Recent progress in understanding gauge topology, confinement and chiral symmetry breaking

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Overview

- Instanton-dyons in SU(2)
- Setup and parameters
- Ensemble of dyons without fermions
- Ensemble of dyons with fermions

Instanton-Dyons

- **Calorons** with non-trivial Polyakov loop found by Kran, van Baal and Lee, Lu
- Seen to be composed of N_c **monopoles** or **dyons**
- Work with dyons as the fundamental degrees of freedom in $SU(2)$
- Amount of M and L dyons not the same
- Dyons have non-zero expectation value of $< A_4^3 >= 2\pi T\nu$, holonomy ν

$$P = \frac{1}{2}\mathrm{Re}\left[< Tr(L) >\right] = \cos(\pi\nu) \tag{1}$$

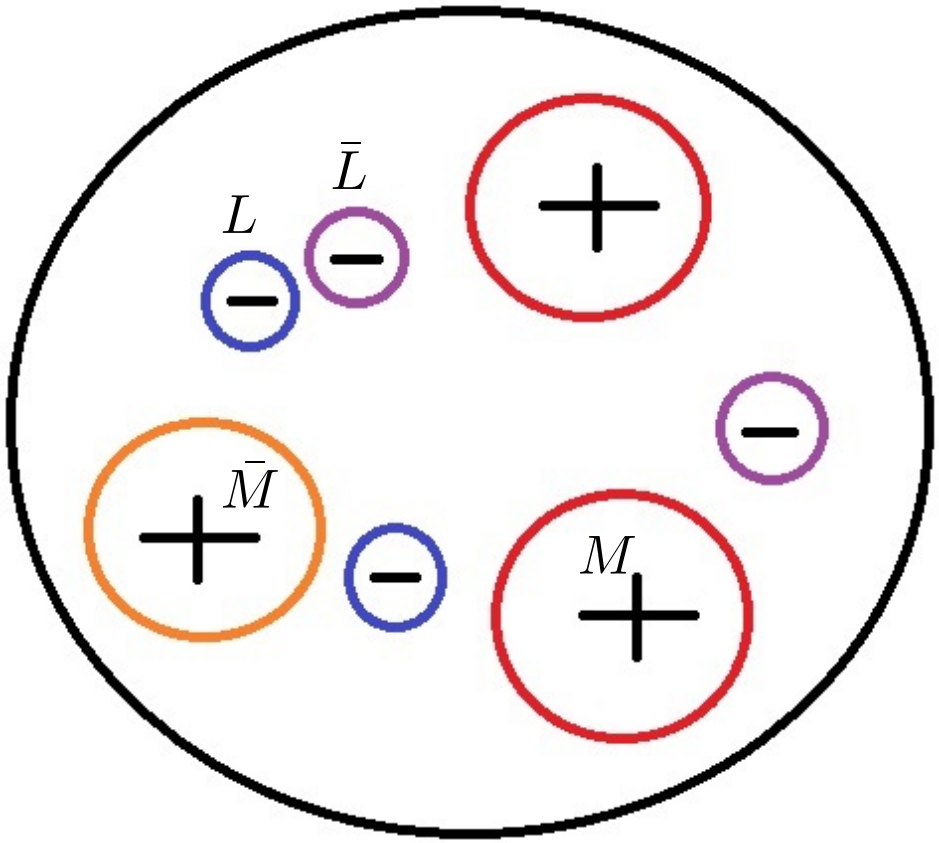
- Confined phase is $P = 0$ and $\nu = 0.5$
- Deconfined phase is $P = 1$ and $\nu = 0$

Ensemble

- Metropolis algorithm used to simulate ensemble, and find free energy density f
- Classical interaction used. Can be found in arXiv:1504.03341 [hep-ph]

- Size of M dyons scales as $\frac{1}{\nu}$
- Size of L dyons scales as $\frac{1}{1-\nu}$
- Action of M dyons are $\nu 8\pi^2/g^2$
- Action of L dyons are $(1-\nu)8\pi^2/g^2$

	M	$\bar{M}$	L	$\bar{L}$
e	1	1	-1	-1
m	1	-1	-1	1

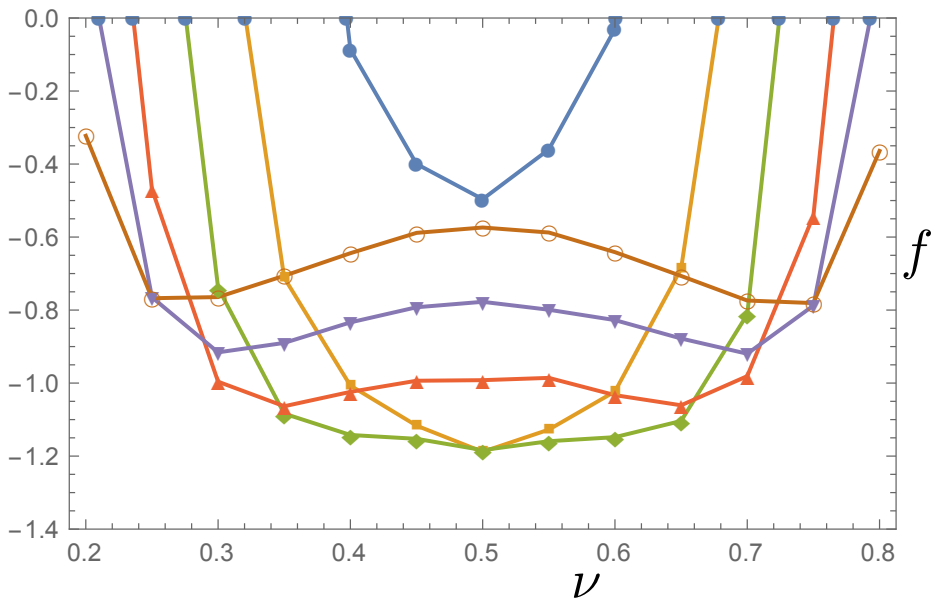


- Holonomy ν related to expectation value of Polyakov loop

$$P = \frac{1}{2} < Tr(L) >= \cos(\pi\nu) \quad (2)$$

- We use a standard method in obtaining free energy from expectation value of action

- We minimize free energy in the following parameters:
  - Density of M dyons n_M and L dyons n_L
  - Holonomy ν
  - Debye mass describing the fall off of the fields

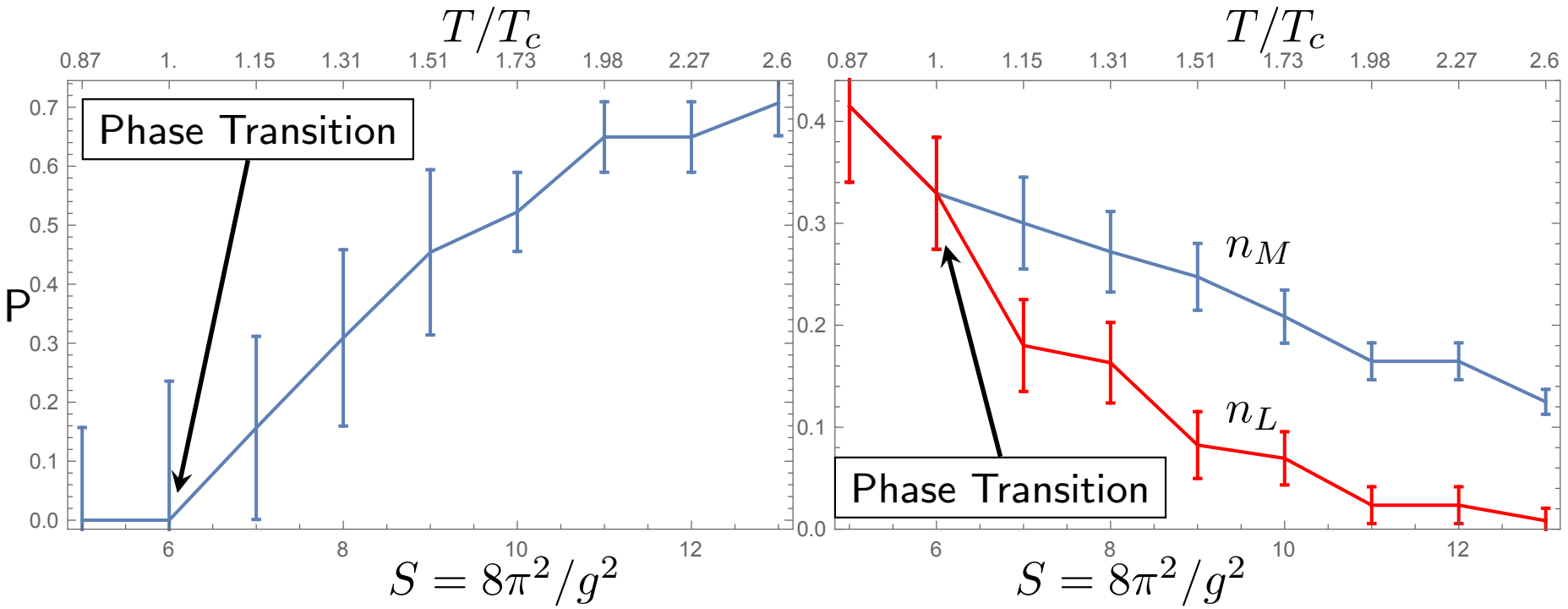


- The minimization is done as a function of Temperature T or Action $8\pi^2/g^2$

- High T: Low density of dyons prefer small holonomy ν such that action is low, but M dyons are large
- Low T: High density of dyons prefer symmetric case where M and L dyons are same size. Maximizes entropy

Pure Gauge: Polyakov Loop

- Density of dyons increases at lower temperature
- Increased density forces M dyons to become smaller
- The **Polyakov loop** and the **dyons density** as a function of action/temperature

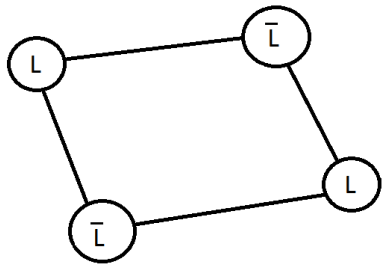


The ensemble of dyons gives confinement for $T < T_c$

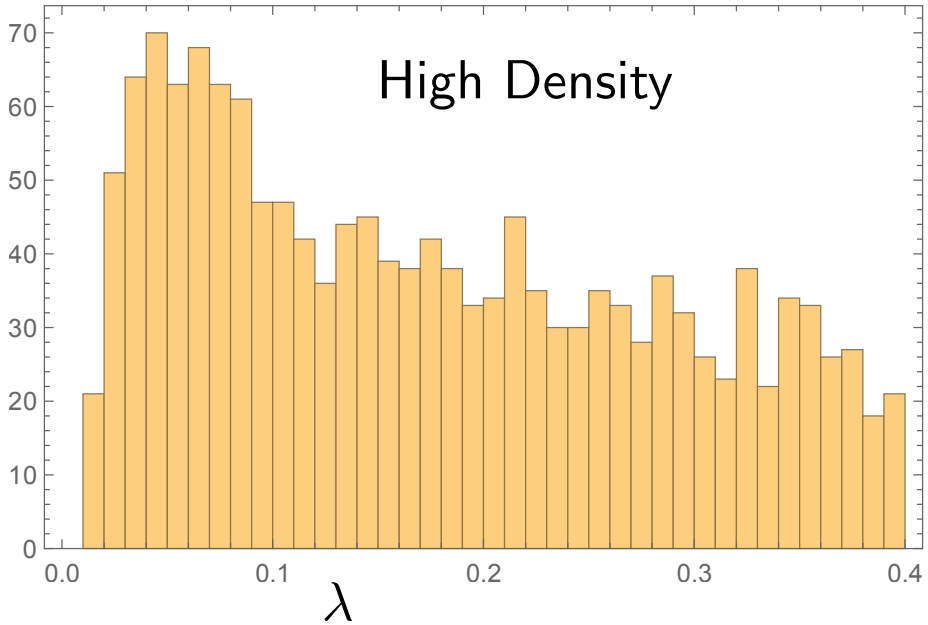
Fermions

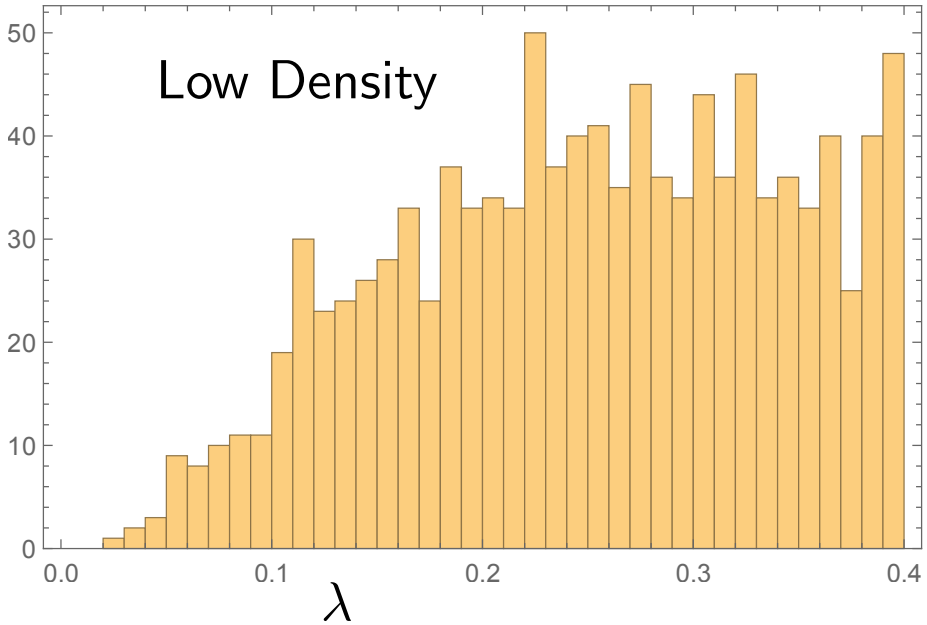
- L dyons have fermionic **zero modes** for anti-periodic fermions
- The determinant of the Dirac operator = closed loops of hopping over L's

$$Det \begin{vmatrix} 0 & T_{ij} \\ T_{ji} & 0 \end{vmatrix} = \sum_{\text{All combinations}}$$



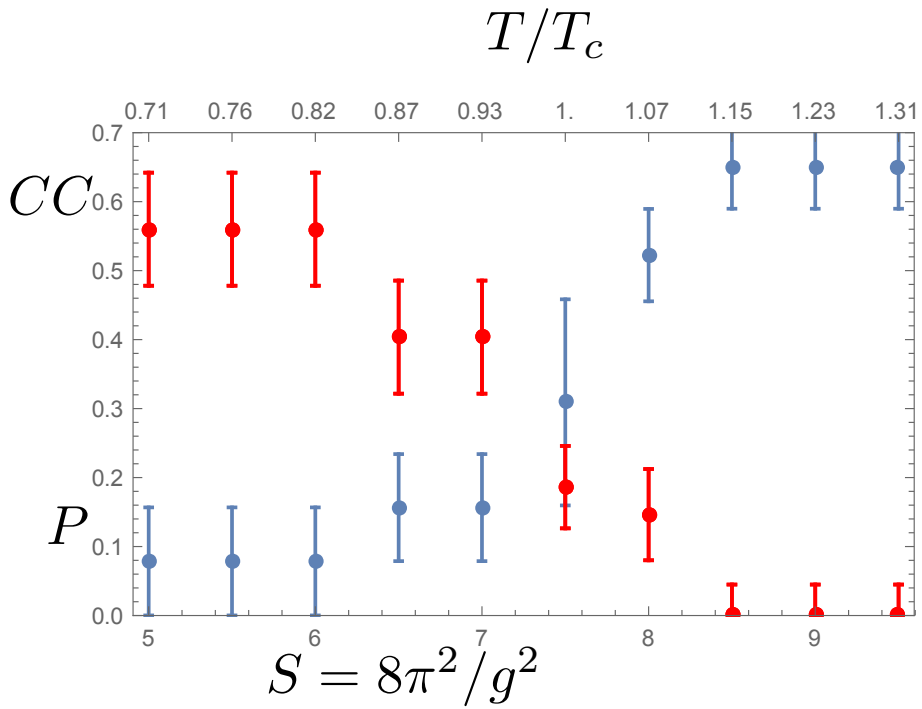
- Low density: Linear attraction makes $L\bar{L}$ pairs
- High density: Collectivizes into large clusters

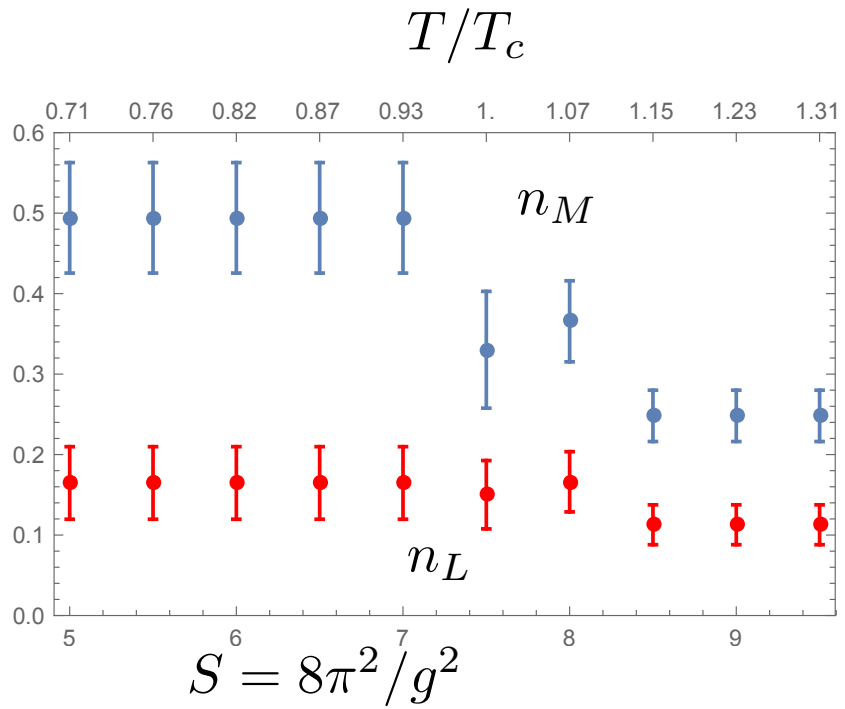




Polyakov Loop and Chiral Condensate for $N_f = 2$

- The drop in the Polyakov loop increases the **effective density** of L dyons, creating a chiral condensate
- M and L dyons density not the same below T_c.





- The mechanisms behind confinement and chiral condensate are closely related. The increased density of dyons.

Summary

1. Simulation of 64 dyons done
2. The free energy as a function of temperature, densities, holonomy and Debye mass has been found
3. High density of dyons pushes holonomy up and Polyakov loop down $\Rightarrow$ Confinement
4. Dirac determinant included through the overlap of fermionic zero-modes
5. At high dyon density the eigen modes collectivizes $\Rightarrow$ Broken chiral symmetry
6. We can now describe the phenomenon of chiral symmetry breaking and confinement through the increase in density of dyons