Measurement of $\Lambda_c$ baryon production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with the STAR experiment

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Quark-gluon Plasma (QGP)

- New state of matter composed of deconfined quarks and gluons
- Expected to exist in neutron stars and in the early Universe

More on QGP in the talk on Wednesday at 10:00 am by Jana Bielčíková
Use charm quarks to probe QGP

• Charm quarks are predominantly produced in hard scatterings during early stages of heavy-ion collision
  
  • \( m_c = 1.28 \pm 0.03 \text{ GeV}/c^2 \gg T_{\text{QGP}} \)
  
  \( m_u = 2.2^{+0.6}_{-0.4} \text{ MeV}/c^2, \)
  
  \( m_d = 4.7^{+0.5}_{-0.4} \text{ MeV}/c^2, \)
  
  \( m_s = 98^{+6}_{-4} \text{ MeV}/c^2 \)

[Chin. Phys. C, 40, 100001 (2016) and 2017 update]

• Good probe of the behavior of QGP as charm quarks experience the entire evolution of the medium

More on charm meson measurements in the talk on Wednesday at 12:15 by Lukáš Kramářik
\( \Lambda_c \) baryon

- Lightest charm baryon
- Valence quarks: u+d+c
- Mass: 2286 MeV/\(c^2\)
- \( c\tau \sim 60 \mu m \)

- First observed in 1975 at BNL 7-ft cryogenic bubble chamber, exposed to a neutrino beam

[Cazzioli et al. PRL 34 (1975) 1125]
Quark coalescence

- Enhancement of baryon-to-meson ratios for light hadrons have been observed in Au+Au collisions compared to that in p+p collisions
- Hadronization mechanisms:
  - Fragmentation: one parton fragments into hadron(s)
  - Coalescence: multiple quarks cluster together to form a hadron
- Coalescence hadronization process is expected to occur in heavy-ion collisions, as compared to only fragmentation hadronization in elementary collisions
- Measurement of $\Lambda_c/D^0$ ratio will provide new insights into whether charm quarks also participate in coalescence hadronization
The Relativistic Heavy-Ion Collider at Brookhaven National Laboratory

- Dedicated facility to study the Quark-Gluon Plasma and proton spin
- Capable of colliding a variety of nuclei as well as polarized protons
- 3.9 km circumference
- Maximum center-of-mass energy: $\sqrt{s_{NN}} = 200$ GeV for Au+Au, $\sqrt{s} = 510$ GeV for p+p
The Solenoidal Tracker at RHIC (STAR)

- Multipurpose particle detector
- Excellent tracking and identification of charged particles with full azimuthal coverage at midrapidity
- Mostly inside of a 0.5T solenoid magnet
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Time-Projection Chamber (TPC)
- Large-volume gaseous detector
- Tracking and particle identification via energy-loss measurement
The Solenoidal Tracker at RHIC (STAR)

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Time-Of-Flight detector (TOF)
- MRPC
- Particle identification via measurement of the time of flight
The Solenoidal Tracker at RHIC (STAR)

- Multipurpose particle detector
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Heavy Flavor Tracker (HFT)
- Installed in 2014 – 2016
- 4 layers of silicon detectors
- Precise vertexing detector
STAR Heavy Flavor Tracker

- The Pixel detector: the first MAPS technology in a collider experiment
- Pointing resolution: \( \sim 20 \, \mu\text{m} \) at high \( p_T \) (exceeds the requirement of \( 55 \, \mu\text{m} \) for 750 MeV/c kaons)
- Recorded \( \sim 9 \times 10^8 \) good Au+Au events in 2014. Results shown in this presentation are based on this data-sample
Topological reconstruction of $\Lambda_c$ with the HFT

- $\Lambda_c^{\pm} \rightarrow p^{\pm} K^{\mp} \pi^{\pm}$, $c\tau \sim 60 \mu m$, $BR = 5\%$
- Experimentally challenging to measure in heavy-ion collisions
- HFT used for reconstruction of secondary vertices with high precision
- Usage of machine learning methods to optimize topological cuts
- Combinatorial background is greatly suppressed
p+K+π invariant mass spectrum

• First measurement of $\Lambda_c$ baryons in heavy-ion collisions

• Measured for
  • Centrality: 10 – 60 %
  • $p_T$: 3 – 6 GeV/c

• Significance: $\frac{S}{\sqrt{S+B}} \sim 5.2$

• Background estimation: p+K+π triplets with incorrect combinations of charge signs

#($\Lambda_c$) = 108 ± 21
$\Lambda_c/D^0$ yield ratio

- Clear enhancement observed compared to the fragmentation scenario predicted by PYTHIA
- Compatible with baryon-to-meson ratios of light hadrons
- Ko model (0-5%), including coalescence of thermalized charm quarks, is consistent with the data for both di-quark + 1 quark, and three-quark scenarios
Summary

• The first measurement of $\Lambda_c$ baryons in heavy-ion collisions

• Enhancement of the $\Lambda_c/D^0$ ratio – indication of charm quark coalescence

• In 2016, STAR recorded about twice more Au+Au events compared to 2014

• Stay tuned!
Thank you for your attention
Backup
Nuclear modification factor $R_{AA}$ of $D^0$ and $D^\pm$

$$R_{AA} = \frac{dN_{AA}/dp_T}{\langle N_{coll} \rangle \times dN_{pp}/dp_T}$$

• Yield at $p_T > 2.5$ GeV/c is greatly suppressed
  • Improved precision with the HFT
  • Results from $D^0$ and $D^\pm$ are consistent
• Models with strong charm-medium interactions describe the data

[STAR: PRL 113 (2014) 142301]
[Theory:
  SUBATECH: PRC 91(2015) 054902 & private comm.;
## Pixel detector (PXL)

| **Radii** | Layer 1 at 2.8 cm  
<table>
<thead>
<tr>
<th></th>
<th>Layer 2 at 8 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pixel size</strong></td>
<td>20.7 μm × 20.7 μm</td>
</tr>
<tr>
<td><strong>Hit resolution</strong></td>
<td>3.7 μm</td>
</tr>
<tr>
<td><strong>Position stability</strong></td>
<td>6 μm RMS (20 μm envelope)</td>
</tr>
</tbody>
</table>
| **Radiation length** | Layer 1: \( X/X_0 < 0.4\% \)  
|               | Layer 2: \( X/X_0 < 0.5\% \) |
| **Number of pixels** | ~ 356 M       |
| **Integration time (affects pileup)** | 185.6 ms |
| **Radiation environment** | 20 – 90 kRad/year  
|               | 2 \( \times 10^{11} \) to \( 10^{12} \) 1 MeV n eq/cm\(^2\) |
| **Installation time** | ~ 1 day         |