Measurement of $D^\pm$ meson production in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV with the STAR experiment

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PHYSICS MOTIVATION

- **Quark-Gluon Plasma (QGP)** can be studied using relativistic heavy-ion collisions.

- At RHIC energies, **charm quarks** are produced predominantly through hard partonic scatterings at **early stage** of Au+Au collisions:
  - They experience **the whole evolution of the medium**.

- **Charm quark energy loss** in the medium can be studied by measurement of open-charm meson nuclear **modification factor** $R_{AA}$.
D⁰ Nuclear Modification Factor

- Nuclear modification factor:
  \[ R_{AA}(p_T) = \frac{dN_{D^{0}}^{AA}/dp_T}{\langle N_{coll}\rangle dN_{D^{0}}^{pp}/dp_T} \]

- D⁰ mesons suppressed in central Au+Au collisions
  - Strong interactions between charm quarks and the medium
  - Suppression of D⁰ mesons comparable to light flavor hadrons at RHIC and D mesons at LHC
  - Reproduced by models incorporating both radiative and collisional energy losses, and collective flow

- Measurement of D± is complementary to that of D⁰
  - Independent cross-check of the D⁰ measurement
  - Important contribution to total charm cross-section
  - Three-body decay, larger decay length than D⁰

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[Graph and data points for Au+Au collisions and D± measurements]
STAR DETECTOR

- **Solenoidal Tracker At RHIC**
- **Heavy Flavor Tracker** (HFT, 2014–2016) is a 4-layer silicon detector
  - MAPS – 2 innermost layers (PXL1, PXL2), Strip detectors – 2 outer layers (IST, SSD)
- **Time Projection Chamber (TPC) and Time Of Flight (TOF)**
  - Particle momentum (TPC) and identification (TPC and TOF)

**$D^\pm$ MEASUREMENTS WITH THE HFT**

- Data used in this analysis are from 2014 and 2016 for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

- Total of ca. 2.3B good minimum bias events after event selection

- The HFT allows direct topological reconstruction of $D^\pm$ mesons through their hadronic decay
  - $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$  
    - $c\tau = (311.8 \pm 2.1) \mu$m  
    - $BR = (8.98 \pm 0.28)\%$

\[F.\text{Niecknig, B.\text{Kubis}}:\text{JHEP 1510, 142, (2015)}\]
**EVENT AND TRACK SELECTION, PID**

- **Event selection**
  - Position of primary vertex along the beam axis

- **Track selection**
  - Low $p_T$ cut – suppresses combinatorial background from low-$p_T$ particles
  - $|\eta| < 1$ – detector acceptance
  - Minimum number of hits in the TPC for each track – good track quality
  - At least three hits in HFT, one in PXL1, one in PXL2 and at least one in IST or SSD

- **Particle identification (PID)**
  - TPC – energy loss of charged particles in the TPC gas
  - TOF – velocity of the charged particles

- **Topological selection criteria**
  - Possible only with use of the HFT
  - Constrain topology of the reconstructed secondary vertex
  - Suppress combinatorial background
  - Optimized using TMVA
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**D± RAW YIELD EXTRACTION**

- Raw yield extracted from invariant mass spectra of Kππ triplets
  - Significant background suppression with TMVA optimization of the topological selection criteria
  - Improved signal significance

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![Mass Spectrum Graphs]

**Manually tuned**

- 2016 Au+Au $\sqrt{s_{NN}} = 200$ GeV
- Centrality 10-40%
- $2.0 < \pt < 2.5$ GeV/c

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**TMVA optimized**

- 2016 Au+Au $\sqrt{s_{NN}} = 200$ GeV
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Invariant yield is calculated according to:

\[
\frac{d^2 N}{2\pi p_T \, dp_T \, dy} = \frac{Y_{\text{raw}}}{2 \pi N_{\text{evt}} \, BR \, p_T \Delta p_T \Delta y \, \varepsilon(p_T)}
\]

- \( Y_{raw} \) = raw yield, \( N_{\text{evt}} \) = number of events, \( BR \) = branching ratio, \( \varepsilon(p_T) \) = total \( D^\pm \) reconstruction efficiency

- **Collision centrality classes:** 0-10%, 10-40%, 40-80%
  - Determined from charged track multiplicity in TPC matched to Glauber model simulation
**Invariant spectra of $D^\pm$ and $D^0$ mesons measured in Au+Au collisions at $\sqrt{s_{_{NN}}}=200$ GeV**

- Spectra are fitted by Levy function
- The $D^\pm$ results help to constrain the total open charm cross-section and for better understanding of charm quark hadrochemistry in Au+Au collisions

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**D± Nuclear Modification Factor**

- Reference: combined D⁰ and D* measurement in 200 GeV p+p collisions using 2009 data

- Similar level of suppression and centrality dependence for D± and D⁰

- High-p_T D± and D⁰ suppressed in central Au+Au collisions
  - Strong interactions between charm quarks and the medium

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The $D^\pm/D^0$ yield ratio is compared to PYTHIA 8 calculation

- Good agreement in all Au+Au centrality classes

- No modification of the $D^\pm/D^0$ yield ratio compared to PYTHIA
CONCLUSION

- STAR has extensively studied production of open-charm mesons in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV utilizing the Heavy-Flavor Tracker

- The HFT allows direct topological reconstruction of hadronic decays of open-charm mesons

- $D^\pm$ invariant spectrum measured for three centrality classes of Au+Au collisions
  - 0-10%, 10-40%, 40-80%

- $D^\pm$ nuclear modification factor is consistent with that of $D^0$
  - $D^0$ and $D^\pm$ mesons are significantly suppressed at high-$p_T$ in central Au+Au collisions
  - Charm quarks interact strongly with the QGP

- $D^\pm/D^0$ yield ratio
  - Agrees with PYTHIA 8 calculation

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THANK YOU FOR ATTENTION

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**Event and Track Selection, PID**

- **Example of analysis cuts for $D^{\pm}$ reconstruction using the HFT**
- **Event selection**
  - Position of primary vertex along the beam axis
- **Track selection**
  - $p_T$ – suppresses combinatorial background from low-$p_T$ particles
  - nHitsFit – large number of TPC hits used for track reconstruction to ensure good track quality
  - Hit in at least three layers of the HFT
- **PID: HFT+TPC+(TOF)**
  - Hybrid TOF = use TOF only for tracks with valid TOF information
- **Topological selection criteria**
  - Possible only with use of the HFT
  - Constrain topology of the reconstructed secondary vertex
  - Suppress combinatorial background
  - Optimization using the TMVA

### Event selection

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Condition</th>
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<tbody>
<tr>
<td>$</td>
<td>V_z</td>
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<tr>
<td>$</td>
<td>V_z - V_z(\text{VPD})</td>
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### Track selection

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Condition</th>
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</thead>
<tbody>
<tr>
<td>$p_T &gt; 300 \text{ MeV}/c$ $(500 \text{ MeV}/c)$</td>
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</tr>
<tr>
<td>$</td>
<td>\eta</td>
</tr>
<tr>
<td>nHitsFit $&gt; 20$</td>
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<tr>
<td>nHitsFit/nHitsMax $&gt; 0.52$</td>
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<tr>
<td>HFT track = PXL1+PXL2+(IST or SSD)</td>
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### PID cuts

<table>
<thead>
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<th>Component</th>
<th>Condition</th>
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<tbody>
<tr>
<td>TPC</td>
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<tr>
<td></td>
<td>$</td>
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<tr>
<td>Hybrid TOF</td>
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### Topological selection criteria

<table>
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<tr>
<td>$L_{D^{\pm}}$</td>
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<tr>
<td>cos($\theta$)</td>
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<tr>
<td>DCA$_{\pi,\text{PV}}$</td>
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<tr>
<td>DCA$_{K,\text{PV}}$</td>
<td></td>
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