Title: Inefficient Detectors Do Not Bar Bell Theorems Without Inequalities

Date: Jul 20, 2006 02:45 PM

URL: http://pirsa.org/06070053

Abstract: Entanglement swapping is such a powerful technique for dealing with EPR problems, that it can handle inefficient counters and Bell Theorems without inequalities, even for two particles. We will examine some of the results and pitfalls.

Two Particle Bell Theorem

No Inequalities

Inefficient Detectors

D. Greenberger

M. Horne

A Zeilinger

(M. Zukowski)

Two Particle Bell Theorem

No Inequalities

Inefficient Detectors

D. Greenberger

M. Horne

A Zeilinger

(M. Zukowski)

Two Particle Bell Theorem

No Inequalities

Inefficient Detectors

D. Greenberger

M. Horne

A. Zeilinger

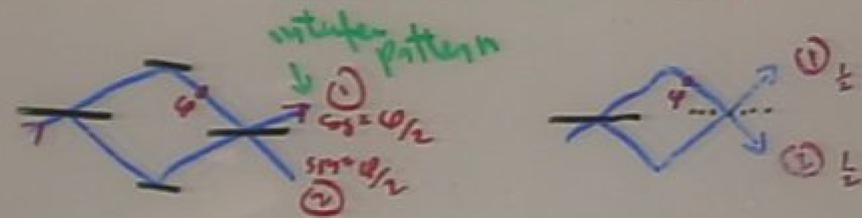
(M. Zukowski)

Entangled States

One feature of QM –
system has NO definite features
until measured.

Ex. – Trajectories

Wheeler – "Delayed Choice Expt."



Traj. not determined until measured

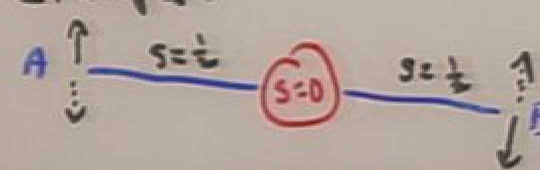
Wheeler – No phenomenon is an
actual phenomenon until it is
a measured phenomenon.

2

In particular —

Identity of indiv. particles not determined until measured.

Example:



singlet state

$$\Psi = \frac{1}{\sqrt{2}}(\uparrow_1\downarrow_2 - \downarrow_1\uparrow_2)$$

called "Entangled state"

Can't factor: $\Psi_{12} \neq \psi_1 \psi_2$

To point out distinction between cl. + QM

EPR (1935) - "El. of Reality"

If you can make a measurement on system A, without in any way disturbing system B, and determine a definite property of system B, then that property is an element of reality (or objective).

Spin above is El. of R.

The EPR Logic

A was measured to be spin up. ⇒ B spin down.
But never touched B ⇒ B spin down before A meas.
⇒ B spin down since they separated.
— Just like envelope.

Bohr Logic.

Could measure A in any direction.
If spin up ⇒ B spin down in that direction.
— How could B know in which direction you would measure A?
⇒ B could not be spin down before meas. A.

Before Bell 1964 - Assumed not expt'ly decidable.

The EPR Logic

A was measured to be spin up. ⇒ B spin down.

But never touched B ⇒ B spin down before A meas.

⇒ B spin down since they separated.

— Just Like envelope.

Bohr Logic.

Could measure A in any direction.

If spin up ⇒ B spin down in that direction.

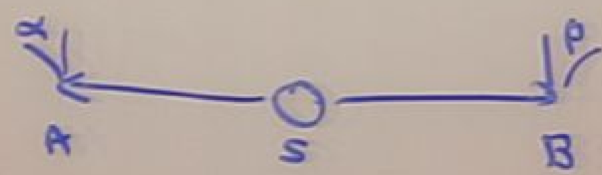
— How could B know in which direction you would measure A?

⇒ B could not be spin down before meas. A.

Before Bell 1964 - Assumed not expt'ly decidable.

2A

4



Bell used EPR hypothesis (+ completeness)

Particle A conditions determined at source

Function $A(\alpha, \lambda) = \pm 1$ for ↑ ↓

"hidden variables" determine all parameters for particles

Particle A doesn't know what angle β will be. Locality

Same for B − $B(\beta, \lambda)$

Perfect corr.

$$A(\alpha,\lambda)\, B(\beta,\lambda) = +1, \quad \beta - \alpha = \pi$$
$$= -1, \quad \beta = \alpha$$

E = Expectation value

5

Subsequent History

Shimony, Horne
Clauser, Horne, Shimony, Holt

Inequalities for inefficient detectors

Need Assumptions – { Random Sampling
others

Expts –
Clauser + Freedman 1st
Fry
Aspect et al   best known
(Rel. non. loc.)

Down conversion → many great expts.

→ 2 coherent
Low ω

one Hi ω

Alley + Shih → Mandel
others

Today –
EPR – Probably the most
disproven hypothesis in History –
– still wont go away!

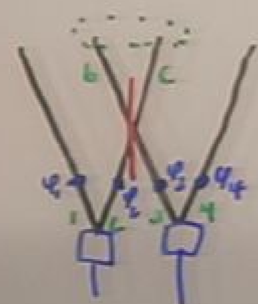
GHZ

6

Zeilinger's grp has shown that there is a new way to Entangle states.

2 independent Down-conversions

(Volkswagen state) VW



① 2 indep. down conversions

② Catch b-c simultaneously in a singlet state

③ Then 1,4 are also in a singlet state.

But particles 1 + 4 have never met!

Called Entanglement Swapping.

(one photon in b, one in c ⇒ singlet state)

(Alt. description. photon 2 – Teleported to 4 or photon 3 teleported to 1.)

G ~~ral~~ state is (using QM) ⑧ ⑥

$$|\Psi_\Sigma\rangle = |\Psi^-_{ab}\rangle|\Psi^-_{cd}\rangle$$

$$\rightarrow \frac{1}{2}\Big\{ +|\Phi^+_{bc}\rangle\left[-|\Phi^+\rangle\cos\xi + |\Psi^-\rangle\sin\xi\right]_{ad}$$
$$+|\Psi^-_{bc}\rangle\left[-|\Psi^-\rangle\cos\xi - |\Phi^+\rangle\sin\xi\right]_{ad}$$
$$+|\Phi^-_{bc}\rangle\left[+|\Phi^-\rangle\cos\eta + |\Psi^+\rangle\sin\eta\right]_{ad}$$
$$+|\Psi^+_{bc}\rangle\left[|\Psi^+\rangle\cos\eta - |\Phi^-\rangle\sin\eta\right]_{ad}\Big\}$$

$$\xi = (\varphi_1 - \varphi_2) + (\varphi_3 - \varphi_4)$$
$$\eta = (\varphi_1 - \varphi_2) - (\varphi_3 - \varphi_4)$$

Above shows some simple correlations always

$$\left.\begin{matrix}\Phi^+_{bc}\\ \Psi^-_{bc}\end{matrix}\right\} \longleftrightarrow \left\{\begin{matrix}\Phi^+_{ad}\\ \Psi^-_{ad}\end{matrix}\right. \text{ thru } \xi$$

$$\left.\begin{matrix}\Phi^-_{bc}\\ \Psi^+_{bc}\end{matrix}\right\} \longleftrightarrow \left\{\begin{matrix}\Phi^-_{ad}\\ \Psi^+_{ad}\end{matrix}\right. \text{ thru } \eta$$

For a class. expl. EPR el. of R. exists.

b-c in set Φ^+, Ψ^-, so is a-d $\quad K = +1$

bc $\quad \Phi^-\ \Psi^+$ so is a-d $\quad K = -1$

... nal State is (using QM) 8 6

$$|\Psi_\Sigma\rangle = |\psi^-_{ab}\rangle|\psi^-_{cd}\rangle$$

$$\rightarrow \frac{1}{2}\Big\{ +|\phi^+_{bc}\rangle\left[-|\phi^+\rangle\cos\xi + |\psi^-\rangle\sin\xi\right]_{ad}$$
$$+|\psi^-_{bc}\rangle\left[-|\psi^-\rangle\cos\xi - |\phi^+\rangle\sin\xi\right]_{ad}$$
$$+|\phi^-_{bc}\rangle\left[+|\phi^-\rangle\cos\eta + |\psi^+\rangle\sin\eta\right]_{ad}$$
$$+|\psi^+_{bc}\rangle\left[|\psi^+\rangle\cos\eta - |\phi^-\rangle\sin\eta\right]_{ad}\Big\}$$

$$\xi = (\varphi_1 - \varphi_2) + (\varphi_3 - \varphi_4)$$
$$\eta = (\varphi_1 - \varphi_2) - (\varphi_3 - \varphi_4)$$

Above shows some simple correlations always

$$\left.\begin{matrix}\phi^+_{bc}\\ \psi^-_{bc}\end{matrix}\right\} \longleftrightarrow \left\{\begin{matrix}\phi^+_{ad}\\ \psi^-_{ad}\end{matrix}\right. \text{ thru } \xi$$

$$\left.\begin{matrix}\phi^-_{bc}\\ \psi^+_{bc}\end{matrix}\right\} \longleftrightarrow \left\{\begin{matrix}\phi^-_{ad}\\ \psi^+_{ad}\end{matrix}\right. \text{ thru } \eta$$

For a class. expl. EPR el. of R. exists.

b-c in set ϕ^+, ψ^-, so is a-d $\quad K = +1$

bc $\phi^-\ \psi^+$ so is a-d $\quad K = -1$

9 6

General State is (using QM)

$|\Psi_\Sigma\rangle = |\psi^-_{ab}\rangle|\psi^-_{cd}\rangle$

$\rightarrow \frac{1}{2}\{ + |\phi^+_{bc}\rangle [-|\phi^+\rangle \cos\xi + |\psi^-\rangle \sin\xi]$ …

$+ |\psi^-_{bc}\rangle [-|\psi^-\rangle \cos\xi - |\phi^+\rangle \sin\xi]$ …

$+ |\phi^-_{bc}\rangle [+|\phi^-\rangle \cos\eta + |\psi^+\rangle \sin$ …

$+ |\psi^+_{bc}\rangle [|\psi^+\rangle \cos\eta - |\phi^-$ …

$\xi = (\varphi_1 - \varphi_2) + (\varphi_3 - \varphi_4)$

$(\varphi_1 - \varphi_2) - (\varphi_3 - \varphi_4)$

In hidden Var. land. (7)

particles a-b created with
a\/b c\/d — same h.v. – λ_1
λ_1 λ_4 — Part. c-d with λ_4

Then $\kappa = \kappa(\lambda_1, \lambda_4)$ — Doesn't depend on φ's

$\zeta_\kappa = (\varphi_1 - \varphi_2) + \kappa(\varphi_3 - \varphi_4)$ – replaces angles ξ η

$\kappa_{bc} = \kappa_{ad} = \kappa$ (Perf. corr. when $\zeta_\kappa = 0, \frac{\pi}{2}, \pi$)

Other hidd. Var. knowledge in polariz. Take $H = +1$, $V = -1$

For 2 particles, take product.

$\Phi^\pm = \frac{1}{\sqrt{2}}(HH \pm VV)$ Prod $= +1$

$\Psi^\pm = \frac{1}{\sqrt{2}}(HV \pm VH)$ Prod $= -1$

For part a, $A(\varphi_1, \lambda_1)$ exists $= \pm 1$

$+ \equiv |H\rangle_a$, $- \equiv |V\rangle_a$

(If measure other 3 polariz, & know Bell state of b-c, know pol of a)

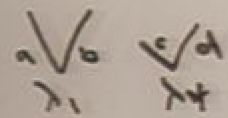
For d $D(\varphi_4 \lambda_4) = \pm 1$.

For b-c $F_\kappa(\varphi_2 \varphi_3, \lambda_1, \lambda_4) = \pm 1$ ← = polariz prod.

κ = Bell state

In hidden Var. land. (7)

Particles a-b created with same h.v. – λ_1



part. c-d with λ_4

Then $\kappa = \kappa(\lambda_1, \lambda_4)$ Doesn't depend on φ's

$\zeta_\kappa = (\varphi_1 - \varphi_2) + \kappa(\varphi_3 - \varphi_4)$ – replaces angles ξ η

$\kappa_{bc} = \kappa_{ad} = \kappa$ (Perf. corr. when $\zeta_\kappa = 0, \frac{\pi}{2}, \pi$)

Other hidden var. knowledge in polariz. Take $H = +1$, $V = -1$

For 2 particles, take product.

$\Phi^\pm = \frac{1}{\sqrt{2}}(HH \pm VV)$ Prod $= +1$

$\Psi^\pm = \frac{1}{\sqrt{2}}(HV \pm VH)$ Prod $= -1$

For part a, $A(\varphi_1, \lambda_1)$ exists $= \pm 1$

$+ \equiv |H\rangle_a$, $- \equiv |V\rangle_a$

(If measure other 3 polariz, & know Bell state of b-c, know pol of a.)

For d $D(\varphi_4 \lambda_4) = \pm 1$.

For b-c $F_\kappa(\varphi_2 \varphi_3, \lambda_1, \lambda_4) = \pm 1 \leftarrow$ = polarizat. prod.

κ = Bell state

In[illegible]den Var. land.

(7)

Particles a-b created with
[illegible] h.v. – λ_1
Part. c-d with λ_4

$a\backslash/b \quad c\backslash/d$
$\lambda_1 \quad \lambda_4$

Then $\kappa = \kappa(\lambda_1, \lambda_4)$ Doesn't depend on φ's

$\zeta_\kappa = (\varphi_1 - \varphi_2) + \kappa(\varphi_3 - \varphi_4)$ – replaces angles $\xi\eta$

$\kappa_{bc} = \kappa_{ad} = \kappa$ (Perf. corr. when $\zeta_\kappa = 0, \frac{\pi}{2}, \pi$)

Other hidd. var. knowledge in polariz. Take $H = +1$
$V = -1$

For 2 particles, take product.

$\phi^\pm = \frac{1}{\sqrt{2}}(HH \pm VV)$ Prod $= +1$

$\psi^\pm = \frac{1}{\sqrt{2}}(HV \pm VH)$ Prod $= -1$

For part a, $A(\varphi_1, \lambda_1)$ exists $= \pm$ ✓

$+ \equiv |H\rangle_a$, $- \equiv |V\rangle_a$

(If measure other 3 polariz, & know Bell state of b-c, know pol of a.)

$\varphi_1\ \varphi_2\ \varphi_3\ \varphi_4$
$a\backslash/b\ c\backslash/d$

For d $D(\varphi_4 \lambda_4) = \pm 1$.

For b-c $F_{\kappa}(\varphi_2 \varphi_3, \lambda_1, \lambda_4) = \pm 1$ ← = polariz. prod.
κ = Bell state

In[illegible] Hidden Var. land. 7

Particles a–b created with
set h.v. – λ_1
Part. c–d with λ_4

a\/b c\/d
λ_1 λ_4

Then $\kappa = \kappa(\lambda_1, \lambda_4)$ Doesn't depend on φ's

$\zeta_\kappa = (\varphi_1 - \varphi_2) + \kappa(\varphi_3 - \varphi_4)$ – replaces angles ξ, η

$\kappa_{bc} = \kappa_{ad} = \kappa$ (Perf. corr, when $\zeta_\kappa = 0, \frac{\pi}{2}, \pi$)

Other hidden var. knowledge in polariz. Take $H = +1$
$V = -1$

For 2 particles, take product.

$\phi^\pm = \frac{1}{\sqrt{2}}(HH \pm VV)$ Prod $= +1$

$\psi^\pm = \frac{1}{\sqrt{2}}(HV \pm VH)$ Prod $= -1$

For part a, $A(\varphi_1, \lambda_1)$ exists $= \pm 1$

$+ \equiv |H\rangle_a$, $- \equiv |V\rangle_a$

(If measure other 3 polariz, & know Bell state of b–c, know pol of a.)

For d $D(\varphi_4 \lambda_4) = \pm 1$.

For b–c $F_\kappa(\varphi_2 \varphi_3, \lambda_1, \lambda_4) = \pm 1$ ← = polariz. prod.

$\uparrow$ = Bell state

(10) (8)

Entire Set of Perfect correlations contained in:

$$A(\varphi_1\lambda_1)\,F_{LL}(\varphi_2\varphi_3\,\lambda_1\lambda_4)\,D(\varphi_4\lambda_4) = 1,\quad \zeta_L = 0, \pm\pi$$
$$= -1,\quad \zeta_L = \pm\frac{\pi}{2}$$

This Eq. guarantees all QM perfect correlations Explained by class H.V. Theory (uses deterministic + local reality (EPR))

BUT it is inconsistent!

For 100% efficient detectors, functions $A, F, D = \pm 1$ for all values of argument.

1st If $\varphi_1 = \varphi_2$, $\varphi_4 = \varphi_3$

$$A(\varphi_2\lambda_1)\,F_L(\varphi_2\varphi_3\,\lambda_1\lambda_4)\,D(\varphi_3\lambda_4) = 1$$

$\xi = \eta = \zeta_L = 0$

so. $F_L(\varphi_2\varphi_3\lambda_1\lambda_4) = A(\varphi_2\lambda_1)\,D(\varphi_3\lambda_4)$

Then $A(\varphi_1\lambda_1)\,A(\varphi_2\lambda_1)\,D(\varphi_3\lambda_4)\,D(\varphi_4\lambda_4) = 1,\ \zeta_L = 0$
$= -1,\ \zeta_L = \frac{\pi}{2}$

Take φ's $= \varphi_1, \varphi_1 + \frac{\pi}{4}, \varphi_2, \varphi_2 + \frac{\pi}{4}$]

$$A(\varphi_1\lambda_1)\,A(\varphi_1 + \tfrac{\pi}{4}\,\lambda_1)\,D(\varphi_2,\lambda_4)\,D(\varphi_2 + \tfrac{\pi}{4}\,\lambda_4) = (-1, \ldots$$

(10) (8)

Entire Set of Perfect correlations contained in:

$$A(\varphi_1 \lambda_1)\, F_{K}(\varphi_2 \varphi_3\, \lambda_1 \lambda_4)\, D(\varphi_4 \lambda_4) = 1, \quad \zeta_K = 0, \pm\pi$$
$$= -1, \quad \zeta_K = \pm\tfrac{\pi}{2}$$

This Eq. guarantees all QM perfect correlations Explained by class H.V. Theory (uses deterministic + local reality (EPR))

BUT it is inconsistent!

For 100% efficient detectors, functions A, F, D = ±1 for all values of argument.

1st If $\varphi_1 = \varphi_2$, $\varphi_4 = \varphi_3$

$$A(\varphi_2 \lambda_1)\, F_K(\varphi_2 \varphi_3\, \lambda_1 \lambda_4)\, D(\varphi_3 \lambda_4) = 1$$

$\xi = \eta = \zeta_K = 0$

so. $F_K(\varphi_2 \varphi_3\, \lambda_1 \lambda_4) = A(\varphi_2 \lambda_1)\, D(\varphi_3 \lambda_4)$

Then $A(\varphi_1 \lambda_1)\, A(\varphi_2 \lambda_1)\, D(\varphi_3 \lambda_4)\, D(\varphi_4 \lambda_4) = 1, \quad \zeta_K = 0$

$= -1, \quad \zeta_K = \tfrac{\pi}{2}$

Take φ's $= \varphi_1, \varphi_1 + \tfrac{\pi}{4}, \varphi_2, \varphi_2 + \tfrac{\pi}{4}$)

$$A(\varphi_1 \lambda_1)\, A(\varphi_1 + \tfrac{\pi}{4}, \lambda_1)\, D(\varphi_2, \lambda_4)\, D(\varphi_2 + \tfrac{\pi}{4}, \lambda_4) = \{-1, \ldots$$

Entire Set of Perfect correlations contained in: (10) (8)

$$A(\varphi_1\lambda_1)\,F_\kappa(\varphi_2\varphi_3\,\lambda_1\lambda_4)\,D(\varphi_4\lambda_4) = 1,\quad \zeta_\kappa = 0, \pm\pi$$
$$= -1,\quad \zeta_\kappa = \pm\tfrac{\pi}{2}$$

This Eq. guarantees all QM perfect correlations Explained by class H.V. Theory (uses deterministic + local reality (EPR))

BUT it is inconsistent !

For 100% efficient detectors, functions $A, F, D = \pm 1$ for all values of argument.

1st if $\varphi_1 = \varphi_2,\ \varphi_4 = \varphi_3$

$$A(\varphi_2\lambda_1)\,F_\kappa(\varphi_2\varphi_3\,\lambda_1\lambda_4)\,D(\varphi_3\lambda_4) = 1$$

$\xi = \eta = \zeta_\kappa = 0$

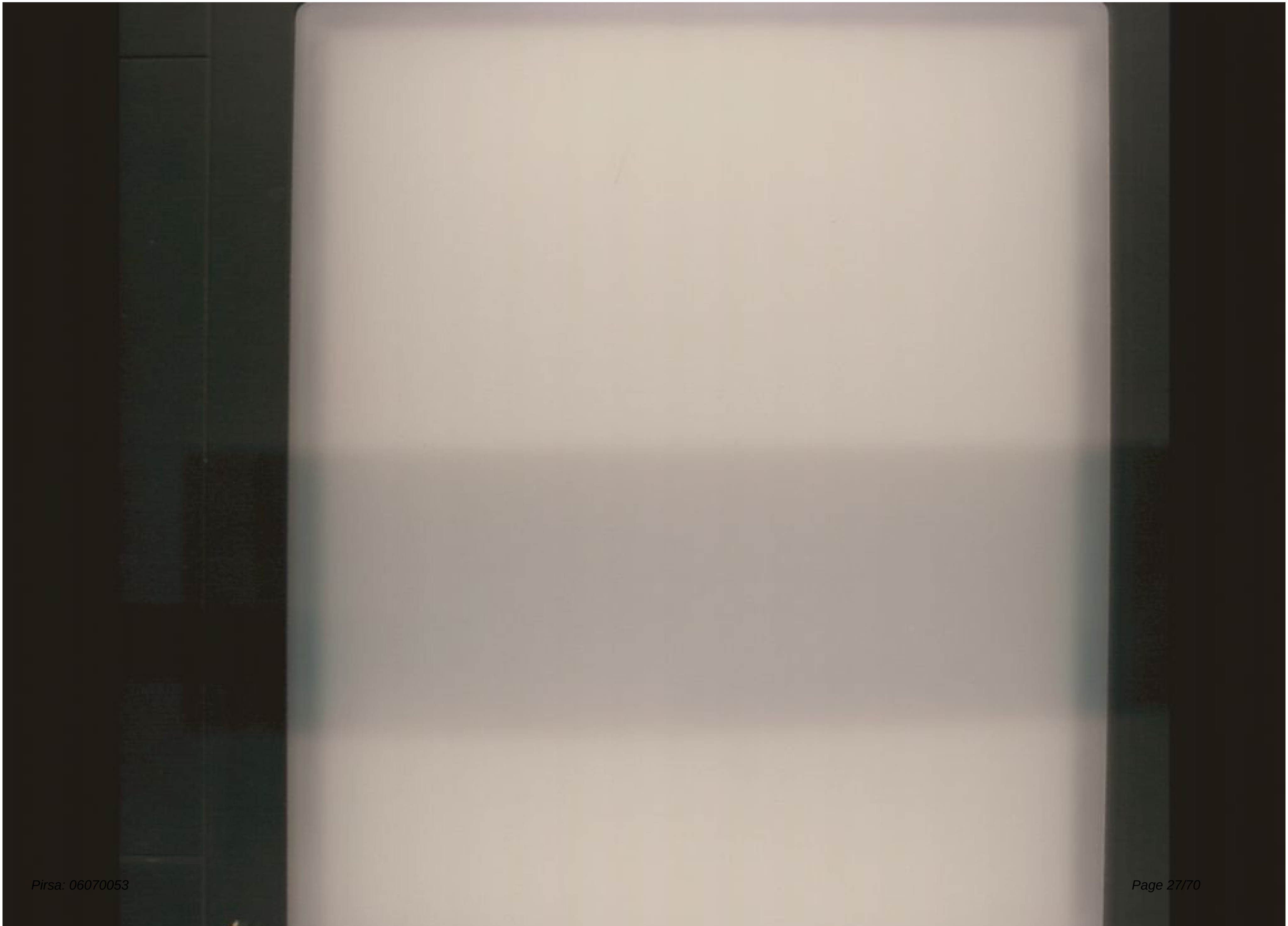
so. $F_\kappa(\varphi_2\varphi_3\lambda_1\lambda_4) = A(\varphi_2\lambda_1)\,D(\varphi_3\lambda_4)$

Then $A(\varphi_1\lambda_1)\,A(\varphi_2\lambda_1)\,D(\varphi_3\lambda_4)\,D(\varphi_4\lambda_4) = 1,\ \zeta_\kappa = 0$

$= -1,\ \zeta_\kappa = \frac{\pi}{2}$

Take φ's $= \varphi_1, \varphi_1 + \frac{\pi}{4}, \varphi_2, \varphi_2 + \frac{\pi}{4}$

$A(\varphi_1\lambda_1)\,A(\varphi_1 + \frac{\pi}{4}\lambda_1)\,D(\varphi_2\lambda_4)\,D(\varphi_2 + \frac{\pi}{4}\lambda_4) = \{-1, \ldots$



We multiply both Eqs. together

$$[A(\varphi_1 \lambda_1) \quad (\varphi_1+\tfrac{\pi}{4}\lambda_1)\, D(\varphi_2,\lambda_4)\, D(\varphi_2+\tfrac{\pi}{4}\lambda_4)]^2 = \begin{cases} -1 & \kappa=+1 \\ -1 & \kappa=-1 \end{cases}$$

$$+1 = -1$$

Contradiction!

Do Expt. with these angles, get QM!

For inefficient counters can't use EPR arg. directly.

If 3 of 4 part. counted,

can predict 4th, but can't predict that it will be counted.

Call this weak EPR.

If not counted, set $A, D, F = 0$

Then

Assump 1 [$A(\varphi_1 \lambda_1)\, F_\kappa(\varphi_2 \varphi_3\, \lambda_1 \lambda_4)\, D(\varphi_4 \lambda_4) = 1, 0, \quad \zeta_\kappa = 0, \pi$

$= -1, 0, \quad \zeta_\kappa = \pm\frac{\pi}{2}$

Take $\varphi_1 = \varphi_3 = \varphi$, $\varphi_2 = \varphi_4 = \alpha$

Deal for simplicity only with case $K = +1$.

If all counted,

$A(\varphi\,\lambda_1)\, F(\alpha\alpha\, \lambda_1\lambda_4)\, D(\varphi\,\lambda_4) = 1 \quad \zeta_+ = 0$

Then $F(\alpha\alpha\,\lambda_1\lambda_4) = A(\varphi,\lambda_1)\, D(\varphi,\lambda_4)$

$F \neq f(\varphi)$, $AD \neq f(\varphi)$

If not, A, D or $F = 0$.

(11) 9

We multiply both Eqs. together

$$[A(\varphi_1\lambda_1) \ldots + \tfrac{\pi}{4}, \lambda_1) D(\varphi_2, \lambda_4) D(\varphi_2 + \tfrac{\pi}{4}, \lambda_4)]^2 = \begin{cases} -1 & \kappa = +1 \\ -1 & \kappa = -1 \end{cases}$$

$$+1 = -1$$

Contradiction!

Do Expt. with these angles, get QM!

For inefficient counters can't use EPR arg. directly.

If 3 of 4 part. counted, can predict 4th, but can't predict that it will be counted.

Call this weak EPR.

If not counted, set $A, D, F = 0$

Then

Assump. 1 [$A(\varphi_1\lambda_1)\, F_\kappa(\varphi_2\varphi_3\lambda_1\lambda_4)\, D(\varphi_4\lambda_4) = 1, 0, \quad \zeta_\kappa = 0, \pi$

$= -1, 0, \quad \zeta_\kappa = \pm\frac{\pi}{2}$

Take $\varphi_1 = \varphi_4 = \varphi$, $\varphi_2 = \varphi_3 = \alpha$

Deal for simplicity only with case $\kappa = +1$.

If all counted,

$A(\varphi\lambda_1)\, F(\alpha\alpha\lambda_1\lambda_4)\, D(\varphi\lambda_4) = 1 \quad \zeta_\kappa = 0$

Then $F(\alpha\alpha\lambda_1\lambda_4) = A(\varphi,\lambda_1) D(\varphi,\lambda_4)$

$F \neq f(\alpha)$, ~~AD~~ $\neq f(\varphi)$

If not, A, D or $F = 0$.

11

We multiply both Eqs. together

$$\left[A(\varphi_1\lambda_1) \ldots (\ldots + \tfrac{\pi}{4}, \lambda_1) D(\varphi_2, \lambda_4) D(\varphi_2 + \tfrac{\pi}{4}, \lambda_4)\right]^2 = \begin{cases} -1 & \kappa = +1 \\ -1 & \kappa = -1 \end{cases}$$

$$+1 = -1$$

Contradiction!

Do Expt. with these angles, get QM!

For inefficient counters can't use EPR arg. directly.

If 3 of 4 part. counted, can predict 4th, but can't predict that it will be counted.

Call this weak EPR.

If not counted, set $A, D, F = 0$

Then

Assump 1

$$A(\varphi_1, \lambda_1)\, F_\kappa(\varphi_2 \varphi_3\, \lambda_1 \lambda_4)\, D(\varphi_4 \lambda_4) = 1, 0, \quad \zeta_\kappa = 0, \pi$$

$$= -1, 0, \quad \zeta_\kappa = \pm\tfrac{\pi}{2}$$

Take $\varphi_1 = \varphi_4 = \varphi$, $\varphi_2 = \varphi_3 = \alpha$

Deal for simplicity only with case $\kappa = +1$.

If all counted,

$$A(\varphi\lambda_1)\, F(\alpha\alpha\, \lambda_1\lambda_4)\, D(\varphi\lambda_4) = 1 \quad \zeta_\kappa = 0$$

Then $F(\alpha\alpha\lambda_1\lambda_4) = A(\varphi, \lambda_1) D(\varphi, \lambda_4)$

$F \neq f(\alpha)$, ~~AD~~ $\neq f(\varphi)$

If not, A, D or $F = 0$.

(11) 9

We multiply both Eqs. together

$$[A(\varphi_1\lambda_1) \ldots \varphi_1+\tfrac{\pi}{4}\lambda_1)\, D(\varphi_2,\lambda_4)\, D(\varphi_2+\tfrac{\pi}{4}\lambda_4)]^2 = \begin{cases} -1 & \kappa=+1 \\ -1 & \kappa=-1 \end{cases}$$

$$+1 = -1$$

Contradiction!

Do Expt. with these angles, get QM!

For inefficient counters can't use EPR arg. directly.

If 3 of 4 part. counted,
can predict 4th, but can't predict that it will be counted.

Call this weak EPR.

If not counted, set $A, D, F = 0$

Then

Assump 1 [$A(\varphi_1\lambda_1)\, F_\kappa(\varphi_2\varphi_3\,\lambda_1\lambda_4)\, D(\varphi_4\lambda_4) = 1, 0,\ \ \zeta_\kappa = 0, \pi$

$= -1, 0,\ \ \zeta_\kappa = \pm\frac{\pi}{2}$

Take $\varphi_1 = \varphi_4 = \varphi,\ \varphi_2 = \varphi_3 = \alpha$

Deal for simplicity only with case $\kappa = +1$.

If all counted,

$A(\varphi\lambda_1)\, F(\alpha\alpha\,\lambda_1\lambda_4)\, D(\varphi\lambda_4) = 1 \quad \zeta_\kappa = 0$

Then $F(\alpha\alpha\,\lambda_1\lambda_4) = A(\varphi,\lambda_1)\, D(\varphi,\lambda_4)$

$F \neq f(\alpha),\ AD \neq f(\varphi)$

If not, A, D or $F = 0$.

We multiply both Eqs. together

[illegible] $= \begin{cases} +1 \\ -1 \end{cases}$

$+1 = -1$

Contradiction!

So start with these angles, get QM!

For inefficient counters can't use EPR arg. directly.

If 3 of 4 part. counted

can predict 4th, but can't predict if 4th will be counted

Call this weak EPR.

If not counted, set $A, D, F = 0$

Then

1 $A(\varphi_1, \lambda_1)\, F(\varphi_2, \varphi_3, \lambda_2, \lambda_3)\, D(\varphi_4, \lambda_4) = 1, 0, \ \ldots = +1$??

$= -1, 0, \ \ldots = -1$??

[illegible]

Deal for simplicity only with case [illegible]

If all counted,

$A(\varphi_1 \lambda_1)\, F(\varphi_2 \varphi_3\, \lambda_2 \lambda_3)\, D(\varphi_4 \lambda_4) = 1$ [illegible]

Then $F(\varphi_2 \varphi_3\, \lambda_2 \lambda_3) = A(\varphi_1 \lambda_1)\, D(\varphi_4, \lambda_4)$

11 9

We multiply both Eqs. together

$$\left[A(\varphi_1\lambda_1)\,A(\;\;\tfrac{\pi}{4},\lambda_1)\,D(\varphi_2,\lambda_4)\,D(\varphi_2+\tfrac{\pi}{4},\lambda_4)\right]^2 = \begin{cases} -1 & \kappa=+1 \\ -1 & \kappa=-1 \end{cases}$$

$$+1 = -1$$

Contradiction!

Do expt. with these angles, get QM!

For inefficient counters can't use EPR arg. directly.

If 3 of 4 part. counted, can predict 4th, but can't predict that it will be counted.

Call this weak EPR.

If not counted, set $A, D, F = 0$

Then

$$A(\varphi_1\lambda_1)\,F_\kappa(\varphi_2\varphi_3\,\lambda_1\lambda_4)\,D(\varphi_4\lambda_4) = 1, 0, \quad \zeta_\kappa = 0, \pi$$
$$= -1, 0, \quad \zeta_\kappa = \pm\tfrac{\pi}{2}$$

Assump 1

Take $\varphi_1=\varphi_4=\varphi$, $\varphi_2=\varphi_3=\alpha$

Deal for simplicity only with case $\kappa=+1$.

If all counted,

$$A(\varphi\lambda_1)\,F(\alpha\alpha\,\lambda_1\lambda_4)\,D(\varphi\lambda_4) = 1 \quad \zeta_+ = 0$$

Then $F(\alpha\alpha\lambda_1\lambda_4) = A(\varphi\lambda_1)D(\varphi,\lambda_4)$

$F \neq f(\alpha)$, $AD \neq f(\varphi)$

If not, A, D or $F = 0$.

We multiply both Eqs. together

$$[A(\varphi_1\lambda_1)A(\ \ \tfrac{\pi}{4},\lambda_1)D(\varphi_2,\lambda_4)D(\varphi_2+\tfrac{\pi}{4},\lambda_4)]^2 = \begin{cases}-1 & \kappa=+1\\ -1 & \kappa=-1\end{cases}$$

$$+1 = -1$$

Contradiction!

Do expt. with these angles, get QM!

For inefficient counters can't use EPR arg. directly.

If 3 of 4 part. counted, can predict 4th, but can't predict that it will be counted.

Call this weak EPR.

If not counted, set $A, D, F = 0$

Then

Assump 1 [$A(\varphi_1\lambda_1)\,F_\kappa(\varphi_2\varphi_3\lambda_i\lambda_4)\,D(\varphi_4\lambda_4) = 1, 0,\ \zeta_\kappa = 0, \pi$

$= -1, 0,\ \zeta_\kappa = \pm\frac{\pi}{2}$

Take $\varphi_1 = \varphi_4 = \varphi$, $\varphi_2 = \varphi_3 = \alpha$

Deal for simplicity only with case $\kappa = +1$.

If all counted, $A(\varphi\lambda_1)\,F(\alpha\alpha\,\lambda_i\lambda_4)\,D(\varphi\lambda_4) = 1 \quad \zeta_+ = 0$

Then $F(\alpha\alpha\,\lambda_i\lambda_4) = A(\varphi,\lambda_1)D(\varphi,\lambda_4)$

$F \neq f(\alpha)$, $AD \neq f(\varphi)$

If not, A, D or $F = 0$.

(11) 9

We multiply both Eqs. together

$$\left[A(\varphi_1\lambda_1)\,A(\varphi_1+\tfrac{\pi}{4},\lambda_1)\,D(\varphi_2,\lambda_4)\,D(\varphi_2+\tfrac{\pi}{4},\lambda_4)\right]^2 = \begin{cases}-1 & \kappa=+1\\ -1 & \kappa=-1\end{cases}$$

$$+1 = -1$$

Contradiction!

Do Expt. with these angles, get QM!

For inefficient counters can't use EPR arg. directly.

If 3 of 4 part. counted, can predict 4th, but can't predict that it will be counted.

Call this weak EPR.

If not counted, set A, D, F = 0

Then

Assump 1 [$A(\varphi_1\lambda_1)\,F_\kappa(\varphi_2\varphi_3\lambda_2\lambda_3)\,D(\varphi_4\lambda_4) = 1, 0,\ \ \xi_\kappa = 0, \pi$

$= -1, 0,\ \ \xi_\kappa = \pm\frac{\pi}{2}$

Take $\varphi_1 = \varphi_3 = \varphi,\ \varphi_2 = \varphi_3 = \alpha$

Does extending theory to <u>deterministic</u> <u>inefficient</u> detectors destroy EPR <u>objectivity</u>?

No!

<u>Remember EPR</u> –

If you can predict a property of particle <u>without interacting with it</u>, you cannot have affected the property, & so property existed <u>before</u> you made the measurement.

Thus this is true, objective property of particle, that must have existed when particle created – <u>or</u> since last interaction.

In our situation – can predict if particle will be detected, but if detected, can predict property precisely.

This particle either possessed property independently, or determined beforehand that it wouldn't be detected.

In either case – existence of property <u>does not</u> depend on measurement

[illegible] is an objective E.P.R.

Does [illegible] [illegible]ending Theory to deterministic insufficient detectors destroy EPR el. of reality?

NO!

Remember EPR –

If you can predict a property of particle without interacting with it, you cannot have affected the property, + so property existed before you made the measurement.

Thus this is true, objective property of particle, that must have existed when particle created – or since last interaction.

In our situation – can't predict if particle will be detected, but if detected, can predict property precisely.

Thus – particle either possessed property beforehand, or determined beforehand that it won't be detected.

In either case – existence of property does not depend on measurement and so is an objective E. of R.

Does extending Theory to deterministic inefficient detectors destroy EPR el. of reality?

NO!

Remember EPR –

If you can predict a property of particle without interacting with it, you cannot have affected the property, & so property existed before you made the measurement.

Thus this is true, objective property of particle, that must have existed when particle created – or since last interaction.

In our situation – can't predict if particle will be detected, but if detected, can predict property precisely.

Thus – particle either possessed property beforehand, or determined beforehand that it won't be detected.

In either case – existence of property does not depend on measurement and so is an objective E. of R.

Does Extending Theory to deterministic inefficient detectors destroy EPR el. of reality?

NO!

Remember EPR –

If you can predict a property of particle without interacting with it, you cannot have affected the property, & so property existed before you made the measurement.

Thus this is true, objective property of particle, that must have existed when particle created – or since last interaction.

In our situation – can't predict if particle will be detected, but if detected, can predict property precisely.

Thus – particle either possessed property beforehand, or determined beforehand that it won't be detected.

In either case – existence of property does not depend on measurement and so is an objective E. of R.

Let: $A(\varphi_1,\lambda_1) = \begin{cases} \pm 1 & \text{if particle counted} \\ 0 & \text{if not counted} \end{cases}$

Then $A(\varphi_1,\lambda_1) = \underbrace{a(\varphi_1,\lambda_1)}_{\pm 1}\ \underbrace{\Delta_A(\varphi_1,\lambda_1)}_{1,0}$

Similarly, $D(\varphi_4,\lambda_4) = d(\varphi_4,\lambda_4)\,\Delta_D(\varphi_4,\lambda_4)$

&

$F(\varphi_2,\varphi_3,\lambda_1\lambda_4) = f(\varphi_2\varphi_3\lambda_1\lambda_4)\,\Delta_F(\;\cdot\;\cdot\;)$

Even with inefficient counters

Then We can prove, a, d, f all factor

$a(\varphi_1,\lambda_1) = a(\varphi_1)\,u(\lambda_1)$

$d(\varphi_4,\lambda_4) = a(\varphi_4)\,v(\lambda_4)$

$f(\varphi_2\varphi_3\lambda_1\lambda_4) = a(\varphi_2)\,a(\varphi_3)\,u(\lambda_1)\,v(\lambda_4)$

Factorize $\Rightarrow$ $a(\alpha) = a(\beta) = \text{const.}$

But $AFD = \begin{matrix} +1 \text{ sometimes} \\ -1 \text{ sometimes} \end{matrix}$

So – whole scheme is inconsistent, (Don't Need Random Sampling)

(Depends on 2 indep. sources)

Let $\ldots(\varphi_1,\lambda_1) = \begin{cases} 1, & \text{if particle counted} \\ 0 & \text{if not counted.} \end{cases}$ (13)

Then $A(\varphi_1\lambda_1) = a(\varphi_1,\lambda_1)\,\Delta_A(\varphi_1,\lambda_1)$

$\qquad a$: ± 1, $\quad \Delta_A$: $1, 0$

Similarly, $D(\varphi_4,\lambda_4) = d(\varphi_4,\lambda_4)\,\Delta_D(\varphi_4,\lambda_4)$

&

$F(\varphi_2,\varphi_3,\lambda_1\lambda_4) = f(\varphi_2\varphi_3\lambda_1\lambda_4)\,\Delta_F(\cdots)$

Even with inefficient counters

Then We can prove, a, d, f all factor

$a(\varphi_1,\lambda_1) = a(\varphi_1)\,u(\lambda_1)$

$d(\varphi_4,\lambda_4) = a(\varphi_4)\,v(\lambda_4)$

$f(\varphi_2\varphi_3\lambda_1\lambda_4) = a(\varphi_2)\,a(\varphi_3)\,u(\lambda_1)\,v(\lambda_4)$

Factorize $\Rightarrow a(\alpha) = a(\beta) = \text{const.}$

But $AFD = \begin{matrix} +1 \text{ sometimes} \\ -1 \text{ sometimes} \end{matrix}$

So – whole scheme is inconsistent. (Don't Need Random Sampling)

(Depends on 2 indep. sources)

C... of proof is

consistency condition

If

$A(\alpha,\lambda_1)\,A(\beta,\lambda'_\beta) = a(\alpha)u(\lambda_1)a(\beta)u(\lambda'_1)$

then $= A(\alpha,\lambda'_1)\,A(\beta,\lambda_1)$

This is true.

necessary condition for factorization,

(not sufficient cond.)

One factorable, then

$A\,F\,D = a(\varphi_1)\,a(\varphi_2)\,a(\varphi_3)\,a(\varphi_4)\,\Delta_A\Delta_B\Delta_D$

$\Rightarrow a(\varphi_1) = a(\varphi_2) = \text{const.}$

Core of proof is
consistency condition

If
$A(\alpha,\lambda_1)\, A(\beta,\lambda'_\beta) = a(\alpha)u(\lambda_1)a(\beta)u(\lambda'_1)$

then $= A(\alpha,\lambda'_1)\, A(\beta,\lambda_1)$

This is true.

Necessary condition for factorization,

(not sufficient cond.)

One factorable, then

$AFD = a(\varphi_1)a(\varphi_2)a(\varphi_3)a(\varphi_4)\,\Delta_A\Delta_B\Delta_D$

$\Rightarrow a(\varphi_1) = a(\varphi_2) = \text{const.}$

Single source vs. 2 sources (19)

Cabello, + (Hardy) [illegible] and have produced equivalent proofs in 100% case, without worrying about 1 source for all 4 particles or 2 sources, as in VW state.

1 source

$$A(\varphi_1\lambda)\,F(\varphi_2\varphi_3\lambda)\,D(\varphi_4\lambda) = 1 \quad \xi = 0, \pm\pi$$
$$= -1 \quad \xi = \pm\tfrac{\pi}{2}$$

Our 100% proof works for single source.

But for $\varphi_2 = \varphi_3 = 0$ (or not there at all)
You need factorizability.
Also for inefficient case, need factorizability.

But you can't factorize single source
$$A(\varphi\lambda)\,F(\alpha\alpha\lambda)\,D(\varphi_4\lambda) = 1$$
can't factor out λ dependence.

Single source vs. 2 sources (14)

(Hardy)
Cabello, + [illegible] and have produced equivalent proofs in 100% case, without worrying about 1 source for all 4 particles or 2 sources, as in VW state.

1 source

$$A(\varphi_1\lambda)\,F(\varphi_2\varphi_3\lambda)\,D(\varphi_4\lambda) = 1 \quad \xi = 0, \pm\pi$$
$$= -1 \quad \xi = \pm\tfrac{\pi}{2}$$

Our 100% proof works for single source.

But for $\varphi_2 = \varphi_3 = 0$ (or not there at all)
You need factorizability.
Also for inefficient case, need factorizability.

But you can't factorize single source
$$A(\varphi\lambda)\,F(\alpha\alpha\lambda)\,D(\varphi_4\lambda) = 1$$
can't factor out λ dependence.

Single S[illegible]rce vs. 2 sources (14)

Cabella, (Hardy,) + Aravind have produced equivalent proofs in 100% case, without worrying about 1 source for all 4 particles or 2 sources, as in VW State.

1 source

$$A(\varphi_1\lambda)\,F(\varphi_2\varphi_3\lambda)\,D(\varphi_4\lambda) = 1 \quad \xi = 0, \pm\pi$$
$$= -1 \quad \xi = \pm\frac{\pi}{2}$$

Our 100% proof works for single source.

But for $\varphi_2 = \varphi_3 = 0$ (or not there at all)
You need factorizability.
Also for inefficient case, need factorizability.

But you cant factorize single source
$$A(\varphi\lambda)\,F(\alpha\alpha\lambda)\,D(\varphi_4\lambda) = 1$$
cant factor out λ dependence.

Single Source vs. 2 Sources (14)

Cabello, (Hardy's) + Aravind have produced equivalent proofs in 100% case, without worrying about 1 source for all 4 particles or 2 sources, as in VW States

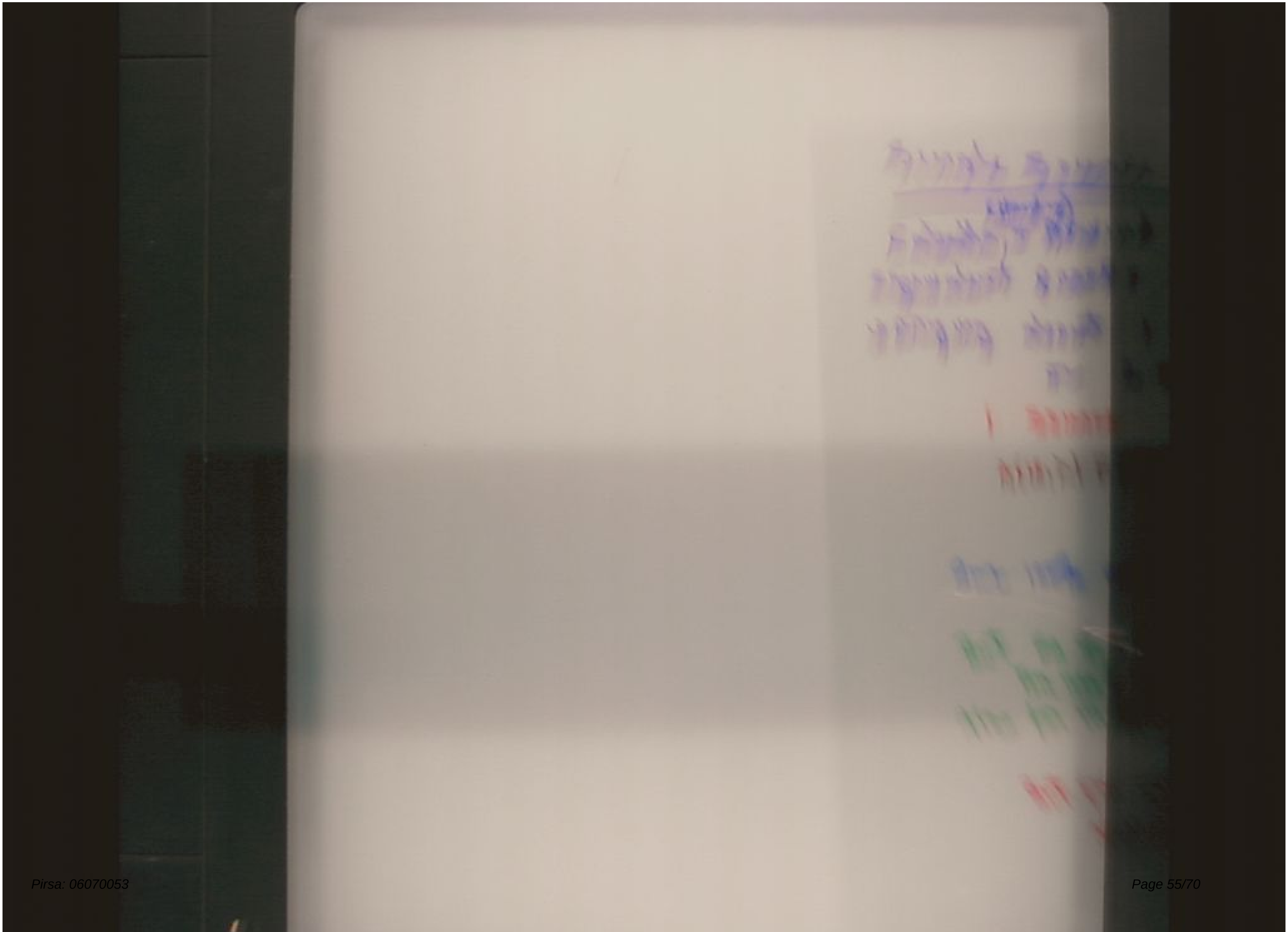
1 Source

$$A(\varphi_1\lambda)\,F(\varphi_2\varphi_3\lambda)\,D(\varphi_4\lambda) = 1 \quad \xi = 0, \pm\pi$$
$$= -1 \quad \xi = \pm\frac{\pi}{2}$$

Our 100% proof works for single source.

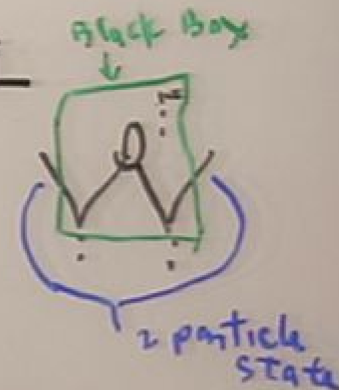
But For $\varphi_2 = \varphi_3 = 0$ (or not there at all)
You need factorizability.
Also for inefficient case, need factorizability.

But you can't factorize single source
$$A(\varphi\lambda)\,F(\alpha\alpha\lambda)\,D(\varphi_4\lambda) = 1$$
can't factor out λ dependence.



Summary

With VW state



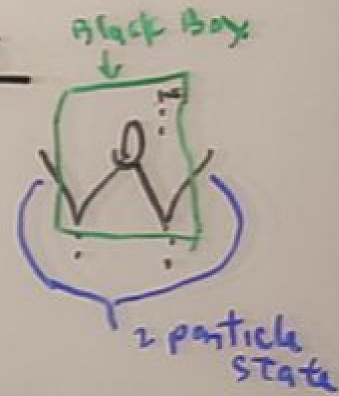
You can prove
any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent - even with
very ineffient counters

Dont need –
Random sampling
efficient detectors.

Our ArXiv paper B - needs correcting
Paper A - GHZ (efficient)
Paper B - GHZZ (inefficient)
↑ Zukowsky

Summary

With VW state



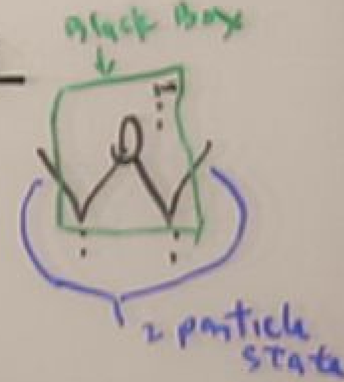
You can prove
any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent - even with very inefficient counters

Dont need—
Random sampling
efficient detectors.

Our ArXiv paper B. needs correcting
Paper A – GHZ (efficient)
Paper B – GHZZ (inefficient)
↑ Zukowsky

(17)

Summary



With VW state

You can prove
any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent. even with
very inefficient counters

Don't need—
Random sampling
efficient detectors.

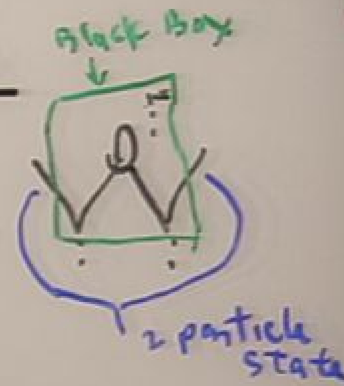
Our ArXiv paper B. needs correcting

Paper A - GHZ (efficient)

Paper B - GHZZ (inefficient)
↑ Zukowsky

(7)

Summary



With VW state

You can prove
any Local, deterministic, Realistic Theory
to explain perfect correlations
is <u>inconsistent</u> - even with
very inefficient counter

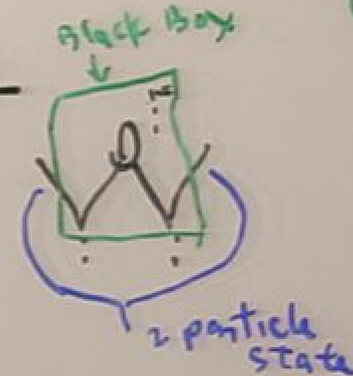
Dont need—
Random sampling
efficient detectors.

Our ArXiv Paper B · needs correcting

Paper A - GHZ (efficient)
Paper B - GHZ Z (inefficient)
↑ Zukovsky

(17)

Summary



With VW state

You can prove

any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent. even with
very ineffient counters

Dont need —
Random sampling
efficient detectors.

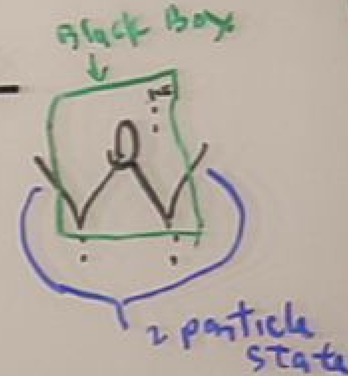
Our ArXiv Paper B · needs correcting

Paper A – GHZ (efficient)
Paper B – GHZ Z (inefficient)
↑ Zukowsky

(17)

Summary

With VW state



You can prove

any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent. even with
very ineffient counters

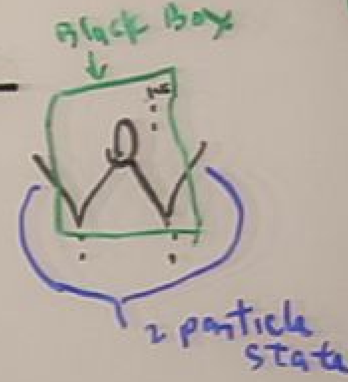
Dont need—
Random sampling
efficient detectors.

Our ArXiv paper B - needs correcting

Paper A - GHZ (efficient)
Paper B - GHZZ (inefficient)
↑ Zukowsky

(17)

Summary



With VW state

You can prove
any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent. even with very inefficient counters

Don't need—
Random sampling
efficient detectors.

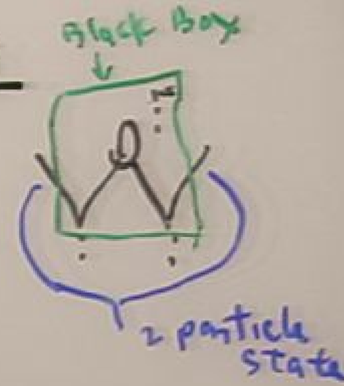
Our ArXiv Paper B · needs correcting

Paper A – GHZ (efficient)
Paper B – GHZZ (inefficient)
↑ Zukowsky

(17)

Summary

With W state



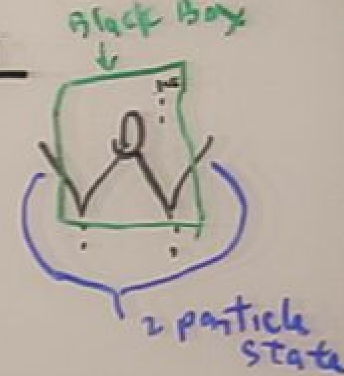
You can prove
any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent. even with very ineffient counters

Dont need—
Random sampling
efficient detectors.

Our ArXiv paper B. needs correcting

Paper A – GHZ (efficient)
Paper B – GHZZ (inefficient)
↑ Zukowsky

Summary



With W state

You can prove
any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent. even with very inefficient counters

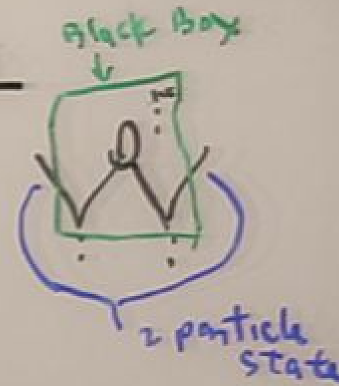
Dont need—
Random sampling
efficient detectors.

Our ArXiv paper B. needs correcting

Paper A - GHZ (efficient)
Paper B - GHZZ (inefficient)
↑ Zukowsky

(17)

Summary



With W state

You can prove
any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent - even with very inefficient counters

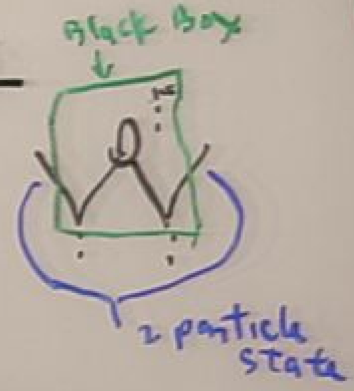
Don't need —
Random sampling
efficient detectors.

Our ArXiv paper B · needs correcting

Paper A - GHZ (efficient)
Paper B - GHZ Z (inefficient)
↑ Zukowsky

(17)

Summary



With VW state

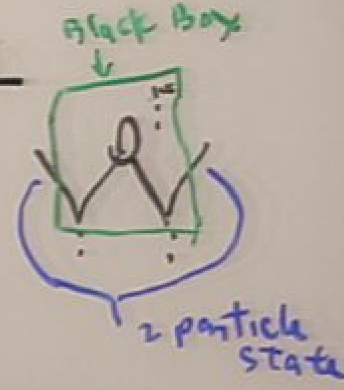
You can prove
any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent. even with very inefficient counters

Dont need—
- Random sampling
- efficient detectors.

Our ArXiv paper B. needs correcting

Paper A – GHZ (efficient)
Paper B – GHZZ (inefficient)
↑ Zukowsky

Summary



With W state

You can prove
any Local, deterministic, Realistic Theory
to explain perfect correlations
is inconsistent. even with
very inefficient counters

Dont need —
Random sampling
efficient detectors.

Our ArXiv Paper B. needs correcting

Paper A – GHZ (efficient)
Paper B – GHZZ (inefficient)
↑ Zukowsky