DO MEASUREMENTS IN QFT NEED SPACE-TIME DEPENDENT STATES?

BASED ON AN ONGOING WORK BY:
PRANZINI, MANISCALCO, KESKI-VAKKURI

SUMMARY

PROBLEMS WITH MEASUREMENTS IN QFT

&

POSSIBLE SOLUTIONS

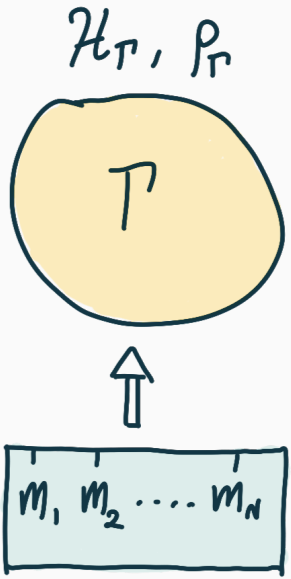
A PROBLEM OF MEASUREMENTS IN QFT

NON-RELATIVISTIC QUANTUM MECHANICS	RELATIVISTIC QUANTUM MECHANICS
MEASUREMENT POSTULATE ↓ MEASUREMENT PROBLEM ↓ INTERPRETATIONS ↓ SOLUTION	

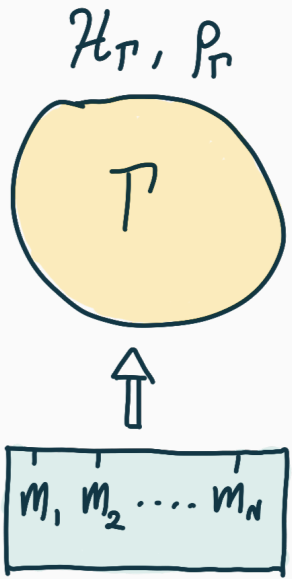
A PROBLEM OF MEASUREMENTS IN QFT

NON-RELATIVISTIC QUANTUM MECHANICS	RELATIVISTIC QUANTUM MECHANICS
MEASUREMENT POSTULATE	~~MEASUREMENT POSTULATE~~
↓	↓
MEASUREMENT PROBLEM	MEASUREMENT PROBLEM
↓	↓
INTERPRETATIONS	INTERPRETATIONS
↓	↓
SOLUTION	SOLUTION

MEASUREMENT POSTULATE



MEASUREMENT POSTULATE



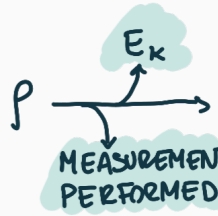
$$m_e \xrightarrow{\Theta} \hat{E}_e : \begin{cases} \Theta(m_e) = \hat{E}_e \geq 0 \\ \Theta(\bigcup_e m_e) = \sum_e \hat{E}_e \\ \Theta(\text{all } m_e) = \mathbb{I} \end{cases}$$

$$P(m_e) = \mathrm{Tr}[\rho_T \hat{E}_e]$$

$$\Rightarrow \{\hat{E}_e\} \text{ POVM}$$

SELECTIVE AND NON-SELECTIVE MEASUREMENTS

WE PERFORM A MEASUREMENT ON T IN ρ:

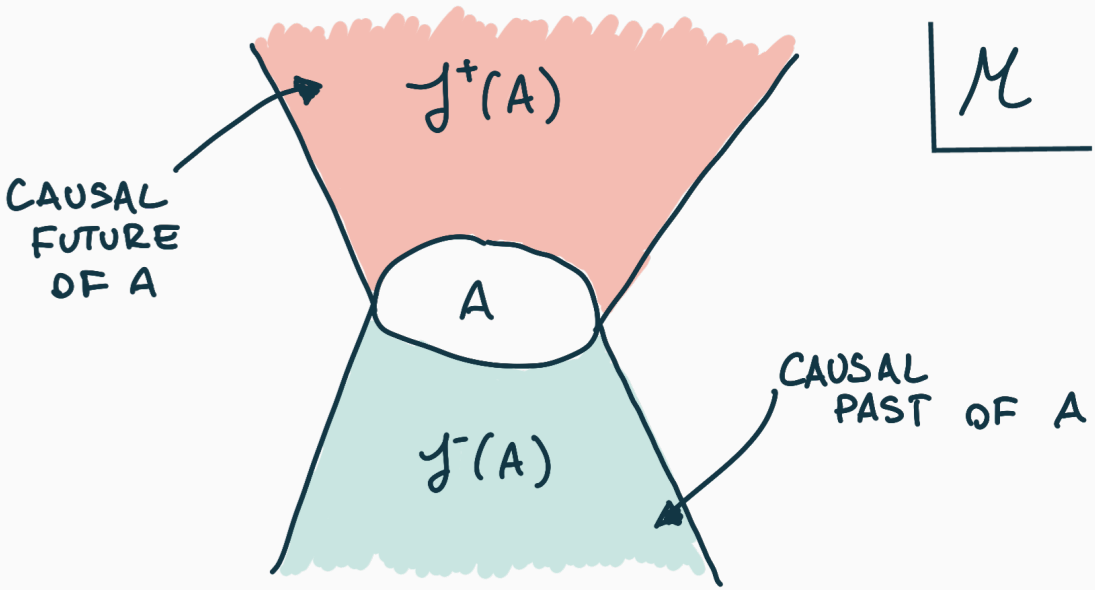
S) 

$$\rho^S(E_k) = \frac{O^\dagger(E_k)\,\rho\,O(E_k)}{Tr\left[O^\dagger(E_k)\,\rho\,O(E_k)\right]}$$

NS) 

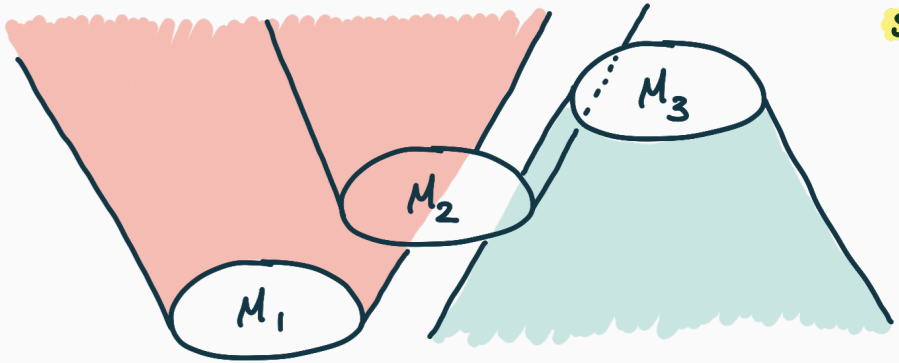
$$\rho^{NS} = \frac{\Sigma_e\,\hat{O}^\dagger(E_e)\,\rho\,\hat{O}(E_e)}{Tr\left[\Sigma_e\,\hat{O}^\dagger(E_e)\,\rho\,\hat{O}(E_e)\right]}$$

CAUSAL STRUCTURE



SORKIN'S IMPOSSIBLE MEASUREMENTS

SORKIN '93



NON-SELECTIVE MEASUREMENTS IN M_1 AFFECT M_3

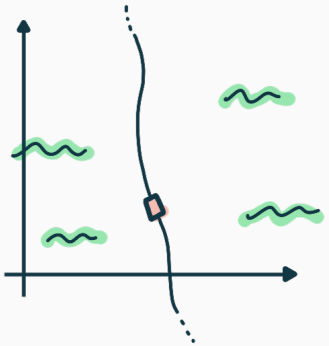
$\Rightarrow$ FTL SIGNALING

FV vs. DETECTOR-BASED FRAMEWORKS

	FEWSTER, VERCH '20	POLO-GOMEZ, GARAY MARTIN-MARTINEZ '22
APPARATUS (PROBE)	RELATIVISTIC FIELD	NON-RELATIVISTIC SYSTEM
LÜDERS' RULE	NO	YES
TOOLS	AQFT	NRQM + STANDARD QFT

UNRUH-DEWITT DETECTORS

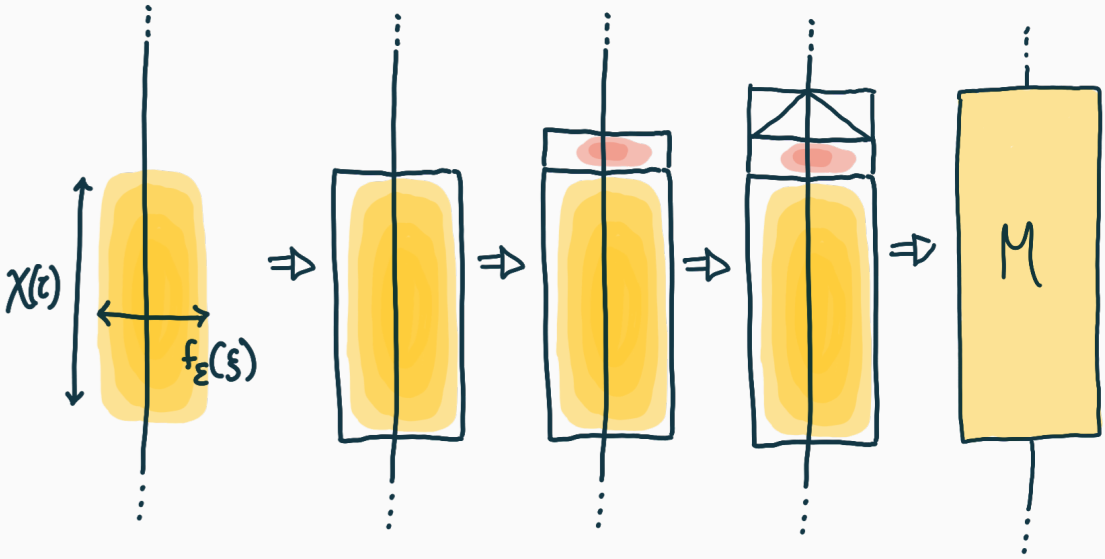
UNRUH '76
DEWITT '79
SCHLICHT '04



$$\hat{H} = \hat{H}_D + \hat{H}_\phi + \lambda \int d\tau\, \chi(\tau) \int d^3\xi\, f_\varepsilon(\xi)\, \hat{m}(\tau) \otimes \hat{\phi}(x(\tau;\xi))$$

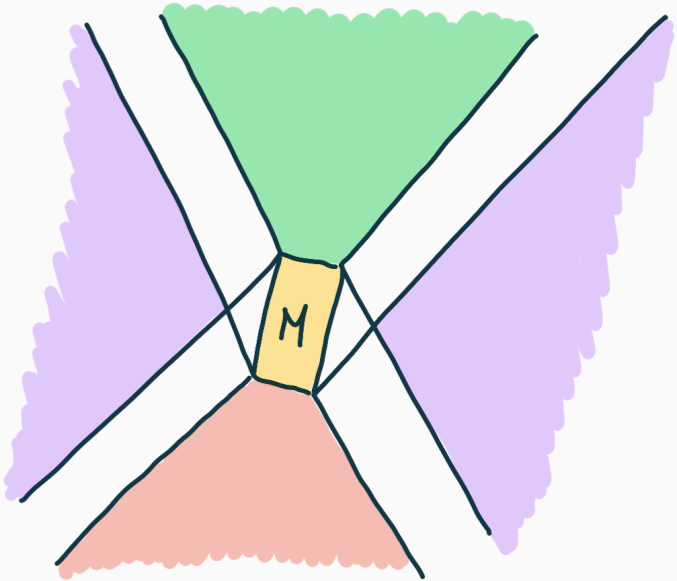
AND THEN WE MEASURE D

MEASUREMENT AS A SPACETIME EVENT



UDW DETECTORS AND MEASUREMENTS

PGGMM '22



$M = \{\hat{E}_K\}$

→ giving "m_K"

= $\rho_0 = |\phi_0 \times \phi_0|$

= $\begin{cases} \rho_0 \\ \rho^{NS} \propto \sum_i p_i \, P(E_i) \end{cases}$

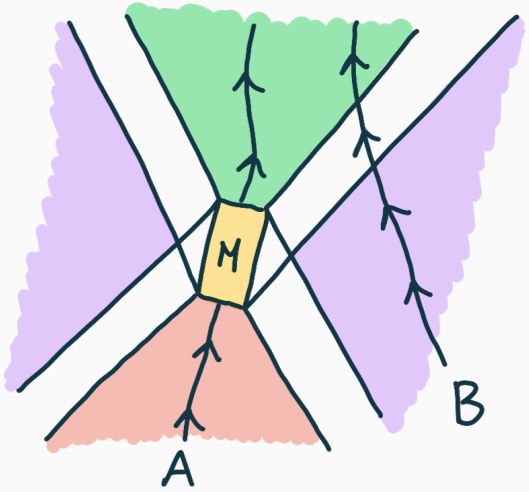
= $\begin{cases} \rho^{NS} \propto \sum_i p_i \, P(E_i) \\ p^S = P(E_K) \end{cases}$

TWO PROBLEMS WITH CONTEXTUAL STATES

1. THE STATE ASSIGNMENT IS CONTEXTUAL TO OBSERVERS
2. INCONSISTENT N-POINTS ASSIGNMENT RULE

TWO PROBLEMS WITH CONTEXTUAL STATES

1. THE STATE ASSIGNMENT IS CONTEXTUAL



B CAN USE ρ_0 IN $J^+(M)$,

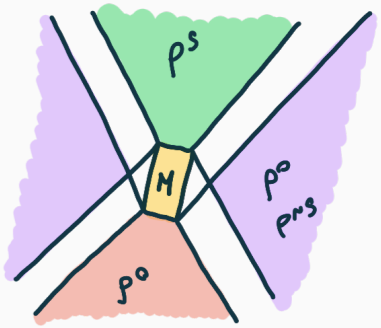
BUT GETS WRONG PHYSICS!

TWO PROBLEMS WITH CONTEXTUAL STATES

2. STATE HAS SPACE-TIME DEPENDENCE

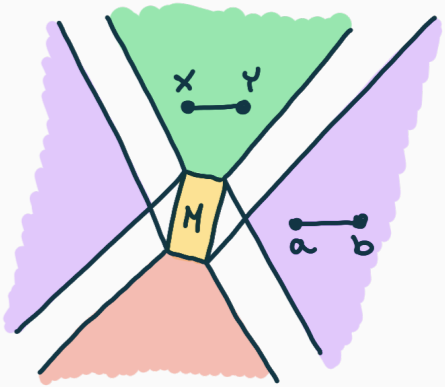
⇒ n-POINT FUNCTIONS

FROM



TO $W(x_1, \ldots, x_n)$

TWO PROBLEMS WITH CONTEXTUAL STATES



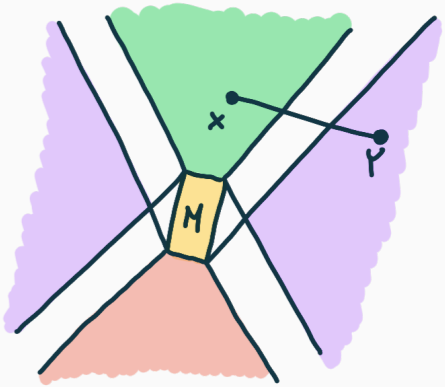
$$W(x,Y) = \langle \phi(x)\phi(Y) \rangle$$

$$= Tr\left[\rho^{S} \phi(x)\phi(Y) \right]$$

$$W(a,b) = \langle \phi(a)\phi(b) \rangle$$

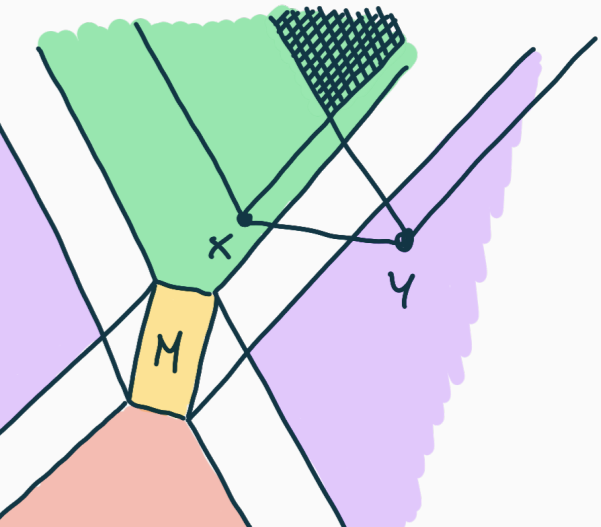
$$= Tr\left[\rho^{NS} \phi(a)\phi(b) \right]$$

TWO PROBLEMS WITH CONTEXTUAL STATES



$W(X,Y) =$

TWO PROBLEMS WITH CONTEXTUAL STATES



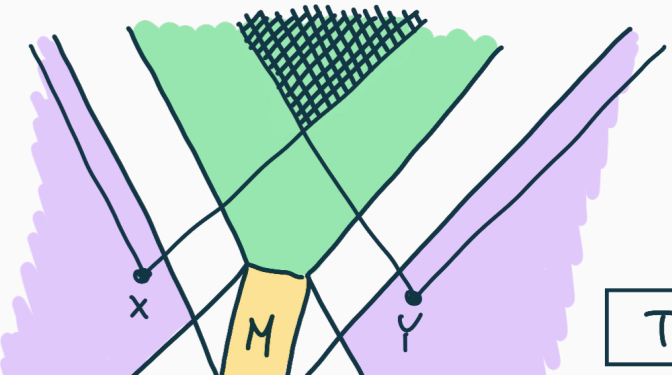
$$W(x,y) = \langle \phi(x)\phi(y) \rangle$$

$$= \mathrm{Tr}\left[\rho^{S} \phi(x)\phi(y) \right]$$

TWO PROBLEMS WITH CONTEXTUAL STATES

2. STATE HAS SPACE-TIME DEPENDENCE

⇒ ~~SOLVED~~ BY n-POINT FUNCTIONS



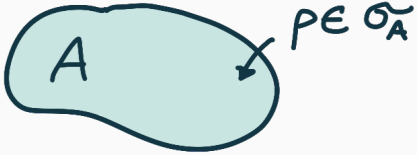
$$W(x,y) =$$

1) $= Tr\left[\rho^{NS}\phi(x)\phi(y)\right]$

2) $= Tr\left[\rho^{S}\phi(x)\phi(y)\right]$

THIS IS ILL-DEFINED

A TENTATIVE SOLUTION : EVENT-DEPENDENT STATES



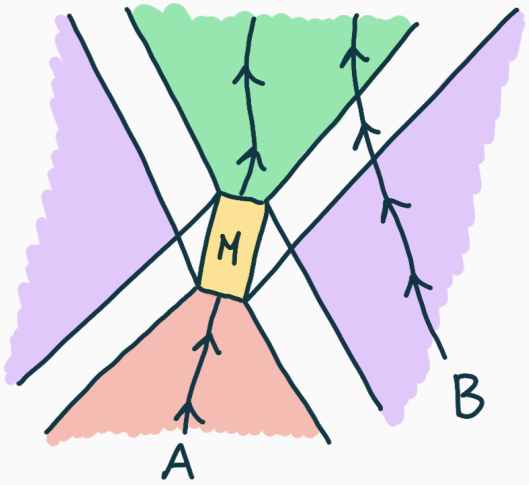
$$\sigma_A = \{\rho \mid \forall \hat{L} \text{ with } \mathrm{Supp}(\hat{L}) \in A,\ \mathrm{Tr}[\rho \hat{L}] = \mathrm{Tr}[\rho_0 \hat{L}]\}$$

FOR SOME FIDUCIAL ρ_0

(EQUIVALENCE CLASSES OF) STATES ACQUIRE A SPACE-TIME DEPENDENCE

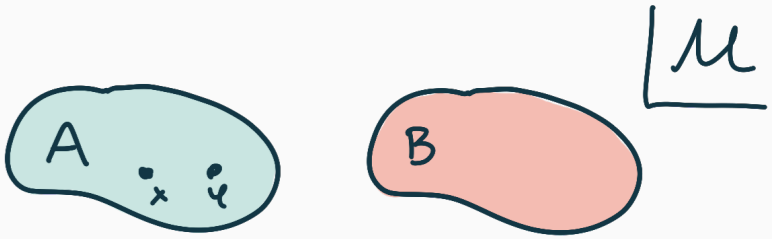
SOLUTION TO THE FIRST PROBLEM

1. THE STATE ASSIGNMENT IS ~~CONTEXTUAL~~



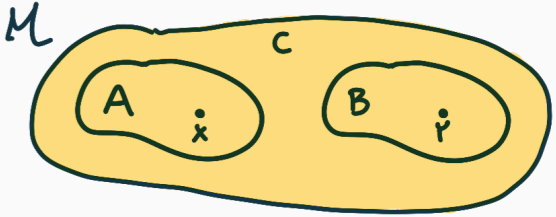
WHEN B ENTERS $J^+(M_d)$, THE FIELD STATE IS $\rho_{E\sigma_{J^+(M_d)}}$

TENTATIVE SOLUTION TO THE SECOND PROBLEM



$$W(x,y) = \mathrm{Tr}\left[\rho_A \phi(x)\phi(y)\right] \quad \text{where} \quad \rho_A \in \mathcal{O}_A$$

TENTATIVE SOLUTION TO THE SECOND PROBLEM



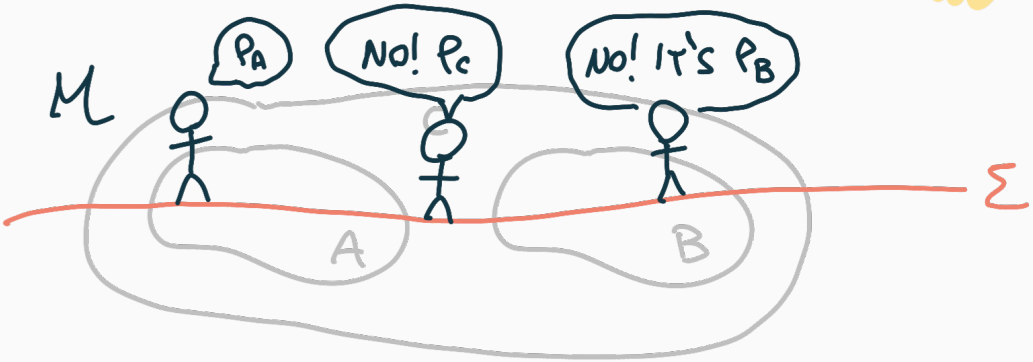
$$W(x,y) = \mathrm{Tr}\left[\rho_C\, \phi(x)\, \phi(y)\right]$$

where $\rho_C \in \sigma_C$

$$\sigma_C = \left\{ \rho \;\middle|\; \begin{array}{l} \mathrm{Tr}[\hat{A}\rho] = \mathrm{Tr}[\hat{A}\rho_A],\ \forall \hat{A}:\ \mathrm{supp}(\hat{A}) \in A,\ \rho_A \in \sigma_A \\ \text{AND}\ \ \mathrm{Tr}[\hat{B}\rho] = \mathrm{Tr}[\hat{B}\rho],\ \forall \hat{B}:\ \mathrm{supp}(\hat{B}) \in A,\ \rho_B \in \sigma_B \end{array} \right\}$$

TENTATIVE SOLUTION TO THE SECOND PROBLEM

DOES $\mathfrak{S}_C$ CONTAIN ANYTHING?



... GNS CONSTRUCTION?

THANKS!

OPEN QUESTIONS

1. ASSESS IF OUR PRESCRIPTION IS VALID EXPERIMENTALLY AND THEORETICALLY

2. EXTEND TO n-POINT FUNCTIONS FOR $n>2$ (NO WICK'S THEOREM)

3. WHAT HAPPENS IN THE REGIONS OF SPACETIME THAT WE DID NOT CONSIDER?

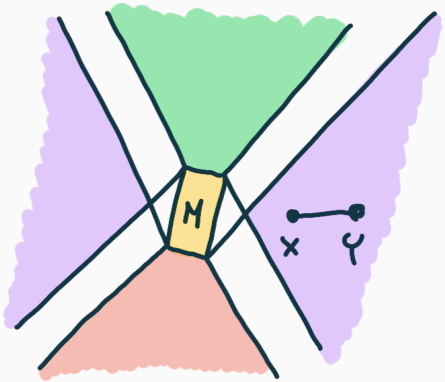
SUMMARY

1. PROBLEMS WITH MEASUREMENTS IN QFT
2. TWO POSSIBLE SOLUTIONS
3. DETECTOR-BASED MEASUREMENTS
4. PROBLEMS WITH THIS APPROACH
5. A TENTATIVE SOLUTION

TWO PROBLEMS WITH CONTEXTUAL STATES

2. STATE HAS SPACE-TIME DEPENDENCE

⇒ SOLVED (?) BY n-POINT FUNCTIONS



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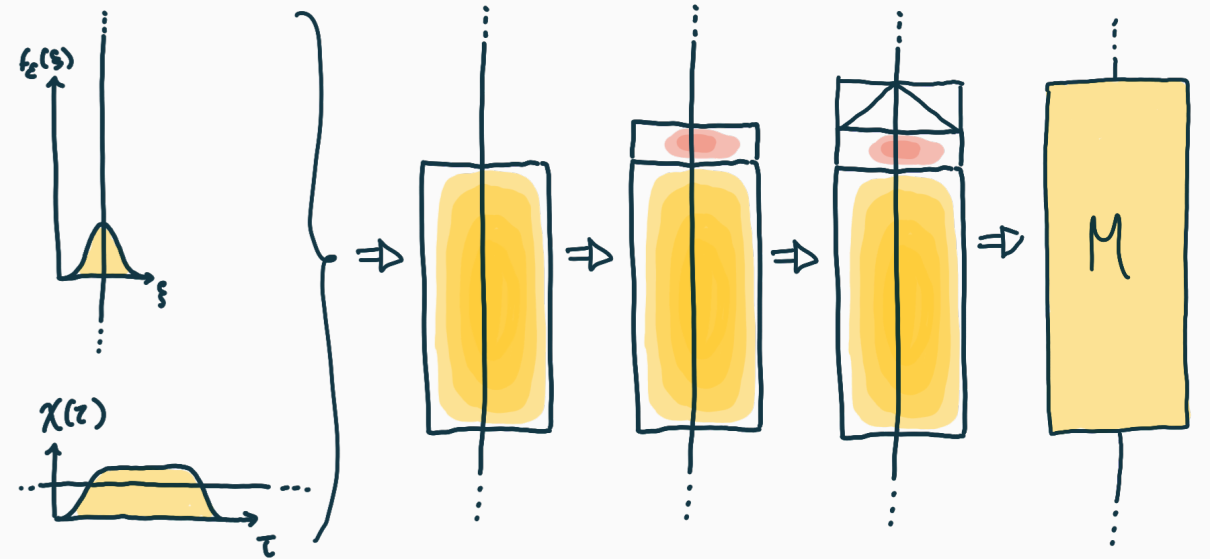
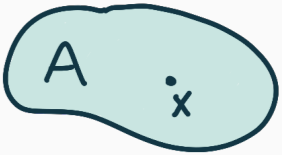
$$= \mathrm{Tr}\left[\rho^{NS} \phi(x)\phi(Y) \right]$$

MEASUREMENT AS A SPACETIME EVENT



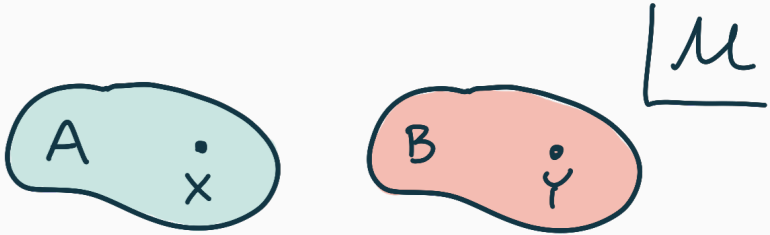
TENTATIVE SOLUTION TO THE SECOND PROBLEM



M

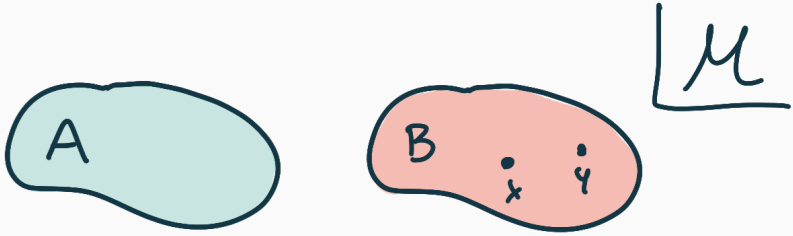
$$W(x) = \langle \phi(x) \rangle = Tr\left[\rho\, \phi(x)\right] \quad \text{where} \quad \rho \in \mathcal{O}_A$$

TENTATIVE SOLUTION TO THE SECOND PROBLEM



$$W(x,y) = \mathrm{Tr}\left[? \;\; \phi(x)\,\phi(y) \right]$$

TENTATIVE SOLUTION TO THE SECOND PROBLEM



$$W(x,y) = \mathrm{Tr}\left[\rho_B \phi(x)\phi(y)\right] \quad \text{where} \quad \rho_B \in \sigma_B$$

SOLUTION TO THE SECOND PROBLEM

$$W(x,y) = \left(\sqrt{\rho_2}\,\phi(y), \sqrt{\rho_1}\,\phi(x)\right) = \mathrm{Tr}\left[\phi(y)\left(\sqrt{\rho_2}\right)^{\dagger}\sqrt{\rho_1}\,\phi(x)\right]$$

$$= \mathrm{Tr}\left[\left(\sqrt{\rho_2}\right)^{\dagger}\sqrt{\rho_1}\,\phi(x)\,\phi(y)\right]$$

where $\rho_1 \in \sigma_A$, $\rho_2 \in \sigma_B$ & $(A,B) = \mathrm{Tr}[A^{\dagger}B]$