Heavy quarks in a QCD plasma: energy loss or more baryons than mesons

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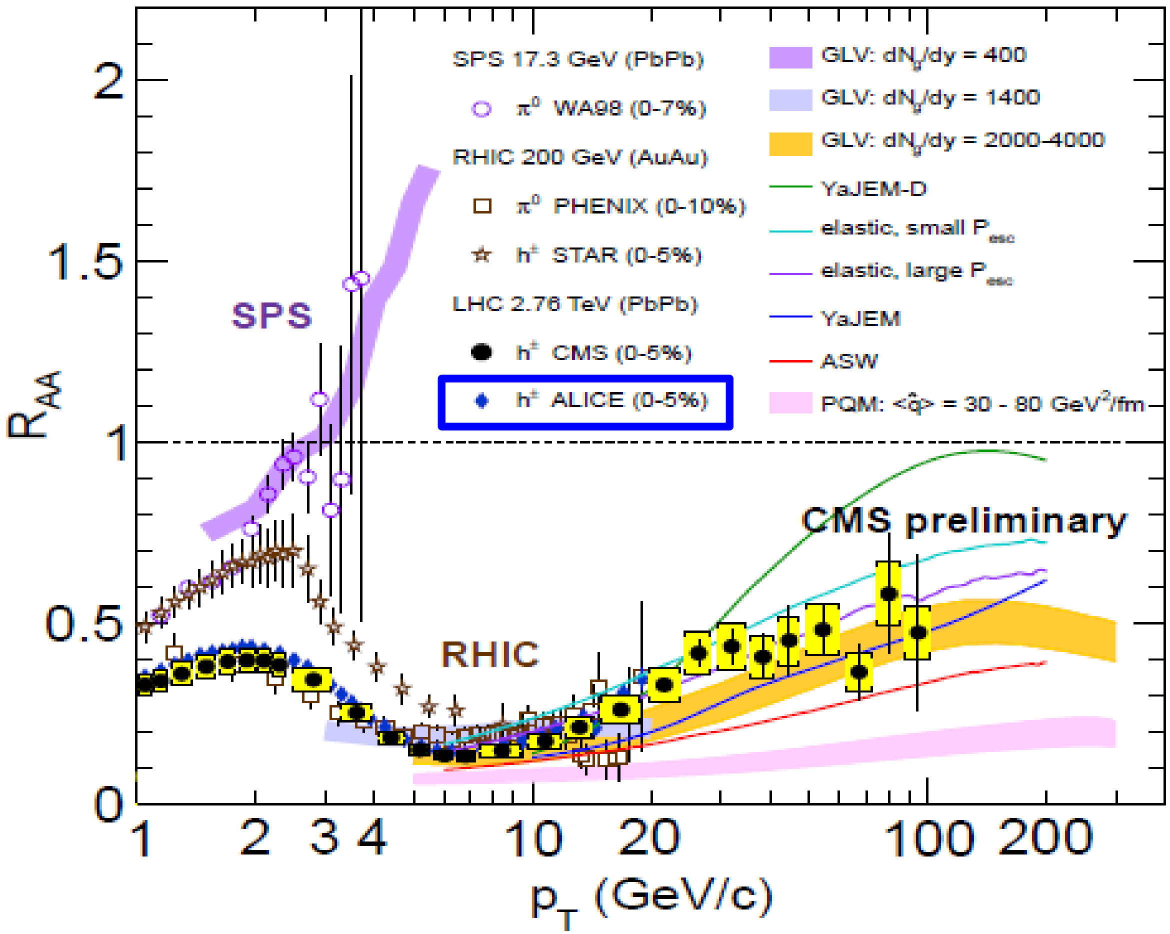
Outline

- *Motivation to measure nuclear modification factor, R_{AA}*
- *Short review on theoretical and experimental results on R_{AA}*
- *R_{AA} from new point of view*

  (R_{AA} baryon/meson ratio dependence vs energy loss)

  - ✓ *$R^D{}_{AA}$ and $R^e{}_{AA}$*
  - ✓ *Results vs experiment*
- *Remarks*

Experimental Nuclear modification factor R_{AA}



Energy ↑ ==> R_{AA} ↓

$$R_{AA}(p_t) = \frac{1}{\langle N_{coll} \rangle} \cdot \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t} = \frac{1}{\langle T_{AA} \rangle} \cdot \frac{dN_{AA}/dp_t}{d\sigma_{pp}/dp_t}$$

$$\sim \frac{\text{"QCD Medium"}}{\text{"QCD Vacuum"}}$$

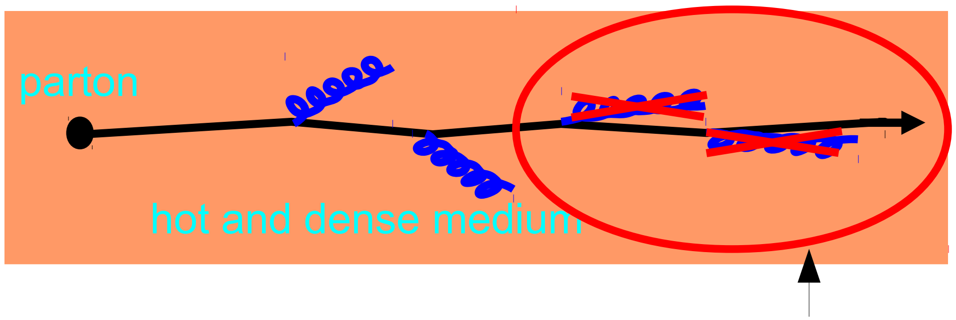
- $R_{AA} > 1$ (enhancement)
- $R_{AA} = 1$ (no medium effect)
- $R_{AA} < 1$ (suppression)

The R_{AA} suppression is one of the most robust evidence for the creation of a new state of the matter in heavy ion collisions. The phenomenon is well described by models which take into account the radiative energy loss of high pt light quarks and gluons propagating through a dense medium of colored quarks and gluons: ***Salgado, C. A. Nucl.Phys.A774 (2006) 267; Wang, X.N. Nucl.Phys.A774 (2006)215***

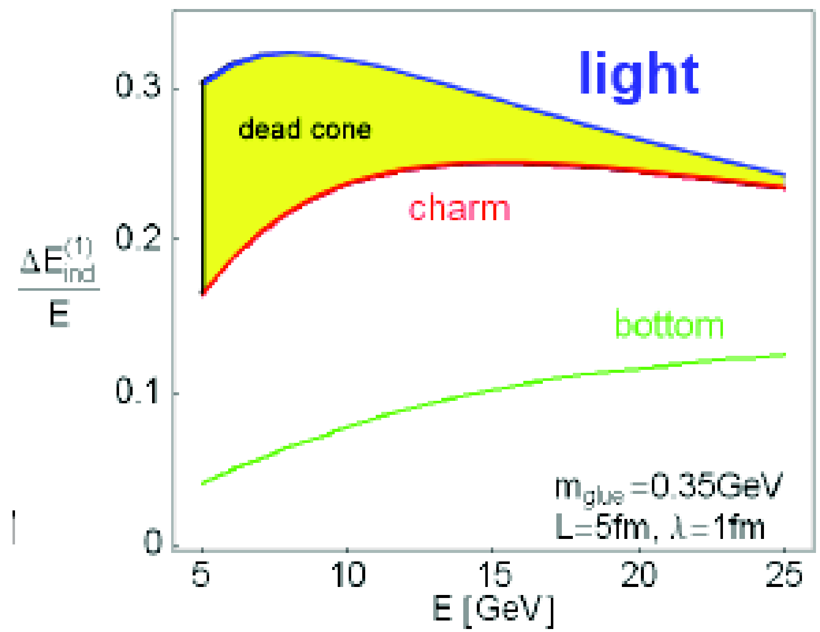
Heavy Flavor and the QGP

- *Heavy quarks produced in initial hard scattering of partons*
  - *Dominant: gg→QQ*
  - *Production rates from pQCD*
  - *Sensitive to initial gluon distributions*
- *Heavy quark energy loss*
  - *Prediction: less than light quark energy loss (dead cone effect)*

Quarks are expected to exhibit different radiative energy loss depending on their mass (D.Kharseev et.al, PLB519 (1999)



Dead cone effect (Θ<m/E)



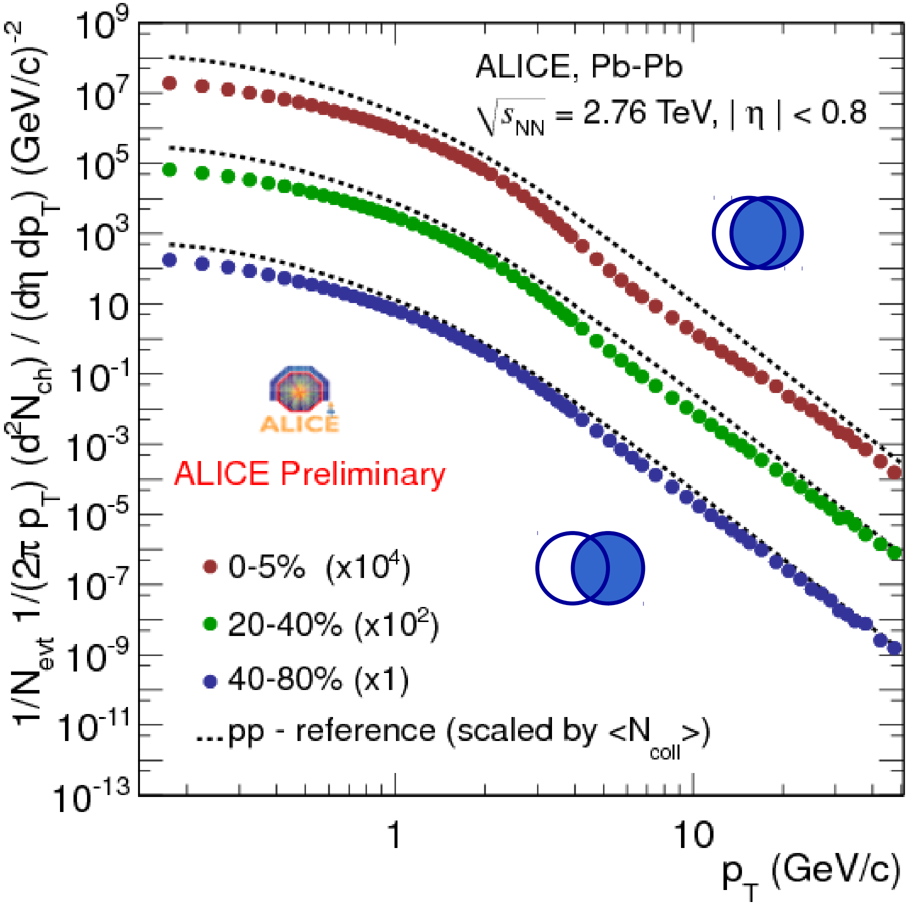
M.Djordjevic PRL 94 (2004)

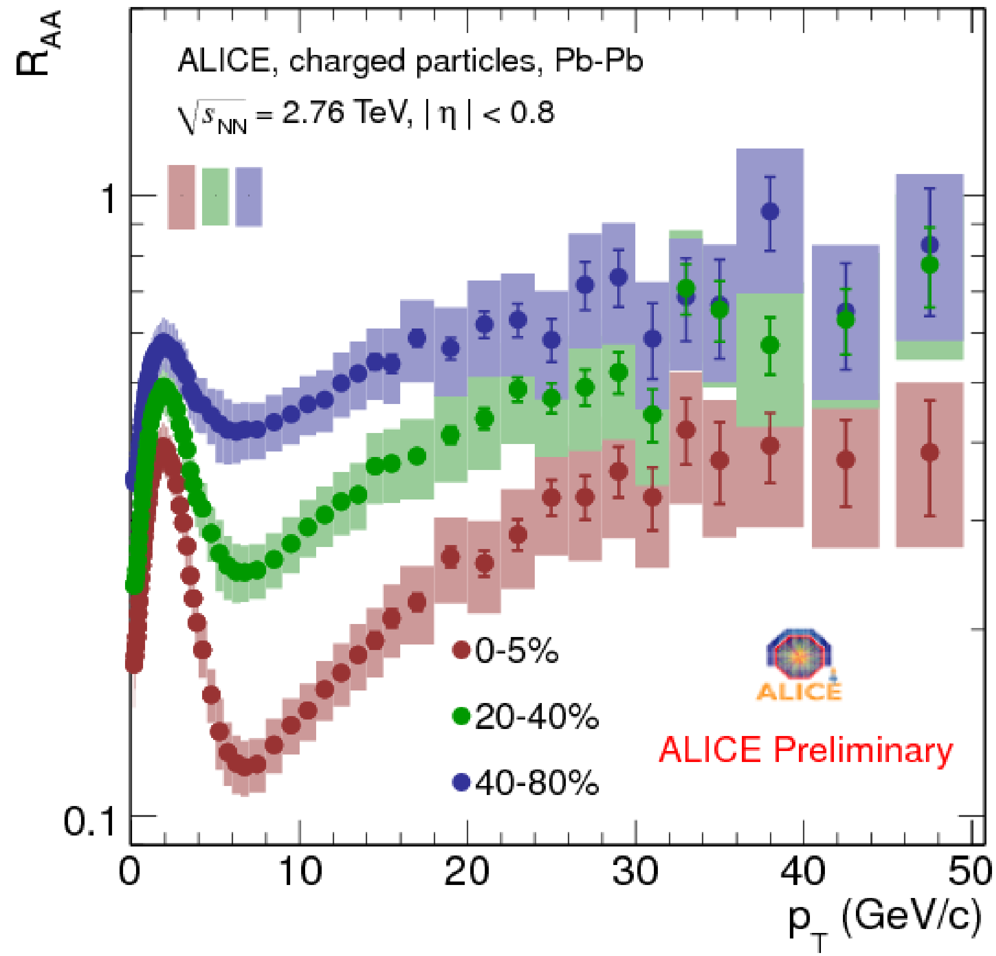
  - *Sensitive to gluon densities in medium*
- *Quarkonium Suppression*

ALICE: Nuclear modification factor

Charged hadron p_T spectra

$$R_{AA} = \frac{dN/dp_T\big|_{Pb+Pb}}{N_{coll}\, dN/dp_T\big|_{p+p}}$$

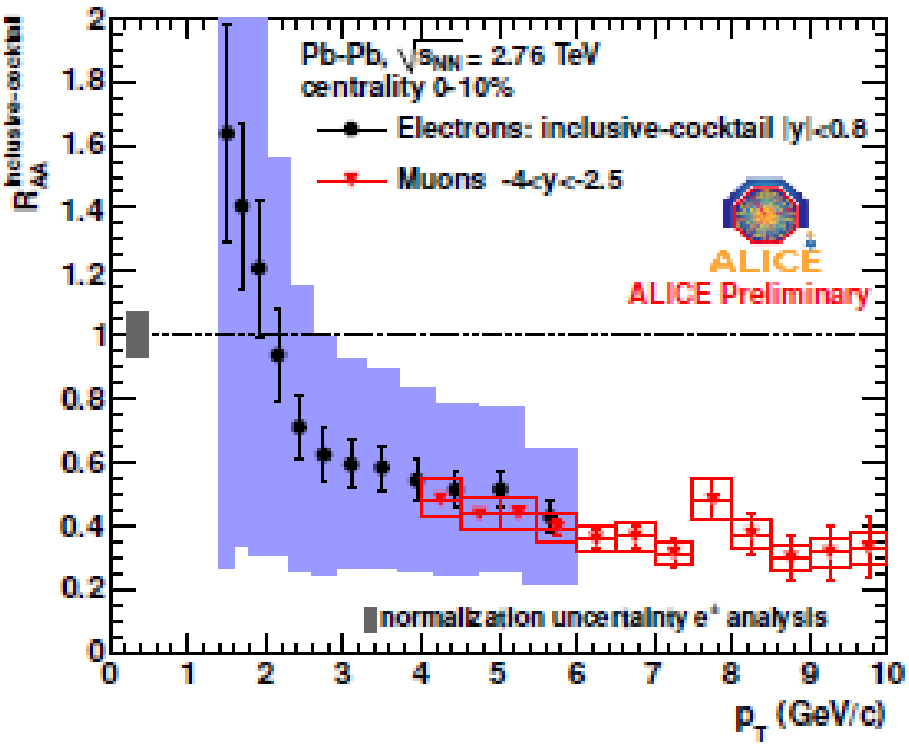


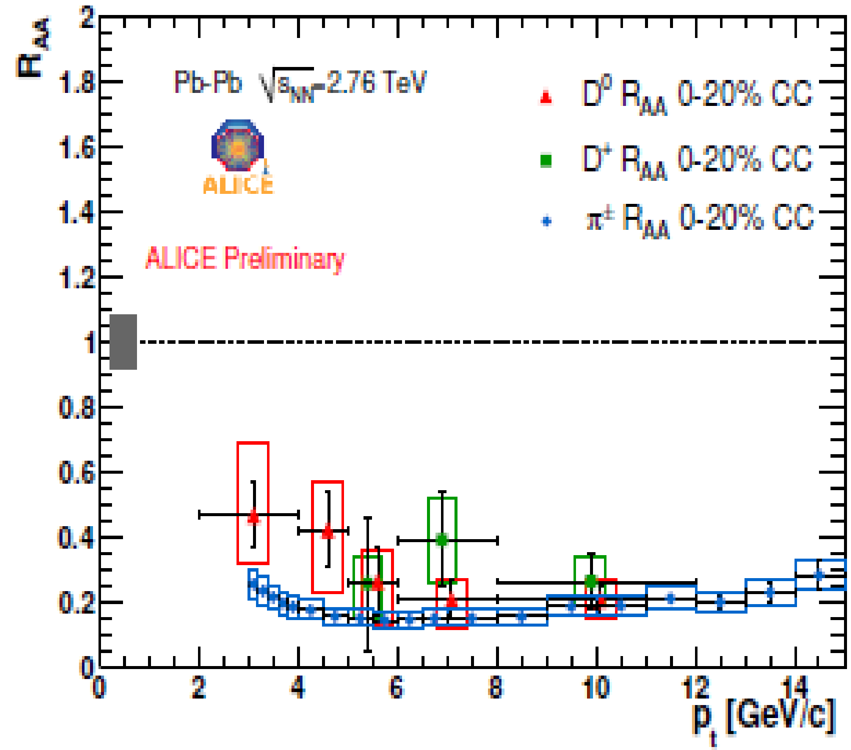


Shape of spectra in Pb+Pb differ from p+p

Large suppression
R_{AA} rises with p_T → relative energy loss decreases

ALICE results on R^{e}_{AA} and R^{D}_{AA}





R^{e}_{AA} for nonphotonic electrons coming from charm and beauty quarks

ALICE: ArXiv:1106.4042, arXiv:1106.6188

R_{AA} for D^0, D^+ and π in central collisions. Suppression reaching a factor 4-5 for pt > 5 GeV

The is an upgrade of the plot in 1204.3579v1.pdf, check other plots there in

IS THERE A NEW POINT OF VIEW?

… But the shift in the hadron momentum in the nuclear medium can come not only from a loss of energy but also from a momentum redistribution when the quarks from the medium form either baryons or mesons: In overage, the three quarks forming baryons come from lower momentum bins than the two quarks making up a mesons. Since there are more quarks with lower momentum there is a larger change to form baryons than mesons.

Nuclear modification factor for D mesons: R^D_{AA}

Number of quark charm produced in AA or pp can be obtained from the corresponding number of hadrons with c-quarks.

$$N^c_{AA\,/\,pp} = (N^D_{AA\,/\,pp} + N^\Lambda_{AA\,/\,pp} + N^{c\bar{c}}_{AA\,/\,pp}).$$

$$N^c_{AA} = \varepsilon \langle n_b \rangle N^c_{pp}$$

Accounting also for a possible energy loss, we introduce a parameter ϵ

$$(N^D_{AA} + N^\Lambda_{AA} + N^{c\bar{c}}_{AA}) = \varepsilon \langle n_b \rangle (N^D_{pp} + N^\Lambda_{pp} + N^{c\bar{c}}_{pp}).$$

Where $N^{c\bar{c}}_{pp}/N^D_{pp}$ is very small

$$R^D_{AA} \simeq \varepsilon \left(1 + \frac{N^\Lambda_{pp}}{N^D_{pp}}\right) \Big/ \left(1 + \frac{N^\Lambda_{AA}}{N^D_{AA}}\right)$$

From this equation, when the Baryon/Meson ratio increase in A-A collisions respect to Proton-proton, the R^D_{AA} decrease, Even in the absence of energy loss (ϵ =1).

R^e_{AA} for heavy flavor electrons

The same enhancement is responsible for suppression of nuclear modification factor for heavy flavor electrons.
Considering electrons originating from the decay of charm quarks in a given momentum bin R^e_{AA} can be expressed as:

$$R^e_{AA} = \frac{1}{\langle n_b \rangle} \frac{N^{\Lambda}_{AA} B^{\Lambda \to e} + N^{D}_{AA} B^{D \to e}}{N^{\Lambda}_{pp} B^{\Lambda \to e} + N^{D}_{pp} B^{D \to e}}$$

$$= \frac{1}{\langle n_b \rangle} \left(\frac{N^D_{AA}}{N^D_{pp}} \right) \left(\frac{B^{D \to e} + \frac{N^{\Lambda}_{AA}}{N^{D}_{AA}} B^{\Lambda \to e}}{B^{D \to e} + \frac{N^{\Lambda}_{pp}}{N^{D}_{pp}} B^{\Lambda \to e}} \right)$$

$$= R^D_{AA} \left(\frac{1 + x N^{\Lambda}_{AA}/N^{D}_{AA}}{1 + x N^{\Lambda}_{pp}/N^{D}_{pp}} \right) \equiv \epsilon\, T^e_{AA}$$

$$x = B^{\Lambda \to e}/B^{D \to e}$$

$$T^e_{AA} \equiv \left[\left(1 + \frac{N^{\Lambda}_{pp}}{N^{D}_{pp}} \right) \Big/ \left(1 + \frac{N^{\Lambda}_{AA}}{N^{D}_{AA}} \right) \right] \times \left(\frac{1 + x N^{\Lambda}_{AA}/N^{D}_{AA}}{1 + x N^{\Lambda}_{pp}/N^{D}_{pp}} \right)$$

Ones again, the equation state that even in the absence of energy loss, the nuclear modification factor, R^e_{AA} for a single electrons is smaller than one, when the ratio of charm baryons to open charm mesons is enhanced in A-A with respect to pp collisions and the electrons are more copiously produced from one charm mesons than baryons ($x<1$)

Phys. Rev. C 80, 064905 (2009)

Momentum distribution from DQRM

The hadron transverse momentum distribution in central AA collision, assuming Bjorken dynamics and transverse velocity expansion v_t is giving by:

$$\frac{dN}{p_t dp_t dy} = g \frac{m_t \Delta y}{4\pi} \frac{\rho_{nucl}}{\Delta\tau} \int_{\tau_0}^{\tau_f} \tau d\tau \mathcal{P}(\tau) \times I_0(p_t \sinh\eta_t / T) e^{-m_t \cosh\eta_t / T}$$

$$v_t = \tanh\eta_t.$$

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

ρ nuclear radius
g to take spin degree of freedom (degeneracy)

To obtain the profile of P(τ) ≈ P(ε), we relay on the Monte Carlo Simulation using the String Flip Model.

The function P(τ) 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.

A. Ayala et al. PRC77, 044901 (2008)
J. Phys G.Nucl.Part.Phys. 35,044060 (2008)

The string-flip model

Horowitz, Moniz, Negele 80's

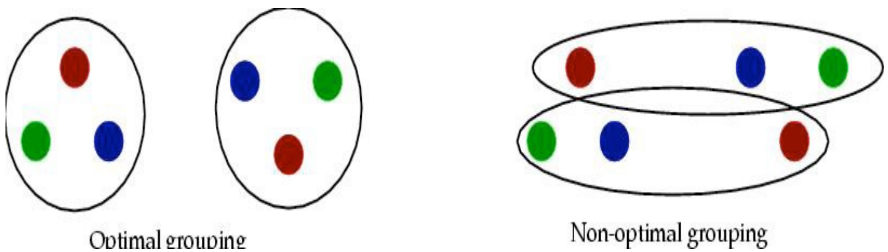
Quarks as degrees of freedom

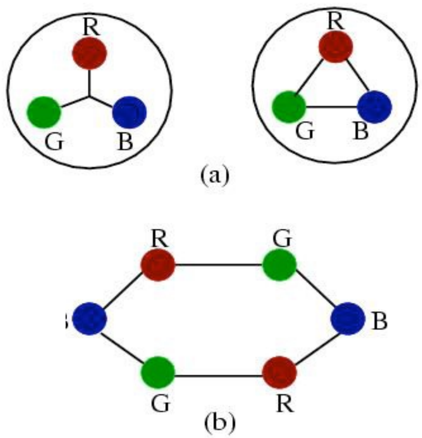
- Colors: red, blue, green

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

Gluon flux tubes producing a minimal configuration of the system.

Color combinations to built singlets.





Optimal two-colors pairing potential

Ex. red and blue quarks

(Similar for color-anticolor)

$$V_{RB} = \min_{P} \sum_{i=1}^{A} v(\mathbf{r}_{iR}, P(\mathbf{r}_{iB}))$$

$$= \min_{P} \sum_{i=1}^{A} \frac{1}{2} k(\mathbf{r}_{iR} - \mathbf{r}_{jB})^2$$

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

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

Monte Carlo Simulation

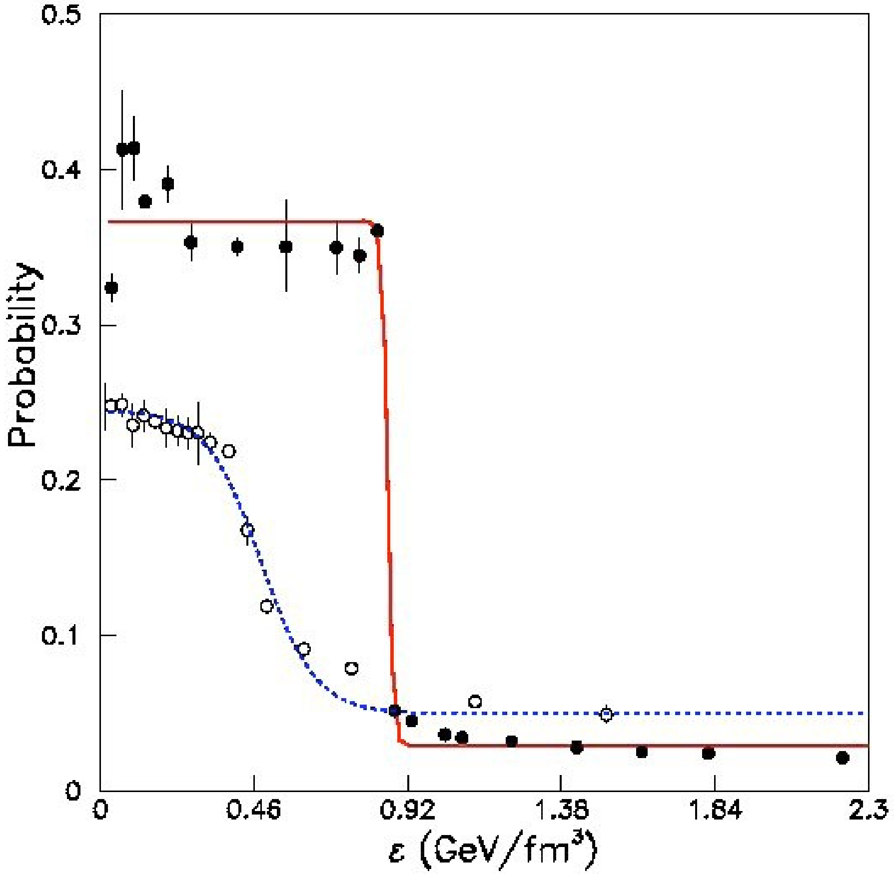
$$\mathbf{E}(\lambda) = \mathbf{T_{FG}} + 2\lambda^2 < \mathbf{W} >_\lambda + < \mathbf{V} >_\lambda$$

A. Ayala et al. PRC77, 044901 (2008)

J. Phys G.Nucl.Part.Phys. 35,044060 (2008)

Production probability in DQRM

Probability to describe as function of the energy density the production of mesons and baryons.



Investigating the model describe the pt spectra:

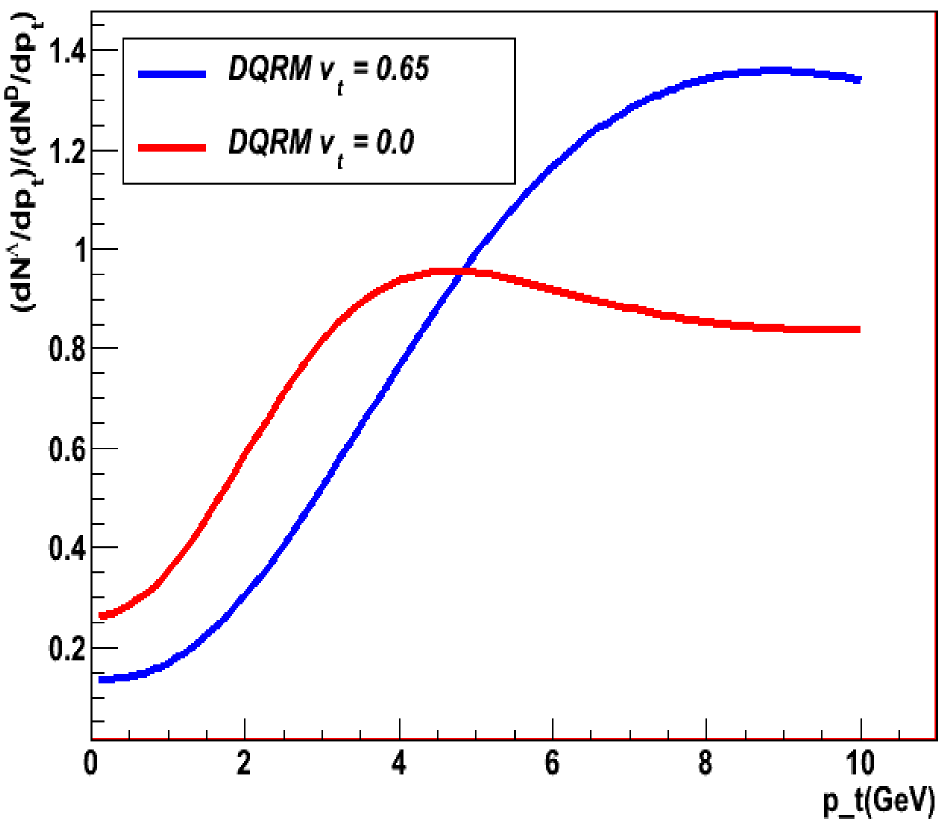
PRC77, 044901 (2008)

J. Phys G.Nucl.Part.Phys. 35,044060 (2008)

Using this model is possible to predict the Shape of the nonphotonic single electron:

Phys. Rev. C 80, 064905 (2009)

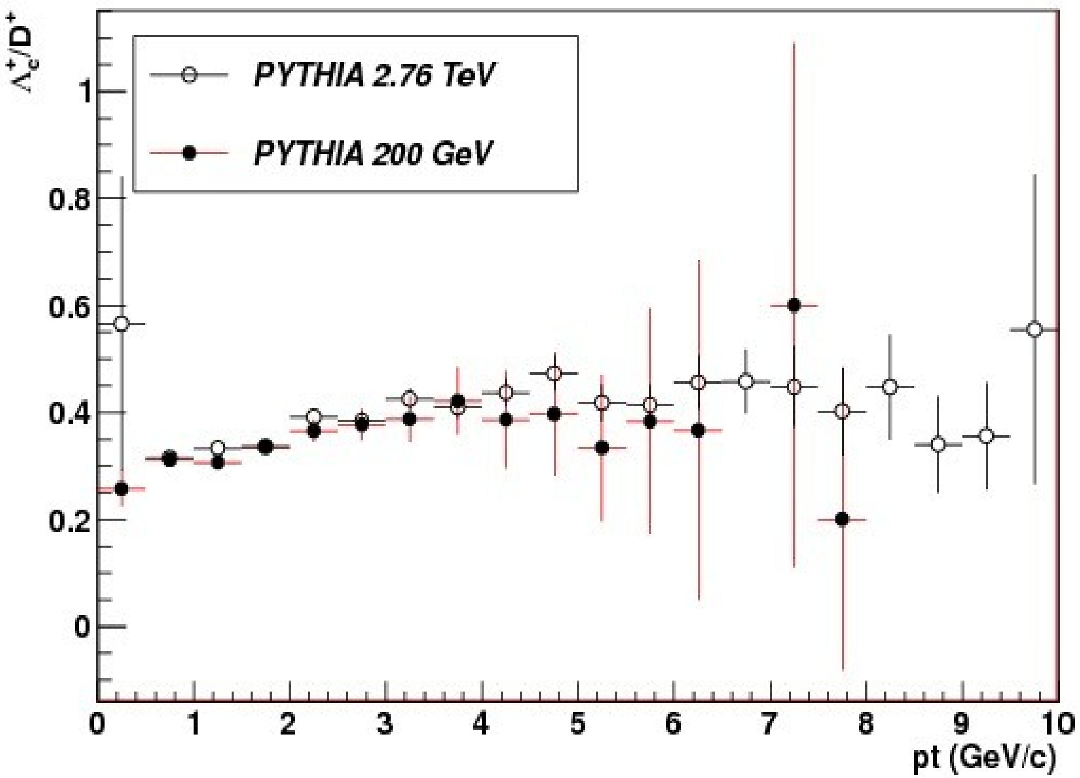
Λ_C / D+ ratio (Pb+Pb) from DQRM



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, t0= 1fm. T0 =200 MeV and Tf =100 Mev, corresponding to a final time 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).

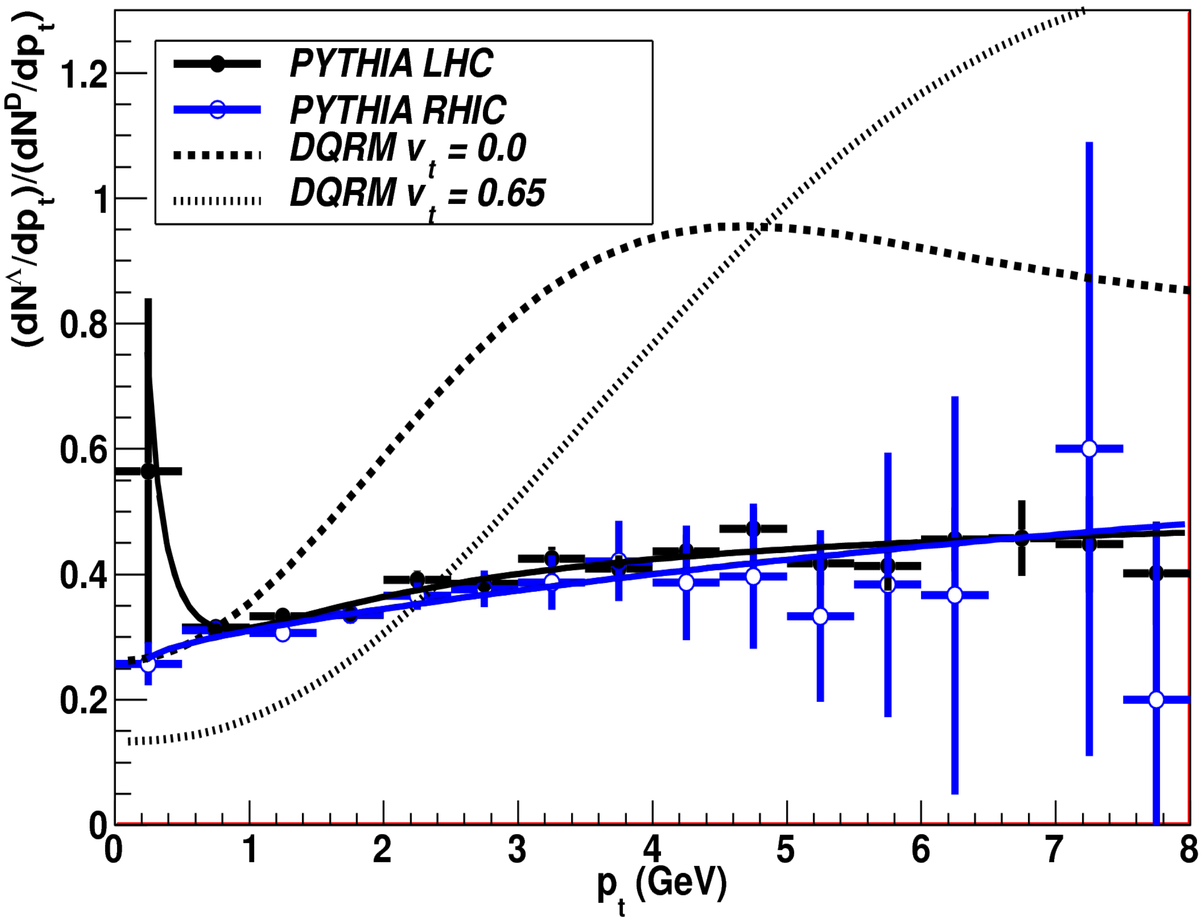
Λ_c^+ / D^+ ratio on p+p



PYTHIA simulation produce a little different ratio from a constant, but it is lower that 1.

The ratio seems present not dependence on the energy but dependence on pt (except at very low pt).

Λ_c^+/D^+ from DQRM and PYHTIA

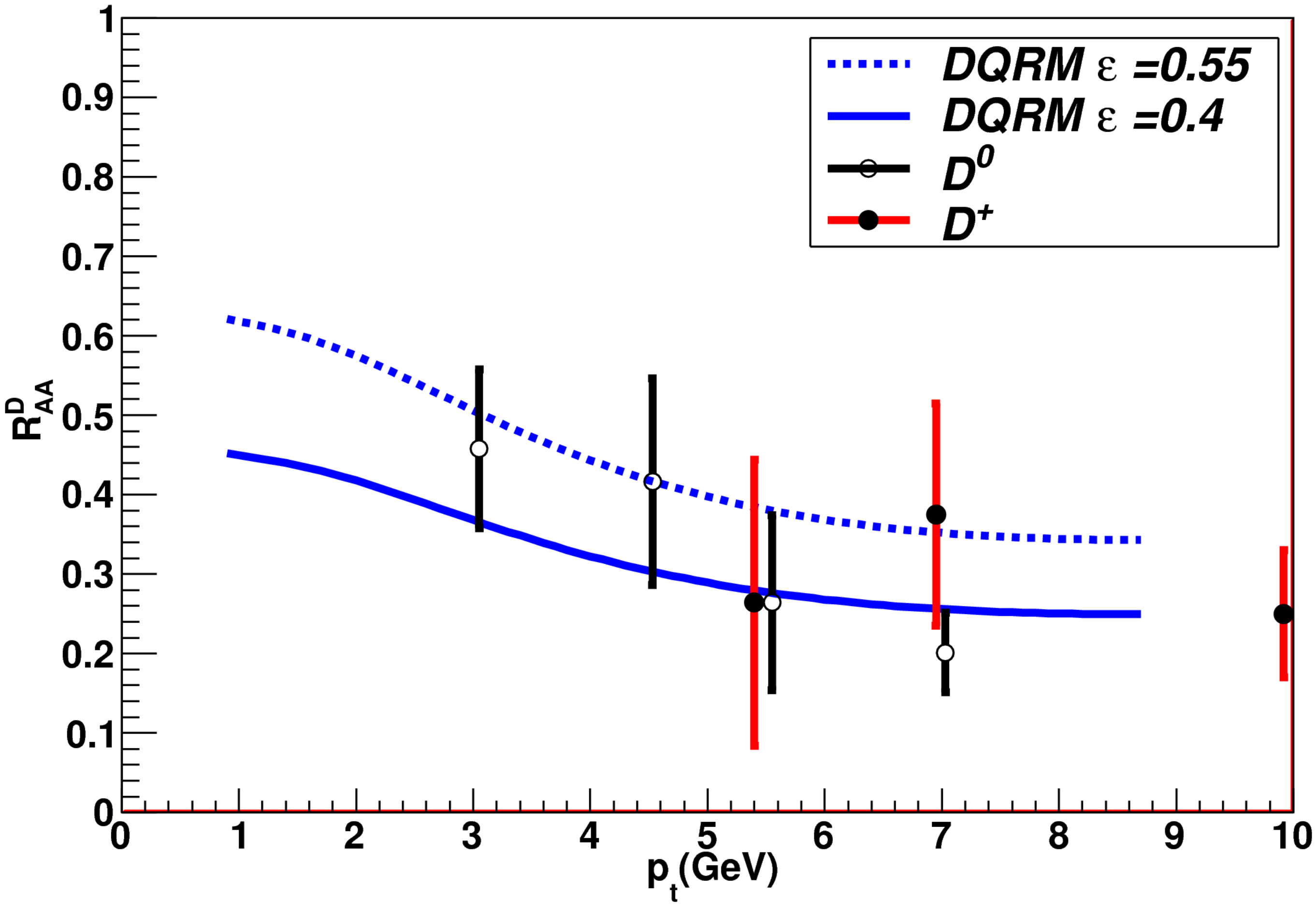


Model of Baryon /Meson ratio for two different transverse velocities.

Simulation of pp collisions can produce at RHIC and LHC energies can produce the ratio Baryon/meson which have behavior different from a constant.

The results are used to estimate the R^D_{AA}

R^{D}_{AA} : model versus ALICE data



For DRQM :
M^{Λ} = 2.29 GeV
M^{D} =1.87 Gev
T_0 =175
T_f=100
V_t = 0.65

The effect of the energy loss parameter was taken as a constant 0.4 and 0.55, which does not need to be as small as in the case of light flavors ($\epsilon \approx 0.2$)

Extract the new exp. Values of Raa for D0 from 1204.3579v1.pdf

R^e_{AA}: model versus ALICE and STAR data

single non.photonic electron nuclear modification factor R^e_{AA} is affected by the thermal enhancement of the heavy-baryon-to-heavy-meson ratio in relativistic heavy-ion collisions with respect to proton-proton collisions. We make use of the dynamical quark recombination model to compute such a ratio and show that this produces a sizable suppression factor for R^e_{AA} at intermediate transverse momenta. We argue that this suppression factor needs to be considered, in addition to the energy loss contribution, in calculations of R^e_{AA}

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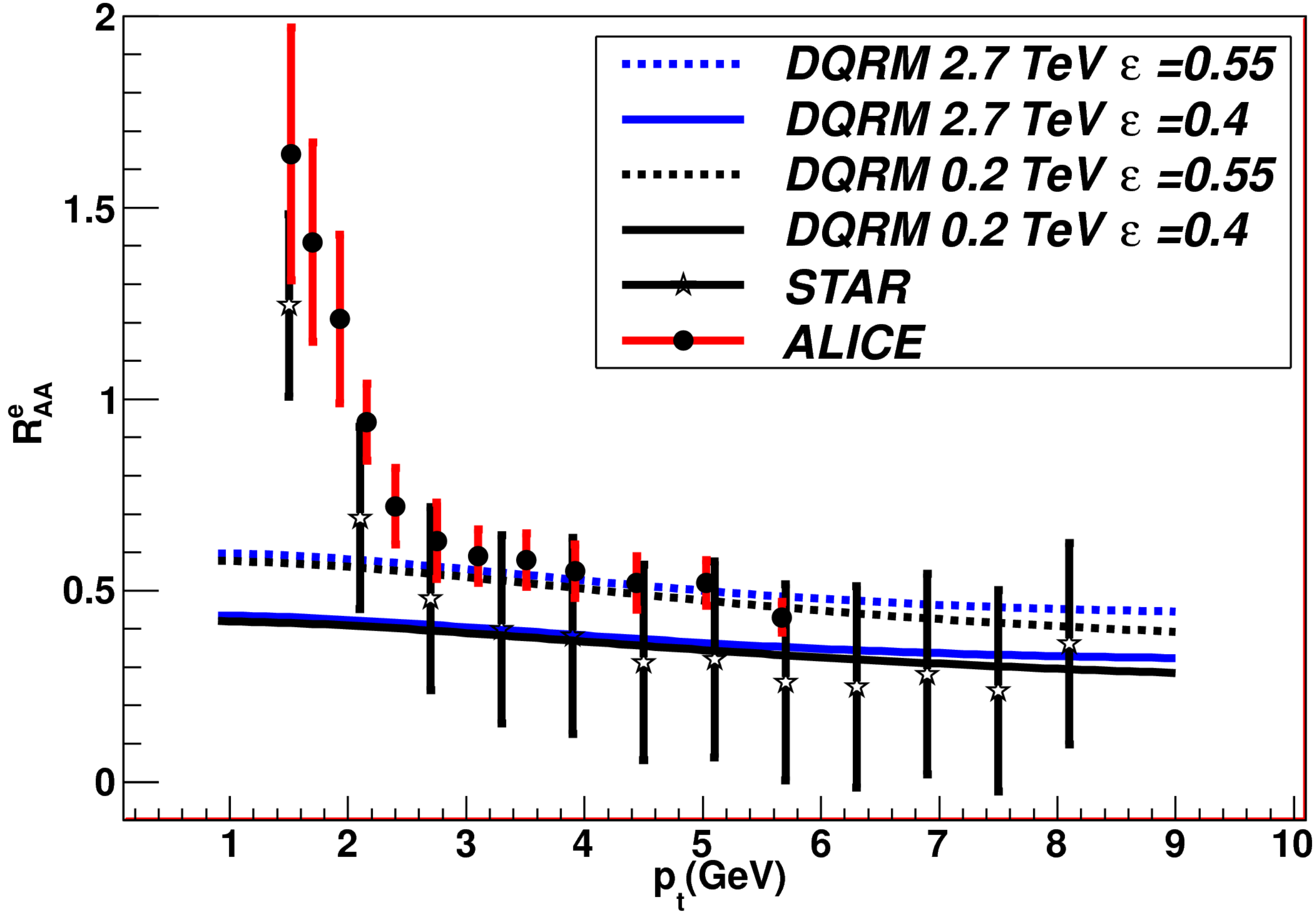

In order to take into account c+b quarks, we take an overage of mass and their branching ratios

For DRQM :
M^{Λ} = 3.95 GeV
M^D =3.57 Gev
T_0 =175
T_f =100
V_t = 0.65 for ALICE
V_t = 0.55 for STAR

The effect of the energy loss parameter was taken as a constant 0.4 and 0.55

Remarks

- *Results on nuclear modification factor was presented considering hadron momentum redistribution when these recombine/coalesce to form mesons and baryons*

- *Nuclear modification factor for heavy flavor as well as for non -photonic single electrons (coming from decay of charm and bottom), can be described without the need of a large energy loss.*

- *The results are valid independent of the model as long as the baryon to meson ratio increase in AA with respect to the pp collisions.*

- *We really need experimental results on $\Lambda c^{+}/D+$ for validate the models (We know that ALICE is working on that).*