Partial deconfinement in QCD at N=3 and N=∞

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Several papers with Gautam, Holden, Knaggs, Ishiki, Jevicki, Maltz, O'Bannon, Peng, Rinaldi, Robinson, Shimada, Watanabe, Wintergerst, ...

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Ongoing discussion with Ohata, Shimada, Watanabe

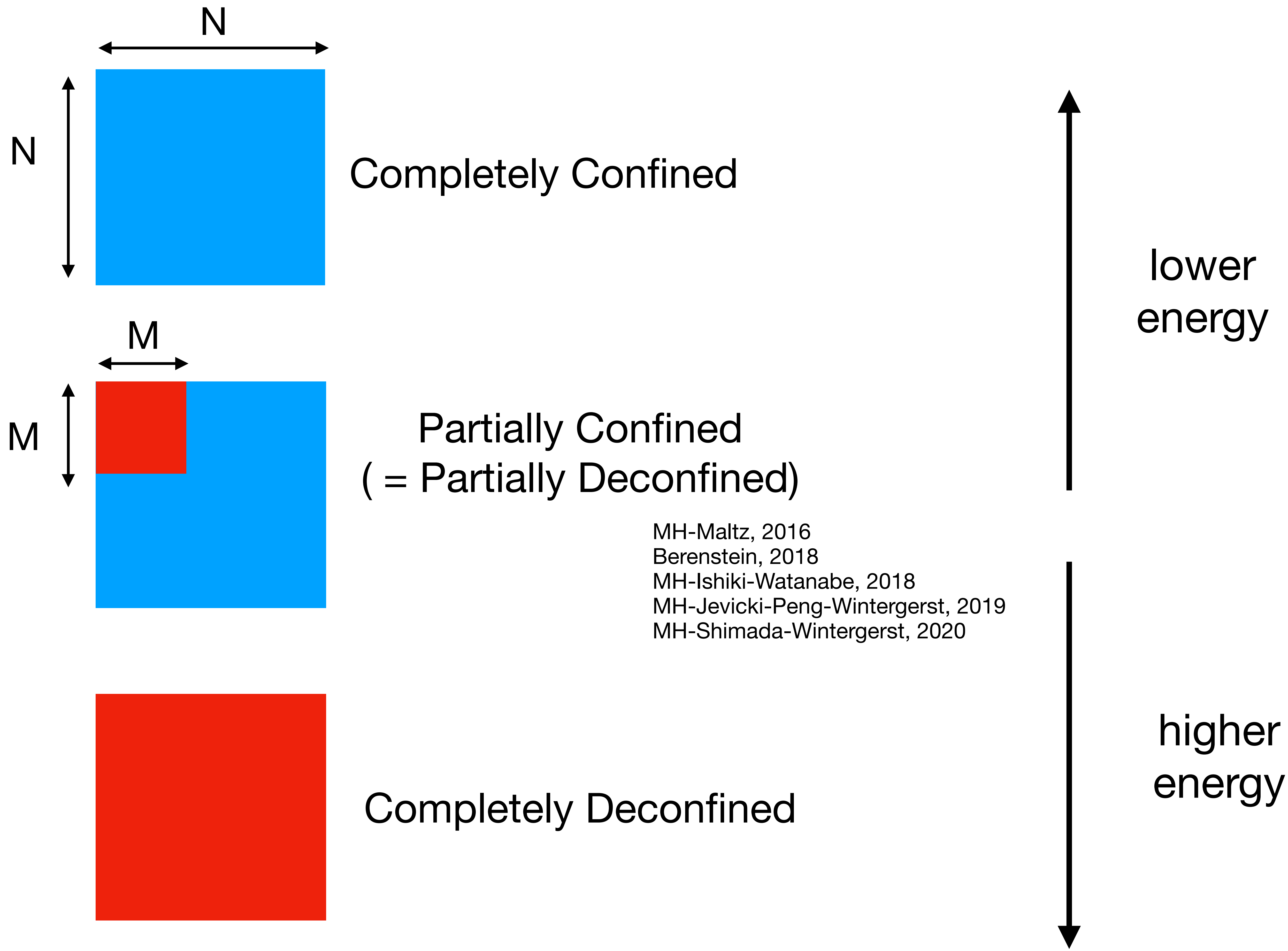
Common belief:

Real-world QCD does not have thermal "phase transition".

No center symmetry, no chiral symmetry

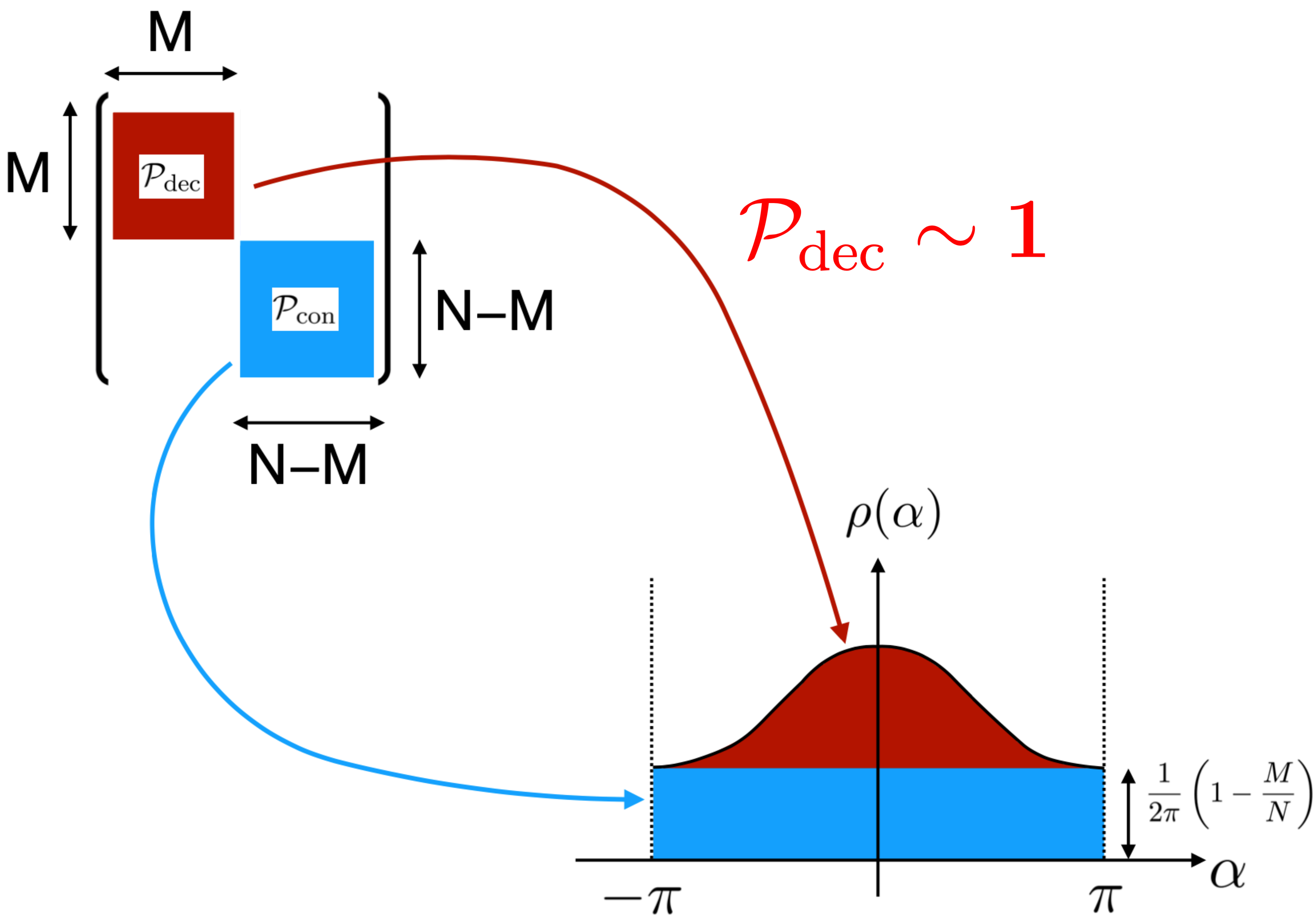
Not "transition", only crossover

At least at large N, such a belief is false.

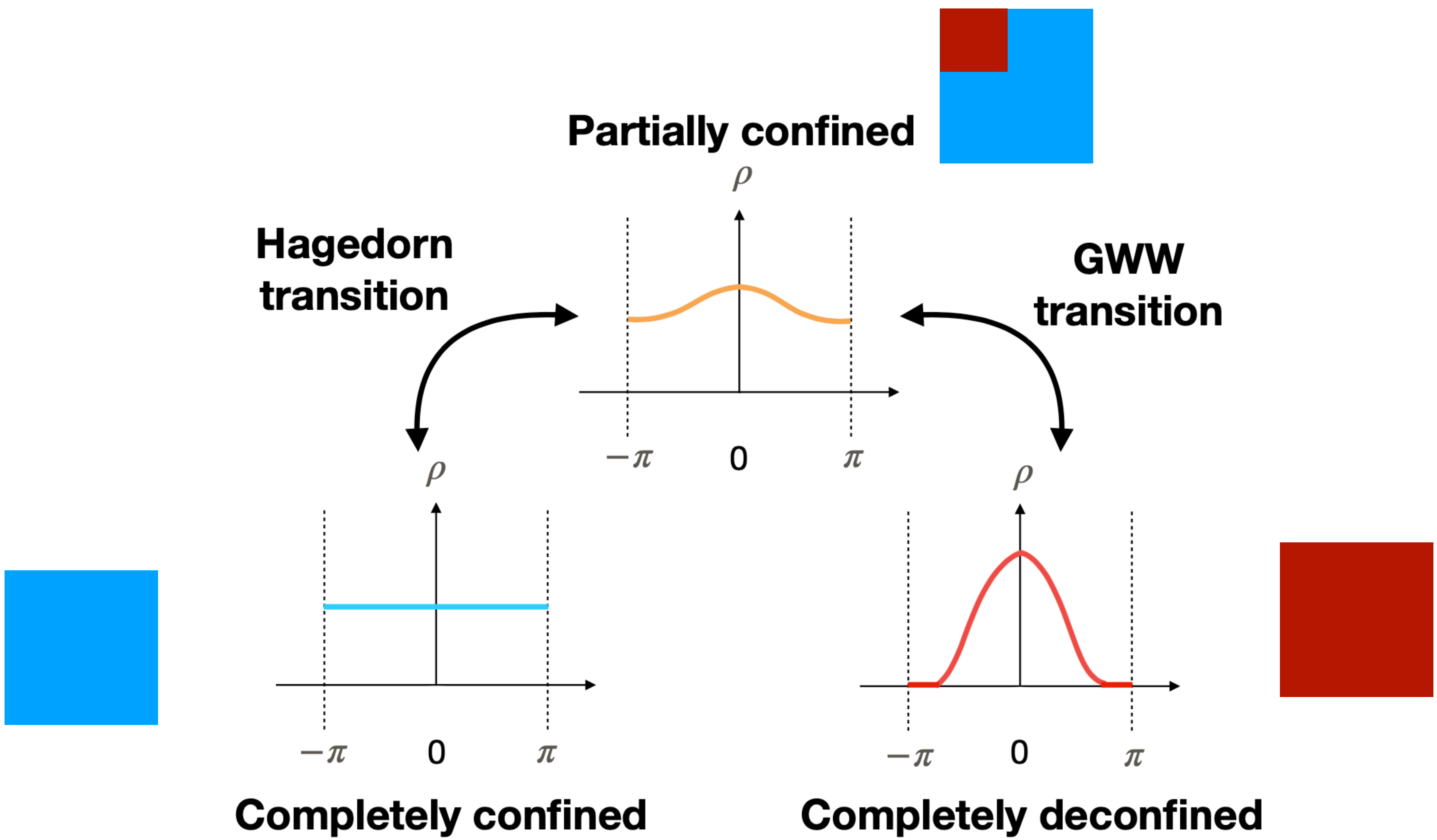


N
N
Completely Confined
lower energy
M
M
Partially Confined
(= Partially Deconfined)
MH-Maltz, 2016
Berenstein, 2018
MH-Ishiki-Watanabe, 2018
MH-Jevicki-Peng-Wintergerst, 2019
MH-Shimada-Wintergerst, 2020
Completely Deconfined
higher energy

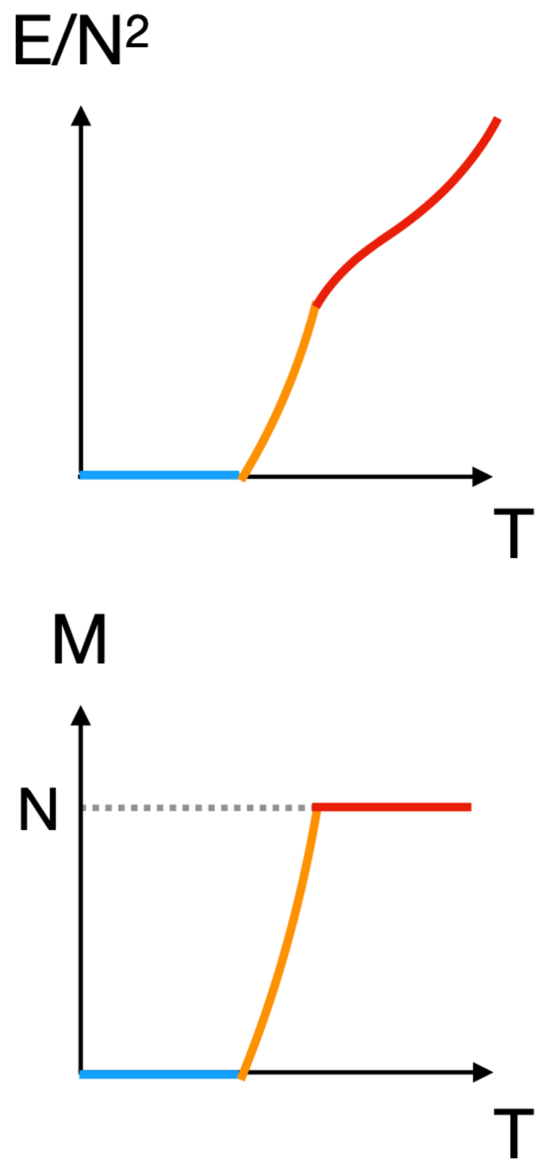
In terms of Polyakov loop:



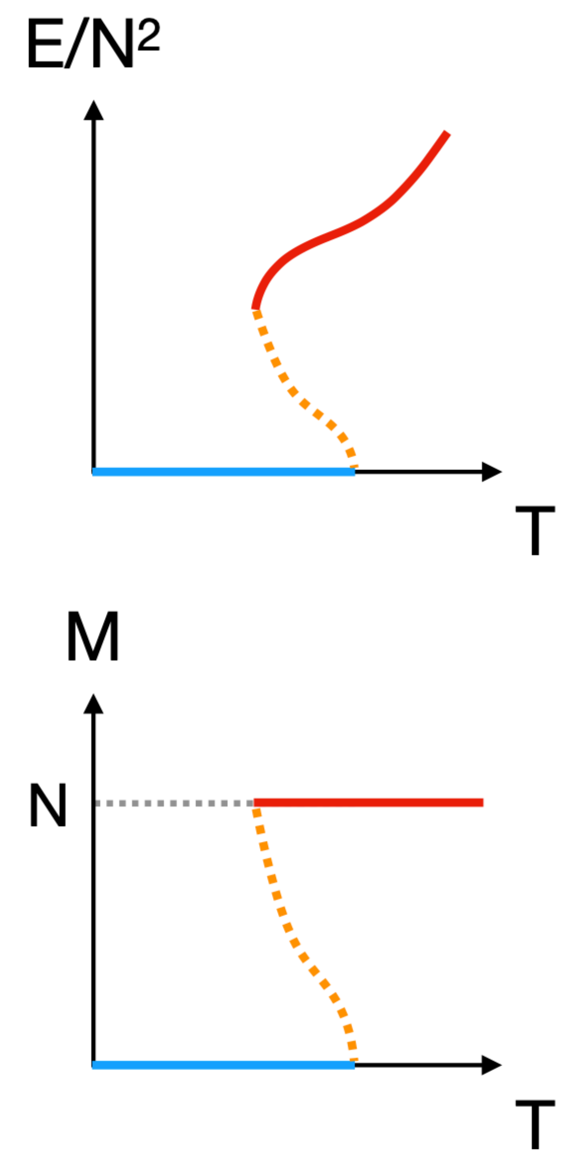
Polyakov Loop $P = \frac{1}{N}\sum_{j=1}^{N} e^{i\theta_j}$



QCD phase transition

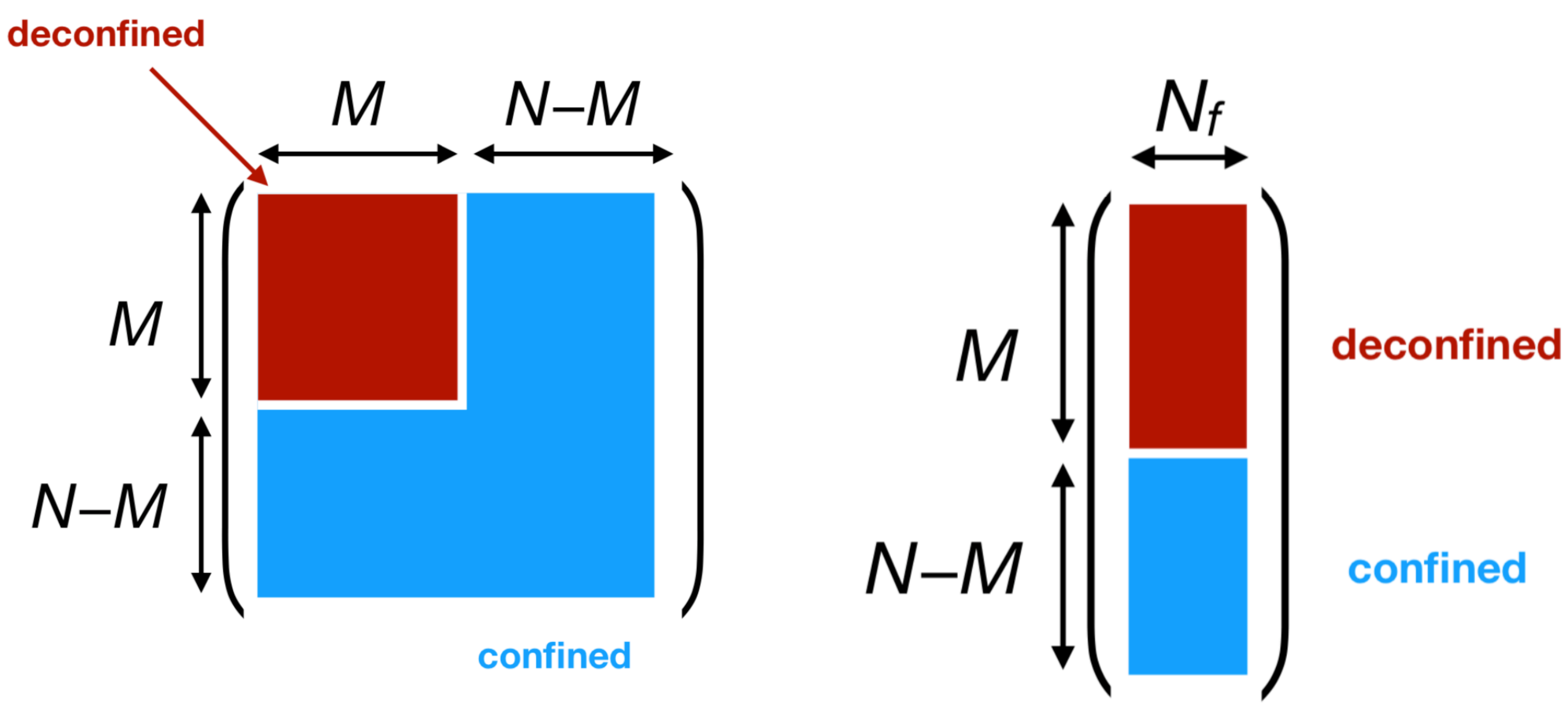


Light quark mass



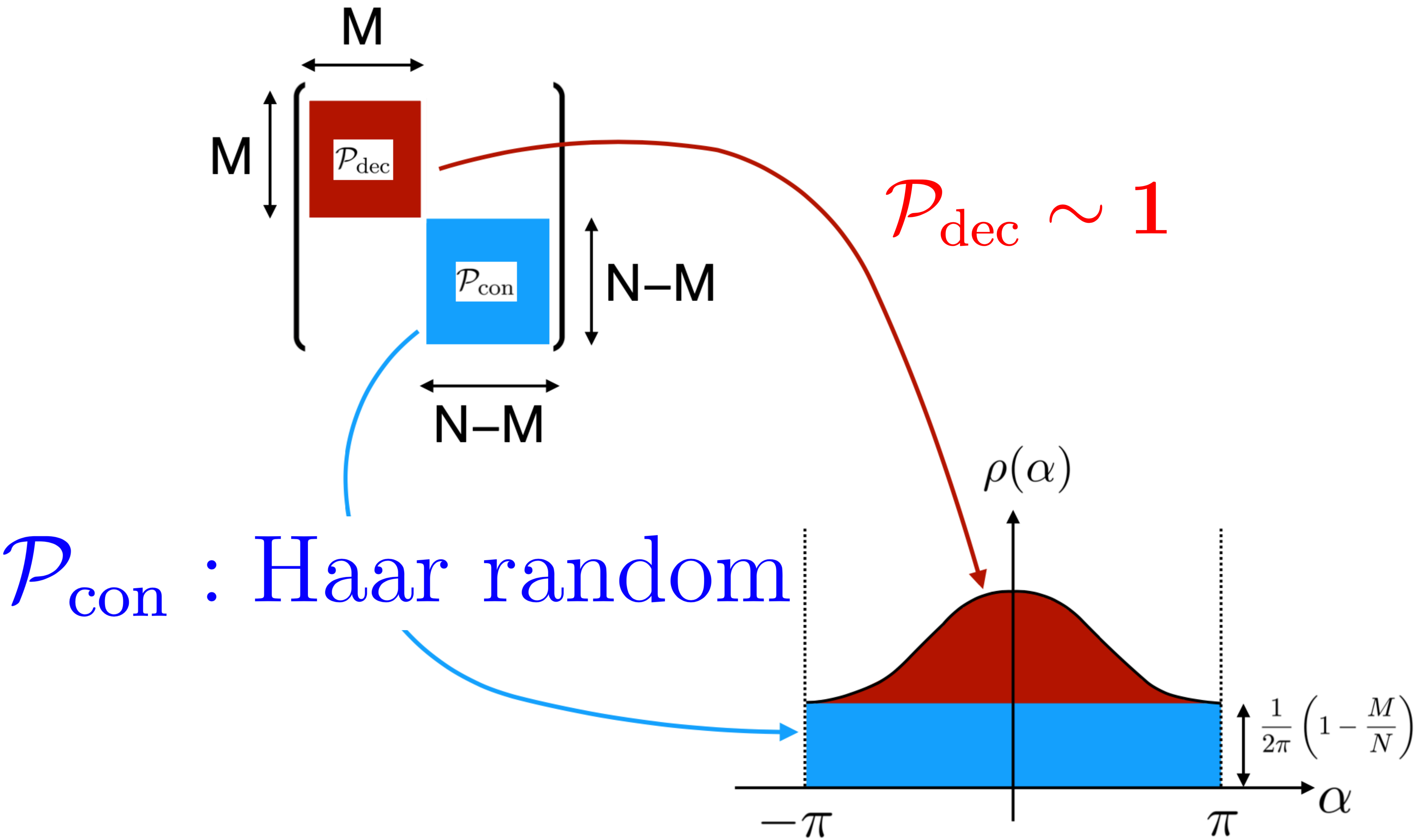
Heavy quark mass

QCD phase transition



Weak-coupling analysis: MH-Robinson 2019

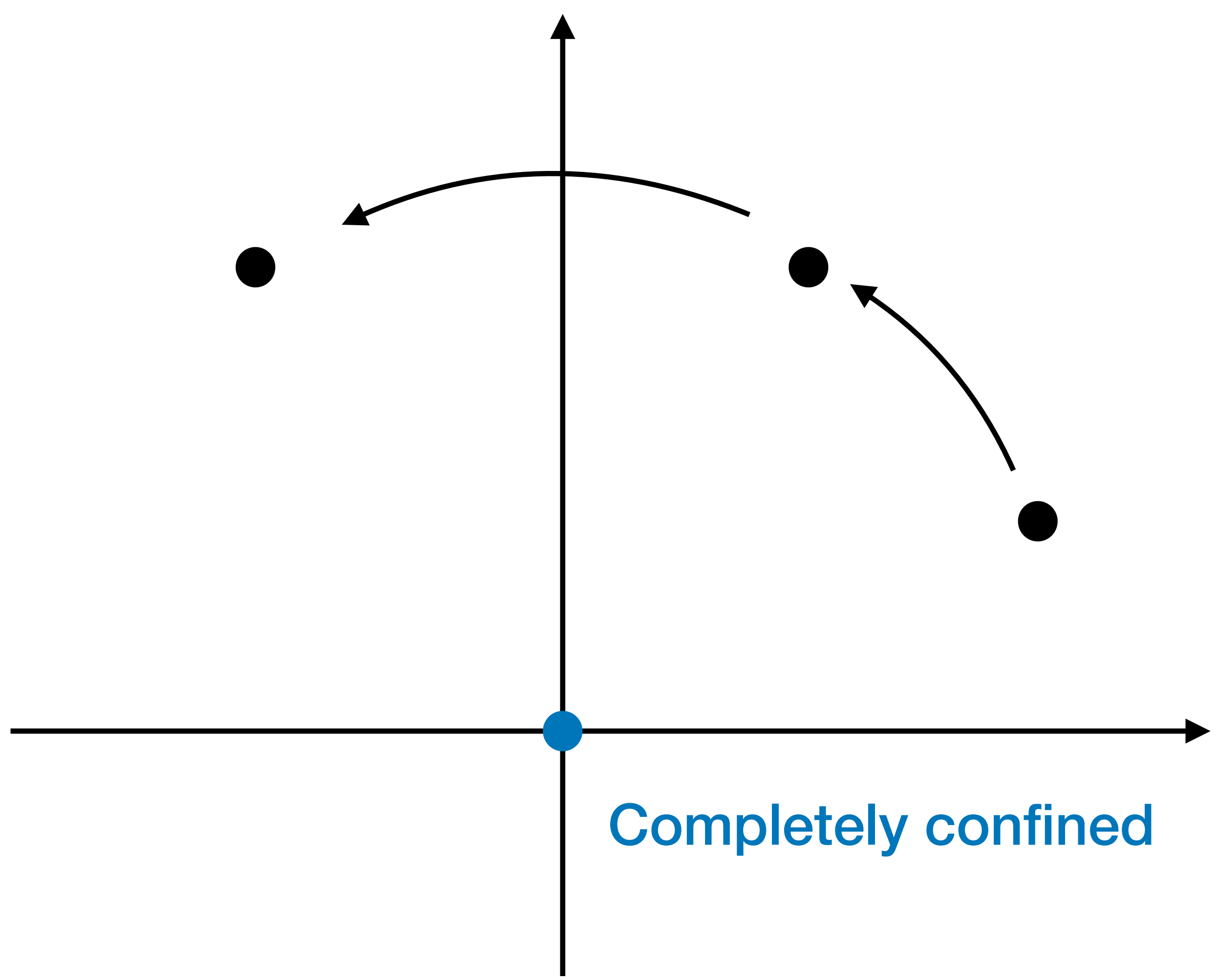
Toward finite-N QCD



M
M
$\mathcal{P}_{\rm dec}$
$\mathcal{P}_{\rm con}$
N−M
N−M
$\mathcal{P}_{\rm dec} \sim 1$
$\mathcal{P}_{\rm con}$: Haar random
$\rho(\alpha)$
$\frac{1}{2\pi}\left(1-\frac{M}{N}\right)$
$-\pi$
π
α

(slightly simplified) picture

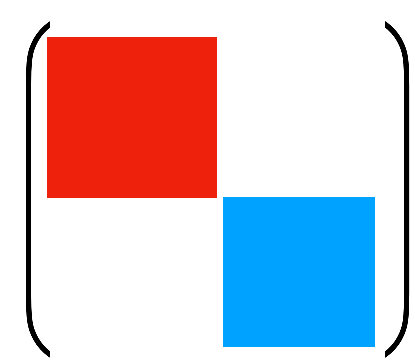
- Extended Hilbert space ⊃ Singlet Hilbert space
- Gauge orbit ⟷ singlet



Orbit = SU(N) / stabilizer

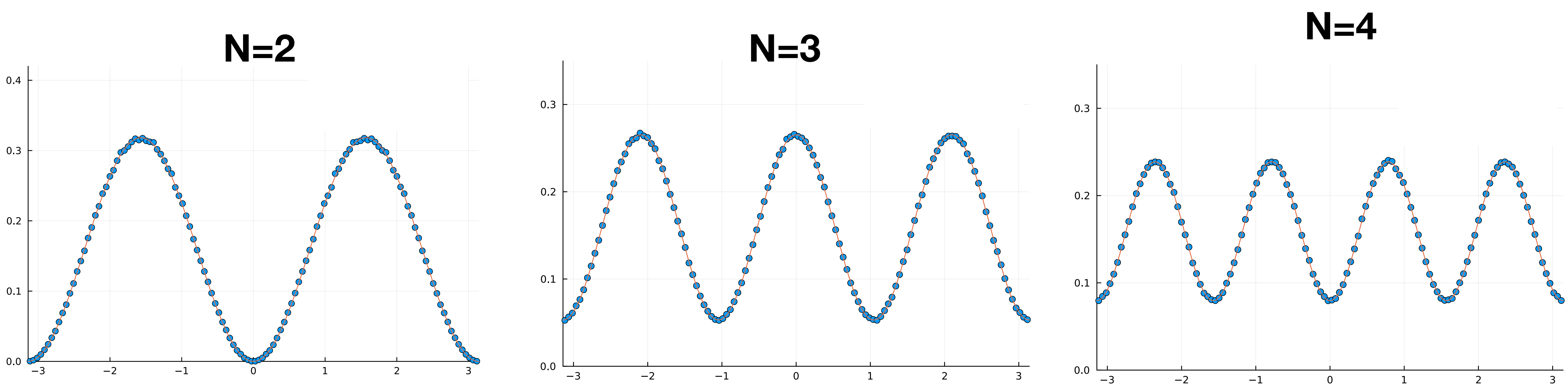
Polyakov loop ~ stabilizer

Stabilizer = SU(N-M)
for partially-deconfined states



Completely-confined → SU(N) Haar random

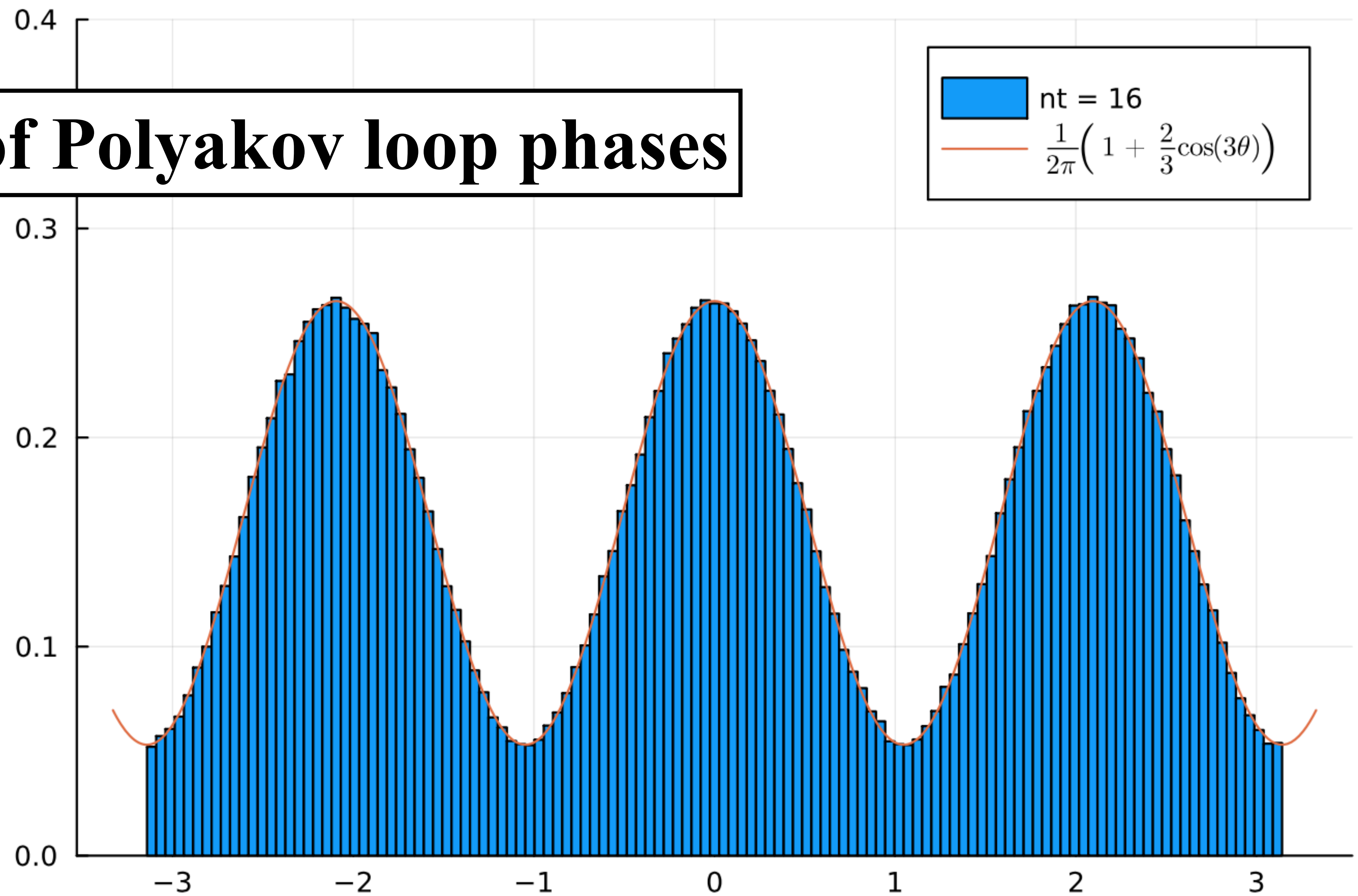
(At sufficiently strong coupling)



$$\rho_{\text{Haar}}(\theta) = \frac{1}{2\pi}\left(1 - (-1)^N \cdot \frac{2}{N}\cos(N\theta)\right)$$

Haar-random distributions
vs
Lattice QCD simulation

Density of Polyakov loop phases



WHOT-QCD configuration, 32^3*16 lattice (174MeV) $m_\pi/m_\rho \simeq 0.63$

$$
\begin{aligned}
\rho_{\mathrm{Polyakov}}(\theta) &= \frac{1}{2\pi} + \frac{1}{2\pi} \sum_{n>0} \left(\tilde{\rho}_n e^{-in\theta} + \tilde{\rho}_{-n} e^{in\theta} \right) \\
&= \frac{1}{2\pi} + \frac{1}{2\pi} \sum_{n>0} 2\tilde{\rho}_n \cos(n\theta) \, .
\end{aligned}
$$

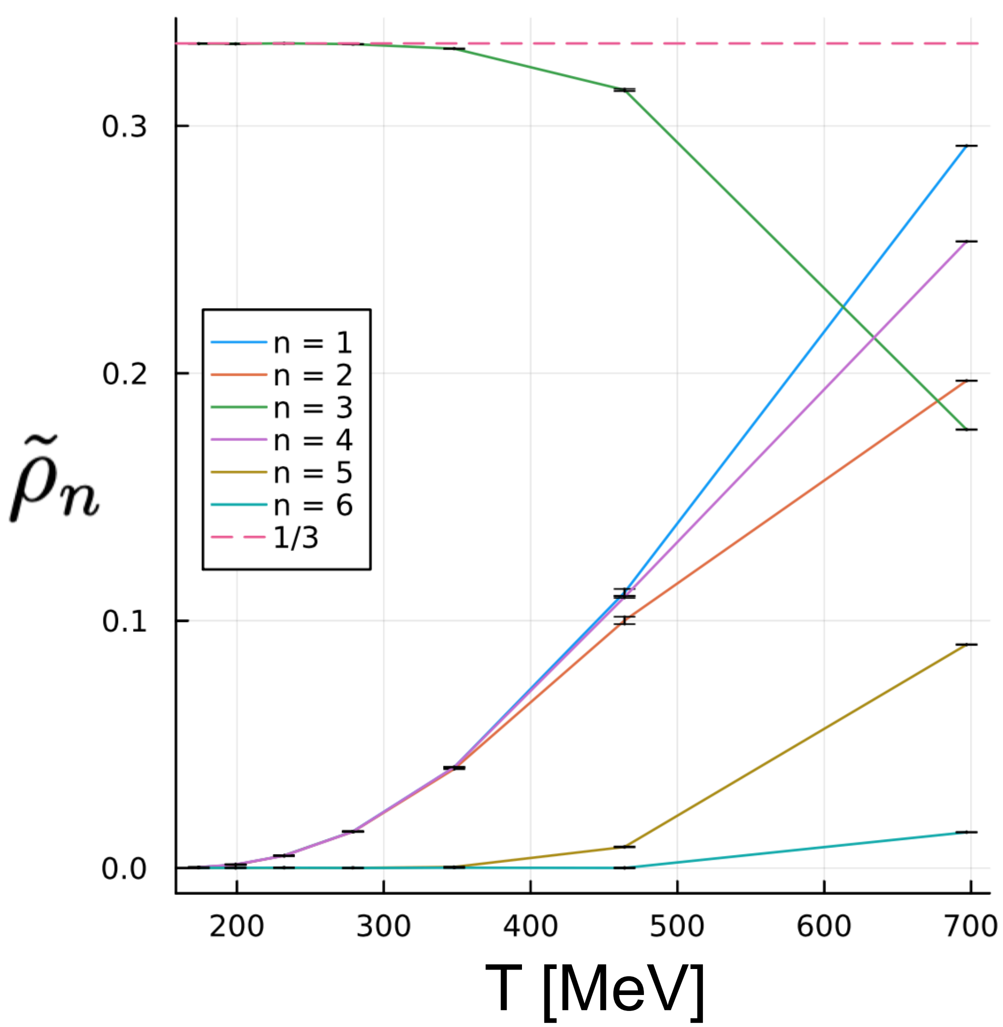
$$
\tilde{\rho}_n = \begin{cases} \frac{(-1)^N}{N} & (n = \pm N) \\ 0 & (n \neq \pm N) \end{cases}
$$

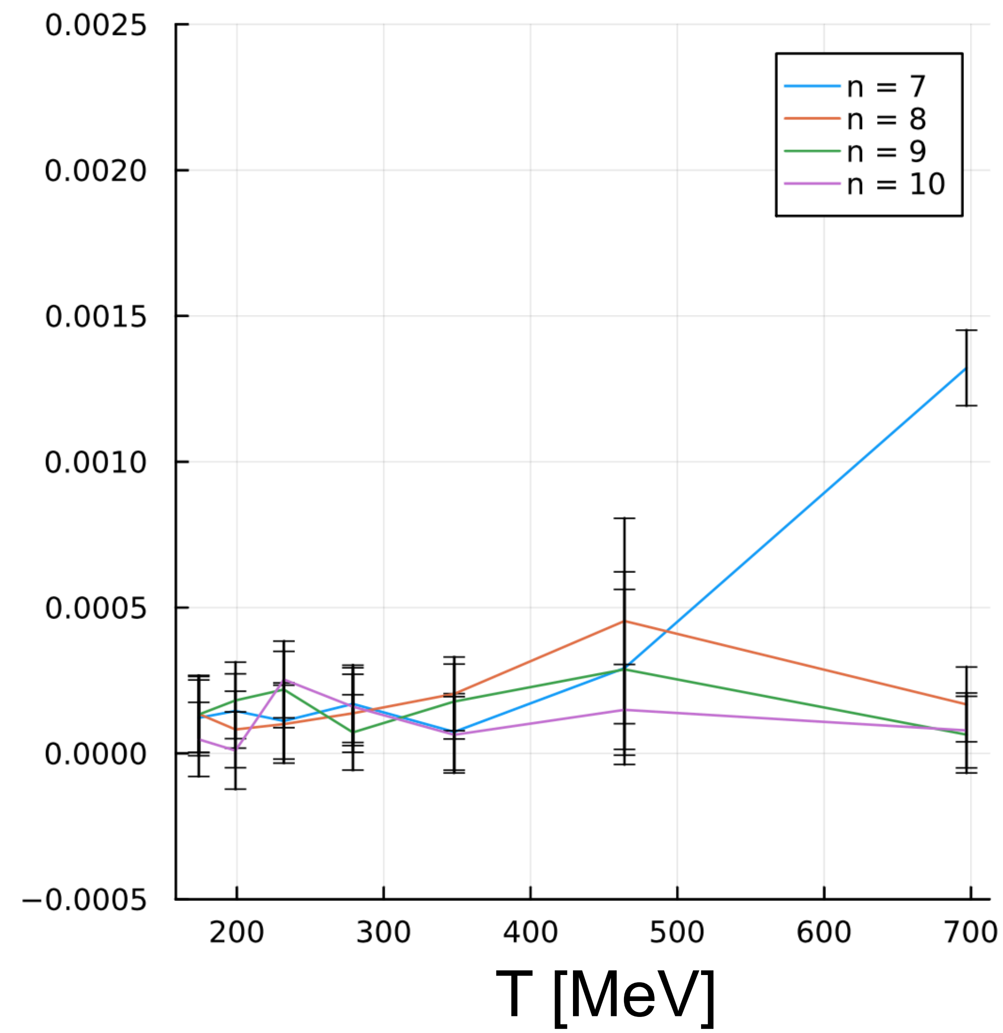
$$
\tilde{\rho}_n = \frac{1}{N} \left\langle \mathrm{Tr}(\mathcal{P}^n) \right\rangle
$$

must be related to baryon

Finite-N counterpart of GWW?

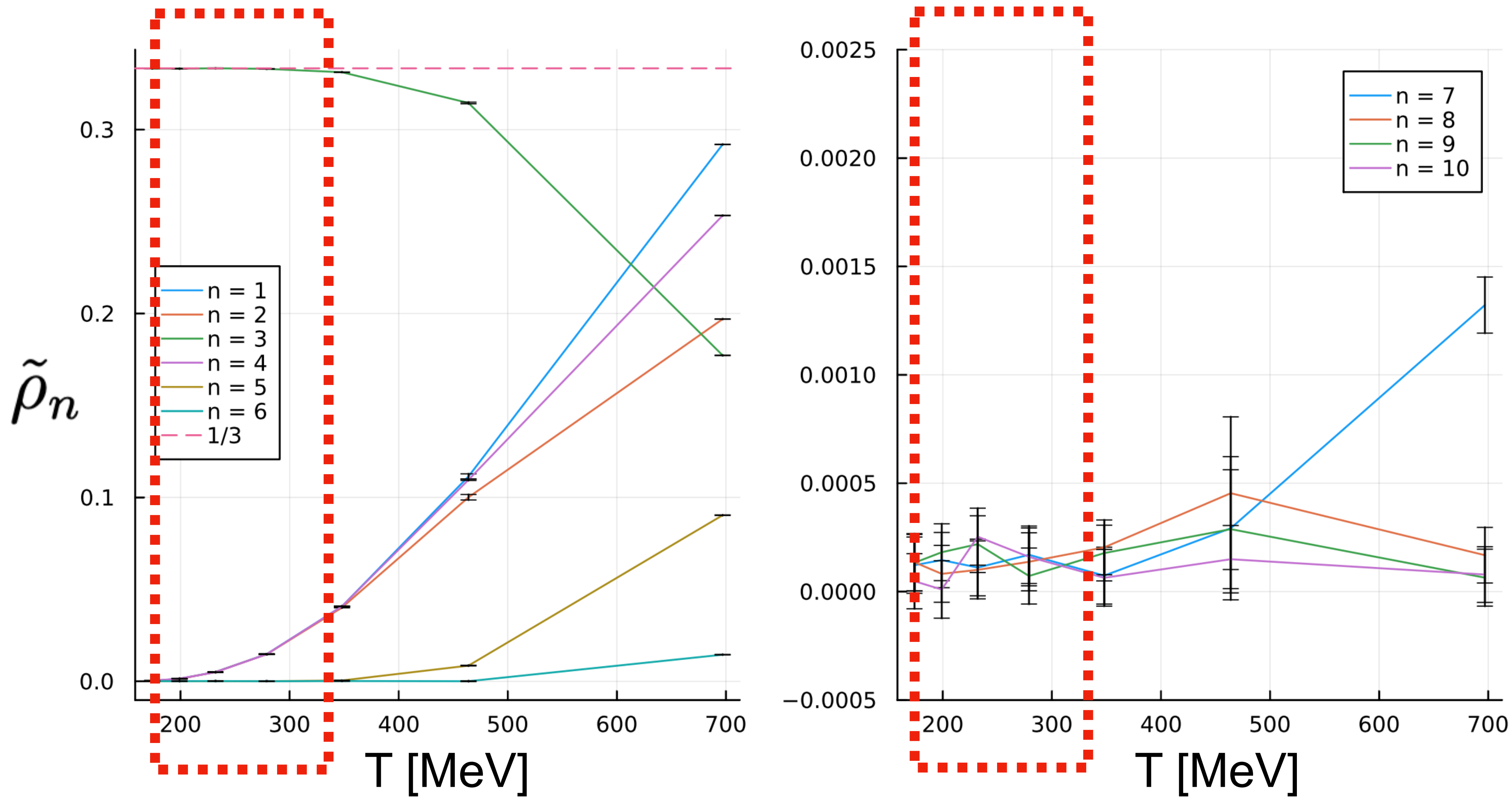
Formation of gap → condensation of higher-order coefficients





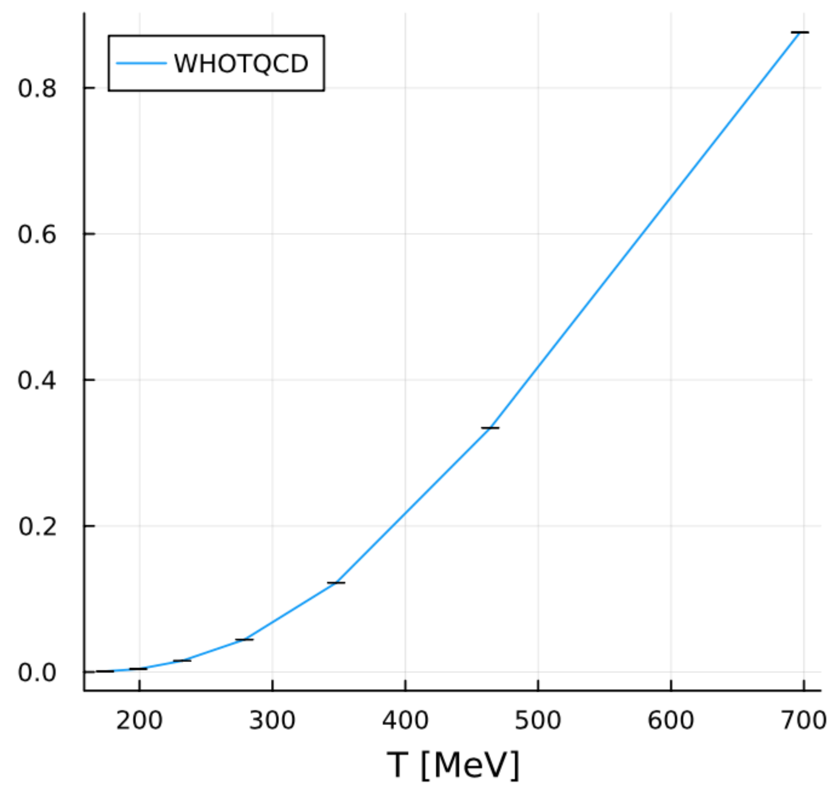
Finite-N counterpart of GWW?

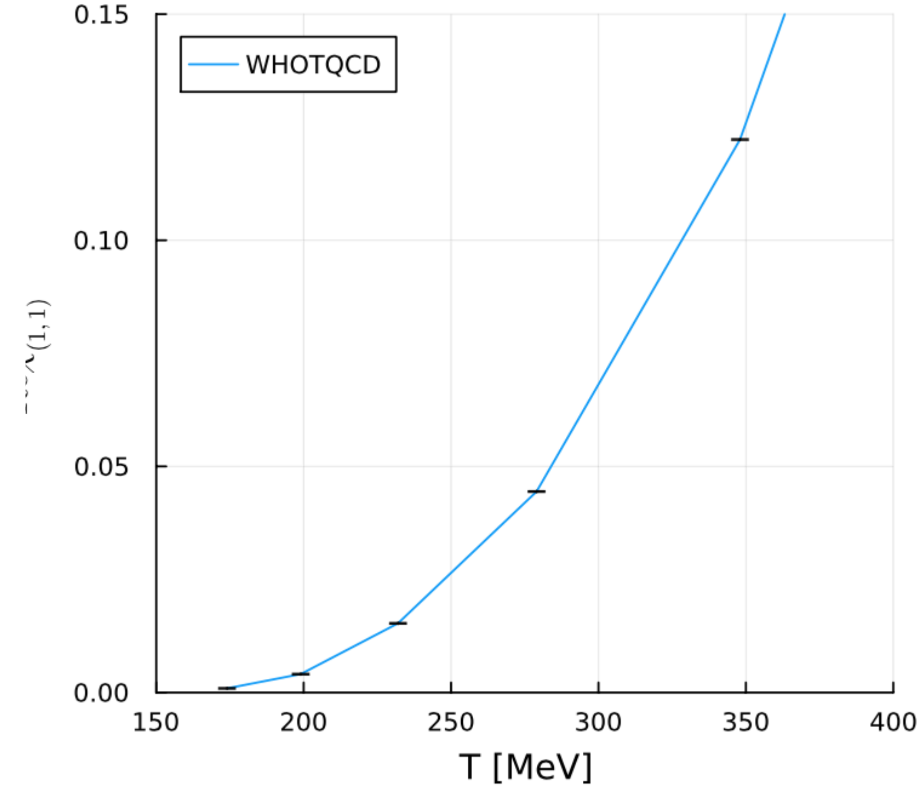
Formation of gap → condensation of higher-order coefficients

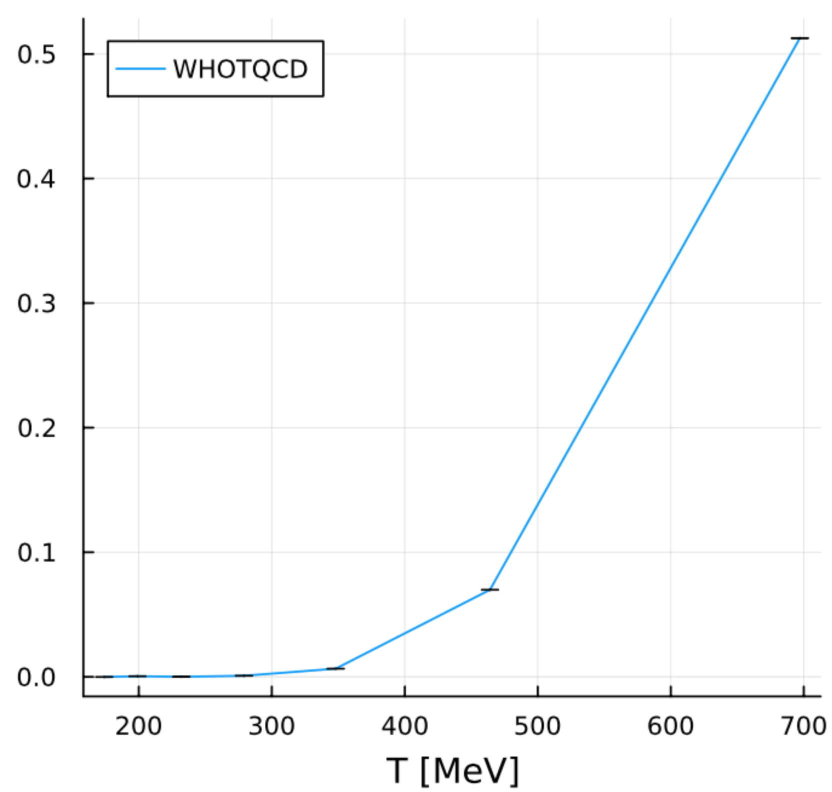


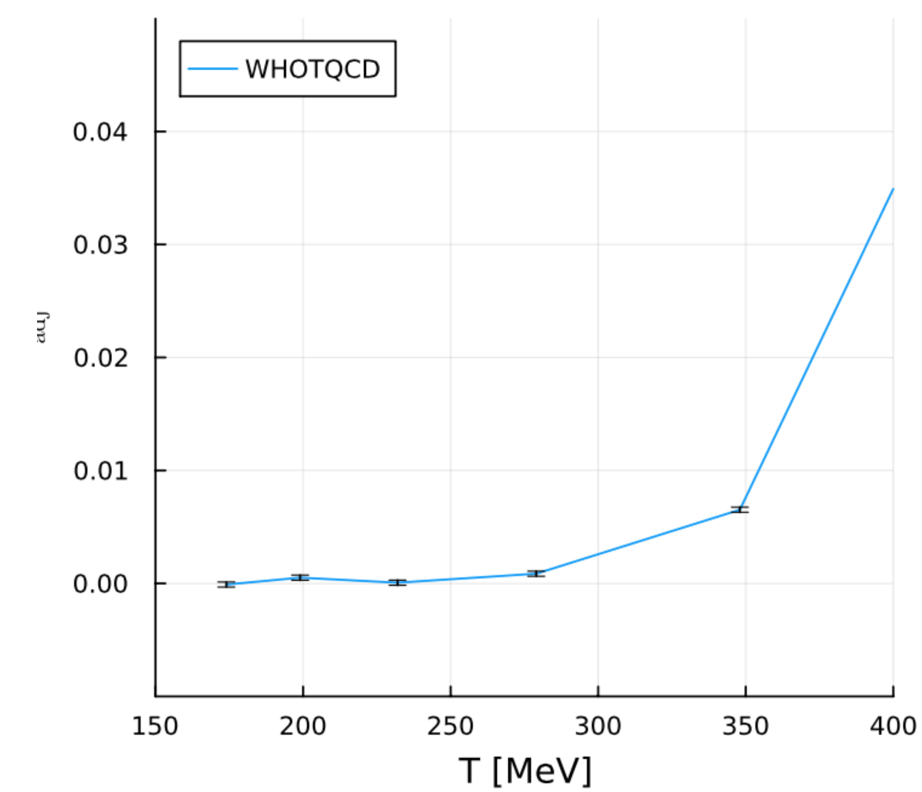
Partially deconfined?

Fundamental representation



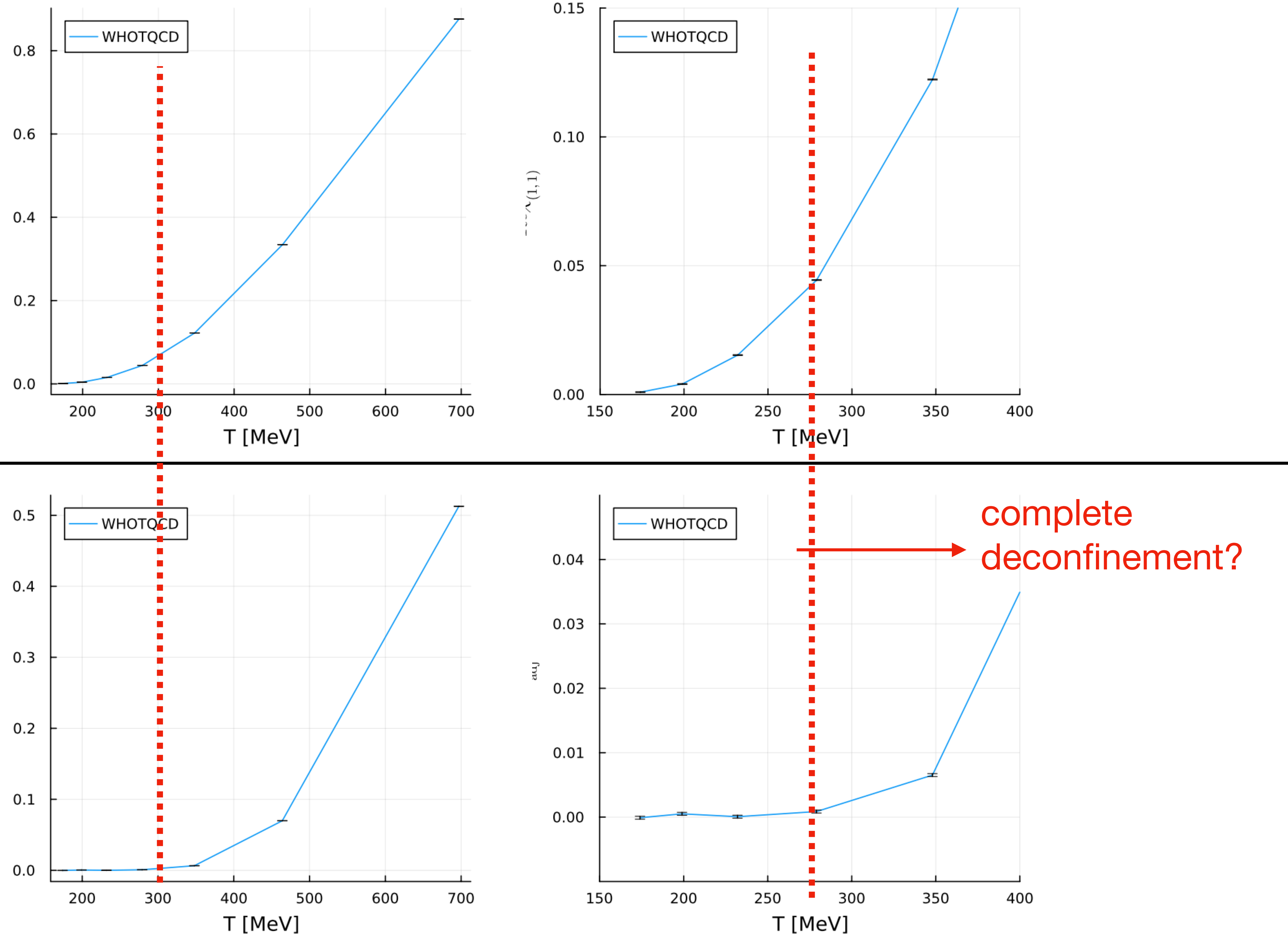






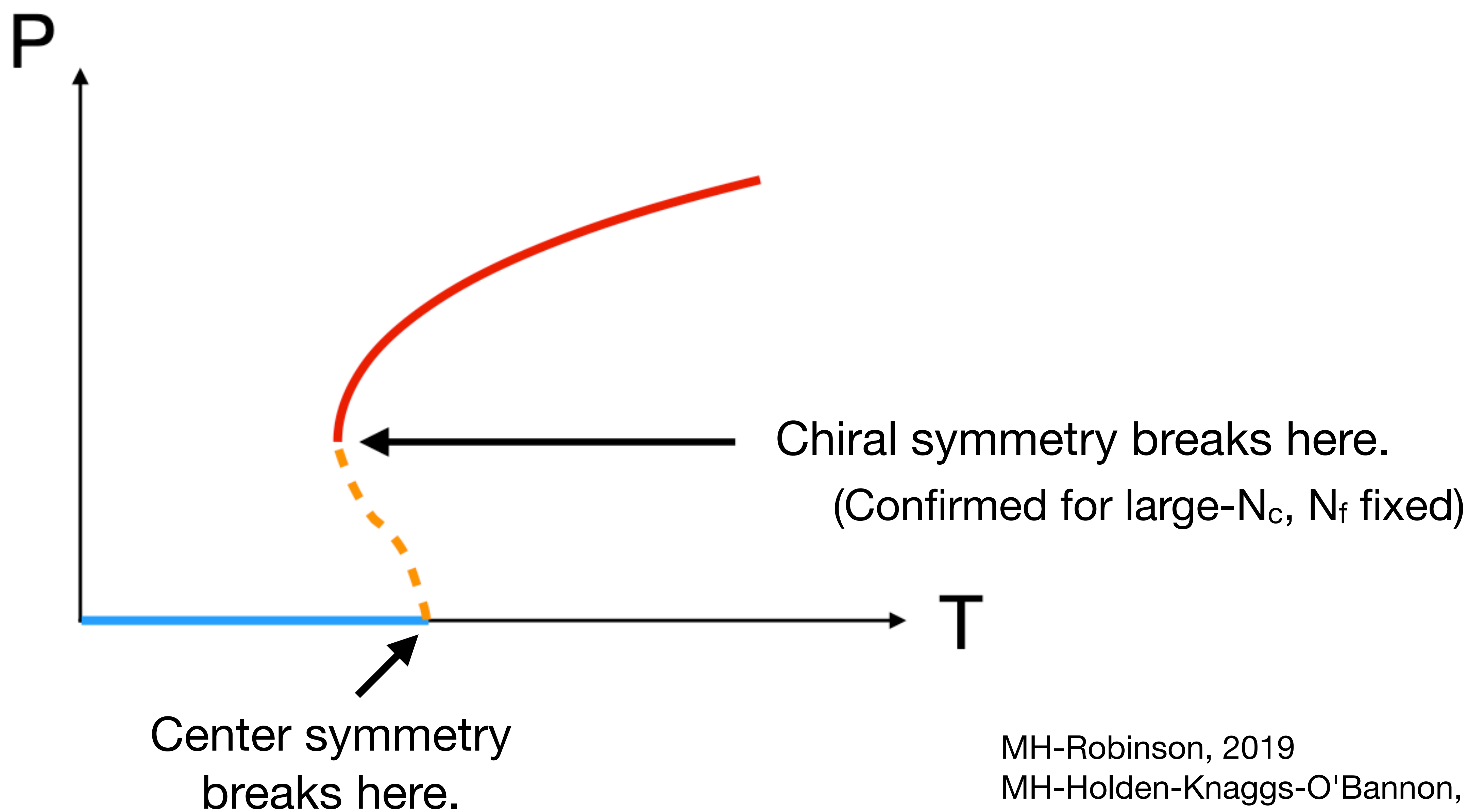
Adjoint representation

Fundamental representation



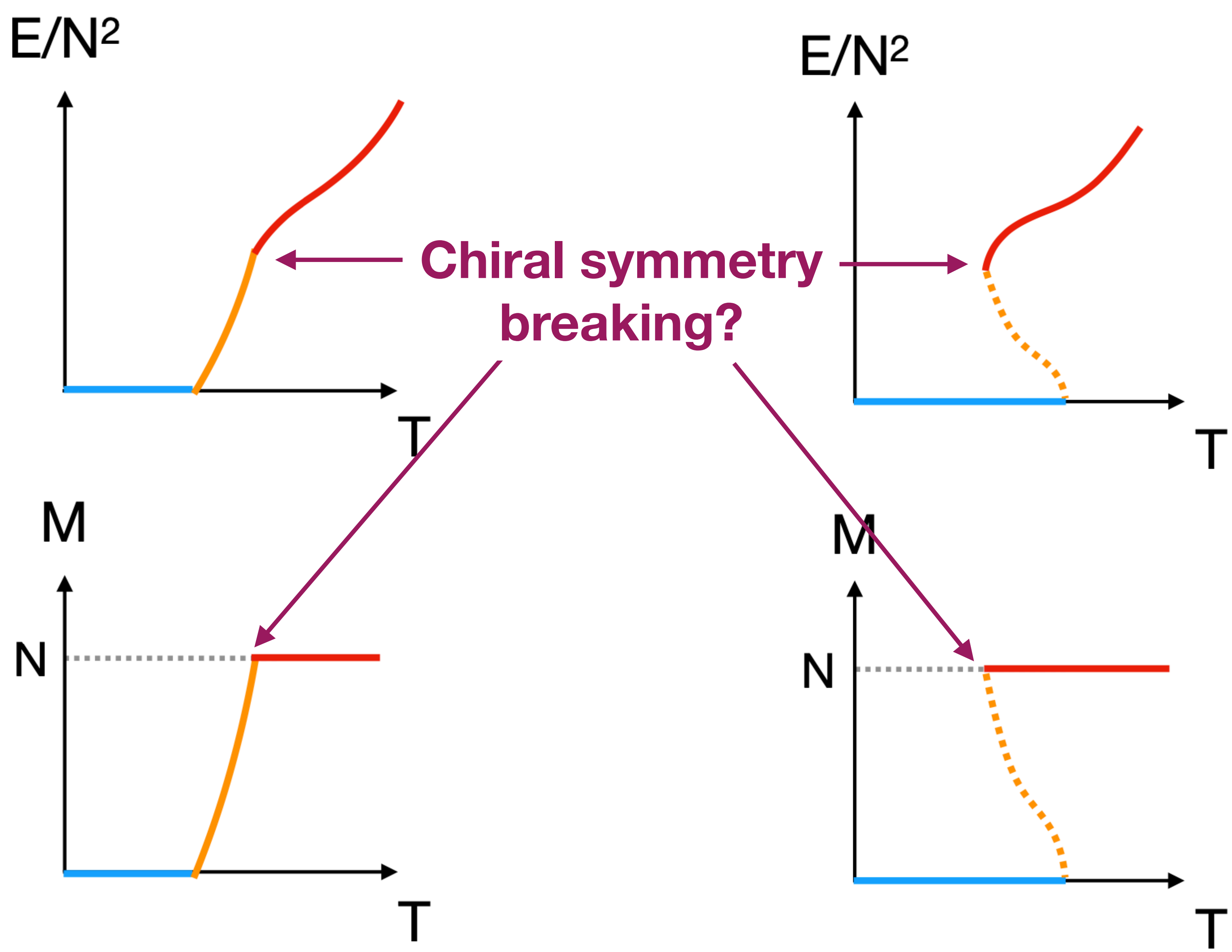
Adjoint representation

Chiral condensate
(in progress)



MH-Robinson, 2019
MH-Holden-Knaggs-O'Bannon, 2021

Chiral symmetry breaking with massless probe quark would corresponds to the GWW point.



Light quark mass

Heavy quark mass

Finite-N study is in progress.

Conclusion

- A new phase in QCD: Partially-deconfined phase.
- Good understanding at large N.
- Crossover region of real-world QCD should be partially deconfined.
- Collider signals....?