# A topological source of quantum light

2018 Fall Journal Club

Oh Seunghoon

# The Research Group

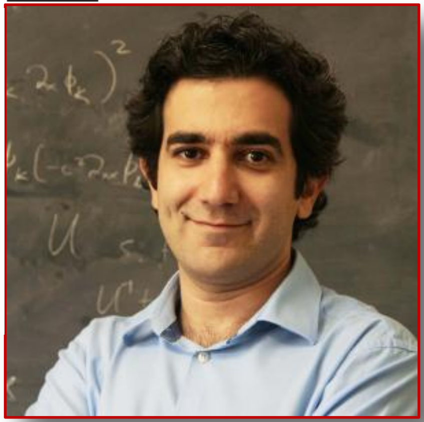
joint quantum institute
RESEARCH
HAFEZI GROUP

## LETTER

https://doi.org/10.1038/s41586-018-0478-3

## A topological source of quantum light

Sunil Mittal[1,2]*, Elizabeth A. Goldschmidt[1,3] & Mohammad Hafezi[1,2,4]

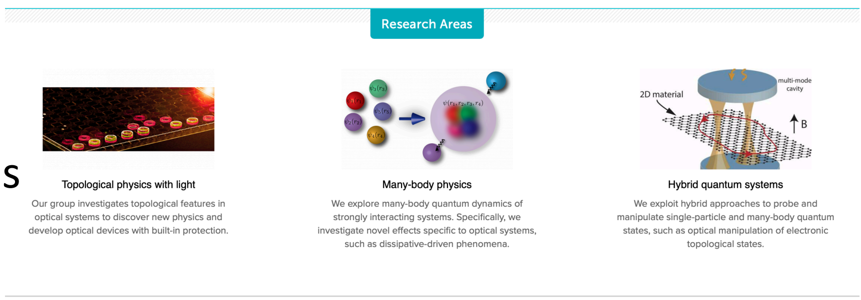


- 1998-2002, B.Sc., Physics (transferred), Sharif University
- 2000 – 2003, Diplome d'ingenieur, Physics-Math, Ecole Polytechnique
- 2003 – 2009, Ph.D. Physics, Harvard University

*"Strongly interacting systems in AMO physics"*

### Research Interests

- Quantum optics, Nanophotonics Optomechanics
- Theoretical and experimental investigation of topological states and strongly correlated systems
- Quantum information: Quantum hybrid systems



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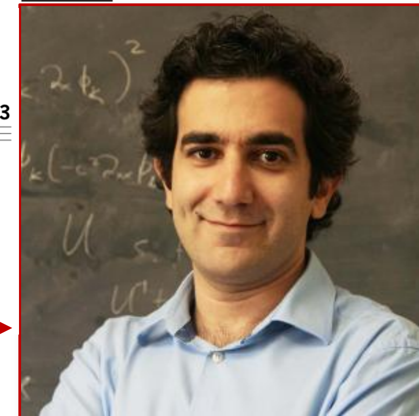


nature physics
ARTICLES
PUBLISHED ONLINE: 21 AUGUST 2011 | DOI: 10.1038/NPHYS2063

Selected for a Viewpoint in *Physics*
PRL **113,** 087403 (2014) PHYSICAL REVIEW LETTERS week ending 22 AUGUST 2014

PRL **112,** 210405 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

**Topologically Robust Trans**

nature photonics
ARTICLES
PUBLISHED ONLINE: 20 OCTOBER 2013 | DOI: 10.1038/NPHOTON.2013.274

**n Photonic Systems**

*ollege Park, Maryland 20742, USA*
d 29 May 2014)

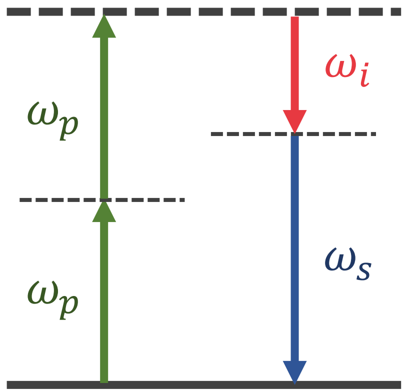
LETTERS
PUBLISHED ONLINE: 22 FEBRUARY 2016 | DOI: 10.1038/NPHOTON.2016.10
nature photonics

## Measurement of topological invariants in a 2D photonic system

Sunil Mittal[1,2], Sriram Ganeshan[1,3], Jingyun Fan[1], Abolhassan Vaezi[4] and Mohammad Hafezi[1,2]*

# Introduction

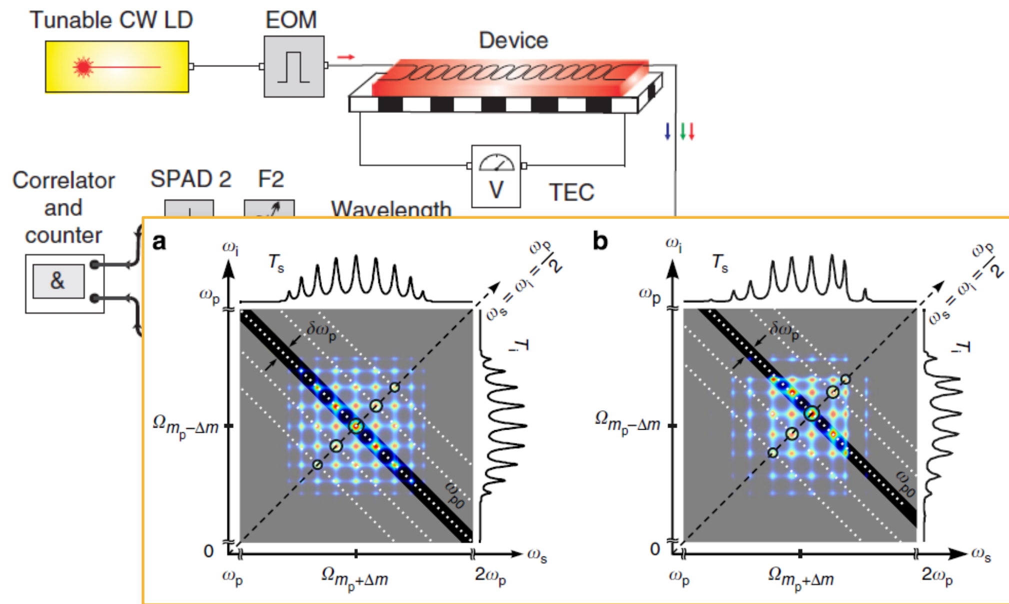
Spontaneous four-wave mixing (SFWM)



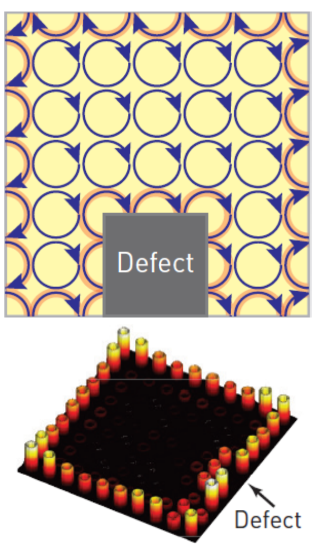

$$2\omega_p = \omega_i + \omega_s$$

$$2k_p = k_i + k_s$$

1D photonic ring resonator array




*Nature Communications* **5**, 5489 (2014)

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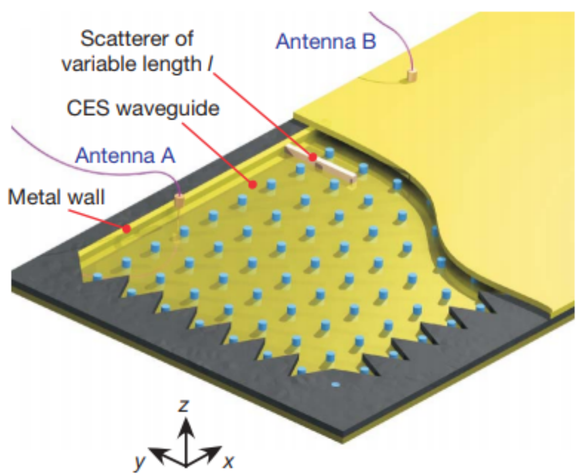
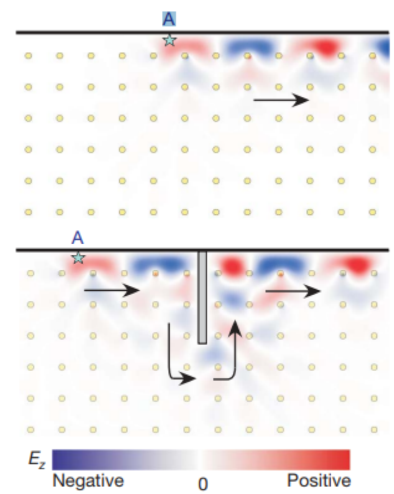



Topologically protected (edge state)

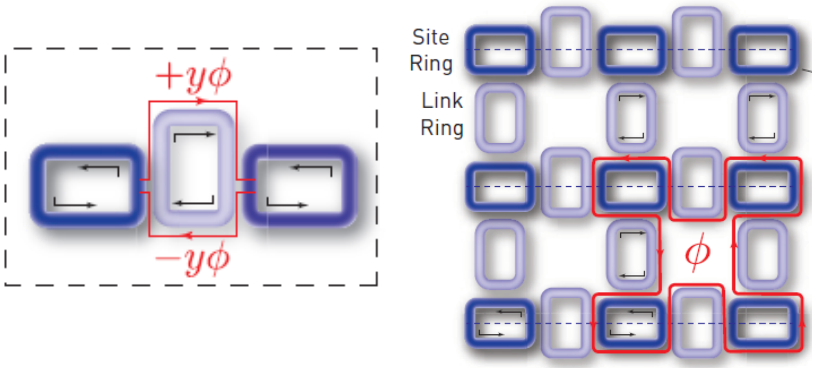
*Nature* **461**, 772–775 (2009)

# Theory

$m = (m_x, m_y)$ site $\qquad\qquad \mu \in \{p, s, i\}$

$$H_L = \sum_{m,n} \omega_{0\mu} a^\dagger_{m,\mu} a_{m,\mu} - J_{m,n}\left(a^\dagger_{m,\mu} a_{n,\mu} e^{-i\phi_{m,n}} + a^\dagger_{n,\mu} a_{m,\mu} e^{+i\phi_{m,n}}\right)$$

**Coupled ring resonators**

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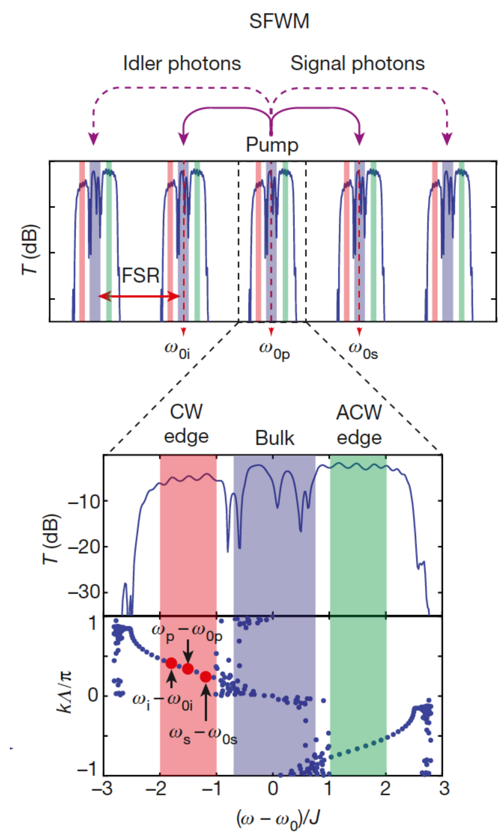
$J_{m,n}$ : hopping rate between $m, n$ state

$\phi_{m,n} = \phi m_y \delta_{m_x, n_x+1} \delta_{m_y, n_y}$ : hopping phase

$\phi$ : uniform synthetic magnetic field flux per plaquette




$$H_{NL} = \eta \sum_m \left(a^\dagger_{m,s} a^\dagger_{m,i} a_{m,p} a_{m,p} - a^\dagger_{m,p} a^\dagger_{m,p} a_{m,s} a_{m,i}\right)$$

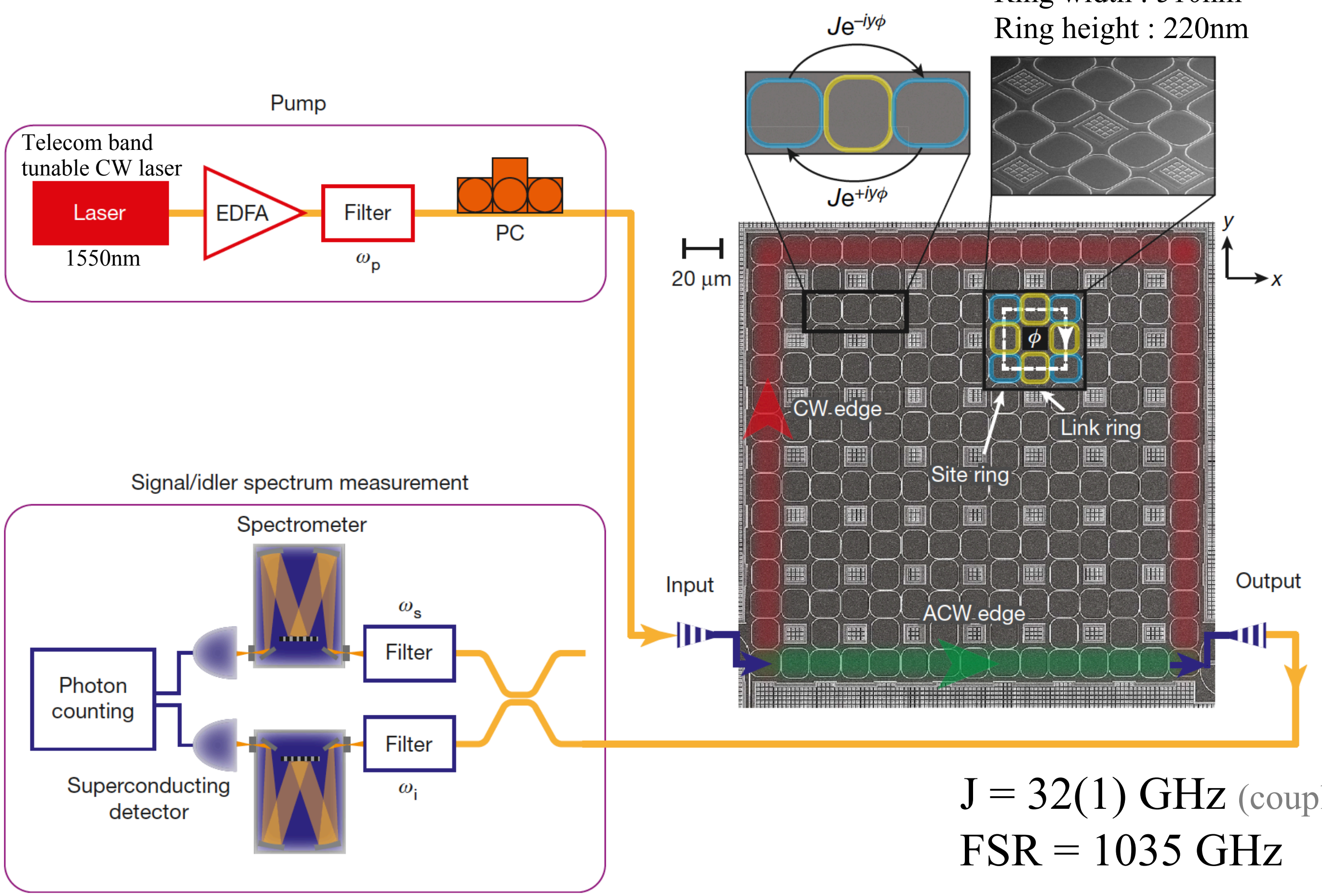
$\eta$ : strength of SFWM

$$-i\omega_p a_{m,p} = i[H_L, a_{m,p}] - \kappa_{in} a_{m,p} - (\delta_{m,I} + \delta_{m,O})\kappa_{ex} a_{m,p} - \delta_{m,I}\sqrt{2\kappa_{ex}} a_{in,p}$$

$$-i\omega_\mu a_{m,\mu} = i[H_L + H_{NL}, a_{m,\mu}] - \kappa_{in} a_{m,\mu} - (\delta_{m,I} + \delta_{m,O})\kappa_{ex} a_{m,\mu} - \delta_{m,I}\sqrt{2\kappa_{ex}} a_{in,\mu}$$

$$a_{out,\mu} = \sqrt{2\kappa_{ex}} a_{O,\mu} \rightarrow \Gamma(\omega_s, \omega_p) = \left|a_{out,s}\right|^2$$

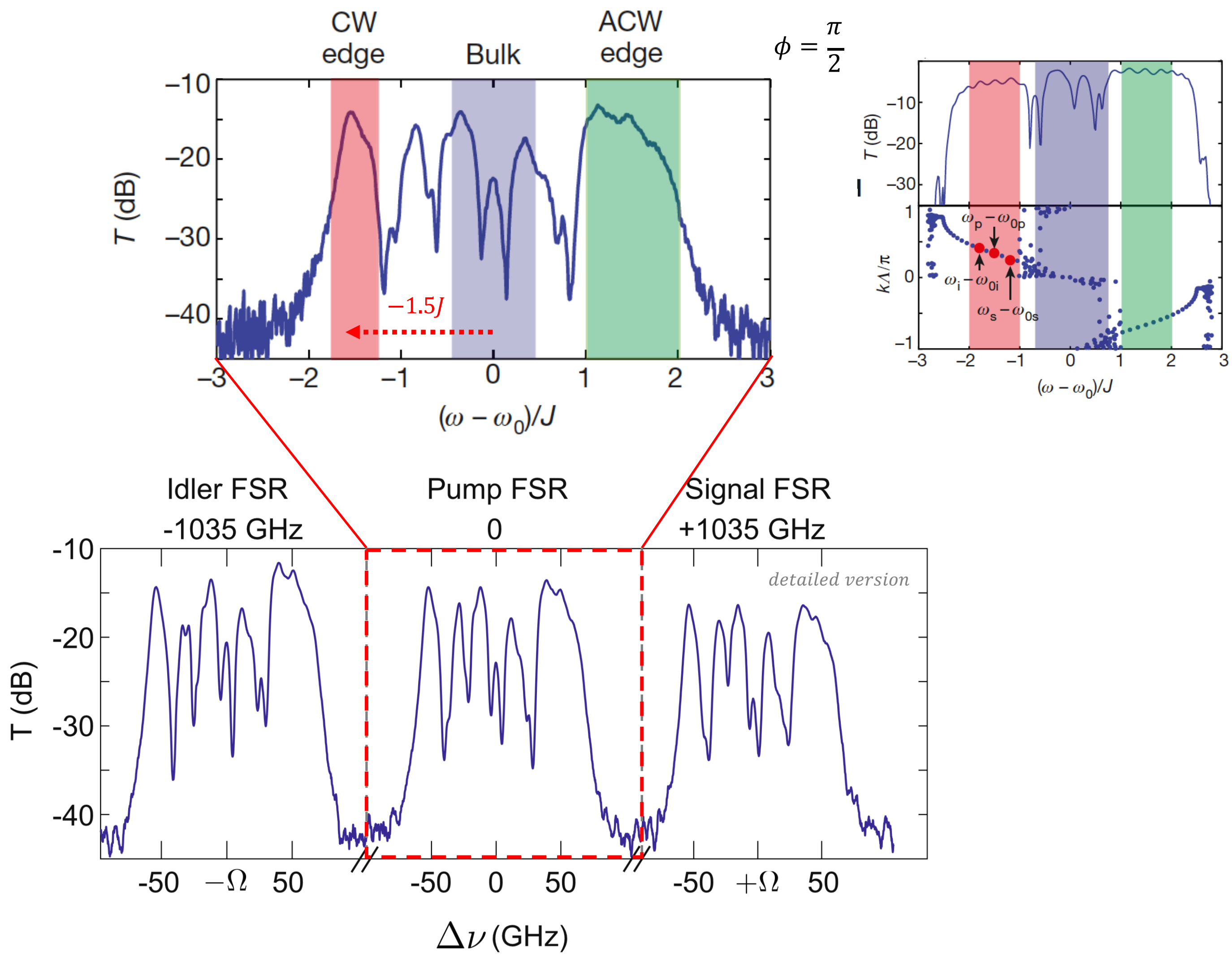
# Experimental Setup




Ring width : 510nm
Ring height : 220nm

J = 32(1) GHz (coupling strength)
FSR = 1035 GHz

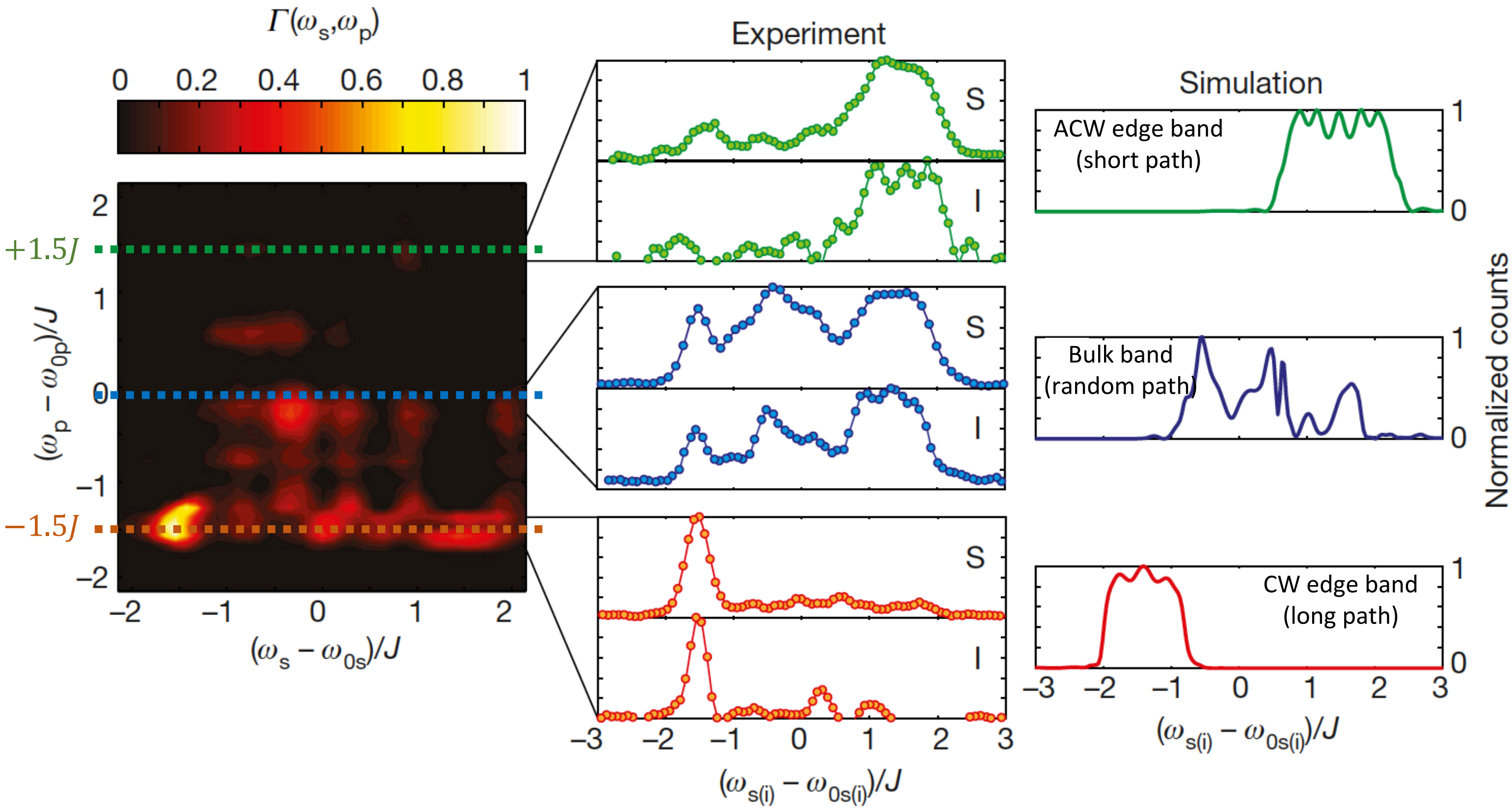
# Spectral distribution of the generated photons




$\Delta\nu$ : frequency relative to the longitudinal mode resonance

$\Omega$ : Free spectral range

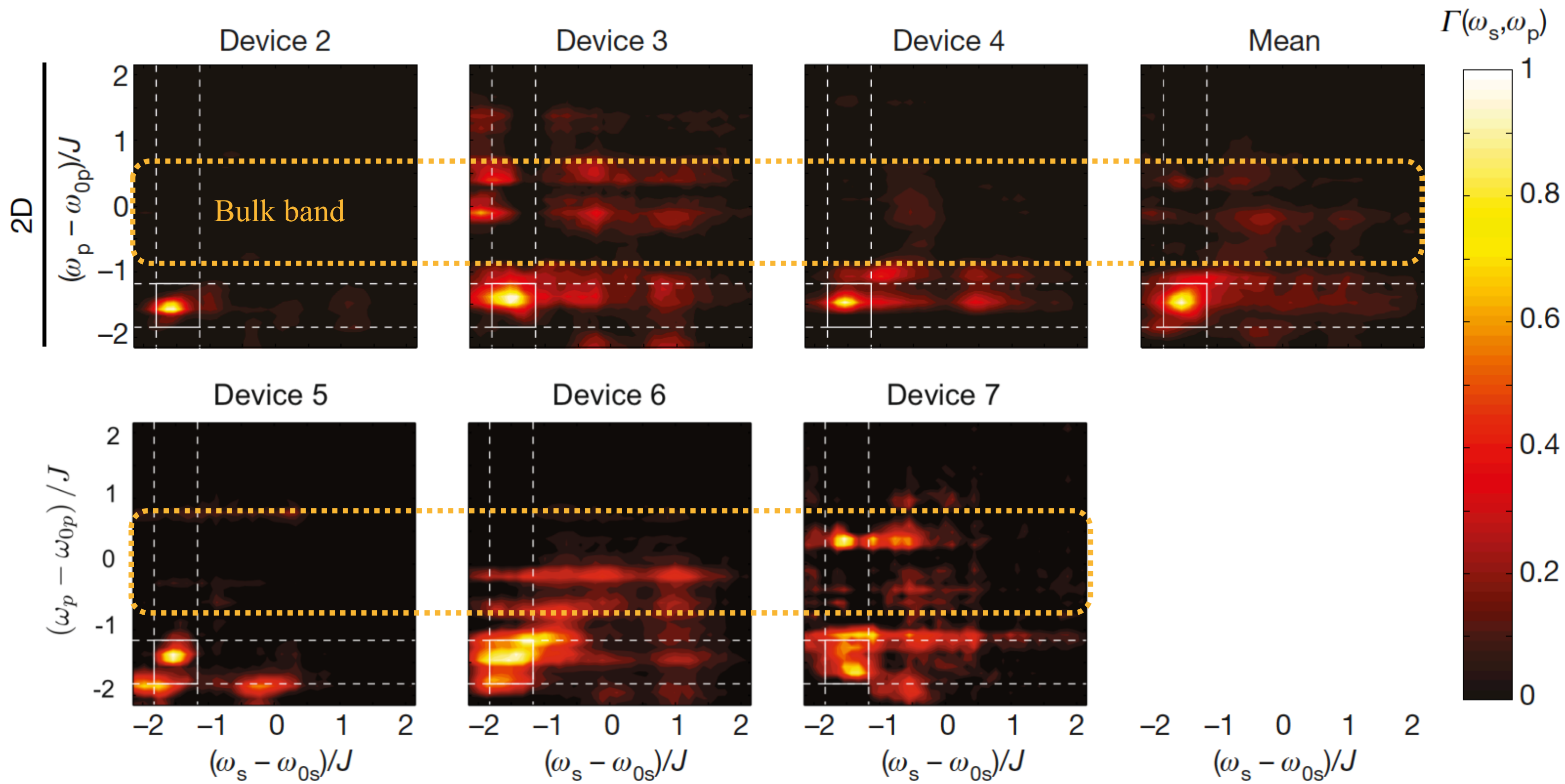
# Spectral distribution of the generated photons



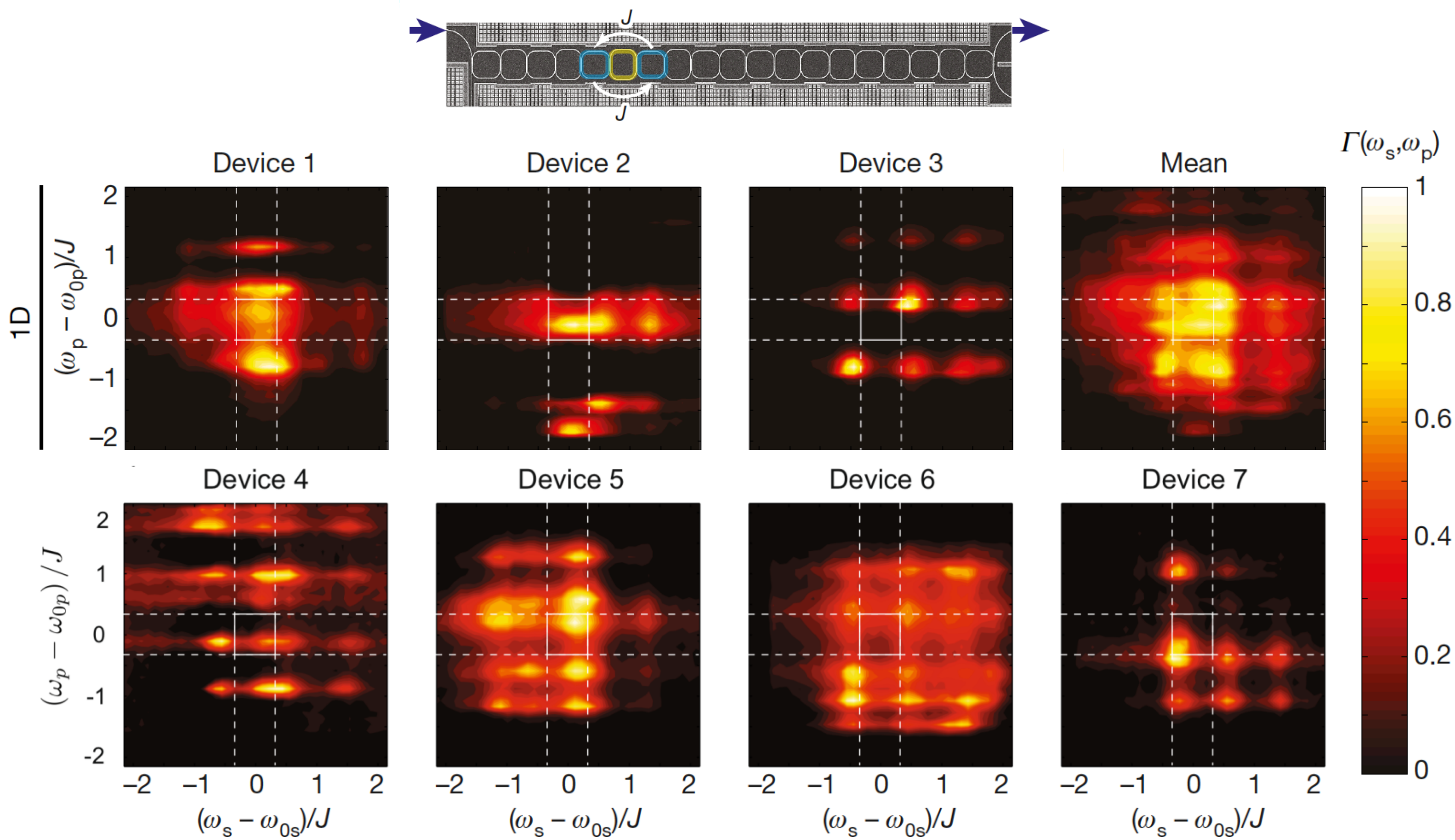

$\Gamma(\omega_s, \omega_p)$ : Intensity of generated photon w/ freq. $\omega_s$ when pump freq. is $\omega_p$

# Experiment results on 7 other devices (2D – edge state)

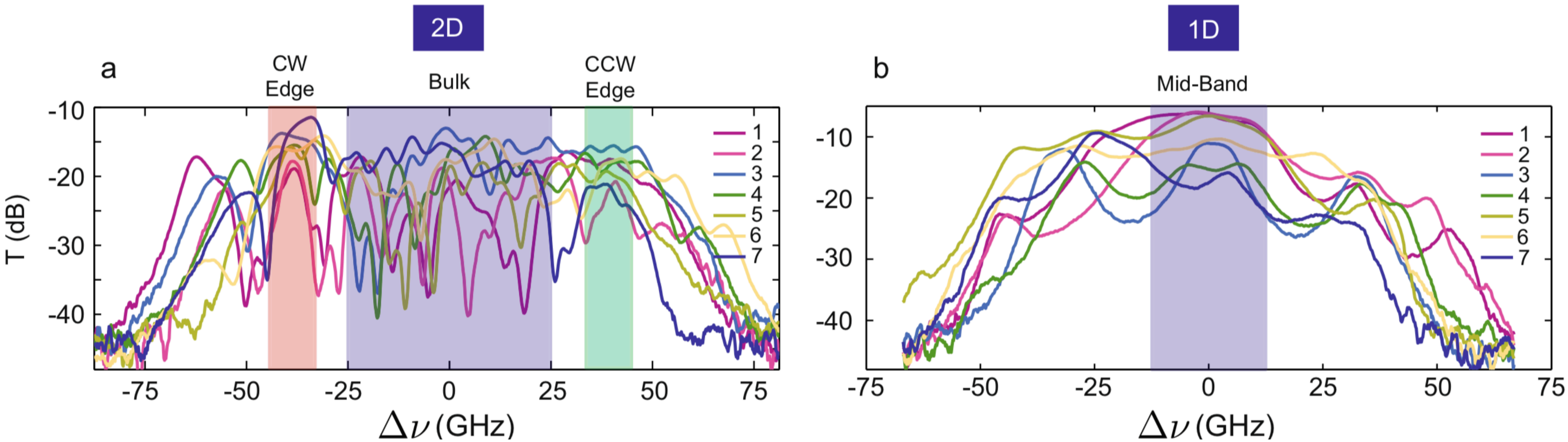
***Robust source of photon pair***



# Experiment results on 7 other devices (1D) comparison

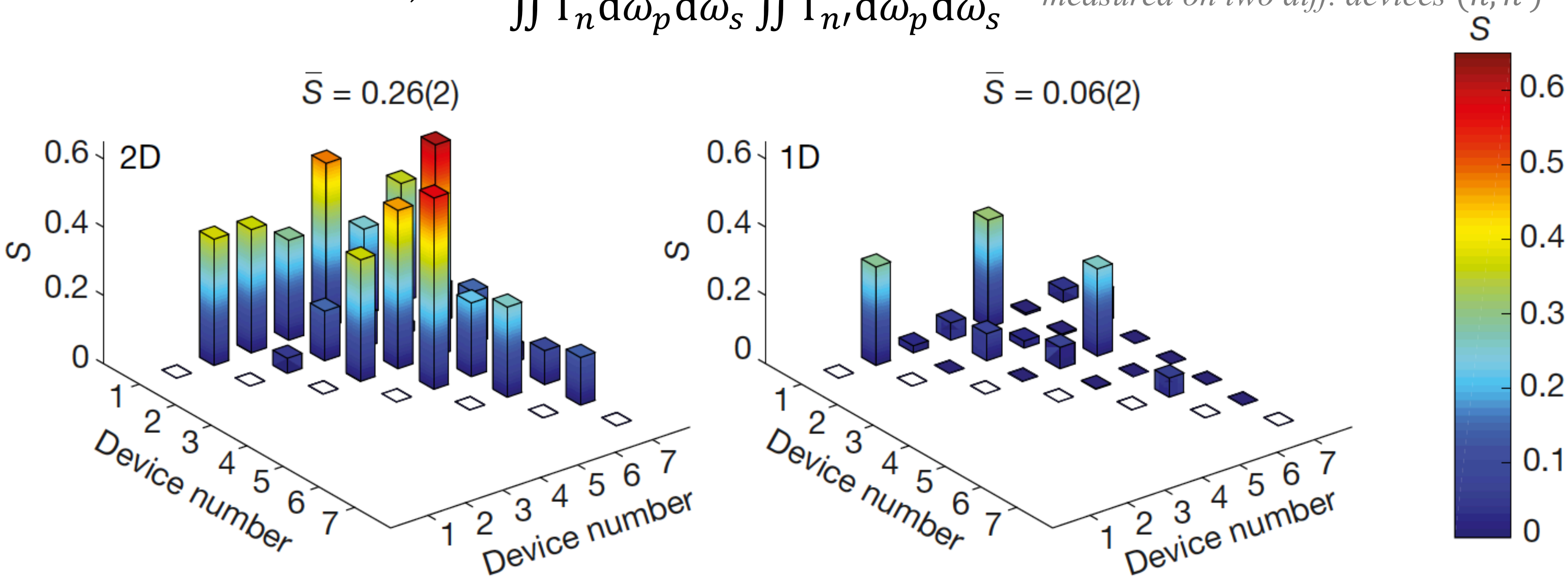


# Comparing the performance between 1D and 2D(edge state)

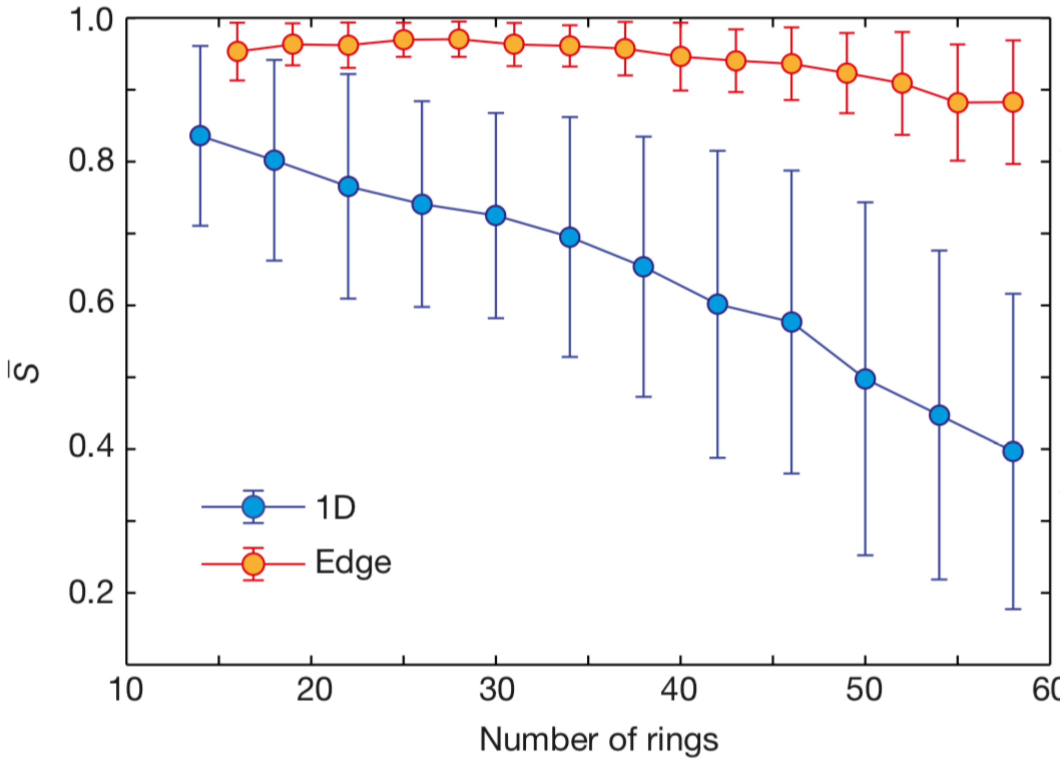



$$S_{n,n'} = \frac{\left(\iint \sqrt{\Gamma_n \Gamma_n'} \mathrm{d}\omega_p \mathrm{d}\omega_s\right)^2}{\iint \Gamma_n \mathrm{d}\omega_p \mathrm{d}\omega_s \iint \Gamma_{n'} \mathrm{d}\omega_p \mathrm{d}\omega_s}$$

*Similarity between $\Gamma(\omega_s, \omega_p)$ measured on two diff. devices $(n, n')$*



# Similarity under scaling (simulation – slightly smaller disorder)

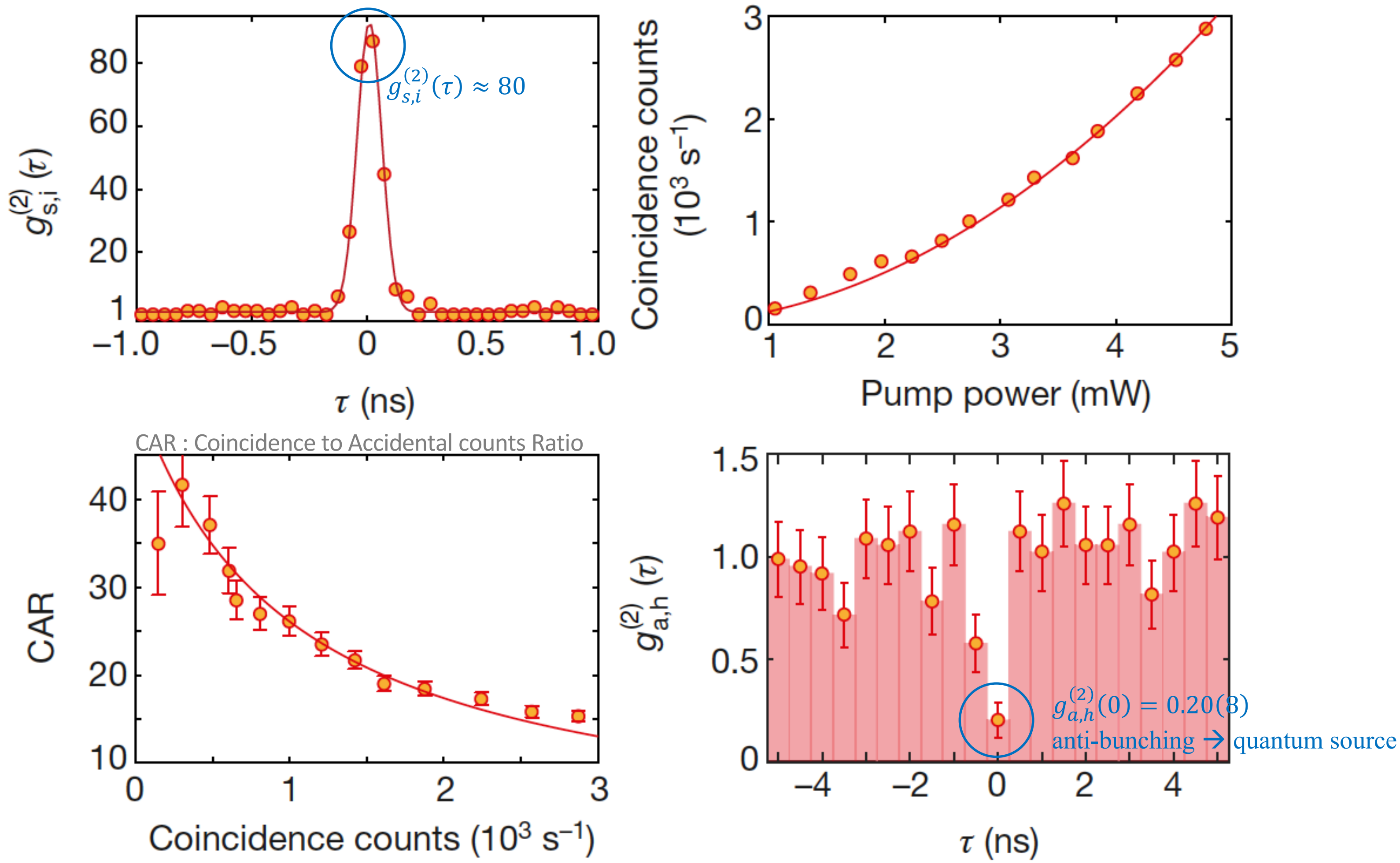



90%
w/ smaller error bar

40%
w/ larger error bar

# Two different correlation functions

$$g_{s,i}^{(2)}(\tau) = \frac{P_{s,i}(\tau)}{P_s P_i}$$ : Cross correlation function




$$g_{a,h}^{(2)}(\tau) = \frac{\mathrm{P}_{s_1,s_2,\mathrm{i}}(\tau)}{P_{s_1,i} P_{s_2,i}}$$ : Autocorrelation function

# Summary

- They demonstrated a robust route to manipulating the structure and vacuum fluctuations of the EM modes by using topological photonics
- Also demonstrated a topological source of quantum correlated photon pairs in which the spectral correlations are robust against fabrication disorder
- Make possibilities on-ship, scalable sources of heralded and entangled photons with identical spectra
- Have a potential for improvement on source brightness with recent development of ultra-low-loss photonic platforms (minimize the propagation loss)
- Low-loss platforms would enable quantum-limited topological amplifiers

# Joint spectral intensity(JSI)