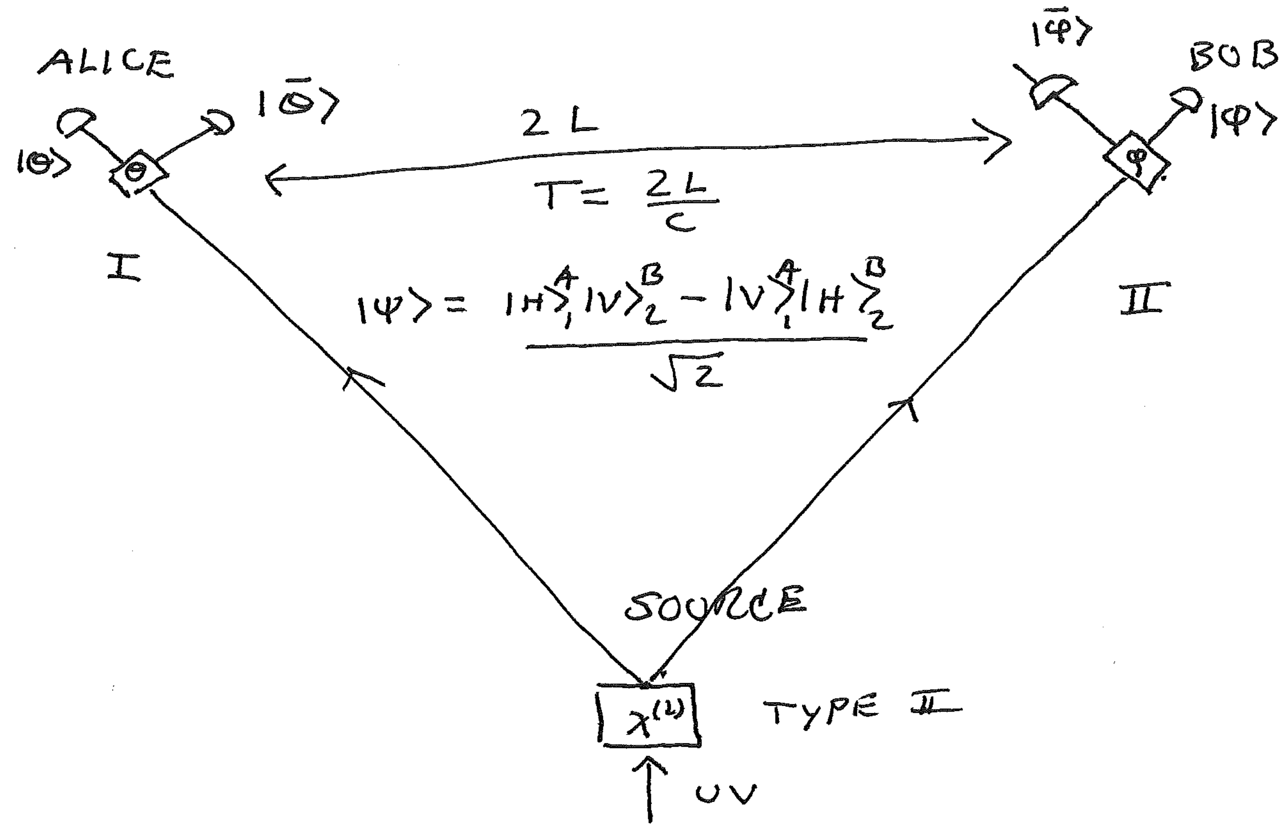
9.6 Testing $QM\ddot{x}$



The goal is to compare $QM\ddot{x}$ to $Lhv\Theta$ Polarization Rotators

ALICE

$$|\theta\rangle_1^A = \cos\theta \, |H\rangle_1^A + \sin\theta \, |V\rangle_1^A$$

$$|\bar{\theta}\rangle_1^A = -\sin\theta \, |H\rangle_1^A + \cos\theta \, |V\rangle_1^A$$

BOB

$$|\varphi\rangle_2^B = \cos\varphi \, |H\rangle_2^B + \sin\varphi \, |V\rangle_2^B$$

$$|\bar{\varphi}\rangle_2^B = -\sin\varphi \, |H\rangle_2^B + \cos\varphi \, |V\rangle_2^B$$

SINCE φ = BOB θ = ALICE WE DROP $\begin{smallmatrix} A, B \\ 1, 2 \end{smallmatrix}$

9.6

Note the <u>inverse</u> $|H, V\rangle \to |\theta, \bar{\theta}\rangle$

$+\theta \to -\theta$

<u>ALICE</u>

$$|H\rangle_1^A = \cos\theta\,|\theta\rangle - \sin\theta\,|\bar{\theta}\rangle$$
$$|V\rangle_1^A = \sin\theta\,|\theta\rangle + \cos\theta\,|\bar{\theta}\rangle$$

<u>BOB</u>

$$|H\rangle_2^B = \cos\varphi\,|\varphi\rangle - \sin\varphi\,|\bar{\varphi}\rangle$$
$$|V\rangle_2^B = \sin\varphi\,|\varphi\rangle + \cos\varphi\,|\bar{\varphi}\rangle$$

HENCE WE CAN WRITE

$$|\psi\rangle = \frac{|H\rangle_1^A|V\rangle_2^B - |V\rangle_1^A|H\rangle_2^B}{\sqrt{2}}$$

$\hbar = c = G = \sqrt{2} = 1$

: TRIG

$$= \cancel{\;}\Big[-\sin[\theta - \varphi]\,|\theta\rangle|\varphi\rangle + \cos[\theta-\varphi]\,|\theta\rangle|\bar{\varphi}\rangle - \cos[\theta-\varphi]\,|\bar{\theta}\rangle|\varphi\rangle - \sin[\theta-\varphi]\,|\bar{\theta}\rangle|\bar{\varphi}\rangle \Big]$$

NOTE $\theta = \varphi$

$$\Rightarrow |\psi\rangle = \frac{|\theta\rangle|\bar{\varphi}\rangle - |\bar{\theta}\rangle|\varphi\rangle}{\sqrt{2}}$$

That is when A and B measure in <u>same</u> basis Find 100% ANTI-CORELLAT

$|\psi\rangle$ invariant under basis change!

Let ALICE CONSTRUCT

$$\hat{\sigma}_x(\theta) = |\theta\rangle\langle\bar{\theta}| + |\bar{\theta}\rangle\langle\theta|$$

$$\hat{\sigma}_y(\theta) = -i\,[\,|\theta\rangle\langle\bar{\theta}| - |\bar{\theta}\rangle\langle\theta|\,]$$

$$\hat{\sigma}_z(\theta) = |\theta\rangle\langle\theta| - |\bar{\theta}\rangle\langle\bar{\theta}|$$

Similar for BOB

$$[\hat{\sigma}_x, \hat{\sigma}_y] = 2i\,\hat{\sigma}_z$$

are pauli spinors so $H, V \equiv \uparrow \downarrow$ spin 1/2

The point is A and B can decide <u>which</u> <u>op</u> to measure long after $T = 2L/c$. Let us suppose measures $\hat{\sigma}_z(\theta) = +1$

she concludes photon was in $|\theta\rangle_A$

Hence if BOB measures also in same basis $\langle \hat{\sigma}^B_z(\theta) \rangle = -1$ However or $|\bar{\theta}\rangle_B$ we can not conclude in QM

that BOB'S STATE WAS DEFINITELY IN $|\bar{\theta}\rangle_B$ BEFORE MEAS. HE <u>COULD</u> HAVE CHOSEN

$\langle \hat{\sigma}^B_x(\theta) \rangle = +1$ IN WHICH CASE HE WOULD CONCLUDE $\dfrac{|\theta\rangle_B + |\bar{\theta}\rangle_B}{\sqrt{2}}$

IN QM BOB'S PHOTON <u>HAS</u> <u>NO</u> <u>STATE</u>

UN-<u>REAL</u>

ALSO IF A CHOOSES $\Theta = 0$ AND

BOB CHOOSES $\Theta = 0$

H	V
V	H
V	H
H	V

ANTICORELLATION ALWAYS HOLDS SO HOW DOES BOB'S PHOTON "KNOW" WHICH BASIS ALICE USED? NONLOCAL!

FIRST QM:

Let $$\hat{A}(\Theta) = \left\{ \begin{array}{ll} +1 & |\Theta\rangle \\ -1 & |\bar{\Theta}\rangle \end{array} \right\} = \hat{\sigma}_z^A(\Theta)$$

$$\hat{B}(\theta) = \left\{ \begin{array}{ll} +1 & |\varphi\rangle \\ -1 & |\bar{\varphi}\rangle \end{array} \right\} = \hat{\sigma}_z^B(\varphi)$$

We define Corellation

$$\boxed{C[\Theta,\varphi] \equiv \mathrm{Avg}\{ A(\Theta)\, B(\varphi) \}}$$

IN QM:

$$C[\Theta,\varphi]_{QM} \equiv \langle \Psi | \hat{\sigma}_x^A(\Theta)\, \hat{\sigma}_y^B(\varphi) | \Psi \rangle$$

$$\vdots \;\; \text{TRIG}$$

$$= \boxed{-\cos[2(\Theta-\varphi)]}$$

Recall $\Theta = \varphi \Rightarrow \boxed{C[\Theta,\Theta] = -1}$

100% PERFECT <u>ANTI</u> CORELLATION

LHVΘ

<u>Now</u> assume A ; B are <u>classical</u> random variables $A(\theta, \lambda) = \pm 1$

$B(\varphi, \lambda) = \pm 1$

$\uparrow$ hidden variable

<u>REALISM POSTULATE</u>

$\forall \lambda$ $A(\theta,\lambda)$ and $B(\theta,\lambda)$ have <u>definite</u> <u>values</u> ± 1 at all <u>times</u>

For each <u>λ</u>

<u>LOCALITY POSTULATE</u>

$A(\theta,\lambda)$ DOES NOT DEPEND ON φ

$B(\varphi, \lambda)$ DOES NOT DEPEND ON θ

$\exists$ $p(\lambda)$ S.T. $\int p(\lambda)\, d\lambda = 1$

<u>PROB</u> DIST

~~LET $X, Y, X', Y' \in \{\pm 1\}$~~

~~RANDOM CLASS VAR~~

~~$S = XY + XY' + X'Y - X'Y'$~~

$$C_{LHVΘ}(\theta, \varphi) \equiv \underbrace{\int d\lambda\, A(\theta,\lambda)\, B(\varphi,\lambda)\, p(\lambda)\, d\lambda}_{\text{CLASSICAL AVE}}$$

LET $x\ y\ x'\ y' \in \{\pm 1\}$

$$\boxed{S \equiv xy + xy' + x'y - x'y' = \pm 2}$$

IF WE TAKE

$x = A(\theta, \lambda) \qquad x' = (\theta', \lambda)$

TWO DIFFERENT SETTINGS A POL

$y = B[\varphi, \lambda] \qquad y' = (\varphi', \lambda)$

BOBS POL

IDEA IS IN ONE RUN θ, φ
ANOTHER RUN θ', φ'

$\cancel{S(\theta, \theta', \varphi, \varphi', \lambda) \le 2}$

$$\Rightarrow -2 \le \int d\lambda\, p(\lambda)\, S(\theta, \theta', \varphi, \varphi', \lambda) \le 2$$

since $0 \le p(\lambda)\, d\lambda \le 1$

$$\Rightarrow \boxed{-2 \le C_{LHVG}(\theta, \varphi) + C_H(\theta', \varphi) + C_H(\theta, \varphi') - C_H(\theta', \varphi') \le 2}$$

$\forall\ \theta, \theta', \varphi, \varphi'$

NOW TAKE $\theta = 0, \ \theta' = \pi/4, \qquad \varphi = \pi/8, \ \varphi' = -\pi/8$

NON ORTHOGONAL

$$S_{Qmx} = C_Q(\theta\varphi) + C_Q(\theta'\varphi) + C_Q(\theta, \varphi') - C_Q(\theta', \varphi')$$
$$= \boxed{-2\sqrt{2} < -2}$$

Detector Loop hole

$\xrightarrow{I_A} D$ —— εI_A

$\xrightarrow{I_B} D$ —— εI_B

$$C_Q(\theta,\varphi) = -\varepsilon^2 \cos[2(\theta-\varphi)]$$

~~Fair sampling~~

$$S_{Qmx} = -\varepsilon^2 2\sqrt{2} < -2 \quad ?$$

$$\varepsilon^4 \cdot 4 \cdot 2 = 4$$

$$\varepsilon^4 = \frac{1}{2}$$

$$\varepsilon = \frac{1}{2^{1/4}} = 0.84$$

Fair sampling

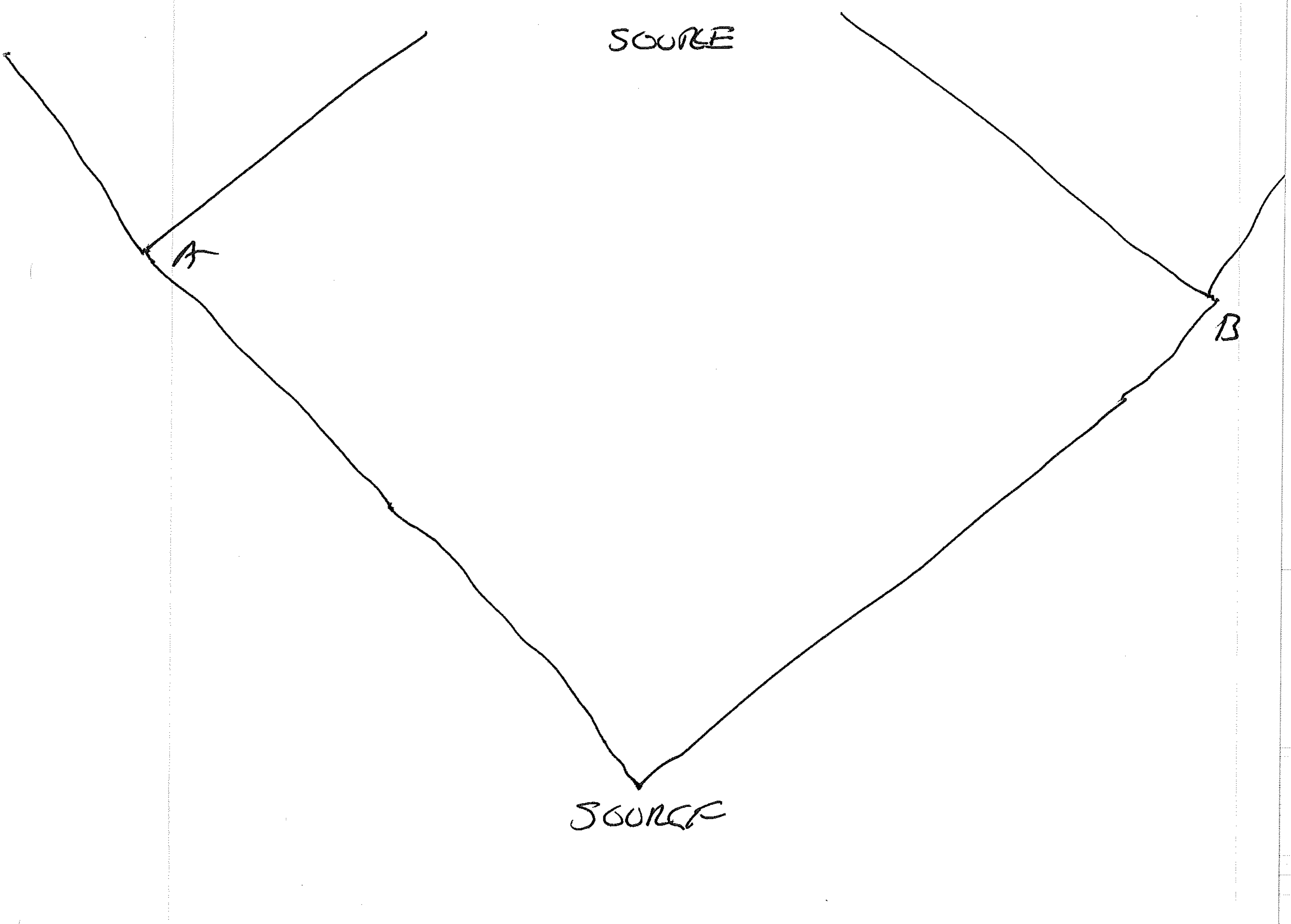
If < 84% of photons detected then these are fair sample of missing photons!

LHVQ Gremlins in detectors could shuffle data!

LIGHT CONE LOOPHOLE

A and B must choose θ, ϕ outside of each others light cone!

Super Fast Gremlins in S, A, B conspire in LHV θ



DET. LOOPHOLE CLOSED IN ION TRAPS

L.C. LOOPHOLE CLOSED IN PHOTON EXP

<u>BOTH</u> NOT CLOSED <u>YET</u>