Two-Colour QCD at finite Baryon density

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JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Motivation

Why QCD-like theories?

- testing effective theories
- $\mu > 0$ equation of state

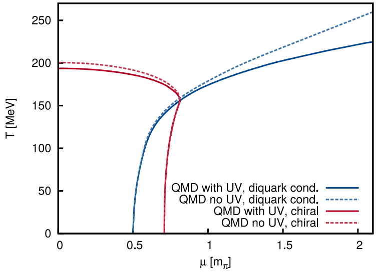
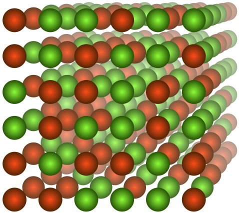


Figure: 2-colour Quark-Meson-Diquark model [Strodthoff, Smekal, Phys. Let. B.2014.03.008]

$$(\det \mathcal{M}(\mu))^* = \det \mathcal{M}(-\mu)$$

- Reweighting
- Taylor expansion
- Lefshetz thimbles
- Complex Langevin
- Effective theories

Outline



QCD-like theories

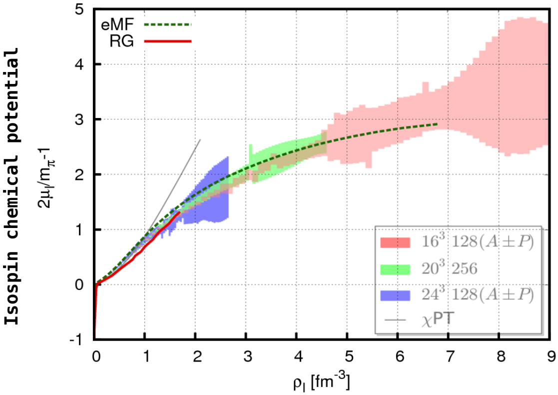
- generator isometry
  $\Rightarrow$ **Anti-unitary sym.**

$$T_a^* = -S T^a S^{-1}$$
$$\Rightarrow [A, D] = [SCK, D] = 0$$

- Dyson classification
  - $\beta = 1$: $A^2 = +1$, $\det D \in \mathbb{R}$
  - $\beta = 2$: ev. $\in \mathbb{C}$
  - $\beta = 4$: $A^2 = -1$, $\det D > 0$, $\det D \in \mathbb{R}$

Isospin chemical potential

$$\det \mathcal{M}(\mu_I) = \det\left(D(\mu_I)D(-\mu_I)\right)$$



[Kamikado, Strodthoff, Smekal, PLB 718 (2013) 1044]

[Detmold, Orginos, Shi, Phys. Rev. D86 (2012) 054507]

G_2-QCD

- 7 colours, 14 gluons
- deconf. 1st order

$$SU(3) \subset G_2 \subset SO(7)$$
$$c_{abc} = c_{def} U_{da} U_{eb} U_{fc}$$
$$c_{abc} = \frac{1}{\sqrt{3}} \psi_{abc}$$

$$SU(2N_f)_{L=R^*} \times Z(2)_B$$

$m_q > 0$: $SU(2N_f)_{L=R^*} \times Z(2)_B \rightarrow SO(2N_f)_V \times Z(2)_B$

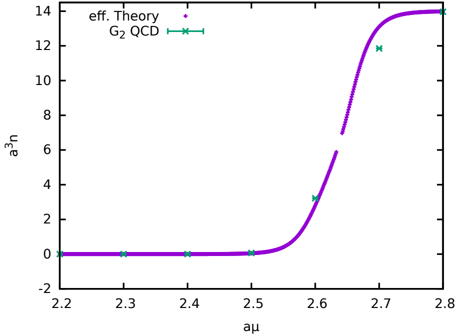
$\mu > 0$: $SU(2N_f)_{L=R^*} \times Z(2)_B \rightarrow SU(N_f)_L \times SU(N_f)_R \times U(1)_B$

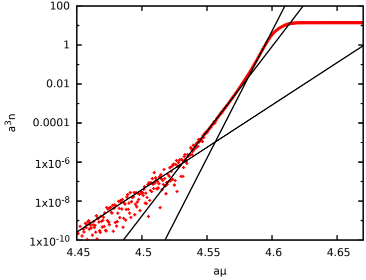
$\mu > 0$: $SO(2N_f)_V \times Z(2)_B \rightarrow SU(N_f)_V \times U(1)_B$

$m_q > 0$: $SU(N_f)_L \times SU(N_f)_R \times U(1)_B \rightarrow SU(N_f)_V \times U(1)_B$

$$SU(N_f)_V \times U(1)_B$$

Effective G_2 Polyakov loop theory





- diquarks $q^T q$
- nucleons $(\bar{q}q)q$, $(q^T q)q$
- hybrid states $qggg$

  $\Rightarrow$ string breaking in G_2-YM

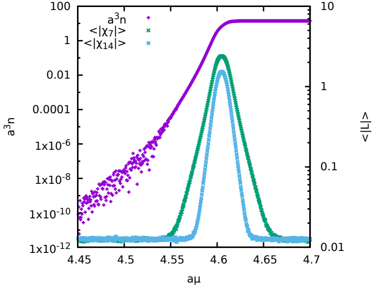


Figure: [P. Scior, PhD thesis, TU Darmstadt 2016]

QC_2D

Previous lattice studies:

- Hands et al., Nucl. Phys. B558, 327-346, (1999)
- Morrison et al., hep-lat/9902012, (1999)
- Kogut et al., Phys. Let. B514, 77-87, (2001)
- Kogut et al., Phys. Rev. D68, 1-32, (2003)
- Boz et al., arXiv/1502.01219, (2015)
- Braguta et al., arXiv/1605.04090, (2016)
- **Talk by V. Braguta this morning**

Quark-Meson-Diquark model

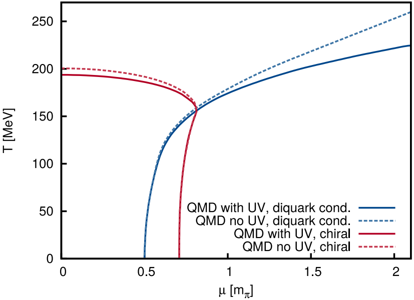
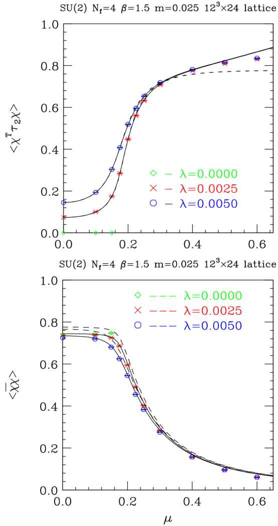
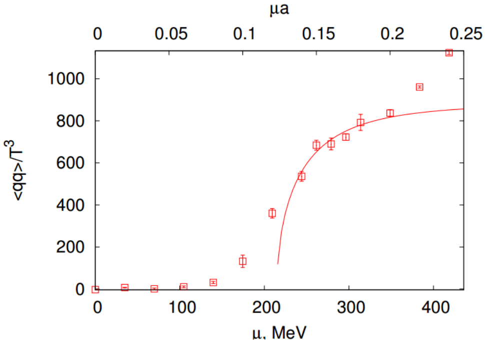


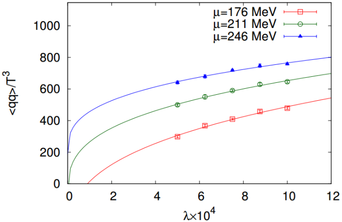
Figure: [Strodthoff, Smekal, Phys. Let. B.2014.03.008]

Previous studies

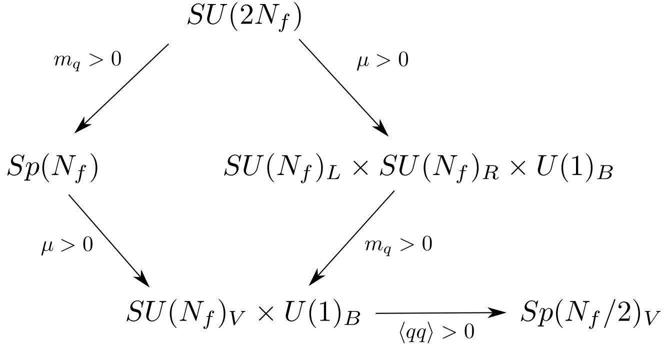


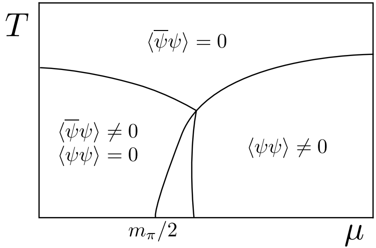
[Kogut, Toublan, PRD68, 054507 (2003)]





[Braguta, Ilgenfritz, Kotov, Molochkov, Nikolaev, arXiv:1605.04090v3 (2016)]





$$T_a^* = -ST^aS^{-1}$$

where $S = i\sigma_2$

q & $\overline{q}$ in equiv. repr.

$$S_f = \frac{1}{2}\left(\overline{\psi}, \psi^T \tau_2\right)\begin{pmatrix} \lambda & D(\mu) \\ -D^\dagger(\mu) & \lambda \end{pmatrix}\begin{pmatrix} \tau_2 \overline{\psi}^T \\ \psi \end{pmatrix}$$

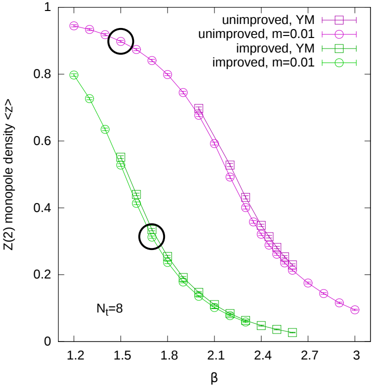


Figure: $\langle z \rangle = 1 - \frac{1}{N_\square} \sum_{C \in \square} \prod_{P \in \partial C} \operatorname{sgn} \operatorname{tr} P$

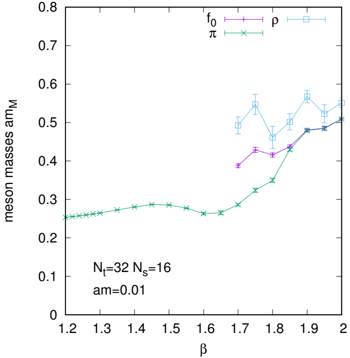


Figure: [D. Scheffler, PhD Thesis, Technische Universität Darmstadt (2015)]

QC_2D with staggered quarks

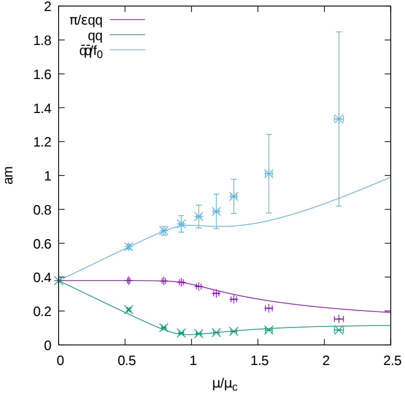


Figure: $\beta = 1.5$: $\langle z \rangle \approx 0.88404(10)$
Dyson index: $\beta = 4$

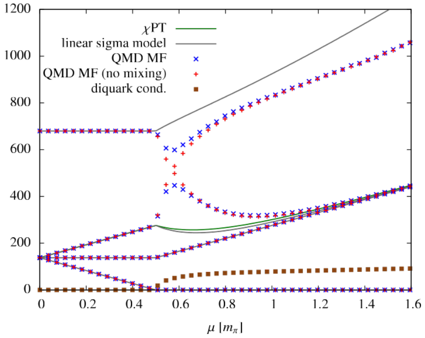


Figure: [Strodthoff, Schaefer, Smekal, Phys. Rev. D.85.074007]

$$f_0/qq : \frac{1}{2}\left(\chi^T \tau_2 \chi + \overline{\chi}\tau_2\overline{\chi}^T\right)\cos\alpha + \overline{\chi}\chi \sin\alpha$$

$$\pi/\epsilon qq : \overline{\chi}\epsilon\chi \cos\alpha + \frac{1}{2}\left(\chi^T \tau_2 \epsilon \chi + \overline{\chi}\tau_2\epsilon\overline{\chi}^T\right)\sin\alpha$$

QC_2D with staggered quarks

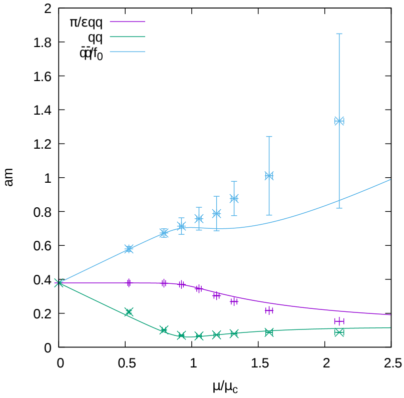


Figure: $\beta = 1.5$: $\langle z \rangle \approx 0.88404(10)$
Dyson index: $\beta = 4$
any-colour, adjoint quarks

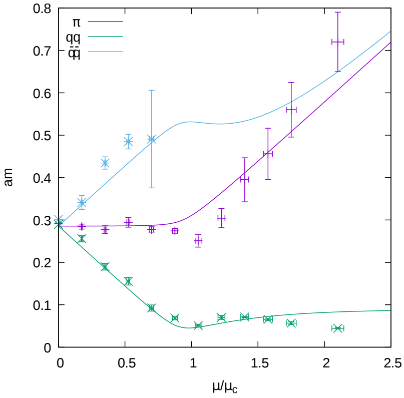
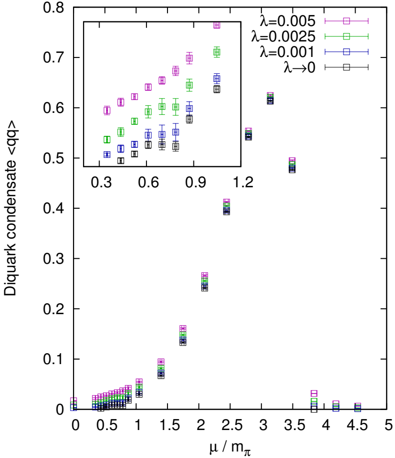
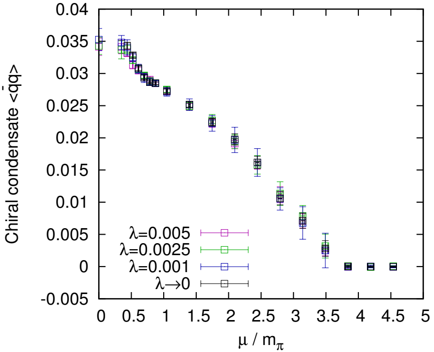
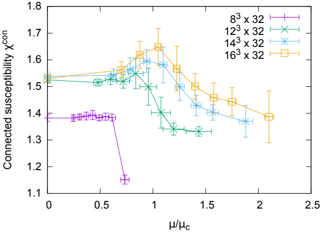


Figure: $\beta = 1.7$: $\langle z \rangle \approx 0.27340(66)$
Dyson index: $\beta = 1$
two-colour, fundamental quarks

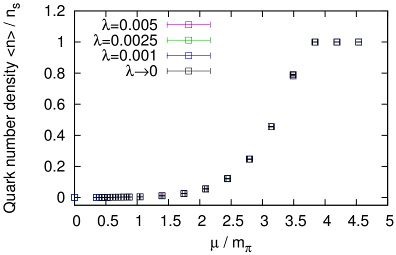
QC_2D with staggered quarks

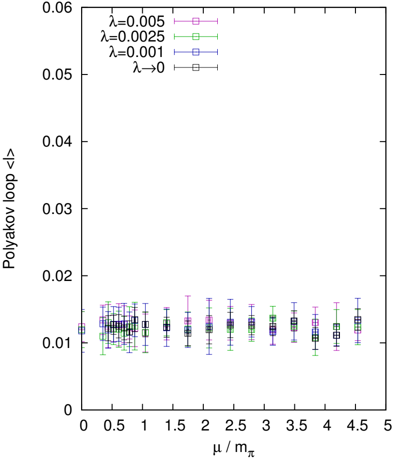


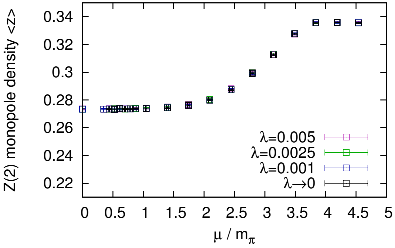




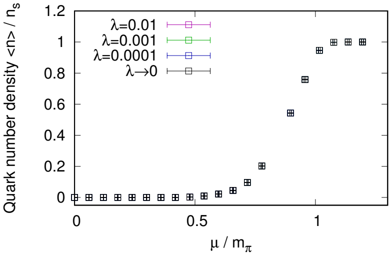
QC_2D with staggered quarks

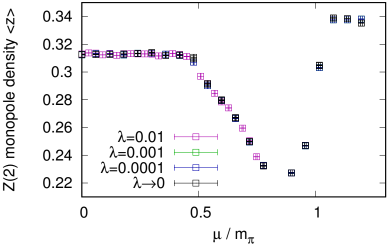


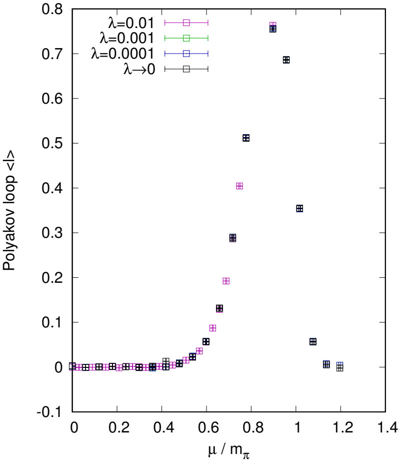




QC_2D with Wilson quarks







Conclusion

- Leaving the bulk phase
- Coninuum sym. breaking pattern $\beta = 4 \to 1$
- Discretization effects

Outlook:

- Renormalization of $\langle\overline{\psi}\psi\rangle$ at $\mu > 0$