Sep. 14, 2002 @ JPS

JHF, GSI における高密度核物質の物理

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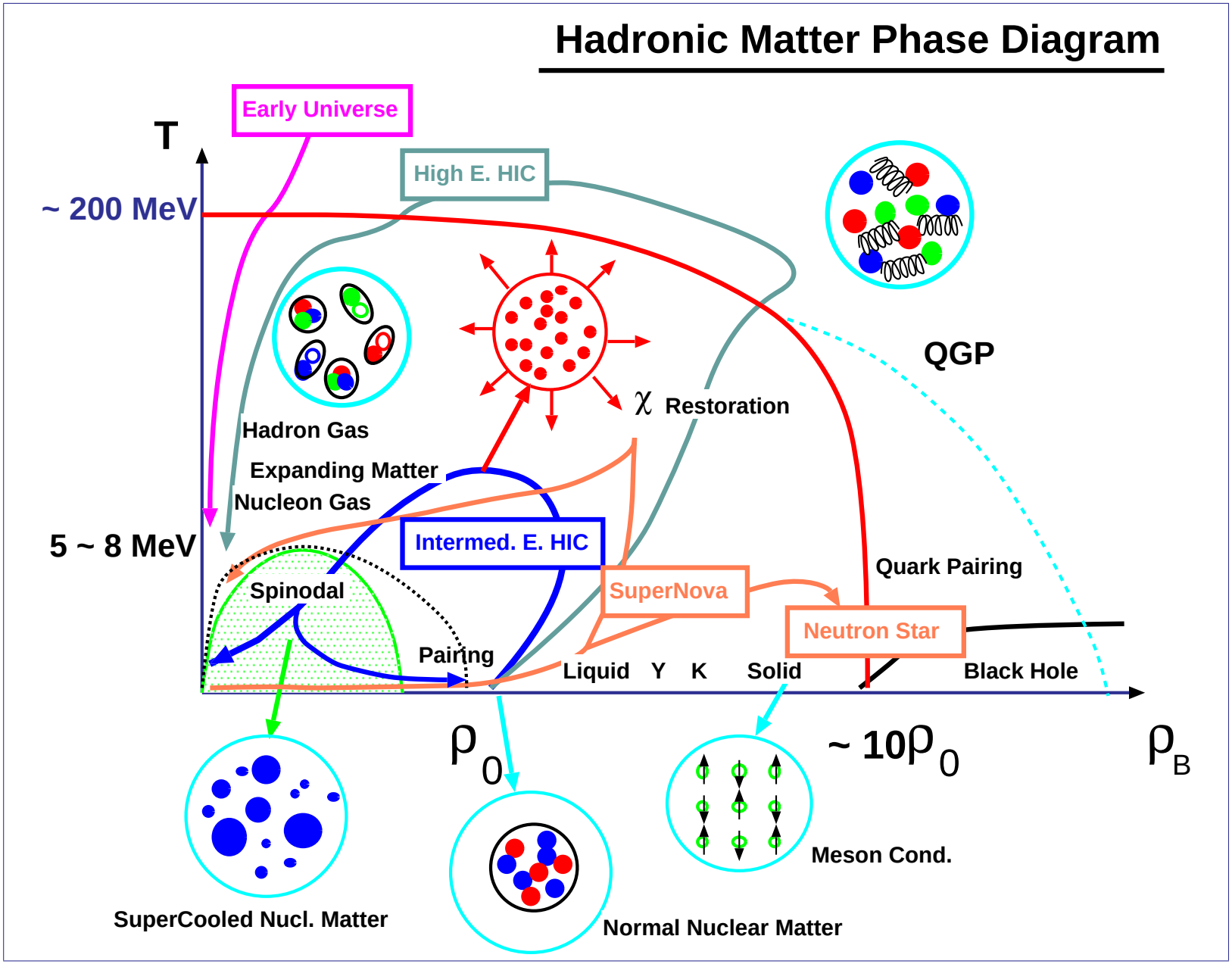
1. What We Can Do with 50 GeV PS Machine ?
   - ⋆ Hadron Phase Diagram
   - ⋆ JHF $\leftrightarrow$ GSI
2. Towards the Highest Density Matter in Lab.
   - ⋆ (ρ_B, T) Trajectory at JHF
   - ⋆ Collective Flow: Probe of Pressure
   - ⋆ Strangeness Enhancement: Rescattering or Potential ?
   - ⋆ Low-Energy Di-Leptons: Probe of Chiral Symmetry Restoration
3. Towards LTHD (Low T & High ρ) Matter & Baryon Rich QGP Formation
   - ⋆ (ρ_B, T) Fluctuation: Can we make (ρ_B, T)=$(10\rho_0, 50$ MeV) ?
4. Summary

⋆ What We Can Do with 50 GeV PS Machine ?

- ⋆ Proton Beam: 600 MeV ∼ 50 GeV (2 orders Energy Range !)
  - Multifragmentation, Particle Production, Hadron Spectroscopy
- ⋆ Various Intense Secondary Beams (n, μ, ν, $\bar{p}$, K, π, ...)
  - Strangeness Nuclear Physics
- ⋆ HI Beam: 25 A GeV → Most Dense Hadronic Matter Formation in Lab.
  - Hydrodynamical Evol., Caloric Curve, EOS, Hadrons in Dense and Hot Matter

☞ Suitable for studying "Phase Diagram", esp., of "Highly Dense Matter"
- Proton Beam: Elem. Proc., incl. Res., Hadron Property at ρ_0
- HI Beam: EOS of Dense Matter
- Pion/Kaon Beam: Strangeness Production, Y Potentials


Hadronic Matter Phase Diagram
T
~ 200 MeV
5 ~ 8 MeV
Early Universe
High E. HIC
Intermed. E. HIC
Hadron Gas
Expanding Matter
Nucleon Gas
χ Restoration
QGP
Spinodal
Pairing
SuperNova
Quark Pairing
Neutron Star
Liquid Y K Solid
Black Hole
ρ0
~ 10ρ0
ρB
SuperCooled Nucl. Matter
Normal Nuclear Matter
Meson Cond.

⋆ Why and How is Dense Matter Study @ JHF Interesting ?

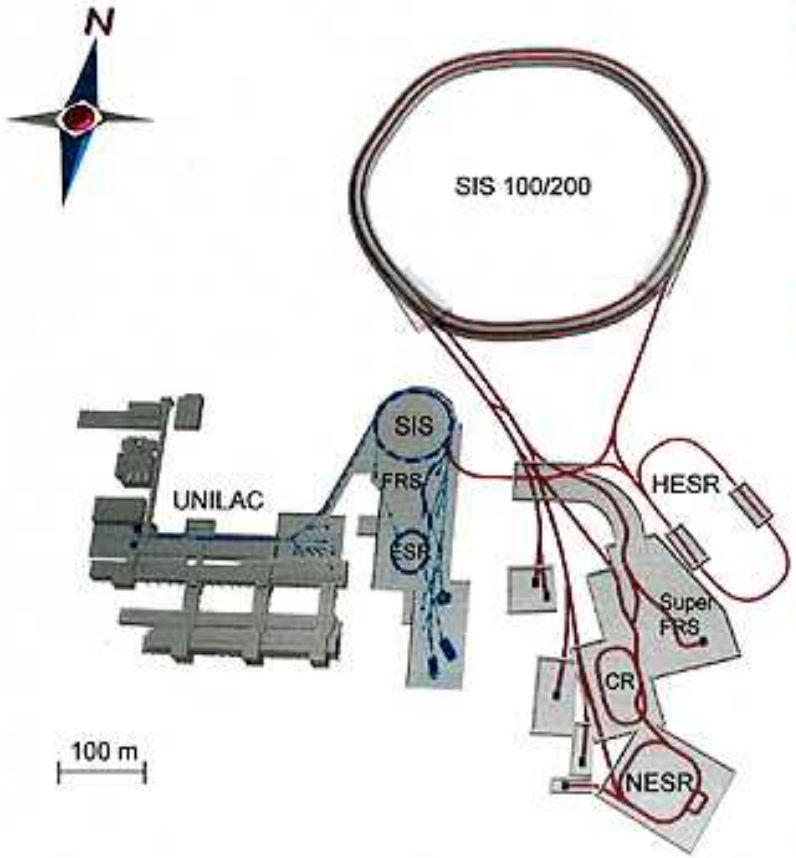
- ⋆ Essential in Understanding Compact Steller Objects.
  $\cdots$ EOS, Particle Ratio, Pairing, ...
  $\leftrightarrow$ Neutron Stars, Supernovae, Black Hole, Neutron Star Merger
- ⋆ In addition to Particle Degrees of Freedom (hadron $\leftrightarrow$ quark & gluon), Interaction plays vital roles.
  $\cdots$ $FREE$ models fail in many ways.
- ⋆ Hadron Natures (sometimes) become clear in medium

  $\cdots$ ρ, σ, K, η, N*, Λ^*, Σ^*
- ⋆ Baryon Rich QGP may be formed at JHF.

Two Projects are Competing !
JHF (Second Stage, 25 A GeV) $\leftrightarrow$ GSI Future Project ($\sim$ 30 A GeV)

Henning (http://www.gsi.de/cbm2002/)

GSI Future Project



Gain Factors

- Primary beam intensity: Factor 100 – 1000
- Secondary beam intensities for radioactive nuclei: up to factor 10,000
- Beam energy: Factor 15

Special Properties

- Intense, fast cooled energetic beams of exotic nuclei
- Cooled antiproton beams up to15 GeV
- Internal targets for high-luminosity in-ring experiments

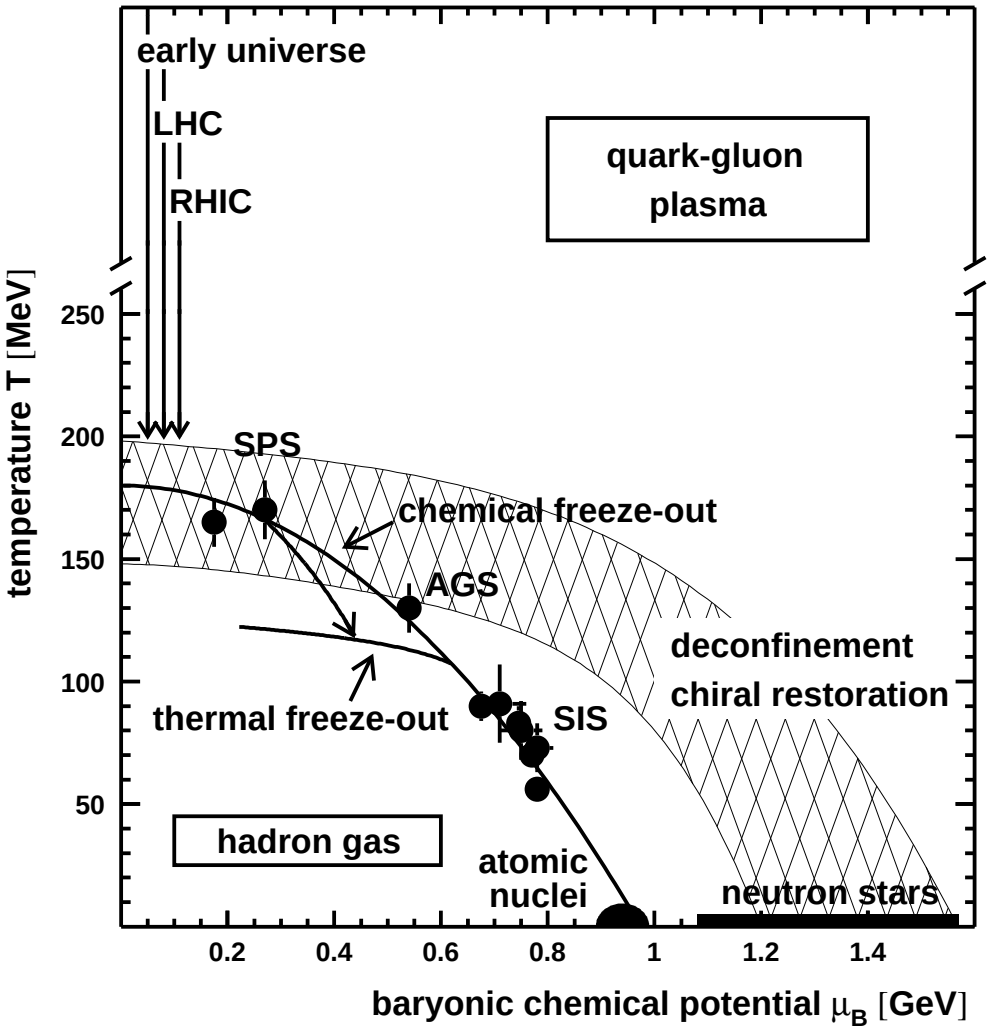
New Technologies

- Fast cycling superconducting magnets
- Electron cooling at high ion intensities and energies
- Fast stochastic cooling

GSI

⋆ Towards the Highest Density Matter in Lab.

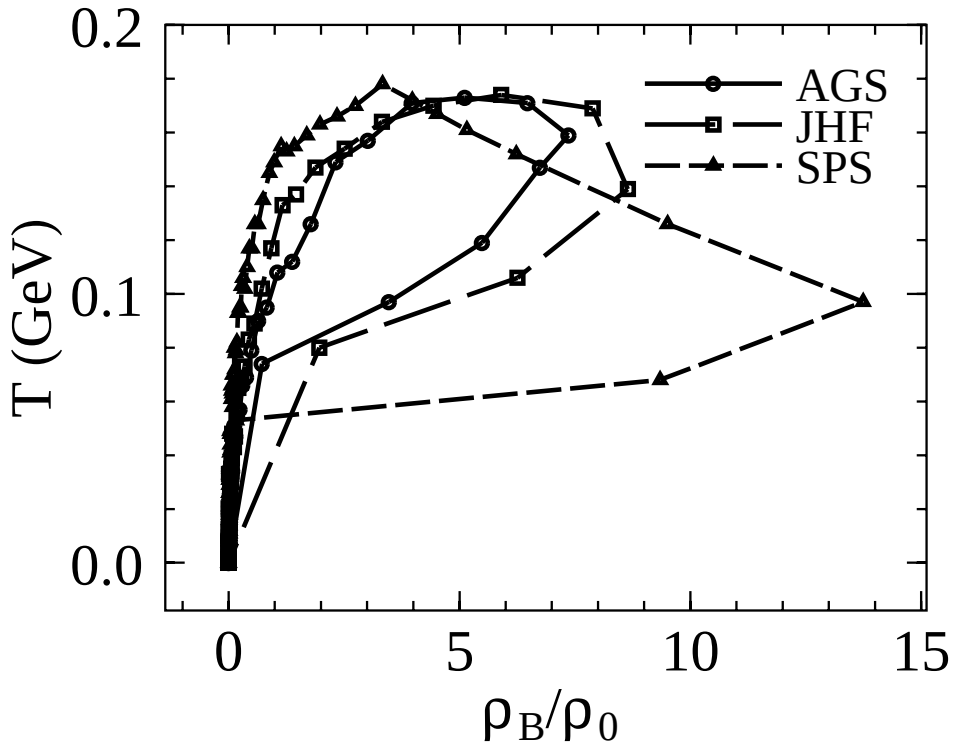
- Freeze-Out Point at SIS, AGS, and SPS



Freeze-out point seems to evolve *SMOOTHLY* as a function of Incident Energy
→ How about Trajectory ?

- HI Collision at 25 A GeV

$\cdots$ would make the Highest Density Hadronic Matter under Approximate Equilibrium



(JAM Calc., Y. Nara,FRONP99, 8/2-4, 1999 at JAERI)

AGS, JHF:

$\rightarrow$ Smooth Evolution in (ρ_B, T)

$\rho_B(\max) > 2\gamma_{cm}\rho_0$

SPS, RHIC:

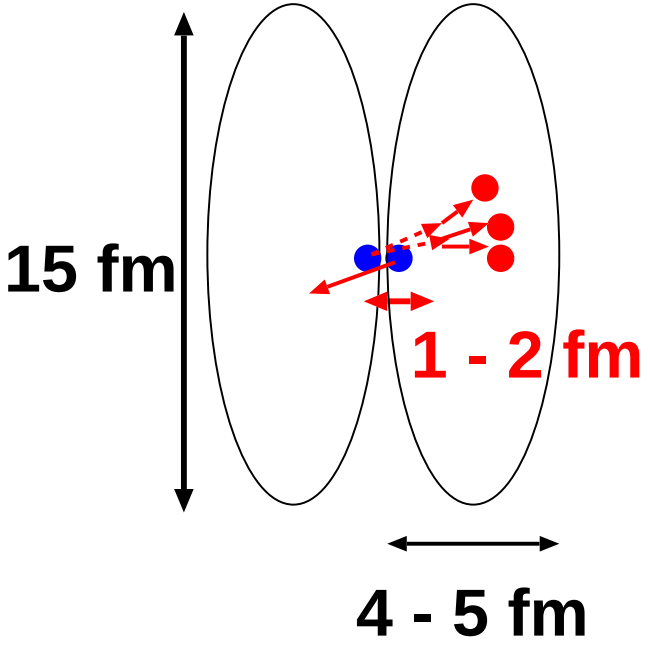
$\rightarrow$ Sudden Jump to (Low ρ_B, High T)

$\rho_B(\max) < 2\gamma_{cm}\rho_0$

☞ IF we can make high ρ_B QGP, it is at JHF.

JHF Energies

$\gamma_{cm} \simeq 3.5$, $\tau \simeq$ 0.5 - 1 fm/c

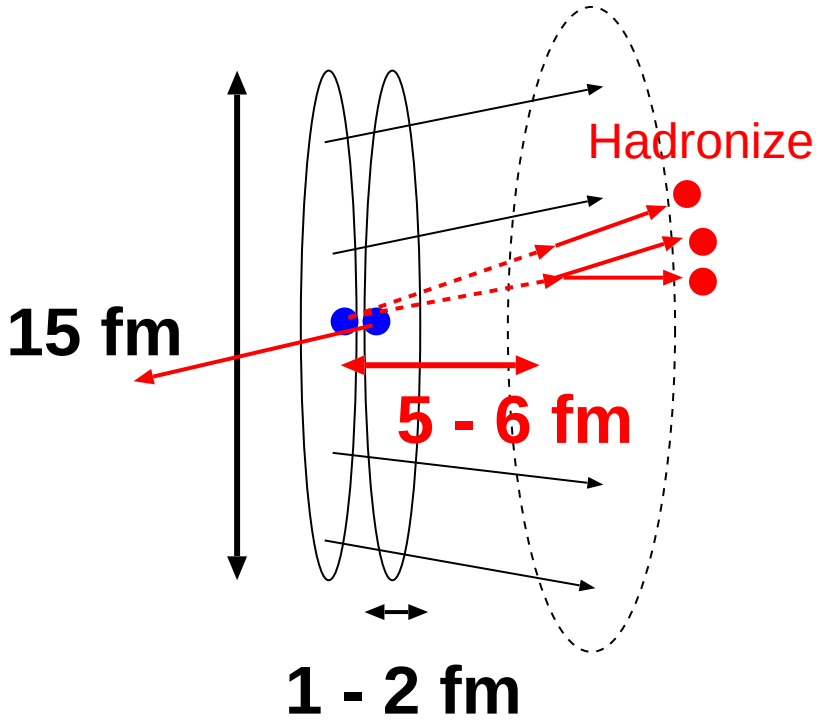


Multiple Hadron-Hadron Collisions

☞ (Approx.) Thermalized Hadron Gas

SPS Energies

$\gamma_{cm} \simeq 10$, $\tau \simeq$ 0.5 - 1 fm/c



String-String, String-Hadron Int.

+ Int. within Co-Movers

- Major Topics in HEHI
  - ⋆ Collective Flow: EOS at High Density
  - ⋆ Low-Mass Lepton Pair: Hadron Masses at High Density
  - ⋆ High-Mass Lepton Pair: J/ψ Suppresion at High Temperature
  - ⋆ Jet Energy Loss: Parton Dynamics at High Gluon Density
  - ⋆ Strangeness Enhancement: Potential at High Density

Study of Highly Dense Hadronic Matter is NECESSARY
and it's difficult to make at SPS and RHIC Energies

⋆ Collective Flows: Probe of Pressure

(Directed) Flow (dP_X/dY)

Stiffness (Low E)
+ Time Scale (High E)

Elliptic Flow (V_2)

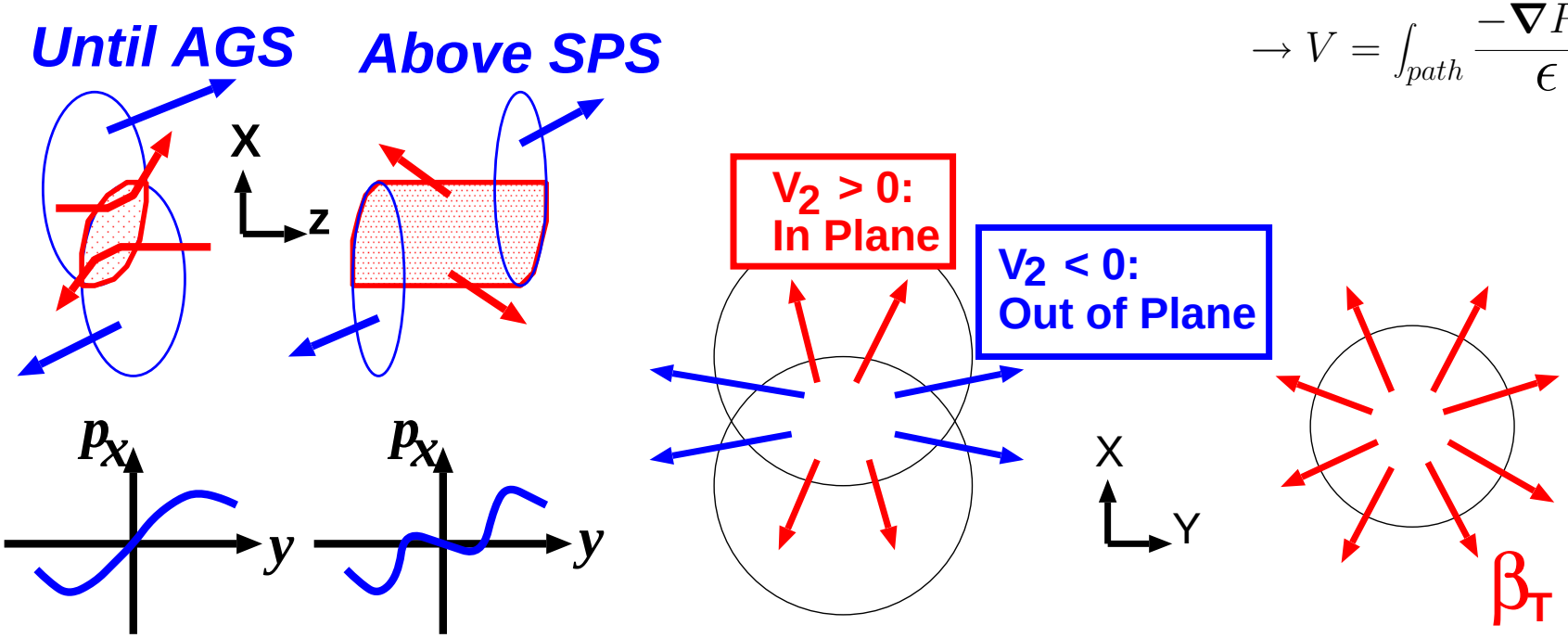
Thermalization
& Pressure Gradient

Radial Flow (β_T)

Pressure History

$$\epsilon \frac{D\boldsymbol{V}}{Dt} = -\boldsymbol{\nabla} P$$

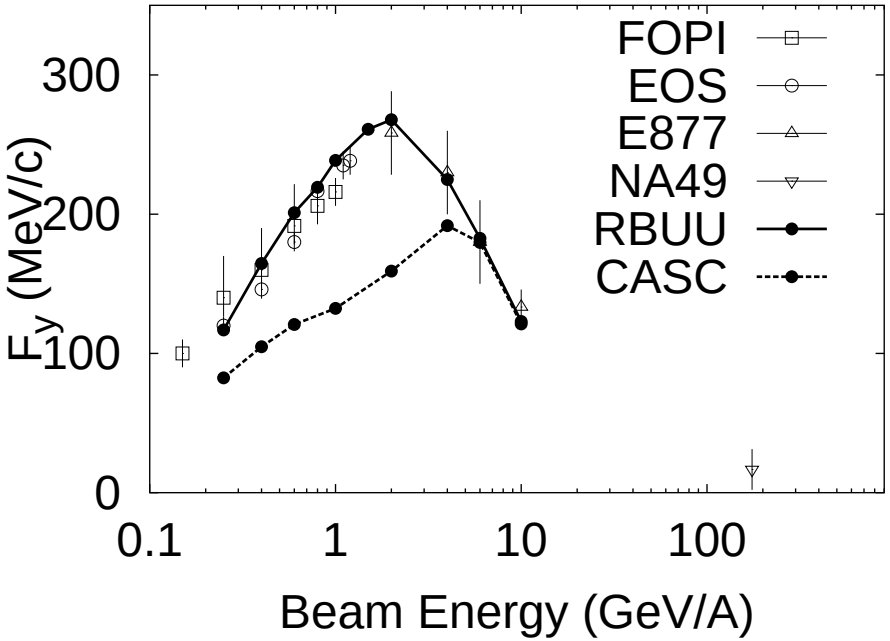
$$\rightarrow V = \int_{path} \frac{-\boldsymbol{\nabla} P dt}{\epsilon}$$



- Incident Energy Dependence

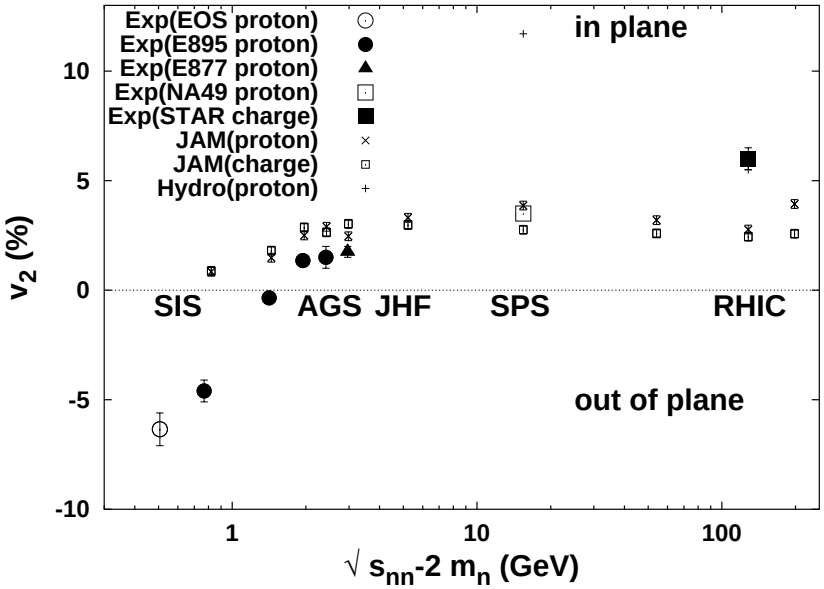
(Directed) Flow (dP_X/dY)

Sahu,Cassing,Mosel,AO, NPA(2000))



Elliptic Flow (V_2)

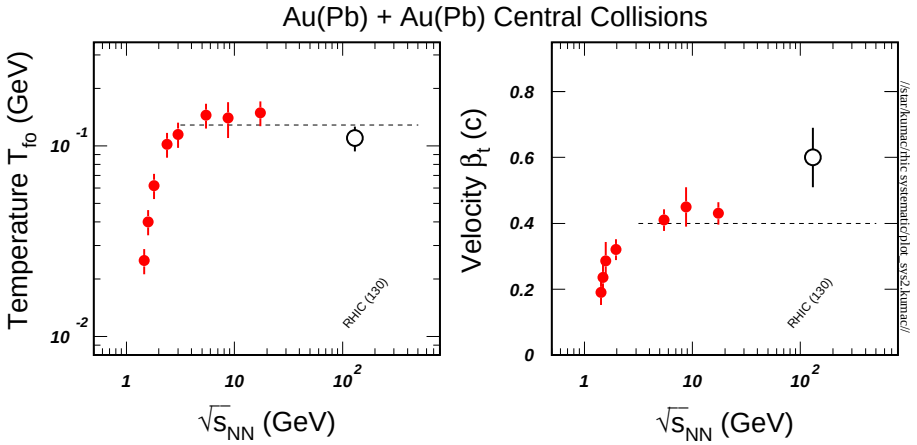
Sahu,Otuka,AO, (nucl-th/0206010)



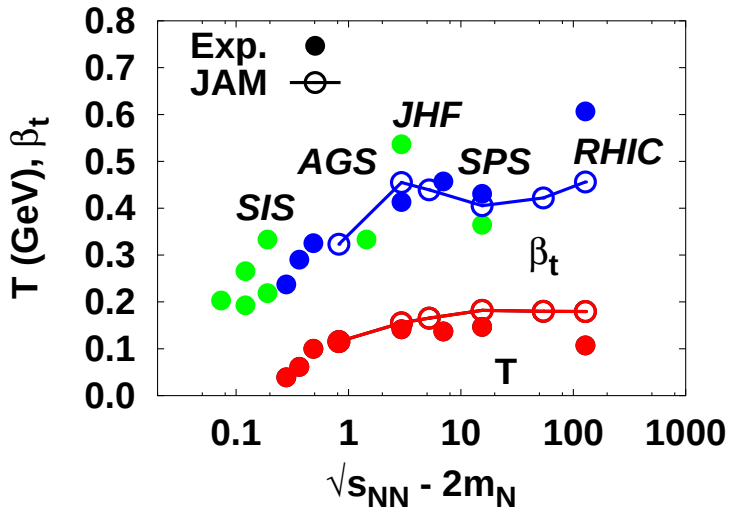
☞ $dP_X/dY \sim 0$, $V_2 \sim$ Saturating Value @ JHF

Radial Flow (β_t)

Exp: Nu Xu and M. Kaneta (STAR)



Otuka,Sahu,Isse,Nara,AO
(nucl-th/0102051)



☞ Local Max. of β_t@ JHF

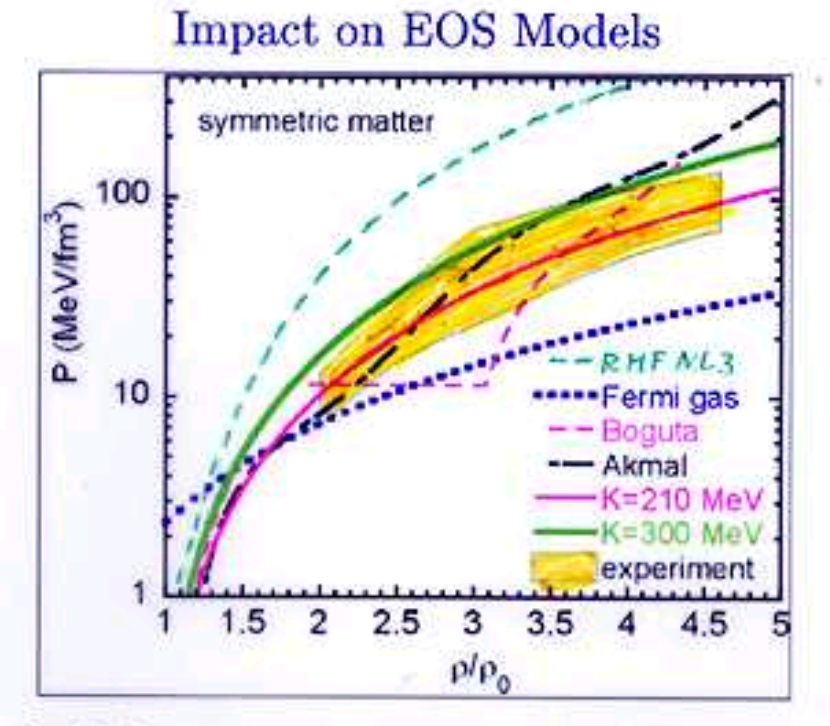
Characteristics of Flow @ JHF

- ⋆ Smaller Spectator-Participant Interaction → Clear Participant Dynamics
- ⋆ Large Radial Flow → Large Baryon Density (Int. Energy)

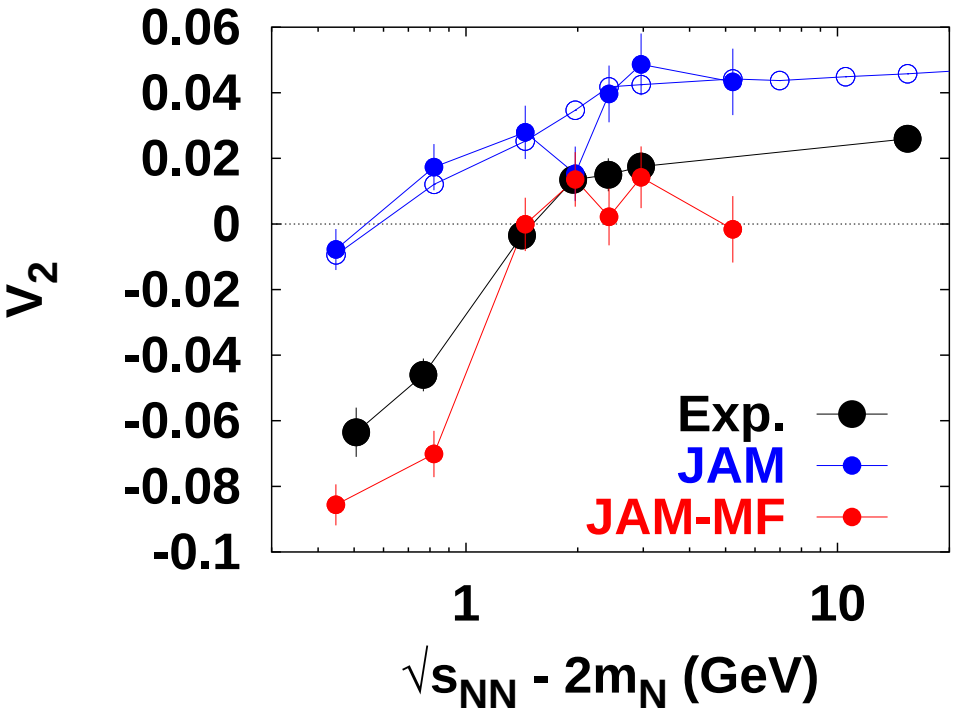
→ Approximately Equilibrated Dense (Baryon Rich) Matter

- Probed (ρ, T) Region

P. Danielewicz
(GSI workshop, 2002)



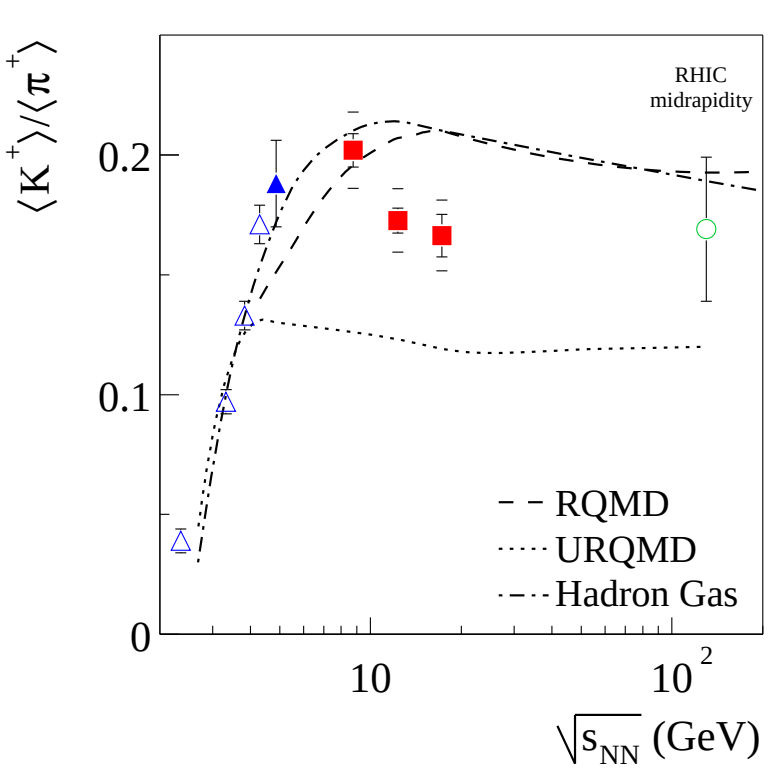
M. Isse (JAM-RQMD/S with p-dep. int.)

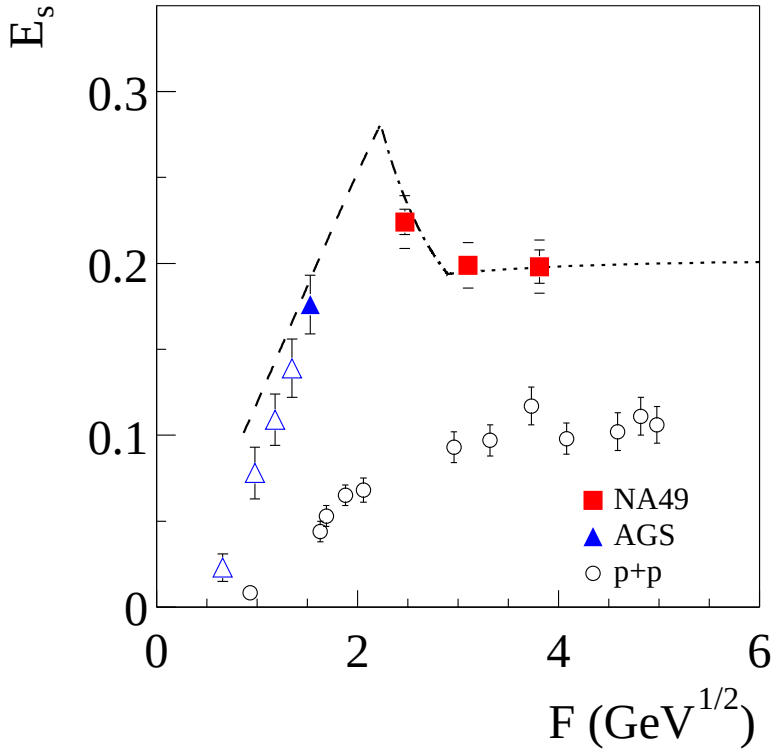


⋆ Strangeness Enhancement: Rescattering or Potential ?

☞ Strangeness is Enhanced Sharply at $E_{inc} = 10 - 40$ GeV/A !

NA49 (nucl-ex/0205002)



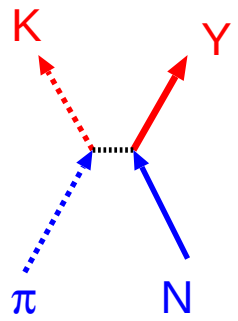


Hadron → Mix → QGP

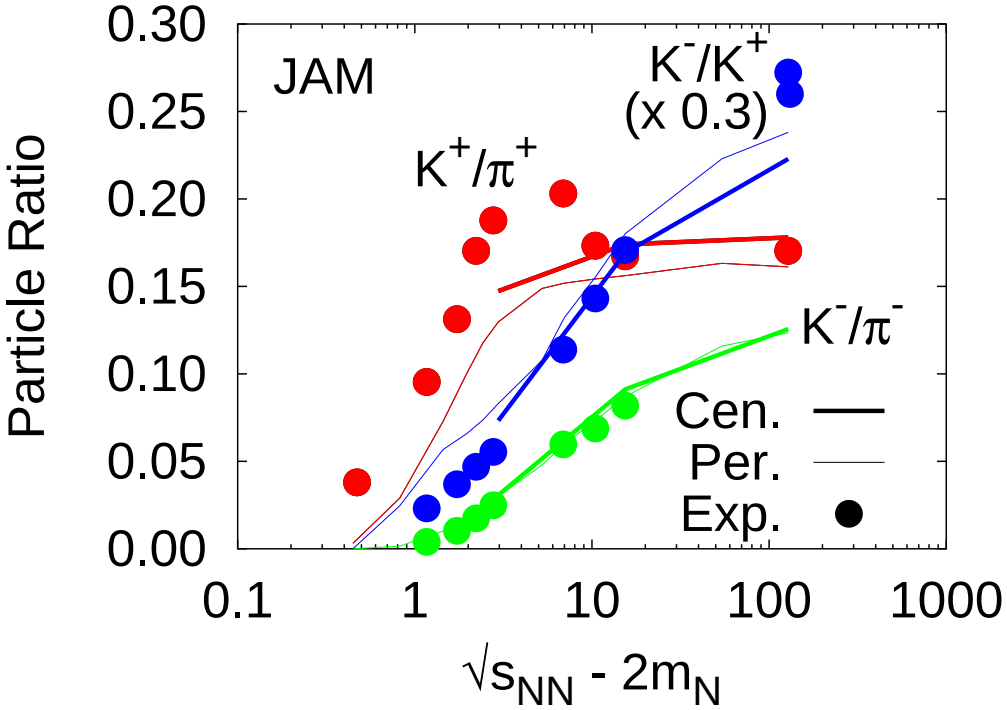
JHF Energy: ∼ Maximum K/π ratio

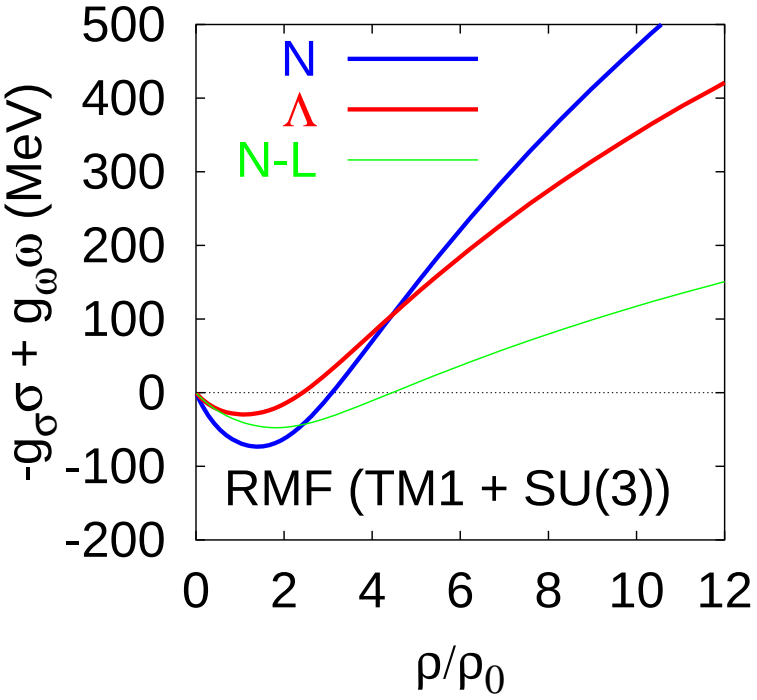
Possible Explanations

- ⋆ Rescattering of Resonances/Strings (RQMD)
- ⋆ Baryon Rich QGP Formation (Right Fig.)
- ⋆ High Baryon Density Effect (Associated Prod. of Y)



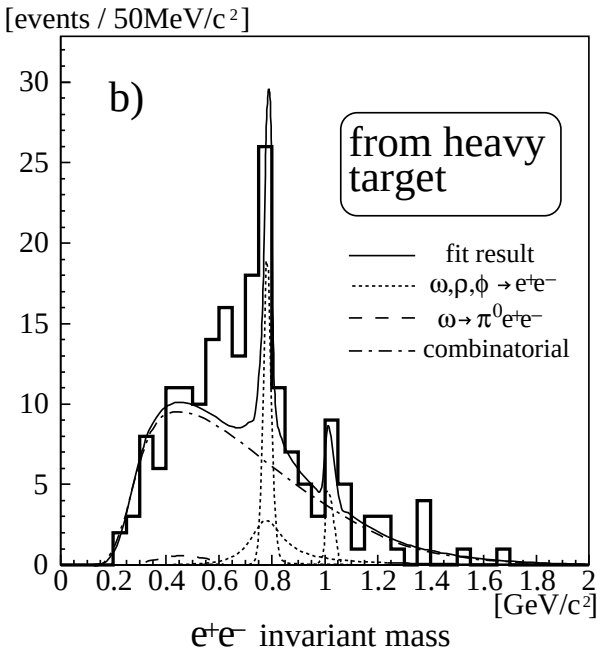
K^+ is enhanced ! → Mean Field Effects for Y ?



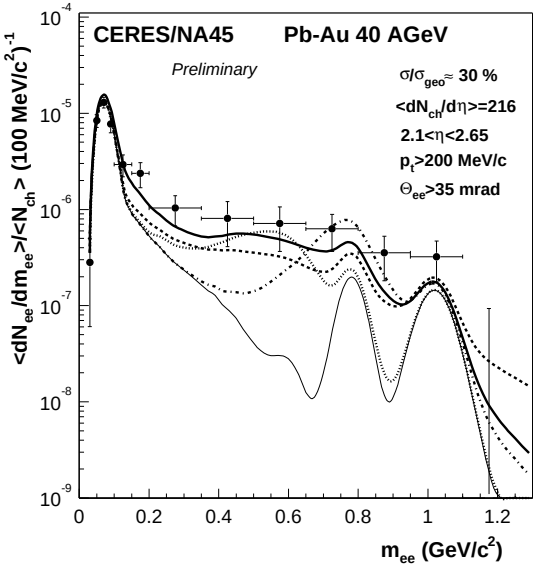


⋆ Low-Energy Di-Leptons: Probe of Chiral Symmetry Restoration

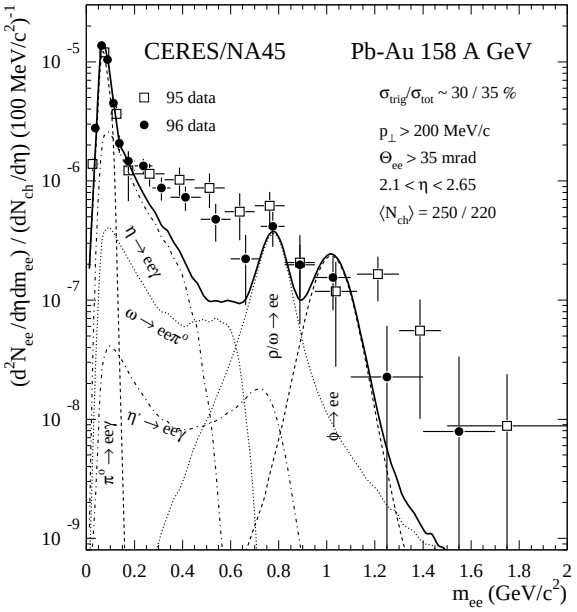
KEK-PS-E325
pA (T $\simeq$ 0, $\rho_B \simeq \rho_0$)



CERN-SPS-CERES/NA45
Pb+Au (40 A GeV)



CERN-SPS-CERES
Pb+Au (158 A GeV)



Possible Explanations:
- ∼ In-Medium Partial Chiral Symmetry Restoration Effects !
- ··· Spectral function mod. (mass shift, broadening), π-π Amplitude mod., σ-ω mixing

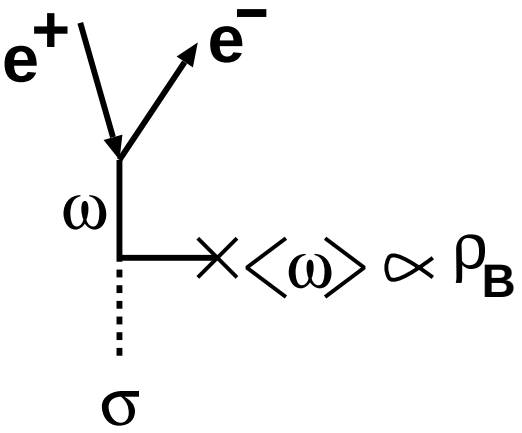
ρ_B Effects are more direct than those of T !

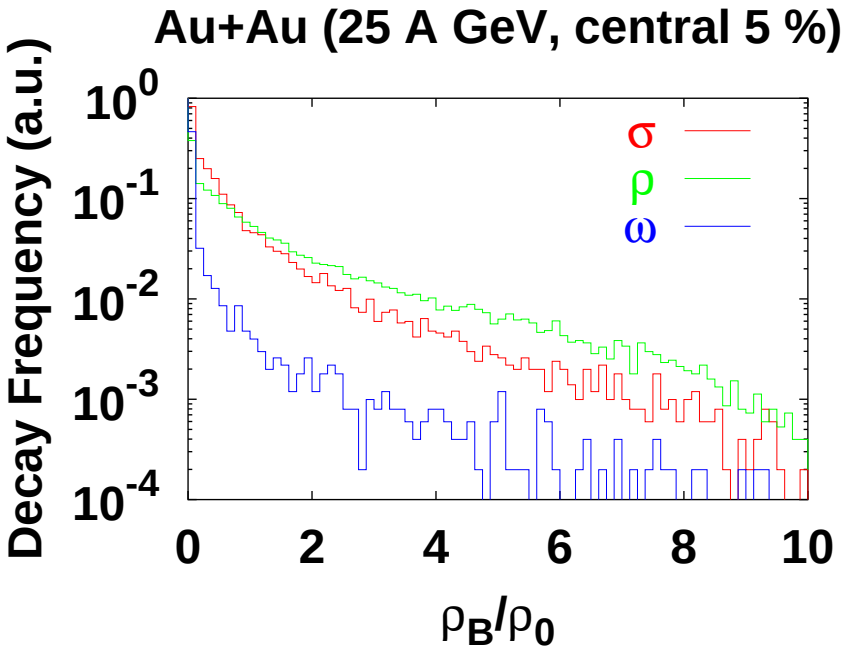
- ⋆ Rho meson mass shift

$$m_\rho^* = m_\rho \left(1 - C\rho_B/\rho_0\right)\left(1 - T/T_c^\chi\right)^a$$

$$(C \sim 0.15, T_c^\chi \sim 200\mathrm{MeV}, a \sim 0.3)$$

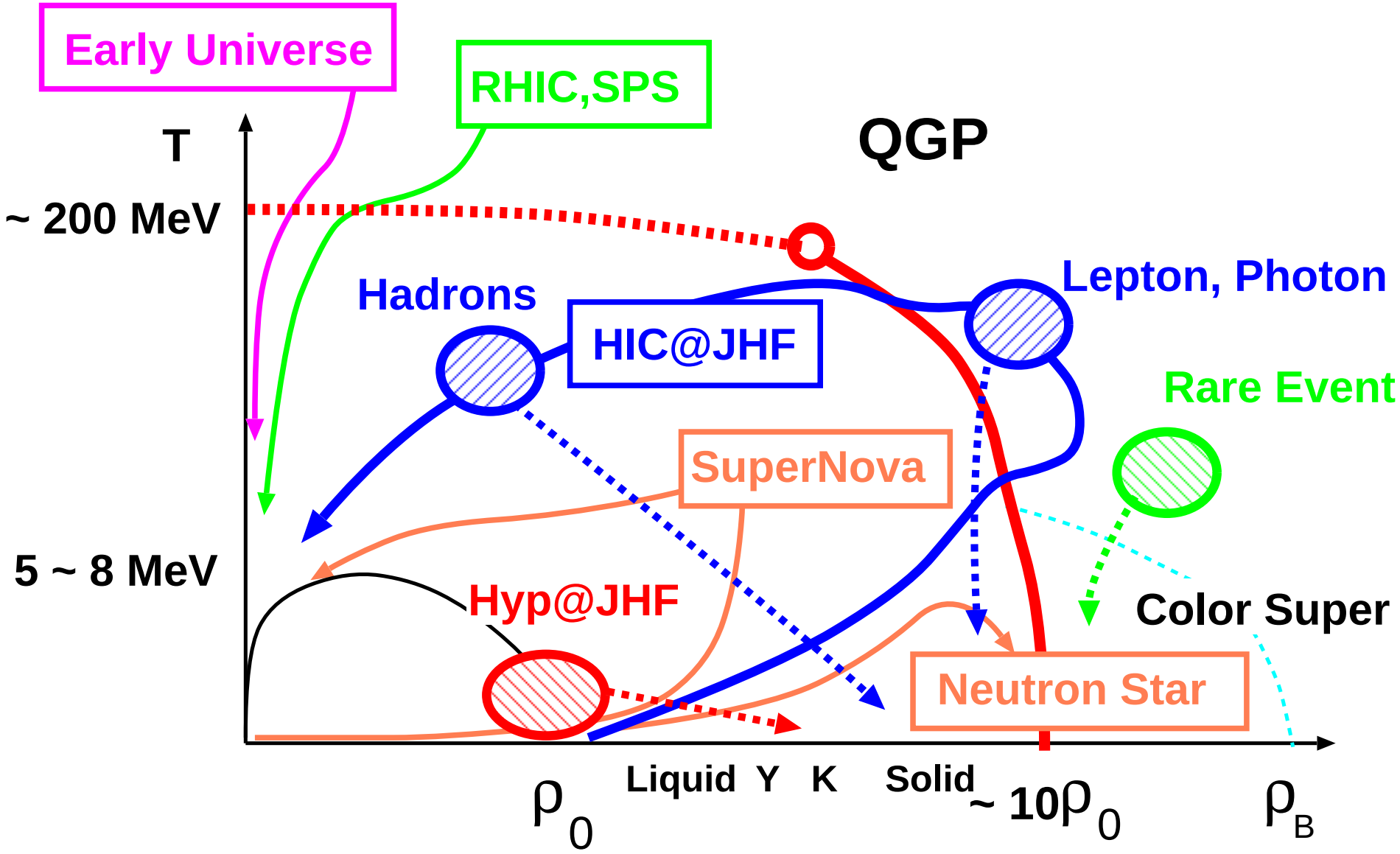
- ⋆ σ-ω Mixing: $\sigma\omega\omega \longrightarrow \sigma\delta\omega < \omega >, < \omega > \propto \rho_B$



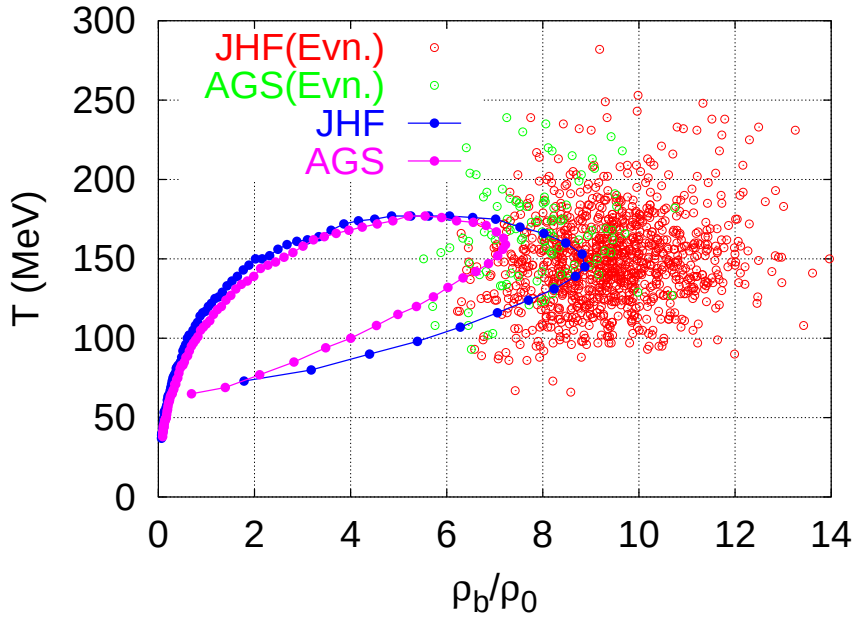


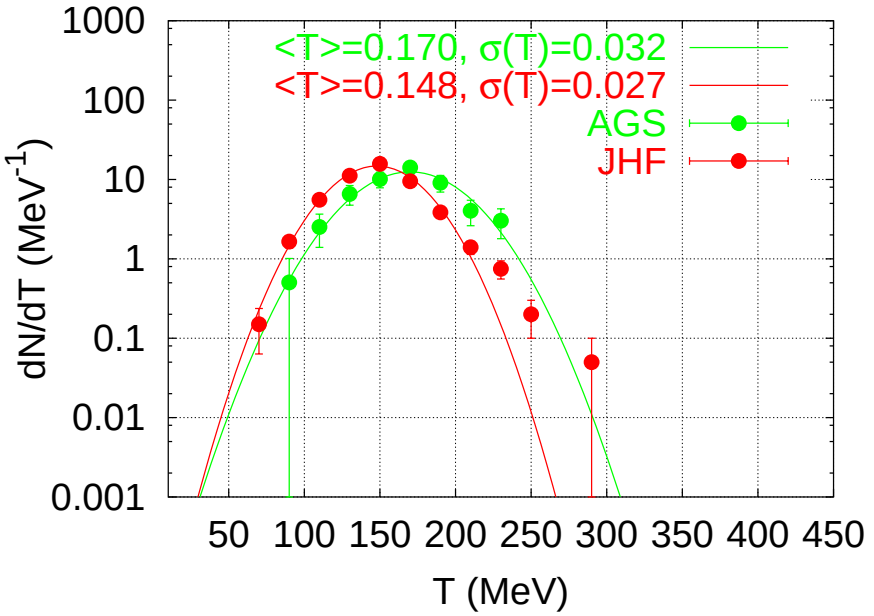
Dilepton Mass Spectrum may show *No Peak* Structure

⋆ Towards LTHD (Low T & High ρ) Matter & Baryon Rich QGP Formation



- How Cold Matter we can make at JHF ?





Finite System Has Fluctuation !

Average: $(\rho_B, T) \sim (9\rho_0, 150\text{MeV})$ → Event Fluctuation: $\sigma(T) \sim 27\text{MeV}$ (JAM)

Events with $T < 50$ MeV at $\rho_B > 5\rho_0 \rightarrow 1/1000 \sim 1/10000$

→ Precursor Signal of CSC ? (Kitazawa, Koide, Kunihiro, Nemoto, 2002)

⋆ Summary

- ⋆ Heavy-Ion Collision Experiment at JHF (JKJ-50 GeV) is Suitable for Exploring "Highly Dense Matter".
  - ◦ Formation Time and γ Factor limit the Incident Energy Region to form Baryon Rich Matter.
  - ◦ EoS of Cold & Dense Matter → Supernova, NStar, Color Super
  - ◦ Hadron Properties in Dense Matter may be very different.... → Chiral Sym., Interaction, Phase Transition, ...
- ⋆ We can probe "Dense Matter" in Three Ways at JHF (JKJ-50 GeV)
  - ◦ Strangenss Nuclear Physics ($\Lambda, \Sigma, \Xi, K, ...$)
  - ◦ Heavy-Ion Physics (High ρ_B and High T)
  - ◦ Rare Event Search in Heavy-Ion Physics (High ρ_B and Low T)