Title: On the road to extracting QPV from holography: building a universal quantum computer in a simple QFT

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on the road to extracting QPV from Holography:

Building a universal quantum computer in QFT

ongoing work w/ Patrick Hayden & Jean Wang

outline

I. Introduction

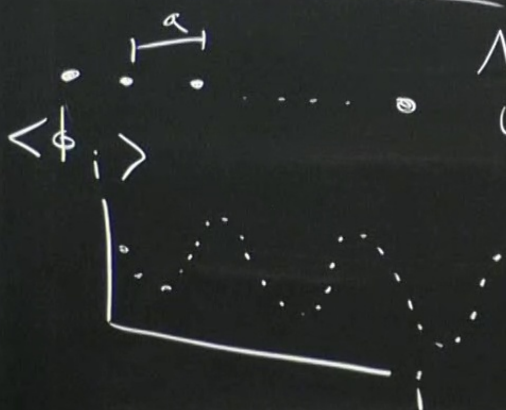
II. Hardware from field states

III. Simulating a multi particle quantum walk

IV. Universality

I. Introduction

What is a QFT?



$\phi_i \to X \qquad \pi_i \to P$

N harmonic osscilators
with quadratures $\{\phi_i, \pi_j\} = \delta_{ij}$

Local Hamiltonian

$$H = \sum_i P_i^2 + X_i X_{i+1} + X_i^2$$

Zoom out to distance $\gg a$

$$\sum_i \to \int dx \qquad \phi_i \to \phi(x)$$

$$L = \int dx\, (\partial_\mu \phi)^2 - \frac{1}{2} m \phi^2 - \frac{\lambda}{4!} \phi^4$$

Why QFT?

1. $\exists$ a holographic model w/ miniturizable quantum computer $\longrightarrow$ QPV is insecure

2. Want to make sure assumption 1 is correct

$\pi_i \to p$

...ilators

...s $\{\phi_i, \pi_j\} = \delta_{ij}$

...tonian

$\ldots_i^2 + X_i X_{i+1} + X_i^2$

distance $\gg a$

$\phi_i \to \phi(x)$

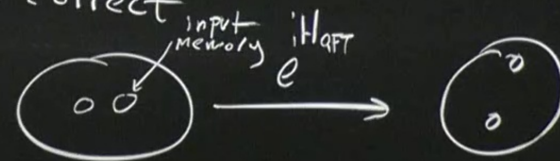
$\ldots \frac{1}{2} m \phi^2 - \frac{\lambda}{4!}\phi^4_{(x)}$

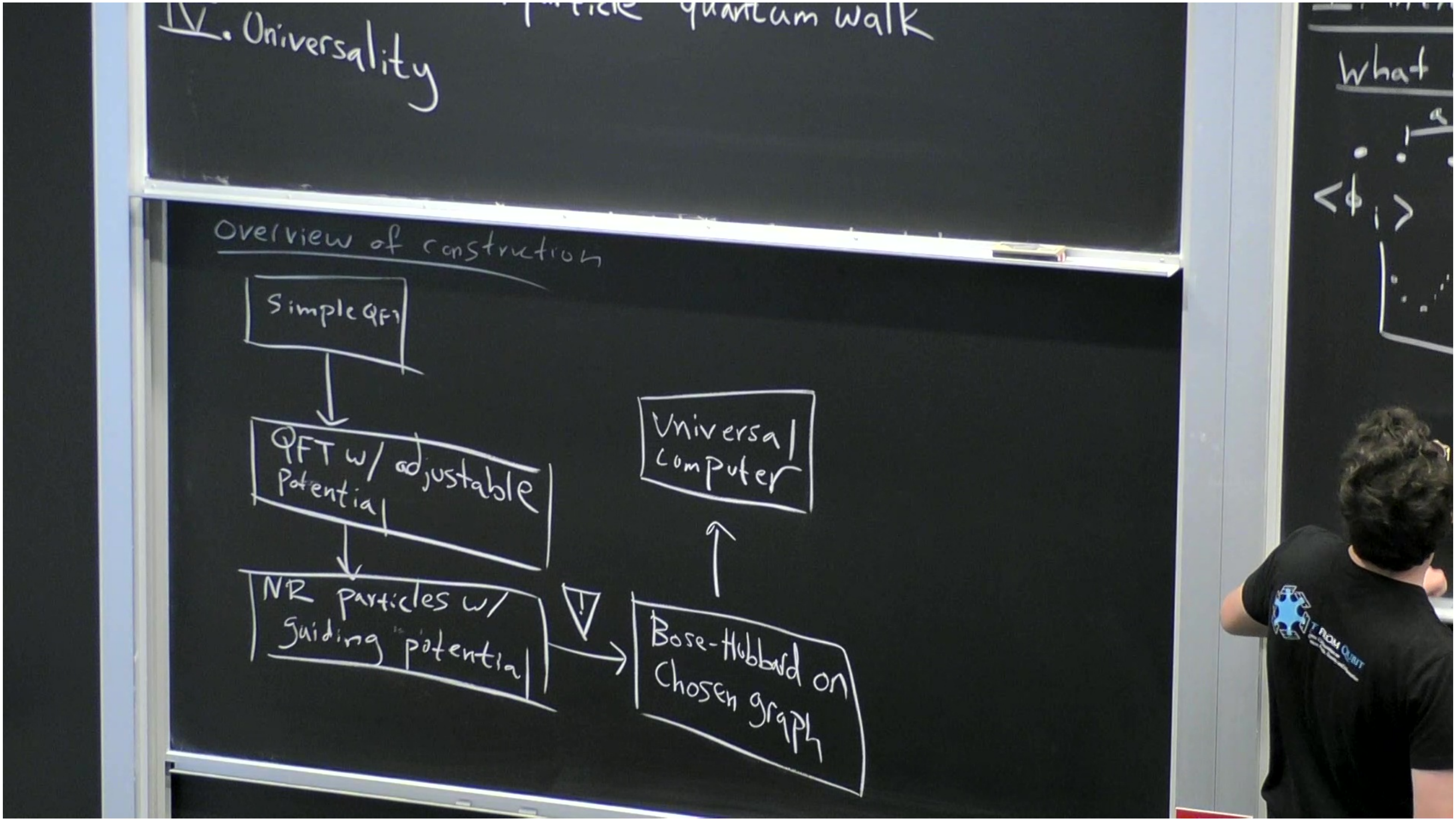
$\mathcal{L}(x) = \mathcal{L}$

Why QFT?

1. $\exists$ a holographic model w/ miniturizable quantum computer $\longrightarrow$ QPV is insecure

2. Want to make sure assumption 1 is correct





quantum walk
IV. Universality
Overview of construction
Simple QFT
QFT w/ adjustable potential
NR particles w/ guiding potential
!
Bose-Hubbard on chosen graph
Universal computer
What

II. ArXiv: 1703.00454

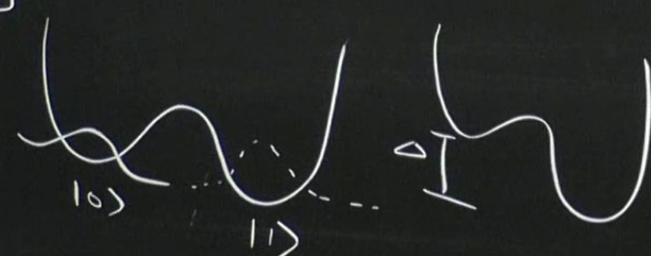
$$\mathcal{L} = \frac{1}{2}\phi(\Box + m^2)\phi - \lambda\phi^4 + J(\vec{x},t)\phi^2$$

$$\Big\downarrow \text{NR}$$

$$H = \sum_{i=1}^{N} \frac{\vec{p}_i^{\,2}}{2m} + J(\vec{x}_i,t) + \sum_{i\neq j} \lambda\delta(x_i - x_j)$$

pick J for dual rail encoding

J



$$\begin{pmatrix} 1 & \\ & e^{i\Delta t} \end{pmatrix}$$

$$\mathcal{L} = \underbrace{-\frac{1}{2}\phi(\Box+m^2)\phi - \lambda\phi^4}_{\mathcal{L}_\phi} - S^*(\Box+M^2)S - g\phi^2|S|^2$$

$M \gg m$ $\quad S \to \underset{\text{classical}}{S_0} + \delta S \quad$ s.t. $\quad (\Box+M^2)S_0 = 0$

$$\to \mathcal{L}_\phi - g\phi^2|S_0|^2 - g\phi^2|\delta S|^2 - 2g\phi^2\,\mathrm{Re}\,S_0\,\delta S - \delta S^*(\Box+M^2)\delta S$$

take $g|S_0|^2$ fixed limit $\quad g|S_0| \to 0$

$$\mathcal{L} = \underbrace{-\frac{1}{2}\phi(\Box+m^2)\phi - \lambda\phi^4}_{\mathcal{L}_\phi} - S^*(\Box+M^2)S - g\phi^2|S|^2$$

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$$\to \mathcal{L}_\phi - g\phi^2|S_0|^2 \cancel{- g\phi^2|\delta S|^2 - 2g\phi^2\,\mathrm{Re}\,S_0^*\delta S - \delta S^*(\Box+M^2)\delta S} \to 0$$

take $g|S_0|^2$ fixed limit $\quad g|S_0| \to 0$

classical

$$\mathcal{L}_\phi - g\phi^2|S_0|^2 - \cancel{g\phi^2|\delta S|^2 - 2g\phi^2\,\mathrm{Re}\,\bar{S}_0\,\delta S - \delta S^*(\Box + m^2)\,\delta S}$$

take $g|S_0|^2$ fixed limit $\quad g|S_0| \to 0$

$$S_0 = \int dk\, \tilde{S}(\vec{k})\, e^{-i(\omega_k t - \vec{x}\cdot\vec{k})} \qquad \omega_k = \sqrt{k^2 + m^2} = m + O\!\left(\cancel{\frac{k^2}{m^2}}\right)$$

$$= e^{-imt}\, S_0(\vec{x}, 0) \to |S_0(\vec{x},t)|^2 = |S_0(\vec{x},0)|^2$$

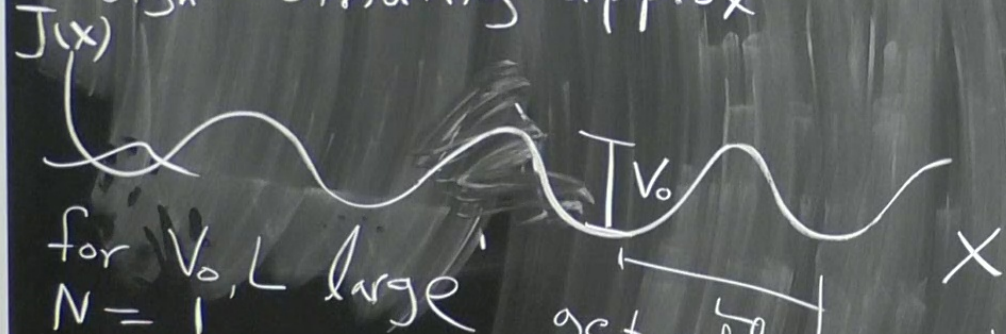
$$\mathcal{L}_\phi - \phi^2 J(\vec{x}, 0)$$

$$\mathcal{L} = \frac{1}{2}\phi(\Box + m^2)\phi - \lambda\phi^4 + J(\vec{x})\phi^2$$

$$\downarrow \text{NR}$$

$$H = \sum_{i=1}^{N} \frac{p_i^2}{2m} + J(x_i) + \sum_{i \neq j} \lambda\delta(x_i - x_j)$$

"tight binding approx"



for V_0, L large

$N = 1$

get effective Ham

$$H_{eff} = \sum_{(u,v)\in E} |u\rangle\langle v| + |v\rangle\langle u|$$

$$\dot{\sigma}_{ab} = N_{ab} + \rho_{ab} - \frac{\kappa}{2} h_{ab} + \left[\text{many terms on } \nabla_a \ln F\right]\Big) \quad \frac{\nabla_a F}{}$$

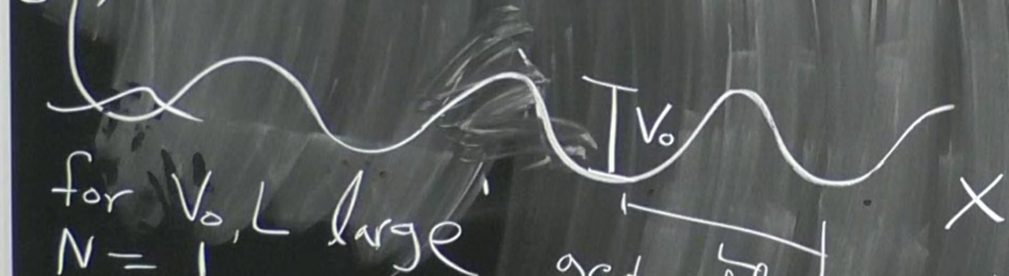
$$\mathcal{L} = \frac{1}{2}\phi(\Box + m^2)\phi - \lambda\phi^4 + J(\vec{x})\phi^2$$

$\downarrow$ NR

$$H = \sum_{i=1}^{N} \frac{p_i^2}{2m} + J(x_i) + \sum_{i\neq j} \lambda\,\delta(x_i - x_j)$$

"tight binding approx"

$J(x)$

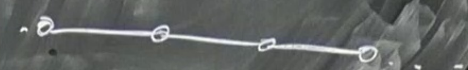


for V_0, L large

$N = 1$

get effective Ham

$$H_{eff} = t\sum_{(u,v)\in E} |u\rangle\langle v| + |v\rangle\langle u| \cdots$$

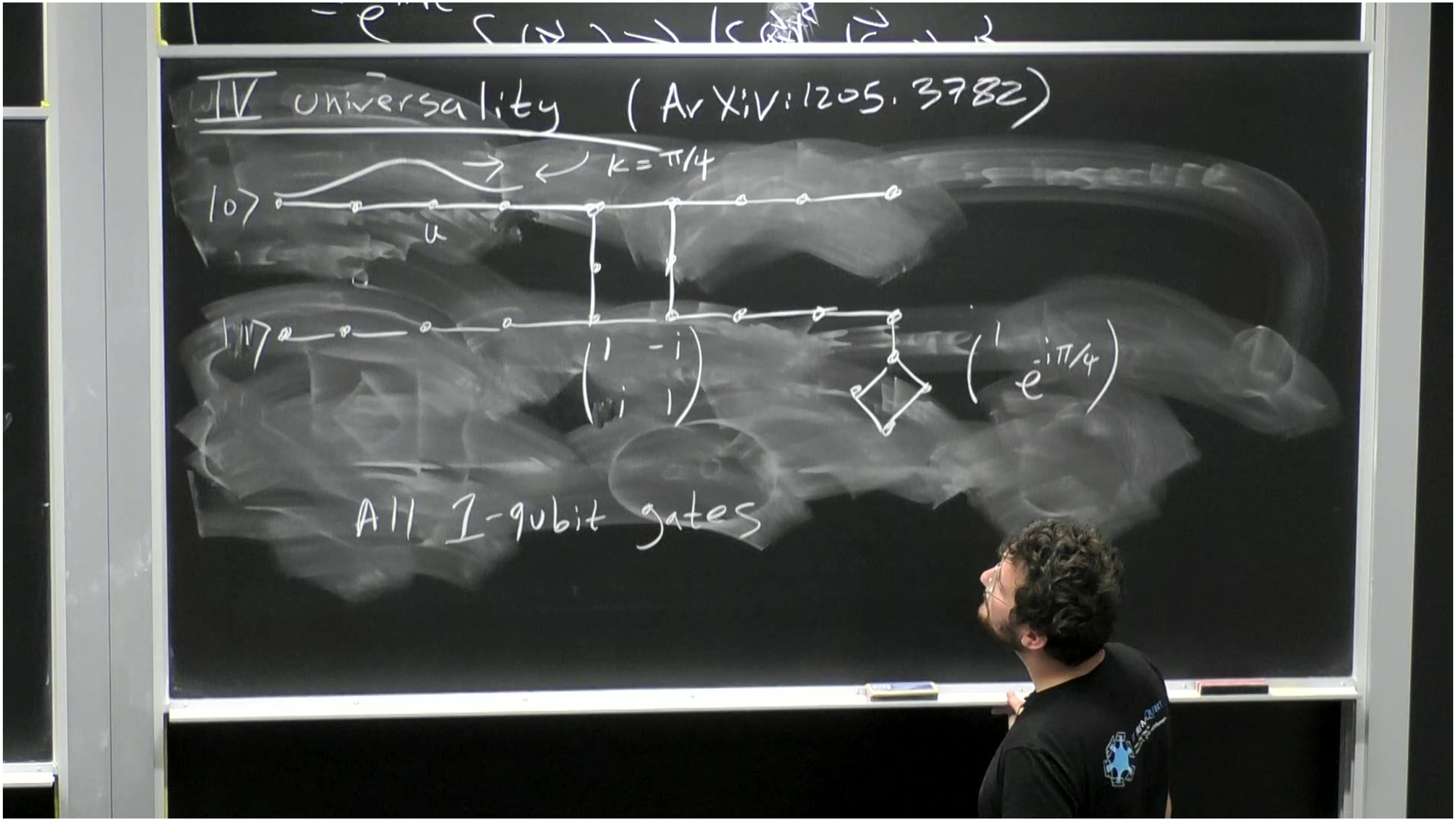


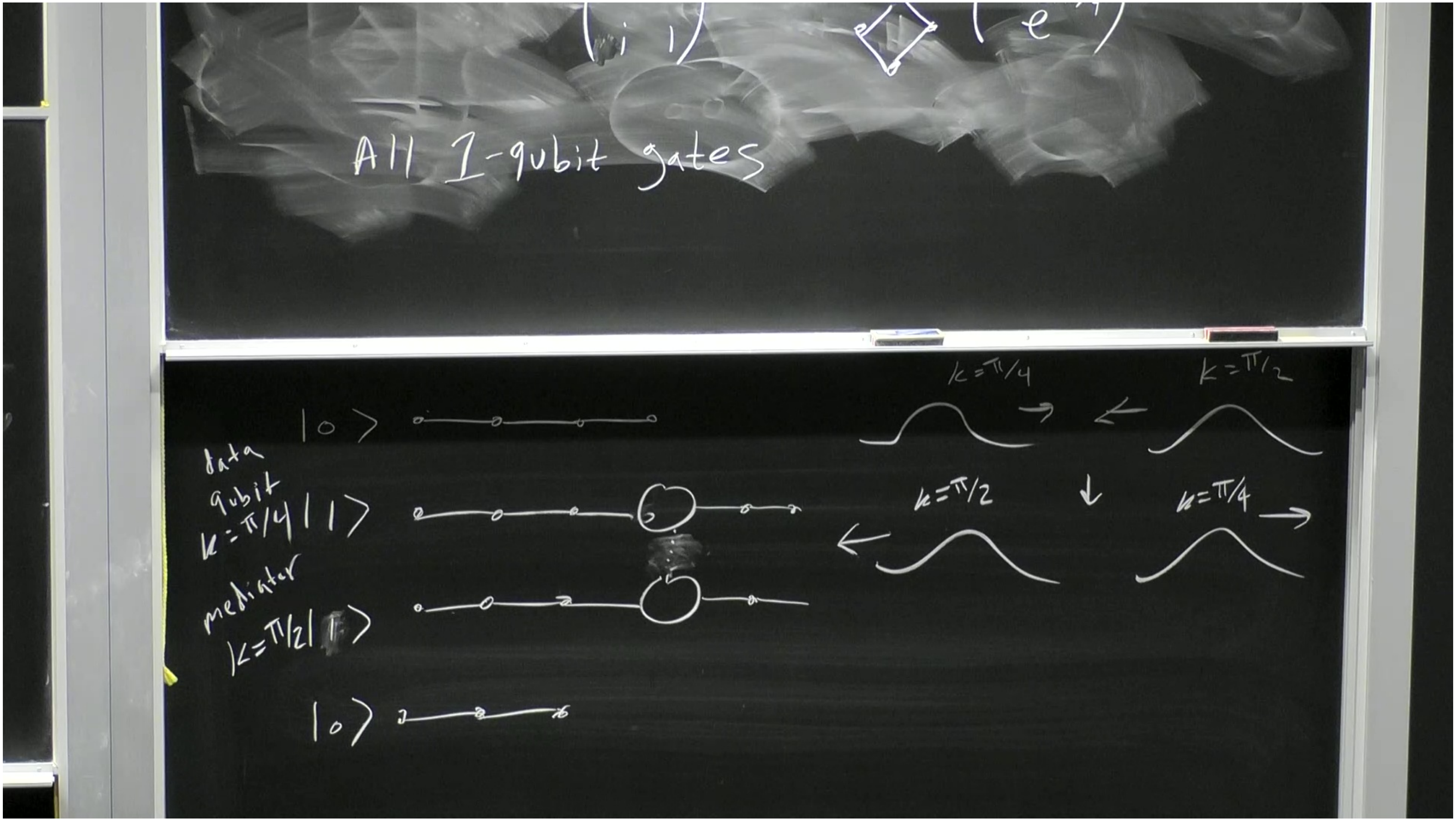
multi-particle

$$H_{eff} = -t\sum_{(u,v)\in E} b_u^\dagger b_v + b_v^\dagger b_u + \sum_{v\in V} n_v^2$$

$$n_v^2 = (b_v^\dagger b_v)^2$$

$\sigma_{ab} = (N_{ab}) + \rho_{ab} - \frac{K}{2} h_{ab} + ($many terms on ∇_a ...$)$


IV Universality (ArXiv:1205.3782)
k = π/4
|0⟩
u
|1⟩
1 -i
-i 1
1
e^{-iπ/4}
All 1-qubit gates


All 1-qubit gates
|0>
data qubit
k=π/4 |1>
mediator
k=π/2 |1>
|0>
k=π/4
k=π/2
k=π/2
k=π/4