University of Gdańsk

International Centre for Theory of Quantum Technologies

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DETECTION OF QUANTUM PHASE TRANSITIONS WITH QUANTUM MACHINE LEARNING TECHNIQUES

with M. Grossi, O. Kiss, S. Vallecorsa, S. Monaco, I. Gramese, C. Zollo, F. De Luca

Geneva, 22 November 2023

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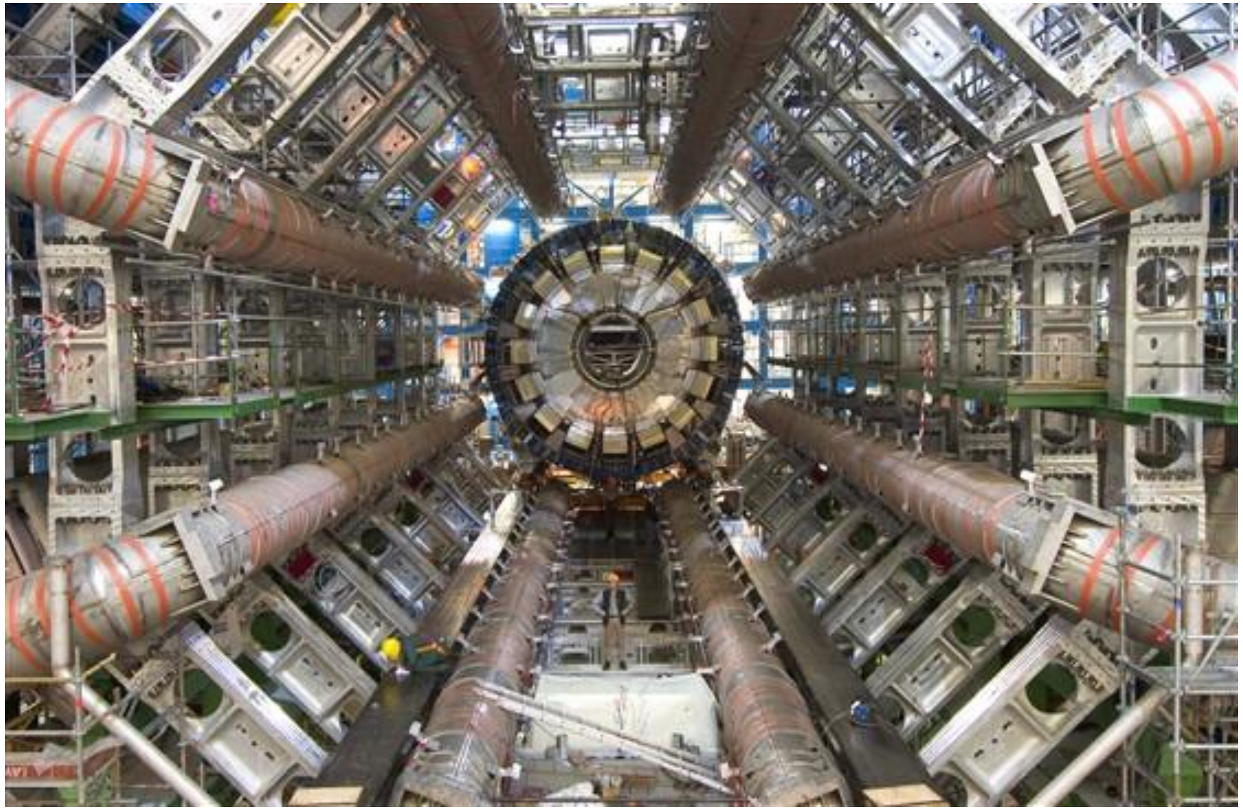
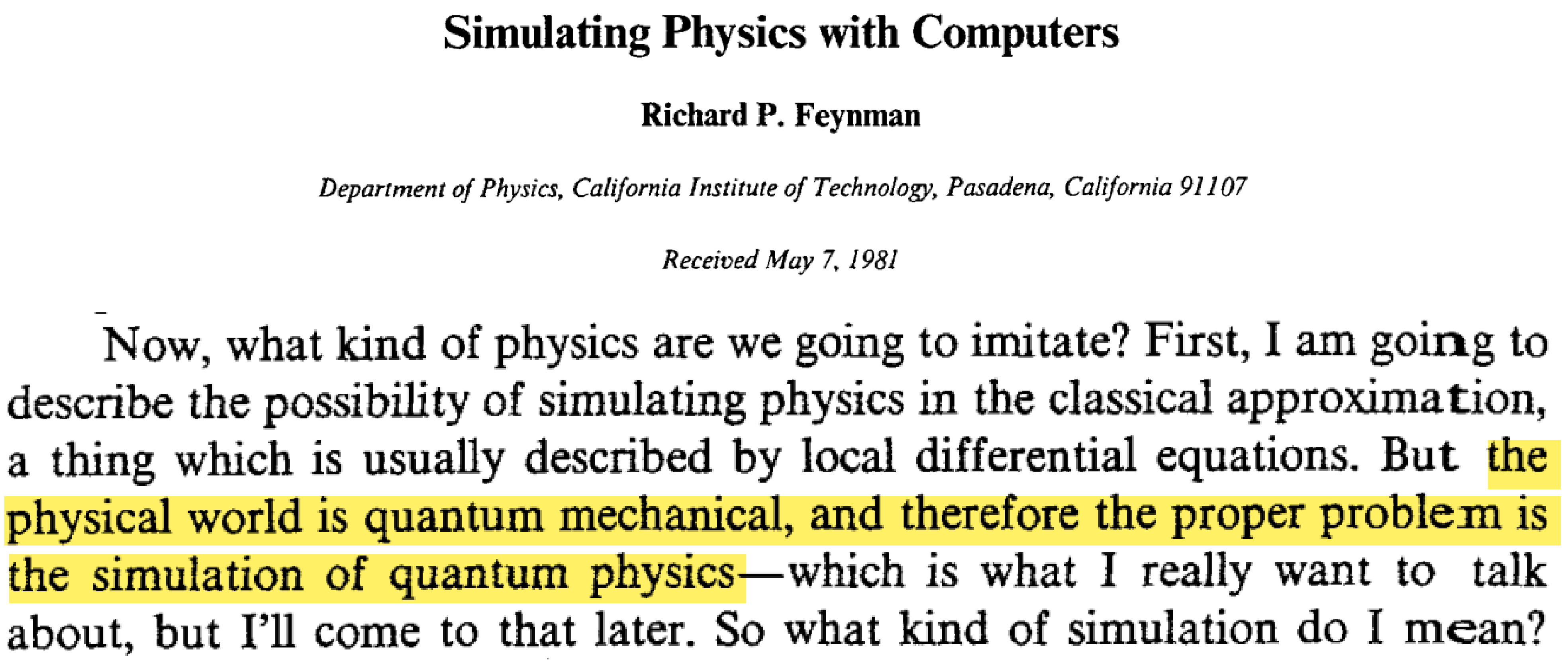
WHY QUANTUM PHASE TRANSITION?



HIGGS MECHANISM

SUPERCONDUCTIVITY

WHY QUANTUM MACHINE LEARNING?


Simulating Physics with Computers

Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

Received May 7, 1981

Now, what kind of physics are we going to imitate? First, I am going to describe the possibility of simulating physics in the classical approximation, a thing which is usually described by local differential equations. But the physical world is quantum mechanical, and therefore the proper problem is the simulation of quantum physics—which is what I really want to talk about, but I'll come to that later. So what kind of simulation do I mean?

WHY QUANTUM SIMULATION?

Quantum phase transition from a superfluid to a Mott insulator in a gas of ultracold atoms

Markus Greiner, Olaf Mandel, Tilman Esslinger, Theodor W. Hänsch & Immanuel Bloch

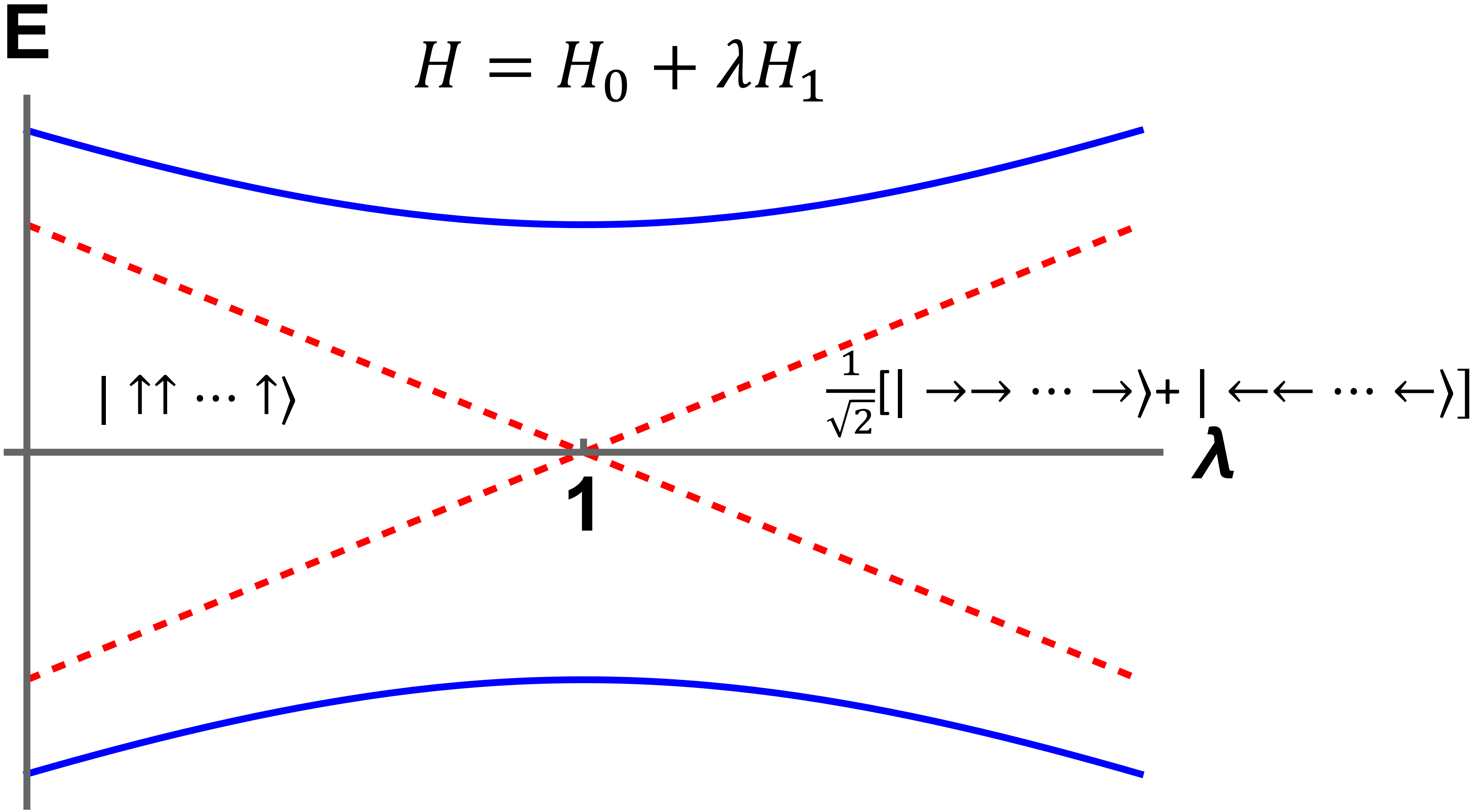
Nature **415**, 39–44 (2002) | Cite this article

Quantum phases of matter on a 256-atom programmable quantum simulator

Sepehr Ebadi, Tout T. Wang, Harry Levine, Alexander Keesling, Giulia Semeghini, Ahmed Omran, Dolev Bluvstein, Rhine Samajdar, Hannes Pichler, Wen Wei Ho, Soonwon Choi, Subir Sachdev, Markus Greiner, Vladan Vuletić & Mikhail D. Lukin

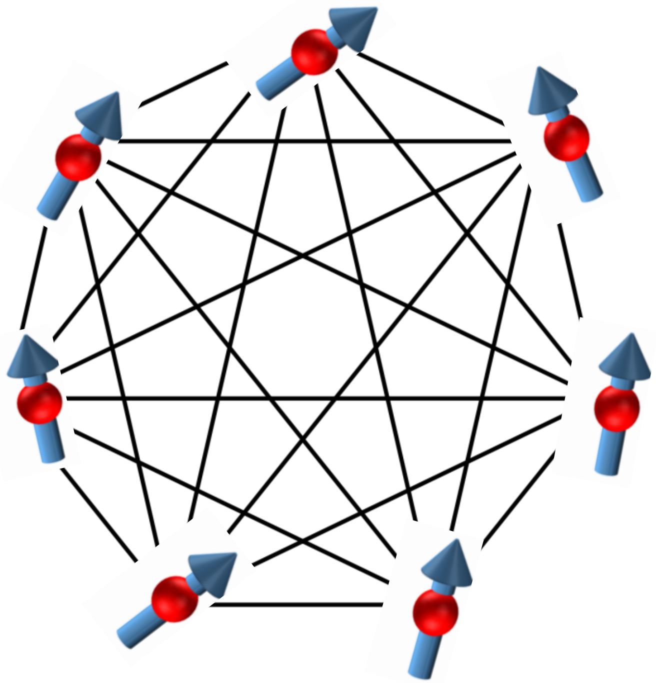
Nature **595**, 227–232 (2021) | Cite this article

WHAT IS A QUANTUM PHASE TRANSITION?



LIPKIN-MESHKOV-GLICK MODEL

$$H = -\frac{1}{N}\sum_{i<j}^{N} \sigma_x^i\sigma_x^j + \gamma\sigma_y^i\sigma_y^j - B\sum_{i}^{N}\sigma_z^i$$



3 Universality Classes

$\gamma = 0$ d=0 Ising Model

$\gamma = 1$ Dicke superradiance

$0 < \gamma < 1$ LMG – large spin molecules

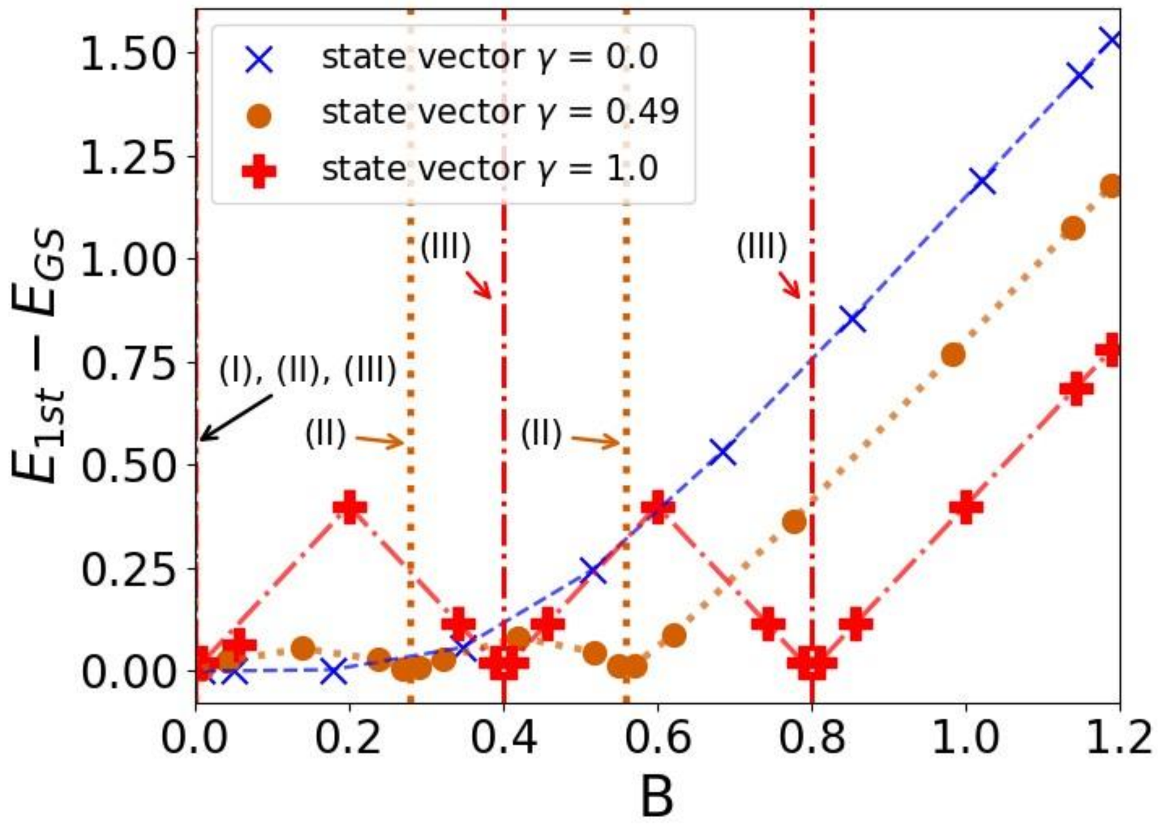
$N+1$ QPT at $B_c \propto \sqrt{\gamma}$

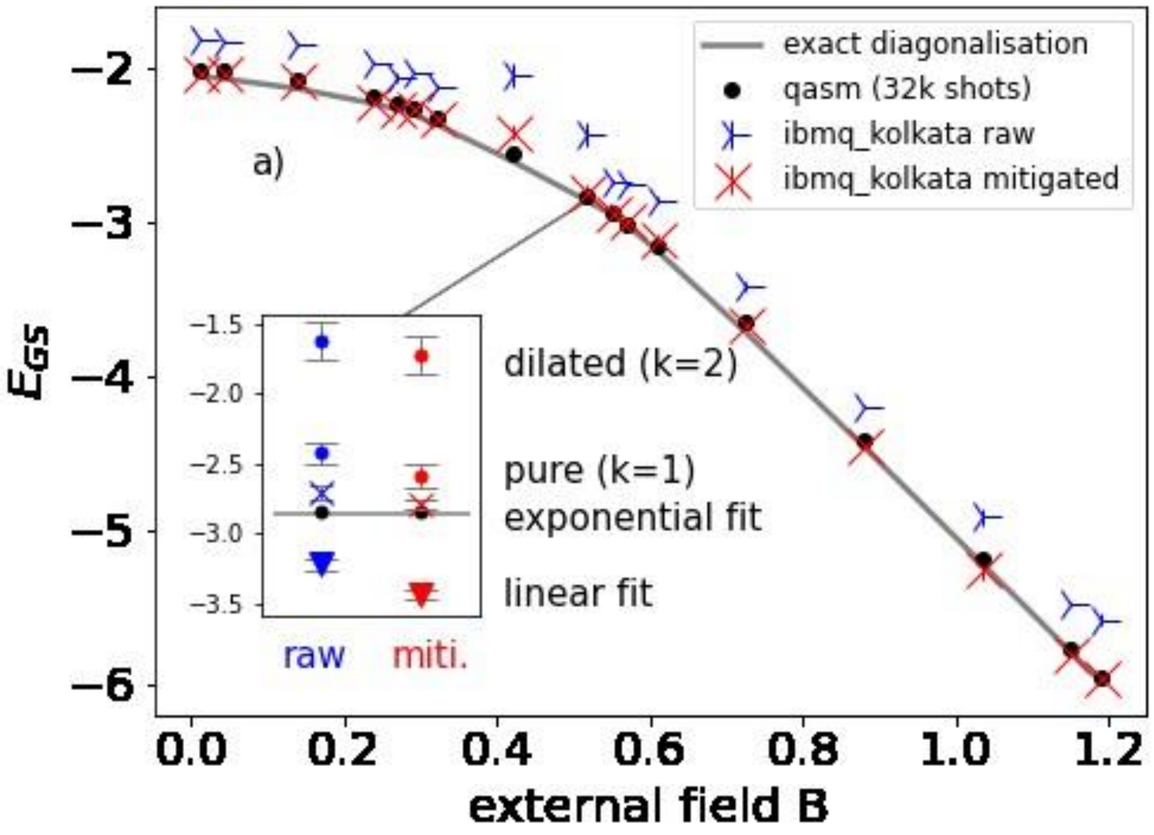
CAN WE USE VQE TO DETECT THEM?

$E_{GS} - E_{1st}$	$\langle S_z \rangle$	$\langle S_x^2 \rangle$
Mass gap	Total magnetization	Correlation Functions

A. Peruzzo, et al., Nat. Commun. 5, 4213 (2014).

VQE FOR LIPKIN-MESHKOV-GLICK MODEL

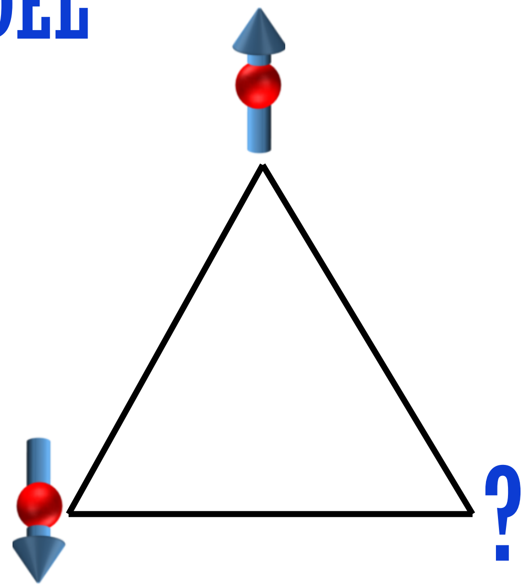




AXIAL NEAREST NEIGHBOUR ISING (ANNNI) MODEL

$$H = \sum_{i=1}^{N} \sigma_x^i \sigma_x^{i+1} - \kappa\, \sigma_x^i \sigma_x^{i+2} + h \sum_{i}^{N} \sigma_z^i$$

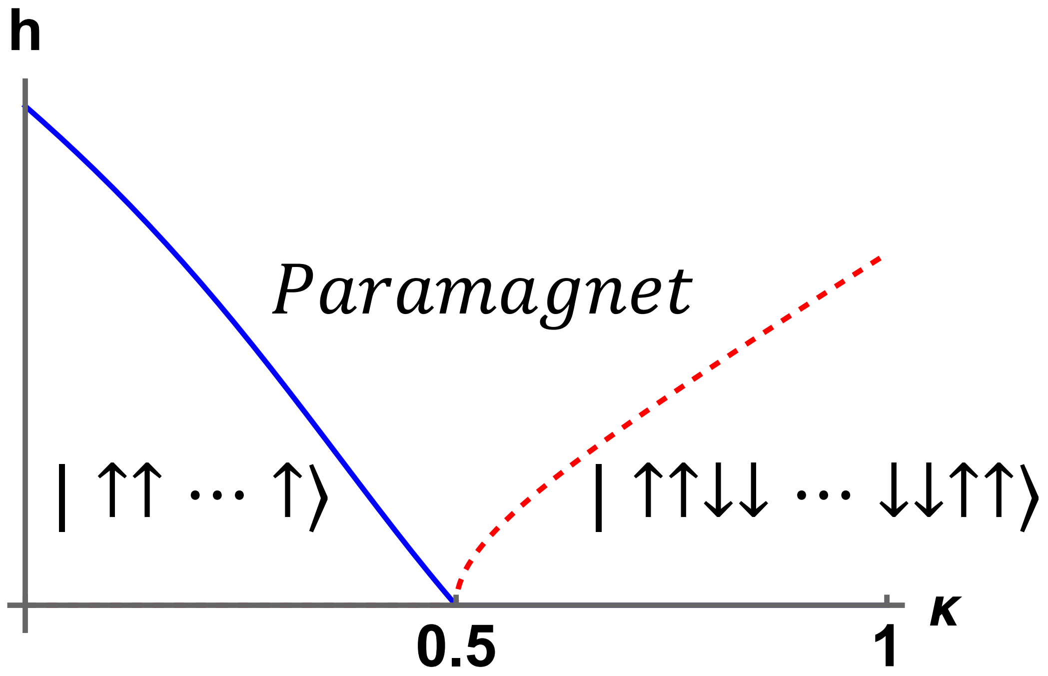
$\kappa > 0$ Competing Interaction (Frustration)



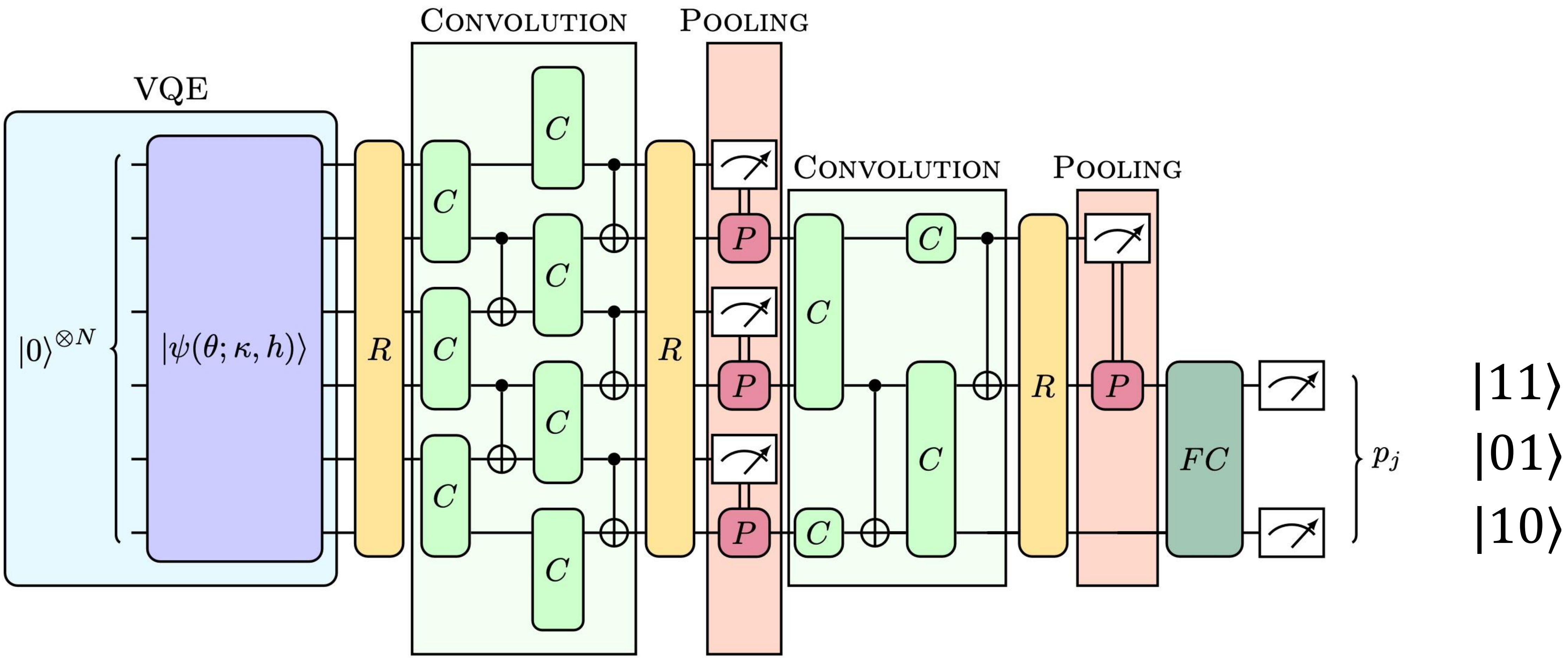
TWO MARGINAL CASES

$\kappa = 0$ 1D Ising model in transverse field

$h = 0$ Semi-classical model



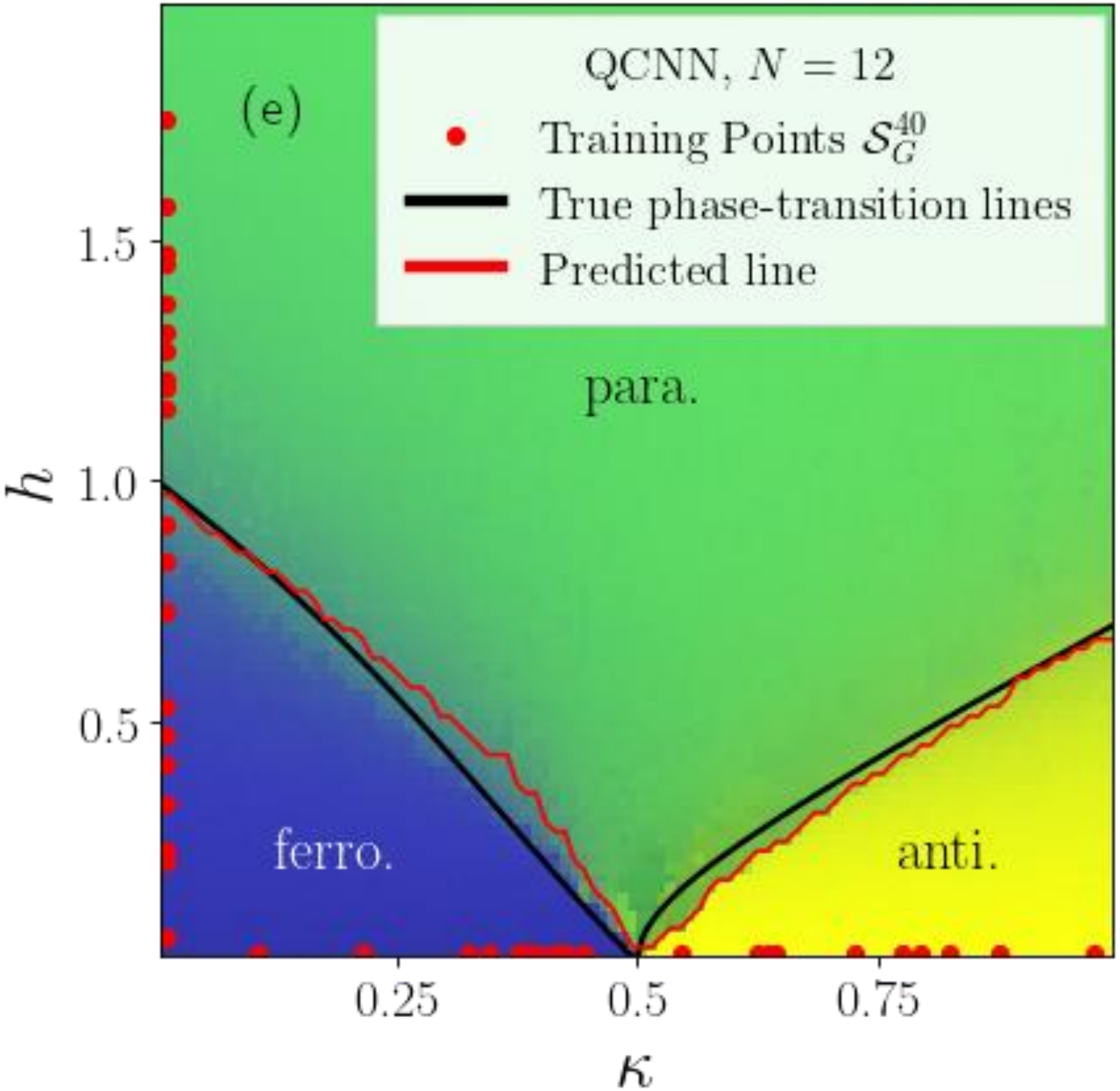
QCNN FOR ANNNI MODEL



We train only on the two marginal integrable cases

I. Cong et al, Nat. Phys. 15, 1273 (2019).

QCNN FOR ANNNI MODEL



CONCLUSIONS BUT NOT SO CONCLUSIVE

There are pieces of evidence that the phase diagram is even richer.

What could be done in the future?

Can we hope for full ability to study new physics with current tools?

There is great chaos - the situation is excellent

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Thank you very much for your attention!

M. Grossi, O. Kiss, F. De Luca, I. Gramese, and A. Mandarino,
Finite-size criticality in fully connected spin models on superconducting quantum hardware
Physical Review E 107, 024113 (2023);

S. Monaco, O. Kiss, A. Mandarino, S. Vallecorsa, M. Grossi,
Quantum phase detection generalization from marginal quantum neural network models
Physical Review B 107, L081105 (2023);

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European Funds Smart Growth

FNP Foundation for Polish Science

European Union European Regional Development Fund

LIPKIN-MESHKOV-GLICK MODEL