MONOPOLES & CONFINEMENT

Adriano DI GIACOMO

PISA UNIV. & INFN

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[FILLING FOR T. DEGRAND]

I. WHY MONOPOLES?

I_1 CONFINEMENT

P. D. G.

- SEARCH FOR QUARKS IN NATURE : NEVER FOUND

$n_q/n_p \lesssim 10^{-27}$ S.C.M. $\frac{n_q}{n_p} \simeq 10^{-12}$ [OKUN]

- SEARCH FOR QUARKS IN HIGH ENERGY REACTIONS

$\sigma_q \equiv \sigma(p+p \to q(\bar{q})+X) \lesssim 10^{-40} cm^2$

P.T $\sigma_q \approx \sigma_{TOT} \simeq 10^{-25} cm^2$

INHIBITION FACTOR $< 10^{-15}$!

NATURAL EXPLANATION

$n_q = 0$ $\sigma_q = 0$

DUE TO SOME SYMMETRY.
CONFINEMENT AN ABSOLUTE PROPERTY [t'Hooft 7…]

- ORDINARY SUPERCONDUCTORS

LIFETIME OF PERMANENT CURRENTS $T > 10^5 y$

$\rho_{SC} \leq 10^{-16} \rho_{NOR} \Longrightarrow \rho_{SC} = 0$ HIGGS BREAKING OF U(1)

- NATURAL SCENARIO:
  DECONFINEMENT IS A CHANGE OF SYMMETRY
  i.e AN ORDER—DISORDER TRANSITION.

- A CROSSOVER UNNATURAL: EXPLAIN
  A CHANGE BY 10^{-15} ACROSS A CONTINUOUS
  PATH!

TO BE CHECKED ON LATTICE.

$\boxed{\text{– WHAT SYMMETRY?}}$

I2 DECONFINEMENT & SYMMETRY.

- SU(3)$_c$ IS AN EXACT SYMMETRY.
  - PERTURBATIVE VACUUM IS COLORLESS
  - NON PERTURBATIVE TEST DIFFICULT.

IS THERE ROOM FOR AN EXTRA SYMMETRY?

- IN PURE GAUGE THEORY : YES

ACTION INVARIANT UNDER $SU(3)/Z_3$

Z_3 IS AN EXTRA SYMMETRY IF THEORY IS FORMULATED IN FUNDAMENTAL REPR. (LATTICE)

ORDER PARAMETER : POLYAKOV LINE $\langle L \rangle$

$$L(\vec{x}) = \mathrm{Tr}\left[P \exp \int_0^{1/T} A_0(\vec{x}, t)\, dt \right]$$

CREATES AN EXTERNAL STATIC QUARK AT $\vec{x}$.

$$G(\vec{x}) \equiv \langle L^{+}(\vec{x})\, L(0) \rangle \underset{|\vec{x}| \to \infty}{\simeq} |\langle L \rangle|^2 + K e^{-\frac{\sigma x}{T}}$$

$$V(\vec{x}) = -T \ln G(x) \underset{x \to \infty}{\simeq} \begin{cases} \sigma x & |\langle L \rangle| = 0 \\ \text{const} & |\langle L \rangle| \neq 0 \end{cases}$$

$$\langle L \rangle \simeq e^{-F_q/T}$$

- IN FULL QCD Z_3 IS NOT A SYMMETRY

- STRING IS BROKEN

- NO WAY TO DEFINE CONFINED vs DECONFINED SEE FIG ! ($N_f=2$ QCD)

- Z_3 IS NOT THE SYMMETRY WE ARE LOOKING FOR.

_ SOME COMMENTS ON FIG 1 _

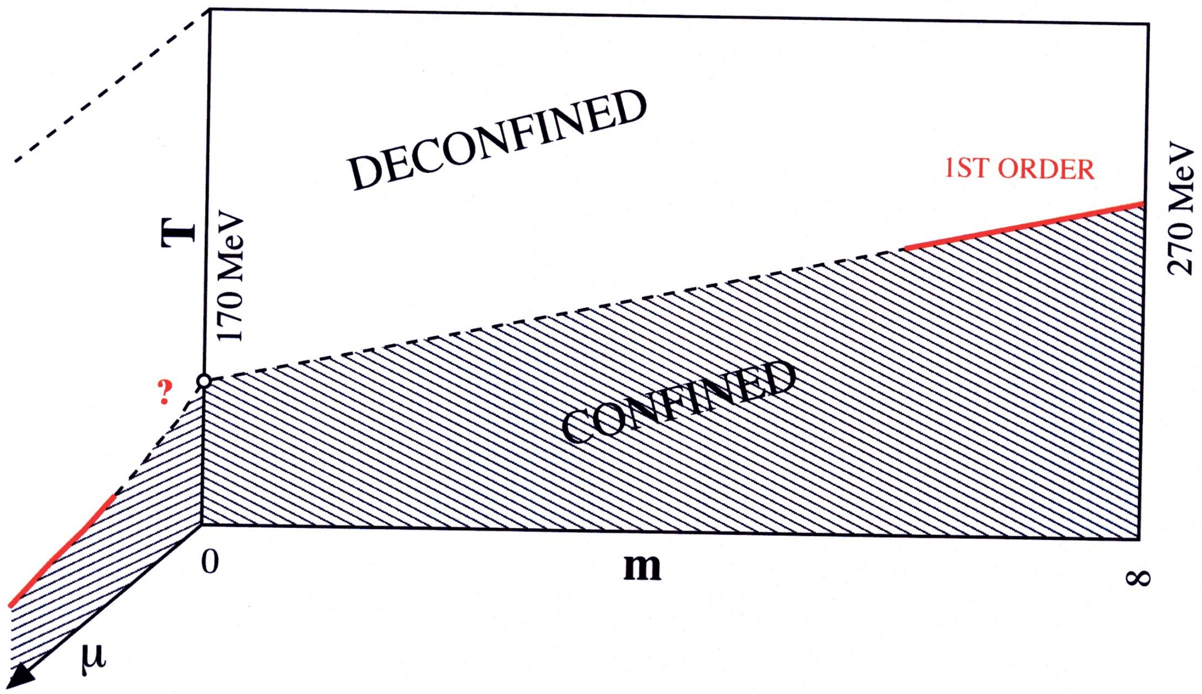
- THE LINE IS DEFINED BY THE MAXIMA OF SUSCEPTIBILITIES C_V, $\chi_{\bar\psi\psi}$, $\chi_{\langle L\rangle}$ WHICH COINCIDE WITHIN ERRORS : HEAT CONTENT, $\langle\bar\psi\psi\rangle$, $\langle L\rangle$ UNDERGO A RAPID CHANGE AT THE SAME T.

- AS $m\to\infty$ THE THEORY → QUENCHED : THE TRANSITION IS FIRST ORDER (WEAK)

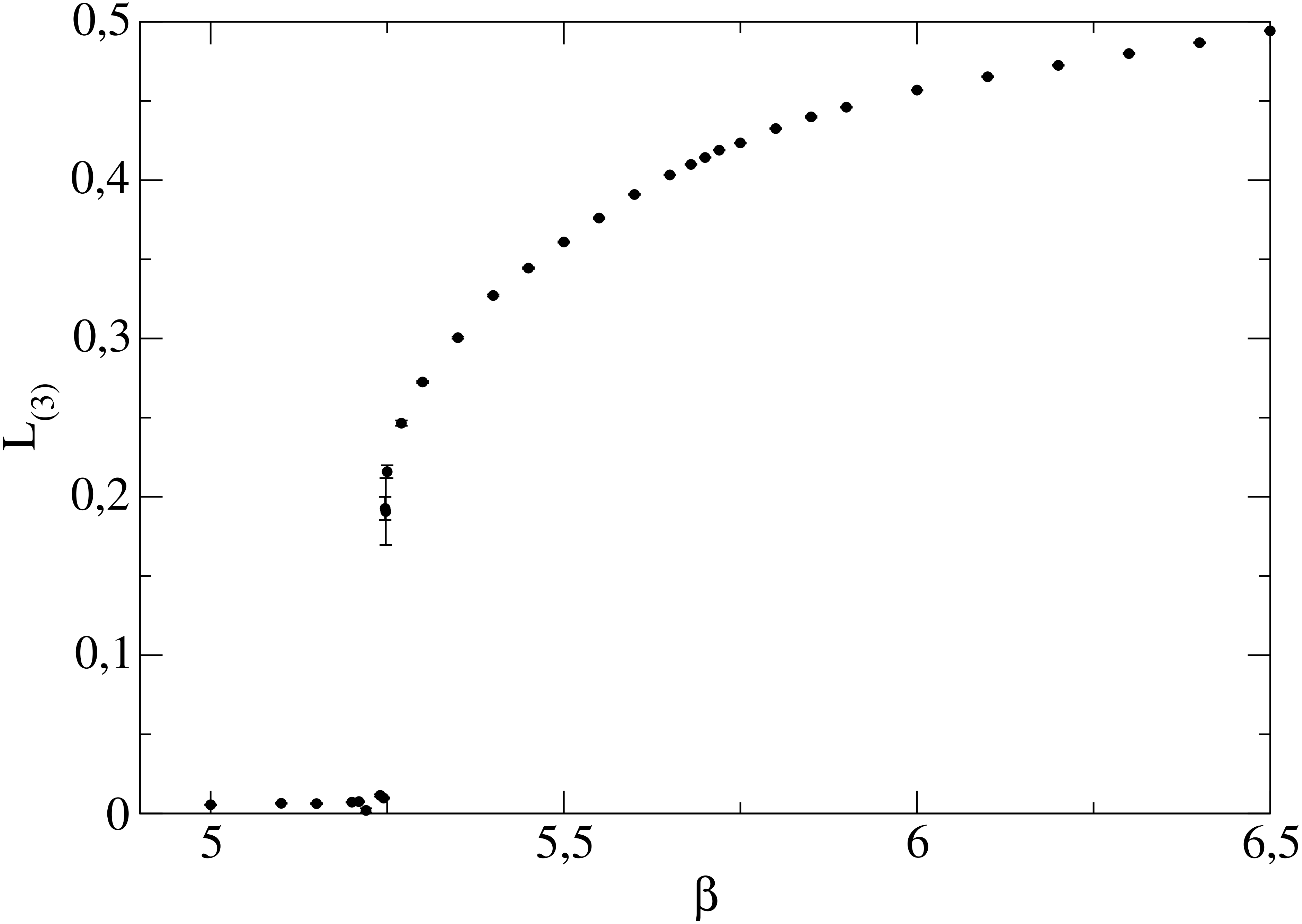
- AT $m=0$ CHIRAL SYMMETRY IS RESTORED AND $U_A(1)$ POSSIBLY

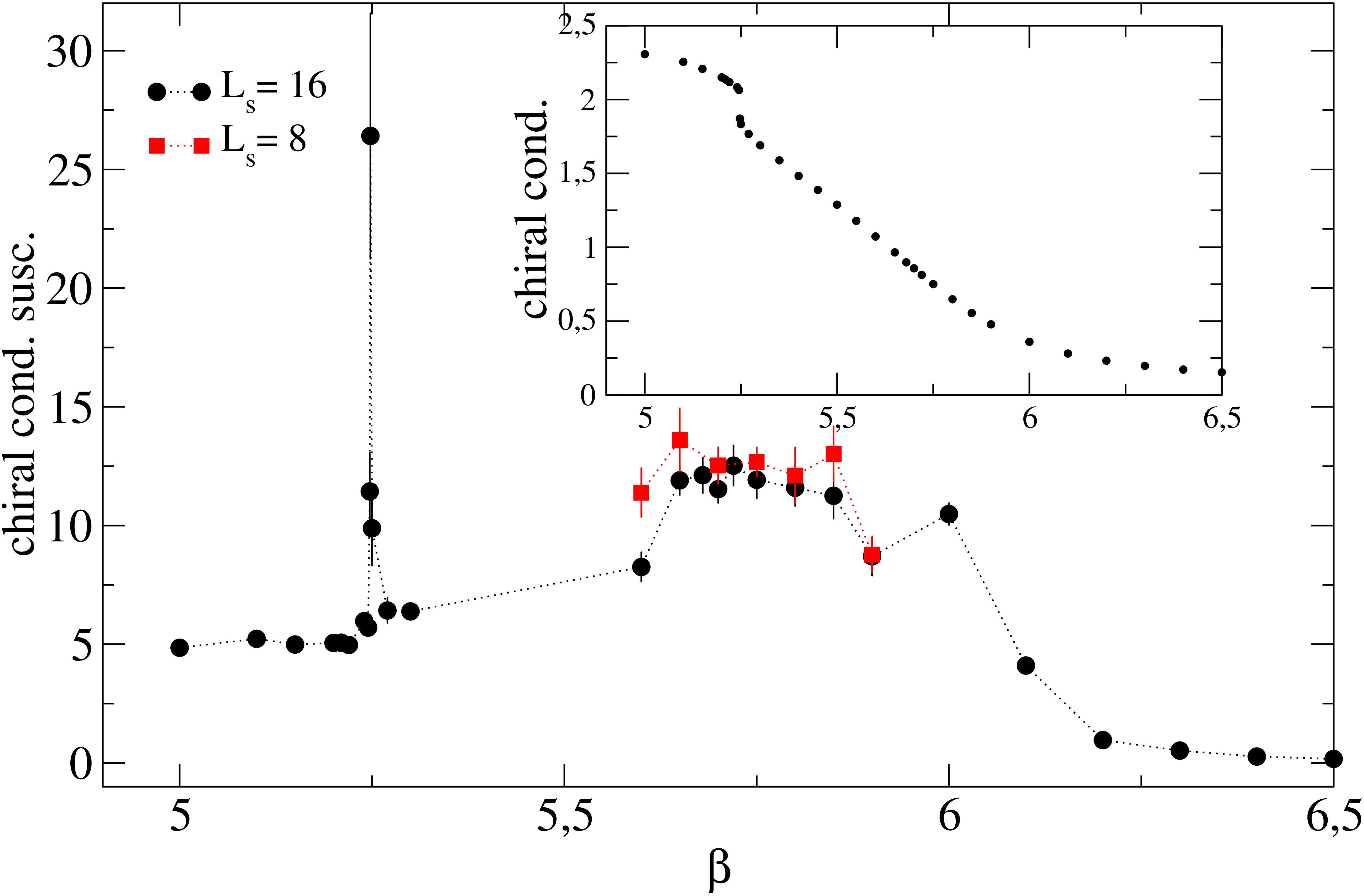
- ASSUMING THAT CHIRAL SYMMETRY IS THE ONLY RELEVANT SYMMETRY [Pisarski, Wilczek 84]
  - EITHER THE TRANSITION AT $m=0$ IS 2nd ORDER O(4) AND AT SMALL m,μ A CROSSOVER [TRICRITICAL POINT]
  - OR IT IS FIRST ORDER BOTH AT $m,\mu=0$ AND SMALL m,μ. [NO TRICRITICAL POINT]

- (DE) CONFINEMENT ? A SYMMETRY NEEDED TO DEFINE IT! → ADJOINT QCD [Karsch et al, B'Elia et al] FIGS.



DECONFINED
1ST ORDER
T
170 MeV
270 MeV
?
CONFINED
0
m
∞
μ


0,5
0,4
0,3
0,2
0,1
0
L(3)
5
5,5
6
6,5
β



chiral cond. susc.
β
$L_s = 16$
$L_s = 8$
chiral cond.
0
5
10
15
20
25
30
5
5,5
6
6,5
0
0,5
1
1,5
2
2,5

I_3 DUALITY

- FINITE T FIELD THEORY

$$Z[T] \equiv \mathrm{Tr}\{e^{-H/T}\} = \int [\mathcal{D}\varphi]\, e^{-\int_{-\infty}^{+\infty} d^3x \int_0^{1/T} dt\, \mathcal{L}[\varphi(\vec{x},t)]}$$

p.b.c FOR BOSONS a.b.c FOR FERMIONS

- LATTICE QCD.

FEYNMAN INTEGRAL : LATTICE $L_s^3 \cdot L_t$

$$a L_s \gg \frac{1}{\Lambda_{QCD}} \qquad L_s \gg L_t$$

$$T = \frac{1}{a(\beta, m) L_t} \qquad \beta \equiv \frac{2N_c}{g^2};$$

m = BARE q MASS.

- $a(\beta, m) \underset{\beta\to\infty}{\simeq} \frac{1}{\Lambda_{QCD}} e^{-\beta b_0}$ $\quad$ $- b_0 = -\frac{1}{(4\pi)^2} \frac{11 N_c - 2N_f}{3}$

ASYMPTOTIC FREEDOM

AS $\beta \to \infty$ $\quad a \to$ SMALL IN PHYSICAL UNITS (CONTINUUM LIMIT)

$$T \cong \frac{\Lambda_{QCD}}{L_t} e^{\beta b_0} \qquad \beta = \frac{2N_c}{g^2}$$

SMALL T $\longleftrightarrow$ LARGE g (DISORDERED) CONF.

LARGE T $\longleftrightarrow$ SMALL g (ORDERED) DECONF.

- DUALITY [Kramers-Wannier 41, Kadanoff Ceva 72]

- 2d ISING MODEL (EXACTLY SOLVABLE) SQUARE LATTICE

$\sigma = \pm 1 \qquad \frac{H}{T} = -\sum_{i,j\,n.n.} J\sigma_i\sigma_j \qquad J = \frac{K}{T} \qquad Z[\sigma, T]$

- CURIE POINT $T_c = 2\cancel{K}/\ln(1+\sqrt{2})$

$T < T_c \quad \langle\sigma\rangle \neq 0 \qquad T \geq T_c \quad \langle\sigma\rangle = 0$

- KINK $\quad \mu_\pm(x_0, t) \quad \{\sigma = \mp 1 \ x < x_0 \,;\ \sigma = \pm 1 \ x \geq x_0 \ t \text{ fix}\}$

$\mu^2 = 1$

$$Z[\sigma, T] = Z[\mu, T^*]$$

$\langle\mu\rangle = 0 \ T \leq T_c$

$\langle\mu\rangle \neq 0 \ T > T_c$

$$\sinh\frac{2}{T} = \frac{1}{\sinh\frac{2}{T^*}} \qquad T \sim \frac{1}{T^*}$$

- TOPOLOGICAL SYMMETRY

$$j_\mu = \frac{1}{2}\varepsilon_{\mu\nu}\Delta_\nu\sigma \qquad \Delta_\mu j_\mu = 0$$

TOPOLOGICAL CHARGE $\quad Q = \int j_0(\vec{x}, t)\, d^3x = \int_{-\infty}^{+\infty} \varepsilon_{0i}\Delta_i\sigma = \frac{1}{2}\left[\sigma(+\infty) - \sigma(-\infty)\right]$

DIRECT DESCRIPTION	DUAL DESCRIPTION
LOCAL FIELDS $\phi(x)$	μ LOCAL
ORDER PARAM. $\langle\phi\rangle$	ϕ NON LOCAL
NON LOCAL TOPOLOGICAL EXCITATIONS μ	$\langle\mu\rangle$ DISORDER PARAM.
- CONVENIENT IN THE ORDERED PHASE $g < 1$	CONVENIENT IN THE DISORDERED PHASE $1/g < 1$

DUALITY MAPS STRONG COUPLING REGIME OF DIRECT TO WEAK COUPLING OF DUAL DESCRIPTION & VICEVERSA

EX. DUALITY • 3d X-Y model DUAL 2d EXCITATIONS

VORTICES (NON TRIVIAL π_1)

[Frölich et al ; di Cecio et al 96]

• 3d Heisenberg model : DUAL exc. WEISS-DOMAINS

[A.dG et al 99]

• 4d U(1) gauge theory → MONOPOLES

NON TRIVIAL π_2 [Frölich et al 86 ; AdG et al 96]

• NON ABELIAN G.T MONOPOLES

NON TRIVIAL π_2.

- FIND THE EXTRA SYMMETRY NEEDED FOR CONFINEMENT IN THE BOUNDARY CONDITIONS.

WITTEN'S "GEOMETRIC LANGLAND'S PROGRAM" CONSIDER THE THEORY IN A SPACE WITH AN ARBITRARY FINITE # OF SINGULARITIES.

PROTOTYPE EXCITATION : t'HOOFT POLYAKOV 74

MONOPOLE : SO(3) HIGGS MODEL.

$$SO(3) \to U(1) \qquad \pi_2\left(SO(3)/U_1\right) = Z/Z_2$$

- EXPLICIT SOLITON SOLUTION

HEDGEHOG GAUGE $\quad \phi = \phi^i \sigma^i \quad \phi^i = \frac{r^i}{r} A(r)$

$$A(r) \xrightarrow[r\to\infty]{} 1$$

A MAPPING OF S_2 ON SO(3)

- UNITARY GAUGE $\quad \phi = \phi_0 \sigma_3 \quad$ SINGULARITY AT $\vec{r}=0$

- RESIDUAL U(1) SYMMETRY σ_3

'tHOOFT TENSOR ['tHOOFT 78]

$$F_{\mu\nu} = \partial_\mu A^3_\nu - \partial_\nu A^3_\mu = \mathrm{Tr}\left\{ \phi G_{\mu\nu} - \frac{i}{g} \phi [D_\mu \phi, D_\nu \phi] \right\}$$

$F_{0i} = 0$ $\qquad$ $F_{ij} = \frac{1}{2} \varepsilon_{ijk} H_k$

$\vec{E} = 0$ $\qquad$ $\vec{H} = \underbrace{\frac{\vec{r}}{g r^3}}_{\text{COULOMB}} + \underbrace{\vec{n}\, \theta(\vec{n}\cdot\vec{x})\, \delta^2(\vec{r}_\perp) \frac{4\pi}{g}}_{\text{STRING}}$

ON THE LATTICE STRING IS INVISIBLE

$$\vec{\nabla} \vec{H} = \frac{4\pi}{g} \delta^3(r)$$

$\partial_\mu F^*_{\mu\nu} = j_\nu \neq 0$ $\qquad$ VIOLATION OF BIANCHI ID.

$\partial_\nu j_\nu = 0$ $\qquad$ DUAL SYMMETRY.

CONSERVATION OF MAGNETIC CHARGE

- IF DUAL SYMMETRY IS HIGGS BROKEN VACUUM IS A "DUAL" SUPERCONDUCTOR - ['tHooft 75; Mandelstam 75]

CONFINEMENT BY DUAL MEISSNER EFFECT.

$E \simeq \sigma r$

- MONOPOLES DO EXIST ON LATTICE CONFIGURATIONS [DEGRAND et AL 80]

- FOR A GENERIC GAUGE GROUP THERE ARE r CONSERVED MAGNETIC CHARGES (r = RANK OF THE GROUP).

- MONOPOLES ARE LOCATED ~~AT~~ AT THE POINTS WHERE TWO EIGENVALUES OF THE EFFECTIVE "HIGGS" FIELD COINCIDE IN A (LATTICE) CONFIGURATION.

- IF # MONOPOLE PER CONFIGURATION IS NOT DENSE, THE GAUGE TRANSFORMATION BETWEEN UNITARY GAUGES OF Φ_1, Φ_2 WILL BE SINGULAR IN A NON DENSE # OF POINTS

THIS PROVES TO BE THE CASE NUMERICALLY

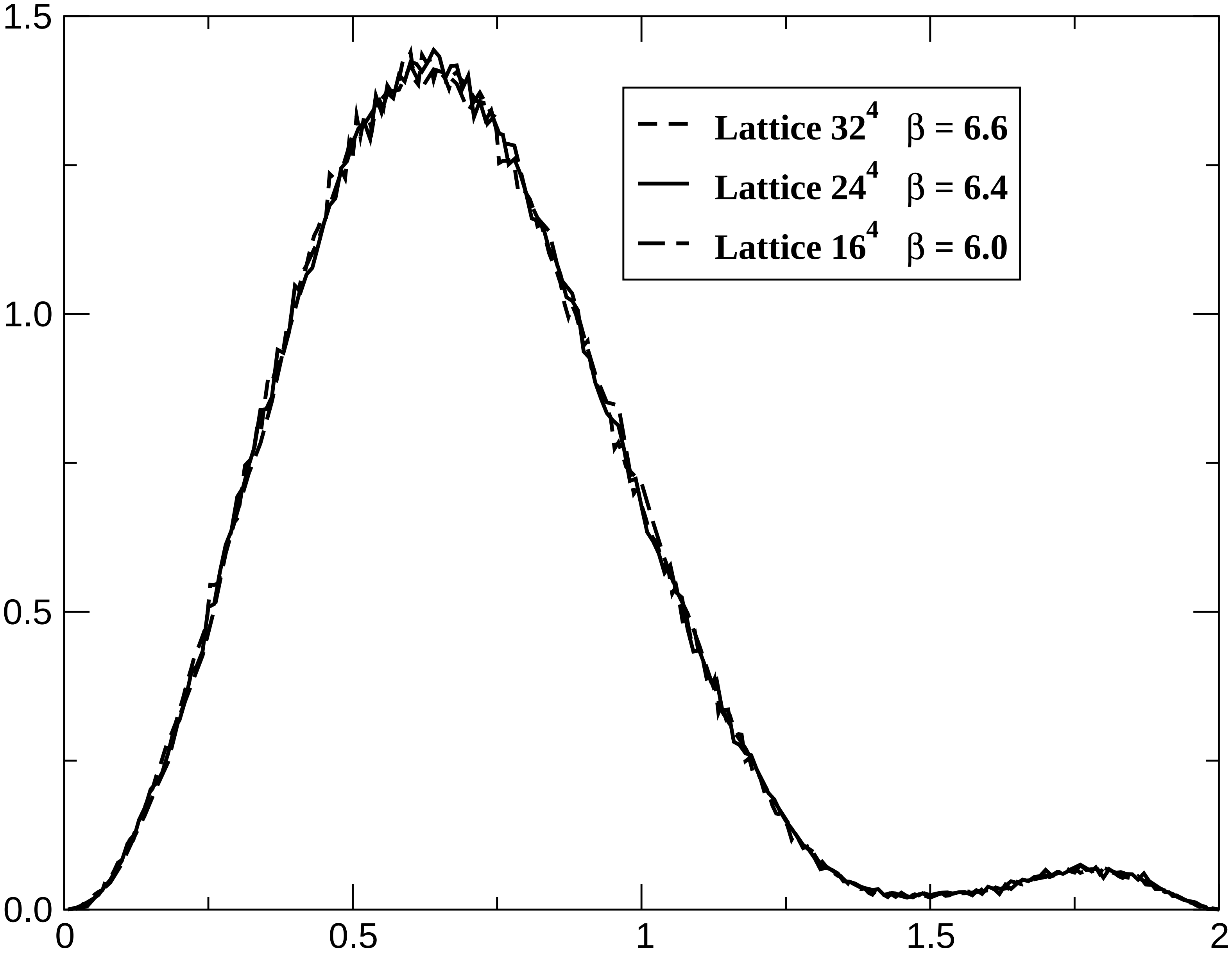
FIG [D'ELIA ET AL. 05]

- WE SHALL DEFINE AN OPERATOR $\mu(\vec{x}, t)$ WHICH CREATES A MONOPOLE AND USE ITS V.E.V. $\langle \mu \rangle$ AS AN ORDER PARAMETER FOR DUAL SUPERCONDUCTIVITY.

μ ADDS A SINGULARITY: IF THE # OF EXISTING SINGULARITIES IS NOT DENSE,

μ WILL CREATE A MONOPOLE IN ALL PROJECTIONS

$\langle \mu \rangle = 0$ $\langle \mu \rangle \neq 0$ IS A STATEMENT INDEPENDENT ON THE CHOICE OF Φ.



Lattice 32^4 $\beta = 6.6$
Lattice 24^4 $\beta = 6.4$
Lattice 16^4 $\beta = 6.0$
0.0
0.5
1.0
1.5
0
0.5
1
1.5
2

II DETECTING DUAL SUPERCONDUCTIVITY

- U(1) GAUGE THEORY (CONTINUUM NOTATION)

[A.D.G. et al 97]

$$\mu = \mu(\vec{x},t) = e^{i\int d^3y\, \vec{E}(\vec{y},t)\frac{m}{2g}\, \vec{b}_\perp(\vec{x}-\vec{y})}$$

$$\mu(\vec{x},t)\,|\vec{A}_\perp(\vec{z})\rangle = |A_\perp(\vec{z}) + \frac{m}{2g}\, \vec{b}_\perp(\vec{x}-\vec{z})\rangle$$

$\vec{E}_\perp$ CONJUGATE MOMENTUM TO $\vec{A}_\perp$

- $e^{ipa}|x\rangle = |x+a\rangle$

$$\vec{b}_\perp(\vec{z}) = \frac{\vec{z}\wedge\vec{n}}{z(z-\vec{n}\cdot\vec{z})} \qquad \vec{\nabla}b_\perp = 0 \quad \vec{\nabla}\wedge\vec{b}_\perp = \frac{\vec{z}}{z^3} + \text{Dirac string}$$

RESCALE $\vec{E}\to g\vec{E}$; GO EUCLIDEAN

$$\mu = e^{-\beta\Delta S} \qquad \Delta S = \frac{m}{2N_c}\int d^3y\, \vec{E}(\vec{y},t)\, b_\perp(\vec{x}-\vec{y}).$$

$$\langle\mu\rangle = \frac{Z(S+\Delta S)}{Z(S)}$$

DIFFICULT TO MEASURE

$\Downarrow$

$$\rho \equiv \frac{\partial \ln\langle\mu\rangle}{\partial\beta} = \langle S\rangle_S - \langle S+\Delta S\rangle_{S+\Delta S} \qquad \langle\mu\rangle = e^{\int_0^\beta \rho(\beta')\,d\beta'}$$

COMPACT
$U(1)$: $\beta_c = 1.01$

$\beta < \beta_c$ CONFINING (AREA LAW FOR WILSON LOOP)

$\beta \geq \beta_c$ FREE PHOTONS

THEOREMS [FROLICH et AL ; ADG et al]

(i) $\langle \mu \rangle \neq 0$ $\beta < \beta_c$ $L_s \to \infty$

(ii) $\langle \mu \rangle = 0$ $\beta \geq \beta_c$ $L_s \to \infty$

(iii) μ A CHARGED GAUGE INVARIANT OPERATOR À LA DIRAC

NUMERICS $\langle \mu \rangle = e^{\int_0^\beta \rho(\beta')\,d\beta'}$

$\beta < \beta_c$ $\rho \to$ FINITE LIMIT AS $L_s \to \infty$ $\langle \mu \rangle \underset{L_s \to \infty}{\neq} 0$ D. SUPERCONDUCTOR

$\beta > \beta_c$ $\rho \xrightarrow[L_s \to \infty]{} -|c| L_s + c'$ $\langle \mu \rangle \underset{L_s \to \infty}{=} 0$ NORMAL

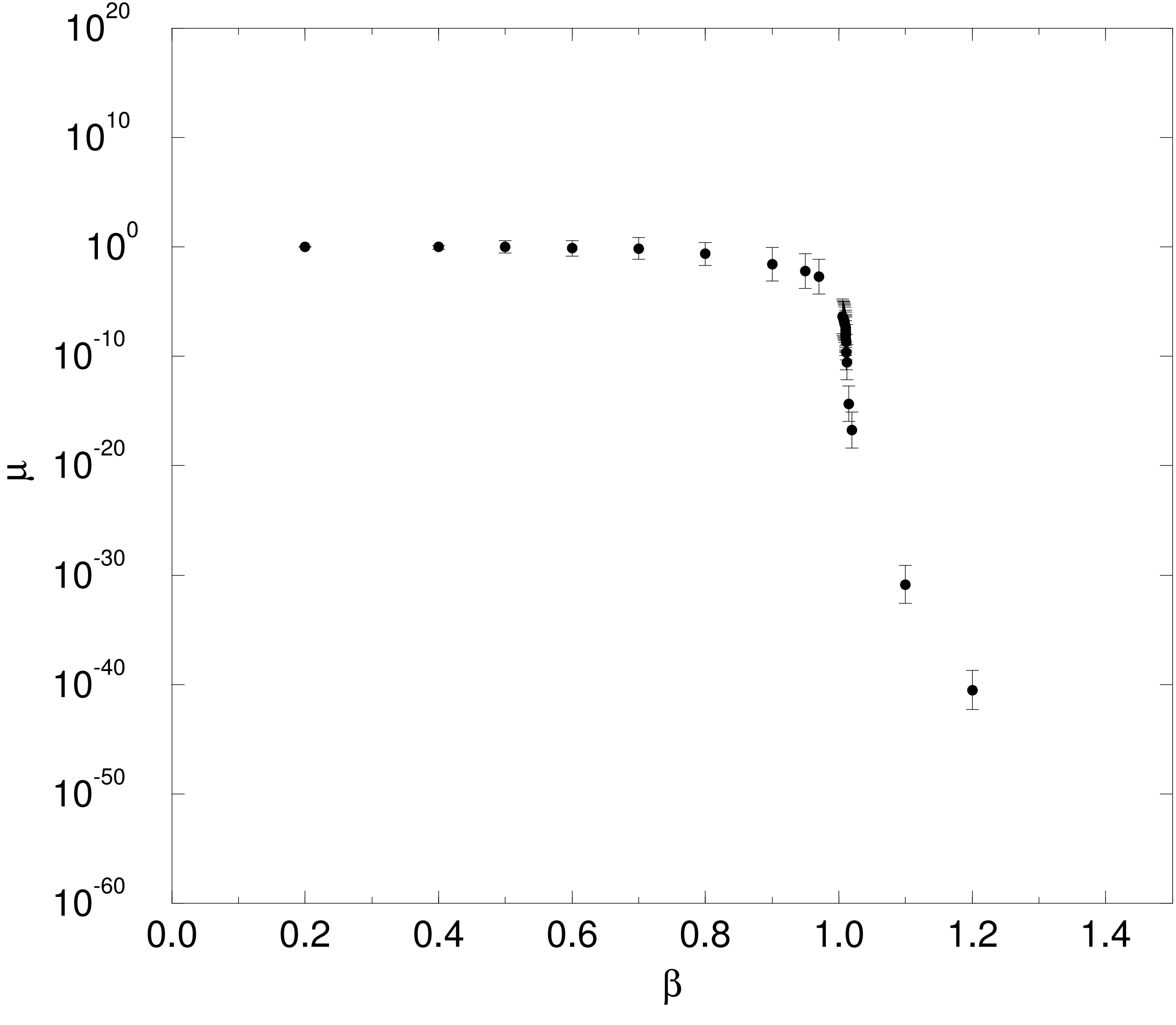
$\beta \simeq \beta_c$ $\langle \mu \rangle \simeq L_s^{z/\nu} \phi(\tau L_s^{1/\nu})$

$$\tau = 1 - T/T_c \simeq 1 - \beta/\beta_c$$

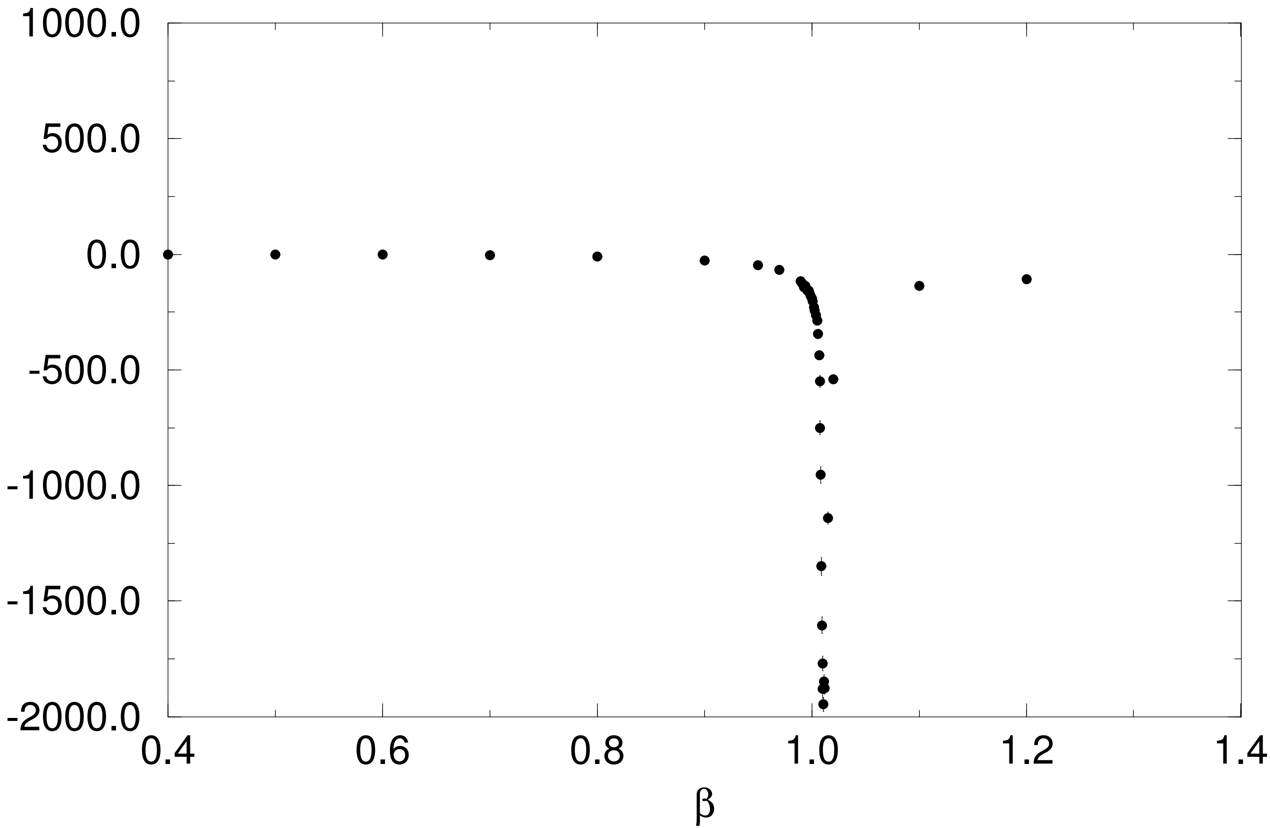
$\lambda \underset{\tau \to 0}{\simeq} \tau^{-\nu}$ $\lambda =$ CORRELATION LENGTH

z ANOMALOUS DIMENSION

$\rho = \dfrac{\partial \ln \langle \mu \rangle}{\partial \beta} = L_s^{1/\nu} \phi'(\tau L_s^{1/\nu})$ $\rho / L_s^{1/\nu} = \phi(\tau L_s^{1/\nu})$ $\Rightarrow \nu$



10^{20}
10^{10}
10^{0}
10^{-10}
10^{-20}
10^{-30}
10^{-40}
10^{-50}
10^{-60}
μ
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
β


1000.0
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
0.4
0.6
0.8
1.0
1.2
1.4
β

- THE CONSTRUCTION OF $\langle\mu\rangle$ CAN BE EXTENDED TO GENERIC GAUGE GROUPS

- A NON TRIVIAL $\Pi_2 \Longrightarrow$ SU(2) SUBGROUP

AN SU(2) IS ASSOCIATED TO EACH ROOT α

$$[E_{\vec\alpha}, E_{-\vec\alpha}] = \vec\alpha \vec H \qquad \left\{ \begin{array}{l} T^{\alpha}_{\pm} = E_{\pm\vec\alpha} / \sqrt{(\vec\alpha,\vec\alpha)} \\ \\ T_3 = \vec\alpha \vec H \end{array} \right\}$$
$$[H, E_{\pm\vec\alpha}] = \pm\vec\alpha E_{\pm\vec\alpha}$$

- EACH ROOT $\vec\alpha$ CAN BE MADE SIMPLE BY A WEYL TRANSFORMATION (GROUP TRANSF)
- HIGGS POTENTIAL G INVARIANT $\rightarrow$ SIMPLE ROOTS. $(a = 1 \ldots r)$
- $\phi \Rightarrow$ FUNDAMENTAL WEIGHT CORRESPONDING TO THE ROOT, $\phi^0_{\vec a}$ $\qquad \phi_{\vec a} = U \phi^0_{a} U^+$
- INVARIANCE (STABILITY GROUP) OF ϕ^{α}: GROUP WITH DYNKYN DYAGRAM OBTAINED BY ERASING THE SIMPLE ROOT $\vec\alpha$ $\times U(1)$

  $H \rightarrow$ LEVY SUBGROUP $\qquad \hat H$

SU(N)

$$\circ - \circ - \times \cdots - \circ \qquad \Longrightarrow \quad SU(a) \otimes SU(N-a) \times U(1)$$

$a = 1 \ldots N-1$.

- IN PRESENCE OF QUARKS

$$\Pi_2 \left(SU(N) / SU(a) \otimes SU(N-a) \otimes U(1) \right) = Z$$

$$-\ \mu_a(\vec x, t) = e^{\, i \int d^3 y\, \vec E_a(\vec y, t) \frac{m}{2g} \vec b_\perp(\vec x - \vec y)}$$

$$\vec E_a = Tr\{\phi_a \vec E\} \qquad \phi_a = U \phi^0_a U^+$$

UNITARY REPR: $\phi_a = \phi^0_a \quad \vec E_a = \vec E_{3\perp}$

- LATTICE IMPLEMENTATION DEFINED UP TO TERMS $\propto a_L^2$ (a_L THE LATTICE SPACING)

(Cossu et al 07)

- $\rho_a = \dfrac{\partial \ln \langle \mu^a \rangle}{\partial \beta}$ $\boxed{N_f = 2 \; SU(3)}$ → Fig

$\beta < \beta_c$ $L_s \to \infty$ (THERMODYNAMICAL LIMIT)

$\rho_a \to$ FINITE LIMIT $\langle \mu^a \rangle = e^{\int^{\beta} \rho_a(\beta') d\beta'} \neq 0$

fig

$\beta > \beta_c$ $\rho_a \cancel{\propto} -|c| \cancel{L} L_s + c'$

fig

$\langle \mu^a \rangle = 0$ $(L_s \to \infty)$

$\beta \simeq \beta_c$ $\rho_a / L_s^{1/\nu} = f(\tau L_s^{1/\nu})$ $\tau = 1 - \dfrac{T}{T_c}$ fig.

O(4) vs 1st ORDER.

- $\boxed{N_f = 2 \;\; adj, SU(3)}$

(Cossu et al 08)

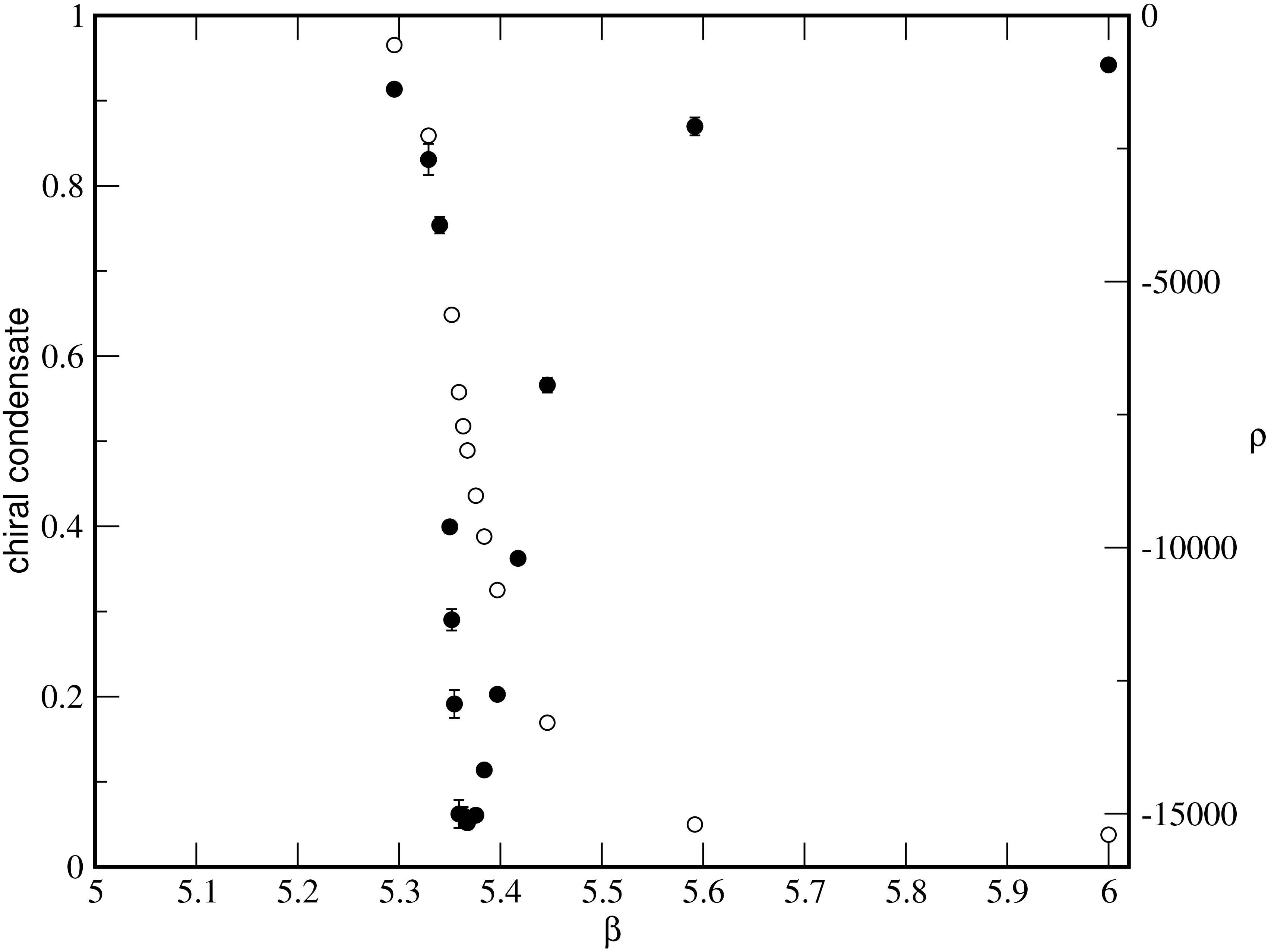
- POLYAKOV LINE fig.
- ρ
- ρ AT LARGE β
- SCALING OF ρ.
- CHIRAL S.B.

- DECONFINEMENT TRANSITION 1st ORDER

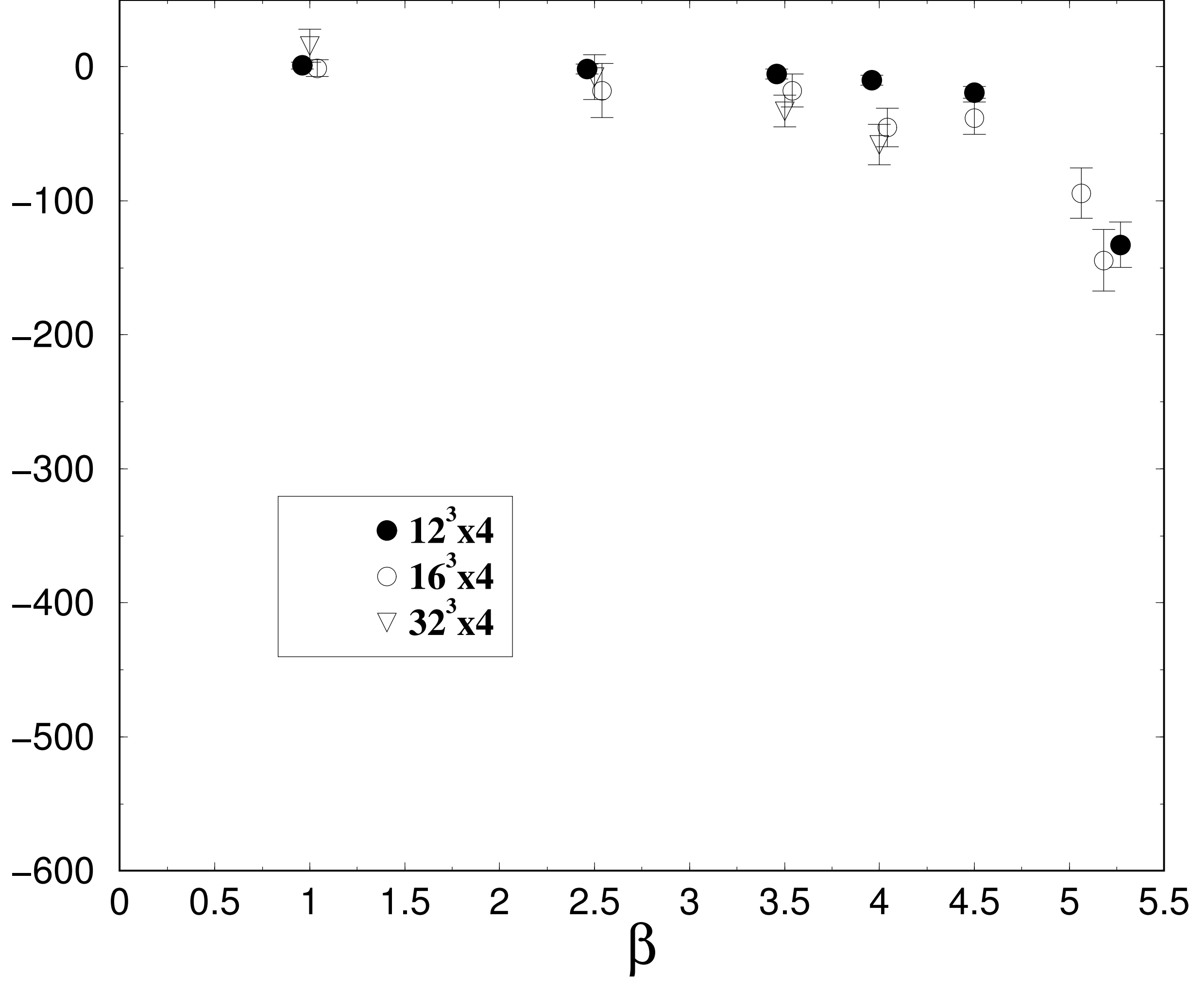
$T_D < T_{chiral}$

- CHIRAL TRANSITION A CROSSOVER

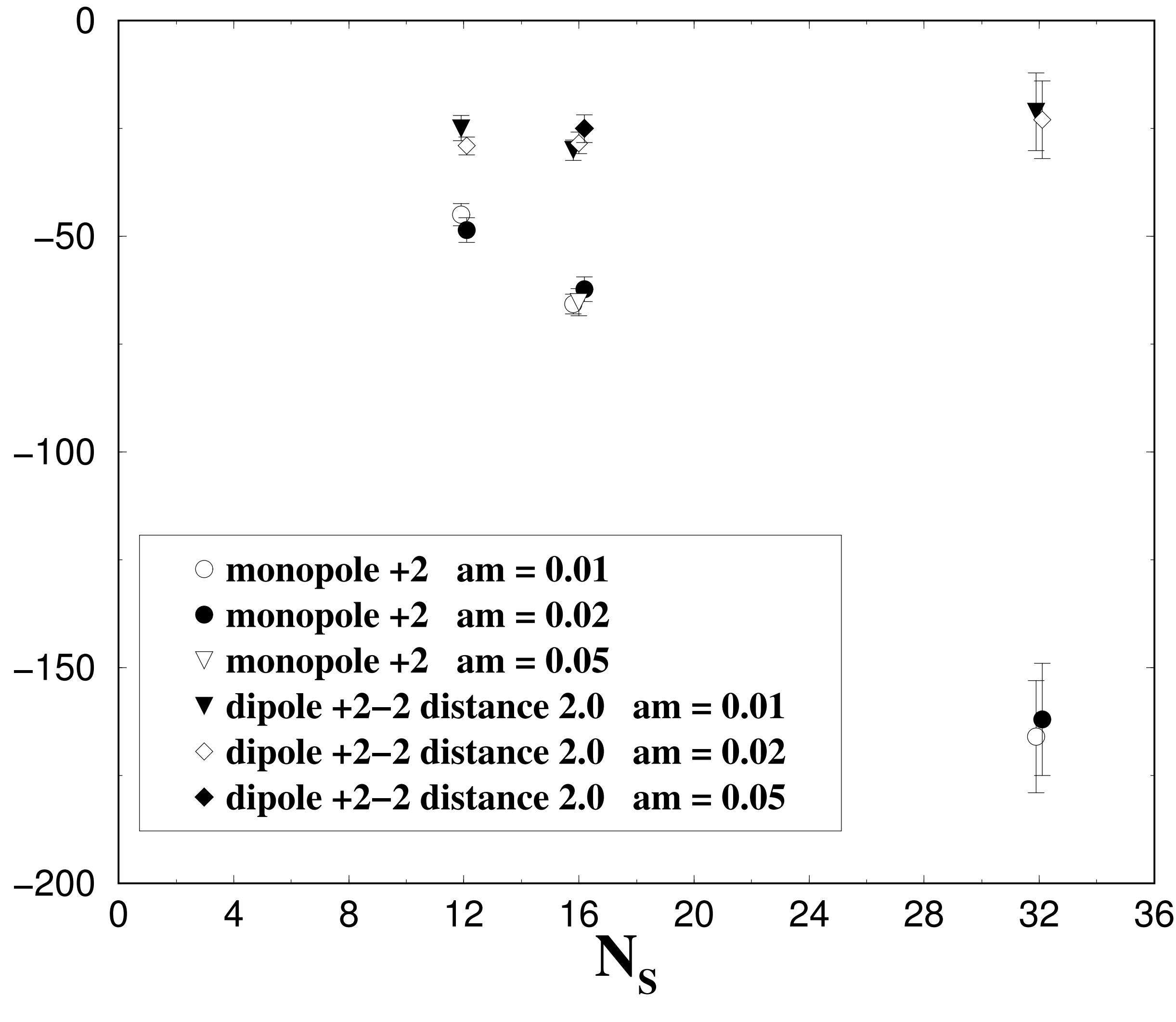
$\Longrightarrow$



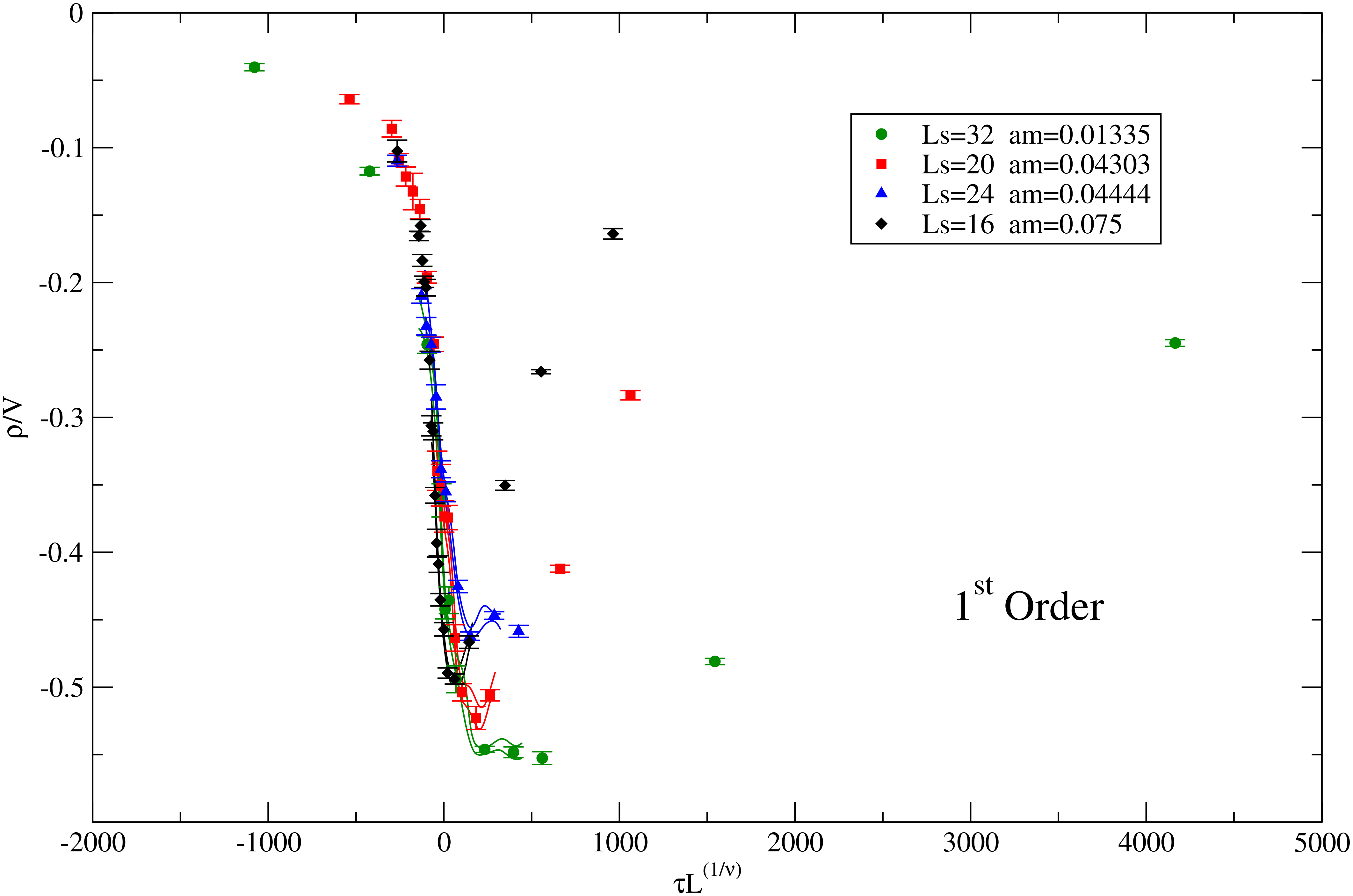
chiral condensate
0
0.2
0.4
0.6
0.8
1
5
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
6
β
0
-5000
-10000
-15000
ρ



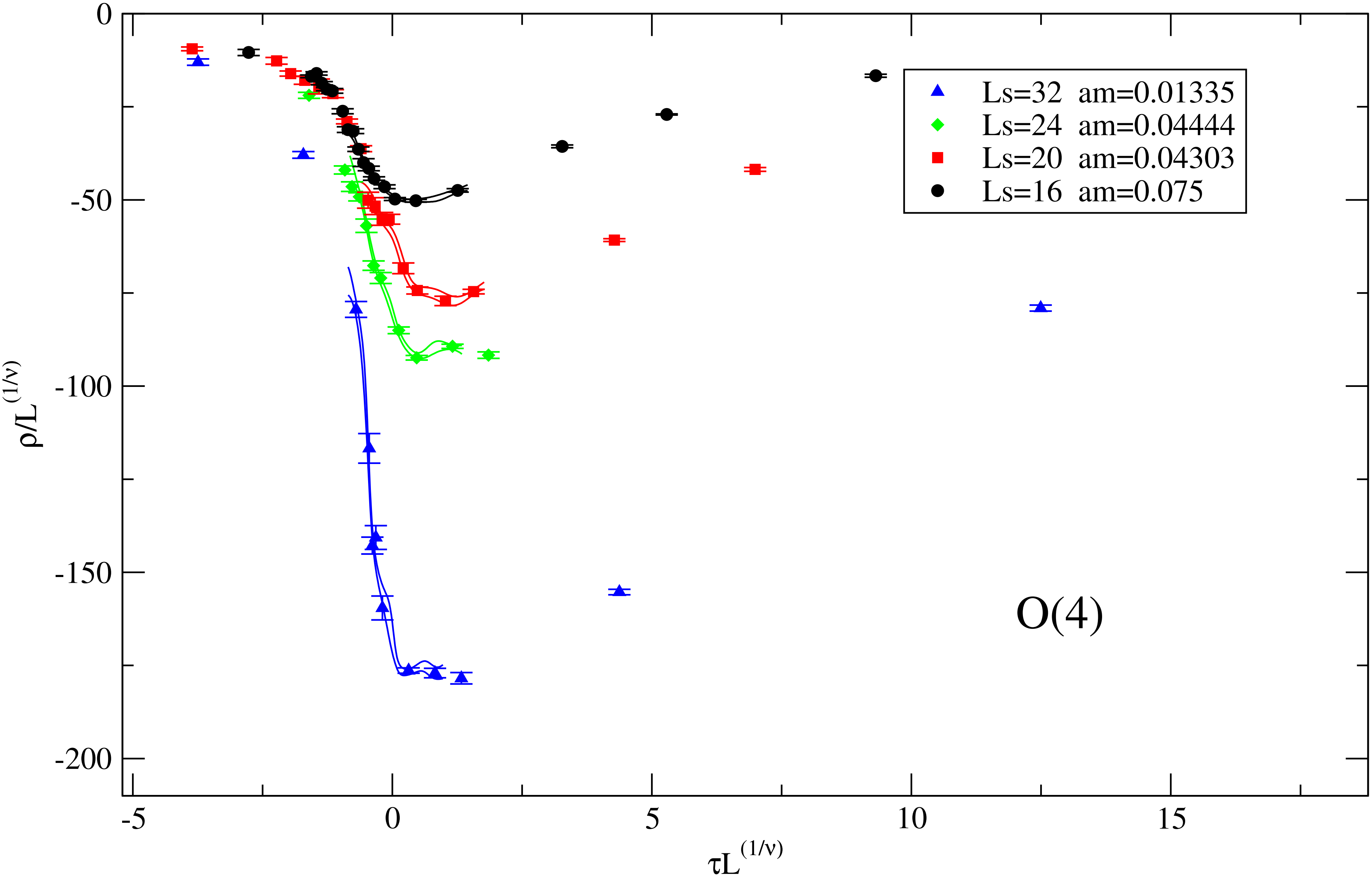
0
−100
−200
−300
−400
−500
−600
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
β
12^3x4
16^3x4
32^3x4



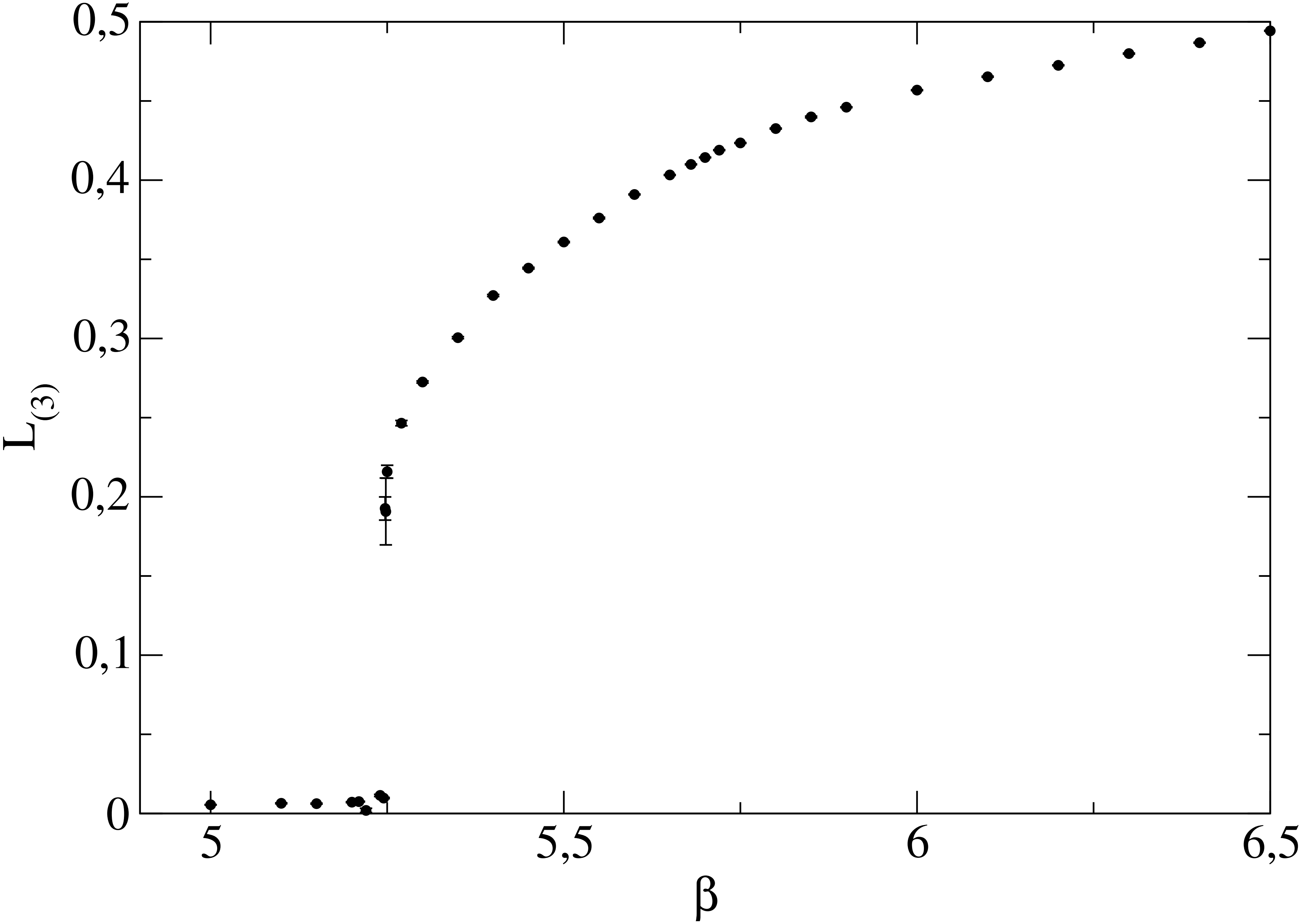
0
−50
−100
−150
−200
0
4
8
12
16
20
24
28
32
36
N_S
monopole +2 am = 0.01
monopole +2 am = 0.02
monopole +2 am = 0.05
dipole +2−2 distance 2.0 am = 0.01
dipole +2−2 distance 2.0 am = 0.02
dipole +2−2 distance 2.0 am = 0.05

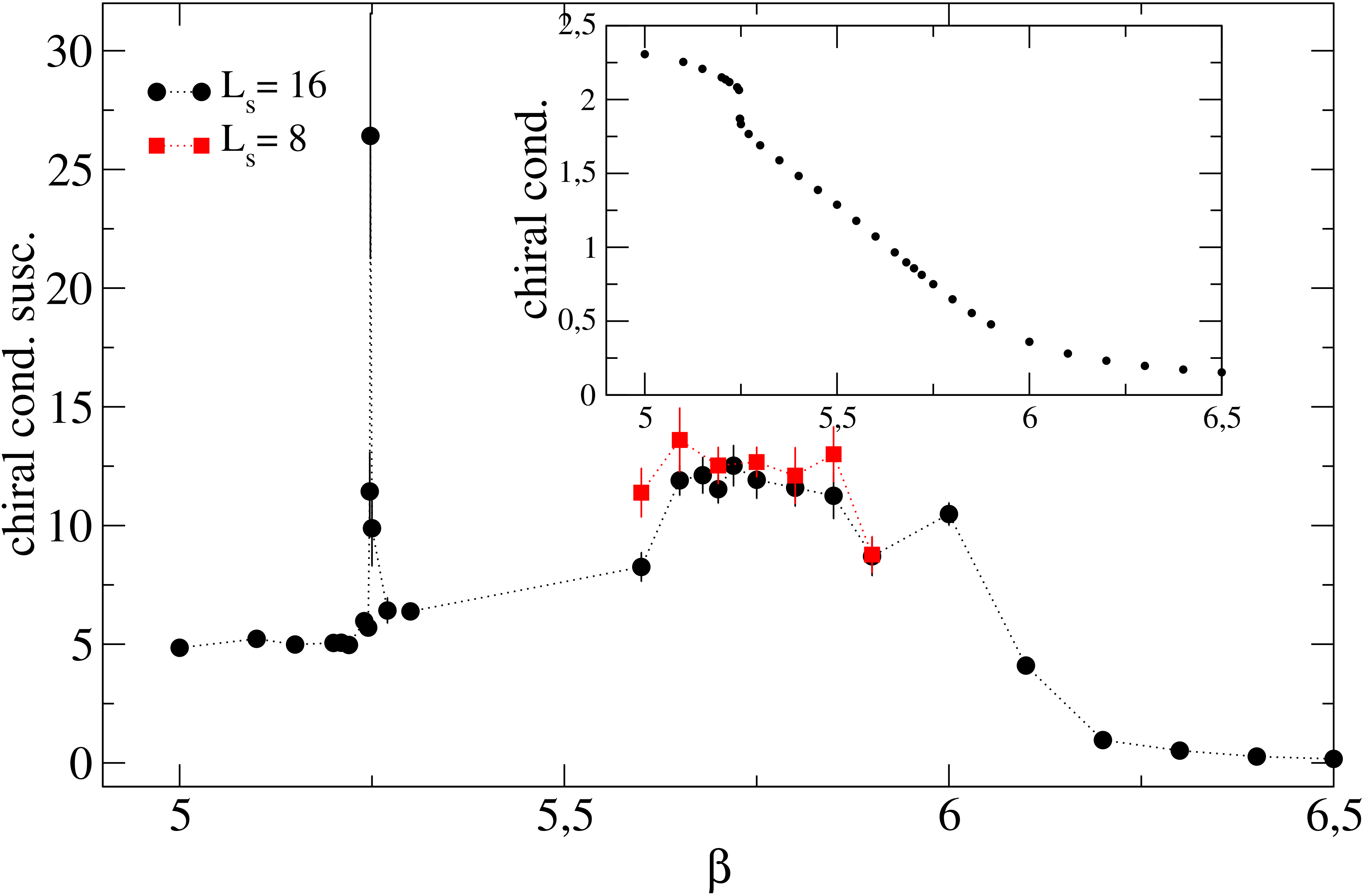


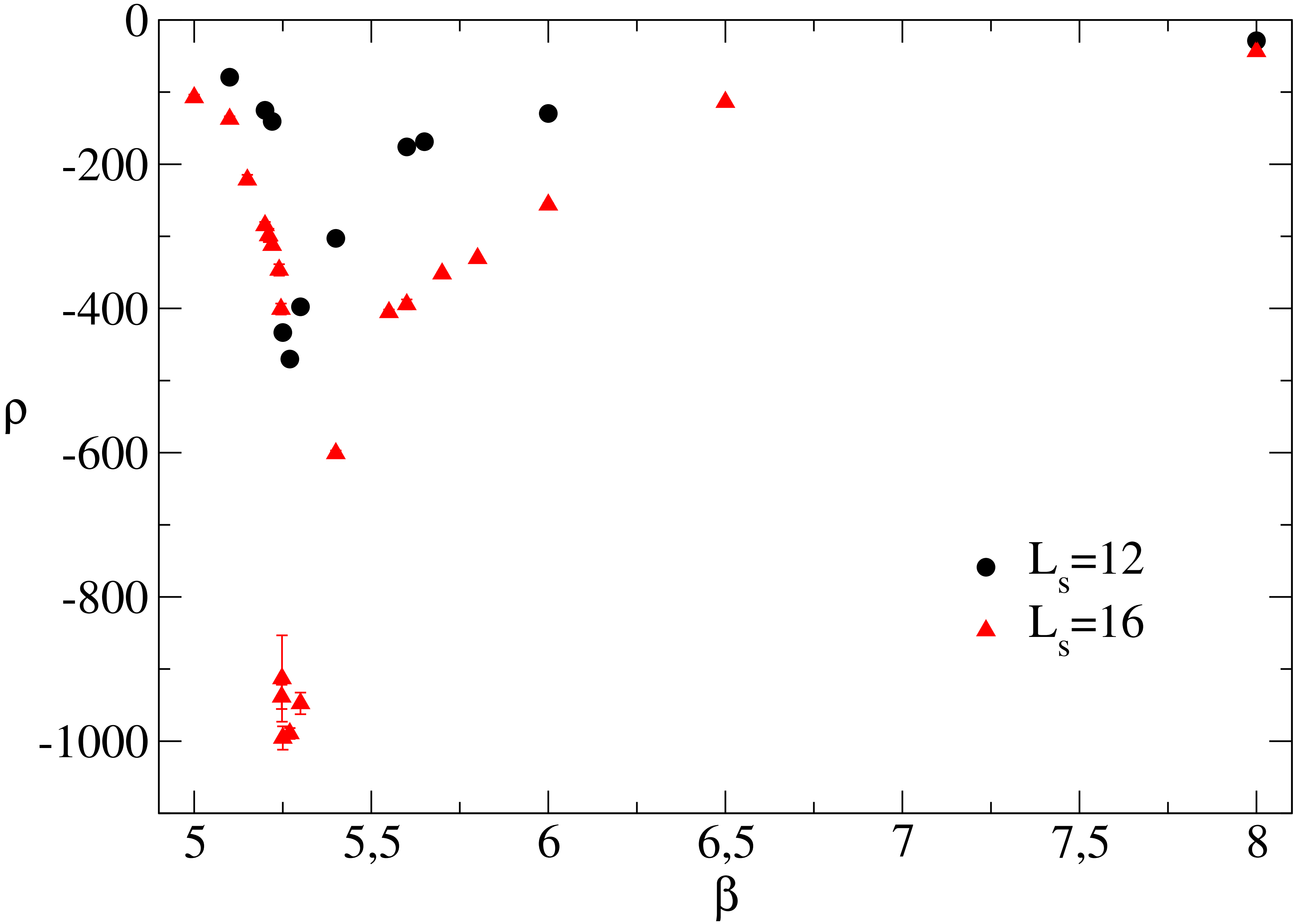
Ls=32 am=0.01335
Ls=20 am=0.04303
Ls=24 am=0.04444
Ls=16 am=0.075
1st Order
ρ/V
τL(1/ν)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-2000
-1000
0
1000
2000
3000
4000
5000



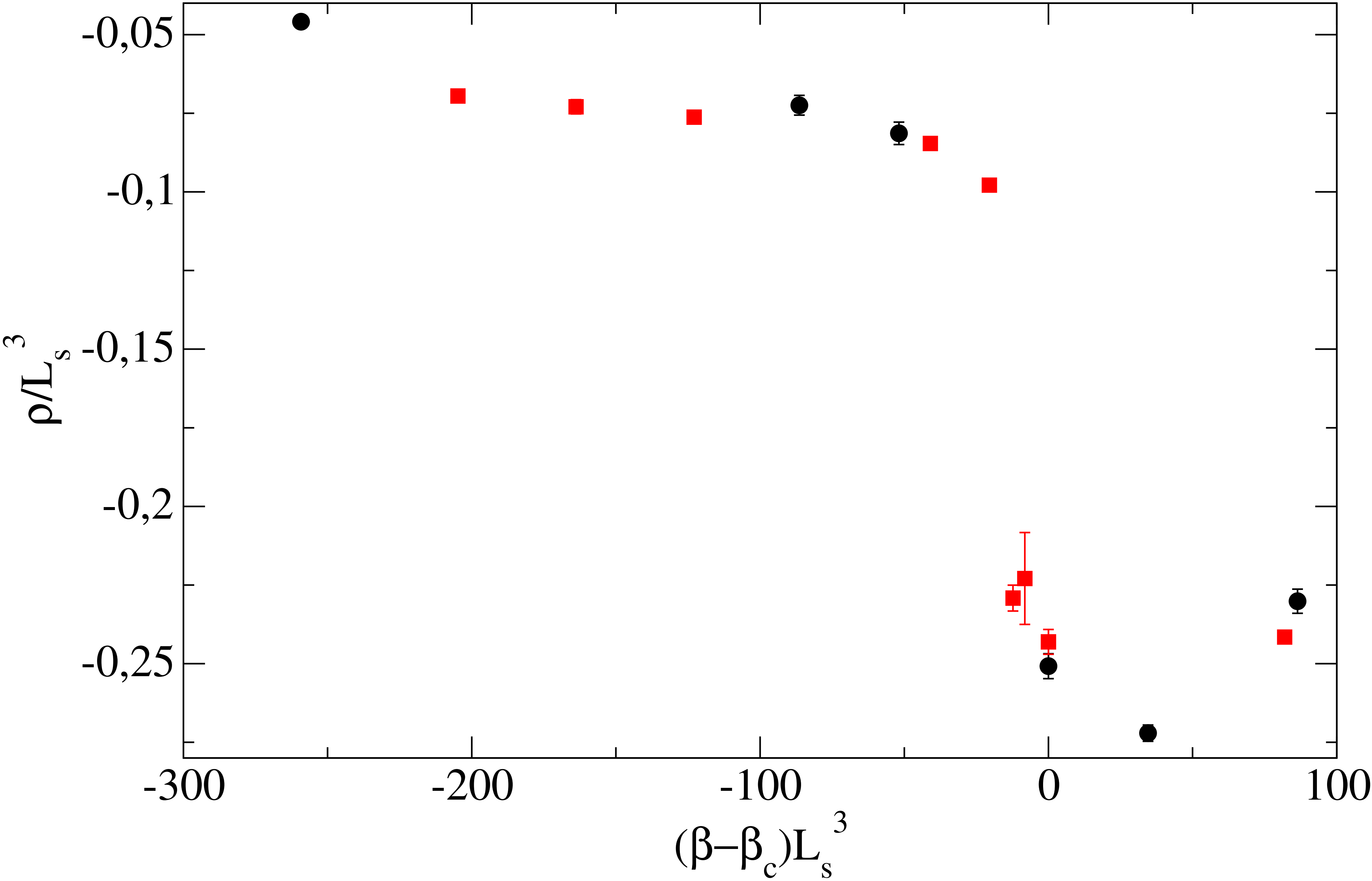
Ls=32 am=0.01335
Ls=24 am=0.04444
Ls=20 am=0.04303
Ls=16 am=0.075
O(4)
$\rho/L^{(1/\nu)}$
$\tau L^{(1/\nu)}$
0
-50
-100
-150
-200
-5
0
5
10
15


0,5
0,4
0,3
0,2
0,1
0
$L_{(3)}$
5
5,5
6
6,5
β


chiral cond. susc.
β
L_s= 16
L_s= 8
chiral cond.
0
5
10
15
20
25
30
5
5,5
6
6,5
0
0,5
1
1,5
2
2,5



0
-200
-400
-600
-800
-1000
ρ
5
5,5
6
6,5
7
7,5
8
β
L_s=12
L_s=16



-0,05
-0,1
-0,15
-0,2
-0,25
ρ/L_s^3
-300
-200
-100
0
100
$(\beta-\beta_c)L_s^3$

- THE OPERATOR μ OBEYS CLUSTER PROPERTY [D'Elia et al 07]

THE CORRELATOR $\langle \mu(x)\, \mu(0) \rangle$ CAN BE USED BOTH TO DETERMINE $\langle \mu \rangle$ AND THE SPECTRUM OF MASSES OF MONOPOLES.

- SIMILAR ANALYSES HAVE BEEN PERFORMED FOR OTHER SYSTEMS WITH DUALITY
  - THE ISING MODEL [carmona et al 00]
  - THE 3d XY MODEL [di Cecio et al 97]
  - THE 3d HEISENBERG MODEL [A.d.G. et al 98]

- ALTERNATIVE APPROACH: OBSERVE MONOPOLE BEHAVIOUR IN LATTICE CONFIGURATIONS [ITEP GROUP, KANAZAWA GROUP, BERLIN GROUP. . .]
  TO OBSERVE MONOPOLES ONE HAS TO FIX THE GAUGE.
  A POPULAR CHOICE: THE MAXIMAL ABELIAN GAUGE, PRACTICALLY CONVENIENT (ABELIAN DOMINANCE, MONOPOLE DOMINANCE), BELIEVED FOR LONG TIME TO BE THEORETICALLY PRIVILEGED.
  RECENTLY SUZUKI [06] DEMONSTRATED NUMERICALLY THAT ALL PROJECTIONS ARE ON THE SAME FOOTING.
  - ATTEMPTS TO CONSTRUCT THE DUAL FREE ENERGY FROM LATTICE DATA [ITEP, KANAZAWA].

III CONCLUSIONS.

- EXPERIMENTAL UPPER LIMITS TO OBSERVATION OF FREE QUARKS SUGGEST THAT CONFINEMENT IS DUE TO SYMMETRY

$\Rightarrow$ DECONFINING TRANSITION ORDER-DISORDER

TO BE CHECKED WITH THE PHASE STRUCTURE [CROSSOVER'S ?, CHIRAL D.O.F DOMINANCE ? adj QCD!]

- ONLY WAY TO HAVE A SYMMETRY IS TO GO DUAL [$\longrightarrow$ MONOPOLES, π_2]

- AN ORDER PARAMETER $\langle\mu\rangle$ $\exists$, WHICH CAN DETECT MONOPOLE CONDENSATION. LATTICE DATA SHOW THAT IT DESCRIBES CONFINEMENT + DECONFINEMENT.

- WHAT RELATION TO ADS/CFT ?