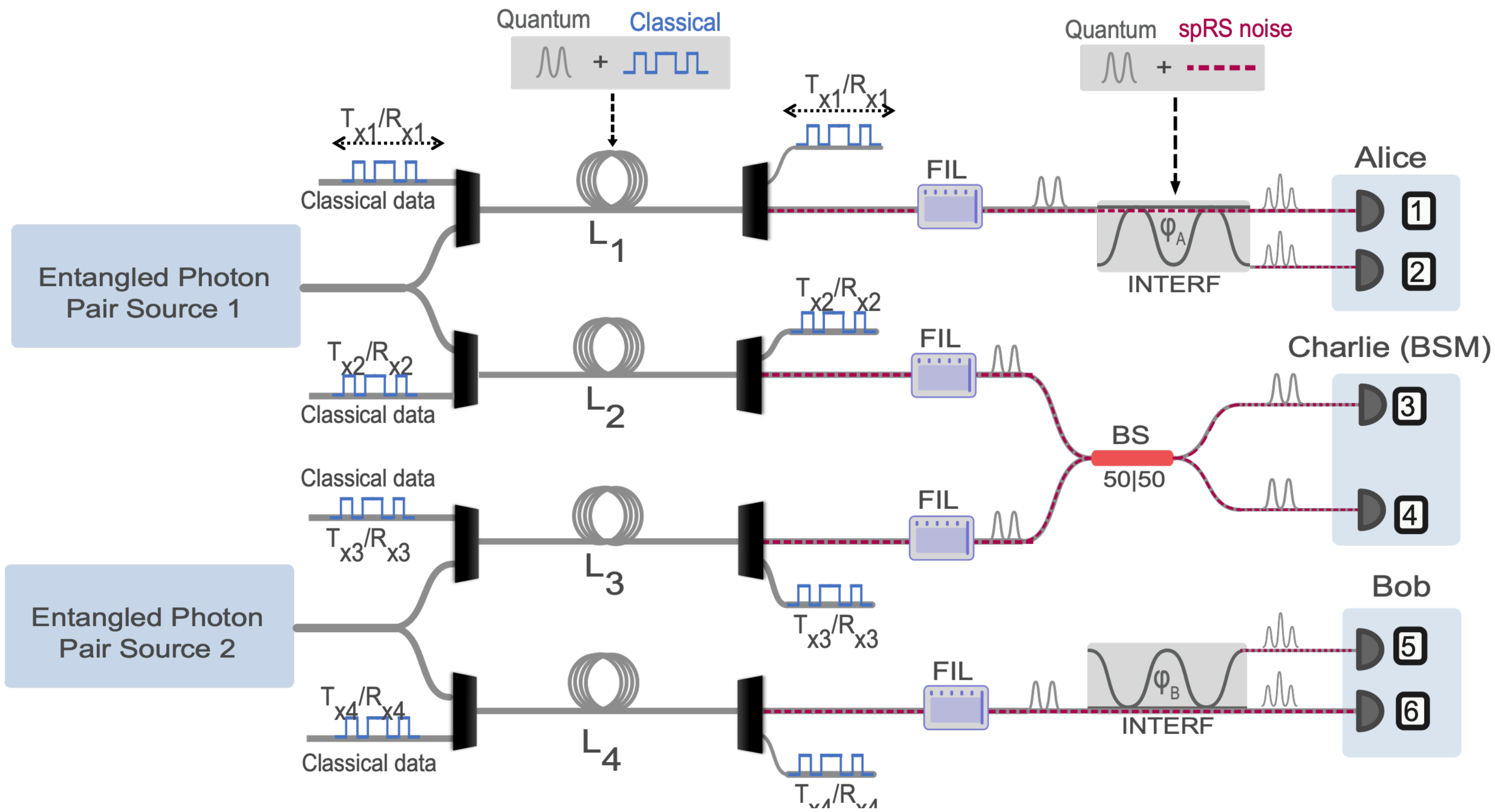
Swapping Quantum-Classical Coexistence Experiments at Fermi

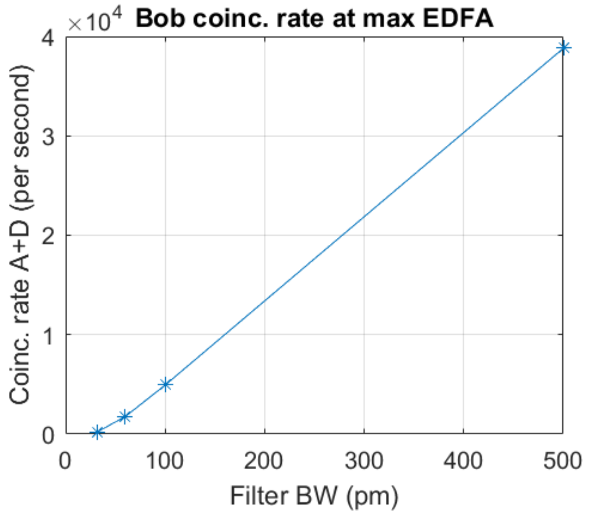


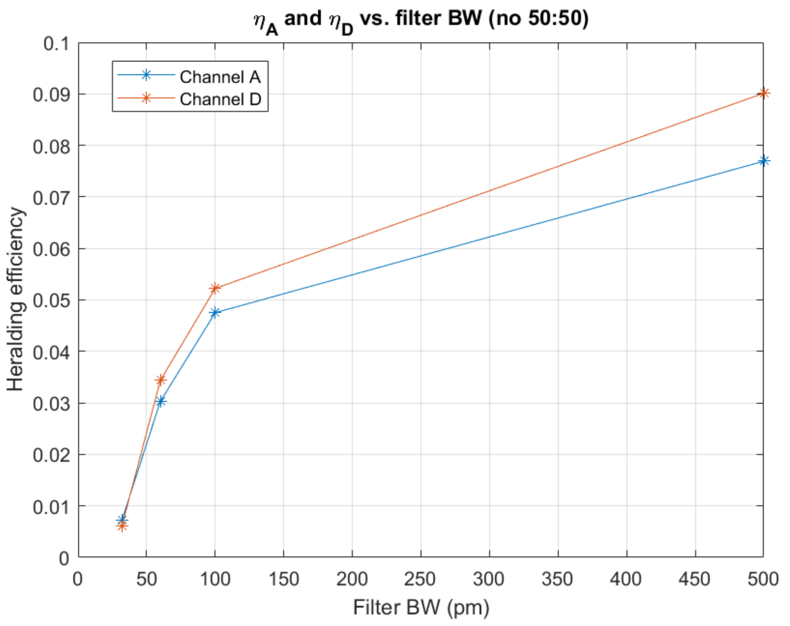
Characterization of current system

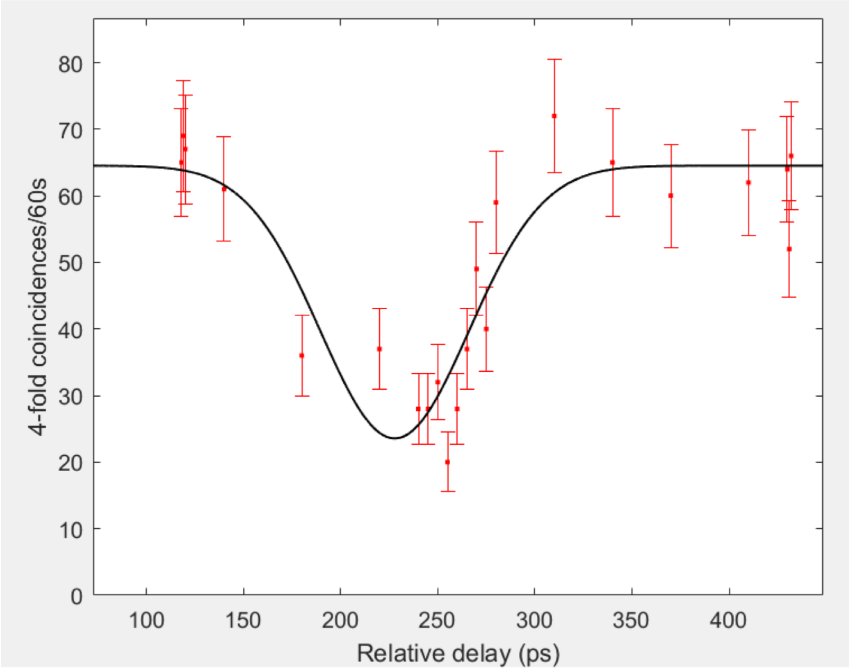
1. Spent first few weeks trying to re-create Caltech’s old results when they worked with this system
   → A lot of debugging various things at first
   → have characterized heralding efficiencies, entanglement visibility, HOM interference

HOM dip → Visibility ~ 65 +/- 5%

Caltech was able to get ~90%, so we are still investigating more optimization







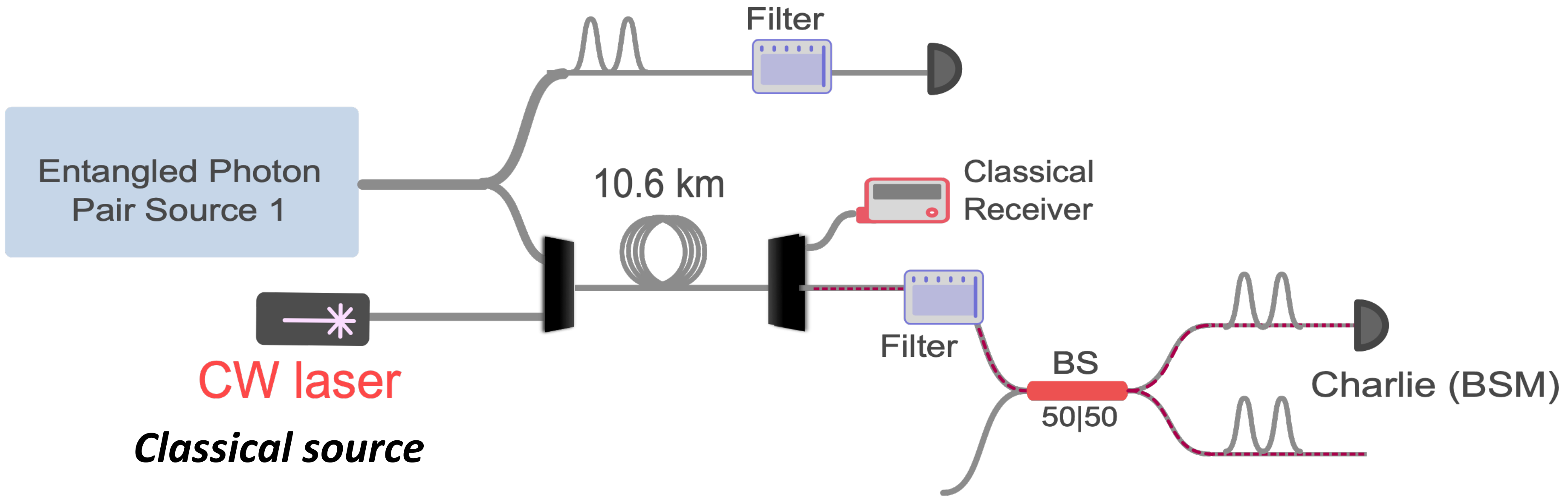
Experiments over 10 km of fiber

We are beginning to do some coexistence experiments over ~10 km of spooled fiber

Step 1: entanglement distribution to the BSM node over 10.6 km fiber

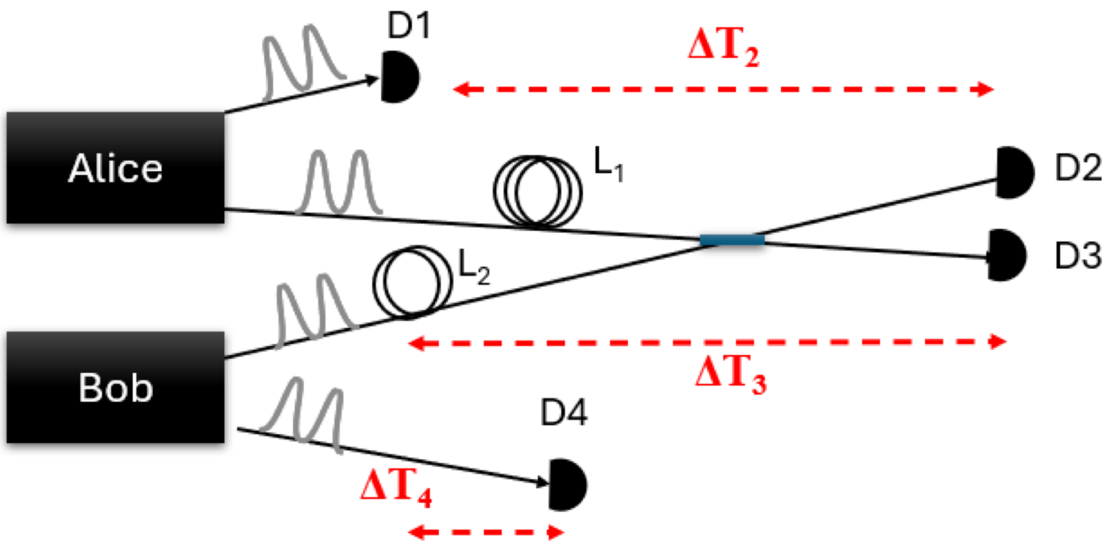
Study the parameters in which Caltech was able to achieve good swapping fidelity to predict how noise may impact system

- → filter bandwidth for indistinguishability, mean photon pair numbers for multi-photon effects, …, as a function of classical power levels and classical source wavelength

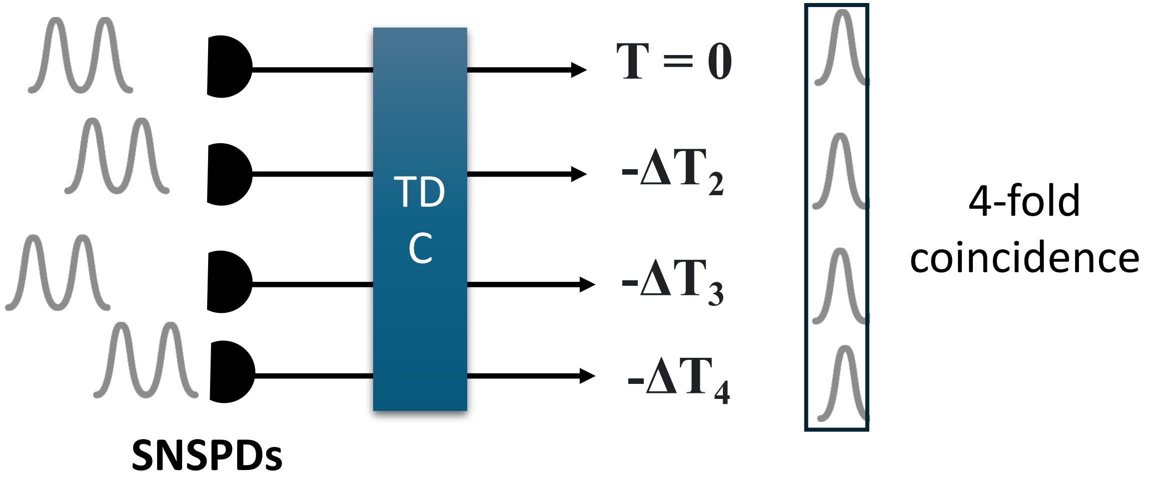


Coincidence detection with long time delays

1. To perform coincidence detection over longer fibers and large time delays between each photon,
   → need to allow the time-tags of the photons to have large delays to match up coincidences with correct time slot
2. Previous data collection only allowed small delays using hardware delay of time-tagger
   → **We have implemented software delay feature of Swabbian time-tagger to allow for delaying each channel by arbitrary amounts**
   → **previously limited to ~nanosecond delays → now allow arbitrary delay (currently doing ~51 μs)**
   → added into GUI data collection system



Record multi-photon coincidences with software delay of time-tags

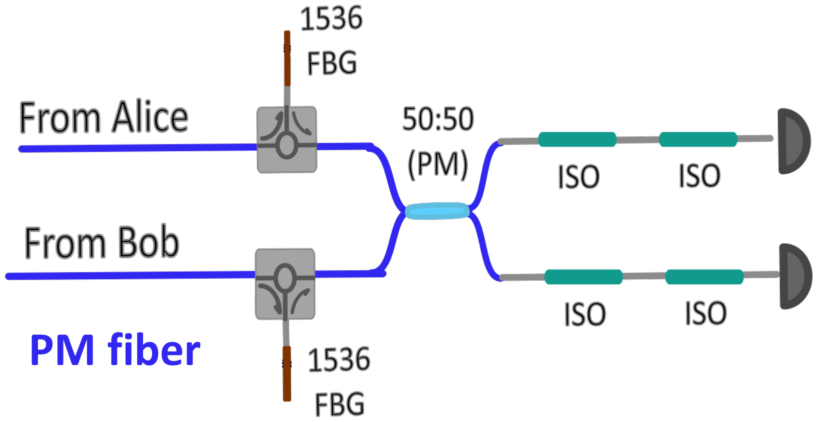


Modified Bell state analyzer for 10-km and coexistence

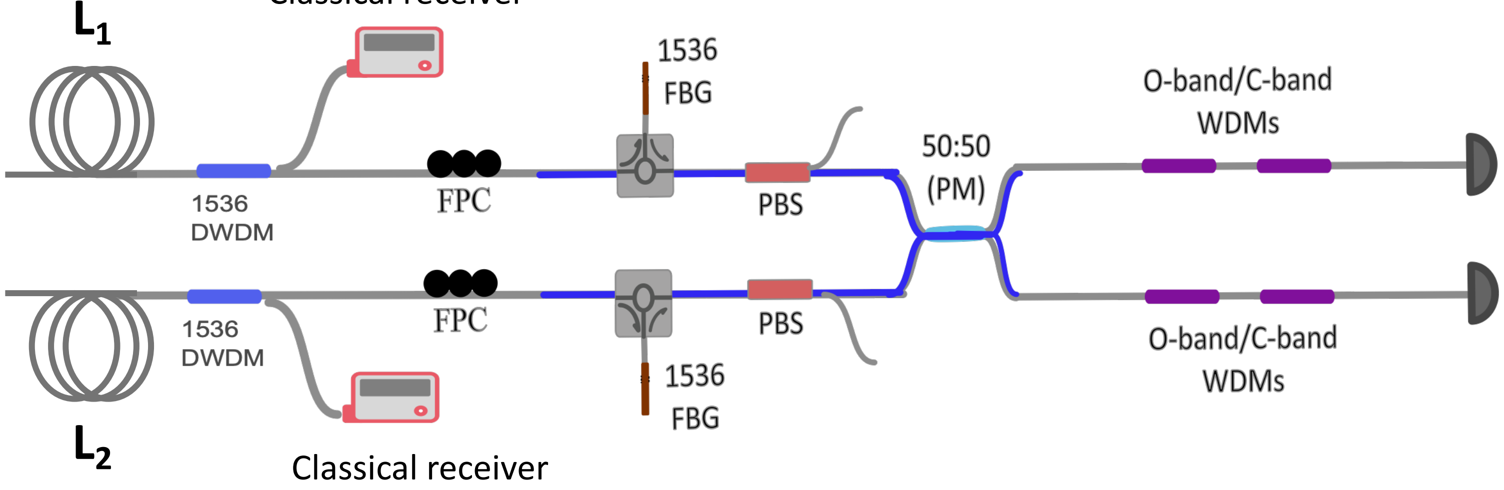
1. **Allowing coexistence with WDMs**
   i. Added in WDMs to de-multiplex classical light and also provide high isolation of the classical light

2. **Polarization control:**
   i. Previous system had polarization maintaining fiber throughout entire system
      → Not compatible with long distance non-PM fiber links
   ii. Added in a FPC+PBS combination before a PM 50:50 splitter
      → guarantees polarization indistinguishability, polarization rotations should only impact rates (not fidelity)

Old setup (PM fiber from source to BSM)



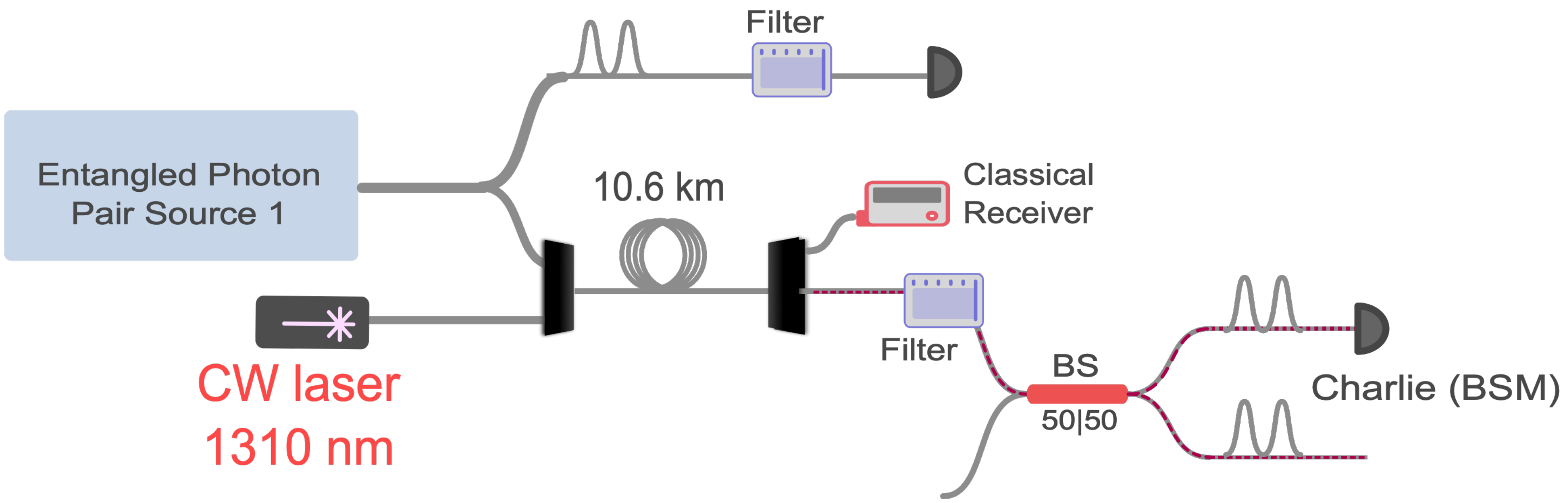
New BSM setup



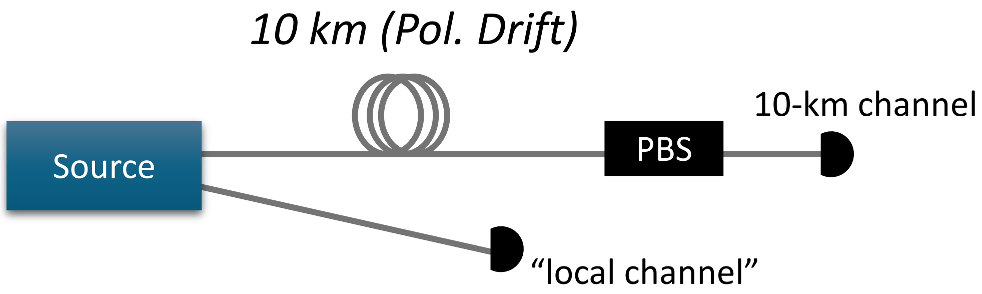
Entanglement Distribution with Coexistence

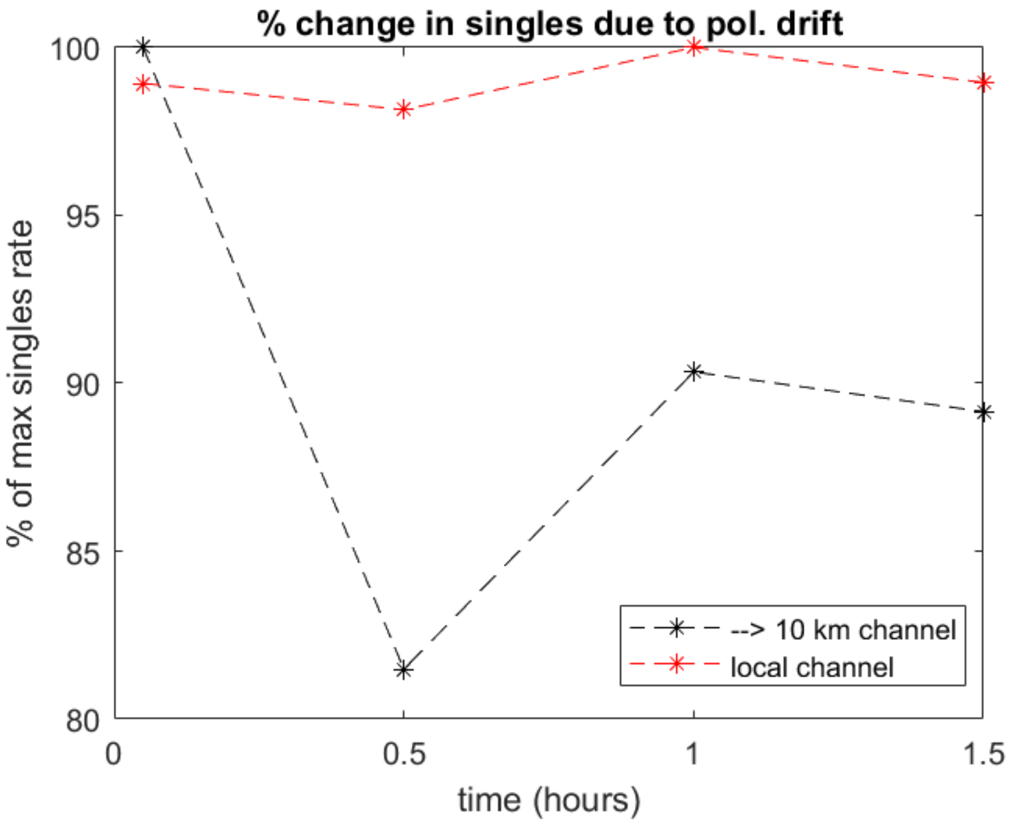
<u>First coexistence experiment:</u>

- Test impact of coexisting 1310-nm classical light on entanglement distribution to BSM
- Investigate different filter bandwidths and mean photon pair numbers as a function of 1310-nm classical power levels



Polarization drift induced intensity changes

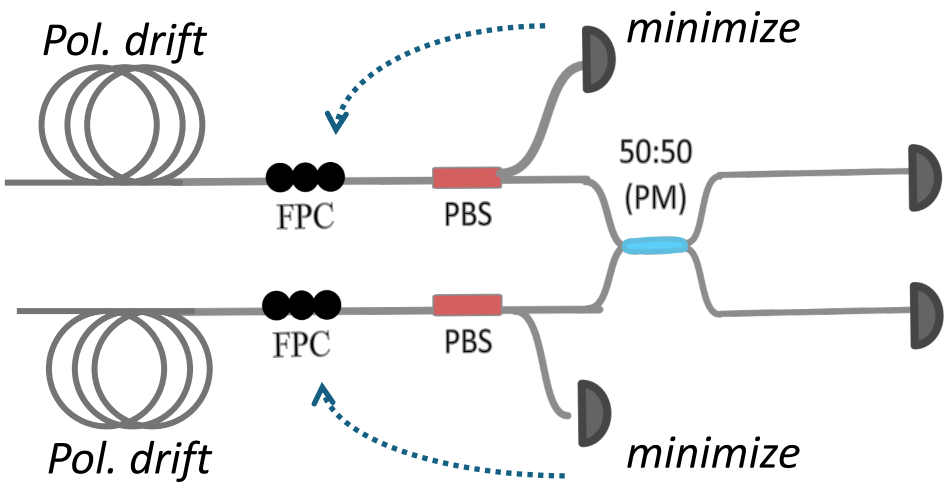




Saw about 20% variation in singles rates in first experiments due to polarization drift over time (~1.5 hours)

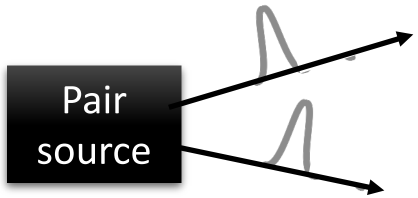
Short term solution = tape all fiber down more, should be okay for initial experiments

Long-term solution = monitor other PBS port as feedback to electronic FPCs to keep singles counts minimized (i.e. maximizing rates in other port)



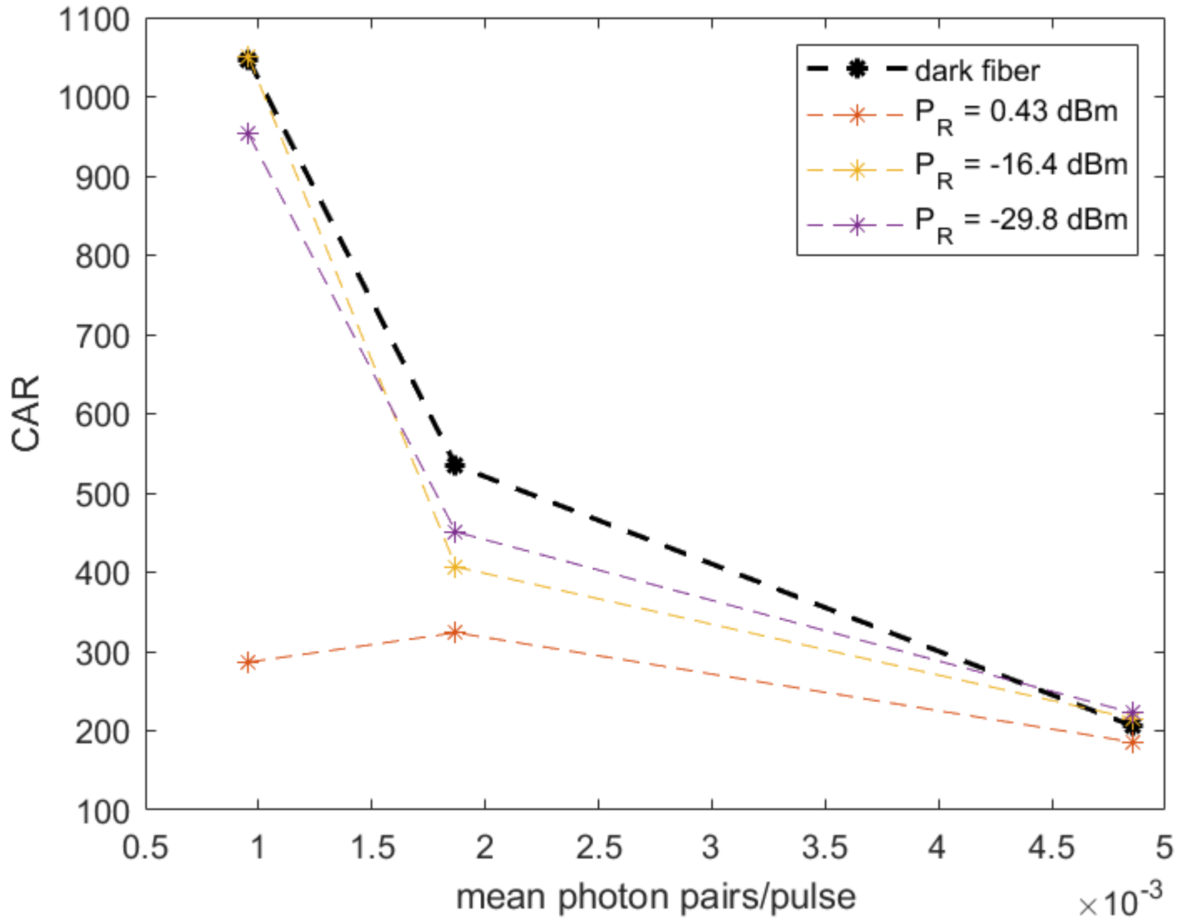
Varying mean photon pairs/pulse with different classical power levels

- First measured coincidence to accidental ratio for photon pair source (not time-bin) as a function of mean photon pair/pulse at different received 1310-nm power levels
- Filter BW = 100 pm



CAR = CC/AC

CC = coincidences in matched time slot
AC = accidental coincidences between un-matched time slots

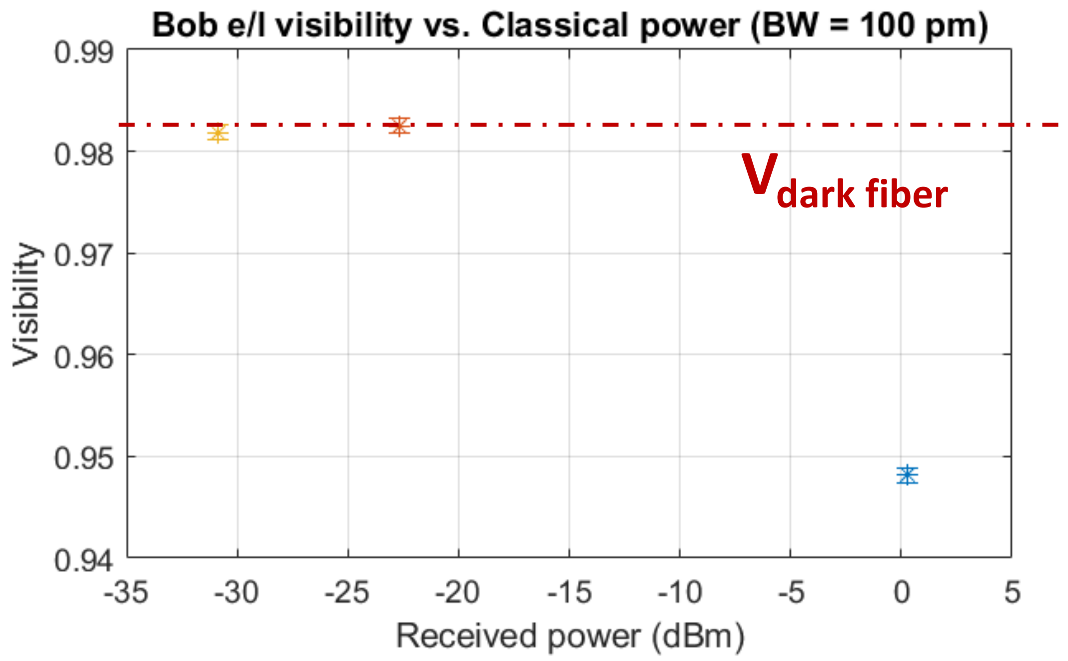


- Most of our classical systems can operate with < -20 dBm received power.
- **CAR not impacted significantly at minimum necessary 1310-nm classical powers**

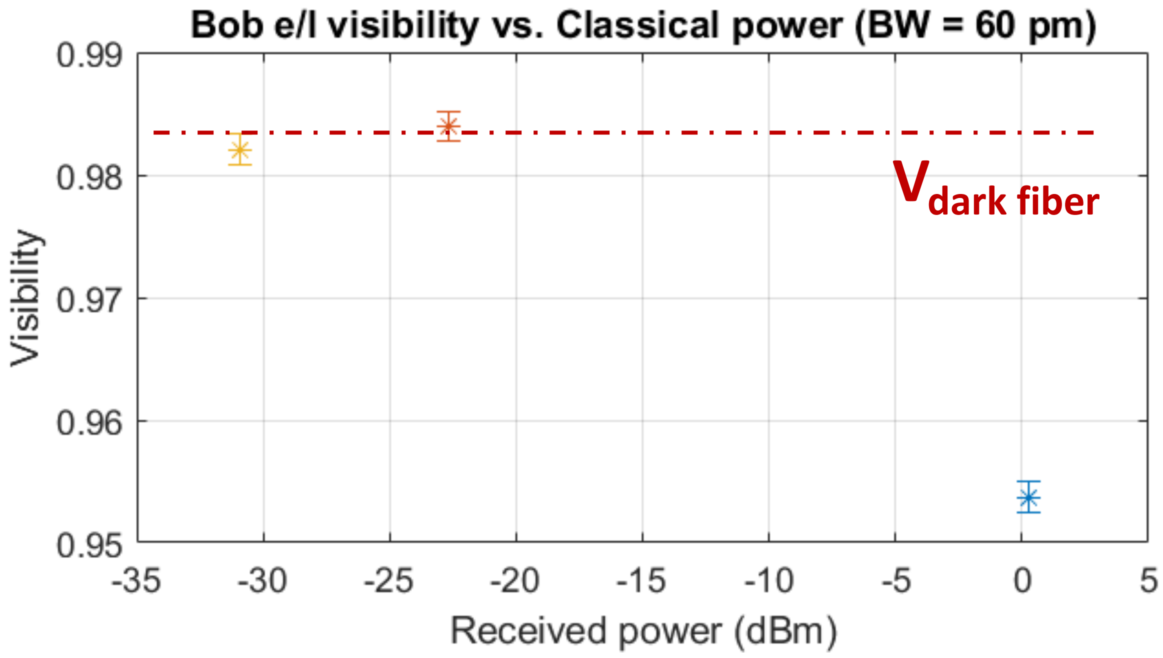
Entanglement Visibility vs. 1310-nm power

- Switched to double pulse, measured Z-basis visibility for two different filter bandwidths (100 pm and 60 pm)

μ ≈ 0.01 pairs/pulse



μ ≈ 0.008 pairs/pulse



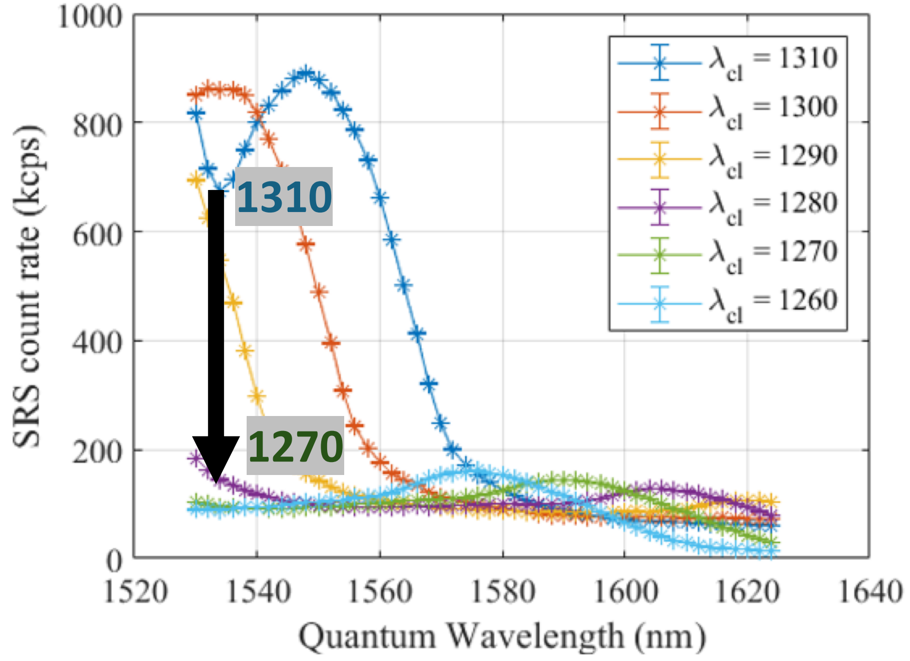
- **Based on this, we are confident that we should be able to perform swapping with coexistence without a large hit on fidelity if we use an optimized system**

Next steps: New classical sources

Want to investigate various possible coexistence sources

- Beginning with 1310-nm laser that was used in previous time sync experiments
- Bought 1270-nm SFPs capable of 10 Gbps classical data
- Should have lower Raman noise compared to 1310 nm
- Will eventually implement 10 Gbps classical channels alongside swapping signals

Quantum signal = 1536 nm



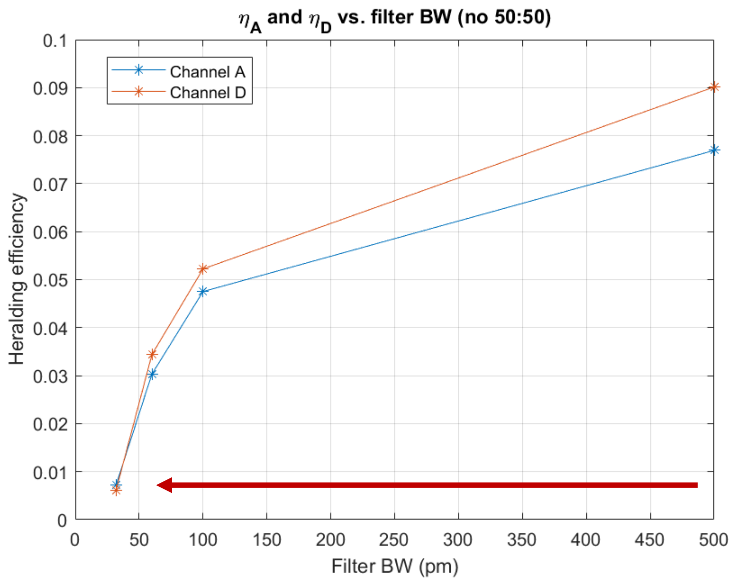
Cisco SFP-10G-BX60U Compatible SFP+ 10GBASE-BX60-U BiDi 1270nm-TX/1330nm-RX 60km DOM Simplex LC/UPC SMF Optical Transceiver Module #124447

TX Power
1~6dBm

Receiver Sensitivity
<-20dBm

Next steps: move towards swapping over 20 km

- Go back to see if we can optimize HOM interference visibility
- Try swapping in e/l basis with coexistence over 10 km+10 km, should be easier to manage
- Investigate how including the 10-km may impact arrival time at the BSM node
- Explore options in how to increase rates via getting lower loss FBGs?
  - *Note: time-bin entanglement distribution coexistence has not been studied yet*



>10 times lower heralding eff. at 32 pm BW
→10,000 lower 4-fold rates