Charmonium resonance production from quark coalescence

Gergő Hamar, Péter Lévai
(MTA KFKI RMKI, Budapest)

July 2009.
EPS HEP 2009, Cracow, Poland

Outlook

- **Experimental data on resonances**
- **Quark coalescence models**
- **Problems with resonance coalescence**
- **Relativistic coalescence for resonances**
- **Charmonia production**
- **Results**
- **Expected yields**
- **Summary**

Resonance measurements

- **NA49**
  - data on K*(892), Λ(1520), ϕ(1020)
  - resonance yields differ from thermal model predictions (difference increases with increasing widths) P.Seyboth J.Phys.G **35** 104008 (2008)
- **RHIC**
  - data on ρ(770), K*(892), ϕ(1020), Σ*(1385), Ξ*(1530), Λ(1520), . . .

Hadronization – Quark coalescence

- Fast hadronization process
- v_2 scaling ~ **valence quark scaling** ~ quark coalescence
- **ALCOR** (Bíró, Lévai, Zimányi 1995)
  - describes hadron yields at SPS and RHIC
- **MICOR** (Csizmadia, Lévai 1999)
  - describes p_T spectra for hadrons
- **Recombination models** (2003)
  - Hwa, Yang; Greco, Ko, Lévai; Fries, Müller, Bass ...
- **Resonance coalescence** (Hamar, Lévai 2008)
  - allows resonance production

MICOR model

- Microscopic rehadronization
- Quantum mechanics based:

$$g_{gh} = V_g \frac{-M_{h,Q'}}{2\pi} \int d^3\vec{x}_1 d^3\vec{x}_2 \cdot \tilde{\Psi}^*(\vec{x}_1, \vec{x}_2) V(\vec{x}_1 - \vec{x}_2) \phi_1(\vec{x}_1) \phi_2(\vec{x}_2)$$

- Prehadron production rate:

$$\langle \sigma^h v \rangle = \frac{\int d^3\vec{p}_1 d^3\vec{p}_2 \cdot f_q(m_1, \vec{p}_1) f_q(m_2, \vec{p}_2) (\sigma(k) v_{12})}{\int d^3\vec{p}_1 d^3\vec{p}_2 \cdot f_q(m_1, \vec{p}_1) f_q(m_2, \vec{p}_2)}$$

- Requires quasi-particle momentum distribution!
- Prehadron --> Hadron
- Produces the meson octet and the baryon decuplet
- Protons, pions, ... came from the decays

Problems with resonance production at coalescence models

- Resonance <=> higher hadron mass
- MICOR hadron masses gives the meson octet :
  - $M_h = m_{q1} + m_{q2}$
- Production rate would increase with the prehadron mass
  - $M_h \sim g_{gh} \Rightarrow \langle \sigma v \rangle \sim |g_{gh}|^2 \sim M_h^{\,2}$
- Resonance extension would be sorely sensitive to the slightly known high energy resonances

  (proper decays, mass, width; still unknown reson.)
- **Solution** : use the real **relativistic kinematics**!

  Thus we can obtain higher invariant masses

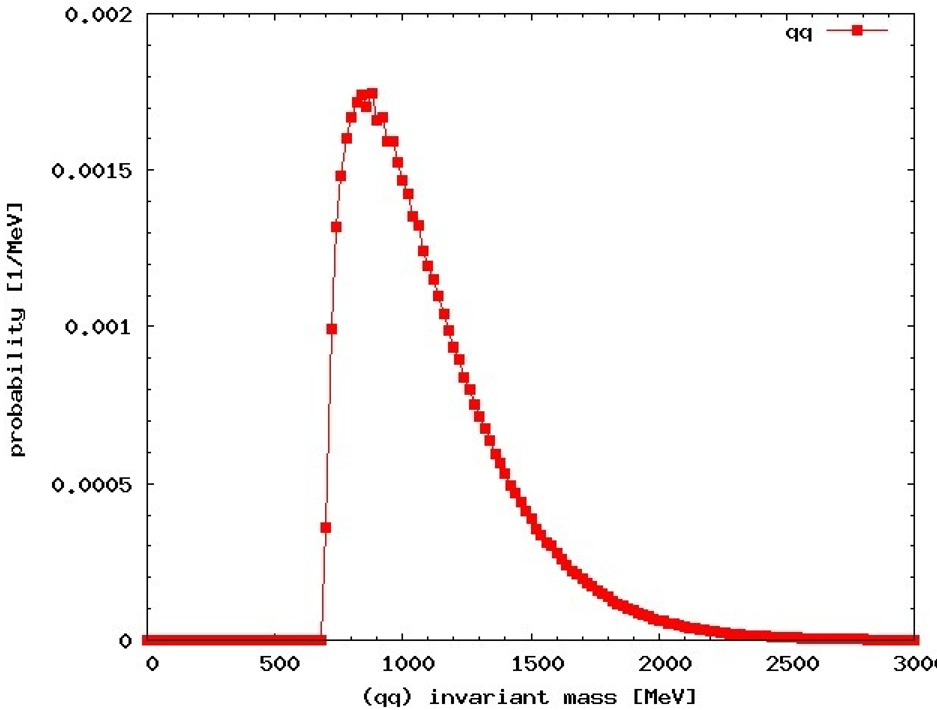
Invariant mass

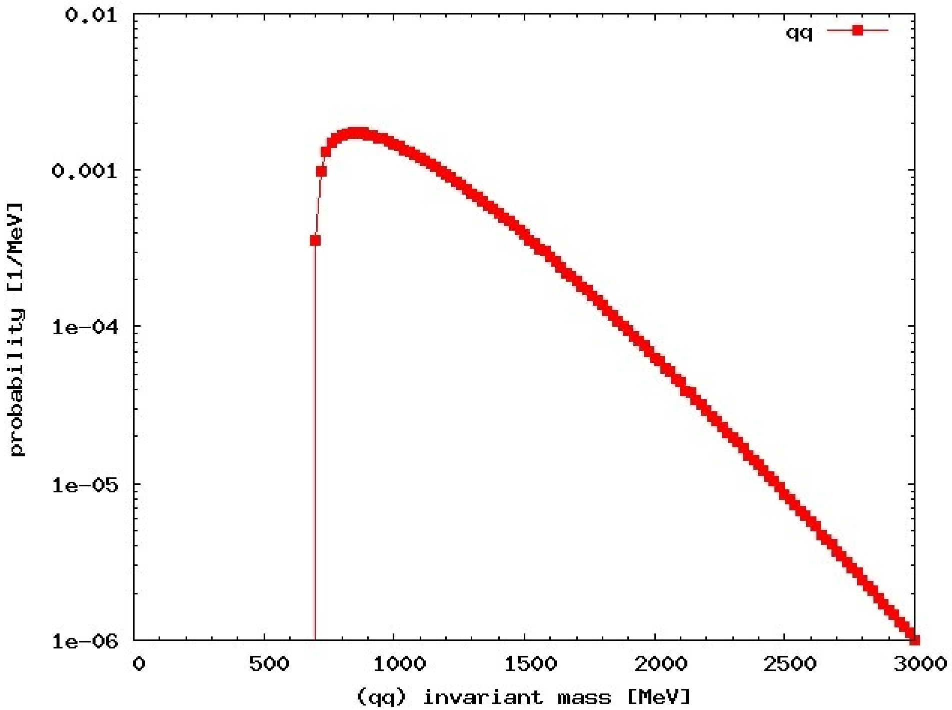
- Massive quasi-particle collision with relativistic kinematics

$$m_{prehadron} = \| p_1^\mu + p_2^\mu \| = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

- Requires initial quark momentum distribution

(one can choose: Boltzman, Jüttner, Tsallis, ...)

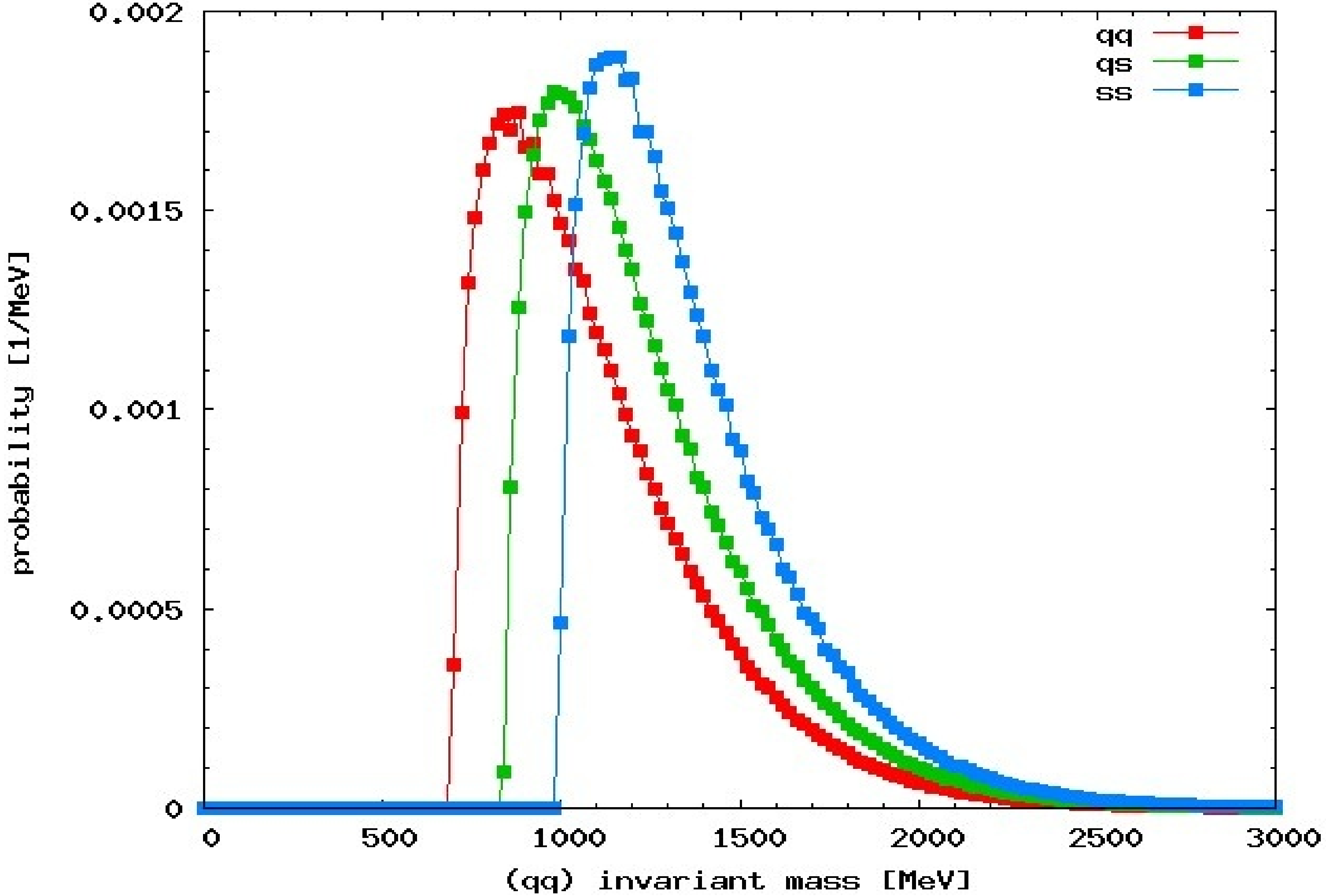




Pre-mesonic invariant mass spectra

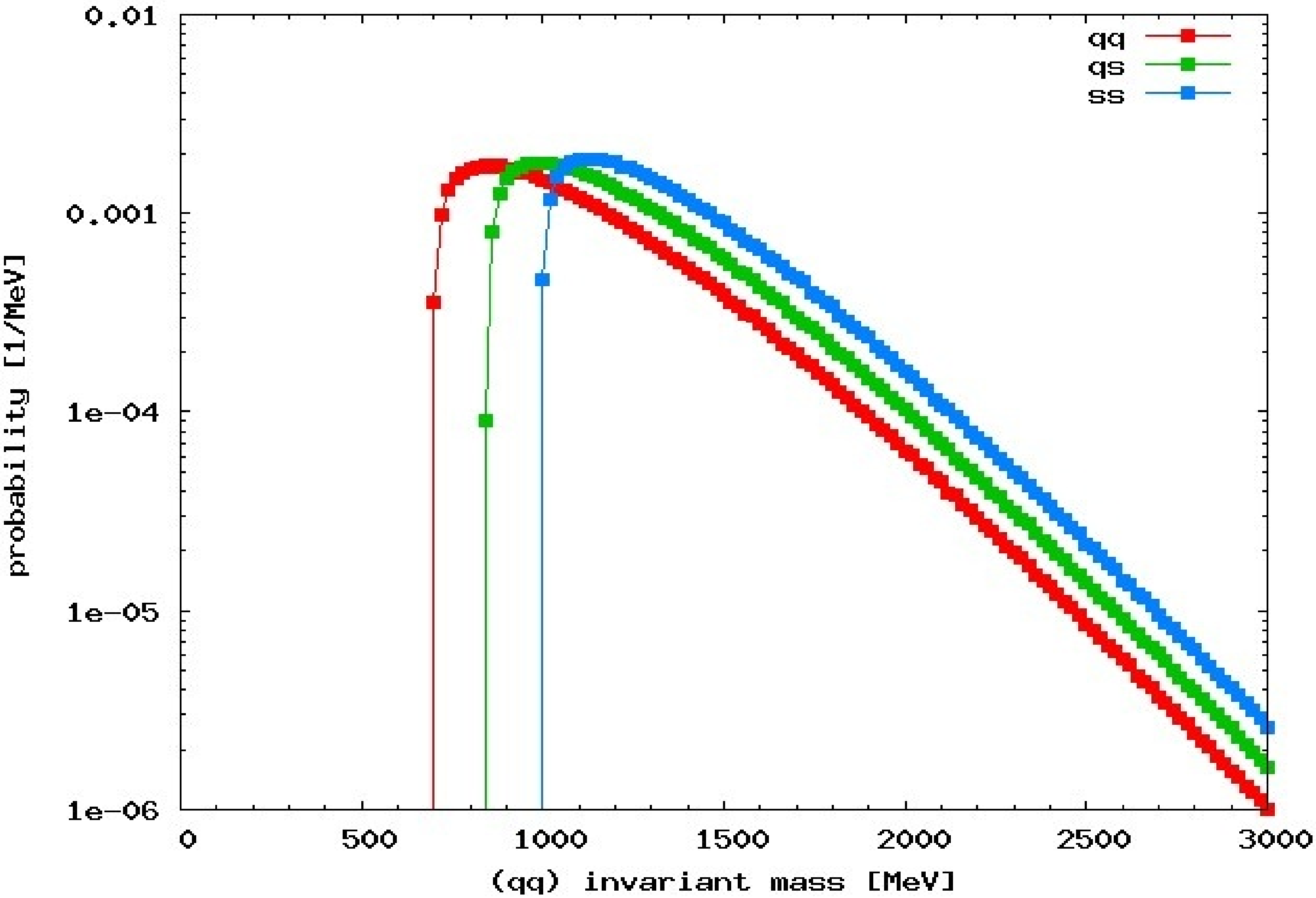
Invariant mass spectrum for given quantum numbers (Q):

$$J^Q(m) = \int d^3\vec{p}_1 \int d^3\vec{p}_2 \, f(m_1, \vec{p}_1) \, f(m_2, \vec{p}_2) \, \delta(m - \| p_1^\mu + p_2^\mu \|)$$



Pre-mesonic invariant mass probabilities

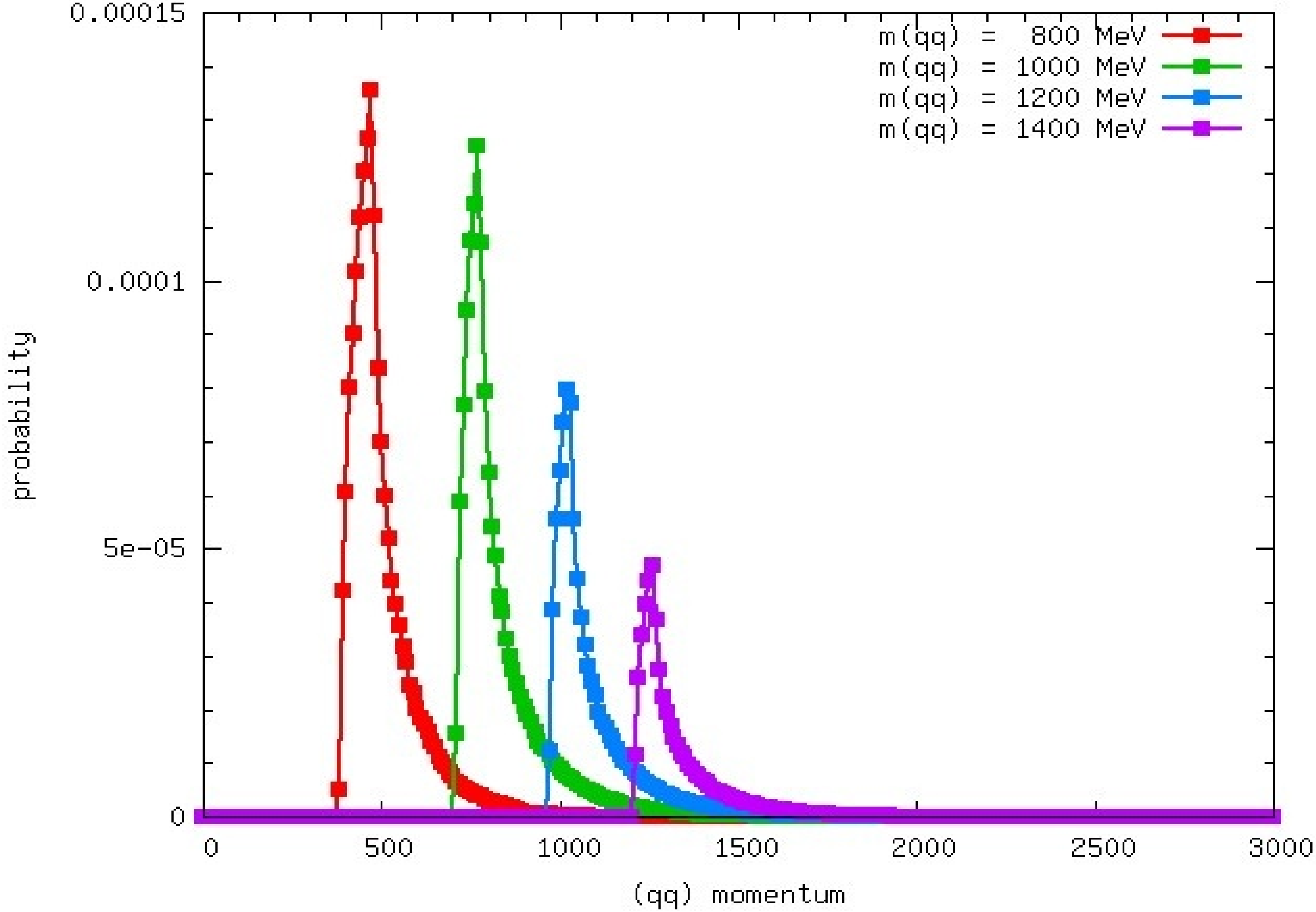
Thermal like exponential decrease at high masses (due to Jüttner d.)



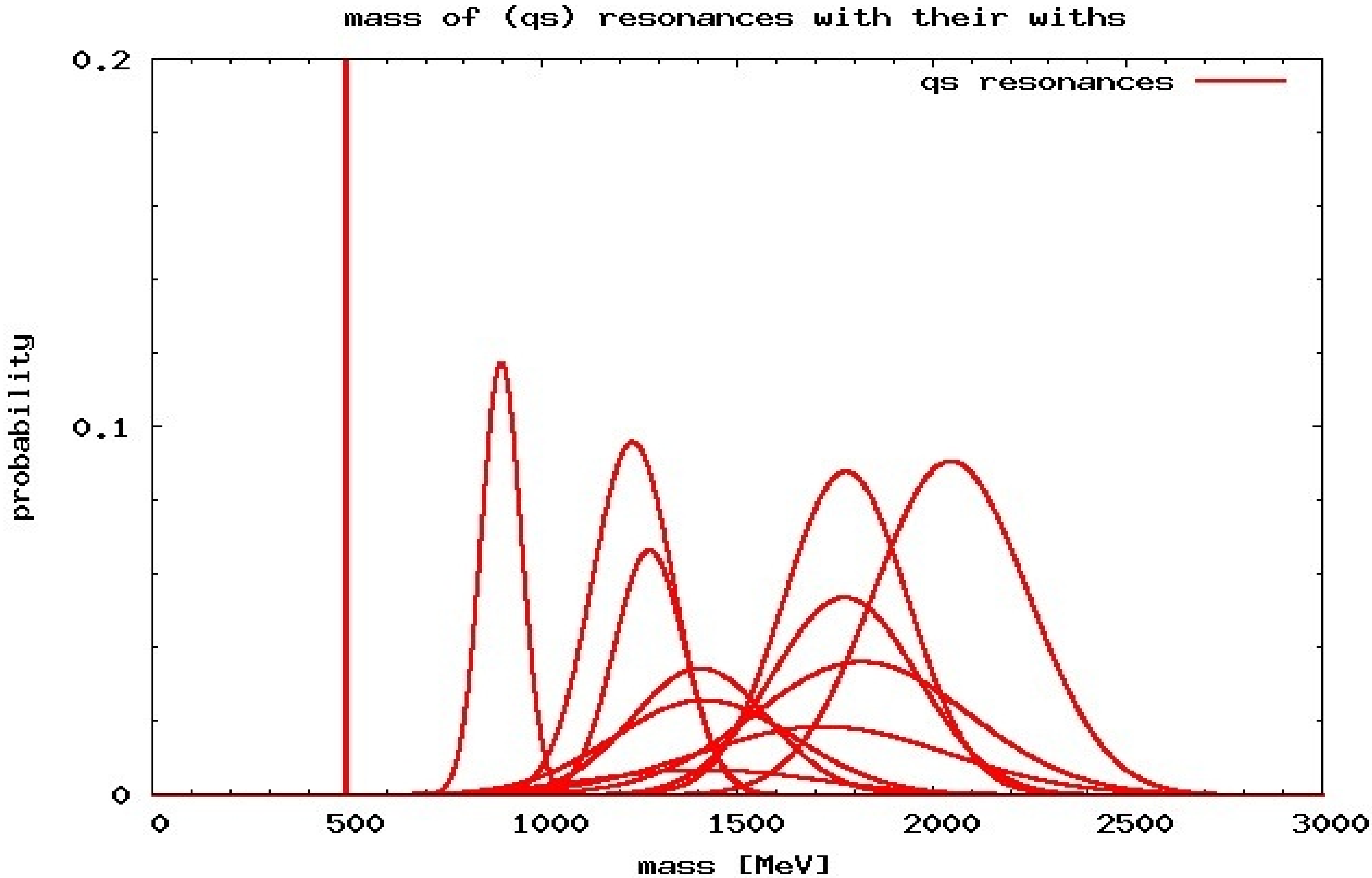
Binded ($q\bar{q}$) momentum distributions

Local frame momentum distibution for a given mass prehadron

becomes calculatable



Mass distribution of the K-resonances



Selecting the proper resonance

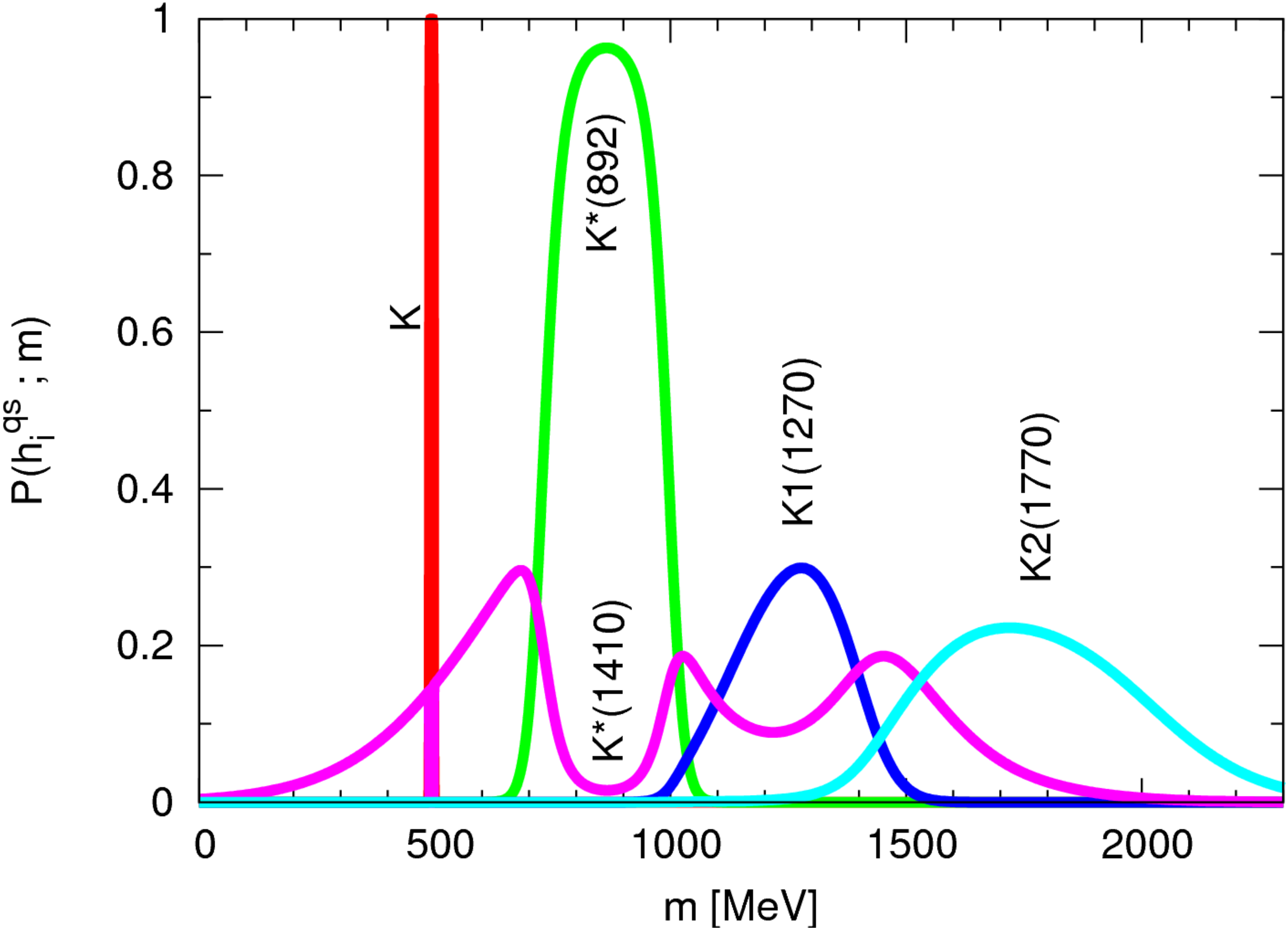
- $q+\bar{q}$ --> $(q\bar{q})$ with: mass = invariant mass
- Which resonance could appear from a $(q\bar{q})$ state?
  - Resonance <u>width</u> characterizes the decay
  - Reverse: Use the same width for production channels

- Define the appearance of a resonance at mass = m

- Probability to produce hadron resonance "H" from (qq) invariant mass m_{qq} :

$$\boldsymbol{P}(H|m_{qq}) = \frac{\exp((m_H - m_{qq})^2/2s_H^2)}{\sum_h \exp((m_h - m_{qq})^2/2s_h^2)}$$

Appearance of resonances



Baryons and Flavours

- **Prebaryons** are made from a **diquark and a quark**
  - qqq invariant mass spectrum (similar to qq)
  - Baryon resonances, width, appearance, ...
- **New flavours can be inserted without problem**
  - Requires mass: $\mathbf{m_{new}}$,

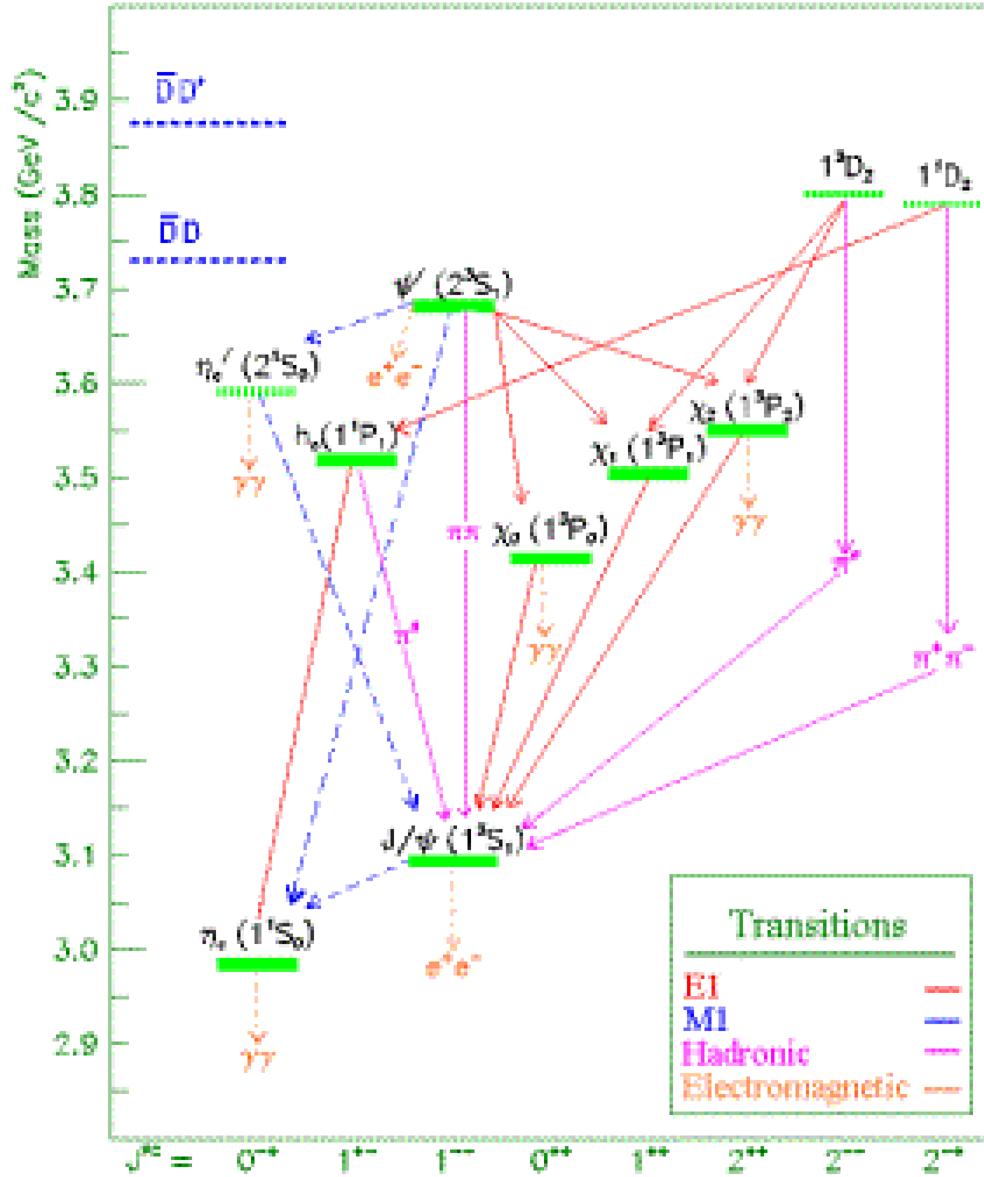
    and momentum distribution: $\mathbf{f_{new}(m_{new},p)}$
  - Hadronic resonance properties with the new flavour
  - Primary new flavour production (via fit)

Predictions at RHIC

- Parity suppression can be checked with
  - $\phi(1020)$ <-> $\phi(1680)$,
    without parity suppression $\phi(1680) / \phi(1020) = 0.22$
  - $\Sigma(1385)$ <-> $\Lambda(1520)$
    without parity suppression $\Lambda(1520) / \Sigma(1385) = 0.91$
- Expected yields for resonances with small width
  - $\rho_3(1690) / \phi(1020) = 0.10$
  - $\Sigma(1660) / \Sigma(1385) = 0.55$

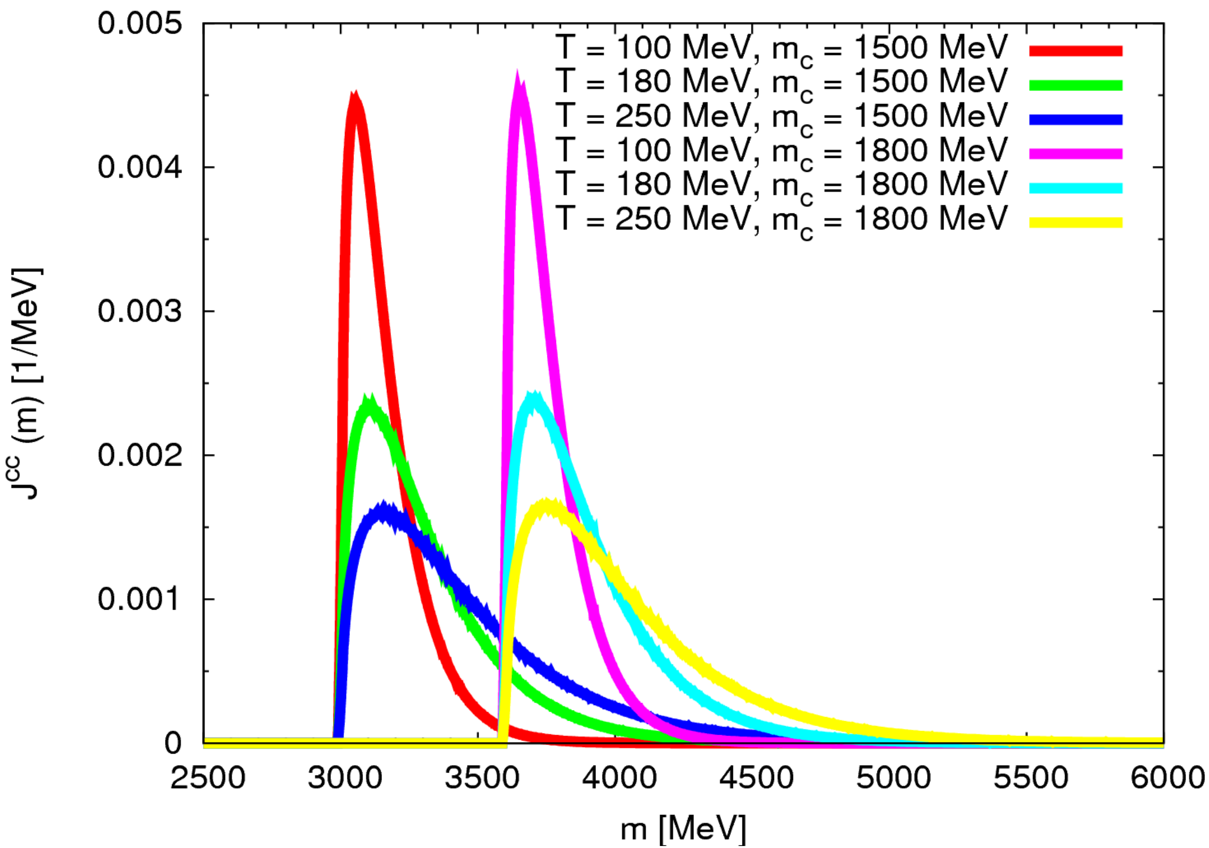
Charm sector

- Insert charm quark into the model
  - mass –> **m_{charm}**
  - f(m,p) –> **Jüttner d.**
  - charm decay table
- Charmonia
  - interesting
  - measurable



Charmonia

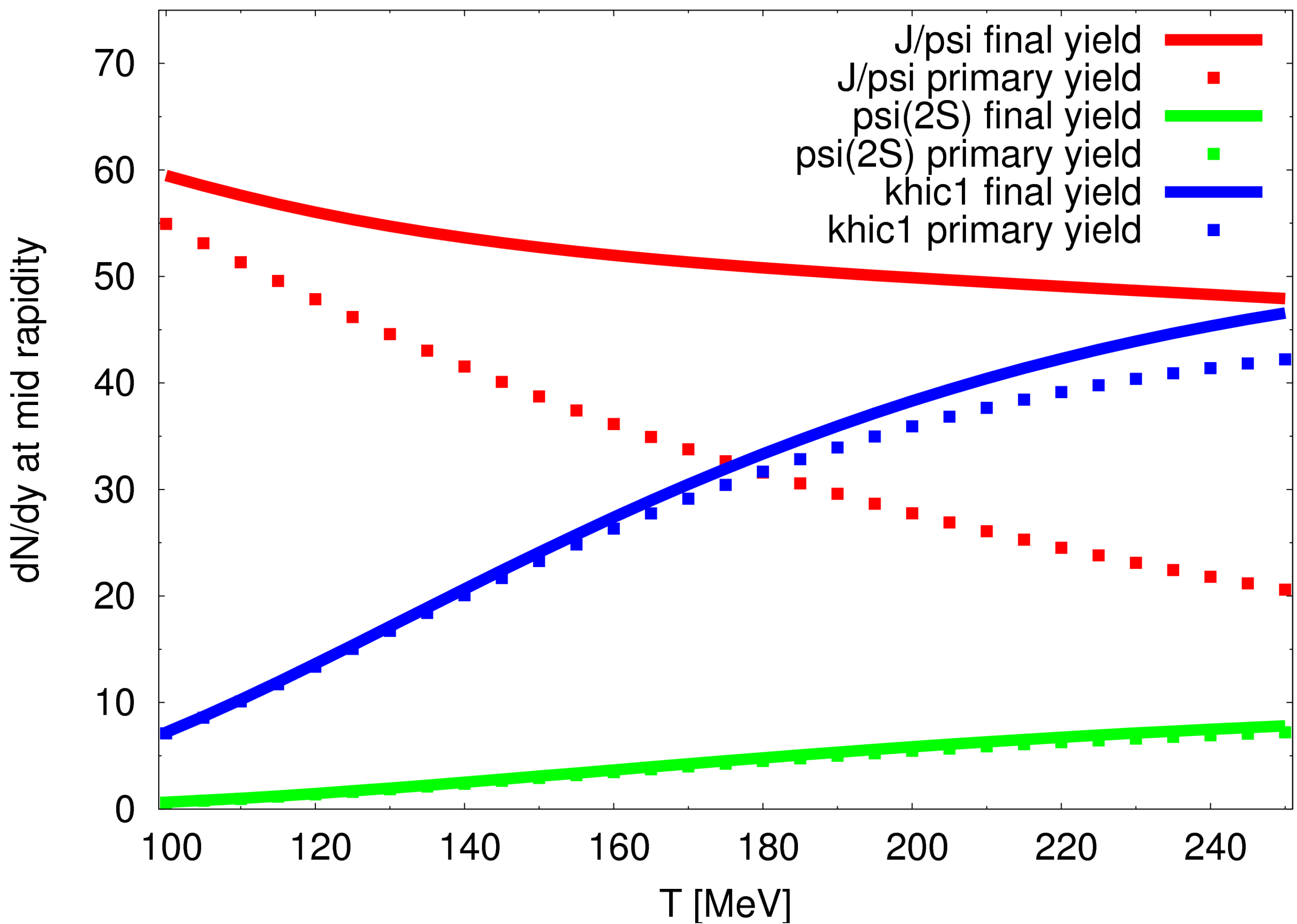
- Lighter charmonium resonances are sparsed heaviers cover the mass scale quiet densely
- Higher premeson mass becomes sufficient
- Temperature and charm mass could be more important



Temperature dependence

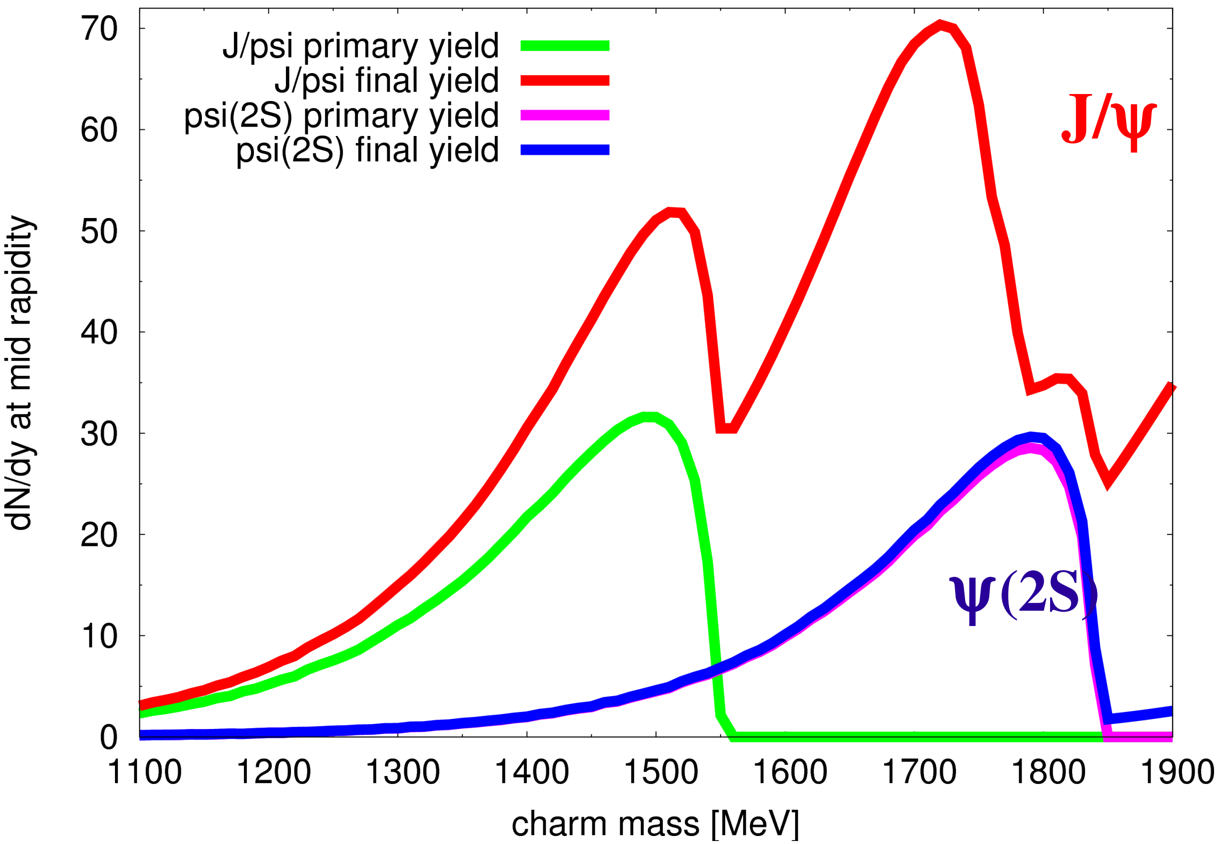
As temperature rises some higher mass resonances thrive

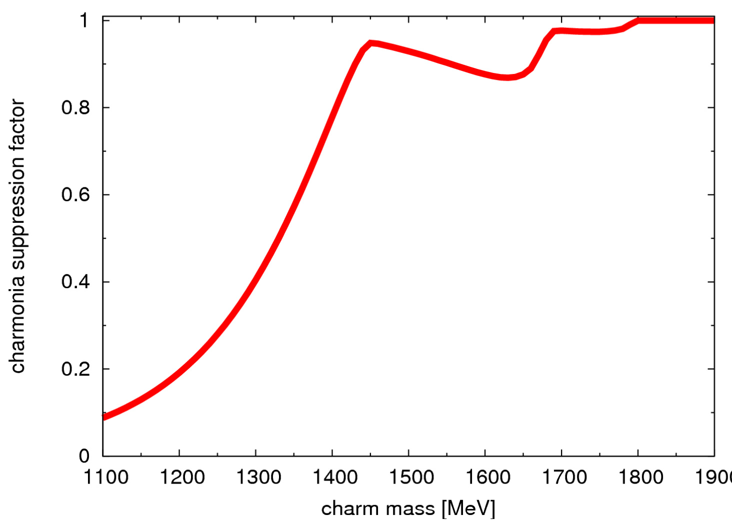
Final J/ψ yield is approximately independent



Charm mass dependence

- Strong charm mass dependence due to the special structure of the mass specrum of charmonium resonces
- Charm mass influences the net charm prodution too





Light charm mass prefer charm mesons to charmonia

Conclusion

- **Resonance coalescence model can be constructed**
  - **Relativistic kinematics** <=> prehadron mass spectrum
  - **Near thermal suppression** for high masses
  - Hadron selection via **decay widths**
- **Successful application for meson and baryon resonances**
- **Method is applicable for all flavours**
  - **up, down, strange** and **charm** sector have been included
- **Charmonia sector : special T and m_c effects**
- **Predictions for measurable hadron resonance ratios**