Quantum Correlations, Beyond Entanglement

A Socio-Scientific Talk

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Sharif University of Technology,
Tehran, Iran.

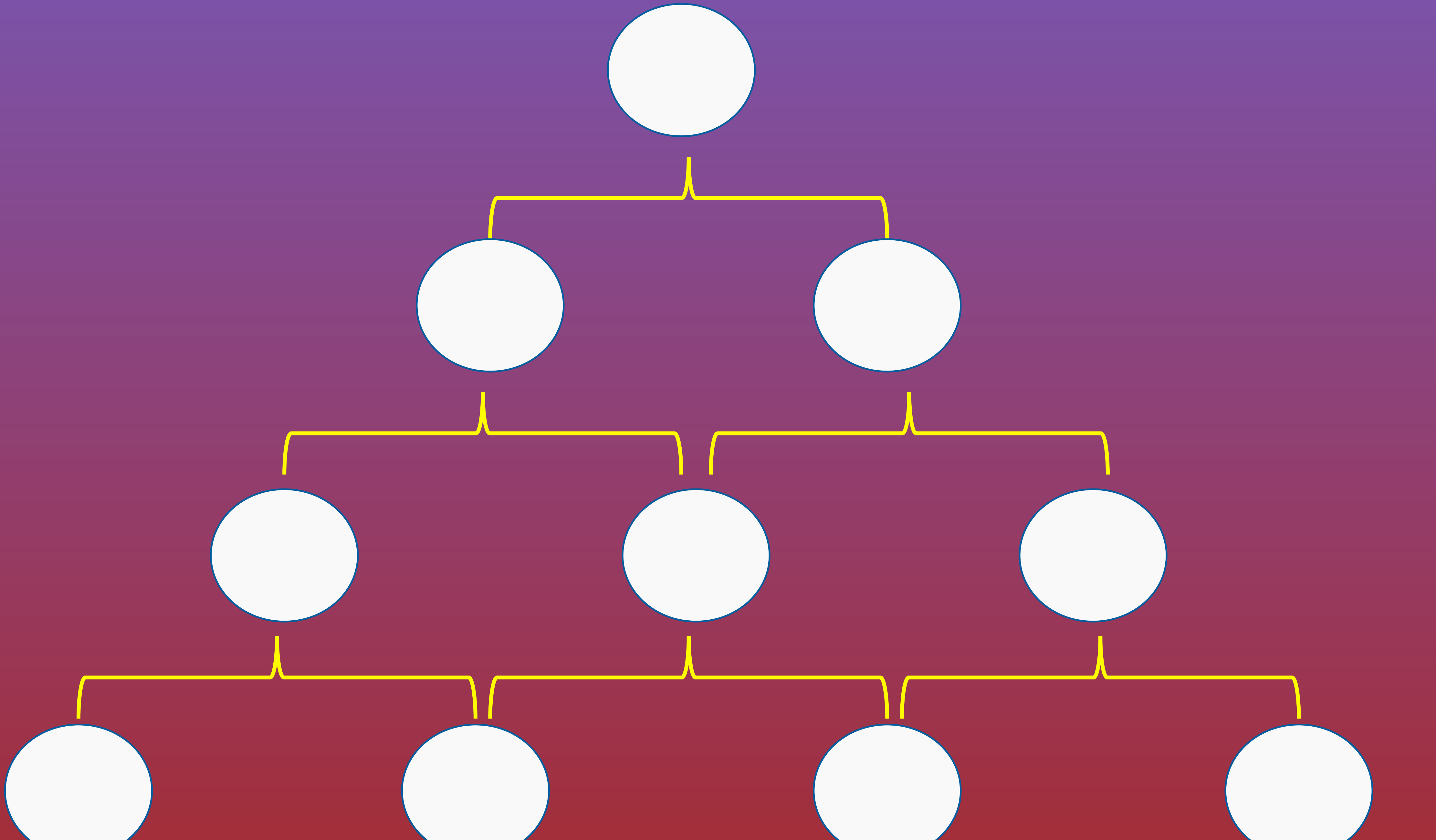
COST Conference 2015
"Fundamental Problems in Quantum Physics"

A tribute to Giancarlo Ghirardi
on the occasion of his 80th Birthday

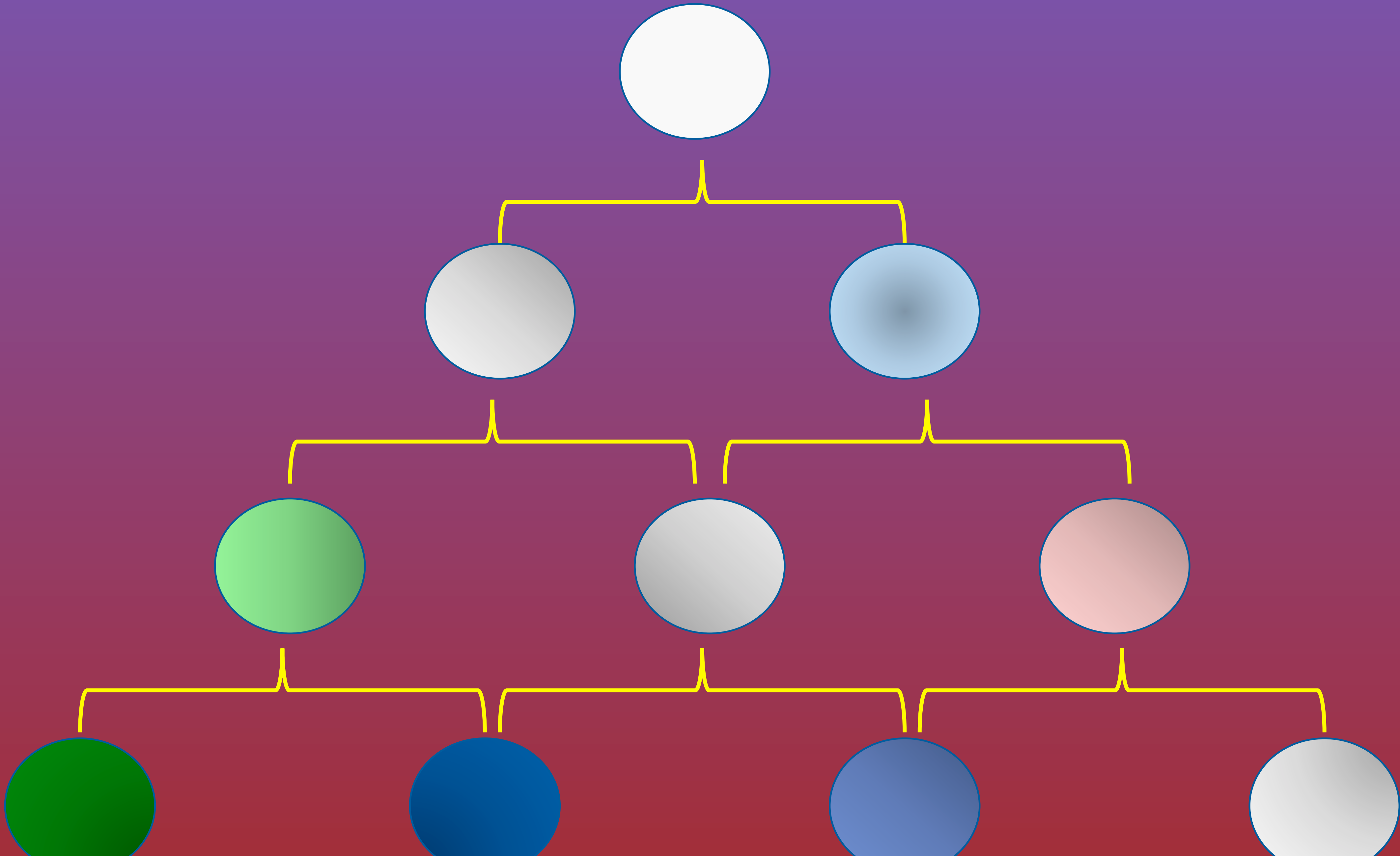
The Initiation of PhD Program (1988)

(1993)

The Next Generations



Diversity



The quality

hysical Review? Very Common,

RL? Rather common,

cience, Nature, PNAS? (sometimes)

- The IICQI series
- 2007,2008,2010,2012

International Iran Conference on Quantum Information - 2010

11-14 Septem
Kish Islanc

Home
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ct Submission
rticipants

Plenary Talks

- **Luiz Davidovich**, Instituto de Física - Universidade Federal do Rio de Janeiro, Brazil
- **Patrick Hayden**, McGill University, Canada

Speake

Plenary T
Keynote Sp
Invited Spe


Since the Choi-matrix is a
Exercise 5 [4]: Show that a CP map is trace preserving
23

The Science Part

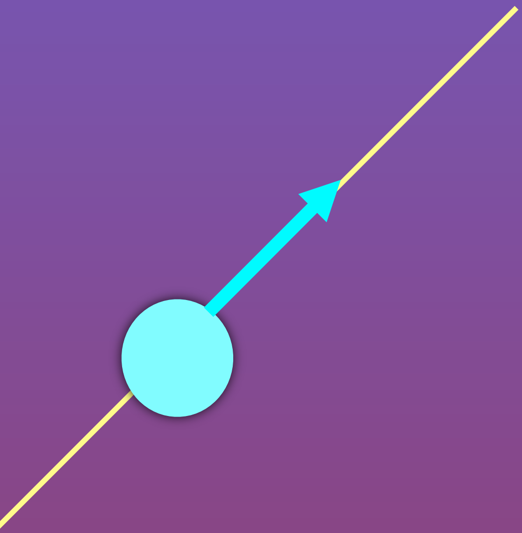
Entangled versus Separable States

Pure States

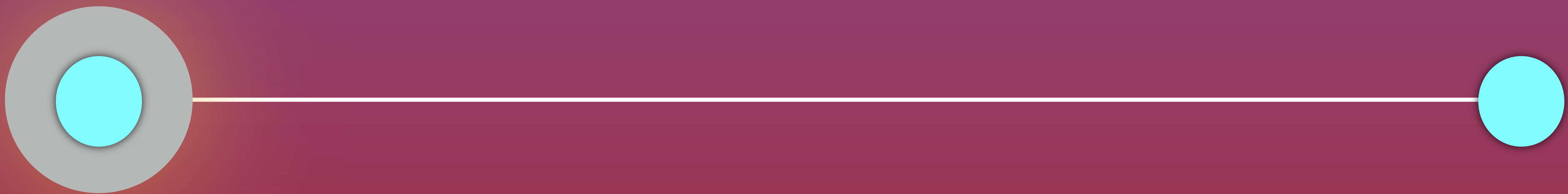
$$|\psi\rangle = |\alpha\rangle \otimes |\beta\rangle$$

$$|\psi\rangle = \sum_i |\alpha_i\rangle \otimes |\beta_i\rangle$$

Local Quantum Uncertainty



$$|\psi\rangle = |\alpha\rangle \otimes |\beta\rangle$$



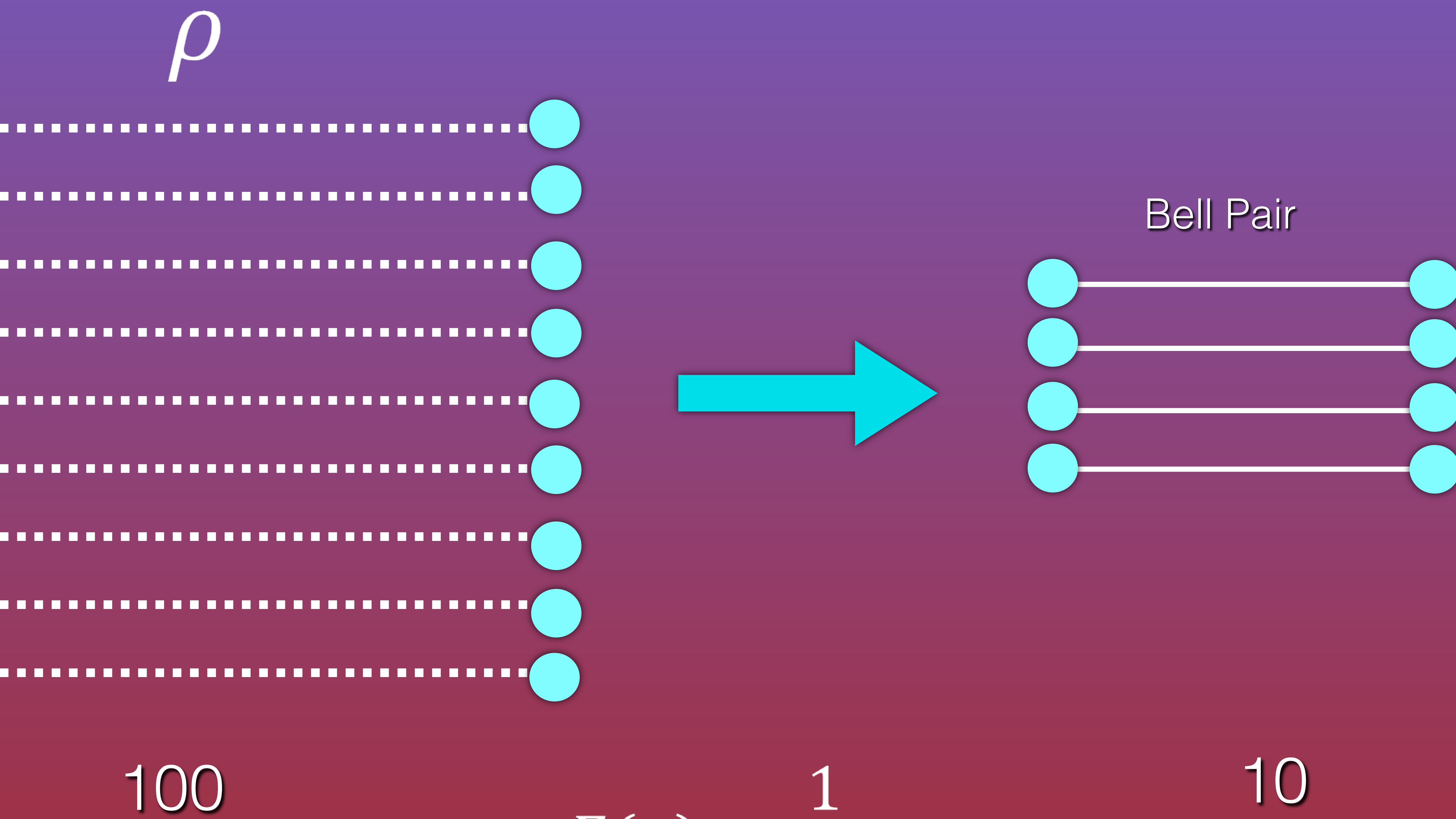
$$|\psi\rangle = \sum_i |\alpha_i\rangle \otimes |\beta_i\rangle$$

Entangled versus Separable States

Mixed States

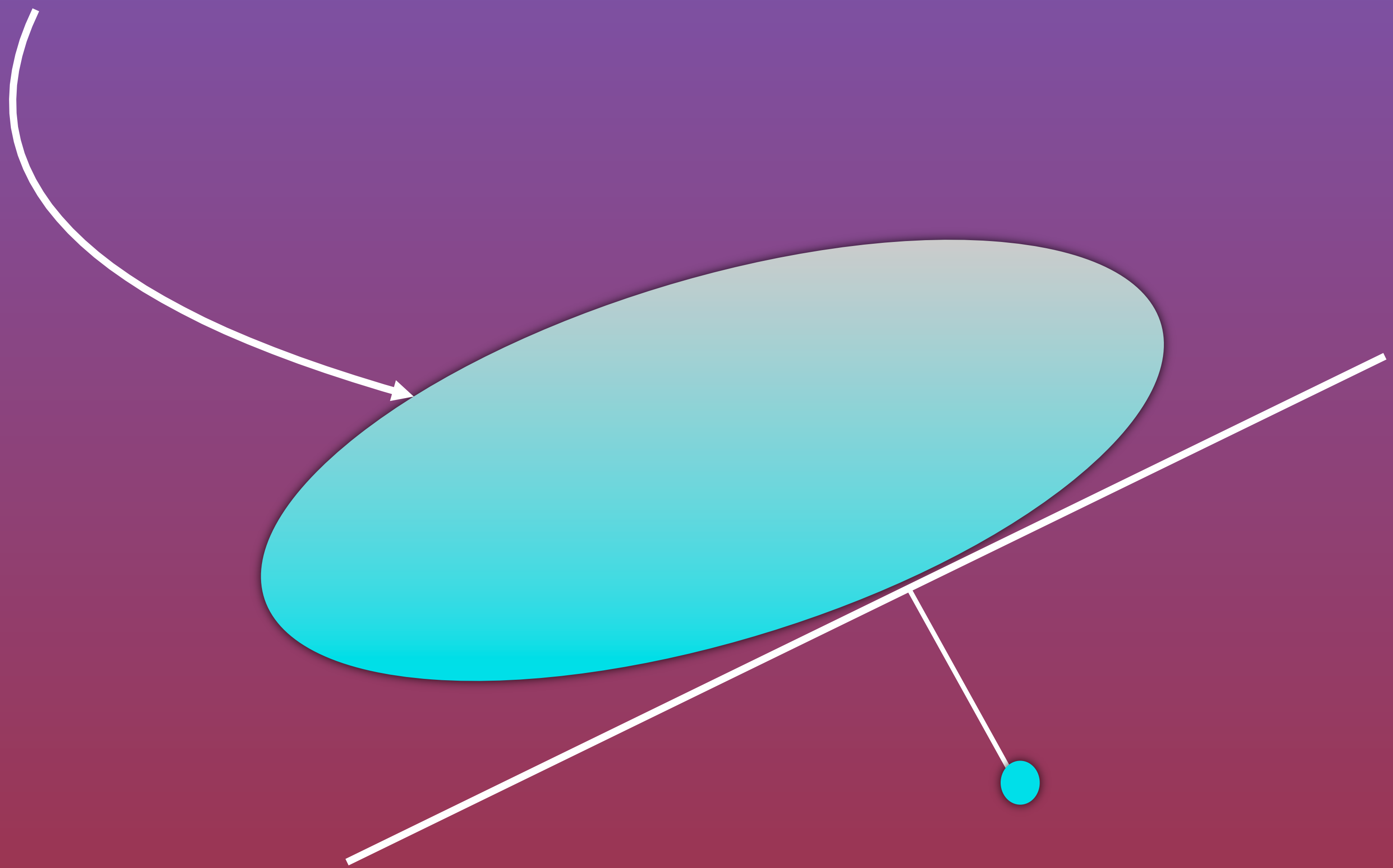
$$\rho = \sum_i p_i \ \rho_A^{(i)} \otimes \rho_B^{(i)}$$

How much Entanglement?



$$E(\rho) = \frac{1}{10}$$

Separable States



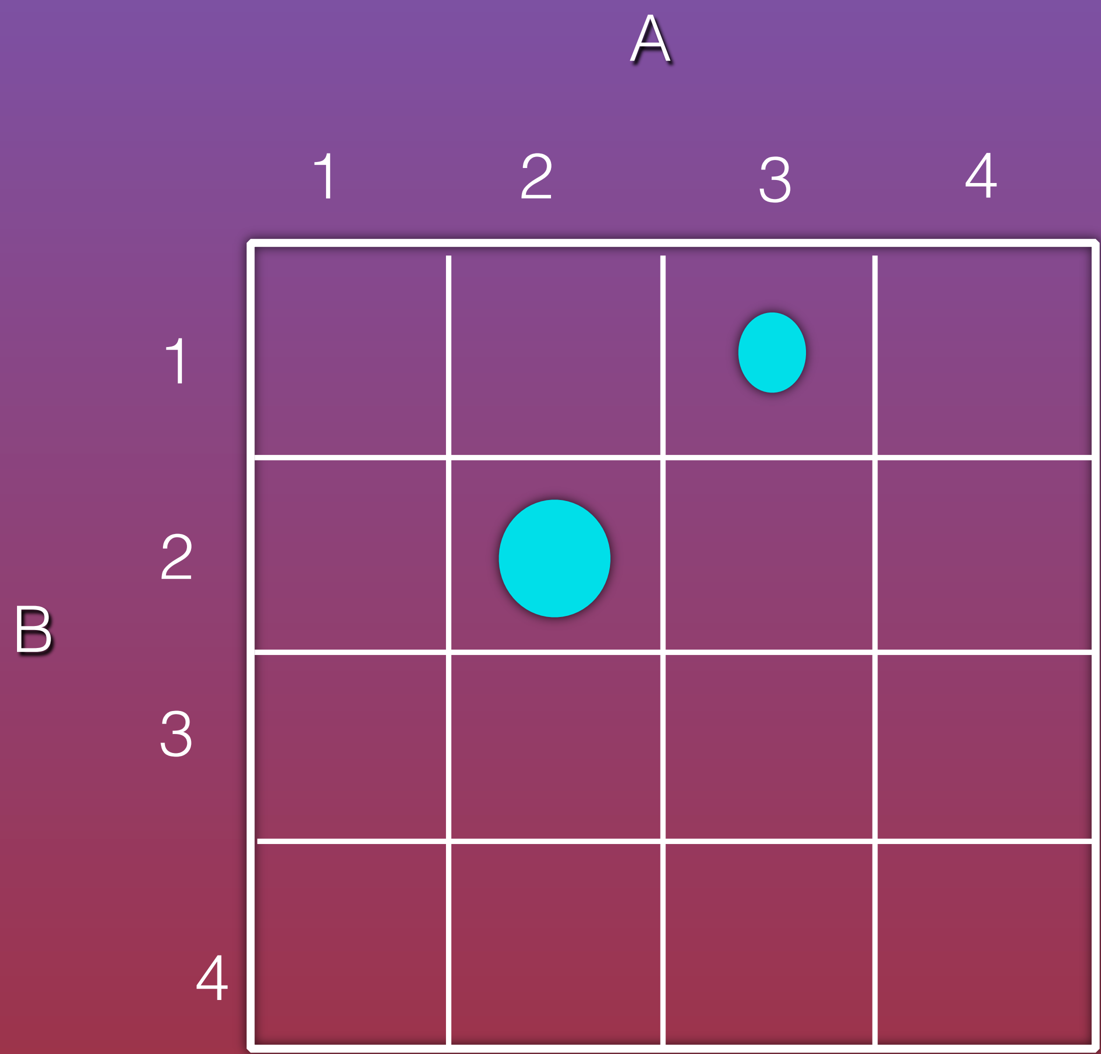
$$E(\rho) = \min_{\sigma \in Sep} d(\rho, \sigma)$$

Quantum Correlations in Separable States

Can separable states show some kind of quantum correlations?

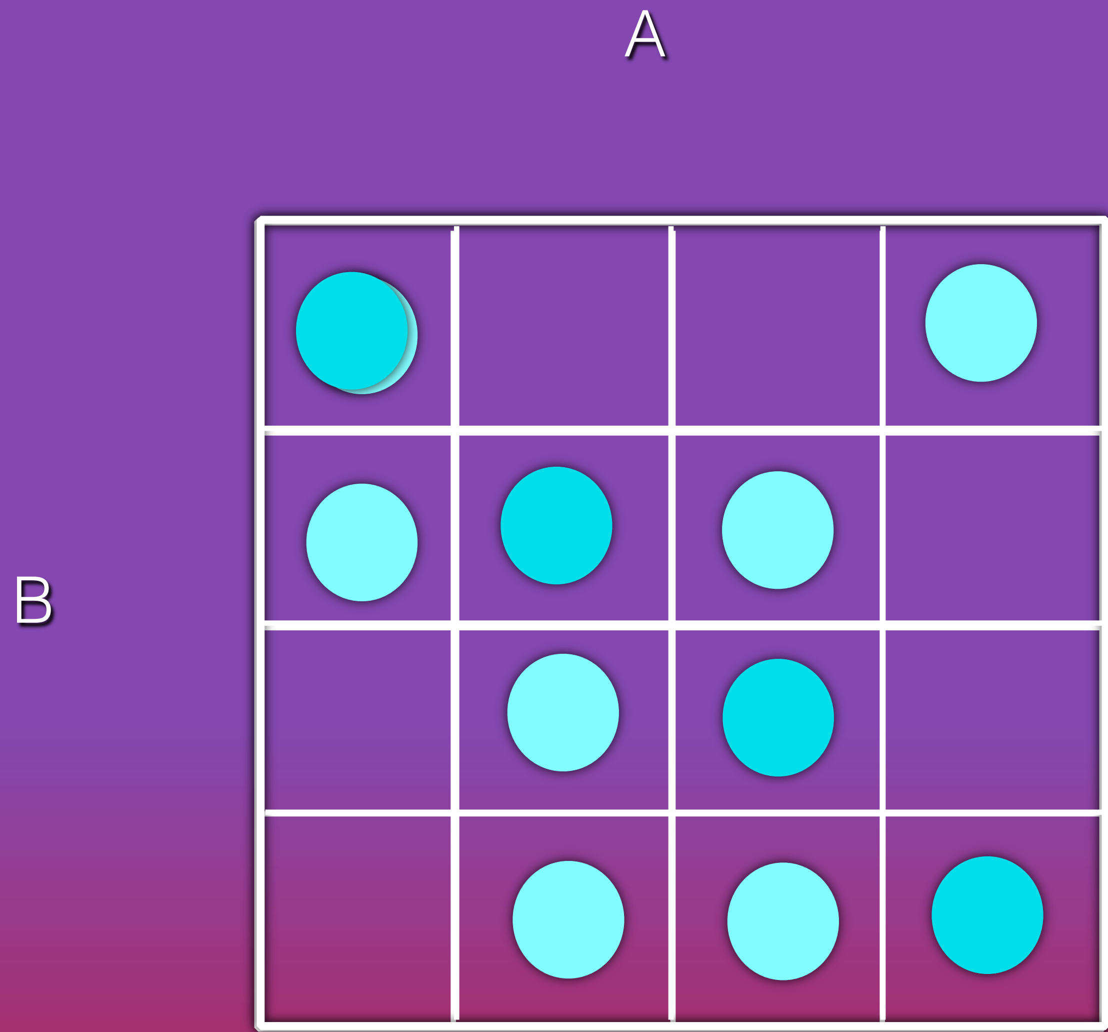
a Measure of Classical Correlation

P_{AB}

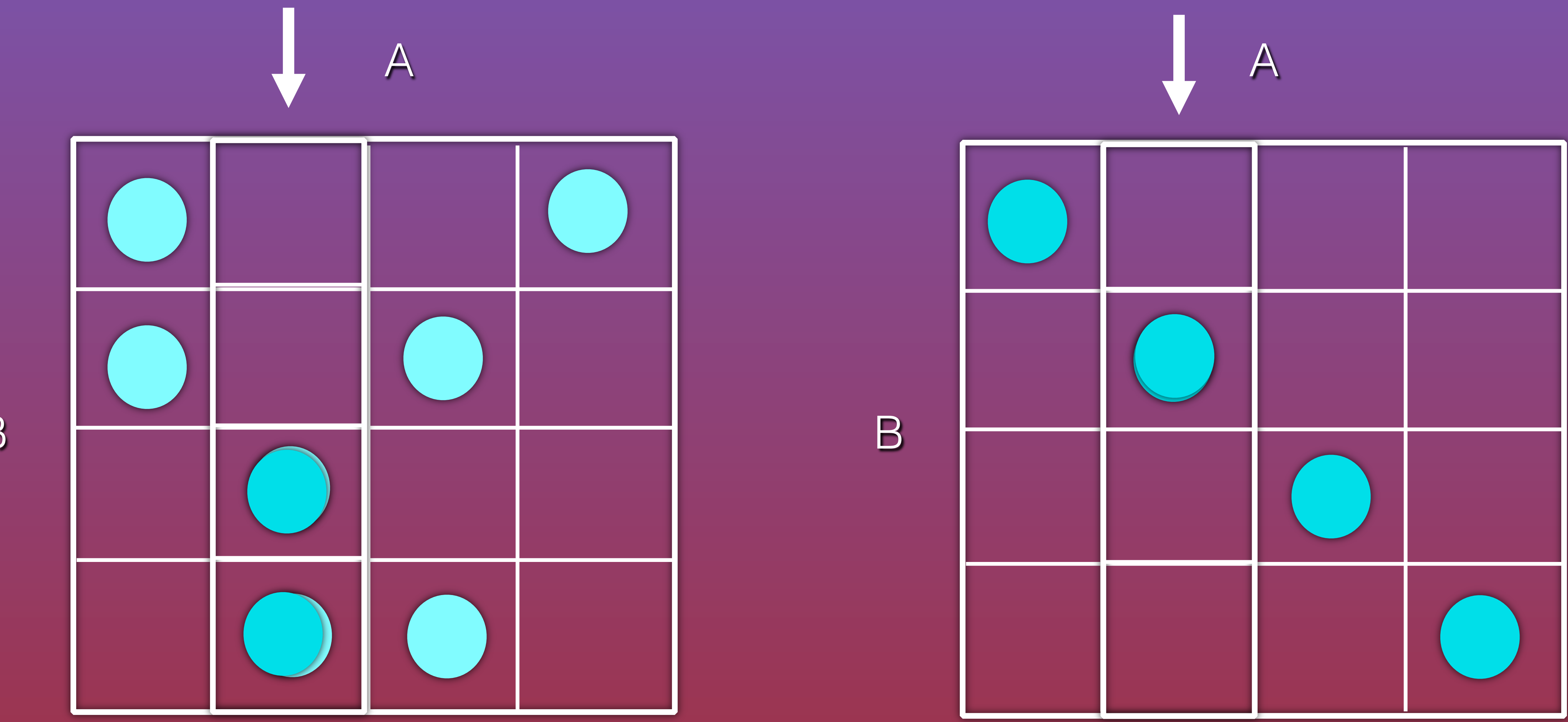


Mutual Information, a Measure of Classical Correlation

P_{AB}



in a probability distribution?



Shannon Entropy

$$H(A) = -\sum_i P_i \log \mathrm{P}_i$$

$$CC(A:B) := H(B) - H(B|A)$$

Conditional Entropy

sical Correlation

Classically Correlated States

$$\rho_{cc} = \sum_{i,j} p_{i,j} |i\rangle\langle i| \otimes |j\rangle\langle j|$$

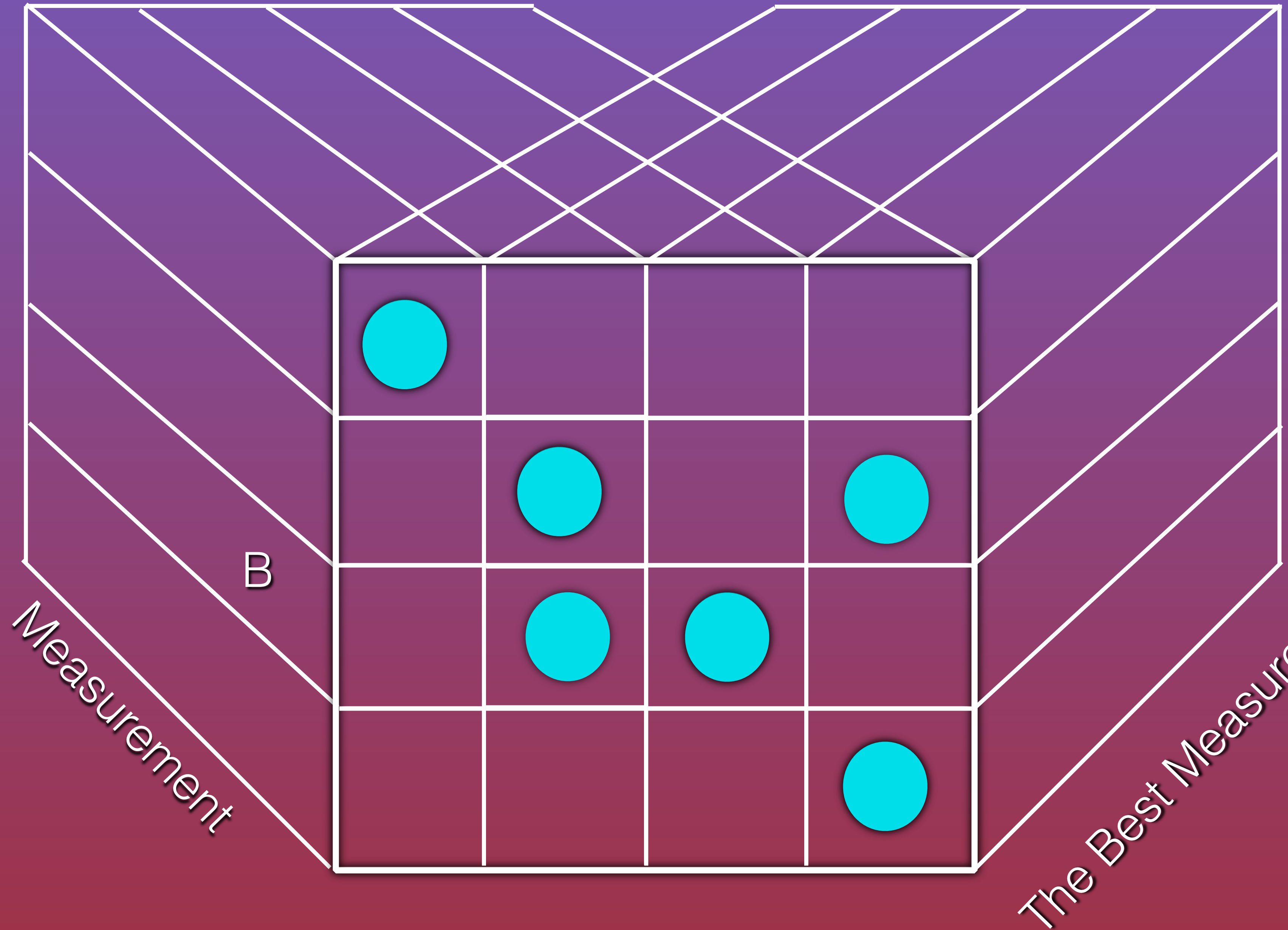
Orthogonal States

What about states like:

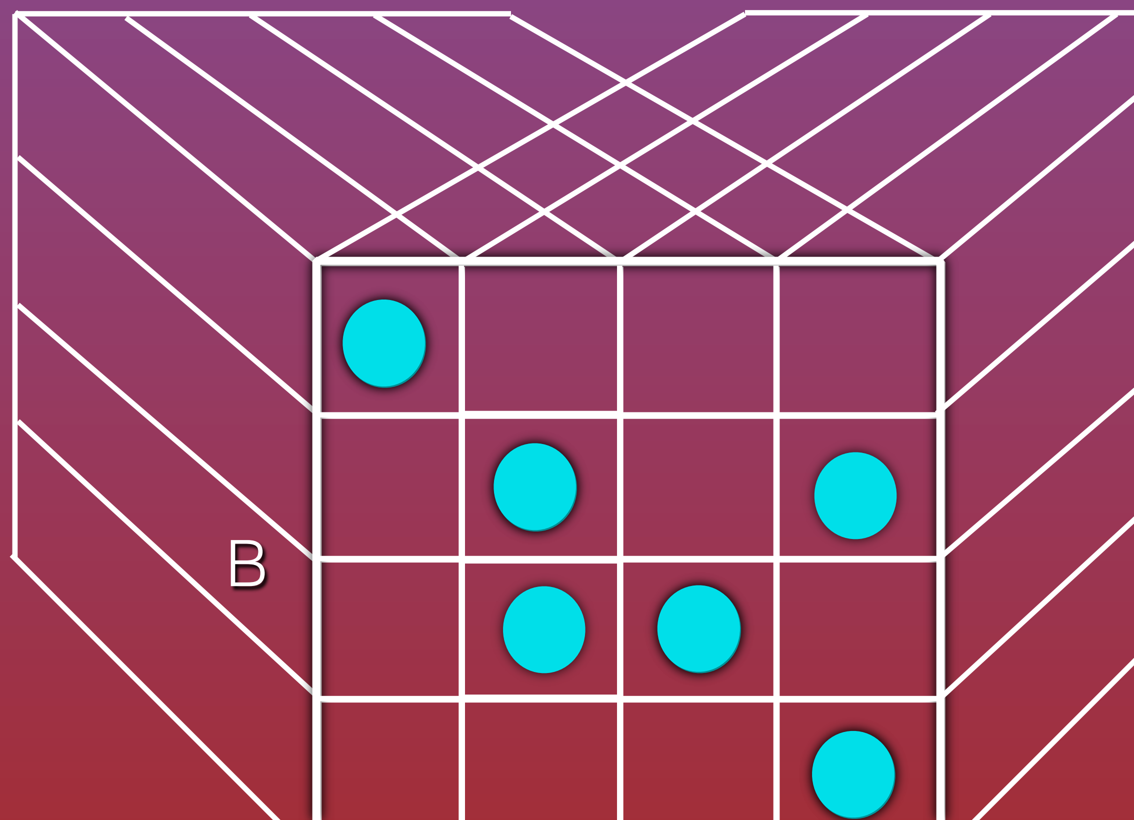
$$\rho = \sum_{\alpha,\beta} P_{\alpha,\beta} \left|\phi_\alpha\right\rangle\left\langle\phi_\alpha\right| \otimes \left|\psi_\beta\right\rangle\left\langle\psi_\beta\right|$$

Non-Orthogonal States

P_{AB}



$$TC(A:B) := H(A) + H(B) - H(A,B)$$

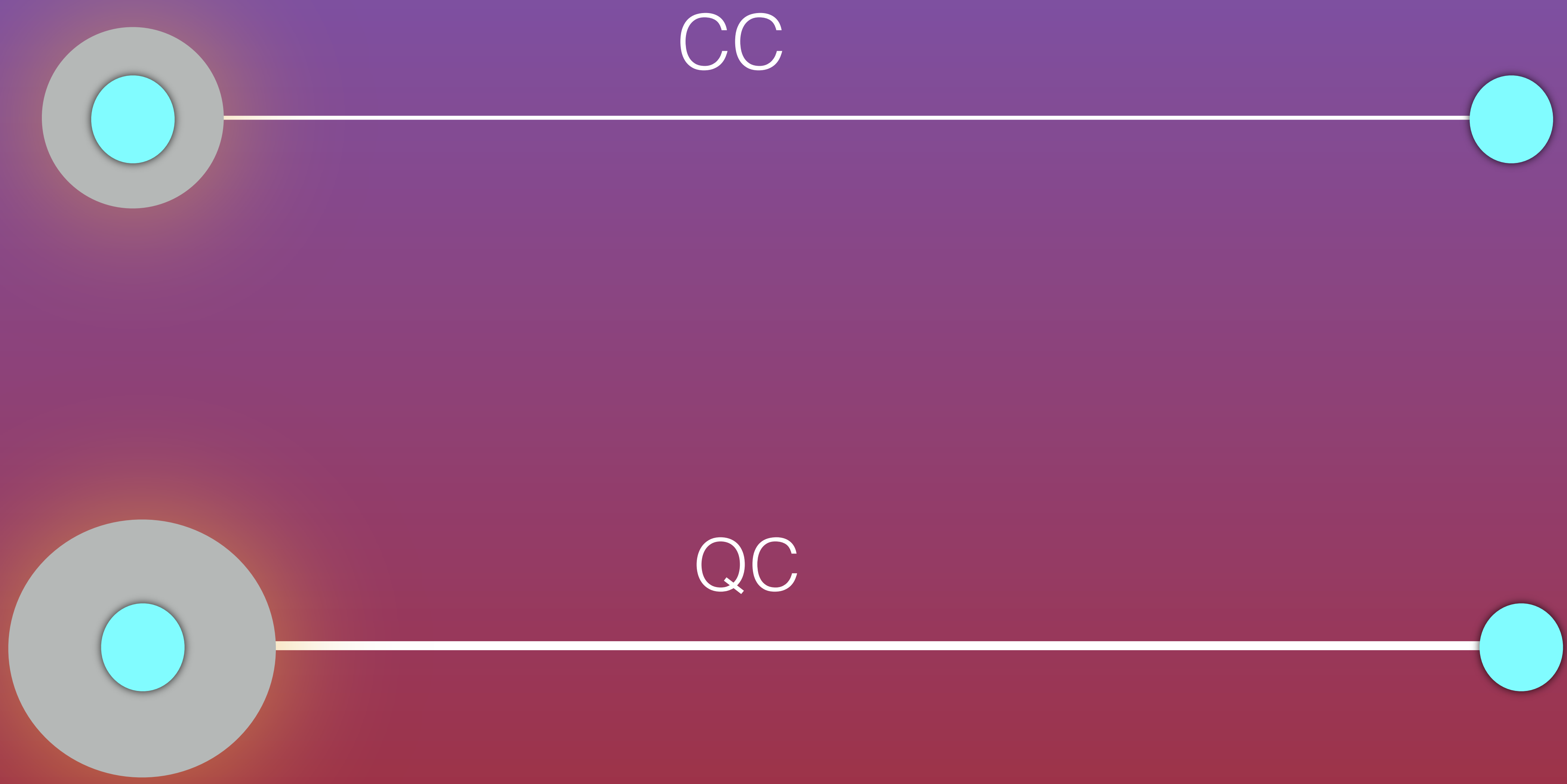


er and Zurek, PRL (2001)

al and Henderson, JPA (2001)

sically Correlated States

$$QC(\rho) = \min_{\sigma \in cc} d(\rho, \sigma)$$


CC
QC

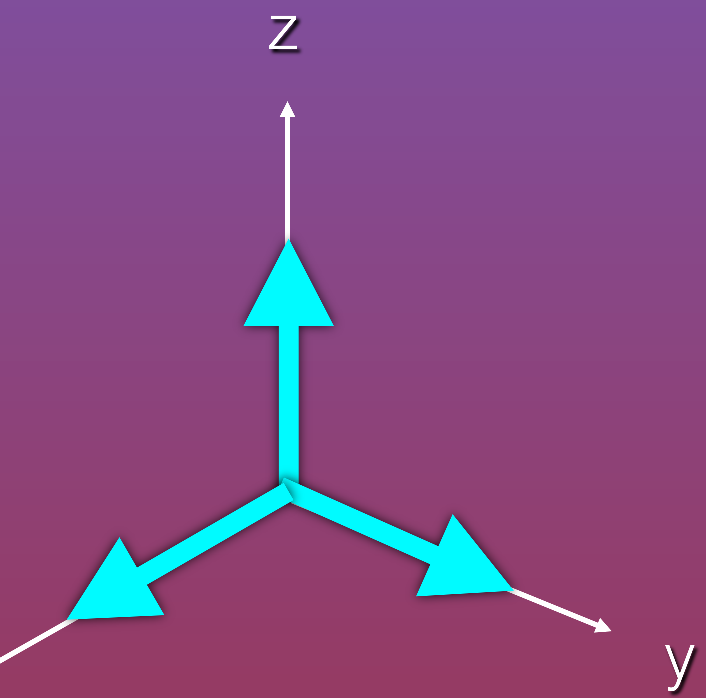
Werner States

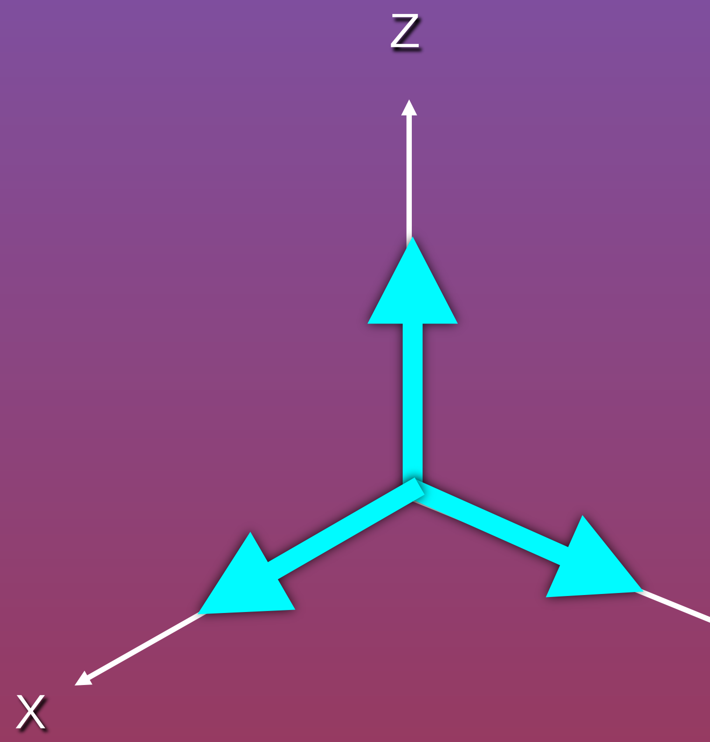
$$W(t) = \frac{1-t}{4} I + t|\psi\rangle\langle\psi|$$

$-\frac{1}{3}$ $\frac{1}{3}$

$W^{\uparrow\uparrow}$ $W^{\uparrow\downarrow}$

$$W^{\uparrow\uparrow} = \frac{1}{3}(XX + YY + ZZ)$$

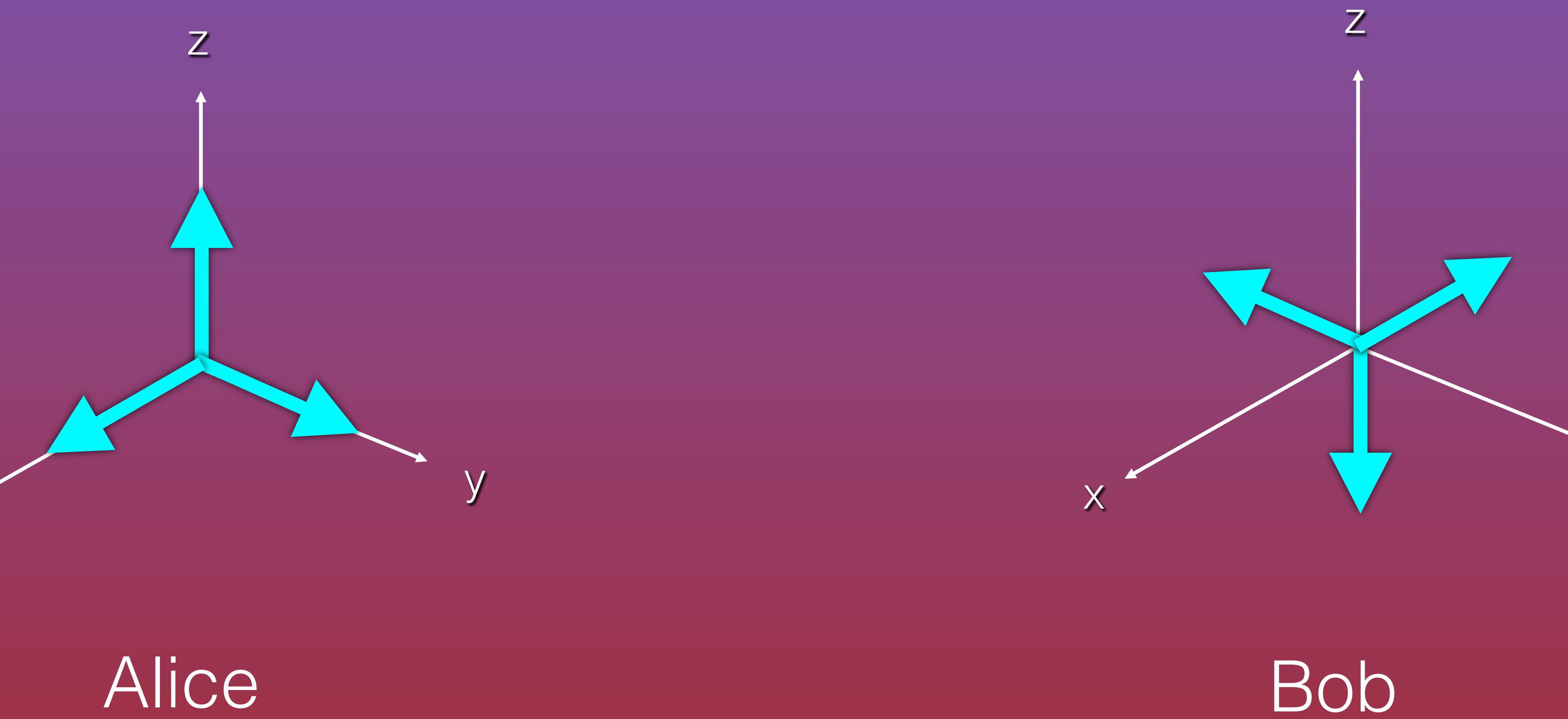




Alice

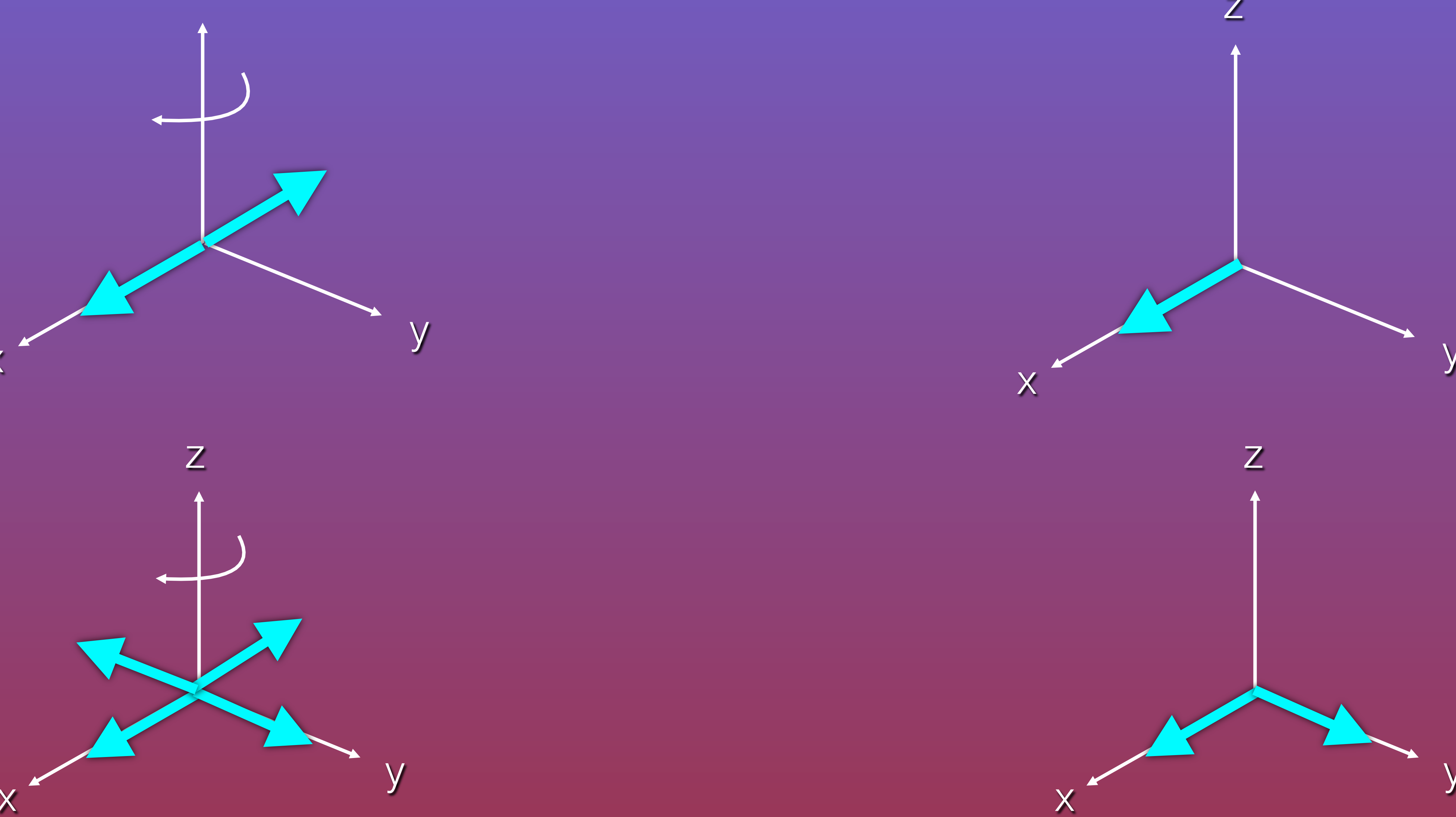
Bob

$$W^{\uparrow\downarrow} = \frac{1}{3}(X\bar{X} + Y\bar{Y} + Z\bar{Z})$$



The Parallel Mixture is more correlated than the anti-parallel mixture!

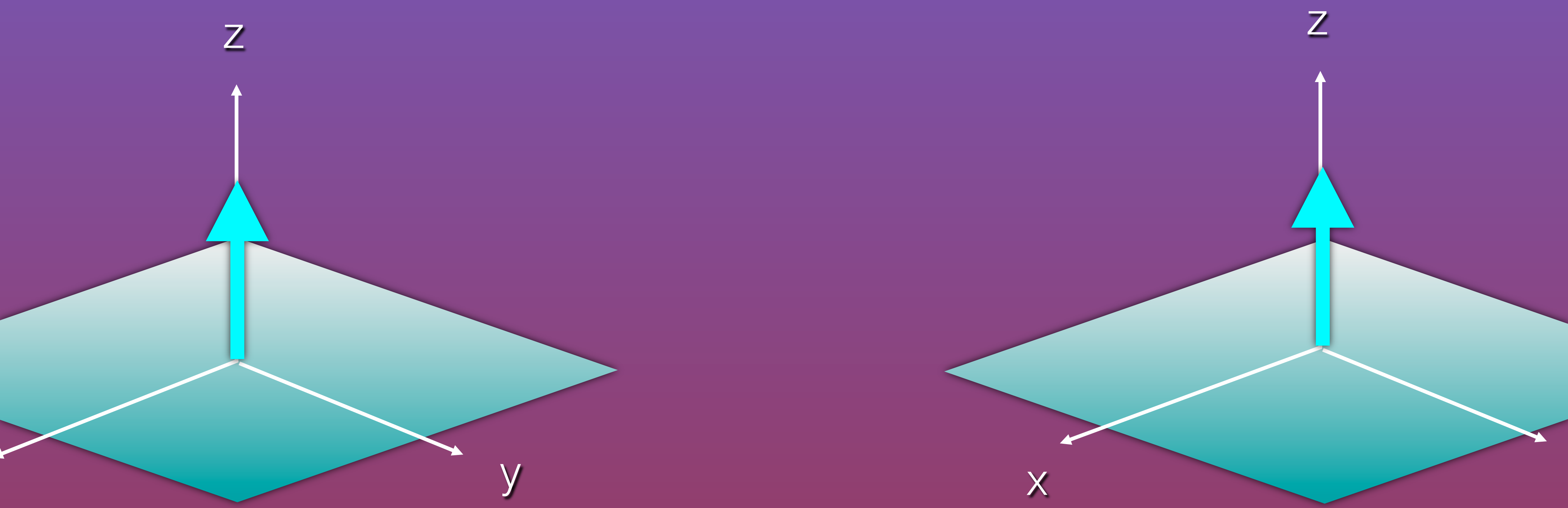
Only when all three directions are present!



There is no Universal NOT operation which can do:

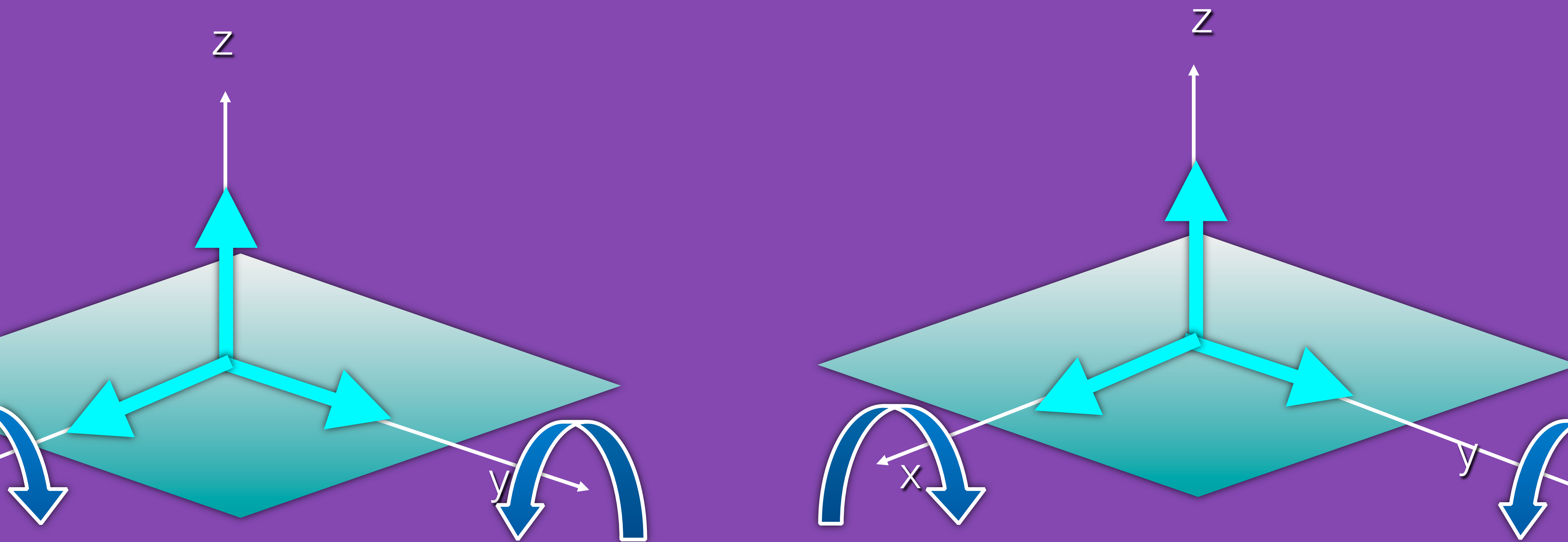
$$|\psi\rangle \rightarrow |\psi^{\perp}\rangle$$

But why the parallel Mixture is more correlated?



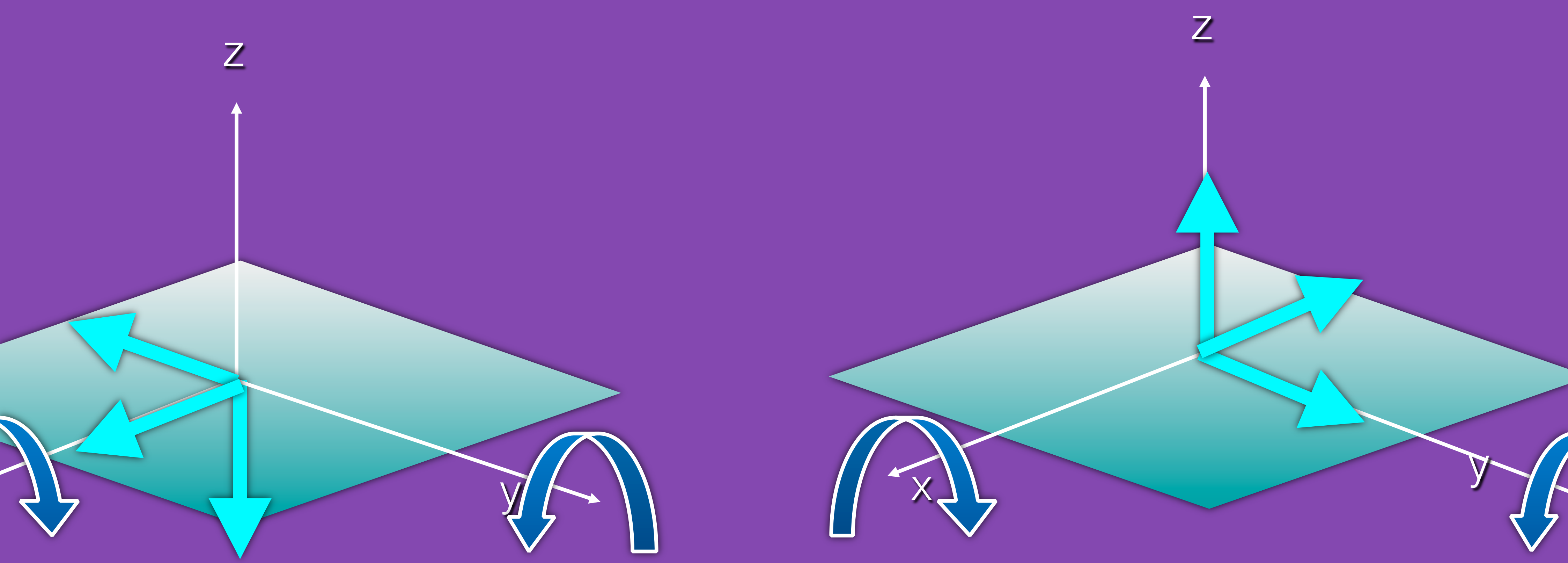
We do not know!

But why we should we be surprised?



$$ZZ \rightarrow \frac{1}{3}\left(XX + YY + ZZ \right)$$

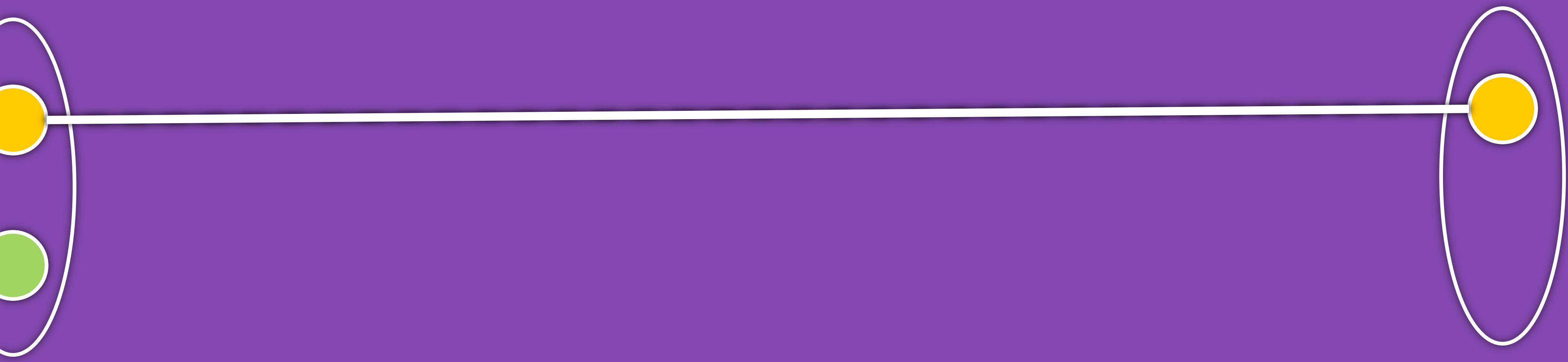
Because we do the same quantum operations on states which have equal classical correlations!



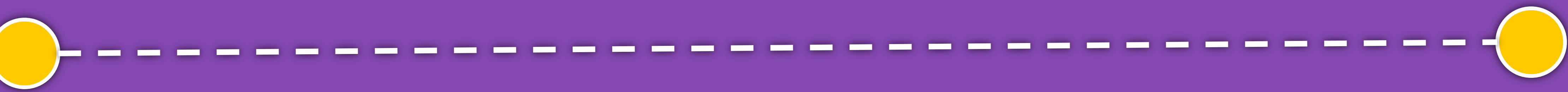
$$Z\bar{Z} \to \frac{1}{2}\left(X\bar{X} + Y\bar{Y} + Z\bar{Z} \right)$$

3 More observations in favor of the parallel mixture.

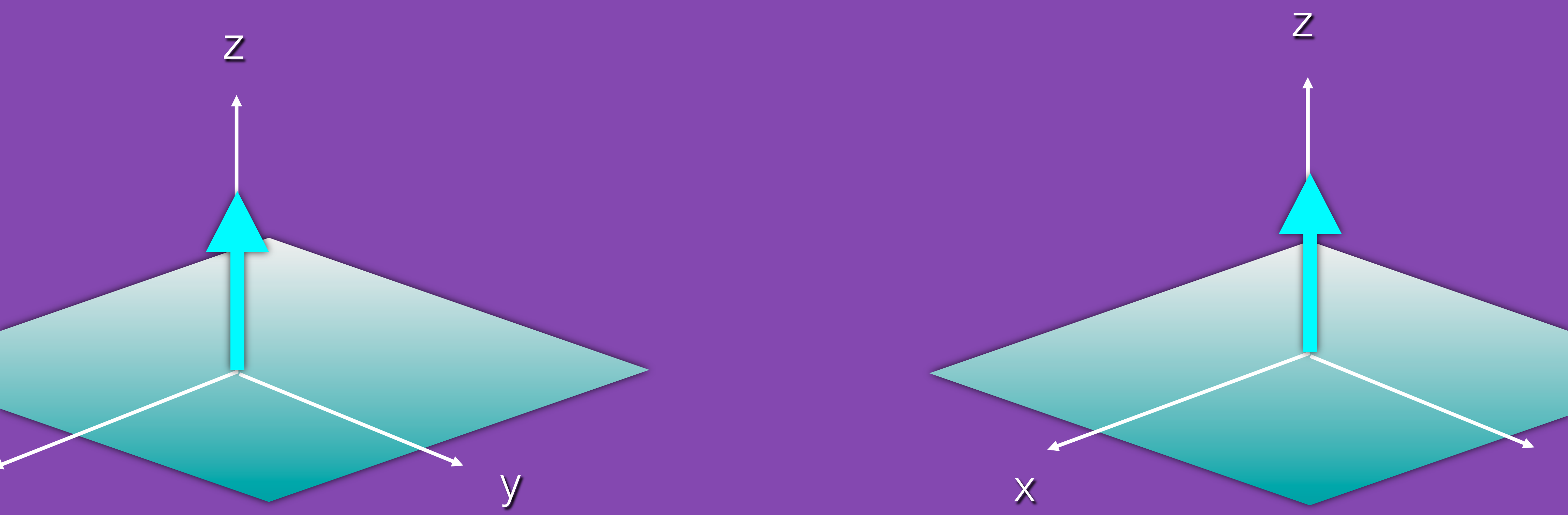
1- Parallel Spins are more useful for QI tasks.



2- Parallel Spins are more fragile against noise.



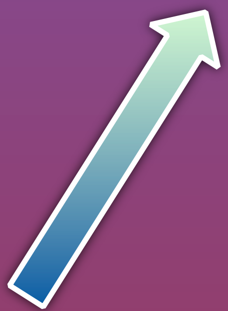
3- It is harder to prepare the parallel mixture?



How to communicate a direction?

n_g

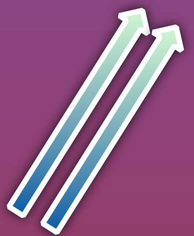
$$F = \frac{1 + n_g g n}{2}$$



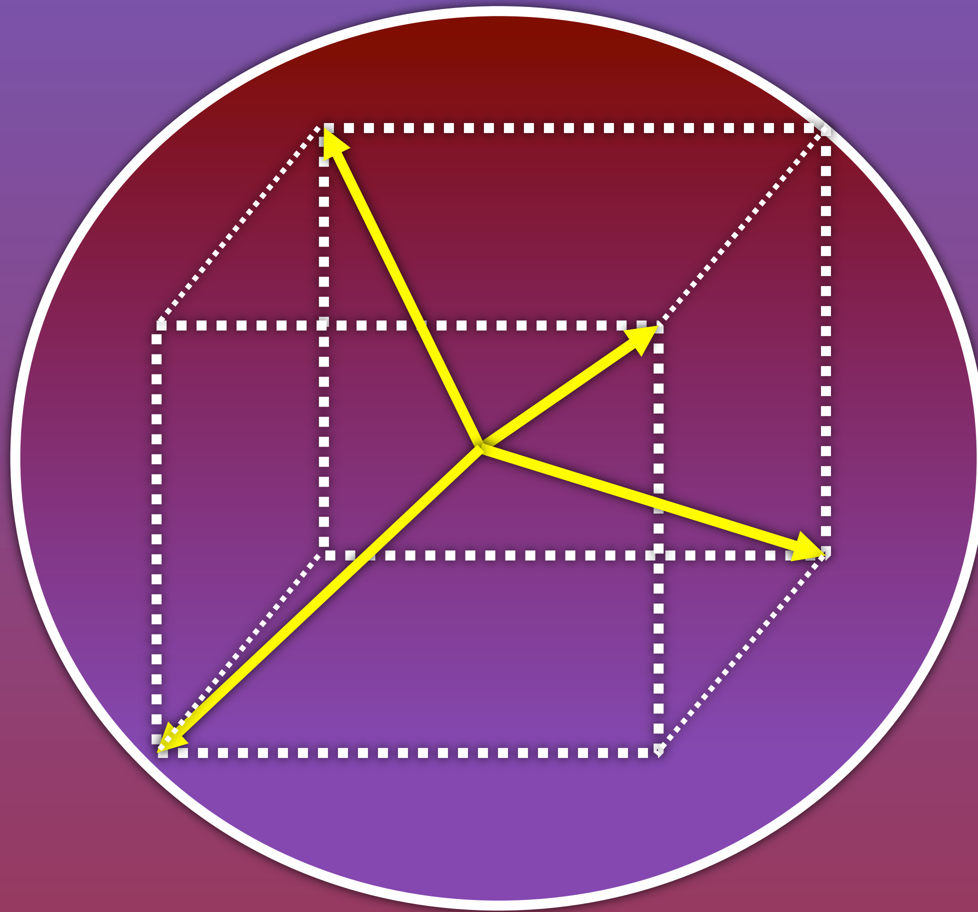
n

$$\bar{F} = \int dn P(n_g \mid n) \frac{1 + n_g . n}{2}$$

Using parallel Spins?

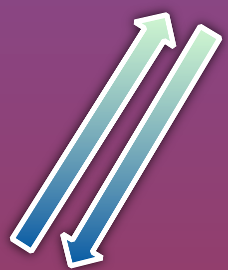


n

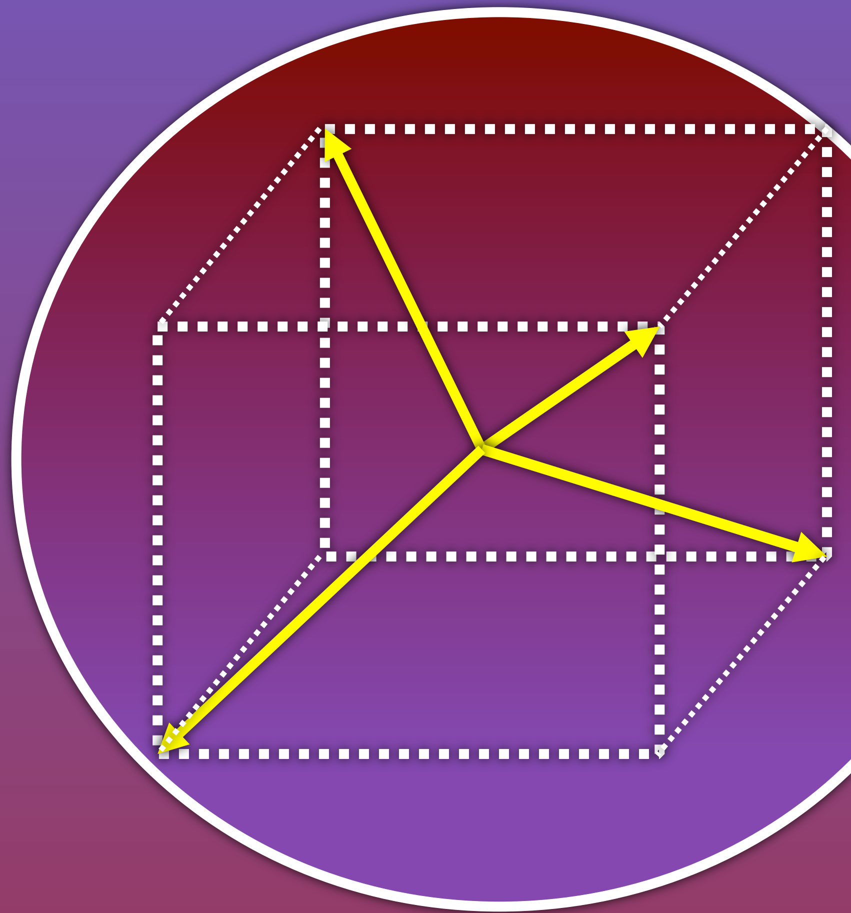


$$|\phi_j\rangle = \frac{\sqrt{3}}{2}|n_j, n_j\rangle + \frac{1}{2}|\psi_-\rangle$$

Using anti-parallel Spins?



n



tellite, use anti-parallel spins.

ks, use parallel spins.

Your bill for classical and quantum correlations is no
et balanced.

- We do not yet understand the measure of quantum
orrelation.

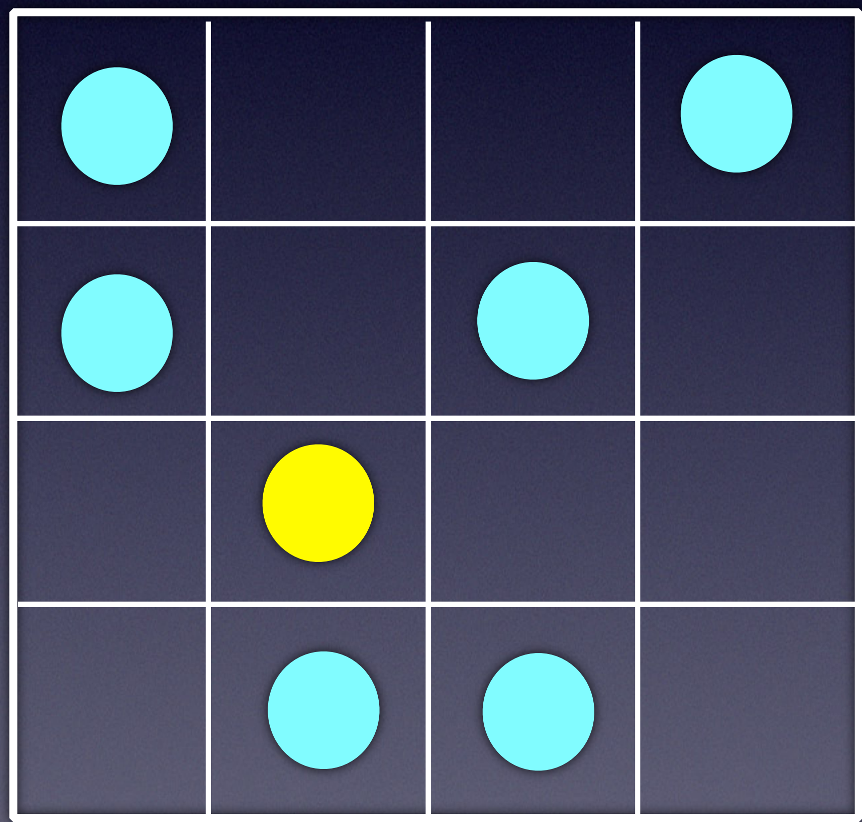
For a while, to a master we have gone

For a while, in our mastery we have flown

In the end, listen to what became of us

From dust we came, with wind have gone

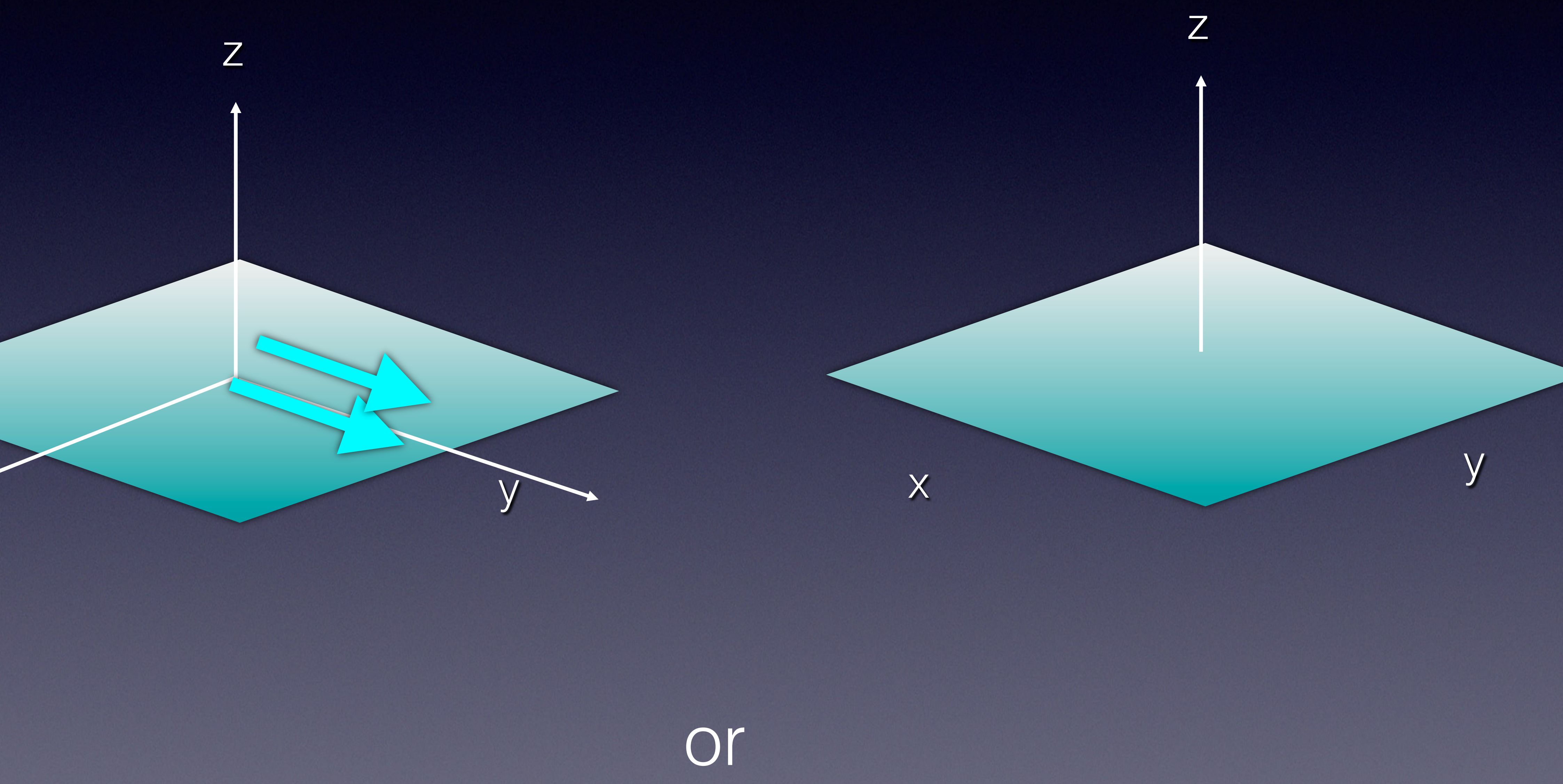
(X) = The average number of yes and no questions to reach the ball



$$(\Delta K)_{\rho} = -\frac{1}{2}\, tr\left([\sqrt{\rho}, K]^{2}\right)$$

$$QC(\rho) = \min_{K} \left(\Delta K_{\rho}\right)$$

How to communicate a direction?



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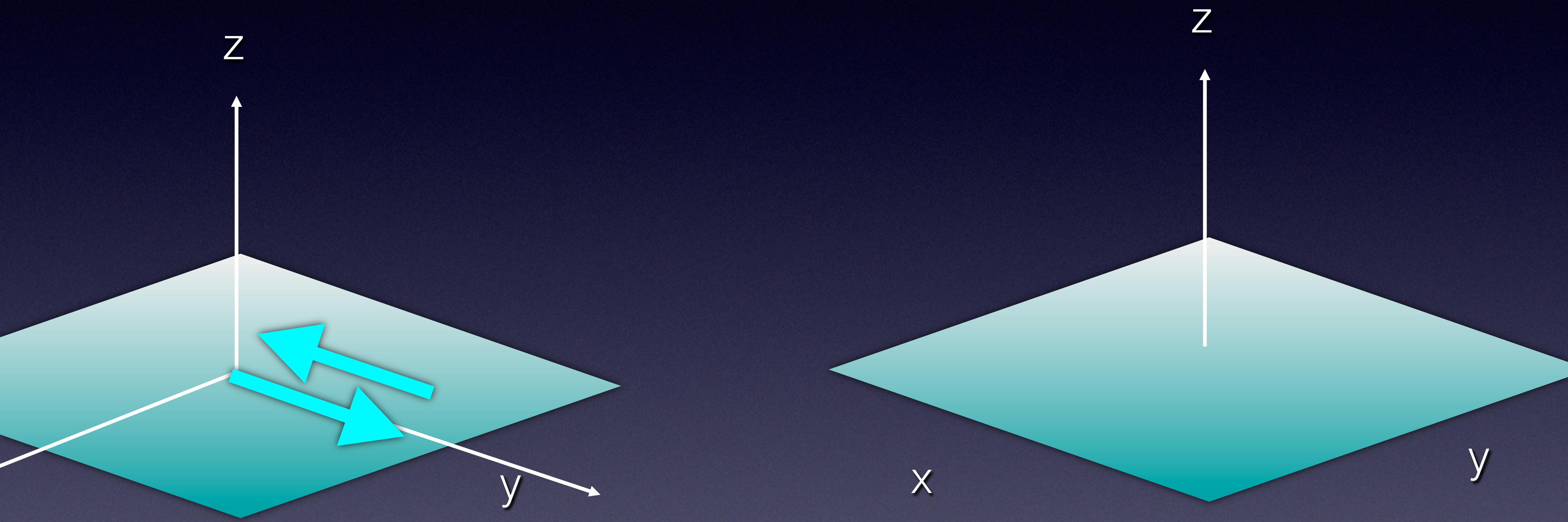

$$F = \int dn P(n_g \mid n) \frac{1 + n_g . n}{2}$$

How you agree on a direction?