Confinement/Deconfinement

in 4D compact QED on the lattice

Lee C. Loveridge[1,2],
Orlando Oliveira[2], Paulo J. Silva[2]

[1] Los Angeles Pierce College
[2] CFisUC, Department of Physics,University of Coimbra, Portugal

July 26, 2021

L.C. Loveridge, O.Oliveira, P.J. Silva, doi:10.1103/PhysRevD.103.094519

los angeles pierce college

Reasons to Study U(1) on the Lattice

- Abelian Higgs Models
- Condensed Matter Physics
- QED corrections to QCD
- Modeling Gauge Theories on Quantum Computers

Compact Lattice $U(1)$ Gauge Theory

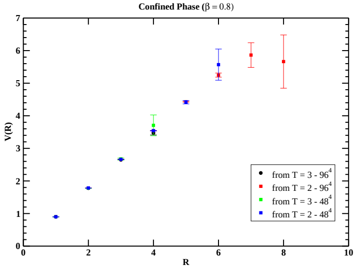
$$S_W(U) = \beta \sum_x \sum_{1 \leqslant \mu,\nu \leqslant 4} \{1 - \Re\,[U_{\mu\nu}(x)]\}\ ,\ \beta = 1/e^2$$

$$U_{\mu\nu}(x) = U_\mu(x)\, U_\nu(x + a\,\hat{e}_\mu)\, U^\dagger_\mu(x + a\,\hat{e}_\nu)\, U^\dagger_\nu(x)$$

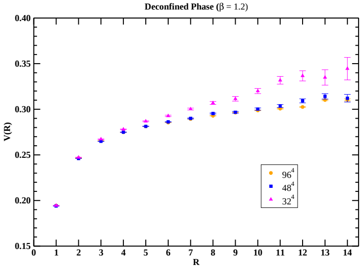
$$U_\mu(x) = \exp\left\{i\, e\, a\, A_\mu\left(x + \frac{a}{2}\,\hat{e}_\mu\right)\right\}$$

Potential

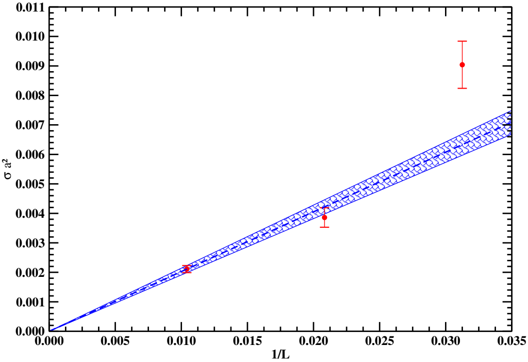
Confined $\beta = 0.8$



Deconfined $\beta = 1.2$



String Tension in the Continuum Limit



Photon Propagator in Landau Gauge

$$\langle A_\mu(p_1)\, A_\mu(p_2)\rangle = V\,\delta(p_1 + p_2)\, D_{\mu\nu}(p_1)$$

$$D_{\mu\nu}(p) = \left(\delta_{\mu\nu} - \frac{p_\mu p_\nu}{p^2}\right) D(\hat{p})$$

How to Recover the Photon (A_μ) Field?

- Linear definition: $A_\mu\left(x+\frac{a}{2}\hat{e}_\mu\right)=\frac{U_\mu(x)-U_\mu^\dagger(x)}{2i}$
  - Argument must be small
  - $SU(3)$ has physical scale
  - No scale in $U(1)$
- Logarithmic definition: $A_\mu\left(x+\frac{a}{2}\hat{e}_\mu\right)=-i\ln\left(U_\mu(x)\right)$
  - Harder than the linear definition
  - Much easier to do in $U(1)$ than in $SU(3)$

Require Different Gauge Fixing for Orthogonality

- Linear: $F[U;g] = \frac{1}{VD} \sum_{x,\mu} \Re \left[g(x)\, U_\mu(x)\, g^\dagger(x + a\,\hat{e}_\mu) \right]$
- Logarithmic: $\widetilde{F}[U;g] = \frac{1}{VD} \sum_{x,\mu} \left\{ 1 - a^2 e^2 \left[A_\mu^{(g)} \left(x + \frac{a}{2} \hat{e}_\mu \right) \right]^2 \right\}$
- First, maximize the linear function
- Second, maximize the log function

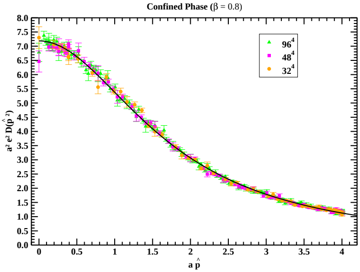
Landau Photon Propagators

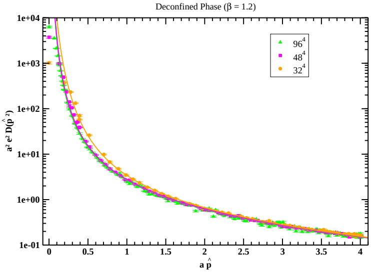
Confined $\beta = 0.8$

$$a^2 e^2 D(a^2 \hat{p}^2) = \frac{z_0}{(a\hat{p})^2 + (am)^2}$$

Deconfined $\beta = 1.2$

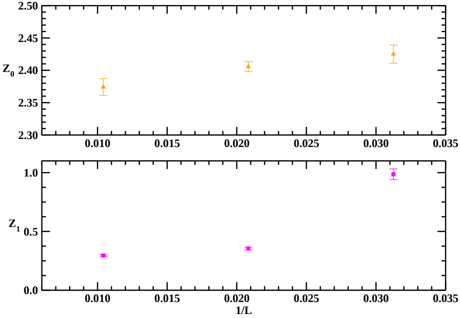
$$e^2 a^2 D(a^2 \hat{p}^2) = \frac{Z_0}{(a\ \hat{p})^2} + \frac{Z_1}{(a\ \hat{p})^4}$$



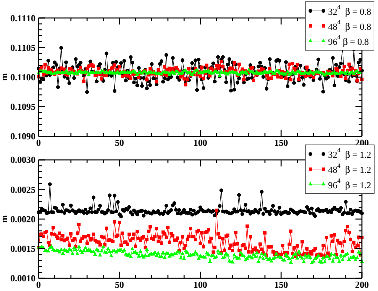


Los Angeles Pierce College

Propagator in the Continuum Limit



Why? Dirac Strings?



When the links of a plaquette make a full 2π rotation.

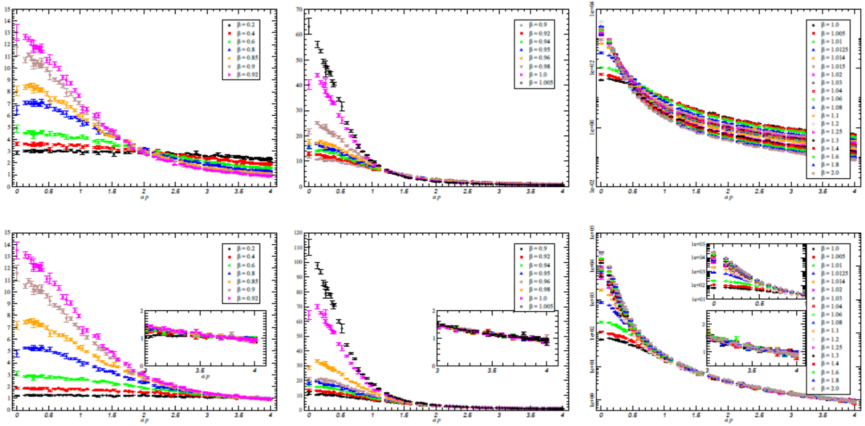
$$U_{\mu\nu}(x) = \exp\left\{ i\,e\,a \left(\Delta A_{\mu\nu}(x) \right) \right\}$$

$$\Delta A_{\mu\nu}(x) = \sum_{\text{loop}} A_\mu + \frac{2\pi m_{\mu\nu}(x)}{ea}$$

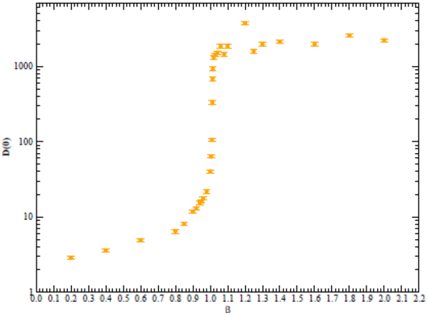
$$m = \frac{1}{6\,V} \sum_{x,\mu<\nu} |m_{\mu\nu}(x)|$$

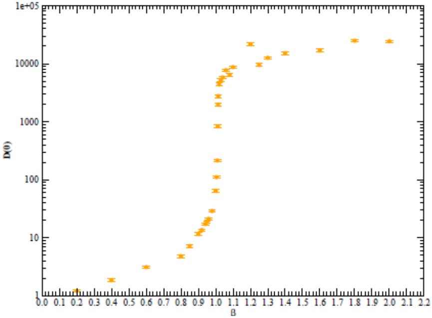
NOT gauge invariant

Inspecting the Transition



$D(0)$ versus β





los angeles pierce college

Acknowledgements and Thanks

- This work was supported by national funds from FCT – Fundação para a Ciência e a Tecnologia, I.P., Portugal, within the project UID/04564/2020.
- Simulations performed in supercomputer Navigator, managed by LCA - University of Coimbra [url: www.uc.pt/lca]
- P. J. S. acknowledges financial support from FCT (Portugal) under Contract No. CEECIND/00488/2017.
- Thanks to
  - CFisUC, O.O., and P.J.S. for hosting me during my sabbatical
  - LACCD and LAPC for granting the time
  - Friends, family, and others who made it possible.

REPÚBLICA PORTUGUESA

FCT Fundação para a Ciência e a Tecnologia

LCA Laboratory for Advanced Computing

CFisUC

los angeles Pierce college