EMMI Rapid Reaction Task Force

TAMU Approach

Part.1: Reaction Rates

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EMMI

Rate Equation Approach

- Kinetic Rate Equation

$$\frac{dN(t)}{dt} = -\Gamma(T(t))\left(N(t) - N^{\mathrm{eq}}(T(t))\right)$$

Loss — Gain

Primordial — Regeneration

- Boltzmann Equation

$$\frac{df(x,p,t)}{dt} = -\Gamma(p,T(t))f(x,p,t) + \Gamma^{\mathrm{reg}}(x,p,T(t))$$

- In Equilibrium:

$$\Gamma^{\mathrm{reg}}(p,T(t)) \simeq \Gamma(x,p,T(t))\gamma_c^2 e^{-E_\Psi/T}$$

Reaction Rates & Parton Density

- Reaction Rates:

$$\Gamma_\Psi(T) = \int \frac{d^3p}{(2\pi)^3} v_{i\Psi} \sigma_{i\Psi \to X} f_i(m_i, T)$$

Parton Density

- Main Mechanisms in QGP:

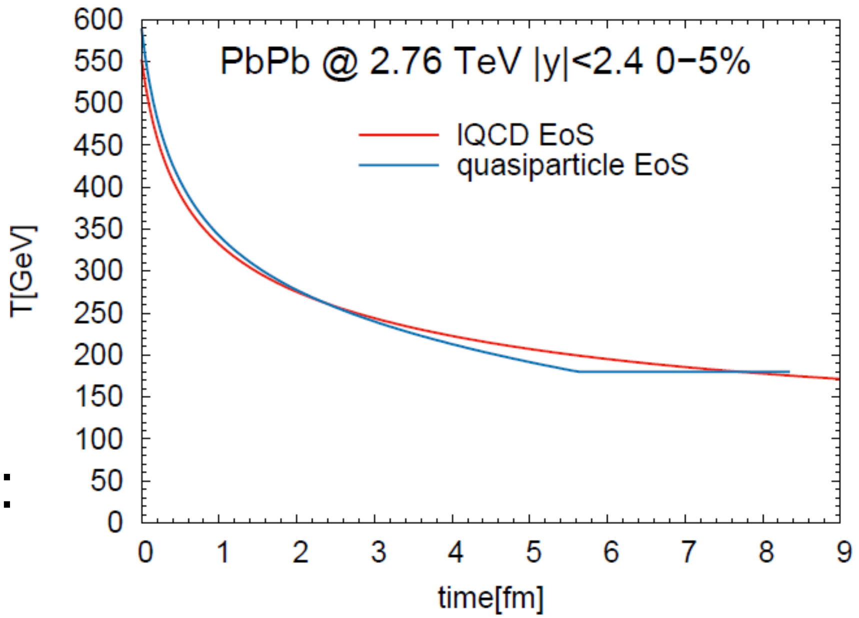
LO Gluo-dissociation & NLO Quasi-free

- Quasiparticle parton mass:

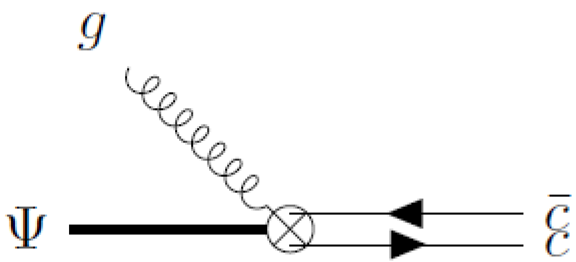
Gluon: $m_g = gT\sqrt{\frac{N_c}{6} + \frac{N_f}{12}}$

Quark: $m_q = gT\sqrt{\frac{N_c^2-1}{8N_c}}$

Compatible with lQCD EoS:

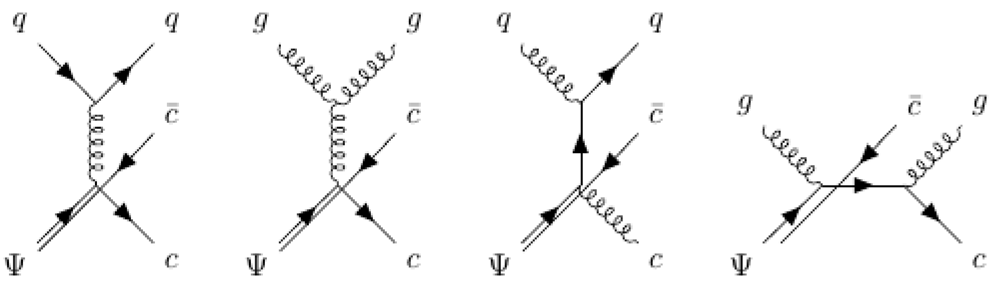


LO Gluo-dissociation



- Key properties:
  - Neglect color octet effect in large N_c limit
  - Coulomb potential wave function
  - Scattering from thermal gluon in medium (massive gluon)
  - α_s ≈0.32 is the key parameter
  - Dies off at $E_g \gg E_B^{\Psi}$

NLO Parton Induced Quasi-Free



- Key properties:
  - Reduction of $2\leftrightarrow 3$ process to $2\leftrightarrow 2$ process.
  - E_B^Ψ encoded in a reduced heavy quark mass $\tilde{m}_c = m_c - E_B^\Psi$
  - Scattering from thermal and massive partons in medium
  - α_s ≈0.32 is the key parameter
  - Twice the heavy quark width $\sigma_{i\Psi\to ic\bar{c}} = 2\sigma_{ic\to ic}$ (with reduced mass)

Interference Effect in Quasi-Free

- Effective implementation:

$$\sigma_{\rm int}(s) \simeq \int dt \frac{d\sigma_{\rm noint}(s,t)}{dt} \left(1 - \frac{\sin(\sqrt{-t}r)}{\sqrt{-t}r}\right)$$

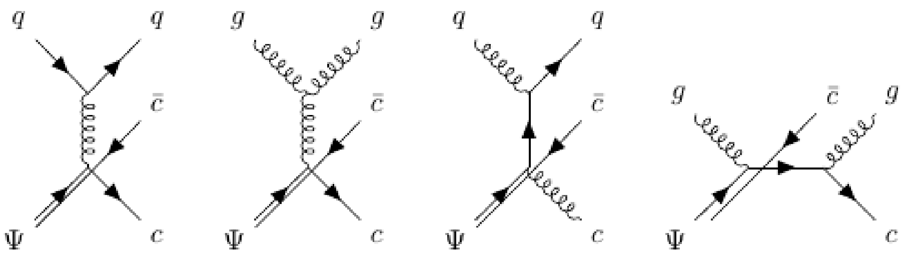
- Key properties:
  - Important for tightly bound state: Y(1S), …
  - Heavily reduced the reaction rates
  - Less than twice the heavy quark width $\sigma_{i\Psi\to ic\bar{c}} \leq 2\sigma_{ic\to ic}$ (with reduced mass)

Coupling and K-factor in Quasi-Free

- Coupling α_s
  - Fitting parameter for J/ψ at SPS/RHIC

- K-factor for $\psi(2S)$
  - For nonperturbative effects,

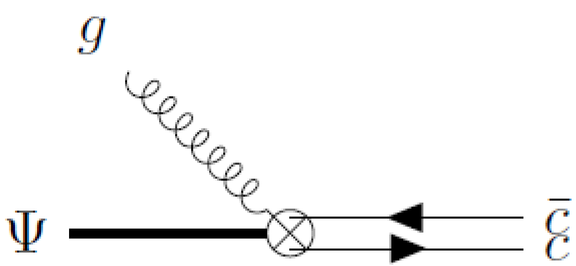
    guided from open heavy flavor

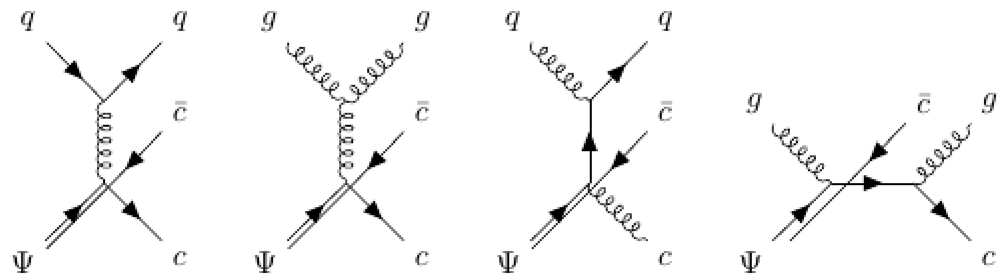


Recall: $\sigma_{i\Psi \to ic\bar{c}} = 2\sigma_{ic \to ic}$

  - K=2~3 for $\psi(2S)$ by fitting to pA/dA data.
  - No K for J/ψ , compensated by interference effect, otherwise, one should fit α_s again
  - Still large uncertainty for K factor (consistency between open/hidden)

Gluo-dissociation vs Quasi-Free



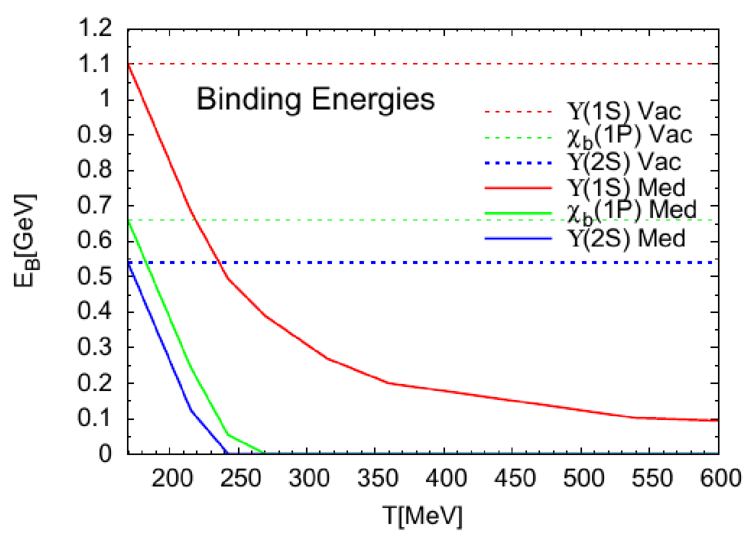


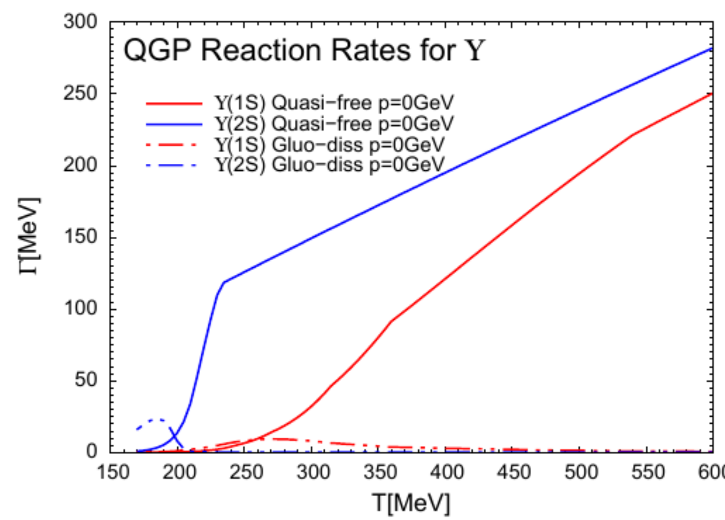
■ Gluo-dissociation

- ■ Smaller phase space
- ■ Dominates at stronger binding

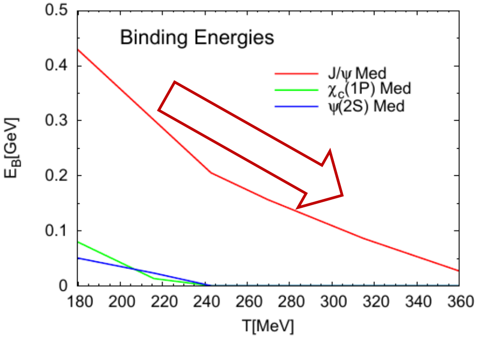
■ Quasi-Free

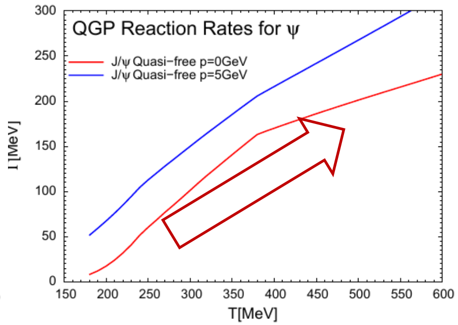
- ■ Larger phase space
- ■ Dominates at weaker binding

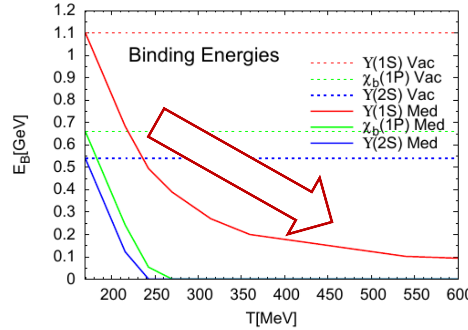


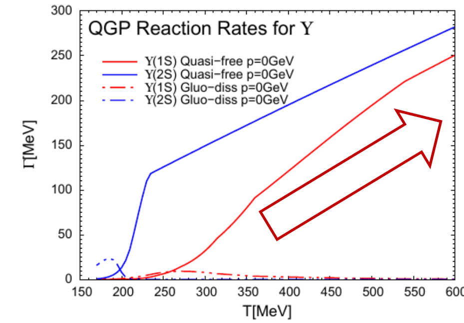


Temperature Dependence

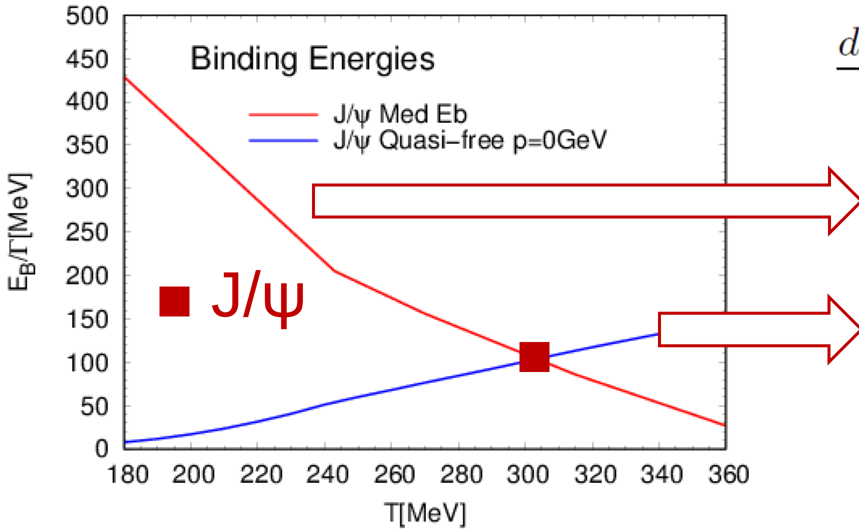








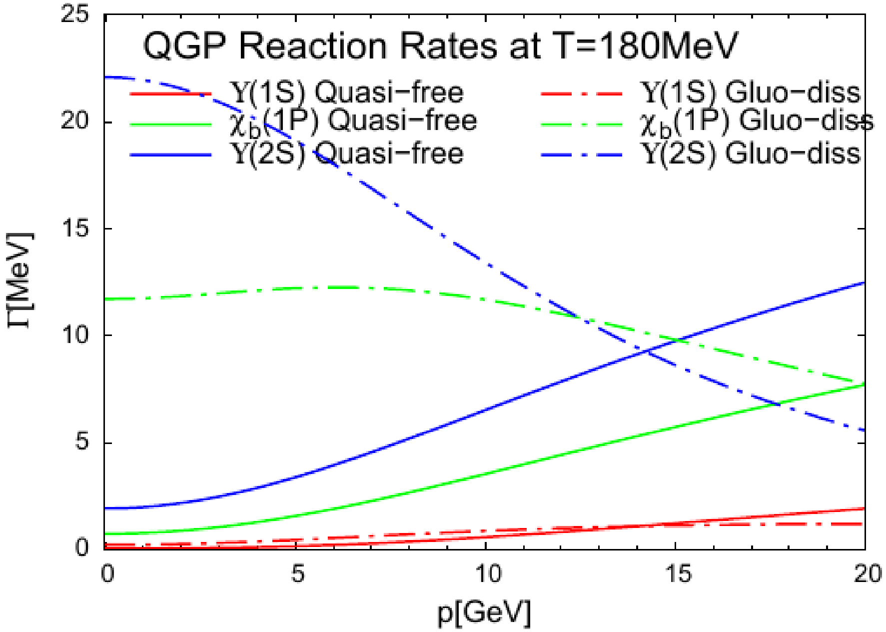
- Charmonium
- Binding Energy from T-matrix with confining
- Bottomonium

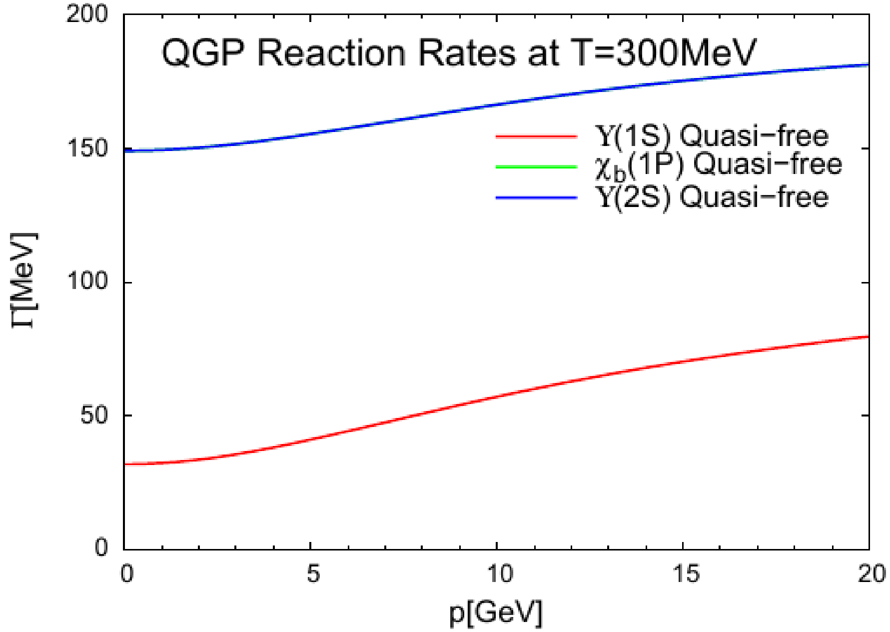


$$\frac{dN(t)}{dt} = -\Gamma(T(t))\,(N(t) - N^{\rm eq}(T(t)))$$

- Well defined quasiparticle
  Dissociation + Recombination
- No more bound state
  Dissociation

Momentum Dependence





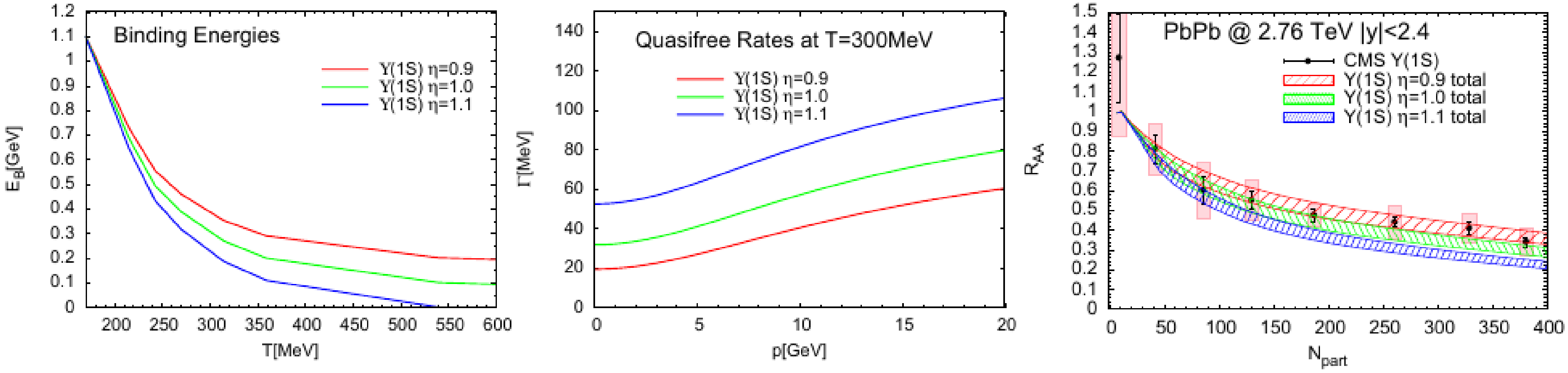
Υ T=180MeV

- Quasi-free & Gluo-diss

Υ T=300MeV

- Quasi-free Dominates

Binding Energy Dependence



Remarks

- Parameter η, larger value $\rightarrow$ Weaker binding
- Excited states $\rightarrow$ Weaker binding
- Weaker binding $\rightarrow$ Larger rates
- Larger rates $\rightarrow$ Larger suppression

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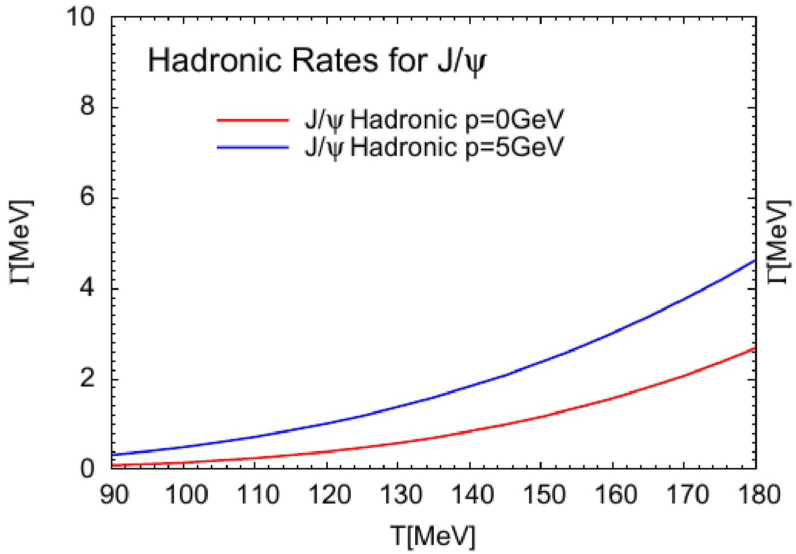
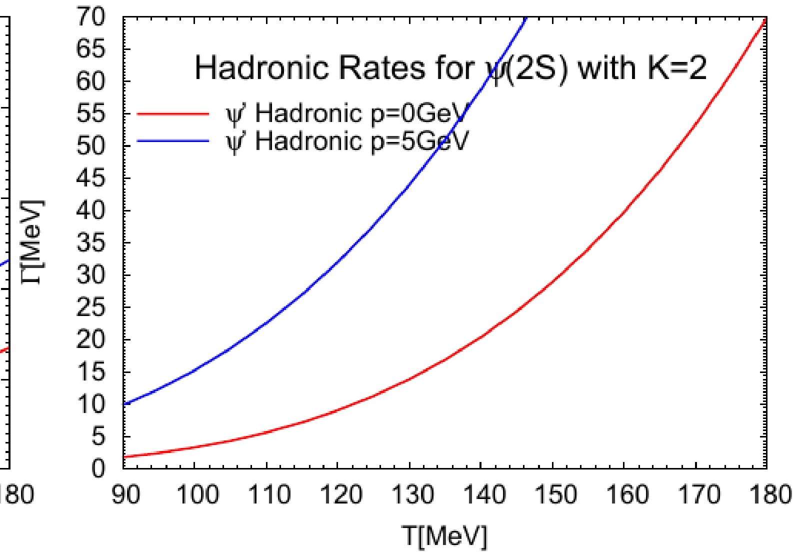
Hadronic Rates

■ SU(4) Meson Exchange Model





- Inclusion of many excited resonances
- Larger (Smaller) form factor Λ=2(0.75)GeV & K-factor=2(1)

  for $\psi(2S)$ (J/ψ) rate, fitting to pA/dA data
- Large uncertainty in parameters

Continuity Across T_c

- First order phase transition
  - QGP/hadronic fraction in mixed phase (at T_c):

$$f^{\rm QGP}(t) = \frac{S_{\rm tot}/V_{\rm FB}(t) - s^{\rm HAD}_{T_c}}{s^{\rm QGP}_{T_c} - s^{\rm HAD}_{T_c}} \qquad f^{\rm HAD}(t) = 1 - f^{\rm QGP}(t)$$

  - Reaction rates in mixed phase:

$$\Gamma_{\rm MIX}(T_c, t) = f^{\rm QGP}(t)\Gamma_{\rm QGP}(T_c) + f^{\rm HAD}(t)\Gamma_{\rm HAD}(T_c)$$

  - Rates have gaps at T_c

$$\Gamma_{\rm QGP}(T_c) \geq \Gamma_{\rm HAD}(T_c)$$

  - Rates smoothly transit from QGP to hadronic stage during evolution
- Crossover
  - Currently neglect hadronic d.o.f

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