A new approach to quantum mechanics

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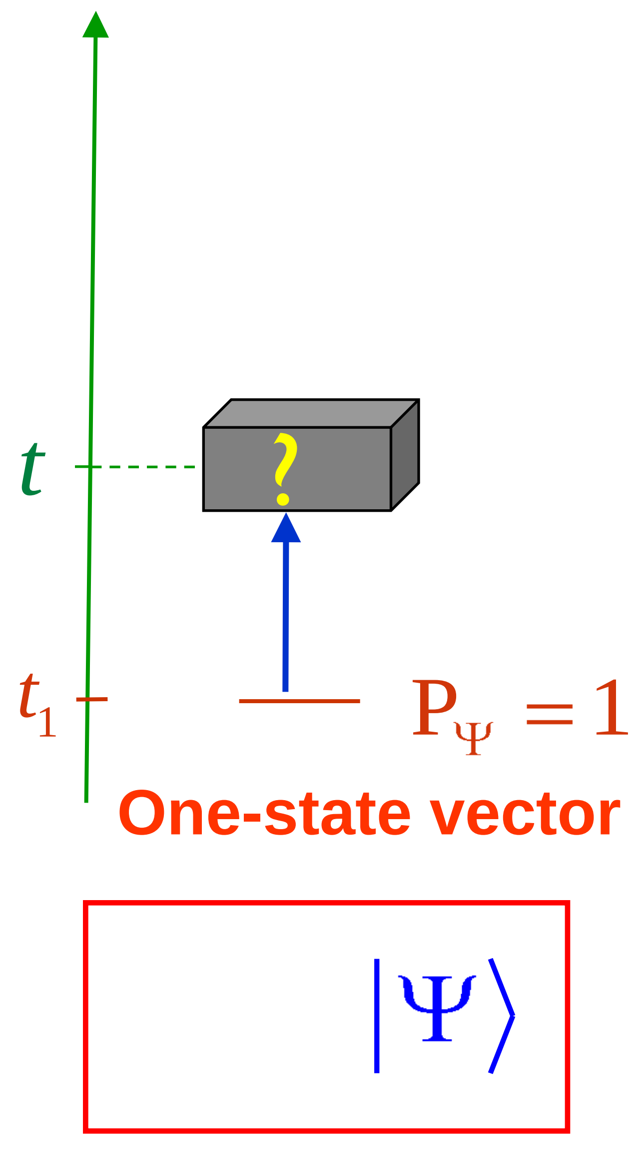
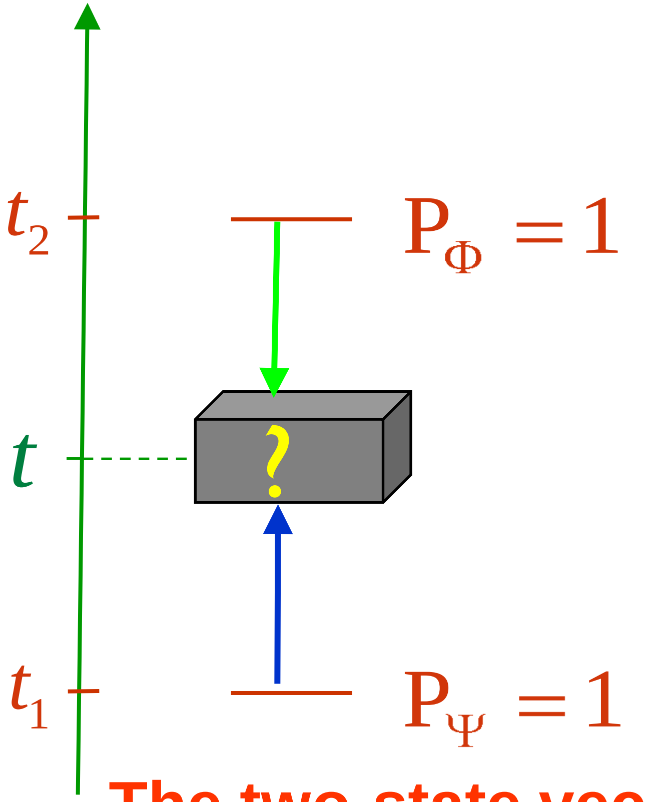
Standard formulation of QM:

- **the state of a system at a given moment is described by one wave-function, evolving from the past to the future**



Time-Symmetric formulation of QM (TSQM)

- **the state of a system at a given moment is described by two wave-functions, one evolving from the past to the future, and one evolving from the future to the past**

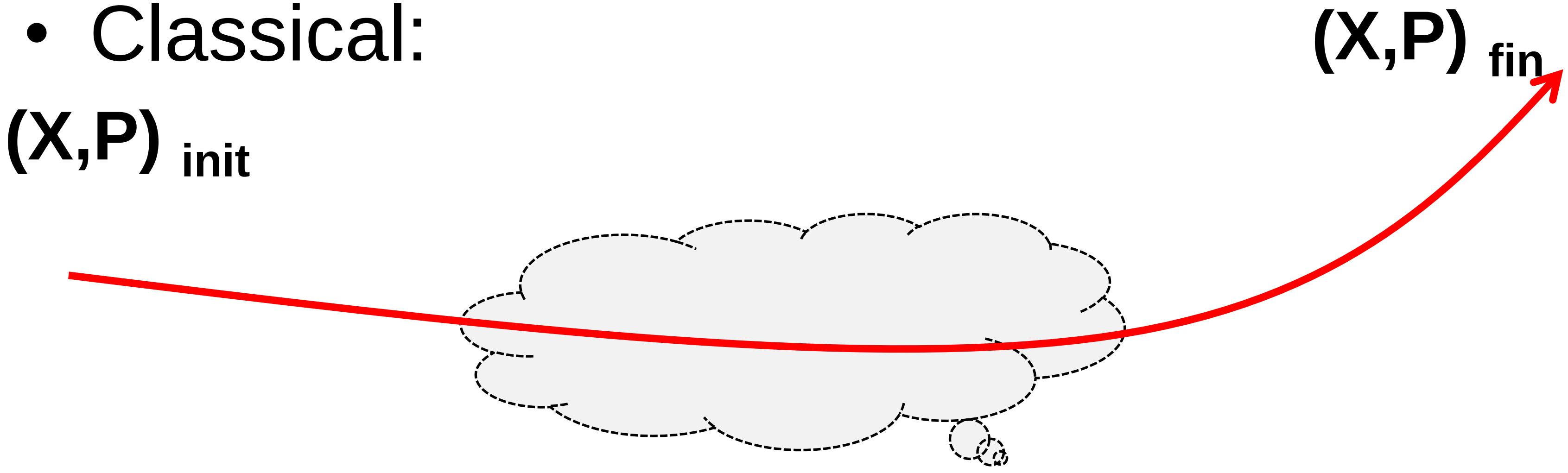


The two-state vector

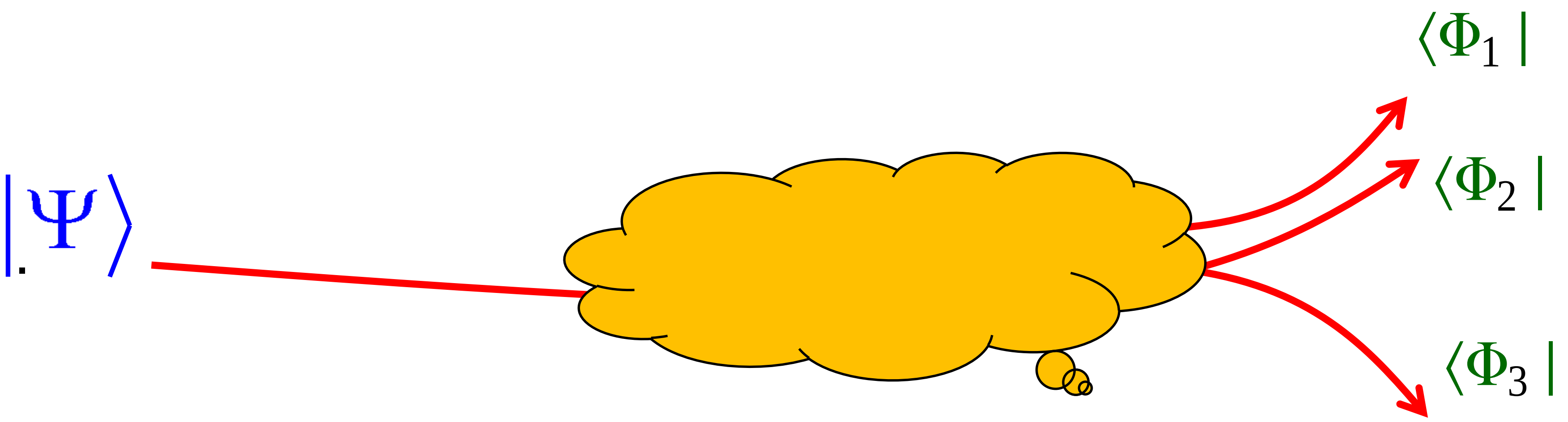
$$\langle \Phi | \quad | \Psi \rangle$$

Boundary conditions: classical vs quantum

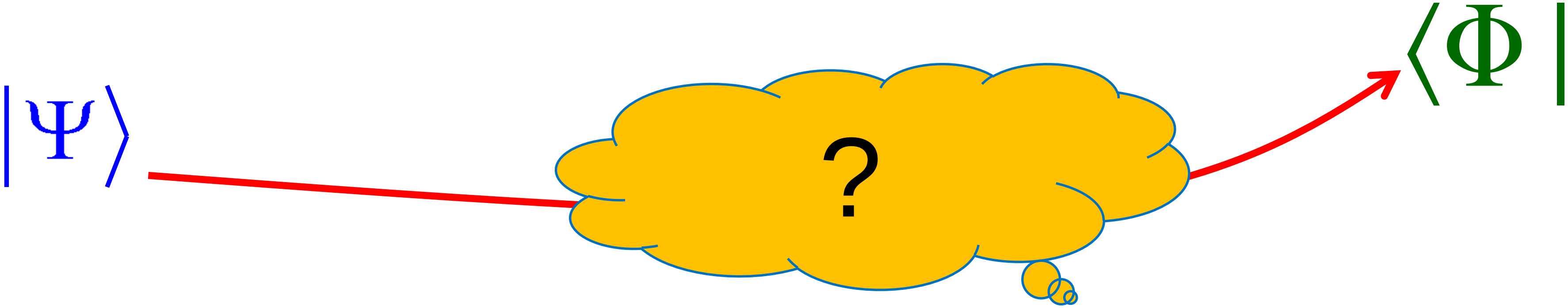
- Classical:



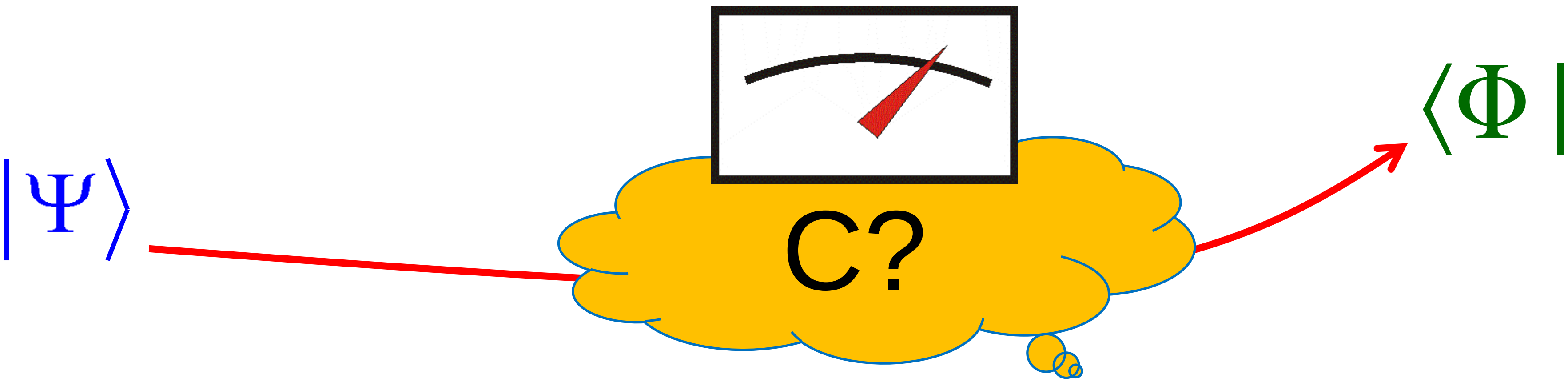
- Quantum:



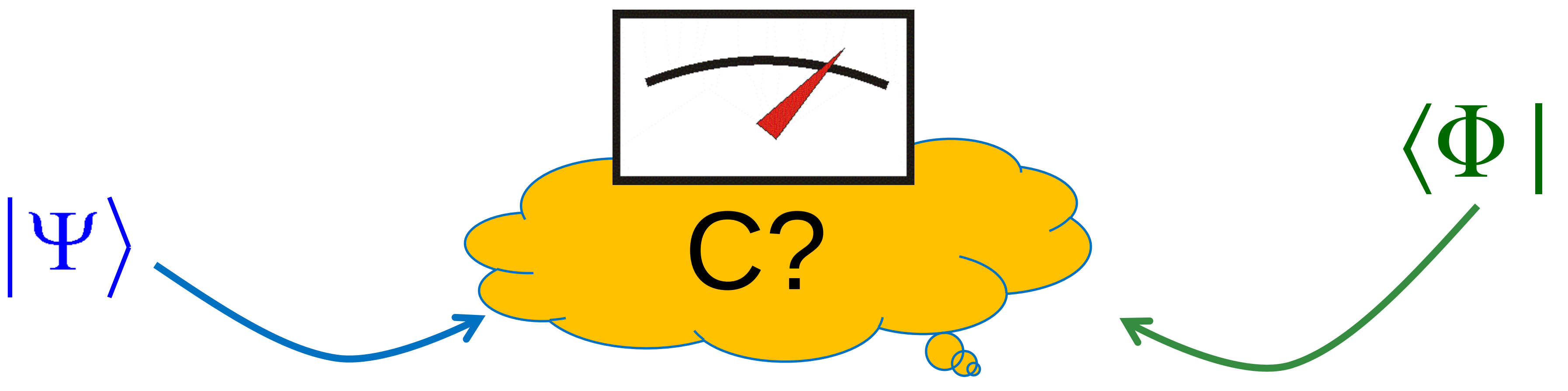
What can we say about the system at the intermediate time?



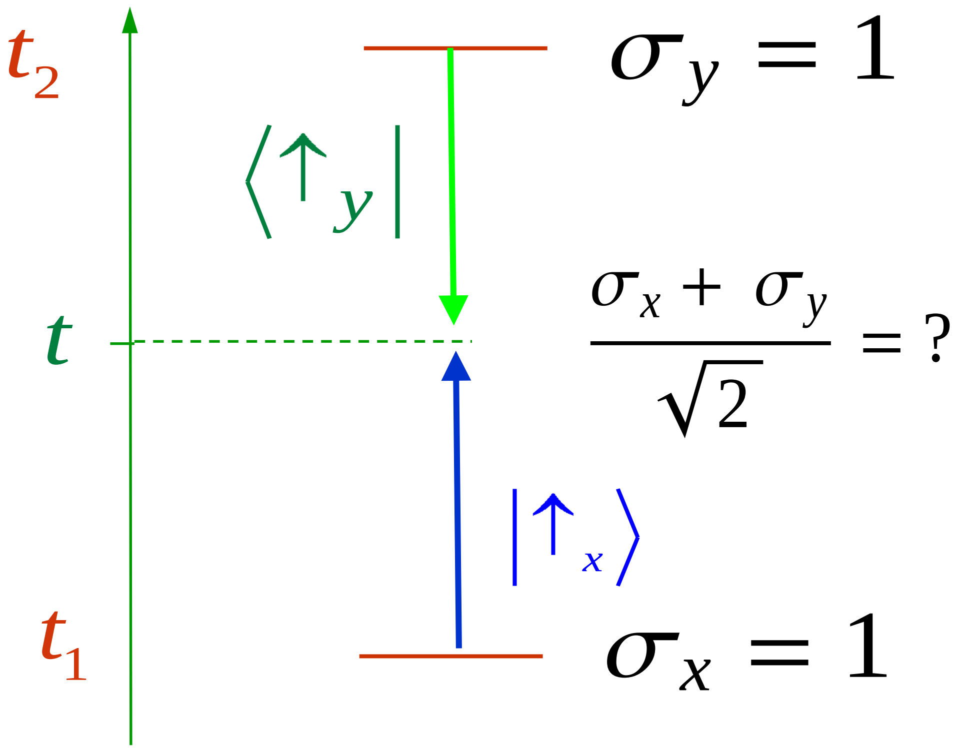
$$P(c) = \frac{|\langle \Phi |\ U(t_2,\ t)\,|\,c\,\rangle|^2\ |\langle\, c\,|\,U(t,\ t_1)\,|\ \Psi\,\rangle|^2}{\sum_{c'} |\langle \Phi |\ U(t_2,\ t)\,|\,c'\,\rangle|^2\ |\langle\, c'\,|\,U(t,\ t_1)\ |\,\Psi\,\rangle|^2}$$



$$P(c) = \frac{|\langle \Phi, t \,|\, c \rangle \langle c \,|\, \Psi, t \rangle|^2}{\sum_{c'} |\langle \Phi, t \,|\, c' \rangle \langle c' \,|\, \Psi, t \rangle|^2}$$

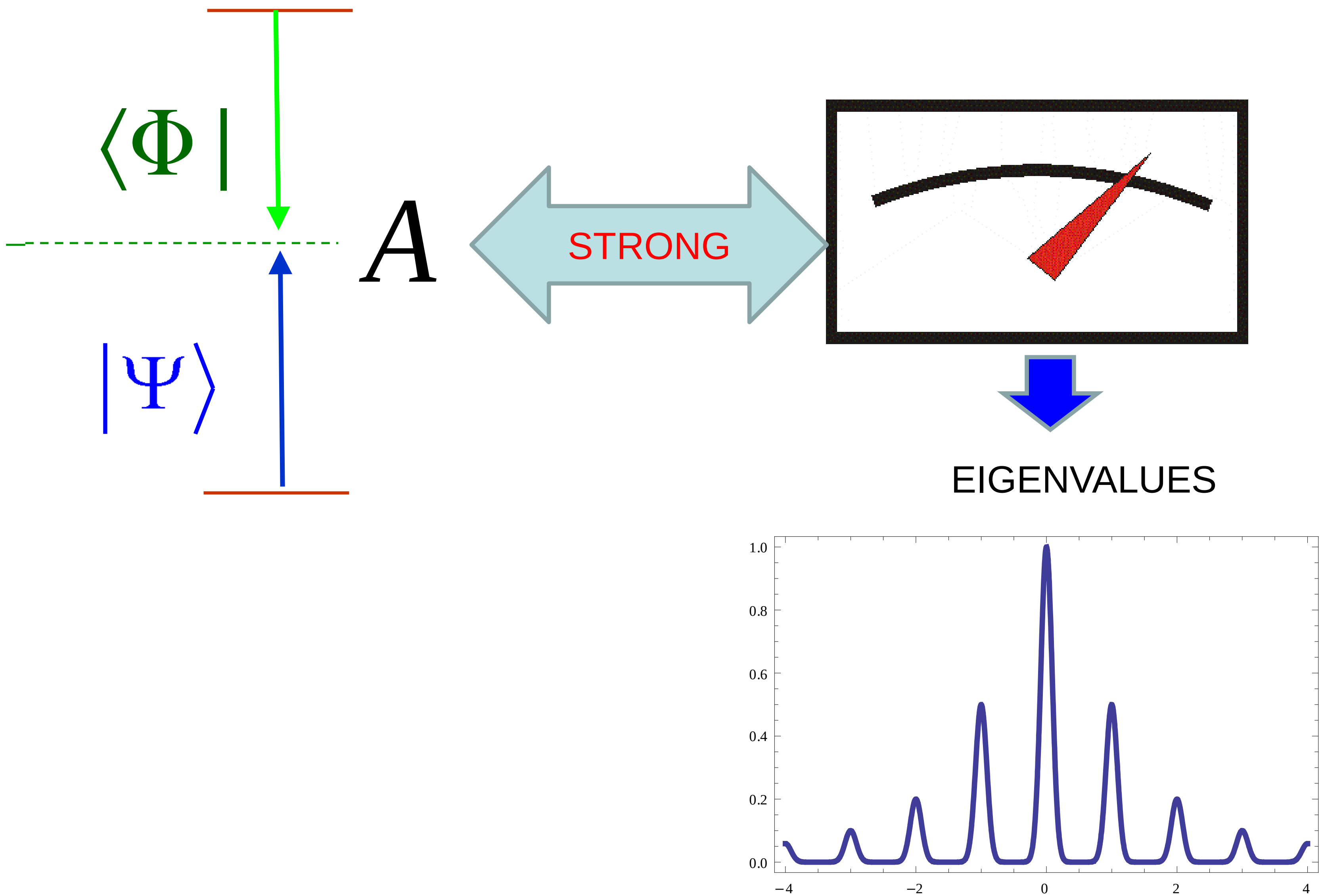


$$|\Psi, t\rangle = U(t, t_1)\,|\Psi\rangle \qquad \langle \Phi, t\,| = \langle \Phi\,|\,U(t_2, t)$$

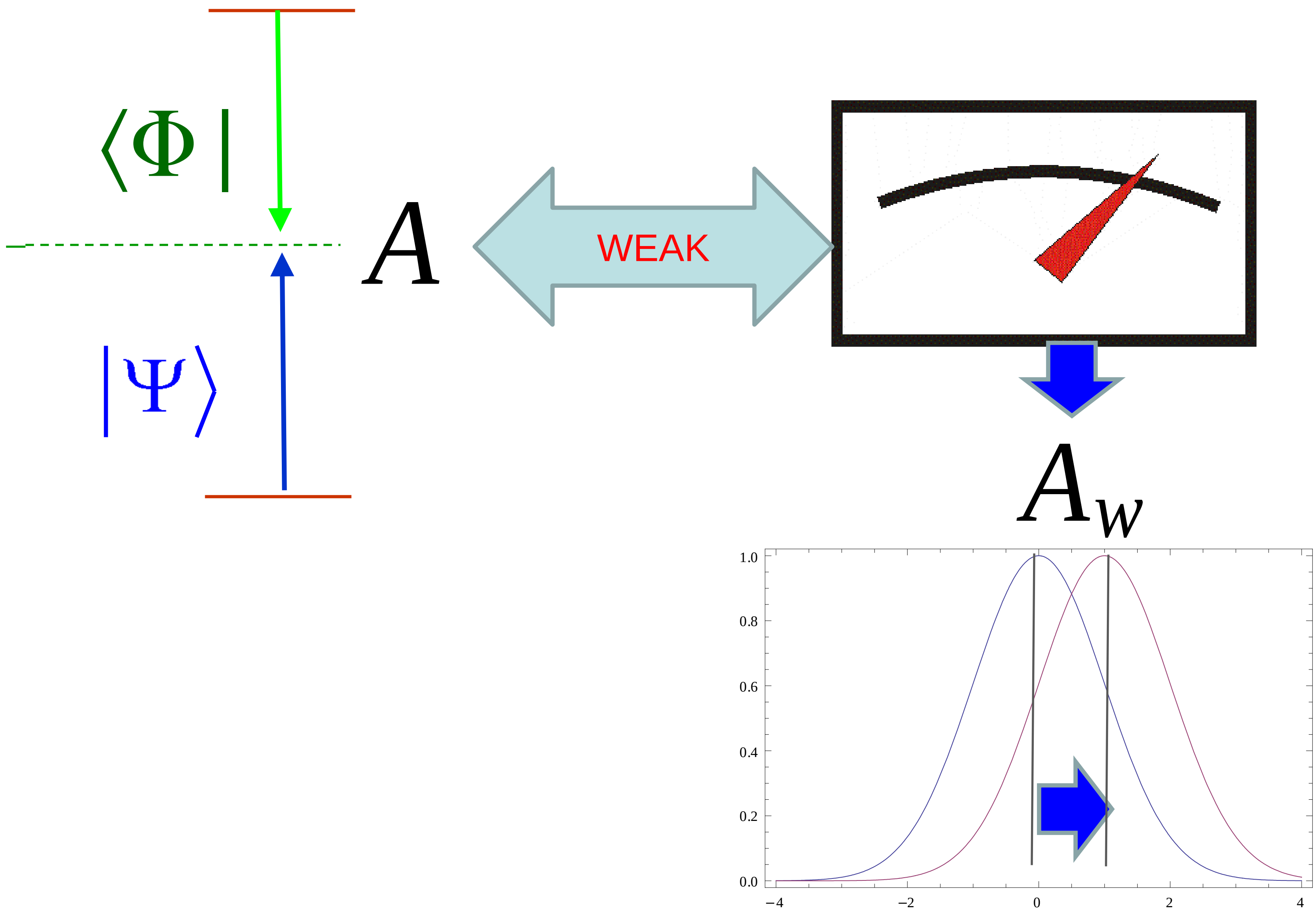


t_2
$\sigma_y = 1$
$\langle \uparrow_y |$
t
$\frac{\sigma_x + \sigma_y}{\sqrt{2}} = ?$
$| \uparrow_x \rangle$
t_1
$\sigma_x = 1$

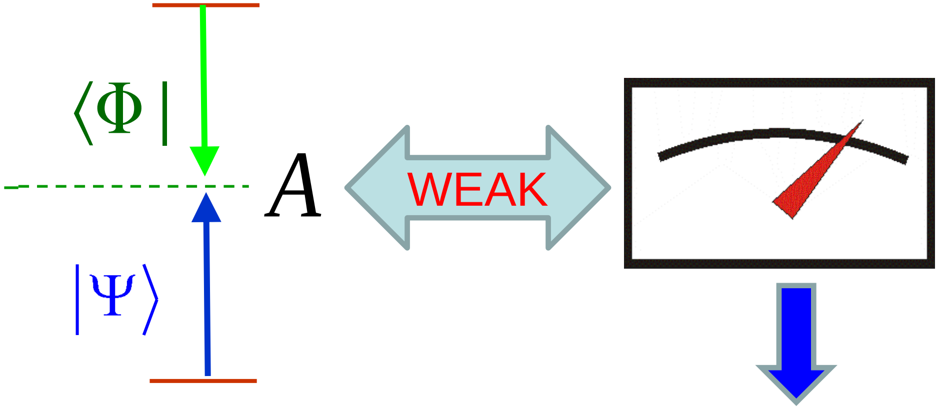
STRONG MEASUREMENTS



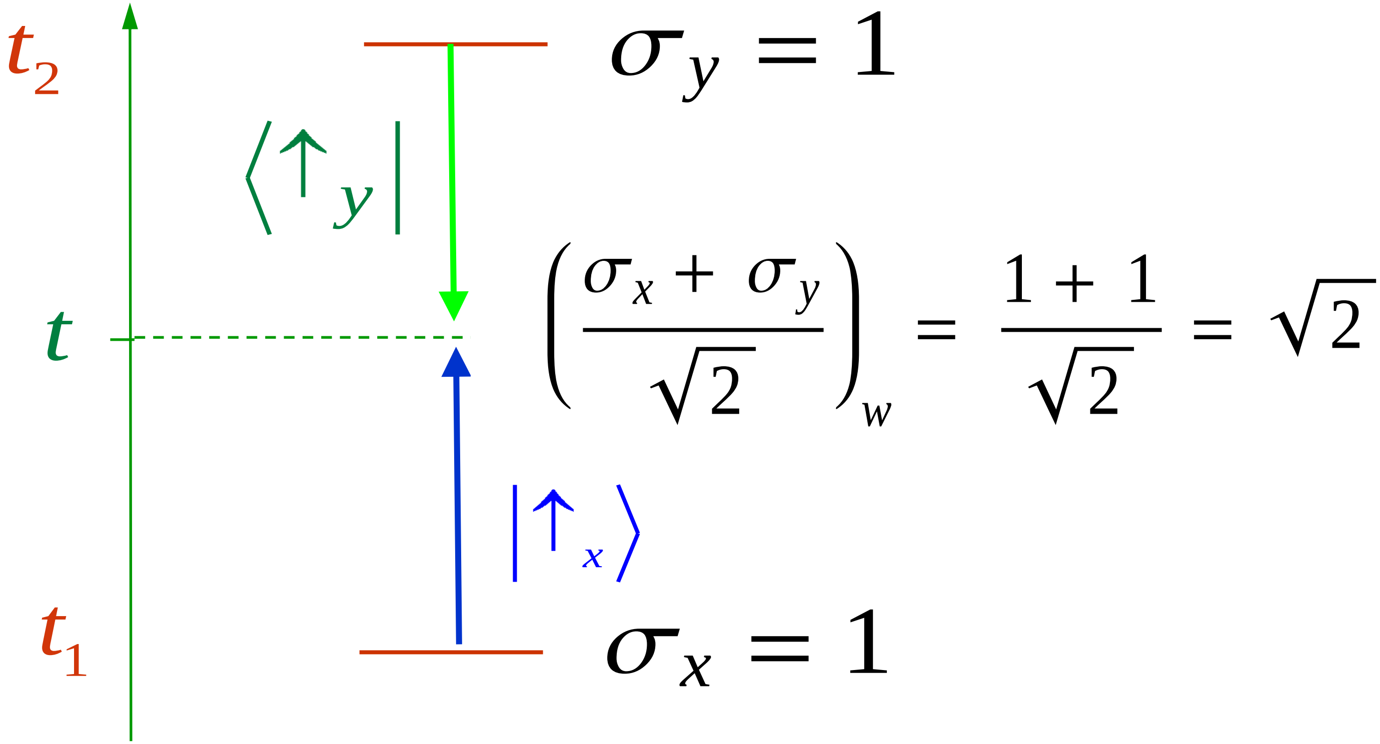
WEAK MEASUREMENTS



WEAK VALUES

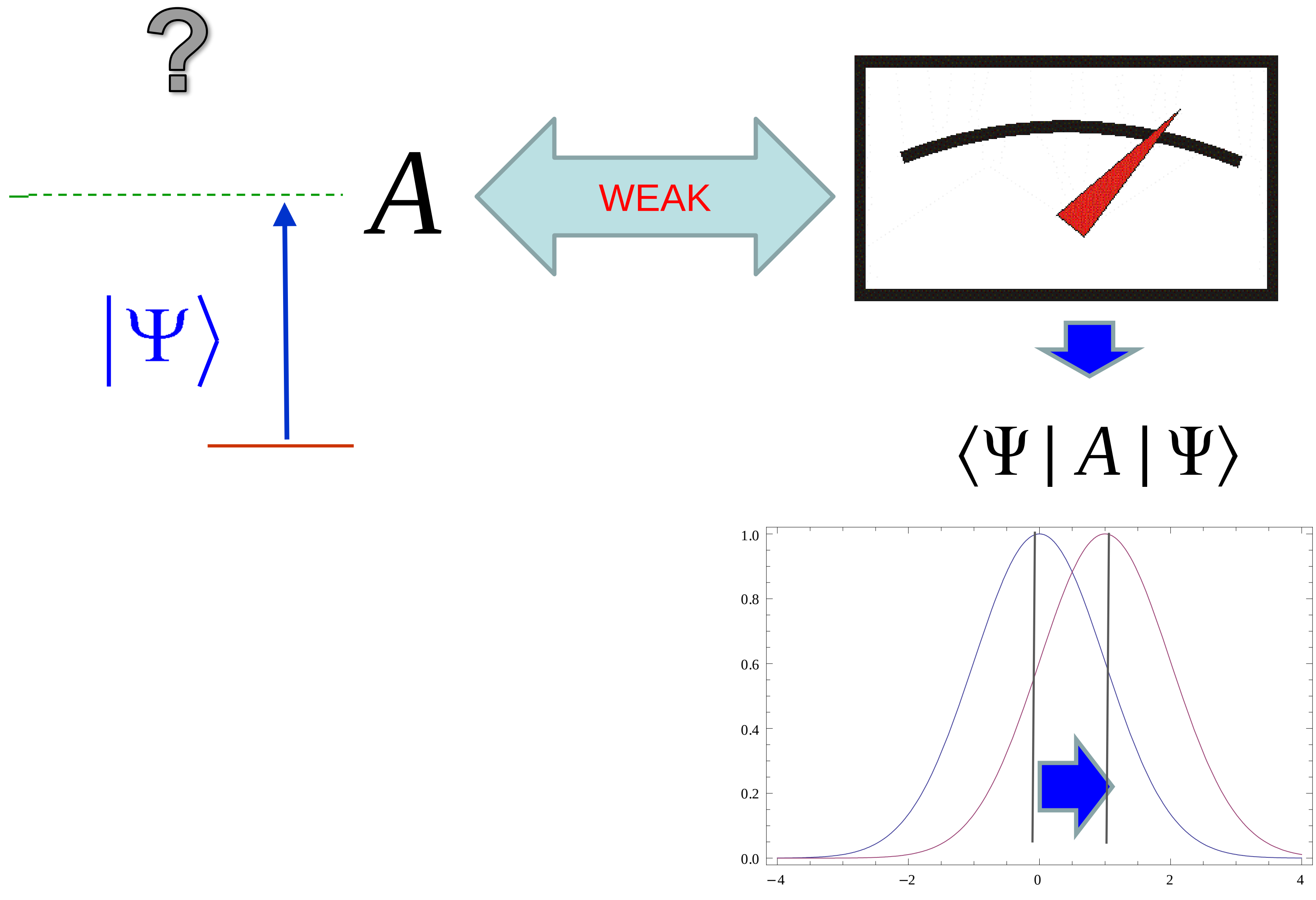


$$A_w = \frac{\langle \Phi | A | \Psi \rangle}{\langle \Phi | \Psi \rangle}$$



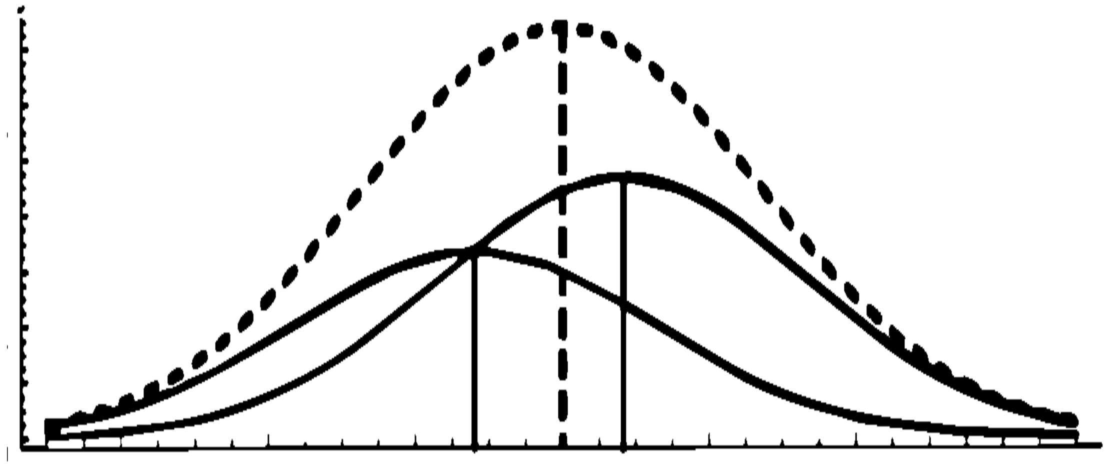
t_2
$\sigma_y = 1$
$\langle \uparrow_y |$
t
$\left(\frac{\sigma_x + \sigma_y}{\sqrt{2}} \right)_w = \frac{1 + 1}{\sqrt{2}} = \sqrt{2}$
$| \uparrow_x \rangle$
t_1
$\sigma_x = 1$

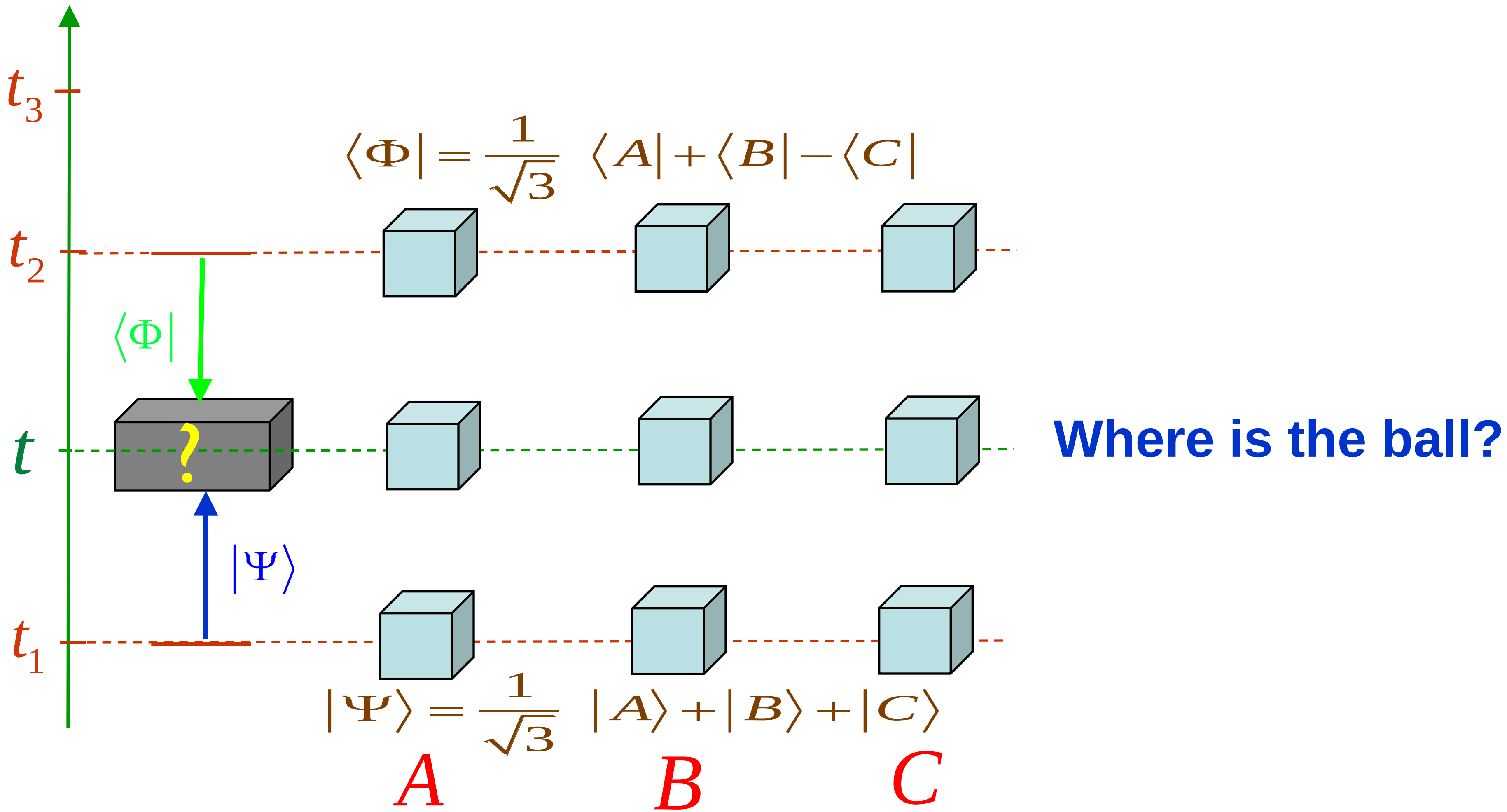
WEAK MEASUREMENTS WITHOUT POSTSELECTION



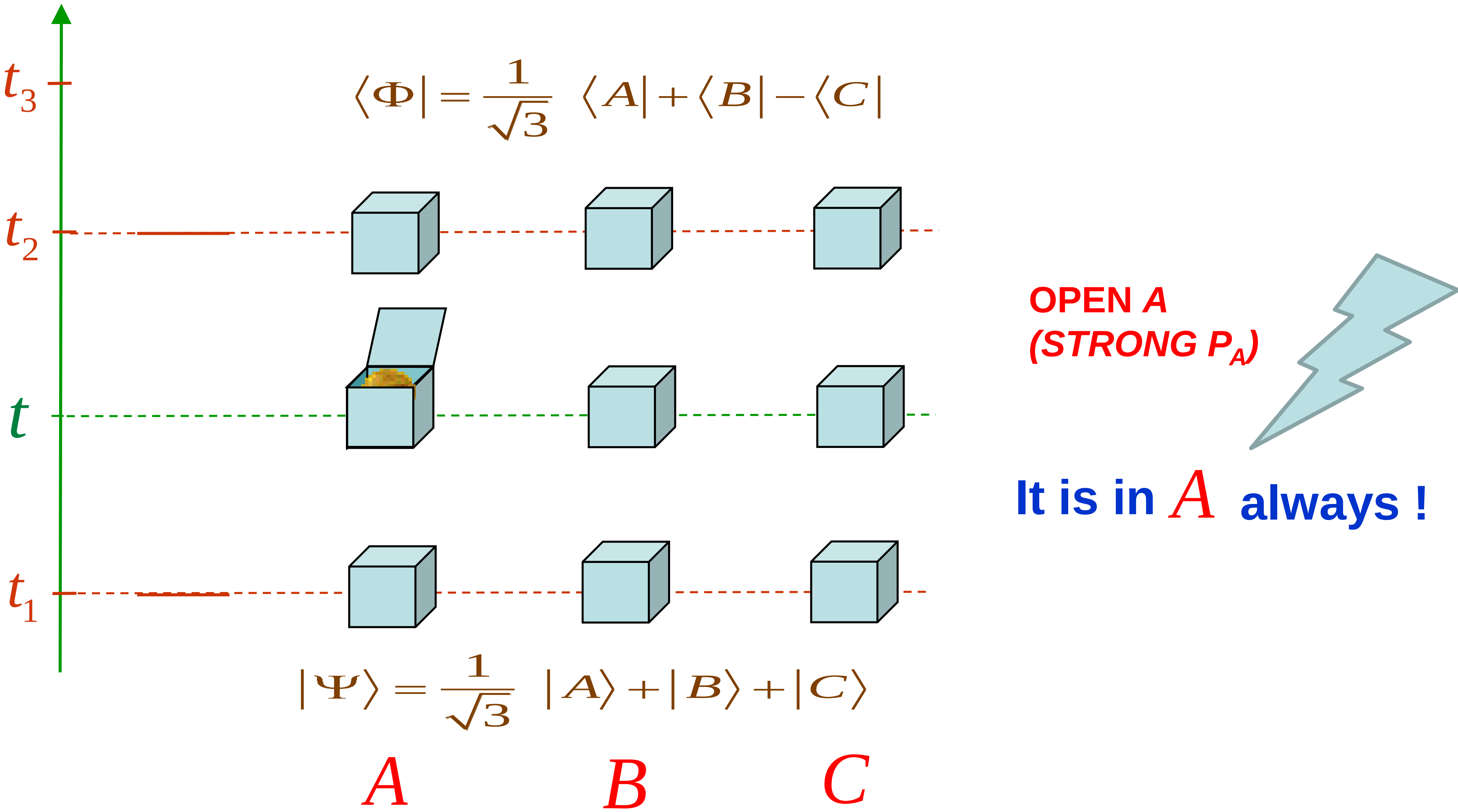
WEAK VALUE SUM RULE

$$\langle \Psi | A | \Psi \rangle = \sum_i P(\Phi_i | \Psi) \frac{\langle \Phi_i | A | \Psi \rangle}{\langle \Phi_i | \Psi \rangle}$$



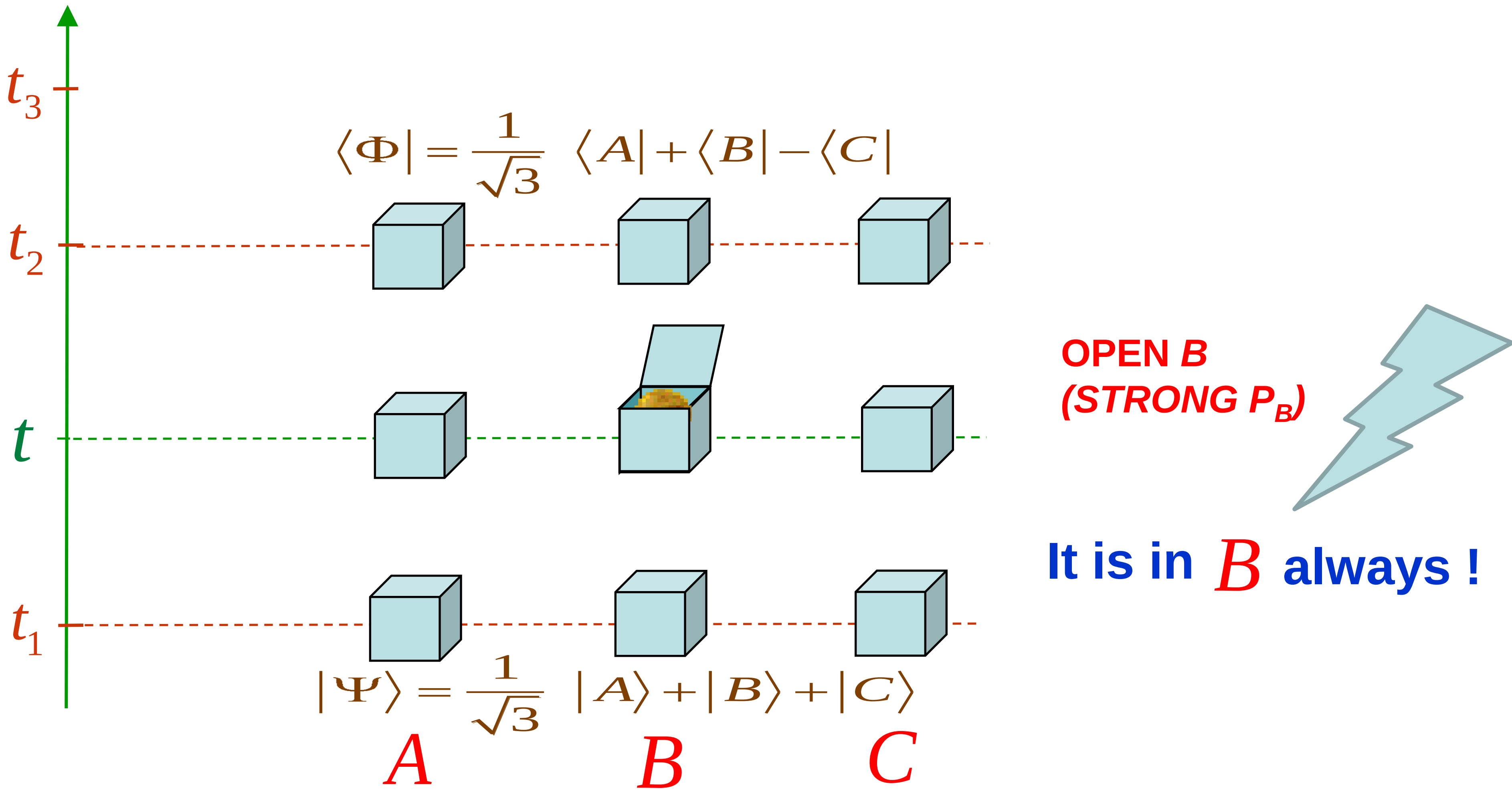


Y. Aharonov and L. Vaidman
J. Phys. A: Math. Gen. **24**, 2315-2328 (1991)



t_3
$\langle\Phi| = \frac{1}{\sqrt{3}} \left(\langle A| + \langle B| - \langle C| \right)$
t_2
OPEN *A*
(*STRONG* P_A)
t
It is in A always !
t_1
$|\Psi\rangle = \frac{1}{\sqrt{3}} \left(|A\rangle + |B\rangle + |C\rangle \right)$
A
B
C

THE THREE BOX PARADOX



WEAK VALUE LOGIC!

$$\mathbf{P}_A = 1 \quad \Rightarrow \quad {\mathbf{P}_A}_{\,w} = 1$$

$$\mathbf{P}_B = 1 \quad \Rightarrow \quad {\mathbf{P}_B}_{\,w} = 1$$

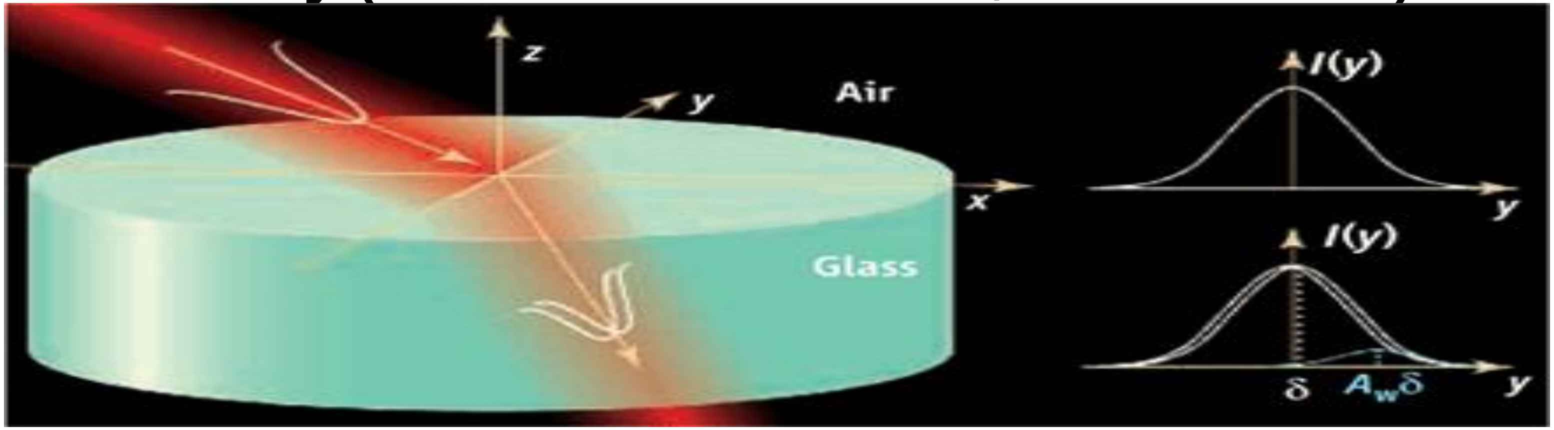
$$\mathbf{P}_A + \mathbf{P}_B + \mathbf{P}_C = 1 \quad \Rightarrow \quad {\mathbf{P}_A + \mathbf{P}_B + \mathbf{P}_C}_{\,w} = 1$$

$$\Rightarrow \quad {\mathbf{P}_C}_{\,w} = -1$$

This has been seen experimentally: Resch, Lundeen, Steinberg PLA 324, 125-131 APR 12 2004

Applications: metrology, algorithms

- **new paradigm for amplifying signals with enhanced sensitivity (Aharonov Vaidman 1990, Tollaksen 2007)**



- Enhanced sensitivity by 10^4 (Hosten, Kwiat, *Science* 2/8/08; Phys Rev Lett 102, 173601, MAY 1, 2009)

Other experimental verifications:

Phys Rev Lett **102**:020404, (2009)
New Journal of Physics **11** (2009) 033011

For weak value resolution of Hardy's paradox

Aharonov. Botero, Popescu, Reznik, Tollaksen, PLA, v301, 130 concerning Hardy's paradox