Dynamical Chiral Polarization in QCD Dirac Spectrum

A. Alexandru & I. Horváth

Large View

- Develop model-independent approaches to the structure of strongly coupled vacuum/thermal states

- Based on Lattice QCD equilibrium configurations

  bottom-up approach (hep-lat/0605008)

- Gauge invariant

- Apply it to the associated phase structure (finite temperature and quantum transitions)

- Use non-standard (non-Pearson) correlations for this purpose = dynamics

Small View (this talk)

- Local chiral properties: correlation coefficient of polarization

- Focus on Dirac (overlap) modes

[arXiv:1405.2968]
[arXiv:1210.7849]
[arXiv:1009.4451]

Plan:

(1) Dynamical polarization and local chirality

(2) Overview and Chiral Symmetry Breaking–Chiral Polarization conjecture

(3) Anomalous mode behavior in thermal pure glue SU(3)
(SChSB without confinement)

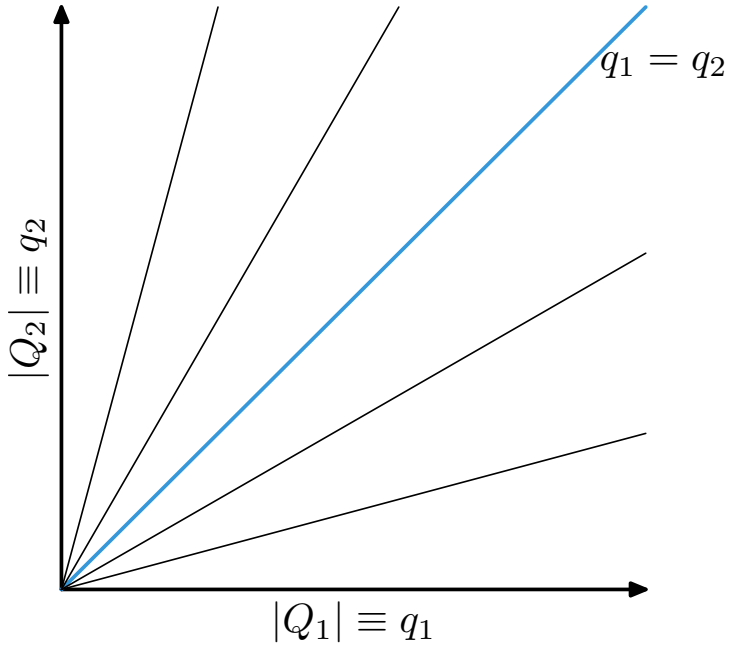
(4) Anomalous mode behavior in N_f=12 !

Anomalous = non-monotonic mode density +

SAMPLE POLARIZATION AS CORRELATION

Simplest: $\mathcal{P}(Q_1, Q_2)$ $Q = Q_1 + Q_2$ $Q_1 \cdot Q_2 = 0$

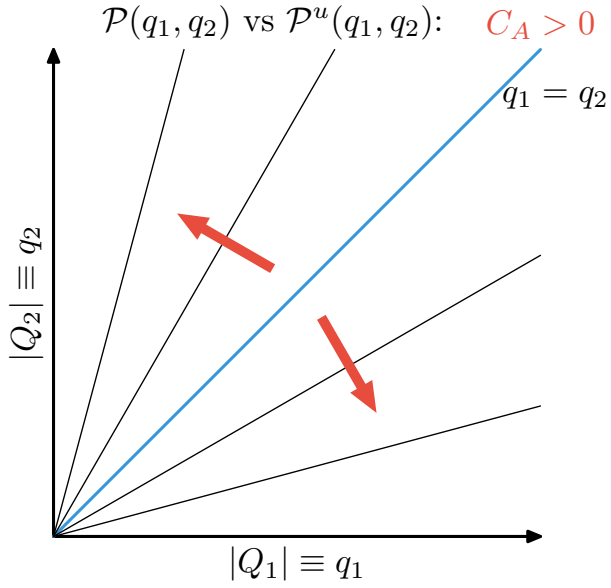
chiral components, dual components etc



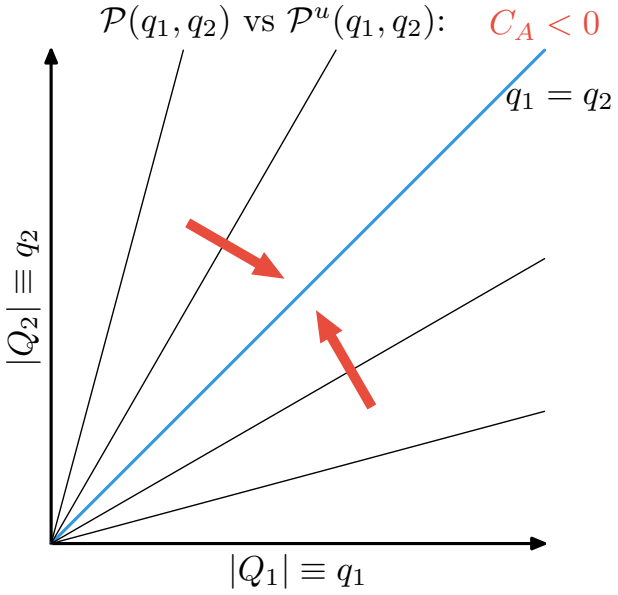
Non-Pearson definition necessary to describe sample polarization as correlation!

Polarization and C_A …

[arXiv:1009.4451]



correlation



anti-correlation

C_A is uniquely defined!

CHIRAL POLARIZATION OF DIRAC MODES (few points)

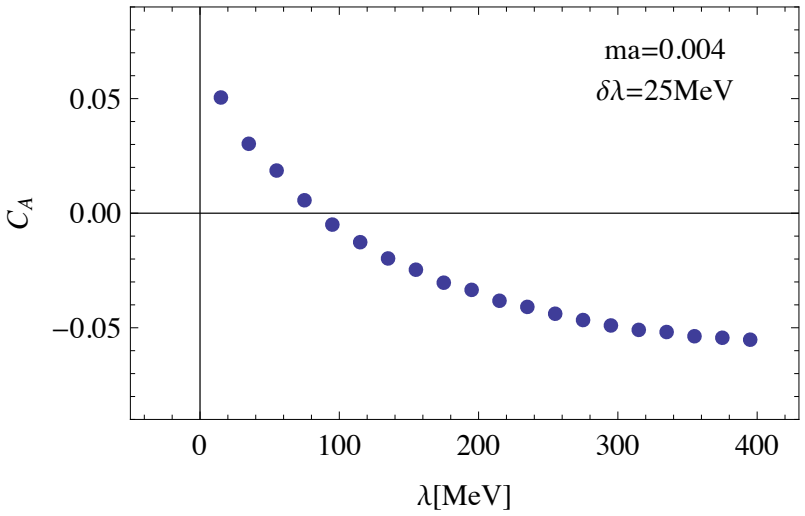
Apply to a given Dirac mode:

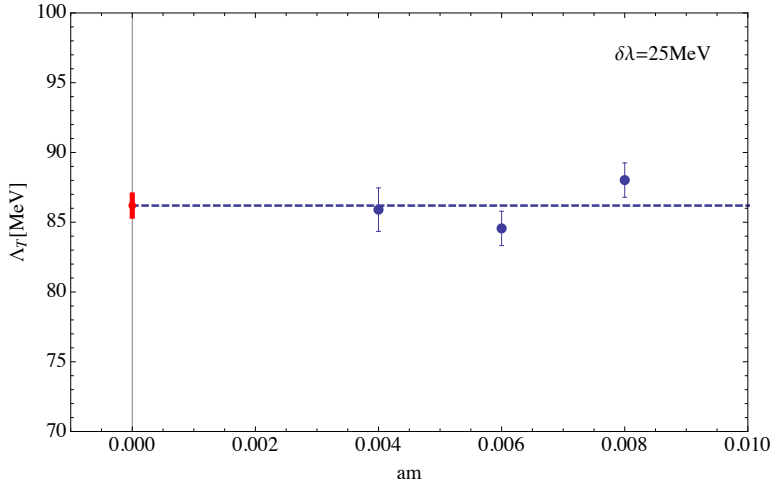
$$Q = Q_1 + Q_2 \quad \longrightarrow \quad \psi = \psi_L + \psi_R$$

$$Q \cdot Q \quad \longrightarrow \quad \psi^+ \psi$$

- N_f=2+1 QCD, Domain Wall Fermions (RBC)
- a = 0.085 fm , V = 32^3x64, lightest $m_\pi \approx 295$ MeV

[arXiv:1210.7849]

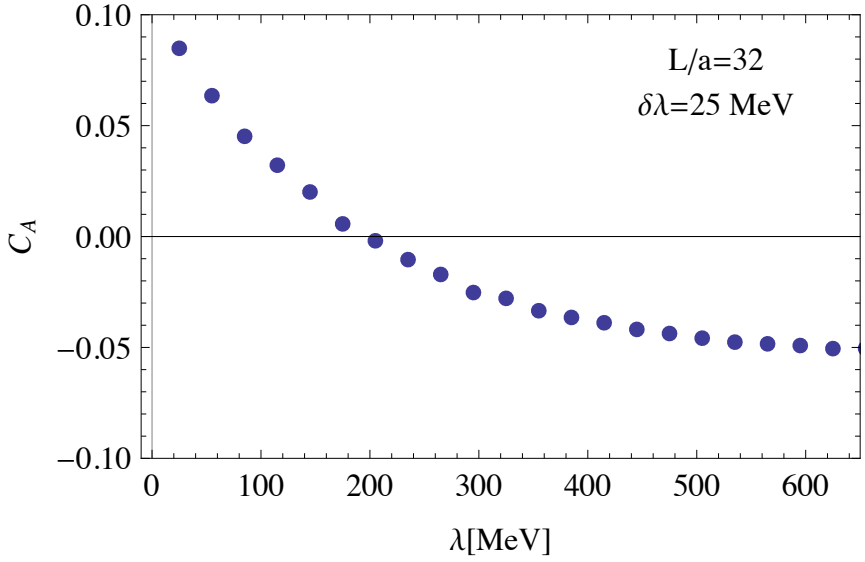


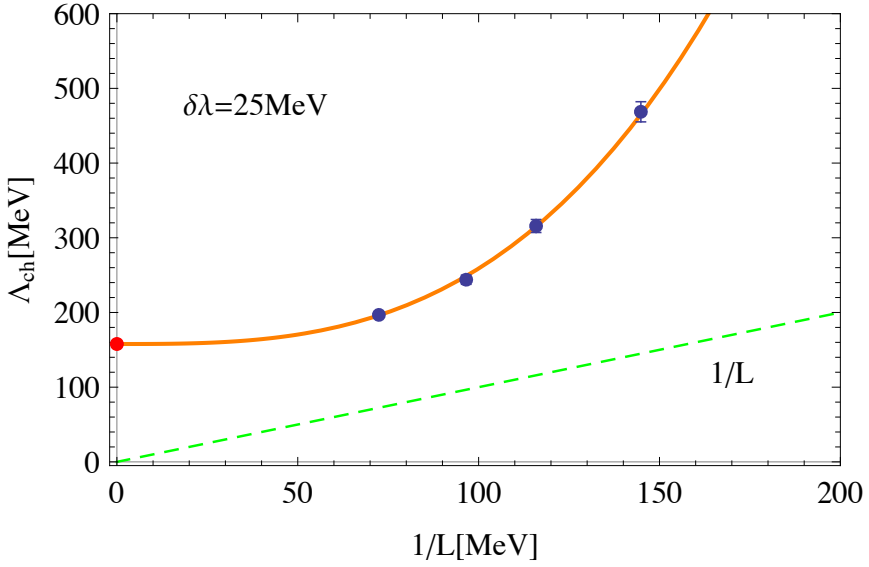


Low Dirac spectrum of “real world” QCD is chirally polarized!

Chiral Polarization…

- N_f=0 QCD, Wilson action, a=0.085 fm (r_0) [arXiv:1210.7849]

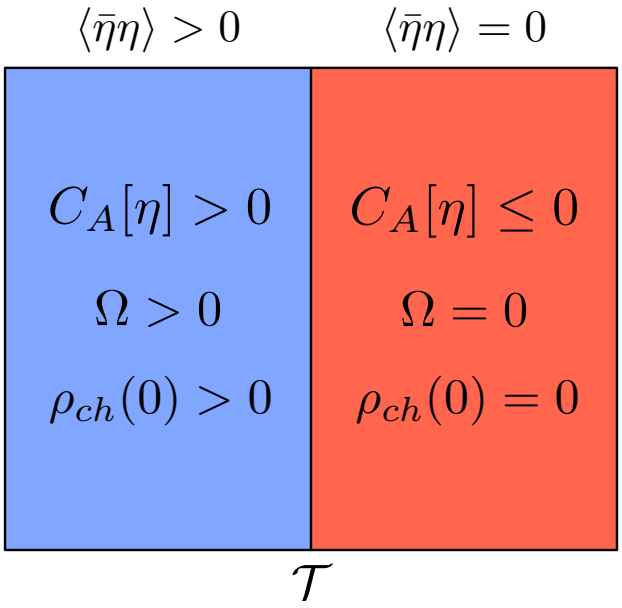




Λ_{ch} is a dynamical scale distinct from infrared cutoff!

vSChSB-Chiral Polarization Correspondence

[arXiv:1210.7849]



$\mathcal{T}$ = SU(3) theories, arbitrary fundamental N_f, masses, temperature

η = massless valence field

Ω = cumulative correlation

ρ_{ch} = spectral chirality density

symmetry breaking $\Longleftrightarrow$ local NP correlation

Fixed quark masses and N_f : defines temperature T_{ch}

Massless quarks and T=0 : defines critical flavors $N_{f,cr}$

Here: Existence of anomalous phase in N_f=12 at low mass! [arXiv:1405.2968]

vSChSB-ChP: the Instruments

◆ For valence Spontaneous Chiral Symmetry Breaking (vSChSB) : use $\rho(\lambda \to 0)$

$$\lim_{m_v \to 0} \lim_{V \to \infty} \langle \bar{\eta}\eta \rangle_V \neq 0 \quad \Longleftrightarrow \quad \lim_{\lambda \to 0} \lim_{V \to \infty} \rho(\lambda, V) > 0$$

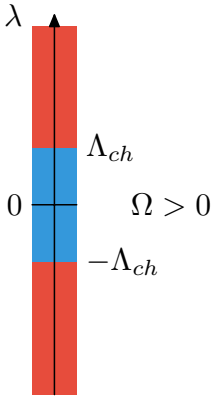
Banks, Casher, 1980

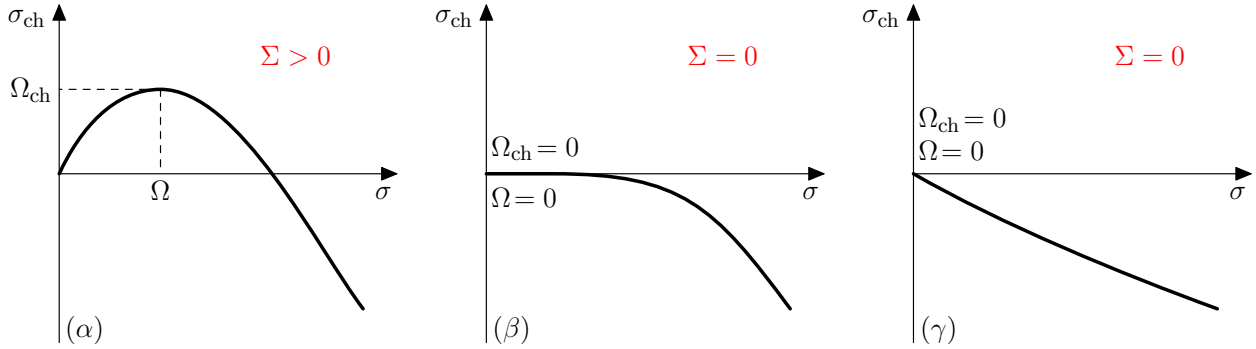
vSChSB $\Longleftrightarrow$ mode condensation

◆ For dynamical Chiral Polarization (ChP) : use Ω

$$\sigma_{ch}(\lambda, V) \equiv \frac{1}{V} \langle \sum_{0 \leq \lambda_k < \lambda} C_{A,k} \rangle_V \qquad \sigma(\lambda, V) \equiv \frac{1}{V} \langle \sum_{0 \leq \lambda_k < \lambda} 1 \rangle_V$$

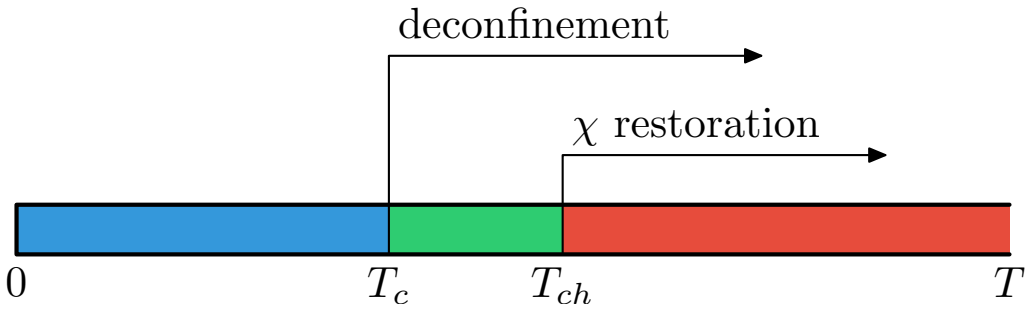
Eliminate λ in favor of σ $\Longrightarrow$ $\sigma_{ch} = \sigma_{ch}(\sigma)$





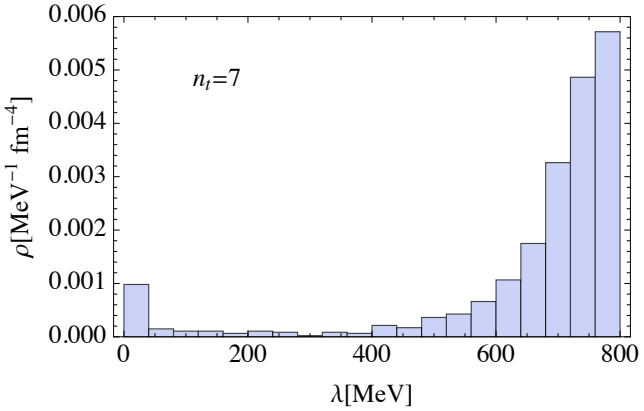
Anomalous Phase $T_c < T < T_{ch}$ in $N_f=0$

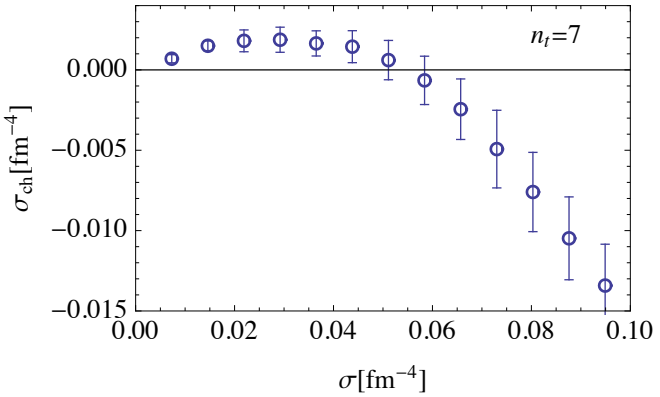
Edwards, Heller, Kiskis, Narayanan, 1999



"real Polyakov line" vacuum

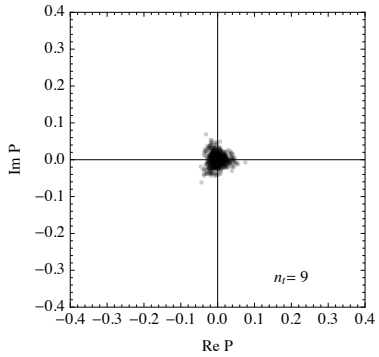
Qualitatively:

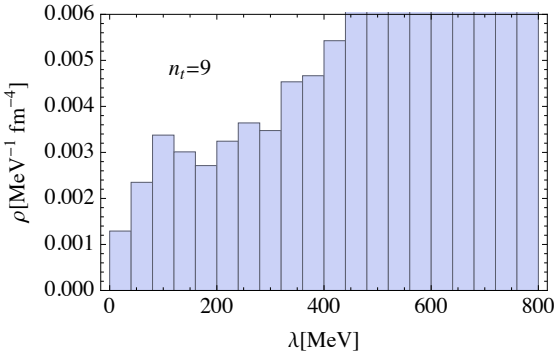


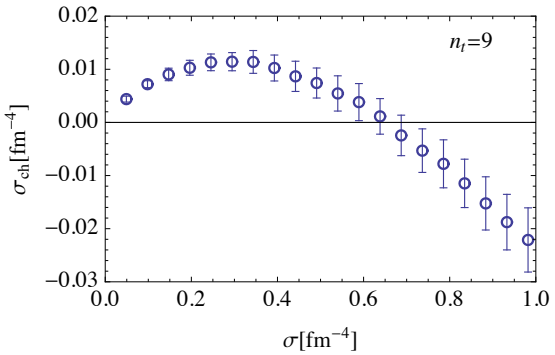


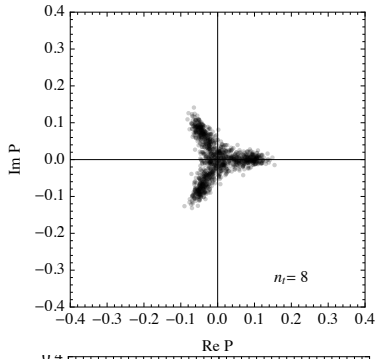
"anomalous" vSChSB

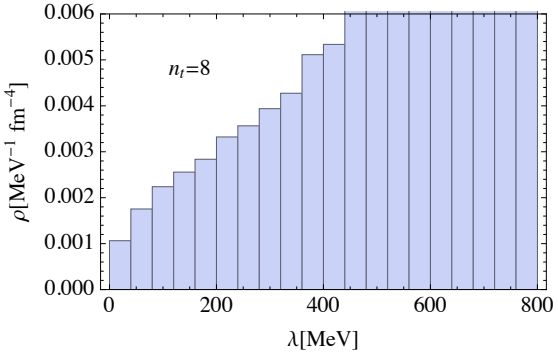
chirally polarized [arXiv:1210.7849]

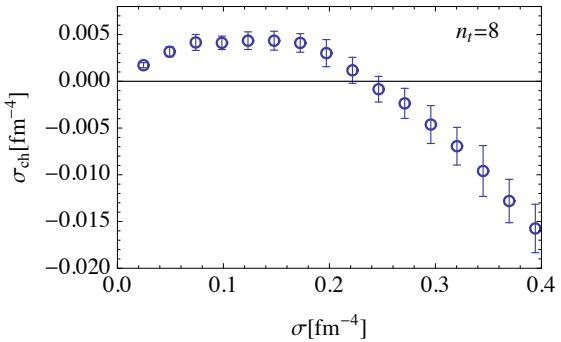

Im P
Re P
n_t= 9

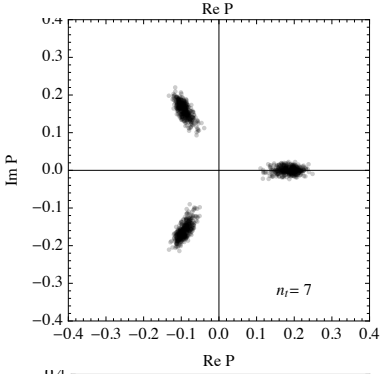

n_t=9
ρ[MeV^{-1} fm^{-4}]
λ[MeV]

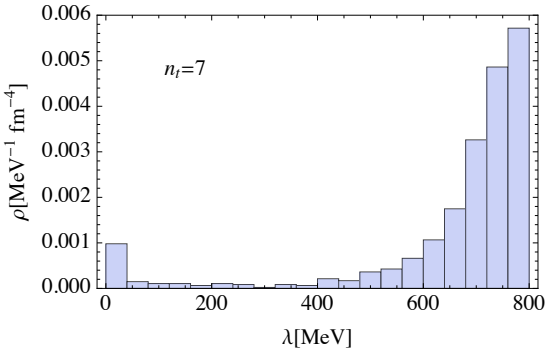

n_t=9
σ_{ch}[fm^{-4}]
σ[fm^{-4}]

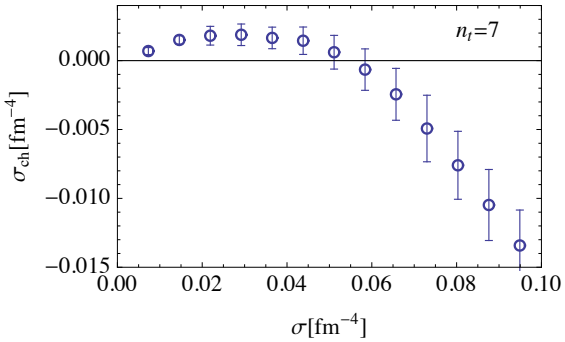

Im P
Re P
n_t= 8

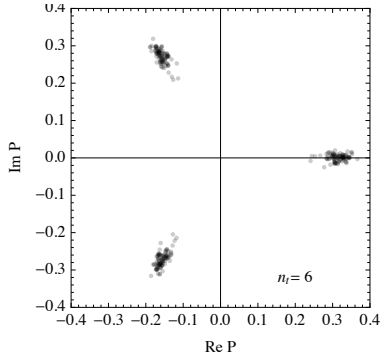

n_t=8
ρ[MeV^{-1} fm^{-4}]
λ[MeV]

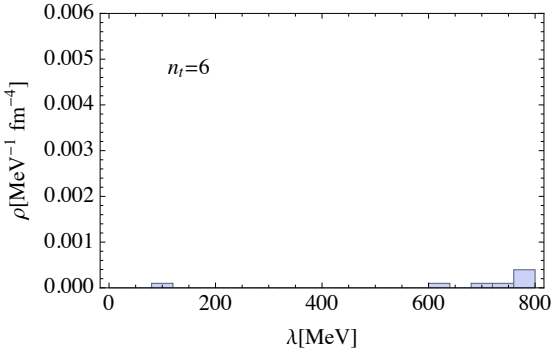

n_t=8
σ_{ch}[fm^{-4}]
σ[fm^{-4}]

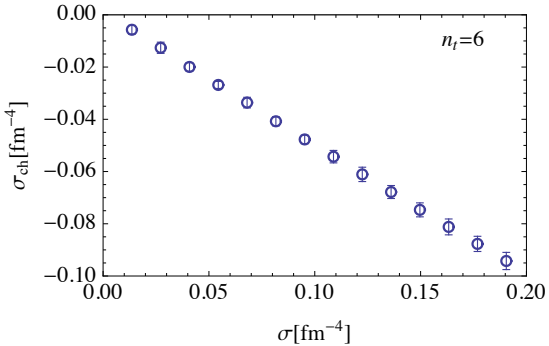

Im P
Re P
n_t= 7


n_t=7
ρ[MeV^{-1} fm^{-4}]
λ[MeV]


n_t=7
σ_{ch}[fm^{-4}]
σ[fm^{-4}]


Im P
Re P
n_t= 6

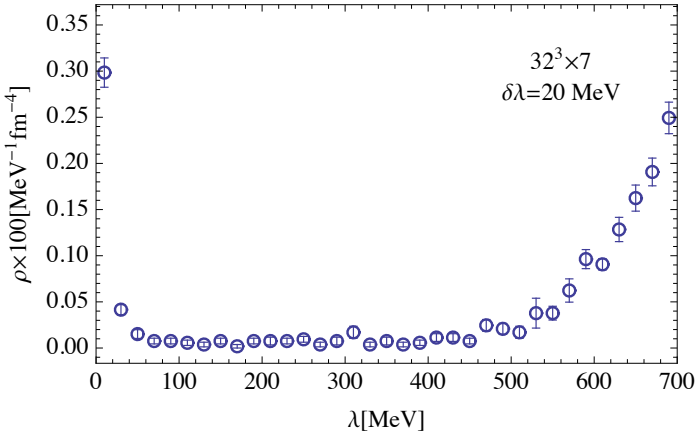

n_t=6
ρ[MeV^{-1} fm^{-4}]
λ[MeV]

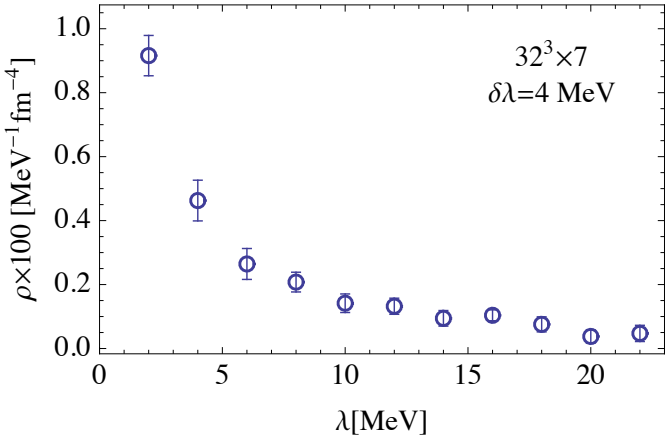

n_t=6
σ_{ch}[fm^{-4}]
σ[fm^{-4}]

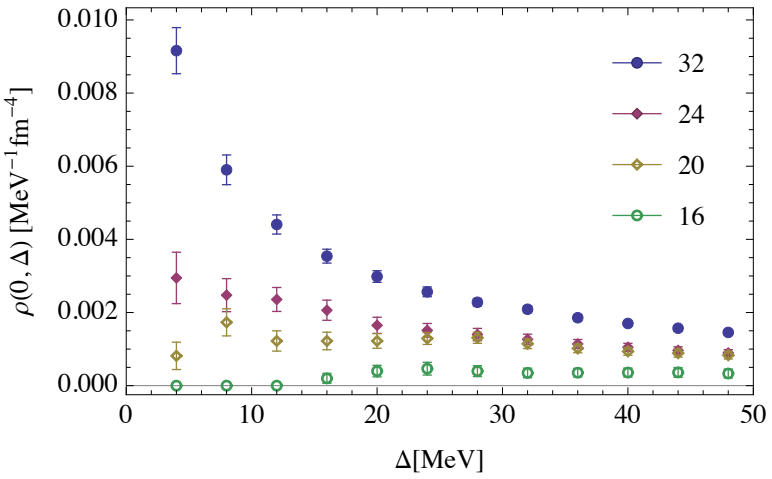
Anomalous phase in N_f=0 is real!

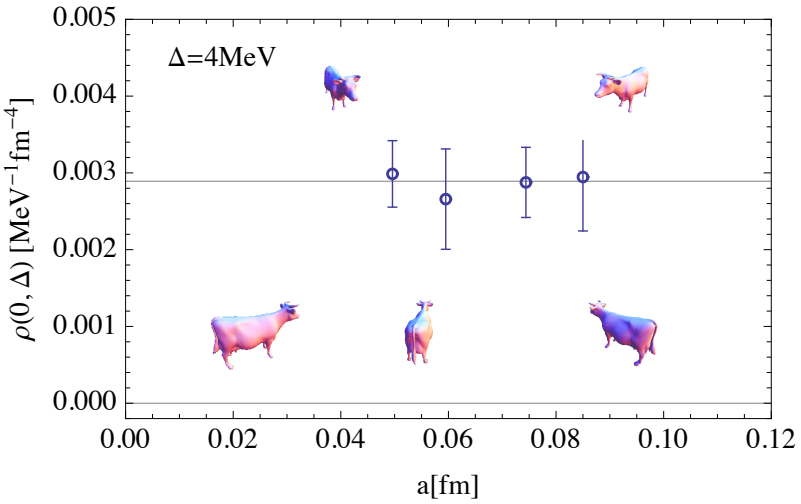
[arXiv:1405.2968]
IH and A. Alexandru, talk, Lattice '14
A. Alexandru, IH, in preparation

N^3 x 7 system at β=6.054, a=0.085 fm









$V_3 = (2\ \text{fm})^3$, $T/T_c = 1.12$

Anomalous Phase $m_{ch} < m < m_c$ in N_f=12 ?

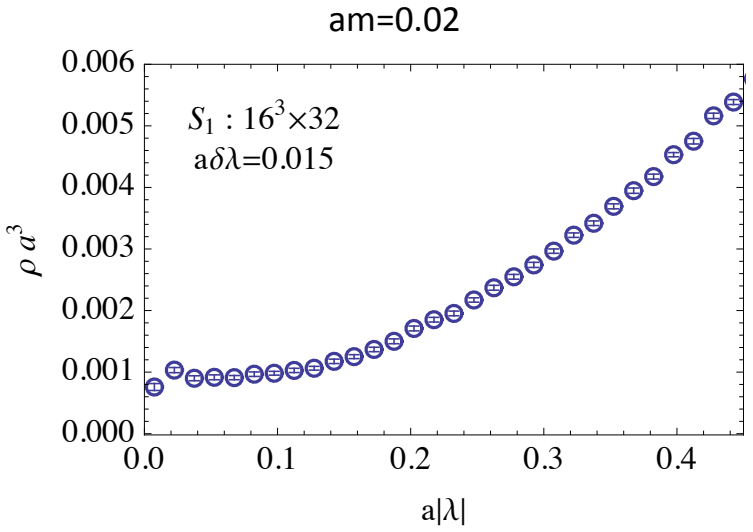
- Ways to restore valence chiral symmetry: increasing T, N_f and lowering m
- Can lowering m lead to anomalous phase at suitable N_f ?
- N_f=12 a suitable candidate
- Controversy over whether $N_{f,cr} < 12$

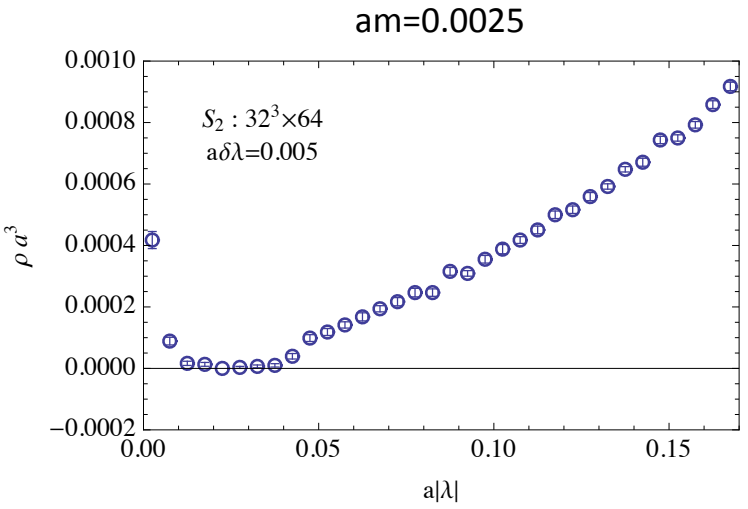
N_f=12 …

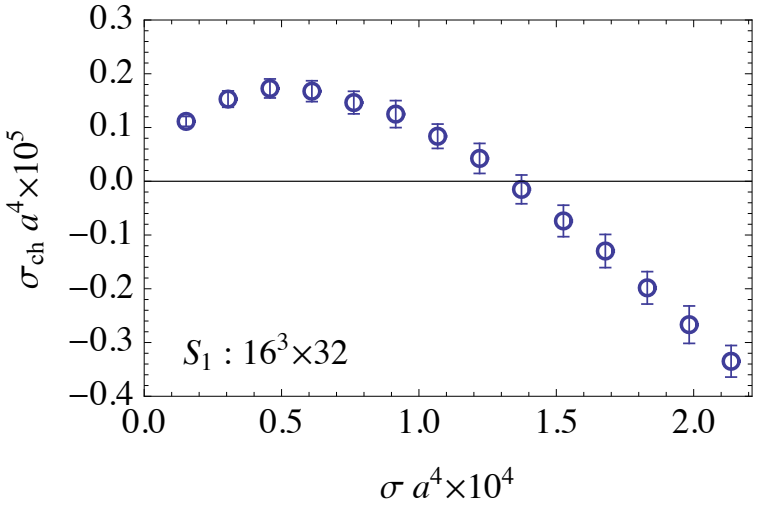
Ensembles from A. Hasenfratz et al, arXiv:1207.7162

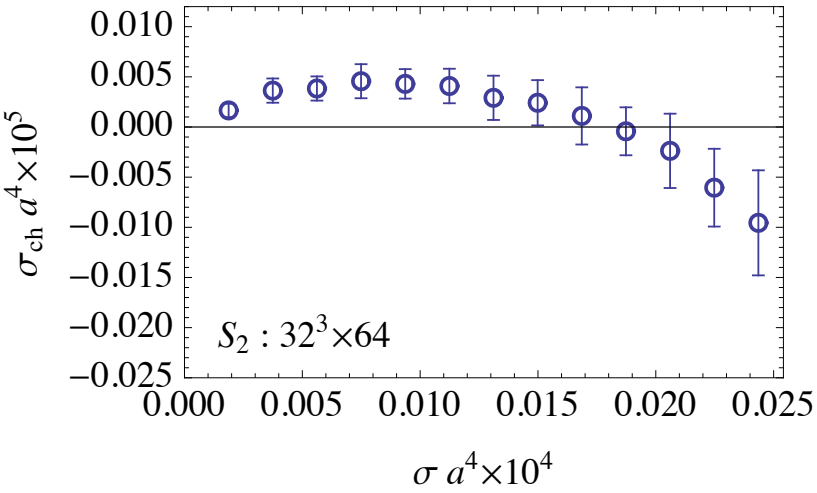
staggered with nHYP, β_F=2.8, β_A/β_F=-0.25

overlap valence probe

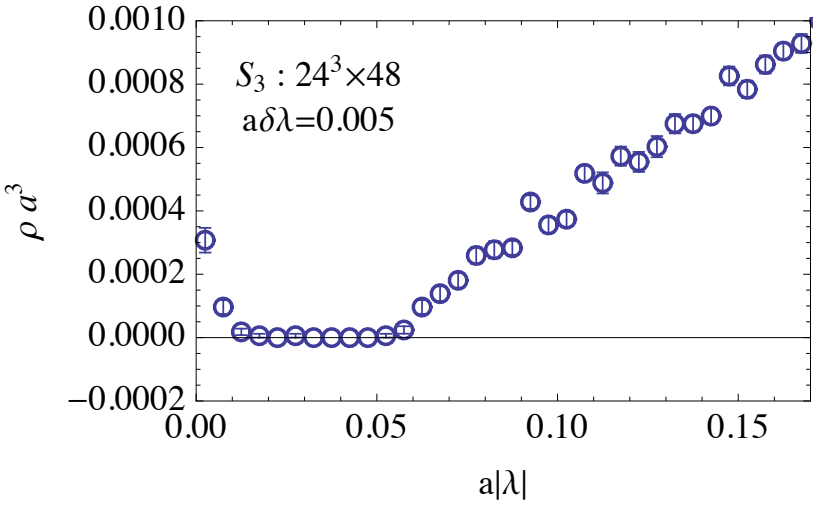


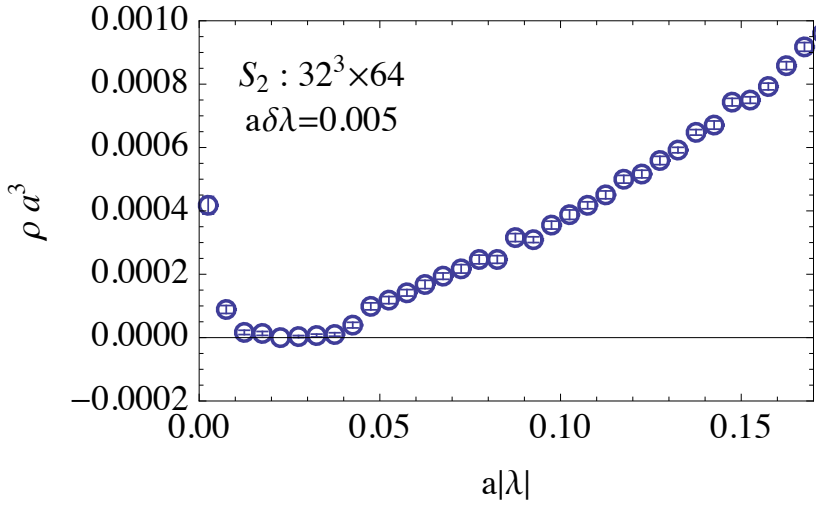


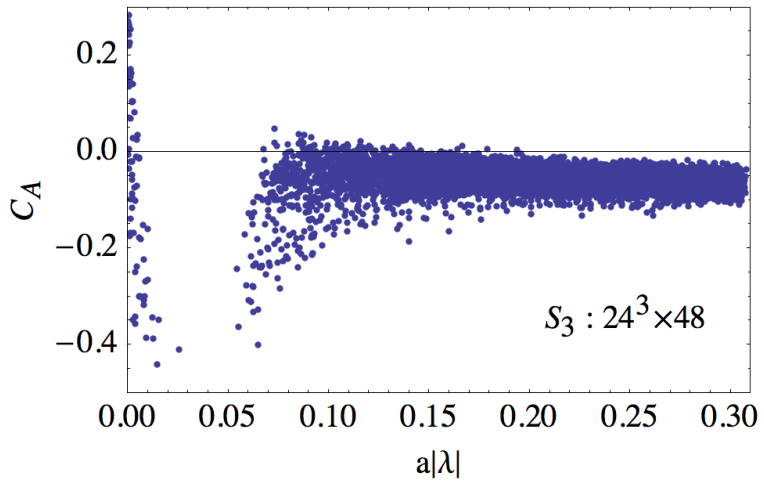


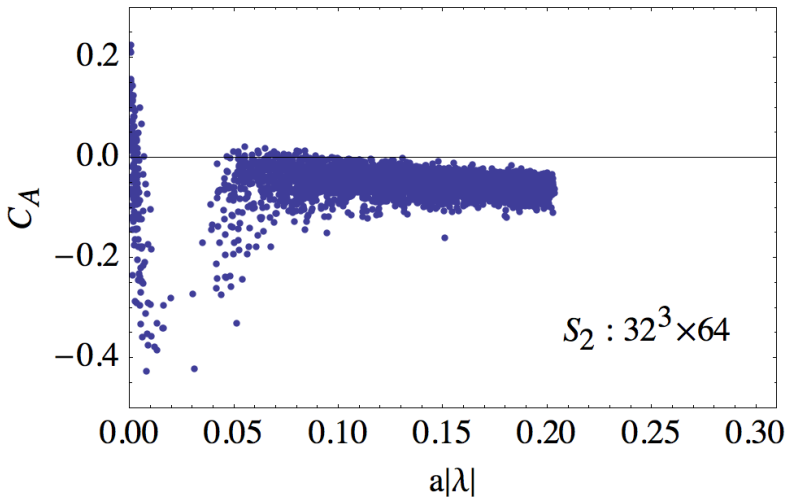


N_f=12 … volume









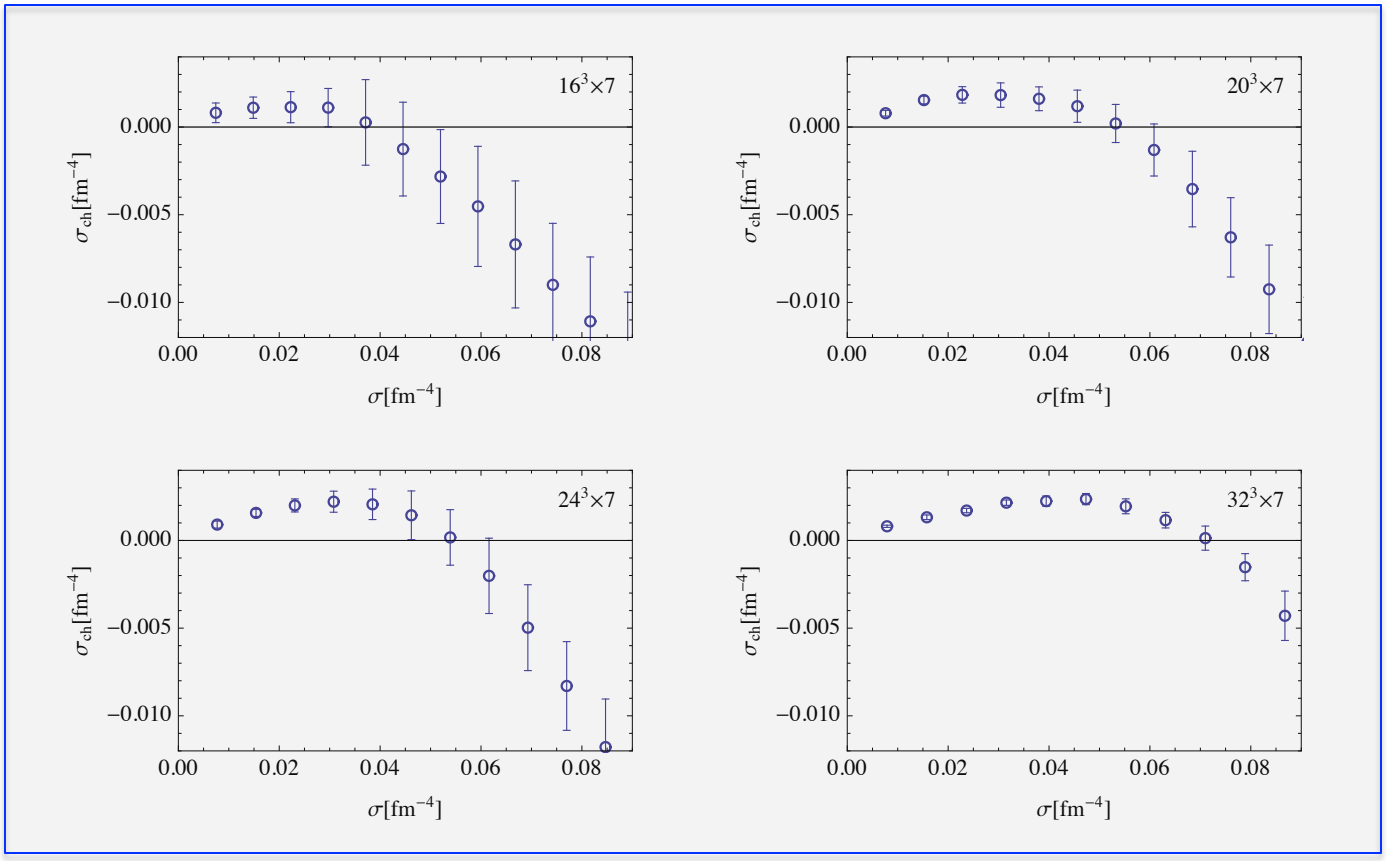
correlation coefficients for individual overlap modes

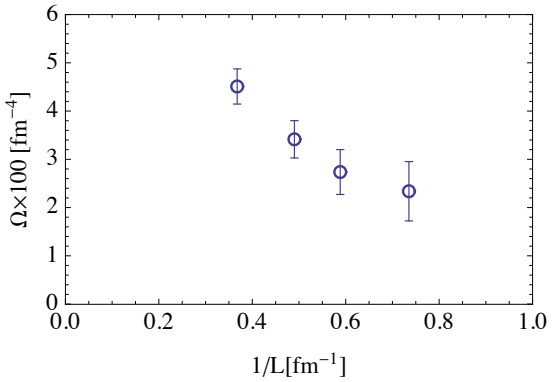
Apparently stable!

Summary

- Underlying idea: symmetry breaking $\Longleftrightarrow$ local NP correlation
- Here: vSChSB $\Longleftrightarrow$ Chiral Polarization
- vSChSB-ChP corespondence holds in all known studied cases!
  [New characterization of QCD vacuum/thermal states. Phase diagrams etc.]
- Anomalous temperature phase in N_f=0 screams it is real!
- *There is an anomalous phase(in mass) at N_f=12!!!*
  - Does it survive continuum limit?
  - Does it exist with fewer flavors?
  - Is m_{cr}>0? (conformal window issue)
  - What are physical consequences?
  - To what extent are thermal fluctuations and quantum fluctuations due to many flavors similar?

Volume at fixed cutoff:





vSChSB – ChP correspondence holds!