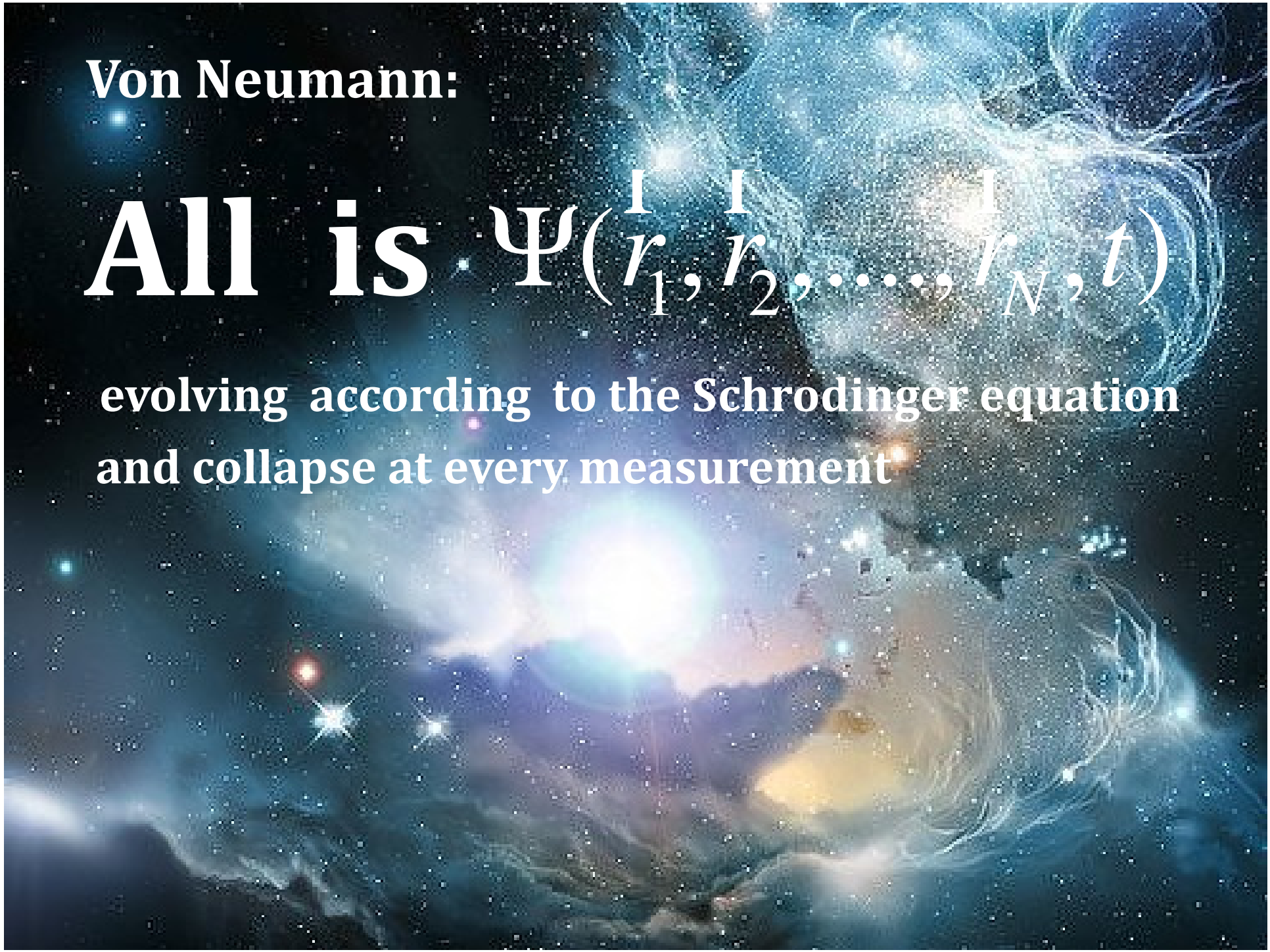

Ontology of the wave function
Lev Vaidman
Vienna 25.10.2015
GIF
EmQM15
Emergent Quantum Mechanics
3rd International Symposium about Quantum Mechanics based on a »Deeper Level Theory«


Quantum Mechanics:
All is Ψ
We do not need a Deeper Level Theory
3rd International Symposium about Quantum Mechanics based on a »Deeper Level Theory«


Von Neumann:
All is $\Psi(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t)$
evolving according to the Schrodinger equation
and collapse at every measurement

Quantum Mechanics: All is Ψ

PROBLEM:

EXPERIENCE $\Leftrightarrow$ $\Psi(\vec{r}_1, \vec{r}_2, ..., \vec{r}_N, t)$

$\Psi(\vec{r}_1, \vec{r}_2, ..., \vec{r}_N, t)$ **IS IN 3N D**

and two postulates:

EXPERIENCE $\Leftrightarrow$ Ψ_{WORLD}

BORN RULE

Schrodinger equation

Collapses at measurements

Or collapses by GRW-Pearle CSL

Bohmian Quantum Mechanics:

All is Ψ

and Bohmian trajectories

Schrodinger equation

EXPERIENCE ⇔ BOHMIAN POSITIONS

BOHMIAN POSITIONS ARE IN 3D

GRW Flashes Quantum Mechanics:

All is Ψ

and GRW Flashes

Schrodinger equation

and collapses at GRW Flashes

EXPERIENCE ⇔ GRW FLASHES

GRW FLASHES ARE IN 3D

Quantum Mechanics:

All is Ψ

Schrodinger equation

Collapses at measurements

Or collapses by GRW-Pearle CSL

PROBLEM:

EXPERIENCE $\Leftrightarrow$ $\Psi(\vec{r}_1, \vec{r}_2, ..., \vec{r}_N, t)$

$\Psi(\vec{r}_1, \vec{r}_2, ..., \vec{r}_N, t)$ **IS IN 3N D**

and two postulates:

EXPERIENCE $\Leftrightarrow$ Ψ_{WORLD}

BORN RULE

WORLD WAVE FUNCTION:

Quantum states of all macroscopic objects are Localized Wave Packets all the time

$$\Psi_{WORLD} = \psi^1_{CM}(\vec{r}^{\,CM}_1)\,\varphi^1_{rel}(\vec{r}_{1i} - \vec{r}_{1j})\,\psi^2_{CM}(\vec{r}^{\,CM}_2)\,\varphi^2_{rel}(\vec{r}_{2i} - \vec{r}_{2j})\ldots\psi^M_{CM}(\vec{r}^{\,CM}_M)\,\varphi^1_{rel}(\vec{r}_{Mi} - \vec{r}_{Mj})\,\Phi^{REST}$$

WE LIVE IN 3D!

EXPERIENCE $\Leftrightarrow$ $\Psi_{WORLD} \cong \Psi_{von\ N} \cong \Psi_{GRWP}$

Ψ **with all macroscopic objects in 3D**

All is Ψ

Quantum Mechanics:

Schrodinger equation

Collapses at measurements

Or collapses by GRW-Pearle CSL

COLLAPSE IS A PROBLEM!

and two postulates:

EXPERIENCE $\Leftrightarrow$ Ψ_{WORLD}

BORN RULE

WORLD WAVE FUNCTION:

Quantum states of all macroscopic objects are Localized Wave Packets all the time

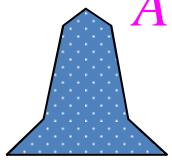
$$\Psi_{WORLD} = \psi^{1}_{CM}(\vec{r}^{\,CM}_{1})\,\varphi^{1}_{rel}(\vec{r}_{1i}-\vec{r}_{1j})\,\psi^{2}_{CM}(\vec{r}^{\,CM}_{2})\,\varphi^{2}_{rel}(\vec{r}_{2i}-\vec{r}_{2j})\ldots\psi^{M}_{CM}(\vec{r}^{\,CM}_{M})\,\varphi^{1}_{rel}(\vec{r}_{Mi}-\vec{r}_{Mj})\,\Phi^{REST}$$

WE LIVE IN 3D!

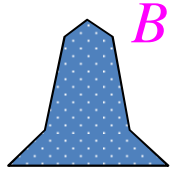
EXPERIENCE $\Leftrightarrow$ $\Psi_{WORLD} \cong \Psi_{von\,N} \cong \Psi_{GRWP}$

Ψ with all macroscopic objects in 3D

All is $|\Psi\rangle$ + Collapse $\Rightarrow$ **randomness action at a distance**



$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|a\rangle + |b\rangle) = \frac{1}{\sqrt{2}}(|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B)$$



$$\rho_A = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \qquad \rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$$

MEASUREMENT IN *A*: $P_A = ?$

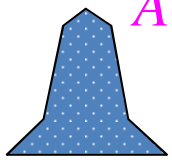
$P_A = 1$

OR

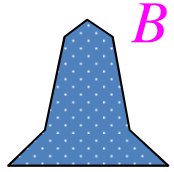
$P_A = 0$

$$\rho_B \rightarrow \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \quad \text{OR} \quad \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$$

All is $|\Psi\rangle$ + Collapse $\Rightarrow$ **randomness action at a distance**



$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|a\rangle + |b\rangle) = \frac{1}{\sqrt{2}}(|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B)$$



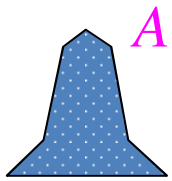
$$\rho_A = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$$

$$\rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$$

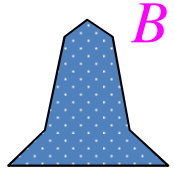
NO MEASUREMENT IN *A* : $P_A = ?$

NO CHANGE

All is $|\Psi\rangle$ + Collapse $\Rightarrow$ **randomness action at a distance**



$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|a\rangle + |b\rangle) = \frac{1}{\sqrt{2}}(|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B)$$



$$\rho_A = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$$

$$\rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$$

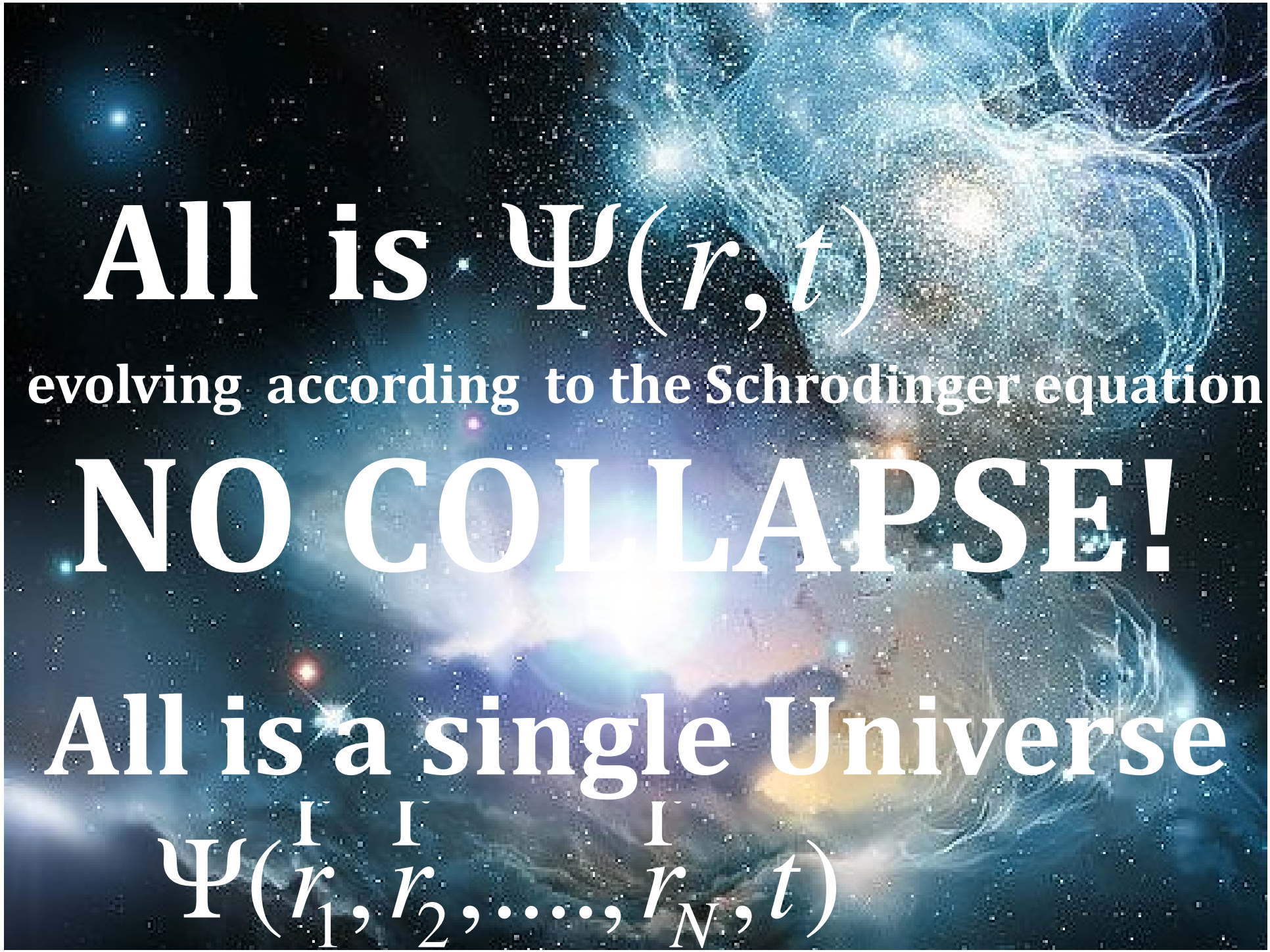
MEASUREMENT IN *A* : $P_A = ?$

NO CHANGE

no collapse

$$\frac{1}{\sqrt{2}}|R\rangle_{MD}(|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B)$$

$$\rightarrow \frac{1}{\sqrt{2}}(|1\rangle_{MD} |1\rangle_A |0\rangle_B + |0\rangle_{MD} |0\rangle_A |1\rangle_B)$$


All is $\Psi(r,t)$
evolving according to the Schrodinger equation
NO COLLAPSE!
All is a single Universe
$\Psi(\vec{r}_1,\vec{r}_2,\ldots,\vec{r}_N,t)$

Quantum Mechanics: All is Ψ

Schrodinger equation

and two postulates:

$\text{EXPERIENCE} \Leftrightarrow \Psi_{WORLD}$

WORLD WAVE FUNCTION:

Quantum states of all macroscop
objects are Localized Wave Packet
all the time

$$\Psi_{WORLD} = \psi^1_{CM}(\vec{r}^{\,CM}_1)\,\varphi^1_{rel}(\vec{r}_{1i} - \vec{r}_{1j})\,\psi^2_{CM}(\vec{r}^{\,CM}_2)\,\varphi^2_{rel}(\vec{r}_{2i} - \vec{r}_{2j})\ldots\psi^M_{CM}(\vec{r}^{\,CM}_M)\,\varphi^1_{rel}(\vec{r}_{Mi} - \vec{r}_{Mj})\,\Phi^{REST}$$

$\text{EXPERIENCE} \Leftrightarrow \Psi_{WORLD} \cong \Psi_{von\,N} \cong \Psi_{GRWP}$

WE LIVE IN 3D!

Ψ with all macroscopic objects in 3D

Quantum Mechanics: All is Ψ

Schrodinger equation

and two postulates:

EXPERIENCE $\Leftrightarrow$ Ψ_{WORLD}

WORLD WAVE FUNCTION:

Quantum states of all macroscopic objects are Localized Wave Packets all the time

BORN-VAIDMAN RULE:

Probability of self-location in a particular world is proportional to its "measure of existence"

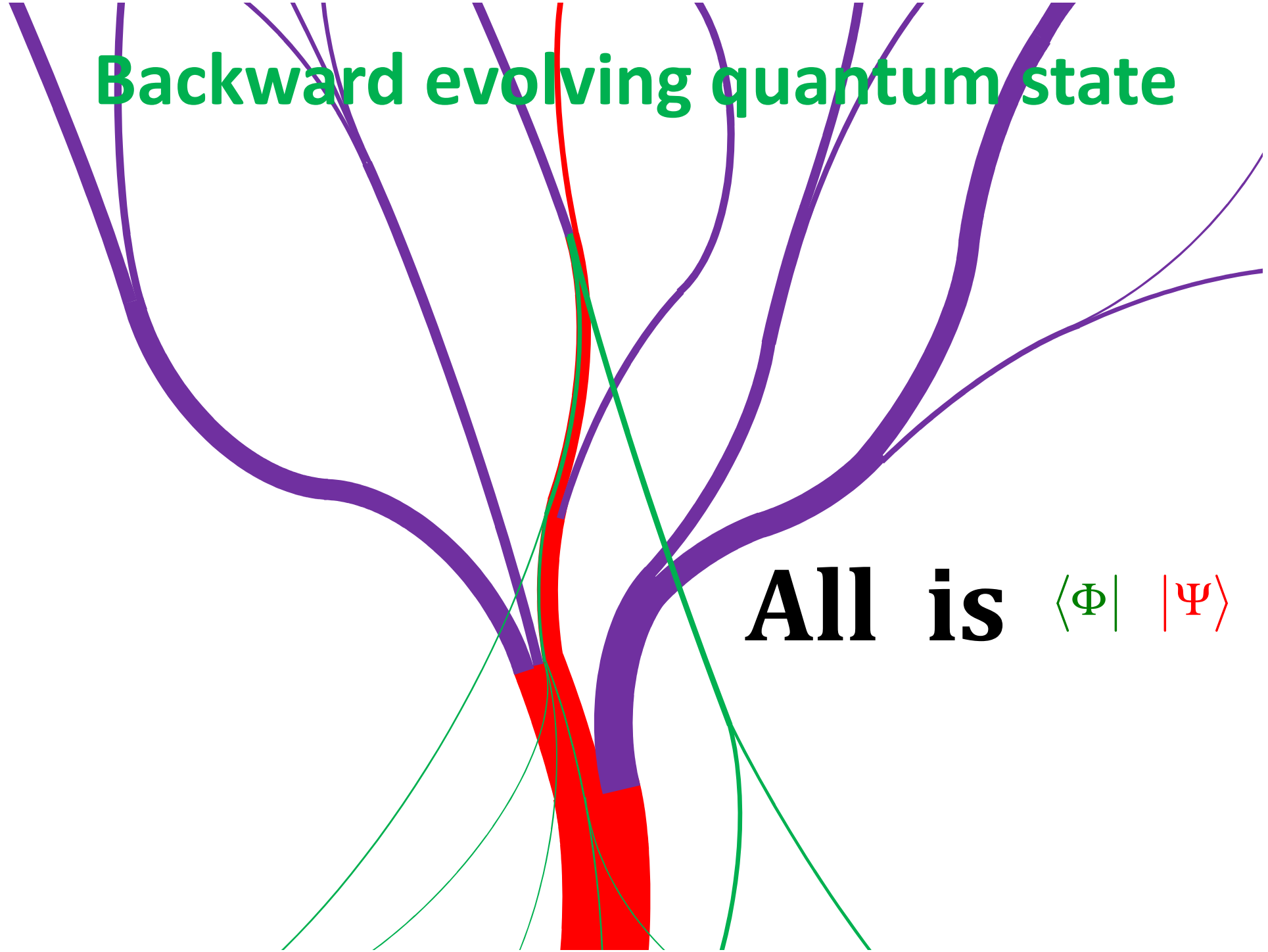
$$\Psi_{WORLD} = \psi^1_{CM}(\vec{r}^{\,CM}_1)\,\varphi^1_{rel}(\vec{r}_{1i} - \vec{r}_{1j})\,\psi^2_{CM}(\vec{r}^{\,CM}_2)\,\varphi^2_{rel}(\vec{r}_{2i} - \vec{r}_{2j})\ldots\psi^M_{CM}(\vec{r}^{\,CM}_M)\,\varphi^1_{rel}(\vec{r}_{Mi} - \vec{r}_{Mj})\,\Phi^{REST}$$

EXPERIENCE $\Leftrightarrow$ $\Psi_{WORLD} \cong \Psi_{von\,N} \cong \Psi_{GRWP}$

WE LIVE IN 3D!

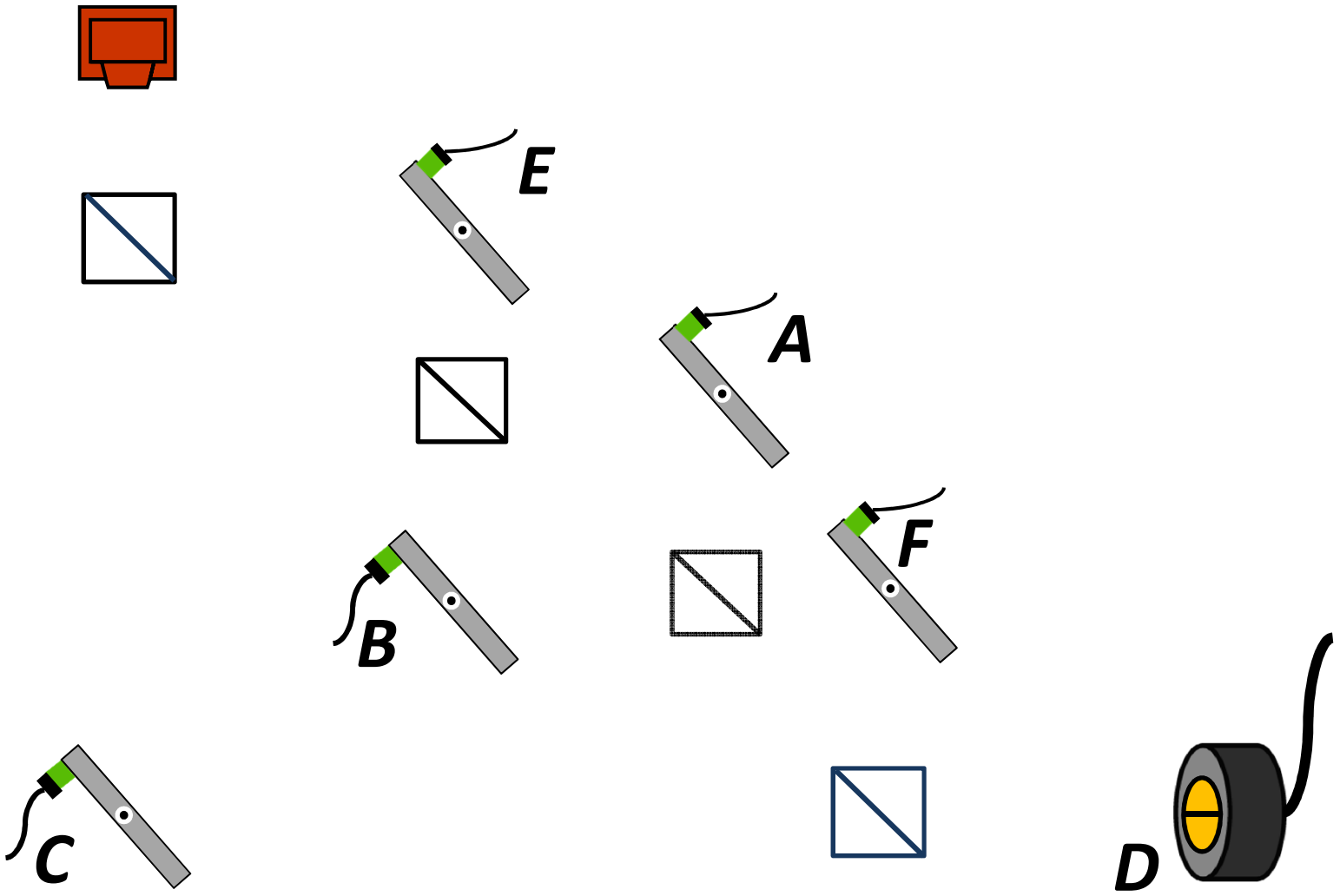
Ψ with all macroscopic objects in 3D

Backward evolving quantum state



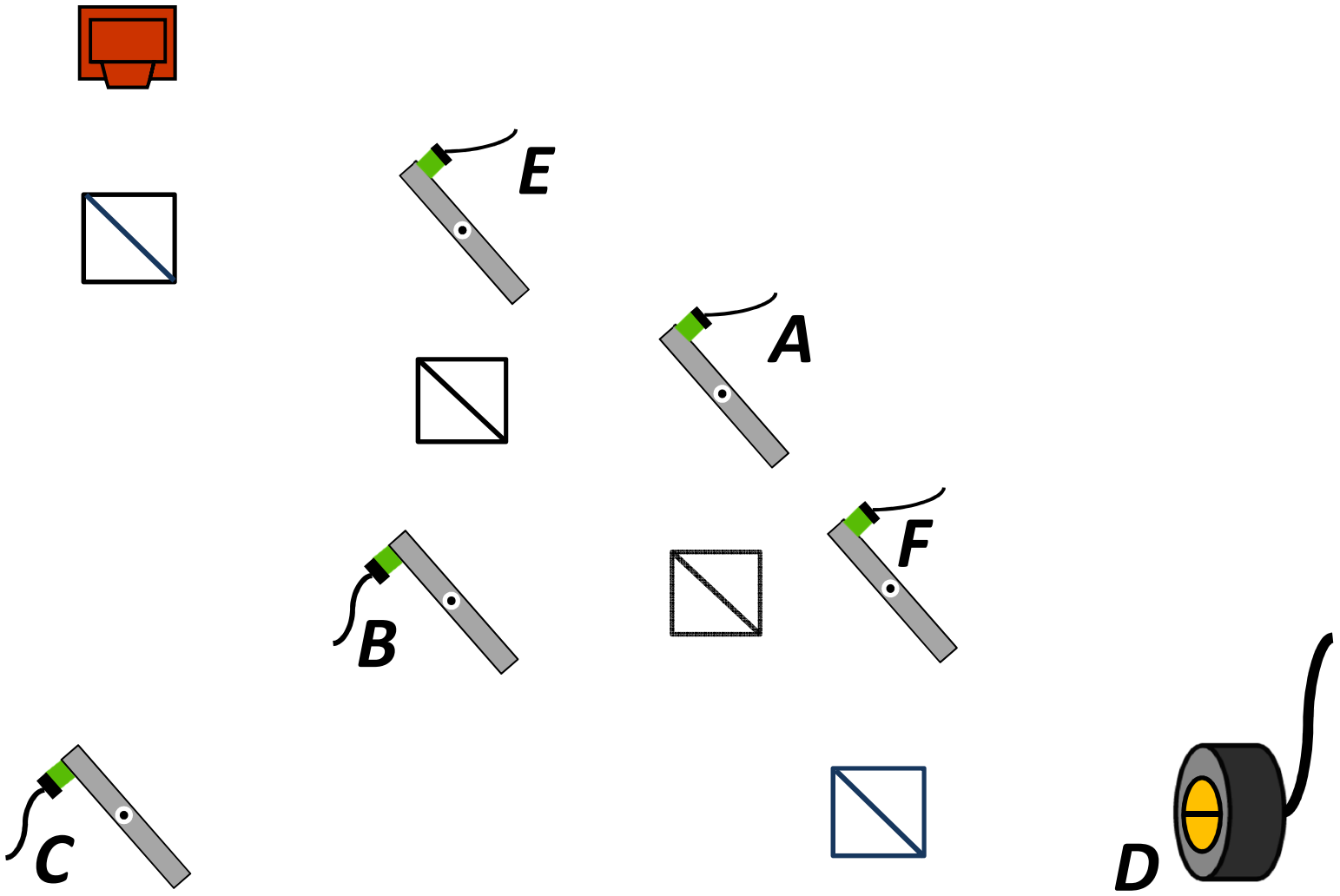
Past of a pre- and post-selected photon

FORWARD EVOLVING QUANTUM STATE



Past of a pre- and post-selected photon

BACKWARD EVOLVING QUANTUM STATE

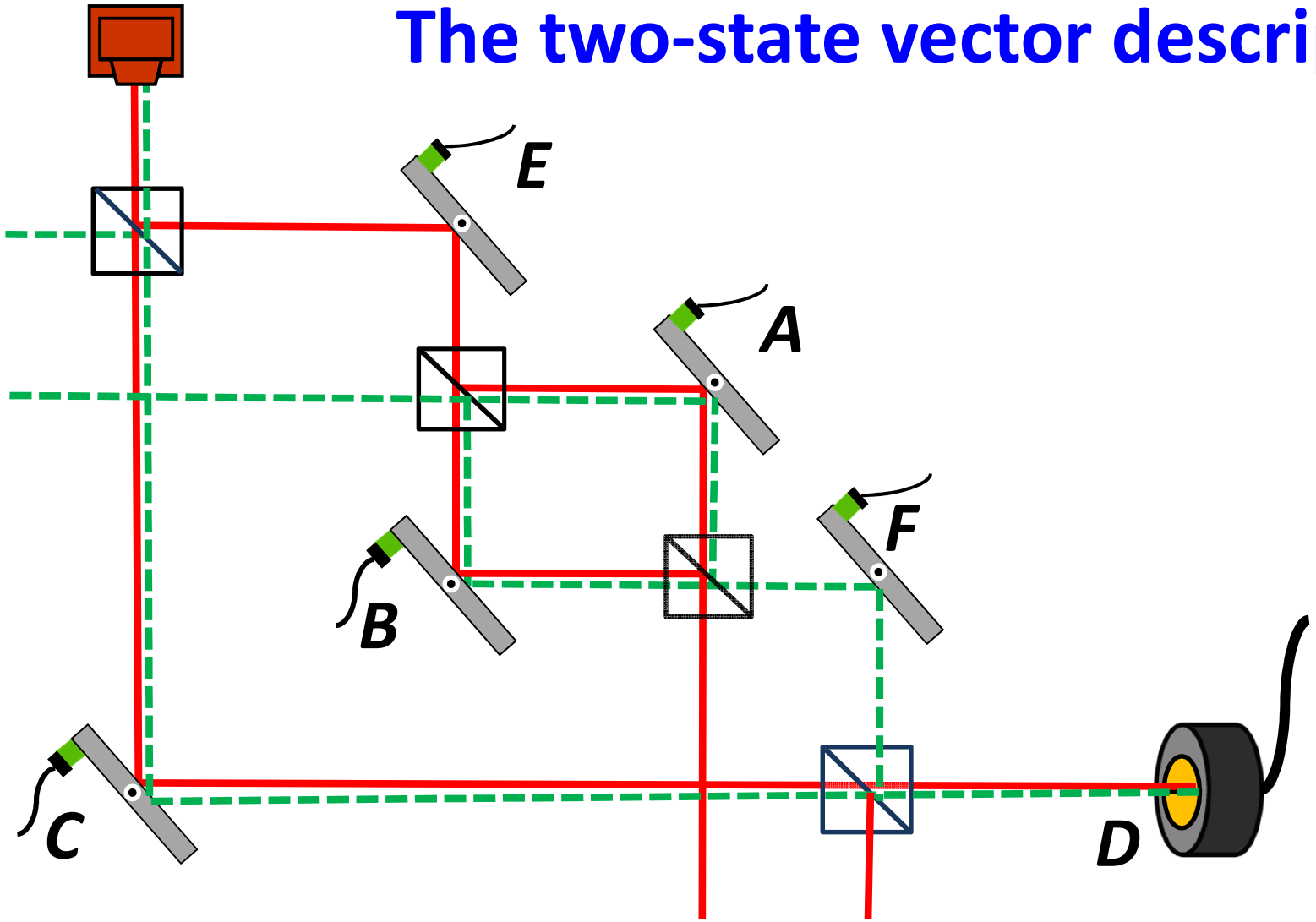


Past of a pre- and post-selected photon

FORWARD EVOLVING QUANTUM STATE

BACKWARD EVOLVING QUANTUM STATE

The two-state vector description

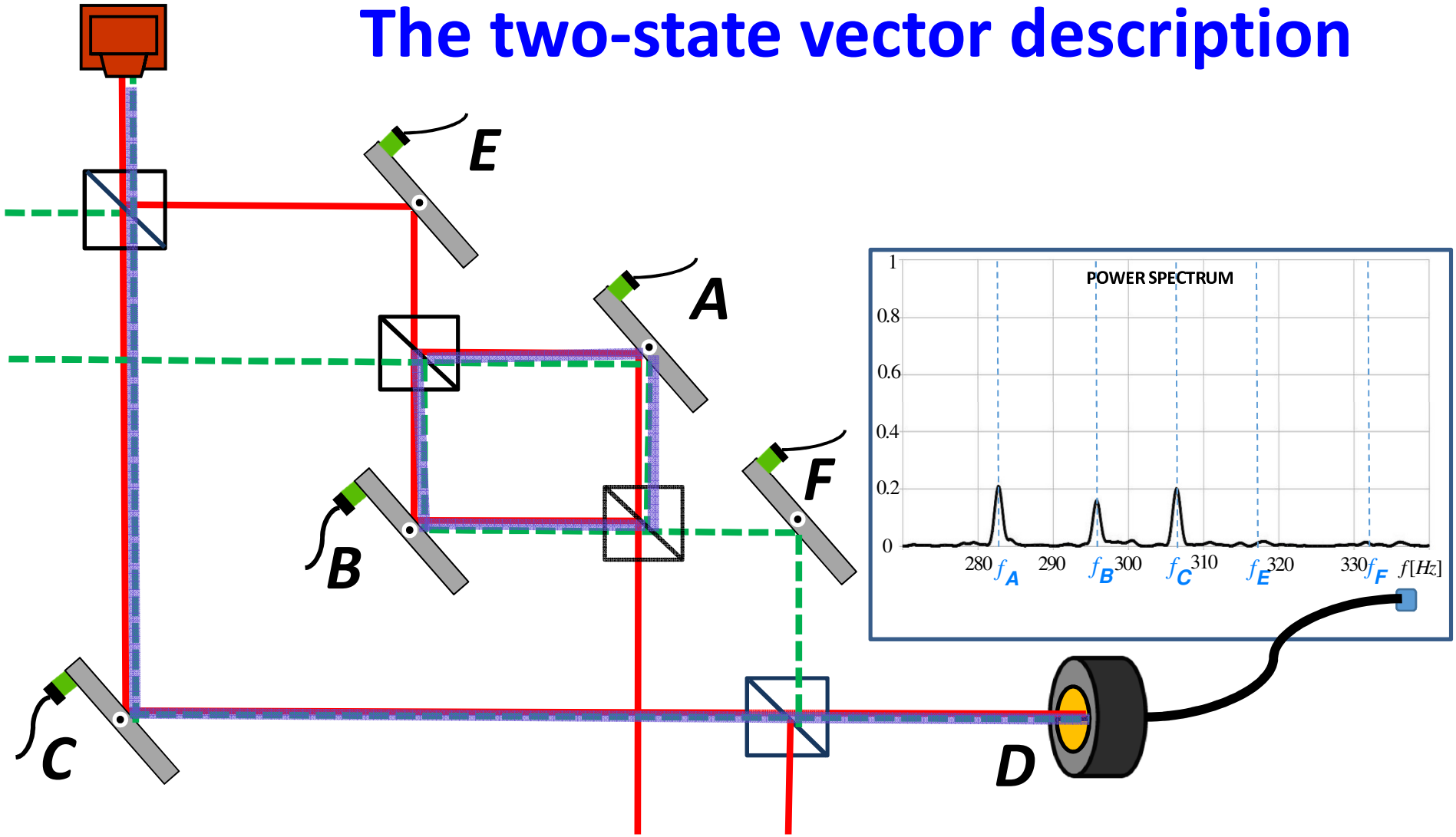


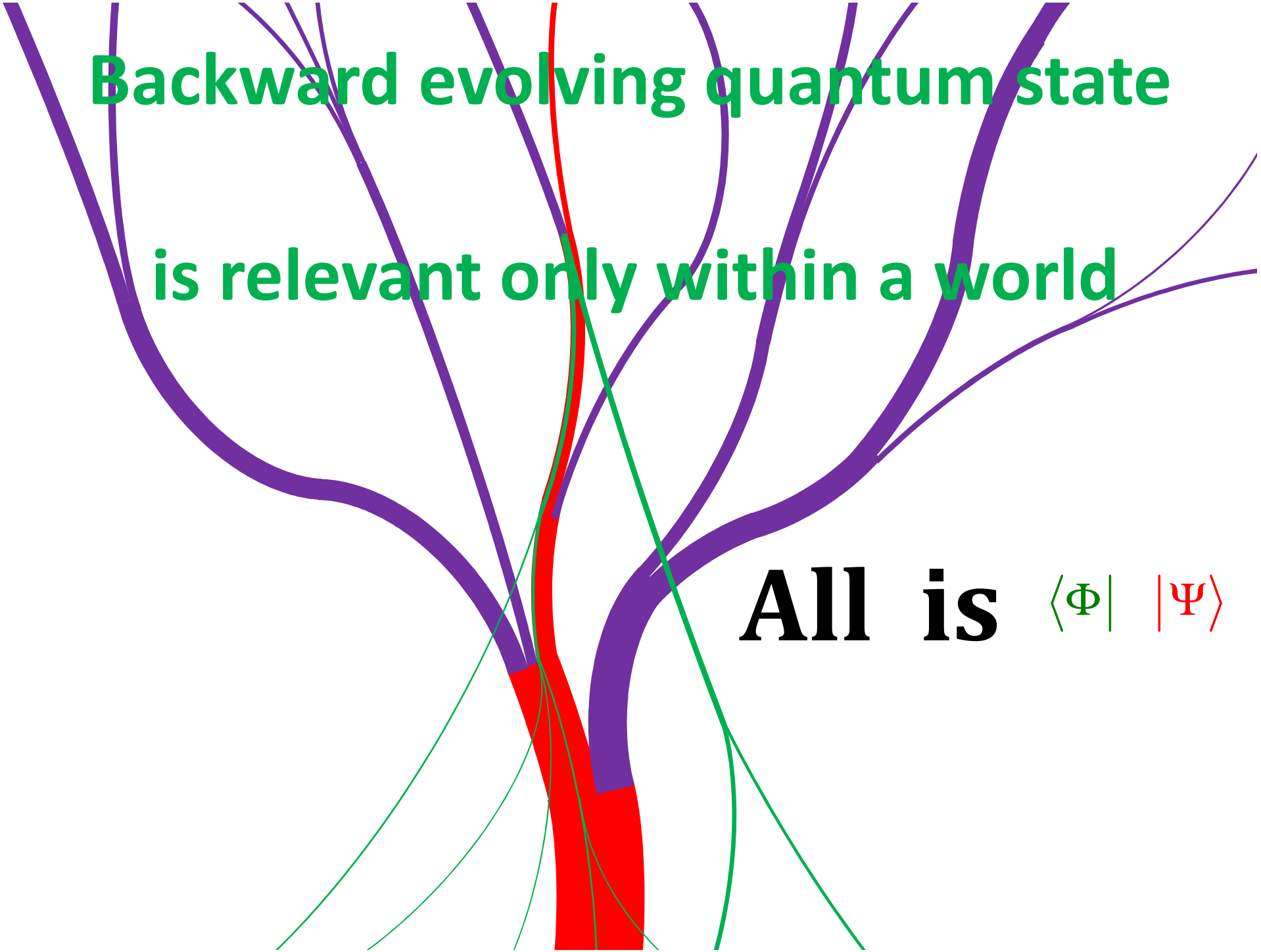
Past of a pre- and post-selected photon

FORWARD EVOLVING QUANTUM STATE

BACKWARD EVOLVING QUANTUM STATE

The two-state vector description




Backward evolving quantum state
is relevant only within a world
All is ⟨Φ| |Ψ⟩

Universal backward evolving quantum state

is the time reversal of the forward evolving quantum state

Summary

The only fundamental ontology of the physical Universe is WFU
Its evolution deterministic and it has no action at a distance

To explain our experience(s) we introduce the concept of a world with corresponding WWF. It is the same as in a collapse interpretation.

Essentially, WWF lives in 3D space

***We* may consider WWFs as ontology too, but it has a different status.**
The evolutions of WWFs are nondeterministic and nonlocal.

It is useful for *us* to describe a world with a TSV (forward and backward evolving WFWs) and, more economically, by their overlapping parts.

Summary

The only fundamental ontology of the physical Universe is WFU

Its evolution deterministic and it has no action at a distance

To explain our experience(s) we introduce the concept of a world with corresponding WWF. It is the same as in a collapse interpretation.

Essentially, WWF lives in 3D space

We may consider WWFs as ontology too, but it has a different status.

The evolutions of WWFs are nondeterministic and nonlocal.

It is useful to describe a world with a TSV (forward and backward evolving WFWs) and, more economically, by their overlapping parts.

There is no (new) backward evolving WFU.

Summary

The only fundamental ontology of the physical Universe is WFU

Its evolution deterministic and it has no action at a distance

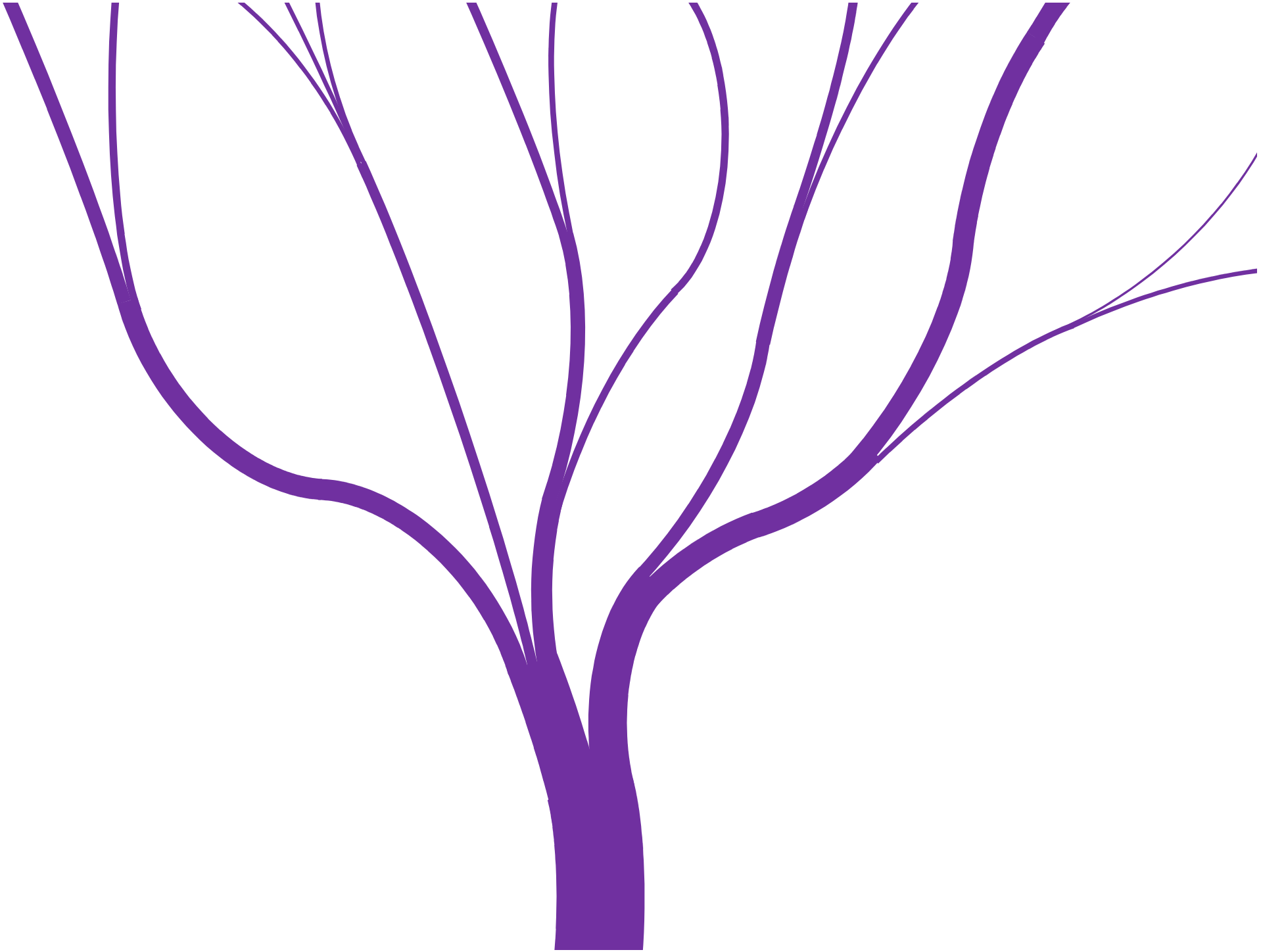
To explain our experience(s) we introduce the concept of a world with corresponding WWF. It is the same as in a collapse interpretation.

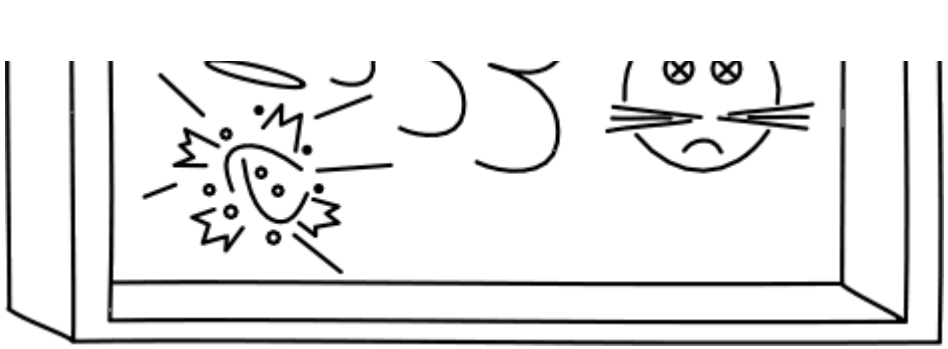
Essentially, WWF lives in 3D space

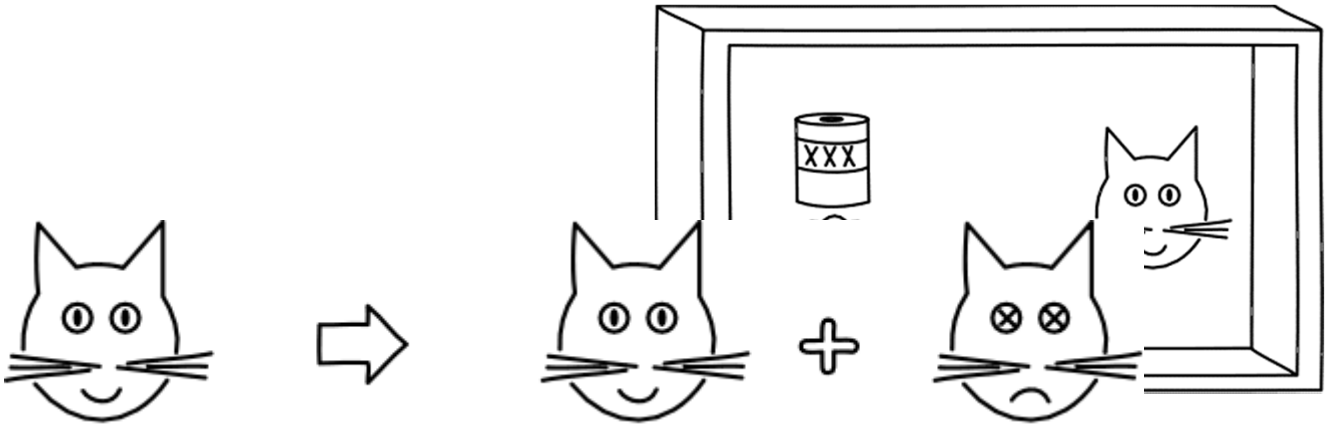
We may consider WWFs as ontology too, but it has a different status.

The evolutions of WWFs are nondeterministic and nonlocal.

It is useful to describe a world with a TSV (forward and backward evolving WFWs) and, more economically, by their overlapping parts.






XXX


$\Psi_{\text{kitty}} = \frac{1}{\sqrt{2}}\Psi_{\text{alive}} + \frac{1}{\sqrt{2}}\Psi_{\text{dead}}$