Tensor networks and quantum computing for particle physics and related issues

Enrique Rico Ortega

Wednesday, 26 November 2025

- Born and undergrad: Madrid
- PhD: Barcelona
- Postdoc: Innsbruck, Vienna, Ulm
- Habilitation: Strasbourg

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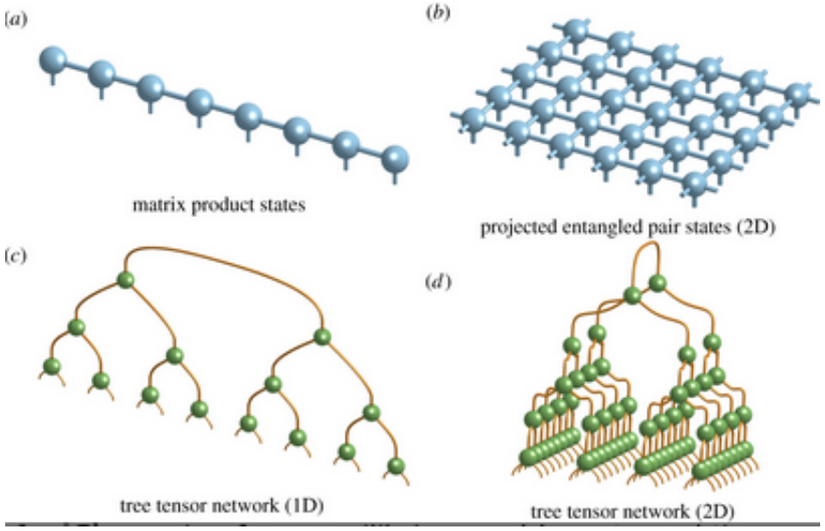
Background and Research interest:

Quantum Information tools to characterise phases of matter, e.g. entanglement entropy.

Quantum technologies to simulate High Energy models

New non-perturbative methods in Hamiltonian formulation and real-time dynamics following the LQCD program

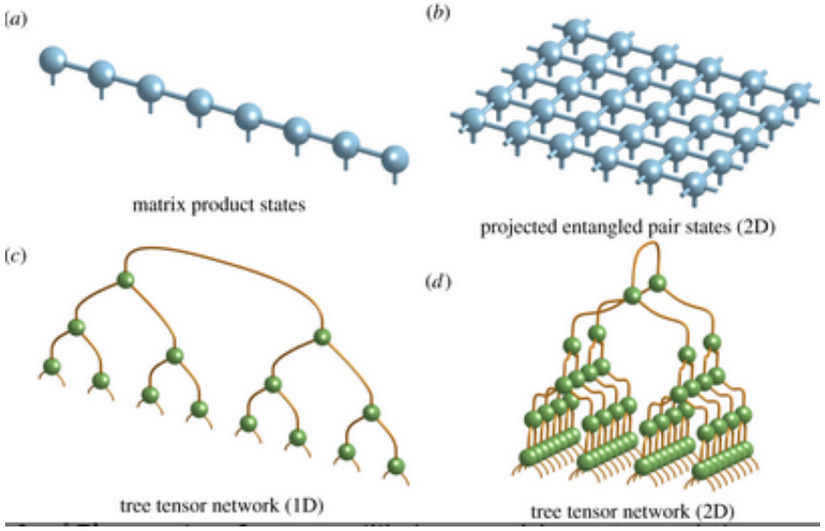


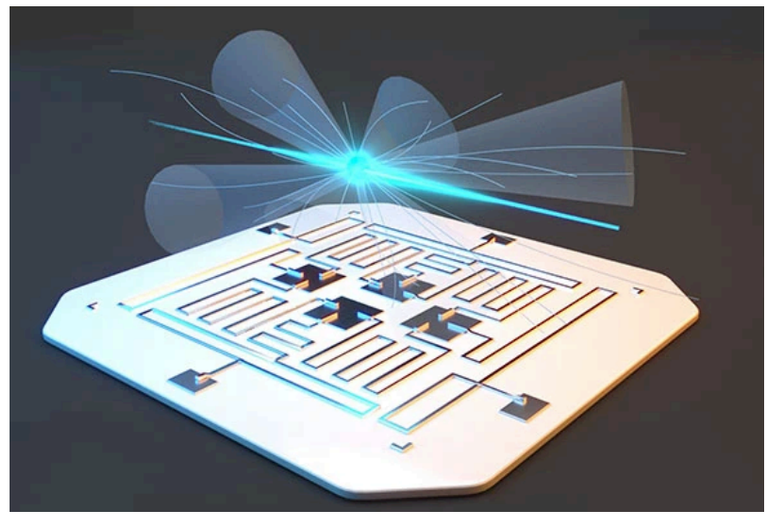
CERN-TH-2025-105

Roughening and dynamics of an electric flux string in a (2+1)D lattice gauge theory

Francesco Di Marcantonio,[1,*] Sunny Pradhan,[1,†] Sofia Vallecorsa,[2,‡]
Mari Carmen Bañuls,[3,4,§] and Enrique Rico Ortega[1,2,5,6,¶]

BasQ Basque Quantum
Donostia International Physics Center
ikerbasque Basque Foundation for Science
Universidad del País Vasco Euskal Herriko Unibertsitatea
EHU QC EHU Quantum Center
CERN





arXiv:2505.23853 CERN-TH-2025-105

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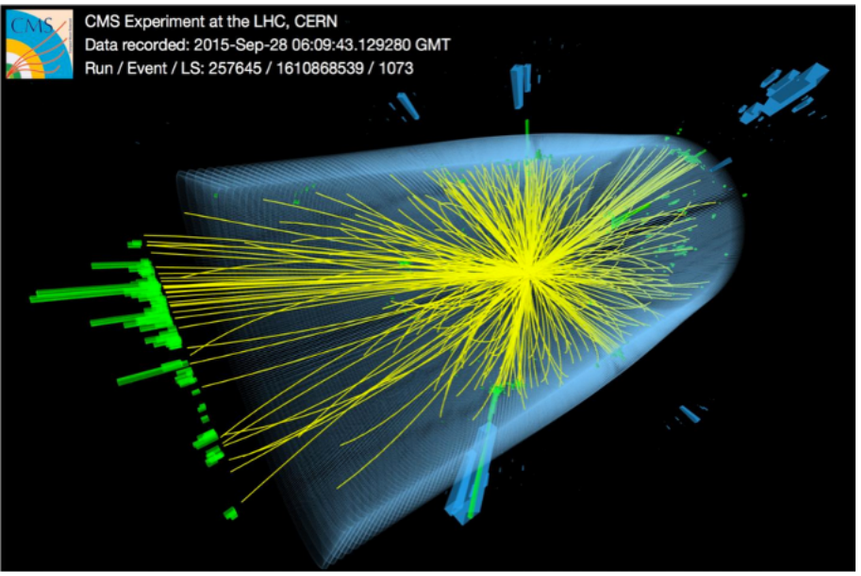
arXiv:2507.08088 CERN-TH-2025-111

Real-Time Dynamics in a (2+1)-D Gauge Theory: The Stringy Nature on a Superconducting Quantum Simulator

Jesús Cobos,[1,*] Joana Fraxanet,[2] César Benito,[3] Francesco di Marcantonio,[1] Pedro Rivero,[2] Kornél Kapás,[4] Miklós Antal Werner,[4] Örs Legeza,[4,5,6] Alejandro Bermudez,[3] and Enrique Rico[1,7,8,9]

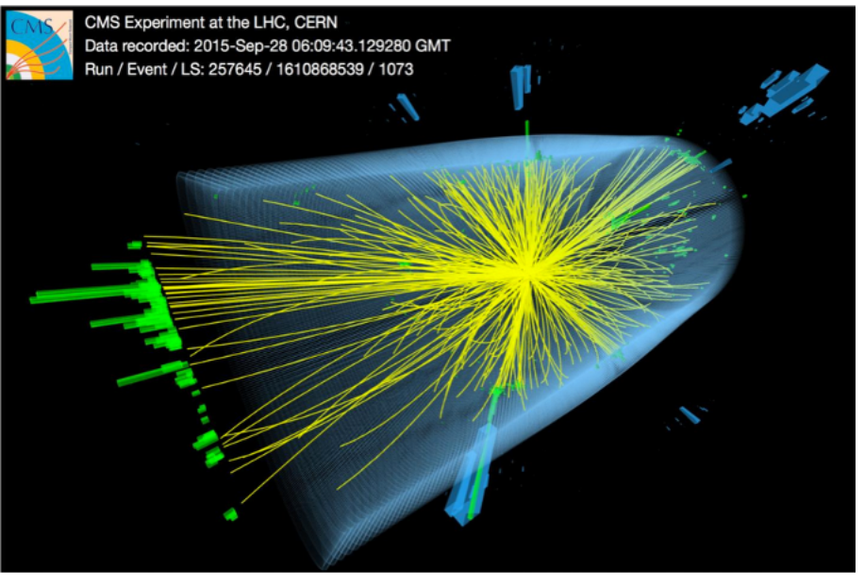


The Grand Challenge:
Simulating the strong force (QCD)

Build purpose-driven hardware to solve fundamental physics

Co-designed hardware as a physics laboratory

“History doesn't repeat itself, but it often rhymes.”



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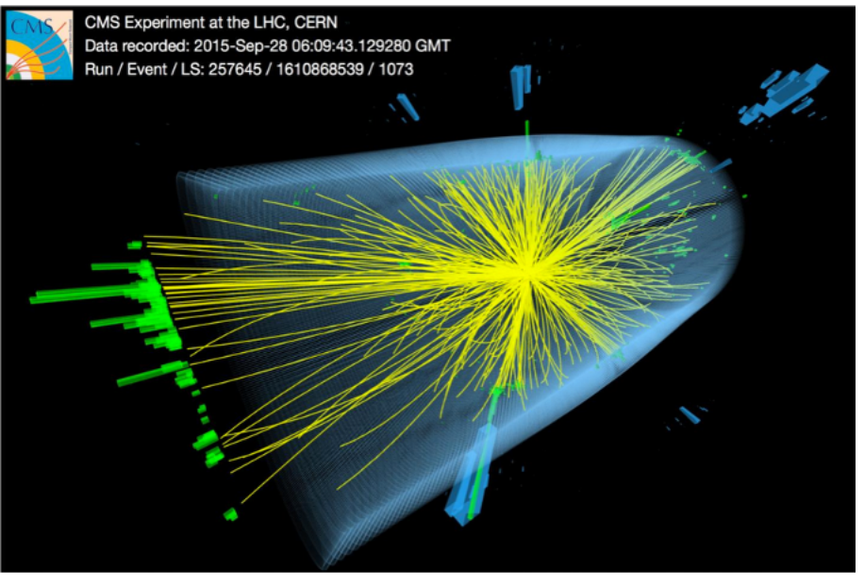
BlueGene & QCDOC

Classical Co-Design for QCD

Solved static properties
(e.g., hadron masses)

Non-efficient for real-time dynamics.



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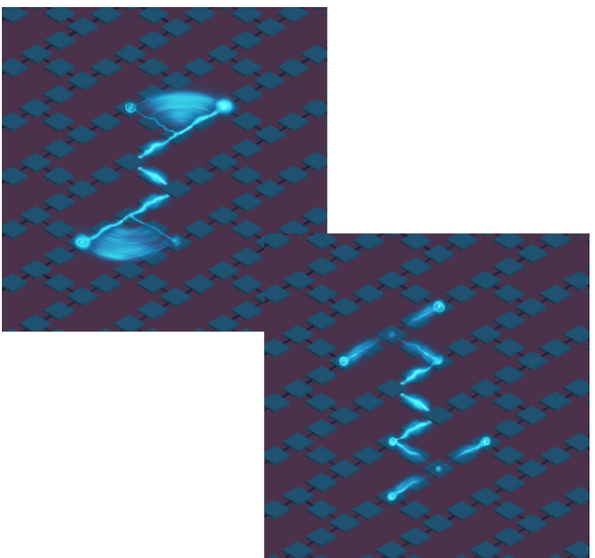
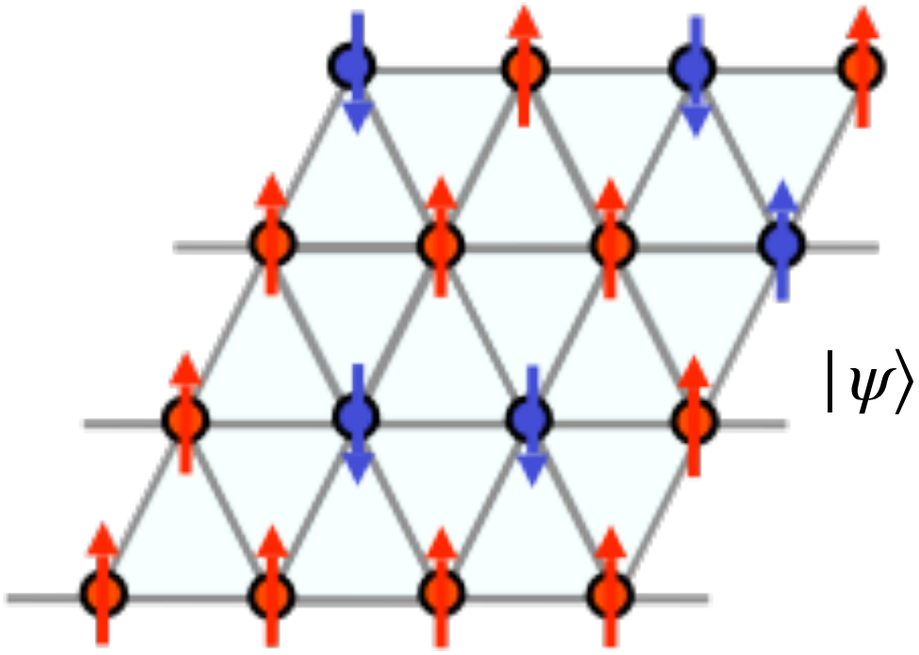


TODAY

Quantum Co-Design for QCD
Solved dynamical properties
(e.g., string dynamics)

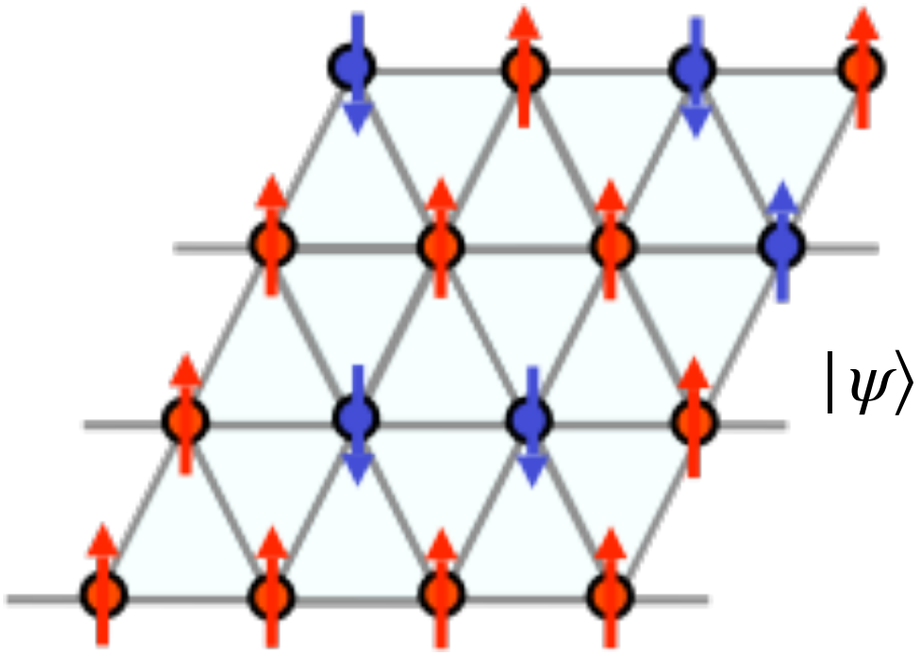


R.P. Feynman, Int. J. Theor. Phys. (1982)

Preparation of a general quantum state

$$|\psi\rangle = c_1 |\uparrow\uparrow\cdots\uparrow\rangle + c_2 |\uparrow\uparrow\cdots\downarrow\rangle + \cdots + c_{2^N} |\downarrow\downarrow\cdots\downarrow\rangle$$

quantum correlations = entanglement



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$$|\psi(t)\rangle = U(t)\,|\psi\rangle$$

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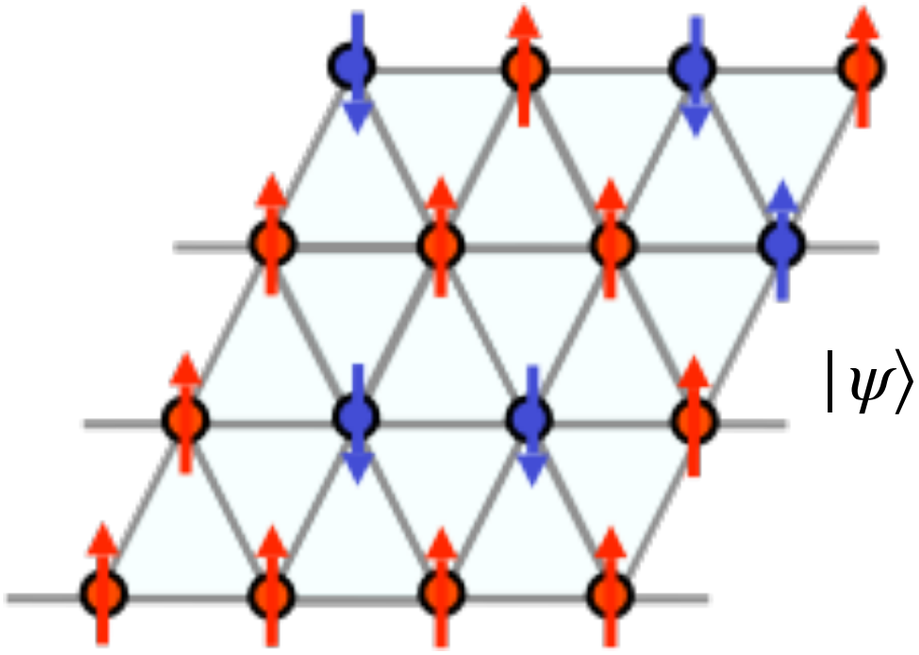

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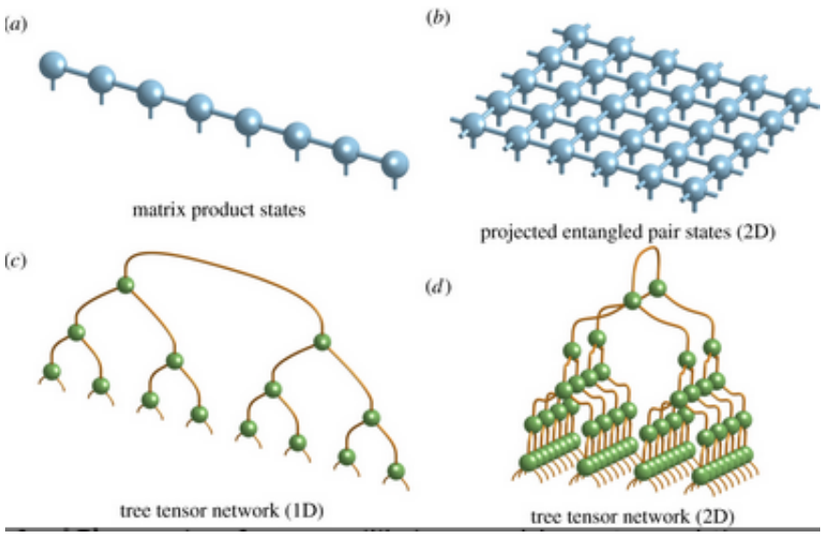

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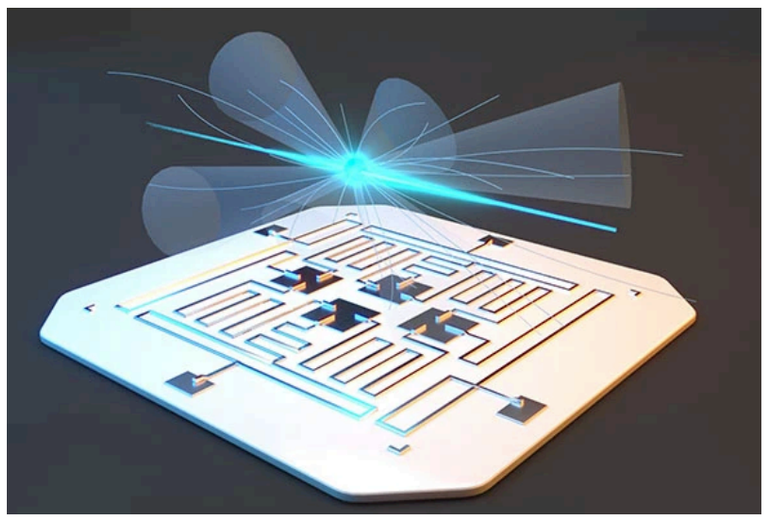


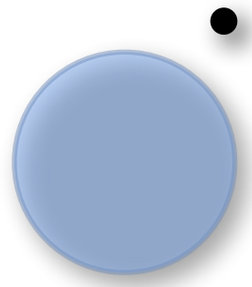
Quantum Simulators &

Entanglement tailored classical algorithms (tensor networks)

Three ingredients to describe Nature

Three ingredients to describe Nature

- Quantum matter as the basic building block



atoms

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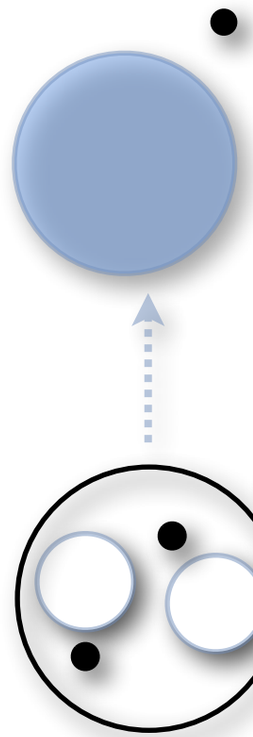


atoms

nucleons

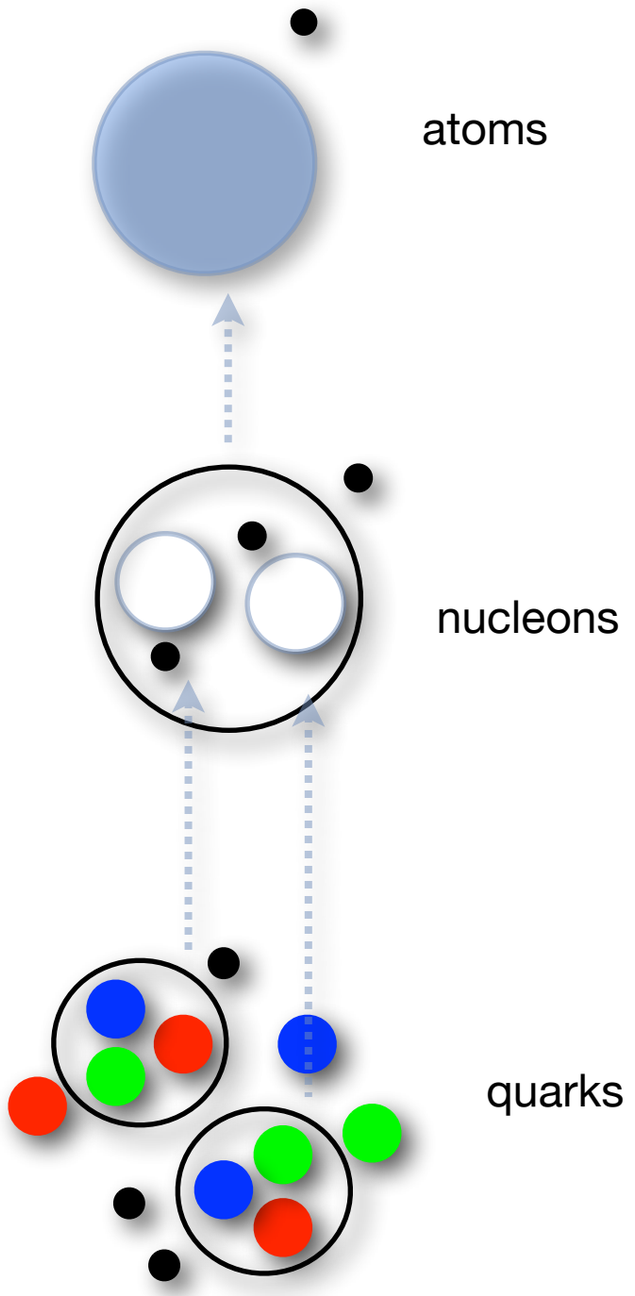
- Gauge symmetry as a fundamental principle and at the origin of every force

Three ingredients to describe Nature

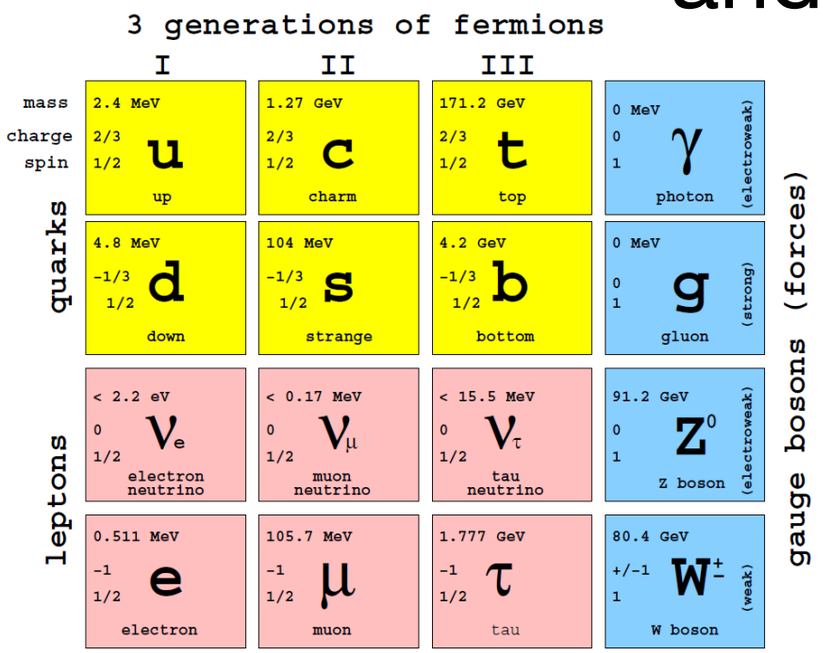
- Quantum matter as the basic building block

- Gauge symmetry as a fundamental principle and at the origin of every force

- Renormalisation group as a tool to study Nature at different scales



Gauge symmetry as a fundamental principle and at the origin of every force



Standard model: for every force there is a gauge boson

The photon is the “carrier” of the electromagnetic force.
The W_+, W_- and Z_0 are the “carriers” of the weak force.
The gluons are the “carriers” of the strong force.

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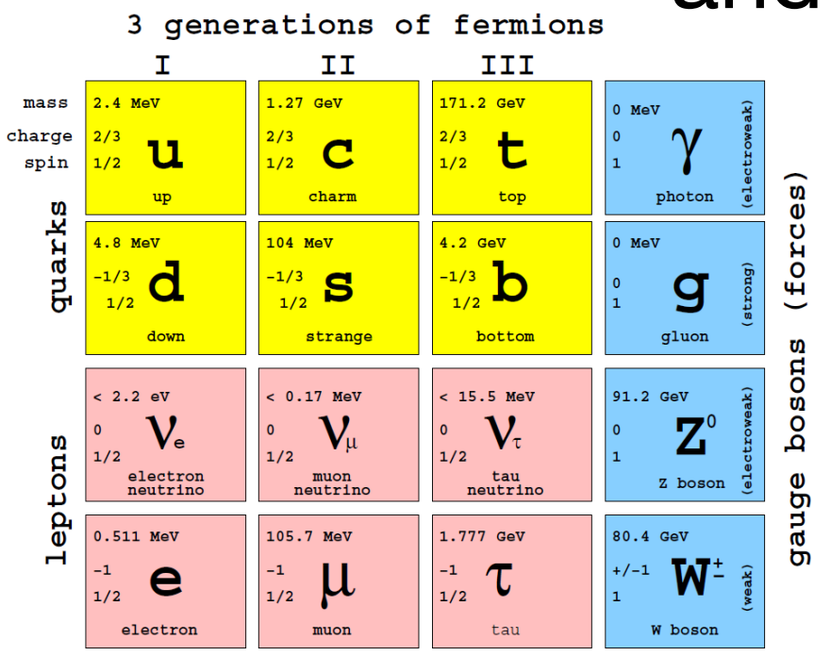

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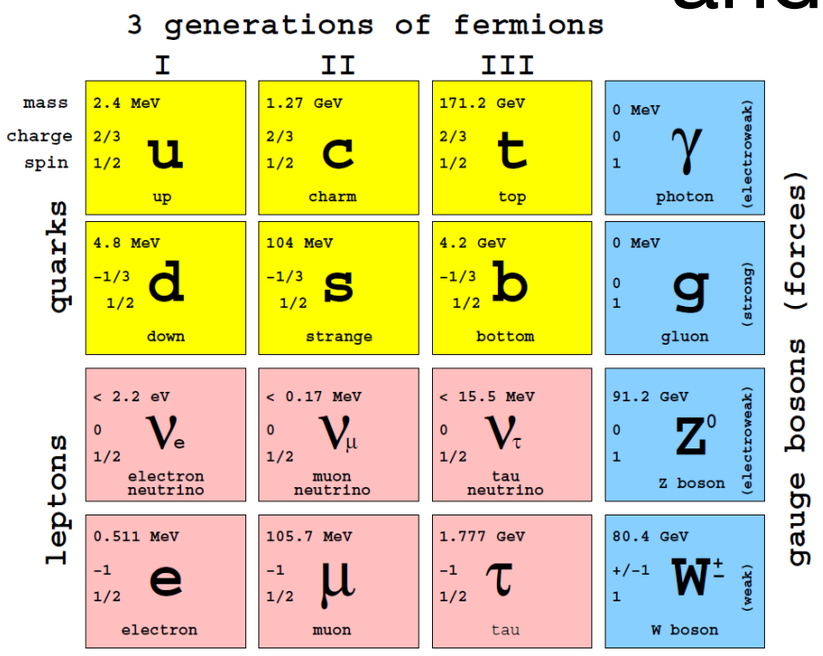
Standard model: a successful story

Non-abelian quantum chromodynamics (QCD) responsible for mass in every-day life
50+ years success story of parton model
40 years success story of (p)QCD (1979: discovery of gluon in e+e- at PETRA)

Gauge symmetry as a fundamental principle and at the origin of every force



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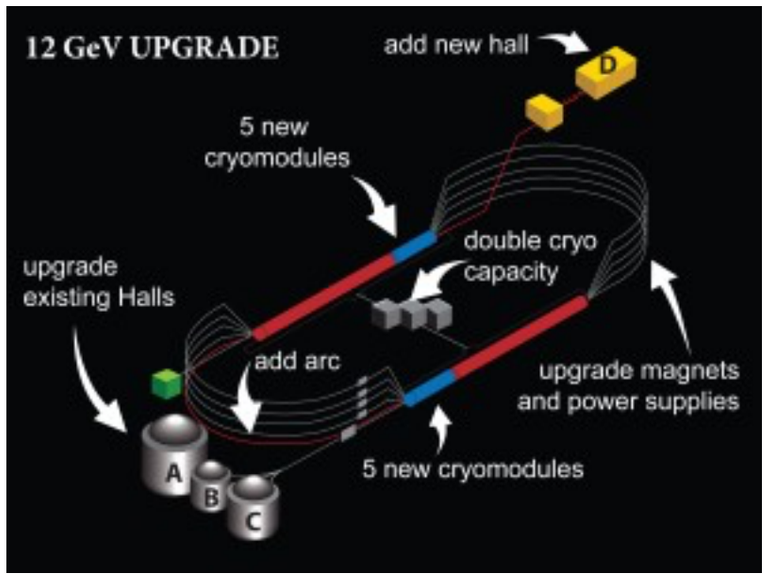
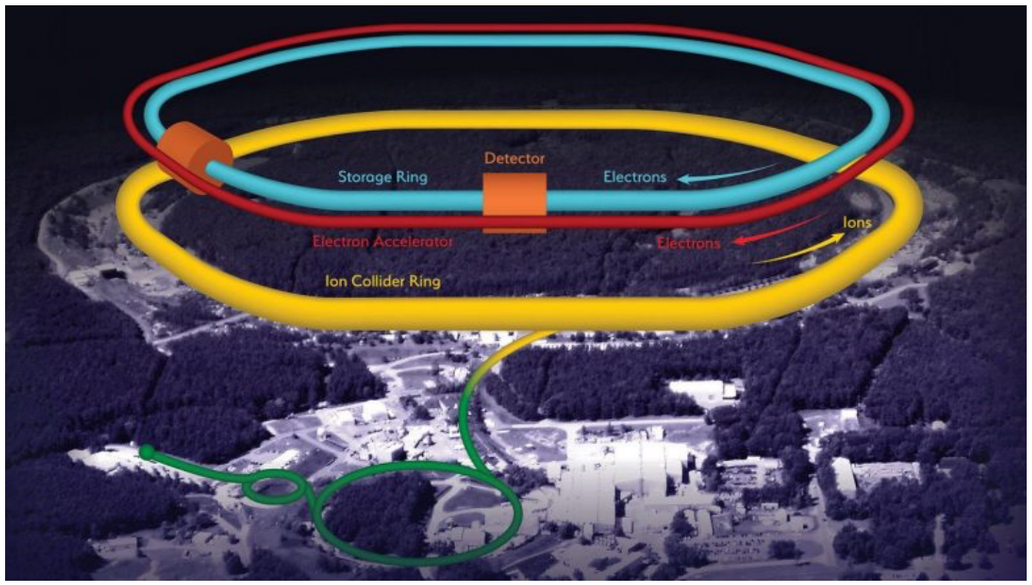
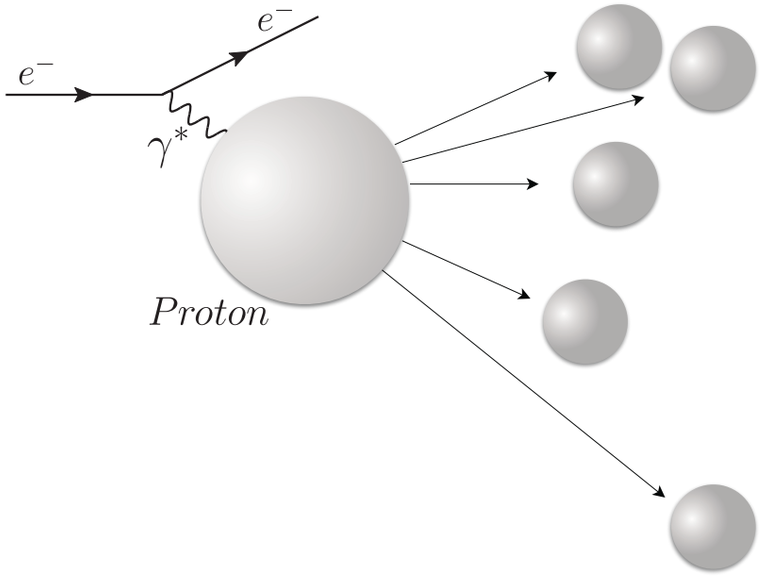
but non-perturbative part (hadron structure and formation) still a vast, partly unexplored field

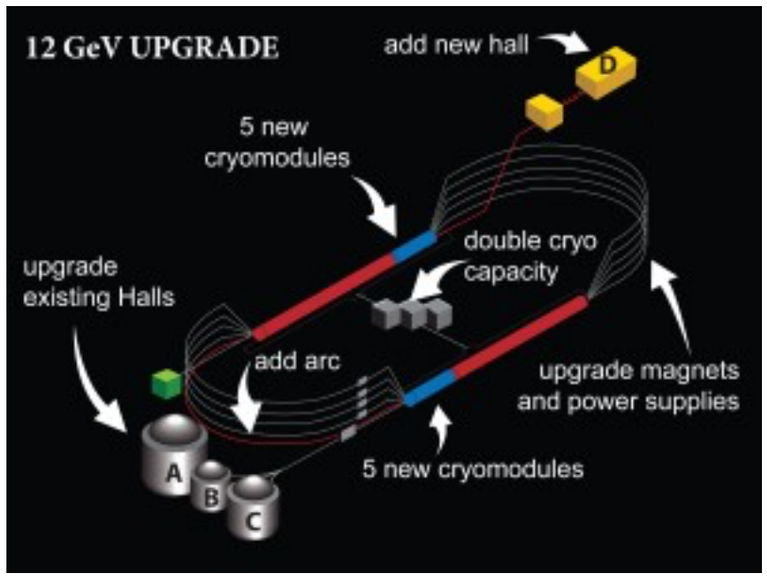


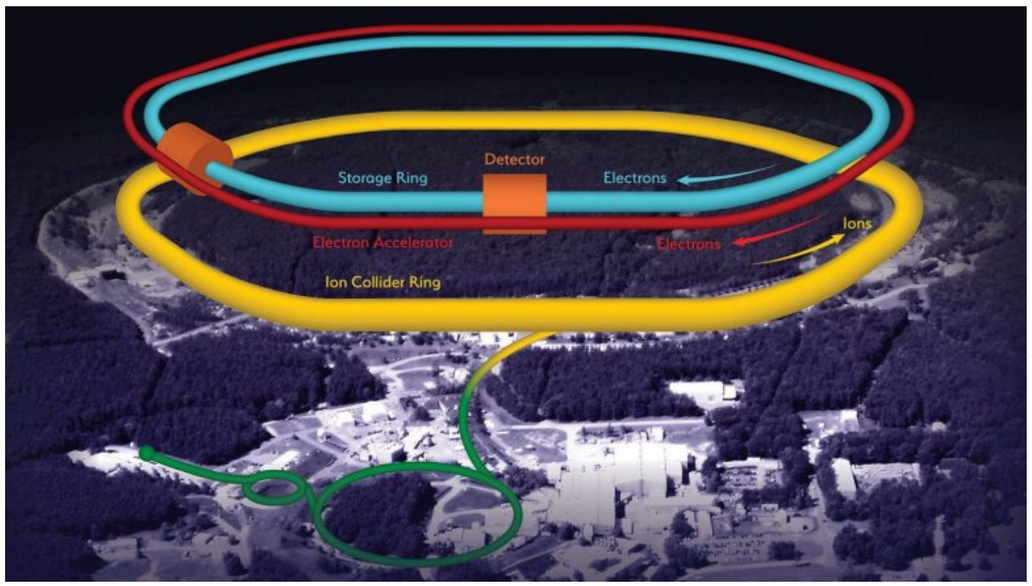


modern microscopes



(semi-inclusive)
deep-inelastic lepton scattering





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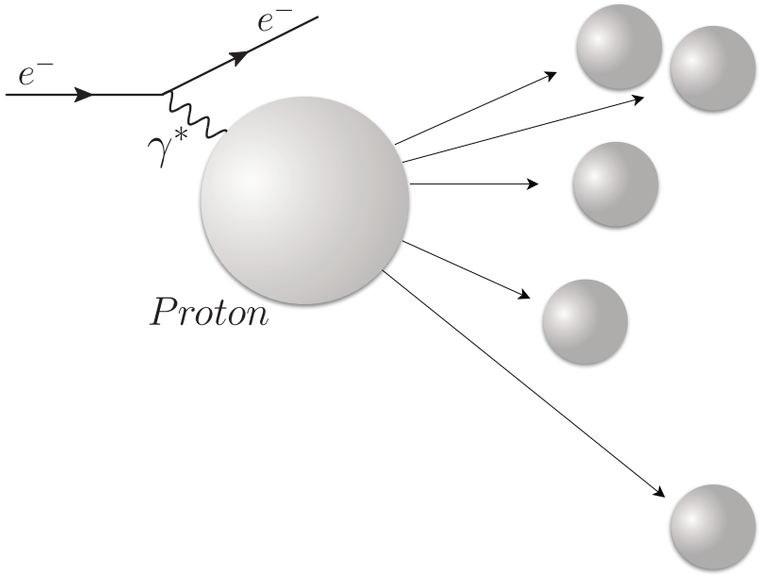

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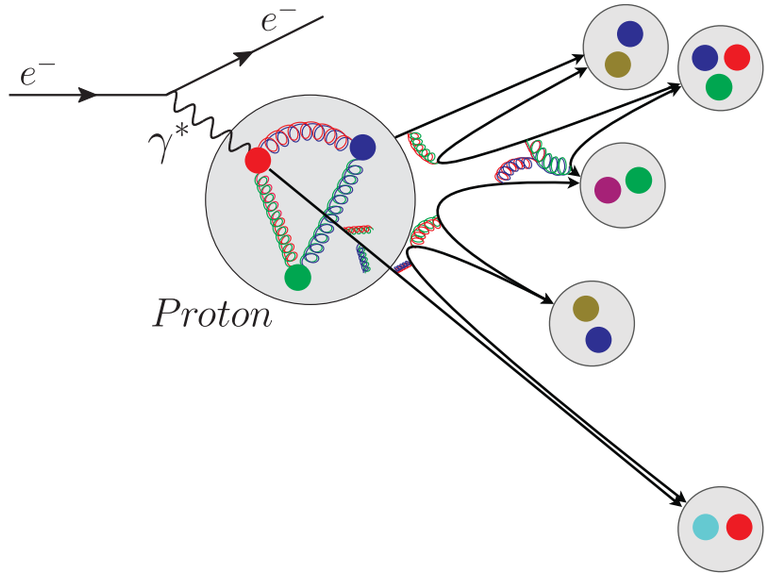
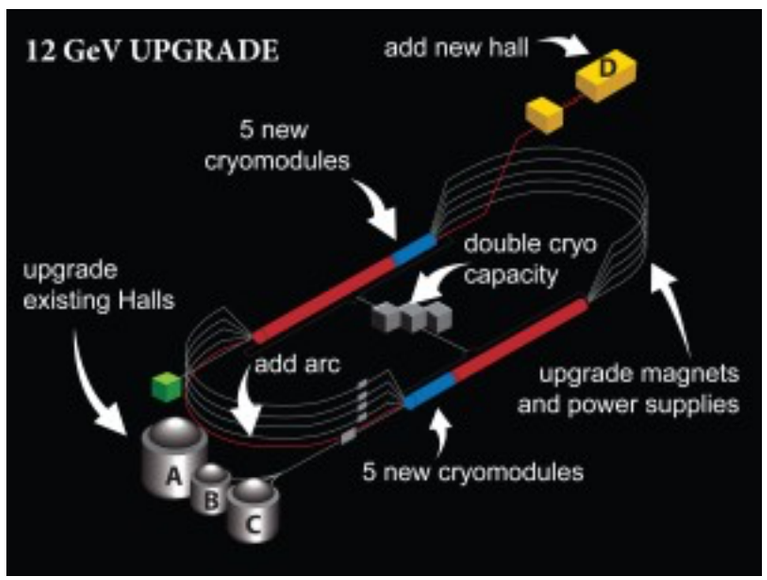
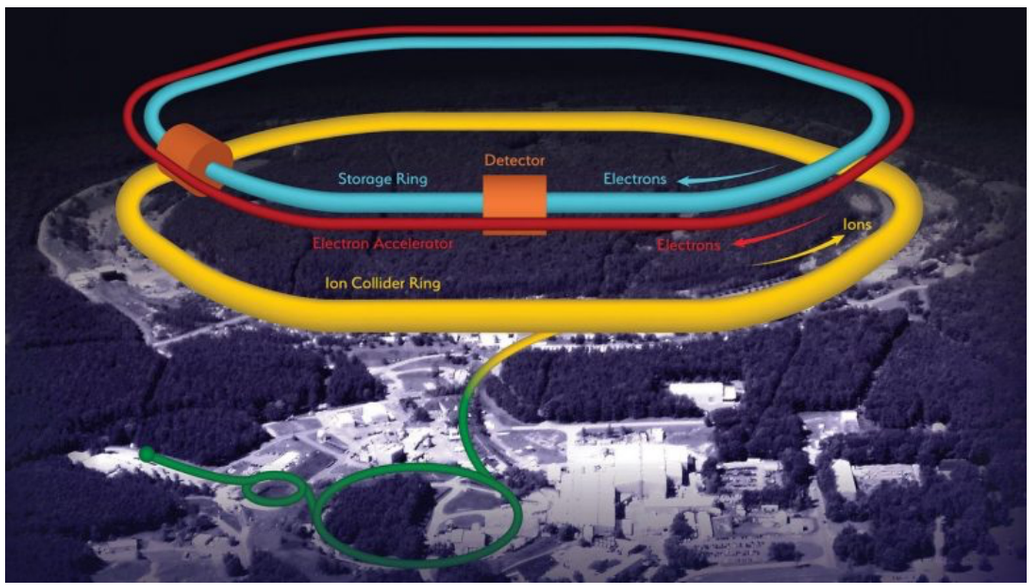


highly virtual photons resolve
inner (partonic) structure





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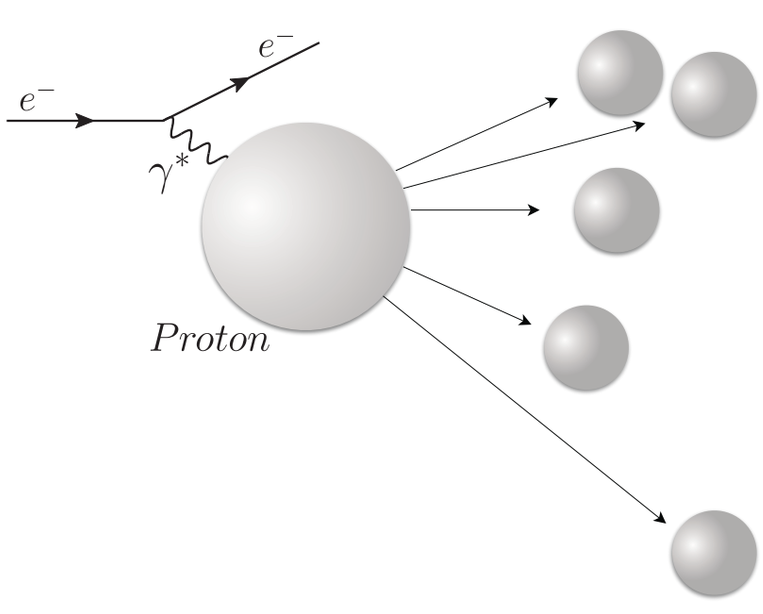

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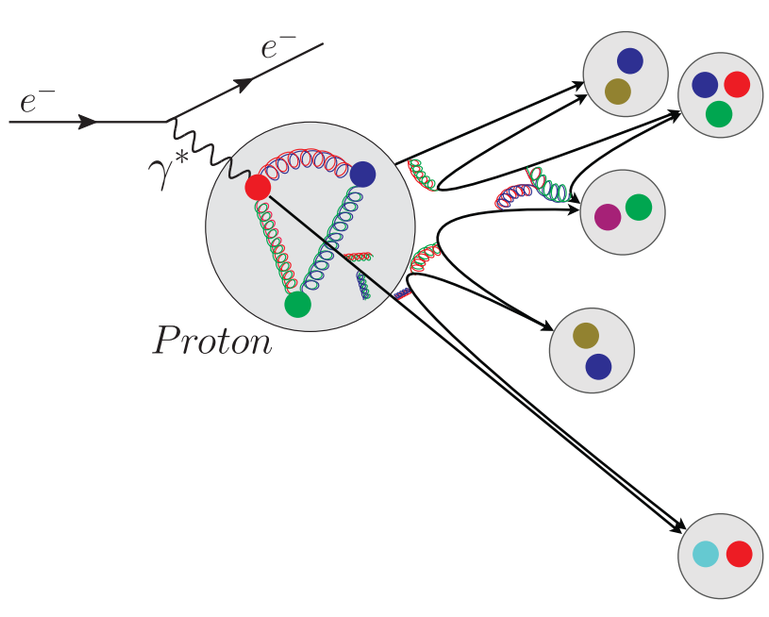

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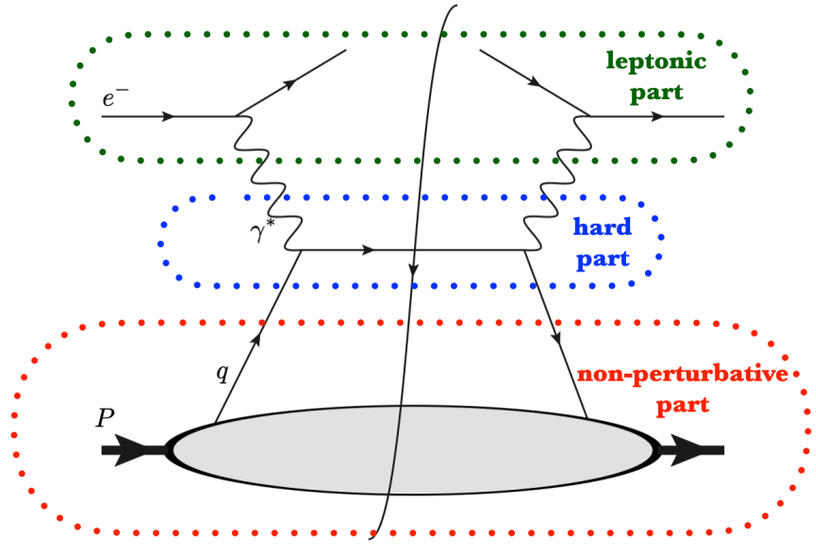


factorization theorems
separate non-calculable from
calculable parts

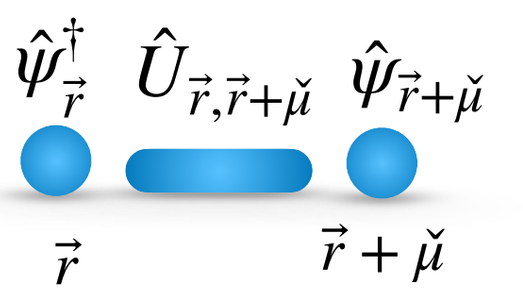
Eur. Phys. J. D (2020) 74: 165
https://doi.org/10.1140/epjd/e2020-100571-8

THE EUROPEAN PHYSICAL JOURNAL D

Colloquium

Simulating lattice gauge theories within quantum technologies

Mari Carmen Bañuls[1,2], Rainer Blatt[3,4], Jacopo Catani[5,6,7], Alessio Celi[3,8], Juan Ignacio Cirac[1,2], Marcello Dalmonte[9,10], Leonardo Fallani[5,6,7], Karl Jansen[11], Maciej Lewenstein[8,12,13], Simone Montangero[14,15,a], Christine A. Muschik[3], Benni Reznik[16], Enrique Rico[17,18], Luca Tagliacozzo[19], Karel Van Acoleyen[20], Frank Verstraete[20,21], Uwe-Jens Wiese[22], Matthew Wingate[23], Jakub Zakrzewski[24,25], and Peter Zoller[3]



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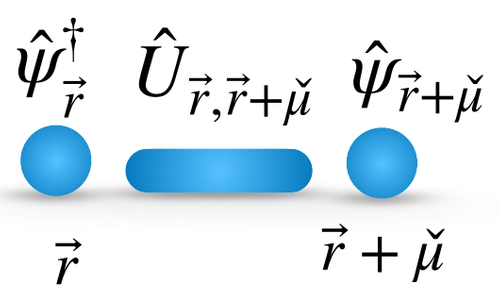
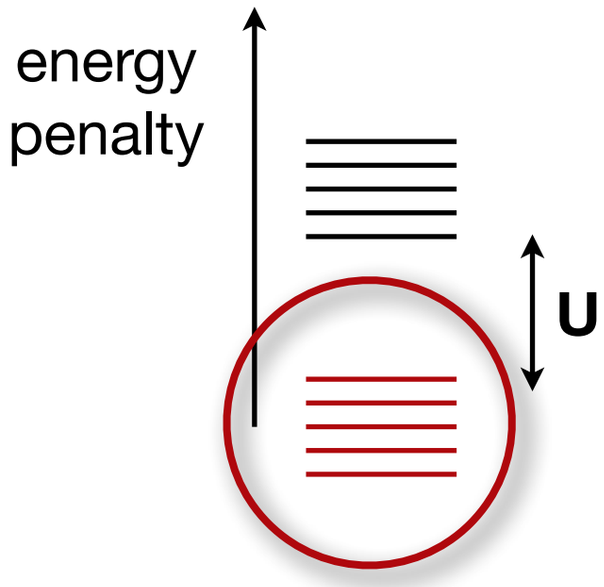
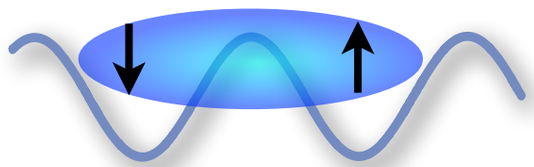


- Implementing the gauge invariant dynamics





color singlet
hopping

Internal symmetry

encoding
gauge invariant
degrees of freedom

PRX QUANTUM **2,** 017001 (2021)

Roadmap

Quantum Computer Systems for Scientific Discovery

Yuri Alexeev,[1] Dave Bacon,[2] Kenneth R. Brown,[3,4,5] Robert Calderbank,[3,6] Lincoln D. Carr,[7] Frederic T. Chong,[8] Brian DeMarco,[9] Dirk Englund,[10] Edward Farhi,[11,12] Bill Fefferman,[8] Alexey V. Gorshkov,[13,14] Andrew Houck,[15] Jungsang Kim,[3,5,16] Shelby Kimmel,[17] Michael Lange,[18] Seth Lloyd,[19] Mikhail D. Lukin,[20] Dmitri Maslov,[21] Peter Maunz,[22] Christopher Monroe,[13,16,*] John Preskill,[23] Martin Roetteler,[24] Martin J. Savage,[25] and Jeff Thompson[15]

PRX QUANTUM **4,** 027001 (2023)

Roadmap

Quantum Simulation for High-Energy Physics

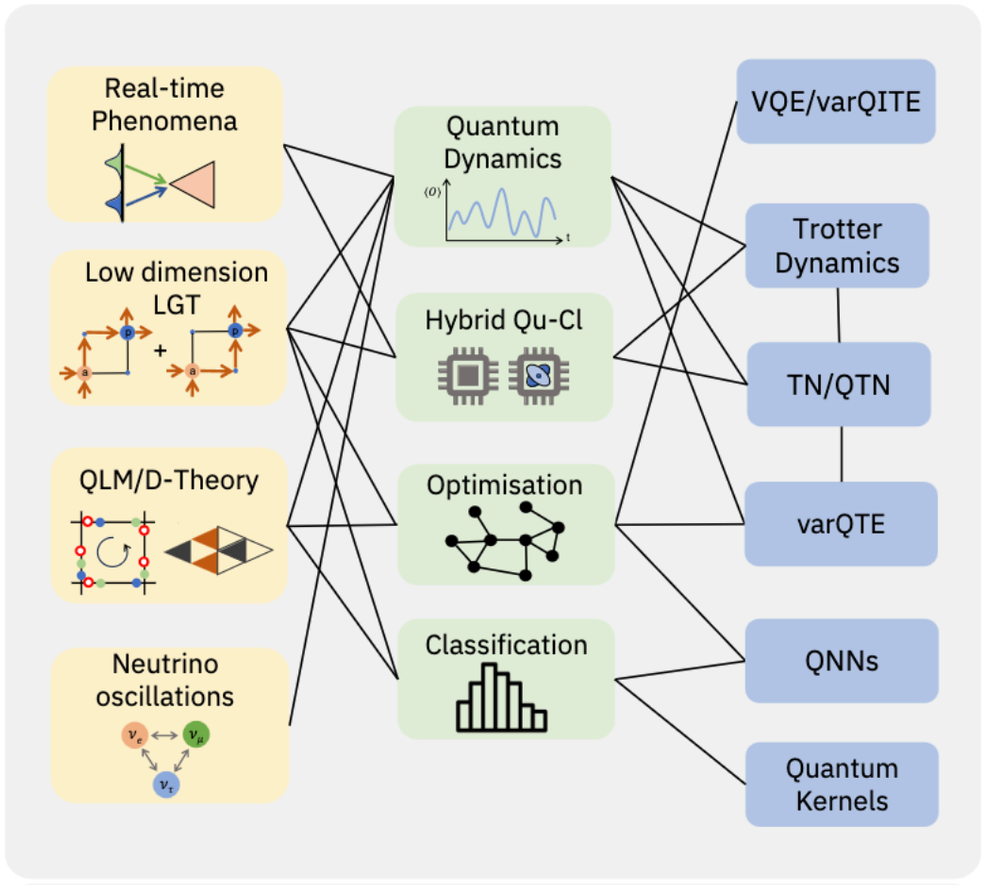
Christian W. Bauer,[1,*] Zohreh Davoudi,[2,†] A. Baha Balantekin,[3] Tanmoy Bhattacharya,[4] Marcela Carena,[5,6,7,8] Wibe A. de Jong,[1] Patrick Draper,[9] Aida El-Khadra,[9] Nate Gemelke,[10] Masanori Hanada,[11] Dmitri Kharzeev,[12,13] Henry Lamm,[5] Ying-Ying Li,[14,15] Junyu Liu,[16,17] Mikhail Lukin,[18] Yannick Meurice,[19] Christopher Monroe,[20,21,22,23] Benjamin Nachman,[1] Guido Pagano,[24] John Preskill,[25] Enrico Rinaldi,[26,27,28] Alessandro Roggero,[29,30] David I. Santiago,[31,32] Martin J. Savage,[33] Irfan Siddiqi,[31,32,34] George Siopsis,[35] David Van Zanten,[5] Nathan Wiebe,[36,37] Yukari Yamauchi,[2] Kübra Yeter-Aydeniz,[38] and Silvia Zorzetti[6]

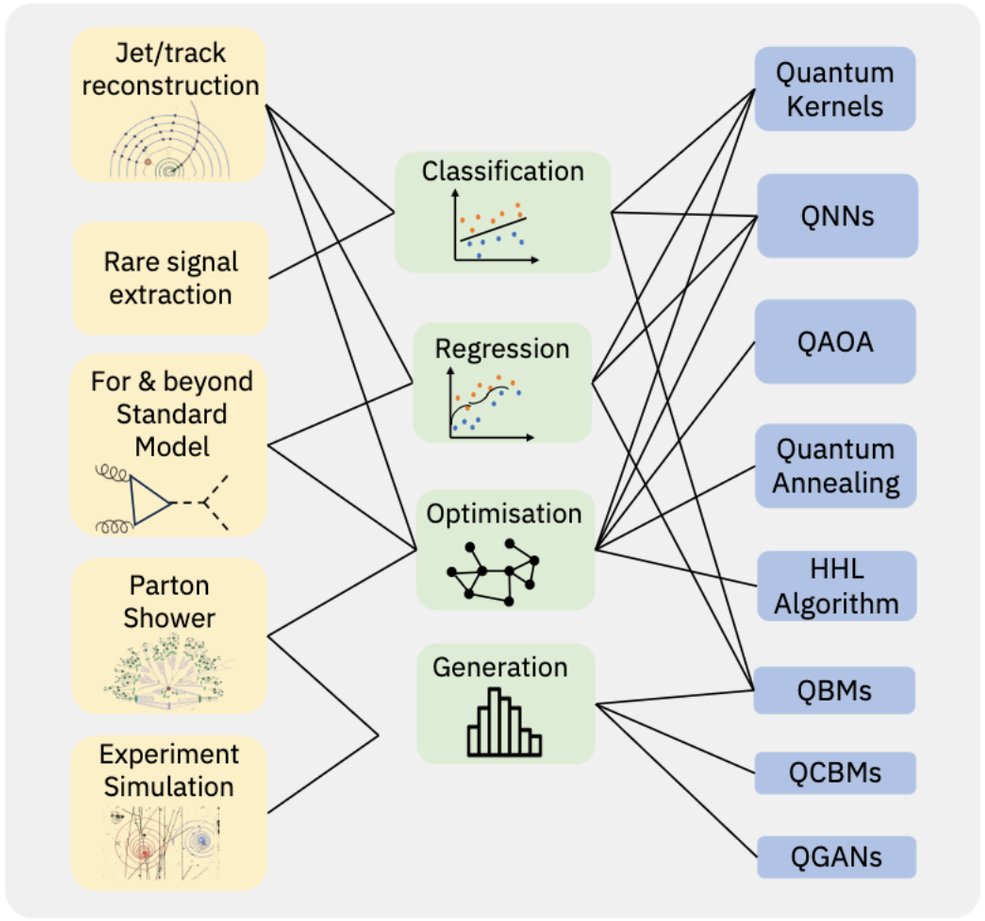
Quantum Computing for High-Energy Physics: State of the Art and Challenges

Alberto Di Meglio,[1,*] Karl Jansen,[2,3,†] Ivano Tavernelli,[4,‡] Constantia Alexandrou,[3,5] Srinivasan Arunachalam,[6] Christian W. Bauer,[7] Kerstin Borras,[8,9] Stefano Carrazza,[1,10] Arianna Crippa,[2,11] Vincent Croft,[12] Roland de Putter,[6] Andrea Delgado,[13] Vedran Dunjko,[12] Daniel J. Egger,[4] Elias Fernández-Combarro,[14] Elina Fuchs,[1,15,16] Lena Funcke,[17] Daniel González-Cuadra,[18,19] Michele Grossi,[1] Jad C. Halimeh,[20,21] Zoë Holmes,[22] Stefan Kühn,[2] Denis Lacroix,[23] Randy Lewis,[24] Donatella Lucchesi,[1,25] Miriam Lucio Martinez,[26,27] Federico Meloni,[8] Antonio Mezzacapo,[6] Simone Montangero,[1,25] Lento Nagano,[28] Vincent R. Pascuzzi,[6] Voica Radescu,[29] Enrique Rico Ortega,[30,31,32,33] Alessandro Roggero,[34,35] Julian Schuhmacher,[4] Joao Seixas,[36,37,38] Pietro Silvi,[1,25] Panagiotis Spentzouris,[39] Francesco Tacchino,[4] Kristan Temme,[6] Koji Terashi,[28] Jordi Tura,[12,40] Cenk Tüysüz,[2,11] Sofia Vallecorsa,[1] Uwe-Jens Wiese,[41] Shinjae Yoo,[42] and Jinglei Zhang[43,44]

Roadmap

PRX QUANTUM **5,** 037001 (2024)



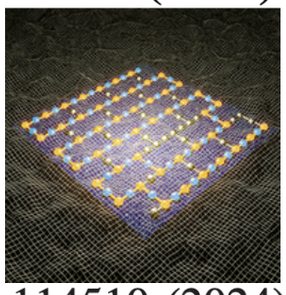


Where are we today?

Scalable Circuits for Preparing Ground States on Digital Quantum Computers: The Schwinger Model Vacuum on 100 Qubits

PRX QUANTUM **5,** 020315 (2024)

Roland C. Farrell,* Marc Illa,† Anthony N. Ciavarella,‡ and Martin J. Savage§



Quantum simulations of hadron dynamics in the Schwinger model using 112 qubits

PHYSICAL REVIEW D **109,** 114510 (2024)

Roland C. Farrell,[1,*] Marc Illa,[1,†] Anthony N. Ciavarella,[1,2,‡] and Martin J. Savage[1,§]

Where are we today?

Scalable Circuits for Preparing Ground States on Digital Quantum Computers: The Schwinger Model Vacuum on 100 Qubits

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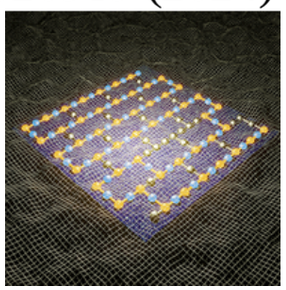

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Observation of string-breaking dynamics in a quantum simulator

arXiv:2410.13815

Arinjoy De* ,[1, 2] Alessio Lerose* ,[3, 4] De Luo ,[2] Federica M. Surace ,[5] Alexander Schuckert ,[1, 6]
Elizabeth R. Bennewitz,[1, 6] Brayden Ware,[1, 6] William Morong†,[1, 6] Kate S. Collins,[1, 6]
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Analysis of the confinement string in $(2+1)$-dimensional Quantum Electrodynamics with a trapped-ion quantum computer

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Arianna Crippa ,[1, 2, *] Karl Jansen ,[3, 1, †] and Enrico Rinaldi [4, 5, 6, 7, ‡]

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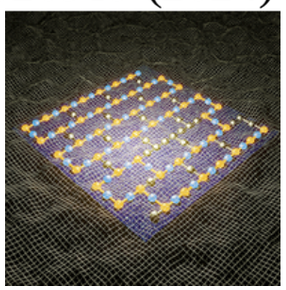

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Visualizing dynamics of charges and strings in (2 + 1)D lattice gauge theories

Nature **642**, 315–320 (2025)

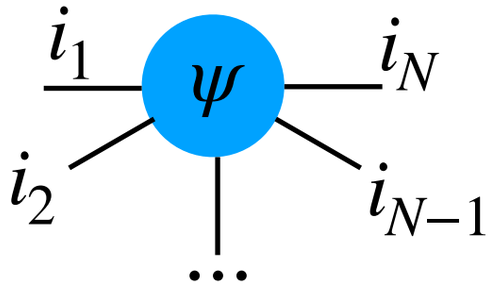
T. A. Cochran, B. Jobst, E. Rosenberg, Y. D. Lensky, G. Gyawali, N. Eassa, M. Will, A. Szasz, D. Abanin, R. Acharya, L. Aghababaie Beni, T. I. Andersen, M. Ansmann, F. Arute, K. Arya, A. Asfaw, J. Atalaya, R. Babbush, B. Ballard, J. C. Bardin, A. Bengtsson, A. Bilmes, A. Bourassa, J. Bovaird, ... P. Roushan

Observation of string breaking on a (2 + 1)D Rydberg quantum simulator

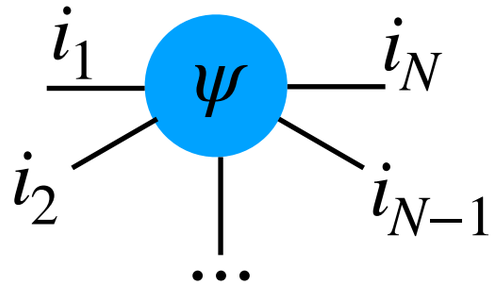
Nature **642**, 321–326 (2025)

Daniel González-Cuadra, Majd Hamdan, Torsten V. Zache, Boris Braverman, Milan Kornjača, Alexander Lukin, Sergio H. Cantú, Fangli Liu, Sheng-Tao Wang, Alexander Keesling, Mikhail D. Lukin, Peter Zoller & Alexei Bylinskii

$$|\psi\rangle = \sum_{i_1,i_2,\cdots,i_N=1}^{d} \psi_{i_1,i_2,\cdots,i_N} |\, i_1, i_2, \cdots, i_N\rangle$$



$$|\psi\rangle = \sum_{i_1,i_2,\cdots,i_N=1}^{d} \psi_{i_1,i_2,\cdots,i_N} |\, i_1, i_2, \cdots, i_N\rangle$$



Schmidt decomposition:

$$|\Psi\rangle = \sum_j c_j |\psi_j\rangle_A \otimes |\psi_j\rangle_B \qquad c_j \geq 0; \qquad \sum_j c_j^2 = 1$$

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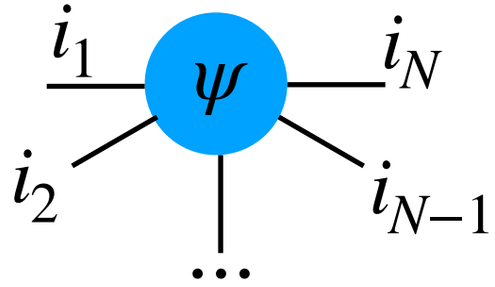

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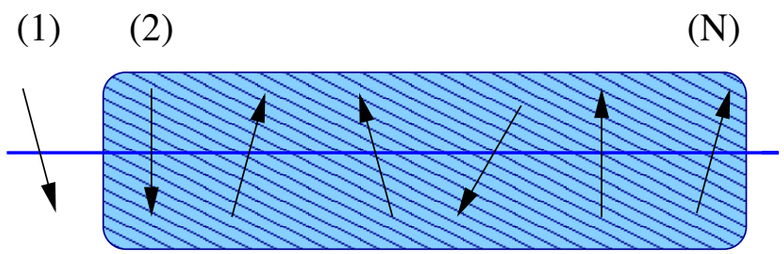
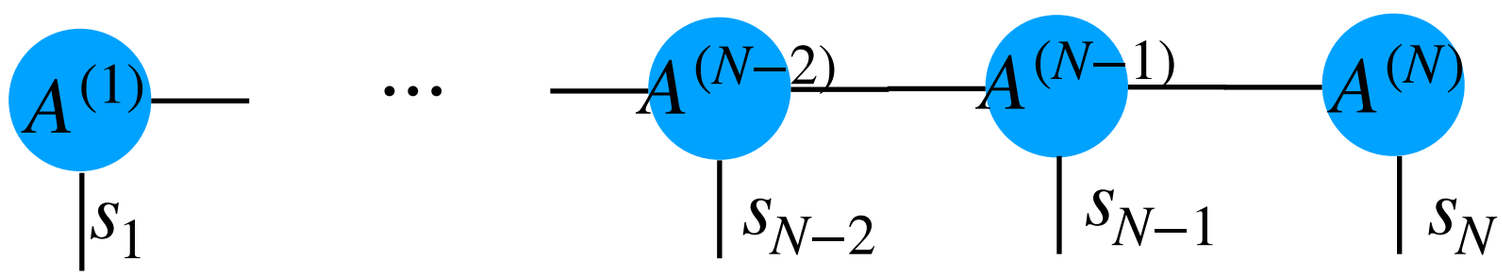
$$|\Psi\rangle = \sum_{a=1}^{D} |\phi_a^{(1)}\rangle \lambda_a^{(1)} |\phi_a^{(2,\ldots,N)}\rangle = \sum_{a=1}^{D} \sum_{s_1=1}^{d} |s_1\rangle\langle s_1|\phi_a^{(1)}\rangle \lambda_a^{(1)} |\phi_a^{(2,\ldots,N)}\rangle$$

$$= \sum_{a=1}^{D} \sum_{s_1=1}^{d} |s_1\rangle A_a[s_1] |\phi_a^{(2,\ldots,N)}\rangle = \sum_{a,b=1}^{D} \sum_{s_1,s_2=1}^{d} |s_1\rangle A_a[s_1] |s_2\rangle A_{ab}[s_2] |\phi_b^{(3,\ldots,N)}\rangle$$

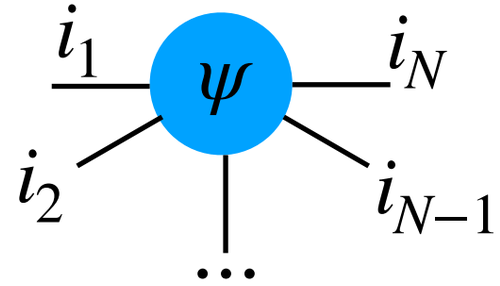
$$= \cdots = \sum_{\{s_j\}=1}^{d} Tr\{A[s_1] \cdots A[s_N]\} |s_1\rangle \cdots |s_N\rangle$$





Matrix Product State (MPS)

$$|\psi\rangle = \sum_{i_1,i_2,\cdots,i_N=1}^{d} \psi_{i_1,i_2,\cdots,i_N} |i_1, i_2, \cdots, i_N\rangle$$



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Parameter count:
NdD^2 vs d^N
Calculation cost:
NdD^3

$$|\Psi\rangle = \sum_{a=1}^{D} |\phi_a^{(1)}\rangle \lambda_a^{(1)} |\phi_a^{(2,\ldots,N)}\rangle$$

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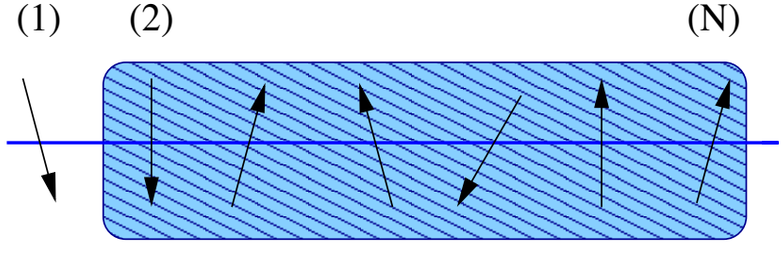
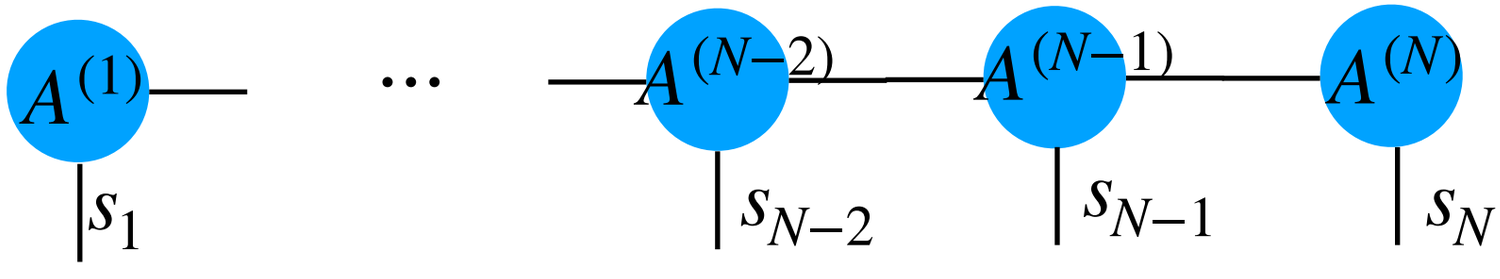




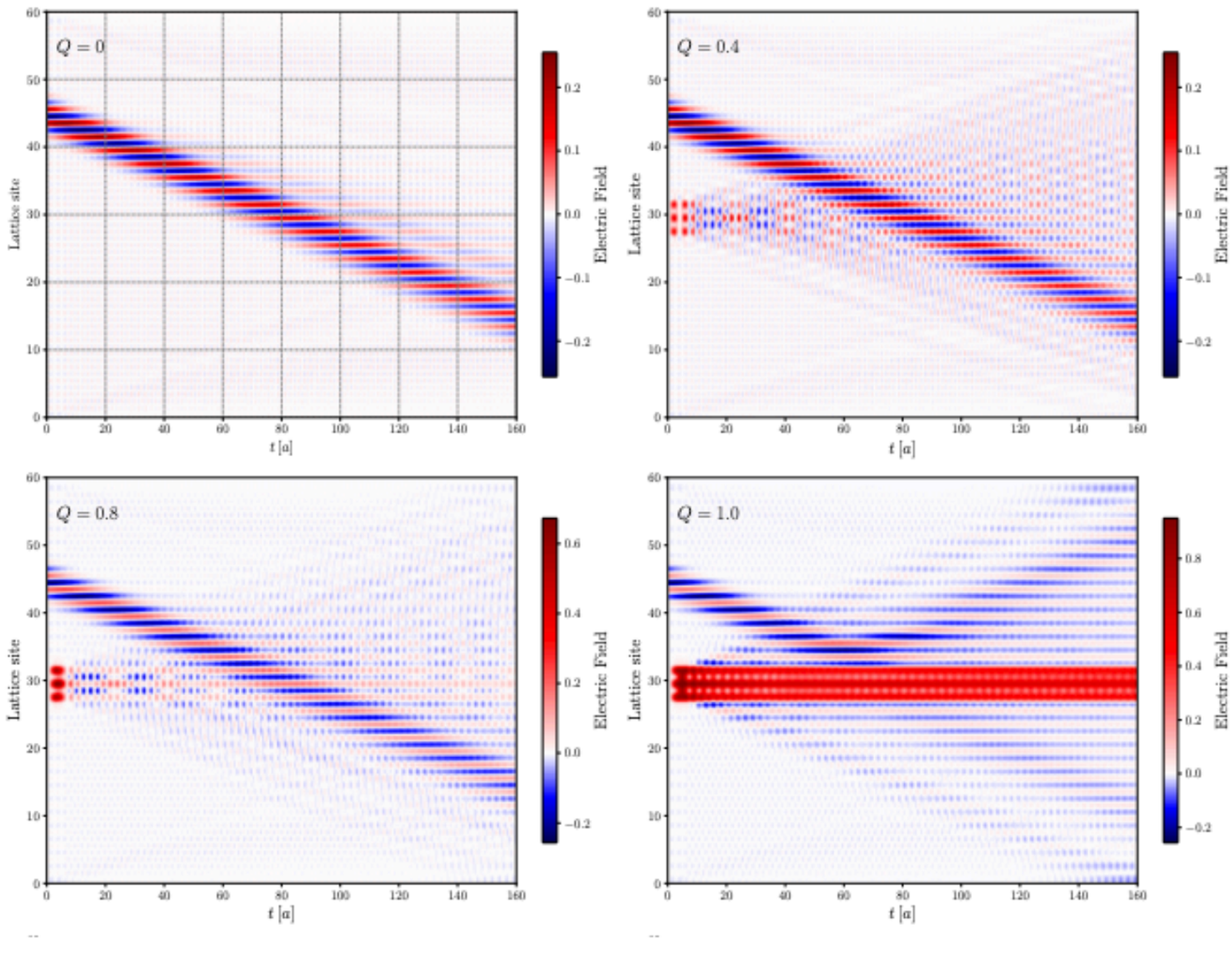
Matrix Product State (MPS)

arXiv:2502.17558v1 [hep-ph] 24 Feb 2025 CERN-TH-2025-019

Real-time simulation of jet energy loss and entropy production in high-energy scattering with matter

João Barata[1,*] and Enrique Rico[1,†]

[1] *CERN, Theoretical Physics Department, CH-1211 Geneva 23, Switzerland*



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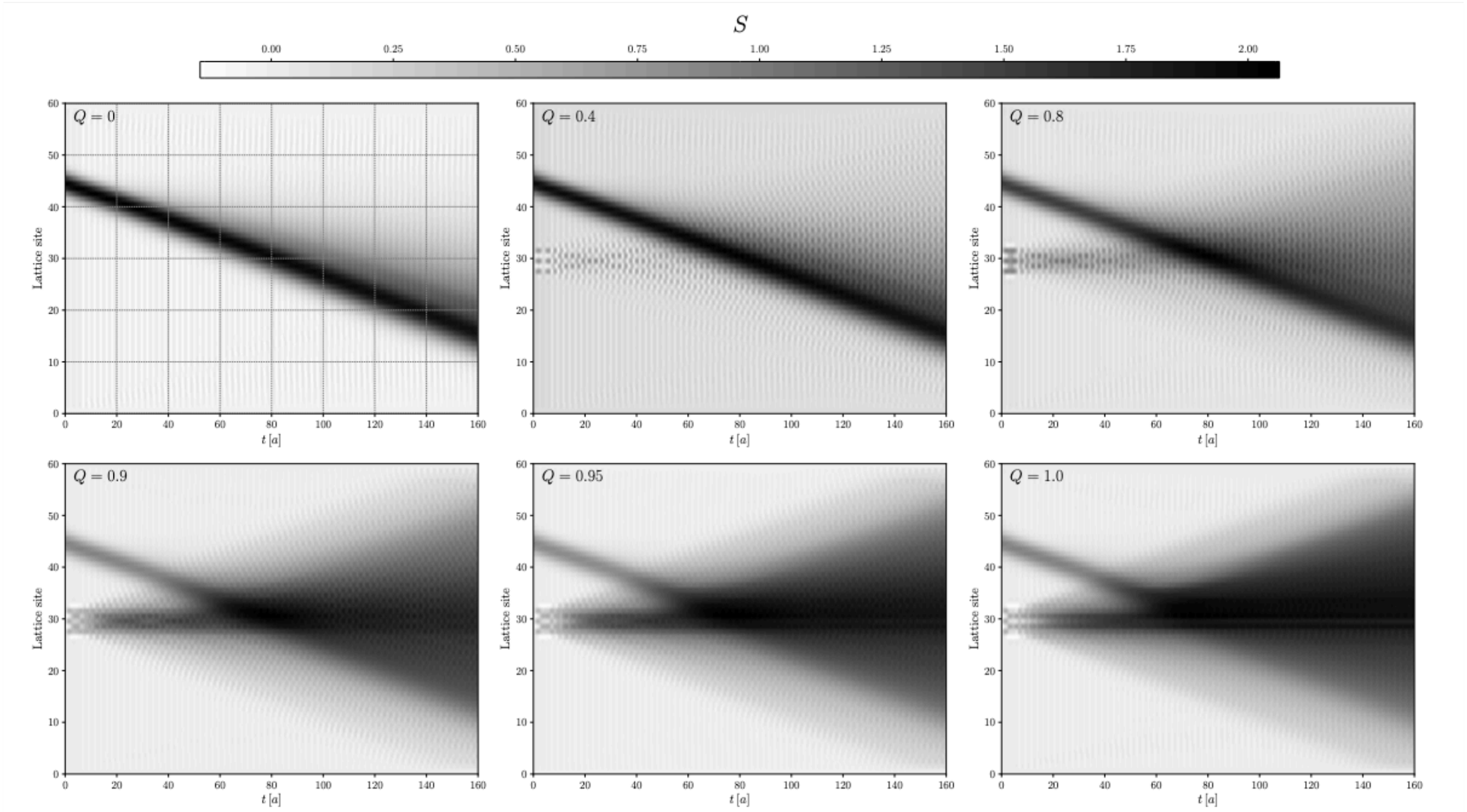
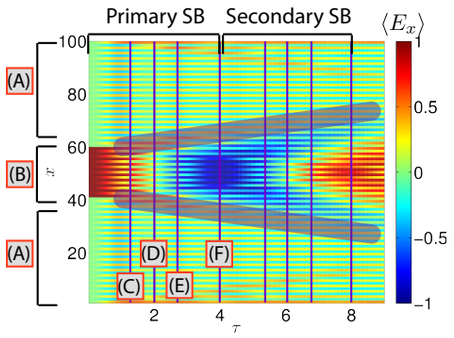




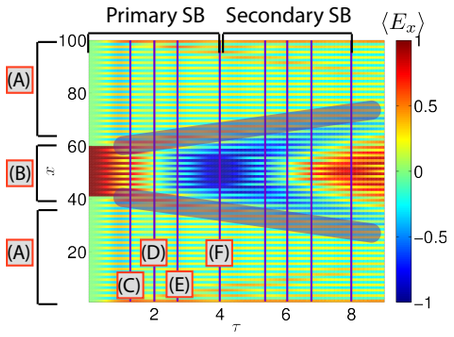
PHYSICAL REVIEW X **6,** 011023 (2016)

Real-Time Dynamics in U(1) Lattice Gauge Theories with Tensor Networks

T. Pichler,[1] M. Dalmonte,[2,3] E. Rico,[4,5,6] P. Zoller,[2,3] and S. Montangero[1]

After a particle collision, pairs of quarks remain confined in color singlet states through a **flux tube (Wilson line)** connecting them.

As the flux tube evolves, it stretches giving rise to the **string** breaking and **string** fragmentation



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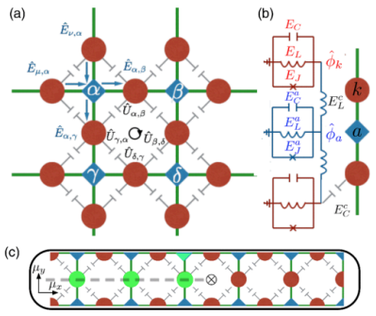
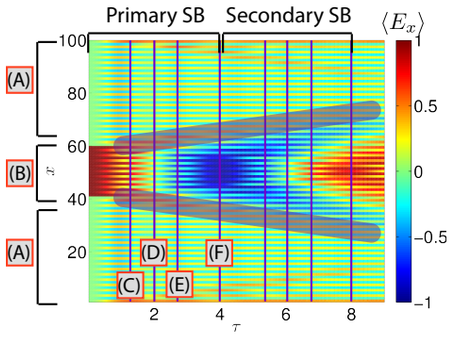


PRL **117,** 240504 (2016) PHYSICAL REVIEW LETTERS week ending 9 DECEMBER 2016

Loops and Strings in a Superconducting Lattice Gauge Simulator

G. K. Brennen,[1] G. Pupillo,[2] E. Rico,[3,4] T. M. Stace,[5] and D. Vodola[2]

The witnesses to the existence of the predicted confining phase of the model are provided by nonlocal order parameters from **Wilson loops** and disorder parameters from **'t Hooft strings.**



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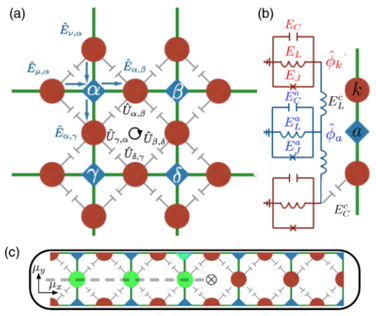

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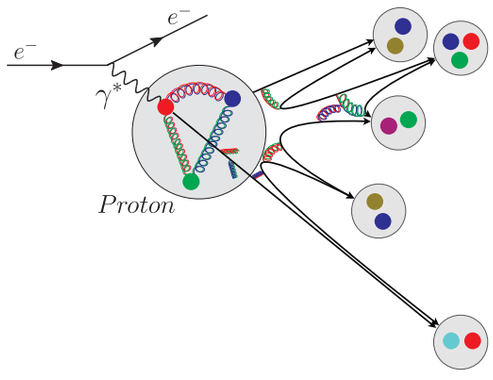

PHYSICAL REVIEW D **104,** 014512 (2021)

Quantum simulation of light-front parton correlators

M. G. Echevarria,[1,*] I. L. Egusquiza,[2,†] E. Rico,[3,4,‡] and G. Schnell[2,4,§]

Hadron structure study requires the measurement of **flux tubes (Wilson lines)** among its constituents (partons) in space and real-time

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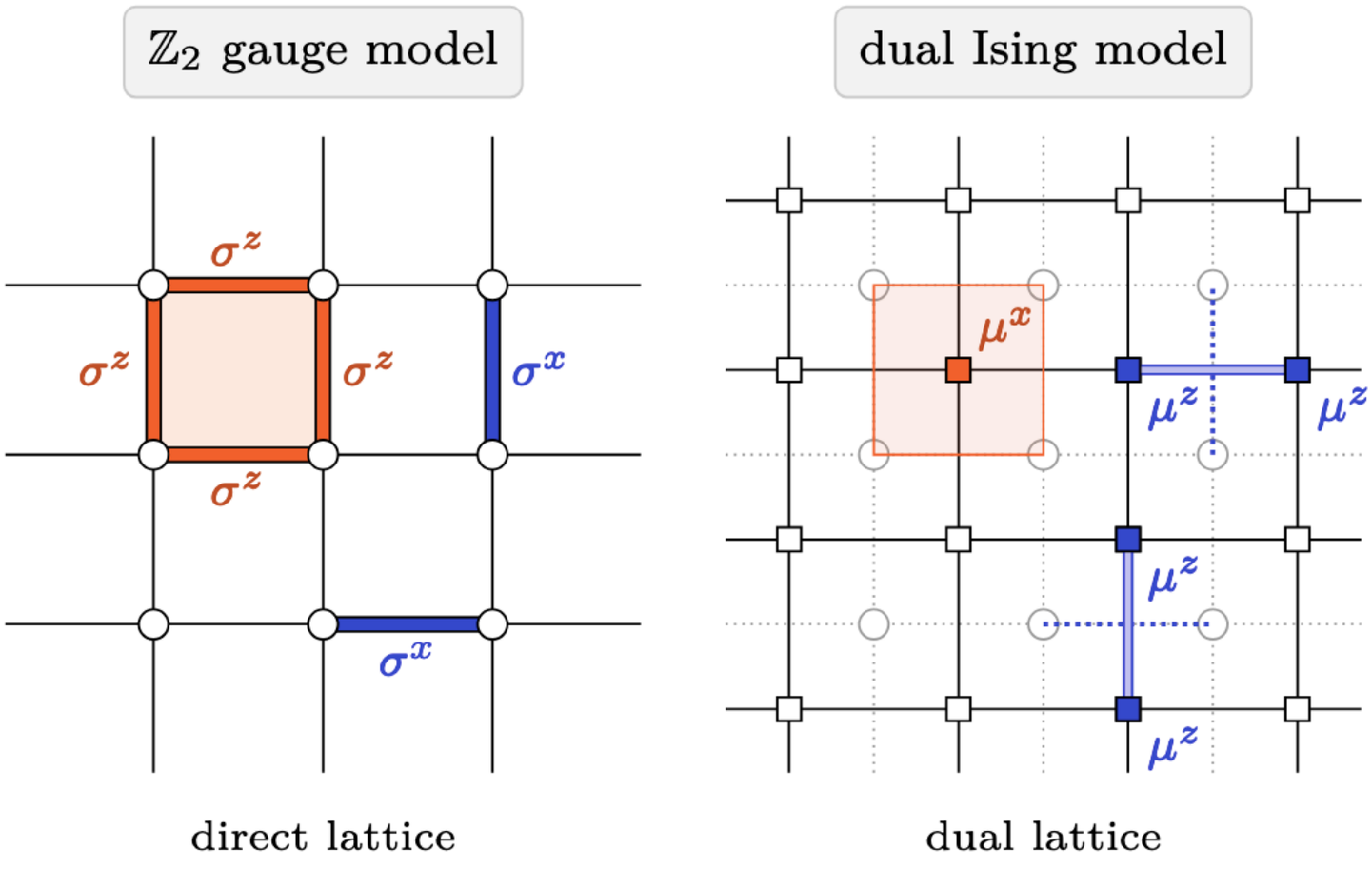
arXiv:2505.23853

CERN-TH-2025-105

Roughening and dynamics of an electric flux string in a (2+1)D lattice gauge theory

Francesco Di Marcantonio,[1,*] Sunny Pradhan,[1,†] Sofia Vallecorsa,[2,‡]
Mari Carmen Bañuls,[3,4,§] and Enrique Rico Ortega[1,2,5,6,¶]



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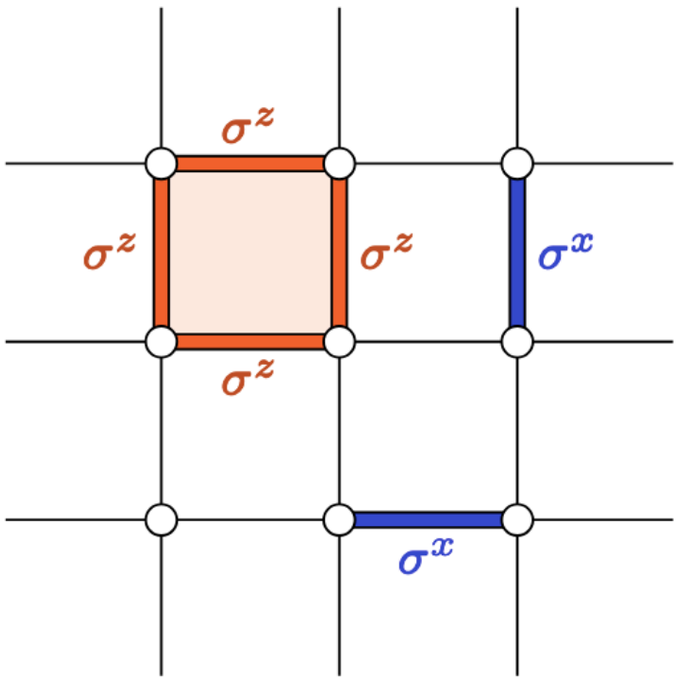
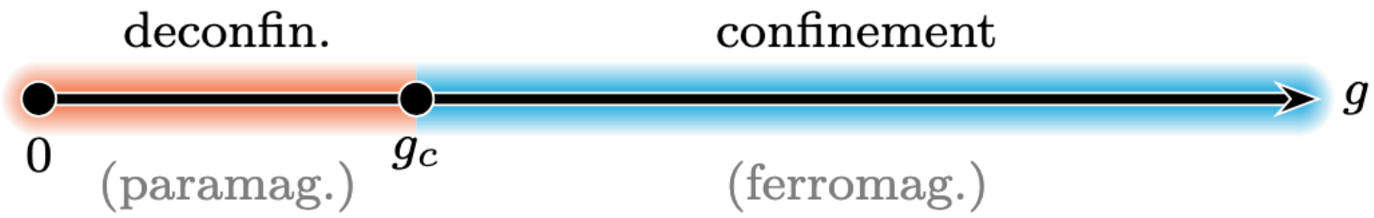
$\mathbb{Z}_2$ gauge model

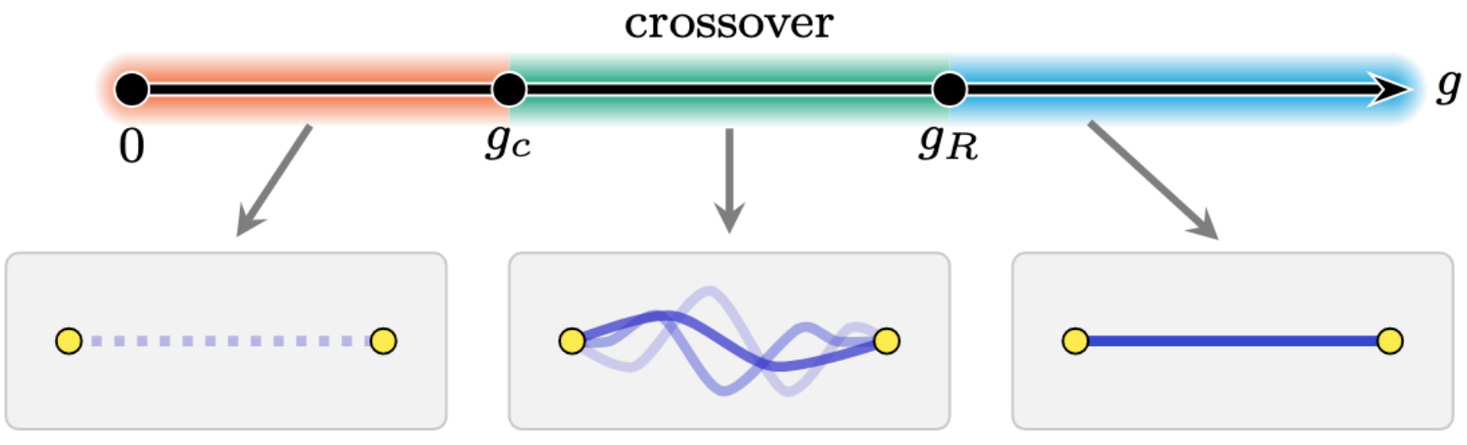


direct lattice

$\mathbb{Z}_2$ vacuum



$\mathbb{Z}_2$ 2-particle



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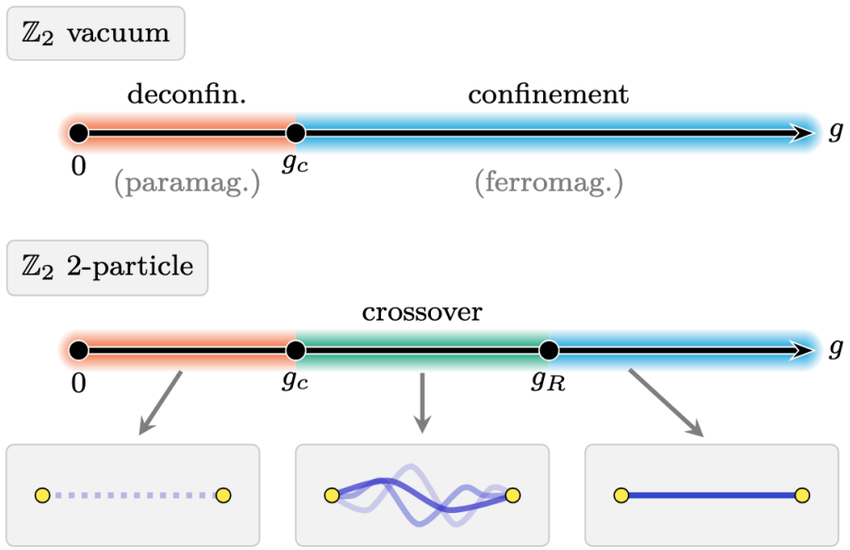

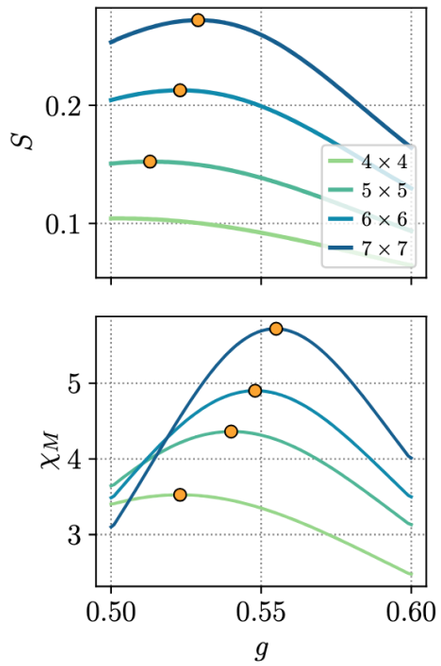

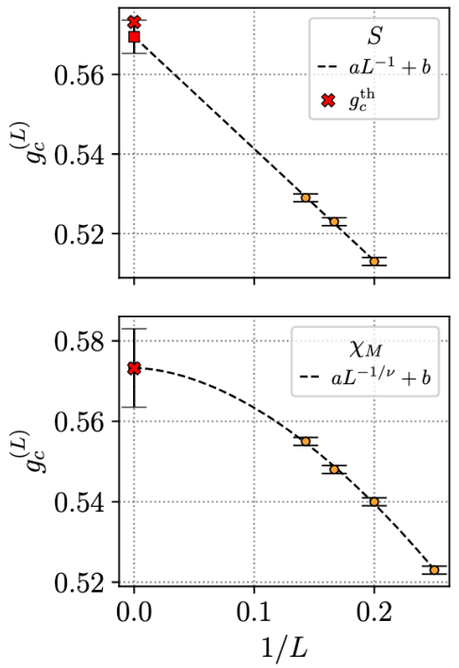

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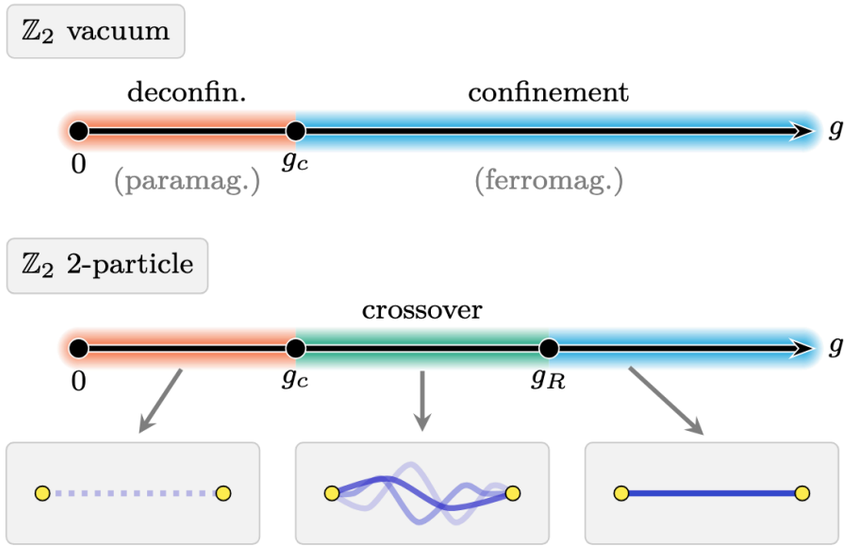

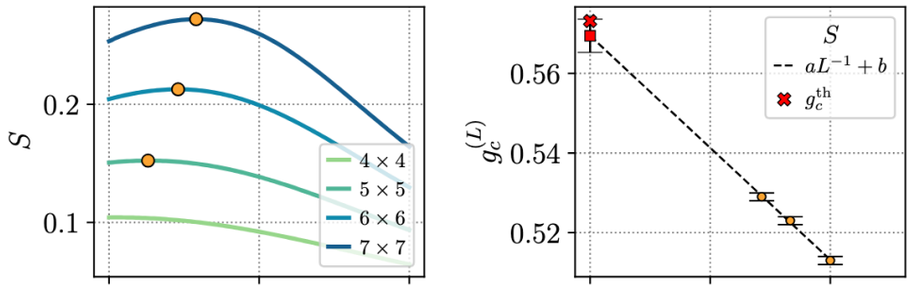

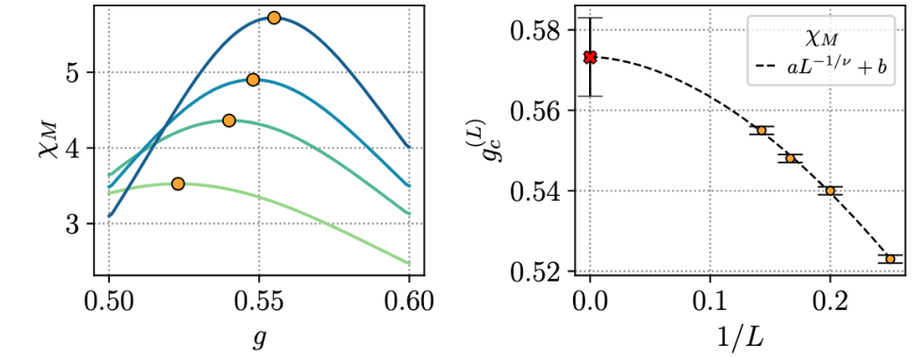

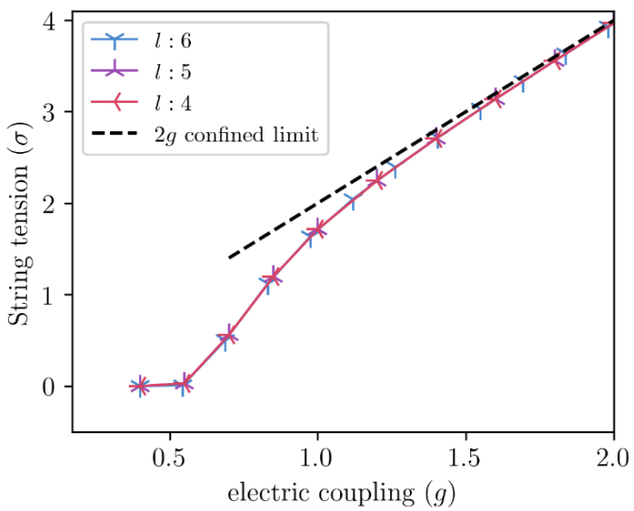

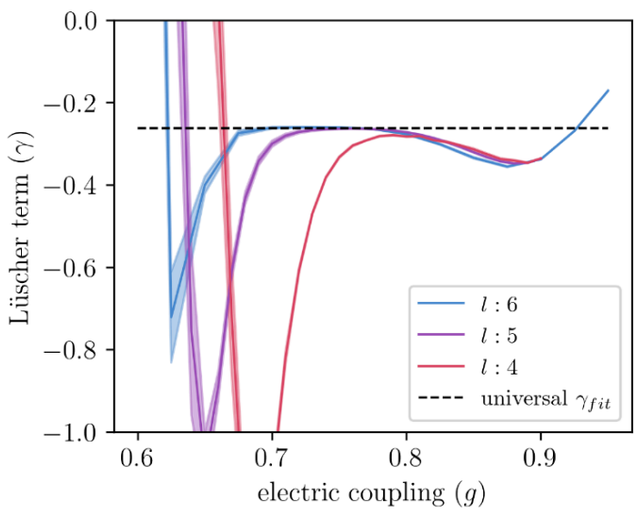

$$V(R,g) = \langle \Omega_{2p} | H^{2p}(g) | \Omega_{2p} \rangle - \langle \Omega_{vac} | H^{vac}(g) | \Omega_{vac} \rangle$$

$$V(R) = \sigma R + c + \frac{\gamma}{R} + O(R^{-3})$$

$$\gamma = -\frac{(d-2)\pi}{24}$$

Universal Luscher term

arXiv:2505.23853

CERN-TH-2025-105

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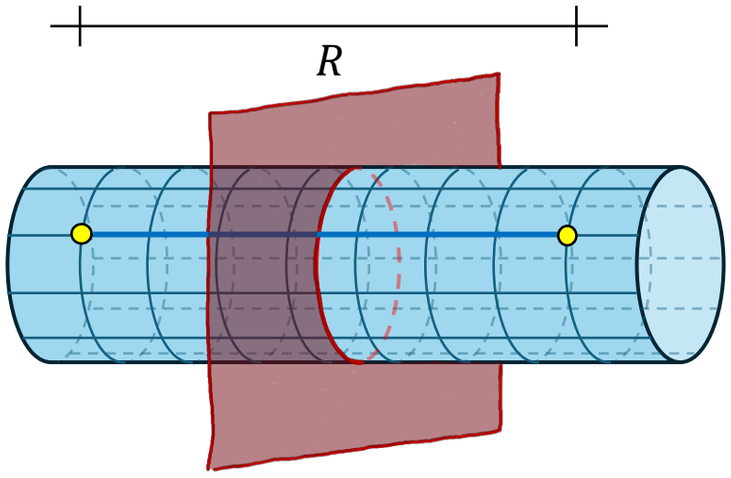
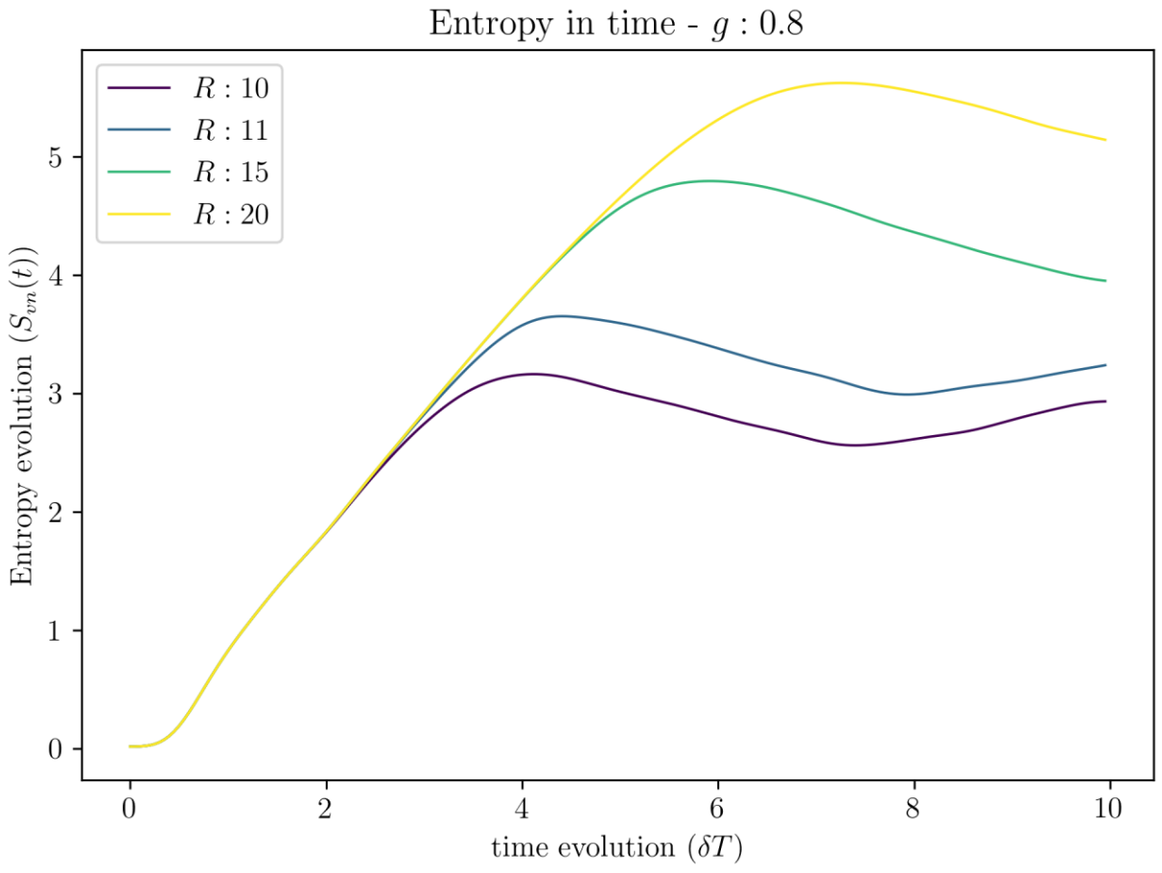
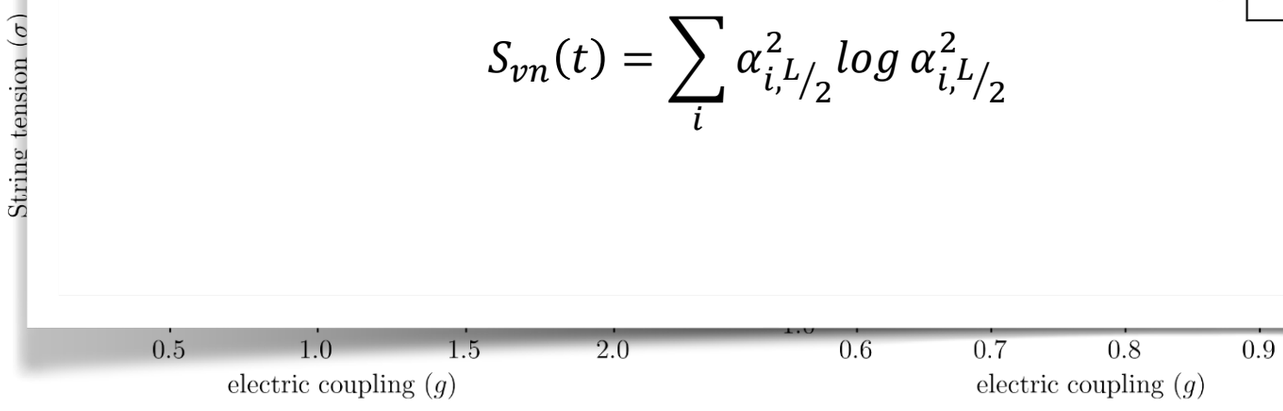
$$|\psi(t,g,R)\rangle = e^{-itH^{2p}(g)}|\Omega_{vac}(g)\rangle$$



$$S_{vn}(t) = \sum_i \alpha^2_{i,L/2} \log \alpha^2_{i,L/2}$$

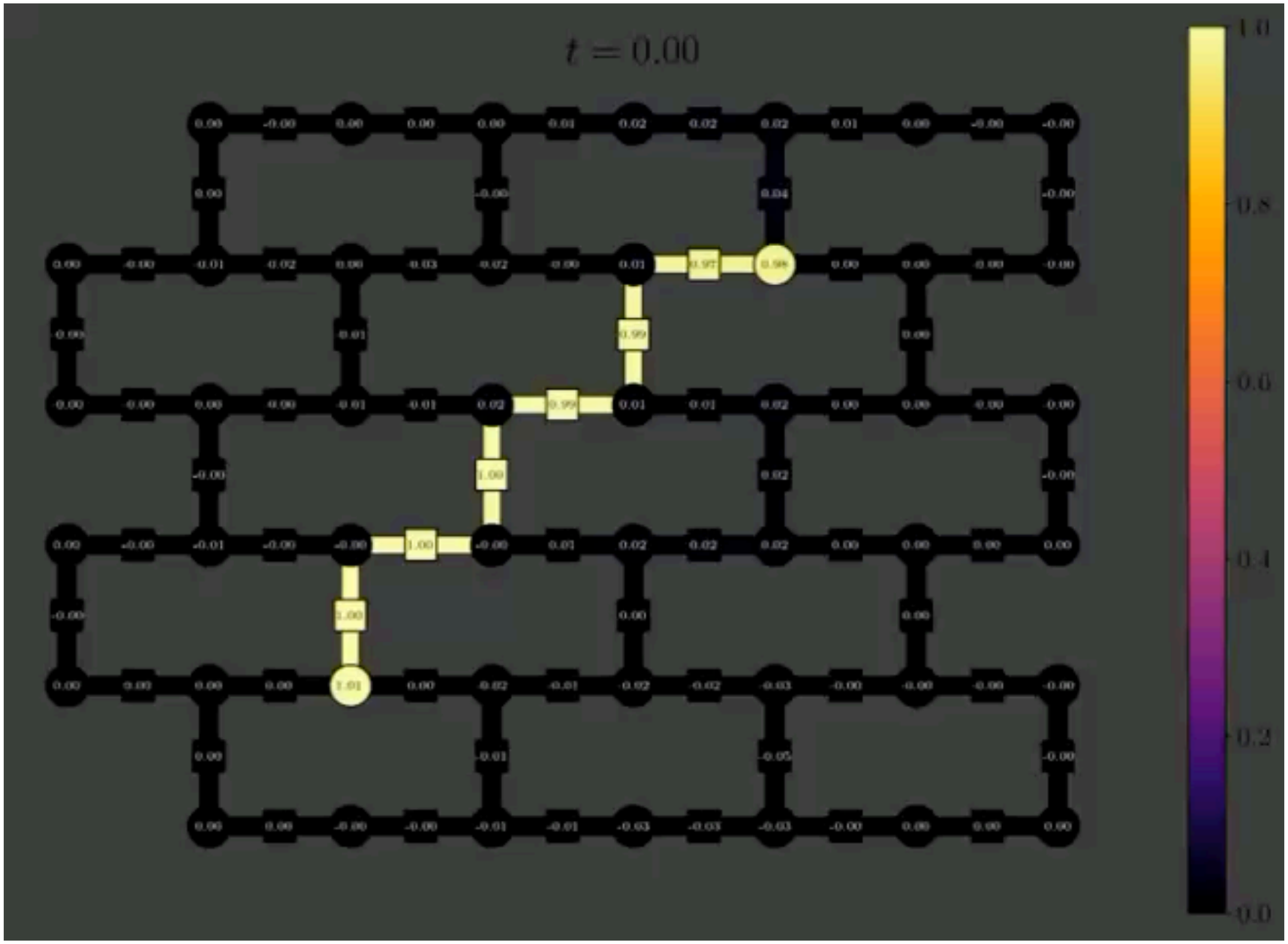




Universal Luscher term

Quantum Real-Time Dynamics of the $\mathbb{Z}_2$ Higgs model

Single string oscillations at m = 0, g = 0 point:



Max. 2Q depth: 192
Num qubits: 144
Total 2Q gates: 7872

Device: ibm_aachen

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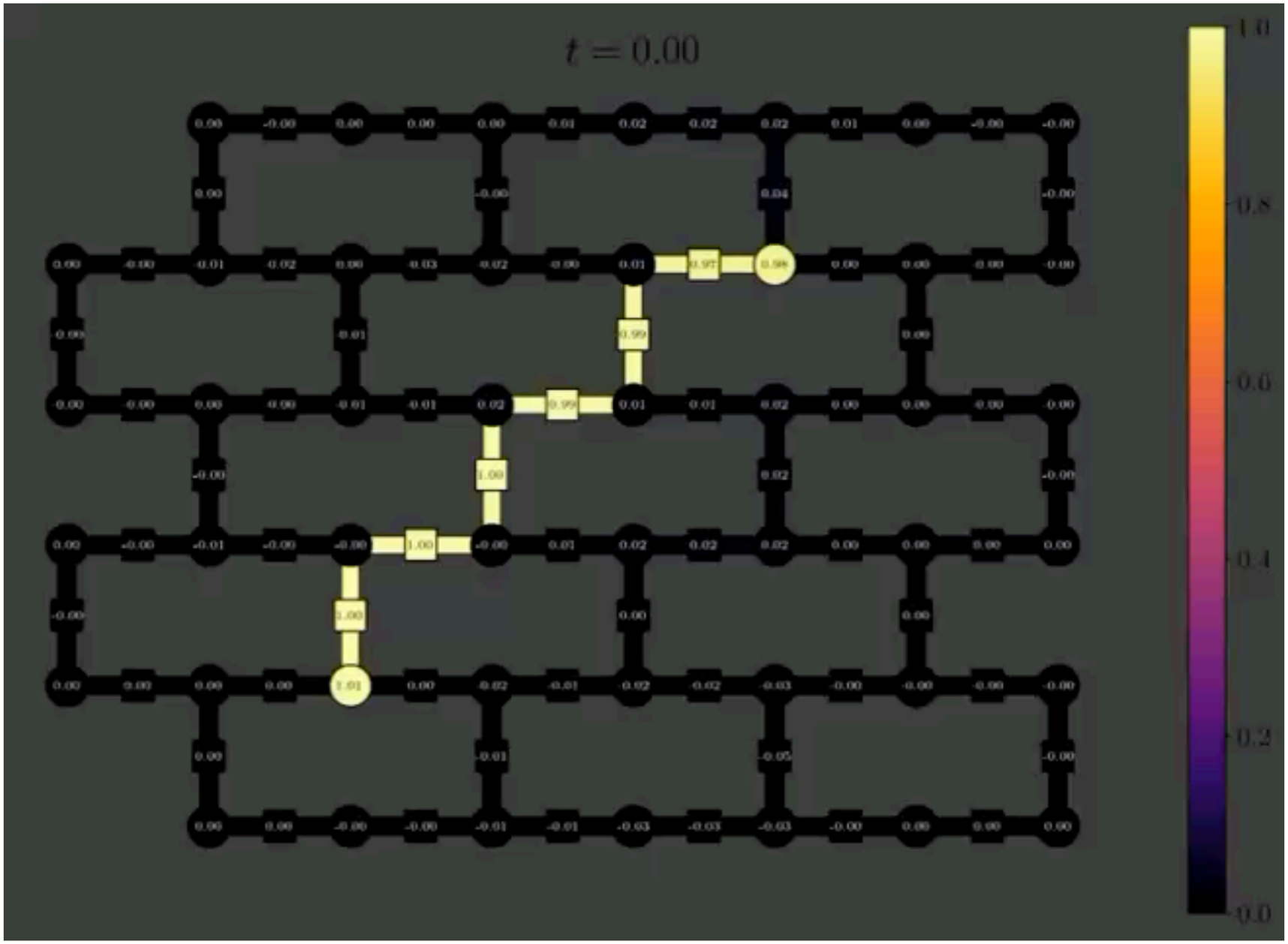

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arXiv:2507.08088

CERN-TH-2025-111

Real-Time Dynamics in a (2+1)-D Gauge Theory: The Stringy Nature on a Superconducting Quantum Simulator

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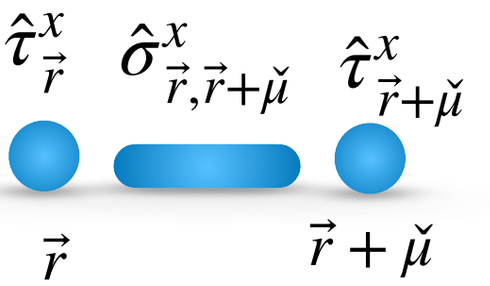

BasQ Basque Quantum · DIPC Donostia International Physics Center · ikerbasque Basque Foundation for Science · Universidad del País Vasco · Euskal Herriko Unibertsitatea · EHU QC EHU Quantum Center · CERN

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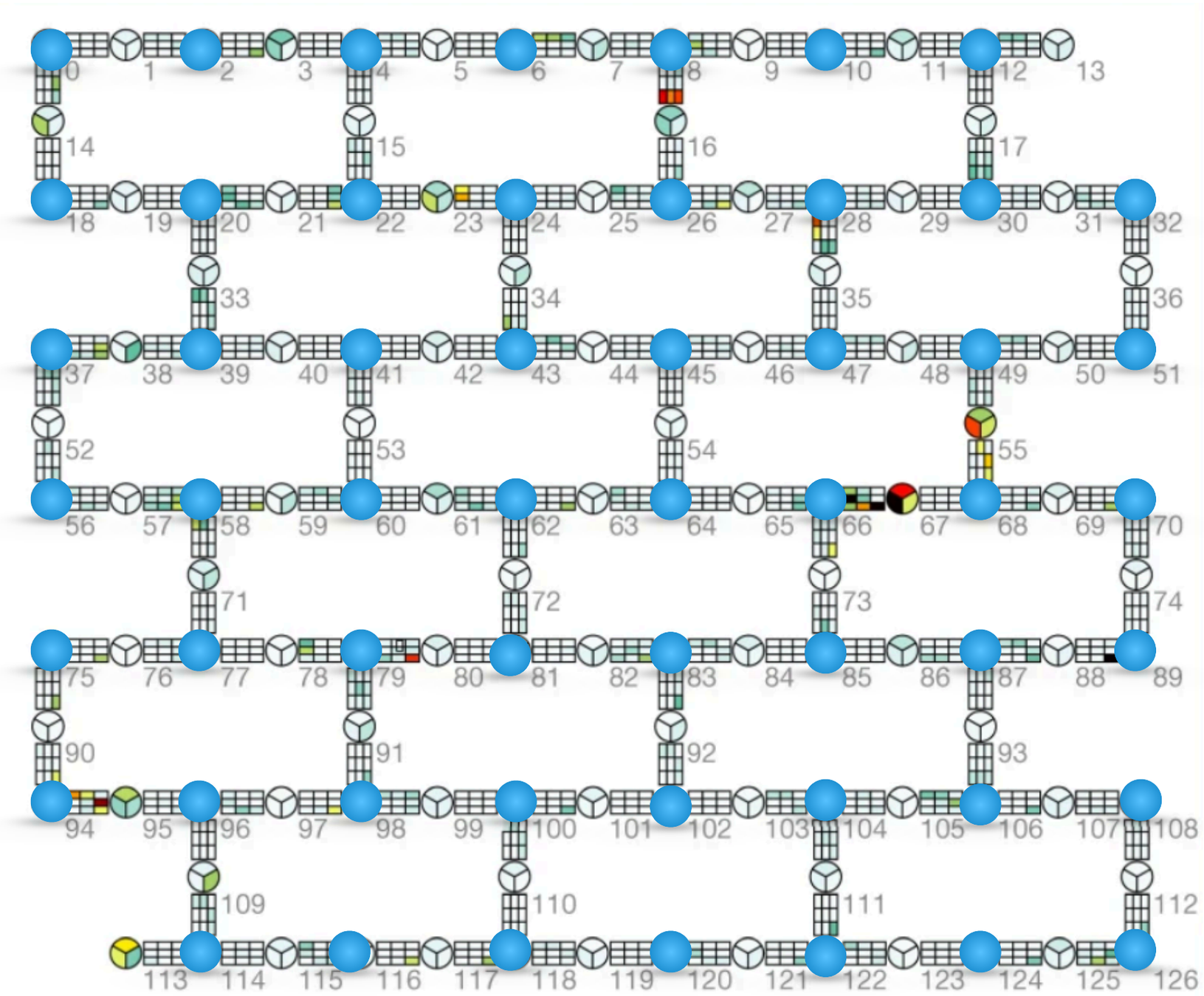

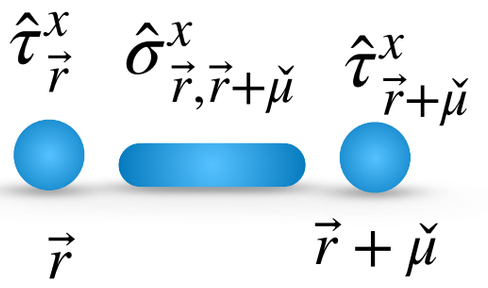

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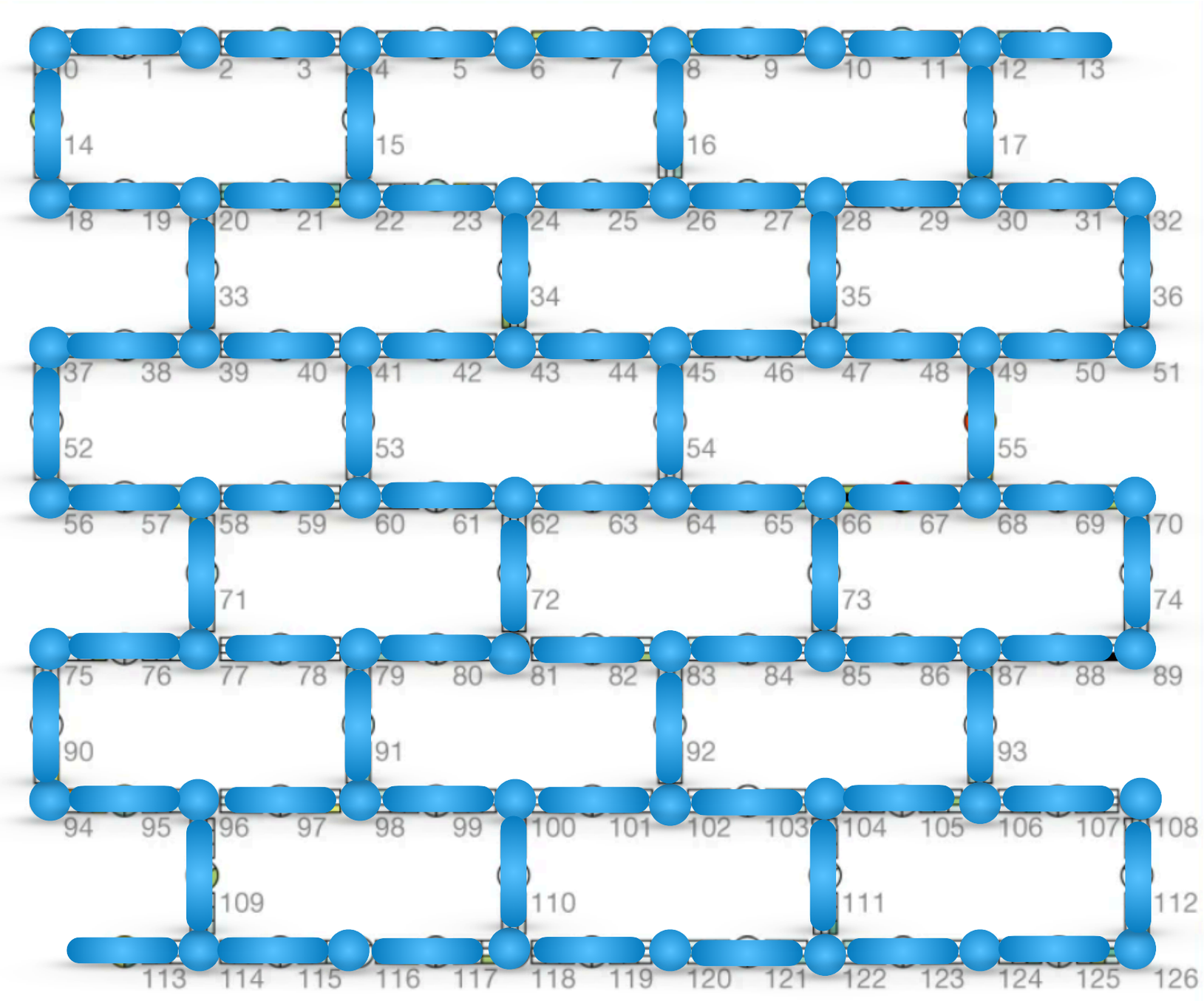
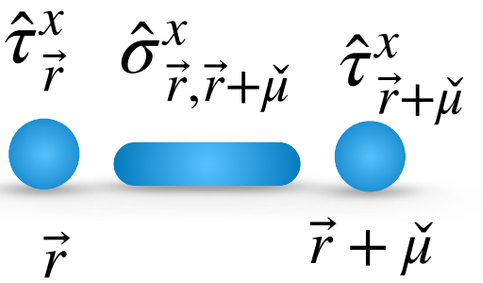
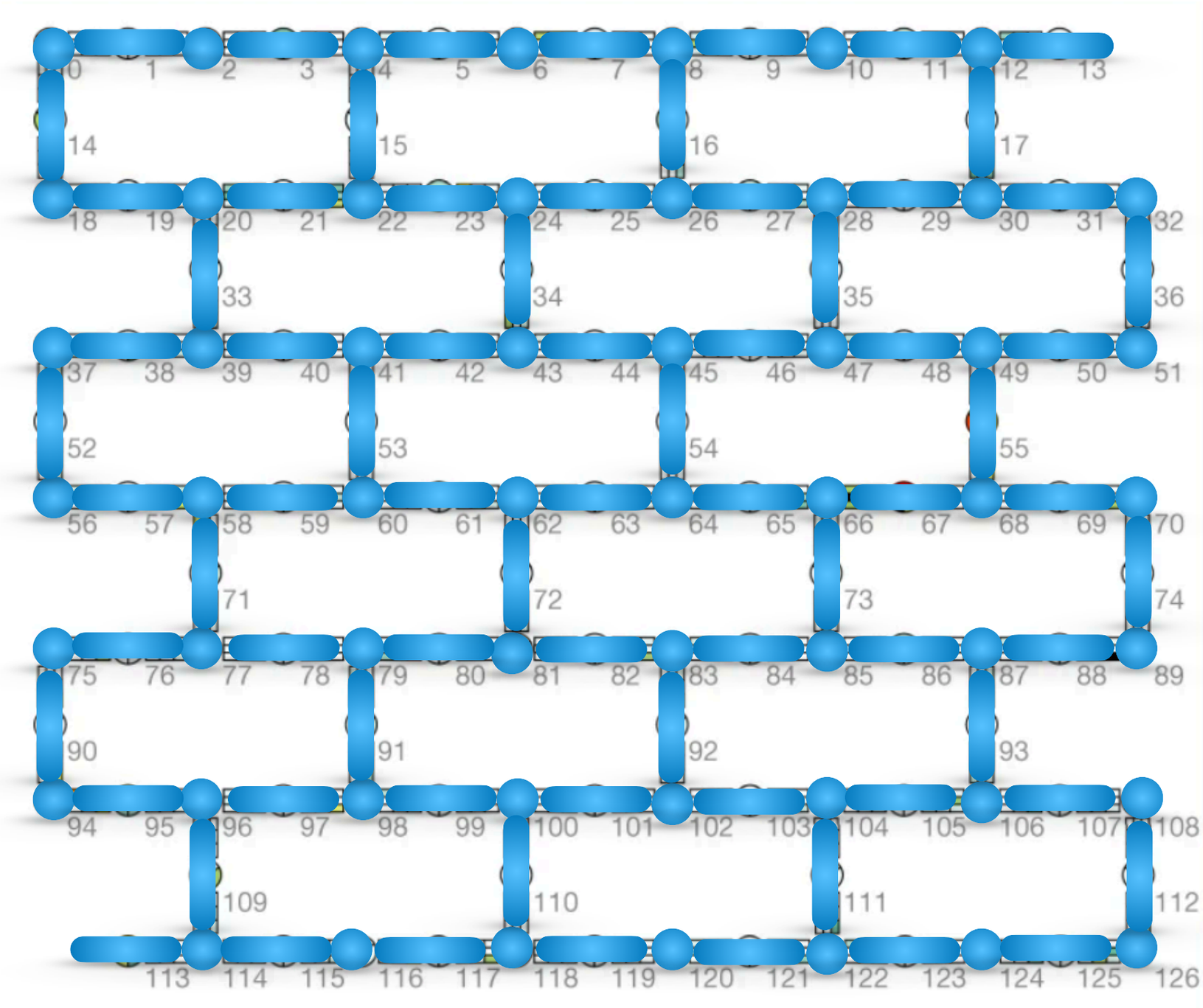






$\hat{\tau}^x_{\vec{r}}$ $\hat{\sigma}^x_{\vec{r},\vec{r}+\breve{\mu}}$ $\hat{\tau}^x_{\vec{r}+\breve{\mu}}$

$\vec{r}$ $\vec{r}+\breve{\mu}$

minimal coupling

$-m\hat{\tau}^z_{\vec{r}}$

$\vec{r}$

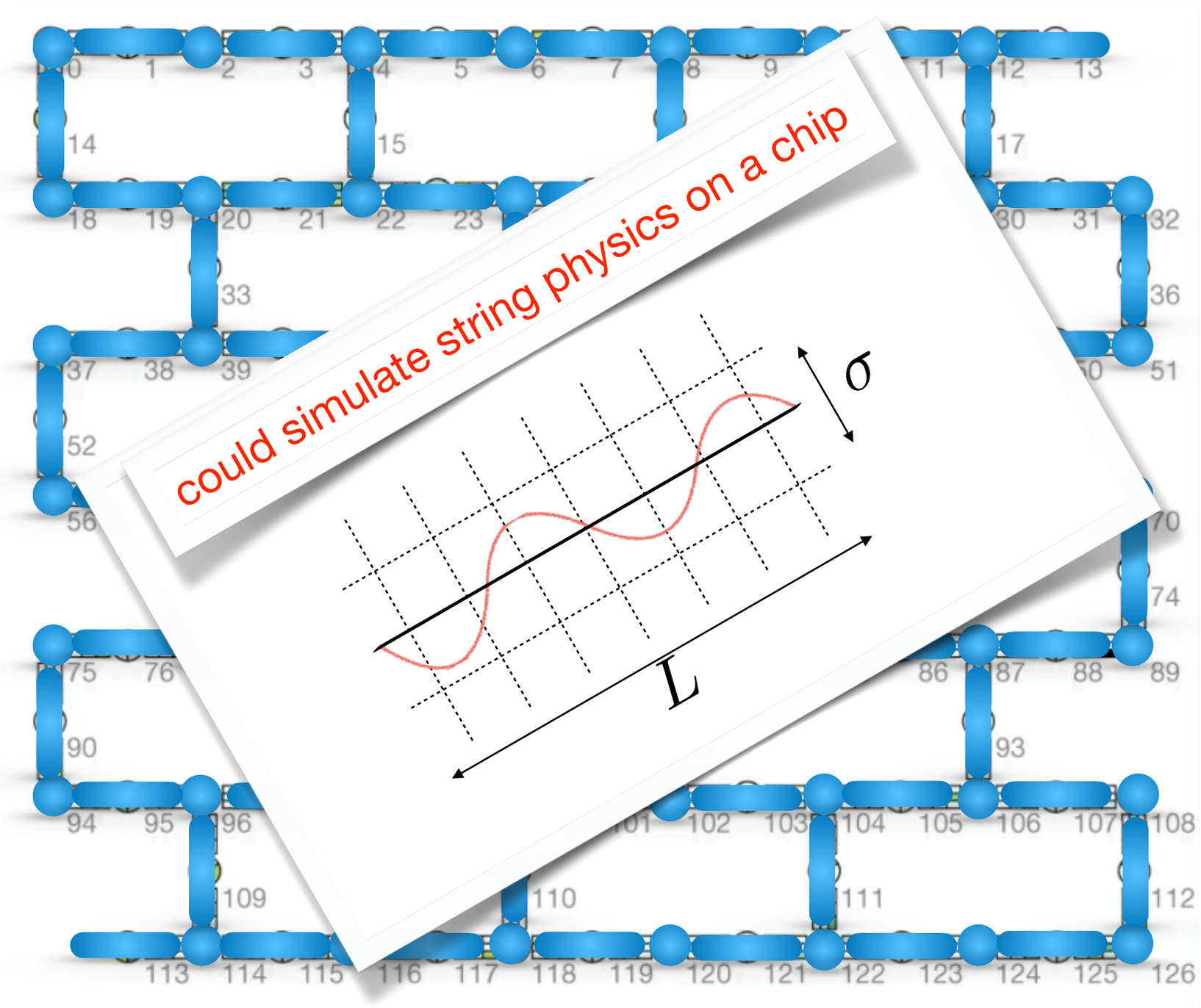
mass-term

$-g\hat{\sigma}^z_{\vec{r},\vec{r}+\breve{\mu}}$

$\vec{r}$ $\vec{r}+\breve{\mu}$

electric energy

$$\hat{H} = -m\sum_v \hat{\tau}^z_v - g\sum_l \hat{\sigma}^z_{i,j} + \sum_l \hat{\tau}^x_i \hat{\sigma}^x_{i,j} \hat{\tau}^x_j \qquad m > g > 1$$



$$\hat{\tau}^x_{\vec{r}} \quad \hat{\sigma}^x_{\vec{r},\vec{r}+\breve{\mu}} \quad \hat{\tau}^x_{\vec{r}+\breve{\mu}}$$

$\vec{r}$ $\vec{r}+\breve{\mu}$

minimal coupling

$$-m\hat{\tau}^z_{\vec{r}}$$

$\vec{r}$

mass-term

$$-g\hat{\sigma}^z_{\vec{r},\vec{r}+\breve{\mu}}$$

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Quantum Real-Time Dynamics of the $\mathbb{Z}_2$ Higgs model

Model: Lattice gauge theory in (2+1) dimensions (heavy-hex)
with spin 1/2 matter and gauge degrees of freedom.

$$H = -m\sum_{n}\tau^z_n - g\sum_{(n,v)}\sigma^z_{n,v} - \lambda\sum_{n,v}\tau^x_{n+v}\sigma^x_{(n,v)}\tau^x_n \qquad \lambda = 1$$

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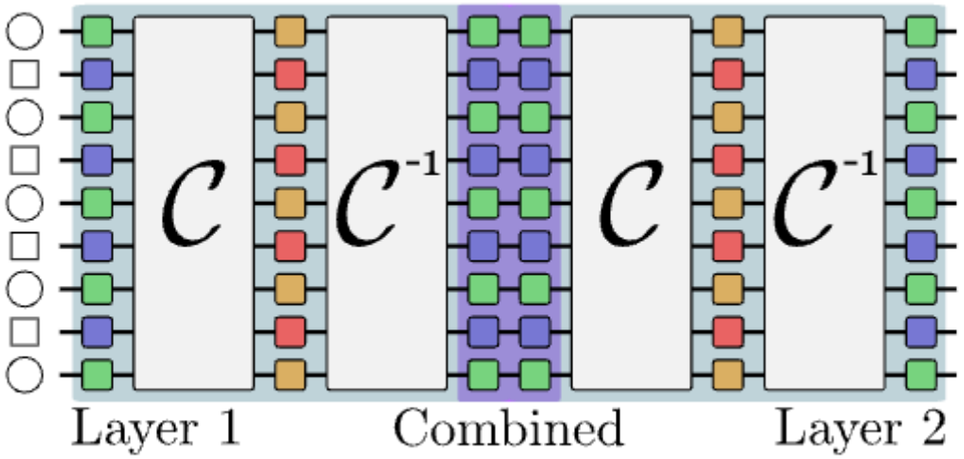
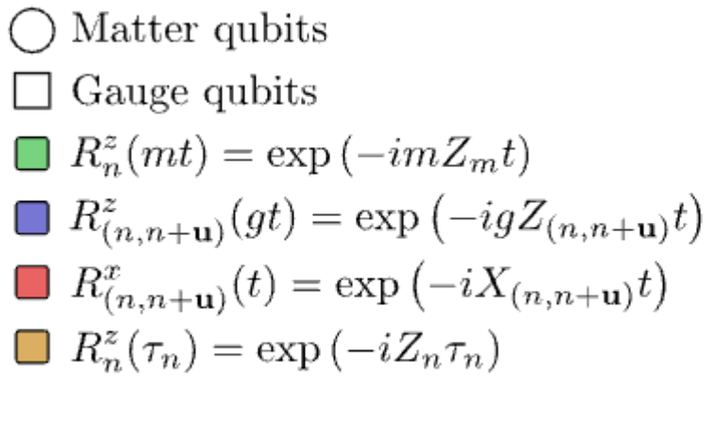
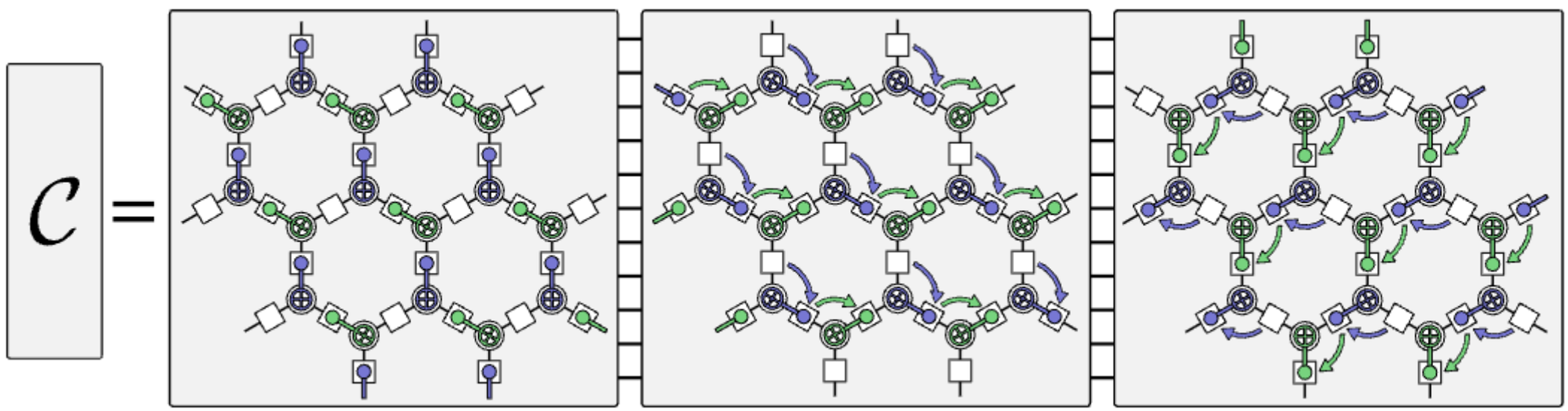
$$H = -m\sum_{n}\tau^z_n - g\sum_{(n,v)}\sigma^z_{n,v} - \lambda\sum_{n,v}\tau^x_{n+v}\sigma^x_{(n,v)}\tau^x_n \qquad \lambda = 1$$

Goal: Simulate time dynamics using 2nd order Trotter circuits

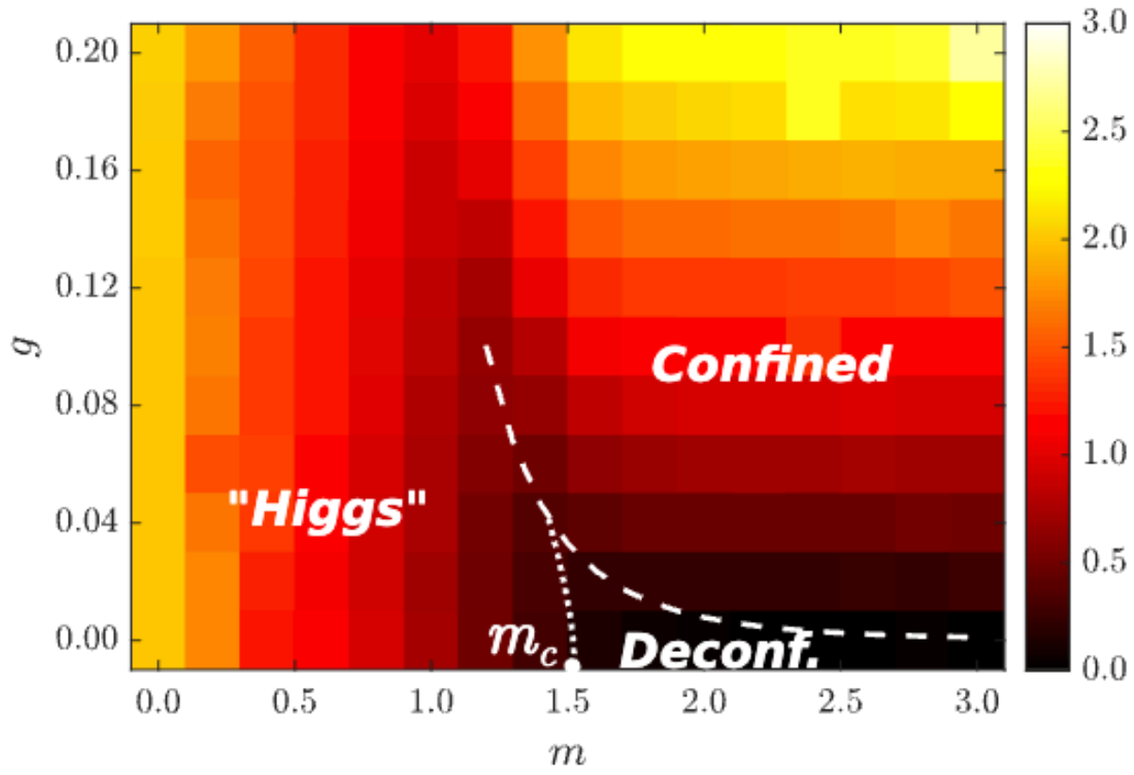






Quantum Real-Time Dynamics of the $\mathbb{Z}_2$ Higgs model

Ground-state phase diagram with tensor networks:



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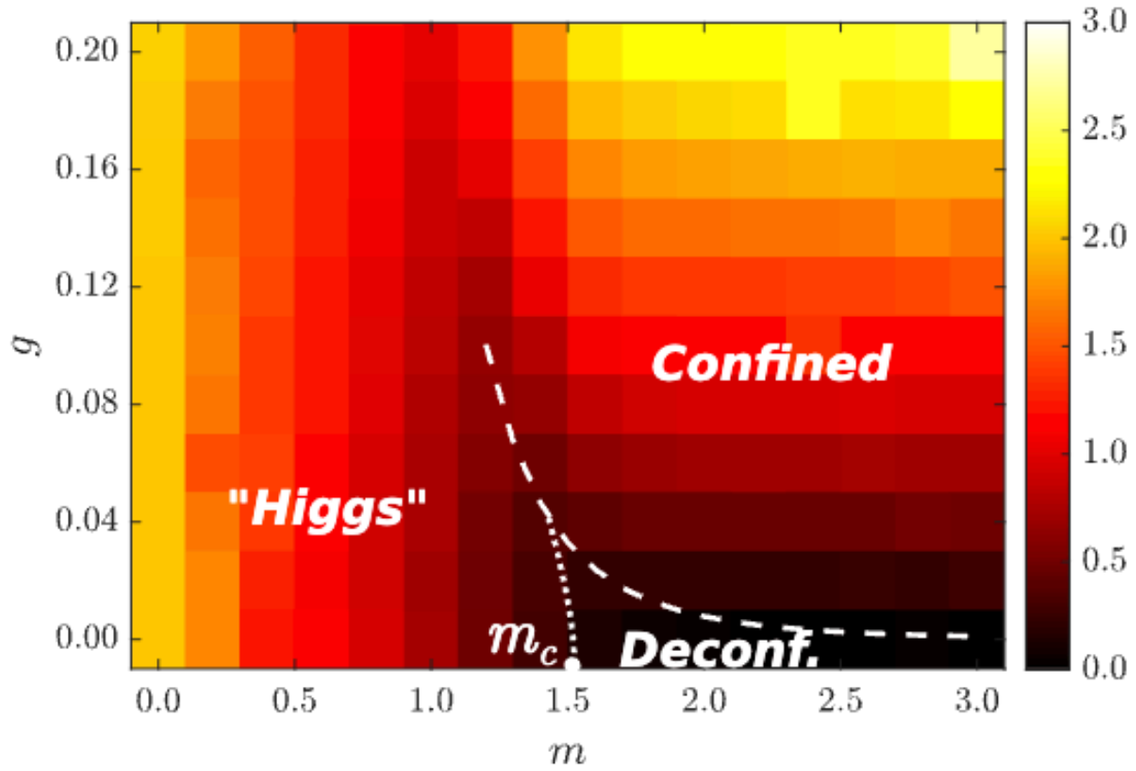
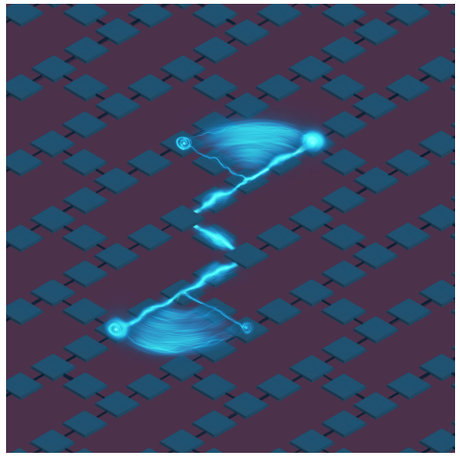
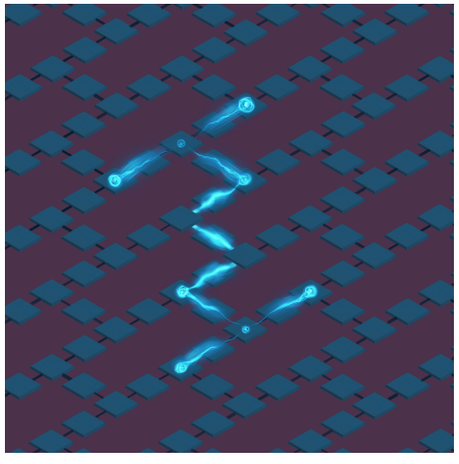
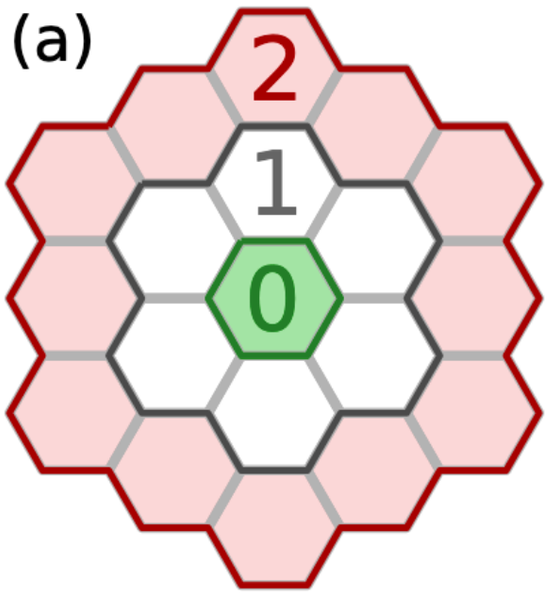


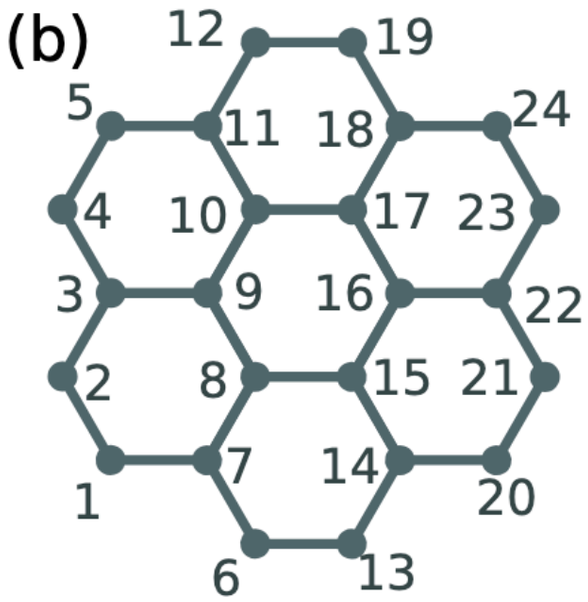
String dynamics: bending mode

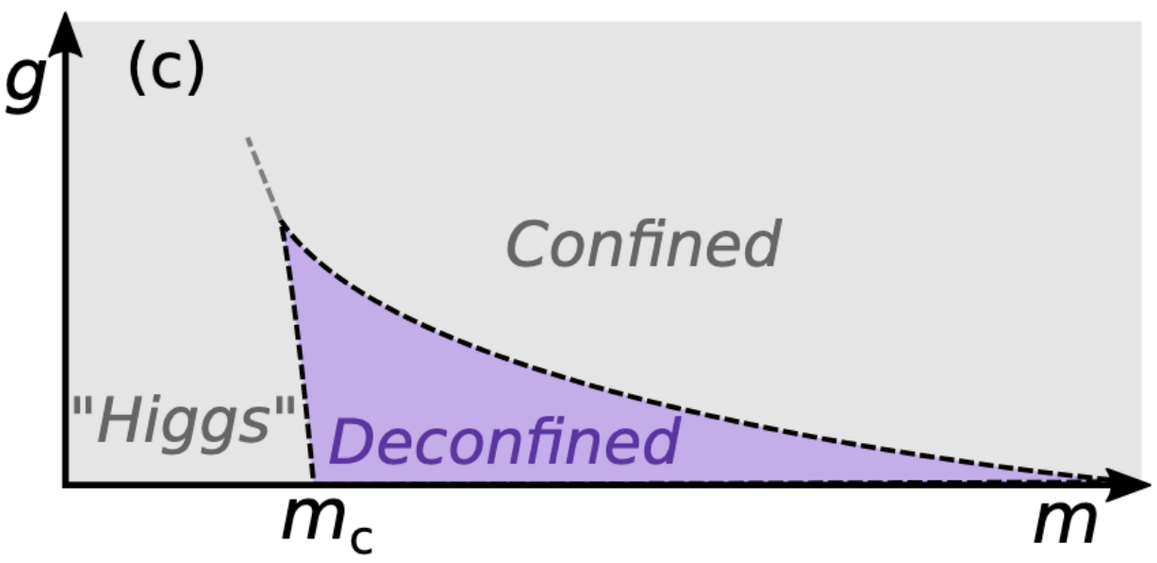


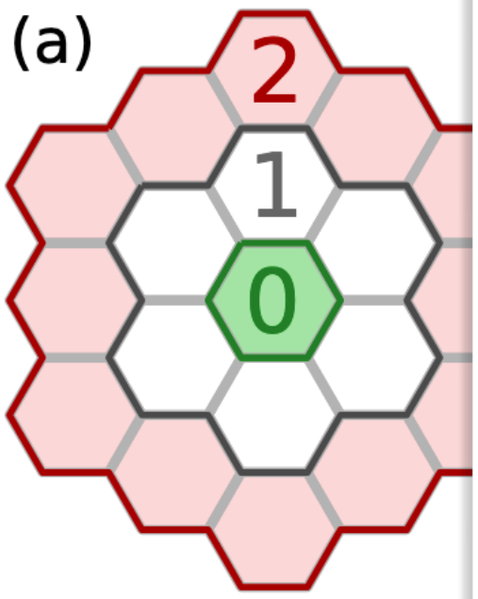
String dynamics: io-io mode

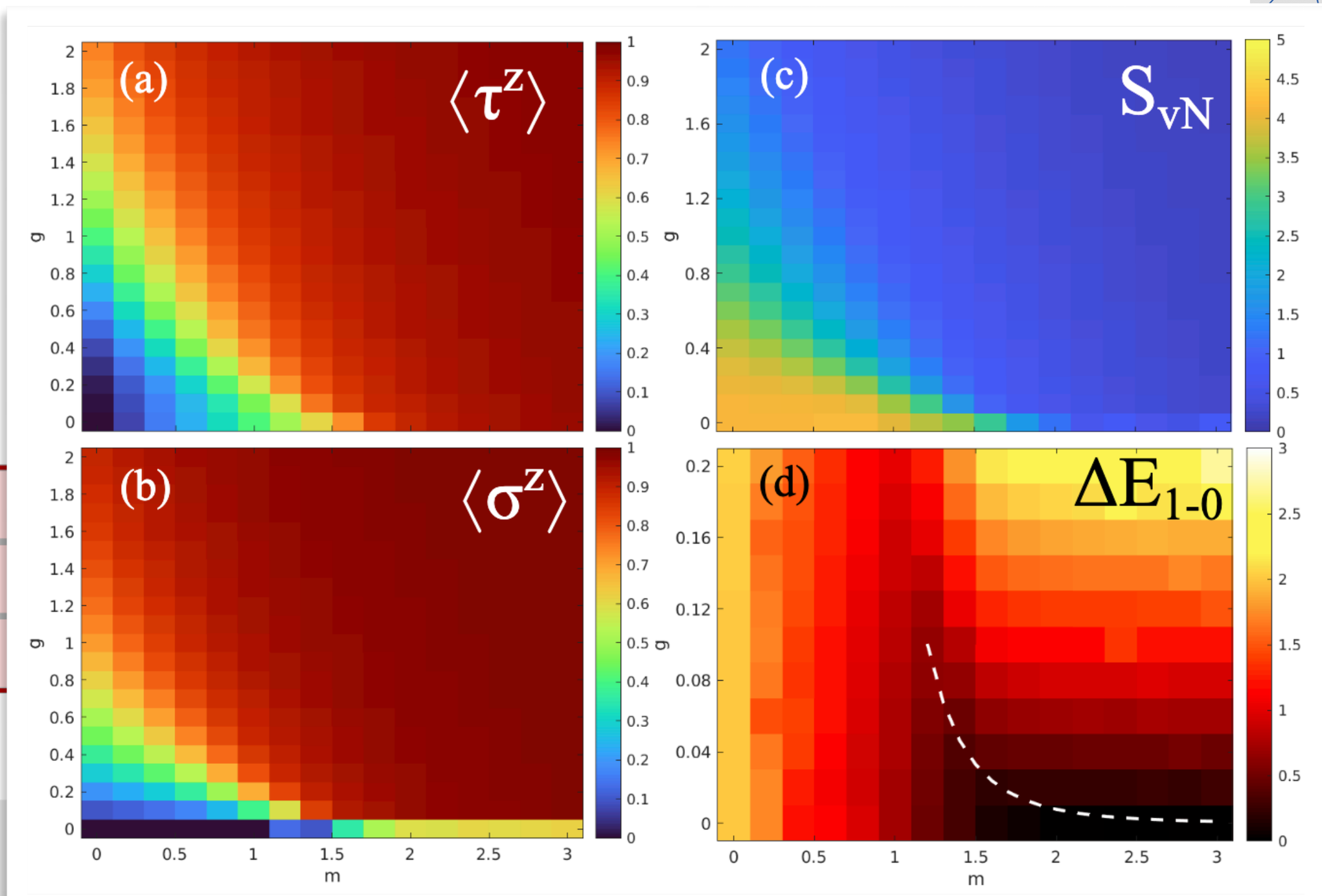


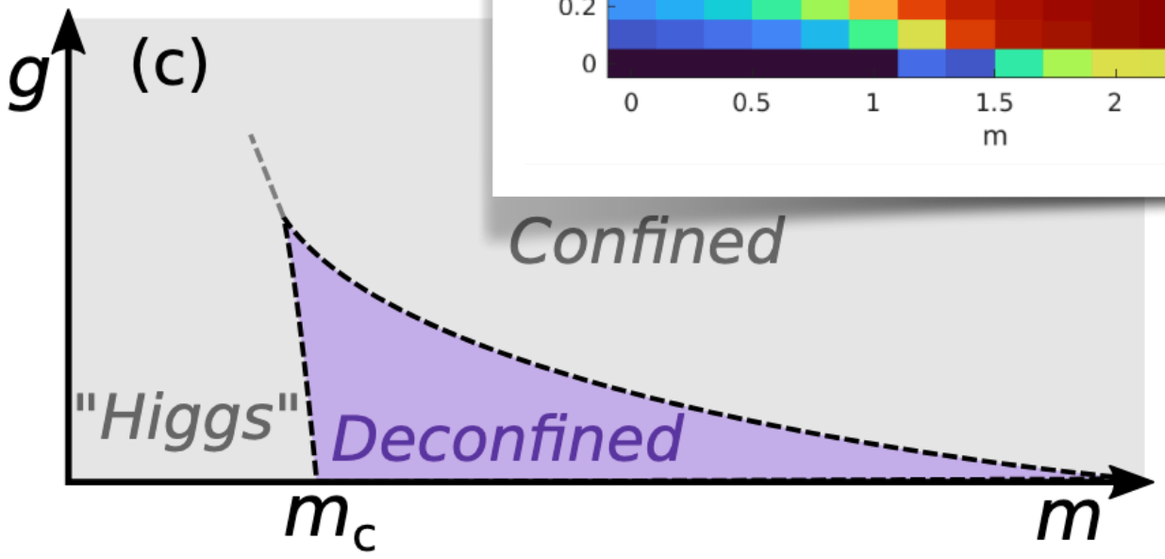

(a)
2
1
0


(b)
12
19
5
11
18
24
4
10
17
23
3
9
16
22
2
8
15
21
7
14
20
1
6
13


(c)
g
Confined
"Higgs"
Deconfined
m_c
m


(a)
2
1
0

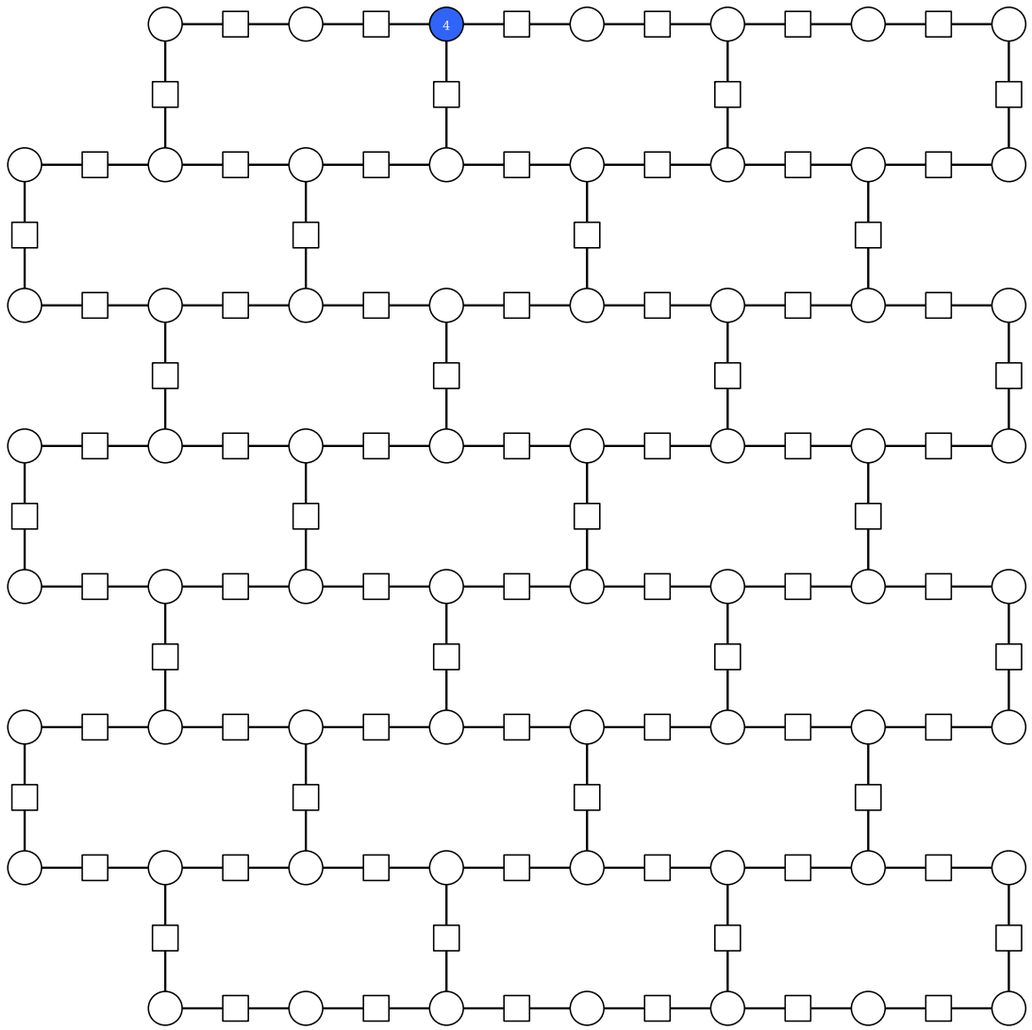

(a)
⟨τ^z⟩
(b)
⟨σ^z⟩
(c)
S_vN
(d)
ΔE_1-0
g
m

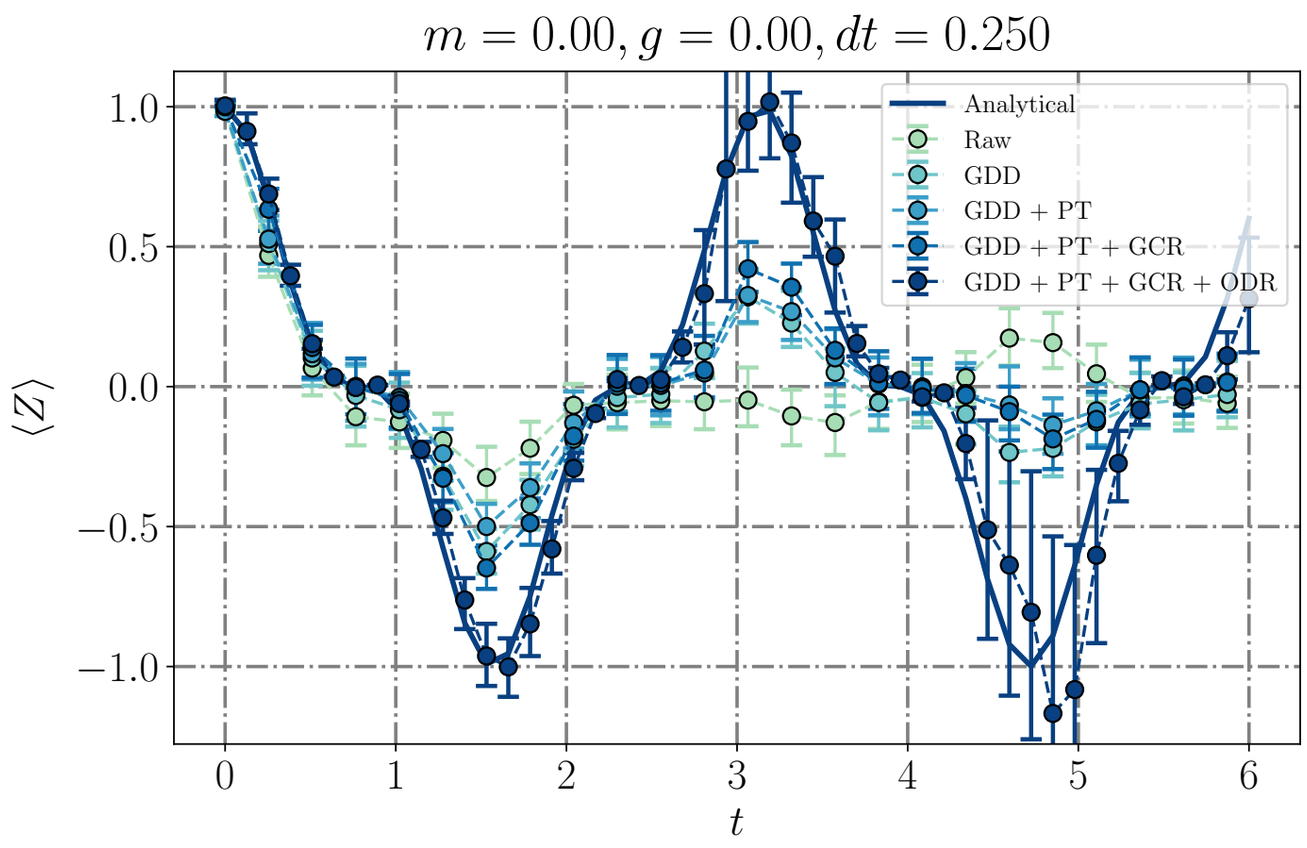

(c)
g
Confined
"Higgs"
Deconfined
m_c
m

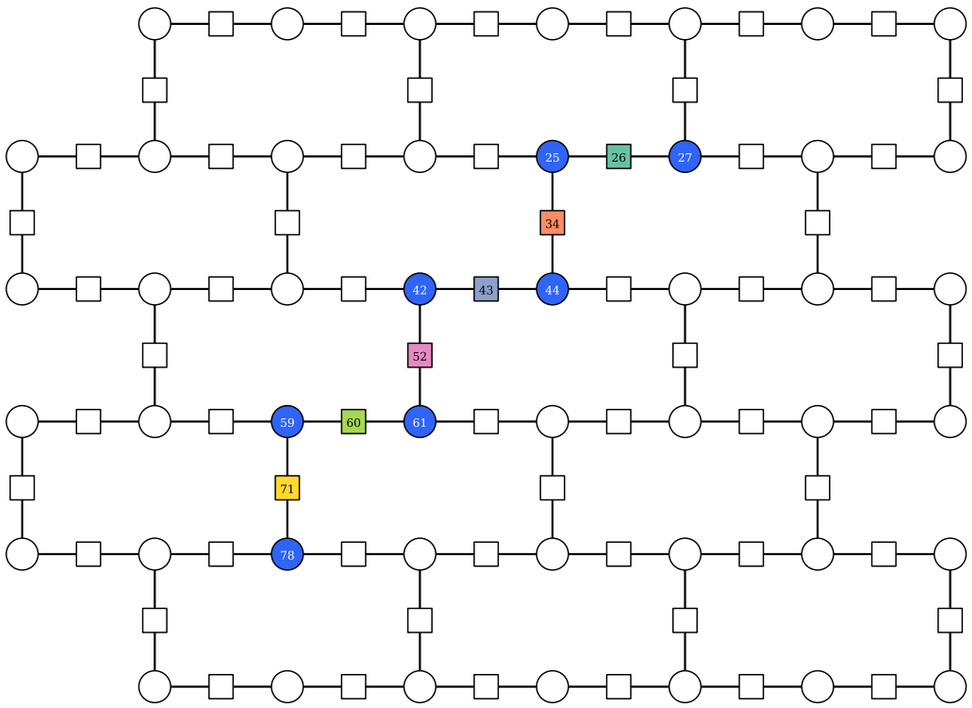
Quantum Real-Time Dynamics of the $\mathbb{Z}_2$ Higgs model

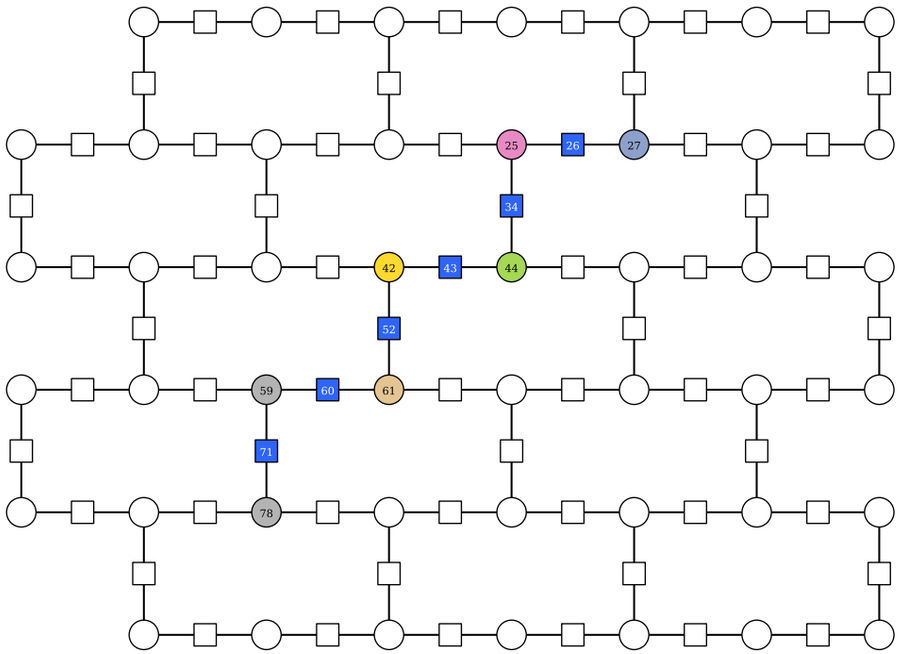
Customized error mitigation techniques:

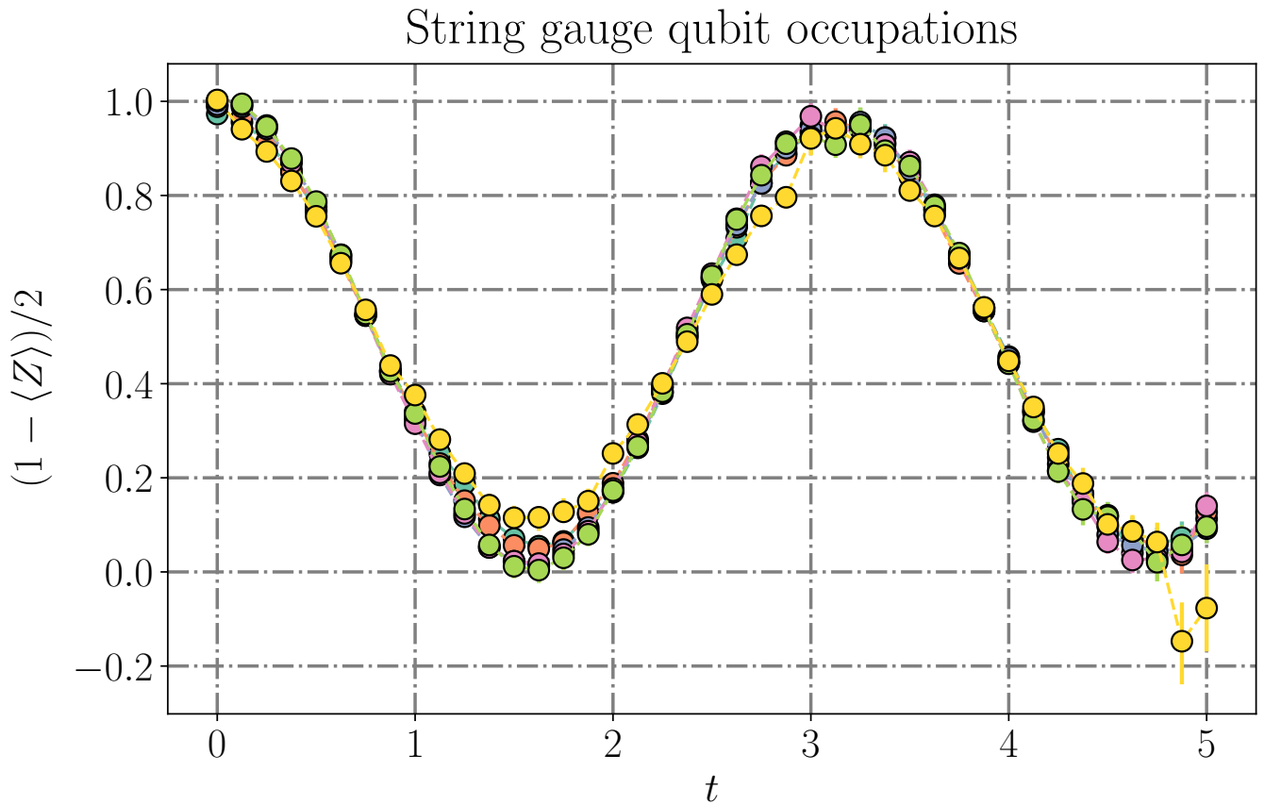
Gauge dynamical decoupling (GDD)
Pauli Twirling (PT)
Gauge configuration recovery (GCR)
Operator decoherence renormalization (ODR)

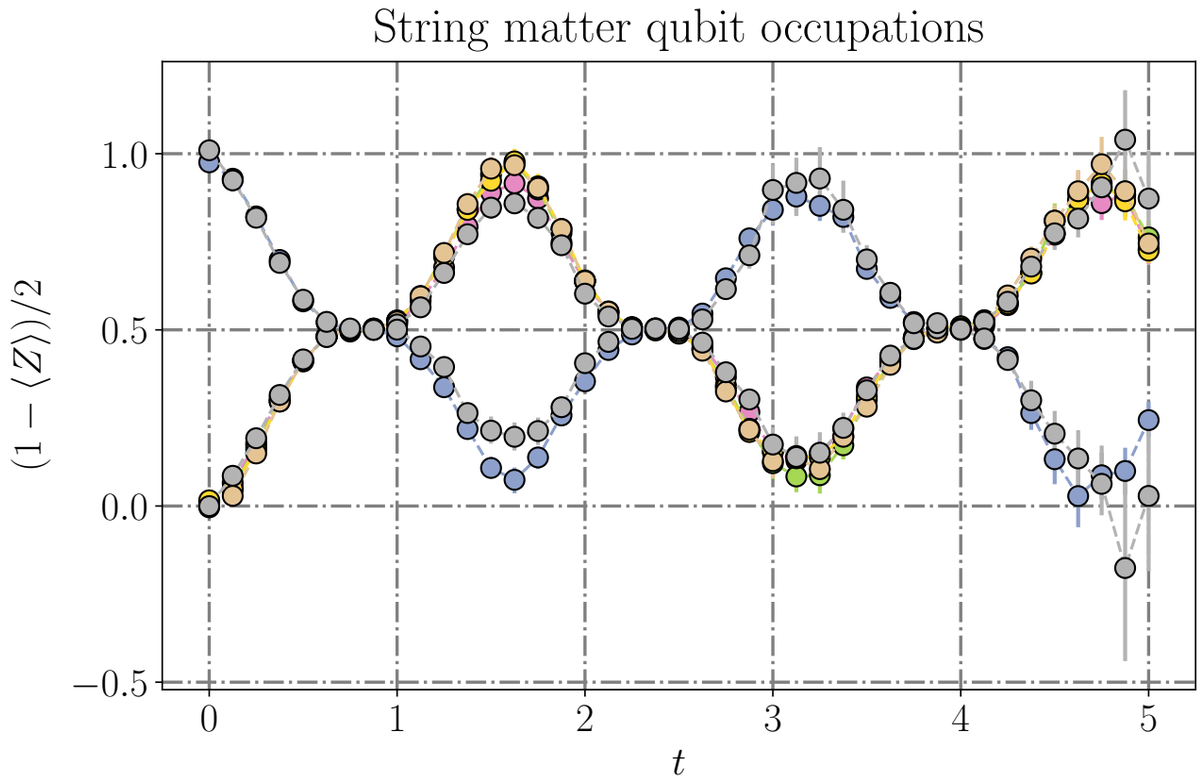





25
26
27
34
42
43
44
52
59
60
61
71
78


25
26
27
34
42
43
44
52
59
60
61
71
78


String gauge qubit occupations
$(1-\langle Z\rangle)/2$
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0
1
2
3
4
5
t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$(1-\langle Z\rangle)/2$
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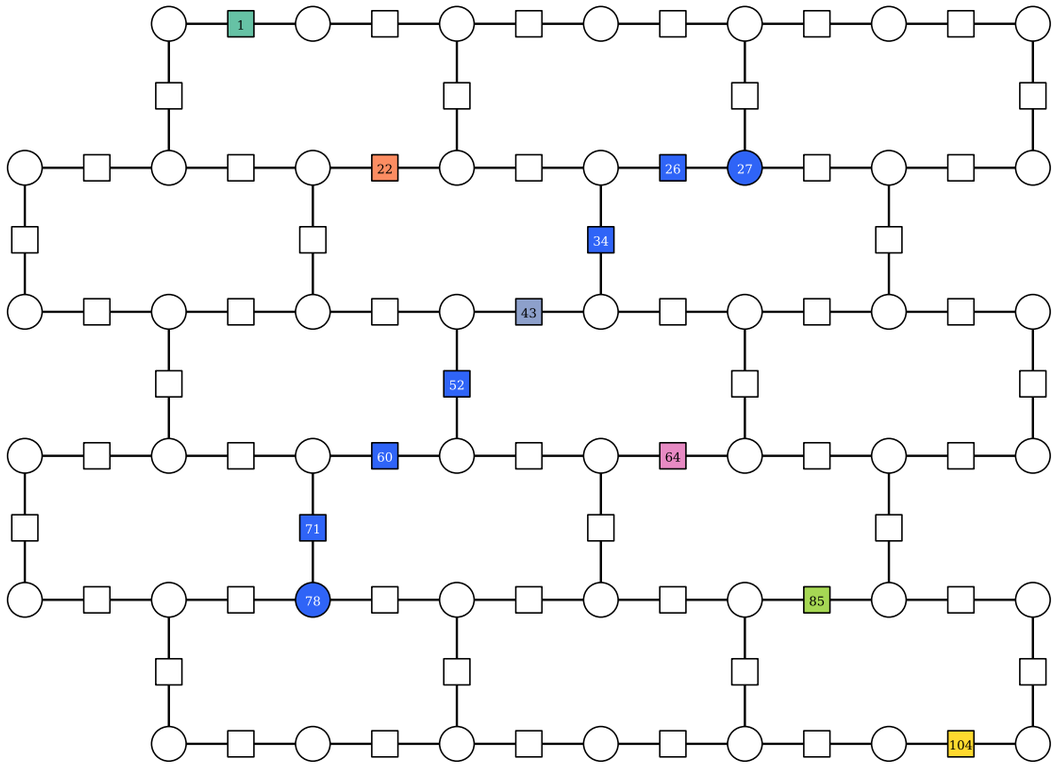
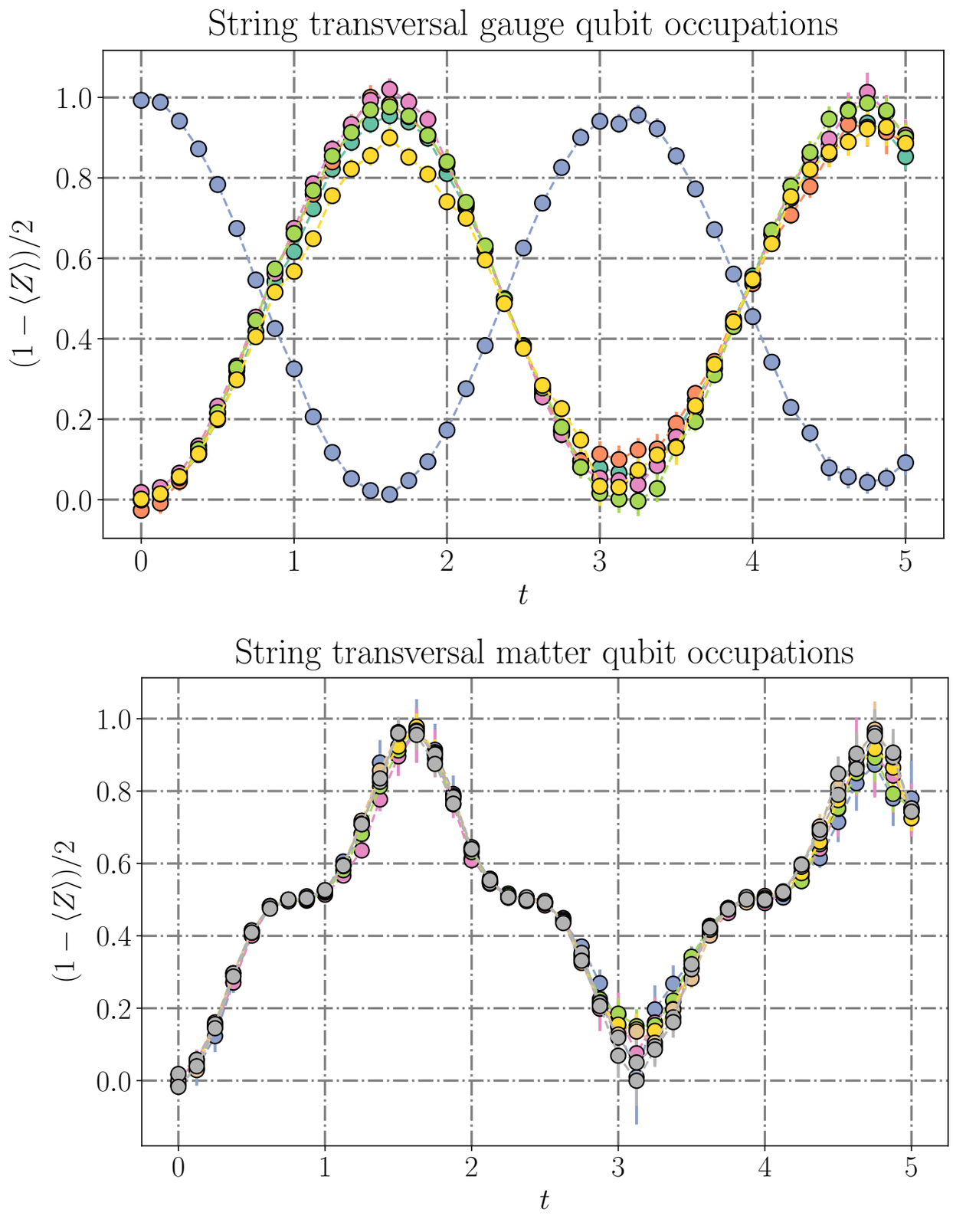
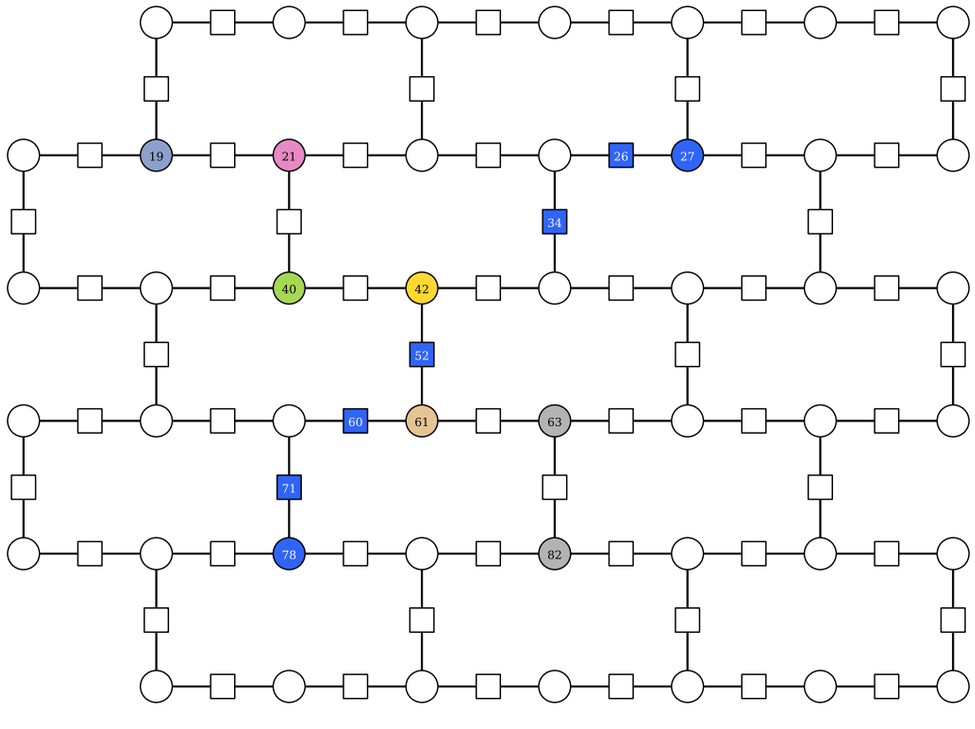
0.5
0.0
−0.5
0
1
2
3
4
5
t


1
22
26
27
34
43
52
60
64
71
78
85
104

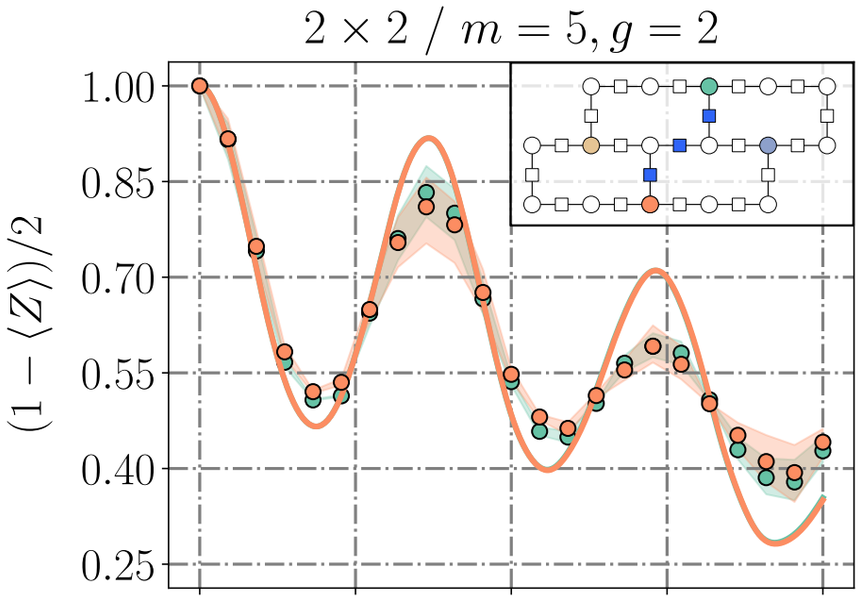

String transversal gauge qubit occupations
$(1-\langle Z\rangle)/2$
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
t
String transversal matter qubit occupations
$(1-\langle Z\rangle)/2$
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
t

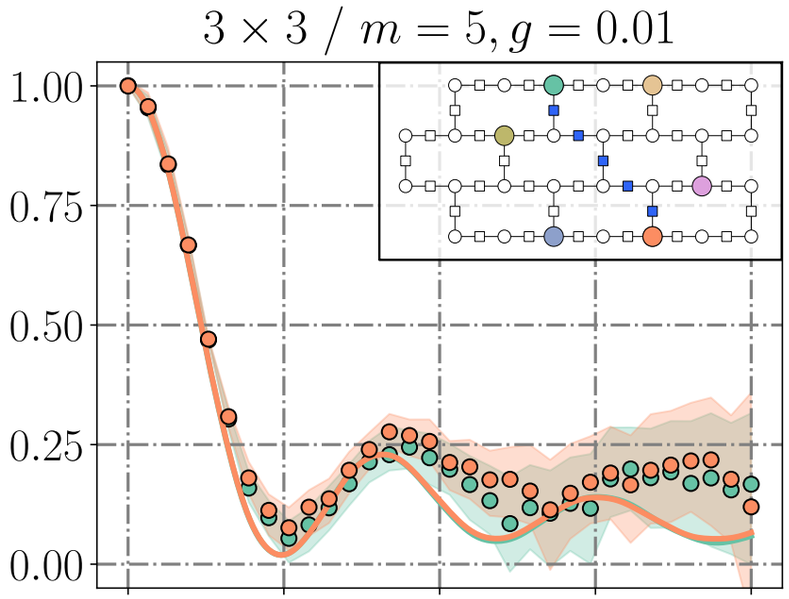

19
21
26
27
34
40
42
52
60
61
63
71
78
82

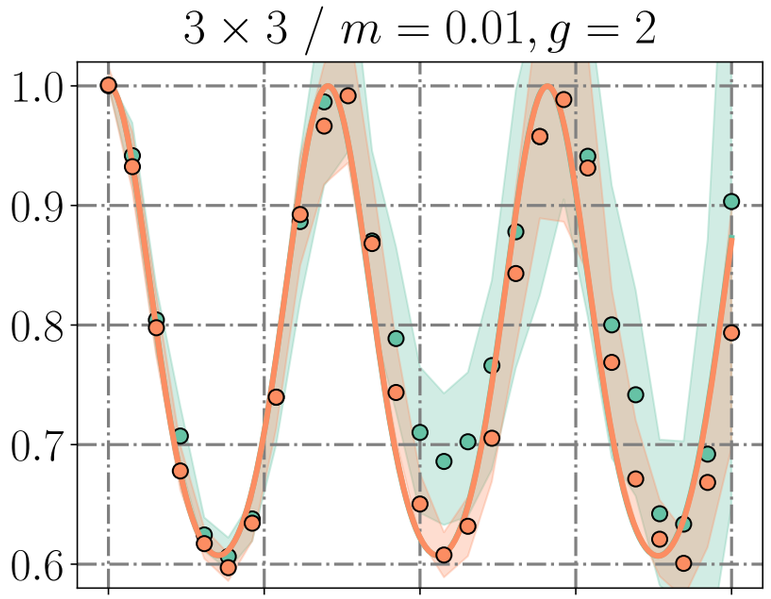
Confined

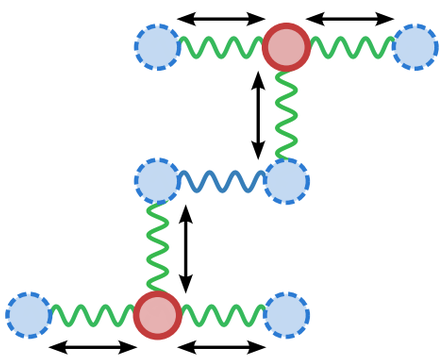
Deconfined

“Higgs”

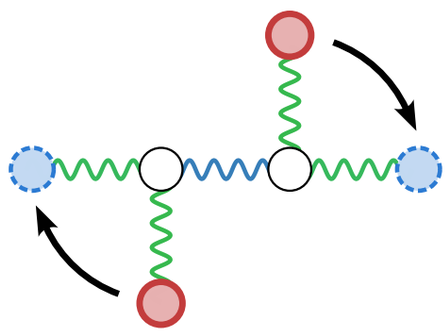




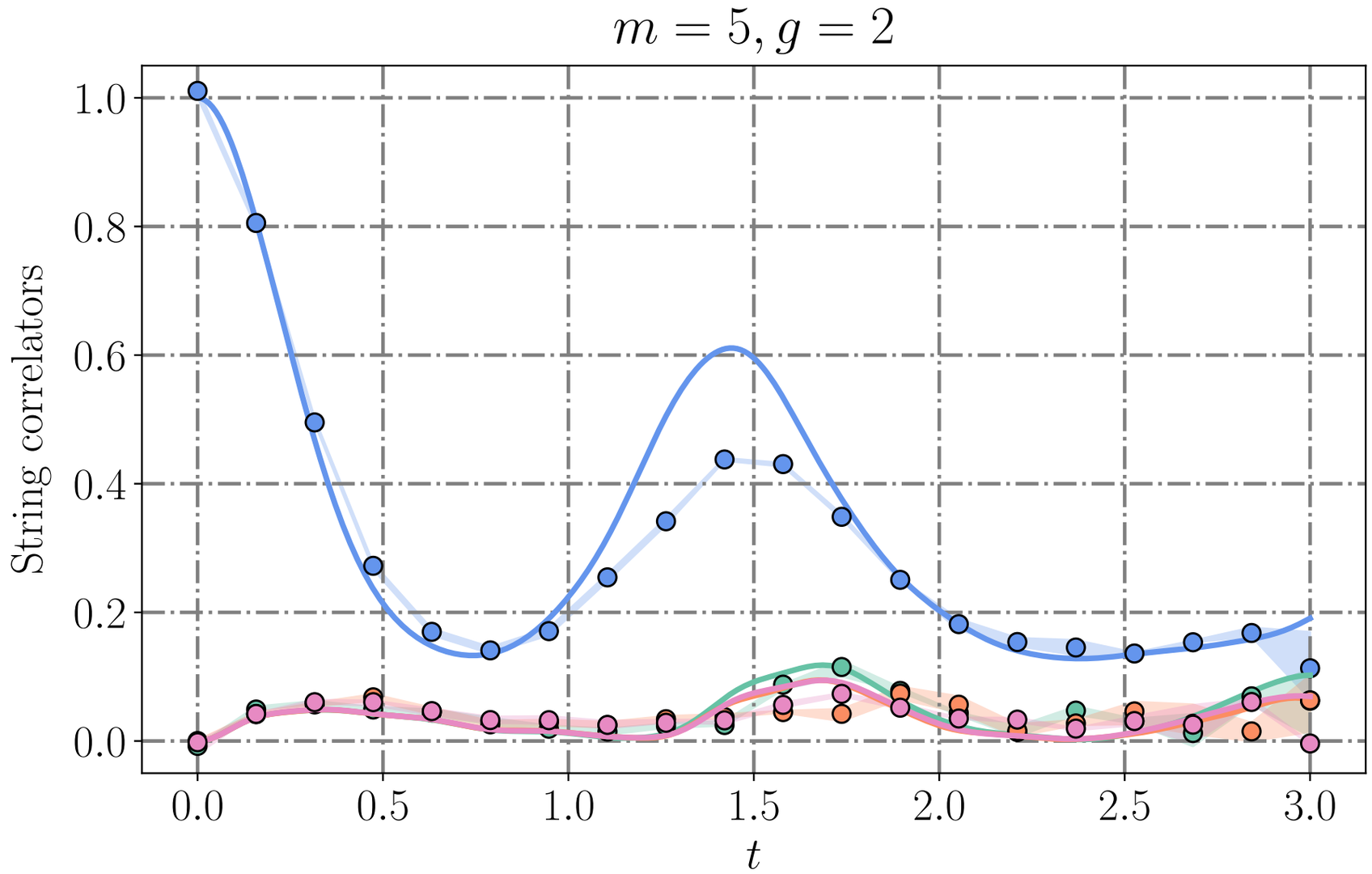


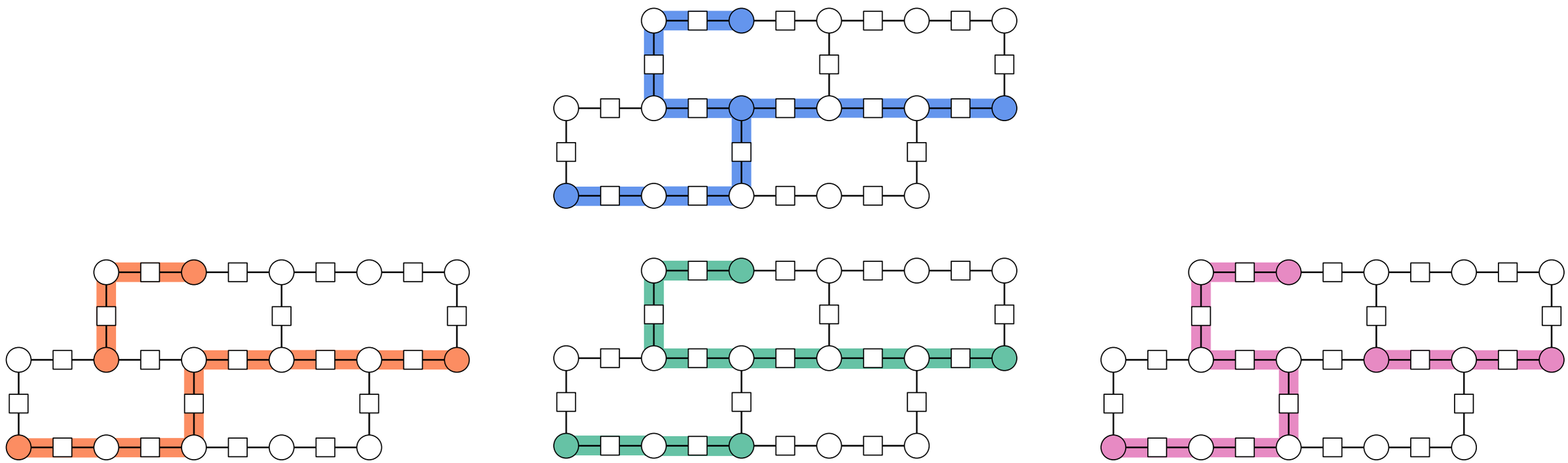


String dynamics:
io-io mode



String dynamics:
bending mode


$m = 5, g = 2$
String correlators
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
t



CERN-TH-2025-105

Roughening and dynamics of an electric flux string in a (2+1)D lattice gauge theory

Francesco Di Marcantonio,[1,*] Sunny Pradhan,[1,†] Sofia Vallecorsa,[2,‡] Mari Carmen Bañuls,[3,4,§] and Enrique Rico Ortega[1,2,5,6,¶]

CERN-TH-2025-111

Real-Time Dynamics in a (2+1)-D Gauge Theory: The Stringy Nature on a Superconducting Quantum Simulator

Jesús Cobos,[1,*] Joana Fraxanet,[2] César Benito,[3] Francesco di Marcantonio,[1] Pedro Rivero,[2] Kornél Kapás,[4] Miklós Antal Werner,[4] Örs Legeza,[4,5,6] Alejandro Bermudez,[3] and Enrique Rico[1,7,8,9]