Quantum Time

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4th Feynman Festival, Olomouc 2009

Quantize time using rules for space, …see what breaks.

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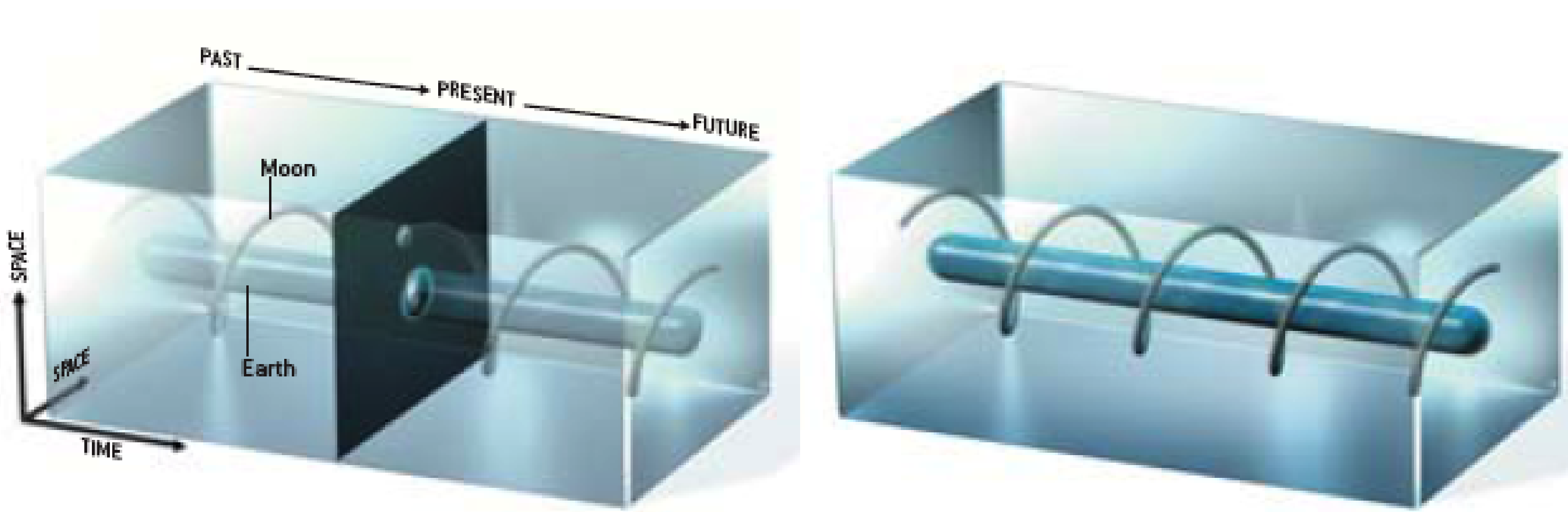
`Clearly,' the Time Traveller proceeded, `any real body must have extension in four directions: it must have Length, Breadth, Thickness, and--Duration. But through a natural infirmity of the flesh, which I will explain to you in a moment, we incline to overlook this fact. There are really four dimensions, three which we call the three planes of Space, and a fourth, Time. There is, however, a tendency to draw an unreal distinction between the former three dimensions and the latter, because it happens that our consciousness moves intermittently in one direction along the latter from the beginning to the end of our lives.'

Block universe

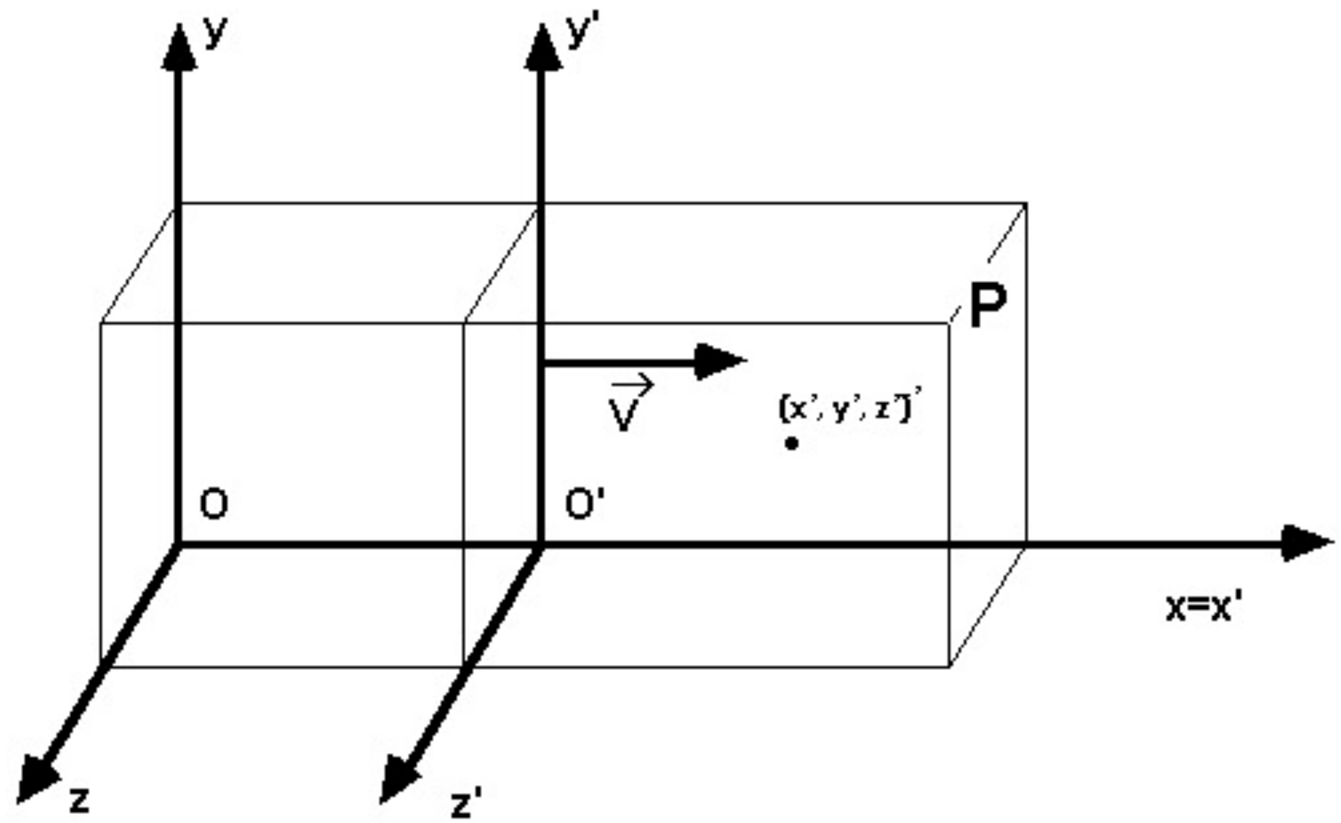


CONVENTIONAL VIEW: Only the present is real

BLOCK UNIVERSE: All times are equally real

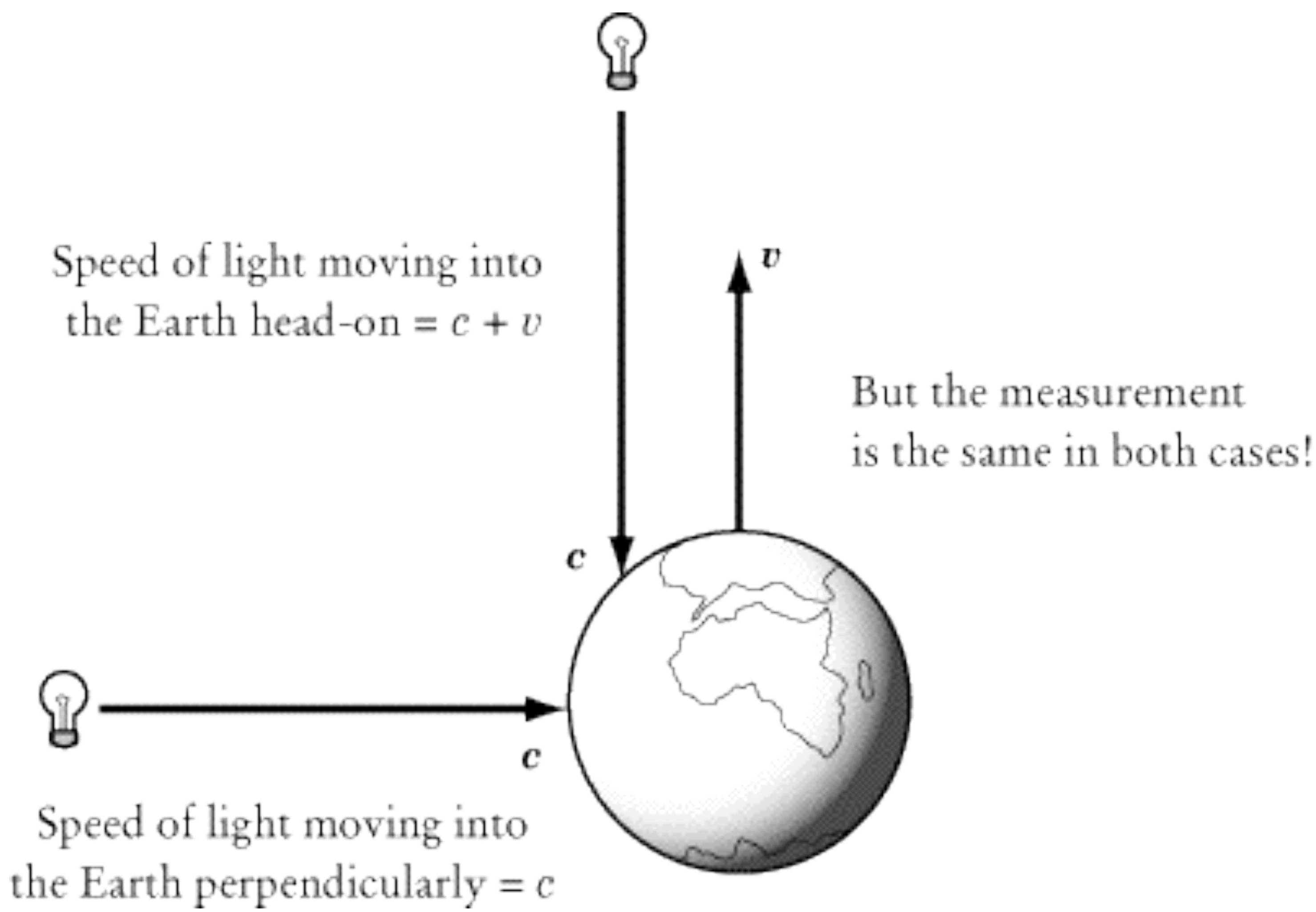
Evolving universe

Galilean Light

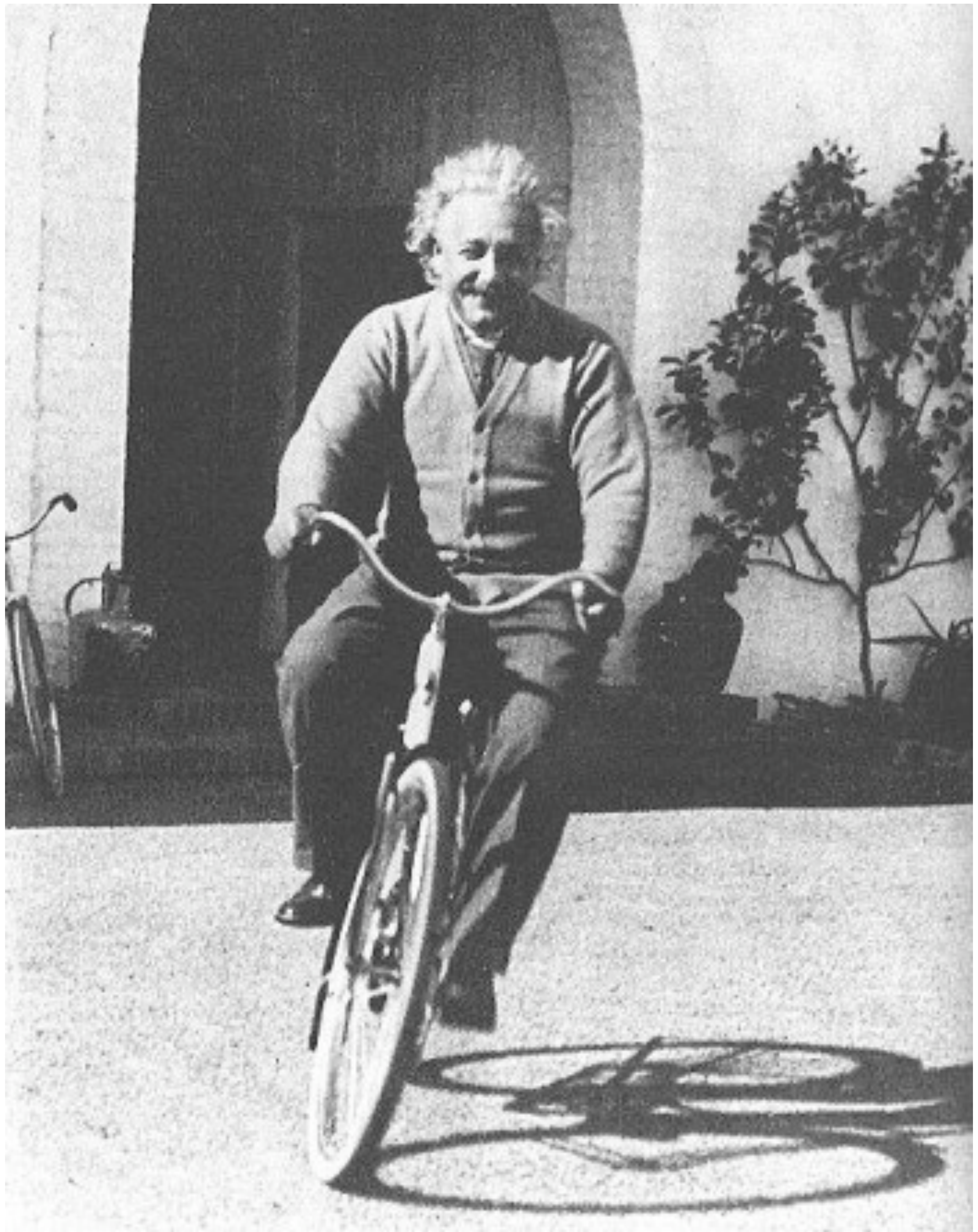


If light is going at speed "c" in the first frame, how fast is it going in the primed frame?

Michelson-Morley Expt



RELATIVITY



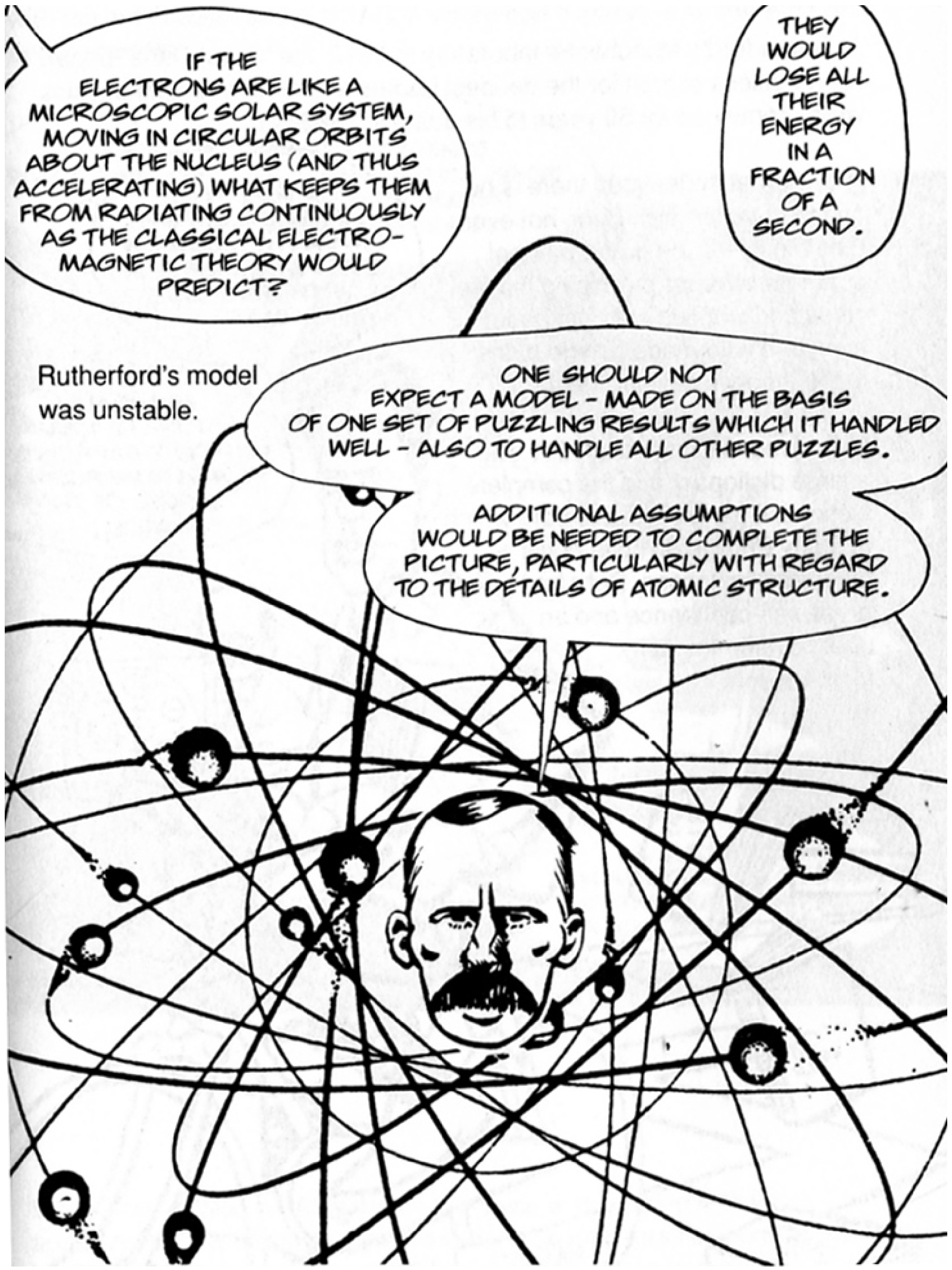
- speed of light constant
- laws of physics the same for all observers*

*but definition of simultaneity may differ!

Relativity

"Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."
-- Minkowski

- time and space mix'd: on way into a black hole, they even change places
- block universe naturally static: 80+ pages to define an evolving time.

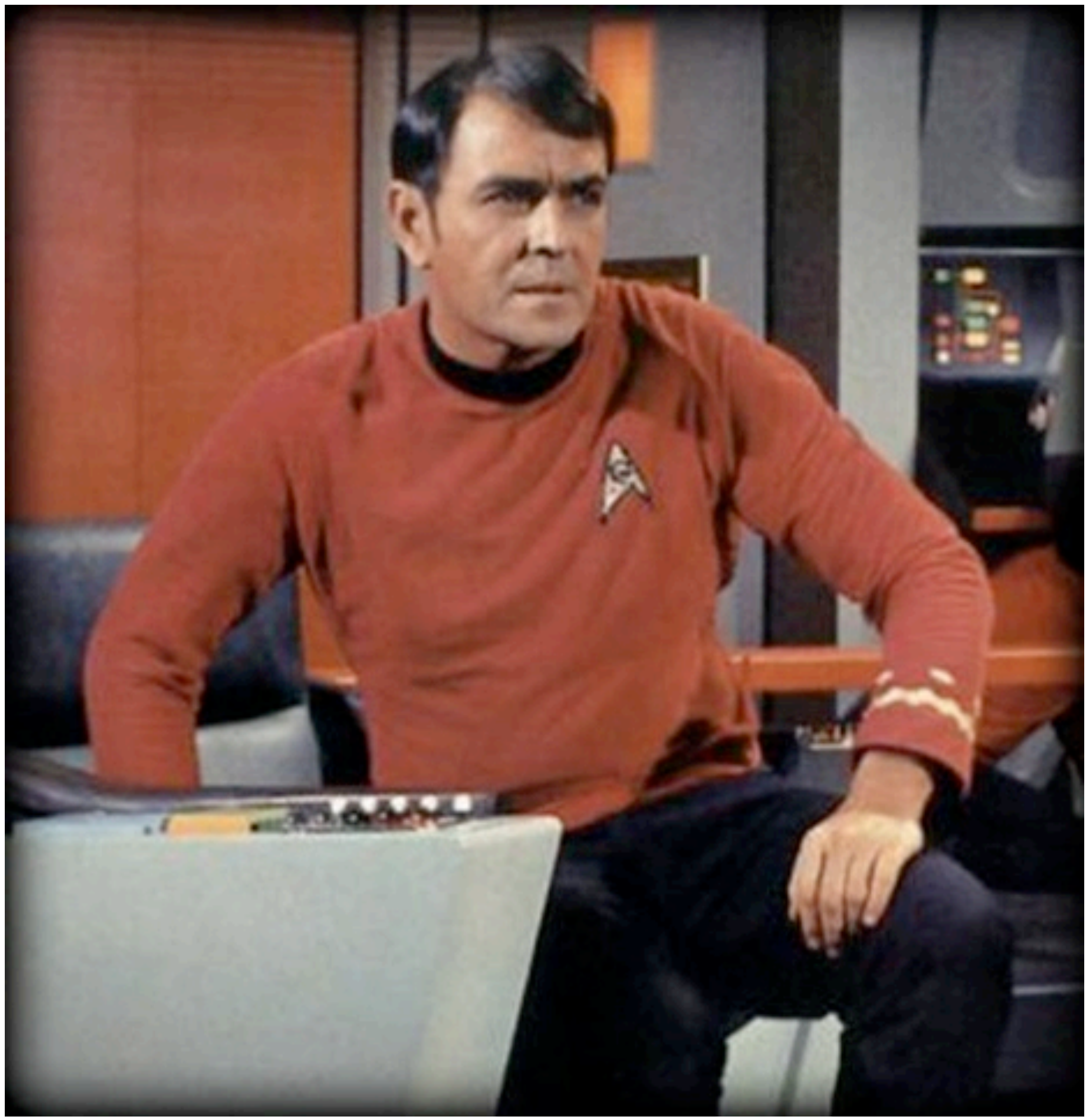


WITHOUT QUANTUM MECHANICS, ATOMS DON'T EXIST!

Introducing Quantum Theory
McEvoy & Zarate

Quantum mechanics

- space is fuzzy
- time is a parameter
- we build the wave function at the next time instant based on the wave function at the current



BUT I CANNA CHANGE THE LAWS OF PHYSICS, CAPTAIN!

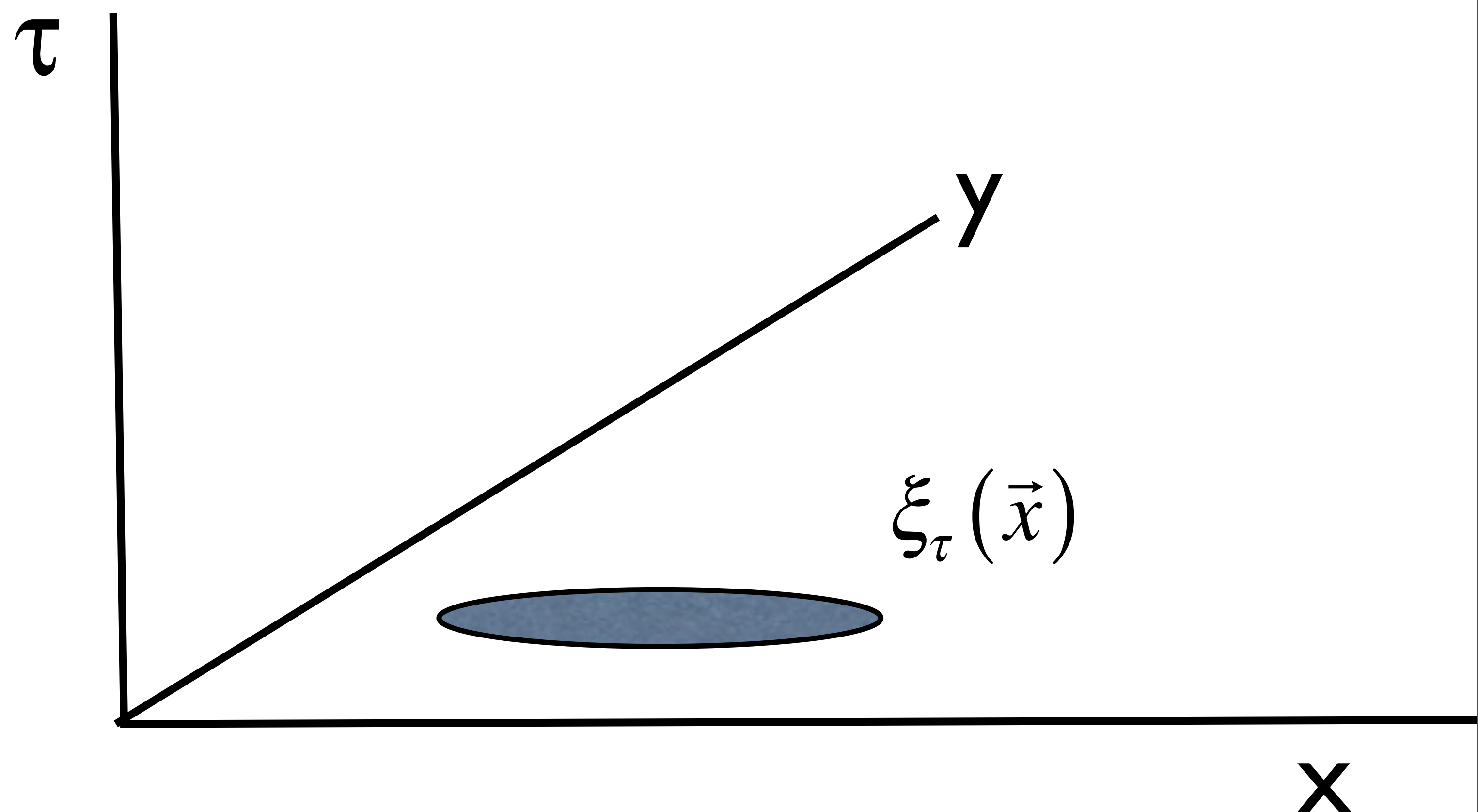
How to combine?

- Strings
- Loop quantum gravity
- Lots of others

All are new physics

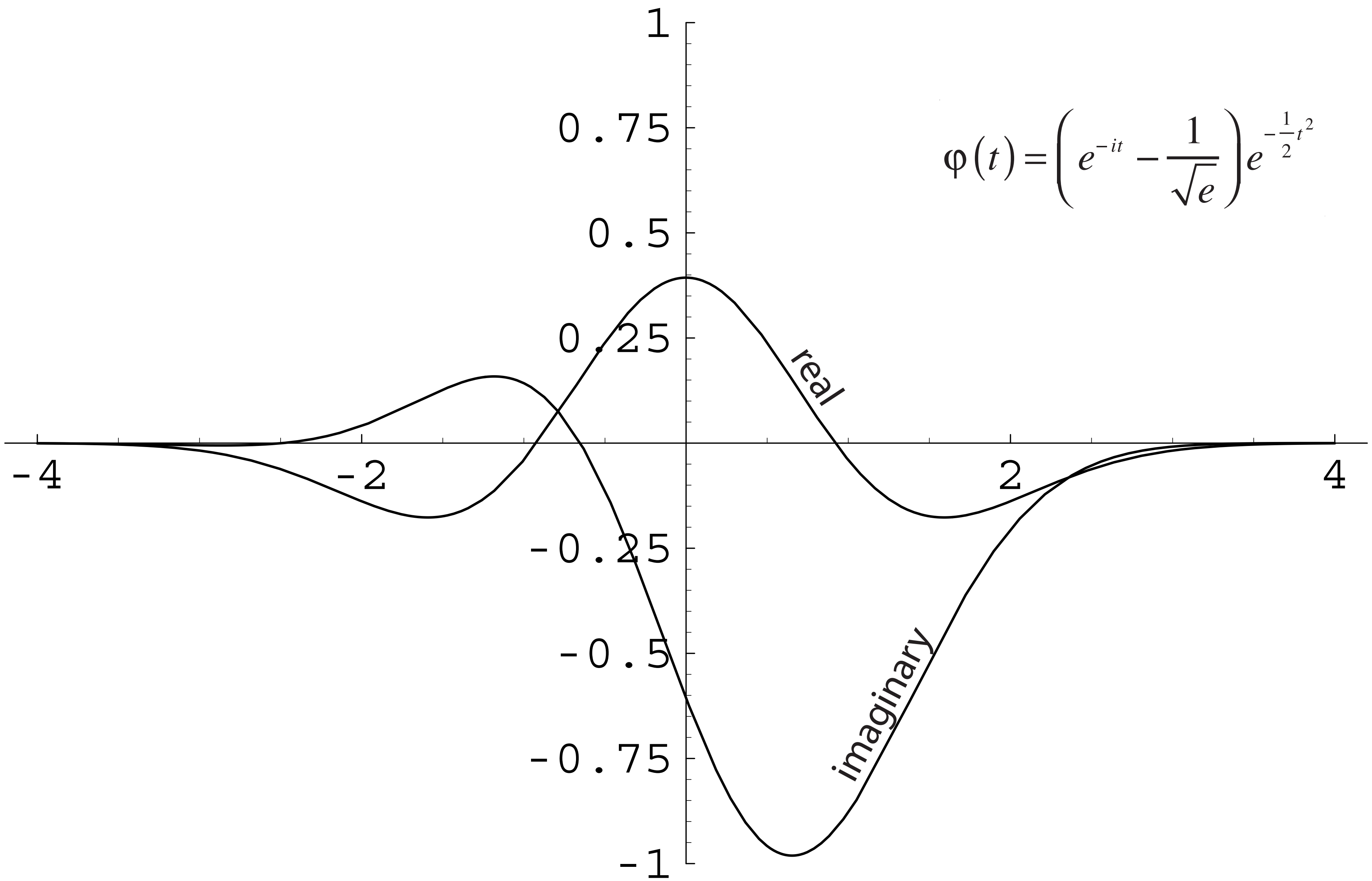
This is often the way it is in physics - our mistake is not that we take our theories too seriously, but that we do not take them seriously enough. It is always hard to realize that these numbers and equations we play with at our desks have something to do with the real world. Even worse, there often seems to be a general agreement that certain phenomena are just not fit subjects for respectable theoretical and experimental effort.
-- Steven Weinberg

Laboratory time

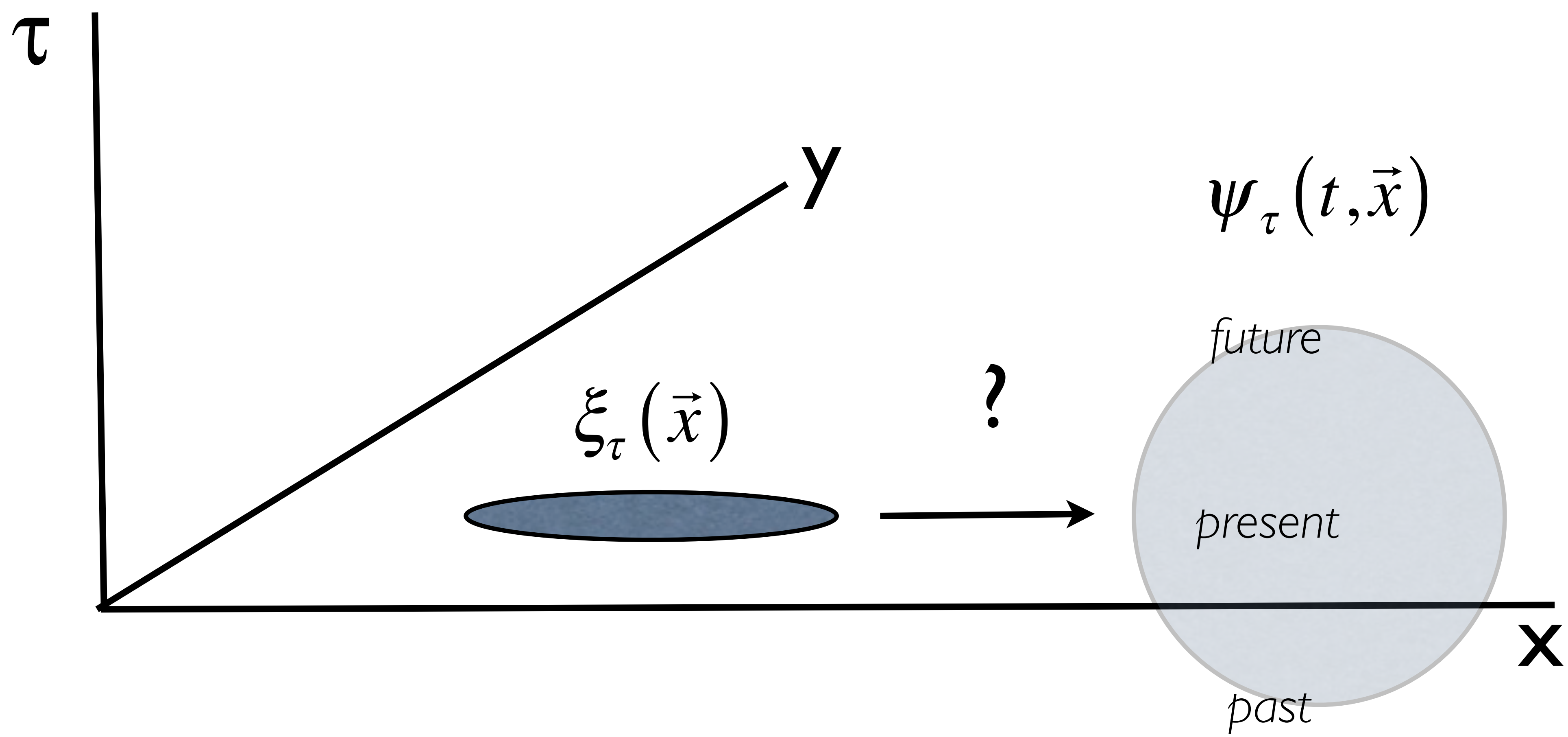


What clocks measure

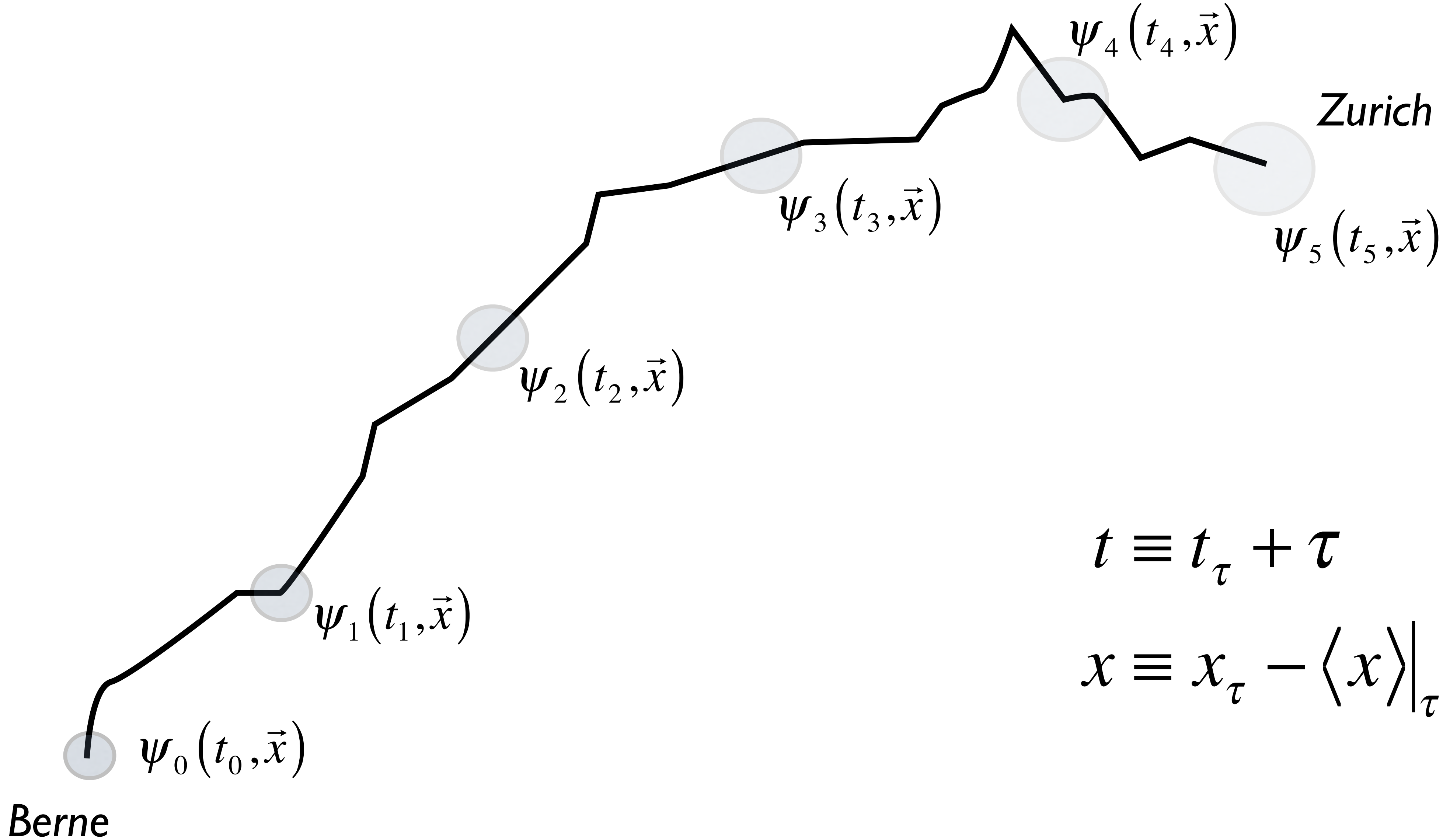
Quantum wave function



Quantum time



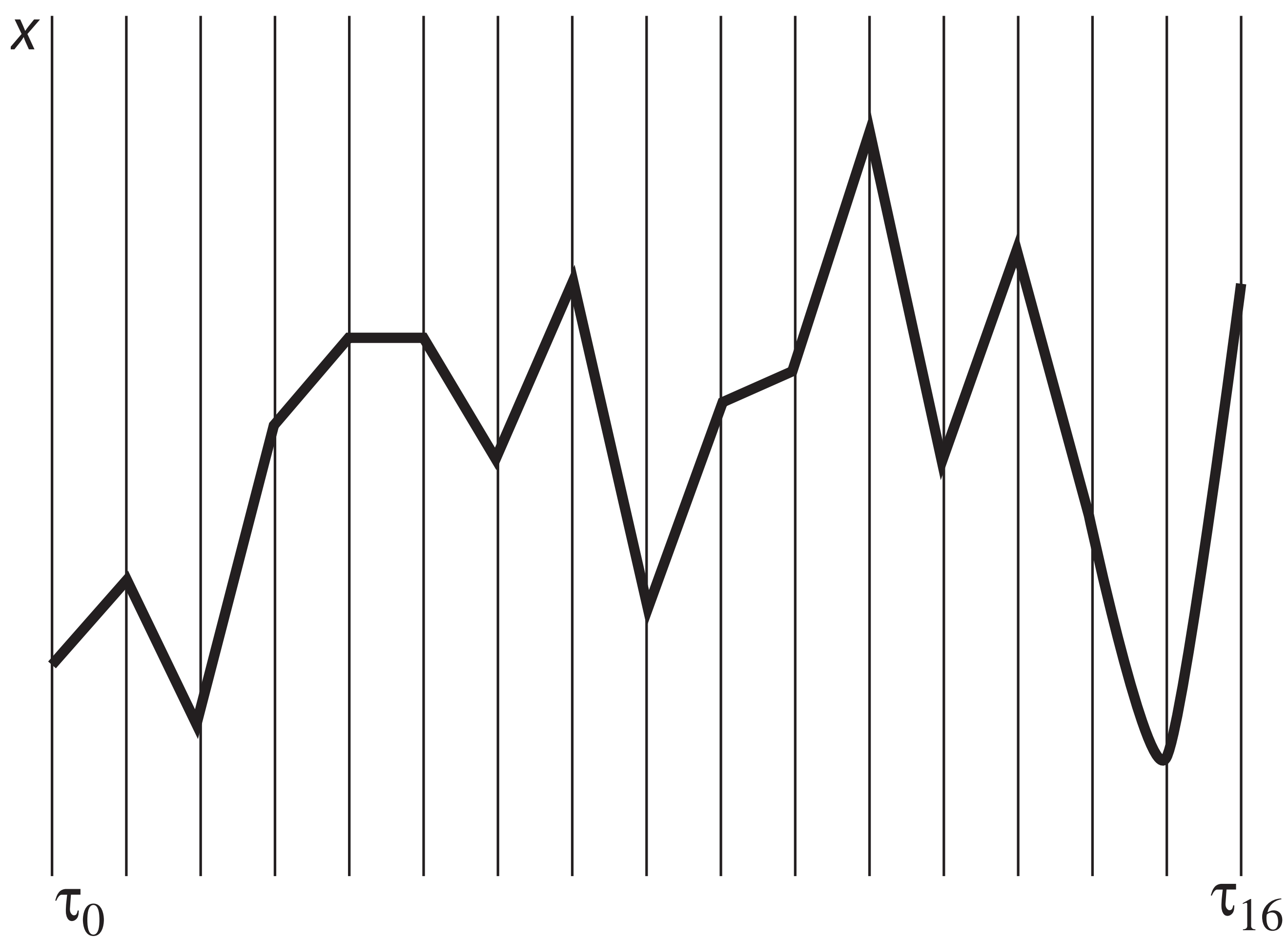
Relative and absolute quantum time



$$t \equiv t_\tau + \tau$$

$$x \equiv x_\tau - \langle x \rangle\big|_\tau$$

Path integrals



$$K_T\left(x''_\mu; x'_\nu\right) = \int \mathcal{D}x \exp\left(-i\int_0^T \mathrm{d}\tau L\left[x_\mu, \frac{dx_\mu}{d\tau}\right]\mathrm{d}\tau\right)$$

$$\mathcal{D}x \sim \prod_{n=1}^{n=N} \mathrm{d}^4 x_n$$

$$\psi_T\left(t'', \vec{x}''\right) = \int \mathrm{d}t'\mathrm{d}\vec{x}' K_T\left(t'', \vec{x}''; t', \vec{x}'\right)\psi_0\left(t', \vec{x}'\right)$$

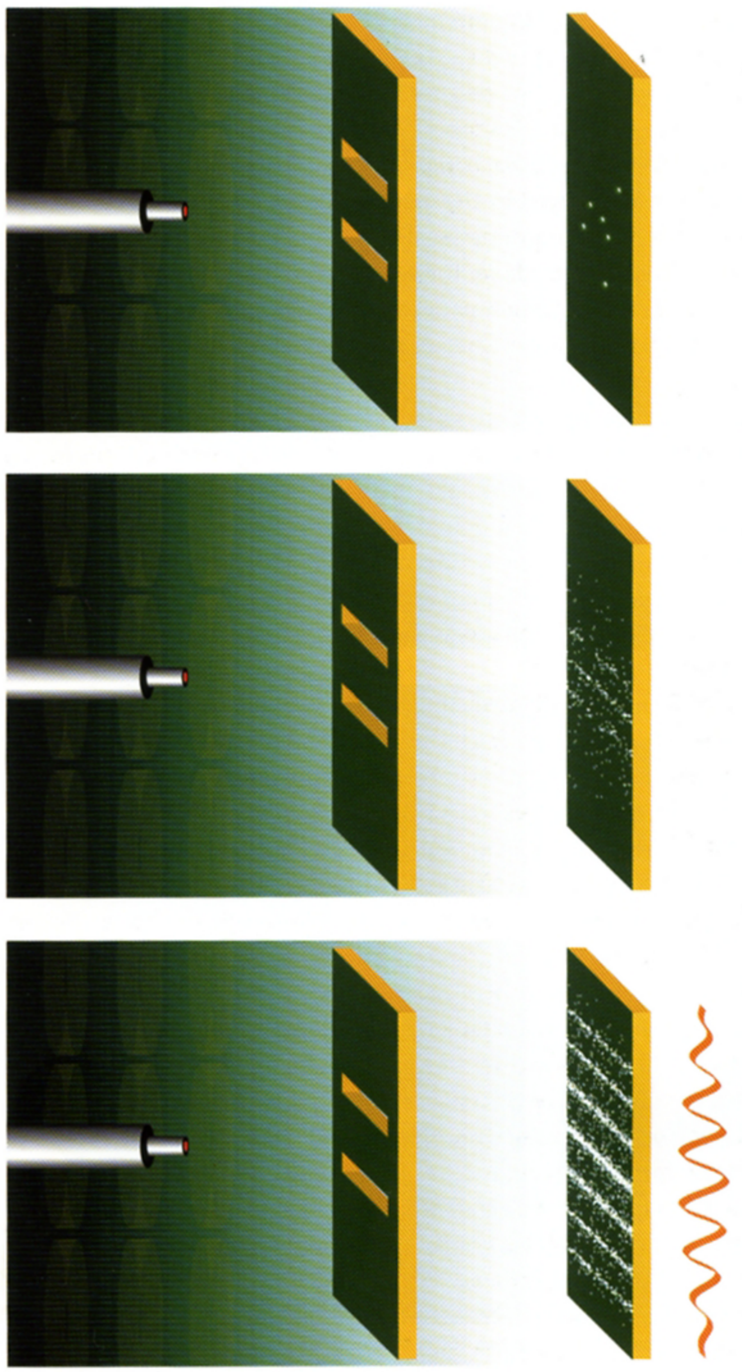
$$\varepsilon \equiv \frac{T}{N}$$

Feynman & Hibbs, Quantum Mechanics and Path Integrals, 1965

small & large dimensions

- trip measured in kilometers
- wave function measured in nanometers
- “real” x is total of large and small
- Now, what happens if we take this position for time???

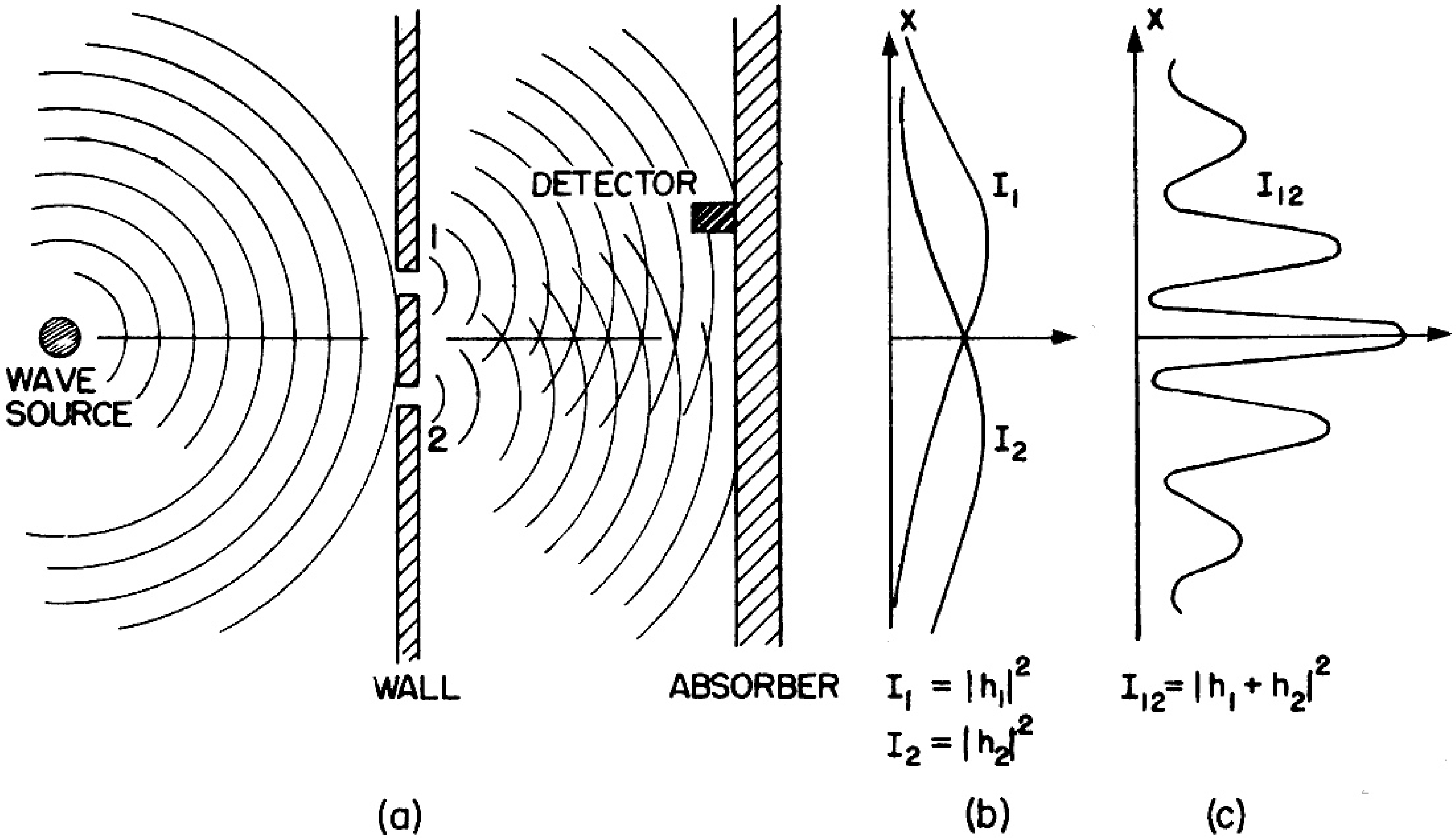
DOUBLE SLIT



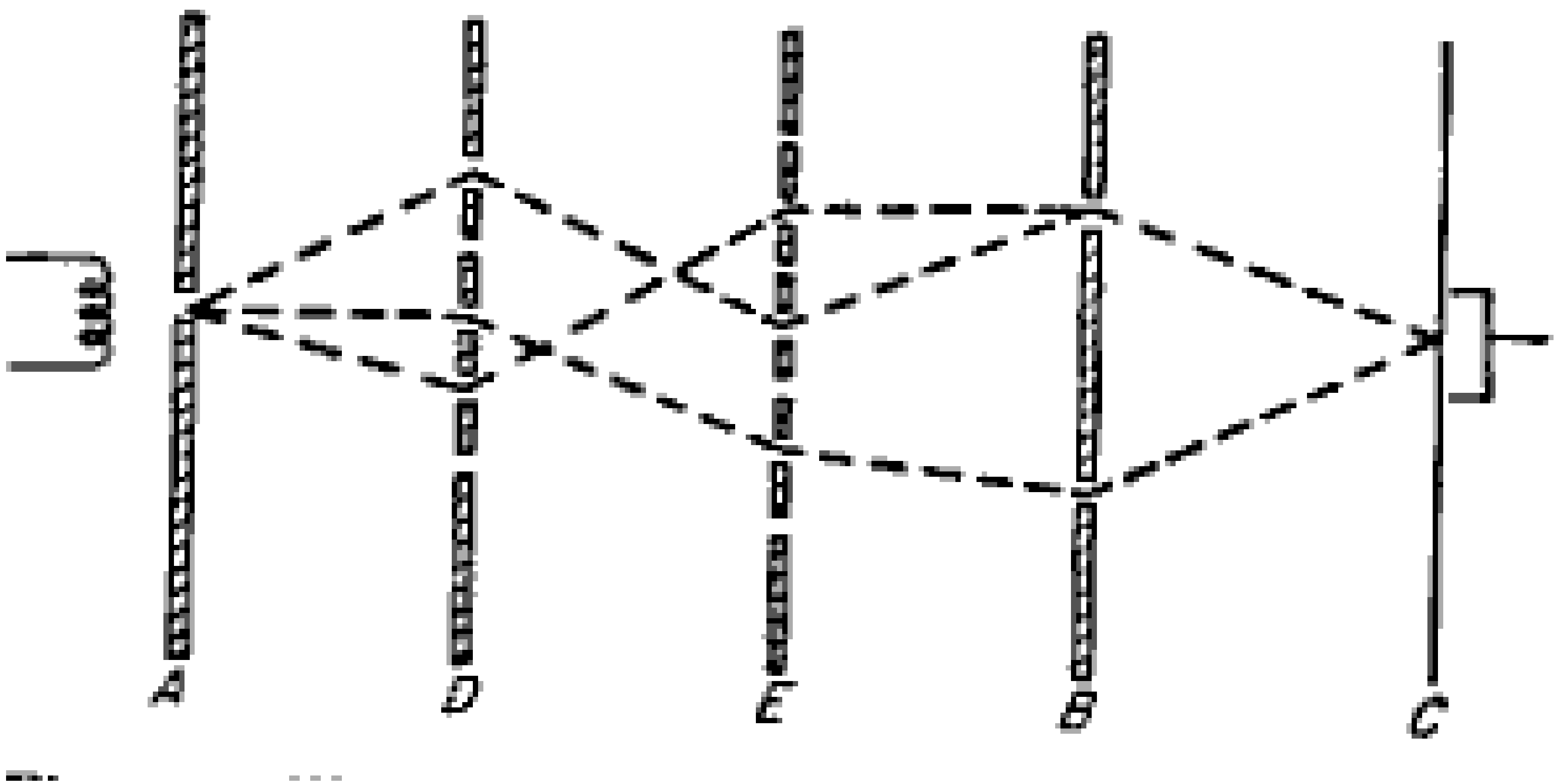
We choose to examine a phenomenon which is impossible, absolutely impossible, to explain in any classical way, and which has in it the heart of quantum mechanics. In reality, it contains the only mystery. We cannot make the mystery go away by 'explaining' how it works. We will just tell you how it works. In telling you how it works we will have told you about the basic peculiarities of all quantum mechanics. - - Feynman

Quantum: A guide for the perplexed -- Al-Khalili

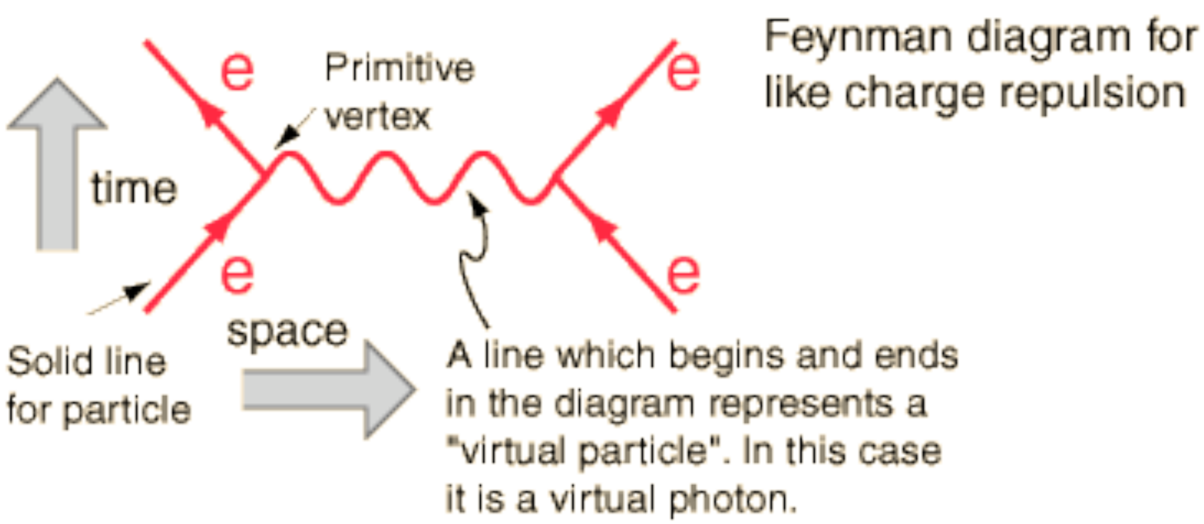
double slit experiment

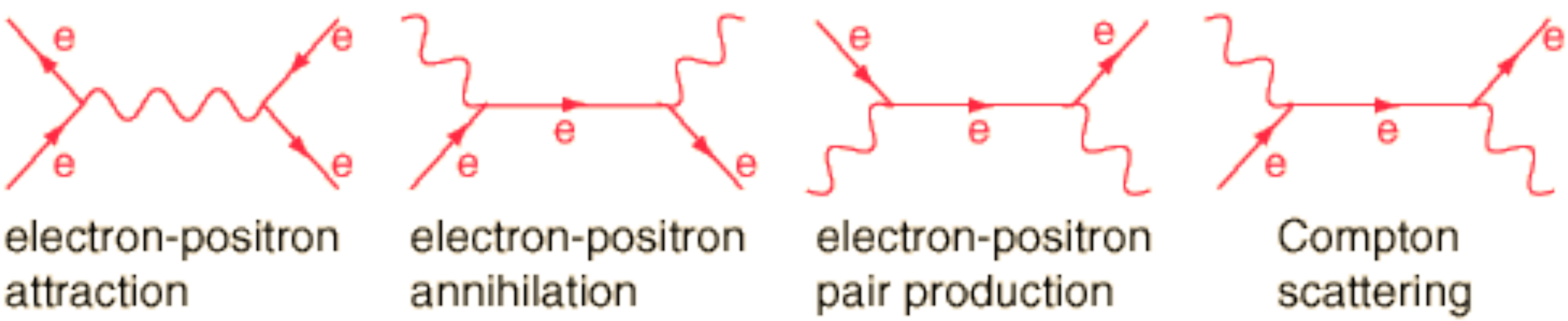


path integrals

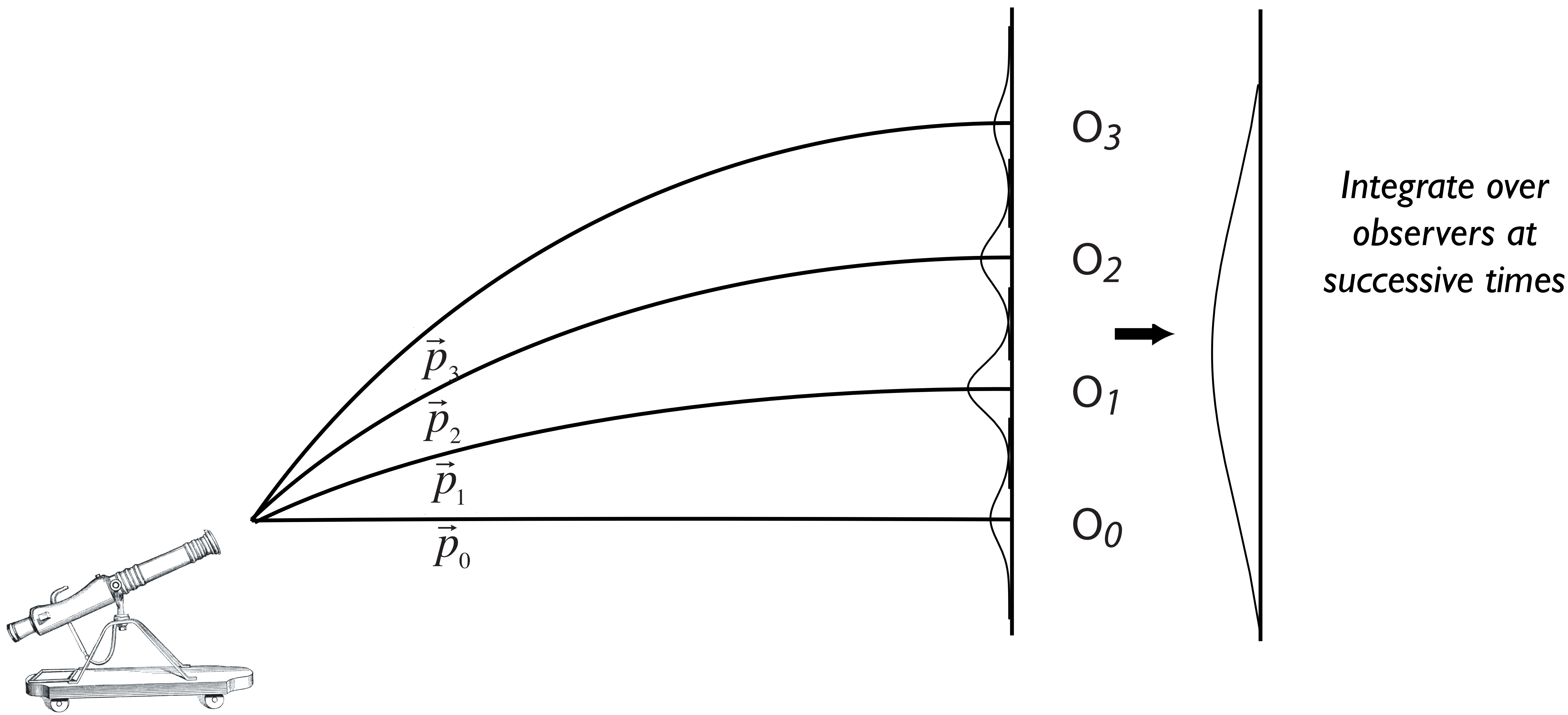


Feynman diagrams





Geodesic time

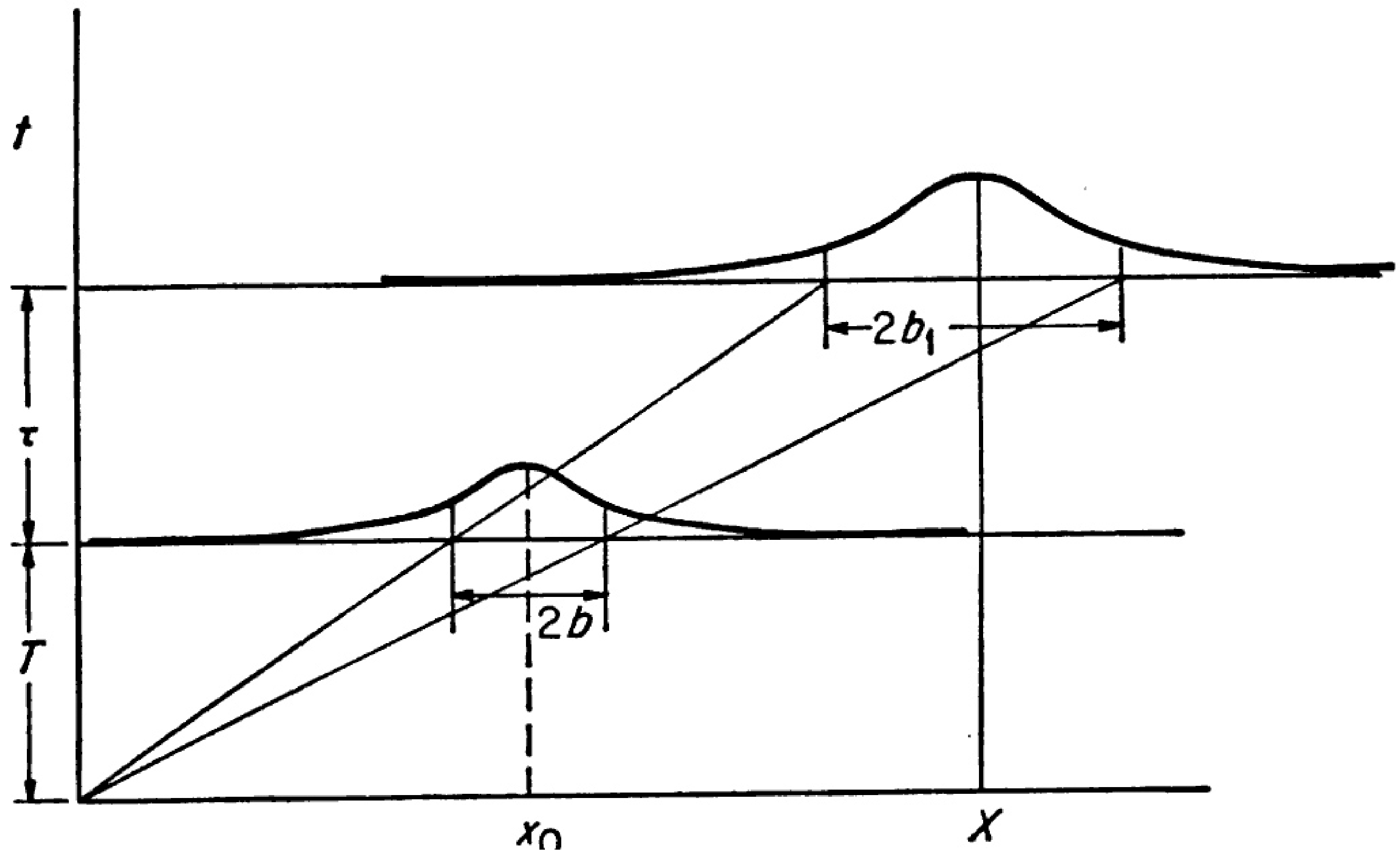


almost no change

- path integrals add sum over paths in time to sum over paths in space
- just 4/3 more algebra
- and a few technical complications which I will not distress you with

did you break anything

- internal contradictions?
- consistent in appropriate limits?
- should it have been seen already?



- thanks to a subtlety of relativistic mechanics, the average trajectory is identical for both quantum time & regular time
- quantum time packets do spread more in time

beam & apparatus must change

- have to send a beam which is changing in time
- through a gate which is open and closed
- normally, we let beams settle down, but now it is fiddly bits at the ends we are interested in

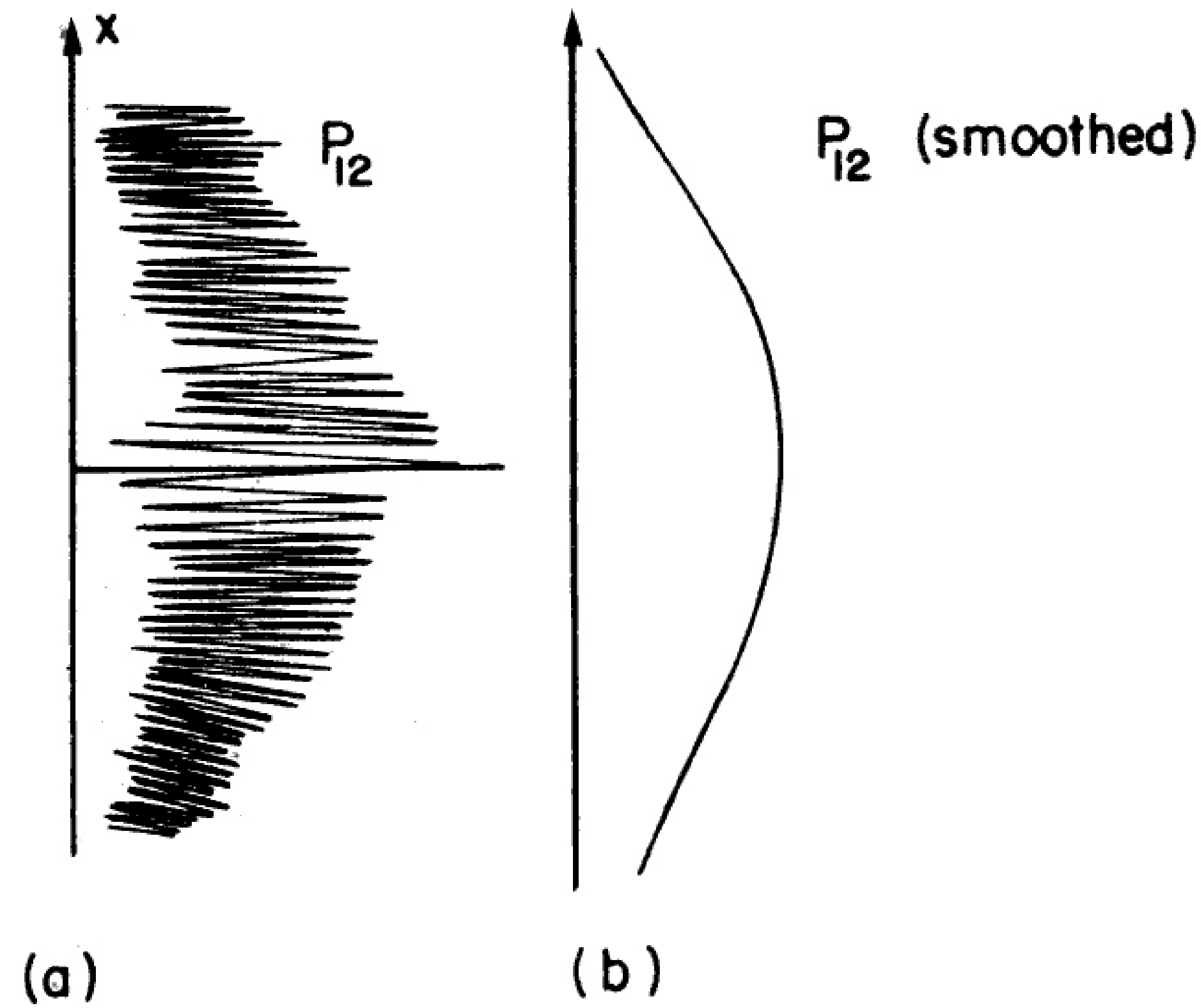
why bound states?

- Bohr rule: fits evenly around the atom
- what is "fits evenly" in time?
- But only those orbits which "fit evenly" add coherently

mass is measure of width in time

- larger is wider
- for electrons, is 10 to the -21st seconds (zeptoseconds)
- for photons is zero (so you can't find effect using only photons)

coherent interference



Experimental tests

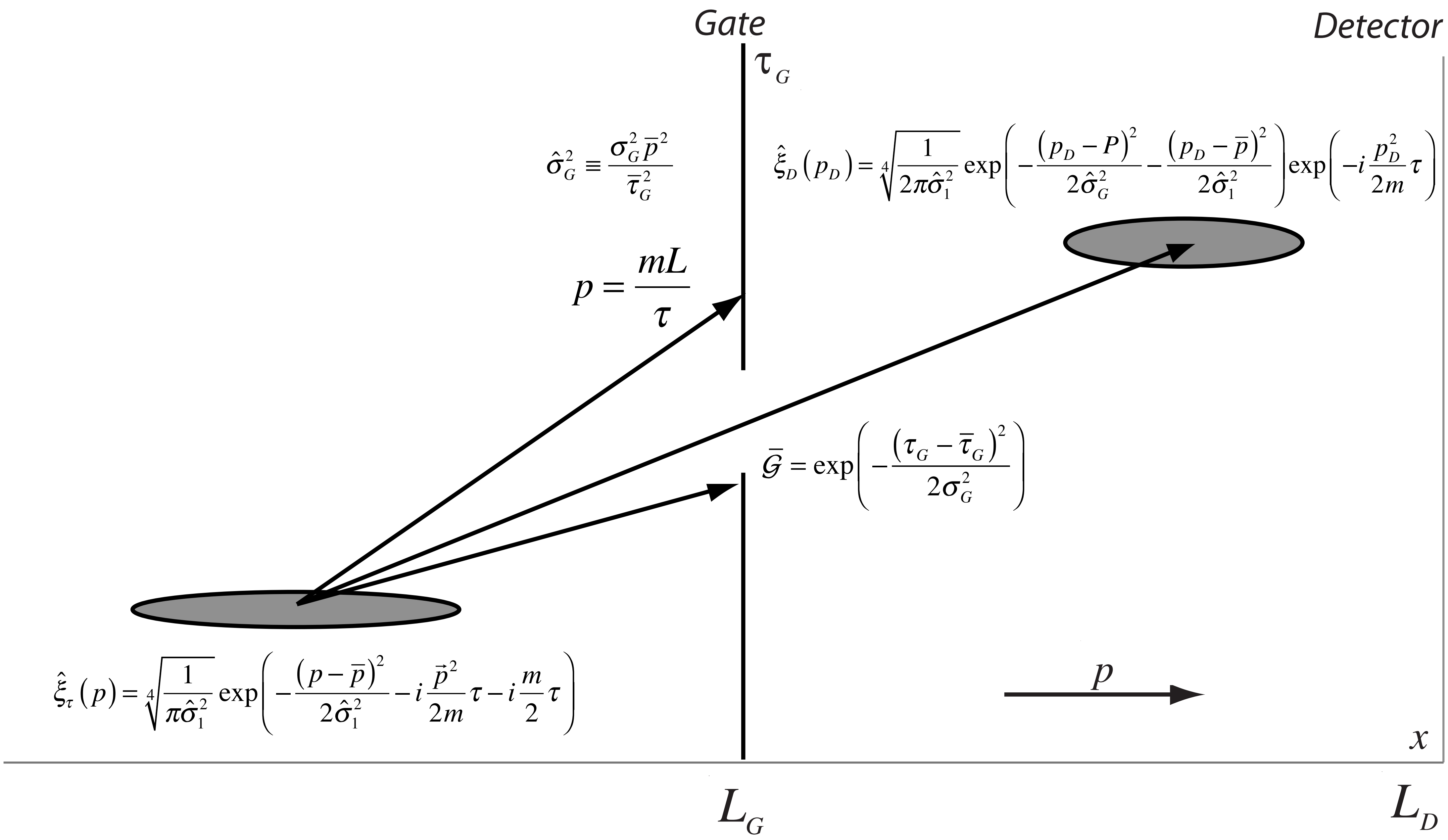
- Perhaps 300 experiments in Auletta alone
- Interchange time and a space dimension, get a test of quantum time
- We look at a few here

S. K. Lamoreaux, A Review of the Experimental Tests of Quantum Mechanics, 1992

P. Ghose, Testing quantum mechanics on new ground, 1999

G. Auletta, Foundations and Interpretation of Quantum Mechanics: In the Light of a Critical-Historical Analysis of the Problems and of a Synthesis of the Results, 2000

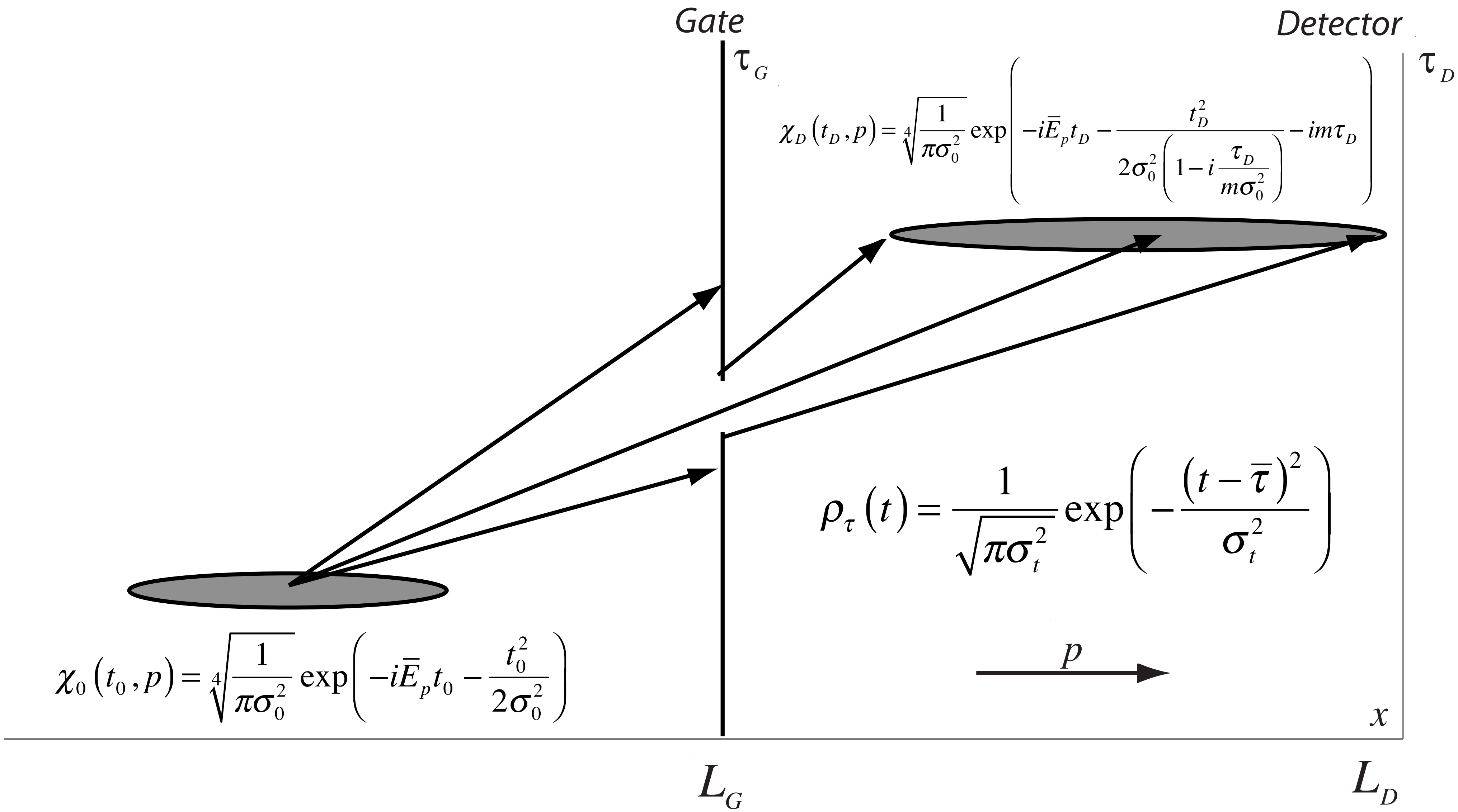
Single slit in laboratory time



$$\hat{\sigma}_1^{(eff)2} \equiv \frac{\hat{\sigma}_G^2 \hat{\sigma}_1^2}{\hat{\sigma}_G^2 + \hat{\sigma}_1^2}$$

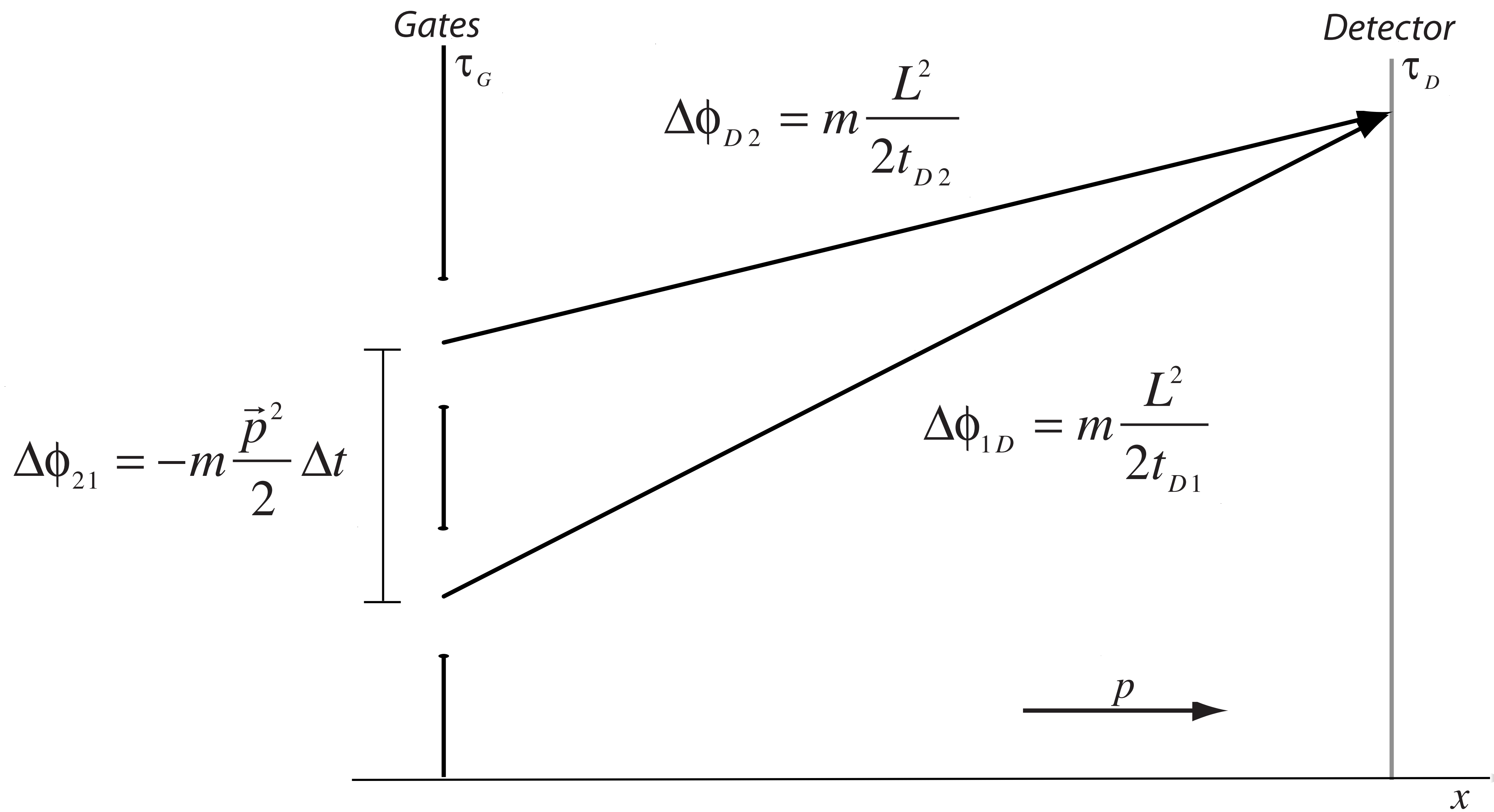
$$\bar{\sigma}_\tau^2 = \frac{\bar{\tau}_D^2}{\bar{p}^2} \hat{\sigma}_1^{(eff)2}$$

And in quantum time



$$\sigma_t^2 = \frac{\sigma_G^2\sigma_0^2}{\sigma_G^2 + \sigma_0^2} + \frac{1}{m^2}\left(\frac{1}{\sigma_0^2} + \frac{1}{\sigma_G^2}\right)\bar{\tau}_D^2 + \frac{\hat{\sigma}_1^2}{\bar{p}^2}\bar{\tau}_D^2$$

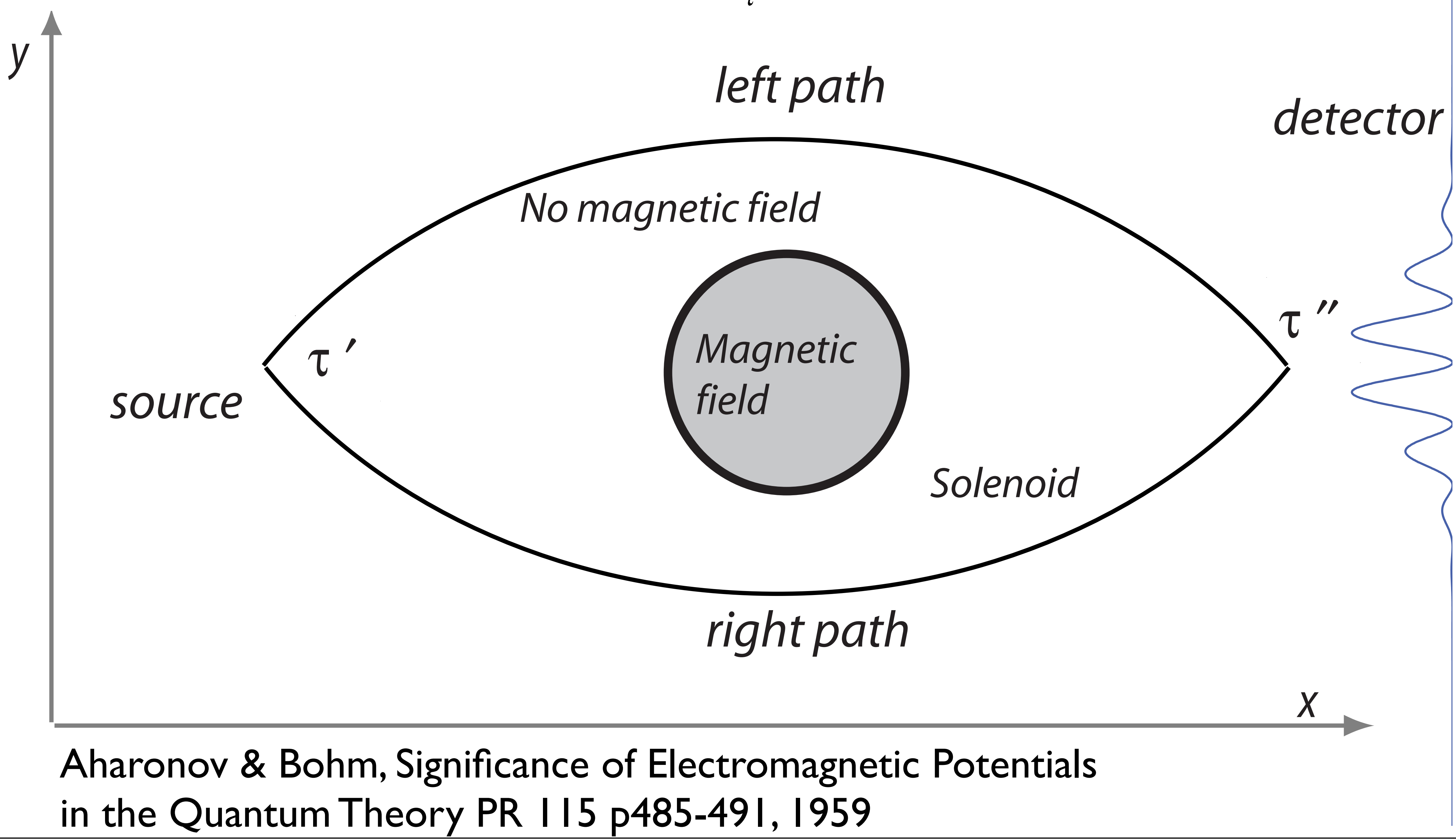
Double slit in time



$$\exp(-iEt) = \exp\left(-i\sqrt{m^2 + \vec{p}^2}\,t\right) = \exp\left(-imt - i\frac{\vec{p}^2}{2m}t\right) \xrightarrow{\langle t\rangle \to \tau} \exp\left(i\frac{\vec{p}^2}{2m}\tau\right)$$

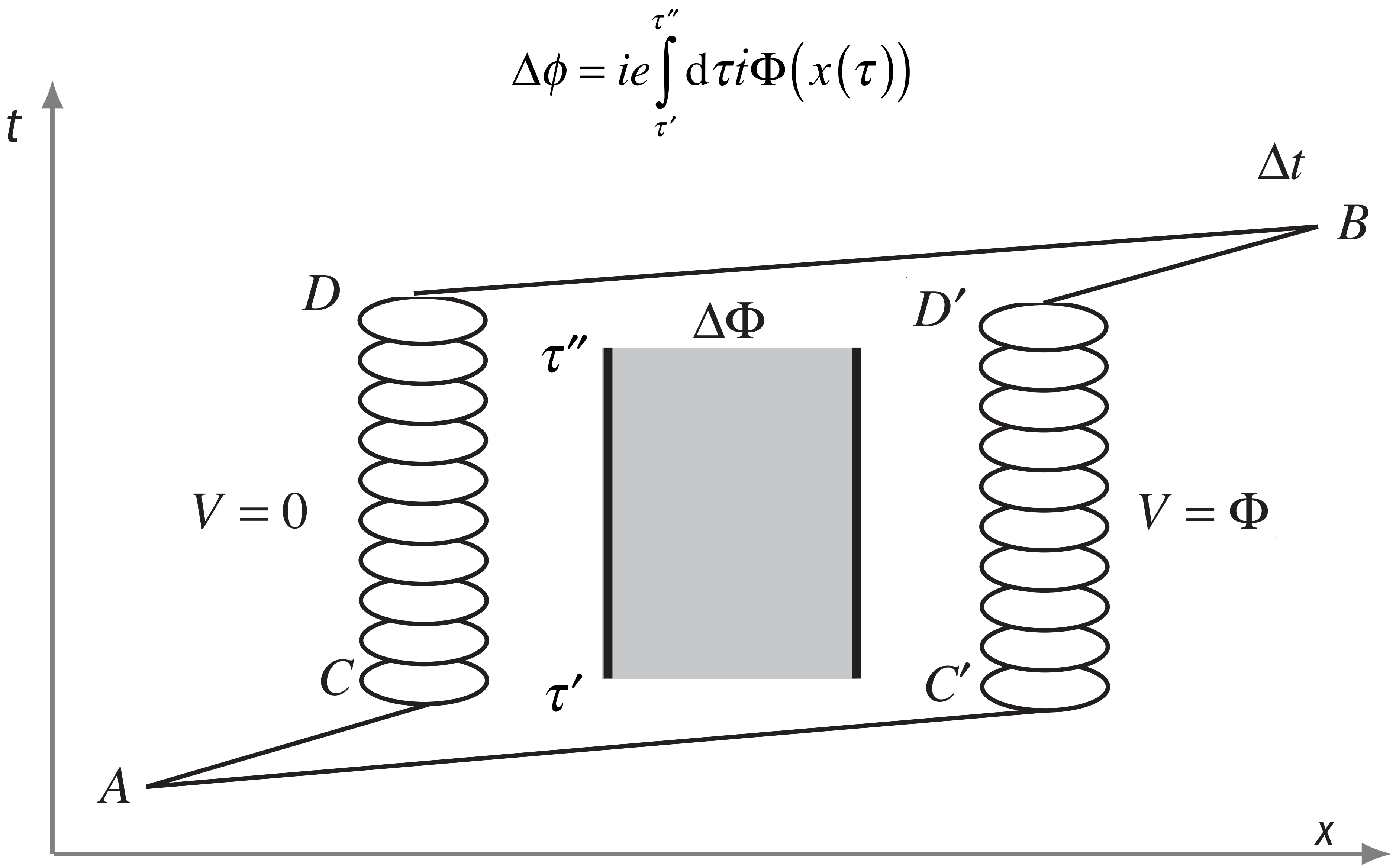
Aharonov-Bohm experiment

$$\Delta\phi = ie\int_{\tau'}^{\tau''} \mathrm{d}\tau \dot{\vec{x}} \cdot \vec{A}\left(\vec{x}(\tau)\right)$$

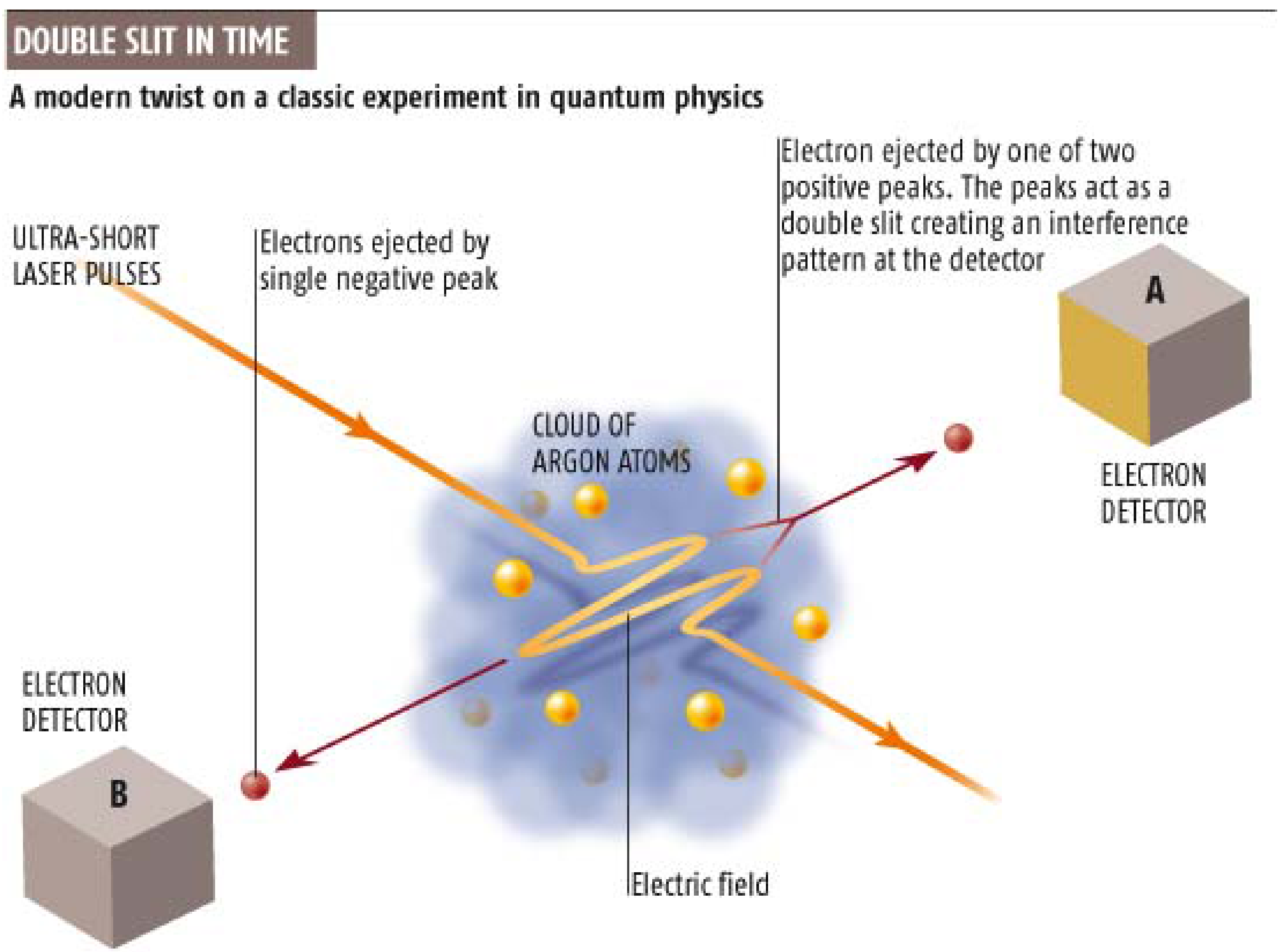


Aharonov & Bohm, Significance of Electromagnetic Potentials in the Quantum Theory PR 115 p485-491, 1959

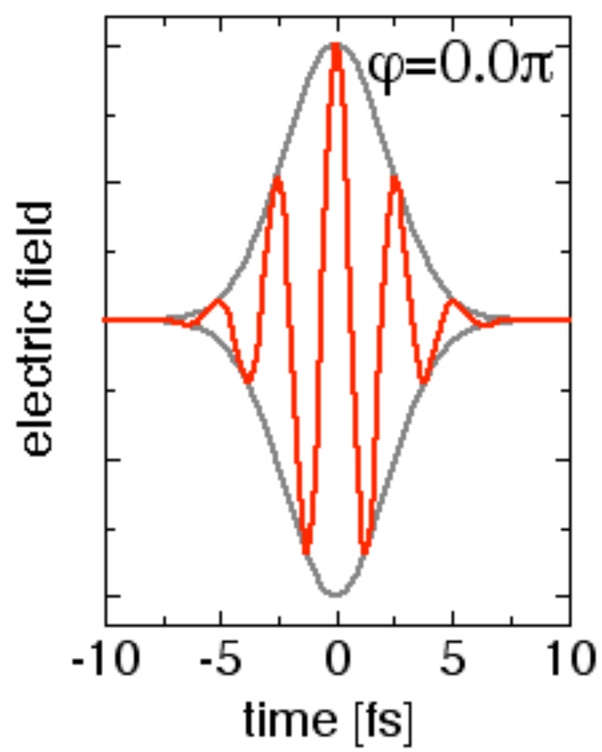
Aharonov-Bohm in time

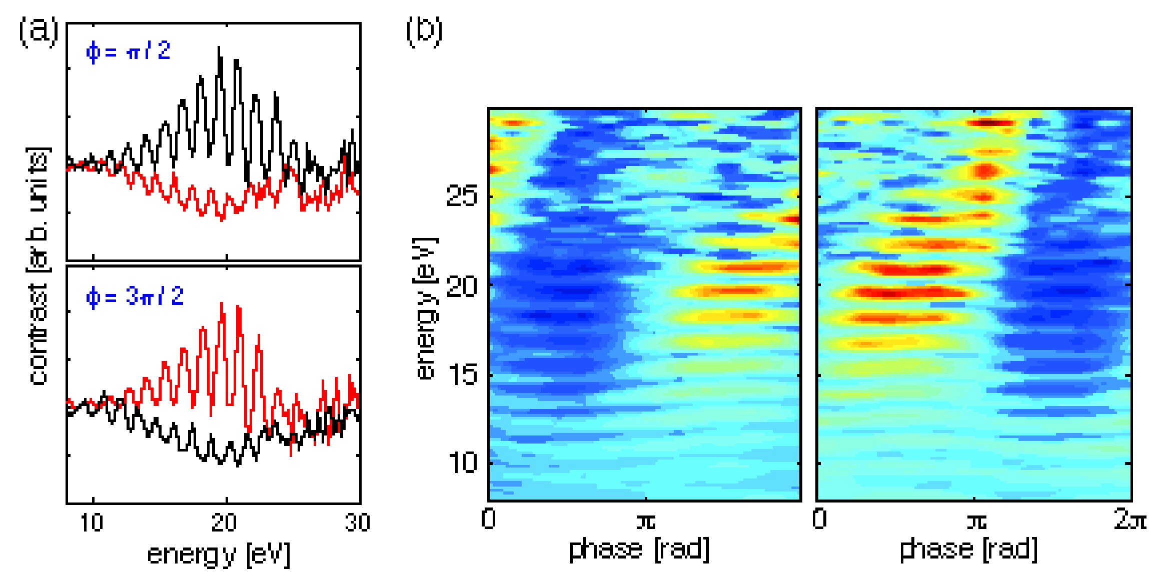


Lindner's double slit in time



Short photon pulse acts like two gates





review of requirements

- well-defined
- symmetric between time and space
- consistent with known
- testable
- reasonably simple

uses

- fun with time
- 300+ experiments
- starting point for quantum gravity
- covert transmissions
- quantum computers

Quantum Time

John Ashmead

$$K_\tau(x'';x') = \int \mathcal{D}x \exp\left(-i\sum_{j=1}^{N+1} m\frac{\left(x_j - x_{j-1}\right)^2}{2\varepsilon} - ie\left(x_j - x_{j-1}\right)\frac{A\left(x_j\right) + A\left(x_{j-1}\right)}{2} - i\frac{m}{2}\tau \right)$$

$$i\frac{d\psi_\tau(x)}{d\tau} = \left(-\frac{\left(E - e\Phi(x)\right)^2}{2m} + \frac{\left(\vec{p} - e\vec{A}(x)\right)^2}{2m} + \frac{m}{2} \right)\psi_\tau(x)$$

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thanks!

- Miriam Kelly
- Jonathan Smith
- Ferne Welch
- Graham & Gaylord Ashmead
- Linda Kalb
- Stewart Personick
- Fred Herz
- Host of quasi-willing ears

- The End of Time - Julian Barbour
- Time Travel in Einstein's Universe - J. Richard Gott
- Physics of the Impossible - Michio Kaku
- Time Traveler - Ronald L. Mallett
- Time's Arrow & Archimedes' Point - Huw Price
- Timeless Reality - Victor J. Stenger
- The New Time Travelers - David Toomey