Exotics hadrons in heavy ion collisions

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Outline

- Introduction
- Statistical model
- Coalescence model
- Production yields of exotics
- Results
- Conclusion

– This talk is based on

Identifying multiquark Hadrons from heavy ion collisions,
ExHIC Collaboration, Phys. Rev. Lett., **106**, 212001 (2011)

Exotic hadrons in heavy ion collisions,
ExHIC Collaboration, Phys. Rev. C, **84**, 064910 (2011)

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Introduction

– Normal hadrons

: Mesons and Baryons

– Multiquark hadrons

1) H dibaryon and scalar tetra quark (1976) $f_0(980)$

$K\bar{K}$ hadronic molecule (1990)

2) Hadronic molecules & multiquark states

$X(3872)$ Belle (2003)

$D_{sJ}(2317)$ BaBar (2003)

Introduction

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1) H dibaryon and scalar tetra quark (1976) $f_0(980)$

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2) Hadronic molecules & multiquark states

$X(3872)$ Belle (2003) $\rightarrow \bar{D}D^*, D\bar{D}^*, q\bar{q}c\bar{c}$

$D_{sJ}(2317)$ BaBar (2003) $\rightarrow DK, c\bar{s}, q\bar{q}cs$

– Exotic hadrons considered in this work

Particle	m (MeV)	g	I	J^P	$2q/3q/6q$	$4q/5q/8q$	Mol.	$\omega_{\mathrm{Mol.}}$ (MeV)	Decay mode
Mesons									
$f_0(980)$	980	1	0	0^+	$q\bar{q}, s\bar{s}(L=1)$	$q\bar{q}s\bar{s}$	$\bar{K}K$	67.8(B)	$\pi\pi$ (Strong decay)
$a_0(980)$	980	3	1	0^+	$q\bar{q}(L=1)$	$q\bar{q}s\bar{s}$	$\bar{K}K$	67.8(B)	$\eta\pi$ (Strong decay)
$K(1460)$	1460	2	1/2	0^-	$q\bar{s}$	$q\bar{q}q\bar{s}$	$\bar{K}KK$	69.0(R)	$K\pi\pi$ (Strong decay)
$D_s(2317)$	2317	1	0	0^+	$c\bar{s}(L=1)$	$q\bar{q}c\bar{s}$	DK	273(B)	$D_s\pi$ (Strong decay)
T_{cc}^{1}[a]	3797	3	0	1^+	—	$qq\bar{c}\bar{c}$	$\bar{D}\bar{D}^*$	476(B)	$K^+\pi^- + K^+\pi^- + \pi^-$
$X(3872)$	3872	3	0	$1^+, 2^-$[c]	$c\bar{c}(L=2)$	$q\bar{q}c\bar{c}$	$\bar{D}D^*$	3.6(B)	$J/\psi\pi\pi$ (Strong decay)
$Z^+(4430)$[b]	4430	3	1	0^-[c]	—	$q\bar{q}c\bar{c}(L=1)$	$D_1\bar{D}^*$	13.5(B)	$J/\psi\pi$ (Strong decay)
T_{cb}^{0}[a]	7123	1	0	0^+	—	$qq\bar{c}\bar{b}$	$\bar{D}B$	128(B)	$K^+\pi^- + K^+\pi^-$
Baryons									
$\Lambda(1405)$	1405	2	0	$1/2^-$	$qqs(L=1)$	$qqqs\bar{q}$	$\bar{K}N$	20.5(R)–174(B)	$\pi\Sigma$ (Strong decay)
$\Theta^+(1530)$[b]	1530	2	0	$1/2^+$[c]	—	$qqqq\bar{s}(L=1)$	—	—	KN (Strong decay)
$\bar{K}KN$[a]	1920	4	1/2	$1/2^+$	—	$qqqs\bar{s}(L=1)$	$\bar{K}KN$	42(R)	$K\pi\Sigma, \pi\eta N$ (Strong decay)
$\bar{D}N$[a]	2790	2	0	$1/2^-$	—	$qqqq\bar{c}$	$\bar{D}N$	6.48(R)	$K^+\pi^-\pi^- + p$
$\bar{D}^*N$[a]	2919	4	0	$3/2^-$	—	$qqqq\bar{c}(L=2)$	$\bar{D}^*N$	6.48(R)	$\bar{D} + N$ (Strong decay)
Θ_{cs}[a]	2980	4	1/2	$1/2^+$	—	$qqqs\bar{c}(L=1)$	—	—	$\Lambda + K^+\pi^-$
BN[a]	6200	2	0	$1/2^-$	—	$qqqq\bar{b}$	BN	25.4(R)	$K^+\pi^-\pi^- + \pi^+ + p$
B^*N[a]	6226	4	0	$3/2^-$	—	$qqqq\bar{b}(L=2)$	B^*N	25.4(R)	$B + N$ (Strong decay)
Dibaryons									
H[a]	2245	1	0	0^+	$qqqqss$	—	ΞN	73.2(B)	$\Lambda\Lambda$ (Strong decay)
$\bar{K}NN$[b]	2352	2	1/2	0^-[c]	$qqqqqs(L=1)$	$qqqqqq\,s\bar{q}$	$\bar{K}NN$	20.5(T)–174(T)	ΛN (Strong decay)
$\Omega\Omega$[a]	3228	1	0	0^+	$ssssss$	—	$\Omega\Omega$	98.8(R)	$\Lambda K^- + \Lambda K^-$
H_c^{++}[a]	3377	3	1	0^+	$qqqqsc$	—	$\Xi_c N$	187(B)	$\Lambda K^-\pi^+\pi^+ + p$
$\bar{D}NN$[a]	3734	2	1/2	0^-	—	$qqqqqq\,q\bar{c}$	$\bar{D}NN$	6.48(T)	$K^+\pi^- + d, K^+\pi^-\pi^- + p + p$
BNN[a]	7147	2	1/2	0^-	—	$qqqqqq\,q\bar{b}$	BNN	25.4(T)	$K^+\pi^- + d, K^+\pi^- + p + p$

[a]Particles that are newly predicted by theoretical models.
[b]Particles that are not yet established.
[c]Undetermined quantum numbers of existing particles.

– The purpose of this work

1) To estimate the possibility of observing predicted exotics with/without heavy quarks in heavy ion collision experiment

2) To find a possible solution to a problem of identifying hadronic molecular states and/or hadrons with multiquark components

– We focus on hadron production yields

1) Normal hadron (light quark hadrons) production yields are well described by the statistical model

2) Many aspects of the heavy ion collision experimental results have been explained by the coalescence model

Statistical model

P. Braun-Munzinger, J. Stachel, J. P. Wessels, N. Xu, Phys. Lett. **B344**, 43 (1995)

1) In a chemically and thermally equilibrated system of non-interacting hadrons and resonances, the particle production yield is given by

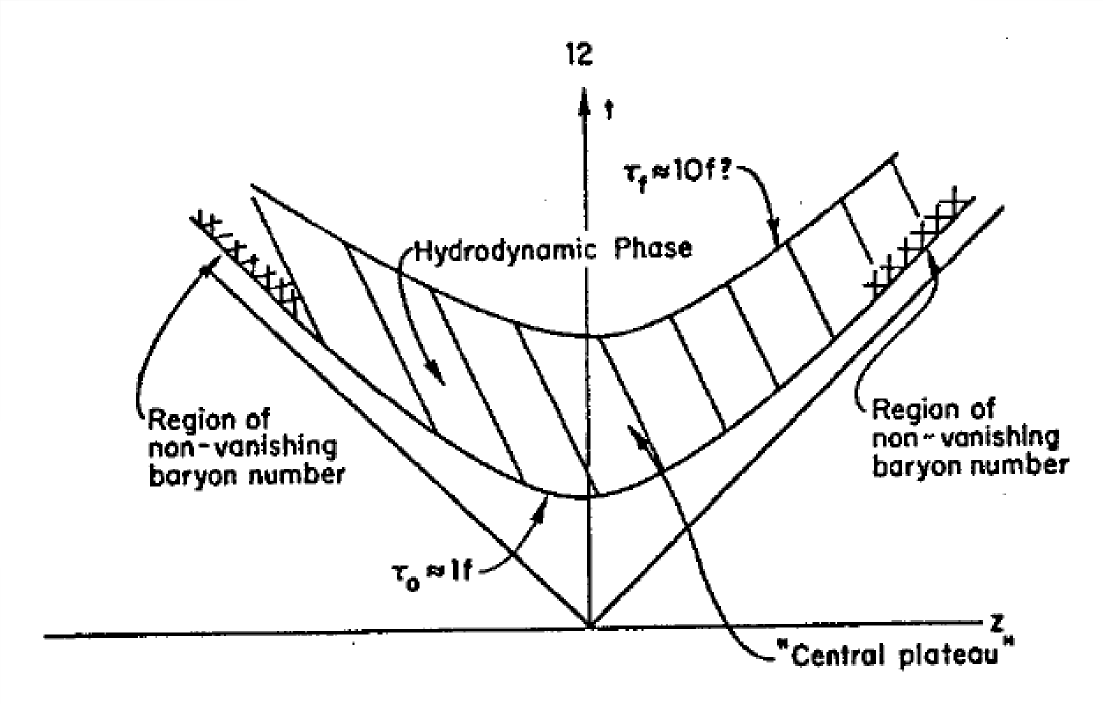
$$N_i = V_H \frac{g_i}{2\pi^2} \int_0^\infty \frac{p^2 dp}{\gamma_i^{-1} e^{E_i/T_H} \pm 1} \qquad E_i = \sqrt{m_i^2 + p_i^2}$$

Take the incomplete strangeness and charm equilibration into account

$$\gamma = \gamma_c^{n_c + n_{\bar{c}}} e^{[\mu_B n_B + \mu_s n_s]}$$

2) The hadronization temperature and the chemical potential are determined from the experimental data

– Time evolution of quark-gluon plasma



$$\tau = \sqrt{t^2 - z^2}$$

J. D. Bjorken, Phys. Rev. D **27**, 140 (1983)

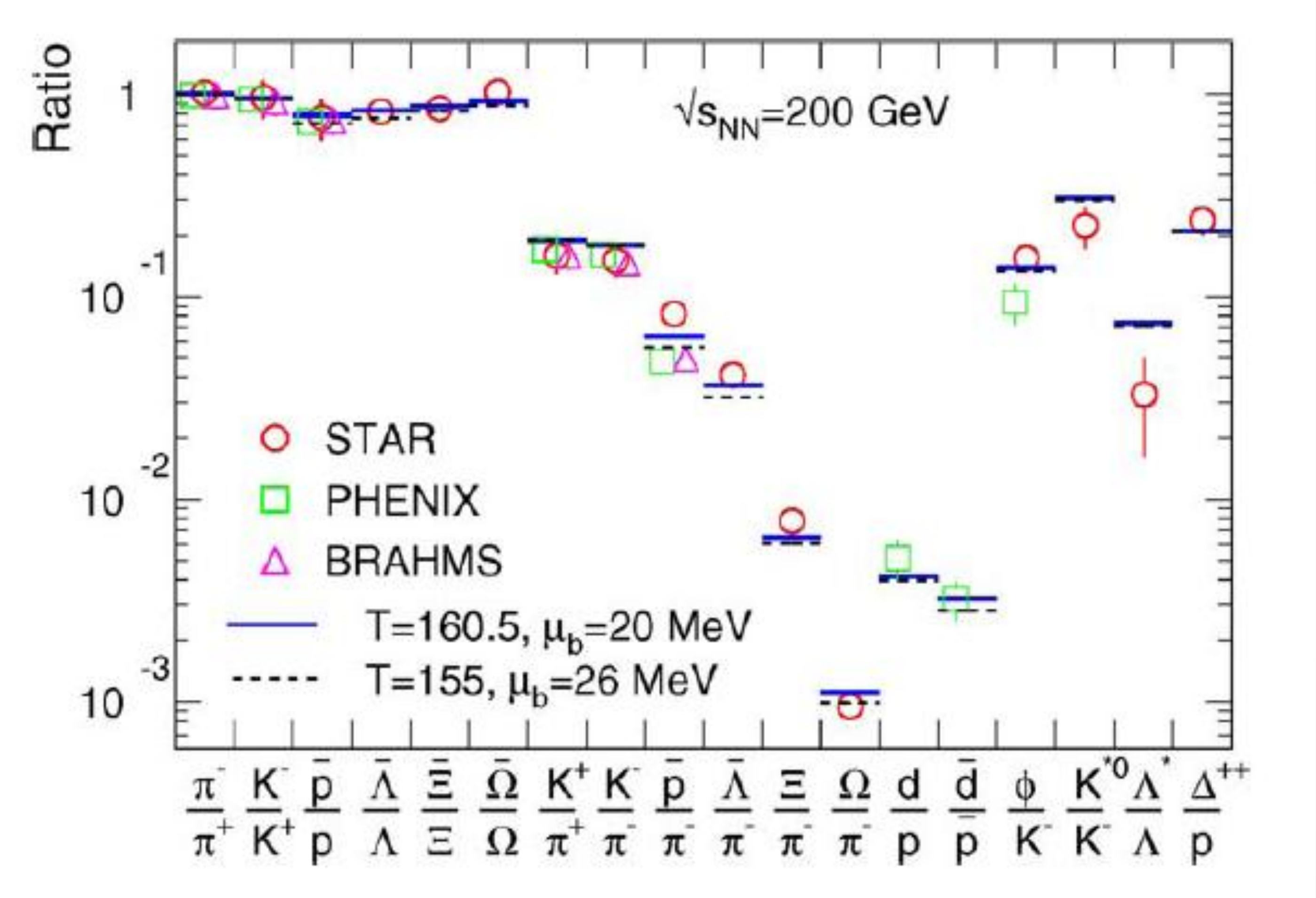
i. Collision

ii. Pre-equilibrium : QGP

iii. Hadronization : Mixed phase

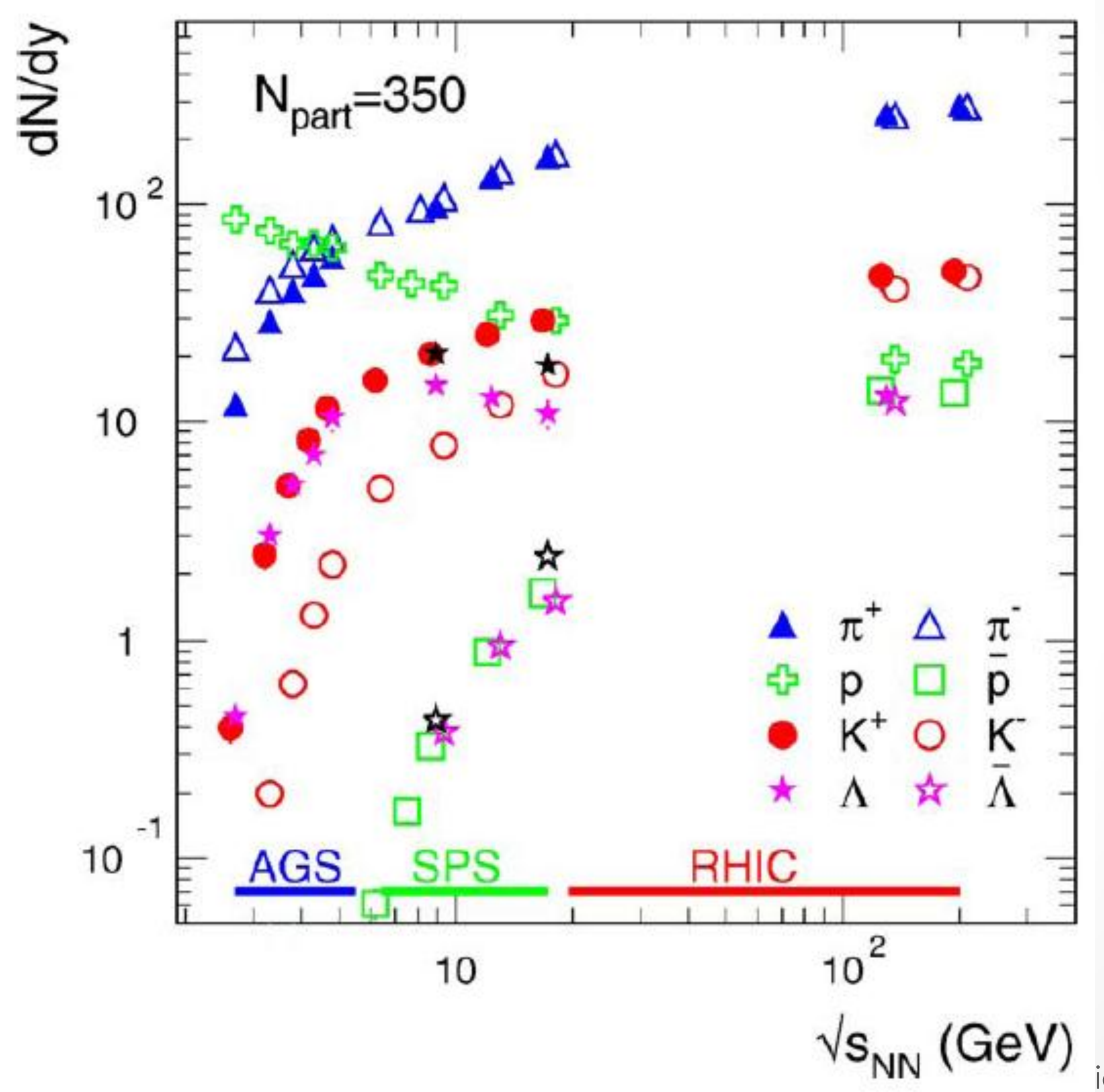
iv. Freeze-out : Hadron gas

3) The temperature obtained from the analysis of the yield ratios reflects the stage of the freeze-out



A. Andronic, P. Braun-Munzinger, and J. Stachel, Nucl. Phys. A **772**, 167 (2006)

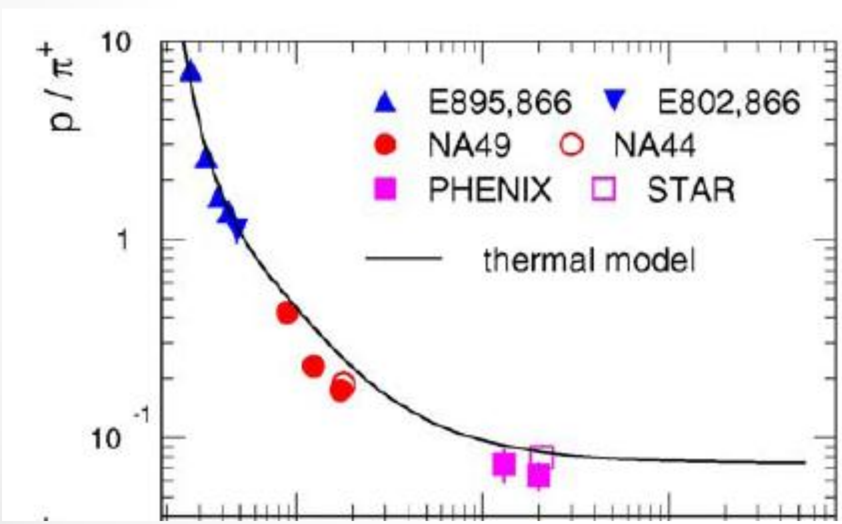
4) The energy dependence of experimental hadron yields at mid-rapidity in central nucleus-nucleus collisions

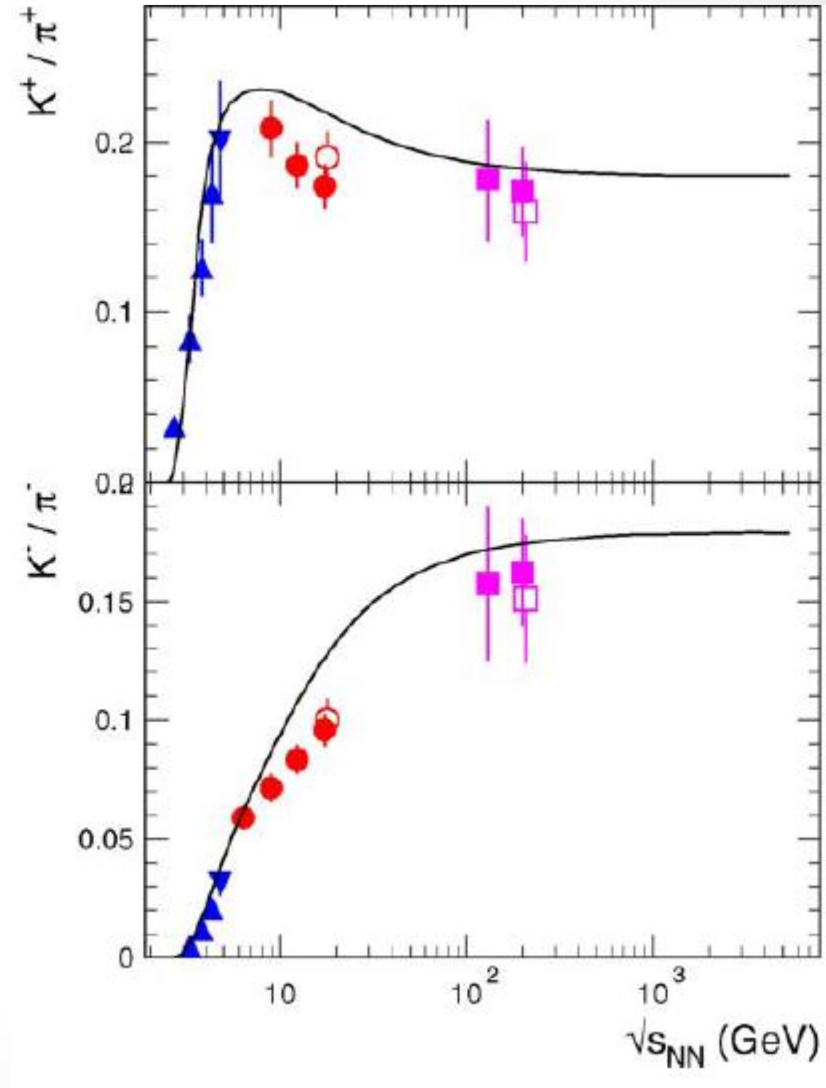


5) The energy dependence of hadron ratios

: The yield is the convolution of two competing contribution as a function of energy

i. The decreasing net light quark
ii. The increasing production of quark-antiquark pairs





Coalescence model

– Yields of hadrons with n constituents

$$N^{Coal} = g\int\left[\prod_{i=1}^{n}\frac{1}{g_i}\frac{p_i\cdot d\sigma_i}{(2\pi)^3}\frac{d^3p_i}{E_i}f(x_i,p_i)\right]f^W(x_1,\cdots,x_n:p_1,\cdots,p_n)$$

describe the dynamic process of converting constituents to a bound state in the presence of a partonic matter

1) Wigner function, the coalescence probability function

$$f^W(x_1,\cdots,x_n:p_1,\cdots,p_n) = \int\prod_{i=1}^{n}dy_i e^{p_i y_i}\psi^*\left(x_1+\frac{y_1}{2},\cdots,x_n+\frac{y_n}{2}\right)\psi\left(x_1-\frac{y_1}{2},\cdots,x_n-\frac{y_n}{2}\right)$$

depends on Lorentz-invariant combinations of the relative coordinates between the particles and parametrizes the overlap integral between the particle wave functions

2) Covariant phase space density involves a Lorentz-invariant phase space integration of a space-like hyper-surface, which counts the number of particles contained in the system

$$\int p_i \cdot d\sigma_i \frac{d^3 p_i}{(2\pi)^3 E_i} f(x_i, p_i) = N_i$$

: The hyper-surface for the spatial integration is the same for all particles involved in the coalescence process.

– Hadron and quark coalescence

1) Confirmation of hadron mechanism, quark recombination or quark coalescence is one of the evidences of the formation of quark-gluon plasma in relativistic heavy ion collisions

– Hadron coalescence

PHYSICAL REVIEW C VOLUME 44, NUMBER 4 OCTOBER 1991

Covariant coalescence model for relativistically expanding systems

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(Received 1 March 1991)

1) A covariant coalescence model for relativistically expanding fireball formed in high-energy nucleus collisions is developed and is applied to predict the formation rate of hadrons like deuteron, or pentaquark

2) The cluster distribution factorizes for arbitrary parent rapidity distributions : Coalescence is basically a nonrelativistic phenomenon

$$\frac{dN_C}{dy} = C\frac{dN_1}{dy}\frac{dN_2}{dy} \qquad N_C = CN_1N_2$$

3) Momentum spectra of the clusters are studied to find

i. whether the transverse mass spectra of the clusters can still be thermally parametrized if one starts with thermal parent distribution

ii. how the longitudinal momentum distribution of the clusters is influenced by the longitudinal expansion

4) Some details

i. A free parameter in Gaussian wave packets for the coalescence factor is proportional to the inverse size of the cluster to be formed

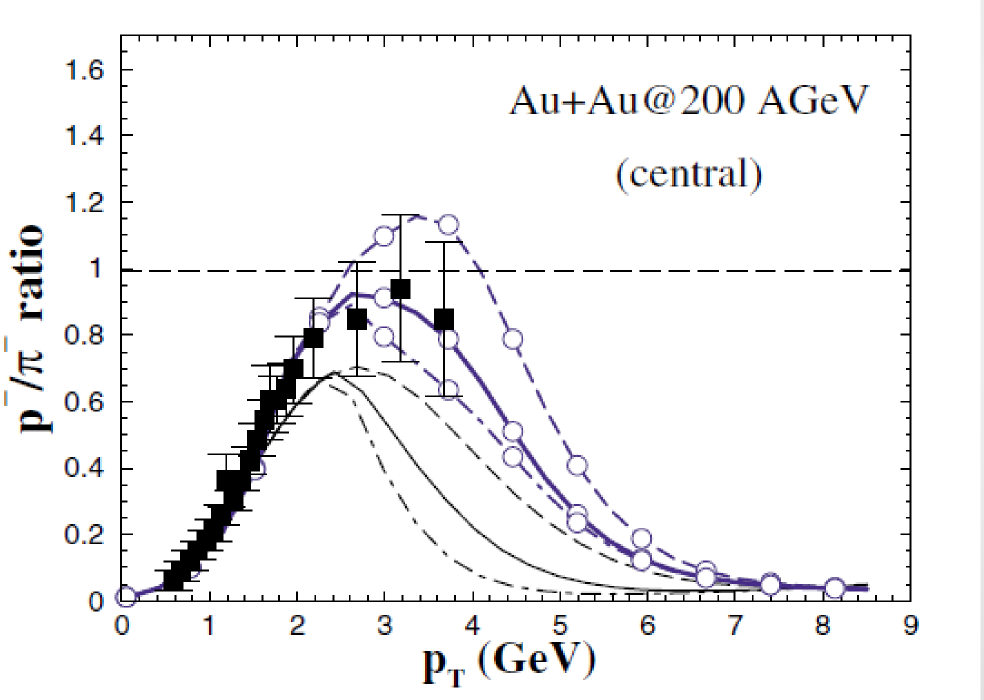
ii. The coalescence rate is proportional to a volume factor which for small clusters approaches the ratio (cluster volume/reaction zone volume) : this dependence can be used to determine the reaction zone volume from the coalescence yield

– Quark coalescence or quark recombination

V. Greco, C. M. Ko, and P. Levai, Phys. Rev. Lett. **90**, 202302 (2003)
R. J. Freis. B. Muller, C. Nonaka, and S. Bass, Phys. Rev. Lett. **90**, 202303 (2003)

1) Fragmentation picture
: A parton spectrum relates the probability for a parton to hadronize into a hadron, carrying a fraction z<1 of the momentum of the parent parton

i. The puzzle in antiproton /pion ratio
Requires a rescaling for a fraction z for all hadrons



ii. There must be a competition between two particle production mechanisms

: A fragmentation dominates at large transverse momenta and a coalescence prevails at lower transverse momenta

$$p_T^{Frag} = \frac{p_T^h}{z} \quad \text{vs.} \quad p_T^{Coal} = \frac{p_T^h}{n}$$

2) Quark number scaling of the elliptic flow

Denes Molnar and Sergei A. Voloshin, Phys. Rev. Lett **91**, 092301 (2003)

$$v_2(p_T) = \langle \cos 2\varphi \rangle_{p_T} = \frac{\int d\varphi \cos 2\varphi \frac{d^2N}{dp_T^2}}{\int d\varphi \frac{d^2N}{dp_T^2}}$$

Assumption : partons have elliptical anisotropy

$$\frac{dN_q}{p_T dp_T d\varphi} = \frac{1}{2\pi} \frac{dN_q}{p_T dp_T} \left[1 + 2v_{2,q}(p_T)\cos(2\varphi) \right]$$

Coalescence model predicts

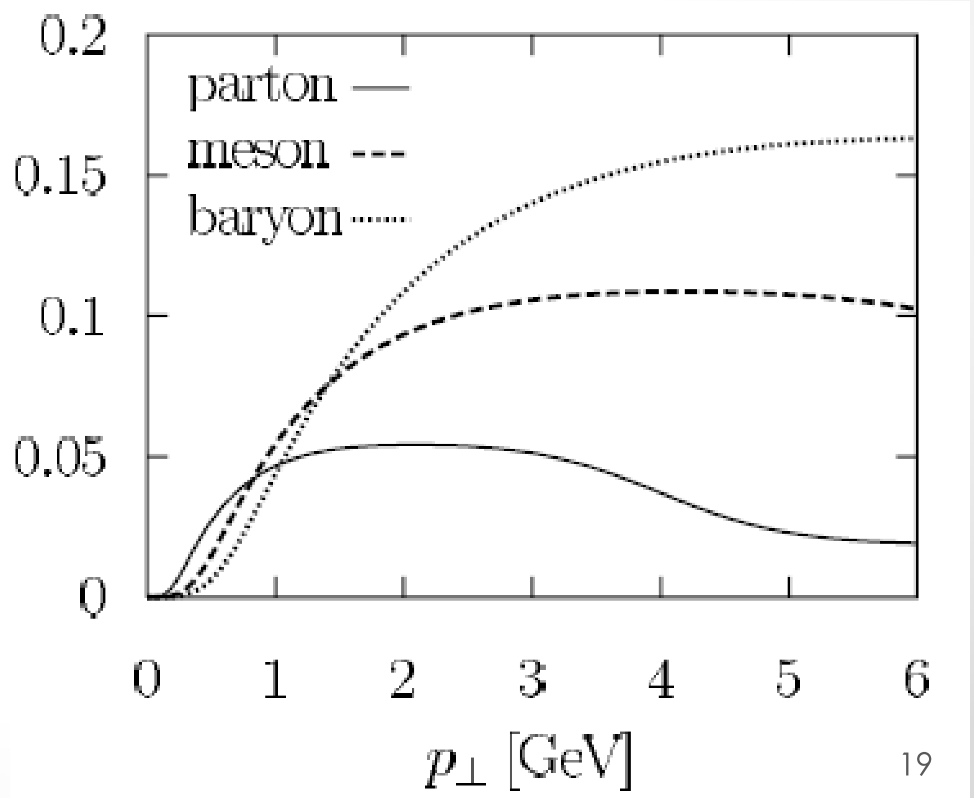
$$v_{2,M}(p_T) = \frac{2v_{2,q}(p_T/2)}{1+2v_{2,q}^2(p_T/2)}$$

$$v_{2,B}(p_T) = \frac{3v_{2,q}(p_T/3)+3v_{2,q}^3(p_T/3)}{1+6v_{2,q}^2(p_T/3)}$$

$$v_{2,h}(p_T) \approx n v_{2,q}\left(\frac{1}{n}p_T\right)$$

3) The coalescence model also nicely explains the yield of antihyperons recently discovered in heavy ion collision at RHIC

STAR Collaboration, Science **328**, 58 (2010)



Production yields of exotics

1) Evaluate the yields of exotic hadrons for all possible structure configurations
; normal hadrons, multiquark hadrons, hadronic molecules

$$N^{Coal} = g \int \left[\prod_{i=1}^{n} \frac{1}{g_i} \frac{p_i \cdot d\sigma_i}{(2\pi)^3} \frac{d^3 p_i}{E_i} f(x_i, p_i) \right] f^W(x_1, \cdots, x_n : p_1, \cdots, p_n)$$

Production yields of exotics

1) Evaluate the yields of exotic hadrons for all possible structure configurations
; normal hadrons, multiquark hadrons, hadronic molecules

$$N_{X(3872)}^{Coal} = g\int \left[- \cdots \quad \begin{matrix} c\bar{c} \\ q\bar{q}c\bar{c} \\ \bar{D}D^{*} \end{matrix} \quad \cdots - \right] f^{W}(x_1, \cdots, x_n : p_1, \cdots, p_n)$$

2) It is expected that the probability to combine n quarks into a compact region is suppressed as n increases

3) The internal structure of hadrons produced is considered

s-wave
$$\frac{N_i}{g_i}\frac{(4\pi\sigma_i^2)^{3/2}}{V(1+2\mu_i T\sigma_i^2)} \sim 0.360$$

p-wave
$$\frac{N_i}{g_i}\frac{(4\pi\sigma_i^2)^{3/2}}{V(1+2\mu_i T\sigma_i^2)}\frac{2}{3}\left[\frac{2\mu_i T\sigma_i^2}{(1+2\mu_i T\sigma_i^2)}\right] \sim 0.093$$

d-wave
$$\frac{N_i}{g_i}\frac{(4\pi\sigma_i^2)^{3/2}}{V(1+2\mu_i T\sigma_i^2)}\frac{8}{15}\left[\frac{2\mu_i T\sigma_i^2}{(1+2\mu_i T\sigma_i^2)}\right]^2 \sim 0.029$$

4) Final results

$$N_h^{Coal} \cong g\prod_{j=1}^{n}\frac{N_i}{g_i}\prod_{i=1}^{n-1}\frac{(4\pi\sigma_i^2)^{3/2}}{V(1+2\mu_i T\sigma_i^2)}\frac{(2l_i)!!}{(2l_i+1)!!}\left[\frac{2\mu_i T\sigma_i^2}{(1+2\mu_i T\sigma_i^2)}\right]^{l_i}$$

$$\sigma_i = \frac{1}{\sqrt{\mu_i\omega}} \qquad \frac{1}{\mu_i} = \frac{1}{m_{i+1}} + \frac{1}{\sum_j^i m_j}$$

– Free parameters

1) Quark coalescence :

: Reference hadrons - $\Lambda(1115),\ \Lambda_c(2286)$

$$N^{Stat,total}_{\Lambda_C(2286)} = N^{Stat}_{\Lambda_C(2286)} + N^{Stat}_{\Sigma_C(2455)} + N^{Stat}_{\Sigma_C(2520)}$$

$$+0.67 \times N^{Stat}_{\Lambda_C(2625)} = N^{Coal,total}_{\Lambda_C(2286)}(\omega_c)$$

$$\rightarrow \omega_s = 519MeV, \quad \omega_c = 385MeV$$

2) Hadron coalescence

: The relation between the binding energy and the root mean square radius

$$B.E. \cong \frac{\hbar^2}{2\mu a_0^2}$$

$$\langle r^2 \rangle \cong \frac{a_0^2}{2}$$

$$\omega = \frac{3}{2\mu\langle r^2 \rangle}$$

$$\rightarrow \omega_{\Lambda(1405)} = \frac{3}{2\mu_{\Lambda(1405)}\langle r^2 \rangle_{\Lambda(1405)}}$$

$$= 20.5MeV$$

Results

1) Summary of exotic hadrons considered (Mesons & Baryons)

Particle	m (MeV)	g	I	J^P	$2q/3q/6q$	$4q/5q/8q$	Mol.	$\omega_{\mathrm{Mol.}}$ (MeV)	Decay mode
Mesons									
$f_0(980)$	980	1	0	0^+	$q\bar{q}, s\bar{s}(L=1)$	$q\bar{q}s\bar{s}$	$\bar{K}K$	67.8(B)	$\pi\pi$ (Strong decay)
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T_{cc}^{1} [a]	3797	3	0	1^+	—	$qq\bar{c}\bar{c}$	$\bar{D}\bar{D}^*$	476(B)	$K^+\pi^- + K^+\pi^- + \pi^-$
$X(3872)$	3872	3	0	$1^+, 2^-$ [c]	$c\bar{c}(L=2)$	$q\bar{q}c\bar{c}$	$\bar{D}D^*$	3.6(B)	$J/\psi\pi\pi$ (Strong decay)
$Z^+(4430)$ [b]	4430	3	1	0^- [c]	—	$q\bar{q}c\bar{c}(L=1)$	$D_1\bar{D}^*$	13.5(B)	$J/\psi\pi$ (Strong decay)
T_{cb}^{0} [a]	7123	1	0	0^+	—	$qq\bar{c}\bar{b}$	$\bar{D}B$	128(B)	$K^+\pi^- + K^+\pi^-$
Baryons									
$\Lambda(1405)$	1405	2	0	$1/2^-$	$qqs(L=1)$	$qqqs\bar{q}$	$\bar{K}N$	20.5(R)–174(B)	$\pi\Sigma$ (Strong decay)
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$\bar{D}^*N$ [a]	2919	4	0	$3/2^-$	—	$qqqq\bar{c}(L=2)$	$\bar{D}^*N$	6.48(R)	$\bar{D} + N$ (Strong decay)
Θ_{cs} [a]	2980	4	1/2	$1/2^+$	—	$qqqs\bar{c}(L=1)$	—	—	$\Lambda + K^+\pi^-$
BN [a]	6200	2	0	$1/2^-$	—	$qqqq\bar{b}$	BN	25.4(R)	$K^+\pi^-\pi^- + \pi^+ + p$
B^*N [a]	6226	4	0	$3/2^-$	—	$qqqq\bar{b}(L=2)$	B^*N	25.4(R)	$B + N$ (Strong decay)

2) Estimated exotic hadron yields at RHIC and LHC

	RHIC				LHC			
	$2q/3q/6q$	$4q/5q/8q$	Mol.	Stat.	$2q/3q/6q$	$4q/5q/8q$	Mol.	Stat.
Mesons								
$f_0(980)$	3.8, 0.73($s\bar{s}$)	0.10	13	5.6	10, 2.0 ($s\bar{s}$)	0.28	36	15
$a_0(980)$	11	0.31	40	17	31	0.83	1.1×10^{2}	46
$K(1460)$	—	0.59	3.6	1.3	—	1.6	9.3	3.2
$D_s(2317)$	1.3×10^{-2}	2.1×10^{-3}	1.6×10^{-2}	5.6×10^{-2}	8.7×10^{-2}	1.4×10^{-2}	0.10	0.35
T_{cc}^{1} [a]	—	4.0×10^{-5}	2.4×10^{-5}	4.3×10^{-4}	—	6.6×10^{-4}	4.1×10^{-4}	7.1×10^{-3}
$X(3872)$	1.0×10^{-4}	4.0×10^{-5}	7.8×10^{-4}	2.9×10^{-4}	1.7×10^{-3}	6.6×10^{-4}	1.3×10^{-2}	4.7×10^{-3}
$Z^{+}(4430)$ [b]	—	1.3×10^{-5}	2.0×10^{-5}	1.4×10^{-5}	—	2.1×10^{-4}	3.4×10^{-4}	2.4×10^{-4}
T_{cb}^{0} [a]	—	6.1×10^{-8}	1.8×10^{-7}	6.9×10^{-7}	—	6.1×10^{-6}	1.9×10^{-5}	6.8×10^{-5}
Baryons								
$\Lambda(1405)$	0.81	0.11	1.8–8.3	1.7	2.2	0.29	4.7–21	4.2
Θ^{+} [b]	—	2.9×10^{-2}	—	1.0	—	7.8×10^{-2}	—	2.3
$\bar{K}KN$ [a]	—	1.9×10^{-2}	1.7	0.28	—	5.2×10^{-2}	4.2	0.67
$\bar{D}N$ [a]	—	2.9×10^{-3}	4.6×10^{-2}	1.0×10^{-2}	—	2.0×10^{-2}	0.28	6.1×10^{-2}
$\bar{D}^{*}N$ [a]	—	7.1×10^{-4}	4.5×10^{-2}	1.0×10^{-2}	—	4.7×10^{-3}	0.27	6.2×10^{-2}
Θ_{cs} [a]	—	5.9×10^{-4}	—	7.2×10^{-3}	—	3.9×10^{-3}	—	4.5×10^{-2}
BN [a]	—	1.9×10^{-5}	8.0×10^{-5}	3.9×10^{-5}	—	7.7×10^{-4}	2.8×10^{-3}	1.4×10^{-3}
$B^{*}N$ [a]	—	5.3×10^{-6}	1.2×10^{-4}	6.6×10^{-5}	—	2.1×10^{-4}	4.4×10^{-3}	2.4×10^{-3}
Dibaryons								
H [a]	3.0×10^{-3}	—	1.6×10^{-2}	1.3×10^{-2}	8.2×10^{-3}	—	3.8×10^{-2}	3.2×10^{-2}
$\bar{K}NN$ [b]	5.0×10^{-3}	5.1×10^{-4}	0.011–0.24	1.6×10^{-2}	1.3×10^{-2}	1.4×10^{-3}	0.026 – 0.54	3.7×10^{-2}
$\Omega\Omega$ [a]	3.2×10^{-5}	—	1.5×10^{-5}	6.4×10^{-5}	8.6×10^{-5}	—	4.4×10^{-5}	1.9×10^{-4}
H_c^{++} [a]	3.0×10^{-4}	—	3.3×10^{-4}	7.5×10^{-4}	2.0×10^{-3}	—	1.9×10^{-3}	4.2×10^{-3}
$\bar{D}NN$ [a]	—	2.9×10^{-5}	1.8×10^{-3}	7.9×10^{-5}	—	2.0×10^{-4}	9.8×10^{-3}	4.2×10^{-4}
BNN [a]	—	2.3×10^{-7}	1.2×10^{-6}	2.4×10^{-7}	—	9.2×10^{-6}	3.7×10^{-5}	7.6×10^{-6}

[a] Particles that are newly predicted by theoretical model.

[b] Particles that are not yet established.

3) The loosely bound exotic hadron molecules are more produced

$$2 < \frac{N^{Coal}_{i,molecule}}{N^{Stat}_i}$$

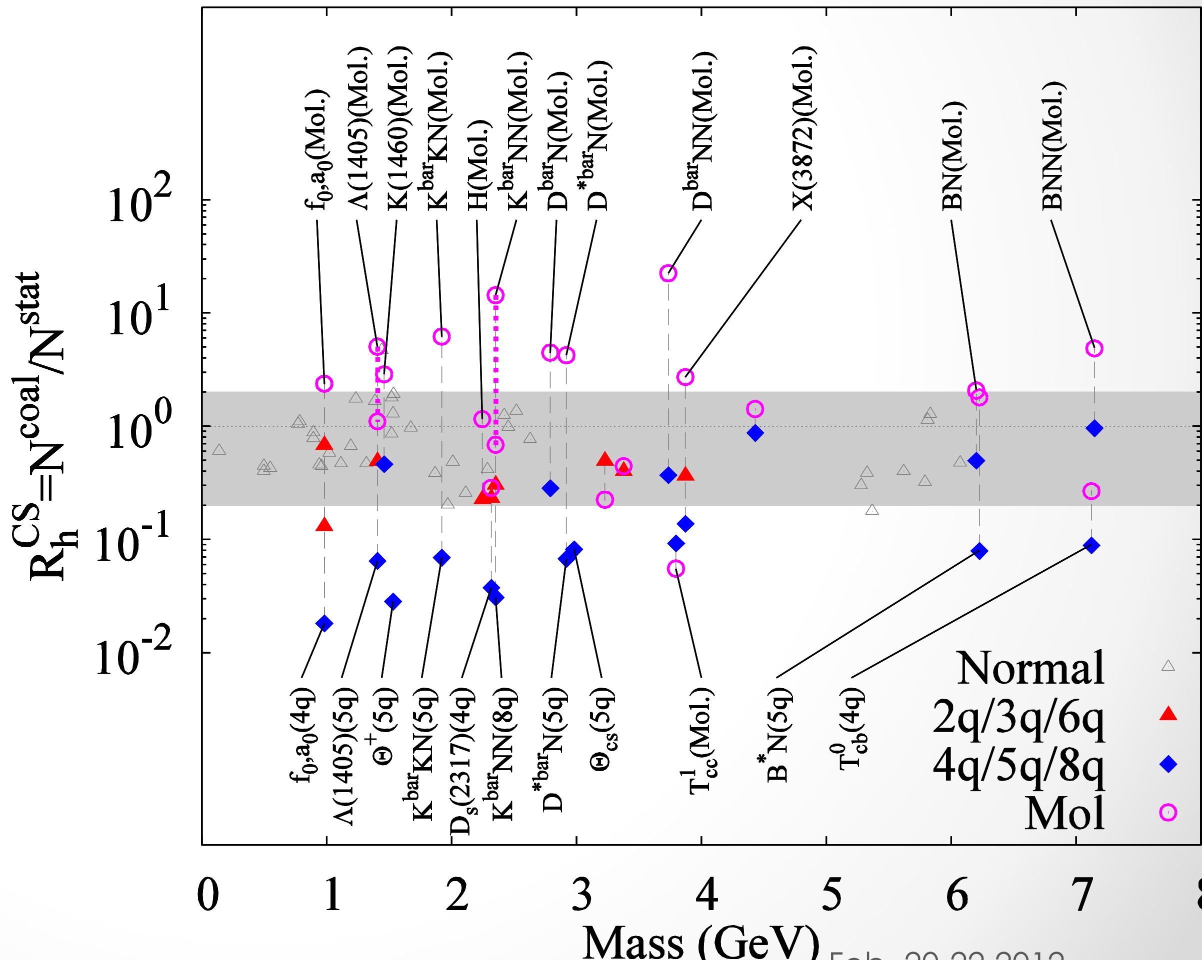
Normal hadron zone

$$0.2 < \frac{N^{Coal}_{i,normal}}{N^{Stat}_i} < 2$$

The exotic multiquark hadrons become suppressed

$$\frac{N^{Coal}_{i,multiquark}}{N^{Stat}_i} < 0.2$$

Coal. / Stat. ratio at RHIC



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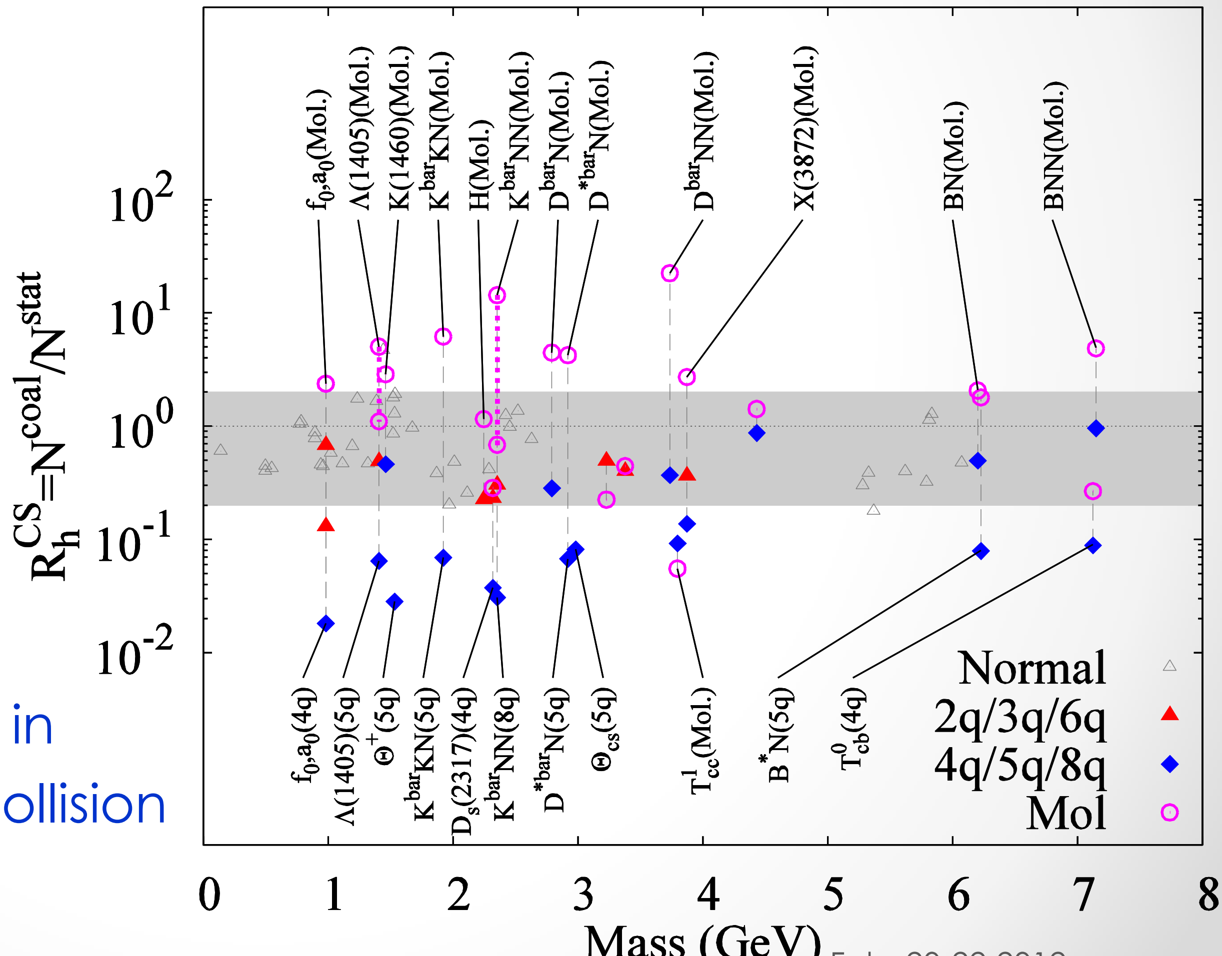
The yield of a hadron in relativistic heavy ion collision reflects its structure!!

Coal. / Stat. ratio at RHIC



4) Comparison to experimental data

: Fortunately, STAR Collaboration has a preliminary measurement for $f_0(980)$

P. Fachini [STAR Collaboration], Nucl. Phys. A **715**, 462 (2003)

$$\frac{N_{f_0(980)}}{N_{\rho_0}} \sim 0.2$$

Can we say whether $f_0(980)$ is a tetraquark hadron or a hadronic $K\bar{K}$ molecule?

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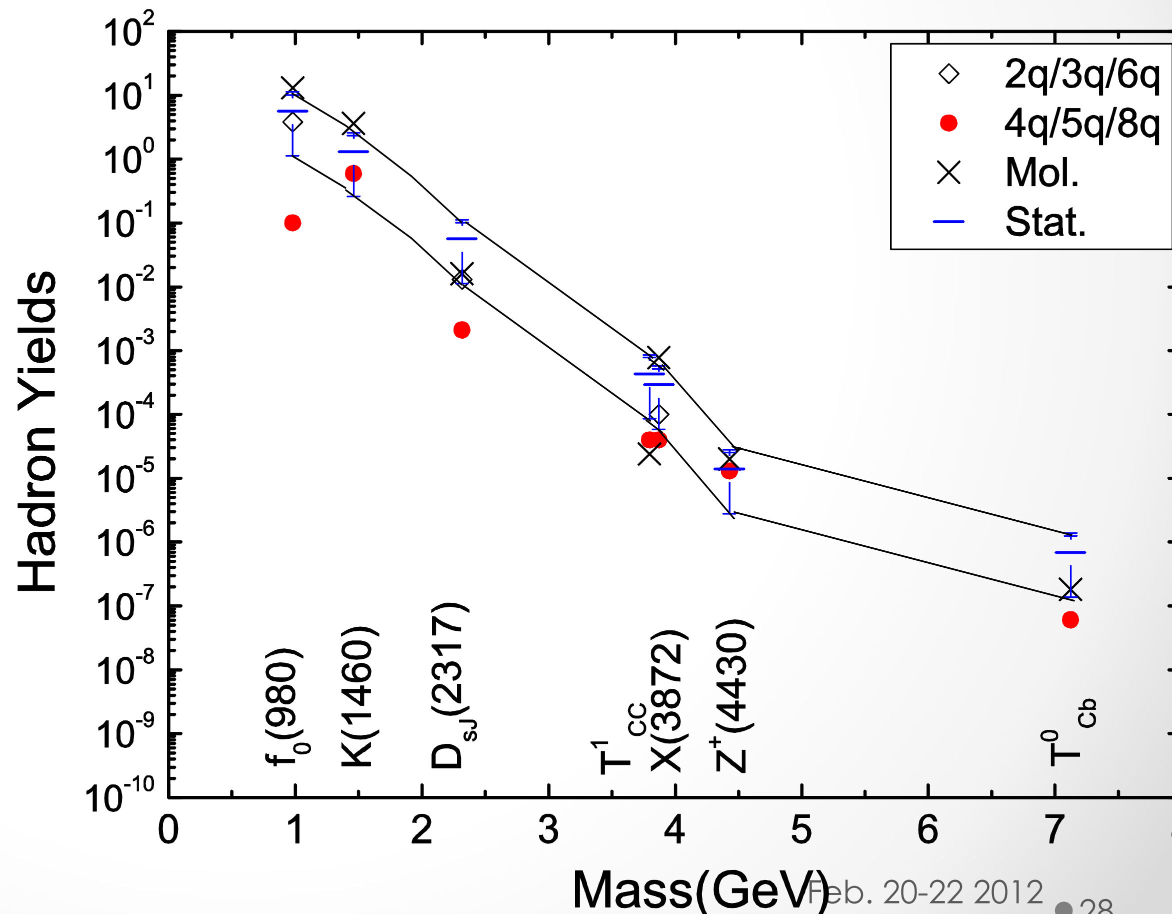

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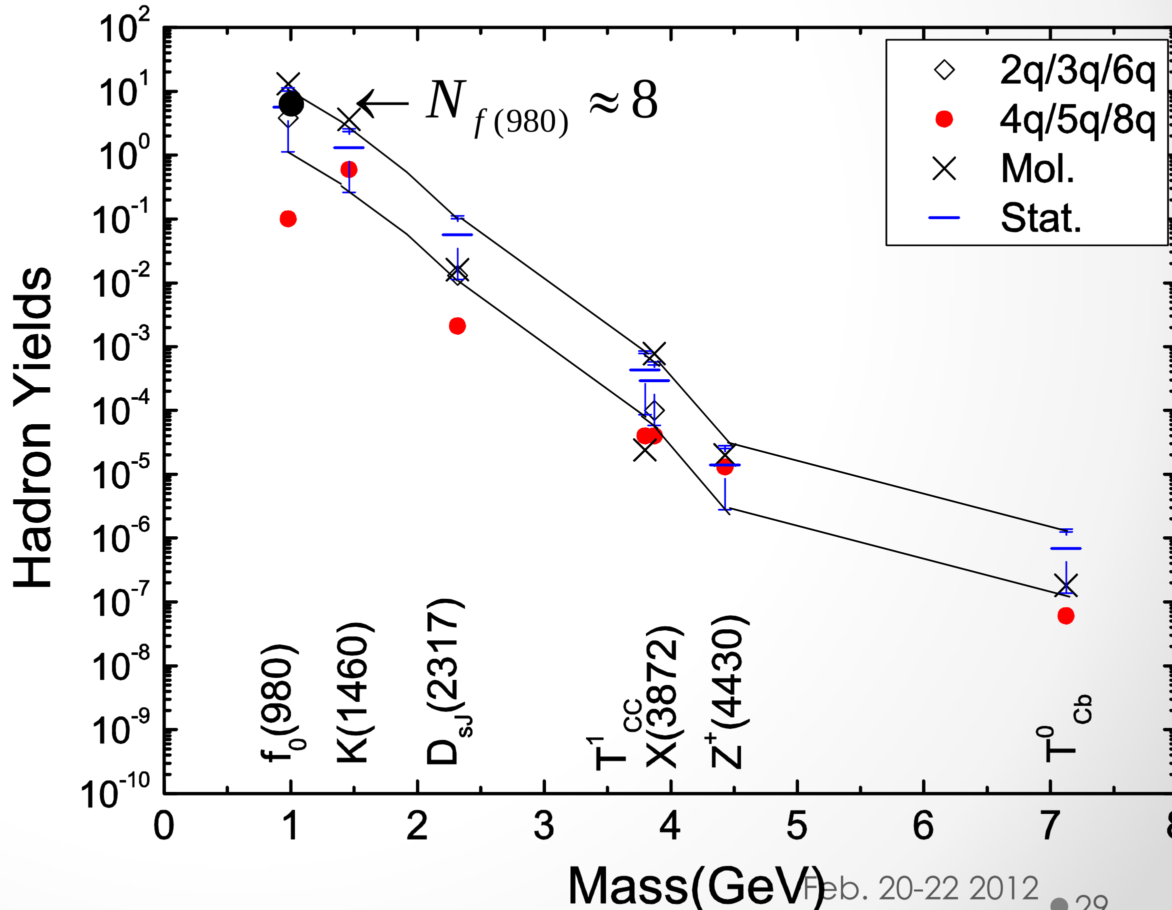
Can we say whether $f_0(980)$ is a tetraquark hadron or a hadronic $K\bar{K}$ molecule?

: At least, $f_0(980)$ must not be a tetraquark hadron



Conclusion

– The models for hadron production yields

1) Normal hadron yields are well described by the statistical model
2) Many aspects of the heavy ion collision experimental results have been explained by the coalescence model

– Production yields of exotic hadrons from heavy ion collisions

1) The yields of exotic hadrons are large enough to be measurable in experiments
2) The probability to combine n quarks into a compact region is suppressed as n increases
3) The yield of a hadron in relativistic heavy ion collision reflects is strongly dependent on its structure