Einerseits

Andererseits

Einerseits

Andererseits

Einerseits

each stick has two ends

Andererseits

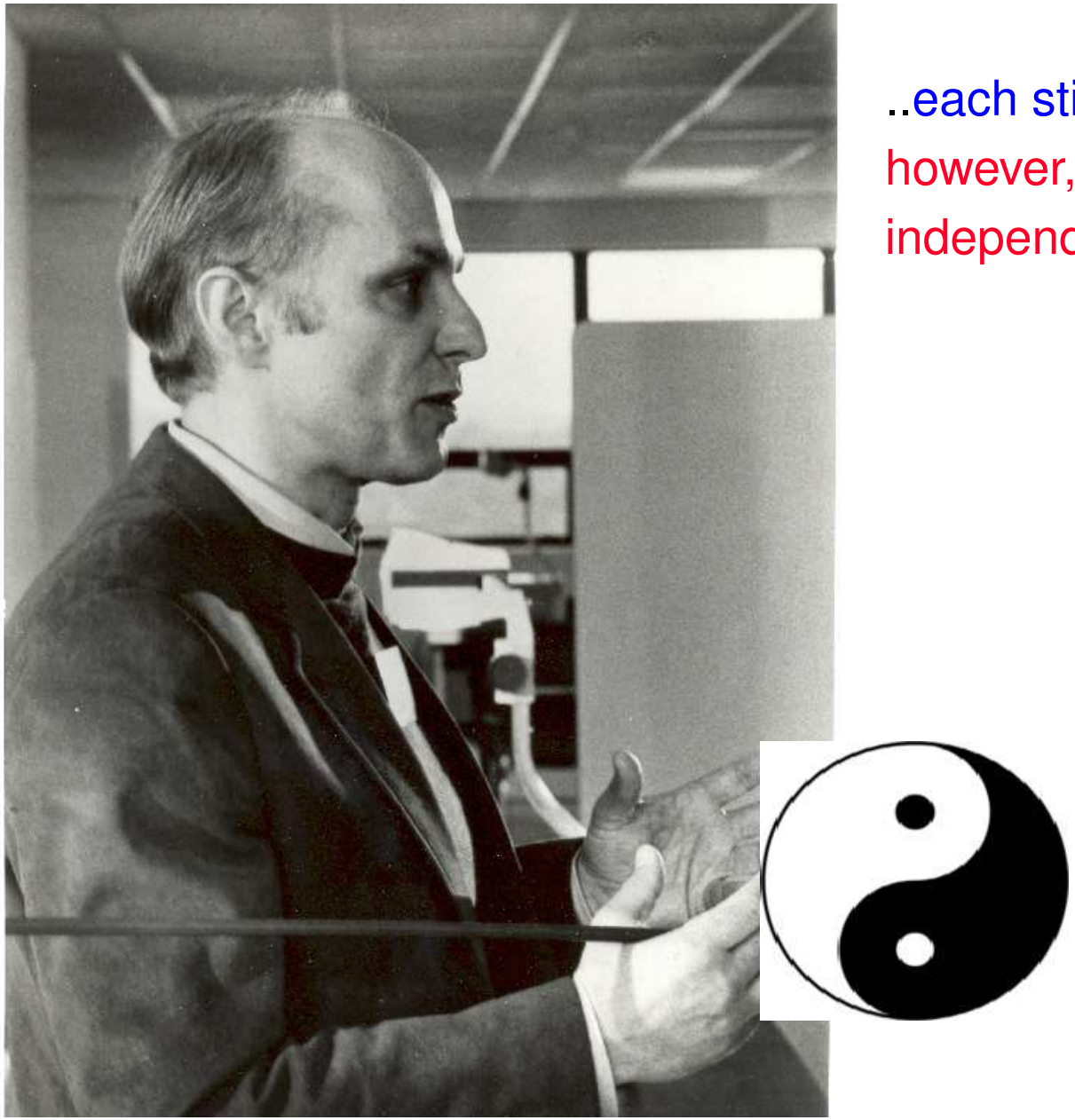
Einerseits

each stick has two ends

Andererseits

however, they cannot exist independently from each other

Teaching the Taoism of Physics



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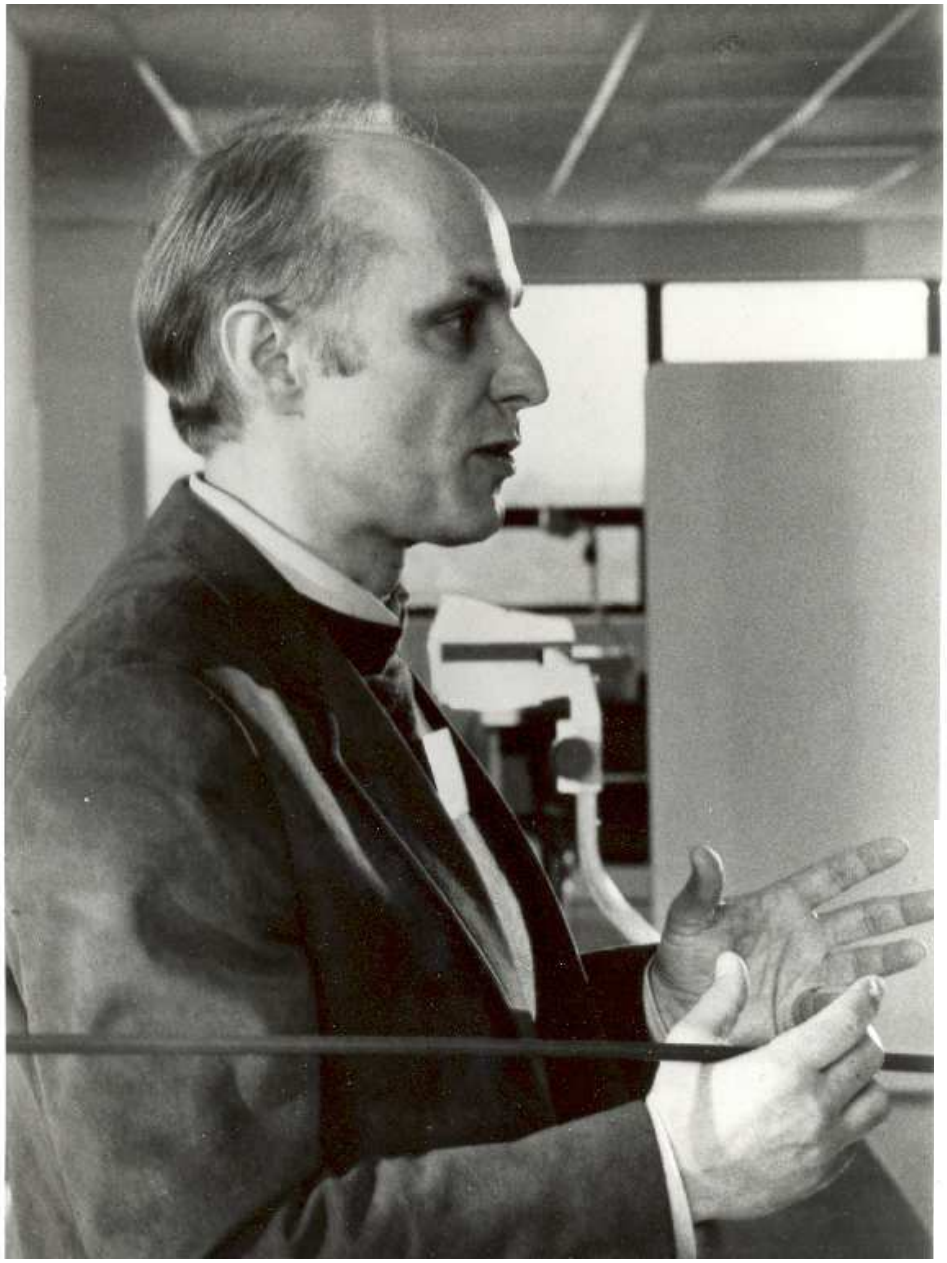

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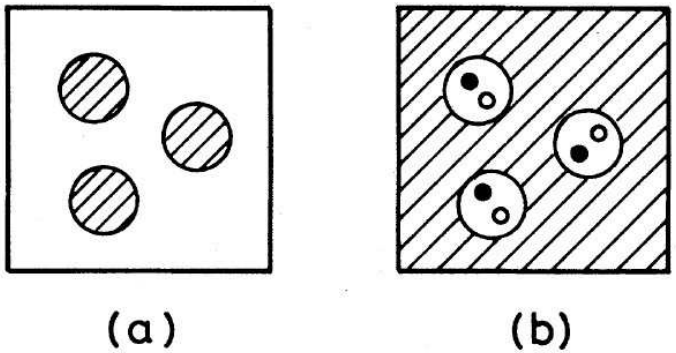

FIG. 1. Strongly interacting matter from a (a) hadronic and from a (b) quark point of view.

...back to the roots – 1977

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AUGUST 1977

STATISTICAL CONCEPTS IN HADRON PHYSICS[+)]

H. Satz

Department of Theoretical Physics
University of Bielefeld
Germany

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AUGUST 1977

STATISTICAL CONCEPTS IN HADRON PHYSICS+)

H. Satz

Department of Theoretical Physics
University of Bielefeld
Germany

This task, the formulation of statistical hadron physics, can be approached in classical fashion along two different lines. On one hand, we can formulate a phenomenological hadron thermodynamics; on the other, we can study the limit of particle number $N \to \infty$ for dynamical models of interest. Both problems, as well as their connection (the "derivation of hadron thermodynamics") are at present far from completed.

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STATISTICAL CONCEPTS IN HADRON PHYSICS[+)]

On a more general level, it is of course also still open if all hadronic systems indeed obey the temperature bound (27), making that relation something of a "fourth law of thermodynamics", or if at sufficiently high energy density a phase transition sets in, from a hadron gas to one of hadronic constituents ("quark gas")[22,23,24], whose interaction is not governed by the dynamics we have considered here.

IV. PHASE TRANSITIONS IN HADRONIC SYSTEMS

The transformation of a hadron gas into a quark gas would in many ways correspond to a conventional phase transition. Since hadrons and their resonances are presumably bound states of confined quarks in definite orbital configurations, a new phase is conceivable, in which these configurations are broken. Particle production at large transverse momentum (very central collisions and hence high energy density) does show features of this nature.

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STATISTICAL CONCEPTS IN HADRON PHYSICS[+)]

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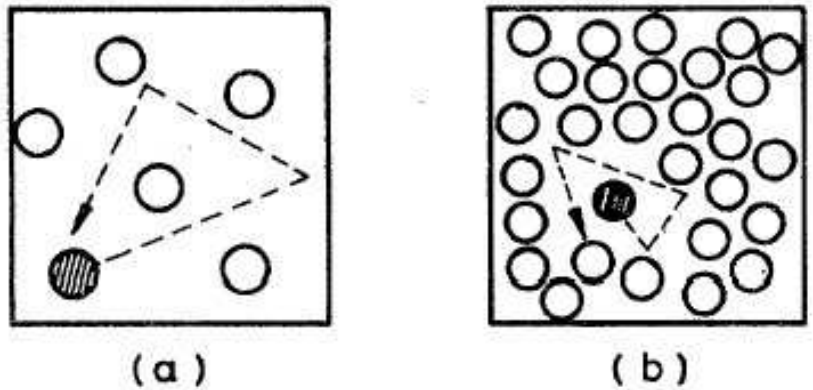
IV. PHASE TRANSITIONS IN HADRONIC SYSTEMS

22) N. Cabibbo and G. Parisi, Phys. Lett. 59B, 67 (1974)

23) J.C. Collins and M.J. Perry, Phys. Rev. Lett. 34, 1353 (1

24) B.A. Freedman and L.P. McLerran, MIT Preprint 541 (1976)

Learning the Taoism of Physics



FK+HS,
On The Thermodynamics
of Extended Hadrons,
PR D21 (1980) 1168

FIG. 4. Particle mobility in a dilute (a) and in a dense (b) system.

Learning the Taoism of Physics

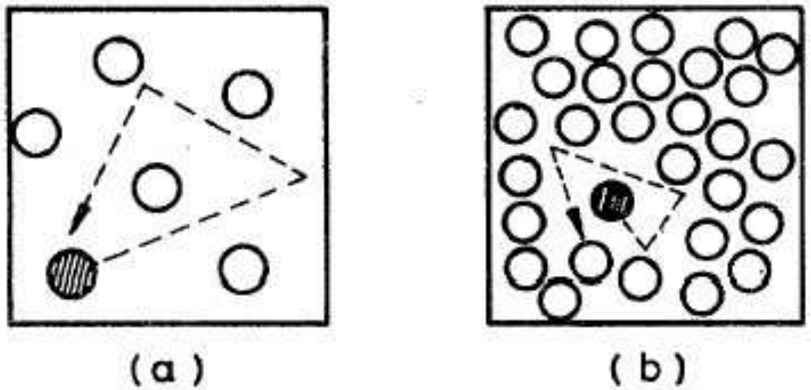


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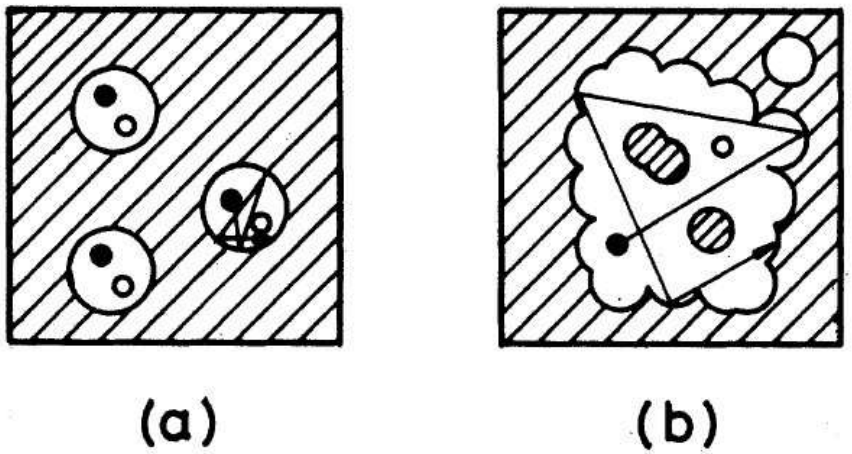
FIG. 4. Particle mobility in a dilute (a) and in a dense (b) system.



FK+HS,
On The Thermodynamics
of Confined Quarks,
PR D22 (1980) 480

FIG. 2. Quark mobility at (a) low and at (b) high density.

The 1980 quantum jump

M. Creutz, Phys. Rev. D21 (1980) 2308

lattice size: 10^4

number of iterations $\mathcal{O}(30)$!!

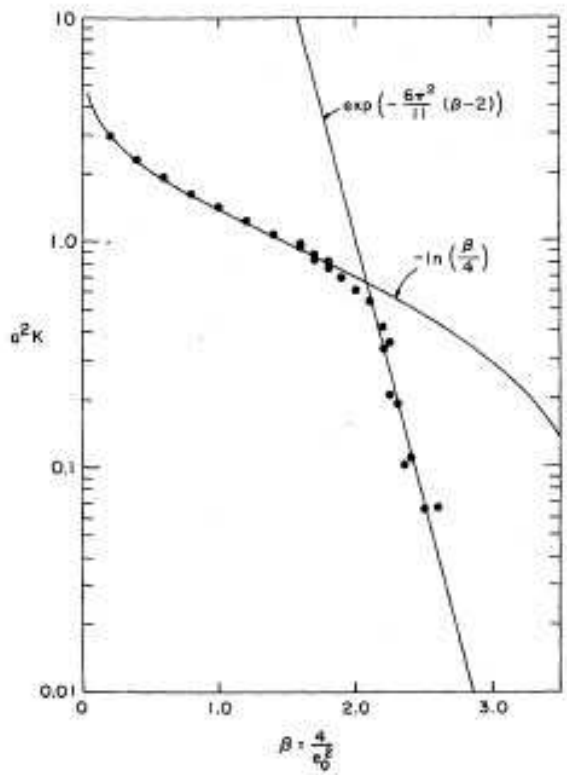


FIG. 6. The cutoff squared times the string tension as a function of β. The solid lines are the strong- and weak-coupling limits.

behavior of Eq. (3.22) occurs rather sharply over a range of about 10% in β about $\beta = 2$. This appearance of the confinement mechanism occurs at

$$\frac{e_0^2}{4\pi} \approx 0.16 . \tag{5.1}$$

The rapid evolution out of the perturbative regime may be responsible for the remarkable phenomenological successes of the bag model.[21] High-temperature-series results,[12] as well as semi-classical treatments,[5] have also suggested an abrupt onset of confinement.

Our analysis allows a determination of the renormalization scale of the coupling in terms of the string tension. Using the observed asymptotic normalization

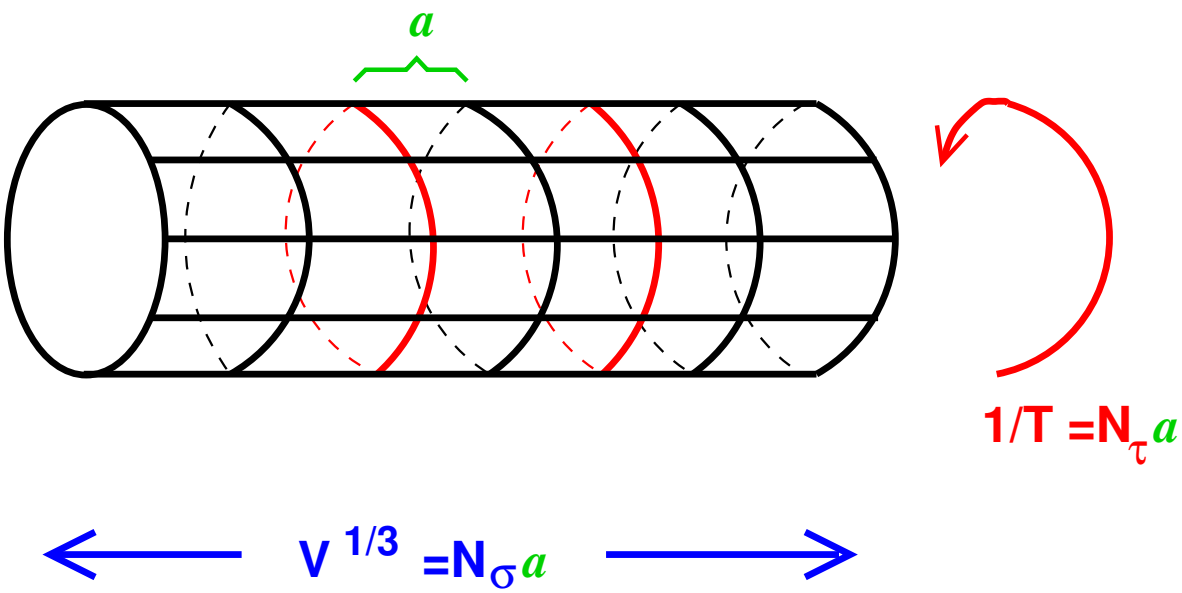
$$a^2K \underset{\beta\to\infty}{\sim} \exp\left(-\frac{6\pi^2}{11}(\beta-2)\right) , \tag{5.2}$$

we can solve for e_0^2 to give

$$\frac{e_0^2}{4\pi} \underset{a\to 0}{\sim} \frac{3\pi}{11\ln(1/a\Lambda)} , \tag{5.3}$$

where the renormalization scale is

Analyzing hot and dense matter on THE LATTICE



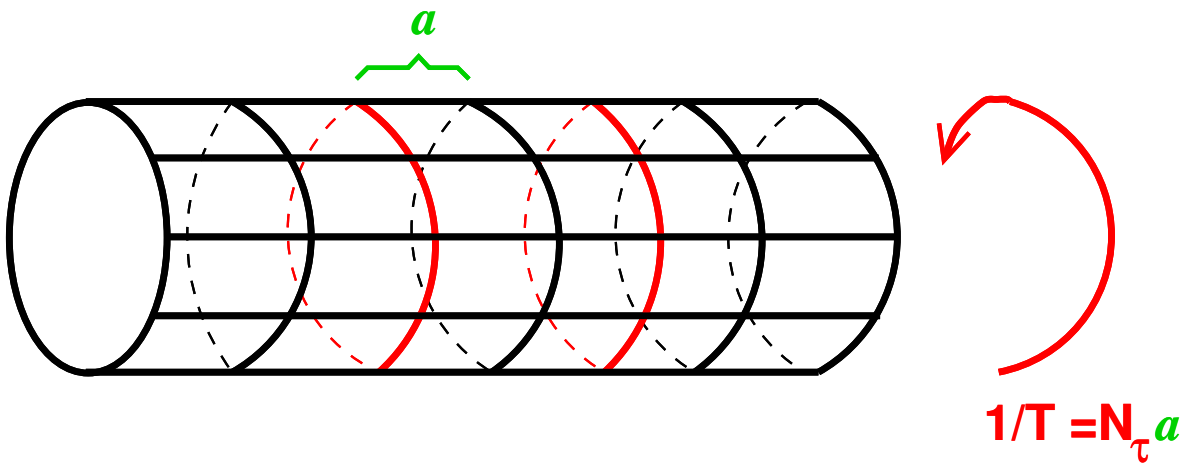
Quantum Chromo Dynamics

partition function: $Z(V,T,\mu) = \int \mathcal{D}\mathcal{A}\mathcal{D}\psi\mathcal{D}\bar{\psi}\ \mathrm{e}^{-S_E}$

$$S_E = \int_0^{1/T} dx_0 \int_V d^3x\ \mathcal{L}_E(\mathcal{A},\psi,\bar{\psi},\mu)$$

temperature volume chemical potential

Analyzing hot and dense matter on THE LATTICE



1980/81

Volume 101B, number 1,2 PHYSICS LETTERS 30 April 1981

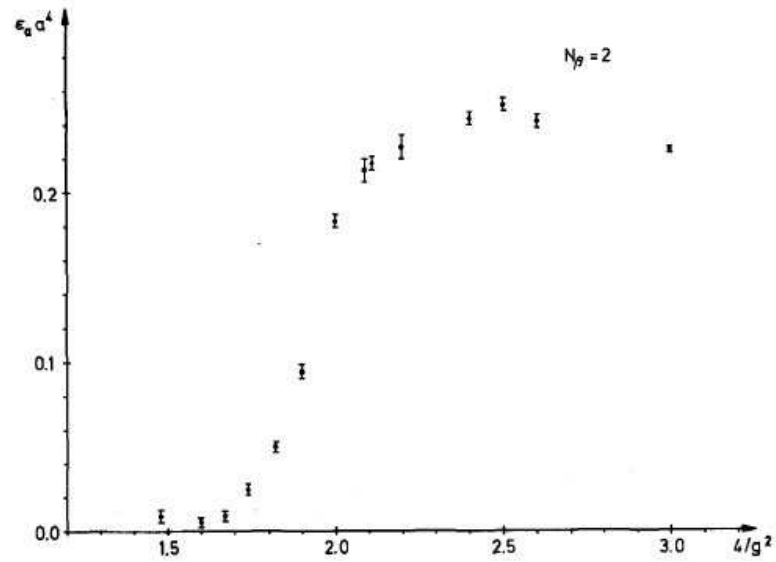


Fig. 3. Energy density of gluon matter versus $4/g^2$, at fixed lattice size $N_\beta = 2$, after about 500 iterations.

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May, 1986 UNIVERSITÄT BIELEFELD BI-TP 86/16

CORRELATION AND SCREENING
IN FINITE TEMPERATURE SU(2) GAUGE THEORY

K. Kanaya
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RWTH Aachen, D-51 Aachen, F.R. Germany

and

H. Satz
Fakultät für Physik
Universität Bielefeld, D-48 Bielefeld, F.R. Germany
and
Physics Department
Brookhaven National Laboratory, Upton, NY 11973, USA

ABSTRACT

We study the temperature dependence of the correlation length in SU(2) gauge theory around the deconfinement point, using high statistics Monte Carlo simulation on large lattices.

Phys. Rev. D34 (1986) 3193

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PHYS. LETT. B, in press

BROOKHAVEN NATIONAL LABORATORY

June 1986 BNL-38344

J/ψ SUPPRESSION BY QUARK-GLUON PLASMA FORMATION

T. Matsui
Center for Theoretical Physics
Laboratory for Nuclear Science
Massachusetts Institute of Technology
Cambridge, MA 02139, USA

and

H. Satz
Fakultät für Physik
Universität Bielefeld, D-48 Bielefeld, F.R. Germany
and
Physics Department
Brookhaven National Laboratory, Upton, NY 11973, USA

ABSTRACT

If high energy heavy ion collisions lead to the formation of a hot quark-gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region. To study this effect, we compare the temperature dependence of the screening radius, as obtained from lattice QCD, with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. We conclude that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark-gluon plasma formation.

Phys. Lett. B178 (1986) 416

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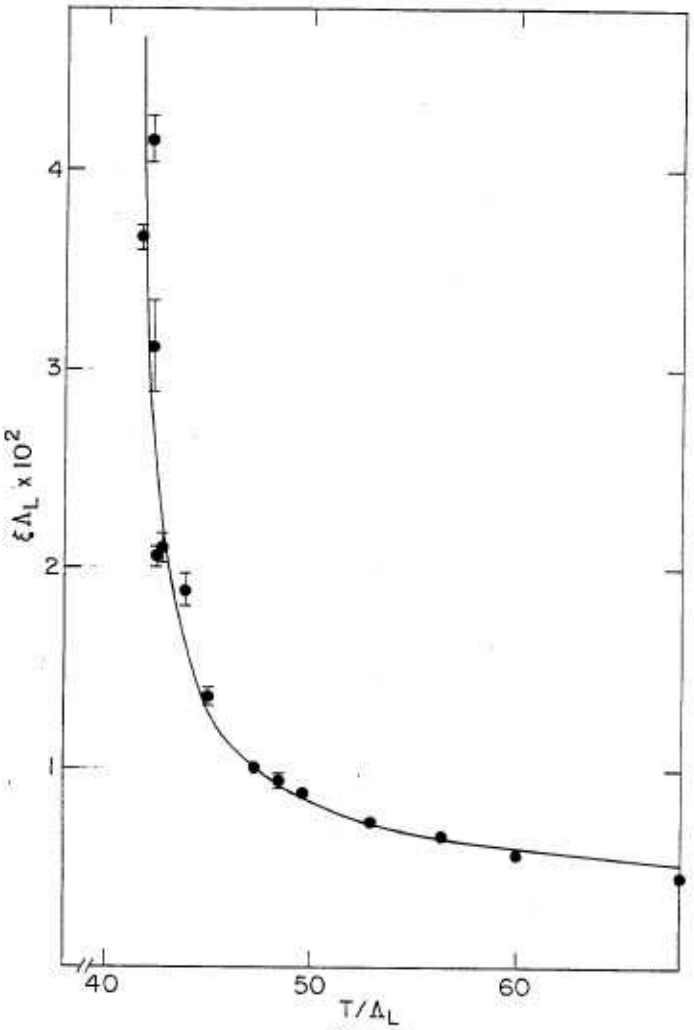

Phys. Rev. D34 (1986) 3193

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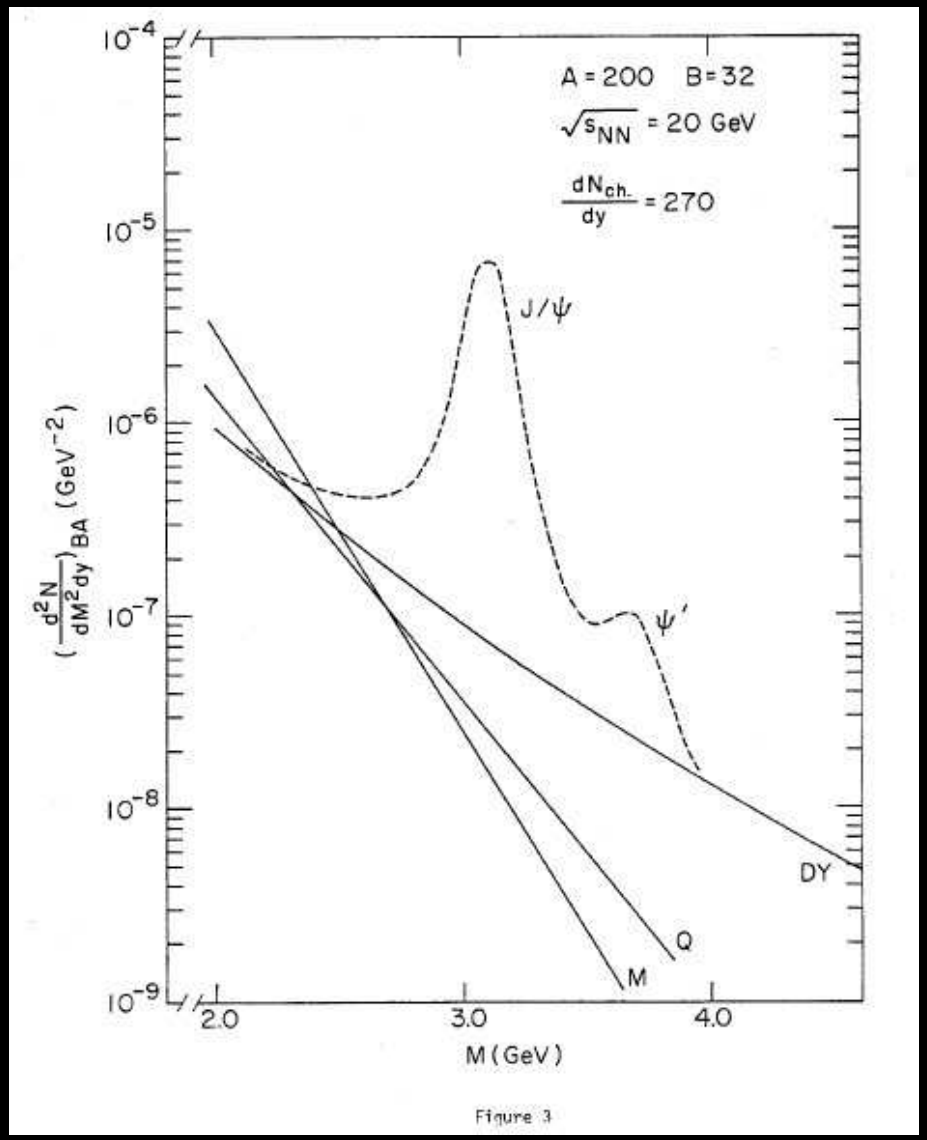
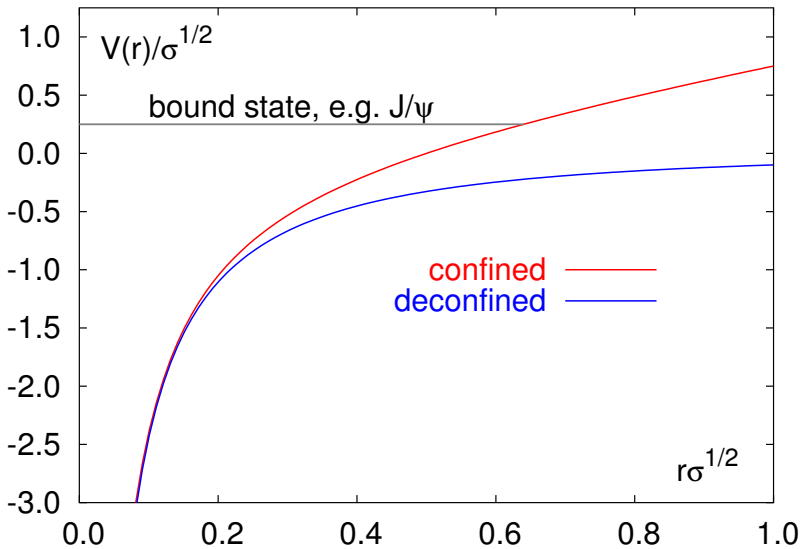


Phys. Lett. B178 (1986) 416

Deconfinement $\Rightarrow$ screening
$\Rightarrow$ quarkonium suppression

The Matsui-Satz argument (1986):

- deconfinement $\Rightarrow$ screening
  $\Rightarrow$ no heavy quark bound states in a QGP



$V_{\bar{q}q}(r,T) \to \infty$ confinement

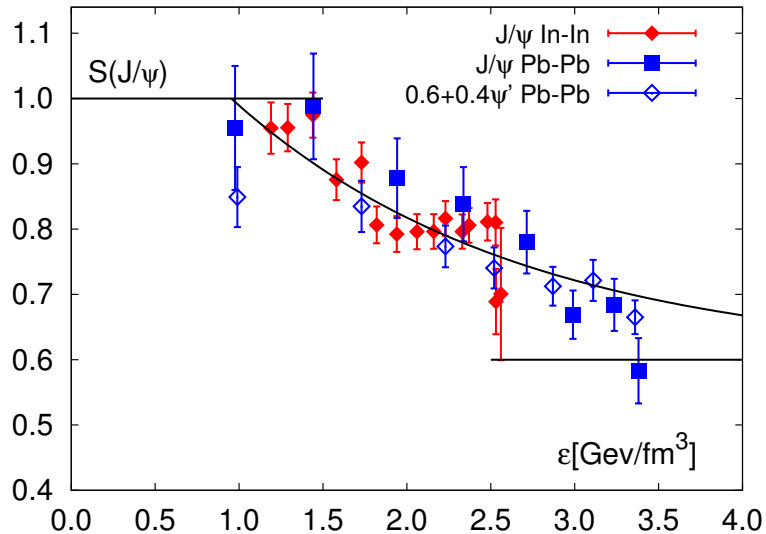
$V_{\bar{q}q}(r,T) < \infty$ deconfinement

J/ψ suppression

- heavy $q\bar{q}$-pairs are rare states in a QGP
  $\Rightarrow$ dissolved pairs never recombine

EoS and Charmonium Suppression

F. Karsch, D. Kharzeev, H. Satz, hep-ph/0512239.



charmonium yield (SPS)

- from centrality (or b) to energy density (ϵ) using Bjorken formula

- data consistent with
  no direct J/ψ suppression;
  only missing feed-down from χ_c
- Where does direct J/ψ suppression set in? $\Rightarrow$ HIC
- Where should direct J/ψ suppression set in? $\Rightarrow$ LGT
- relate T_{diss}/T_c to energy density using lattice EoS

Can we reach a consistent (LGT vs. HIC) picture for heavy quark bound state properties at high temperature ?

Thermodynamics on QCDOC and apeNEXT

US/RBRC QCDOC

20.000.000.000.000 ops/sec

BI – apeNEXT

5.000.000.000.000 ops/sec

$\sim$ 8 TFlops (peak)

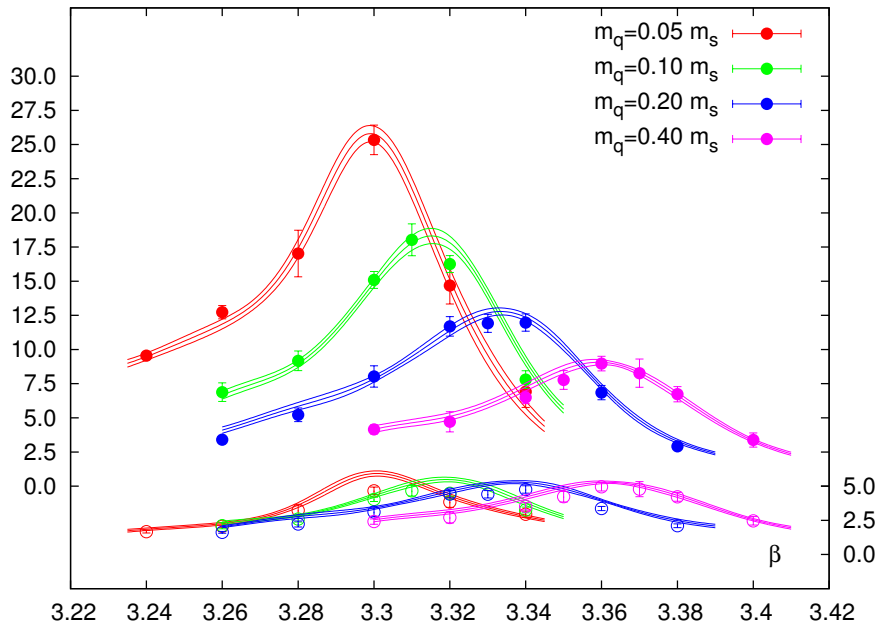
for QCD-Thermodynamics

today: 2.4 TFlops

A new determination of T_c

- (2+1)-flavor QCD with a physical strange quark mass and "almost" physical light quarks ($m_\pi \simeq 200$ MeV)
- (2+1)-flavor QCD calculation of critical couplings for several quark masses and lattice sizes ($N_\tau = 4,\ 6..,\ N_\sigma = 8,\ 16,\ 32$)

- reached small quark masses: $m_{PS}/m_V \ \simeq \ 0.2$
- achieved high statistics: up to 40.000 traj. per β-value
- control over volume ($N_\sigma = (8 - 32)$) cut-off ($N_\tau = 4, 6$) and quark mass dependence



critical couplings from maxima of $\bar{\psi}\psi$ and L-susceptibilities

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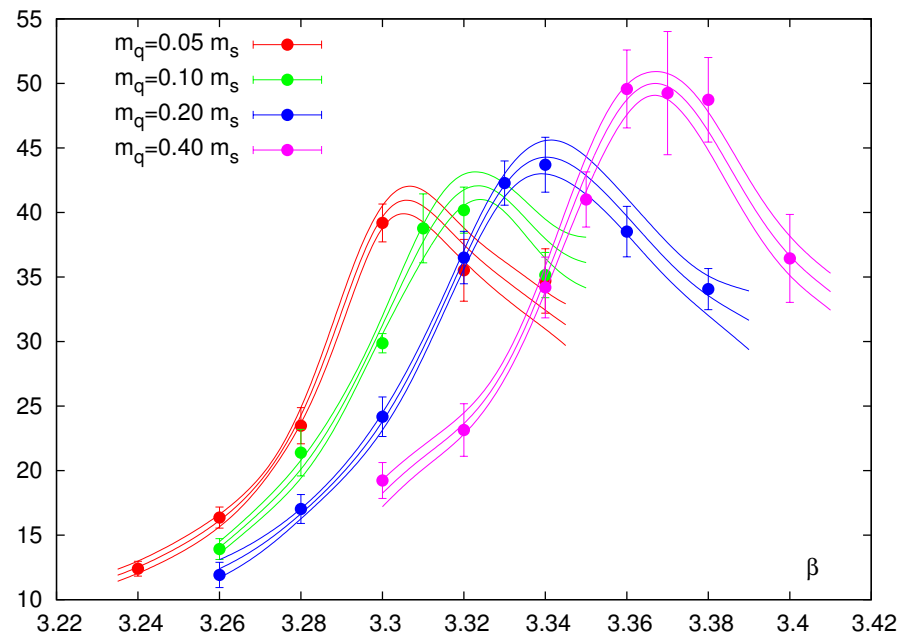
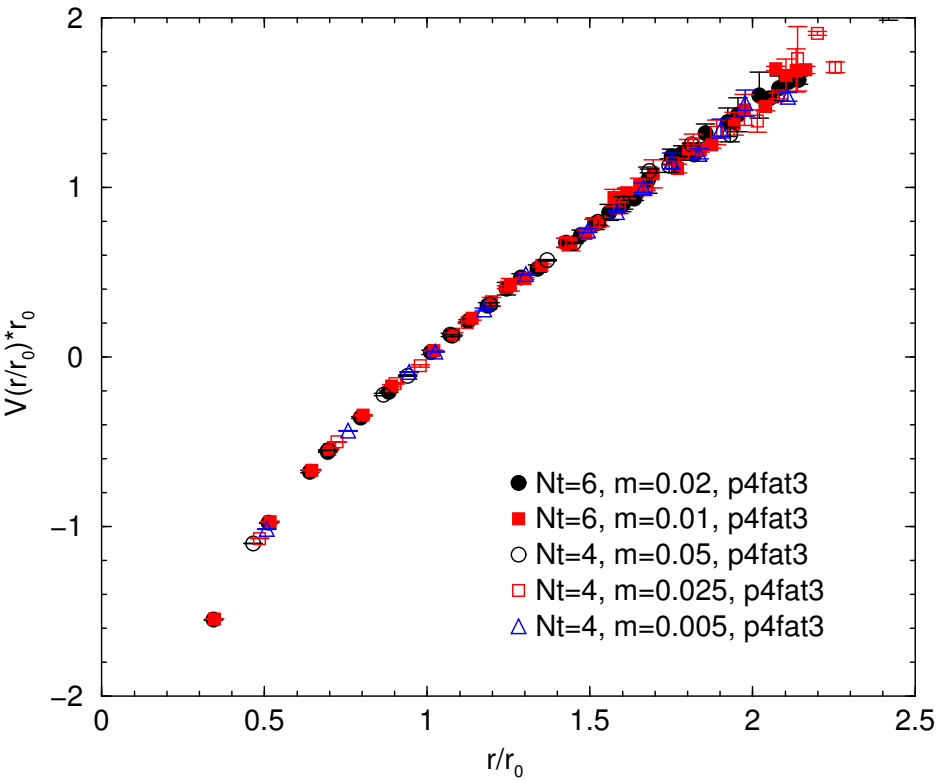
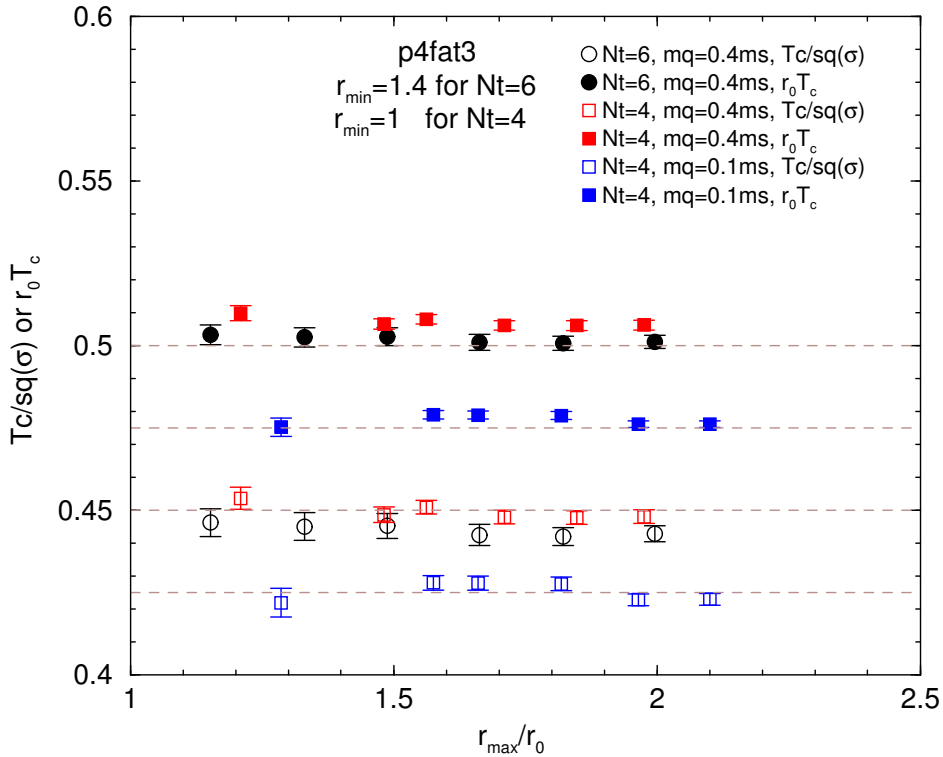


critical couplings from maxima of $\bar{\psi}\psi$ and L-susceptibilities

$\Rightarrow \quad r_0 T_c,\ T_c/\sqrt{\sigma}$

- determine scale from potential calculations at β_c for $N_\tau = 4$ and 6 on $16^3 \times 32$ lattices





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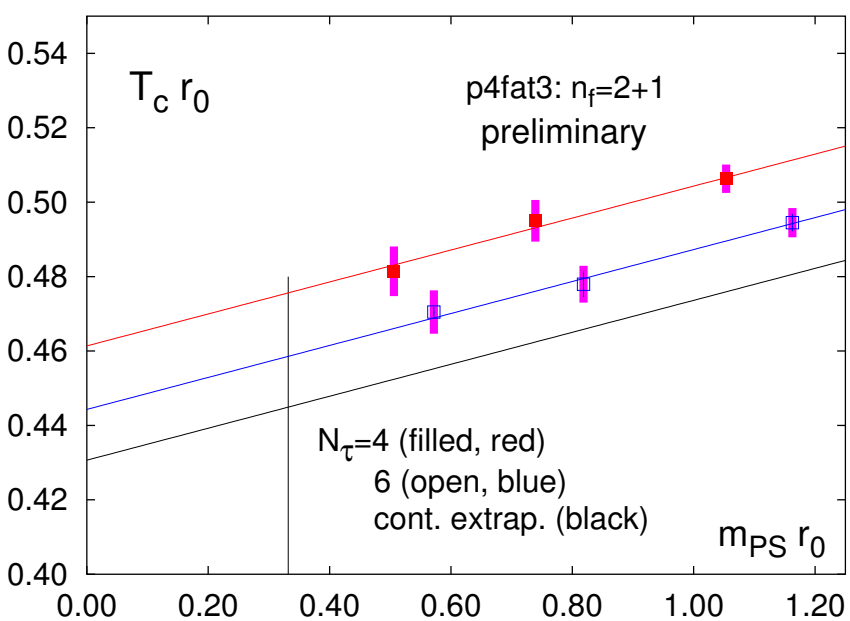
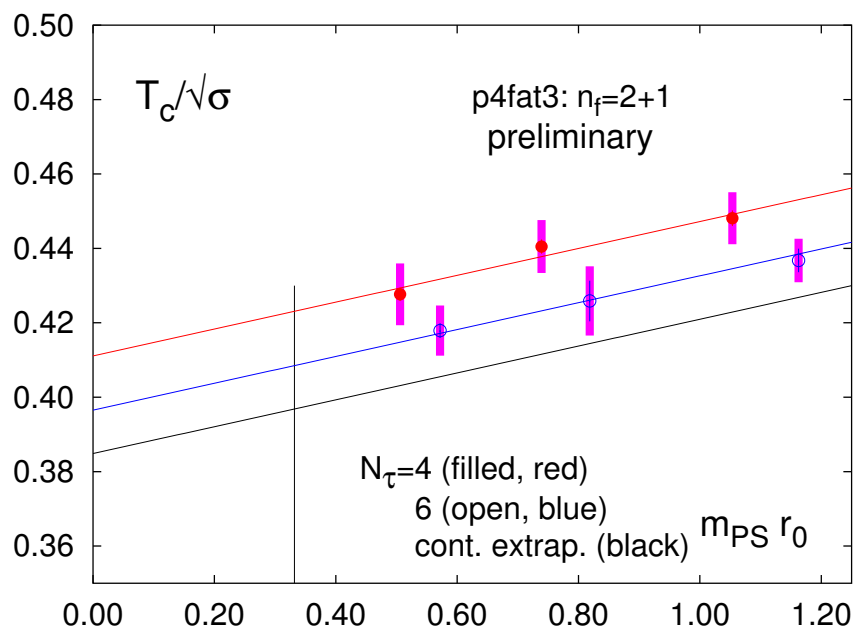
- extrapolate to chiral and continuum limit

$$(r_0 T_c)_{N_\tau} = (r_0 T_c)_{cont.} + b m_{PS} r_0 + c/N_\tau^2$$





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$$(r_0 T_c)_{N_\tau} = (r_0 T_c)_{cont.} \; + \; b m_{PS} r_0 \; + \; c/N_\tau^2$$

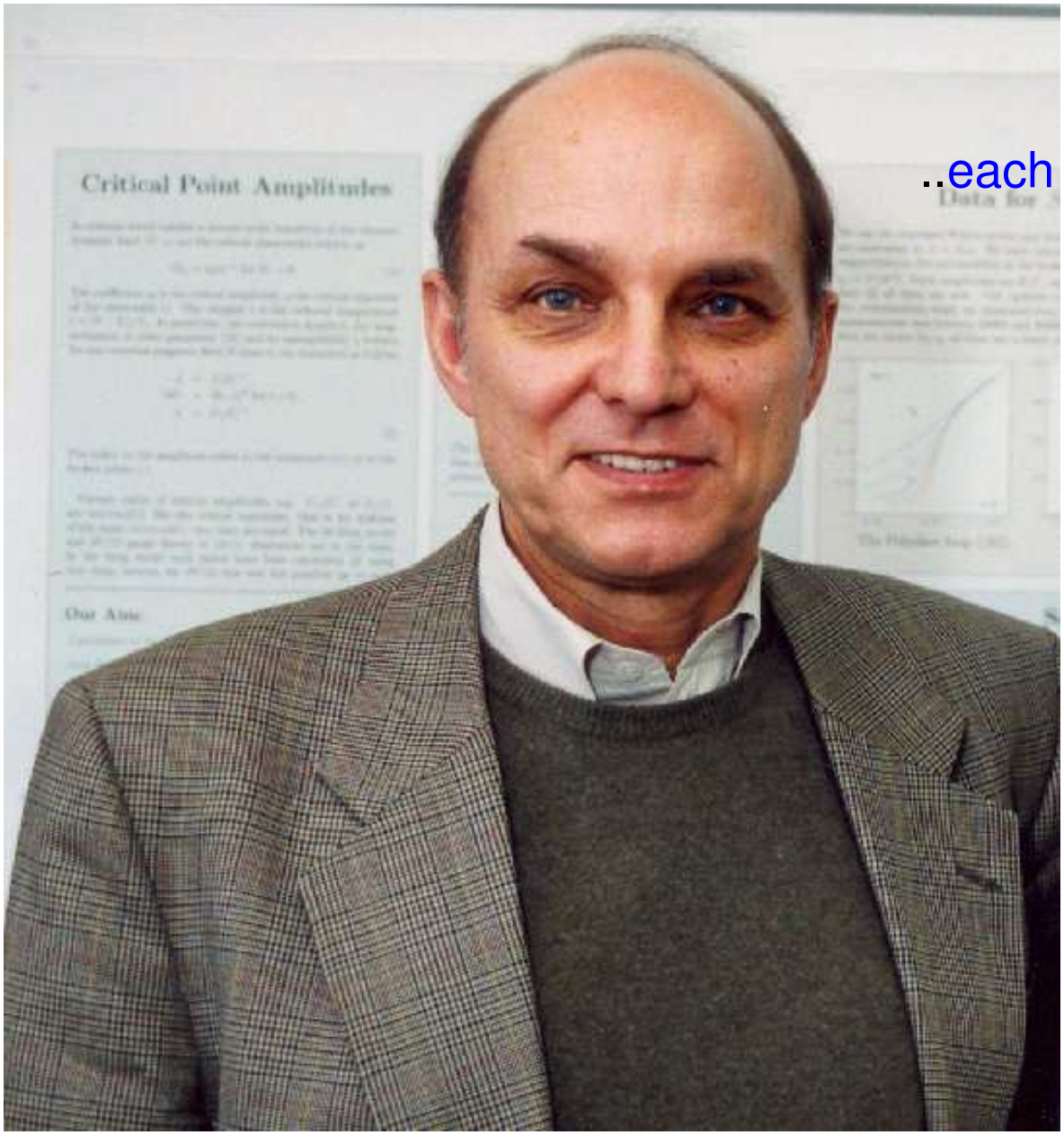
preliminary!

$\Rightarrow \quad r_0 T_c = 0.431(8) \quad , \quad T_c/\sqrt{\sigma} = 0.385(10)$

use $r_0 = 0.462(11)(4)$ fm, $r_0\sqrt{\sigma} \simeq 1.12$ to convert to physical values

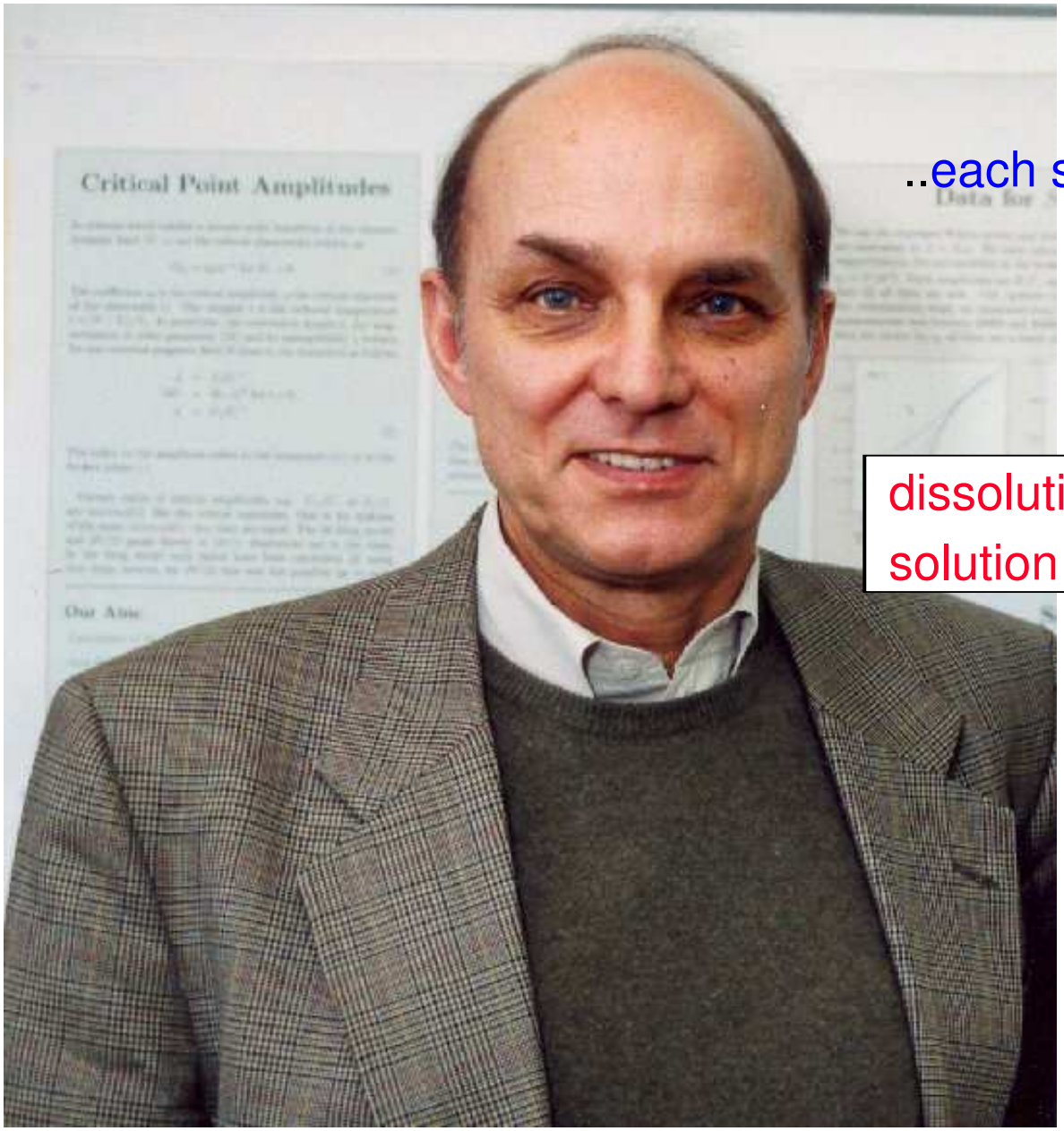
$\Rightarrow \quad T_c \simeq 180$ MeV for $m_q = 0$

...we learned our lesson



..each stick has two ends...

...we learned our lesson



..each stick has two ends...

dissolution is the solution!!

Thank you

Thank you

– for showing me the right end of the stick

Thank you

– for showing me the right end of the stick
– for introducing me to Lattice Gauge Theory

Thank you

– for showing me the right end of the stick
– for introducing me to Lattice Gauge Theory
– and for teaching me all you knew about computational physics

Finally

Finally

– In case, you get tired of Bielefeld,...

Finally

– In case, you get tired of Bielefeld,...

– there exist places in New York that look (almost) like Hoberge-Uerentrup

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Uncommon places - America, Stephen Shore

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