Time-Resolved Detection of Photon-Surface-Plasmon Coupling at the Single Quanta Level

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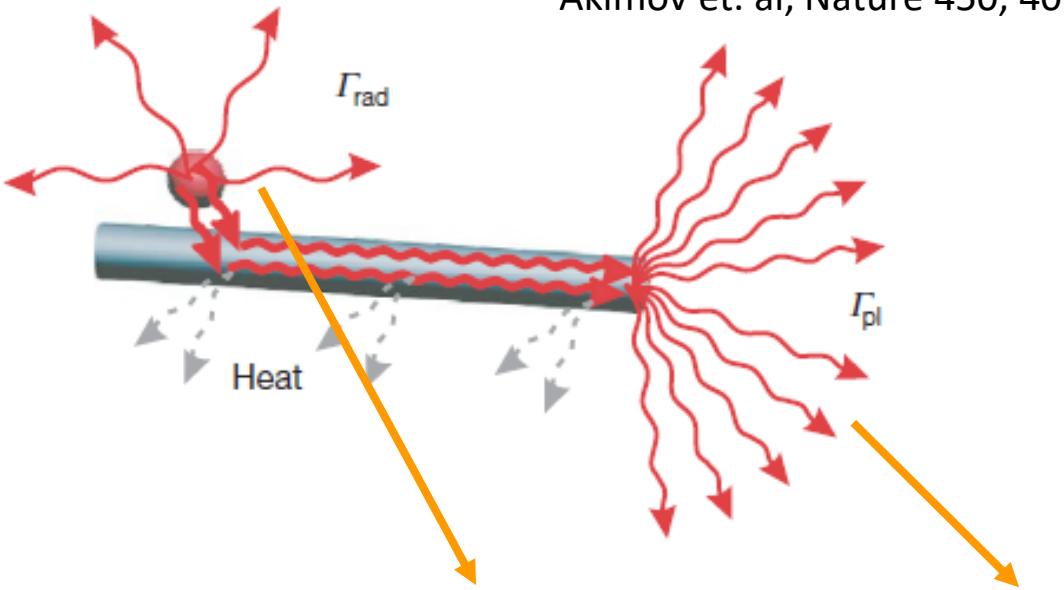
Outline

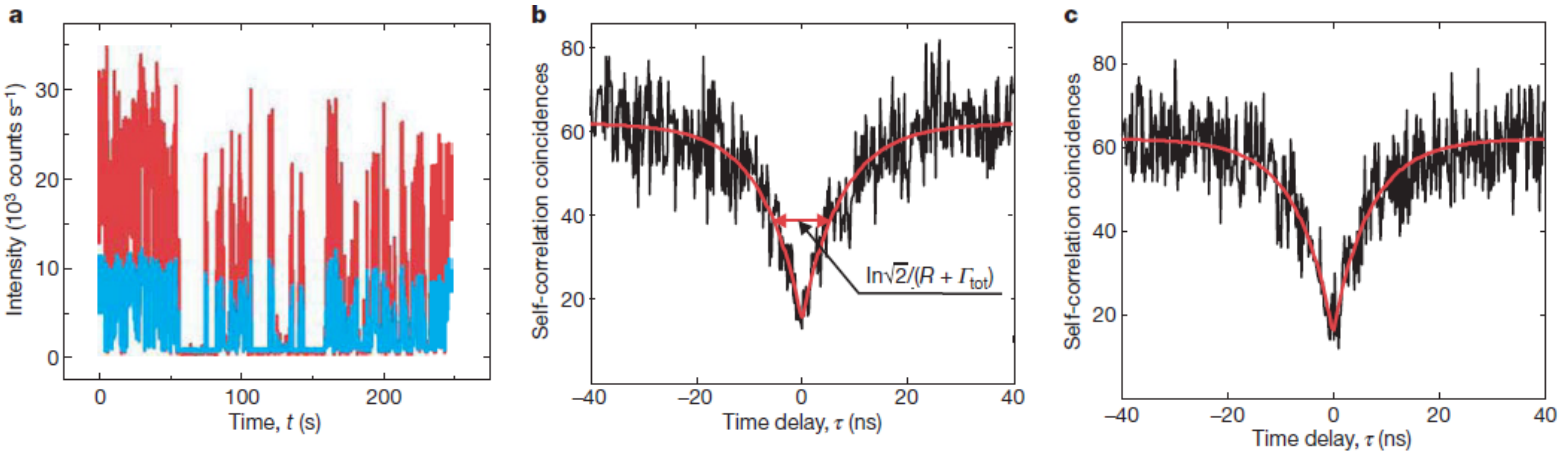
- Motivation
- Scientific goals
- Experimental setup
- Results
- Conclusion and Outlook

Light-Matter Interaction

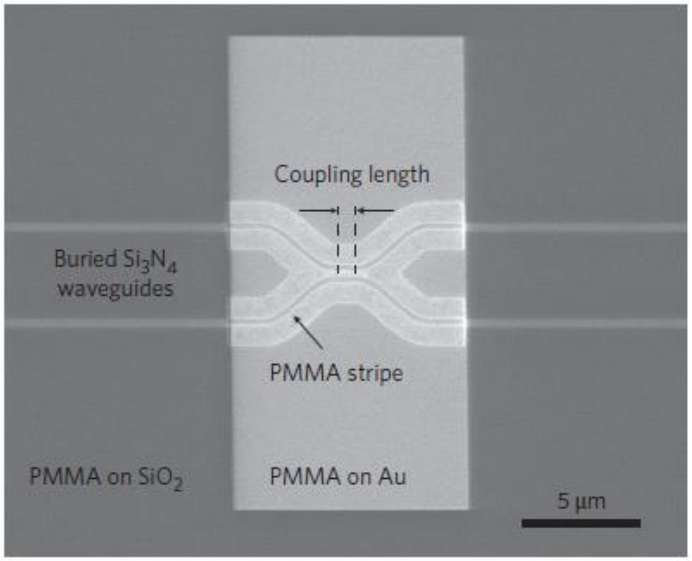
Light-Matter Interaction with Plasmonics

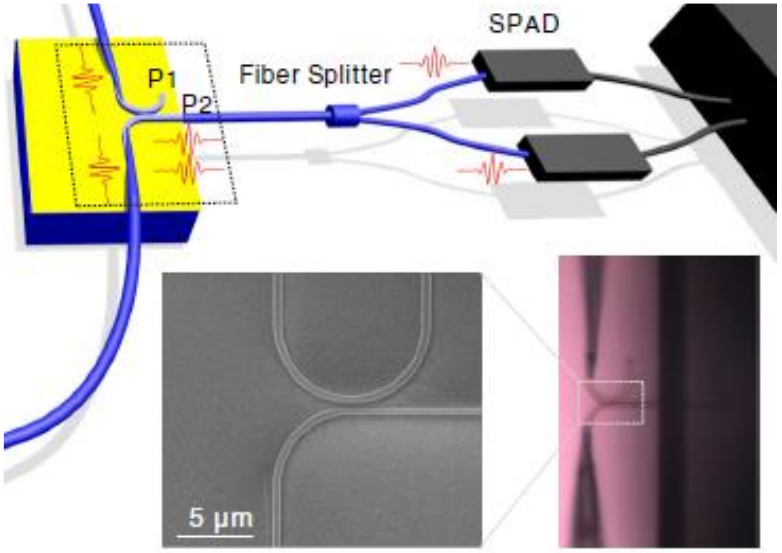
Akimov et. al, Nature 450, 402 (2007)

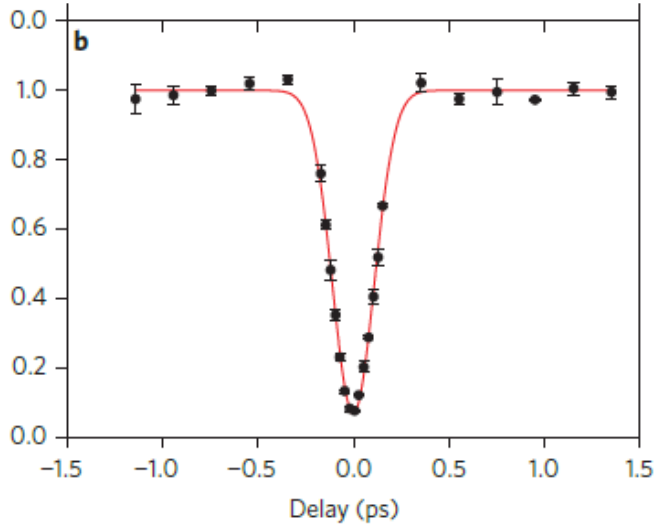


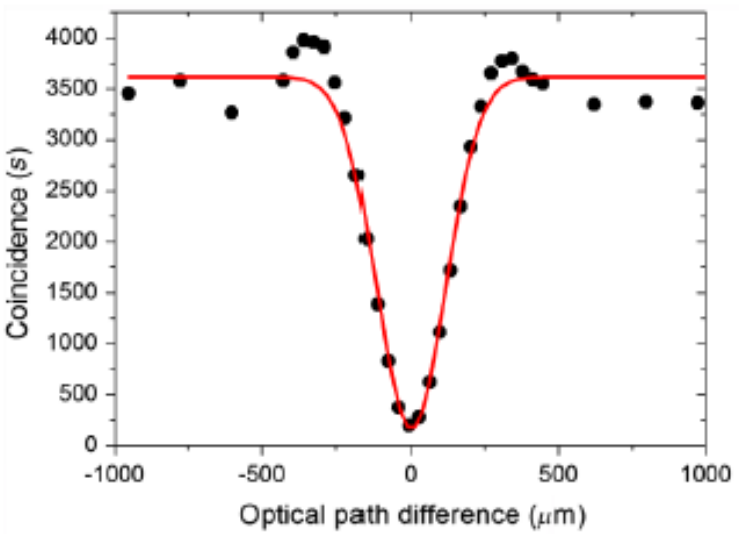


Hong-Ou-Mandel Interference





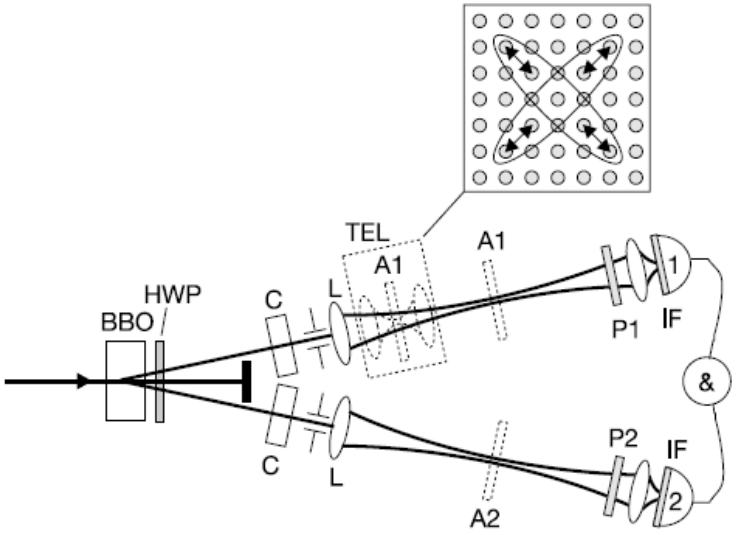


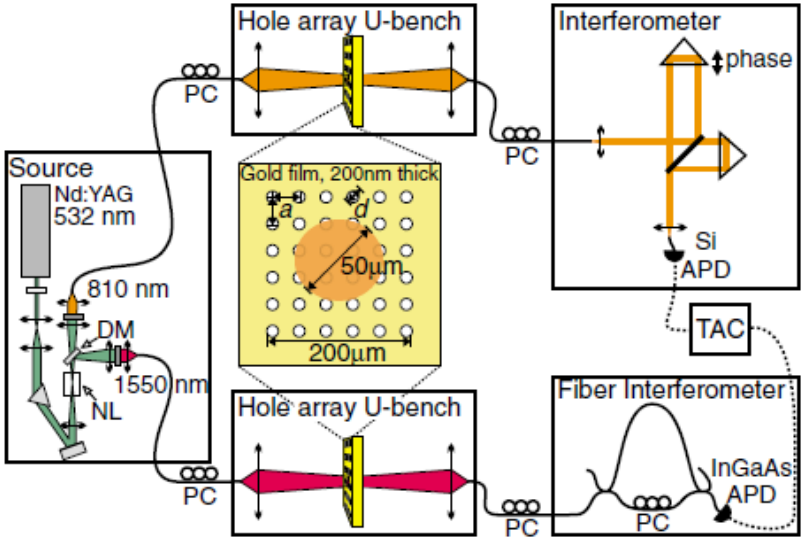


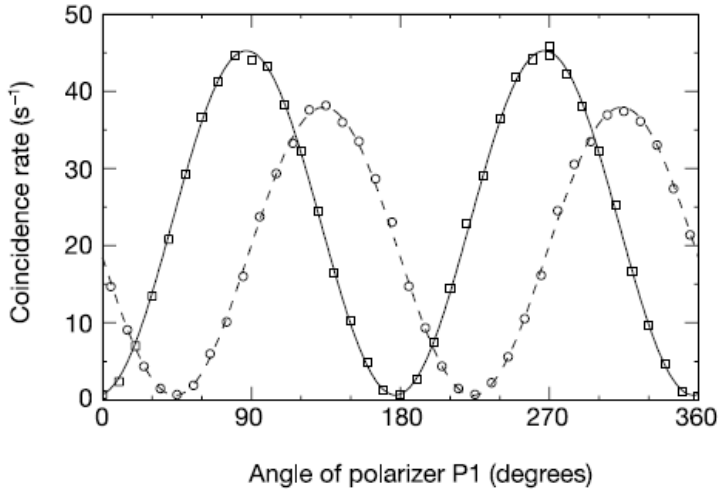
Fakonas et. al, Nat. Photonics 8, 317 (2014)

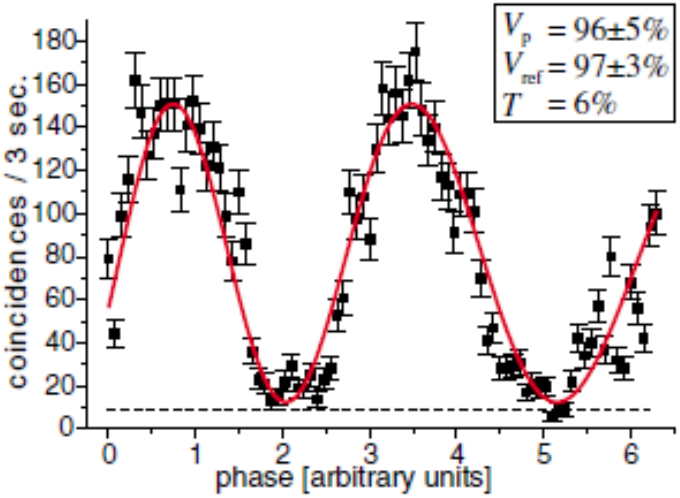
Cai et. al, Phys. Rev. Applied 2, 014004 (2014)

Transmission of Entanglement







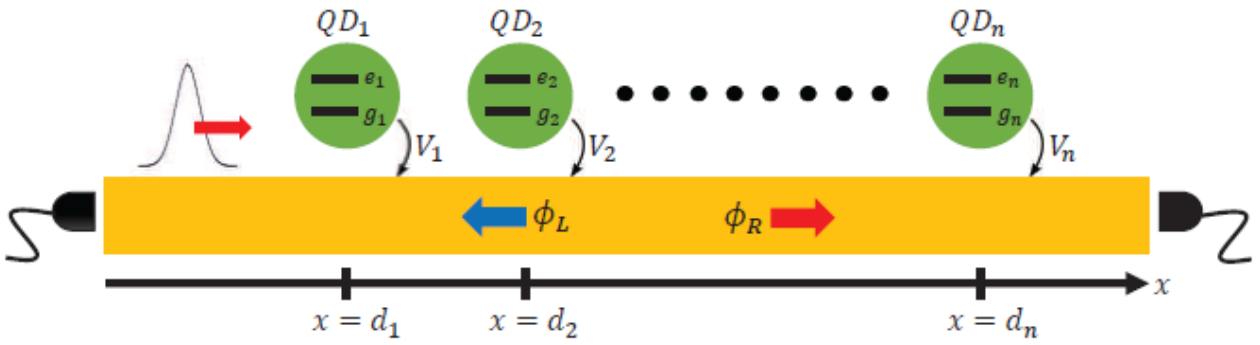


Altewischer et. al, Nature 418, 304 (2002)

Fasel et. al, Phys. Rev. Lett. 94, 110501 (2005)

Generation of Entanglement

Chen and Chuu, Opt. Express (in press)



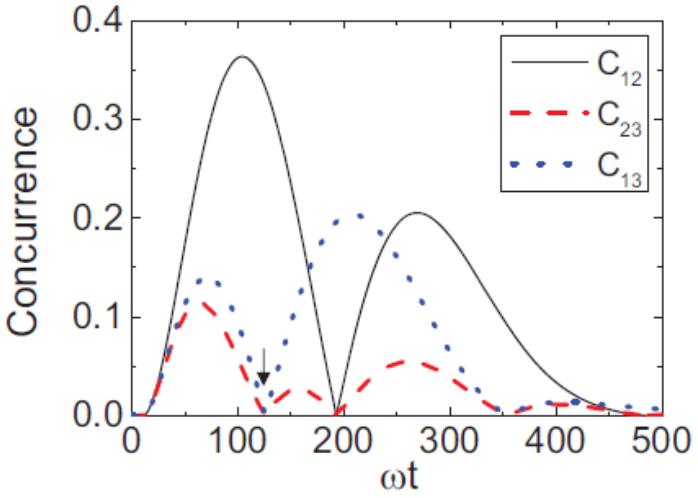
1. *W* state

$$|W\rangle = \frac{1}{\sqrt{3}}\left(|e_1, g_2, g_3\rangle + |g_1, e_2, g_3\rangle + |g_1, g_2, e_3\rangle\right)$$

2. *W*-like state

$$|W'\rangle = \frac{1}{\sqrt{6}}\left(2\,|e_1, g_2, g_3\rangle + |g_1, e_2, g_3\rangle + |g_1, g_2, e_3\rangle\right)$$

3. Death and revival of entanglement



Time-Resolved Detection and Manipulation

- **Formation of single optical plasmons**

  -- Temporal wavepacket (Glauber correlation function)

$$G^{(2)}(\tau) = \langle a_i^{\dagger}(t+\tau)a_s^{\dagger}(t)a_s(t)a_i(t+\tau)\rangle$$

  -- Nonclassical correlation (Cauchy-Schwarz inequality)

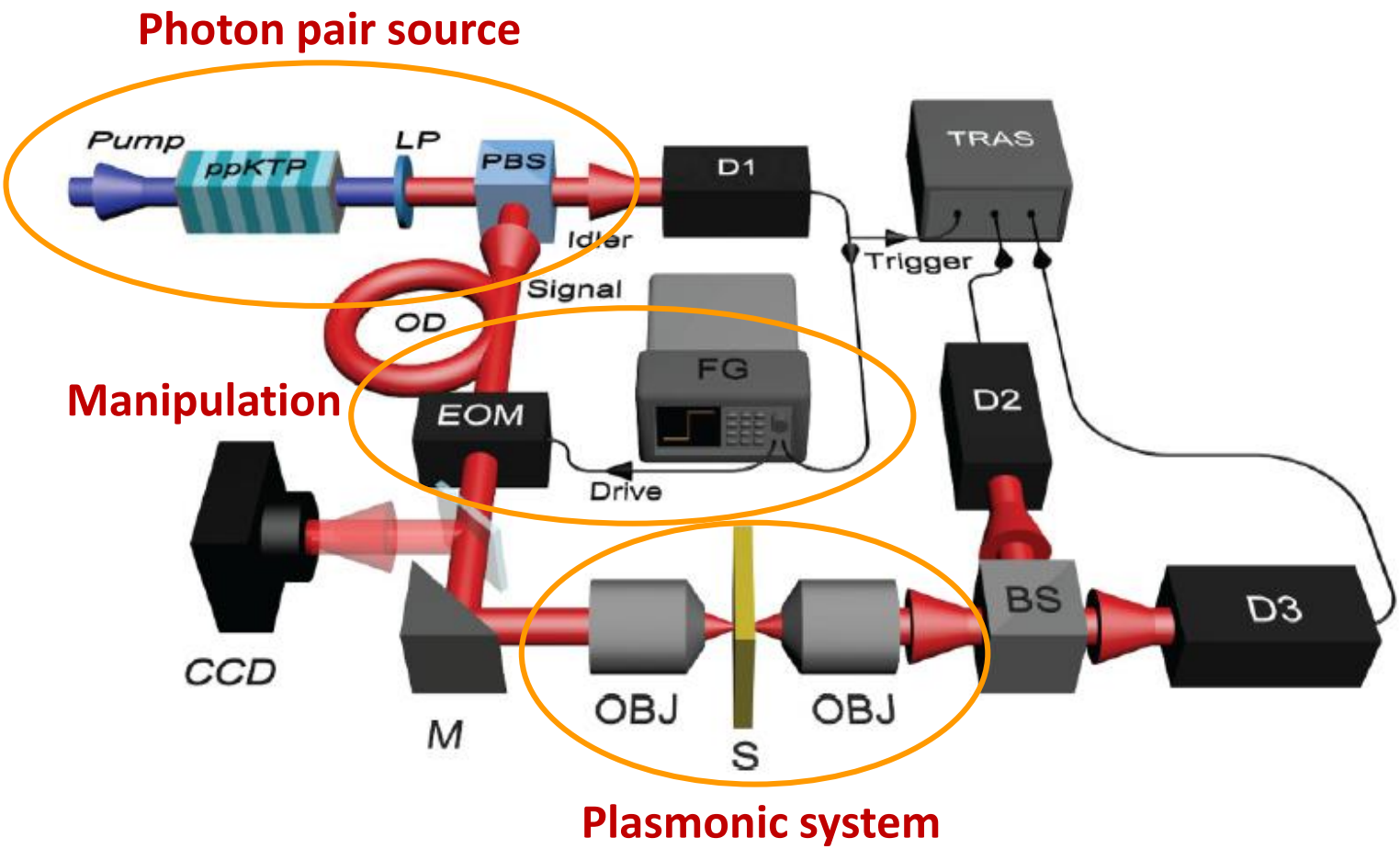
$$C(\tau) = g_{i,r}^2(\tau)/g_{i,i}(0)g_{r,r}(0) \leqslant 1$$

  -- Coherence (Hong-Ou-Mandel Interference)

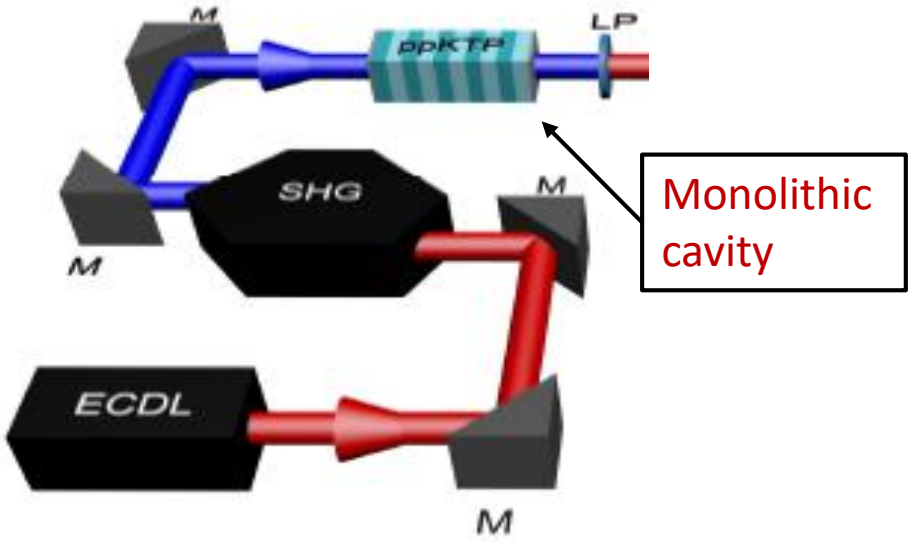
- **Manipulation of single optical plasmons**

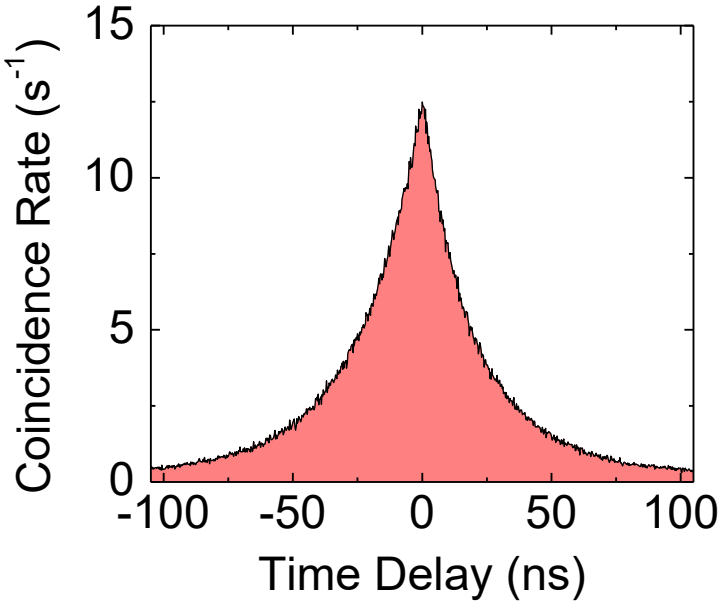
  -- Wavefunction shaping

Experimental Setup

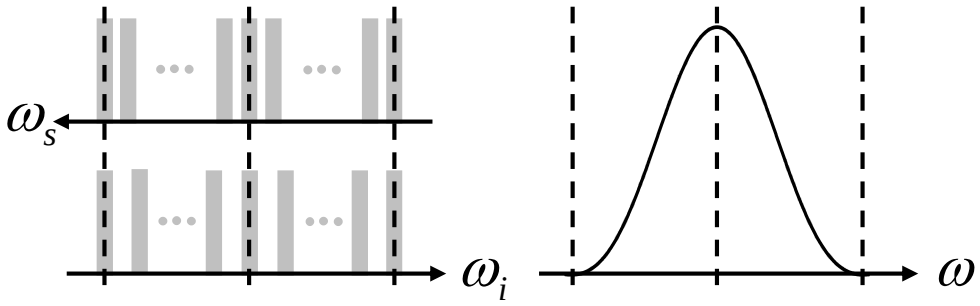


SPDC-Based Photon Pair Source





Doubly resonant modes

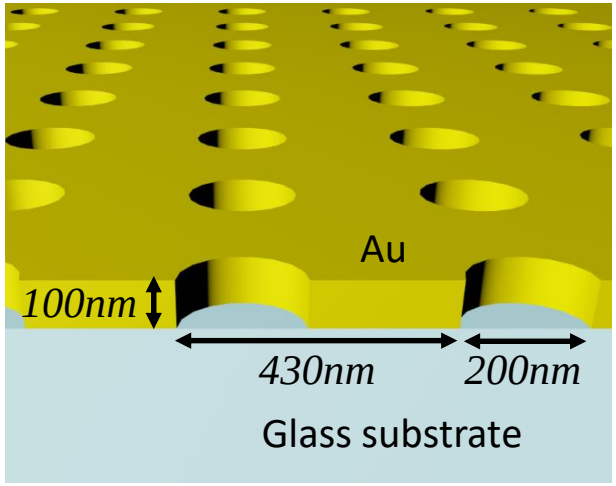


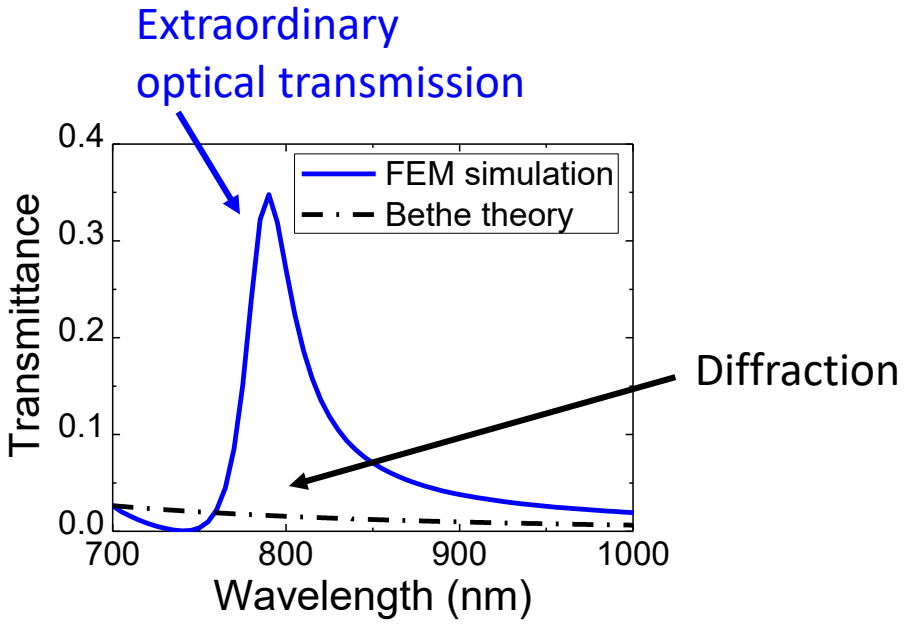
Single mode without external filters

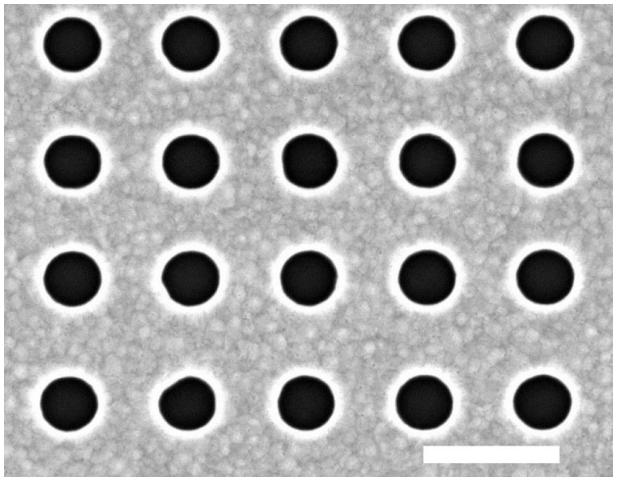
Bandwidth = 4.5 MHz
Paired rate = 2000 s^{-1} @ 30μW
Wavelength = 795 nm

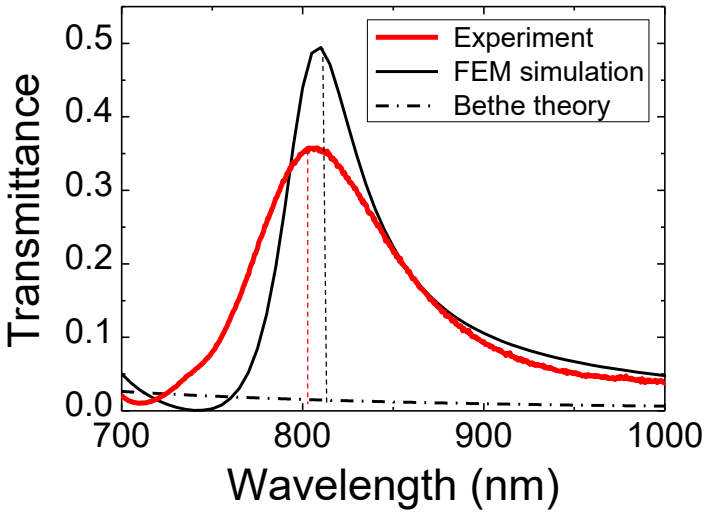
Phys. Rev. A 96, 023811 (2017)
Appl. Phys. Lett. 101, 051108 (2012)

Plasmonic System

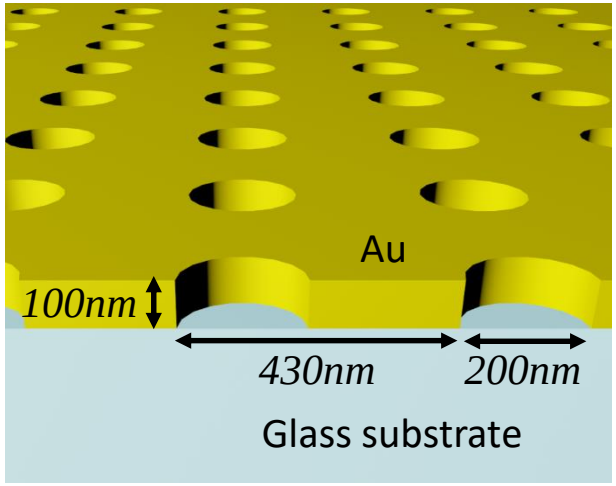


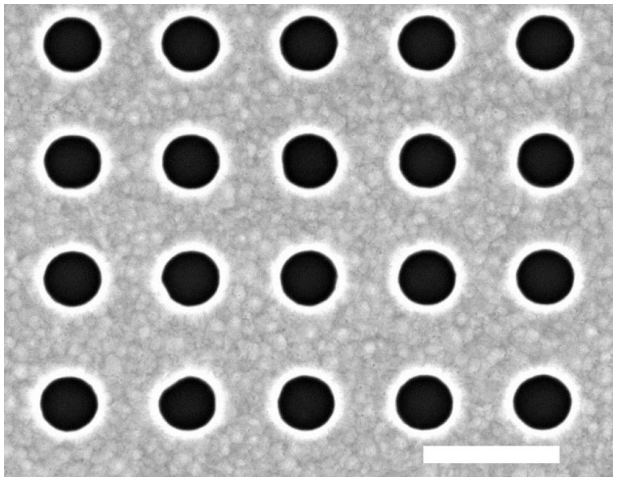




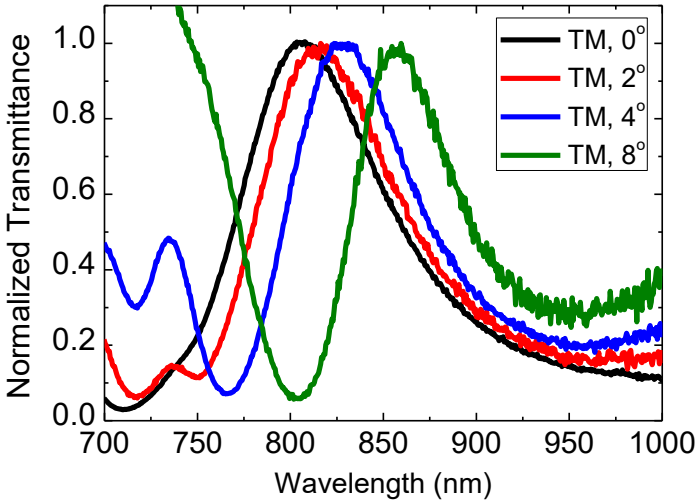


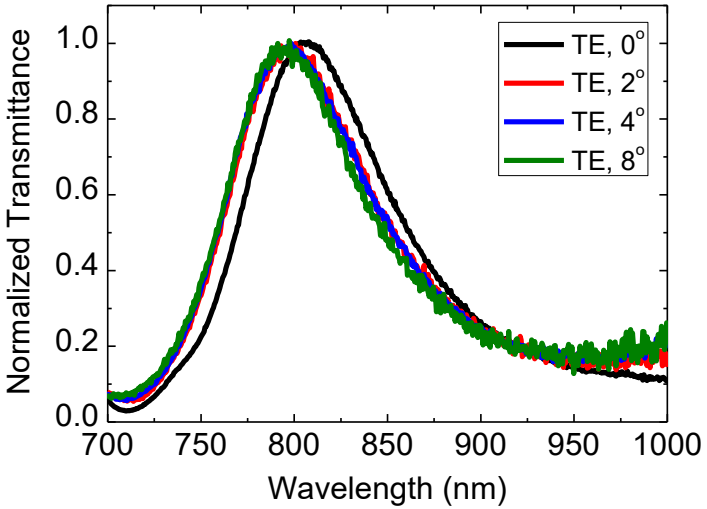
Plasmonic System



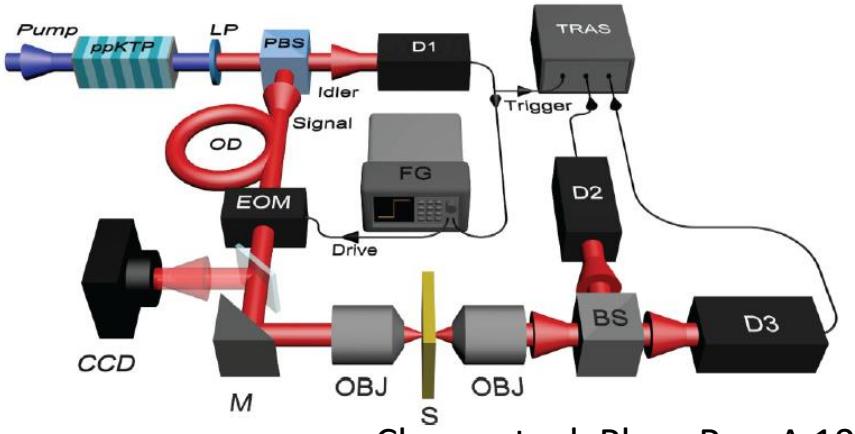


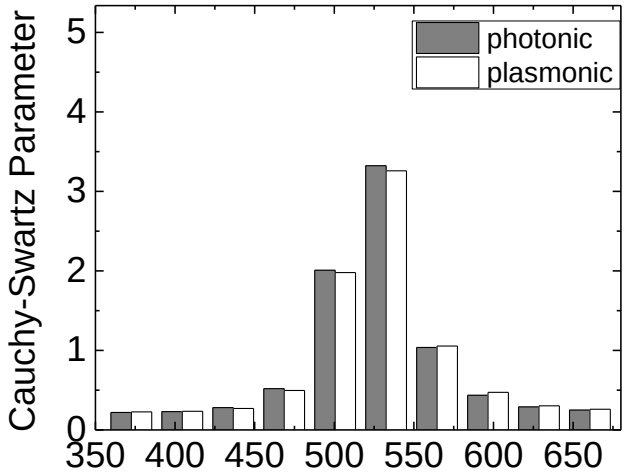
Polarization-resolved transmission





Non-Classical Correlation (CS Inequality)



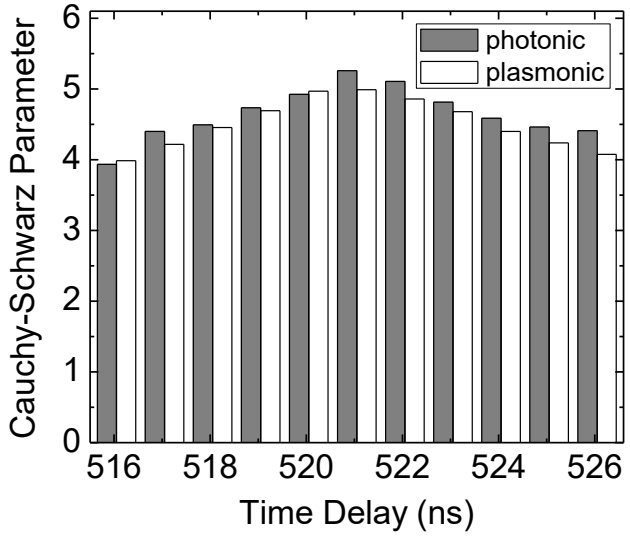


Cheng et. al, Phys. Rev. A 102, 033724 (2020)

$$g^{(2)}(0) = p_{123}/p_{12}p_{13}$$

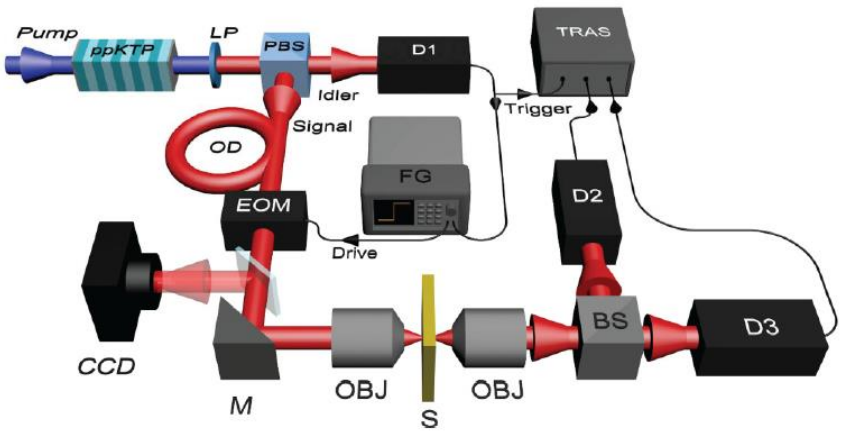
Single-photon quality

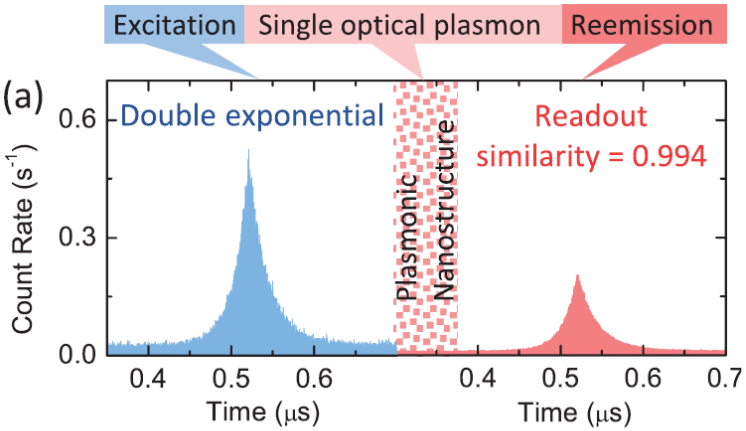
Incident photon	Reemitted photon
0.019 ± 0.003	0.015 ± 0.003
0.019 ± 0.003	0.009 ± 0.003



Cheng et. al, Phys. Rev. A 102, 033724 (2020)

Temporal Wavepacket





Conversion efficiency = 44%

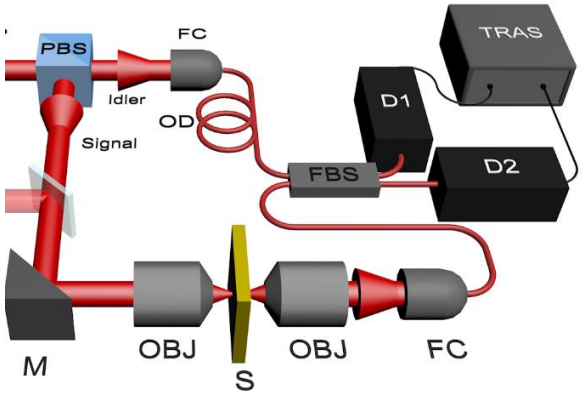
$$g^{(2)}(0) = p_{123}/p_{12}p_{13}$$

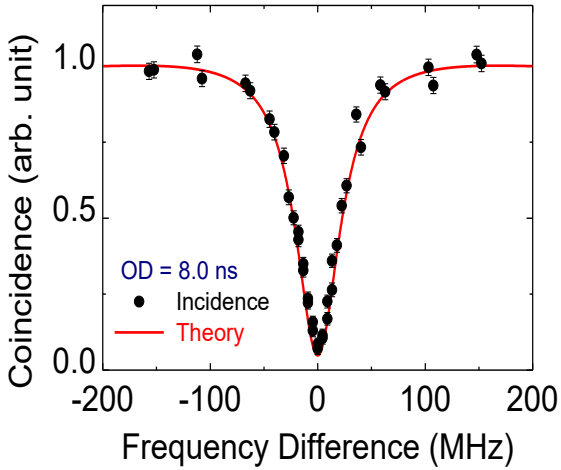
Single-photon quality

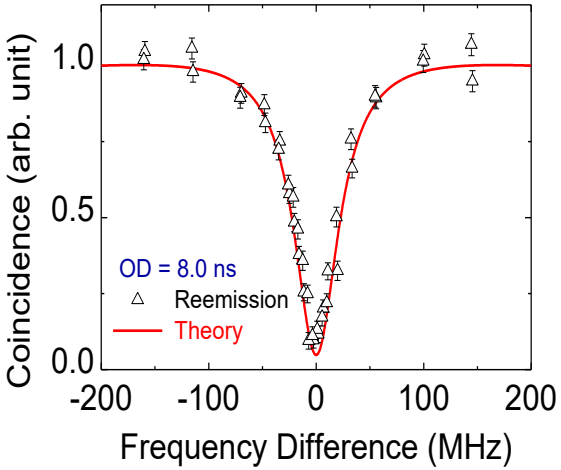
Incident photon	Reemitted photon
0.019 ± 0.003	0.015 ± 0.003
0.019 ± 0.003	0.009 ± 0.003

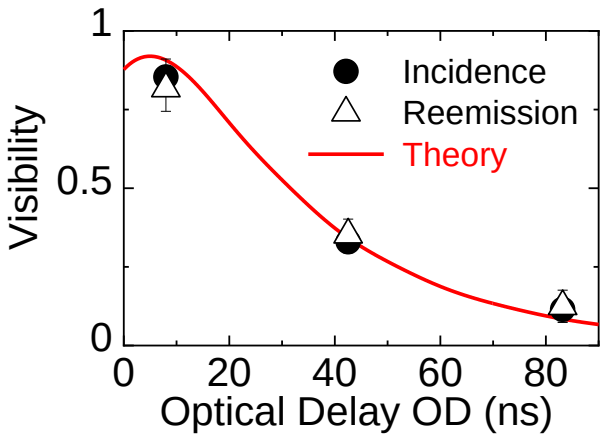
Cheng et. al, Phys. Rev. A 102, 033724 (2020)

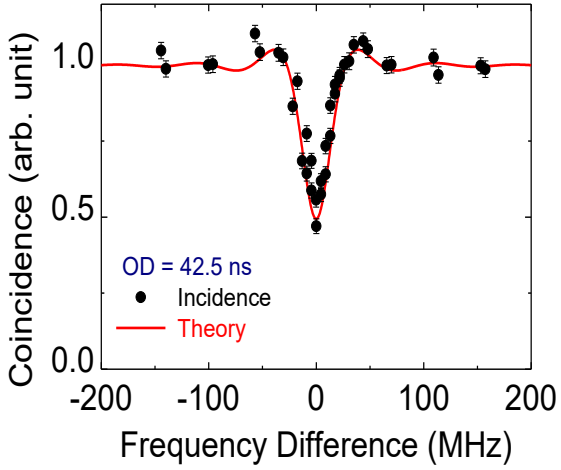
Conversion Process: Coherent or Incoherent?

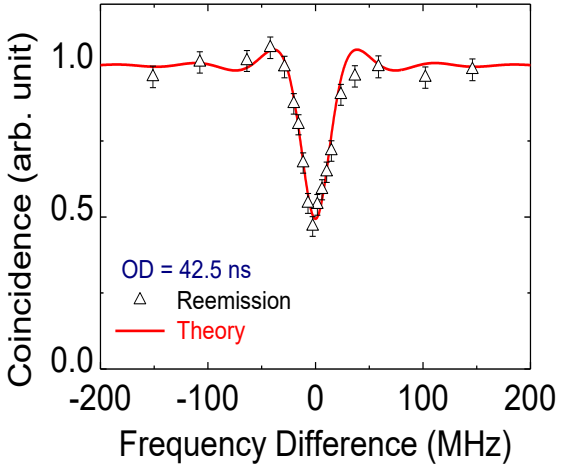








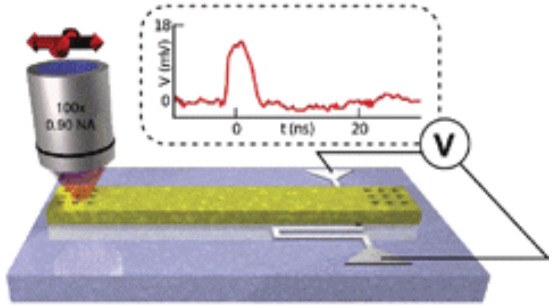




Cheng et. al, Phys. Rev. A 102, 033724 (2020)

Conclusion and Outlook

- A technique of time-resolved detection is developed to study the formation and manipulation of single optical plasmons.
- The technique can also be applied to the plasmonic waveguides.
- Direct detection of single optical plasmons is possible with on-chip superconducting detectors.



Zwiller group (KTH)