Title: PSI 2017/2018 - Relativistic Quantum Information - Lecture 8

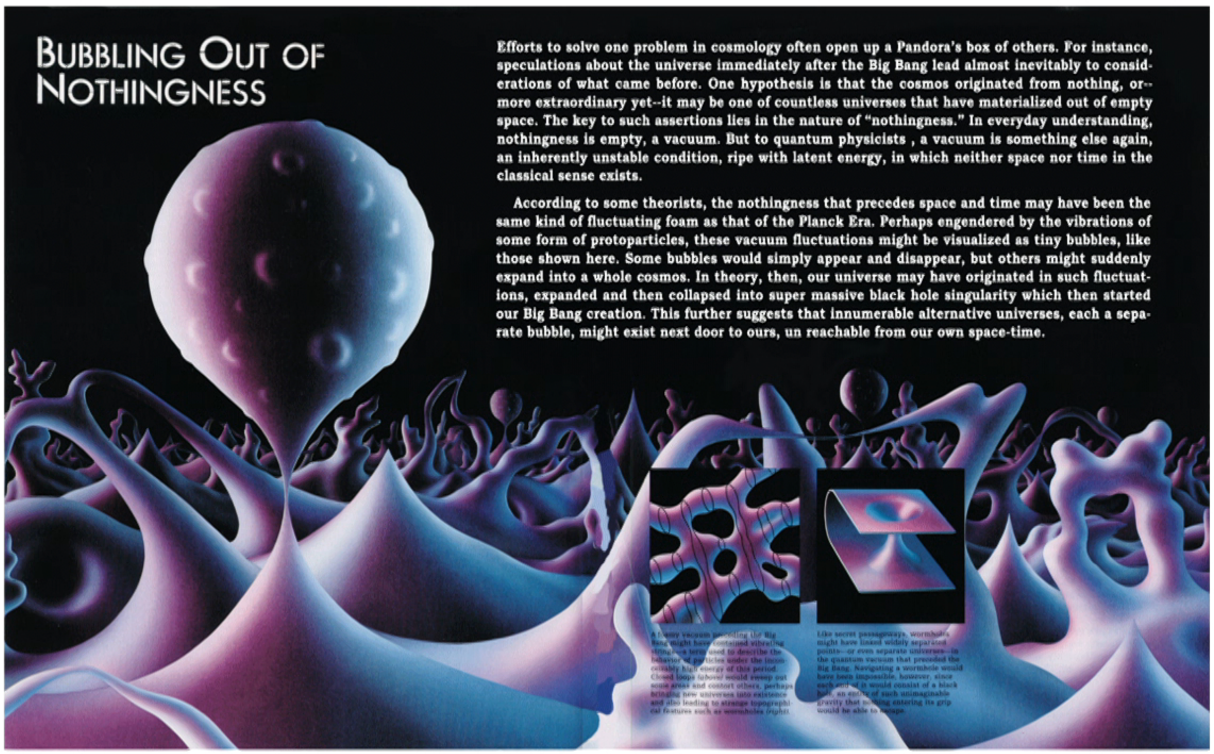
Date: Mar 28, 2018 09:00 AM

URL: http://pirsa.org/18030035

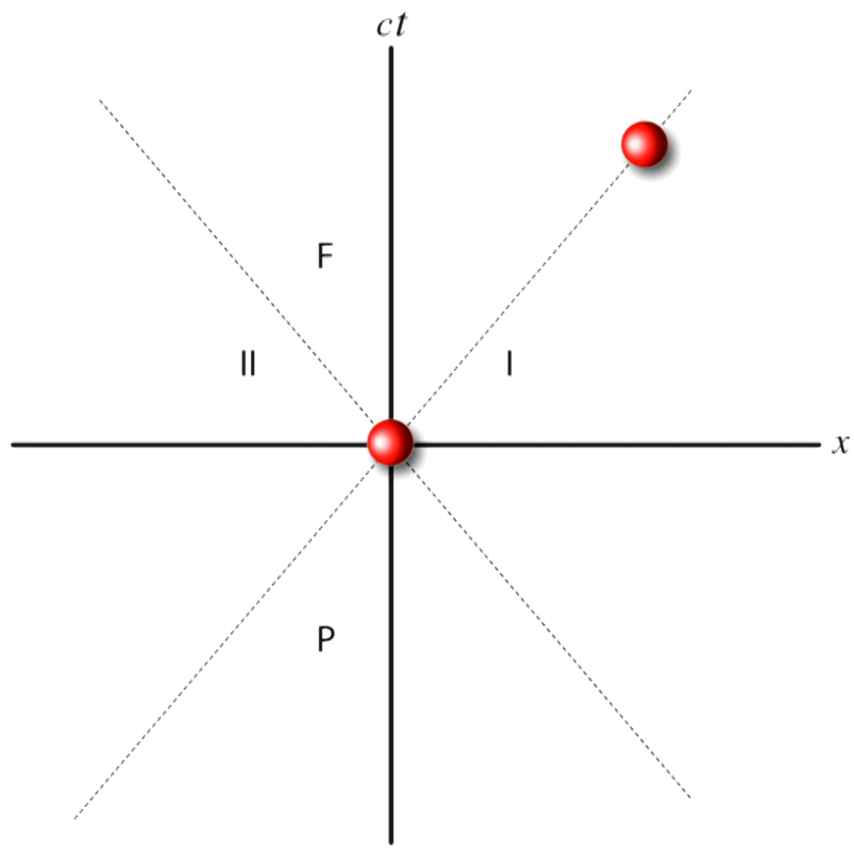
Abstract:

The Quantum Vacuum

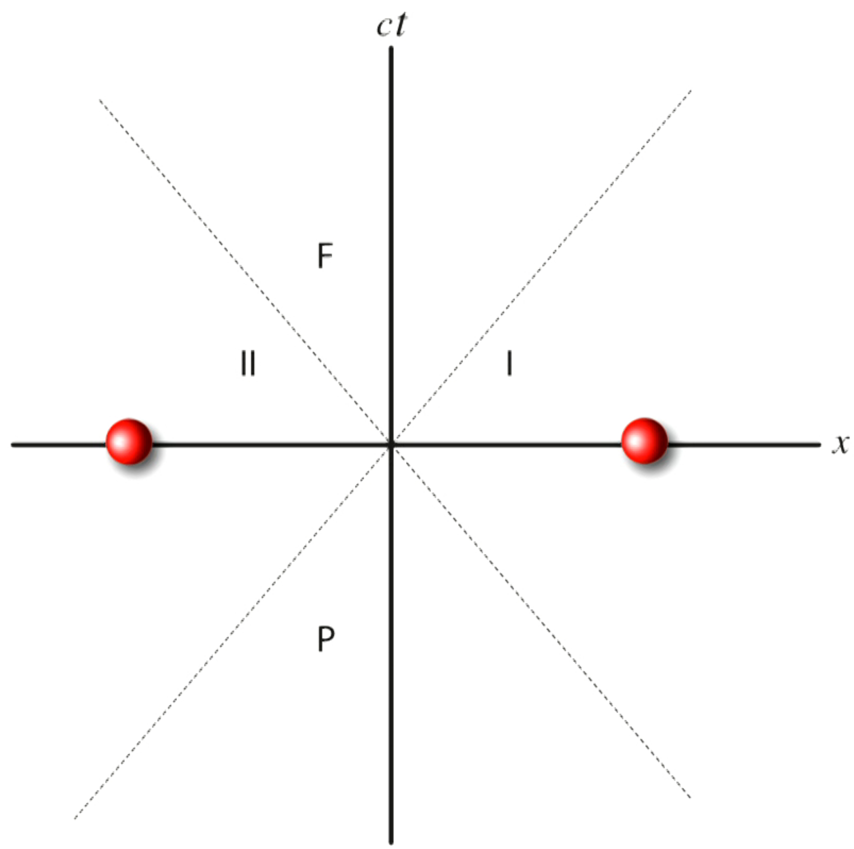
The Vacuum is not empty



Entanglement Harvesting

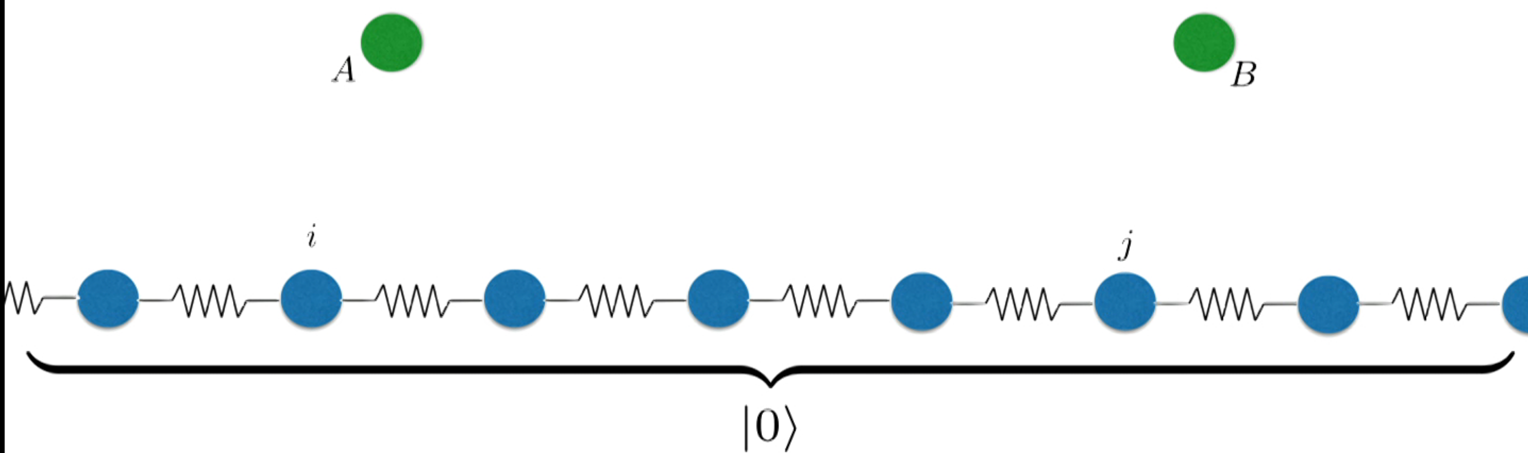


(Spacelike) Entanglement Harvesting



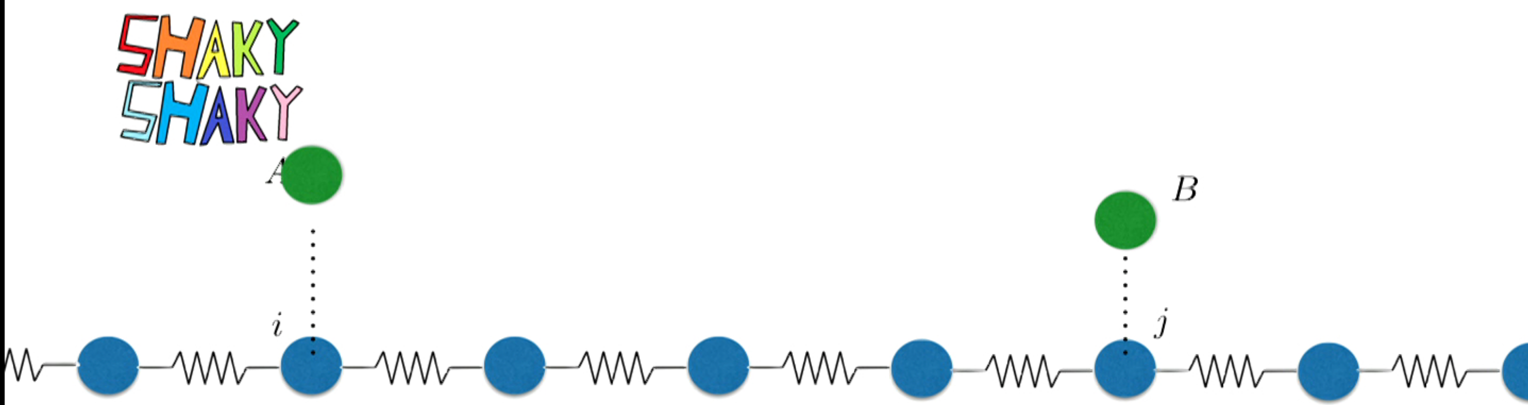
1-D Harmonic lattice in the Ground state

How do we get two systems entangled by means of local interactions with a lattice in the ground state?



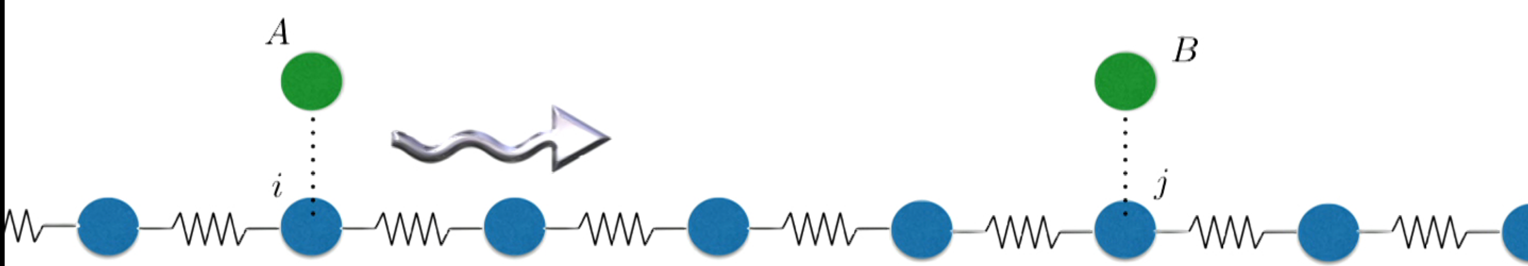
Two possible mechanisms.

1-D Harmonic lattice in the Ground state



1) Communication via phonons

1-D Harmonic lattice in the Ground state



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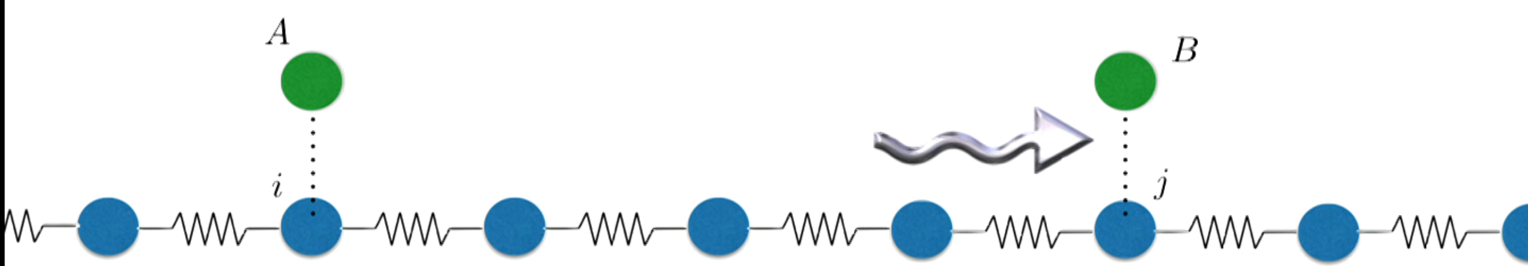
1-D Harmonic lattice in the Ground state



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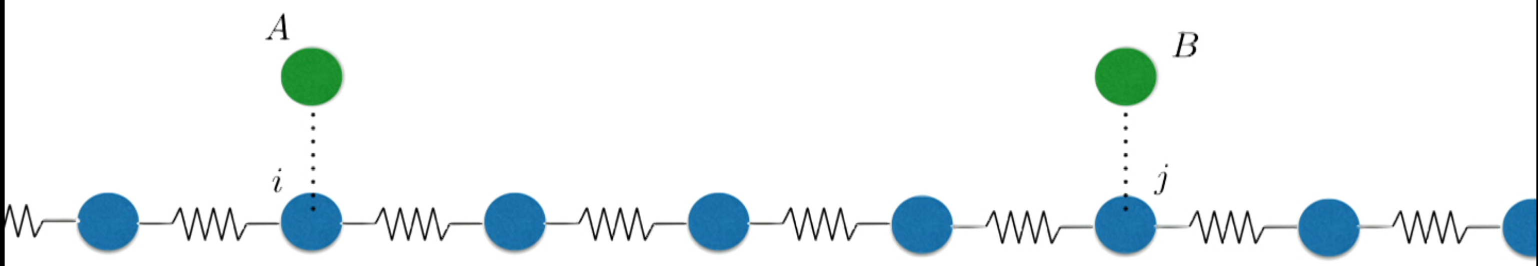
1-D Harmonic lattice in the Ground state



1) Communication via phonons

1-D Harmonic lattice in the Ground state

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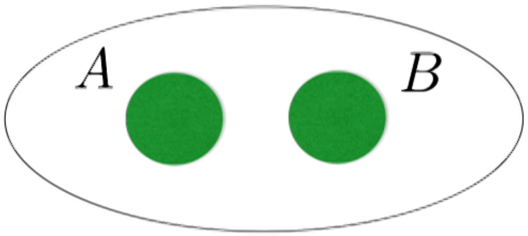
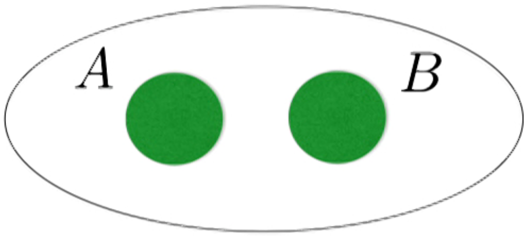


$$\rho_{AB} \neq \sum_i p_i \rho_A^i \otimes \rho_B^i$$

Limited by the speed of 'sound'

1-D Harmonic lattice in the Ground state

1) Communication via phonons



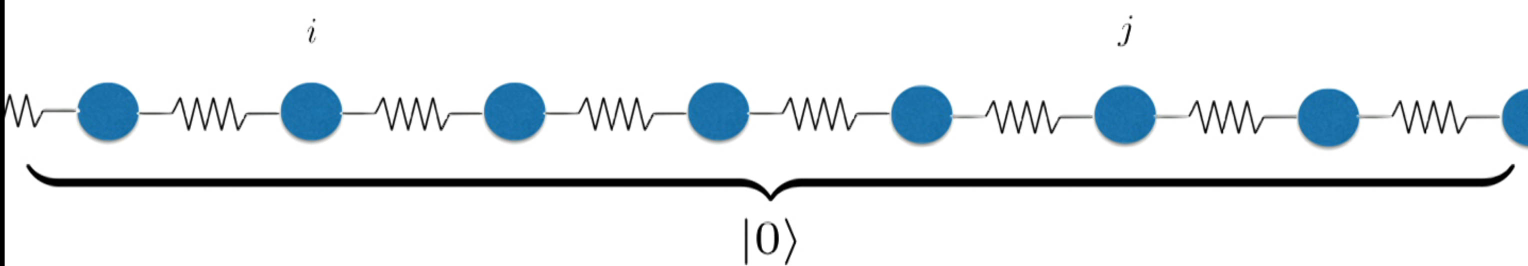
$$\rho_{AB} \neq \sum_i p_i \rho_{A_i} \otimes \rho_{B_i}$$

Limited by the speed of 'sound'

1-D Harmonic lattice in the Ground state

There's another possibility:

Take advantage of pre-existent entanglement

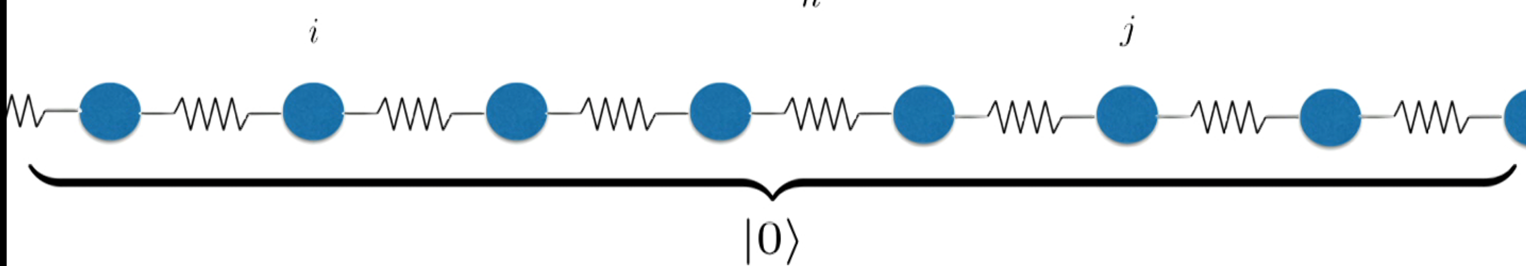


1-D Harmonic lattice in the Ground state

'Non-local' basis: Normal modes $|0\rangle\,, |1\rangle\,, |2\rangle\,, \ldots$

'Local' basis: individual number states $\{|n_1, \ldots, n_i, \ldots, n_j, \ldots\rangle\}$

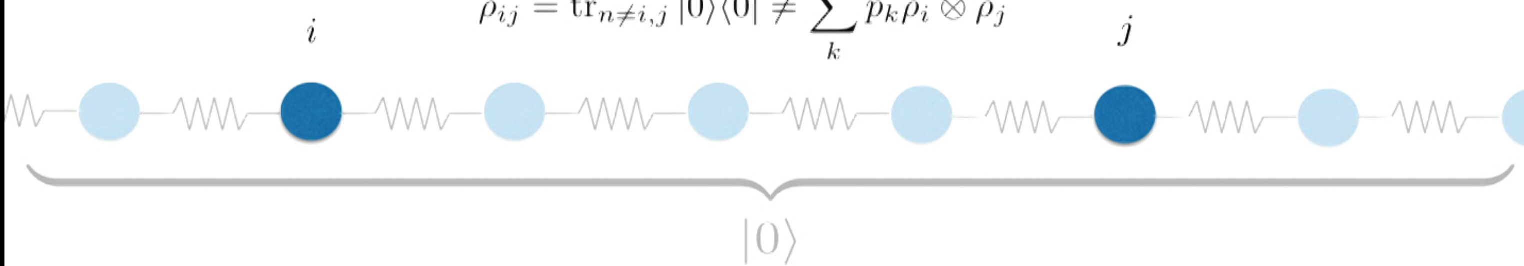
$$|0\rangle \neq \bigotimes_n |0_n\rangle$$



1-D Harmonic lattice

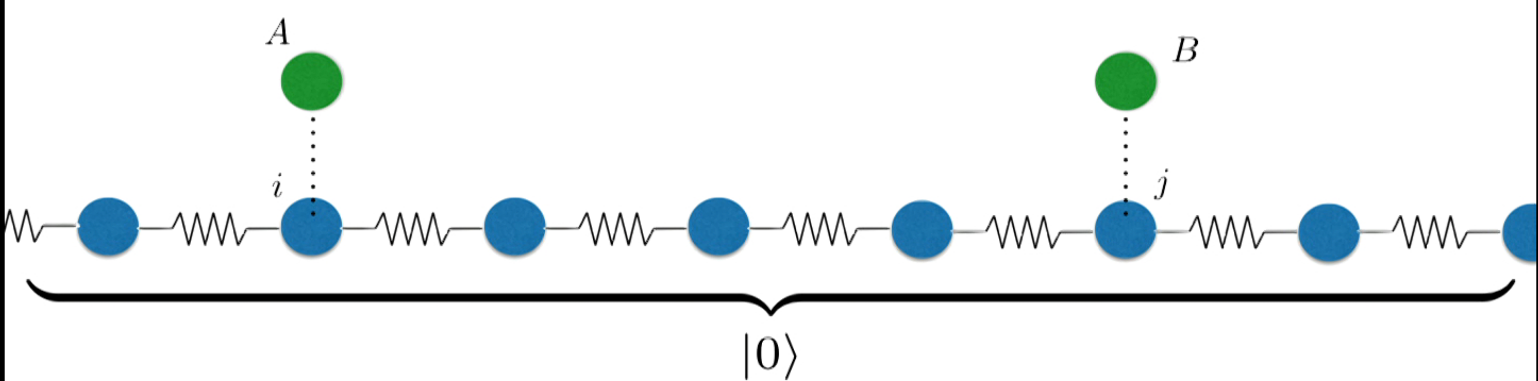
$$|0\rangle \neq \bigotimes_n |0_n\rangle$$

$$\rho_{ij} = \mathrm{tr}_{n\neq i,j}\, |0\rangle\langle 0| \neq \sum_k p_k \rho_i \otimes \rho_j$$



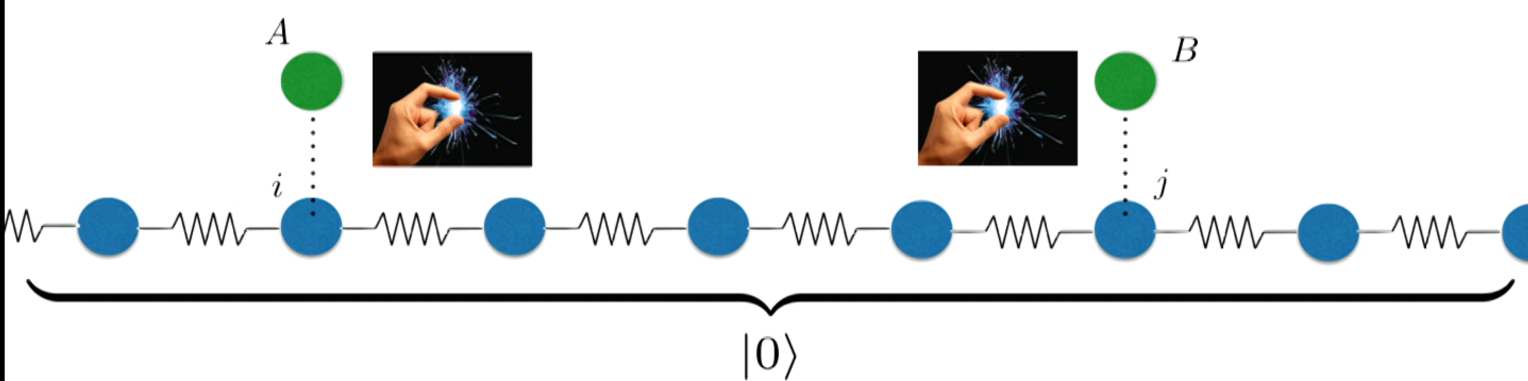
1-D Harmonic lattice in the Ground state

2) Swapping ground state entanglement

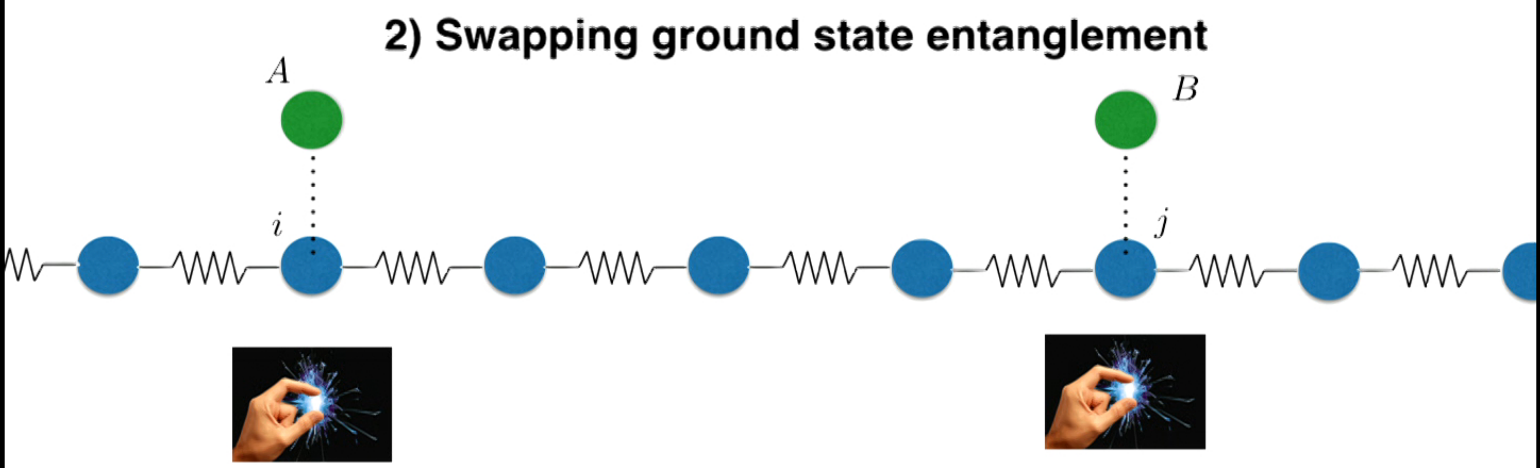


1-D Harmonic lattice in the Ground state

2) Swapping ground state entanglement

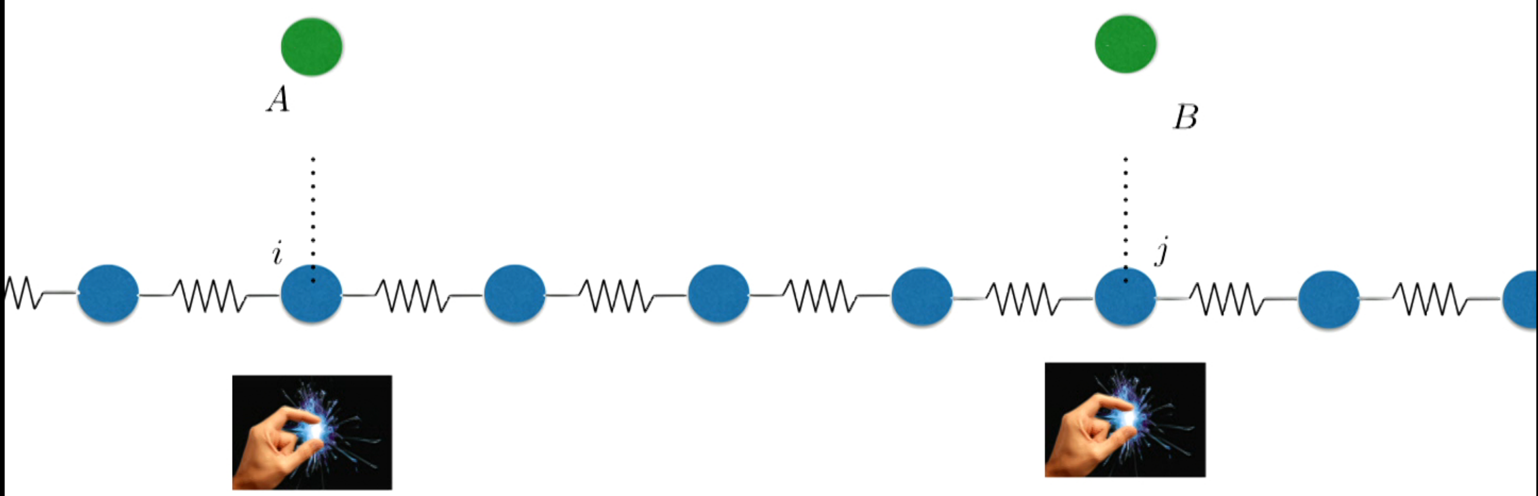


1-D Harmonic lattice in the Ground state



1-D Harmonic lattice in the Ground state

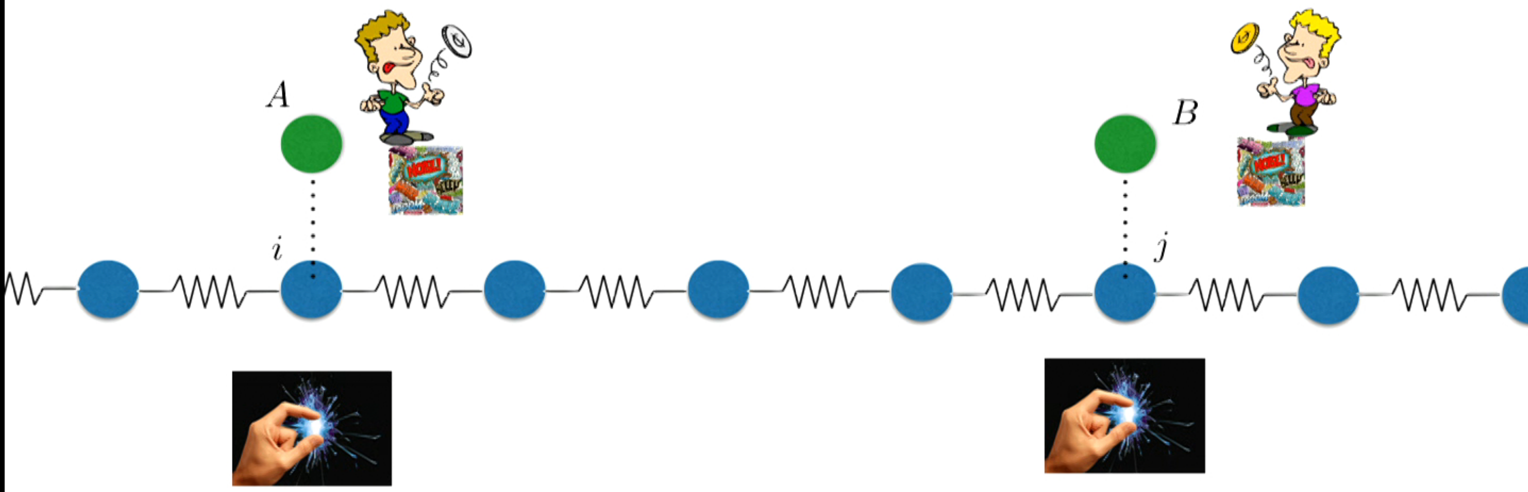
Local coupling to the vacuum: Observed fluctuations are correlated



2) Swapping ground state entanglement

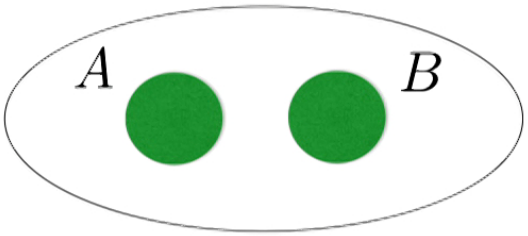
1-D Harmonic lattice in the Ground state

2) Swapping ground state entanglement



1-D Harmonic lattice in the Ground state

2) Swapping ground state entanglement

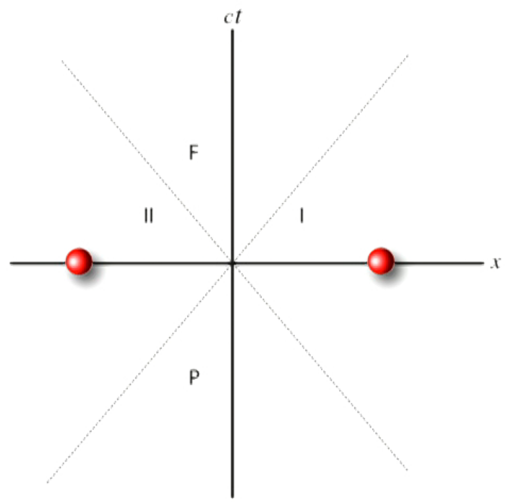


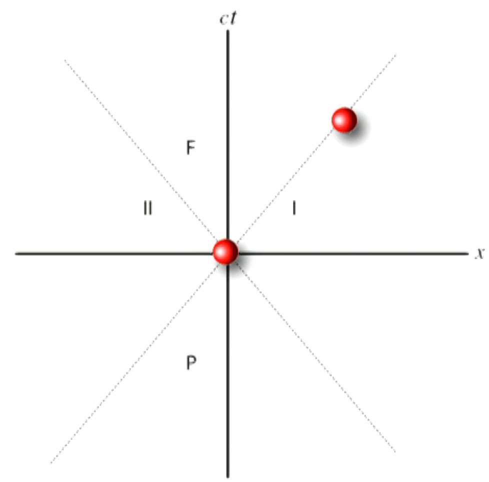
$$\rho_{AB} \neq \sum_i p_i \rho_A^{i} \otimes \rho_B^{i}$$

NOT Limited by the speed of ‘sound’

Quantum Fields

A 1D quantum field can be thought as the 'continuum limit' of such a lattice

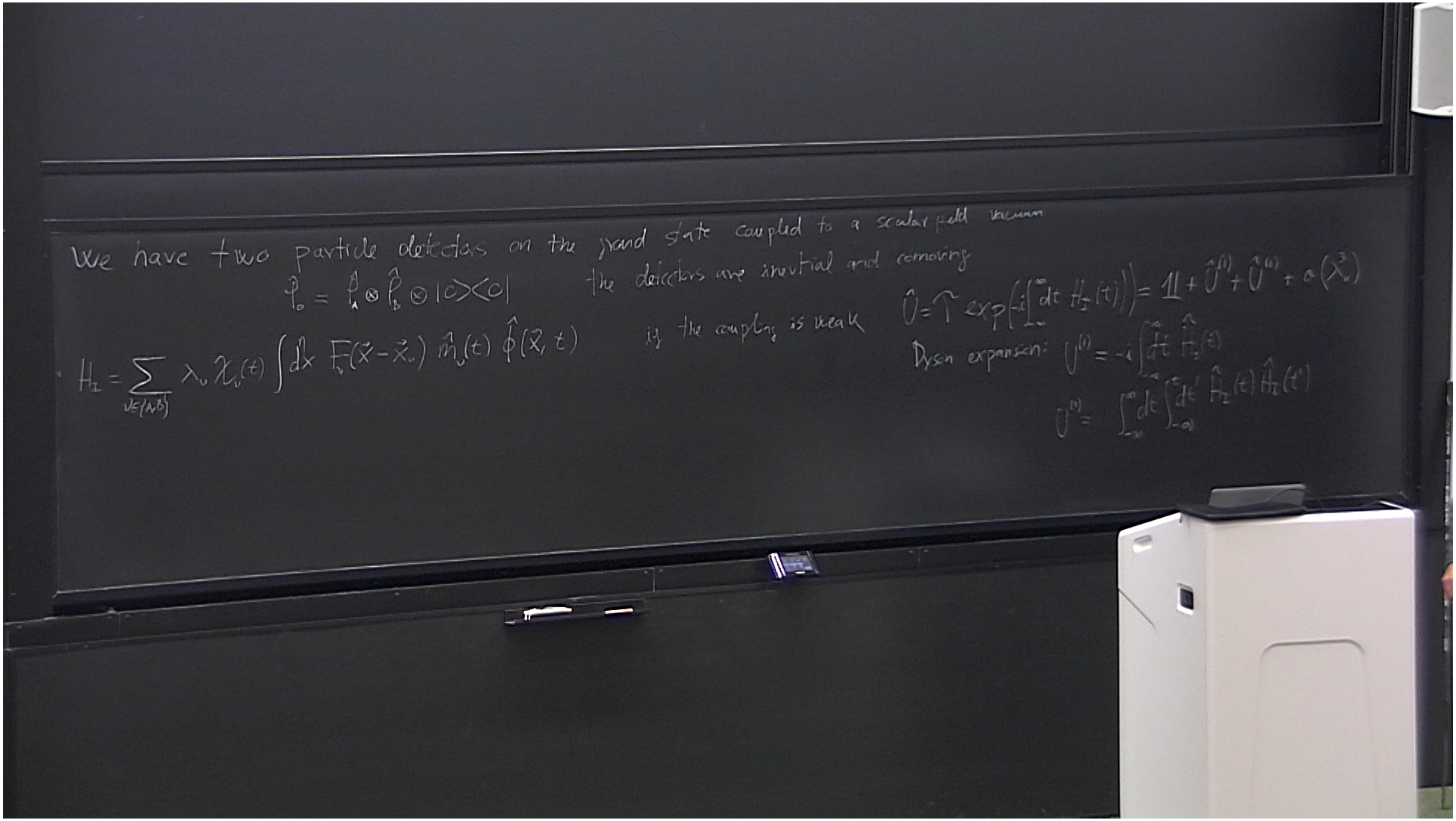


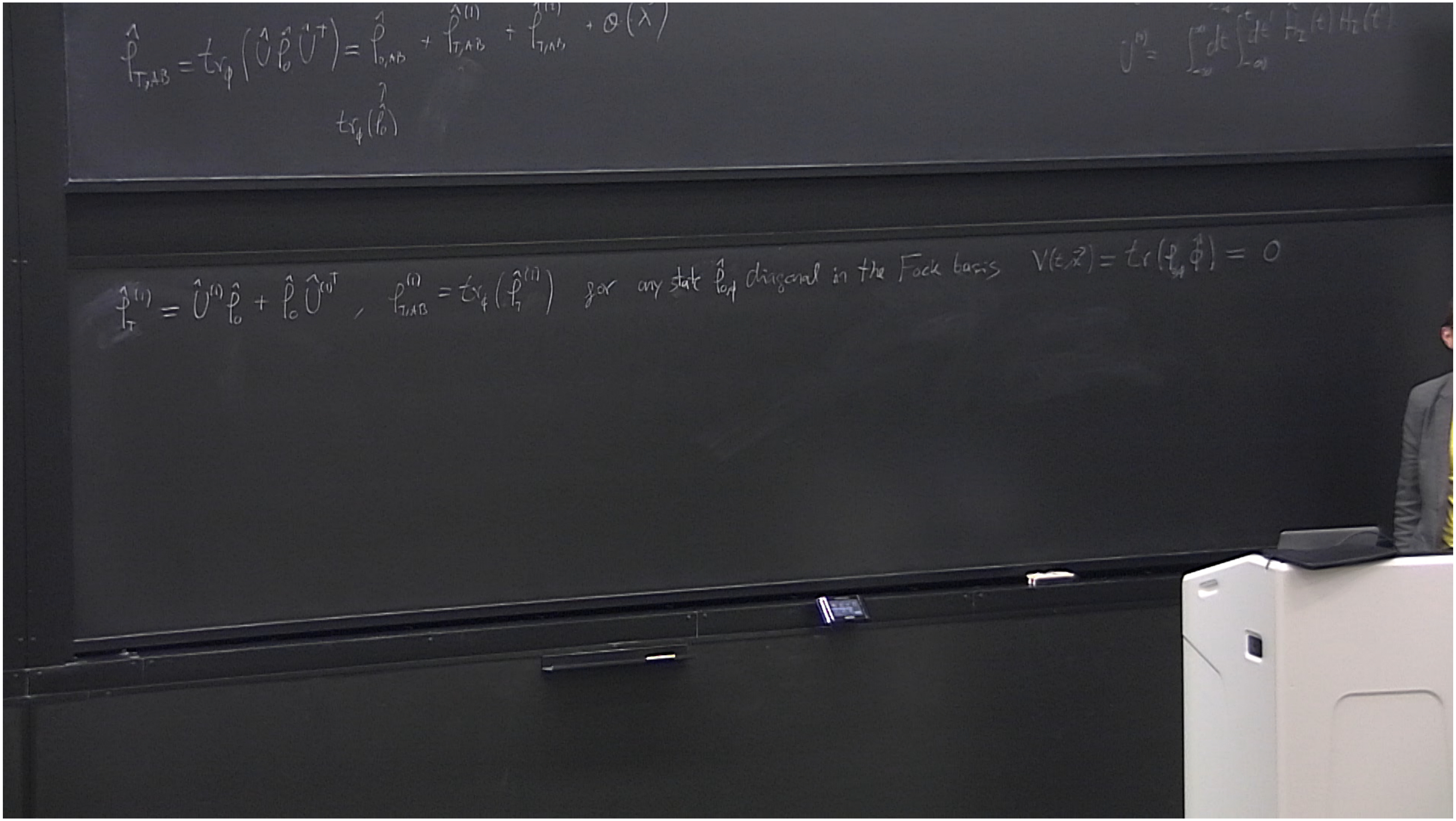


Two mechanisms to get 'atoms' entangled via interaction with quantum fields:

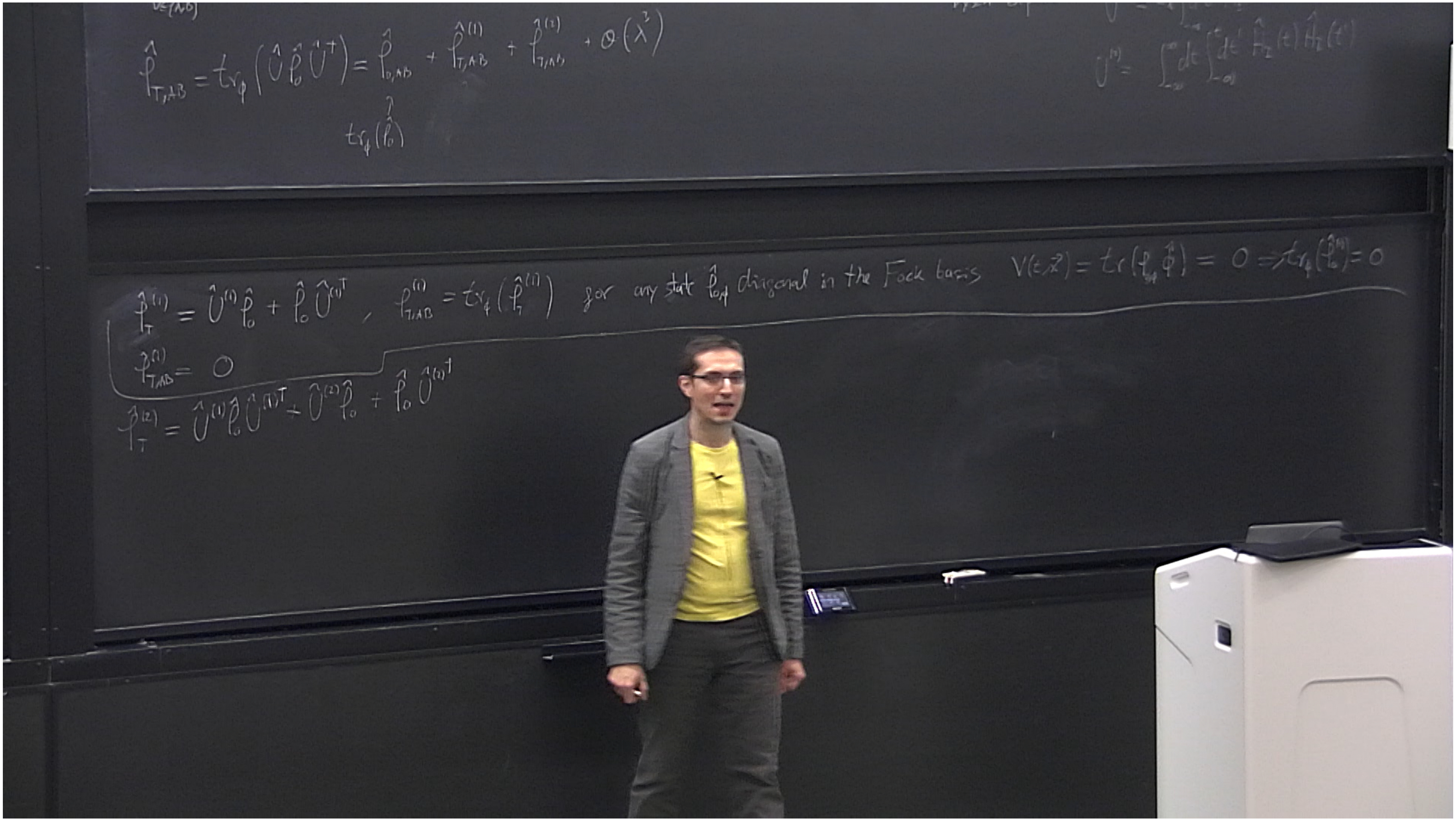
1) Via exchange of real field quanta

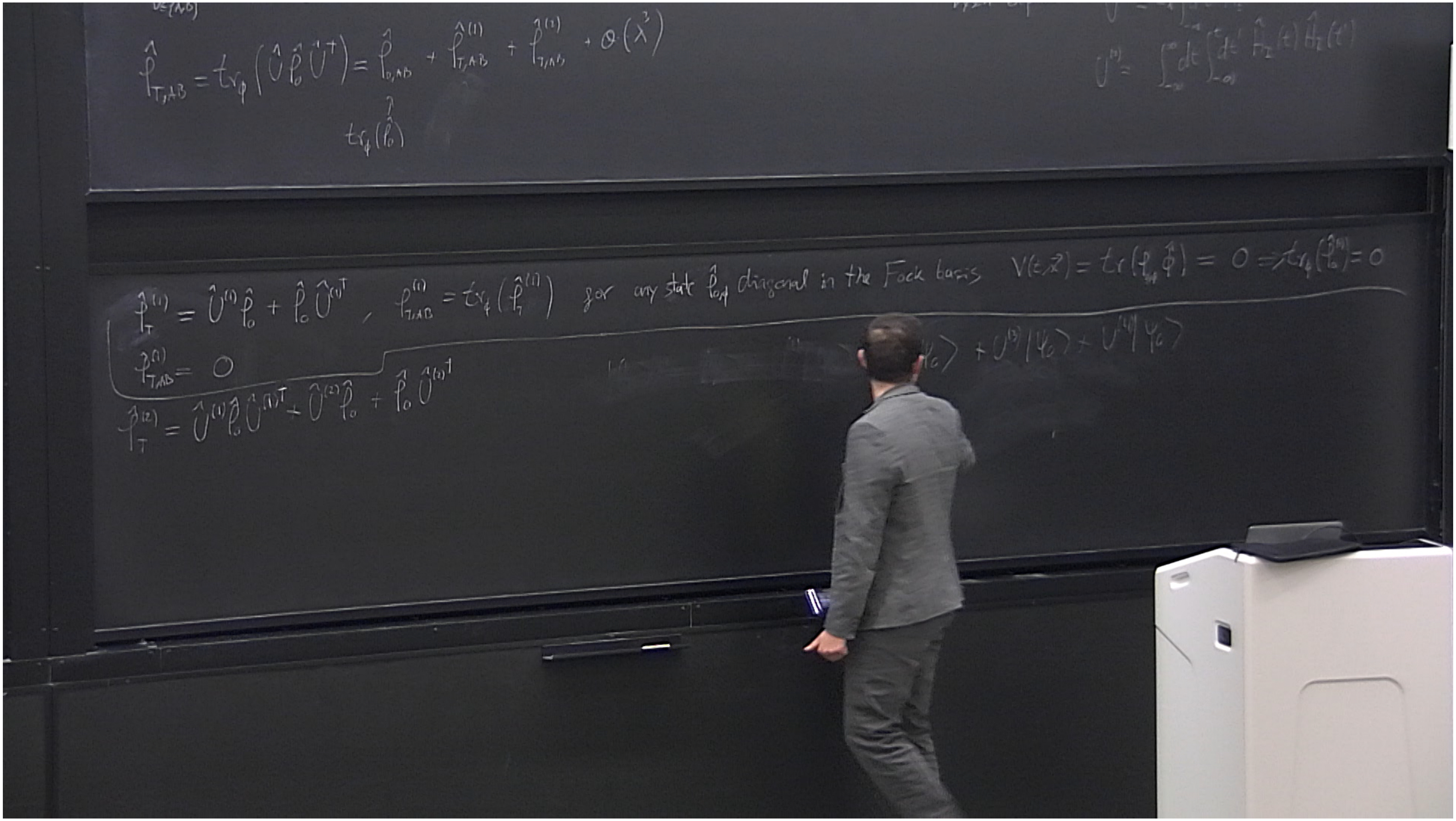
2) Swapping vacuum entanglement

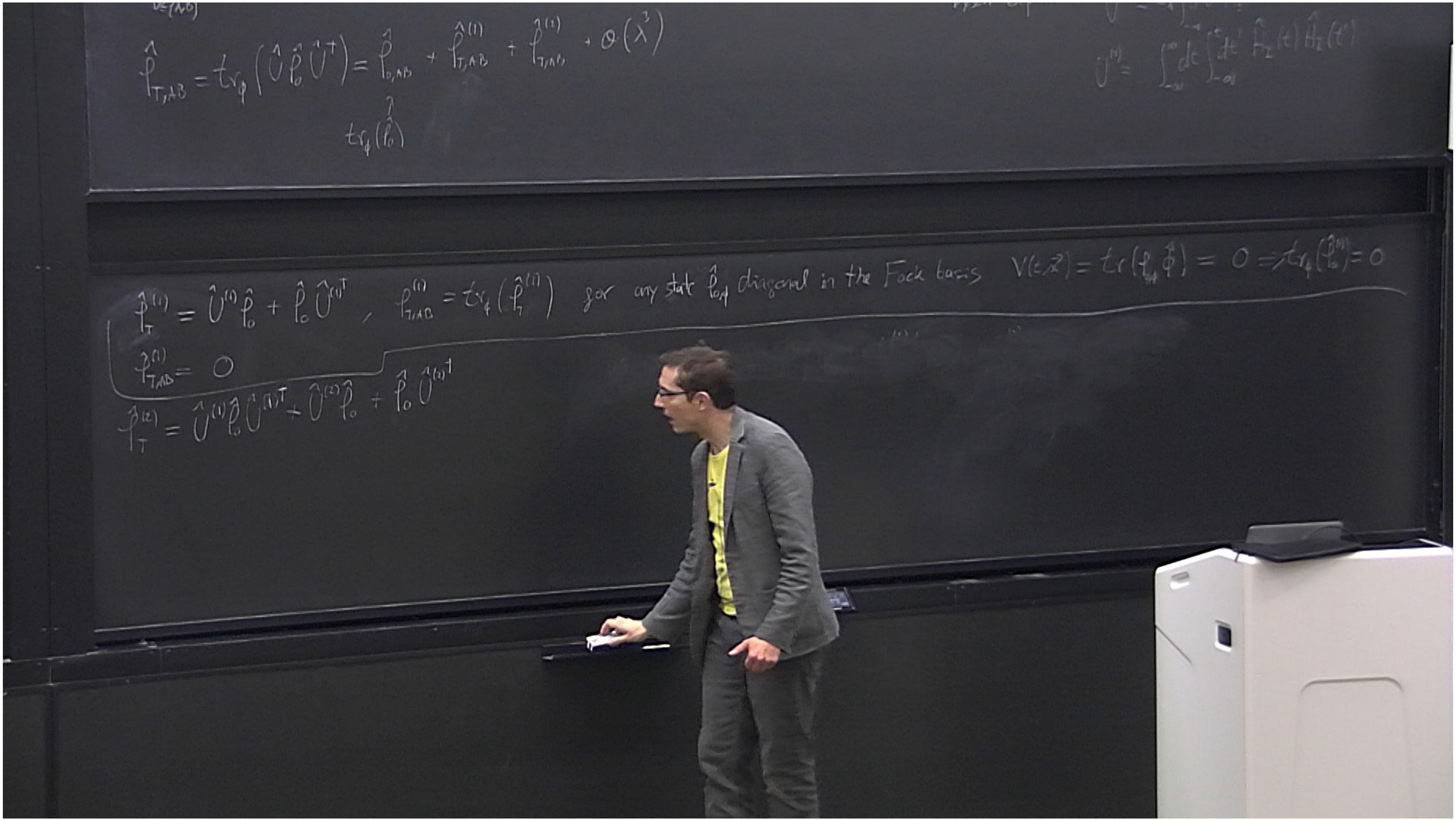

We have two particle detectors on the ground state coupled to a scalar field vacuum
$\hat{\rho}_0 = \hat{\rho}_A \otimes \hat{\rho}_B \otimes |0\rangle\langle 0|$
the detectors are inertial and comoving
$H_I = \sum_{\nu \in \{A,B\}} \lambda_\nu \chi_\nu(t) \int d^3x\, F_\nu(\vec{x}-\vec{x}_\nu)\, \hat{m}_\nu(t)\, \hat{\phi}(\vec{x},t)$
if the coupling is weak
$\hat{U} = \mathcal{T} \exp\left(-i\int_{-\infty}^{\infty} dt\, H_I(t)\right) = \mathbb{1} + \hat{U}^{(1)} + \hat{U}^{(2)} + O(\lambda_\nu^3)$
Dyson expansion:
$U^{(1)} = -i\int_{-\infty}^{\infty} dt\, \hat{H}_I(t)$
$U^{(2)} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{t} dt'\, \hat{H}_I(t)\, \hat{H}_I(t')$

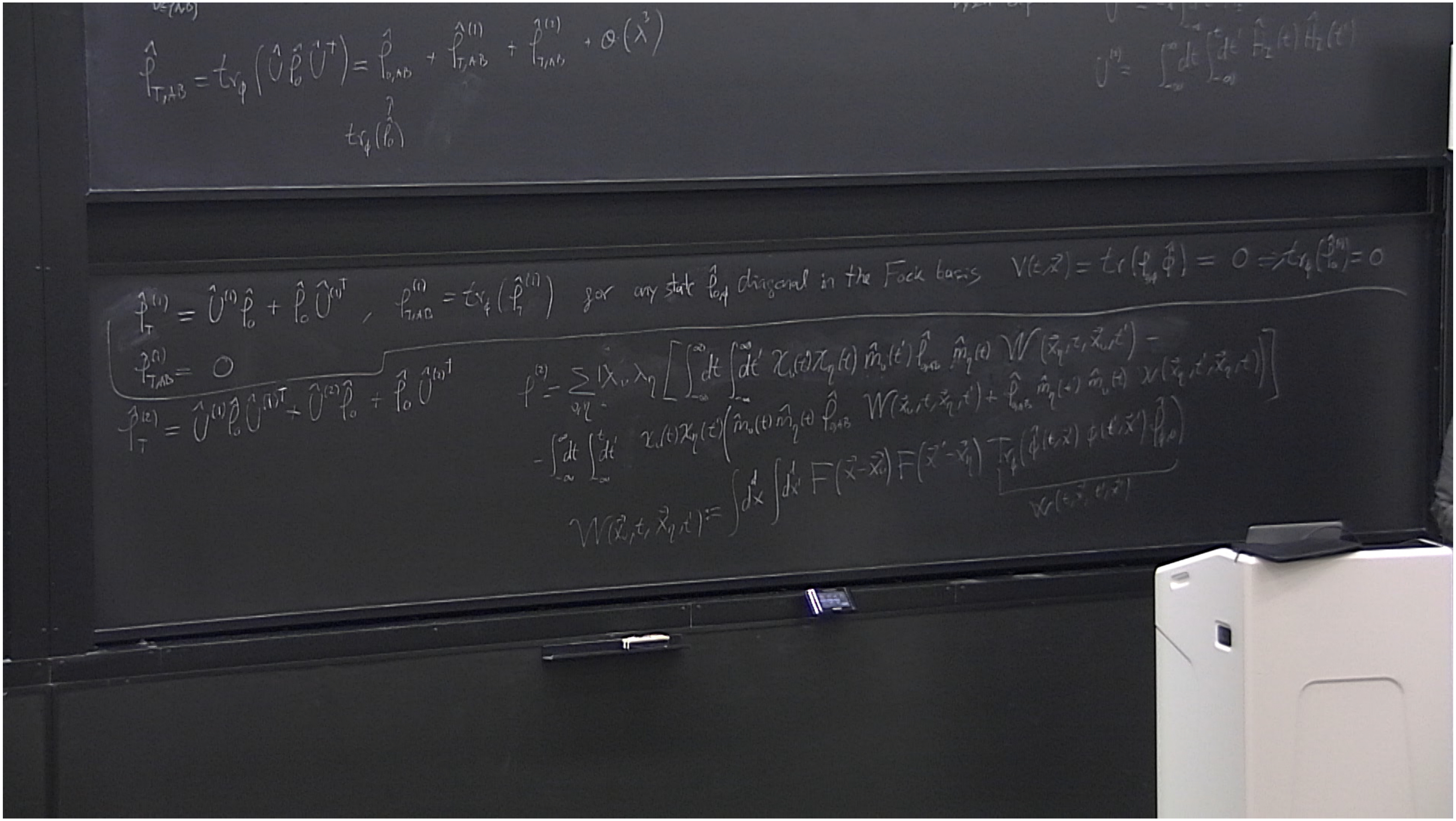


$\hat{\rho}_{T,AB} = \mathrm{tr}_\phi\left(\hat{U}\hat{\rho}_0\hat{U}^\dagger\right) = \hat{\rho}_{0,AB} + \hat{\rho}^{(1)}_{T,AB} + \hat{\rho}^{(2)}_{T,AB} + O(\lambda^3)$
$\mathrm{tr}_\phi(\hat{\rho}_0)$
$\hat{U}^{(2)} = \int_{-\infty}^{\infty} dt \int_{-\infty}^{t} dt' \, \hat{H}_I(t) \hat{H}_I(t')$
$\hat{\rho}^{(1)}_T = \hat{U}^{(1)}\hat{\rho}_0 + \hat{\rho}_0\hat{U}^{(1)\dagger}$, $\rho^{(1)}_{T,AB} = \mathrm{tr}_\phi(\hat{\rho}^{(1)}_T)$ for any state $\hat{\rho}_{0,\phi}$ diagonal in the Fock basis $V(t,\vec{x}) = \mathrm{tr}(\rho_\phi \hat{\phi}) = 0$


for any state diagonal in the Fock basis


$\hat\rho_{T,AB} = tr_\phi(\hat U \hat\rho_0 \hat U^\dagger) = \hat\rho_{0,AB} + \hat\rho^{(1)}_{T,AB} + \hat\rho^{(2)}_{T,AB} + O(\lambda^3)$
$tr_\phi(\hat\rho_0)$
$\hat\rho^{(1)}_T = \hat U^{(1)}\hat\rho_0 + \hat\rho_0 \hat U^{(1)\dagger}$, $\rho^{(1)}_{T,AB} = tr_\phi(\hat\rho^{(1)}_T)$ for any state $\hat\rho_{0,\phi}$ diagonal in the Fock basis $V(t,\vec x) = tr(\rho_{0,\phi}\hat\phi) = 0 \Rightarrow tr_\phi(\hat\rho^{(1)}_0) = 0$
$\hat\rho^{(1)}_{T,AB} = 0$
$\hat\rho^{(2)}_T = \hat U^{(1)}\hat\rho_0 \hat U^{(1)\dagger} + \hat U^{(2)}\hat\rho_0 + \hat\rho_0 \hat U^{(2)\dagger}$


for any state diagonal in the Fock basis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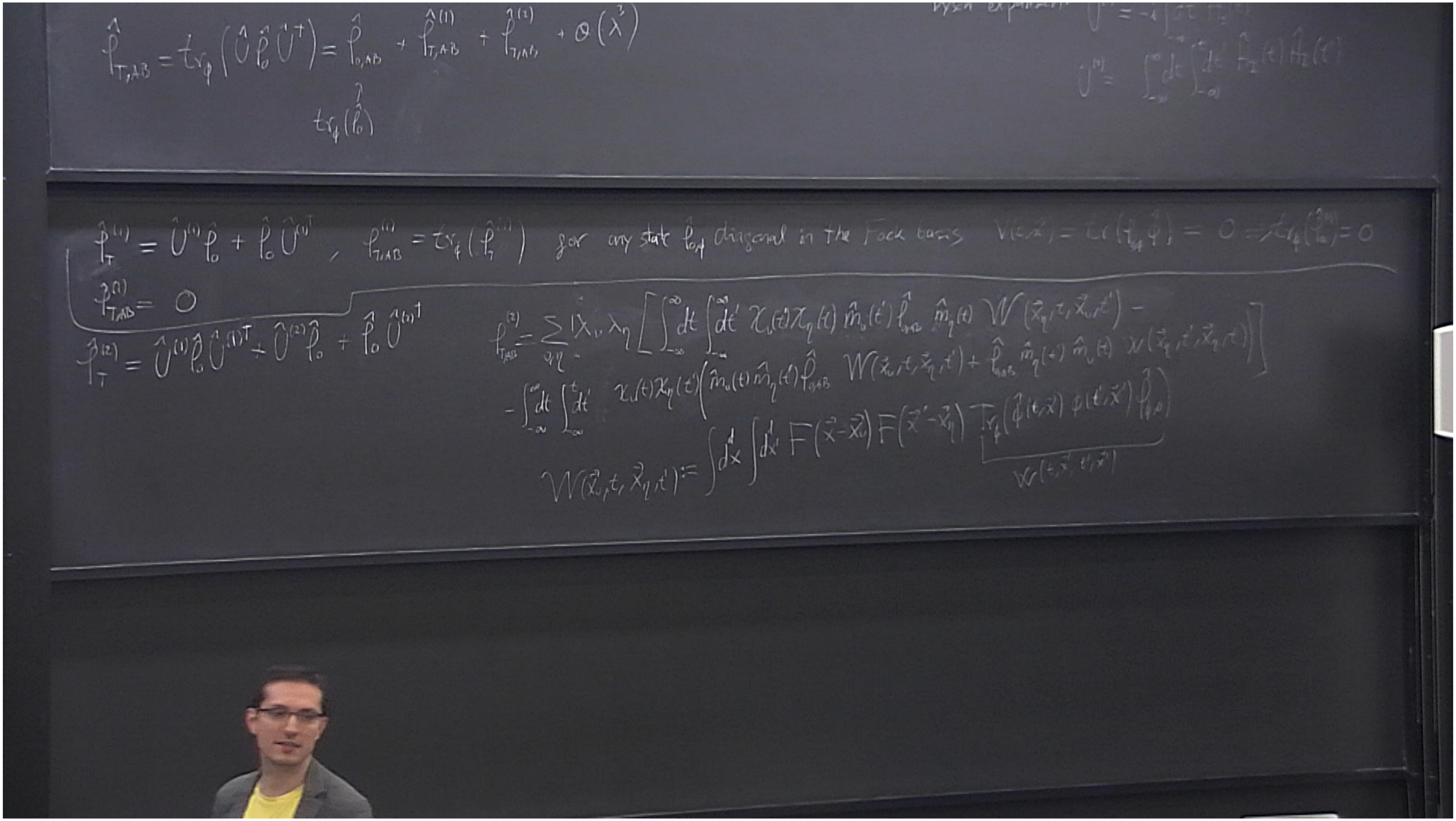
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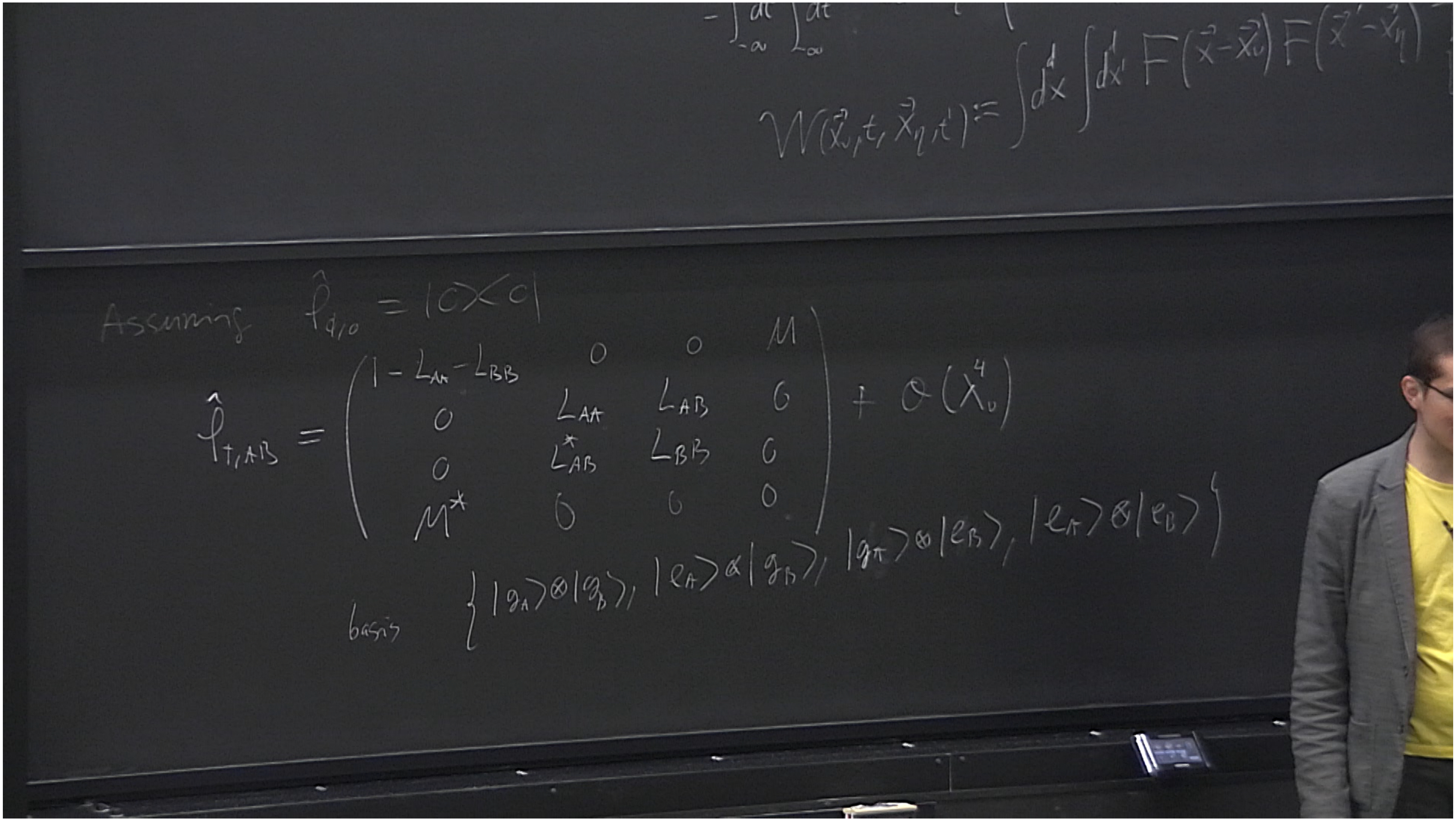
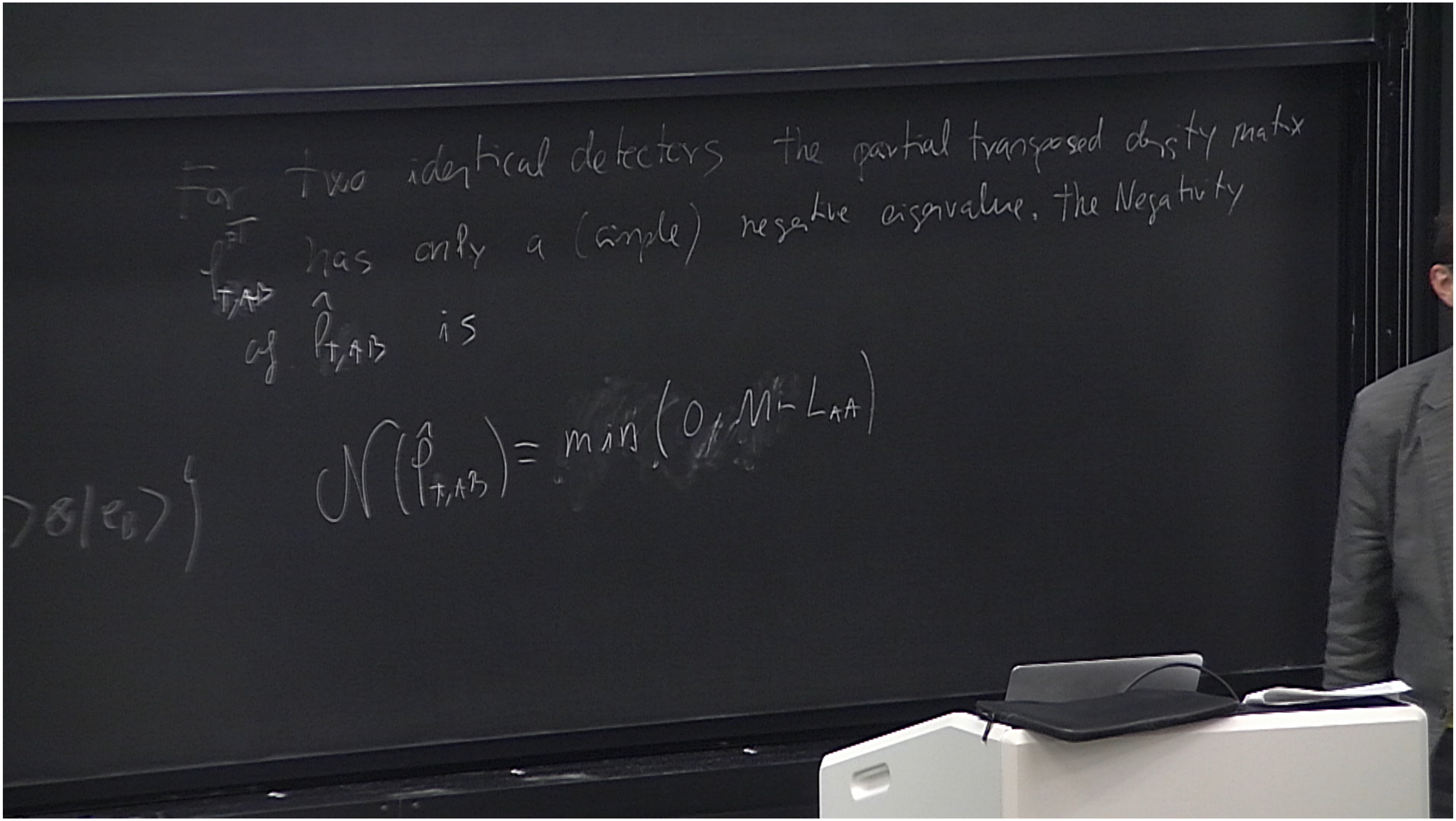
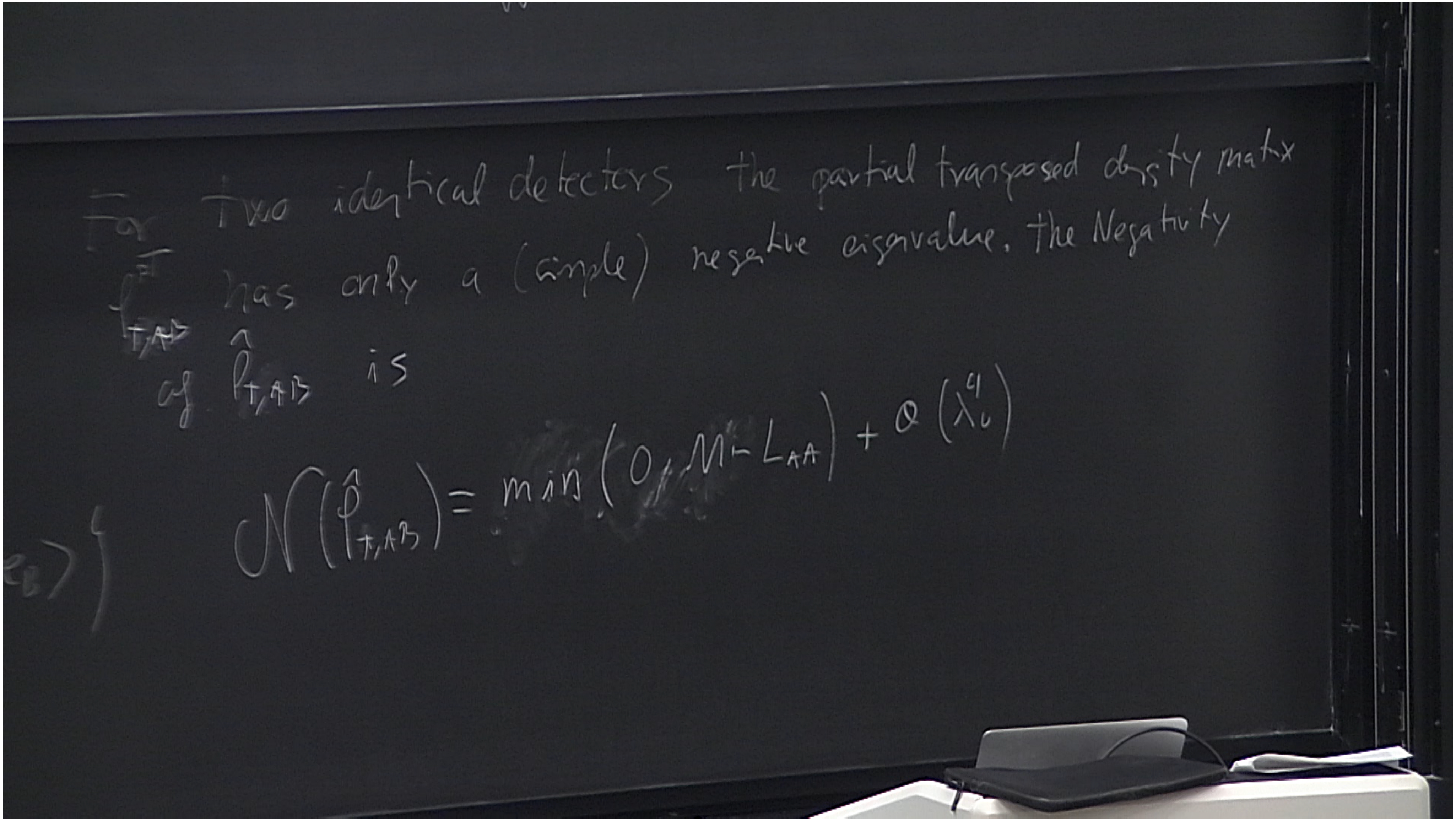

W(x_u, t, x_η, t') := ∫d^d x ∫d^d x' F(x − x_u) F(x' − x_η)
Assuming ρ_{φ,0} = |0⟩⟨0|
ρ_{t,AB} = (1 − L_AA − L_BB, 0, 0, M; 0, L_AA, L_AB, 0; 0, L*_AB, L_BB, 0; M*, 0, 0, 0) + O(λ_u^4)
basis {|g_A⟩⊗|g_B⟩, |e_A⟩⊗|g_B⟩, |g_A⟩⊗|e_B⟩, |e_A⟩⊗|e_B⟩}

$$\rho_{AB} = \rho_A \otimes \rho_B$$


For two identical detectors the partial transposed density matrix
$\hat\rho^{T}_{T,AB}$ has only a (simple) negative eigenvalue, the Negativity
of $\hat\rho_{T,AB}$ is
$\mathcal{N}(\hat\rho_{T,AB}) = \min(0, M - L_{AA})$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ρ^T_{T,AB} has only a (simple) negative eigenvalue, the Negativity
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N(ρ̂_{T,AB}) = min(0, M − L_{AA}) + O(λ^4)