Towards a Quantum Dot-Based Single Photon Source

photon antibunching from a single charge-tuneable quantum dot

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SET Award

Best Physics Student:

- National competition
- Round 1: Reference
- Round 2: Current Performance
- Round 3: Project Synopsis
- Round 4: Interview

Sponsors/Judges Include:

- NPL
- IOP
- UCL
- Imperial

Single Photon Applications

Quantum Computing:

- Spin-interaction and interference for binary 1 or 0 states
- Quantum Teleportation
- Ultrafast low-energy computation

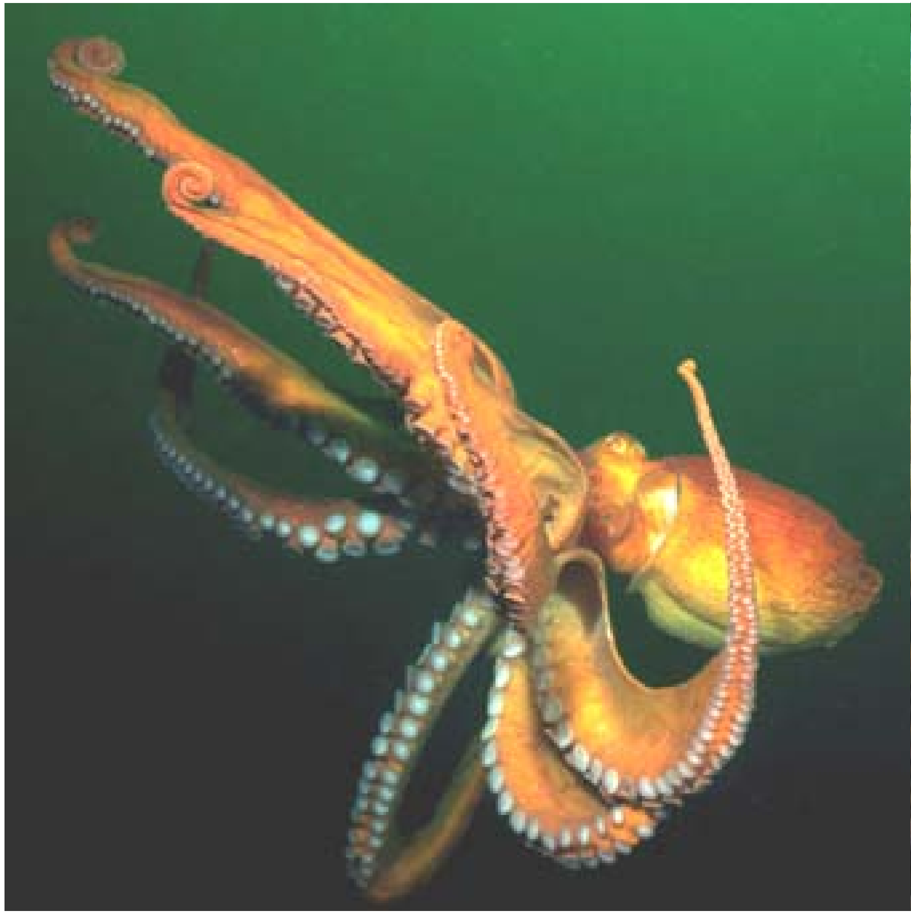
Quantum Cryptography:

- Indeterministic nature of quanta
- Verifiably secure information transfer

Single Photon Applications

<u>Quantum Cryptography:</u>

• Imagine you’re an Octopus



Single Photon Applications

Quantum Computing:

- Spin-interaction and interference for binary 1 or 0 states
- Quantum Teleportation
- Ultrafast low-energy computation

Quantum Cryptography:

- Indeterministic nature of quanta
- Verifiably secure information transfer

…… providing single photons can be reliably produced *on demand*

Single Photon Production

Highly Attenuated Laser Pulse Trains (RT):

• Multi-photon pulses (Poissonian probability)

Single Atom/Molecule emission (~RT):

• Difficult selection and microscopy <Å

• Bleaching and Blinking

Single-QD regimes (4.2K):

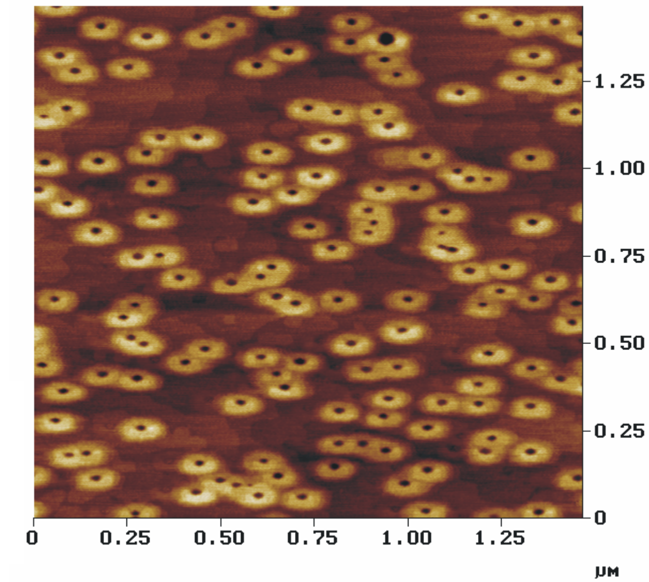
• nm-scale island of semiconductor

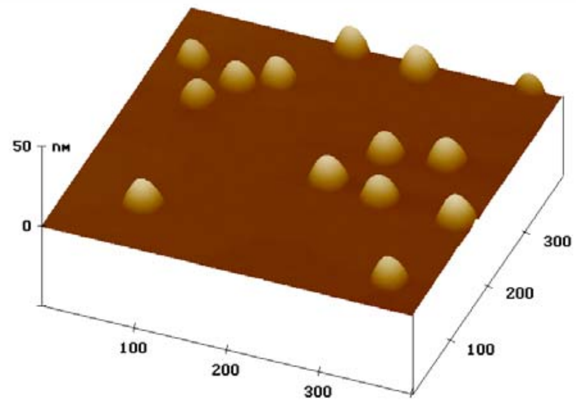
• Artificial atom

• 3D confining potential

• ~Parabolic quantum well

• None of above problems



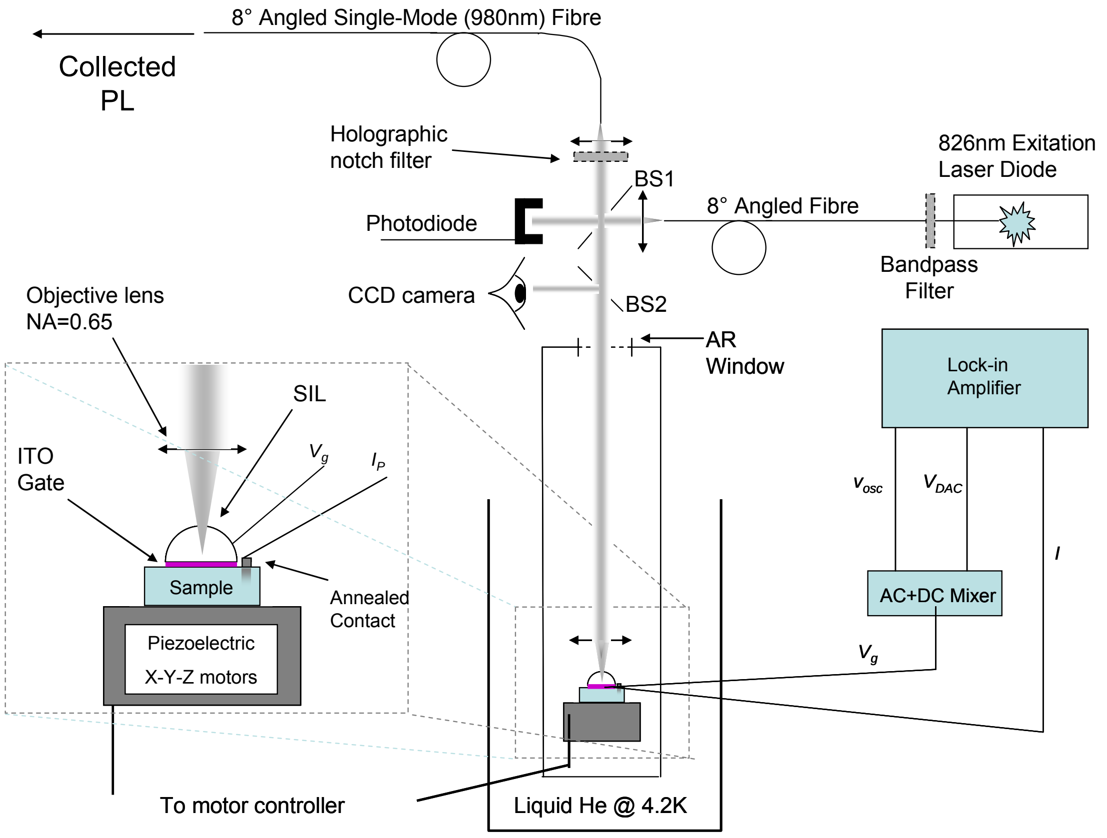


Atomic force micrograph image
Axel Lorke

Looking at Single QDs at 4.2K

Confocal Microscopy:

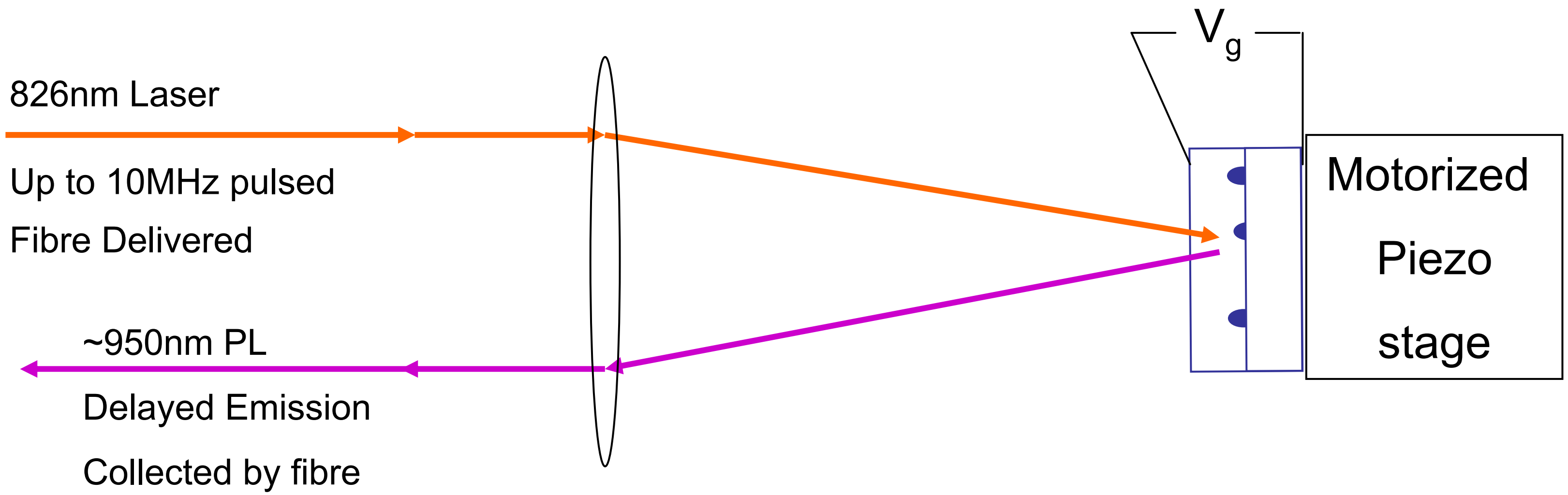
- high-stability, liquid-helium-cooled, solid-immersion-lens-enhanced, diffraction-limited, confocal microscope



Looking at Single QDs at 4.2K

Confocal Microscopy:

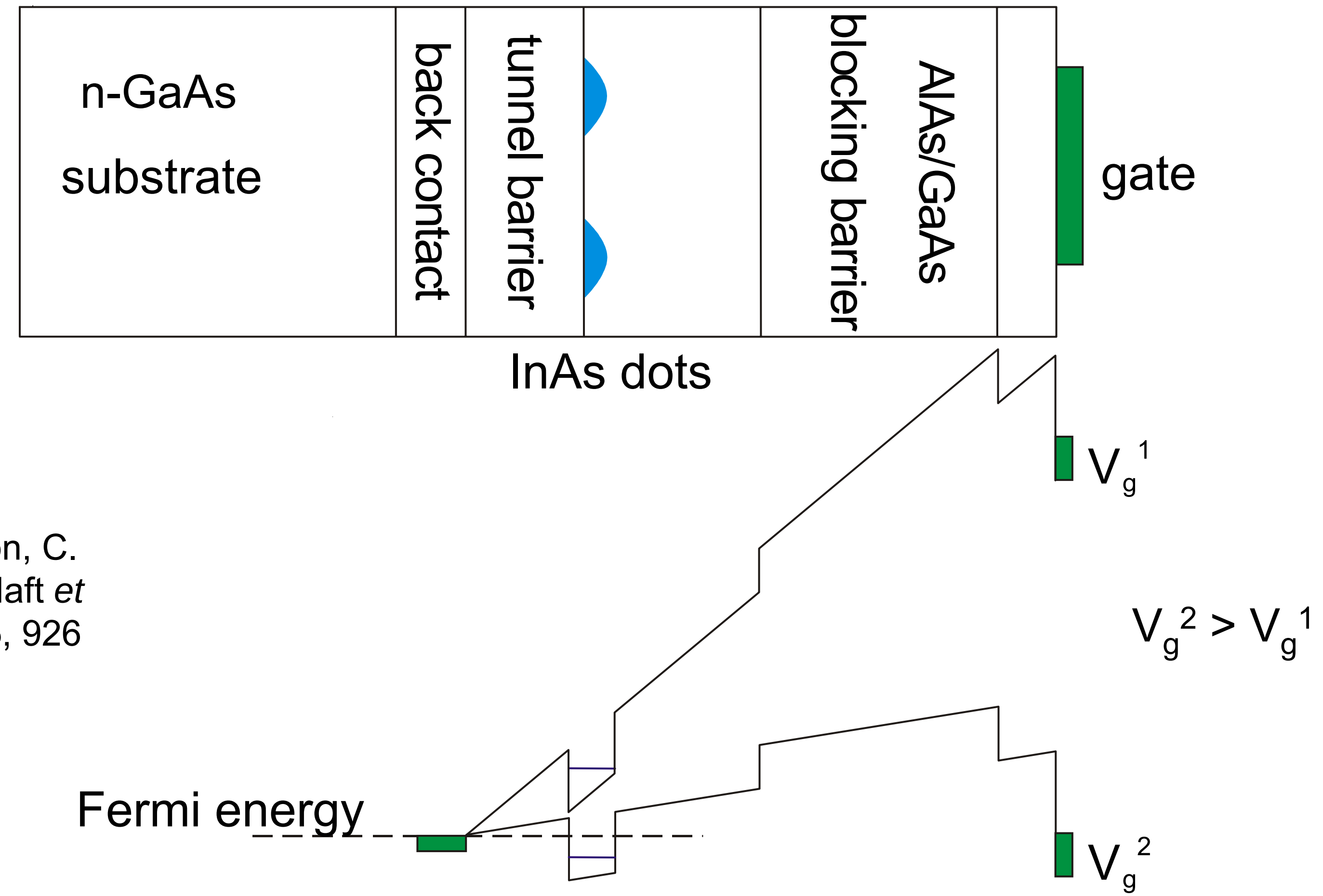
- Not as complicated as it looks…. Slightly
- Light from other dots thrown away.



Fibre Apertures High NA lens Sample @ 4.2 K

MISFET Structure

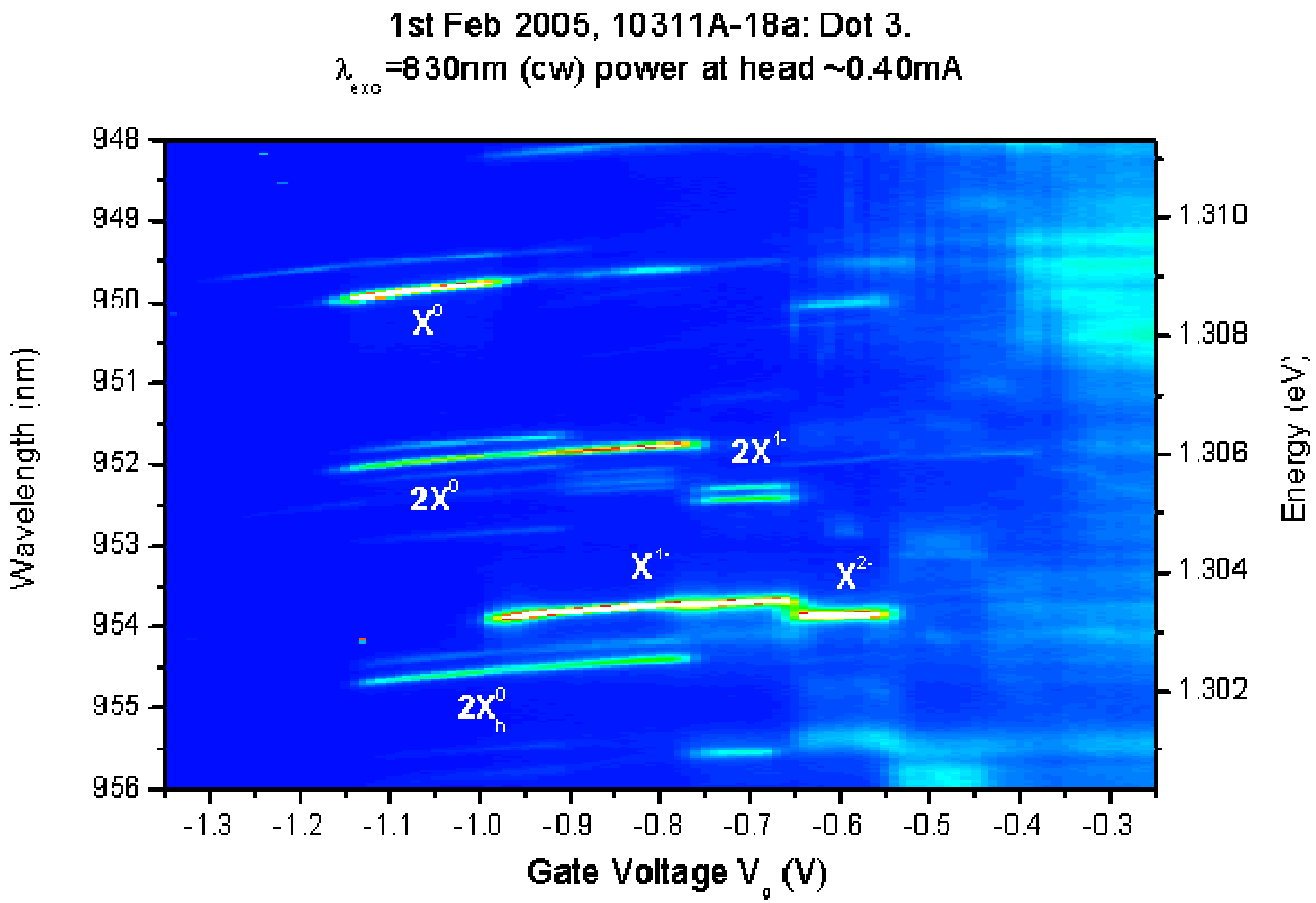
Metal - Insulator - Semiconductor Field Effect Transistor:



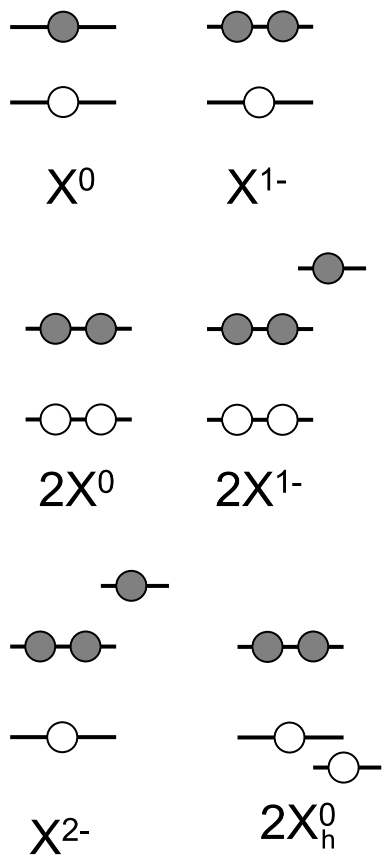
R. J. Warburton, C. Schäflien, D. Haft *et al.*, Nature **405**, 926 (2000)

Charge-Tuneable PL

Exiton Spectroscopy:



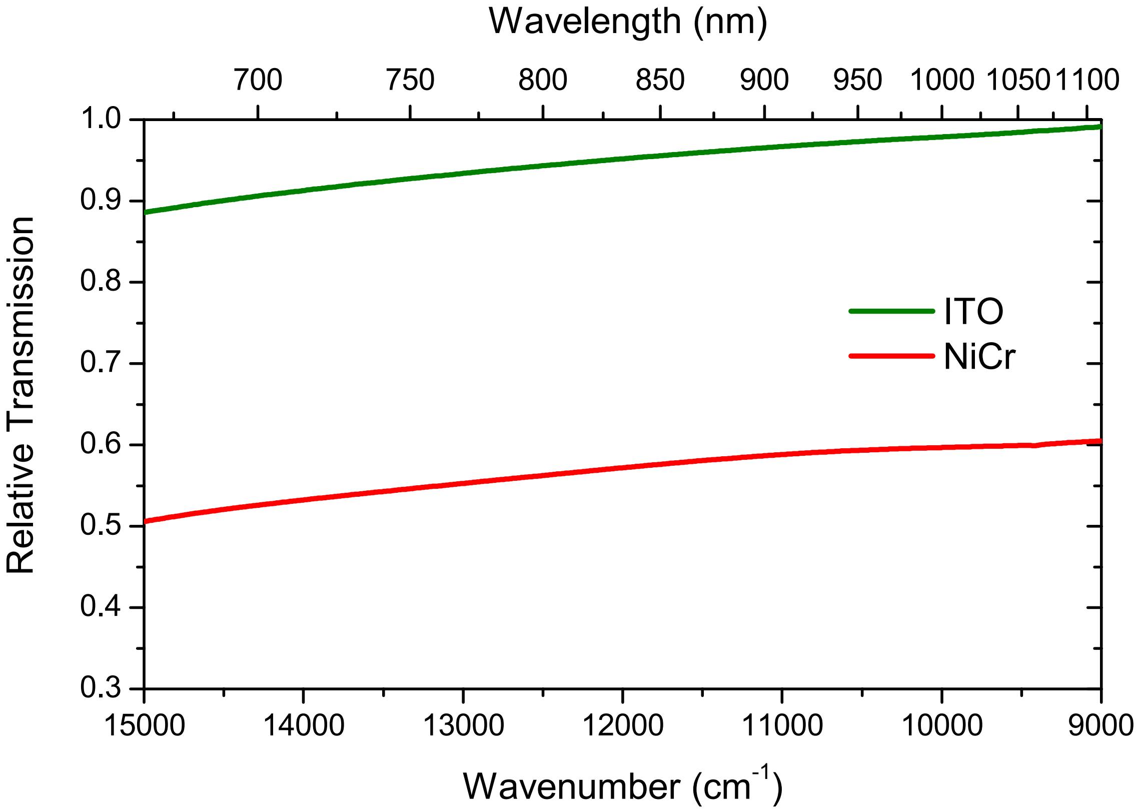
Example State Configurations (spin omitted)



Sample Preparation

Gate Contact:

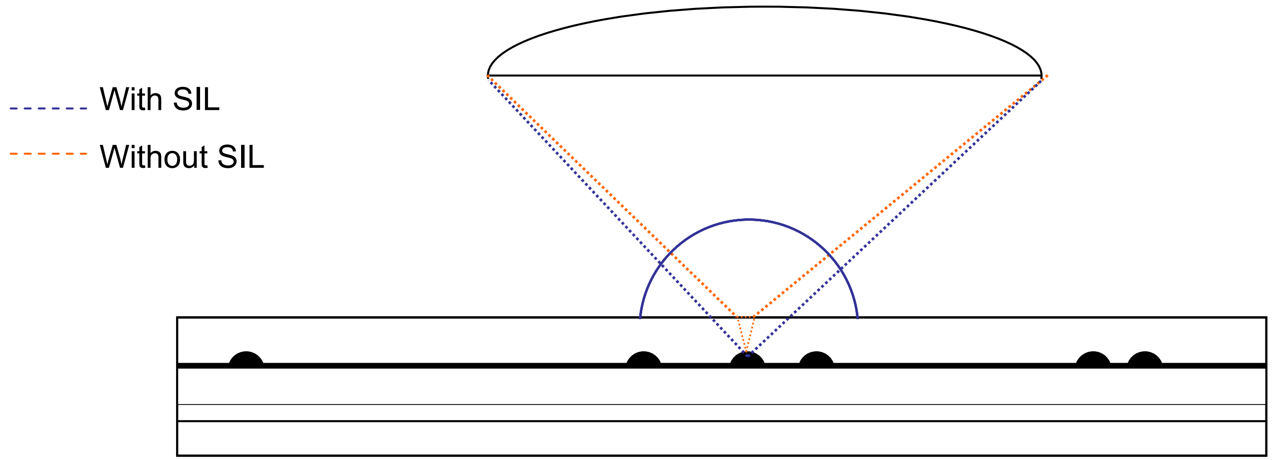
- Higher collection efficiency = better statistics
- Improve transmission, move to Indium Tin Oxide



Sample Preparation

Solid Immersion Lens SIL:

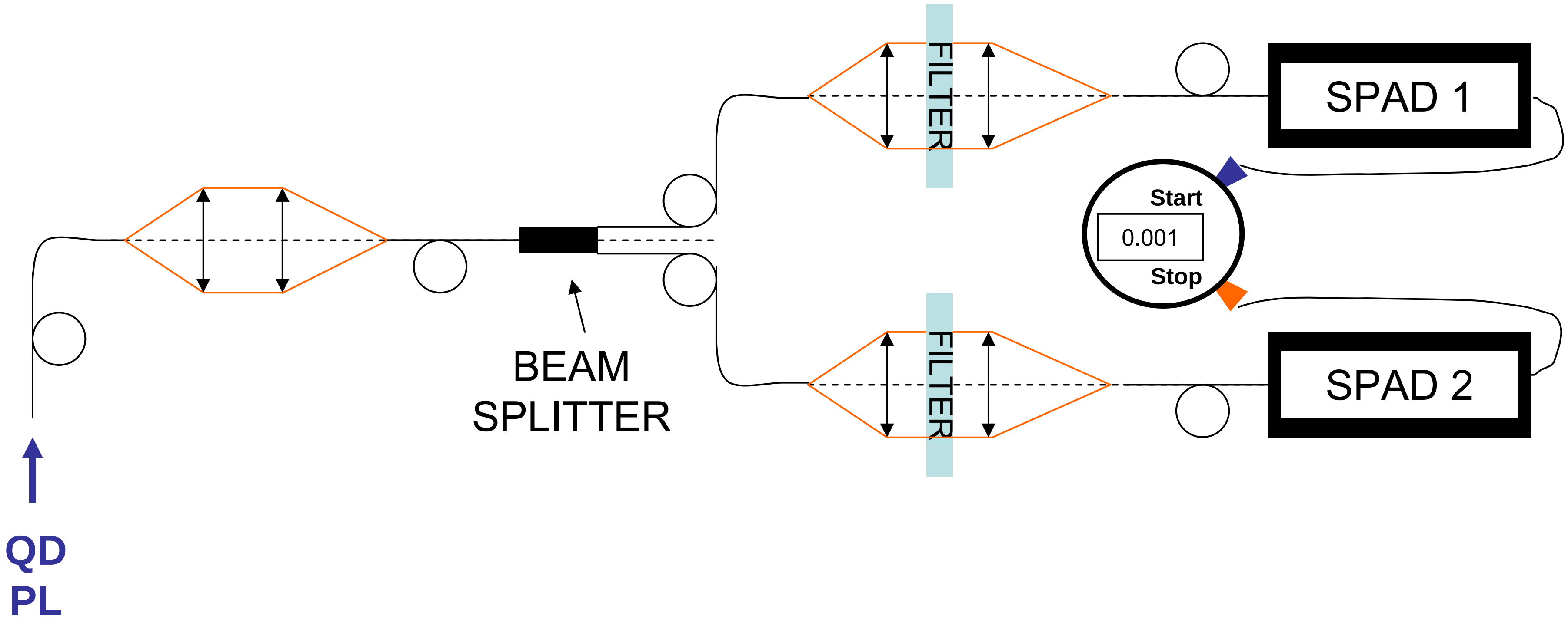
- Lower Refraction at Semiconductor Interface
- Increase Refractive Index
- Wider angle = More Light + Better resolution = Easier selection



Experiment

Photon Counting Statistics:

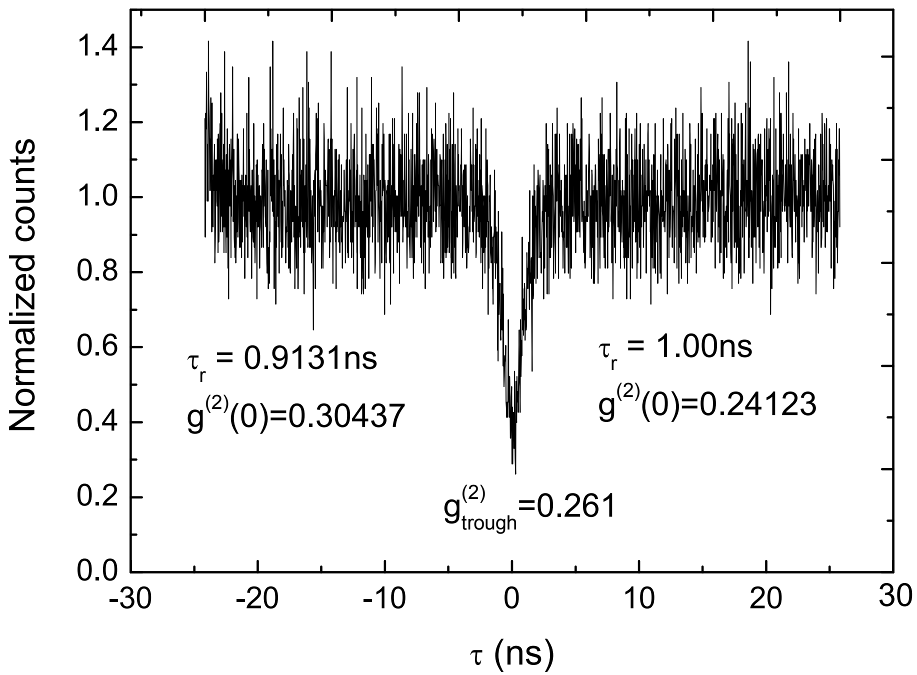
- Hanbury-Brown Twiss Interferometer

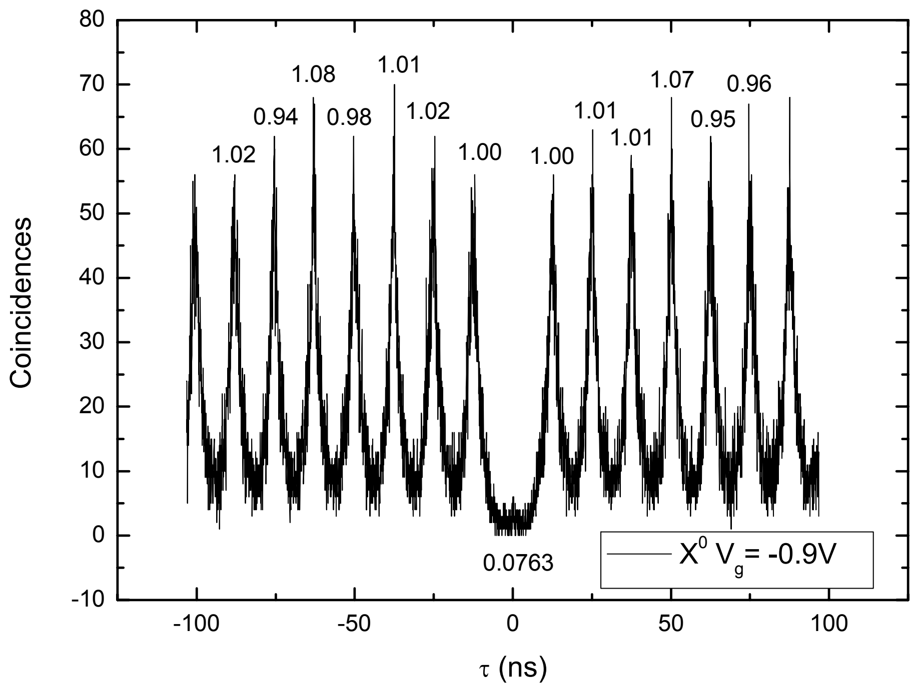


Auto-Correlation

Photon Counting Statistics:

- Hanbury-Brown Twiss Interferometer
- CW and Pulsed antibunching 2nd-order autocorrelation





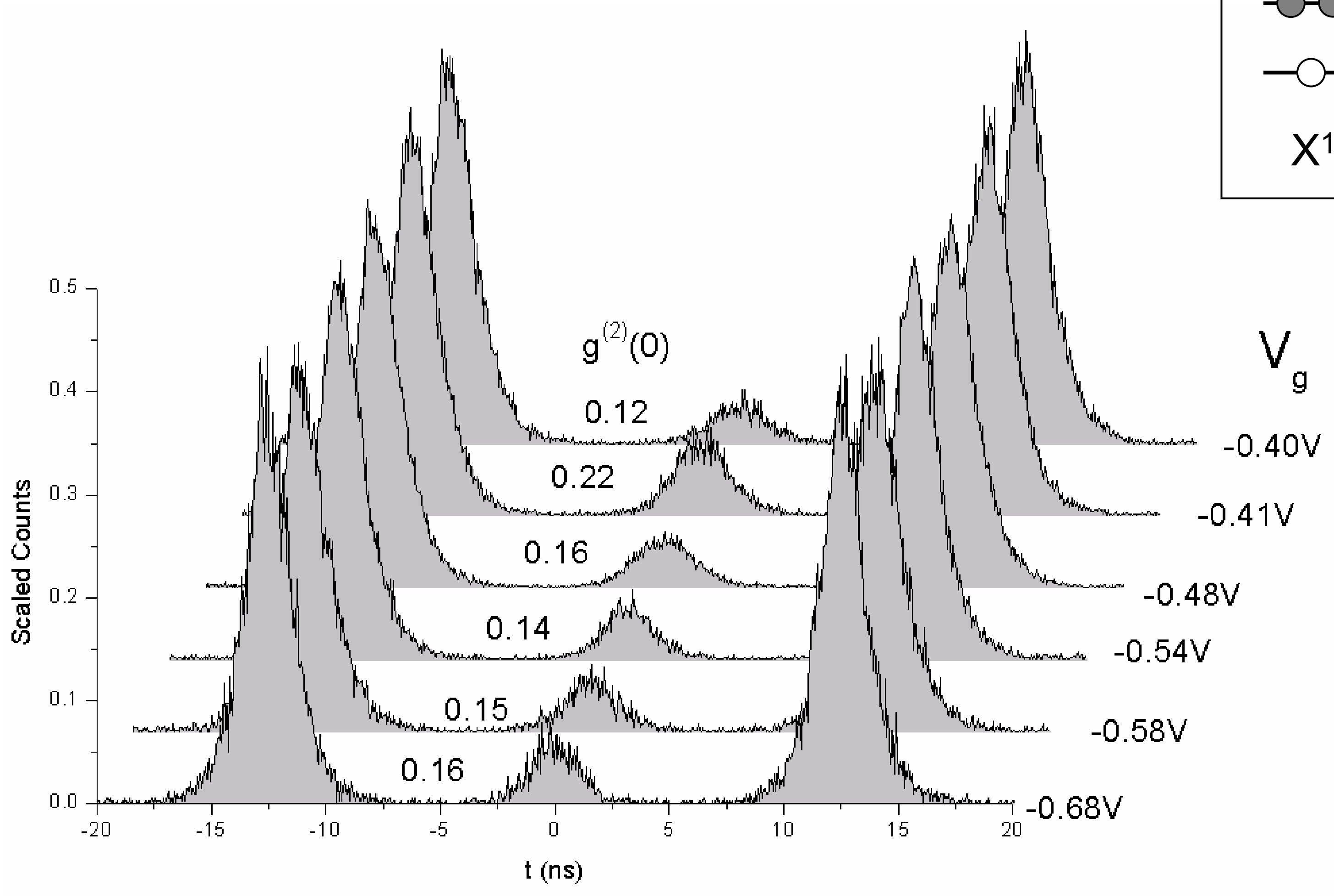
Anti-Bunching

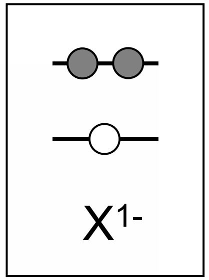
Unexpected results:

- Gate-voltage dependant antibunching
- Difference in dependance between X^0 and X^{1-} ***for the same dot***

Results

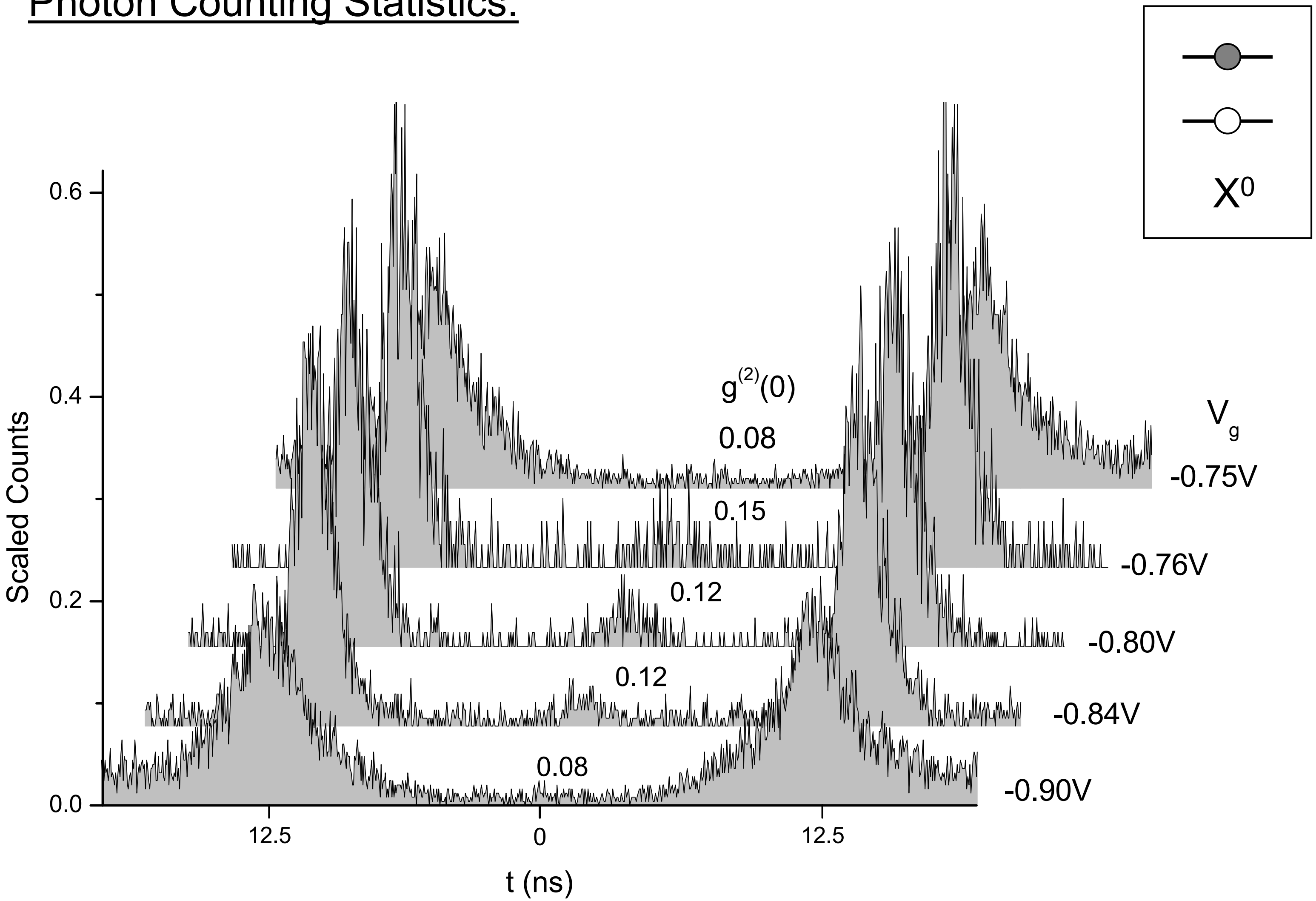
Photon Counting Statistics:





Results

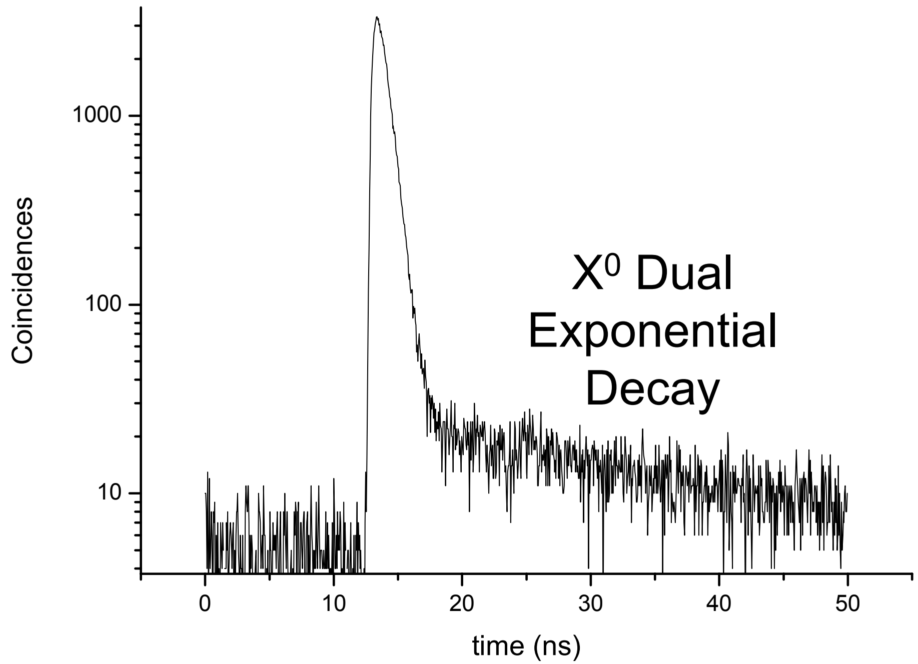
Photon Counting Statistics:

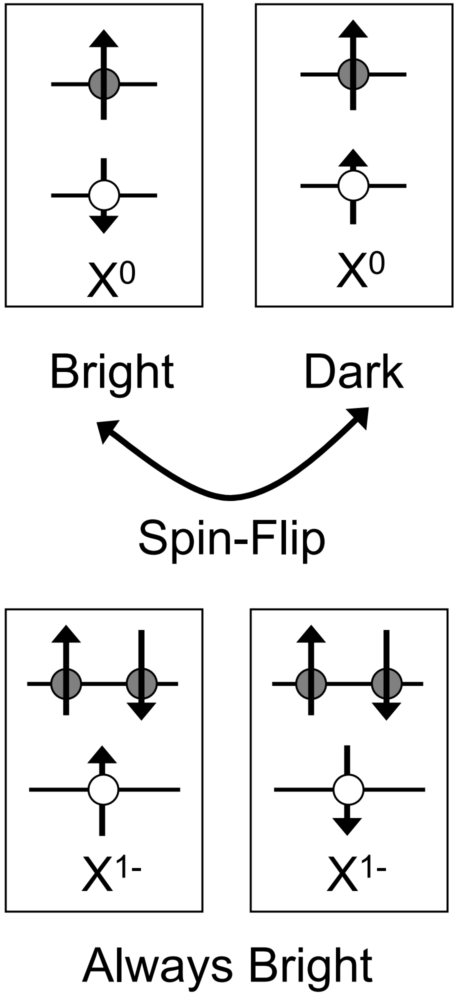


Time Resolved Photo-Luminescence

Photon Counting Statistics:

- Direct comparison to TRPL data
- Neutral Exciton fine structure



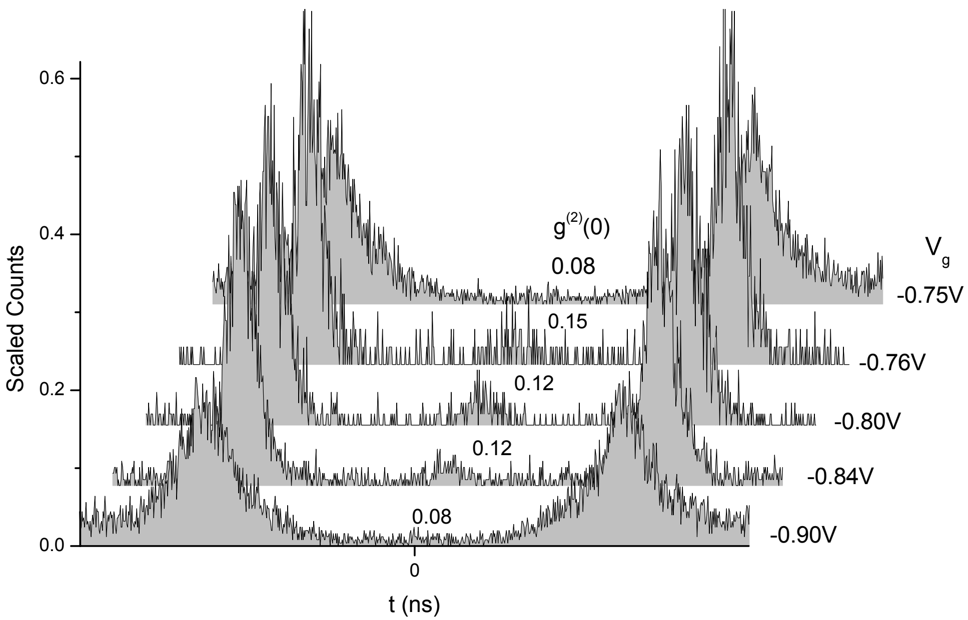


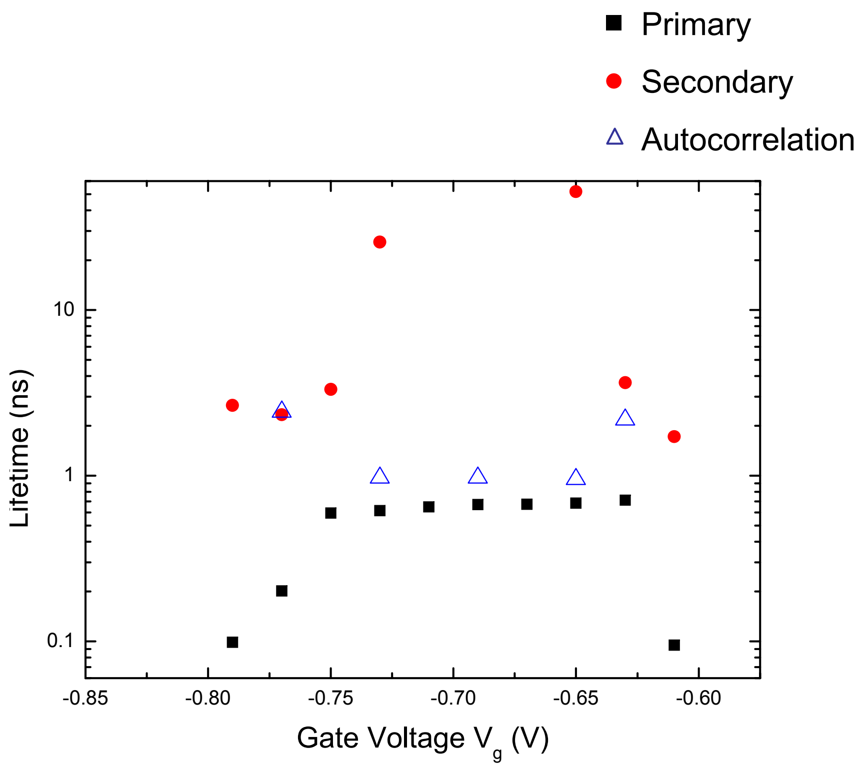
Fine structure discussed in J.M. Smith, P.A.Dalgarno, R.J. Warburton et. al PRL v. 94 n. 19 (2005) pp 197402

Comparison with TRPL

Photon Counting Statistics:

- Decay lifetimes/amplitudes vary with gate voltage
- Coulomb Blockade Model
- Agreement with Autocorrelation

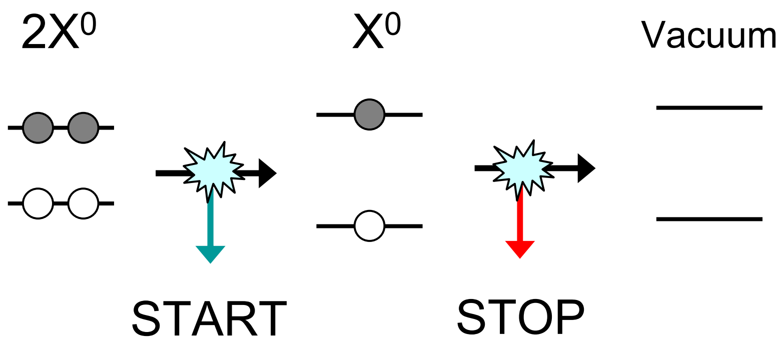


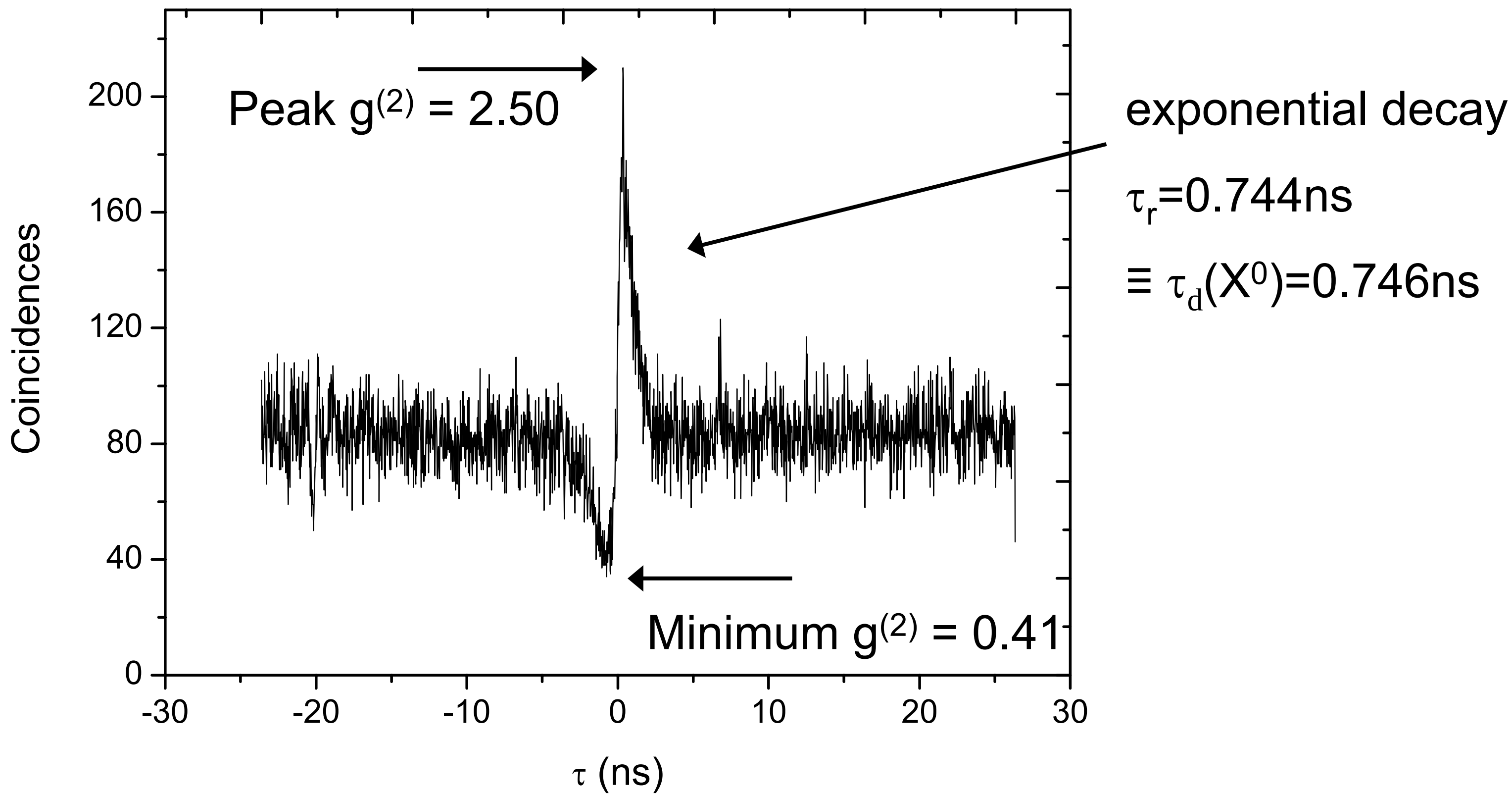


Cross-Correlation

Photon Counting Statistics:

- Quantum Cascade

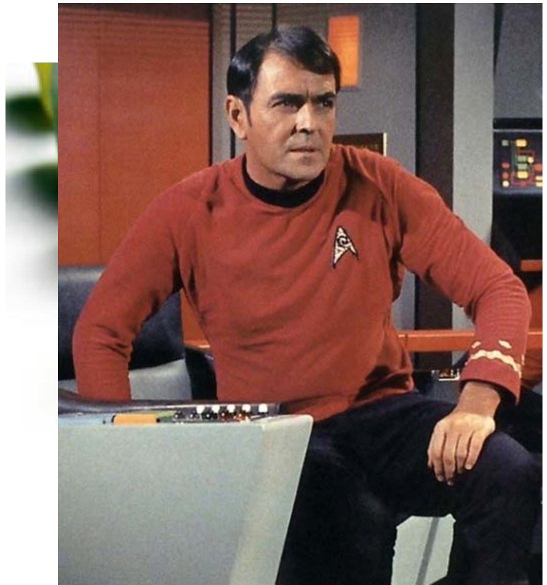




Summary

- ITO+SIL = Better collection efficiency = Higher statistics+Better Resolution
- Verified Antibunching @ 4.2K = Single Photons from QD
- Single Photons = Proof of Second Quantization
- Agreement with TRPL on the same QD for the first time
- Quantum cascade witnessed = Possible trigger for photons on demand

Outlook



QDs provide Single Photons

- Secure information
- Good news for Bob and Alice

QD Single photons are indistiguishable

- Quantum Teleportation
- Good news for Scotty/Kirk

QD single photon sources for supercomputers?

•Good news for Boffins everywhere

Possibly a lot more talks on this subject in the future

- Bad news for Jellybabies