DISPERSION ENGINEERING FOR COMPLETE COHERENT CONVERSION

Alexander S. Solntsev[1], Sergey V. Batalov[2,3], Nathan K. Langford[1], Andrey A. Sukhorukov[4,5]

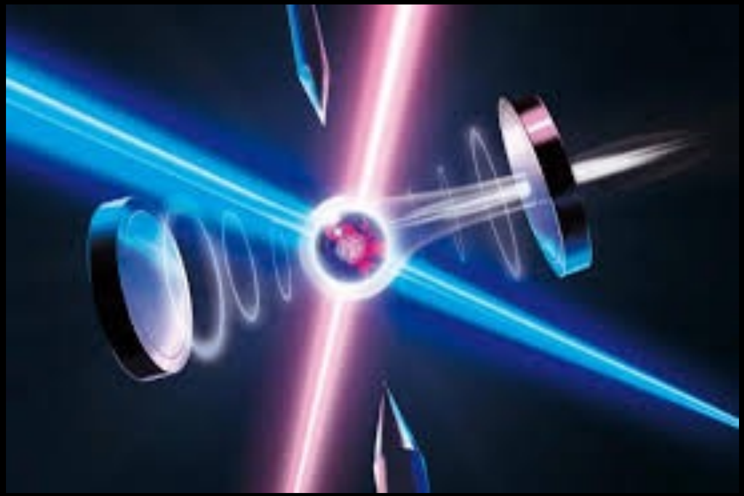
[1]School of Mathematical and Physical Sciences, University of Technology Sydney, 15 Broadway, Ultimo NSW 2007, Australia
[2]Institute of Metal Physics, UB RAS, Sofia Kovalevskaya str., 18, Ekaterinburg, 620108, Russia
[3]Institute of Physics and Technology, Ural Federal University, Mira str. 19, Ekaterinburg, 620002, Russia
[4]Research School of Physics, Australian National University, Canberra, ACT 2601, Australia
[5]ARC Centre of Excellence for Transformative Meta-Optical Systems (TMOS), Australia

QUANTUM OPTICS

Applications of quantum optics

Secure communication

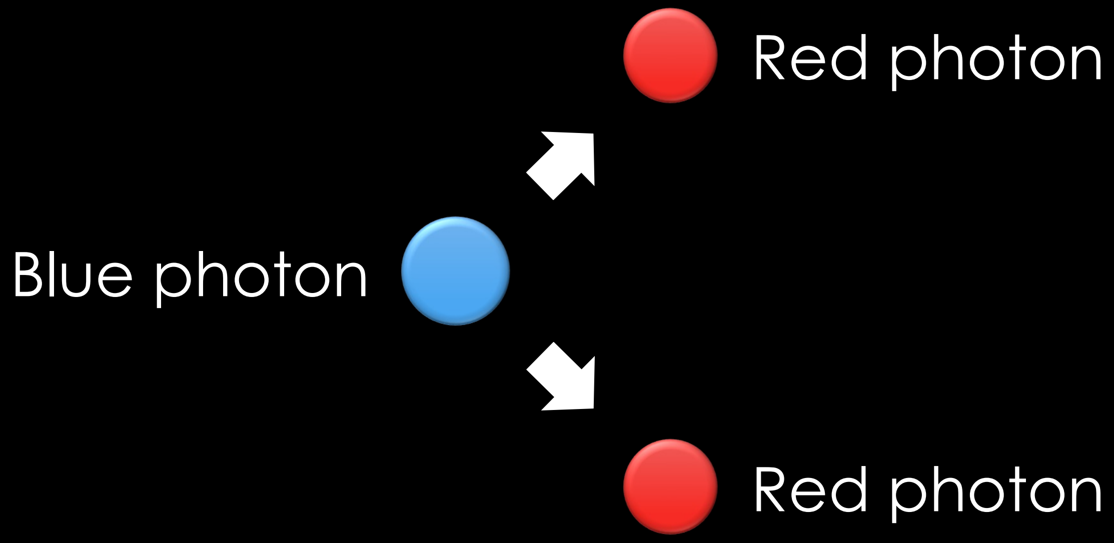
Fast computation



Precise metrology

NONLINEAR OPTICS

- Intense light changes matter
- Different colors of light interact through matter
- Light color can be changed



NONLINEAR OPTICS

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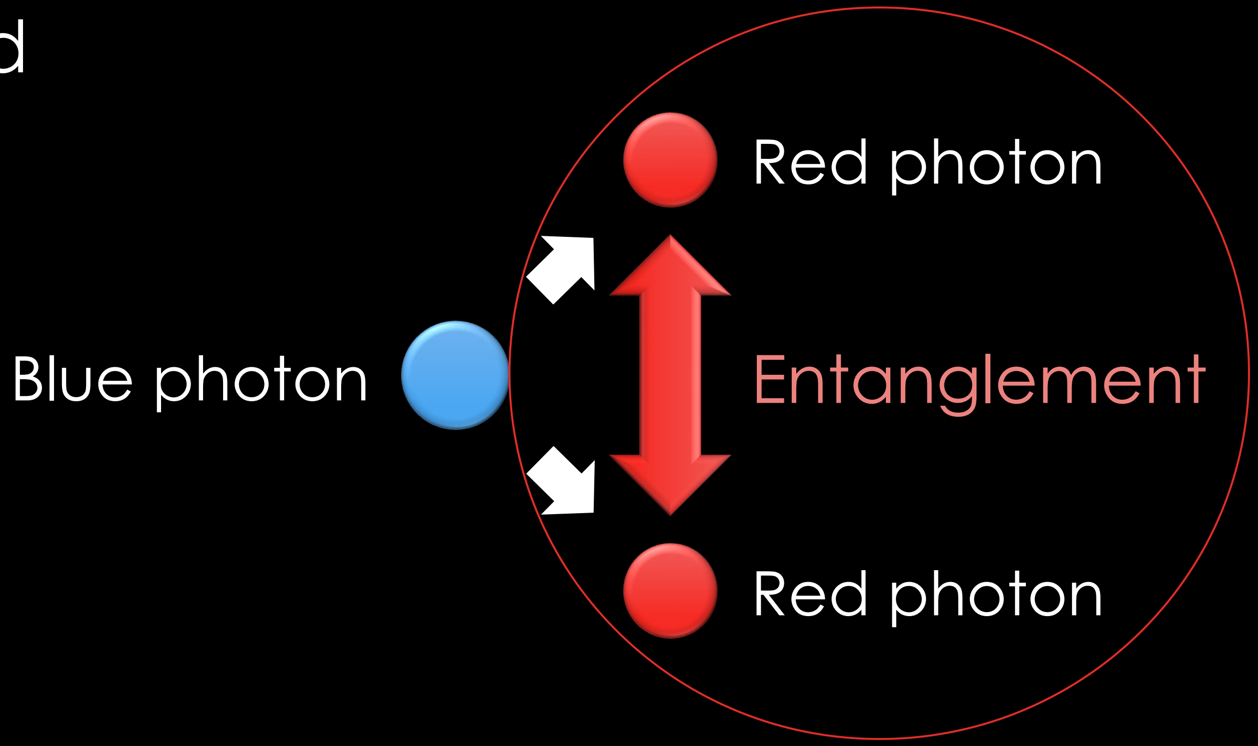
- Different colors of light interact through matter
- Light color can be changed

Creating a pair of entangled photons using nonlinearity (SPDC)



MINIATURIZATION

- Nonlinear quantum optics
- On-chip integration

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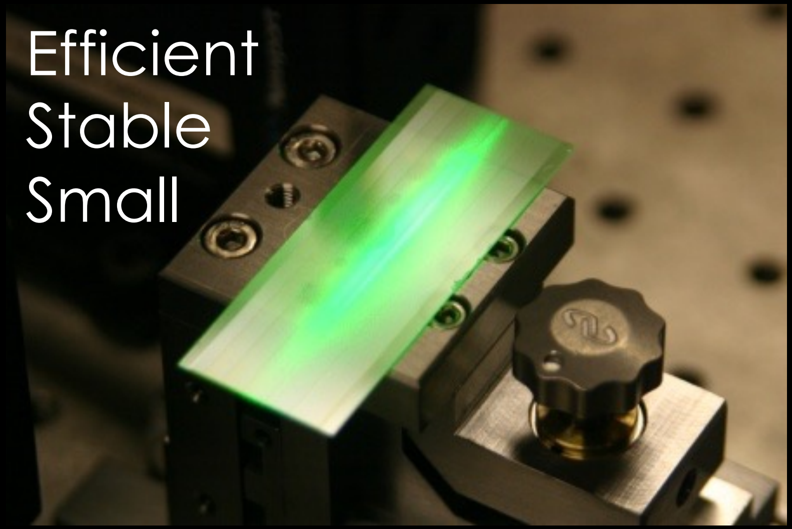
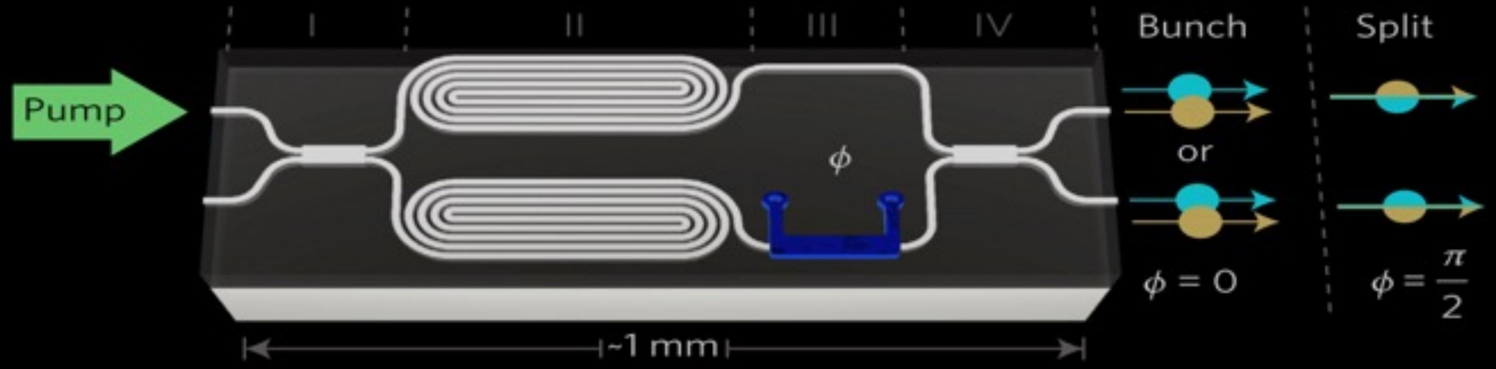
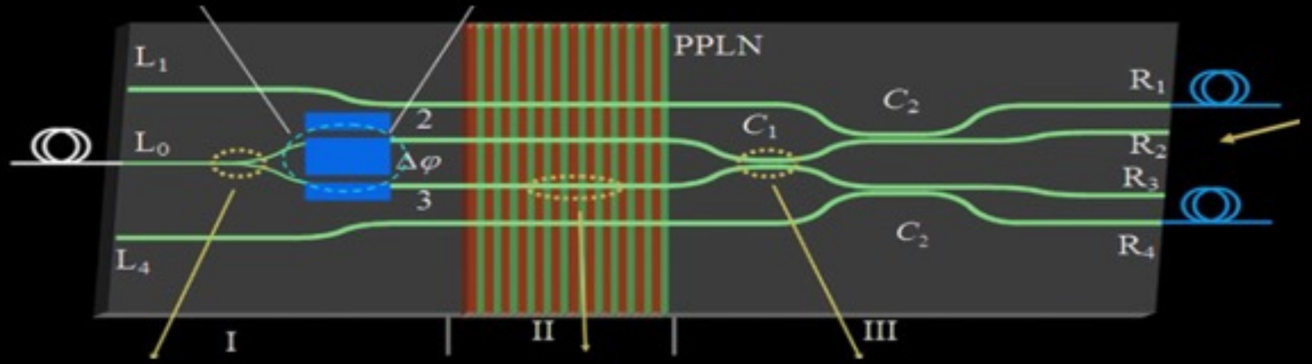


ON-CHIP QUANTUM OPTICS

- Generating entangled photons on a nonlinear chip
- Control is complex, requires thermo-optical or electro-optical tuning



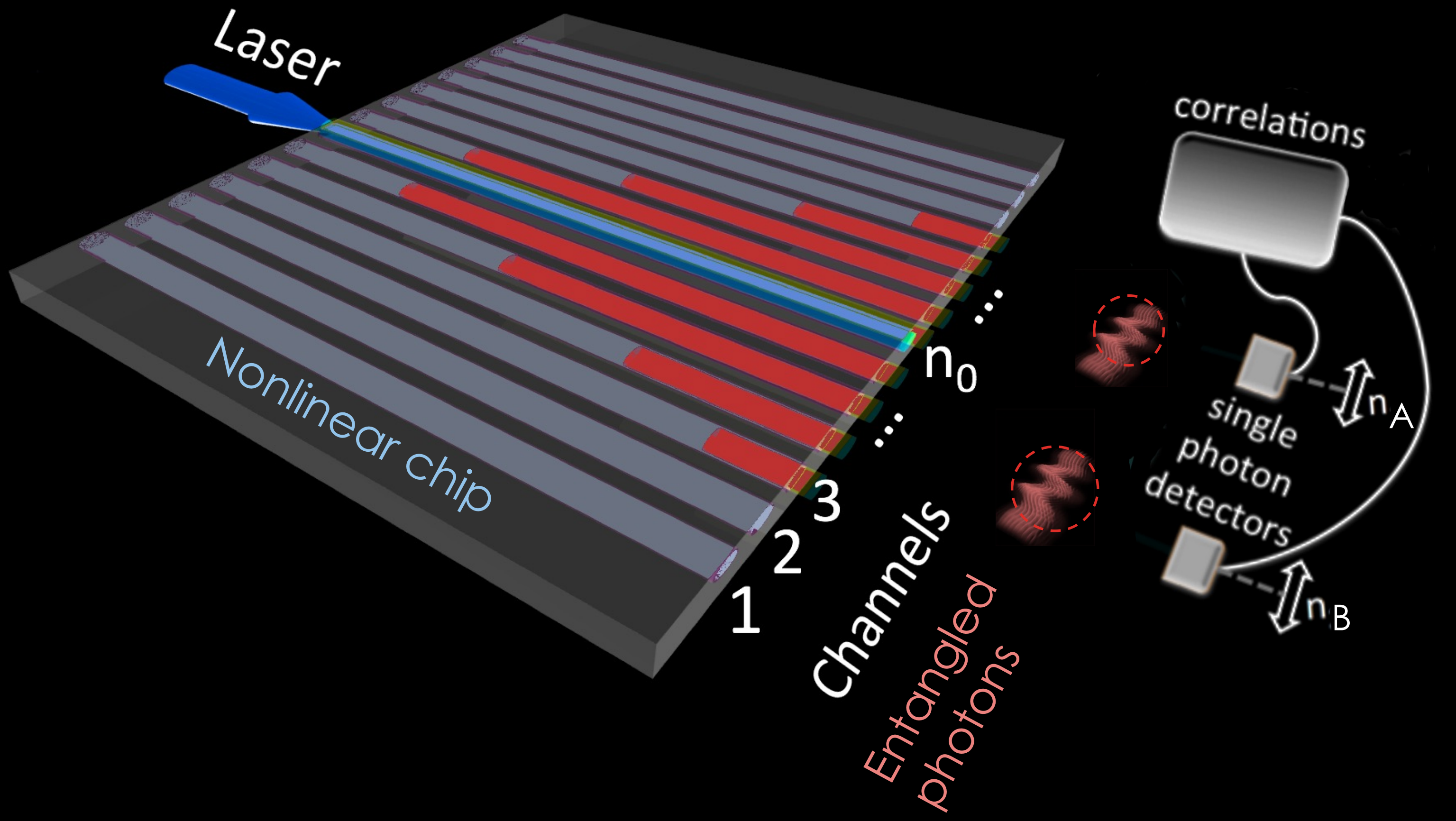
Silverstone et al., Nature Photonics **8**, 104 (2014)

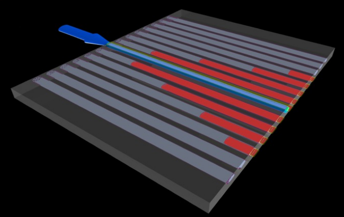


Jin et al., Phys. Rev. Lett, **113**, 103601 (2014)

LASER AND TWO PHOTONS ON A CHIP

Experiment

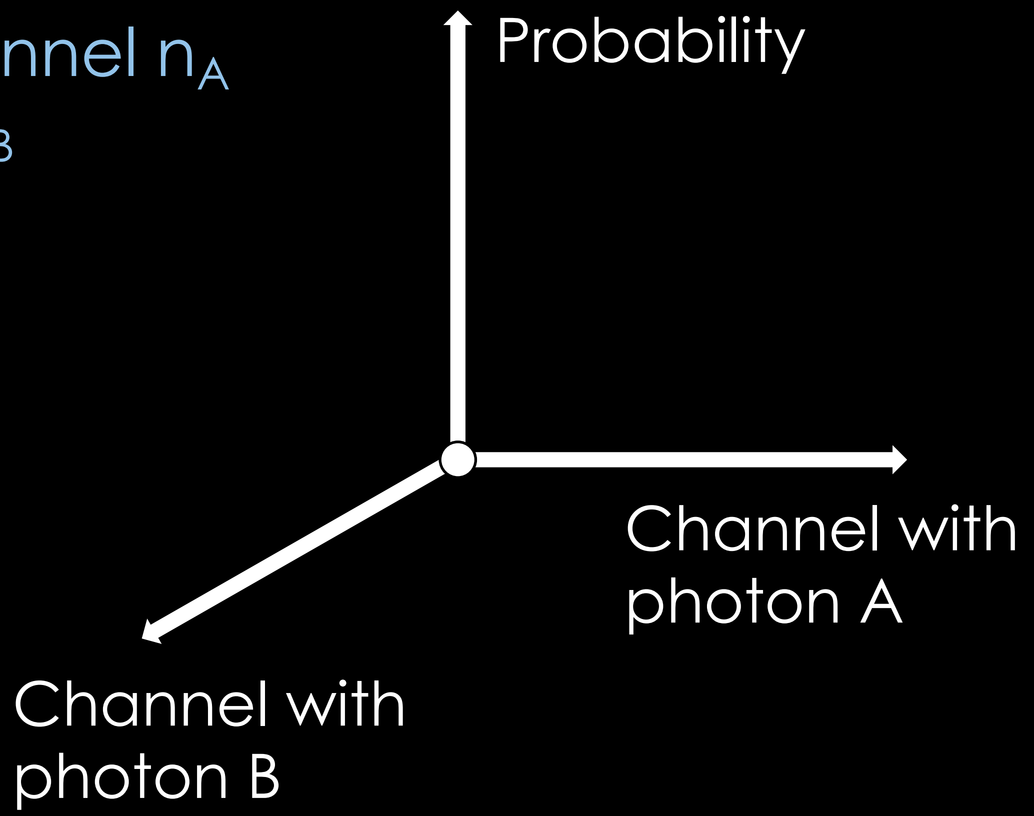


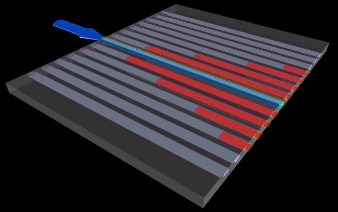


LASER AND TWO PHOTONS ON A CHIP

Correlations

- Probability of photon A in the channel n_A while photon B is in the channel n_B



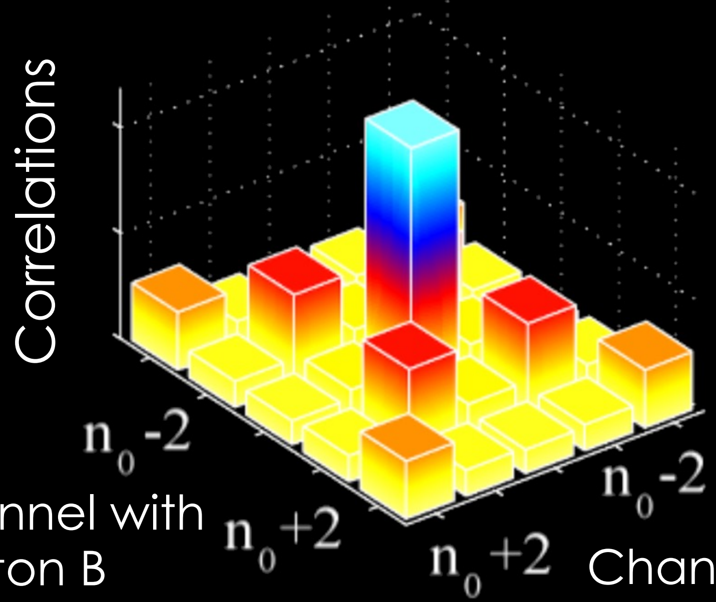


LASER AND TWO PHOTONS ON A CHIP

Results

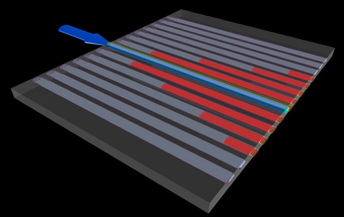
Theory

Entanglement!



Solntsev et al., PRL 108, 023601 (2012)

LASER AND TWO PHOTONS ON A CHIP

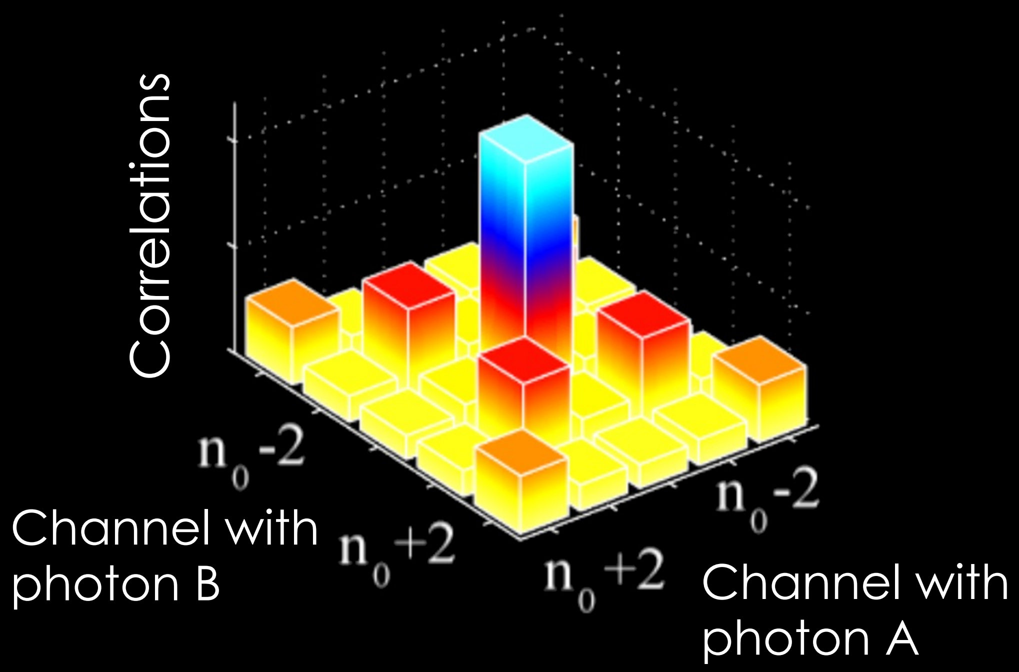


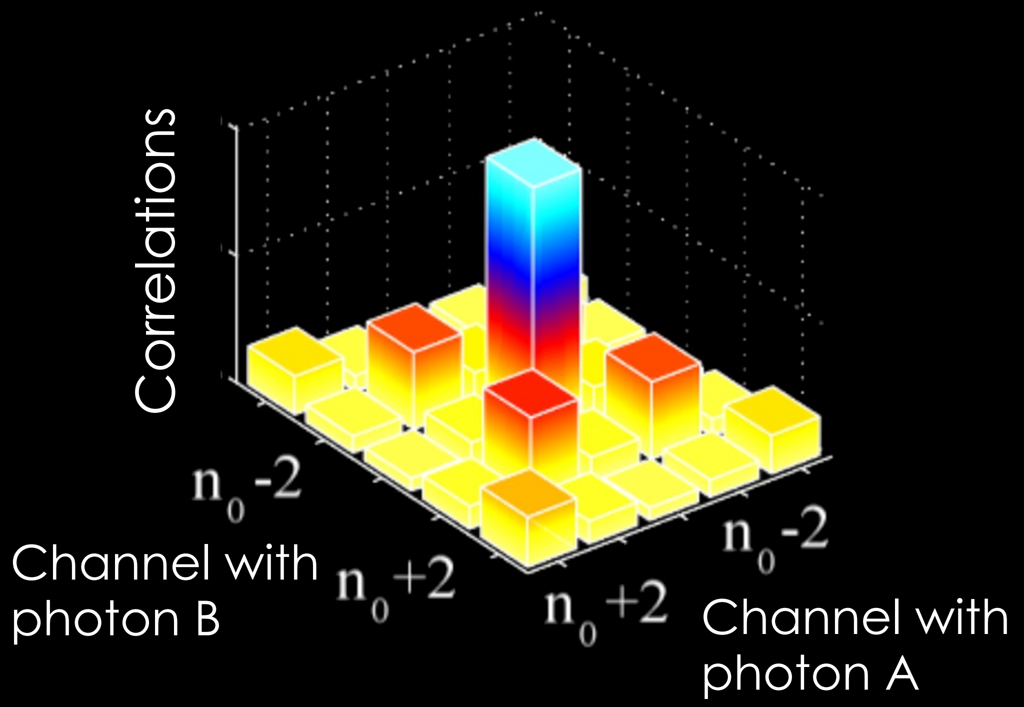
Results

Theory

Entanglement!

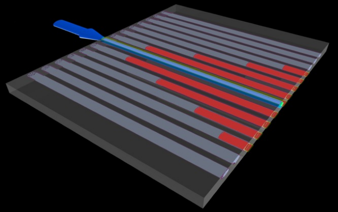
Experiment





Solntsev et al., PRL 108, 023601 (2012)

Solntsev et al., PRX 4, 031007 (2014)



LASER AND TWO PHOTONS ON A CHIP

Results

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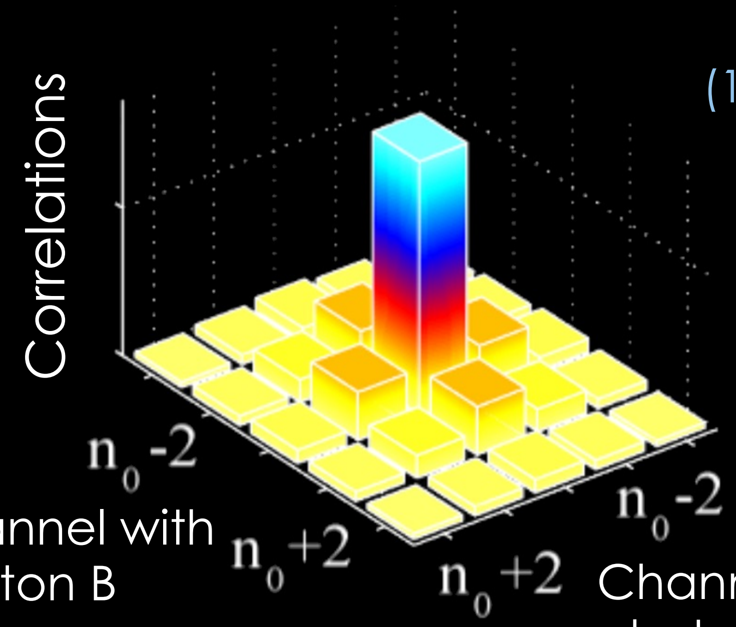


Channel with photon B

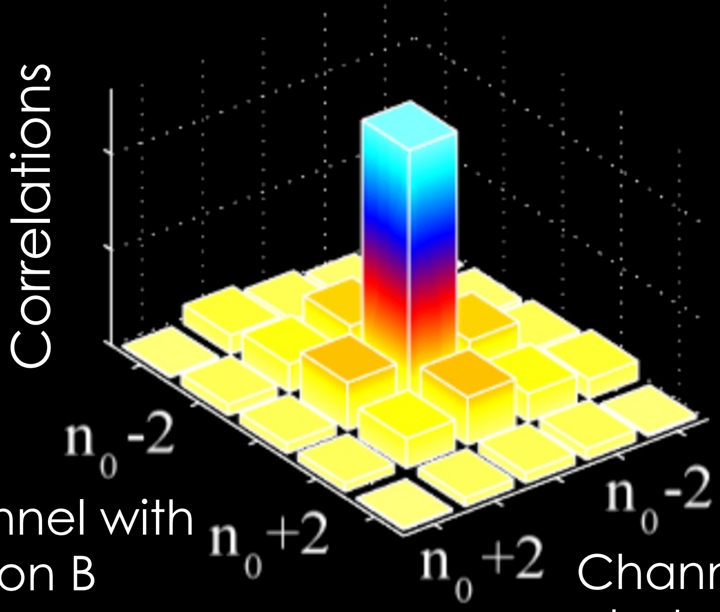
Channel with photon A

Slightly different laser colour

(1 nm wavelength shift)

Entanglement Suppressed!

Experiment



Channel with photon B

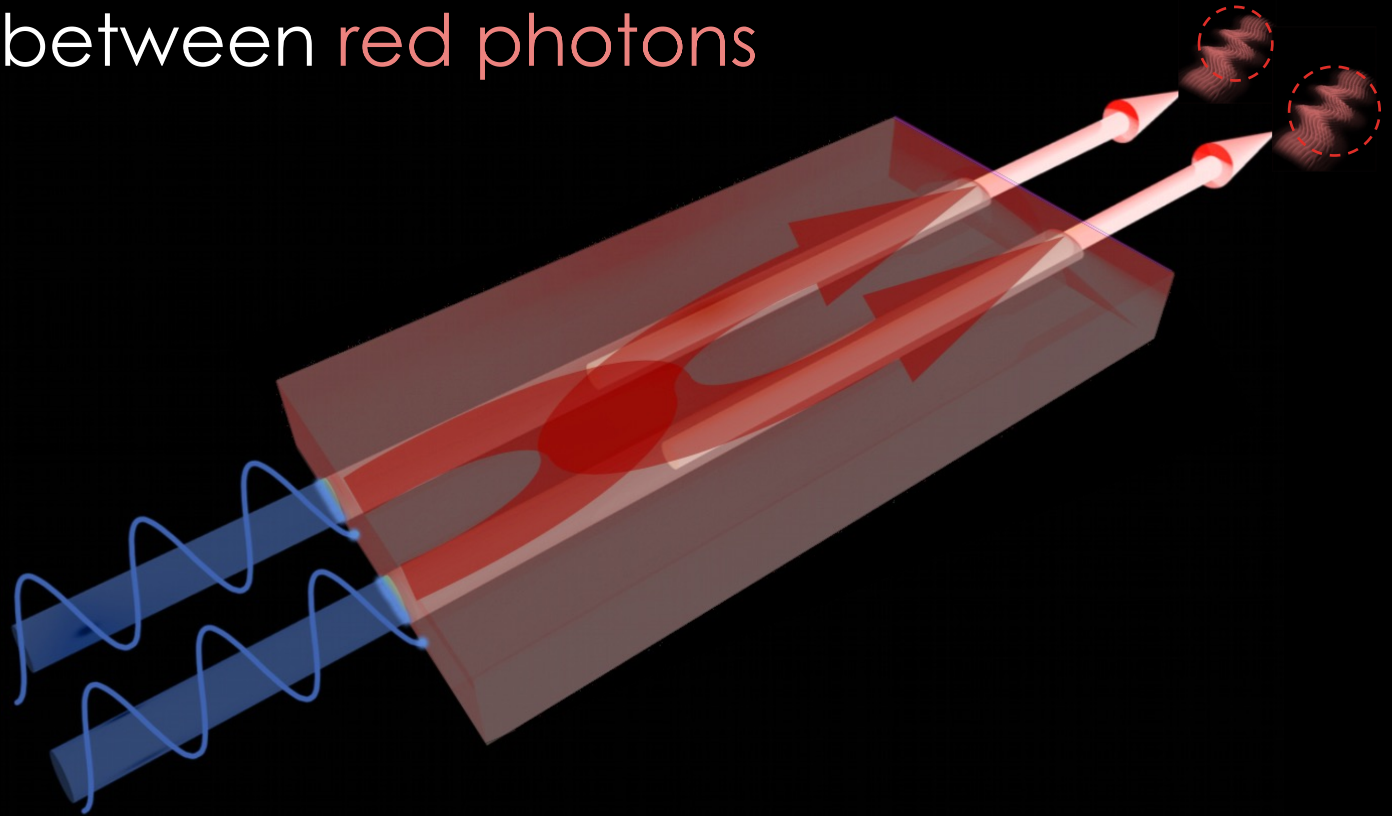
Channel with photon A

Solntsev et al., PRL 108, 023601 (2012)

Solntsev et al., PRX 4, 031007 (2014)

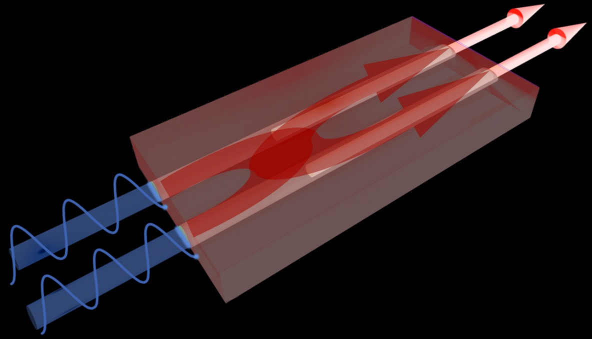
2 LASER BEAMS
2 CHANNELS
2 PHOTONS

Controlling the phase between blue laser beams
to tune entanglement between red photons



Setzpfandt, Solntsev et al., Laser & Photonics Reviews 10, 131-136 (2016)

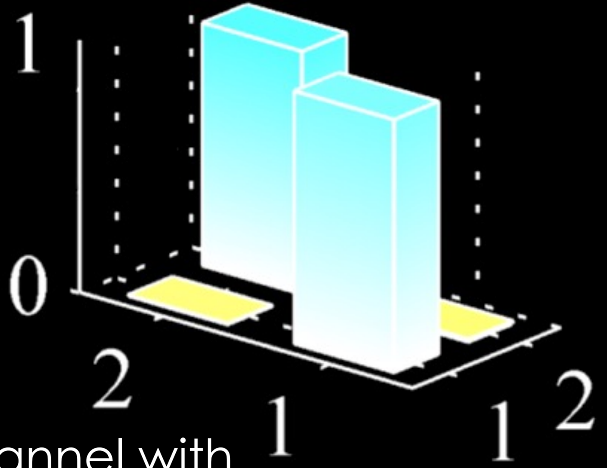
2 LASER BEAMS
2 CHANNELS
2 PHOTONS



Experimental results

Counter-phase laser beams

Entangled photons $|A_1,B_1\rangle + |A_2,B_2\rangle$

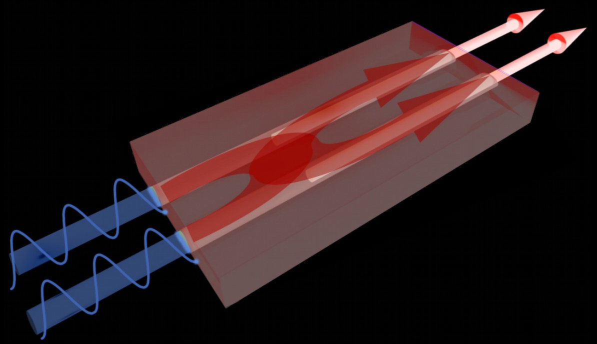


Channel with photon B

Channel with photon A

Setzpfandt, Solntsev et al., Laser & Photonics Reviews 10, 131-136 (2016)

2 LASER BEAMS
2 CHANNELS
2 PHOTONS

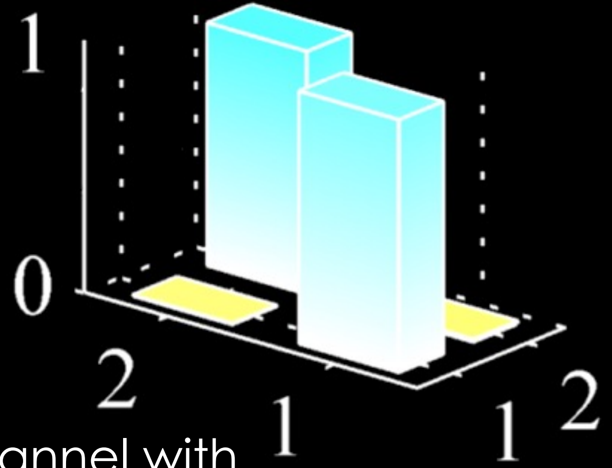


Experimental results

Counter-phase laser beams

⬇

Entangled photons $|A_1,B_1\rangle + |A_2,B_2\rangle$



Channel with photon B

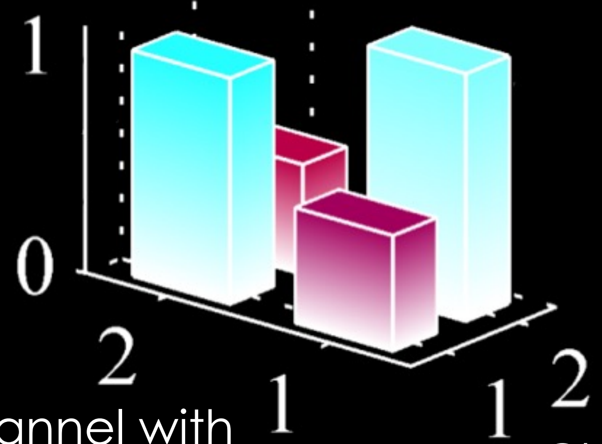
Channel with photon A

Tuning Entanglement!

In-phase laser beams

⬇

Entangled photons $|A_1,B_2\rangle + |A_2,B_1\rangle$



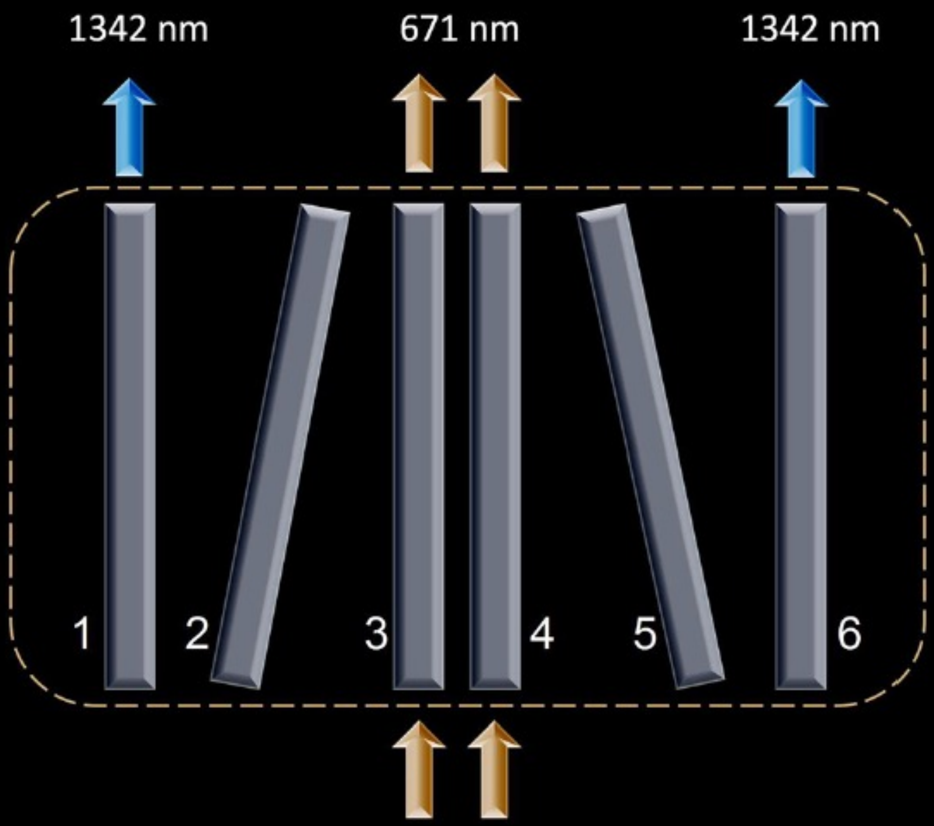
Channel with photon B

Channel with photon A

Setzpfandt, Solntsev et al., Laser & Photonics Reviews 10, 131-136 (2016)

WAVEGUIDE ENGINEERING

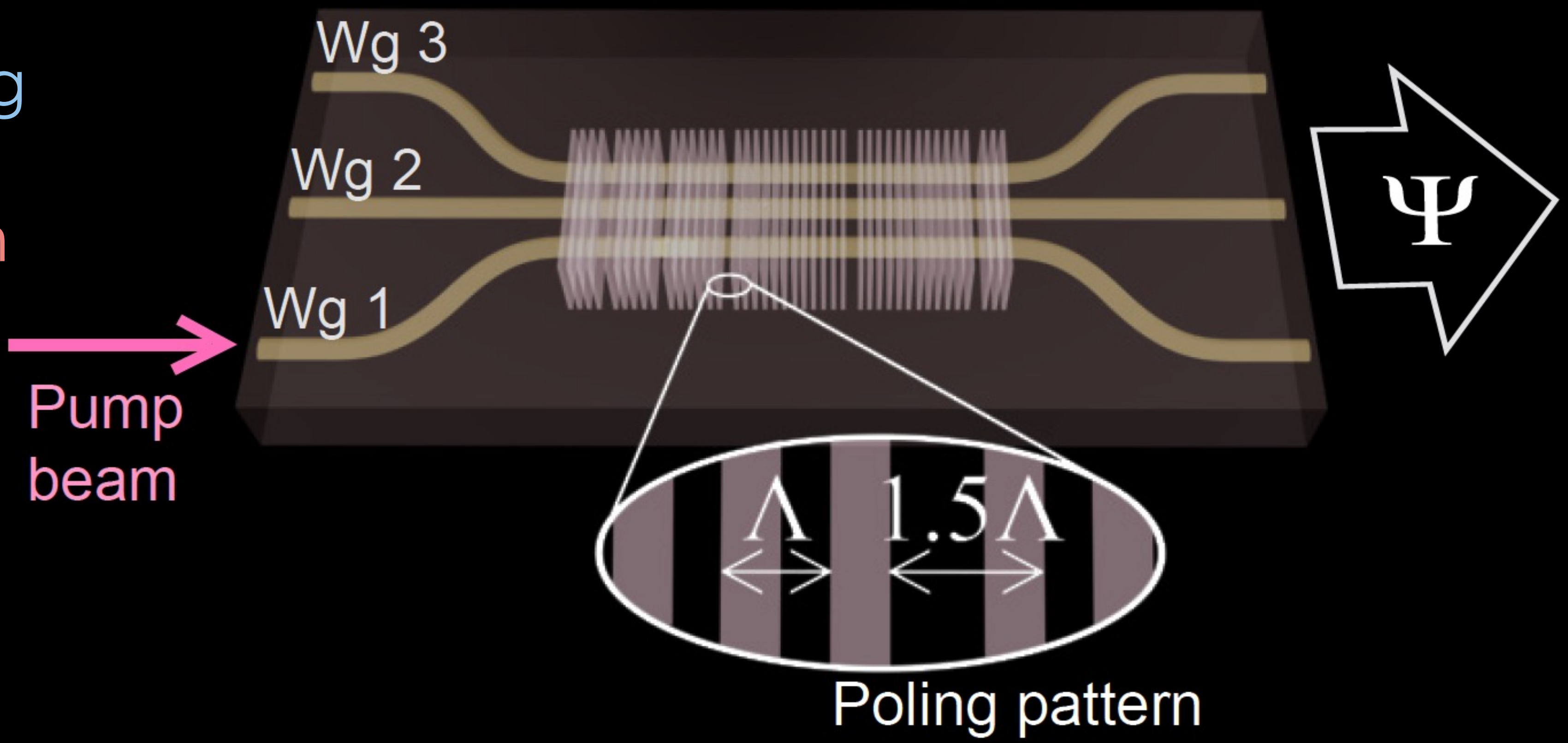
- Laser remains in central channels
- Pairs of photons couple to side channels
- Preserves Entanglement



Solntsev et al., APL 111, 261108 (2017)

POLING ENGINEERING

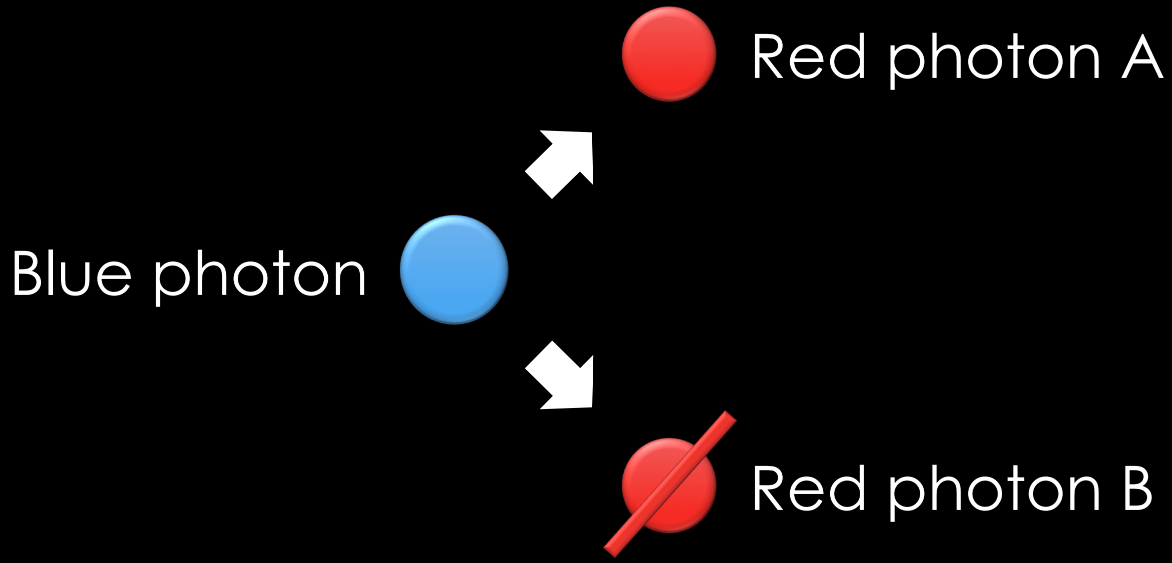
- Poling engineering allows generating arbitrary quantum states

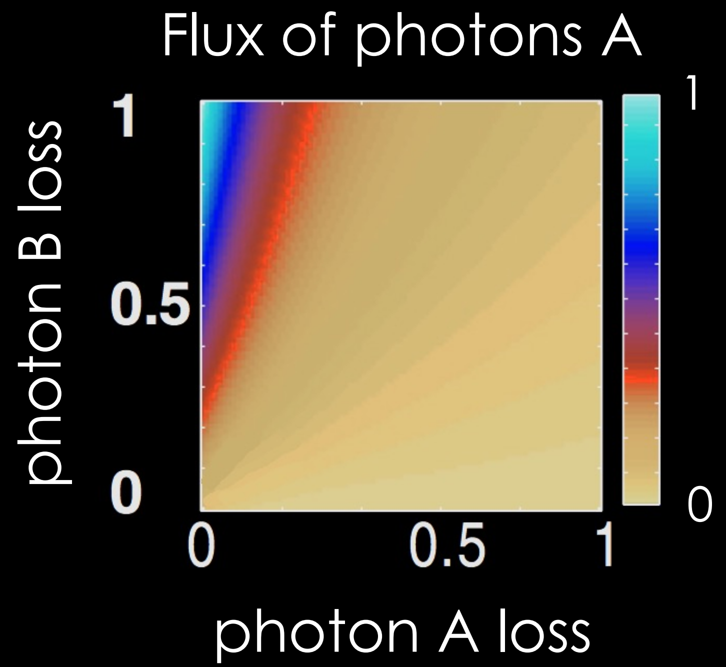


Lenzini, Titchener et al., LSA 7, 17143 (2018)
Titchener et al., PRA, 101, 023809 (2020)

LOSS ENGINEERING

- Plasmonics uses metals - optical loss is high
- Dialectics have scattering loss
- Tricks to make loss useful

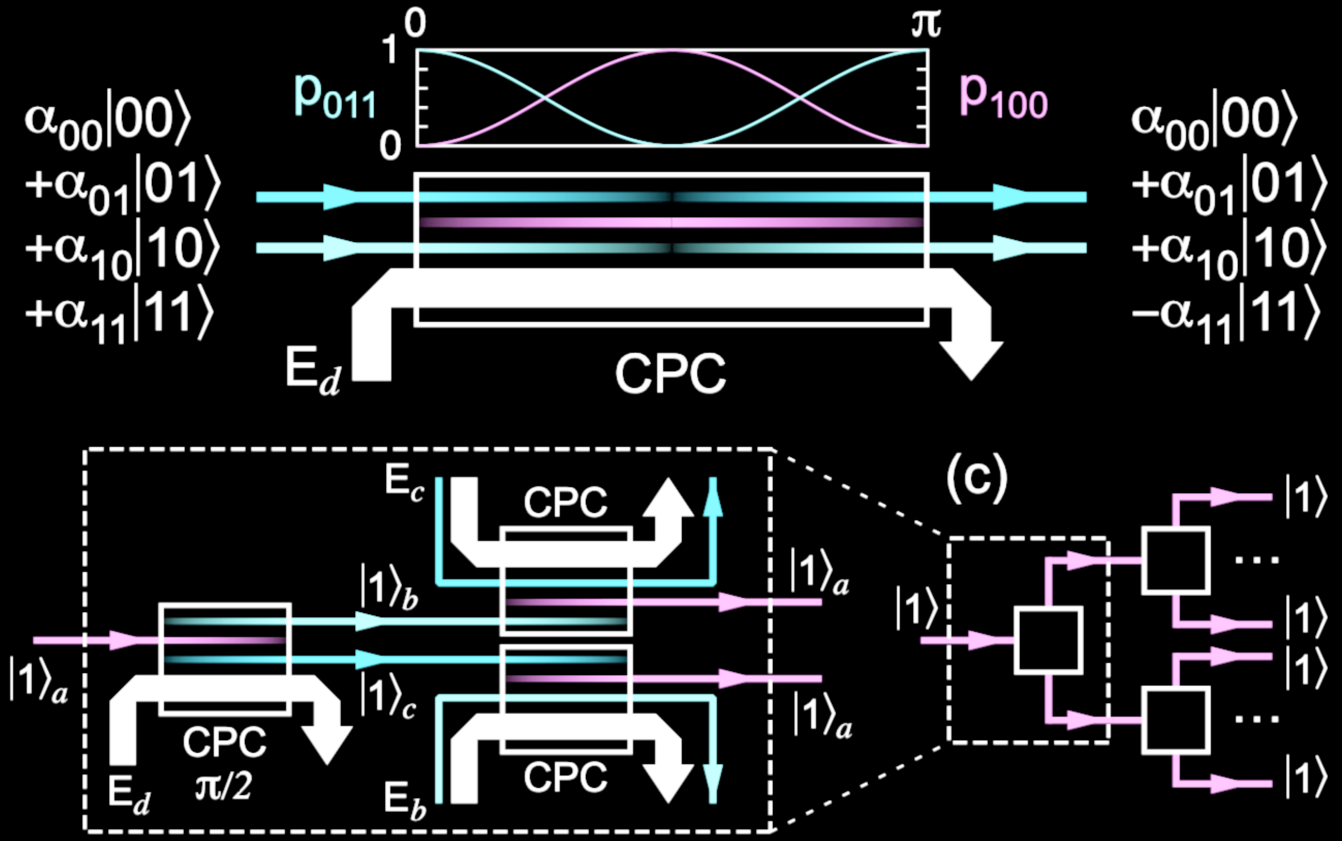




Antonosyan, Solntsev, Sukhorukov
PRA 90, 043845 (2014)
Photonics Research 6, A6-A9 (2018)

COHERENT PHOTON CONVERSION

- Efficient quantum computing
- Using coherent photon conversion to build deterministic controlled-phase gates



Langford at al., Nature 478, 360–363 (2011)

DISPERSION

- Dispersion control can help with coherent photon conversion

Multimode analysis of a conditional phase gate based on second-order nonlinearity

Balakrishnan Viswanathan and Julio Gea-Banacloche
Phys. Rev. A **92**, 042330 – Published 27 October 2015

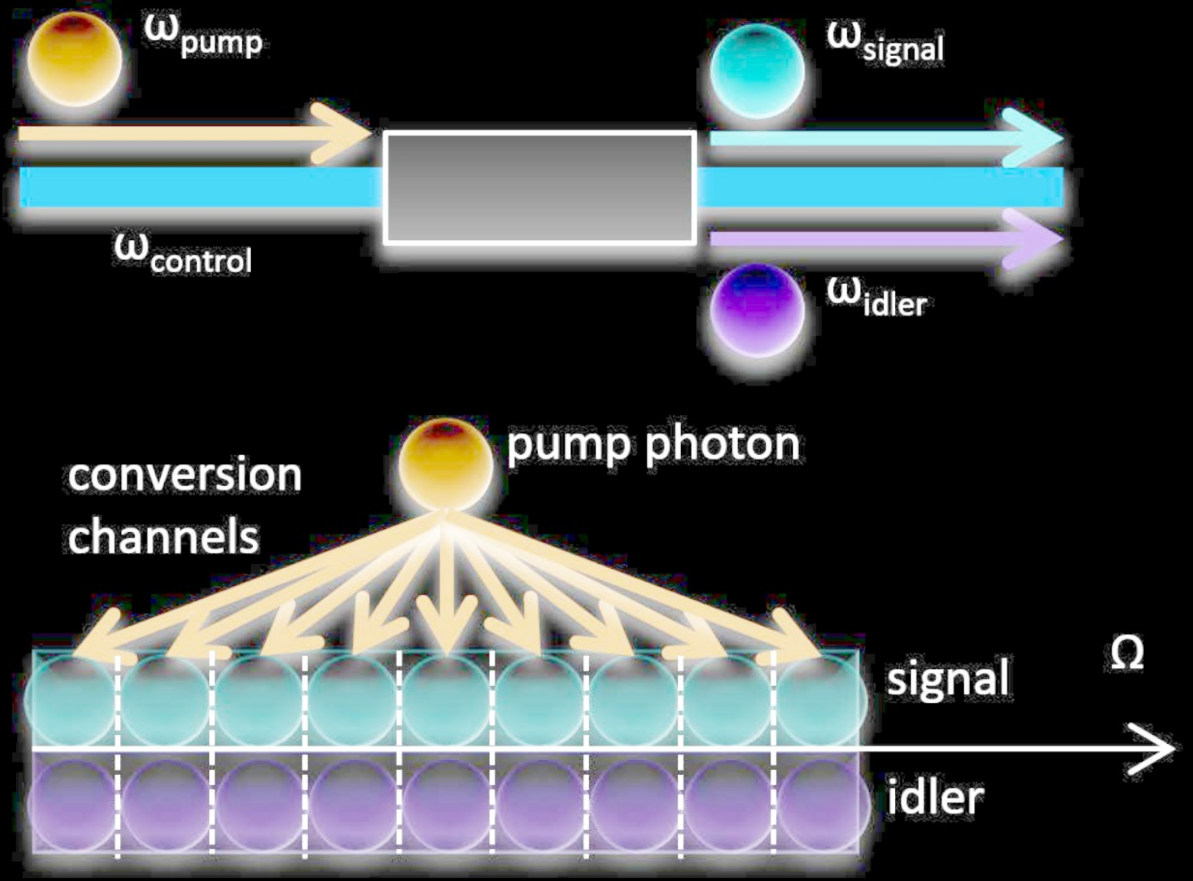
Passive CPHASE Gate via Cross-Kerr Nonlinearities

Daniel J. Brod and Joshua Combes
Phys. Rev. Lett. **117**, 080502 – Published 18 August 2016

What about broadband regime and dispersion limitations?

BROADBAND COHERENT PHOTON CONVERSION

- Utilising a larger number of coherent photon conversion channels
- Increasing the generated photon-pair bandwidth
- Increases the efficiency of the process

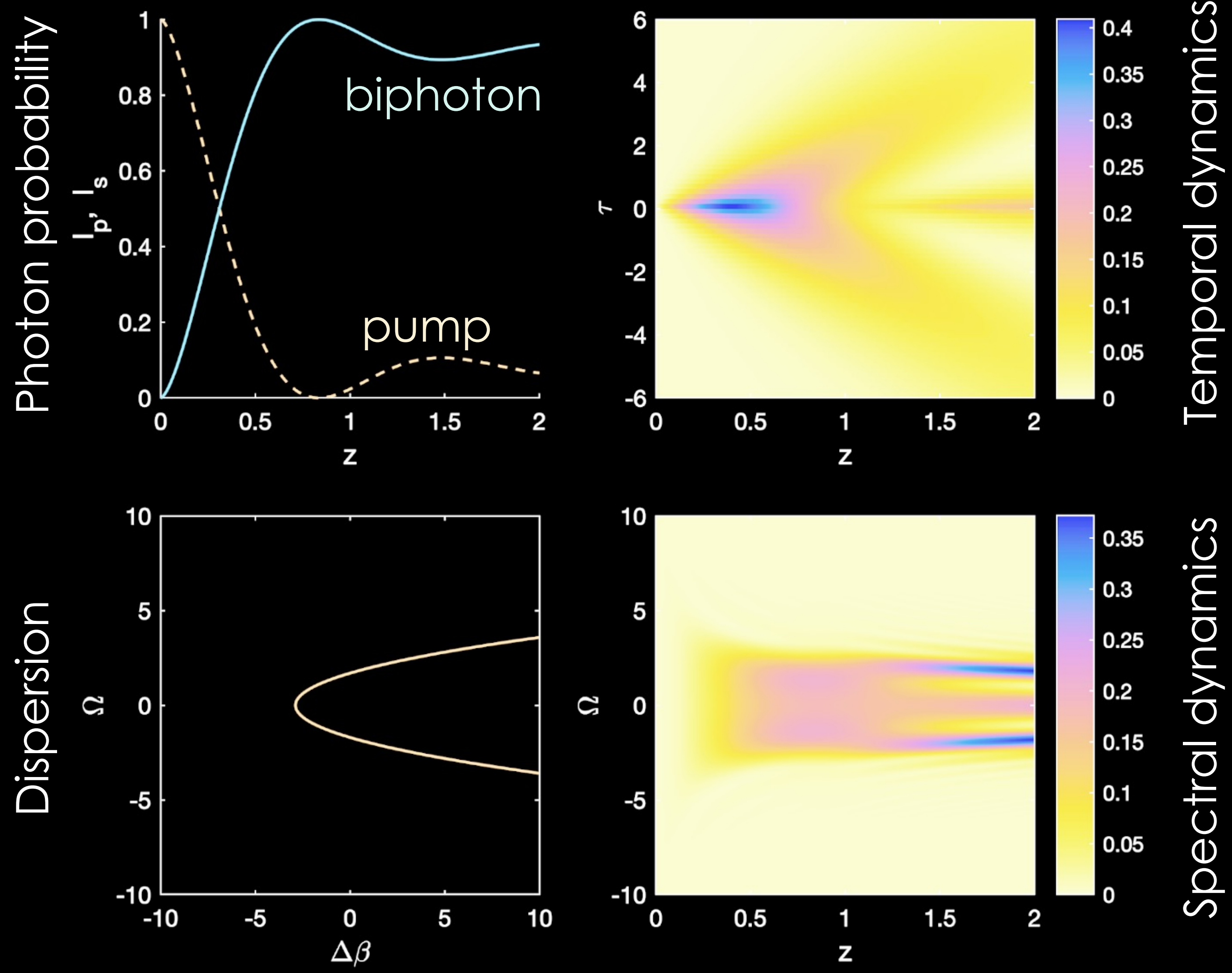


Solntsev at al., New J. Phys. 24 065002 (2022)

$$\Delta\beta = \Omega^2 - 2.88$$

QUADRATIC DISPERSION

- Complete conversion of one photon into two
- At a finite propagation distance

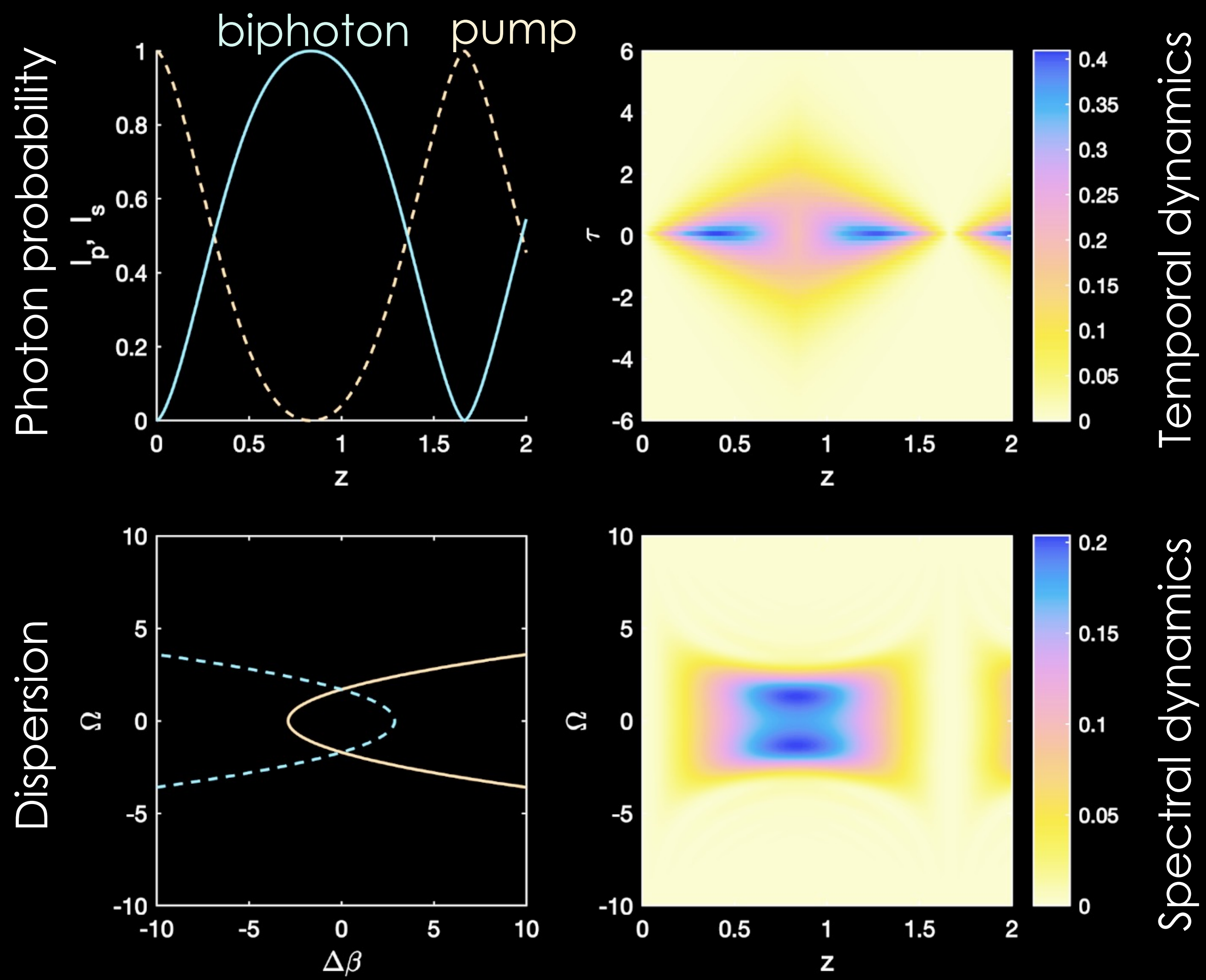


Solntsev at al., New J. Phys. 24 065002 (2022)

$$\Delta\beta = \Omega^2 - 2.88 \text{ for } z \leq z_{\text{inv}}$$
$$\Delta\beta = -\Omega^2 + 2.88 \text{ for } z > z_{\text{inv}}$$

FLIPPED DISPERSION

- Forward and backward conversion between one- and two-photon states
- Achieved by reversing the sign of the dispersion

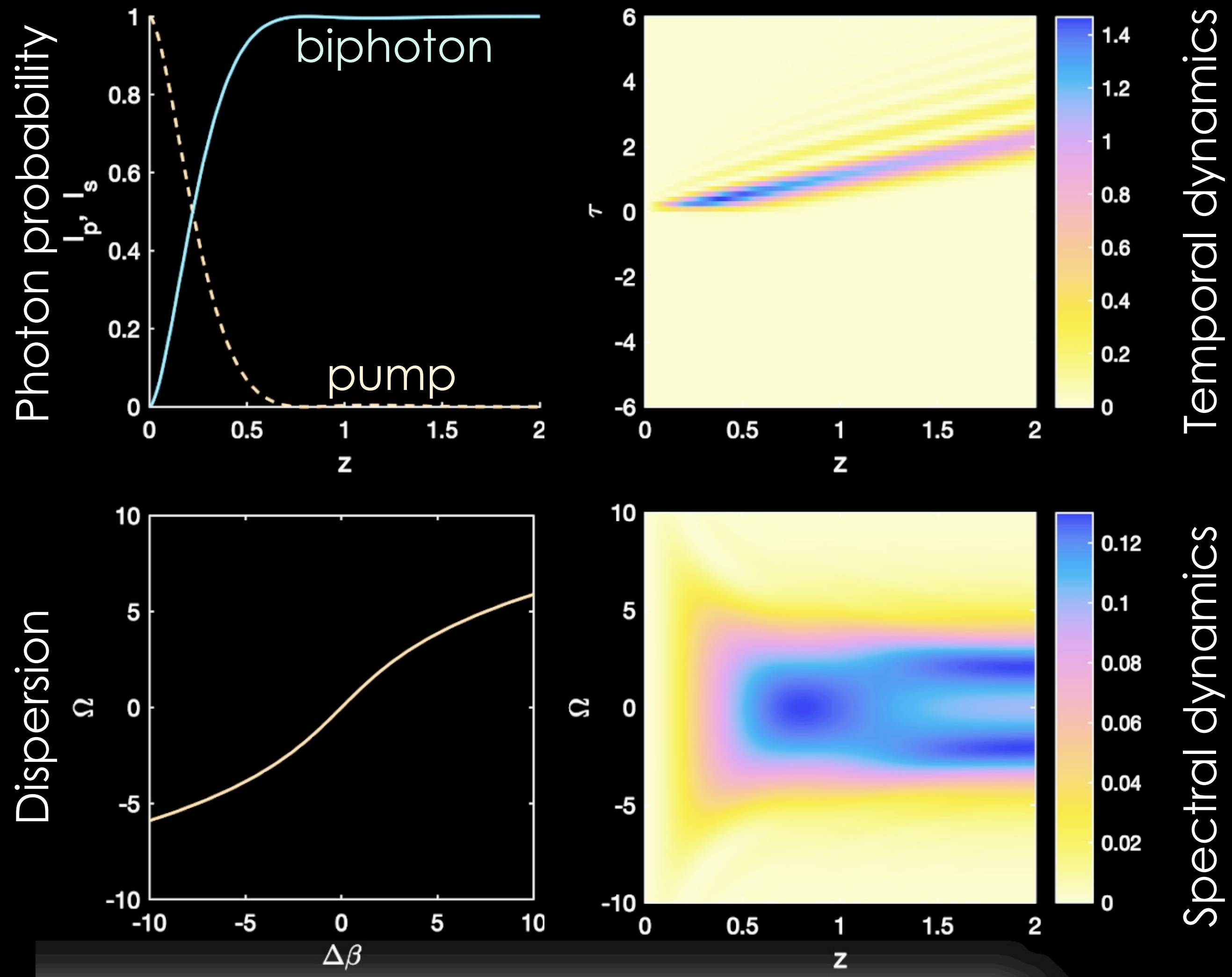


Solntsev at al., New J. Phys. 24 065002 (2022)

$$\Delta\beta = \beta_3\,\Omega^3 + \Omega, \text{ with } \beta_3 = 0.02$$

CUBIC DISPERSION

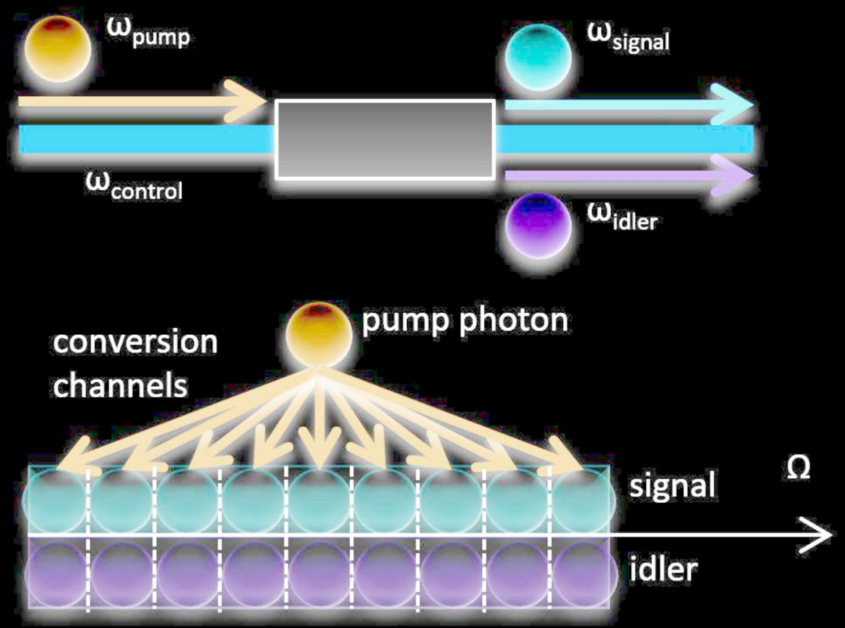
- Robust conversion between one and two photons
- Achieved through engineering higher-order frequency dispersion



Solntsev at al., New J. Phys. 24 065002 (2022)

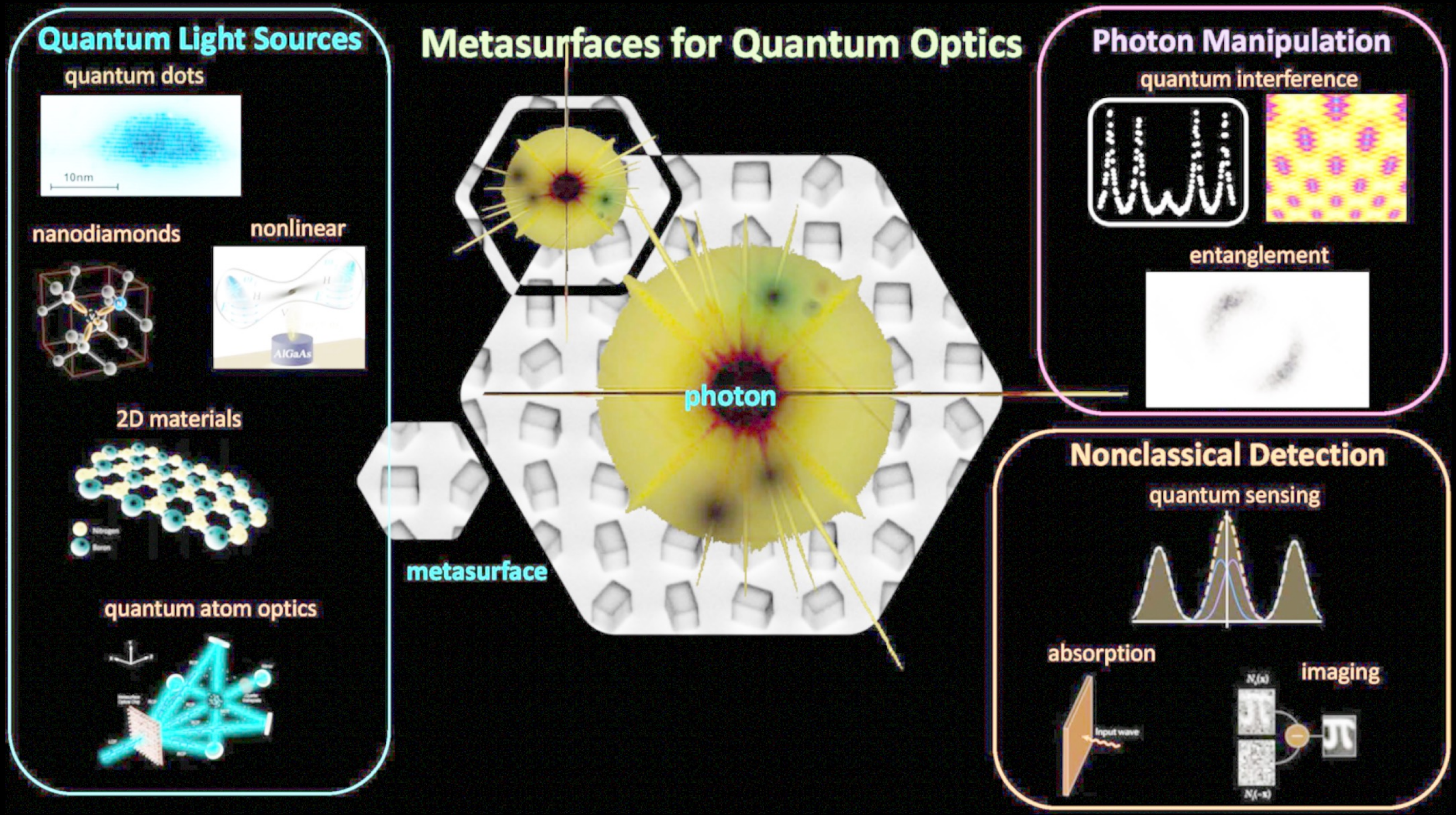
CONCLUSION

- Dispersion engineering - promising way to tune and optimise coherent photon conversion



Solntsev at al., New J. Phys. 24 065002 (2022)

OUTLOOK



Solntsev at al., Nature Photonics 15, 327–336 (2021)