Title: 3 >> 2

Date: May 11, 2011 10:50 AM

URL: http://pirsa.org/11050031

Abstract: Three-partite quantum systems exhibit interesting features that are absent in bipartite ones. Several instances are classics by now: the GHZ argument, the W state, the UPB bound entangled states, Svetlichny inequalities... In this talk, I shall discuss some on-going research projects that we are pursuing in my group (in collaboration, or in friendly competition, with other groups) and that involve three-partite entanglement or non-locality: * Activation of non-locality in networks. * Device-independent assessment of the entangling power of a measurement. * Can one falsify all models of hidden communication with finite speed? * Information causality in the three-partite scenario. I shall conclude by a blind excursion into uncertainty relations and cryptography, which also shows 3>>2 albeit with a different meaning.

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Post-doc position open

Commitment to fairness: in case of otherwise equally competent candidates,

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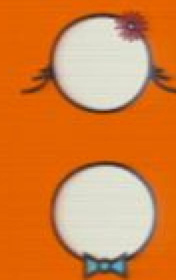
3>>2



Valerio Scarani
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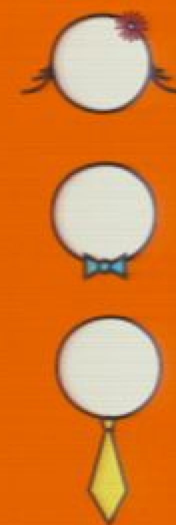
National University of Singapore

3>>2



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The classic examples of 3>>2

- Non-locality
  - GHZ argument
  - Svetlichny
- Entanglement theory
  - Unequivalent classes of entanglement (GHZ and W)
  - Bound entanglement for qubits
  - Bound information proved to exist

Here: four topics

1. Activation of non-locality in networks
2. Device-independent tests of entangling measurements
3. Falsify “hidden signaling”
4. Information causality in the 3-partite scenario

ACTIVATION OF NON-LOCALITY IN NETWORKS

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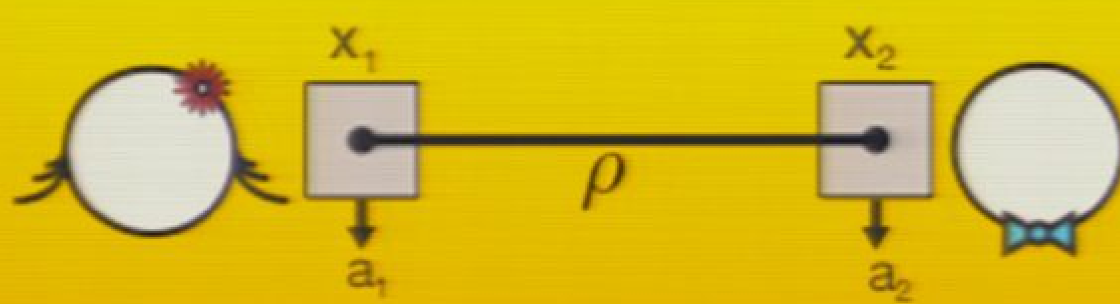
D. Cavalcanti, M. Almeida, V.S., A. Acín, Nature Comm. 2, 184 (2011)

R. Rabelo, D. Cavalcanti, V.S., in preparation

2 parties

$$P(a_1 a_2 | x_1 x_2) \neq \sum_\lambda p(\lambda) P(a_1 | x_1, \lambda) P(a_2 | x_2, \lambda)$$



Can be "local" even if ρ is entangled

2 parties

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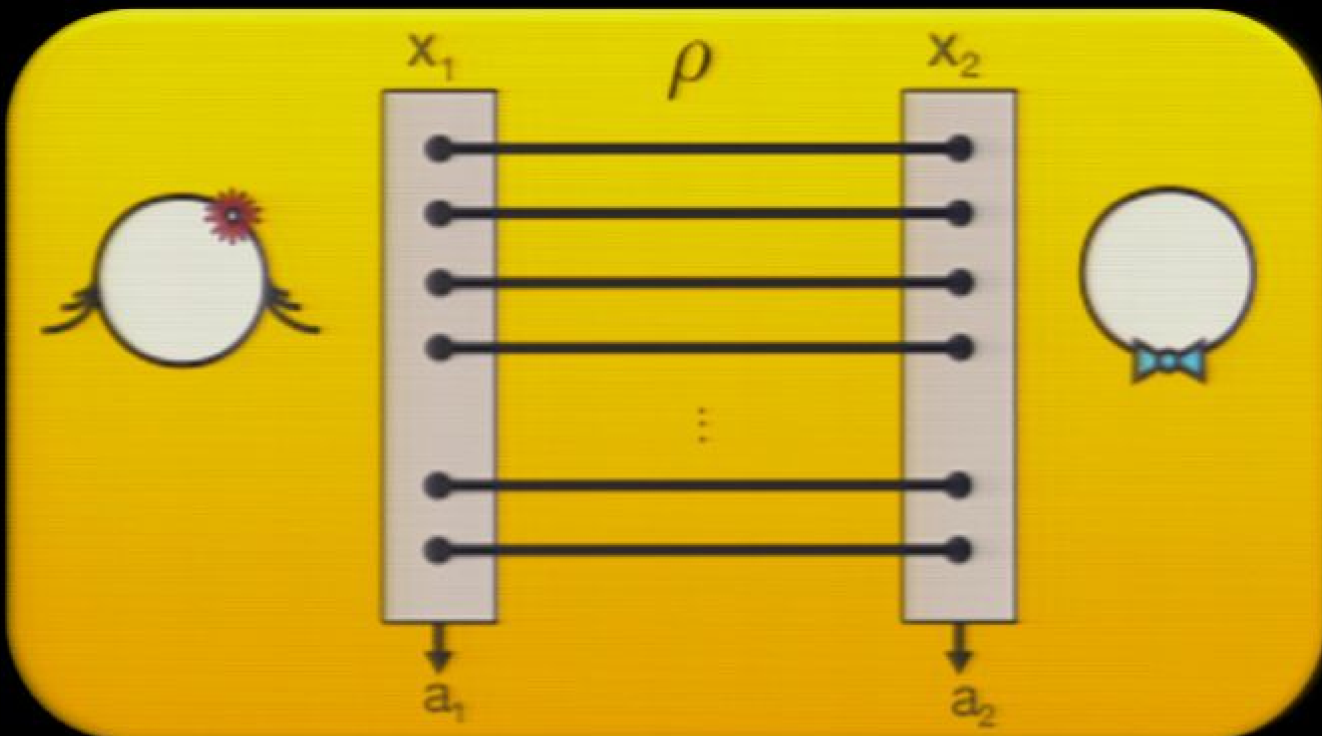

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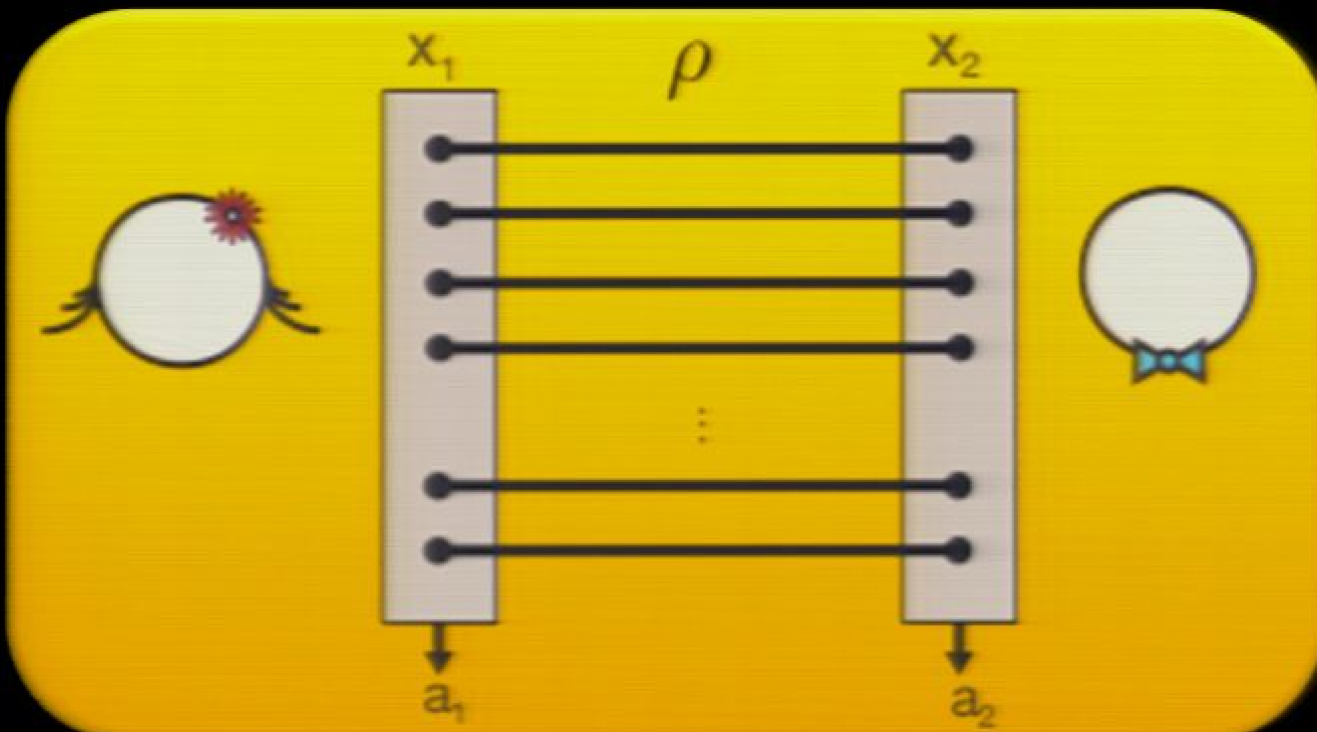

- Can one see non-locality better with many copies?

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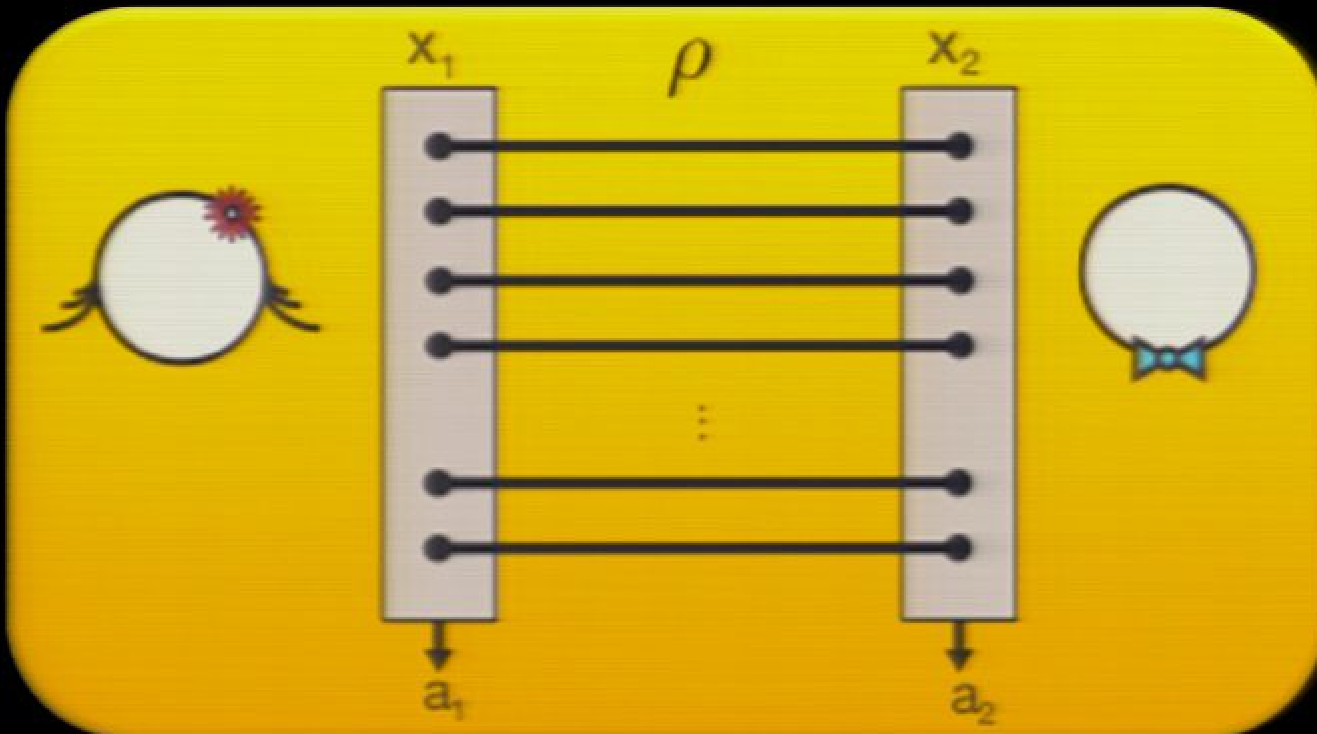

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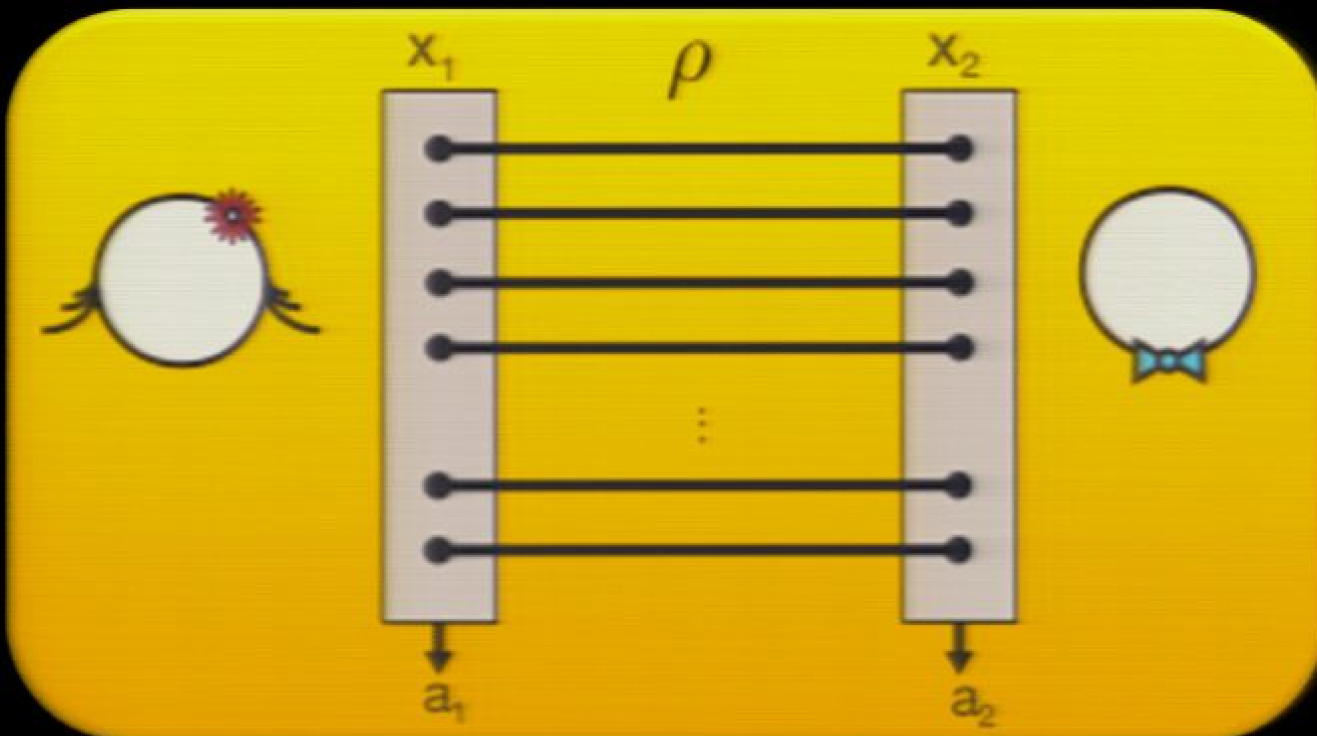
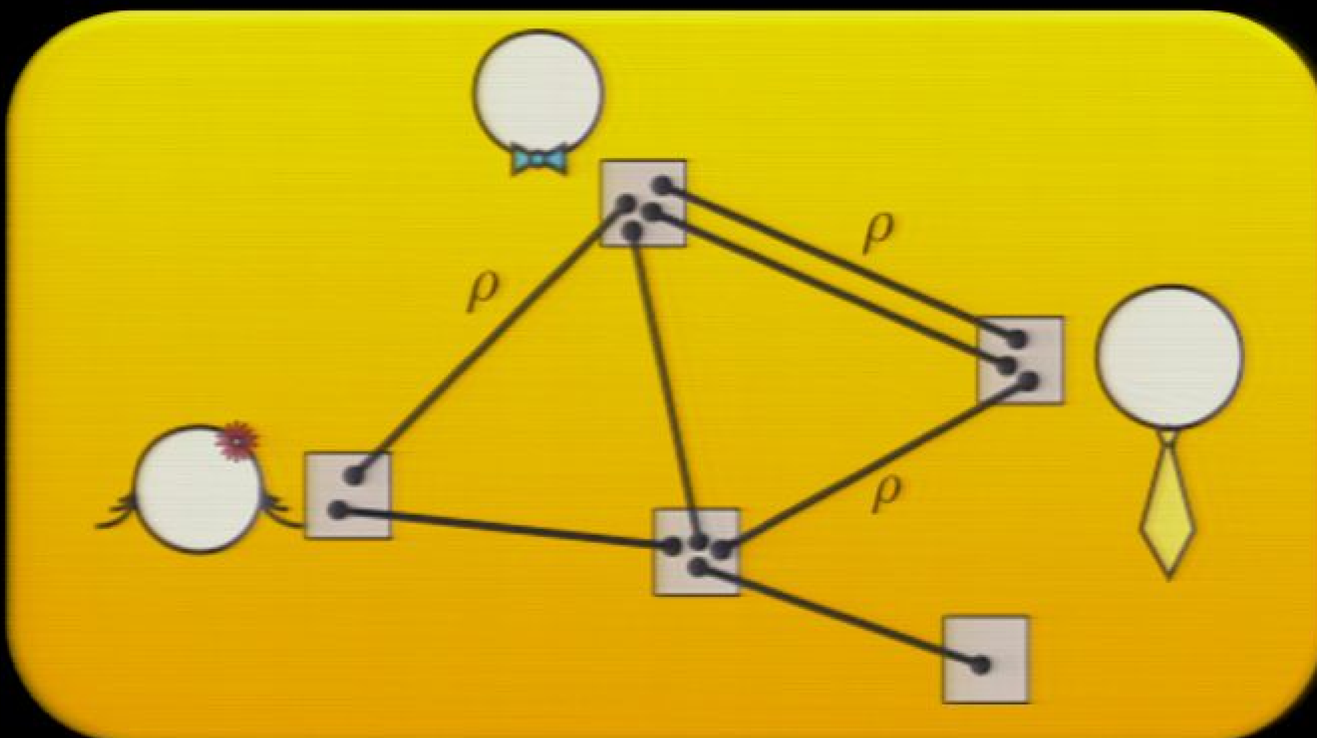


- Can one see non-locality better with many copies?
- Not equivalent to entg distillation: CC not allowed
- Problem basically open (Navascues-Vertesi: CHSH…)

Network scenario

Network scenario: distribute ρ among more than 2 parties

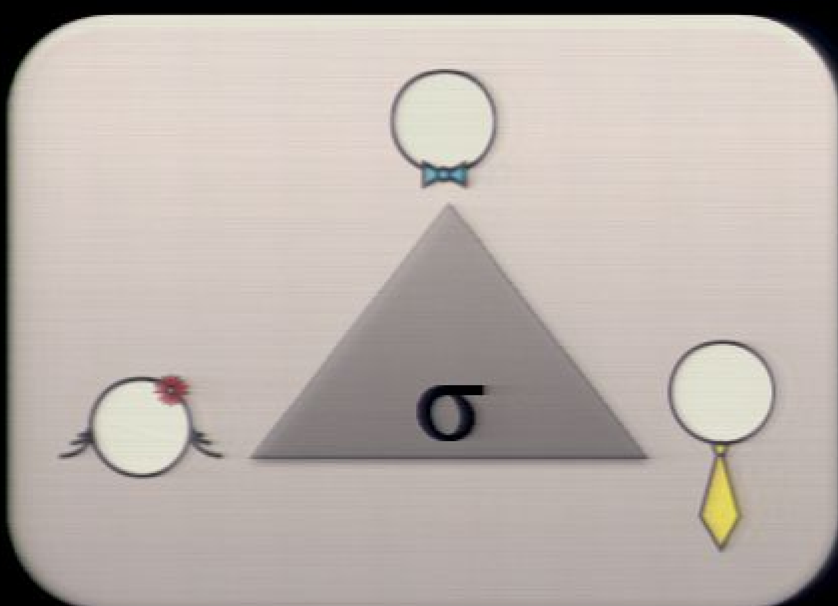


ρ is a "non-local resource" if it can provide non-locality for some network

Observation

If there exist local measurements by k parties such that, for one measurement outcome, the resulting state among the remaining N-k parties violates a Bell inequality, then the initial N-party state violates a Bell inequality.

Rk: stronger requirement than hidden-non-locality (Popescu; Masanes-Liang-Doherty)



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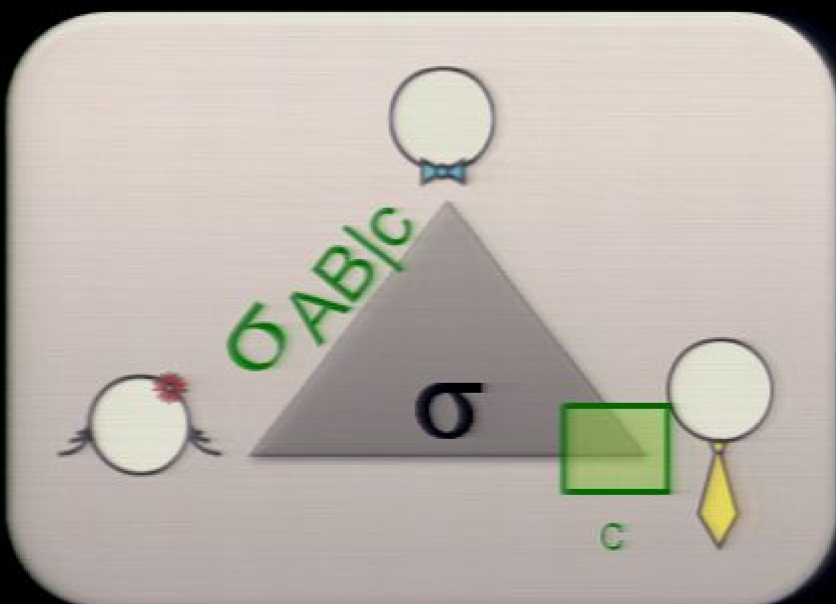

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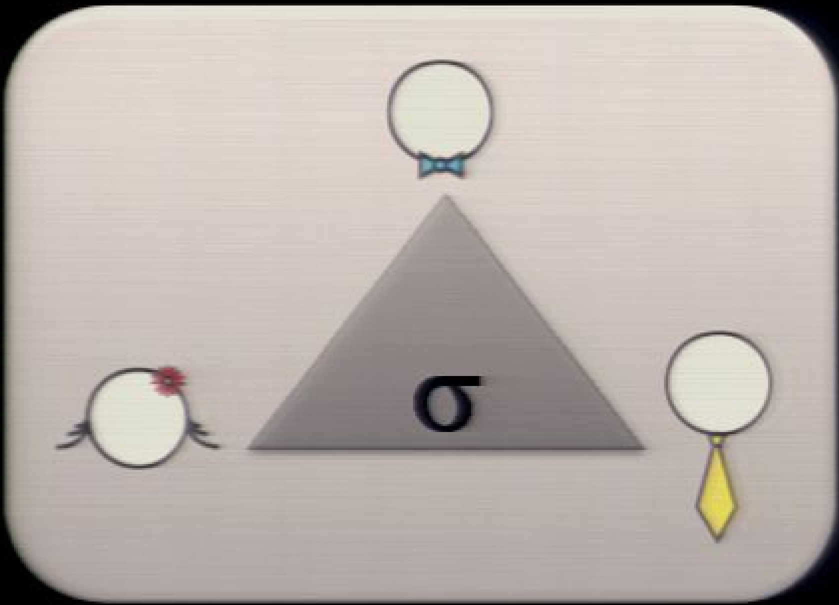

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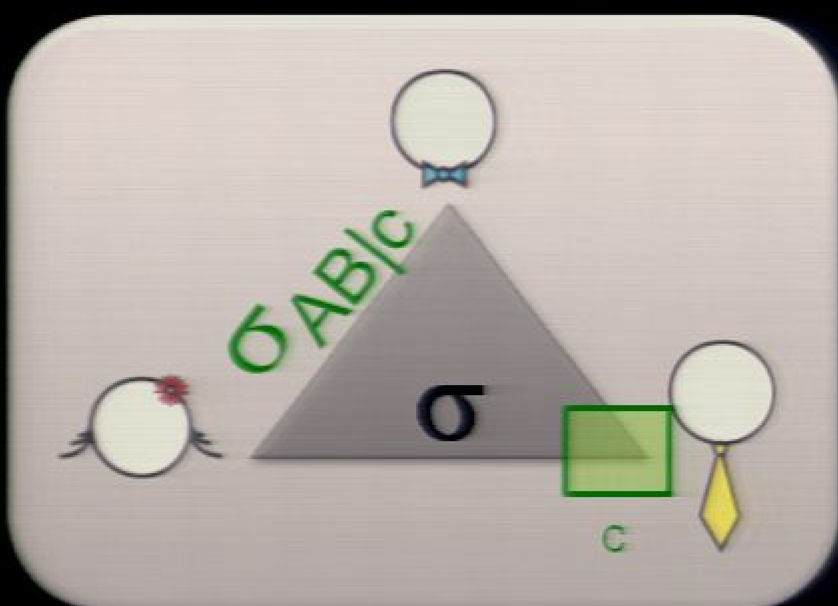
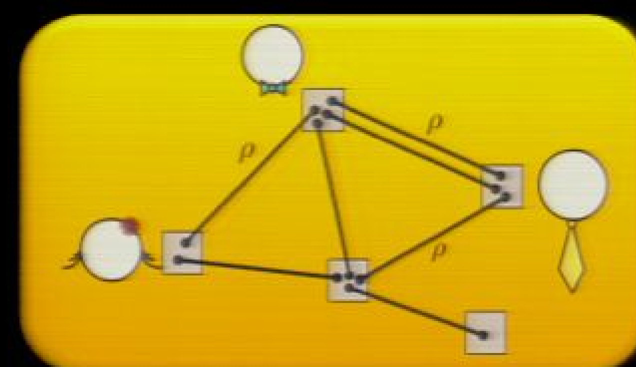
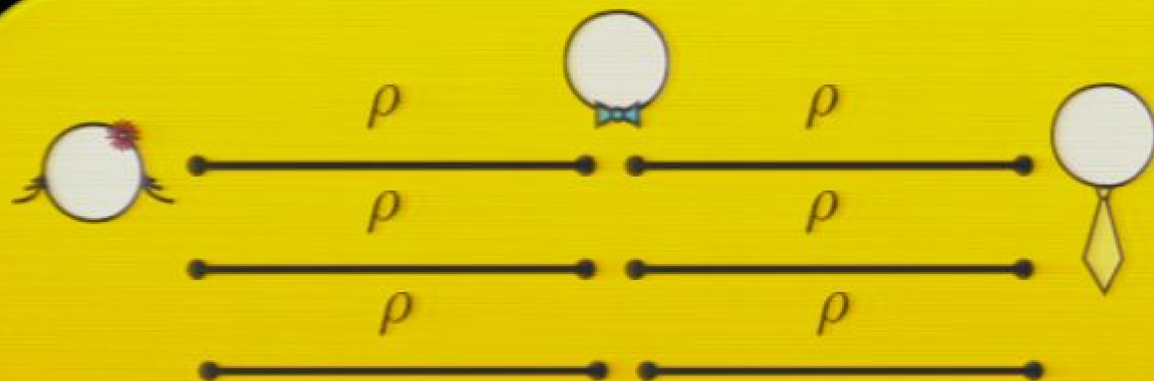




In the case the N-party state is constructed as a network of ρ, this criterion can be used to prove that ρ is a non-local resource

One-way entg dist ⇒ NL (1)



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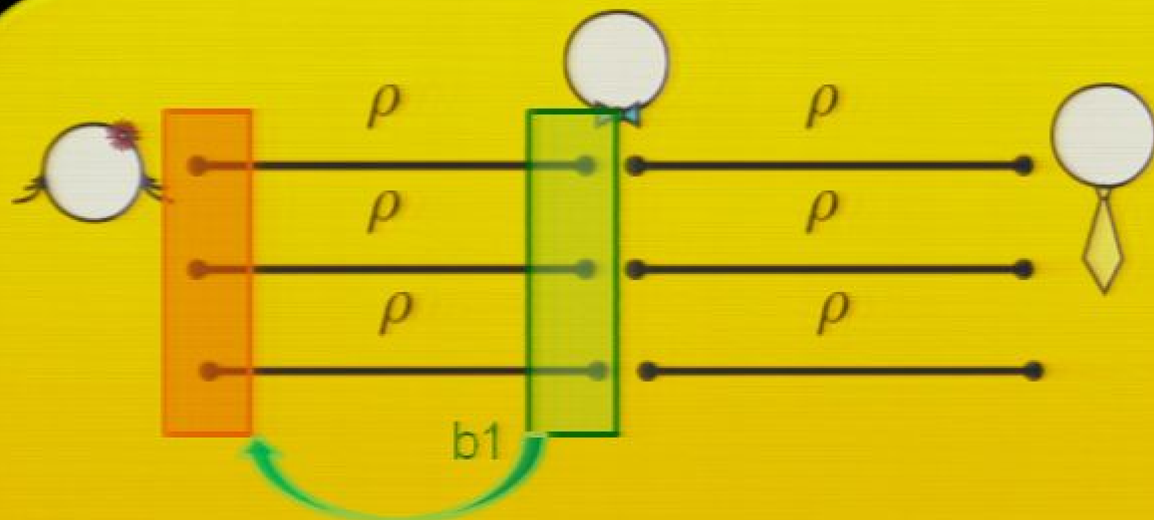

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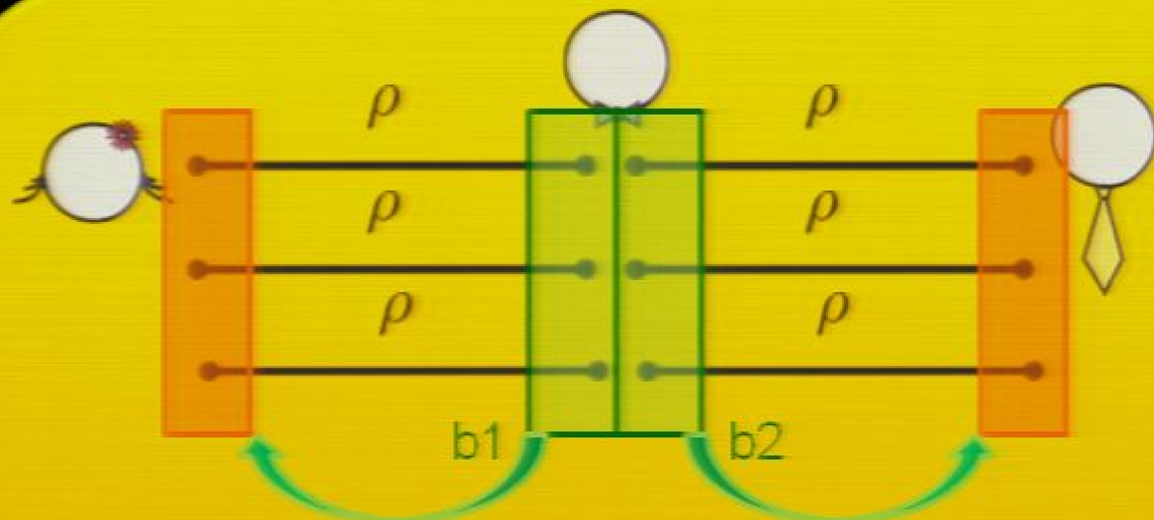

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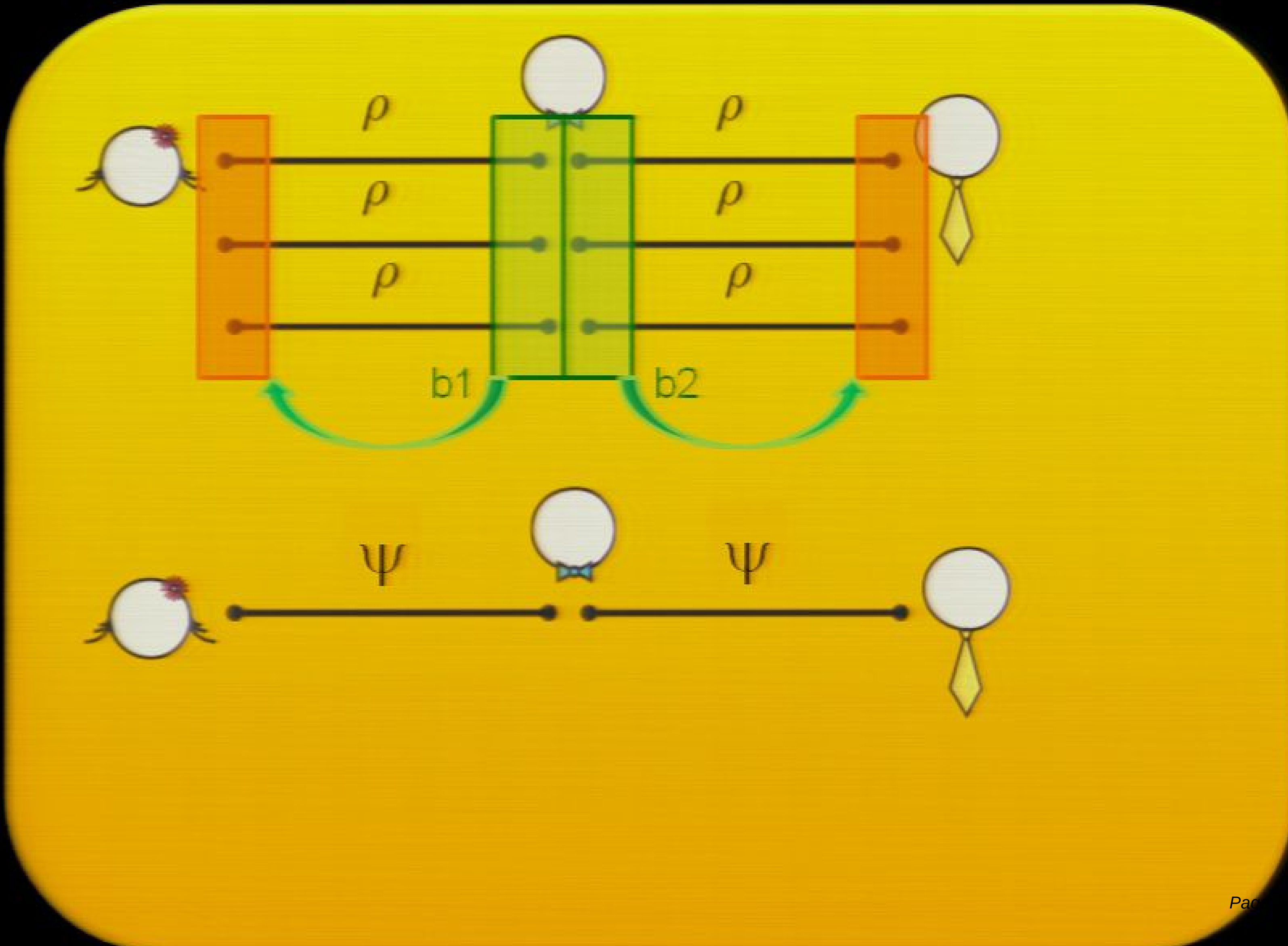

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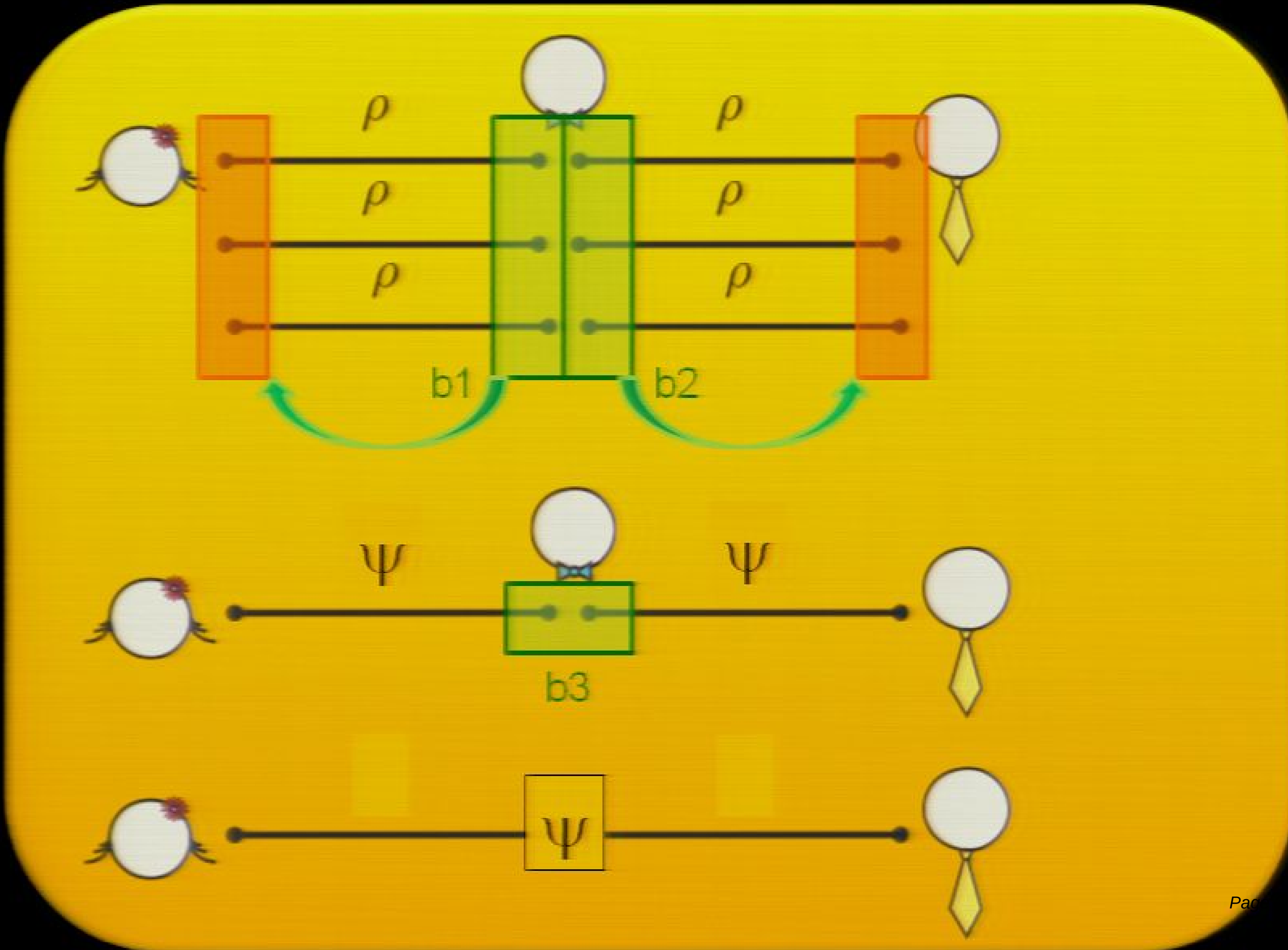

One-way entg dist $\Rightarrow$ NL (2)

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An example of activation of non-locality:
Take the state produced by an erasure channel:

$$\rho = \frac{1}{k}|\Phi_+\rangle\langle\Phi_+| + (1-\frac{1}{k})\frac{\mathbb{I}}{2}\otimes|2\rangle\langle 2|$$

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- is one-way distillable B$\rightarrow$A for all k $\Rightarrow$ is a non-local resource √
- is k-shareable between Alice and k Bobs $\Rightarrow$ cannot violate any Bell inequality with k measurements on Bob and arbitrarily many on Alice √

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Isotropic states = depolarizing channel

$$\rho = p|\Phi_+\rangle\langle\Phi_+| + (1-p)\frac{I}{d^2}$$

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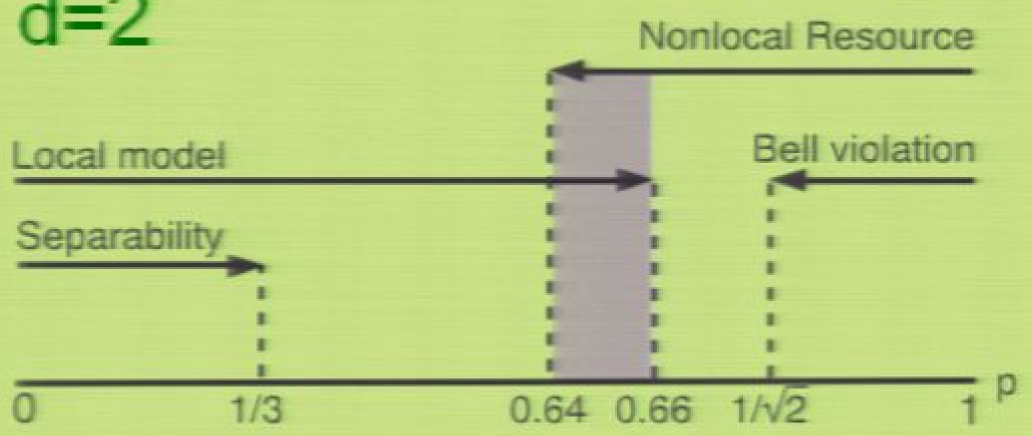
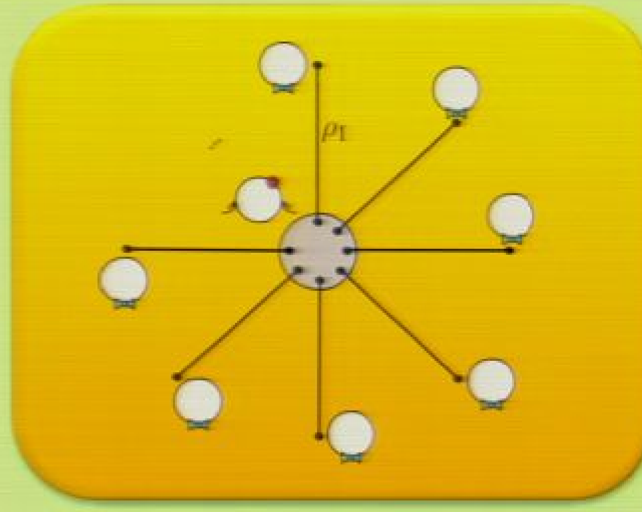
d=2





cf. A. Sen et al. PRA 2006

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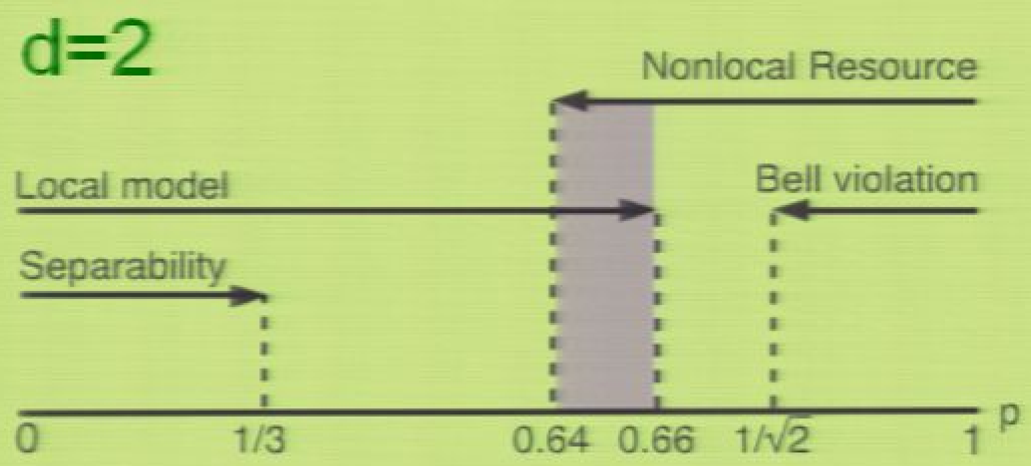

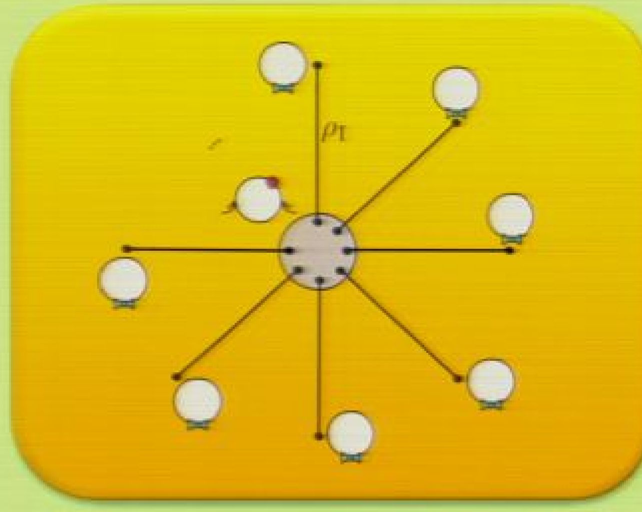

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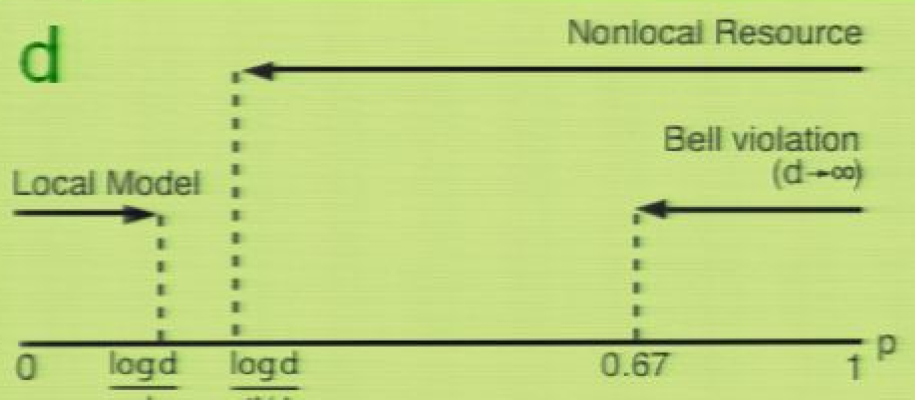

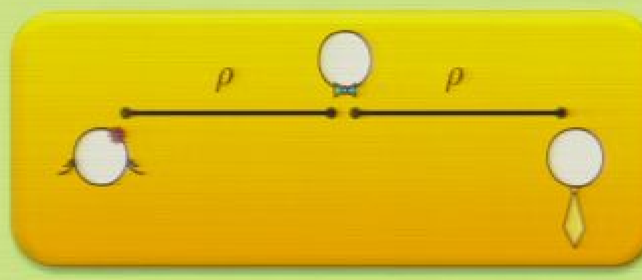

cf. Junge et al., PRL 2010

Violation of Bell's inequalities in a shopping mall (Kurtsiefer et al.)

Activation of non-locality

Local states (like Werner states) can lead to violation of Bell's inequalities if shared among more than two parties.

DEVICE-INDEPENDENT TEST OF ENTANGLING MEASUREMENTS

R. Rabelo, M. Ho, N. Brunner, D. Cavalcanti, V.S., in preparation

Motivation: circuit testing

A vendor sells allegedly quantum devices: you can buy "sources of entangled pairs", "local unitaries"…

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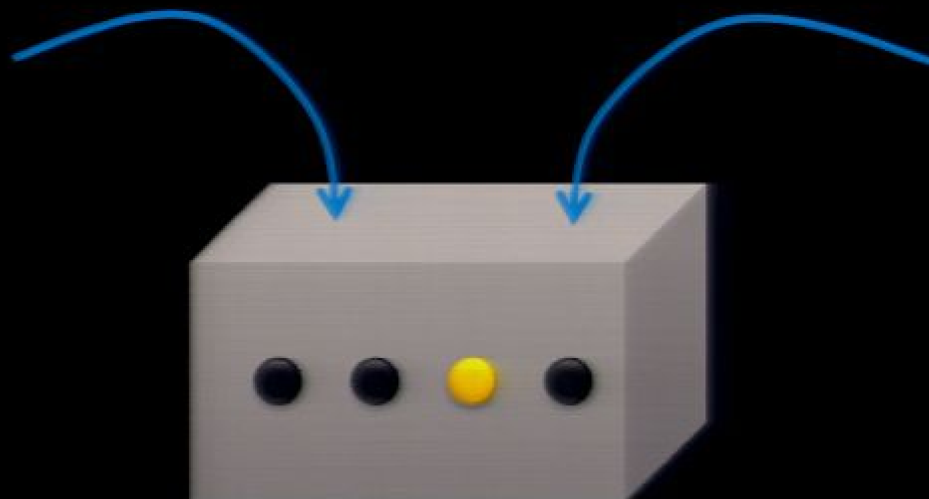

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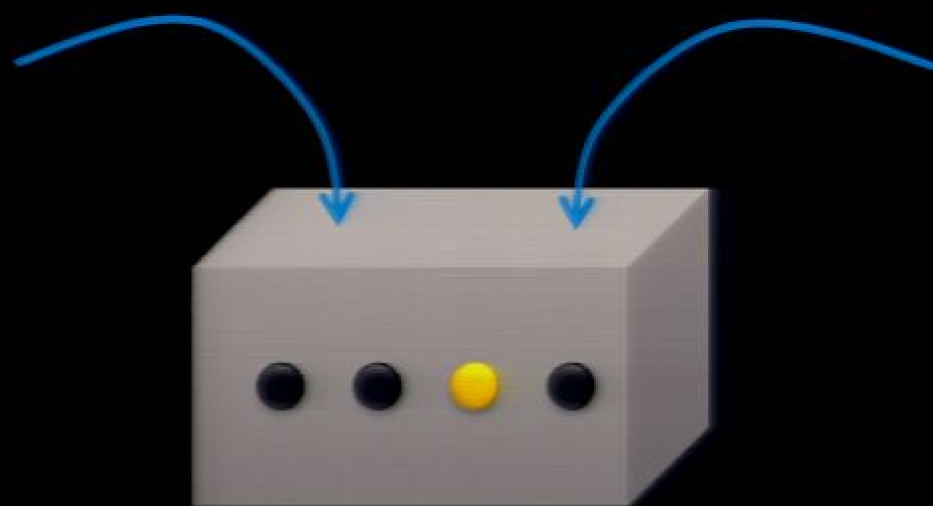

Is this box performing a Bell-state measurement?

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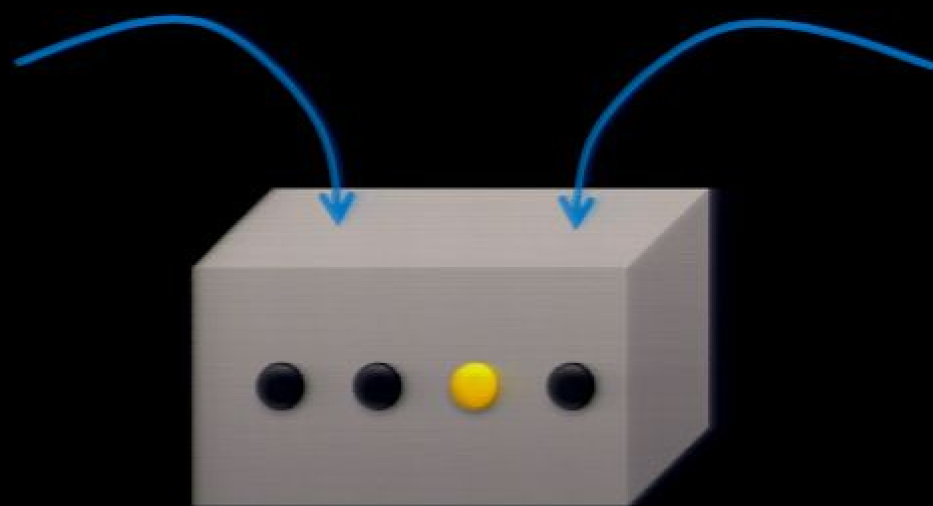

Is this box performing a Bell-state measurement?

- A perfect one? Certainly not!

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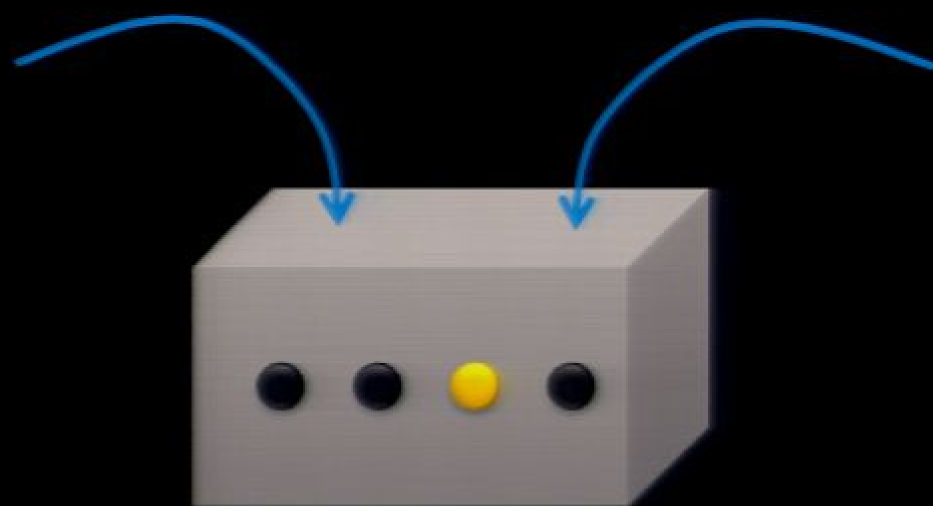

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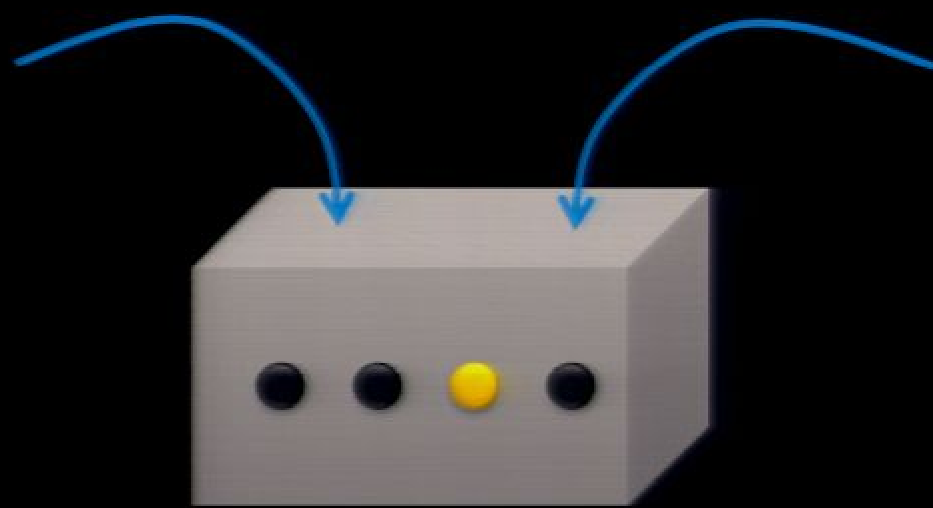

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How close is this box from performing a Bell-state measurement on some 2-dimensional sub-systems in the incoming signals?

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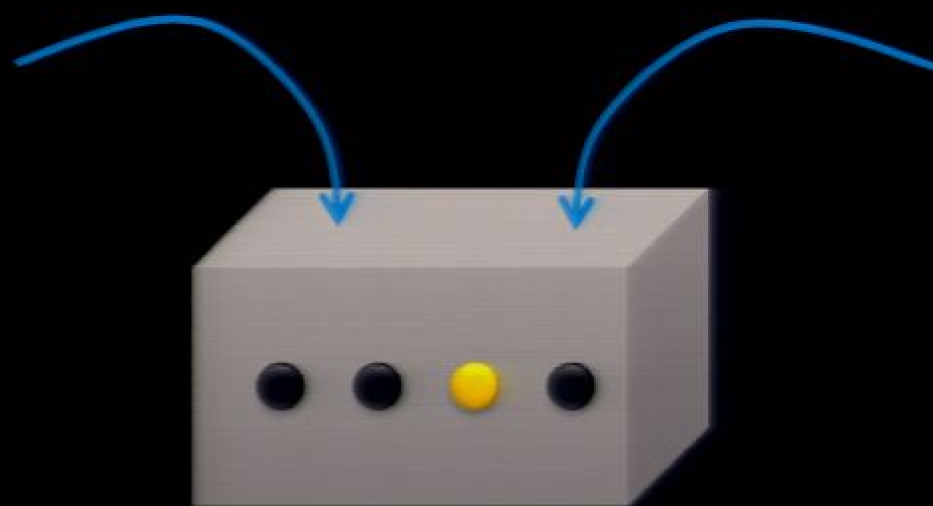

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How close is this box from performing a Bell-state measurement on some 2-dimensional sub-systems in the incoming signals?

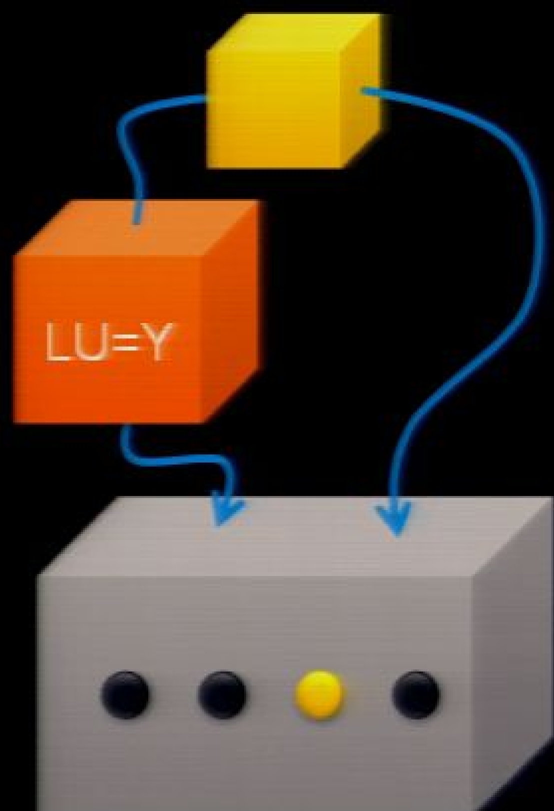
Of course, everything must be checked with the same vendor's products!

What does not work

0. Buy a "source", "local measurements", a "local unitary" and a "BSM"

1. Check the entanglement of the source (e.g. Bardyn et al PRA 2009)

2. Set the local unitary to I, X, Y, Z and check that one light clicks deterministically for each



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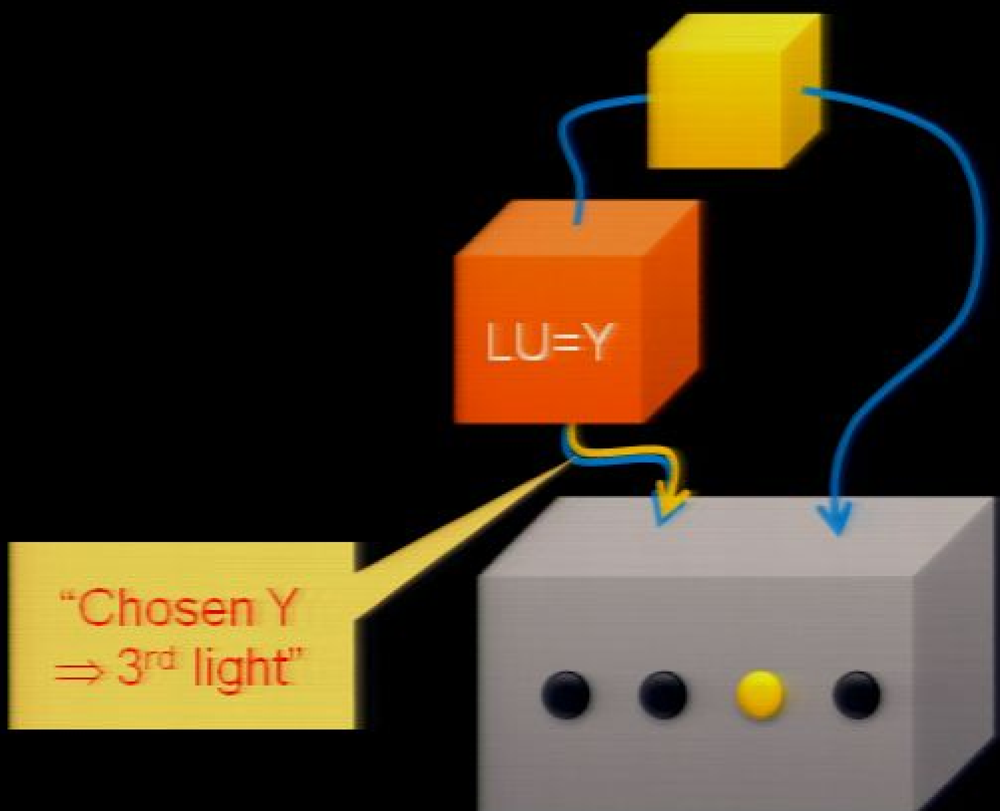
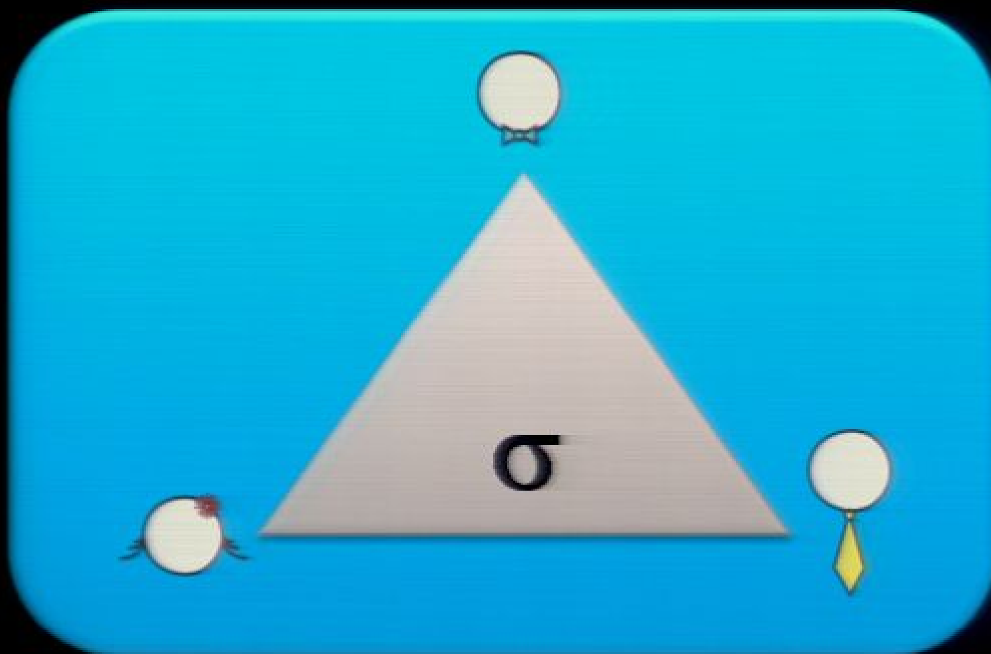


A three-partite strategy

Local measurements: A0,A1,C0,C1: 2 outputs; B0,B1,B2: four outputs



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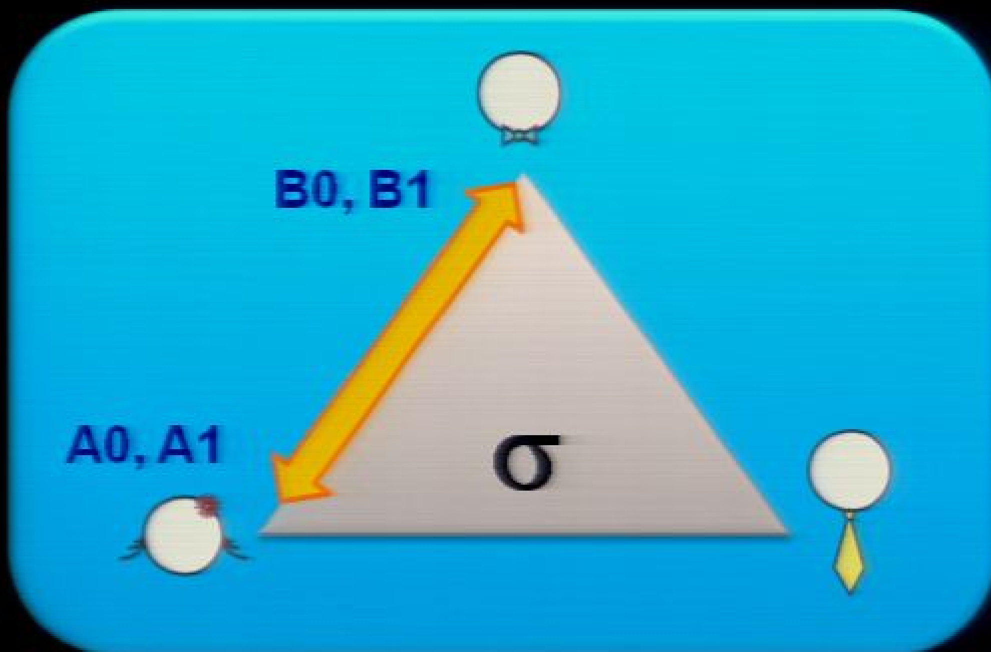

1a. Check CHSH (A0,A1;B0,B1)

A three-partite strategy

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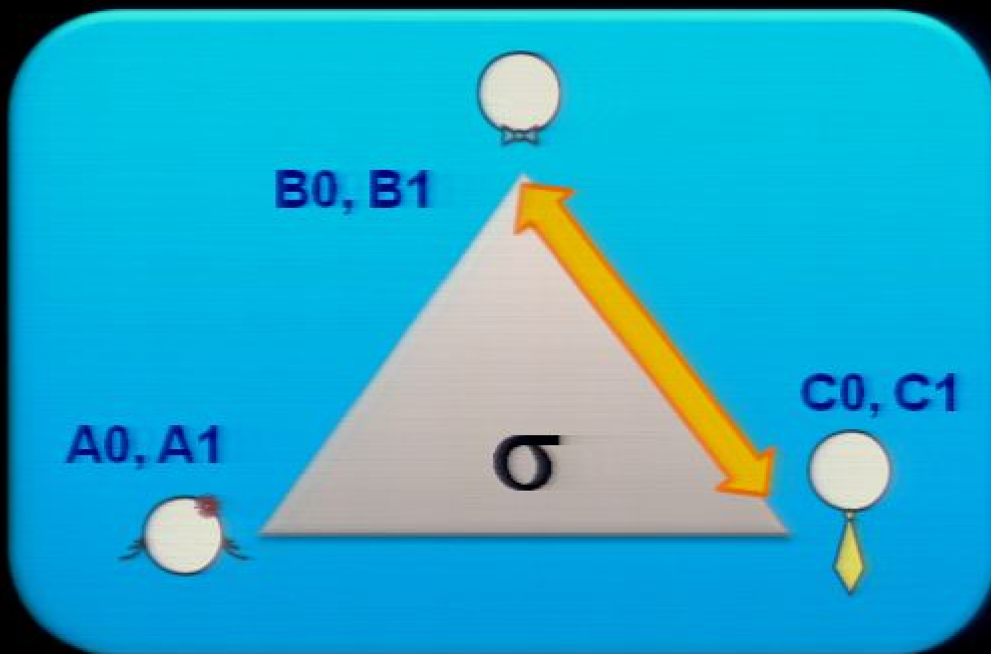

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A three-partite strategy

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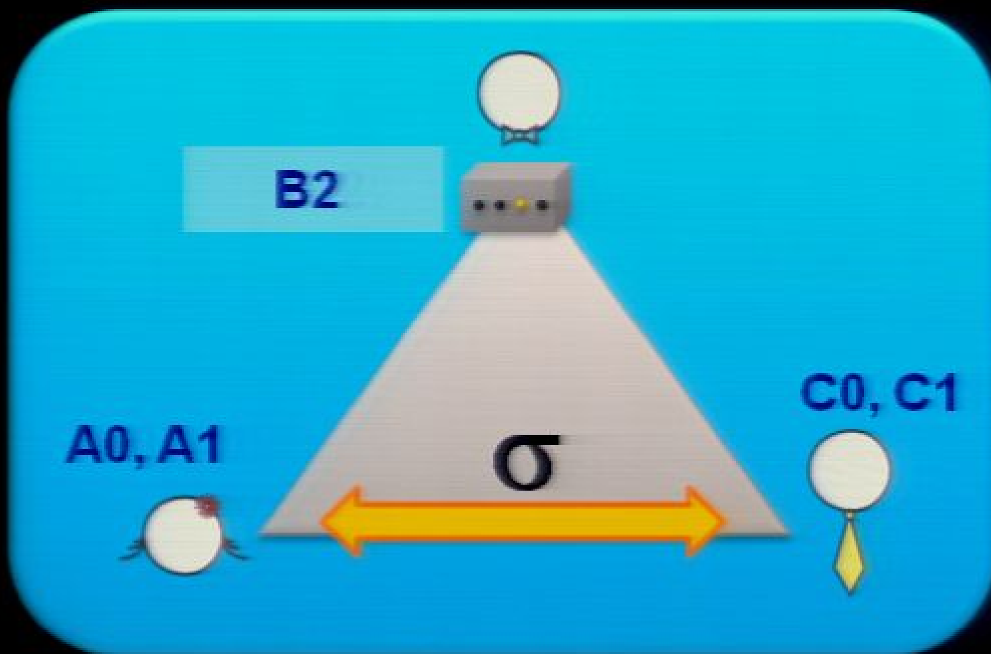


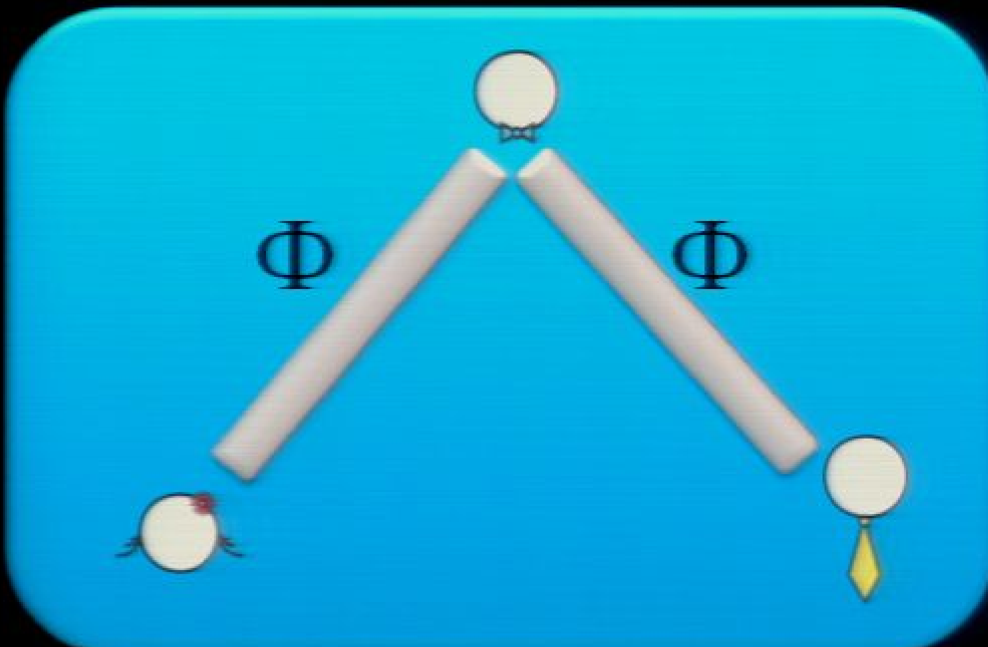
1a. Check CHSH (A0,A1;B0,B1)

1b. Check CHSH (C0,C1;B0,B1)

2. Check CHSH (A0,A1;C0;C1) conditioned on B2 = b2

Intuition

What QM can do: entanglement swapping of two singlets



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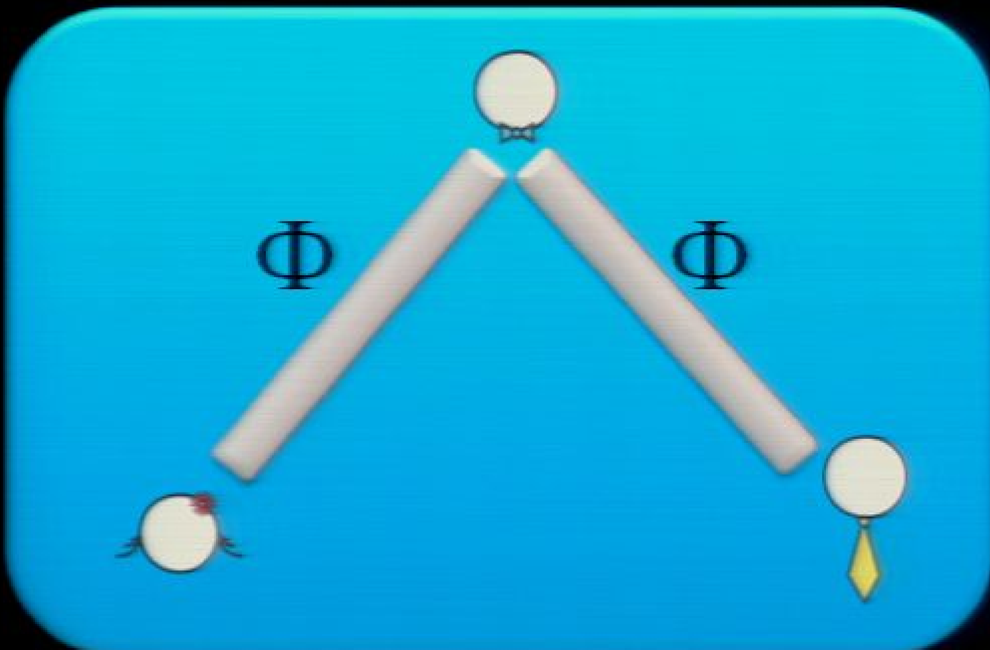

CHSH(A,B) = 2√2
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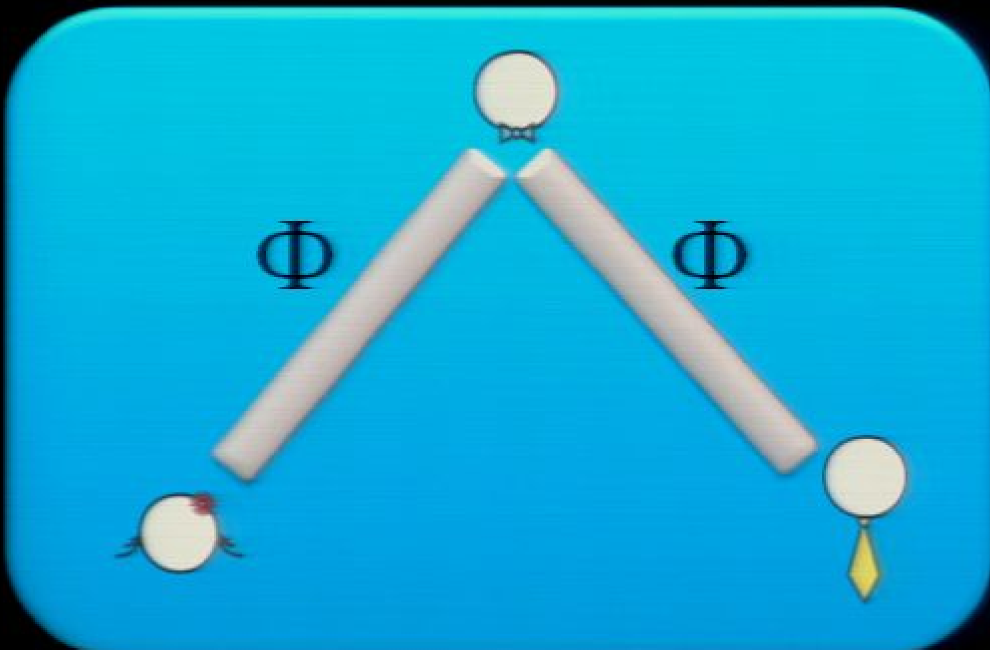

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If B2 = perfect BSM:
CHSH(A,C|b2) = 2√2

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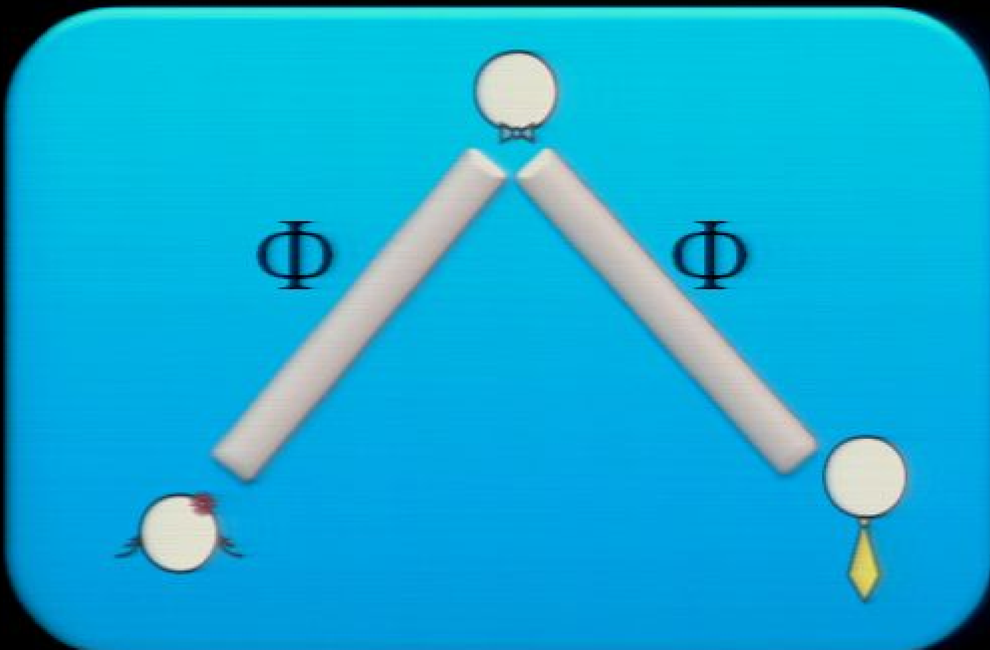

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CHSH(A,C|b2) < 2

Intuition

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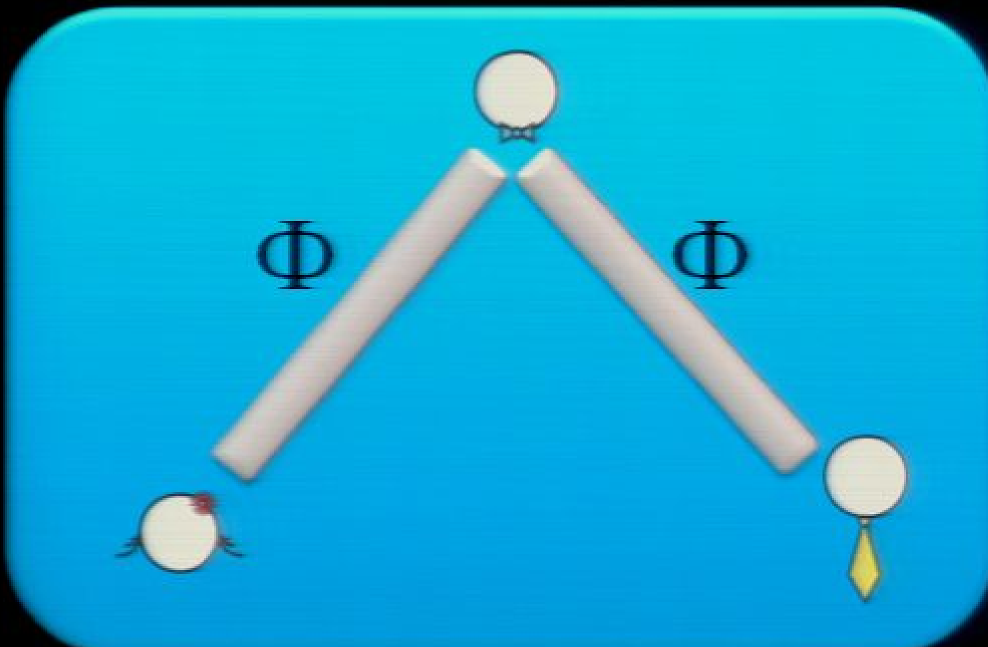

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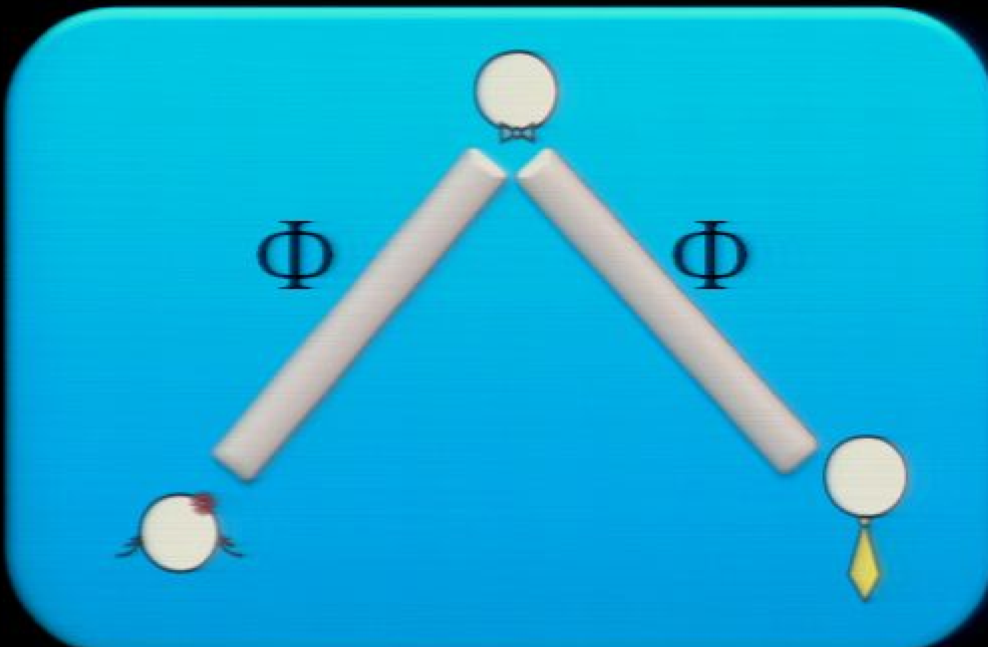
This last bound is device-independent!
CHSH(A,B)=$2\sqrt{2} \Rightarrow$ A is measuring on an effective qubit, max entg with something in B (Popescu-Rohrlich, McKague) $\Rightarrow$ not entg with C before B2.

Intuition

What QM can do: entanglement swapping of two singlets



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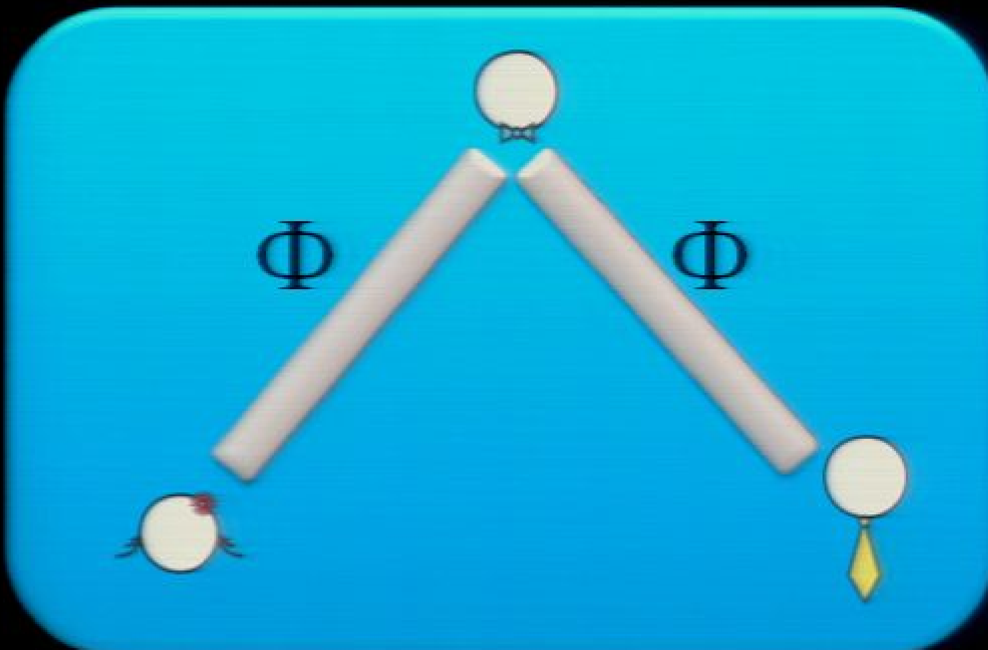
DI gap between "separable measurement" and "BSM"
⇒ a competent company CAN convince you to buy their BSM

Intuition

What QM can do: entanglement swapping of two singlets



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CHSH(A,C|b2) < $\sqrt{2}$

This last bound is device-independent!
CHSH(A,B)=$2\sqrt{2}$ ⇒ A is measuring on an effective qubit, max entg with something in B (Popescu-Rohrlich, McKague) ⇒ not entg with C before B2.

DI gap between "separable measurement" and "BSM"
⇒ a competent company CAN convince you to buy their BSM

Three remarks

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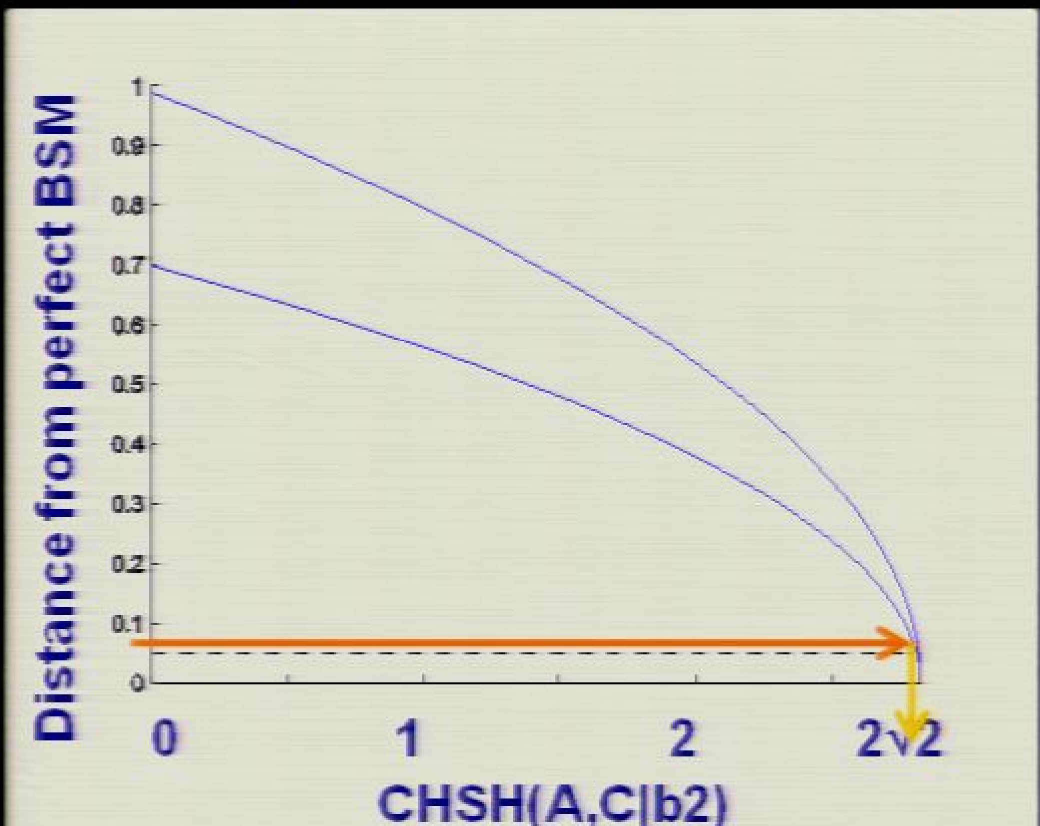

Certify BSM at 5% of failure probability

⇓

CHSH ≥ 2√2 – 0.5%

Device-dependent group excursion

DI entangling measurement

After QKD, randomness & state estimation, here is another device-independent task.

FALSIFY HIDDEN SIGNALING WITH FINITE SPEED

V.S., N. Gisin, Braz. J. Phys. 35, 328 (2005)
S.Coretti, E. Hänggi, S. Wolf, arXiv:1102.5685

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A "reverse-Bell" theorem

Classical mechanism

Correlations at distance ⇐
- Pre-established agreement (LHV)
- Communication (signal)

- NO LHV: Bell violation
- NO hidden signal:
  - Correlation with space-like separation
  - no "signal" can travel faster than light

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A “reverse-Bell” theorem

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Can one assume “hidden signaling models” and falsify them by a direct look at the statistics, without ruling them out by a principle?

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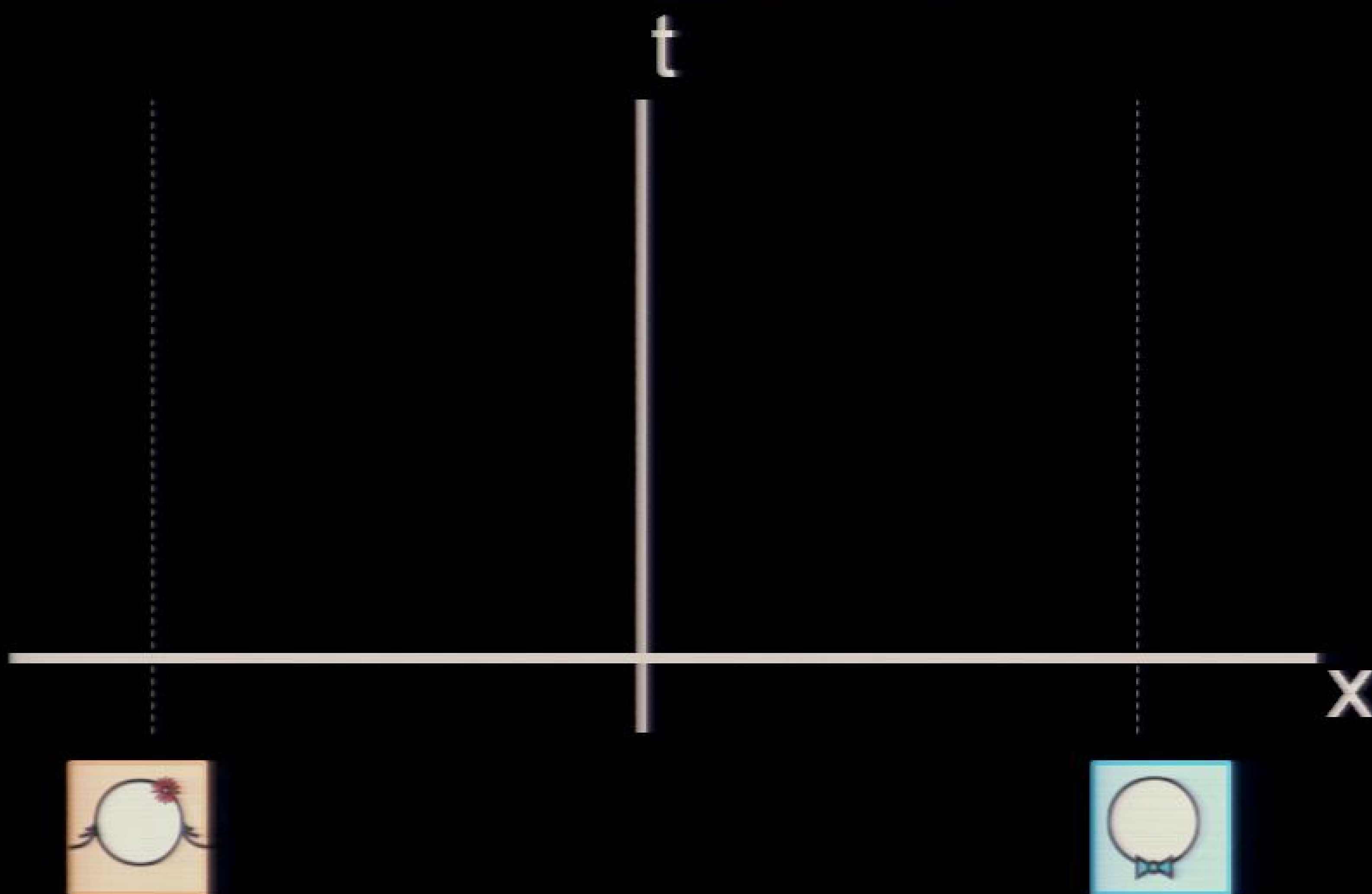
Can one assume “hidden signaling models” and falsify them by a direct look at the statistics, without ruling them out by a principle?

For $v=\infty$, there is a model equivalent to QM: Bohmian mechanics.
What about $c<v<\infty$ in some (unspecified) preferred frame?

2 parties



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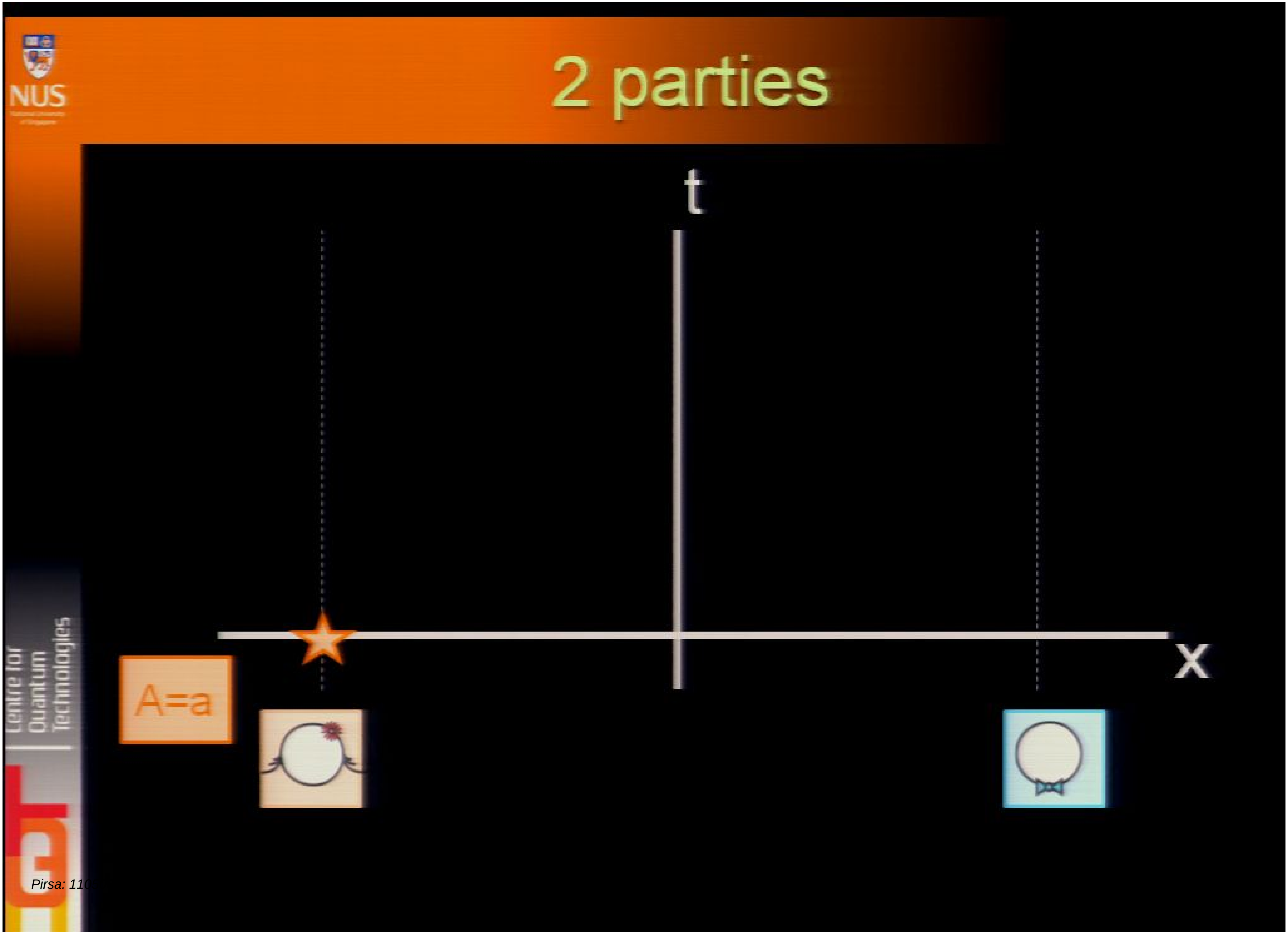
2 parties
NUS
t
x
A=a
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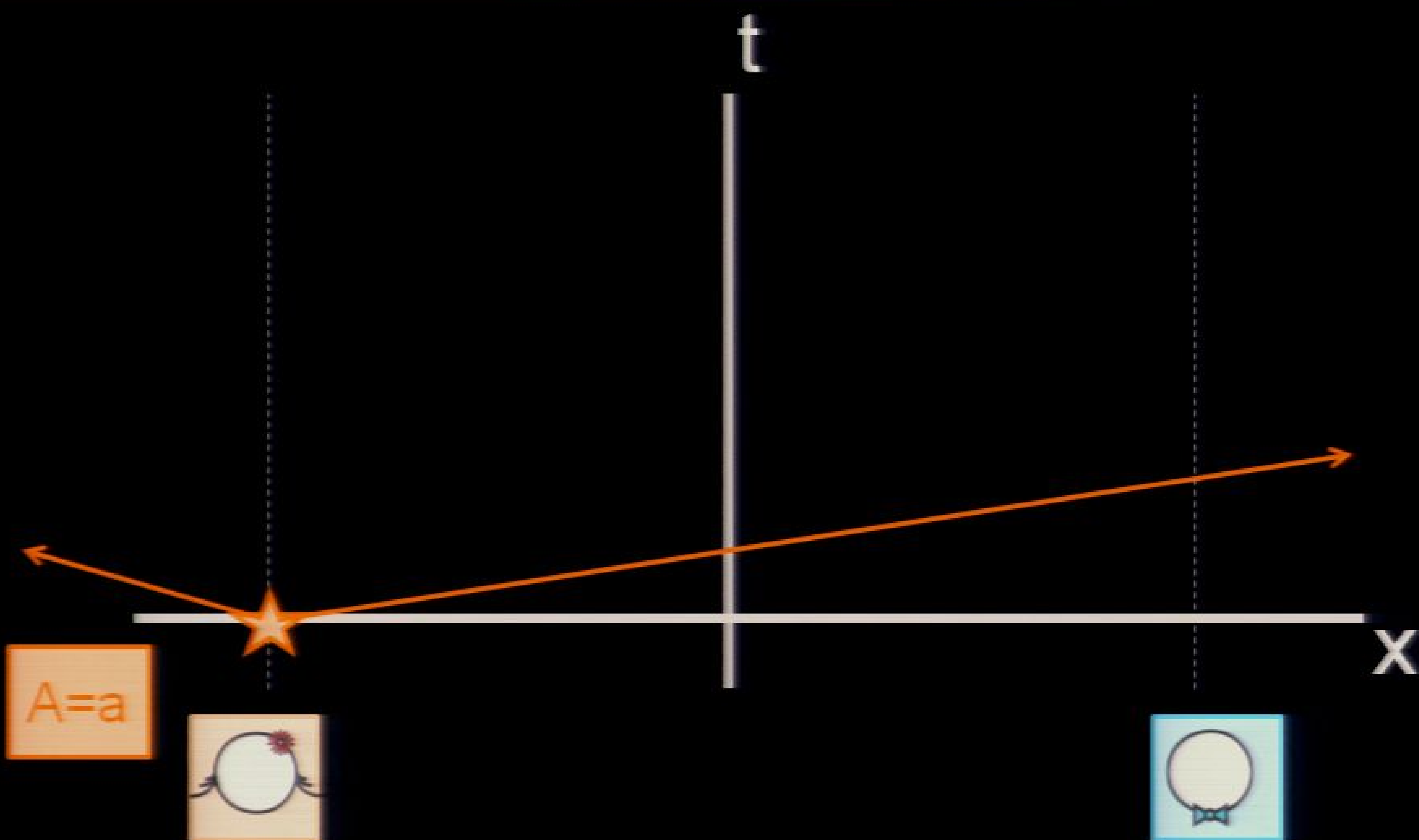

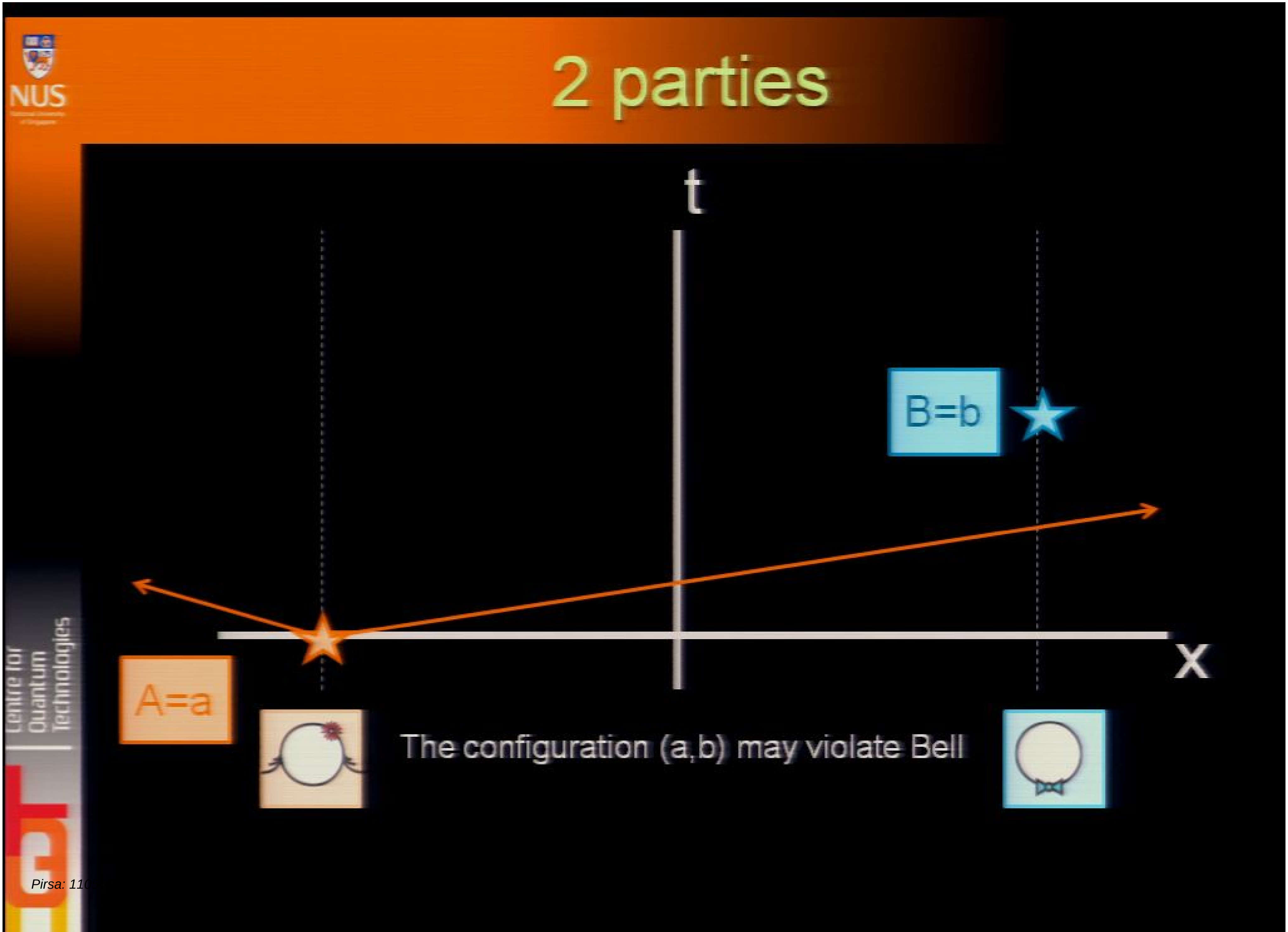

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2 parties
t
B=b
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The configuration (a,b) may violate Bell
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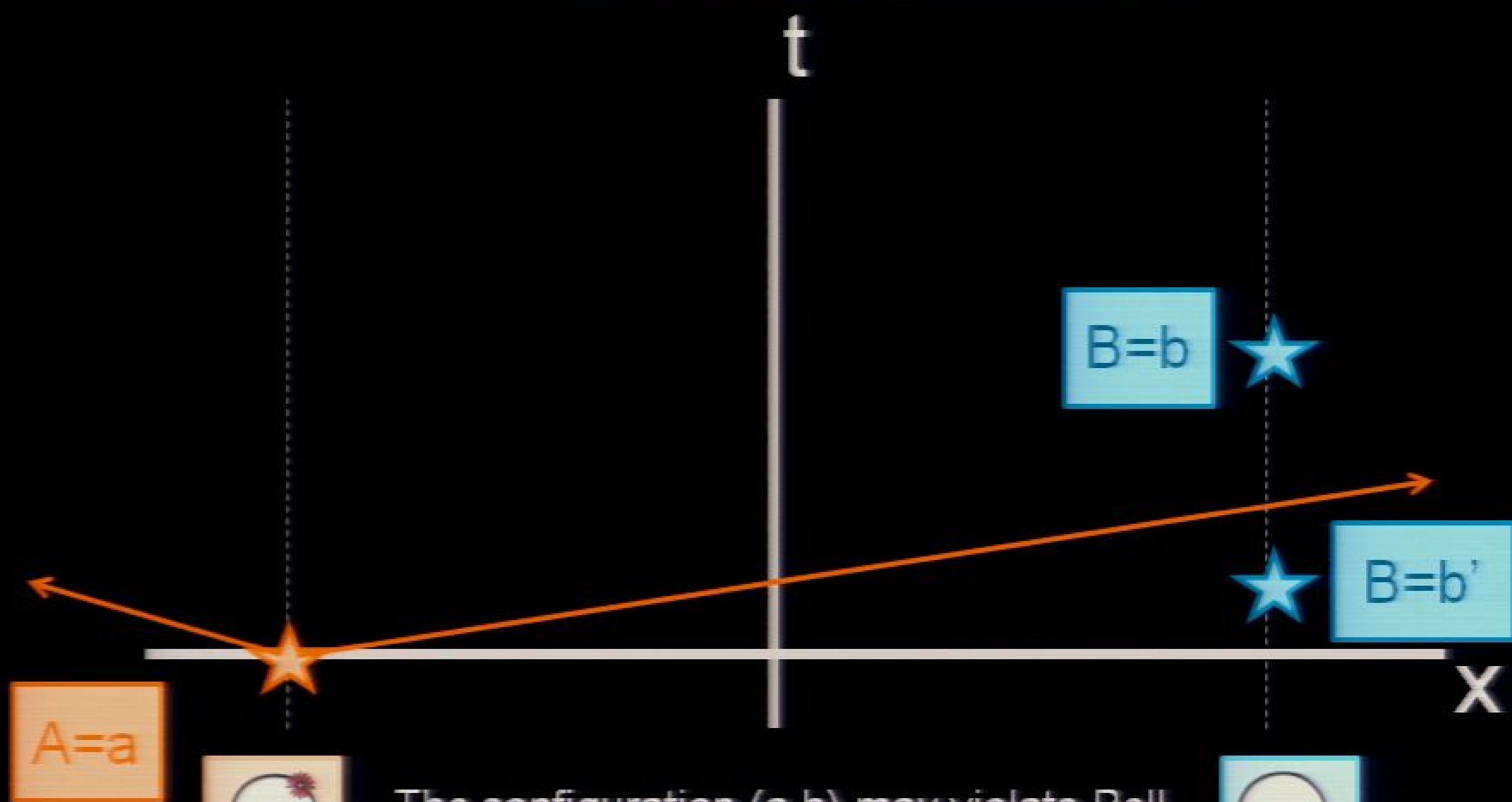
2 parties



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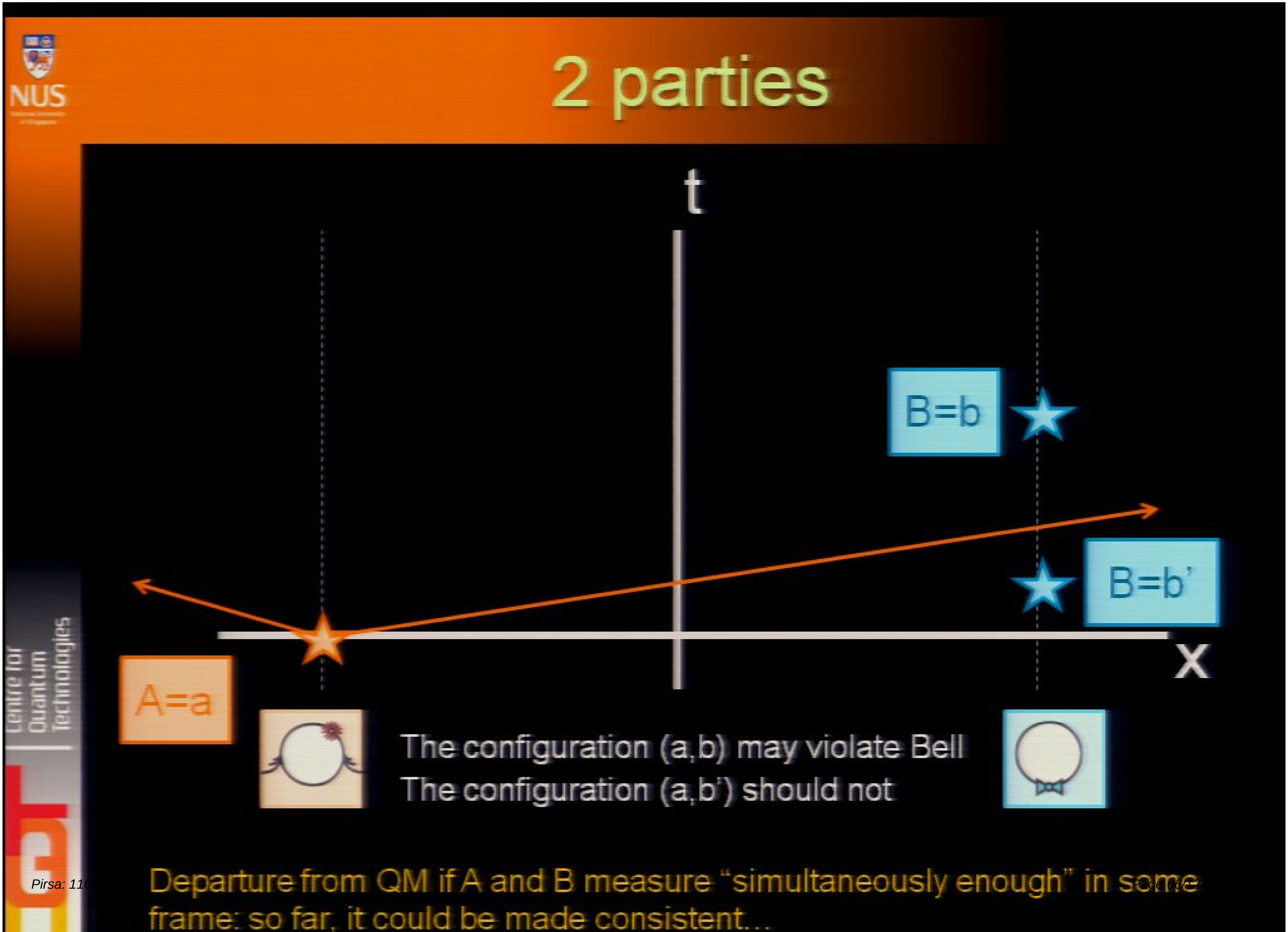
NUS
2 parties
t
x
B=b
B=b'
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The configuration (a,b) may violate Bell
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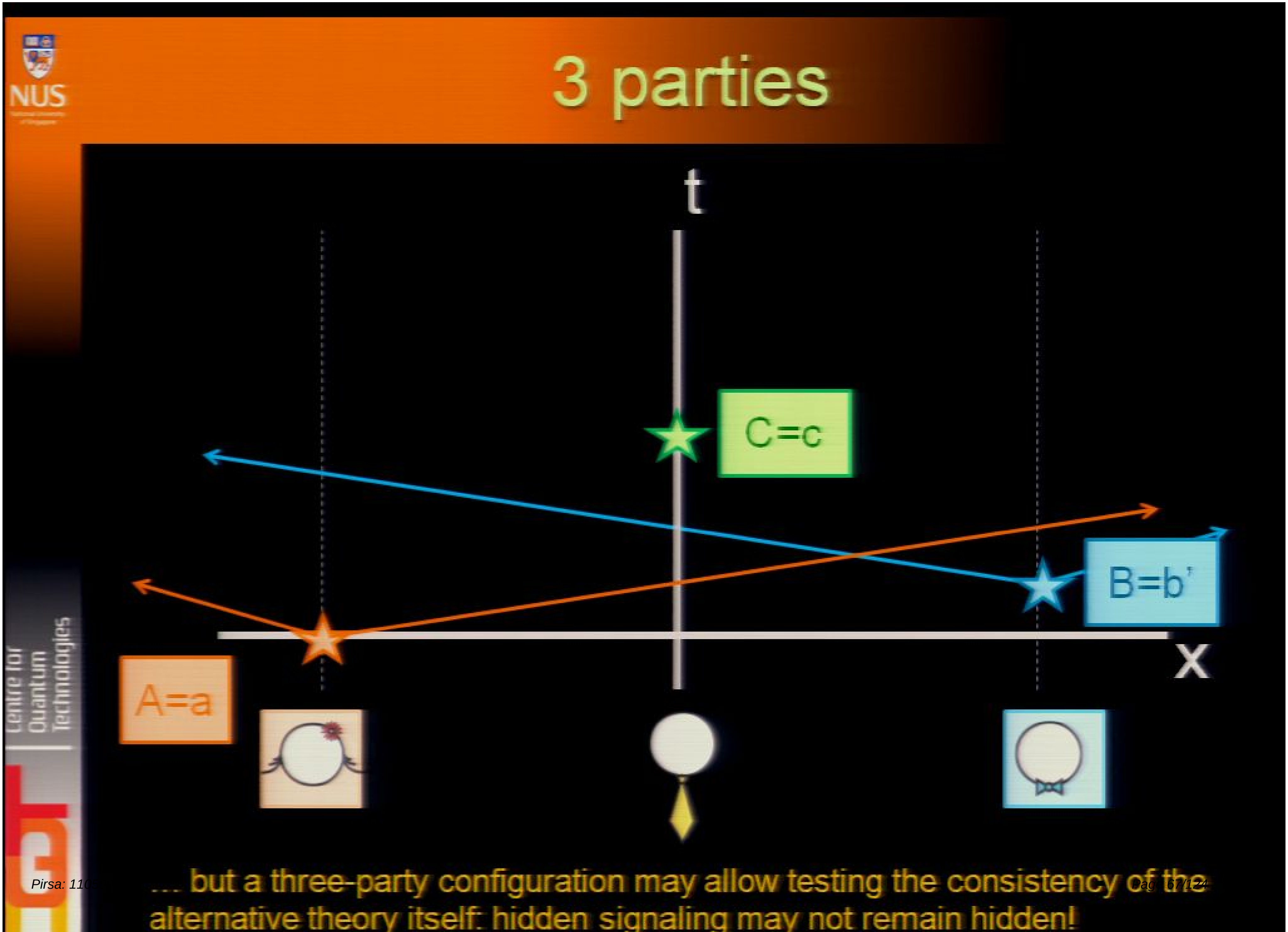
Departure from QM if A and B measure "simultaneously enough" in some frame: so far, it could be made consistent…


3 parties
t
x
C=c
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A=a
NUS
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… but a three-party configuration may allow testing the consistency of the alternative theory itself: hidden signaling may not remain hidden!

Idea of the argument

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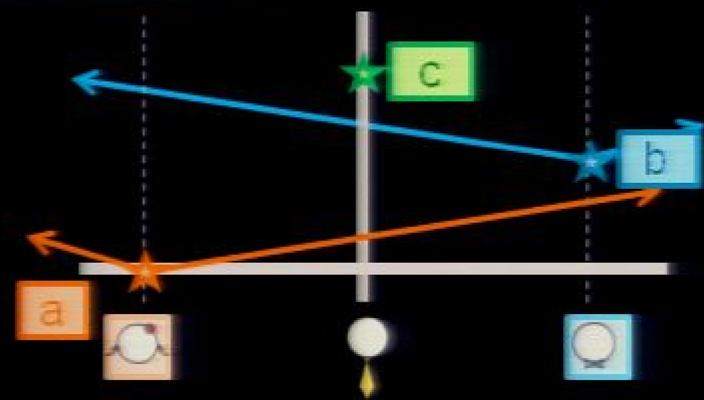
Starting point: if all hidden signals arrive in sequence, we have QM:
$P_Q(a,b,c)=\mathrm{Tr}(\rho\, A_a B_b C_c)$



Pirsa: 110

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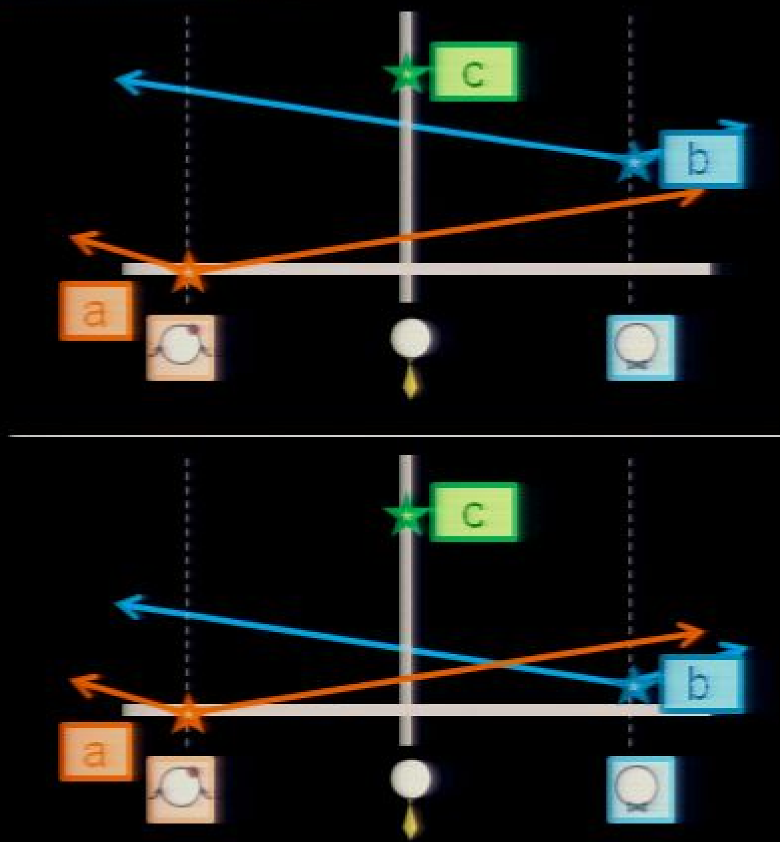

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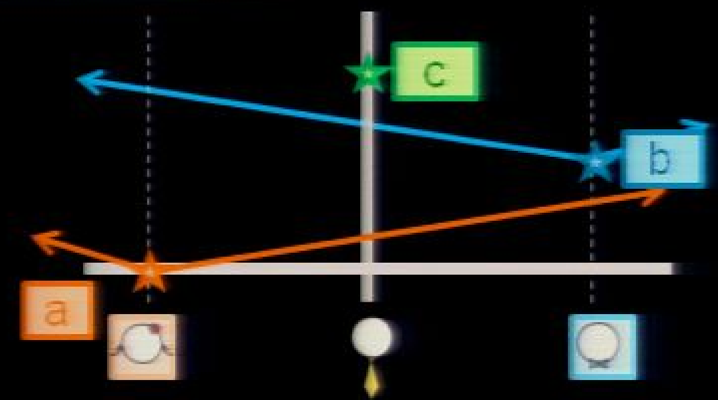

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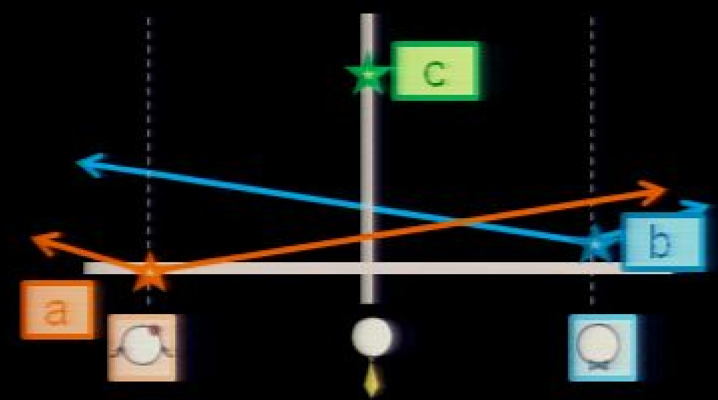

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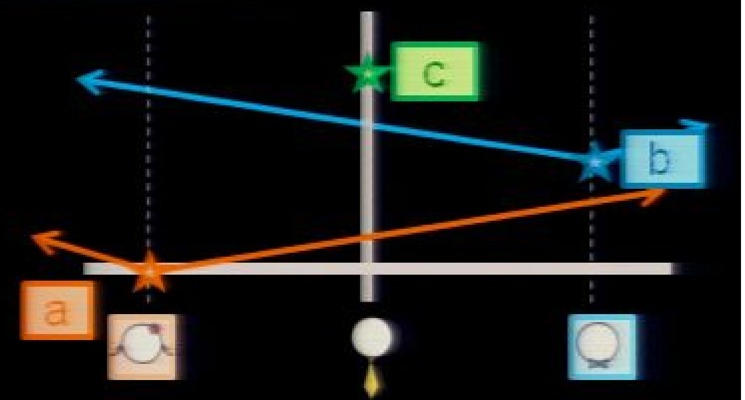

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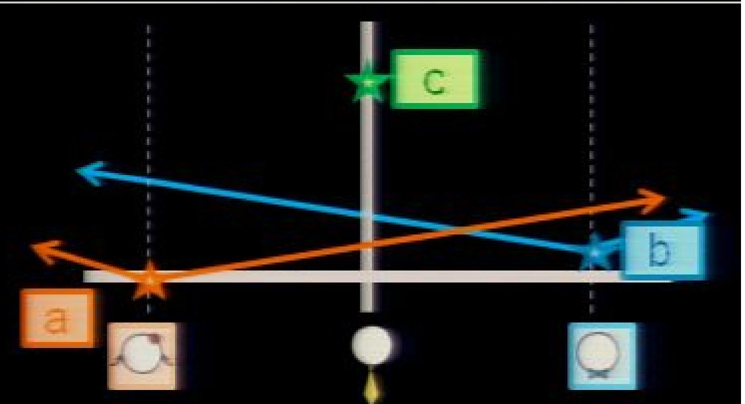

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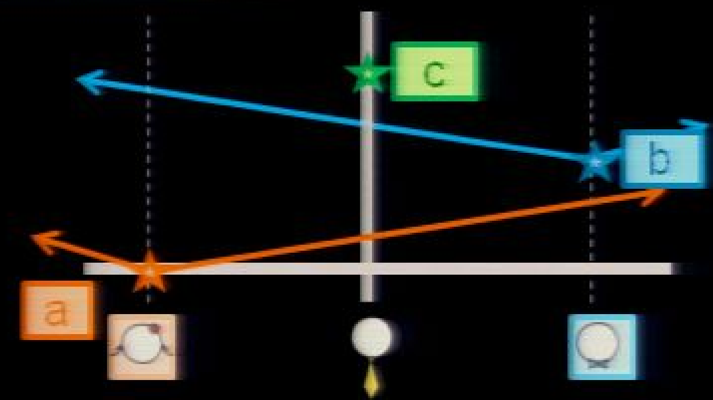

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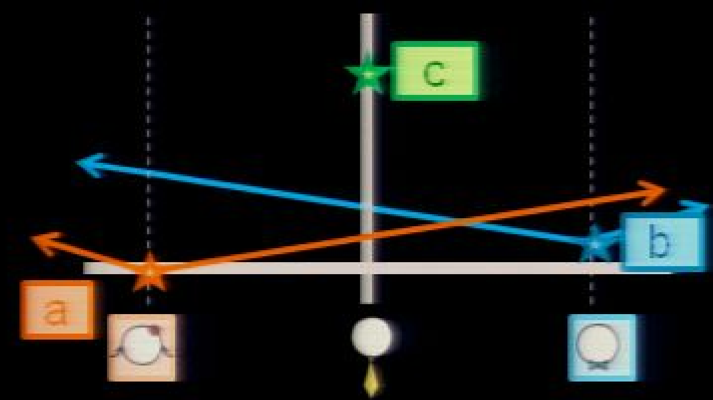

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- If one restricts the possible P's to those that can be written as Tr(some state…), then hidden signaling falsified
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- There exist no-signaling distributions with the desired property, but it is not known if they can be obtained by measuring a quantum system
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- Last step: find a P_Q such that…

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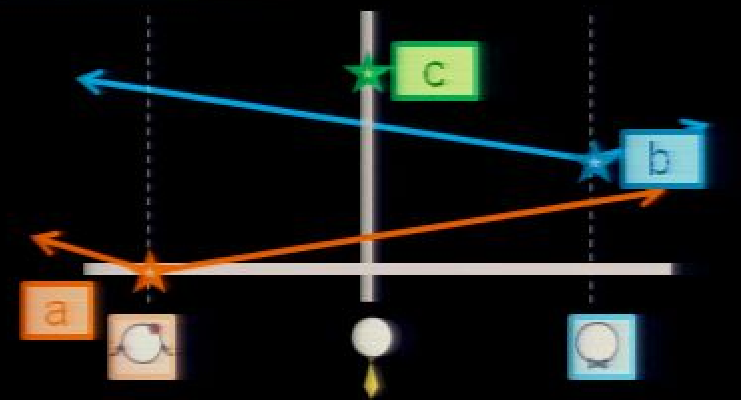

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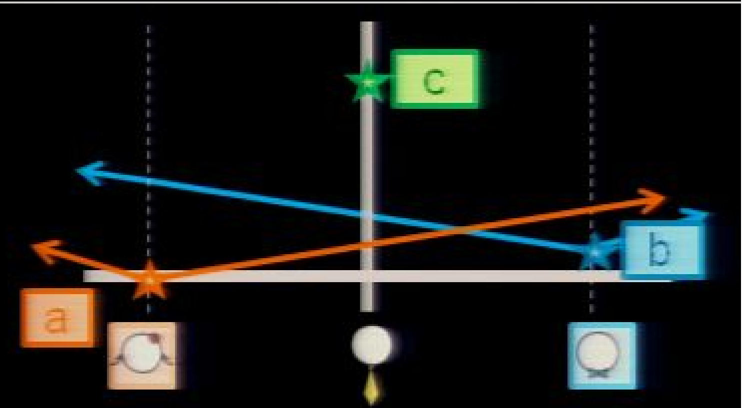

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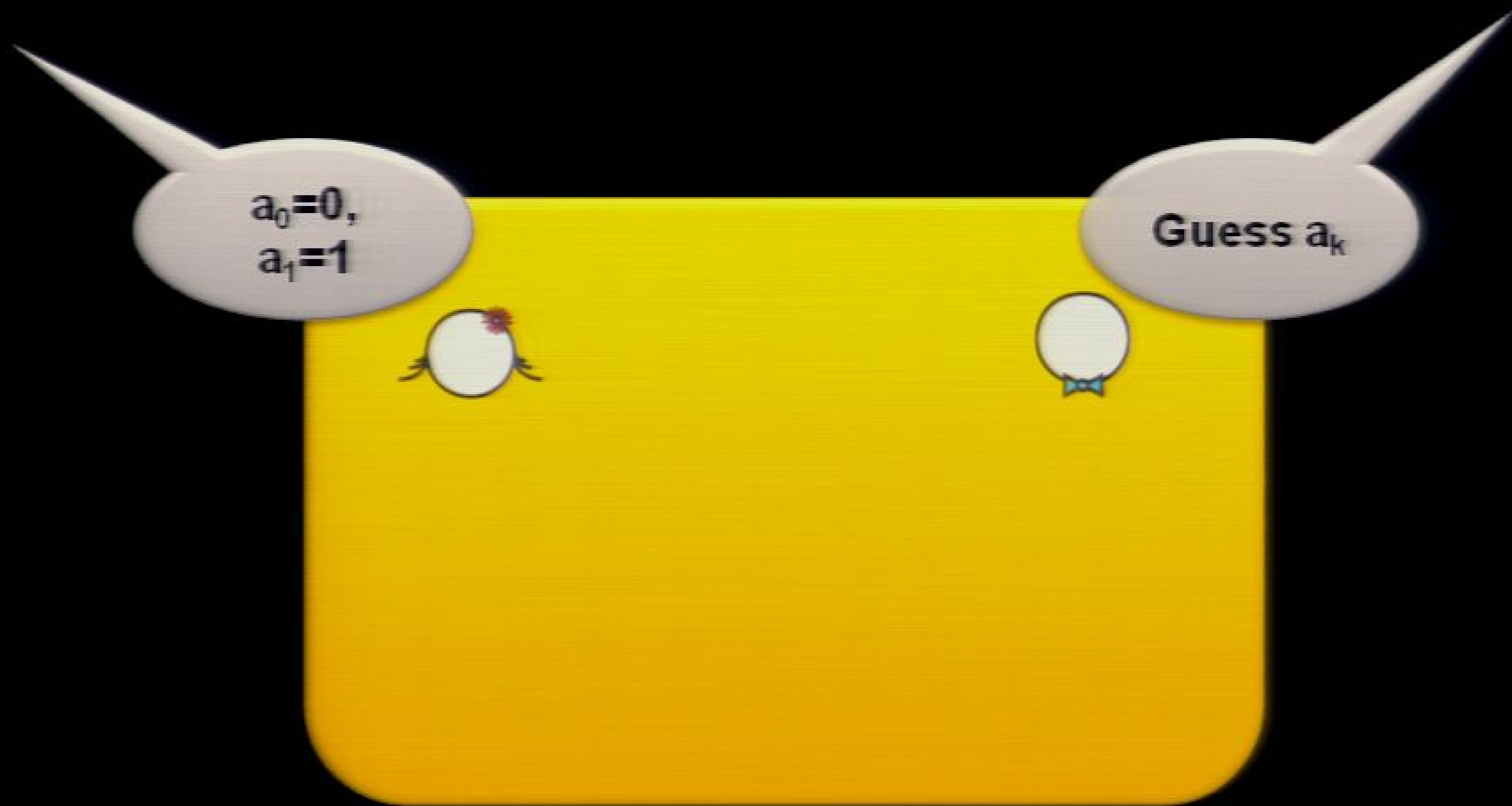
Just graduated (hmmm… maybe with 4 parties it's even better?)

Falsifying hidden communication

It looked impossible, but hopefully YES, we can!

INFORMATION CAUSALITY IN THE THREE-PARTITE SCENARIO

2 parties



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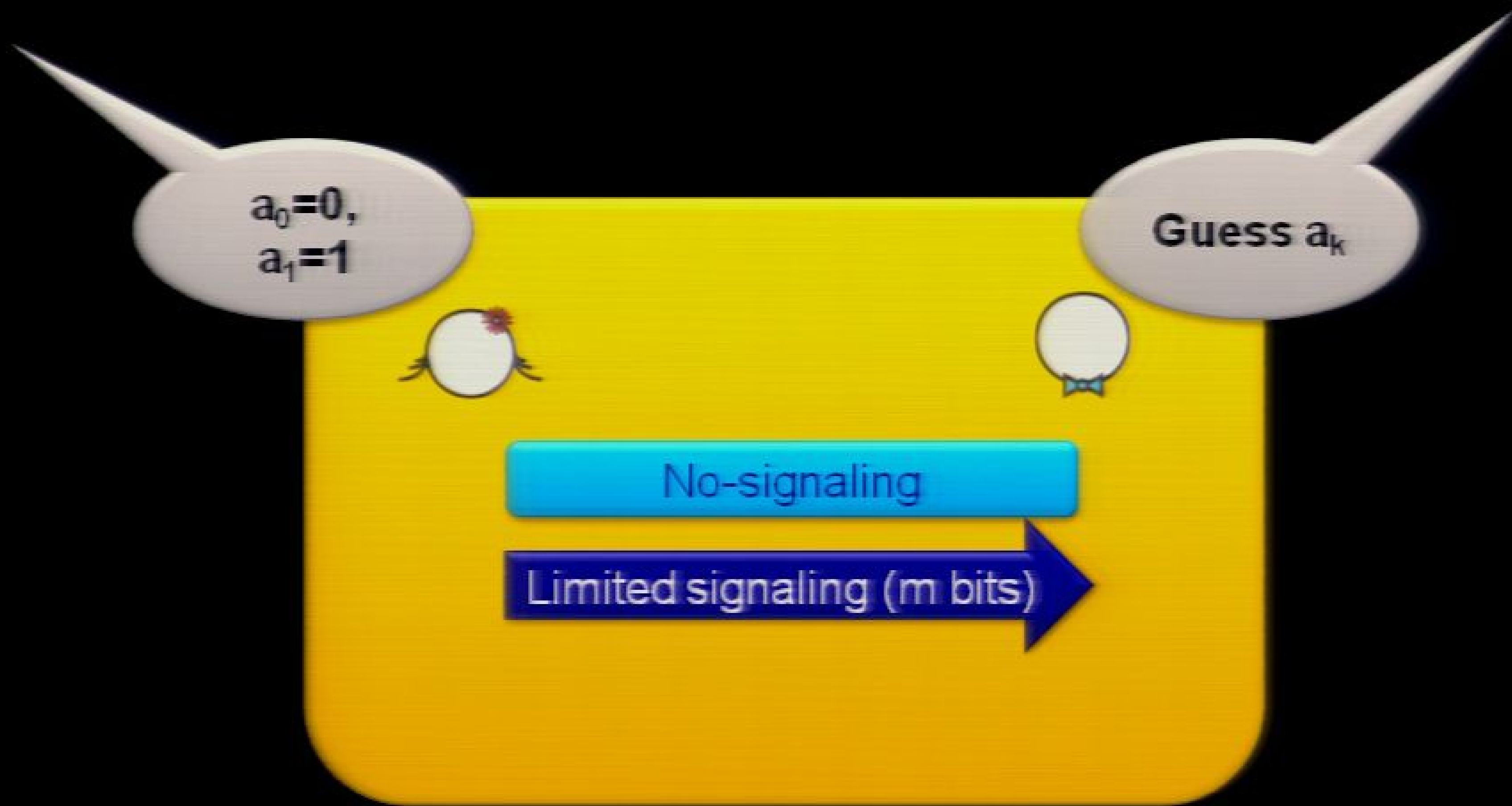

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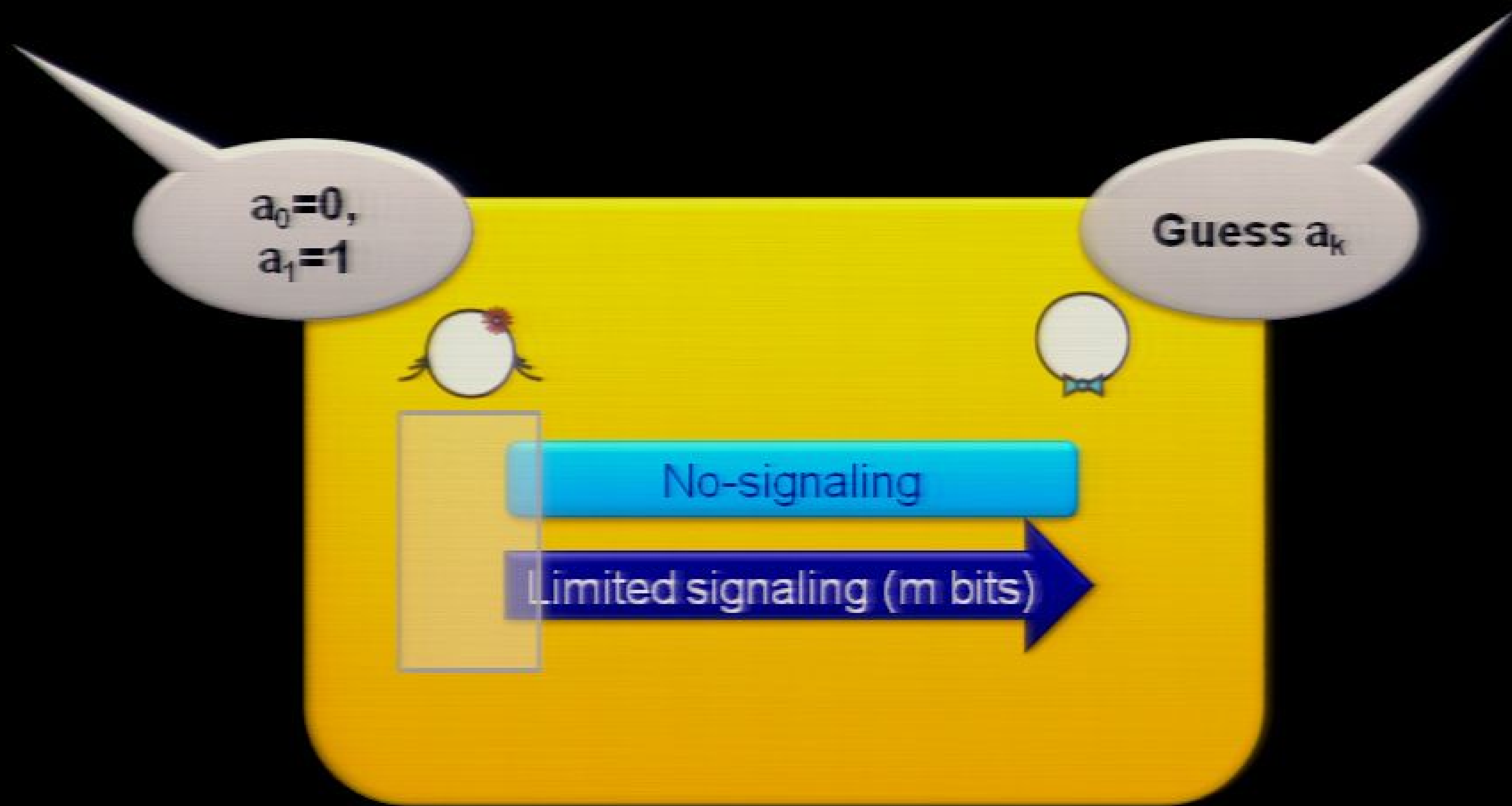

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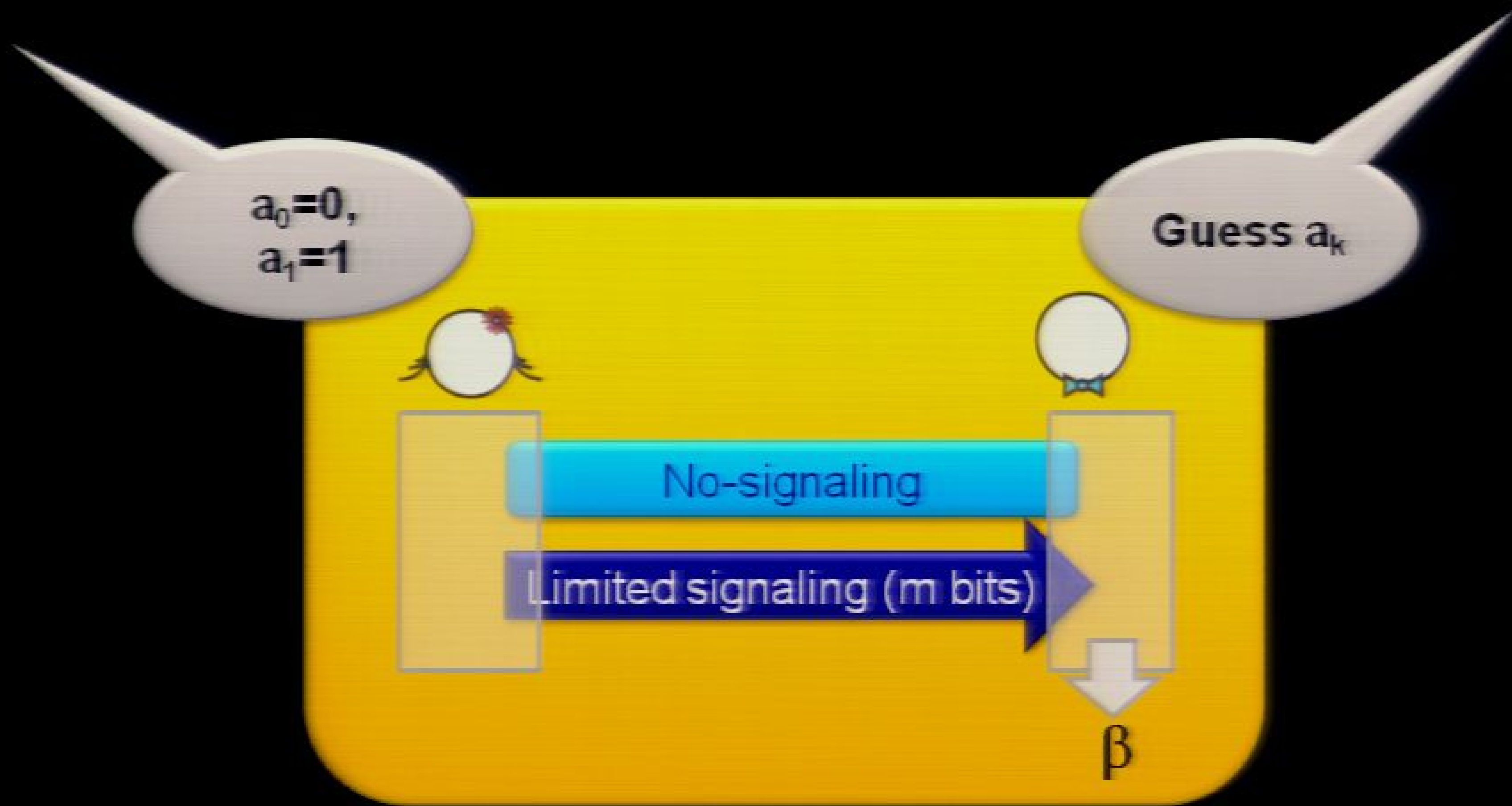

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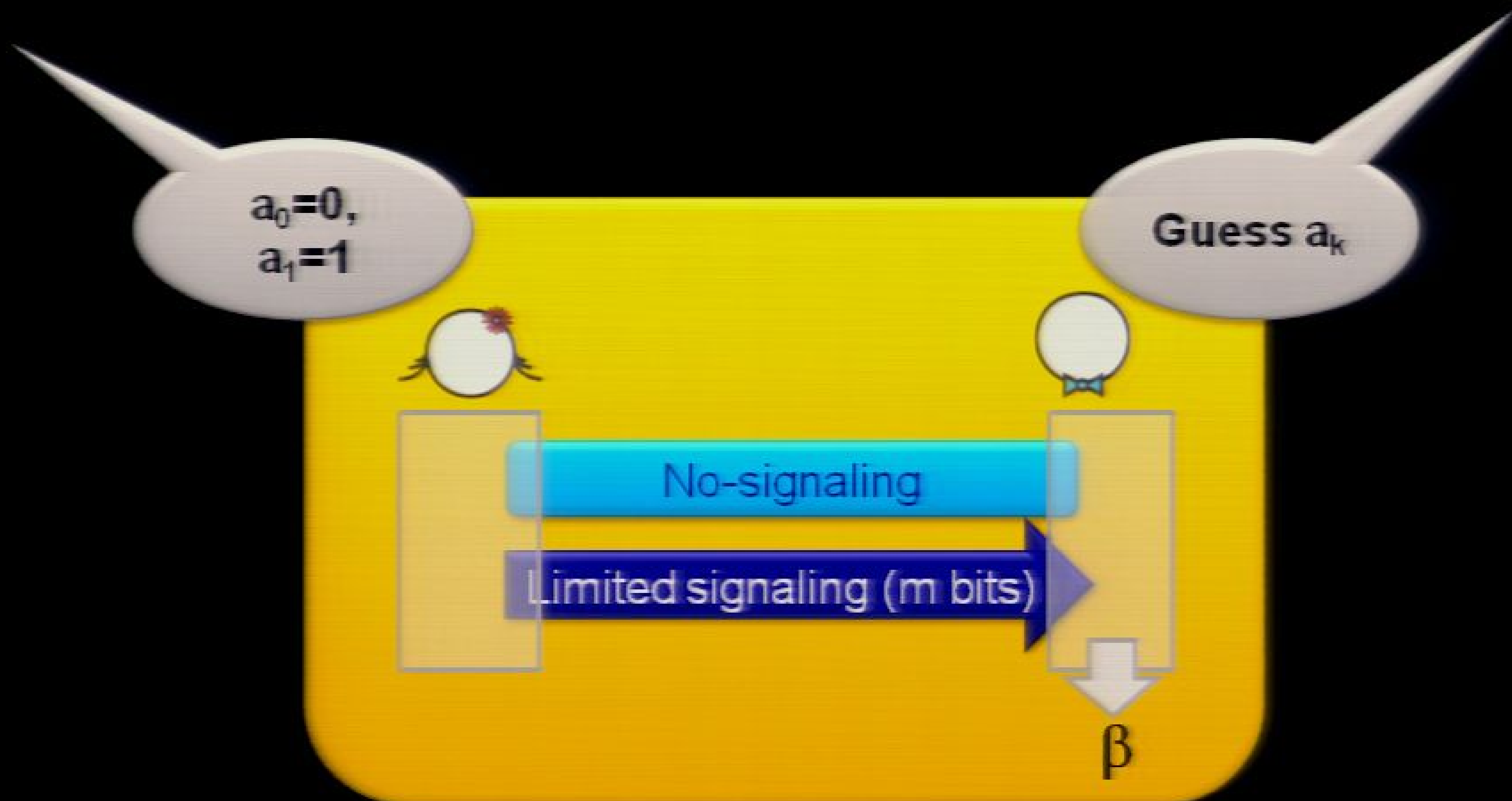

IC respected if $\sum_{k=1}^{N} I(a_k : \beta \,|\, b=k) \le m$

What IC can do for you

Consider (2,2;2,2)

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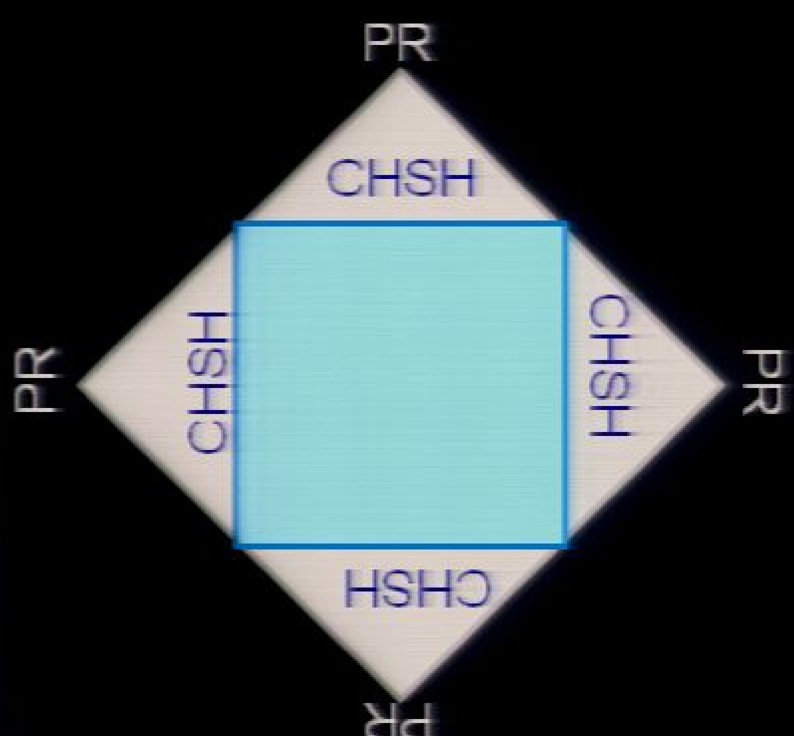
No-signaling polytope



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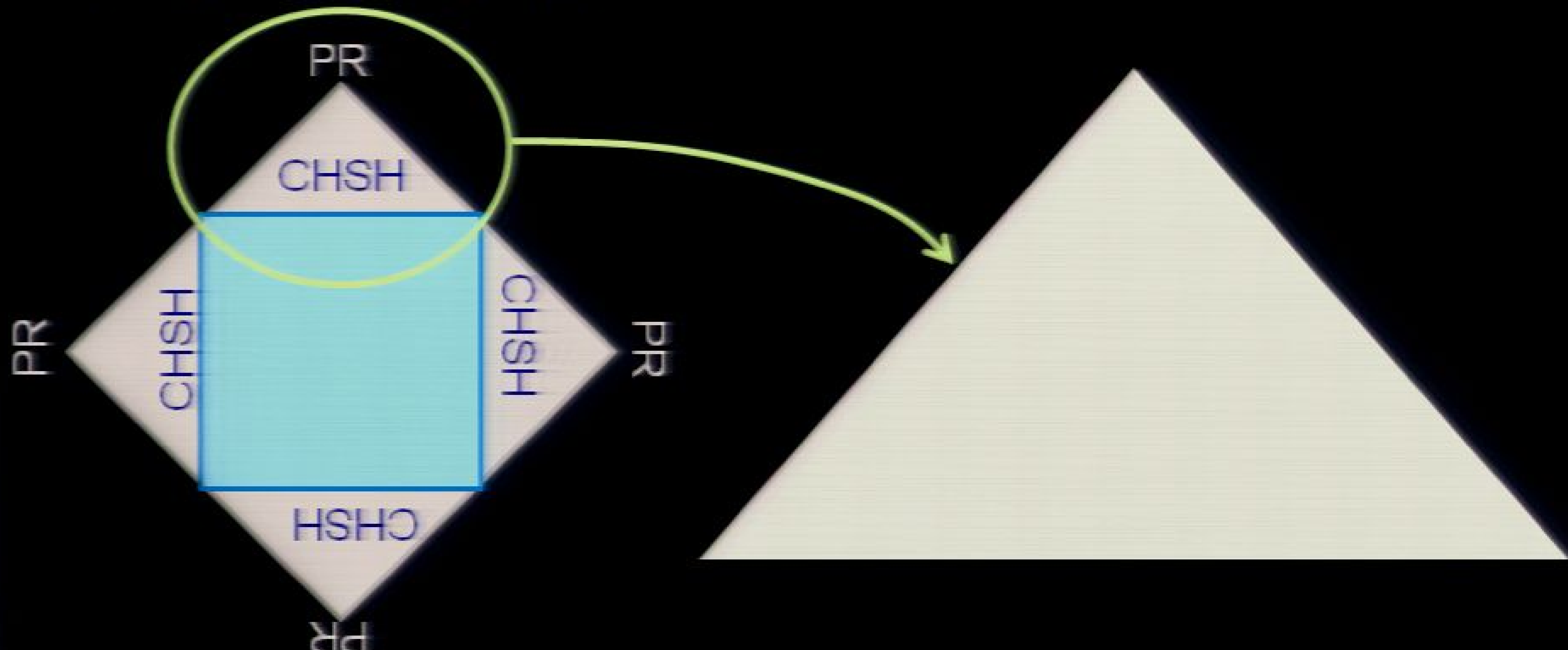

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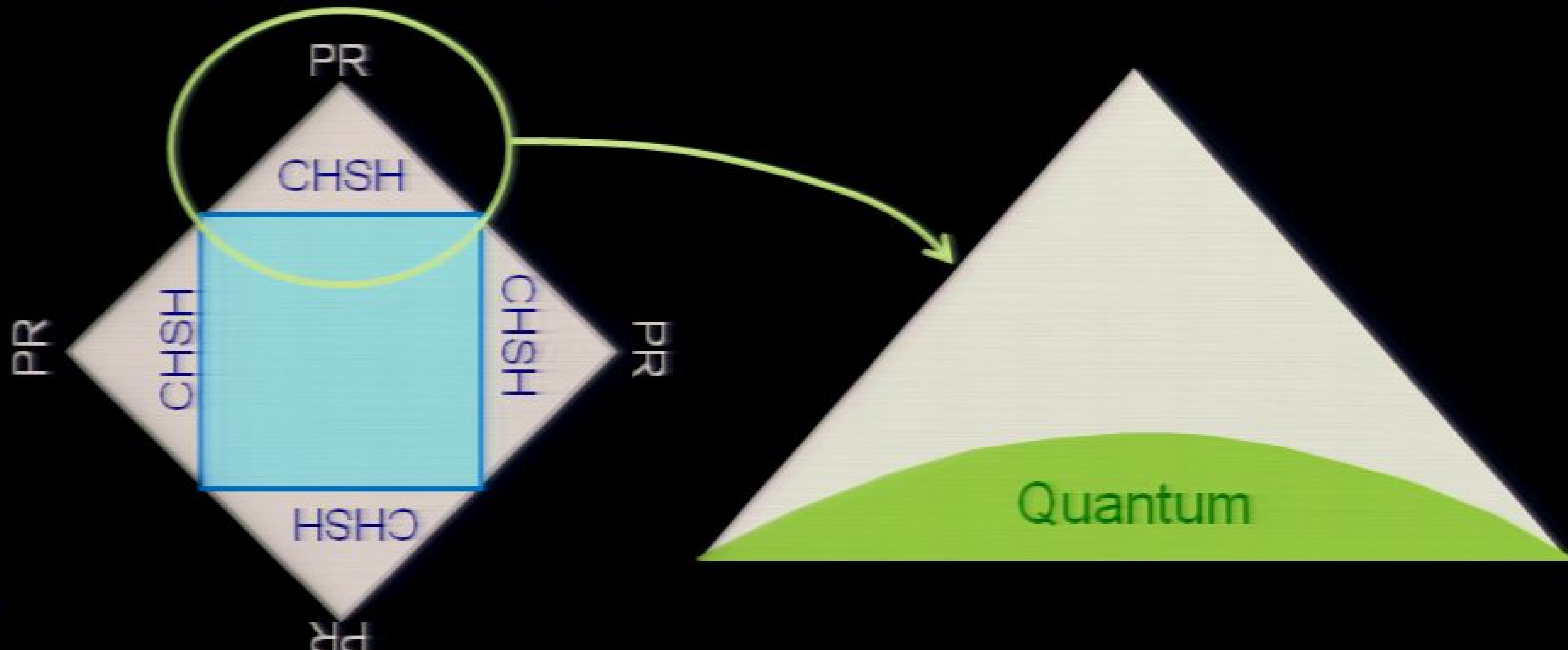

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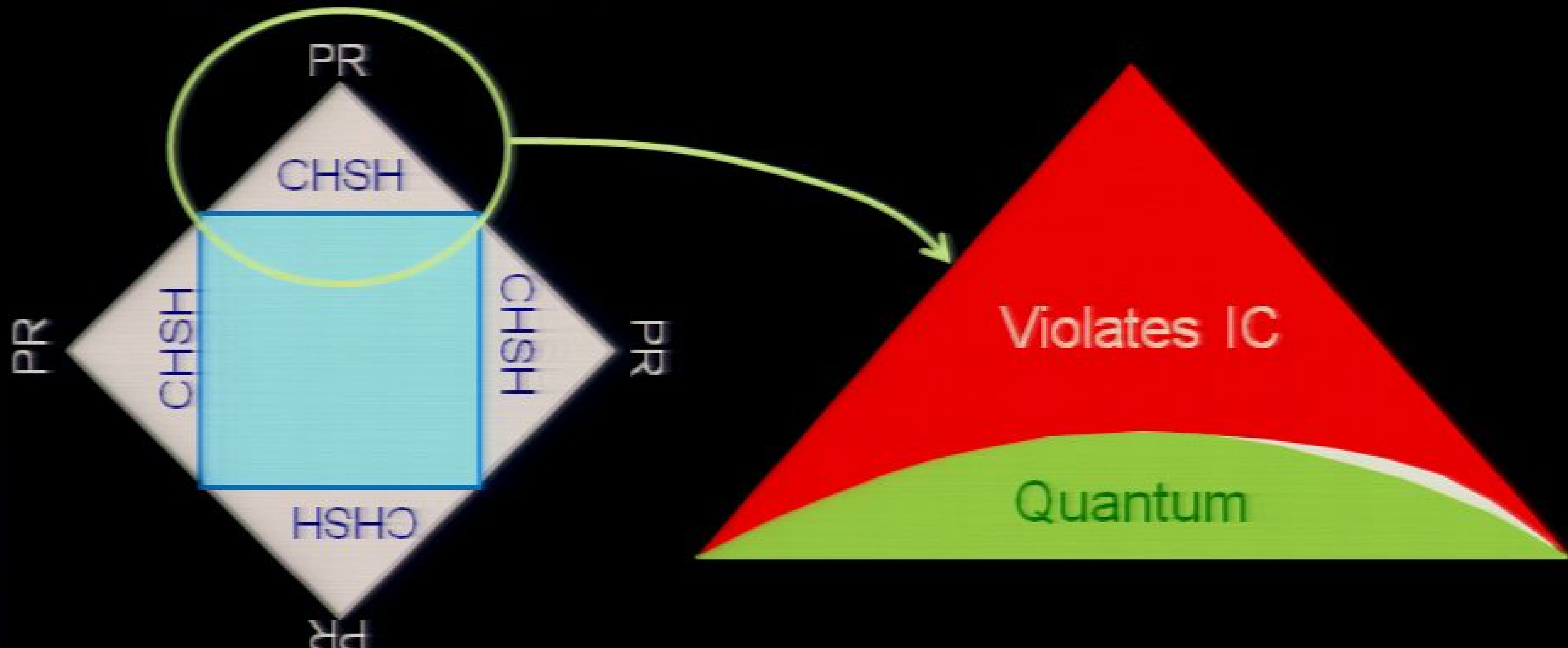

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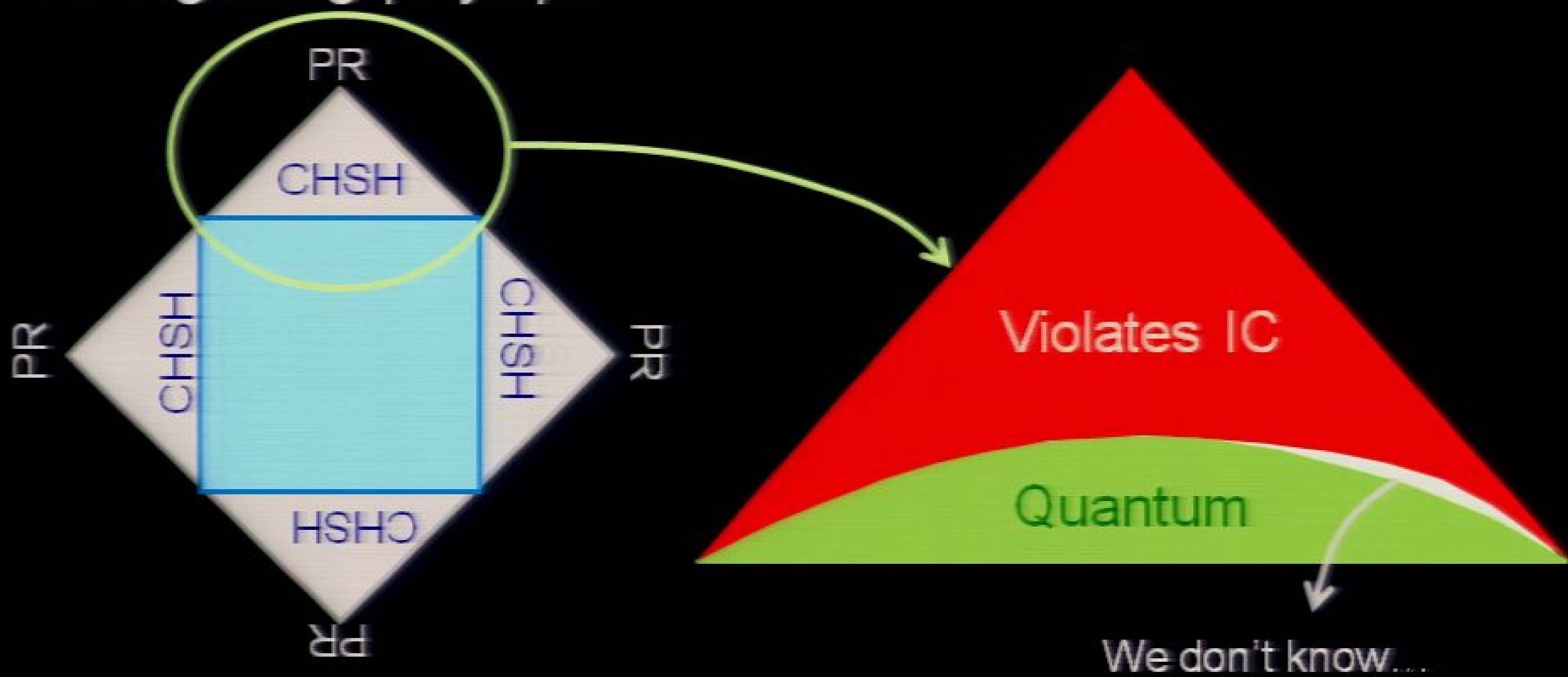

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- Ultimately, one would like to find a solution without having to study each scenario separately…
- And – hey! QM allows more than two parties…

Polytopes: 3>>>>>>>>>>>>>2 ☹

Consider (2,2;2,2;2,2)

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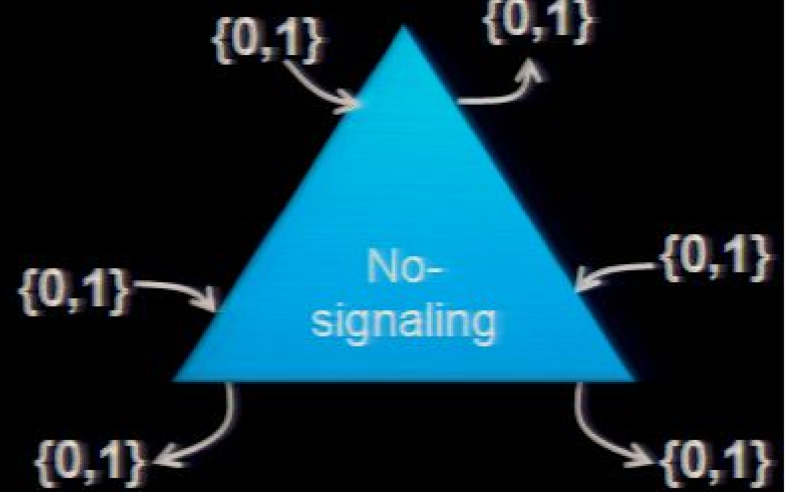

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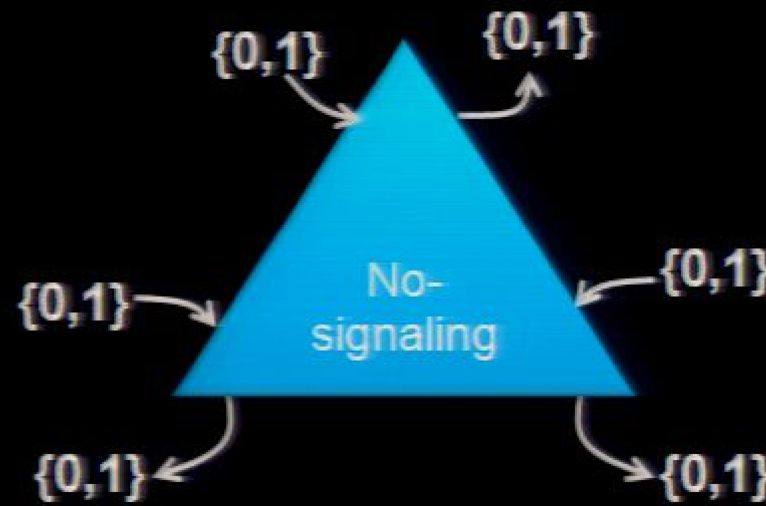

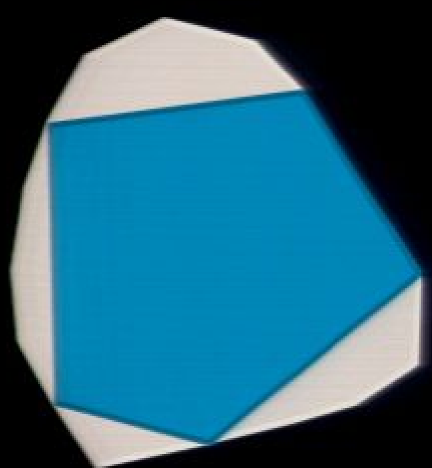

[Lazy-artist representation]

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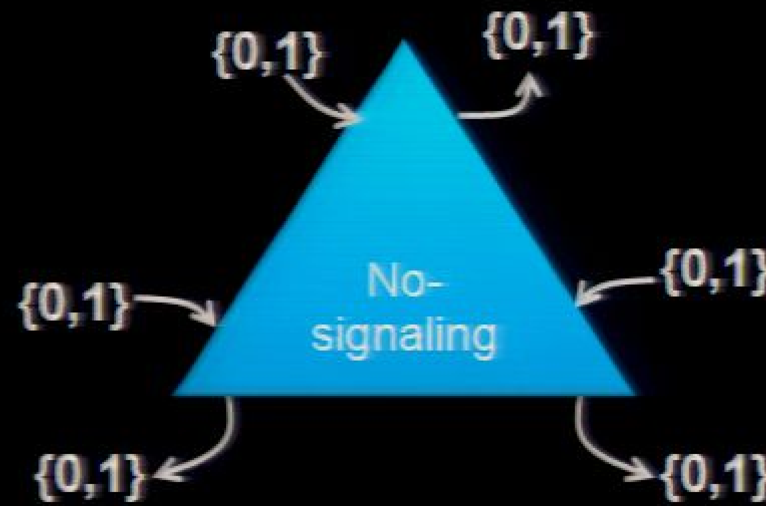

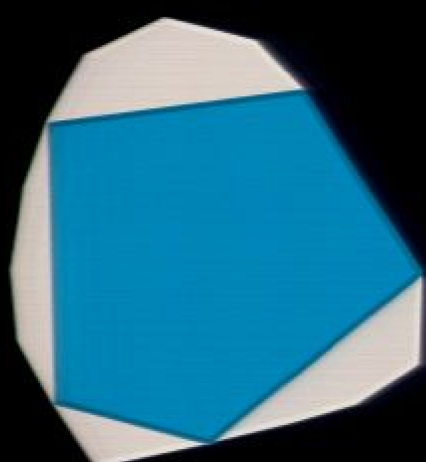

[Lazy-artist representation]

IC: even the complete study of this special case seems hopeless… but one has to start somewhere…

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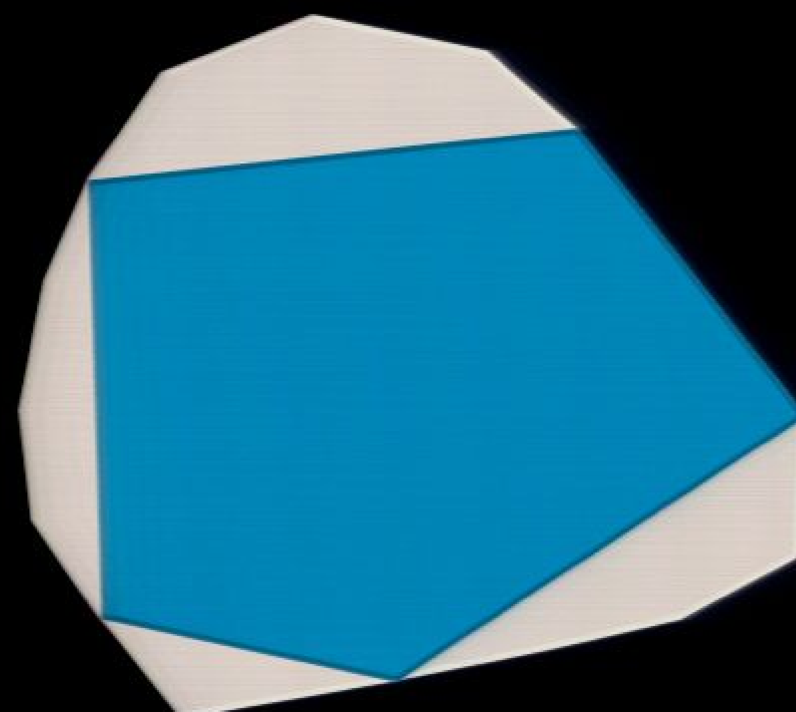
Partial results



Partial results

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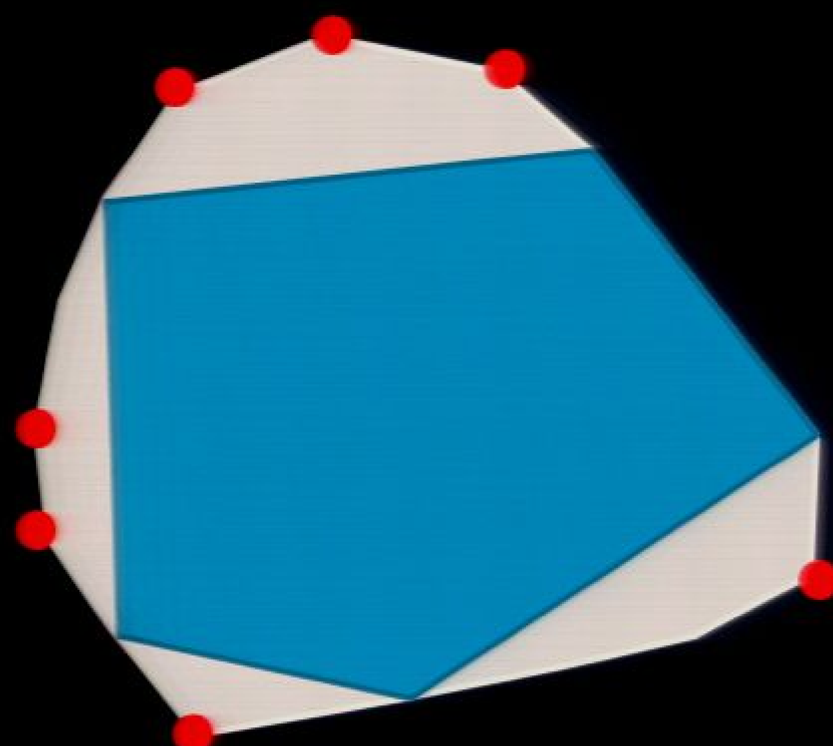

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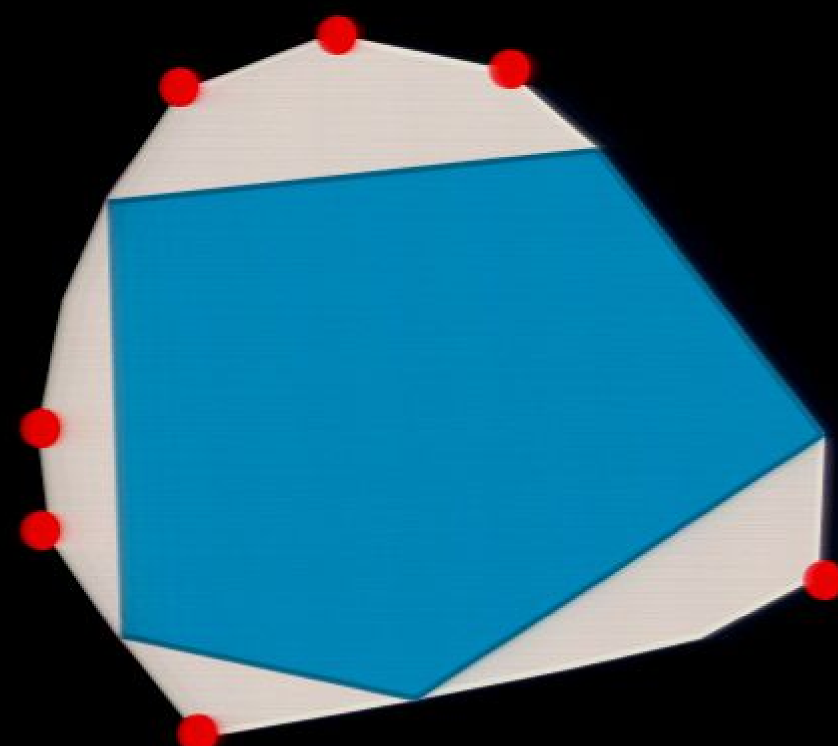

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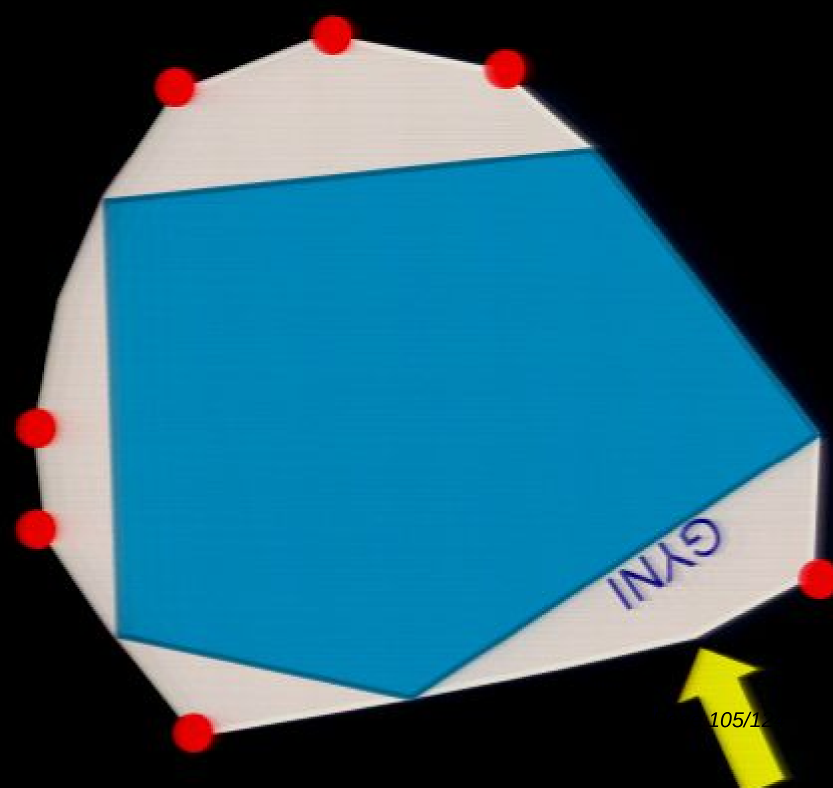

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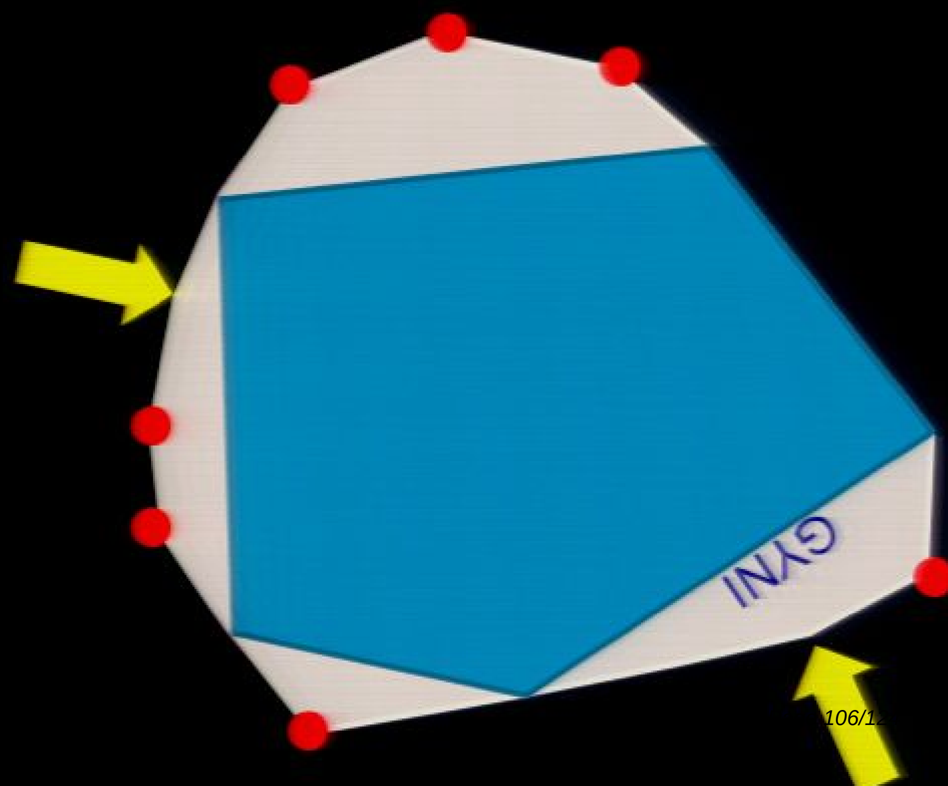

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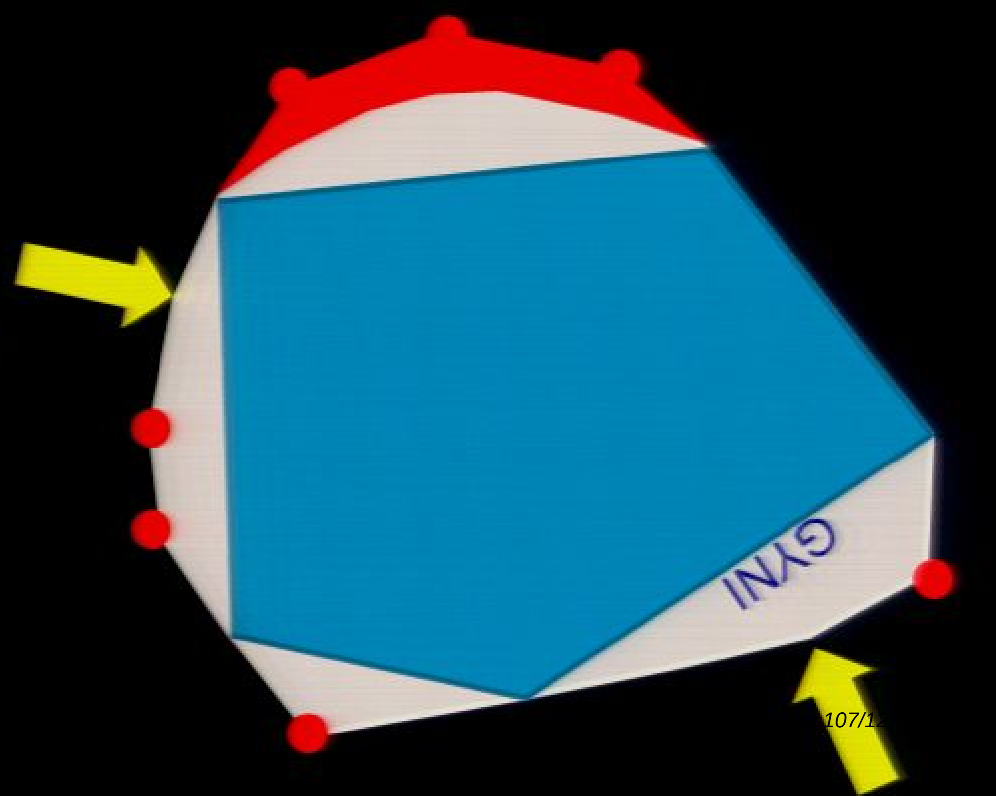

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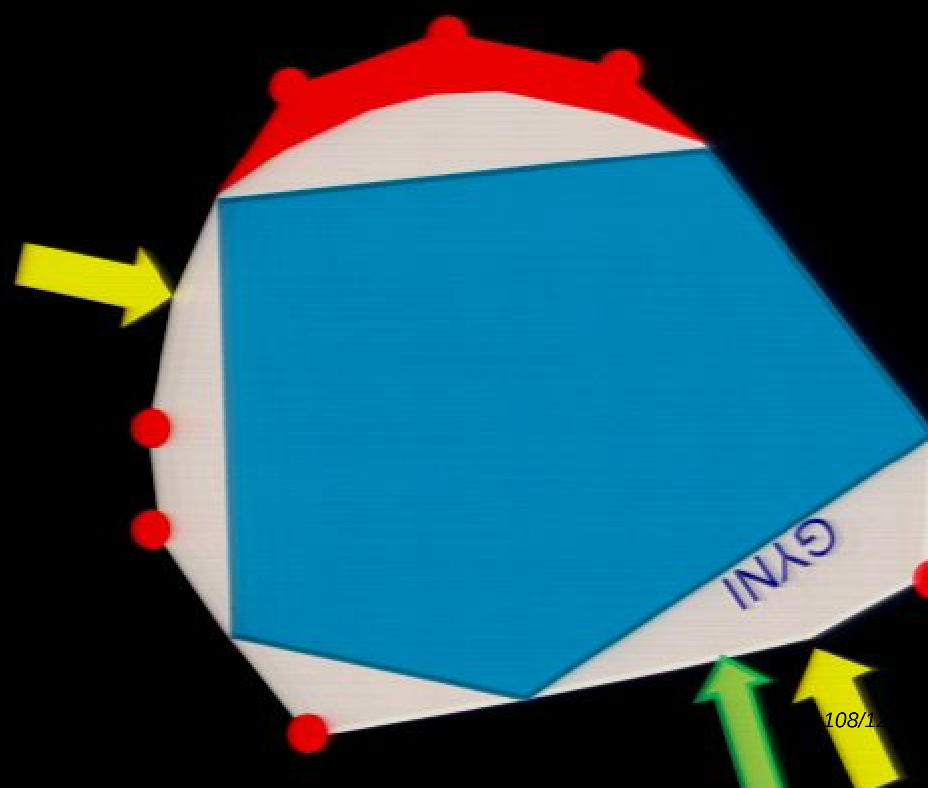
3. IC is violated if the Uffink inequality is violated $\Rightarrow$ if the Svetlichny is violated above the quantum bound (true also for N>3)

4. There is a non-extremal point that certainly won't violate bipartite IC (Acin)



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In Singapore, we care for the principles of physics!

IC multipartite

If we hope to prove IC=QM, we need:

(i) a multipartite definition of IC

(ii) Go beyond case-by-case studies

3>>2 in a different sense

BB84 $H_{\min}(Z_A \mid E) = 1 - h(e_X)$

3>>2 in a different sense

BB84 $H_{\min}(Z_A | E) = 1 - h(e_X)$

inspiration $\downarrow \uparrow$ elegant proof

Unc. rel. $H_{\min}(Z_A | E) = 1 - H_{\max}(X_A | B)$

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Temptation: QKD ⇔ uncertainty relations

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Temptation: QKD ⇔ uncertainty relations

Six states

$$H_{\min}(Z_A|E) = 1 - e_Z h\left(\frac{1-(e_X - e_Y)/e_Z}{2}\right) - (1-e_Z) h\left(\frac{1-(e_X + e_Y + e_Z)/2}{1-e_Z}\right)$$

Good luck to find the corresponding unc. rel. ☺

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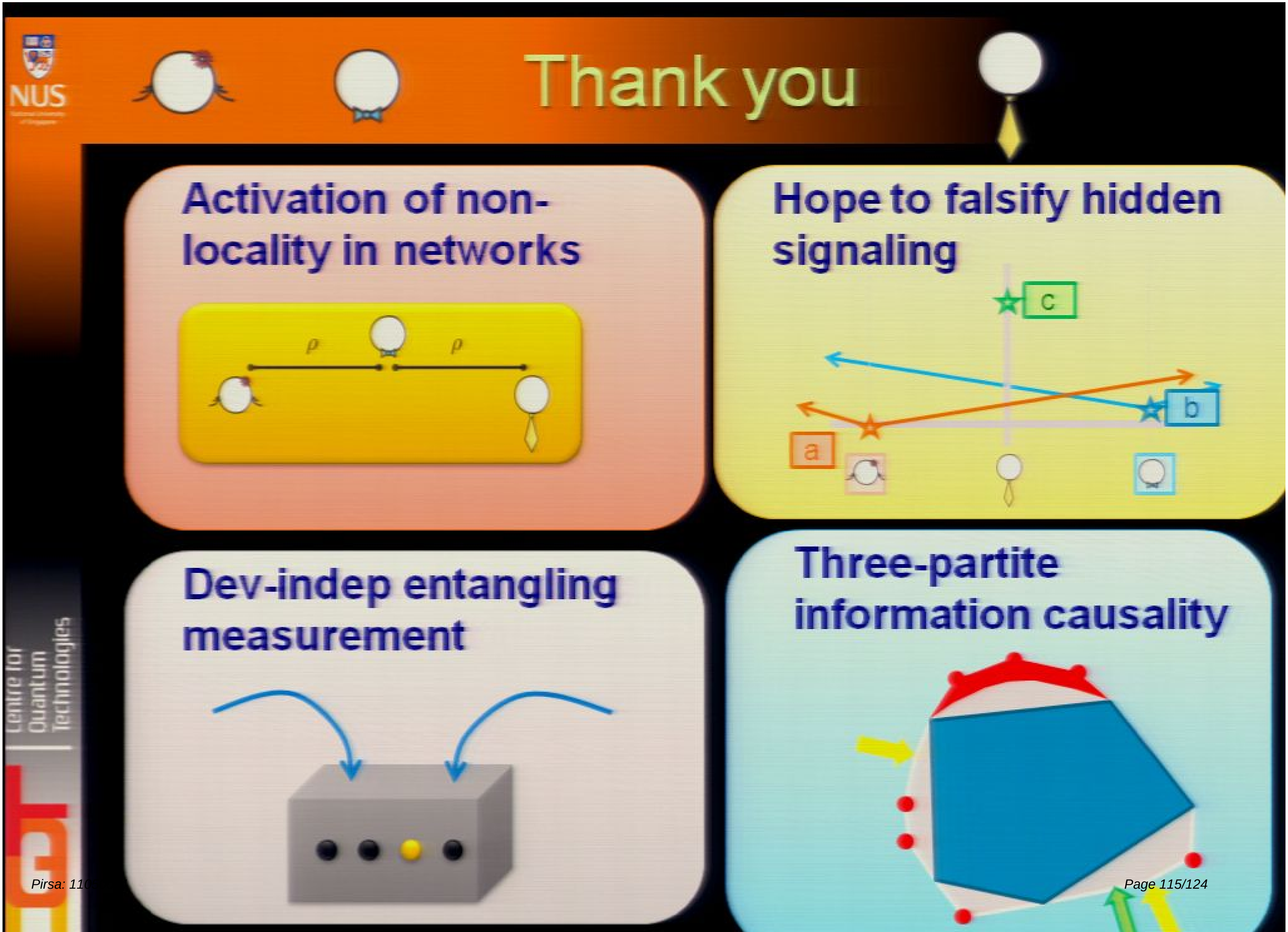
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Thank you
Activation of non-locality in networks
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Hope to falsify hidden signaling
c
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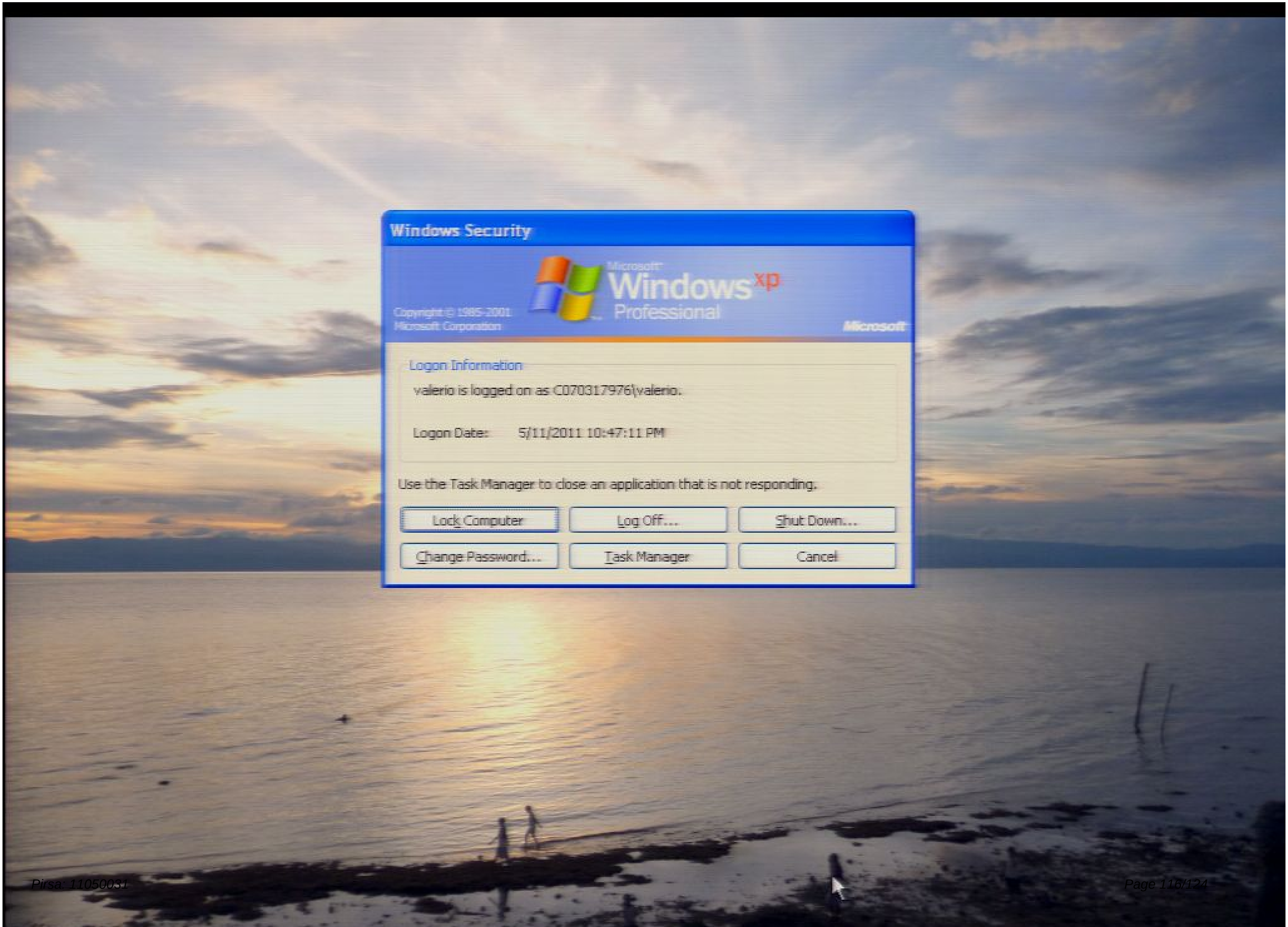
Dev-indep entangling measurement
Three-partite information causality
Centre for Quantum Technologies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Windows xp
Professional
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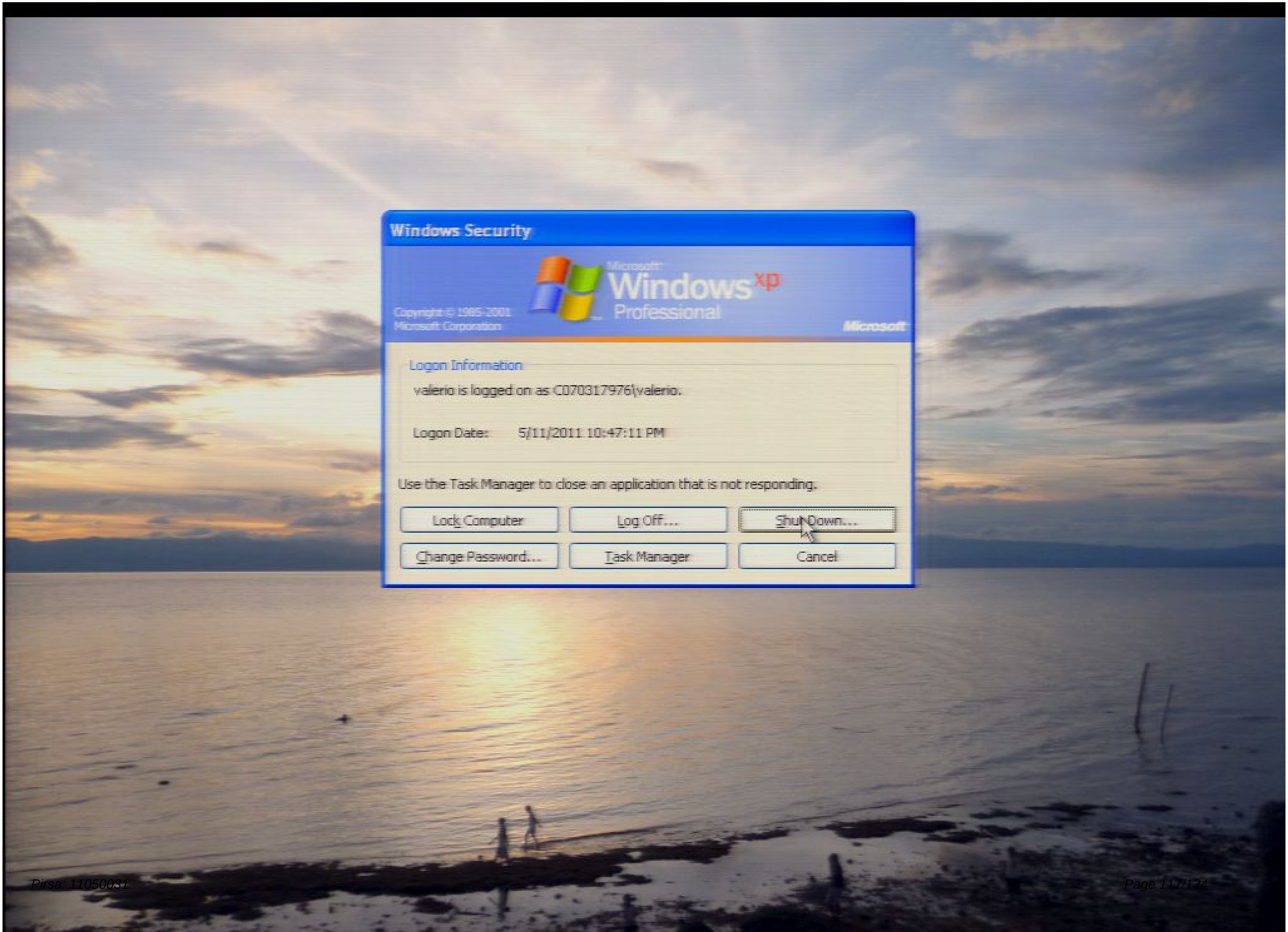
Logon Information
valerio is logged on as C070317976\valerio.
Logon Date: 5/11/2011 10:47:11 PM
Use the Task Manager to close an application that is not responding.
Lock Computer
Log Off...
Shut Down...
Change Password...
Task Manager
Cancel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valerio is logged on as C070317976\valerio.
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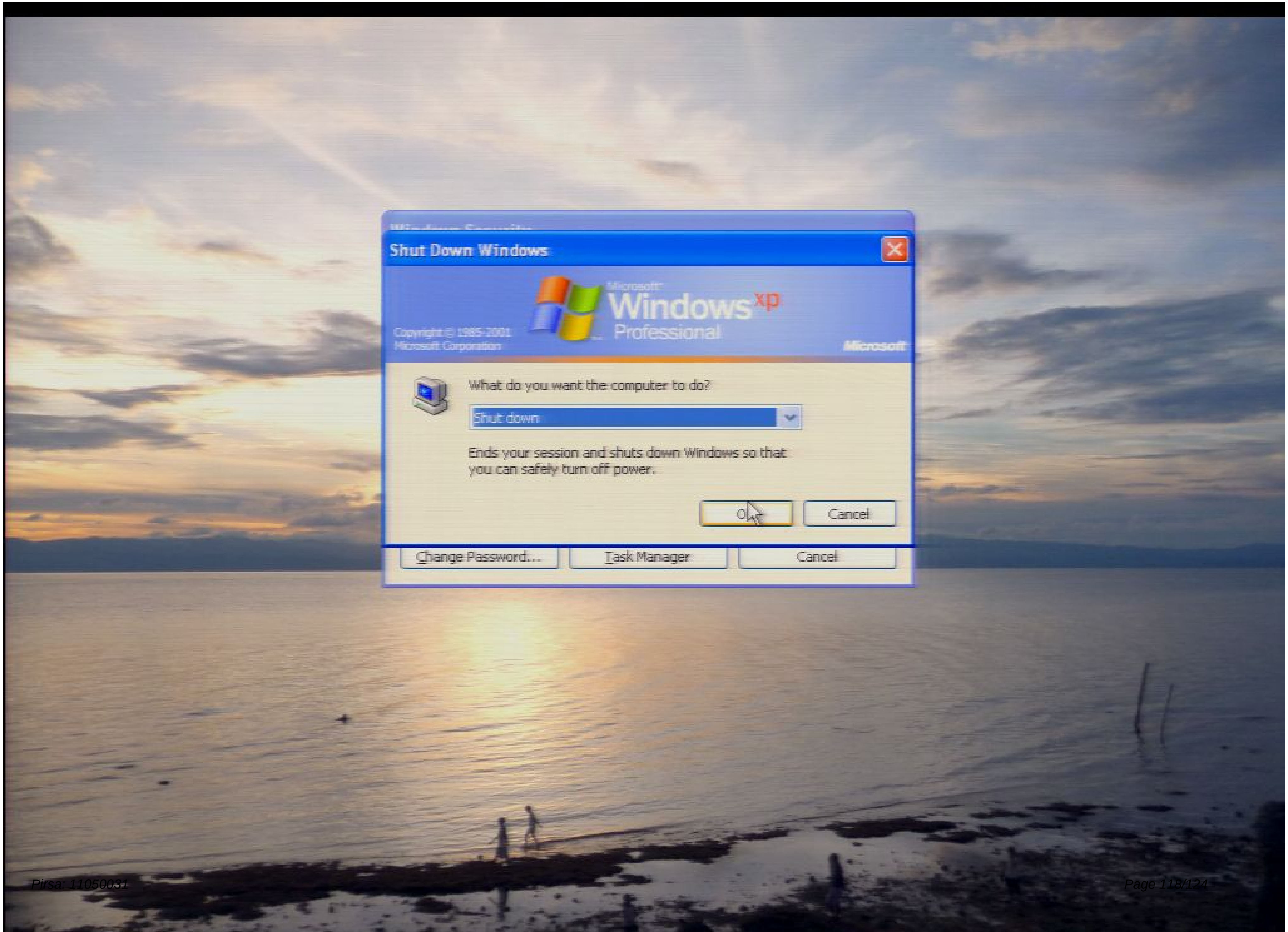
Shut Down Windows
Microsoft
Windows xp
Professional
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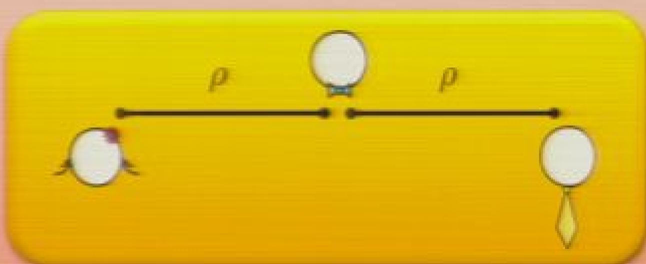
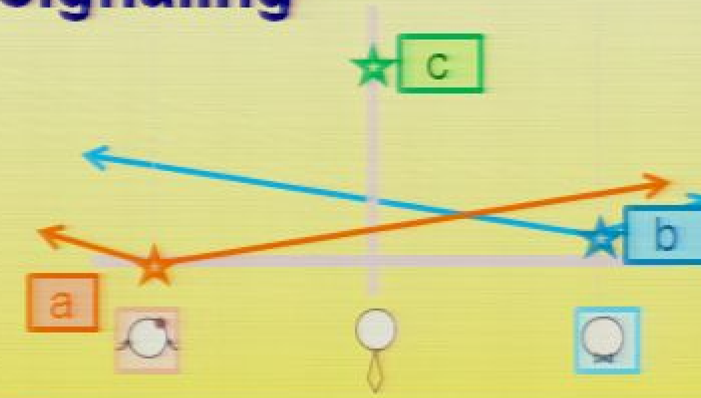
Microsoft
What do you want the computer to do?
Shut down
Ends your session and shuts down Windows so that
you can safely turn off power.
Cancel
Change Password...
Task Manager
Cancel

Thank you

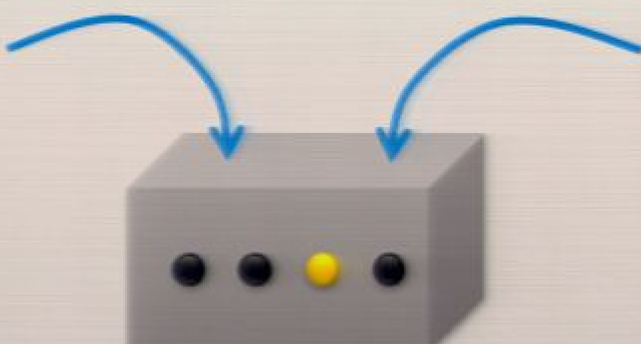
Activation of non-locality in networks



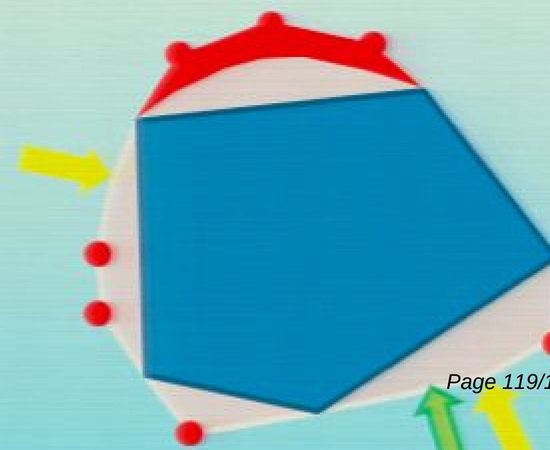
Hope to falsify hidden signaling



Dev-indep entangling measurement

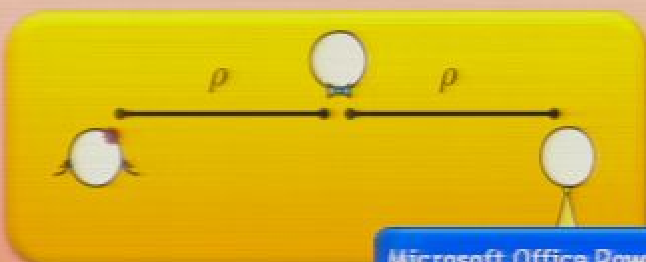


Three-partite information causality



Thank you

Activation of non-locality in networks



Hope to falsify hidden signaling

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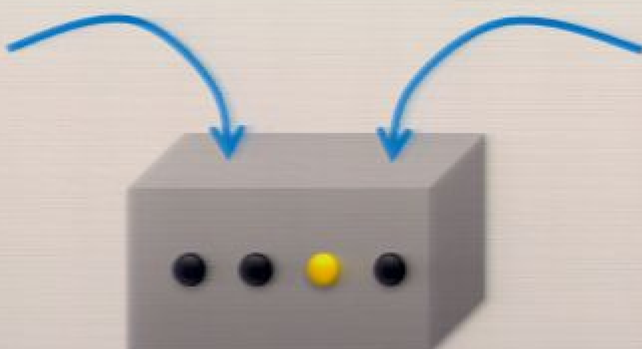
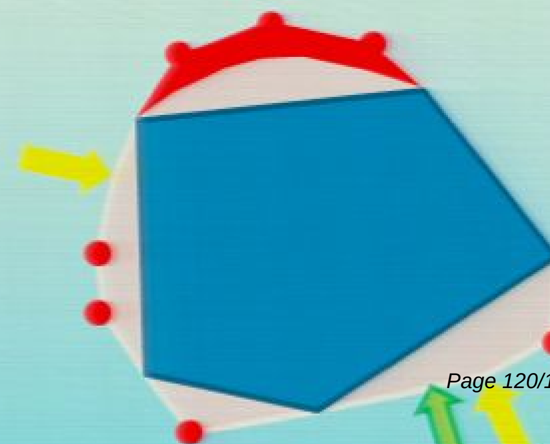
Yes No Cancel

Dev-indep entangling measurement



…e-partite information causality



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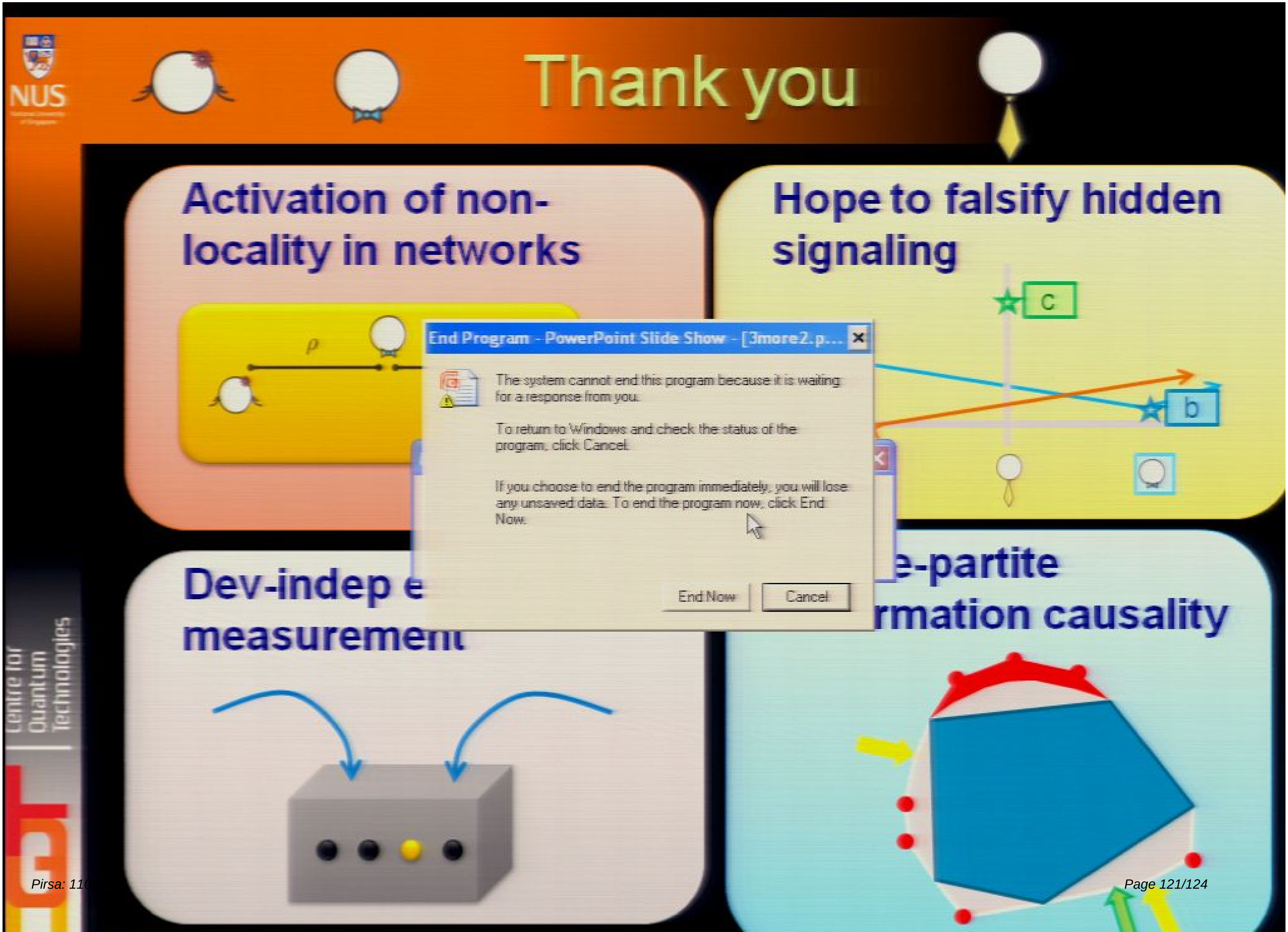
NUS
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Activation of non-locality in networks
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Hope to falsify hidden signaling
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b
Dev-indep e
measurement
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rmation causality
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To return to Windows and check the status of the program, click Cancel.
If you choose to end the program immediately, you will lose any unsaved data. To end the program now, click End Now.
End Now
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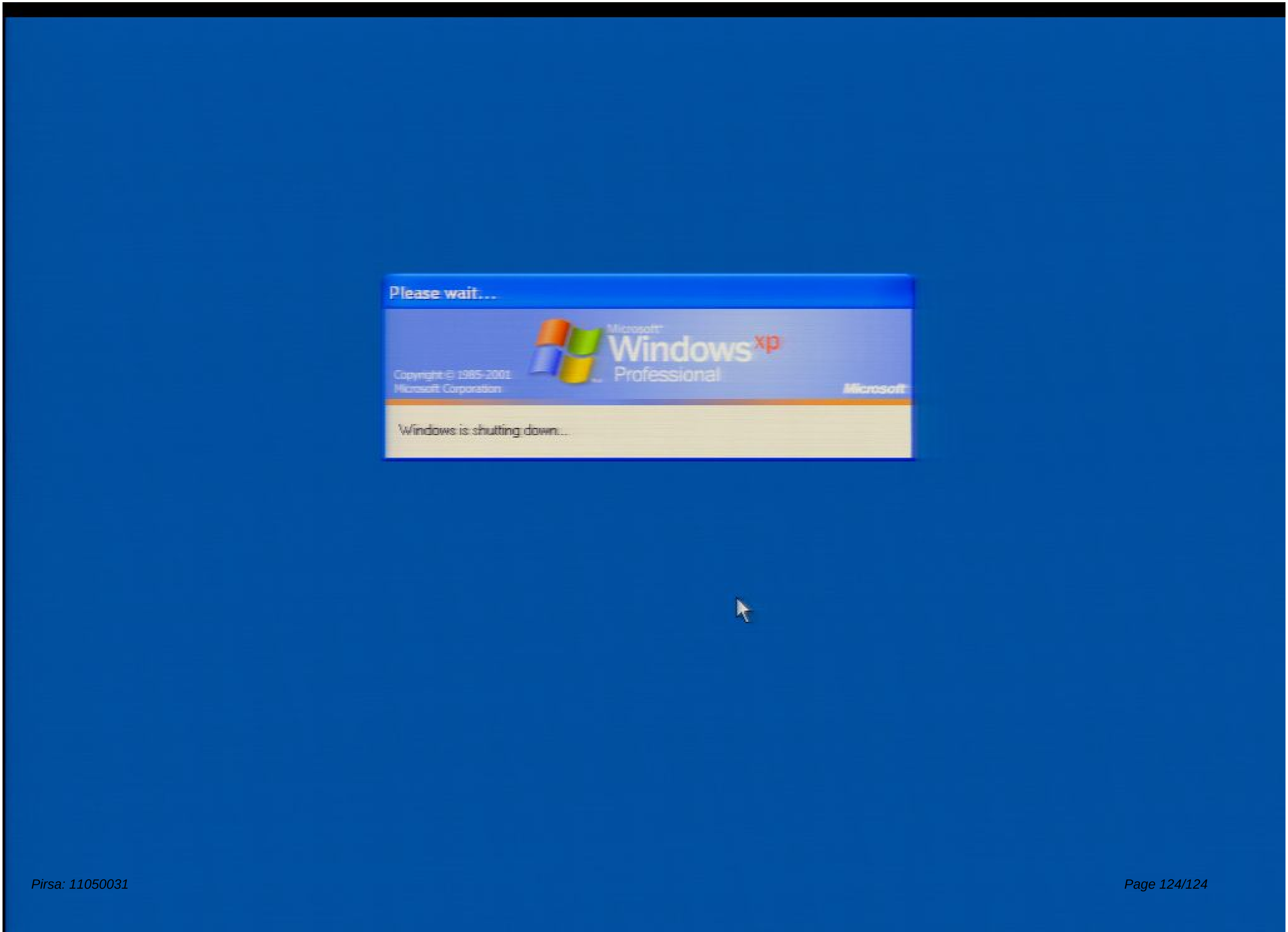
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