NuCrypt
Securing Optical Communication Networks

Multi-Channel Fiber-Based Source of Polarization Entangled Photons with Integrated Alignment Signal

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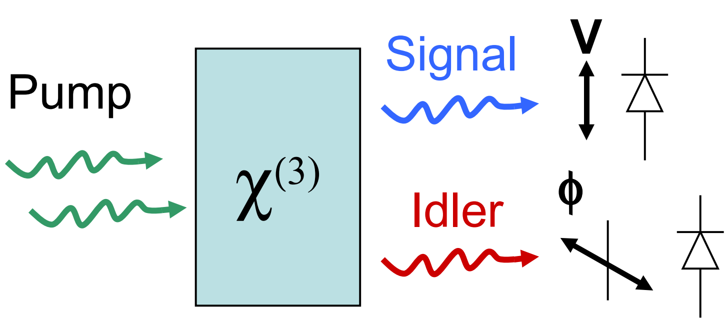
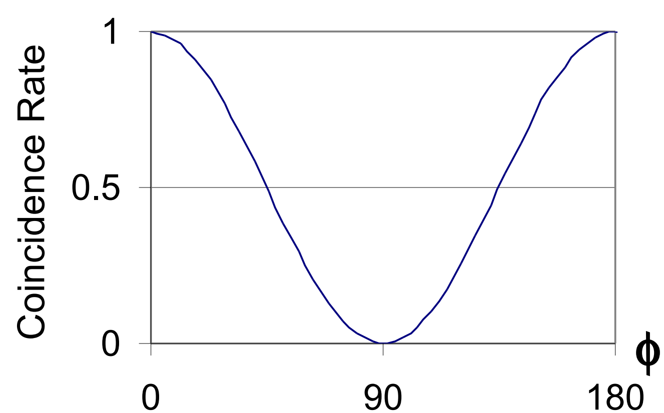
*information contained herein does not necessarily reflect the position or the policy of the Government, and no official endorsement should be inferred

Entangled Photons

- Quantum "linkage" between a pair of photons: Signal and Idler
- For polarization entanglement: signal and idler are individually unpolarized but polarizations are non-locally correlated
- Considered a core tool of quantum information systems
- Need a spontaneous two-photon process: Parametric downconversion {$\chi^{(2)}$ crystal} or four-wave mixing (FWM) {$\chi^{(3)}$ fiber}
- Scientific experiments such as teleportation and tests of Bell's inequality (non-local realism of quantum mechanics)
- Quantum Communications applications such as Quantum cryptography, Quantum games (efficient bidding and auctions), Quantum metrology, …?





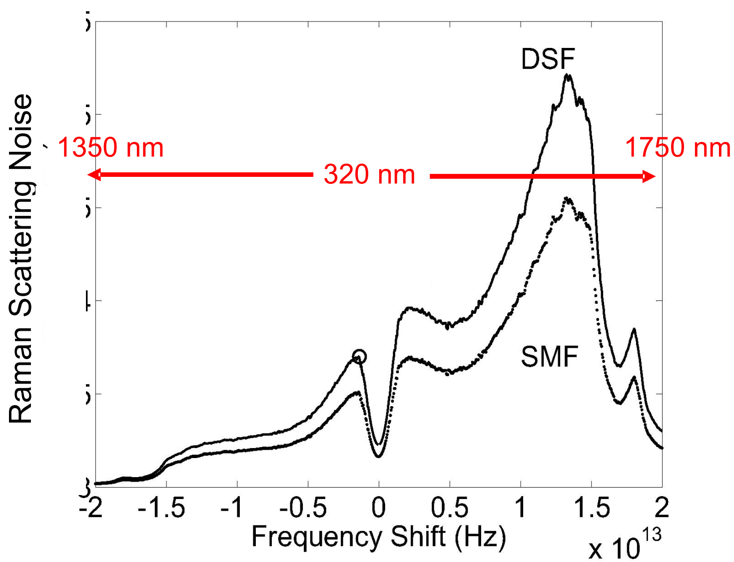
Fiber-Based Generation

Why Generate Entanglement in Fiber?

- Low loss coupling to fiber for long distance distribution
  – maximum coincidence counts ~$(\text{Loss})^2$
- Scalable to high repetition rates (no power handling issues)
- Potential for low-cost manufacturability with rugged, reliable operation

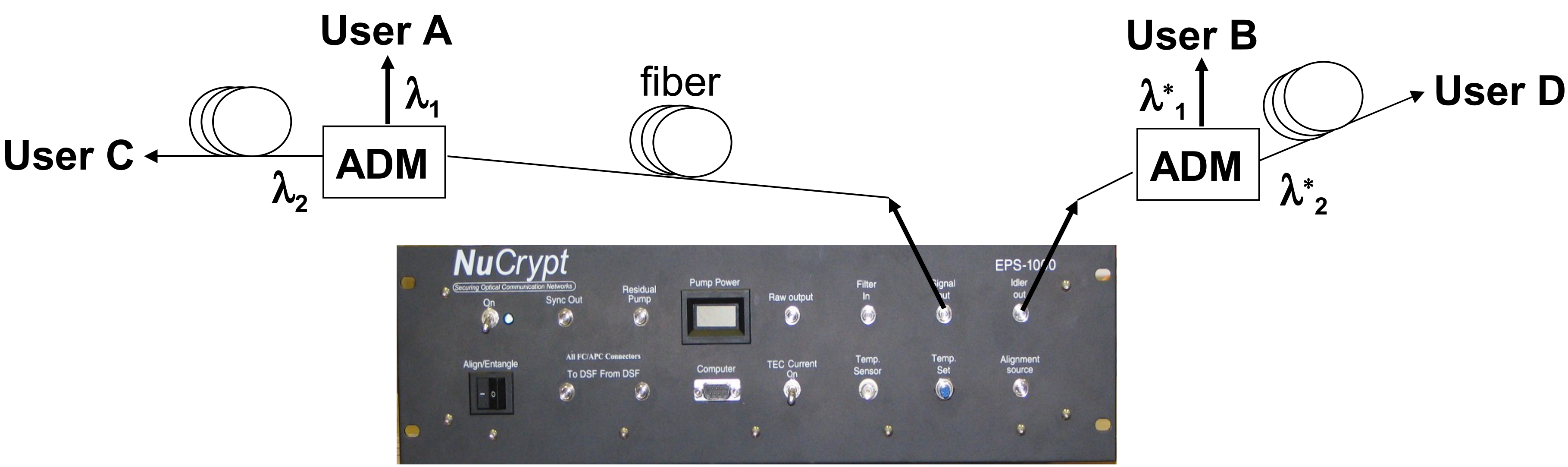
Main Issue with Fiber:

- Raman scattering can limit performance and usable spectral bandwidth
  - For telecom pairs control Raman by spacing signal and idler closely and/or cooling fiber
  - But multiple signal-idler pairs require wide operating bandwidth (WDM entanglement)

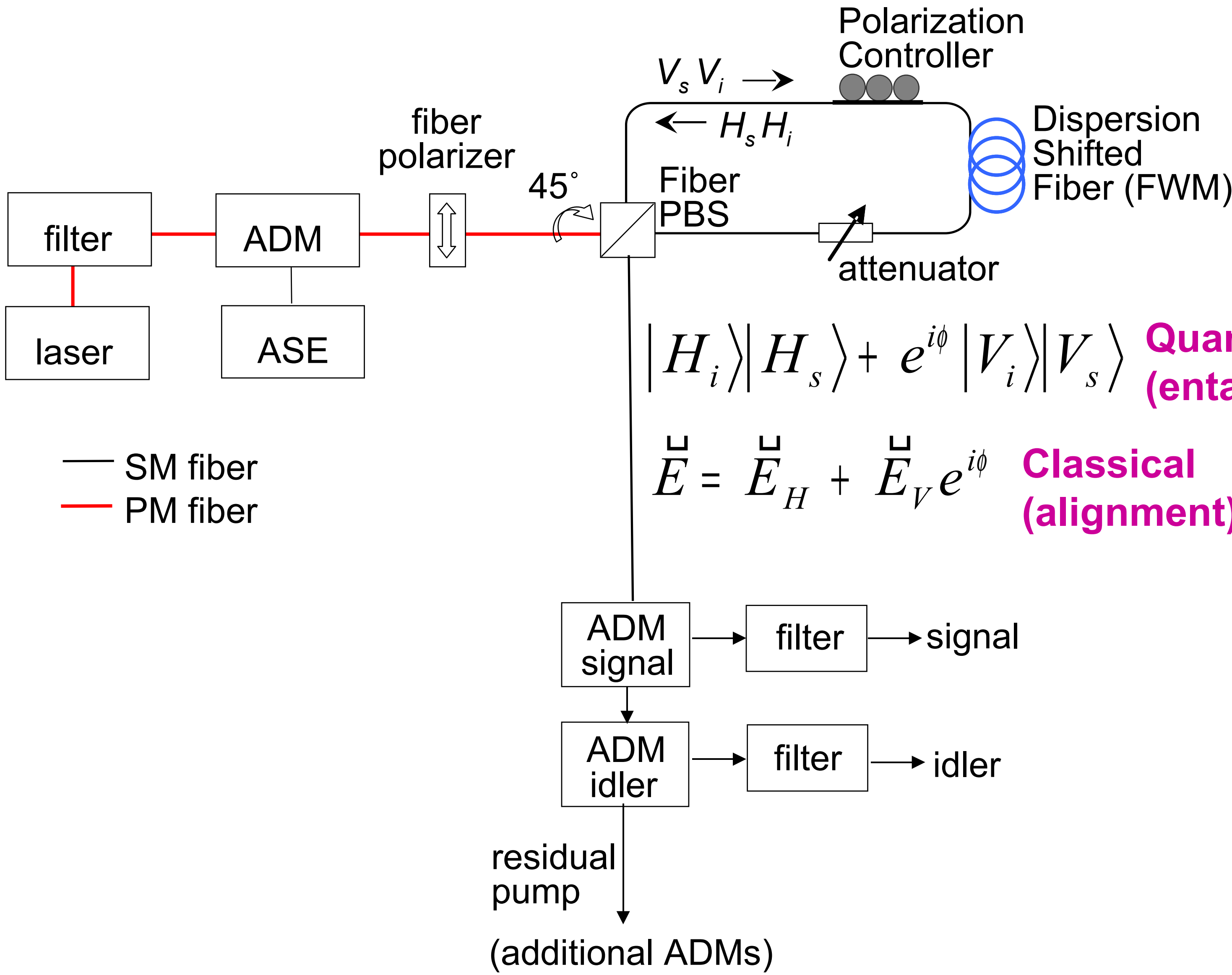


Practical Fiber-Based Entangled Photon Source (EPS)

- Generate multiple entangled photon pairs in fiber
- All commercially available fiber-coupled components
- Provisioning of alignment signal to orient external measurement axis
  - Entangled light is unpolarized - hard to align measurement axis
  - Built in classical signal with definite orientation to the generation axis
  - No moving parts required
- Systematic alignment procedure is fully automatable



Schematic Diagram of the EPS



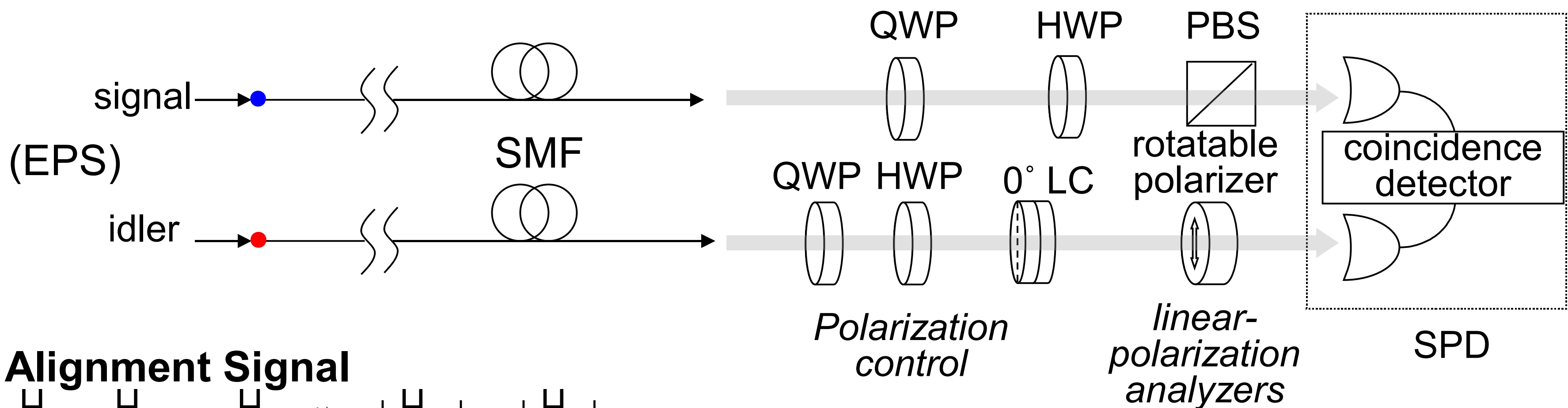
$$|H_i\rangle|H_s\rangle + e^{i\phi}|V_i\rangle|V_s\rangle$$

Quantum (entangled)

$$\vec{E} = \vec{E}_H + \vec{E}_V e^{i\phi}$$

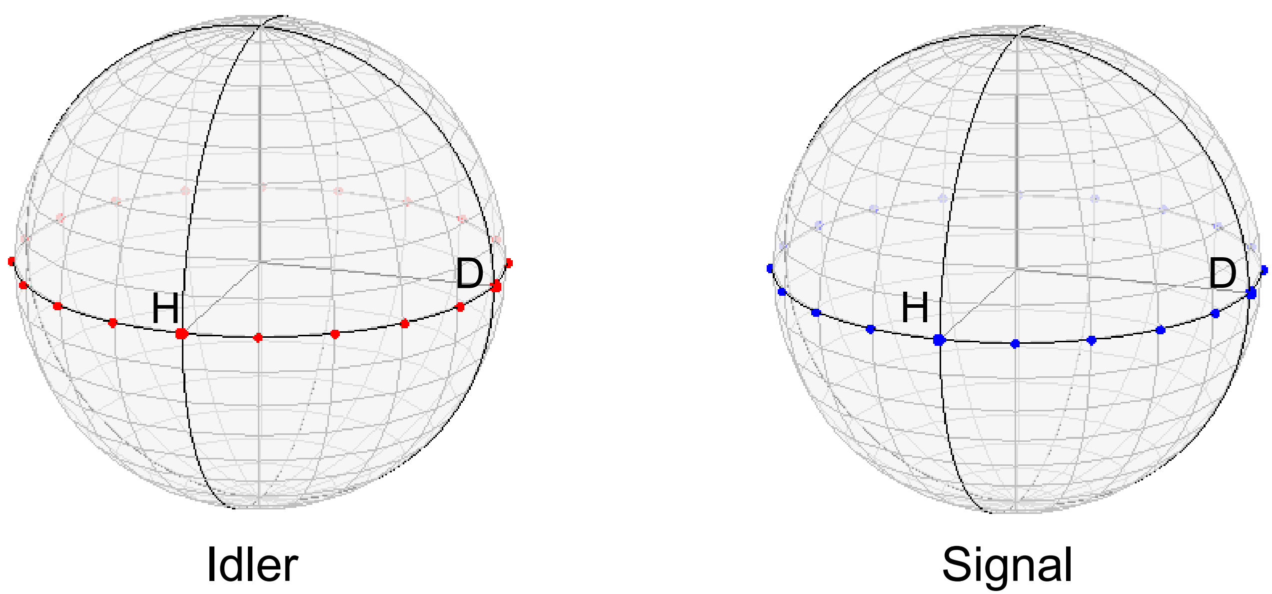
Classical (alignment)

Measurement Setup and Procedure



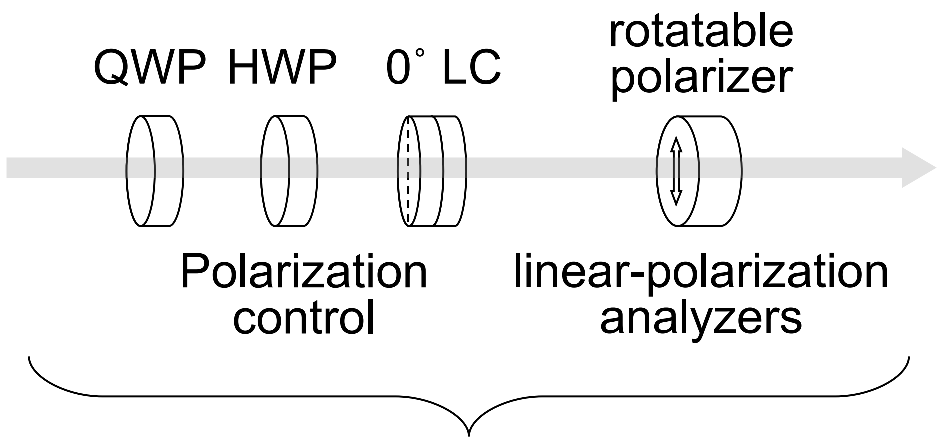
Alignment Signal

$$\vec{E} = \vec{E}_H + \vec{E}_V e^{i\phi}, \quad |\vec{E}_H| \approx |\vec{E}_V|$$

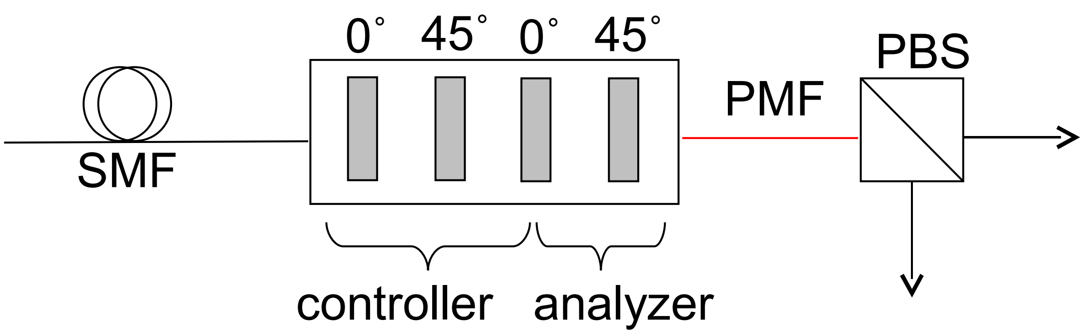


All Fiber Measurement Setup

Manual Polarization Analyzer



4-layer LC Electronically Controlled Polarization Analyzer



Quality of Entanglement

Metrics:

•Two Photon Interference (TPI) Visibility

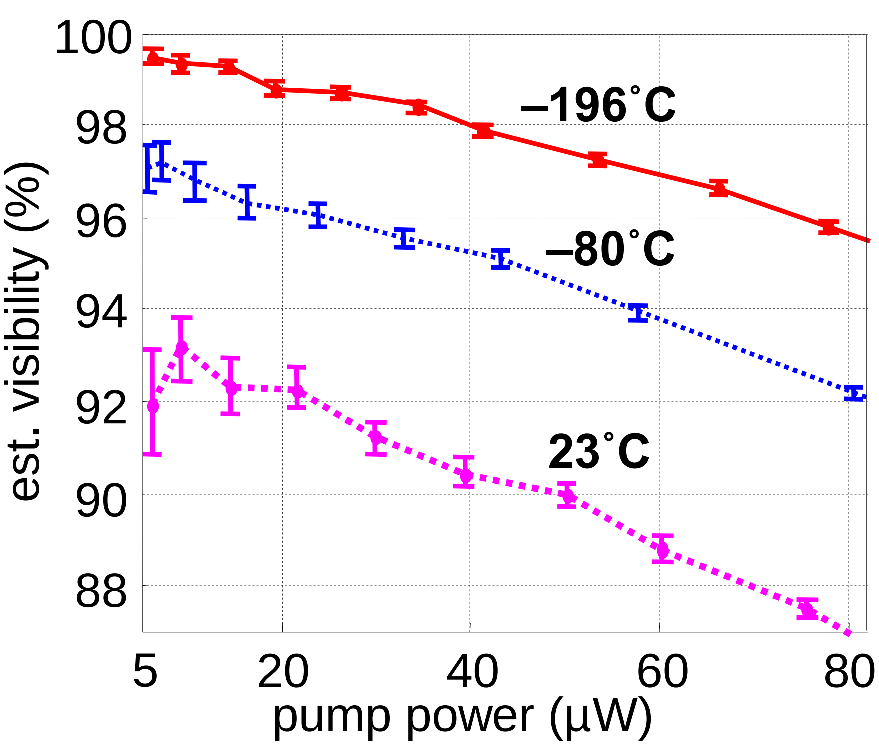
•Coincidence Count Rate

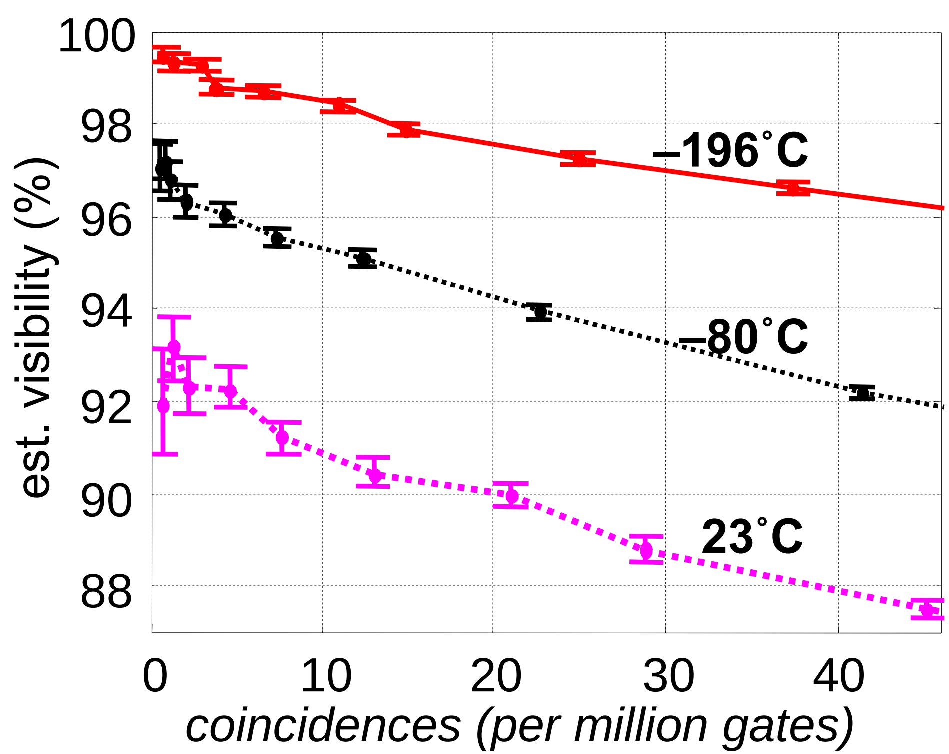
Estimated Visibility: $$Vis_{est} = \frac{C_{max} - A}{C_{max} + A}$$

C_{max} – coincidence counts at peak of TPI fringe

A – Accidental coincidence counts

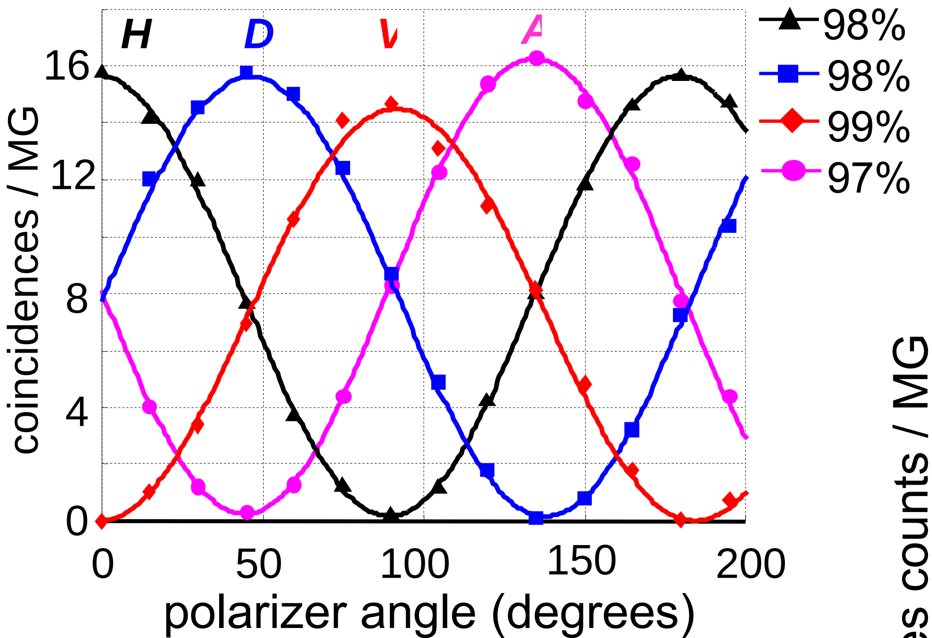
Note: All values are dark count subtracted



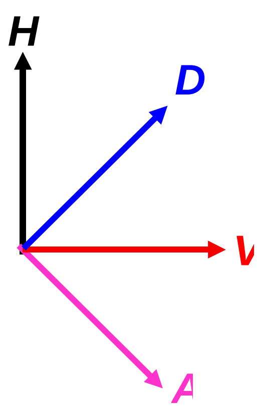


Full TPI Measurements in Multiple Bases

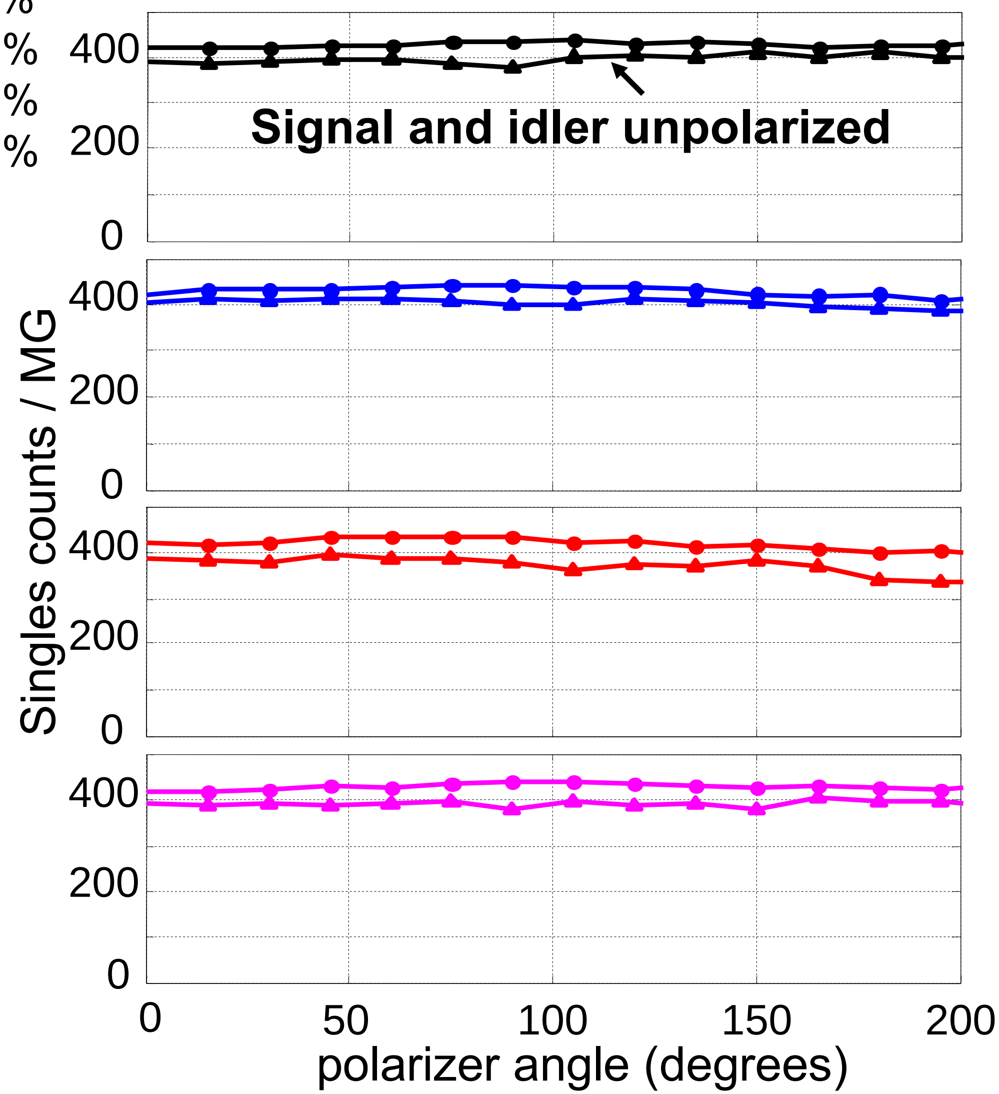
TPI at 4 different bases, –196˚C



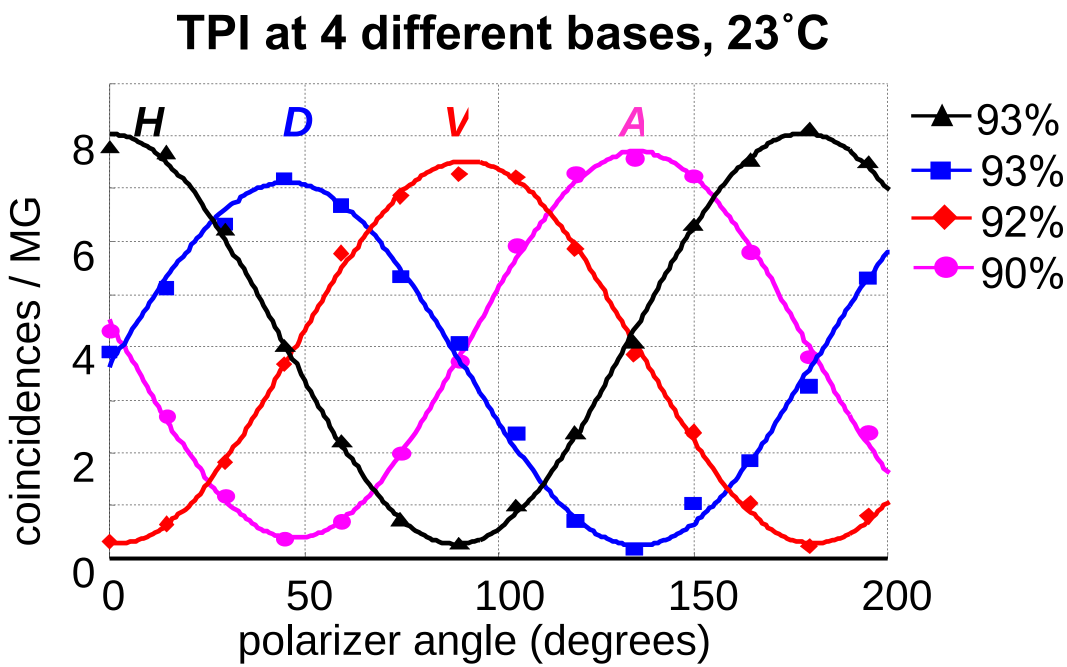
Fixed Polarizer Position



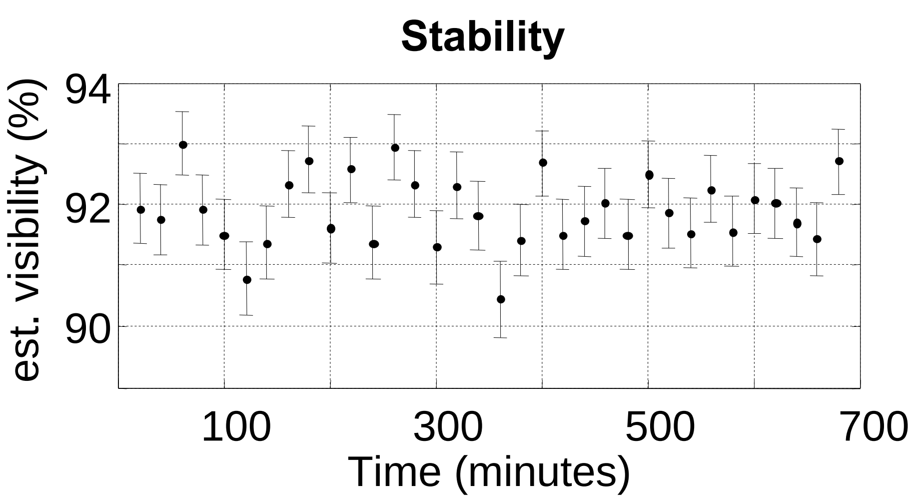
Singles Counts



Room Temperature and Stability Data

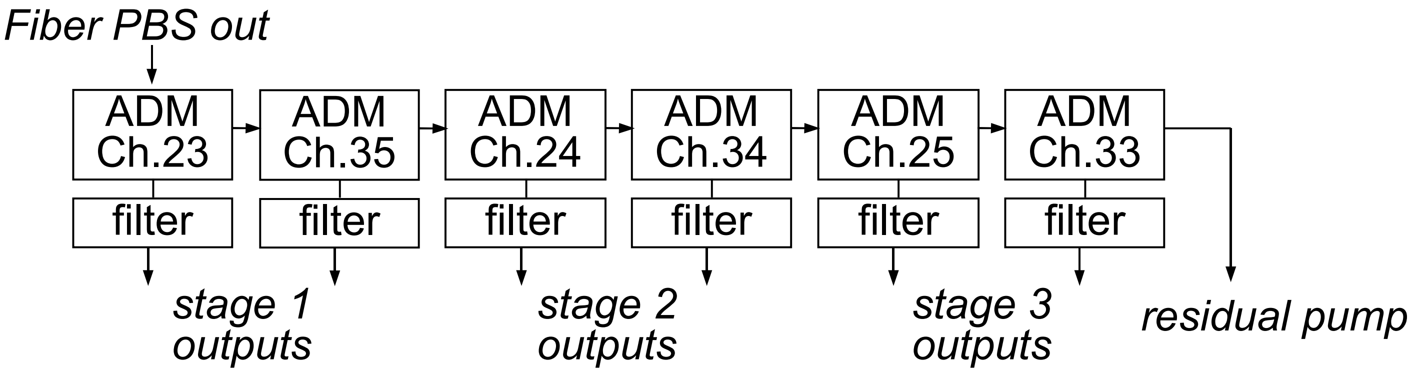


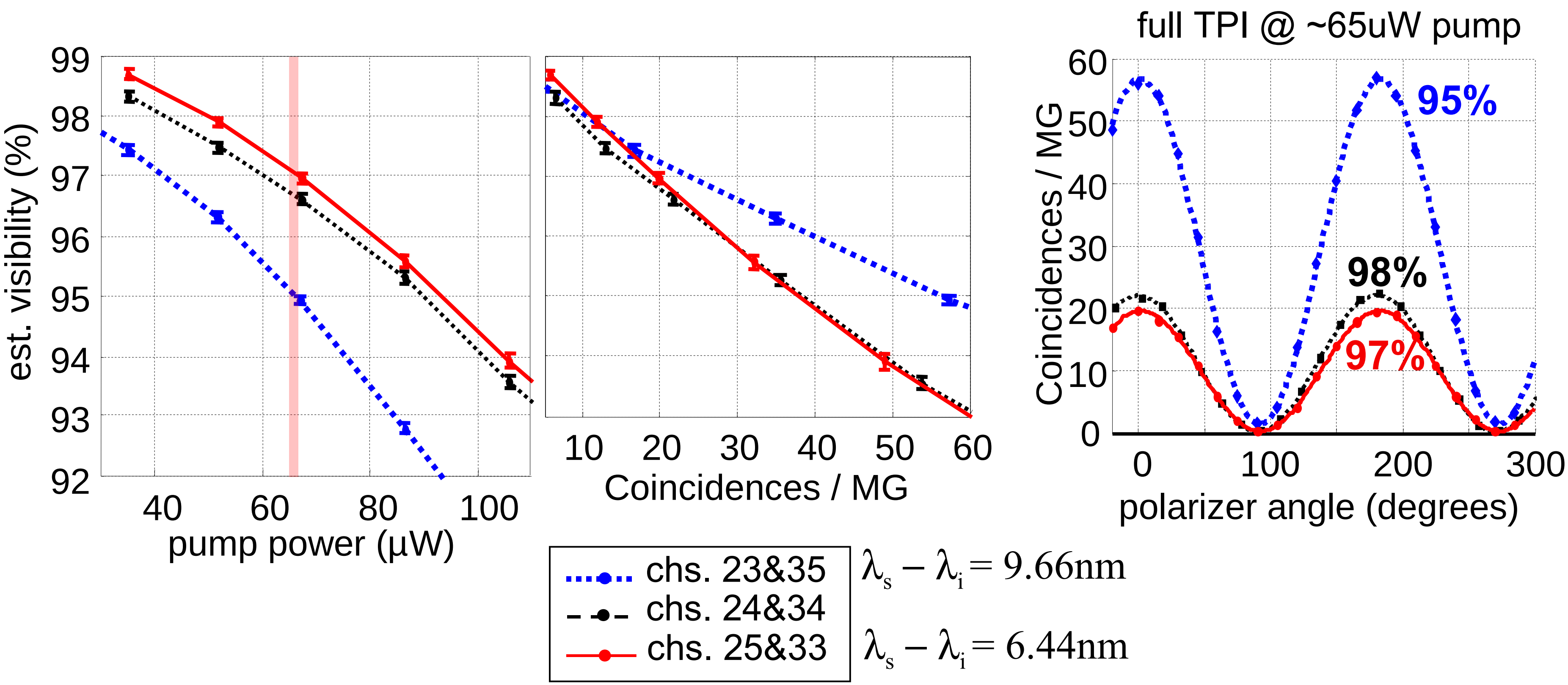
- **Performance still good**
  - **- TPI > 0.71 indicates violation of Bell's inequalities (nonclassical statistics)**



- **Sit at fringe minimum with no adjustments to source**
- **Very stable output**

Multi-Channel Experiment





$\lambda_s - \lambda_i = 9.66\text{nm}$

$\lambda_s - \lambda_i = 6.44\text{nm}$

Summary

- Entangled photon pairs generated directly in fiber in three channel-pairs on the ITU grid
- Systematic, automatable scheme for aligning measurement basis by using built-in alignment signal
- Source constructed entirely of commercially available fiber coupled components
- Two-photon interference performance comparable to laboratory experiments (92% visibility at room temperature) while being manufacturable, stable, and easy to use