Deconfined Matter

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strongly interacting matter $\Leftrightarrow$ QCD

(quarks & gluons)

1. EoS: quasi-particle model
   - (i) $\mu = 0 \Longleftarrow$ lattice data
   - (ii) $\mu > 0$: conventional predictions
2. quark stars: strange, light, small
3. dileptons: glow of the plasma at SPS?

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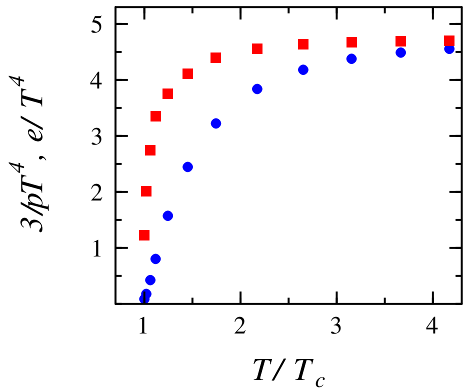
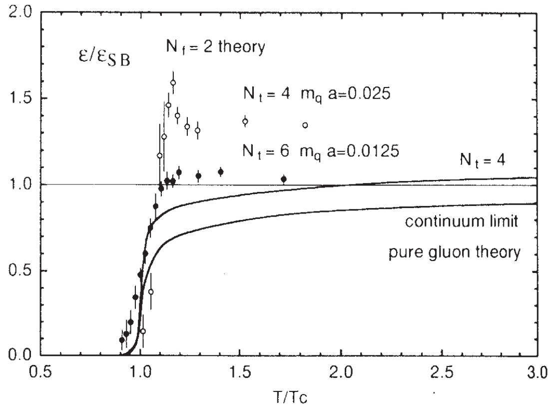
[a]supported by BMBF, with A. Peshier, K. Gallmeister, W. Müller, O.P. Pavlenko

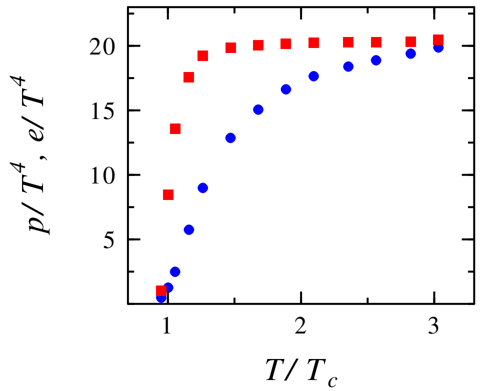
Lattice Data



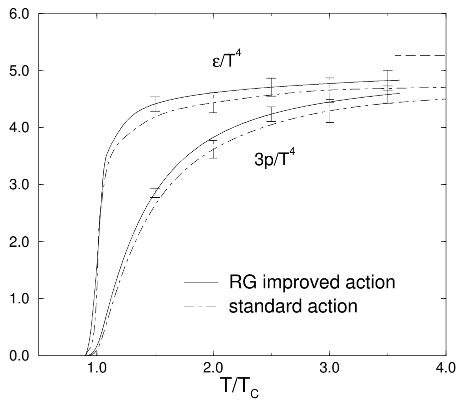
pure glue, cont. extrapol.
Bielefeld



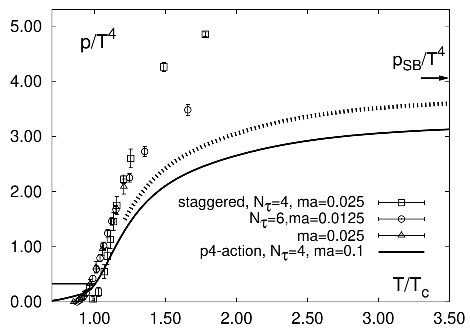
2 light flavors,
MILC



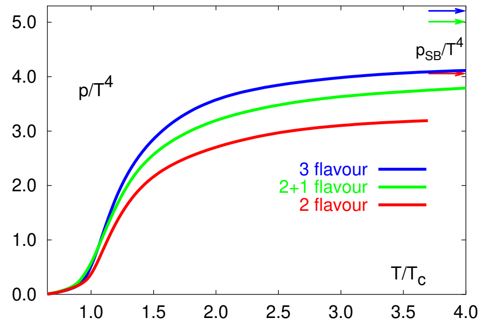
4 light flavors, chiral limit
(cont. extrapol?) Bielefeld



pure glue, cont. extrapol
CP-PACS



2 light flavors,
(cont. estimate) Bielefeld



2, 2+1, 3 flavors
Bielefeld

lattice data $\approx$ "full" QCD $\Longrightarrow$ EoS

interpretation of data is needed:

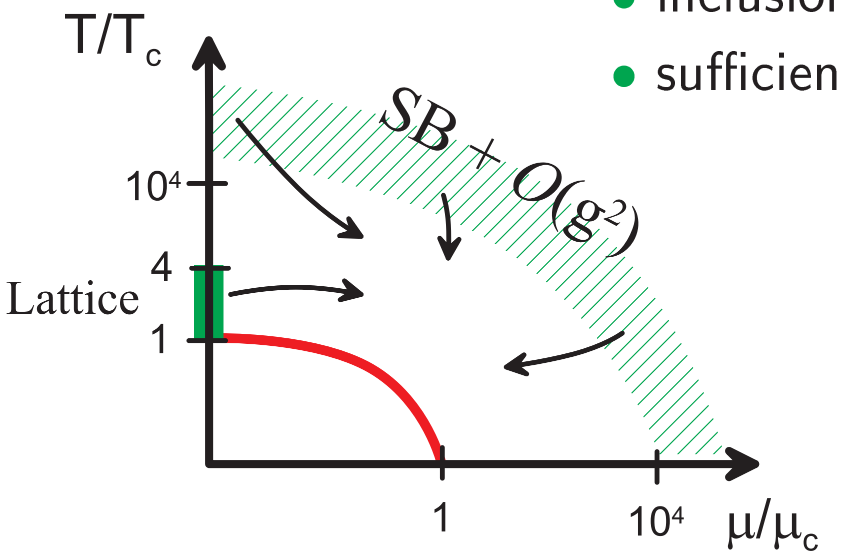
quasi-particle model $\Longrightarrow$ interpolating EoS

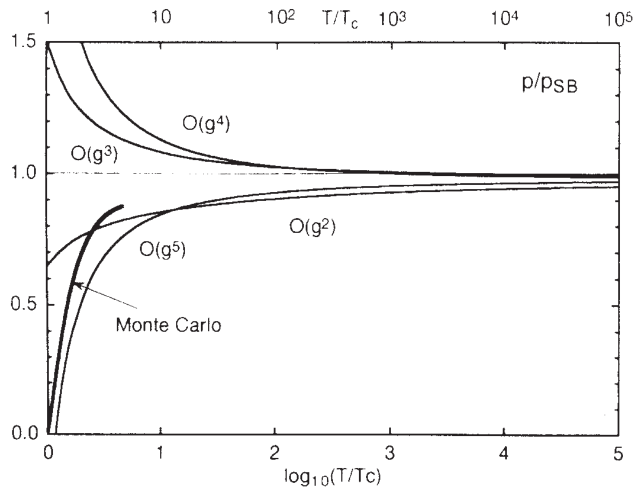
$\Uparrow$

some (relevant) features of QCD

goal: $p(T,\mu)$ of deconfined matter:

- $p(T,\mu=0)|_{T=T_c\cdots 4T_c}$ = lattice data $(N_f=0,4)$
- $p(T\to\infty,\mu\to\infty) = p^{\mathrm{QCD}}[\mathcal{O}(g^0,g^2)]$
- inclusion of strangeness
- sufficiently simple





Quasi-Particle Model

1) $n = \sum_q \left(n_q^{\rm id}(T,\mu;m_q[T,\mu]) - n_{\bar q}^{\rm id}(T,\mu;m_q[T,\mu]) \right)$

parametrize all interactions

2) $s = s_g^{\rm id}(T,\mu;m_q[T,\mu]) + \sum_q s_q^{\rm id}(T,\mu;m_q[T,\mu])$

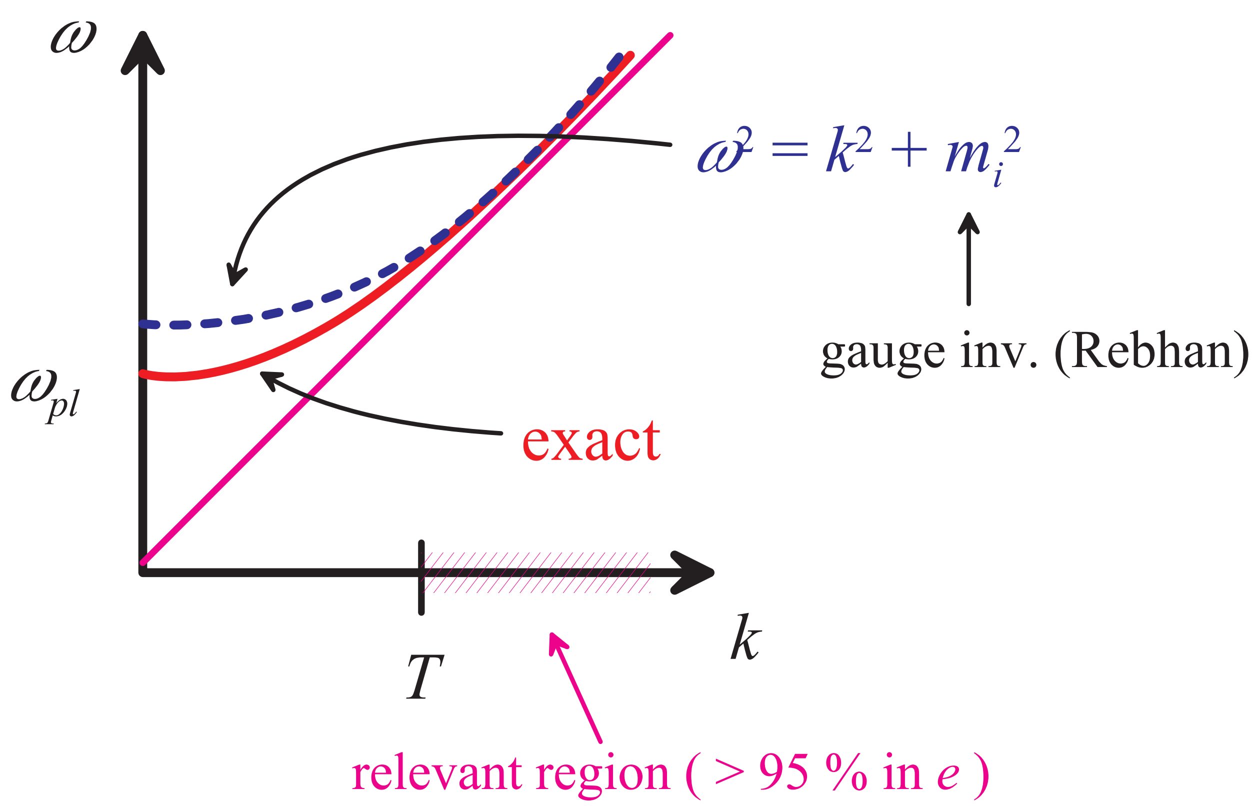
cf. Baym/Pethick: Landau Fermi-liquid theory
kinetics: $s = s^{\rm id} + s^{\rm correl}$

1-loop

3) $m_i^2 = m_i^{(0)\,2} + \Pi_i^*(T,\mu;g^2,m_i^{(0)})$
$\Pi_i^* \Longrightarrow g^2\, f_i(T,\mu)$ 1-loop

$1/log\left(\frac{Q^2}{\Lambda^2}\right)$ at large $Q^2 \propto T^2, \mu^2$
fixed by lattice data

1-loop dispersion relation: $\omega^2 = k^2 + \Pi(\omega, k; T, \mu; g^2, m^{(0)})$



plasminos & long. gluons (Pisarski): modes are exp. damped at $k \gg g\,T$

$\Longrightarrow$ neglect

Peshier: HTL is good near light cone for arbitrary momenta

$$m_g^2 = g^2 \frac{1}{6} [T^2 (N_c^2 + \frac{1}{2} N_f) + \frac{3 N_f}{2\pi^2} \mu^2]$$

$$m_q^2 = g^2 \frac{N_c^2 - 1}{8 N_c} [T^2 + \frac{1}{\pi^2} \mu^2] \quad \text{for} \quad m_q^{(0)} \to 0$$

Baym/Pethick: results follow from general arguments (symmetries, conservation laws), not from detailed microscopic correlations

no condensates, monopoles, instantons $\cdots$

consequences:

1) $p = p_g^{\rm id}(T, \mu; m_g) + \sum_q p_q^{\rm id}(T, \mu; m_q) - B(\Pi_i^*)$

interaction contribution

2) Lee/Yang: $p(\Pi_i)$: $\frac{\delta p}{\delta \Pi_i} = 0 \to \frac{\partial p}{\partial \Pi_i^*} = 0$

$\Longrightarrow s = \frac{\partial p}{\partial T}, \quad n = \frac{\partial p}{\partial \mu}, \quad e + p - Ts = \mu n$

thermodynamic consistency

3) chiral condensate $< \bar\Psi_q \Psi_q > \propto \frac{\partial p}{\partial m_q^{(0)}} = 0$ for $m_q^{(0)} \to 0$

4) $\frac{\partial p^{\rm id}}{\partial m_i^2}\frac{\partial \Pi_i^*}{\partial T} = \frac{\partial B}{\partial T}, \qquad \frac{\partial p^{\rm id}}{\partial m_i^2}\frac{\partial \Pi_i^*}{\partial \mu} = \frac{\partial B}{\partial \mu}$

$\Longrightarrow$ eq. for $B(T, \mu = 0)$

for a certain parametrization of $g(T, \mu = 0)$

Ansatz: $g^2 \to g^2_{\rm eff} = \frac{48\pi^2}{(11N_c - 2N_f)\log\left(\frac{T+T_s}{T_c/\lambda}\right)^2}$

fit parameters: $T_s, \lambda \quad N_g = 17$ $(N_f = 0)$ or 20 $(N_f = 4)$

5) $p =$ potential $\Longrightarrow \frac{\partial n}{\partial m_i^2}\frac{\partial \Pi_i^*}{\partial T} = \frac{\partial s}{\partial m_i^2}\frac{\partial \Pi_i^*}{\partial \mu} \Longrightarrow$ part. diff. eq. for g^2

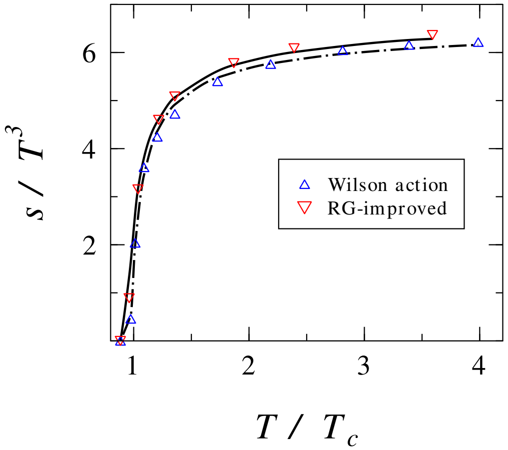
$\Longrightarrow$ mapping $\mu = 0$ data into $T - \mu$ plane

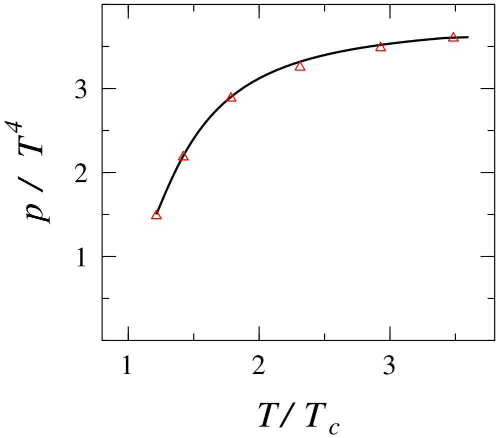
characteristics: asympt. constant B or g

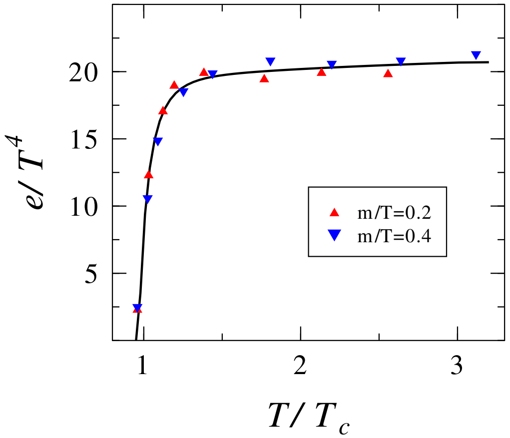
6) $p(T \to \infty, \mu \to \infty) = p^{\rm QCD}(\mathcal{O}[g^0, g^2])$

important: asymptotic "masses"

Tests of the Model

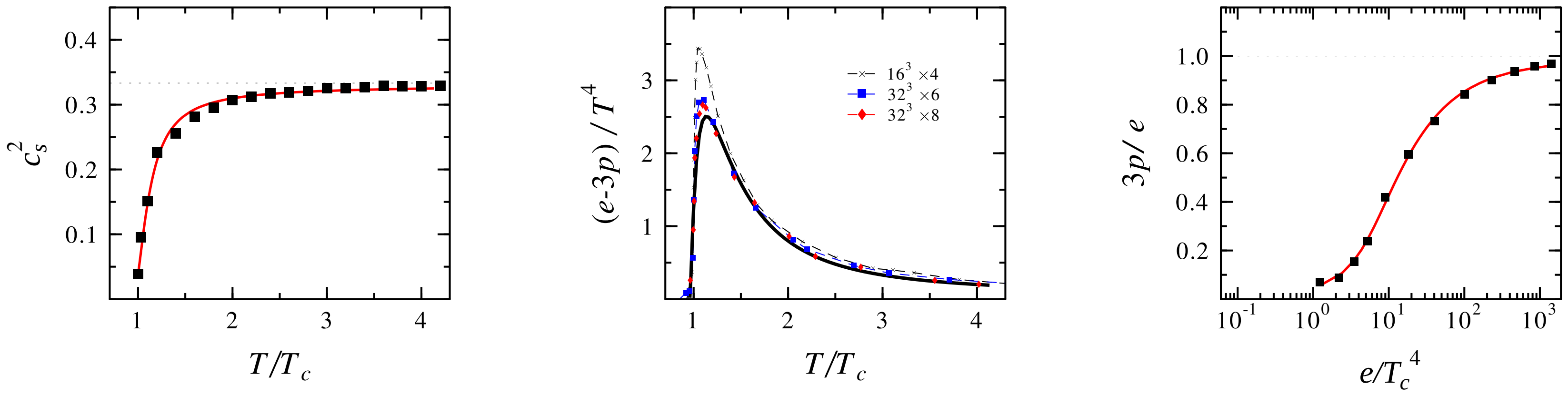




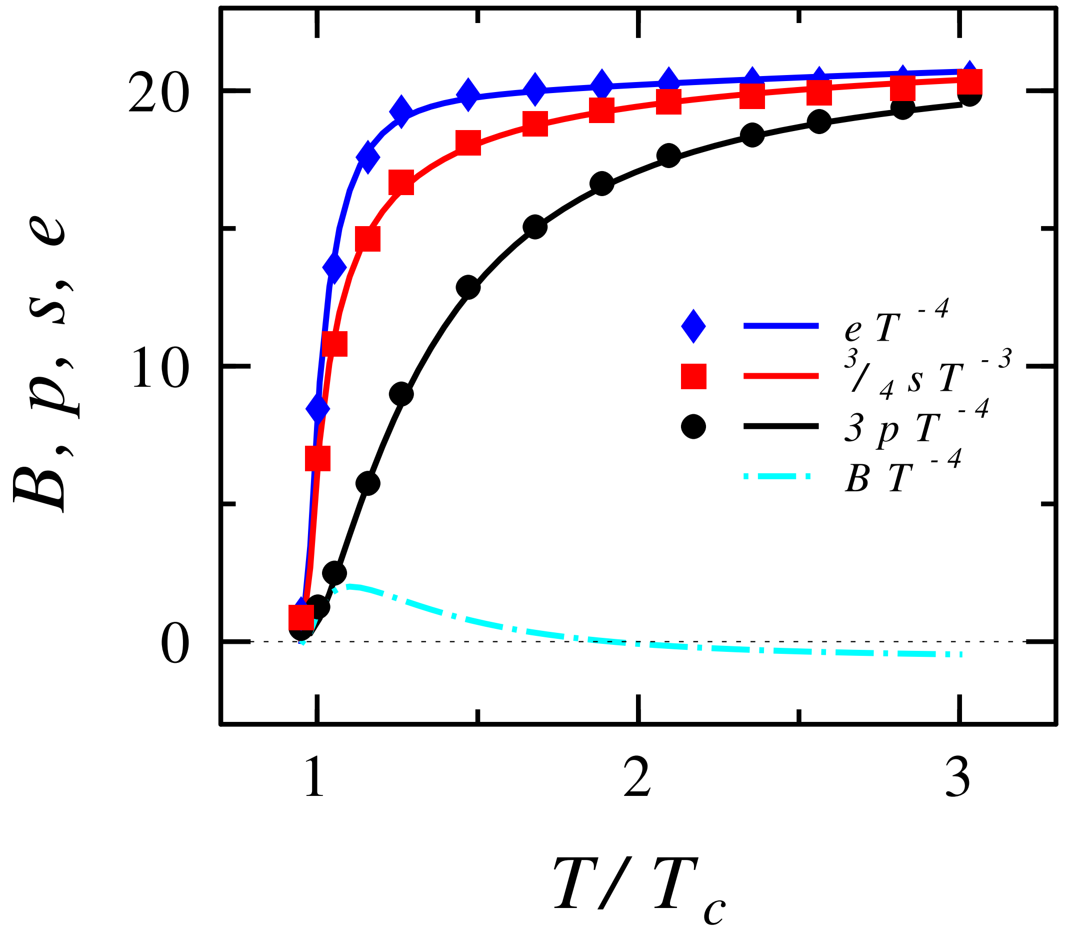


Okamoto et al. hep-lat/9905005	Karsch, hep-lat/9909006	Engels et al. PLB 396 (1997)
fig. 7	fig. 4 right	
SU(3), cont. limit	$N_f = 2$, cont. extraplol.	$N_f = 4$, light quarks

Further tests of the model (SU(3) glue)

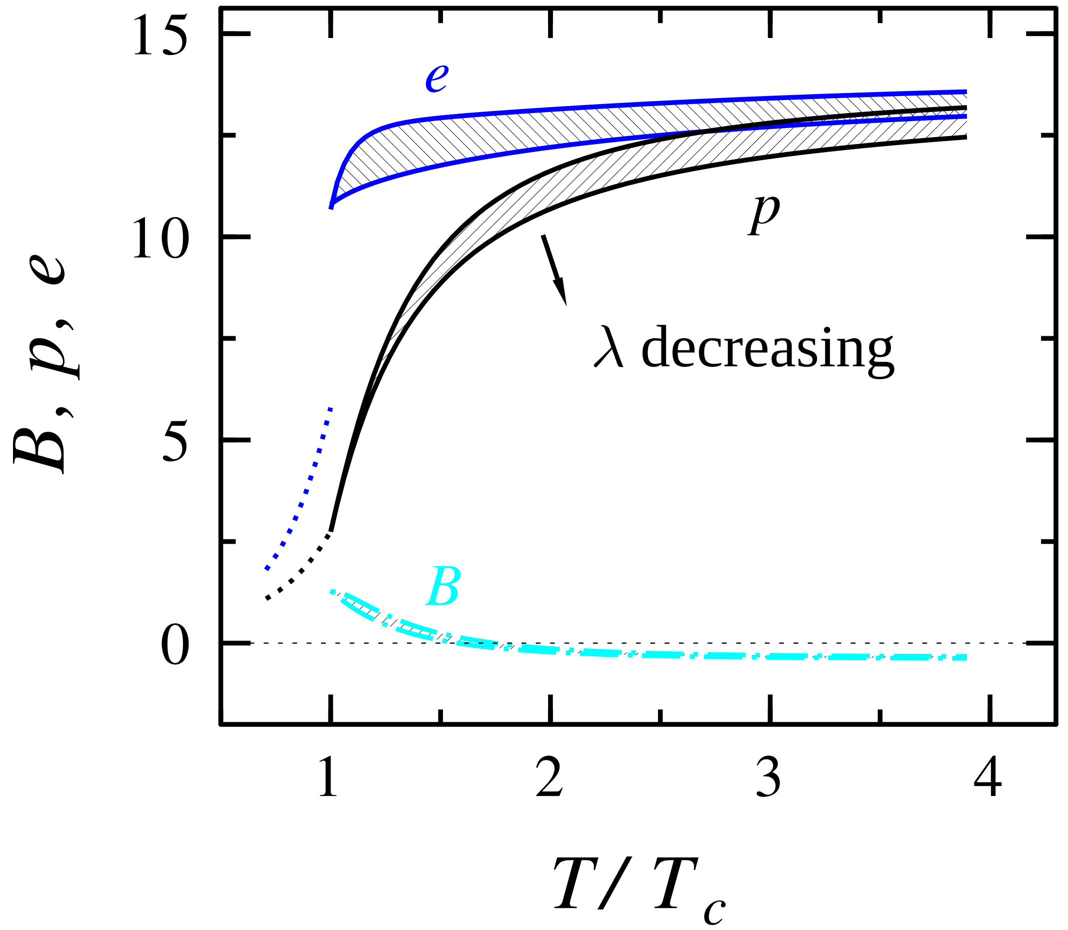


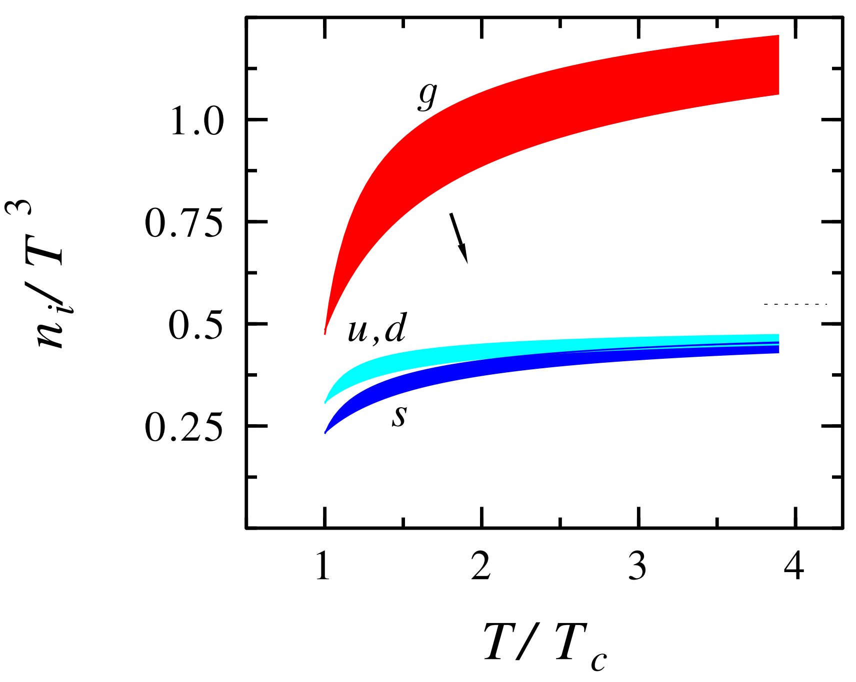
$\mu = 0$, 4 flavors in chiral limit, Bielefeld '97 data



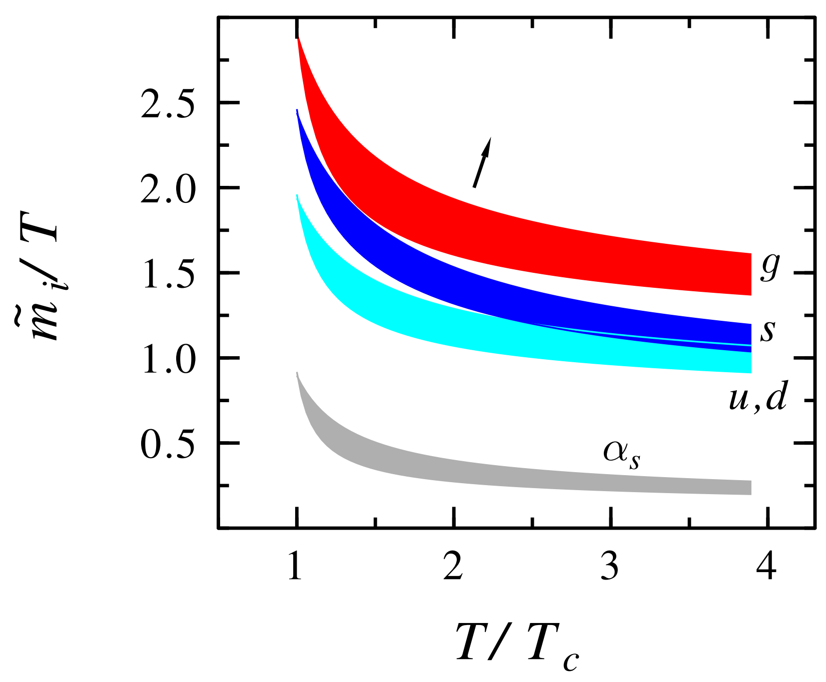
A Prediction: u,d,s quarks + gluons at $\mu = 0$

$m_s^0 = 150$ MeV



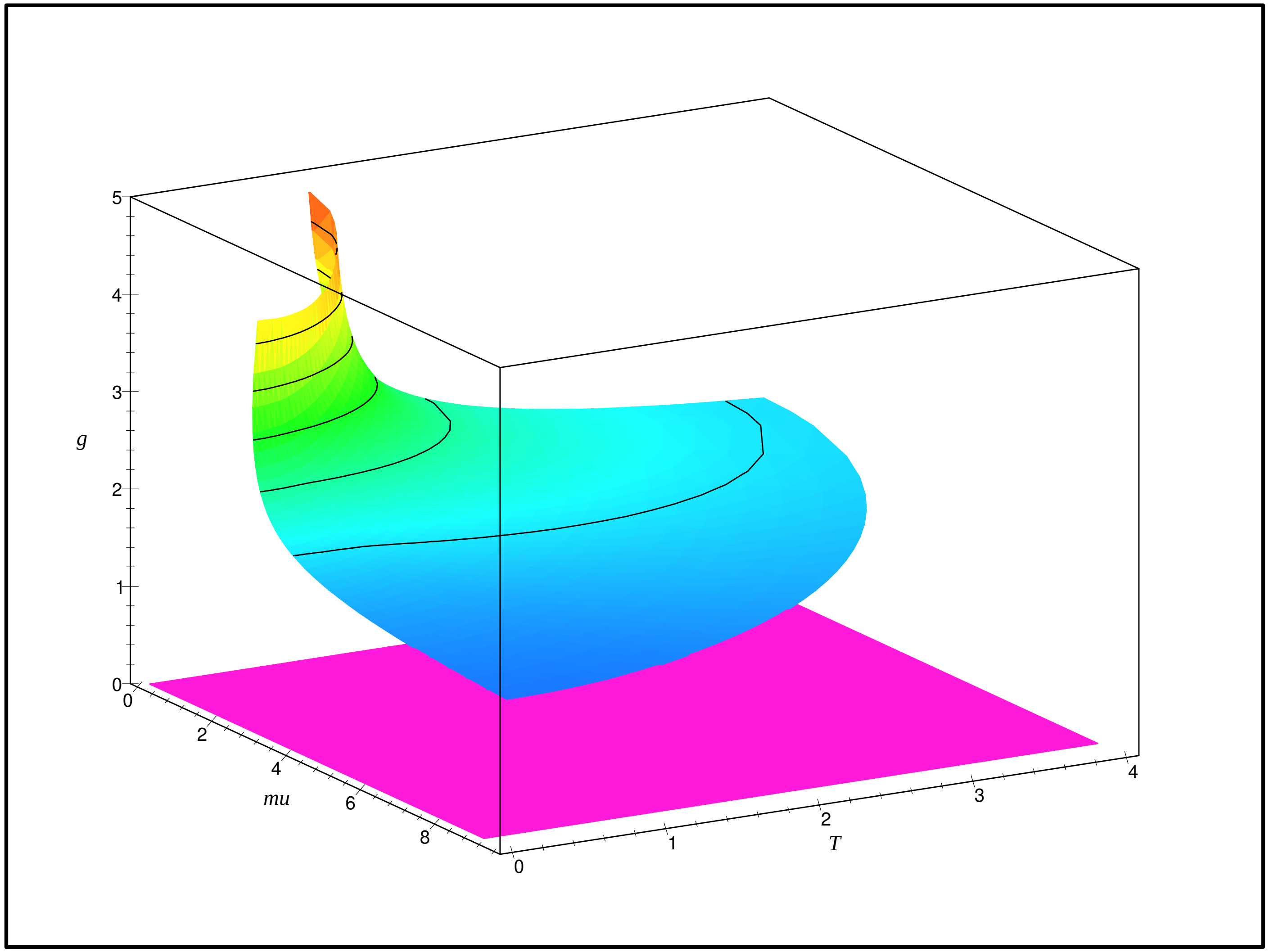


n_i / T^3
1.0
0.75
0.5
0.25
g
u,d
s
1
2
3
4
T/T_c

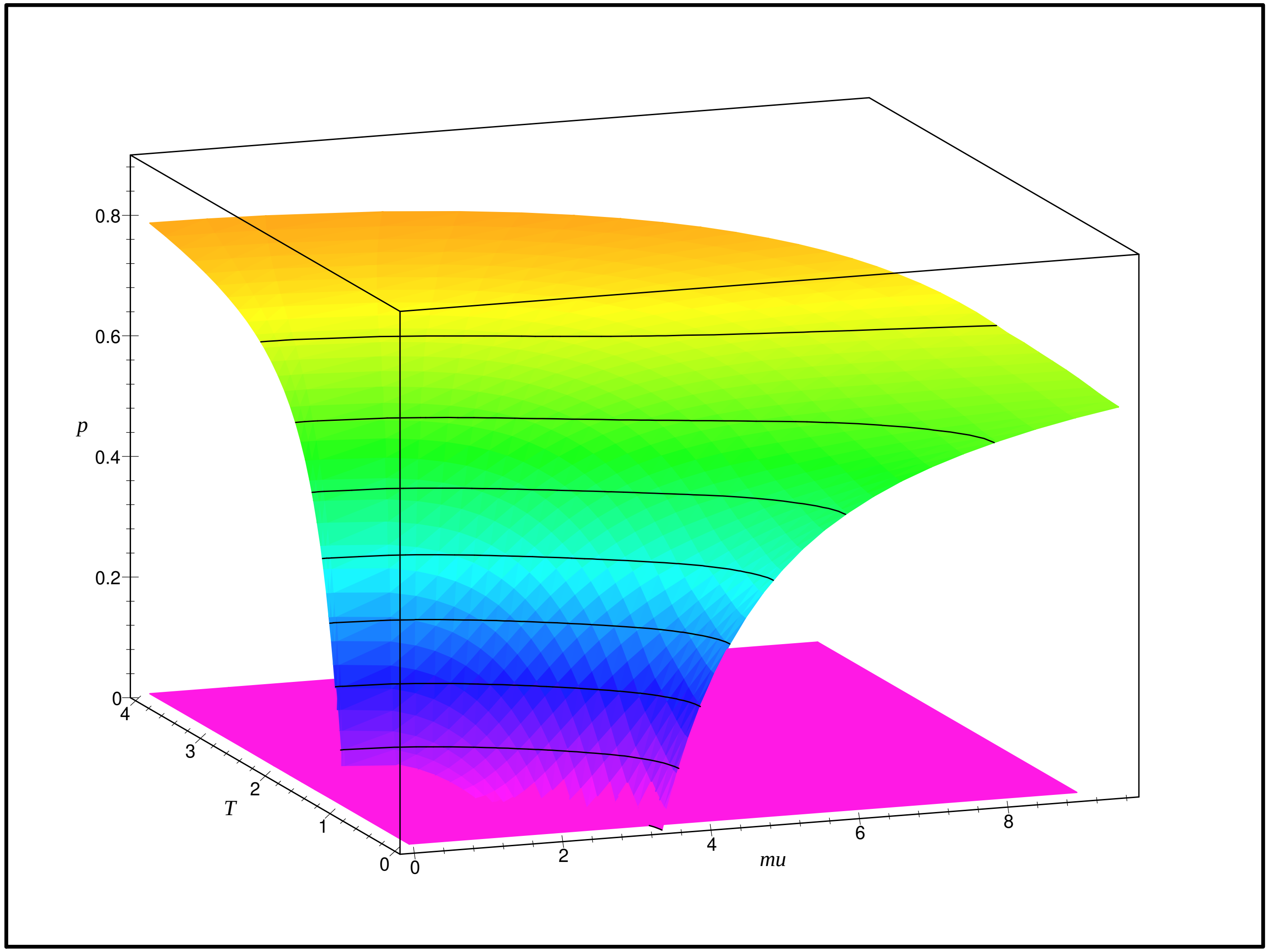


$\tilde{m}_i / T$
2.5
2.0
1.5
1.0
0.5
g
s
u,d
α_s
1
2
3
4
T/T_c

$N_f = 4$ lattice data + asymptotics: coupling strength:

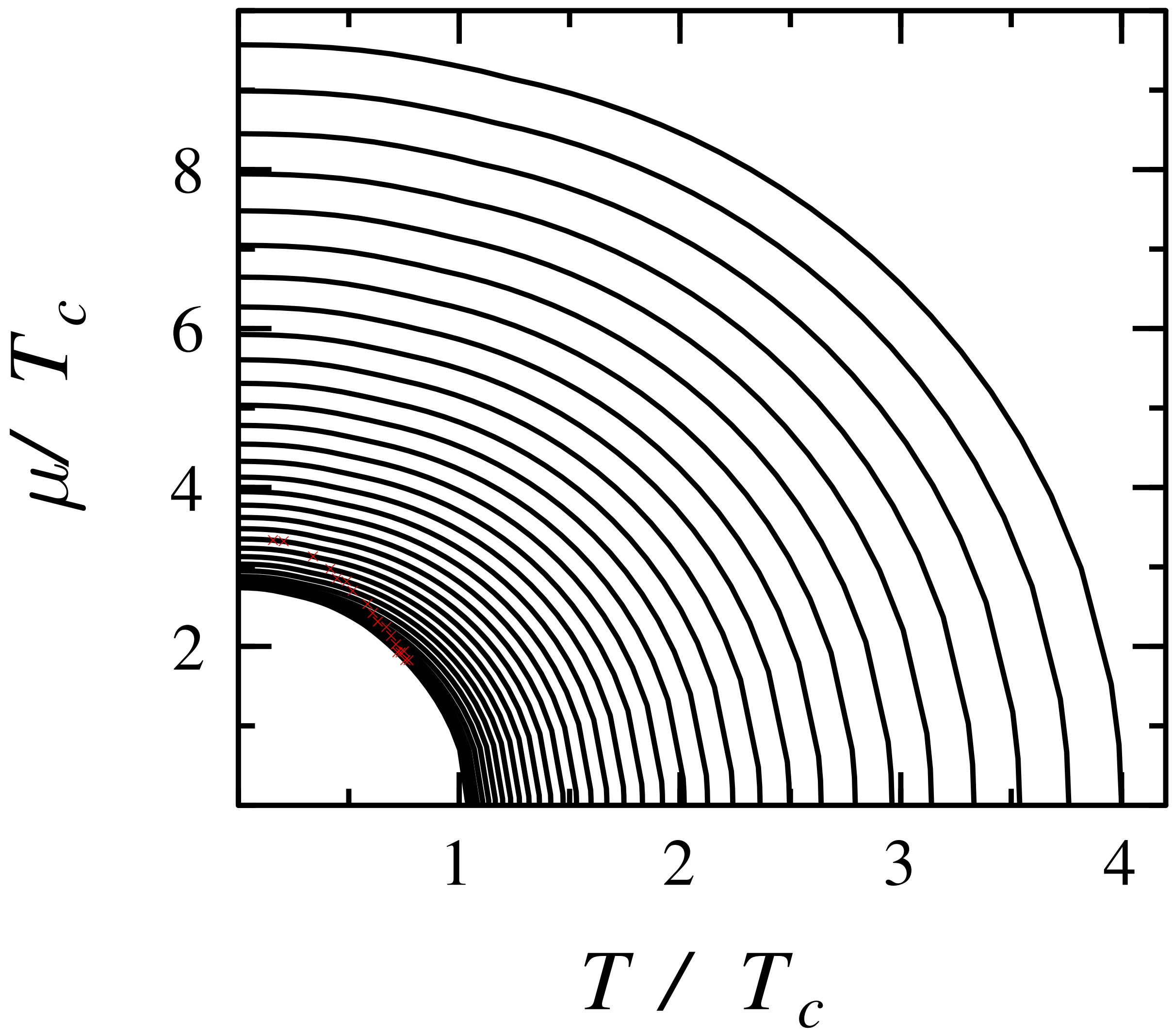


pressure:



characteristics:

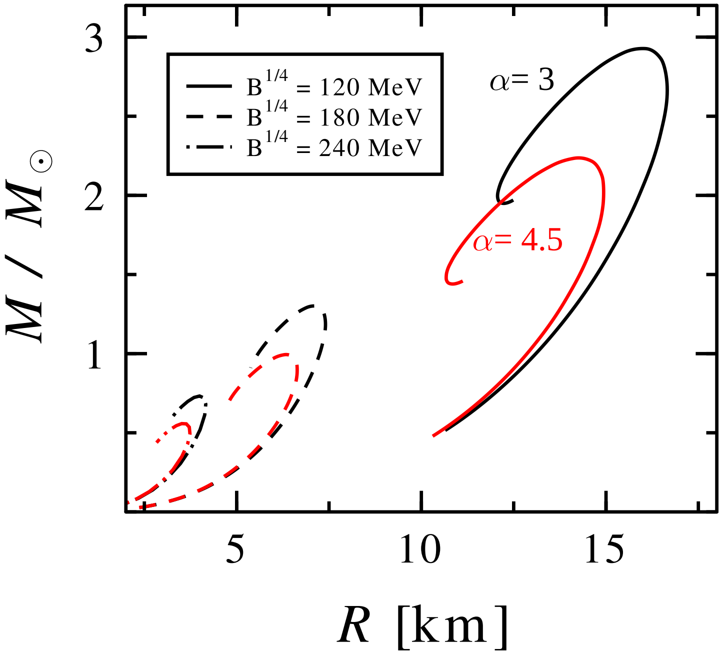
4-flavor lattice data & asympt. g^2

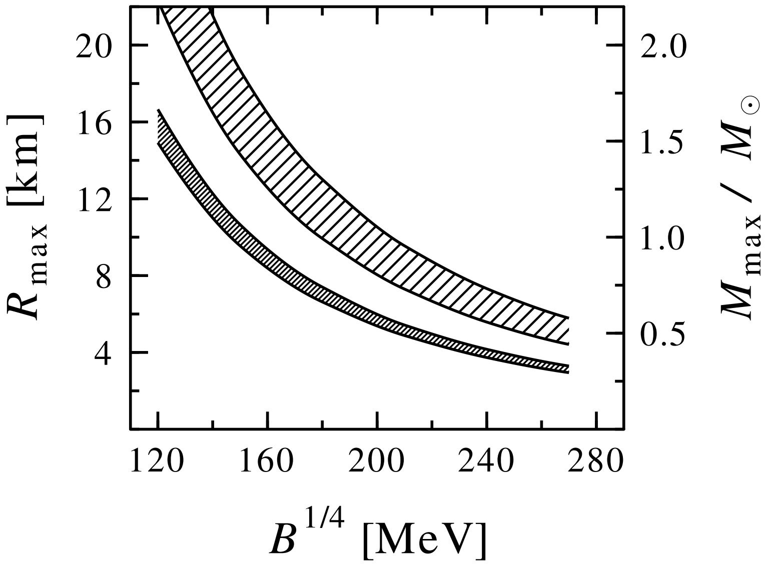


implications:

- thermal $\bar{c}c$ prodcution via $gg \to \bar{c}c$ (Vogt/Levai)
- threshold effects in $\bar{q}q \to e^+e^-$ (Peshier)
- (strange) quark cores in neutron stars (Weber/Glendenning/Thoma $\cdots$)
- strangeness in cosmological confinement transition

Pure Quark-Matter Stars





Dilepton Yields at SPS

1. Hadron – quark duality: Huang, Leonidov & Ruuskanen, Rapp & Wambach

$dR_h = dR_{q\bar{q}}$ (chiral symmetry restoration?)

2. Rate:

$$\frac{dR}{d^4Q\, d^4x} = \frac{5\alpha^2}{36\pi^4} \exp\left\{\frac{u\cdot Q}{T}\right\}$$

$$\frac{dN}{dM} \propto \int dt\, d^3x \frac{dR}{d\cdots}$$

$u \cdot Q \neq E$

strong impact of flow

$\bar{v}_\perp < 0.5$, $Y \approx 0$, small $Q_\perp$: neglect flow

3. Parameters: for lead beam at SPS

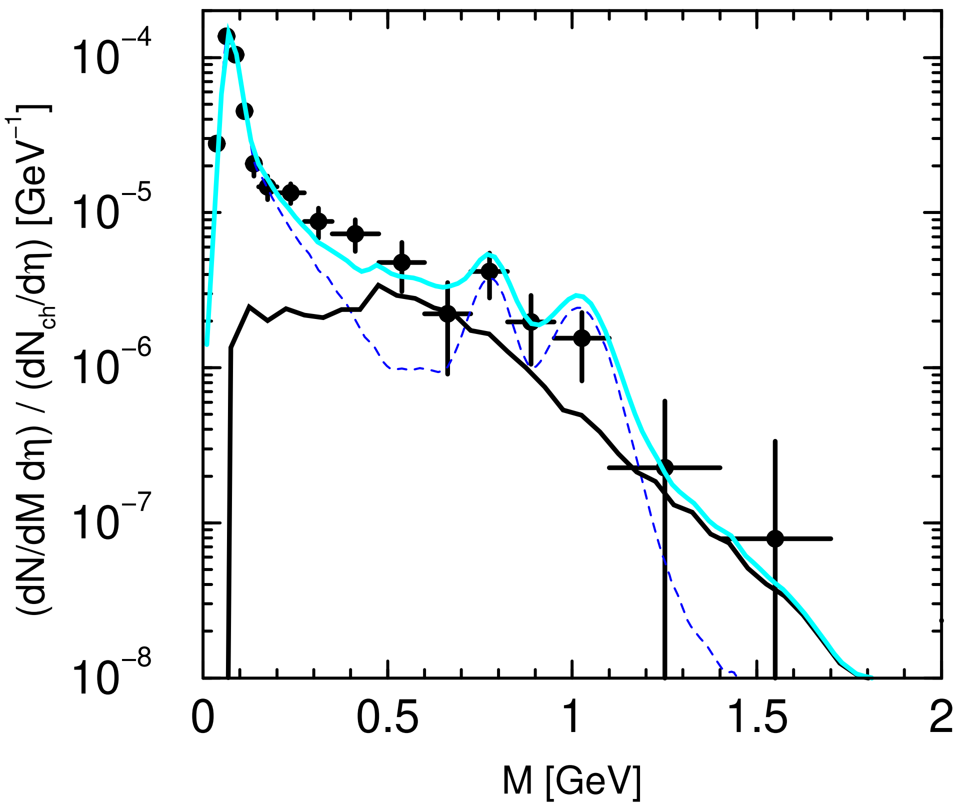
adjust to CERES data (e^+e^-):

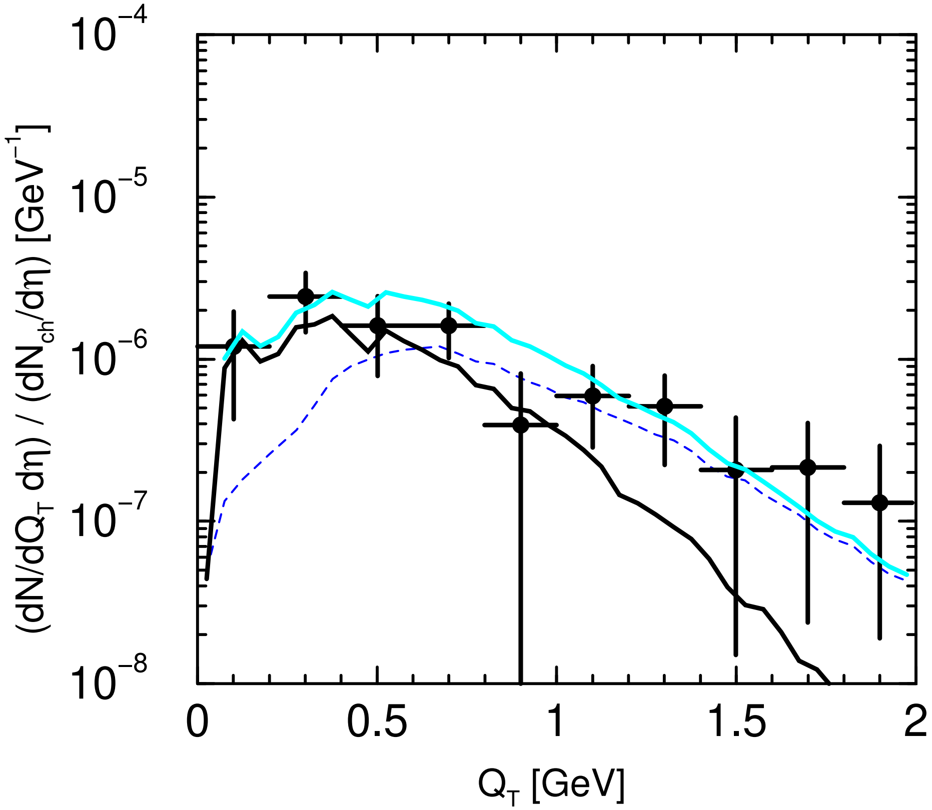
$$
\begin{aligned}
T &= (T_i - T_\infty)\exp\left\{-\frac{t}{t_2}\right\} + T_\infty\,, \\
V &= N\exp\left\{\frac{t}{t_1}\right\}
\end{aligned}
$$

$T_i = 210$ MeV, $T_\infty = 110$ MeV, $t_1 = 5$ fm/c, $t_2 = 8$ fm/c,
$N = \frac{A+B}{2.5 n_0}$, $T_f = 130$ MeV

$\Longrightarrow$ describe NA50 data ($\mu^+\mu^-$))

CERES: Pb (158 AGeV) + Au





NA50: Pb (158 AGeV) + Pb