Highlights from STAR

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**Open heavy flavor**
- How do charm quarks interact with and lose energy in QGP? How about bottom?
- How do charm quarks in QGP hadronize?
- Does total charm cross-section in HI collisions scale with $N_{\text{binary}}$?

**Quarkonium production**
- Are more weakly bound quarkonium states more suppressed in HI collisions? Cold nuclear matter effects? Understand better charmonium production in p+p collisions.

**Jet and di-hadron correlation measurements at RHIC energy**
- Features of jet modification in QGP: dependences on jet angular scale, jet radius, constituent $p_T$, event geometry etc
- Suppression of $\gamma_{\text{dir}}$-triggered jet

**Di-lepton production**
- Low $p_T$ di-electron excess in peripheral collisions
- Di-muon spectra with improved muon identification
Sooraj Radhakrishnan

- **HFT**: 2014 - 2016
  \[ |\eta| < 1.0 \]
- **MTD**: 2014 -
  \[ |\eta| < 0.5, \text{45\% in } \phi \]
- **EMC**:
  - Barrel, \[ |\eta| < 1.0 \]
  - Endcap, \[ 1 < \eta < 2 \]
- **Tracking and PID**
  - TPC, \[ |\eta| < 1.0 \]
  - TOF, \[ |\eta| < 1.0 \]
  - Full azimuthal coverage

- HFT significantly improves charm and bottom hadron measurements
- MTD enables muon identification, improve quarkonium measurements
• $\Lambda_c$ production in heavy ion collisions

• $\Lambda_c/D^0$ yield ratio provide insight into charm hadronization mechanism in QGP

• HFT provides excellent vertex resolution, allows topological reconstruction of heavy flavor hadrons

• $c_T$ for $\Lambda_c = 60$ $\mu$m!

• Supervised Learning Methods (BDT) used to improve signal-background separation for $\Lambda_c$ reconstruction

Talk by G. Xie: 04/10 Thu, 11.25 (P3)
Sooraj Radhakrishnan

**STAR Preliminary**

Au+Au, $\sqrt{s_{NN}} = 200$ GeV

- Ko: three quark (0-5%)
- Ko: di-quark, (0-5%)
- Greco (0-20%)
- PYTHIA

**Talk by G. Xie: 04/10 Thu, 11.25 (P3)**

- **Strong enhancement of $\Lambda_c$ production compared to PYTHIA calculations**
- **Suggest coalescence hadronization of charm quarks in QGP at intermediate $p_T$ (2-6 GeV/c)**


ALICE : JHEP 04 (2018) 108
• Measurement of $D^0$ spectra extending to zero $p_T$ in HI collisions!

• $D^0$ shows similar suppression as light hadrons at high $p_T$ in central collisions

• Transport models with charm quark energy loss can describe the data

Talk by G. Xie: 04/10 Thu, 11.25 (P3)
Directed flow ($v_1$) of $D^0$

- Sensitive to initial tilt of fireball and viscous drag on charm quarks from QGP [1].
- Also difference between $D^0$ and anti-$D^0$ $v_1$ predicted to be sensitive to initial EM field

Order of magnitude larger $v_1$ than for light flavor hadrons!
In agreement with the prediction of large $D^0$ $v_1$ by hydro models


Talk by L. He: 02/10 Tue, 11.05 (P3)
Charm production in Au+Au collisions

- Cross-section for $D^0$ production lower than in p+p

\[ \text{Au+Au @ 200 GeV} \quad \text{p+p integrated $D^0$ cross-section} \]

- Enhancement for $\Lambda_c$ (and $D_s$) and suppression for $D^0$
- But total charm cross-section is found to be consistent with p+p

<table>
<thead>
<tr>
<th>Charm Hadron</th>
<th>Cross-section (μb)</th>
</tr>
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<tbody>
<tr>
<td>$D^0$</td>
<td>$41 \pm 1 \pm 5$</td>
</tr>
<tr>
<td>$D^+$</td>
<td>$18 \pm 1 \pm 3$</td>
</tr>
<tr>
<td>$D_s^+$</td>
<td>$15 \pm 1 \pm 5$</td>
</tr>
<tr>
<td>$\Lambda_c^+$</td>
<td>$78 \pm 13 \pm 28^*$</td>
</tr>
<tr>
<td>Total</td>
<td>$152 \pm 13 \pm 29$</td>
</tr>
<tr>
<td>Total pp 200 GeV</td>
<td>$130 \pm 30 \pm 26$</td>
</tr>
</tbody>
</table>

* derived using $\Lambda_c^+/D^0$ ratio in 10-80%

Talk by G. Xie: 04/10 Thu, 11.25 (P3)
• Charm quarks interact strongly with QGP, how about bottom?
• Is there a flavor (mass) dependent energy loss? Is $\Delta E_b < \Delta E_c$?

- Indication of less suppression for $B \rightarrow e$ than $D \rightarrow e$ ($\sim 2\sigma$ difference)
- Results from 2014 data (except $B \rightarrow J/\psi$), 2 - 5 times more data from 2016 being analyzed

Talk by X. Chen: 02/10 Tue, 09.20 (P3)
- Improved precision by combining 2011 di-electron, 2014+2016 di-muon datasets
- $Y(2S+3S)$ $R_{AA}$ smaller than $Y(1S)$ $R_{AA}$ in central collisions

**Talk by Z. Liu: 03/10 Wed, 09.00 (P3)**
Quarkonia production in p+p and p+Au

- $J/\psi$ $R_{pAu}$ lower than models with nPDF effects
- NRQCD: includes color octet contributions to $J/\psi$ production, can describe the data

Talk by Z. Liu: 03/10 Wed, 09.00 (P3)

Sooraj Radhakrishnan
Features of jet modification: Di-jet imbalance

- How jets are modified in the presence of QGP?
- Dijet asymmetry quantifies momentum imbalance between dijets

\[
A_J = \frac{p_{T,\text{Lead}} - p_{T,\text{SubLead}}}{p_{T,\text{Lead}} + p_{T,\text{SubLead}}}
\]


- **Hard-core jets**: Jets recostructed with constituents above a high \( p_T \) cut
- **Matched jets**: Hard-core jets with soft particles above \( p_T = 0.2 \) GeV/c included

- \( p+p \) events embedded into \( Au+Au \)
- Hard-core dijets in \( Au+Au \) more imbalanced than in \( p+p \)
- \( A_J \) consistent with \( p+p \) for \( R=0.4 \) jets, with soft particles included

**Talk by N. Elsey: 02/10 Tue 11:25 (P2)**
Do all jets get balanced?

• How does the momentum imbalance evolve with hard constituent $p_T$ cut and jet radius?
• Looking at matched jets with different hard constituent $p_T$ cuts

• All jets unbalanced at small jet radius
• Jets with higher hard constituent $p_T$ cuts get balanced as jet radius is increased and soft contribution is included

Talk by N. Elsey: 02/10 Tue 11:25 (P2)
Jet angular scale dependence

- Cluster all constituents into anti-\(k_T\) jets of smaller radii (\(R = 0.1\))
- Choose leading and subleading subjets
  
  \[
  z_g = \frac{p_T^{\text{Subleading SJ}}}{p_T^{\text{Leading SJ}} + p_T^{\text{Subleading SJ}}}
  \]

- \(\theta_{SJ} = \Delta R(\text{Leading SJ axis, SubLeading SJ axis})\)

- Interaction of the jet with medium could depend on the jet’s angular scale

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Majumder, A and Putschke, J, Phys Rev C 93 054909
Mehtar Tani, Y and Tywoniuk, K arXiv:1707.07361

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Talk by R. Elayavalli: 04/10 Thu, 11.25 (P2)
\[ \theta_{SJ} = \Delta R(\text{Leading SJ axis, SubLeading SJ axis}) \]

- **Hard-core jets** unbalanced for all \( \theta_{SJ} \) selections
- No large difference among different \( \theta_{SJ} \) selections
Jet angular scale dependence

\[ \theta_{SJ} = \Delta R(\text{Leading SJ axis}, \text{SubLeading SJ axis}) \]

- **Matched jets** (R = 0.4) recover balance (w.r.t p+p) for all \( \theta_{SJ} \) selections

Talk by R. Elayavalli: 04/10 Thu, 11.25 (P2)
Away side broadening with path length

- Width of away-side jet-like peak for high $p_T$ trigger particles

- Flow background subtracted
- Unfolded for smearing of $\phi_s$ from EP resolution

- Path length dependent increase of away-side peak width

$$\phi_s = \phi_{\text{trig}} - \Psi_{2, \text{EP}}$$
• Measurement of correlated production of hadrons with D⁰, sensitive to charm energy loss mechanisms
• Widths of Near Side (NS) peak measured from fit to data

- Increase in widths of NS peak in Δη and Δφ from peripheral to central collisions
- Broadening of jet-like peak, increase by medium interactions
• Charged jets recoiling from $\gamma_{\text{dir}}$ trigger are excellent probes to study energy loss

• First measurement of fully unfolded $\gamma_{\text{dir}} + \text{jet}$ spectra at RHIC energy
• Similar suppression for away-side jets associated with $\gamma_{\text{dir}}$ and with $\pi^0$ ($p+p$ reference taken from PYTHIA)

Talk by N. Sahoo: 02/10 Tue, 15.00 (P1)
MTD provides precise time resolution (≈100 ps) and good spatial resolution for hits, allowing Muon identification.

- Muon id. is improved with use of Deep Neural Networks.
- Templates for DNN response generated from MC and then fit to data.

First $\mu^+ \mu^-$ mass spectra from STAR.

DNN response for pairs.
Large excess of di-electron yields at very low $p_T$ ($p_T < 0.15$ GeV/c) in peripheral collisions.

The average $p_T^2$ larger than from just photon-photon interactions.

Could be a probe for the strong EM field trapped in the QGP!

Sooراج Radhakrishnan
Strongly interacting charm quarks in QGP
- Similar high $p_T R_{AA}$, (and $v_2$) for $D^0$ as light flavor hadrons
- Much larger $D^0 v_1$, compared to light flavor hadrons. Predicted by hydro

Evidence for coalescence hadronization of charm quarks
- Strong enhancement of $\Lambda_c$ production
- Charm cross section consistent with p+p, but hadrochemistry significantly modified

Stronger suppression of $Y(2S+3S)$ than $Y(1S)$ in central Au+Au

Jets in QGP: Momentum transfer to soft particles. Broadening of angular distributions of associated particles with path length
- $A_J$ for jets with higher hard const. $p_T$ cut get balanced (w.r.t p+p) with increase in jet radius and inclusion of soft constituents
- No strong dependence on jet angular scale seen
- Broadening of away side when going from in-plane trigger to out-of-plane trigger
- Broadening of jet-like peak in $D^0$-hadron correlations from peripheral to central

Low $p_T$ di-electron excess - probe for initial photon flux and (potentially) EM field
1. Xiaolong Chen, 02/10 Tue, 09.20 (P3): *Measurements of open bottom hadron production via displaced J/Psi, D0 and electrons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR*

2. Shuai Yang, 02/10 Tue, 09.20 (P4): *Low-pT e+e- pair production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV at STAR*

3. Liang He, 02/10 Tue, 11.05 (P3): *Measurement of directed flow of D0 and D0bar mesons in 200 GeV Au+Au collisions at RHIC using the STAR detector*

4. Nick Elsey, 02/10 Tue 11:25 (P2): *Systematic studies of di-jet imbalance measurements at STAR*

5. Nihar Sahoo, 02/10 Tue, 15.00 (P1): *Measurement of the semi-inclusive distribution of jets recoiling from direct photon and pi0 triggers in central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with the STAR experiment*

6. Alex Jentsch, 02/10 Tue, 15.20 (P3): *Studies of Heavy-Flavor Jets Using D0-Hadron Correlations in Azimuth and Pseudorapidity in Au+Au Collisions at 200 GeV at the STAR Experiment*

7. Liang Zhang/Li Yi, 02/10 Tue, 16.45 (P2): *Event-plane dependent away-side jet-like correlation shape in 200 GeV Au+Au collisions from STAR*

8. Zhen Liu, 03/10 Wed, 09.00 (P3): *Quarkonium measurements in heavy-ion collisions at $\sqrt{s_{NN}} = 200$ GeV with the STAR experiment*

9. Daniel Brandenburg, 03/10 Wed, 11.45 (P4): *Measurement of the $\mu+\mu$ Invariant Mass Spectra in p+p and p+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV with the Muon Telescope Detector at STAR*

10. Raghav Elayavalli, 04/10 Thu, 11.25 (P2): *Measurements of the jet internal structure and its relevance to parton evolution in p+p and Au+Au collisions at STAR*

11. Guannan Xie, 04/10 Thu, 11.25 (P3): *Measurements of $\Lambda_c^\pm$, $D_s^\pm$, $D^*\pm$ and $D^{0}(\overline{D^{0}})$ Production in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR*