Plasmon-assisted transmission of quantum entanglement

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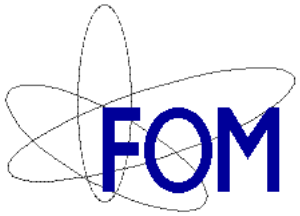
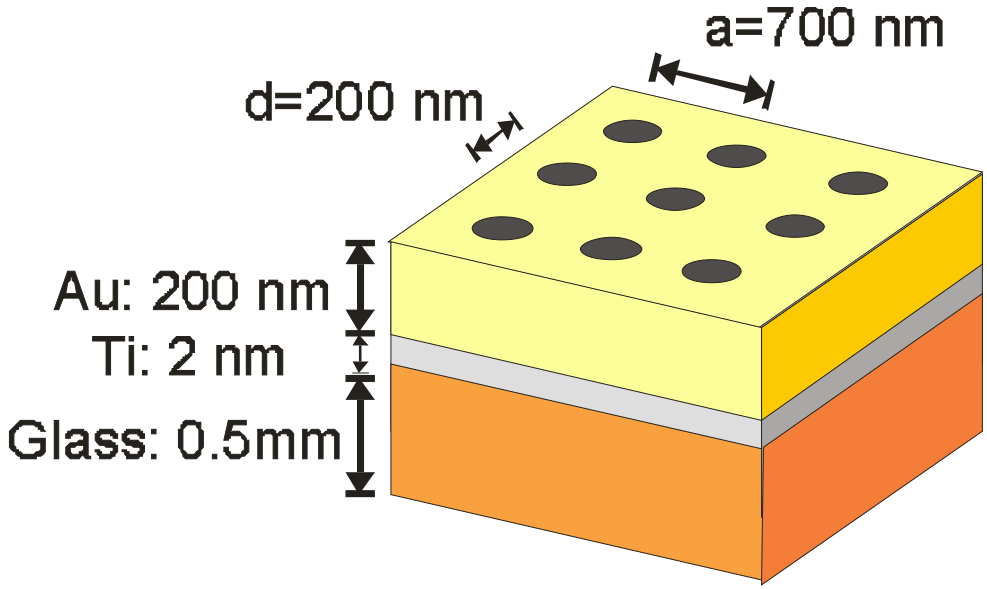
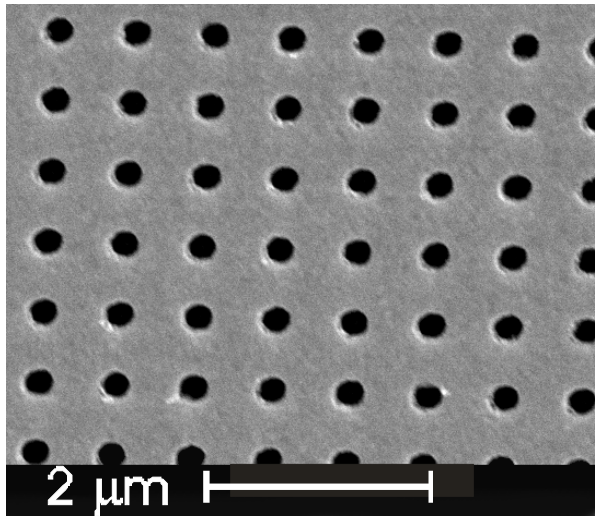


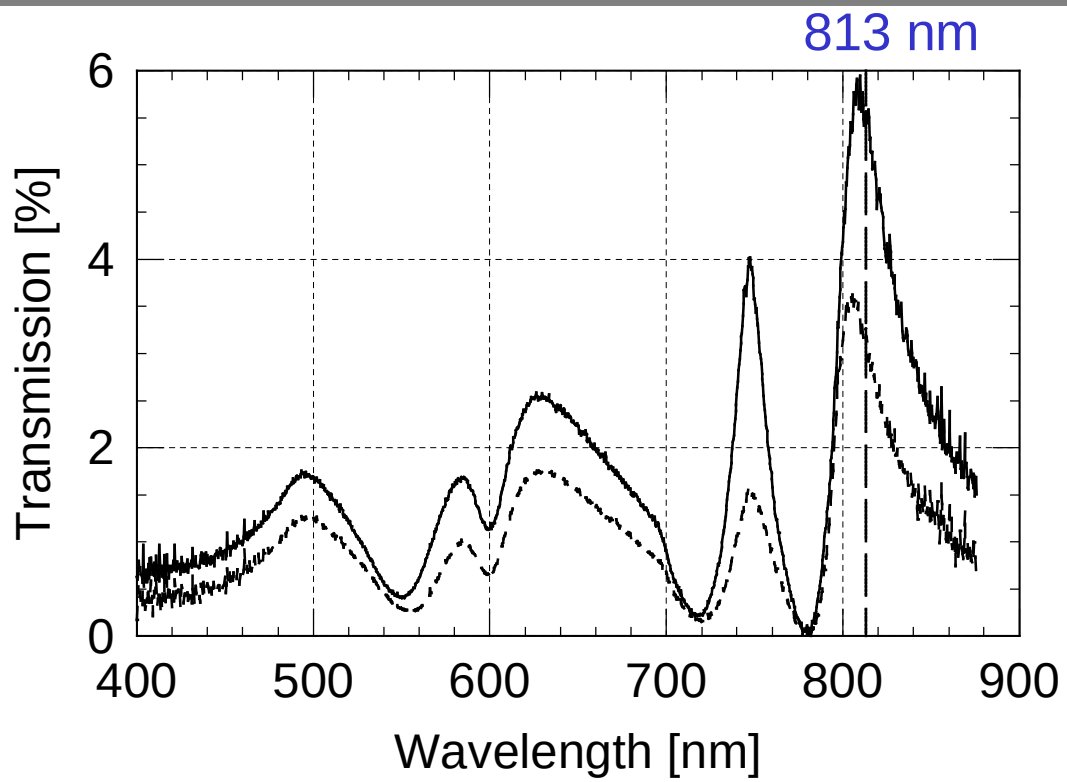
Subwavelength metal hole arrays





- hole diameter 200 nm ; hole spacing 700 nm
- layers: Au film, thickness 200 nm (>> skindepth!)
  Ti layer, thickness 2 nm (< skindepth)
  Glass substrate, 0.5 mm
- made at DIMES, Delft

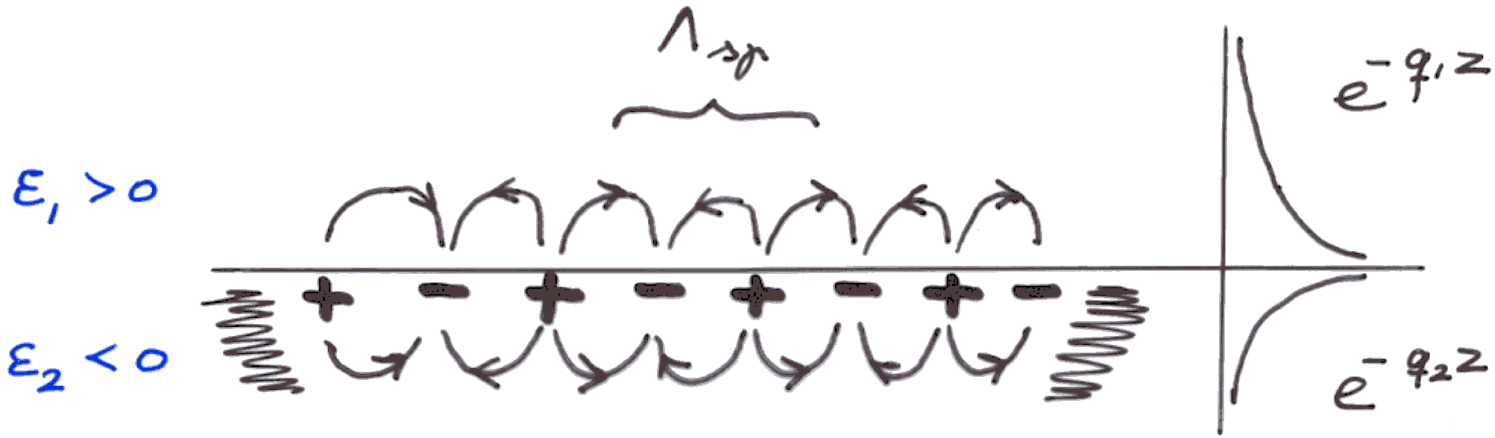
Extraordinary large transmission through hole array



- First results by Ebbesen et al. (Nature **391**, 667 (1998))
- Transmission much larger than expected from diffraction theory
- Sharp resonances

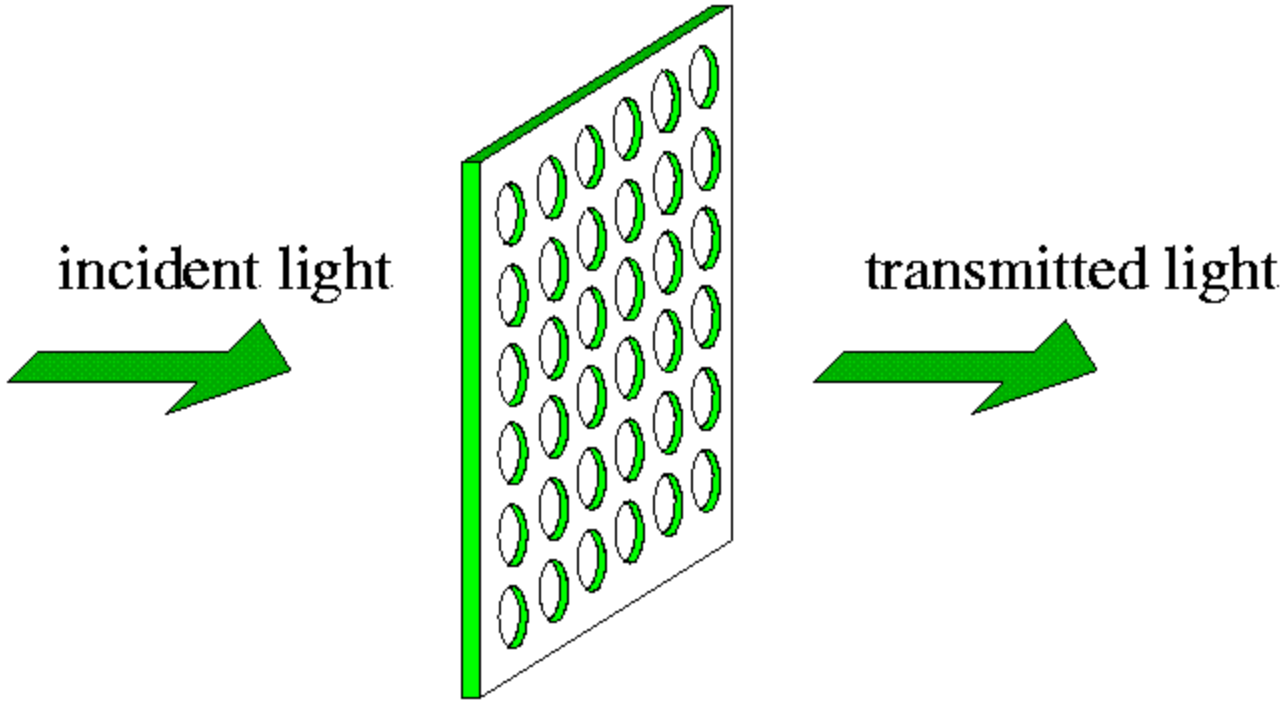
=> surface plasmons

Surface plasmons



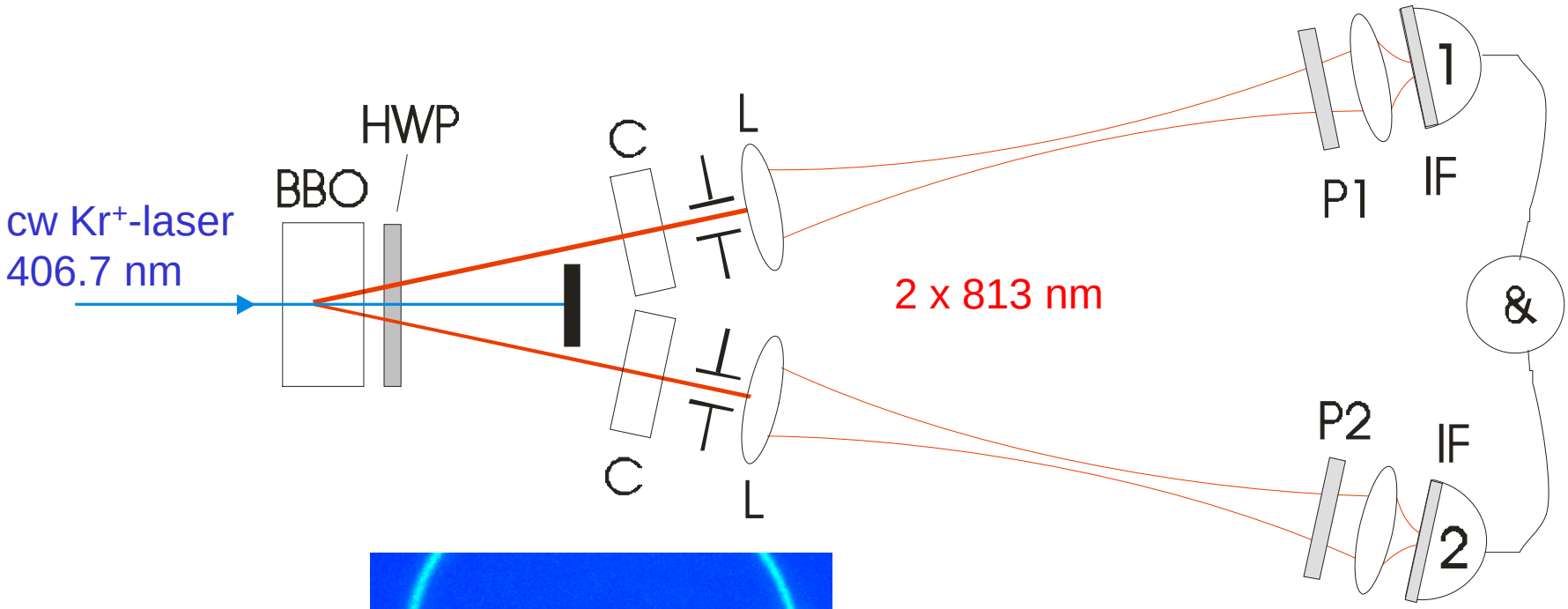
- Combined optical and electronic excitation
- Trapped at interface metal-dielectric (penetration typ. 15 nm, 200 nm)
- Travel at nearly speed of light
- Longitudinal polarization parallel to direction of propagation
  - Lifetime ≈ 15 fs ó Propagation length ≈ 4 μm

Explanation for extraordinary transmission

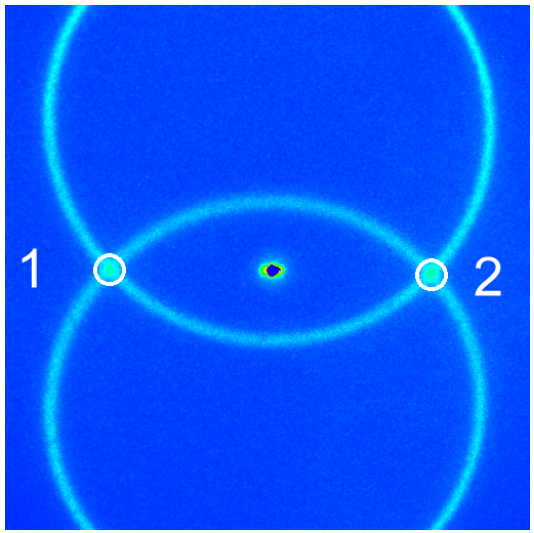


photon in => SP frontside <=> SP backside => photon out

Experimental setup type-II SPDC



ICCD image 8° × 8°

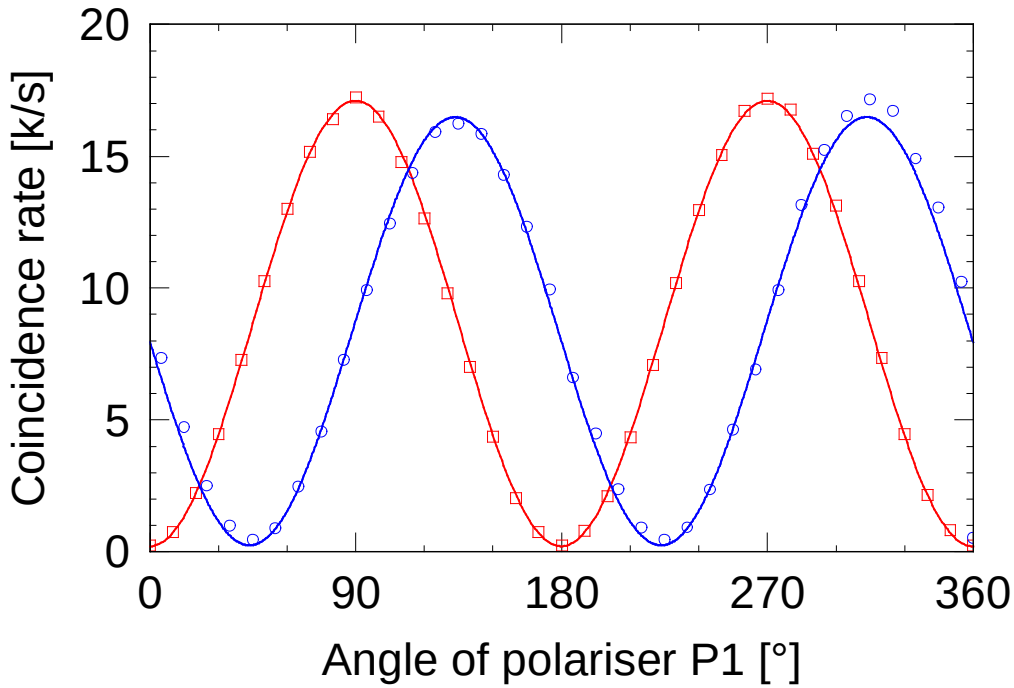


Polarization entanglement:

$$|f\rangle = \frac{1}{\sqrt{2}}\left(|H_1V_2\rangle + e^{ij}\,|V_1H_2\rangle\right)$$

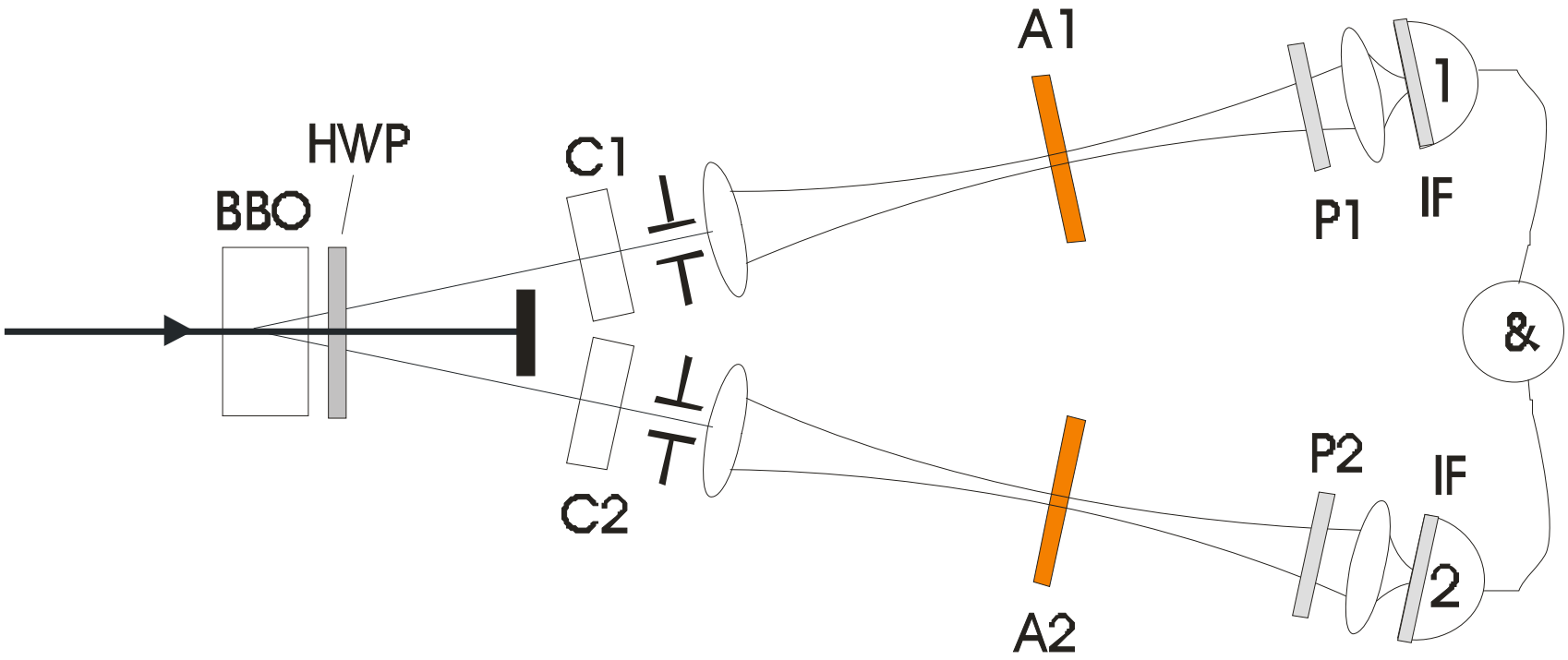
Proof of quantum entanglement

P2 angle fixed at 0° (RED) and 45° (BLUE)



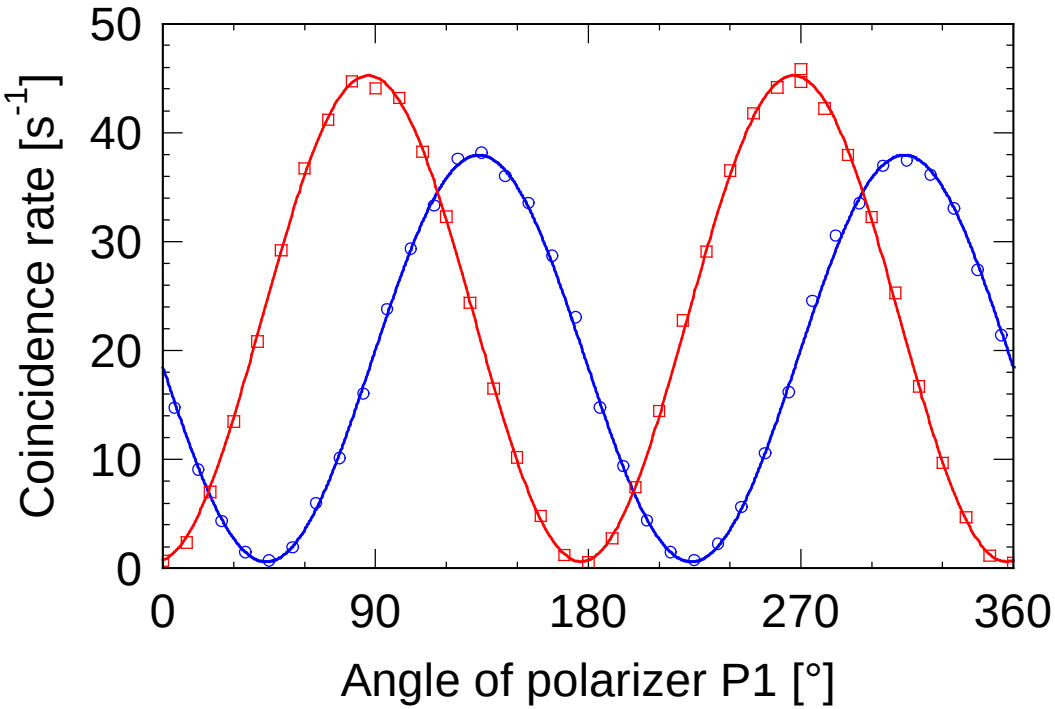
- Visibility:
  - $V_{0°} = 99.4\%$
  - $V_{45°} = 97.1\%$
- Bell parameter
  - $|S| = 2.753 \pm 0.002$

The key question



- Will the (fragile) quantum entanglement survive the conversion ?

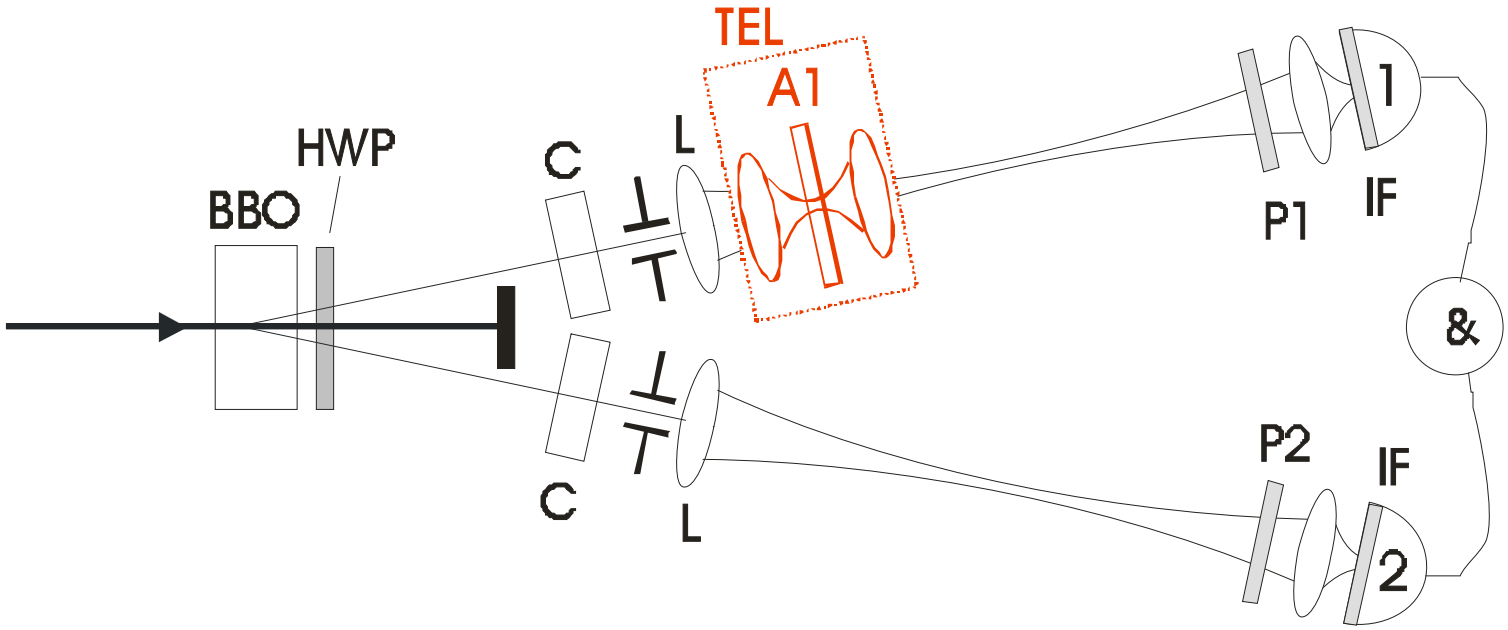
The answer: YES !



P2 angle fixed at
0° (RED) and 45° (BLUE)

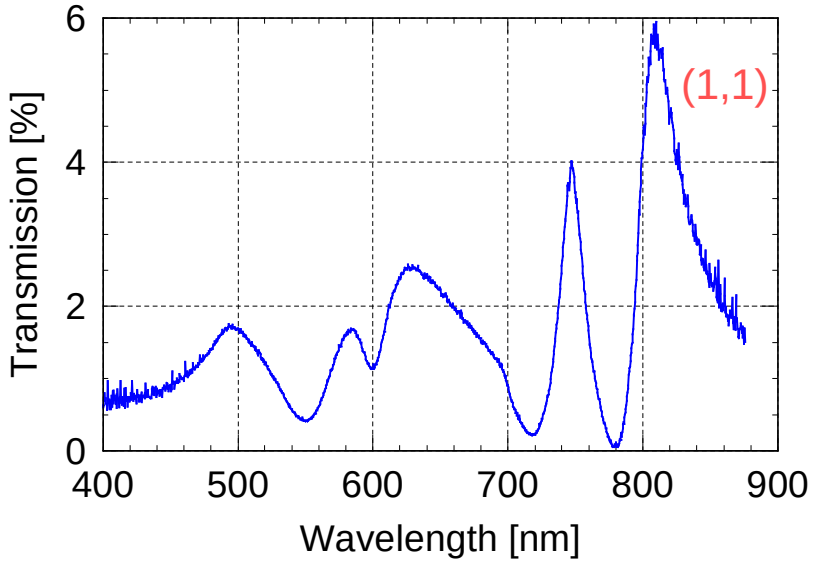
	Without arrays	**With arrays**
$V_{0°}$	99.4 %	97.1%
$V_{45°}$	97.1 %	97.2%
$\|S\|$	2.753 ± 0.002	2.71 ± 0.02

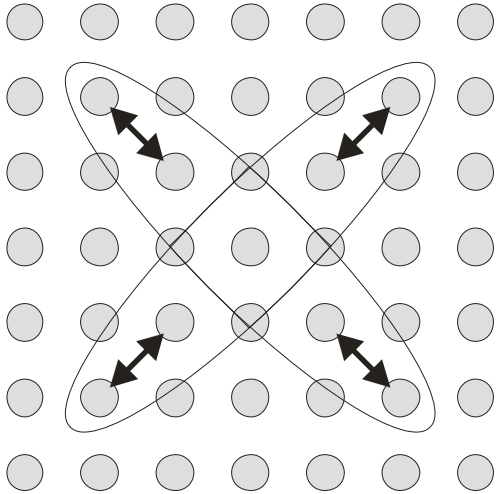
Follow up experiment: focusing on one hole array



	Without focus	**With focus**
Coincidence rate	1.6×10^3 s^{-1}	1.1×10^3 s^{-1}
$V_{0°}$	99.4%	73%
$V_{45°}$	97.1%	87%

Which way information kills entanglement





- Surface plasmons propagate
- SP propagation direction linked to polarization
- Two incident polarization components split in hole array !
  - which-way label can kill entanglement $-V_{0°} = 73\ \%$

    $-V_{45°} = 87\ \%$

Summary

- Quantum entanglement survives the conversion
  - photon in => surface plasmon (2x) => photon out
- Surface plasmons are true quantum object
  - quasi particles involving millions of electrons
- Entanglement is limited by the “non-local” nature of surface plasmons:
  - propagation introduces “which-way” labels
- Challenge:
  - Manipulate the surface plasmons (via their electronic component)

Nature 418, 304 (2002)