May 19-20, 50 GeV LOI Workshop @ KEK

Physics of Heavy-Ion Collision at JHF (JKJ-50 GeV)

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1. What We Can Do with 50 GeV PS Machine ?
   - ⋆ 50 GeV proton / 25 A GeV HI / Various Secondary Beams
2. Towards the Highest Density Matter
   - ⋆ Hadronic Matter Phase Diagram
   - ⋆ Towards the Highest Density Matter in Lab.
   - ⋆ Towards the Low Temperature Highest Density Matter in Lab.
3. Summary

⋆ What We Can Do with 50 GeV PS Machine ?

- Primary Beams: 50 GeV proton / 25 A GeV HI

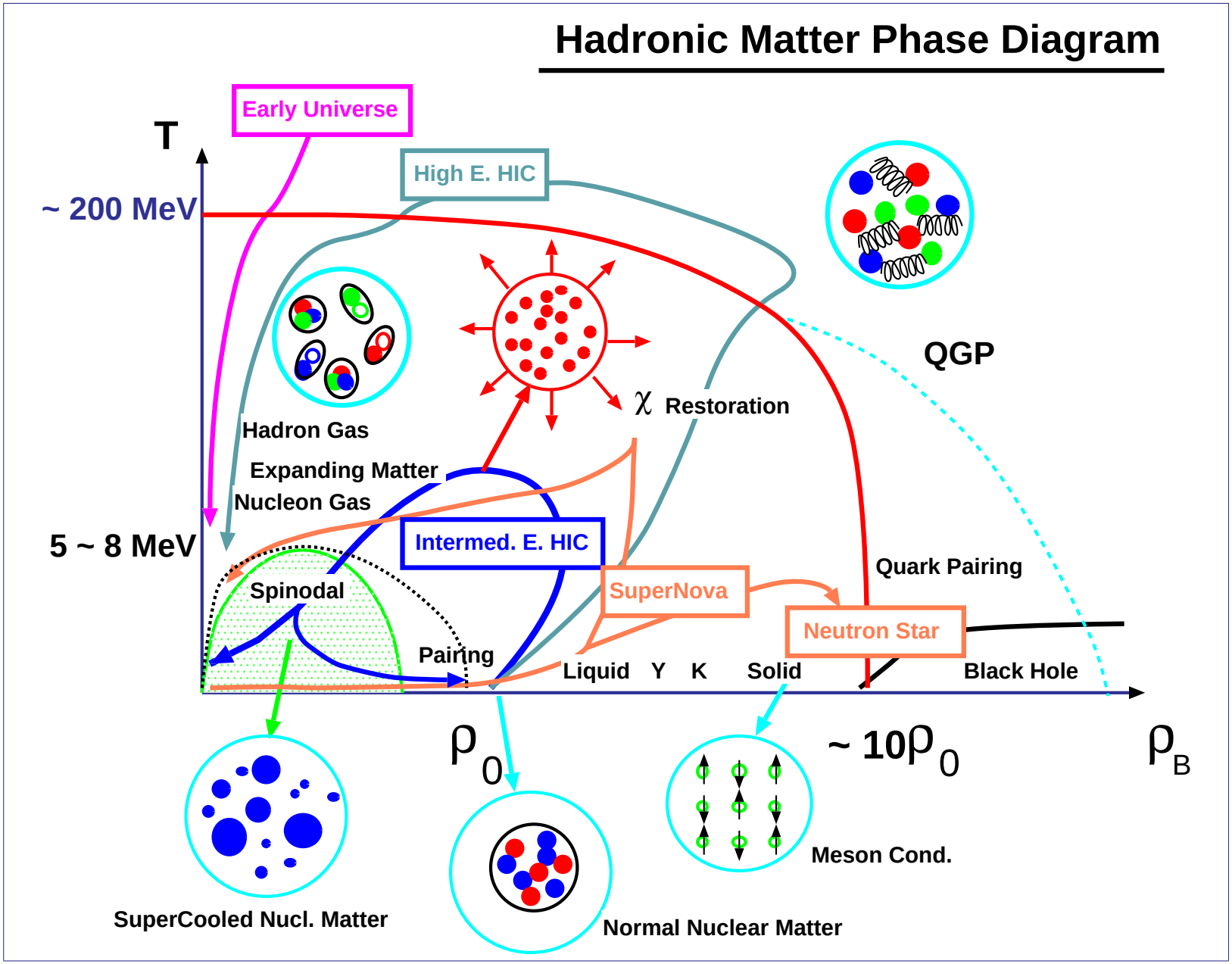
  ⋆ Proton Beam: 600 MeV $\sim$ 50 GeV (2 orders Energy Range !)
  - Multifragmentation, Particle Production, Hadron Spectroscopy

  ⋆ HI Beam: 25 A GeV $\rightarrow$ Most Dense Hadronic Matter Formation in Lab.
  - Hydrodynamical Evol., Caloric Curve, EOS, Hadrons in Dense and Hot Matter

- Secondary Beams:

⋆ Exotic Nuclei, Neutron, Muon, Neutrino, Anti-Proton, ...
⋆ Intense Pion/Kaon Beam and Hyperon Beam (?)

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

⋆ What is Necessary to Understand Cold and Dense Matter ?

- Strangeness DOF
  - ⋆ Hyperon Potentials in Nuclear Matter (U(ρ), M*): Λ, Σ, Ξ
  - ⋆ Kaon Potentials (Potential Depth, Momentum Dep.)
  - ⋆ Hyperon-Hyperon Interaction: Λ-Λ etc.

$\cdots$ Extapolation from $\rho_B = \rho_0$ to Large ρ_B

- Nuclear EoS at High ρ_B
  - ⋆ Stiffness of Nuclear Matter
  - ⋆ Medium Effects on Hadrons (Meson Mass & Width, N & B* Mass, ...)
  - ⋆ Isospin Dep. of EoS

$\cdots$ Extapolation from High T & ρ_B to Low T

⋆ Towards the Highest Density Matter in the Universe

• What Happens in the Neutron Star Core ?

- ⋆ Neutron Superfluid ($^1S_0$, $^3P_2$)
- ⋆ Pion Condensation
- ⋆ Hyperon Matter ← Strangeness

  · · · Tsuruta-Cameron (66), Langer-Rosen (70), Pandharipande (71), Itoh(75), Glendenning, Weber-Weigel, Sugahara-Toki, Schaffner-Mishustin, Balberg-Gal, Baldo et al., Vidana et al., Nishizaki-Yamamoto-Takatsuka...
- ⋆ Kaon Condensation ← Strangeness

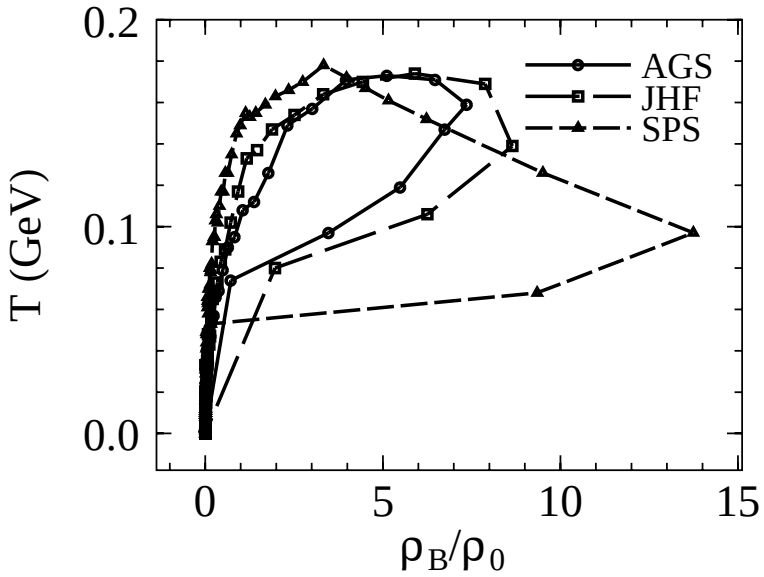
  · · · Kaplan-Nelson(88), Forkel-Rho et al.(SUNY), Davidson-Miller, Claymans et al., Politzer-Wise, Miller et al., Muto-Tatsumi, Brown-Thorsson-Lee-Rho-Min, Fujii et al., Yabu et al, Maruyama et al., Ellis-Knorren-Prakashi (with Y), Li-Ning, Li-Brown, Tiwari-Prasad-Singh, Glendenning-Schaffner, ...
- ⋆ Quark-Gluon Plasma

We cannot understand Highly Dense Hadronic Matter
without the Knowledge of Strangeness Nuclear Physics

⋆ Towards the Highest Density Matter in Lab.

- HI Collision at 25 A GeV

· · · would make the Highest Density Hadronic Matter under Approximate Equilibrium



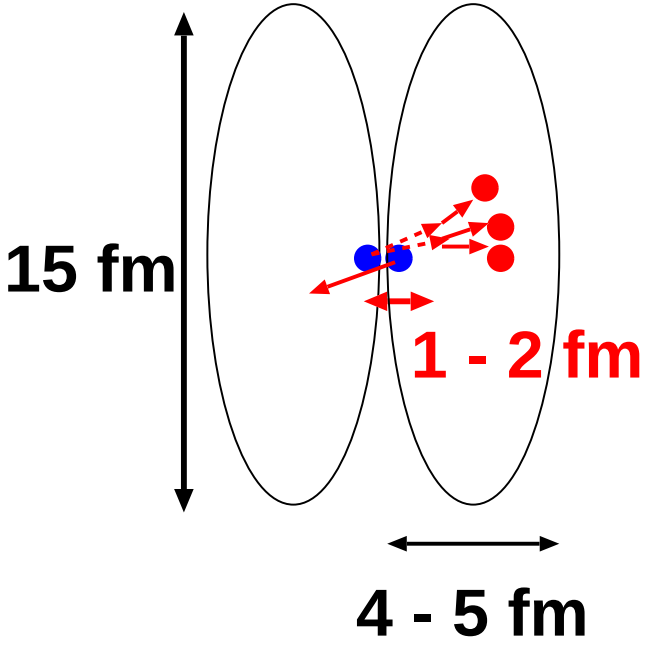
(JAM Calc., Y. Nara,FRONP99, 8/2-4, 1999 at JAERI)

AGS, JKJ:
→ Smooth Evolution in (ρ_B, T)
SPS, RHIC:
→ Sudden Jump to Low ρ_B and High T

☞ IF we can make high ρ_B QGP,
it is at JKJ-50 GeV.

JHF Energies

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

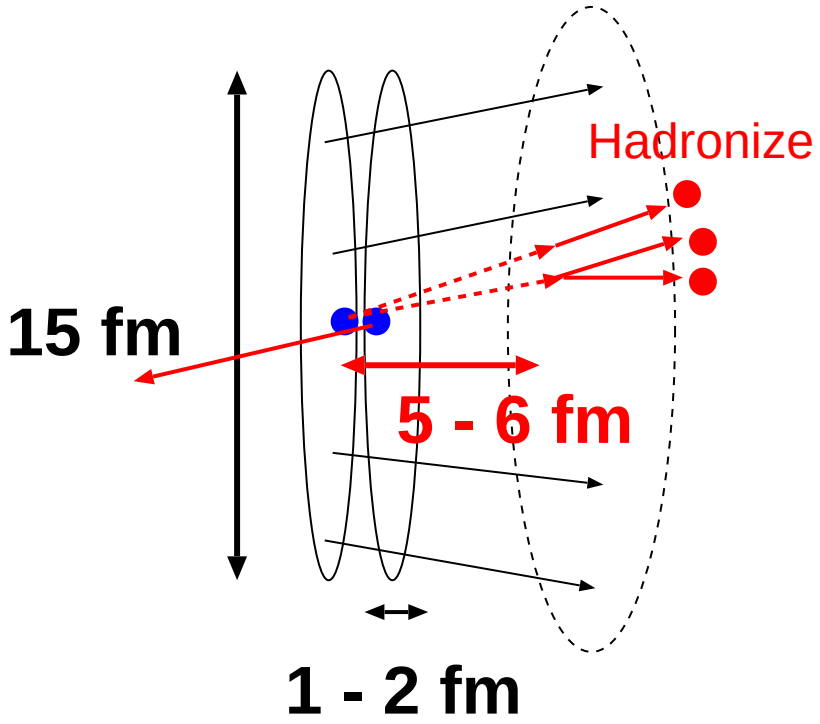


Multiple Hadron-Hadron Collisions

☞ (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 (e.g.: 40 A GeV @ SPS)

- Flow Measurements at JKJ-50 GeV

Systematics Suggests Followings.

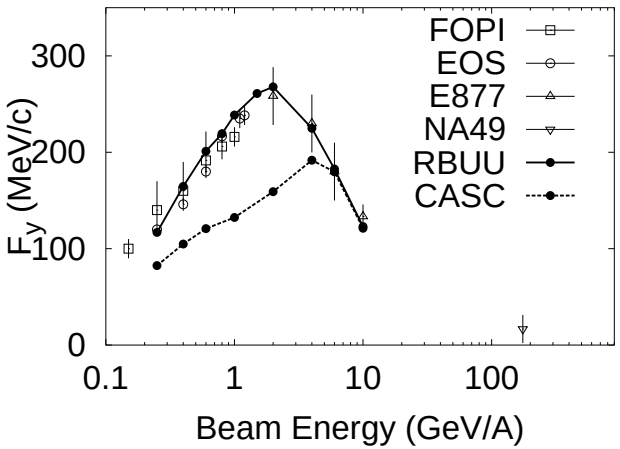
⋆ Directed Flow (or V_1): Almost Zero or Negative Flow

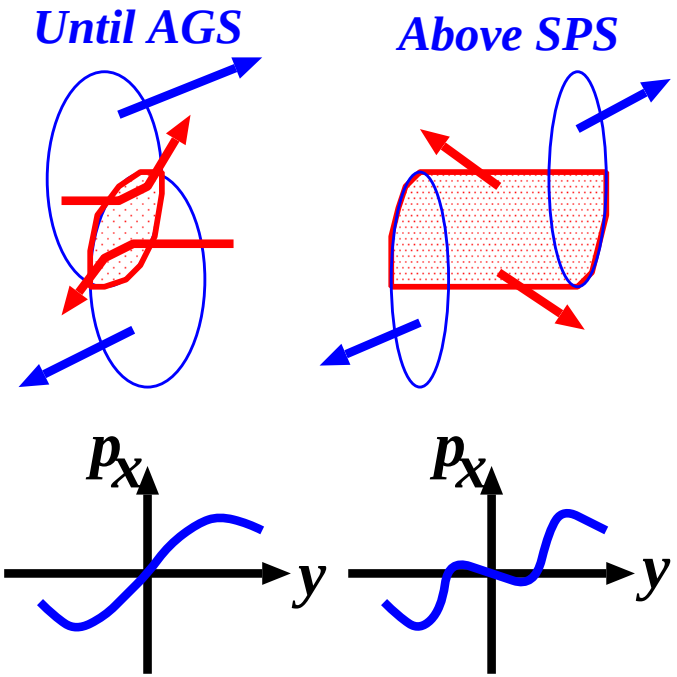
⋆ Elliptic Flow (V_2): $V_2(\mathrm{AGS}) < V_2(\mathrm{JKJ}) < V_2(\mathrm{SPS})$

⋆ Radial Flow: around Local Maximum at JKJ

(Directed) Flow: Stiffness (Low E) + Time Scale (High E)

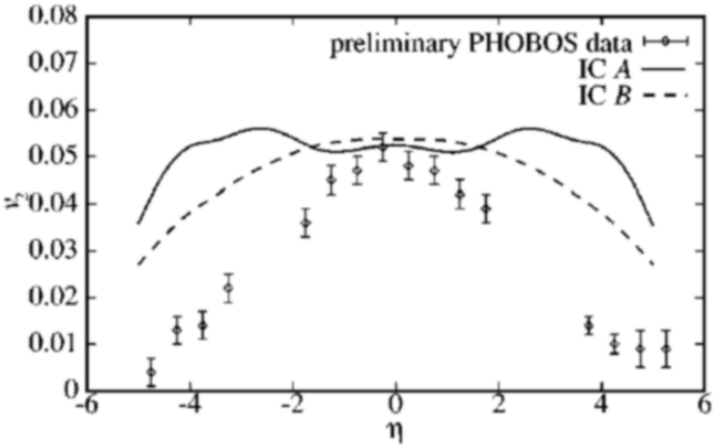
Calculation & Exp.:
Sahu et al. NPA(2000))



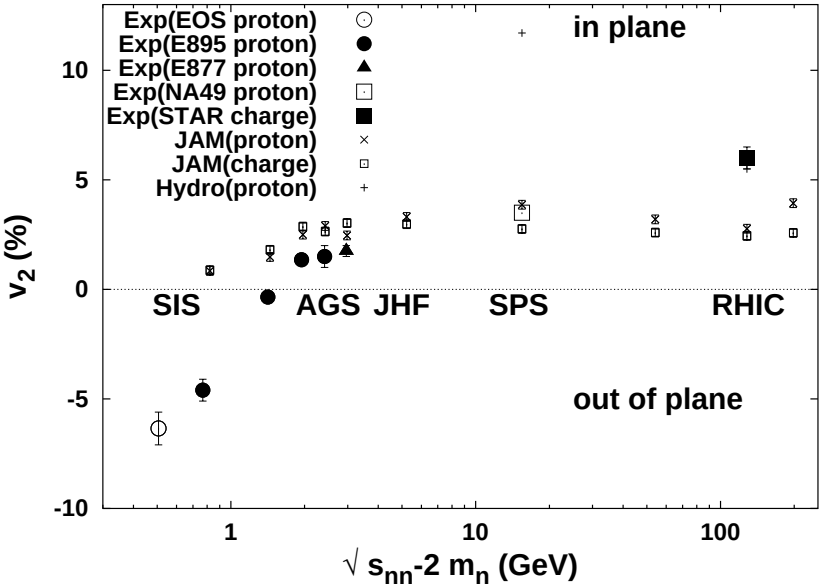


Elliptic Flow (V_2): Thermalization & Pressure Gradient Above AGS

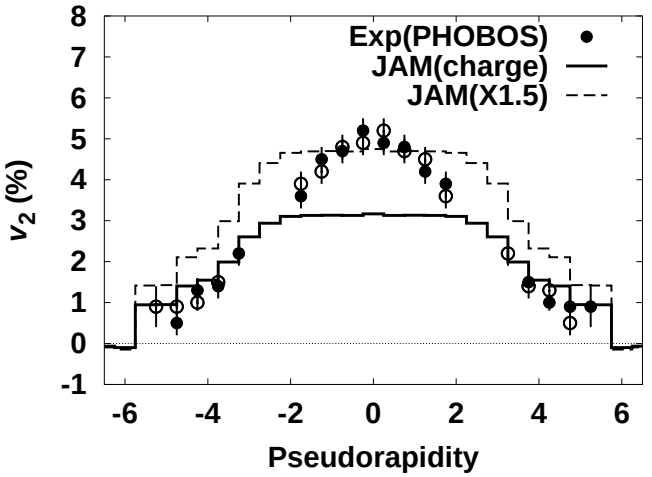
Hydro: Hirano (2001)



Incident Energy Deps.



Cascade: P.K.Sahu et al. (2002)

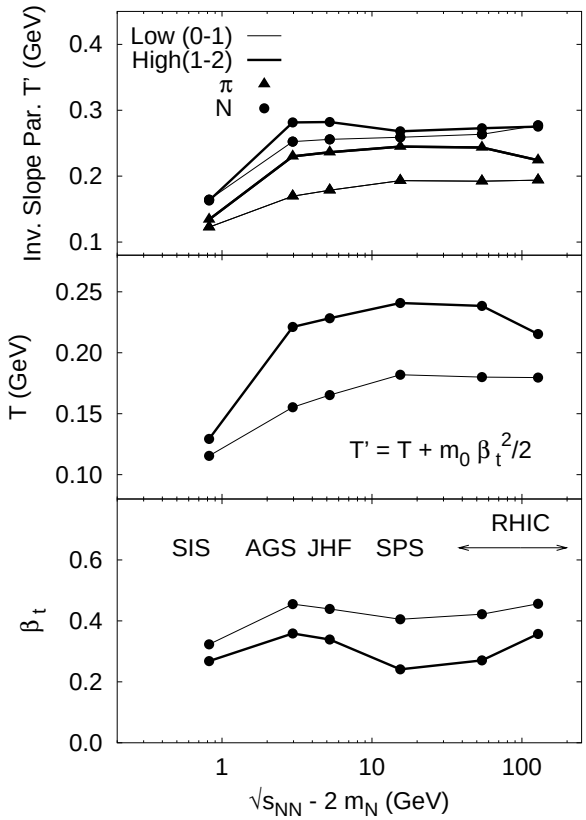


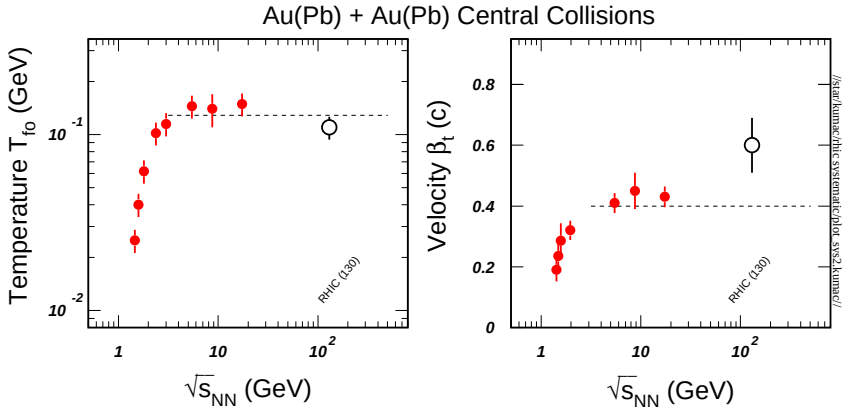
Radial Flow $= \sqrt{P/E}$ (?)

$\cdots$ Up (LBL$\sim$JKJ) $\rightarrow$ Down (JKJ$\sim$SPS) $\rightarrow$ Up (SPS$\sim$RHIC) $\rightarrow$ Stay (RHIC$\sim$)

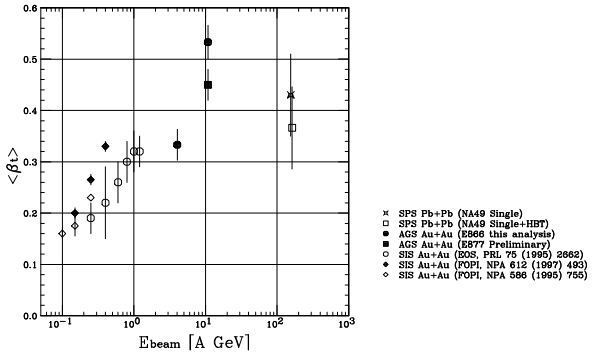
Exp: Nu Xu and M. Kaneta (STAR)

Calculation:
Otuka et al.(Eprint, 2001)





Exp: Chujo, PhD Thesis



Local Max. may appear around JKJ energies

⋆ Simple Model

⋆ Hadron Gas = Massless Pion Gas

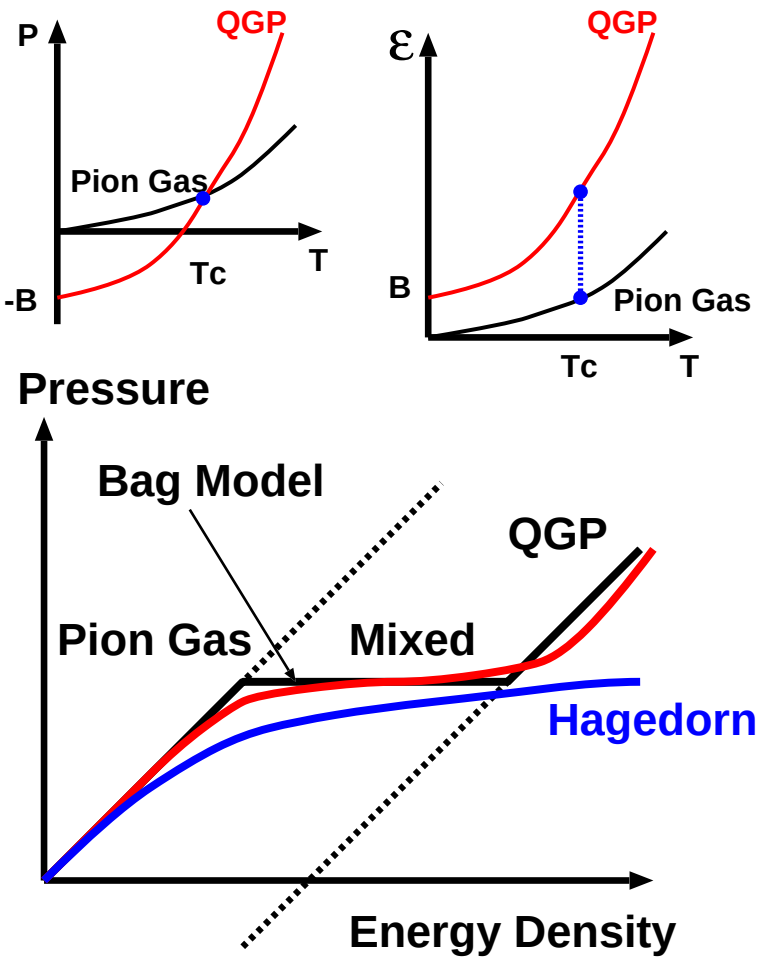
$$P = \frac{\pi^2}{90} g_\pi T^4 \ , \epsilon = \frac{\pi^2}{30} g_\pi T^4 \ (g_\pi = 3) \rightarrow P = \epsilon/3 \ .$$

⋆ QGP = Bag model

$$\begin{aligned} P &= \frac{\pi^2}{90} g_{qgp} T^4 - B \ , \epsilon = \frac{\pi^2}{30} g_{qgp} T^4 + B \\ &\rightarrow P = (\epsilon - 4B)/3 \ , \\ g_{qgp} &= 2 \times 8(\text{gluon}) \\ &+ \frac{7}{8}(2 \times 2 \times 3 \times 3) \\ &\quad (\text{quark, spin, } q, \bar{q}, \text{ color, flavor}) \end{aligned}$$

⋆ Hydrodynamics

$$\epsilon \frac{D\boldsymbol{V}}{Dt} = -\boldsymbol{\nabla} P \rightarrow V = \int_{path} \boldsymbol{\nabla} P \cdot d\boldsymbol{r}/\epsilon$$



First Local Max. β = Starting Point of QGP Form.

- Towards Highest Densities: More Conclusive Experiments

Low-E Dileptons

Key Questions: How are Low-E Dileptons Enhanced ?

- ⋆ Partial χ Restoration: T or ρ
- ⋆ σ-ω Mixing: Baryon Effects

→ Hadron-Dilepton Coincidence Measurement

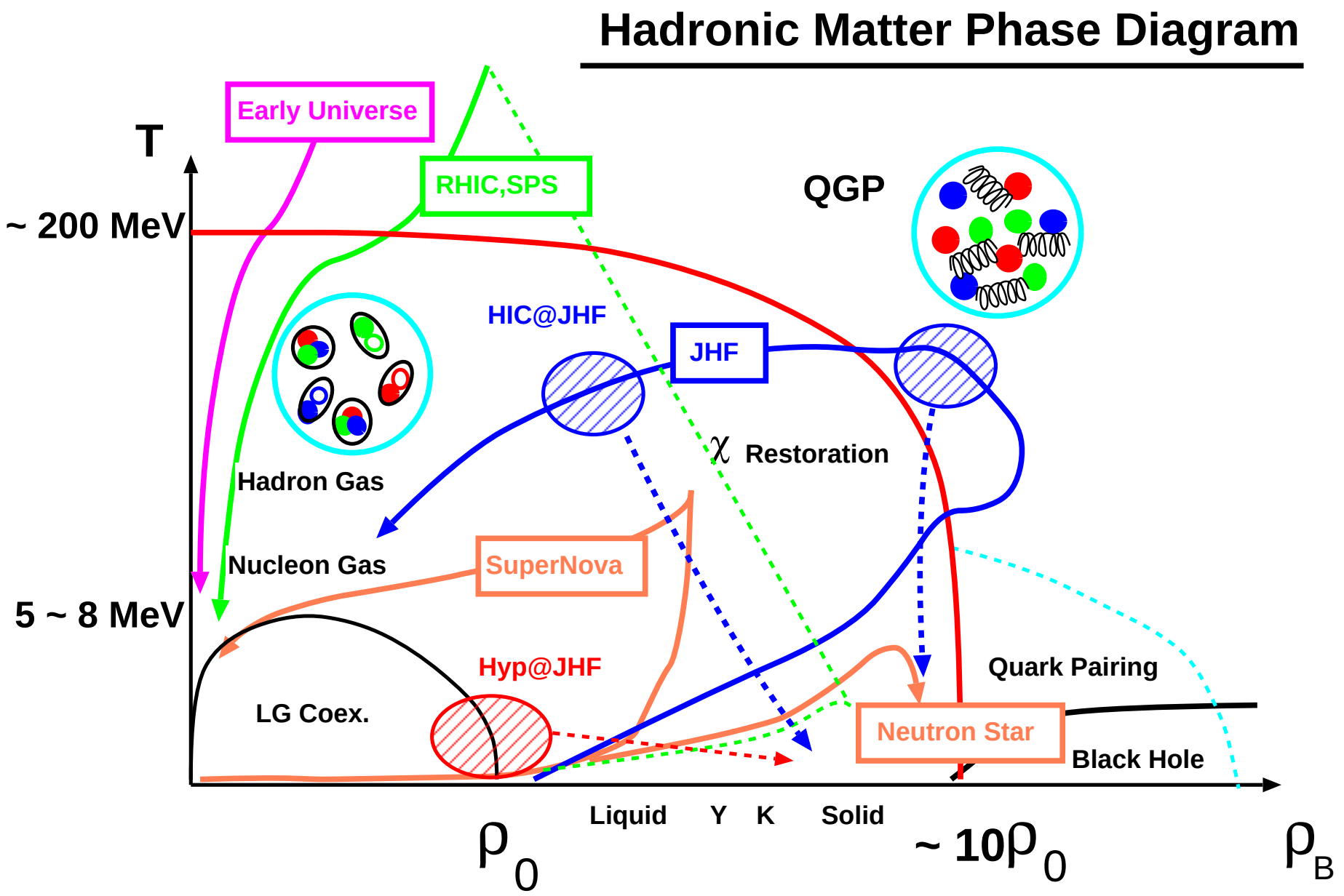
Strangeness Enhancement and Interaction

Observed at GSI-SIS and BNL-AGS: Potential or Rescattering ?

- ⋆ Subthreshold K^+ → Rescattering (Giessen)
- ⋆ K^- Enhancement → Potential
- ⋆ How about Σ Flow ?

Hadron Natures (sometimes) become clear in medium

e.g. ρ, σ, K, η, N*, Λ^*, Σ^*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Black Hole
Liquid
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K
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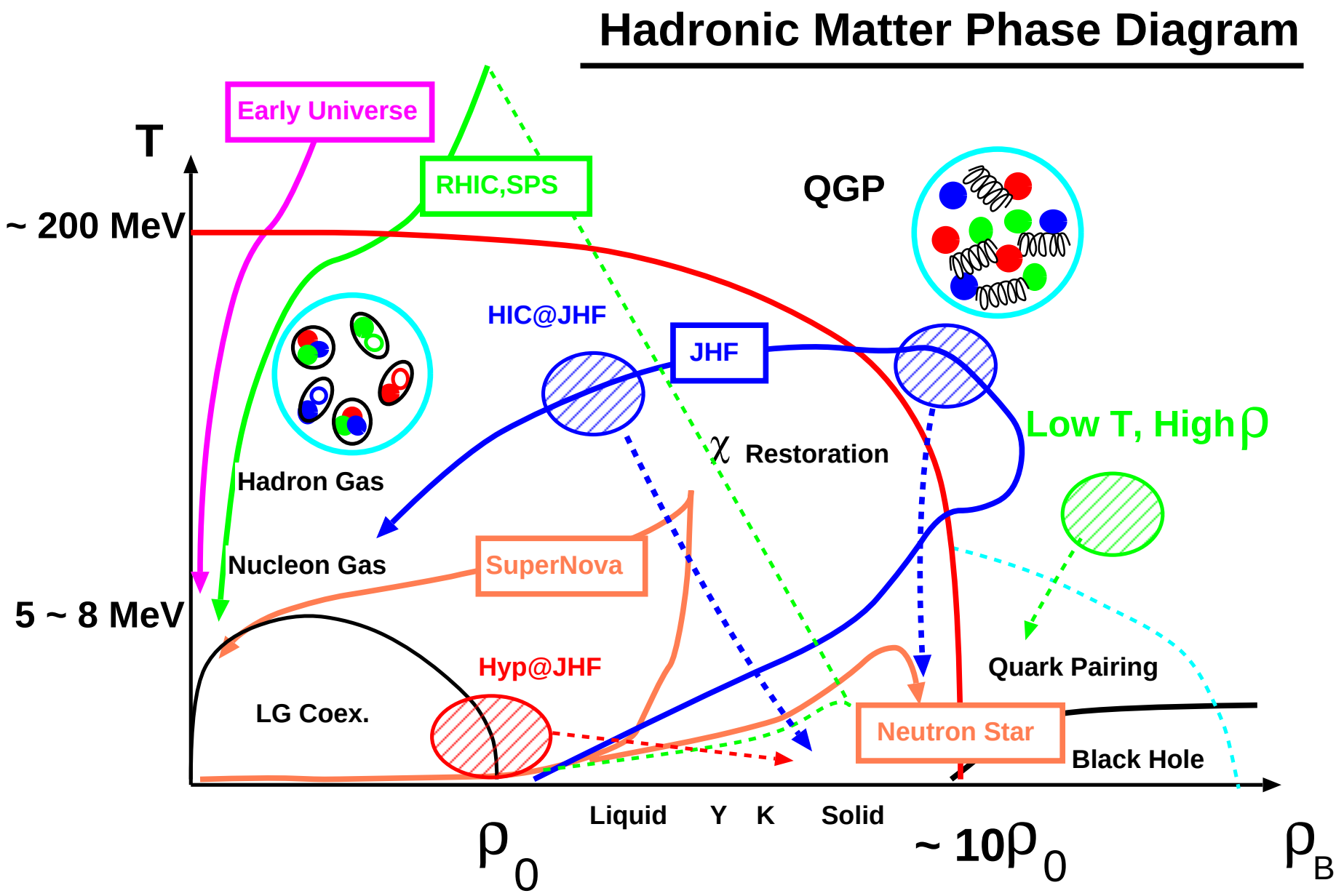
~ 10ρ0
ρB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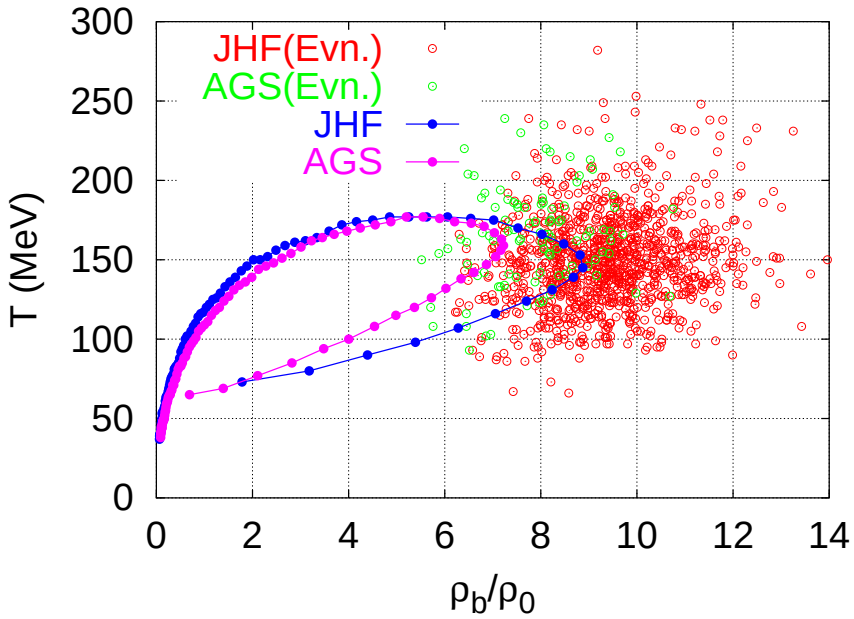
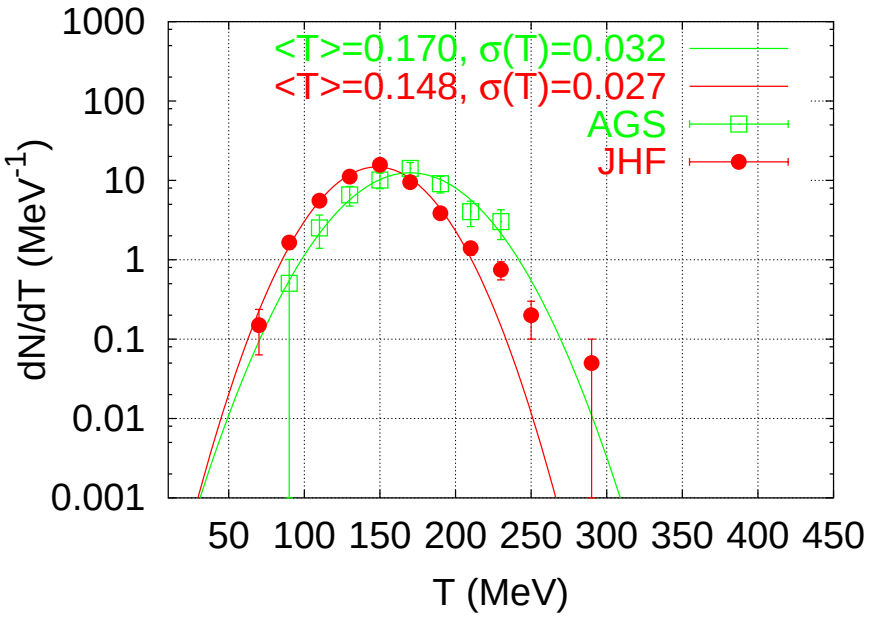
⋆ Towards LTHD (Low T & High ρ) Matter

- How Cold Matter we can make in JKJ-50 GeV ?





Finite System Has Fluctuation !

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

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

- Physics of JHF (JKJ-50 GeV)

50 GeV proton & 25 A GeV HI

Physics for Dense Matter (Strangeness Nuclear Physics)

- Physics of JHF (JKJ-50 GeV)

50 GeV proton & 25 A GeV HI

Physics for Dense Matter (Strangeness Nuclear Physics)

of Dense Matter (HI Collisions)

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Physics for Dense Matter (Strangeness Nuclear Physics)

of Dense Matter (HI Collisions)

by using Finite Nuclei (K^-A, AA)
and Many-body Theory (n-rich, Frag., ...)

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50 GeV proton & 25 A GeV HI

Physics for Dense Matter (Strangeness Nuclear Physics)

of Dense Matter (HI Collisions)

by using Finite Nuclei (K^-A, AA)
and Many-body Theory (n-rich, Frag., ...)

= Physics of Nuclear Matter,
will cover a large part of Strong Activities in Japan

⋆ Summary

⋆ One of the Catch Phrases of JHF (JKJ-50 GeV) can be "Dense Matter"

- EoS of Cold & Dense Matter → Supernova, NStar, Color Super
- Hadron in Dense Matter may be very different....
  Chiral Sym., Interaction, Phase Transition, ...
  - RHIC, LHC → QGP Search, Hottest Matter → Early Univ.
  - J-Lab. → Probing Smallest Objects

→

  - RIBF → Most Unstable Nuclei, Heaviest Nuclei → R-process
  - JHF → Densest Matter → Supernova, Neutron Stars

⋆ We can probe "Dense Matter" in Three Ways at JHF (JKJ-50 GeV)

- Strangenss Physics ($\Lambda, \Sigma, \Xi, K, ...$)
- Heavy-Ion Physics (High ρ_B and High T)
- Rare Search in Heavy-Ion Physics (High ρ_B and Low T)