Measurements of D^0 Production in d+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV by the STAR Experiment

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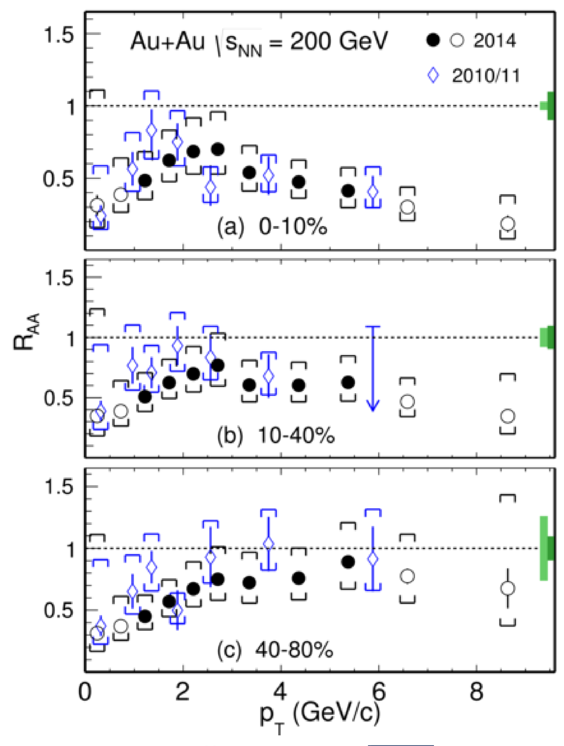
ABSTRACT

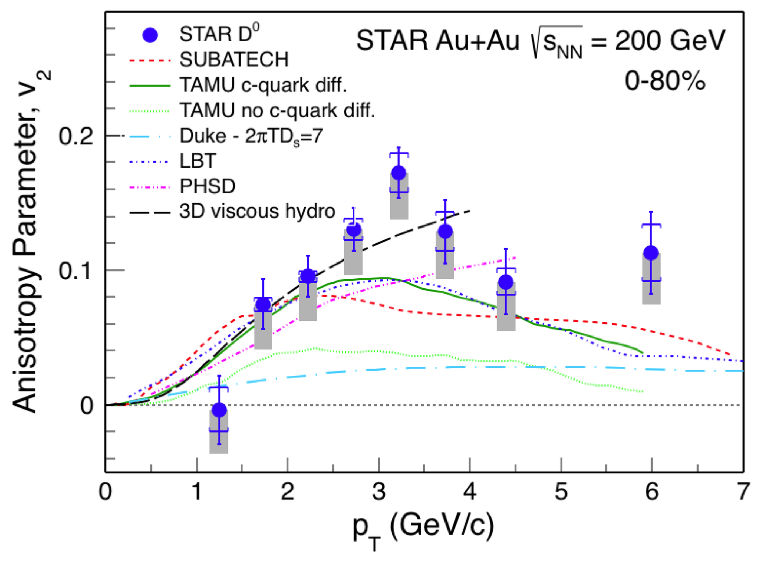
Owing to their large mass, charm quarks are predominantly produced through initial hard scatterings in heavy-ion collisions. Therefore, they can serve as penetrating probes to study the intrinsic properties of the hot medium created in heavy-ion collisions. However, Cold Nuclear Matter (CNM) effects can also affect the charm quark production in nuclear collisions with respect to p+p collisions. These effects can be measured in small systems such as d+Au collisions. In this poster, we report on the first measurement of D^0 production in d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV by the STAR experiment taking advantage of its high-precision Heavy Flavor Tracker detector. D^0 ($\overline{D^0}$) mesons were topologically reconstructed from their hadronic decay channel D^0 ($\overline{D^0}$) → $K^-\pi^+$ ($K^+\pi^-$). In order to further improve the signal significance, a supervised machine learning algorithm (Boosted Decision Trees) was used.

MOTIVATION

- Heavy-flavor quarks are produced in hard scatterings at the early stage of nuclear collisions, therefore they experience the entire evolution of the system including the **quark-gluon plasma (QGP)** phase.
- Open charm mesons at RHIC exhibit strong suppression at high p_T in the 0–10% most central Au+Au collisions, indicating substantial energy loss of charm quarks in the medium.
- The collective behavior of charm quarks reflects **the degree of thermalization** of charm quarks in the medium and carries information about the bulk properties of the QGP.
- For quantitative studies of the QGP properties (e.g. charm transport coefficients), understanding of the **cold nuclear matter effects**, accessible via proton-nucleus or deuteron-nucleus collisions, is required.



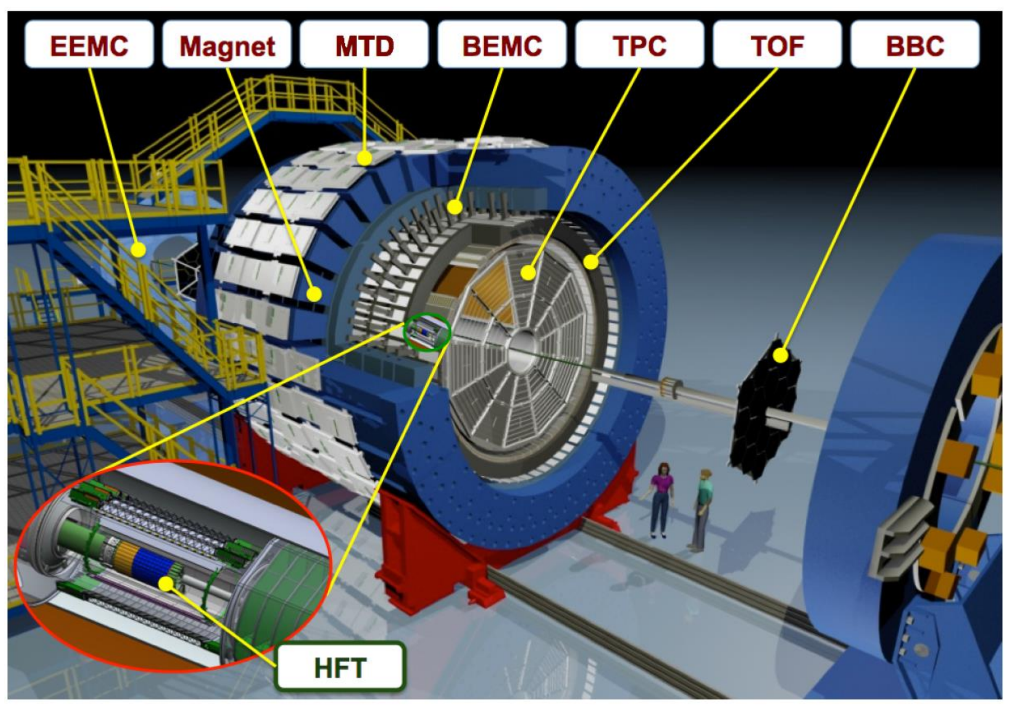
D^0 R_{AA} in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV [1]



Elliptic anisotropy v_2 for D^0 mesons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, compared to theoretical calculations [2]

STAR DETECTOR

- STAR has excellent tracking and charged particles identification at mid-rapidity ($|\eta|$ < 1) with full azimuthal coverage.
- Most of the subsystems are immersed in a 0.5 T solenoidal magnetic field.



Time Projection Chamber (TPC):
- main tracking detector, momentum determination, particle identification via ionization energy loss (dE/dx).

Time Of Flight (TOF):
- particle identification via velocity (β).

Heavy Flavor Tracker (HFT):
- inner tracking system composed of three silicon detectors – the PIXEL made of two layers of Monolithic Active Pixel Sensors, Intermediate Silicon Tracker (IST) and Silicon Strip Detector (SSD),
- excellent DCA_{xy} and DCA_z resolution: **30 μm for kaons at p_T = 1.5 GeV/c**,
- installed for data taking in years 2014–2016.

ANALYSIS METHOD

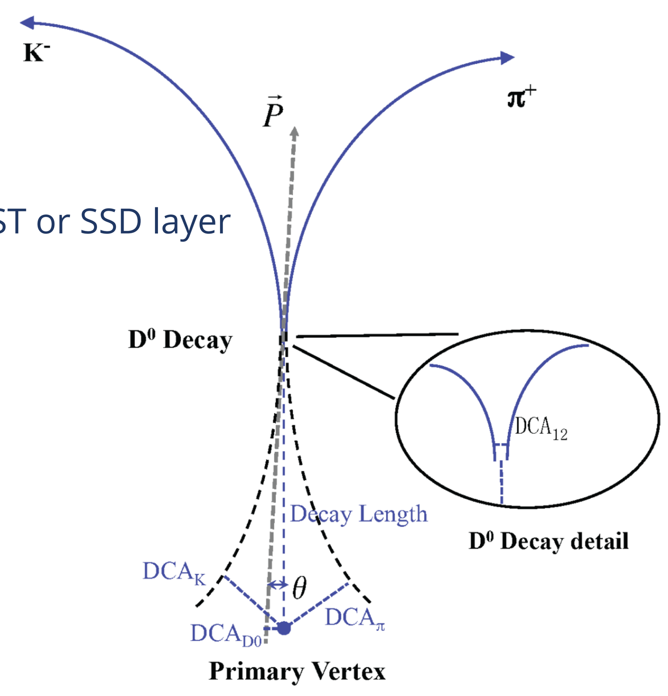
- About 350 million d+Au events at $\sqrt{s_{NN}}$ = 200 GeV recorded in 2016 are used for this analysis.
- $\overline{D^0}$ → $K^+\pi^-$, D^0 → $K^-\pi^+$ decay channels with BR = (3.95 ± 0.03) %.

Event selection:
- Pile-up rejection through requirement of correlation of primary vertex reconstructed using TPC and Vertex Position Detector (VPD) $|V_{z,VPD} - V_{z,TPC}|$ < 6 cm
- Vertex position in beam direction $|V_z|$ < 6 cm → HFT coverage

Track selection:
- At least 15 space points in the TPC for track reconstruction
- Track pseudorapidity $|\eta|$ < 1
- Daughter p_T > 0.15 GeV/c
- Requirement of hits in both PIXEL layers and at least one of the IST or SSD layer

Particle identification:
- TPC dE/dx: $|n\sigma_\pi|$ < 3, $|n\sigma_K|$ < 2
- TOF used only for tracks which have valid TOF information: $|1/\beta_{theo.} - 1/\beta_{meas.}|$ < 0.03

Topological cuts for D^0 reconstruction:
- Used topological properties of D^0 decays are:
  1. decay length
  2. daughter $DCA_{K,\pi}$ to primary vertex (PV)
  3. DCA_{12} between daughter kaon and pion
  4. reconstructed D^0 candidate DCA_{D0} to primary vertex
  5. pointing angle θ between reconstructed D^0 momentum and decay length vector



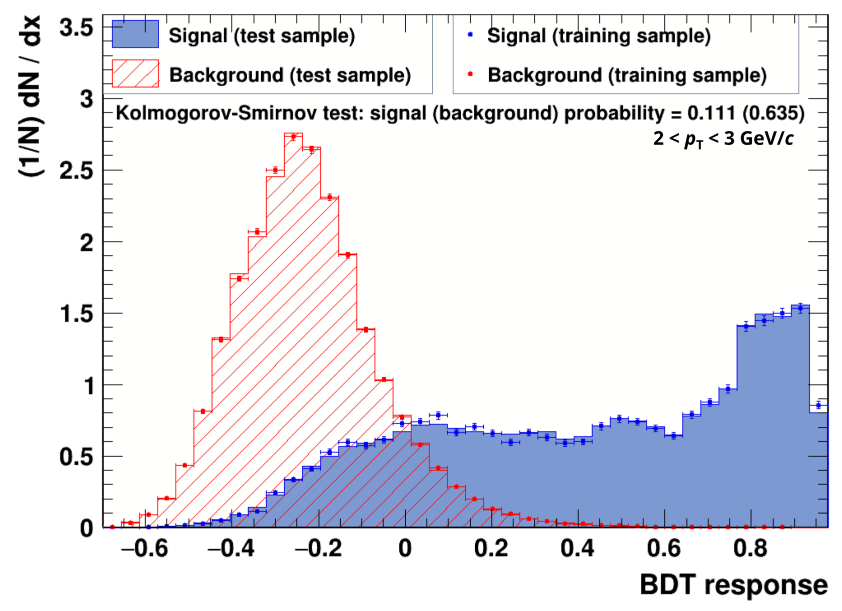
- Signal and background separation is optimized with the **Toolkit for Multivariate Data Analysis** (TMVA) package [3].

MACHINE LEARNING ALGORITHM TRAINING

- The TMVA - **Boosted Decision Trees** (BDT) method was used.
  - Classifier is a binary structured decision tree.

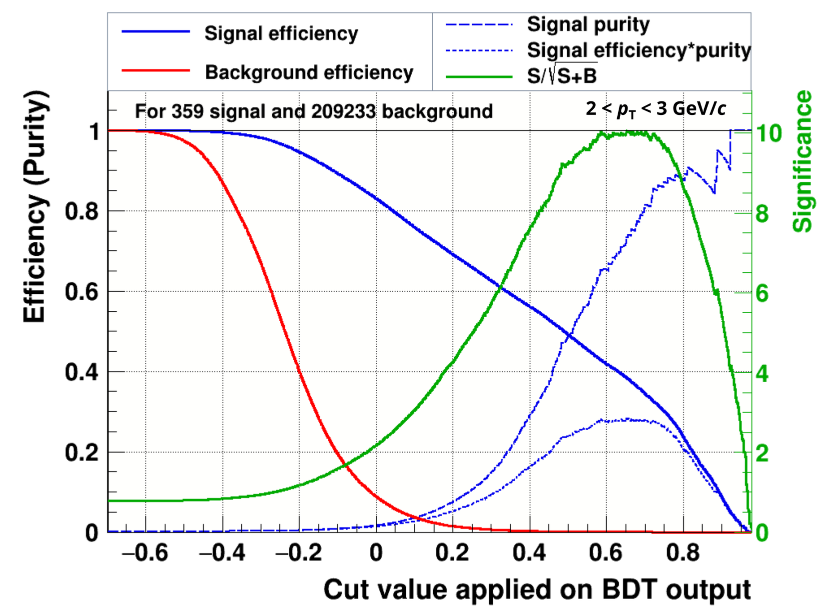
Signal sample for training:
- D^0 decay is simulated using PYTHIA.
- Momenta and DCA of daughter particles are smeared in accordance to the detector response.

Background sample for training:
- wrong(like)-sign pairs at the D^0 mass region taken directly from data.



Classifier output distributions

- Both signal and background input pairs are divided to training and test samples of equal size.
- The trained BDT is applied on both samples.
- Overtraining check: if distributions obtained from training and test samples are consistent, BDT is not overtrained.

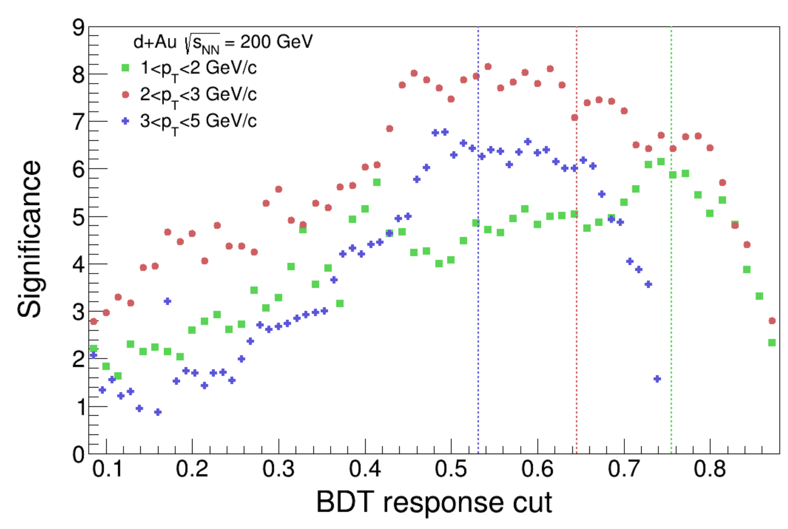


Classifier cut efficiencies

- In order to find the cut with the maximum signal significance, estimates of **number of signal** (N_S) and **background** (N_B) before BDT application are needed.
- N_S is estimated using D^0 invariant yield measured in p+p collisions and the detector reconstruction efficiency.
- N_B is evaluated from the number of wrong(like)-sign pairs in the data.

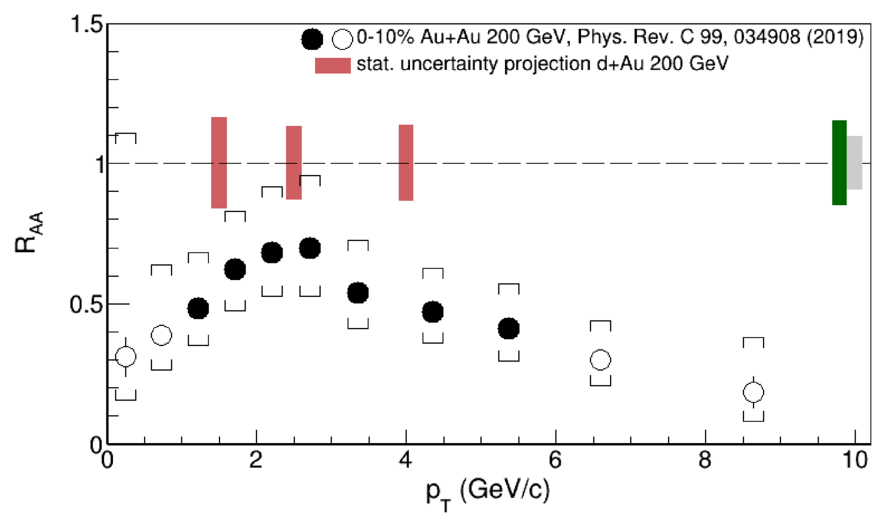
BDT APPLICATION ON DATA

- BDT is applied **on both correct(unlike)-sign pairs and wrong(like)-sign** pairs from the data.
- Distribution of invariant mass of pairs that fulfill the **cut on BDT response** is used for significance calculation.
- Background from **wrong(like)-sign** combinations of daughter particles ($K^+\pi^+$, $K^-\pi^-$) is subtracted from the **correct(unlike)-sign** combinations.



Scan of cut on BDT response on data

- Intervals of pair p_T used for analysis:
  - 1–2, 2–3, 3–5 GeV/c.
- BDT is trained separately in these intervals.
- Lines shows the cuts with maximum significances calculated using classifier cut efficiencies and estimates of N_S and N_B.



Statistical error projection of R_{dAu}

- Green box: uncertainty in determining N_{bin} in d+Au collisions.
- Grey box: global p+p uncertainty.

CONCLUSIONS AND OUTLOOK

- D^0 mesons are reconstructed via their hadronic decay channels in d+Au collisions thanks to excellent precision of the **Heavy Flavor Tracker at the STAR experiment**.
- Extraction of D^0 signal from d+Au data has been optimized using the TMVA Boosted Decision Trees method in different intervals of p_T bins.
- Evaluations of the efficiency corrections on D^0 raw yields and systematic uncertainties are under way, to determine the invariant yield and **nuclear modification factor** R_{dAu} in d+Au collisions.

REFERENCES

[1] J. Adam et al. (STAR Collaboration), Phys.Rev. C99 (2019) no.3, 034908.
[2] L. Adamczyk et al. (STAR Collaboration), PRL 118 (2017) 212301.
[3] A. Hocker et al., PoS ACAT, 040 (2007).

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