The spectrum of QCD at finite isospin density

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Lattice 2017

QCD at finite isospin chemical potential

- QCD with $N_f = 2$ and chemical potential

  up quark: μ_u down quark: μ_d

- rewrite as baryon and isospin chemical potentials

  $\mu_B = \frac{3}{2}(\mu_u + \mu_d)$ $\mu_I = \mu_u - \mu_d$

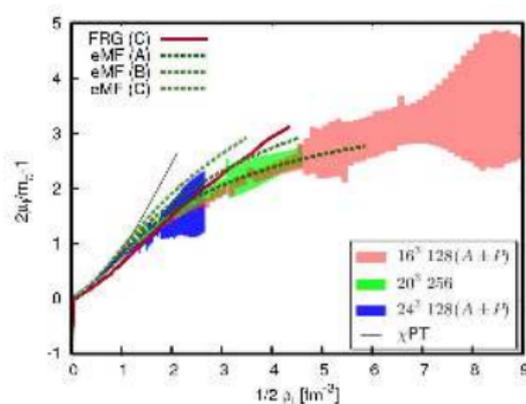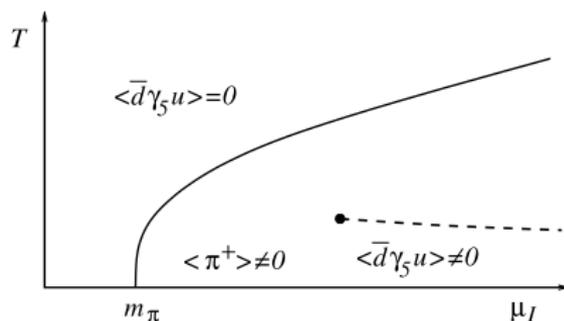- μ_I introduces isospin imbalance

- occurs in nuclei, heavy-ion collisions, neutrons stars, possibly early universe

- here: $\mu_u = -\mu_d \rightarrow \mu_B = 0$

- fermion determinant: $\det(D(\mu_u))\det(D(-\mu_u)) > 0 \rightarrow$ no sign problem

Phasediagram

Earlier works by:

- Son, Stephanov PRL86 (2001)

- Kogut, Sinclair PRD66 (2002)

- Detmold et al. PRD87 (2013)

- Kamikado et al. PLB718 (2013)

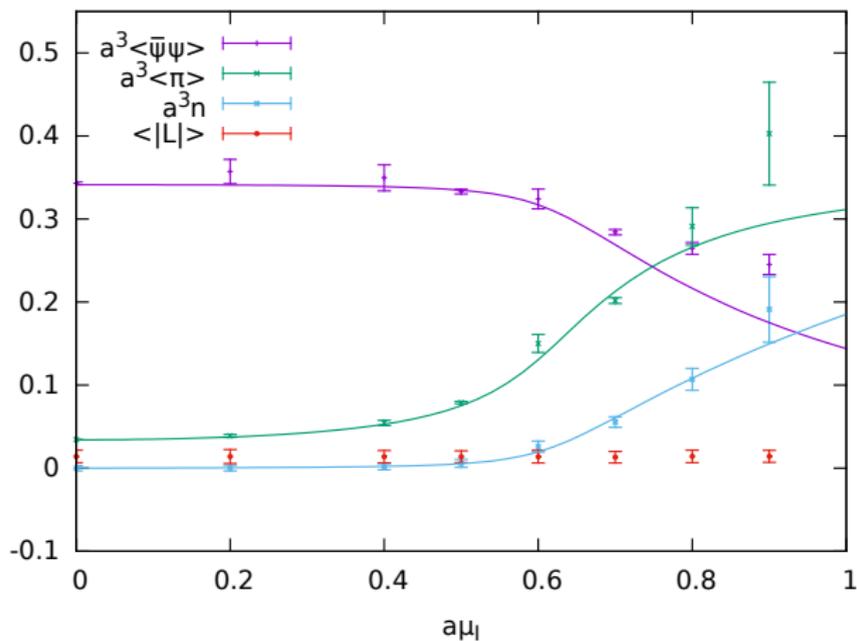- Brandt, Enrodi, Gavai, ...

  [this session]

Setup

- tree-level Symanzik improved gauge action

- finite pion source term

  quark matrix:

  $$M = \begin{pmatrix} D_\mu & \lambda \eta_5 \\ -\lambda \eta_5 & D_{-\mu} \end{pmatrix}$$

- D_μ is the staggered Dirac operator

Phasediagram

Lattice parameters:

$\beta = 4.0$, $m = 0.05$, $\lambda = 0.005$, $N_s = 16$, $N_t = 24$

Staggered Spectroscopy

- indentify the operators corresponding to the desired states in the continuum limit

Operator	J^P	Particle
$\eta_4 \bar{\chi}\chi$	0^+	-
	0^{-+}	π
$\eta_i \eta_5 \zeta_i \bar{\chi}\chi$	1^{++}	a_1
	1^{--}	ρ
$\eta_i \eta_5 \eta_4 \zeta_i \zeta_4 \bar{\chi}\chi$	1^{+-}	b_1
	1^{--}	ρ
$\epsilon_{abc} \chi_a \chi_b \chi_c$	$\frac{1}{2}^-$	N(1535)
	$\frac{1}{2}^+$	N

Spectroscopy with finite pions source

- finite λ: quark propagator is non diagonal in isospin space

  $\rightarrow$ new terms in correlators

- disconnected contributions for all mesons $\sim \lambda^2$:

  we choose $\frac{\lambda}{m} < 0.01 \rightarrow$ neglect disconnected contributions

- additional terms for some connected parts

$$\langle \pi^0(x)\bar{\pi}^0(0)\rangle = \eta_4(x)\eta_5(x) \, \mathrm{Tr}_c[G_{dd}^\dagger(x,0,\mu)G_{uu}(x,0,\mu) - G_{du}^\dagger(x,0,\mu)G_{du}(x,0,\mu)$$
$$- G_{ud}^\dagger(x,0,\mu)G_{ud}(x,0,\mu) + G_{uu}^\dagger(x,0,\mu)G_{dd}(x,0,\mu)]$$

- baryons: only connected pieces, additional terms

Spectroscopy at $\mu_I = 0$

two parametersets: both on $16^3 \times 24$ lattice:

(1) $\beta = 4.0$, $m = 0.05$, $\lambda = 0.005$

(2) $\beta = 3.5$, $m = 0.01$, $\lambda = 0.001$

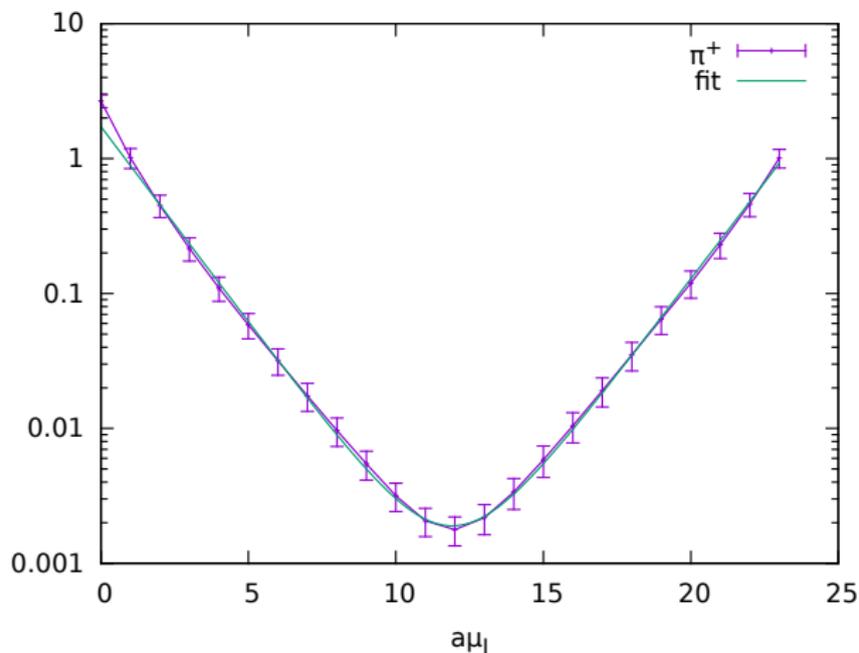| Particle	(1)	(2)
am_π	0.66(1)	0.2597(1)
am_ρ	1.04(3)	-
am_N	1.64(5)	-

(1) pion is too heavy

(2) bad signal to noise ratio, unable to extract am_ρ, am_N

Spectroscopy at $\mu_I = 0$
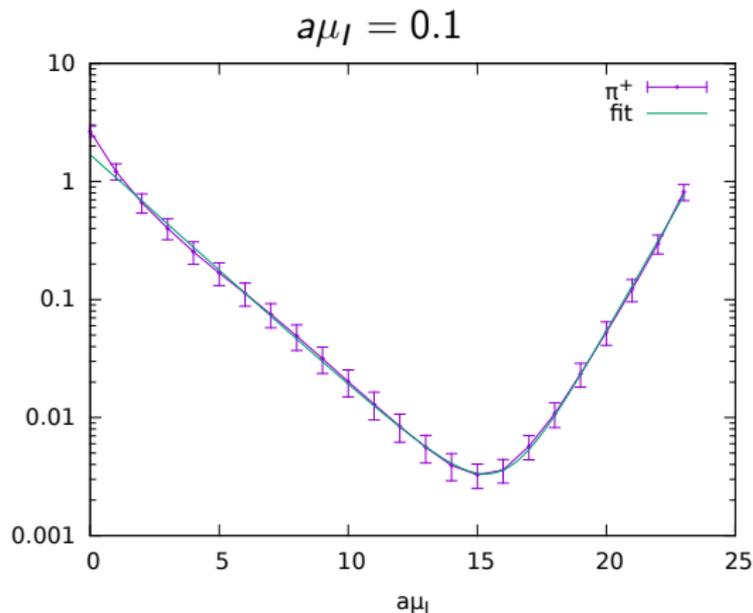
π^+ correlator:

$$C(t) = A(-1)^t(e^{-m_\pi t} + e^{-m_\pi(N_t - t)})$$
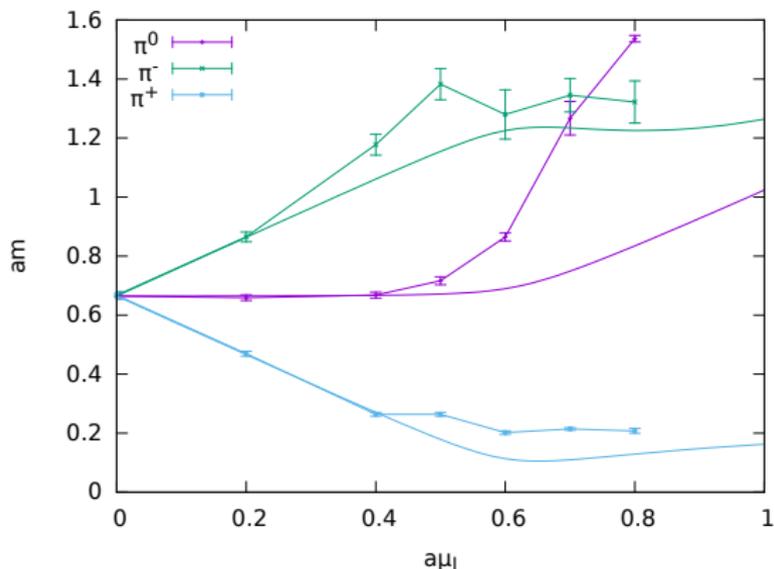
Spectroscopy at finite μ_I

particles with positiv isospin are prefered over their anti-particles

$$C(t) = A(-1)^t(e^{-m_{\pi^+} t} + e^{-m_{\pi^-} + (N_t - t)})$$

Spectrum af finite μ_I

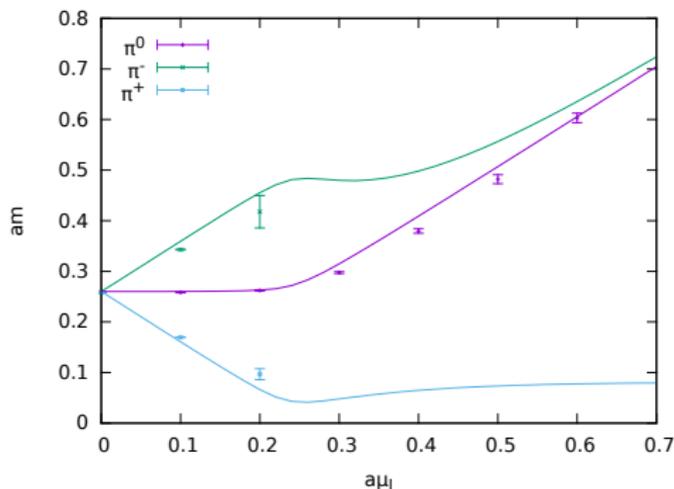pion masses at finite μ_I in comparison with predictions from χPT

Lattice parameters:

$\beta = 4.0, \ am = 0.05, \ \lambda = 0.005, \ N_s = 16, \ N_t = 24$

Spectrum af finite μ_I

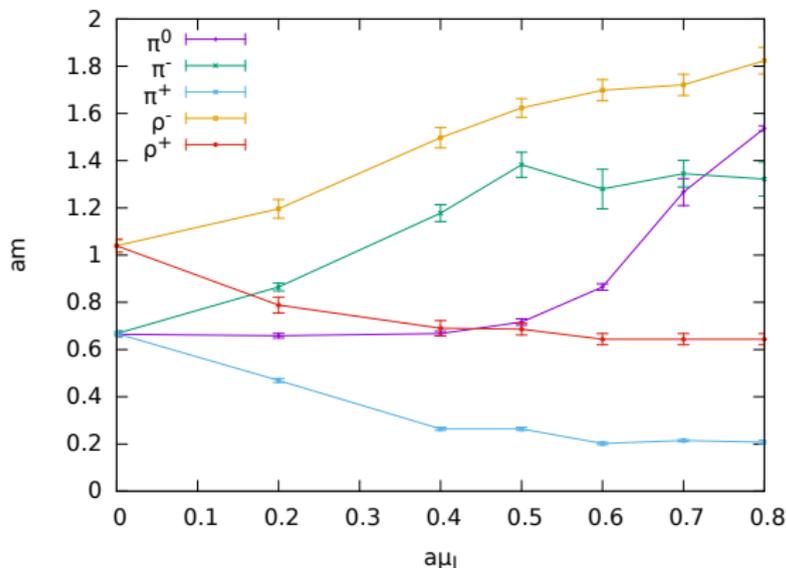pion masses at finite μ_I in comparison with predictions from χPT

Lattice parameters:

$\beta = 3.5,\ am = 0.01,\ \lambda = 0.001,\ N_s = 16,\ N_t = 24$

Bad signal for all other hadron chanels

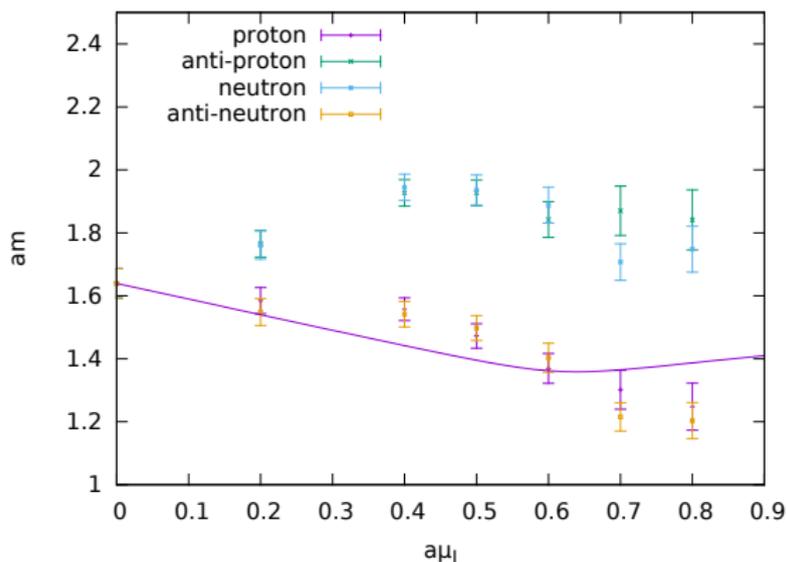# Spectrum af finite μ_I

comparison of pion and ρ masses

Lattice parameters:

$\beta = 4.0,\ am = 0.05,\ \lambda = 0.005,\ N_s = 16,\ N_t = 24$

Spectrum af finite μ_I

baryon masses at finite μ_I

in comparison with predictions from χPT

Summary & Conclusion

- QCD at finite isospin density

- started spectroscopy in- and outside pion condesation phase

- find better parameter set for simulations

- include disconnnected contributions to meson correlators

- include stout-smearing

- $\lambda \to 0$ extrapolation