

# Identification of defects and center vortices

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ML approaches in Lattice QCD

S. Bulusu, M. Favoni, A. Ipp, D. I. Müller, D. Schuh, Phys. Rev. D **104**, 074504

Code: [gitlab.com/openpixi/scalar-ml](https://gitlab.com/openpixi/scalar-ml)



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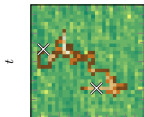
Der Wissenschaftsfonds.



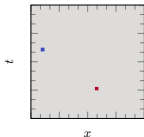
# Detecting flux violations

- Complex scalar field in 1+1D with nonzero chemical potential
- Sign problem solved by a dual formulation:  $\phi_x \rightarrow \{k_{x,\nu}, l_{x,\nu}\}$  integer fields
- The field  $k$  obeys the conservation law  $\sum_{\nu} (k_{x,\nu} - k_{x-\hat{\nu},\nu}) = 0$ . We artificially created flux violations to be detected by the models.

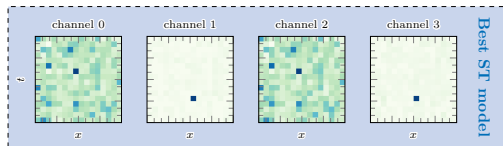
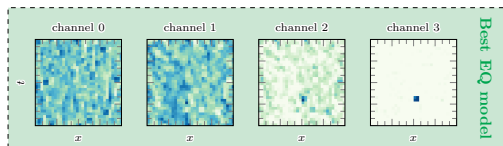
field configuration



flux violation



(a) Example field configuration



(b) Feature maps of convolutional network in best EQ and ST models

# Center vortices and confinement

There is strong evidence showing that center vortices are responsible for quark confinement

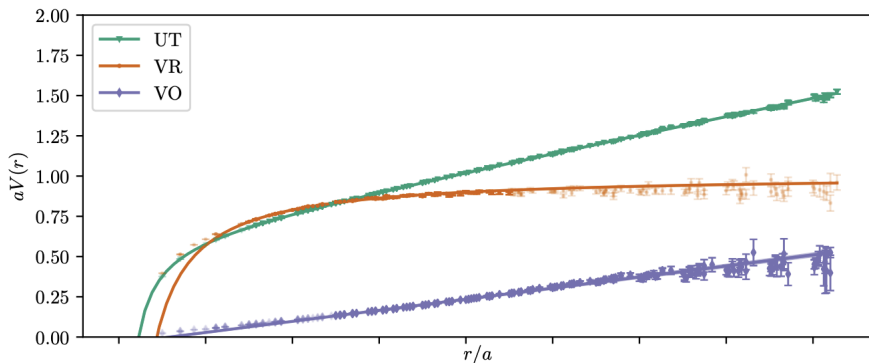
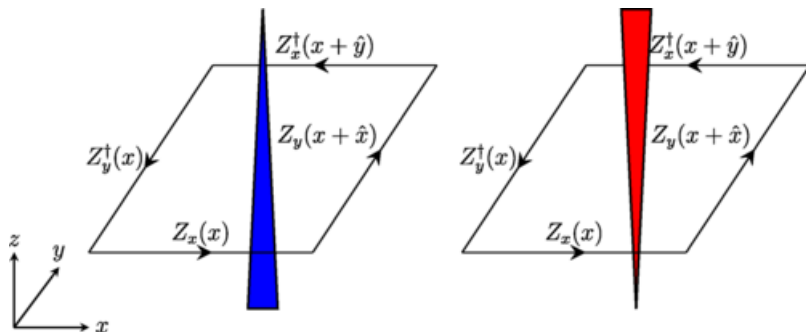


Image from [arXiv:2206.00844](https://arxiv.org/abs/2206.00844)

# Center vortices and confinement

- In order to identify center vortices, it is necessary to transform a gauge link configuration to the maximal center gauge (MCG)
- This is done by maximizing  $R = \frac{1}{VDN_c^2} \sum_{x,\mu} |\text{Tr} U_\mu^\Omega(x)|^2$  then projecting the links to the closest center element



# Center vortices and confinement

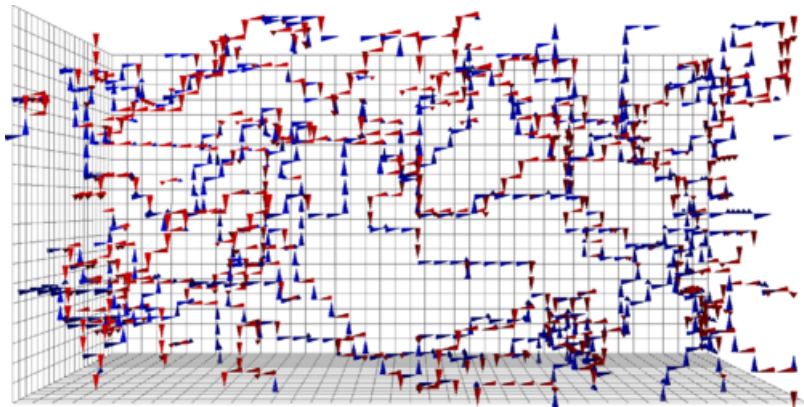


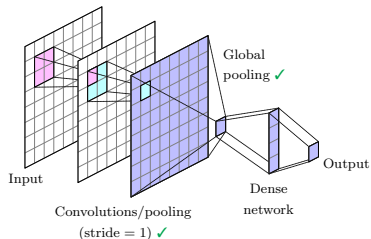
Image from [arXiv:1912.09531](https://arxiv.org/abs/1912.09531)

# How can ML be useful?

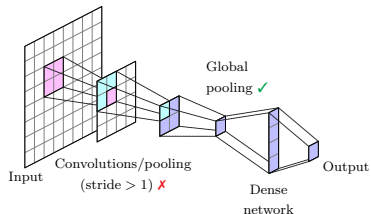
- A neural network can be used to perform the transformation to the MCG
- In a similar fashion to the defect identification, one can use the number of vortices as a label and extract information from the feature map

## Backup slides

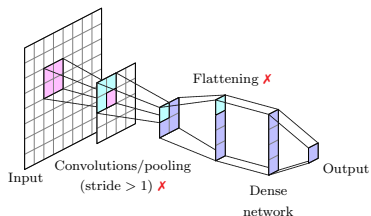
# Architecture types



Equivariant architecture (EQ)



Strided architecture (ST)



Flattening architecture (FL)



# Results

Training at  $N_{\text{worms}} = (0, 5)$  on  $8 \times 8$  lattices; testing at  $N_{\text{worms}} \in \{0, \dots, 10\}$  on 4 lattice sizes

