Charm meson production in proton-nucleus collisions in the STAR experiment

Michal Svoboda

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Supervisor: doc. Mgr. Jaroslav Bielčík Ph.D.
Consultant: Ing. Jan Vaněk

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Outline

- Motivation
- Quark-Gluon Plasma
- STAR detector at RHIC
- Cold Nuclear Matter Effects
- D^0 meson
- Analysis of D^0 meson in p+Au collisions
- Conclusions

Motivation

- Quark-Gluon Plasma - state of matter present in Universe shortly after the Big Bang
- Possible to produce at large particle colliders in heavy-ion collisions
  - Pb+Pb collisions at LHC in CERN and Au+Au collisions at RHIC in BNL
- To correctly describe QGP, it is necessary to understand so called Cold Nuclear Matter (CNM) Effects
- CNM effects are studied in p+Pb, p+Au and d+Au collisions
- D mesons can serve as a probe of these effects

Quark-Gluon Plasma

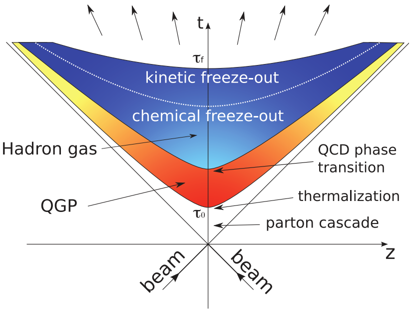


Figure: Illustration of the time evolution of the QGP. Taken from Ref. [1].

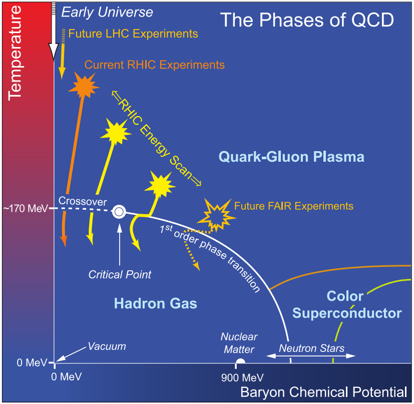


Figure: An illustration of QCD phase diagram. Taken from Ref. [2].

STAR Experiment at RHIC

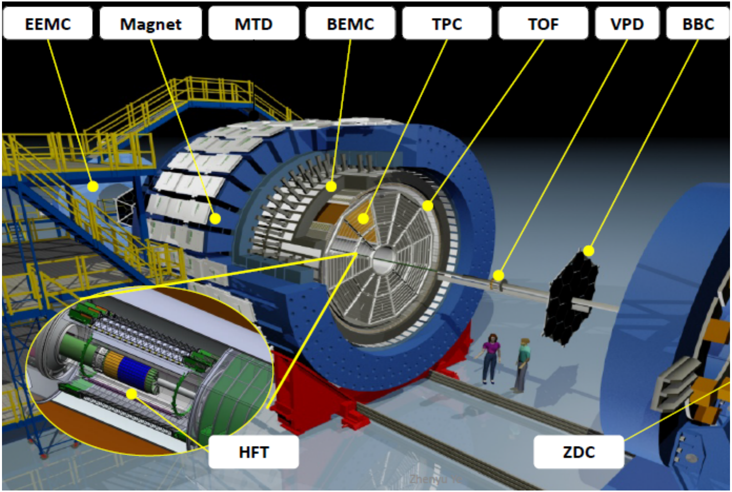


Figure: STAR detector and its sub-detectors. Taken from Ref. [3].

Cold Nuclear Matter Effects

- QGP is studied in A+A collisions and p+p collisions serve as a baseline
- To describe QGP correctly it is necessary to estimate effects caused by a presence of nucleus, so called Cold Nuclear Matter Effects
- In p+A collisions is often assumed that no QGP is present and thus can serve for the description of CNM effects
  - Parton Distribution Function Modification
  - Parton Saturation
  - Multiple Parton Scattering
  - Quarkonia Absorption

Modification of parton distribution function

- PDF $f(x, Q^2)$ describes the probability of finding the parton with a momentum fraction x at a scale Q^2
- Modification of PDF in the A+A with respect to p+p collisions caused mainly by different behavior of partons in a free proton and that bound in a nuclei
- To quantify the modification can be used the shadowing factor R_i^A

$$R_i^A(x, Q^2) = \frac{f_i^A(x, Q^2)}{f_i^{nucleon}(x, Q^2)} \quad (1)$$

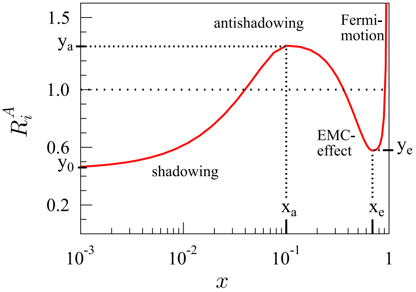


Figure: Visualization of the shadowing factor R_i^A depending on the Bjorken x. Taken from Ref. [4].

Parton saturation

- For small x hadron might seem to be "denser"
- At some point arises the saturation and the gluons recombine instead of creating more partons (gg $\rightarrow$ g, gg $\rightarrow$ q)
- Important observable for saturation is rapidity dependence of R_{AA}

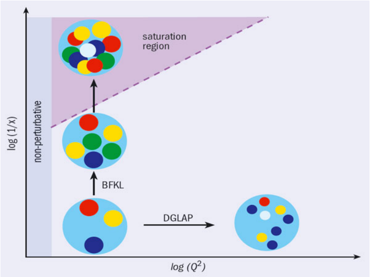


Figure: Hadron structure in $1/x$ and Q^2 plane. Each circle is a parton with a fraction of momentum x. Different evolution regimes and saturation area are shown. Taken from Ref. [5].

Multiple Parton Scattering

- Also called Cronin effect
- Can arise in nucleus before or after the hard scattering or both
- Partons scatter, exchange gluons and thus loose energy (both radiation and collision)
- Leads to broadening of p_T spectra
- At few GeV/c we can talk about Cronin-like enhancement

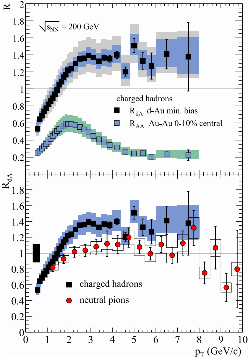


Figure: Nuclear modification factor R_{dA} in d+Au and comparison to R_{AA} in Au+Au central collisions (0–10 %) Taken from Ref. [6].

Quarkonia Absorption

- When travelling through nucleus, created quarkonium can interact inealastically
- We observe quarkonia yield suppression
- Important parameter is absorption cross-section
- This effect is negligible at LHC, but might play bigger role at lower energies

D^0 Meson

- Consist of charm quark c and antiquark up $\overline{u}$
- Lightest charm particle
- Mass
  $m = (1864.84 \pm 0.05)$ MeV$/c^2$ [7]
- Decay length $c\tau = 123$ µm [7]
- $D^0 \rightarrow K^-\pi^+$
  - (BR (3.89 ± 0.04) % [7])
- D^0 and $\overline{D^0}$ analysed together to enhance signal

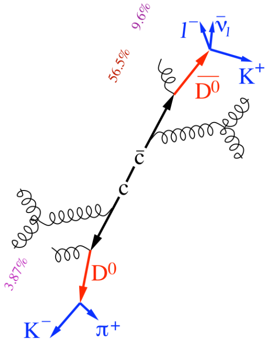


Figure: Fragmentation of c quark. Taken from Ref. [8].

Signal and background estimation

- Each kaon candidate combined with each pion candidate of opposite charge Unlike-sign (US)
- combinatorial background estimated using Like-sign (LS) invariant mass spectrum

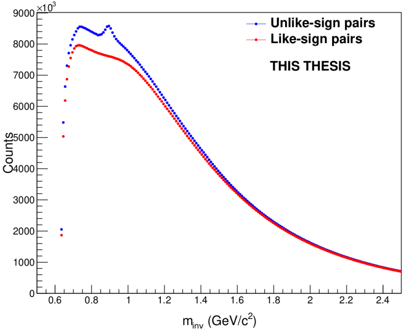


Figure: Opposite charge kaon and pion pairs with the combinatorial background estimated by LS method.

Invariant Mass Spectra I.

- No significant signal observed after subtraction of US and LS

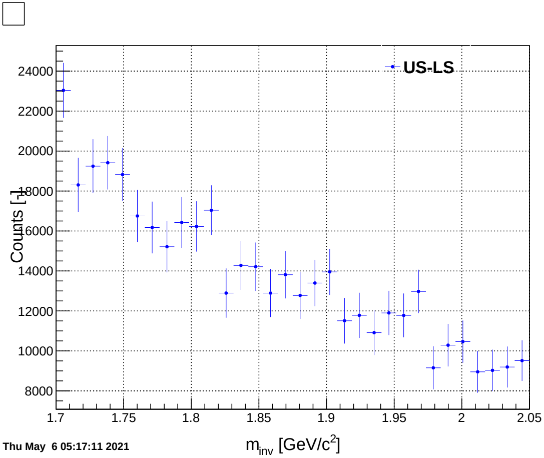


Figure: Invariant mass spectrum of $K\pi$ pairs after subtraction of LS from the US

Candidates selection

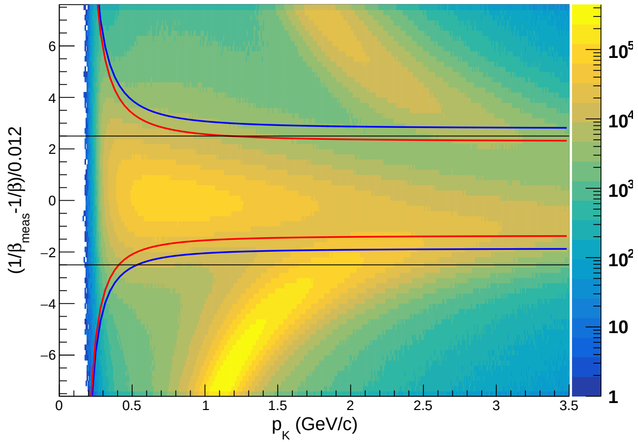


Figure: $1/\beta$ of kaons as a function of momentum p. Three different cuts are shown.

Invariant Mass Spectra II.

- Still no significant signal

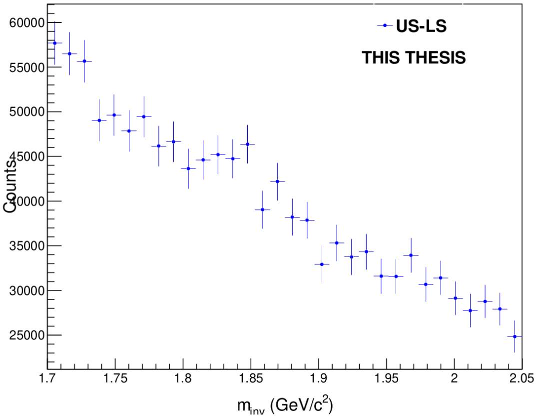


Figure: Invariant mass spectrum of $K\pi$ pairs after subtraction of LS from the US

Invariant Mass Spectra III.

- Another method for the background estimation was used
- US invariant mass spectra were fitted by a 3rd order polynomial using only points outside of $\pm 3\sigma$ (taken from Ref. [8]) band around expected signal peak

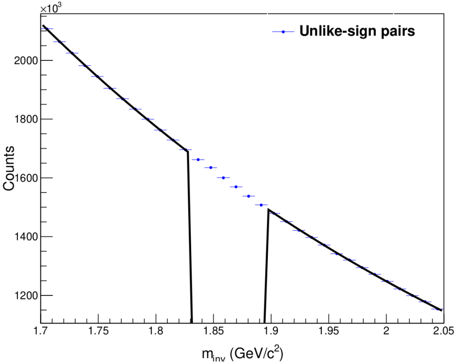


Figure: Third order polynomial fit of US pairs in the shown area.

Invariant Mass Spectra IV.

- Hint of peak in the expected area appeared
- Many choices of the omitted area were used and multiple attempts to fit the peak were done

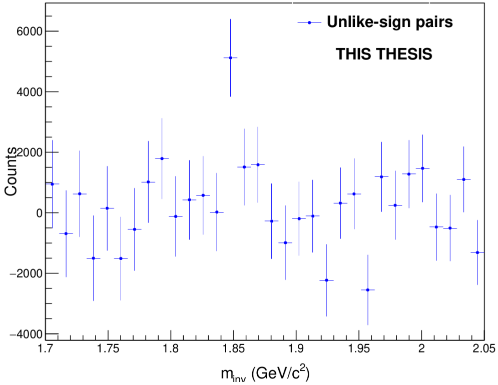
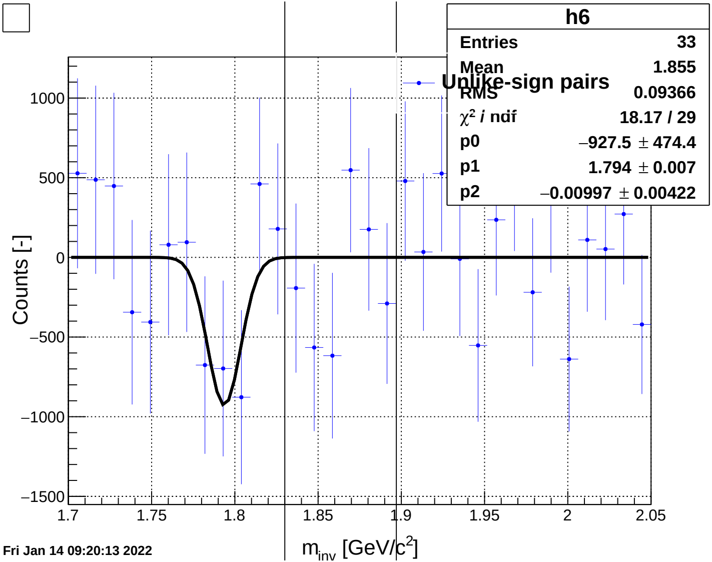


Figure: US spectrum with subtracted polynomial fit of the background.

Invariant Mass Spectra V.



Invariant Mass Spectra VI.

- However the signal is still insignificant and could be interpreted as a statistical fluctuation

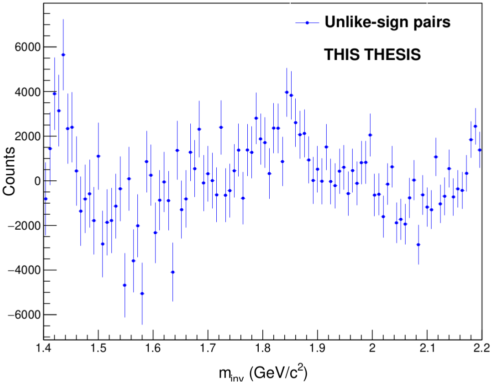


Figure: US spectrum with subtracted polynomial fit of the background.

Possible improvements

- Current selection methods based on analysis in p+p collisions
- Higher background levels in p+Au might require improved selection criteria
- Optimization of selected criteria using supervised machine learning techniques
- Implementing new variable cuts might improve the signal
- Another method for background estimation (event-mixing)
- Currently I am working on D^* (excited D^0) analysis in the same dataset to enhance signal

Conclusions

- Study of heavy-flavor particles is a useful tool for probing properties of the QGP
- For the complete understanding, CNM effects have to be studied
- Results of the measurement of D^0 mesons in p+Au collisions measured in 2015 by STAR has been shown
- Several iterative methods and sophisticated techniques were used improve observed signal
- Considerable improvement (compared to simple US-LS) has been made but another steps are needed
- Significant signal of D^0 not observed yet
- It is necessary to improve candidate selection and implement another methods for background suppression
- Such tools might be another variables or machine-learning techniques

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Backup

Dataset and Event Selection

- p+Au, $\sqrt{s_{\rm NN}} = 200$ GeV, measured in 2015 by STAR
- Events had to pass criteria listed below to be accepted
  - pass the trigger BHT1*VPDMB-30_nobsmd,
  - $|V_{z[\rm VPD]} - V_{z[\rm TPC]}| < 6$ cm
  - $|V_{z[\rm TPC]}| < 30$ cm

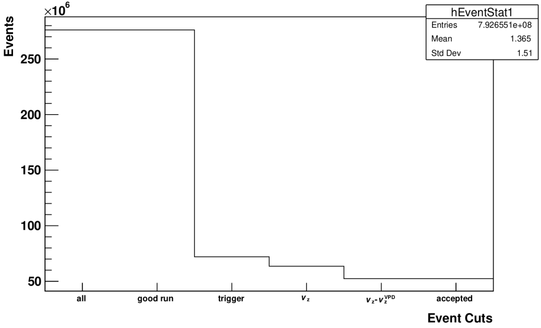

Figure: Number of events that passed individual event selection criteria.

Particle Identification

- Track quality selection criteria
  - number of TPC hits > 15
  - $\frac{\text{number of TPC hits}}{\text{maximal possible number of TPC hits}} > 0.52$
  - $p_T > 0.15$ GeV/c
  - global DCA < 2 cm
- Hybrid TOF PID used

Candidates selection

- First step - simple cuts TPC $n\sigma_\pi < 3$, $n\sigma_K < 2$, TOF $1/\beta < 0.03$ for both pions and kaons
- $1/\beta$ resolution at lower momentum ($\sim < 0.4$ GeV/c) not so precise
- Caused by multiple rescattering in TPC volume
- Momentum dependent cuts used to solve this issue
- $1/\beta$ distribution split into slices, each fitted by gaussian function
- Sigmas (f_{res}) and means (f_{pos}) fitted by function

$$f = p_0 + \frac{p_1}{(p + p_2)^{p_3}} \tag{2}$$

- Final cut range

$$3 \cdot f_{\mathrm{res}} + f_{\mathrm{pos}} > \Delta\frac{1}{\beta}\frac{1}{0.012} > -2 \cdot f_{\mathrm{res}} + f_{\mathrm{pos}} \tag{3}$$