

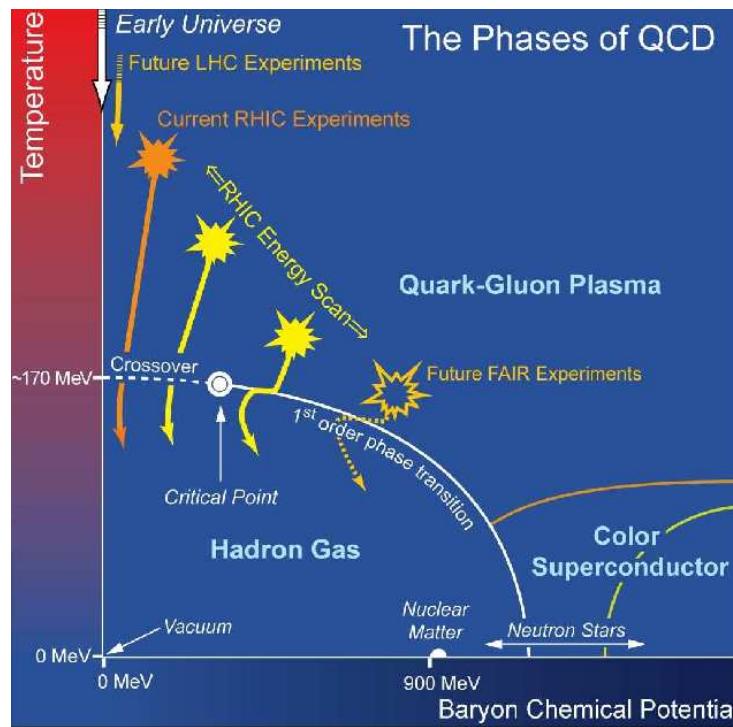
QUINTO CONVEGNO NAZIONALE SULLA FISICA DI ALICE

Trieste, 14 Settembre 2009

QUARK AD ALICE : FINALMENTE LIBERI!!!

M.P. Lombardo - LNF INFN

LE FASI DELLA MATERIA , E LHC



From NSAC Long Range Plan

CROMODINAMICA QUANTISTICA (QCD)

Teoria di Quark e Gluoni in interazione

$$\mathcal{L} = \sum_q \mathcal{L}_{YM} + \bar{\psi}(i\gamma_\mu D_\mu + m_q)\psi$$

q=up, down, strange, charm, bottom, (top)

Proprieta:

Sempre: Liberta' Asintotica

$T < T_c$:

Schiavitu' Infrarossa

$T > T_c$ SPS, RHIC:

Deconfinamento

$T >> T_c$ LHC :

Quark e Gluoni 'Liberi'

\leftarrow Lattice \rightarrow QCD

Osservazioni:

La Temperatura Critica

Le Interazioni

Lo Spettro
charmonio, bottomonio,
esotici, stati leggeri, ..

La Termodinamica :
Osservazione dei gradi di liberta'

OUTLINE

1) Lattice QCD

2) Osservazioni:

La Temperatura Critica

Le Interazioni

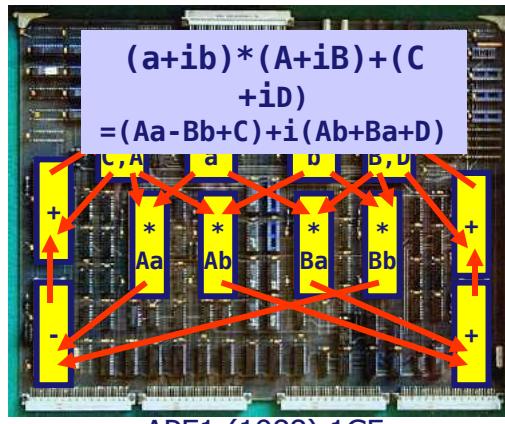
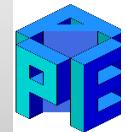
Lo Spettro

**charmonio, bottomonio,
esotici, stati leggeri, ..**

La Termodinamica :
**Conteggio dei gradi di lib-
erta'**

3) Discussione





APE1 (1988) 1GF



APE1000 (1992) 25GF, SP, REAL



APEmille (1999) 128GF, SP, Complex



apeNEXT (2004) 800GF, DP, Complex

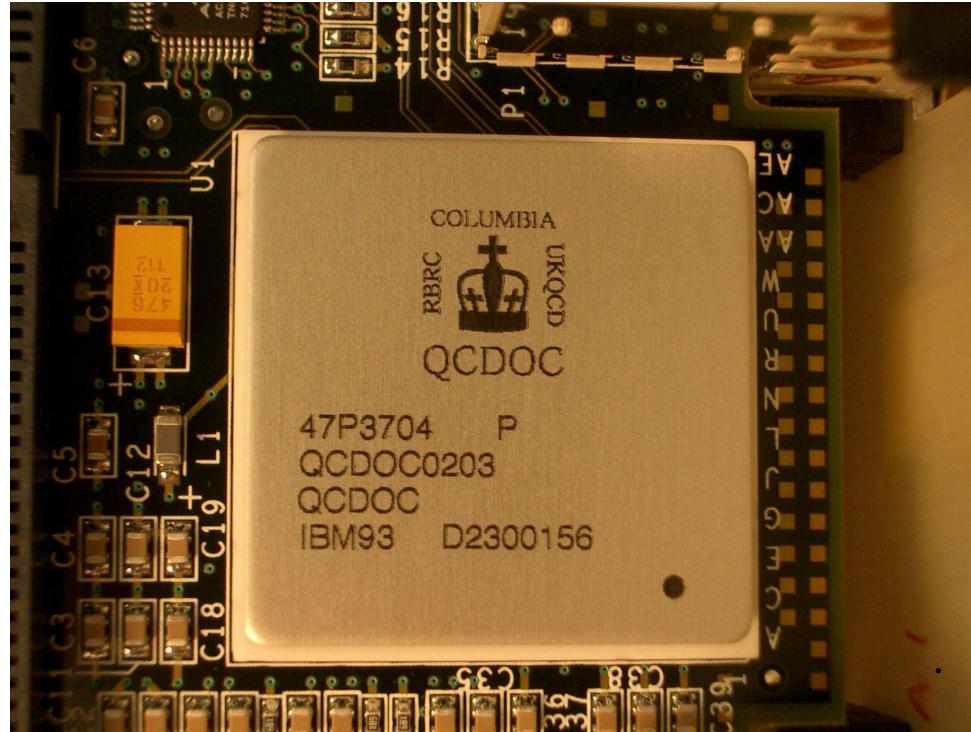
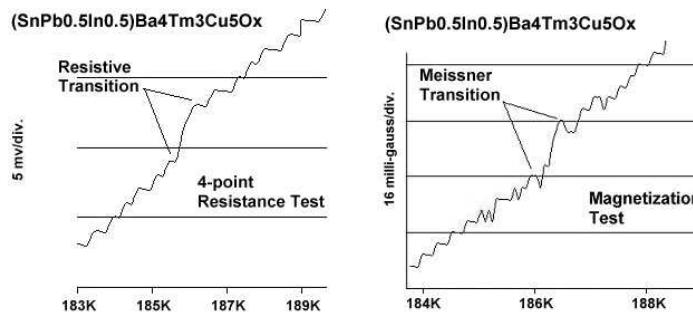


Image credit UKQCD Collaboration

50 milioni di transistor

5 Watts con un clock di 400 MHz.

Come si studia una transizione di fase in QCD?



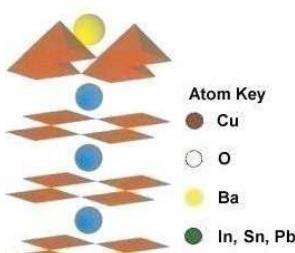
The First Ambient Temperature Superconductor

- Antarctica is Cold Enough -

14 March 2008
Superconductors.ORG

On 21 July, 1983, the Vostok Research Station in Antarctica logged the coldest temperature ever measured on earth at -89.2 C. This is equivalent to 183.95 Kelvin. On March 6, 2008, Superconductors.ORG measured signs of superconductivity just over 185 Kelvin in an optimized 1223/1212 intergrowth, marking the first observation of superconductivity at earth ambient temperatures.

Like the [181K superconductor](#) reported in January of 2008, the 185K superconductor appeared as a minority phase in a 1223/1212 host that was doped with extra Tm and Cu (see structure types at page bottom). Through trial-and-error Tc was found to peak with slightly more lead (Pb) and slightly less indium (In) than the 181K formulation. Eight separate tests of the compound produced an average Tc of 185.6K. Interestingly, the 3-to-1 ratio of 4A to 3A metals in the insulating layer is also the ratio that produces the highest transition temperatures among [binary alloy superconductors](#).



The structure type responsible for this record high Tc is believed to be a 1245/1212 intergrowth (shown at left) with formula $(\text{Sn}_{1.0}\text{Pb}_{0.5}\text{In}_{0.5})\text{Ba}_4\text{Tm}_5\text{Cu}_7\text{O}_{20+}$. This structure does not form stoichiometrically. It results as a byproduct only. So, commercial prospects of this discovery will hinge on manufacturers developing a method of mass producing and refining it into a pure form.

The graphs at page top show a resistive transition just above 185K and a Meissner transition just above 186K. The volume fraction of the 1245/1212 phase is less than 1% of the bulk, which would normally require multiple plots to be summed together to improve the signal-to-noise ratio.

UN DIZIONARIO

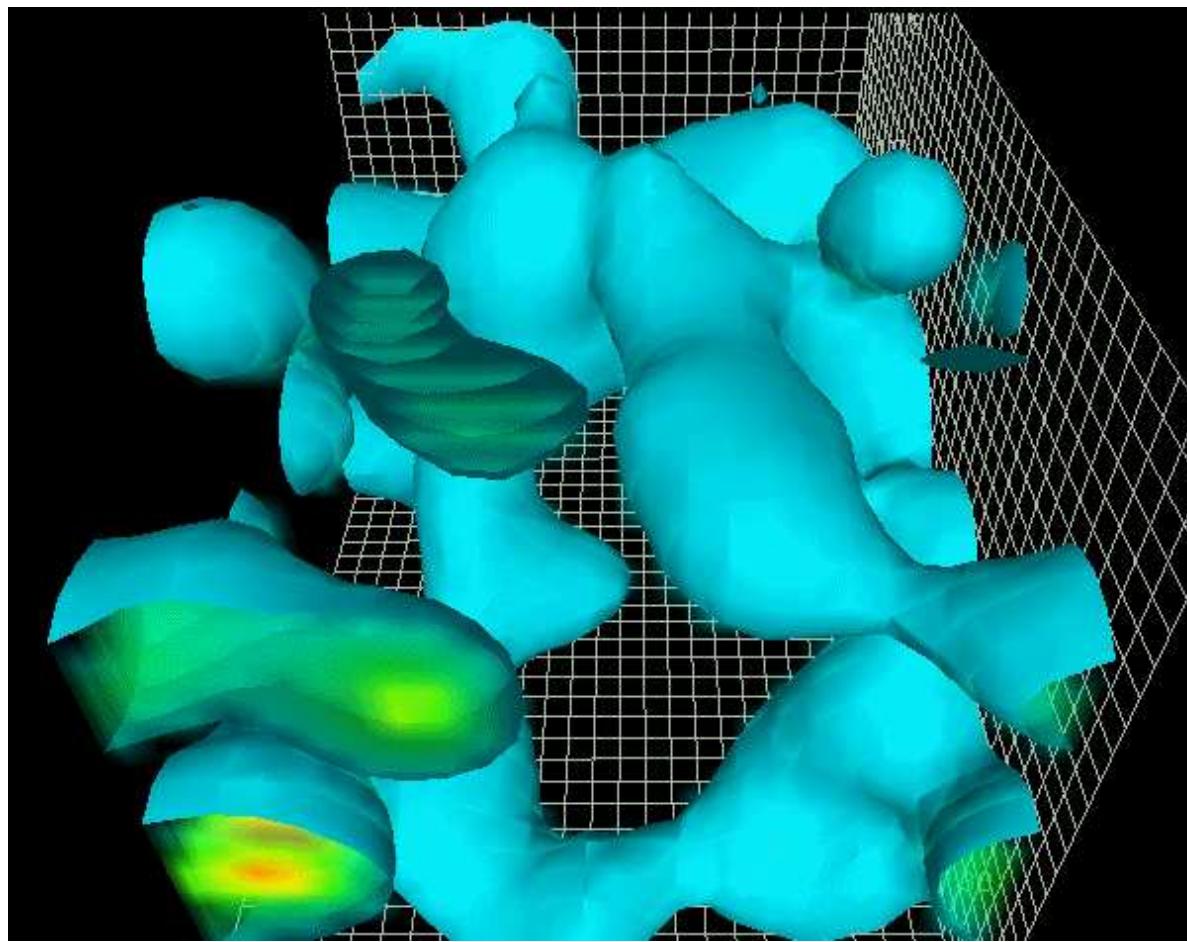
Campione \longleftrightarrow Configurazione di campi di gauge

Statistica \longleftrightarrow Molte Configurazioni

Temperatura, H \longleftrightarrow Temperatura, masse dei quark

Controllo della sistematica \longleftrightarrow Volume, discretizzazione

Osservabili: scelta della 'sperimentatore'



Adelaide SSC

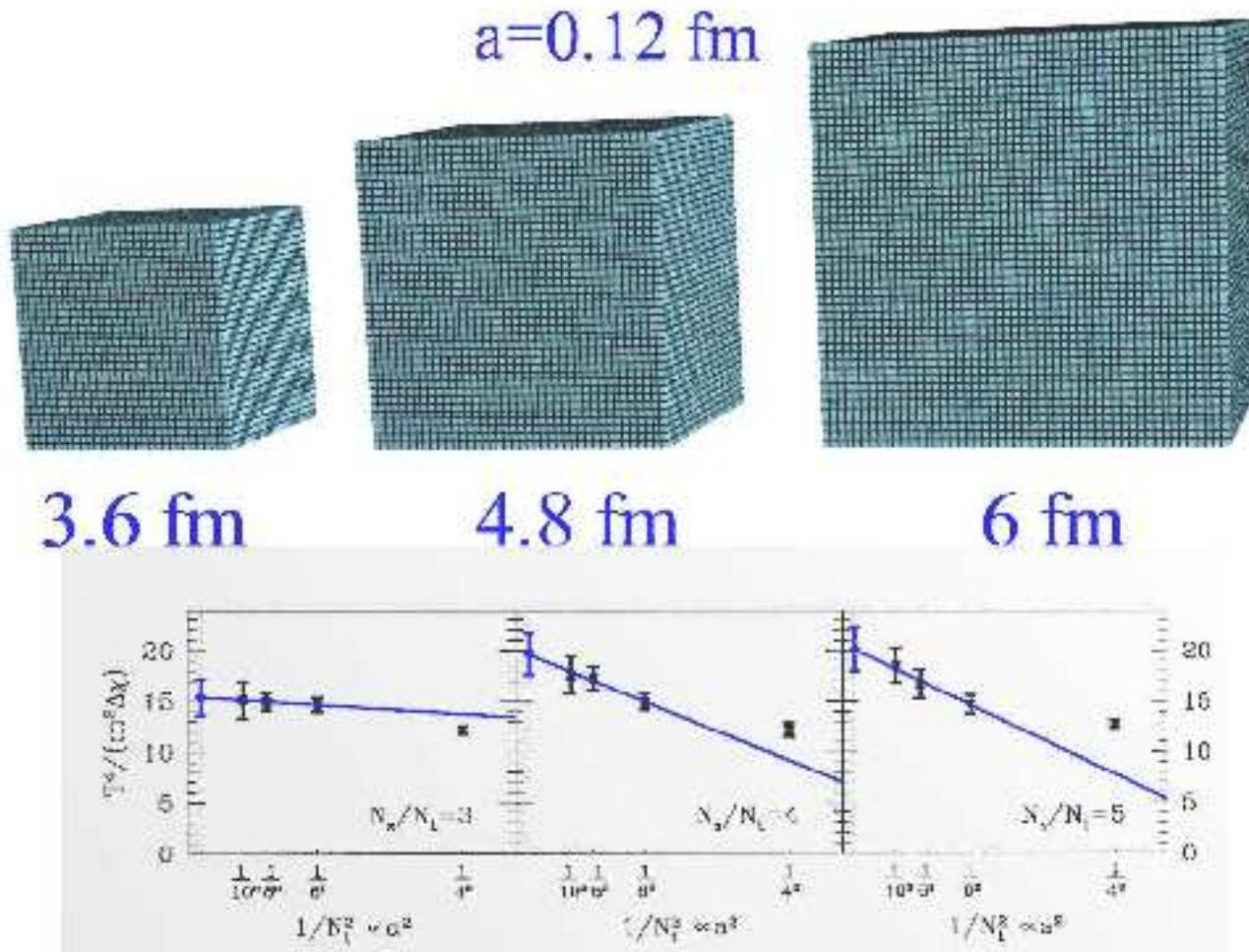
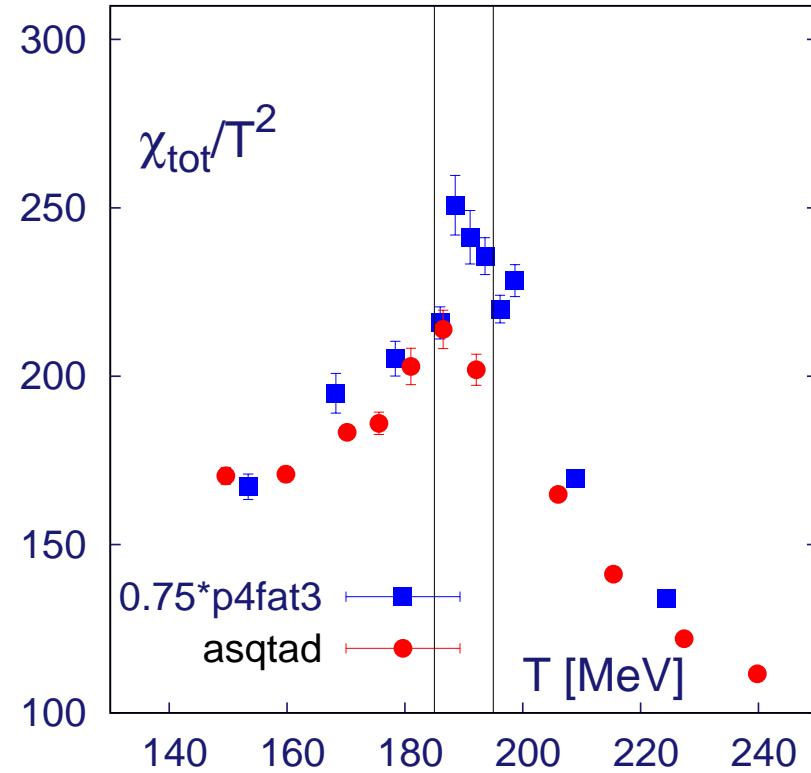


Figure 3. The upper pictures show three different physical V -s with our finest discretization. The lower plots show the dimensionless quantity $T^4 / (m^2 \Delta \chi)$ as a function of a^2 and their continuum extrapolated values. No V dependence is observed.

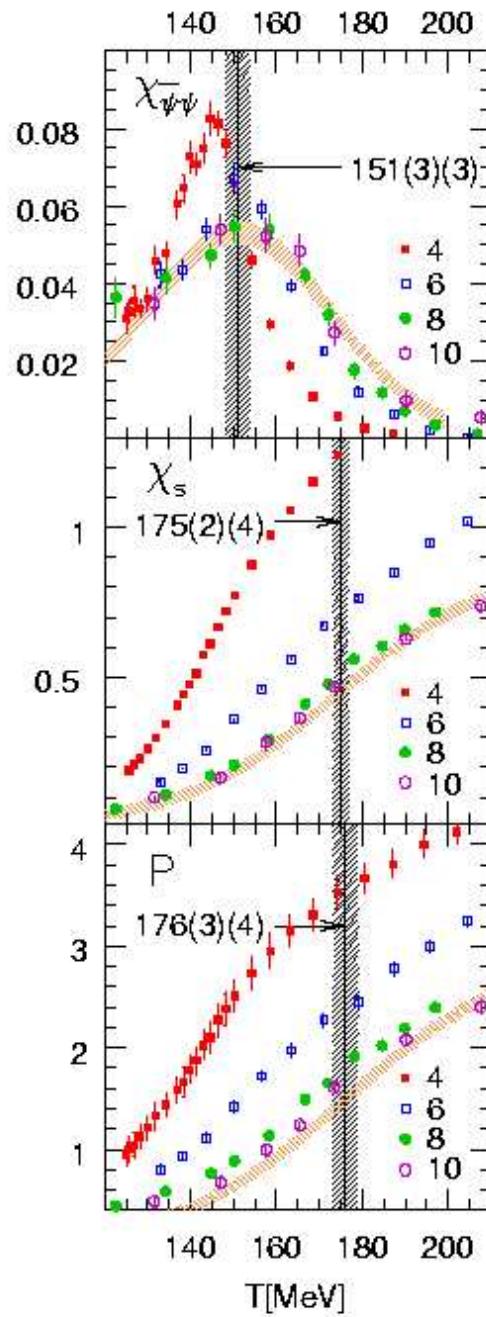
Wuppertal

La Temperatura Critica

T_c :
RBC-BIELEFELD



T_c :
WUPPERTAL-JUELICH



T_c AT $\mu_B = 0$: STATUS AT THE END OF 2008

RBC-BIELEFELD :

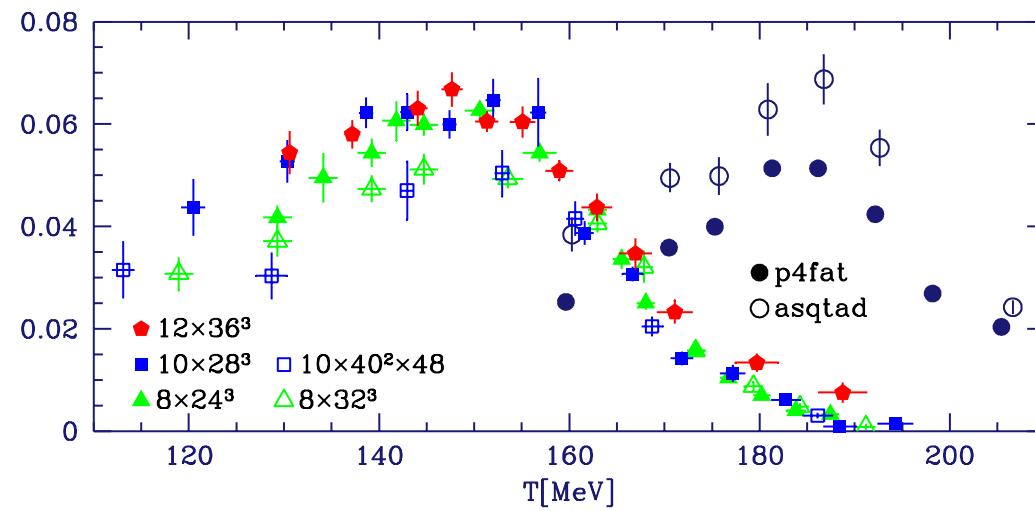
$$T_c = 190(5) \text{ MeV}$$

WUPPERTAL-JUELICH :

$$T_c = 175(5) \text{ MeV (Glue)}$$

$$T_c = 151(6) \text{ MeV (Fermions)}$$

IL CONFRONTO PIU' RECENTE



Possibili origini della discrepanza

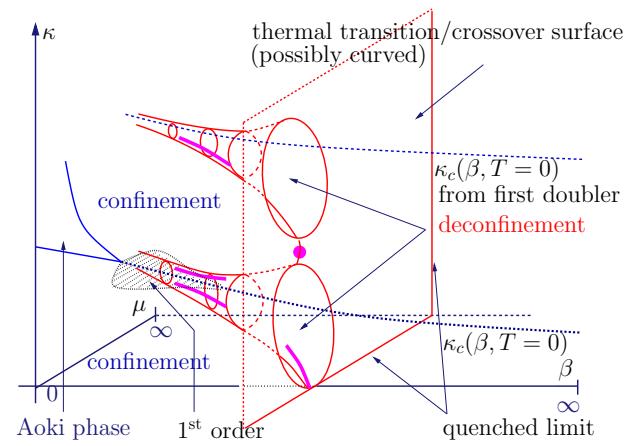
- Controllo degli effetti di spaziatura del reticolo
- Metodo di misura della suscettività (normalizzazione)

Possibili Risoluzioni

- Controllo sistematica
- Nuove formulazioni su reticolo, miglior limite continuo

UNA NUOVA STRATEGIA PER IL LIMITE CONTINUO

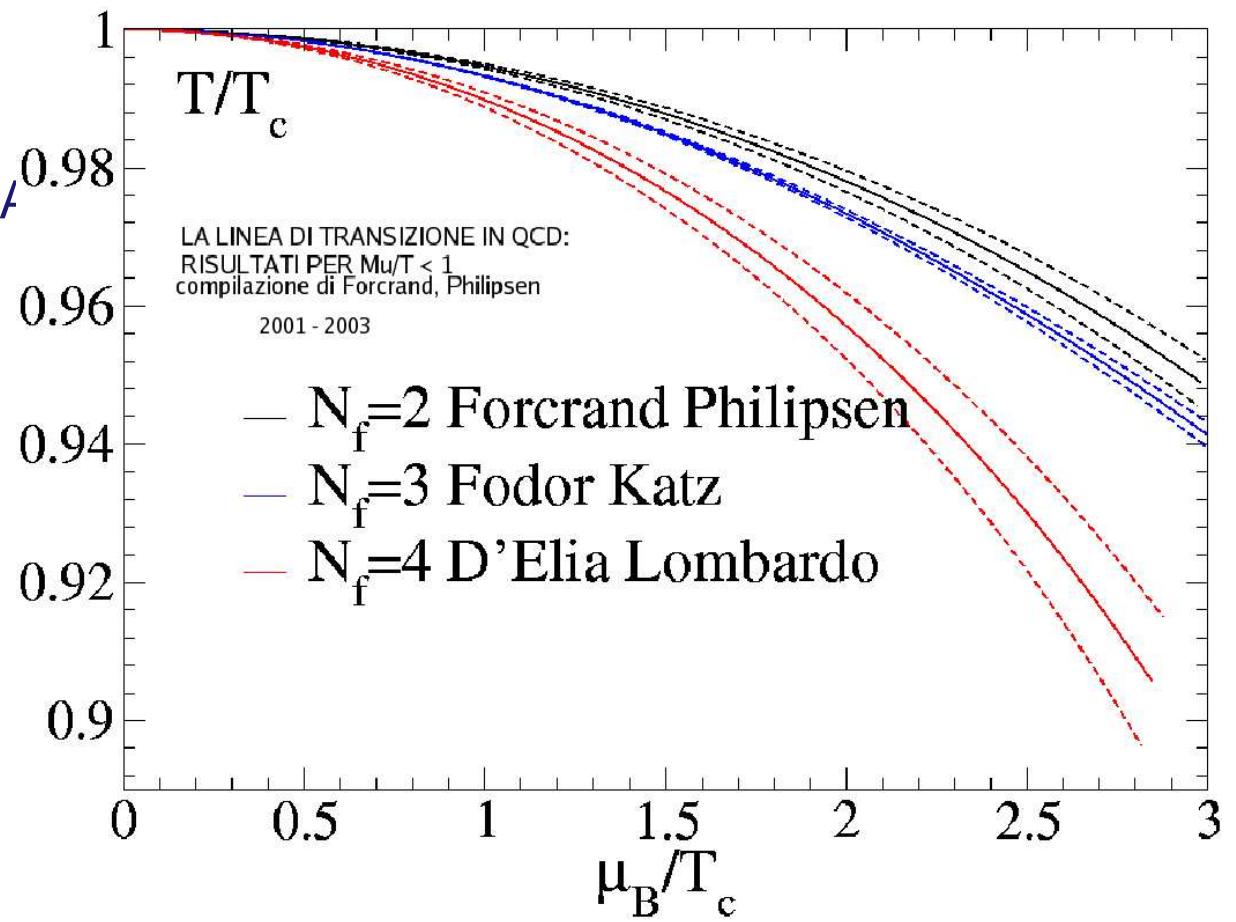
The tmfT Collaboration : E.-M. Ilgenfritz, K. Jansen, M. P. Lombardo, M. Müller-Preussker,
M. Petschlies, O. Philipsen, and L. Zeidlewicz - 2006–2009..



THE (PSEUDO)CRITICAL LINE AT SMALL μ_B

$$T = T_c - K \mu_B^2$$

$$K \propto N_f/N_c$$



Coefficient K in the Taylor expansion of the transition line, from $N_t = 4$
 Compilation by Owe Philipsen, 2008

$$\frac{T_c(\mu)}{T_c(0)} = 1 - K(N_f, m_f) \left(\frac{\mu}{\pi T} \right)^2 + \mathcal{O} \left(\left(\frac{\mu}{\pi T} \right)^4 \right) .$$

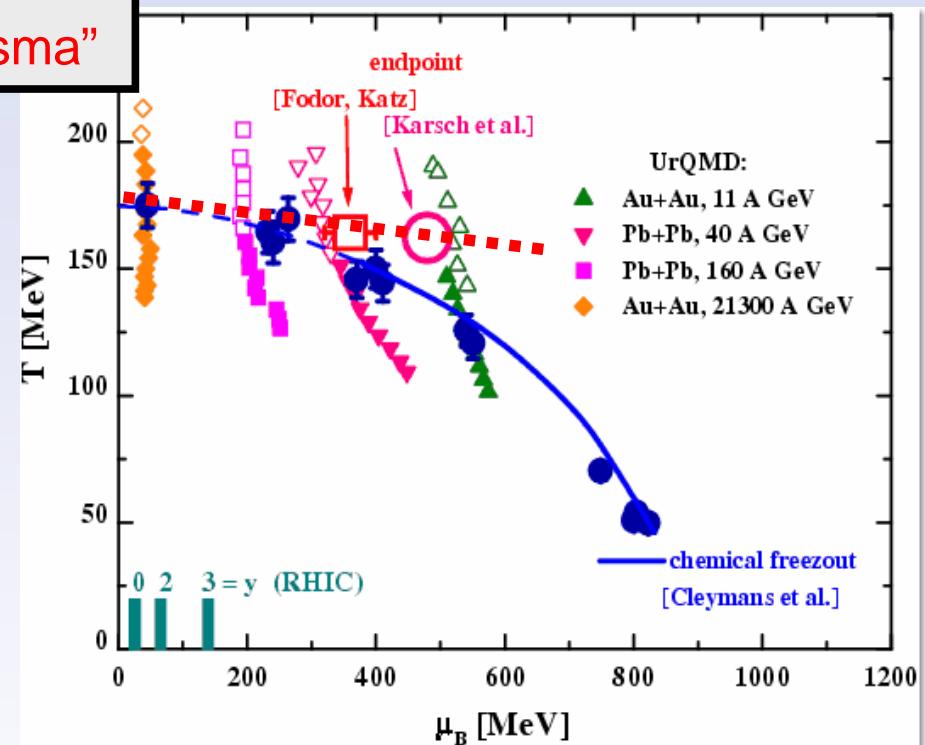
N_f	am	N_s	K	Action	β -Function	Method
2	0.1	16	0.69(35)	p4	non-pert.	Taylor+Rew.
	0.025	6,8	0.500(34)	stag.	2-loop pert.	Imag.
3	0.1	16	0.247(59)	p4	non-pert.	Taylor+Rew.
	0.026	8,12,16	0.667(6)	stag.	2-loop pert.	Imag.
	0.005	16	1.13(45)	p4	non-pert.	Taylor+Rew.
4	0.05	16	0.93(9)	stag.	2-loop pert.	Imag.
2+1	0.0092,0.25	6-12	0.284(9)	stag.	non-pert.	Rew.

Berechnung der Eigenschaften heißer und dichter QCD-Materie:

“Suche nach dem Quark-Gluon-Plasma”

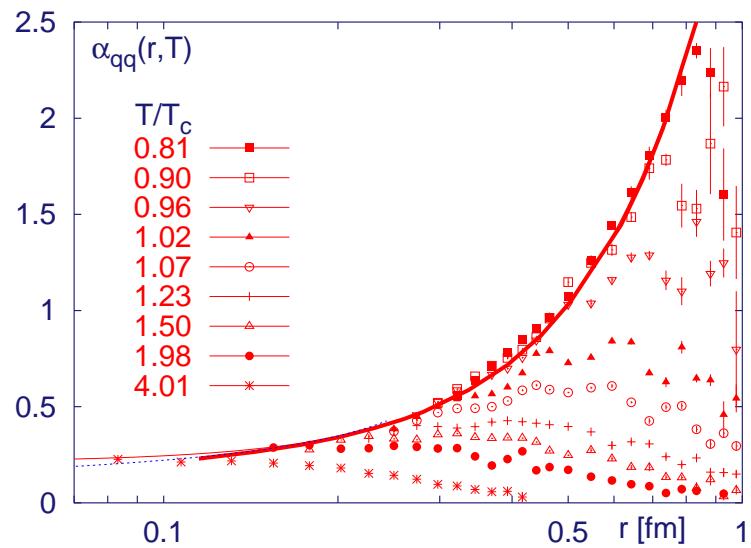
Theoretische Interpretationshilfe,
Zusammenarbeit und Vorhersagen
für

- GSI-SIS und GSI-FAIR:
→ HADES und CBM
- CERN-SPS und CERN-LHC
→ NA49, CERES, NA60, ALICE
- BNL-RHIC:
→ STAR

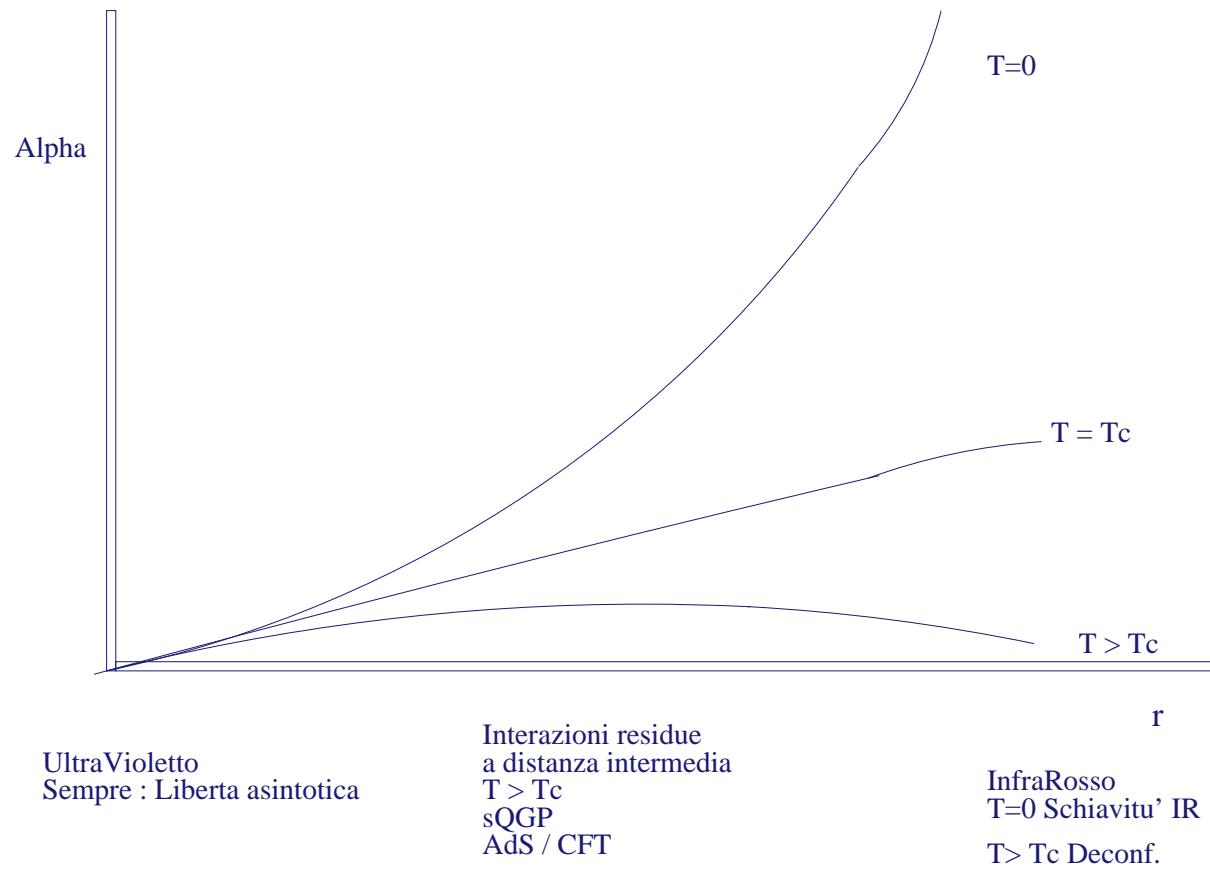


Running Coupling e Spettro

II running coupling α

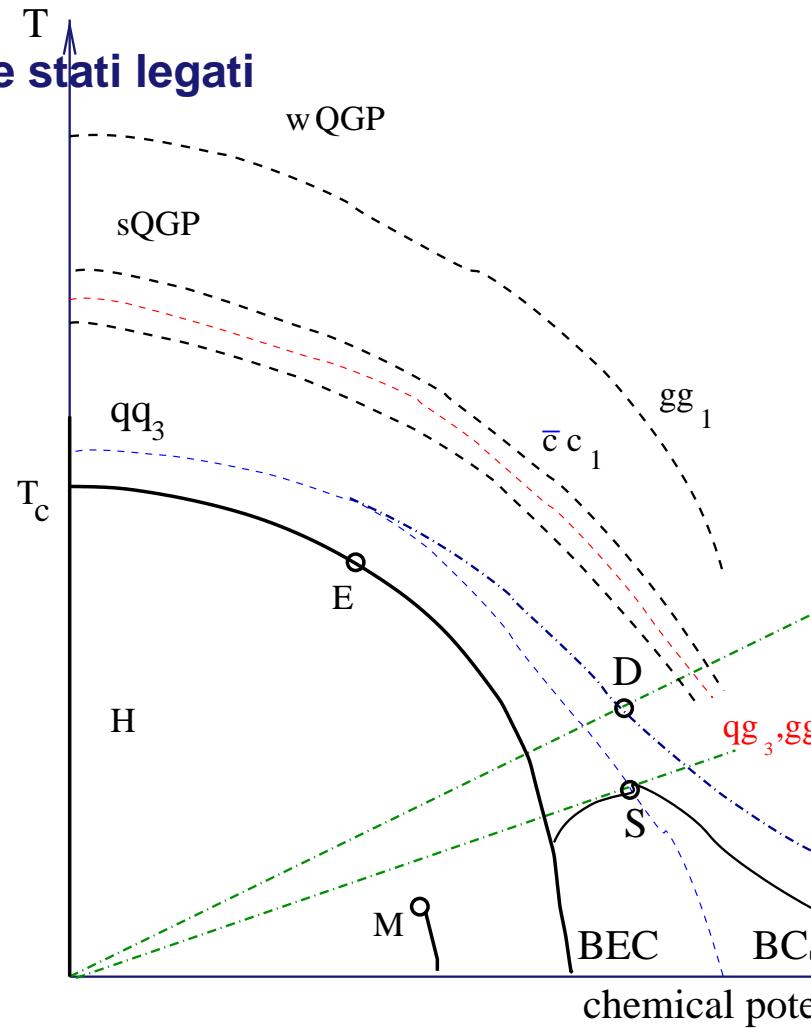


Kaczmarek e Zantow 2005



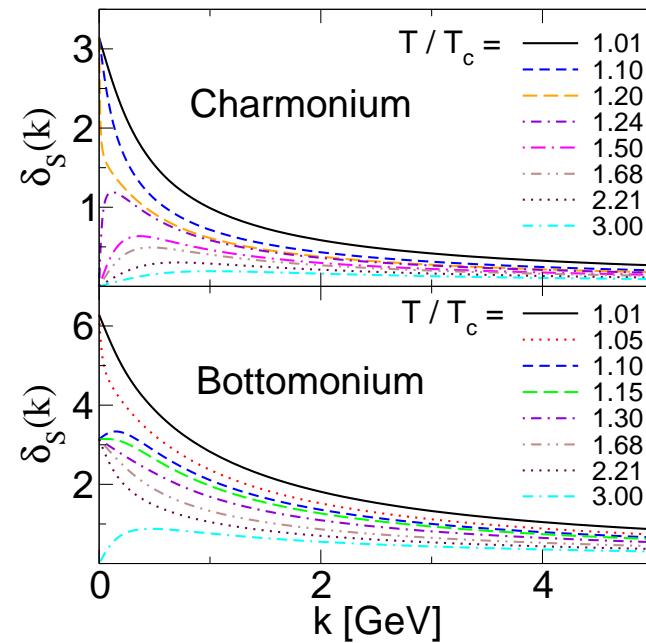
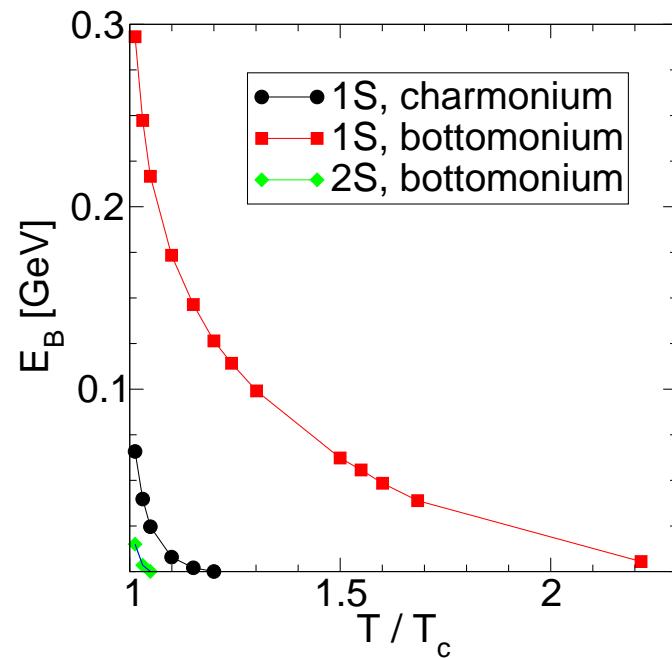
$T \gg T_c$ Quark Liberi : $g \geq 0$ a tutte le distanze!!

Diagramma di fase e stati legati



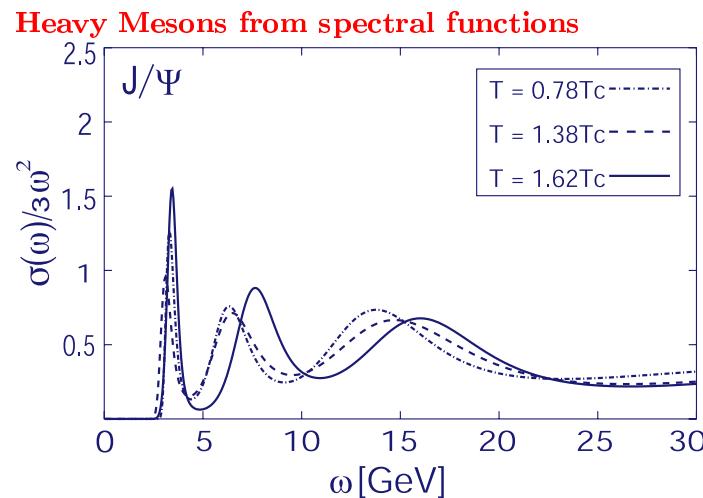
Shuryak 2006 –

Stati legati di Charm e Bottom

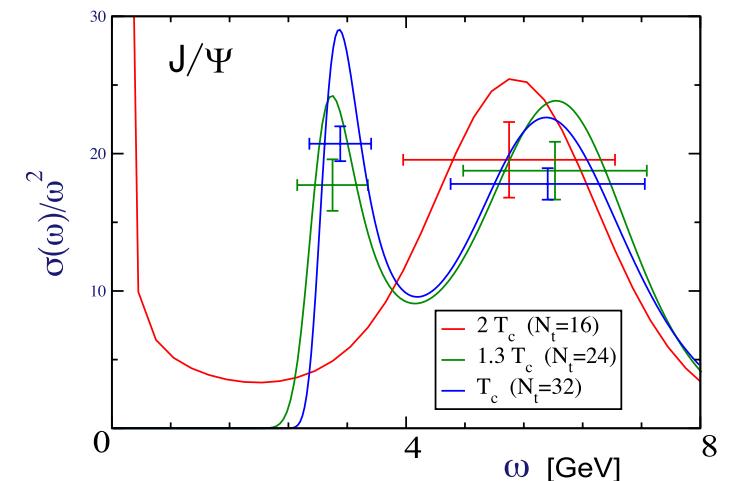


Solutions of the Schrödinger equation for heavy quarkonia with the screened potential identified with the singlet free energies of the left panel: binding energies (left) and scattering phase shifts (right)

Blaschke 2005.



Asakawa



Aarts et al. (TRINLAT Collaboration)

- Il principio e' chiaro : il quarkonio e' un termometro per il plasma
- Una comprensione quantitativa soddisfacente ancora non c'e'. Gli approcci semplici non sono rigorosi, e gli approcci rigorosi non sono semplici!

La fisica del **b** e del **bottomonio** e' particolarmente attuale:
Nuova frontiera delle simulazioni.

Gli stati esotici

- Tentativi di osservazione dei *monopoli magnetici* predetti da Shuryak D'Elia, D'Alessio, Ratti..
- Nuove osservazioni sulle **glueballs**: la glueball 0^{++} diventa lo stato piu' leggero in
 - Quark Gluon Plasma
Maezawa et al. [WHOT-QCD] 2008
 - Dense Matter
Lombardo, Paciello, Petrarca, Taglienti 2008
 - Conformal phases
Del Debbio, Pica, Rago, Patella, Lucini, 2009
- Ricerca di stati esotici (diquark, tetraquark) ad alta temperatura

Sembrano esclusi

Karsch, Redlich

Forse visibili ad alta densita barionica

D'Elia, Di Renzo, Lombardo

Termodinamica

Osservabili termodinamiche

Energy, Pressure

Number Density : accessible at **imaginary chemical potential**.

$$n_{u,d}(T, \mu_u, \mu_d, m_u, m_d) = \frac{\partial p(T, \mu_u, \mu_d)}{\partial \mu_{u,d}}; p(T, \mu_u, \mu_d) = \frac{T}{V} \ln Z(T, \mu_u, \mu_d)$$

Susceptibilities: accessible at **at $\mu = 0$**

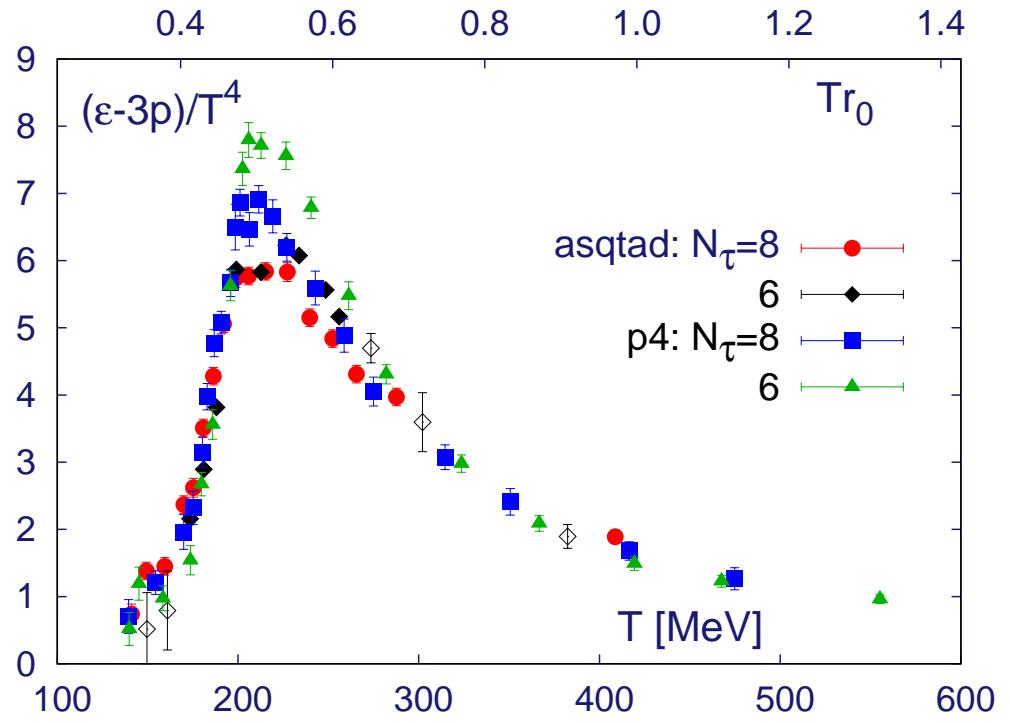
$$\chi_{j_u, j_d}(T) = \left. \frac{\partial^{(j_u + j_d)} p(T, \mu_u, \mu_d)}{\partial \mu_u^{j_u} \partial \mu_d^{j_d}} \right|_{\mu_u = \mu_d = 0}.$$

Test for fluctuations.

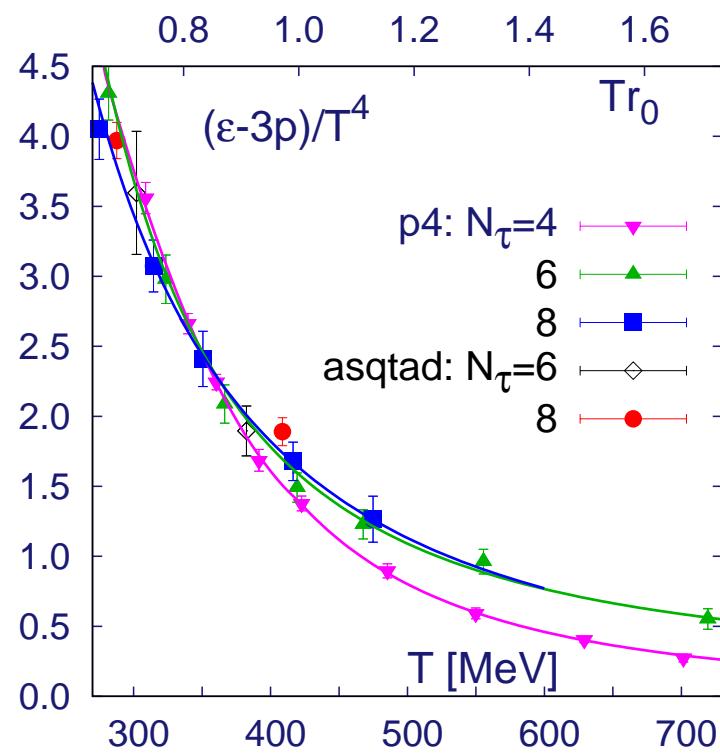
Taylor coefficients of the excess pressure:

$$\Delta p(T, \mu_u, \mu_d) \equiv p(T, \mu_u, \mu_d) - p(T, \mu_u = 0, \mu_d = 0) = \sum_{j_u, j_d} \chi_{j_u, j_d}(T) \frac{\mu_u^{j_u}}{j_u!} \frac{\mu_d^{j_d}}{j_d!},$$

containing information about baryon density effects in the EoS.

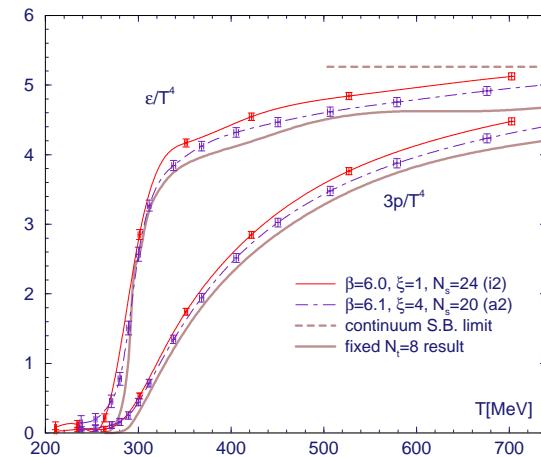
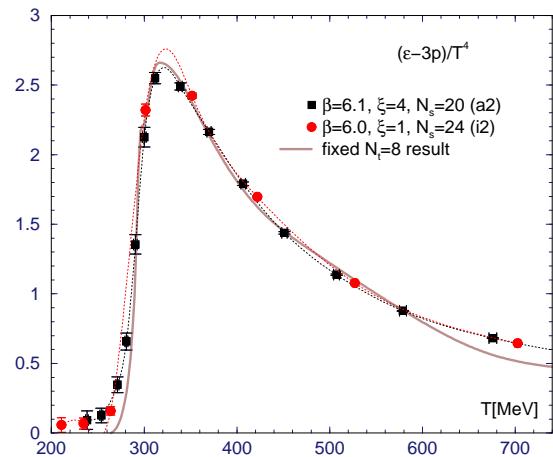


Bazazov et al. 2009



Bazazov et al. 2009

Nuove strategie per il limite continuo



Umeda et al. 2009

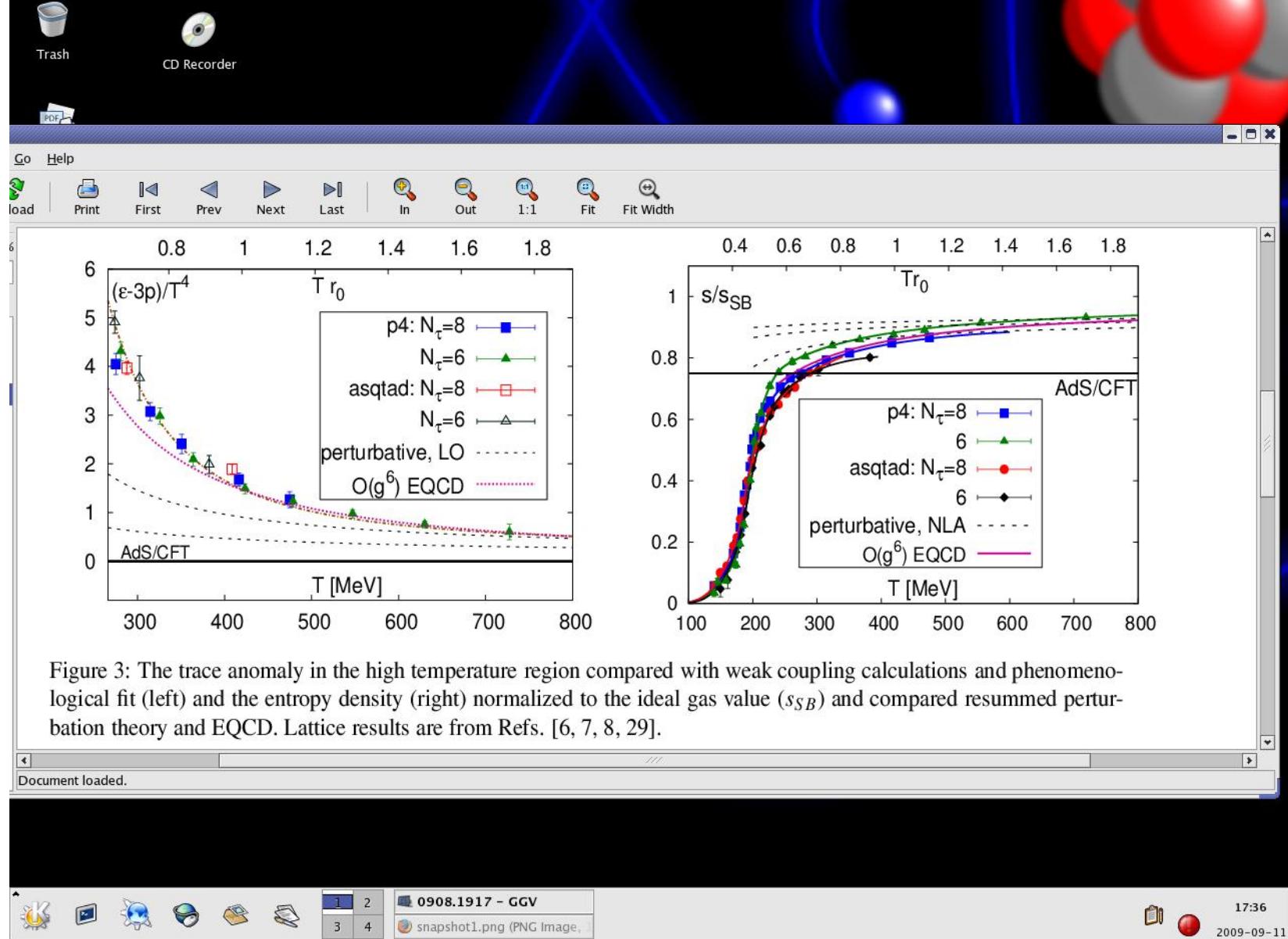
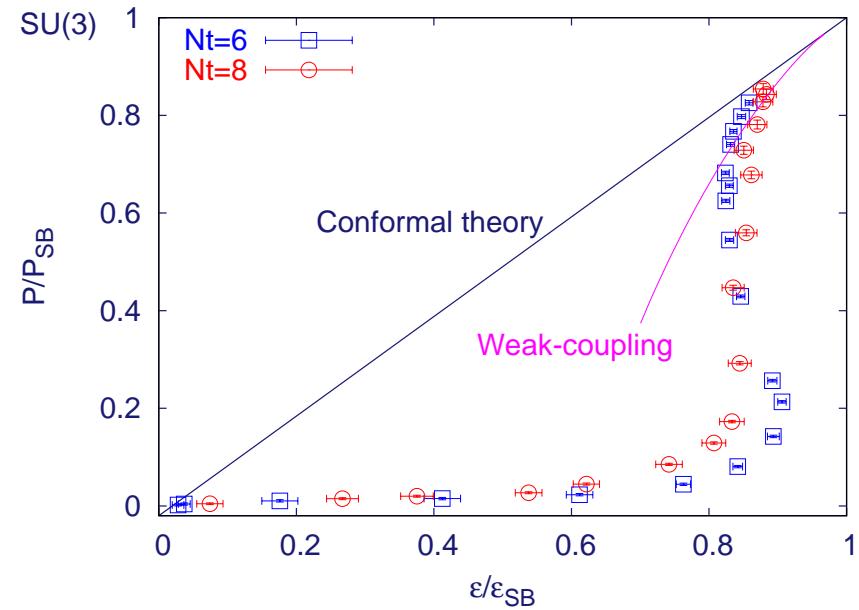


Figure 3: The trace anomaly in the high temperature region compared with weak coupling calculations and phenomenological fit (left) and the entropy density (right) normalized to the ideal gas value (s_{SB}) and compared resummed perturbation theory and EQCD. Lattice results are from Refs. [6, 7, 8, 29].

Petreczky 2009

The conformal limit of QCD

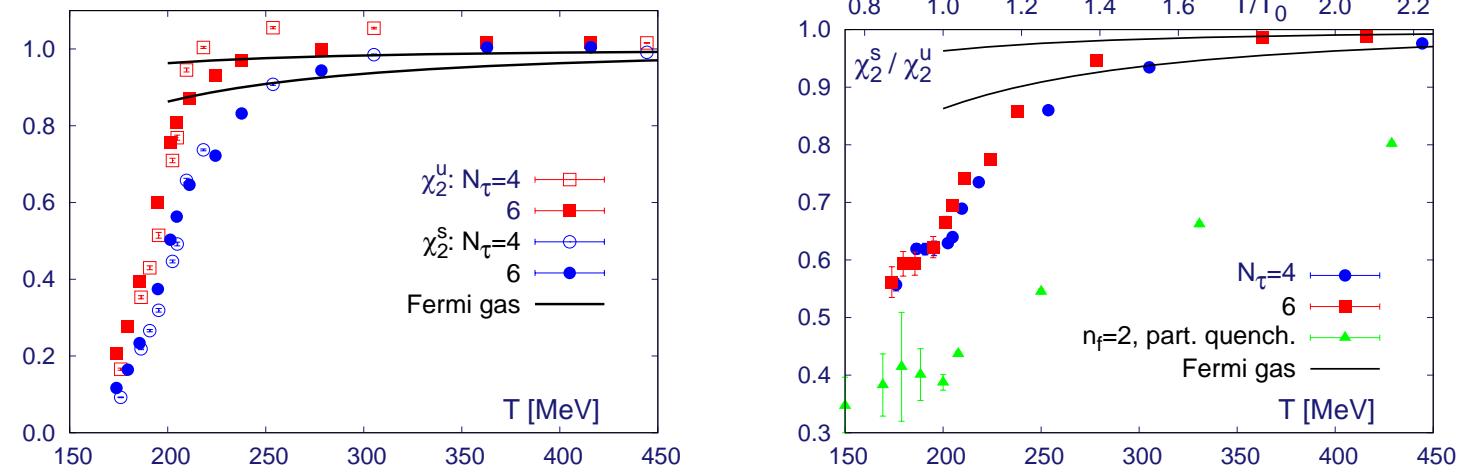


Datta and Gupta 2009

Light and Heavy(Strange) Quarks Fluctuations

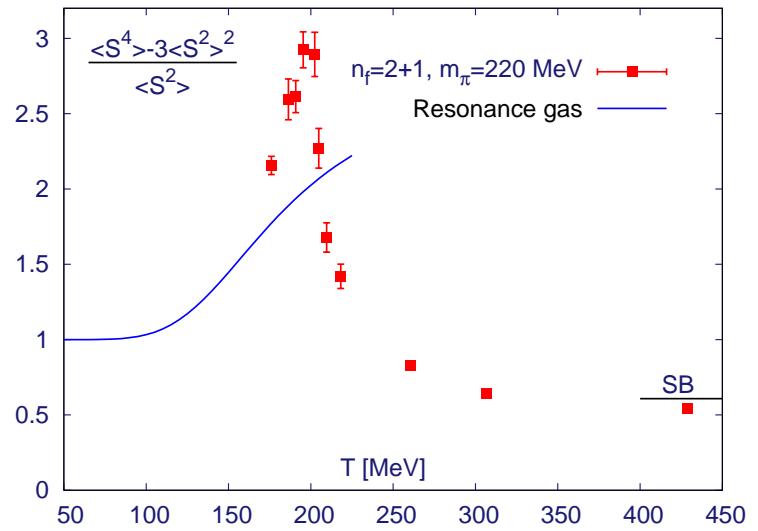
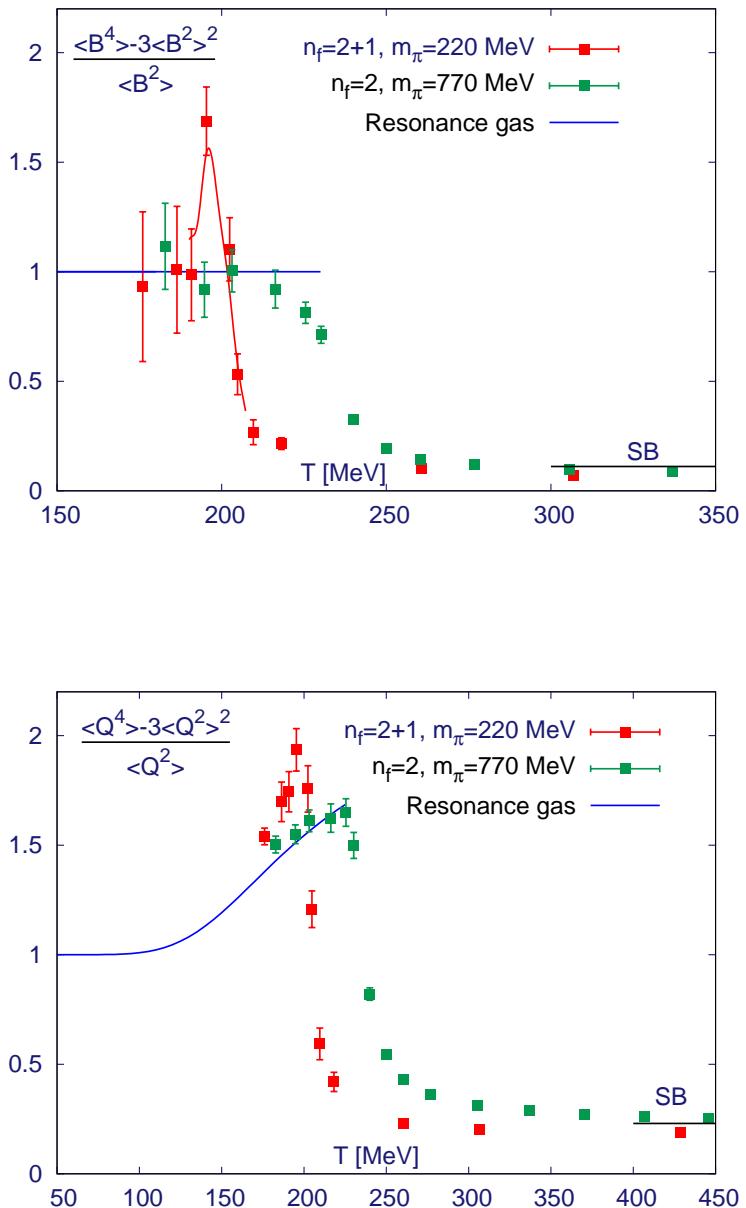
Cheng et al. 2009

- At the LHC the net baryon number is small and QCD at vanishing chemical potential provides a good approximation.
- The transition from the low temperature hadronic to the high temperature plasma regime is continuous and fluctuations are not expected to lead to any singular behavior.
- Nonetheless, they provide direct insight into the structure of the thermal medium, the relevant degrees of freedom and their correlations.
- Furthermore, enhanced fluctuations provide hints for nearby singularities in the QCD phase diagram related to the chiral limit at vanishing net baryon number as well as for a possible critical point at physical values of the quark masses at non-vanishing net baryon number density .



Cheng et al. 2009

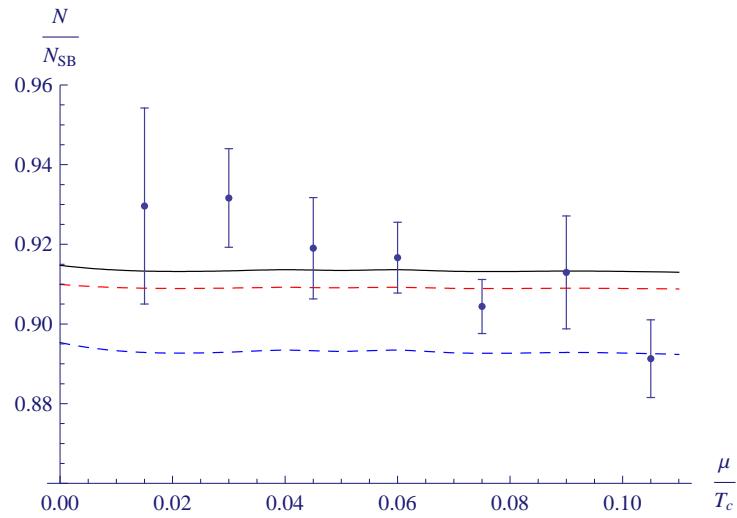
Hadron Gas, Fluttuazioni, Ricerca del punto critico



2+1 Flavor, $m_\pi = 220 \text{ MeV}$

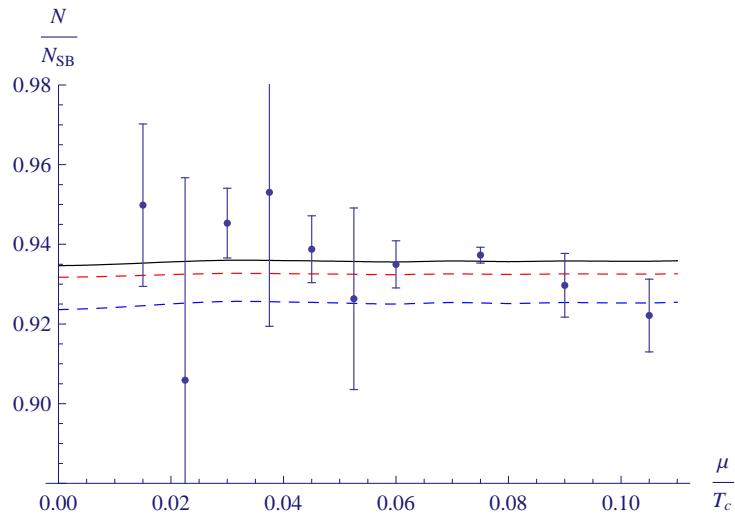
**RBC-Bielefeld QM2008;
courtesy C. Schmidt**

Il limite di Stefan-Boltzmann a densità finita



$$T = 1.5T_c$$

D'Elia, Di Renzo, Lombardo, Vuorinen, 2008

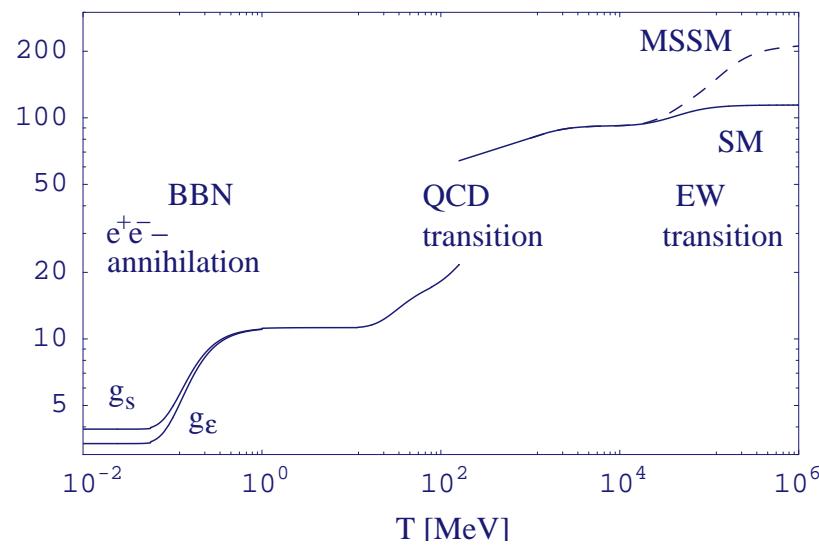


$$T = 3.5T_c$$

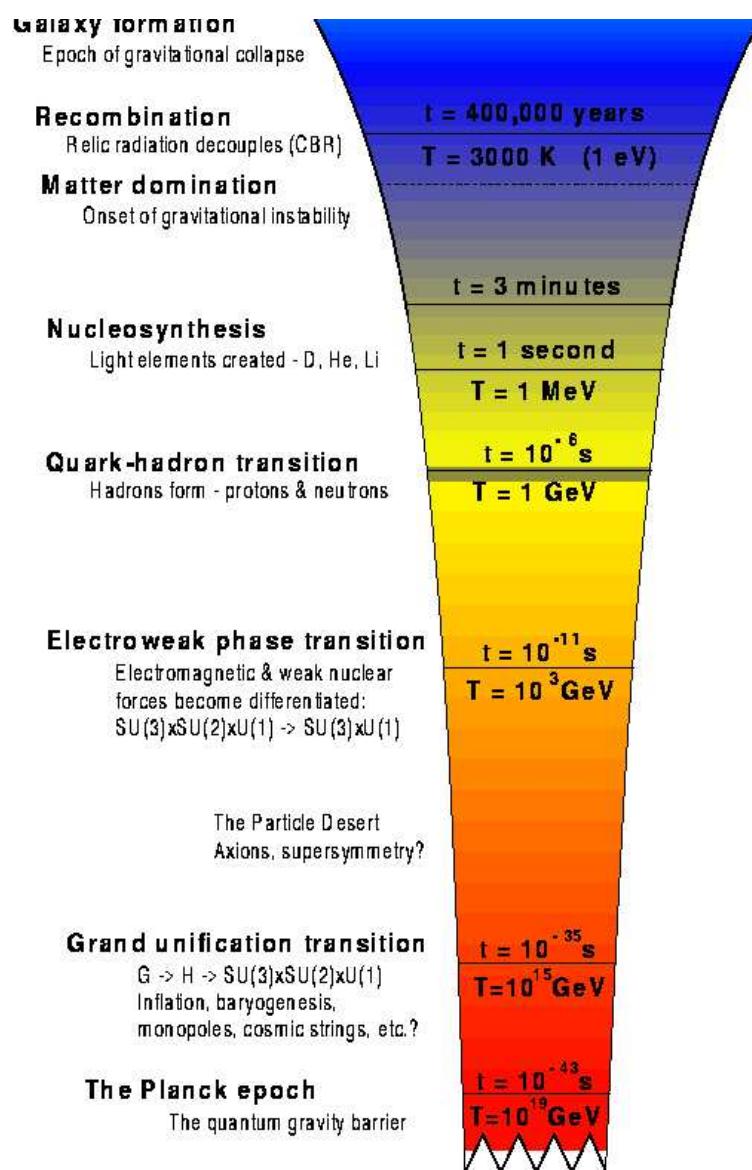
Termodinamica e Transizioni di Fase

Gradi di liberta' = numero di particelle **libere** vs T

$$P(T, \mu) = \frac{\pi^2}{45} T^4 \left(8 + 7 N_c \frac{N_f}{4} \right) + \frac{N_f}{2} \mu^2 T^2 + \frac{N_f}{4\pi^2} \mu^4$$



Schwarz, 2003



THE HISTORY OF THE UNIVERSE

From Cambridge Cosmology Group

← Standard Cosmology

← Particle Cosmology
1. $\text{GeV} \simeq 10^{13} \text{ K}$

← Quantum Cosmology

Sommario

- I risultati del reticolo indicano che alle temperature raggiunte ad LHC entriamo in un nuovo, non esplorato regime della QCD qualitativamente diverso da quello visto a RHIC.
- LHC 'osservatorio' per quark e gluoni 'quasi liberi' - piu' vicino al loro stato primordialissimo. .
- Quarkonium in media capito semiquantitativamente ma gli errori sistematici non del tutto sotto controllo.
- Nuova epoca per la fisica del bottom. Spettroscopia di precisione importante per la diagnostica delle proprietà del QGP.
- Incertezze residue su T_c che possono essere sistematicamente ridotte. Nuove formulazioni.
- Laboratorio teorico per fisica BSM: AdS/CFT nel sQGP e limite conforme della QCD ad altissime temperature.

Sommario

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Domande

**Quali misure e' importante migliorare?
Quali nuovi studi potrebbero essere utili?**