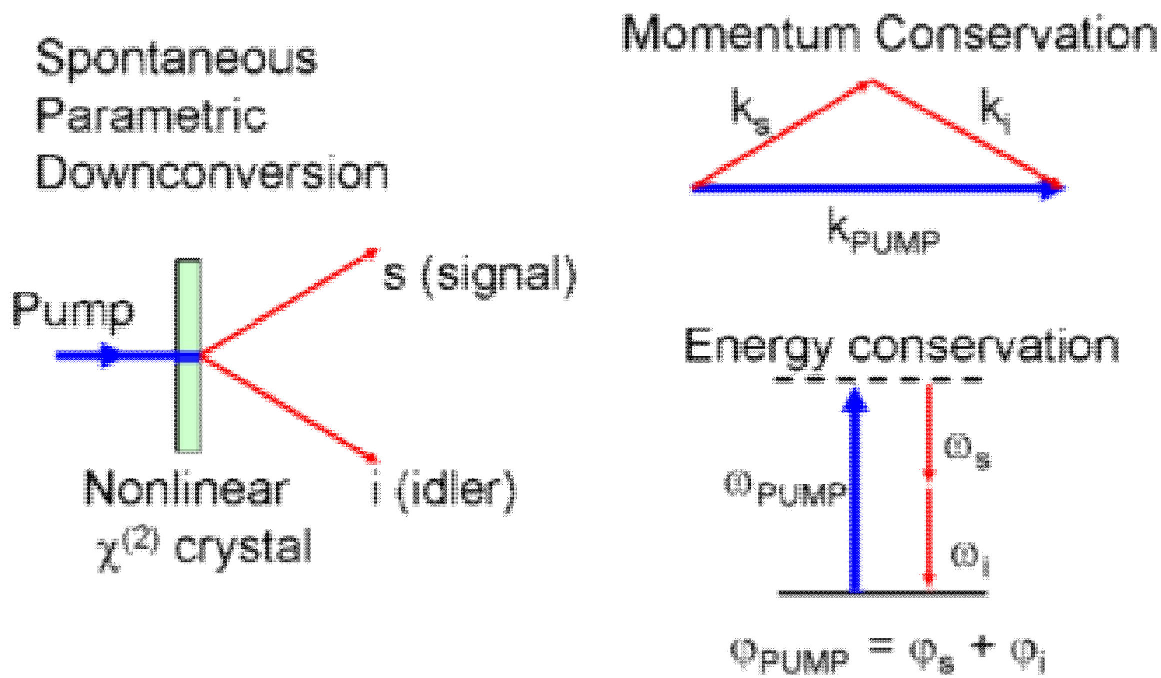
Spontaneous Parametric Down Conversion

Sean Gallivan & Kerry Olivier

General Overview



Conservation of Energy: $\omega_{pump} = \omega_A + \omega_B$

Conservation of Momentum: $k_{pump} = k_A + k_B$

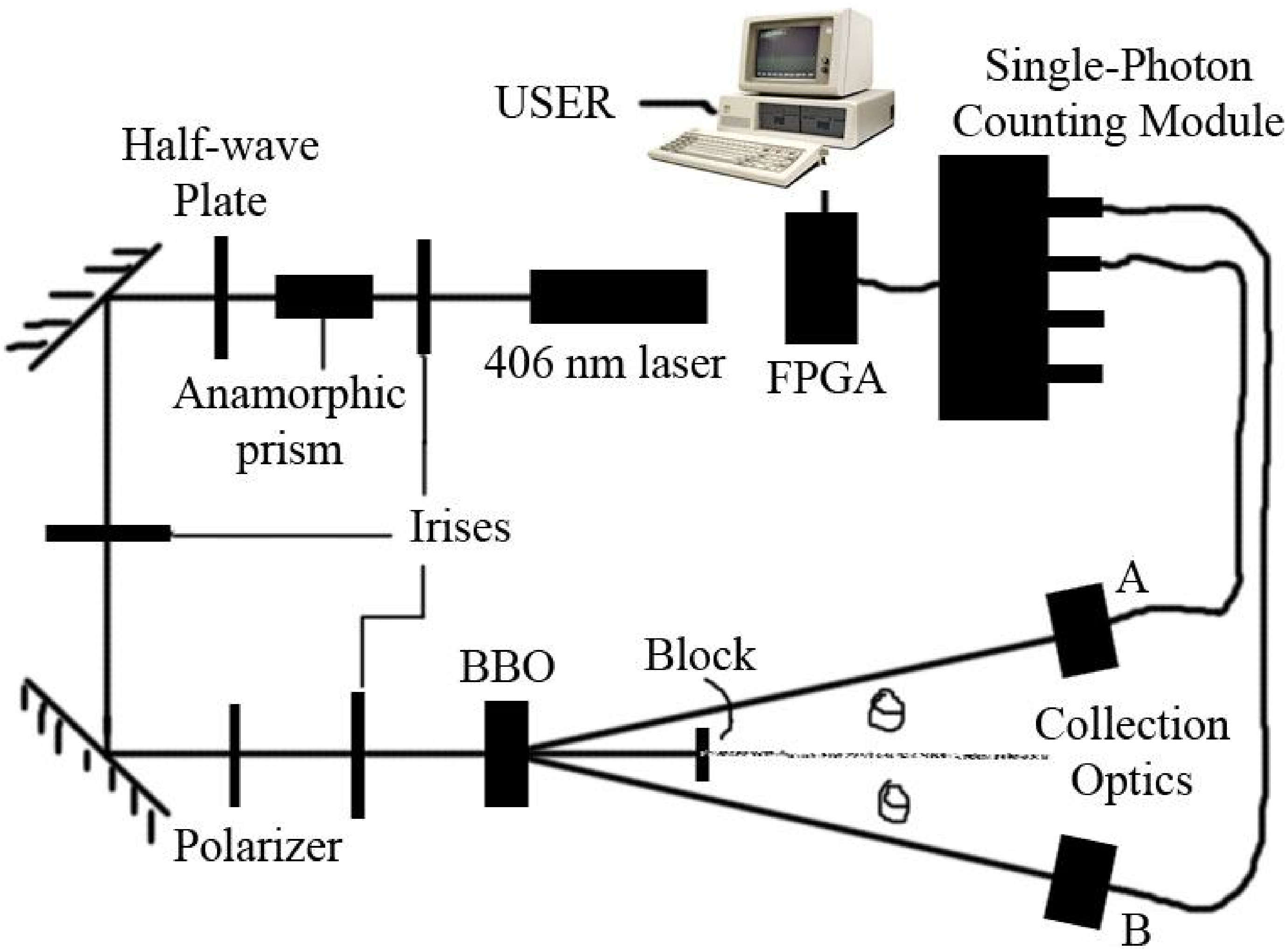
Why is it called SPDC?

- Spontaneous: Generated by quantum vacuum fields
- Parametric: Phase relationship between input and output fields
- Down Conversion: Signal & Idler frequencies are lower than pump

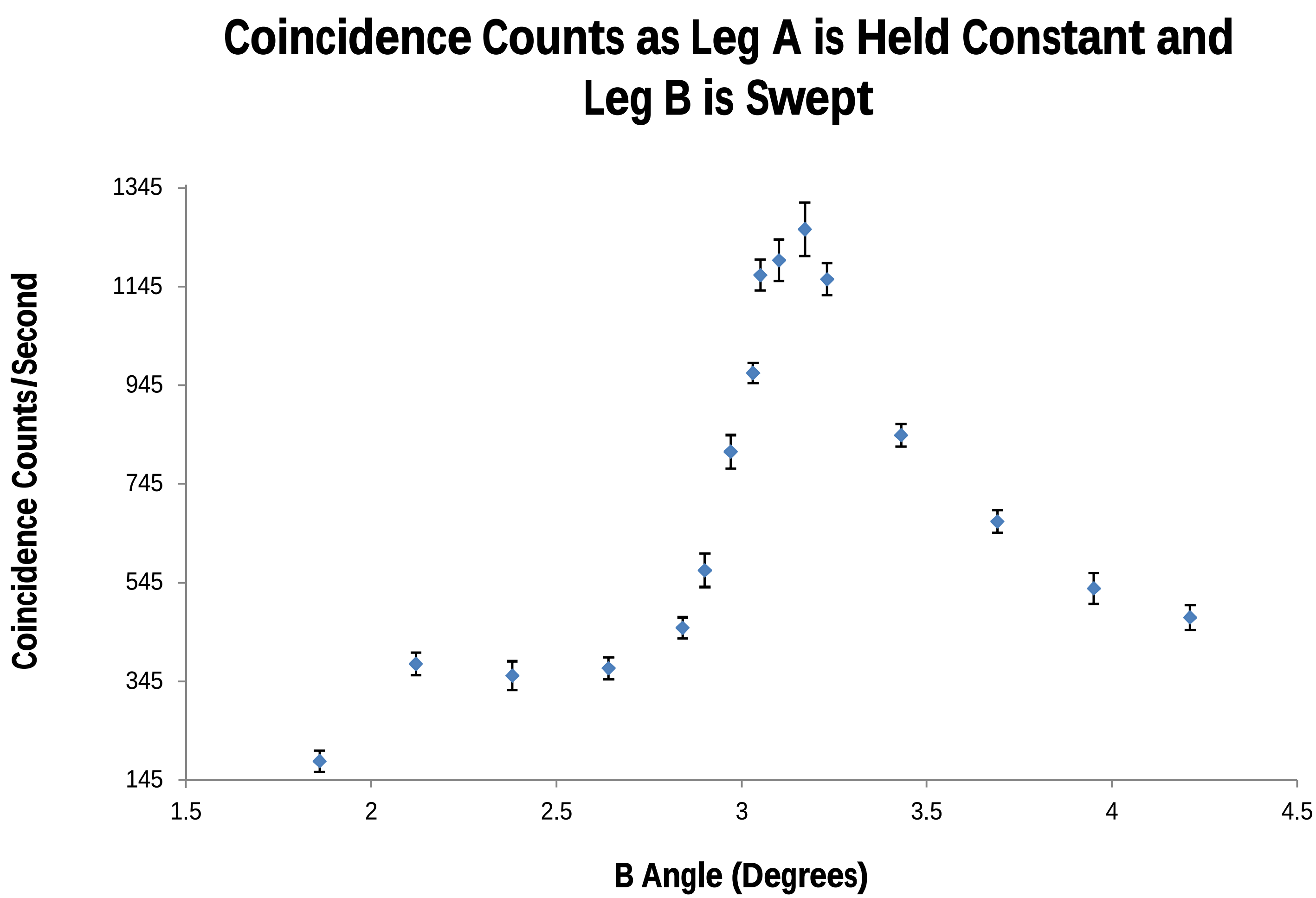
Why Should I Care?

- Production of single photons
- Photon entanglement is ripe for quantum information experiments
- It's cool!

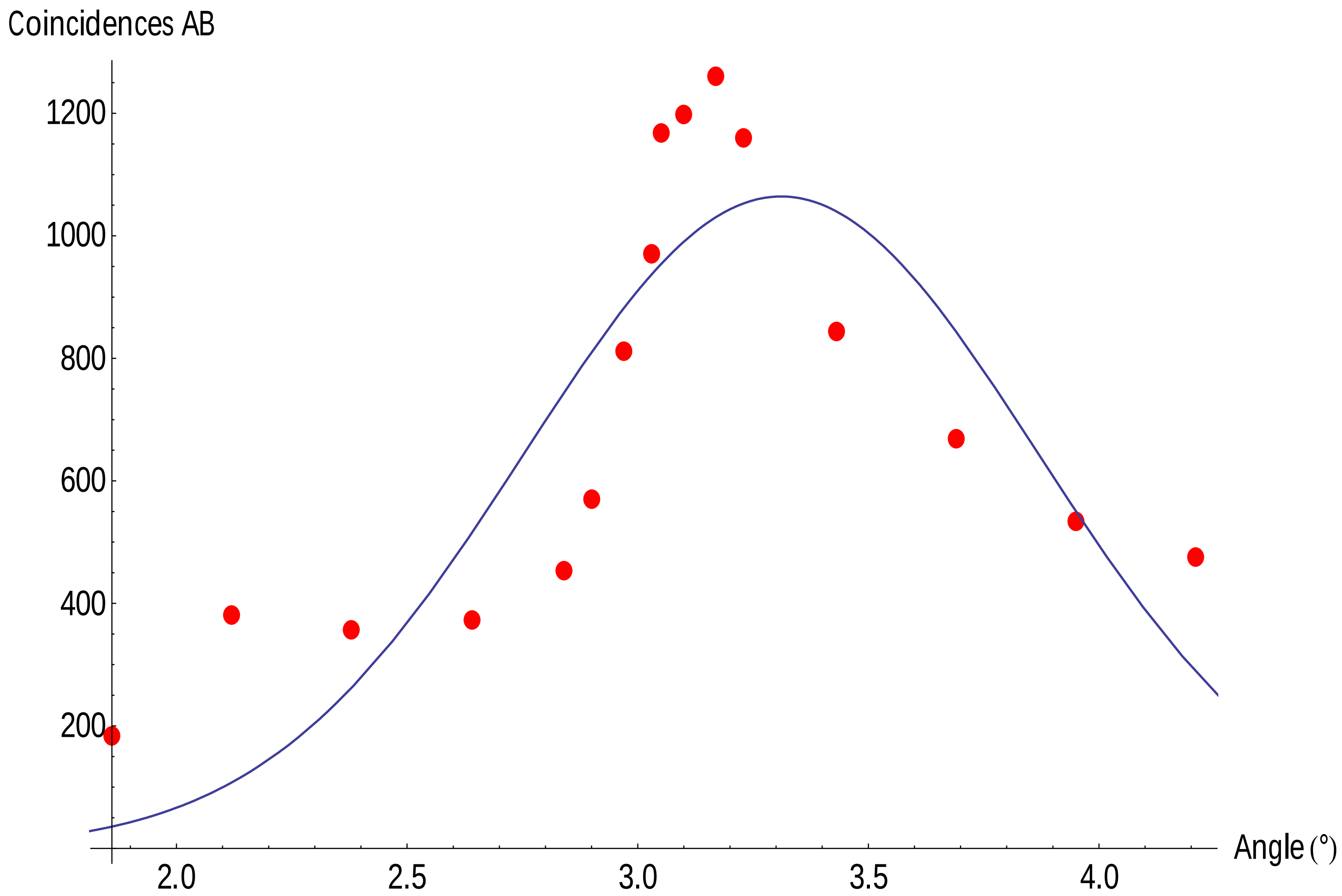
Lab Setup to Investigate SPDC



Results of SPDC Investigation

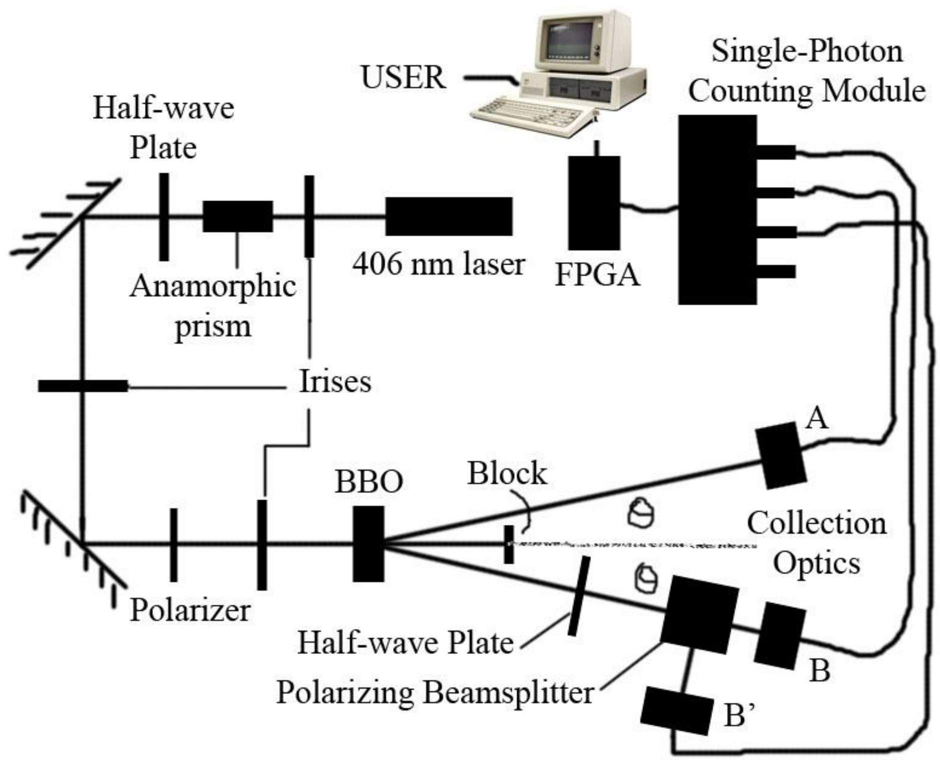


Gaussian Fit of Data



Measurement of $g^2(0)$

- Classical system: $g^2_{B,B'}(\tau) = \frac{\langle I_B(t+\tau) I_{B'}(t)\rangle}{\langle I_B(t+\tau)\rangle\langle I_{B'}(t)\rangle}$
- $g^2(0) \geq 1$ for classical fields
- $g^2(0) < 1$ for quantum fields, for single photons $g^2 = 0$



$g^2(0)$ Results

- Best measurement: $g^2(0)$ = .713

  Standard Deviation = .0123

  >23 Standard Dev.'s below 1

  (10 measurements, 10s per measurement)

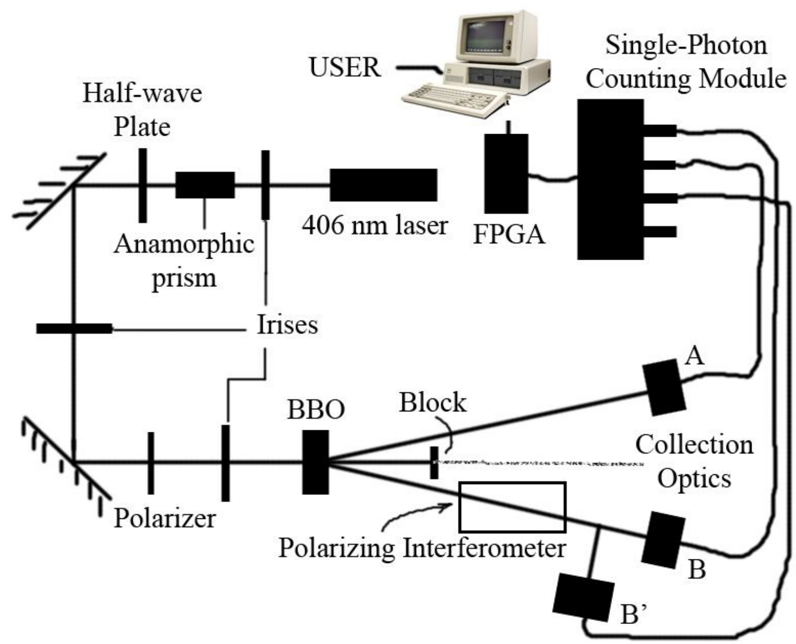
- Worst measurement: $g^2(0)$ = .702

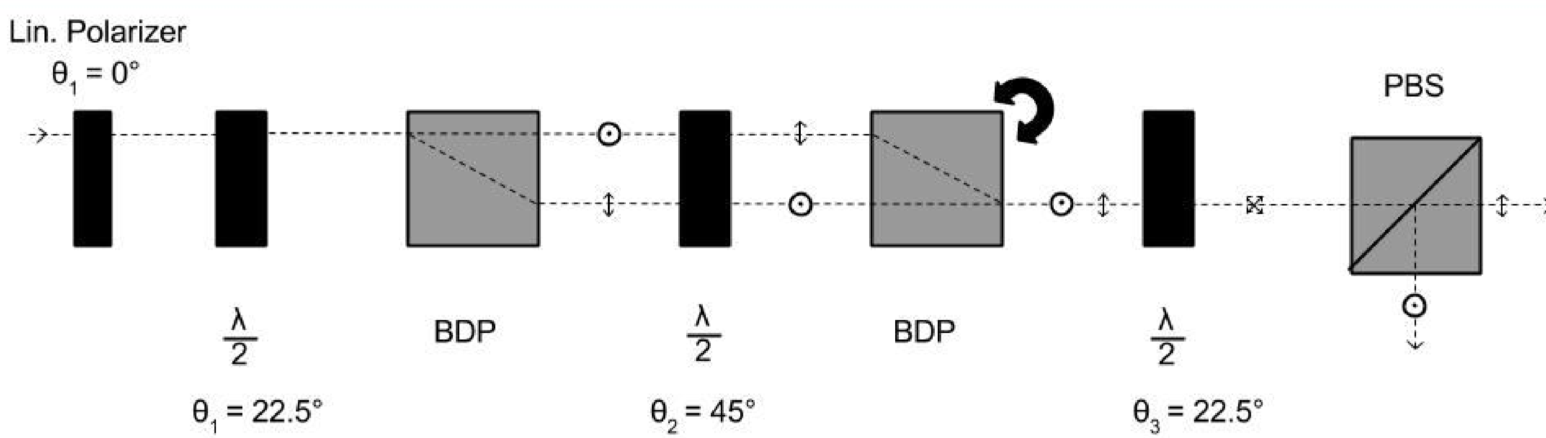
  Standard Deviation = .052402

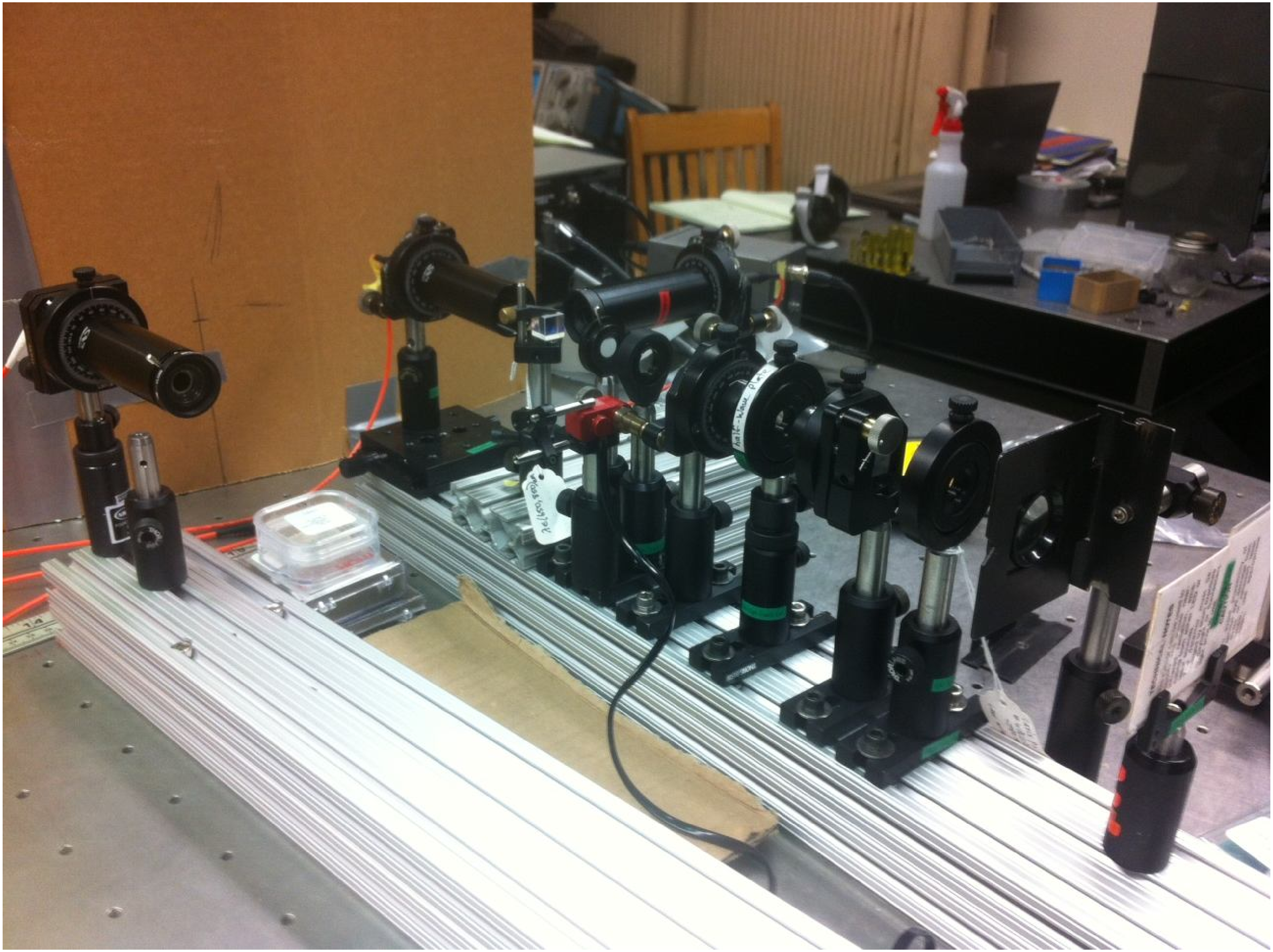
  >5 Standard Dev.'s Below 1

  (10 measurements, 1s per measurement)

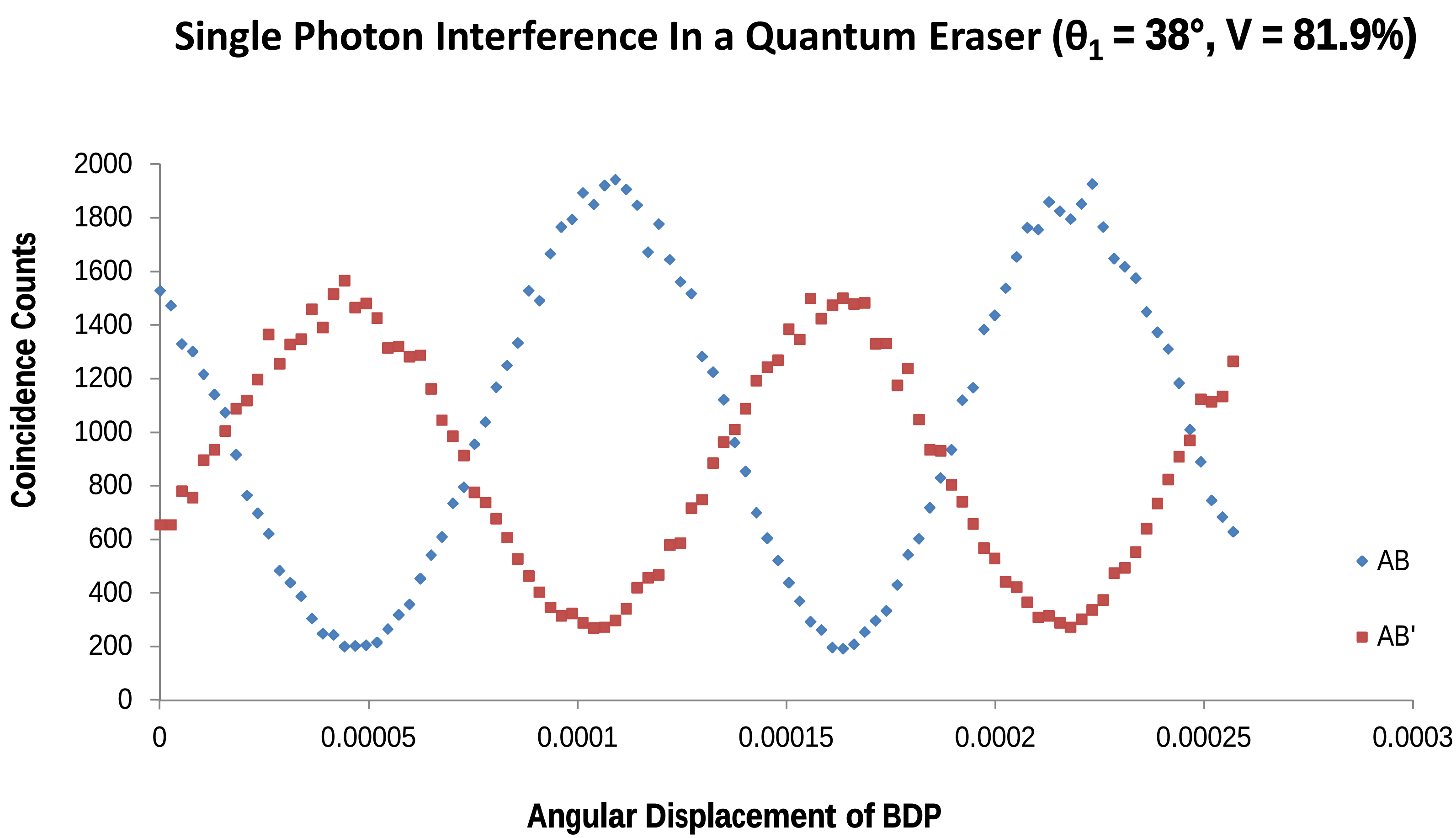
Single Photon Interference







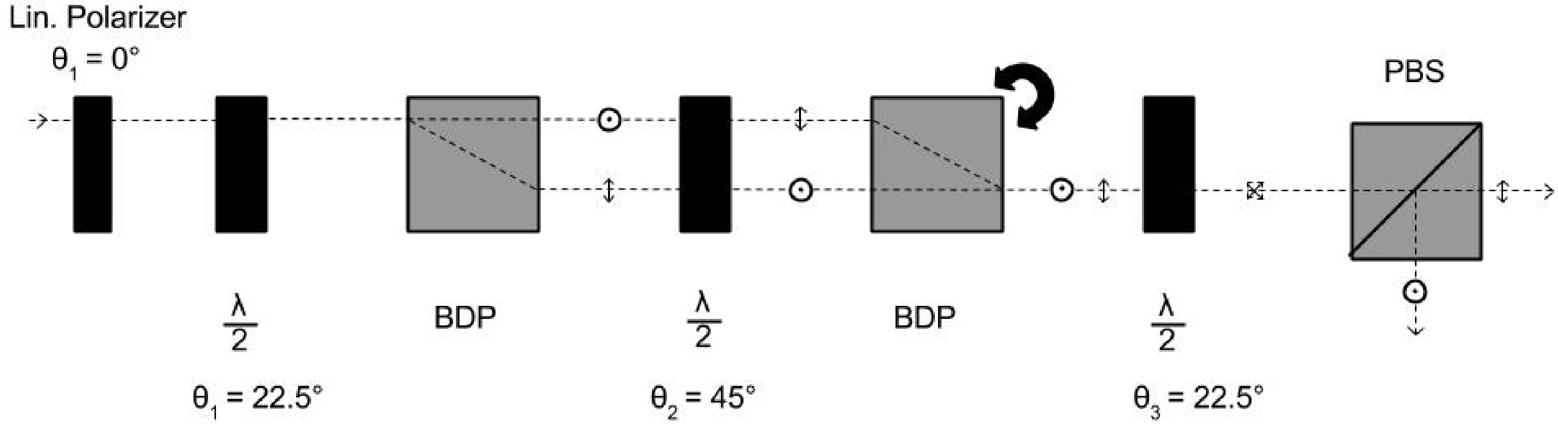
Results of Single Photon Interference



Visibility of Interference Patterns & Quantum Erasers

$$Visibility = \frac{N_{bmax} - N_{bmin}}{N_{bmax} + N_{bmin}}$$

- $\theta_1 = 38°$, Visibility = 81.9%, Expected g2 = .24 (SD = .42)
- $\theta_1 = 10°$, Visibility = 30.2%, Expected g2 = .24 (SD = .36)
- $\theta_1 = 0°$, Visibility = 31.4%, Expected g2 = .24 (SD = .29)
- $\theta_3 = 0°$, Visibility = 17.5%, Expected g2 = .24 (SD = .16)



Local Realism

- **Locality**: A measurement in one location cannot affect a measurement performed elsewhere
- **Reality**: ‘real’ objects have measurable quantities regardless of if we look at them or not

Bell's Inequality & Testing Local Realism

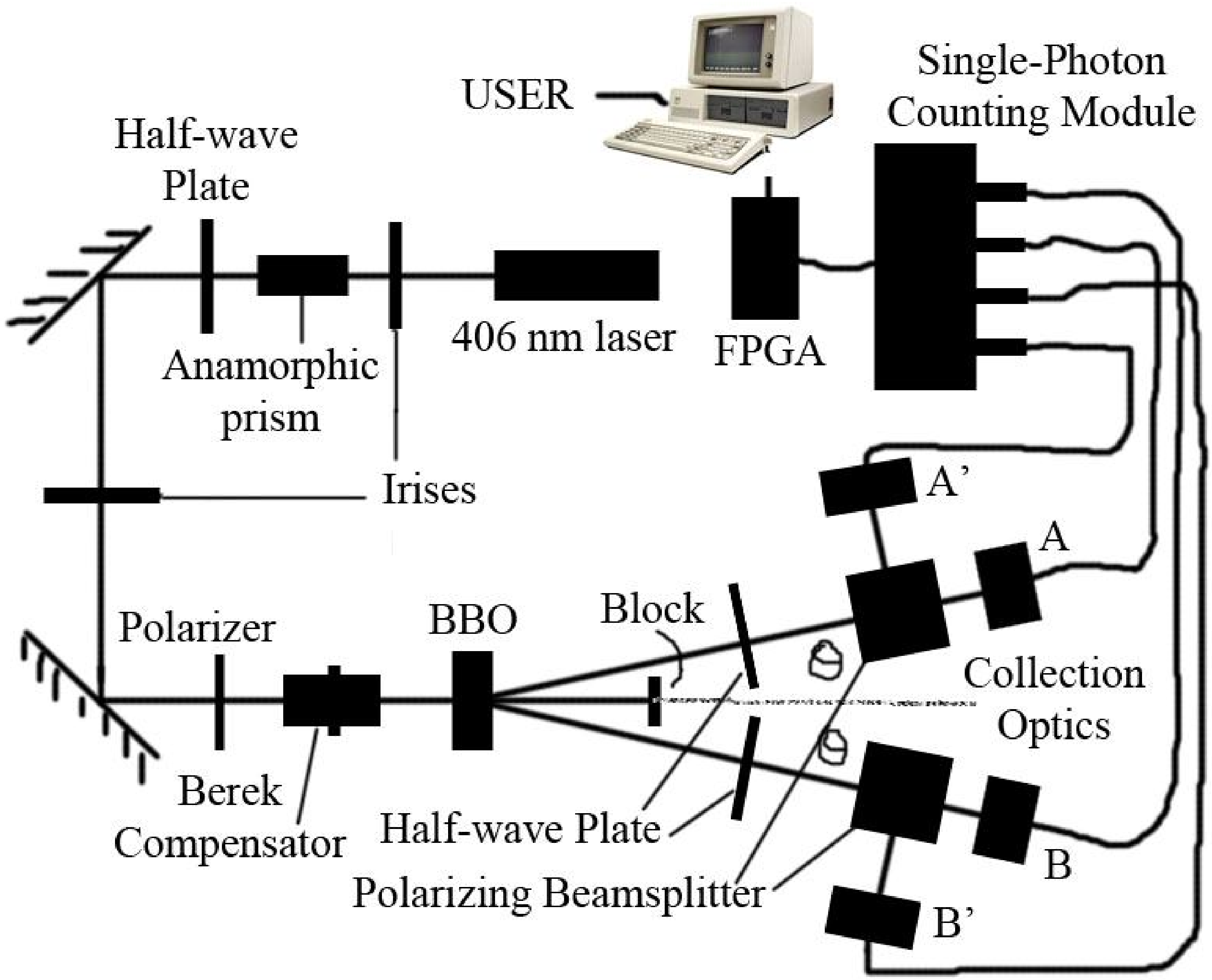
- Joint probability of photons polarized in 2 directions:

$$P(\theta_A, \theta_B) = \frac{N_{AB}}{N_{AB} + N_{AB'} + N_{A'B} + N_{A'B'}}$$

- Bell-Clauser-Horne Inequality:

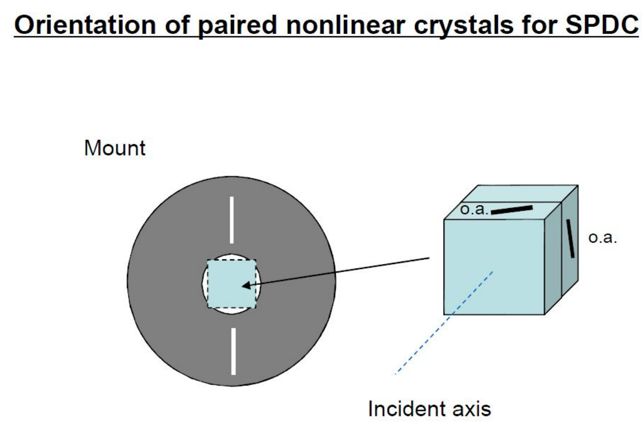
$$P(\theta_{A1}, \theta_{B1}) \le P(\theta_{A2}, \theta_{B2}) + P\left(\theta_{A1}, \theta_{B2}{}^{\perp}\right) + P\left(\theta_{A2}{}^{\perp}, \theta_{B1}\right)$$

Attempted Local Realism Setup



New Equipment for Local Realism

- Paired BBO

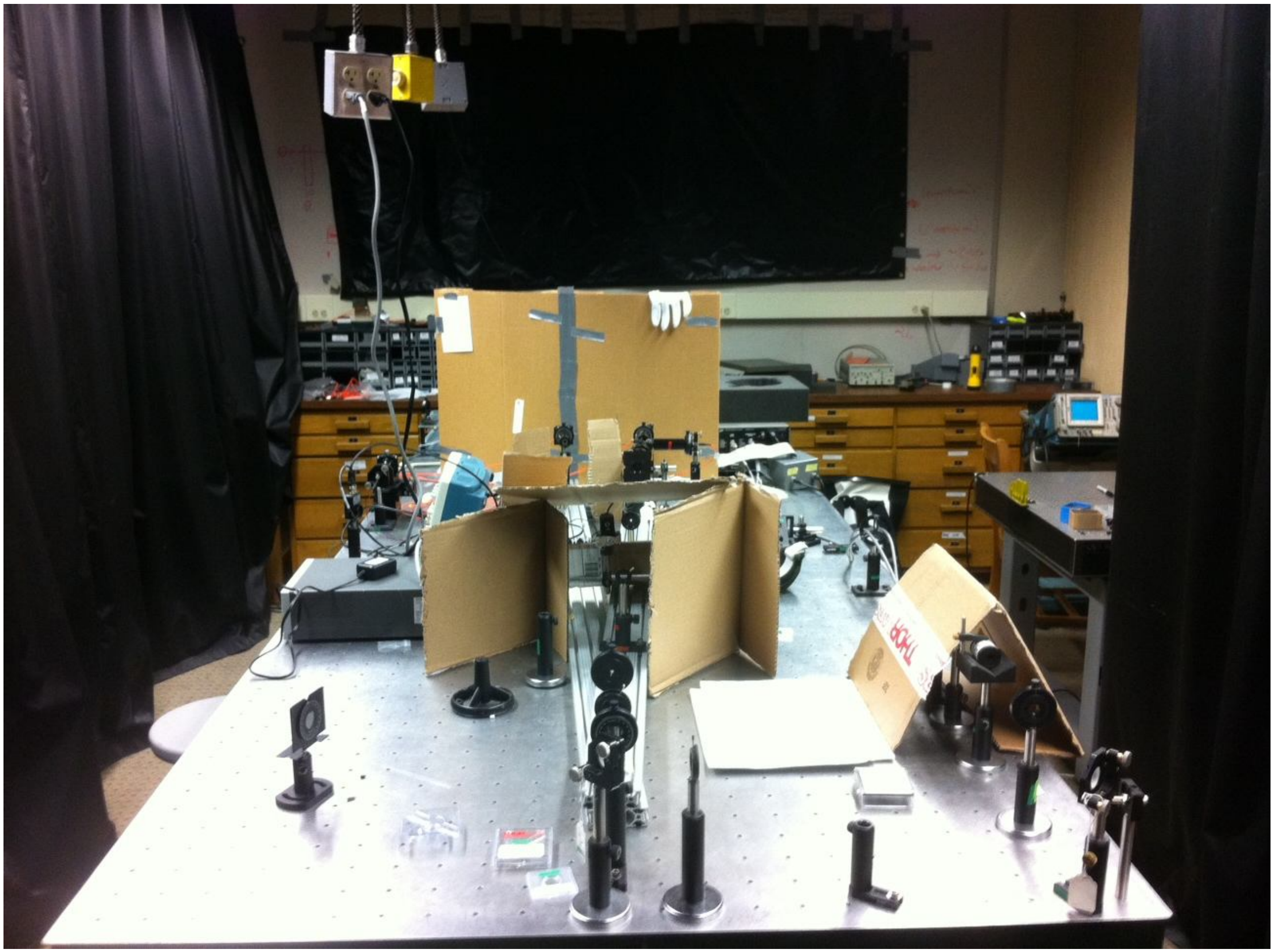


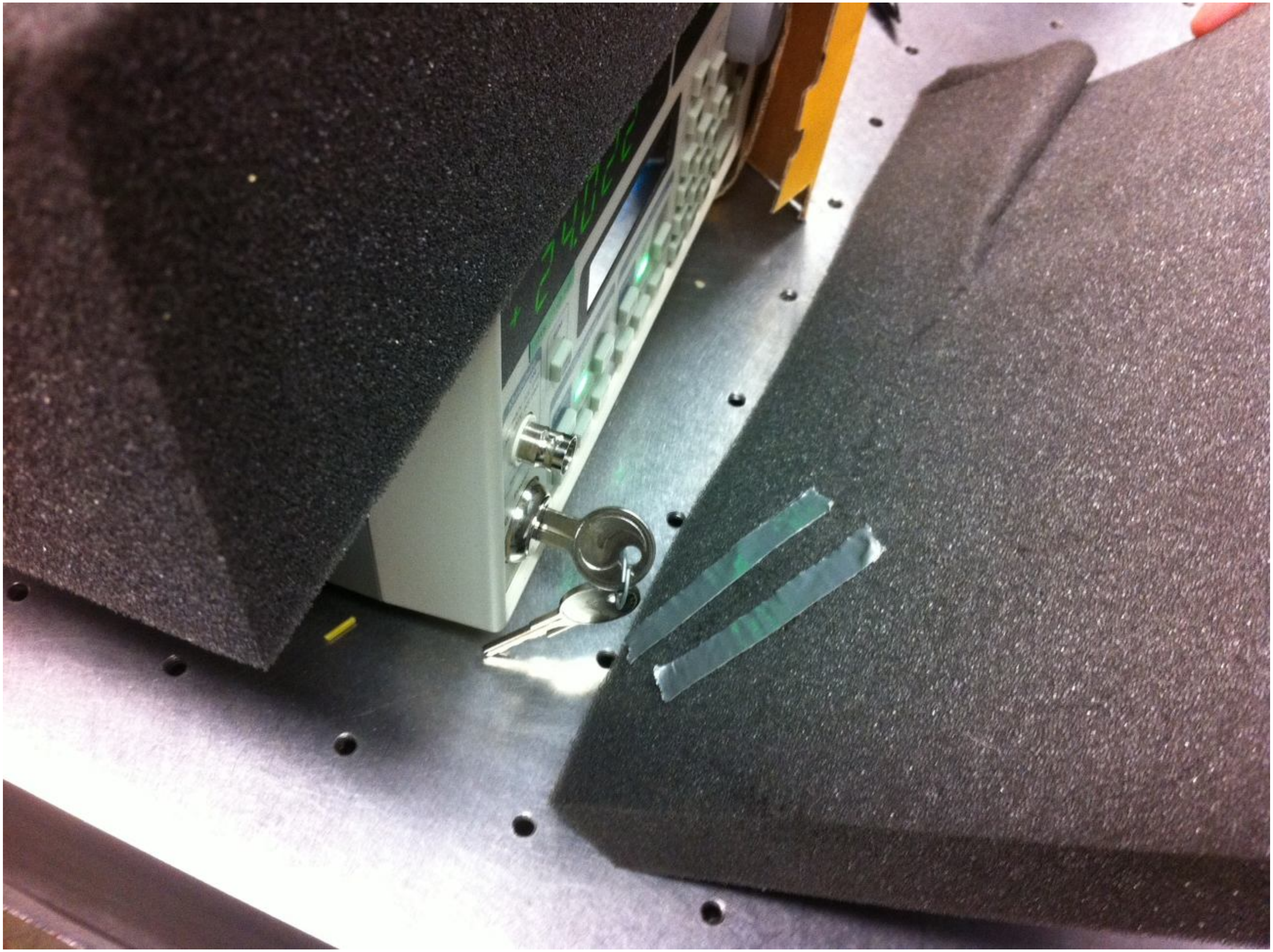
- Berek Compensator

Retardance Indicator: How much retardance to apply

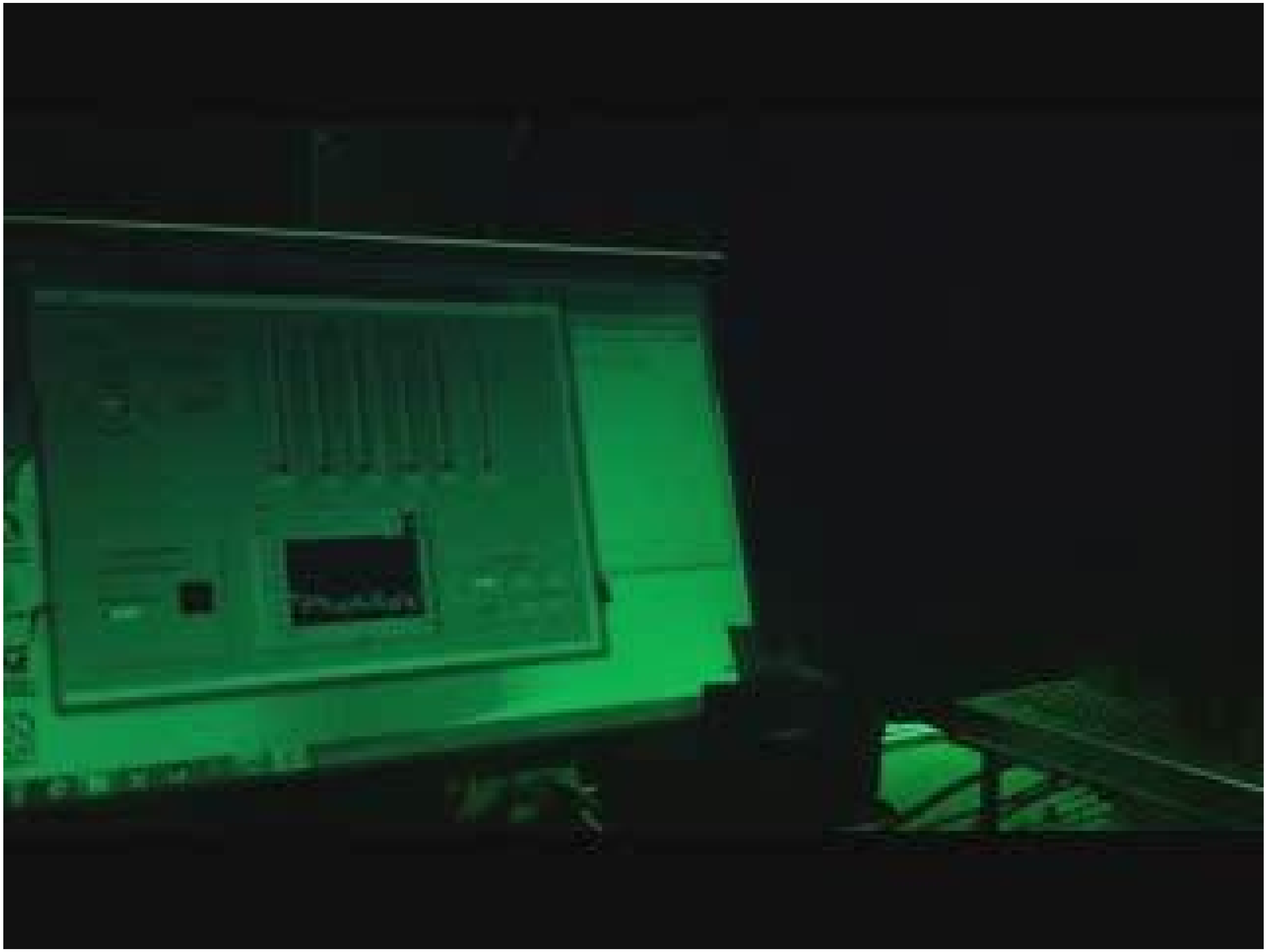
Orientation Dial:
Rotates housing (orienting the slow axis of the compensator plate)

Minimizing Noise





Clothing makes a big difference



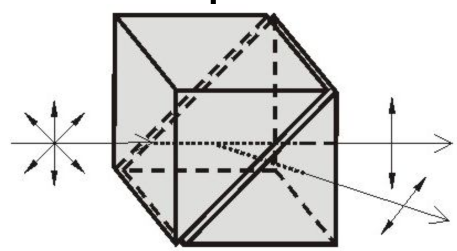
Future Project Plans

- Labview Programming for Local Realism/obtain motorized waveplates
- Find optimal density filter attenuation
- Get 4 of the same density filters
- Find some way of better regulating A' and B' leg angles (they swivel too easily)
- Set up a curtain to pull back and forth across the white board

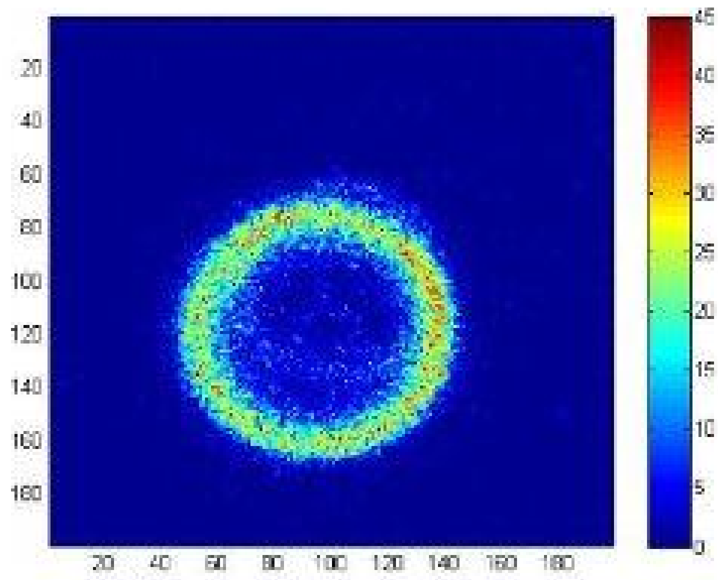
Questions?

More on SPCD & BBOs

- Angle of down converted photon emission is defined by orientation of optical axis of BBO with respect to the orthogonal face



- BBO emits down conversion photons in a cone (for type I down conversion)



Piezo Actuators

Drive Source	Name	Displacement Range	Displacement Accuracy	Generative Force	Response Speed
Air Pressure	Air pressure motor	Rotation	—	5 kgm	10 sec
	Air pressure cylinder	100 mm	100 μm	10^{-2} kg /mm^2	10 sec
Oil pressure	Oil pressure motor	Rotation	—	10 kgm	1 sec
	Oil pressure cylinder	1000 mm	10 μm	10 kg/mm^2	1 sec
Electricity	AC Servo motor	Rotation	—	3 kgm	100 msec
	DC Servo motor	Rotation	—	20 kgm	10 msec
	Step Motor	1000 mm	10 μm	30 kg	100 msec
	Voice Coil Motor	1 mm	0.1 μm	30 kg	1 msec
	Peizoelectric actuator	0.1 mm	0.01 μm	3 kg/mm^2	0.1 m sec

Calculating Angular Displacement

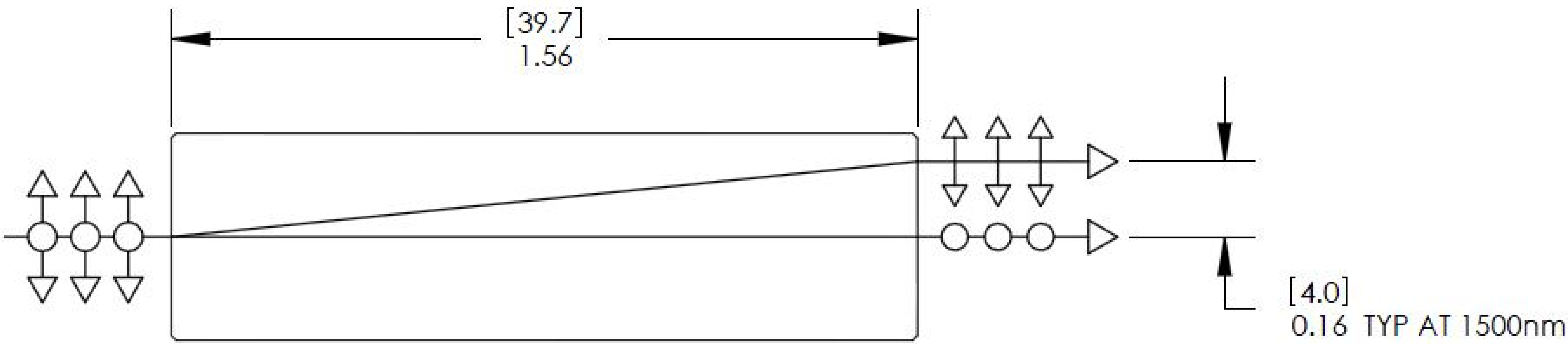
$$\Delta x = \frac{N\lambda}{2n}$$

Beam separation as a function of optical axis angle theta and block length D

$$d = \frac{D\,(n_e^2 - n_o^2)\tan\theta}{n_e^2 + n_o^2 \tan^2\theta} = 4.38\,mm$$

$$\tan\theta \approx \theta \approx \frac{\Delta x}{d}$$

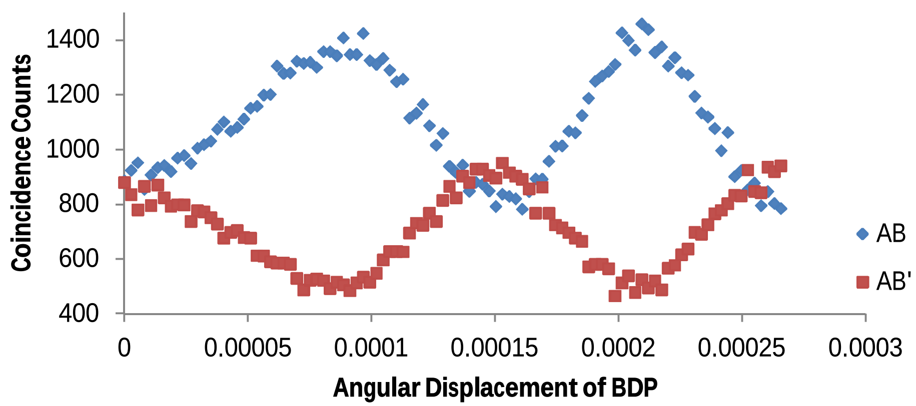
Beam Displacement Polarizers



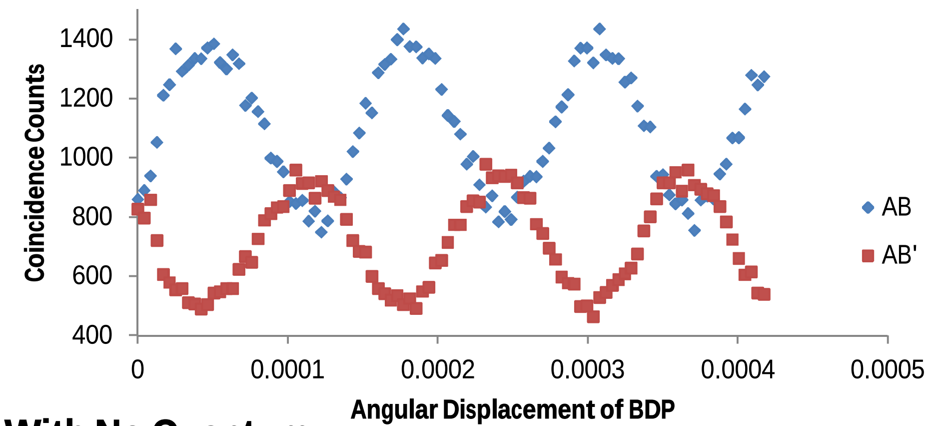
SIDE VIEW OF UNMOUNTED PRISM WITH RAY TRACE

‘Interference’ Without Quantum Erasure

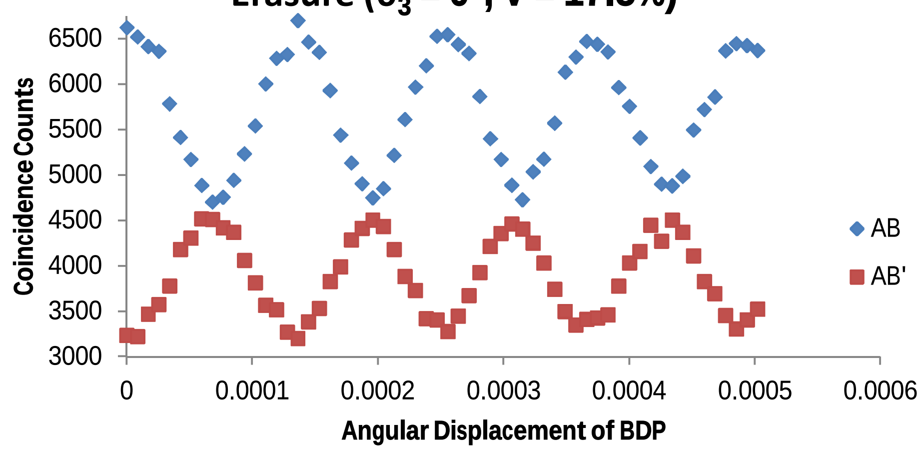
Interference Pattern With No Quantum Erasure ($\theta_1 = 10°$, V = 30.2%)



Single Photon Interference With Little Quantum Erasure ($\theta_1 = 0°$, V = 31.4%)



Interference Pattern With No Quantum Erasure ($\theta_3 = 0°$, V = 17.5%)



Avalanche Photodiodes

- Utilizes photoelectric effect
- Impact ionization allows for small signal detection (i.e. single photons) due to ‘self-sustaining avalanche’ with current in mAs
- This current is then subsided by lowering bias voltage down to breakdown voltage

Entangled States

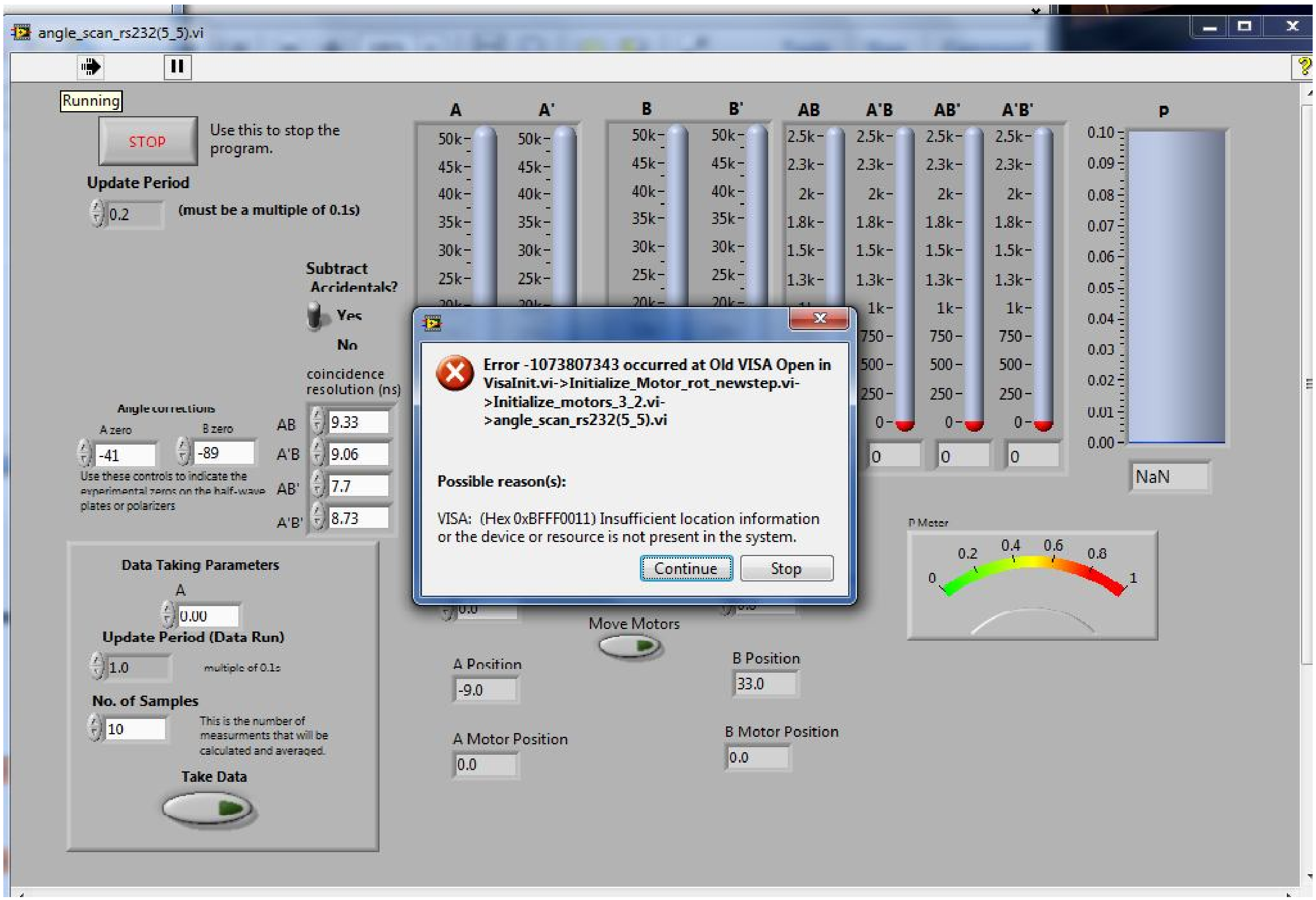
- Assuming pump is at 45 degrees & BBO pairs are sufficiently close together: 2 photon pairs are indistinguishable
- Thus we must consider them to be superpositions of both possible polarizations:

$$|\phi^+\rangle = \frac{1}{\sqrt{2}}(|H\rangle_s|H\rangle_i + |V\rangle_s|V\rangle_i)$$

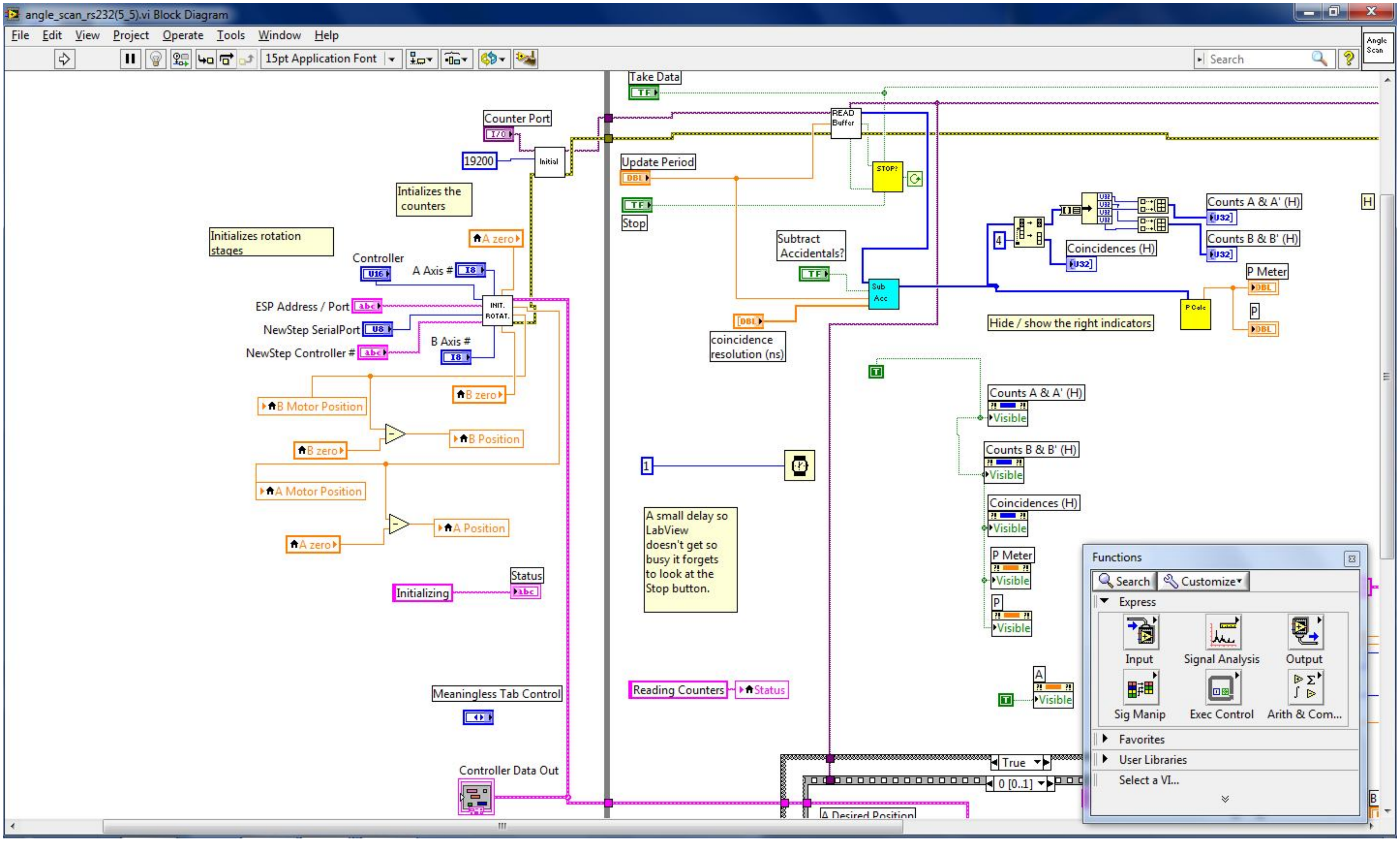
Individual & Joint Probabilities

- If 2 photons are in entangled state, then measurements made on 1 photon are **random**
- Measurements made on **pairs** of photons will be **perfectly correlated**

Labview Woes



Labview Woes Cont'd



Overview of Troubleshooting Processes

Testing to see if you're even getting down conversion:

- Try blocking the path down converted photons would take right after the crystal: if the number decreases you are seeing down conversion, if it remains the same you are not
- for experiments other than 1, try rotating the waveplate: down converted light will oscillate back and forth, noise will remain constant
- try turning the pump off and on and simply look at how much of a difference you get

If you're getting **<u>0</u>** for any detection or coincidence, something is wrong.

- Check to see if all the detectors are on (on the front panel)
- Check the fpga switches