

Title: Inefficient Detectors Do Not Bar Bell Theorems Without Inequalities

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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 )

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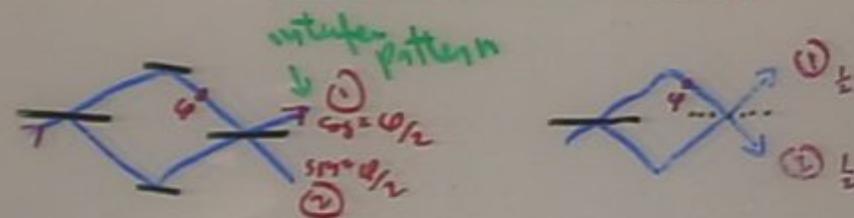
①

## 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:

$$\begin{array}{ccccc} A & \xrightarrow{s=\frac{1}{2}} & \textcircled{s=0} & \xrightarrow{s=\frac{1}{2}} & B \\ \uparrow & & & & \downarrow \\ & & & & \end{array} \quad \begin{array}{l} \text{singlet state} \\ \Psi = \frac{1}{\sqrt{2}} (\uparrow_1 \downarrow_2 - \downarrow_1 \uparrow_2) \end{array}$$

called "entangled state"

Canc 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 (+ objective).

Spin above is El. R.  
two spins above

(3)

### The EPR Logic

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

### Bohr Logic -

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

Before Bell 1964 - Assumed not exptly  
decidable.

(3)

### The EPR Logic

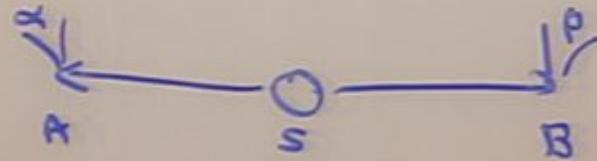
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(2A)  
(4)



Bell used EPR hypothesis (+ completeness)

Particle A conditions determined at source

Function  $A(\alpha, \lambda) = \pm 1$  for  $\uparrow \downarrow$

"hidden variables"

determine all parameters  
for particles

Particle B doesn't know what  
angle  $\beta$  will be. Locality

Same for B -  $B(\beta, \lambda)$

perfect corr.

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

$E = \text{Expectation value}$

(5)

### Subsequent History

Shimony, Home  
Clauser, Home, Shimony, Holt }

Inequalities for inefficient detectors

Need assumptions - { Random sampling  
others }

Expts -  
Clauser-Freedman 1T  
Aspect et al best known  
(Rel. non-local.)

Dem. conversion  $\rightarrow$  many great expt.

$\xrightarrow{\text{one HW}}$   $\xrightarrow{\text{one HW}}$   $\rightarrow$  2 coherent  
 $\downarrow$   $\downarrow$   $\downarrow$  low  $\omega$

Allen - Shih  $\rightarrow$  Mandel  
others

Today -  
EPR - Probably the most  
disproven hypothesis in History -  
- still won't go away!

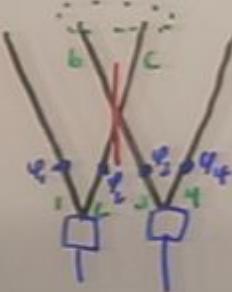
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Zeilinger's group has shown that  
there is a new way to entangle states.

2 independent Down-conversions

(Volkswagen state)



- 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  $\Rightarrow$  singlet state)

(Alt. description - Photon 2 - Teleported to 4  
or Photon 3 teleported to 1.)

C real state is (using QM) ⑨ ⑩

$$|\Psi_c\rangle = |\Psi_{ab}^-\rangle |\Psi_{cd}^-\rangle$$

$$\begin{aligned} \rightarrow & \frac{1}{2} \left\{ +|\Phi_{bc}^+\rangle [-|\Phi^+\rangle \cos \xi + |\Psi^-\rangle \sin \xi]_{ad} \right. \\ & + |\Psi_{bc}^-\rangle [-|\Psi^-\rangle \cos \xi - |\Phi^+\rangle \sin \xi]_{ad} \\ & + |\Phi_{bc}^+\rangle [+|\Phi^+\rangle \cos \eta + |\Psi^+\rangle \sin \eta]_{ad} \\ & \left. + |\Psi_{bc}^+\rangle [|\Psi^+\rangle \cos \eta - |\Phi^+\rangle \sin \eta]_{ad} \right\} \end{aligned}$$

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

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

Above shows some simple correlations always

$$\left. \begin{array}{c} \Phi_{bc}^+ \\ \Psi_{bc}^- \end{array} \right\} \leftrightarrow \left. \begin{array}{c} \Phi_{ad}^+ \\ \Psi_{ad}^- \end{array} \right\} \text{ thru } \xi$$

$$\left. \begin{array}{c} \Phi_{bc}^- \\ \Psi_{bc}^+ \end{array} \right\} \leftrightarrow \left. \begin{array}{c} \Phi_{ad}^- \\ \Psi_{ad}^+ \end{array} \right\} \text{ thru } \eta$$

For a class. expt. exp. etc. R. exists.  
b-c m set  $\Phi^+, \Psi^-$  so is a-d  $K=+1$

$$\text{b-c } \left. \begin{array}{c} \Phi^- \\ \Psi^+ \end{array} \right\} \text{ so is a-d } K=-1$$

real state is (using QM) ⑨ ⑩

$$|\Psi_c\rangle = |\Psi_{ab}^-\rangle |\Psi_{cd}^-\rangle$$

$$\begin{aligned} \rightarrow \frac{1}{2} \{ & + |\Phi_{bc}^+\rangle [-|\Phi^+\rangle \cos \xi + |\Psi^-\rangle \sin \xi]_{ad} \\ & + |\Psi_{bc}^-\rangle [-|\Psi^-\rangle \cos \xi - |\Phi^+\rangle \sin \xi]_{ad} \\ & + |\Phi_{bc}^+\rangle [+|\Phi^+\rangle \cos \eta + |\Psi^+\rangle \sin \eta]_{ad} \\ & + |\Psi_{bc}^+\rangle [|\Psi^+\rangle \cos \eta - |\Phi^+\rangle \sin \eta]_{ad} \} \end{aligned}$$

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

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Now shows some simple correlations always

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For a class. expt. exp. etc. R. exists.  
b-c in set  $\Phi^+, \Psi^-$  so is a-d  $K=+1$

$$\begin{array}{ccccc} bc & \Phi^- \Psi^+ & \text{so is a-d} & K=-1 \\ \cancel{\text{a-d}} & \cancel{\text{a-d}} & & \end{array}$$

using QM) ⑤ ⑥

General state is

$$|\Psi_{\Sigma}\rangle = |\Psi_{ab}\rangle |\Psi_{acd}\rangle$$

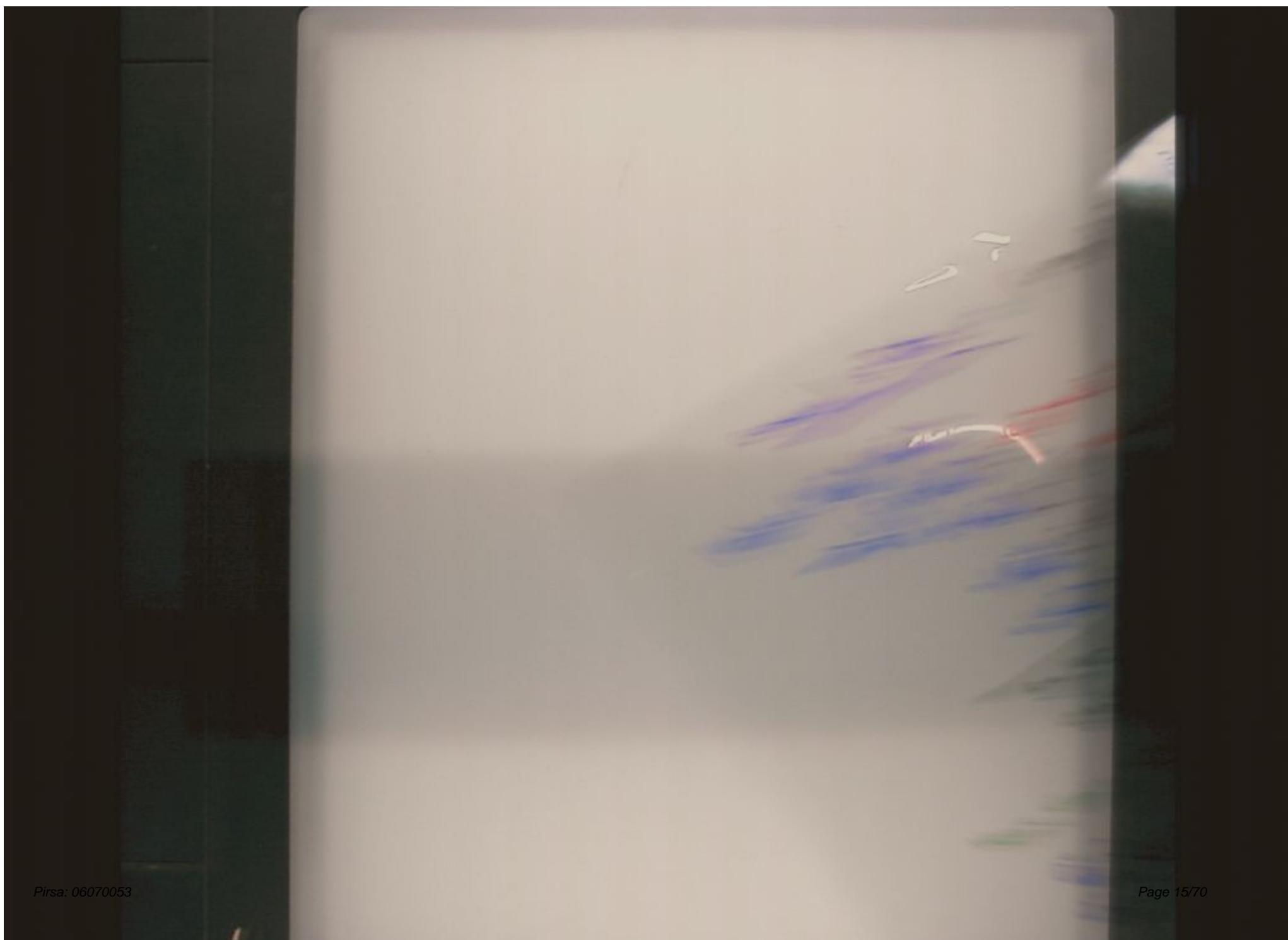
$$\rightarrow \left[ +|\Phi^+\rangle \times |\Psi_{bc}\rangle \right] \left[ -|\Phi^+\rangle \times |\Psi_{bc}\rangle \right]$$

$$+ |\Phi^-\rangle \left[ -|\Psi^-\rangle \times |\Psi_{bc}\rangle \right] - |\Phi^-\rangle \left[ +|\Psi^-\rangle \times |\Psi_{bc}\rangle \right]$$

$$+ |\Psi^+\rangle \left[ +|\Phi^-\rangle \times |\Psi_{bc}\rangle \right] + |\Psi^+\rangle \left[ -|\Phi^-\rangle \times |\Psi_{bc}\rangle \right]$$

$$\xi = (\epsilon_1 - \epsilon_2) + (\epsilon_3 - \epsilon_4)$$

$$(\epsilon_1 - \epsilon_2) - (\epsilon_3 - \epsilon_4)$$







## In n. $\rightarrow$ Var. 1nd.

(7)

articles a-b created with  
 $\lambda_1 \quad \lambda_4$  part. b-c -  $\lambda_1$   
 part. c-d with  $\lambda_4$

Then  $K = K(\lambda_1, \lambda_4)$  doesn't depend  
 on  $\varphi$ 's

$$S_K = (\psi_1 - i\varphi_2) + K(\varphi_3 - i\varphi_4) \sim \text{replace angles } \frac{\pi}{2} \eta$$

$K_{ab} = K_{cd} = K$  (Prob. cons., when  $S_K = 0, \frac{\pi}{2} \eta$ )

Other with Var. Knowledge in  
 polariz. Take  $H=+1$

$$V=-1$$

For 2 particles, take product,

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

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

For part a,  $A(\varphi_1, \lambda_1)$  exists  $\Leftrightarrow \pm \Phi$

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

$\checkmark$   $\begin{matrix} \psi_1 \\ \psi_2 \\ \psi_3 \\ \psi_4 \end{matrix}$  (If measure other 3 polariz, + find out  
 Bell state & b-c, know pol of a)  
 And  $D(\varphi_4 \lambda_4) = \pm 1$ .

For b-c  $F_K(\varphi_2 \varphi_3, \lambda_1, \lambda_4) = \pm 1 \leftarrow$  = polariz & prod.  
 $\frac{1}{\sqrt{2}}$  = Bell state

## In w. Var. I and.

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• Alice a-b created with  
 $\lambda_1 \quad \lambda_4$  part. b-c -  $\lambda_1$   
 part. c-d with  $\lambda_4$

Then  $K = K(\lambda_1, \lambda_4)$  doesn't depend  
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$$S_K = (\psi_1 - i\psi_2) + K(\psi_3 - i\psi_4) \quad \text{--- replaces angles } \frac{\pi}{2} \eta$$

$$K_{AB} = K_{AD} = K \quad (\text{Prob. cons., when } S_K = 0, \eta = \pi)$$

Other with Var. Knowledge in  
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$$V = -1$$

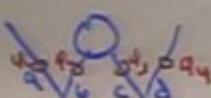
For 2 particles, take product,

$$\Phi^+ = \frac{1}{\sqrt{2}}(HH + VV) \quad \text{prob} = +1$$

$$\Psi^+ = \frac{1}{\sqrt{2}}(HH - VV) \quad \text{prob} = -1$$

For part a,  $A(\varphi_1, \lambda_1)$  exists  $\Leftrightarrow \pm \Phi$

$$+ \equiv HH_A, - \equiv VV_A$$

$\checkmark$  

(If measure other 3 polariz, + find out  
Bell state & b-c, know pol of A)

$$\text{and } D(\varphi_4 \lambda_4) = \pm 1.$$

$$\text{For b-c } F_K(\varphi_2 \varphi_3, \lambda_1, \lambda_4) = \pm 1 \leftarrow \text{polariz. prod.}$$

$\frac{1}{\sqrt{2}}$  = Bell state

## THE SOUTHERN STATES

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U.S. GOVERNMENT PRINTING OFFICE: 1919

卷之三

卷之三

如上所述，在（中）国，人们都在想，如何能使人们更快乐，更快乐的生活。

$\theta_{\text{eff}} = (\theta_1 + \theta_2) / 2$  (the effective angle between the two angles)

1996-1997 学年 第一学期

中大二校(中華書局) 93年三月  
中大二校(中華書局) 93年三月

单兵制导反坦克导弹系统  
发射重量 10kg，弹重 1.7kg

(This mapping often requires the input  
that is shown by the name and by the

Tn den Van Land.

(7)

$\begin{matrix} \checkmark_0 & \checkmark_1 \\ \lambda_1 & \lambda_4 \end{matrix}$  Particles a-b created with  
out h.v. -  $\lambda_1$ ,  
part. c-d with  $\lambda_4$

Then  $K = K(\lambda_1, \lambda_4)$  doesn't depend  
on  $\varphi$ 's

$$\begin{aligned} S_K &= (\varphi_1 - \varphi_2) + K(\varphi_3 - \varphi_4) && \text{replaces angles } \frac{\pi}{2} \text{ or } \pi \\ K_{ab} &= K_{cd} = K && (\text{Post. cons., when } S_K = 0, \frac{\pi}{2}, \pi) \end{aligned}$$

Other with Van. Knowledge in  
polariz. Take  $H = +1$

$$V = -1$$

For 2 particles, take product.

$$\Phi^+ = \frac{1}{\sqrt{2}}(H\bar{H} + VV) \quad \text{Prob} = +1$$

$$\Phi^- = \frac{1}{\sqrt{2}}(H\bar{V} + V\bar{H}) \quad \text{Prob} = -1$$

For part a,  $A(\varphi_1, \lambda_1)$  exists  $\Rightarrow \pm \Phi$   
 $\mp \equiv |H\rangle_a, - \equiv |V\rangle_a$

$\begin{matrix} \checkmark_0 & \checkmark_1 \\ \checkmark_2 & \checkmark_3 \end{matrix}$  (If measure other 3 polariz, + find  
Bell state of b-c, know pol of a)

$$\text{Find } D(\varphi_4, \lambda_4) = \pm 1,$$

$$\text{For b-c } F_K(\varphi_2, \varphi_3, \lambda_1, \lambda_4) = \pm 1 \leftarrow \text{polariz of end.}$$

= Bell state

In den Jon. Land.

(7)

$\begin{matrix} \checkmark_0 & \checkmark_1 \\ \lambda_1 & \lambda_4 \end{matrix}$  Particles a-b created with  
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Other with Jon. Knowledge in  
polariz. Take  $H = +1$

$$V = -1$$

For 2 particles, take product.

$$\Phi^+ = \frac{1}{\sqrt{2}}(H + VV) \quad \text{Prob} = +1$$

$$\Phi^- = \frac{1}{\sqrt{2}}(H + IVH) \quad \text{Prob} = -1$$

For part a,  $A(\varphi_1, \lambda_1)$  exists  $\Rightarrow \pm \Phi$   
 $\mp \equiv |H\rangle_a, - \equiv |V\rangle_a$

$\begin{matrix} \checkmark_0 & \checkmark_1 & \checkmark_4 \\ \lambda_1 & \lambda_4 \end{matrix}$  (If measure other 3 polariz, & know  
Bell state of b-c, know pol of a)

$$\text{Find } D(\varphi_4, \lambda_4) = \pm 1,$$

$$\text{For b-c } F_K(\varphi_2, \varphi_3, \lambda_1, \lambda_4) = \pm 1 \leftarrow \text{polariz of b-c}$$

= Bell state



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

$$A(\varphi, \lambda) F_n(\varphi = \varphi_3, \lambda_1, \lambda_4) D(\varphi_3, \lambda_4) = 1, \quad \zeta_n = 0, \pm \pi \\ = -1, \quad \zeta_n = \pm \frac{\pi}{2}$$

This ex. guarantees all QM perfect correlations explained by classic H.V. Theory  
 (uses deterministic + local reality (STR))

BUT it is inconsistent!

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

Let if  $\varphi_1 = \varphi_2, \varphi_3 = \varphi_4$   
 $A(\varphi_2, \lambda_1) F_n(\varphi_2 = \varphi_3, \lambda_1, \lambda_4) D(\varphi_3, \lambda_4) = 1$   
 $\zeta_1 = \zeta_2 = \zeta_n = 0$   
 so.  $F_n(\varphi_2, \varphi_3, \lambda_1, \lambda_4) = A(\varphi_2, \lambda_1) D(\varphi_3, \lambda_4)$

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

Take  $\varphi_1 = \varphi_2, \varphi_3 = \varphi_4, \lambda_1 = \lambda_4, \lambda_2 = \lambda_3$   $\zeta_1 = \zeta_2 = \zeta_n = \pi$

$A(\varphi_2, \lambda_1) A(\varphi_3, \lambda_4) D(\varphi_3, \lambda_4) D(\varphi_4, \lambda_4) = (-1, 1)$

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

$$A(\varphi, \lambda) F_n(\varphi_2 \varphi_3 \lambda_1 \lambda_2) D(\varphi_4 \lambda_4) = 1, \quad \zeta_n = 0, \pm \pi \\ = -1, \quad \zeta_n = \pm \frac{\pi}{2}$$

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 $A(\varphi_2 \lambda_1) F_n(\varphi_2 \varphi_3 \lambda_1 \lambda_2) D(\varphi_4 \lambda_4) = 1$   
 $\zeta_1 = \zeta_2 = \zeta_n = 0$   
 so.  $F_n(\varphi_2 \varphi_3 \lambda_1 \lambda_2) = A(\varphi_2 \lambda_1) D(\varphi_3 \lambda_2)$

Then  $A(\varphi_2 \lambda_1) A(\varphi_3 \lambda_2) D(\varphi_3 \lambda_2) D(\varphi_4 \lambda_4) = 1, \zeta_n = 0$   
 take  $\varphi_1 = \varphi_2, \varphi_3 = \varphi_4, \lambda_1 = \lambda_2$   $\zeta_1 = \zeta_2 = \frac{\pi}{2}$   
 $A(\varphi_2 \lambda_1) A(\varphi_2 \lambda_2) D(\varphi_2 \lambda_2) D(\varphi_2 \lambda_2) = (-1, 1)$

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

$$A(\varphi, \lambda) F_n(\varphi_2 \varphi_3, \lambda_1 \lambda_2) D(\varphi_4 \lambda_4) = 1, \quad \zeta_n = 0, \pm \pi \\ = -1, \quad \zeta_n = \pm \frac{\pi}{2}$$

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

Let if  $\varphi_1 = \varphi_2, \varphi_4 = \varphi_3$   
 $A(\varphi_2 \lambda_1) F_n(\varphi_2 \varphi_3, \lambda_1 \lambda_2) D(\varphi_4 \lambda_4) = 1$   
 $\zeta = \eta = \zeta_n = 0$   
 so.  $F_n(\varphi_2 \varphi_3, \lambda_1 \lambda_2) = A(\varphi_2 \lambda_1) D(\varphi_3 \lambda_4)$

Then  $A(\varphi_2 \lambda_1) A(\varphi_3 \lambda_4) D(\varphi_3 \lambda_4) D(\varphi_4 \lambda_4) = 1, \zeta_n = 0$   
 take  $\varphi_i = \varphi, \varphi + \frac{\pi}{2}, \varphi, \varphi + \frac{\pi}{2}$   $\zeta_n = \pm \frac{\pi}{2}$   
 $A(\varphi_2 \lambda_1) A(\varphi_3 \lambda_4) D(\varphi_3 \lambda_4) D(\varphi_4 \lambda_4) = \{-1, 1\}$



We multiply both eqns. together (II)

$$\left[ A(\varphi_1) \left( \varphi_1 + \frac{\pi}{4} \right)_1 D(\varphi_2, \lambda_4) D\left(\varphi_2 + \frac{\pi}{4}, \lambda_4\right) \right]^2 = \begin{cases} -1 & \kappa=+1 \\ -1 & \kappa=-1 \end{cases}$$

$$+1 = -1$$

Contradiction!

Do expt. with these angles, get QM!

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

If 3 & 4 part. counted,  
can predict 4<sup>th</sup>, but can't predict if it will be counted.

Call this weak EPR.

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

Then Assume 1  $A(\varphi, \lambda) F(\varphi_1, \varphi_2, \lambda, \lambda_4) D(\varphi_4 \lambda_4) = 1, 0, -1, 0$   
 $= -1, 0, 1, -1$

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

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

If all counted,

$$A(\varphi, \lambda) F(\varphi, \lambda, \lambda_4) D(\varphi, \lambda_4) = 1, 0, 0$$

$$\text{then } F(\varphi, \lambda, \lambda_4) = A(\varphi, \lambda) D(\varphi, \lambda_4)$$

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

If not,  $A, D \cap F = 0$ ,

We multiply both Eqs. together

$$[A(\varphi_1 \lambda_1) + \frac{I}{4} \delta_{11} D(\varphi_2, \lambda_4) D(\varphi_2 + \frac{I}{4} \lambda_4)]^2 = \begin{cases} -1 & k=+1 \\ -1 & k=-1 \end{cases}$$

$$+1 = -1$$

(ii)

9

contradiction!

Do exp. with these angles, get QM!

For inefficient counters can't use SFR any. directly.

If 3 & 4 part. counted,

can predict 4<sup>th</sup>, but can't predict if it will be counted.

Call this week  $\Sigma \mathcal{D} R$ .

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

Then  $A(\varphi_i \lambda_i) F(\varphi_2 \lambda_3, \lambda_4) D(\varphi_4 \lambda_4) = 1, D, S_k = 0, \Pi$   
 $= -1, D, S_k = \pm \frac{\Pi}{2}$

$$\text{Take } \varphi_1 = \varphi_2 = \varphi, \varphi_3 = \varphi_4 = \varphi$$

Deal by simplifying only with case  $k=+1$ .

If all counted,

$$A(\varphi \lambda) F(\varphi \lambda, \lambda_4) D(\varphi \lambda_4) = 1, S_k = 0$$

$$\text{Then } F(\varphi \lambda, \lambda_4) = A(\varphi \lambda) D(\varphi \lambda_4)$$

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

$$\text{If not, } A, D \cap F = 0,$$

We multiply both Eqs. together

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

$$+1 = -1$$

(II)

9

Contradiction!

Do exp. with these angles, get QM!

For inefficient counters can't use SFR any. direction.

If 3 & 4 part. counted,  
can predict 4<sup>th</sup>, but can't predict if it will be counted.

Call this weak SFR.

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

Then  $A(\varphi_i \lambda_i) F(\varphi_2 \lambda_3, \lambda_4) D(\varphi_4 \lambda_4) = 1, 0, S_k = 0, \text{II}$   
 $= -1, 0, S_k = \pm \frac{\pi}{2}$

Assume  
1

$$\varphi_1 = \varphi_3 = \varphi, \quad \varphi_2 = \varphi_4 = \varphi$$

Deal in simplifying only with case  $k=+1$ .

If all counted,

$$A(\varphi \lambda) F(\varphi \lambda, \lambda_4) D(\varphi \lambda_4) = 1, \quad S_k = 0$$

$$\text{Then } F(\varphi \lambda, \lambda_4) = A(\varphi \lambda) D(\varphi \lambda_4)$$

$$F = f(\varphi), \quad A \neq f(\varphi)$$

$$\text{If not, } A, D \cap F = 0,$$

We multiply both Eqs. together

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

$$+1 = -1$$

(II)

9

Contradiction!

Do EXP. with these angles, get Q.M.!

For inefficient counters can't use S.P.R. any. directly.

If 3 & 4 part. counted,  
can predict 4<sup>th</sup>, but can't predict if it will be counted.

Call this week  $\Sigma \Delta R$ .

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

Assume 1 [ Then  $A(\varphi_i \lambda_i) F(\varphi_2 \lambda_3, \lambda_4) D(\varphi_4 \lambda_4) = 1, 0, \Sigma_k = 0, \text{II}$   
 $= -1, 0, \Sigma_k = \pm \frac{\pi}{2}$

$$\text{Take } \varphi_1 = \varphi_3 = \varphi, \varphi_2 = \varphi_4 = \varphi$$

Deal in simplifying only with case  $k=+1$ .

If all counted,

$$A(\varphi \lambda) F(\varphi \lambda \lambda_3 \lambda_4) D(\varphi \lambda_4) = 1 \quad \Sigma_k = 0$$

$$\text{Then } F(\varphi \lambda \lambda_3 \lambda_4) = A(\varphi \lambda) D(\varphi \lambda_4)$$

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

If not,  $A, D \cap F = 0$ ,

We are trying with ~~the~~ ~~empty~~  
~~(incomplete)~~ ~~definition~~.  
 $\vdash A \rightarrow A$

contradiction?  
Do ~~not~~ with this right, yet again!

For sufficient conditions and use  
SPP only directly.  
If  $\exists \beta \forall \gamma$  part counted  
can predict  $\alpha$ , but can predict  $\beta$ ?  
it will be counted

call this weak SPP.

If not covered, set  $A, D, F \equiv 0$

then  $\Delta(\alpha, \beta) \leq (\alpha, \beta, \gamma, \delta, \eta) D(\text{pred}) + 1, 0, 0, 0, 0$   
 $\leq 1, 0, 0, 0, 0$

Deal on completing using with case  $H=H$ ,

$\leq$  all counted,  
 $\Delta(\alpha, \beta) \leq (\alpha, \beta, \gamma, \delta, \eta) D(\text{pred}) + 1, 0, 0, 0$   
then  $\beta = (\alpha, \beta, \gamma, \delta, \eta) + \Delta(\alpha, \beta) D(\text{pred})$

We multiply both eqs. together

$$[A(\varphi_1 \lambda_1) A^T (\varphi_2 \lambda_2) D(\varphi_3 \lambda_3) D(\varphi_4 \lambda_4)]^2 = \begin{cases} -1 & \kappa = +1 \\ -1 & \kappa = -1 \end{cases}$$
$$+1 = -1$$

(1) 9

contradiction!

Do expt. with these angles, get QM!

For inefficient counters can't use EPR any. direction.

If 3 & 4 part. counted,

can predict 4<sup>th</sup>, but can't predict if it will be counted.

call this weak EPR.

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

Then  $A(\varphi_1 \lambda_1) F(\varphi_2 \varphi_3 \lambda_1 \lambda_2) D(\varphi_4 \lambda_4) = 1, 0, \sin \theta, 0, \pi$   
 $= -1, 0, \sin \theta, 0, \pi$

$$\text{Take } \varphi_1 = \varphi_2 = 0, \quad \varphi_3 = \varphi_4 = \pi$$

Deal by simplifying only with case  $\kappa = +1$ .

If all counted,  $A(\varphi \lambda) F(\varphi \lambda \lambda_1 \lambda_2) D(\varphi \lambda \lambda_3 \lambda_4) = 1, 0, 0, 0$

$$A(\varphi \lambda) F(\varphi \lambda \lambda_1 \lambda_2) = A(\varphi \lambda) D(\varphi \lambda \lambda_3 \lambda_4)$$

$$F \neq \pm \delta(\kappa), \quad M \neq \mp \delta(\kappa)$$

If not,  $A, D \cap F = 0$ .

We multiply both eqs. together

$$[A(\varphi_1 \lambda_1) A^* - I_{\lambda_1}) D(\varphi_2 \lambda_2) D(\varphi_3 + \frac{\pi}{4} \lambda_4)]^2 = \begin{cases} -1 & \kappa = +1 \\ -1 & \kappa = -1 \end{cases}$$
$$+1 = -1$$

contradiction!

Do expt. with these angles, get QM!

For inefficient counters can't use EPR any. direction.

If 3 & 4 part. counted,

can predict 4<sup>th</sup>, but can't predict that it will be counted.

call this weak EPR.

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

Then

$$A(\varphi_1 \lambda_1) F(\varphi_2 \varphi_3 \lambda_2 \lambda_3) D(\varphi_4 \lambda_4) = 1, 0, 5_{\kappa=0, \frac{\pi}{2}}$$
$$= -1, 0, 5_{\kappa=\frac{\pi}{2}}$$

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

Deal by simplifying only with case  $\kappa = +1$ .

If all counted,

$$A(\varphi \lambda) F(\varphi \lambda \lambda \lambda) D(\varphi \lambda) = 1, 0, 0$$

$$\text{Then } F(\varphi \lambda \lambda \lambda) = A(\varphi \lambda) D(\varphi \lambda)$$

$$F \neq \pm S(\kappa), M \neq S(\kappa)$$

If not,  $A, D \cap F = 0$ ,



We multiply both Eqs. together

$$\left[ A(\varphi_1 \lambda_1) A(\varphi_1 + \frac{\pi}{4} \lambda_1) D(\varphi_2 \lambda_2) D(\varphi_2 + \frac{\pi}{4} \lambda_2) \right]^2 = \begin{cases} -1 & k=+1 \\ -1 & k=-1 \end{cases}$$
$$+1 = -1$$

contradiction!

Do expt. with these angles, get QM!

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

If 3 & 4 part. counted,  
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call this weak EPR.

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

Then  $A(\varphi_1 \lambda_1) F(\varphi_2 \varphi_3 \lambda_1 \lambda_2) D(\varphi_4 \lambda_4) = 1, 0, 5k=0, \pi$   
 $= -1, 0, 5k=\pm \frac{\pi}{2}$

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



Does something having to do with the  
existing situation nothing with objectivity?

NO!

Measurement to PR -

If you can predict a property of particle  
without interaction with it, you cannot have  
what that the property, & so property exists  
before you make the measurement.

This means is true, objective property  
is particle, which must have existed when  
particle exists - on some last interaction.

In our situation, if each particle  
will be scattered, not to interact, can predict  
property scattering.

Now - particle with predicted property  
scattered, or scattered, implying that it  
won't be scattered.

In another case - suppose if  
scattering does not depend on measurement  
and so we can do nothing w.r.t. P.

Does adding Theory to deterministic  
sufficient detectors destroy EPR el. 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.O.R.

Does Wording Theory to deterministic  
sufficient detectors destroy EPR el. 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 where  
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In either case - existence of  
property does not depend on measurement  
and so is an objective E.o.R.

Does Extending Theory to deterministic  
sufficient do. ors destroy EPR cl. & 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  
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property precisely.

Thus - particle either possessed property  
beforehand, or determined beforehand that it  
wont be detected.

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





$\alpha_1(u_1, \lambda_1) = \begin{cases} 1 & \text{if } u_1 = \lambda_1 \\ 0 & \text{otherwise} \end{cases}$

$$\text{Then } \alpha(u_1, \lambda_1) = \alpha_1(u_1, \lambda_1) \alpha_0(u_1, \lambda_1)$$

$\stackrel{?}{\pm 1} \quad \stackrel{?}{1,0}$

Similarly,  $\alpha(u_4, \lambda_4) = \alpha(u_4, \lambda_4) \alpha_0(u_4, \lambda_4)$

$F(u_1, u_2, \lambda_1, \lambda_4) = f(u_1, u_2, \lambda_1, \lambda_4) \Delta_F(\dots)$

Even with inadherent counts

Then we can prove,  $\alpha, d, f$  all factor

$$\alpha(u_1, \lambda_1) = \alpha(u) \alpha(\lambda_1)$$

$$d(u_4, \lambda_4) = \alpha(u_4) \cup (\lambda_4)$$

$$f(u_1, u_2, \lambda_1, \lambda_4) = \alpha(u_1) \alpha(u_2) \alpha(\lambda_1) \cup (\lambda_4)$$

Factorize  $\Rightarrow \alpha(u) = \alpha(b) = \text{const.}$

But AFD = +1 sometimes  
-1 sometimes

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

(Depends on 2 indep. sources)

Let  $\zeta_{(u_i, \lambda_i)} = \begin{cases} 1 & \text{if particle counted} \\ 0 & \text{if not counted.} \end{cases}$

(13)

$$\text{Then } \alpha(u_i, \lambda_i) = \alpha(u_i, \lambda_i) \Delta_{\alpha}(u_i, \lambda_i) \\ \zeta_i \quad ?_0$$

Similarly,  $D(u_i, \lambda_i) = d(u_i, \lambda_i) \Delta_d(u_i, \lambda_i)$

$F(u_1, u_2, \lambda_1, \lambda_2) = f(u_1, u_2, \lambda_1, \lambda_2) \Delta_f(\dots)$

Even with inexact counts

Then we can prove,  $\alpha, d, f$  all factor

$$\alpha(u_i, \lambda_i) = \alpha(u_i) \alpha(\lambda_i)$$

$$d(u_i, \lambda_i) = d(u_i) d(\lambda_i)$$

$$f(u_1, u_2, \lambda_1, \lambda_2) = f(u_1) f(u_2) f(\lambda_1) f(\lambda_2)$$

Factorize  $\Rightarrow \alpha(u) = \alpha(\theta) = \text{const.}$

But AFD = +1 sometimes  
-1 sometimes

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

(Depends on 2 indep. sources)



Condition of proof is  
consistency condition

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

This is true.

Necessary condition for factorization,  
(not sufficient cond.)

One factorable, then

$$A = D = \alpha(u_1) \alpha(u_2) \alpha(u_3) \alpha(u_4) D_1 D_2 D_3$$
$$\Rightarrow \alpha(u_1) = \alpha(u_2) = \text{const.}$$

Case of proof is  
consistency condition

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

This is true.

Necessary condition for factorization,  
(not sufficient cond.)

One factorable, then

$$A \in D = \alpha(u_1) \alpha(u_2) \alpha(u_3) \alpha(u_4) \Delta_1 \Delta_2 \Delta_3$$
$$\Rightarrow \alpha(u_1) = \alpha(u_2) = \text{const.}$$





## Single Source vs. $\geq$ sources (1)

Cabella, + [Handwritten] and have produced equivalent proofs in 100% case, without varying about 1 source for all 4 particles or 2 sources, as in VW state,  
1 source

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

Our 100% proof works for single source.

But for  $\varphi_2 = \varphi_3 = 0$  (isn't there at all)

You need factorizability.

Also for inefficient case, need factorizability.

But you can't factorize single source

$$A(\varphi\lambda) F(\varphi\varphi\lambda) D(\varphi\varphi\lambda) = 1$$

can't fact'n out  $\lambda$  dependence.

## Single Source vs. $\geq$ sources

(11)

Cabella + <sup>(Hand)</sup> and have produced equivalent proofs in 100% case, without varying about 1 source for all 4 particles or 2 sources, as in VW state.  
1 source

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

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

$$A(\varphi\lambda) F(\varphi\varphi\lambda) D(\varphi+\lambda) = 1$$

can't fact'n out  $\lambda$  dependence.

## Single source vs. 2 sources (1)

(Handy)  
Cabella, + Aravind have produced  
equivalent proofs in 100% case, without  
varying about 1 source for all 4 particle  
or 2 sources, as in VW state.  
1 source

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

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

$$A(\varphi \lambda) F(\alpha \alpha \lambda) D(\beta \varphi_4 \lambda) = 1$$

can't factor out  $\lambda$  dependence.

## Single source vs. $\sum$ sources (1)

(Handwritten)  
Cabella + Aravind have produced  
equivalent proofs in 100% case, without  
varying about 1 source for all 4 particles  
or 2 sources, as in VW state,  
1 source

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

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$$A(\varphi \lambda) F(\alpha \alpha \lambda) D(\beta \varphi_4 \lambda) = 1$$

can't factor out  $\lambda$  dependence.

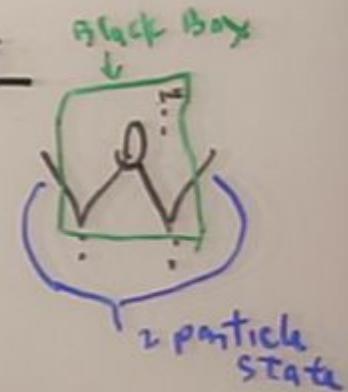
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## Summary

with VW state



(1)

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

Random sampling  
efficient detectors.

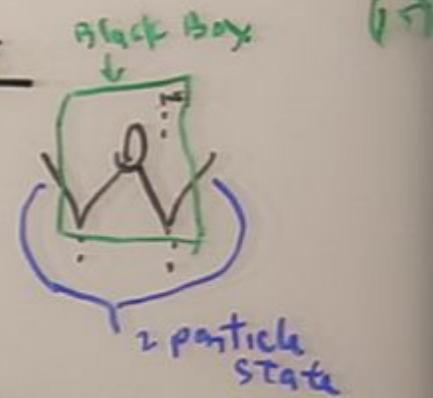
Our ARXIV paper B - needs correcting

Paper A - GHZ (efficient)

Paper B - GHZ  $\in$  (inefficient)  
zukovsky

## Summary

with VW state



(1)

You can prove  
any Local, deterministic, realistic Theory  
to explain perfect correlations  
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very inefficient computers  
Dont need -  
Random sampling  
efficient detectors.

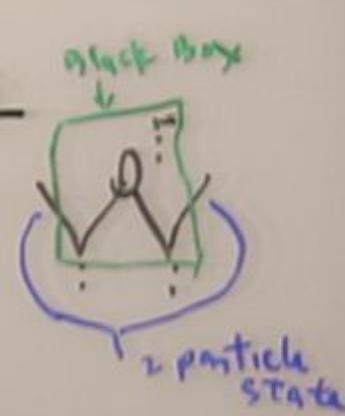
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Paper A - GHZ (efficient)

Paper B - GHZ  $\in$  (inefficient)  
zukovsky

## Summary

with VW state



6.3

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.

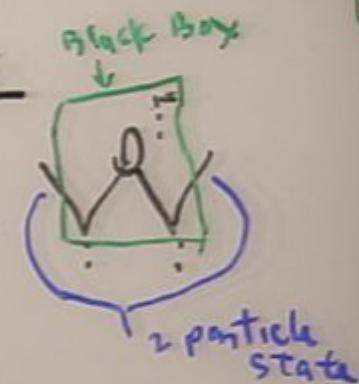
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Paper A - GHZ (efficient)

Paper B - GHZ ↗ (inefficient)  
Eckansky

## Summary

with VW state



67

You can prove

my Local, deterministic, realistic Theory  
to explain perfect correlations

is inconsistent. even with  
very inefficient computers

Dont need -

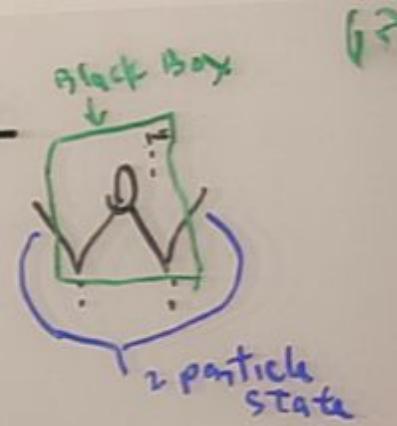
Random sampling  
efficient detectors.

Our Arxiv paper B - needs correcting

Paper A - GHZ (efficient)

Paper B - GHZ  $\in$  (inefficient)  
 $\uparrow$   
Eckansky

Summary  
with VW state



You can prove  
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Random sampling  
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Our ArXiv paper B - needs correcting

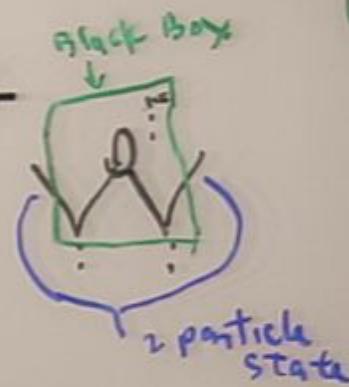
Paper A - GHZ (efficient)

Paper B - GHZ ↗  
Eckansky (inefficient)

13

## Summary

with VW state



You can prove

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Dont need -

Random sampling  
efficient detectors,

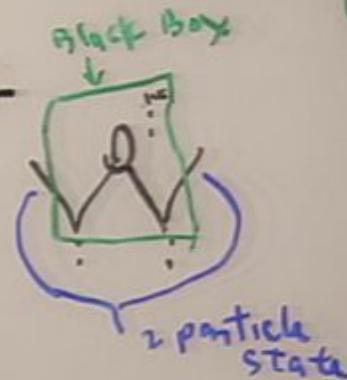
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Paper A - GHZ (efficient)

Paper B - GHZ (inefficient)  
↑ Zukowski

67

Summary  
with VW state



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Dont need -

Random sampling

efficient detectors,

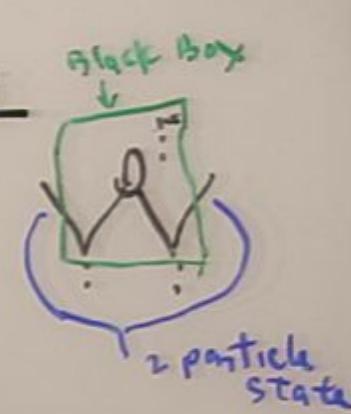
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Paper A - GHZ (efficient)

Paper B - GHZ ↑  
(inefficient)  
Eukovsky

## Summary

with VW state



(1)

You can prove

my Local, deterministic, realistic Theory  
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is "inconsistent" - even with  
very inefficient computers

Dont need -

Random sampling  
efficient detectors.

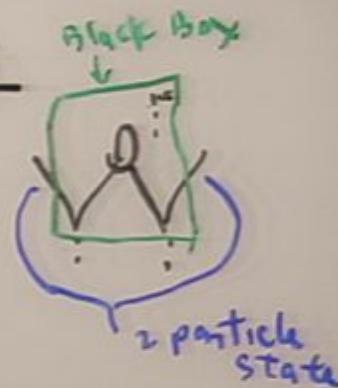
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Paper A - GHZ (efficient)

Paper B - GHZ  $\in$  (inefficient)  
zukowski

## Summary

with VW state



67

You can prove

any Local, deterministic, realistic Theory  
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Random sampling

efficient detectors.

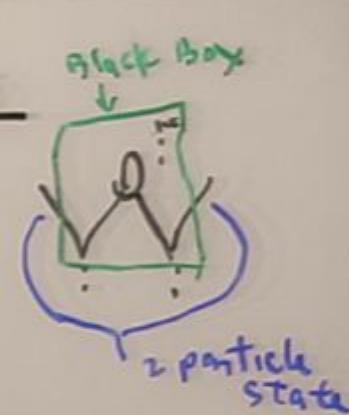
Our ArXiv paper B - needs correcting

Paper A - GHZ (efficient)

Paper B - GHZ  $\stackrel{\text{zukovsky}}{=}$  (inefficient)

## Summary

with VW state



(17)

You can prove

my Local, deterministic, realistic Theory  
to explain perfect correlations

is "inconsistent" - even with  
very inefficient counters

Dont need -

Random sampling  
efficient detectors.

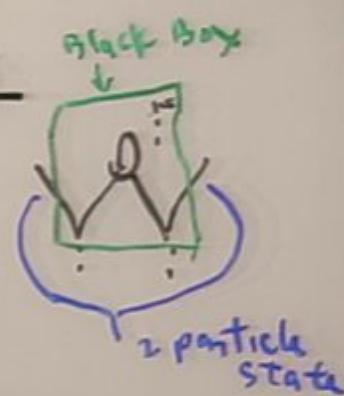
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Paper A - GHZ (efficient)

Paper B - GHZ  $\in$  (inefficient)  
zukovsky

## Summary

with VW state



17

You can prove

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Dont need -

Random sampling  
efficient detectors.

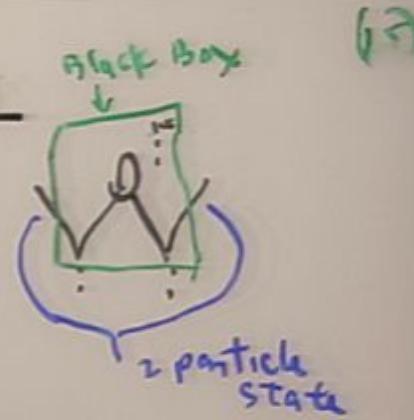
Our ArXiv paper B . needs correcting

Paper A - GHZ (efficient)

Paper B - GHZ  $\stackrel{?}{=}$  (inefficient)  
 $\nwarrow$  Zukowski

## Summary

with VW state



(1)

You can prove

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Dont need -

Random sampling  
efficient detectors.

Our ARXIV paper B - needs correcting

Paper A - GHZ (efficient)

Paper B - GHZ  $\in$  (inefficient)  
↑ Zukovsky



