Charm and bottom flavored hadrons production from strangeness rich quark gluon plasma hadronization

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We study QGP hadronization at given b, c quark content. We predict the yields of charm and bottom flavored hadrons within statistical hadronization model. The important new feature is that we take into account **high** strangeness and entropy content of QGP, conserving strangeness yield and entropy at hadronization.

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Motivations

- Probe of QGP properties, confirmation of deconfinement
- Information on temperature of hadronization of heavy flavored hadrons
- Understanding of properties of phase transition between deconfinement phase and hadronic gas (HG) phase in strangeness rich QGP.

Main model assumptions

- We do not assume chemical equilibrium for quark flavors.
- We work in framework of fast hadronization to final state. Physical conditions (system volume, temperature) do not change.
- Flavor conservation: $\frac{dN_i^{HG}}{dy} = \frac{dN_i^{QGP}}{dy}$

fixes statistical parameters (γ_b^H, γ_c^H, γ_s^H) for quark yield.

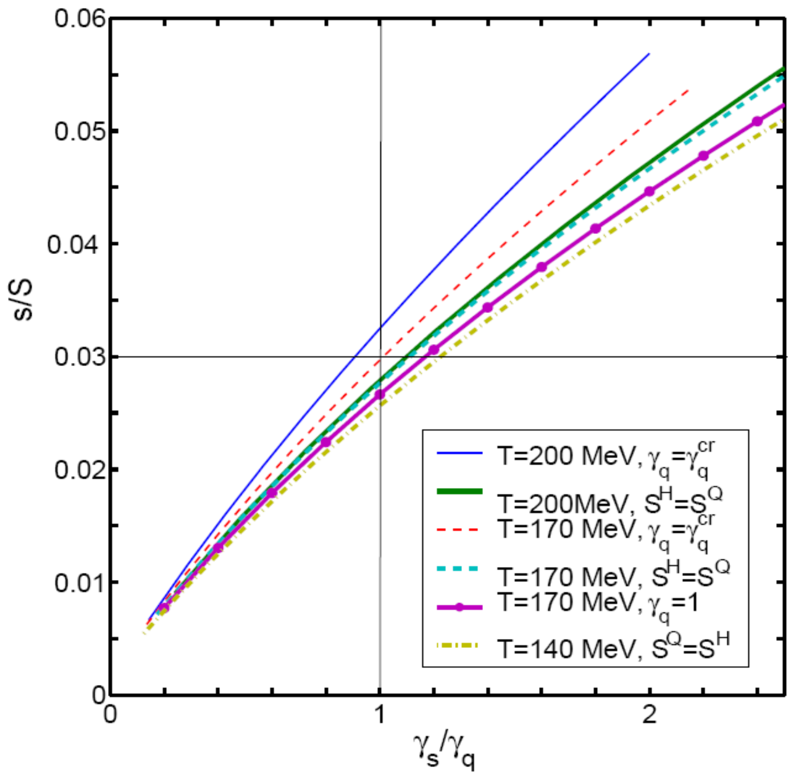
$\left(\frac{dN_i}{dy} = \gamma_i n_i^{eq} \frac{dV}{dy} \right)$ $\gamma_i = 1$, $n_i = n_i^{eq}$ is chemical equilibrium

- Entropy conservation: $\frac{dS^{QGP}}{dy} = \frac{dS^{HG}}{dy}$ fixes $\gamma_q^{HG} (\neq 1)$
- In QGP $\gamma_q^{QGP} = 1$

(The entropy of expanding QGP is conserved: $T^3 \frac{dV}{dy} \approx const.$)

Strangeness

- Strangeness (s) production in thermal gluon fusion follows in time entropy (S) production
- Ratio s/S depends on energy of collision, s increases faster with energy then S. The hot state, where the threshold for s production is exceeded, lives longer
- At RHIC energies s/S ~ 0.03, at LHC expect 0.03 ≤ s/S ≤ 0.05



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G. Torrieri, S. Steinke, W. Broniowski, W.Florkowski, J. Letessier and J. R, Comput. Phys. Commun. 167, 229 (2005) (SHARE 1) [arXiv:nucl-th/0404083];
G.Torrieri, S.Jeon, J.Letessier and J. R, Comput. Phys. Commun. 175, 635 (2006) (SHARE 2) [arXiv:nucl-th/0603026]

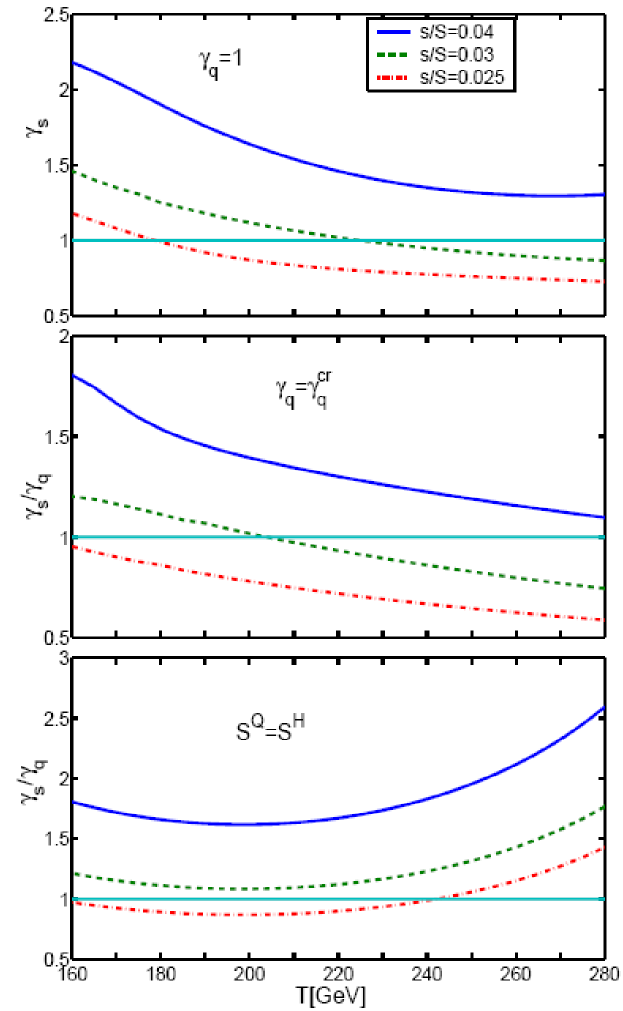
Webpage:

http://www.physics.arizona.edu/~torrieri/SHARE/sharev1.html

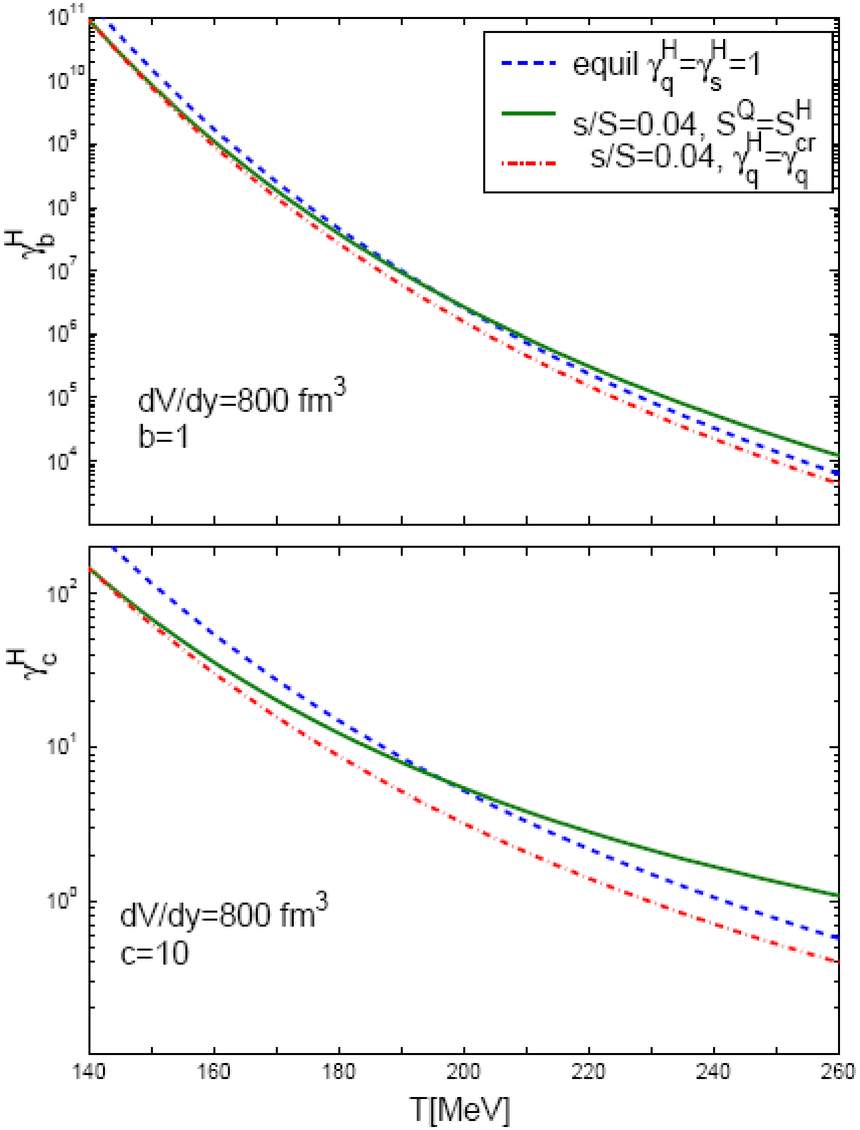
Strangeness conservation during hadronization

$$s = \frac{dV}{dy}\left[\gamma_s^H\left(\gamma_q^H n_K^{eq} + \gamma_q^{H\,2} n_Y^{eq}\right) + 2\gamma_s^{H\,2}\gamma_q^H n_\Xi^{eq}\right]$$

- The equilibrium densities n_i^{eq} are sums of all known states densities for given particle i.



Charm (bottom) hadronization



- c,b quarks produced in first nn collisions.
- c=10, b=1;
- Flavor conservation equation

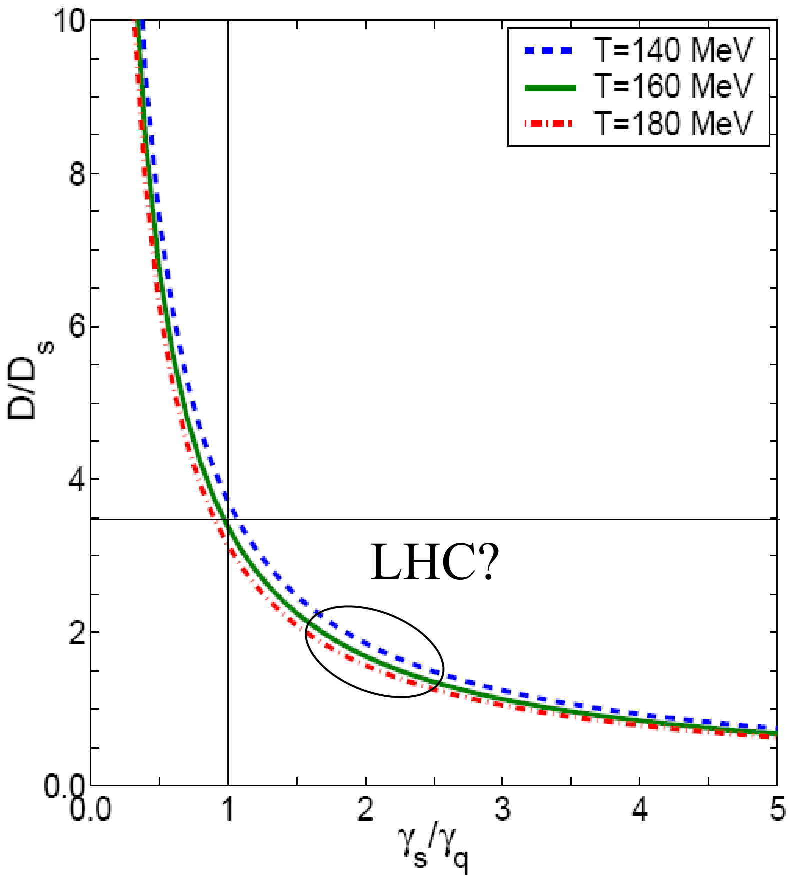
$$c = \frac{dV}{dy}\left[\gamma_c^H n_{open}^c + \gamma_c^{H\,2}\left(n_{hid}^c + 2\gamma_q^H n_{ccq}^{eq} + 2\gamma_s^H n_{ccs}^{eq}\right)\right];$$

$$n_{open}^c = \gamma_q^H n_D^{eq} + \gamma_s^H n_{D_s}^{eq} + \gamma_q^{H\,2} n_{qqc}^{eq} + \gamma_s^H \gamma_q^H n_{sqc}^{eq} + \gamma_q^{H\,2} n_{ssc}^{eq};$$

$$n_{hid}^c = \gamma_c^{H\,2} n_{\bar{c}c}^{eq}.$$

- $\gamma_b^H \gg \gamma_c^H \gg \gamma_s^H$
- Equilibrium case when $\gamma_q^H = \gamma_s^H = 1$

Effect of strangeness on ratio $D/D_{s.}$



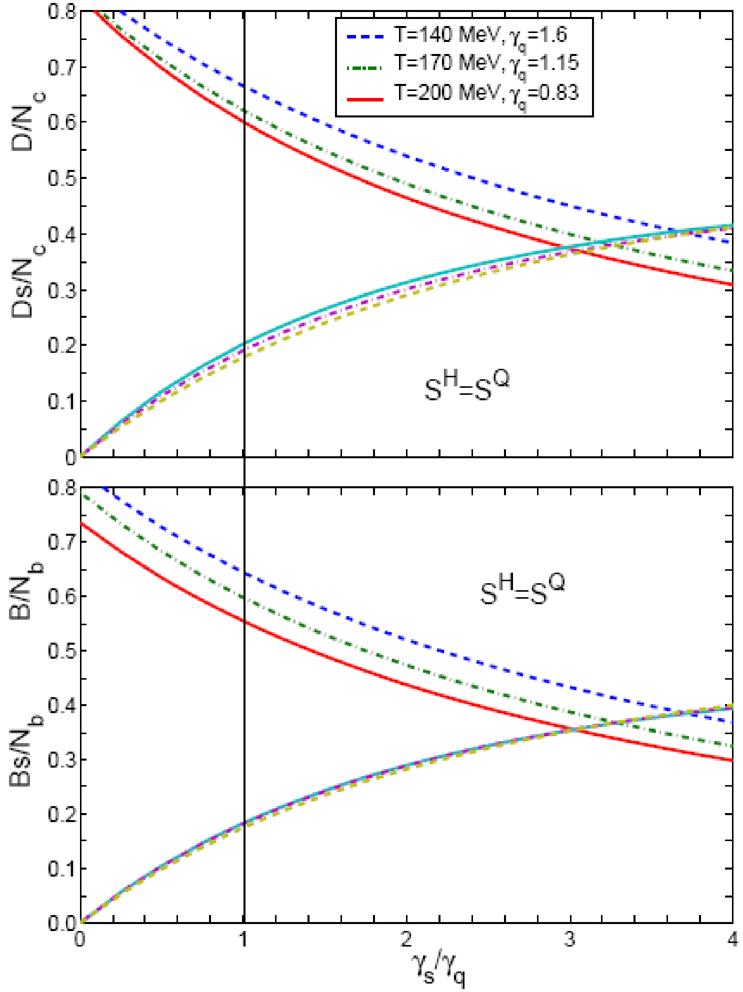
$$\frac{D}{D_s} = \left(\frac{\gamma_s^H}{\gamma_q^H}\right)^{-1} f(T)$$

$$D_s = \gamma_c \gamma_s n_{Ds}^{eq} = \gamma_c \gamma_s \sum_i n_{Ds_i}^{eq}$$

$$D = \gamma_c \gamma_q n_D^{eq} = \gamma_c \gamma_q \sum_i n_{D_i}^{eq}$$

	hadron		M[GeV]	hadron		M[GeV]	g
D	$D^0(0^-)$	$c\bar{u}$	1.8646	$B^0(0^-)$	$b\bar{u}$	5.279	1
	$D^+(0^-)$	$c\bar{d}$	1.8694	$B^+(0^-)$	$b\bar{d}$	5.279	1
	$D^{*0}(1^-)$	$c\bar{u}$	2.0067	$B^{*0}(1^-)$	$b\bar{u}$	5.325	3
	$D^{*+}(1^-)$	$c\bar{d}$	2.0100	$B^{*+}(1^-)$	$b\bar{d}$	5.325	3
	$D^0(0^+)$	$c\bar{u}$	2.352	$B^0(0^+)$	$b\bar{u}$	5.697	1
	$D^+(0^+)$	$c\bar{d}$	2.403	$B^+(0^+)$	$b\bar{d}$	5.697	1
	$D_1^{*0}(1^+)$	$c\bar{u}$	2.4222	$B_1^{*0}(1^+)$	$b\bar{u}$	5.720	3
	$D_1^{*+}(1^+)$	$c\bar{d}$	2.4222	$B_1^{*+}(1^+)$	$b\bar{d}$	5.720	3
	$D_2^{*0}(2^+)$	$c\bar{u}$	2.4589	$B_2^{*0}(2^-)$	$b\bar{u}$	(5.730)	5
	$D_2^{*+}(2^+)$	$c\bar{d}$	2.4590	$B_2^{*+}(2^+)$	$b\bar{d}$	(5.730)	5
D_s	$D_s^+(0^-)$	$c\bar{s}$	1.9868	$B_s^0(0^-)$	$s\bar{b}$	5.3696	1
	$D_s^{*+}(1^-)$	$c\bar{s}$	2.112	$B_s^{*0}(1^-)$	$s\bar{b}$	5.416	3
	$D_{sJ}^{*+}(0^+)$	$c\bar{s}$	2.317	$B_{sJ}^{*0}(0^+)$	$s\bar{b}$	(5.716)	1
	$D_{sJ}^{*+}(1^+)$	$c\bar{s}$	2.4593	$B_{sJ}^{*0}(1^+)$	$s\bar{b}$	(5.760)	3
	$D_{sJ}^{*+}(2^+)$	$c\bar{s}$	2.573	$B_{sJ}^{*0}(2^+)$	$s\bar{b}$	(5.850)	5

D(B), Ds(Bs) mesons yield as a function of γ_s/γ_q.

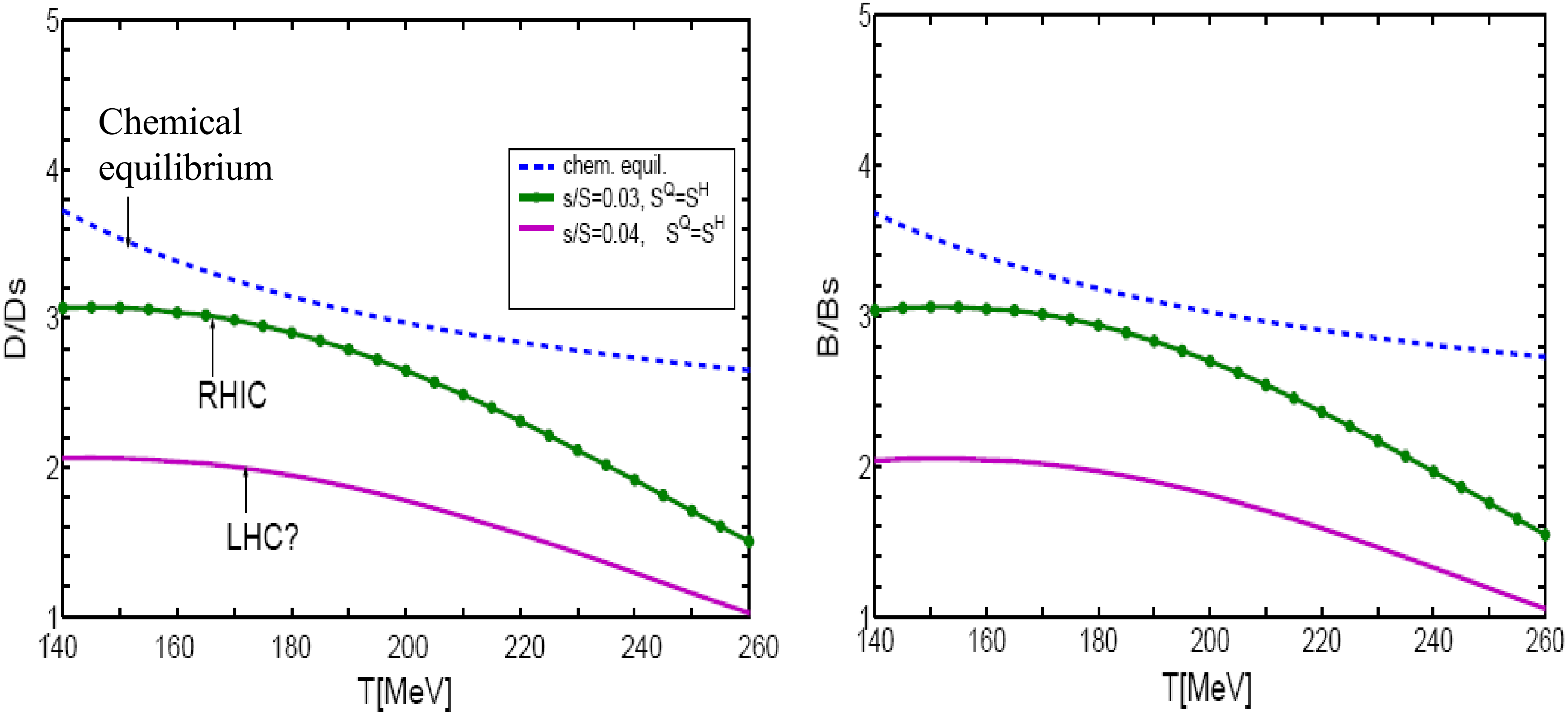


$$D(B)/N_{c(b)} \propto \gamma_{c(b)}\gamma_q/N_{c(b)}$$

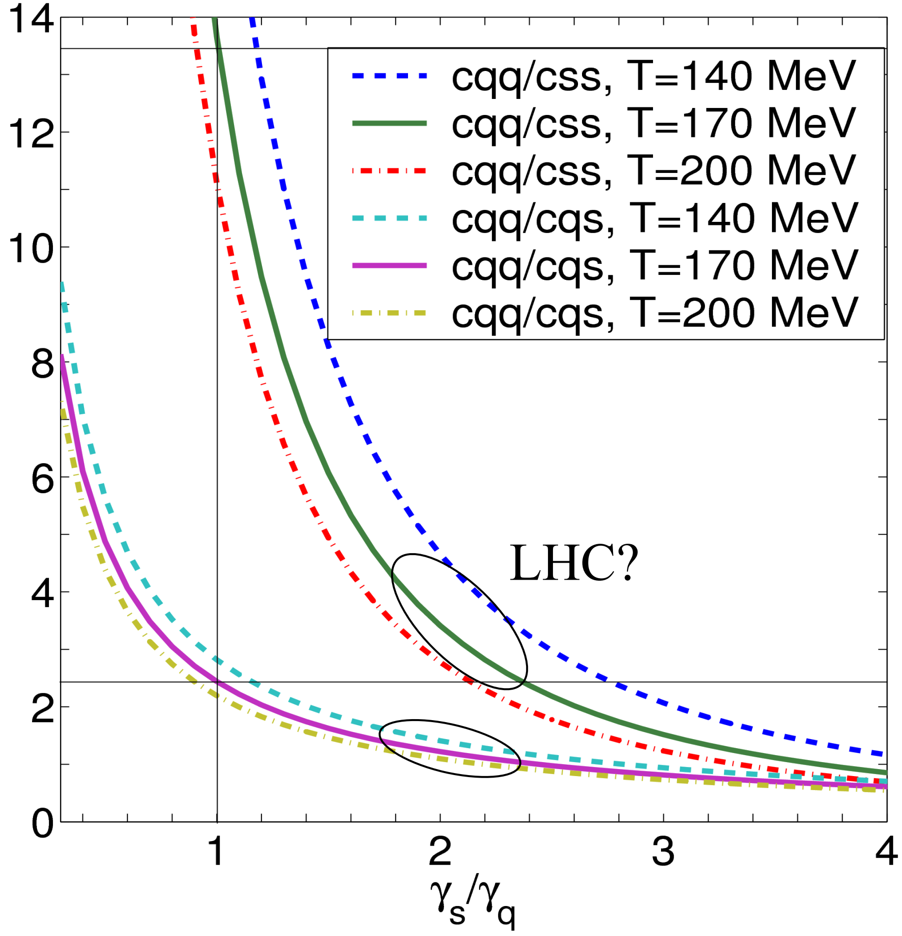
$$D_s(B_s)/N_{c(b)} \propto \gamma_{c(b)}\gamma_s/N_{c(b)}$$

$\gamma_{c(b)}/N_{c(b)}$ is almost independent from $N_{c(b)}$.

Ratio $D(B)/D_s(B_s)$ as a probe of T at measured s/S



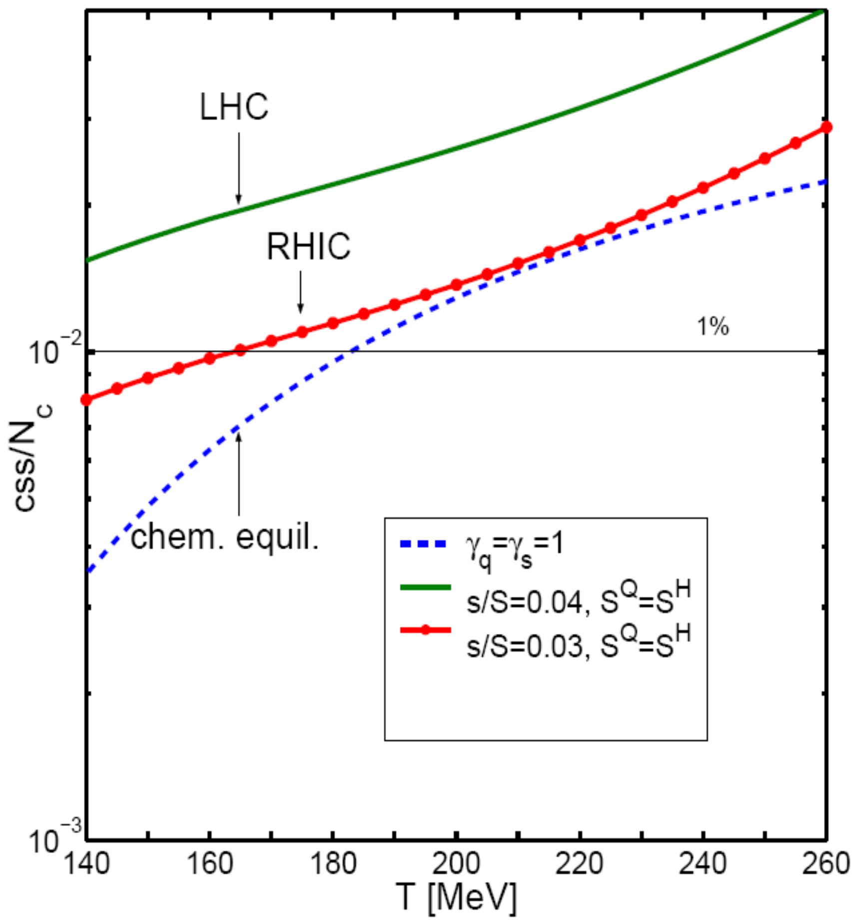
Non-strange to strange charm baryons yields ratios as a function of γ_s/γ_q ratio



$$cqq\,/\,cqs \propto (\gamma_s\,/\,\gamma_q)^{-1}$$

$$cqq\,/\,css \propto (\gamma_s\,/\,\gamma_q)^{-2}$$

Double strange charm baryons (Ω_c^0) yield as a function of hadronization temperature T

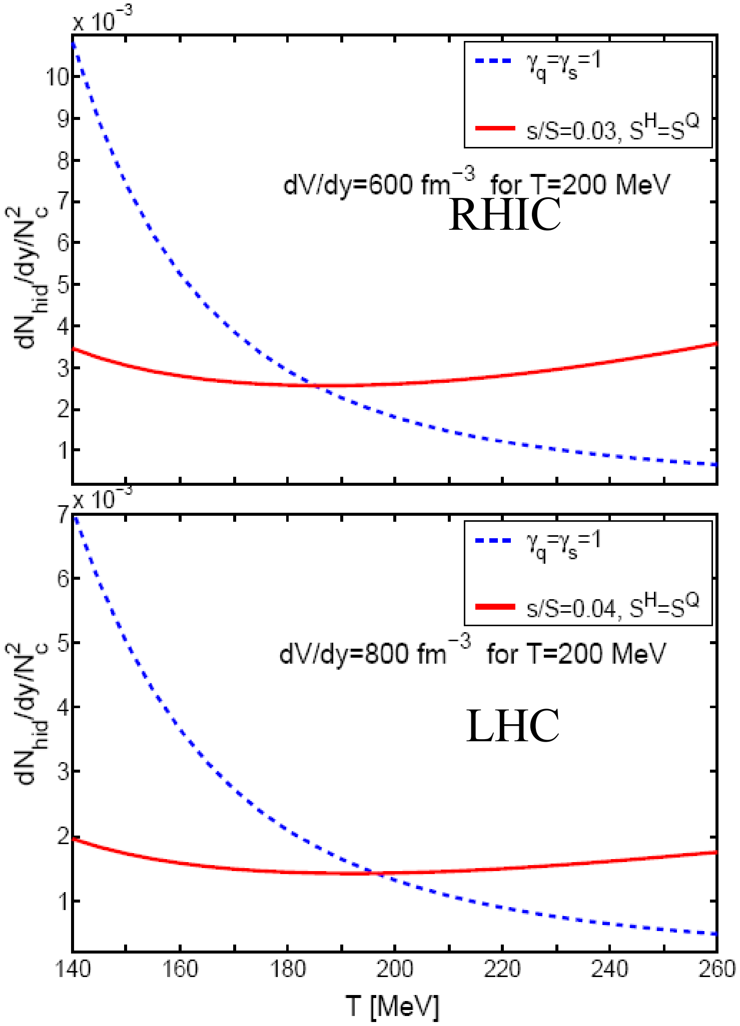


Ω_c^0 (2700 MeV) decay modes (seen):

- $\Sigma^+ K^- K^- \pi^+$
- $\Xi^0 K^- \pi^+$
- $\Xi^- K^- \pi^+ \pi^+$
- $\Omega^- \pi^+$
- $\Omega^- \pi^+ \pi^0$
- $\Omega^- \pi^- \pi^+ \pi^+$

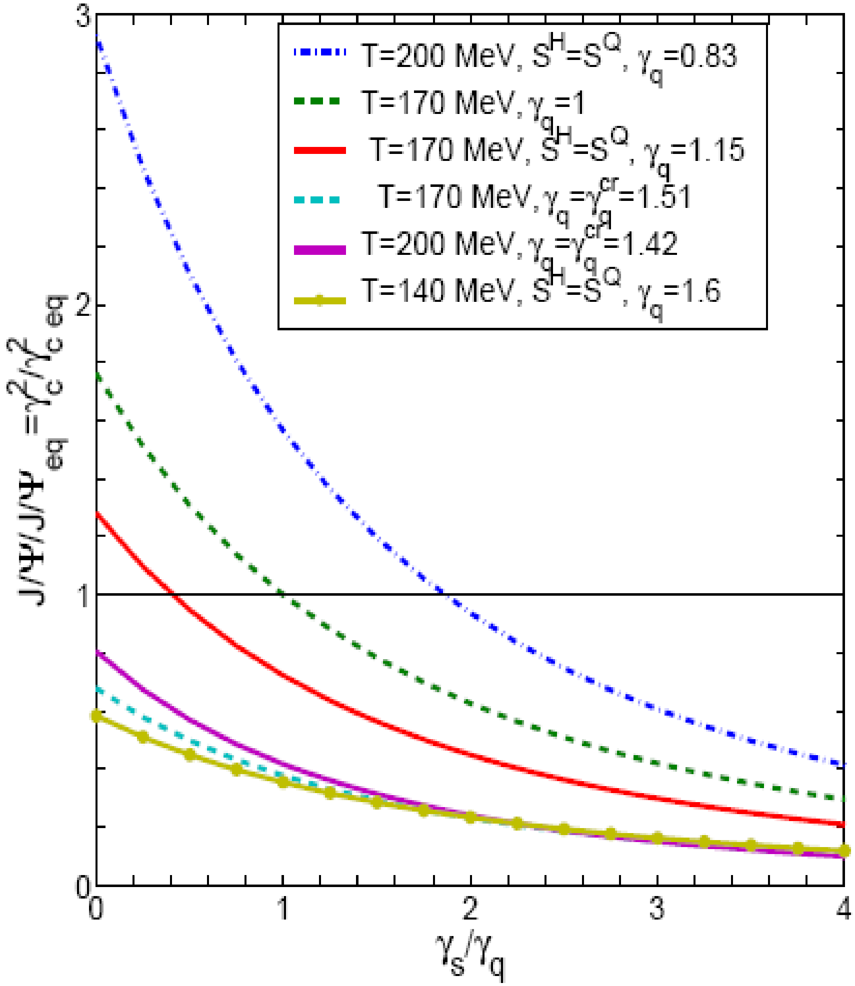
c tau = 21 mum

Total yield of all hidden charm mesons as a function of T.



hadron		mass(GeV)	g
$\eta_c(1S)$	$c\bar{c}$	2.9779	1
$J/\Psi(1S)$	$c\bar{c}$	3.0970	3
$\chi_{c0}(1P)$	$c\bar{c}$	3.4152	1
$\chi_{c1}(1P)$	$c\bar{c}$	3.5106	3
$h_c(1P)$	$c\bar{c}$	3.526	3
$\chi_{c2}(1P)$	$c\bar{c}$	3.5563	5
$\eta_c(2S)$	$c\bar{c}$	3.638	1
$\psi(2S)$	$c\bar{c}$	3.686	3
ψ	$c\bar{c}$	3.770	3
ψ	$c\bar{c}$	3.836	5
ψ	$c\bar{c}$	4.040	3
ψ	$c\bar{c}$	4.159	3
ψ	$c\bar{c}$	4.415	3

J/Ψ yield as a function of γ_s/γ_q



- Both entropy and strangeness contents enhancement may result to J/Ψ suppression.
- More light and\or strange quarks more probability for charm to bound to these quarks than to find anti-charm quark.

Conclusions

- Phase space occupancy factors of strange and light quarks have strong influence on heavy flavor hadron production.
- Significant increase of the yield of strange quark-containing charm (bottom) mesons and baryons with increase of s/S as compared to the chemical equilibrium yields.
- The change in the yield of hadrons without strangeness but with light quark(s) depends on both s/S and γ_q. The ratio of these hadrons to similar strange hadrons always decreases with increase of s/S.
- Yields of hadrons with two heavy quarks, as J/Ψ, decrease compared to chemical equilibrium when γ_q and\or $\gamma_s > 1$.

This provides a new mechanism of J/Ψ suppression.

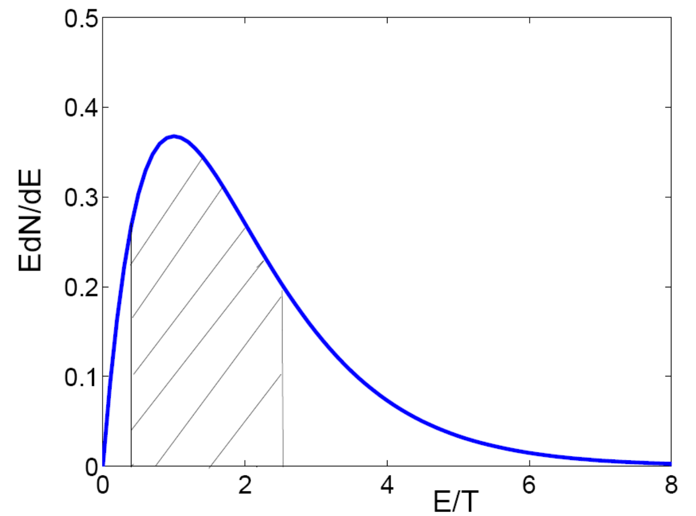
Statistical model

Assumed Boltzman distribution for

b, c, s, hadrons: $\frac{dN_i}{dy} = \gamma_i n_i^{eq} \frac{dV}{dy}$,

$$n_i^{eq} = \lambda_i \frac{T^3}{2\pi^2} g_i W(m_i/T),$$

where $W(x) = x^2 K_2(x)$



- λ=1 ($\mu = T \ln \lambda = 0$) for all particles
- γ_i : phase space occupancy factor; for γ_i =1, $n_i = n_i^{eq}$
- γ_i^Q is in QGP i=c, b, s, q (q is u or d)

γ_i^H after hadronization, e.g. for D mesons: $\gamma_D^H = \gamma_c^H \gamma_q^H$

Entropy after hadronization

- Because of liberation of color degree of freedom

$$\sigma^{Q} \geq 3\sigma^{H}$$

- The excess of entropy is observed in the multiplicity of particles in final state.
- After hadronizaton $S^{Q} \approx S^{H}$, $\gamma_q^{H} > 1$.
- When $\gamma_q^{H} = \gamma_q^{cr}$: Bose singularity for pions;

Maximum of possible entropy content after hadronization