

Hydrodynamic Expansion with the QCD Critical Point

Nagoya University

Chiho NONAKA

PRC71:044904,2005, arXiv:0803.2449 [nucl-th](PRL)

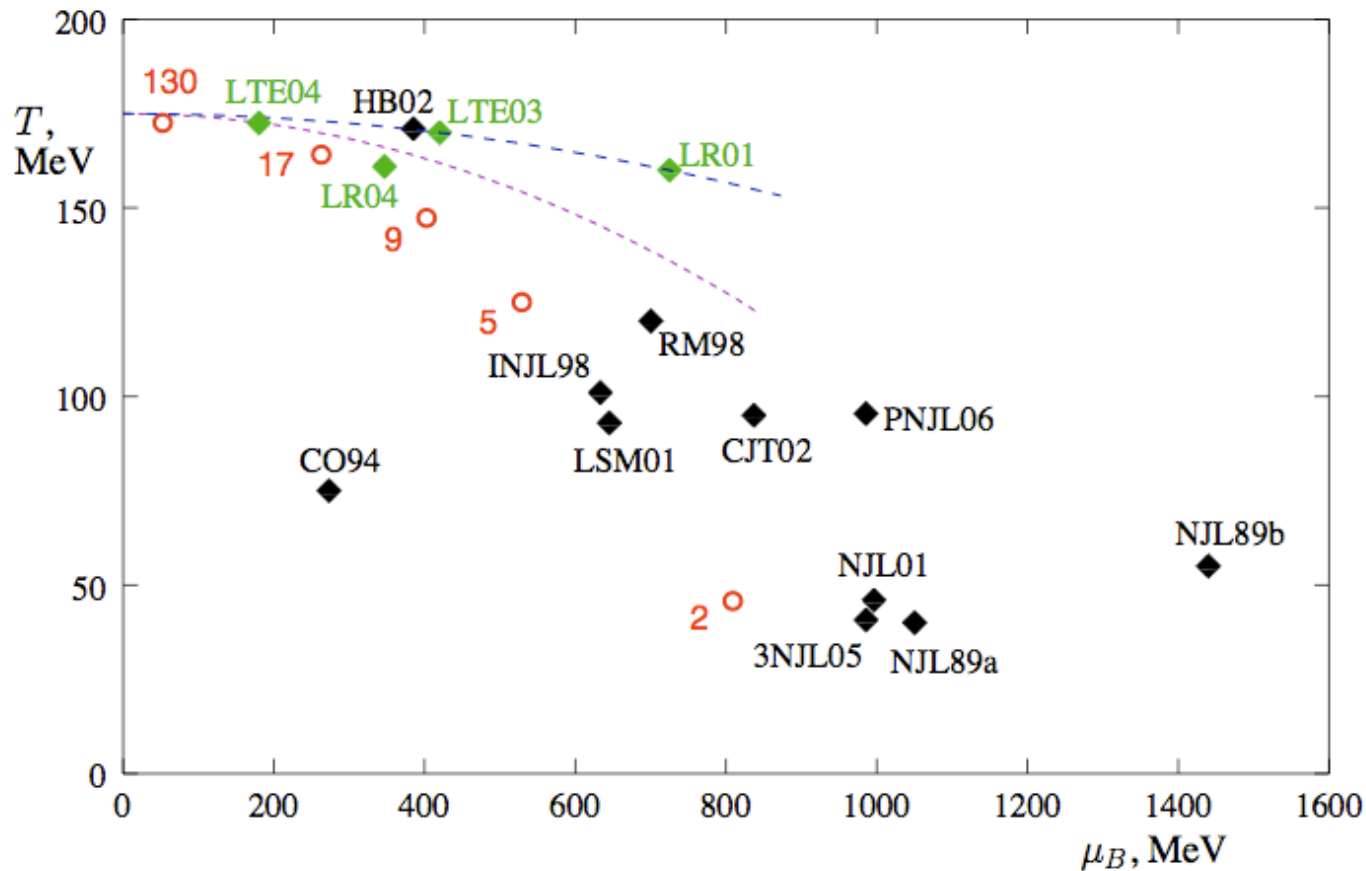
In collaboration with

M.Asakawa(Osaka), S.A.Bass(Duke) and B.Mueller(Duke)

September 3, 2008 @TQFT, Kyoto

Where is the QCP?

■ Lattice QCD, Effective models...

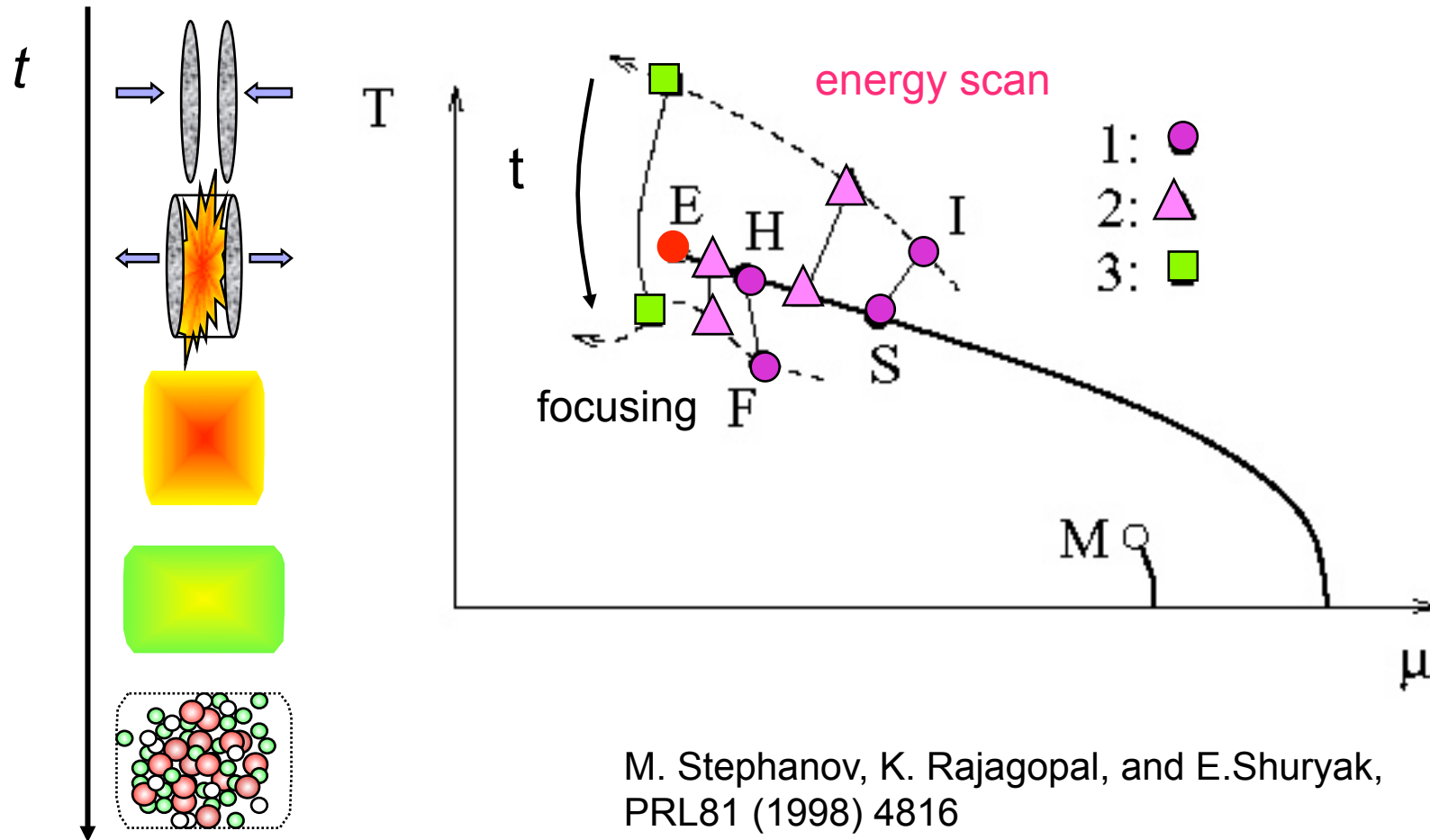


QCD Phase Diagram

Stephanov, hep-lat/0701002

QCP Search in HIC

- The QCD critical point search from phenomenology and experiments



M. Stephanov, K. Rajagopal, and E. Shuryak,
PRL81 (1998) 4816

Toward Quantitative Analyses

■ Realistic Dynamical Model

- 3D Hydro + UrQMD Model

■ The QCD Critical Point

- Focusing effect near the QCD critical point in isentropic trajectories on the $T-\mu_B$ plane

■ Emission Time Dependence

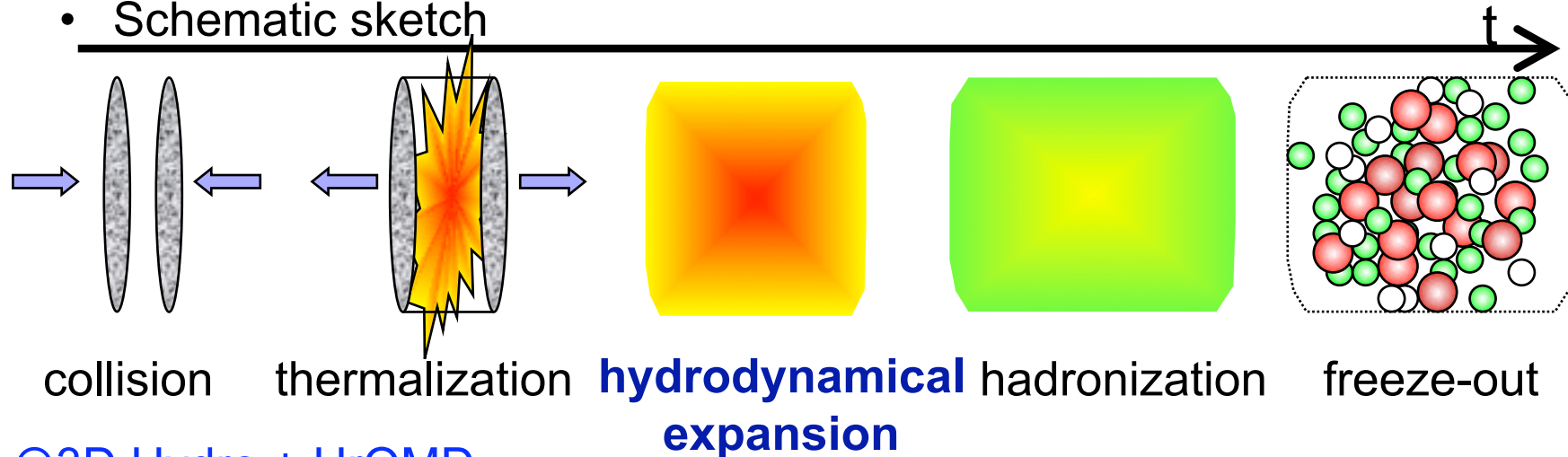
- High P_T particles emit at earlier time

3D Hydro+UrQMD Model

Nonaka and Bass PRC75:014902(2007)

■ Relativistic Heavy Ion Collision

- Schematic sketch



⊙ 3D Hydro + UrQMD

Full 3-d Hydrodynamics

EoS : 1st order phase transition
QGP + excluded volume model

Hadronization

Cooper-Frye
formula
Monte Carlo

UrQMD

final state
interactions

T_C

T_{SW}

t fm/c

T_C : critical temperature $> T_{SW}$: Hydro \rightarrow UrQMD

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EOS with QCD Critical Point

Nonaka and Asakawa, PRC71,044904(2005)

■ Singular part near QCD critical point + Non-singular part

- Non-singular part
QGP phase and hadron phase
- Singular part

3d Ising Model

$$r = \frac{T - T_c}{T_c}$$

h : external magnetic field



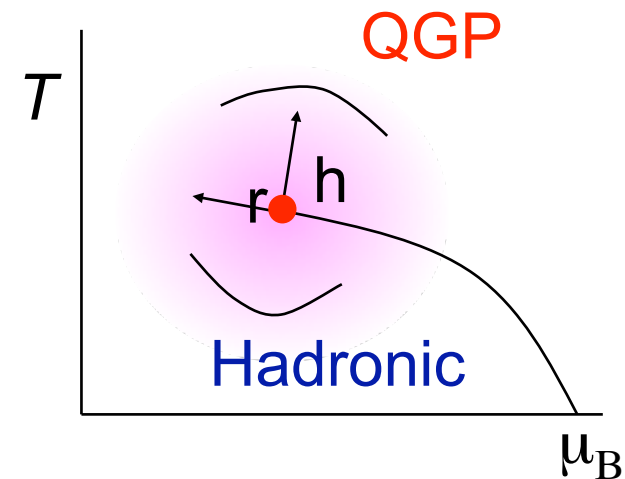
Same Universality Class

QCD

T, μ_B

$$(r, h) \longleftrightarrow (T, \mu_B)$$

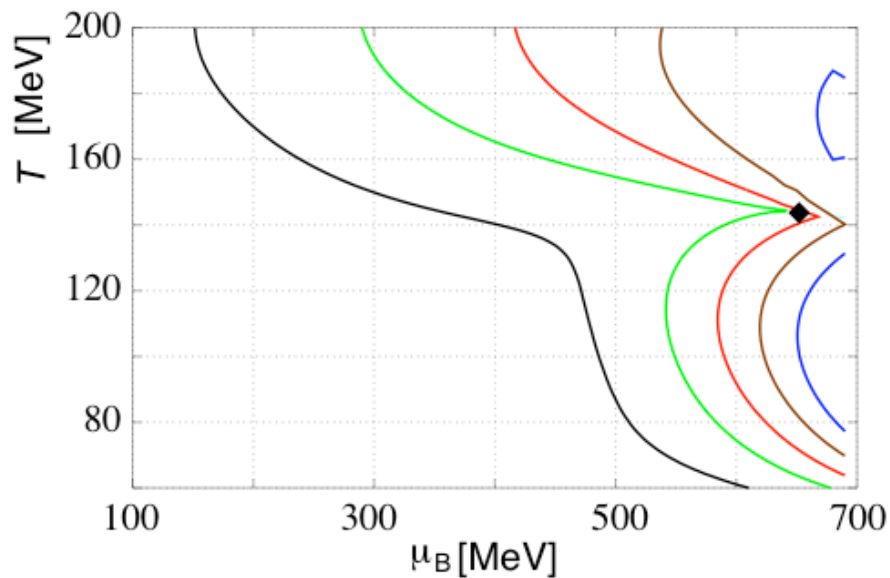
- Mapping $(r, h) \rightarrow (T, \mu_B)$
- Matching with known QGP and hadronic entropy density
- Thermodynamical quantities



Focusing Effect

■ Isentropic trajectories on T - μ_B plane

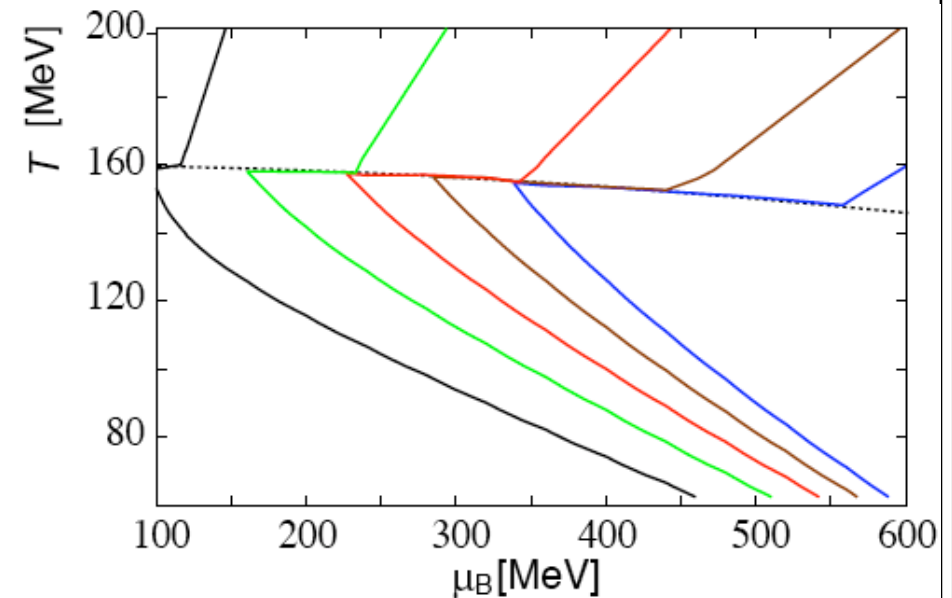
With QCD critical point



Focused

Bag Model +
Excluded Volume Approximation
(No Critical Point)

= Usual Hydro Calculation



Not Focused

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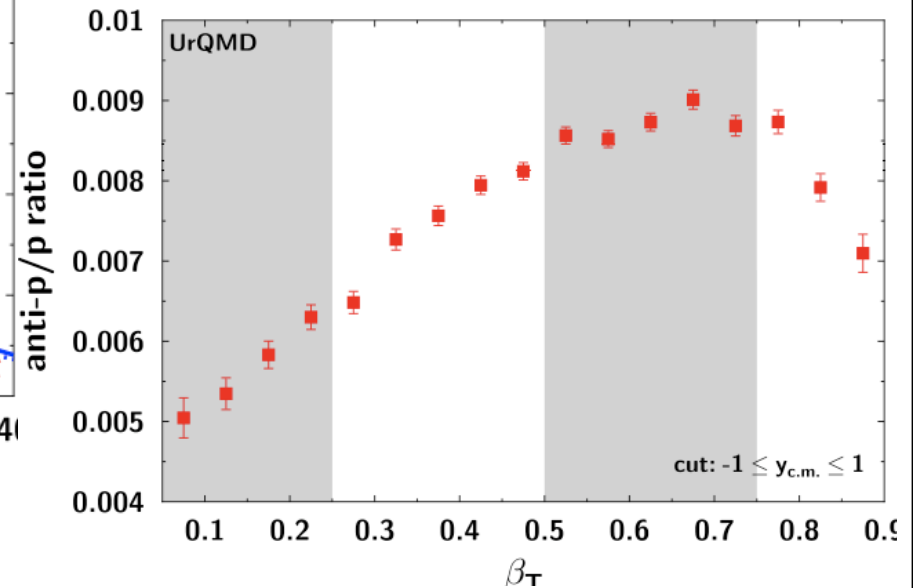
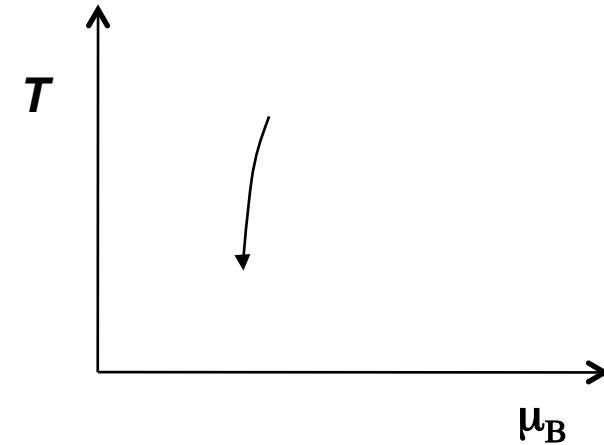
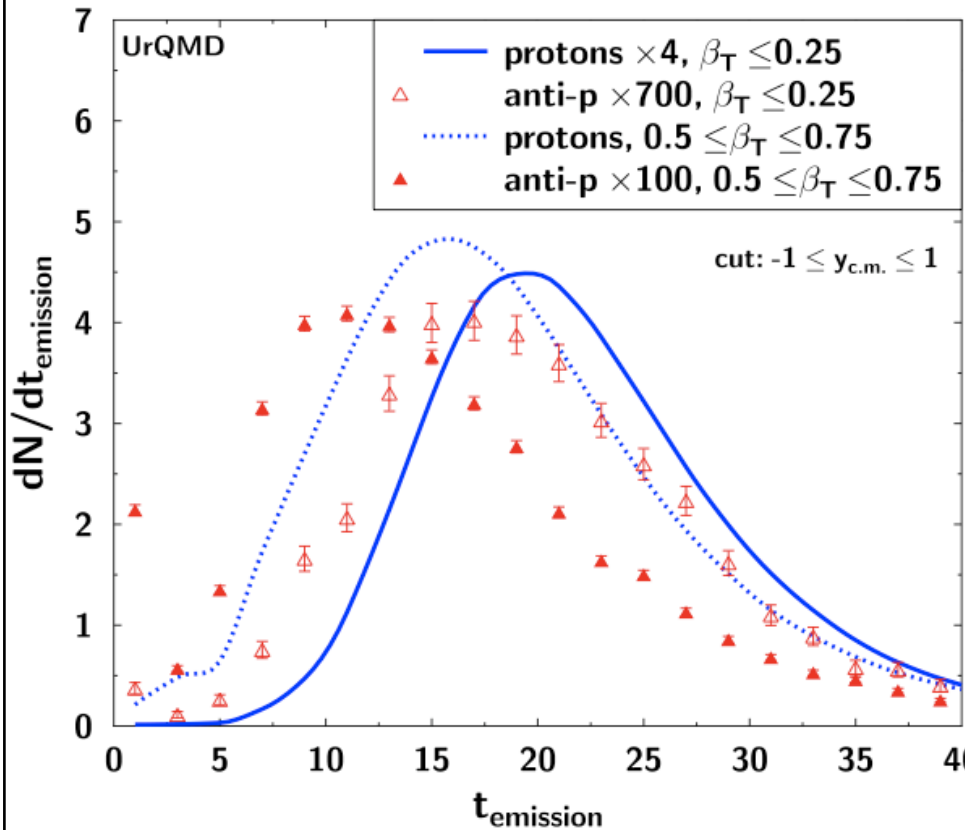
■ Emission Time Dependence

- High P_T particles emit at earlier time

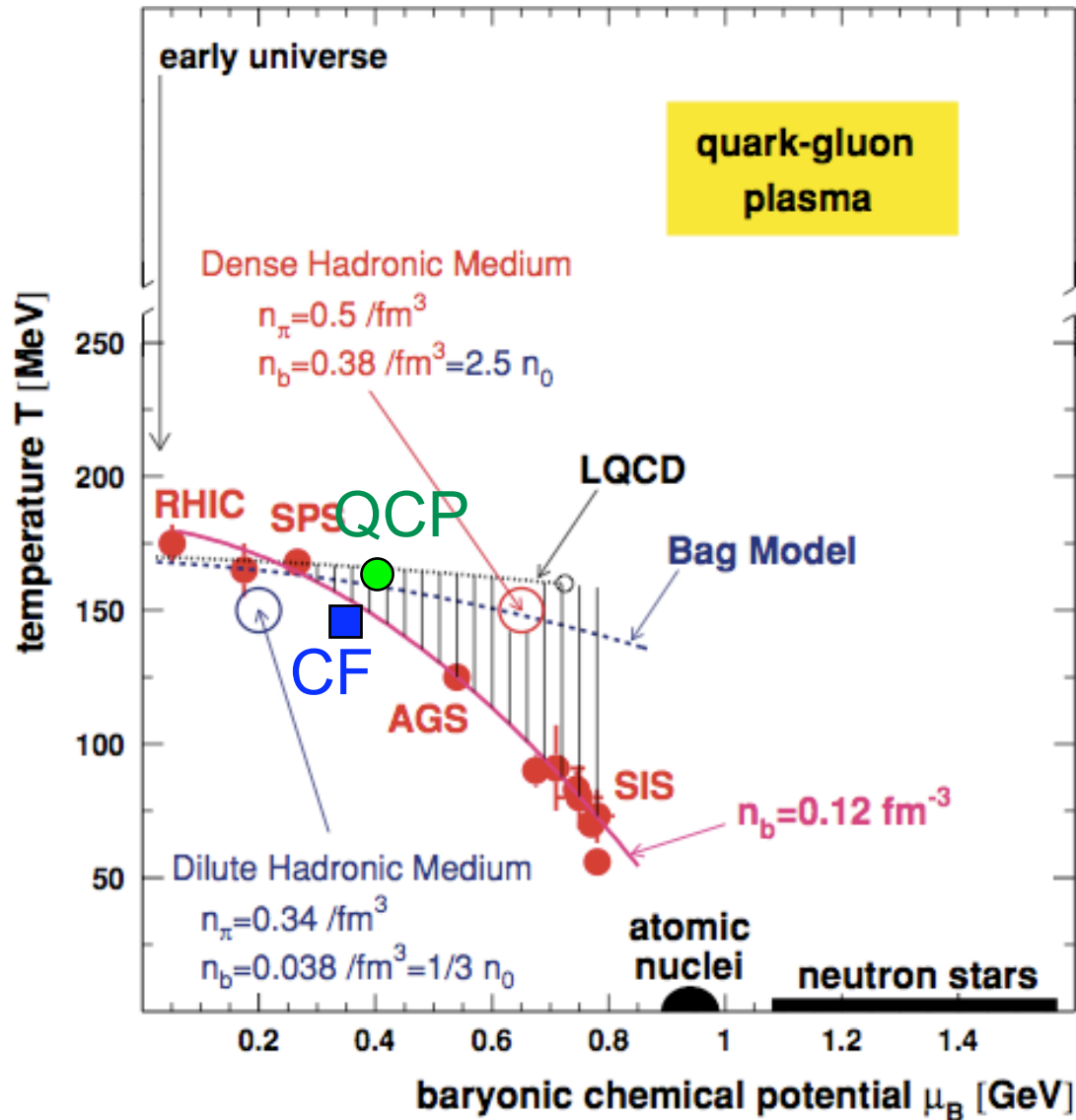
Emission Time Distribution

UrQMD : no QCD critical point

Au+Au, $E_{\text{lab}}=40 \text{ GeV/A}$



Demonstration

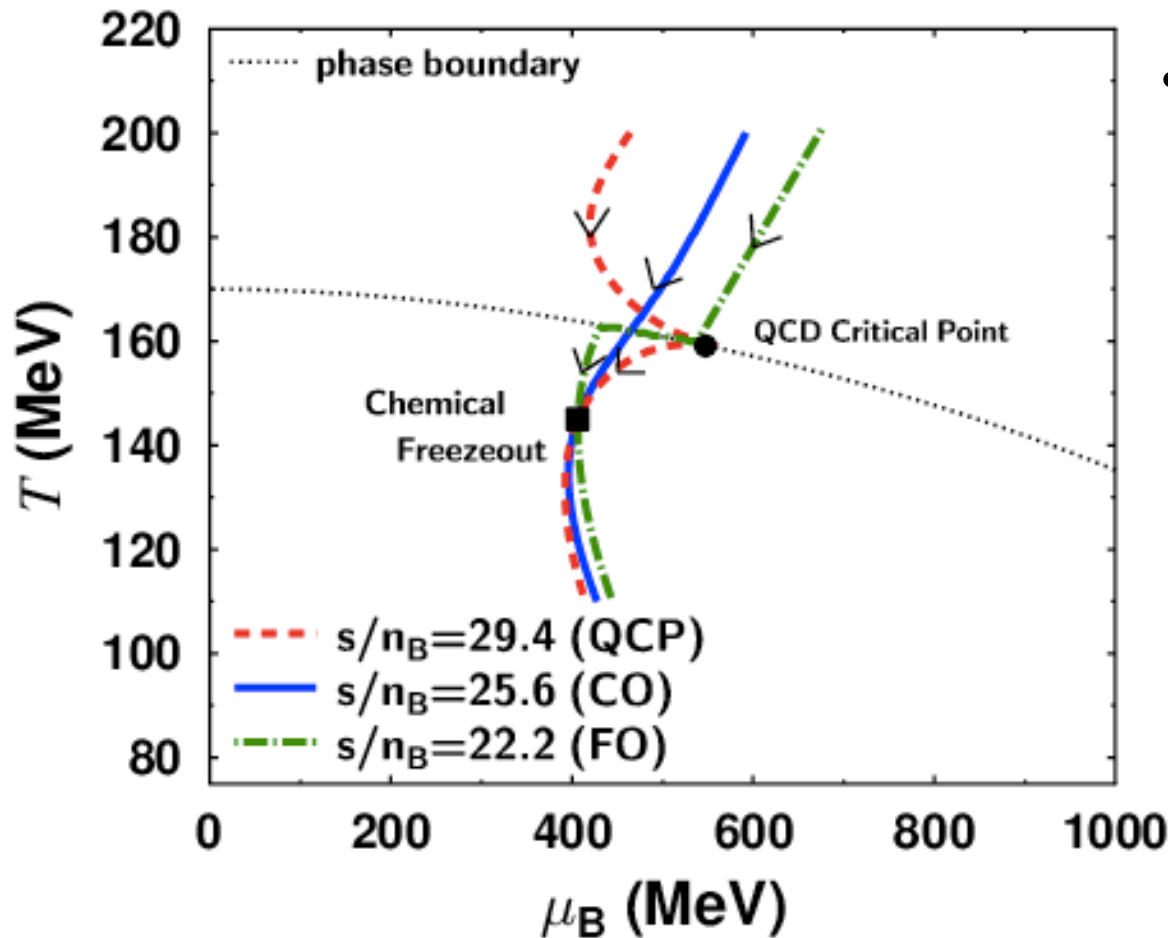


Search of the QCD critical point from experiments

NA49:

- Location of QCP
 $(\mu_B, T)=(550, 159)$
- Critical Region
- Chemical freezeout point
 $(\mu_B, T)=(406, 145)$
 from statistical model

Isentropic Trajectories



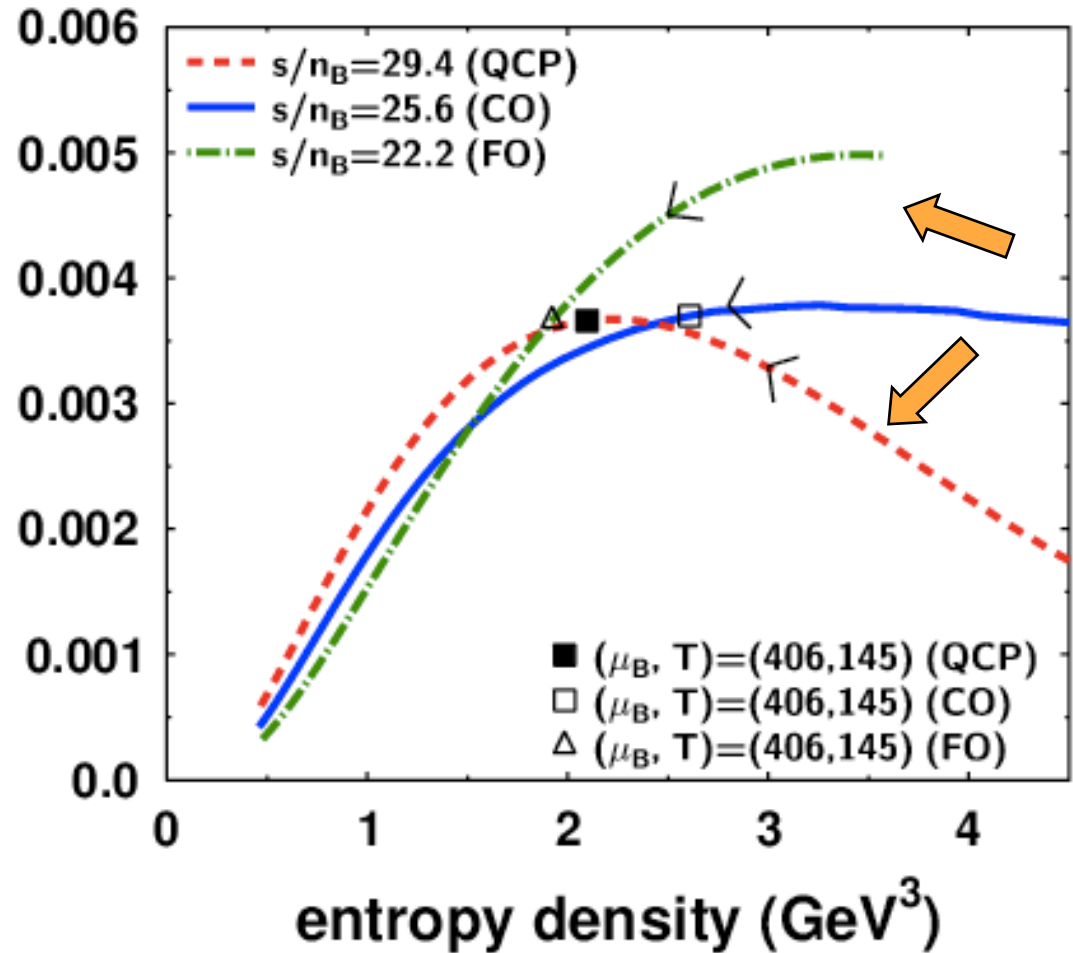
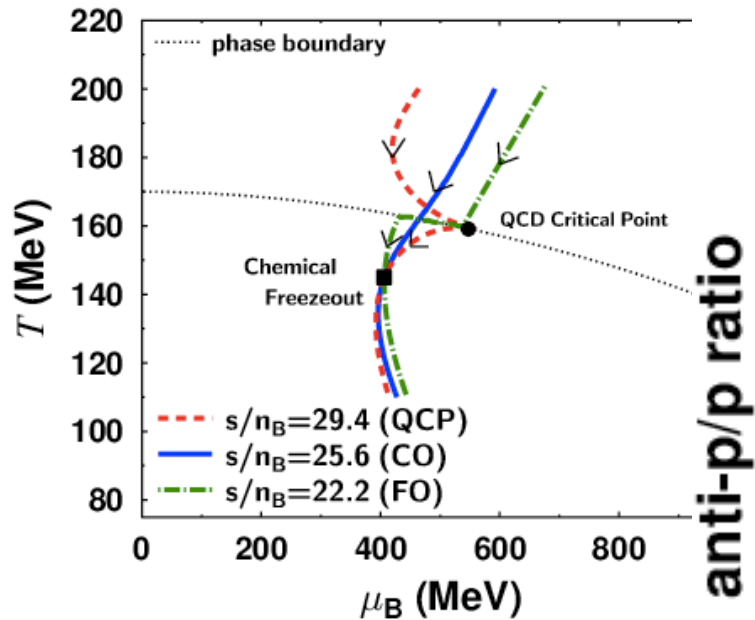
- Hadronization occurs from the phase boundary and chemical freezeout point

$$\left\{ \begin{array}{l} \bullet \text{FO, CO} \nearrow \\ \bullet \text{QCP} \longrightarrow \end{array} \right. \frac{\mu_B}{T}$$

→ \bar{p}/p ratio

$$\bar{p}/p \sim \exp\left(-\frac{2\mu_B}{T}\right)$$

Signature of QCP



$$\bar{p}/p \sim \exp\left(-\frac{2\mu_B}{T}\right)$$

- decreases (FO,CO)
- increases (QCP)

with QCP
steeper \bar{p} spectra at high P_T

Toward Detailed Analyses

■ Realistic Dynamical Model

- 3D Hydro + UrQMD Model

■ The QCD Critical Point

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Location of the QCD critical point
Critical region

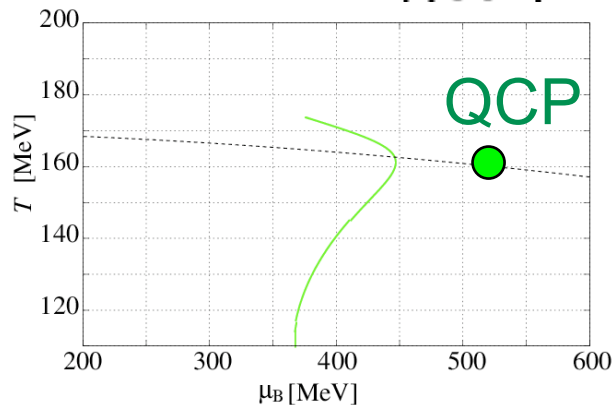
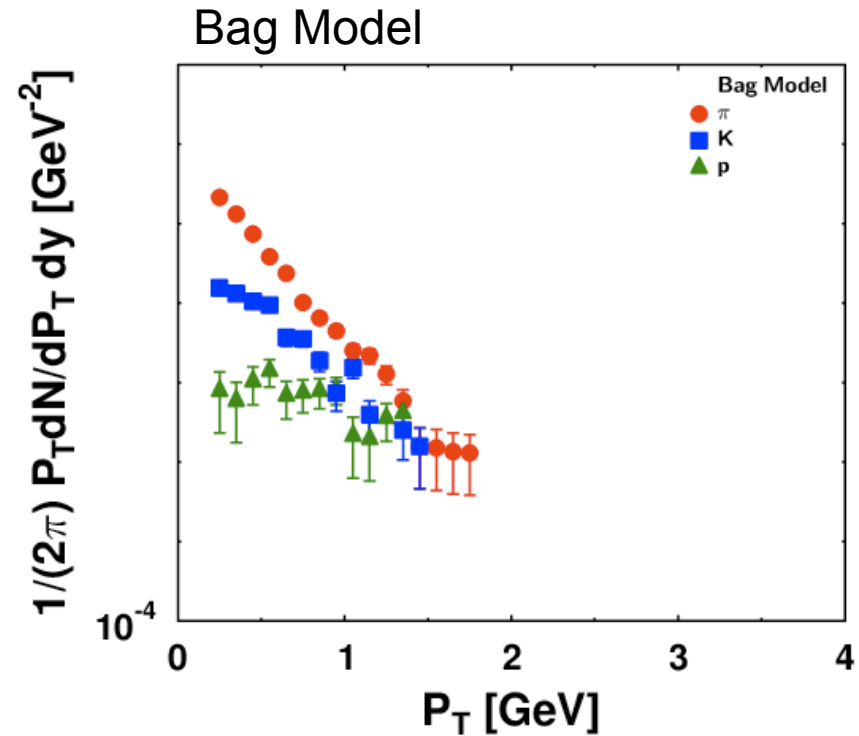
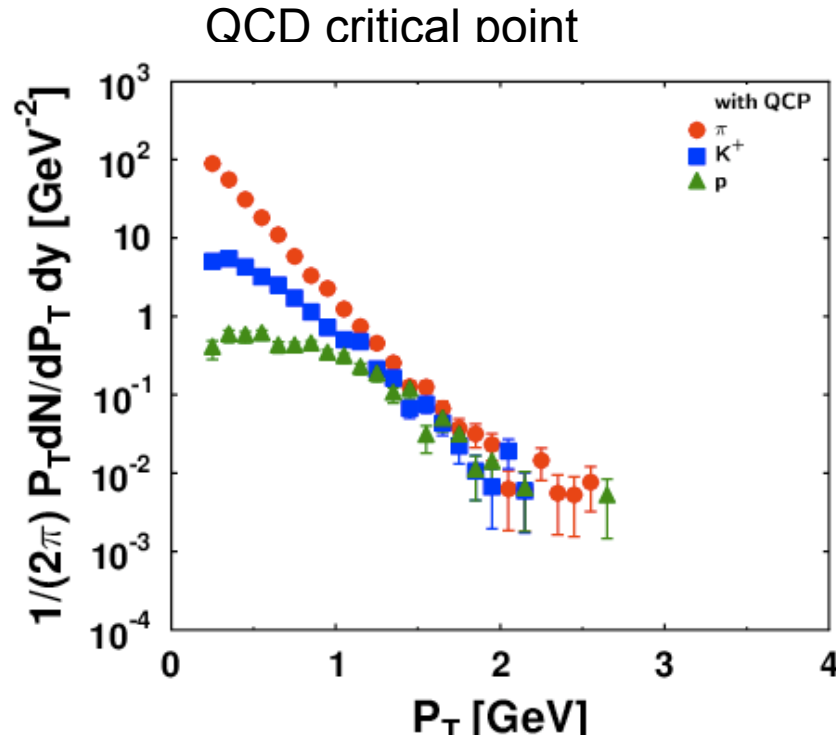


lattice QCD
experiments

■ Emission Time Dependence

- High P_T particles emit at earlier time

P_T Spectra (3D Hydro + UrQMD)



Because of focusing effect

$$\text{At } T_{\text{SW}} \quad \langle \mu_B \rangle_{\text{QCP}} > \langle \mu_B \rangle_{\text{BG}} \implies \frac{p}{\pi}_{\text{QCP}} > \frac{p}{\pi}_{\text{BG}}$$

Summary

■ 3D Hydro + UrQMD Model with the QCD critical point

- Isentropic trajectories
- P_T spectra, hadron ratio

■ From experiments

information of the QCD critical point
location, critical region, existence...

■ Physical observables

- Anti-p/p ratio : promising and clear signature

