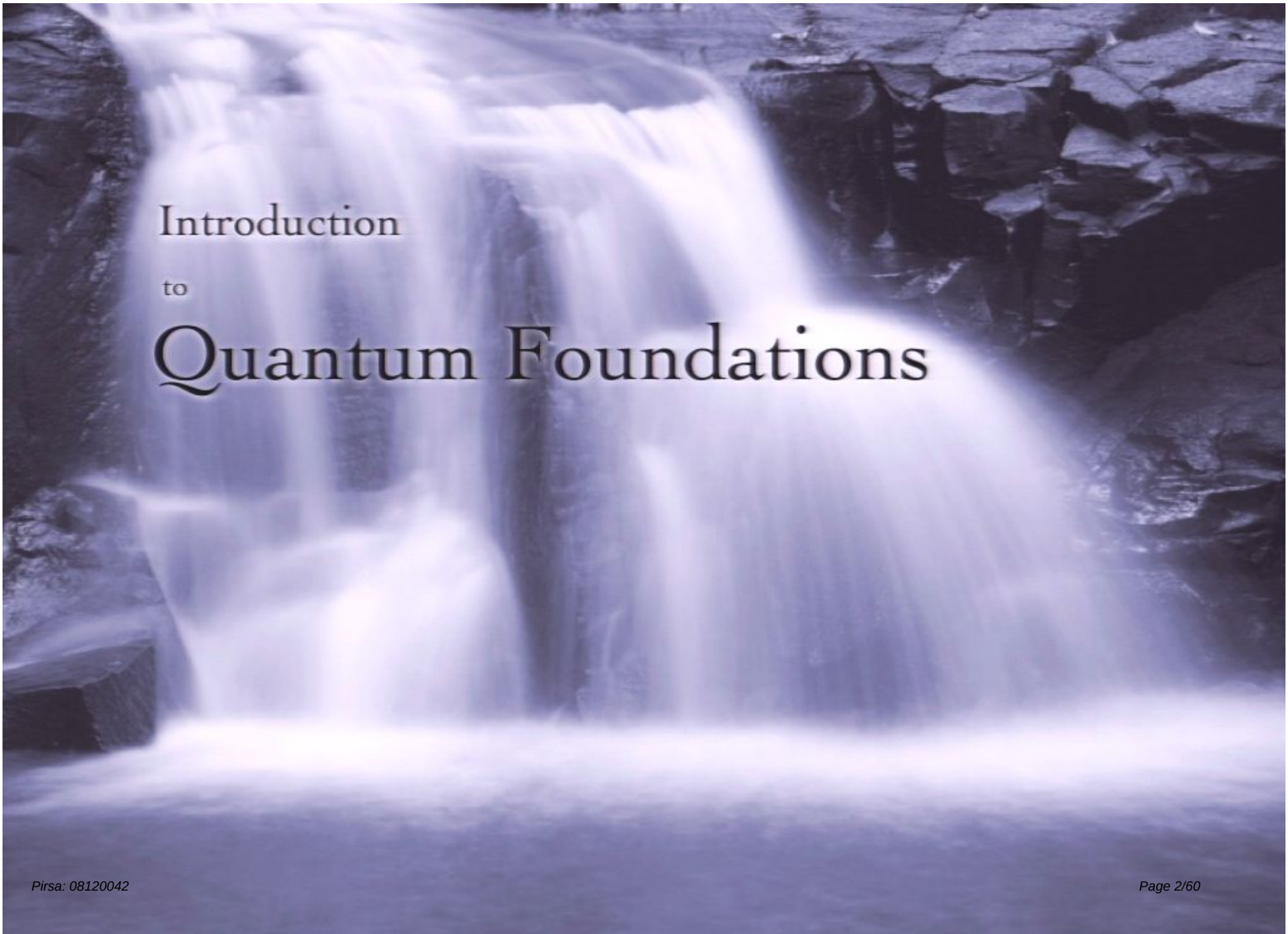
Title: Introduction to Quantum Foundations

Date: Dec 10, 2008 03:20 PM

URL: http://pirsa.org/08120042

Abstract:


Introduction
to
Quantum Foundations

Newtonian Mechanics

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Classical Mathematical Framework

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Mechanical Conception of Reality

Newtonian Mechanics

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Classical Mathematical Framework

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Mechanical Conception of Reality

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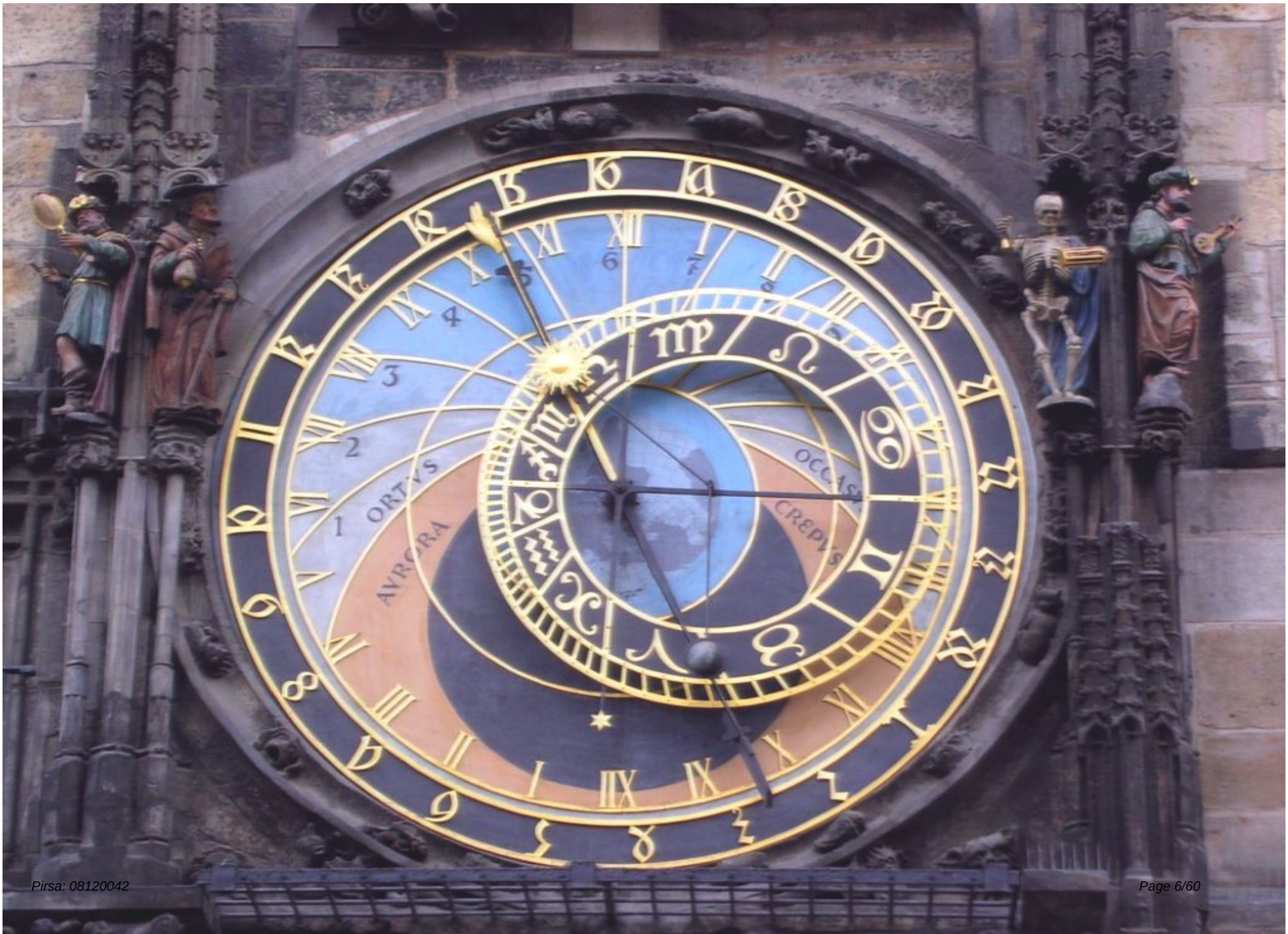
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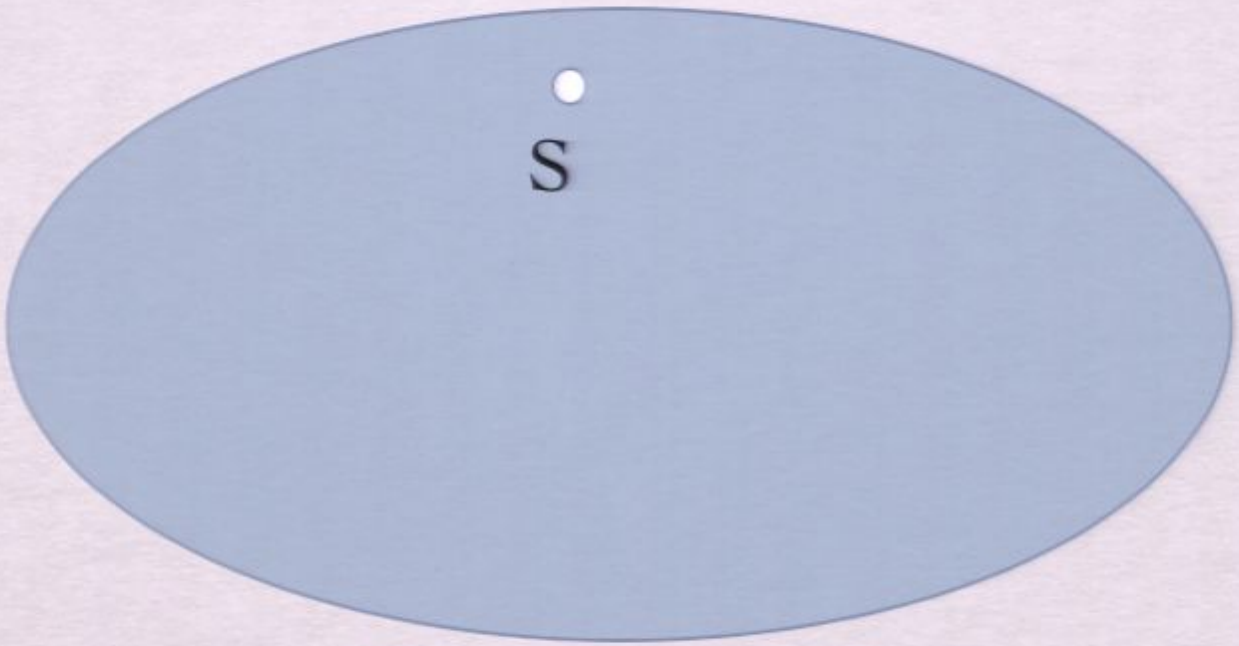
AVRORA
CREPVS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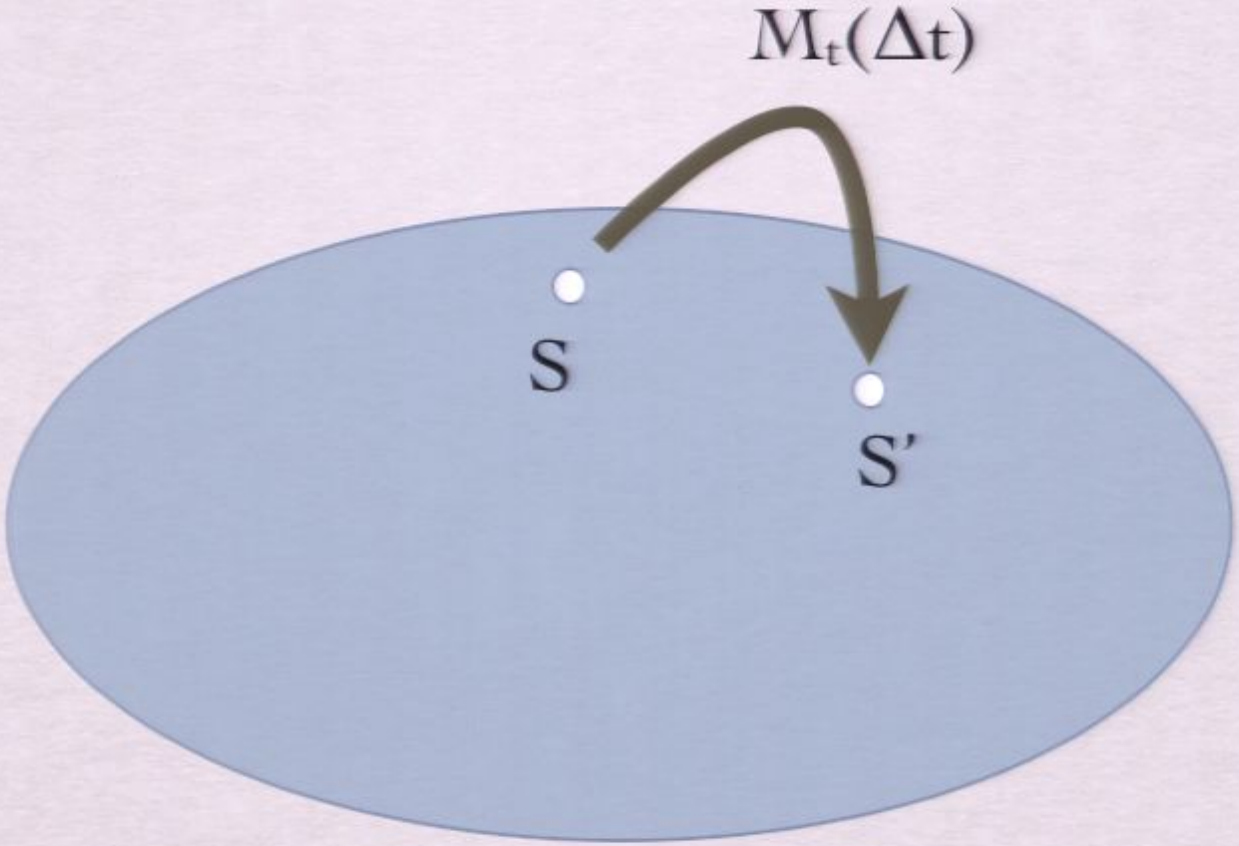
$M_t(\Delta t)$
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S'

Schroedinger's Mechanics

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Quantum Mathematical Framework

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Schroedinger's Mechanics

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Quantum Mathematical Framework

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Unknown Conception of Reality

Schroedinger's Mechanics

Statistical Interpretation

Complementarity

Wave lives in configuration space

Presupposition of Classical World

Complex Numbers & Born Rule

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Complex Numbers & Born Rule

State of a system: $\mathsf{v} \in \mathbb{C}^N$

Dynamics: $\mathsf{U}_t(dt) = \exp(i\mathsf{H}\, dt/\hbar)$

Measurements: $\mathsf{A}\mathsf{v}_i = a_i \mathsf{v}_i$

Composite Systems: $\mathsf{v} = \mathsf{v}^{(1)} \otimes \mathsf{v}^{(2)}$

Classical Framework

Classical Framework

Quantum Framework

Classical Framework	Quantum Framework

Classical Framework	*Quantum Framework*
Universality	"System", "Environment", "Measurement" Cuts
Deterministic outcomes	Probabilistic outcomes
Continuum of possible outcomes	Discrete number of outcomes

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State Transparency	Complementarity

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	Classical Framework	*Quantum Framework*
States	Set of Real Numbers	Set of Complex Numbers
Dynamics	One-to-one map	Unitary transformations

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Entanglement

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left[|\uparrow_1\downarrow_2\rangle - \downarrow_1\uparrow_2\rangle\right]$$

Entanglement

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left[|\uparrow_1\downarrow_2\rangle - \downarrow_1\uparrow_2\rangle\right]$$

$$\neq \left[a\,|\uparrow_1\rangle + b\,|\downarrow_1\rangle\right] \otimes \left[c\,|\uparrow_2\rangle + d\,|\downarrow_2\rangle\right]$$

Steering

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left[|+_\theta -_\theta\rangle - |-_\theta +_\theta\rangle\right]$$

Steering

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left[|+_\theta -_\theta\rangle - |-_\theta +_\theta\rangle\right]$$

Alice gets +

$$|\psi\rangle = |+_\theta -_\theta\rangle$$

No-Signaling

$|\psi\rangle$

No-Signaling

Bob's state: $|-\theta\rangle$

Alice gets +

$|\psi\rangle$

No-Signaling

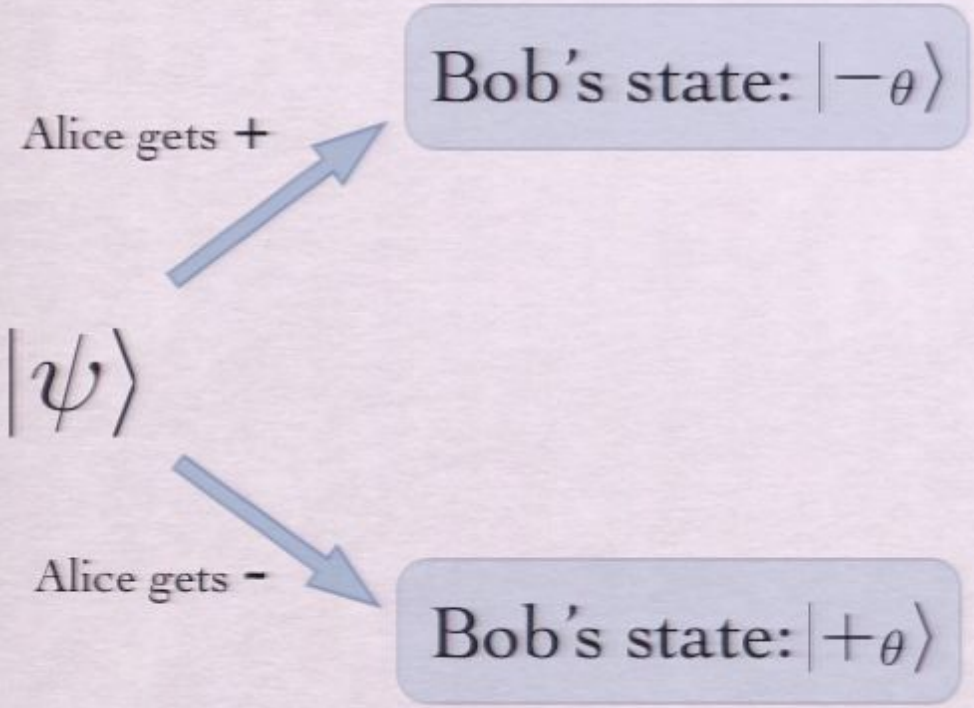
Bob's state: $|-_\theta\rangle$

Alice gets $+$

$|\psi\rangle$

Alice gets $-$

No-Signaling



No-Signaling

Alice gets +

Bob's state: $|-_\theta\rangle$

$$\Pr(\uparrow|+) = \sin^2(\theta/2)$$

$$\Pr(\downarrow|+) = \cos^2(\theta/2)$$

$|\psi\rangle$

Alice gets -

Bob's state: $|+_\theta\rangle$

No-Signaling

$|\psi\rangle$

Alice gets +

Bob's state: $|-_\theta\rangle$

$$\Pr(\uparrow|+) = \sin^2(\theta/2)$$

$$\Pr(\downarrow|+) = \cos^2(\theta/2)$$

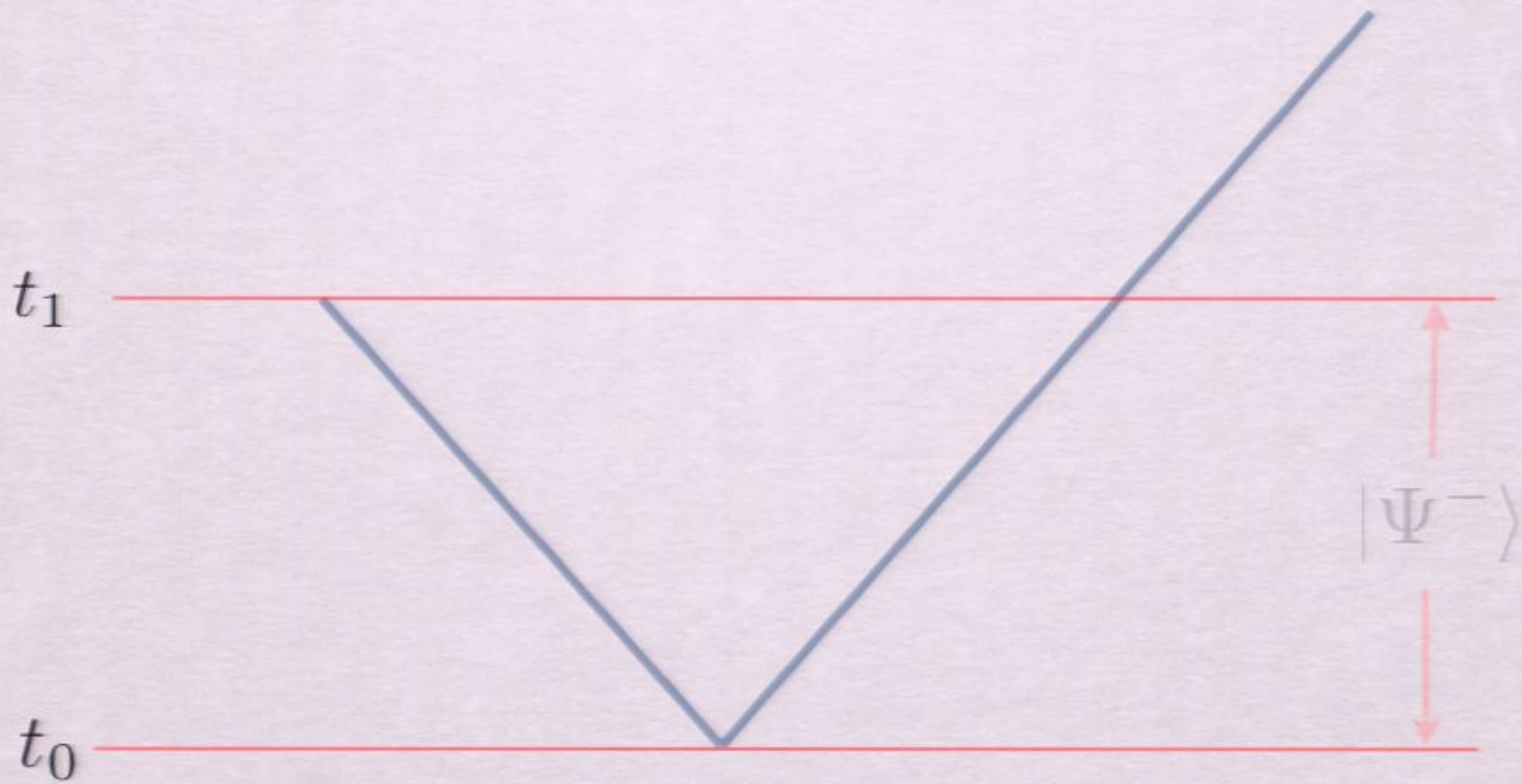
Alice gets -

Bob's state: $|+_\theta\rangle$

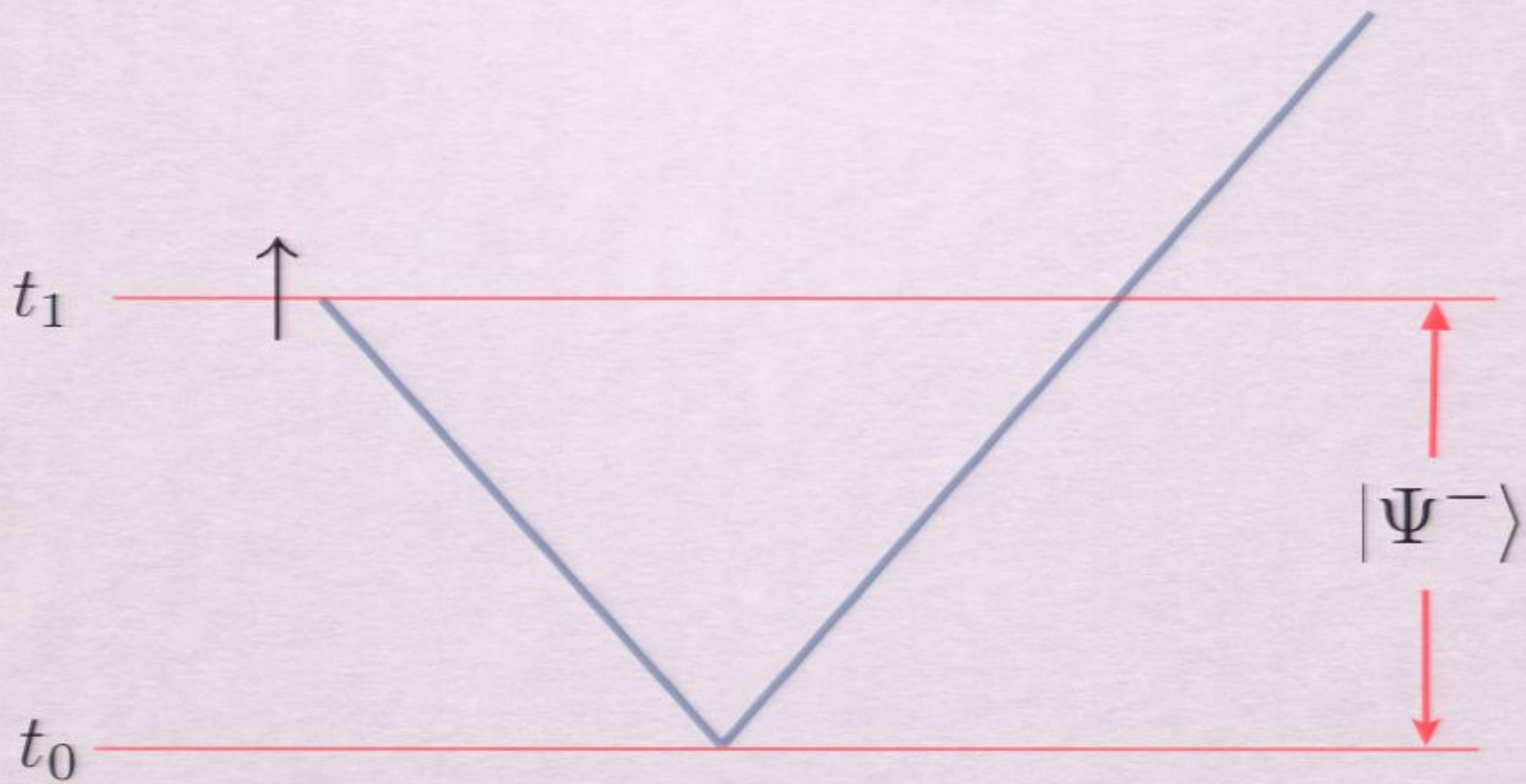
$$\Pr(\uparrow|-) = \cos^2(\theta/2)$$

$$\Pr(\downarrow|-) = \sin^2(\theta/2)$$

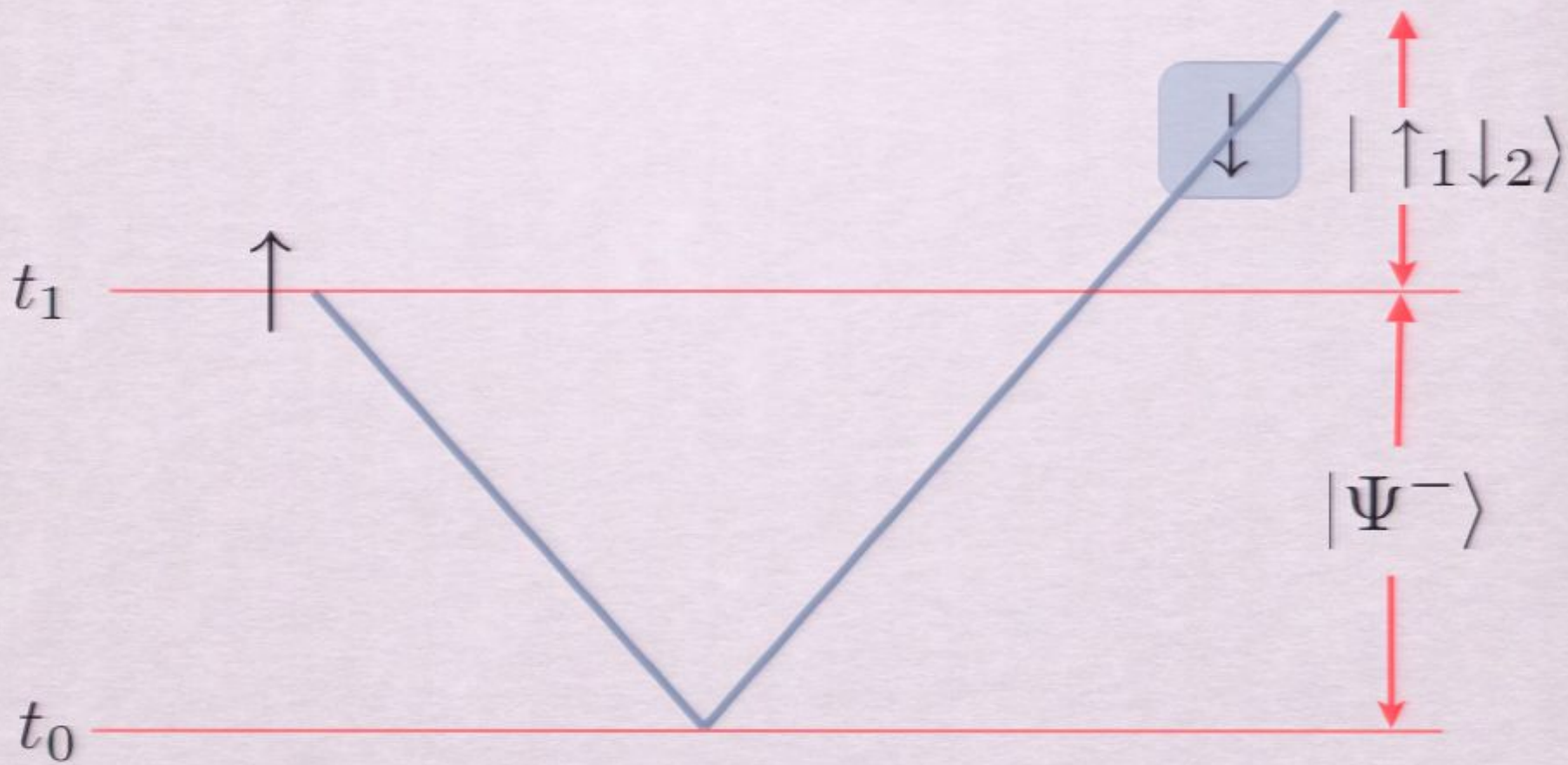
EPR Argument



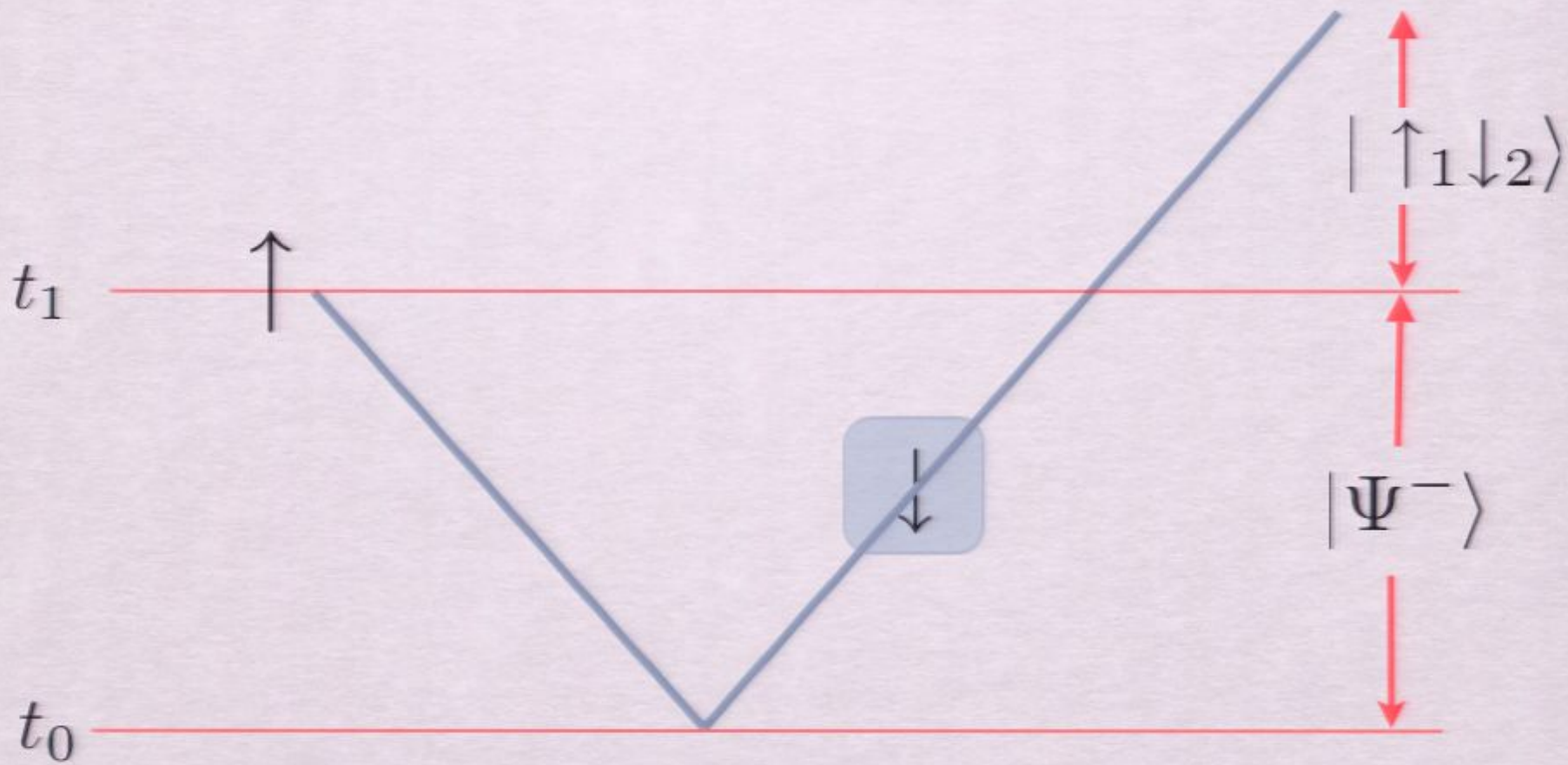
EPR Argument



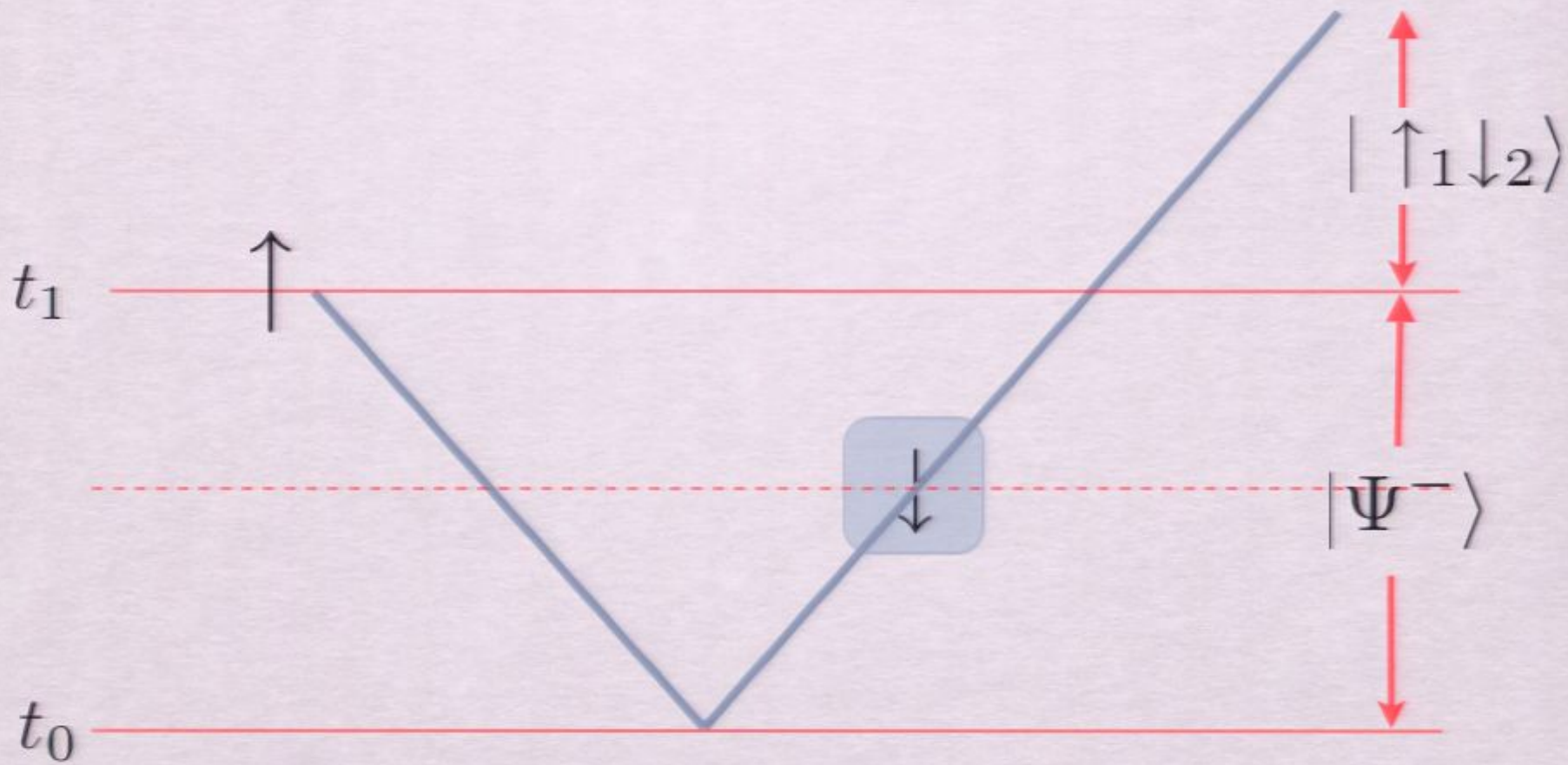
EPR Argument



EPR Argument



EPR Argument

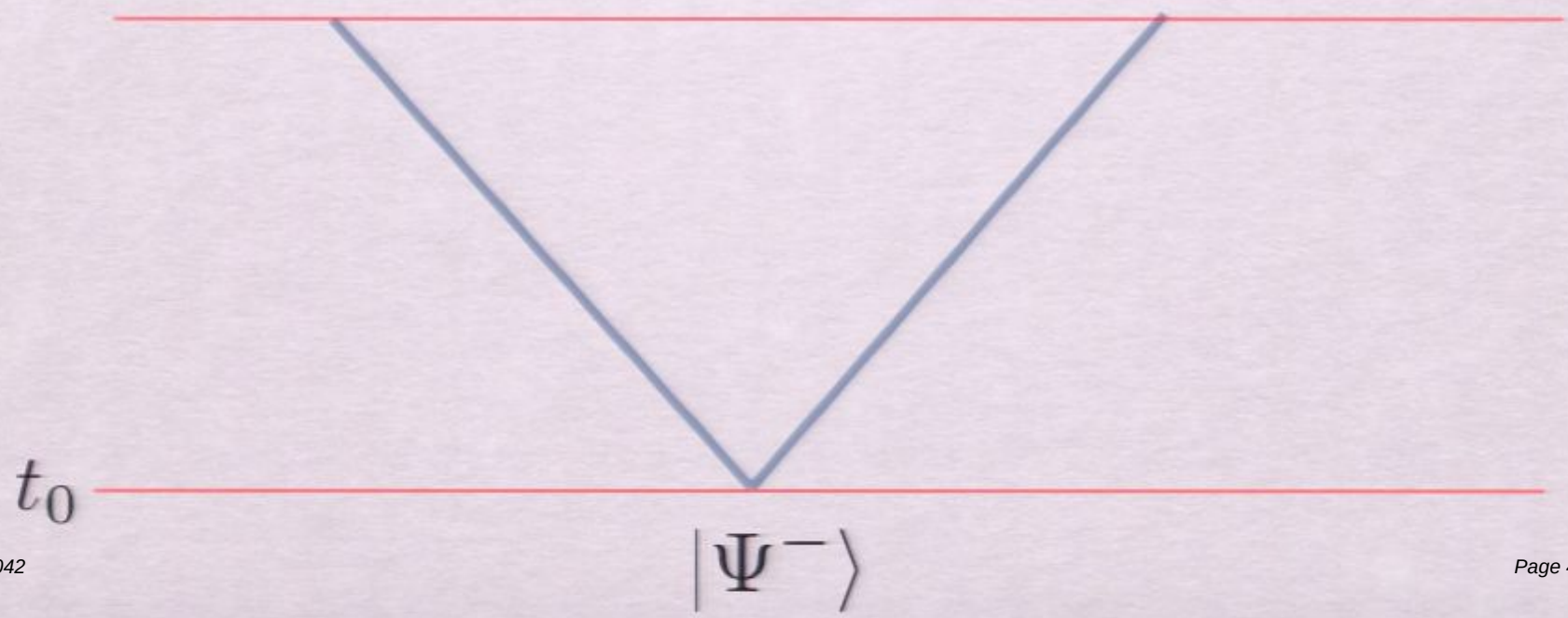


Bell's Theorem

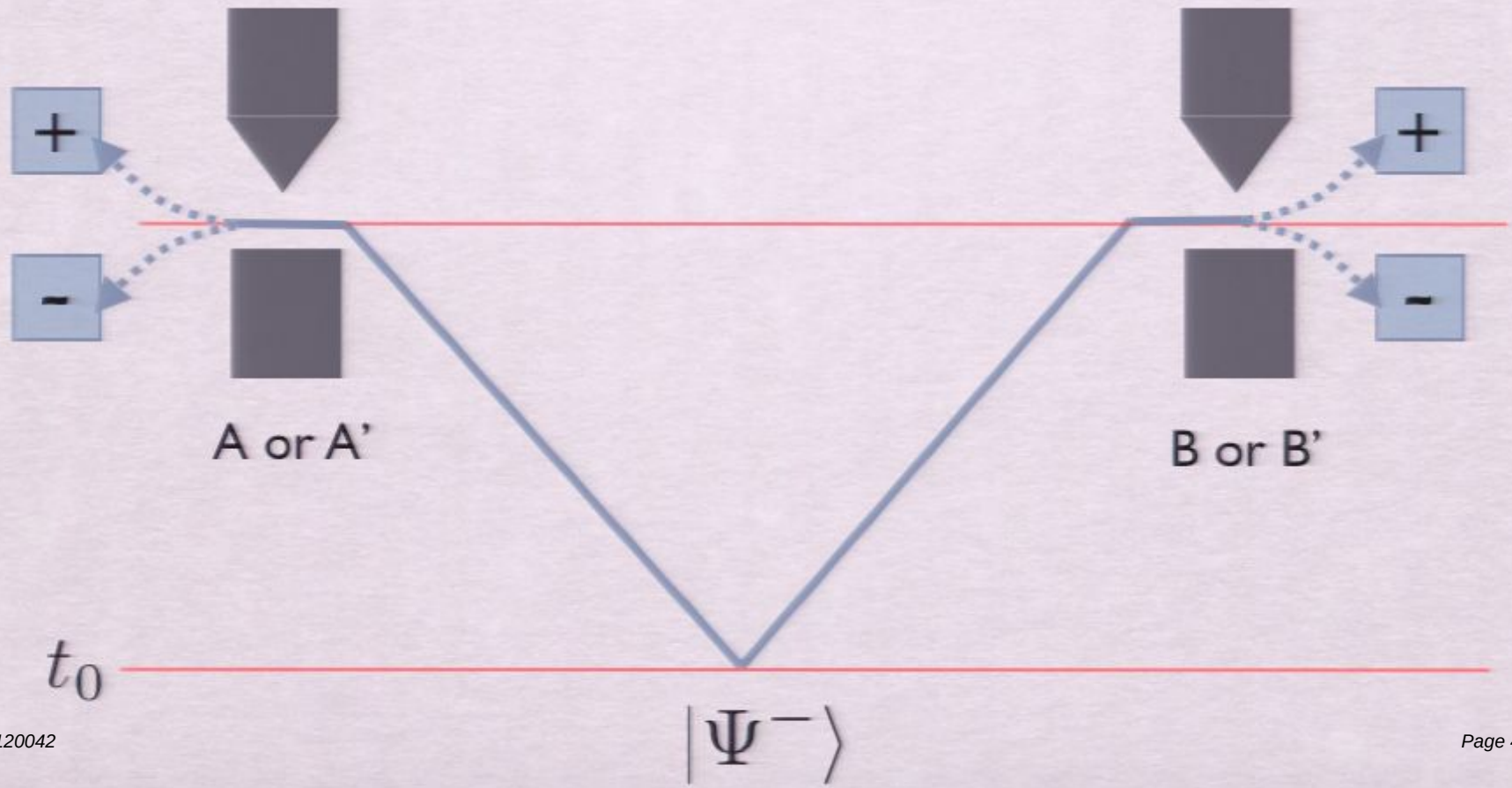
t_0

$|\Psi^-\rangle$

Bell's Theorem



Bell's Theorem



Expt.#	1	2	3	4	5	6	7	8	9	10	11	12	13
Alice's M'ment	A	A'	A	A	A'	A	A'	A	A	A	A'	A'	A'
Alice's Result	+	+	-	+	+	-	+	-	+	-	+	+	+
Alice's M'ment	B	B	B'	B	B'	B	B'	B	B'	B'	B'	B	B
Alice's Result	+	-	+	+	-	+	+	-	+	+	-	+	-

Expt.#	1	2	3	4	5	6	7	8	9	10	11	12	13
Alice's M'ment	A	A'	A	A	A'	A	A'	A	A	A	A'	A'	A'
Alice's Result	+	+	-	+	+	-	+	-	+	-	+	+	+
Alice's M'ment	B	B	B'	B	B'	B	B'	B	B'	B'	B'	B	B
Alice's Result	+	-	+	+	-	+	+	-	+	+	-	+	-

$$\mathbf{E}(ab|A,B)$$

Expt.#	1	2	3	4	5	6	7	8	9	10	11	12	13
Alice's M'ment	A	A'	A	A	A'	A	A'	A	A	A	A'	A'	A'
Alice's Result	+	+	-	+	+	-	+	-	+	-	+	+	+
Alice's M'ment	B	B	B'	B	B'	B	B'	B	B'	B'	B'	B	B
Alice's Result	+	-	+	+	-	+	+	-	+	+	-	+	-

$\mathbf{E}(ab|A,B)$ $\mathbf{E}(ab|A,B')$

Expt.#	1	2	3	4	5	6	7	8	9	10	11	12	13
Alice's M'ment	A	A'	A	A	A'	A	A'	A	A	A	A'	A'	A'
Alice's Result	+	+	-	+	+	-	+	-	+	-	+	+	+
Alice's M'ment	B	B	B'	B	B'	B	B'	B	B'	B'	B'	B	B
Alice's Result	+	-	+	+	-	+	+	-	+	+	-	+	-

$\mathbf{E}(ab|A,B) \qquad \mathbf{E}(ab|A,B')$

Expt.#	1	2	3	4	5	6	7	8	9	10	11	12	13
Alice's M'ment	A	A'	A	A	A'	A	A'	A	A	A	A'	A'	A'
Alice's Result	+	+	-	+	+	-	+	-	+	-	+	+	+
Alice's M'ment	B	B	B'	B	B'	B	B'	B	B'	B'	B'	B	B
Alice's Result	+	-	+	+	-	+	+	-	+	+	-	+	-

$\mathbf{E}(ab|A,B)$ $\mathbf{E}(ab|A,B')$ $\mathbf{E}(ab|A',B)$

Expt.#	1	2	3	4	5	6	7	8	9	10	11	12	13
Alice's M'ment	A	A'	A	A	A'	A	A'	A	A	A	A'	A'	A'
Alice's Result	+	+	-	+	+	-	+	-	+	-	+	+	+
Alice's M'ment	B	B	B'	B	B'	B	B'	B	B'	B'	B'	B	B
Alice's Result	+	-	+	+	-	+	+	-	+	+	-	+	-

$$\mathbf{E}(ab|A,B) \qquad \mathbf{E}(ab|A,B') \qquad \mathbf{E}(ab|A',B)$$

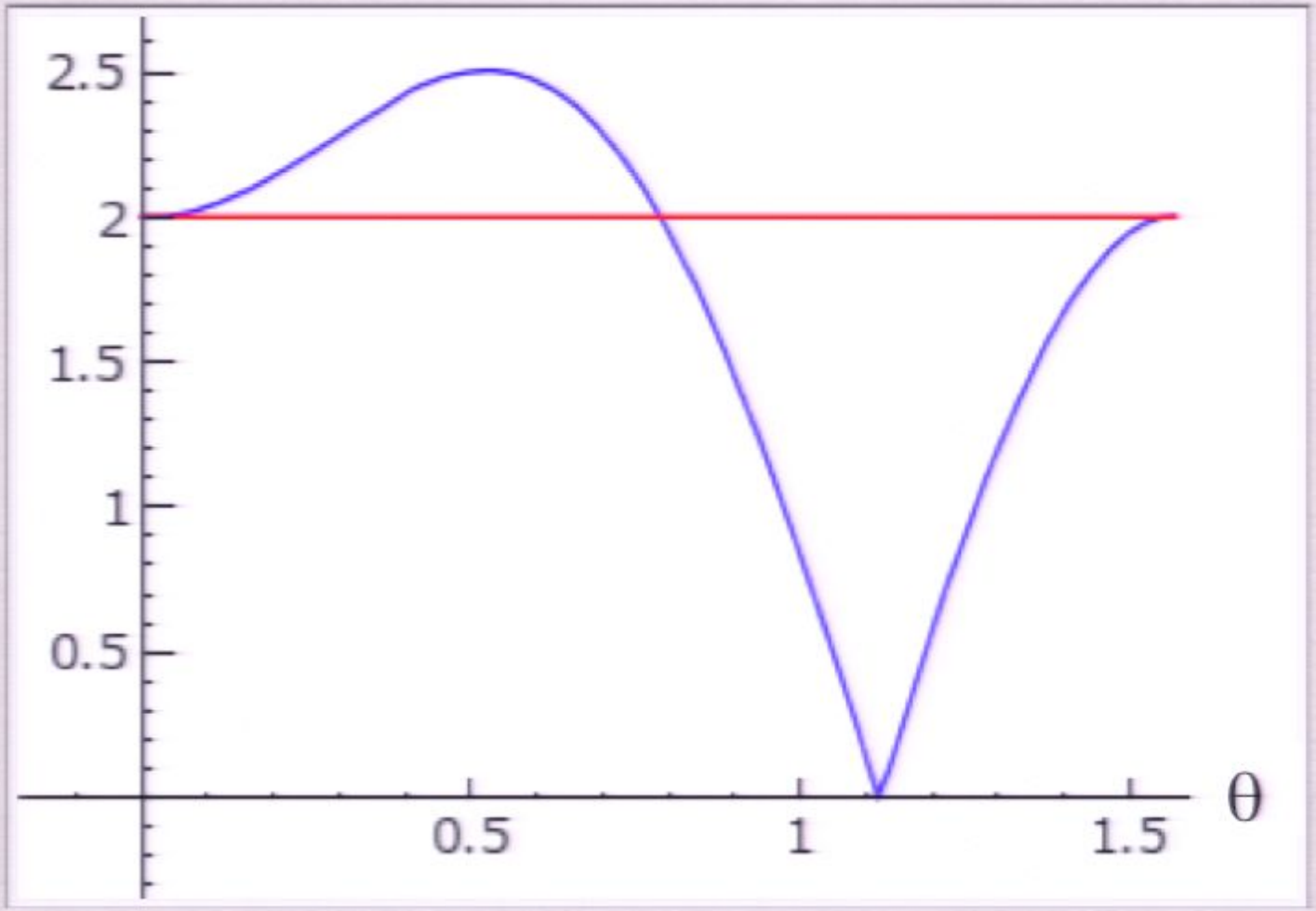
Expt.#	1	2	3	4	5	6	7	8	9	10	11	12	13
Alice's M'ment	A	A'	A	A	A'	A	A'	A	A	A	A'	A'	A'
Alice's Result	+	+	-	+	+	-	+	-	+	-	+	+	+
Alice's M'ment	B	B	B'	B	B'	B	B'	B	B'	B'	B'	B	B
Alice's Result	+	-	+	+	-	+	+	-	+	+	-	+	-

$\mathbf{E}(ab|A,B)$ $\mathbf{E}(ab|A,B')$ $\mathbf{E}(ab|A',B)$ $\mathbf{E}(ab|A',B')$

Expt.#	1	2	3	4	5	6	7	8	9	10	11	12	13
Alice's M'ment	A	A'	A	A	A'	A	A'	A	A	A	A'	A'	A'
Alice's Result	+	+	-	+	+	-	+	-	+	-	+	+	+
Alice's M'ment	B	B	B'	B	B'	B	B'	B	B'	B'	B'	B	B
Alice's Result	+	-	+	+	-	+	+	-	+	+	-	+	-

$$\left|\mathbf{E}(ab|A,B) + \mathbf{E}(ab|A,B') + \mathbf{E}(ab|A',B) - \mathbf{E}(ab|A',B')\right| \leq 2$$

CHSH Inequality Violation



CHSH Upper Bound

Quantum Prediction (Singlet-State)

Recent Developments

- Non-locality and no-signalling as *axioms* for reconstruction of quantum theory?

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- Are there *tasks* that entanglement enables?

Recent Developments

- Non-locality and no-signalling as *axioms* for reconstruction of quantum theory?
- Are there *tasks* that entanglement enables?
- Turning the tables: *non-locality* as fundamental & *locality* as emergent?