

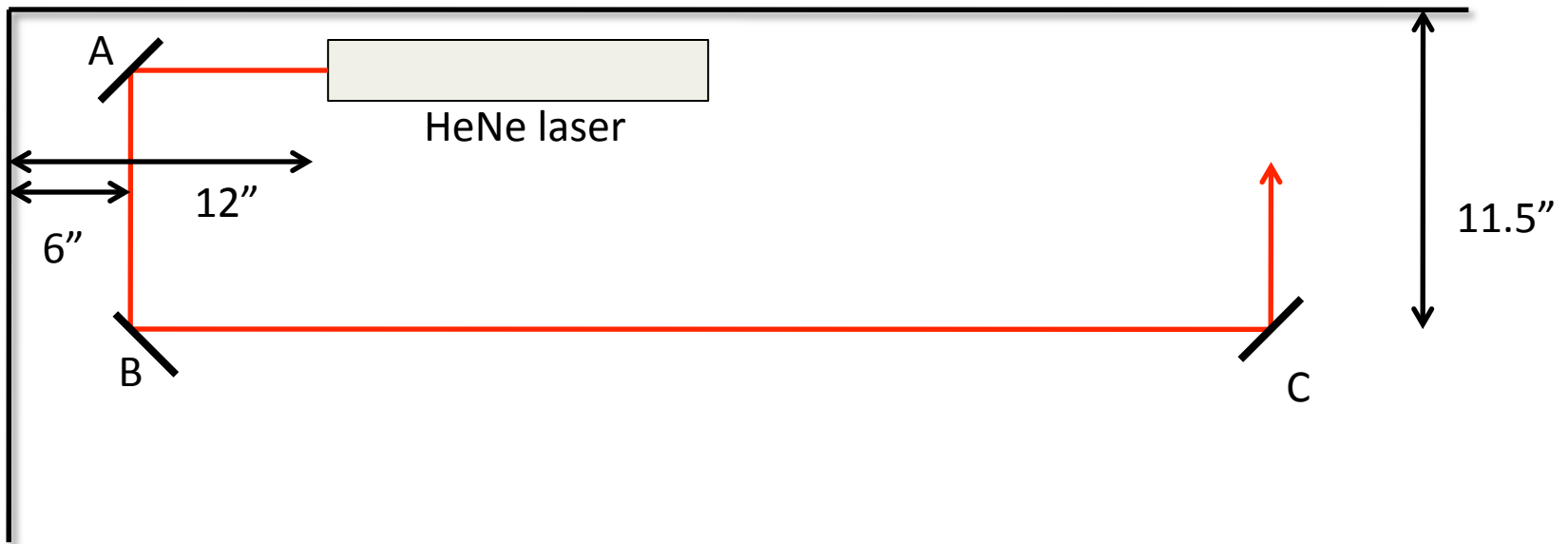
Alpha Immersion – Hands-on Activities

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Activity I (Tuesday AM) - Basic Alignment

- Goal: To get hands-on experience with optical alignments.
- Materials:
 - 2'x5' optical breadboard
 - HeNe laser
 - 3 mirrors with mounts (A, B, C)
 - Iris and mount,
 - 4 $\frac{1}{4}$ -20 screws/knurled knobs

Activity I (Tues. AM): Basic Alignment

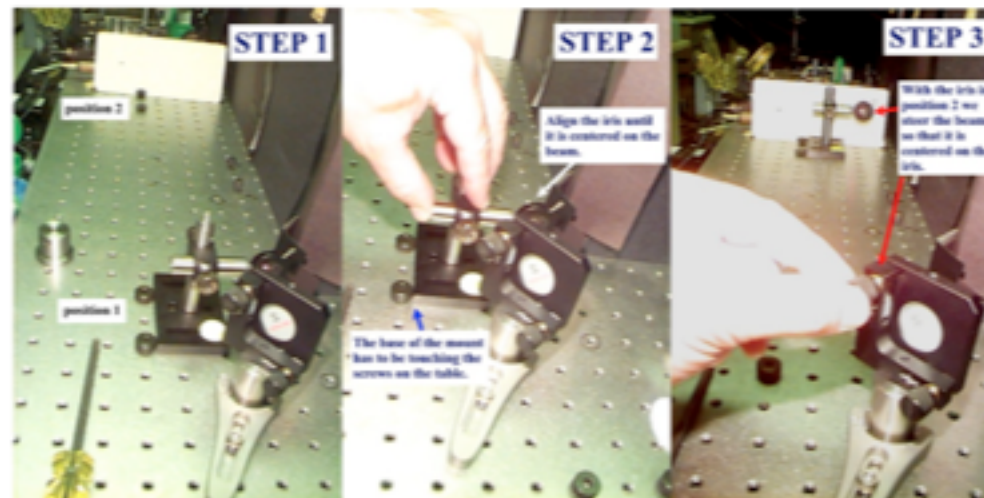


1. Add mirror A. Align reflection with iris and knurled screws.
2. Add mirror B (with straight edge). Reflection must be close to the edge of the mirror. Align reflection with iris and knurled screws according to instructions in the next page.
3. Add mirror C. Align reflection with iris and knurled screws.

Activity I (Tues. AM) cont. Aligning the beam to be parallel to the holes in the breadboard/optical table.

- i. Suppose that we wish to align a beam after it is reflected off a mirror. The alignment goes as follows: the beam is first aimed by eye to be parallel to the holes on the breadboard. We put pairs of screws along the same row of holes in two positions: # 1 (near) and # 2 (far). (The screws with the knurled heads from Thorlabs are very good—we have plenty of these after replacement in other parts with the spring-loaded knobs model TS25) This is shown in “step 1” of Fig. 7.
 1. An iris is put in position # 1 with its mount touching the two screws in that position. The iris is then adjusted so that the beam goes through the iris, as shown in “step 2” of Fig. 7.
 2. The iris is now put in position # 2, with its mount touching the screws, as in position # 1. If the beam goes through the iris, then it is aligned because from positions # 1 to # 2 the iris has been translated along a line parallel to the holes on the breadboard. If the beam does not go through the iris in position # 2 then the beam must be steered by tilting the mirror until the beam goes through the iris, as shown in “step 3” of Fig. 7.

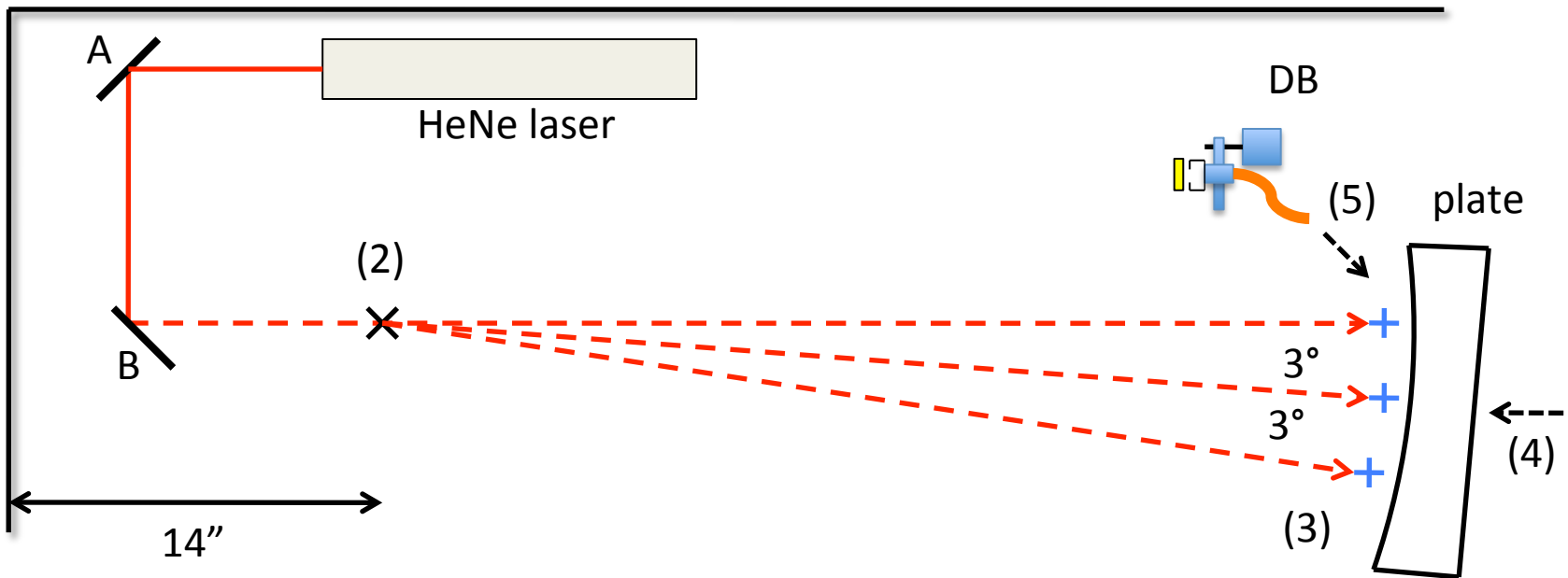
Iterate the previous two steps until the alignment converges.



Activity II (Tuesday AM) – Parametric down-conversion

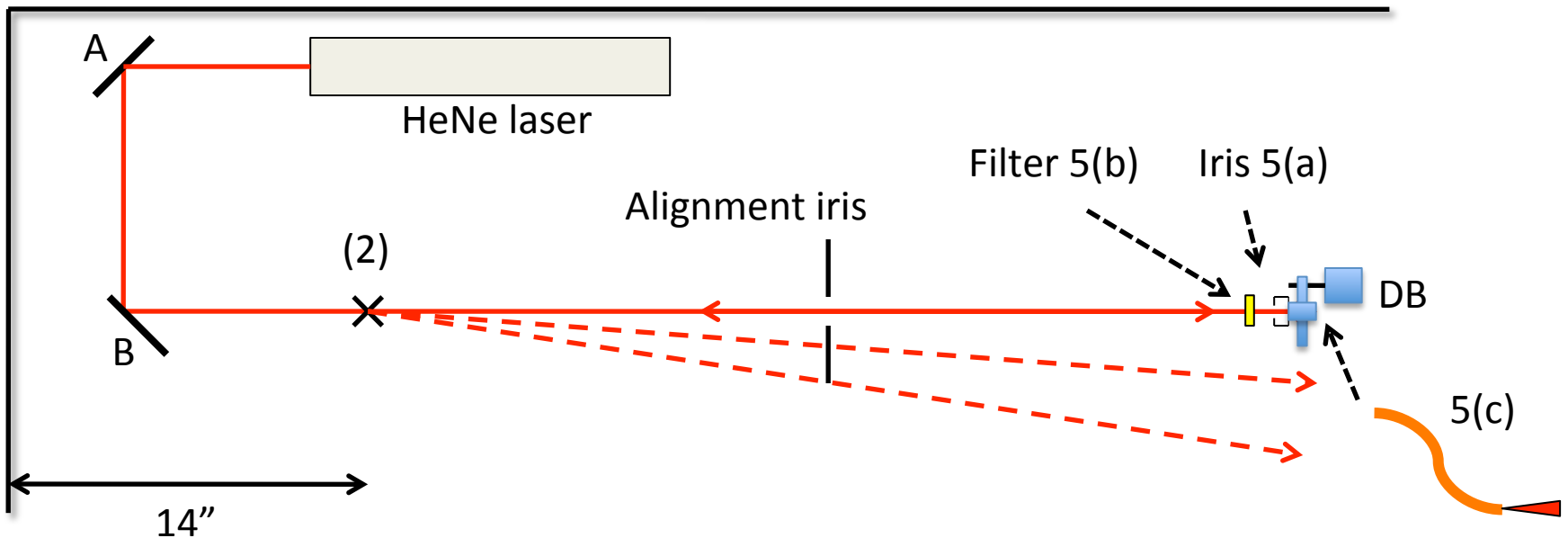
- Goal: To set-up and measure photon counts produced by spontaneous parametric down-conversion.
- Materials:
 - Hardware:
 - Flip-mirror (F_m) and translation stage (F_s)
 - Plumb-bob and extra iris with mount
 - Plate with 1-m radius curvature
 - GaN (blue) diode laser
 - BBO crystal and mount (X1)
 - Folding mirror on translation stage (D)
 - 2 fiber collimators with iris on mounts
 - 2 multimode fibers (DA and DB)
 - 2 band-pass filters that screw before iris
 - Beam dump (K)
 - Electronics:
 - 2 single-photon detectors,
 - Altera board,
 - PC with Matlab (will use program “ContinuousCountingAltera”)

Activity II (Tues. AM) cont. Parametric Down Conversion



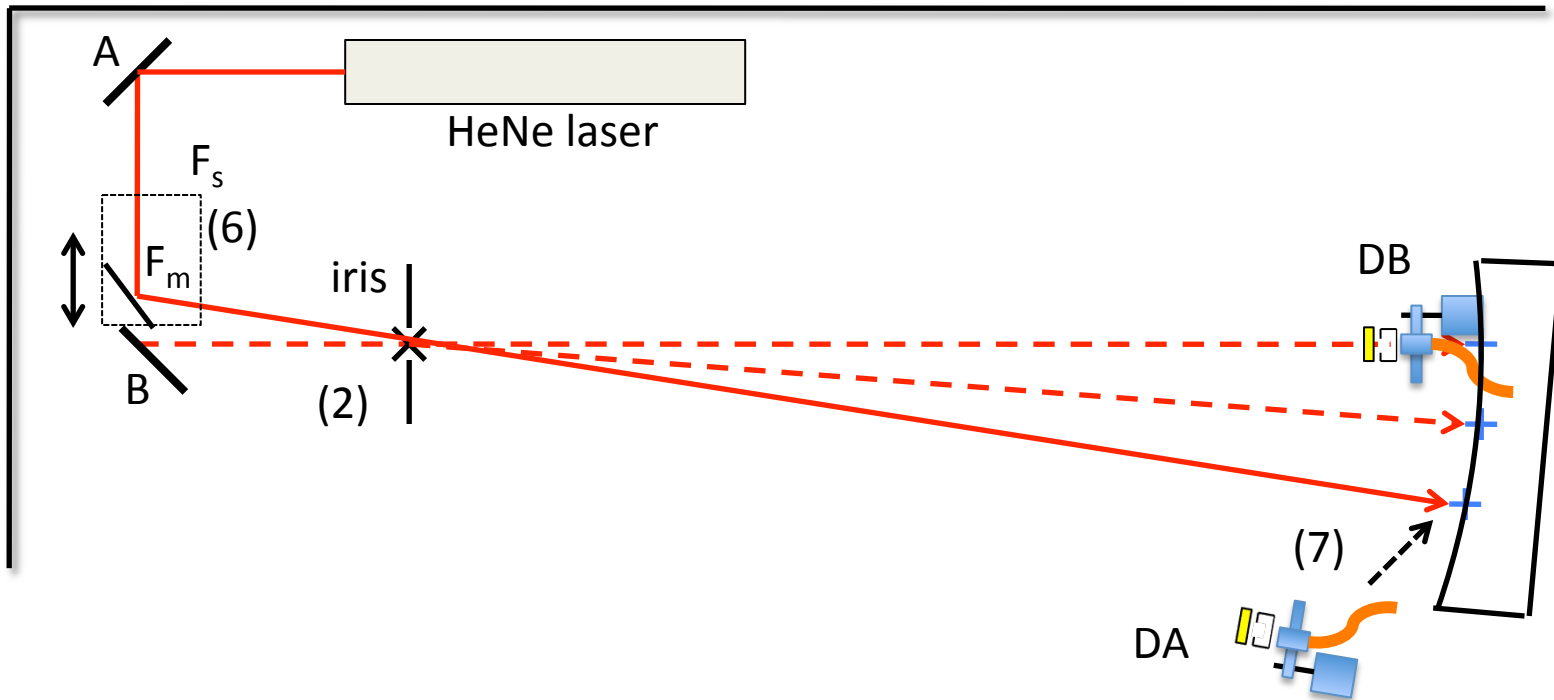
1. Remove mirror C.
2. Make a pencil mark "X" where the crystal will go (in path of the HeNe beam and 14" from left edge of the breadboard).
3. Place three "+" marks 1-m away from "X" as shown (3 degree from each other- 1 m away, 3 degrees is 5.2 cm in the transverse direction). Use plumb bob.
4. Place plate with 1-m radius of curvature (if available) over marks.

Activity II (Tues. AM) cont. Collimator alignment



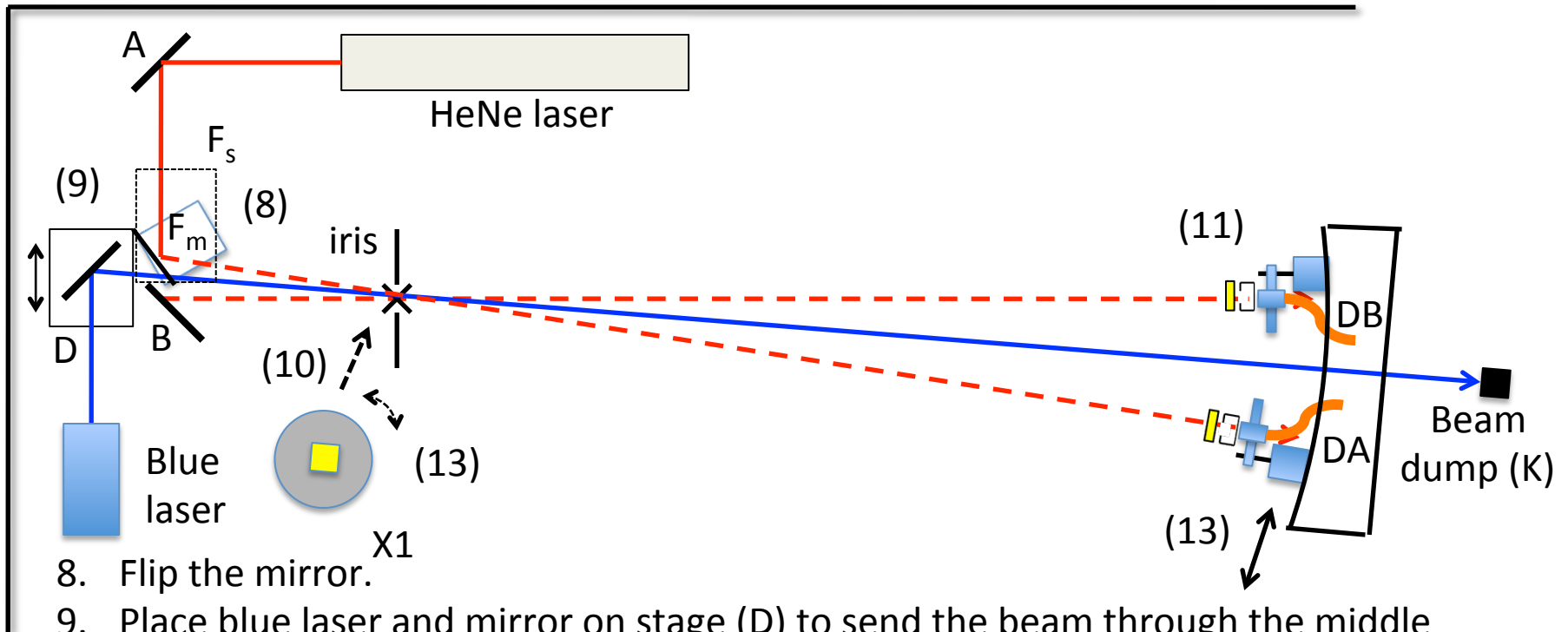
5. Place a free-standing alignment iris in path of HeNe beam.
 - a. Place the collimator mount DB up against the plate, unscrew the filter on the mount uncovering the iris, and adjust the position of the collimator on the mount so that the beam is centered on the iris. This is a critical step.
 - b. Screw the filter onto the iris and adjust collimator mount's tilt so that beam is reflected straight back through the alignment iris. Once done, remove the filter and check that beam is still centered on the iris. If not repeat (a) and (b).
 - c. Screw and lock the fiber onto the collimator and look for light coming out of the other end. Adjust the tilt of the collimator so that beam is as narrow as possible and as bright as possible.
 - d. Screw the filter onto the iris+collimator and connect the fiber to the detector.

Activity II (Tues. AM) cont. Aligning the second collimator



6. Place and clamp the translation stage (F_s), and place the flipper mirror (F_m) it on the stage. Align the mirror's position with the stage, and tilt the flipper mount so that the beam to goes over the 3rd "+" mark. Use plumb bob and 2 irises.
7. Place second collimator in the path of the beam and against the plate so that the light comes at the other end of the fiber (repeat previous step #5 for this alignment).
8. Connect collimator to detector fiber DA.

Activity II (Tues. AM) cont. Putting it all together

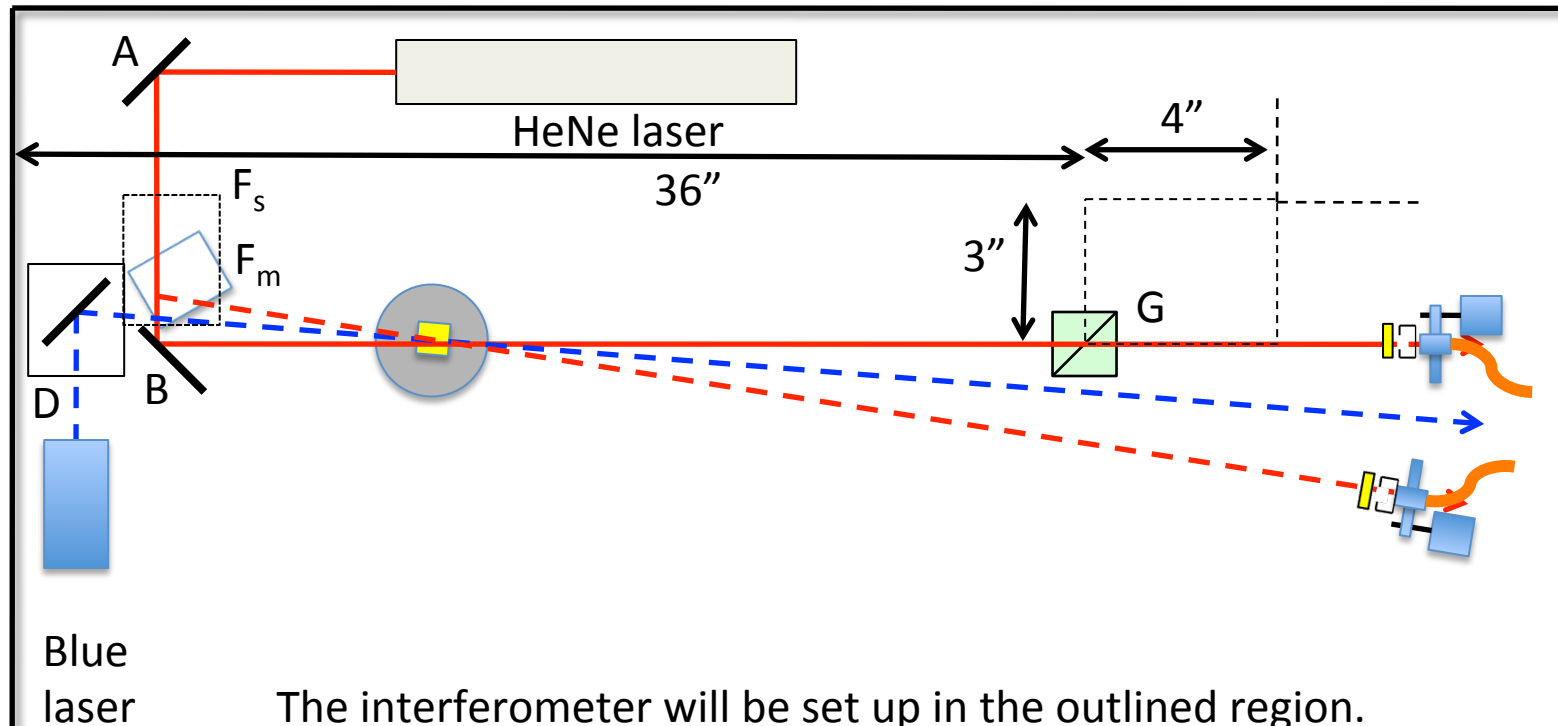


8. Flip the mirror.
9. Place blue laser and mirror on stage (D) to send the beam through the middle path shown. Use plumb bob and iris.
10. Place the down conversion crystal over the "x".
11. Make sure the filters are on the collimators.
12. Turn off the lights. Turn on the electronics. Look for coincidences AB using the program "ContinuousCounting."
13. Maximize coincidences by (1st) tilting the crystal, (2nd) tilting the collimators, and (3rd) translating (slightly!) one of the collimators along the track. They should be more than accidental coincidences: $N_{acc} = N_A N_B T$ where $T = 50\text{ns}$ (rule of thumb if $N_A = N_B = 10\text{k} \rightarrow N_{acc} = 5$).

Activity III (Tuesday PM)– Single-photon interference

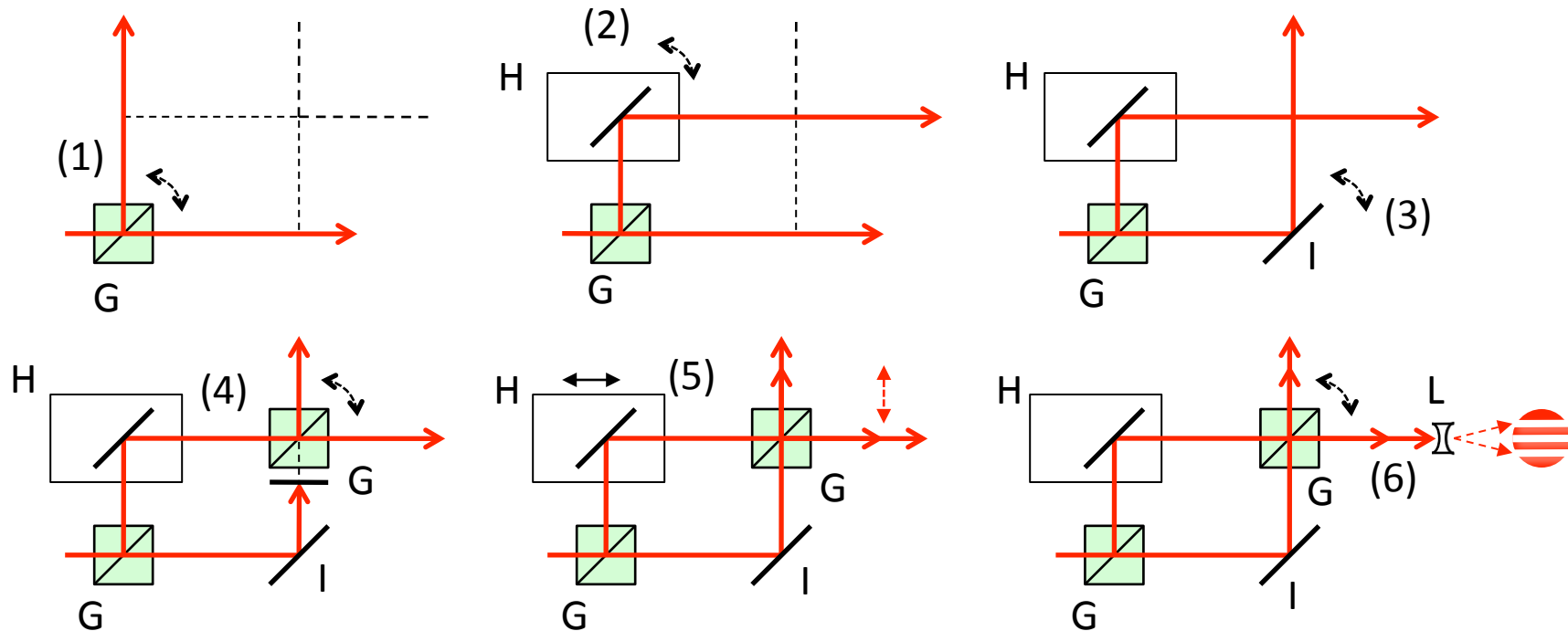
- Goals:
 - To set-up a zero-path-difference Mach-Zehnder interferometer.
 - Measure single-photon interference.
- Materials (mounts are pedestal type):
 - Hardware:
 - 2 identical broadband NIR beam splitters with mounts (G).
 - 1 mirror with mount (I).
 - 1 mirror (identical to previous) on a translation stage (H).
 - Piezo electric stack added as spacer to stage.
 - Diverging lens and mount (L)
 - Electronics:
 - Arduino-based D/A.
 - x10-15 voltage amplifier (for piezo)
 - PC spectrometer (we use Ocean Optics)
 - Small incandescent light bulb

Activity IV (Tues. AM/PM): Setting up an interferometer.



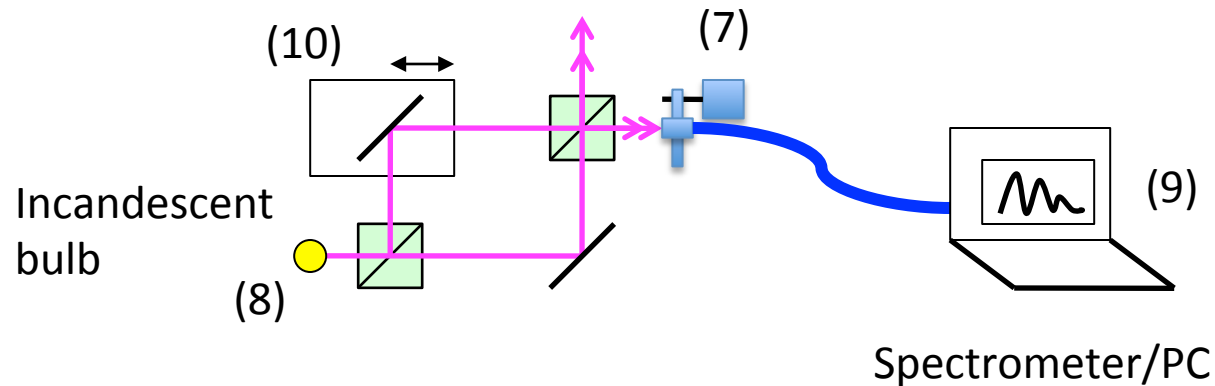
The interferometer will be set up in the outlined region. It needs to be as small as possible but still large enough fit in waveplates M on each arm (jump and see the final layout of slide #22). See next steps in setting up the interferometer.

Activity III (Tues. PM): Setting up an interferometer (BE SCRUPULOUS!).



0. Make sure that the incoming beam is aligned with the holes of the breadboard.
1. Insert beam splitter G. Align 90° reflection with irises and knurled knobs.
2. Insert mirror on linear stage H. Align 90° reflection with irises and knurled knobs.
3. Insert mirror on mount I. Align reflection with irises and knurled knobs.
4. Insert 2nd beam splitter G. Align reflection with irises and knurled knobs.
5. Adjust translation stage so that the two beams overlap. They should not be vertically displaced. If they are, there is a bad reflection that has to be redone.
6. Add diverging lens L to expand the beam and adjust tilt of second beam splitter for broadest fringes

Activity IV (Tues. PM): Setting up an interferometer- cont.



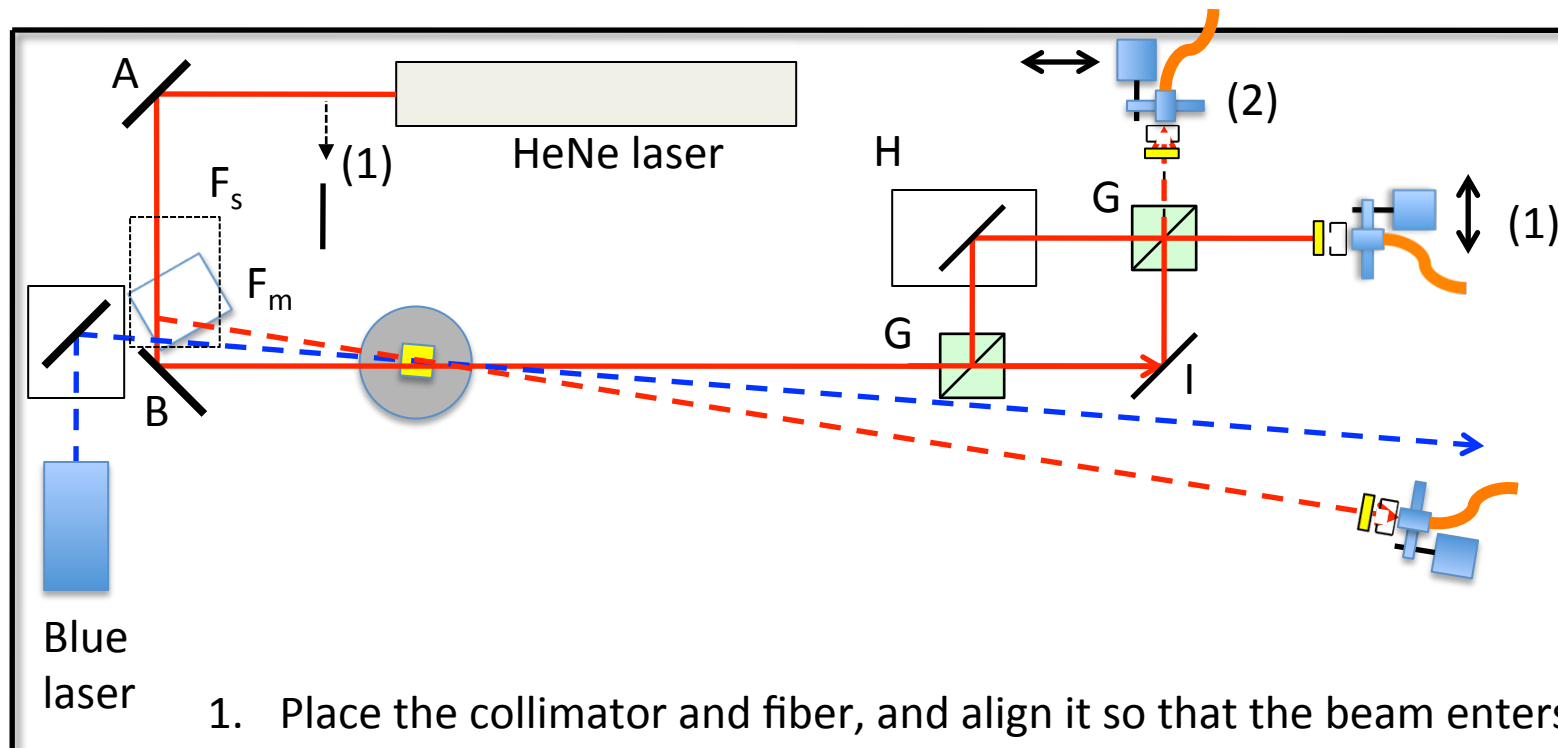
7. Place the fiber mount and spectrometer looking into the output of the interferometer.
8. Place an incandescent bulb at the input of the interferometer.
9. Observe the fringes of the spectrum; They reveal the difference in path

length: $\Delta L = \frac{\lambda^2}{\Delta\lambda}$ where $\Delta\lambda$ is the difference in wavelength between

adjacent maxima.

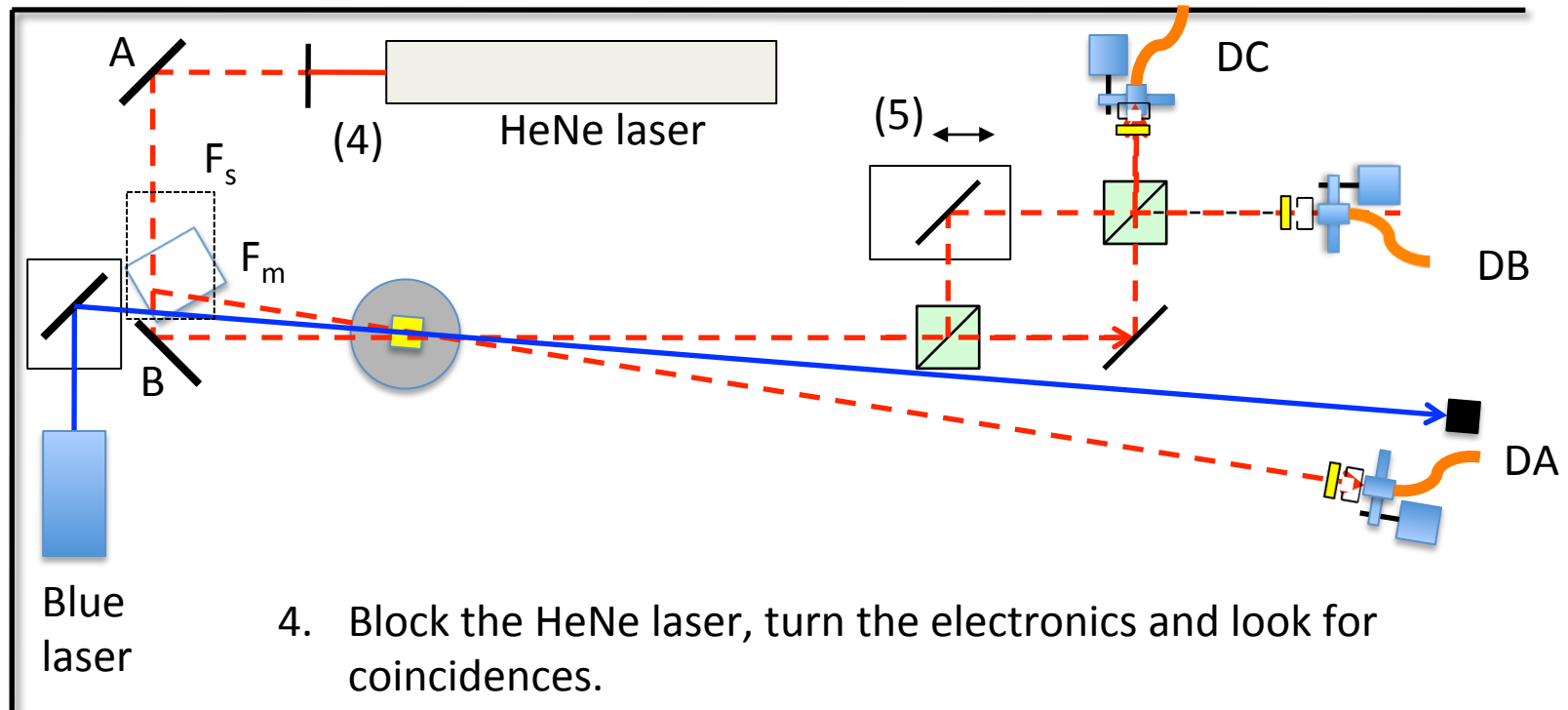
10. Broaden the fringes by translating the stage.
11. Remove the bulb and spectrometer and allow HeNe beam to go through the interferometer. Check that the interferometer is still aligned.
12. If previous is negative, align and repeat (7)-(10).

Activity IV (Tues. PM): Single-photon interference.



1. Place the collimator and fiber, and align it so that the beam enters the collimator. Optionally, place a straight plate guide to translate the collimator into alignment. You should not need to align it vertically. Otherwise it is not a good sign. Place also the filter in front of the fiber.
2. Align the second collimator in the second output of the interferometer. This second detector is nice but not critical.

Activity IV (Tues. PM/Wed. AM): Single-photon interference.

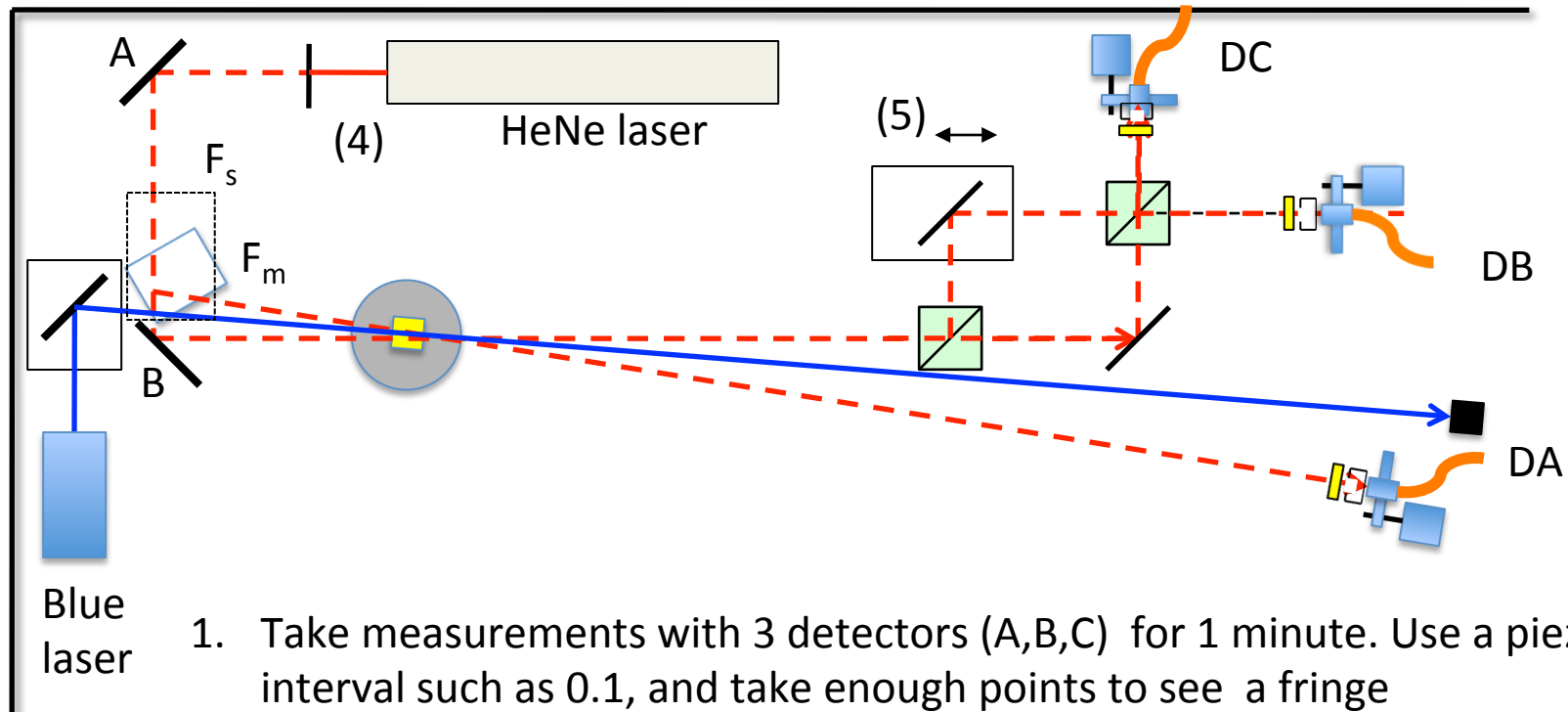


4. Block the HeNe laser, turn the electronics and look for coincidences.
5. Run the Matlab program "ContinuousCountingPiezo." With this program you can manually set up the voltage on the piezo and see the interference. The best test is, of course, adjusting the piezo for a minimum and then blocking one arm.
6. Do piezo scan with Matlab program "PiezoScan_3Detectors_Altera." DB and DC should show complementary fringes.

Activity III (Tues-PM/ Wed-AM)– Single-photon existence and the Hanbury-Brown-Twist Test

- Goals:
 - To prove that photons exist.
 - Measurement of the anti-correlation parameter.
- Materials (Same as previous setup):

Activity IV (Tues. PM/Wed. AM): Single-photon interference.



1. Take measurements with 3 detectors (A,B,C) for 1 minute. Use a piezo interval such as 0.1, and take enough points to see a fringe
2. Hanbury-Brown-Twiss test: compute for each data point.

$$g = \frac{N_{ABC} N_A}{N_{AB} N_{AC}}$$

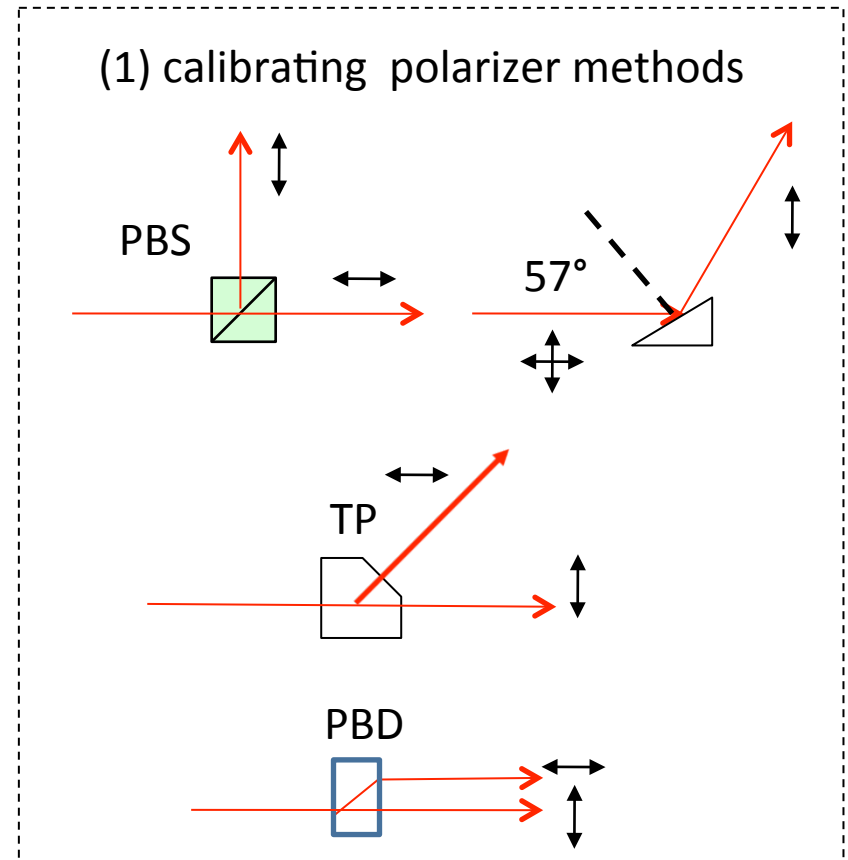
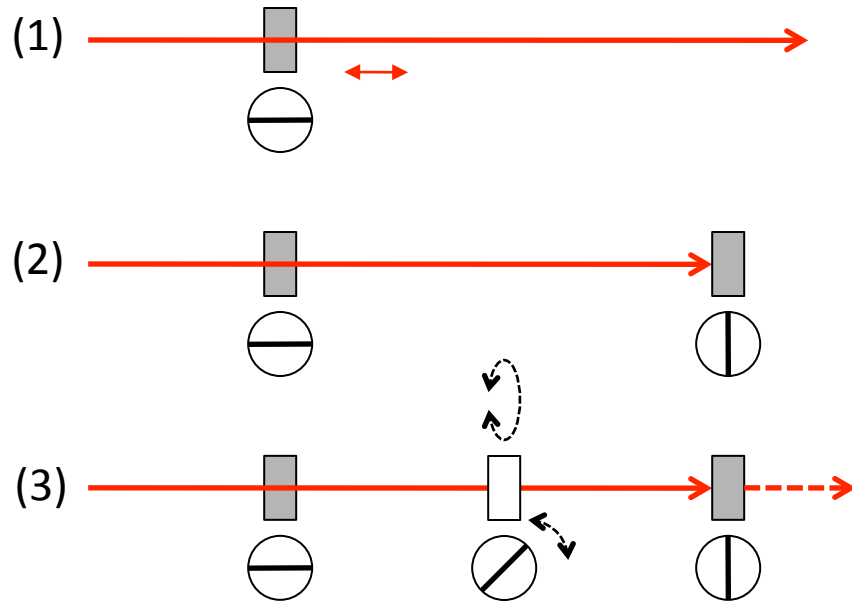
3. The error is approximately $\Delta g = \frac{g}{\sqrt{N_{ABC}}}$

if $g < 1$ then you are measuring single photons! Even though detectors B and C show interference the photon is detected in only one place. ¹⁷

Activity V (Wednesday AM)– Waveplates

- Goals:
 - To learn how to align and set up waveplates.
- Materials:
 - Hardware:
 - Glan-Thompson polarizers (Q)
 - Polarizing beam splitter (N)
 - 2 half-wave plates M on a rotation mounts (best if they have an adjustable zero setting).

Activity V (Wed. AM): Setting up waveplates (already done for you, but verify it).

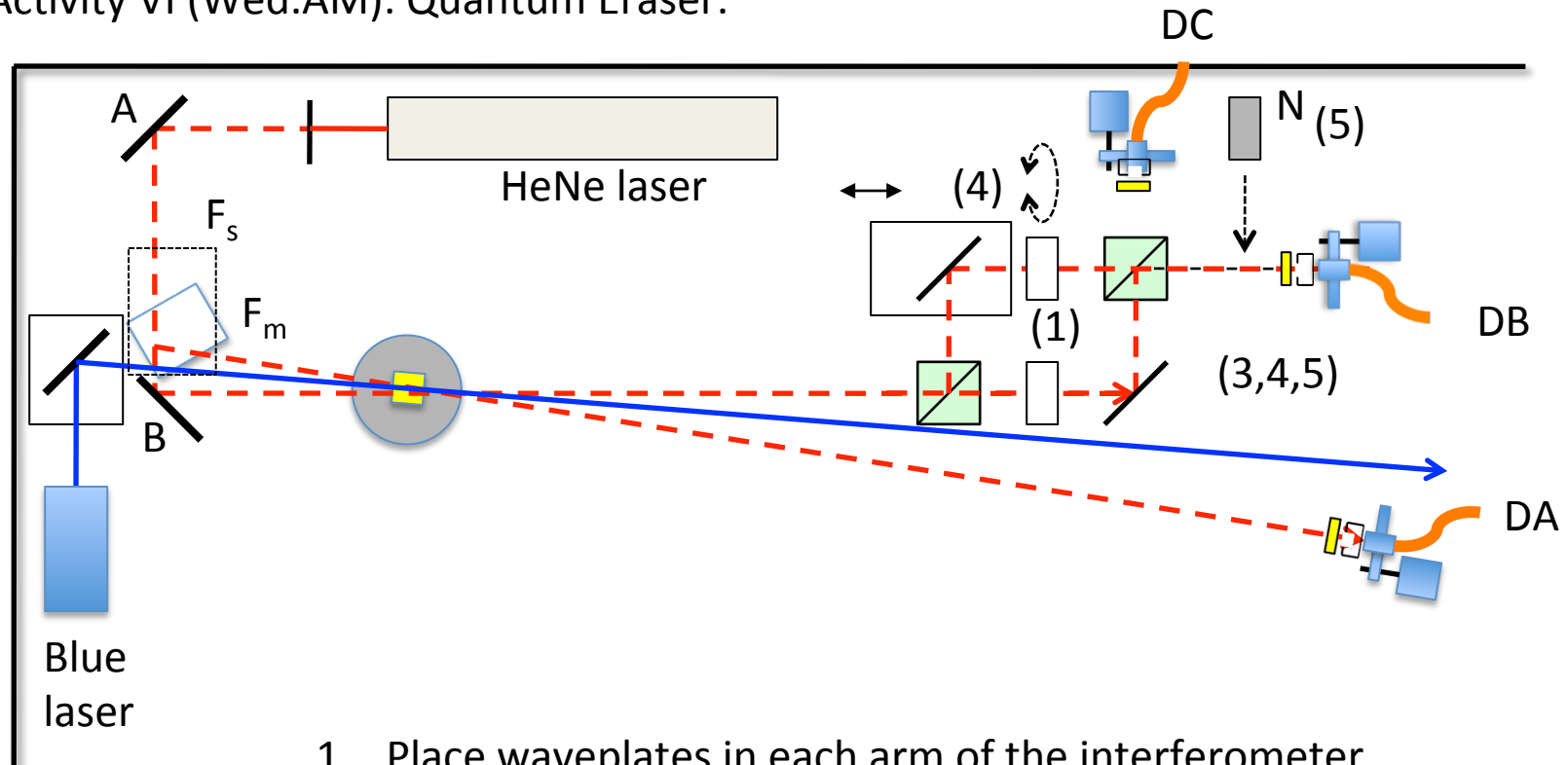


1. Set a polarizer with its transmission axis horizontal. Calibrate the polarizer using: either polarizing beam splitter (PBS), Thompson prism (TP), polarizing beam displacer (PBD) or Brewster reflection of glass prism. The polarizers (Q) you have are already calibrated.
2. Insert a second polarizer with its transmission axis vertical so no light is transmitted.
3. Insert the half-wave plate in between the polarizers. When the axis of the waveplate is aligned with either polarizer (it does not matter which), there should be no light transmitted through the second polarizer.
4. Use this method to find the axes of both waveplates.

Activity VI (Wednesday AM, PM)– Quantum eraser

- Goals:
 - To learn how to setup and take data on the quantum eraser.
- Materials:
 - Hardware:
 - Interferometer from Activity IV.
 - 2 waveplates M
 - Polarizing beam splitter N from Activity IV. The polarizer should be oriented 45 degrees from horizontal.
 - Plate-guide P to position the polarizer in the dark.

Activity VI (Wed.AM): Quantum Eraser.

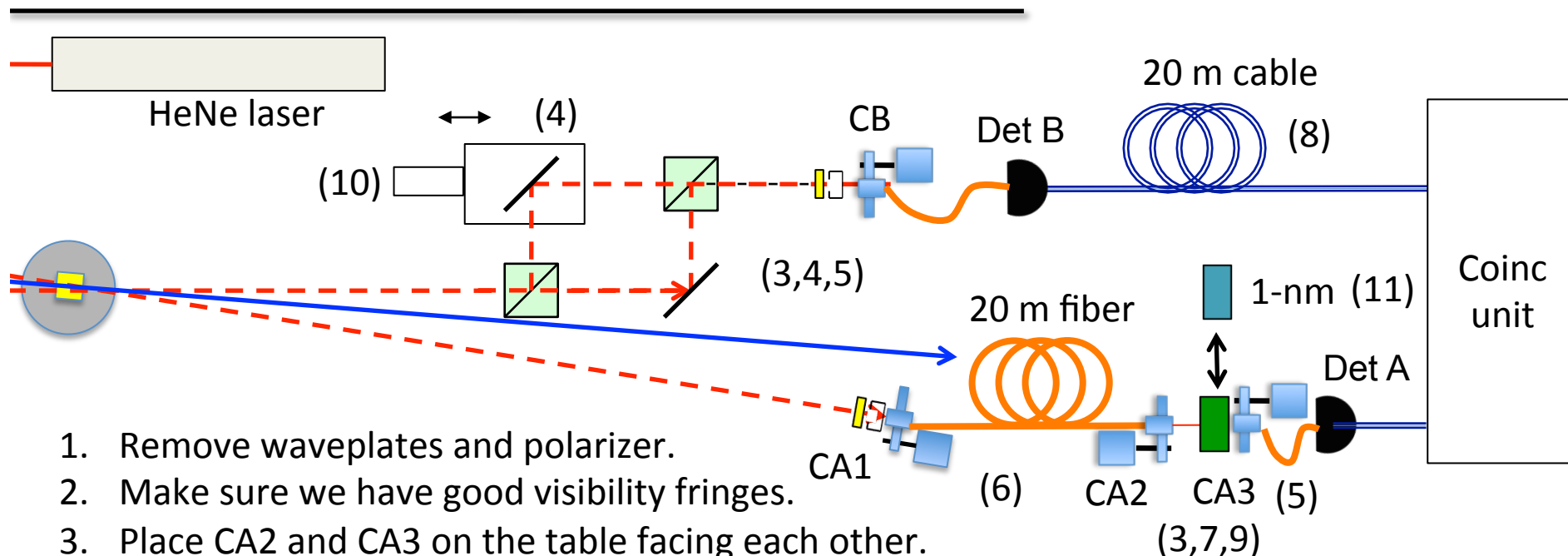


1. Place waveplates in each arm of the interferometer.
2. Redo the white-light fringes adjustment.
3. Do a piezo scan. It should show high-visibility fringes.
4. Rotate one of the waveplates by 45 degrees. Redo the scan. It should show no fringes.
5. Place the polarizer (N) tilted 45 degrees after the interferometer. Redo the scan. Fringes in DB should reappear at half the amplitude.

Activity VII (Wednesday PM) Delayed Choice

- Goals:
 - To learn to set up delayed choice
 - Get immersed in its implications
- Materials:
 - Same setup as the quantum eraser
 - Additional Hardware:
 - 2 additional collimators
 - 1-nm filter
 - 20-m coaxial cable
 - 20-m multimode fiber

Activity VII (Wed.PM): Delayed Choice.



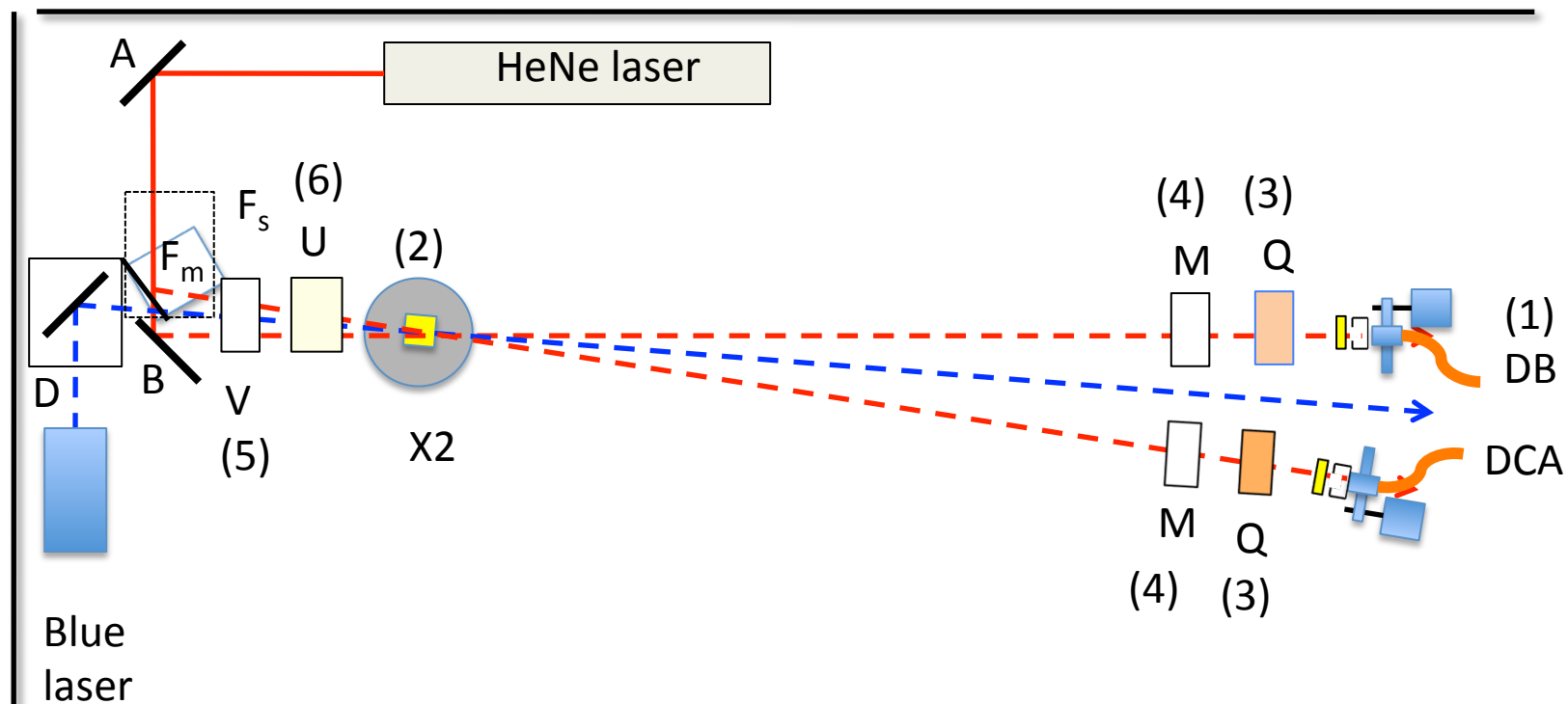
1. Remove waveplates and polarizer.
2. Make sure we have good visibility fringes.
3. Place CA2 and CA3 on the table facing each other.
4. Remove 40-nm filter from CA1
5. Disconnect fiber from CA1 and connect to CA3.
6. Connect 20-m fiber from CA1 to CA2.
7. Align CA2 and CA3 so that the light from CA2 goes into CA3. Do this with the NeNe laser. Make sure that the light goes all the way to CA3.
8. Inset 20-m coaxial cable in the path of the electronic signal from Detector B.
9. Place 40-nm filter in between CA2 and CA3 and observe single-photon fringes.
10. "Nudge" micrometer of the interferometer and observe fringes. Repeat until there are no fringes.
11. Replace 40-nm filter between CA2 and CA3 with 1-nm filter. Take scan.

Activity VIII (Wednesday PM, Thursday AM)

Entanglement and Bell

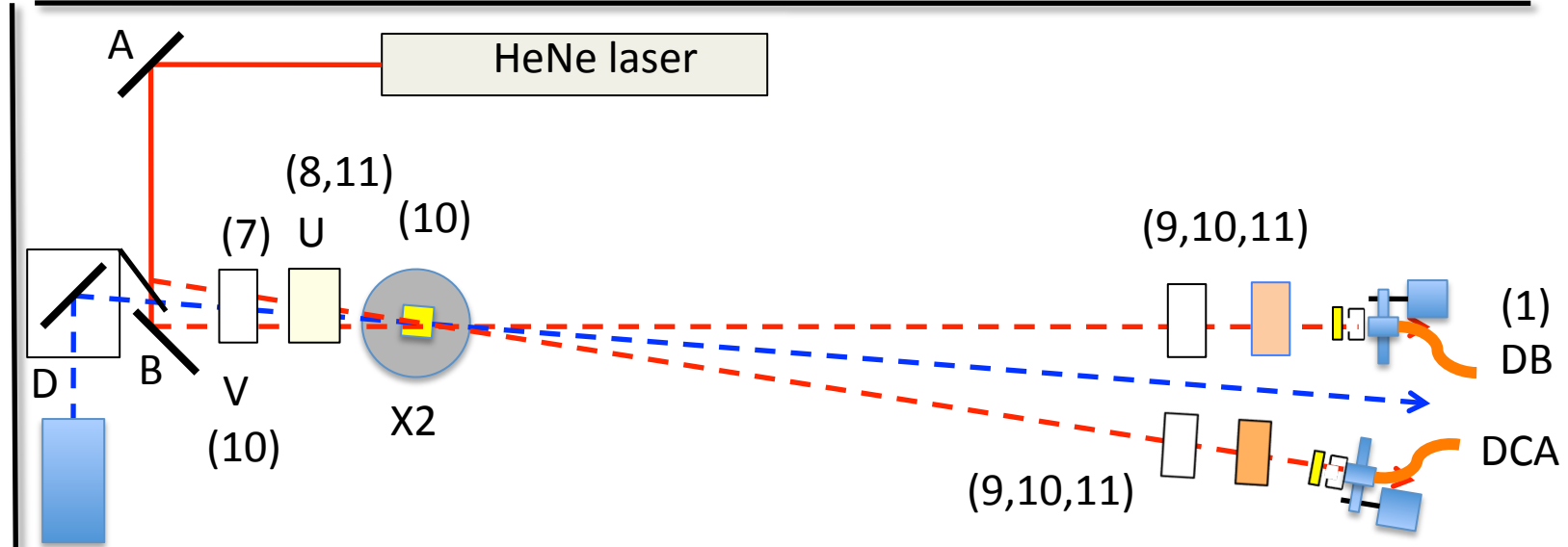
- Goals:
 - To learn how to setup an entangled state
 - To measure nonlocal correlations
 - To do a measurement of a Bell inequality
- Materials:
 - Hardware:
 - Setup from Activity II, but with two-crystal BBO (X2)
 - 2 waveplates (M)
 - Polarizers Q set to transmit horizontal polarization.
 - Half-wave plate for blue laser V.
 - Compensating quartz crystal U.

Activity VII (Wed. PM): Entanglement.



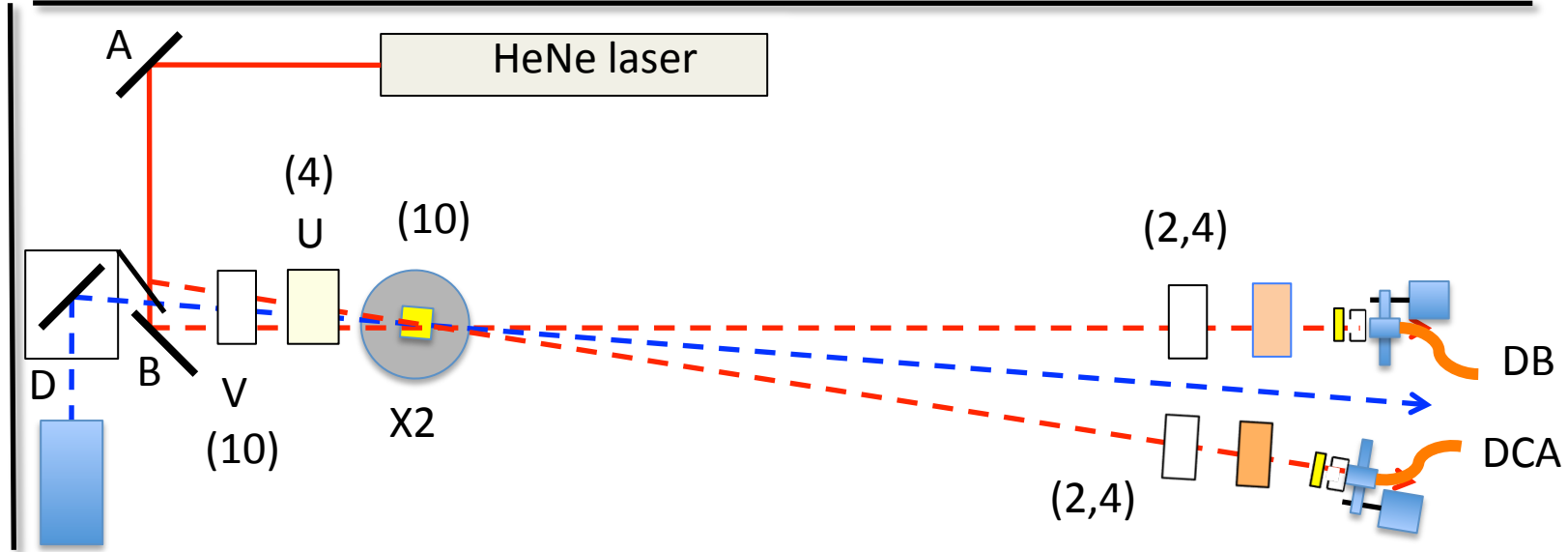
1. Remove the interferometer and relocate DB.
2. Place Crystal X2 (the pair of type-I crystals).
3. Place polarizers Q before the filters.
4. Place zero-order half waveplates M before the polarizers.
5. Place zero-order half waveplate V (for 405 nm) before the crystals.
6. Place compensating crystal U before the down-conversion crystal.

Activity VII (Wed. PM): Entanglement.



7. Rotate pump polarization to 45-degrees with HWP (to 22.5 deg).
8. Compensating crystal axis should be aligned the same as the second down-conversion crystal of the pair. If not known (common), guess.
9. Polarizers should be fixed. The HWP-polarizer pair are to be set up so that they act as a rotating polarizer (remember that HWP rotates at twice the angle).
10. Measure coincidences and tilt the crystal pair so that:
 - HH and VV should be maximum (and \sim equal). Hor(vert) tilt for VV(HH).
 - HV and VH should be a minimum (ideally zero)
11. Tilt the compensating crystal so that:
 - DD and AA are maximum (as much as HH or VV)
 - DA and AD must be minimum (ideally zero) – if no success, then rotate U 90 degrees about its axis.

Activity VII (Wed. PM): Entanglement.



1. Understand the table on the right.
2. Take data by moving the two half-wave plates. Use program "Paused_3Detectors_Altera"
3. Do the calculation using the spreadsheet provided. They should violate the Bell inequality.
4. Rotate the quartz plate by 90 degrees to put the light in a mixed state, or add an additional dephasing optics, and repeat the measurements. They should *not* violate Bell inequality.

#	State	Hwp-A	Hwp-B	Coinc(2)	Coinc(4)
1	a',b	22.5	11.25		
2	a',b+	22.5	56.25		
3	a'+,b	67.5	11.25		
4	a'+,b+	67.5	56.25		
5	a',b'	22.5	33.75		
6	a',b'+	22.5	78.75		
7	a'+,b'	67.5	33.75		
8	a'+,b'+	67.5	78.75		
9	a,b	0	11.25		
10	a,b+	0	56.25		
11	a+,b	45	11.25		
12	a+,b+	45	56.25		
13	a,b'	0	33.75		
14	a,b'+	0	78.75		
15	a+,b'	45	33.75		
16	a+,b'+	45	78.75		

(1)