Photon super-bunching from a metal-metal tunnel junction

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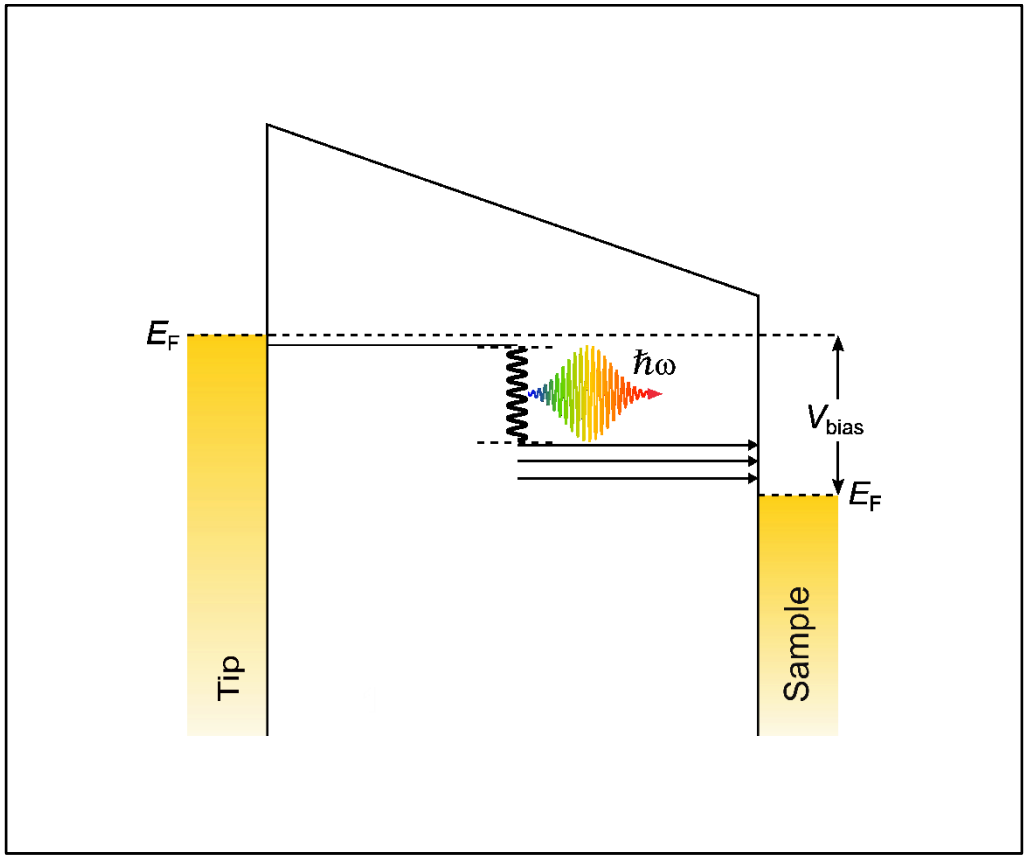
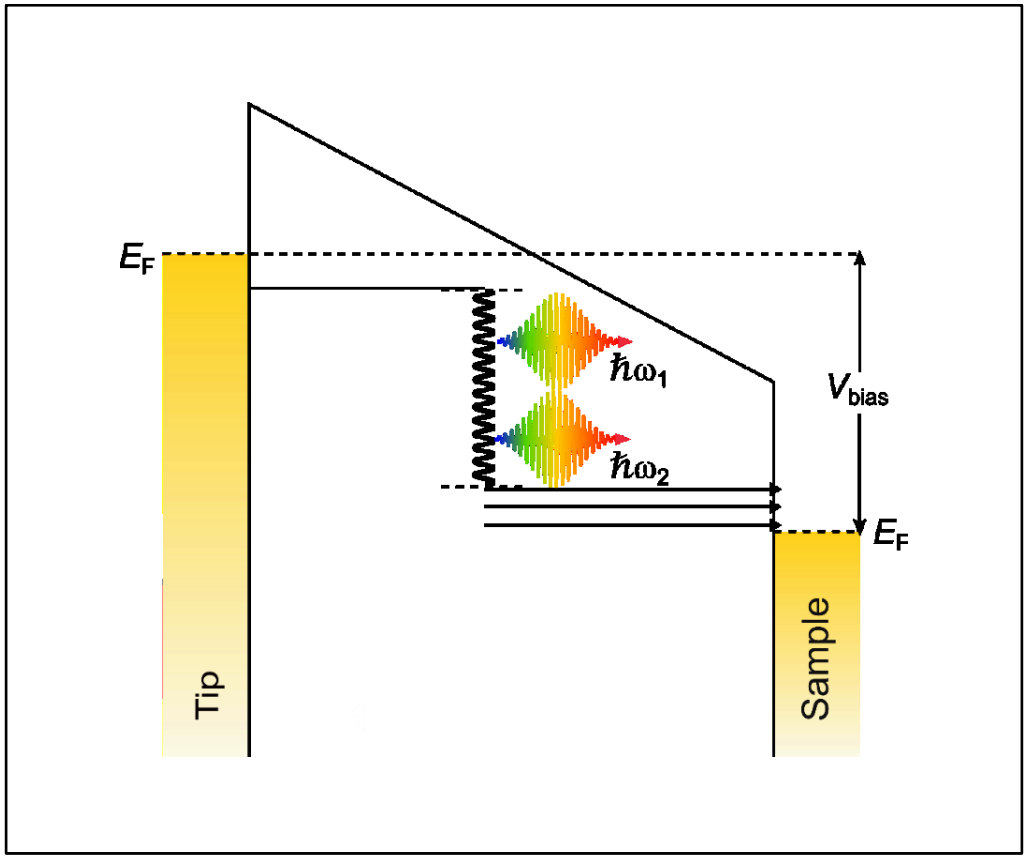
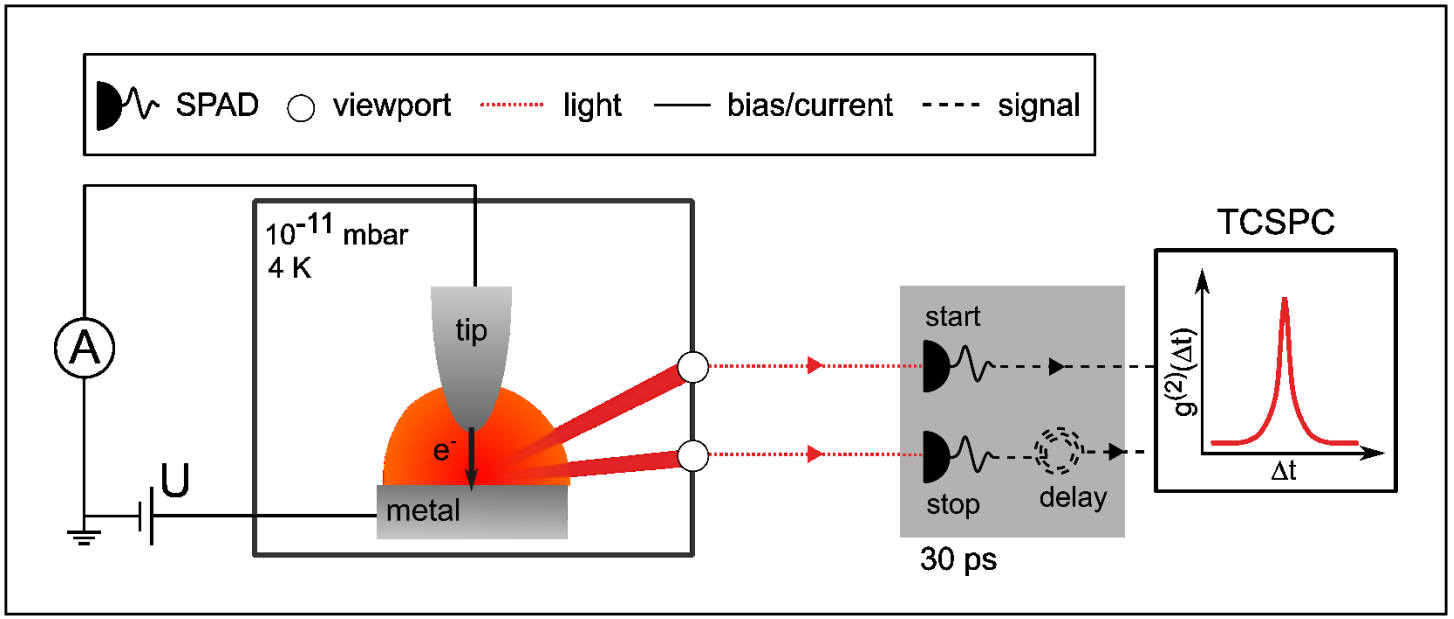
Inelastic electron tunneling



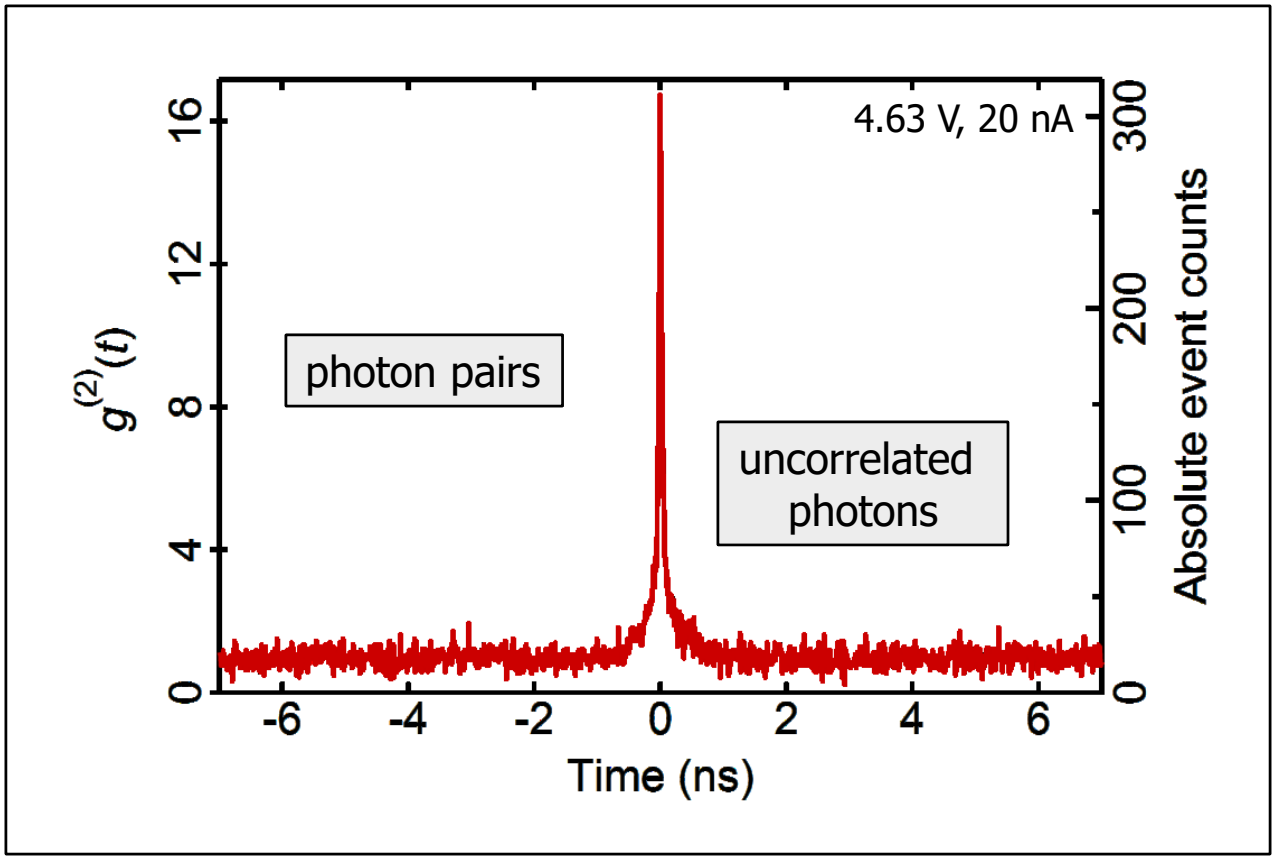
Photon pair emission



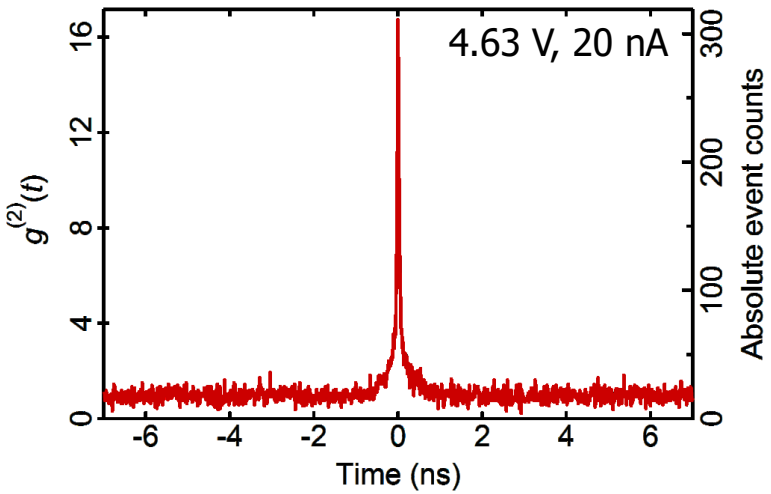
Hanbury Brown Twiss-STM

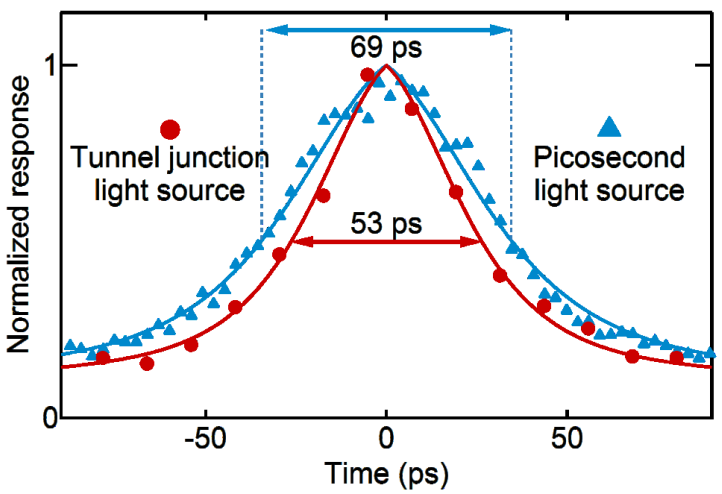


Photon super-bunching



Pairs within 50 ps of each other





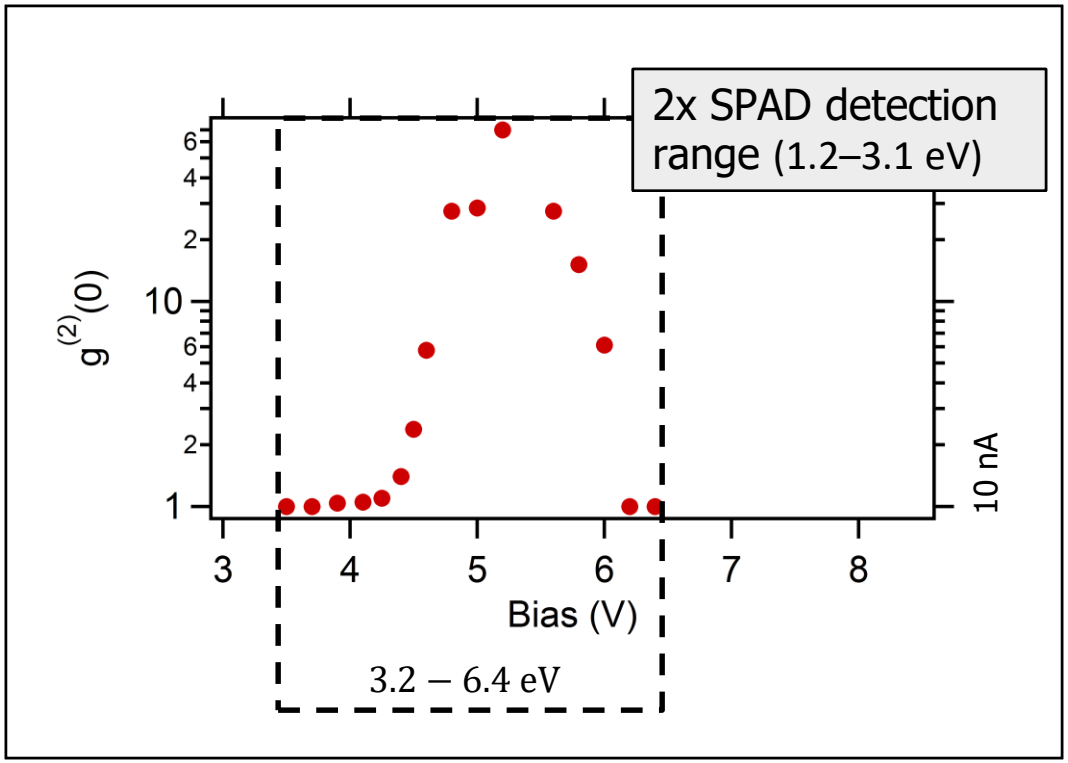
$g^2(0) > 2$ (limit for chaotic light)

Observed for:

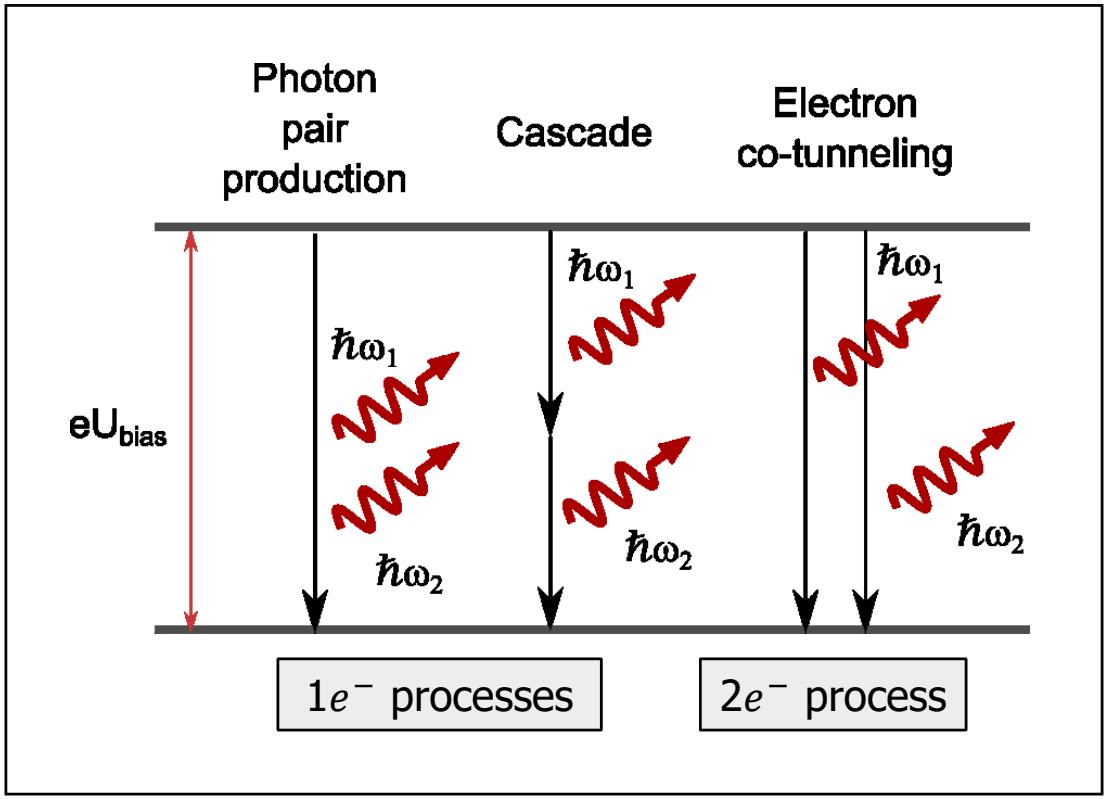
- Ag(111) – Au tip
- Au(111) – Au/PtIr tip
- Cu(111) – Au/AuAg tip

Closer to the instrumental time-resolution (< 50 ps) than the reference measurement using ps light-source

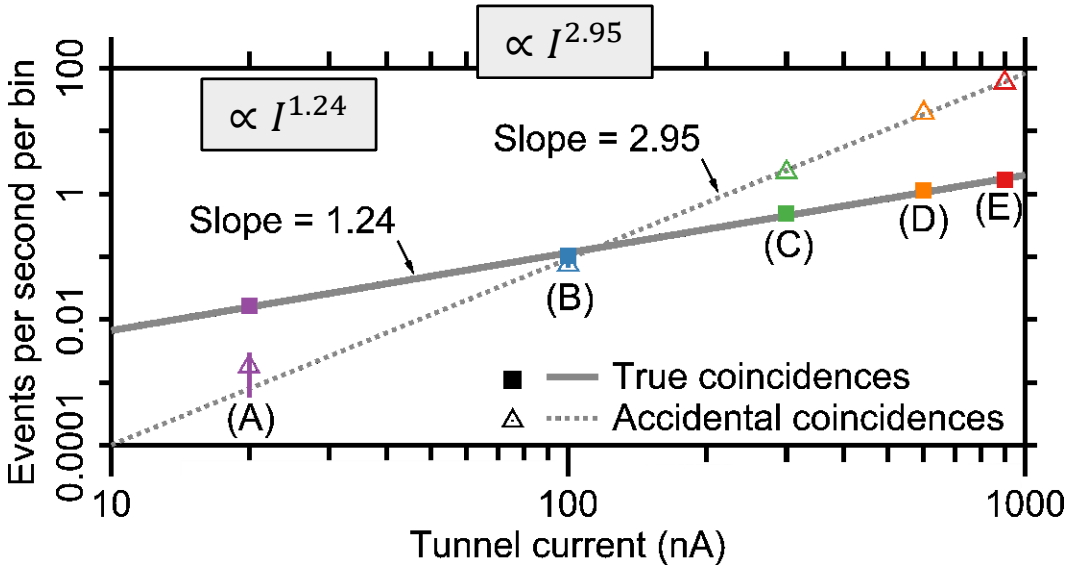
Observation limited by detection range



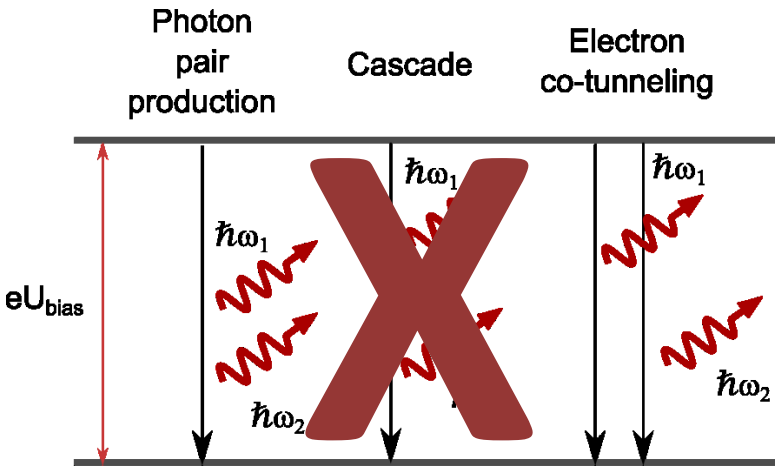
Possible mechanism

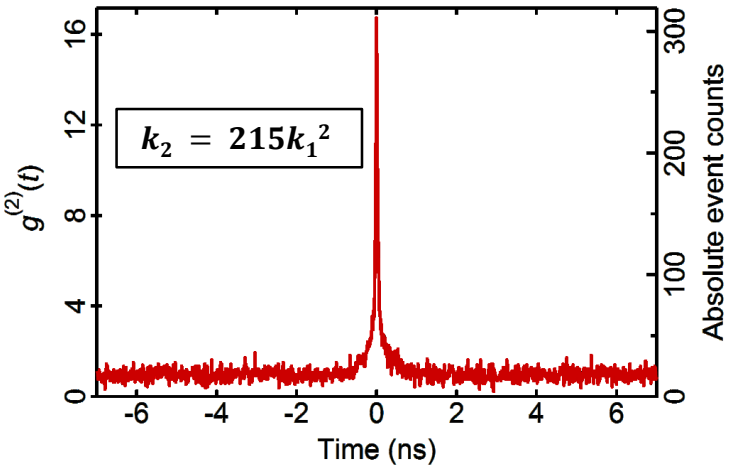


$g^2(t)$ vs tunneling current



Not a cascade





k_1 – rate for emitting one photon k_2 – rate for emitting two photons

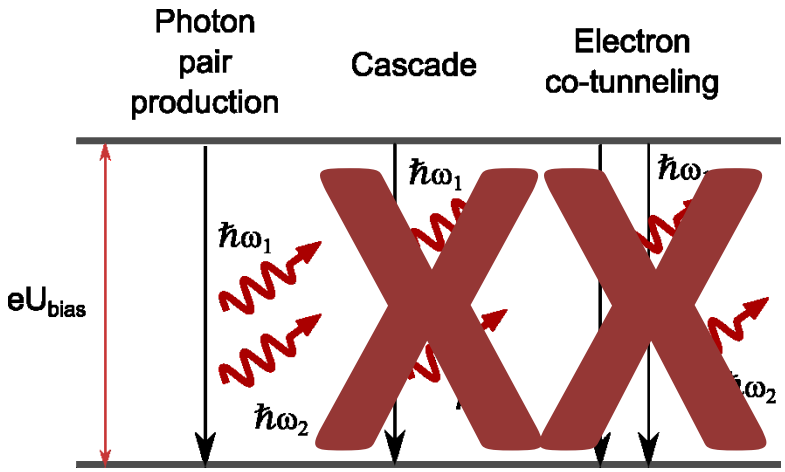
If cascade then, $\boldsymbol{k_2 = k_1^2}$

But we see, $\boldsymbol{k_2 = 215k_1^2}$ – it is easier to get a pair than two single photons

Spectral-filtering dependent correlation

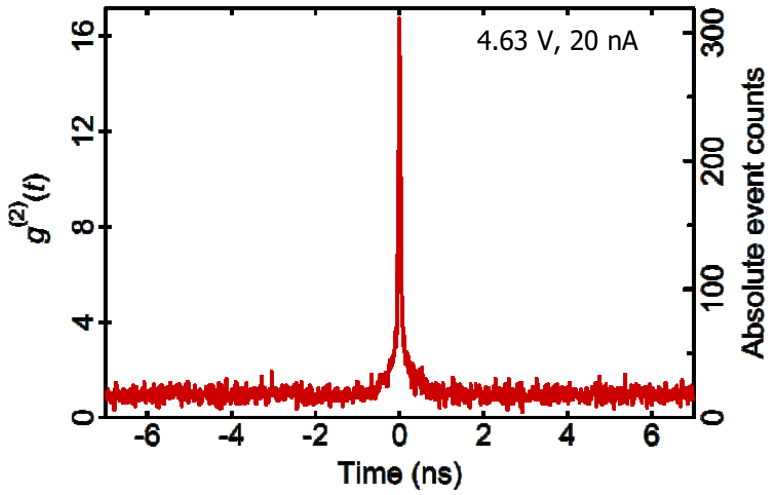
$$\hbar\omega_1 + \hbar\omega_2 \leq e \cdot V_{\text{bias}}$$

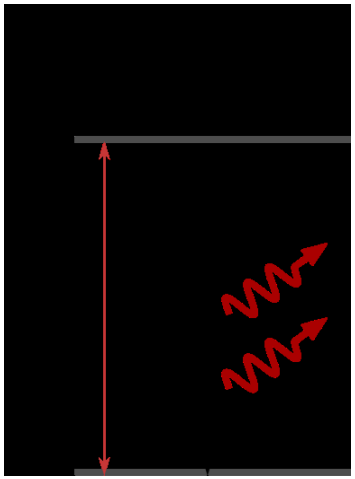
Not e^- co-tunneling either



- Photon pair creation can be made possible by the spontaneous parametric down-conversion of plasmon polaritons (optical non-linearity alleviates phase-matching conditions)
- Photon pairs emitted within 50 ps of each other: possibly entangled?

Conclusion

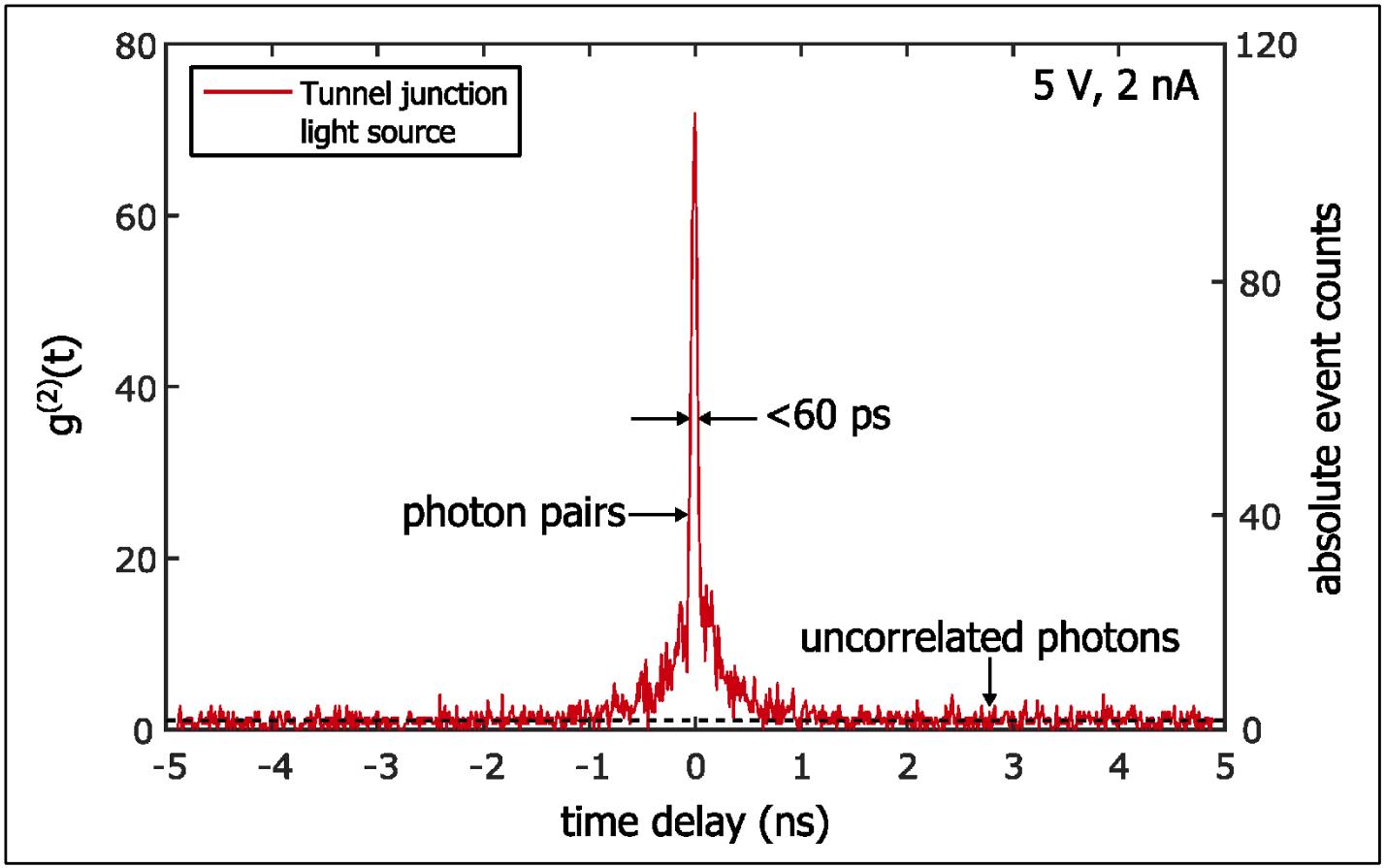




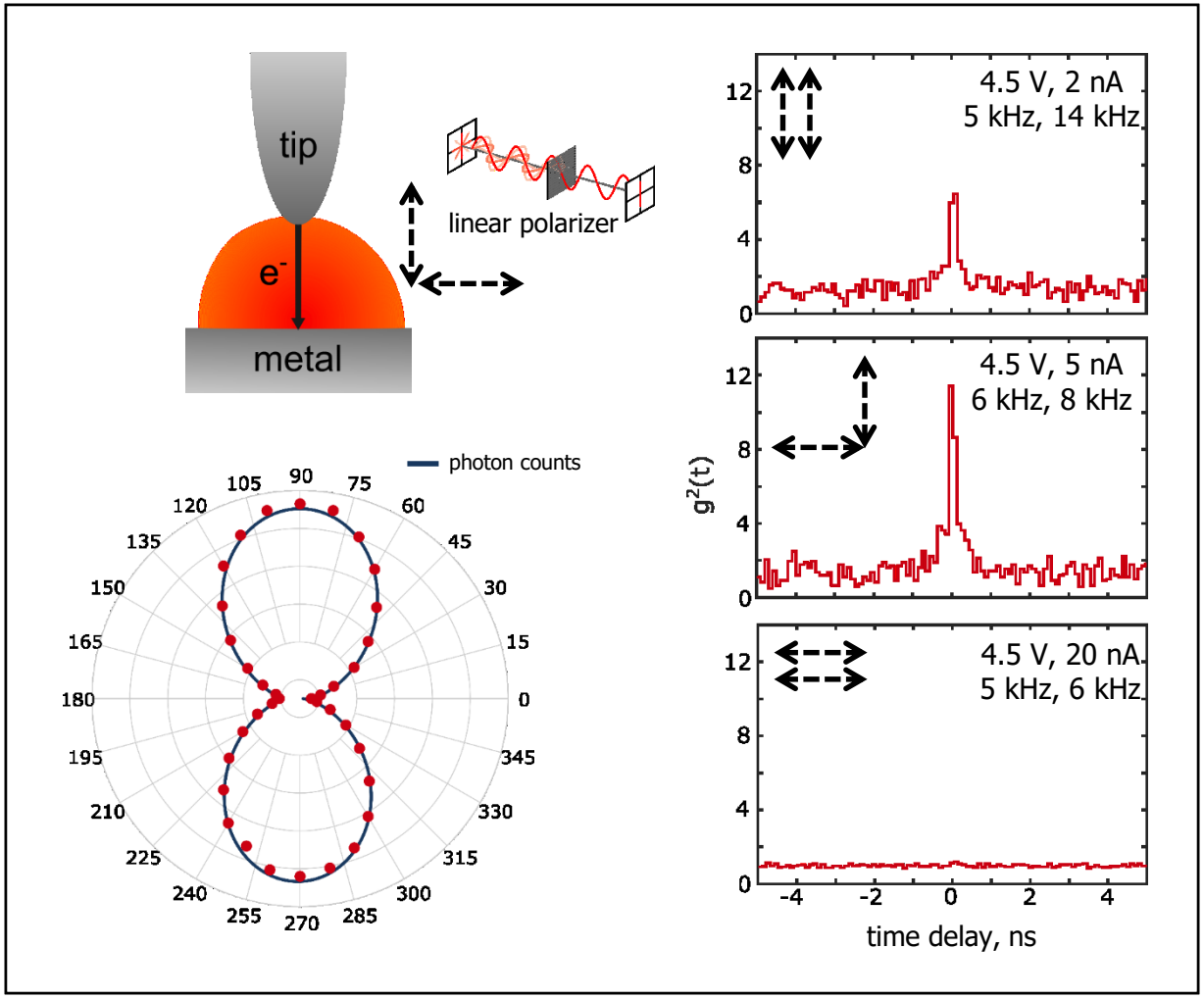
Future experiments: Hong-Ou-Mandel interference (check for indistinguishability of photons), measuring entanglement in linear momentum (Two particle interference)

Leon, C. C., *et al.* Sci. Adv. aav4986 (in press)
arXiv:1805.10234

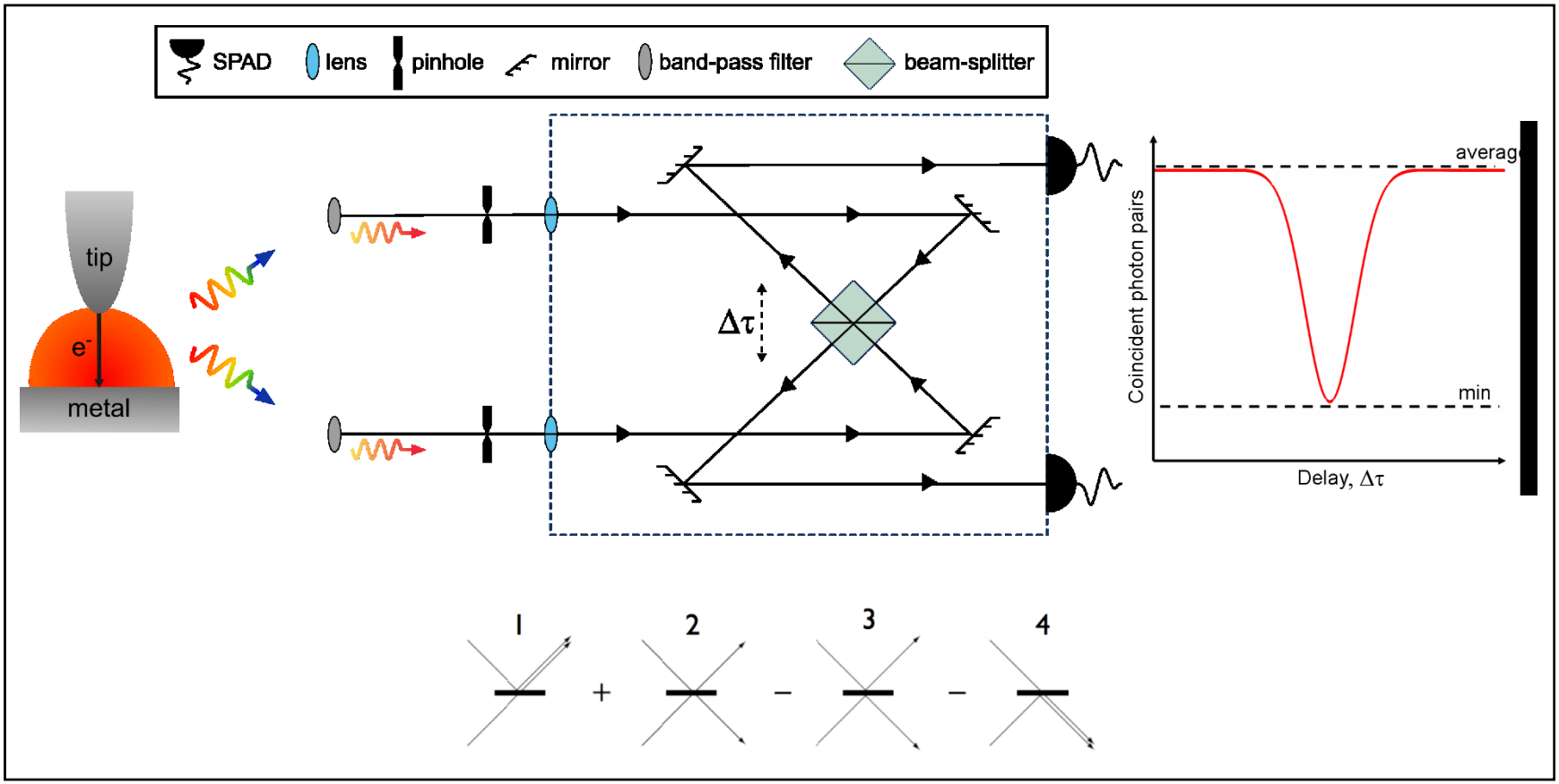
Max. bunching observed



Polarization dependent correlation



Quantum interference of photon pairs



Hong, C. K., *et al.* Phys. Rev. Lett. 59, 2044 (1987)

Detecting entanglement in STM

For single detection, $p(U_1|\phi_1,\phi_2) = p(L_1|\phi_1,\phi_2) = p(U_2|\phi_1,\phi_2) = p(L_2|\phi_1,\phi_2) = \frac{\eta}{2}$

For joint detection,
$$p(U_1,U_2|\phi_1,\phi_2) = p(L_1,L_2|\phi_1,\phi_2) = \eta^2\left[\frac{1}{4}+\frac{1}{4}\cos(\phi_2-\phi_1+\theta)\right]$$
$$p(U_1,L_2|\phi_1,\phi_2) = p(L_1,U_2|\phi_1,\phi_2) = \eta^2\left[\frac{1}{4}-\frac{1}{4}\cos(\phi_2-\phi_1+\theta)\right]$$

$g^2(t)$: (U_1, U_2), (L_1,L_2), (U_1, L_2), (L_1, U_2)

Horne, M. A., *et al.* Phys. Rev. Lett. 62, 2209 (1989)