An ML approach to the classification of phase transitions in many flavor QCD

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Pisarski and Wilczek

Remarks on the chiral phase transition in chromodynamics

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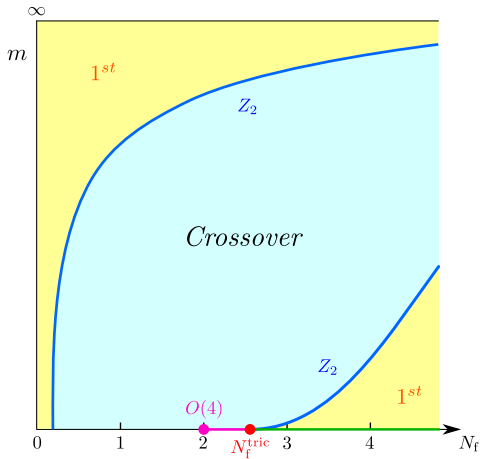
(Received 27 October 1983)

The phase transition restoring chiral symmetry at finite temperatures is considered in a linear σ model. For three or more massless flavors, the perturbative ϵ expansion predicts the phase transition is of first order. At high temperatures, the $U_A(1)$ symmetry will also be effectively restored.

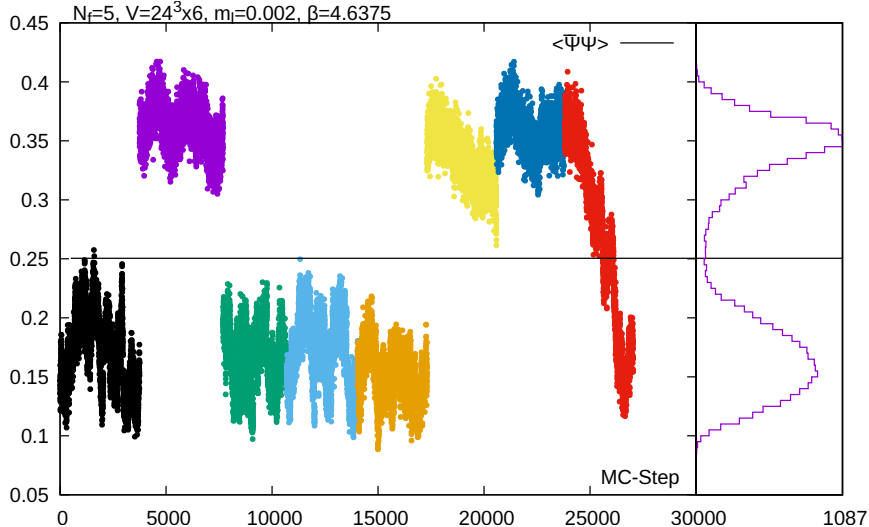
The setup



Cuteri et al.

- HISQ fermions
- plan: look at regions, where a 1st order signal is expected
  - small masses
  - large N_f
- $N_f = 5$
- $m_l = 0.001 - 0.016$
- $V = 16^3 - 24^3 \times 6$
- $\beta = 4.50 - 5.35$

Time histories



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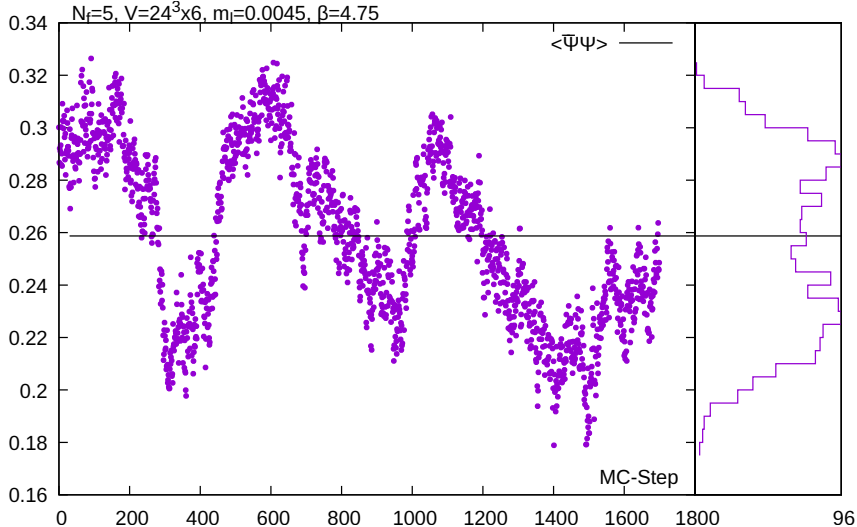

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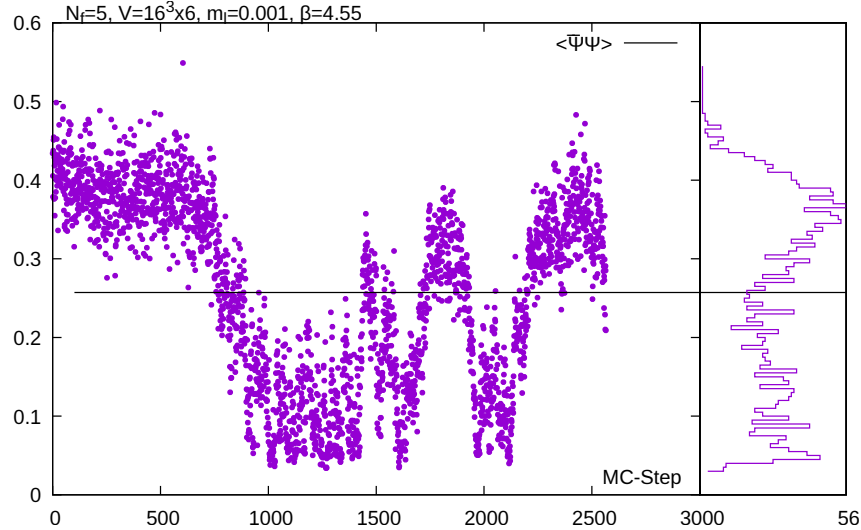
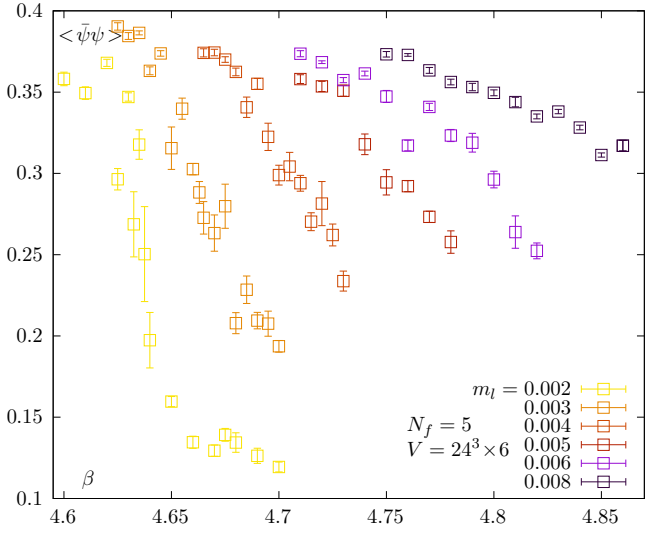


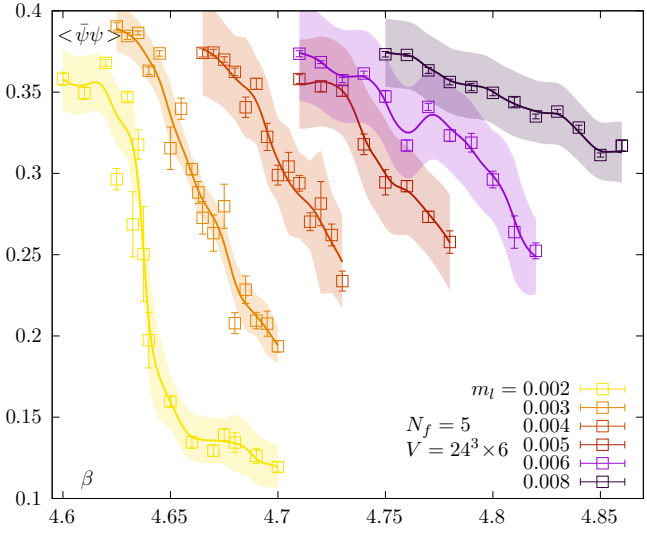
β-reweighting

- way to interpolate any observable between βs
  - this includes histogram bins
- reweighting in volume or mass not possible
- fine sampling in β required

β-reweighting



β-reweighting



Number of measurements per volume and mass

n_s	0.001	0.002	0.003	0.0035	0.004	0.0045	0.005
16	17601	19167	11526	0	18866	0	0
24	5294	87176	149135	24278	29821	14904	15212

n_s	0.006	0.008	0.010	0.012	0.014	0.016
16	59782	60420	61456	61456	61256	61256
24	24756	40237	23648	13380	25574	25499

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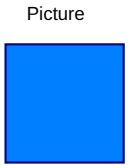
about 300.000 GPUh

Convolutional neural networks (CNNs)



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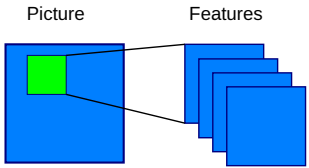

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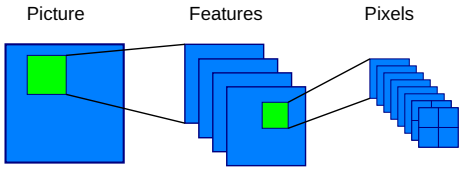

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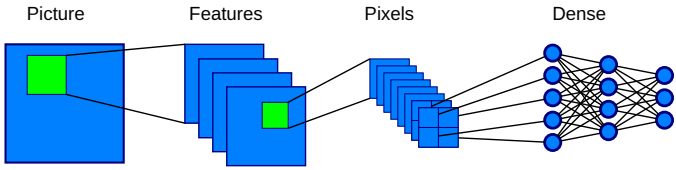

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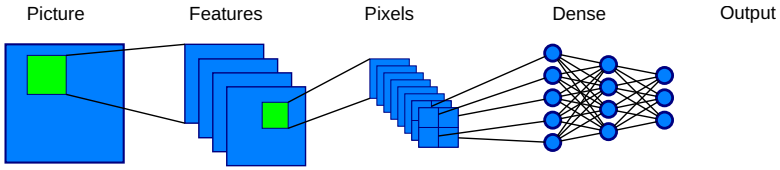

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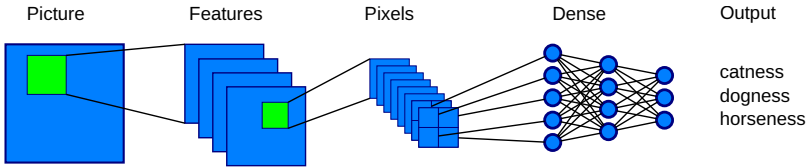

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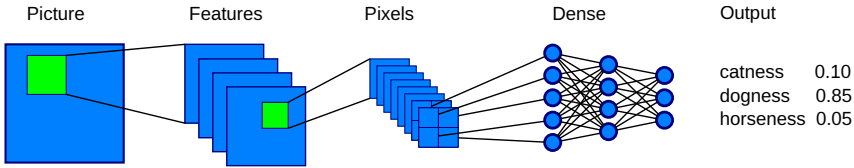

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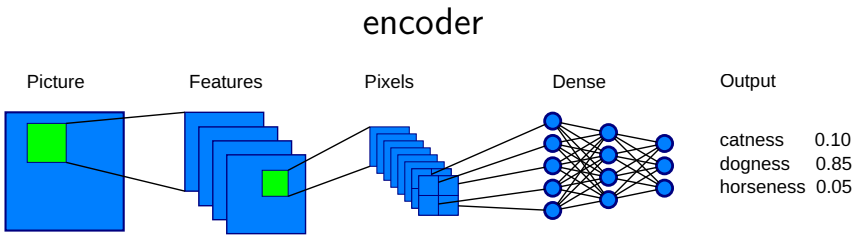
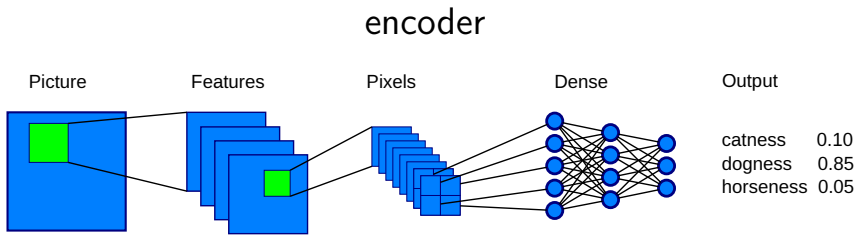


Transposed CNNs



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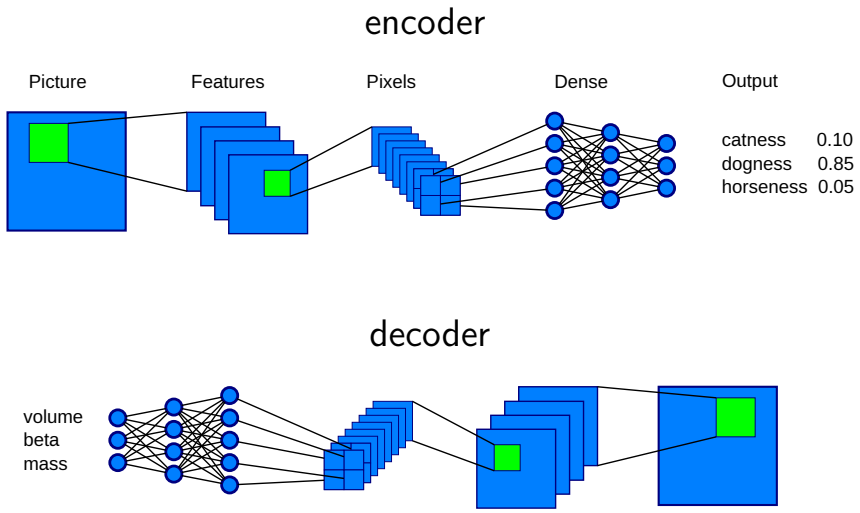
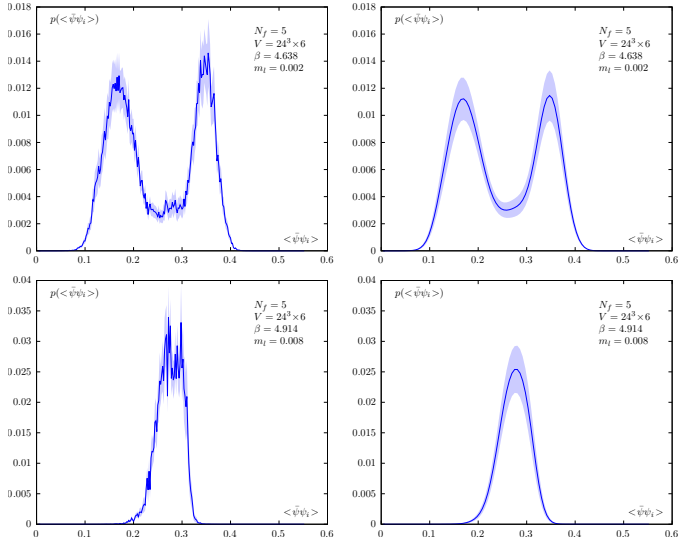


Model Output: $p\ (<\bar{\psi}\psi_i>)$

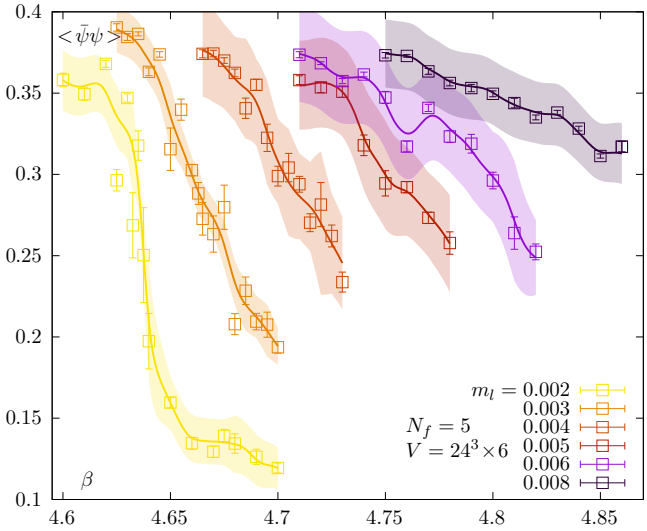


Decoder only Model Summary

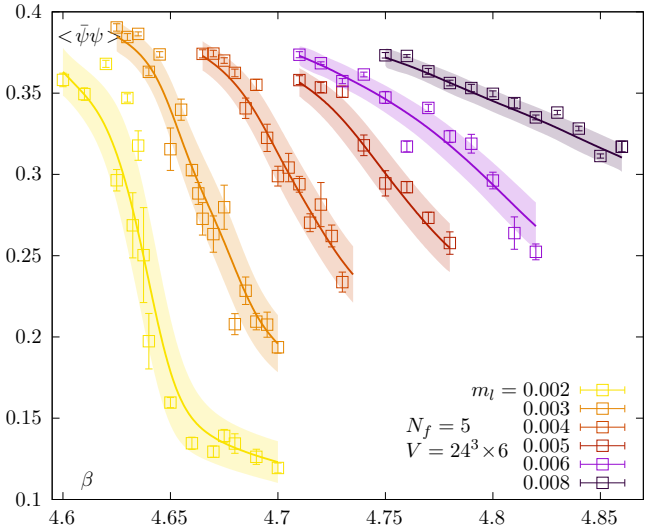
layer	shape
input	units $= 3$
Dense	units $= 64$
Dense	units $= 265$
Dense	units $= 1024$
Reshape	shape $= (32, 32)$
Conv1DTranspose	filters $= 64$, kernel size $= 2$
Conv1DTranspose	filters $= 128$, kernel size $= 5$
Conv1DTranspose	filters $= 275$, kernel size $= 10$, activation $=$ softmax
output	GlobalAveragePooling1D

- Dropout (rate $= 0.2$) between all layers
- loss: categorical crossentropy
- implemented in Tensorflow Keras
- model maps 3 parameters (N_σ, β, m_l) to 275 histogram bins

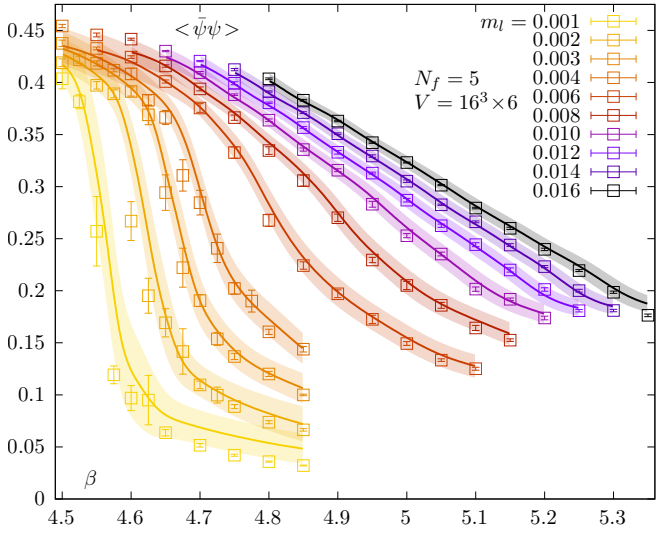
reweighted chiral condensate



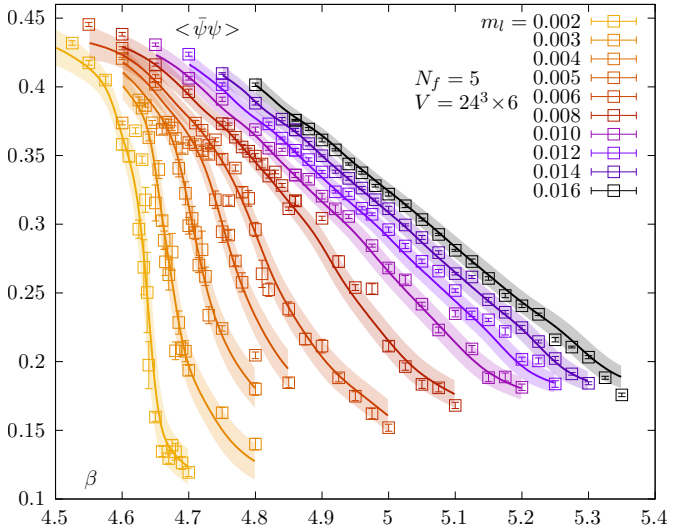
ML-reweighted chiral condensate



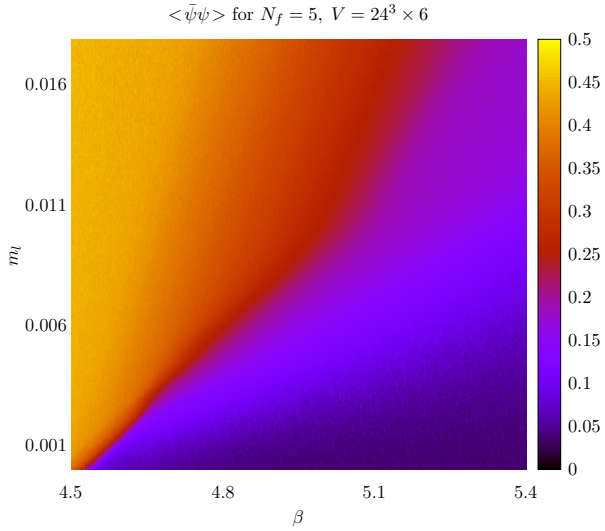
ML-reweighted chiral condensate



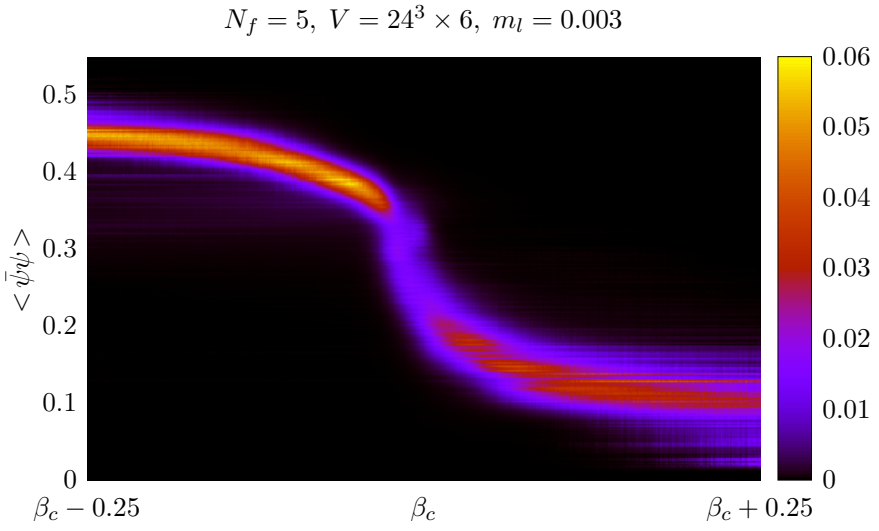
ML-reweighted chiral condensate



five flavor phase diagram



An equation-of-state-meter



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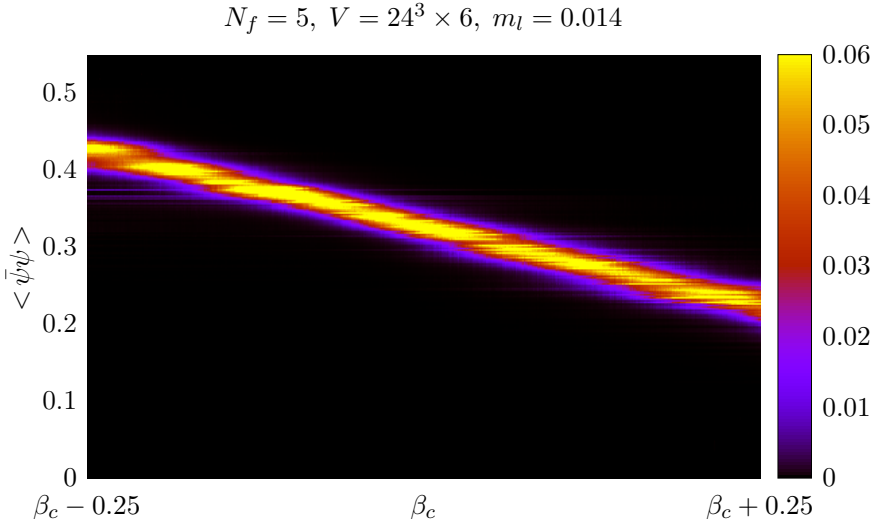

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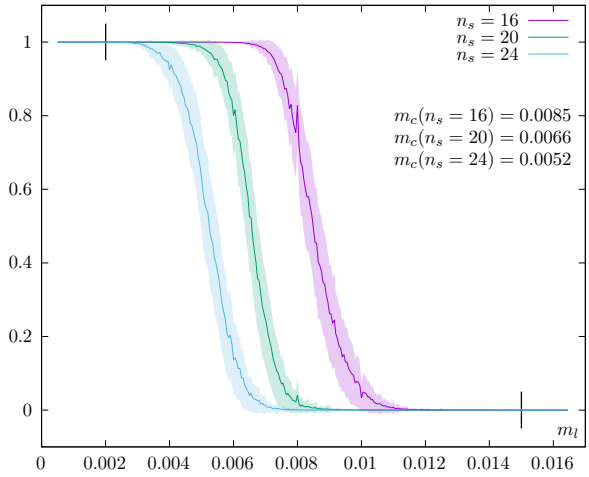
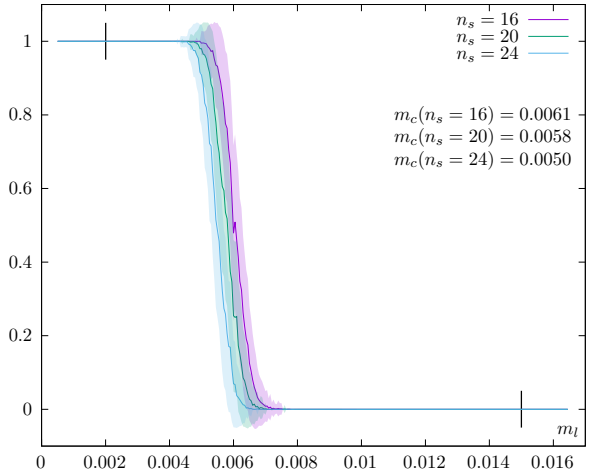


H. Petersen et al., 2016: An equation-of-state-meter of QCD transition from deep learning, arXiv:1612.04262

An equation-of-state-meter with Transformers



Encoder only Model Summary

layer	shape
input	units $= (500, 275)$
Conv2D	filters $= 50$, kernel size $= 10$, strides $= (5, 10)$
Conv2D	filters $= 10$, kernel size $= 3$, strides $= (2, 2)$
Pooling	GlobalAveragePooling2D
Dense	units $= 32$
Dense	units $= 16$
output	units $= 2$, activation $=$ sigmoid

- activation $=$ relu for all layers
- Dropout (rate $= 0.2$) between all layers
- loss: binary crossentropy
- implemented in Tensorflow Keras
- model maps (500×275) pixels to firstordernes / crossoverness

Conclusion

- 1^{st} order chiral phase transition observed for small m_l, $N_f = 5$, $N_\tau = 6$ in HISQ
- good interpolation of p ($<\bar{\psi}\psi_i>$) in N_σ, m_l and β
- "phase transition of the phase transition" described by decoder-only CNN ML model
- Work in progress: m_c extraction via "EOS-meter"
  - add N_σ dependence (done now)
- next: add N_f and N_τ dependence to ML model