Strangeness in Baryon to meson ratio

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Outline

- *Motivation: Baryon to meson ratio*
- *Dynamical Quark Recombination Model*
  - *Transverse momentum distributions*
- *Combinatorial probabilities*
- *Model comparison vs data*
- *Summary*

Motivation:

- *Long time ago: Strangeness easier produced in QGP than in an hadronic enviroment.* (Phys. Rev. Lett. 48, 1066 (1982))

- *The meson baryon ratio produced at LHC energies, could be different from the ratio produced at low energy, since the first are predominantly from hard collisions. The differences among the successful Statistical Model, might lead to new insight into the hadronization mechanism* (J. Cleymans, et. al. PRC74, 34903 (2006)).

- *Heavy flavor production in heavy ions collisions is an ideal probe to study the early time dynamics of these nuclear collisions.*

Many different studies have been performed

- *Percolation model:* I. Bautista, et al. PRC 82,34912(2010); Acta Phys. Polon. Supp. 6, 165 (2013)
- *Recombination vs. Frag.*: R.J. Fries, et al. PRL90, 202303(2003); PRC 68, 44902 (2003).
- *Statistical model:* S. Wheatron, et al. Comp. Phys. Comm.180, 84 (2009); P. Braun, PLB 518, 41 (2001).
- *Recombination model*: Rudolph C. Hwa, et al. PRC 84, 64914 (2011)

- *Experimental results from RHIC*: PRC75,64901(2007)
- *Experimental results from ALICE*: J. Phys. G. 38, 124078 and 124025 (2011)

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Motivation:

- *In proton-proton, the hadrons are produced predominantly by parton fragmentation, and the ratio B/M reflect the ratio of the corresponding fragmentation functions.*

- *In Ion-Ion, B/M ratio grows with collision energy. This behavior partially arise from the increase of the radial flow.*

- *Other ingredient that need to be understand is how this ratios are influenced by the relative abundance of baryons to mesons, when these are produced in ion-ion collisions. The question:* does the probability differ for baryons and mesons, and how this can affect to the dynamical properties of the quarks clustering.

- *It is know that hadronization is not instantaneous process, it happen in a window of temperature.*

- *Could the experimental baryon to meson ratio, provide the relation of heavy to light quarks?*

Dynamical recombination with finite hadronization time

In the hydrodynamic description of the relativistic heavy ion collisions, we can relate the thermodynamical variables of the system to the proper time.
The particle spectrum can be set with a degeneracy factor given in the recombination model:

$$\frac{dN}{p_T\, dp_t\, dy} = g\, \frac{m_T\, \Delta y \rho^2_{nucl}}{4\pi \Delta\tau} \int \tau\, d\tau\, \boxed{P(\tau)}\, I_0\left(P_T \sinh(\eta_T)/T\right) e^{-m_T \cosh(\eta_T)/T}$$

Incorporate probability of forming a given hadron with proper time from an initial evolution

Taking the Bjorken scenario for the space time evolution of the collision where the temperature is given by:

$$T = T_0 \left(\frac{\tau_0}{\tau_f}\right)^{v_s^2}$$

To obtain the profile of $P(\tau) \approx P(\varepsilon)$, we relay on the Monte Carlo Simulation using the String Flip Model.
The function $P(\tau)$ gives the information about the evolution of the system with proper time and accounts for a hadronization process which is not instantaneous but that occurs over a proper time interval.

Based on : Phys.Rev.C77, 044901 (2008)
J. Phys G.Nucl.Part.Phys. 35,044060 (2008)
Phys. Rev. C80, 064905 (2009)

The string-flip model

C. J. Horowitz, E. J. Moniz, and W. Negele: PRD31,1689 (1985)

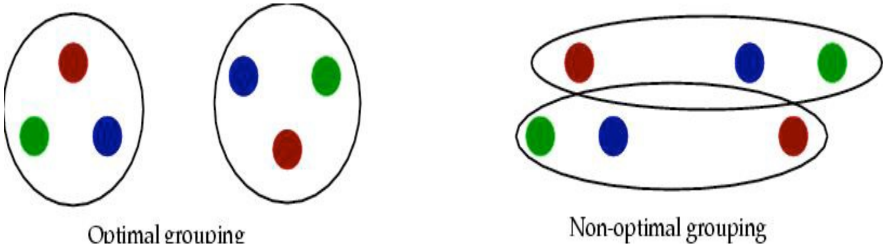
Quarks as degrees of freedom

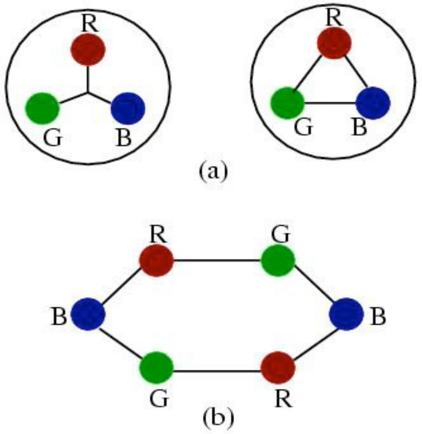
- *Colors: red, blue, green*

$$\boxed{\Psi = e^{-\lambda V}\,\Phi_{FG}}$$

Color combinations to built singlets.

Gluon flux tubes producing a minimal configuration of the system.





Optimal two-colors pairing potential
Ex. red and blue quarks
(Similar for color-anticolor)

$$\begin{aligned} V_{RB} &= \min_{P}\sum_{i=1}^{A} v(\mathbf{r}_{iR}, P(\mathbf{r}_{iB})) \\ &= \min_{P}\sum_{i=1}^{A} \frac{1}{2}k(\mathbf{r}_{iR}-\mathbf{r}_{jB})^2 \end{aligned}$$

Monte Carlo Simulation

$$V_{baryon} = V_{RB} + V_{RG} + V_{GB}$$

$$V_{meson} = V_{RR} + V_{GG} + V_{BB}$$

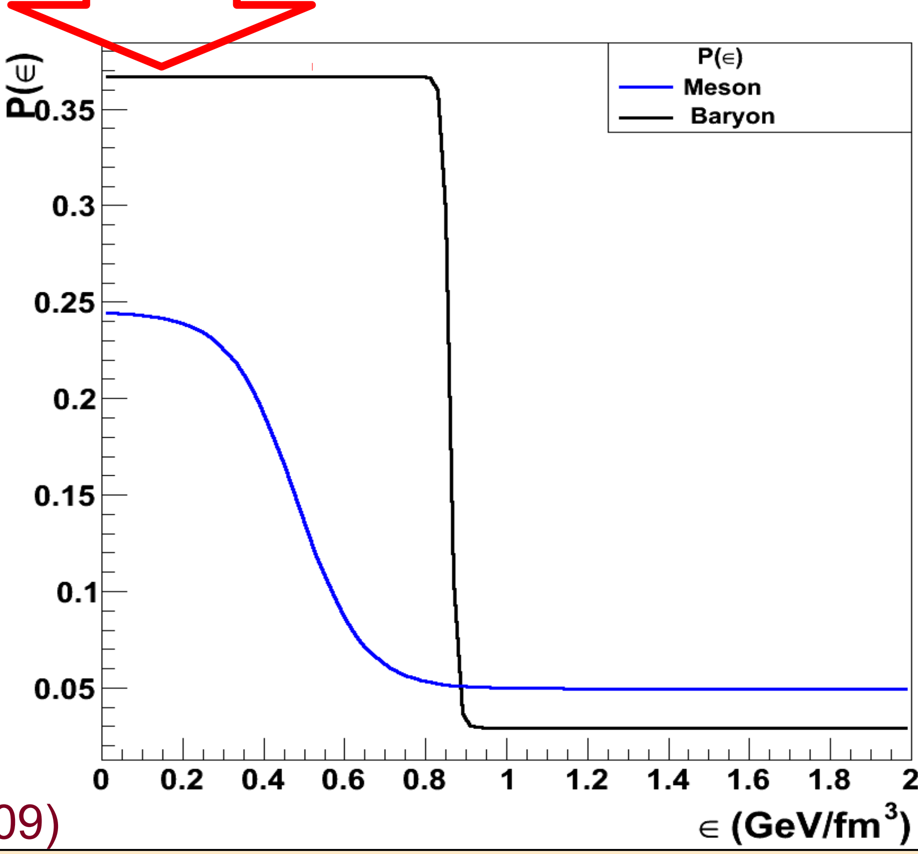
$$\boxed{\mathbf{E}(\lambda) = \mathbf{T}_{\mathbf{FG}} + \mathbf{2}\lambda^{2} < \mathbf{W} >_{\lambda} + < \mathbf{V} >_{\lambda}}$$

Based on : Phys.Rev.C77, 044901 (2008)

Transverse momentum distributions

Using DRQM, the transverse momentum distribution is obtained by

$$\frac{dN}{p_T\,dp_t\,dy} = g\,\frac{m_T\,\Delta y\,\rho^2_{nucl}}{4\pi\Delta\tau}\int \tau\,d\tau\,\boxed{P(\tau)}\,I_0\left(P_T\sinh\left(\eta_T\right)/T\right)e^{-m_T\cosh\left(\eta_T\right)/T}$$



Input parameters:
- *Meson mass(fixed)*
- *Baryon mass (fixed)*
- *Hadronization time(free)*
- *Temperatura (free)*
- *Flow velocity (free)*

Phys. Rev. C80, 064905 (2009)

Combinatorial Probabilities

Considering the case where one starts out with a set of
n u-quarks (light),
m Q-quarks (heavy, c or s quarks)

Each coming in three colors. *The number of possible colorless baryons and meson formed with light (u quarks) and heavy quarks (Q):*

Kind	Number B
uuu	n^3
uuQ	$3n^2m$
uQQ	$3nm^2$
QQQ	m^3

Kind	Number M
$u\bar{u}$	$3n^2$
$u\bar{Q}$	$3nm$
$Q\bar{u}$	$3nm$
$Q\bar{Q}$	$3m^2$

Relative abundance: $$\frac{2\text{x}3\text{n}^2 m}{2\text{x}(n+m)^3}$$

Relative abundance: $$\frac{3nm+3nm}{3\text{x}(n+m)^2}$$

Considering n = l m, l >1

$$\frac{\boldsymbol{B}}{\boldsymbol{M}} = \frac{\mathbf{3n}}{\boldsymbol{n+m}} \rightarrow \frac{\mathbf{3l}}{\mathbf{2}(\boldsymbol{l}+\mathbf{1})}$$

Combinatorial Probabilities

Considering the case where one starts out with a set of

n ***u-quarks,***
(l=n) ***d-quarks***
m ***s-quarks.***

Kind	Number of B	
uuu	n^3	
uud	$3n^2l$	
udd	$3nl^2$	
ddd	l^3	
uus	$3n^2m$	
uss	$3nm^2$	
sss	m^3	**Ω**
dds	$3l^2m$	
dss	$3lm^2$	
uds	$3nml$	**Λ**

Kind	Number of M	
$u\bar{u}$	$3n^2$	
$u\bar{s}$	$3nm$	
$\bar{u}s$	$3nm$	
$s\bar{s}$	$3m^2$	**Φ**
$d\bar{d}$	$3l^2$	
$u\bar{d}$	$3nl$	
$\bar{u}d$	$3nl$	
$\bar{s}d$	$3ml$	**K_s^0**
$s\bar{d}$	$3ml$	

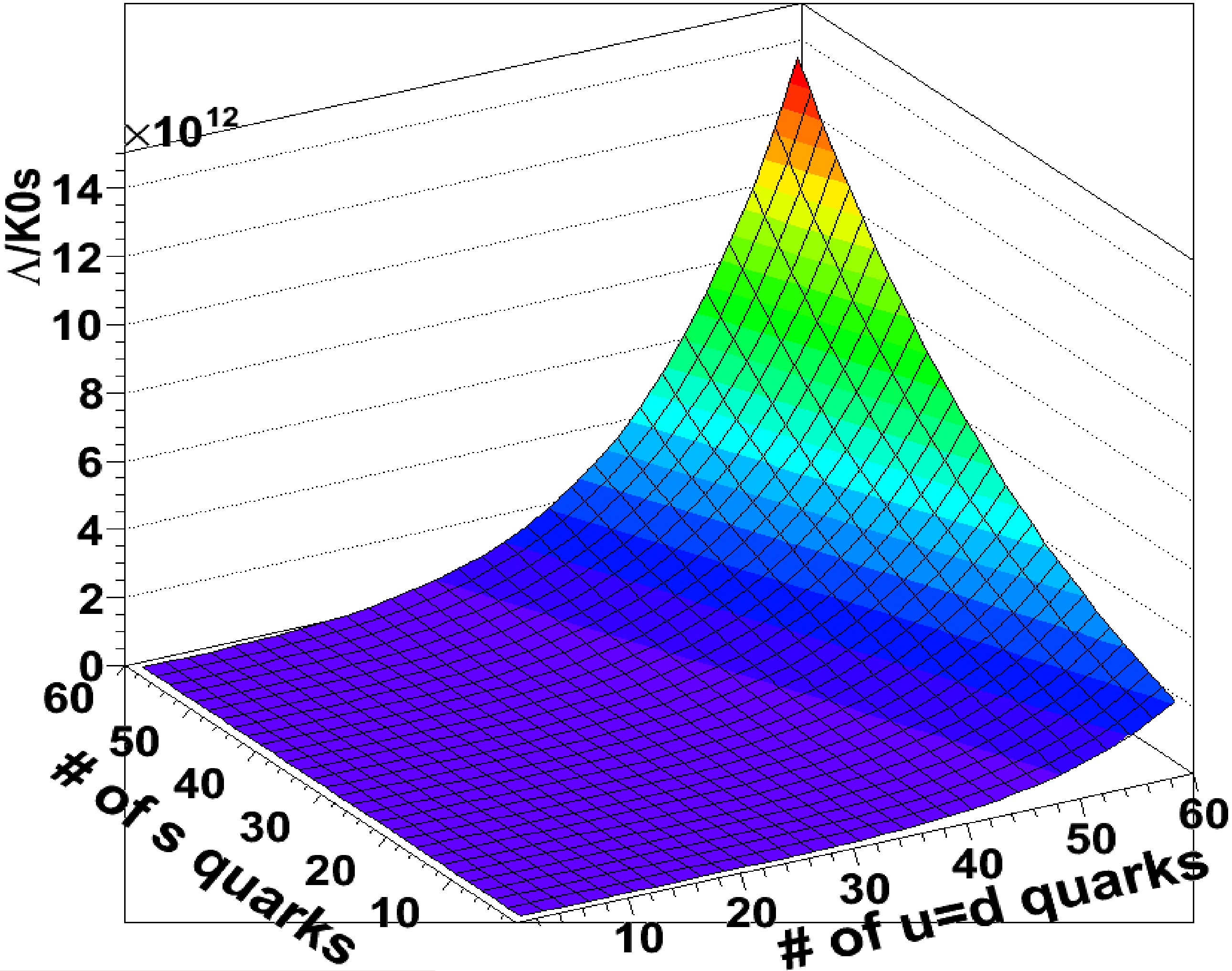
$$\frac{\Omega(sss)}{\varphi(s\bar{s})}=\frac{4m^2n+m^2}{8n^3+3n^2m+6nm^2}$$

$$\frac{\Lambda(uds)}{K_s^0(d\bar{s})}=\frac{3n}{2}\,\frac{4n^2+4nm^2+m^2}{8n^3+m^3+9n^2m+6m^2n}$$

Λ/K_s^0 ratio versus number of u=d and s quarks

Considering a system with
n u quarks
n d quarks
m s quarks

Computing the total number of meson and baryons and then taking only the fraction of those meson ($d\bar{s}$) and the fraction of baryons system (uds). Finally taking the ratio we get:

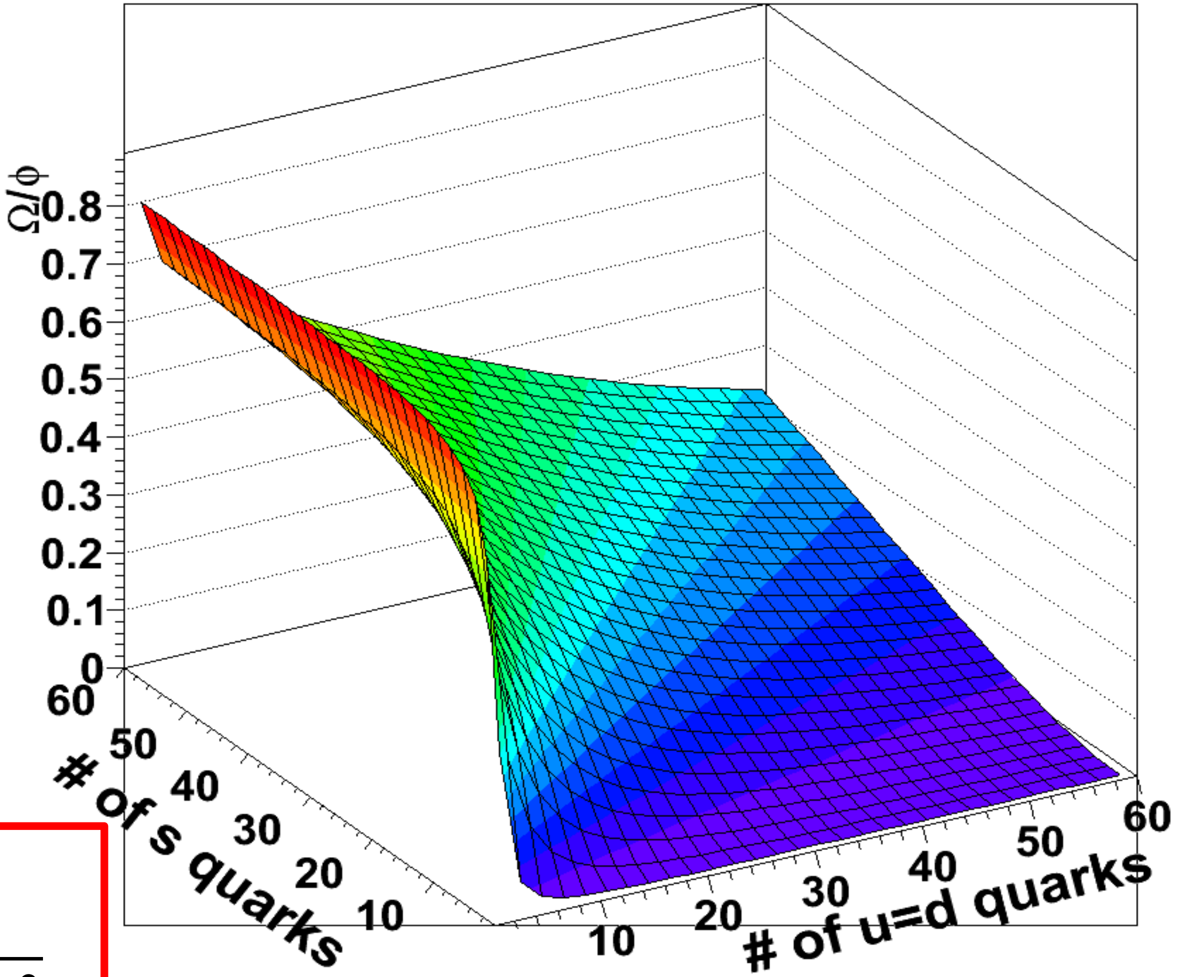


$$\frac{\Lambda(uds)}{K_s^0(d\,\bar{s})}=\frac{3n}{2}\,\frac{4n^2+4n\,m^2+m^2}{8n^3+m^3+9n^2\,m+6m^2\,n}$$

Ω/Φ ratio versus number of u=d and s quarks

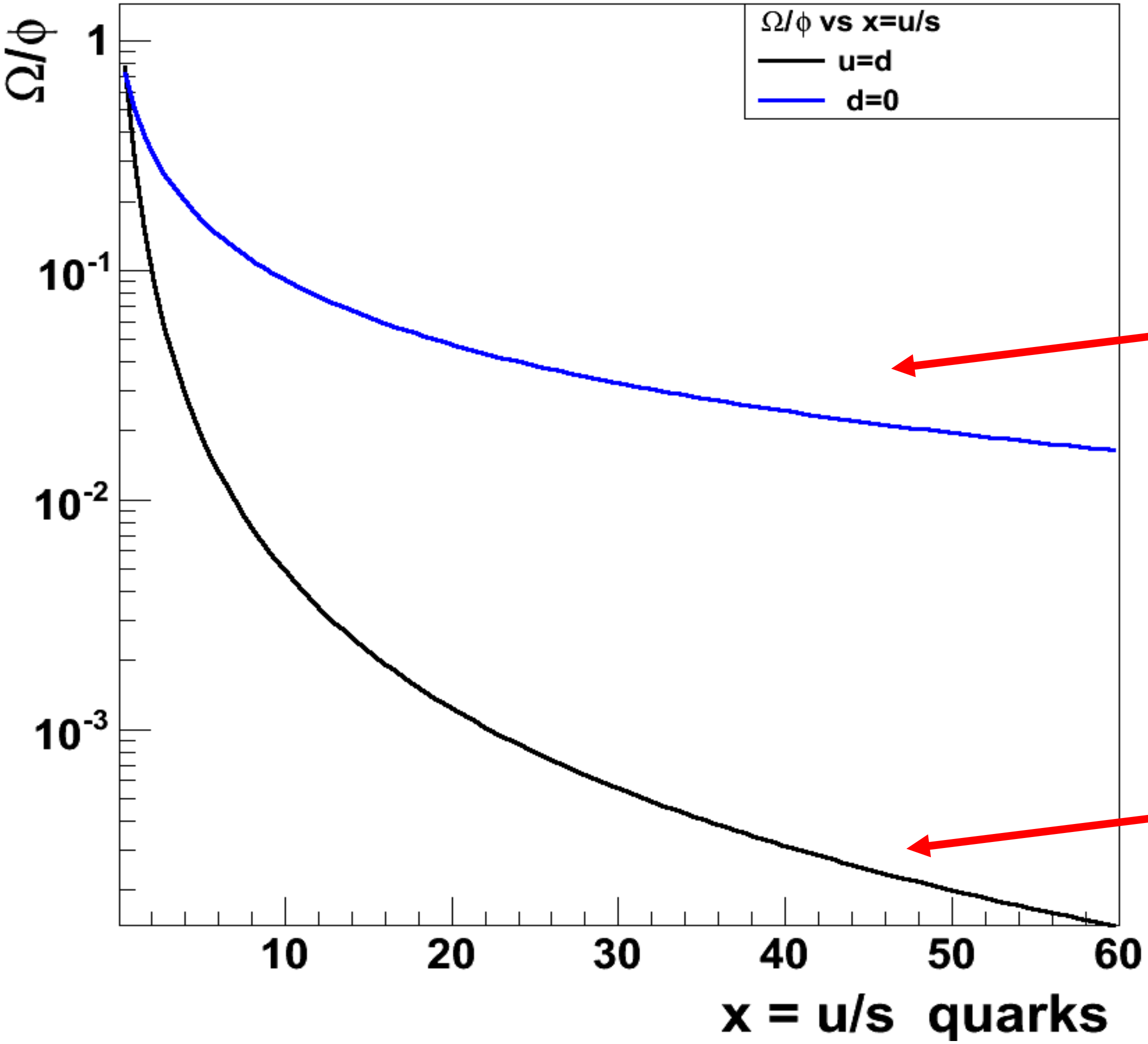
Considering a system with
n u quarks
n d quarks
m s quarks

Computing the total number of meson and baryons and then taing only the fraction of those meson (ss) and the fraction of baryons system (sss). Finally taking the ratio we get:



$$\frac{\Omega\left(sss\right)}{\varphi\left(s\,\bar{s}\right)}=\frac{4\mathrm{m}^2 n+m^2}{8\mathrm{n}^3+3\mathrm{n}^2 m+6\mathrm{nm}^2}$$

Ω/Φ ratio versus relative fraction of u to s quarks



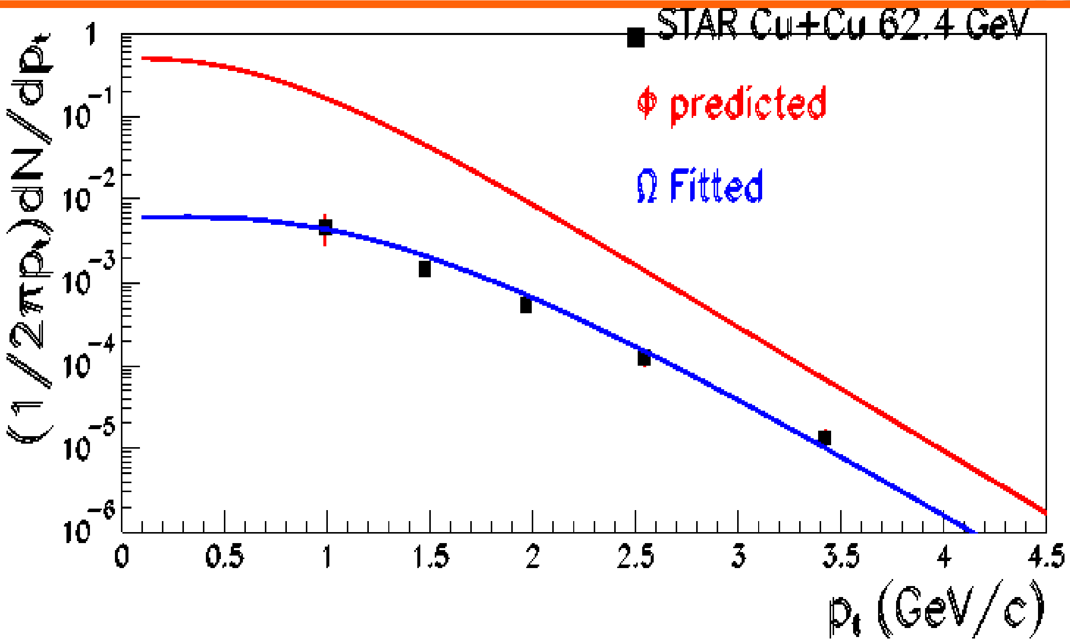
u= x s quarks, x > 1.
d=u quarks

$$\frac{\Omega(sss)}{\varphi(s\bar{s})}=\frac{4x+1}{8x^3+3x^2+6x}$$

u= x s quarks, x > 1.
d=0 quarks

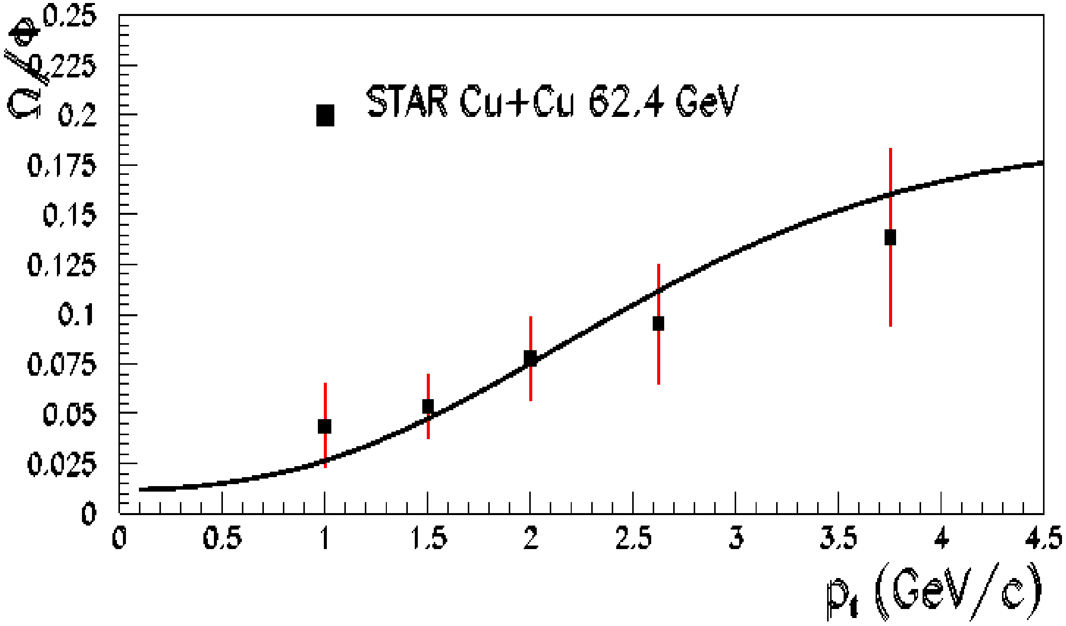
$$\frac{\Omega(sss)}{\varphi(s\bar{s})}=\frac{1}{x+1}$$

Results



Results obtained as follow:

a) the Ω spectrum is fitted to experimental results of STAR at 62.4 GeV, where βt and normalization are free parameters.
Results indicate βt=0.40



b) Ratio Ω/Φ is fitted with normalization of Φ as free parameter. Consequently Pt spectrum of Φ looks like a prediction!.

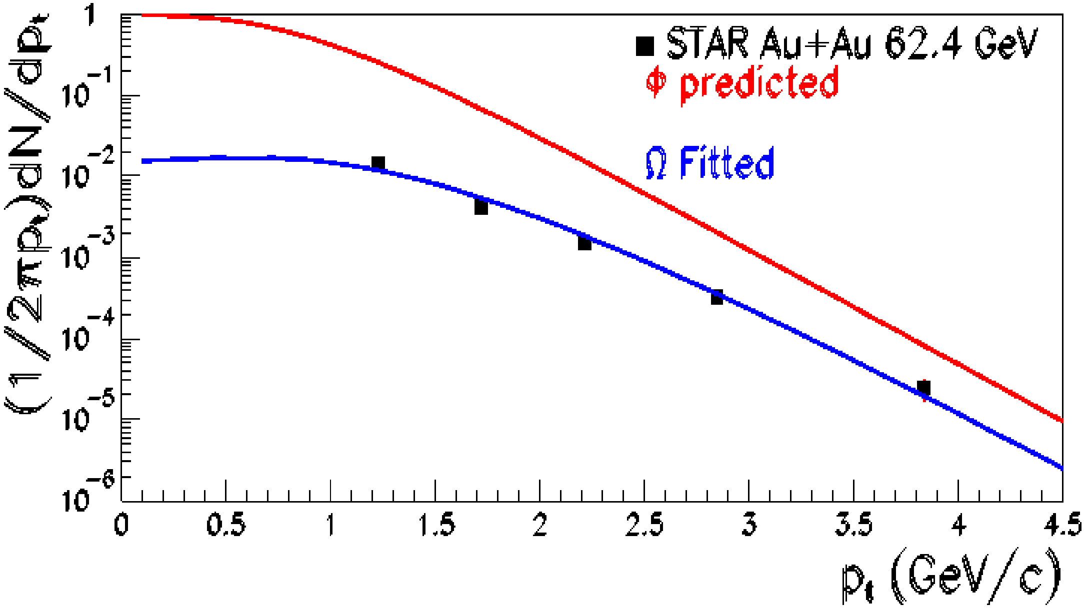
m_B =M_Ω GeV,
m_M=MΦ GeV,
t_0= 1fm.
T_0 =200 MeV
Tf =100 Mev,
t_f =8 fm.

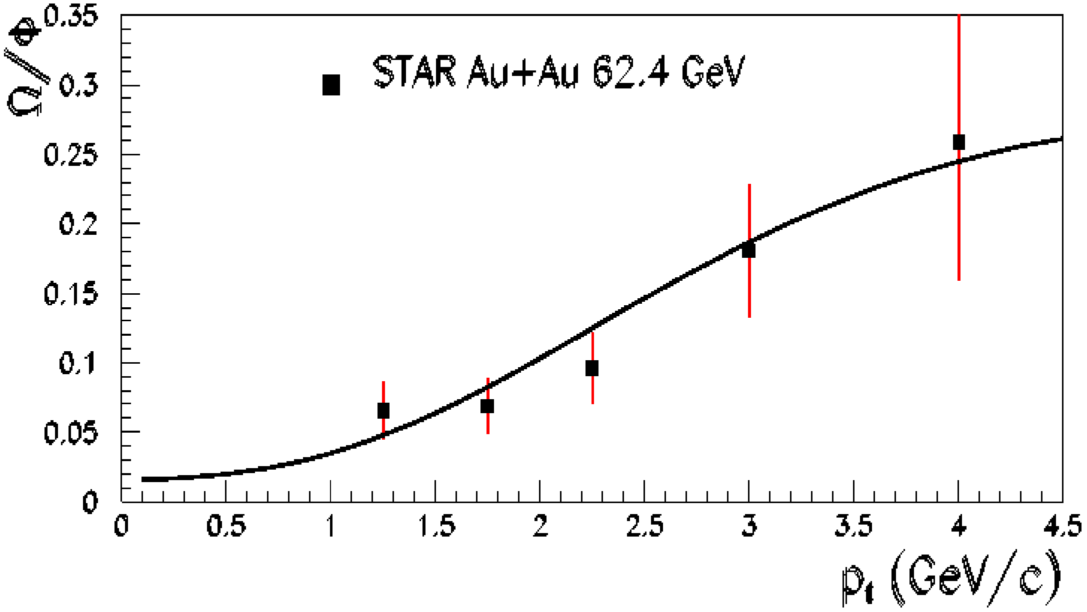
Results obtained as follow:

a) the Ω spectrum is fitted to experimental results of STAR at 62.4 GeV, where βt and normalization are free parameters.

Results indicate βt=0.45

b) Ratio Ω/Φ is fitted with normalization of Φ as free parameter. Consequently Pt spectrum of Φ looks like a prediction!.





According to DQRM

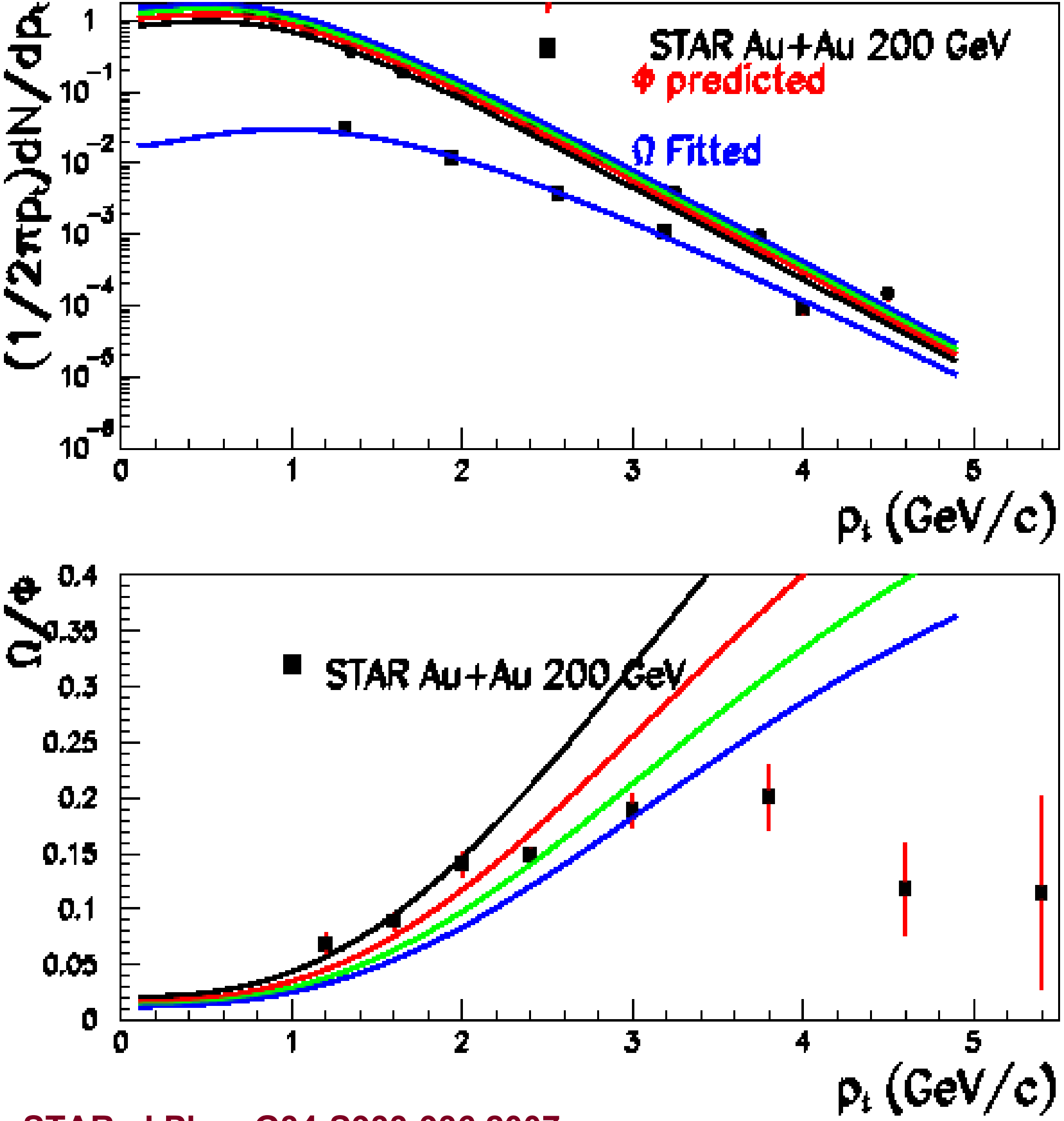
$$\frac{P_B(\varepsilon=0)}{P_M(\varepsilon=0)}=\frac{3}{2}$$

$$\frac{2}{3}\frac{C_b P_n(\varepsilon)}{C_m P_M(\varepsilon)}=\frac{1}{1+x}$$

Naively we can get:

Cb	Cm	x
12	20	1.5
12	25	2.125
12	30	2.75
12	35	3.375

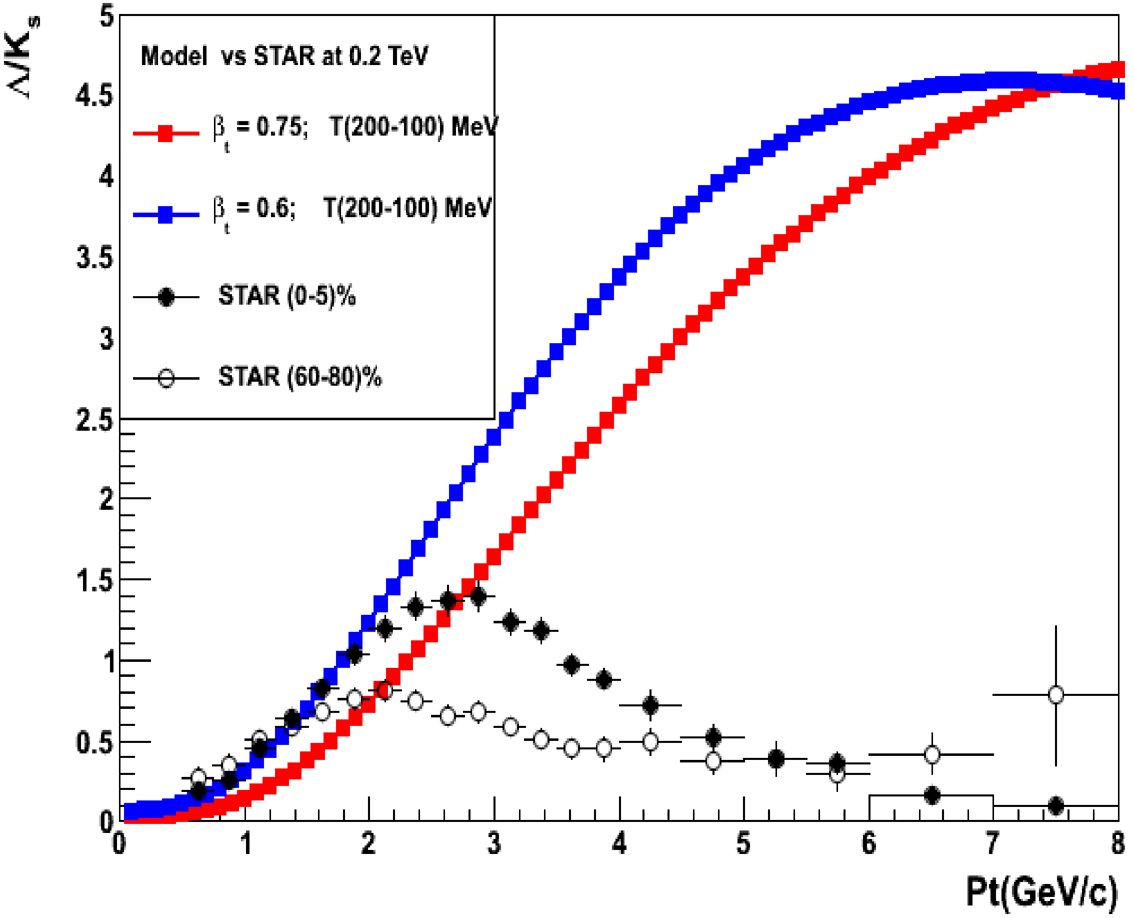
Ω/Φ results from Au+Au at 200 GeV



STAR: J.Phys.G34:S933-936,2007

J. Phys. G. Nucl. Part. Phys. 35 (2008) 104074

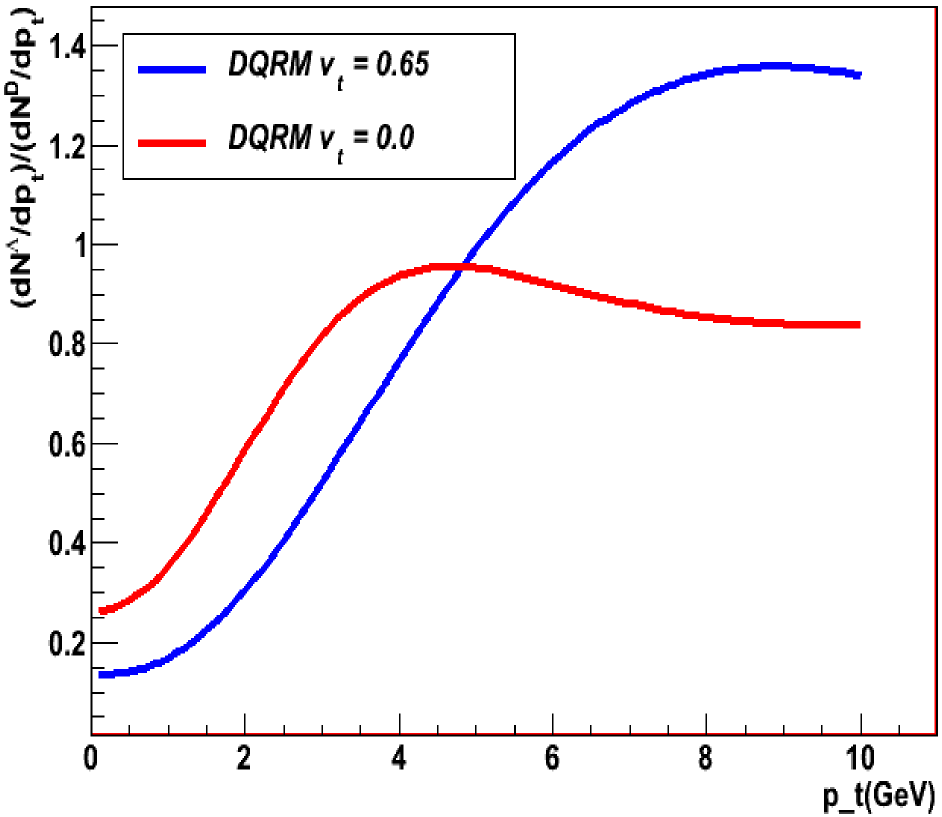
Prediction: $\Lambda^0 / K^0{}_s$ ratio (Pb+Pb) from DQRM



Prediction of the ratio from model to PbPb at 2.76 TeV.

Parameters used:
Trasverse flow βt =0,6; 0.75
Temperatura 200-100 MeV
Hadronization time 1 fm

Prediction: Λ_c / D+ ratio (Pb+Pb) from DQRM



Charmed baryon-to-meson ratio, as function of transverse momentum.

The parameters used in the calculation are

m_B =2.29 GeV,
m_M=1.87 GeV,
t_0= 1fm.
T_0 =200 MeV
Tf =100 Mev,
t_f =8 fm.

Shown is a range when varyin the transverse expansion velocity v_t from 0 (upper curve at low pt) to 0.4 (lower curve at low pt).

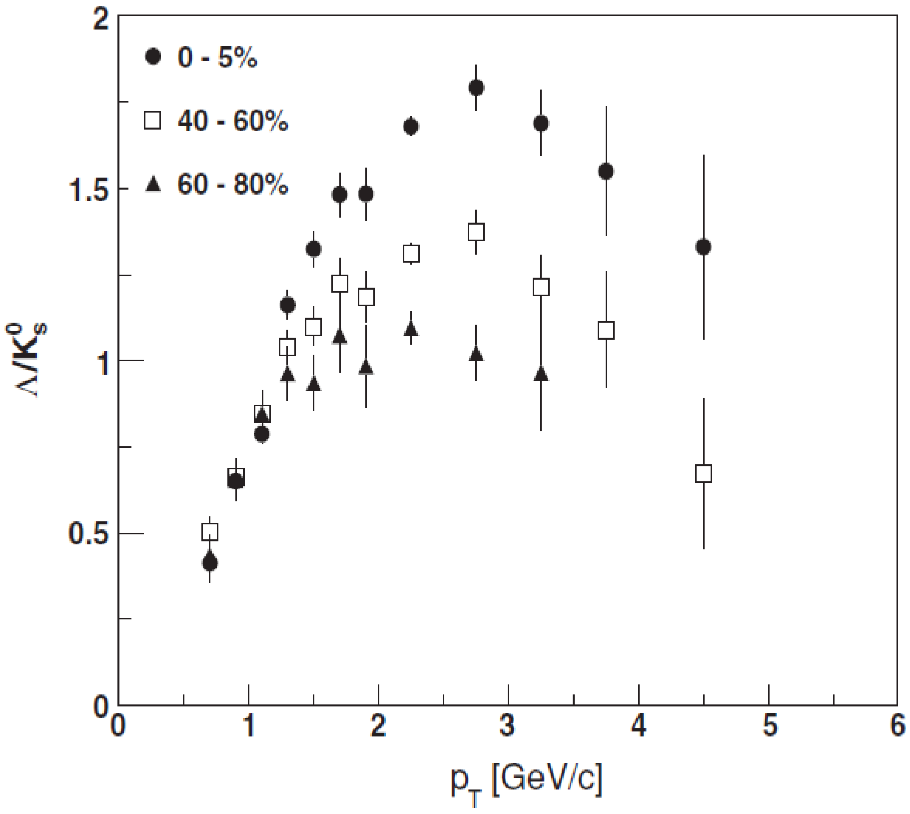
Summary

We have been presented a model based on recombination and probability to form colorless baryons and mesons. The model allow to calculate transverse momenta distributions of baryons and meson in relativistic heavy ion collisions.

- *The model explain the rise of baryon/meson ratio (low pt), up to RHIC energy*

- *The results indicate an increase of the flow with collision energy. Consistent with values of the transverse velocity expansion (flow), its increase with collision energy and density of the energy reach in the collision*

- *Constrains on probability together with pt data could help us to find the fraction of u quarks respect to the heavy ones, c or s. (for that we need to take into account fragmentation processes to describe the high pt processes).*



Ratio at 62.4: STAR PRC 83 024901 (2011)