HAUNTED QUANTUM ENTANGLEMENT WHEN THE ENTANGLED ENTITIES ARE DISTANT FROM EACH OTHER AND WHERE ONLY PHOTONS ARE THE ENTANGLED ENTITIES

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MODIFIED ABSTRACT

HAUNTED QUANTUM ENTANGLEMENT INVOLVES ENTANGLEMENT BETWEEN TWO ENTITIES WHERE ENTANGLEMENT IS BASED ON ONE ENTITY SUPPLYING WHICH-WAY INFORMATION TO THE OTHER. THIS ENTANGLEMENT IS LOST BEFORE WHICH-WAY INFORMATION EMBODIED IN THE ENTANGLEMENT BECOMES AVAILABLE IN THE ENVIRONMENT.[i] THE RESULT OF LOSING ENTANGLEMENT IS THE LOSS OF WHICH-WAY INFORMATION EMBODIED IN THE ENTANGLEMENT. ONE OBTAINS YOUNG INTERFERENCE AS IF WHICH-WAY INFORMATION NEVER EXISTED IN THE DISTRIBUTION OF THE ENTITY THAT HAD BEEN SUPPLIED WHICH-WAY INFORMATION BY THE OTHER ENTITY WITH WHICH IT HAD BEEN ENTANGLED (NOT FRINGES AND ANTI-FRINGES THAT REQUIRE CORRELATION OF DETECTION DATA FOR THE ENTANGLED ENTITIES AS IN A QUANTUM ERASER). IN ONE HQE SCENARIO PRESENTED, WHICH-WAY INFORMATION SUPPLIED BY PHOTONS AS CONCERNS THE DISTRIBUTION OF ATOMS WITH WHICH THEY ARE ENTANGLED IS ELIMINATED AT A DISTANCE BETWEEN THE PAIRED ATOM AND PHOTON WHEN THE PHOTON IS ESSENTIALLY LOST

IN CLASSICAL MICROWAVE RADIATION BEFORE WHICH-WAY INFORMATION EMBODIED IN THE ENTANGLEMENT BECOMES AVAILABLE IN THE ENVIRONMENT. IN THE SECOND HQE SCENARIO, ENTANGLEMENT BETWEEN PAIRED SIGNAL AND IDLER PHOTONS IS LOST BEFORE WHICH-WAY INFORMATION EMBODIED IN THE ENTANGLEMENT BECOMES AVAILABLE IN THE ENVIRONMENT. THE RESULT IS THAT WHICH-WAY INFORMATION PROVIDED BY IDLER PHOTONS AS CONCERNS THE DISTRIBUTION OF THEIR PAIRED SIGNAL PHOTONS IS LOST. THE ENTANGLED PHOTON PAIRS ARE CREATED IN A SIMILAR PROCESS TO THAT USED BY KIM ET AL. IN THEIR QUANTUM ERASER. IN THE SECOND HQE SCENARIO, THE PHOTON CARRYING THE WHICH-WAY INFORMATION (I.E., THE IDLER PHOTON) IS EFFECTIVELY LOST THROUGH THE RELEASE OF CLASSICAL EM RADIATION OF A SIMILAR CHARACTER TO THE IDLER PHOTON INTO A BOX THAT IS EVACUATED (EXCEPT FOR THE IDLER PHOTON THAT TRAVERSES THE BOX INITIALLY ON ONE OF TWO POSSIBLE PATHS TO A DETECTOR) BEFORE THE SIGNAL PHOTON REACHES ITS DETECTION AXIS. ``TWO SLIT'' INTERFERENCE FOR THE SIGNAL PHOTON SHOWS NO EVIDENCE THAT WHICH-WAY INFORMATION EVER EXISTED REGARDING THE SIGNAL PHOTON.

TEXT

MY PAPER CONCERNS HAUNTED QUANTUM ENTANGLEMENT. MY INTEREST IN THIS TOPIC GREW OUT OF READING ABOUT THE HAUNTED

MEASUREMENT AND THE QUANTUM ERASER. I HAVE EIGHT FIGURES THAT I INTEND TO USE TO ILLUSTRATE MY POINTS.

FIGURE 1 **IS A DEPICTION OF*:***

- **GREENBERGER AND YASIN'S HAUNTED MEASUREMENT**

  THERE IS A NEUTRON INTERFEROMETER WITH AN ISOLATED FLEXIBLE MIRROR APPARATUS ALONG ONE ARM.

  WHILE THE NEUTRON PASSES THROUGH THE FLEXIBLE MIRROR APPARATUS, THERE IS WHICH-WAY INFORMATION REGARDING THE PATH OF THE NEUTRON. THE WHICH-WAY INFORMATION IS PRODUCED BY THE CHANGE IN MOMENTUM AND POSITION OF THE FLEXIBLE MIRROR APPARATUS THAT RESULTS FROM ITS INTERACTION WITH THE NEUTRON.

  AFTER THE NEUTRON EXITS THE FLEXIBLE MIRROR APPARATUS, ALL WHICH-WAY INFORMATION IS ELIMINATED AND INTERFERENCE IS RESTORED AS IF THE WHICH-WAY INFORMATION NEVER EXISTED. THE ORIGINAL MOMENTUM AND POSITION OF THE FLEXIBLE MIRROR APPARATUS ARE RESTORED.

  RELEVANT EQUATIONS FOR A HAUNTED QUANTUM MEASUREMENT ARE FOUND AT THE END OF THE PRESENTATION.

FIGURE 2 **IS A DEPICTION OF*:***

- **SCULLY, ENGLERT, AND WALTHER'S QUANTUM ERASER**

  AN ATOM ENTERS THE MICROMASER CAVITY SYSTEM, ON THE LEFT OF THE FIGURE, AND EMITS A PHOTON INTO ONE OF THE TWO CAVITIES. THE CAVITIES HAVE NO OTHER PHOTONS IN THEM, AND THEY ARE TUNED TO THE SAME FREQUENCY. THE CAVITIES ARE SEPARATED BY SHUTTERS. BETWEEN THE SHUTTERS IS A PHOTODETECTOR.

  THE ATOM EXITS THE CAVITY SYSTEM, PASSES THROUGH THE DOUBLE SLIT, AND PASSES ON TO THE DETECTION SCREEN. SOMETIME AFTER EXITING THE CAVITY SYSTEM, THE SHUTTERS ON THE MM CAVITIES ARE OPENED AND THE PHOTODETECTOR IS EXPOSED. THERE IS A 50-50 CHANCE THE PHOTON WILL BE DETECTED AT THE PHOTODETECTOR.

  WHETHER OR NOT THE PHOTON IS DETECTED AT THE PHOTODETECTOR, WHICH-WAY INFORMATION IS LOST. THE RESULT IS FRINGES AND ANTI-FRINGES WHEN ATOM DETECTION DATA AND PHOTODETECTION DATA ARE CORRELATED.

- **THE AUTHORS OF THE ARTICLES ON THE HAUNTED MEASUREMENT AND THE QUANTUM ERASER ACKNOWLEDGED SIMILARITIES IN THEIR WORK.**

- **BOTH THE HAUNTED MEASUREMENT AND THE QUANTUM ERASER CREATE WHICH-WAY INFORMATION THROUGH ENTANGLEMENT AND WHICH-WAY INFORMATION IS SUBSEQUENTLY ELIMINATED.**

- **THERE IS A DIFFERENCE BETWEEN THE HAUNTED MEASUREMENT AND THE QUANTUM ERASER:**

  IN THE HAUNTED MEASUREMENT, INTERFERENCE IS RESTORED AS IF THE WHICH-WAY INFORMATION NEVER EXISTED.

  IN THE QUANTUM ERASER, THERE ARE FRINGES AND ANTI-FRINGES THAT SUM TO AN *OVERALL ONE WIDE HUMP INDICATIVE OF WHICH-WAY INFORMATION*.

- **WHAT IS THE BASIS FOR THE DIFFERENCE IN THE DISTRIBUTION PATTERNS IN THE HM AND THE QE?**

  IN A HAUNTED MEASUREMENT, THE ENTANGLEMENT IS LOST BEFORE ANY MEASUREMENT INFORMATION BECOMES AVAILABLE IN THE ENVIRONMENT. THE FLEXIBLE MIRROR APPARATUS IS ISOLATED.

  IN THE QUANTUM ERASER, THE ENTANGLEMENT IS MAINTAINED. I SUSPECT THE ENTANGLEMENT IS MAINTAINED IN PART DUE TO THE AVAILABILITY OF INFORMATION IN THE ENVIRONMENT THAT

A WHICH-WAY MEASUREMENT HAS OCCURRED WITH THE PASSAGE OF THE ATOM THROUGH THE DOUBLE SLIT. THE INTERIORS OF THE MM CAVITIES THEMSELVES ARE ISOLATED, AND THUS WHICH *SPECIFIC* PATH THE ATOM TOOK FROM ONE OF THE CAVITIES TO ONE OF THE SLITS IN THE DOUBLE SLIT IS NOT AVAILABLE IN THE ENVIRONMENT.

WITH THE OPENING OF THE SHUTTERS BETWEEN THE MM CAVITIES, INFORMATION REGARDING IN WHICH *SPECIFIC* MM CAVITY THE PHOTON WAS EMITTED IS LOST. INFORMATION THAT A WHICH-WAY MEASUREMENT HAS OCCURRED IS PRESERVED DUE TO THE EARLIER AVAILABILITY OF THIS INFORMATION IN THE ENVIRONMENT.

RELEVANT EQUATIONS FOR THE QUANTUM ERASER ARE FOUND AT THE END OF THE PRESENTATION.

- **IN A SETUP LIKE THE QUANTUM ERASER, CAN ONE OBTAIN INTERFERENCE AS IF THE WHICH-WAY INFORMATON NEVER EXISTED AND WHERE THE WHICH-WAY INFORMATION WAS CARRIED BY THE PHOTON?**

TO ACCOMPLISH THIS TASK, THE QE SCENARIO NEEDS TO BE CHANGED SO THAT THE ENTANGLEMENT BETWEEN THE PHOTON AND THE ATOM IS LOST *BEFORE* THE ATOM REACHES THE

DOUBLE SLIT SCREEN. THIS PROCESS IS HAUNTED QUANTUM ENTANGLEMENT.

FIGURE 3

- **AT END OF THE QE PAPER, THE AUTHORS PRESENT A SCENARIO LIKE THE QE BUT IN WHICH THE ATOM CARRIES THE WHICH-WAY INFORMATION, NOT THE PHOTON. THERE IS A SINGLE WALL SEPARATING THE MM CAVITIES. THE MICROMASER CAVITIES ARE FILLED WITH CLASSICAL MICROWAVE RADIATION, AND THE PHOTON THAT THE ATOM EMITS IS LOST IN THIS RADIATION. IT IS NOT KNOWN INTO WHICH CAVITY THE PHOTON WAS EMITTED.**

  THE ATOM ITSELF CARRIES WHICH-WAY INFORMATION BECAUSE THE MICROMASER CAVITIES ARE TUNED TO *DIFFERENT* FREQUENCIES. AT ONE EXIT OF THE MM CAVITY SYSTEM, AN RF COIL IS PLACED SO THAT IF THE ATOM PASSED THROUGH THE CAVITY ASSOCIATED WITH THAT EXIT, THE ATOM IS PLACED IN THE SAME STATE IT WOULD BE IN IF IT HAD EXITED THE OTHER CAVITY. THE RESULT IS AN INTERFERENCE PATTERN LIKE GREENBERGER AND YASIN'S, AS IF THE WHICH-WAY INFORMATION HAD NEVER EXISTED.

FIGURE 4

- **TO ACCOMPLISH THE GOAL OF OBTAINING INTERFERENCE AS IF WHICH-WAY INFORMATION NEVER EXISTED AND WHERE THE PHOTON CARRIED THE WHICH-WAY INFORMATION, A SINGLE WALL SEPARATES THE MICROMASER CAVITIES. THERE ARE RESERVOIRS OF CLASSICAL MICROWAVE RADIATION ADJACENT TO EACH MM CAVITY. IF THE CLASSICAL MICROWAVE RADIATION IS NOT RELEASED INTO THE MM CAVITIES, THE RESULTING DISTRIBUTION OF THE ATOMS IS THE ONE WIDE HUMP CHARACTERISTIC OF WHICH-WAY INFORMATION.**
- **[SHOW FIGURE 2 AND POINT OUT ONE WIDE HUMP.]**

FIGURE 5

CONTINUING ON WITH THE STEPS NEEDED TO ACCOMPLISH THE GOAL OF OBTAINING INTERFERENCE AS IF WHICH-WAY INFORMATION NEVER EXISTED AND WHERE THE PHOTON CARRIED THE WHICH-WAY INFORMATION, THE ENTANGLEMENT IS ELIMINATED BY LOSING THE PHOTON *BEFORE* THE ATOM REACHES THE DOUBLE SLIT. THE PHOTON IS LOST BY FILLING BOTH MM CAVITIES WITH CLASSICAL MICROWAVE RADIATION *AFTER* THE PHOTON IS EMITTED AND THE ATOM EXITS THE CAVITY SYSTEM.

ANY POSSIBILITY OF THE ATOM ITSELF CARRYING WHICH-WAY INFORMATION IS ELIMINATED BY PLACING AN RF COIL THAT EXTENDS A FIELD OVER BOTH PATHS FROM THE EXITS OF THE

MICROMASER CAVITIES THAT PLACES THE ATOM IN THE STATE IT HAD BEFORE IT EMITTED THE PHOTON.

- **THIS IS HAUNTED QUANTUM ENTANGLEMENT WHERE INTERFERENCE IS OBTAINED AS IF THE WHICH-WAY INFORMATION NEVER EXISTED AND THE PHOTON CARRIED THE WHICH-WAY INFORMATION FOR THE ATOM THAT IS DISTANT FROM IT. THE WHICH-WAY INFORMATION CARRIED BY THE PHOTON IS ELIMINATED *AT A DISTANCE* FROM THE ATOM WITH THE LOSS OF THE ENTANGLEMENT BETWEEN THE ATOM AND THE PHOTON. IN ESSENCE, THERE IS A DELAYED CHOICE WHETHER TO OBTAIN A ONE WIDE HUMP DISTRIBUTION CHARACTERISTIC OF WHICH-WAY INFORMATION OR A MULTIPLE NARROW HUMP DISTRIBUTION CHARACTERISTIC OF INTERFERENCE. RELEVANT EQUATIONS FOR HAUNTED QUANTUM ENTANGLEMENT ARE FOUND AT THE END OF THE PRESENTATION.**

GREENBERGER AND YASIN DEMONSTRATED HAUNTED QUANTUM ENTANGLEMENT IN THEIR EXPERIMENT WHERE THEY OBTAINED INTERFERENCE AS IF THE WHICH-WAY INFORMATON PROVIDED BY THE FLEXIBLE MIRROR APPARATUS HAD NEVER EXISTED. WHICH-WAY INFORMATION IN THEIR HAUNTED MEASUREMENT, THOUGH, IS ELIMINATED BY A DIRECT INTERACTION BETWEEN THE FLEXIBLE MIRROR APPARATUS AND THE NEUTRON INSTEAD OF AT A DISTANCE BETWEEN THEM AS OCCURS IN THE HQE SCENARIO PRESENTED HERE.

FIGURE 6

SO FAR, WE HAVE BEEN CONCERNED WITH PHOTONS AS WELL AS ATOMS IN OUR SCENARIOS. THE HQE SCENARIO JUST PRESENTED CAN BE EXTENDED TO ONE WHERE WE ARE DEALING ONLY WITH PHOTONS. TO DO SO, ONE CAN MODIFY THE QUANTUM ERASER SCENARIO OF KIM, YU, KULIK, SHIH, AND SCULLY.

- **KIM AND HIS COLLEAGUES PERFORMED A NOVEL FORM OF QUANTUM ERASER EXPERIMENT THAT INCORPORATED THE SAME FUNDAMENTALS AS THOSE DISCUSSED ABOVE FOR THE EXPERIMENT BY SCULLY AND HIS COLLEAGUES. KIM AND HIS COLLEAGUES USED A DEVICE THAT COULD ACT AS AN INTERFEROMETER WITH TWO POSSIBLE SEPARATE PHOTON-PAIR SOURCES.**

THE ENTANGLED SIGNAL-IDLER PHOTON PAIRS WERE PRODUCED BY KIM AND HIS COLLEAGUES AT ONE OF TWO POSSIBLE LOCATIONS (LIKE ONE SLIT IN A TWO SLIT SCREEN). THE ENTANGLEMENT INCORPORATED THE IDLER PHOTON'S PROVIDING WHICH-WAY INFORMATION CONCERNING THE PATH OF THE SIGNAL PHOTON THAT MANIFESTED ITSELF IN THE DISTRIBUTION OF THE SIGNAL PHOTONS AT THEIR DETECTION AXIS. THE SIGNAL PHOTON ITSELF ESSENTIALLY CARRIED NO WHICH-WAY INFORMATION AS REGARDS ITS DISTRIBUTION AT ITS DETECTION AXIS. (THAT IS

WHAT ALLOWED THE SIGNAL PHOTON TO EXHIBIT INTERFERENCE IN THE FORM OF FRINGES OR ANTI-FRINGES WHEN DETECTION DATA FOR THE ENTANGLED ENTITIES IS CORRELATED AFTER WHICH-WAY INFORMATION CARRIED BY THE IDLER PHOTON IS LOST.)

BESIDES FUNCTIONING AS AN INTERFEROMETER, KIM AND HIS COLLEAGUES ALSO USED THIS APPARATUS SO THAT ONE-HALF OF THE IDLER PHOTONS PASSING THROUGH THE FIRST PART OF THE DEVICE, SPECIFICALLY THAT PART OF THE DEVICE FROM M TO Y OR Z, PROVIDE WHICH-WAY INFORMATION REGARDING THE PATH OF THE OTHER PAIRED SIGNAL PHOTON. THEY ACCOMPLISHED THIS THROUGH THE USE OF BEAM SPLITTERS INSTEAD OF FULL-SILVERED MIRRORS AT Y AND Z. IN THEIR EXPERIMENT, ½ OF THE GENERATED IDLER PHOTONS TRAVELED THROUGH THE BEAM SPLITTERS AT Y AND Z INSTEAD OF BEING REFLECTED AT Y AND Z TOWARD BEAM SPLITTER BS AT N.

THE SIGNAL PHOTON TRAVELS AWAY FROM THE INTERFEROMETER AND IMPACTS A DETECTION SYSTEM THAT DETECTS THE LOCATION OF THIS PHOTON ALONG AN AXIS. WITH REGARD TO THE IDLER PHOTONS TRAVELING *THROUGH* THE BEAM SPLITTERS AT Y AND Z (I.E., BS_Y AND BS_Z), THE TWO DISTRIBUTIONS OF THE DETECTED SIGNAL PHOTONS CORRELATED WITH THE DETECTIONS OF THEIR PAIRED IDLER PHOTONS EACH SHOWED THE ONE BROAD HUMP CHARACTERISTIC OF WHICH-WAY INFORMATION. (BOTH OF THESE DISTRIBUTIONS OF THE SIGNAL PHOTONS HAD THE GENERAL

SHAPE OF THE DISTRIBUTION IN FIG. 4, NAMELY A SINGLE WIDE HUMP. THE TWO DISTRIBUTIONS SUMMED TO AN OVERALL ONE BROAD HUMP AS WELL.)

FOR THE ½ OF THE GENERATED IDLER PHOTONS THAT ARE INSTEAD REFLECTED AT THE BEAM SPLITTERS AT Y OR Z TOWARD BS AT N AND THAT ARE SUBSEQUENTLY DETECTED AT DETECTORS D1 *OR* D2, THE DISTRIBUTIONS OF THE SIGNAL PHOTONS DETECTED ALONG A SPATIAL AXIS X CORRELATED WITH THE DETECTIONS OF THEIR PAIRED IDLER PHOTONS ARE TWO MULTIPLE NARROW HUMP SUB-DISTRIBUTIONS THAT INDICATE THE PRESENCE OF INTERFERENCE (I.E., FRINGES AND ANTI-FRINGES).

THE FRINGES AND ANTI-FRINGES SUB-DISTRIBUTIONS FOR THE SIGNAL PHOTONS SUM TO THE ONE WIDE HUMP CHARACTERISTIC OF WHICH-WAY INFORMATION. THESE FRINGES AND ANTI-FRINGES INDICATE THE *LOSS* OF WHICH-WAY INFORMATION CONCERNING THE *SPECIFIC* PATH THROUGH THE INTERFEROMETER OF THE PAIRED IDLER PHOTONS THAT PASS THROUGH, OR ARE REFLECTED FROM, BS AT N. THIS SPECIFIC WHICH-WAY INFORMATION CONCERNING THE PATH OF THE IDLER PHOTON THROUGH THE INTERFEROMETER UNTIL BS AT N STEMMED FROM THE ORIGIN OF THE ENTANGLED IDLER AND SIGNAL PHOTON PAIRS AT ONE SPECIFIC LOCATION OF TWO POSSIBLE ONES IN WHICH THE SIGNAL-IDLER PHOTON PAIRS COULD BE GENERATED. THESE TWO

LOCATIONS WERE LIKE THE TWO SLITS IN A DOUBLE SLIT EXPERIMENT USED TO DEMONSTRATE INTERFERENCE.

EVEN THOUGH SPECIFIC WHICH-WAY INFORMATION IS LOST CONCERNING THE PATH OF THE IDLER PHOTON THROUGH THE INTERFEROMETER, GENERAL WHICH-WAY INFORMATION THAT A WHICH-WAY MEASUREMENT OCCURRED APPEARS TO BE PRESERVED IN THE ONE WIDE HUMP DISTRIBUTION OF THE SIGNAL PHOTONS IN THE SIGNAL-IDLER PHOTON PAIRS THAT IS THE SUM OF THE FRINGES AND ANTI-FRINGES. THIS WHICH-WAY INFORMATION IS LIKELY THE RESULT OF THE TWO "SLITS" IN THE IDLER INTERFEROMETER WHERE THE SIGNAL-IDLER PHOTON PAIRS COULD ORIGINATE AT ONE OF THE "SLITS". THOSE SLITS ARE NOT ISOLATED AND INFORMATION CONCERNING THEM IS CONTINUOUSLY AVAILABLE TO THE ENVIRONMENT.

AS NOTED, WHICH-WAY INFORMATION REGARDING THE DISTRIBUTION OF THE SIGNAL PHOTON AT ITS DETECTION AXIS IS NOT PROVIDED IN THE KIM EXPERIMENT BY THE *SIGNAL* PHOTON ITSELF TRAVELING AWAY FROM THE INTERFEROMETER AND TOWARD THE SPATIAL AXIS WHERE ITS LOCATION IS DETECTED. SHORTLY AFTER THE SIGNAL IDLER PHOTON PAIR IS GENERATED, THE COMPONENT WAVE FUNCTIONS FOR THE SIGNAL PHOTON FOR THE TWO POSSIBLE LOCATIONS WHERE THE SIGNAL IDLER PHOTON PAIR WERE CREATED OVERLAP. ESSENTIALLY, WE HAVE A KIND OF "DELAYED CHOICE" EXPERIMENT (WHEELER, 1978, 1984) WHERE

THE "DELAYED CHOICE" INVOLVES WHETHER THE IDLER PHOTON PASSES THROUGH ONE OF THE HALF-SILVERED MIRRORS (THAT TAKE THE PLACE OF FULL SILVERED MIRRORS) AND TRAVELS TO A DETECTOR OR INSTEAD IS REFLECTED OFF ONE OF THE HALF-SILVERED MIRRORS, PASSES THROUGH THE BEAM SPLITTER AT THE INTERSECTION OF THE TWO POSSIBLE PATHS OF THE IDLER PHOTON THROUGH THE INTERFEROMETER AND IS THEN DETECTED. WHICH-WAY INFORMATON FOR THE SIGNAL PHOTON AS REGARDS THIS "DELAYED CHOICE" IS DEPENDENT ON THE PAIRED IDLER PHOTON. THE DIMENSIONS OF THE DOUBLE SLIT RELATIVE TO THE WAVELENGTH OF THE SIGNAL PHOTONS SUPPORTS INTERFERENCE IN THE DISTRIBUTION OF THE SIGNAL PHOTONS AT THEIR DETECTION AXIS IN THE ABSENCE OF WHICH-WAY INFORMATION PROVIDED BY THE IDLER PHOTONS.

FIGURE 7

- **IN ORDER TO EXTEND HQE TO A SCENARIO WHERE WE ARE DEALING ONLY WITH PHOTONS, THE APPARATUS OF KIM AND HIS COLLEAGUES CAN BE CHANGED AS FOLLOWS. THE DEVICE RETAINS THE FIRST LEGS OF THE TWO ARMS OF AN INTERFEROMETER WITH TWO POSSIBLE PHOTON SOURCES (CALL THIS PART OF THE APPARATUS THE IDLER APPARATUS.)**

THE IDLER PHOTON MOVING THROUGH THE IDLER APPARATUS IS INITIALLY ENTANGLED WITH A SECOND PAIRED PHOTON (THE

SIGNAL PHOTON) INITIALLY GENERATED AT A SINGLE LOCATION (ONE OF TWO POSSIBLE "SLITS"). THE IDLER PHOTON TRAVELS FROM ITS LOCATION OF ORIGINATION OF THE SIGNAL-IDLER PHOTON PAIR AT ONE "SLIT" OF THE "DOUBLE SLIT" ARRANGEMENT, TRAVELS ALONG THE PARTICULAR PATH ASSOCIATED WITH THE "SLIT" WHERE THE PARTICLE PAIR WAS CREATED, AND INTERACTS WITH ONE OF TWO DETECTORS. EACH DETECTOR IS LOCATED AT THE END OF ONE OF THE TWO LEGS OF THE IDLER APPARATUS.

EXCEPT FOR THE TWO IDLER PHOTON DETECTORS, THE IDLER APPARATUS (INCLUDING THE "DOUBLE-SLIT" ARRANGEMENT INVOLVED IN THE GENERATION OF THE SIGNAL-IDLER PHOTON PAIRS) IS PLACED IN A CONTAINER THAT PREVENTS INFORMATION CONCERNING THE STATE OF THE IDLER PHOTONS FROM BEING AVAILABLE IN THE ENVIRONMENT. THIS CONTAINER IS EVACUATED EXCEPT FOR THE IDLER PHOTON THAT TRAVERSES IT. ANOTHER CONTAINER ENCOMPASSES THE AREA BETWEEN THE LENS THAT THAT PRODUCES THE FAR FIELD EFFECT FOR THE SIGNAL PHOTONS UNTIL JUST BEFORE THE SIGNAL PHOTONS REACH THE DETECTOR AXIS. THIS CONTAINER IS ALSO EVACUATED EXCEPT FOR THE SIGNAL PHOTON THAT TRAVERSES IT. [ii]

IN OTHER WORDS, THE IDLER PHOTONS ARE ISOLATED UNTIL THE IDLER PHOTONS EXIT THE IDLER APPARATUS CONTAINER WHICH OCCURS JUST BEFORE THEY REACH THE IDLER PHOTON

DETECTORS. THE SIGNAL PHOTONS THEMSELVES ARE ISOLATED IN A CONTAINER UNTIL JUST BEFORE THEY REACH THEIR DETECTION AXIS. WHICH-WAY INFORMATION CONCERNING THE SIGNAL PHOTONS HELD BY IDLER PHOTONS IS MADE PUBLIC IN DETECTION OF IDLER PHOTONS AT THE IDLER PHOTON DETECTORS. IN THIS WAY, ISOLATION OF THE SIGNAL PHOTONS IS REMOVED AT THE SAME TIME THE IDLER PHOTON ISOLATION IS REMOVED BECAUSE OF THE ENTANGLEMENT OF THESE PHOTONS. THE SIGNAL AND IDLER PHOTON PATHWAYS ARE SET UP SO THAT THE IDLER PHOTON IS DETECTED BEFORE ITS PAIRED SIGNAL PHOTON IS DETECTED.

- ATTACHED TO THE CONTAINER OF THE IDLER APPARATUS ARE TWO RESERVOIRS OF CLASSICAL EM RADIATION WHERE THE COMPONENT PHOTONS ARE SIMILAR IN CHARACTER TO THE IDLER PHOTON. WHERE THE RESERVOIRS ARE CLOSED OFF FROM THE IDLER PHOTON APPARATUS SO THAT NONE OF THE CLASSICAL EM RADIATION ENTERS THE EVACULATED IDLER APPARATUS, WHICH-WAY INFORMATION CONCERNING THE IDLER-SIGNAL PHOTON PAIRS IS POTENTIALLY AVAILABLE AS THE IDLER PHOTON TRAVERSES ONE OR THE OTHER OF THE PATHS OF THE ISOLATED IDLER APPARATUS.

  THIS WHICH-PATH INFORMATION DERIVES ORIGINALLY FROM THE TWO POSSIBLE PHOTON SOURCES IN THE IDLER APPARATUS, EACH SOURCE ASSOCIATED UNIQUELY WITH ONE PATH FOR THE IDLER

PHOTONS THROUGH THE IDLER APPARATUS. IN THIS SCENARIO WHERE THE IDLER PHOTON IS DETECTED AT ONE OF TWO DETECTORS, THE OVERALL SIGNAL PHOTON DISTRIBUTION IS THE ONE WIDE HUMP CHARACTERISTIC OF WHICH-WAY INFORMATION DUE TO THE CHARACTER OF THE SIGNAL-IDLER PHOTON ENTANGLEMENT.[iii]

FIGURE 8

- **IF CLASSICAL EM RADIATION (WHERE THE PHOTONS COMPRISING THIS RADIATION ARE SIMILAR TO THE IDLER PHOTON) IS INJECTED INTO THE EVACUATED IDLER PHOTON CONTAINER (EXCEPT OF COURSE FOR THE IDLER PHOTON) WHILE THE IDLER PHOTON IS TRAVERSING THE CONTAINER AND BEFORE THE SIGNAL PHOTON REACHES THE AXIS WHERE IT IS DETECTED, THE DISTRIBUTION OF THE SIGNAL PHOTONS IS CHARACTERISTIC OF YOUNG-LIKE INTERFERENCE AS IF WHICH-WAY INFORMATION NEVER EXISTED FOR THE SIGNAL PHOTONS. THIS DISTRIBUTION IS OBTAINED BECAUSE THE IDLER PHOTON IS EFFECTIVELY LOST WITH THE INJECTION OF THE CLASSICAL EM RADIATION. MORE SPECIFICALLY, THE ENTANGLEMENT BETWEEN THE SIGNAL AND IDLER PHOTONS IS LOST IN THIS PROCESS AND IN LOSING THE ENTANGLEMENT THE WHICH-WAY INFORMATION CONCERNING THE SIGNAL PHOTON SUPPLIED BY THE IDLER PHOTON IS ALSO LOST. WITH NO WHICH-WAY INFORMATION FOR THE SIGNAL PHOTONS SUPPLIED BY THE PAIRED IDLER PHOTONS, THE SIGNAL PHOTONS**

EXHIBIT YOUNG INTERFERENCE IN THEIR DISTRIBUTION AS IF WHICH-WAY INFORMATION NEVER EXISTED (NOT FRINGES OR ANTI-FRINGES THAT THAT REQUIRE CORRELATION OF DETECTION DATA FOR THE ENTANGLED ENTITIES AND THAT SUM TO AN OVERALL WHICH-WAY DISTRIBUTION PATTERN AS OCCURS IN A QUANTUM ERASER).

- AS DISCUSSED, SINCE THE DOUBLE SLIT SETUP AT WHICH THE SIGNAL IDLER PHOTON PAIRS ARE FORMED SUPPORTS A KIND OF "DELAYED CHOICE" IN THE KIM EXPERIMENT WHERE THE IDLER PHOTONS ARE INVOLVED IN THE "DELAYED CHOICE" AND PROVIDE FOR WHICH-WAY INFORMATION OR INSTEAD INTERFERENCE FOR THE DISTRIBUTION OF THE SIGNAL PHOTONS. IN THE PRESENT DEVICE, THE DIMENSIONS OF THE DOUBLE-SLIT RELATIVE TO THE WAVELENGTH OF THE SIGNAL PHOTON ARE THE SAME AS IN THE KIM EXPERIMENT AND ALLOW FOR THE DEVELOPMENT OF INTERFERENCE IN THE DISTRIBUTION OF THE SIGNAL PHOTONS. THUS, THE DOUBLE SLIT SUPPORTS INTERFERENCE IN THE DISTRIBUTION OF THE SIGNAL PHOTONS IN THE PRESENT DEVICE AS IF WHICH-WAY INFORMATION NEVER EXISTED CONCERNING THE SIGNAL PHOTONS WHERE THE PAIRED IDLER PHOTONS ARE LOST THROUGH THE INJECTION OF CLASSICAL EM RADIATION (WHERE THE PHOTONS COMPRISING THIS RADIATION ARE SIMILAR TO THE IDLER PHOTON). THE DIMENSIONS OF THE DOUBLE SLIT RELATIVE TO THE WAVELENGTH OF THE SIGNAL PHOTONS SUPPORTS INTERFERENCE IN THE DISTRIBUTION OF THE SIGNAL PHOTONS AT

THEIR DETECTION AXIS IN THE ABSENCE OF WHICH-WAY INFORMATION PROVIDED BY THE IDLER PHOTONS. THE LOSS OF THE IDLER PHOTON RESULTS IN THE LOSS OF THE SIGNAL-IDLER PHOTON ENTANGLEMENT. IT WAS THROUGH THIS ENTANGLEMENT THAT WHICH-WAY INFORMATION WAS PROVIDED BY THE IDLER PHOTON TO THE SIGNAL PHOTON.[iv]

EQUATIONS FOR HAUNTED QUANTUM ENTANGLEMENT

AFTER ENTANGLEMENT OCCURS IN AN ISOLATED ENVIRONMENT, THE EQUATION FOR THE HAUNTED QUANTUM ENTANGLEMENT WOULD BE:

$$\psi = 1/\sqrt{2}\ [(A\_U)|P\_U> + (A\_L)|P\_L>] \qquad [1]$$

WHERE A REPRESENTS THE ATOM IN THE FIRST HAUNTED QUANTUM ENTANGLEMENT SCENARIO PRESENTED AND THE SIGNAL PHOTON IN THE SECOND HQE SCENARIO AND P REPRESENTS THE PHOTON EMITTED BY THE ATOM IN THE FIRST HQE SCENARIO AND THE IDLER PHOTON IN THE SECOND HQE SCENARIO. IN THE FIRST HQE SCENARIO, U AND L REPRESENT THE DIFFERENT MICROMASER CAVITIES AND POTENTIALLY THE SPECIFIC SLIT ASSOCIATED WITH EACH SPECIFIC CAVITY. IN THE SECOND HQE SCENARIO, U REPRESENTS THE TWO PATHS FOR THE PAIRED SIGNAL AND IDLER PHOTONS ORIGINATING AT ONE SLIT AND L REPRESENTS THE TWO PATHS FOR THE PAIRED SIGNAL AND IDLER PHOTONS ORIGINATING AT THE OTHER SLIT.

THIS EQUATION ALSO REPRESENTS A HAUNTED MEASUREMENT WHERE FOR EXAMPLE THE NEUTRON IS INTERACTING WITH THE FLEXIBLE MIRROR APPARATUS (A REPRESENTS THE NEUTRON, P REPRESENTS THE FLEXIBLE MIRROR APPARATUS ALONG ONE INTERFEROMETER ARM AND ITS IMAGINED EQUIVALENT ON THE OTHER INTERFEROMETER ARM, U REPRESENTS ONE ARM OF THE INTERFEROMETER, AND L REPRESENTS THE OTHER ARM OF THE INTERFEROMETER).

|P_U> AND |P_L> THEN SERVE AS WHICH-WAY MARKERS IN THAT ONE OBTAINS:

$$|\psi|^2 = 1/2\ [|(A_U)|^2 \langle P_U|P_U\rangle + |(A_L)|^2 \langle P_L|P_L\rangle + (A_U^* A_L) \langle P_U|P_L\rangle + (A_L^* A_U)\langle P_L|P_U\rangle] \qquad [2]$$

OR

$$|\psi|^2 = 1/2|(A_U)|^2 + 1/2|(A_L)|^2 \qquad [3]$$

SINCE

$$\langle P_U|P_L\rangle = 0$$

$$\langle P_L|P_U\rangle = 0$$

WITH ELIMINATION OF THE ENTANGLEMENT BETWEEN THE ATOM AND THE EMITTED PHOTON IN THE FIRST SCENARIO AND THE PAIRED SIGNAL AND IDLER PHOTONS IN THE SECOND SCNENARIO (AND THUS ALL WHICH-WAY INFORMATION CONCERNING THE ATOM OR THE SIGNAL PHOTON) WHILE THE SYSTEM IS STILL ESSENTIALLY ISOLATED:

$$\psi = [1/\sqrt{2} [(A\_U) + (A\_L)]] \qquad [4]$$

THE PHOTON IN SCENARIO 1 AND THE IDLER PHOTON IN SCENARIO 2 ARE ESSENTIALLY LOST, AND THUS ENTANGLEMENT IS LOST AS WELL. EQN. 4 ALSO REPRESENTS THE STATE OF THE NEUTRON IN A HAUNTED MEASUREMENT AFTER THE NEUTRON EXITS THE FLEXIBLE MIRROR APPARATUS.

IN CONTRAST TO HAUNTED QUANTUM ENTANGLMENT, THE ENTANGLEMENT BETWEEN THE ATOM AND EMITTED PHOTON IN THE SCULLY EXPERIMENT OR PAIRED SIGNAL AND IDLER PHOTONS IN THE KIM EXPERIMENT IS MAINTAINED UNTIL DETECTIONS OF THESE ENTITIES ARE MADE. THE INITIAL EQUATION REPRESENTING THE ENTANGLEMENT HAS THE FORM OF EQN. 1. THE FORM IN WHICH THE ENTANGLEMENT IS EXPRESSED WITH QUANTUM ERASURE CHANGES TO:

$$\psi = 1/\sqrt{2} [(A\_S)|P\_S> + (A\_A)|P\_A>] \qquad [5]$$

WHERE (A_S) AND |P_S> REPRESENT SYMMETRIC WAVE FUNCTIONS AND (A_A) AND |P_A> REPRESENT ANTI-SYMMETRIC WAVE FUNCTIONS, AND

$$A\_U = 1/\sqrt{2} [A\_S + A\_A)], \qquad [6]$$

$$A\_l = 1/\sqrt{2} [A\_S - A\_A], \qquad [7]$$

$$|P\_U> = 1/\sqrt{2} [|P\_S> + |P\_A>], \qquad [8]$$

$$|P\_L> = 1/\sqrt{2} [|P\_S> - |P\_A>] . \qquad [9]$$

THUS IN THE QUANTUM ERASER, ONE MAINTAINS THE OVERALL ONE WIDE HUMP INDICATIVE OF WHICH-WAY INFORMATION EVEN THOUGH ONE CAN ALSO OBTAIN FRINGES AND ANTI-FRINGES WITH QUANTUM ERASURE THAT SUM TO THE OVERALL ONE WIDE HUMP DISTRIBUTION OF THE ATOMS OR THE SIGNAL PHOTONS.

THE FULL TRANSFORMATION FOR THE QUANTUM ERASER IS GIVEN BY:

$$\psi = 1/\sqrt{2}\ [(A_U)|P_U\rangle + (A_L)|P_L\rangle] \qquad [1]$$

$$\psi = 1/\sqrt{2}\ [[[1/\sqrt{2}\ [(A_S + A_A)]]\ [[1/\sqrt{2}\ [|P_S\rangle + |P_A\rangle]]$$
$$+\ [[1/\sqrt{2}\ [(A_S - A_A)]]\ [[1/\sqrt{2}\ [|P_S\rangle - |P_A\rangle]]] \qquad [10]$$

$$\psi = 1/\sqrt{2}\ [[[1/\sqrt{2}\ (A_S)]\ [1/\sqrt{2}\ |P_S\rangle] + \cancel{[1/\sqrt{2}\ (A_S)]\ [1/\sqrt{2}\ |P_A\rangle]} +$$
$$\cancel{[1/\sqrt{2}\ (A_A)]\ [1/\sqrt{2}\ |P_S\rangle]} + [1/\sqrt{2}\ (A_A)]\ [1/\sqrt{2}\ |P_A\rangle]]$$
$$+$$
$$[[1/\sqrt{2}\ (A_S)]\ [1/\sqrt{2}\ |P_S\rangle] + \cancel{[1/\sqrt{2}\ (A_S)]\ [-1/\sqrt{2}\ |P_A\rangle]} +$$
$$\cancel{[-1/\sqrt{2}\ (A_A)]\ [1/\sqrt{2}\ |P_S\rangle]} + [-1/\sqrt{2}\ (A_A)]\ [-1/\sqrt{2}\ |P_A\rangle]]] \qquad [11]$$

$$\psi = 1/\sqrt{2}\ [[2[1/\sqrt{2}\ (A_S)]\ [1/\sqrt{2}\ |P_S\rangle]] +$$
$$[2[1/\sqrt{2}\ (A_A)]\ [1/\sqrt{2}\ |P_A\rangle]]] \qquad [11]$$

$$\psi = 1/\sqrt{2}\ [(A_S)|P_S\rangle + (A_A)|P_A\rangle] \qquad [5]$$

SUMMARY

THE DIFFERENCE BETWEEN THE QUANTUM ERASER AND HAUNTED QUANTUM ENTANGLEMENT IS THE FOLLOWING. WITH QUANTUM ERASURE, THE ENTANGLEMENT (WHICH INITIALLY INCORPORATES WHICH-WAY INFORMATION) IS MAINTAINED (ALBEIT IN TERMS OF SYMMETRIC AND ANTI-SYMMETRIC WAVE FUNCTIONS) UNTIL WHICH-WAY INFORMATION

EMBODIED IN THE ENTANGLEMENT BECOMES AVAILABLE IN THE ENVIRONMENT. IN HAUNTED QUANTUM ENTANGLEMENT, THE ENTANGLEMENT IS ELIMINATED (AND THEREFORE THE WHICH-WAY INFORMATION CARRIED IN THE ENTANGLEMENT IS ELIMINATED) BEFORE WHICH-WAY INFORMATION EMBODIED IN THE ENTANGLEMENT BECOMES AVAILABLE IN THE ENVIRONMENT.

AS A RESULT IN THE QUANTUM ERASER, ONE OBTAINS FRINGES AND ANTI-FRINGES THAT SUM TO AN OVERALL ONE WIDE HUMP DISTRIBUTION PATTERN AND THESE FRINGES AND ANTI-FRINGES ARE SEEN ONLY WHEN CORRELATIONS ARE MADE BETWEEN THE DETECTIONS OF BOTH ENTANGLED ENTITIES. IN HAUNTED QUANTUM ENTANGLEMENT ON THE OTHER HAND, ONE OBTAINS AN OVERALL INTERFERENCE DISTRIBUTION PATTERN AS IF WHICH-WAY INFORMATION NEVER EXISTED. THERE IS OF COURSE NO NEED TO CORRELATE DETECTIONS BETWEEN THE PREVIOUSLY ENTANGLED ENTITIES SINCE THEY ARE NO LONGER ENTANGLED AND THE ENTITY [1] THAT SUPPLIED WHICH-WAY INFORMATION TO THE OTHER ENTITY [2] OF THE PREVIOUSLY ENTANGLED PAIR NO LONGER ESSENTIALLY EXISTS AS CONCERNS THIS OTHER ENTITY [2]. THEREFORE, ENTITY [1] NO LONGER SUPPLIES WHICH WAY INFORMATION FOR ENTITY [2].

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[i] **Detections of the photons certainly are included in the category of "making information available to the environment". It may also be that not isolating the "two slits" in the Kim experiment to be discussed or the double slit in the Scully experiment to be discussed may also be making general which-way information (i.e., that a which-way information has occurred but it is unknown through which particular slit the "idler photon" or "atom" passed) to the environment.**

[ii] **It may be important that the idler photon as well as the signal photon are isolated until detections are made. By isolating the idler photon, one approximates closely the situation of the emitted photon in the micromaser cavity system in the first scenario for hqe and also Greenberger and YaSin's haunted measurement.**

[iii] Also, even before the idler photons are detected (i.e., while the idler photons are in the process of traversing the idler apparatus), the same distribution of signal photons would be obtained even though a which-way measurement of the idler photon is not completed by its arrival at one or the other detector if nothing is altered in the idler apparatus container while the idler photon is traversing the idler apparatus.

[iv] With the loss of the idler photon in classical em radiation in haunted quantum entanglement, the signal photon is not left in a state of *just not knowing* through which slit the signal photon passed but knowing that it had *indeed* passed through one specific slit of the two slits. If that were the case, fringes and anti-fringes in the quantum eraser of Kim and his colleagues would not be obtained when correlations are made between paired signal and idler photon detections or atom and emitted photon detections (or lack thereof where the emitted photon does not interact with the photodetector). Fringes and anti-fringes demonstrate interference, meaning that entities (signal photons or the emitting atoms) are detected at locations in frequencies that they would not be detected if it is just not known specifically through which slit the signal photon or atom passed but that we *definitely* know that it did pass through either one or the other (in other words, if there was still really which way information). If we have a case of just not knowing what in fact is the case, the case being that the idler photon or atom passed through one slit or the other, the distributions of the detected signal photons or the emitting atoms that would be obtained when correlations between idler and signal photon detections or between emitting atom and emitted photon are made could not show interference fringes and anti-fringes since specific which-way information indeed exists. With obtaining fringes and anti-fringes in the correlated detections mentioned, which-way information is indeed lost.

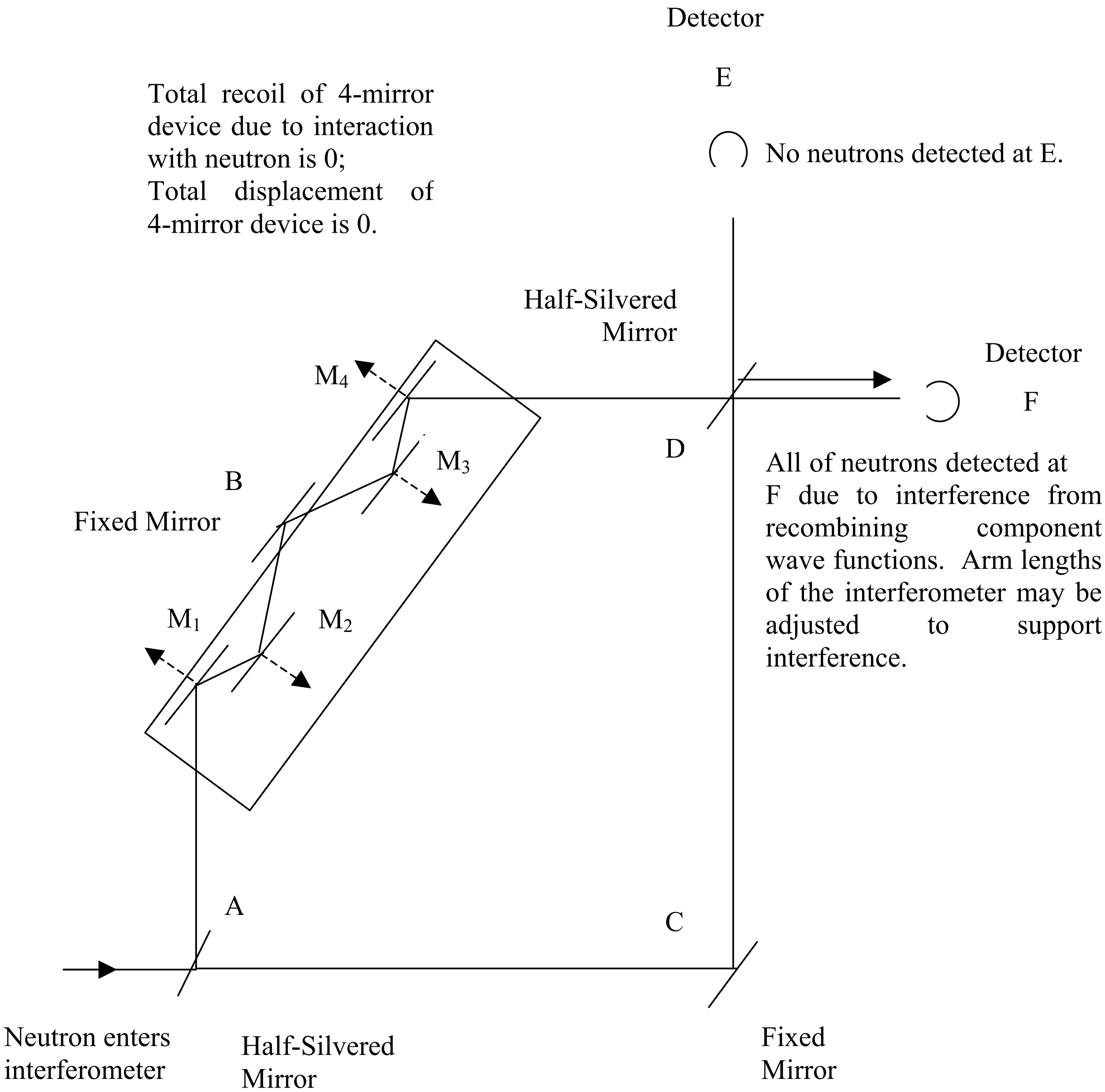


Figure 1: Interferometer with 4-Mirror Device Separated from the Environment: Component Wave Functions Are Recombined to Demonstrate Interference

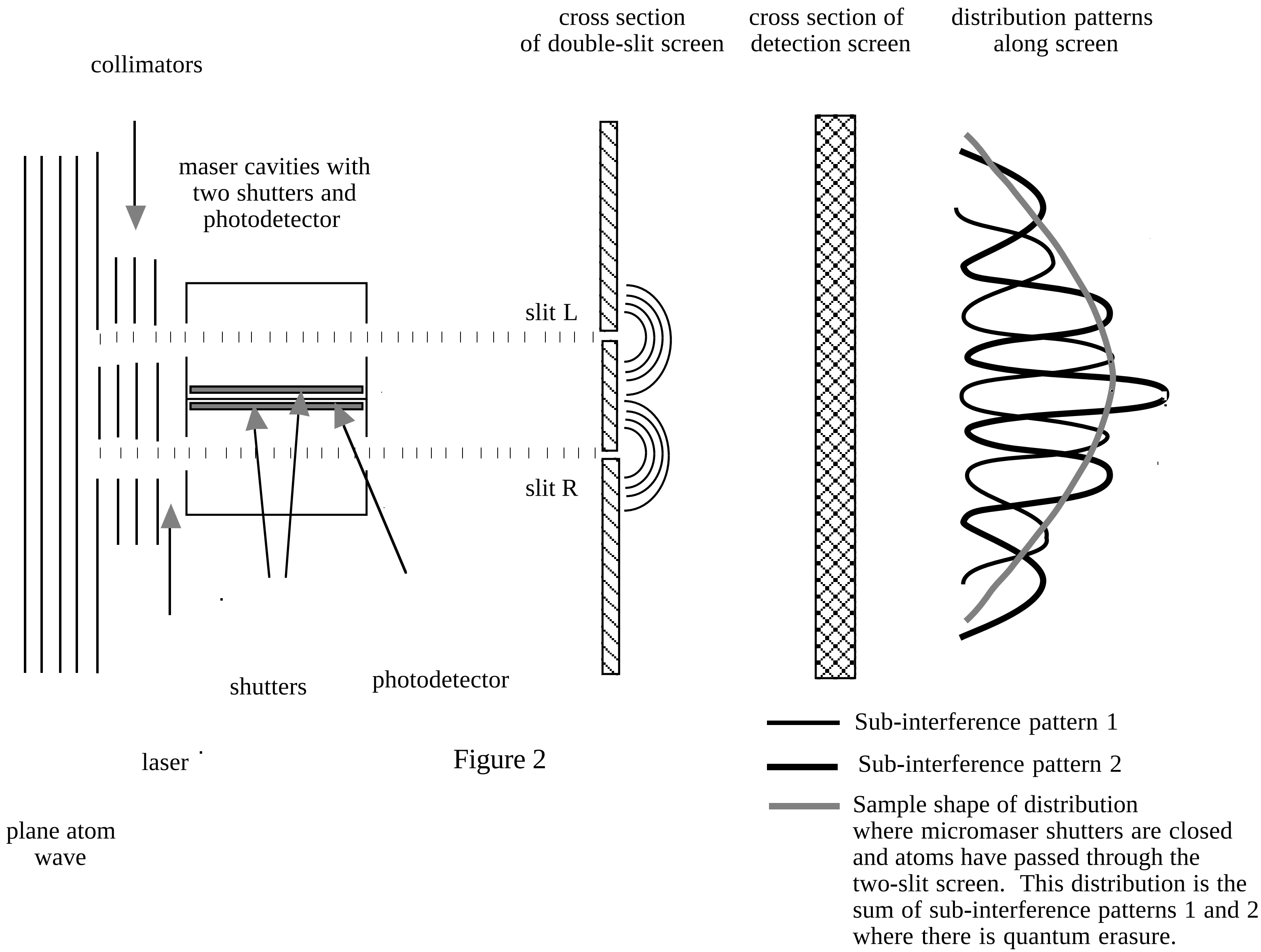

cross section
of double-slit screen
cross section of
detection screen
distribution patterns
along screen
collimators
maser cavities with
two shutters and
photodetector
slit L
slit R
shutters
photodetector
laser
plane atom
wave
Sub-interference pattern 1
Sub-interference pattern 2
Sample shape of distribution
where micromaser shutters are closed
and atoms have passed through the
two-slit screen. This distribution is the
sum of sub-interference patterns 1 and 2
where there is quantum erasure.

Figure 2

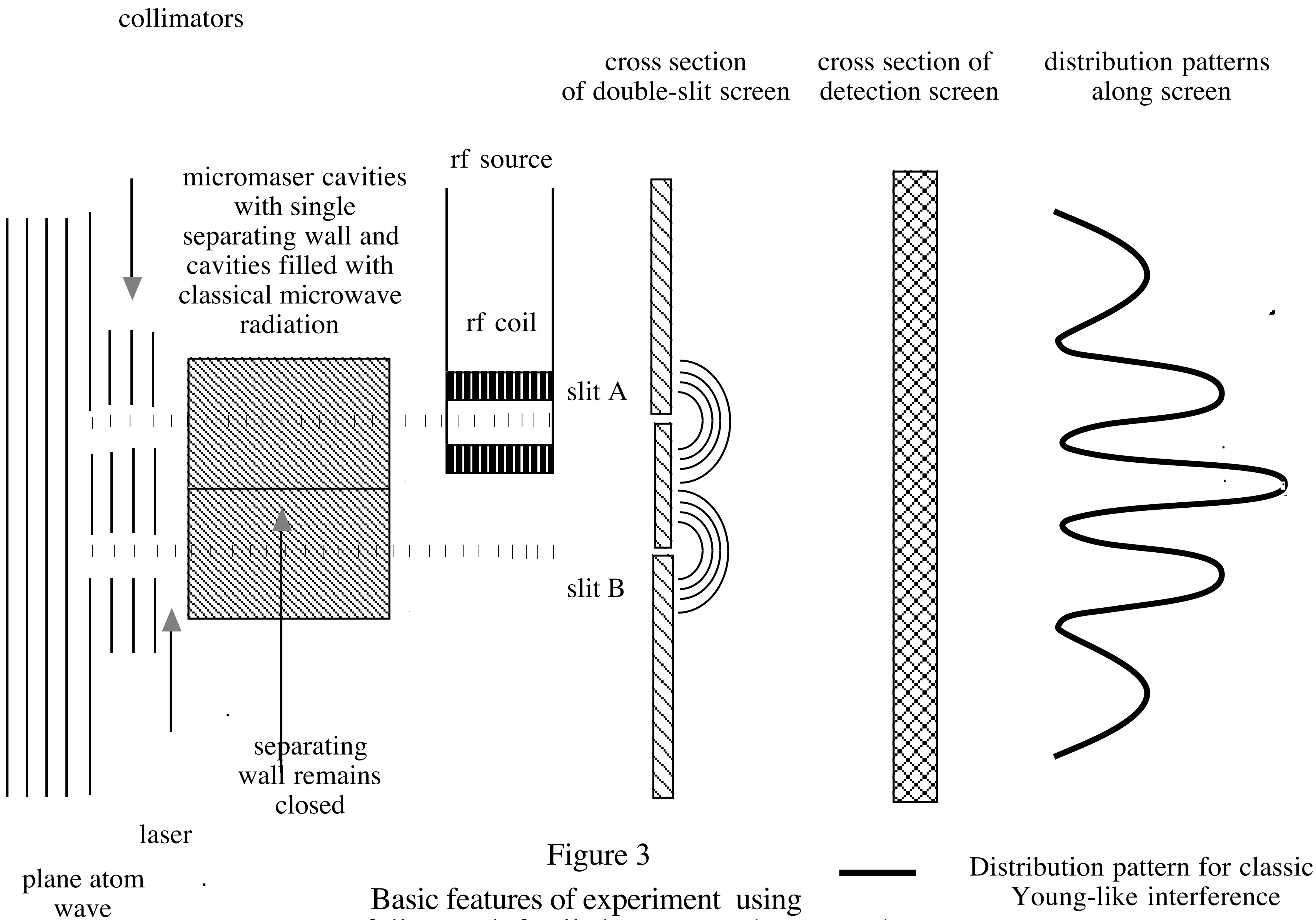


Figure 3

Basic features of experiment using
a carefully tuned rf coil along one path proposed
by Scully and colleagues where
passage by coil changes state of atom
on path to slit A to the same state the
atom would have were it on path to slit B.

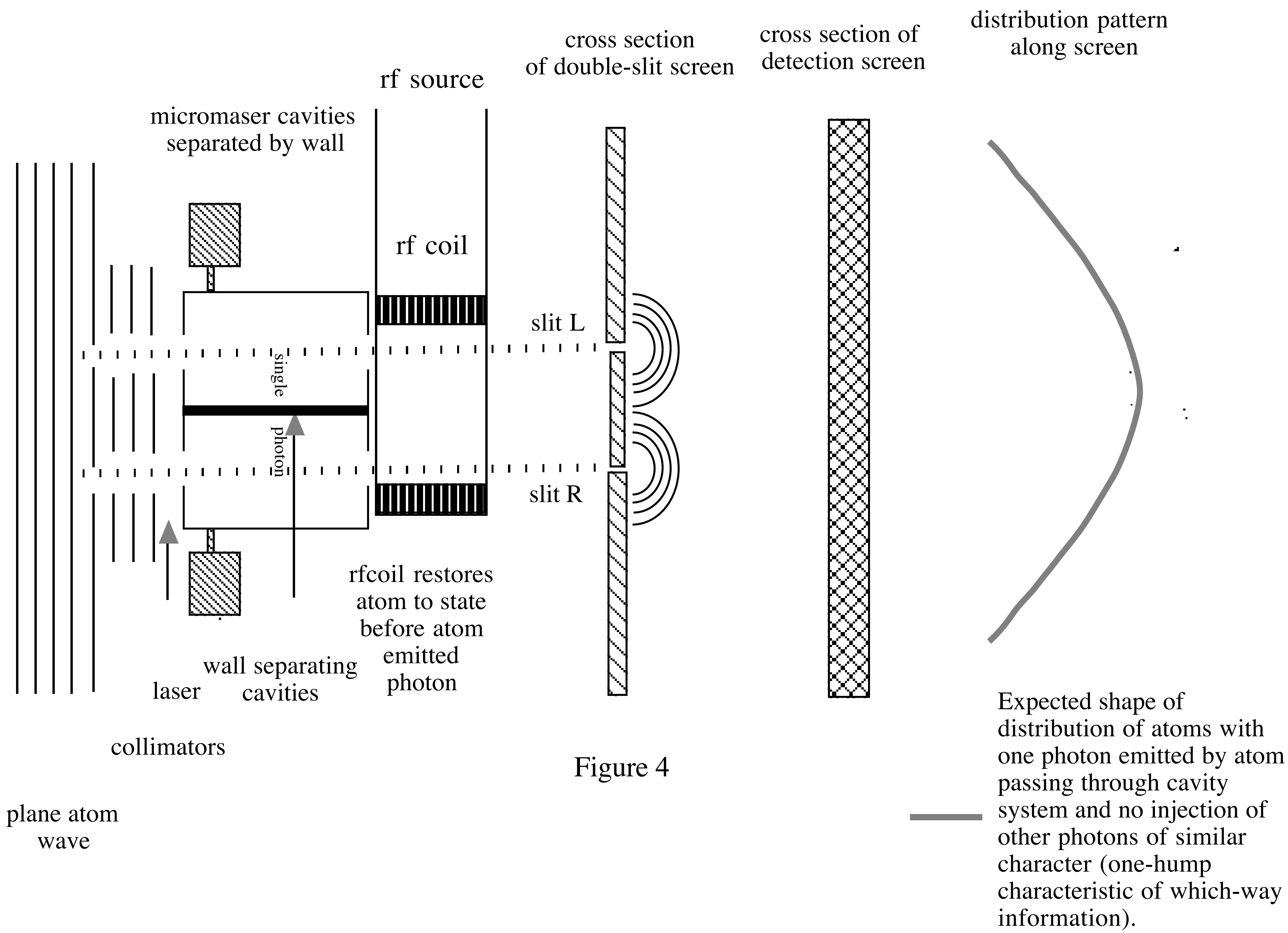

distribution pattern
along screen
cross section
of double-slit screen
cross section of
detection screen
rf source
micromaser cavities
separated by wall
rf coil
slit L
single
photon
slit R
rfcoil restores
atom to state
before atom
emitted
photon
wall separating
cavities
laser
collimators
plane atom
wave
Expected shape of
distribution of atoms with
one photon emitted by atom
passing through cavity
system and no injection of
other photons of similar
character (one-hump
characteristic of which-way
information).

Figure 4

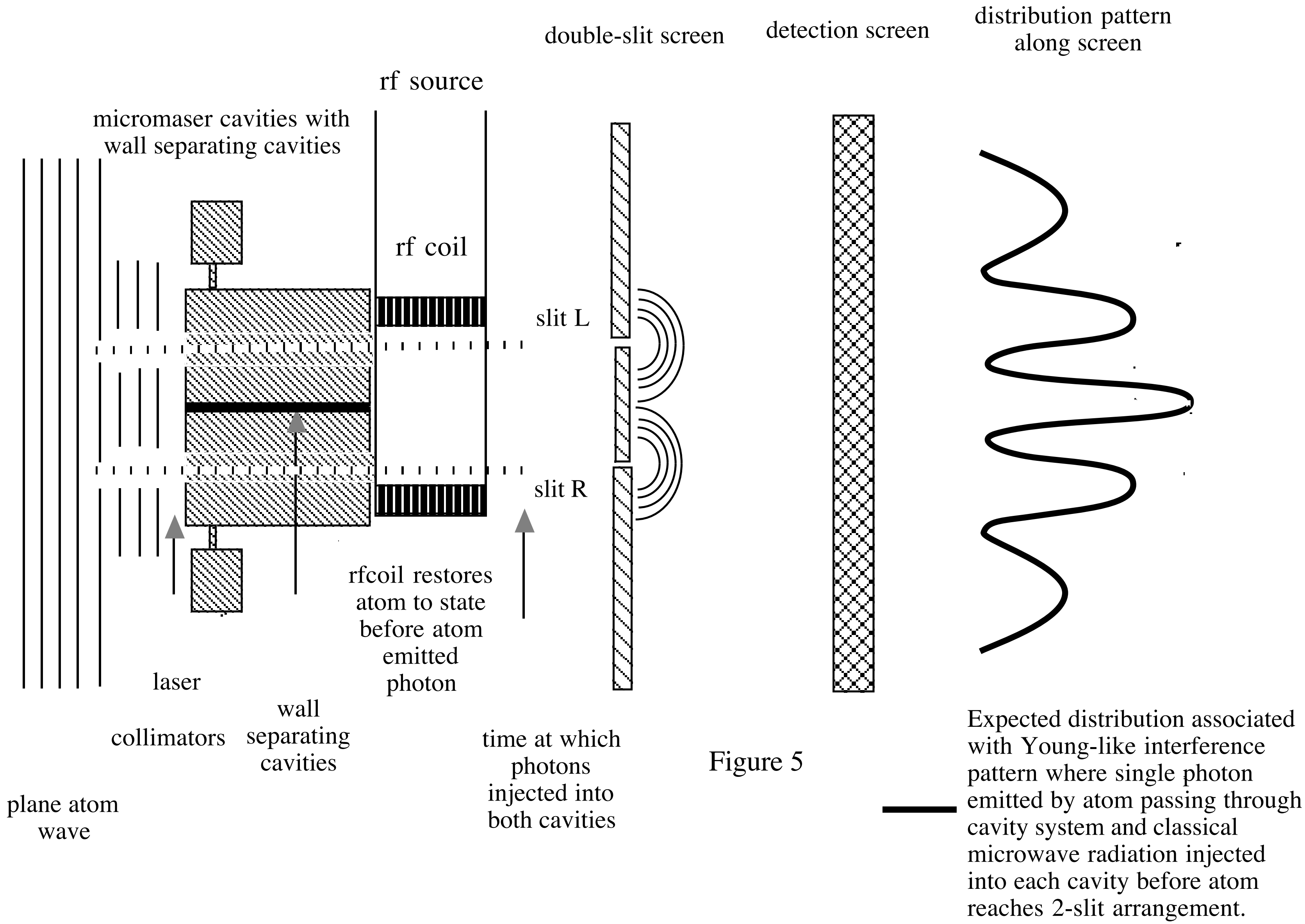
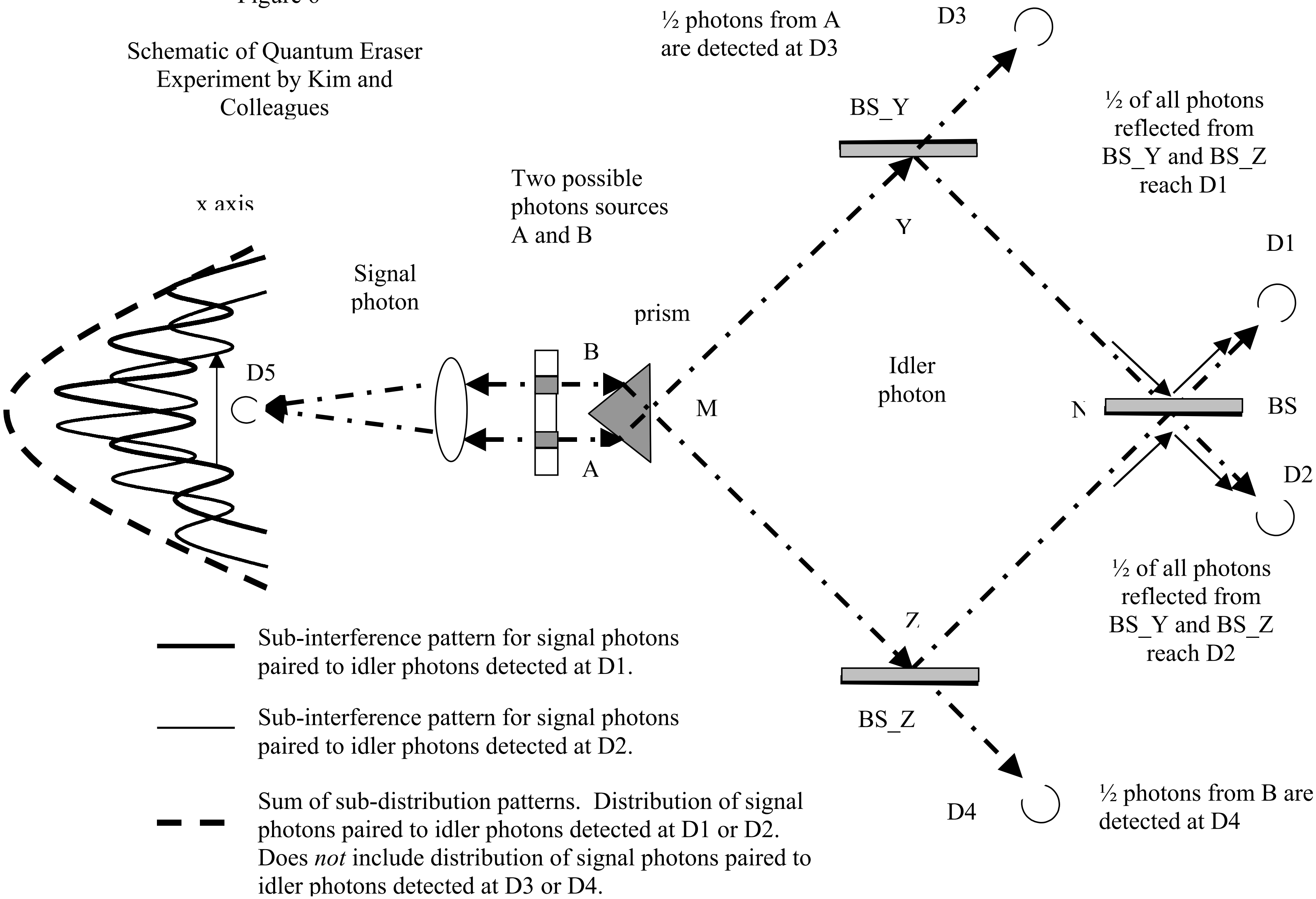
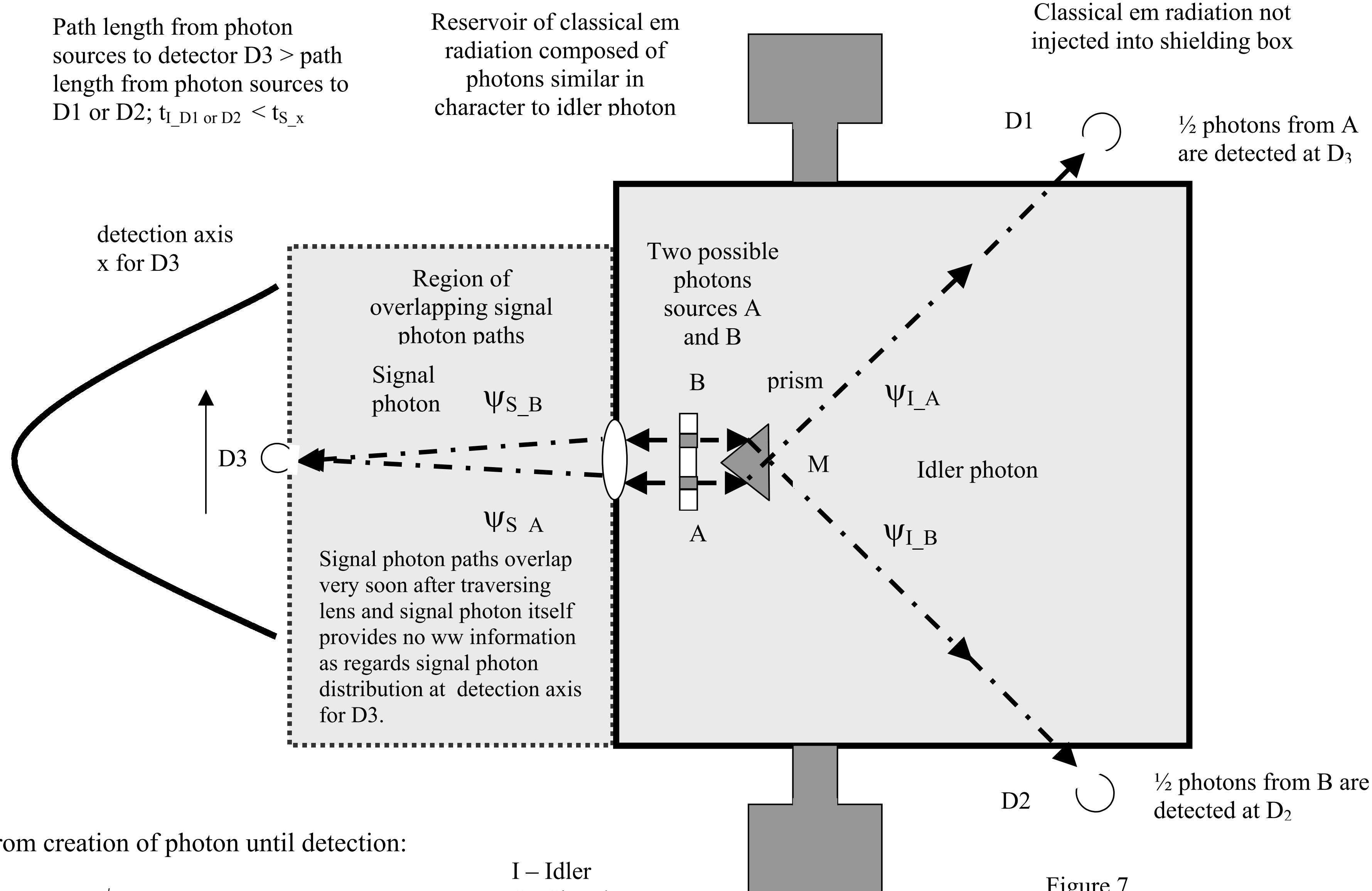

double-slit screen
detection screen
distribution pattern along screen
rf source
micromaser cavities with wall separating cavities
rf coil
slit L
slit R
rfcoil restores atom to state before atom emitted photon
laser
wall separating cavities
collimators
time at which photons injected into both cavities
plane atom wave
Expected distribution associated with Young-like interference pattern where single photon emitted by atom passing through cavity system and classical microwave radiation injected into each cavity before atom reaches 2-slit arrangement.

Figure 5

Figure 6

Schematic of Quantum Eraser Experiment by Kim and Colleagues

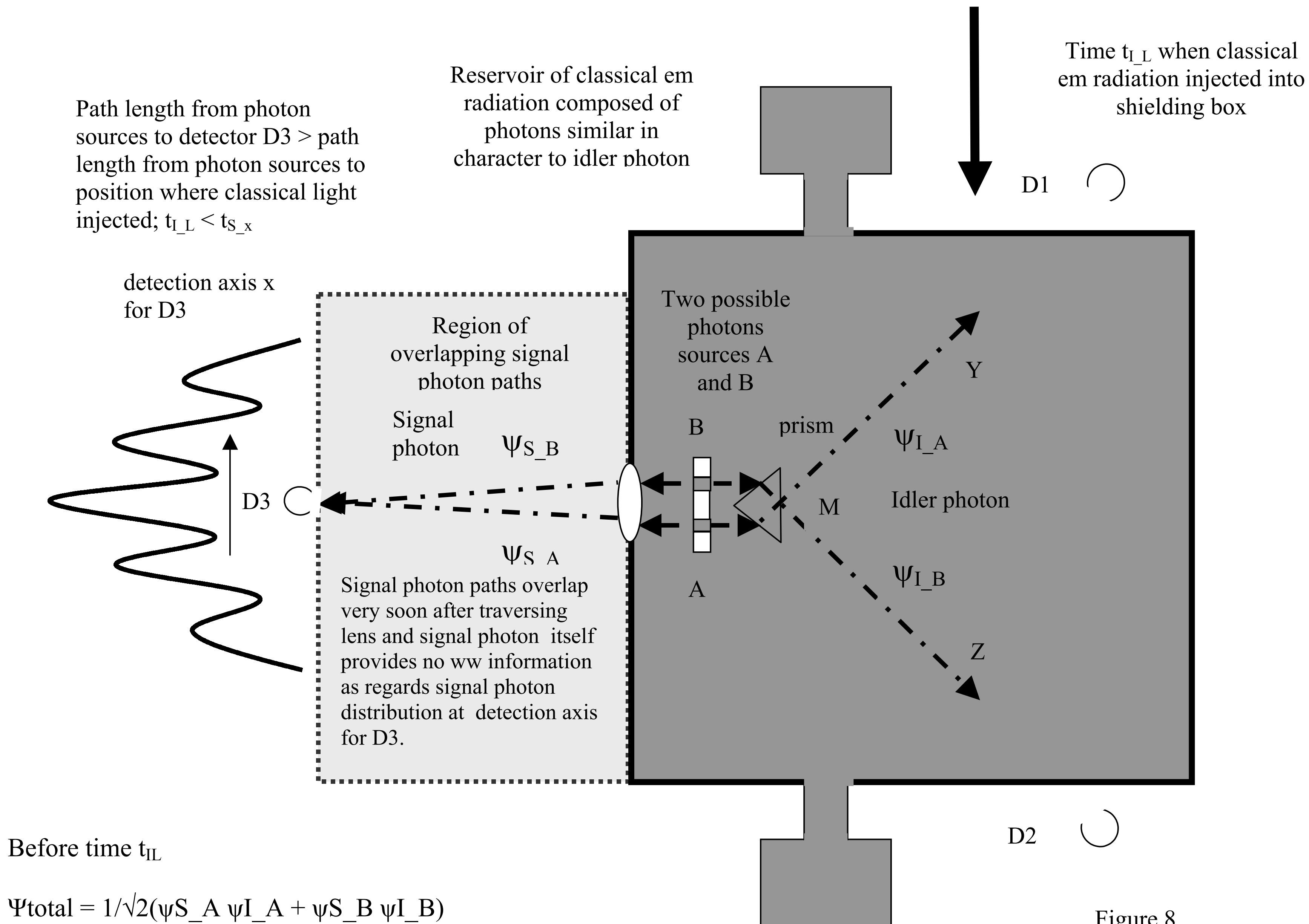




From creation of photon until detection:

$$\Psi total = 1/\sqrt{2}(\psi S\_A\ \psi I\_A + \psi S\_B\ \psi I\_B)$$
$$\langle \psi I\_A \mid \psi I\_B \rangle = 0$$
$$\langle \psi I\_B \mid \psi I\_A \rangle = 0$$

Figure 7
Schematic of Two Photon Haunted Quantum Entanglement Where Classical EM Radiation Not Injected Into Evacuated Box



Before time t_{IL}

$$\Psi total = 1/\sqrt{2}(\psi S\_A\ \psi I\_A + \psi S\_B\ \psi I\_B)$$
$$\langle \psi I\_A \mid \psi I\_B \rangle = 0$$
$$\langle \psi I\_B \mid \psi I\_A \rangle = 0$$

I – Idler
S - Signal

After time t_{IL}

$$\Psi total\_signal = [1/\sqrt{2}\ [\psi S\_A + \psi S\_B]]$$

Idler photon effectively lost.

Figure 8
Schematic of Two Photon Haunted Quantum Entanglement Where Classical EM Radiation Injected Into Evacuated Box