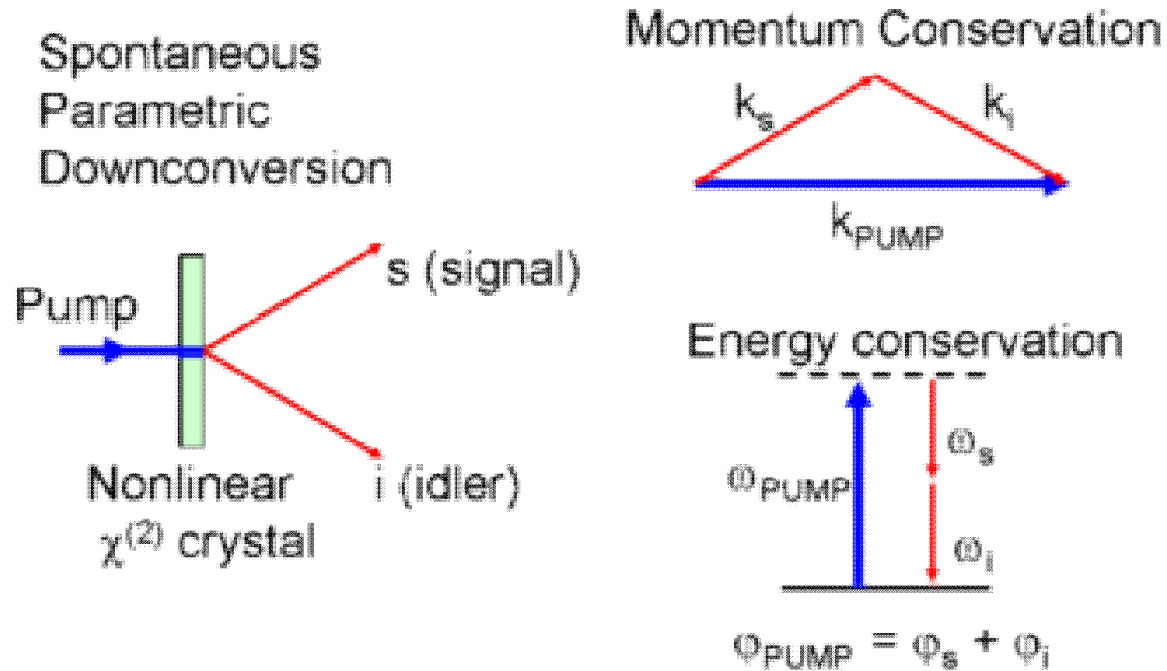


Spontaneous Parametric Down Conversion

Sean Gallivan & Kerry Olivier

General Overview



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

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

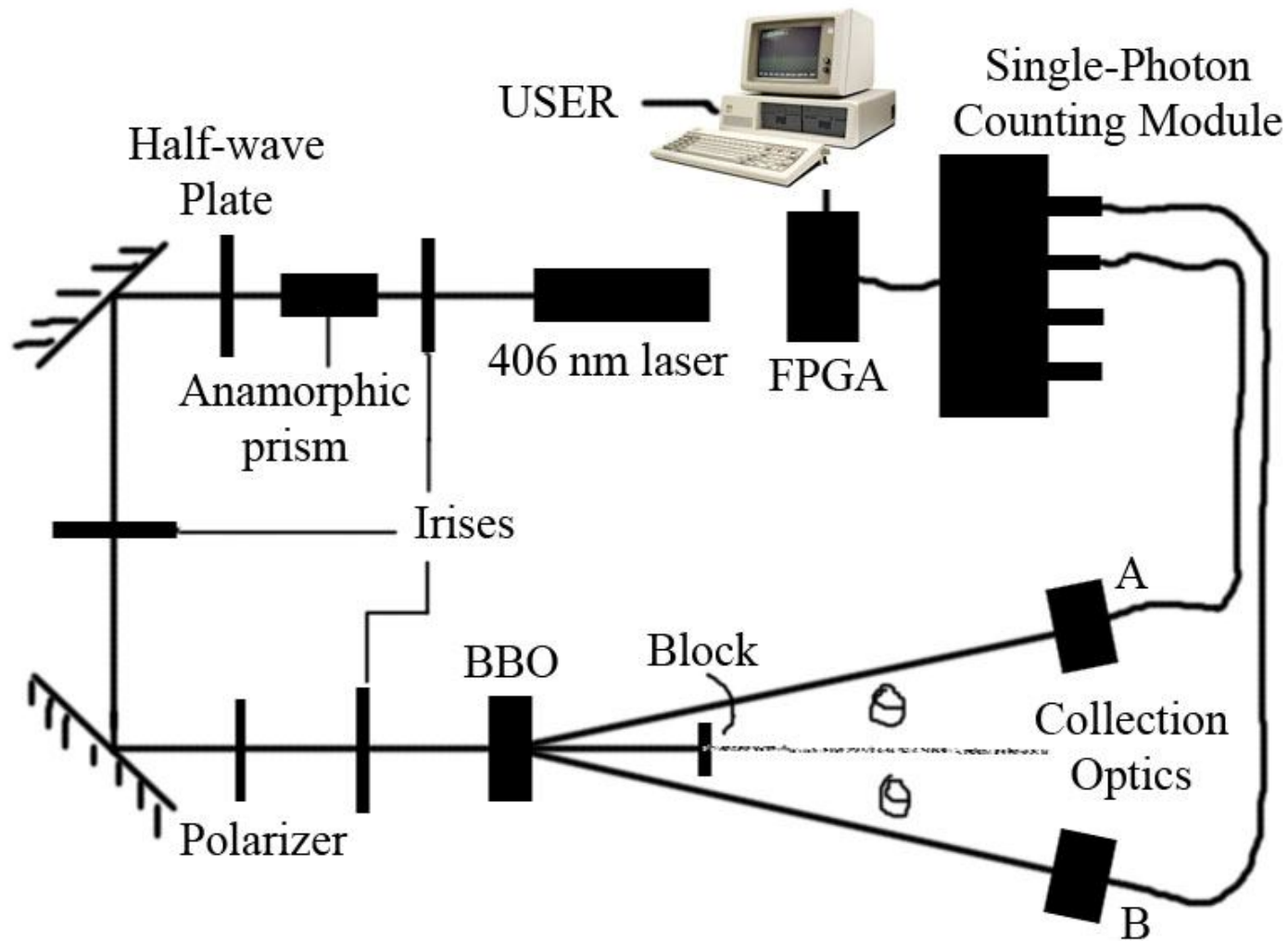
Why is it called SPDC?

- 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?

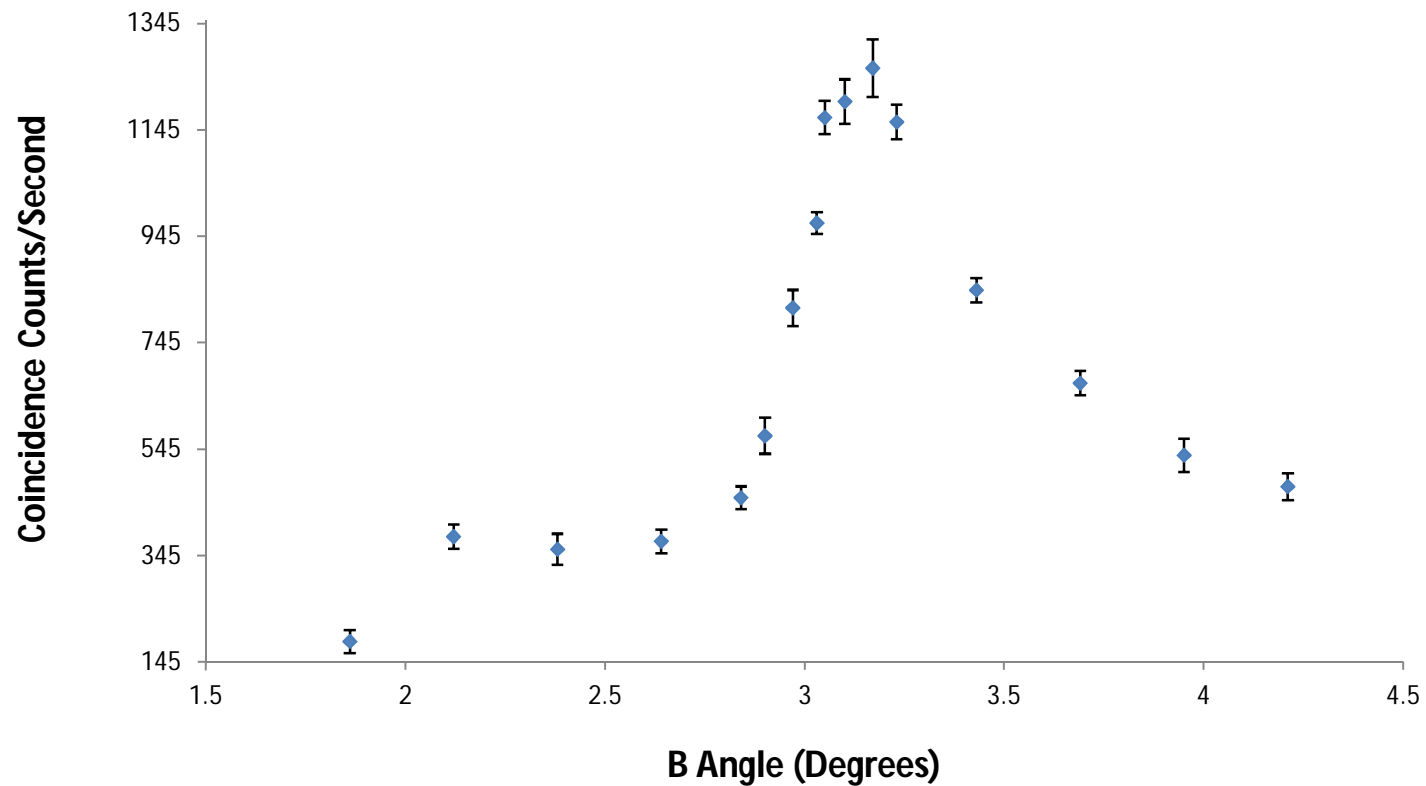
- Production of single photons
- Photon entanglement is ripe for quantum information experiments
- It's cool!

Lab Setup to Investigate SPDC

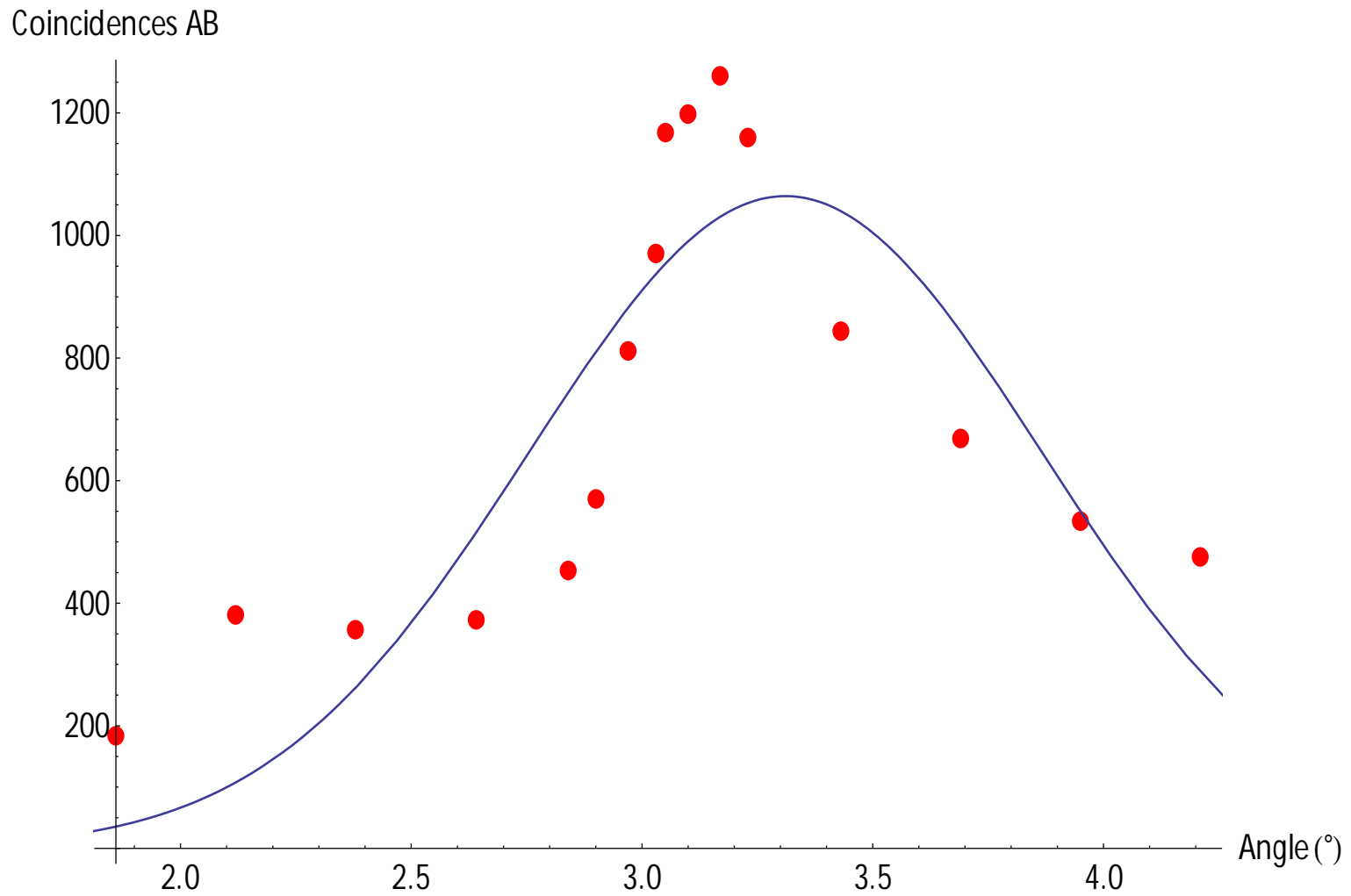


Results of SPDC Investigation

Coincidence Counts as Leg A is Held Constant and Leg B is Swept

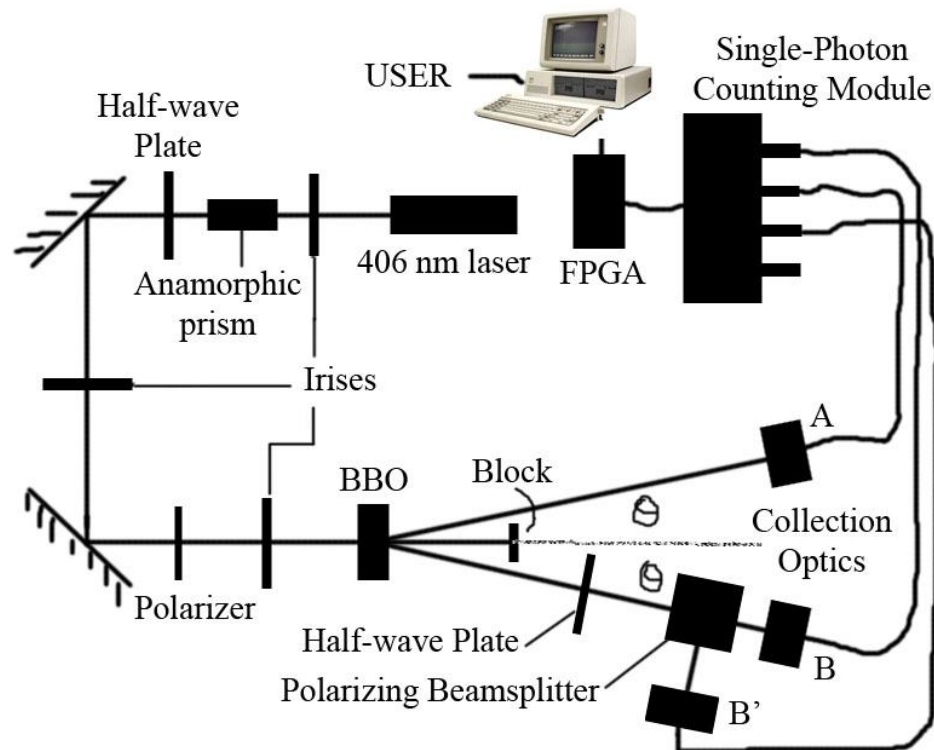


Gaussian Fit of Data



Measurement of $g^2(0)$

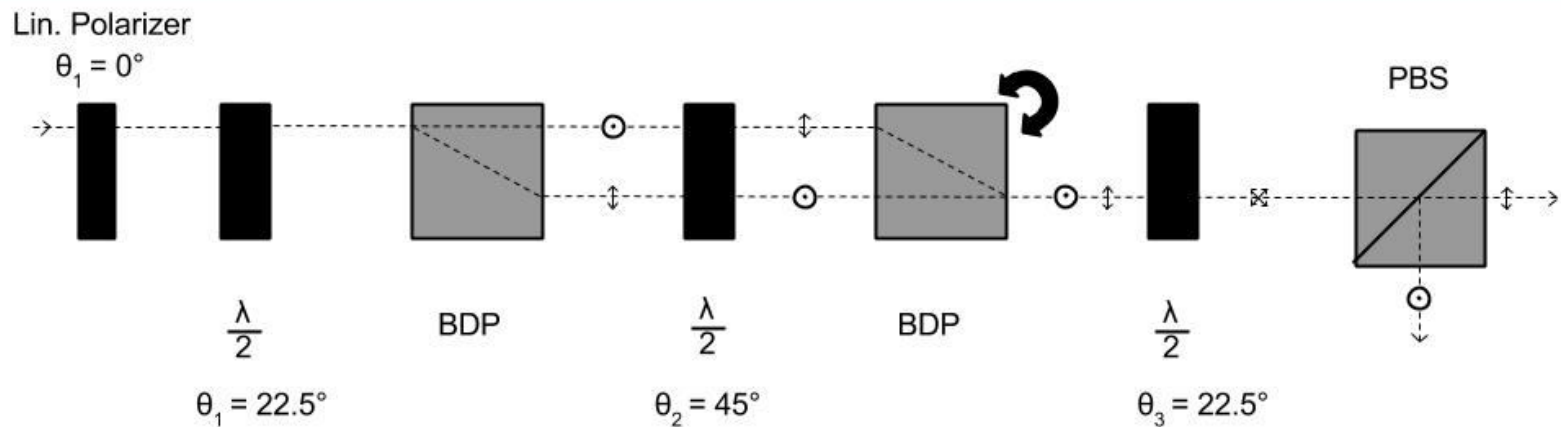
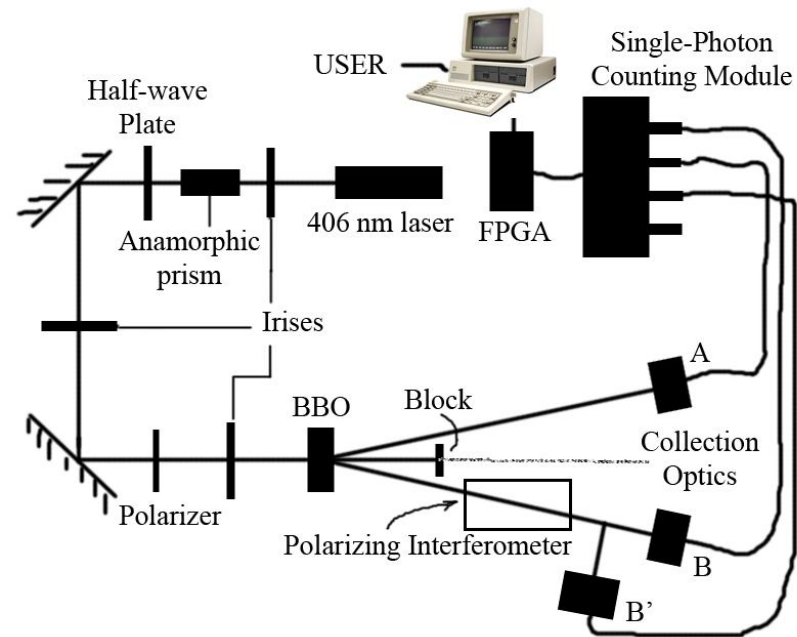
- Classical system: $g_{B,B'}^2(\tau) = \frac{\langle I_B(t+\tau)I_{B'}(t) \rangle}{\langle I_B(t+\tau) \rangle \langle I_{B'}(t) \rangle}$
- $g^2(0) \geq 1$ for classical fields
- $g^2(0) < 1$ for quantum fields, for single photons $g^2 = 0$

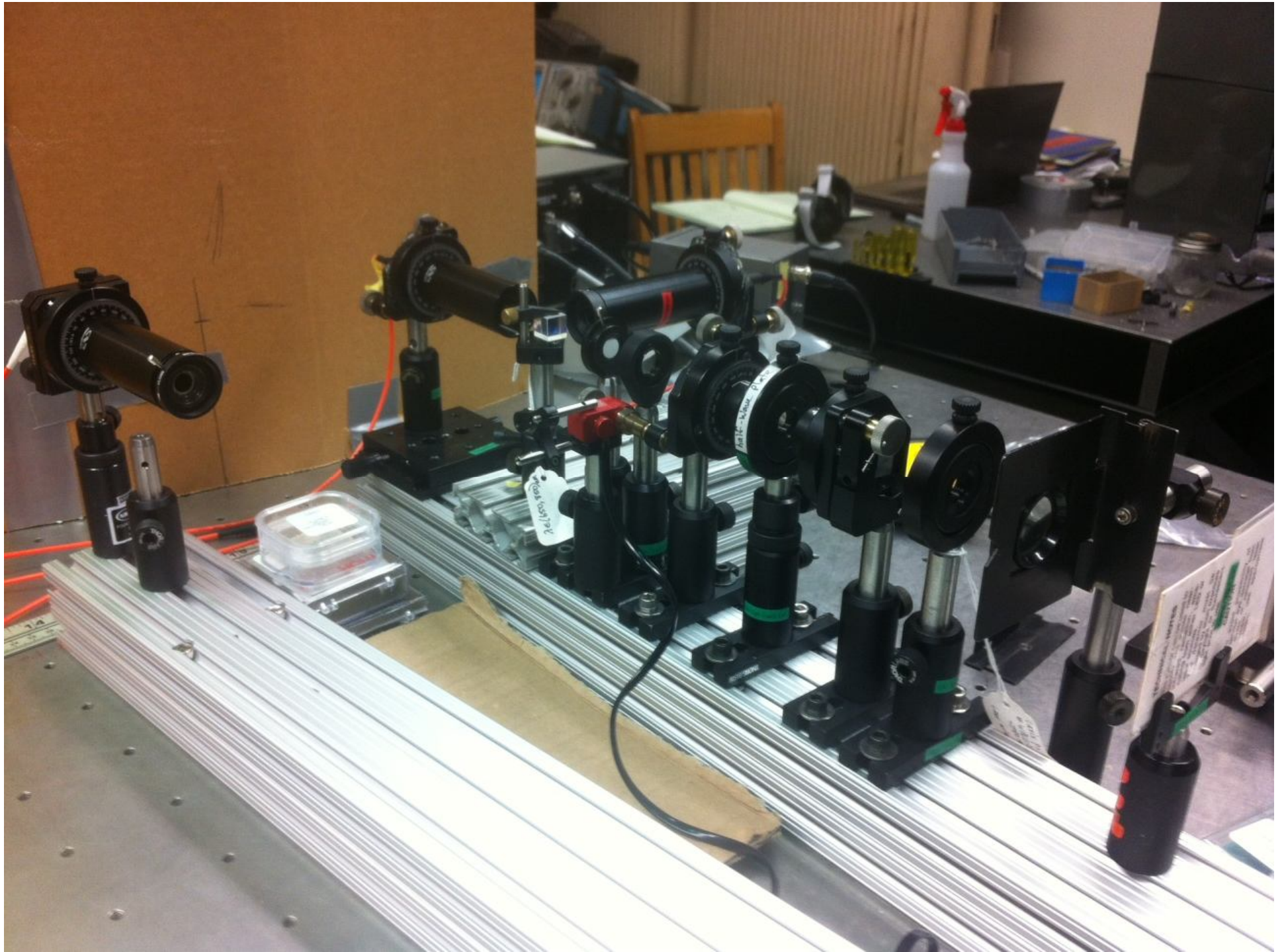


$g^2(0)$ Results

- 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)

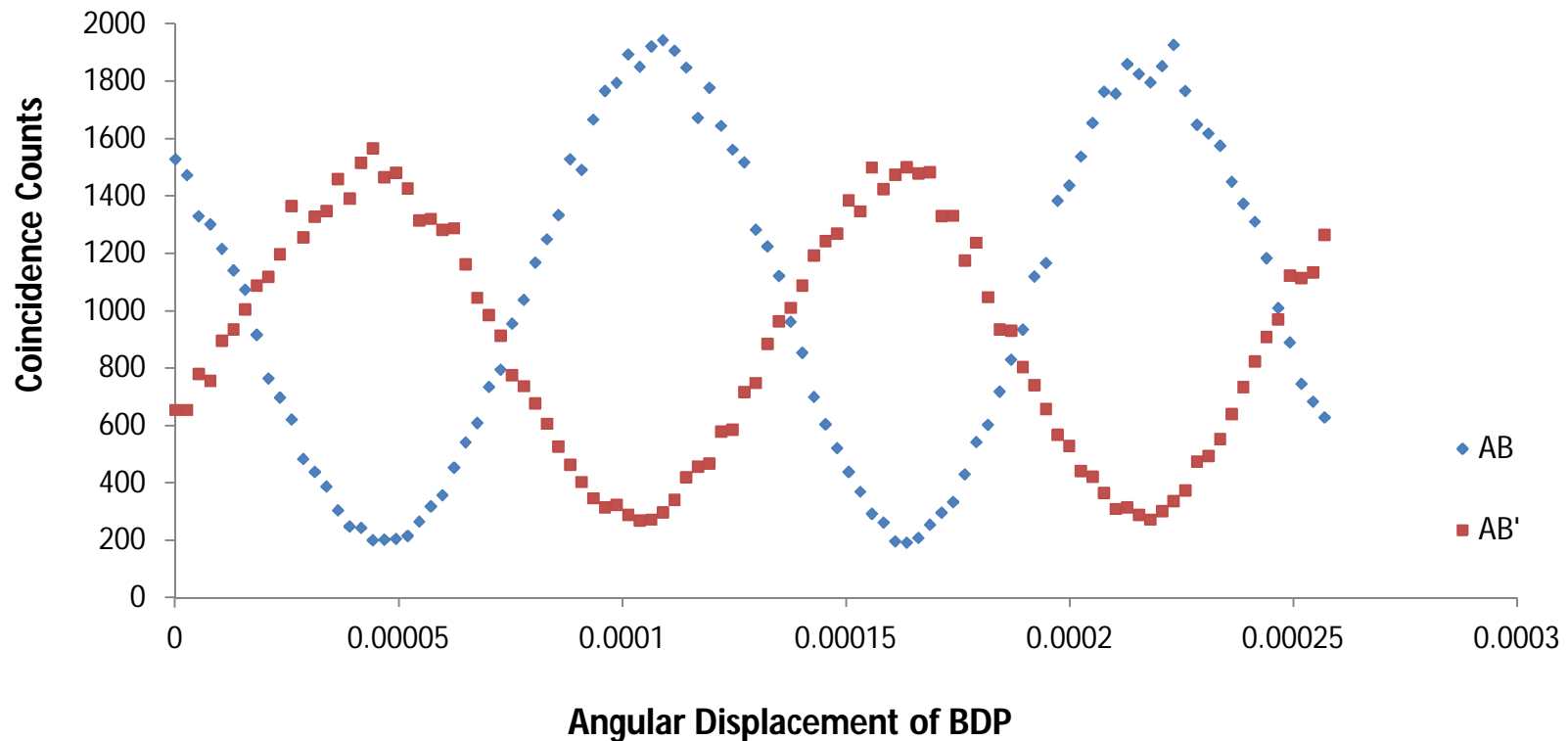
Single Photon Interference





Results of Single Photon Interference

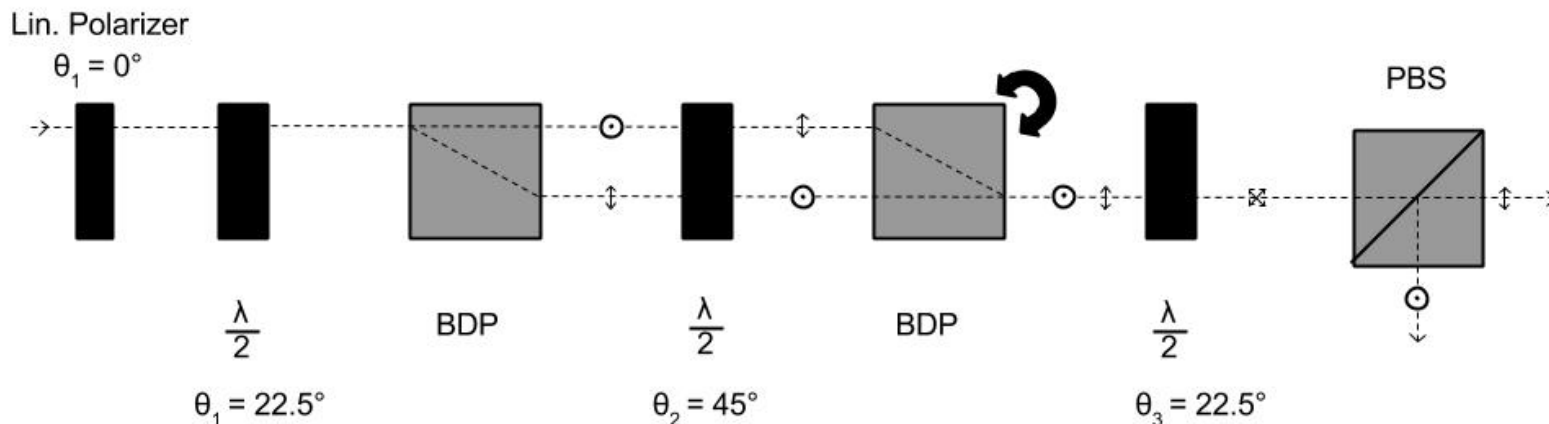
Single Photon Interference In a Quantum Eraser ($\theta_1 = 38^\circ$, $V = 81.9\%$)



Visibility of Interference Patterns & Quantum Erasers

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

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

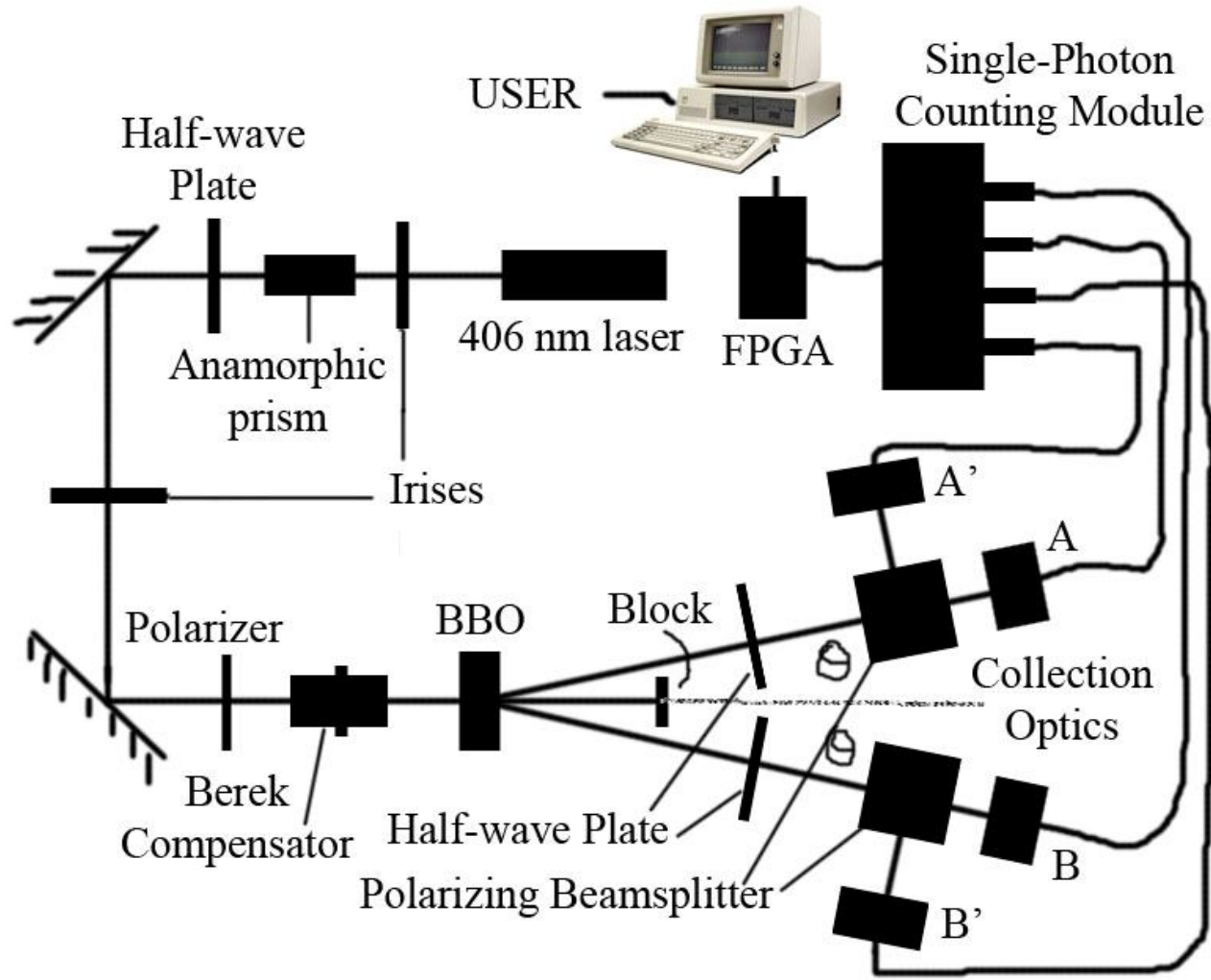
- Joint probability of photons polarized in 2 directions:

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

- Bell-Clauser-Horne Inequality:

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

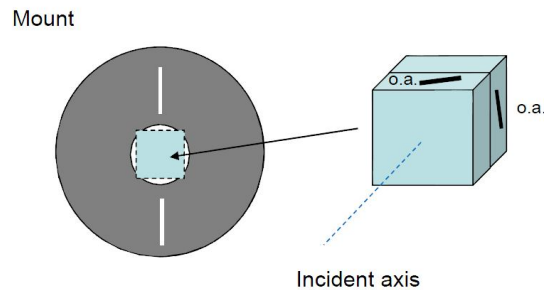
Attempted Local Realism Setup



New Equipment for Local Realism

Orientation of paired nonlinear crystals for SPDC

- Paired BBO



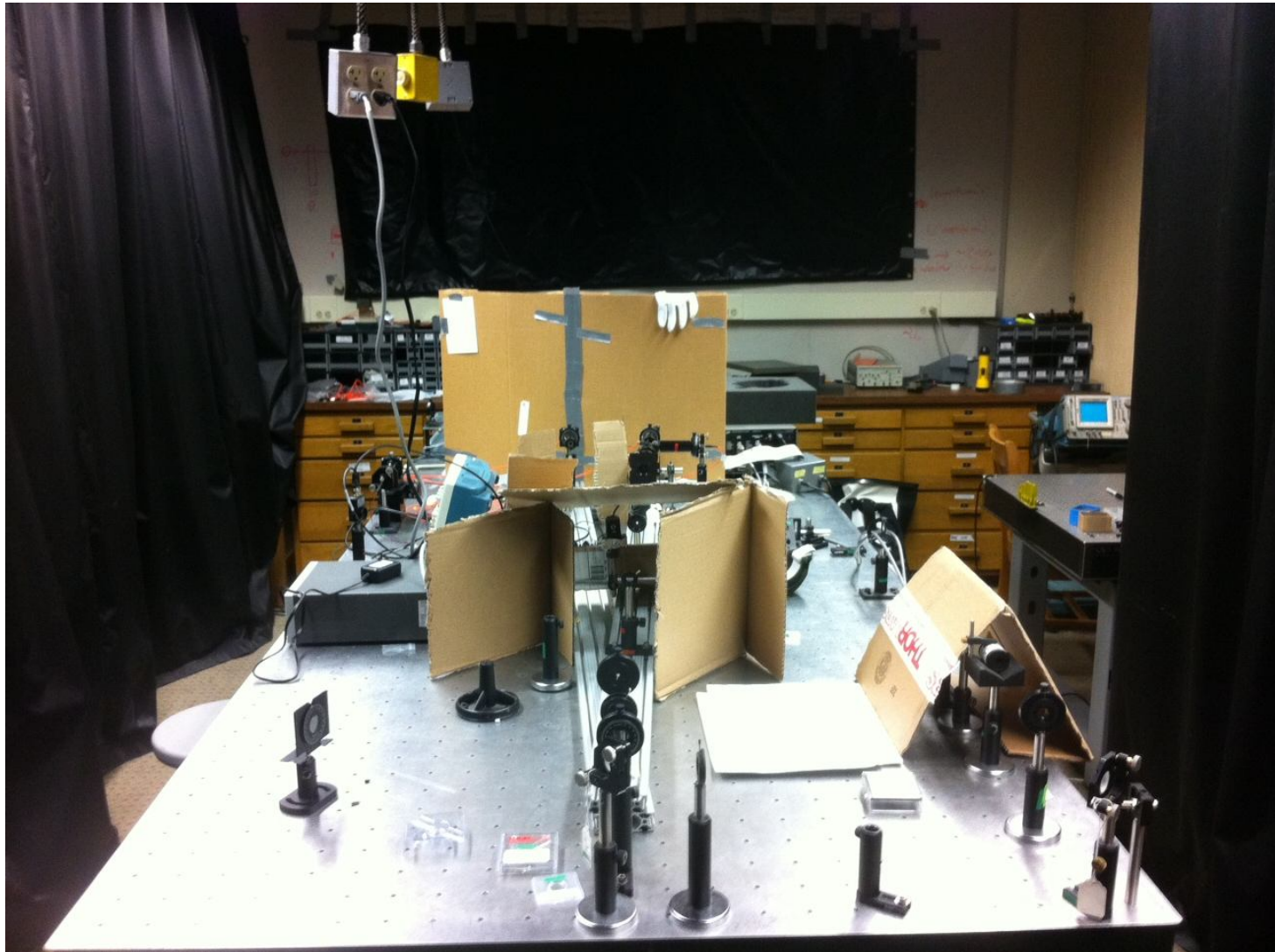
- Berek Compensator

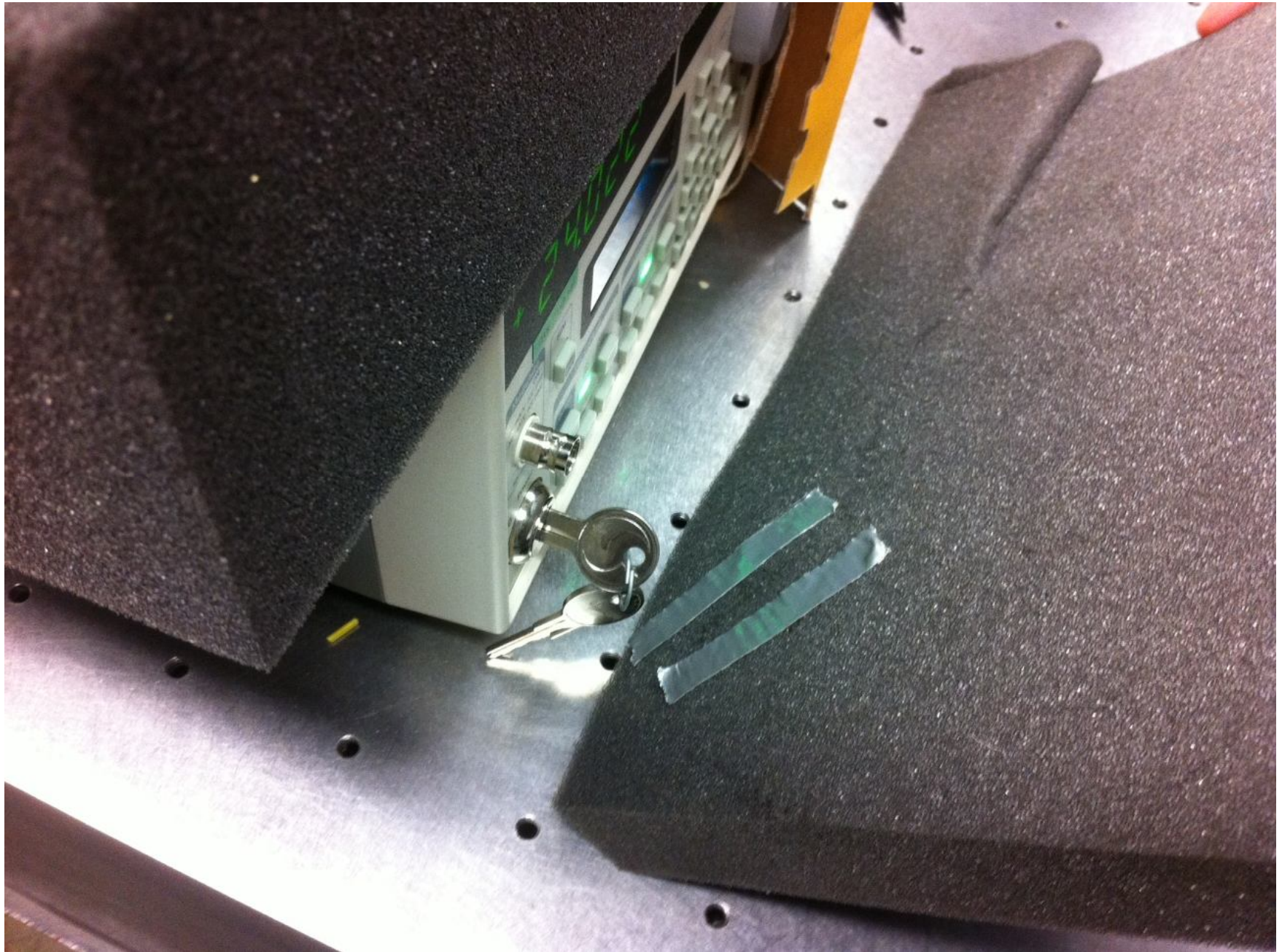
Retardance Indicator: How much retardance to apply

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



Minimizing Noise





Clothing makes a big difference



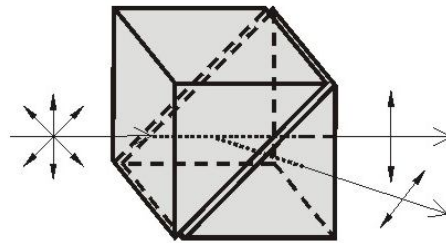
Future Project Plans

- 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

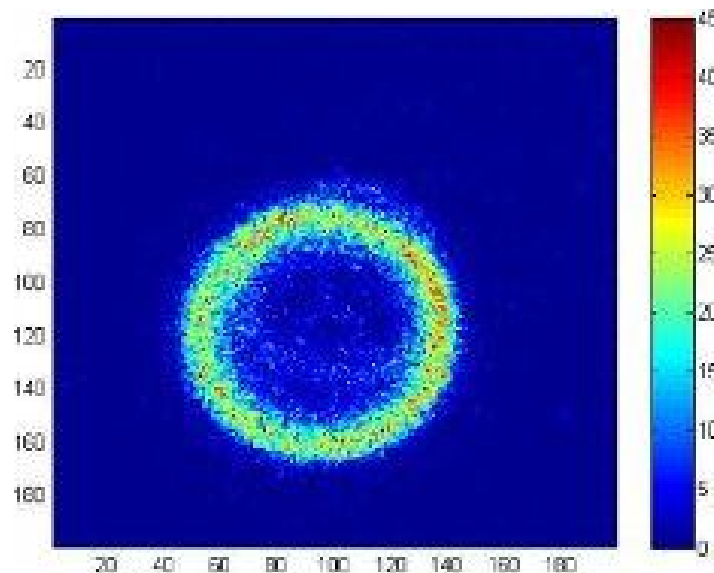
Questions?

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
	Peizeolectric actuator	0.1 mm	0.01 μm	3 kg/mm ²	0.1 m sec

Calculating Angular Displacement

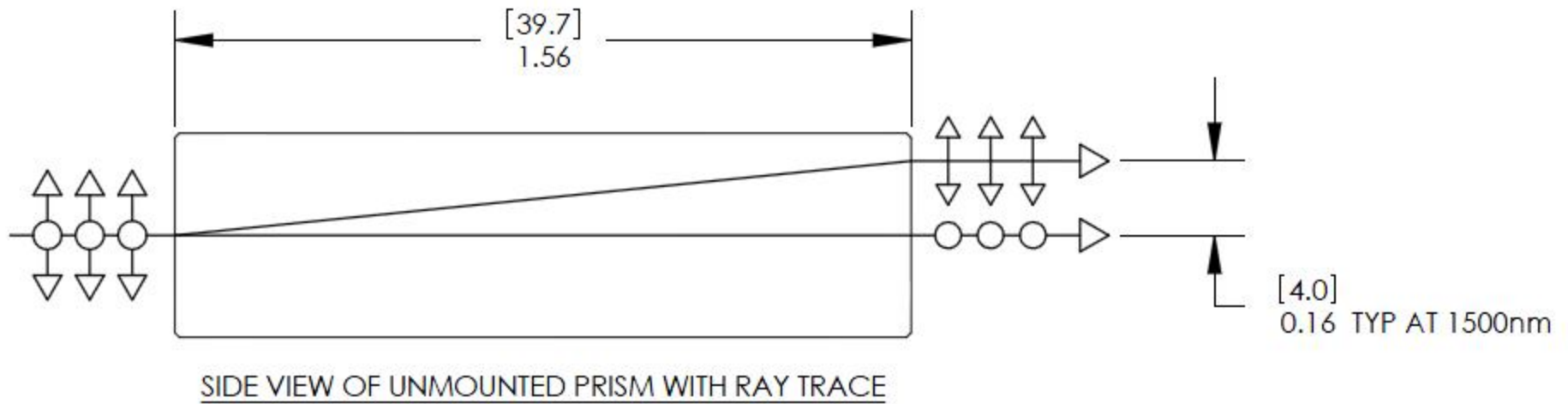
$$\Delta x = \frac{N\lambda}{2n}$$

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

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

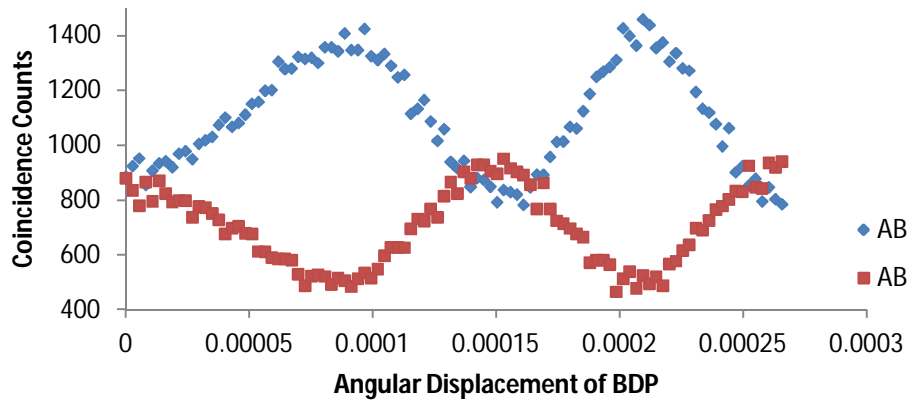
$$\tan \theta \approx \theta \approx \frac{\Delta x}{d}$$

Beam Displacement Polarizers

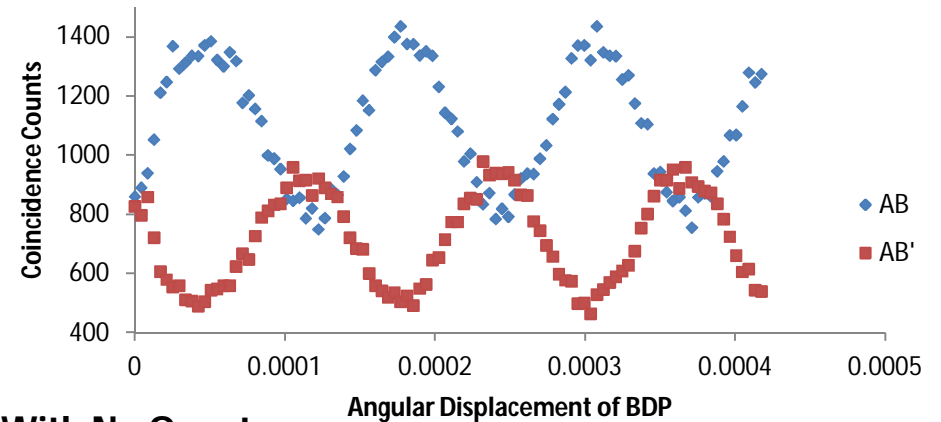


'Interference' Without Quantum Erasure

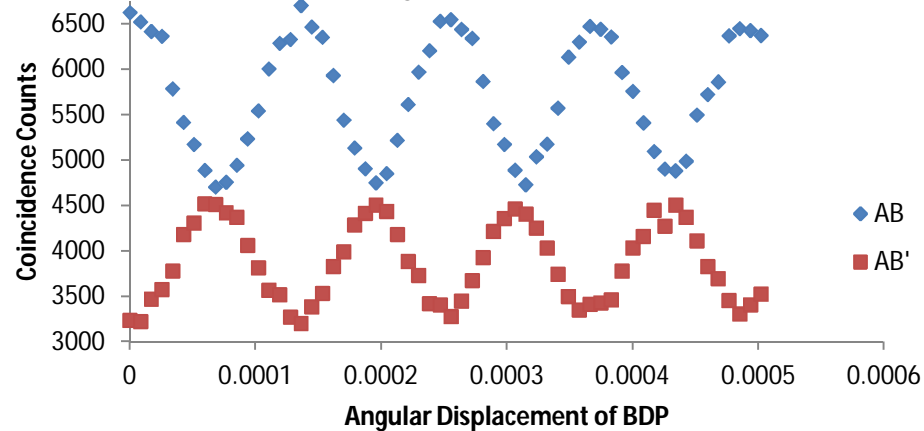
Interference Pattern With No Quantum Erasure ($\theta_1 = 10^\circ$, $V = 30.2\%$)



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



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



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

angle_scan_rs232(5_5).vi

Running

STOP Use this to stop the program.

Update Period
0.2 (must be a multiple of 0.1s)

Subtract Accidentals?
 Yes
 No

coincidence resolution (ns)

Angle corrections
A zero: -41, B zero: -89
Use these controls to indicate the experimental zero on the half-wave plates or polarizers

Data Taking Parameters
A: 0.00
Update Period (Data Run): 1.0 (multiple of 0.1s)
No. of Samples: 10 (This is the number of measurements that will be calculated and averaged.)
Take Data

A	A'	B	B'	AB	A'B	AB'	A'B'	P
50k	50k	50k	50k	2.5k	2.5k	2.5k	2.5k	0.10
45k	45k	45k	45k	2.3k	2.3k	2.3k	2.3k	0.09
40k	40k	40k	40k	2k	2k	2k	2k	0.08
35k	35k	35k	35k	1.8k	1.8k	1.8k	1.8k	0.07
30k	30k	30k	30k	1.5k	1.5k	1.5k	1.5k	0.06
25k	25k	25k	25k	1.3k	1.3k	1.3k	1.3k	0.05
20k	20k	20k	20k	1k	1k	1k	1k	0.04
15k	15k	15k	15k	750	750	750	750	0.03
10k	10k	10k	10k	500	500	500	500	0.02
5k	5k	5k	5k	250	250	250	250	0.01
0	0	0	0	0	0	0	0	0.00

NaN

P Meter
0 0.2 0.4 0.6 0.8 1

Move Motors

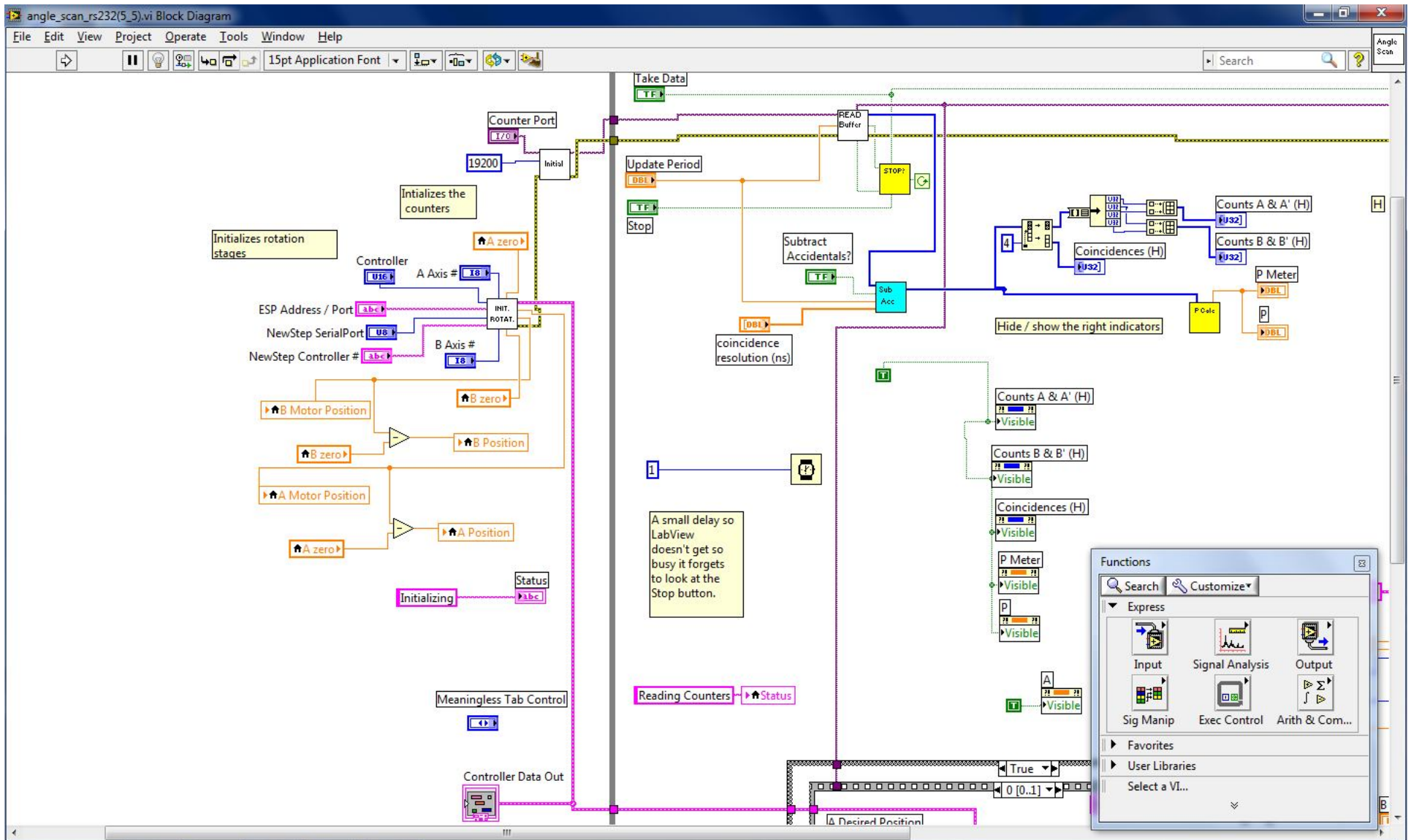
A Position: -9.0, B Position: 33.0
A Motor Position: 0.0, B Motor Position: 0.0

Error -1073807343 occurred at Old VISA Open in VisaInit.vi->Initialize_Motor_rot_newstep.vi->Initialize_motors_3_2.vi->angle_scan_rs232(5_5).vi

Possible reason(s):
VISA: (Hex 0xBFFF0011) Insufficient location information or the device or resource is not present in the system.

Continue Stop

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 0 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