Charmonium spectral functions in quark-gluon plasma from lattice QCD with large spatial volume

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LQGP collaboration
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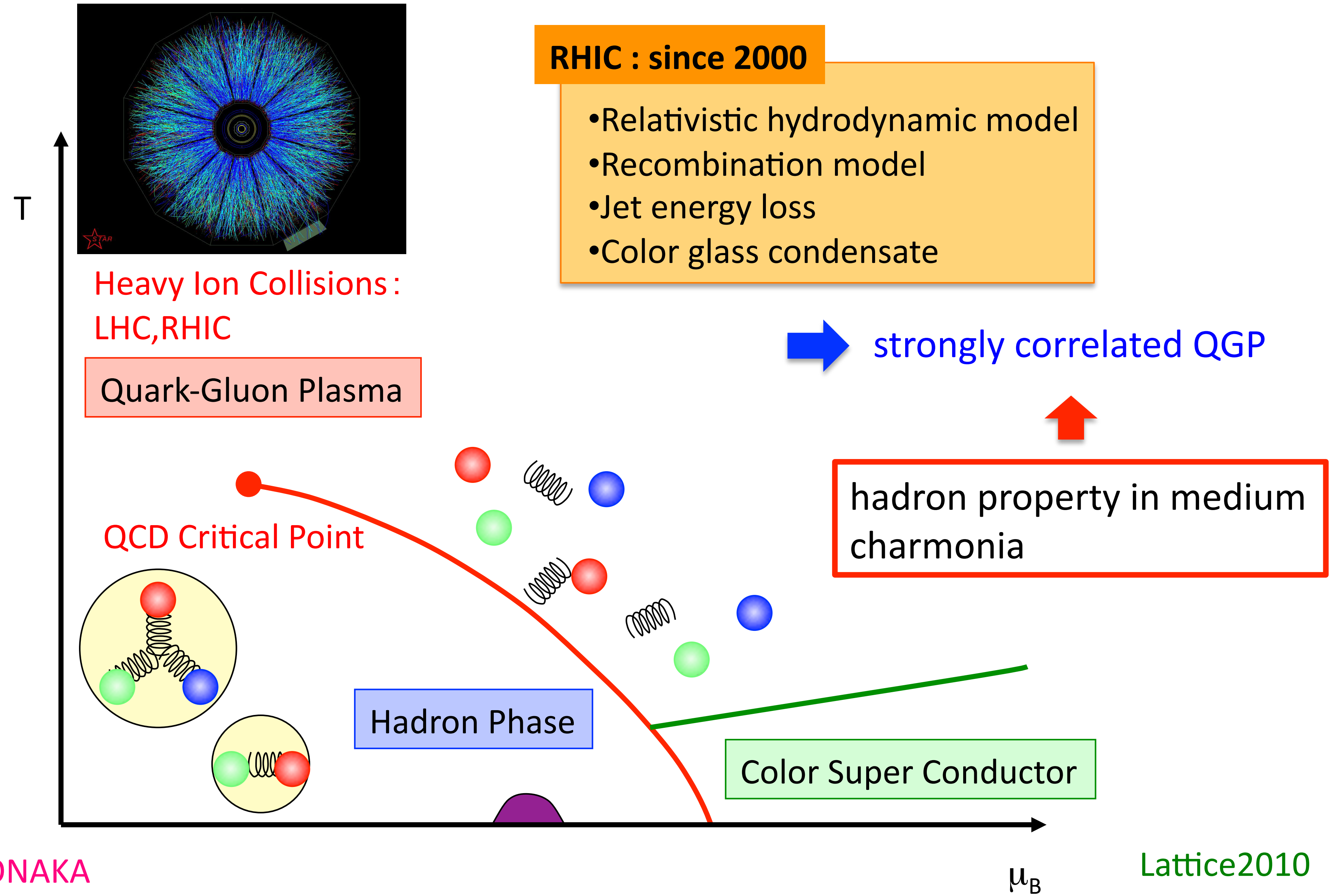
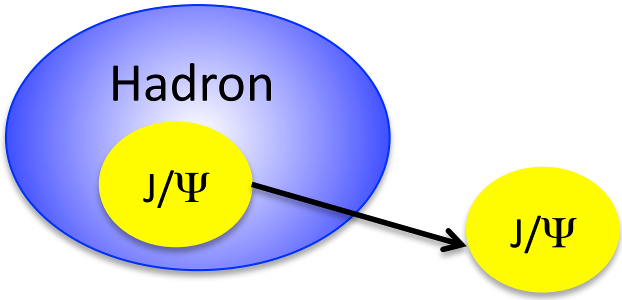
Quark-Gluon Plasma

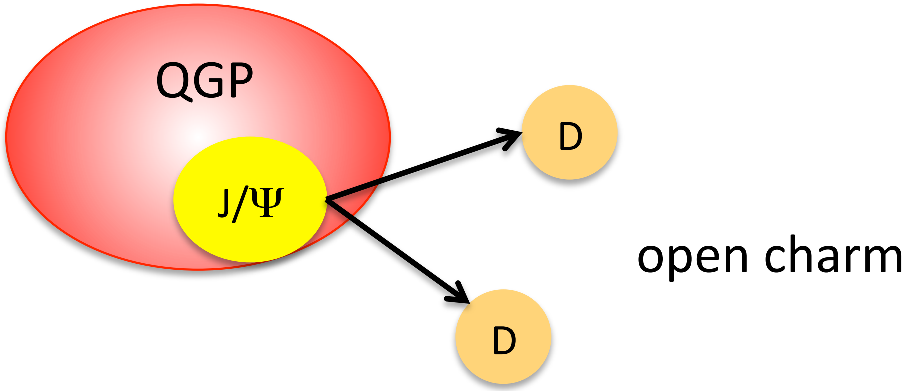


J/Ψ Suppression

- QGP signature in heavy ion collisions

Matsui and Satz, Miyamura… '86

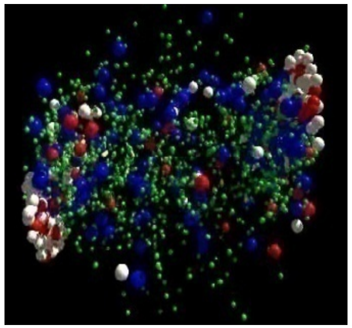




- Current situation
  - charmoia in medium

  J/Ψ survives at T ~1.7T_c, Asakawa,Hatsuda,Umeda,…..

- Relativistic heavy ion collisions



space-time expansion

temperature ~ 200 MeV
charmonia ~ 3.0 GeV

➡ finite momentum

Charmonia in Heavy Ion Collisions

- Spectral functions with finite momentum
- Ill-posed problems

$$C(t,\vec{p}) = \int d\omega \rho(\omega,\vec{p}) K(t)$$

correlators on lattice — spectral function — kernel

noisy, discrete $\sim O(10)$

continuous $\sim O(10^3)$

⇨ **Maximum Entropy Method**

$$C(T,\vec{p}) = \sum_x \exp(i\vec{p}\cdot\vec{x}) \langle O_\Gamma(\vec{x},t)\Gamma O_\Gamma^\dagger(\vec{0},0)\rangle$$

$$O_\Gamma(\vec{x},t) = \bar{\Psi}(\vec{x},t)\Gamma\psi(\vec{x},t)$$

Maximum Entropy Method

Asakawa, Hatsuda, Nakahara

$$C(t,\vec{p}) = \int d\omega \rho(\omega,\vec{p}) K(t)$$

- Baye's theorem

$$P[\rho|CH] = \frac{P[C|\rho H]P[\rho|H]}{P[C|H]}$$

C: lattice data
H: all definitions and prior knowledge

χ^2-likelifood function

$$P[C|\rho H] = \exp(-L)/Z_L$$

Shannon-Jaynes entropy

$$P[\rho|H] = \exp(\alpha S)/Z_S$$

$$S = \int \left[A(\omega) - m(\omega) - A(\omega)\log\left(\frac{A(\omega)}{m(\omega)}\right)\right]$$

m: default model

$$P[\rho|CH] \propto \exp(\alpha S - L)$$

- MEM solution: maximum of $\alpha S - L$
- Error analysis : essential in MEM analysis

Parameters

- Actions

Asakawa, Hatsuda PRL

  - standard plaquette action, Wilson fermion
  - quenched approximation ← heavy flavor

- Lattice sizes
  - anisotropic lattice: $\xi=a_\sigma/a_\tau=4$
  - β=0.7. $a_\tau=9.75\times10^{-3}$ fm
  - large spatial volume: $N_\sigma \times N_\tau = 64^3 \times N_\tau$, P_{min}~0.5 GeV

PACS-CS@Tsukuba
Blue Gene@KEK

N_t (T/Tc)	96 (0.78)	54 (1.38)	46 (1.62)	44 (1.70)	42 (1.78)	40 (1.87)	32 (2.33)
# of conf.			400	400	400	400	400
# of correlator			343			393	

heat bath : overrelaxation=1:4 1000 sweeps between measurements

Parameters

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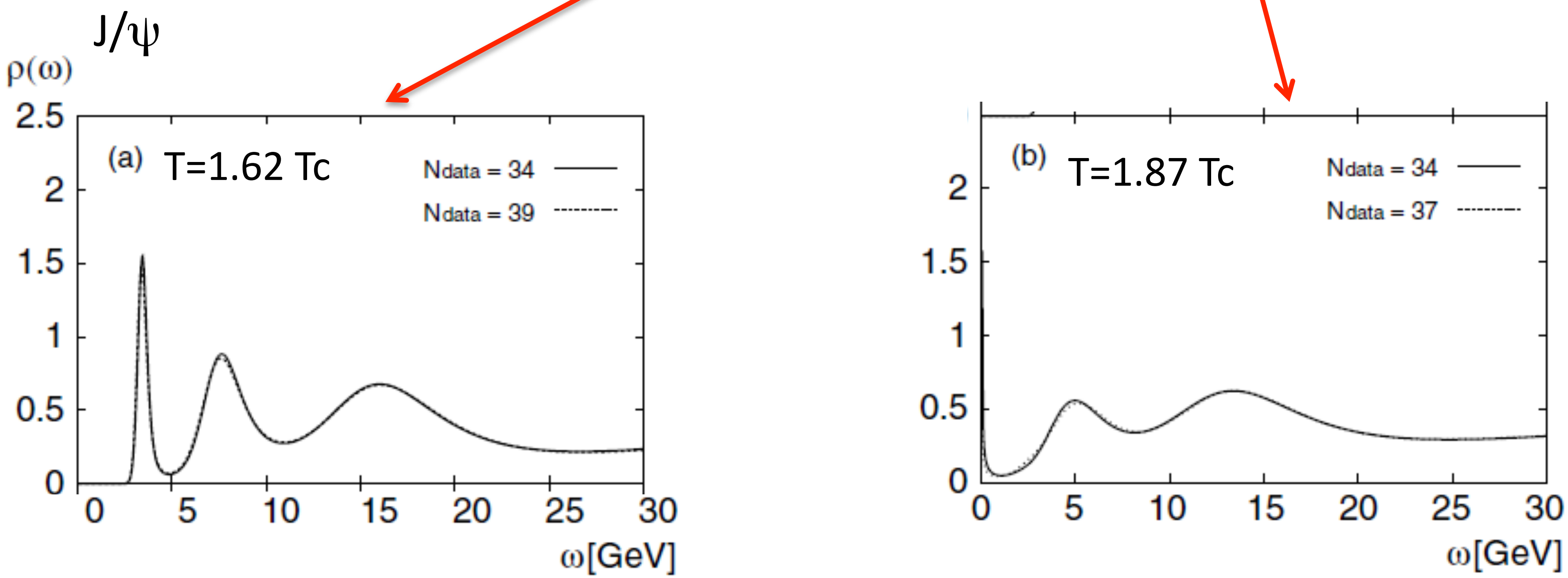
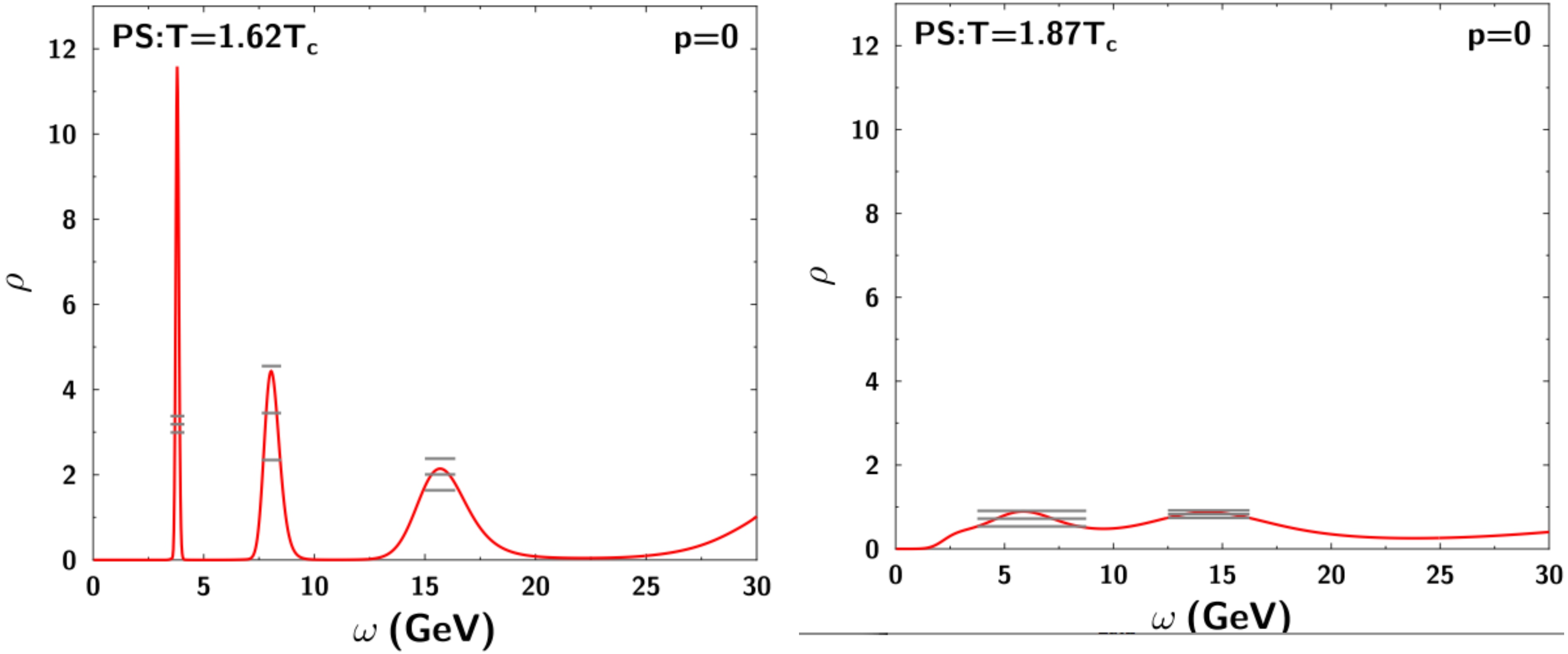


Asakawa, Hatsuda, PRL92

PS Channel

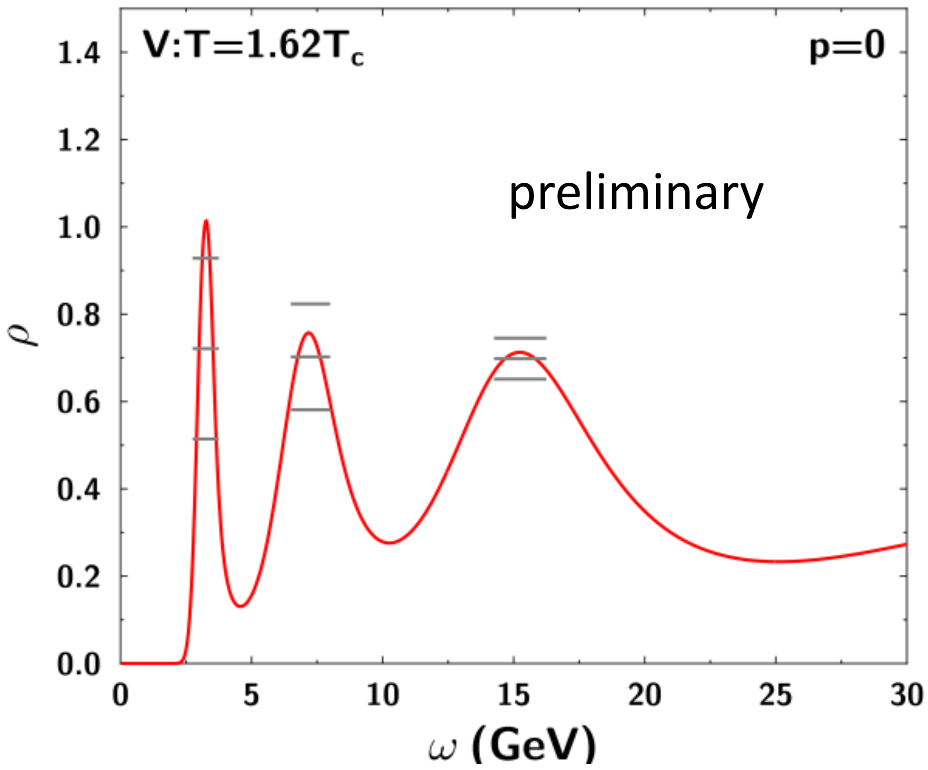
κ=0.08285 η_c

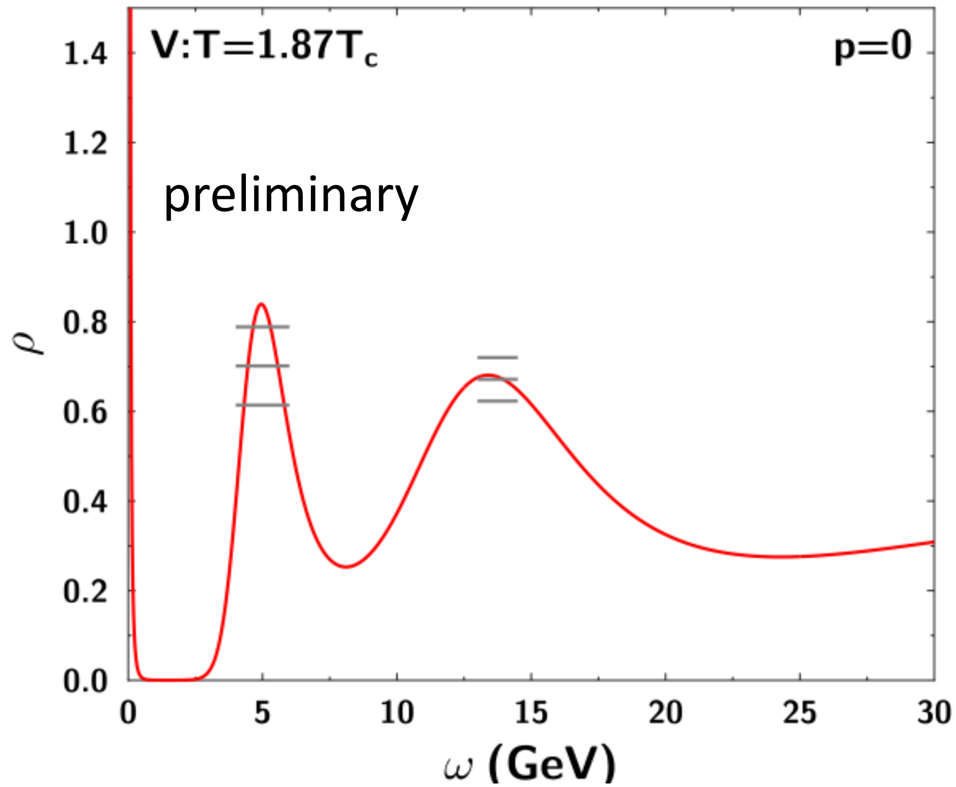


- At T=1.62 T_c a clear peak exists around 3~4 GeV
- η_c melts between T=1.62T_c and T=1.87T_c

Vector Channel

κ=0.08285 J/Ψ

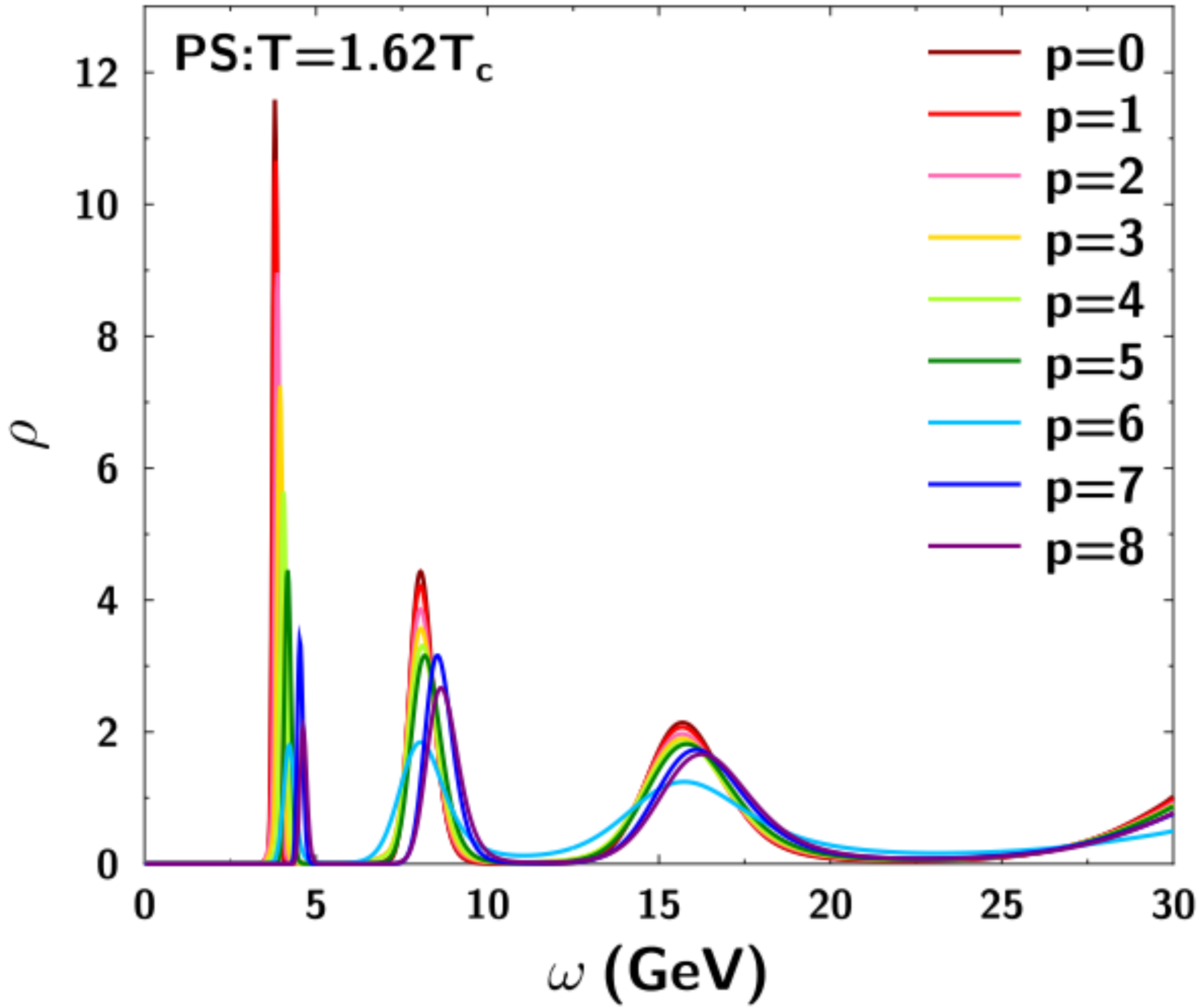




- At T=1.62 T_c a clear peak exists around ~4 GeV
- The shape of J/Ψ spectral function changes.

Spectral functions at P≠0

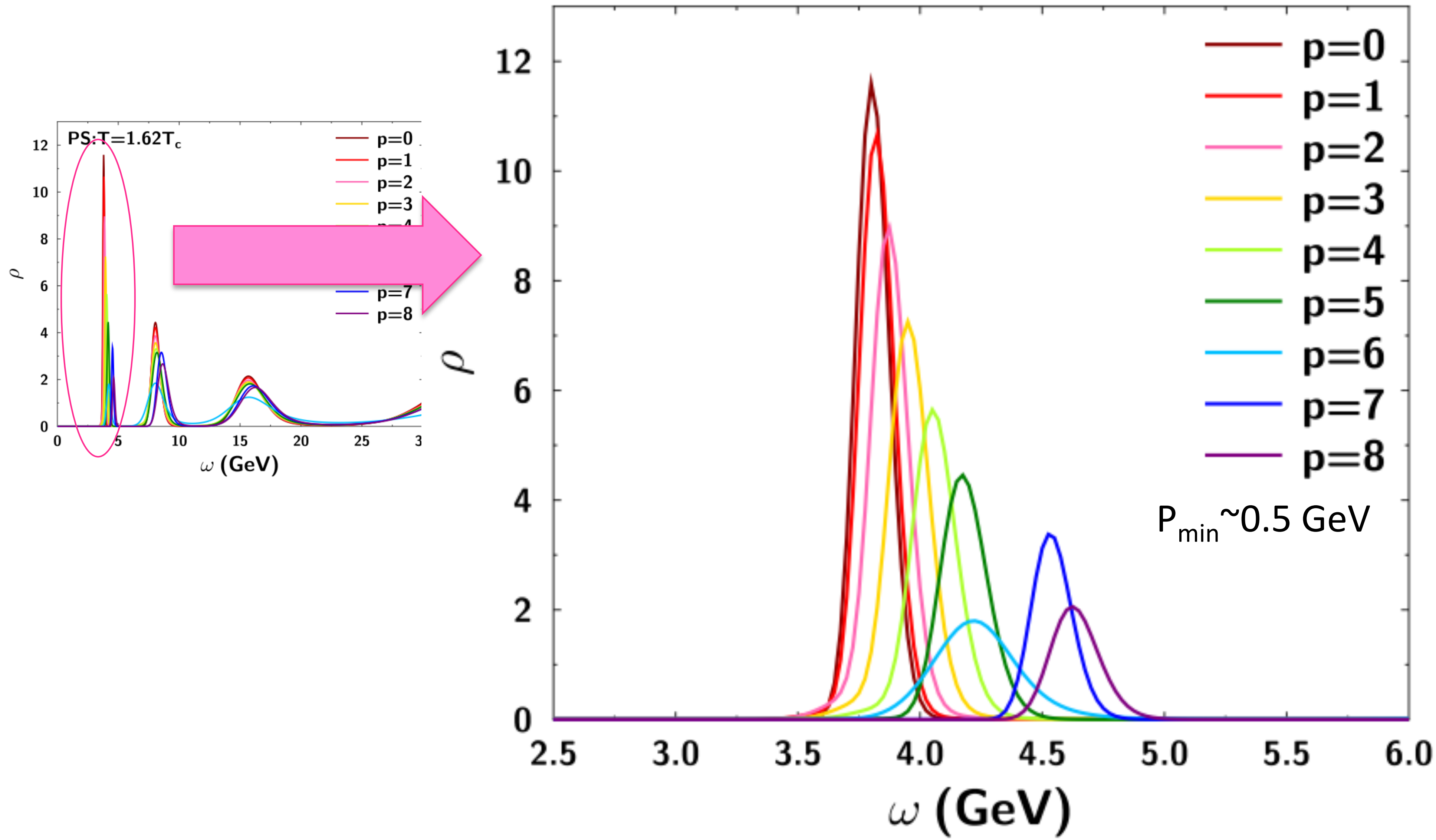
κ=0.08285 η_c



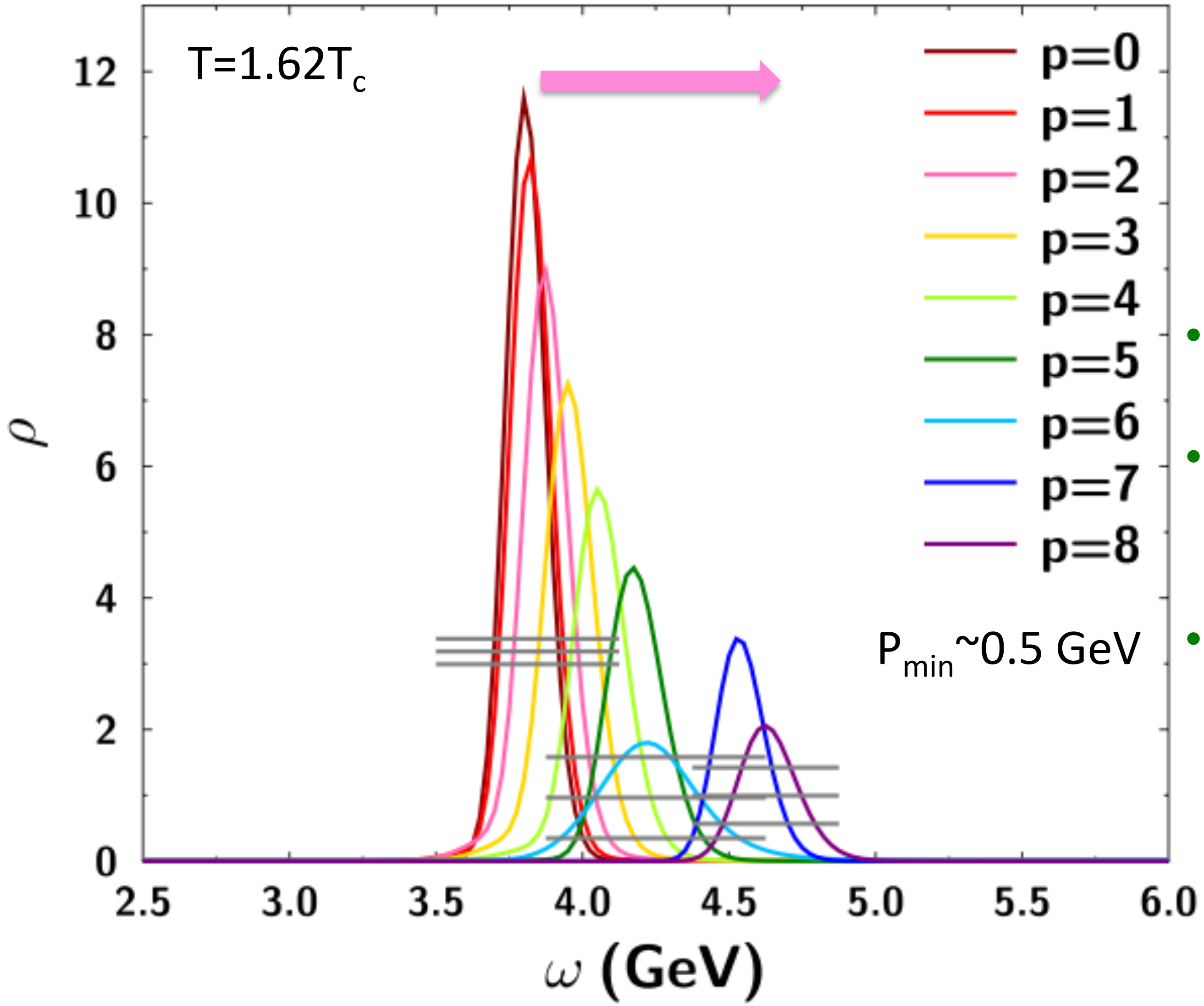
P_{min}~0.5 GeV

Qualitatively
the shape of spectra
functions at p≠0
is almost the same.

Momentum Dependence



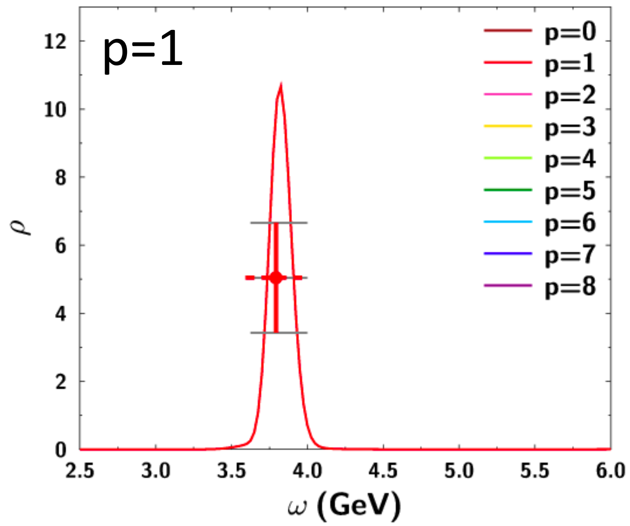
Spectral Functions with Error bar



- η_c is stable even at higher momentum.
- The area which is surrounded by the peak becomes smaller at higher momentum.
- The peak shifts to larger ω at high momentum.

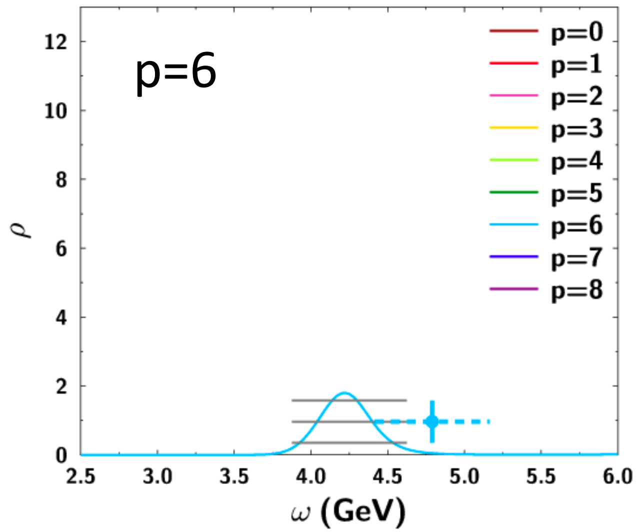
➔ check at $T<T_c$

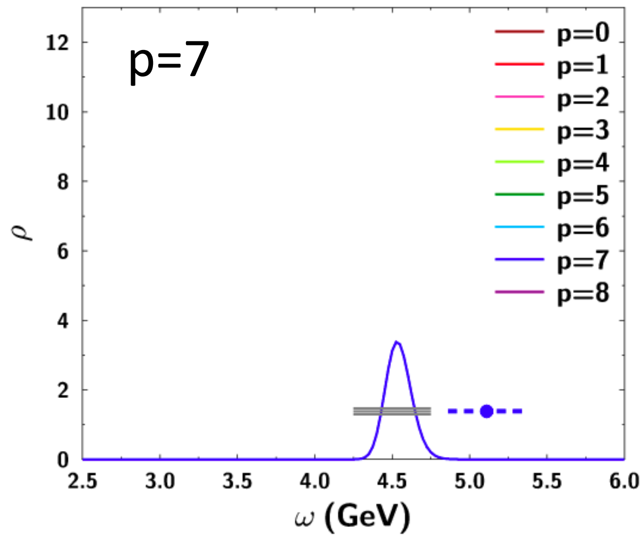
Dispersion Relation

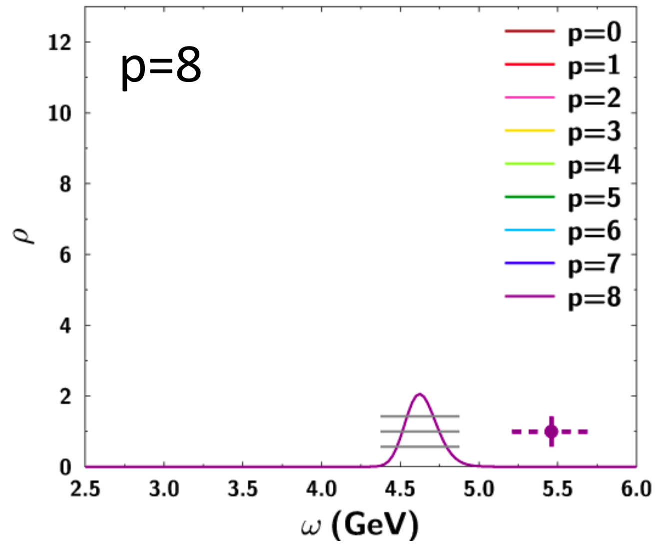


$$\omega^2 = m|_{p=0}^2 + p^2$$

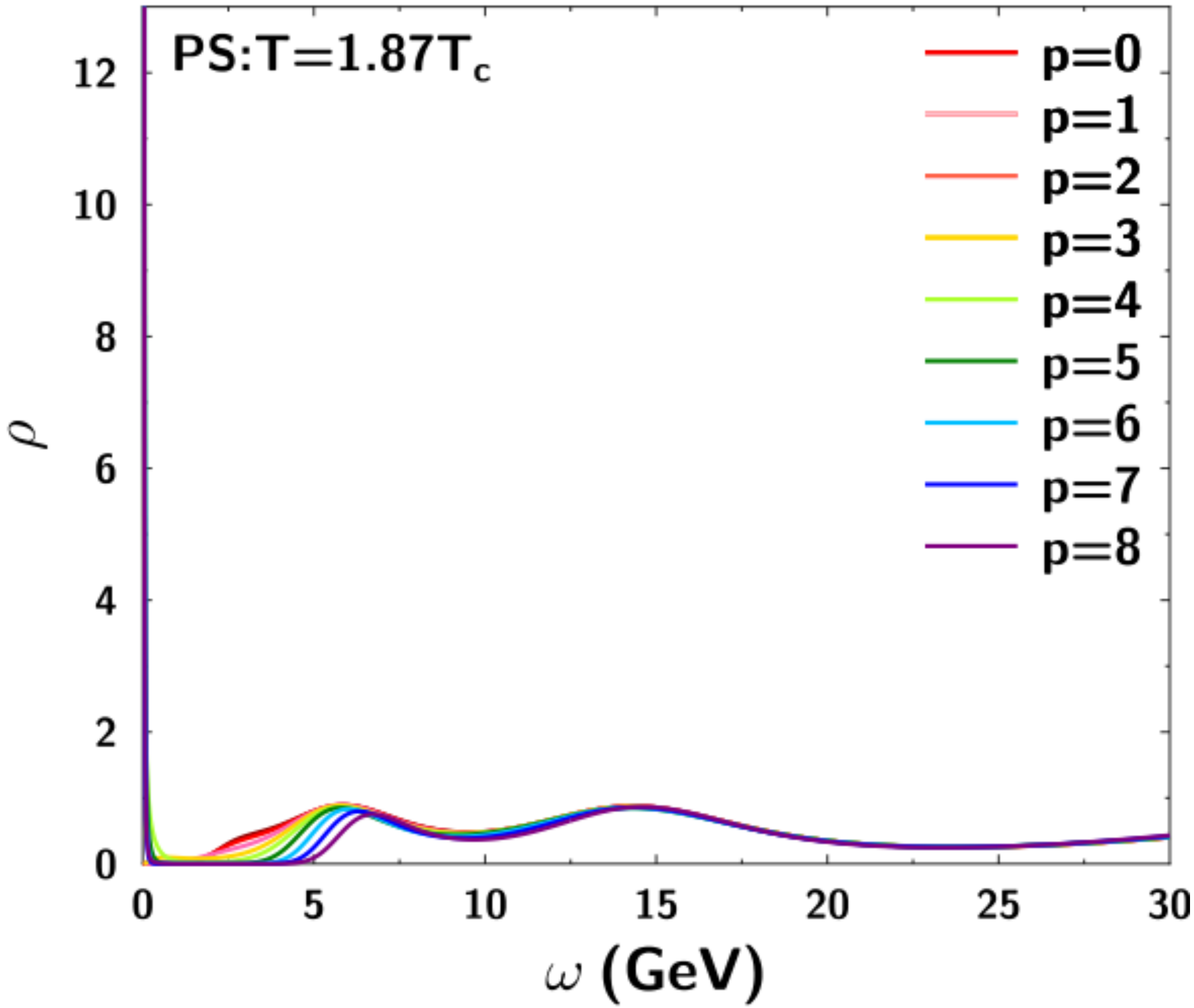
- The deviation from dispersion relation at vacuum starts to appear around p~3.0 GeV.
  ➔ medium effect







Spectral Functions at $T=1.87T_c$



- small p dependence appears only at the first peak.

Summary

- Charmonia in Relativistic Heavy Ion Collisions
  - spectral functions with large spatial volume
  - at p=0 (T=1.62Tc, T=1.87Tc)
    - η_c, J/Ψ survive even above the critical temperature
      🡐 consistent with the previous studies
  - at p≠0 (T=1.62Tc)
    - η_c: stable, medium effect
- To Do
  - check at other temperatures : T= 0.78. 1.38, 1.70. 1.78, 2.33 T_c
  - statistics (V channel)
- Future
  - dilepton productions
    experimental data (NA60@SPS, PHENIX@RHIC)
    ex. light mesons (ρ, ω…)

Backup

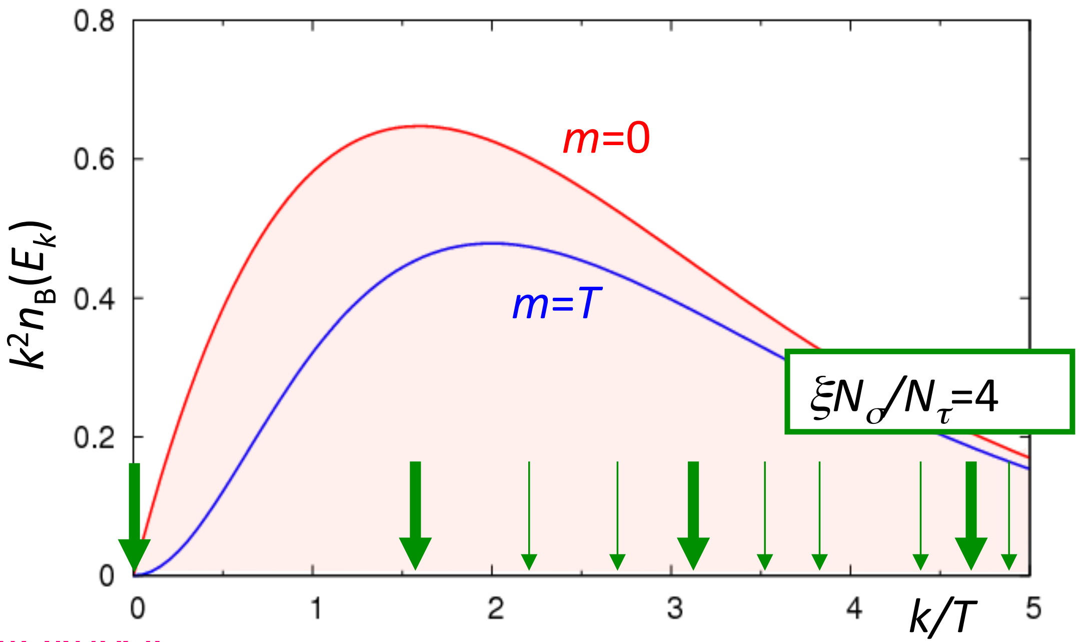
Soft Scale

- $p_{\min}$ on the lattice

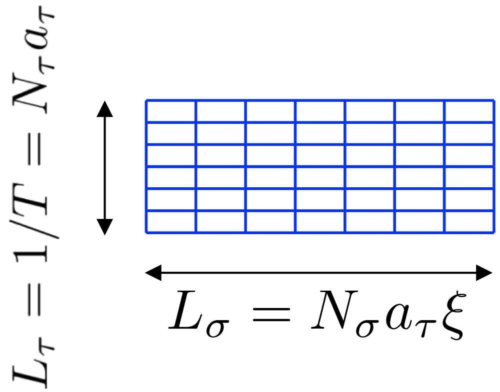
$$p_{\min} = \frac{2\pi}{L_\sigma} = 2\pi \frac{\xi N_\sigma}{N_\tau} T$$

- $T > T_c$

$$\frac{1}{8} \leq \frac{N_\tau}{\xi N_\sigma} < \frac{1}{4} \Rightarrow 0.79T \leq p_{\min} < 1.57T$$

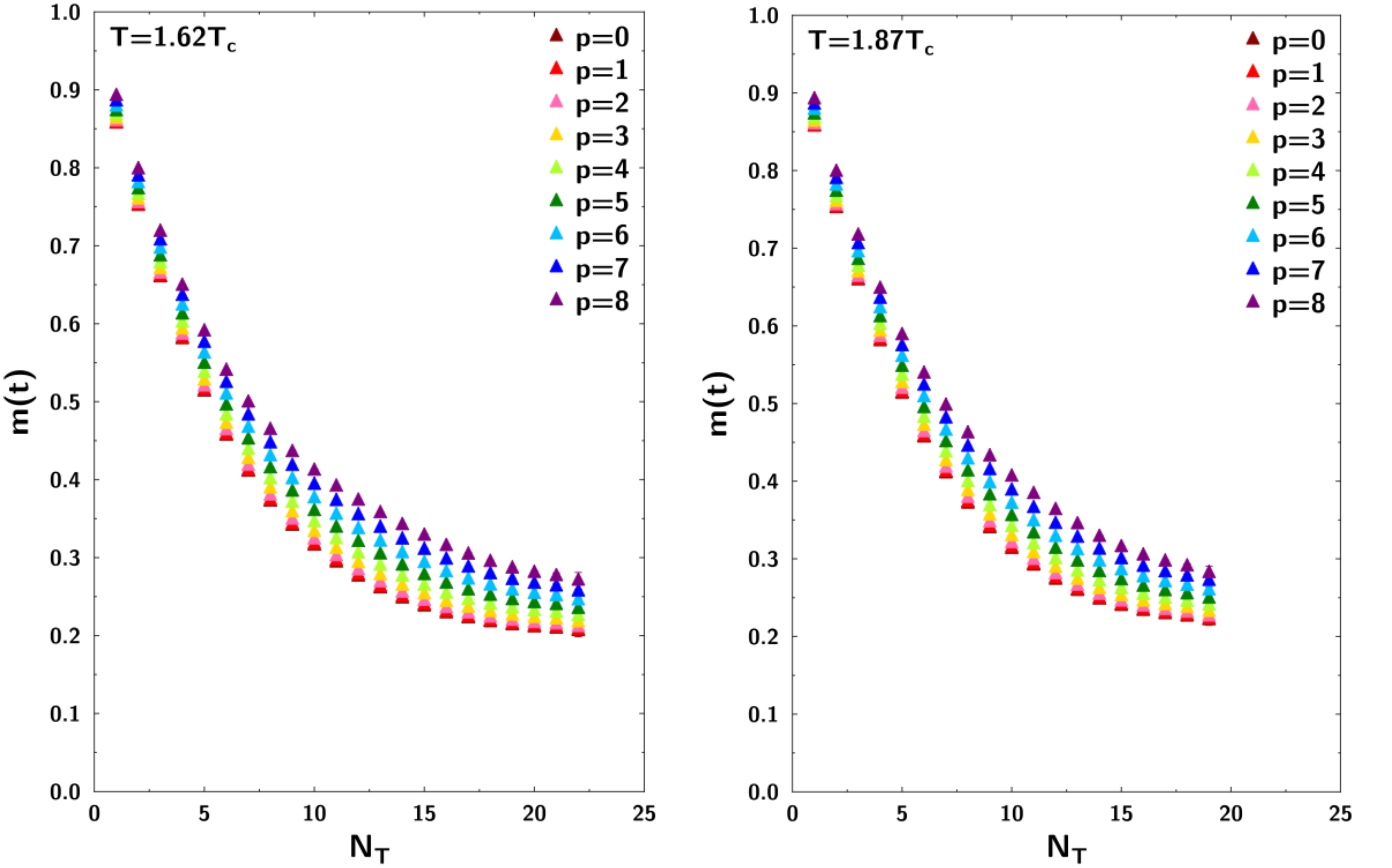


- anisotropy : $\xi = 4$
- lattice size : $N_\sigma^3 \times N_\tau = 64^3 \times N_\tau$
  N_τ=96,54,46,44,42,40,32



- MEM : $N_\tau > 30$
- realistic computational time @ PACS-CS, Blue Gene

Effective Mass:PS



Effective Mass:V