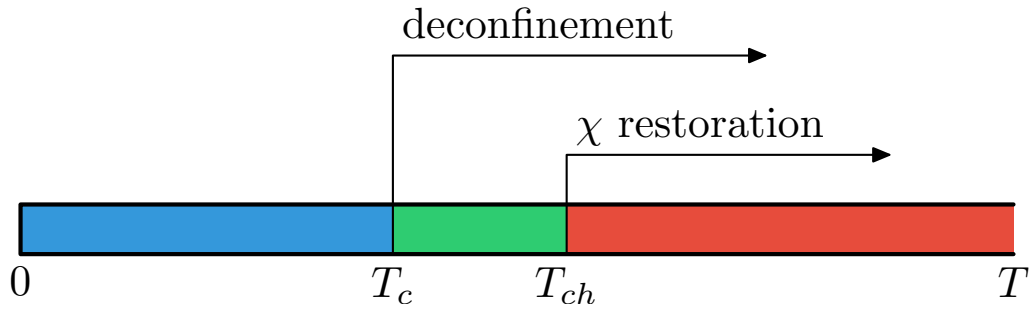
Deconfinement, Chiral Symmetry Breaking and Chiral Polarization

A. Alexandru & I. Horváth

Interested in two aspects:

(1) The existence of "mixed phase" in N_f=0 theory

Edwards, Heller, Kiskis, Narayanan, 1999

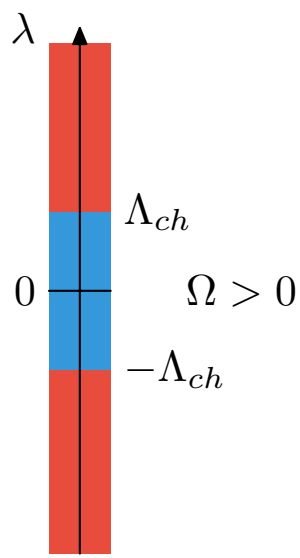


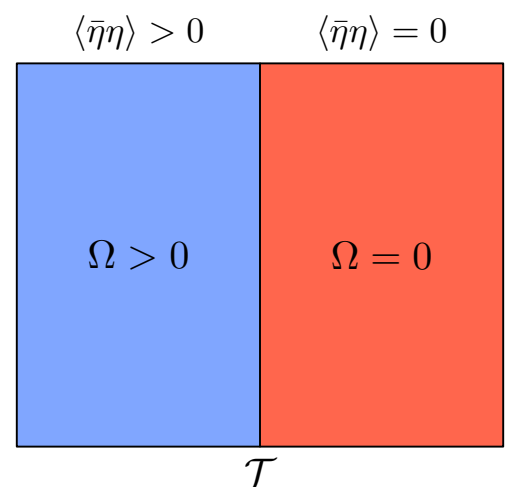
Real Polyakov line vacuum!

(2) Valence SChSB – Chiral Polarization correspondence

Alexandru, Horvath, 2012

$$\langle \bar{\eta}\eta \rangle > 0 \quad \Longleftrightarrow$$





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

Two Questions/Goals:

(A) Is mixed phase in N_f=0 QCD for real? [finite cutoff & continuum]

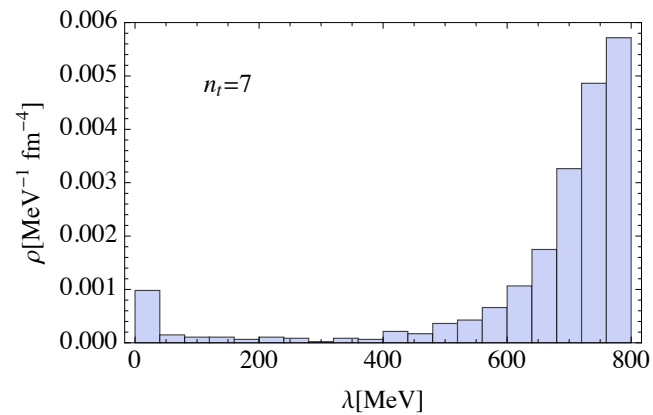
(B) Does vSCHSB – ChP correspondence hold there? [finite cutoff & continuum]

Discussion with three parts:

(i) Qualitative overview

[A.Alexandru, IH, arXiv:1210.7849, arXiv:1211.3728]

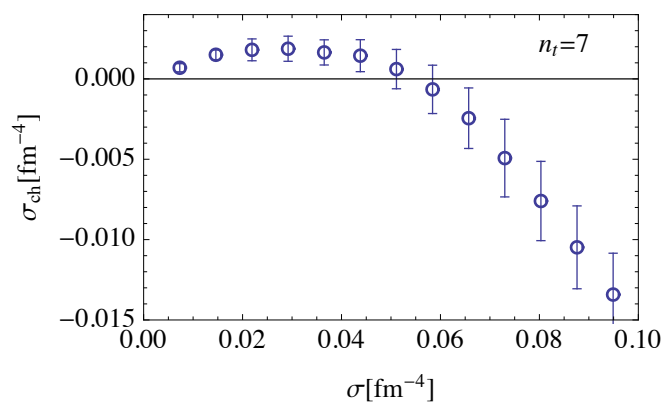
- Overlap massless valence probe appears important



(ii) (A) and (B) at finite cutoff

[A.Alexandru, IH, arXiv:1405.2968]

- Infinite-volume considerations essential



(iii) (A) and (B) in the continuum limit

[A.Alexandru, IH, ongoing work]

The Tools:

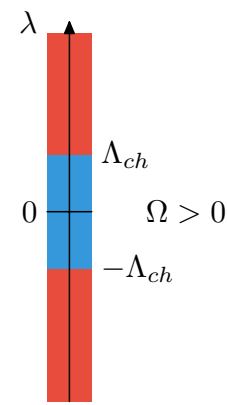
◆ For valence Spontaneous Chiral Symmetry Breaking (vSChSB) : use $\rho(\lambda \to 0)$

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

$$\text{vSChSB} \quad \Longleftrightarrow \quad \text{mode condensation}$$

Banks, Casher, 1980

◆ For dynamical Chiral Polarization (ChP) : use Ω



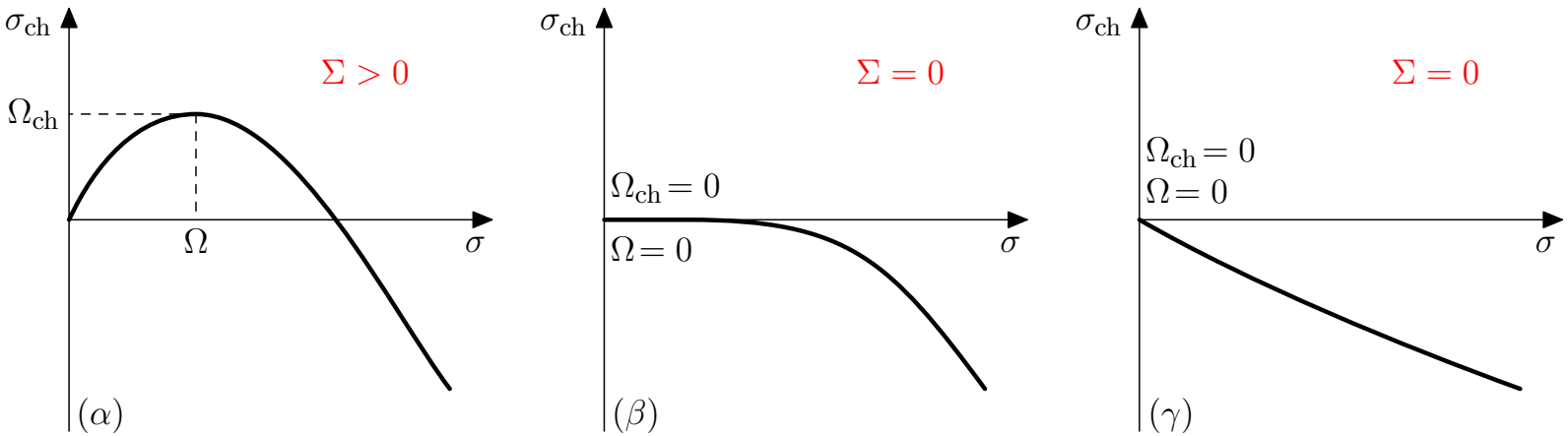
C_A – correlation coefficient of polarization (non—Pearson)

Alexandru, Draper, Horvath , Streuer, 2010

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

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

…continued:



Lattice setup:

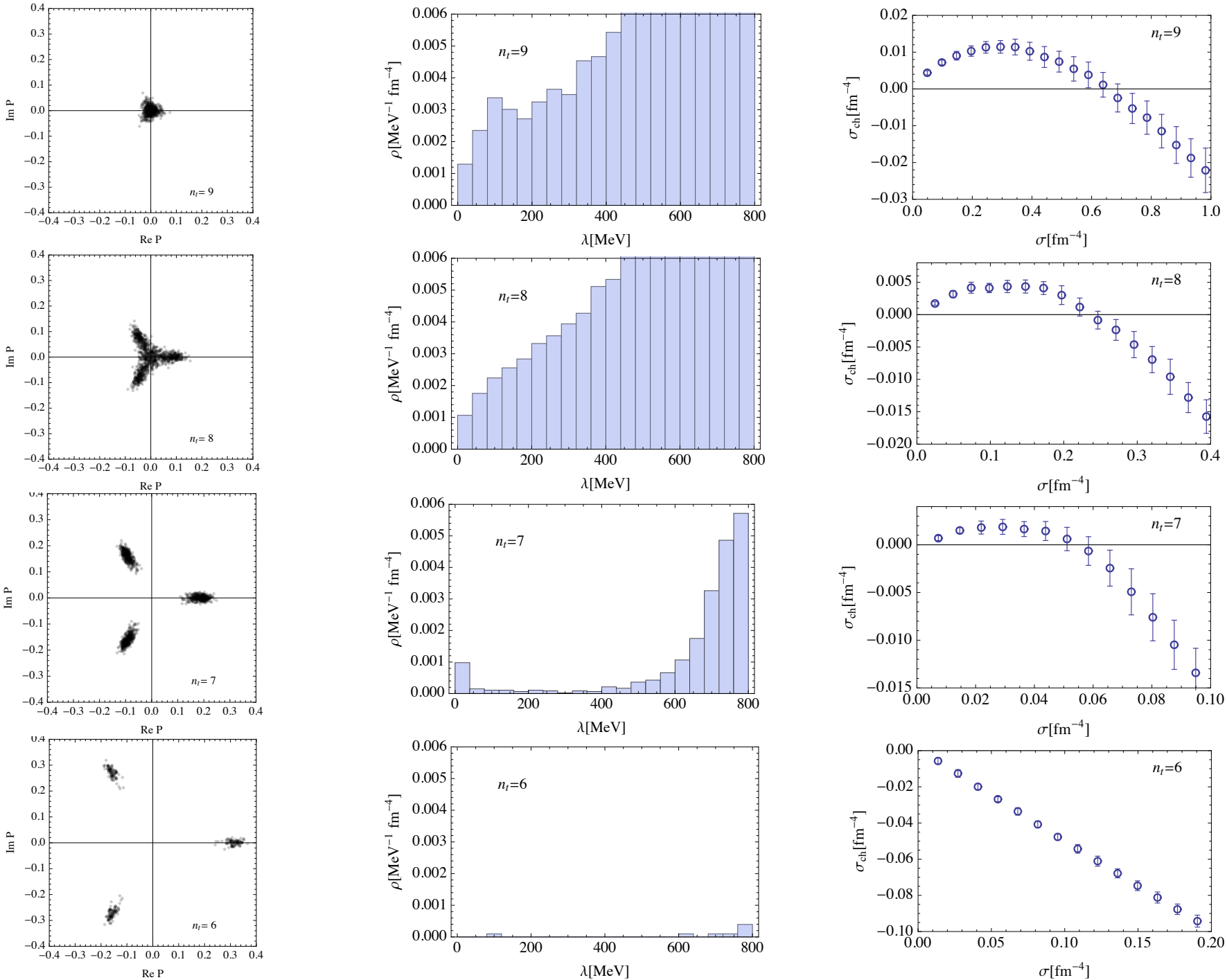
- Wilson gauge action: scale from r_0=0.5 fm
- Overlap valence probe with Wilson kernel: r=1, ρ=26/19

(i) Qualitative overview

- Change temperature with fixed 3-volume
- Fixed-scale approach
- Focus on transition region here

Ensemble	N_t	T/T_c	T[MeV]	N_{cfg}	$\lvert\lambda\rvert^{av}_{min}$	$\lvert\lambda\rvert_{min}$	$\lvert\lambda\rvert^{av}_{max}$	$\lvert\lambda\rvert_{max}$
E_1	20	0.42	116	100*	0.0204	0.0027	0.6128	0.6160
E_2	12	0.70	193	200*	0.0320	0.0065	0.7241	0.7270
E_3	10	0.84	232	200	0.0379	0.0018	0.7658	0.7701
E_4	9	0.93	258	200	0.0402	0.0039	0.7912	0.7944
E_5	8	1.05	290	400	0.0859	0.0011	0.8208	0.8246
E_6	7	1.20	331	400	0.2473	0.0006	0.8631	0.8675
E_7	6	1.39	386	100	0.4038	0.0498	0.9233	0.9283
E_8	4	2.09	579	100	0.7868	0.7129	1.1608	1.1673

$20^3 \times N_t$ system at β=6.054, a=0.085 fm


Im P
Re P
n_t= 9
n_t= 8
n_t= 7
n_t= 6
ρ[MeV^{-1} fm^{-4}]
λ[MeV]
n_t=9
n_t=8
n_t=7
n_t=6
σ_{ch}[fm^{-4}]
σ[fm^{-4}]

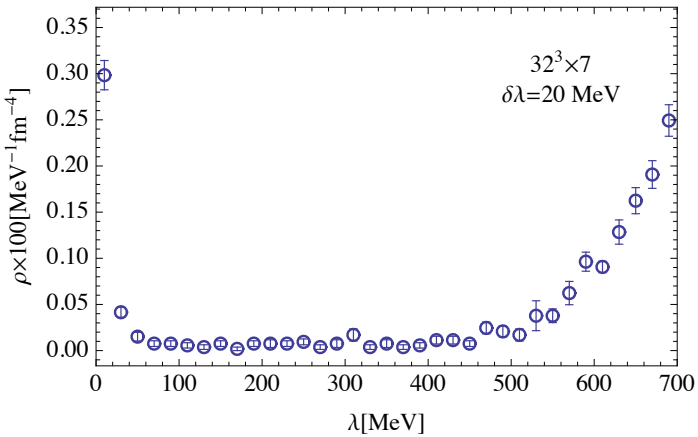
(ii) Fixed Cutoff

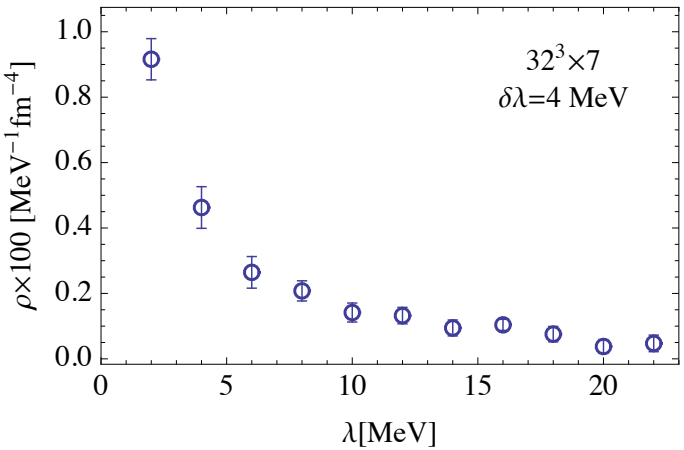
- Change 3-volume at N_t=7 of candidate mixed phase

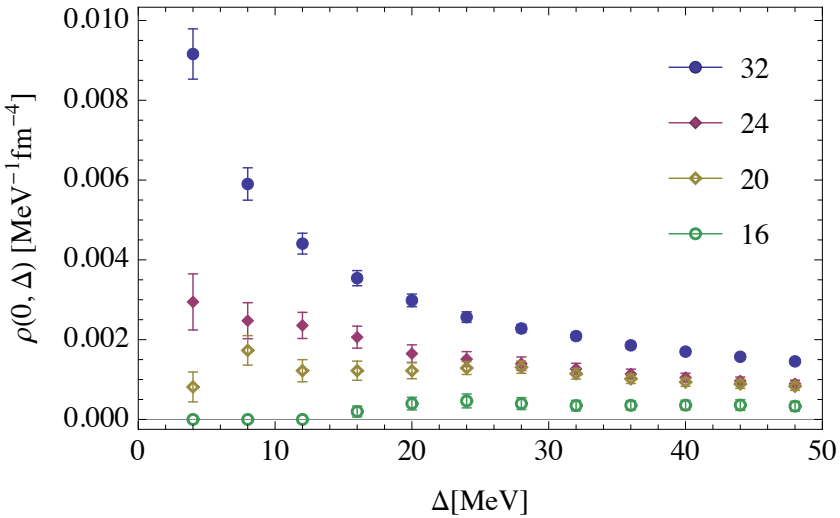
Ensemble	N	L[fm]	N_{cfg}	$\lvert\lambda\rvert^{av}_{min}$	$\lvert\lambda\rvert_{min}$	$\lvert\lambda\rvert^{av}_{max}$	$\lvert\lambda\rvert_{max}$
G_1	16	1.36	400	0.30151	0.00551	1.02954	1.03476
E_6	20	1.70	400	0.24730	0.00060	0.86310	0.86750
G_2	24	2.04	400	0.20030	0.00009	0.74692	0.75336
G_3	32	2.72	200	0.06746	0.00005	0.59845	0.60793

N^3 x 7 system at β=6.054, a=0.085 fm

… Fixed Cutoff: vSChSB





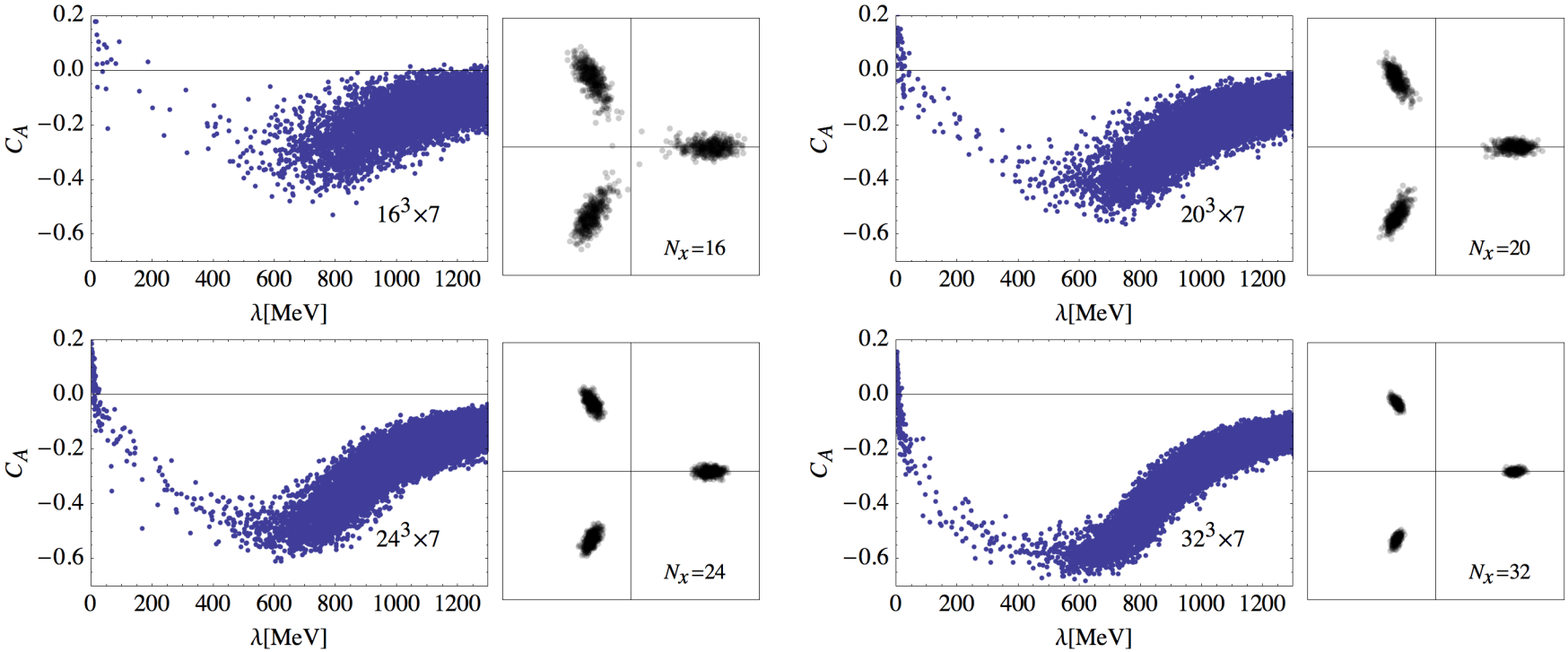


$$\rho(\lambda=0,\Delta,V) \equiv \frac{1}{\Delta}\,\sigma(\lambda=\Delta,V)$$

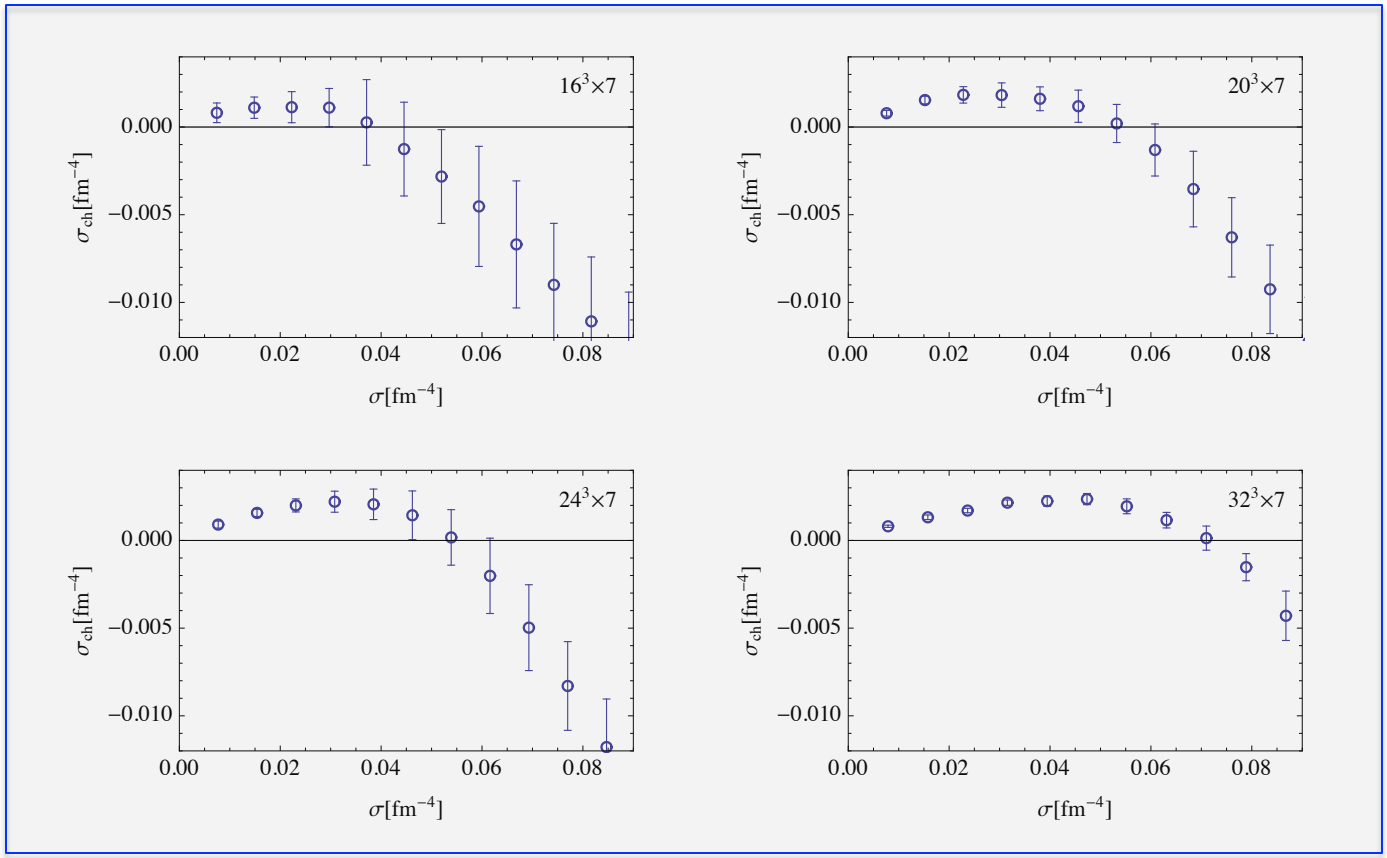
Coarse—grained mode—condensation parameter

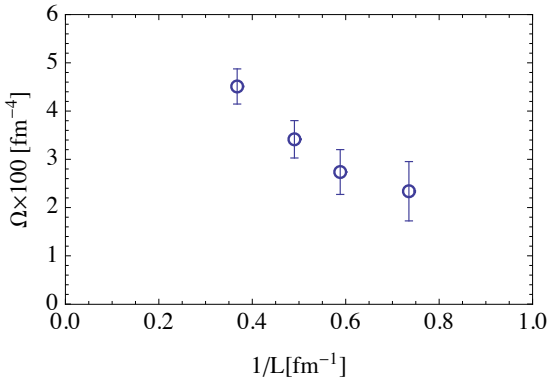
Very little doubt that this is
a mode—condensing theory!

… Fixed Cutoff: Chiral Polarization



… Fixed Cutoff: Chiral Polarization…





Very little doubt that the theory is chirally polarized!

vSChSB – ChP correspondence holds!

(iii) Continuum Limit

Work in progress!

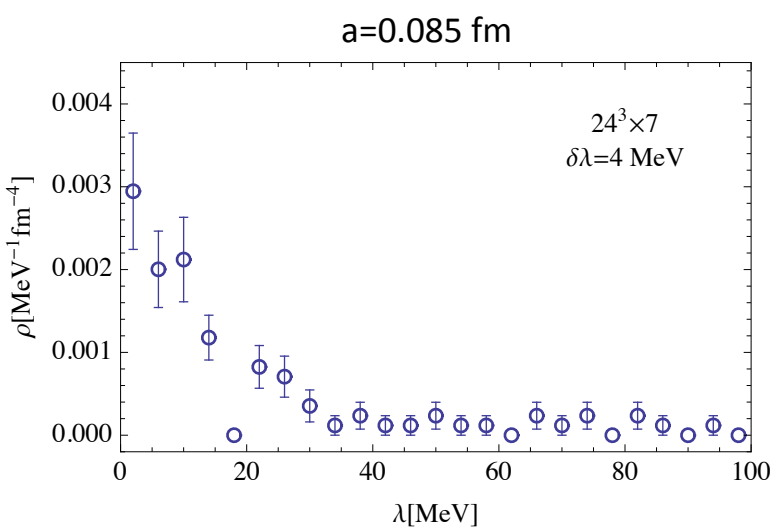
- Change β while keeping T/T_c and 3-volume fixed (corresponds to N_t=7 at β=6.054)

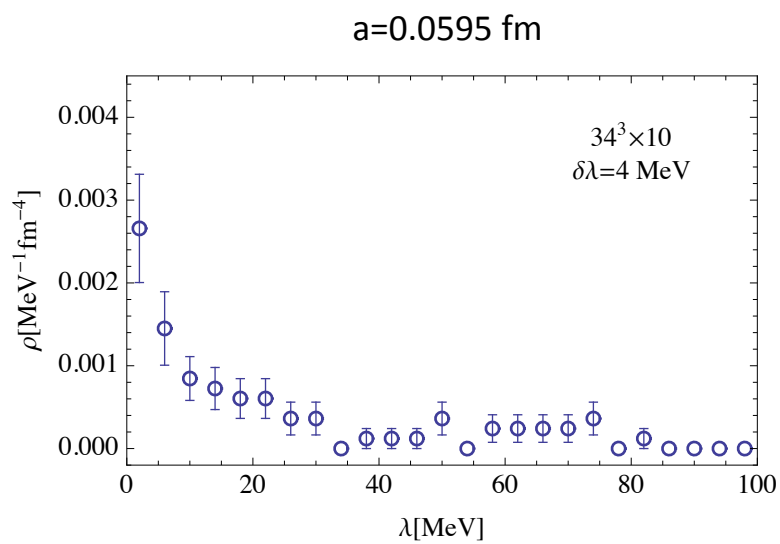
N_t	a[fm]	a/r_0	N	L[fm]
6	0.0992	0.1984	20	1.984
7	0.0850	0.1701	24	2.040
8	0.0744	0.1488	28	2.083
9	0.0661	0.1323	32	2.115
10	0.0595	0.1190	34	2.023
11	0.0541	0.1082	38	2.056
12	0.0496	0.0992	42	2.083

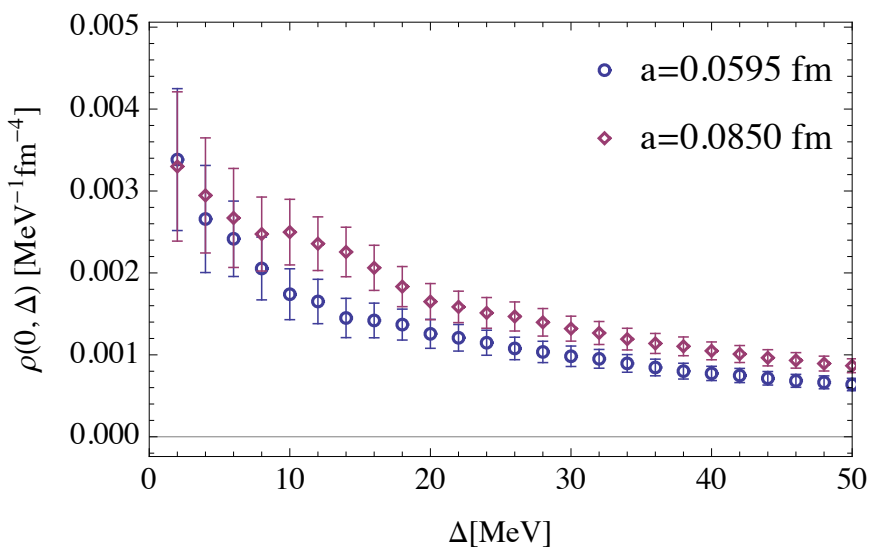
$N^3 \times N_t$ system

$T=1.12\ T_c$

Continuum Limit…vSChSB

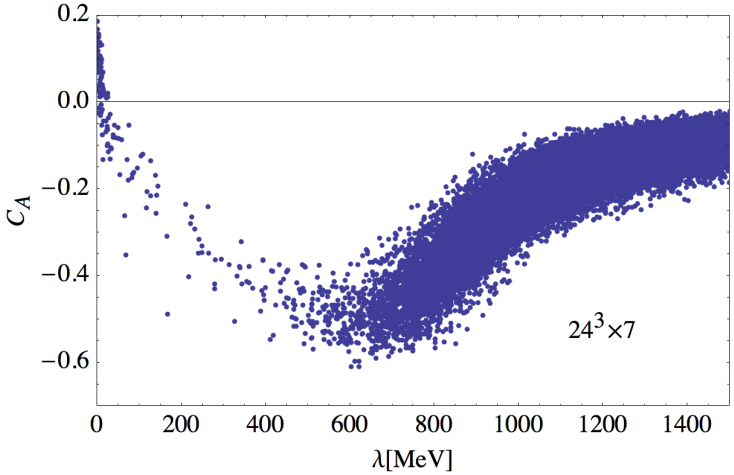




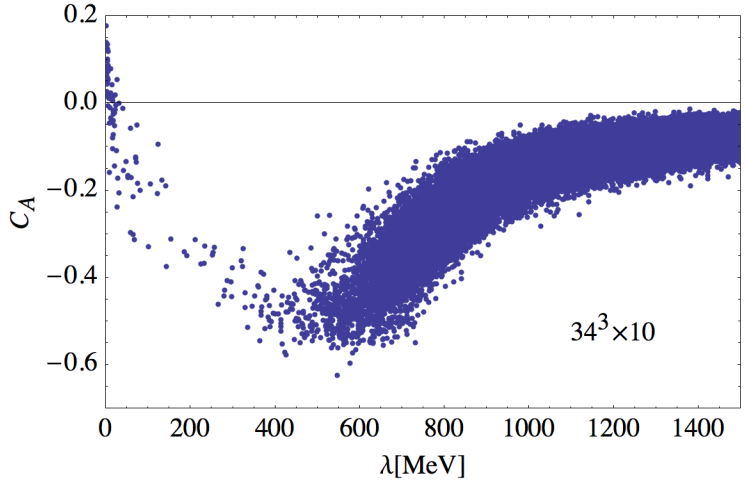


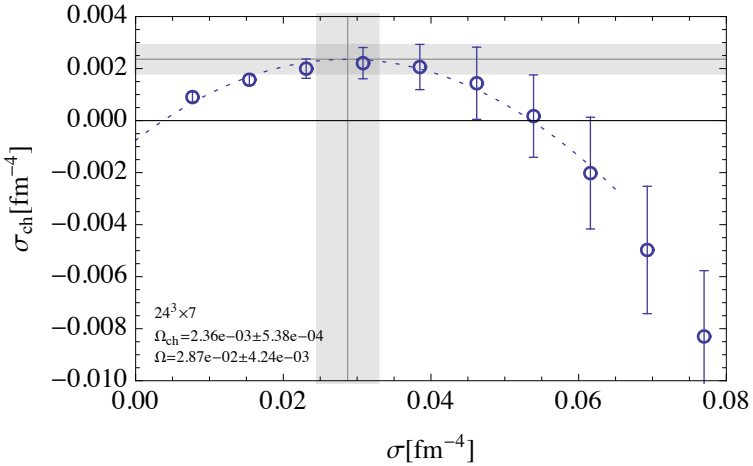
Continuum Limit…Chiral Polarization

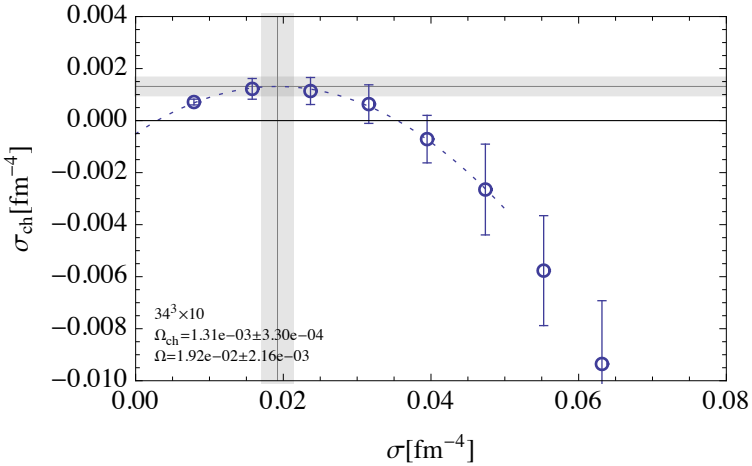
a=0.085 fm



a=0.0595 fm







Additional ensembles need to be examined!

Summary and Discussion

- The mixed phase in N_f=0 theory at finite ultraviolet cutoff is for real and it complies with vSChSB—ChP correspondence!

- Non—trivial cutoff increase doesn't change the situation qualitatively! But making statement in the continuum requires detailed quantitative analysis. In progress…

- Important that this gets resolved because it determines how one views sightings of similar anomalous behavior in more physical setups.

  Sharma et al arXiv:1311.3943, Bukhov et al arXiv:1309.4149

- If it turns out to be the lattice phase only then curious role played by overlap/domain wall operator.

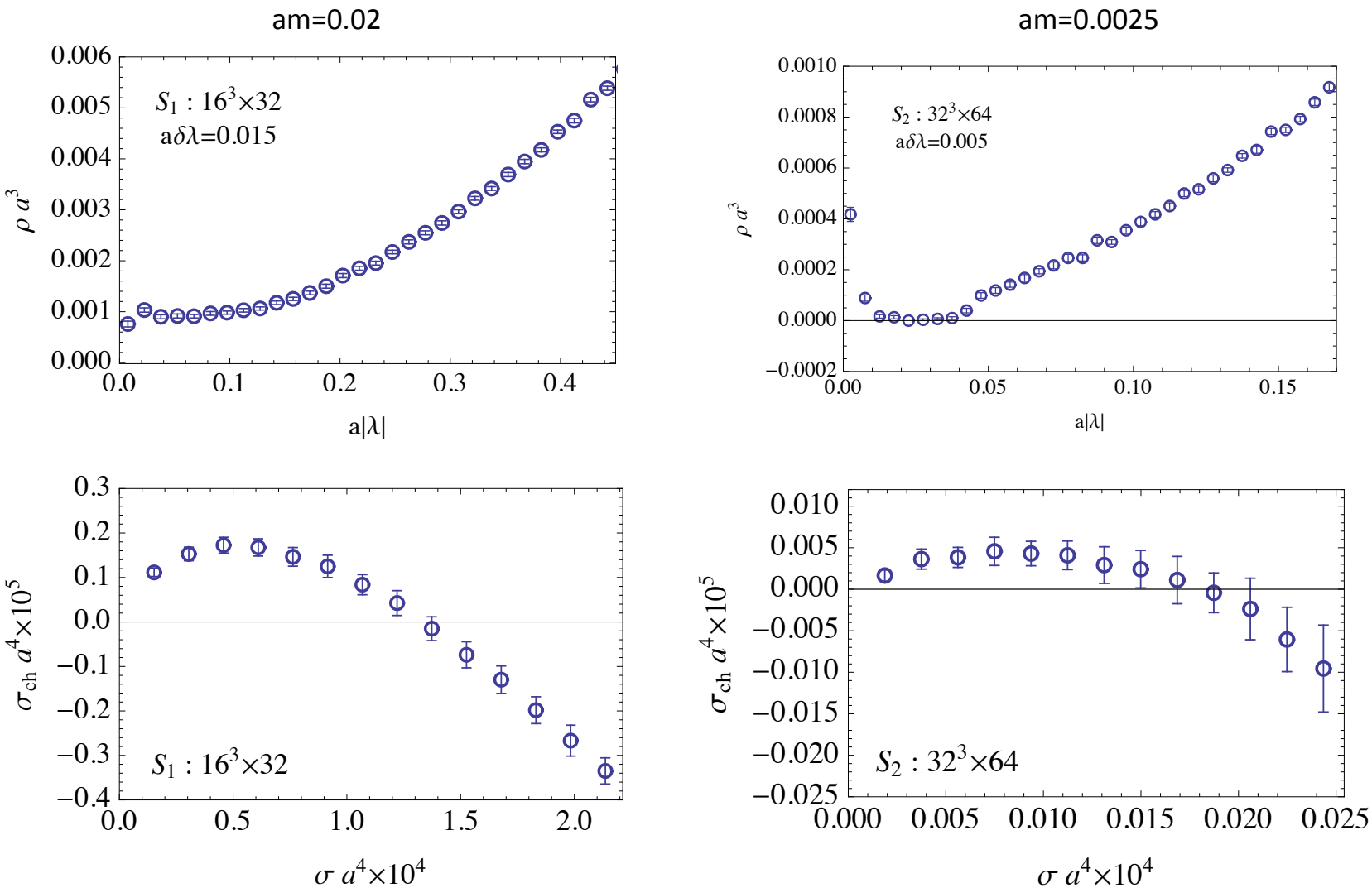
- Similar "anomalous phase" also seen in N_f=12 by overlap on staggered backgrounds when lowering quark mass.

  Alexandru, Horvath, arXiv:1405.2968 Thanks to Anna Hasenfratz & David Schaich for ensembles!

Thanks to Mingyang Sun!

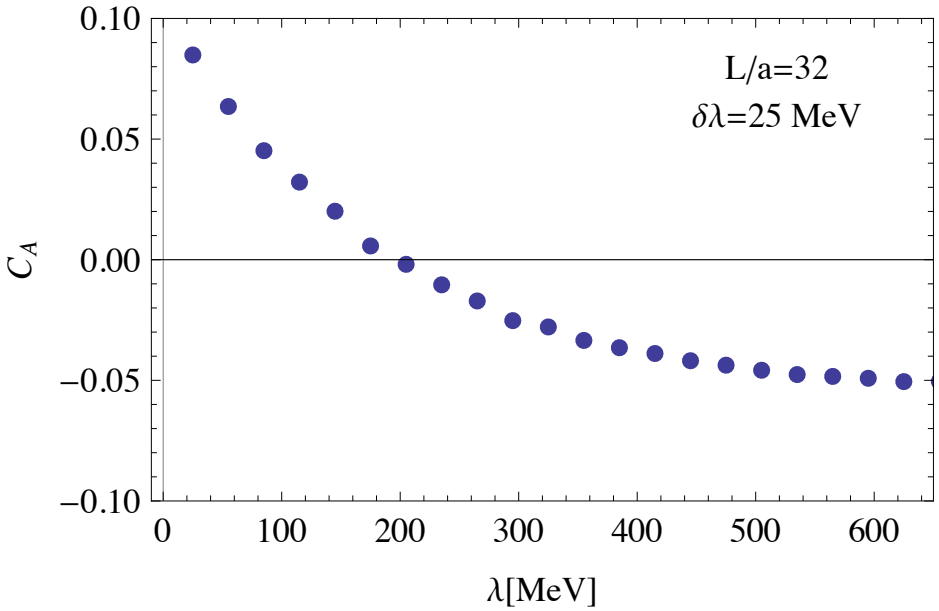
N_f=12 "anomalous" phase via lowering the quark mass

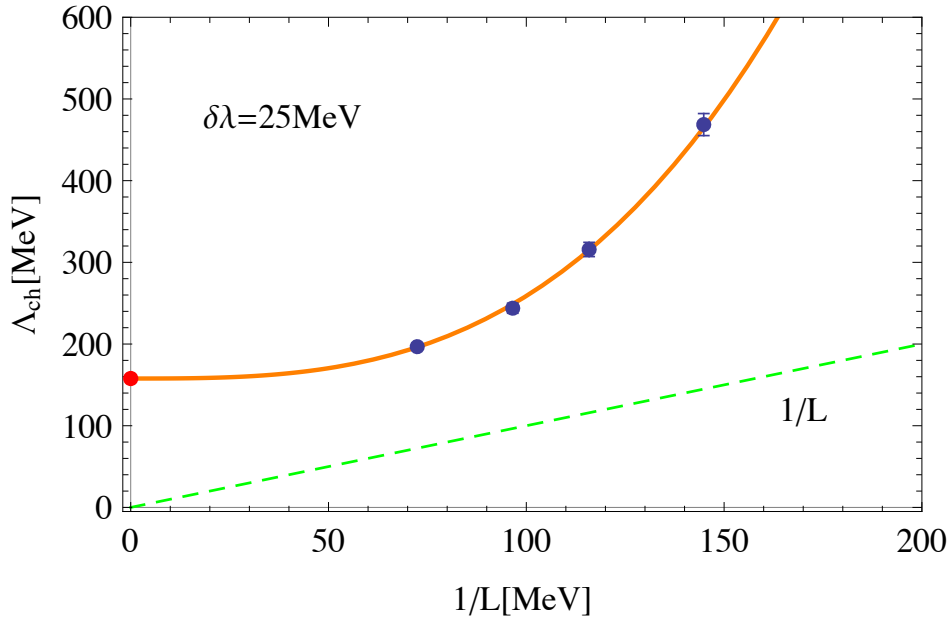
Ensembles from A. Hasenfratz et al, arXiv:1207.7162



Infinite Volume at Zero Temperature

- N_f=0 QCD, Wilson action, overlap Dirac operator
- a=0.085 fm (r_0)
- V = 16^4, 20^4, 24^4, 32^4

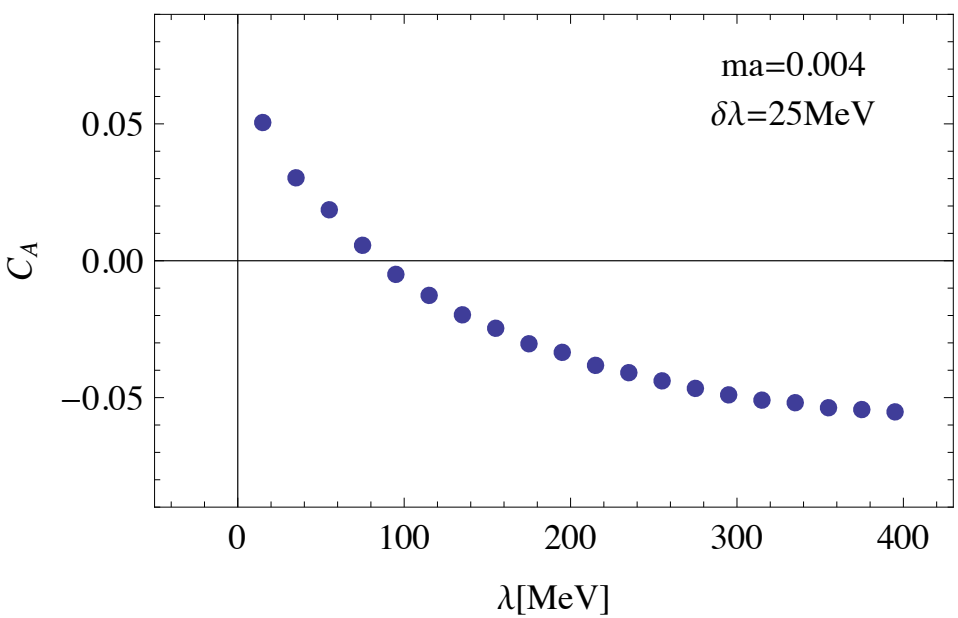


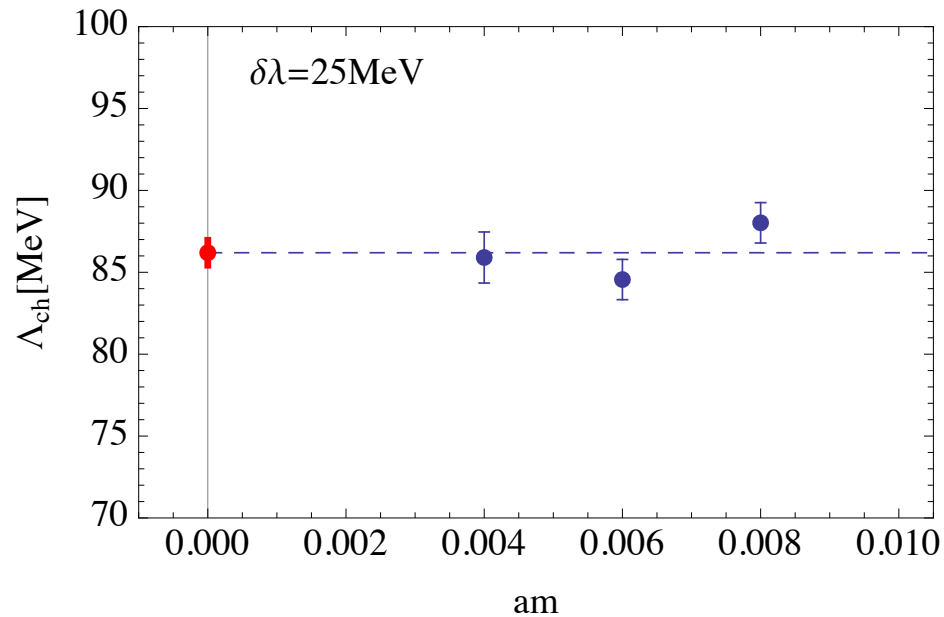


Λ_{ch} IS A TRUE DYNAMICAL SCALE, DISTINCT FROM INFRARED CUTOFF

Light Quarks at Zero Temperature

- N_f=2+1 QCD, Domain Wall Fermions (RBC), overlap Dirac probe
- a = 0.085 fm
- V = 32^3x64, am_l=0.004, 0.006, 0.008 lightest $m_\pi \approx$ 295 MeV





CHIRAL POLARIZATION IN MASSLESS LIMIT! FEATURE OF SChSB.

Old fact:

$$\lim_{m\to 0}\langle\bar{\psi}\psi\rangle_m \neq 0 \quad \Longleftrightarrow \quad \lim_{m\to 0}\rho(\lambda\to 0, m)\neq 0$$

SChSB $\Longleftrightarrow$ mode condensation

New Conjecture:

$$\lim_{m\to 0}\langle\bar{\psi}\psi\rangle_m \neq 0 \quad \Longleftrightarrow \quad \lim_{m\to 0}\rho_{ch}(\lambda\to 0, m)> 0$$

SChSB $\Longleftrightarrow$ chirality condensation

$$\rho_{ch}(\lambda, M, V) \equiv \frac{1}{V}\sum_k \langle\, \delta(\lambda-\lambda_k)\, C_{A,k}\,\rangle_{M,V}$$

density of chiral polarization