optimization



Change amplitude

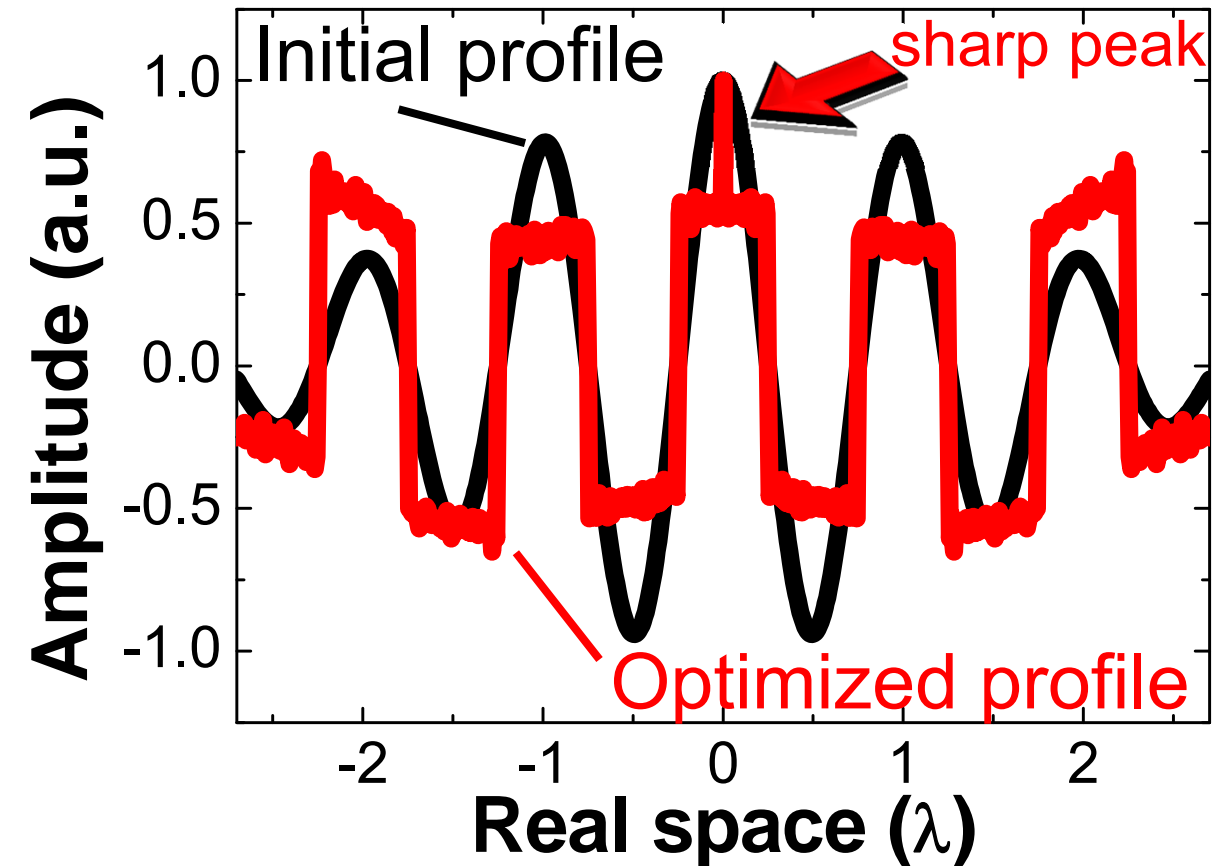


➡ Smooth profile

Pixel-to-pixel optimization method



▶ Optimized mode profile

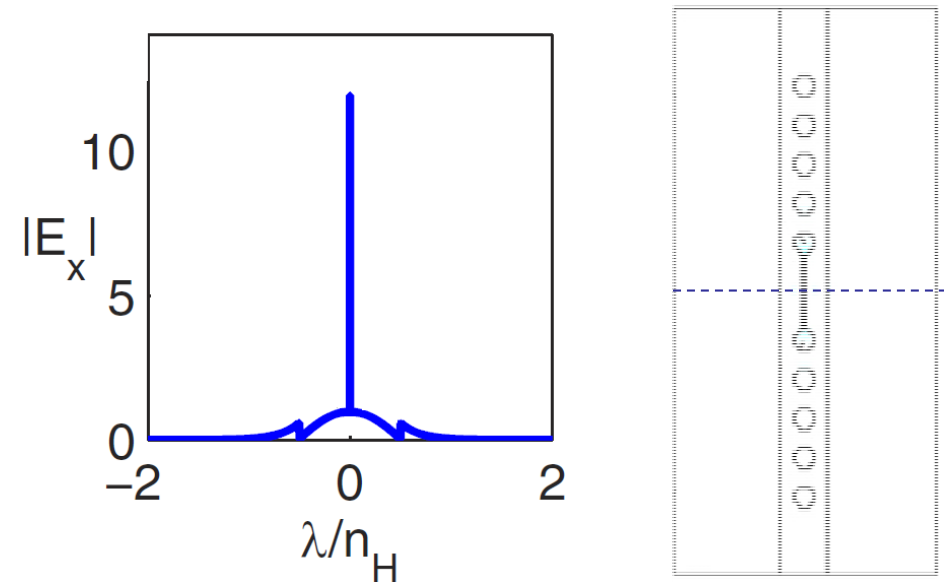


Cost

$$5.03 \times 10^{-4} \rightarrow 2.03 \times 10^{-4}$$

Better than Gaussian profile

▶ Slot cavity (understanding physics)



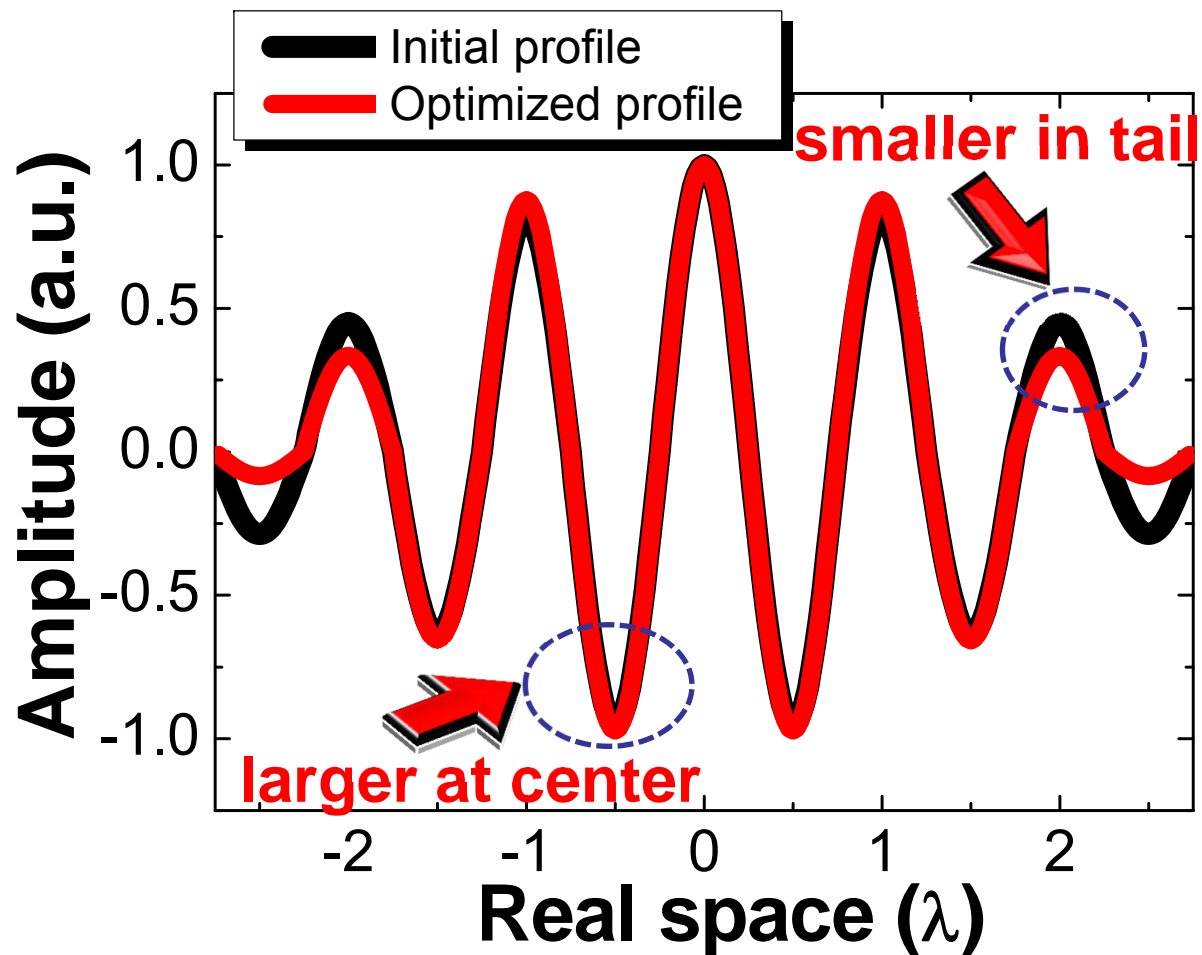
J. Robinson, et al., Phys. Rev. Lett. **95**, 143901 (2005)

Slot cavity successfully found
but contains discontinuity

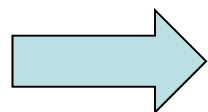
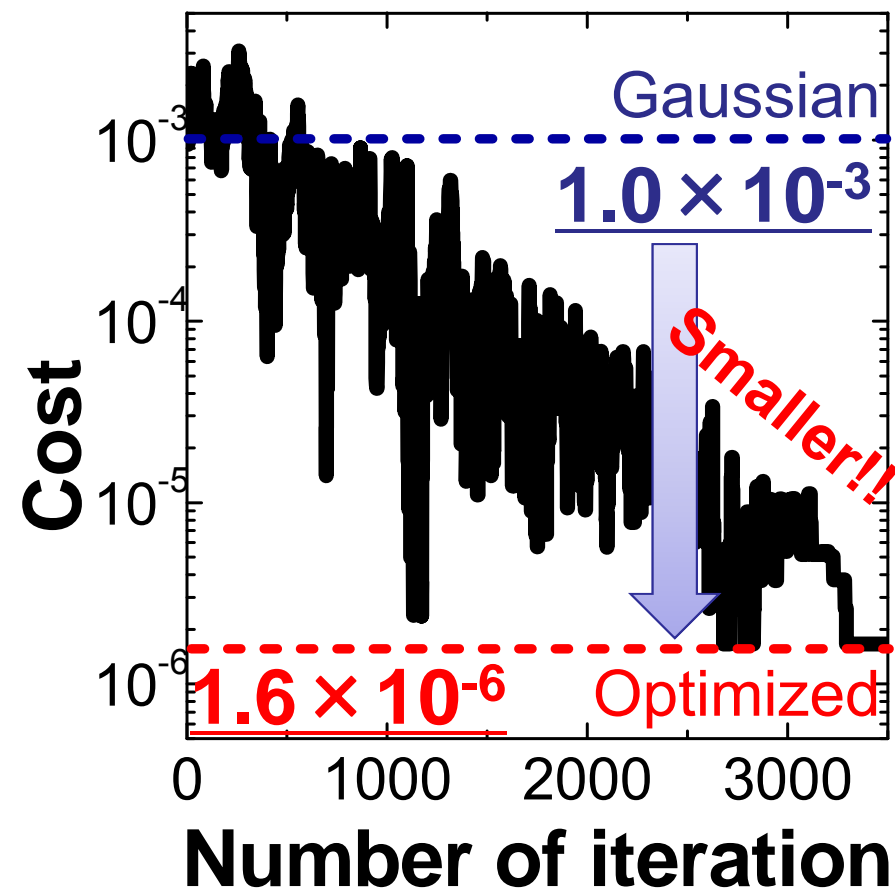
Cosine amplitude optimization method



▶ Optimized mode profile

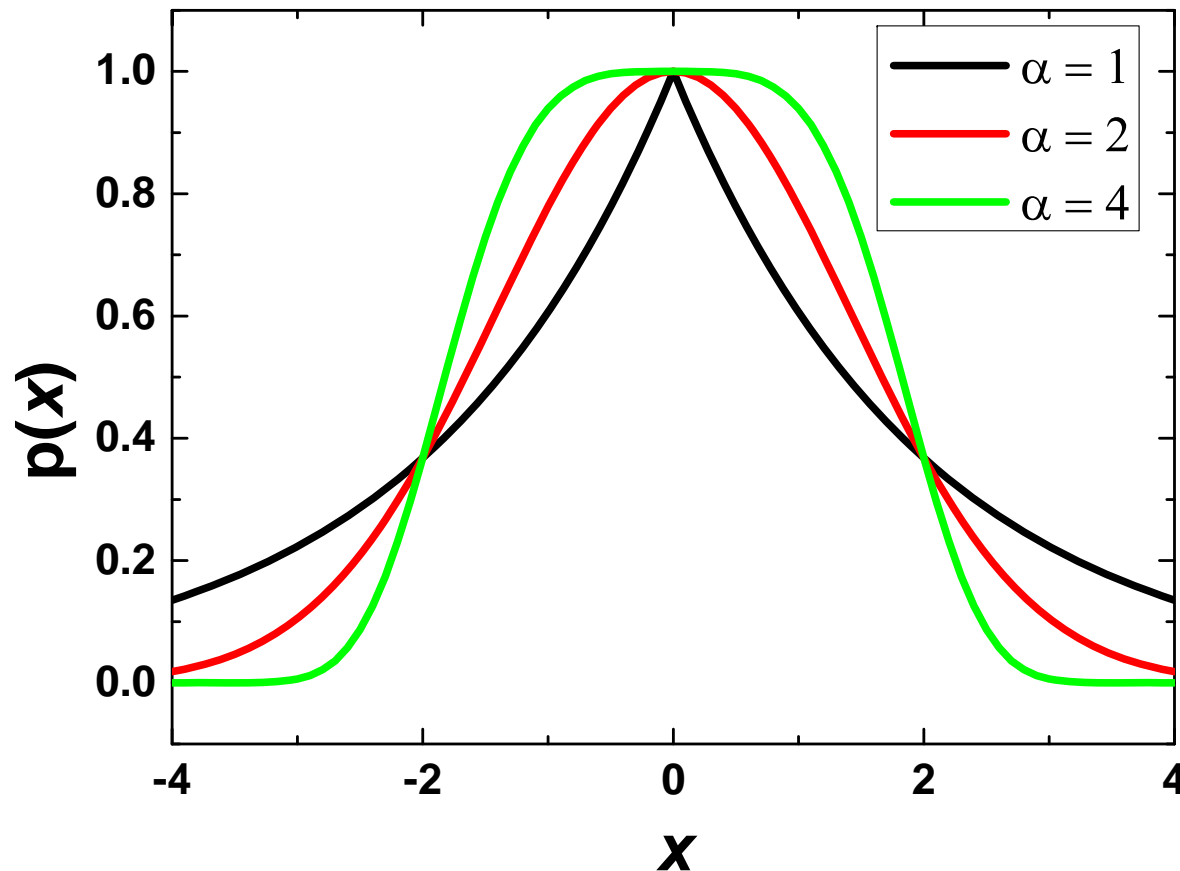


▶ Minimized cost



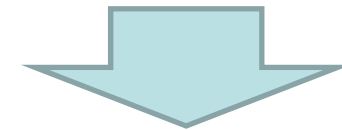
Exponential power distribution

Exponential power distribution



$$p(x) = \exp \left\{ - \left(\frac{|x|}{w} \right)^\alpha \right\}$$

As power index α becomes larger, the profile's tail becomes sharper



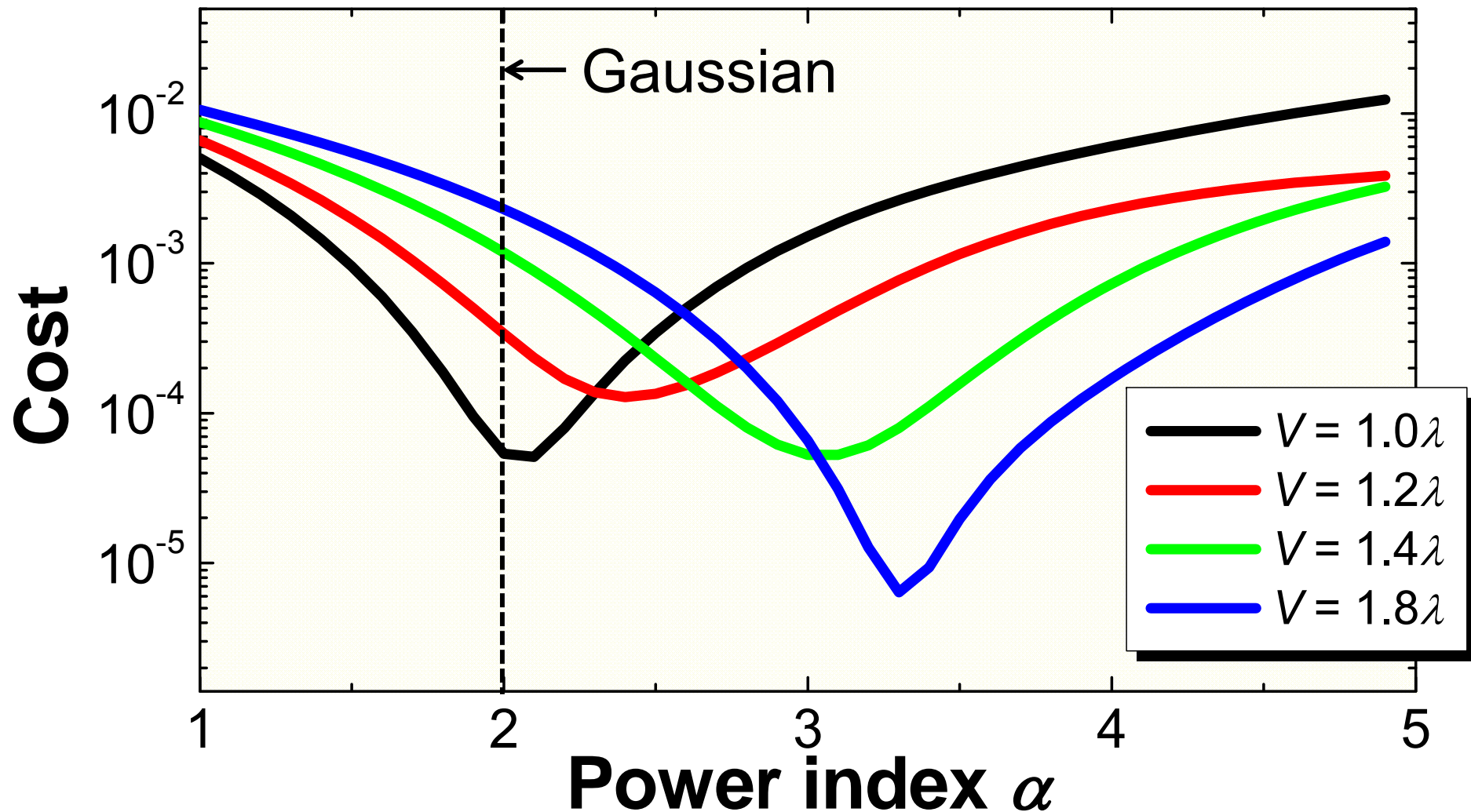
Exponential power distribution was found from the optimization

Contain various distributions

$\alpha = 1 \Rightarrow$ Laplace distribution

$\alpha = 2 \Rightarrow$ Gauss distribution

Power index dependency

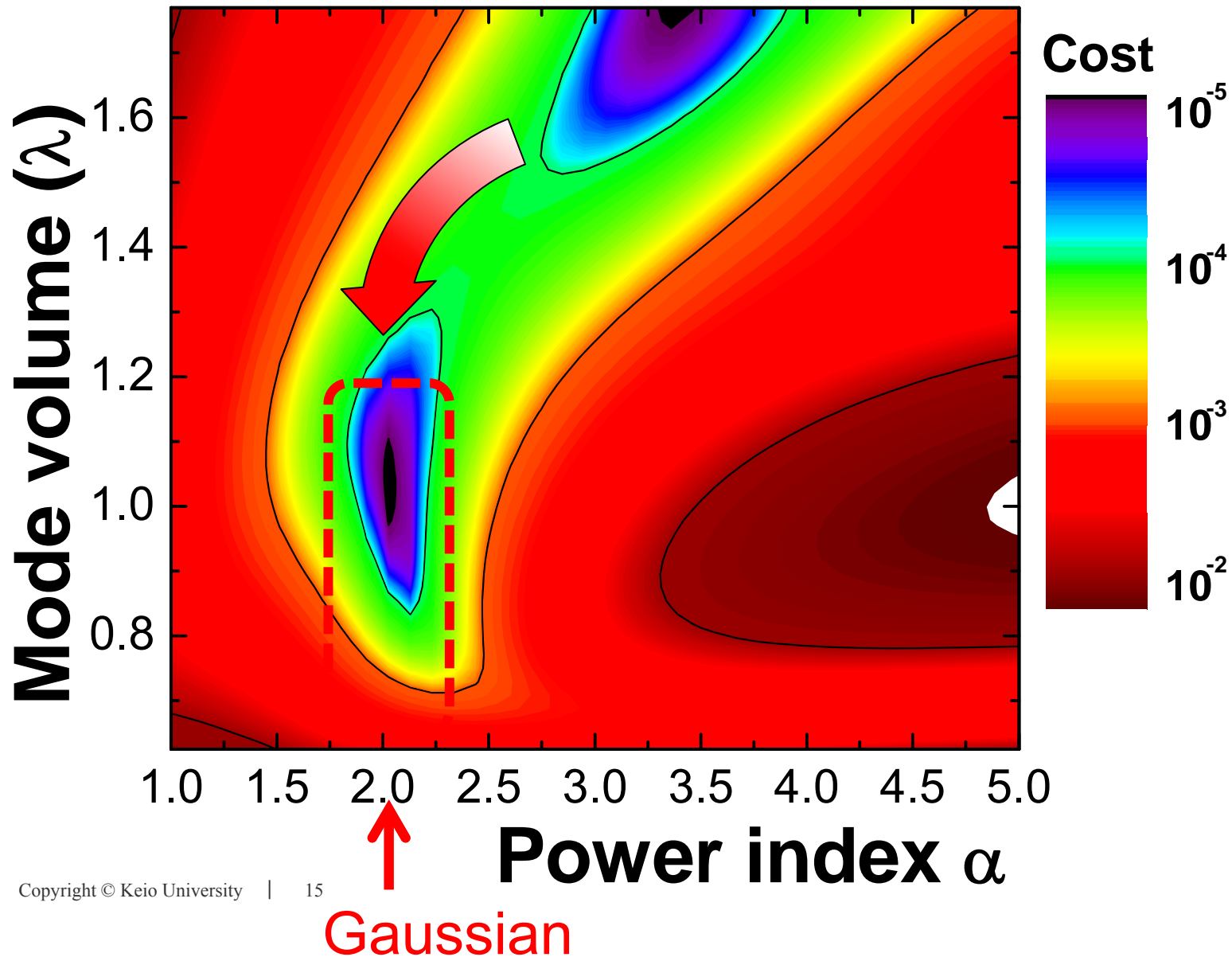


- ✓ Optimum shape depends on the cavity mode volume
- ✓ Gaussian profile is not always the best profile

Mode volume vs. power index



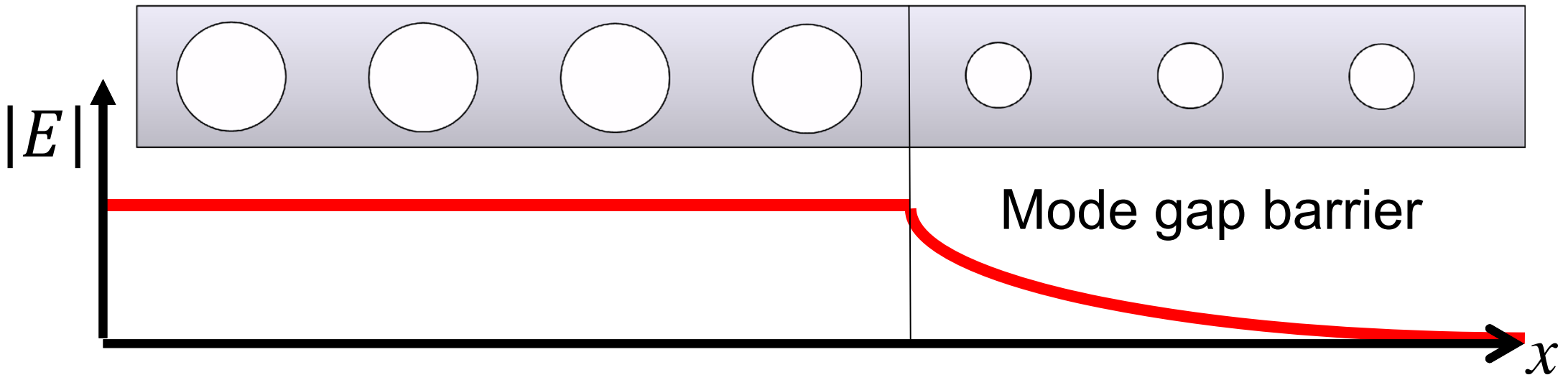
- ▶ Cost for different volumes & power indexes



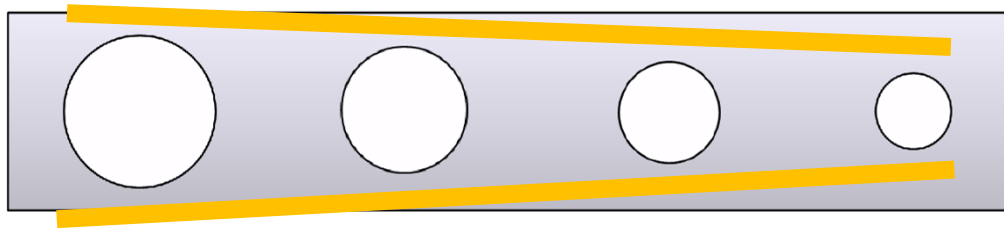
Gaussian
profile is best
ONLY for a
cavity with
mode volume
smaller than
 1.2λ

Design for nanobeam cavity (1D PhC nanocavity)

$$\text{decay} = \exp(-\kappa x)$$



Nanobeam cavity



Air hole radius

decreases linearly

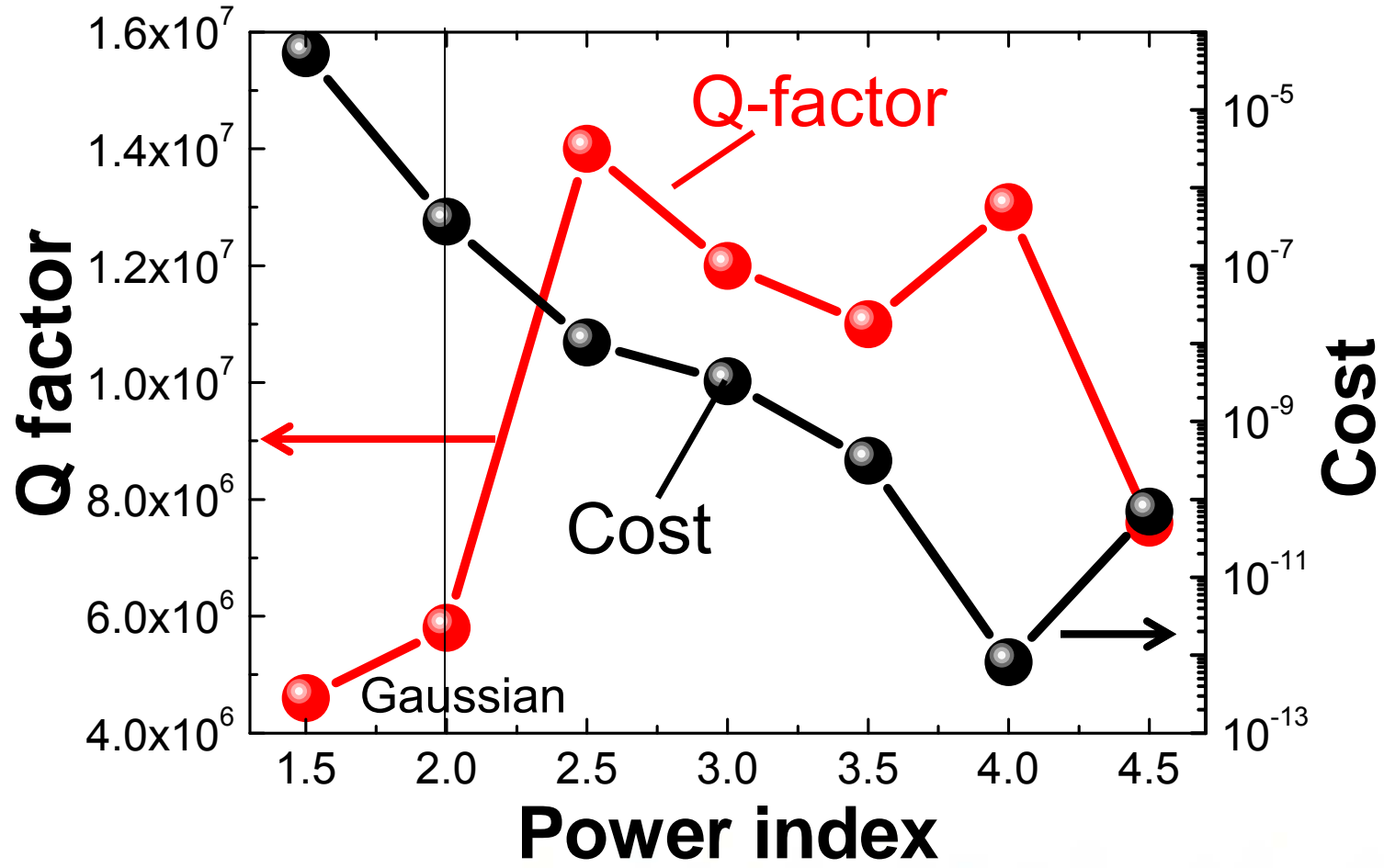
→ Gaussian profile

decreases nonlinearly

→ **Exponential power distribution**

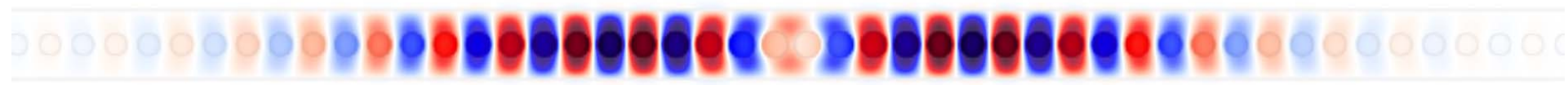
1D-PhC ncavity w/ exponential power distribution

▶ 3D-FDTD calculation & cost vs. alpha



Larger Q factor found than a Gaussian ($\alpha = 2.5$)

$$V \sim (1.8 \lambda/n)^3$$



3D-FDTD result for $\alpha = 2$

Summary



1. Optimization algorithm

- ✓ Optimization helped us to find an exponential power distribution as an ideal mode profile

2. Exponential power distribution

- ✓ Exponential power distribution has a high Q/V
- ✓ Optimized profile differs depending on cavity parameters
- ✓ A mode w/ higher Q (than a Gaussian) is found w/ 1D-PhC nanobeam cavity