Collider-Physik mit Schwerionen

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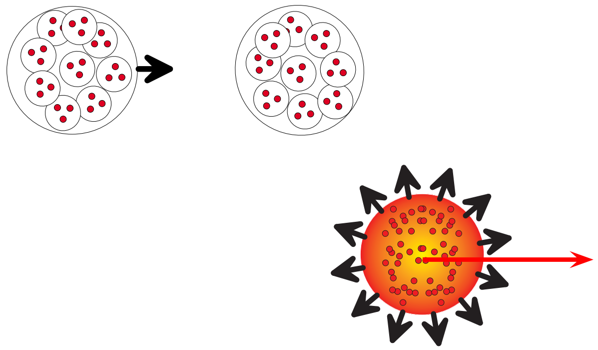
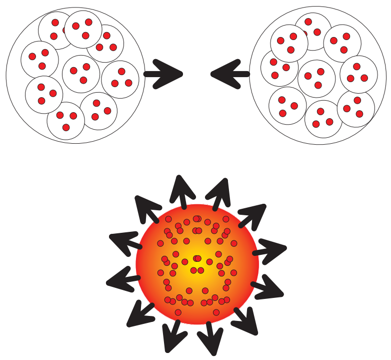
Forschungszentrum Rossendorf/Dresden



SPS: $\sqrt{s} \leq 20$ GeV

$(\cdots 2000 \cdot)$ $N_{\rm ch} \approx 1200$, $\frac{dN_{\rm ch}}{dy}|_{y=0} \approx 400$



RHIC: $\sqrt{s} \leq 200$ GeV

$(2000 \cdots)$ $N_{\rm ch} \approx 4000$, $\frac{dN_{\rm ch}}{dy}|_{y=0} \approx 750$

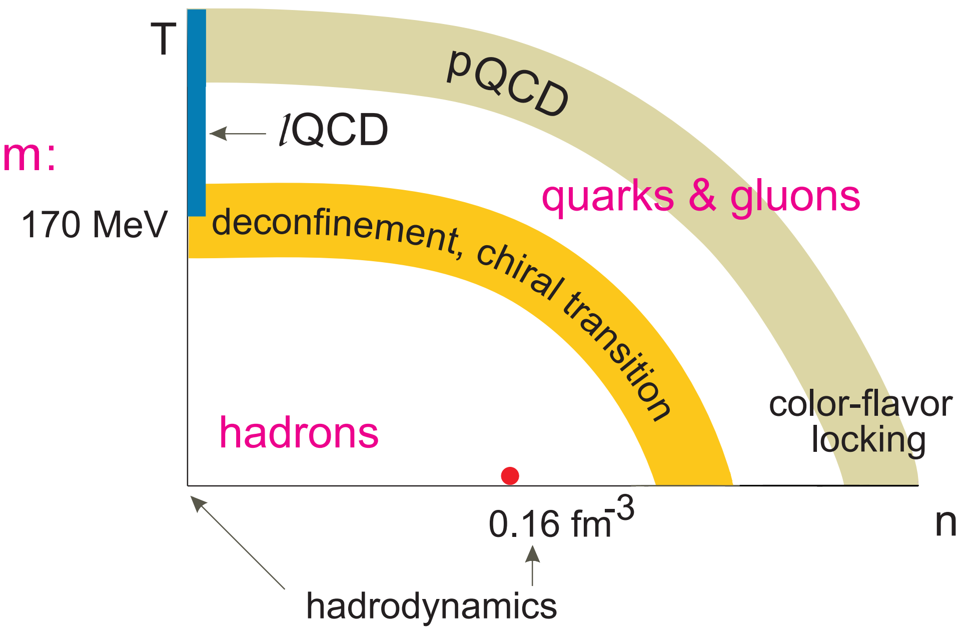
LHC: $\sqrt{s} \leq 5500$ GeV

$(2005 \cdots)$ $N_{\rm ch} \approx 40000$, $\frac{dN_{\rm ch}}{dy}|_{y=0} \approx 5000$

kin. Energie $\rightarrow$ Materie (Hadronen) physics motivation: explore strongly interacting matter &

QCD phase diagram

full equilibrium:



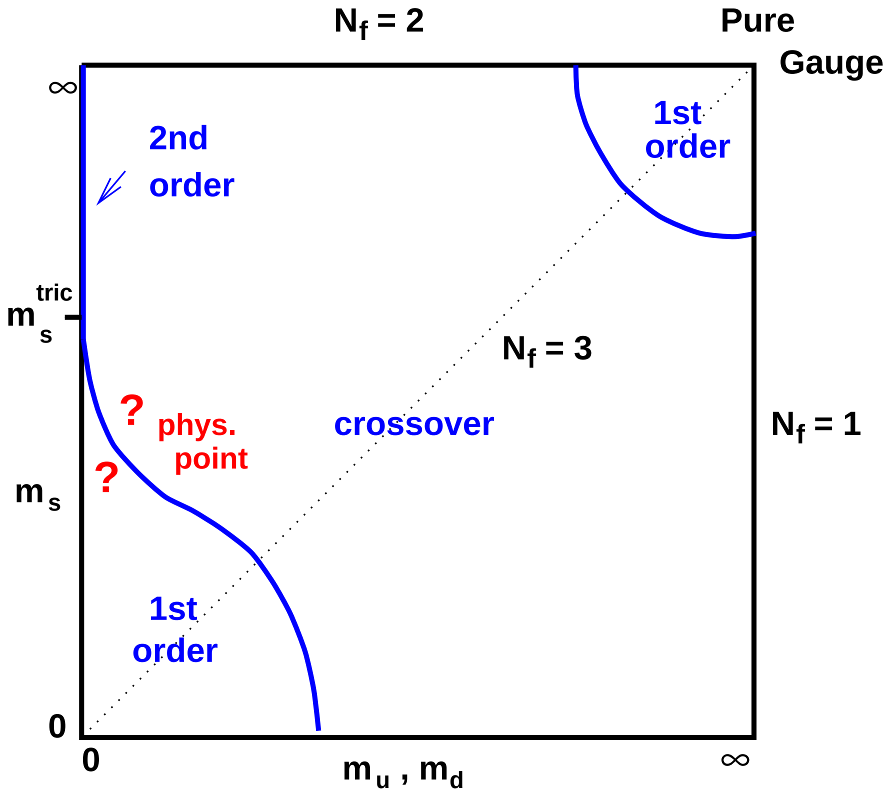
lQCD $\to e_c \sim 1$ GeV/fm^3 $\quad = 7 e_{\rm g.s.} = e_p$

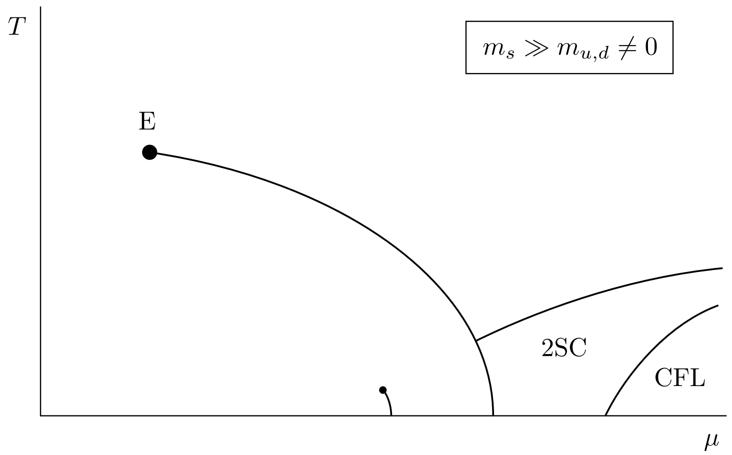
overlap of 2 swarms (non-interacting): $e = 2\gamma^2 e_0, \quad n = 2\gamma\, n_0$ $\quad$ but $s = 0$

$\to$ transient thermodynamics: $\quad \Omega(T, \mu; \Delta v, \cdots) \leftarrow$ off-equlibrium

educated phase diagram

$$\mathcal{L}_{\rm QCD} = \bar\psi(i\gamma_\mu D^\mu[g,A] - m)\psi - \frac{1}{4}F^2(g,A)$$



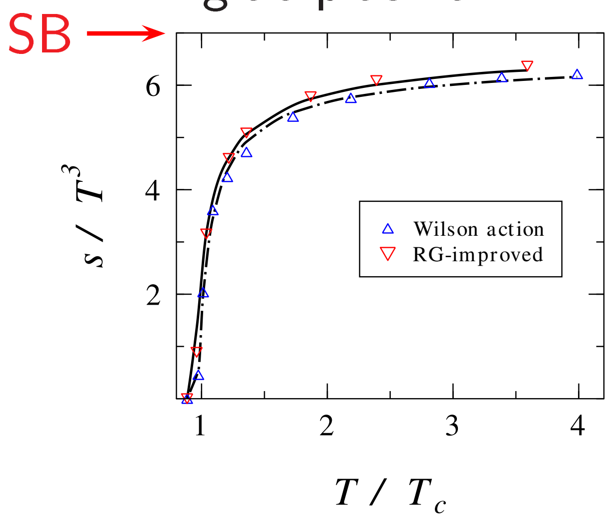


PT vs. cross over   deconfinement $\overset{?}{=}$ chiral symmetry restoration

$\mathcal{L}_{\rm QCD} \to l$QCD $\to$ EoS: $p(T)|_{\mu\equiv 0}$

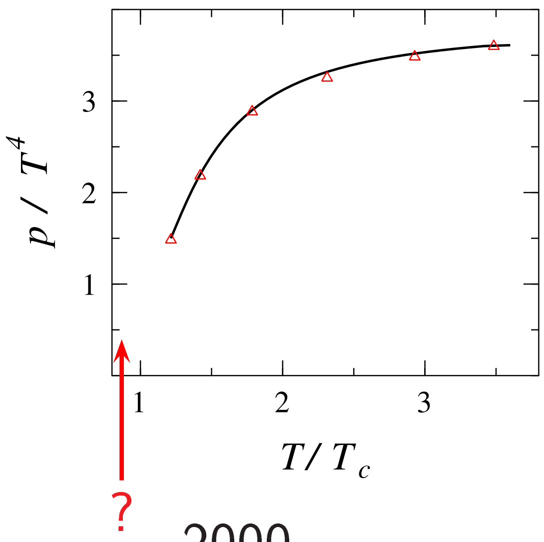
$T_c = 170 \pm 8$ MeV

glue plasma



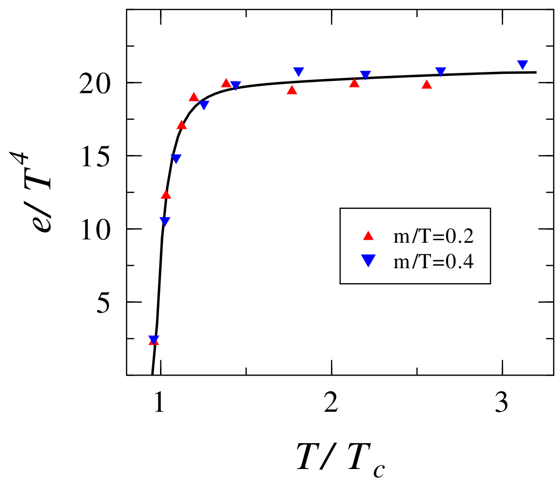
1980 ··· 1995

$N_f = 2$



2000 ···

$N_f = 4$



2000 ···

lQCD vs. – Φ derivable functional (LW), resummation, approx. approximations

– quasi-particle models, e.g. Rossendorf/Dresden $\to p(T, \mu)$

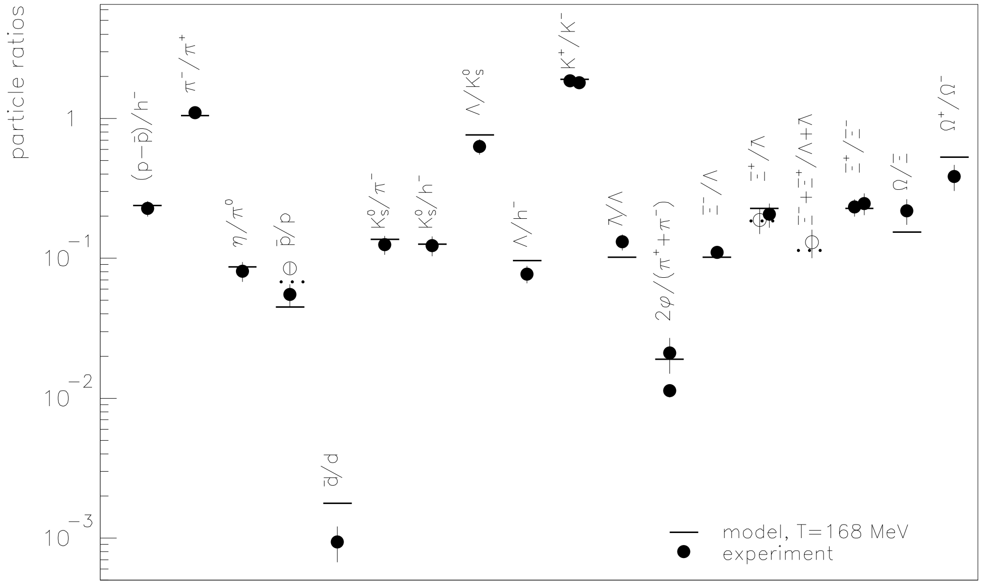
– condensate of Wilson lines

Equilibrium-like Observables in HICs

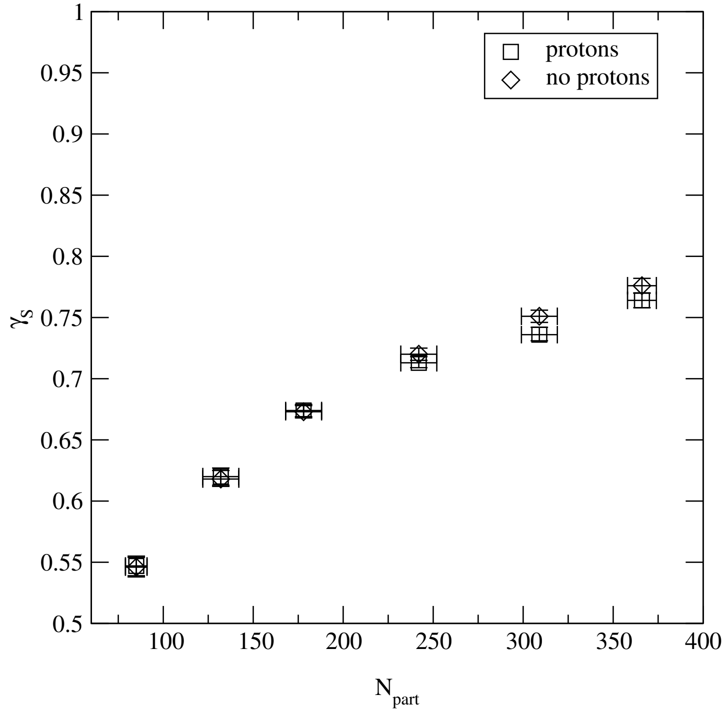
1. Hadron Yields:

quantum statistics $\rightarrow$ (grand) canonical ensemble & ratios of yields $\rightarrow T_{\text{chem}},\ \mu$

SPS central

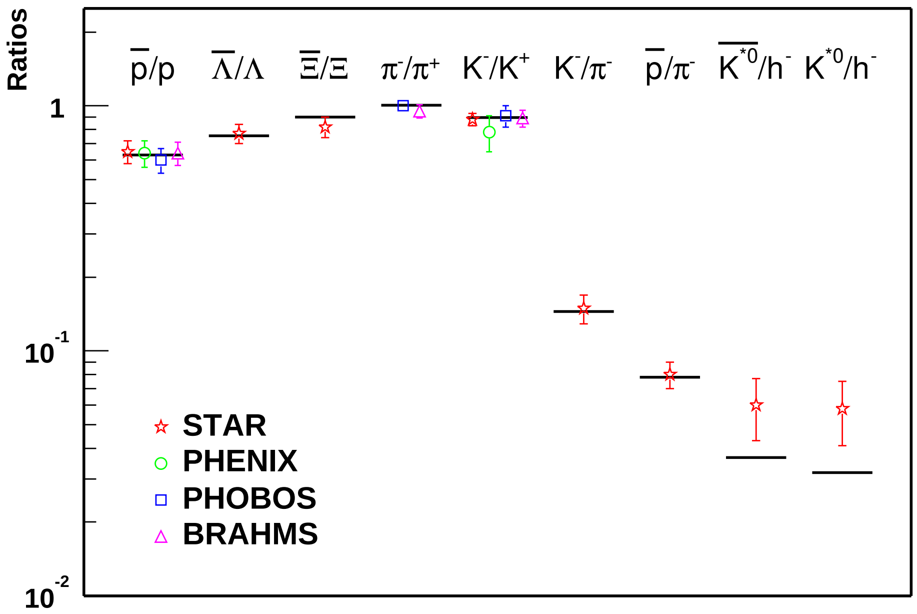


SPS

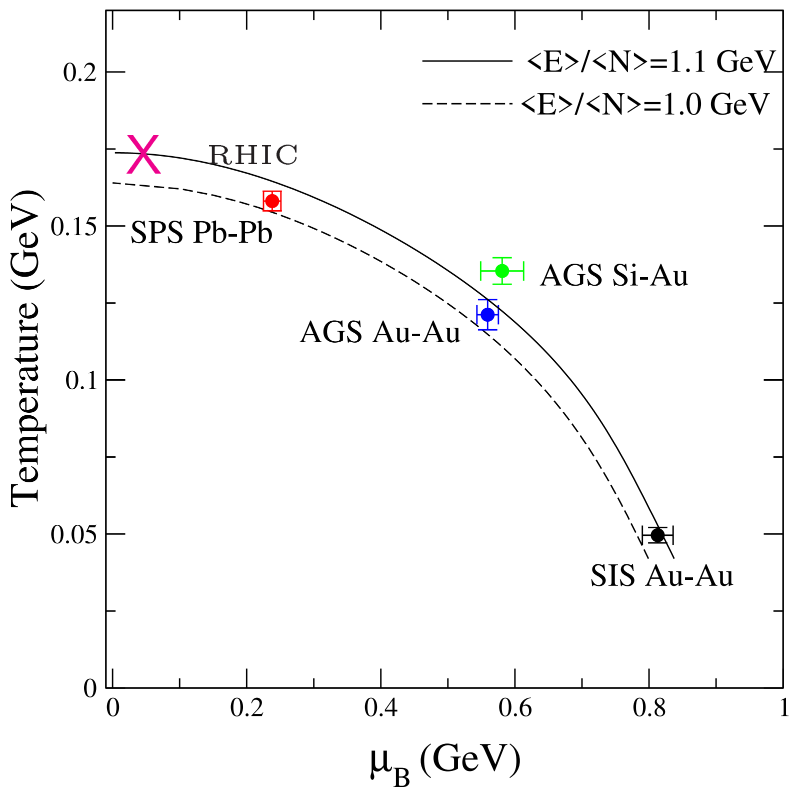


PBM, J. Stachel

RHIC



all



"pre-fabricated chemical equilibrium"

PBM, J. Stachel

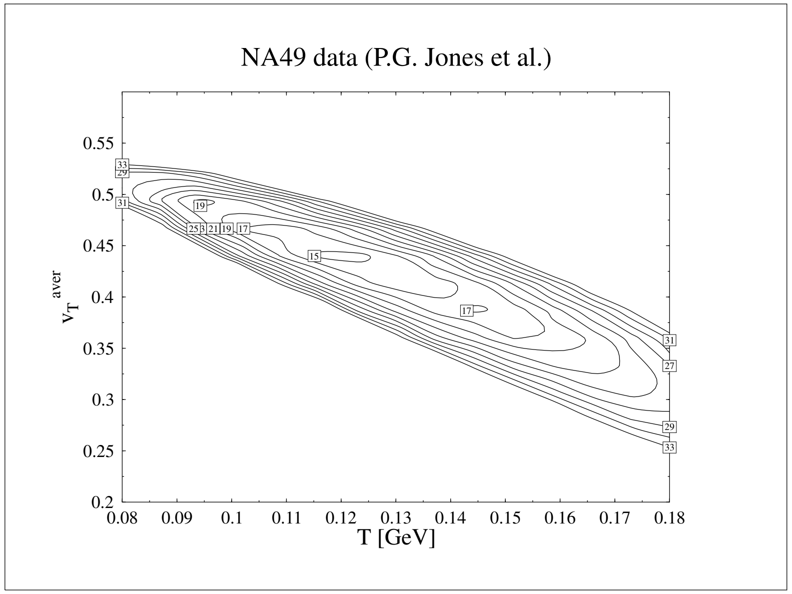
J. Cleymans, K. Redlich

2. Hadron Flow:

(i) (late) transverse flow $\leftrightarrow$ rescattering & local thermal equil.

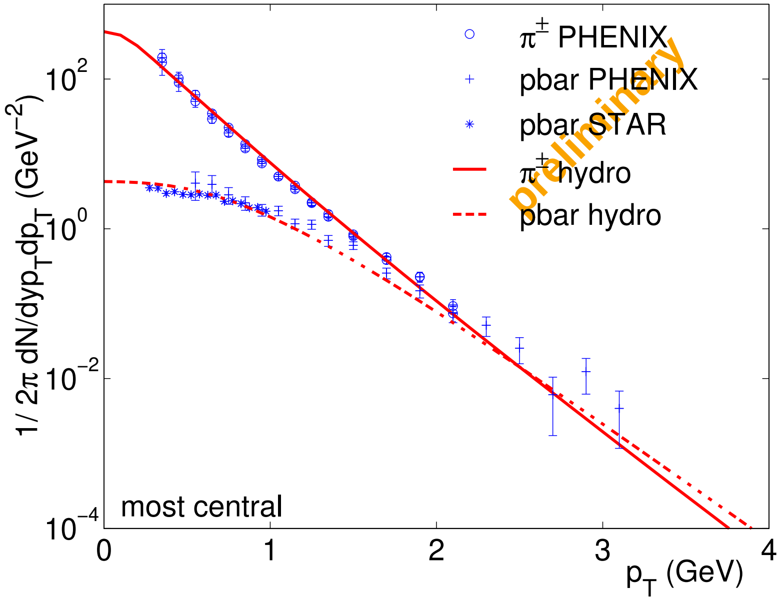
hydrodynamics $\to$ $p_\perp$ spectra $\to$ $T_{\rm kin}$, $v_\perp$

SPS



$\pi^\pm, K^\pm, p^\pm, K_s^0, \Lambda, \bar\Lambda, d$

RHIC

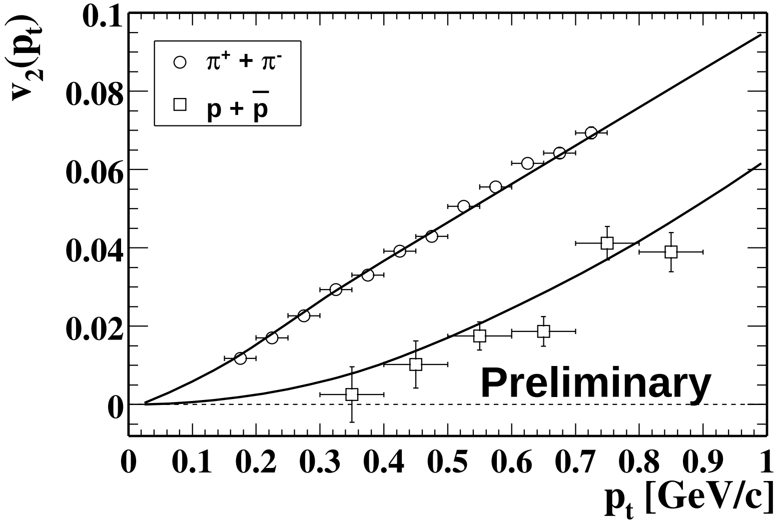


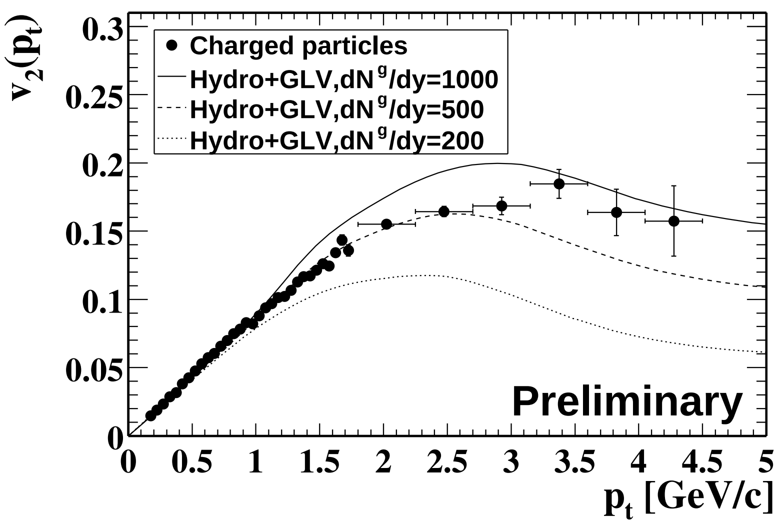
U.Heinz

(ii) (early) elliptic flow $\leftarrow$ pressure

$b > 0 \rightarrow$ anisotropic transverse pressure $\rightarrow$ anisotropic flow

RHIC:





U. Heinz

M. Gyulassy, P. Levai

3. Dileptons & Photons:

e.m. emissivity (l.o. parton matter [$\sim$ duality]) $\rightarrow$ $T_{\rm eff}$, $V_{\rm eff}$

$$\boxed{\textbf{data} = \sum \textbf{hard} \quad + \quad \textbf{thermal} \quad + \quad \textbf{hadronic decays}}$$

Drell-Yan

T

cocktail

open charm: $gg \rightarrow c\bar{c} \rightarrow D\bar{D}$

$\mu^- X$

$\mu^+ X'$

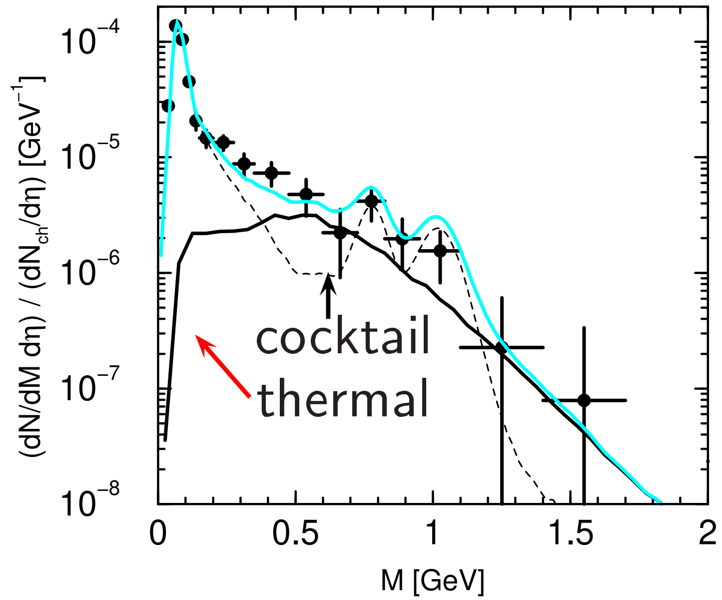
S(200 AGeV): CERES$_S$, NA38, HELIOS/3, WA80

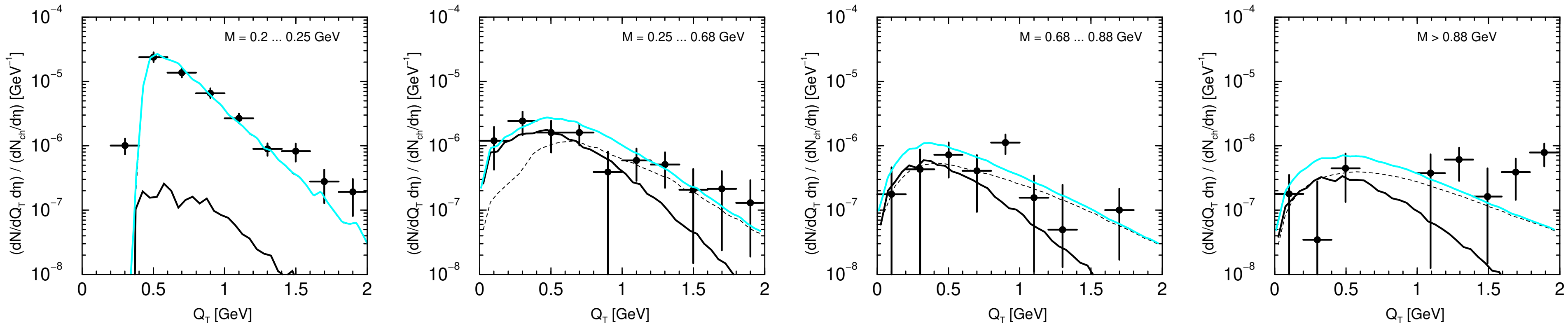
Pb(158 AGeV): CERES$_{Pb}$, NA50, WA98

Pb(40 AGeV): CERES$_{40}$

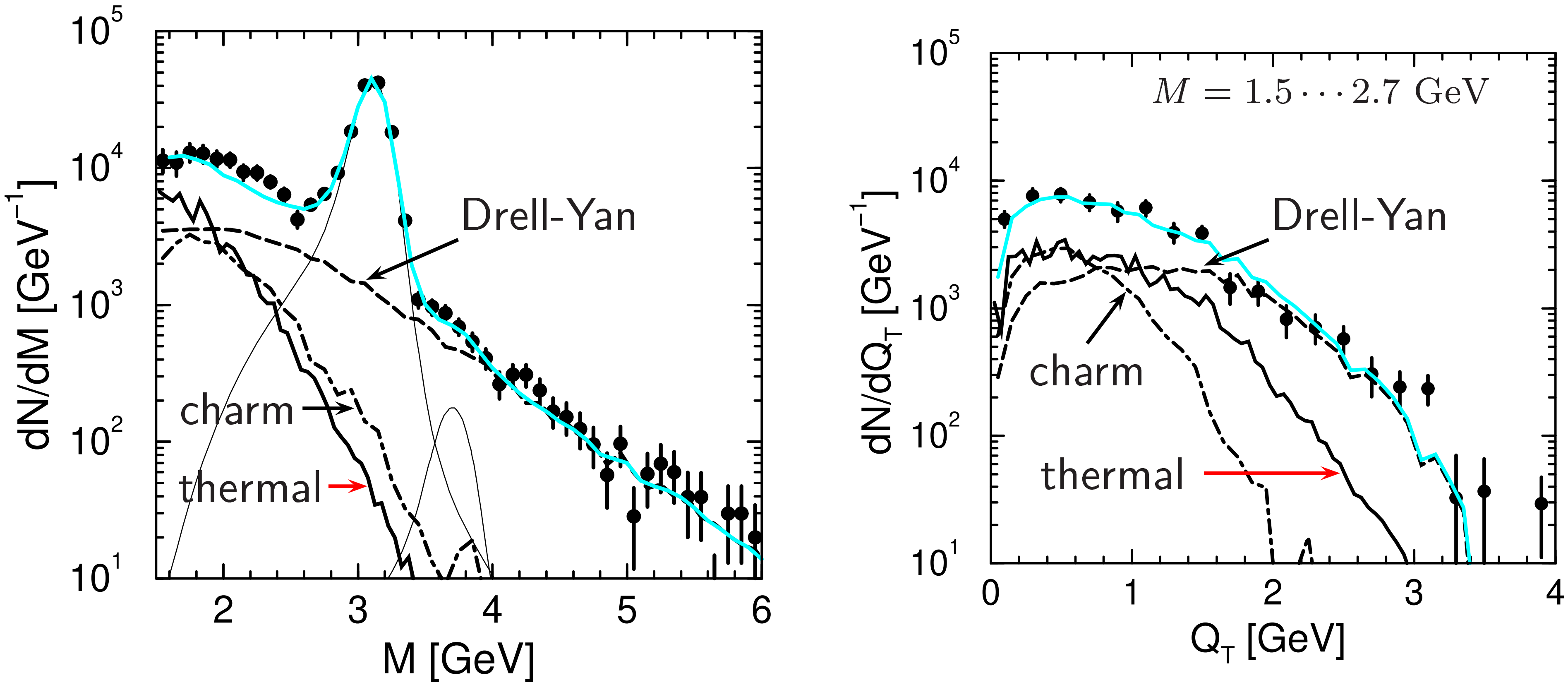
1. Lead beam experiments at CERN

CERES: central Pb(158 AGeV) + Au $\to X + e^+e^-$





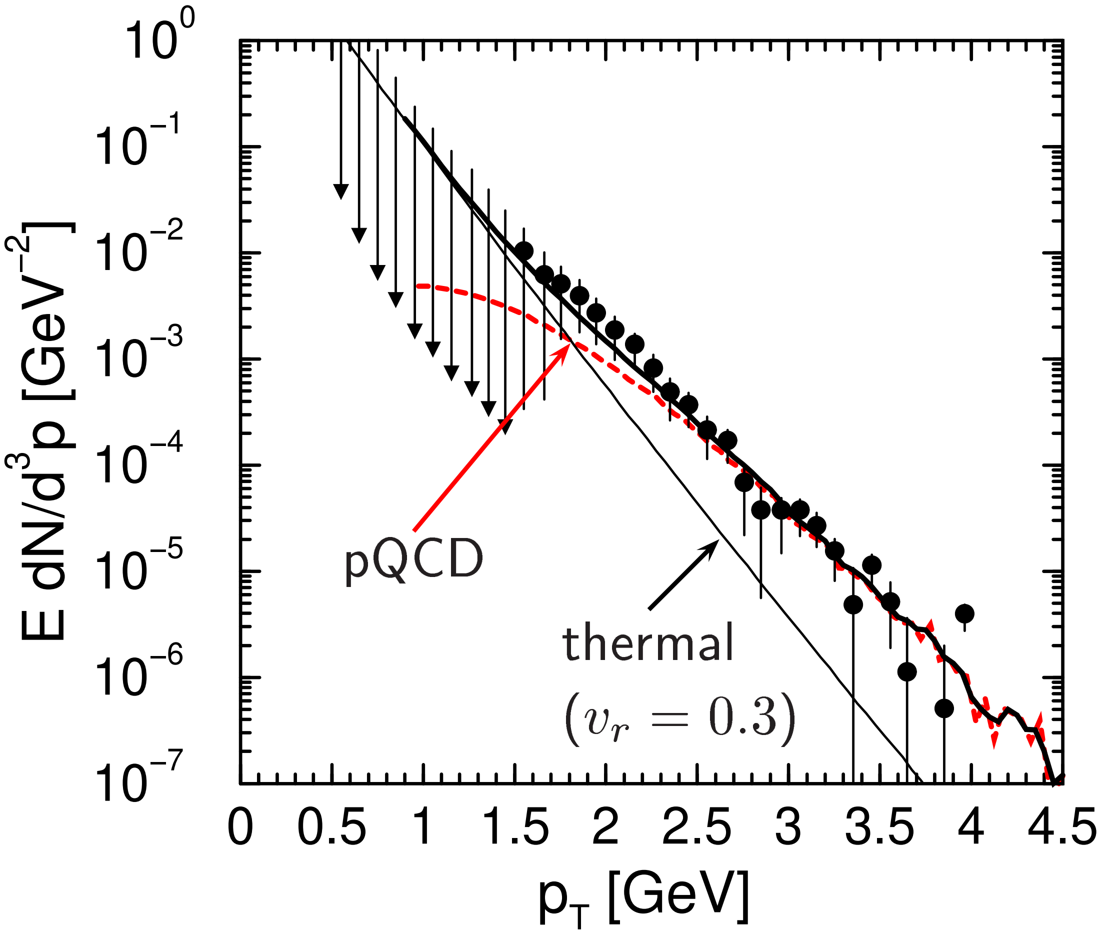
NA50: central Pb(158 AGeV) + Pb $\to X + \mu^+\mu^-$



no charm enhancement needed

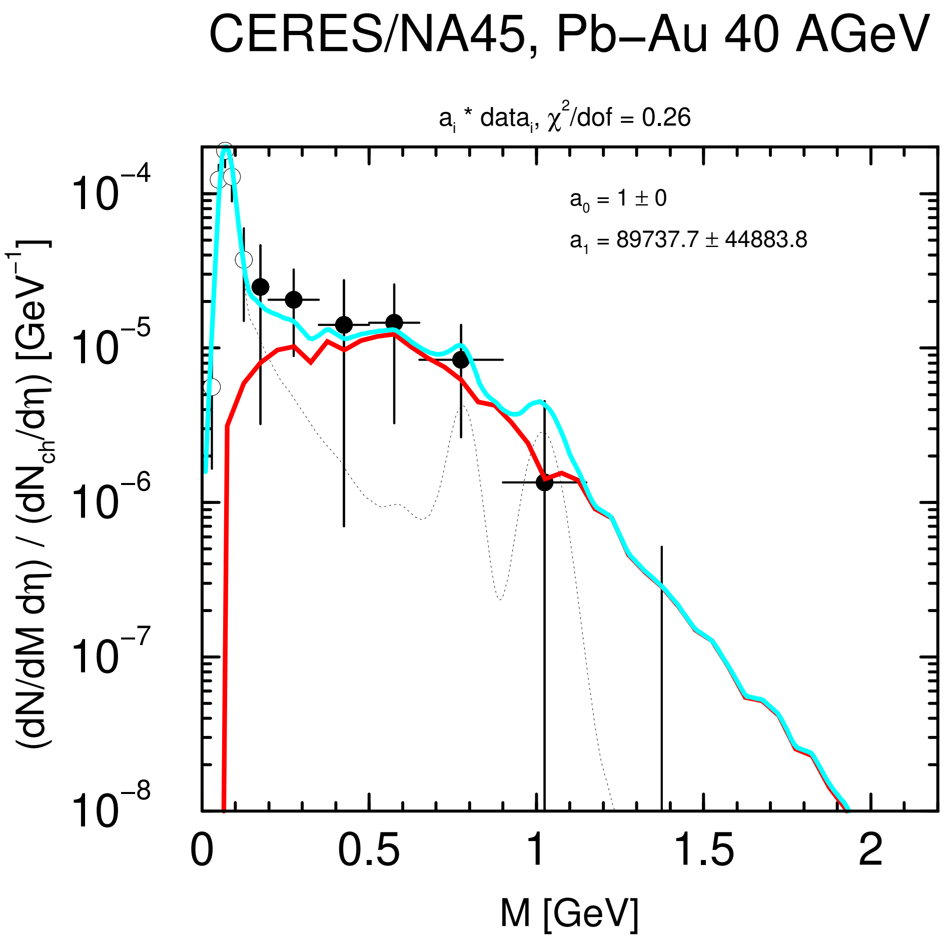
flow

WA98: central Pb(158 AGeV) + Pb $\rightarrow X + \gamma$

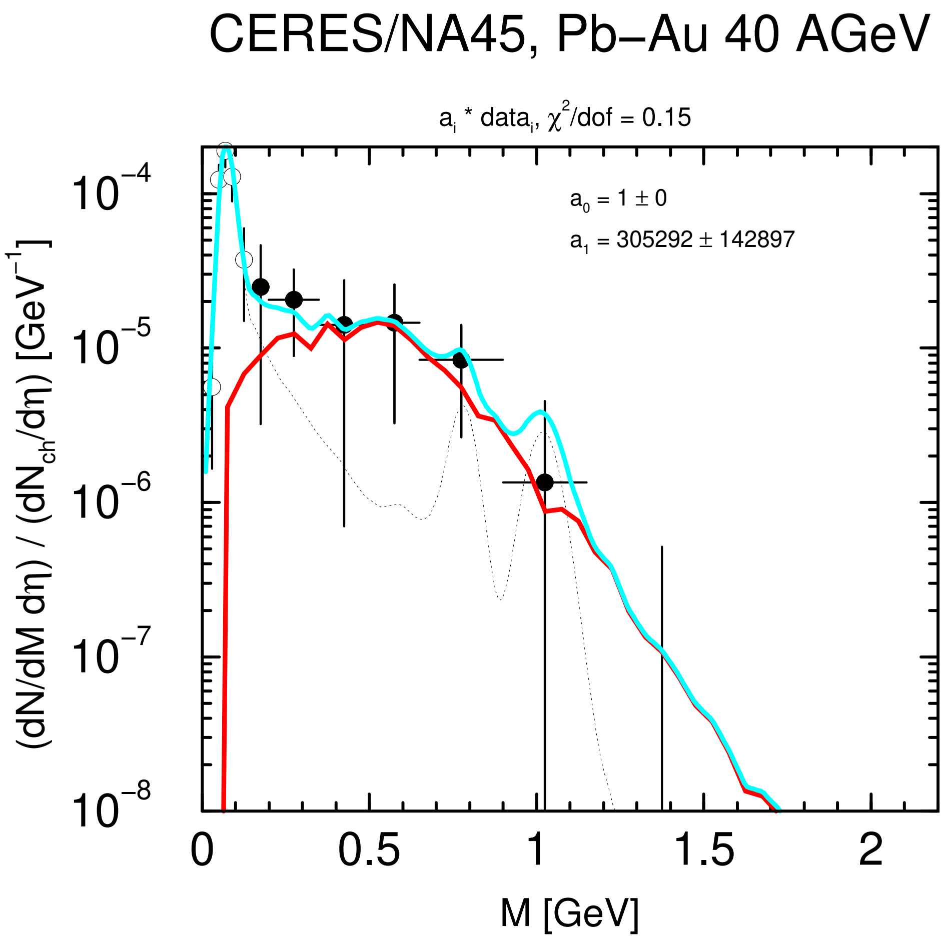


CERES + NA50 + WA98: $T_{\rm eff} = 170$ MeV $\quad N_{\rm eff} = \int dt V(t) = 3.3 \times 10^4$ fm^4

CERES: central Pb(40 AGeV) + Au $\to X + e^+e^-$



$T = 145$ MeV

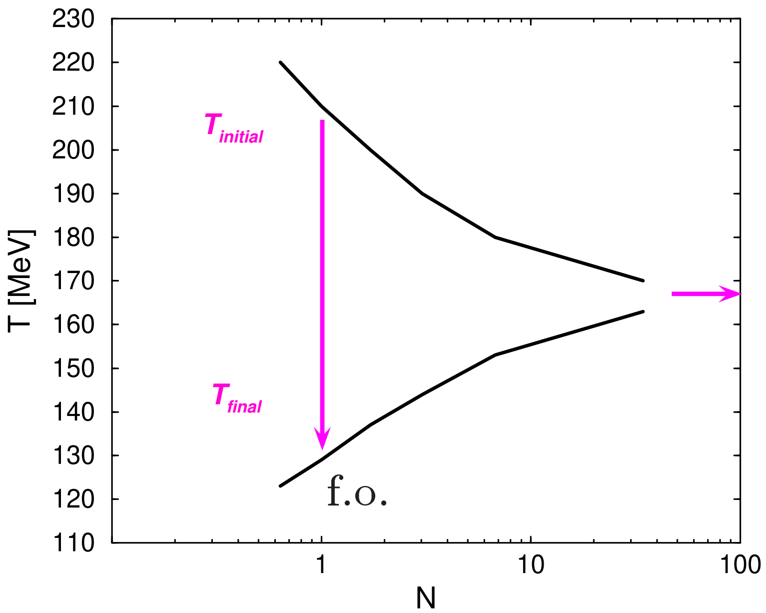


$T = 120$ MeV

analogue: 2. sulfur beam experiments at CERN

Time Evolution Effects

transport models $\Longrightarrow T(t)$, $V(t)$:

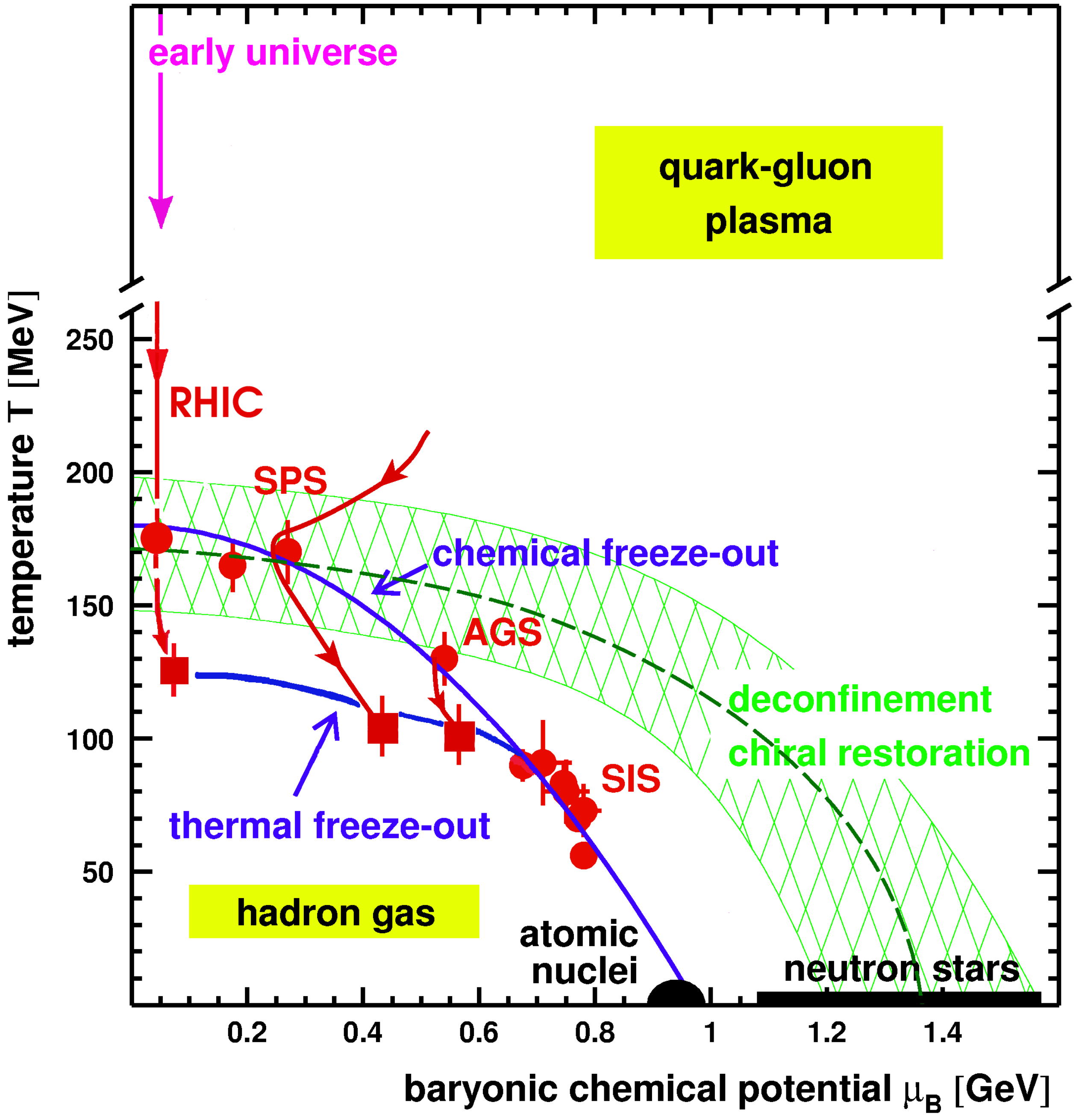


CERES + NA50 data:

$\boxed{T_i = 210 \text{ MeV} > T_c}$

as WA98 data

Problems: $\mathcal{K}$ factors, initial parton $\sqrt{\langle k_\perp^2 \rangle}$, "hard photon rate"


early universe
quark-gluon plasma
RHIC
SPS
chemical freeze-out
AGS
deconfinement
chiral restoration
SIS
thermal freeze-out
hadron gas
atomic nuclei
neutron stars
temperature T [MeV]
250
200
150
100
50
0.2
0.4
0.6
0.8
1
1.2
1.4
baryonic chemical potential μ_B [GeV]